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SESSION: (A1) Mechanisms of S2S predictability

(A1-01)

Identifying wave processes associated with predictability across subseasonal to seasonal time scales

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The key to better prediction of S2S variability and weather regimes in a changing climate lies with improved understanding of the fundamental nature of S2S phase space structure and associated predictability and dynamical processes. The S2S variability can be partitioned with the Modified Lagrangian Mean (MLM) approach in terms of slow diabatic processes, such as radiative forcing, and adiabatic dynamical processes. The latter can be decomposed into a finite number of relatively large-scale discrete-like Rossby waves with coherent space-time characteristics using Empirical Normal Mode (ENM) analysis. ENM analysis is based on principal component analysis, conservation laws and normal mode theories. These modes evolve in a complex manner through nonlinear interactions with themselves and transient eddies and weak dissipative processes. The foundations and potential value of the ENM approach are presented but novel research is required to understand the predictability and dynamical processes of these modes, including their excitation by resonant mechanisms.

Keywords

S2S; Predictability; Rossby Waves; Modified Lagrangian Mean; Empirical Normal Modes; Conservation Laws; Principal Component Analysis.

SESSION: (A1) Mechanisms of S2S predictability

(A1-02)

Predictive signal and noise in sub-seasonal to decadal forecasts

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The prediction of the state of dynamical systems involve the estimation, and through temporal relationships, the projection of the current state into the future. In non-periodic systems like the coupled atmosphere - ocean - land - ice, or more generally, the Earth system, information about the exact state of the system is lost due to the chaotic growth of errors originating from the initial condition and the numerical model of the system. We distinguish between "traceable" predictability where the phase and amplitude of individual events can be still tracked, and "climatic" predictability where only the statistics of selected events (such as their frequency), but not their timing or position, can be predicted.

Though some high impact events such as heat waves, cold spells, or certain types of floods are associated with low frequency, large scale events that are more predictable, many high impact weather events such as severe storms, tornados or flash floods are associated with smaller scale events that lose traceable predictability relatively quickly. Even after their traceable predictability is lost, the frequency or other statistics of such smaller scale and potentially high impact weather events may still exhibit deviations from climatology, contingent on the traceable predictability of larger scale processes (i.e., climatic predictability of thunderstorms at a given location, as a function of the phase of ENSO). In this study, the effectiveness of algorithms designed to separate the predictable (traceable or climatic) signal from noise in S2S and S2D predictions such as spatial, temporal, or ensemble-based averaging will be critically reviewed.

SESSION: (A1) Mechanisms of S2S predictability

(A1-03)

Sources of tropical subseasonal predictability beyond the MJO

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The relative importance of ENSO and the MJO to tropical subseasonal predictability is assessed with a coupled linear inverse model (LIM) derived from the simultaneous and 5-day lag covariances of observed 5-day running mean atmospheric and oceanic anomalies for the years 1982-2009. The oceanic portion of the LIM state vector is made up of sea surface temperature (SST) and sea surface height (SSH) anomalies, whereas the atmospheric portion is made up of outgoing longwave radiation (OLR) and 200 and 850 hPa zonal and meridional wind anomalies. A comparison of the LIM (cross-validated) hindcast skill with that of the operational versions of the NCEP CVSv2 and ECMWF models for the years 1999-2010 is also made. LIM S2S skill (Weeks 3-6) is comparable with both forecast models. The ECMWF hindcasts generally have highest skill for Weeks 3-4, with both the LIM and ECMWF hindcasts having about the same skill in Weeks 5-6.

Given that its forecast skill is comparable with operational coupled GCMs and it reproduces observed spatio-temporal statistics, the much simpler LIM is useful for diagnosis of predictability, which may be determined from its forecast signal-to-noise ratios. The state-dependence of potential LIM skill is assessed and shown to compare well both with the LIM and operational model realized skill. Further analysis is performed based on the fact that the eigenvectors of the LIM dynamical evolution operator separate into two distinct, but nonorthogonal, subspaces: an “internal” space governing the nearly uncoupled subseasonal dynamics, and a “coupled” space governing the strongly coupled longer-term dynamics. These subspaces arise naturally from the LIM analysis; no bandpass frequency filtering need be applied. The internal space eigenmodes typically have much shorter periods and e-folding time scales than the coupled space eigenmodes. Additionally, the MJO mostly lies in this internal space, whereas ENSO mostly lies in the coupled space. Anomalies that project onto the coupled space are shown to more predictable than those projecting onto the internal space, even for relatively “short” Weeks 3-4 leads. That is, ENSO is the primary contributor to overall tropical skill even on the Weeks 3-4 time scale, and provides almost all of it on longer S2S forecast leads.

SESSION: (A1) Mechanisms of S2S predictability

(A1-04)

Characteristics of the QBO-Stratospheric Polar Vortex Connection on Multi-decadal Time Scales

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The strength of the relationship between the quasi-biennial oscillation (QBO) and the Northern Hemisphere stratospheric polar vortex, or Holton-Tan (H-T) relationship, on multi-decadal timescales is investigated using a 10-member ensemble of historical simulations for the period 1957-2015. The experiments were conducted with the higher-top Community Atmosphere Model Version 5 (CAM5) that is capable of internally generating the QBO. Consistent with reanalysis, the model ensemble-mean shows a strengthening (weakening) of the polar vortex with westerly (easterly) phase of the QBO. However, substantial variations across individual ensembles with respect to the strength of the H-T relationship and subsequent tropospheric impacts on ~60-year timescales are found that are closely linked to variations in the frequency of occurrence of major stratospheric sudden warmings in the QBO east phase. It is shown that this sensitivity is consistent with the QBO's modulation of the zero-wind line in the lower stratosphere affecting planetary wave propagation. Implications for evaluating the H-T relationship in atmospheric circulation model and QBO's role as source of predictive skill on subseasonal to seasonal timescales are discussed.

SESSION: (A1) Mechanisms of S2S predictability

(A1-05)

Impact of statistically forecasted sea-ice boundary condition on the sub-seasonal prediction using atmospheric general circulation model

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Sub-seasonal and seasonal prediction model has been extensively developed and tested especially in recent several years, but the predictability for one-month ahead or longer remains still challenging. Recently, an enhanced year-to-year variability of the Arctic sea-ice has been emphasized in its role for controlling mid-latitude climate variability. In this study, we implemented a sub-seasonal prediction model named Korea Polar Prediction System (KPOPS) based on the Community Atmosphere Model version 4 (CAM4) by incorporating statistically predicted sea-ice boundary condition. Sea-ice concentration (SIC) in the model is predicted during the forecast period using the statistical method based on the Seasonal-reliant Empirical Orthogonal Function (S-EOF) method. The statistical prediction of SIC using the S-EOF generally outperforms dynamic sea-ice prediction providing a good motivation for this study. Sea surface temperature (SST) out of the Arctic region is prescribed using the forecasted SST from the climate forecast system (CFS) model. One-month prediction skill of the KPOPS and CFS-Reforecast are compared for the early winter (November – December) and late winter (January – February) from 2001/2002 to 2014/2015. Overall forecast skill of KPOPS outperformed the CFS-Reforecast. Especially, in the early winter, the forecast skill of the KPOPS was superior in the Arctic region, apparently. In the late winter, the forecast skill over East Asia and North America was significantly higher than the CFS-Reforecast. Therefore, we conclude that the sub-seasonal prediction using statistically forecasted sea-ice boundary condition exhibits a new possibility of better prediction given the situation that current state-of-the-art fully coupled models do not provide a reliable prediction product of SIC.

SESSION: (A1) Mechanisms of S2S predictability

(A1-06)

The characteristics of Kelvin waves in the atmosphere-ocean coupled system

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We use the technique developed in Baranowski et al (2017) that allows to identify the individual Kelvin waves in the observed TRMM precipitation to evaluate prediction skill of the individual Kelvin waves and Kelvin wave climatological characteristics in the set of forecasts using the new coupled Navy global prediction model. While the variability in the coupled model in the Kelvin wave portion of the spectrum appears to be well represented, the features of the individual waves are of interest as well. In particular, our earlier work shows that the interaction of Kelvin waves with the local circulations over the Maritime continent could have an impact on propagation of the Kelvin waves and possibly MJO through the Maritime Continent, depending on the time of the day the waves reach Sumatra and Borneo. In this work we examine Kelvin wave characteristics in the coupled model forecasts to establish how their intensity, the location of the origin and decay and interaction with the Maritime continent compares to observations and how these characteristics are linked with MJO propagation and MJO prediction skill.

SESSION: (A1) Mechanisms of S2S predictability

(A1-07)

Diagnosing sources of operational forecast model errors in tropical-extratropical interactions

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The atmospheric response to variations in latent heating in the tropics is known to extend well beyond its source region and therefore it is thought that a reduction of tropical forecast errors is beneficial for forecast skill over remote regions such as North America.

In this presentation, the impact of the quality of tropical forecasts in extra-tropical week 1 to 4 forecast skill is evaluated, using reforecasts from the S2S project. It is shown that in most models there is a positive correlation between performance of tropical forecasts and extra-tropical forecast at later lead times. The strength of these correlations varies with lead time, variable and model. One interpretation is that when tropical heat sources are well (poorly) predicted, extra-tropical skill is gained (lost) due to properly (improperly) triggered Rossby-like wavetrains. The quality of the S2S tropical forecasts is shown to be related to each model's ability to simulate the MJO, as well as higher frequency convectively coupled equatorial waves. This analysis also suggests that model physics, rather than dynamics, control the link between tropical and extra-tropical skill.

SESSION: (A1) Mechanisms of S2S predictability

(A1-08)

ENSO modulation of MJO teleconnection to the North Atlantic & Europe and implications for subseasonal predictability

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The Madden-Julian Oscillation (MJO), an organized eastward propagating source of enhanced convection, acts as a Rossby wave source and as a global tropical driver of subseasonal predictability. An example pathway leads this source of predictability out of the tropics to the North Atlantic / European (NAE) region, known as a teleconnection, via the jet stream and stratosphere. Through this teleconnection the MJO can influence regimes of large-scale weather patterns, including the North Atlantic Oscillation (NAO). The aim of this study is to investigate the dependence of the MJO – NAE teleconnections on the interannual variations in the background state associated with the El Niño Southern Oscillation (ENSO).

We use the Cassou (2008) framework to show that these teleconnections from the MJO to the NAE weather and jet regimes are strongly dependent on the phase of ENSO. For example, during El Niño years the MJO to NAO+ teleconnection is strongly enhanced and persists throughout more MJO phases, dominating the climatological mean picture, whilst during La Niña this teleconnection to the NAO+ is weak and short-lived. Further NAE regime transitions and in situ development also become clearer via this perspective separated by ENSO background state. We also discuss the seasonal mean response to ENSO in the NAE region through rectification of these subseasonal teleconnections onto the seasonal mean.

The dependence on the background state has strong implications for subseasonal predictability, including implications for interannual variations in subseasonal predictive skill and also the need for models to get the background state correct in order to correctly represent these teleconnections. We analyze the representation of these teleconnections and their dependence on the background state in models contributing to the S2S database.

*This work is submitted as part of the InterDec project, funded under the 2015 joint JPI Climate-Belmont Forum call.

SESSION: (A1) Mechanisms of S2S predictability

(A1-09)

The impact of Northern Hemisphere mid-latitude variability on tropical teleconnections

Cristiana Stan (1), Erik Swenson(2)

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The role of Northern Hemisphere mid-latitude variability on atmospheric rivers (AR) with landfall on the west coast of the U.S. is evaluated in two sets of ensemble re-forecasts for the winter 2014/2015. The first set of re-forecasts defines the control experiment. In the second set of re-forecasts the variability of the Northern Hemisphere mid-latitudes is relaxed to the climatological mean state of the model. The AR events occurring in observations during this winter are first divided based on the moisture source location and trajectory, which ultimately determines the landfall location. During this winter, in observations all AR events primarily originate in the tropics, whereas the re-forecasts show some events with moisture descending from the extra-tropics. Secondly, the re-forecasts of these category of events are compared between the control experiment and the experiment with smoothed mid-latitude variability. By removing the synoptic scale variability of winds, temperature and moisture, the West Pacific trough becomes anchored and starts to deepen at 40 N after one week. The probability of occurrence of AR with tropical origin increases at all lead times up to four weeks, whereas the probability of occurrence of extra-tropical events decreases. After two weeks, AR events with moisture ascending from the tropics tend to become more persistent and zonally-oriented and by weeks 3-4 they can extend across the whole Pacific basin.

SESSION: (A1) Mechanisms of S2S predictability

(A1-10)

Predicting the dominant patterns of subseasonal variability of wintertime surface air temperature in extratropical Northern Hemisphere

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Skillfully predicting persistent extreme temperature anomalies more than 10 days in advance remains a challenge although it is of great value to the society. Here the two leading modes of subseasonal variability of surface air temperature over the extratropical Northern Hemisphere in boreal winter are identified with pentad (5-days) averaged data. They are well separated geographically, dominating temperature variability in North America and Eurasia, respectively. There exists a two-pentad lagged correlation between these two modes, implying an inter-continental link of temperature variability. Forecast skill of these two modes is evaluated based on three operational subseasonal prediction models. The results show that useful forecasts of the Eurasian mode (EOF2) can be achieved four pentads in advance, which is more skillful than the North American mode (EOF1). The influence of the Madden-Julian Oscillation (MJO) on the forecast skill of these two temperature modes is also analyzed.

SESSION: (A1) Mechanisms of S2S predictability

(A1-11)

The role of cloud diabatic processes in the life cycle of Atlantic-European weather regimes

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The large-scale midlatitude flow is dominated by Rossby wave activity along the upper-level midlatitude wave guide and jet stream. This activity often occurs in preferred quasi-stationary, persistent, and recurrent states, so-called weather regimes (e.g. Vautard, 1990). Many of these regimes are dominated by a blocking anticyclone. In the Atlantic-European region, weather regimes explain most of the atmospheric variability on sub-seasonal time scales. From a forecasting perspective, the onset, persistence, and transition of weather regimes present a severe challenge in current numerical weather prediction models (Ferranti et al., 2015).

Recently, Pfahl et al. (2015) showed that transport of air mass into the upper troposphere driven by latent heat release in ascending air streams is a first-order process in blocking onset and maintenance. This study systematically investigates the role of such diabatic outflow in the life cycle of all European weather regimes.

An extended definition of 7 year-round Atlantic-European weather regimes from 37 years of ERA-Interim reanalysis data is used (Grams et al. 2017). This is based on an EOF analysis and k-means clustering of normalized low-pass-filtered 500hPa geopotential height anomalies. The weather regime index of Michel and Rivière (2011) is used to further objectively define important life cycle stages such as the regime onset, mature stage, decay, or transition. The role of cloud-diabatic processes in European weather regimes is assessed based on time lag analysis of warm conveyor belt (WCB) activity at these life cycle stages.

Results indicate that the period prior to regime onset is characterized by important changes in location and frequency of WCB occurrence. These changes persist during the early stage of a regime life cycle and weaken thereafter. Most importantly, prior to the onset of regimes characterized by blocking, a statistically significant increase in WCB activity occurs upstream of the evolving blocking anticyclone even before blocking is detectable. This suggests that the injection of air mass into the upper troposphere by diabatic WCB outflow helps to establish the blocking anticyclone. Furthermore, diabatic WCB outflow helps maintaining the blocking anticyclone later during the life cycle. Finally, a recent forecast bust demonstrates the challenges in predictability of weather regime life cycles imposed by the multi-scale interactions established through diabatic outflow.

This study corroborates the importance of correctly representing cloud-diabatic processes in numerical weather prediction (NWP) models across multiple scales in order to predict the large-scale circulation accurately. A seamless NWP approach that is able to predict European weather regimes on subseasonal time scales would allow for manifold applications such as in the energy sector.

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SESSION: (A2) Modelling issues in S2S prediction

(A2-01)

The art and science in sub-seasonal forecast system design

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An operational forecast system requires a high level of forecast quality, timeliness and cost-efficiency under various competing resource requirements. As such, it is vitally important for operational modelling centres to design and configure forecast systems, including the sub-seasonal forecast system, so as to maximize the accuracy, forecast skill, and benefits of forecast information.

Apart from modelling issues in representing physical and dynamics processes, there are many unresolved issues in the forecast system design and configuration: initialization, model resolution, ensemble size, ensemble generation, hindcast and forecast configurations. The choice of these configurations demands careful consideration since each choice impacts cost and quality. Under the constraint of fixed resources, these choices compete against one other in the tradespace.

This presentation reviews current practices in sub-seasonal forecast system design at operational centres and discusses the pros and cons of several approaches. Existing issues regarding the optimal forecast system design for the sub-seasonal predictions include (1) benefits and deficiencies of burst and Lagged Average Forecasting (LAF) ensemble approaches for operational forecasts, (2) optimal configurations of real-time forecasts such as frequency and ensemble size, (3) optimal configurations of reforecasts in terms of ensemble size, length and frequency, (4) techniques of ensemble generation and data assimilation. The sub-project “ensemble generation” in the S2S Phase 2 focuses on some of these issues.

Initial shocks and model drifts are other important aspects in sub-seasonal forecast systems. In the big picture of the sub-seasonal forecast systems, global observations and analyses of past and present are essential in maintaining the operational sub-seasonal forecast service. Oceanic observations are necessary for systems employing atmosphere-ocean coupled models. With increases in the complexity of forecast systems, it is becoming difficult to make the system consistent in hindcasts and forecasts. In the sub-seasonal time-range, the initial shocks and gradual increase of model biases (model drifts) appear due to the imbalance and difference between model and analysis states. The inconsistency of analysis and model states causes initial shocks in different time scales, for example, initial shocks of the atmosphere may last about one week and those of the ocean and land may last several weeks and more. Therefore reducing these shocks and drifts is one of major foci of the sub-seasonal system development.

All of the above aspects affect the quality of forecasts and need to be properly configured to create an optimized system, a “masterpiece” of a sub-seasonal forecast system.

SESSION: (A2) Modelling issues in S2S prediction

(A2-02)

Initialisation and model error simulation in the ECMWF coupled ensembles

Buizza, Roberto (1), Bonavita, Massimo (1), Holms, Elias (1), Laloyaux, Patrick (1), Lang, Simon (1),
Leutbecher, Martin (1), Lock, Sarah-Jane (1), Vitart, Frederic (1)

(1) European Centre for Medium-Range Weather Forecasts (ECMWF)

One key element of the ECMWF ensembles is the methodology used to simulate initial uncertainties, which is based on a combination of singular vectors and perturbations defined by the ECMWF ensemble of data assimilations (EDA). A second key element of the ECMWF ensembles is the use of stochastic schemes to simulate model uncertainties. In this talk, I will be reviewing these two aspects of the ECMWF ensembles.

SESSION: (A2) Modelling issues in S2S prediction

(A2-03)

Development of a Unified Forecast System at NCEP for S2S Prediction

Saha, Suranjana (1), Wu, Xingren (2), Wang, Jiande (3), Tripp, Patrick (4), Woollen, Jack (5), Lee, Hyun-Chul (6), Bhattacharjee, Partha (7), van den Dool, Huug (8), Pena, Malaquias (9)

EMC/NCEP, USA (1), EMC/IMSG, USA (2), EMC/IMSG, USA (3), EMC/IMSG, USA (4), EMC/IMSG, USA (5), EMC/IMSG, USA (6), EMC/IMSG, USA (7), CPC/Innovim, USA (8), EMC/IMSG, USA (9)

NCEP's mission for S2S prediction requires developing a successor model to the present operational CFSv2. For several years, a concerted effort has taken place, both internal and external to EMC/NCEP, to create the infrastructure of a multi-component global coupled system in the NEMS framework. At the present time, the atmospheric spectral GSM is coupled with the MOM5.1 ocean model and the CICE5 seaice model. The land surface model is still internal to the GSM. This configuration will change when the spectral dynamics will be replaced by the FV3 dynamic core and the ocean model will be upgraded to MOM6. A verification module has been developed to validate the UFS as it evolves and converges to its final configuration. This module consists of making 144 35-day forecasts from the 1st and the 15th of each month, over a 7-year period from April 2011 to March 2018. Calibration climatologies are first prepared for all variables that are studied by fitting four harmonics and the mean to the model time series, as well as to the matching observed time series used for verification. Some of the variables studied are z500, SST, T2m and PRATE, as well as U850, U250 and OLR to study MJO prediction. Forecasts of the various configurations and the control operational CFSv2 are compared in terms of RMSE and AC, both with and without systematic error correction (SEC). Special emphasis is given to NH Z500, US-land T2m and PRATE verified against CPC-'daily' observations, and SST and PRATE for the Nino3.4 area. Preliminary results show that the new system with MOM6 and CICE5, without any type of tuning, is equal or better than the control operational CFSv2 over the last 7 years.

In the near future, the final configuration, which may include the Wavewatch-III for waves, GOCART for aerosols and Noah-MP for the land surface, will be fine-tuned for optimal performance, especially with regard to the physics parameterizations of convection, radiation, microphysics and clouds and the coupling between the different components. The verification module described above will help guide the rapid development of the UFS as it can be executed quickly to get interim assessments. Beyond such first steps, many more integrations to build an ensemble, covering longer forecast ranges, using more frequent initial states and many more years will be required. A weakly coupled DA system of all the components is also being developed to provide initial states for the UFS. A complete Reanalysis from 1979 to the present and subsequent Reforecasts of the system will also be carried out to provide stable calibration and skill estimates of the system before it is made operational at NCEP.

SESSION: (A2) Modelling issues in S2S prediction

(A2-04)

Sufficient resolution for S2S predictions

Sardeshmukh, Prashant (1,2), Magnusson, Linus (3), Wang, Aaron (1,2), Bacmeister, Julio (4)
CIRES, CU, USA (1), PSD/ESRL/NOAA, USA (2), ECMWF, UK (3), NCAR, USA (4)

Subseasonal to Seasonal (S2S) predictions are inherently probabilistic. They are about predicting the probability distributions of future states given initial conditions and external forcing. The question is whether one needs ultra-high-resolution models to represent such distributions, or whether lower resolution models with a suitable combination of deterministic plus stochastic parameterizations of small-scale feedbacks are sufficient for this purpose. From a computational viewpoint, lower resolution models are obviously more attractive, especially for generating large forecast ensembles to pin down the forecast probability distribution. On the other hand one could argue that ultra-high resolution is necessary, given the existence of coherent structures at every scale and the absence of a spectral energy gap, to adequately capture multi-scale interactions and the statistics of extreme values i.e. the tails of the generally non-Gaussian probability distributions.

Comparisons of the probability distributions of daily anomalies in long global atmospheric GCM runs made at ECMWF and NCAR at resolutions ranging from T95 (about 130 km) to T2047 (about 6.5 km) are, however, revealing in this regard. The distributions are indeed non-Gaussian, but to an excellent approximation differ only in their widths but not their shapes at the different resolutions. This remarkable result is argued to be consistent with the stochastically generated skewed (SGS) nature of the distributions, and that beyond T511 (about 25 km) the main impact of higher resolution is merely to enhance the effectively stochastic forcing of the large-scale eddies by small-scale fluxes. This suggests that a resolution of about T511, utilizing a suitable combination of deterministic and stochastic parameterizations to accurately represent variances and energy spectra, should be sufficient for S2S predictions. Indeed we have recently confirmed in a large ensemble forecast experiment performed with the NCEP/GFS model (80-member 15-day forecasts at T254 resolution for 100 forecast cases) that adding stochastic parameterizations to the model not only increases the ensemble spread but also unambiguously reduces the error of the ensemble mean forecast. This increases both the deterministic and probabilistic skill of the forecasts at Day 15, and makes it indistinguishable from that of the much higher resolution operational GFS forecasts. The increase of ensemble spread through the additional stochastic forcing is not surprising, but the unambiguous reduction of the ensemble mean error is. It results from a multiplicative (state-dependent) noise-induced modification of the deterministic forecast evolution operator, as will be described in the talk

SESSION: (A2) Modelling issues in S2S prediction

(A2-05)

Seasonal prediction experiments in a global coupled system based on a non-hydrostatic global atmospheric model

Jung-Eun Esther Kim, Myung-Seo Koo, and Song-You Hong

KIAPS

The Korea Institute of Atmospheric Prediction Systems (KIAPS) began a national project in developing a new global atmospheric model system in 2011. As of February 2018, the 12-km Korean Integrated Model (KIM) system, which consists of a new spectral-element non-hydrostatic dynamical core on a cubed sphere and the state-of-the-art physics parameterization package, has been launched in a real-time forecast framework, with the initial conditions obtained from the advanced hybrid four-dimensional ensemble variational data assimilation (4DEnVar) over its native grid. Further, KIM has been coupled with the ocean model, HYCOM, for expansion of the application to seasonal prediction and climate studies. Predictability experiments with this couple system are being conducted and the results will be presented at the conference, with a focus on the stochastic coupling of ocean and atmosphere.

SESSION: (A2) Modelling issues in S2S prediction

(A2-06)

Toward Reducing Cloud-Radiation Errors from Day 1 to Week 4 Prediction

Benjamin, Stan (1), Grell, Georg (2)

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Cloud-radiation representation in models for subgrid-scale clouds is a known gap from subseasonal-to-seasonal models down to storm-scale models applied for forecast duration of only a few hours. NOAA/ESRL is confirming this issue from 3-km model (HRRR) for short-range forecasting including sub-grid-scale cloud representation up to a 60-km subseasonal model testing a common suite of scale-aware physical parameterizations. Resulting refinements to this common suite of physical parameterizations for scale-aware deep/shallow convection and boundary-layer mixing over this wide range of time and spatial scales will be reported in this presentation. Evaluation of components of this suite is being evaluated for cloud/radiation (using SURFRAD, CERES, METAR ceiling) and near-surface (METAR, mesonet, aircraft, rawinsonde).

ESRL/GSD has developed a parameterization suite (turbulent mixing, deep/shallow convection, 9-layer land/snow/vegetation model) to improve PBL biases (temperature and moisture) including better representation of clouds and precipitation. This parameterization suite development has been accompanied by an effort for improved data assimilation of clouds, near-surface observations and radar for the atmosphere-land system.

The Grell-Freitas scheme (2014, Atmos. Chem. Phys.) and MYNN boundary-layer EDMF scheme (Olson / Benjamin et al. 2016 Mon. Wea. Rev.), and RUC land-surface model (Smirnova et al. 2016 Mon. Wea. Rev.) have been applied and tested extensively for the NOAA hourly updated 3-km High-Resolution Rapid Refresh (HRRR) and 13-km Rapid Refresh model/assimilation systems over the United States and North America, with targeting toward improvement to boundary-layer evolution and cloud-radiation representation in all seasons. This representation is critical for both warm-season severe convective storm forecasting and for winter-storm prediction of snow and mixed precipitation.

At the same time the Grell-Freitas scheme has been applied also as an option for subseasonal forecasting toward improved US week 3-4 prediction with the FIM-HYCOM coupled model (Green et al 2017, MWR, and Sun et al 2018a,b, MWR, accepted).

SESSION: (A2) Modelling issues in S2S prediction

(A2-07)

Mean state bias, cloud-radiation feedbacks, and MJO prediction skill in the S2S models

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University of Washington, USA (1), Seoul National University, South Korea (2)

The Madden-Julian Oscillation (MJO), the dominant mode of tropical intraseasonal variability, provides a major source of tropical and extratropical predictability on subseasonal timescale. We examined the relationship of MJO prediction skill with biases in the column water mean state and longwave cloud-radiation feedbacks in the models participating in subseasonal- to-seasonal (S2S) prediction project. In most S2S models, a notable dry bias develops within a few days of forecast lead time in the deep tropics, especially across the Maritime Continent. The dry bias weakens the horizontal moisture gradient over the Indian Ocean and western Pacific, likely dampening the organization and propagation of the MJO. Most S2S models also underestimate the longwave cloud-radiation feedbacks in the tropics, which may affect the maintenance of the MJO convective envelope. The models with smaller bias in the mean horizontal moisture gradient and the longwave cloud-radiation feedbacks show higher MJO prediction skills, suggesting that improving those biases would enhance MJO prediction skill of the operational models.

SESSION: (A2) Modelling issues in S2S prediction

(A2-08)

Process-based MJO hindcast evaluation in SubX

Hyemi Kim (1), Matthew A. Janiga (2), Deepthi Achuthavarier (3,4), Kathy Pegion (5)

Stony Brook Univ., USA (1), NRL, USA (2), USRA, USA (3), GMAO, USA (4)

George Mason Univ., USA (5)

There is a growing interest in forecasting weather and climate within the subseasonal time range. The Madden-Julian Oscillation (MJO), an organized envelope of tropical convection, is recognized as one of the leading sources of subseasonal predictability. Theoretical models and field campaigns such as the Dynamics of the MJO (DYNAMO) experiment have led to a better understanding of the processes which are critical to simulating the MJO in numerical models. This has guided improvements to numerical models, particularly cumulus parametrizations, leading to significant advances in MJO prediction. Nevertheless, estimates of the potential predictability of the MJO suggest that there is still considerable room for improvement.

The goal of this study is to examine how the ability of operational models to represent critical physical processes which are important to the MJO is related to MJO prediction skill. Recent studies have identified several process-based metrics which are related to the ability of numerical models to represent MJO behavior in multi-year climate runs and MJO hindcast performance during case-studies. Up until now, however, evaluations of MJO fidelity in subseasonal forecasts over multiple years have focused on performance-based rather process-based metrics. International collaborative efforts such as the NOAA/MAPP SubX and WWRP/WCRP S2S projects, which make available numerous fields from the current generation of subseasonal prediction systems, present an unprecedented opportunity to relate MJO performance to process-based metrics. In this study, we relate MJO prediction skill in SubX hindcasts to four process-based metrics: (i) errors in the mean state of moisture and the representation of (ii) moisture-convection, (iii) radiation-convection (iv) air-sea interaction process. Results from this comparison shed light on which physical processes in the atmosphere-ocean system need to be better represented in numerical models to produce better MJO predictions.

SESSION: (A2) Modelling issues in S2S prediction

(A2-09)

The ocean-atmosphere dialog in the MJO: Physical processes vs. systematic biases in forecast models

DeMott, Charlotte A. and Klingaman, Nicholas P.

Colorado State University (CAD) and University of Reading (NPK)

Convection and circulation anomalies driven by the Madden Julian oscillation regulate fluxes of energy, momentum, and fresh water to the upper ocean throughout the Warm Pool. The ocean responds to this forcing, and feeds back to the atmosphere through the SST-modulation of surface fluxes on intraseasonal and shorter timescales, and through column moisture variations on low-frequency timescales.

Many studies have demonstrated improved MJO prediction skill when ocean feedbacks are included in dynamic forecast models, indicating an important role for ocean-atmosphere communication within the MJO. Understanding the essential processes of this ocean-atmosphere communication, or dialog, has been hindered by the complexity of processes that regulate the ocean response to MJO forcing, the substantial event-to-event variability in apparent ocean feedbacks to MJO convection, and the broad diversity of changes to MJO prediction skill among atmosphere-only models when coupled to dynamic ocean models.

In Part I of this study, we first assess the “nature of the conversation” between ocean and atmosphere in coupled prediction models (CPMs) by applying a newly developed set of air-sea interaction diagnostics to CPM members of the S2S database. We find that many CPMs are overly reliant on SST-modulated surface fluxes for the maintenance and propagation of MJO convection. The larger-than-observed SST variability in these models and its contribution to the MJO moisture budget is rooted in dry biases in the atmospheric boundary layer that over-amplify intraseasonal surface latent heat fluxes.

In Part II of this study, we assess sources of ocean predictability for MJO forecasts by CPMs in the S2S database. We focus on periods when the equatorial Indian Ocean exhibits enhanced eastward or enhanced westward surface currents, which have been linked to the regulation of MJO intensity (Moum et al. 2016); and on periods when the upper ocean is calm, favoring the formation of diurnal warm layers and a diurnal cycle of shallow convection (Ruppert and Johnson 2015).

Moum, J. N., K. Pujiana, R.-C. Lien, and W. D. Smyth, 2016: Ocean feedback to pulses of the Madden-Julian oscillation in the equatorial Indian Ocean. *Nature Comm.*, DOI: 10.1038/ncomms13203.

Ruppert, J. H., and R. H. Johnson, 2015: Diurnally modulated cumulus moistening in the preonset stage of the Madden-Julian oscillation during DYNAMO. *J. Atmos. Sci.*, 72, 1622–1647

SESSION: (A3) S2S ensemble predictions and forecast information

(A3-01)

How far in advance can we predict changes in large-scale flow leading to severe cold conditions over Europe?

Ferranti Laura, Magnusson Linus, Vitart Frederic, Richardson David

ECMWF

The potential of early warning for severe cold conditions is explored using the S2S data archive. We use of a 2 dimensional phase space to study the time evolution of flow patterns associated with high-impact temperature anomalies. A number of S2S systems have some skill in the prediction of cold spells over Europe, well beyond the medium range. We find that the MJO impact on the predictive skill of large-scale flow over Europe is asymmetric.

SESSION: (A3) S2S ensemble predictions and forecast information

(A3-02)

A verification framework for South American sub-seasonal precipitation predictions

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Center for Weather Forecast and Climate Studies (CPTEC),
National Institute for Space Research (INPE), Brazil (1)

We propose a verification framework for South American sub-seasonal (weekly accumulated) precipitation predictions produced one to four weeks in advance. The proposed framework assesses both hindcast and near real time forecast quality focusing on a selection of the most fundamental attributes (association, discrimination, reliability and resolution). These attributes are measured using various deterministic and probabilistic verification scores. Such an attribute-based framework allows the production of verification information in three levels according to the availability of sub-seasonal hindcasts and near real time forecasts samples. The framework is also useful for supporting future routine sub-seasonal prediction practice by helping forecasters to identify model forecast merits and deficiencies and regions where to best trust the model guidance information. The three information levels of the proposed framework are defined according to the verification sampling strategy and are referred to as target week hindcast verification, all season hindcast verification, all season near real time forecast verification. The framework is illustrated using ECMWF sub-seasonal precipitation predictions. For the investigated period (austral autumn), reasonable accordance was identified between hindcasts and near real time forecast quality across the three levels of verification information produced. Overall, sub-seasonal precipitation predictions produced one to two weeks in advance presented better performance than those produced three to four weeks in advance. The northeast region of Brazil consistently presented favorable sub-seasonal precipitation prediction performance through the computed verification scores, particularly in terms of association and discrimination attributes. This region was therefore identified as a region where sub-seasonal predictions produced one to four weeks in advance with the ECMWF model are most likely to be successful in South America. When aggregating all predictions over the South American continent the probabilistic assessment showed modest discrimination ability, with predictions clearly requiring calibration for improving reliability and possibly combination with predictions produced by other models for improving resolution. The proposed framework is also useful for providing feedback to model developers in identifying strengths and weaknesses for future sub-seasonal predictions systems improvements.

SESSION: (A3) S2S ensemble predictions and forecast information

(A3-03)

How much can Model Output Statistics improve sub-seasonal predictive skill?

A.G. Munoz (1), C.A.S. Coelho (2), A.W. Robertson (1) and S.J. Mason (1)

IRI, USA (1), CPTEC, Brazil (2)

Recent research has highlighted the potential for improving predictive skill at the sub-seasonal timescale, which could be the basis for enhanced, actionable forecasts for climate services involving water and disaster management, health, energy and food security. The WMO's World Weather and World Climate Research Programme's Subseasonal-to-Seasonal Prediction Project (S2S) has made available an extensive database with both hindcasts and almost-realtime forecast at this timescale. Lead times are long enough that much of the information in the atmospheric initial conditions is lost, but at the same time are too short for other sources of predictability (e.g., ocean boundary conditions) to have a strong influence in skill. Presently, sub-seasonal skill is still limited, and in general raw uncalibrated forecasts cannot be used to develop climate services. An obvious alternative is to make use of a variety of robust bias-correction and calibration methods --also known as Model Output Statistics, MOS-- available for other timescales, such as the seasonal one. Nonetheless, some technical issues can hinder this approach. We discuss problems and advantages of applying MOS to sub-seasonal forecasts, analyzing the spatio-temporal variability of skill in several models and methods.

SESSION: (A3) S2S ensemble predictions and forecast information

(A3-04)

Regime-dependent predictability and forecast error spectra of initialized forecasts

Berner, Judith

NCAR, USA

Recent work has demonstrated that forecasts initiated from states that project onto certain large-scale patterns typically associated with low-frequency variability, can exhibit extended forecast skill. So are e.g. forecasts initialized in the negative phase of the North Atlantic Oscillation more skillful over the Euro-Atlantic sector than average.

Here we will use the S2S database to investigate if these findings carry over to other modes of variability, such as e.g. the Pacific North American pattern (PNA). We will determine if initialization from a positive or negative PNA phase in the S2S database are associated with changes in sub-seasonal predictability.

Finally we examine the forecast error growth of these initialized forecasts in an attempt to link extended predictability to the classical predictability theory proposed by Lorenz (1969).

SESSION: (A3) S2S ensemble predictions and forecast information

(A3-05)

Advancing Atmospheric River and Blocking Forecasts into Subseasonal-to-Seasonal Timescales

Barnes, Elizabeth (1), Baggett, Cory (1), Maloney, Eric (1), Mayer, Kirsten (1), Mundhenk, Bryan (1), Nardi, Kyle (1), Tseng, Kai-Chih (1)

(1) Colorado State University

Atmospheric rivers (ARs) are narrow corridors of high atmospheric water vapor transport that can cause flooding and high winds where they occur. We demonstrate here that the potential exists to advance forecast lead times of atmospheric rivers into S2S timescales through knowledge of two of the atmosphere's most prominent oscillations; the Madden-Julian oscillation (MJO) and the Quasi-biennial oscillation (QBO).

The dynamical relationship between atmospheric rivers, the MJO and the QBO is hypothesized to occur through modulation of North Pacific blocking. We present an empirical prediction scheme for anomalous atmospheric river activity based solely on the MJO and QBO and demonstrate skillful subseasonal "forecasts of opportunity" 5+ weeks ahead. We then go on to discuss the ability of state-of-the-art Numerical Weather Prediction models (from the S2S Database) to forecast atmospheric river characteristics and the MJO-induced blocking patterns on S2S timescales.

SESSION: (A3) S2S ensemble predictions and forecast information

(A3-06)

Identifying the capacity of dynamical models to forecast subseasonal extremes: Multi-model ensembles

Collins, Dan (1), LaJoie, Emerson (1), Jia, Liwei (1), Strazzo, Sarah (1), Becker, Emily (1)

NOAA, USA (1)

Forecasting temperature and precipitation on subseasonal timescales beyond two weeks lead-time is at the limits of predictability and modeling capabilities. The NOAA Climate Prediction Center (CPC) relies on both dynamical and statistical models to make operational and experimental, above and below median, temperature and precipitation forecasts for weeks 3-4. Both statistical and dynamical forecast models attempt to utilize the enhanced predictability during active climate events, related to modes of climate variability, such as ENSO and the Madden-Julian Oscillation. Other than the predictability due to decadal timescale changes in climate, much of the skill of subseasonal forecasts is related to these drivers of climate variability. Furthermore, much of the utility of subseasonal forecasts lies in the forecast of extremes in temperature and precipitation, which by their nature are intermittent and likely associated with high amplitude climate drivers. While a calibrated multi-model ensemble (MME) of dynamical model forecasts has proven to be one of the most skillful tools in CPC operational, subseasonal forecasts, skill remains low for precipitation forecasts and at times, near zero for all forecasts. Therefore, identification of forecasts of opportunity, when predictability is enhanced, could greatly improve the utility of forecasts on this timescale. To analyze the potential to identify forecasts of opportunity, we examine the skill of forecasts of extremes (identified as the 15th and 85th percentiles from the past climatological distributions) when they are predicted, using hindcasts from the SubX MME. In this way, we examine if intermittent forecasts of larger magnitude signals represent the best opportunity to obtain information for extended-lead subseasonal forecasts (weeks 3-4) including extremes, and determine appropriate metrics of forecasts of opportunity. It has been found that a multi-model ensemble significantly improves the capacity to identify forecasts of opportunity for extremes.

SESSION: (A3) S2S ensemble predictions and forecast information

(A3-07)

The Subseasonal Experiment (SubX)

Pegion, Kathy (1), Kirtman, Ben (2), Collins, Dan (3), Burgman, Rob (4), Lajoie, Emerson (5,3)

George Mason University (1), RSMAS/U. Miami (2), Florida International University (3), NOAA/CPC (4), Innovim, Inc (5)

The Subseasonal Experiment (SubX) is a NOAA/Climate Testbed project focused on subseasonal predictability and predictions. Seven global models have produced seventeen years of ensemble retrospective forecasts initialized weekly to investigate subseasonal prediction and predictability. Additionally, this project began producing real-time predictions in support of the NOAA/NWS Climate Prediction Center as guidance for their week-3/4 outlooks in July 2017.

This presentation will provide an overview of the project and the publically available datasets. We will also show a comprehensive evaluation of deterministic and probabilistic skill for weeks 1-4, as well as model biases, for the individual models and multi-model ensemble, demonstrating the value of the multi-model ensemble prediction system.

SESSION: (A3) S2S ensemble predictions and forecast information

(A3-08)

Subseasonal prediction of wintertime East Asian temperature based on atmospheric teleconnections

Yoo, Changhyun (1), Johnson, Nathaniel (2), Chang, Chueh-Hsin (3), Feldstein, Steven (4), Kim, Young-Ha (1)

Ewha Womans Univ., Korea (1), Princeton Univ., USA (2), National Taiwan Univ., Taiwan (3), Penn State Univ., USA (4)

A statistical model is constructed based on the lagged composite fields associated with the Northern Hemisphere teleconnection patterns to predict the East Asian wintertime surface air temperature for lead times out to 6 weeks. The prediction skill of the statistical model is compared with that of hindcast simulations of the Global Seasonal forecasting model version 5. We found that four teleconnections, i.e., the West Pacific, East Atlantic, Scandinavian, and East Atlantic/Western Russian teleconnection patterns, provide skillful predictions over East Asia for lead times beyond 4 weeks. When combinations of the teleconnections is used, the statistical model outperforms the climate model for lead times beyond 3 weeks, especially during those times when the teleconnections are in their active phases.

SESSION: (A3) S2S ensemble predictions and forecast information

(A3-09)

Forecasting springtime Sahelian heat waves at seasonal and sub-seasonal time scales

Batté, Lauriane (1), Ardilouze, Constantin (1), Déqué, Michel (1)

CNRM UMR 3589 (Météo-France / CNRS), France (1)

This study evaluates the skill of Météo-France seasonal and sub-seasonal forecasting systems in anticipating extreme heat conditions over the West African region. Both systems are based on the CNRM-CM coupled global climate model.

The skill in capturing interannual variability of minimum, maximum and humidity-corrected apparent temperature heat wave indices is analyzed for the March to June (MAMJ) peak season in re-forecasts initialized end of January over a 22-year period. Although correlation is limited at a grid-point level, significant skill is found for regional-scale indices when comparing to both ERA-Interim and BEST reference datasets.

At the sub-seasonal scale, correlation drops sharply beyond the deterministic range.

Real-time forecasts for the 2016 season are then studied both in terms of anomalies and using a weather type approach. This analysis sheds more light on the potential information and limitations of early-warning systems at these extended time scales and the conditional skill related to large-scale phenomena such as ENSO.

SESSION: (A3) S2S ensemble predictions and forecast information

(A3-10)

Advances in operational sub seasonal prediction of heat and cold waves for U.S. cities

Toma, Violeta (1), Curry, Judith (2), Marks, Jesse (3), Webster, Peter (4)

Climate Forecast Applications Network (1), (3), University of Washington (2)

CFAN has been making operational probabilistic forecasts of surface air temperature, heat and cold waves for selected U.S. cities since 2010 to address needs of the energy sector in anticipating natural gas demand. An innovative multi-model prediction system using the CFSv2 and ECMWF forecasts has been developed to exploit the advantages of each model. Several categories of heat and cold waves are predicted for each city, based on both the severity and duration of the event. The ECMWF and CFSv2 forecast streams are calibrated against hindcasts using a Rank Analog approach, together with a PDF mapping technique. Additionally, ensemble clustering is used separately for the ECMWF and CFSv2 forecast streams, based on self clustering and dominant weather regimes, that takes into account combinations of well-known NH teleconnection patterns. An objective weighting technique based on past performance of each model is used to provide CFAN's final forecast. A forecast confidence assessment is made for each forecast based on identification of forecast 'windows of opportunity' determined from the current and predicted strength of teleconnections. Forecast evaluation statistics are presented as a function of region, season and circulation regime.

SESSION: (A4) S2S forecasts for decision making

(A4-01)

Applications of subseasonal to seasonal (S2S) predictions

White, Christopher J. (1,2); Carlsen, Henrik (3); Robertson, Andrew W. (4); Klein, Richard (5); Lazo, Jeffrey K. (6); Kumar, Arun (7); Vitart, Frederic (8); Coughlan de Perez, Erin (4,9); Ray, Andrea J. (10); Brown, Timothy J. (11)

(1) Department of Civil and Environmental Engineering, University of Strathclyde, Glasgow, UK; (2) Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Australia; (3) Stockholm Environment Institute, Stockholm, Sweden

While long-range seasonal outlooks have been operational for many years, until recently the 2 weeks to a season timescale – referred to as ‘subseasonal-to-seasonal’ (S2S) and which sits between the medium- to long-range forecasting timescales – has received relatively little attention. The S2S timescale has long been seen as a ‘predictability desert’, yet a new generation of S2S predictions are starting to bridge the gap between weather forecasts and longer-range prediction. Decisions in a range of sectors are made in this extended-range lead time, therefore there is a strong demand for this new generation of predictions.

At least ten international weather centres now have some capability for issuing experimental or operational S2S predictions, including the European Centre for Medium-Range Weather Forecasting (ECMWF) and the National Oceanic and Atmospheric Administration (NOAA). International efforts are now underway to identify key sources of predictability, improve forecast skill and operationalise aspects of S2S forecasts, however challenges remain in advancing this new frontier. If S2S predictions are to be used effectively, it is important that along with scientific advances, we learn how to develop, communicate and apply these forecasts.

In this presentation, we present the potential of the emerging operational S2S forecasts to the wider weather and climate applications community. We present the first comprehensive review of sectoral applications of S2S predictions, including public health, disaster preparedness, water management, energy and agriculture, which was recently published in *Meteorological Applications*: <https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/met.1654>. We explore the value of applications-relevant S2S predictions, and highlight the opportunities and challenges facing their uptake. We show how social sciences can be integrated with S2S development – from communication to decision-making and valuation of forecasts – to enhance the benefits of ‘climate services’ approaches for extended-range forecasting. We highlight the availability of data repositories of near real-time S2S forecasts and hindcasts, including the WWRP-WCRP (<http://apps.ecmwf.int/datasets/data/s2s>) and North American Multimodel Ensemble (NMME; <http://www.cpc.ncep.noaa.gov/products/NMME/data.html>) repositories, and discuss how they are promoting the use (and aiding the development) of S2S predictions.

While S2S forecasting is at a relatively early stage of development, we conclude that it presents a significant new window of opportunity that can be explored for application-ready capabilities that could allow many sectors the opportunity to systematically plan on a new time horizon.

SESSION: (A4) S2S forecasts for decision making

(A4-02)

Developing new watershed-based climate forecast products for hydrologists and water managers

Sarah Baker (1,2), Andrew Wood (3), Balaji Rajagopalan (1), Flavio Lehner (3), Peitao Peng (4), and Kevin Werner (5)

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Operational sub-seasonal to seasonal (S2S) climate predictions have advanced in skill in recent years but are not yet broadly utilized by stakeholders in the water management sector. While some of the challenges that relate to fundamental predictability are difficult or impossible to surmount, other hurdles related to forecast product formulation, translation, and accessibility can be directly addressed. These include products being misaligned with users' space-time needs, products disseminated in formats users cannot easily process, and products based on raw model outputs that are biased relative to user climatologies. In each of these areas, more can be done to bridge the gap by enhancing the usability, quality, and relevance of water-oriented predictions. In addition, water stakeholder impacts can benefit from short-range extremes predictions (such as 2-3 day storms or 1-week heat waves) at S2S time-scales, for which few products exist.

We present results from a research to operations (R2O) effort sponsored by the NOAA MAPP Climate Testbed to (1) create post-processed climate prediction products to reduce hurdles in water stakeholder adoption, and to (2) create new products depicting the probability of extremes at S2S lead times. The project is currently using NCEP's Climate Forecast System version 2 (CFSv2) and National Multi-model Ensemble (NMME) reforecasts and forecasts to develop real-time watershed-based climate forecast products, and to train post-processing approaches to enhance the skill and reliability of raw real-time S2S forecasts. Prototype S2S climate data products (forecasts and associated skill analyses) are now being operationally disseminated from NCAR on a public website to facilitate further product development through interactions with water managers. Products include CFSv2-based bi-weekly climate forecasts (weeks 1-2, 2-3, and 3-4) for sub-regional scale hydrologic units, and NMME-based monthly and seasonal prediction products.

Website: <http://hydro.rap.ucar.edu/s2s/>

SESSION: (A4) S2S forecasts for decision making

(A4-03)

Improving the predictability of streamflow for hydropower production in Canada using S2S ensemble meteorological forecasts

Bazile, Rachel (1), Boucher, Marie-Amélie (2), Perreault, Luc (3), Leconte, Robert (4)

Université de Sherbrooke, Canada (1), Université de Sherbrooke, Canada (2), IREQ, Canada (3),
Université de Sherbrooke, Canada (4)

Currently, long-term hydrological forecasts at Hydro-Quebec (Quebec's main hydro-power producer) are Extended Streamflow Predictions (ESP), derived from climatology. This process rests on a strong assumption of stationarity which may not hold in a changing climate. Our main working hypothesis is that hydrological forecasts based on dynamic meteorological forecasts have better predictive skill than ESP. By « better », we mean they are more skillful than ESP for lead-times longer than 10 days. In many operational contexts, ESP are used instead of dynamical forecasts beyond this period.

To verify our hypothesis, we rely on a testbed of ten catchments exploited by Hydro-Quebec for hydropower. HSAMI, the conceptual global hydrological model used operationally by Hydro-Québec, was successively fed by three different types of ensemble meteorological forecasts: 1- the 30-day ahead forecasts produced by the European Center for Medium range Weather Forecasts (ECMWF), retrieved from the global S2S database (Vitart et al. 2017); 2- the 7-month ahead forecasts from ECMWF's System4 (Molteni et al. 2011); 3- the ECMWF's SEAS5 forecasts (released in November 2017). In all cases, the forecasted precipitation and temperature (min and max) were used as inputs to HSAMI, with daily time steps. The period from 1995 to 2014 is the same for the three types of forecasts, although they have different issue dates.

Biases in raw meteorological forecasts were first quantified. In some cases, biases were so large that raw forecasts did not lead to any gain in predictability and one might as well use climatology instead of forecasts as inputs to HSAMI. Consequently, biases were removed from precipitation and temperature forecasts using a simple but efficient linear scaling.

Hydrological forecasts skill was assessed using the Continuous Ranked Probability Score (CRPS), as well as the reliability diagram and the rank histogram. ESP were used as a benchmark, as they represent « the system to beat ».

For streamflow forecasts, performance metrics and diagrams were computed using (1) the observed streamflow; and (2) a simulation run for which HSAMI was fed with precipitation and temperature observations. The latter allows for an assessment of forecasts that is free from model and observation uncertainties. However, we consider important to verify forecasts skill against real-life observations, despite the associated flaws and uncertainties, as the goal of forecasting is precisely to anticipate those observations.

The relative performance of the three different types of ensemble forecasts is discussed and compared according to watersheds and seasons. For most watersheds, streamflow and volume forecasts computed from dynamical forecasts were found to be more skillful than ESP for the first 30 days, which confirms our hypothesis. Surprisingly however, streamflow forecasts based on 30-day meteorological forecasts from the S2S database did not in general outperform those based on System4 and SEAS5.

Issues related to the fair comparison of different types of forecasts which do not share common issue dates still need to be addressed in future studies, as well as possibilities for a seamless combination of medium and long term meteorological forecasts into the same hydrological forecasting framework.

SESSION: (A4) S2S forecasts for decision making

(A4-04)

Experimental subseasonal forecasting of atmospheric river variations for the western U.S. during Winters 2017-2018 and 2018-2019

Duane Waliser(1), Mike DeFlorio(1), Alex Goodman(1), Aneesh Subramanian(2), Marty Ralph(2), Bin Guan(3), Frederic Vitart(4), Jeanine Jones(5)

JPL/Caltech/NASA USA (1), CW3E/UCSD USA (2), UCLA USA (3), ECMWF UK (4), California Dept. Water Resources USA (5)

We utilize the Guan and Waliser (2015) atmospheric river (AR) detection algorithm and DeFlorio et al. (2018) AR activity forecast approach on three operational subseasonal forecast systems (ECMWF, NCEP, and ECCO) to predict AR activity over the eastern Pacific Ocean and western U.S., with a focus on subseasonal variations, and in particular the week-3 lead time. The predictand for these subseasonal forecasts is the likelihood of an AR occurring at any time during a given week, with the primary focus being the week-3 window. Forecast verification statistics for these subseasonal AR forecasts will be presented, as well as case studies demonstrating periods where the AR activity appeared to exhibit enhanced/diminished predictability and how well and consistently the models performed during these periods. This is a collaborative activity between the Jet Propulsion Laboratory/NASA, the Center for Western Weather and Water Extremes of the University of California at San Diego, and the Joint Institute for Regional Earth System Science (JIFRESSE) at the University of California, Los Angeles, with sponsorship from the California Department of Water Resources. This activity leverages the ECMWF, NCEP and ECCO hindcasts of the Subseasonal to Seasonal (S2S) Prediction Project, along with their real-time data stream counterparts, and represents one of the S2S Prediction Project's Pilot Projects for applications use. We will also discuss the "operational" framework for the collaboration, the interferences from the 2017-18 winter, and changes and plans for the 2018-19 winter.

SESSION: (A4) S2S forecasts for decision making

(A4-05)

Stratospheric influences on European month-ahead wind power generation and its predictability on subseasonal time scales

Büeler, Dominik (1, 2), Beerli, Remo (3, 2), Grams, Christian M. (1, 2), Wernli, Heini (2)

IMK-TRO, KIT, Germany (1), IAC, ETH Zurich, Switzerland (2), AXPO Trading AG, Switzerland (3)

Wind power is playing an increasingly important role in Europe's electricity generation. Accurate forecasts of wind-power output on various spatial and temporal scales are therefore of high interest for the energy industry. However, predictability of near-surface wind particularly on subseasonal timescales has received relatively little attention. The stratosphere is an important source of subseasonal predictability in winter. We thus investigate how the lower-stratospheric circulation affects month-ahead wind electricity generation in European winter and how this effect influences the skill of subseasonal numerical weather forecasts. In a first step, we use the ERA-Interim reanalysis and the wind-power dataset Renewables.ninja to demonstrate a strong correlation between the strength of the lower-stratospheric circulation and month-ahead wind electricity generation in different regions of Europe. This relationship exists due to episodes of troposphere-stratosphere coupling, which lead to prolonged periods of either the positive or negative phase of the North Atlantic Oscillation (NAO). Since these persistent NAO periods are associated with strong surface wind anomalies, they have an important impact on wind electricity generation, in particular in Northern Europe. Motivated by this empirical relationship, we develop a simple statistical forecasting approach based on the strength of the lower-stratospheric circulation, which provides skillful forecasts of month-ahead wind electricity generation in Europe. In a second step, we investigate the skill of different subseasonal forecast models from the S2S database in predicting month-ahead 10-m wind speed as a proxy for wind electricity generation. The skill of the S2S models is generally higher than the skill of the simple statistical forecast, particularly for short lead times. It is substantially driven by the strength of the lower-stratospheric circulation at initialization time and the associated state of the NAO throughout the forecast, which reflects the empirical relationship from the reanalysis data also in the models. However, there are substantial differences in the skill between different European regions as well as models, with implications for both the energy industry and the numerical modeling community. In a future step, the study will be expanded on other meteorological fields relevant for the energy industry.

SESSION: (A4) S2S forecasts for decision making

(A4-06)

Sub-seasonal to seasonal climate predictions for energy: the S2S4E project

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Despite becoming cost competitive in many settings, renewable energy diffusion remains limited largely due to its generation variability. To foster renewable energy deployment while maintaining energy security, the S2S4E project will provide sub-seasonal to seasonal (S2S) climate forecasts. The main objective of S2S4E is to make the European energy sector more resilient to climate variability and high impact events, such as heat waves, by exploring the potential of S2S predictions tailored to users' needs. This information will enable the energy industry to assess the renewable energy sources capacity to meet demand over extended time horizons (weeks to months), focusing on the impact of climate variables on energy outputs. Based on a user-centric approach of climate services development, S2S4E will provide access to tailored real-time climate prediction products to optimise decision making across all levels of the energy sector community. A Decision Support Tool (DST) will be co-designed and co-developed with relevant industrial partners of the consortium which represent different needs and interests in terms of regions, renewable energy sources (wind, solar and hydro) and electricity demand. The DST will be developed taking into account eight historical case studies pointed as the most relevant by industrial partners, i.e. periods with an unusual climate behaviour affecting the energy market. To illustrate S2S potential, one of these case studies will be presented. In winter 2016 a significant decrease of wind speed was observed through all central and southern Europe leading to a reduction of wind energy generation. At the same time the cold wave observed in December had a significant impact on the power system. It created a combination of large increase in electricity demand and lower than usual renewable energy generation.

SESSION: (A4) S2S forecasts for decision making

(A4-07)

**Excessive Heat Events and Health: Building Resilience based on Global Scale
Subseasonal-to-Seasonal Excessive Heat Outlook Systems**

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UMCP-ESSIC. USA

Excessive heat events (EHE) are the primary cause for mortality resulting from atmospheric extremes. As the population becomes older and EHE intensity and frequency is increasing mortality is expected to grow and thus early warning systems become crucial. Data from the S2S database are used to demonstrate the feasibility of S2S forecasting of EHE. The paper concludes with the presentation of an experimental S2S quasi-operational excessive heat outlook system that focuses on human health.

SESSION: (A4) S2S forecasts for decision making

(A4-08)

Using hydrologic prediction skill elasticity to quantify the benefits of s2s climate information for hydrologic forecasting

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Water resources decision-making commonly relies on monthly to seasonal streamflow forecasts among other kinds of information. The skill of such predictions derives from the ability to estimate a watershed's initial moisture and energy conditions and to forecast future weather and climate. A recent project sponsored by the US water agencies (the US Army Corps of Engineers and the Bureau of Reclamation) investigated the role of each source of predictability at S2S time scales to assess where and when improvements in each area can improve streamflow forecasts for use in water management. The study used hydrologic simulation models for 424 US watersheds in an idealized predictability framework to characterize the influence of varying levels of skill in each predictability area on streamflow prediction skill. It enabled the calculation of derivatives in hydrologic predictability (ie, skill elasticities) throughout the initial conditions and future forcing skill space. We find that regional and seasonal variations in watershed hydro-climatology strongly control the relative importance of initial hydrologic conditions and S2S climate forecasts, leading to striking differences between rainfall driven and snowmelt driven watersheds. The resulting analysis provides insights on the relative benefits of investments toward improving watershed monitoring (through modeling and measurement) versus improved climate forecasting and application. A somewhat counterintuitive but encouraging finding was that climate forecast skill improvements can be amplified in streamflow prediction skill, which means that climate forecasts may have greater benefit for S2S flow forecasting than may be expected from climate forecast skill alone.

SESSION: (A4) S2S forecasts for decision making

(A5-01)

The Land Surface “Sweet Spot” Between Weather and Climate

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Weather forecasting is typically considered a deterministic initial value problem of the atmosphere. Climate on seasonal to decadal time scales is strongly driven by ocean surface temperatures and near-surface heat content, and forecasts at these longer time scales are probabilistic in nature. In the difficult transition region between deterministic and probabilistic forecasts, the land surface has its greatest potential impact on numerical forecasts. Anomalies in land surface states affect the atmosphere through anomalous surface fluxes that manifest via the diurnal cycle. This occurs where and when the atmosphere is sensitive to its lower boundary, where the land surface anomalies are large enough and persistent enough to have a significant effect. This terrestrial source of potential predictability is a “low-hanging fruit” but has been under-exploited in operational forecasting for a number of reasons. Reliable, high-quality real-time observations of land surface states needed to initialize this component of forecast models are only now becoming widely available, and land data assimilation systems that can ingest this information are relatively new. Models have not been developed, calibrated or validated with regards to the coupled processes that link land and atmosphere, partially because of the historical lack of necessary surface, near-surface and boundary-layer data, and partly because the culture of model development has been fragmented along traditional disciplinary lines. This has resulted in both land surface and atmospheric modelers spending much time and effort trying to compensate for the systematic errors passed across the model interface, rather than developing an appropriately coupled model system. The opportunity is now to realize the potential predictability of from the land surface, whose inherent memory is at the subseasonal timescales that are of such great interest today.

SESSION: (A5) Land initialization and processes

(A5-02)

The role of the midlatitude ocean in sub-seasonal prediction

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Intrinsic oceanic variability exhibits longer time scales and smaller spatial scales than atmospheric variability. This is due, in part, to the larger heat capacity of the ocean and, in the middle latitudes, to the smaller Rossby radius of deformation. Due to the slowly evolving nature of the ocean, the oceanic state is usually assumed to be invariant for the purposes of weather prediction. However, on subseasonal timescales, the oceanic state does evolve, especially on the fine scales associated with oceanic fronts and mesoscale eddies. This talk will survey recent studies that have focused on the influence of the midlatitude on oceanic variability on atmospheric storm tracks. This interaction has potential implications for subseasonal forecast skill. Dry dynamics is unlikely to be responsible for this interaction, due to the mismatch in the Rossby radius of deformation between the atmosphere and the ocean. This suggests a role for moist dynamics in this interaction.

SESSION: (A5) Land initialization and processes

(A5-03)

An improved approach to land-surface initialization in the Met Office's Global Seasonal Forecasting System (GloSea)

Davis, Philip (1), Comer, Ruth (1), Fereday, David (1), Knight, Jeff (1), MacLachlan, Craig (1), Scaife, Adam (1)

Met Office, Hadley Centre, UK (1)

The land surface is a crucial component in the climate system; the exchange of heat and moisture flux between the land and atmosphere has an important impact on near-surface temperatures and precipitation.

Here, we describe experiments to initialize the land surface (notably soil moisture) in the UK Met Office's (MO) state-of-the-art Global Seasonal Forecasting System (GloSea). GloSea employs a coupled atmosphere-ocean model, using MO's Unified Model and Nucleus for European Modeling of the Ocean. Land interactions are modeled using the Joint UK Land Environment Simulator (JULES).

Due to the challenge in obtaining consistent information for both the historical and real-time periods, we have to resort to using a climatology for both hindcasts and forecasts. Inconsistencies in the initialization (and therefore the forecast/ hindcast model climatology) can result in a biased forecast. This work hopes to improve the current initialization scheme.

Owing to the availability of real-time data, we investigate land-surface initialization using the Japanese 55-year Reanalysis Project (JRA-55), provided by the Japanese Meteorological Agency. Our goal is to replace the existing climatology used for the forecasts with soil moisture calculated from the daily data. Hindcasts, as for our experiments, will be initialized using a time-series from a JULES reanalysis forced with the JRA-55 data.

We discuss the impact of the new initialization scheme on standard skill scores, as well as case studies of the European and Russian heat-waves of 2003 and 2010.

SESSION: (A5) Land initialization and processes

(A5-04)

Land-surface initialisation affects Indian monsoon subseasonal predictability

Tuinenburg, Obbe

Utrecht University, The Netherlands

The influence of the land surface wetness state on precipitation is known to vary across the world. In areas where there exists such a strong coupling between land and atmosphere, land surface wetness state information can be used to increase the predictability of precipitation on several timescale, varying from the daily to the seasonal timescale.

Whether there is a strong coupling between land surface and precipitation depends on how the surface energy balance affects turbulent atmospheric boundary layer processes and cloud formation. If the atmosphere is too dry, no precipitation will occur regardless of land surface conditions. If the atmosphere is too moist, precipitation will always occur regardless of land surface conditions. Moreover, there should be some conditional instability to allow convective precipitation to occur.

India is a location with a strong coupling between land and atmosphere. Moreover, atmospheric models have a strong dry bias during the monsoon season.

Here, we will study India's summer monsoon predictability based on (sub-)seasonal atmospheric simulations (S2S-project archive) up to the seasonal timescale. We specifically analyse the precipitation difference between ensemble members and regress these differences against the different land surface initialisations of the ensemble members. This regression is used to determine how sensitive monsoon precipitation is to land surface conditions for each model.

Finally, we analyse this sensitivity based on local land-atmosphere coupling as well as atmospheric moisture transport.

Initial results show that there is a strong relation between initialised surface wetness and India summer monsoon precipitation. An analysis of land surface wetness-precipitation coupling in the S2S-database, as well as its atmospheric moisture transport pathways, will be presented..

SESSION: (A6) Ocean initialization and processes

(A6-01)

Impact of ocean observation systems on ocean analyses and subseasonal forecasts

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SIO-UCSD, USA (1), ECMWF, UK (2), Tsukuba University, Japan (3)

We evaluate the relative merits of different ocean observation systems (moored buoys, Argo, satellite, XBTs, and others) by their impact on ocean analyses and subseasonal forecast skill. Several ocean analyses were performed where different ocean observation platforms were withheld from the assimilation in addition to one ocean analysis where all observations were assimilated. We then use these ocean analyses products for initializing a set of subseasonal forecasts to evaluate the impact of different ocean analyses states on the forecast skill. We use the European Centre for Medium-Range Weather Forecasts (ECMWF) ensemble prediction system for the twenty-year sub-seasonal hindcast experiments. Results from these hindcast experiments will be presented to highlight changes in the ocean analyses states and their impact on the forecast skill of the MJO, monsoon intraseasonal oscillations, atmospheric rivers as well as global temperature and precipitation.

Coupled air-sea interaction processes relevant to intraseasonal variability (e.g. the MJO, MISO, atmospheric blocking) in the earth's climate system are inadequately represented in regional and global coupled models. These inaccuracies could be related to either poor parameterization of model physics or insufficient model resolution to resolve the critical processes. New efforts in observations, process understanding, and translation into weather and climate models are necessary for improvements in simulation and prediction of the intraseasonal variability and associated weather events. We will discuss the merits of different ocean observation platforms in this context and also future observation and model improvement pathways.

SESSION: (A6) Ocean initialization and processes

(A6-02)

Sea Ice and Filling Data Gaps for S2S Prediction

Chidong Zhang

NOAA PMEL

Sea ice has been identified as one of the major sources of predictability on S2S timescales. Prediction of sea ice itself has been a challenge. How S2S prediction depends on our ability of understanding and predicting sea-ice variability has yet to be determined. Satellite observations of sea-ice environment are rudimentary at best. In situ observations from open water adjacent to sea ice have been unavailable up to recently. New observing technology has demonstrated that observational measurement of the upper ocean, atmosphere and their interface near the edge of sea ice is now possible and promising. Further explorations are needed to optimally use such observations to benefit S2S prediction. This is but one example of issues related to data need for S2S prediction that should be addressed by the S2S Project.

SESSION: (B1) Mechanisms of S2D predictability

(B1-01)

On the mechanisms that give rise to predictability on Seasonal-to-decadal time-scales

Robson, Jon

University of Reading

Providing the best climate information available for smaller regions, and on shorter timescales, is a crucial goal for Climate Science in order to aid planning and adaptation decisions. Therefore, over the last 10-15 years, or so, there has been an explosion in the interest in so called “near-term” climate predictions, which aim to predict both the regional impact of forced changes and the internal variability. There is now significant evidence showing that initialising coupled climate models from observations leads to improved retrospective predictions of a range of variables on inter-annual, multi-year and decadal time-scales. However, to confidently predict future variability, it is crucial that the mechanisms that give rise to predictive skill on these time-scales are understood. As prediction is also the ultimate test of our understanding and of our models, climate predictions on seasonal-to-decadal time-scales also represent a powerful tool to explore our understanding of regional climate dynamics, and to improve our models. Therefore, in this talk I’ll give a brief overview of the mechanisms that are important for delivering skill on different time-scales. I’ll also provide some commentary on what mechanisms we think are more robust, and those which need more understanding. Finally, I’ll discuss ways in which novel experiments using seasonal-to-decadal predictions can be used to probe our understanding further.

SESSION: (B1) Mechanisms of S2D predictability

(B1-02)

Initialized decadal prediction for transition to positive phase of the Interdecadal Pacific Oscillation and resumption of larger rates of global warming

Meehl, Gerald A.(1), Hu, Aixue(1), Teng, Haiyan(1)

NCAR, USA (1)

The negative phase of the Interdecadal Pacific Oscillation (IPO), a dominant mode of multi-decadal variability of sea surface temperatures (SSTs) in the Pacific, contributed to the reduced rate of global surface temperature warming in the early 2000s. A proposed mechanism for IPO multidecadal variability indicates that the relative magnitude of decadal timescale upper ocean heat content in the off-equatorial western tropical Pacific could provide conditions for an interannual El Niño/Southern Oscillation (ENSO) event to trigger a transition of tropical Pacific SSTs to the opposite IPO phase. Evidence is presented from a set of initialized hindcasts with CCSM4 to show this role for El Niño in the 1970s transition to positive IPO, and for La Niña in the late 1990s transition to negative IPO. A decadal prediction initialized in 2013 shows that the Niño3.4 SSTs qualitatively tracked the observations through 2015. The year 3-7 average prediction (2015-2019) from the 2013 initial state shows a transition to the positive phase of the IPO from the previous negative phase, and a resumption of larger rates of global warming over the 2013-2022 period consistent with a predicted positive IPO phase.

SESSION: (B1) Mechanisms of S2D predictability

(B1-03)

Tropical Atlantic impacts on subdecadal variability in the Pacific

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JAMSTEC, Japan (1), The University of Tokyo, Japan (2)

We demonstrate the significant impact of the tropical Atlantic Ocean on the Pacific climate on subdecadal timescales, by the so-called pacemaker experiments (partial data assimilation experiments). In mid-2000s when the positive peak of the Atlantic Multidecadal Oscillation was observed, the high sea surface temperature over the tropical Atlantic Ocean strengthened the equatorial Pacific trade wind and worked to keep warm and cold tendencies in the western and eastern Pacific Oceans, respectively. In addition, an anti-cyclonic surface wind anomaly formed in the off-equatorial area of the North Pacific works to raise the upper ocean heat content below and contributes to the subsequent warming in the western Pacific Ocean. These changes of the off-equatorial surface winds are similar to common responses to seasonal warming of the tropical Atlantic Ocean, while the deepening of the ocean thermocline is also simulated as dynamical ocean response on subdecadal timescales. Our CMIP5 decadal hindcasts with initialization insufficiently reproduce this subdecadal modulation in mid-2000s even a few years in advance.

SESSION: (B1) Mechanisms of S2D predictability

(B1-04)

Multi-year Predictability of Total Soil Water, Drought, and Wildfire over the Globe

June-Yi Lee (1), Axel Timmermann (2), Yoshiitsu Chikamoto (3)

Pusan National University (1), IBS Center for Climate Physics (2), Utah State University, Logan (3)

Severe drought and increased chance in wildfire occurrence have significant impacts to a wide range of sectors such as agriculture, energy, food security, forestry, drinking water, and tourism. This study aims to assess multi-year predictability and prediction skill for total soil water, drought, and wildfire occurrence over the Globe using a multi-year dynamical prediction system based on the Community Earth System Model version 1.0.3 and to better understand sources of their predictability. We demonstrate that the dynamical prediction system has a high degree of skill in forecasting total soil water, drought, and wildfire probabilities up to 2~4-year lead time over many parts of the Globe including the southern part of North and South America, Central America, the northern part of South Africa, Maritime Continents, Europe and Asia. The important sources of multi-year predictability identified in the study include the Trans-basin variability (TBV) between the Atlantic and Pacific sea surface temperature (SST), the low-pass filtering characteristics of soils, and anthropogenic radiative forcing. In particular, the positive phase of TBV, characterized by the relatively warmer SST over the Atlantic than the Pacific, is favorable for less precipitation, less soil water, drought, and more wildfire occurrence over the southern part of North and South America, the northern part of South Africa and many parts of Europe and Asia. However, the opposite condition tends to prevail in Central America, the southern part of South Africa and the Maritime Continent. The multi-year predictability of drought and wildfire occurrence can be utilized for Humanitarian Crisis Management.

SESSION: (B1) Mechanisms of S2D predictability

(B1-05)

The Pacific Decadal Precession: Our current understanding of its dynamics, regional climate effects, and predictability

Anderson, Bruce (1), Furtado, Jason (2), Di Lorenzo, Emanuele (3), Capotondi, Antoinette (4)

Boston University, USA (1), University of Oklahoma (2), Georgia Institute of Technology (3),
University of Colorado (4)

Events of recent years highlight the profound impact of decadal-scale climate shifts upon physical, biological and socioeconomic systems. Previously, research to understand, anticipate, and prepare for the regional effects that accompany decadal-scale climate shifts invoked well-known modes of decadal climate variability and change—e.g., the Atlantic Multidecadal Oscillation (AMO), the Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO). Here we will discuss the sources and physical processes giving rise to a recently revealed mode of decadal climate variability termed the Pacific Decadal Precession (PDP), a ~10-year counter-clockwise progression of an atmospheric pressure dipole around the North Pacific. During its progression, the PDP has teleconnected links to multiple climate extremes including: sustained droughts across the western and central US; enhanced fire severity in Alaska and California; the propensity for more frequent cold extremes over the eastern US; and the formation and persistence of prolonged marine heatwaves in the Northeast Pacific. Further, it has signatures that extend from the tropical Pacific subsurface through to the Arctic stratosphere. In this talk we will characterize the PDP's local and teleconnected interactions with, and impacts on, multiple earth system components, including atmosphere, ocean, terrestrial, and cryospheric systems. We will also analyze and diagnose the underlying phenomena and processes that sustain the PDP and its regional climate effects. Finally, we will start to examine which components of the PDP's evolution are statistically and/or dynamically predictable; which regional-scale effects are impacted by these predictable components; what oceanic, atmospheric, and/or terrestrial conditions sustain these predictable components; and what underlying processes are fundamental for generating these predictable components. Overall, understanding the sources and physical processes giving rise to the predictability of the PDP's evolution will provide valuable information to many communities and allow them to anticipate and prepare for the social, economic, environmental impacts of its decadal- and regional-scale climate effects.

SESSION: (B1) Mechanisms of S2D predictability

(B1-06)

Decadal variability and predictability in the Southern Ocean - implications for interpreting recent observed trends

Delworth, Thomas (1), Zhang, Liping (1,2), Cooke, William (1,3), Yang, Xiaosong (1,3)

GFDL/NOAA (1), Princeton University (2), UCAR, USA (3)

While decadal variability and predictability in the North Atlantic and North Pacific have received considerable attention, there has been less work on decadal variability and predictability in the Southern Ocean. As shown previously, a coherent mode of decadal to centennial variability exists in multiple climate models. The mechanism involves a multidecadal accumulation of heat in the subsurface of the Southern Ocean. This accumulation of heat in the subsurface tends to reduce ocean stratification, eventually leading to the onset of intense oceanic convection and venting of heat to the atmosphere. The discharge of heat from the interior ocean, combined with surface freshening, restratifies the water column and the cycle begins again with the accumulation of subsurface heat. During the phase when the accumulated subsurface heat is released through oceanic convection, there can be considerable regional scale climatic impacts, along with substantial impacts on ocean heat uptake. Using a large suite of perfect predictability experiments, in concert with long control simulations and experimental hindcasts, we show that this variability has a high degree of predictability on decadal scales. We present further results that show this type of variability may play an important role for interpreting recently observed trends of sea ice and temperature in the Southern Ocean. Specifically, observed trends over the last several decades resemble a particular phase of this variability in which reduced oceanic convection leads to subsurface warming and surface cooling and freshening, with associated increases in sea ice extent. This phase of natural variability may substantially contribute to observed decadal trends, working in concert with other factors.

SESSION: (B1) Mechanisms of S2D predictability

(B1-07)

Variability and Teleconnections in the Indian Ocean: Mechanisms, Predictability and Climatic Influence

Chapman, Christopher (1), Bernadette Sloyan (1)

CSIRO Oceans and Atmosphere (1)

The Indian Ocean basin is host to variability on a variety of spatio-temporal scales that exert a strong influence on the climate system as a whole, through influences on the Asian and Australian Monsoons, the Indian Ocean Dipole (IOD) and the Hadley Cell. However, how variance enters and propagates throughout the Indian Ocean, how it ultimately imprints on the greater climate system and the potential predictability on time-scales exceeding 12 months are not currently well understood and impede current forecasting systems.

Using a combination of ocean observation, a long, fully coupled control simulation, and a shorter data-assimilating ensemble of simulations, we investigate the physical mechanisms driving variability on annual to decadal time-scales in the Indian Ocean. We demonstrate using band-selective periodograms that, in contrast to variability on sub-annual timescales, variance at time scales exceeding 12 months lies not in the tropics, but in the Southern Hemisphere sub-tropical regions associated with mode-water formation. Teleconnection pathways between these sub-tropical high-variance regions and the tropics will be elucidated, showing several distinct pathways linking mid and low latitudes over longer time scales. By studying disturbances propagating along these teleconnection pathways, we are able to determine characteristic time-scales of propagation and persistence, as well as their dominant length-scales. The disturbances are shown to be large, multi-scale and to propagate significantly slower than linear Rossby waves, suggestive of a dominant role being played by non-linearity in the underlying dynamics. The potential predictability of disturbances propagating along these pathways is then briefly discussed using the results of the large, data-assimilating ensemble of simulations.

Finally, the influence of oceanic signals emanating from the subtropical Southern Indian Ocean on the climate system will be discussed, primarily through their influence on the anomalous sea-surface heights and sea-surface temperatures.

SESSION: (B1) Mechanisms of S2D predictability

(B1-08)

Dynamical and thermodynamical impacts of the Atlantic Multidecadal Variability on the European climate

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The Atlantic Multidecadal Variability (AMV) is known for influencing the mid-latitudes climate variability. The physical mechanisms between the AMV and the European winter climate are assessed with the CNRM-CM5 model with large ensembles of simulations in which the North Atlantic Sea Surface Temperature (SST) is restored to SST anomalies characterizing the observed AMV. The restoring pattern is obtained with the superimposition of observed SST anomalies (computed from the regression of the observed interannual SST on the standardized AMV index) on the model's monthly climatology. The influence of the AMV amplitude on the teleconnection has been evaluated with three sets of 40-member of 10 years for each AMV phase. Each set corresponds to SST anomalies related to one, two or three standard deviations of the observed AMV (respectively named 1*AMV, 2*AMV and 3*AMV experiments). Each member starts from a random date of the so-called pre-industrial control run (a 850-yr long integration where all external forcings are kept constant to their estimated 1850 pre-industrial values).

We find that a change of the AMV phase in the 1*AMV experiment is not associated with a significant anomaly of surface air temperature (SAT) over Europe. Conversely, in the 2*AMV and 3*AMV experiments, a significant warming is found up to $\sim 0.5^{\circ}\text{C}$ over western Europe, and up to 1°C over Scandinavia. Precipitation changes in the 1*AMV experiment are not significant but an increase of $\sim 6\%$ is found over central Europe in the 2*AMV and 3*AMV experiments.

We quantify the impacts of the AMV on the European climate with an analog method separating the influence of large-scale circulation changes from the thermodynamical effect due to the SST variability. The decomposition shows that SAT over Europe in the 1*AMV experiment is equally driven by both the circulation anomalies and the residual (mainly containing the thermodynamic effects). In the 2*AMV and 3*AMV experiments, SAT anomalies are driven by the residual while the amplitude of the dynamical response remains stable, at the 1*AMV level. For the precipitation anomalies, both dynamical and residual influences contribute to the total response in the three experiments. We show that the residual component is mainly driven by the advection of heat and humidity from the ocean by the mean westerly flow. The dynamical component related to the circulation anomalies over Europe is found to be likely explained by the tropical Atlantic where a Gill-like response influences the position and the speed of the jet, which enhances the northward propagation of Rossby waves during a positive phase of the AMV. An influence from the North Pacific is also detected with the propagation of longer Rossby waves potentially interacting with the shorter ones propagating from the tropical Atlantic.

SESSION: (B1) Mechanisms of S2D predictability

(B1-09)

Antarctic stratospheric ozone and seasonal predictability over southern Africa

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Seasonal predictive skill over southern Africa is highest during the mid-summer period of December to February, and particularly so during seasons associated with El Niño or La Niña events. Forecast skill is significantly less for seasons associated with a neutral El Niño Southern Oscillation (ENSO) state. Most El Niño events are associated with drought over southern Africa, but the signal is not linear, and there are instances where the teleconnection has failed. A key example of the latter is the super El Niño of 1997/98, which was associated with normal rainfall over southern Africa. Seasonal forecasts of mid-summer rainfall have also been demonstrated to be overconfident in predicting drought over southern Africa during seasons associated with El Niño events. In this study we address the role of a largely unexplored potential source of seasonal predictability of southern Africa climate, namely the radiative forcing originating from anomalous Antarctic stratospheric ozone concentrations. The focus is specifically on the prediction of mid-summer rainfall and circulation patterns over southern Africa, given that the critical period for radiative forcing from Antarctic stratospheric ozone is the austral spring when sunlight returns to the South Pole. The signal that originates in the Antarctic stratosphere in spring from anomalous ozone concentrations has long been known to affect the Southern Hemisphere troposphere in lower latitudes with a lag of a few months. However, impacts on mid-summer climate variability, and associated predictability, have remained largely unexplored. Our focus is on determining whether this form of radiative forcing can provide useful skill in the prediction of rainfall over southern Africa during ENSO neutral seasons, and also whether anomalous Antarctic stratospheric ozone forcing has an impact on the ENSO teleconnection to southern Africa (and thus on predictability).

The investigation relies on a set of Atmospheric Model Intercomparison Project (AMIP) - style sensitivity experiments performed using the conformal-cubic atmospheric model (CCAM) of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The model was forced with sea-surface temperatures (SSTs) and sea-ice concentrations for the period 1871-2015 obtained from the Coupled Model Intercomparison Project Phase Six (CMIP6) data base. Ozone and carbon dioxide concentrations as well as aerosol emissions are prescribed in the simulations using CMIP5 forcings. In the simulations CCAM ran fully coupled to the dynamic land-surface model CABLE (CSIRO Atmosphere Biosphere Land Exchange) and utilised a prognostic aerosol scheme. The CCAM-CABLE system was applied at a resolution of about 200 km in the horizontal and with 27 levels in the vertical. A twelve member ensemble of simulations was generated, with each member using slightly different initial conditions. A second ensemble of simulations was generated by following exactly the same experimental design except that the time-varying ozone forcing files were replaced with seasonally varying climatologies (this constitutes the control experiment). The simulations are thus designed to determine whether inter-annually varying prescribed ozone concentrations and associated radiative forcing provide enhanced skill in simulations of mid-summer climate anomalies in the presence of a perfect description of historical ENSO events (compared to the case where only climatological ozone forcing is used). The simulations were subsequently analysed to determine their ability to represent inter-annual variations in spring and mid-summer circulations patterns over the Southern Hemisphere and the corresponding variations in rainfall over southern Africa. The results statistically differentiate in model skill for seasons of El Niño, La Niña and neutral states, and are supplemented by case studies of the simulations obtained for selected individual seasons, including the 1997/1998 El Niño event.

SESSION: (B1) Mechanisms of S2D predictability

(B1-10)

Impacts of the Atlantic Multidecadal Variability on the tropical climate and tropical cyclone activity

Yohan Ruprich-Robert (1,2,3), Hiroyuki Murakami (2,3), Tom Delworth (3), Rym Msadek (4), Frederic Castruccio (5), Stephen Yeager (5), Gokhan Danabasoglu (5)

Barcelon Supercomputing Center, Spain (1), Princeton University, USA (2), GFDL, USA (3), Cerfacs, France (4), NCAR, USA (5)

The Atlantic Multidecadal Variability (AMV) is associated with marked modulations of climate anomalies over many areas of the globe. This includes droughts in Africa and North America, decline in sea ice, changes of tropical cyclone activity in the Atlantic, and changes in the atmospheric large-scale circulation. However, the shortness of the historical observations compared to the AMV period (~60-80yr) makes it difficult to show that the AMV is a direct driver of these variations. To isolate the AMV climate response, we use a suite of global coupled models from GFDL and NCAR, in which the North Atlantic sea surface temperatures are restored to the observed AMV pattern, while the other oceanic basins are left fully coupled. To explore and robustly isolate the AMV impacts on weather extremes (e.g., heat waves, tropical cyclones), we perform large ensemble simulations (between 30 and 100 members) that are integrated for 10 years.

During boreal summer, in all models the AMV warming alters the Walker Circulation and modifies the surface winds over the tropical Pacific Ocean. During boreal winter, the AMV warming is associated with large anomalies over the Pacific that project onto a negative phase of the Pacific Decadal Oscillation (PDO). This PDO response comes from a lagged adjustment of the tropical Pacific to the summer AMV forcing, highlighting the necessity of

using a global coupled framework to fully capture the AMV climate impacts. Finally, it is shown that the AMV warming leads to changes in the tropical cyclone activity over the entire tropical belt, with more tropical cyclones over the Atlantic and less tropical cyclones over the Pacific. These changes are very similar to the fluctuations of the tropical cyclone activity observed over the last 40 years. It hence suggests that the 1995/96 phase shift of the AMV has partly driven these variations.

SESSION: (B1) Mechanisms of S2D predictability

(B1-11)

Oceanic and Atmospheric Sources of Seasonal Tropical Cyclone Predictability

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Tropical cyclones (TCs) are among the costliest and deadliest natural hazards. The goal of this research is to improve seasonal prediction and future projection of TC activity by understanding the physical relationships between TCs, modes of climate variability, and atmospheric internal variability using observations and ensembles of high-resolution climate model experiments. One major source of seasonal TC predictability is sea-surface temperature (SST) patterns, which can be predictable in advance of the hurricane season and can influence environmental favorability for TCs. We discovered that: 1) Atlantic and Pacific SST patterns drive compensating and constructive influences on Atlantic hurricane seasons, with concurrent La Niña and positive Atlantic Meridional Mode (AMM) conditions supporting the most active hurricane seasons, and strong concurrent El Niño and positive AMM driving near-average seasons; 2) The location of El Niño's SST warming plays a critical role in the degree of Atlantic TC suppression, with Central Pacific/Warm Pool El Niño substantially more effective at reducing Atlantic TCs than East Pacific/Cold Tongue El Niño, for equal warming intensity. This is physically explained by the strong zonal gradient in background tropical Pacific SST, together with the (climate-variant) SST threshold for deep convection. Less warming is needed in the Central Pacific to reach the SST threshold for deep convection, which is the key link to the teleconnected Atlantic vertical wind shear response; 3) Variability in the typical Atlantic TC precursor, African Easterly Waves (AEWs), provides little seasonal TC predictability, as suggested by mechanistic regional climate model simulations in which AEWs are prescribed or removed through the model's lateral boundary conditions; and 4) The tropical SST biases common to generations of coupled atmosphere-ocean climate models cause substantial errors in simulated TC activity, with an under-simulation of 50% in the Atlantic and over-simulation of 80% in the East Pacific. This work highlights key regions where reducing SST bias could improve predictions and projections of TC activity.

SESSION: (B1) Mechanisms of S2D predictability

(B1-12)

Sources of skill in decadal predictions of Sahel precipitation

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The new, 40-member Large Ensemble of decadal predictions with the Community Earth System Model (CESM-DP-LE) shows considerable skill in predicting precipitation anomalies over the African Sahel region several years in advance. Such skillful predictions of the Sahel precipitation

would provide decision makers with the ability to mitigate the impacts of a drought. Here, we assess the sources of this skill in the CESM-DP-LE through comparisons with its predecessor based on an earlier version of the CESM; its uninitialized Large Ensemble counterpart; persistence; and with observations. The relationships of Sahel precipitation with surface and upper tropospheric conditions are examined globally, but with a particular focus on regions and processes that have been previously identified as important for Sahel rainfall predictability. We first examine how skill in Atlantic SST associated with Atlantic Multidecadal Variability affects prediction skill for Sahel rainfall. We also investigate the influence of ocean-driven hemispheric SST asymmetry on the Sahel through application of an energetic framework that connects high latitude surface heat fluxes to tropical atmospheric overturning and precipitation. We then assess the role of atmospheric stability across the tropics and study whether improved representation of tropical tropospheric structure in the CESM-DP-LE is important. This connection to the upper troposphere may help to explain how long lead time skill in the tropical Indian and Pacific Oceans contributes to improved skill in predictions of Sahel precipitation.

SESSION: (B1) Mechanisms of S2D predictability

(B1-13)

Projected Changes in S2D Hydroclimate Predictability in North America in CESM-LE

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Potential S2D predictability of North American hydroclimate anomalies, and its sensitivity to external forcing, is evaluated within the 40 climate realizations from the Community Earth System Modeling Large Ensemble (CESM-LE). Each ensemble member experiences the same external forcing scenario (observed + RCP8.5) over the years 1950 to 2070. The hydroclimate variables examined are soil moisture (0-1 m depth), Palmer Drought Severity Index (PDSI), and precipitation. As remote predictors, we consider the leading mode of Pacific sea surface temperature variability within three different domains: the Tropical Pacific (30°S-30°N; e.g., ENSO), the Indo-Pacific (20°S-70°N; e.g., the IPO), and the North Pacific (20-70°N; e.g. the PDO). We also include land surface memory by specifying soil moisture or PDSI state 12 months prior as a local source predictor. By performing simple and multiple linear regression analyses across successive 20-year periods, where the externally-forced signal represented by the ensemble mean is first removed, we can then evaluate the changing relative importance of Pacific forcing and land surface memory upon predictability, measured by a signal-to-noise (S2N) ratio between explained and unexplained variances. Comparison is also made with a similar analysis applied to the observational record over the years 1950-2015.

The relative importance of the remote Pacific and local memory predictors was found to have significant regional variation in the CESM-LE. The Pacific contribution was large across the southern tier of the United States, dominating predictability in the North American Southwest. In other regions, the land surface memory process was more important; in particular, soil moisture memory dominated central Canada predictability, yielding a S2N ratio of comparable magnitude (~0.5) as ENSO over the Southwest US. For some regions, such as the central US, the two sources were about equally important. We also assessed the relative importance of the three Pacific predictors, finding that ENSO yields the highest S2N ratios, with the IPO predictor yielding similar S2N patterns, though slightly weaker, and the PDO slightly weaker still. We also found that precipitation is very poorly correlated to the previous year's precipitation anomalies, while for annual soil moisture anomalies the memory has a more significant footprint. PDSI predictors show similar patterns as for soil moisture, albeit with slightly lower S2N ratios.

We found that for most North American regions, the CESM projects hydroclimate predictability to increase in the warmer climate, even though there is no significant change in overall hydroclimate variability. This is due primarily to a strengthening of the Pacific-related predictable component which coincides with a pronounced increase in the variance of tropical Pacific sea surface temperatures. In contrast, predictability due to land surface memory remains the same or slightly decreases over time. These findings suggest that interannual hydroclimate predictability over certain regions of North America could be improved by combining remote and local sources of hydroclimate predictability.

SESSION: (B1) Mechanisms of S2D predictability

(B1-14)

ENSO: towards breaching the springtime predictability barrier

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The springtime predictability barrier in ENSO predictions (ref Webster Song) arises from stochastic processes occurring in the tropical Pacific that are tied to the annual cycle. As a result, forecast initialized prior to May (and in some years, as late as July) have shown little skill in ENSO prediction from late summer to the end of the year. Recent advances in global seasonal forecast models appear to be breaching the predictability barrier to some extent. We assess the ENSO hindcast skill of the latest version of the ECMWF Seasonal Forecasting System (SEAS5), relative to the previous version (SEAS4). Extended predictability of Niño 3.4 from SEAS5 shows correlation coefficients 0.7 for all initialization months (including spring) for forecasts 5-6 months in advance. We have conducted a climate dynamics analysis seeking to identify the sources of this extended range ENSO predictability. We have identified DJF precursor signals in upper tropospheric and stratospheric anomalies at high latitudes of both hemispheres, consistent with research showing important extratropical forcing of surface wind anomalies and SST responses in the equatorial and off-equatorial Pacific. We have updated the analysis of ENSO – precipitation relationships in the U.S. by analyzing shifts in the statistical distribution of rainfall during warm (El Niño) and cold (La Niña) phases of the Southern Oscillation for the period 1981-2016. An evaluation is presented of the skill of ECMWF SEAS5 in predicting U.S precipitation anomalies associated with ENSO.

SESSION: (B1) Mechanisms of S2D predictability

(B1-15)

Multi-scale enhancement of climate prediction over land by increasing the model sensitivity to vegetation variability

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The effective sub-grid vegetation fractional coverage varies seasonally and at interannual time-scales in response to leaf-canopy growth, phenology and senescence. Therefore it affects biophysical parameters such as the surface resistance to evapotranspiration, albedo, roughness length, and water from soil field capacity exploitable by vegetation. To adequately represent this effect in the EC-Earth ESM, we included an exponential dependence of the vegetation cover on the Leaf Area Index according to the Lambert Beer law of extinction of light under vegetation canopy.

By comparing two sets of simulations performed with and without the new variable fractional-coverage parameterization, spanning from centennial (20th Century) simulations and retrospective predictions to the decadal (5-years), seasonal (2-4 months) and weather (4 days) time-scales, we show for the first time a significant enhancement in climate simulation and prediction over land that is consistently obtained at the multiple time-scales considered. Particularly large effects at multiple time scales are shown over boreal winter middle-to-high latitudes over Canada, West US, Eastern Europe, Russia and eastern Siberia due to the implemented time-varying shadowing effect by tree-vegetation on snow surfaces. Over Northern Hemisphere boreal forest regions the improved representation of vegetation-cover consistently correct the winter warm biases, significantly improves the climate change sensitivity, the decadal potential predictability as well as the skill of forecasts at seasonal and weather time-scales. Significant improvements of the prediction of 2m temperature and precipitation are also shown over transitional land surface hot spots. Both the potential predictability at decadal time-scale and seasonal-forecasts skill are enhanced over Sahel, North American Great Plains, Nordeste Brazil and South East Asia, mainly related to improved performance in the surface evapotranspiration.

This work demonstrates, for the first time, that the implementation of a realistic representation of vegetation in Earth System Models (ESMs) can significantly improve climate prediction across multiple time-scales, and the details of the results are discussed in a peer-review paper just published on Climate Dynamics (Alessandri et al., 2017; doi:10.1007/s00382-017-3766-y).

SESSION: (B1) Mechanisms of S2D predictability

(B1-16)

Investigating the impact of soil moisture on European summer climate predictions

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Due to the limited skill of state-of-the-art prediction systems, high expectations on summer seasonal forecasts over Europe are only marginally fulfilled. A number of studies have shown the prominent impact of soil moisture anomalies on summer mid-latitude climate variability and predictability. However, because of model systematic errors, even the best possible initialization of soil moisture conditions falls short in estimating the theoretical upper limit of predictive skill induced by soil moisture boundary conditions. The present study aims at addressing this question by comparing idealized ensemble re-forecast-like simulations in which soil moisture conditions are prescribed from the ERA-Interim LAND reanalysis with initialized dynamical re-forecasts in which soil moisture evolves freely. Two regional climate models with domains centered over Europe contribute to these experiments and generate very similar results. Simulations with constrained soil moisture display significantly increased correlation between observed and simulated seasonal anomalies of maximum temperature precipitation and surface solar radiation, as compared to the reference re-forecast. This widespread increase is not restricted to regions already known as hot-spots of land-atmosphere coupling. In spite of a limited change of the ensemble spread, the idealized simulations better perform in capturing anomalies exceeding a defined threshold. A focus on two case studies reveals contrasted results between the 2003 and 2010 heat waves. These results suggest that soil moisture may be a larger source of summer predictability than expected from previous works.

SESSION: (B1) Mechanisms of S2D predictability

(B1-17)

The northern hemisphere circumglobal teleconnection in a seasonal forecast model and its relationship to European summer forecast skill

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Recent research has led to improvements in European winter seasonal forecasts, however there has been less of a focus on the summer season and summer forecast skill remains relatively low. The European climate is affected by a large range of influences, which include influences from tropical regions, and better understanding of the mechanisms behind these tropical-extratropical teleconnections can inform our evaluation of seasonal forecast systems and priorities for model development.

One potential source of predictability for Europe is the Indian summer monsoon (ISM), which can affect European weather via a global wave train known as the "Circumglobal Teleconnection" (CGT, Ding and Wang 2005). Here we assess the ability of the ECMWF coupled seasonal forecast model to represent this teleconnection mechanism. We use seasonal hindcasts for JJA which are initialised on the 1st May, with 25 ensemble members, for the period 1981-2014. We show that the representation of the CGT wave pattern in the model is weaker than observed, particularly in August when the observed CGT wavetrain is the strongest, and the model has errors in forecasting geopotential height in several key regions ("centres of action") for the teleconnection mechanism. Several possible causes of these errors will be shown. First, model variance in geopotential height in west-central Asia (an important region for the maintenance of the CGT) is lower than observed in July and August, associated with a poor representation of the link between this region and Indian monsoon precipitation. Second, analysis of the Rossby wave source shows that the source associated with monsoon heating is both too strong and displaced to the northeast in the model. This is related to errors in monsoon precipitation over the Bay of Bengal and Arabian Sea, where the model has more precipitation than is observed. Third, the model jet is systematically shifted northwards by several degrees latitude over large parts of the northern hemisphere, which may affect the propagation characteristics of Rossby waves in the model. In order to further understand how these errors are related to errors in summer predictability over Europe, we will present results from several relaxation experiments, including relaxing regions over west-central Asia and northwest Europe. These experiments have been designed to identify possible causes of errors in the teleconnection pathway, and to explore how improving the representation of the CGT impacts on European Summer forecast skill.

SESSION: (B2) Modelling issues in S2D prediction

(B2-01)

Demands on the MPI Earth System Model to perform seasonal-to-decadal climate predictions

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The Max-Planck-Institute Earth System Model (MPI-ESM) is the baseline for the German Climate Forecast System (GCFS) and contributes to the upcoming CMIP6 experiments. An overview is presented on the latest developments of MPI-ESM as a seasonal-to-decadal climate prediction system. Results are shown with a focus on two topics: (i) the increased spatial resolution, and (ii) the initialization, each with respect to the (expected) subsequent prediction skill.

Compared to its precursors provided for CMIP5, a higher-resolved version of MPI-ESM (MPI-ESM-HR) has been developed, which represents in its atmospheric component a doubling in horizontal resolution (T127, ~100km). The model-tuning is straight-forward to targets of global mean temperatures, Arctic sea-ice, a well-balanced radiation budget and a stable ocean circulation. Two examples are presented by which a simple increase in resolution and a straight-forward tuning has and has not led to the desired improvement in prediction skill. First, the winter North Atlantic Oscillation (NAO) is considered, for which high prediction skill for the first winter has been found in a lower-resolved model version (T63, ~ 200km). Surprisingly, in MPI-ESM-HR the prediction skill is reduced. An examination of the predictants of the winter NAO reveal, that in particular the troposphere-stratosphere linkage is only weakly represented in MPI-ESM-HR. A mechanism that was not given much attention during the tuning process. Second, the storm track bias is substantially reduced over the North Atlantic and Europe in the MPI-ESM-HR compared to its lower-resolved version. Initialized experiments reveal substantially higher prediction skill for storm-track density in MPI-ESM-HR, and positive skill is found for years 1-5.

In addition, progress has been made in the initialization of decadal climate predictions. Approaches based on a nudging procedure of atmosphere and ocean reanalyses in to MPI-ESM induced imbalances in North Atlantic heat transport and budget. The induced transport modifications continue to be present in the freely running predictions and are seen to reduce forecast skill. The imbalances vary with different reanalysis products and with application of full fields or anomalies. The assimilation of anomaly fields largely keeps the heat transport and budget in balance and the according prediction skill is significantly higher compared to initializations from full fields. This result reflects the need for a “model-consistent” assimilation. In this respect an Ensemble Kalman Filter (EnKF) has been implemented in the oceanic component of the lower-resolved version of MPI-ESM. Initialized experiments with the EnKF assimilating EN4 and HadISST outperform experiments based on nudging techniques in terms of prediction skill in particular in the Pacific and the North Atlantic. The implementation of EnKF in MPI-ESM-HR is currently investigated.

SESSION: (B2) Modelling issues in S2D prediction

(B2-02)

Process-Oriented Model Diagnosis to Improve Modeling Systems

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The NOAA Model Diagnostics Task Force has led an activity since 2016 to produce a community-designed, flexible software package that integrates process-oriented metrics for model evaluation. Process-oriented metrics in this case are model diagnostics that go beyond evaluation of raw performance of a model and provide physical insight into the sources of major biases in models. The desired end result is pathways to improve model performance via process-focused diagnosis of model error. The effort has been led by NCAR, GFDL, and academic community scientists, and a broad array of diagnostics have been contributed to the software package from a diverse pool of investigators and institutions. This paper will discuss process-oriented diagnostics as a pathway to model improvement and provide an update on the Task Force's progress. Metric packages such as this one can help advance model and prediction system development, where improvements are often made in a heavily performance-oriented framework.

SESSION: (B2) Modelling issues in S2D prediction

(B2-03)

Diagnosing the sources of systematic SST biases in CESM using ensemble seasonal hindcasts

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In this study, we investigate the emergence and growth of systematic SST biases in ensemble seasonal hindcasts from the Community Earth System Model (CESM) version 1. Six-month long, twenty-four member ensemble hindcast simulations covering the period 2001-2005 are performed, with initial conditions derived from ERA-Interim for the atmosphere and from NCAR-DART for the ocean. The equatorial Pacific and northern subtropical Pacific and Atlantic oceans develop a cold bias after two to three months, reaching comparable magnitudes to climatological biases within six months of lead-time. Further analysis of the equatorial Pacific cold bias reveals that hindcasts with start dates during the upwelling period (boreal summer to fall) exhibit a strong drift from the reanalyses and observations as well as a large ensemble spread. In contrast, those with start dates outside of the upwelling period show minimal drift and spread. This implies that the cold bias develops quickly during the upwelling period, but takes longer than six months to emerge outside the upwelling period. An upper ocean heat budget analysis confirms that the anomalous cooling comes from too strong vertical advection in the ocean. The vertical advection bias is associated with easterly wind stress anomalies, which emerge as early as the first two months of lead-time, preceding the onset of the cold SST bias. The too strong easterlies are accompanied by excessive precipitation north of the equator. The sensitivity of the wind and precipitation biases to the representation of low-level circulation and moist convection in the model are further explored.

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SESSION: (B2) Modelling issues in S2D prediction

(B2-04)

Estimating errors in model variability: a comparison between seasonal re-forecasts and continuous multi-decadal simulations with the ECMWF coupled model

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ECMWF, Reading, U.K. (1, 2, 3, 4, 5)

In seasonal and decadal predictions initialised from real-world conditions, the drift of the model's climate (including both mean state and variability) from the observed state to its long-term attractor makes the estimation of systematic model errors particularly demanding, since errors during the drifting phase are dependent on both the phase of the seasonal cycle and the forecast time. Typically, in order to calibrate seasonal forecasts and assess their errors, a large set of ensemble re-forecasts is run, with initial dates spanning all months for at least two or three decades. Because of the substantial overlap between integrations started from dates in consecutive weeks or months, seasonal re-forecast require a total integration time possibly reaching thousands of years: for example, the operational ECMWF system SEAS5 is calibrated using 25-member ensemble re-forecasts spanning 36-years, for a total of 6,300 years of simulation.

In inter-comparison projects aimed at estimation of climate change, the “current” model climatology is usually estimated by running continuous integrations spanning the historical period, initialised from a model state obtained from a long spin-up run. Since all (or at least most of) the climate drift is supposed to occur during the spin-up phase, historical multi-decadal simulations provide estimates of the model mean-state and variability which are representative of the model's asymptotic attractor. A challenging question is to what extent diagnostics of modelled variability in multi-decadal historical runs match corresponding results obtained from initialised re-forecasts in a state of climate drift.

ECMWF has run historical multi-decadal simulations for the 1950-2014 period as a contribution to the EU-funded H2020 PRIMAVERA project, using a version of the coupled model almost identical to that used in the seasonal forecast system SEAS5. This talk will compare diagnostics of low-frequency variability and teleconnections derived from the SEAS5 re-forecasts and the PRIMAVERA historical runs, with a focus on tropical-extratropical interactions during the northern winter and teleconnections associated with monsoon systems. We show that a number of differences (or similarities) between observed and model statistics on atmospheric variability show a similar pattern in the initialised and multi-decadal runs. On the other hand, multi-decadal runs are able to reveal errors in the slow components (deep ocean, sea-ice) of the climate system which are difficult to detect significantly in seasonal experiments because of a smaller signal-to-noise ratio. Therefore, we argue that continuous, multi-decadal historical simulations represent a valuable and conceptually simple addition to the traditional experimental set-up for the optimization of coupled models used in initialised predictions.

SESSION: (B2) Modelling issues in S2D prediction

(B2-05)

Approaches to reduce model biases to improve in climate prediction

N. Keenlyside (1,2,4), F. Counillon (1,2,4), M. Devilliers (2,4), S. Koseki (1,4), I. Bethke (3,4), T. Demissie (3,4), G. Duane (1), A. Gupta (3,4), M.-L. Shen (1,4), L. Svendsen (1,4), T. Toniazzo (3,4), Y. Wang (2,4)

Geophysical Institute, University of Bergen (1); Nansen Environmental and Remote Sensing Center (2); Uni Research (3), Bjerknes Centre for Climate Research (4)

Systematic model error is the cause of large biases climate models. The aim of this presentation is to first discuss the impact of these biases on prediction skill and second, to introduce the supermodel approach to reduce model systematic errors.

To illustrate the first point, we present seasonal prediction results for the equatorial Atlantic performed with a standard and an anomaly-coupled configuration of the Norwegian Climate Prediction Model (NorCPM). The biases in this region are particularly large and persistent among models. A significant reduction in these biases is achieved in NorCPM by anomaly coupling (i.e., by a static correction of the momentum and SST fields exchanged between oceanic and atmospheric model components). Reduction of the bias is shown to improve the simulated variability, enhance the quality of the ocean reanalysis, and significantly increase the skill in seasonal prediction of equatorial Atlantic climate. These improvements are related to a better representation of ocean-atmosphere interaction.

A superior representation is provided by a supermodel that can be constructed by interactively combining a number of different models in run time so that their individual model errors are made to compensate. We show that the approach is able to mitigate the double intertropical convergence zone bias found in most climate models. Importantly, non-linear ocean-atmosphere interaction enables the super model to out perform the standard averaging of the coupled models run separately. To demonstrate the broad applicability of the approach we have now used data assimilation between models to create a supermodel from three state-of-the-art climate models – NorESM, MPIESM, and ECEARTH. Initial results from this new supermodel will be presented.

SESSION: (B2) Modelling issues in S2D prediction

(B2-06)

SEAS5: The new ECMWF seasonal forecast system

Stephanie Johnson, Tim Stockdale, Laura Ferranti, Magdalena Balmaseda, Franco Molteni, Linus Magnusson, Steffen Tietsche, Damien Decremet, Antje Weisheimer, Anca Brookshaw

ECMWF

In this presentation we will describe SEAS5, ECMWF's fifth generation seasonal forecast system, which became operational on Nov. 5, 2017. Compared to its predecessor, System 4, SEAS5 is a substantially new system which includes upgraded versions of the IFS atmosphere and NEMO ocean models at higher resolutions, and introduces the LIM2 interactive sea ice model.

We will discuss SEAS5's performance, and how it compares to System 4. Many aspects of forecast skill have improved, but there are a few exceptions where forecast skill decreases. SEAS5 tropical SST biases have significantly improved over System 4, including a two degree improvement in the equatorial Pacific. Two-metre temperature prediction skill in the tropics has improved and there are also improvements in some aspects of ENSO forecast skill. The increased ocean resolution in SEAS5 changes SST biases in the northern extratropics, especially in regions associated with western boundary currents. In the Northwest Atlantic, SEAS5 poorly captures observed decadal variability of the subpolar gyre, which results in a local degradation of DJF 2-metre temperature prediction skill. Introducing the prognostic sea ice model gives SEAS5 the ability to forecast sea-ice cover in the coming seasons. In summary, SEAS5 continues to be a state-of-the-art seasonal forecast system, with a particular strength in ENSO prediction.

SEAS5 data and graphical forecast products are available to the public, under free access licence, through ECMWF's Copernicus Climate Change Service (C3S). We will present the multi-system seasonal forecast service of C3S, to which ECMWF is a core contributor and SEAS5 is one of the components. A brief description of the other participating forecast systems will be presented, as will the set of graphical and data products currently available and planned for the near future.

SESSION: (B2) Modelling issues in S2D prediction

(B2-07)

The German Climate Forecast System GCFS2.0

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The German seasonal forecast system (GCFS) has been jointly developed by Max Planck Institute for Meteorology (MPI-M), Universität Hamburg (UHH) and Deutscher Wetterdienst (German Meteorological Service, DWD). Forecasts are published starting in October 2016. Since summer 2017 DWD is one of 13 Global Producing Centres of Long-Range Forecasts to the WMO Multi-Model Ensemble. Starting summer 2018 DWD provides its forecast data also to the Copernicus Climate Change Service C3S.

The first system started from a CMIP5 version of the climate model MPI-ESM (Max Planck Institute Earth System Model) and has been adapted for the demands of climate forecasts, therefore bearing the name GCFS1.0. The second version GCFS2.0 is now based on a higher resolved MPI-ESM both in atmosphere and ocean and gets its historical forcing data from CMIP6. Alongside with an improved version of the climate model the ensemble configuration has been also increased. GCFS2.0 now uses 30 members for the hindcasts and 50 members for the forecasts. Initial conditions for the atmosphere are taken from ERA-Interim or IFS-analyses while the ocean model is initialised by ORAS5, the new ocean reanalysis of ECMWF. We will show how and where the model climate and forecasts have been improved, e.g. in terms of skill scores, ENSO forecasts and special weather regimes, and where the challenges still are.

SESSION: (B2) Modelling issues in S2D prediction

(B2-08)

Development and current S2D prediction skill of the Norwegian Climate Prediction Model

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The Norwegian Climate Prediction Model (NorCPM), developed within the Bjercknes Center, combines the Norwegian Earth System Model (NorESM) with the ensemble Kalman filter data assimilation method. NorCPM can currently assimilate observations of ocean and sea ice into the ocean and sea ice components, while the other model components are left unchanged by data assimilation. We present the development and S2D prediction capacity of the version of NorCPM that will contribute to CMIP6 DCP. With the assimilation of SST data only, NorCPM can achieve competitive skills at 6- and 12-month lead time compared to the North American Multimodel Ensemble (NMME). It can predict the variability of SST in the Nordic Seas and the sea ice extent in the Barents Sea up to one year in advance. Complementing the system with the assimilation of ocean subsurface data shows moderate improvements for seasonal prediction but shows great improvements for interannual to decadal prediction in the North Atlantic Subpolar Gyre region and into the Arctic. The prediction skill of the prototype that also assimilates sea ice concentration will be briefly presented.

SESSION: (B2) Modelling issues in S2D prediction

(B2-09)

The importance of stratospheric initial conditions on wintertime seasonal predictability in the Euro-Atlantic sector and implications for the signal-to-noise paradox

O'Reilly, Christopher (1), Woollings, Tim (1), Weisheimer, Antje (1,2)

University of Oxford, UK (1), ECMWF, UK (2)

In this study we investigate the influence of atmospheric initial conditions on the predictability of the NAO in seasonal hindcast experiments. Three ensemble hindcast experiments are presented: an experiment initialised from a reanalysis that assimilates a comprehensive set of observations, one initialised from a reanalysis that assimilates only surface observations and one initialised from a random atmospheric initial condition. The skill of the NAO is analysed in the different hindcast experiments. The stratospheric initial conditions, and in particular the QBO teleconnection to the NAO, emerge as an important source of skill in the hindcast experiments. However, the QBO-NAO teleconnection appears to be somewhat weaker than in the observations, which results in a signal-to-noise issue in the most skillful hindcast experiment. These results have potential implications for the signal-to-noise paradox in operational seasonal forecasting systems.

SESSION: (B2) Modelling issues in S2D prediction

(B2-10)

Subtropical North Atlantic preconditioning key to skillful subpolar gyre prediction

Bethke, Ingo (1,2), Wang, Yiguo (3,2), Counillon, Francois (3,2), Kimmritz, Madlen (3,2), Keenlyside, Noel (4,2)

Uni Research Climate, Norway (1), Bjerknes Centre for Climate Research, Norway (2), Nansen Environmental and Remote Sensing Center, Norway (3), University of Bergen, Norway (4)

We compare decadal hindcast results for the Subpolar North Atlantic (SPNA) region from two configurations of the Norwegian Climate Prediction Model. The first configuration obtains its initial conditions by anomaly-assimilating SST-only observations into the ocean component of the coupled Earth system model. The second configuration is identical to the first one except that it additionally anomaly-assimilates temperature and salinity profiles. Prior to 1995, both configurations precondition the SPNA in a cold state with a strong subpolar gyre (SPG) circulation. Differences emerge, however, during the hindcast periods: while the first hindcast set exhibits a rapidly warming SPNA once the assimilation is released, the second set maintains the anomalous cold state over a longer period of time and compares favourably with other prediction systems that have demonstrated SPG hindcast capability. The rapid SPNA warming in the first set primarily originates from a too warm Subtropical North Atlantic (STNA) initial state, leading to excessive northward heat transport that causes the SPG to prematurely rebound. Salinity and dynamical effects identified in previous research likely contribute as well but to a lesser extent. Our results illustrate that a realistic initial state in the SPNA does not alone guarantee decadal forecast skill in that region, regardless of additional degradation due to model bias. Remote effects, in particular the thermodynamic state of the STNA, have to be considered as well to maximise SPNA prediction capability.

SESSION: (B2) Modelling issues in S2D prediction

(B2-11)

Can decadal climate predictions be improved by ocean ensemble dispersion filtering? Any impact on seasonal predictions?

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Decadal predictions by Earth system models aim to capture the state and phase of the climate several years in advance. Atmosphere-ocean interaction plays an important role for such climate forecasts. While short-term weather forecasts represent an initial value problem and long-term climate projections represent a boundary condition problem, the decadal climate prediction falls in-between these two time scales. The ocean memory due to its heat capacity holds big potential skill on the decadal scale. In recent years, more precise initialization techniques of coupled Earth system models (incl. atmosphere and ocean) have improved decadal predictions. Ensembles are another important aspect. Applying slightly perturbed predictions results in an ensemble. Instead of using and evaluating one prediction, but the whole ensemble or its ensemble average, improves a prediction system. However, climate models in general start losing the initialized signal and its predictive skill from one forecast year to the next. Here we show that the climate prediction skill of an Earth system model can be improved by a shift of the ocean state toward the ensemble mean of its individual members at seasonal intervals. We found that this procedure, called ensemble dispersion filter, results in more accurate results than the standard decadal prediction. Global mean and regional temperature, precipitation, and winter cyclone predictions show an increased skill up to 5 years ahead. Furthermore, the novel technique outperforms predictions with larger ensembles and higher resolution. Our results demonstrate how decadal climate predictions benefit from ocean ensemble dispersion filtering toward the ensemble mean.

More informations about this study in the AGU Journal of Advances in Modeling Earth Systems: DOI: 10.1002/2016MS000787 <https://doi.org/10.1002/2016MS000787>

This study is part of MiKlip (fona-miklip.de) - a major project on decadal climate prediction in Germany.

We focus on the Max-Planck-Institute Earth System Model using the low-resolution version (MPI-ESM-LR) and MiKlip's basic initialization strategy as in the published decadal climate forecast from 2018:

<http://www.fona-miklip.de/decadal-forecast/decadal-forecast-for-2018-2027>

In addition to the workshop focus, we add some new(!) results of the ensemble dispersion filter and its impact on seasonal near-surface air temperature prediction of the first winter (DJF). The reference prediction system shows low correlation values over Europe. The ensemble dispersion filter shows positive and significant values over Europe. As the reference system already lost the initialized signal on the seasonal scale in the first months of the prediction, the ensemble dispersion filter keeps the forecast on track and shows a significant improvement over Europe in the winter prediction (DJF).

SESSION: (B2) Modelling issues in S2D prediction

(B2-12)

Climate-mode initialization for decadal predictions

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Based on the Earth System Model from the Max Planck Institute for Meteorology (MPI-ESM) we designed a climate-mode initialization method for the decadal prediction system MiKlip. The idea of the initialization method is in improving the ESM's prediction skill through the initialization of balanced components of the initial conditions and filtering out components inconsistent with the dynamics of climate model. As the current MiKlip prediction system is using anomaly nudging toward ORAS4 reanalysis in the ocean, the proposed method is expected to eliminate inconsistencies between the prediction system and the non-native ocean reanalysis by synchronizing their oscillation patterns.

To this end, the temperature and salinity anomalies from the ORAS4 reanalysis are projected onto modes of variability derived from an ensemble of historical simulations (15 ensemble members) performed with the MPI-ESM. The climate modes are calculated as statistical modes based on the bivariate empirical orthogonal function (EOF) analysis. The explained standard deviation in the filtered reanalysis amounts to 66%. As this value is somewhat lower than what we expected, we assume that modes of variability of the reanalysis are not exactly compatible with the modes from the prediction system or that they are not yet sufficiently sampled by the available data used to construct the EOFs. The analysis of filtered and original reanalysis anomalies shows that the signal over the whole Pacific basin is well captured and represented, while in the Southern Ocean and the North Atlantic large fraction of the signal is filtered out. The filtered reanalysis' anomalies are then added to the model's climatology and are used as initial states for a set of retrospective decadal predictions. The climate-mode initialization method is compared against the commonly used anomaly initialization method.

A comparison of the climate-modes initialization with the reference initialization indicates an improved surface temperature skill over the tropical Pacific Ocean at seasonal-to-interannual timescales in terms of accuracy and correlation with the observations. This result shows a potential for improving seasonal forecasts of the El-Nino Southern Oscillation. For the 2-5 lead years averages, climate-mode initialization method outperforms the skill of the anomaly initialization for the surface temperature as well as the upper ocean heat content over the central and northern Pacific Ocean. For the North Atlantic subpolar gyre region, the climate-mode initialization experiments rather resemble a trend of the historical simulations than that of ORAS4 or the observations. Also they show smaller amplitudes of variability as compared to the non-filtered initialization. This suggests the need to further improve the design of the climate-mode initialization method attempting to capture better the variability modes in the North Atlantic in an larger EOF-basis.

SESSION: (B2) Modelling issues in S2D prediction

(B2-13)

Application of normal mode functions for the improved balance in the CAFE data assimilation system and characterisation of modes of variability

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In the context of multi-year simulations of the atmosphere and ocean, the goal of data assimilation (DA) is to both shift the simulations toward the physical observations and attempt to achieve a balanced state. In general, the DA process of incrementing the simulated flow fields such that the resulting analysis fields approach the observations, can introduce further imbalance into the system. With application to the CSIRO Climate Analysis Forecast Ensemble (CAFE) decadal prediction system, we demonstrate the use of normal mode functions (NMFs) to filter out the imbalanced component of the atmosphere. In the CAFE system an ensemble transform Kalman filter of 96 ensemble members is used to assimilate observations of the atmosphere and ocean in a fully coupled manner. That is all observations, regardless of their realm, impact both the ocean and atmosphere via a dynamically evolving cross-variance matrix. The NMF filtering is applied online to the atmospheric fields of the individual ensemble members immediately following each DA cycle.

The advantage of using NMFs is that they act as a physically based filter. They result from the eigensolutions of a primitive equation model on a sphere. For a specified static stability profile the NMFs simultaneously represent the fluctuations in the mass and velocity fields in the atmosphere. Note, in comparison, spherical harmonics are the eigenvectors of the global barotropic vorticity equation and hence represent a simplified physical view of the atmosphere. Each NMF is characterised by a zonal wavenumber, meridional wavenumber, and vertical mode number. From the properties of the eigenvectors, the NMFs are additionally classified as being either balanced modes (Rossby wave like), imbalanced westerly propagating inertial gravity waves or imbalanced easterly propagating inertial gravity waves. The balanced modes are slower evolving and potentially predictable. The inertial gravity modes have much shorter time scales (for a given spatial scale) and dominate the predictability error growth. We perform the NMF calculations using the MODES code developed at the National Center for Atmospheric Research as described in Žagar et. al. (2015).

In addition, we use the NMFs as an offline diagnostic tool to both determine the extent of balance in the final dataset, and also to characterise various modes of variability. In fact, we have devised an index representing the Madden-Julian Oscillation (MJO) using the NMFs, which agrees with the widely adopted index of Wheeler & Hendon (2004). However, as our NMF based index is derived from the equations of motion it additionally has the ability to interact with other modes of variability and potentially capture the onset of MJO events.

References:

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SESSION: (B3) S2D ensemble predictions and forecast information

(B3-01)

**Near-term hydroclimate outlooks based on the
CESM Decadal Prediction Large Ensemble**

Yeager, Steve

NCAR

The Community Earth System Model (CESM) Decadal Prediction Large Ensemble (DPLE) is a new public data resource for studying Earth System prediction that offers unprecedented statistical power for assessing hindcast accuracy and skill, quantifying the benefits associated with initialization, and exploring the probabilistic attributes of decadal predictions of climate and the carbon cycle. The

CESM-DPLE consists of 40-member ensembles initialized each year between 1954 and 2015, and it represents the initialized counterpart to the 40+ member CESM Large Ensemble of historical/projection simulations that were spun up from preindustrial conditions (CESM-LE; Kay et al. 2015). In this talk, I will present a global survey of decadal precipitation forecasts through 2025 based on CESM-DPLE, focusing on land regions characterized by significant hindcast skill enhanced through initialization and for which there exist at least tentative mechanistic links to ocean-driven sea surface temperature signals. The survey will encompass both seasonal mean hydroclimate and, where appropriate, outlooks for precipitation extremes. If resources permit and operational issues associated with near real time ocean initialization can be surmounted, more recent start dates will be added to extend the considered forecast range through 2027.

SESSION: (B3) S2D ensemble predictions and forecast information

(B3-02)

How early could the current La Niña have been predicted?

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NCAR, USA (1), University of Texas Institute for Geophysics (2,3)

Historical observations show that one in two La Niña events have lasted for two consecutive years. Despite their outsized impacts on drought and flooding, little is known about the predictability of these 2-year La Niña events. We addressed this question using a hierarchy of simulations performed with the Community Earth System Model Version 1 (CESM1) – a model that simulates realistic 2-year La Niña. First we explored mechanisms and potential predictability under “perfect model” conditions. Then we applied those results to the prediction of the current 2-year La Niña event. We used initialized predictions from the CESM Decadal Prediction Large Ensemble (CESM-DPLE) – a suite of ensemble forecasts initialized on every November since 1954. These CESM hindcasts show similar mechanisms and prediction skill for observed 2-year La Niña as in our “perfect model” forecasts. This allowed us to predict the evolution of the current La Niña using the ensemble initialized in November 2015, at the peak of the most recent El Niño. The CESM-DPLE predicted subsequent La Niña conditions lasting for 2 years. The probability of La Niña for the second year, i.e. the current winter, were 60% according to the initialized forecasts and 80% according to an empirical model combining observed and simulated predictors. Together these results demonstrate that, under specific initial conditions, La Niña events can be predicted two years in advance.

SESSION: (B3) S2D ensemble predictions and forecast information

(B3-03)

Multi-year ENSO prediction

Jing-Jia Luo, Hanh Nguyen, Harry Hendon, Oscar Alves, Guoqiang Liu, Nick Dunstone, Craig MacLachlan

Australian Bureau of Meteorology (1), UK Met Office (2)

El Niño and La Niña strongly affect the year-to-year variability of Australian climate, which exerts intense pressure on water resources and environmental management. Well-known examples include the severe floods in 2010-11 and 1998-2000 in association with multi-year persistent La Niña events, and strong drought in 2002 in association with El Niño. Growing evidence suggests that some ENSO events may be predictable at lead times beyond one to two years, which is longer than the forecasts currently issued by most operational forecast centres worldwide. However, it is still unclear how well ENSO can be predicted at multi-year timescales and what essential dynamics underpins such multi-year predictability. In collaboration with the UK Met Office, three sets of ensemble multi-year hindcasts were produced using the high-resolution ocean-atmosphere coupled model, ACCESS-S. The first set of experiments contain 30-member ensemble predictions of 16 target months starting 1 November for every year during the period 1980-2014. The second set of experiments consist of 10-member ensemble predictions of 66 target months starting 1 November every 2-3 years during the period 1960-2014. The third set of experiments involves using 23 ensembles of 36-month predictions to examine the multi-year predictability of the back-to-back La Niña during 1998-2001 and the 2002-03 central-Pacific El Niño event. Results suggest that, despite considerable model bias in simulating the annual mean states and seasonal cycle of the Indo-Pacific climate, ENSO over the past 35 years can be skilfully predicted out to 16 months ahead. Some ENSO events can be well predicted with a 3-year lead. In addition, the results also show good skill in predicting global warming related signals at multi-year timescales. Without any downscaling, the high-resolution model also displays encouraging skill in predicting local climatology and anomalies in Australia at seasonal to multi-year timescales.

SESSION: (B3) S2D ensemble predictions and forecast information

(B3-04)

How skilful are decadal climate predictions?

Smith, Doug (1), Eade, Rosie (1), Scaife, Adam (1,2), Caron, Louis-Philippe (3), Doblas-Reyes, Francisco (3), Dunstone, Nick (1), Hermanson, Leon (1), Müller, Wolfgang (4,5)
Pohlmann, Holger (4) and Yeager, Stephen (6)

Met Office, UK (1), Exeter University, UK (2), BSC, Spain (3), MPI, Germany (4),
DWD, Germany (5), NCAR, USA (6)

We assess the skill of decadal climate predictions using new state of the art model hindcasts combined with a multi-model ensemble from CMIP5 starting each year since 1960. The resulting 71 member ensemble mean shows significant skill at forecasting year 2 to 9 averages of near surface temperature, rainfall and mean sea level pressure over many regions. We propose and describe a new approach for assessing the impact of initialisation on forecast skill that is more powerful than the simple difference in correlation skill between initialised and uninitialized hindcasts used previously. We show that initialisation significantly improves the skill in many regions, including over land. However, the underlying patterns of skill are captured by the uninitialized simulations, suggesting that initialisation is mainly improving the simulated response to external factors rather than predicting internal variability. We also find that the signal to noise ratio is anomalously small in the model ensemble, suggesting that the signal to noise paradox recently discovered in extratropical seasonal forecasts also applies on decadal timescales.

SESSION: (B3) S2D ensemble predictions and forecast information

(B3-05)

Evaluation of re-calibrated decadal hindcast using a common verification framework

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Decadal predictions deal with the time scale which is important for decision makers and infrastructural planners for the near-term future. For usability of those predictions it is important to know about their forecast skill. Recent work suggest verification frameworks to answer the key questions whether initialization of the forecast model leads to higher skill in comparison to the uninitialized simulations and whether the spread of the ensemble represents the forecast uncertainty?

Initialized model simulations typically have to deal with biases which are dependent on forecast lead time, also known as model drift. Additionally, this behavior can depend on initialization time, i.e. bias and drift can be different for simulations which are initialized in the 1960s in comparison to most recent hindcasts.

This study uses a "Decadal Forecast Recalibration Strategy" (DeFoReSt) which adjusts mean and conditional bias as well as ensemble spread, taking lead time and initialization time into account. A common verification framework is used to analyze the skill of decadal hindcasts simulated with the general circulation model MPI-ESM under the umbrella of MiKlip, which is the German initiative for decadal prediction. For near surface temperature and precipitation it is shown how the initialized simulations perform using the lead time dependent anomaly adjustment recommended by the DCP. Furthermore the improvement through the use of the sophisticated post processing procedure (DeFoReSt) is discussed.

SESSION: (B3) S2D ensemble predictions and forecast information

(B3-06)

Skill assessment of the CSIRO multi-year Climate Analysis Forecast Ensemble system

Dougie Squire (1), James Risbey (2), Carly Tozer (3), Didier Monselesan (4), Vassili Kitsios (5), Terry O'Kane (6)

CSIRO (all)

Meaningful decadal-scale forecasts are crucial for informing adaptation strategies in response to climate variations. Yet, the predictability of the global state at multi-year time scales is not well understood. CSIRO has recently begun development of a probabilistic, decadal-scale, ensemble climate forecast system to investigate the predictability of oceanographic, atmospheric, biogeochemical and ice processes. In this talk we will assess the performance and predictability of the new forecast system using a variety of new and existing verification metrics.

SESSION: (B3) S2D ensemble predictions and forecast information

(B3-07)

Prediction of short-term climate extremes using the North American Multi-Model Ensemble

Becker, Emily; van den Dool, Huug

NOAA Climate Prediction Center and INNOVIM

This study examines the forecast skill of extreme monthly and seasonal mean 2 m temperature (t2m) and precipitation using the North American Multi-Model Ensemble (NMME), an ensemble of state-of-the-art coupled global climate models. The NMME currently provides real-time guidance for NOAA's operational short-term climate forecasts, and includes a database of retrospective forecasts (1982-2010), used for bias correction, calibration, and skill studies. Seven models from the NMME contribute to this study: NCEP-CFSv2, Environment Canada's CanCM3 and CanCM4, GFDL's CM2.1 and FLOR, NASA-GEOS5, and NCAR-CCSM4. Both deterministic and probabilistic forecasts for extremes are considered, and forecast skill assessments find that skill scores are equal to or greater for extremes than for non-extreme cases. Results are assessed for the real-time and hindcast periods, and for varying combinations of models in the multi-model ensemble.

SESSION: (B3) S2D ensemble predictions and forecast information

(B3-08)

Calibration and Combination of NMME precipitation forecast over South America using Ensemble Regression

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Centro de Investigaciones del Mar y la Atmosfera (CIMA-UBA/CONICET)

In this study we calibrate the climate predictions available at the North American Multi Model Ensemble to develop seasonal precipitation forecast tools over South America. Forecasts valid at each overlapping season made with initial conditions of the prior month (Lead 1 month) over the period 1982-2010 are considered. A Multi-Model Ensemble (MME) using 8 models with around 10 ensemble members was constructed and its performance was evaluated against CMAP and CPC-UNI database. The domain of application spans [15°N-60°S;275°E-330°E] and it is also divided in two subdomains: tropical South America and extratropical South America.

The Ensemble Regression technique (EREG) applies a regression equation developed for the ensemble mean to each ensemble member to obtain a probability density function (PDF) which represents the ensemble prediction. EREG is first applied to each model and its ensemble members to calibrate them. Then, the relative importance of each model is determined by weighting them according to their historical performance. To do this, the magnitude of each calibrated PDF is evaluated at the observation point and the weight is proportional to the number of times this magnitude was maximum for each model. Finally, two approaches are used to obtain the consolidated PDF. The first one consists in using the weighted MME in a new ensemble regression, resulting in a weighted super-ensemble regression (WSEREG) to get the consolidated PDF. The other technique consists in obtaining the consolidated PDF computing the normalized summing of the weighted models' PDF (weighted PDFs, WPDFS). The consolidated PDFs obtained are used to forecast the three equally probable categories below, near and above normal. These forecast are confronted against those obtained counting the proportion of ensemble members of the MME falling in each category (counting estimate technique, CE).

Results show that both WPDFS and WSEREG outperform CE in terms of the Ranked Probabilistic Skill Score (RPSS) and Brier Skill Score (BSS) in both seasons. However, only in northern South America the performance of both consolidation techniques is slightly better than the climatological values of the predictand (three categories equally probable). In extratropical South America both RPSS and BSS values change from less than -0.5 for CE to near 0 for both WPDFS and WSEREG. On the other hand, reliability diagrams computed over the entire domain shows that WPDFS and WSEREG substantially improve the forecast in terms of reliability respect to than obtained with CE.

Further studies are being conducted to test the sensitivity of the skill to changes in the model's original spread as well as changes in the way that weights between models are being determined. The results of these studies will be presented during the conference.

SESSION: (B3) S2D ensemble predictions and forecast information

(B3-09)

Evaluating a new calibration method for Seasonal Probabilistic Prediction for Indian Summer Monsoon

Acharya Nachiketa (1), Robertson Andrew (1), Vigaud Nicolas (1), Tippet Michael (1,2), Goddard Lisa (1) and Pai D.S. (3)

IRI, Columbia University, USA (1), Department of Meteorology, King Abdulaziz University, Jiddah, Saudi Arabia (2), IMD, India (3)

Though a plethora of study exists to make deterministic model for predicting seasonal Indian summer monsoon rainfall (ISMR), a few studies have described probabilistic prediction which conveys the inherent uncertainty of the forecast. Probabilistic seasonal prediction can be done based on the general circulation model (GCM)'s outputs, however the output from these ensemble prediction systems cannot be used directly and requires further calibration in order to produce reliable forecasts. In this study, Extended Logistic Regression (ELR) based calibration method implemented in models from The North American Multi-Model Ensemble (NMME) project with gridded data from Indian Meteorological Department. Though, ELR method has been successfully applied in the past to ensemble weather and sub-seasonal forecast, this is the first time to our knowledge that it has been used to produce seasonal probabilistic forecast of ISMR. ELR methods also allowed generating forecast in more flexible format in addition to commonly used tercile probability forecast. The flexible format enables users to extract information for those parts of the forecast distribution of greatest interest to them, especially the probability of extremely dry/wet conditions. The skill of ELR-based forecasts is evaluated over 1982-2010 following a leave-one-year-out cross-validation and are found to be more skillful than the more familiar approach of estimating the forecast probabilities by counting how many members exceed a certain threshold.

SESSION: (B3) S2D ensemble predictions and forecast information

(B3-10)

Potential of combined statistical-dynamical sub-sampling approach.

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UK (3), Met Office Hadley Centre, UK (4)

The potential of a combined statistical-dynamical sub-sampling approach is analysed in the seasonal forecasts currently contributing to Copernicus Climate Change Service (C3S). For four seasonal forecast systems, we analyse the enhancement of winter North Atlantic Oscillation (NAO) prediction skill. First, Teleconnections between the autumn state of sea surface temperature, sea ice, snow depth, and stratospheric temperature and the subsequent winter NAO are established as NAO predictors in the ERA-Interim reanalysis from 1979-2000. Second, these NAO predictors are used to derive a statistical "first guess" for each winter NAO from 2001 to 2017. Third, every "first guess" NAO is used as a reference for the sub-sampling of each dynamical ensemble for every seasonal prediction system. For all used system, NAO prediction skill is considerably improved, while surface properties such as sea level pressure or surface temperature mostly show a regional improvement, also dependent on the forecasts systems ability to simulate NAO teleconnections.

SESSION: (B3) S2D ensemble predictions and forecast information

(B3-11)

Room for Improvement in Seasonal-to-Decadal Climate Prediction

Sang-Ik Shin, Matthew Newman

CIRES, University of Colorado and PSD, NOAA/ESRL

The hindcast skill, for leads from a season to a decade, of the current generation of coupled GCMs (CGCMs) is assessed and benchmarked with skill of an empirical model, a Linear Inverse Model (LIM). Both systems produce sea surface temperature (SST) and sea surface height (SSH) forecasts. For seasonal forecast leads, the CGCM ensemble mean hindcasts come from the North American Multimodel Ensemble (NMME), while for interannual-to-decadal leads the CMIP5 hindcasts are analyzed. The LIM, constructed from near global (60oS-65oN) observed monthly anomalies during the period 1961-2010, produces forecasts from 1 month to 9 years lead.

The LIM skill is comparable to or better than the CGCM ensemble mean, as well as local univariate AR(1) process, at all timescales and all locations. Notably, the LIM is significantly more skillful than the CGCM ensemble mean over the extratropics, especially at longer forecast lead. For example, significant skill in the Pacific Decadal Oscillation (PDO), in both PDO phase and amplitude, up to 6-9 yr lead in LIM are well compared to relatively low insignificant skills in CMIP5 models.

Analysis of the LIM suggests that possible error in representing the SST-SSH coupling, rather than uncertainty in forecast initialization, is a major cause of reduced SST and SSH skill in the CGCMs. This also suggests that reducing this model error should improve model prediction skill of seasonal-to-decadal SST and SSH anomalies.

SESSION: (B4) S2D forecasts for decision making

(B4-01)

Climate Predictions for Fisheries Applications

Tommasi, Desiree (1), Charles Stock (2)

NOAA SWFSC, USA (1), NOAA GFDL, USA (2)

The productivity and distribution of fish populations is strongly influenced by climate variability. The inability of fisheries managers to anticipate such environment-driven fluctuations in fish dynamics can lead to overfishing and stock collapses. Here we demonstrate how recent advances in global dynamical climate prediction systems have allowed for skillful sea surface temperature anomaly predictions at a scale useful to understanding and managing fisheries. Such predictions present opportunities for improved fisheries management and industry operations. Pioneering case studies demonstrating the utility of seasonal climate predictions to inform fisheries decisions will be highlighted. We conclude by offering remarks on priority developments required for the expanded use of climate predictions for fisheries management.

SESSION: (B4) S2D forecasts for decision making

(B4-02)

Application of operational seasonal prediction systems for seasonal prediction of fire danger : a case study of the extreme wildfire events in California, Spain and Portugal of 2017

Etienne Tourigny (1), Joaquin Bedia(2), Raul Marcos, Omar Bellprat, Francisco J. Doblas-Reyes (1,3)
Barcelona Supercomputing Center (1), Santander Meteorology Group, Predictia Intelligent Data Solutions (2), ICREA (3)

The extreme wildfire events in California, Portugal and Spain during the fire seasons of 2017 caused considerable economic, environmental and human life losses and gathered much media attention. These events highlighted the need for both short and medium-term forecasts of wildfire danger, the latter useful for raising awareness and preparing for wildfire prevention and suppression strategies. The European countries most affected by wildfires are in the Mediterranean basin, with summer fires occurring during periods of drought. While countries such as the United States, Canada and Australia have developed extensive and reliable short-term and seasonal wildfire forecasting systems, similar systems in Europe are comparatively less well established. 11 1

For example, the European Forest Fire Information System (EFFIS) produces short-term (1-10 days) fire danger forecasts, but does not provide seasonal forecasts. These short-term forecasts rely on Canadian Fire Weather Index (FWI) values computed from the operational weather predictions from ECMWF. The McArthur Forest Fire Danger Index (FFDI) is a similar system originating from Australia. FWI and FFDI are computed from daily values of temperature, precipitation, relative humidity and wind data, accounting for factors that are important for fire severity and spread. These daily meteorological variables can be obtained from observations, climate predictions or climate projections.

Our approach to seasonal prediction of fire risk is to use operational forecasts such as those from ECMWF's System 5 forecast system to issue predictions of the fire danger indices FWI and FFDI. As operational forecasts produce ensemble predictions of daily values of the relevant meteorological variables, we are able to compute ensemble daily predictions of fire danger indices at a global scale, which can be used to formulate probabilistic predictions. Global observations of burned area from the MCD64 global burned area product and the Global Fire Emissions Database version 4 (GFED4) are used to evaluate the skill of the predictions. We will show the skill of the predictions for the Iberian Peninsula and California, with a focus on the extreme wildfire seasons such as that of 2017. 1

SESSION: (B4) S2D forecasts for decision making

(B4-03)

Using Subseasonal to Seasonal Forecast Guidance to Support Famine Early Warning Systems Network International Food Security Assessments

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NOAA/Earth System Research Laboratory (1), Famine Early Warning Systems Network (2)

Early warning of acute food insecurity requires robust agro-climatological assessments at many time horizons, from the monitoring of current conditions to forecasts ranging from weekly to interannual time scales. This poses a unique challenge to Famine Early Warning Systems Network (FEWS NET) physical science partners comprised of individuals from NOAA, USGS, NASA and USDA. One aspect of this unique challenge lies in the integration of all relevant forecasts in the context of emerging predictability information gathered through research and the clear communication of key forecast information to the social scientists, who also consider markets, trade nutrition and health when they produce food security outlooks. The food security outlooks are ultimately used to inform the programming of limited aid resources for the times and places where they will be most needed.

We summarize how FEWS NET physical scientists provide agro-climatological guidance over the subsequent 9 months for countries in sub-Saharan Africa, Central Asia, Central America and Caribbean. FEWS NET's physical science partners: (1) monitor current agro-climatological conditions, such as soil moisture, precipitation, temperature and crop health, (2) gather and interpret weather and climate projections to better understand the likely future conditions on weekly to interannual time scales, and (3) research the drivers of regional agro-climatic variability on sub-seasonal to interannual to decadal time scales in the context of a changing climate.

Key positive features of FEWS NET climate services include:

(1) Direct communication of agro-climatological questions by food security analysts to the physical scientists, resulting in reduced need to speculate about what agro-climatological information might be relevant and (2) frequent direct communication between FEWS NET physical scientists and food security analysts generates highly relevant research questions, and the resulting research findings consequently have a fast track to application and generation of societal benefits.

SESSION: (B4) S2D forecasts for decision making

(B4-04)

8-Month Snowpack Prediction Potential

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(1) GFDL/NOAA (2) UCAR (3) Princeton University (4) USGS (5) UCLA (6)

Western U.S. snowpack—snow that accumulates on the ground in the mountains—plays a critical role in regional hydroclimate and water supply with 80% of snowmelt runoff being used for agriculture. Utilizing observations, climate indices, and a suite of global climate models, we demonstrate the feasibility of seasonal snowpack predictions and quantify the limits of predictive skill 8 months in advance. This physically-based dynamic system outperforms observation-based statistical predictions made on 1 July for March snowpack everywhere except the Southern Sierra Nevada, a region where prediction skill is nonexistent for every predictor presently tested. Additionally, in the absence of externally forced negative trends in snowpack, narrow maritime mountain ranges with high hydroclimate variability pose a challenge for seasonal prediction in our present system; natural snowpack variability may inherently be unpredictable at this time scale. This work highlights present prediction system successes and provides a roadmap for testing future seasonal prediction systems to improve prediction skill. We find that a prediction system must be specifically designed for user needs (e.g. lead times, choice variables, events of interest), highlighting the need for engagement with stakeholders for future prediction system development.

SESSION: (B4) S2D forecasts for decision making

(B4-05)

Harnessing NMME predictions to support seasonal hydrologic prediction

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NCAR, USA (1), Bureau of Reclamation, USA (2), NRCS NWCC, USA (3), ECMWF, UK (4)

Recent studies document an increasing influence of temperature on streamflow across the American West, including snow-melt driven rivers such as the Colorado or Rio Grande. At the same time, some basins are reporting decreasing skill in seasonal streamflow forecasts, termed water supply forecasts (WSFs), over the recent decade. While the skill in seasonal precipitation forecasts from dynamical models remains low, the little skill there is in seasonal temperature forecasts could potentially be harvested for WSFs in these temperature-sensitive basins. Here, we show that WSF skill can be improved by incorporating seasonal temperature forecasts from the National Multi-Model Ensemble (NMME) into traditional statistical streamflow forecast models. We find improved skill relative to traditional WSF approaches in a majority of headwater locations in the Colorado and Rio Grande basins at lead times of 1-5 months. Incorporation of temperature into WSFs can increase the resilience of streamflow forecasting and water management systems in the face of continuing warming as well as decadal-scale temperature variability and thus help to mitigate the impacts of climate non-stationarity on streamflow predictability. We discuss the potential for incorporation of these results into dynamic hydrologic forecasting models and explore NMME model weighting schemes to potentially further boost hydrologic prediction skill across the American West.

SESSION: (B4) S2D forecasts for decision making

(B4-06)

UDECIDE: Understanding Decision-Climate Interactions on Decadal Scales

James Done (1), Jeffrey Czajkowski (2), Tapash Das (3), Ming Ge (1), Joshua Hewitt (4), Jennifer Hoeting (4), Heather Lazrus (1), Rebecca Morss (1), Armin Munévar (3), Erin Towler (1), Mari Tye (1) and Alex Van Zant (5)

National Center for Atmospheric Research, USA (1), Wharton, University of Pennsylvania, USA (2), CH2M, USA (3), Department of Statistics, Colorado State University, USA (4), Rutgers Business School, USA (5).

Water resource and flood managers increasingly require predictive climate information in decision-relevant terms to enable appropriate planning and adaptation to future conditions. A number of decisions stand to benefit from predictive information on decadal scales. The UDECIDE (Understanding Decision Climate Interactions on Decadal Scales) project brings together practitioners, engineers, statisticians, social scientists and climate scientists to understand the role of decadal climate information for water resource and flood management decisions.

UDECIDE proceeds in two overlapping parts. Part 1 explores current information needs and use, through in-depth understanding developed across flood and water resource managers in Colorado and California. Part 2 explores what can be skillfully predicted on decadal scales through the development of new statistical-dynamical modeling techniques. Prototype presentations of decadal predictions are developed at the intersections of what is needed and what is skillful. These presentations are tested with stakeholders and iterated upon to build understanding of the role of decadal climate prediction for decisions.

This presentation will outline the emerging points of intersection. Potential roles for decadal climate prediction based on interviews with water resource and flood managers will be presented. These potential roles have informed the development of a new geostatistical model of precipitation that simultaneously accounts for the effects of local and remote covariates, and global dynamical modeling of atmospheric river characteristics and predictability under decadal modes of variability. Implications for water and flood risk management practice over the next decade will be discussed.

SESSION: (B4) S2D forecasts for decision making

(B4-07)

Incorporating decadal predictions into water management

Towler, Erin (1), Done, James (1), Yates, David (1)

NCAR, USA (1)

To understand their climate sensitivities, water managers use hydrologic models to translate climate information into parameters that are relevant to their operations and decision-making. Many water managers are familiar with seasonal climate forecasts and long-term climate change projections, and have started to consider this information in their planning and management. Decadal climate predictions are less well-known among water managers, but meet a planning horizon need. Decadal prediction usage can benefit from some of the lessons learned from usage of predictions at other time scales, but are also unique, warranting new study. This presentation will draw upon a recently developed framework that explores how decadal predictions can be used. Specifically, we will use a case study approach in the water sector, whereby decadal predictions are statistically downscaled to be used as inputs to a hydrological model. By comparing current practices for using seasonal forecasts and climate change projections in water management, we will discuss the differences and similarities, needs and benefits, as well as remaining challenges, of incorporating decadal predictions in water management decisions. This work is part of an ongoing National Science Foundation (NSF)-funded project, Understanding Decision-Climate Interactions on Decadal Scales (UDECI), that aims to understand the role of decadal climate information for water management decisions.

SESSION: (B4) S2D forecasts for decision making

(B4-08)

Seasonal and decadal prediction services of the Copernicus Climate Change Service (C3S) - current status and plans for the future

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European Centre for Medium-Range Weather Forecasts (1)

Copernicus is the European Commission's flagship Earth observation programme that delivers freely accessible data to an operational schedule and information services. ECMWF has been entrusted to operate two key parts of the Copernicus programme, which will bring a consistent standard to the measurement, forecasting and prediction of atmospheric conditions and climate change.

The Copernicus Climate Change Service (C3S) currently provides a portfolio of products and services that include seasonal as well as centennial time scales, as well as the use of such products for key economic sectors in need of tailored climate information. Here we present the current role of seasonal prediction in the service, as well as future plans for climate prediction in the service.

An important element of C3S, at present, is a seasonal forecast service, based on a multi-system framework. Data from state-of-the-art seasonal forecast systems with operational status at a number of European institution is collected by C3S, where forecast products are generated and made available to the public in graphical and digital format. Some of the elements of the participating forecast systems have been harmonised, to optimise the benefits available to users (e.g. minimum hindcast period and ensemble size). The outputs - which include real-time forecasts and hindcasts, as well as graphical products from the individual contributing systems and as a combination - are available at a standard resolution, in standardised formats. The systems currently participating in the C3S seasonal service are from ECMWF, UK Met Office, Meteo France, CMCC and DWD; in the next year non-European Centres are also likely to join the service as in-kind contributors.

A large fraction of the sectoral users are keen to obtain information on the short time-scales (e.g., seasonal and sub-seasonal). Seasonal predictions from C3S models have been used for energy and water applications. In particular, one C3S contract implemented an operational hydrological service operating at a pan-European level. The analysis of the skill of this system has revealed areas where the skill in river-flow is significantly larger than the skill that exists in the atmospheric drivers of river-flow variability.

The seasonal component of the C3S will continue to expand: in the near-term by increasing the number of graphical and digital products, and in the longer term by increasing the number of contributors to the multi-model system, thus providing enhanced information in support of climate services (e.g. WMO Regional Climate Centres, Regional Climate Outlook Forums).

Even though many users have also shown an interest in obtaining information on the longer time scale, decadal prediction products were not included in the initial C3S portfolio, due to the lack of maturity of the science to make it an operational service from the outset. C3S is now taking stock of the progress that has been made since then, to reconsider whether decadal predictions could be part of the new C3S portfolio. An important element of this component would be the provision of a scientifically sound framework for the evaluation of decadal hindcasts and the statistical post-processing of decadal predictions.

SESSION: (B4) S2D forecasts for decision making

(B4-09)

Co-production of seasonal forecasts: experiences from Norway

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The Seasonal Forecasting Engine (SFE) research project aims to develop a state-of-the-art operational seasonal climate prediction system for Northern Europe and the Arctic. Our motivation is that many companies and public stakeholders face climate-related risks that must be managed to stay competitive and to protect life, property and the environment. To our users, the SFE will be accessible through a flexible interface which can be queried to obtain predictions of relevant climate indices and variables. Under the hood, our 'engine' consists of statistical algorithms that merge vast amounts of data into unified forecasts. In this talk I will share some of our experiences from working with our users from the public sector and large business corporations. From the public sector, I will focus on the Norwegian coast guard, who are primarily interested in sea ice forecasts in the Barents Sea. How do we reconcile their demands for high-resolution (both spatially and temporally) forecasts with the forecast skill on the seasonal time scale? The same balance has to be found in dialogue with our business users, which come from hydropower, wind power, weather services, and insurance. I believe that these experiences are of general interest to providers of seasonal forecasts and climate services more generally.

SESSION: (B5) Hindcast and forecast quality assessment

(B5-01)

Recent Developments in Forecast Quality Assessment

Timothy DelSole and Michael K. Tippett

George Mason University (1) and Columbia University (2)

This talk gives a general overview of some recent developments in forecast quality assessment. First, I discuss the problem of deciding whether one forecast is superior to another, which is a basic question in multi-model forecasting and in model development. I will show that standard statistical tests based on differences in correlation (or mean square error) do not give correct results when the skill measures are computed from data over a common period or with a common set of observations. I then discuss several other tests that give correct results, including a relatively new test called the random walk test. In probabilistic forecast verification, I discuss the importance of proper scores and how non-local scores can lead to counter-intuitive results. I also show how proper scores can be subjected to rigorous hypothesis tests. Finally, I discuss multivariate techniques for assessing forecast fields.

SESSION: (B5) Hindcast and forecast quality assessment

(B5-02)

Robust evaluation of seasonal forecast quality using teleconnections

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In response to the high demand for more reliable climate information at the seasonal timescale, innovative climate prediction systems are developed with improved physics and increased spatial resolution. Alongside the model development process, seasonal predictions need to be evaluated on past years to provide robust information on the forecast performance. This work presents the quality assessment of an intermediate version of the Météo-France coupled climate prediction system based on CNRM-CM. In order to have a robust evaluation, the experiment is performed with 90 ensemble members over a 37-year re-forecast period from 1979 to 2015. We focus on the boreal winter season (December to February) initialised in November. Beyond typical skill measures we evaluate the model capability in reproducing ENSO and NAO teleconnections with precipitation and near surface temperature respectively. Such an assessment is carried out first through a composite analysis, and shows that the model succeeds in reproducing the main patterns for near surface temperature and precipitation. A covariance method leads to consistent results. Finally we find that shortening to 23 years the verification period and reducing to 30 members the ensemble size does not impact the representation of teleconnections in the model re-forecasts. In a second stage of the study, two different versions of the model used in the operational seasonal forecasting systems 5 and 6 at Météo-France are shown and compared, using experiments that follow the operational standards (30 members, 24 year verification period).

SESSION: (B5) Hindcast and forecast quality assessment

(B5-03)

Signal and noise in regime systems: understanding NAO predictability

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Oxford University

Over the last decade, NWP models have begun to exhibit significant skill at predicting the wintertime North Atlantic Oscillation (NAO) index. In particular, recent studies conducted by the UK Met Office reported significant skill over a hindcast period ranging from 1980 to 2015. At the same time, a very low signal-to-noise ratio was observed. This was captured using the 'ratio of predictable components' (RPC) metric, designed to measure the extent to which reality is more or less predictable than the model itself. An RPC less than 1 indicates that the model is more predictable than reality, and greater than 1 that it is less predictable. A 'signal-to-noise paradox' was described in Siegert et. al (2016) as the observation that, while the ensemble mean of their hindcasts correlated strongly with observations, the RPC was significantly greater than 1, suggesting the model is in some sense highly underconfident despite its notable level of skill.

Many studies have emphasized the role played by regimes in modulating North Atlantic weather. We will examine how actual skill, potential predictability and RPC are expected to behave in an idealized two-state regime system. Here the two states can be loosely be thought of as 'positive NAO' (zonal jet structure) and 'negative NAO' (more wavy jet structure), and regime transitions are assumed to take place on daily timescales. Predictability is assumed to be induced as a consequence of seasonal deviations of the persistence probabilities of the two states from their climatological means. Model skill is then assumed to be a consequence of the models ability to correctly capture these seasonal variations. We show that in this framework, the combination of high levels of skill and large RPC values can be expected for any model which captures the signal, but systematically reduces the overall level of regime persistence. In particular, a high RPC value on seasonal timescales may be expected even when the models level of internal noise on daily timescales is perfectly realistic. This lack of persistence is shown to be a common feature of several current NWP models.

Finally, we will compare the RPC metric with another commonly used method of evaluating over/under-confidence of models, namely the ratio of the RMS error to ensemble spread. It is shown that for models that are not statistically perfect, these metrics may not give the same answer, depending on if the underlying system is assumed to be highly linear, or e.g. a more non-linear regime-like system. This emphasizes the importance, when evaluating hindcast quality, of the choice of statistical model used to describe the system.

SESSION: (B5) Hindcast and forecast quality assessment

(B5-04)

Canonical skill analysis of tropical Pacific variability in the CCCma decadal hindcasts

Reinel Sospedra-Alfonso

ECCC/CCCma

This study identifies the predictable components and the canonical skill components of winter tropical Pacific sea surface temperature anomalies (SSTAs) in decadal hindcasts from the Canadian Centre for Climate Modelling and Analysis (CCCma) CanCM4 climate model. Predictable components are obtained by applying a principal component analysis to the hindcast ensemble that maximizes the signal-to-noise ratio, a procedure known as predictable component analysis (PrCA). Canonical skill components are derived by finding the spatial weights of the signal portion of the hindcasts (in the sense of PrCA) and those of the verifying observations that maximize the temporal mean square skill score of modeled and observed averaged SSTAs, a procedure that is analogous to canonical correlation analysis. The conditional bias of these averaged hindcasts vanishes resulting in canonical mean square skill scores that equal the square of the canonical correlations. It is shown that the actual correlation of the filtered hindcasts and the raw observations can be expanded exactly by the sum of the correlation of the canonical patterns multiplied by the canonical correlations, plus a residual representing a portion of the observed variance that can be made arbitrarily small. This decomposition enables one to determine the components of the hindcasts that contribute to actual skill. The hindcasts filtered by predictable component analysis and canonical skill analysis are shown to be generally more skilful than the raw hindcasts on seasonal to multi-annual time scales.

SESSION: (B5) Hindcast and forecast quality assessment

(B5-05)

An advanced score for evaluating seasonal forecast skill

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Inst. of Oceanography, CEN, Univ. of Hamburg, Germany (1), Meteorological Inst., Univ. of Bonn, Germany (2), Hans Ertel Center for Weather Research, Climate Monitoring Branch (3)

A common tool to evaluate the performance of seasonal and decadal predictions are the Anomaly Correlation Coefficient (ACC) and the root-mean-square error (RMSE). Both methods rely on assumptions, among others normality assumptions of the data or uncertainty. Failing these assumptions can lead to under- or overestimation of the skill. Also, RMSE and ACC show different characteristics of the forecast skill, but do it in a non-comparable way.

We have developed a new score for predictions, which is independent of the data distribution. The score categorises the model and observational data and creates a multi-categorical contingency table (MCT). On this a metric from image processing, the two-dimensional Earth Mover's Distance (EMD), is applied and a score estimated. Applying a categorisation allows to evaluate clearly non-gaussian datasets like precipitation, but also for variables like temperature, which are assumed to be gaussian.

We demonstrate this at the hand of an analysis of seasonal prediction. We show strategies to generate spatial patterns with this new score, which are similar to the ACC and RMSE and so bring both procedures to the same basis and making them comparable. We also show differences for the ACC, when the normality assumption is dropped.

SESSION: (B5) Hindcast and forecast quality assessment

(B5-06)

How skillful are the multi-annual forecasts of Atlantic hurricane activity?

Caron, Louis-Philippe (1), Hermanson, Leon (2), Dobbin, Alison (3), Imbers, Jara (3), Lledo, Llorenç (1), Vecchi, Gabriel A. (4)

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The recent emergence of near-term climate prediction has prompted the development of three different multi-annual forecasting techniques of North Atlantic hurricane frequency. Descriptions of these three different approaches, as well as their respective skill, are available in the peer-review literature, but because these various studies are sufficiently different in their details (e.g. period covered, metric used to compute the skill, measure of hurricane activity), it is nearly impossible to compare them. Using the latest decadal re-forecasts currently available, we present a direct comparison of these three multi-annual forecasting techniques with a combination of simple statistical models, with the hope of offering a perspective on the current state-of-the-art research in this field and the skill level currently reached by these forecasts. Using both deterministic and probabilistic approaches, we show that these forecast systems have a significant level of skill and can improve on simple alternatives such as climatological and persistence forecasts, and have skill similar to, or better than, statistical forecasts currently used by the cat modeling industry.

SESSION: (B5) Hindcast and forecast quality assessment

(B5-07)

Making sense of seasonal sea-ice forecasts

Tietsche, Steffen (1), Balan-Sarojini, Beena (1), Mayer, Michael (1,2), Alonso Balmaseda, Magdalena (1)

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With the recent introduction of prognostic sea-ice models into seasonal forecasting systems, routine seasonal sea-ice forecasts that are useful to society are within reach. These are directly relevant for planning marine operations in high latitudes, and scientific evidence is accumulating that they have far-reaching implications for predicting large-scale anomalies of circulation and temperatures. However, current systems suffer from strong biases in the sea-ice state, which are difficult to correct a-posteriori because of their non-Gaussian, non-linear nature. Deficiencies in current sea-ice forecast are often rooted in sea-ice thickness. Here, we make the case that model biases and initialization methods for sea-ice thickness need to be improved in order to make progress with seasonal sea-ice forecasts, and that these improvements need to be guided by innovative satellite observations of sea-ice thickness. We discuss the skill of the recently implemented ECMWF seasonal forecasting system SEAS5 in predicting sea ice, using innovative metrics of integrated ice-edge error and integrated ice thickness error. We find that forecast errors in ice edge and ice concentration can be quantified with high certainty, but forecast errors of ice thickness are much less certain, because observational products and reanalyses have large discrepancies. We illustrate this by discussing experiments where sea-ice thickness has been initialized from observational data sets and conclude that progress with sea-ice predictions requires close collaboration between different communities, in order to improve the fidelity of both earth observations and forecasting models.

SESSION: (B6) Frontiers in earth system prediction

(B6-01)

Decadal predictability of the ocean carbon uptake variation

Li, Hongmei (1), Ilyina, Tatiana (1), Müller, Wolfgang (1), Landschützer, Peter (1)

Max Planck Institute for Meteorology, Germany (1)

The global oceans, as an important sink of CO₂ emitted by humans, play an essential role in modulating the global carbon cycle and hence the global climate change. To achieve the Paris Agreement goals of limiting surface warming below 2.0°C and even pursuing to limit it to 1.5°C relative to the preindustrial level, one major requirement will be discerning the anthropogenic carbon emission pathway in the Earth System in order to verify the effectiveness of fossil fuel emissions reduction measures. Recent observation-based studies have revealed unprecedented strength in decadal variation of the ocean carbon uptake in the last decades, challenging our ability to predict the variability of the ocean carbon sink and the future global warming on decadal timescales.

Grand ensemble simulations starting from different initial states revealed possibility for Earth system models (ESM) to produce the decadal variation of ocean carbon sink that is comparable to observations, and suggested an essential effects of initial conditions on the evolution of ocean carbon sink [Li and Ilyina 2018]. By applying decadal prediction framework to the Max Planck Institute ESM (MPI-ESM), we found a potential predictive skill of North Atlantic CO₂ uptake up to 4-7 years through improvement of the initial states in the ocean physics [Li et al., 2016]. Séférian et al. [2018] confirmed the potential predictive skill of the ocean carbon sink up to 6 years based on a 'perfect model' approach. Such a skill was confined to the model world due to large gaps in observations.

We extend our decadal predictions by assessing the skill of the global ocean carbon sink against observation-based estimates. Based on a high resolution configuration of MPI-ESM, assimilating observed temperature and salinity, we are able to reproduce the observed carbon uptake variability. We demonstrate a predictive skill of the global ocean carbon sink in 2 years through ensembles of hindcast simulations starting from the assimilation state, which is close to observations. Such a predictive skill is more prominent in winter months, mainly because of the improved representation of the ocean dynamics due to initialization.

Decadal prediction study of the ocean carbon uptake and corresponding processes is still at its early stage and facing a number of challenges arising from limited ocean biogeochemical observations and lack of proper initialization strategies.

Li, H., and T. Ilyina (2018), Current and future decadal trends in the oceanic carbon uptake are dominated by internal variability, *Geophys. Res. Lett.*, 45, 916–925.

Li, H. M., T. Ilyina, W. A. Muller, and F. Sienz (2016), Decadal predictions of the North Atlantic CO₂ uptake, *Nature Communications*, 7, 11076.

Séférian, R., S. Berthet, and M. Chevallier (2018), Assessing the decadal predictability of land and ocean carbon uptake, *Geophys. Res. Lett.*, doi: 10.1002/2017GL076092.

SESSION: (B6) Frontiers in earth system prediction

(B6-02)

Integration of carbon cycle components into ESM-based prediction systems

Tatiana Ilyina (1), Hongmei Li (1), Raffaele Bernardello (2), Laurent Bopp (3), John Dunne (4), Pierre Friedlingstein (5), Chris Jones (6), Andrew Lenton (7), Nicole Lovenduski (8), Jong-yeon Park (4), Roland Séférian (9), Stephen Yeager (10)

Max Planck Institute for Meteorology (1), Barcelona Supercomputing Center (2), CNRS/Ecole Normale Supérieure/IPSL (3), NOAA GFDL (4), University of Exeter (5), Met Office (6), CSIRO (7), University of Colorado (8), Météo-France/CNRS (9) NCAR (10)

Advancement of ESM-based prediction systems by integrating the carbon cycle components enables predictions of variations of the ocean and land carbon sinks. This new knowledge is pivotal for predicting the fate of anthropogenic CO₂ emissions and for facilitating verification of near-term emission trends in support of the UNFCCC global stocktakes.

Such prediction systems are typically forced with prescribed historical atmospheric CO₂ concentrations and assimilate only the physical climate data, albeit using different assimilation and initialization designs. The land and ocean carbon cycle models run as passive components adjusting to the state and the phase of the physical climate system.

Due to the lack of coherent biogeochemical datasets, recent studies mostly focused on the potential prediction skill of the carbon sinks. These perfect model studies provide mechanistic understanding of the sources of predictability of the carbon cycle variations with assessment of uncertainties. They furthermore suggest a large contribution of natural variability that take place in the background of the forced signal driven by rising CO₂ emissions. Despite substantial uncertainties associated with quantitative estimates of yearly to decadal variations in the land and ocean carbon sinks, there is a robust potential prediction skill established in a number of prediction systems. For instance, potential prediction skill for land and ocean carbon sink is about 4 years (Séférian et al. 2018) and regionally in the North Atlantic it is up to 7 years (e.g. Li et al., 2015).

Available observational synthesis products based on neural networks or satellite observations of land and ocean biogeochemistry enable assessment of the effective prediction skill. Moreover, newly emerging ocean and land biogeochemical measurements facilitate the development of novel carbon cycle initialization techniques.

It is becoming standard across several major modeling centers to include the land and ocean carbon cycle components into their decadal and seasonal prediction systems. Yet, these different prediction systems use various approaches regarding initialization, data assimilation, and spin up techniques. What are the implications of these different methodologies for the carbon cycle predictability? Furthermore, to date multi-model assessments are not yet available, but first insights from different prediction systems suggest consistent features of the carbon cycle predictability. What are the sources and time scales of predictability of the carbon cycle, as well as of the other biogeochemical variables in different prediction systems? These questions will be addressed in the context of carbon cycle predictions available from different ESM-based prediction systems..

SESSION: (B6) Frontiers in earth system prediction

(B6-03)

Seasonal to multi-annual marine biogeochemical prediction using GFDL's Earth System Model

Park, Jong-Yeon (1,2), Stock, Charles A. (2), Dunne, John P. (2), Yang, Xiaosong (2), Rosati, Anthony (2), John, Jasmin (2), Zhang, Shaoqing (3)

Princeton University (1), NOAA/GFDL (2), Physical Oceanography Laboratory/CIMST (3)

While physical ocean prediction systems routinely assimilate observations and produce seasonal to decadal forecasts, ocean biogeochemical (BGC) prediction systems are less mature due to additional challenges. A first impediment is the high BGC sensitivity to transient momentum imbalances that arise during physical data assimilation. In this study, we develop a strategy to robustly integrate the GFDL's ocean BGC model with the ensemble coupled-climate data assimilation (ECDA) system used for GFDL's seasonal to decadal global climate predictions. The ocean and atmosphere data constraints in the assimilation system are optimally modified to reduce BGC biases caused by momentum imbalances while retaining the information of observed physical states. We then performed retrospective prediction runs by initializing the model with the output from our ECDA run coupled with BGC model and investigated seasonal to multi-annual prediction skills of BGC variables over 1991 to 2016. We found that our earth system prediction system can provide skillful global marine biogeochemistry predictions about one year in advance in many ocean basins although forecast skill varied by region and initialization month. We further investigated potential utility of our earth system prediction system for marine resource management and found that reported temporal variability of annual fish catch in the Large Marine Ecosystem around the United States is well explained by predicted fish catch estimated from predicted BGC variables.

SESSION: (B6) Frontiers in earth system prediction

(B6-04)

A change in the forecast: Ocean biogeochemistry over the next decade

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University of Colorado Boulder, USA (1), NCAR, USA (2)

Observations collected over the past few decades and projections from climate models suggest that anthropogenic climate change has influenced and will continue to alter ocean biogeochemistry. Superimposed on the background of long-term changes in ocean biogeochemistry is natural variability in the physical and biogeochemical system that manifests on timescales of years to decades. While there has been considerable research in the field of decadal climate prediction of the physical oceanographic system, decadal predictability of ocean biogeochemistry remains relatively unexplored.

Here, we explore the predictability and predictive skill of ocean biogeochemistry generated by the Community Earth System Model Decadal Prediction System (CESM-DP), with a particular focus on ocean carbon uptake and marine plankton productivity. Our promising first results indicate regional predictability in these quantities on interannual to decadal timescales. Standard anomaly correlation analysis of CESM-DP retrospective forecasts reveals significant predictability in ocean carbon uptake in the California Current, eastern subtropical south Pacific, and North Atlantic basins on forecast lead times of 1-6 years. Mean square skill score statistics suggests that model initialization engenders predictability of carbon uptake in these regions. For marine productivity, the Atlantic basin, western boundary current regions, and eastern boundary upwelling systems have particularly long-lasting predictive skill that derives from initialization. Our findings suggest potentially important implications for the development of carbon dioxide emission and fisheries management strategies.

SESSION: (B6) Frontiers in earth system prediction

(B6-05)

Predicting ocean oxygen: capabilities and potential

Long, Matthew; Yeager, Stephen

NCAR

Advanced prediction of ocean biogeochemistry fields has the potential to provide actionable information for marine conservation and fisheries managers. We present results from recent decadal prediction experiments conducted with the Community Earth System Model (CESM)—the first instance of such experiments with this model that include ocean biogeochemistry. We demonstrate that advanced prediction at multi-annual forecast lead times is possible for key quantities such as net primary productivity and interior dissolved oxygen concentrations. In this presentation, we focus on dissolved oxygen predictability and discuss the mechanisms enabling advanced prediction of anomalies. The results suggest that dissolved oxygen concentrations in thermocline depth ranges, for instance, have substantial predictability with forecast lead times of several years over much of the global ocean. Comparisons with uninitialized forecasts demonstrate that predictability can be attributed to initialization in many regions. Prediction is enabled in some cases by initializing anomalies within mode and intermediate water formations; forecast skill arises as the model transports anomalies in the interior. We consider predictability in both a perfect model sense and with direct comparison to available observations. In addition to demonstrating existing capabilities with CESM, we highlight key issues with the oxygen simulation that are common to coarse resolution models and speculate on defining requirements for successful oxygen prediction more generally.

SESSION: (B6) Frontiers in earth system prediction

(B6-06)

Application of Earth system modeling tools to explore predictability of marine ecosystem stressors

Rodgers, Keith (1), Fröhlicher, T (2), and Timmermann, Axel (1)

IBS Center for Climate Physics, South Korea (1), and University Bern, Switzerland

Marine ecosystems are increasingly stressed by human-induced changes. The ocean is getting warmer, more acidic, and its oxygen content is declining. These stressors may cause large-scale shifts in marine biodiversity, with consequences for potential fisheries catches, livelihood, and food security. In addition to long-term trends sustained through anthropogenic perturbations to the Earth system, potential marine ecosystem stressors are known to exhibit variations over wide range of spatial and temporal scales associated with natural variability in the climate system. For resource management of marine ecosystems, it would be of great value if fluctuations of stressors were to be predictable with modeling resources.

Here we explore the predictability of ocean ecosystem stressors with a comprehensive global Earth system model that has been extensively evaluated against observational constraints, namely GFDL's ESM2M. Potential predictability is explored through the application of infinitesimal initial condition perturbations to a preindustrial control simulation with ESM2M in large ensemble (40 members) mode, using 6 different randomly chosen initial conditions from the pre-industrial run. Thus a total of 240 separate simulations have been performed, each of these for a duration of 10 years. The variables considered are sea surface temperature, sea surface pH, subsurface oxygen concentrations, and net primary productivity. In addition to identifying the upper limits of predictability of these variables within the Earth system model, it is also our objective to identify the relative predictability of the four variables under consideration. Given the potential importance of acidification as a stressor, the analysis will include the broader range of carbon dioxide-related variables for the surface ocean.

SESSION: (B6) Frontiers in earth system prediction

(B6-07)

Regional Arctic sea-ice prediction: Potential versus operational seasonal forecast skill

Mitch Bushuk (1,2), Rym Msadek (3), Michael Winton (1), Gabriel Vecchi (4), Xiaosong Yang (1,2),
Anthony Rosati (1,2), Rich Gudgel (1)

GFDL, USA (1), UCAR, USA (2), CNRS/CERFACS, France (3), Princeton University, USA (4)

Seasonal predictions of Arctic sea ice on regional spatial scales are a pressing need for a broad group of stakeholders, however, most assessments of predictability and forecast skill to date have focused on pan-Arctic sea-ice extent (SIE). In this work, we present the first direct comparison of perfect model (PM) and operational (OP) seasonal prediction skill for regional Arctic SIE within a common dynamical prediction system. This assessment is based on two complementary suites of seasonal prediction ensemble experiments performed with a global coupled climate model. First, we present a suite of PM predictability experiments with start dates spanning the calendar year, which are used to quantify the potential regional SIE prediction skill of this system. Second, we assess the system's OP prediction skill for detrended regional SIE using a suite of retrospective initialized seasonal forecasts spanning 1981-2016. In nearly all Arctic regions and for all target months, we find a substantial skill gap between PM and OP predictions of regional SIE. The PM experiments reveal that regional winter SIE is potentially predictable at lead times beyond 12 months, substantially longer than the skill of their OP counterparts. Both the OP and PM predictions display a spring prediction skill barrier for regional summer SIE forecasts, indicating a fundamental predictability limit for summer regional predictions. We find that a similar barrier exists for pan-Arctic sea-ice volume predictions, but is not present for predictions of pan-Arctic SIE. The skill gap identified in this work indicates a promising potential for future improvements in regional SIE predictions.

SESSION: (B6) Frontiers in earth system prediction

(B6-08)

Skillful seasonal forecasts of Arctic sea ice retreat and advance dates in a dynamical forecast system

Sigmond, Michael (1), Reader, Cathy (1), Flato, Gregory(1), Merryfield, William (1), Tivy, Adrienne (2)
CCCma, ECCC, Canada (1), CIS, ECCC, Canada (2)

The need for skillful seasonal forecasts of Arctic sea ice is rapidly increasing. Technology to perform such forecasts with coupled atmosphere-ocean-sea ice systems has only recently become available, with previous skill evaluations mainly limited to area-integrated quantities. Here we show, based on a large set of retrospective ensemble model forecasts, that a dynamical forecast system produces skillful seasonal forecasts of local dates at which ice forms (the advance date) and melts (the retreat date) - variables that are of great interest to a wide range of end-users. Advance dates can generally be skillfully predicted at longer lead times (~5 months on average) than retreat dates (~3 months). The skill of retreat date forecasts mainly stems from persistence of initial sea ice anomalies, whereas advance date forecasts benefit from longer timescale and more predictable variability in ocean temperatures. Initial steps taken and challenges encountered in translating these results into operational products will be described. These results suggest that further investments in the development of dynamical seasonal forecast systems may result in significant socio-economic benefits.

SESSION: (B6) Frontiers in earth system prediction

(B6-09)

ENSO prediction using an earth system model incorporating a high-resolution tropical ocean nesting model

Yukiko Imada (1), Goro Yamanaka(1), Hiroyuki Tsujino(1), Shogo Urakawa(1), Yasushi Takatsuki(1)

(1) MRI, JMA, Japan

Mesoscale eddies in the tropical oceans have significant impacts on the oceanic mean states, atmospheric circulation, ENSO characteristics, and other natural variabilities. Here, we found a significant improvement of ENSO prediction skill by incorporating a high-resolution (eddy-permitted) tropical ocean nesting model into a seasonal prediction system based on an earth system model MRI-ESM1. Because of the realistic representation of tropical instability waves (TIWs), the simulated eddy heat flux improved not only tropical oceanic mean states but also spatial distributions of mean surface wind stress and precipitation in the nested version of MRI-ESM1. ENSO characteristics (amplitude, period, spatial pattern, teleconnection) were also modified through the changes of mean state. Nonlinear eddy heat transports due to TIWs increased the ENSO skewness and improved the characteristics of ENSO asymmetry. These improvements resulted in more accurate ENSO prediction several months ahead.

SESSION: (C1) Initialization initialization shock and model error (includes data assimilation)

(C1-01)

Climate-model initialization for near-term climate-prediction: a survey of recent advances and anticipated trends

Karspeck, Alicia

Jupiter Intelligence, SK Analytics, National Center for Atmospheric Research

Over 15 groups participated in the decadal prediction experimental protocol designed under CMIP5. For some of these groups, this marked the first foray into climate-model initialization for the purpose of near-term prediction. For other groups, the experiments called for in the CMIP5 DP protocol were achieved through the extension of initialization procedures already in place to support either seasonal prediction activities or existing research-focused long-term prediction. In this overview talk, we survey the methods that have been used in the last decade to move the science and skill of near-term climate prediction forward. As production of CMIP6 commences, we also consider how initialization procedures have evolved (and why) and discuss anticipated trends, including coupled assimilation.

SESSION: (C1) Initialization initialization shock and model error (includes data assimilation)

(C1-02)

Non-linear and non-stationary forecast errors: should we revisit the current forecast strategies?

Magdalena A. Balmaseda, Laura Ferranti, Stephanie Johnson, Michael Mayer, Christopher Roberts, Tim Stockdale, Steffen Tietsche, Frederic Vitart, Hao Zuo.

ECMWF

Current approaches for sub-seasonal and seasonal forecast use a set of initialized coupled hindcast to bias correct the forecast products. This approach implicitly assumes stationarity of forecast errors and neglects non-linear interaction between mean state and variability. Here we review a number of cases where these assumptions do not hold, resulting in degradation of forecast skill. The limitations of the a-posteriori linear bias approach in ENSO have discussed in previous studies, and are summarized here. We also discuss results from the latest ECMWF seasonal forecasting system, which exhibits a clear decadal modulation of the forecast errors associated with different regimes of the Atlantic Meridional Circulation. These pathological cases raise the question of whether better forecasts could be obtained by modifying the current forecast or initialization strategies. A framework for an alternative forecast strategy, where the model errors are explicitly accounted for during the model integration via empirical modelling is presented. This framework will exploit the information from coupled data assimilation increments to train the error model. The strengths and weakness of such an approach will be outlined.

SESSION: (C1) Initialization initialization shock and model error (includes data assimilation)

(C1-03)

Coupled data assimilation and ensemble initialization with application to multi-year ENSO prediction

O'Kane, Terence (1), Sandery, Paul (1), Monselesan, Didier (1), Chamberlain, Matt (1), Sakov, Pavel (2), Matear, Richard (1)

CSIRO Oceans and Atmosphere (1), Australian Bureau of Meteorology (2)

We develop and compare variants of coupled data assimilation (DA) systems based on ensemble optimal interpolation (EnOI) and ensemble transform Kalman filter (ETKF) methods. The assimilation system is first tested on a simple multiscale paradigm model of the coupled tropical-extratropical climate system, then implemented for a coupled general circulation model (GCM). Strongly coupled DA was employed to perform an observing system simulation experiment (OSSE) and to assess the impact of assimilating ocean observations on the atmospheric state analysis update via the cross-domain error covariances from the coupled-model background ensemble. We examine the relationship between ensemble spread, analysis increments and forecast skill in multi-year ENSO prediction experiments with a particular focus on the atmospheric response to tropical ocean perturbations. Various approaches to generating flow dependent initial forecast perturbations, either in terms of ETKF and bred vectors (BV) whose norms are based on 3-D inband variance structures (within isosurfaces).

Our focus is on seasonal and longer timescales, and in particular ENSO. Therefore, our premise underpinning the OSSEs is that predictability primarily resides in the oceans and the fast atmosphere acts as a stochastic driver on the longer timescale ocean variability. While the ETKF analysis was generally less biased and with lower errors, both systems performed comparably in the tropics. Outside the tropics the ETKF system produced dramatically lower forecast bias and forecast mean absolute deviation error than the EnOI system. The reason for the low analysis error in the EnOI system in the tropics was found to be a result of larger ensemble spread in the EnOI background covariances, relative to the ETKF, systematically weighting observations more.

BVs representative of growing coupled tropical instabilities were found to modify tropical convection, in particularly in the region of the maritime continent, which in turn generate a coherent modulation of the Hadley circulation. A direct renormalization of thermocline disturbances was found to be most effective in communicating information from the tropical ocean to the midlatitude atmosphere on timescales of a couple of weeks to a month. Comparison of ensemble forecasts based on bred perturbations centred about the EnOI analysed state reveal a substantial reduction in uncertainties, where disturbances not directly associated with thermocline variability are masked. In particular, excluding SST disturbances led to a significant reduction in forecast errors in multi-year ENSO predictions. Ensemble forecasts initialised with ETKF perturbations were very much less skilful, even after bias correction was applied.

The OSSEs and methods discussed form a systematic basis for coupled DA relevant to multi-year near term climate forecasts. The masked isosurface BV approach allows for the specific targeting of regions of large scale variability pertinent to dynamical processes that determine predictability on seasonal to interannual spatio-temporal scales. Beyond a season, strongly coupled data assimilation, where the slow ocean modes are explicitly constrained including projection onto the background atmospheric states (i.e. jets, cells etc) while leaving the fast atmospheric dynamics free, including targeted forecast perturbations, offers a systematic approach to determining the mechanisms and predictability of the key climate modes.

SESSION: (C1) Initialization initialization shock and model error (includes data assimilation)

(C1-04)

Sub-seasonal to Decadal Predictability and Prediction with an Ocean Eddy Resolving Global Coupled Model

Ben Kirtman

University of Miami, USA

Increasingly, high resolution observations and coupled model experiments with eddy-resolving oceans indicate that western boundary currents are regions of strong ocean-atmosphere interactions that are critical components of the climatic mean state and variability. The high SSTs and strong SST gradients couple with the atmosphere to pump moisture into the marine boundary layer, accelerate winds, sharpen SST fronts, and introduce significant sub-seasonal to decadal climate variability that affects the frequency and intensity of extreme events (e.g., heat waves, cold spells, droughts, floods, extreme winds) at remote locations. These extreme events are embedded within sub-seasonal to decadal variability that may be predicted by global models. This talk documents a 30-year set of sub-seasonal to seasonal retrospective forecasts with an ocean eddy-resolving coupled model in comparison with a parallel set of retrospective forecasts with an ocean eddy-permitting coupled model used for the North American Multi-Model Ensemble (NMME) project. The forecast from both systems use identical initial conditions derived from CFSR and use the same modeling systems (CCSM4) except for resolution. On the decadal time-scale, the talk emphasizes identical twin predictability experiments with the ocean eddy-resolving model. Results include both sets of analysis focus on how the resolved ocean eddies affect prediction skill and predictability, particular emphasis is place on extreme events.

SESSION: (C2) Research to operation (includes seamless prediction)

(C2-01)

From reliable initialised forecasts to skilful climate projection: a dynamical systems approach

Christensen, Hannah (1,2), Berner, Judith (1)

NCAR, USA (1), University of Oxford, UK (2)

While models for initialised forecasts can be rigorously tested by performing and evaluating many hindcasts, the limited observational record restricts the degree to which climate models and their projections can be evaluated. Therefore a key question of interest is: to what degree can we evaluate the potential skill of a climate model's projections by evaluating short-range initial value forecasts produced by the same model? We address this question using a dynamical systems framework. We derive the mean climate response of a general dynamical system to a small external forcing, and relate this response to the reliability of initial value forecasts. We find that in order to capture the mean climatic response, the forecast model must correctly represent the slowest modes in the system. Reliable forecasts on seasonal and longer timescales could therefore be indicative that the climate model of interest will respond correctly to an applied anthropogenic forcing. This indicates the potential of using the 'seamless prediction' framework in evaluating climate models. We also highlight some important caveats: an unreliable seasonal forecast does not necessarily indicate an incorrect climate projection, as correct representation of fast processes is also necessary for reliable seasonal forecasts.

SESSION: (C2) Research to operation (includes seamless prediction)

(C2-02)

Moving from concept to climate service; how we can meet the needs of a climate smart community

Andrew B. Watkins, David Jones, Catherine Ganter, David Walland

Bureau of Meteorology, Melbourne Victoria, Australia

While many of us know how to make a climate outlook, and what products our research could ultimately produce, the question of why we produce it is sometimes not front of mind. The "why" is ultimately to help decision makers in weather and climate sensitive sectors - from farmers to insurance pricers to governments – make better choices. This is where research becomes a climate service. The ultimate goal of a climate service is to take sometimes-complex climate science and raw model output, and convert that combination into true climate intelligence that can be easily interpreted by a non-specialist. But a climate service is not (just) a fancy web page or dazzling graphics. It involves supporting reliable, on-time, clearly communicated climate information that meets a clear and demonstrable user need. It can involve partnerships between users and met services or science agencies. We will aim to take you along the journey from the germ of an idea to its research phase and then the final climate service. Ultimately it should become clearer how people can make their research 'climate service ready.

SESSION: (C2) Research to operation (includes seamless prediction)

(C2-03)

US Navy's Earth System Prediction Capability Effort

Reynolds C, Barton N, Bishop C, Flatau M, Frolov S, Janiga M, McLay J, Ridout J, Ruston B, Whitcomb T (1), Eleuterio D (2), Hogan P, Jacobs G, Metzger E J, Rogers E, Rowley C (3), Richman J (4)

NRL Marine Meteorology, USA (1), Office of Naval Research, USA (2), NRL Oceanography, USA (3), Florida State University, USA (4)

The National Earth System Prediction Capability (National ESPC) is a U.S. multi-agency collaborative effort to leverage resources to develop the next generation environmental forecasting system. As part of this effort, U. S. Navy is developing a fully coupled global system including the Navy Global Environmental Model (NAVGEM), the HYbrid Coordinate Ocean Model (HYCOM), the Los Alamos Community Ice Code (CICE), and the Wavewatch III ocean surface wave model. This system is being developed to meet Navy needs for high-resolution global environmental forecasts on timescales from days to months. The design and implementation of the coupled architecture uses the Earth System Modeling Framework (ESMF) with the National Unified Operational Prediction Capability (NUOPC) standard in order to maximize flexibility in adopting future models. Initial operational capability is planned for 2019 and will include daily high-resolution deterministic forecasts (with 19 km atmospheric resolution, 1/250 ocean and sea ice resolution, and 1/80 wave model resolution) and weekly extended-range ensemble forecasts (with 37 km atmospheric resolution, 1/120 ocean and sea ice resolution, and 1/40 wave model resolution). One aspect that makes the system unique is the relatively high resolution of the ocean and ice models, reflecting the Navy's strategic and tactical interests in these realms. A 17-year archive of 45-day forecasts four times per week at the ensemble resolution has been produced as part of the Navy's participation in the NOAA Subseasonal eXperiment (SubX) project. The performance of the system in simulating the Madden-Julian Oscillation and other tropical phenomena is comparable to other state-of-the-art systems. The Navy system has also shown good performance relative to other systems in multi-month forecasts of arctic sea ice as part of the Sea Ice Prediction Network September Sea Ice Outlook. Plans for ensemble design, coupled data assimilation, and other future developments will also be presented.

SESSION: (C2) Research to operation (includes seamless prediction)

(C2-04)

**TRANSFERRING SCIENCE TO PRACTICE: NEARLY TWO DECADES OF SEASONAL
FORECASTING FOR WEATHER-SENSITIVE INDUSTRIES**

Crawford, Todd

The Weather Company, an IBM Business

In 2000, a seasonal forecasting program was started at what was then WSI Corporation, in support of a new business line aimed at the recently-deregulated energy trading industry. A \$500K investment was made in an Alpha computing cluster, which ran a 16-member ensemble of the NCAR CCM 3.6.6 climate model. From there, various statistical forecasting algorithms were developed to supplement the climate model forecasts. Over time, the CCM was abandoned in favor of the newer generation of climate models, including the ECMWF, CFS, and more recently the calibrated NMME suite, in support of twice-monthly seasonal forecasts for North America, Europe, and Asia. Further, statistical models have been refined based on the latest science and our experience.

More recently, as we have been acquired by IBM, we have added purely automated and gridded seasonal forecasts for the rest of the world, using a blend of NMME and ECMWF outputs. Finally, we are currently working towards our first formal attempt at probabilistic seasonal output since our initial failed attempt in 2000.

Along the way, there have been numerous successes, failures, and lessons learned, as the tricky task of translating seasonal weather information into a language and format easily digestible for not-always-rational energy traders has been a challenging experience. This talk will provide a practitioner's view of seasonal forecasting and some suggestions for what's ahead.

SESSION: (C3) Time scale interaction (includes teleconnections)

(C3-01)

MULTI-SCALE INTERACTIONS IN A HIGH-RESOLUTION TROPICAL-BELT EXPERIMENT USING WRF MODEL

Tieh-Yong KOH (1), Ricardo FONSECA (2), Chee-Kiat TEO (1)

Singapore University of Social Sciences, Singapore (1), Lulea University of Technology, Kiruna, Sweden (2)

The Weather Research and Forecasting (WRF) model is used to dynamically downscale 27 years of the Climate Forecast System Reanalysis (CFSR) in a tropical belt configuration at 36 km horizontal grid spacing. WRF is found to give a good rainfall climatology as observed by the Tropical Rainfall Measuring Mission (TRMM) and to reproduce well the large-scale circulation and surface radiation fluxes. The impact of conventional and Modoki-type El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) are confirmed by linear regression in the model. Madden-Julian Oscillation (MJO) and Boreal Summer Intra-seasonal Oscillation (BSISO) are also well-simulated. However, WRF does not capture well the diurnal cycle of precipitation over the Maritime Continent. For the investigation of multi-scale interactions through the local diurnal cycle, TRMM data is used instead.

The WRF simulation shows that in the boreal summer, conventional ENSO modifies the MJO amplitude while Modoki-type ENSO and IOD impacts are MJO-phase dependent; in boreal winter, inter-annual variations have little impact on MJO amplitude. The TRMM observations show that in the Maritime Continent, moderate ENSO modifies the MJO's influence on the diurnal cycle in specific ways; strong ENSO leads to non-linear impacts on the diurnal cycle.

SESSION: (C3) Time scale interaction (includes teleconnections)

(C3-02)

North America winter circulation regime change and implications on S2S/S2D

Simon Wang

Utah State University, USA

The 2018 New Year extreme coldness in the eastern U.S. created hazards, while western states like California and CO underwent a wild swing from drought to flooding and to fires. The heat/cold contrast or “dipole” may be a new normal. We show progress in understanding the dipole variation in the decadal time scale and the effect of tropical and Arctic forcings at the S2S spectrum.

SESSION: (C3) Time scale interaction (includes teleconnections)

(C3-03)

Predictability of blocking and tropical cyclone activities? -- An assessment with a large ensemble simulation --

Kimoto, Masahide (1), Chiba, Joutaro(2)

(1) Atmosphere and Ocean Research Institute, The University of Tokyo (2) Japan Meteorological Agency

Potential seasonal predictability is investigated by a large ensemble experiment with an atmospheric general circulation model (AGCM) with prescribed sea surface temperature (SST) and sea ice (the database for policy decision making for future climate change; d4PDF; Mizuta et al. 2017). We use the present-day component of the data set which consists of 100 ensemble members for observed 1961-2010 boundary conditions. The large ensemble enables us to explore potential seasonal predictability of not only seasonal averages, but also modulation of day-to-day weather disturbances. Here we take up midlatitude blocking and tropical cyclone activities to see if there is useful seasonal predictability on the measures of their activities. Significant forced signals are found for North Pacific blocking and northwestern tropical cyclone activities in the data set, and they do show correlation with observations.

SESSION: (C3) Time scale interaction (includes teleconnections)

(C3-04)

Relating winter NAO skill to jet variability across timescales

Woollings, Tim (1), Parker, Tess (1), Baker, Laura (2), Weisheimer, Antje (1), Shaffrey, Len (2), O'Reilly, Chris (1)

University of Oxford, UK (1), NCAS and University of Reading, UK (2)

There has been encouraging progress in recent years in the skill of seasonal forecast models to predict the winter North Atlantic Oscillation (NAO). The NAO reflects a combination of variability in the strength and position of the North Atlantic eddy-driven jet stream. Here we investigate the NAO skill in operational hindcasts and a long, atmosphere-only re-forecast of the ECMWF system. This shows that the skill in these systems largely arises from predicting the position, rather than speed of the jet, on the interannual timescale.

As the timescale lengthens to decadal, the variability in jet speed makes up a larger fraction of the observed NAO variability. Hence, the predictable NAO signals on this timescale will have a different balance of mechanisms than the seasonal timescale, so that seasonal skill in a forecast system may not necessarily translate into decadal skill.

In addition, we show that the slow decadal variations in jet speed act to modulate the amount of jet latitude variability on subseasonal to seasonal timescales. Hence, the potentially predictable signals on the S2S timescales might be modulated by the decadal variability.

SESSION: (C3) Time scale interaction (includes teleconnections)

(C3-05)

Seasonal Forecasts of the 20th Century: Multi-Decadal Variability in Predictive Skill of the Winter NAO

Antje Weisheimer (1,2), Nathalie Schaller (2,3), Chris O'Reilly (2), David MacLeod (2) and Tim Palmer (2)

ECMWF, Reading, UK (1), University of Oxford, UK (2), Cicero, International Centre for Climate Research, Oslo, Norway (3)

Based on skill estimates from hindcasts made over the last couple of decades, recent studies have suggested that considerable progress has been made in forecasting winter climate anomalies over the Euro-Atlantic area using current-generation forecast models. However, previous-generation models had already shown that forecasts of winter climate anomalies in the 1960s and 1970s were less successful than forecasts of the 1980s and 1990s. Given that the more recent decades have been dominated by the NAO in its positive phase, it is important to know whether the performance of current models would be similarly skilful when tested over periods of a predominantly negative NAO.

To this end, new ensembles of retrospective seasonal forecasts covering the period 1900 to 2009 have been created with uncoupled and coupled versions of the ECMWF model, providing unique tools to explore many aspects of seasonal climate prediction. In this study we focus on the multi-decadal variability in predicting the winter NAO. The existence of relatively low skill levels during the period 1950s -1970s has been confirmed in the new dataset. This skill appears to increase again for earlier and later periods. Whilst these interdecadal differences in skill are, by themselves, only marginally statistically significant, the variations in skill strongly co-vary with statistics of the general circulation itself suggesting that such differences are indeed physically real. The mid-Century period of low forecast skill coincides with a negative NAO phase but the relationship between the NAO phase/amplitude and forecast skill is more complex than linear.

SESSION: (C3) Time scale interaction (includes teleconnections)

(C3-06)

The role of tropical-extratropical interactions on the optimal growth of Madden-Julian Oscillation events

Henderson, Stephanie (1), Vimont, Dan (2)

Center for Climatic Research, University of Wisconsin-Madison (1,2)

The influence of tropical-extratropical interactions on the Madden-Julian Oscillation (MJO) is investigated using linear inverse modeling (LIM). Extratropical circulation and tropical heating optimal initial conditions for MJO events are identified for all MJO phases. The extratropical initial condition for some MJO phases includes a dipole circulation anomaly over the Atlantic basin, as well as circulation anomalies near the Pacific subtropical jet likely associated with previous MJO phases. The impact of tropical-extratropical interactions on MJO growth is examined using a LIM that removes these interactions. Results suggest that removing the influence of the extratropical circulation reduces the amplitude of MJO heating and decreases MJO variance.

SESSION: (C3) Time scale interaction (includes teleconnections)

(C3-07)

Impact of intraseasonal oscillations on onset and demise of the Indian summer monsoon rainfall.

Karmakar, Nirupam (1), Misra, Vasubandhu (1,2,3)

Florida State University (1), Florida Climate Institute (2), Center for Ocean- Atmospheric Prediction Studies, Tallahassee (3)

Two of the most important hydroclimatic features of the Indian summer monsoon rainfall (ISMR) are its onset/demise and intraseasonal variability manifested by the active-break cycles. In this study, we aim to understand the quantitative association between these two phenomena. An objective definition of local onset and demise of ISMR based on more than a century long India Meteorological Department (IMD) rain-gauge observation is taken into consideration in this study. Onset and demise are defined over the native grids (0.25 deg x 0.25 deg) of the IMD data. This definition of onset and demise avoids false onset and advantageous as it has a close correspondence with the seasonal rainfall anomaly.

Using a non-parametric spectral approach, we identify intraseasonal oscillatory (ISO) modes in rainfall over India and extracted two classes of variability: low- and high-frequency ISO (LF-ISO and HF-ISO). They exhibit periodicities of 25–60-days and 10–20-days, respectively. Rainfall over India is highly modulated by these two modes and active spell with copious rainfall at a location is marked by concurrent peaks of these two oscillations. LF-ISO is characterized by northward march of rainfall bands from the southern-most part of India to the foothills of the Himalayas. HF-ISO shows comparatively more complex and small-scale structures, with a north- westward propagation along central India.

Using the definition of local onset and demise and LF-ISO and HF-ISO characterized at each location, we aim to understand the association between them. In other words, how ISO modes modulate the onset and demise at each location. We calculate the phases of the ISO modes based on its periodic nature and determined the phases of ISO during onset and demise occurred at each grid point. It is observed that the probability of occurrence of local onset is remarkably high when LF- and HF-ISO exhibit favorable conditions over that location. Onset dates are mostly marked by the ascending limb of the positive part of the ISO cycle, with LF-ISO showing stronger modulation. Similar results are seen for local demise, which is mostly seen over the descending limb. The results presented here establish an important aspect of the predictability of monsoon onset and demise. Association between the two phenomena raises the hope for the predictability of local onset and demise, as they could be related to slowly evolving large-scale circulation. This could be an important avenue in the problem of forecasting onset/demise using numerical simulations.

SESSION: Plenary

(PI-05)

Subseasonal to Seasonal Science and Predictions Initiatives of the NOAA MAPP Program

Annarita Mariotti (1) and Dan Barrie(1)

(1) NOAA, OAR/Climate Program Office

Scientific communities have historically organized themselves around the weather and climate problems, but the subseasonal to seasonal (S2S) time scale range is overall recognized as new territory, for which a concerted shared effort is needed. For instance, the climate community, as part of programs like CLIVAR, has historically tackled coupled phenomena and modeling, keys to harnessing predictability on longer timescales. In contrast, the weather community has focused on synoptic dynamics, higher-resolution modeling, and enhanced initial conditions, of importance at the shorter timescales and especially for the prediction of extremes. The processes and phenomena specific to the intermediate S2S range require a unified approach to science, modeling, and predictions. Internationally, the WWRP/WCRP S2S Prediction Project is a promising catalyzer for these types of activities. Among the various contributing U.S. research programs, the NOAA Modeling, Analysis, Predictions and Projections (MAPP) program, has put in place a set of coordinated research activities to help address the sub-seasonal-seasonal prediction gap.

This presentation will describe ongoing MAPP program S2S science and prediction activities, specifically the MAPP S2S Prediction Task Force and the SubX prediction experiment. An overview of results from these research initiatives will be presented.

SESSION: Plenary

(PI-07)

WGSIP/DCPP – Project achievements and future plans

Merryfield, William , Doug Smith

CCCma, Canada (1), INM/RAS, Russia (2), Hydrometcentre of Russia (3), Barcelona Supercomputing Center, Spain (4), MRI/JMA, Japan (5)

SESSION: Plenary

(PL-08)

Subseasonal to Decadal Prediction: Looking back on 40 years of progress - and projecting forward another 40 years

Palmer, Tim

University of Oxford

In this talk I want to reflect back on some of the key successes across the range of initialised predictions on the sub-seasonal to decadal timescales over the last 40 years. This includes the first ensemble forecast systems, the first dynamical predictions of El Nino and the development of links between decadal modes of sea temperature variability and Sahel Drought. However, over these 40 years, predictive skill has been compromised by persistent model systematic error. Model intercomparison programmes have shown that model biases are only slowly reducing over time. For the sake of society, we must start accelerated programmes of research to eliminate them. Some suggestions on how to do this will be outlined.

SESSION: Plenary

(PL-09)

Research Needs for Advancing Operational S2D Forecasting Infrastructure

KUMAR, Arun

Climate Prediction Center

Advances in understanding of predictability of climate variability on sub-seasonal to decadal time scale has led to the establishment of operational infrastructure in support of providing routine predictions to interested stakeholders. This is highlighted by the designation of Global Producing Centers (GPCs) for seasonal and annual to decadal predictions under the purview of the World Meteorological Organization (WMO). The infrastructure of GPCs is further augmented by associated lead-centers that play the role of collecting, synthesizing and disseminating forecast information from individual GPCs. Despite tremendous advances in the development of operational forecasting on S2D time-scales, challenges remain that compromise the realization of inherent predictability as prediction skill. These challenges span considerations such as configuration of operational forecast systems, development and verification of forecast products, strategies for the communication of forecast information, etc. In this talk, research needs to address challenges for advancing operational S2D forecasting infrastructure will be discussed.

SESSIONS: (A7/A8) Stratosphere/Chemistry

(A7-01)

Impacts of NASA's Earth Observations on Subseasonal and Seasonal Forecasts

Steven Pawson, Andrea Molod and Eric Hackert

Global Modeling and Assimilation Office , NASA Goddard Space Flight Center

NASA's suite of Earth-observing satellites provides a unique view of many processes on Earth, with relevance on timescales ranging from hours to weeks and even years. NASA's observations span all parts of the Earth system: atmospheric, ocean, land and cryosphere, and include physical, chemical and biological components. This presentation explores use of NASA observations in extended-range prediction, from many days to months, using the Goddard Earth Observing System (GEOS) assimilation and predictive modeling capabilities.

The skill of a weather forecast is linked to the fidelity of the initialization process (data assimilation) and the realistic representation of "fast" physical processes in the model. At longer time horizons, the slower "feedback" processes in the Earth System begin to take a more prominent role in the accuracy of the forecast. Simultaneously, forecast-skill attribution transitions away from feature-based metrics that emphasize smaller scales (e.g., representations of fronts and vortices) to metrics that emphasize the statistical distributions of large-scale features (e.g., ENSO diagnostics and teleconnections).

This presentation will summarize studies performed using the GEOS-S2S (subseasonal to seasonal) system that explore the impacts of NASA observations on the fidelity of the forecasts. The GEOS-S2S system is configured for the atmosphere-ocean-land-ice model and is initialized using in-situ and space-based observations, including atmospheric aerosols and ozone which are not typically analyzed in such systems. The GEOS-S2S model routinely includes aerosol feedbacks, which systematically impact the realism of the forecasts, providing a first example of how suitable NASA observations impact the performance of the GEOS-S2S system. Studies in which a stratospheric chemistry module is activated in the GEOS-S2S system allow the impacts of ozone radiative feedbacks to be isolated. Space-based observations of sea-surface temperature and altimetry are routinely analyzed for the initialization of the GEOS-S2S system; recent advances allow the use of NASA's sea-surface salinity data, which are shown to impact the long-range skill of the forecasts.

SESSIONS: (A7/A8) Stratosphere/Chemistry

(A8-01)

The role of the stratosphere in sub-seasonal to seasonal predictability

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Knowledge of the state of the stratosphere has the potential to enhance predictability of the troposphere on sub-seasonal to seasonal timescales. Here, we provide a broad overview of our current understanding of how the stratosphere couples to the troposphere in the tropics and extratropics, via processes such as the Madden-Julian Oscillation and the El Niño-Southern Oscillation. We discuss progress to date in trying to harness stratosphere-troposphere coupling to enhance predictability on the sub-seasonal to seasonal (S2S) timescale, a key focus of the WCRP/SPARC Stratospheric Network for the Assessment of Predictability (SNAP) project. Finally, we examine open questions and provide some suggestions on where and how improved understanding and simulation of stratosphere-troposphere coupling is most likely to lead to improved skill.

SESSIONS: (A7/A8) Stratosphere/Chemistry

(A8-02)

Effect of Sudden Stratospheric Warmings on Subseasonal Prediction Skill in the NASA S2S Forecast System

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Sudden stratospheric warmings (SSW) represent a major mode of subseasonal variability in the winter atmosphere, representing a potential for “Forecasts of Opportunity” in S2S systems. So-called “major SSWs” appear as dramatic polar cap warmings of 20o or more accompanied by weakening of the circumpolar zonal wind and reversal from the normal westerly to easterly. SSW anomalies can develop rapidly over days, descend in time over 1-2 weeks, and persist at the tropopause for 1-2 months. These stratospheric wind changes affect the vertical and latitudinal propagation of planetary waves throughout the atmosphere. Thus extreme stratospheric wind events, whether extremely weak or strong, are statistically associated with anomalous southward or northward shifts in the storm tracks with associated surface temperature and precipitation pattern shifts. Previous work has suggested enhanced prediction skill at the 16-60 day forecast range when forecasts are initialized during SSW events. However, prediction skill of the SSWs themselves remains poor beyond 10 days.

NASA’s Global Modeling and Assimilation Office (GMAO) at Goddard Space Flight Center has recently released a new subseasonal to seasonal forecast system, GEOS-S2S version 2.1. Compared to GMAO’s previous system, the new version runs at higher atmospheric resolution (approximately 1/2o globally), contains a substantially improved model of the cryosphere, includes additional interactive aerosol model components, and the ocean data assimilation system has been replaced with a Local Ensemble Transform Kalman Filter. A set of retrospective 45-day forecasts was initialized based on the MERRA2 reanalysis at 5-day intervals throughout years 1999 to 2015, with 4 ensemble members per initialization date. Our analysis of these retrospective forecasts reveals surface anomaly patterns in the period following SSW events, and compares key measures of forecast skill, contrasting forecasts initialized during an SSW to those initialized during normal conditions. We compare these results to those previously published using other forecast systems, and we examine the potential role of stratospheric wind biases and orographic gravity wave drag on the forecast skill.

SESSIONS: (A7/A8) Stratosphere/Chemistry

(A8-03)

Predictability of Sudden Stratospheric Warmings in sub-seasonal forecast models

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We analyze the skill of the Arctic stratospheric retrospective ensemble forecasts (hindcasts) of subseasonal forecast models from the s2s database with a focus on the predictability of the major sudden stratospheric warmings (SSWs) during the period 1981-2013. Predictability is assessed in both deterministic, based on ensemble-mean forecasts, and probabilistic sense. To estimate forecasted SSW probability we use the spread of ensemble members. We show that some SSWs can be predicted with high (0.9) probability at lead times of 12-13 days if a difference of 3 days between actual and forecasted SSW is allowed. Focusing on SSWs with significant impacts on the tropospheric circulation we find that, on average, the forecasted SSW probability is small at lead times of more than two weeks and then increases rapidly to nearly 1 at day 7 before SSWs. The period between days 8-12 is when most of the SSWs are predicted by the models with a probability 0.5-0.9 which is considerably larger than the observed SSW occurrence frequency. Therefore this period can be thought of as an estimate of the SSW predictability limit. We also find indications that predictability limit for some SSWs may be longer than two weeks; however more studies are needed to understand when and why such long predictability is possible.

SESSIONS: (A7/A8) Stratosphere/Chemistry

(A8-04)

The role of stratosphere - troposphere coupling in sub-seasonal to seasonal prediction using the S2S database

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Over the past decades, the stratosphere has been found to strongly couple with surface processes, especially in winter. In the light of improving predictions on sub-seasonal to seasonal timescales, the stratosphere has been found to potentially represent a crucial source of predictability, in particular after stratospheric extreme events. It however remains to be quantified to what extent this predictability is reproduced in sub-seasonal model predictions. In a community effort, we explore the predictability arising from stratosphere – troposphere coupling on sub-seasonal timescales in a wide range of models from the S2S database. Surface predictability arising from a range of stratospheric events such as sudden and final stratospheric warmings, strong vortex events, and negative wave-1 heat flux events is quantified, as well as predictability of the stratosphere itself, arising from remote connections in the climate system. A comparable analysis is performed for the Southern Hemisphere. This contribution will provide an overview of the state-of-the-art of the currently available forecast skill arising from the coupling between the troposphere and the stratosphere.

SESSIONS: (A7/A8) Stratosphere/Chemistry

(A8-05)

A signal and noise analysis of stratosphere-troposphere coupling in the S2S models

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On sub-seasonal timescales, coupling between the stratosphere and troposphere represents a significant source of skill for northern mid and high-latitudes. Previous studies have examined this skill either on a case-by-case basis or from the perspective of the additional skill present during sudden stratospheric warming (SSW) or strong polar vortex events. Here we complement these approaches by fitting a simple statistical model to the full hindcast set available from the S2S database. The statistical model used enable us to separate the predictable signal and noise in the annular mode present in each hindcast set. While all models in the S2S database exhibit some degree of stratosphere-troposphere coupling in the annular mode, there are significant differences between them. In the middle and lower stratosphere, models have high skill out to week four, with large signal to noise ratio. In the troposphere, annular mode skill is weaker in weeks three and four. In the lower stratosphere, many models have low spread and are over-confident. In the troposphere, there is similar overconfidence, particularly in week 3. Models with the largest overconfidence in the lower stratosphere also exhibit the largest overconfidence in the troposphere. In the troposphere, the overconfidence is due to an over estimation of the size of the predictable signal in most models.

Correlation between the extracted signal in the lower stratosphere and surface varies significantly between models. Taken together with the over-estimation of the size of the predictable signal in the troposphere in these models suggests that some models have excessively strong stratosphere-troposphere coupling on sub-seasonal timescales.