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CLIVAR Annual Progress Report

(Submitted by Drs Howard Cattle and Jim Hurrell and
Professor Martin Visbeck)

CLIVAR Annual Progress Report 2009 for JSC-31

Submitted by Howard Cattle, Jim Hurrell and Martin Visbeck

CLIVAR- background

CLIVAR's mission is "*to observe, simulate and predict changes in the Earth's climate system with a focus on ocean-atmosphere interactions, enabling better understanding of climate variability, predictability and change, to the benefit of society and the environment in which we live"*. In line with the WCRP overarching objectives and strategic plan, CLIVAR acts to encourage and facilitate national and international activities that contribute to our understanding of climate variability and our ability to provide improved climate predictions on seasonal, interannual, decadal and centennial timescales. It seeks to encourage the development and implementation of sustained observations of the climate system, field and modelling studies that help our understanding of climate processes and how they can be represented in models, analytical studies to assist our understanding of climate variability and coordinated effort in climate prediction. CLIVAR has activities directly in support of the cross cutting science topics of WCRP, in particular on seasonal prediction, monsoons, decadal variability and anthropogenic climate change. It also has a particular focus on the role of the oceans in climate, including ocean observations, and the representation of the oceans in models for climate prediction. CLIVAR's focus is on the physical climate system on both regional and global scales. It links with other programmes on the wider biogeochemical, ecological and human dimension aspects of the Earth system. In order to deliver CLIVAR Science, the CLIVAR SSG has established a number of global and regional panels and working groups defined in the footnote below[1]**.** These, liaising as appropriate with other international bodies and national programmes, develop internationally coordinated activities attractive to national agency funding. Indeed the international dimension which CLIVAR brings adds value to the individual national agency efforts.

End users of CLIVAR-facilitated research include the sponsors of WCRP, a wide variety of international organizations including IPCC and UNFCCC, national agencies, the science community and beneficiaries of CLIVAR-sponsored workshops and training activities. In addition there are feedbacks (e.g. through IPCC) to policymakers and to governments and aid and planning agencies, commercial users and a wider public.

Imperatives for CLIVAR research – a focus for CLIVAR SSG-16

As input to the WCRP Implementation Plan 2010-15, a major focus of CLIVAR SSG-16 (Madrid, Spain, 19-22 May 2009) was to build consensus on the overall imperatives for CLIVAR science and its implementation over the coming 5 years. The outcome was encapsulated into the following structure, key topics and actions:

Imperative I - Anthropogenic climate change

> *<u>Topics:</u> Natural variability versus forced change; climate sensitivity and feedbacks; regional phenomena; Extremes.*
> *<u>Actions:</u> Complete CMIP5*

[1] These comprise the JSC/CLIVAR Working Group on Coupled Modelling (WGCM); Working Group on Seasonal to Interannual Prediction (WGSIP); the Working Group on Ocean Model Development (WGOMD). CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI); Global Synthesis and Observations Panel (GSOP); CLIVAR/PAGES Panel; Variability of the American Monsoon System (VAMOS) Panel; Variability of the African Climate System Panel (VACS); Asian Australian Monsoon Panel (AAMP); Atlantic Implementation Panel (AIP); Pacific Panel; CLIVAR//GOOS Indian Ocean Panel (IOP); CLIVAR/CliC/SCAR Southern Ocean Panel and the CliC/CLIVAR Arctic Climate Panel. The International CLIVAR Project Office (ICPO) is responsible for the coordination of the scientific and administrative aspects of CLIVAR, acting as the executive arm of the SSG under its general direction.

Imperative II – Decadal variability, predictability and prediction

Topics: *Determine predictability; mechanisms of variability; role of the oceans including the impact of ocean variations on land, temperature, precipitation, etc; adequacy of the observing system; initialization; prediction uncertainty; drought;*

Actions: *Build links pan-WCRP; complete CMIP; complete the Climate System Historical Forecast Project (CHFP) - see the WGSIP report, this volume – complete the Coordinated Ocean and sea ice Reference Experiments (CORE)*

Imperative III – Intraseasonal and seasonal predictability and prediction

Topics: *Monsoons, El Nino-Southern Oscillation, tropical Atlantic variability, MJO/Intraseasonal variability; prediction uncertainty.*

Actions: *Build links pan-WCRP; complete CHFP.*

Imperative IV – Improved atmosphere and ocean component models of Earth System Models

Topics: *Analysis and evaluation; climate process teams (process studies).*

Actions: *Build links pan-WCRP, IGBP; complete COREs*

Imperative V – Data synthesis, analysis, reanalysis and uncertainty

Topics :Ocean; coupled data assimilation systems

Actions: *Build links with IGBP – carbon, biogeochemistry, ecosystems*

Imperative VI – Ocean observing system

Topics: *Advocacy for sustained observations; development, implementation and system design.*

Actions: *Build links with IGBP – carbon, biogeochemistry, ecosystems.*

Imperative VII – Capacity building

Topics/Actions: *Topical workshops, summer schools, expert training.*

In order to develop the process further, tiger teams were established to develop short (up to 5 page) summaries of the key science questions, implementation plans and timelines for each of the 7 imperatives. These summaries are provided for the JSC in a separate document. They are being developed further to guide CLIVAR activities over the next several years, having been initially fed into the WCRP's Implementation Plan 2010-2015. A further focus for CLIVAR SSG-16 was progress by CLIVAR's panels and working groups, summaries of which were published in the July 2009 edition of CLIVAR Exchanges at www.clivar.org/publications/exchanges/exchanges.php. Recent highlights of developments in CLIVAR and future plans are given below.

CLIVAR - major activities and achievements in 2009

CLIVAR Modelling activities

- Planning and implementation of CMIP5 under WGCM continues apace. Over 20 modelling groups are participating in CMIP5. It is likely that about 5 groups will have 50 km class AOGCMs for decadal prediction, and at least 10 groups will have ESMs. The full set of forcings (emissions and concentrations) are available from the PCMDI CMIP5 website. Model simulations to be assessed in the IPCC AR5 will be completed in 2010 with PCMDI beginning to compile model data mid-2010. Analysis of model data begins late 2010 and will continue through 2011. Modelling groups will continue CMIP5 simulations through 2013. Coordinated experimentation to study multi-decadal prediction and near-term climate change continues to be overseen by the joint WGCM/WGSIP/CLIVAR/WCRP sub-group.

- CLIVAR, through Jim Hurrell, Tim Stockdale and Lisa Goddard led white papers for WCC-3 on the status of decadal predictability and on providers and users aspects of seasonal prediction respectively.

- The WCRP Climate-system Historical Forecast Project (CHFP) continues to provide the focus for WGSIP as the key contribution to the WCRP Seasonal Prediction Cross Cut. CHFP provides a multi-model and multi-institutional experimental framework for sub-seasonal to decadal complete physical climate system prediction to provide:

    - A baseline assessment of seasonal prediction capabilities using the best available models and data for initialization
    - An experimental framework for focused research on how various components of the climate system interact and affect one another
    - A test bed for evaluating IPCC class models in seasonal prediction

  Participating Groups are: EU-ENSEMBLES, APEC, CLiPAS, NCEP, GFDL, COLA-Uni Miami, GMAO, BMRC, JMA, CCCma, CPTEC, IRI with local and distributed data centres (CIMA-Argentina, ENSEMBLES-UK, APEC-Korea). Within WCRP, contributions from core projects include:

    - CLIVAR; Seasonal and CMIP5 Near Term hindcast simulations; CLIVAR Regional Panels are requested to lead the application interface for seasonal prediction skill assessment
    - GEWEX Global Land-Atmosphere Coupling Experiment (GLACE-2): to determine prediction skill associated with accurate initialization of land surface states.
    - SPARC: Stratosphere-resolving HFP experiment (StratHFP): high and low top models will be used to quantify improvements in *actual* predictability by initializing and resolving the stratosphere in seasonal forecast systems.
    - CliC: Sea-Ice Predictability Experiments to explore seasonal predictability associated with snow and sea ice.

- A key activity for WGOMD surrounds the concept of Coordinated Ocean-ice Reference Experiments (CORE) that provide benchmark simulations for global ocean-ice models. Detailed protocols, facilitate solution comparisons from different models. CORE-I provided multi-century simulations with a repeat annual cycle forcing (Large & Yeager 2004, 2008) with the outcomes published in Griffies et al., 2009: Coordinated Ocean-ice Reference Experiments (COREs) *Ocean Modelling*, **26**, 1-46. Focus is now on CORE-II hindcast simulations with 1948-2007 forcing (Large & Yeager, 2008). These provide the framework both to evaluate ocean model performance and to investigate mechanisms of ocean phenomena and their variability from seasonal to decadal time scales. To enable this, a framework has been established where the experimental design is flexible and subject to refinement as the community gains experience and provides feedback.

- WGOMD also held a Workshop on Ocean Mesoscale Eddies: Representations, Parameterizations and Observations (April 2009, Met Office, Exeter UK) that attracted some 140 participants. It also contributed white papers to WGCM/CMIP5 and OceanObs'09 (Griffies et al. (2009) Sampling Physical Ocean Fields in WCRP CMIP5 Simulations, ICPO Publication Series 137, WCRP Informal Report 3/2009; Griffies et al. (2009): Problems and Prospects in Large-Scale Ocean Circulation Models, OceanObs '09). Work to develop the WGOMD Repository for Evaluating Ocean Simulations (REOS) has also continued.

<u>Synthesis and Observations</u>

- OceanObs'09 provided a major focus for CLIVAR's GSOP during the year, and for CLIVAR more widely, in particular its Ocean Basin Panels and WGOMD. Detlef Stammer (co-chair of GSOP) acted as one of the three co-chairs of the organizing committee for OceanObs'09 and the CLIVAR community contributed substantially to the Community White Papers for the symposium. CLIVAR basin panels took part in an OceanObs'09 Community Forum "Towards integrated ocean basin observations planning" during the symposium with presentations on the ocean observations in each of each of the Atlantic, Pacific, Indian and Southern Oceans from which a number of recommendations for CLIVAR emerged. In the context of ocean synthesis, GSOP also contributed to two workshops during the year, namely the 8th Workshop on "Decadal climate variability: Decadal climate predictability and prediction – where are we?" (Maryland, USA, October 2009) and the Workshop on "Earth system initialization for decadal predictions" (KNMI, Utrecht, The Netherlands, November 2009). The panel met at JAMSTEC, Tokyo, Japan from in November 2009.

- The IOC-SCOR International Ocean Carbon Coordination Programme/CLIVAR Global Ocean Ship-based Hydrographic Investigations Programme (GO-SHIP) has developed a strategy for a sustained global repeat hydrography programme via an oceanObs'09 Community White Paper which a newly-established GO-SHIP Committee is taking forward. GO-SHIP is also actively progressing revision of the WOCE Handbook in the context of future repeat hydrography. Formal international/intergovernmental agreements on the GO-SHIP strategy and its implementation are on-going.

- The joint CCL/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices held 4 capacity-building regional workshops during 2009 in Mexico (March), at the Service Météorologique Mauricien, Vacoas, Ile Maurice - Pays de la Commision de l'Océan Indien in October and in Indonesia, as part of DiDaH Project (data recovery) in December. Recommendations on 'Issues of Scaling' for Comparing Modelled and Observed Extremes were drawn together in a report from a CLIVAR-sponsored ad-hoc meeting on "Issues of Scaling", KNMI, Netherlands, May 2008. A WMO document providing Guidelines on Analysis of Extremes in a Changing Climate in Support of Informed Decisions for Adaptation was also issued together with a set of Guidelines for Calculating and Assessing Extremes in CMIP5. ETCCDI has strong cross membership and interaction with the International Detection and Attribution Group which has made substantial contributions to the IPCC process and the US CCSP activities and which is engaged in reviewing advances in detection and attribution of extremes.

- CLIVAR/PAGES has finalized its vision document outlining its programme over the coming years. Identified areas of research where the paleo-climate community can directly help with uncertainties in modern and future climate include:

  - Internal and forced variability over the last few millennia
  - Sensitivity of the North Atlantic circulation
  - Hydrological changes and interactions with the land surface
  - Tropical Cyclones, Extreme Precipitation Events

  The Paleoclimate Reconstruction Challenge promoted by the Panel is well underway with planned production of model runs, intercomparison and analysis. It has, as its objective, independent evaluation of state-of-the-art reconstruction methods through ouble blind tests of pseudo-proxy networks and simulations of climate change during the last few millennia. For CMIP5, the paleo-component has been adopted from PMIP3, with the last millennium under tier 1 and the mid Holocene and Last Glacial Maximum under tier 2 of the CMIP5 organizational structure.

<u>CLIVAR Ocean Basin activities</u>

- As part of the coordination of Atlantic Meridional Circulation (AMOC) activities, panel members actively participated in the first US AMOC meeting in Annapolis, USA, (May 2009); a South Atlantic MOC workshop in July 2009 in Paris, France and the RAPID annual science meeting (Cambridge, UK, July 2009). Panel members also contributed to several Community White papers for OceanObs'09 and to the organization of the Workshop on Earth System Initialization for Decadal Predictions (KNMI, Utrecht, The Netherlands, November 2009)

- Endorsed by CLIVAR, the Tropical Atlantic Climate Experiment (TACE) to advance the understanding of coupled ocean-atmosphere processes and improve climate prediction for the Tropical Atlantic region continues to make progress, providing enhanced observations in the tropical Atlantic spanning a period of approximately 6 years (2006-2011). The observational network includes: the PIRATA array; AMMA field campaigns, particularly the French EGEE program; nationally funded TACE projects (US-TACE, German BMBF Nordatlantik). CLIVAR's Atlantic panel sponsored a meeting in Toulouse, France providing liaison between PIRATA, TACE and the African Monsoon Multidisciplinary Analysis (AMMA) in February 2009.

- The CLIVAR Pacific Panel met in Perth, Australia in March 2009, where it sponsored and organized a WCRP Workshop on El Niño and climate change. The Panel is coordinating a number of regional projects in the Pacific including the Southwest Pacific Ocean Circulation and Climate Experiment (SPICE) and the North Pacific Ocean Circulation Experiment, an implementation Workshop for which was held in Xiamen, China in January 2010 with CLIVAR participation.

- Under the coordination of the CLIVAR/GOOS Indian Ocean Panel (IOP), which met in La Reunion, France, in June 2009, the Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction (RAMA) continues to develop and is now some 53% complete. A surface buoy at (8S, 100E) will be deployed in Feb/Mar 2010 by FIO, and to complete the line at 8S. However, vandalism and piracy remain problematic. To aid deployments, an IndOOS Resource Forum, advised by the IOP, has been established by IOGOOS and a RAMA summary paper appeared in 2009 (McPhaden, et al., 2009: RAMA: The Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction. Bull. Am. Meteorol. Soc.). IndOOS/RAMA data are now being actively used in research, for example, in four studies of Tropical Cyclones Nargis and Dora; in the monitoring of surface fluxes in MJO events and in investigations of the heat budget of the eastern tropical ocean during the positive IOD event in 2006. IOP is also developing links to IGBP IMBER through the Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER) programme.

- The CLIVAR/CliC/SCAR Southern Ocean Panel, which last met in January 2009, has, as a primary focus, the development of the Southern Ocean Observing System (SOOS) and provided substantial contributions to the OceanObs'09 community white paper on the SOOS.

<u>CLIVAR Monsoon and African Climate activities</u>

- CLIVAR's Asian-Australian Monsoon Panel has current primary focus on the Monsoon Intra-Seasonal Oscillation/MJO. The panel is coordinating a programme of MISO/MJO hindcast experimentation involving a number of centres which ahs been extended it to the year of Tropical Convection (YOTC) period: The panel has also promoted an (ongoing) assessment of real-time MJO prediction that has been endorsed by WGNE, has participated in the MJO metrics and model evaluation activities of the US CLIVAR MJO Working Group and has worked to promote the establishment of the WCRP/WWRP YOTC MJO Task Force. In addition, the Panel has helped to refine the science and implementation plans for AMY (Asian Monsoon Years (2007-2012)) and has reviewed Indian Ocean observational campaigns in collaboration with IOP (e.g., CINDY/DYNAMO, TRIO) for CLIVAR SSG endorsement.

- CLIVAR VAMOS has initiated an activity on extremes, with focus on their physical-dynamic forcing, linking activities related to drought and studies of extremes in the La Plata Basin (LPB). The overall focus is improving our understanding of the mechanisms and predictability of warm season extremes over the Americas on subseasonal to decadal and longer time scales.

- The VAMOS Ocean-Cloud-Atmoshere-Land Study (VOCALS) Chilean Upwelling Experiment (CUpEx) took place in Nov-Dec 2009. Several VOCALS-related meetings took place during the year including a session at the AGU Fall meeting (December 2009). In addition a special Issue on VOCALS was published in Atmospheric Chemistry and Physics, EGU Journals.

- The VAMOS North American Monsoon Experiment (NAME) project is sunsetting as a funded programme through 2009-10. However several lines of research in warm season precipitation prediction are continuing, climate change impacts studies are underway and a handful of field observation projects are on-going. Oral and poster sessions on the N. American Monsoon featured at the Fall AGU meeting

- The VAMOS MESA (Monsoon Experiment South America) science and implementation plan was updated during the year. A review paper "New developments on the functioning, characteristics and variability of the South American Monsoon System (SAMS)" was submitted to International Journal of Climatology and hydrological applications related to SAMS have been promoted for seasonal prediction and climate change projections. MESA is also currently coordinating with monitoring activities in the Atlantic Ocean through the Ministry of Science and Technology-INPE, Brazil.

- An LPB Regional Hydroclimate Project International Summer School on "Land cover change and hydroclimate of the La Plata Basin" (Itaipu, Brazil, Noverber 2009) attracted some 100 application with 45 places funded, thanks to IAI

- A new VAMOS programme on the Intra-Americas Study of Climate Processes was endorsed during the year by both CLIVAR and the US CLIVAR Programme. Seven IASCLIP projects have been funded by NOAA/CPO/CPPA and planning for enhanced monitoring in the Caribbean is underway.

- The CLIVAR VACS African Climate Atlas based at Oxford, UK, has a focus on the observed and modelled climate of Africa. The Atlas currently has seven parts as follows: Part I - Climatology Part II - Anomalies Part III - TOMS Absorbing Aerosol Index (interactive visualization) Part IV - ERA40 Pressure Level Climatologies & Composites Part V - WCRP CMIP3 multi-model archive Analysis Part VI – FAQs on African Climate Part VII – Climate change extremes and thresholds.

- Africa through the Agulhas and Somali Current Large Marine Ecosystem Project, the University of Cape Town and Rhodes University through buoy and Argo float deployments have made a major contribution to the Indian Ocean Observing System Research moored array for African-Asian-Australian Monsoon Analysis and prediction (RAMA) that is coordinated by the GOOS/ CLIVAR Indian Ocean Panel.

- The Horn of Africa Regional Climate Model Inter- comparison Project (AFRMIP) is contributing to the broader goals of CLIVAR-VACS. The activities of the project are designed to specifically address, through numerical modelling, some of the outstanding science questions on the physical and dynamical processes associated with Greater Horn of Africa (GHA) climate variability and predictability across space and time scales. The specific objectives of AFRMIP are to: (i) Develop objective criteria for modifying and improving the parameterizations of various physical processes as would be appropriate for improving the performance (skill) of RCMs over the GHA sub-region, (ii) Develop a regional seasonal climate dynamical prediction system for the GHA, and (iii) Generate high-resolution regional climate change scenarios. AFRMIP is coordinated by Dr. Richard Anyah (University of Connecticut, USA) and several well-known international regional modelling groups are active participants in the project.

CLIVAR – interactions (especially with sponsor organizations)

CLIVAR has a wide variety of activities and therefore interactions. These include WWRP (through YOTC and the MJO Task Group, and via WGNE); WCRP sponsor organisations, in particular with IOC through joint activity with GOOS (co-sponsorship of the IOP) and OOPC and the IOCCP/CLIVAR GO-SHIP. CLIVAR also has joint activity with IGBP Past Global Changes (PAGES) through the CLIVAR/PAGES Panel, and other links to IGBP through IMBER and GLOBEC. The WMO Commission for Climatology, JCOMM and CLIVAR jointly co-sponsor ETCCDI (delivering to each) and CLIVAR, CliC and SCAR the Southern Ocean Panel. Links to SCOR include the Agulhas Current Working Group on which there is WCRP/CLIVAR represention.

Publications through 2009

These include:

- *Review papers:*

Multi-century simulations with a repeat annual cycle forcing (Large & Yeager 2004, 2008): Griffies et al., 2009: Coordinated Ocean-ice Reference Experiments (COREs) *Ocean Modelling*, **26**, 1-46.
McPhaden, M.J., G. Meyers, K. Ando,Y. Masumoto, V.S.N. Murty, M. Ravichandran, F. Syamsudin, J. Vialard, L. Yu, and W. Yu, 2009: RAMA: The Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction. Bull. Am. Meteorol. Soc., 90, 459-480.
Meehl, G. A., *et al*., 2009: Decadal prediction: Can it be skillful? *BAMS*.,DOI: 10.1175/2009BAMS2778.1.

- *Special editions of Journals*

Special Issue on VOCALS in Atmospheric Chemistry and Physics, EGU Journals

- *WMO Guidelines Publication*

A. M.G. Klein Tank, F. W. Zwiers and X. Zhang, 2009, Climate Data and Monitoring WCDMP-No. 72, WMO-TD No. 1500, 56pp.

- *OceanObs Community White papes*

Rintould et al (2009): Southern Ocean Observing System (SOOS): Rationale and strategy for sustained observations of the Southern Ocean.
Griffies et al. (2009): Problems and Prospects in Large-Scale Ocean Circulation Models, OceanObs '09).

- *ICPO numbered publications:*

135: Report of the 5th Meeting of the CLIVAR Indian Ocean Panel, 12-14 May 2008, Bali, Indonesia. Southampton, UK
136: Report of the Twelfth Session of the JSC/CLIVAR Working Group on Coupled Modelling (WGCM)
137: Sampling Physical Ocean Field in SCRP CMIP5 Simulations: CLIVAR Working Group on Ocean Model Development (WGOMD) Committee on CMIP5 Ocean Model Output
138: Report of the 12th Session of the JSC/CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP), 12-14 January 2009, Miami, USA.
139: Report of the Ninth Meeting of the Atlantic Implementation Panel, 18 - 19 September 2008, Woods Hole Oceanographic Institution, U.S.A.
140: Report of the Eighth Session of the Working Group on Ocean Model Development, 30th April - 1st May 2009, Exeter, United Kingdom.
141: Report of the Third Session of the Global Synthesis and Observations Panel, NOC, Southampton, UK, 13-14 March 2008
142: Hood., E.M. & Co-Authors (2009). Ship-based Repeat Hydrography: A Strategy for a Sustained Global Survey. In *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2)*, Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E., & Stammer, D., Eds., ESA Publication WPP-306. ICPO Publication 142

- *Editions of CLIVAR Exchanges were as follows:*

Feb 2009, No 48 Joint edition with VAMOS Newsletter
Apr/Jul 2009, No 49/50 Special edition on CLIVAR SSG-16
Oct 2009, No. 51 General edition

- *Web publication*

PAGES/CLIVAR vision document - www.clivar.org/organization/pages/docs/Pages_CLIVAR_Vision_2009.pdf

ICPO, program administration and management

Following a review of the work of the ICPO during the previous 5 years and submission of a new case for continued funding, the UK Natural Environment Research Council (NERC) awarded the ICPO a new contract for 3 years with effect from 1 April 2010. In addition, the ICPO continues to be generously supported by NASA, NOAA and NSF through US CLIVAR. The current complement of the ICPO is 3.5 staff scientists plus the Director and Office Manager. The Director, Office Manager and one staff scientist continue to be hosted by the National Oceanography Centre, Southampton. Another staff member has visiting scientist status at NOCS. Others are hosted by GFDL, Princeton, USA; University of Buenos Aires, under US CLIVAR funding. With the announcement of the retirement of the present Director with effect from 1 April 2010**,** the post was advertised in the 4th quarter of 2009 but no replacement candidate was identified. The post is currently being re-advertised with interviews planned for 29 April 2010. The JSC should note that finding an ICPO Director acceptable to NERC is essential to funding of the ICPO by NERC beyond 31 March 2011.

Look ahead – CLIVAR and CLIVAR-sponsored meetings and workshops planned for 2010

Activity	**Date**
Contribution to Workshop on Predicting The Climate Of The Coming Decades, RSMAS, Miami, USA	Jan 11-14, 2010
NPOCE Implementation workshop, Xiamen, China	17 – 18 Jan 2010
GO-SHIP International Planning Meeting, Portland, Oregon, USA	21 Feb 2010
10th session of the CLIVAR Atlantic Implementation Panel.	28Feb-11 Mar 2010
CLIVAR SSG-17, Boulder, Co, USA	Week of 17-21 May 2010
International workshop on North Pacific West Boundary Current dynamics, Qingdao, China	May 2010
CLIVAR/CliC/SCAR Southern Ocean Symposium and Panel Meeting, NOCS, Southampton, UK	14-17 Jun 2010
AAMP panel meeting, Workshop on Modelling monsoon intraseasonal variability, 1st meeting of the YOTC MJO Task Force and 10th session of AAMP. APCC, Busan, Korea	15-19 Jun 2010
7th session of the Indian Ocean Panel, with the 1st meeting of INDOOS Resources Forum, 7th meeting of IOGOOS and IGBP IMBER SIBER Workshop. Perth, Australia	Week of 12 Jul 2010
13th session of WGSIP, CIMA, Buenos Aires, Argentina in conjunction with 13th session of the VAMOS Panel in conjunction with WGSIP, Buenos Aires, Argentina	28-31 Jul 2010
IAI Training Institute on the Use of Seasonal Predictions for Applications in Latin America, Buenos Aires, Argentina	2–13 Aug 2010
2nd GSOP XBT Fall Rate Equation Workshop, Hamburg, Germany	End August
Third VOCALS Science Meeting	Jul 2010
WGOMD/GSOP Workshop on "Decadal Variability and Predictability – the ocean's role", and 9th session of WGOMD NCAR, Boulder, USA.	20-24 Sep 2010
Pacific Panel SPCZ Workshop, Samoa Islands.	Aug 2010
International Workshop on ENSO, Decadal Variability and Climate Change in South America: 'Trends, teleconnections and potential impacts" and the 5th Session of the Pacific Panel, Guayaquil, Ecuador.	12-16 Oct 2010

14th session of WGCM, Met Office, Exeter, UK	4-6 Oct 2010
GSOP data workshop.	2nd half of 2010
VACS meeting/workshop	tbd

CLIVAR Imperatives 2010-25
(DRAFT)

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> _Actions:_ *Complete CMIP5*

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> _Topics:_ *Determine predictability; mechanisms of variability; role of the oceans including the impact of ocean variations on land, temperature, precipitation, etc; adequacy of the observing system; initialization; prediction uncertainty; drought;*
> _Actions:_ *Build links pan-WCRP; complete CMIP; complete the Climate System Historical Forecast Project (CHFP) - see the WGSIP report, this volume – complete the Coordinated Ocean and sea ice Reference Experiments (COREs) – see WGOMD report, this volume).*

Imperative III – Intraseasonal and seasonal predictability and prediction

> _Topics:_ *Monsoons, El Nino-Southern Oscillation, tropical Atlantic variability, MJO/Intraseasonal variability; prediction uncertainty.*
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Imperative IV – Improved atmosphere and ocean component models of Earth System Models

> _Topics:_ *Analysis and evaluation; climate process teams (process studies).*
> _Actions:_ *Build links pan-WCRP, IGBP; complete COREs*

Imperative V – Data synthesis, analysis, reanalysis and uncertainty

> _Topics:_ *Ocean; coupled data assimilation systems*
> _Actions_: *Build links with IGBP – carbon, biogeochemistry, ecosystems*

Imperative VI – Ocean observing system

> _Topics:_ *Advocacy for sustained observations; development, implementation and system design.*
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Imperative VII – Capacity building

> _Topics/Actions_: *Topical workshops, summer schools, expert training.*

In order to develop the process further, tiger teams were established to develop short (up to 5 page) summaries of the key science questions, implementation plans and timelines for each of the 7 imperatives to guide CLIVAR activities over the next several years. This Annex documents those summaries for WCRP JSC-31.

Imperative I - Anthropogenic climate change

Prepared by: Gerald Meehl, Sandrine Bony, Francis Zwiers and Wenju Cai

Background and motivation

Human activity has changed our climate over the past century, and further change is inevitable over the next several decades, even if we take strong mitigation actions. Thus it is imperative to undertake predictive science that aims to inform the adaptation decisions that we must collectively make. This includes improving our ability to predict the future state of the climate system, including variations in the likelihood of extremes, drought and the availability of water, on time scales of seasons to decades and longer, and in particular, to better understand how human influences on the climate system exacerbate (or damp) these variations on regional to global scales. This will require us to further improve our understanding of the processes that govern the natural variability of the climate system on these scales and of how those processes are affected by human influence, and to use this understanding to provide observational constraints that can be used to improve predictions and projections.

On the longer time scale, the extent to which we undertake mitigation will have a profound impact on the climate that will be experienced by our children and grand children later in this century and beyond. Thus it also also imperative that we undertake science that informs policy makers about the constraints that natural variability, physical and biogeochemical feedback processes, and human activity that alters these feedback processes (such as land use change) impose upon policy choices concerning areas such as emissions, land use, long term water use planning.

A paradigm shift in climate change science

The CMIP3 climate change experiments coordinated by the Working Group on Coupled Models (WGCM) represented the end of the era of non-mitigation scenarios represented by the SRES suite with the main climate change projection time frame being near the end of the 21st century. The paradigm shift that occurred after the publication of the IPCC AR4 involved a move toward mitigation scenarios, with implied policy actions, to better quantify various feedbacks, including carbon cycle, relevant to longer term climate change out to 2100 and beyond, as well as an enhanced focus on shorter term climate change out to about 2035. This paradigm shift grew out of the research assessed for the AR4 that recognized the need to understand and interpret observed climate changes in order to understand how much we can attribute to human activity, to internal variability, or to exernal forcings (natural and anthropogenic). This built on the growing need for climate science to inform adaptation and mitigation decisions.

CMIP5 climate change experiments

This led to the formulation of a new set of climate change experiments that has become known as CMIP5. The experimental design for CMIP5 recognized the two timescales mentioned above, and that better quantification of climate change would likely involve two classes of new generation climate models to address scientific questions directly arising from processes and interactions involved with those two timescales. Therefore, CMIP5 has experiments to address what is now being called “decadal prediction” with initialized higher resolution models to study, for example, regional climate change and extremes, and longer term experiments run with either AOGCMs or the new generation of Earth System Models (ESMs) with candidate components of coupled carbon cycle, chemistry, aerosols and dynamical vegetation added to the tradition AOGCMs.

Near-term climate change experiments

For decadal prediction, the CMIP5 experiments have, as a primary focus, hindcasts to quantify decadal predictability, as well as predictions out to 2035 to address short term climate change. One of the main science questions involves how best to initialize the ocean, and how much additional regional prediction skill (over and above un-initialized runs) can be obtained from an initialized climate model. This science question bridges the climate change problem to seasonal to interannual prediction, and decadal prediction is bringing together these two communities to address this problem. Another challenging problem related to initialization is how much additional regional predictive skill can be obtained by resolving regional internal decadal variability mechanisms in addition to the climate change produced by commitment and changes in external forcing. The CMIP5 hindcasts involve 10 year runs initialized with the climate state every five years starting with 1960 and continuing to 2005. Then three of these ten year runs will be extended to 30 years for starting dates of 1960, 1980, and 2005. Therefore, for the 30 year experiments, two will be hindcasts, and one (starting in 2005) will be a prediction. Since the various scenarios do not diverge much until about 2030, only one scenario will be used for the decadal predictions (RCP4.5, see below) and, consequently, these decadal predictions are most relevant to inform adaptation strategies.

Long-term climate change experiments

For the long term experiments, four new mitigation scenarios will be used for the 21st century (2005 to 2100) and beyond to 2300. A low overshoot mitigation scenario with an approximate radiative forcing of 2.6 Wm^{-2} in 2100 is called "RCP2.6", the two medium mitigation scenarios are termed "RCP4.5" and "RCP6.0", and the high scenario is "RCP8.5". The focus of the long term integrations is to provide information on how feedbacks in the climate system contribute to the magnitude of climate change in the future for various mitigation strategies. Therefore, these simulations are relevant to mitigation and adaptation, with climate sensitivity in the different models contributing to the size of the feedbacks and climate change. It is on these longer timescales that sea level rise and the role of the melting of ice sheets will come into play. The combination of the various scenarios and feedbacks will provide information on possible abrupt climate change as well.

Climate change detection and attribution

The simulations leading up to the long term integrations will start in 1850, and will be run from 1850 to 2005 with observed natural (solar and volcano) and anthropogenic (GHG, aerosols, ozone) forcings for analyses relevant to climate change detection/attribution. A new aspect of these 20th century (and 21st century) simulations will be specified time-evolving land use change so that, for the first time, the contribution of land use change to local, regional and global climate change can be addressed.

Understanding inter-model differences in climate change projections

Additionally, there will be several experiments to quantify the magnitude and nature of the carbon cycle feedback, and to understand the origin of inter-model differences in the climate response to a given perturbation. Some experiments will allow us to diagnose climate sensitivity and radiative forcings from coupled models. Idealized experiments (e.g. atmosphere-only experiments forced by prescribed SST perturbations, aqua-planet experiments) will make it possible to assess both the robustness and the uncertainties of the climate change response predicted by coupled models, and to better interpret the origin of inter-model differences in the simulation of clouds, precipitation and large-scale dynamics. This will help to understand the climate change response simulated by climate models, and to assess some components of this response using observations or process studies.

Imperative II - Decadal Variability, Predictability and Prediction

Prepared by S. Griffies, H. Drange, W. Hazeleger, B. Kirtman, A. Timmermann

CLIVAR challenges for decadal variability and prediction

Decadal climate variability and the growing impacts from anthropogenic climate forcing present scientists with an increasingly important challenge: to skillfully predict climate fluctuations and trends for the coming decades. Scientifically meeting this challenge requires identifying and mechanistically understanding phenomena that offer some degree of predictability, and in turn to develop accurate dynamical prediction systems able to realistically capture all forms of climate predictability. This challenge of decadal climate prediction is at the heart of CLIVAR's mandate. More precisely, a key aim of CLIVAR is to quantify sources of climate predictability on interannual to decadal timescales, and to provide probabilistic regional forecasts with skill sufficient for planning and decision making purposes. Fully "cracking" the climate prediction problem involves an unprecedented multi-disciplinary collaborative effort that includes many of the varied communities focused on earth system science. Indeed, the earth science community has been building its capabilities over multiple generations towards this aim. Faced with a radically changing planet, society demands nothing less from its investments in the science.

To make progress towards CLIVAR's decadal prediction goal requires addressing many scientific and engineering challenges, each requiring long-term commitment from CLIVAR, other scientific organizations, and various funding agencies. We identify here six goals that encapsulate many of the key tasks required to meet this challenge.

- To garner improved scientific insight into the statistical properties and dynamical mechanisms of low-frequency climate variability.

- To quantify the level of committed climate change due to past greenhouse gas emissions, and to understand how anthropogenic climate change interacts with natural variability modes on all relevant time scales.

- To identify those phenomena possessing useful predictability, and to ensure that model systems possess accurate representations of all relevant components so to approach predictability limits with realistic prediction systems.

- To remedy sources of model biases at global and regional scales that render disagreements with observations, and which can lead to simulation features that vary widely between different model systems.

- To initialize dynamical predictions using data assimilative methods, and to quantify forecast skill by comparing to historical climate variations.

- To exploit high-quality and high-resolution paleo-climate records to help evaluate decadal climate simulations and predictions.

Scientific elements of decadal variability and prediction

The earth's climate possesses a broad range of space-time variations, and those variations extending from the inter-annual to longer times involve ocean and/or coupled ocean-atmosphere-ice dynamics. Furthermore, the space-time scale of natural decadal climate variations overlaps with expected trends and patterns associated with anthropogenic climate warming (Figure 1). This overlap presents a difficult signal-to-noise problem for attributing observed trends over the next few decades: is the observed fluctuation natural or anthropogenically induced? Understanding the mechanisms of decadal climate variations, quantifying predictability of these variations, coordinating the required observing system, and developing prediction systems, are goals fundamental to CLIVAR's mission.

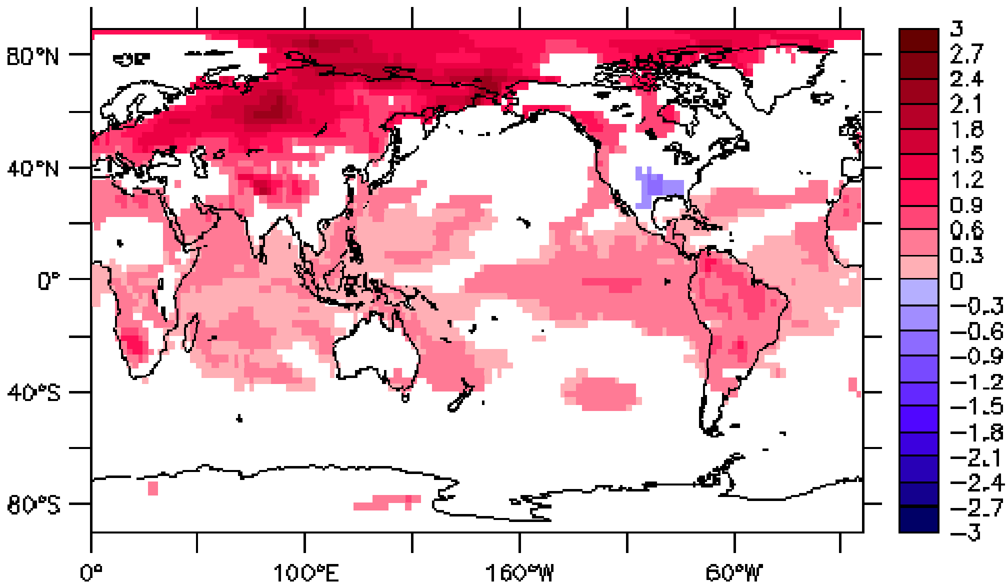

Figure 1: Multi-model and multi-scenario ensemble 30-year surface air-temperature trend derived from the CMIP-3 database. Blank areas exhibit a higher level of natural variability as compared to the anthropogenic trend.

Observed decadal variations in the Atlantic and Pacific

The Atlantic Multi-decadal Oscillation (AMO) is a basin-wide fluctuation evidenced by 50-70 year swings in sea surface temperature (see Figure 2). While anthropogenic radiative forcing (i.e., greenhouse gasses and aerosols) may have contributed to shaping the observed AMO during the 20th century, model simulations suggest that similar variability can be generated naturally as a result of variations in the strength of the Atlantic Meridional Overturning Circulation

(AMOC). The AMO is known to influence the position of the Intertropical Convergence Zone over northern Africa, causing multi-year droughts (Zhang and Delworth, 2006); it has been demonstrated to affect the strength of the Indian Monsoon (Figure 2), climate over Europe (Collins et al. 2006; Pohlmann et al. 2006); and potentially impacts tropical and mid-latitude cyclones.

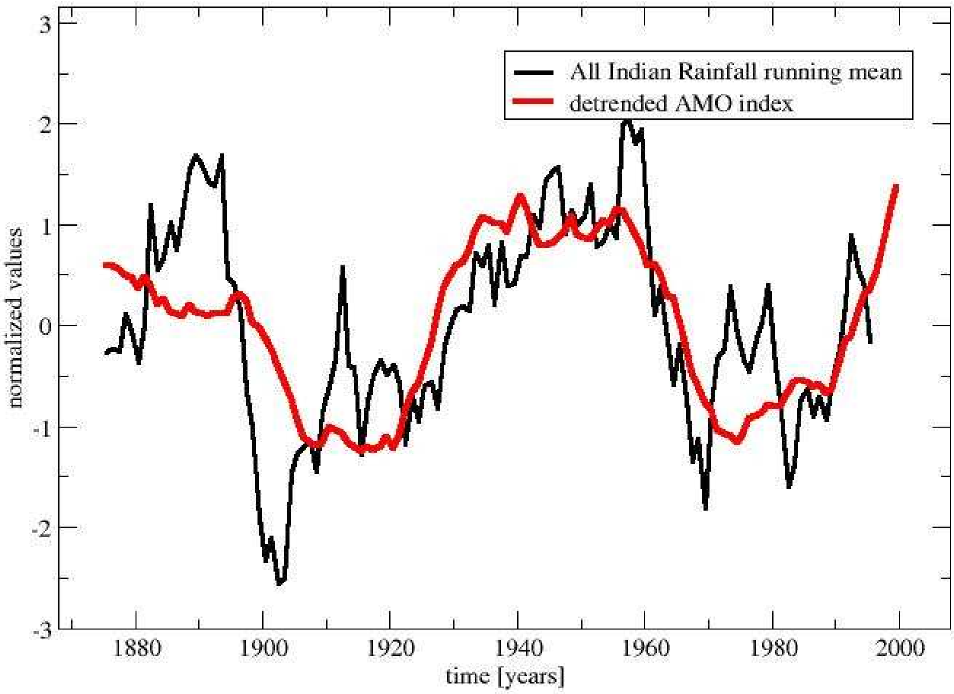

Figure 2: Normalized and detrended timeseries of the Atlantic Multidecadal Oscillation (red) and the 10-year running mean of the All Indian Rainfall Index.

On time scales from years to decades, the formation, propagation and decay of temperature and salinity anomalies in the North Atlantic subpolar gyre (SPG) have received considerable attention because of the SPGs strong and rapid variability, its importance for the marine climate and ecosystems, its relation to variations in the AMOC, and its potential predictability. The abrupt collapse of the SPG starting in the mid 1990s has motivated extensive studies of its dynamics (Häkkinen and Rhines, 2004, 2009; Hatun et al., 2005, 2009a; Böning et al., 2008; Lohmann et al., 2009). Recent shifts in the North Atlantic SPG have led to an extensive warming and salinification of the region, first in the eastern and thereafter throughout the northern North Atlantic (Hatun et al.; 2005, Holland et al., 2008; Sarafanov et al., 2008). The rapid melting of some outlet glaciers on the western coast of Greenland (Holland et al., 2008), as well as large shifts in the marine ecosystem in the northern North Atlantic (Hatun et al., 2009a,b), have also been attributed to the recent collapse of the North Atlantic SPG.

In the Pacific, two independent modes dominate climate variations on decadal timescales – the Pacific Decadal Oscillation (PDO or IPO) (Mantua et al. 1997) and the North Pacific Gyre Oscillation (NPGO) (Di Lorenzo et al. 2008). Both modes affect temperature, sea-level, salinity, weather patterns, and marine ecosystems. Not all coupled general circulation models reproduce these modes realistically. It has been demonstrated (Qiu et al. 2007) that decadal sea-level variations in the Northwestern Pacific can be predicted 5-7 years ahead using observed wind-stress fields and simple ocean dynamical models. Integrating atmospheric noise associated with the North Pacific Oscillation (NPO) the NPGO forces decadal variations in the strength of the Kuroshio jet 3-5 years later (see Figure 3). These relationships are expected to form the basis of future decadal prediction systems. In many cases it is the traveling time of Rossby waves at different latitudes that provides important sources of decadal predictability. Exploiting this robust process for the prediction of sea level anomalies, associated ocean transport anomalies, and nutrient anomalies years ahead will become an important component of the decadal prediction efforts in the Pacific region.

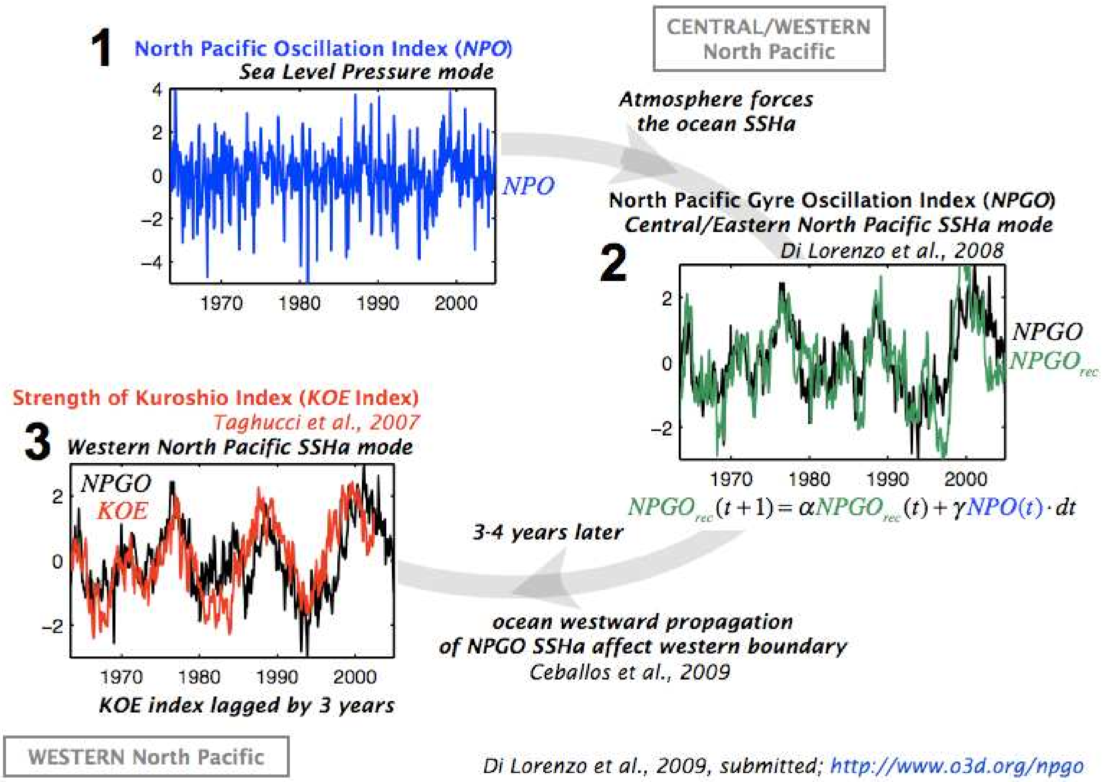

Figure 3: Relationship between the North Pacific Oscillation, the North Pacific Gyre Oscillation and the zonal strength of the Kuroshio in the Kuroshio Extension Region.

Towards a science of predictions

On timescales less than one year, climate is dominated by internal variability. Predictions of seasonal to inter-annual fluctuations are thus largely initial value problems. On centennial time scales, climate is dominated by changes in external forcing, with anthropogenic changes in greenhouse gas concentrations having become the dominant external climate forcing in recent decades. A centennial projection thus represents a boundary value problem. The intermediate decadal to multi-decadal time scales are perhaps the most complex and least understood from a prediction perspective. It is here that anthropogenic forcing is superimposed on natural modes of internal climate variability; where the oceans role, including the deep ocean, is fundamental; and where coupled interactions amongst the various components of the climate system play important roles in setting the space-time scales of fluctuations. The decadal prediction problem thus represents a mixed initial-boundary value problem of immense complexity. As for weather forecasting, a vigorous interaction between prediction system development, mechanistic studies with models and observations, and theoretical analysis is essential to build the scientific foundation for decadal prediction.

In recent years, there has been extensive focus on establishing a predictive capability for the Atlantic basin, aiming to examine whether the perfect model predictability examined by (Griffies and Bryan 1997; Grötzner et al. 1999; Collins et al. 2006) can be realized in practice. Predicting the natural low-frequency and anthropogenically-forced variations of the AMOC poses an important challenge to climate models. Particular difficulties include uncertainties in mechanisms of observed variations; biases in climate model simulations; difficulties assimilating the sparse network of observed ocean data into climate models in order to initialize the predictions; and a lack of reliable long-term data to evaluate prediction skill. Nonetheless, climate models initialized with observed ocean conditions appear to have skill in the Atlantic basin on decadal timescales (Zhang et al. 2007; Smith et al., 2007; Keenlyside et al., 2008). A concerted community effort is required to fully develop the scientific basis for such predictions, and more thoroughly examine the robustness of the predictive skill.

For the Pacific, attempts are underway to make longterm decadal predictions of sea-level and thermocline depth, exploiting the role of ocean dynamics on these variables. It is at this stage unclear, how much potential predictive skill decadal PDO and NPGO-related SST and climate variations have. A thorough concerted multi-model assessment is needed to quantify the levels of potential decadal skill in the Pacific region for variables of societal interest.

Topics for CLIVAR research

The decadal prediction problem will not be solved by one grand event. Instead, it is anticipated that the process of developing skillful prediction systems will occur in parallel to the continued research into mechanisms, and the furtherance of observational capabilities. Many steps are required, and there will likely be false starts along the way before the community absorbs the necessary experience and tools required to produce decadal predictions of use for society, should the climate system provide phenomena allowing such skill. Here, we offer a list of key topics for CLIVAR to consider over the course of the next few years. Addressing these topics involves an unprecedented multi-disciplinary effort that includes all elements of the earth science community, thus making it important for CLIVAR to support bridges to the many relevant scientific organizations.

- What are the basic physical processes and mechanisms that generate decadal and multi-decadal variability? Given that patterns of decadal climate variability are large-scale, it is critical to study multi-basin teleconnections on these timescales. The classical basin-panel view of CLIVAR might be suboptimal to address this issue.

- What determines the predictability limits? Detailed studies need to be conducted to determine those physical processes that contribute to the long-term memory of the climate system, and how this memory impacts societally relevant climate phenomena. In addition to studying the ocean, possible sources of predictability live in the cryosphere, as well as vegetation and land-surface processes.

- What physical and biogeochemical variables have the best signal-to-noise ratio, and which are of societal relevance for impacting predictability? Even if the AMOC exhibits a high signal-to-noise ratio on decadal timescales, it may minimally impact climate variations relevant to society. If, however, the AMOC strongly affects North Atlantic SSTs and wind and rainfall patterns over Europe, predicting the AMOC would be of tremendous relevance and use for climate adaption strategies. Potential applications may include fisheries, forestry, water management, construction, agriculture, tourism, infrastructure planning, energy planning and the health sector.

- How can we disentangle the impact of anthropogenic radiative forcing and low frequency natural climate fluctuations? This issue can be studied by performing ensemble integrations starting from different initial conditions of the atmosphere and ocean. Due to its large heat capacity, the ocean plays a key role for the long time scales in the climate system.

- How can we address the issues of regional decadal climate predictions, at the scale where society is most impacted? Understanding and simulating the regional aspects of decadal climate change requires high-quality long-term observational records as well as climate model simulations that resolve and capture regional processes accurately. A committed effort to downscale global model control simulations to regional scales using dynamical as well as statistical techniques is required. Similar challenges will be faced when predicting the regional manifestations of anthropogenic climate change.

- What are the best initialization strategies for decadal predictions? Of particular importance will be the implementation of an initialization strategy that avoids the need for expensive spin-up and transient simulations. Other components that can potentially affect the slow manifold are soil moisture, sea-ice, and snow. Impact of the initialization of these components on decadal predictions is, however, unclear and thus a challenge for future research.

- How should model biases be addressed during initialization of predictions? A key difficulty with the initialization of decadal prediction systems is that climate models generally have a climate distinct from the real world. A choice is thus generally made between specifying the observed state as an initial condition, or the observed anomalies with respect to an observed climate mean. The first option has the disadvantage of drift due to inconsistencies between the modeled climate and the real climate. The second option has the disadvantage that anomalies may be related to the mean state, which is different from the model and the real world. Also, coupled model data assimilation poses difficult challenges that are only just now being addressed.

- Do we have enough ocean data for skilled initializations? Ocean data is relatively sparse in space and time. Only since the last decade with ARGO do we have a reasonable estimate of global ocean variations. However, it is unclear whether the current density of ARGO floats is sufficient (3000 world wide), and whether their limited depth range (only to 2000m) will prove to be a limitation for predictions of climate variability that involves Deep Water formation regions of the North Atlantic. Also, choices need to be made which data to include in the initialization of models (e.g., temperature, salinity, sea surface height, sea ice, etc.)

- How do we best fill out the climate attractor with ensemble predictions? In weather prediction, techniques (e.g. singular vectors) have been developed for this purpose. Should such methods be used, or generalized, for decadal predictions?

- How can decadal predictions be evaluated for their potential skill? Forecasts are validated against an independent period and dataset. With very few recorded realizations of decadal variability in the observational record, this task will be a major challenge for decadal predictions. Proper skill assessment of forecasts is nonetheless required in order for society to understand the relevance of the predictions. The paleo-community (PAGES) is presently collecting high-resolution datasets that might prove useful for the validation task. Including this community in discussions on decadal predictability will be essential.

- How can CLIVAR usefully interface with the impacts community? By advancing understanding of the dynamics and predictability of decadal scale variability, CLIVAR will help to narrow the current gap between observed climate and IPCC-type climate projections. The decadal time window is of key interest and importance for a variety of sectors, like water availability, agriculture and fisheries, transportation, tourism and energy production. At the same time, there is a need for information about regional changes in climate. At these scales climate is substantially governed by fundamental decadal scale modes. The necessary information can only be produced using realistic numerical climate models of the type used in CLIVAR. Therefore, decision-making bodies working to develop and implement strategies for mitigation and adaptation of climate change will greatly benefit from CLIVARs decadal variability, predictability, and prediction activities.

Strategies

The magnitude of the decadal climate prediction problem is such as to make any detailed strategy difficult to develop. Nonetheless, there are avenues that CLIVAR should support in the coming years.

- CMIP5 prediction experiments: A central element of decadal climate prediction research involves the planned prediction component of CMIP5. These initialized prediction experiments will help to identify areas of potential skill. CLIVAR should continue to play a leading role in the analysis of these experiments, and to sponsor a selection of workshops aimed at scientifically rationalizing the results.
- Biases: It is anticipated that the CMIP5 prediction experiments will highlight present limitations and biases of the various model prediction systems. CLIVAR should play a leading role in supporting the improvements of the systems, in particular by encouraging the reduction of model biases so that the mechanisms active in the real world are accurately represented by the models. One avenue for supporting the improvement of ocean model components includes the CORE-II hindcast experiments.
- Workshops: In general, key workshops will be required to communicate developments, discuss and debate alternative priorities and research paths, etc.
- CLIVAR should foster the WGSIP/WGCM decadal prediction experimental design. One example of this is the Nov2009 Amsterdam workshop coordinating the initialization strategies for decadal prediction.
- A decadal prediction workshop being planned at University of Miami, will have an emphasis on how the forecasts might be used.
- Given the multi-disciplinary features of the decadal prediction problem, CLIVAR meetings on decadal prediction should include selected representatives from the relevant scientific groups.
- There is a US CLIVAR working group on decadal prediction that is attempting to ensure that the community is well positioned to analyze the CMIP5 runs as they come available. International CLIVAR needs to identify where it fits with this activity.

Imperative III – Intraseasonal and seasonal predictability and prediction

Prepared by Ben Kirtman, H Hendon, E H Berbery, K R Sperber

Our ability to predict the seasonal variations of climate dramatically improved from the early 1980s to the late 1990s with the advent of dynamical coupled model forecast systems, primarily due to their ability to predict El Niño/Southern Oscillation and some of its global teleconnections. After the late 1990s, our ability to predict climate fluctuations reached a plateau with only modest subsequent improvement in skill. This is particularly true for seasonal fluctuations of the monsoon systems throughout the globe.

Robust simulation of subseasonal (or intraseasonal) variability has remained elusive, and in fact difficulties on the sub-seasonal time-scale are likely impacting our ability to predict the seasonal monsoon fluctuations. Given the plateau of forecast quality on seasonal time-scales and the relatively slow progress in improving the representation of sub-seasonal phenomena, new prediction strategies have emerged, largely based on multi-institutional international collaborations. These include (i) the multi-model ensemble strategy, which may be the best current approach for minimizing model error and forecast uncertainty; and (ii) the need to include all the interactions among the relevant components of the climate system [i.e., atmosphere (including stratosphere), land, cryosphere, and ocean] for sub-seasonal and seasonal prediction.

CLIVAR has taken the lead in fostering activities to understand the limits of predictability, such as the Climate System Historical Forecast Project (CHFP). This project represents a major scientific research crosscut throughout WCRP (e.g. interactions among SPARC, CliC, GEWEX and CLIVAR), and because it includes a sub-seasonal focus, collaboration between WCRP and WWRP will be enabled. Clearly, continuing and expanding international involvement in this project is a core activity of CLIVAR that has large implications for WCRP.

Science Background and Grand Challenge

About a third of the world's population lives in countries influenced significantly by climate anomalies. Many of these countries have economies that are largely dependent upon their agricultural and fishery sectors. The climate forecast successes of the 1980s and 1990s brought great promise for societal benefit in the use and application of seasonal forecast information. However this promise has not been fully realized partly because there have not been adequate interactions between the physical scientists involved in seasonal prediction research and production, applications scientists, decision makers and operational seasonal prediction providers, but also because there is still scope for improving forecasts. Improving forecasts, particularly at intraseasonal time scales requires a better understanding of the processes that are involved in initiating and maintaining an intraseasonal signal, and more broadly in accounting all the critical interactions among all the elements of the climate system (ocean-atmosphere-biosphere-cryosphere). Additional considerations include the need for a well-maintained and expanded suite of observations, and the ability to adequately blend (assimilate) the observations with the models to make the best possible forecasts. An additional consideration is the non-stationarity of climate and the role that natural or anthropogenic forcing may play in modifying the predictability of the climate system.

The feasibility of seasonal prediction rests on the existence of slow, and predictable, variations in the Earth's boundary conditions. Within the paradigm of atmospheric predictability due to external forcing, the potential for skilful forecasts depends on the ratio of the externally forced signal relative to the atmospheric generated internal noise. The majority of external variance is known to originate from tropical sea surface temperature variations. Less is known about the seasonal signals due to other external forcings of the total climate system, such as soil moisture, land use, sea ice, atmospheric chemical composition and aerosols. Additional skill due to atmospheric initial conditions is expected for certain slow modes of the atmosphere (for instance, annular modes), but there is little evidence that atmospheric initial conditions contribute to skill for lead times beyond a few weeks. Seasonal forecast quality can be improved by taking into account processes in the cryosphere, land surface, and stratosphere. The following factors have the potential of improving the predictability of variability at seasonal timescales:

- Sea ice is highly coupled to the ocean-atmosphere system from synoptic to decadal timescales with large sea ice anomalies tending to persist due to positive feedback in the ocean-atmosphere-ice system. Sea ice anomalies in the Southern Hemisphere can be predicted statistically at seasonal timescales by a linear Markov model and cross-validation with observed estimates can yield correlations of 0.5 even at 12 month lead times. Land ice and snow cover in the Northern Hemisphere is a highly variable surface condition, both spatially and temporally, and can be related to atmospheric variability.

- Soil moisture anomalies, which can persist for weeks to months, can generate rainfall and air temperature anomalies in transitional zones between wet and dry regions. Other potential land-based sources of predictive skill, in addition to snow cover, are subsurface heat reservoirs and vegetation health (leafiness).

- The stratosphere acts as a boundary condition for the troposphere since the characteristic time scales for stratospheric circulation variations are much longer than those in the troposphere. In particularly sensitive areas, such as northern Europe in winter, model results suggest that the influence of stratospheric variability on land surface temperature can exceed the local effect of SST.

The monsoon regions of the world, where over ½ of the global population lives, are especially challenging. Interannual variability of the mean monsoon rainfall is relatively low (~10% of the mean), but seasonal variations of the monsoon have a profound impact on agriculture and water availability. Predictable variations of the monsoons associated with El Niño are typically confined to pre-monsoon and post monsoon, while most of the variability of the main monsoon appears to be associated with internally-generated (i.e. independent of slow boundary forcing) intraseasonal variations. Monsoon failure (or extreme drought) is often a result a extended intraseasonal monsoon breaks. Monsoon intraseasonal variability is not well simulated or predicted in climate models of the sort used for seasonal prediction, which compounds the problem of trying to predict relatively low interannual variability together with the modest relationship with El Niño. Monsoon variations have also been tied to other components of the climate system that are not well simulated or predicted including local air-sea interactions, and variations of the cryosphere, aerosols, and land surface.

The impact of the different components of the climate system on seasonal prediction quality remains an area in need of active research, both in terms of initialization and in terms of model development (e.g., resolution of stratospheric processes, stratosphere-troposphere coupling). The CLIVAR Working Group on Seasonal Prediction (WGSIP) encourages the seasonal prediction community to participate in the Climate-system Historical Forecast Project (CHFP), which is an experimental test bed to assess the untapped potential seasonal predictive skill to be gained by resolving interactions between components of the fully coupled physical climate system.

The Challenge of Intraseasonal Prediction

Subseasonal climate prediction is a promising area for evaluating the progressing utility and application of climate forecasts, especially for the many regions of the globe where slow variations of tropical SST may not have a large impact, but where impacts from slow variations of internal modes (eg the annular modes and the Madden-Jullian Oscillation, MJO) are significant. This is especially true in the monsoons, where seasonal variability and predictability is relatively low but intraseasonal variability is large. Monsoon intraseasonal prediction may be feasible because of the strong signature of the MJO and other Monsoon Intraseasonal Oscillations (MISO), whose intrinsic timescale is much longer than extratropical weather, but much shorter than El Niño and other modes of coupled ocean-atmosphere climate variability. Predictability of monsoon intraseasonal variability (ISV) associated with the MJO and other convectively coupled MISO’s is largely unknown, due mainly to the inadequate simulation of the MJO/MISO, and, in general, the inadequate simulation of the interaction of organized tropical convection with large-scale circulation.

A multitude of forecast techniques have been developed to provide experimental forecasts of the MJO. These range from empirical and statistical models, to dynamical forecasts. The approaches include linear regression, linear inverse modelling, frequency-wavenumber decomposition and extrapolation of forecasts, and projection of forecast data onto observed MJO EOF’s. The US CLIVAR MJO Working Group (MJOWG) has established an experimental forecast system based on the combined EOF’s of near-equatorial averaged outgoing longwave radiation and the zonal wind at 200hPa and 850hPa. With the endorsement of the WCRP, seven NWP centers are providing output for making real-time experimental MJO forecasts using this methodology. Thus, for the first time a standard assessment of skill in dynamically forecasting the MJO will be obtained by this effort. Importantly, his multi-national effort will facilitate the benefit of using of a multi-model ensemble to predict the MJO. This work, and that of improving our understanding of basic processes that are important for the initiation and maintenance of the MJO, will be carried out by the newly established WCRP/WWRP MJO Task Force, which is the follow-on of the MJOWG. Additionally, CLIVAR has facilitated cooperation among international partners in the development of (1) an ocean observing system in the Indian Ocean (IndOOS), (2) process studies for better understanding of monsoon intraseasonal variability (e.g., Cooperative Indian Ocean experiment on intraseasonal variability in the Year 2011, CINDY 2001), and (3) numerical experimentation to assess the predictability of the MJO (e.g., Hindcast Experiment for Intraseasonal Prediction).

Monsoon variability is associated with the large scale dynamics, but during its early stages, when the surface is not sufficiently wet, soil moisture anomalies may also modulate the onset and development of precipitation. Likewise, there is evidence that vegetation conditions previous to the monsoon may delay or advance the date of the monsoon onset. When the soil is not too dry or not too wet, the soil conditions can control the amount of water being evaporated, and also can produce fundamental changes in the PBL structure that affects the development of convection and precipitation. Adequate representation of the land surface conditions should be carefully included in seasonal simulations.

Clearly, the maximum predictability of the climate system has yet to be achieved in operational intraseasonal-seasonal forecasting. Model error, particularly in the Tropics, continues to limit forecasting skill and, since not all the interactions in the climate system, such as land-atmosphere interactions or atmosphere-cryosphere interactions, are currently fully resolved, there may still be untapped sources of predictability. Uncertainty due to model formulation can be improved by multi-model methodologies though the approach is currently *ad hoc* since the choice of models has not been optimized and there is no best strategy on how to combine models. Forecast initialization with ocean data assimilation also improves forecast quality and coupled initialization continues to be an area that requires active research. It is an entirely open question of how climate change impacts seasonal prediction. The observational requirements for seasonal prediction are not being adequately met. Dynamical model forecasts can also be improved by calibration and the synergistic use of empirical techniques. CLIVAR is ideally suited and well positioned to foster progress on all of these issues.

Another relevant consideration is that current climate models have been limited by resolution and physical parameterizations in their representations of the statistics of internal atmospheric (e.g., synoptic weather systems and tropical waves) and oceanic (e.g., poorly resolved tropical instability waves) dynamics and, thus, the interactions of these intrinsic motions with climate. Moreover, the specification of accurate initial conditions in the full climate system may be critical to accurately capture the high frequency phenomena of relevance (e.g., the dependence of the Madden-Julian Oscillation (MJO) on the upper ocean state). For example, was the failure to capture the early onset and the extreme amplitude of the 1997/98 ENSO event because all the models fail to adequately capture the MJO and the associated sub-seasonal variability? Additionally, it would be desirable to be able to credibly simulate coupled features that depend on the initial state with affects on regional weather and climate such as El Niño or Pacific decadal variability. It would seem that a way forward to improve predictions on timescales longer than weeks would be to better resolve the weather-climate link. The issue then becomes what are the important missing elements of the simulation of day-to-day weather, and what is the best strategy for being able to better represent them in the AOGCMs.

Requirement to Meet this Challenge

1) Complete the CHFP core experiment with extension to the challenge of intraseasonal prediction. This extension necessarily needs to be well coordinated with THORPEX activities and YOTC.

2) Coordinated and targeted focus on simulation and prediction of slow internal, intraseasonal variability, including the convectively coupled tropical modes such as the MJO but also the extratropical annular modes that may be responding to external forcing. This may require a focused task force or working group that can bring together researchers from WWRP and WCRP.

3) Foster the numerical experimentation on climate system interactions, including modes of variability that are poorly represented that are associated with organized tropical convection. CLIVAR needs to maintain mechanisms to ensure that the Pan-WCRP momentum established by the Task Force for Seasonal Prediction is maintained.

4) Foster research on coupled climate system data assimilation through workshops and meetings.

5) Accelerate model improvement efforts – this may require the establishment of a task force or working group on, say tropical biases. The approach envisaged would build on previous activities, and would additionally attempt to encourage observationalists, process modelers and large scale modelers to work together on the problem of how best to develop a multipronged attack for reducing tropical biases in CGCMs. By definition this type of activity would reach across the entire CLIVAR community thus requiring a WG or TF approach.

6) Enable multi-scale interaction research. The distinction across timescales from weather to climate prediction is becoming more blurred. The incorporation of chemical, hydrological and biological processes into weather and climate models will allow a much broader range of

environmental parameters to be forecast, including air quality, flooding, sand and dust storms, changes in vegetation etc. Many of the applications and impacts of weather and climate share a common underlying scientific basis. Based on these considerations, CLIVAR needs to work to develop a unified approach to multidisciplinary weather, climate, water and environmental prediction research. The first steps in this regard are increase collaborations between the TIGGE and CHFP projects.

Time Line

2009: Complete the control CHFP Experiment and make the data available
2009-: Improved understanding of monsoons through the Asian Monsoon Years Experiment
2009: Establishment of the WCRP/WWRP MJO Task Force
2009: Coordinated analysis and experiments between CHFP and TIGGE
2010: Completion of TFSP diagnostic sub-projects
2010: Assess MJO predictability in the Hindcast Experiment for Intraseasonal Prediction
Improve understanding of convectively coupled waves through YOTC
AAMP hosts an intraseasonal variability workshop (models and obs)
2011-12: Complete CHFP climate system interaction experiments
2011: Assess seasonal prediction skill in decadal forecast experiments (CMIP5)
2011: Assess monsoon variability in CMIP5 models
CINDY2011 observational campaign (data release in 2012)
2011: Coupled data assimilation workshop
2012-: Synthesis of process level data, theoretical understanding of MJO, and the evaluation of hierarchical modelling techniques (CRMs, MMF, NWP, GCMs) with the goal of improving MJO simulation in climate models
2012: Final CHFP workshop

Imperative IV – Improved atmosphere and ocean component models of Earth System Models

Prepared by: Sandrine Bony, Stephen Griffies, Tim Stockdale.

The science and the associated "grand challenges"

The Earth's climate has changed over the last century and is expected to further change in the future. Predicting the evolution of the climate system on time scales of seasons to decades and longer has never been more required than today to inform the decisions that society must take to adapt to natural climate variations or anthropogenic climate change. Climate models are the tools through which such predictions can be made. However, the skill of seasonal and longer forecasts is substantially limited by model biases in the representation of atmospheric and oceanic processes. These biases in turn handicap the ability of modelers to deliver reliable information about regional climate fluctuations and change, with this information crucial for policy makers to implement adaptation measures.

Model biases occur over a wide range of time and space scales. Some biases have been persistent and long-standing problems for climate modelers, such as the tendency of coupled ocean-atmosphere models to simulate a double ITCZ; a too extended cold tongue; a wrong diurnal cycle of tropical convection; difficulties in simulating correct characteristics of tropical atmospheric waves and the associated intraseasonal variability; biases in ocean water mass properties that impact heat and tracer storage and sea level; and in general with properly representing modes of climate variability. Incorrect simulations of mean climate patterns are problematic for seasonal prediction, and biases in the simulation of short-term climate variability (e.g. synoptic variability, intraseasonal oscillations) negatively affects the simulation of climate on longer time scales (e.g. interannual or decadal variability). Biases in the simulation of some processes (e.g. cloud and moist processes) is problematic for the simulation of climate on all time and space scales.

To gain confidence in the simulations of future climate changes, it is not sufficient to assess the quality of the models' mean climate. The *sensitivity* of climate and processes to a change in environmental conditions, or to an external forcing, also should be assessed and improved. It is the case in particular of cloud properties, whose sensitivity to changes in temperature, static stability or large-scale dynamics is critical for assessing cloud-climate feedbacks, but is poorly simulated by current climate models. Additionally, parameterizations of ocean eddies must properly respond to changes in atmospheric forcing, such as observed wind stress changes in the Southern Ocean.

Earth System Models (ESMs) must incorporate a broad suite of physical and biogeochemical processes. Interactions between these processes make biases in one component (e.g. simulation of precipitation by the atmospheric component) problematic for other components (e.g. the simulation of carbon fluxes between continental surfaces and the atmosphere). Therefore, the increasing complexity of climate models, and the development of ESMs, has not reduced the models' biases. On the contrary, it has made improvement of the basic atmospheric and oceanic components more imperative than ever.

There is evidence that refining the horizontal and vertical resolution of models can reduce some biases (e.g. biases in the intensity of extreme precipitation events; simulation of mid-latitudes atmospheric baroclinic waves; structure of the oceanic boundary currents), but not all of them. Improving climate models therefore requires an enhanced fundamental physical basis upon which the models are framed. This need is particularly important for the parameterizations of subgrid-scale processes, as well as the treatment of boundary conditions and couplings between components. The initialization of climate models is another aspect to be improved. Seasonal prediction has given us some experience, but is not clear how appropriate the methods used are for other parts of the climate system or for longer timescales. Improving the techniques of coupled model initialization for use at a full range of timescales is another major challenge for the modeling community.

Opportunities and plans for the next few years

Opportunities

Many resources are currently available and potentially useful to evaluate models and help their development. For example, on the atmospheric side, a new generation of satellite observations using both passive and active sensors makes it possible to evaluate multiple aspects of the model simulations with consistent datasets and in a much more constraining manner (e.g. the CloudSat and Calipso satellites make it possible to evaluate for the first time the vertical structure of clouds). On the oceanic side, information from the ARGO profiling floats, complemented by satellite measurements, provide means for evaluating the water mass properties, energetics of currents, and fluctuations of surface ocean fields in ocean climate simulations. In addition, several instrumented sites, field campaigns and observational arrays have been collecting a large amount of in-situ data, that can be used to better understand processes and to carry out process-oriented evaluations of models. Meteorological and oceanographic analyses have greatly improved during the last decade, and coupled ocean-atmosphere analyses are emerging. On the modeling side, the increase of computing power makes it possible to refine model resolution, and to use very fine-resolution models (useful to develop parameterizations) on larger domains and longer time scales. Finally, the modeling community is also becoming more coordinated at the international level. Through WGCM, WGOMD and WGSIP, coordinated experiments (e.g. CMIP5, CORE, CHFP) have been designed that will be used over the next 5 years to address issues such as the relative merits of different model initialization techniques for intraseasonal to decadal predictions.

General strategy

The number of processes needing improvement in climate models is immense. To ensure a rapid improvement of ESMs, it is therefore important to identify the aspects of climate models associated with their most critical deficiencies, and for which the available resources are the most likely to lead to improvement. Some *guidance* is needed to identify these processes and to set priorities.

In addition, for cultural or practical reasons, it might not be straightforward to use the available observational or modeling resources for model improvement. In these cases, *bridges* need to be built between the large-scale modeling community and the communities involved in satellite observations, field campaigns or fine-scale process modeling.

Once the root cause of model deficiencies is identified, developments have to be made to improve models. This process usually requires expertise and experience, and is generally associated with a very small community of researchers. It is thus imperative to highlight and foster activities associated with *model development*, to attract and engage young scientists into this area, and recognize this activity as a fundamental part of climate research.

Guidance

The in-depth analysis of climate model simulations coordinated by WGCM (CMIP), WGOMD (CORE) or WGSIP (CHFP) will help to identify the systematic model errors that are problematic for several space and time scales and for many applications (e.g. both for synoptic variability, seasonal climate prediction and climate change projections). This leadership will then provide the necessary guidance for prioritizing the model improvements that are most critical. The upcoming CMIP5 analysis holds this potential. Namely, as each model will be used in a large variety of experiments and configurations (coupled, atmosphere-only, aqua-planet), it will be possible to test robustness of the model biases and to better identify possible root causes. For these analyses to contribute to the improvement of climate models, it will be imperative to synthesize the results obtained from all analyses, and to facilitate discussions and the communication between the different WCRP and IGBP communities (e.g. those focused on the ocean, the stratosphere or the cryosphere) so that the possible cause of biases may be more clearly identified and specific improvements proposed. Specialized workshops are required for this purpose.

Some errors commonly seen in long term climate simulations may be revealed after relatively short model integrations (a few days to a season) when models are run in a prediction mode. This approach facilitates the testing of hypotheses about the origin of these errors and of likely remedies. Experimental protocols to help modelers run climate models in weather prediction mode (aka transpose-AMIP) are being established to foster this type of evaluation. These new modes of evaluation of climate models should be used more widely over the next few years.

Bridges

Comparing climate model simulations and satellite observations is not always straightforward. In some cases, it requires bridges across communities, such as *satellite simulators* to diagnose from model outputs what satellites would observe if they were flying above an atmosphere similar to that simulated by the model. This approach will be widely used over the next few years for evaluating the atmospheric component of ESMs using the A-Train constellation of satellites (e.g. CloudSat, Calipso, Parasol), geostationary satellites (e.g. ISCCP), and hopefully other satellites (e.g. TRMM, GPM).

To test and improve models through comparisons between model outputs and in-situ data from instrumented sites or field campaigns, a promising approach consists in running a *single-column model* version of a climate model over this site by using large-scale forcings from meteorological analyses. Such an approach is at the basis of the GCSS (GEWEX Cloud System Study) strategy to improve atmospheric parameterizations using in-situ data. It should be developed over the next few years.

From the ocean perspective, there has traditionally been a disconnection between oceanographers focused on particular physical processes, and ocean climate scientists analyzing features of CMIP simulations. For CMIP5, however, there is a broad new suite of fields to be archived from the ocean model components that will foster studies that ask questions about how model parameterizations impact simulated climate mean, variability, predictability, and stability. This work represents just a beginning, with more input by process scientists needed for the design of large model comparison projects, such as CMIP5 and CORE, to ensure that models archive information necessary to address mechanistic questions related to fundamental processes.

Finally, better bridging between observations and modeling might require access by the modeling community to a large ensemble of observations. Those ensembles may be distributed upon the example of climate model simulations (e.g. the multi-model CMIP3 database at PCMDI), using a single portal, a specified format and a documentation.

More importantly, it is essential that once specific deficiencies have been identified among models, specific Climate Process Teams (CPTs) be established to tackle the problem through a combination of observational analysis, theories, climate modeling, and process studies. Such an approach has been very fruitful in the past (e.g., US-CLIVAR CPTs).

Implementation and rough timeline of activities

Identification of key deficiencies and systematic biases in ESMs
In 2009-2010, a first survey about key deficiencies and systematic biases in CMIP3 climate models will be carried out in interaction with the modeling groups participating in WGCM, WGOMD and WGSIP, and the different CLIVAR regional or topical panels (e.g. MJO, monsoon, etc). The results will be synthesized and reported to CLIVAR SSG and JSC in 2010.

The first version of the interannually forced CORE simulations (global ocean-ice hindcasts) will be completed during 2010. Analysis will be coordinated through WGOMD, who will also organize a workshop late 2010 to address questions of oceanic mechanisms for decadal variability and predictability, and to identify causes of biases that impact our ability to make skillful dynamically based decadal predictions.

At the end of 2010, CMIP5 climate simulations will become available, and the scientific community will start analyzing them immediately. Part of the studies on the evaluation and the identification of systematic biases in ESMs will be assessed by the IPCC AR5 in 2011-2012 (other analyses will go on through 2013). A workshop on systematic errors and key deficiencies in ESMs might then be organized in 2011, so as to select a few ones to be tackled in priority. This selection should take into account the availability of new observational or modeling resources and the assessment of the potential progress associated with them.

Climate Process Teams set up to tackle key problems
A few strong collaborative actions may then be organized as CPTs or Task forces among WCRP projects (GEWEX, CLIVAR, SPARC, CLIC) and working groups (WGCM, WGOMD, WGSIP), in collaboration with WGNE (for the development of parameterizations), WWRP (NWP techniques for models' initialization and climate prediction) and IGBP (e.g. AIMES for biogeochemical processes).

Collaborations among these different bodies have already been in place for the CMIP5 experimental design. This should facilitate further collaborations on the improvement of climate models.

Imperative V – Data synthesis, analysis, reanalysis and uncertainty

Prepared by: D. Stammer, T. Palmer, K. Trenberth

The changing state of the ocean is a critical component of the whole climate system. As such, the oceans have stored more than 90% of the energy content change of the earth system since 1955 and sea-level is rising at a rate that appears now higher in the last 50 years compared with the first 50 years of the twentieth century (Bindoff, Willebrand et al. 2007). Perhaps more importantly, all of these changes are projected to continue and accelerate through to 2100 (Meehl et al 2007). However, to provide credibility to projections of the future of the climate system, we have to understand the past, and what is happening now in the ocean.

Yet determining past changes of the climate system and inferring dynamics and feedbacks from the limited observations available during the last 50 years, let alone the last century, is challenging, especially due to the profound under-sampling of the ocean. As an example, providing answers to questions about past heat content and global sea level changes in the ocean is presently not feasible with great confidence prior to the most recent decade. The past decade has been characterized by increased sampling of the ocean, especially through the advent of altimetry, the Argo float system, moored buoy arrays, and other in situ and satellite components. It will require a long-term continuation of satellite altimetry, and top-to bottom Argo-like profile measurements of temperature and salinity globally, including regions under sea ice cover, to improve our understanding of regional and global sea level, heat content, as well as changes in the water cycles of the ocean. In addition regional changes in sea level are much larger than global numbers, implying that one needs a local tide gauge network on top of global estimates to answer urgent questions about sea level change and coastal security. To properly attribute ocean variability to natural variability or anthropogenic causes, we also need to gather information on changes of the external forcing by the atmosphere, cryosphere and other components of the Earth System (e.g., run-off and river discharge into the oceans). Attribution of ocean variations to changes in these forcing fields is fundamentally about the science of climate predictability, including for climate variability (e.g., El Niño-Southern Oscillation (ENSO), seasonal variability, etc.), as well as long-term climate change.

The ability to analyze climate variability from limited climate data sets depends fundamentally on our ability to bring all available data into consistency with the dynamics of the ocean and the full climate system, as embedded in ocean or climate models. This enables use of the results for studies of variability or changes of either the ocean alone or of the fully coupled climate models, and for the initialization of climate models. In the past, reanalyses in the atmosphere and syntheses/analyses in the ocean were performed individually dealing with each fluid in isolation. This work has led to important results (see statement of 3rd reanalysis conference) and it is obvious that respective activities need to continue. At the same time, the challenge WCRP and climate research in general is facing in the future, is to deal with a truly coupled system, which includes the performance of syntheses/reanalyses and analyses in a truly coupled context and by doing so to improve our ability to initialize the coupled system. Respective work is underway under the auspices of CLIVAR's Global Synthesis and Observations Panel (GSOP) and the WCRP Observation and Assimilation Panel (WOAP). It will form an essential element of climate research over the next decade as outlined in the imperatives of WCRP for the coming years.

Several steps are involved, including:

- Ocean synthesis and analysis
- Coupled data assimilation system
- Estimating uncertainties
- Building links to IGBP carbon, biogeochemistry, and ecosystems

Ocean Syntheses

Assessing all changes occurring presently in the ocean requires a global and long-term observing system, capturing the full state of the ocean. As an example, assessing sea level changes, globally and regionally requires a detailed description of the changes in heat and freshwater content over the entire water column and over many decades, as well as changes in the mass of the ocean. All those measurements became feasible only recently, essentially since the advent of altimetry and through ARGO and GRACE (before then large parts of the ocean where hardly observed even once over the last 100 years). However, the need is to estimate climate changes in the ocean over the last decades to centuries.

To obtain reliable estimates of long-term variations of climate indices from a limited database, all existing data should be used as best and as carefully as possible. Given the imminent problems associated with anthropogenic climate change, it is essential to learn as much as possible from the past. But using the existing data in the ocean for investigations of decadal and longer term climate variations requires the reprocessing of the entire climate data base to assure that uncertainties from the observations are reduced as best as possible (e.g., remove uncertainties in the XBT fall rate, biases in temperature or salinity profiles, etc). CLIVAR and WCRP must continue to show a significant leadership in this direction. An important step in obtaining the best possible estimates of the changing ocean as part of the climate system is then to analyze climate-quality ocean observations in a holistic approach by using all information available and analyzing it in ways consistent with our dynamical understanding as embedded in ocean and climate models. Such an approach has to take in account uncertainties of observations as well as of models in which data are being assimilated.

Retrospective work is ongoing in form of regional and global ocean synthesis. GSOP provides a comprehensive list of available ocean syntheses. As can be seen from that list (http://www.clivar.org/data/synthesis/directory.php), several reanalyses of historical ocean observations have been constructed and are being evaluated through the CLIVAR GSOP intercomparison project. Available information from ocean syntheses is used to compute important climate indices, such as heat content of the global ocean and to start attributing changes to various sources, including erupting volcanoes through their effects on atmospheric aerosols.

Future ocean syntheses for climate research must be sustained in support of climate research and climate services. Not every ocean synthesis is useful for this purpose. Results depend on the assimilation approach: some are tailored for mesoscale predictions or for the initialization of SI models. It is essential that ocean syntheses are accompanied by uncertainty measures (see also below). Ultimately the community should compile ocean syntheses from multi-model, multi-approach ensemble estimates that are supposed to be of better quality than any estimate alone. However, the science has to go a long way to reach that goal, which as a pre-requisite requires prior as well as a posteriori error information.

Coupled Data Assimilation

Projecting the ocean state over the next decade or even centuries requires running a coupled climate forecast system, which requires information about the initial/present climate state as well as boundary conditions to the ocean. Indeed one of the goals for an ocean observing and synthesis system is to provide proper initial conditions for ocean and climate forecasts on seasonal to decadal time scales. For predictions of a season to a year or so, the ocean state is most critical although information about sea ice extent, soil moisture, snow cover, and state of surface vegetation over land are all important.

Initialization of a coupled system has three main components: the observing system leading to climate records, the assimilation method leading to estimates of the initial conditions, and the coupled climate model leading to predictions. Uncertainties in each element will impact the skill of predictions. In practice, initial conditions for the ocean component of the coupled model are usually produced in an ocean-only context and are being fed into the coupled model subsequently. This will inevitably lead to mismatches in the physics of the initial condition and the coupled model and major uncertainties in predictions (SI and DEC/CEN) originate from uncertainties in the models initial condition and from errors in coupled models (including the initial coupling shock and subsequent adjustments).

Ocean data assimilation is used operationally in several SI forecast centers around the world to initialize seasonal forecasts with coupled models, and it is from that experience that decadal prediction efforts will build. Temperature and salinity from ocean syntheses have already been used to initialize models for decadal forecasts (Smith et al. 2007, Pohlmann et al. 2009). In this way, modeling groups without data assimilation schemes can perform initialized climate predictions. However, mismatches in model physics leads to initialization shocks; while errors in coupled models lead to fast degradation. To overcome those, the climate community needs to work both on improving initialization procedures, but also on improving coupled climate models to better represent and simulate present day climate variability. In particular, the assimilation needs to be performed in the coupled model framework to obtain proper initial conditions. At the same time a coupled assimilation system will lead to reduced model errors through parameter optimization. In fact it is highly likely that confronting models with observations in this way will lead to improved understanding of error sources and to model improvements.

Fully-coupled data assimilation schemes that take advantage of covariances between ocean and atmospheric variables to generate an optimal estimate of the climate system are expected to offer the greatest forecast skill for SI and decadal predictions. Such schemes are under development with some encouraging results (e.g., Zhang et al. 2007). The related activities are to improve and initialize climate models and make “seamless” ensemble climate predictions for the oceans for the time horizons of 30 years. Developing and evaluating coupled assimilation and forecast systems for decadal predictions should be a core activity of WCRP over the next decade and beyond.

Uncertainties

A recent inter-comparison of ocean syntheses reveals a wide spread of results and highlights the need for specifying proper uncertainties for model and data errors. These uncertainties in the ocean state become especially relevant for understanding climate change in the ocean, including the joint relationship between atmospheres and oceans, and for understanding future projections of the ocean state in the context of the regional change and with short time horizons. A significant effort is therefore required to understand uncertainties in estimates of climate indices, how they depend on the underlying method and how they affect aspects of prediction.

In analyses of the ocean and the atmosphere, uncertainties arise from several elements:

1) observing system
2) data processing
3) model errors
4) approaches to estimate the ocean or the climate state
5) initialization procedures of coupled models

Historically the sub-surface ocean has been very sparsely observed, and some of the data appear to be significantly biased (Domingues et al. 2008), making the development and testing of ocean initialization schemes difficult even for the 80th. For instance, the non-stationary nature of the ocean observing system, particularly due to the paucity of salinity data as well as XBT data only going to 500 m, can give rise to spurious decadal variability making the assessment of forecasts based on such analyses difficult. More emphasis has to put on the last 10 -15 years when sufficient amounts of data are available over the global ocean to infer changes.

An ultimate use of ocean syntheses is to use information to initialize the ocean in coupled climate forecast models. The problem of model error is critical for decadal prediction, since the sub-surface ocean state associated with the initial condition may be significantly different than the climate of the free running coupled model.

A substantial uncertainty can also emerge from the specific choice of estimating initial conditions. Various choices can be made ranging from computationally simple to mathematically rigorous but computationally demanding. All approaches usually can be summarized as “filters” and “smoothers”. A significant effort is required to understand the impact of the approach on the result as well as the validity of the approach for climate time scales.

Finally understanding uncertainties not only in models or data (and realizing that data errors can be significant) but understanding the a priori uncertainties of estimated climate indices needs to be of high priority for WCRP since without that information the use of ocean or atmospheric analyses is only of limited value, regardless of application.

Building links to IGBP carbon, biogeochemistry, and ecosystems

Many processes in the ocean depend fundamentally on the physical state of the ocean. An important link between CLIVAR and other programs, such as IGBP, is therefore to provide best possible estimates of the changing physical ocean to the carbon and ecosystems communities so as to better constrain their problems. An important question to investigate in this context is that of the uptake of CO_2 by the ocean. The ocean circulation does play a fundamental role in this context and obtaining best possible descriptions of the ocean climate state during the past, present and future is of great importance for understanding the climate response under future CO_2 scenarios. Ultimately we want to perform joint syntheses between the physical and the carbon communities so as to better understand the ocean circulation but also to better understand the observed changes of CO_2 in the ocean and at the same time utilize the observational constraints in both. This calls for a close link between ocean and coupled climate syntheses and carbon syntheses.

Climate change on time scales of decades and centuries has profound impacts on the ecosystems of the ocean. Ongoing assessments of the physical, biogeochemical and ecosystems of the ocean are important and should be implemented by WCRP jointly with IGBP.

Imperative VI – Ocean observing system (to be completed post OceanObs'09)

The world ocean has not been well enough observed in space and time to address many of the key aspects of its role in climate variability and change. Some examples include: only in the last few years have temperature and salinity been systematically observed in the ice free upper ocean; ocean reanalysis efforts suggest that the historical data base may not be sufficient even to constrain upper ocean heat content trend over recent decades; at present it is challenging to reconcile the trends of the past 15 years of global sea level rise with those of global upper ocean heat content; there is insufficient information to determine the extent to which ocean circulation is affecting the recent extreme Arctic summer sea ice reductions.

Considerable progress has been made within the past ten years in implementing an initial global ocean observing system for climate, following recommendations developed primarily by the international climate research community. This system is intended to support, among other things, development of initial conditions for seasonal to decadal climate forecasts, to illuminate variability and change in the overturning circulations as well as oceanic transports of heat, freshwater and carbon, and to provide reference information about air-sea fluxes at a few key locations. It is critical for the success of CLIVAR that this system be sustained. Moreover, it needs to evolve according to what we are learning about the sampling requirements from its observations and the analyses and reanalyses we are doing with data from it as well as from the earlier historical record as well as our learning from field programmes providing short-term enhanced observations.

Imperative VII – Capacity building

Prepared by V Detemmerman, L Goddard, F Zwiers, H Cattle

The WCRP Implementation Plan 2010-15 sets out WCRP's approach to capacity building which CLIVAR will be a partner in. In particular it will carry out activities to help meet WCRP's major objectives to:

- Broaden the church of those involved in WCRP activities
- Provide vocational training its area of science through opportunities for early career scientists and scientists in the developing world to attend training seminars and participate in CLIVAR-sponsored meetings, workshops, summer schools and conferences.
- Promote helping climate practitioners to be able to better analyses and interpret climate information products
- Seek to make research results useful and easily accessible to end users such has adaptation planners, policy and decision makers.

In order to meet these overall objectives and so contribute effectively to those of the WCRP as a whole, CLIVAR will organize various capacity building activities, including topical workshops, summer schools and expert training (including "train the trainer" exercises) and will invite young and developing country scientists to participate in workshops and conferences. Indeed effective

adaptation to the changing climate requires not only more and better information about future changes in climate from improved climate models, but also requires bettr information about past and current climate. To address this need the CLIVAR/CCl/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) has coordinated the formulation of a suite of climate indices that describe different aspects of temperature and precipitation extremes, including frequency, intensity and duration. Environment Canada also developed open source software for the calculation of indices and for climate data homogenization, and has made this software freely available. These tools, together with a series of ETCCDI-coordinated regional capacity-building workshops, have played and will continue to play and important role in monitoring changes in extremes, climate model evaluation and assessment of future climate, which in turn provide climate information that is required for climate change adaptation.
In developing its capacity-building activities further, CLIVAR will scope various suggested approaches, including:

- Contributing to the education of the next generation of climate scientists with a particular focus on interdisciplinary studies and scientists from developing countries. CLIVAR Panels and Groups will be encouraged to organize workshops targeted at graduate students and post-docs that have a high interdisciplinary content and, where practical, involve contact with operational activities.

- Providing global and regional fora for the exchange of ideas and knowledge amongst climate researchers and students. Support will be sought to bring young scientists and those from developing countries to CLIVAR meetings and conferences.

- Encouraging extended visits to research labs through exchange programmes for young scientists.

- A programme to support experts in selected areas of climate science from developed countries to spend a few weeks (2-3) in climate research institutions to provide training for targeted group of scientists based in developing nations. This should be sustained through train-the-trainer programs. For instance, in Sub-Saharan Africa, the experts from developed nations could be based at ICPAC, ACMAD, etc and given specific mandate to provide specialized for African climate scientists (identified in collaboration with National Meteorological and Hydrological Services). This paradigm of training the trainers in African institutions would be more effective than the common practice of organizing short-term training visits abroad. The advantages are twofold. One, the cost of such training will be reduced significantly. Two, this model of home-based training will have a multiplier effect both in helping leverage training facilities locally, but also trainers will have to improvise to meet their training objectives under limited resources.

- Encouraging the making research outputs useful and easily accessible to the broader scientific community and to end-users such as adaptation planners, policy makers and decision makers in climate-sensitive sectors such as agriculture, energy and construction. A few targeted workshops to bring together climate scientists and specific sector user communities will provide fora for communication, with a focus on developing a common understanding of uncertainty in climate forecasts. A specific activity could be to extend the ETCCDI indices workshops to include comparisons with model outputs. This activity could be held in conjunction with the Regional Climate Outlook Fora organized by WMO.

- With initial focus on in sub-Saharan Africa, developing capacity that targets scientists working on climate change adaptation using outputs from models and observations and encourages interaction with interdisciplinary groups from water resources, agriculture, marine sciences, etc. This type of capacity-building activity will enrich CLIVAR (WCRP) contribution to the next IPCC AR5 report that will be focusing assessment of regional climate change impacts on Africa. Furthermore, it will ensure training of a critical mass of local scientists who can appropriately merge local knowledge and expert training to interpret climate change information and uncertainties for adaptation purposes.

- Exploring the feasibility of a summer School on regional climate change scenarios and adaptation in collaboration with ICTP. ICTP has a long experience in organizing such workshops targeting mainly young scientists from developing countries and therefore well placed to rally effective participation of scientists from developing countries as well as facilitators from the advanced climate centers. If funding is available this could be an annual activity.

- Targeted training workshops (TTWs) on prediction and predictability of monsoon on intra-seasonal, seasonal and decadal time scales may be held for monsoon countries. While the hosting country may contribute significantly to funding such TTWs, WCRP should motivate and some of the leading scientists to commit to spend some time and lecture in these workshops. The goal would be to build capacity in the developing countries to make these predictions using the state of the art tools and not just be limited to analyzing outputs from other centres.

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