Section 5

Development of and studies with regional and smaller-scale atmospheric models, regional ensemble, monthly and seasonal forecasting

Prospects of hurricane variability analysis in dynamically downscaled tropical cyclone simulations

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North Atlantic tropical cyclone (TC) activity has been observed to vary over a wide range of timescales, from sub-seasonal to decadal (and possibly longer), and multiple attempts have been made to relate these variations to a large array of climate variables. The lower frequency variations are generally considered to be related to the slowly varying thermodynamic conditions, driven in large part by changes in local sea surface temperatures (SSTs), whereas higher frequencies tend to be driven by teleconnections from factors external to the tropical Atlantic. For instance, North Atlantic TC activity is modulated at the interannual time scale by El Niño Southern Oscillation (ENSO): El Niño (La Niña) years are usually associated with lower (higher) TC activity in the North Atlantic. At slightly longer time scales, the North Atlantic TC activity is strongly tied to the Atlantic Multidecadal Oscillation (AMO), a slow oscillation in Atlantic SSTs linked to the Atlantic meridional overturning circulation. Changes in the AMO are often used to explain the heightened TC activity observed since the mid-1990s.

An approach to quantifying the relationship between climate and tropical cyclone activity is to use modeling. Among the models, downscaled models are often used as they can provide the necessary high-resolution to accurately simulate tropical cyclone activity. Such technique is capable of resolving tropical cyclones using boundary conditions supplied by the reanalysis datasets. This combines the advantage of relatively robust estimates of large-scale conditions by the reanalysis with the high fidelity simulation of tropical cyclones by the embedded high-resolution models.

In this study, we will use a series of tropical cyclone tracks produced by randomly seeding (in space and time) weak, warm-core vortices in different reanalysis datasets. The tracks of the resulting storms are then given by a beta-and-advection model driven by the flows derived from the reanalysis wind fields whereas the intensity of the storm is evaluated from a high-resolution atmosphere-ocean coupled tropical cyclone intensity model (Emanuel, 2006). It should be noted that most of the disturbances seeded in the environment dissipate before they can intensify to tropical storm status.

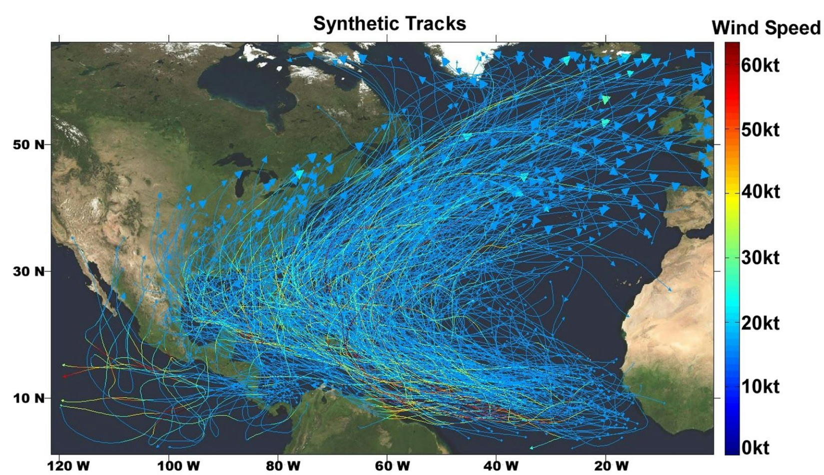
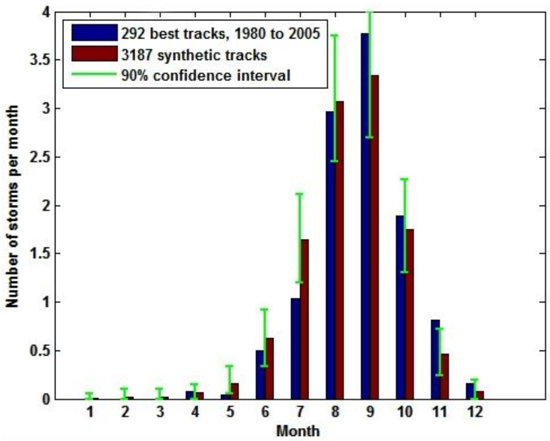


Figure 1: 500 synthetic tracks produced using MERRA reanalysis dataset.

We show in figure 1 the geographical distribution of 500 synthetic tracks obtained with the downscaling technique, which produce randomly seeding disturbances evolving in the environmental conditions provided by MERRA reanalysis. The tracks follow a relatively realistic trajectory, with many storms forming off the



coast of Africa (where so-called Cape Verde storms tend to form) and propagating westward towards Central and South America. There is a small bias over the Gulf of Mexico and the storms tend to live longer than the real world counterpart, but overall, the trajectory of the tracks and their geographical distribution tend to be fairly realistic. The tracks also have a realistic intensity distribution (not shown) and a realistic seasonal cycle (figure 2), with most storms forming in the August-October period.

Figure 2: Average number of storms per season for observed (blue) and synthetic (red) tracks. The green bars represent the 90% confidence interval (synthetic tracks).

The synthetic tracks have thus been shown to have a fairly realistic geographical, seasonal and intensity distribution. Their interannual variability has also been studied (Emanuel, 2010) and was shown to be highly correlated to the observed variability (see figure 3 for an example derived from MERRA reanalysis). What is unknown at this time is which of the observed climate-hurricane connections were captured by this technique. This is what we plan to investigate. We will use Poisson regression, which is a classical approach to analyze count data, in conjunction with the full list of climate factors previously identified as influencing cyclone variability over the North Atlantic basin. This list of climate influences will include influences such as ENSO, the North Atlantic Oscillation and the precipitation over the Western Sahel region, to name a few.

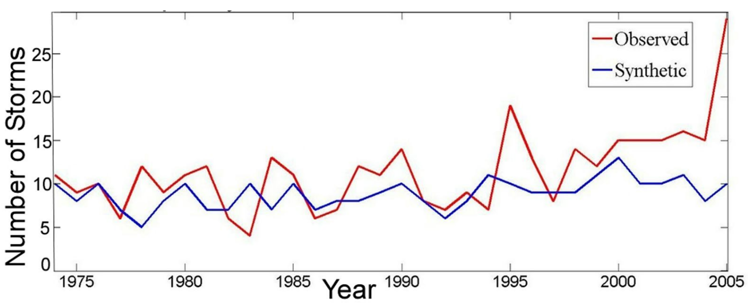


Figure 3: Observed (red) and simulated (blue) time series of Atlantic Tropical cyclones. The synthetic tracks were produced using MERRA reanalysis.

By analyzing the statistical significance of the regressions resulting from downscaled reanalysis, we will be able to identify the climate-cyclones links that are captured in the downscaled TC. Furthermore, we will compare the statistical significance of results obtained by downscaling typical reanalysis product with a reanalysis product that assimilates only surface information (NOAA-CIRES 20th Century Reanalysis). Because the latter only assimilates surface information, we expect the results to be somewhat degraded compared to the former. By comparing the relationship observed in both downscaling exercises, we hope to learn more about the processes controlling North Atlantic TC variability and which of these processes the downscaling model manage or fail to capture. This will suggest possible modifications/improvements to models used for dynamical forecasts.

Acknowledgments
The authors would like to thank Kerry Emanuel for providing the synthetic tracks and Glenn Thompson and Alexandra Farrell for their assistance with Matlab.

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Tropical Storm Relocation in the North America Model (NAM)

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1. Introduction

The operational North America Model (NAM) at NCEP has been complementary to the global forecast system (GFS) in providing higher resolution products to forecasters. But it has been lagging the GFS in the tropical storm track forecasts. One reason is because the storm center in the analysis, on which forecasts are based, is sometimes too far off from the observed storm location. The GFS has instituted a storm center relocation which the NAM currently does not have. In order to increase the accuracy of NAM track forecasts, the storm center relocation scheme is tested by moving the analyzed storm center to the observed location, hence making the NAM initial conditions more in alignment with reality.

Indeed, results show that not only the initial analysis location of a relocated storm center is closer to the observed than that without relocation; the forecast accuracy of storm tracks is also increased as the initial conditions are improved. The plan is to implement TS relocation into the operational NAM in an upcoming upgrade.

2. Technical procedures for relocating a storm center to the observed location

It is basically a so-called "mechanical relocation" scheme and the automated system involving many steps: (a) Detect TC vitals, define a storm domain and determine the number of storms; (b) Run NPS (NAM Preprocessing System) to get boundary conditions from GDAS 6hr forecasts, and create a 70x70 lat-lon nest centered on the storm center; (c) Get NDAS variable fields to be relocated from the restart files; (d) Combine GDAS and NDAS data, using GDAS data to fill in NDAS data gaps; (e) Generate environment fields, splitting the perturbation from environment (the perturbation patches are on a 30x30 lat-lon nest); (f) Combine perturbations with environment fields in the new location, smoothing gradually toward the edges; (g) Merge the relocated fields into the restart file; (h) Repeat the process for multiple storms if necessary; (i) In the prep buffer data, remove SYNDATA and dropwinsonde within a 200km radius from the center of the storm; (j) Use the relocated restart file to produce the analysis. The procedures are carried out at T-06 and T-00 hours. At the end of the T-00 procedure, 84-hour forecasts are produced.

3. Retrospective relocation and control experiments

Two experiments are carried out using the most recent NAM version (nam.v3.1.0) at the time: the first using the relocation scheme and the second without relocation as the control experiment. Everything else in the NAM is exactly the same.

There are 8 named tropical storms from 2012 to 2014 chosen for these experiments due to their impacts on land. Geographically they are distributed over the Atlantic Basin, Gulf of Mexico and East Pacific Basin. Figure 1 shows the zonal wind differences before and after relocation for Hurricanes Sandy and Tony on 12Z October 25, 2012. It is clear that the winds near the storm centers have been altered. The rest of the forecast area is identical, which is exactly what the system is designed to do – moving the storm perturbation to the observed location without impacting the outside area.

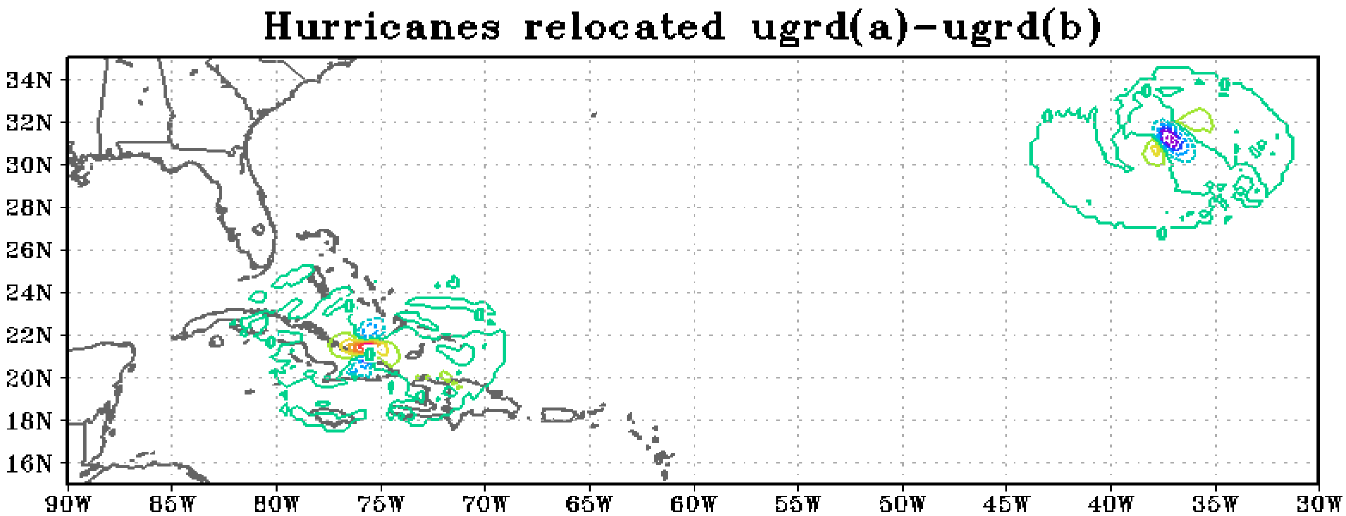

Figure 1. Zonal wind differences before and after relocation is done

4. Statistical results

All verifications are against real time NHC storm center reports. Figure 2 shows track errors for the relocated centers (blue), control (red) and operational NAM (green). It is clear that the relocated center errors are always smaller than the control run errors. This demonstrates that not only initial center errors are reduced (0.67 NM), but also the forecast track errors are consistently decreased (up to 2.93 NM at 72 hours) compared to the control runs.

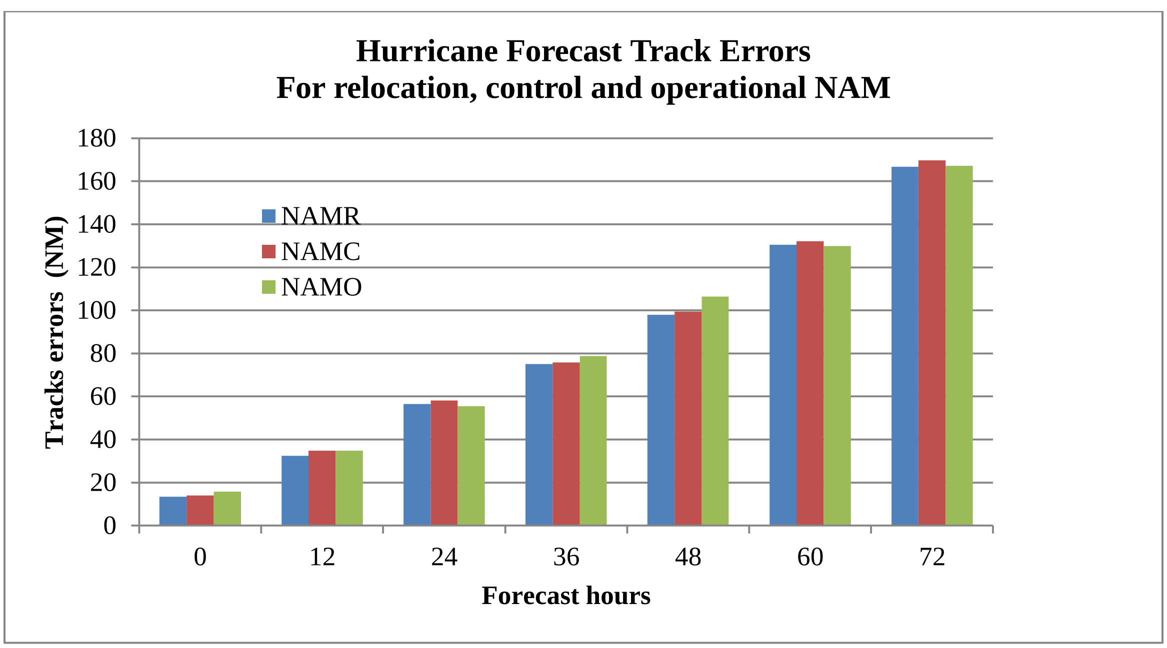

Figure 2. Track errors for NAM (R-relocation, C-control, O-operational)

NOAA's National Air Quality Forecast Capability for ozone and fine particulate matter

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The NOAA National Air Quality Forecast Capability, NAQFC, is designed to provide 2 day model forecasts of ozone and fine particulate matter surface concentrations twice per day at the 06 and 12 UTC cycles. The NAQFC operational forecast for O_3 for the nation was implemented in September 2007 and for particulate matter in January 2015. The NAQFC is made up of the North American Non-Hydrostatic Multiscale Model (NAM-NMMB) 12 km numerical weather prediction model and the EPA Community Model for Air Quality (CMAQ) using Carbon Bond-V (CB-V) gas phase chemistry and AERO-IV particulate processing. Predictions are available in real-time for the continental U.S., Alaska and Hawaii.

Offline coupling between NAM and CMAQ is achieved at hourly intervals by interpolation from the NAM to CMAQ horizontal and vertical grids. Anthropogenic emissions are updated monthly from the EPA National Emission Inventory for the base year 2011. Wild fire smoke emissions were included in 2015 and based upon the U.S. Forest Service BlueSky smoke emission system and the NESDIS Hazardous Mapping System (HMS) fire locations updated daily. Dust emissions were also included in 2015 using a friction velocity and soil moisture criteria based approach. Lateral boundary conditions for dust are provided by the NCEP NEMS Global Aerosol Capability (NGAC) with climatological values for other species provided by NASA GEOS-Chem. Predictions are available to U.S. state air quality forecasters and the public from the NWS National Digital Guidance Database (NDGD) at http://airquality.weather.gov/ with experimental model predictions at http://www.emc.ncep.noaa.gov/mmb/aq/.

NWS HYSPLIT atmospheric transport and dispersion modeling

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Understanding and predicting atmospheric transport and dispersion is essential for protecting the health and welfare of the public and emergency response personnel when harmful substances are released into the air in significant quantities. The Federal National Response Framework, approved by the President in January, 2008, assigns to NOAA the responsibility for atmospheric transport and dispersion (ATD) prediction of smoke and radioactive and hazardous materials, maintenance and development of the Hybrid Single Particle Lagrangian Integrated Trajectory model (HYSPLIT) and coordination with the World Meteorological Organization (WMO) on international incidents. NOAA's Air Resources Laboratory (ARL) develops many of NOAA's capabilities for these services.

Needs for ATD or "plume" understanding and tools are continually evolving, driven by demands for more accurate predictions, estimates of uncertainties, finer spatial resolution, easier-to-use tools, and tools to address evolving risks. For instance, in 2008 the GAO[1] recommended that the Secretary of Homeland Security "work with the federal plume modeling community to accelerate research and development to address plume model deficiencies in urban areas and improve federal modeling and assessment capabilities. Such efforts should include improvements to meteorological information, plume models, and data sets to evaluate plume models." NCEP works with ARL's research and development (R&D) to address each of these areas within the HYSPLIT dispersion modeling system.

Currently, the HYSPLIT system is used to provide the following operational atmospheric dispersion products:

- 48-hour wild-fire smoke forecasts from the daily 06 UTC cycle for CONUS, Alaska, and Hawaii driven by the 12 km North American Model (NAM).
- 48-hour dust forecasts from 06 and 12 UTC cycles for CONUS.
- 48-hour volcanic ash forecasts whenever requested by the International Civil Aviation Organization (ICAO)-designated U.S Volcanic Ash Advisory Centers (Washington, DC and Anchorage, AK). This is typically GFS-driven, although other model output can be used.
- 72-hour radiological emergency response plume forecast when requested per the WMO-designated Regional Specialize Meteorological Center (RSMC) arrangements (IAEA or another nation's NMS). This is typically GFS- driven, although other model output can be used.
- 16-hour dispersion forecast for HAZMAT-type (chemical spill, explosion, etc.) incident upon the request of a Weather Forecast Office (WFO), almost always driven by 12-km NAM, though other model output can be used.
- 16-hour dispersion forecasts for HAZMAT-type incidents, driven by 12 km NAM, for about 25 locations run four times a day to support WFOs ("canned" runs).
- 48-hour back-tracking product when requested per the WMO/RSMC arrangements. This is typically GFS-driven, although the NAM can be used.
- HYSPLIT-formatted meteorology files created for input to the above dispersion applications.
    - GFS (1 degree, pressure-level), GDAS (1 degree, pressure-level), NAM (hybrid-level: CONUS, Alaska, Hawaii nest, fire weather nest CONUS nest; and pressure-level: CONUS), and Rapid Analysis and Prediction system (RAP: 20 km, pressure-level).
- HYSPLIT-formatted meteorology files disseminated to ftpprd.ncep.noaa.gov, where they are

[1]GAO, 2008. First Responders' Ability to Detect and Model Hazardous Releases in Urban Areas is Significantly Limited. GAO-08-180 Homeland Security.

- Automatically retrieved by the Web Operations Center to operationally support the web-based HYSPLIT interface for NWS WFO (https://www.hysplit.noaa.gov).
- Automatically retrieved by ARL to support
  - a test of HYSPLIT trajectories-by-email for the NWS Fire Weather program,
  - customers on the ARL REal-time Access and Display sYstem (READY) website (http://ready.arl.noaa.gov/).

For all applications, dispersion is simulated using either the multi- or single-processor version of the same code. The smoke and dust forecast guidance is sent in gridded form to the NOAA/MDL (Model Diagnostics Laboratory) National Display and Graphics System (NDGD) for distribution to forecasters and emergency managers at the individual state level.

RSMC predictions are initiated by the NCEP/SDM (Senior Duty Meteorologist) and distributed to National Forecast Centers via fax. Digital and graphical products are also shared between other nations' RSMCs through a protected ARL (non-operational) web page. Monthly exercises are performed by the SDM with other RSMCs.

The volcanic ash predictions are initiated by NCEP, NESDIS/SAB (Synoptic Analysis Branch), or NWS AAWU (Alaska Aviation Weather Unit) and distributed via World Area Forecast System (WAFS) and made available over the Internet operationally at the Aviation Weather Center (AWC) and non-operationally at ARL and SAB.

The HAZMAT-type output is made available on a secure NCEP server (https://hysplit.ncep.noaa.gov/). NCEP/AWC is able to initiate a HAZMAT-type model run.

In 2016, HYSPLIT was improved to meet the NCEP requirements for volcanic ash product dissemination and NOAA requirements for back-tracking support to the Comprehensive Test Ban Treaty Organization (CTBTO). Improvements were accomplished mainly by upgrading the wet deposition scheme for radiological materials and volcanic ash. The success of the implementation is measured both for quality and timeliness. The threat score should be predicted 0.08 for the 24 hour averaged smoke forecast. Volcanic ash forecasts will be evaluated against satellite derived ash plumes. The ARL DATEM (Data Analysis of Tracer Experiments and Meteorology) database of previous dispersion field experiments is used for RSMC, HAZMAT-type prediction verification.

Upgrade of the NCEP GFS to a 4D Hybrid Ensemble Variational Data Assimilation

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The National Centers for Environmental Prediction (NCEP) is upgrading the GFS Analysis and Forecast System in May, 2016. The upgrade includes changes to both the Global Data Assimilation System (GDAS) and to the GFS Global Spectral Model and post-processing software.

The GDAS changes include an upgrade of the 3D Hybrid Ensemble Variational to a 4D Hybrid Ensemble Variational Data Assimilation System, where the 4D increments are constructed by figuring out the best combination of 4D ensemble perturbations. The ensemble provides an updated estimate of situation dependent background error every hour as it evolves through the ensemble window. The weights for ensemble members are kept constant throughout the assimilation window. This 4DHybrid uses 50 outer and 150 inner iterations with variational quality control turned on after 25 iterations. This flow dependent statistical estimate is combined with a fixed estimate; the weights for static and ensemble are 12.5% and 87.5%, respectively. Tangent Linear Normal Mode Constraint (TLNMC) and Digital Filter Initialization (DFI) are used in the ensembles while additive error inflation is removed. Ozone cross co-variances are also in the 4DHybrid, and localization is reduced to 50% in the troposphere.

Other changes to the GDAS include the following:

- Assimilation of all sky Advanced Microwave Sounding Unit (AMSUA) Radiances;
- Assimilation of Advanced Very High Resolution Radiometer (AVHRR) winds and monitoring of Visible Infrared Imaging Radiometer Suite (VIIRS) winds;
- Implementation of Geostationary Operational Environmental Satellites – R series (GOESR) data readability;
- An update of the Community Radiative Transfer Model (CRTM) to v2.2.1 with bug fixes in wind direction, including use of FAST Microwave Emissivity Models (FASTEM6 and FASTEMX) reflection correction for cloudy situations;
- Improved bias correction for aircraft observations;
- Modified relocation and storm tracking to allow hourly tropical cyclone relocation;
- Modified thinning/weight in time for Atmospheric Motion Vectors (AMVs) and radiances.

The changes to the GFS Global Spectral Model and post-processing software include corrected land surface characteristics for grassland and cropland categories to reduce summertime warm and dry biases over the Great Plains, upgraded convective gravity wave drag, and an upgraded tracer adjustment in the semi-Lagrangian dynamic core.

There are also changes to model products, including a new Global Forecast Icing Severity (GFIS) icing severity parameter, improved Global Forecast Icing Potential (GFIP) products, the addition of an hourly forecast product out to 120 hours, and the addition of five more vertical levels (7, 5, 3, 2, and 1 hPa).

This upgraded system was tested using more than three years of forecasts plus the Hurricane Sandy case. New evaluation methodologies were developed in coordination with other NCEP centers and National Weather Service regional headquarters and forecast offices. Maps of three months of real time operational and upgraded forecasts were available to operational forecasters for evaluation, and selected case studies recommended by forecasters were conducted on more than three years of forecasts.

Objective verification against observations and the model's own analyses showed that week 1 forecasts were significantly improved except in the upper stratosphere. The upgraded system produced much smaller analysis increments. Anomaly correlations for 5 day forecasts of 500 hPa improved significantly by .004 in the Northern hemisphere and .007 in the Southern Hemisphere, with larger improvements for zonal wavenumbers 10-20. RMS errors of selected atmospheric fields decreased by 10% for day 1 forecasts, 4% for day 3 and 2% for day 5 when verified against the model's own analyses. Forecasts of 2 m temperatures and dew points and 10 m winds verified against surface observations over the continental United States and Alaska improved significantly. RMSE errors for 96 hour forecasts of 2m temperature and dew point improved by 2% in the western United States and 3% in the east while 96 hour forecasts of 10 m winds improved by 4% in the west and 8% in the east when verified against surface stations. The new system further increased a GFS tendency towards too much drizzle, but showed significant improvement in forecasting 2-25 mm/day precipitation thresholds over the continental United States. Forecasts of CAPE over the United States and jet streams showed significant improvement. Forecasts of tropical storm genesis, track and intensity also improved. Synoptic evaluation of the new GFS yielded no major new concerns; the operational and experimental systems often produced very similar forecasts with the GFSX performing better in some cases. An extensive evaluation site is available at:

http://www.emc.ncep.noaa.gov/gmb/noor/4dGFS/synergy%20announcementjan08.htm

This implementation followed a new implementation procedure with a considerably longer official evaluation period and more active engagement with and participation of the other NCEP centers and NWS regional headquarters and forecast offices.

A spatio-temporal Stochastic Pattern Generator for use in ensemble prediction and ensemble data assimilation

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Introduction

Model errors (i.e. imperfections in the forecast-model equations and boundary conditions) are a substantial contributor to forecast errors and therefore need to be adequately represented in ensemble prediction and ensemble data assimilation systems. In this study, we propose a Stochastic Pattern Generator (SPG) for model-error simulation. The SPG produces 2D and 3D spatio-temporal pseudo-random fields with tunable spatial and temporal length scales and meaningful space-time interactions. The SPG operates on a limited-area domain. The technique is implemented as a Fortran program freely available from https://github.com/gayfulin/SPG.

Methodology

The SPG is based on a stochastic differential equation in time with a pseudo-differential spatial operator:

$$\left(\frac{\partial}{\partial t} + \frac{U}{\lambda}\sqrt{1-\lambda^2\Delta}\right)^3 \xi(t,\mathbf{s}) = \alpha(t,\mathbf{s}). \tag{1}$$

Here ξ is the random field in question (the output of the SPG), t is time, $\mathbf{s}$ is the spatial vector, Δ is the spatial Laplacian, $\alpha(t,\mathbf{s})$ is the white in time and space noise, λ is the scalar that controls the spatial length scale, and U is the velocity-dimensioned parameter that controls the temporal length scale.

Equation (1) is numerically solved using a finite difference scheme in time and a spectral scheme in space. For motivation, derivations, properties, numerical scheme, simulation results, and other details, see Tsyrulnikov and Gayfulin (2016b) and Tsyrulnikov and Gayfulin (2016a).

Results

Figure 1 displays the spatio-temporal correlation function for an SPG random field. One can see that the larger is the time lag, the broader are the spatial correlations. This is a manifestation of the non-separability of the spatio-temporal correlations often observed in the real world (e.g. Cressie and Huang, 1999, Fig.8). More specifically, the spatio-temporal structure of the SPG fields is scale dependent, so that longer spatial scales 'live longer' than shorter spatial scales, which "die out" quicker. This desirable property was called "proportionality of scales" in (Tsyroulnikov, 2001). The SPG is embedded into the Fortran code of the limited-area meteorological non-hydrostatic model COSMO (Baldauf et al., 2011). Results of a numerical experiment are displayed in Fig.2.

Conclusions

A generator of spatio-temporal pseudo-random Gaussian fields that satisfy the "proportionality of scales" property is presented. The generator is a third-order in time stochastic differential equation with a pseudo-differential spatial operator defined on a limited area 2D or 3D domain in the Cartesian coordinate system. The spatio-temporal covariances are non-separable. The spatial covariance functions of the generated fields belong to the Matérn class. A spectral-space numerical solver is implemented. The generator is tested with the COSMO model as a source of additive spatio-temporal perturbations to the forecast model fields. The SPG can be used to generate spatio-temporal perturbations of the model fields (in the additive or multiplicative or other mode), as well as the boundary conditions.

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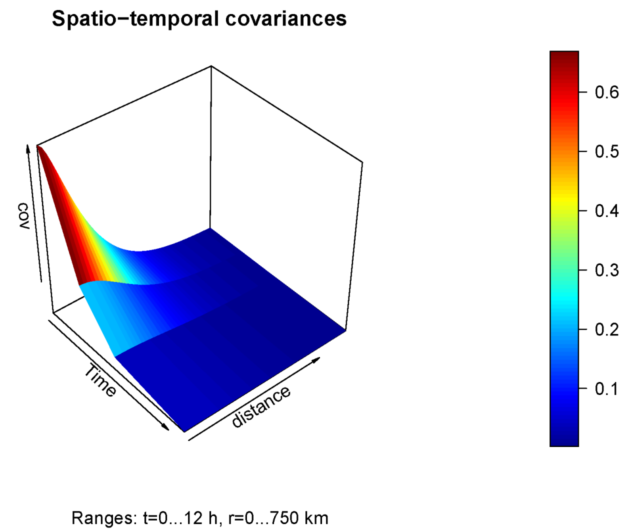

Figure 1: The theoretical spatio-temporal SPG correlation function.

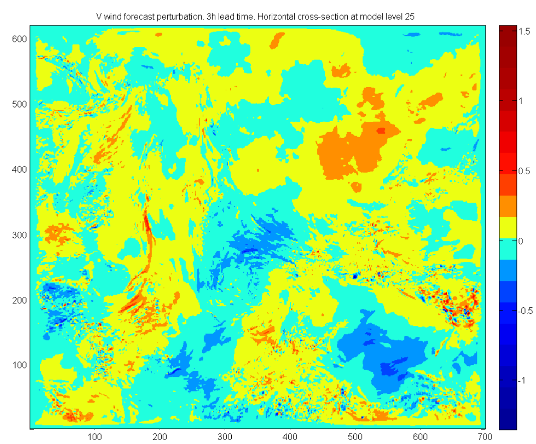

Figure 2: COSMO forecast V-wind perturbation field in response to the additive SPG perturbations of temperature, pressure, and both wind components after 3 hours of time integration (bottom). The SPG perturbations were added every 15 minutes.

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Improve and maintain LSM in NAM

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In weather and climate models, land surface models (LSMs) represent the land surface interactions with the atmosphere. The surface-atmosphere interactions have important impacts on atmospheric boundary layer dynamics and weather and climate variability. To improve the NAM (North American Model) performance, work has been conducted in two fields related to its LSM to: (1) accurately present timely land surface physical characteristics in land surface models; and (2) improve the parameterizations which represent the land surface interactions with the atmosphere.

1. Improve land surface physical parameters used in the NAM system.

    1.1 Incorporate real time fire products derived from satellite remote sensing into the NAM system. Wild fires can cause significant and rapid changes in land surface physical characteristics. Two fire burned area products have been developed: 1 km resolution data twice a day which covers the area between 20°N and 70°N, and 12 km resolution data four times a day which covers the area from the equator to the North Pole. A parameterization for land surface physical characteristics of burning areas in land surface models was developed. In this scheme, the changes in vegetation cover, surface albedo and surface roughness length caused by wild fires are considered. The parameterization was tested with the several fire cases, and has been implemented in the parallel NAM system.

    1.2 Incorporate a high resolution lake surface temperature climatology into the NAM system. Thousands of lakes in N. America on the scale of 4km (NAM target) are not resolved by the SST analysis. The influence of previously unresolved lakes may be felt on this scale and can no longer just be "filled in". Lakes significantly affect the structure of the atmospheric boundary layer and therefore surface momentum, mass and heat fluxes. Lake storage of runoff regulates stream outflow by sustaining low flows and suppressing peak discharges. Lake-effect precipitation occurs on the downwind coastal area of many medium to large size temperate lakes in winter. A lake-effect on air temperature has been observed near a small lake (less than 200 km^2) (Takahashi and Itagaki, 1980). In order to consider lake effects in the NAM system, a 1 km resolution lake surface temperature climatology was created by using Flake and 30 year NARR climatology data. Then this lake surface temperature climatology was combined with real time SST, and has been implemented in the parallel NAM system.

1.3 Incorporate a real time green vegetation fraction product in the NAM system. Green vegetation fraction is a very important parameter for representing the land surface interactions with the atmosphere. Monthly mean values from five year data from 1985 to 1989 is currently used in the NAM. Obviously, this data cannot represent the current real situation. Therefore, a new satellite product at 1 km resolution is under development. This new product has a weekly value updated daily, and has been tested in the NAM.

2. Improve the parameterizations which represent the land surface interactions with the atmosphere.

2.1 Snow cover significantly affects the earth surface albedo which can lower the short wave radiation absorbed by the surface and increase the long wave radiation emitted by the surface. Snow cover can also cause insulating effects for vegetation and wildlife. In addition, snow cover can affect water supplies, transportation, cultural practices, travel, and recreation for millions of people. Therefore, accurately forecasting snowfall and surface snow accumulation is important. In the previous version of the NAM, surface snow accumulation was based on the binary assumption of snow or no-snow, and surface snow density was based on the lowest model level air temperature. Recently, the rime factor from microphysics was added to the NCEP NAM land surface model (Noah) to expand the range of possible snow densities. Higher rime factor values allow greater snow density, which in turn decreases the snow depth. Incorporating rime factor information into the snow density calculation in the land surface model is based on the hypothesis that snowfall and accumulation forecasts in regions with mixed-phase precipitation would be improved. This new scheme has been implemented in the parallel NAM system.

2.2 Improve the energy budget calculation over frozen soil in the NAM. The total soil moisture can be divided into three parts: solid (ice), liquid (water) and gas (water vapor). The gas part is ignored in most LSMs. In summer (nonfrozen soil), the liquid soil moisture is the same as total soil moisture. However, in winter (frozen soil), the liquid soil moisture is the difference between the total soil moisture and soil ice. In most LSMs, the calculation of latent heat is based on total soil moisture, not the liquid soil moisture. This causes an inconsistency between the latent heat calculation in summer and winter. This is also the case in the NAM. The NAM obviously over-forecasts 2 m dew point temperatures in winter seasons, so a modification was made in the calculation. The latent heat is now calculated based on the liquid soil moisture. This not only removes the inconsistency between summer and winter seasons but also improves NAM performance. This modification has been implemented in the parallel NAM system.