JP4.27 BRIDGING THE GAP BETWEEN WEATHER AND CLIMATE FORECASTING: RESEARCH PRIORITIES FOR INTRA-SEASONAL PREDICTION

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1. INTRODUCTION

On April 27, 2006, a small workshop was convened at the National Centers for Environmental Prediction (NCEP) of the National Weather Service (NWS), National Oceanic and Atmospheric Administration (NOAA), to discuss the links between numerical weather and climate forecasting. The workshop topic is a key area in broader discussions covering the connections between weather and climate. The workshop was convened by NOAA's THORPEX (THe Observing system Research and Predictability Experiment) program, a World Weather Research Program under the World Meteorological Organization, and was attended by a group of NOAA and external experts (Table 1) along with interested NCEP scientists. This report provides a brief summary of workshop discussions, along with a list of open questions that the participants identified as most important in bridging the gap between weather and climate forecasting.

2. BACKGROUND

The focus of NOAA's THORPEX program is to improve the skill and utility of forecasts over the 3-14 day lead-time range. No hard barrier, however, exists at day 14. Users require a forecast product suite that is seamless across different time ranges; and scientifically speaking, predicting weather at shorter ranges, or its various statistics at longer time ranges is based on the same laws of physics.

In the past, various methodologies have been used to predict the weather at different time ranges. Numerical prediction was first applied at short time ranges. With improved initialization and modeling techniques, the time range of useful NWP forecasts has been consistently expanding. The goal of THORPEX is, in fact, to accelerate this expansion from the current 7- to 10- day-limit out to 14 days by the introduction of a new forecast paradigm.

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Beyond the skilful range of NWP-based forecasting, an array of statistical methods has been traditionally used for longer range predictions. During the past decade, however, Numerical Climate Prediction (NCP) activities have gained ground. Like the models used in NWP, Atmospheric General Circulation Models (AGCM) are coupled with an ocean and land surface model, for seasonal climate prediction applications. Such NCP forecasts, after they are statistically corrected for systematic errors, are now competitive with the best statistical methods at predicting future climate conditions at and beyond 2 months lead-time.

3. SIMILARITIES AND DIFFERENCES IN NUMERICAL WEATHER AND CLIMATE FORECASTING

The different sub-systems of the coupled Atmosphere – Land surface – Ocean (ALO) system continually interact with each other and at any one time the conditions of a component depend not only on its own past but also that of the other sub-systems. Of the three main subsystems, the atmosphere, if uncoupled from the influence of the others, exhibits changes on the fastest time scales (or alternatively, has the least persistence or memory in a general sense). In contrast, the land surface (for up to a season) and especially the ocean subsystem (yearly and decadally) exhibit much slower time scales and more memory. Correspondingly, the atmosphere is often referred to as the fast and the ocean as the slow components of the coupled atmosphere – land surface – ocean system.

Forecasts of future atmospheric conditions, irrespective of whether they are for the shorter or longer (i.e., seasonal) lead-time ranges, attempt to predict the same reality; the weather (or some statistics of it) based on the same physical principles. In either case an initial value problem is solved: the analyzed state of the system is projected into the future. *An important observation is that at shorter lead times (say for less than 7 days), the future state of the atmosphere is sensitive mainly to the initial condition of the atmosphere, while at longer lead times (say* *beyond 90 days) is sensitive to the initial condition of the slow ocean (and possibly the intermediate land surface) component(s) only.*

The current practice of using two different approaches for NWP and NCP applications exploits the differences in sensitivity to initial conditions as a function of lead times that were described above. In the NWP application, the most accurate initial conditions are sought for the atmosphere while ignoring or oversimplifying changes in the slowly varying ocean conditions. In contrast, NCP applications focus on capturing the initial conditions of the slowly varying component of the coupled system (i.e., the ocean, land surface, and their atmospheric response) at the expense of a poorer initialization and short range forecasts of the rapidly varying components of the atmosphere.

4. OPPORTUNITIES FOR CONSOLIDATION

The current practice of using distinct approaches for weather and seasonal climate forecasting work reasonably well for the shorter (less than 7-day NWP) and longer (more than 90-day lead time NCP), respectively. However, evidence is accumulating to suggest that neither approach is tenable for the intermediate, 10-60 day, Intra-Seasonal (IS) lead-time forecast range. Arguably, atmospheric conditions in this intermediate lead time range, situated between the traditional weather and seasonal climate ranges, are *influenced by initial conditions of both the fast (atmosphere) and the slow and intermediate (ocean and land surface) components of the coupled system*. Recognizing the limits of both of the current approaches (NWP or NCP), one can seek further forecast improvements by exploiting initial value information from both the fast and slow components of the coupled atmosphere – land surface – ocean system.

The 10-60 day Intra-Seasonal time range is a natural meeting ground between scientists who have been primarily working on the shorter weather or the longer climate applications. The weather and climate forecast communities must work together to realize the full predictability within the IS lead-time range. Converging and eventually unifying weather and climate forecasting approaches that have been developed somewhat separately over the past decades is a difficult task not only from a scientific but also from a cultural point of view.

However, the enhanced collaboration and the ensuing closer ties between the two communities have great potential. Beyond improving IS forecasting, the collaboration may, at least in some situations, also have a positive effect on short 1-7 day forecasts (e.g., improved hurricane intensity forecasting due to more realistic ocean temperature forecasts) and on longer than 60-day forecasts (e.g., capturing the initiation or modulation of an ENSO cycle by an MJO). In addition, a unified approach may also contribute to the establishment of a seamless suite of probabilistic weather, water, and climate products, ranging from hours to seasons ahead.

The NOAA THORPEX program will engage in collaborative research with all interested partners in the weather and climate forecast communities to achieve these challenging goals. Continued separate development of the NWP and NCP approaches or the addition of yet a third new approach for IS forecasting may in the short term bring improved performance. The maintenance and continued development of two or three separate forecast systems, however, has its own costs. And to realize the full potential of weather and climate forecasting will eventually require the development of a more unified approach. How to balance in operational forecasting the goal of immediate skill improvements with the goal of laying the groundwork for longer-term advances when the available resources are limited is a challenge in itself.

The current dual approach and distinct techniques for weather and climate forecasting reflect a knowledge gap in our understanding of the coupled system and how it is captured in our numerical modeling systems. To accelerate improvements in the 10-60 day forecasting range, the NOAA THORPEX program promotes joint research by the weather and climate communities aimed at closing the existing knowledge gap. The questions below highlight the priority research areas for various aspects of IS forecasting for the next 8-10 years.

5. OPEN SCIENCE QUESTIONS

5.1 *Observing systems:*

What observations of the coupled atmosphere - land surface – ocean system are needed for capturing details of the initial conditions for successful predictions in the 10-60 days lead-time range?

Issues to be explored are which approaches are best to assess the status of the divergent component of the atmosphere (possibly through enhanced precipitation measurements in the tropics), the mixed layer of the ocean (by assessing the depth of the mixed layer), the soil moisture in the land surface system, the tropical-mid-latitude transport of energy (heat, moisture, potential vorticity, etc), and the annual mode. More accurate and comprehensive measurements of these processes, related to fluxes and various balance constraints between variables in the coupled system, can benefit both shorter and longer-range predictions. Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs) with coupled ALO models can help answer what new observations may be most relevant for achieving these goals.

5.2 *Data assimilation:*

What are the best approaches that avoid the well-known problem of initialization shock due to the typically strong model drift (spin-up) characteristic of most coupled modeling systems?

The answer to this complex question may well hold the key to successful IS prediction. Even minor inconsistencies between the energetics of the simulated and real sub-systems may lead to an unrealistic drift in the behavior of the full coupled modeling system, also called "initialization shock". Model related errors are clearly behind this behavior. Such model behavior can destroy or mask vital information contained in the initial condition of the coupled system, making forecasting attempts in the IS time range futile. Novel approaches for initializing imperfect models to capture the state of the real coupled system on or close to the slow manifold of the model attractor may fulfill the promise of successful IS forecasting. Can current data assimilation methods that initialize the sub-components be separately modified to resolve this problem? Or will new, possibly ensemble-based methods, specifically for initializing coupled systems have to be developed?

5.3 *Numerical model simulations:*

What are the most promising ways for improving the realism of coupled ALO models for IS prediction?

What phenomena critical to IS forecasting are or are not represented in numerical coupled ALO model simulations? Do NWP or NCP setups exhibit more realism? Can simplified strategies, such as the use of mixed-layer ocean models, play a role until the fundamental problems arising in more complex coupled models are adequately addressed? Will better physics or model coupling, or higher spatial resolution bring more benefits?

5.4 *Predictability:*

How does information contained in the initial condition of the fast (atmosphere) and slow (ocean) sub-components of the ALO system support predictability in the IS range?

A fundamental question behind IS predictability pertains to the level of detail in the fast components of the coupled system ("weather") that needs to be realistically represented in a forecast to successfully predict the statistics of weather (i.e., shifts in the mean of the system or changes in variability) at longer ranges. What is the level of "weather noise" that needs to be simulated and/or forecast in order to get the "climate signal" right? Since coupled model simulations do not yet exhibit key phenomena such as the Madden-Julian waves with convincing realism, vital information is lacking on the predictability of such features. What the level of predictability is for these features at different lead times, and what are the best ways of quantifying this predictability are open questions. Is the use of complex coupled numerical models for extended-range prediction always warranted, or can observationally based studies, including those using empirically tuned simple quasi-linear models, also play a role?

5.5 *Ensemble prediction:*

What is the best forecast system configuration to realize the maximum skill given the inherent limits in predictability of the coupled system and the limitations in its numerical modeling?

Through what procedures can the loss of skill due to imperfect initial conditions and numerical models be captured and realistically propagated throughout the IS forecast range? What are the relevant instabilities responsible for the loss of predictability and skill? Does the use of multiple models offer a solution to the problem of representing most model related errors in an ensemble, or is there a need for scientifically more innovative methods? What are the optimal trade-offs between model complexity and ensemble size? Depending on the results from predictability studies suggested above, may a cascading reduction of model resolution with increasing lead time be a sensible way of drastically reducing computational demand without sacrificing skill? Without answers to these and similar questions, the full potential of IS forecasting will not be realized.

5.6 *Post-processing:*

What are the best methods of a posteriori enhancing the value of numerical IS forecasts?

Bias correction and spatial and temporal "downscaling" that make the forecasts more relevant for users are important tasks. The limitations of and potential for using statistical methods vs. running higher resolution limited area model (LAM) simulations, forced by coarser resolution coupled ALO models, for a posteriori enhancements of the skill of IS forecasts are not well understood. Do LAM integrations offer the most efficient use of computing resources, as compared to higher resolution ALO forecasts followed by statistical corrections? What observational and/or numerical analysis data are required for statistical downscaling for regional or local applications? What is the value added as the size of hind-casts for statistical post-processing is increased? Would the cost of continually re-generating the hind-casts with the newest model version (as compared to freezing the coupled ALO model for a longer period of time and using a fixed set of hind-casts) be compensated for by the incremental improvements due to continual model upgrades? What is the added value to the users of communicating forecasts post-processed in a generic manner? Which user groups can benefit from additional, user specific statistical post-processing? It is important to recognize that such post-processing requires, beyond the actual forecast, communication of the full hind-cast dataset for proper user specific processing. Will periodic improvements to a forecast system associated with an appropriate hind-cast dataset pose a potential problem in a complex user environment due to inadequate user responses related to the updates?

5.7 *Socio-economic applications:*

How can the existing gap between providers and users of IS forecasts be narrowed?

Despite continued efforts especially related to seasonal and longer term forecasting, a major information barrier still exists between providers and users of weather/climate forecasts. A typical user needs information on multiple time scales from annual, seasonal, weekly, and daily down to hourly lead time ranges, often first using the more skilful shorter range forecasts. What issues need to be addressed for such a user, to make their applications seamless? Can forecasts that are generated for different lead time ranges by different forecast systems be made truly seamless? What is the optimal form of forecast, considering multiple potential applications? How can the needs of users with very different levels of sophistication be best served? Would the use of multiple formats (i.e., prepared generic products for basic users, to full ensemble information for advanced users wishing to exploit the full range of benefits from the nonlinear information present in an ensemble) be practical and beneficial? Which are the best ways of communicating forecast uncertainty? What tools are needed for a user to extract all relevant information from an ensemble of forecasts?

5.8 *Value of forecasts:*

What is the potential socio-economic value of improved forecast information at different lead time ranges?

This is an important question, especially for IS and longer lead time forecasts with marginal skill. Who are the existing and potential users of IS forecast information? Given limited resources, should socio-economic applications research focus on a few key user groups such as water management, or try to cover as broad a spectrum as possible? To realistically assess their true value, it is critical that all forecasts are also evaluated after post-processing, in a form as close as possible to their actual use. Information on socio-economic value can also serve as guidance regarding the choice of socially relevant summary verification statistics. And to maximize value to the users, decisions on upgrades to the system must be made based on the quality of post-processed forecasts accessible to the user community. This is just a partial list of open questions and critical issues, indicating the depth of inquiries needed in the socio-economic applications research area.

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Table 1. List of invited and other workshop participants