

The Future of Seasonal Prediction

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1. Introduction

Zebiak and Cane (1987) first demonstrated the feasibility of seasonal prediction of ENSO anomalies using an idealised dynamical model. Since then, fostered by the Tropical Ocean Global Atmosphere (TOGA) program, many dynamical models have been developed, ranging from simple shallow water models to fully coupled ocean/atmosphere general circulation models. Seasonal climate predictions are now made routinely at a number of operational meteorological centres around the world, using comprehensive coupled models of the atmosphere, oceans and land surface (e.g. Alves et al 2003; Stockdale et al. 1998; Mason et al. 1999; Kanamitsu et al 2003).

The socio-economic benefit from accurate seasonal forecasts now justifies the support for a range activities from basic model development to applications studies. Coupled model seasonal forecasts are now becoming more competitive with more traditional statistical based forecasts. Coupled models offer the long term potential to provide seasonal predictions in an era of a possible changing climate, whereas, by definition, statistical approaches cannot be used if climate relationships are changing. However, many problems still exist with coupled models, most suffer significant climate drift and most have trouble adequately simulating some of the details of some fundamental modes of variability.

This paper reviews the current trends and issues associated with coupled model seasonal prediction. It also discusses the future directions for seasonal prediction.

2. Current issues and trends

(a) Coupled Models

One of the basic components in a dynamical seasonal prediction system is a coupled model, constituting of atmospheric, oceanic and land-surface model components. Most coupled models are formed from existing models either used for operational weather prediction or for climate simulations.

ENSO is the dominant mode of inter-annual variability in the tropics, and it is the most important source of predictability on inter-annual time scales. Other sources of potential predictability come from, for example, land surface conditions, sea ice conditions and other modes of variability (e.g. Southern Annular Mode). A primary focus in seasonal prediction has been the prediction of ENSO and its impacts, for example, ENSOs impact on regional rainfall.

Coupled models have been plagued by climate drift, most models have drift in SST comparable to the signal that they are trying to predict, typically 1-2°C. The most common approach is to let the models drift with forecast time and then remove the drift *a posteriori*, e.g. by referencing anomalies to the model climate (e.g. BMRC, ECMWF, UKMO). There is the hope that coupled models will continue to improve and that the drift will become less of an issue. Other groups have tried to deal with this drift by only exchanging anomalies between the ocean and atmosphere and constraining the model mean state (e.g. NCEP, COLA).

Perhaps of more concern is the models ability to simulate the major modes of variability. While all coupled models when run in free mode can generate ENSOs, the detailed characteristics of those ENSOs have deficiencies. Typical problems are: ENSOs are too frequent, too strong or

too weak, warming extends to be far west, too short lived, too long lived, wrong phase with respect to seasonal cycle, etc. Coupled model development is also being hampered by our lack of understanding of the underlying mechanisms responsible for ENSO. Traditional ENSO theories are too simple to completely explain ENSO. One of the key questions is how predictable is ENSO, for example, what role does atmospheric noise play during the onset of ENSO. There is much debate in the community about the role of the Madden/Julian Oscillation (MJO) during the onset of ENSO. Until recently most coupled models were not even able to generate MJOs.

(b) Initialization

Coupled model seasonal prediction is essentially an initial value problem where skill comes from information contained in the initial states of the ocean, atmosphere and land surface. Most important is the information contained in the ocean initial conditions. Alves et al (2003) showed that ocean subsurface data assimilation, in general, overcame errors in ocean model simulation associated with model or forcing errors and hence led to better seasonal forecasts of ENSO. Many centres employ ocean data assimilation systems to provide ocean initial conditions. Over the past few years schemes based on optimum interpolation or 3-D Variational assimilation have been developed. These commonly assimilate sub-surface ocean observations. A small subset also assimilate altimeter data.

Observations of salinity and currents have been too sparse to even attempt their assimilation. With the advent of Argo, assimilation of salinity data is now becoming feasible. Some groups have attempted to adjust salinity and/or currents to maintain some kind of dynamical balance or physical constraint e.g. geostrophic balance, preservation of T/S characteristics.

The equatorial Pacific is sensitive to dynamical imbalances between the zonal equatorial pressure gradient and wind forcing. These imbalances can project onto Kelvin wave modes on the equator and these can propagate eastwards quite rapidly. Maintaining dynamical balance near the equator is therefore important. More sophisticated 4-dimensional approaches, such as 4D-Var and Ensemble Kalman Filters are also being developed. These provide the potential for more dynamically balanced initial conditions, and in the latter case, time evolving flow-dependent error covariance statistics.

The role of land and atmospheric initial conditions, while not as important as ocean initial conditions, may also provide significant predictability. Several centres use analysed atmospheric states for their real-time seasonal forecasts (e.g. BMRC, ECMWF, NCEP, JMA). However, the importance of atmospheric initial conditions has not yet been demonstrated. The lack of land surface observations make it difficult to produce analysis of soil conditions. A typical approach is integrate land surface models with estimates of observed precipitation.

(d) Skill assessment

The need for common verification methods has been recognised by the WMO Commission for Basic Systems and an internationally accepted standardized verification system is being prepared, following the experience from numerical weather prediction. Basic skill measures like anomaly correlation and root-mean-square errors, as well as probabilistic based skill measures (e.g. reliability diagrams, relative operating characteristic score, Brier score, ranked probability skill score and potential economic value curves) have been utilised.

A fundamental problem with assessing the skill of seasonal predictions is the relatively short time period over which hind-casts can be performed. For example, consider the prediction of ENSO. In order to obtain reliable skill measures one would need to run hind-casts covering a few tens of independent ENSO events, i.e. forecasts over a period of at least 100 years. However, seasonal prediction systems dependent on ocean data assimilation and therefore on the ocean observing network. Prior to the instalment of the TOGA-TAO array (early 1990's) only XBT data

from research vessels or from the Ship-Of-Opportunity Program existed. These data are very sparse and mainly concentrated along shipping routes. Furthermore, it is only with the introduction of Argo in the late 1990s/early 2000s that assimilation of salinity data has become feasible.

Clearly the quality of ocean initial conditions in the Argo period, 2000s, is likely to be better than say the 1990s. And likewise because of the TOGA-TAO array, initial conditions in the 1990's are likely to be better than previous periods. Before the 1980's very little ocean sub-surface data were available. This leaves at most a period of around 25 years over which model skill can be assessed.

(e) Ensemble Forecasting

The coupled system contains an inherently internal chaotic component. This means that forecasts need to be probabilistic rather than deterministic. Ensemble forecasts are used to generate forecast probabilities. Methods for generating forecast ensembles are in general simple compared to those used in NWP (e.g. singular vectors). That said it is not clear that methods such as singular vectors that maximise error growth in a relative short period at the start of the forecast are appropriate for seasonal prediction. Maximum error growth may occur later in the forecast, e.g. due to an intra-seasonal event.

A rapidly growing trend is the use of multi-model ensembles. The ability of multi-model forecasts of seasonal climate risk over single model ensembles has been addressed by the Prediction of Climate Variations on Seasonal to Interannual Timescales (PROVOST) project funded by the European Union and also a sister project, Dynamical Seasonal Prediction (DSP) undertaken in USA. Development of a European Multimodel Ensemble System for Seasonal to Interannual Prediction project (DEMETER: Palmer et al 2004), funded by the European Union, was a successor to PROVOST and looked at the benefit of multi-model ensembles of coupled models. Its aim was to advance the concept of multi-model ensemble prediction by installing seven state-of-the-art global coupled ocean atmosphere models on a single computer. Korea is setting up a regional centre for multi-model ensemble seasonal prediction (APCN), funded by APEC. APCN use the technique developed by Krishnamurti et al (1999) where each model is weighted by their respective skill over a hindcast period. The benefits of a multi-model ensemble approach are believed to arise because the model systematic error is averaged out when taking the mean of forecasts from models with independent errors.

A recent development is the generation of model ensembles by perturbing the atmospheric model physics during the model integration (stochastic physics). The best method to generate model ensembles remains an open question. For a given ensemble generation method there is also uncertainty as to what exactly the model ensemble represents and whether it can be interpreted as a forecast probability density function.

(f) Regional predictions

The ultimate goal of coupled predictions is the prediction of local variables, such as precipitation. Rainfall remains a difficult variable to predict. Some centres produce rainfall products directly from coupled model output (tier-1 system, e.g. ECMWF) while others use the coupled model forecast SST anomalies to drive atmosphere only integrations (tier-2 system, e.g. NCEP). Tier-2 systems have the advantage that the atmospheric forecasts use SST anomalies superimposed on top of a true mean state and therefore do not suffer from coupled model SST drift. On the other hand, Tier-2 systems assume that rainfall variability is driven by both remote and local SST, so that purely coupled processes cannot be represented. There is no agreement over which method is better.

There is demand for higher resolution forecasts than those available from global models. Two options exist for adding increased resolution: (i) dynamical downscaling and (ii) statistical downscaling. Both methods are being explored at present.

3. The future

It is clear that there are still significant deficiencies in the ability of coupled models to simulate the mean climate and climate variability. Even the most fundamental modes of variability such as ENSO and the MJO are not adequately simulated by coupled models. This is hampered by our lack of understanding of these processes, in part due to the lack of a long observational record. However, coupled models can help understand real climate variability. Climate model development needs to proceed hand-in-hand with research using coupled models to understand climate variability.

Data assimilation is a critical component of a seasonal prediction system. Advanced data assimilation techniques, such as 4D-VAR and Ensemble Kalman Filters, need to be developed to best exploit the limited set of observational data in a manner consistent with the model dynamics. These approaches are complex and very computationally demanding. Processes such as ENSO are coupled atmosphere phenomena and so initialisation techniques may need to be developed to assimilated data directly into the coupled model to enable consistency between the atmospheric and oceanic initial conditions.

The applications of seasonal prediction are growing rapidly. Ensemble predictions are critical for probabilistic forecasts. A better understanding of the processes that lead to uncertainty is required before the best methods for generating model ensembles can be determined. Multi-model ensembles are growing rapidly in popularity, however it is not clear whether the apparent increased skill from multi-model ensembles is simply a reflection of the relatively low skill of current coupled models. Different approaches for creating model ensembles need to be explored.

It must be recognised that coupled model seasonal prediction is still in its infancy. Improvement of coupled models and data assimilation systems must progress hand-in-hand with increased utilisation of coupled model products, either directly or through downscaling, by the user and applications community.

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