POAMA: Bureau of Meteorology Coupled Model Seasonal Forecast System

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Abstract

POAMA (Predictive Ocean Atmosphere Model for Australia) is a coupled ocean/atmosphere general circulation model seasonal forecast system developed jointly by the Bureau of Meteorology Research Centre (BMRC), Melbourne and CSIRO Marine Research (CMR), Hobart. It is based on the latest version of BMRC's unified climate/weather atmosphere model (BAM) and the Australian Community Ocean Model (ACOM2). The ocean model is initialised with oceanic fields produced by an ocean data assimilation scheme developed at BMRC. It uses optimum interpolation to combine ocean sub–surface observations with a model background field. The atmosphere model is initialised with fields from Bureau of Meteorology operational weather analyses.

The POAMA system is run in real-time by the operational section of the Bureau of Meteorology. Every day an eight-month forecast is produced. This uses initial conditions from the data assimilation systems, which are also run in real-time using observations from the Global Telecommunications System. This means that each forecast is initialised with the very latest oceanic and atmospheric states.

The initial focus of POAMA is the prediction of El Nino. Results are presented based on hind-casts produced for the 1980s and 1990s. These show that the skill of POAMA forecasts is at least as good as other international models. Central Pacific SST anomaly correlations reach over 0.9 at one and two months lead time and reach over 0.8 at six months lead time. One of the notable features of the model is that it is able to represent intra-seasonal variability characteristic of the Madden-Julian Oscillation.

1. Introduction

POAMA (Predictive Ocean Atmosphere Model for Australia) is a seasonal to inter-annual climate prediction system based on coupled ocean and atmosphere general circulation models. It was developed in a joint project involving the Bureau of Meteorology Research Centre (BMRC) and CSIRO Marine Research (CMR), with some funding coming from the Climate Variability in Agriculture Program (CVAP) of Land and Water Australia.

The POAMA model is a significant improvement over earlier versions of coupled models for seasonal forecasting at BMRC (Wang et al 2001, Kleeman et al 1995, Zhong et al 2001). It uses the latest state of the art ocean and atmosphere general circulation models. In addition, real time oceanic and atmospheric initial states are used to initialised the coupled model. These are provided by an ocean data assimilation system that is run in real time as part of the POAMA system and by the Bureau of Meteorology operational weather analyses system (GASP).

The structure of this paper is as follows. Section 2 describes the different components of the POAMA seasonal forecast system. Section 3 describes the operational set up and shows some sample results. Section 3 describes a set of hind-casts and presents some results from these hind-casts, in particular, an assessment of model skill. Finally, in section 5 is a summary and a list of priorities/issues for future research.

2. Components of the POAMA system

2.1. Atmosphere Model

The atmospheric component of the coupled model used in POAMA is the Bureau of Meteorology unified atmospheric model (BAM). As well as climate prediction it is also used for decadal and climate change research and operationally for daily weather prediction. The latest version (BAM 3.0d) was used in the forecasts described in this report. It has a horizontal spectral resolution of T47 and has 17 vertical levels. The performance of this model forced with observed SST is described by Zhong et al (2002).

For the operational version of POAMA (version 1.0) described in this paper a modified convection closure was used based on CAPE closure rather, than moisture convergence closure used in the standard version of BAM. This feature was found to better simulate intra-seasonal variability, such as the Madden-Julian Oscillation.

2.2. Ocean Model

The ocean model component is the Australian Community Ocean Model version 2 (ACOM2). It was developed by CMR and was based on the GFDL MOM2 code. Improvements produced by CMR include: a mixing scheme and penetration of solar radiation into the upper ocean appropriate for tropical oceans, tidal mixing in areas near Australia where this process influences SST and representation of islands and straits in the Indonesian region to give realistic representation of the Pacific to Indian Ocean Indonesian throughflow. The grid spacing is 2 degrees in the zonal direction. The meridianal spacing is 0.5° within 8° of the equator, increasing gradually to 1.5° near the poles. There are 196 grid points from south to north and 182 grid points from west to east. There are 25 levels in the vertical, with 12 in the top 185 metres. The maximum depth is 5,000 metres. The level thicknesses range from 15 metres near the surface to almost 1,000 metres near the bottom. Technical details of ACOM2 are given in CMR Reports 227 and 240 (Schiller et al., 1997; Schiller et al. 2002).

2.3. Coupler

The ocean and atmosphere models are coupled using the Ocean Atmosphere Sea Ice Soil (OASIS) coupling software (developed by CERFACS, France, Therray and Thual, 1995). This coupler gives high flexibility for changing model components in the future as models further improve.

2.4. Ocean data assimilation

The ocean data assimilation scheme is based on an optimum interpolation (OI) technique described by Smith et al (1991). Only temperature observations are assimilated and only measurements in the top 500 are used. The OI scheme is used to correct the model background field every 3 days using a 3 day observation window, one and a half days either side of the assimilation time. Current corrections are calculated by applying the geostrophic relation to the temperature corrections, similar to the method described by Burgers *et al.* (2002), see Alves (2001) for a discussion.

The ocean model is used to integrate the ocean state between analysis cycles. The background field for one analysis is a three day integration from the previous analysis. During the ocean model integration it is forced with six hourly surface forcing fields. Wind stress zonal and merideonal components are used to force the ocean model momentum equations and to provide an estimate of the wind induced turbulent mixing for the vertical mixing scheme. The net heat flux is used to modify the top model layer temperature. Penetration of the solar radiation is taken into account using the input net solar radiation field. During the data assimilation cycle SST observations are not used. Instead the model is strongly relaxed to an observed SST analysis with an e-folding time scale of 3 days.

2.5. Atmospheric initial conditions

For the real time forecasts the atmospheric component is initialised with NWP analysis from the Bureau of Meteorology's operational NWP system (GASP). This means that the seasonal forecast model knows about the latest intra-seasonal state of the tropical atmosphere.

For the hind-casts GASP analyses were not available. An attempt was made to use NCEP re-analysis but these were found to lead dynamic instability in the east Pacific. This is being investigated further. The hind-casts described in this report used the atmospheric state from a long integration of the atmosphere model used in POAMA forced at the surface with observed weekly Reynolds SSTs.

3. The real-time system

The POAMA system has been run every day in real-time by the Bureau of Meteorology operations branch since 1st October 2002. This real-time system consists of two suites: main ocean analysis cycle and forecast cycle.

3.1. Main analysis cycle

The main analysis cycle aims to use as many observations as possible to provide an estimate of the ocean state in near-real time. To allow as many observations as possible to be used the system is run approximately 10 days behind real-time. Each day the ocean state is integrated forward one day using the ocean model. The ocean model is forced with six-hourly fields from the GASP NWP system.

Every three days observations are assimilated into the ocean model. All available sub-surface temperature observations from the Global Telecommunications System (GTS) are used.

Surface temperature observations are no assimilated. Instead, the ocean model surface temperature is relaxed to the SST analysis field used in the GASP system with an e-folding time scale of 3 days.

3.2. Catch-up analysis and forecast cycles

A significant number of ocean observations are received over the GTS within a day of real-time, for example, observations from the TRITON/TAO array. This means that more is know about the latest state of the ocean than the information that went to produce the main analysis, since this analysis is produced 10 days behind real-time. For this reason a catch up analysis is produced every day as part of the forecast cycle. The ocean model is integrated forward from the main analyses to the present and an assimilation is performed every three days as in the main analyses. The catch-up analysis does not have any impact on the main analyses.

Every day a 9 month coupled model forecast is produced using the very latest ocean state from the catch-up analysis and the latest atmospheric state from the GASP analysis.

3.3. Post-processing of model output

The coupled model experiences some coupled model drift during the forecast, a feature characteristic of most climate models. This is taken into account in the products produced from the forecasts by referencing all anomalies relative to the climatology of the model forecasts. A forecast anomaly is calculated as:

$$a_{im}(t) = f_{im}(t) - \sum_{y} f_{ym}(t)$$

where $a_{im}(t)$ is the anomaly corresponding to the forecast value $f_{im}(t)$ starting in month m and year i and as a function of lead time t. y represents the hind-cast years used to calculate the climatology (1987-2001). Thus, the climatology used to calculate each anomaly depends both on start time of the year of each forecast and also on forecast lead time. This is similar to the method of Stockdale (1997). The reference climatology period used is 1987-2001.

3.4. Sample products

The initial focus of the POAMA system is the prediction of the ENSO phenomenon. Initially products will focus on the structure of the upper ocean in the tropics. Research is underway to investigate how best to produce forecasts of local variables, for example, precipitation. Such products will be made available in due time.

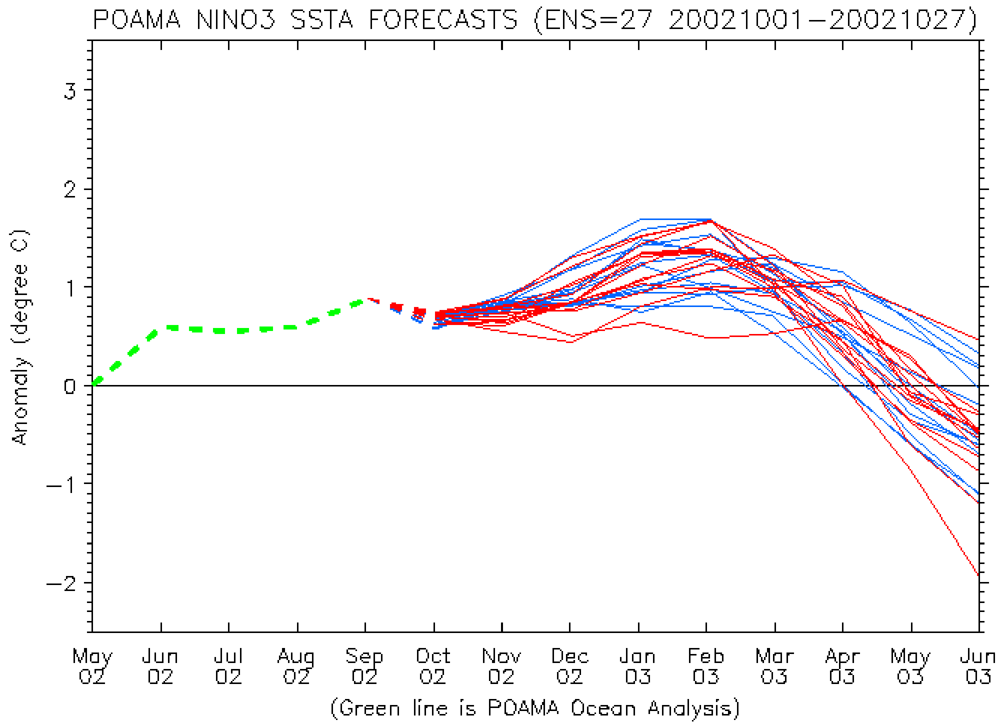

Figure 1: Nino 3 anomaly plumes for all forecasts starting between 1st October and 27th October 2002 (red – last fifteen forecasts, blue –previous fifteen forecasts).

The main product for ENSO is the forecast plume of NINO3 anomalies. The latest forecast is shown in figure 1. It shows all forecasts available since 1st October 2002. The model shows the maintenance of weak El Nino conditions in the next 3-5 months. In northern hemisphere spring of 2003 all members show cooling and the decay of the El Nino conditions. Also, there is considerable increase in ensemble spread with some members going to La Nina conditions while others going into neutral conditions. Many other plots are available on the POAMA web site (http://www.bom.gov.au/bmrc/ocean/JAFOOS/POAMA). These include horizontal plots of SST anomalies for each lead time as well as equator/time plots with daily resolution of SST, 20C isotherm depth and surface zonal wind anomalies. These are produced as means of monthly ensembles, mean of last 30 forecasts and also individual forecasts. These plots are updated each day as each model forecast is produced.

4. Coupled model hind-casts and system skill

4.1. Hind-cast

Testing of the coupled model used the so-called "hindcast-test". This method initializes a prediction on, for example, 1 March 1987 using only information available before that date. The test of the model is then based on comparing the prediction to information collected during the remainder of 1987. Hindcast tests initialized at many past dates can be combined into a statistic to evaluate the accuracy of forecasts, and provide a measure of "skill" of the model.

A set of 60 forecasts, one per season (1^{st} of March, June, September and December) for the years 1987 to 2001, have been used to assess the performance of the model. Ocean initial conditions were taken from an ocean data assimilation that was carried out from 1982 to 2001 using the same assimilation system as was used for the operational version. GASP atmospheric initial conditions were not available. Instead the atmospheric state taken from the appropriate date during an integration of the atmosphere model forced with observed weekly Reynolds SST. Land surface conditions where also taken from this forced run of the atmosphere model.

All anomaly products are measured relative to the model anomaly during this hind-cast period. They depend on initial time of year and lead time as discussed in the previous section for the operational products.

4.2. Forecast skill

One measure of forecast skill is the anomaly correlation coefficient for NINO 3 SST anomalies. This is shown in figure 2 for both model and persistence, as a function of lead time. The plot shows that the model beats persistence at all lead times, even at month one (i.e. the mean for the first month of the forecast).

Horizontal patterns of anomaly correlation skill are shown in figure 3 for lead times of two, four and six months. At all lead times the peak in skill is concentrated in the central and eastern Pacific, associated with the El Nino Phenomenon. At two months lead time the anomaly correlation reaches over 0.9 in the central Pacific. At six months lead time it reaches up to 0.8 in the central Pacific south of the equator. These skill measures are at least comparable to other international models.

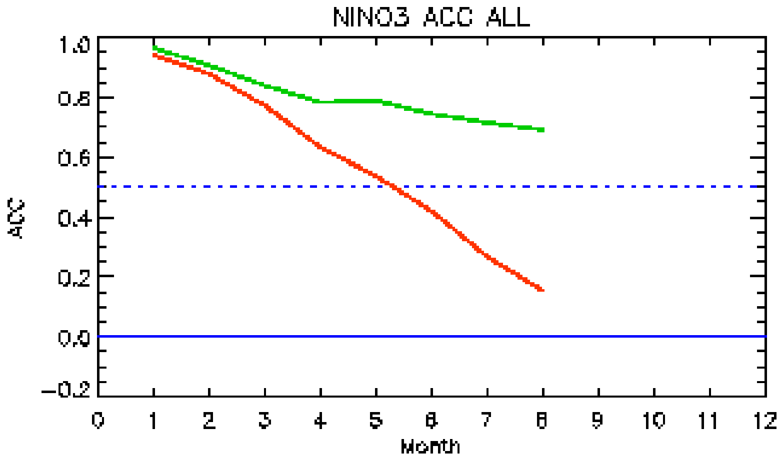

Figure 2: Nino 3 anomaly correlation as a function of lead time for 60 forecasts starting one person during the period 1987-2001. Red – persistence of initial SST anomalies, Green – POAMA coupled model.

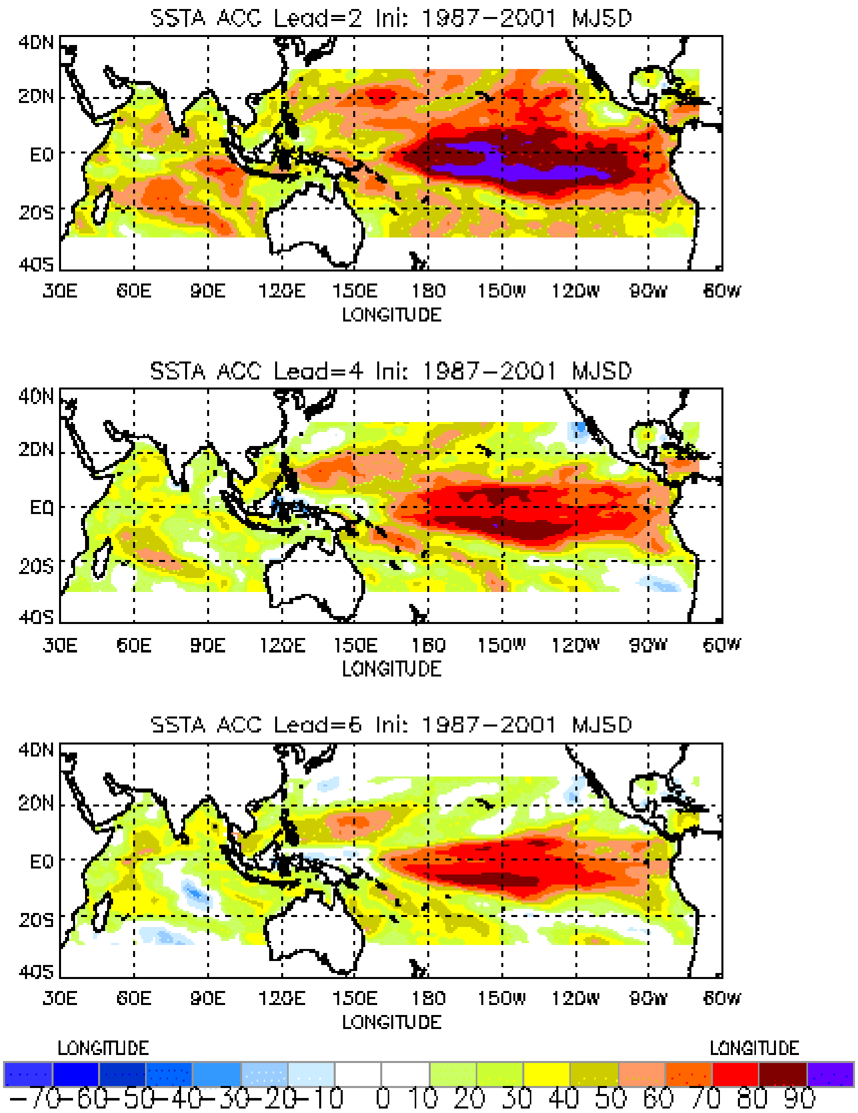

Figure 3: Spacial distribution of anomaly correlation of SST anomaly (x100). Top- 2 month lead time, middle – 4 month lead time and bottom – 6 month lead time.

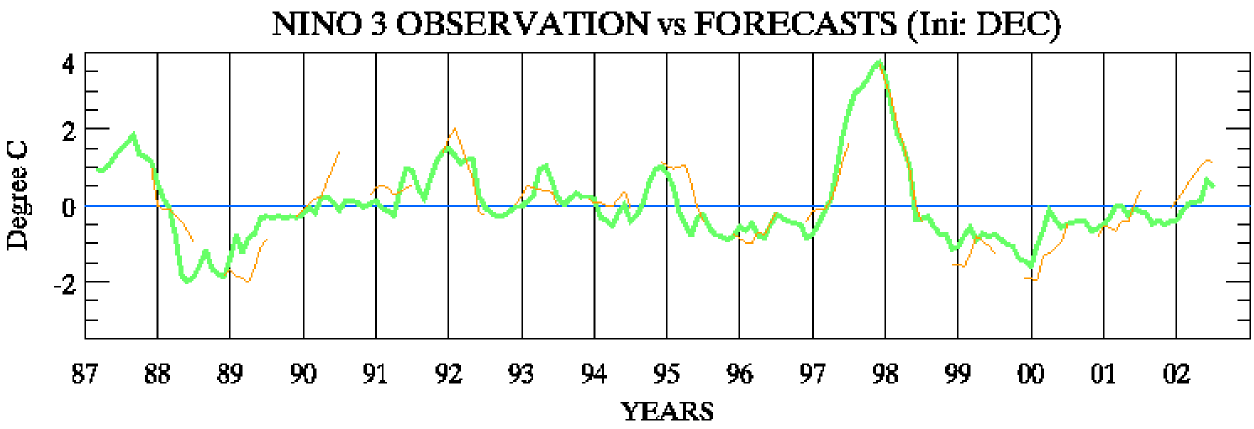

Figure 4: Nino 3 SST anomaly curves. Green – observed, orange – model forecasts starting on the 1st December each year.

All the individual forecasts of Nino 3 SST anomaly starting on 1st December of each year are shown in figure 4. Notably good forecast are those of the onset (starting 1st December 1996) and the decay (starting 1st December 1997) of the 1997/8 El Nino. Forecasts for other years are also reasonably close to observations, the only except is the later part of the forecast starting 1st December 1989. However, some caution is necessary in interpreting these plots since only one ensemble member has been run. Ideally a large ensemble would be produced, this will be done as computing resources allow.

4.3. Intra-seasonal variability

One of the concerns regarding the statistical significance of skill scores discussed in the previous section is the relatively short hind-cast period of 15 years. This only covers two major El Nino/La Nina events and a few minor events. This is a serious constraint on the estimation of dynamical coupled model skill. Extending the forecast period further into the past has problems since the ocean observing network is significantly degraded, the TOGA-TAO network was built up over the late 80's and early 90's. Several people have shown that the assimilation of sub-surface ocean observations has a significant impact on forecast skill (Alves et al 2002, Ji et al 1996, Wang et al 2001).

One method of assessing the quality of the forecast system is to find ways of analysing how well the model represents the physical processes of relevance to seasonal prediction. For example, how well can the model represent intra-seasonal variability, such as the Madden-Julian Oscillation (MJO). There is growing evidence of the importance of the MJO for triggering the development of El Nino. Yet atmosphere models generally have poor simulations of the MJO, see for example Hendon (2000).

Figure 5 shows wave number /frequency spectra of surface zonal wind variability along the equator using daily data from both observations and two sets of forecasts (Marshall et al, 2002a,b). Figure 5a shows the observed spectra. There is a clear peak at wave numbers 1 and 2 and period of 30-90 days characteristic of the MJO. Figure 2b. shows the corresponding spectra from a set of forecasts using an earlier version of the atmosphere model which used moisture convergence criteria for its convection closure. It shows no clear peak on the MJO space and time scales. Furthermore, the forecasts from this model shows spurious westward propagation at intra-seasonal scales (this is a common feature of atmosphere models).

In figure 5c are the spectra from forecasts discussed in this paper produced using the latest version of the atmosphere model. This version used CAPE criteria, with a threshold to delay the onset of convection, in the closure for its convection scheme. The spectra are significantly different from that using the earlier version of the atmosphere model. There is a clear peak for eastward propagating wave numbers 1 and 2. The period ranges from 30 to 110 days. This model exhibits variability characteristic of the MJO, although slightly smaller amplitude and slightly longer time scales. Also the spurious westward propagation is no longer present.

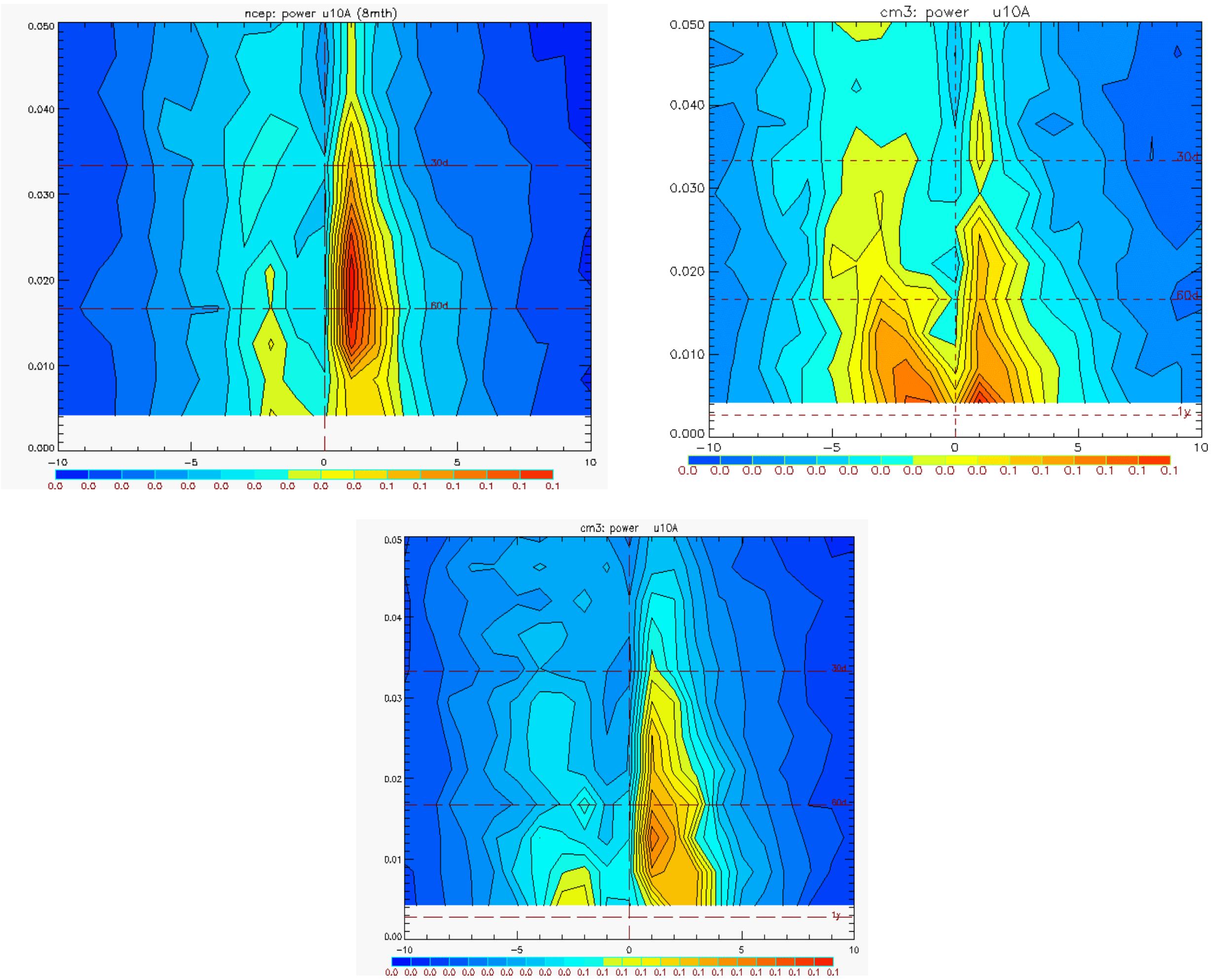

Figure 5: Frequency/wavenumber spectra of surface zonal wind along the equator using daily data. Top left: observed from NCEP re-analysis, top right: 60 coupled model forecasts using older version of atmosphere model with moisture convergence convection closure, bottom: 60 coupled model forecasts using operational version of coupled model which used CAPE criterion for its convection closure.

5. Summary/Discussion

The new Bureau of Meteorology seasonal forecast system called POAMA is now run in real-time and produces an eight month forecast every day using the very latest ocean and atmosphere initial conditions. The ocean state is taken from an ocean analyses system also running in real time, based on optimum interpolation and using all sub-surface ocean observations received over the GTS. Atmospheric initial conditions are taken from the Bureau of Meteorology operational weather prediction system (GASP).

The forecast skill in terms of NINO 3 SST anomaly correlation based on 15 years of hind-casts is very promising. The model beats persistence at all lead times. In the central Pacific SST anomaly correlation reaches over 0.9 in the first one and two months and over 0.8 after six months.

One of the notable features of the model is its ability to represent intra-seasonal variability characteristic of the MJO. This is one of the measures of the ability of the model to represent the physical mechanisms relevant to seasonal prediction; many models have difficulty simulating realistic intra-seasonal variability.

While this first version of the POAMA system shows that the model is performing at least comparable to other international models several issues still remain. These form the core of dynamical coupled model seasonal forecasting research at BMRC which is aimed towards understanding climate variability on intra-seasonal to inter-annual time scales and towards improving the POAMA seasonal forecasting system. A summary of the main areas of future research and/or scientific issues follows:

a) Model systematic error: the model experiences systematic drift, improving both the ocean and atmospheric components remains a priority for model development at BMRC and CMR

b) Modes of variability: long integrations of the coupled model are underway to understand the model's modes of variability e.g. its mechanisms for ENSO variability and intra-seasonal variability

c) Ocean data assimilation: present data assimilation systems are based on univariate single time approaches. More advanced techniques which allow corrections to salinity and the use of time dependent error covariances are being investigated based on the Ensemble Kalman Filter technique.

d) Intra-seasonal variability and ENSO: understanding this connection is a key priority for ENSO forecasting and how best to produce ENSO forecasts, for example, how to best generate model ensembles to sample forecast uncertainty.

e) Climate variables: this initial version of POAMA focuses on predicting SST anomalies associated with the ENSO phenomenon. In future we will investigate the ability of the coupled model to predict local variables such as precipitation. This includes the use of dynamical or statistical downscaling techniques.

f) Atmospheric initial conditions: what role do these play if any. If intra-seasonal variability is important then accurately initialising this variability may provide up to an extra months increase in skill at times where there is strong intra-seasonal variability.

g) Model skill: assessment of model skill remains a key issue because the number of years that we can run hind-casts using a system similar to the present is very limited, particularly so because of changes to the ocean observing system. Different methods to assess the quality of seasonal forecast systems other than simple skill measures will have to be explored.

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