Seasonal Forecasting at ECMWF

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Abstract

An overview is given of the use of coupled ocean-atmosphere models at ECMWF for seasonal and monthly forecasting. Key issues addressed include the impact of model drift on the forecasts; the sources of uncertainty in the ocean initial conditions, and our representation of these in an ensemble forecast; the possibility of multi-model ensemble techniques; and the importance of high quality observed SST fields. The evolution towards a suite of coupled ocean atmosphere forecasts covering different timescales is also noted.

1. Introduction

ECMWF has been involved in seasonal forecasting for a number of years. The approach taken is to use comprehensive numerical models of the coupled ocean-atmosphere system. Although empirical methods can also be used for preparing seasonal forecasts, the numerical approach is in keeping with ECMWF's traditional strengths, and is expected eventually to be the dominant method of forecasting on these timescales. The ocean is a key component in seasonal forecasting: the evolution of the upper ocean is partly predictable, and has an influence on the atmospheric circulation via the sea surface temperature (SST). El Nino related SST variability is the most important source of predictability for the atmosphere on seasonal timescales, and hence the ability of models to handle El Nino is vital. But the influence of SST anomalies on the atmosphere is widespread, and a fully successful seasonal forecasting model needs to be globally competent.

The coupled ocean atmosphere model used at ECMWF for seasonal forecasting consists of a T_L95 40 level version of the IFS coupled to a global ocean model. The IFS version is Cy23r4, which was used for operational medium range weather forecasting in 2001, and includes an interactive ocean surface wave model. The ocean model is called HOPE, and is run with a mid-latitude resolution of 1º by 1º, and a meridional resolution of 0.3º near to the equator - this allows better resolution of equatorial dynamical processes important for El Nino variability. Vertical resolution is 10m near to the surface, with 29 levels in total. The ocean initial conditions are taken from an assimilation system based on an Optimal Interpolation analysis of temperature, but with multivariate adjustments to the salinity and velocity fields. In forecast mode, the models are coupled once every 24 hours using accumulated fluxes; this means there is no diurnal cycle in the ocean. The basic strategy at ECMWF is simply to initialize the model components as accurately as possible, couple them, and integrate forward in time. The inevitable model drift is removed during post-processing.

2. Forecasts in the presence of model drift

To remove the model drift or systematic error from a forecast, we must estimate the drift from the past history of the model performance. Since we have a limited set of past cases, we simply estimate the mean bias as a function of calendar start date and forecast lead time. If the system were completely linear, then removing the mean bias would be an adequate way to deal with model biases. Of course, we do not really believe the system is completely linear, although previous work (eg Stockdale, 1997) has shown that mean bias removal is a viable way of producing model forecasts.

An interesting case to study is the 1997 El Nino, where observed anomalies were exceptionally large, and the possible impact of non-linear effects might be expected to be large. Because our present forecasting system underestimates the amplitude of this event (more so than the real-time forecast system which was used at the time), several experiments have been made to investigate aspects of the model performance at this time. In one, a large heat flux correction was made to cool the eastern Pacific SSTs. This correction is active in a full set of integrations made for different years, and makes the mean state of the ocean substantially cooler (see Figure 1a). We can then compare the forecast anomalies from the experiments with the cooling to an equivalent set without (Figure 1b). In a linear system, applying the same cooling to both the actual forecast and the climate of the model will result in anomalies that are unchanged. In a non-linear system, a possible scenario is that with a mean state which is already several degrees too warm, it will not be possible to develop anomalies of 4 deg C above this, because of physical processes which limit the absolute SST to some saturation value. In this case, the forecast anomalies might be very different in the presence of a correction to the mean state. As Figure 1b demonstrates, although there are slightly higher anomalies in the case with the colder mean state, the effect is very small, and the system is thus close to linear even in this extreme case. For a full discussion of these results, see Anderson et al, 2003.

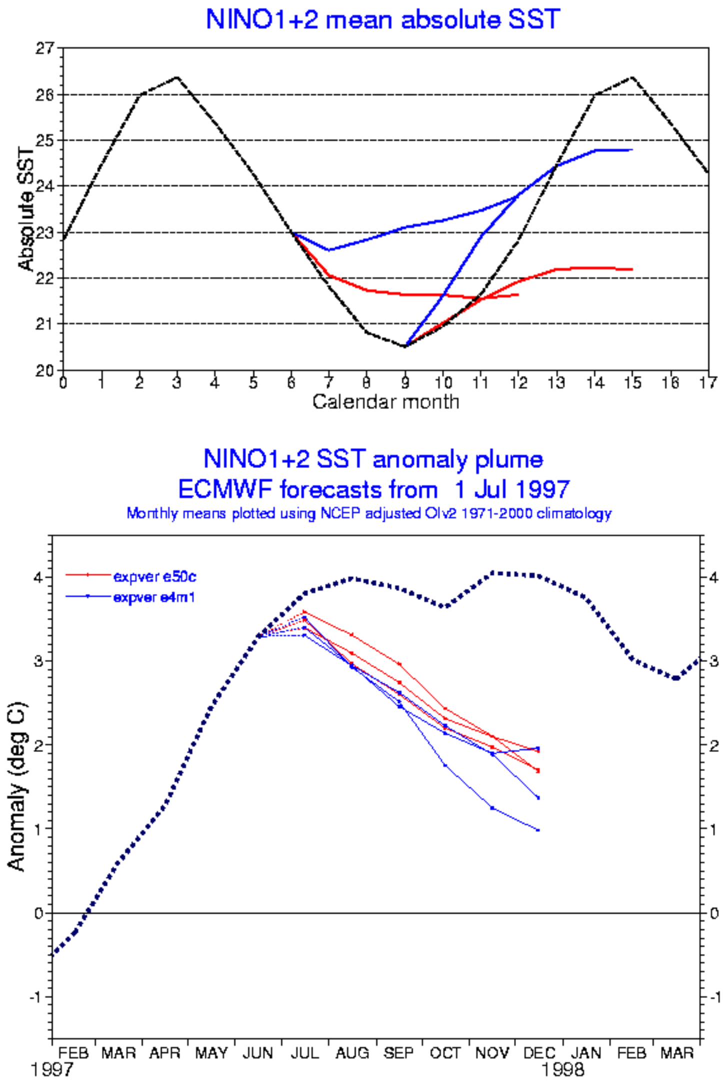


Figure 1(a) The climatological evolution of model SST in the Nino 1+2 area (0-10S, 90-80W) for the default version of the model (blue), and a version using a heat flux adjustment (red). Black dashed lines show the observed climatology. (b) The corresponding model predicted anomalies for forecasts starting on the 1 July 1997. Note that the substantial improvement in the mean state SST of the flux adjusted experiment results in very little change in the forecast of the anomalies.

Note that this experiment demonstrates a robust linearity against certain sorts of changes in the mean state (eg SST drift driven by heat fluxes). Other sorts of error (for example SST drift driven by incorrect mean winds) can result in SST anomaly forecasts which are more sensitive to non-linear mean state / anomaly interactions. The non-linear impact of errors on the atmospheric behaviour is also likely to be important. Evidence suggests that, at least for the major circulation patterns, the errors in the mean state of the atmosphere are similar in both coupled integrations (with drifting SST) and uncoupled integrations (with prescribed observed SST). These systematic errors do not seem to cause major problems for predicting the largest circulation anomalies such as those seen in the winter of 1997/98, but clearly an accurate representation of the atmospheric mean state is a requirement for reliable seasonal forecasting.

3. Ensemble generation techniques

The ocean-atmosphere system does not behave as a deterministic system on seasonal timescales, and numerical seasonal forecasting thus requires ensemble techniques. An ideal ensemble forecasting system would represent the uncertainty in the initial conditions of the ocean-atmosphere system, and the growth of these initial uncertainties would give an ensemble of possible future states of the system. There are many ways in which a set of initial conditions could be specified for starting an ensemble seasonal forecast. In all cases, 'noise' in the atmosphere model will provide a significant source of spread in the forecasts. The system at ECMWF attempts to include realistic representations of some of the major sources of uncertainty in the initial conditions. We use perturbations in the wind field used to generate the ocean analyses, perturbations in the initial SST field, and stochastic physics within the atmospheric model during its integration.

Wind perturbations are estimated from differences between monthly mean analyses of wind, one from an SOC in-situ based dataset (Josey et al 2002), the other from ECMWF analyses. Randomly sampled monthly differences are interpolated in time and added to the daily values used in generating the ocean analyses. Five different ocean analyses are generated in this way. Experiments with and without the assimilation of ocean sub-surface data show that the data give a significant reduction in the spread of the analyses, but do not eliminate the spread completely. That is, our use of the ocean observing system reduces, but does not remove, the uncertainty in the ocean initial conditions. SST perturbations are based on sampling differences between the NCEP OIv2 and NCEP 2dvar SST analysis products, and a different perturbation field is added to the initial condition surface layer of each of the 40 members of the forecast ensemble. Stochastic physics perturbs the physical tendencies of each realization of the atmospheric model during the whole of the integration.

Figure 2 shows how the spread of the forecast ensemble relates to the error of the ensemble mean forecast. For our old system (shown in blue), the rms error was nearly 0.3 deg C even in the first month of the forecast, while the spread was below 0.1 deg C. This version of the model did not have a 'realistic' construction of initial errors. For the present system (shown in red), the rms forecast errors are reduced at all lead times. The spread is substantially enhanced in the first month, giving a much better agreement between spread and actual error. However, the model error continues to grow substantially with lead time, while the ensemble spread does not. The fact that the forecast errors are often large compared to the predicted uncertainty may be partly due to an imperfect construction of the set of initial conditions. However, most of the discrepancy is likely to be due to error in the forecast model.

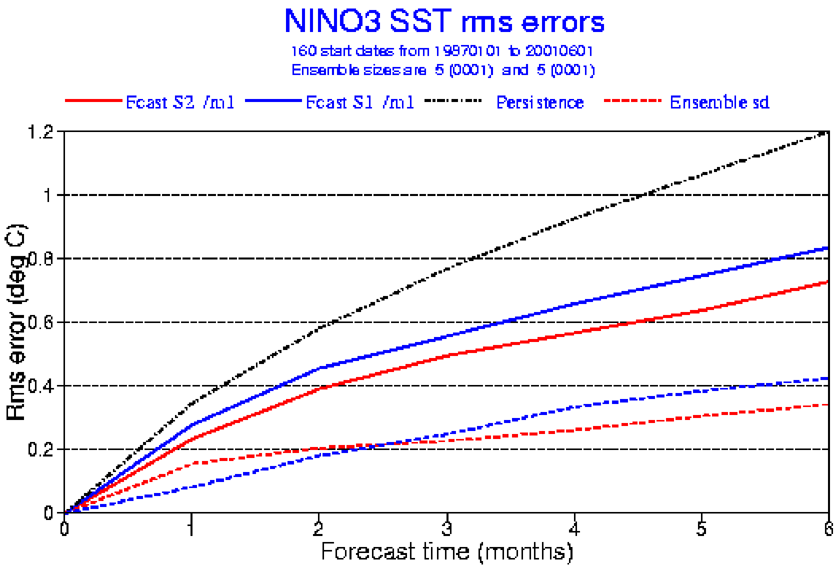


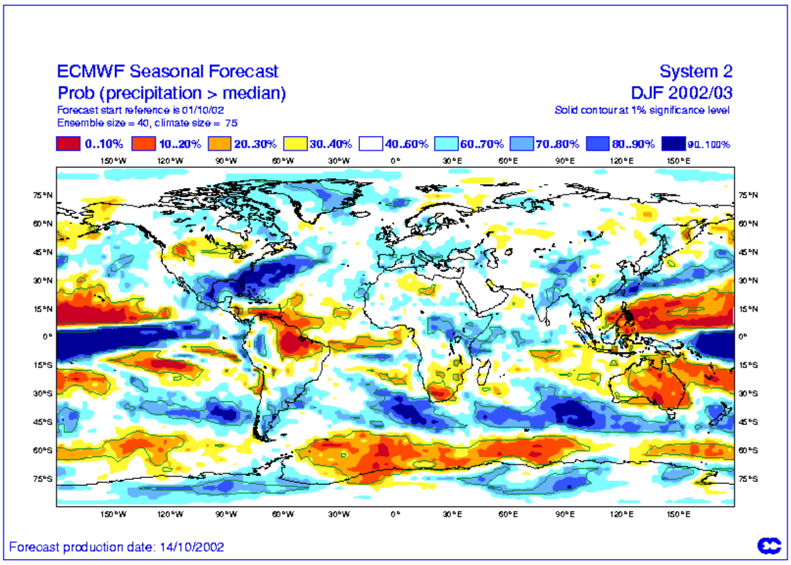
Figure 2 A comparison of model error with model spread, for forecasts of SST in Nino 3 (5N-5S, 90-150W). Solid lines show the rms error of the ensemble mean forecasts from the new system (red) and the old one (blue). The red and blue dashed lines show the spread within the ensembles; in a perfect system this should equal the rms error. The new system has a better match between error and spread in the early stages of the forecast, but there is still a large discrepancy between error and spread in the later stages.

4. Multi-model ensembles

One approach to dealing with model error is to use a multi-model ensemble. The idea is that different models will have (to some extent) different errors, and that by creating an ensemble of forecasts from different models the ensemble mean is improved and, maybe, a plausible range of outcomes is produced. A major European research project called DEMETER has investigated multi-model ensemble seasonal forecasting, using 6 different coupled ocean atmosphere GCMs. The multi-model averaging appears to be strongly beneficial. Full details are available on the Demeter web-site, http://www.ecmwf.int/research/demeter .

The use of multiple models for real-time forecasting is also under development. At the moment both the ECMWF and UKMO seasonal forecast models are run in a common fashion at ECMWF, with the data archived in compatible structures. This enables combined products to be produced, as illustrated in Figure 3. In this case both models are in broad agreement on many of the predicted rainfall signals, and the multi-model product (panel c) represents these agreed signals well. Many of the smaller 'signals' in the individual models are averaged out, leaving a cleaner and probably more reliable forecast. Results from DEMETER show that this is due to the differences in the models, and is not just a simple case of averaging over larger samples. MeteoFrance is expected to join in with real time multi-model seasonal forecasting soon.

a)



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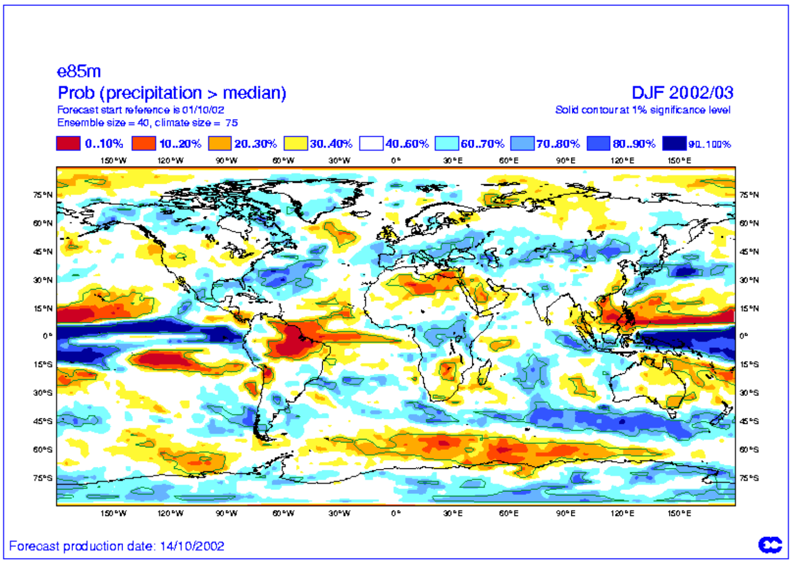

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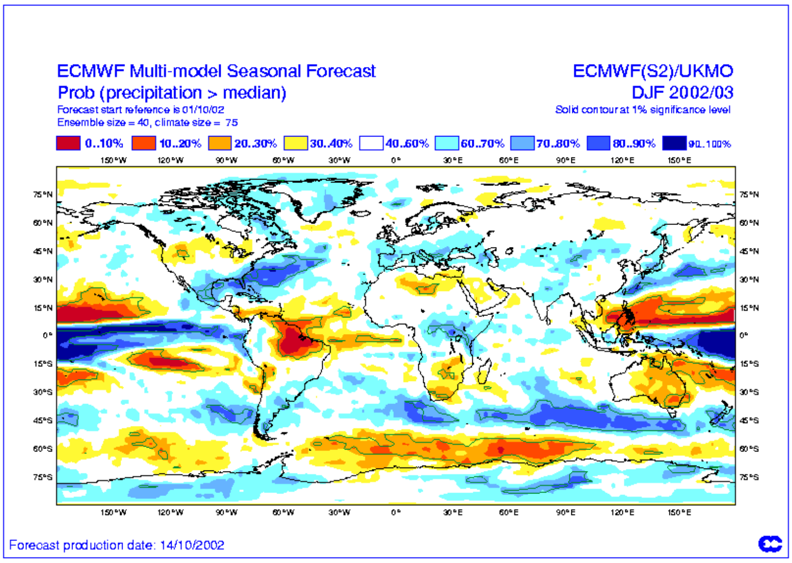

Figure 3 (a) The ECMWF model forecast of the probability of above median precipitation for the period DJF 2002/03; (b) the corresponding UKMO model forecast of the probability; (c) the multi-model probability forecast, constructed from the two models.

5. Short range forecast errors and accuracy of SST fields

We can attempt to learn about some of the causes of forecast errors by looking at short range errors. If we do this by looking eg at the SST errors for the first month, we can see clear patterns of regime-dependent errors in some geographical areas. The most extreme form of short range error analysis is to look at the daily evolution of SST errors in the first few weeks of the forecast. On these timescales we immediately hit the problem of inadequate data. Only a limited number of SST datasets are available with daily resolution, and the accuracy of these is less than we would like. Figure 4 shows an instructive example of a comparison between model and analysed daily SST, for an ensemble forecast starting in July 2002. The daily analysis (light blue) shows considerable fluctuations on timescales of days to up to a week. The weekly analysis (dark blue), generally regarded as being of higher quality, does not show much variability on the weekly timescale, and in this sense contradicts the daily analysis. The coupled model has a level of variability much closer to the weekly analysis. The daily analysis fluctuations probably do include a substantial component of erroneous noise. On the other hand, it may well be that the ocean model underestimates high frequency variations in SST. An important issue is the appropriate definition of SST - the skin temperature is what is seen by satellite infrared instruments, the sub-skin temperature can be detected by microwave instruments, and the bulk temperature is what is measured in situ - at various different depths, according to the measuring platform. The uncertainty in SST is the biggest single factor in giving us uncertainty in the initial conditions for our ensemble seasonal forecast. This is also illustrated by Figure 4, where it is seen that the ensemble has a fairly wide spread right from the first day of the forecast, in this particular case encompassing the range of apparent (partially questionable) daily variability.

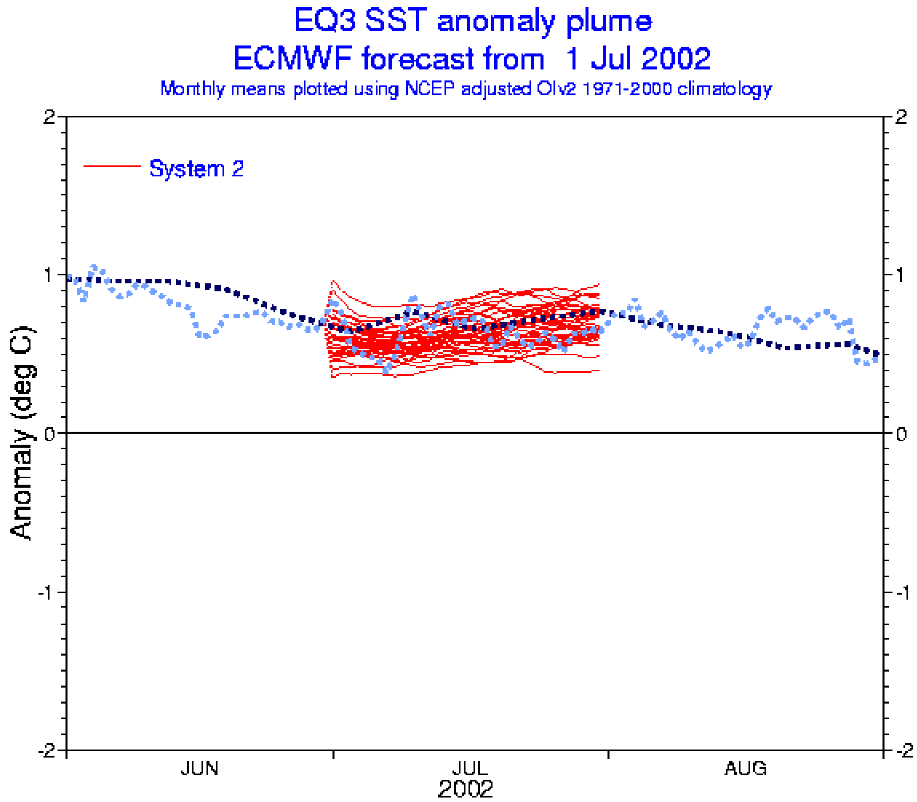

Figure 4 Daily values of SST in the EQ3 region of the west Pacific (5N-5S, 150E-170W). The light and dark blue dashed lines show observed values according to the NCEP daily and weekly analyses respectively, while the red lines show the daily values from the first month of the ensemble seasonal forecast. The NCEP daily and weekly analyses are inconsistent with regards to the amount of high frequency variability. The model forecasts have only a small amount of high frequency variability, but the ensemble spread roughly matches the range of values seen in the NCEP daily analyses.

6. Monthly forecasting

Brief mention must be made of our experimental monthly seasonal forecasting system. This uses a higher resolution version of the atmospheric model (T_L159) coupled to the ocean model, and consists of a 51 member ensemble. The forecasts are run once every 2 weeks, out to 1 month. The atmospheric initial conditions are perturbed using the same singular vector machinery as the operational medium range ensemble prediction system (EPS). The system is designed so that the output and products can be directly compared to the EPS. Weekly mean products are also created, which are essentially analogous to the seasonal mean products from the seasonal forecast system. This system has run since March 2002. Preliminary results are encouraging, with substantial evidence of skill beyond day 10, and generally reasonable probabilistic performance. A specific requirement for the monthly forecast system is real time ocean initial conditions (in contrast to the seasonal forecasts, which use a delayed ocean analysis). A real time analysis for the ocean is not trivial, in that some of the desired data arrives only after a number of days. This is particularly true for reliable SST fields. This problem is circumvented for the monthly forecasts by running a short 'ocean forecast' to bring the ocean state up to the time of the start of the coupled forecast.

7. Summary and future evolution

We presently use coupled ocean atmosphere models for seasonal and monthly range forecasts. Specifically, we have a 40 member ensemble seasonal forecast that runs once per month, and is now fully operational. We also have a 51 member ensemble monthly forecast that runs once every 2 weeks, and is for the moment considered experimental. The 10 day medium range forecast systems at ECMWF do not yet have any form of coupling with the ocean circulation, but assume a simple persistence of SST. This is not the best SST field which could be used for these timescales: even something as simple as adding a climatological evolution of SST would improve the rms accuracy in overall terms. How important the evolution of SST is during a typical 10 day forecast is not firmly established, although there is evidence of substantial impact in very specific circumstances such as the interaction of tropical cyclones with the ocean surface. Over time, we expect the use of an active ocean model (or perhaps active ocean mixed layer), to be extended from longer timescales to shorter timescales. How this is done, and how soon, is yet to be established.

References

Anderson, D., T. Stockdale, M. Balmaseda, L. Ferranti, F. Vitart, P. Doblas-Reyes, R. Hagedorn, T. Jung, A. Vidard, A. Troccoli, T. Palmer, 2003: Comparison of the ECMWF seasonal forecast systems 1 and 2, including the relative performance for the 1997/8 El Nino. *ECMWF Technical Memorandum 404*, available at www.ecmwf.int.

Josey, S.A., E.C. Kent and P.K. Taylor, 2002: Wind stress forcing of theocean in the SOC climatology: comparisons with the NCEP-NCAR, ECMWF, UWM/COADS and Hellerman and Rosenstein datasets. *J. Phys. Oceanog*r. **32**, 1993-2019.

Stockdale, T.N., 1997: Coupled ocean atmosphere forecasts in the presence of climate drift. *Mon. Wea. Rev.* **125**, 809-818.