ECMWF long-range forecast

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In 1995 ECMWF started an experimental programme in seasonal forecasting. From then on a seasonal forecast system was developed and experimental seasonal forecasts were made. Successful predictions of the exceptional El Niño event of 1997 encouraged the seasonal forecast activity. The ECMWF seasonal forecasting system, based on coupled General Circulation Models (GCM) integrations, was successful in predicting the occurrence of the 1997-98 events, its maintenance and its decay, a few months in advance.

Since then a range of seasonal products has been issued routinely every month. In 2000 the seasonal forecasts became part of the operational products and by mid-2000 the seasonal forecast products became available to the all the WMO members. During 2002, a substantial upgrade was made to the seasonal forecasting system. A brief description of the new system is given in section 1. In section 2 forecast performance and forecast verification are discussed. Predictions for the European summer 2003 are also commented in this section. Section 3 describes envisaged future implementations.

1 The current seasonal forecasting systems

The current seasonal forecasting system (S2) was introduced into operational use at the beginning of 2002. It differs from the original system in a number of ways. The atmospheric component is CY23r4 of the IFS with a horizontal resolution of T_L95 and 40 levels in the vertical. This is the same cycle of the IFS as was used in the ERA-40 re-analysis. The ocean model resolution was increased to 0.3° meridionally near the equator and to 1°×1° at higher latitudes; the vertical resolution of the ocean increased from 20 to 29 levels. Changes were also made to the ocean model physics, mainly the parameterisation of vertical mixing.

Substantial changes were made to the ocean assimilation system. The ocean initial conditions are provided not from a single ocean analysis but from a 5-member ensemble of ocean analyses. The analyses differ in that a measure of uncertainty in the surface winds used to force the ocean is taken into account. In the absence of ocean data assimilation, the uncertainty in ocean state is relatively large, but in the presence of ocean data assimilation it is much smaller.

The ensemble ocean analysis is part of the new method of ensemble generation in S2. Each ensemble forecast consists of 40 members all with initial conditions on the 1st of the month. The ensemble forecast's design aims to represent the most important uncertainties in the initial conditions. Uncertainties in SST values are represented by 40 different SST perturbations added to the 5 ocean analyses in order to create a 40-member set of ocean initial conditions from which the forecasts are launched. In addition, stochastic physics (*Palmer* 2000) is used to perturb the coupled integrations throughout the forecast period. This gives a significant decorrelation of the atmospheric flow in the tropics in the first few days of the forecast, compensating for the fact that perturbations to the atmospheric initial conditions are not included. The 40-member ensemble can be run once the ocean analyses are available, generally on the 11th of each month. Because a large amount of computation is involved, and to ensure reliable delivery, the operational release date for the forecast is set at the 15th of the month. This is still a big improvement in timeliness over the original system.

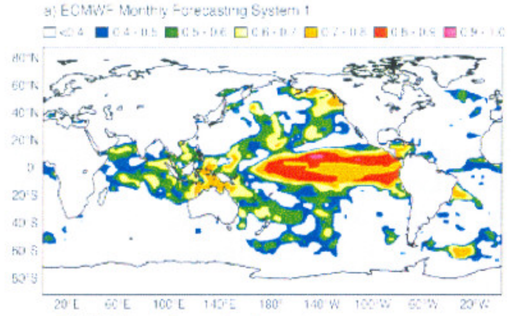
As with all models, the seasonal forecast system is not perfect. One symptom of this is climate drift: the model climatology does not match that in nature. To allow for this, the forecasts need to be referenced to the model climatology.

The estimate of the model climatology is based on an ensemble of 5 integrations spanning the years 1987–2001. This 15-year climate gives a more stable basis for computing anomalies than the 6-year climate available in the original system. For a further description of the original and operational system, including an assessment of their different characteristics see *Anderson et al.* 2003.

2 Seasonal forecast performance and verification

2.1 *SST forecast skill*

Although the original seasonal forecasting and the current one are substantially different their Sea Surface Temperature forecast skill is comparable. Figure 1 shows the point correlation of predicted SSTs with analyses for forecasts started between 1991 and 2001 indicating the general broad similarity of skill between the two systems.


a) ECMWF Monthly Forecasting System 1

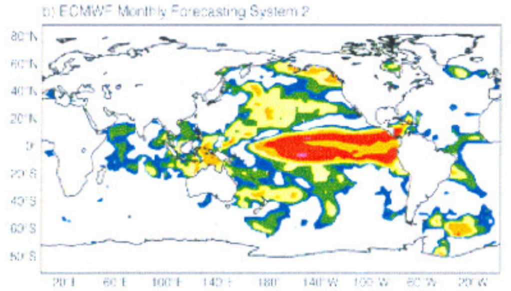
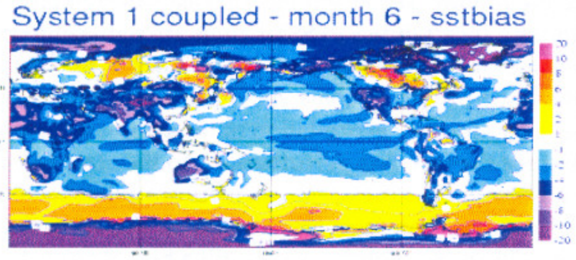

b) ECMWF Monthly Forecasting System 2

Fig. 1 Spatial map of the temporal anomaly correlation between forecasts and SST analysis, for the forecasts for months 3–5 and for the years 1991–2001 for a) the original system and b) the operational system.

However, in the current system the biases in surface temperature are reduced. For example, shown in Figure 2 is the mean error in surface temperature six months into a coupled model forecast for a) original system and b) current system. The biases in surface temperature are large, especially over land. Errors over the ocean may look smaller, but are still significant compared with the size of inter-annual variability in SST. Figure 2 shows that the bias is considerably reduced in the upgraded system, particularly over the tropical oceans. Although the temperature biases in the current system are reduced relative to the original system, not all aspects of the system have been improved. For example the amplitude of SST variability is underestimated by the current system - as a consequence it is not able to develop or sustain SST anomalies as large as those seen in the 1997 El Niño. Part of the reason for this is that the winds in the atmospheric model do not respond to changing SST anomalies as vigorously as observations suggest they should. The cause of the reduced wind variability is not entirely understood, and may not be helped by the drift in the coupled model, but is present even in uncoupled integrations of the atmospheric model.


System 1 coupled - month 6 - sstbias

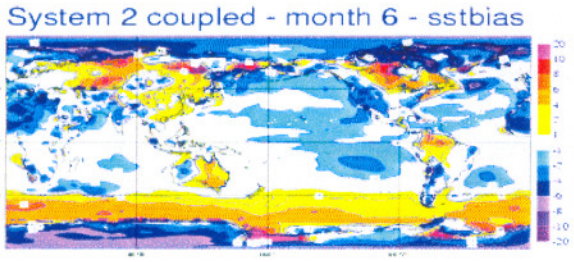

System 2 coupled - month 6 - sstbias

Fig. 2 The bias in surface temperature after 6 months for a) Original system and b) Operational system. The reference climatology is ERA-40.

2.2 *How good were the seasonal predictions for the 2003 summer over Europe?*

Followed by a fairly cold winter and a dry spring, the summer 2003 of, in Europe has been one of the hottest summers on record. In May temperatures started to rise well above the average, and the warm conditions persisted during the whole summer. In addition to that a sequence of heat waves augmented the anomalies to unprecedented levels. As a result many records of seasonal mean temperature were broken across Europe. Were the seasonal predictions able to predict such hot summer months in advance?

It is important to keep in mind that, although several components can contribute to the predictability of extreme anomalies, most of the skill of seasonal predictions comes from the ability to forecast the evolution of Sea Surface Temperature (SST) anomalies, in particular the El Niño cycle and its impact on the atmospheric circulation.

Since the last peak of El Niño in late 2002, SST anomalies have steadily decreased throughout the central and eastern equatorial Pacific. From April 2003 onwards atmospheric and oceanic conditions over the El Niño area were near to normal. During such a neutral phase of El Niño limited skill is expected.

SST predictions from the seasonal forecast were quite successful in reproducing the cooling over the Tropical eastern Pacific and the persistence of a SST anomaly pattern over the Atlantic Ocean. However, over the Indian Ocean, positive SST anomalies were not predicted. In this area of warm waters, relatively small anomalies (about +0.5 degree) can have a significant impact to the monsoon circulation and in turn can affect the summer circulation over the Mediterranean basin.

Fig. 3 shows the probability pattern for the upper tercile of 2 m temperature from the ensemble of forecasts started in May 2003 forecasting the period June-July-August. The upper tercile represents the warmest third of previously predicted summers. Over much of France probabilities in the range of 50-60% are evident. This might seem quite impressive, but unfortunately the forecast from April didn't indicate such warm conditions over the same area. During the last 2 weeks of April the Mediterranean basin warmed quite rapidly. It is possible that the May forecast produced a better signal by persisting this SST anomaly However, the warm conditions over the Mediterranean sea didn't help the forecast initiated in June to make realistic predictions for the July to September period.

To what extent such inconsistent forecasts are due to model errors or are related with the 'true' low predictability level of this event is difficult to establish. Experimentation to address this issue is in progress. Preliminary results seem to indicate that even with the forcing of observed SST conditions the European hot summer was difficult to predict. Considering that the spring of 2003 was a rather dry season, it is possible that the lack of soil moisture has contributed to enhance the local heating. Further analysis is needed to assess the extent of this feedback and its contribution to the predictability.

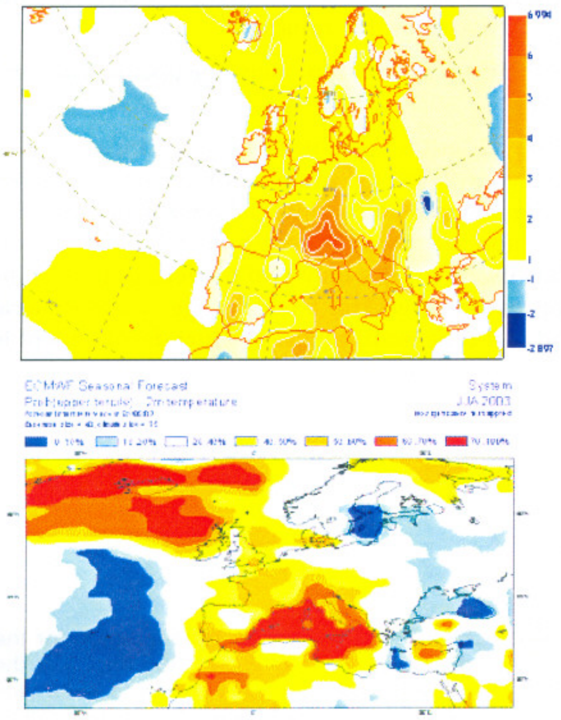


Fig. 3 Top panel: 2m-temperature anomaly for June July August 2003 with respect to ERA-40 climate (1958-2001) Bottom panel: Probability of exceeding the upper tercile of 2m temperature in the model climate distribution for JJA 2003. The forecast started the first of May 2003.

2.3 *Verification*

For a correct interpretation of seasonal predictions the user needs to complement the forecast products with knowledge of the forecast skill. The site at http://www.ecmwf.int/products/forecasts/d/charts/seasonal/verification provides a comprehensive documentation of skill levels, using methods that have been agreed at the international (WMO) level for the evaluation of long-range forecast systems. Estimates of model bias for a wide range of variables, including zonal averages, time series of a set of indices of SST and large-scale patterns of variability such as: the Southern Oscillation Index (SOI), the Pacific North American Pattern (PNA) and the North Atlantic Oscillation (NAO) are available. A suite of verification scores for deterministic (e.g. spatial anomaly correlation and Mean Square Skill Score Error (MSSE)) and probabilistic forecasts can be viewed.

The robustness of verification statistics is always a function of the sample size. For the operational seasonal forecast system, the sample size of 15 years is considered barely sufficient. Verification is performed in cross-validation mode using the whole set of forecast data available: hind-casts and real time forecasts with no distinction.

Since the seasonal forecast skill depends very strongly on the season, forecasts started in February, May, August and November are evaluated separately. Results are shown as 90-day means with 1 and 3 month forecast lead. GPCP data are used to verify precipitation, while the other atmospheric parameters are verified against the ERA 40 analysis. For the period when the re-analysis is not yet available, the operational analysis is used. The verification period is 1987 to 2002. Every year the site is updated by adding another year to the verification period.

Although we can take advantage of the experience in the medium range forecast verification, evaluating seasonal forecast skill involves dealing with a generally small signal to noise ratio and limited sample of cases. Significance testing methods are therefore particularly relevant and this is something we hope will be increasingly reflected in the verification statistics.

3 Developments and future implementations

Looking at the SST predictions over the Niño regions (http://www.ecmwf.int/products/forecasts/d/charts/seasonal/forecast/plumes) it is not uncommon to see that the observed anomalies lie outside the ensemble. This indicates that the spread of the ensemble is not sufficient and in turn the predictions might be over confident.

At the moment the forecast ensemble is constructed by sampling the uncertainties associated with wind and SST. Not all types of initial condition errors are represented in the ensemble. In addition the uncertainties related with the forecast error component due to the coupled model itself are not well accounted for.

A multi-model ensemble - a forecast made from an ensemble of different models by sampling model errors as well as uncertainties in the initial conditions, gives a better representation of the range of possible outcomes. The DEMETER project has addressed the multi-model approach to seasonal forecasting in greater detail, using a series of hindcasts covering the last 43 years. DEMETER results showed that the skill from a multi-model ensemble is larger than the skill from a single-model ensemble of similar ensemble size. DEMETER results showed that the benefit of a multi-model approach is visible over mid-latitudes as well as over the tropics.

Figure 4 shows the root mean square errors and spread from two different forecast models (the operational forecast in blue, the seasonal system from the UK Met. Office in green).

The UK model has both a larger spread and larger errors than S2, but a comparable level of inconsistency between spread and error. The red curves show the spread and the error for the multi-model ensemble, i.e. an ensemble consisting of both sets of forecasts. The rms errors of the ensemble mean forecast are smaller than for either individual model, and the spread in the ensemble matches more closely the forecast error. It is not shown here, but the anomaly correlation is also generally increased. This example uses only two models, but a significantly larger number of models is desirable. The multi-model approach is useful for a wide range of atmospheric variables, not just SST. Further work on ensemble generation and real-time multi-model product development is in progress.

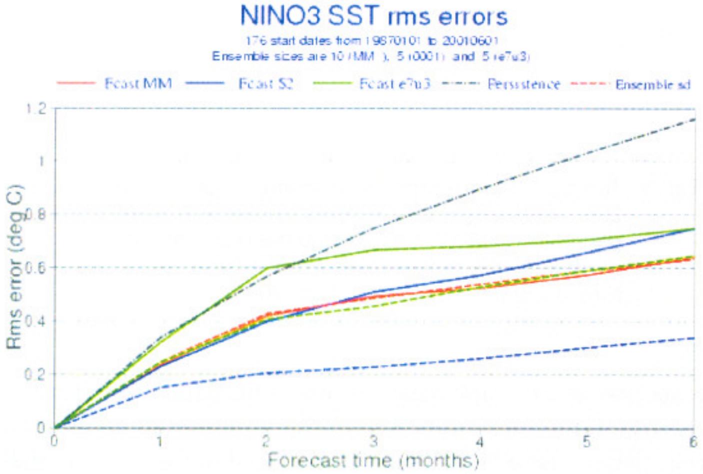


Fig. 4 Plot of error growth in Niño-3 region for the operational system (solid blue line) and the growth of the ensemble spread (dashed blue line). Green as for blue but for the Met. Office model, and red for the two models combined. The spread of the Met. Office forecasts is larger than for ECMWF as is the root mean square error, but the error is reduced in the two-model case and the spread matches the error.

References

Anderson, David, Tim Stockdale, Magdalena Balmaseda, Laura Ferranti, Frederic Vitart, Paco Doblas-Reyes, Renate Hagedorn, Thomas Jung, Arthur Vidard, Alberto Troccoli, Tim Palmer, 2003, Comparison of the ECMWF seasonal forecast Systems 1 and 2, including the relative performance for the 1997/8 El Niño. *ECMWF Technical Memorandum* **404**. Available on-line at www.ecmwf.int.

Palmer, T.N., 2000, Predicting uncertainty in forecasts of weather and climate, *Rep. Prog. Phys.*, **63**, 71-116.