THE ECMWF SEASONAL FORECASTING SYSTEM

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The lower boundary conditions of the atmosphere such as sea surface temperature (SST) or soil moisture and snow cover often have a considerably longer memory than that of weather, and are at least partly predictable on time-scales of weeks to months. One of the most important influences on weather patterns is El Nino, the irregular warming of sea surface temperature in the equatorial Pacific. When it appears, El Nino can have a strong impact on the weather worldwide, but even without El Nino there are many factors which influence the weather. The large El Nino of 1997/98 caused climate perturbations worldwide costing billions of dollars -$35 billion is the WMO estimate though this figure is liable to considerable error.

In recent years both our ability to predict changes in SST and our understanding of their global impact has improved for two principal reasons: firstly, the development of a fairly comprehensive in situ ocean observing system in the equatorial Pacific and an expanding, though still sparse, observing system in the tropical Atlantic and secondly improvements in numerical models of the atmosphere and ocean, although these are still flawed and require extensive further refinement. Since it is the slower time-scale in the ocean that brings predictability, any attempt to predict seasonal changes in general or El Nino in particular must involve both atmospheric and oceanic models. ECMWF has developed such a coupled model.

A 200-day integration of the coupled atmosphere-ocean model is made each day. Over a period of a month an ensemble of 30 or 31 members is created. The ocean products which are put on the web consist of the Nino3 SSTs for each ensemble member. These plume diagrams give a sense not only of the future evolution of SST but also the spread arising from chaotic processes. The atmospheric products consist of the anomalies of the ensemble mean and a measure of the degree to which the ensemble differs from usual. Predictions of three different quantities are given: rainfall, surface pressure and 2m temperature at 00Z. They are available on the web: first go to `http://www.ecmwf.int`, then go to Seasonal Forecasting project.

Each plot is labelled with the period for which it is valid; e.g. ASO 98 is the three-month period August to October 1998. The ensemble is made up of forecasts initialised during a one-month period centred on the forecast start reference date. For example, an ensemble with a forecast reference date of 1 July would consist of forecasts with initial conditions from 16 June to 15 July. The number of forecasts in the ensemble and the number that define the climate are also given. The fields have been subjected to a local significance test before plotting. Points where the ensemble distribution is not significantly shifted compared to the climate distribution are blanked out. The 95% significance level is used: under the null hypothesis of no signal, one would expect 5% of the globe to show a spurious signal. The probability that a particular signal is real will depend on how much signal is present globally i.e. how large are the SST anomalies and where are they located. When strong perturbations are present (as in the 1997/98 El Nino), the probability of a model signal being real is relatively high. Probability plots of a given variable (e.g. precipitation) being greater or less than the climate median are also produced.

However, a model signal is no guarantee of a signal being present in reality since our models do not represent the ocean and atmosphere perfectly, nor do we know the state of the ocean or atmosphere precisely, at the start of our integrations. The limited size of our ensembles (typically 30) means that there is a noticeable amount of sampling error in these estimates of probabilities, which should only be considered approximate. It is also important to remember that even perfect sampling would

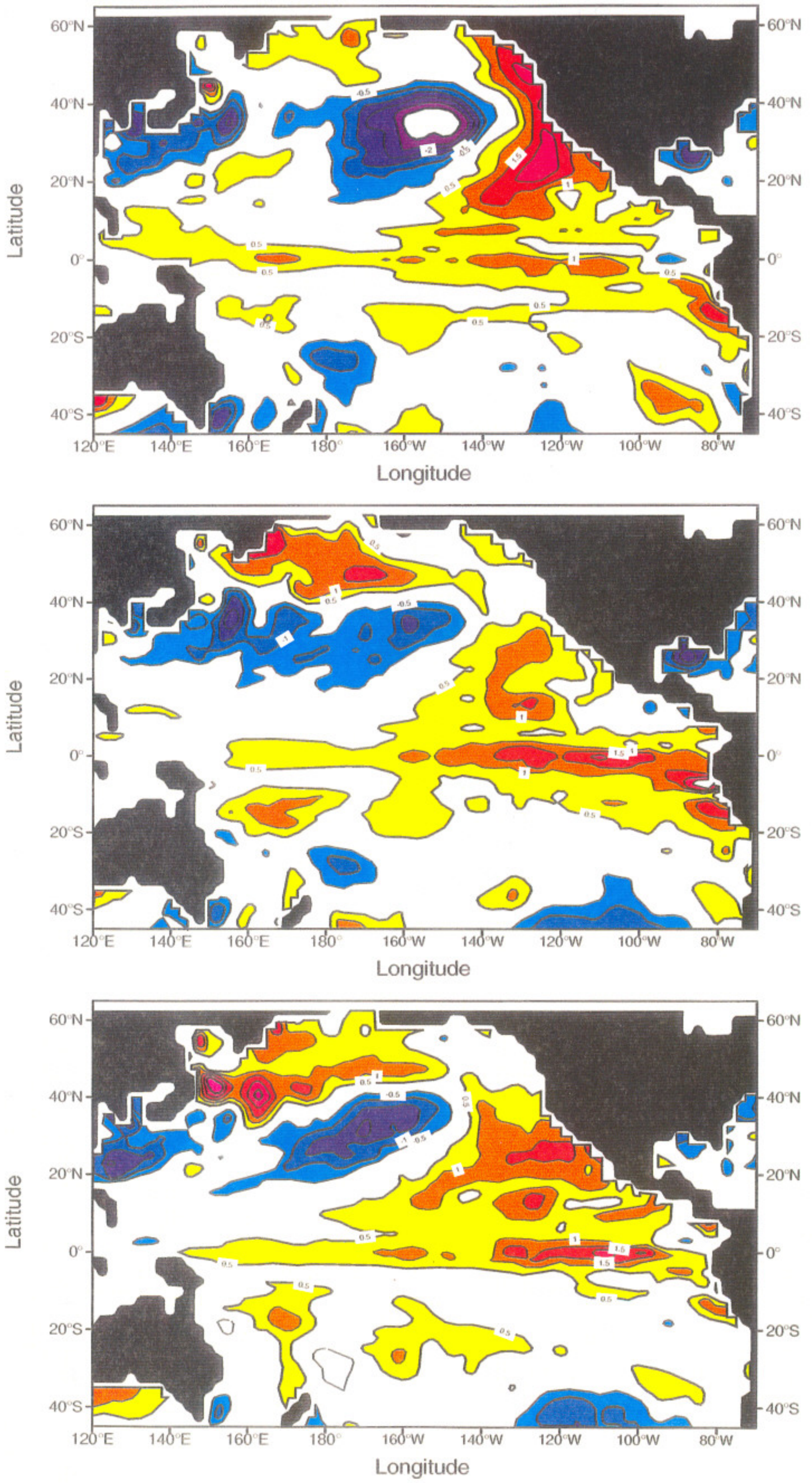

Fig. 2 Spatial plot of the predicted SST anomalies averaged over the last 3 months of a 6-month forecast. The purpose of this plot is to show the different SSTs which result from the chaotic nature of the atmosphere. Such differences basically show the limits to predictability since the initial conditions are all equally plausible yet give different forecasts.

show only model-estimated values, not the true probabilities. A true statement of the chances for above average rainfall (or temperature or pressure) must also take account of the risk of the model being wrong. The probabilities do not include uncertainty arising from model error, or from inaccuracies in the ocean initial conditions. It is much harder to quantify these uncertainties.

The model performed well on predictions for the major El Nino of 1997/98. Fig 1 shows the sea surface temperatures in the eastern central equatorial Pacific as forecast, and the heavy line shows the temperatures which were later found to occur. The multiple lines on the figure show individual forecasts. The differences are largely due to the chaotic response of the system (see abstract by Palmer). The uncertainties in SST are graphically illustrated in fig 2 which shows three different forecasts, starting just one day apart. An alternative way of interpreting this figure is to think of the differences in the forecasts as arising from small differences in the initial conditions. Fig 2 then illustrates the variability in the ocean response arising from small perturbations and indicates the limits to predictability. All that can be forecast is a probability density function (PDF). There is no definitive forecast. This makes verification difficult, especially for weaker signals. When there is a strong El Nino present, one expects the weather signal to be more strongly disrupted, especially in the tropics, and so some partial verification may be performed. Strictly, however, forecast skill should be based on probability evaluation as discussed by the previous speaker.

To show the skill of atmospheric variables, fig 3 shows a plot of the predicted rainfall field. Two plots are given: Fig 3a shows the amount by which the ensemble mean is displaced, and fig 3b shows the probability of rainfall being above average (blue) or below average (red). Fig 3c is similar to fig 3a except that we have applied a statistical test. Where the figure is blank, the PDF of rainfall was not statistically significantly different from the climate PDF. Quite large areas are blank, even in El Nino conditions, saying that for this variable (rainfall) there was no predictable signal, i.e. chaos reigns. In times of weaker signal, one would expect more of the globe to be white. The regions which have a signal will depend on which parameter is being considered. Thus it is quite possible to have a signal for rainfall but not for temperature.

For verification we show the rainfall anomaly which actually occurred in fig 3d. One can see that the predictions were quite good especially in the tropics where the signal is strongest. Even here however, the forecasts were not perfect. In fact as explained in the previous talk as well, validating a PDF is somewhat hard on such a short record as we have for climate purposes.

The models we are using, although at the top end of what is currently feasible computationally, are at a resolution which does not well represent the details of tropical storms. None-the-less we can look to see if the model can reproduce some of the interannual variability in storm genesis. We are not yet able to accurately reproduce the tracks and lifetimes of hurricanes but we can see differences in their frequency of occurrence and their genesis region. Fig 4 shows such a plot.

In addition to the products distributed either on the web, or to member states, we could produce products which are used in financial derivatives market, such as heating or cooling degree-days. As explained above these would be probability distributions, based on the ensembles. As degree-days are frequently regional with the value of the cut-off varying locally, it is probably best that this product be derived for specific locations on an as-requested basis. All the data required to calculate them is available but the skill is unclear as it will vary regionally and has not been validated.

The skill of our system is highest in the tropics and decreases as the atmosphere becomes more chaotic. Europe seems to be a particularly difficult region to forecast accurately. It is also a region where the models have systematic errors. Forecasts have been performed on the period 1991-

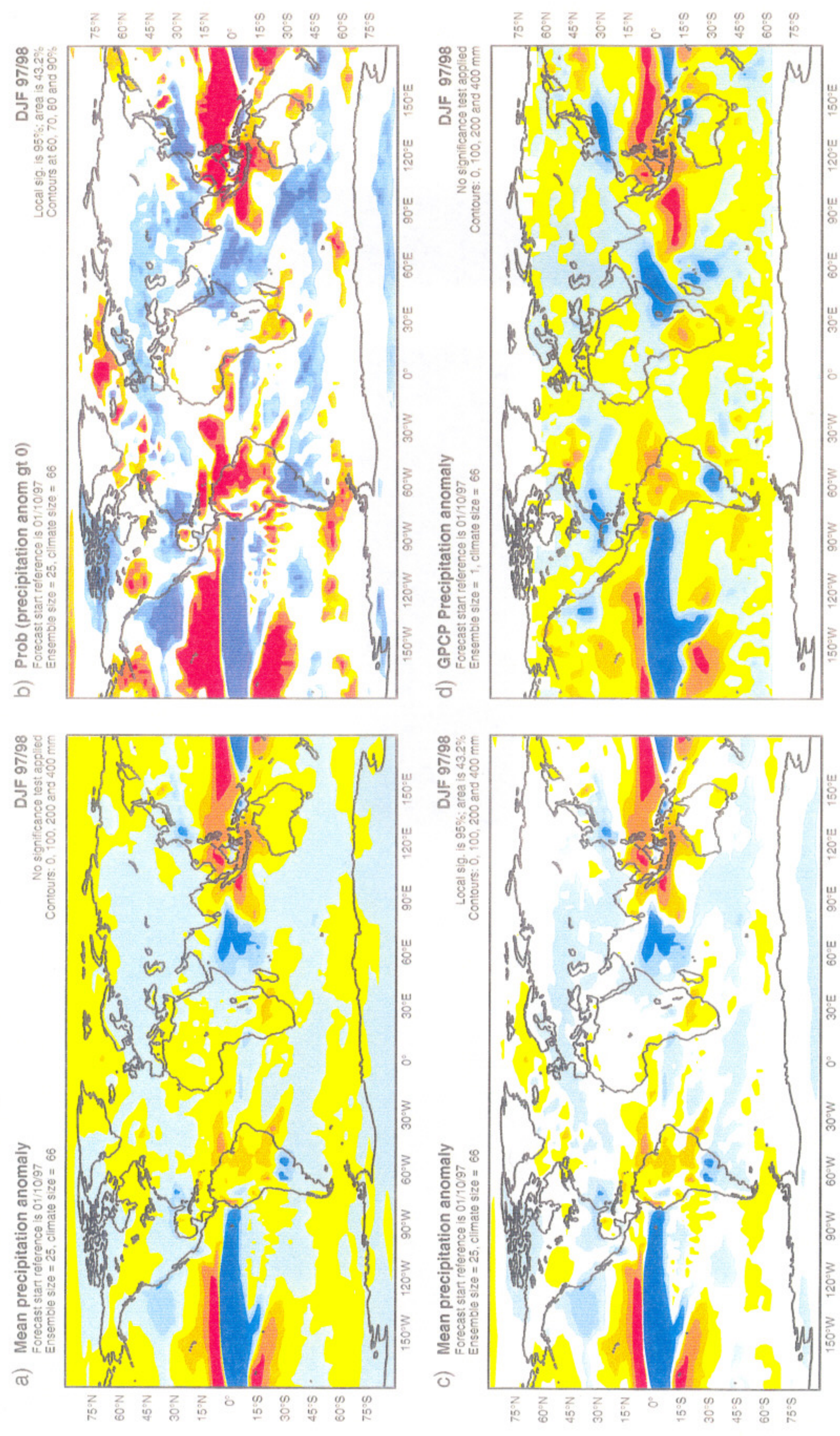

Fig. 3 a) Plot of the predicted ensemble mean rainfall anomaly for Dec, Jan Feb 97/98 i.e. at the height of the last E1 Nino. b) Plot of the probability of above average rainfall (blue) and below average rainfall (red). c) As a), but with regions which are not statistically significant at the 95% level blanked out. d) Observed rainfall anomaly, from GPCC.

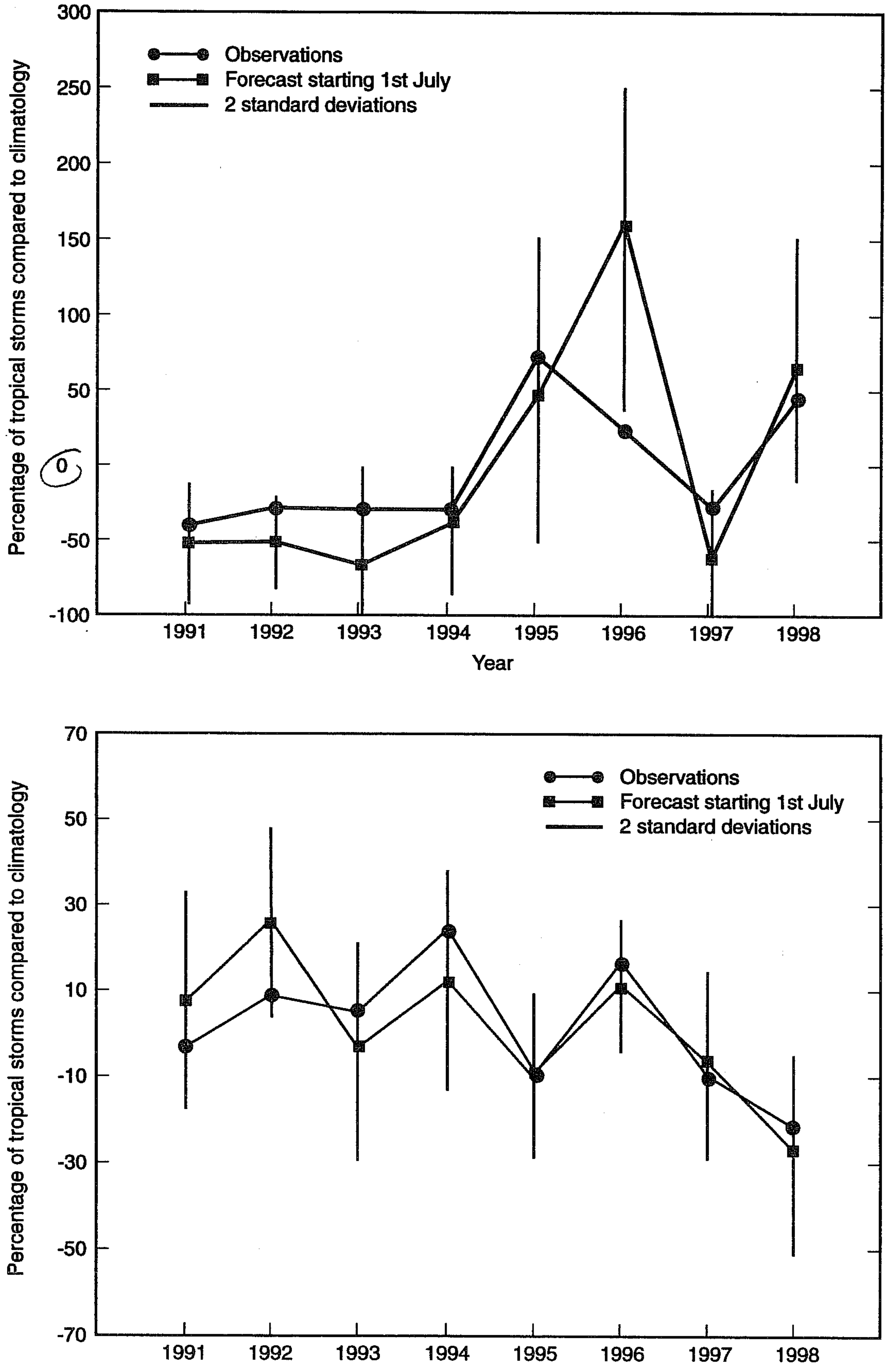

Fig. 4 Plot of the interannual variation in hurricane frequency and of the observed variation. The model underestimates the hurricane frequency of genesis, so normalised values are given. a) North Atlantic, b) North Pacific

present. This encompasses one large El Nino and some smaller El Nino/ La Nina variability but is too short a period to reliably estimate model performance.

Summary

Seasonal forecasting using coupled models of the atmosphere and ocean is a developing field. ECMWF started only 4 years ago. The models still have systematic errors which makes interpreting the model results not straightforward. Our experience is that in middle latitudes especially in the European sector, the systematic error in the coupled model is comparable to that in uncoupled runs using specified SST and therefore most of the systematic mid-latitude error is of atmospheric origin. In the tropics atmospheric model error is also likely to be significant. Skill is highest in the tropics and lower at higher latitudes. However, this is not a uniform decrease: certain areas are more predictable than others, even in middle latitudes. Europe is likely to be a difficult area. Over the coming years model error will be reduced but this is likely to be a slow process involving a great deal of hard work.

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