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INPUT TO ICTT ON CC, ON THE ESTABLISHMENT OF APPROPRIATE OPERATIONAL INFRASTRUCTURE FOR THE PRODUCTION AND EXCHANGE OF LRF

(Submitted by Dr L. Ferranti, ECMWF, United Kingdom)

Summary and purpose of document

This document summarizes the operational infrastructure for the production of long-range forecast at ECMWF.

Action proposed

The Team is invited to develop its recommendations taking into account the proposals submitted in this document.

1. INTRODUCTION

ECMWF started an experimental program in seasonal predictions in 1995. Since then a substantial progress has been made by reaching a quasi-operational production of seasonal predictions. ECMWF seasonal forecast system, providing global predictions for the ocean and atmospheric parameters has a wide range of potential applications.

A summary of the state-of-the-art in seasonal forecasting is given in section 2. Details are provided in the appendix together with an outlook on future developments of the system.

The ECMWF seasonal forecast products for the global domain have been available on the Centre's web pages for WMO members since mid-2000. The access to the global seasonal products is password protected and is restricted to national Meteorological and Hydrological Services (NMHS) and a few research organizations with particular interest in seasonal forecasting. Over 50% of the WMO members have requested and been given access to the products on the web. The range of ECMWF seasonal forecast products currently available to the meteorological community (NMHSs) and to the public is summarised in section 3.

The ECMWF seasonal forecast range is complemented by a set of documentation describing the forecasting system, some guidance on the quality of the products and post-performance evaluation based on hind-casts. Section 4 includes preliminary information on verification, including an assessment of the quality of the forecasts.

On a regular basis, ECMWF organizes workshop and meetings, with the intent to inform the users on the confidence level of seasonal predictions, to exchange experience about the potential applications of seasonal forecasts and to collect user requirements. Training on the use of seasonal predictions is part of the regular training courses that the Centre provides to the NMHS of the Member States and Co-operating States. Section 5 summarises the user requirements and give an outlook on future products and their availability on the web.

2. SEASONAL FORECASTING AT ECMWF - SUMMARY

The Centre has a state-of-the-art seasonal forecasting system with full coupling between the atmosphere and the ocean. The resolution in the atmosphere of the current system is T63 spectral with 31 levels in the vertical. The ocean model has a lower resolution in the extra-tropics but higher in the equatorial region to resolve the baroclinic waves and processes close to the equator. There are 20 levels in the vertical with a high resolution in the upper 200 m of the ocean. A 200-day integration of the coupled system is made each day. Over a period of a month, an ensemble of approximately 30 members is created from which the products provided on the web are derived. The main products are the ocean sea surface temperature forecasts and the forecasts of anomalies and ensemble means of some weather parameters. Details are given in section 3.

3. DISSEMINATION OF SEASONAL FORECAST PRODUCTS AT ECMWF

The range of products routinely available from the seasonal forecast suite is given in Table 1.

Table 1: Products routinely available from the ECMWF forecast suite.

1. Ocean analysis

Parameter:
Temperature anomaly along the equator (ocean cross-section)
Sea level anomaly
Zonal wind stress anomaly

Area: Tropical belt
Period and valid time: 7-day mean, updated weekly

2. Seasonal forecasts:

Nino-3 SST anomaly plumes
Forecast charts:
Parameter:
Precipitation Temperature at 2 metres Mean sea level pressure Sea surface temperature

Area: Global and sub-areas
Type: Ensemble mean value- Probability of below/above average climate value
Lead time: 1, 2, 3 months
Period and valid time: 3-month averages, updated monthly

The Member States and Co-operating States have access to the global range of products defined in Table1 through the Internet from the Centre's server. The NMHSs of the WMO Members have a password protected access to the same range of products. Similar range of products but limited to the tropical belt and issued with one week of delay is also available to the public through the ECMWF public Web server.

The access to the ECMWF seasonal forecast's web pages is provided under the following conditions: "Seasonal forecasts products are available to professional users aware of the state-of-art in seasonal forecast. This use falls under their full responsibility. The ECMWF seasonal products available on the web may not be provided to any third party and their commercial use is prohibited."

All products are available in graphical form. The access of the seasonal forecast data through the ECMWF archiving system (MARS) in GRIB encoded digital format is available to Member and Co-operating States. For research use seasonal forecast data can also be requested from data Services

A selection of seasonal products will be part of the catalog of ECMWF real-time products and it will be available for commercial use in the near future.

4. VERIFICATION OF SEASONAL FORECAST PRODUCTS

The issue of providing the users receiving seasonal forecast products with some quantitative information on the quality they can expect is an important issue that ECMWF has to address. There is however a lack of commonly agreed procedures to provide this information in a consistent way. An Expert Team has been set up under the auspices of WMO/CBS to propose a common set of verification procedures both for the exchange of results among the seasonal forecasting centres and to attach a minimum set of verification information to the products issued to potential users. (report is available at http://www.wmo.ch/web/www/reports/ECMWF-AUG-99.html).

ECMWF will work to meet these requirements although some recommendations made by the WMO/CBS/ET cannot yet be implemented, such as the provision of results over a long hind-cast period (ideally 30 years). The participation of ECMWF in the EU-funded DEMETER project is however a significant investment to meet such requirements.

Assessing probability forecasts is quite difficult, especially given that the climate record is short. The long-term strategy approved by Council foresees preparation by 2003 of an assessment of seasonal forecast skill over the last 40 years. In fact the ocean observing system has been in existence in the equatorial Pacific only for a few years, which is short, given the low-frequency of El Nino. Since the El Nino of 97/98 was a large one this is a good single event on which to gauge the system, but it is, of itself, incomplete.

El Niño forecasts, issued monthly on the web site, are represented in the form of SST anomalies averaged over the Nino-3 region (5N-5S, 150W-90W). Figure 1 shows forecasts for the key region in the equatorial Pacific (Nino 3). Each line shows a single ensemble member. The subsequently-observed SST is plotted as the heavy curve. Several different start dates are shown with the purpose of illustrating that the forecasts were generally good.

- Statistics, are available on the web since early 2000 at the following address: (http://wms.ecmwf.int/ecmwf/seasonal/verstats/nino), indicate a rather high skill for seasonal predictions of tropical Pacific Sea Surface Temperature (SST) anomalies. Although the statistics are based on a relatively short time period dominated by the single large El Niño event of 1997/98 and may therefore not be highly representative of other periods, they indicate that the skill is substantial and is also well above the skill of persistence.

- Fluctuations in ocean temperatures during El Niño and La Niña are accompanied by even larger-scale fluctuations in air pressure known as the Southern Oscillation. The Equatorial Southern Oscillation Index (EQSOI) is one measure of the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific (i.e., the state of the Southern Oscillation) during El Niño and La Niña episodes.

- Fig.2 shows three months running mean of EQSOI computed from the ECMWF operational analysis (red line) and from the seasonal forecast for the whole period for which the seasonal forecast data are available.

- Historically, there is considerable variability in the ENSO (El Niño / Southern Oscillation) cycle from one decade to the next. The 1990's featured a very active ENSO cycle, with 3 El Niño episodes (1991-1993, 1994/95, and 1997/98) and 2 La Niña episodes (1995/96, 1999-2000). This period also featured one of the strongest El Niño episodes of the century (1997/98), as well as two consecutive periods of El Niño conditions during 1991-1995 without an intervening cold episode. SOI seasonal predictions (3 months ahead) are quite close to the analysis for the period 1991-1996. The sudden reduction of the low level easterly flow related to the sudden warming of the sea surface temperature over the East equatorial Pacific during the first part of 1997 was predicted with some delay and its maximum amplitude was underestimated. However the transition from El Niño to La Niña was well captured. During the second half of 1998 the intensity of the Walker circulation was over-forecasted.

- The seasonal forecast skill is compared with the skill that would have been obtained by a simple persistence of the observed anomaly. Persistence is generally hard to beat in the short range (less than 3 months, say), but forecast schemes should be better than persistence in the 3-6 month range and beyond. Correlation between forecast and analysis (0.84) is higher than the correlation between persistence and the analysis (0.77) indicating that EQSOI forecasts 3 months ahead have a higher predictive skill than persistence.

Seasonal forecast verification has progressed and new products are being produced. For example grid point correlation and an extensive set of rainfall indices have been computed for all seasons. Seasonal predictions of Pacific North American (PNA) pattern and North Atlantic Oscillation (NAO) have been studied and compared with results from uncoupled atmospheric simulations forced by observed Sea Surface Temperature. PNA seasonal predictions (Fig. 3) are as skilful as the ones from atmospheric simulations while for the NAO (Fig. 4) both ensembles have a rather limited skill. Probabilistic verifications, consistent with the results from the atmospheric regimes, indicate that the seasonal forecast skill is comparable with the skill of atmospheric simulations forced by a “perfect ocean”. A large part of this validation material will be made available on the web within the next few months.

Diagnostics of the system that are not directly related to users needs, but rather try to assess the intrinsic performance of the coupled modelling system on the large scale are considered an essential to complement the verification. An example of such work was a comparison of the winter variability of the coupled model over the period 1991-1996 and of NCEP re-analysis over the period 1949-1994. The good correspondence between the two is an indication that the bias that affect the coupled model is not a severe limitation for the representation of the atmospheric large scale variability.

5. USER REQUIREMENTS AND FUTURE WEB SERVICES FOR SEASONAL FORECASTING

Potential applications of seasonal forecasts includes a wide range of industry and public service sectors, including electricity services, water resources management, agro-meteorology (crop yield research), health epidemics (malaria) and weather derivatives industry. Although limitations of seasonal forecasting are taken in consideration by most users, there is an expanding market for a wide range of seasonal forecast applications, providing new opportunities for commercial use of the products. This is particularly the case

of recently developed insurance products linked with weather parameters, or the recently developed electricity market where prices depend heavily on water resources. The probabilistic nature of seasonal forecasting is accepted by many end users, some of whom can utilise the predicted probability density estimates (PDE) of weather events as an essential input to risk models and risk evaluation, e.g. the insurance industry.

The users noted that the reliability of the forecast was an important issue and that the seasonal forecasts need to be provided with verification statistics and quality evaluations based on validations and past performance assessments in order to get an optimal benefit from their use.

Among product requirements from seasonal forecasting system there are integrated quantities such as predictions of heating days/degree days and PDE of the occurrence of weather or seasonal events such as the onset of the rainy season, the snow melt or extreme events, such as gales or the occurrence of tropical cyclones.

Following requests from users the Centre’s web pages will be enhanced to give more information about the seasonal forecasting system, its capability and the quality of the products based on past performance evaluation. Thorough evaluation will require study of multiple decades. ERA-40 will provide a basis for this, but in any case, this evaluation will take several years.

APPENDIX

SEASONAL FORECASTING AT ECMWF

1. Forecasting system

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 world-wide, but even without El Nino there are many factors which influence the weather. The large El Nino of 1997/98 caused climate perturbations world-wide costing billions of dollars. (35 billion is the WMO estimate for the 97/98 ENSO 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. The coupled model currently consists of the ECMWF atmospheric model (cycle 15r8), coupled to the HOPE ocean general circulation model, developed at the Max Planck Institute in Hamburg. Currently the atmospheric model is run at T63 resolution (1.8 x 1.8 degrees) with 31 levels in the vertical. The ocean model has lower resolution in the extratropics but higher resolution in the equatorial region in order to resolve ocean baroclinic waves and processes which are tightly trapped to the equator. The ocean model has 20 levels in the vertical. Since it is the heat content of the upper ocean which is most important for interaction with the atmosphere on seasonal timescales, 8 of the levels are in the upper 200m.

Full coupling is applied between the atmosphere and ocean. Every day the fluxes of momentum, heat and fresh water accumulated by the atmosphere over the previous day are passed to the ocean and used to force the model. In exchange, sea surface temperature is passed to the atmosphere and used to force the atmospheric model. No steps are taken at this stage to limit the interaction of the two media: errors in say the atmospheric model will induce errors in the ocean which may then degrade the atmosphere and so on leading, inter alia, to model drift. The drift in sea surface temperature (SST) is not small compared with the size of the signal being predicted. For example, in a 6-month integration it can it can be as large as ~2 degrees in the tropical Pacific, which is comparable to the amplitude of a moderate El Nino. It varies throughout the year and must be calculated for every start month, requiring considerable computation. The drift is subtracted from the model fields once the integration is complete. Various forecast products are generated, showing both predicted anomalies of SST and the predicted atmospheric response.

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 Nino 3 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: accumulated rainfall, surface pressure and 2m temperature at 00Z.

Each plot is labelled with the period for which it is valid, e.g. ASO 98 is the three month period August - October 1998. The ensemble is made up of forecasts initialized 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. the magnitude of 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 being real is no guarantee of a signal being present in reality. The limited size of our ensembles (typically 30) means that there is a noticeable amount of sampling error in these estimates of probabilities, which must therefore be considered approximate. It is also important to remember that even perfect sampling would 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 plotted probably sample the uncertainty arising from chaotic processes reasonably well, but do not include uncertainty arising from model error, or from inaccuracies in the ocean initial conditions. It is much harder to quantify these uncertainties.

To provide ocean initial conditions for the coupled forecasts, a global analysis of the ocean is performed daily. To obtain the initial state of the ocean, the model is forced with the fluxes from the atmospheric analysis system (the stress, all components of the heat flux, and of the moisture flux). In addition all available thermal data are assimilated. Because the forcing fields are less well known than we would like, and the ocean observing system still developing, there are likely to be sizeable errors in the initial state conditions of the ocean. Currently only thermal data are analysed as for ECMWF. The ocean data are bunched into a data window of a few days (currently 10 days) and an Optimal Interpolation (OI) is performed. The increments derived are then fed in slowly to the model over the next few days until the next assimilation time. By putting the increments in gradually, the model should be able to develop an appropriate velocity field consistent with the density field. However, by spreading the increment over a few days we blur some of the information in the thermal data. For example a Kelvin wave can travel more than 2000 km in the 10 days currently used. The data are automatically quality controlled by comparing with analyses performed without a given datum. One departure from normal OI procedure, is that data are interpolated to model level rather than model interpolated to datum level. This allows an OI to be performed level by level. No vertical coherence is imposed in the assimilation process. No salinity analysis is performed. This is clearly an undesirable feature as there are reasons to believe that salinity plays a nontrivial role in shaping the density field. It is imposed upon us as there are essentially no real-time salinity data with which to perform an analysis. The sensitivity of seasonal predictions to errors in the salinity field is unknown.

2. Future developments of the Centre's Seasonal Forecasting System

An upgraded system with its atmospheric component identical to the atmospheric model used for ERA40 is running in parallel with the operational system. The atmospheric resolution is T95 with 40 vertical levels.The ocean model has higher resolution globally but still not sufficient to resolve eddies in mid latitudes. There are no major changes to the OI scheme per se.

The way the ensemble forecasts are made is the major innovation. A five-member ensemble of ocean analysis is generated to reflect uncertainties in the forcing fields used to drive the ocean model. Each of these analysis is additionally perturbed to reflect uncertainty in SST and to create initial conditions from which a forecast ensemble of 40 members is generated on the 1st of the month..

Although some aspects of uncertainty in ocean initial conditions and in atmospheric physics will be taken into account in generating the ensembles, this is unlikely to represent the full uncertainty. This can be better represented by using several differently-formulated models. To begin with we will investigate a two-model ensemble. The UKMO is installing their coupled model at ECMWF. The ocean initial conditions will be generated independently of the ECMWF analyses, but the models will be run in a similar way, the model output will be made as similar as possible and a common range of products developed. These products will be displayed on the web in the same way and a combined product will be developed. Other NMS may wish to join this initiative.

The model we are using, although at the top end of what is currently feasible computationally, is at a resolution, which does not well represent the detail of tropical storms. We are not yet able to accurately reproduce the tracks, life times and intensities of tropical storms, but we find that the model does reproduce some of the inter-annual variability in tropical storm occurrence.

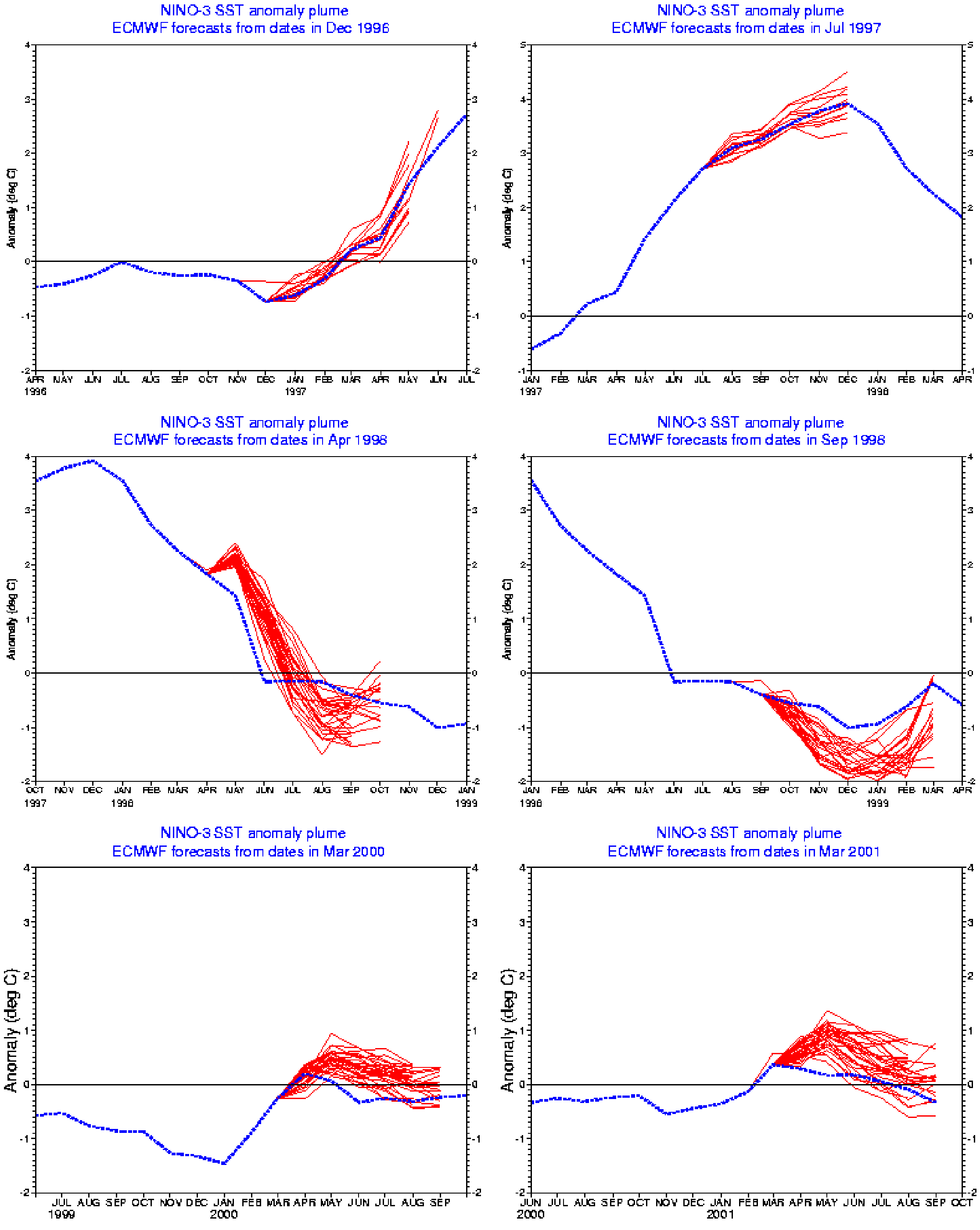

Fig.1 Plume diagrams of Nino-3 SST anomaly for several ensemble forecasts. a) forecast values of monthly mean anomalies from individual members (red curves), b) Reynolds' verifying analysis where available (dashed blue curve).

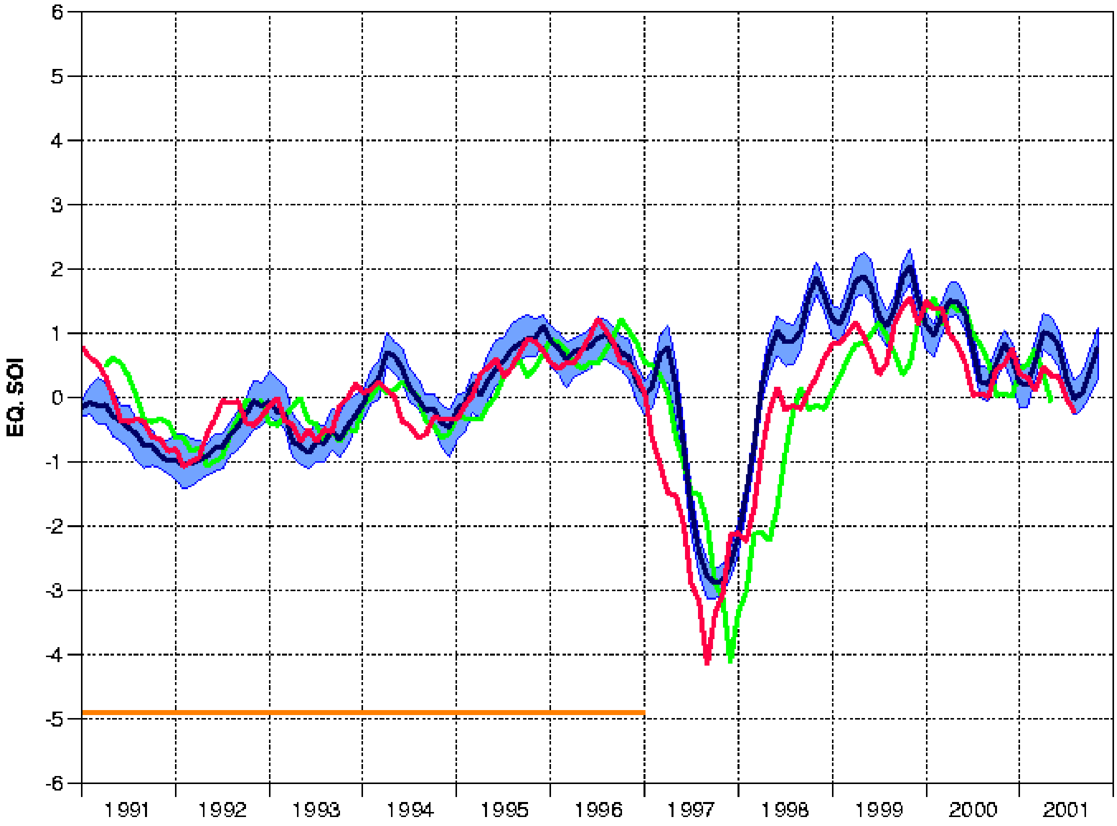

Fig.2 Three-month running mean of Equatorial Southern Oscillation Index (EQSOI): ECMWF operational analysis (red line), median (blue line) and intervals between 0.25 and 0.75 quartile for each ensemble forecast (light blue band), analysis values persisted for 3 months (green line). The forecast anomalies and the verifying anomalies are all computed with respect to model climate and observed climate respectively for the 1991-1996 base period.

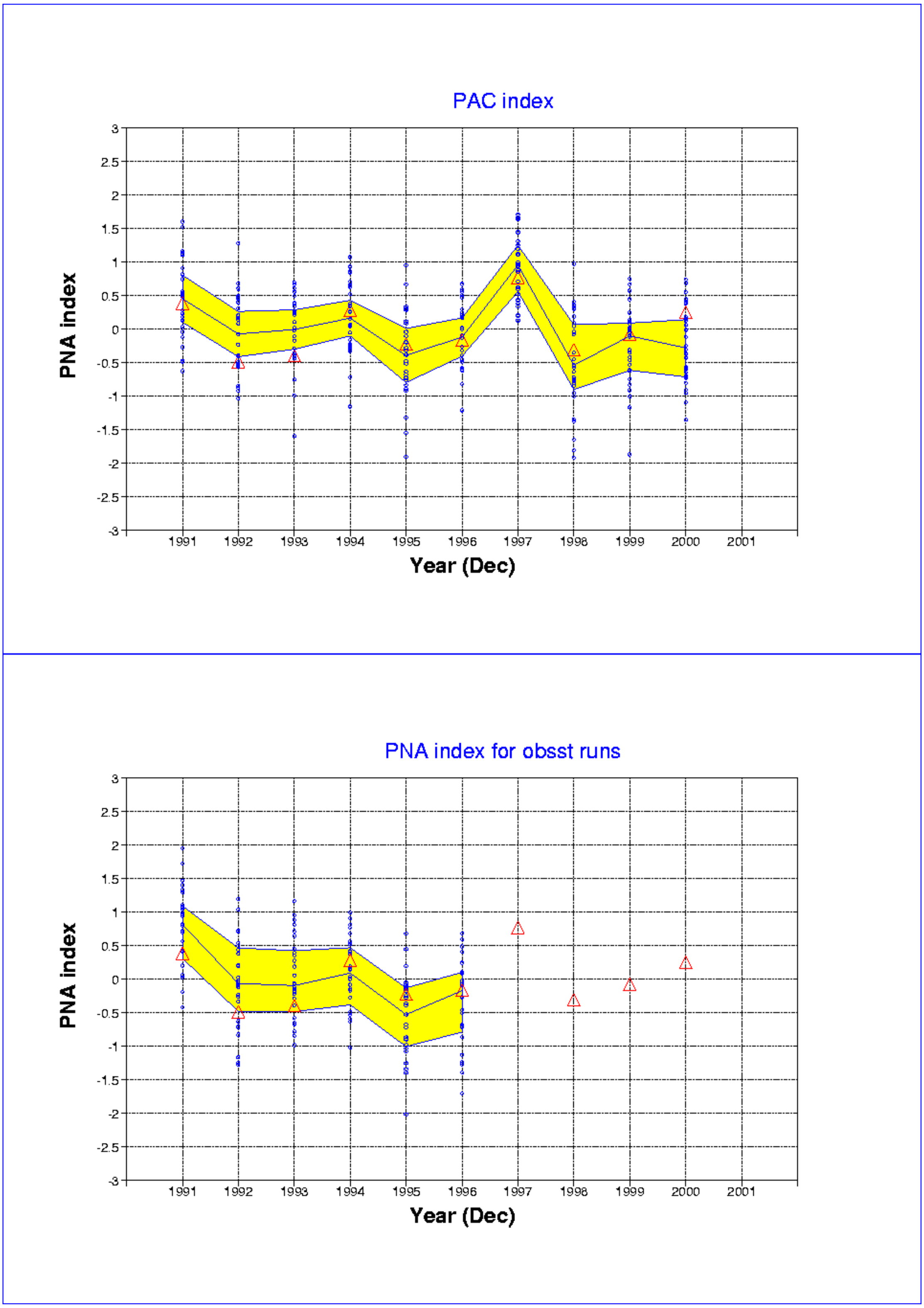

Fig.3 a)Seasonal predictions of Pacific North American pattern, made throughout the 1990's. b) Atmospheric integrations forced by observed SST. Individual forecast values (circles) and observed values (triangles)

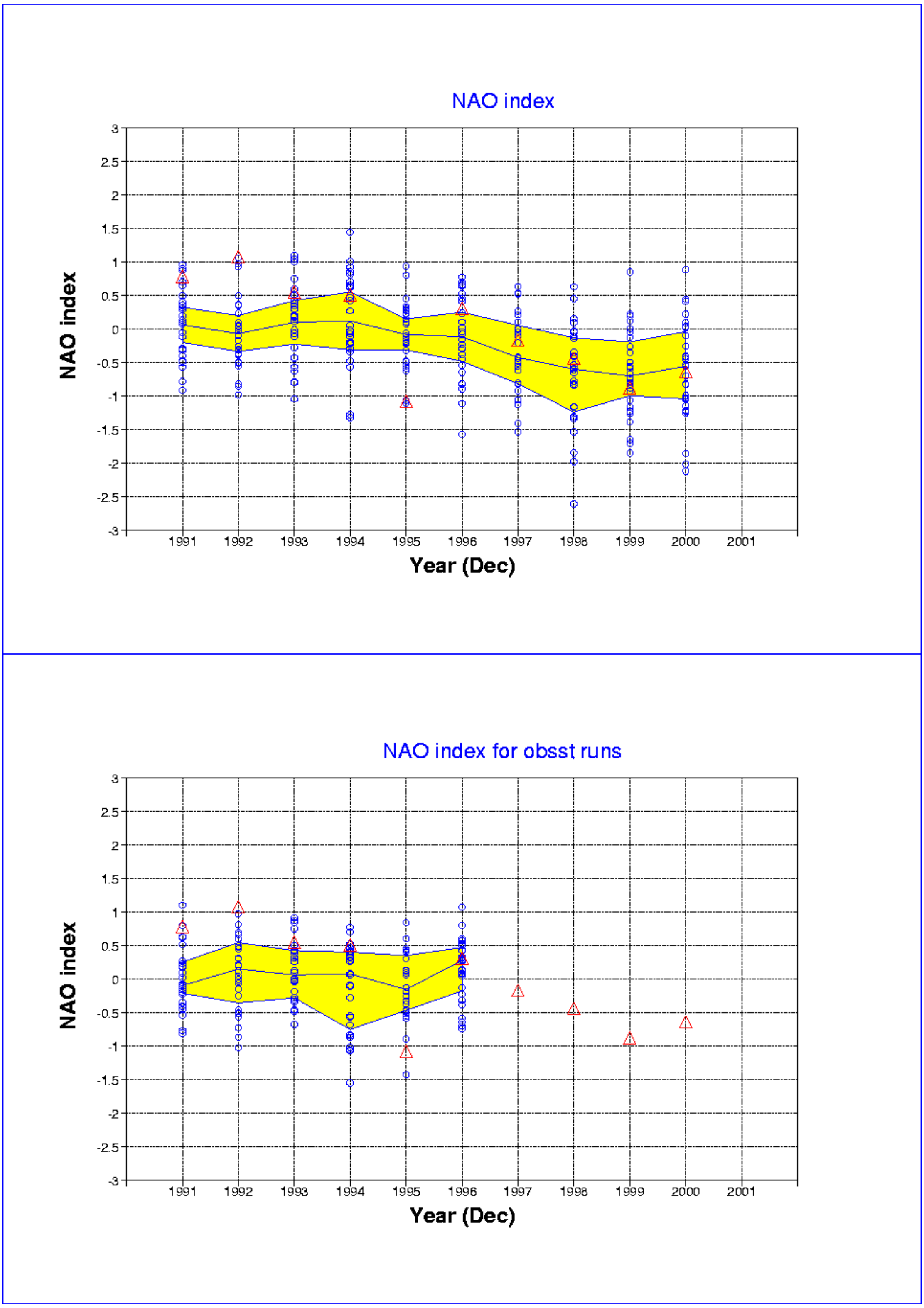

Fig.4 a)Seasonal Predictions of North Atlantic Oscillation pattern, made throughout the 1990's. b) Atmospheric integrations forced by observed SST. Individual forecast values (circles) and observed values (triangles)