Verification of model predicted precipitation over India during the summer monsoon of 1997

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At the National Centre for Medium Range Forecasting in India a spectral model at T80 resolution is integrated everyday to produce a five-day forecast. The precipitation prediction from this model for the monsoon (1st June to 30th September) of 1997 is verified against the observed values from 1333 rain gauge stations over India. The method followed is to get the area average of observed precipitation, by the Thiessen method, for the grid boxes surrounding the 135 grid points covering India. This area average precipitation values are used for comparison with the model forecasts and standard statistical parameters are computed. Since the observed rainfall is measured as accumulated between 0300 UTC of successive days, the model forecast is accumulated between 0300-2700, 2700-5200, 5100-7500 and 7500-9900 hours of forecasts starting with 0000UTC initial conditions.

The grid box average seasonal precipitation for 1997 shows the three regions of heavy rain, namely the leeward sides of western ghat hill range along the west coast of India, the Khasi and Jayantia hills to the north of Bangladesh and eastern end of the monsoon trough adjoining the head of the Bay of Bengal. A plot of the difference between the 27-hr forecast and observed precipitation shows that the rate of forecast precipitation is higher than that observed over the rain shadow in the lee of the western ghat and also over the monsoon trough area while the forecast rain rate is less elsewhere. The total rainfall, summed over all the grid boxes, is close to observed up to the forecast length of 75hrs.

The correlation coefficient between the 27-hr forecast and the observed precipitation has a magnitude exceeding 0.4 over a large part of central India. Since precipitation is the variable most difficult to predict by numerical modelling, this value of correlation coefficient is encouraging.

The quantities like bias, false alarm rate, threat score etc. that give idea about the skill of the forecast have been computed by dividing the range of precipitation in to classes defined by the India Meteorological Department. Results show that the model predicts precipitation on more number of occasions in the light and moderate category while it under predicts events in the rather heavy, heavy and very heavy categories,

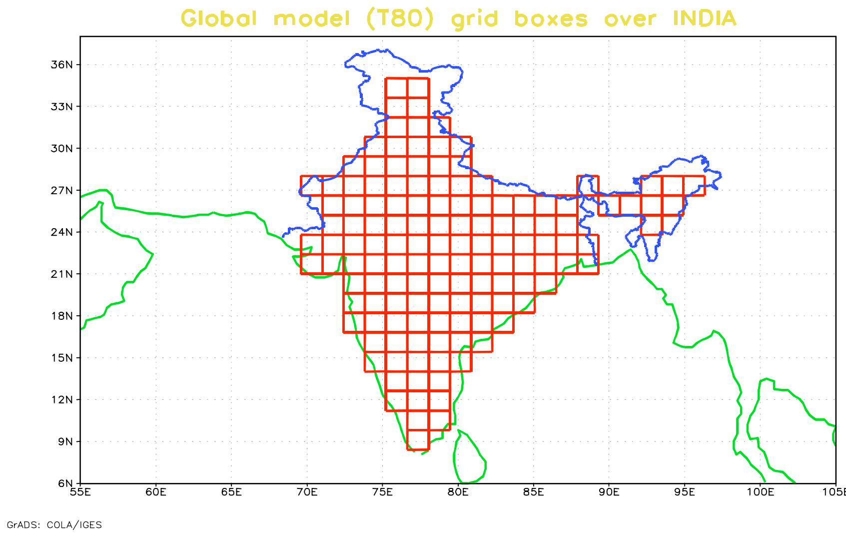
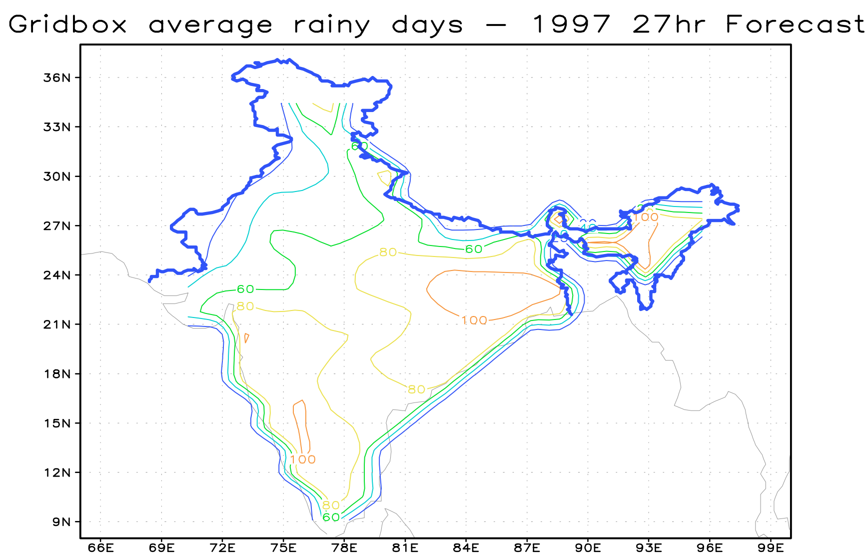
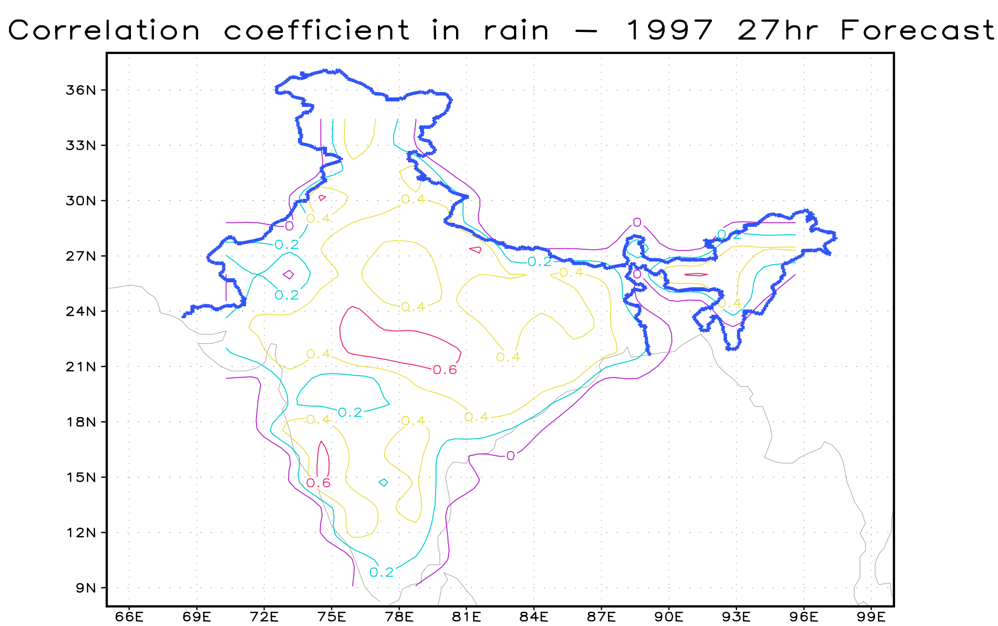


Figure 1. Distribution of 135 grid boxes over India





The Characteristics and Statistics of Daily Extreme Precipitation Events over the United States

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1. Introduction

Extreme weather events (e.g. hurricanes or winter blizzards) can clearly have a major impact on our lives. Yet the link between such extreme events and climate variability and climate change is poorly understood. In this study we examine the regional and seasonal differences in the characteristics of extreme precipitation events over the United States. We present here some initial results of our analysis of both observations and model simulations in which we address the impact of El Nino on extreme events and how well AGCMs produce realistic extreme events and their statistics. The NASA/NCAR GCM is based on the finite-volume dynamical core developed at the DAO (Lin and Rood 1996), with physical parameterizations from the NCAR CCM-3. Three 20 year runs were made, forced with idealized a) cold, b) neutral and c) warm ENSO SST anomalies with 2x2.5 resolution and 32 levels. The simulated climate is described in Chang et al. (2001). We use NOAA daily precipitation observations over the United States for the period 1963-1998. Extreme precipitation is defined from the monthly and annual maximum daily precipitation. The relationships between extreme precipitation at selected grid points and atmospheric circulation are based on composites and regression of daily precipitation anomalies, 300mb height, 850mb wind and sea level pressure anomalies from the model and NCEP/NCAR reanalysis as described below.

2. Linear Regression Model

We consider the simple linear regression model in which a variable Y is regressed against the precipitation extremes X at a base point o. The regression model has the form

$$Y(j,k) = a\,X(o) + e.$$

Where j is the j-th grid point, k is the time lag in days and e is the error in the regression model. The regression links daily extreme precipitation for a particular point $X(o)$ with precipitation and related quantities at all other points Y. We show the average of Y over all times when $X(o)$ is an extreme event (the average conditions that occur when $X(o)$ is an extreme). We also show the regression coefficient a. These show the co-variability, or structure and time evolution of the extreme events.

3. Results

Figure 1 shows a composite of the precipitation (shading), 300mb heights (contours) and 850mb wind (vectors) during extreme precipitation events for each month at base grid point (77.5W, 40N). The left figure shows the results based on 36 years (1963-1998) of daily NOAA precipitation observations and reanalysis. The right figure shows the results based on 60 years of AGCM model simulations. The results show the expected large regional and seasonal changes in the structure and scales of the extreme precipitation events, with continental-scales and strong dynamical controls during the cold season, and highly localized events during the warm season. The AGCM does remarkably well in reproducing the basic structures of the extreme events, though there are some clear deficiencies such as excessive ridging during northwest events. Figure 2 shows the regression coefficient a relating the precipitation extremes at the base point (77.5W,40N) to precipitation at other grid points and at different time lags. The southwest-northeast orientation of the precipitation and its propagation are consistent with the northeastward motion of cyclones along the East Coast. The results indicate that our analysis method appears to work well in characterizing the structure and temporal evolution of extreme precipitation events over the US. Many of the structures are clearly identifiable with well-known intense synoptic systems.

Applying a standard extreme value analysis technique to the annual extreme precipitation, we estimate 10-, 20-, and 50-year return values of simulated and observed climate at every grid point. Extreme value analysis is performed in this study by fitting the generalized extreme value (GEV) distribution to the sample of annual extreme at each grid point using the method of L moments (Hosking 1990). GEV fits samples of extreme values to the distributions that provide more stable estimates of the wings. The T-year return value is estimated by inverting the fitted distribution function. We use a variant of the bootstrap method to estimate the uncertainty in our estimates (see Zwiers et al 1997). Our initial assessment of the impact of the warm and cold ENSO SST forcing indicates that the warm SSTs lead to a greater likelihood of more intense precipitation events in the Gulf States.

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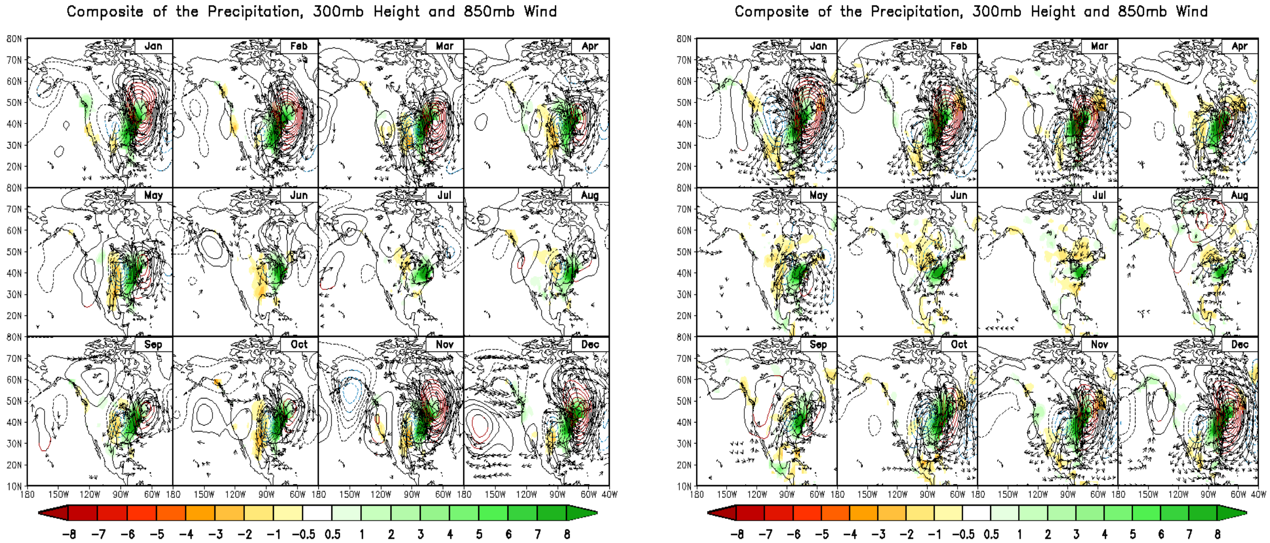

Figure 1. A composite of the precipitation (shading), 300mb heights (contours) and 850mb wind (vectors) during extreme precipitation events for each month at base grid point (77.5W, 40N). Left figure: The results based on 36 years (1963-1998) of daily NOAA precipitation observations and NCEP/NCAR reanalysis. Right figure: The results based on 60 years of NASA/NCAR model simulations. Precipitation has units of mm/day. Height contours are 20m. Colored contours are significant at the 5% level.

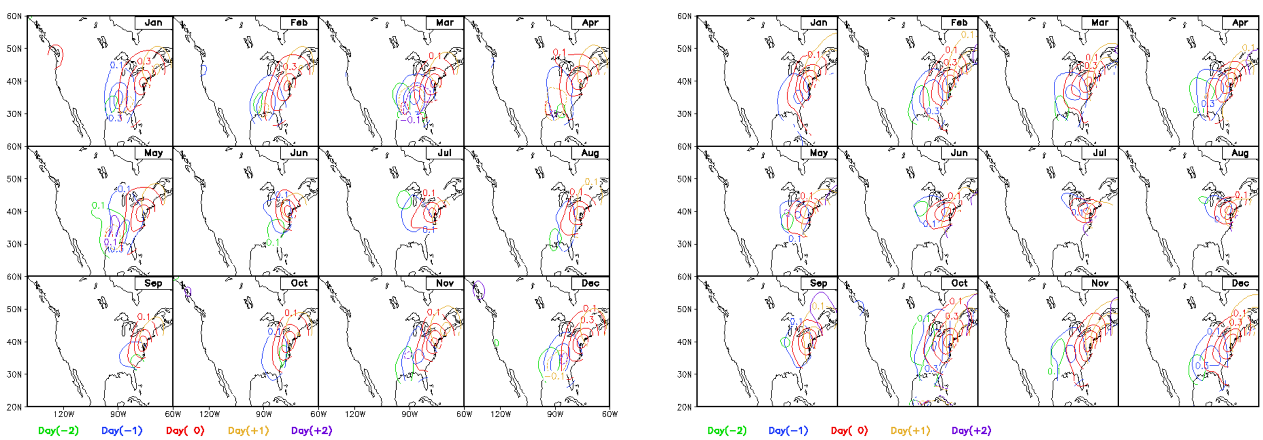

Figure 2. The regression coefficient ***a*** relating the precipitation extremes at the base point (77.5W, 40N) to precipitation at other grid points and at different time lags. Left panel is for the observation, and right panel is for the model. The colors indicate the lag in days. The southwest-northeast orientation of the precipitation and its propagation are consistent with the northeastward motion of cyclones along the East Coast.

Further development of new dynamics for the Met Office Unified Model

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1 Model Features

At the Met Office, the Unified Model is used for all NWP activities and climate change studies, from short-range mesoscale to centuries-long climate runs. A new dynamics for the UM (Cullen et al 1997) is expected to become operational for NWP in the spring of 2002 and for climate change from 2004. The main dynamics features are:

1. Non-hydrostatic deep atmosphere equations.
2. Hybrid-height terrain-following vertical coordinate.
3. Charney-Phillips vertical staggering, C-grid horizontal staggering.
4. 2 time-level semi-implicit, semi-Lagrangian predictor-corrector scheme.
5. 3d variable coefficient, iterative elliptic solver.
6. No basic state profile nor vertical separation elliptic problem.

The physics parametrizations are also being upgraded; details of which will appear elsewhere. In pre-operational and climate testing a number of problems have been identified. Below we highlight a few problems that have been rectified.

2 Vertical coordinate flattening

The South East Asian jet was seen to decelerate during the forecast leading to significant errors in this region. The problem resulted from the vertical coordinate transition from terrain-following at the surface to horizontal at an appropriate upper level. The original scheme involved three regions and two interfaces. The lowest region (nominally the boundary layer levels) was fully terrain following. The topmost region had constant height levels (i.e. horizontal in height). In between the layers were gradually flattened linearly between the two interfaces. This resulted in discontinuities in the volume weighting term ($\Delta z/\Delta\eta$) at the interfaces. These discontinuities may be avoided if the lower interface is removed and if the gradual flattening is made quadratic. Starting the flattening process at the first level results in fewer levels being either fully or nearly terrain-following. With this alternative flattening strategy, the South East Asian jet shows no sign of deceleration and the large errors have been eliminated.

3 Idealised test problems

The ability to set up and run various idealised configurations is being built into the latest release of the UM. These include limited-area tests with fixed, forced or open (cyclic) lateral boundaries. This will allow the running of idealised tests over a very wide range of resolution scales (metres to hundreds of kilometres).

4 Excessive drying in tropical lower stratosphere

In climate runs, excessive drying of the tropical lower stratosphere occurred within a month or two and persisted thereafter. Evidence of such drying was also noted in forecast runs but was controlled somewhat in the data assimilation cycles. Changes to the parametrizations (e.g. fall speed of cloud droplets etc) had little effect. Experiments using higher-order interpolation (quintic rather than cubic) in the semi-Lagrangian advection of moisture variables gave a more satisfactory performance. In fact, it was found that the quintic interpolation needed to be applied only in the vertical to give essentially the same performance. We therefore apply quintic interpolation in the vertical on moisture variables in all configurations.

5 Improved conservation under advection

The lack of conservation under semi-Lagrangian advection is widely recognised by users of such schemes. Limiters can be applied to maintain conservation but to work properly we need to know the mass at the arrival point. In our scheme, we use the semi-Lagrangian advection as a predictor step which means that the mass (or in our case the density) at the arrival point (new time-level) is not available. To ensure conservation of a passive tracer we can do the semi-Lagrangian advection step after the correction step. Applying the conservation constraint then does indeed give good conservation. However, for moisture variables we need to do a preliminary semi-Lagrangian step before the correction step to allow for moist effects in the dynamics and we also need to store the increments due to the physics to be used later in the conservative semi-Lagrangian step. If the physics acts on a tracer (e.g. scavenging by precipitation) we need only store the increments due to the physics until application of the conservative semi-Lagrangian advection. To save re-calculating trajectories and departure points we store the departure points for use in the conservative semi-Lagrangian step.

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Multimodel Superensemble Forecasting of Tropical Cyclones in the Pacific

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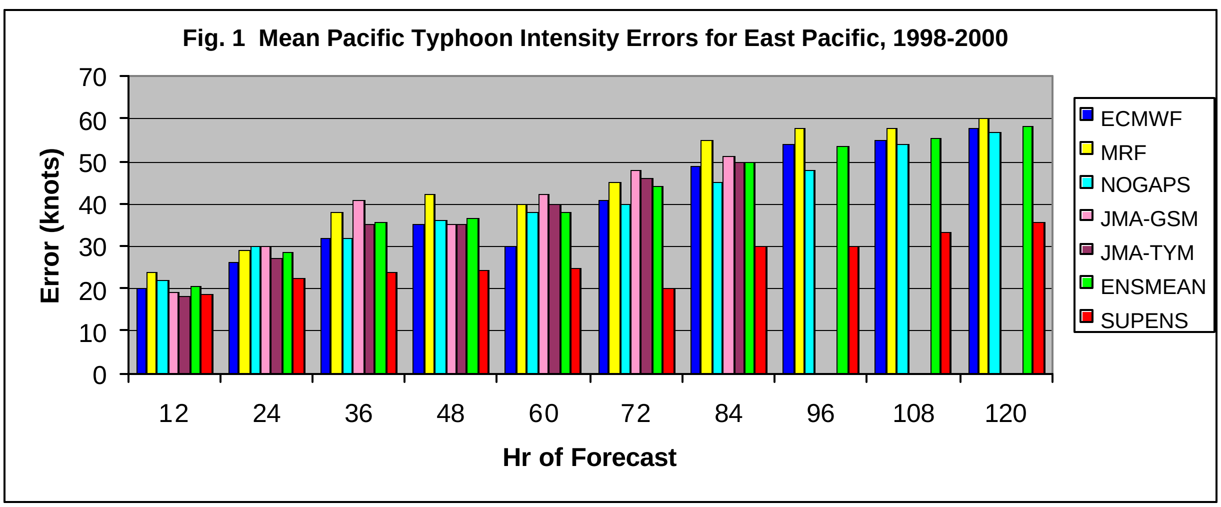
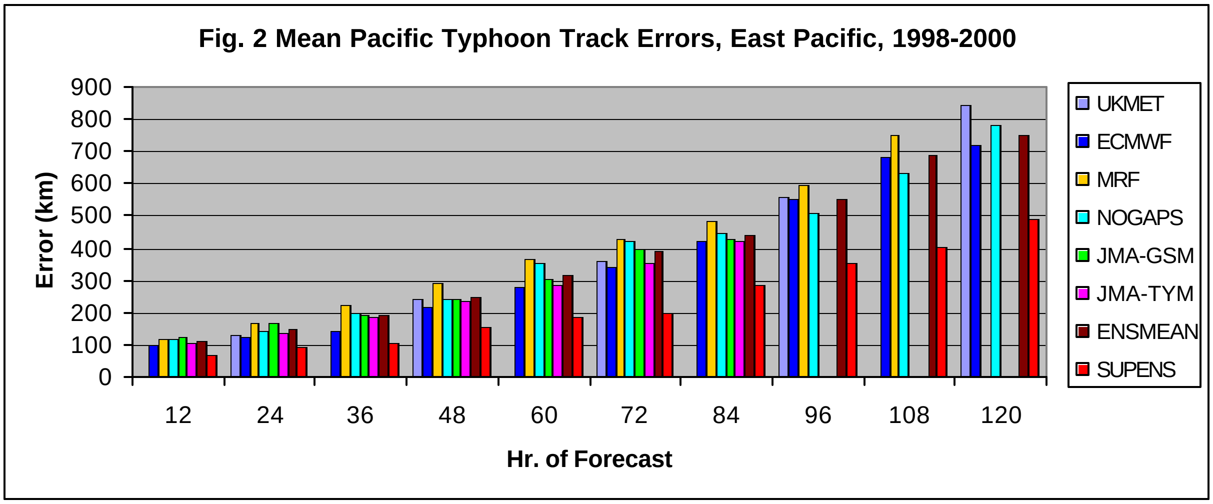
Reduction in position and intensity errors of typhoons (or hurricanes) is a vital forecast issue. It turns out that some measurable improvements are possible from the superensemble methodology (Krishnamurti et al., 1999, 2000, 2001). The current state of the multimodel data sets is far from ideal for performing such studies. Nevertheless, we show in these experimental forecasts that this procedure can be very useful as an operational tool.

Using currently available operational forecast data sets on the tracks and intensity of tropical cyclones over the Pacific Ocean for the years 1998, 1999 and 2000 we have constructed a multimodel superensemble, following our earlier work on the Atlantic hurricanes, Williford et al. (2002). The models included here comprise forecasts from the ECMWF, EMC/NCEP (AVN and MRF), NOGAPS, UKMET and JMA. The superensemble methodology includes a collective bias estimation from a training phase where a multiple regression based least square minimization principle for the model forecasts with respect to the observed measures is employed. This is quite different from a simple bias correction where a mean value is simply shifted. These bias estimates are described by separate weights at every 12-hour of forecasts for each of the member models. Superensemble forecasts for track and intensity are then constructed up to 144-hr into the future using these weights. Some 100 past forecasts of tropical cyclone days are used to define training phase for each basin.



A summary of the mean track and intensity errors for the years 1998-2000 for the forecast phase of superensemble are shown in Figure 1 and Figure 2. The position (Figure 1) and intensity (Figure 2) errors at 12-hour intervals are shown for the member models, ensemble mean and the superensemble for the entire Pacific Ocean region.



We note that the skill from the superensemble is consistently high compared to the member models and the ensemble mean. It is found that we can obtain skill improvements of the order of 61, 138, 159 and 198 km for the tropical cyclone position errors over the best models for forecasts at the end of days 1, 2, 3 and 4 respectively. The intensity forecast skills (rms errors) at days 1, 2, 3 and 4 of forecasts by the superensemble exceed those of the best models by 5, 10, 13 and 20 knots.

This study appears to hold promise for possible use in real time typhoon forecasts. The real time implementation of this methodology does require that we reduce or eliminate altogether the need for long training period from the early storms of the same year. These are issues that need to be addressed by the real time forecast application group who wish to pursue this approach.

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The Ensemble Prediction System for Medium-Range Weather Forecasting at JMA

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The JMA ensemble prediction system (EPS) for medium-range weather forecasting has been operated since March 2001. It produces 9-day forecasts once a day with GSM-T106L40. The ensemble size is 25, of which initial perturbations are generated by bred vectors.

When it became operational, initial perturbations are generated only in the extratropical Northern Hemisphere (90N-20N). This perturbation area may be enough to predict baroclinic disturbances. This version of the EPS is called EPS-0103.

In summer, the weather condition around Japan is influenced by convective activities over the tropical ocean, especially around the Philippines islands. It was found that the ensemble spread of EPS-0103 was smaller than errors of the ensemble mean forecast in the Far East in summer. So initial perturbations were extended into the tropics (90N-20S) and the amplitude of humidity perturbations was increased by about 40% because the analysis error of humidity is relatively larger. This version of the EPS is called EPS-0202. Details of EPS-0202 are as follows.

1. The perturbation area is extended to the tropics.
2. In the breeding cycle, the perturbation amplitude which is based on the total climatological rms variance is increased from 10% to 15%.
3. In EPS-0103, when adding perturbations to the analysis for generating the ensemble of initial conditions, their amplitude was increased by 50%. This procedure was removed in EPS-0202.
4. The order of the perturbation amplitudes of humidity is 21%.

Fig.1 shows that the spread of EPS-0202 is larger than that of EPS-0103. Fig.2 shows that the probabilistic forecasts of EPS-0202 are more skillful than those of EPS-0103 in the Brier score. Fig.3 compares the Brier score for the probabilistic forecasts for intensity tropical cyclones. It is found that EPS-0202 is skillful than EPS-0103.

Based on the above results, EPS-0202 was put into operation in February 2002.

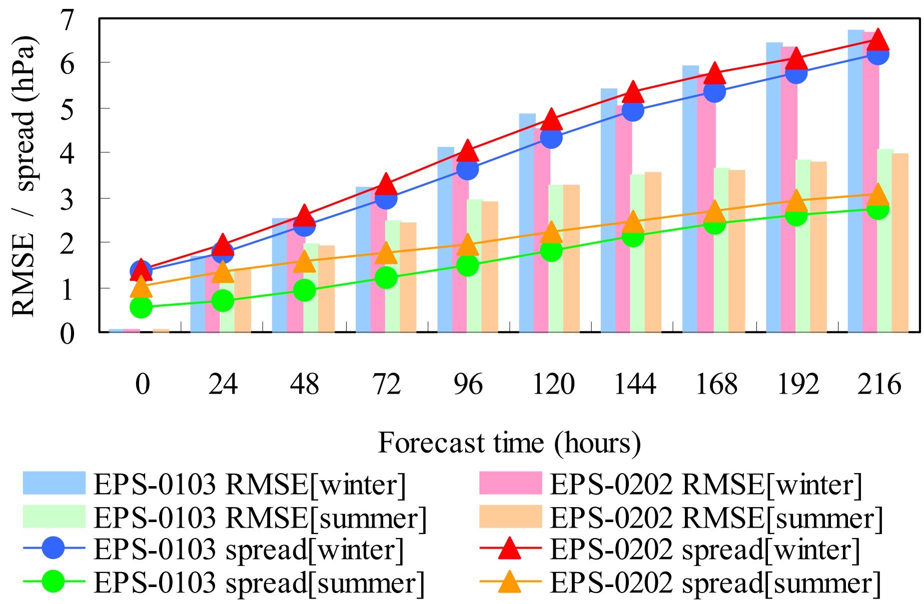

Fig.1 Spread and RMSE of the ensemble mean forecast for MSLP in the Far East in summer(21 June - 20 July 2001) and winter(1 – 31 December 2001).

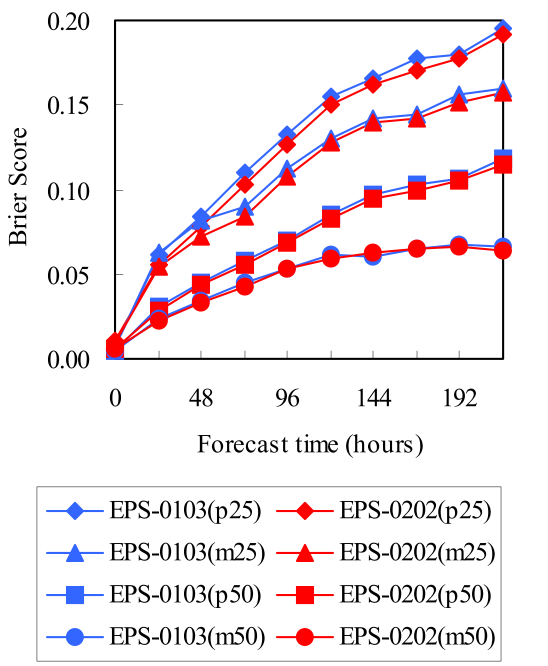

Fig.2 Brier score for the probability forecasts for the Far East 500hPa height for period of 21 June - 20 July 2001. P25,m25,p50 and m50 denote the probabilistic forecasts of height anomalies of more than +25m, less than –25m, more than +50m and less than –50m, respectively.

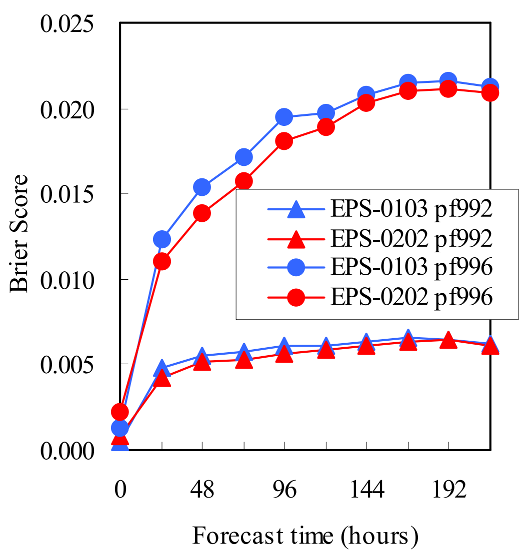

Fig.3 Brier score for the probability forecasts for intensity of tropical cyclones in the Northern Hemisphere sea level pressure for period of 1 July - 24 August 2001. Pf992 and pf998 denote the probabilistic forecasts of sea level pressure around the tropical cyclone below 992hPa and 998hPa, respectively.

Simulation of monsoon disturbances during summer monsoon 1997 in an AGCM

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Monsoon disturbances (MD) such as lows, depressions and cyclones, which produce widespread rainfall during their passage over India, are an important component of Indian Summer Monsoon (ISM). Researchers using observeations have, extensively studied these systems that usually form over Bay of Bengal and move along west/northwest direction. However, very few studies have been reported on the simulation of MDs by Atmospheric General Circulation Models (AGCMs). (Manabe et.al. (1970), Ashok et.al. (2000)). These studies have shown that AGCMs are capable of simulating tropical disturbances although with much lower intensity than the observed. One of the strongest El Niño's in the last century occurred during 1997, the growth rate and intensity of which were exceptional. The sub seasonal behavior of ISM rainfall during June-September (JJAS) 1997 shows pronounced peak in August, which is associated with activity of monsoon depressions. Three depressions formed in August and one each during June and July and a cyclonic storm in September. All these formed in Bay of Bengal and gave widespread rainfall over India (IMD, 1998). The objective of the present work is to investigate whether a relatively low resolution AGCM such as Hadley Center Climate Model (HadAM2b) is capable of simulating MDs in ensemble integrations during 1997. 10-member ensemble integrations for 2-years from 1996-1998, with weekly observed SSTs and initial conditions corresponding to 1st September of 10-years (1986-1995) taken from long term integrations of the same model, are used in the study. The criteria adopted for the classification of MDs is same as that of India Meteorological Department (IMD, 1998). Table-1 shows the frequency of MDs in different categories for JJAS1997 in 10-member ensemble integrations by HadAM2b model.

Table1: Frequency of systems during JJAS1997 in 10-member ensemble simulations by HadAM2b GCM

Ensemble Member	SCIL	DCIL	Depression	Deep Depression	Cyclonic storm	Total
1	9	1	1	0	0	11
2	4	0	1	0	0	5
3	7	1	3	0	0	11
4	4	0	1	0	1	6
5	6	0	0	0	2	8
6	5	0	1	2	2	10
7	4	1	0	0	0	5
8	2	0	0	2	0	4
9	4	0	0	1	0	5
10	8	0	1	0	0	9
Observed	5		1	4	1	11

SCIL stands for Single closed Isobaric Low; DCIL stands for double closed isobaric low

It is seen that the majority of ensemble members simulated the frequency of lows and depressions, reasonably well compared to observations. However, they differ from observations in simulation of frequency of intense systems such as deep depressions and cyclonic storms. Figure 1(a-p) shows spatial distribution of Mean Sea Level Pressure, precipitation, and Relative vorticity at 850hPa and 500hPa, during cyclonic storm simulated by the model for the period 13-16 September respectively. It is seen (Fig.1 (a-d)) that cyclone moves from Bay of Bengal in northwest direction and associated precipitation rate is of the order of 90mm. (fig.1 (e-h)). The cyclonic vorticity with a peak $10*10^{-5}$ sec^{-1} is noticed on 14-15 September. The cyclonic circulation is seen to be significant at 500 hPa (fig.1 (m-p)), which has reduced upward from 850hPa.

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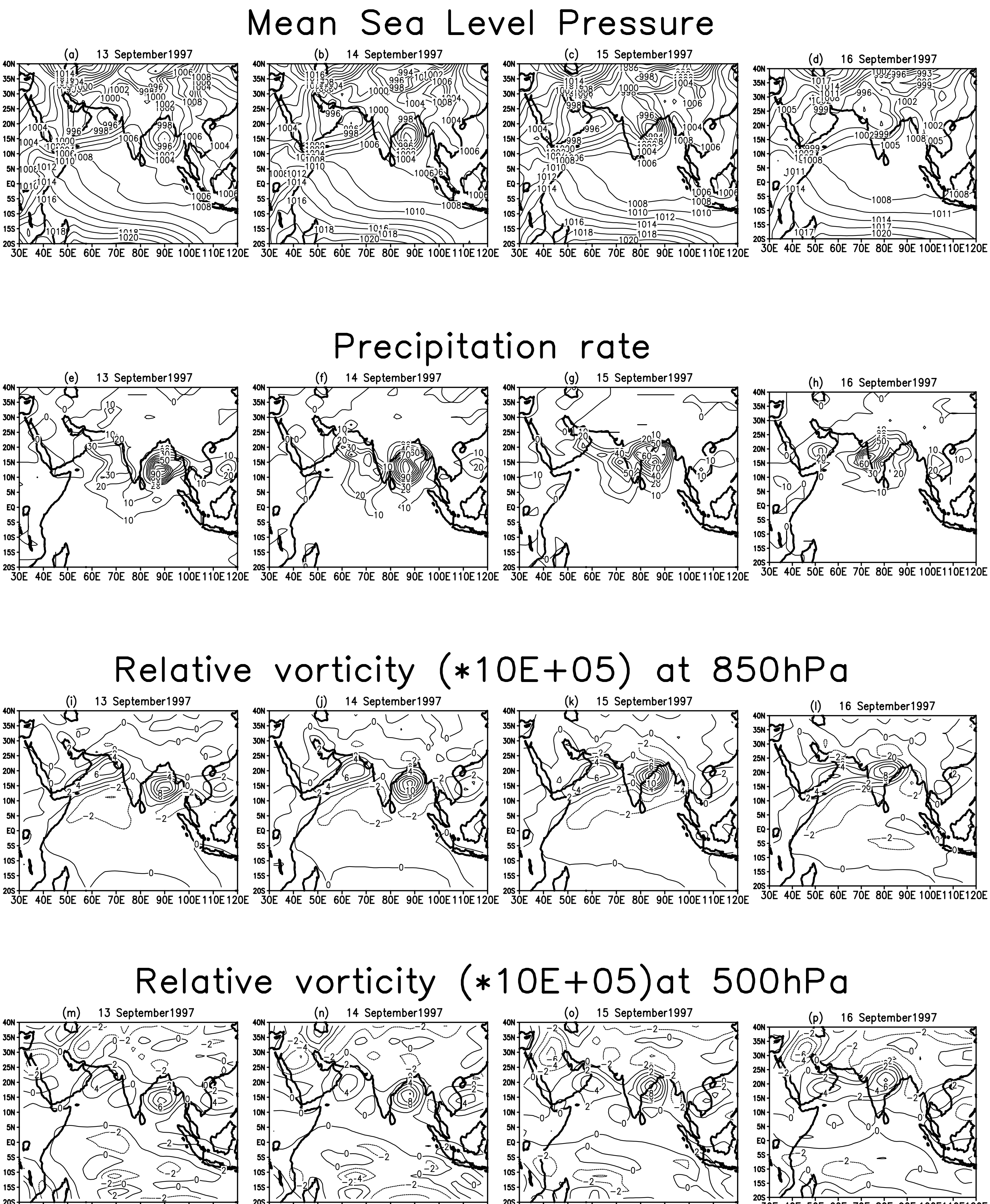
Mean Sea Level Pressure
(a) 13 September1997
(b) 14 September1997
(c) 15 September1997
(d) 16 September1997
Precipitation rate
(e) 13 September1997
(f) 14 September1997
(g) 15 September1997
(h) 16 September1997
Relative vorticity (*10E+05) at 850hPa
(i) 13 September1997
(j) 14 September1997
(k) 15 September1997
(l) 16 September1997
Relative vorticity (*10E+05)at 500hPa
(m) 13 September1997
(n) 14 September1997
(o) 15 September1997
(p) 16 September1997

FIGURE 1

Pre-Operational trials of the new Met Office Global NWP Model

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In spring 2002 the Met Office is planning to update the formulation of the Unified Model which is used for both global and mesoscale NWP. The formulation changes include both a new dynamical core for the model (Cullen *et al* (1997), (see also article by Davies et al in this issue)) and a new package of parametrizations.

The current dynamics is a split-explicit scheme consisting of a forward-backward scheme for the adjustment steps and a Heun scheme for advection. This is being replaced by a semi-implicit, semi-Lagrangian formulation. The new model is also non-hydrostatic with height as the vertical coordinate and has a changed horizontal and vertical grid staggering. In the vertical a Charney-Phillips grid staggering is used i.e. potential temperature and vertical velocity are now on the same half levels whereas everything else is held on the full levels. An Awakawa C grid staggering is utilised in the horizontal.

In addition to the new dynamical core many of the physical parametrizations are either new or have been reformulated. There is a new radiation scheme (Edwards and Slingo (1996)), based on the two-stream equations in both the long-wave and short-wave spectral regions. A new boundary layer scheme has also been introduced into the model (Lock *et al* (2000)) and allows for non-local mixing in unstable regimes, and a cloud microphysical scheme with prognostic ice has been introduced (Wilson and Ballard (1999)). The convection scheme is modified to take into account the changes in the boundary layer scheme and also to include a new scheme for shallow convection. The new model takes advantage of the more accurate GLOBE orography dataset and the gravity wave drag scheme has been reformulated and includes a flow blocking scheme.

A comprehensive set of trials have been carried out to compare the performance of the new model (NM) to that of the current operational global NWP model (OP). In general the NH RMS errors against observations in the NM have been reduced versus the OP model by up to 5%. Long standing systematic biases have been reduced, such as the tropospheric cold bias.The NM shows a marked reduction in numerical noise especially within strong jets near the pole. This reduction can be attributed to the semi-implicit time-stepping.

One area of increasing focus for current NWP forecast models is their ability to forecast extreme events successfully. Two examples are presented in this report. The first is the French storm of 12UTC 27/12/1999 (Figure 1(a)). The NM forecast cyclone at T+72 is significantly deeper (8hPa) than the OP model and has a structure and position much closer to the analysis. Tropical cyclones are also consistently improved with the NM. Statistics calculated over a large number of tropical cyclones shows that the NM is better able to maintain the intensity of the cyclones over the forecast period (Fig. 1(b)) compared to the OP model. The NM also shows on average a 5% improvement in skill predicting the track of the tropical cyclones. One possible reason for this improvement in the prediction of extreme events is that the NM requires significantly less horizontal numerical diffusion than the OP model in order to maintain stability. The new modelling system includes options for idealised studies of the dynamical core and a single column version of the physical parameterizations. Versions still under development include a climate configuration (HadGEM) and a portable version.

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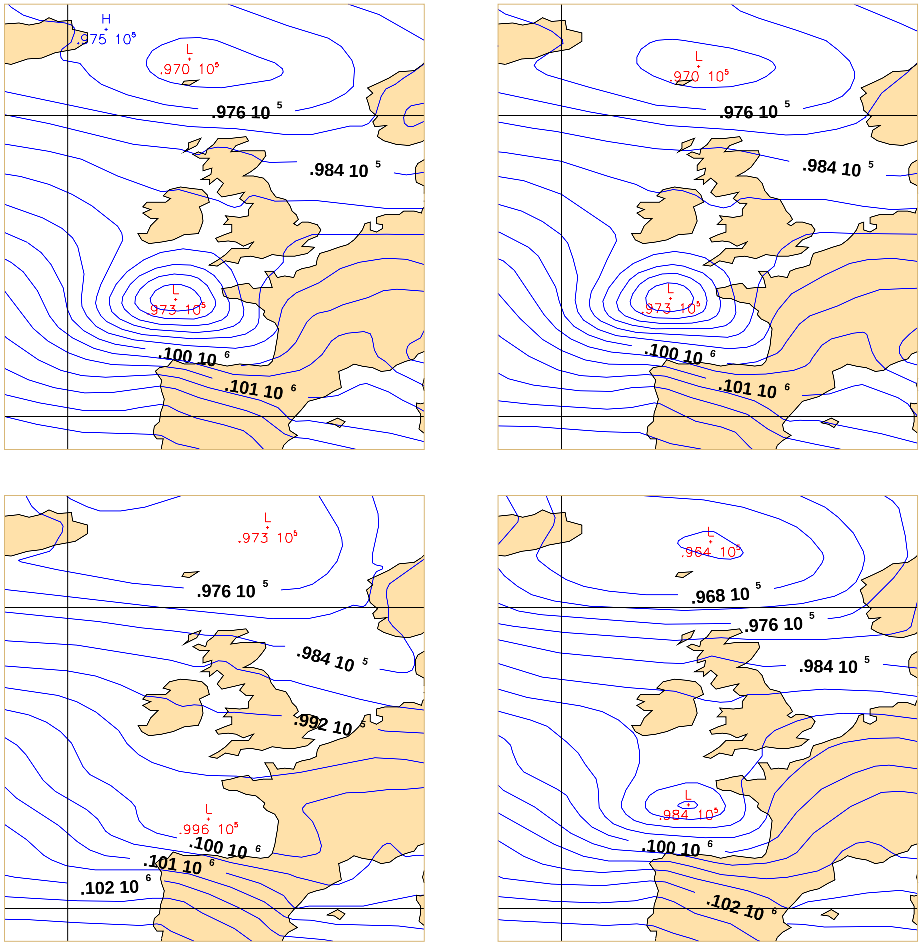
(a)



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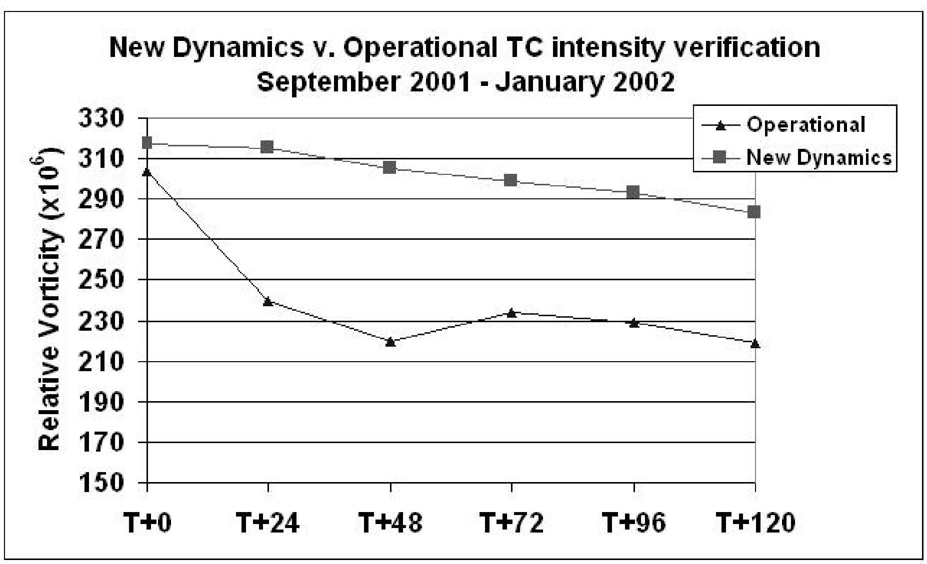

Figure 1: (a) the French storm of 12UTC 27/12/1999. Top left and top right are shown the operational (OP) and new model (NM) analysis respectively. Bottom left and bottom right are shown the OP and NM forecasts at T+72. The NM forecast is 8hPa deeper and has a superior structure. (b) Tropical cyclone verification statistics for Sep 2001 to Jan 2002. The new model (NM) maintains more intense TC throughout the forecast period. Note new dynamics in the plot is equivalent to the new model described in the text.

Short Range Ensemble Forecasting at Météo-France : a preliminary study

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Over the past few years ensemble prediction has come to the fore as a major element in the operational weather forecasting. After being exploited in the medium-range prediction, ensembles begin to be used in the short-range frame (Tracton et al, 1998). We are presenting here the description of an experimental ensemble developped at Météo-France in the PEACE[1] project. This ensemble is devoted to detect rare severe events such as storms in the short range (24-48h). Emphasis is placed on assessing skill of predicting strong wind speed probabilities.

Because of heavy computational cost, the ensemble is limited to 11 members (10 perturbed + 1 control). It is based on the global spectral ARPEGE model (Courtier et al, 1991) with a nominal truncature of T199 and a stretching coefficient of 3.5 (which corresponds to an equivalent grid mesh of about 20 km over France). Initial perturbations used in the ensemble are generated by the singular vectors technics. One particular feature is the vectors optimization over a limited area (fig. 1) including the Western Europe as it was done in Hersbach (2000). By this way, we insure that pertubations will be efficient in the area of interest. Different areas and optimization times are under test. No physics (apart a simplified physics including diffusion) is used in singular vectors computation. Total energy norm is used both at initial and final time with T63 linearized and adjoint versions of the model.

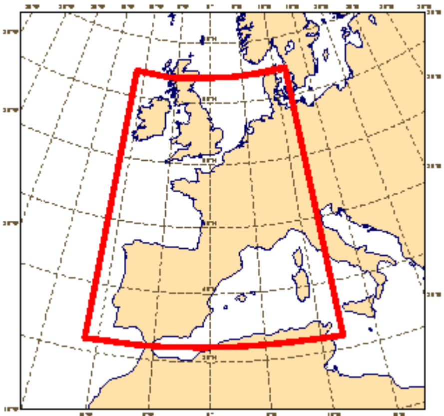

fig.1 Targetting area

The experimental ensemble was tested and compared to ECMWF Ensemble Prediction System over a sample of 61 cases of observed or/and forecast storms between Winter 1998 and Spring 2001. The ensemble distribution statistical consistancy was checked and probabilty scores were computed for different wind speed thresholds.

Results show a usefull information in the skill prediction especially for the mean sea level pressure and most of the time an improvement in the ensemble mean RMS score compared to the control. Concerning the probabilistic score on the 10 m Wind speed, allthough the EPS gets (fig. 2) a better reliability (which can be explained by the higher number of members and can be improved by the way of calibration), the experimental ensemble (named “REF” on the figures) seems to be more skillfull in terms of resolution (fig. 3). This is an encouraging point because resolution represents an intrinsic quality of the ensemble and quantify the informative skill of the ensemble.

[1] PEACE : Prévision d’Ensemble A Courte Echéance

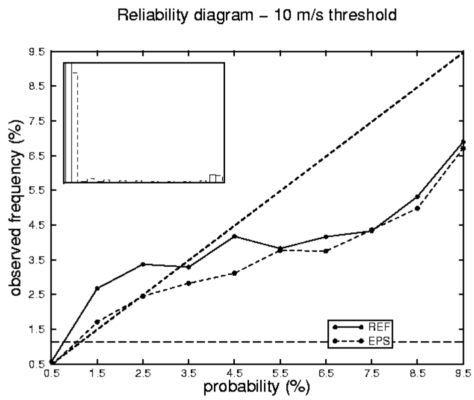

fig. 2 reliability diagram 10m Wind Speed – 10 m/s threshold

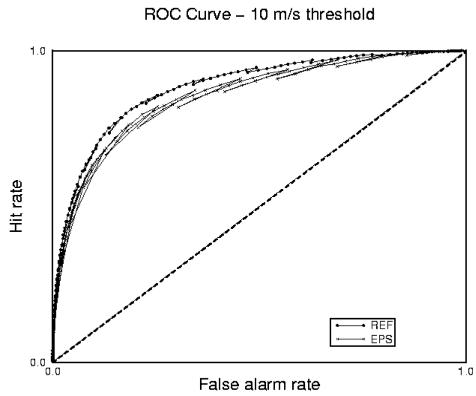

fig.3 ROC curve 10m Wind Speed – 10 m/s threshold

The development of this short range ensemble is in its first stage. Improvements will be necessary in different ways :

- Inclusion of past errors in the initial state uncertainties sampling. Different methods will be tested :
  - evolved singular vectors
  - hessian norm in the SV computation (including analysis error statistics)
  - blending-breeding cycle. This last method uses a breeding cycle, but instead of re-scaling the perturbations, the large scales/low waves are kept from the control analysis at each assimilation cycle step (every 6 hours) while the the small scales/short waves come from the perturbed guess. The selection is done by means of the digital filter technics.
- Enhancement of model perturbations by tunning physical parametrizations.

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Spectrum of Linearized Operator of Atmospheric Circulation Hydrodynamic Model: Method of Evaluation and Applications

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Eigen vectors of a linearized operator of an atmospheric circulation hydrodynamic model are well known in meteorology as singular vectors (SV's). A method of evaluation of these vectors is known as a breeding-method. The concern to SV's has arisen in connection with usage of an ensemble of hydrodynamic forecasts (Tracton and Kalnay, 1993).

Consider a method of SV's evaluation. Let Δt be a short time interval, $\boldsymbol{X}_0$ be an initial state (initial data) in an instant t_0, $\boldsymbol{Y}_0$ be a result of integration of a model on a time interval $[t_0,t_0+\Delta t]$. Let $\Delta\boldsymbol{X}_0$ be an initial perturbation and let the norm ($|\Delta\boldsymbol{X}_0|=<\Delta\boldsymbol{X}_0,\Delta\boldsymbol{X}_0>^{0.5}$, $<*,*>$ is a scalar product) of this perturbation be a peer to the standard of errors of measuring and analysis. By $\boldsymbol{Y}_1$ denotes the result of integration of a model on the time interval $[t_0,t_0+\Delta t]$ from an initial state $\boldsymbol{X}_0+\Delta\boldsymbol{X}_0$, we have $\Delta\boldsymbol{X}_1=\Delta\boldsymbol{Y}_0|\Delta\boldsymbol{X}_0||\Delta\boldsymbol{Y}_0|^{-1}$, where $\Delta\boldsymbol{Y}_0=\boldsymbol{Y}_1-\boldsymbol{Y}_0$. Obviously $\Delta\boldsymbol{Y}_0\approx\mathbf{L}\Delta\boldsymbol{X}_0$, where $\mathbf{L}$ is an operator of a hydrodynamic model linearized on the time interval $[t_0,t_0+\Delta t]$.

Using this iterative method $\Delta\boldsymbol{X}_{k+1}=\Delta\boldsymbol{Y}_k|\Delta\boldsymbol{X}_0||\Delta\boldsymbol{Y}_k|^{-1}$, where $\Delta\boldsymbol{Y}_k=\boldsymbol{Y}_{k+1}-\boldsymbol{Y}_0$, $\boldsymbol{Y}_{k+1}$ is a result of integration of a model on the time interval $[t_0,t_0+\Delta t]$ from an initial state $\boldsymbol{X}_0+\Delta\boldsymbol{X}_k$ ($\Delta\boldsymbol{Y}_k\approx\mathbf{L}\Delta\boldsymbol{X}_k$), we shall receive the first SV. The ratio $<\Delta\boldsymbol{Y}_k,\Delta\boldsymbol{X}_k>/<\Delta\boldsymbol{X}_k,\Delta\boldsymbol{X}_k>$ tends to the first (maximum) eigen value λ_1.

For deriving remaining SV's it is necessary to use orthogonalization. For introduction of metric relations the energy scalar product will be used. Scaleted SV's with $\lambda_i>1$ will be used as the perturbation of a hydrodynamic model in the ensemble of forecasts and ensure a maximum ensemble scatter (or variance) (Pichugin et. al., 1998).

The surveyed method is identical to a well-known method of linear algebra. It is R. von Mises method of iterative evaluation of eigen vectors and eigen values of a matrix.

Consider two SV-spectrum applications.

1) All SV's are populations of fields of perturbations. We can consider the perturbation of one of the field, for example H_{500}, we shall denote it as $\boldsymbol{F}(\varphi,\psi)$, where φ and ψ are also geographical coordinates. The spatial distribution of $\boldsymbol{F}$ demonstrates where the most sensitive to errors of measuring and analysis and the most related to dynamic instability geographical bands are posed. Where the absolute values of $\boldsymbol{F}$ are higher there measuring errors influence most hardly the result of integration of a model.

If the major sampling SV's ($\boldsymbol{F}$) is accumulated, then using the sampling principal components (of $\boldsymbol{F}$) regression and regression experiments design methods we can realize selection of the most informative geographical points related to the dynamic instability (Pichugin and Pokrovsky, 1992).

2) SV-spectrum $\{\lambda_i\}$ is a performance of instability of an initial state. For example a spectral radius (λ_1) is a good statistical predictor (regressor) for dynamic forecast skill (of error of the forecast). On experimental data, λ_1 correlates with a mean square error of a hydrodynamic monthly forecast of the field H_{500} (r=0,4 with a significance level α=0.001, after elimination of seasonal effects r=0,24 with a significance level α=0.05). For statistical prediction of an error of hydrodynamic forecast in the regression equation to this predictor it is possible to add the other

predictors describing instability of hydrodynamic forecast (or an initial state), for example estimations of variances of the field H_{500} in different geographical points obtained by hydrodynamic forecast ensemble (and see 1-st application).

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Extended configuration of the Met Office Unified Model.

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The Met Office Unified Model (UM) (Cullen 1993) is used for atmospheric modelling on timescales ranging from hours for weather forecasting to centuries for climate prediction. We describe developments of a vertically extended version of this model.

New dynamical core.

The new dynamical core (Staniforth et al 2001) improves on the continuous equations used in the previous model (White and Bromley 1995) by including acceleration (Dw/Dt) in the vertical momentum equation. Solutions are obtained using a semi-implicit 2 time-level approach and advection is carried out by a 3D Semi-Lagrangian scheme. This new version of the UM runs on an Arakawa C grid in the horizontal and a Charney-Phillips grid on a height-based coordinate in the vertical (Cullen et al. 1997). See Davies et al (this report) for further details. The choice of levels for an extended model was constrained by computing costs incurred by including extra levels to span the stratosphere and a requirement that lower levels coincide with levels in the tropospheric model to allow clear intercomparisons and use of the same parametrizations. A 50-level model that meets these requirements is being tested. Consecutive levels in the lower stratosphere are just over 1km apart. This increases with height to around 5km near the model top at 63km, in the lower mesosphere.

The upper panels in Fig.1 show winds from the 50-level model with the same parametrizations as used for tropospheric modelling. The basic stratospheric annual cycle is reproduced but stratospheric winds are overestimated and do not show the observed upper stratospheric maxima. The tropical winds are in more serious error. Fig.2 (upper) shows evidence of a semi-annual oscillation (SAO) but with a strong easterly bias and the quasi-biennial oscillation (QBO) is absent from this integration.

Updated physical parametrizations.

Including a version of the Ultra Simple Spectral Parameterization for gravity waves (Warner and McIntyre 2001) was previously shown to improve the middle atmosphere version of this model (Scaife et al 2000, 2002). Fig.1 shows that a similar experiment for the 50-level model alleviates biases in upper level winds. Resulting winds have reasonable strength, especially if all remaining momentum flux from the spectral gravity wave parametrization is dissipated in the top model layer (as might be expected given the downward control theory of Haynes et al (1991)). The tropical stratosphere in the model is greatly improved (Fig.2) with a realistic looking QBO and improvement in the SAO (c.f. Scaife et al 2002). Nevertheless, upper level easterly biases remain in the tropics and winter jets do not tilt far enough towards the equator.

Other horizontal resolutions are being investigated and the 50-level model will be tested for possible use in operational forecasting and climate prediction work.

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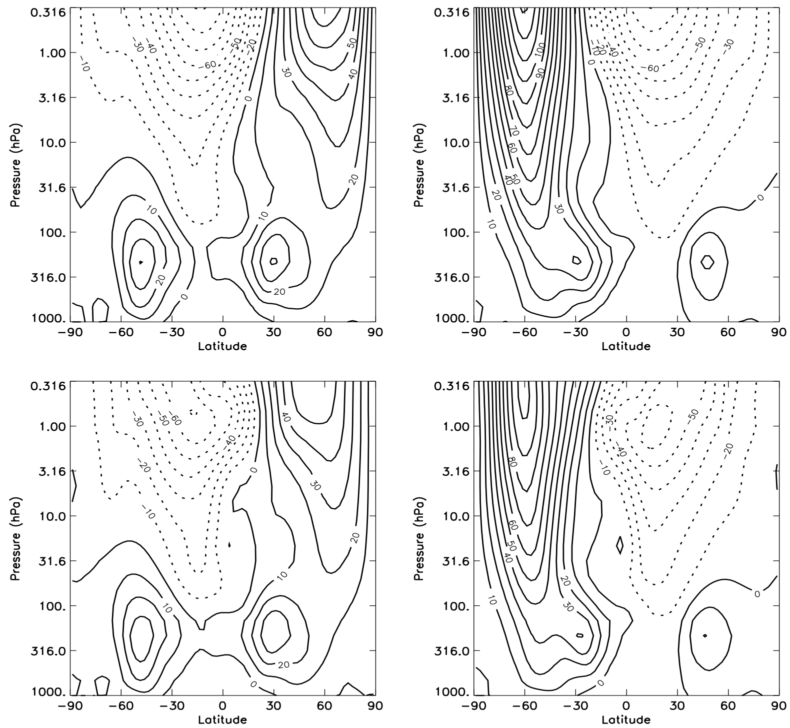

Figure 1: Zonal wind for January (left) and July (right) for the N48L50 model with the new dynamical core (upper) and new dynamical core plus improved parametrizations (lower). (N48=>96x73 lat-lon grid)

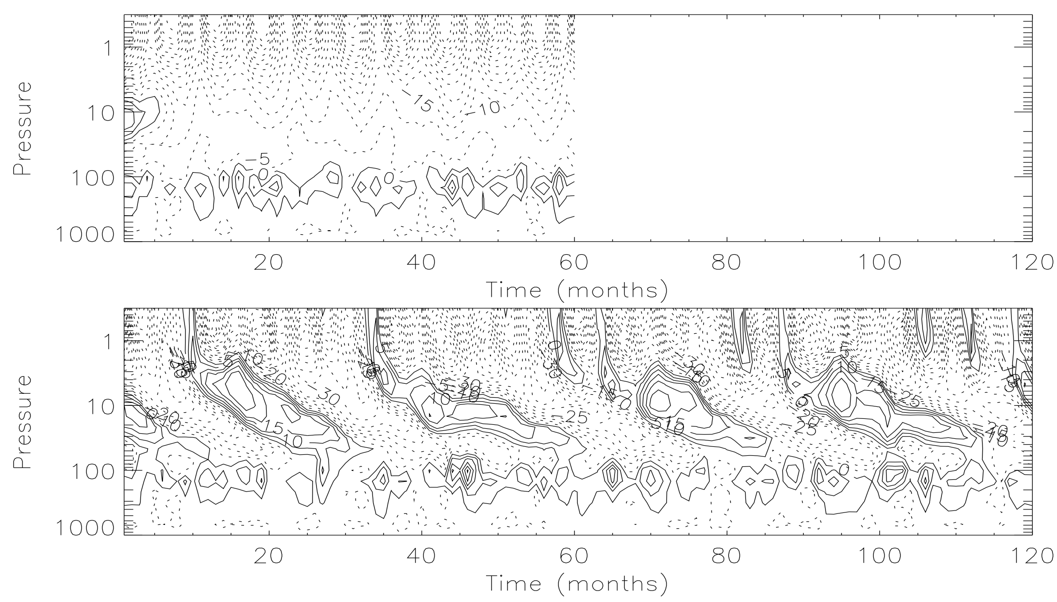

Figure 2: Zonal wind over the equator for the N48L50 model with the new dynamical core (upper) and new dynamical core plus improved parametrizations (lower).

Simulations of Long-Term Drought in the United States Great Plains

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The United States Great Plains experienced a number of major droughts during the last century. The 1930s drought was the most severe, lasting for almost a decade, and affecting about 2/3 of the country and parts of Canada. A second major drought occurred during the 1950s. In this study, we present recent progress in understanding the nature of these multi-year droughts in the Great Plains and provide some insight into their predictability. The results are based on an ensemble of nine 70-year (1930-1999) simulations carried out with the NASA Seasonal-to-Interannual Prediction Project (NSIPP-1) atmospheric-land general circulation model (AGCM) run at a horizontal resolution of 2° latitude by 2.5° longitude, and forced by observed sea surface temperatures (SSTs).

Time series (not shown) of the simulated Great Plains precipitation indicate that the model does tend to produce dry conditions during the 1930s (though not during the 1950s). Figure 1 shows the correlation between the ensemble-mean low pass filtered (time scales greater than 6 years) Great Plains precipitation and the SST at all points. The correlations, with a sign change to emphasize the connection with dry conditions over the Great Plains (lower panel), show a large-scale coherent structure that has some similarity to the cold phase of an El Nino/Southern Oscillation (ENSO) event. Reduced precipitation in the Great Plains on these long time scales is associated with negative SST anomalies throughout the central tropical Pacific Ocean, extending northward toward the west coast of North America. The negative SST anomalies are flanked by positive anomalies that extend poleward and eastward from the western tropical Pacific. The upper panel of Figure 1 shows the correlation between the ensemble-mean filtered Great Plains precipitation and the filtered ensemble-mean 200mb height field at all points. The correlations show that Great Plains precipitation is associated with global-scale height anomalies. Dry conditions are associated with positive height anomalies in the middle latitudes of both hemispheres, and reduced heights in the tropics and the high latitudes. We note that the zonally-symmetric structure of the height anomalies found here is similar to that found on interannual time scales during northern summer (Schubert et al. 2001).

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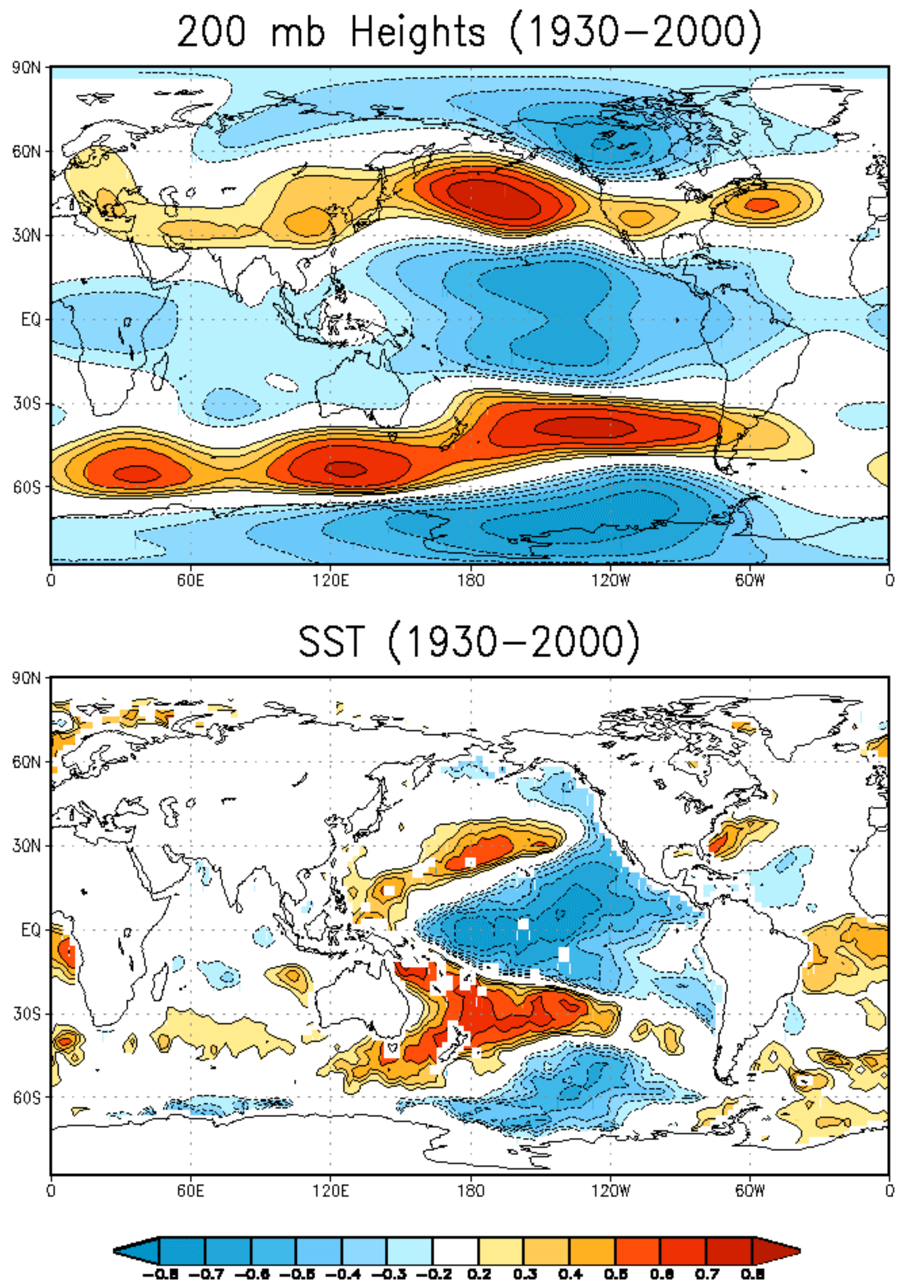

Figure 1: The negative of the correlation between the low-pass filtered ensemble mean simulated precipitation anomalies over the Great Plains and 200mb height (top panel), and SST (bottom panel) for the period 1930-2000.

Superensemble Precipitation Forecasts using TRMM and DMSP Satellite Microwave Imager Products

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This study evaluates short- to medium-range quasi-operational ensemble rainfall forecasts over the global tropics through use of satellite measurements (e.g. TRMM and SSM/I), as a comprehensive extension of the previous multimodel/multianalysis superensemble (SE) studies of rainfall forecasts (Krishnamurti et al., 2001).

Three different precipitation ensemble configurations are first established from a great number of numerical experiments. These configurations are multianalysis (MA), multicumulus-scheme (MC), and multimodel (MM) configurations. A set of MA ensemble comes from the use of several different satellite-derived rain rates through the physical initialization procedure within the Florida State University Global Spectral Model (FSUGSM) system. Six different state-of-the art cumulus parameterization schemes are incorporated into the FSUGSM in order to introduce the MC ensemble configuration. The MM configuration is composed of an FSU control forecast and those provided by five operational numerical weather prediction centers.

The SE is a method of combining individual forecasts from a group of models to produce an optimal ensemble forecast. It differs from a regular ensemble (RE) mean forecast in that different models are weighed by sets of statistics obtained during a training period prior to the forecast mode. In addition to the original technique (SEO), a possible SE enhancement technique (regression dynamic linear model using the Kalman Filter algorithm (SEK), see West and Harrison, 1997) is then proposed and applied to the above three configurations of ensemble members as well as all of them together (i.e. ALL configuration).

Figures 1 and 2 display respectively 15-day averaged (August 1 to 15, 2000) RMSEs and spatial correlation coefficients of T126 precipitation forecasts for (a) MA, (b) MC, (c) MM, and (d) ALL ensemble configurations over the global tropics, 45^{o}S to 45^{o}N. The forecast skills of RE mean, SEO, individually bias-corrected ensemble (BCE), and SEK are compared with different bars. The training period includes the preceding 4 months (April 1 to July 31). It is clearly shown in the figures that the best precipitation forecasts are achieved by the SEK method for most of the configurations and forecast days. The skills of MM and ALL configurations are better than those of MA and MC.

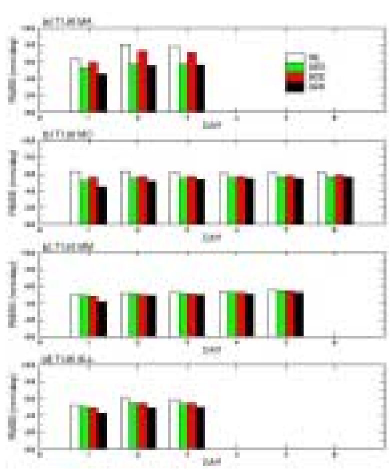

Fig. 1

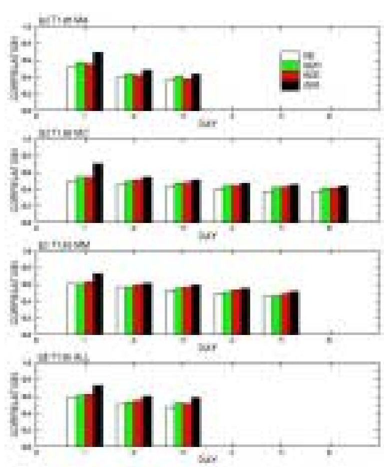

Fig. 2

Figures 3 and 4 show the equitable threat score (ETS) and the bias score (BS) (> 5 mm/d threshold) respectively inspected for 15-day mean precipitation forecasts for MA, MC, MM, and ALL ensemble configurations over the global tropics. The ETS diagram proves also that the SEK is the most effective technique for precipitation forecasts. Unlike that of RMSE or correlation coefficient, the score of SEO surpasses that of BCE in the ALL configuration. It implies that both SE approaches have their superiority to the simple bias correction forecast with improved ensemble members (such as, MM). Their superiority are much more evident in the BS diagram (Figure 4). While the scores of RE and BCE show unrealistically large rain extent, those of both SEO and SEK forecasts remain near the 1.0 line. As the forecast lead time increases, the SEK forecasts seem to be slightly under-forecasting of precipitation in the MA and MC configuration. On the other hand, slightly over-forecasting areas are maintained in MM and ALL configurations, but closest to the 1.0 line. Here, it is clear that compared to the SEO and SEK, the BCE can not efficiently remove the bias areas.

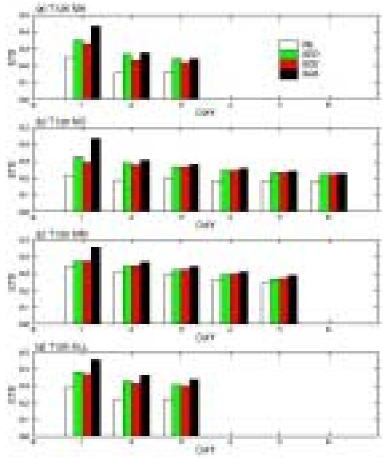

Fig.3

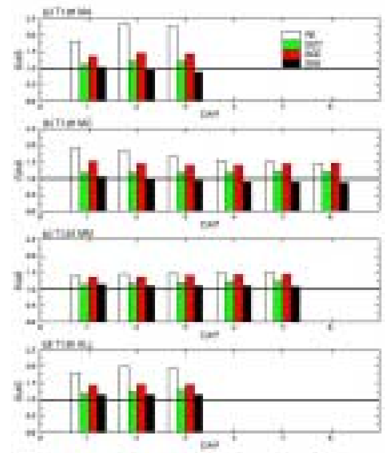

Fig.4

In summary, SE precipitation forecasts exhibit invariably superior forecast results to various conventional forecasts, such as individual model, RE mean, and BCE mean forecasts. A notably improved quantitative precipitation forecast is exhibited by the newly proposed SE technique (SEK). The success of the SE concept is owing to its selective nature in the construction of an optimal combination of available forecast products by eliminating spurious information contained in some models. In other words, the better the forecast performances are, the higher the weights, for each ensemble forecast at each grid point for each day of the forecast.

This work was supported by the following grants: NASA: NAG5-4729, NAG5-9662, NSF: ATM-9710336, ATM-9910526, NOAA: NA86GP0031, NA77WA0571, and FSU Research Foundation Cornerstone Award. Computational support was provided by ACNS at the FSU.

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Improvement of Long-Term Forecasts Using Multi-Model Superensemble Technique

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A considerable amount of research may be necessary to address the seasonal forecast issue. Can one provide useful guidance on whether a given region will be wet or dry, warmer or colder, during the coming season? Recently there has been a considerable interest in long-term climate prediction, where the effects of the surface boundaries (the ocean and snow cover) and the internal non-linear dynamics have been explored in numerues studies. Krishnamurti et al. (1999, 2000) produced weather and seasonal climate super-ensemble forecasts using different models and a multiple linear regression. The studies have covered forecasts of hurricanes, global NWP, precipitation and seasonal climate. Basically, the main result from these studies was that the superensemble-based forecasts were quite superior in comparison to participating member models and the bias-removed ensemble mean.

Yun and Krishnamurti (2001) improved Multi-Model Superensemble model using SVD, EOF, and Z-transformation technique. The new postprocessing algorithm based on multiple regression of multi-model solutions toward observed fields during a training period is one of the best solutions for long-term prediction. Due to the cancellation of biases among different models, the forecast superensemble errors are quite small. Our study shows that the new superensemble techniques reduce the forecast errors below those of the bias-removed ensemble mean and the conventional superensemble technique.

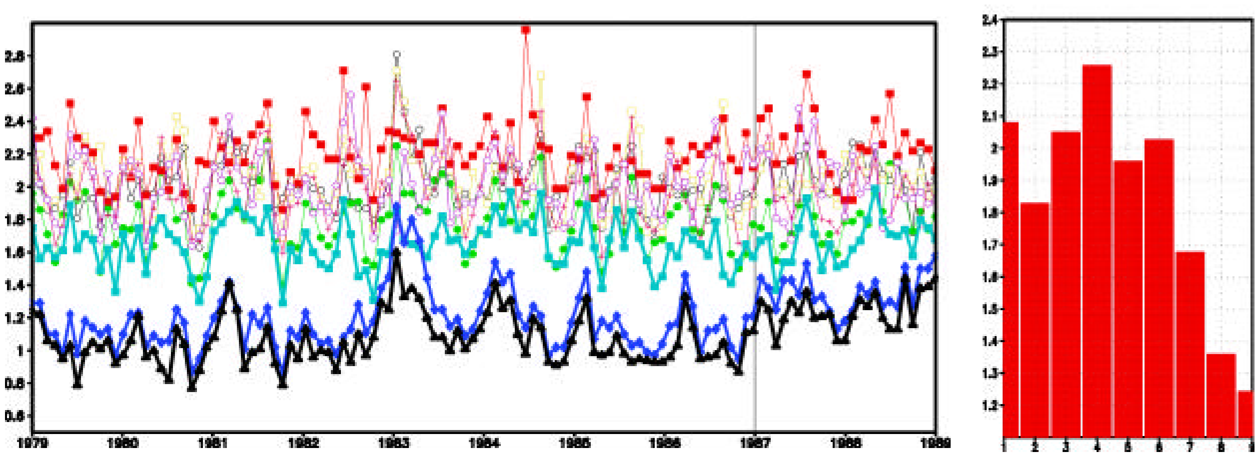

Fig. 1. The RMS errors of global precipitation forecast for the multimodels (marked line) and for the ensemble mean (green line), and conventional (blue line) and new (black line) superensemble method. The numbers from 1 to 6 in the right figure denotes mean RMSE of 6 multi-models and the numbers 7, 8, and 9 indicate the RMSE of the ensemble mean, conventional -, and new method, respectively. Units: mm/day

Using six AMIP models, the performance of the old and new multiple regression methods are compared. The first two approaches utilize a simple pointwise multiple linear regression technique based on Gauss-Jordan and SVD (Singular Value Decomposition) regression models. These were constructed using covariance matrices where the bias and annual cycle were removed. In another new technique, weights were determined for the superensemble forecast using PCs of EOF analyses and low frequency filtered data. The regression is performed in EOF space and in the frequency domain. It is shown that the results of the proposed techniques are clearly better than those of the conventional superensemble method. The superensemble forecast based on the SVD method appears to give the best results due to the computing of the covariance matrix. Obviously, the SVD technique explains the variance in the first case better than the EOF technique in the second case. In the latter, it appears advisable to compute the regression coefficients in the signal space.

Construction of multi-model superensemble using SVD

The singular value decomposition (SVD) is applied to the construction of the superensemble forecast to the computing of the correlation coefficients between different model forecasts, since the SVD is one way of diagonalizing the symmetric covariance matrix. $F_{i,t} = f_{i,1} \cdots f_{i,t}$ describes the model forecast fields in the time domain. The cross-covariance matrix of the anomaly (F') forecast fields with the seasonal cycle-removed is built for both the Gauss-Jordan and SVD methods.

$$C_{i,j} = \sum_{t=1}^{T} \sum_{l=1}^{L} F'_{i,l}(t) F'_{j,l}(t), \tag{1}$$

where, t and l denote time and gridpoint indices, respectively. The SVD of the covariance matrix is its decomposition of the product of three different matrices. This pointwise regression of the SVD method removes the singular vector problem that can't be entirely solved with the conventional Gauss-Jordan elimination method. An aspect of variance analysis, SVD is the method for solving most linear least-squares problems and produces a solution that is the best approximation in the least-square sense. Thus the SVD method explains the maximum variance using the orthonormal basis.

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