Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 1751-1757.

THE MASTER SUPER MODEL ENSEMBLE SYSTEM (MSMES)

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1. INTRODUCTION

Motivated by:

(a) A model Intercomparison Program established in 2003 in South America as part of the SALLJEX campaign (a joint CLIVAR/GEWEX activity) in order to test the ability of regional and global models to reproduce a particular convective mesoscale system in the northern part of Argentina;
(b)The existence of about ten different model forecasts up to 5 days in addition to the products of the main global forecast centers, several running ensemble forecasting, totaling about 40 different daily forecasts;
(c)The THORPEX goals to improve predictability in the prediction of weather, several research and operational institutions agreed on the initiative of the Regional Laboratory of Regional Meteorology and Applications – MASTER at the University of São Paulo in Brazil to conduct an operational model intercomparison activity aiming the construction of a super-model ensemble for South America, with emphasis in the Plata Basin. The availability of such a large set of numerical forecast products available through internet provided an unique opportunity to explore predictability is an area where weather events, particularly rain producing, are very significant for the regional economy (about 2/3 of the S. American economy is located in the Plata Basin). Predictability of the weather events (Palmer 2003) is clearly associated in this particularly complex in view of the interaction of tropical and extratropical systems. Typical mid-latitude systems are fed with moisture from the Amazon and perturbations in the trade winds bring additional complexity to weather forecasting in the Plata Basin.

The experience provided by Krishnamurti et al (2000) with the concept of super-model ensemble in forecasting hurricane trajectories and rain forecasting supports the idea that improvement of the forecasts can be obtained by the proper combination of the individual forecasts through the use of appropriate statistical algorithms. Yun et al. (2002) found that a linear regression system provided an optimal choice of parameters to combine the available numerical forecasts. In the present case, a simple approach based on the concepts of data assimilation provided the mechanism to construct a super-model ensemble with products available on line and open to the general users. A large number of users have been daily accessing the information since the November 2003 (about 2.500 accesses on a daily basis).

The metric of evaluation of the forecast quality implemented in this program is fully based on the ability of the models to reproduce observed values at the surface.

2. IMPLEMENTATION

There are several models outputs currently available of regular basis in S. America. The global models are: CPTEC, NCEP, JMA, ECMWF, UKMO, CMS) and the regional models are:

(a) The Center for Weather Forecasting and Climate Research in Brazil – CPTEC, runs two regional models: the ETA (40 and 20 km resolution, with initial conditions provided by the

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NCEP global analysis and with their own assimilation cycle with and without a data assimilation system) and a Brazilian version of the RAMS model called BRAMS (at 30 km resolution over S. America and 10km over part of the Plata Basin);
(b) The National Meteorological Institute in Brazil - INMET (running the DWD regional model) and different resolution (from 25 km over S. America to 7 km over small areas) with initial conditions provided the DWD global model;
(c) MASTER – USP running about 5 different options of BRAMS on resolutions from 25 over the whole area to 2 km in small areas; (initial conditions from CPTEC and NCEP);
(d) The Meteorological System of the State of Paraná in Brazil – SIMEPAR, with BRAMS at 16km resolution and the ARPS model at the same resolution; (initial condition from CPTEC and NCEP);
(e) The Federal University of Rio de Janeiro with the MM5 model at about 20km resolution over part of the basin and running an ensemble of 10 different executions with perturbations in the physics; (initial condition from NCEP);
(f) The Federal University of Rio Grande do Sul with the BRAMS system at 40 km resolution but higher over the southern part of Brazil; (initial condition from CPTEC and NCEP);
(g) The National Laboratory of Scientific Computation (LNCC) with the ETA model at 27 km resolution; (initial conditions from NCEP and CPTEC);
(h) The meteorological service of the Brazilian marines services running the DMD regional model at 25 km resolution over most of the area and higher at a small domain with initial conditions provided by the global DWD mode;
(I) The University of Buenos Aires with their own limited area model (LMD) with initial conditions provided by NCEP;
(j) The Argentinean Meteorological Service with the ETA model at about 20km resolution (initial conditions also from NCEP);
(k) The University of Chile in Santiago with the MM5 model at about 20km resolution (NCEP initial conditions);
(l) The meteorological system of the State of Santa Catarina in Brazil with the BRAMS systems at 10km resolution, with initial conditions provided by the CPTEC global model;

Almost all models regularly operated by these institutions provide numerical guidance between 48 and 72 hours. A few extend the downscaling of the global products up to 5 days.

Global model forecasts are available from:

(a) CPTEC – the atmospheric models at T126 version up to 15 days, a T213 up to 7 days, with initial conditions provided by the NCEP analysis, a T126 version with the CPTEC data assimilation system (up to 7 days), a coupled ocean-atmosphere model at T126 resolution in the atmosphere up to 30 days and the ensemble forecast system with 15 members (initial condition perturbation), twice a day;

(b) NCEP – the fast cycle of the GFS system (up to 15 days), the latter forecast (available in this case only up to 7 days) and the mean ensemble (out of about 20 members).

There is a special effort now by CPTEC and INMET to make available forecasts of other global centres to the project in order to increase the number of members and explore the possible improvement in predictability.

The question now is: how can we combine several forecasts in an optimal way? A possible solution in based on basic concepts of data assimilation. The objective it to combine the several forecast through the optimisation problem based on the cost function: T= $\sum (T_i-B_i)/MSE_i$, where T_i is the forecast provided by the i^{th} model B_i is the ith model bias and MSE_i is the i^{th} model mean square error. However, the model bias and MSE need an averaging period and how long is this period? Two years is the typical length for MOS. From the point of view of practical applications one should consider much shorter periods: 10, 15, 20, 30 … days? Given that a strong intraseasonal signal has been detected in the model bias it is suggested that a shorter period may lead to stable results. The preliminary experience with the models available in S. America indicates that 15 days provides a rather stable statistical measure.

The products of the intercomparison program and the optimal combination of the all available numerical forecasts are available at the homepage www.master.iag.usp.br and a shortcut can be reached through at http://www.master.iag.usp.br/intercomp.
The first part of the product allows the intercomparison of all available forecasts at the airports (METAR), regular meteorological stations of the national services (SYNOP), automatic data stations operated by CPTEC and other institutions in S. America and more recently the PIRATA buoys in the tropical Atlantic Ocean.

The metric of evaluation is totally centred in the fit of the model forecasts of surface parameters such as temperature, dew point, wind, surface pressure and precipitation. As far as precipitation is concerned, the evaluation is based on: (a) the observed values reported in SYNOP and the automatic data stations participating in the effort, (b) satellite estimates based on three different algorithms.

3. EXAMPLES

A simple example of the improvement of the quality of the forecasts is described in this session. The metric of evaluation is based on the BIAS, Mean Square Error (EMQM) and a normalized parameter based on the mean square error after bias removal divided by the standard deviation of the observed variable at the forecast validation time (EMQMN). This last parameter provides a measure of the forecast variability in comparison with the natural data variability. Figure 3 shows the bias, mean square error and normalized mean square error of several models, averaged over a particular region (Southeast Brazil – figure 1), over a period of time (December 1, 2005 to February 26, 2006). The system is sufficiently flexible for the user to change validation area and time period and, if necessary, analyses the results at a single observation station.

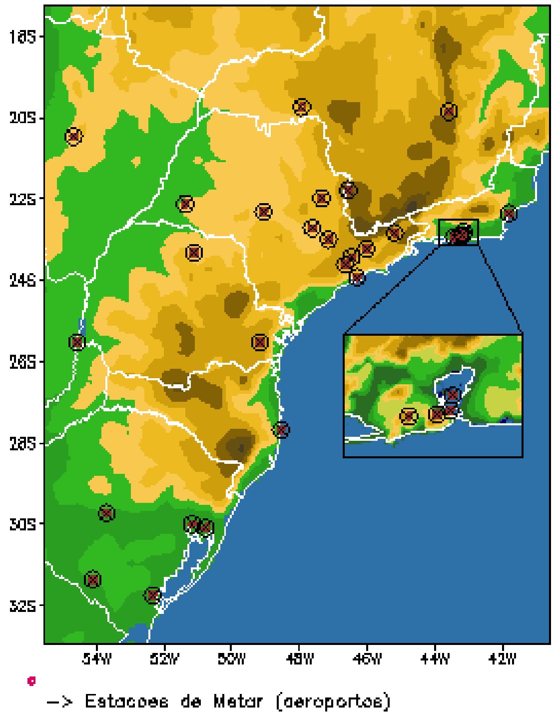
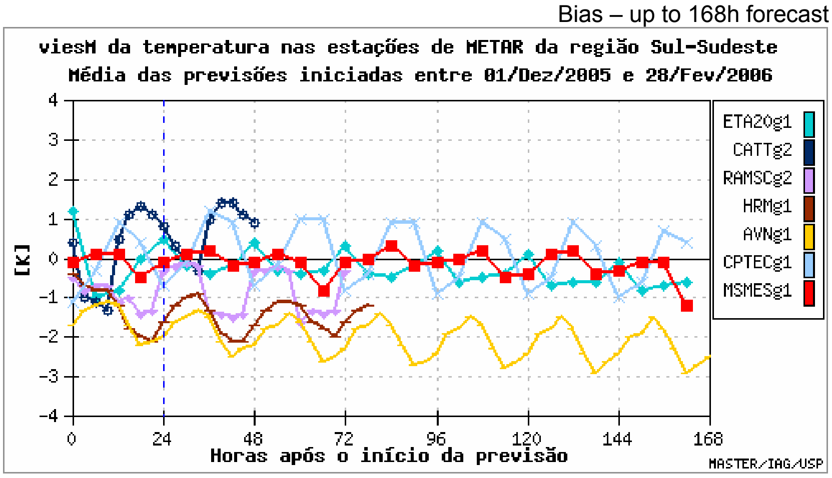
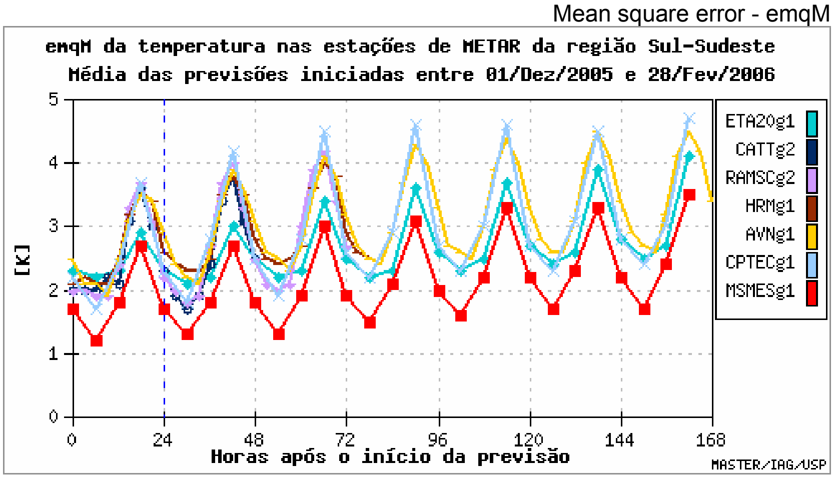


Figure 1: Stations used in the mean.

Bias – up to 168h forecast



Mean square error - emqM



Normalized mean square error - emqMN

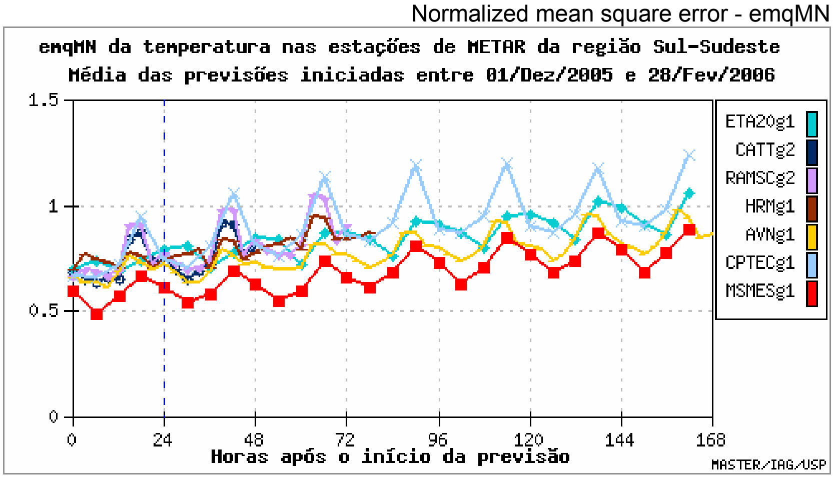


Figure 2: Bias, mean square error and normalized mean square error of the temperature forecasts at 2m up to forecast time 168hr for several models validated over the South-eastern region of Brazil, as indicated in the map, averaged over the period December 01, 2005 to February 28, 2006. The red curve represents the optimal combination of the forecasts.

As shown in Figure 2, the optimal combination of the forecasts (red curve) has near zero bias e the smallest mean square error throughout the period. The normalized mean square error indicates that the products are quite useful at least up to day 7, in spite of the fact that some models fail to produce reliable forecasts. Figure 2 also shows that the largest improvement of the optimal combination is attained up to day 3 because the number of available independent models drops significantly after this time (all regional models provide information up to 60 or 72 hours).

Figure 3 provides the same information as Figure 2 but for sea level pressure. It is again quite evident that the optimal combination satisfies the criteria of minimum bias and mean square error. The normalized mean square error indicated the high quality of the optimal combination against all other models in the mean sense.

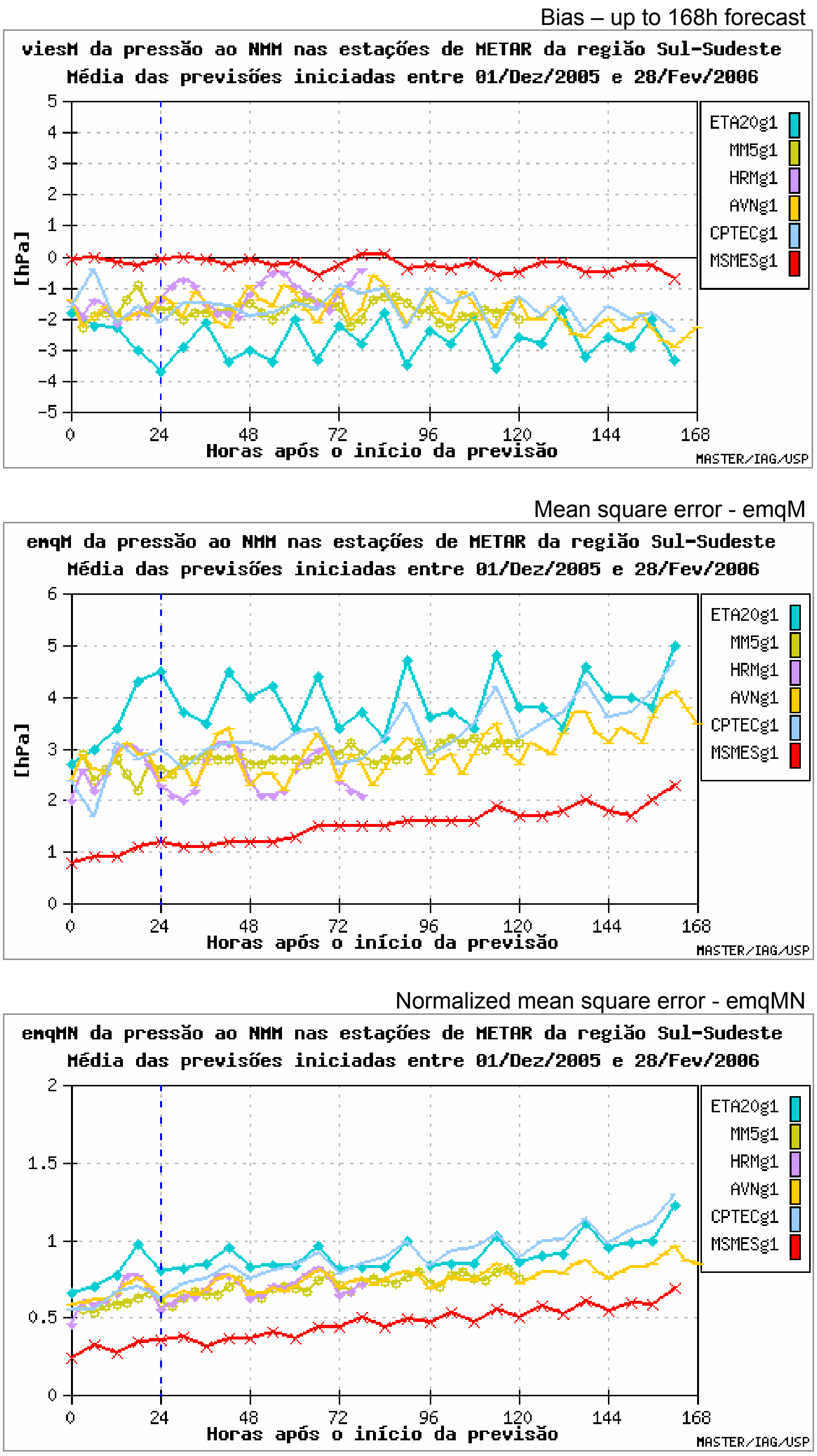
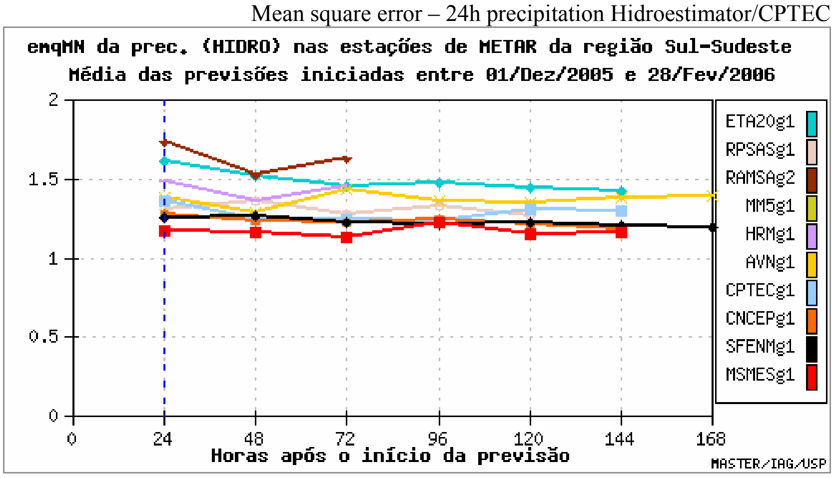


Figure 3: Same as Figure 2 but for sea level pressure.

The optimal combination of the forecasts for precipitation forecasts is more complex in view of the higher uncertainty in the estimates. However, the same methodology still provides statistically significant and stable relations, provided the validation time extends to the daily precipitation accumulation and averages over larger areas are considered. Figure 4 shows the evaluation of the 24h precipitation accumulation of several models, based on the same period as Figure 2 and 3 based on the CPTEC HIDROESTIMATOR available at the homepage with information over S. America (http://satelite.cptec.inpe.br/htmldocs/precipitacao/novo/precipitacao_novo.htm). Also shown in Figure 4 is the bias of the precipitation forecasts based on the 3 to 6h data provided by the TRMM and GOES combination. It is again quite evident that the optimal combination provides a significant improvement in the sense of minimizing the mean square error and near zero bias. Larger impact is obtained up to 72h forecast as clearly indicated in Figure 4 (upper panel): after 72 h the optimal combination (red curve) is quite close to the values representative of the CPTEC global model ensemble. However, the normalized mean square error does not show values smaller than the unity throughout the forecast period (figure not shown). This is an indication that the uncertainty in the determination of the truth is still poor.

Mean square error – 24h precipitation Hidroestimator/CPTEC



Bias – 3 hr to 6 hr precipitation – TRMM/GOES estimate

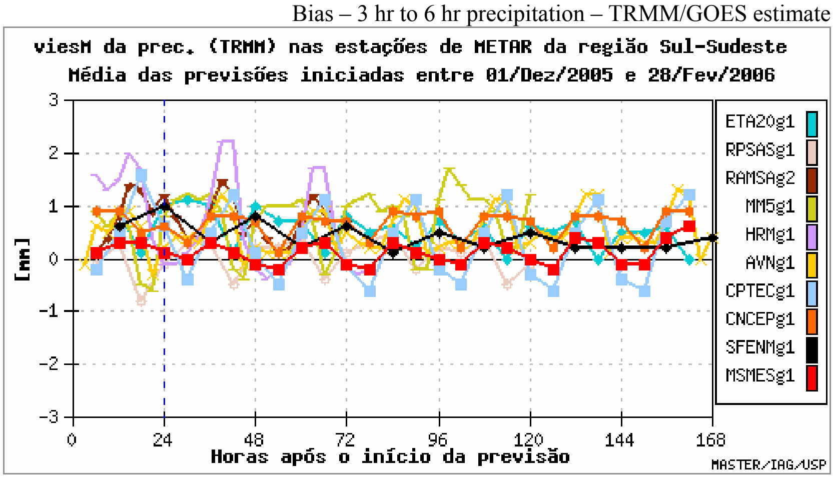


Figure 4: Mean square error of the precipitation forecast validated against the 24h accumulated precipitation by the CPTEC HYDROESTIMATOR (combination of satellite and surface measurements) and bias of the 3 to 6h precipitation based on the TRMM/GOES estimate.

4. CONCLUSION

It is concluded that the simple procedure based on data assimilation principles was quite successful and the results are routinely available at the MASTER Laboratory and CPTEC homepages (www.master.iag.usp.br and www.cptec.inpe.br). Future implementations are based on the optimal choice of the averaging period for computing bias and MSE using Kalman filters and neural networks (Hsieh and Tang, 1999) and the use of probabilistic forecasts in the case of precipitation (Gahrs et al. 2003).

The experience has been quite successful not only in terms of providing a realistic statistical estimate of the optimal forecast up to 7 days but also in terms of the exchange of experience among participating groups. An experimental analysis is currently being performed in order to extend the forecast period up to 14 days. The preliminary results that useful results can be obtained in some phases of the Madden Julian Oscillation.

Acknowledgments:

This work would not be possible without the support by CPTEC and INMET in Brazil, regional services such as SIMEPAR, CLIMERH and several universities UFRJ, SIMEPAR, UFRGS, CLIMERH, UBA. Products from the Argentinean Meteorological Service and NCEP are also used.

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