Comparison between Grell and Kuo cumulus parameterizations schemes for South America

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Abstract

Real-time precipitation forecasts over tropical South America for September 1999 and March 2000 performed using PSU/NCAR MM5 with Grell cumulus parameterization scheme were compared with simulations performed under the same model conditions but using Kuo scheme. The area of study was divided into regions with an area of $5° \times 5°$ and monthly precipitation averages were calculated for each of these. The same averaging was done on satellite-based precipitation estimates. A precipitation score index was defined using the model precipitation and the satellite estimates and used to evaluate the precipitation skill of MM5 for each region. The model precipitation data was also correlated with the satellite estimates in different regions of South America in order to evaluate if the precipitation patterns were correctly reproduced by the model using the two schemes.

Our results show that, in general, Grell scheme represented the precipitation patterns correctly, specially in the equatorial region (10°S-10°N), although it over-estimated rainfall in this region during March 2000. Kuo scheme tends to underestimate over the tropical region and does not represent adequately the precipitation patterns.

1 Introduction

Good precipitation forecasts with two or more days in advance are very important in Peru, as it is likely that episodes of intense precipitation would cause flooding or mud-slides which can have devastating consequences. Since March 1998, the Instituto Geofísico del Perú (IGP) is making real-time weather predictions operationally with PSU/NCAR MM5 for a forecast time of 60 hours. The domains used have resolutions of 81 km (coarse) and 27 km and correspond to South America and Peru, respectively.

The operational model at IGP uses Grell scheme and the predicted precipitation is been compared daily with GOES-8 infrared images, which give an idea of where convective activity is taking place. This comparison shows that Grell scheme tends to produce intense convective nuclei in the equatorial region which are not necessarily present in the satellite images.

However, it is necessary to quantify to some extent the skill of the precipitation forecast so that a decision may be taken on which cumulus parameterization scheme is the most apropriate in tropical South America, but this is very difficult to do. One problem with direct validation with station observations is their sparcity. Associated to this, as precipitation can be a very local phenomenon, observations may not be representative of the regions with horizontal scales compared to the model resolution. Another approach is to use satellite-based precipitation estimates as reference for the validation. Although the estimates themselves need to be validated, we adopt this as a first approach to validate the precipitation forecasts.

2 Methodology

For the validation we used the GOES-8 infrared rainfall estimation from NOAA/NESDIS/ORA with a resolution of 4 km as reference. According to Vicente *et al.* (1998), validation of these estimates in test cases in North America shows

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that these are best for deep convective systems although they are poor for stratiform type cloud precipitation and they point out that there is a tendency of over-estimating high precipitation rates and under-estimating low ones. They also found that the correlation between the measured data with the estimates increased as the grid size used increased, so that at a grid size of 3° the correlation coefficient was 0.91 in one of the test cases. In this work, we did not attempt to validate the GOES-8 estimates in tropical South America but assume that the conditions of validity of these remain the same as in North America. If this is the case, then the GOES-8 estimates are adequate for the representation of the convective systems which we try to forecast with the model.

The model data we used was the daily 24 hour precipitation forecast, using both Grell and Kuo cumulus parameterization schemes, over South America (80°W-40°W, 40°S-10°N) for March 2000 and September 1999. For the purpose of validation, we calculated the average precipitation rate (mm/day) of the model data and the GOES-8 estimates over each month. This would have the effect of isolating the systematic geographically related flaws associated to each parameterization scheme. These precipitation rates were then averaged in space over 5°×5° regions so as to maximize the correlation between the GOES-8 estimates and the reality.

We used two approaches to do the validation. The first one was defining a score index based on the relative error between the model precipitation rate and the GOES-8 estimate. Let M stand for the averaged model precipitation rates E for the analogue for GOES-8 satellite estimate. Then, we define the precipitation score index I as:

$$I = \begin{cases} +1 & ; \quad (M-E)/E > 0.5 \\ 0 & ; \quad -0.5 \leq (M-E)/E \leq 0.5 \\ -1 & ; \quad (M-E)/E < -0.5 \end{cases}$$

The values of $+1$ and -1 indicate over- and under-estimation, respectively, while a value of 0 indicates moderate skill. This index would give us an idea of what the spatial distribution of systematic over- and under-estimation is, although we have considered only the regions where $E > 0.1$. This is reasonable, since the GOES-8 estimates are not useful for low precipitation rates. An upper bound for E was not considered because we were interested on doing the validation over regions with moderate to heavy rainfall. However, this could have the effect of producing good skill on regions where both the model and the satellite estimate over-estimate rainfall.

The second approach adopted was to define regions within the original domain, in which the correlation coefficient was calculated for M and E. This coefficient would indicate how well the spatial distribution of rainfall was reproduced by the model in these regions regardless of the actual forecasted values. We defined two regions: the equatorial region (80°W-40°W, 10°S-10°N) and the subtropical region (80°W-40°W, 30°S-10°S).

3 Results

Analysis of the spatial distribution of the score index I for the precipitation rates obtained from the use of Grell scheme show that in the equatorial region there is a predominance of $I = 1$ in March 2000 (Fig.1a), while in September 1999, values of $I = 0$ are dominant with the notable exception of the region 55°W-40°W, 5°N-10°N, where I is mostly 1 (Fig.1b). A possible explanation of this difference is that rainfall associated with the convection over the Amazon in March, which is not as deep as in September, is probably not well represented by the GOES-8 estimates.

In Fig.2 as, in general, M tends to be similar to E where E is low, whereas for higher values of E, M tends to be larger still. The values of the correlation coefficient are high for March 2000 (Table 1), which indicates a good reproduction of the rainfall pattern. In September 1999, however, the correlation appears to be very low. This is really a consequence of the presence of an intense precipitation nucleus produced by the model in the north-east of the region which doesn't have an analogue in the GOES-8 estimate. If the correlation is calculated without the points corresponding to this nucleus, the resultant value is high too (Table 1). The existence of this nucleus, which was also noted as a region of $I = 1$ in the previous analysis remains to be explained.

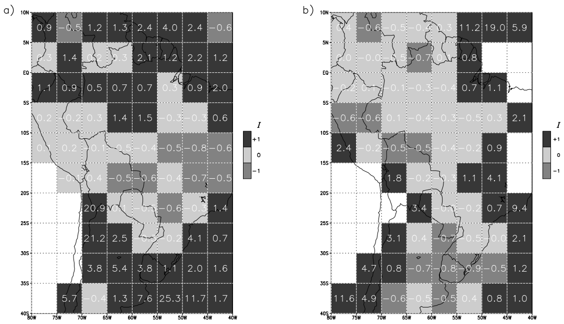

Figure 1: Precipitation score index I (shaded) and relative error for Grell cumulus parameterization scheme (values) in equatorial South America for a) March 2000 and b) September 1999.

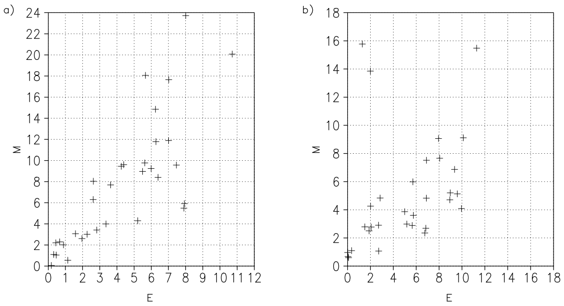

Figure 2: Satellite based precipitation rate (E) vs. MM5 precipitation rate (M) using Grell cumulus parameterization scheme in equatorial South America for a) March 2000 and b) September 1999.

The analysis for the results of the simulations performed using Kuo scheme on the equatorial region shows that for March 2000 the model produced rainfall which is more realistic quantitatively (Fig.3a), although the pattern is not well represented (Fig.4a, Table 2). For September 1999, the model generally under-estimated the precipitation (Fig.3b) and the pattern, again, was not well represented (Fig.4b, Table 2). It is worth noting that in September 1999 the model over-estimated the rainfall in the north-east of the region, similarly to Grell scheme, which leads to believe that this is not a flaw of the cumulus parameterization schemes, but that this is more likely related to the model dynamics.

In the subtropical region, for both March 2000 and September 1999 Grell scheme has a better skill than Kuo scheme, as the latter tends to under-estimate precipitation (Figs.1 and 3).

Region	Mar 2000	Sep 1999
Equatorial	0.79	0.09*
Subtropical	0.45	0.61

* This value becomes 0.78 when values $M > 10$ are not considered.

Table 1: Correlation index for Grell scheme.

However, the results from both schemes show low correlation to the GOES-8 estimate (Tables 1 and 2), although it is greater for Grell scheme.

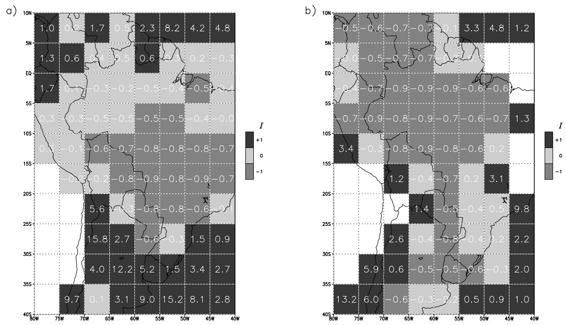

Figure 3: Precipitation score index I (shaded) and relative error for Kuo cumulus parameterization scheme (values) in equatorial South America for a) March 2000 and b) September 1999.

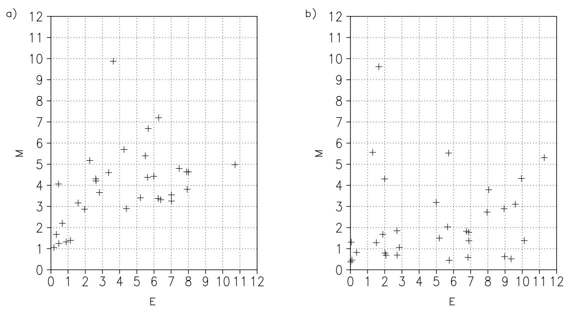

Figure 4: Satellite based precipitation rate (E) vs. MM5 precipitation rate (M) using Kuo cumulus parameterization scheme in equatorial South America for a) March 2000 and b) September 1999.

At higher latitudes both schemes present similar skill distribution according to the score index I (Figs.1 and 3). For March 2000 both schemes showed over-estimation, but for September 1999 there was no clear tendency in neither.

Region	Mar 2000	Sep 1999
Equatorial	0.44	0.12
Subtropical	0.15	0.35

Table 2: Correlation index for Kuo scheme.

4 Concluding remarks

Our results show that Grell cumulus parameterization scheme is quite adequate for the tropical region of South America, at least in a climatological fashion. Kuo scheme, on the other hand, does not seem well suited for this region. This indicates the need to adapt this scheme for the tropical zone, as the simulations we performed were done without any modification to the distributed version of the scheme.

These are preliminary results, however, as our greater interest is the short term prediction of intense precipitation episodes. Validation at a greater temporal and spatial resolution should be made, although this would require also the validation of the satellite estimates we use as reference using direct observations. Also, a more thorough work similar to the one presented here should be done but for longer periods, thus creating a climatology of the model with different schemes. This should be done using analyzed data instead of forecasts for the boundary conditions so as to minimize the influence of the GCM on the results.

5 References

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Vicente, G. A., Scotfield, R. A., Menzel, W.P., 1998: The operational GOES infrared rainfall estimation technique. *Bull. Amer. Meteor. Soc.*, **79**, 1883-1898