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Scale-dependent precipitation forecast error in the GFS

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1. Introduction

Precipitation has been one of the most difficult forecast fields for modern numerical weather prediction (NWP). The precipitation forecast skill in an NWP model has lagged considerably behind skills of many other meteorological fields, such as temperature, winds, etc. To improve this situation, we must first understand the characteristics of precipitation forecast errors better.

The representation of precipitation physics in atmospheric models is typically categorized into resolvable and unresolvable processes. For the resolvable precipitation process, the key issue to improving the forecast relies very much on the improvement of data assimilation. For unresolvable physical processes, parameterization schemes must be used. Literally, these parameterization schemes will depend heavily upon a set of model parameters, which need to be tuned to best fit training observations. Two paradigms can lead to precipitation forecasts with a "spatial bias" and a "situational bias", respectively, when using these parameterization schemes. First, because many convective parameterization schemes were developed on the basis of our limited knowledge of some particular convective or storm structure (e.g., a deep-convection process), the general application of this parameterization often fails (for instance, for precipitation due to a shallow cloud process). This scenario is what we referred to as the "situational bias". Second, many convective parameterization schemes are developed and validated using observational data available for certain spatial locations, such as on continental areas where a relatively dense observational network exists. The question of whether such tested parameterization schemes are also suitable for precipitation forecasts over the oceans may give rise to an issue of spatial bias. Furthermore, the representation of resolvable and unresolvable precipitation processes in atmospheric models implies two different scales of forecast errors. Tracking down the model deficiency parties partly depends on how we are able to untangle the scales of those errors.

In this study, precipitation forecasts from a global weather forecast model are verified against satellite observations. Forecast errors are computed and averaged for summer and winter seasons. A spatial 2-D wavelet is used to decompose these errors. The scale-dependent forecast errors are analyzed.

2. Forecast model and observational data

The National Center for Environmental Prediction's (NCEP) Global Forecast System (GFS) is the U. S. operational global weather forecast model. In this study, precipitation forecasts from the GFS are verified against satellite precipitation observations. The satellite observations are from UC-Irvine's PERSIANN satellite data products, which provide a 6-hourly precipitation total on a 0.25x0.25-degree grid for a global domain excluding high latitudes (> 50 degree south and north). The GFS has a model gridspacing of 36 km, but the forecast output is archived on 1x1 degree latitude-longitude grids. Daily aggregated precipitation is used to compare the satellite's 24-h precipitation amount. One year's worth of GFS precipitation forecast data and PERSIANN satellite data are analyzed. Some data were missing due to a satellite orbit problem (Yuan et al. 2007).

Figures 1a and 1b show RMS errors for summer and winter, respectively. Large RMS errors understandably correlate to global major rain regions, such as the intertropical convergence zone (ITCZ), the south Pacific convergence zone (SPCZ), the western Pacific warm pool, the Amazon tropical rain forecast, and western Africa.

3. Analyses of scale-dependent forecast errors using wavelet

In order to characterize scale-dependent precipitation forecast errors, a 2-D spatial-wavelet decomposition is applied to the RMS errors obtained in section 3. A 2-D wavelet transformation can localize a 2-D physical field, $f(x,y)$, in space, as well as characterize its scales (Wang and Lu, 2007). Mathematically, this transformation can be expressed as

$$\hat{f}[s,(x,y)] = \iint f(x',y')\ \psi^{*}_{s,(x,y)}(x',y')\ dx'dy' \tag{1}$$

where $\psi_{a,(x,y)}(\zeta,\xi) = |a|^{-1}\psi[a^{-1}(\zeta - x, \xi - y)]$ is a locally-supported transformation kernel (asterisk denotes the complex conjugate). The scale parameter a, which is inversely proportional to the wavelength, and the parameter combining (x,y), which gives a horizontal spatial location, are respectively the dilation and translation parameters. In this study, we use the Halo mother function as the transformation kernel (Wang and Lu, 2007).

Using wavelet transformation (1), we can decompose the RMS errors computed in section 3 for various scales. Two representative scales for forecast errors are selected here. The 1000-km scale represents the large-scale forecast errors (can be interpreted as errors for resolvable precipitation). The 200-km scale represents the convective-scale forecast errors (can be interpreted as errors for unresolvable precipitation). The gridspacing for the GFS model is 36 km, and the archived GFS data is interpolated onto a 1x1-degree grid, resulting in a relatively smoothed precipitation field. Therefore, it is justifiable to choose the 200-km scale as the smallest scale (the Nyquist wavelength) for this data.

Figures 2a and 2b show the 200- and 1000-km forecast error for the summer season in the GFS. In the summer season, the resolvable forecast errors (Fig. 2b) in the GFS are mainly in the tropical western Pacific warm pool, the Asian summer monsoon precipitation (including MeiYu fronts), some segments of the ITCZ and SPCZ, Central America, and western Africa. The GFS seems to have a serious problem in forecasting precipitation at the southern tip of South America. This may be a false signal, because some satellite data were missing in that part of the world (the white region in Fig. 1a). For convective precipitation (Fig. 2b), the largest errors are in the SPCZ, the Asian summer monsoon (particularly over the India subcontinent and South-east Asia), and Central America. For the U.S., severe storms in the Central Plain and thunderstorms in Florida and on the East Coast account for GFS forecast errors in spring and summer seasons. Despite the fact that the tropics possesses a large amount of rain, the presence of both convective and large-scale errors in the tropical regions indicates that the GFS needs to improve both data assimilation and parameterization in these areas.

The GFS decomposed forecast errors at 200- and 1000-km scales for the winter season are shown in Figs. 3a and 3b. The most noticeable large-scale precipitation forecast error is related to the winter monsoon, and now is located over New Guinea and the north coast of Australia. This feature also constitutes a part of the SPCZ. It is interesting to note that the northwest coast of the U. S., which is the entrance region for Pacific winter storms, gives rise to one of only a few regions where the GFS displays large-scale forecast errors over land. For the winter convective storms, most GFS forecast errors are in the tropical oceans and southern hemisphere continents, particularly for the ITCZ and SPCZ precipitation. In the northern hemisphere, there are three regions where GFS needs to improve its unresolvable precipitation forecast: the Pacific tropical and extratropical transition (ET) region, the northwest coast of North America, and for Mediterranean winter rains. While the landfall of northwest coast extratropical cyclones causes major impact on U.S. winter weather, an inaccurate forecast in the Pacific ET region can lead to an inaccurate forecast of Pacific extratropical cyclongenesis and cyclone development.

4. Conclusions

The present study identifies where, when, and for what scale of precipitation systems that the GFS has the most forecast errors. The goal of this study is to aid global forecast models in improving their precipitation forecast. In particular, the spatial-scale decomposition, coupled with the seasonal climatological classification of precipitation forecast errors, provides an insightful diagnosis, which seems to be useful for improving model precipitation parameterizations and data assimulation strategies.

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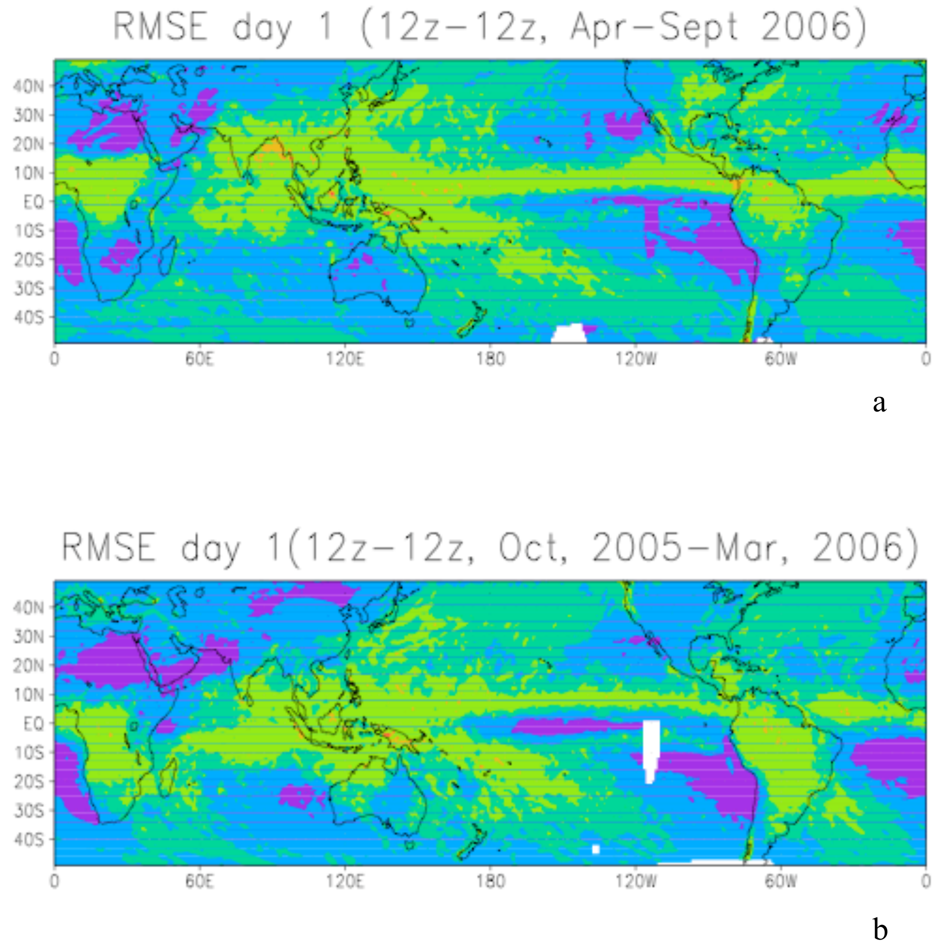
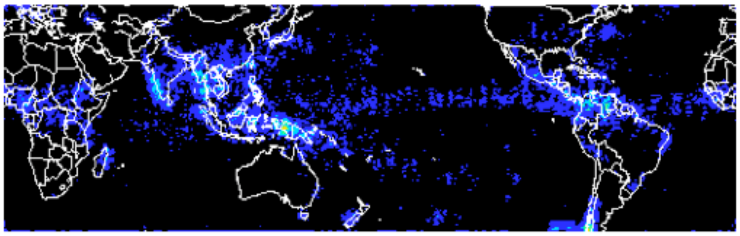

RMSE day 1 (12z−12z, Apr−Sept 2006)

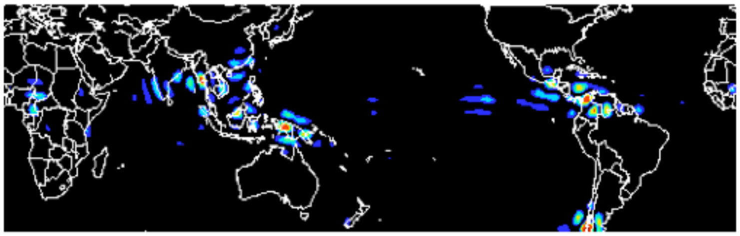
RMSE day 1(12z−12z, Oct, 2005−Mar, 2006)

Fig. 1: RMS errors from GFS global precipitation forecast a) for summer season (Apr.-Sept. 2006), and b) for winter season (Oct. 2005-Mar. 2006). The forecast leadtime is 1 day, and the verifying field is 24-h accumulation precipitation.



200-km scale

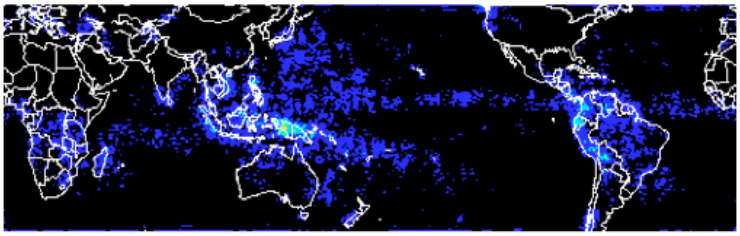
a



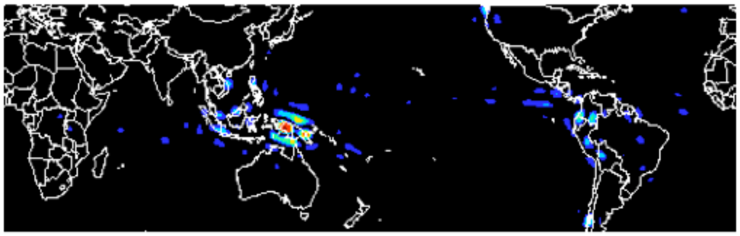
1000-km scale

b

Fig. 2: Wavelet-decomposed RMS errors from GFS global precipitation forecast for summer season (Apr.-Sept. 2006), a) for convective scale (200-km), and b) for large scale (1000-km).



200-km scale



1000-km scale

Fig. 3: Wavelet-decomposed RMS errors from GFS global precipitation forecast for winter season (Oct. 2005-Mar. 2006), a) for convective scale (200-km), and b) for large scale (1000-km).