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CAN GFS GLOBAL FORECASTS BE USEFUL FOR ASTRONOMERS?

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RESUMEN

Varios observatorios astronómicos operan actualmente en Chile. Estos necesitan pronósticos atmosféricos exactos con días de anticipación para optimizar la planificación de observaciones y reducir costos de operación. El modelo GFS (Global Forecast System) produce pronósticos atmosféricos cuatro veces al día y sus salidas están disponibles gratis en internet. En este trabajo se presentan resultados preliminares de la estimación y pronóstico de propiedades atmosféricas en los observatorios APEX y Paranal. El modelo GFS muestra una buena correspondencia con observaciones en la predicción de PWV (precipitable water vapor) en APEX, particularmente en el rango entre 0–1 mm usando el PWV calculado a partir de perfiles de razón de mezcla de vapor de agua (q_v). El modelo puede ser también usado con cierta confianza para predecir variables cerca del suelo en observatorios con el uso de un filtro de Kalman. El PWV estimado a partir de datos de GOES pudiera ser usado como método diagnóstico aunque se recomienda mejor usar modelos numéricos siempre que estén disponibles.

ABSTRACT

Several astronomical observatories are currently in operation in Chile. They need accurate weather forecasts in order to have a better observational scheduling and reduce operational costs. The Global Forecast System (GFS) model produces global weather forecasts four times per day and its outputs are freely available on the web. Preliminary results in the estimation and forecasting of several atmospheric properties over APEX and Paranal observatories using the GFS model are presented in this work. The GFS model shows a very good agreement in the prediction of PWV (precipitable water vapor) at APEX, particularly in the PWV range from 0–1 mm using a PWV calculated from water vapor mixing ratio (q_v) profiles. The GFS model can also be used with some confidence to predict near-surface variables over astronomical sites with the implementation of a Kalman filter. PWV estimated from GOES data could be used as a diagnostic tool although it is best recommended the use of numerical models anytime they are available.

Key Words: atmospheric effects — methods: numerical

1. INTRODUCTION

The Global Forecast System (GFS) model is an operational numerical model that produces global weather forecasts up to 16 days in advance. It is run at NCEP (National Centers for Environmental Prediction, USA) 4 times per day at 00, 06, 12 and 18 UTC. GFS forecast outputs at 0.5° of horizontal resolution are freely available on the web. They include several field variables like temperature, humidity, wind speed, precipitable water vapor (PWV), among others, at 21 pressure levels in the atmosphere from 1000 hPa to 100 hPa and near the surface. This work presents preliminary results obtained with the GFS model in the estimation and prediction of several atmospheric properties over astronomical sites in order to analyze how useful GFS forecasts can be for the astronomical community.

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2. METHODOLOGY

2.1. *Meteorological observations*

Near-surface observations from APEX (Atacama Pathfinder EXperiment) and Paranal weather stations were used to validate GFS forecasts over the astronomical sites. In addition, PWV from the model was compared with values obtained from APEX radiometer and those calculated from radiosonde observations taken during several campaigns at APEX and Paranal.

2.2. *PWV forecasts*

The GFS model includes PWV among its field variables. However, it does not show very good agreement with APEX radiometer, possibly due to the low resolution of GFS data. For this reason, a

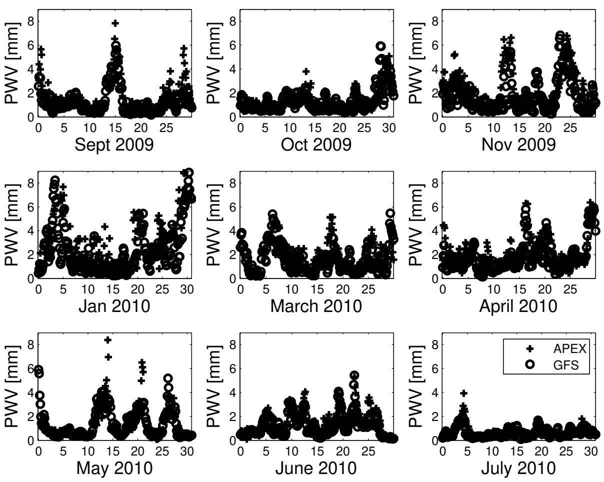

Fig. 1. Time evolution of PWV from the GFS model (circle) and APEX radiometer (plus) during 2009–2010. Time series created with first 24 h forecasts.

new PWV variable was calculated integrating GFS water vapor mixing ratio (q_v) profiles at the nearest point to APEX from 550 hPa (the typical surface pressure at APEX) to 100 hPa using equation (1):

$$\mathrm{PWV} = \frac{1}{g}\int_{p_1}^{p_2} q_v dp\,. \tag{1}$$

2.3. *PWV estimation from GOES data*

The methodology to estimate PWV from GOES data is based on Soden & Bretherton (1993) and Erasmus (2002). First, GOES radiances from the water vapor channel are converted to brightness temperature (T_b). A cloud-clearance algorithm is used to remove cloudy pixels in order to obtain clear-sky T_b for the water vapor channel. Mean upper troposphere relative humidity (UTH) is obtained using the following relation from Soden & Bretherton (1993):

$$\mathrm{UTH} = \frac{\exp(a + b\cdot T_b)\cdot\cos(\theta)}{P_o}\,, \tag{2}$$

where θ is the satellite zenith angle and $a = 31.5$, $b = -0.115$ and $P_0 = 1.0073$. Finally, PWV is obtained using the following relation:

$$\mathrm{PWV} = \frac{1}{g}\int_{p_1}^{p_2} \mathrm{UTH}\cdot q_{vs} dp\,, \tag{3}$$

for APEX site, and:

$$\mathrm{PWV} = \frac{1}{g}\int_{p_1}^{p_2} \mathrm{UTH}\cdot q_{vs} dp + \frac{1}{g}\int_{p_{sfc}}^{p_1} q_v dp\,, \tag{4}$$

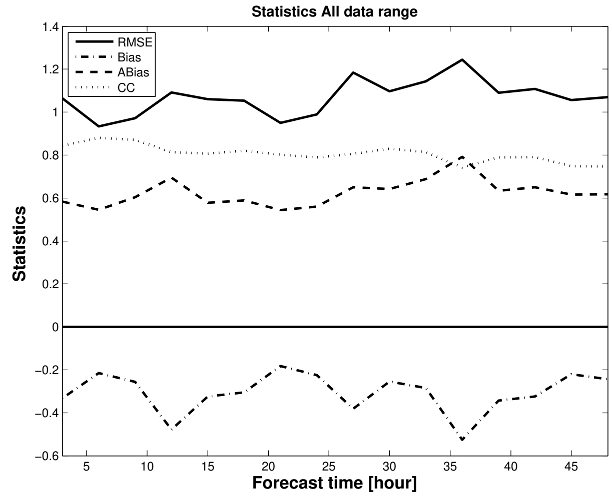

Fig. 2. PWV statistics between GFS forecasts and APEX radiometer for the first 48 h forecasts. All PWV values are included.

for Paranal. Vertical profiles of q_v and q_{vs} (saturated water vapor mixing ratio) were obtained from the GFS model. Pressure limits p_1 and p_2 correspond to 550 hPa and 100 hPa, where UTH is approximately averaged. The second term at Paranal integrates from surface pressure at Paranal (≈700 hPa) to 550 hPa in order to obtain the complete integration of the atmosphere above Paranal.

2.4. *Kalman filter*

To remove systematic errors in GFS forecasts, a Kalman filter was implemented based on the methodology of Homleid (1995). It takes account of the diurnal cycle of errors in near-surface variables. The filter was applied to improve GFS forecasts over astronomical sites.

3. RESULTS

3.1. *PWV forecasts*

PWV values calculated using equation (1) were compared to PWV values obtained from the APEX radiometer. Figure 1 shows the PWV time evolution from the model and radiometer during several months in 2009 and 2010. In general, a good agreement is observed between GFS forecasts and APEX radiometer. The largest errors are observed during periods of increasing PWV while the smallest errors are found during low PWV times.

A quantitative assessment of errors is shown in Figure 2 where RMSE, mean error (ME), mean absolute error (MAE) and correlation coefficient (CC) during the first 48 h of GFS forecasts are analyzed.

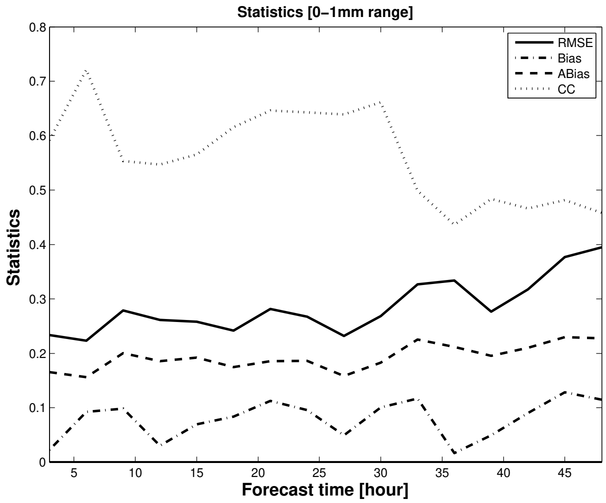

Fig. 3. PWV statistics between GFS forecasts and APEX radiometer for the first 48 h forecasts. Only PWV values between 0–1 mm are included.

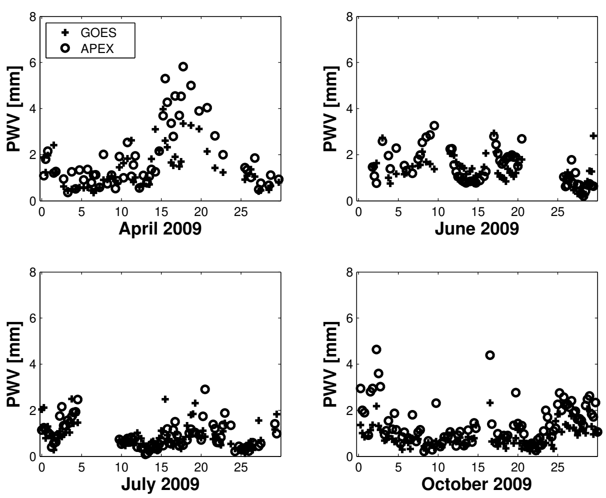

Fig. 4. Time evolution of PWV estimations from GOES and APEX radiometer during several months of 2009.

The RMSE is <1.2 mm during the 48 h forecasts and near 1 mm for the first 24 h. The MAE is near 0.6 mm at almost all forecast times. The same analysis was made but for the PWV range from 0 to 1 mm (Figure 3). The RMSE varied from 0.2 mm to 0.4 mm and the MAE was near 0.2 mm for all forecast times.

3.2. *PWV estimation from GOES*

Figure 4 shows the time evolution of PWV estimated from GOES data and APEX radiometer for several months of 2009. In general, the PWV estimation shows a good agreement with the radiometer. The largest errors are observed during periods of increasing PWV and the smallest errors are observed during periods of low PWV values.

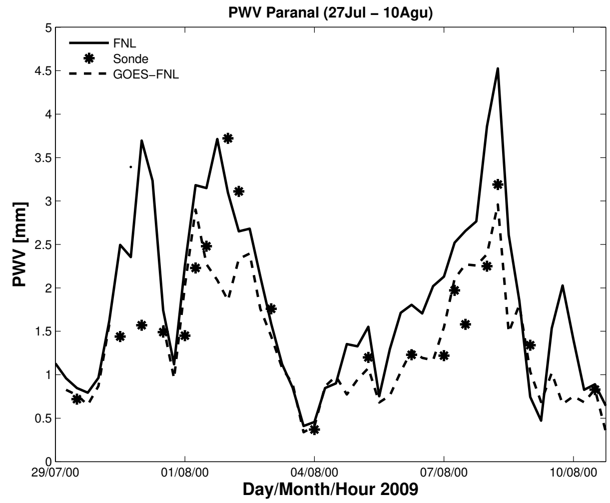

Fig. 5. Time evolution of PWV estimated from GOES, calculated from radiosondes and GFS analyses during July-August 2009 at Paranal.

PWV estimations from GOES were evaluated during one of the radiosonde campaigns at Paranal carried out in July-August 2009. A good agreement between PWV estimations from GOES and PWV calculated from radiosondes is observed in Figure 5. GFS analyses (FNL analyses) are also plotted in order to determine its influence in the PWV estimated from GOES. The figure indicates that errors are not always related to GFS biases. It is important to note that no correction was made to radiosonde humidity biases (Miloshevich et al. 2009), which could be a likely source of error.

3.3. *Kalman corrections*

GFS forecasts of near-surface variables show large systematic errors at astronomical sites. They are mainly due to the low horizontal resolution and the inaccurate representation in the model of the complex topography where observatories are located. The implementation of a Kalman filter aimed to remove those systematic errors to improve forecasts of near-surface variables. Figure 6 shows the time evolution of observed and forecasted 2 m temperature at APEX during October 2009. Raw GFS forecasts show large biases with observations. These errors decrease when the Kalman filter is applied. Forecasts corrected with the filter show a much better diurnal cycle. The largest errors are observed in the early

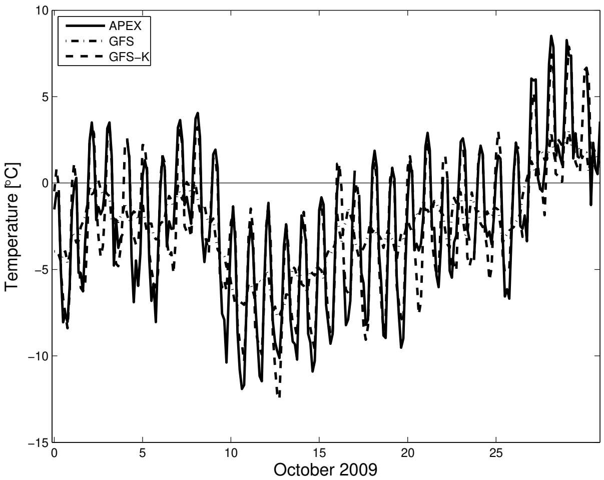

Fig. 6. Time evolution of 2 m temperature from APEX weather station, raw and Kalman-corrected GFS forecasts during October 2009. GFS corresponds to raw-forecasts and GFS-K corresponds to Kalman-corrected forecasts.

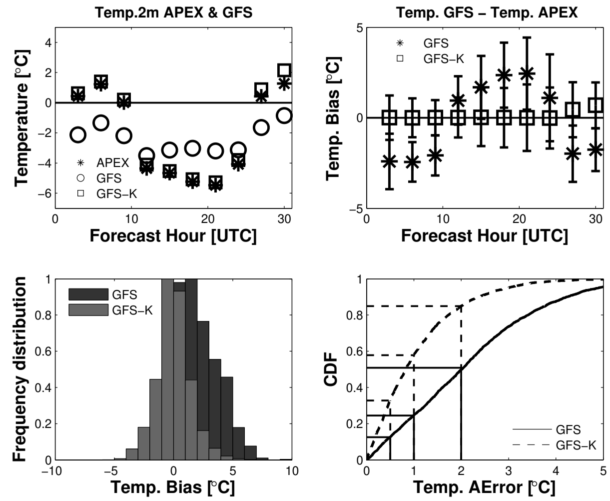

Fig. 7. Time evolution of 2 m temperature from APEX weather station, raw and Kalman-corrected GFS forecasts during October 2009. GFS corresponds to raw-forecasts and GFS-K corresponds to Kalman-corrected forecasts.

morning during minimum values while the smallest errors are found in the afternoon and night hours when maximum values are present.

A summary of statistics for 2 m temperature at APEX is shown in Figure 7. Kalman-corrected forecasts have the mean temperatures closer to mean observations. The mean bias is completely removed and its frequency distribution is centered around 0. The cumulative distribution of errors shows that 60% of errors are $<1^{\circ}$C while 80% are $<2^{\circ}$C in Kalman-corrected forecasts.

4. CONCLUSIONS

The GFS model shows a very good agreement in the prediction of PWV at APEX, particularly in the PWV range between 0–1 mm using a PWV calculated from q_v profiles. The GFS model can also be used with some confidence to predict near-surface variables over astronomical sites with the implementation of a Kalman filter. Kalman-corrected forecasts show a larger fraction of data with smaller errors and the mean bias is completely removed in comparison with raw-forecasts.

The estimation of PWV from GOES data could be used as a diagnostic tool over astronomical sites. However, the use of different data sources and assumptions in its methodology lead us to recommend the use of numerical models instead of its use anytime model outputs are available.

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