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PWV FORECAST VALIDATION AT ALMA SITE

D. Pozo,[1] L. Illanes,[1] M. Caneo,[1] and M. Curé[1]

RESUMEN

En este estudio se implementó el modelo WRF (Weather Research and Forecasting) y se evaluó su sensibilidad con el fin de pronosticar las condiciones atmosféricas, principalmente el vapor de agua precipitable (en inglés, PWV) en el sitio de ALMA (Atacama Large Millimeter/Submillimeter Array). Se evaluaron 5 configuraciones del WRF con diferentes opciones físicas de capa límite, de modelo de suelo y microfísica, que fueron comparadas con datos observados de radiómetro y estación meteorológica, entre abril y diciembre de 2007. Los resultados mostraron que todas las simulaciones sobrestiman los valores de PWV, particularmente en los meses de verano. Además, los cambios de parametrización de microfísica no influyen significativamente en el pronóstico, observándose mejores resultados con el modelo de suelo Noah. Los menores errores fueron obtenidos con la configuración YSU-Noah, sugiriendo ser apropiada para usarse en el pronóstico operativo de PWV en ALMA.

ABSTRACT

In this study, the WRF (Weather Research and Forecasting) model was implemented to predict the atmospheric conditions, particularly the precipitable water vapor (PWV) in the North of Chile. Its performance was evaluated over the ALMA (Atacama Large Millimeter/submillimeter Array) site. Five WRF configurations with different physical options for boundary layer, soil model and microphysics were compared with observations from a radiometer and a weather station from April to December 2007. The results show that all the simulations overestimate PWV values, particularly in summer months. In addition, the microphysics parameterization changes do not notably affect the forecast, observing improved results with the soil model Noah. The errors were smallest with the YSU-Noah configuration, suggesting that it is appropriate to be used in operational forecasting of PWV in ALMA.

Key Words: atmospheric effects — radioastronomy — site testing

1. INTRODUCTION

The Chajnantor plateau, located in the region of Antofagasta (Chile) at 5104 m above sea level, was selected to install the large set of radiotelescopes ALMA (Atacama Large Millimeter/submillimeter Array). The radioastronomical observations at millimeter and submillimeter wavelengths are affected by atmospheric water vapor content, which absorbs the incoming electromagnetic signal, affecting the radiotelescopes observations (Radford et al. 1998).

The Chajnantor region is characterized by atmospheric transparency and low water vapor content during most of the year (Bustos et al. 2000). The water vapor content can be measured quantitatively through the PWV (Precipitable Water Vapor), which is the measure of the total content of water vapor in a vertical atmospheric profile.

Considering the influence of atmospheric conditions, particularly the PWV, in radioastronomy, the WRF (Weather Research and Forecasting) model was implemented over the ALMA site in order to validate the PWV forecasts. The WRF model has a wide range of physical options, which can be selected according to the study area to obtain the best performance. Once the best WRF configuration is obtained, it could be used as a good prognostic tool, allowing a better planification of observational hours at ALMA and reducing operational costs. The validation period extends from 1 April to 31 December 2007.

This study was executed in the framework of the research project ALMA-CONICYT n°310700200, "Strengthening Astrometeorology group of Universidad de Valparaíso".

2. DATA AND METHODS

The WRF model was run non-hydrostatic, with 4 nested domains (Table 1) and 27 vertical levels. This study evaluates the domain with higher horizontal resolution (d04 at 1 km) centered on the APEX (Atacama Pathfinder Experiment) site, where a prototype ALMA antenna is operating at 23.00° South Latitude and 67.76° West Longitude.

[1]Grupo de Astrometeorología, Departamento de Física y Astronomía, Universidad de Valparaíso. Av. Gran Bretaña 1111, Valparaíso, Chile (diana@dfa.uv.cl, michel.cure@uv.cl).

TABLE 1

DESCRIPTION OF WRF MODEL DOMAINS

Domains	Grid point	Resolution
d01	43×47	27 km
d02	52×49	9 km
d03	61×64	3 km
d04	70×70	1 km

Meteorological data from NCEP (National Centers for Environmental Prediction) FNL analysis, with spatial resolution of $1° \times 1°$ were used as initial and boundary conditions for WRF model simulations every 6 hours. The simulations started daily at 00 UTC and were run for 72 hours (3 days), saving outputs every 3 hours from 1 April to 31 December 2007.

The PWV is largely influenced by the processes that occur in the lower layers of the atmosphere. For this reason, five configurations using different planetary boundary layer (PBL), soil model and microphysics parameterizations (Table 2) were validated. Each configuration differs from the control one in only one parameterization. All simulations were performed using RRTM longwave radiation, Dudhia shortwave radiation and Kain-Fritsch (new) convective parameterization, (Skamarock et al. 2005).

The simulations were compared with observational data from the weather station and 183 GHz radiometer data at the APEX site. In addition, an analysis of synoptic conditions using GOES-12[2] satellite water vapor images was made.

PWV was obtained from WRF model outputs by the integration of water vapor mixing ratio (q_v [kg/kg]) profiles, horizontally interpolated to the site coordinates at each level:

$$PWV = \frac{1}{g} \int_{P_0}^{P} q_v \, dp \qquad (1)$$

where g is the acceleration due to gravity [m/s^2], P_0 is the atmospheric pressure at the surface [hPa], P is the atmospheric pressure at the top of the atmospheric column [hPa] and PWV is the precipitable water vapor [mm].

3. RESULTS

This study shows the results of the comparison between WRF simulations and PWV observations

[2]GOES-Este, Geostationary Operational Environmental Satellite.

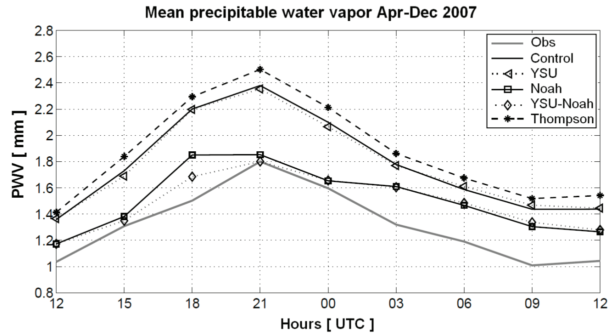

Fig. 1. Mean PWV daily cycle from April to December 2007 at APEX.

at APEX site. The mean PWV diurnal cycle (Figure 1) shows that Noah and YSU-Noah configurations, which include the effects of soil moisture, reproduce better the observed daily cycle (Obs), with significant improvements during daytime hours compared with other configurations.

Cumulative density Functions (CDFs) of PWV absolute errors at 12h, 18h, 24h and 30h of forecasts for the analyzed period (Figure 2), show that Noah and YSU-Noah configurations present a higher frequency of smaller errors at all hours, although YSU-Noah has smaller errors at 18h. The Thompson configuration shows the highest frequency of large errors. Similar results are found when forecasts hours from 36 to 72 are analyzed.

The temporal evolution of PWV at 12h for the analyzed period (Figure 3) shows that WRF simulations follow a similar trend than observations, with correlation coefficients larger than 0.7. However, simulations largely overestimate PWV on days when it rapidly increases. An example of this overestimation is indicated by the dotted circle in Figure 3 for 22 November 2007. The GOES satellite water vapor image for that day at 12 UTC shows the presence of a humid mid to upper level atmosphere over ALMA site (Figure 4).

Times with large overestimations in PWV represent less than 10% of the total during the study period. However, they increase the root mean square error (RMSE) by 30%. This can be seen in scatterplots of simulated and observed PWV at 12h using all times during the study period (Figure 5a) and when the six times with the largest absolute errors were removed (Figure 5b), wich caused a mark decrease in RMSE in all configurations. Thompson was the configuration that showed the largest errors at all hours as can be seen in Figures 5a and 6 at 18h of forecast.

TABLE 2

WRF CONFIGURATIONS

Physics	Control	YSU	Noah	YSU-Noah	Thompson
Microphysics	Simple Ice[1]	Simple Ice	Simple Ice	Simple Ice	Thompson[2]
Land-Surface Model	Thermal Dif.[3]	Thermal Dif.	Noah LSM[4]	Noah LSM	Thermal Dif.
Planetary Boundary Layer	Mellor-Yamada[5]	Yonsei Univ.[6]	Mellor-Yamada	Yonsei Univ.	Mellor-Yamada

[1]Hong et al. 2004; [2]Thompson et al. 2006; [3,4]Skamarok et al. 2007; [5]Janjic 2002; [6]Hong et al. 2006.

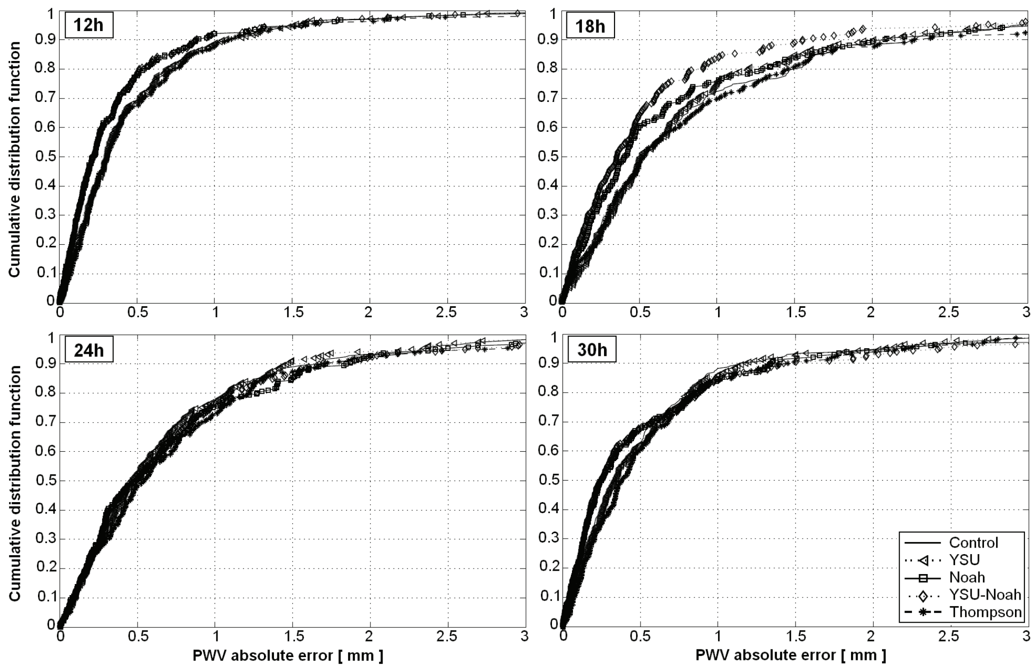

Fig. 2. Cumulative density function of PWV absolute errors from April to December 2007 at APEX.

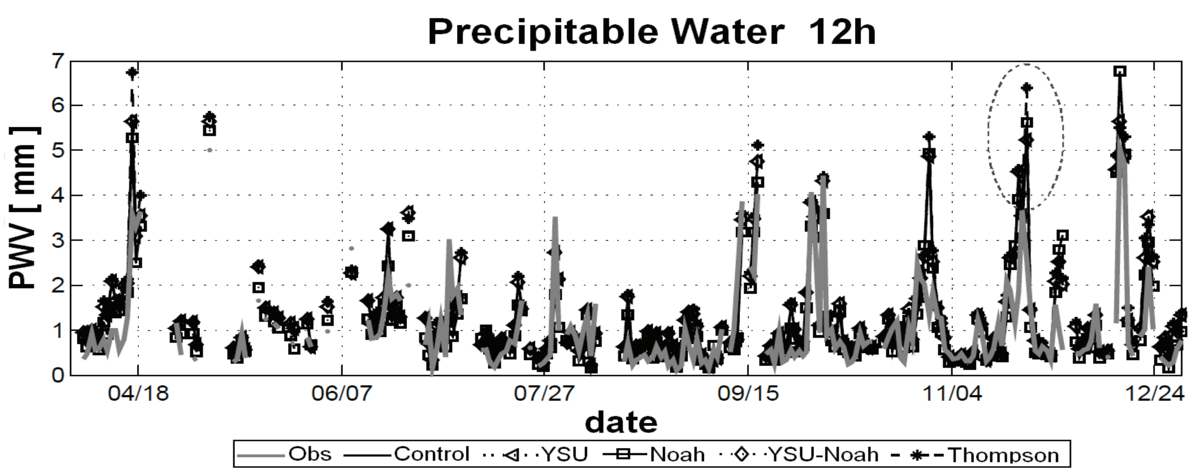

Fig. 3. Time evolution of PWV simulations and APEX radiometer at 12 hour from April to December 2007. Dotted circle (gray) shows the day with the highest overestimation (11/22/2007).

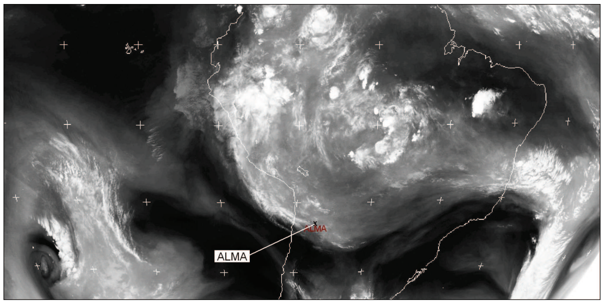

Fig. 4. Goes water vapor image, 11/22/07, at 12 UTC.

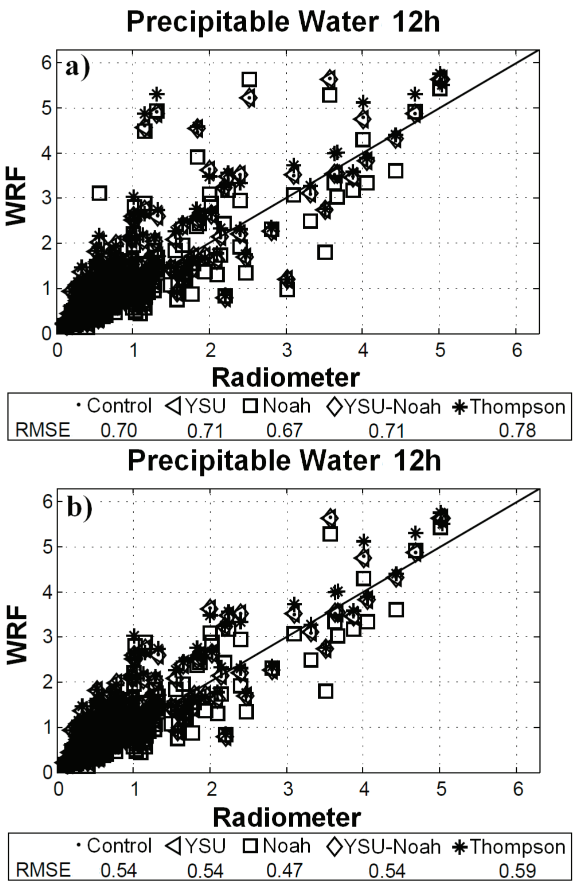

Fig. 5. Scatter plot of simulated PWV and APEX radiometer data at 12 UTC from April to December 2007. (a) Showing all data. (b) All data without the 6 points with the largest absolute errors.

4. CONCLUSIONS

In general, the WRF model shows very good results predicting precipitable water vapor (PWV) over the Chajnantor region. The best WRF configuration uses Noah Land surface Model, Simple Ice scheme for microphysics and the planetary boundary layer parameterization from Yonsei University

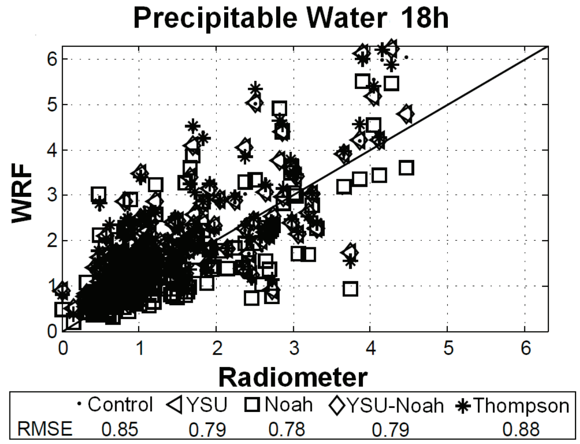

Fig. 6. Scatter plot of simulated PWV and APEX radiometer data at 18 UTC from April to December 2007. All data is shown.

(YSU-Noah), suggesting it can be used with confidence to predict the atmospheric conditions over Chajnantor.

No difference in PWV forecasts was evident between both microphysics parameterizations evaluated. The YSU PLB parameterization better represents the convective PBL and thus the meteorological variables in the afternoon hours but Mellor-Yamada PBL is better under stable conditions.

Better WRF forecasts could be obtained including weather station observations and satellite data into the initial conditions of simulations to decrease initial large errors.

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