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# A COMPARISON BETWEEN SOUNDING DATA AND WRF FORECASTS AT APEX SITE

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RESUMEN

Cinco configuraciones de WRF usando diferentes modelos de suelo y parametrizaciones de microfísica y de capa límite planetaria se evaluaron con sondeos lanzados durante una campaña de mediciones en el sitio de APEX (Atacama Pathfinder EXperiment). Los resultados indican que los cambios en la parametrización de microfísica no producen cambios apreciables en los perfiles de humedad. El modelo de suelo de Noah muestra menores errores en los perfiles verticales de las variables analizadas en comparación con el esquema de difusión térmica de 5 capas. El análisis de condiciones sinópticas mostró que las dificultades en predecir la variación diurna en la dirección del viento en condiciones de buen tiempo y la aparición de capas secas poco profundas en la atmósfera son algunas fuentes de errores en los pronósticos.

ABSTRACT

Five WRF configurations using different soil model, microphysics and planetary boundary layer parameterizations are compared with sounding data launched during a field campaign at APEX (Atacama Pathfinder EXperiment) site. The WRF model does a very good job forecasting PWV and temperature, wind speed and direction vertical profiles over the APEX site. Changes in microphysics parameterizations do not produce appreciable changes in humidity profiles. The Noah land surface model greatly improves the forecasts compared to the 5-layer thermal diffusion scheme. The analysis of daily synoptic conditions shows that difficulties in predicting the diurnal variation of wind direction in clear conditions and the occurrence of dry shallow layers in the atmosphere are some of the error sources in forecasts.

*Key Words:* atmospheric effects — site testing



## 1. INTRODUCTION

The Chajnantor plateau is located in the Antofagasta region, Chile. Several site testing campaigns chose it as the best place to host the ALMA (Atacama Large Millimeter Array) project. This region is located at 5100 m of altitude and presents large atmospheric stability and very low humidity. A climatological study using 52 years of reanalysis data shows that the Chajnantor area is indeed a place with very low atmospheric humidity, with clear seasonal indications of higher humidity during the austral summer (Bustos 2000). Stratocumulus clouds are predominant during winter months and cumulus clouds are present only in the summer.

The amount of water vapor in the atmosphere contained in a vertical column of unit cross-sectional area above a site extending between two levels is called the Precipitable Water Vapor (PWV). Its forecast is helpful for astronomers for a better observational scheduling and saving of financial resources. In addition, bad weather is an inconvenient for astronomical observations. For these reasons, the WRF (Weather Research and Forecasting) model was implemented over Chajnantor to predict the atmospheric conditions at ALMA site.

A set of WRF simulations using different configurations were performed and compared with radiosonde data deployed at the APEX site from 7 to 12 July 2009 and from 13 to 16 July 2009 at Sequitor operational APEX base under the ESO project "Study of Precipitable Water Vapor at Llano de Chajnantor, Chile". This comparison aims to determine the model configuration that best reproduces the meteorological characteristics at Chajnantor in order to use it in operational forecasts.

## 2. METHODOLOGY

Four nested domains were used in the simulations and their characteristics are shown in Table 1. These domains have a land-use, vegetation and topography resolution of 1 km. The maximum horizontal resolution in the model is 1 km for the innermost domain, which includes the Radio-observatory location. These high resolution simulations are intended to improve the weather forecasts over this

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TABLE 1

DOMAIN DESCRIPTION

| Domain | Dimension | Resolution |
|---|---|---|
| 1 | 43 × 47 | 27 km |
| 2 | 52 × 49 | 9 km |
| 3 | 61 × 64 | 3 km |
| 4 | 70 × 70 | 1 km |

region with complex orography. GFS forecasts every 6 hours were used as initial and boundary conditions to WRF.

Five WRF configurations were selected for this study. They include different parameterizations for the water phase change and boundary layer (PBL) processes, and two different soil models. Table 2 shows the details of these configurations. Each configuration differs from the control one in only one parameterization. All simulations were run using the RRTM longwave radiation, Dudhia shortwave radiation and Kain-Fritsch (new) convective parameterization.

Temperature and water vapor mixing ratio at 2 m and wind speed and direction at 10 m from the weather station at APEX provide observations near the surface to compare with simulations. PWV from the model was compared with values obtained from 183 GHz radiometer at APEX site and radiosondes. Data from radiosondes launched at 12 and 00 UT were averaged between half WRF levels to be compared with simulations values at 12 (36) and 24 (48) forecast hours. The PWV was obtained by the integration of water vapor mixing ratio (qv [kg/kg]) profiles horizontally interpolate them at each level:

$$PWV = \frac{1}{g}\int_{p_0}^{p} q_v \cdot dp\,,$$

where $g$ [m/s$^2$] is the acceleration of gravity and $p$ is pressure [hPa]. The integration was performed using the trapezoidal rule. Note that with this definition, the PWV is expressed in kg m$^{-2}$ (1 kg m$^{-2}$ is 1 mm in conventional PWV unit). A larger set of sounding data is needed to support these work conclusions. Nevertheless, the comparison with this small soundings dataset was helpful to study the performance of the model far from the surface.

## 3. RESULTS

### 3.1. *Vertical profiles*

Mean PWV vertical profiles (Figure 1a) show that Noah and YSU Noah configurations have the smallest errors at all levels and suggest that including humidity in the surface model calculation (as in Noah LSM) the water vapor forecasts can be improved at several levels above the surface. There are not larger differences between microphysics parameterizations. However, despite the Thompson parameterization includes a more complex physics, it shows slightly worse results in the PWV comparison than the Simple Ice scheme. The largest errors were found at 500 mb in all simulations. This value represents the PWV integrated between 500 and 450 hPa. The largest errors were observed at 12 and 15 July in the simulations, which affected the mean error.

Figure 1b shows the mean temperature vertical profiles. Simulations overestimate temperature at all levels except at the surface. The RMSE and mean absolute error (MAE) were about 1°C above 500 mb and increased to values around 2°C near the surface. However, during the period when soundings were deployed at APEX the errors were lower than 1°C. This indicates that soundings launched over Sequitor can describe the atmosphere in APEX over 500 mb but fails at levels influenced by the surface. The performance of temperature forecasts is very similar for all configurations during this period.

The mean wind speed profiles (Figure 2a) show that simulations underestimate this magnitude at higher levels. The daily analysis shows that the jet stream height was very well forecasted. The mean wind speed at the surface is overestimated by the model with MAE of 2.5 m/s and days where radiosondes were deployed at Sequitor present larger errors. Surface winds show a large variability and are strongly influenced by the orography. For this reason, near-surface wind values at Sequitor may be very different from that at APEX.

Wind direction (Figure 2b) is better simulated by Noah LSM configuration. The model does not represent accurately its daily cycle amplitude.

### 3.2. *PWV time series*

PWV values obtained from the APEX radiometer and soundings show similar results (Figure 3 at 12 UTC). The modeled PWV shows the same tendency but overestimate observations in most cases. Thompson configuration presents the largest overestimation in cloudy conditions. The largest errors for this period are observed at 12 and 15 July with MAE of 1.22 mm and 1.43 mm, respectively, in Noah configuration. A synoptic analysis for these days was performed in order to understand why the model shows such errors.

In 12 July, a cut-off low was located over Chajnantor area. This system was reinforced by a cold

TABLE 2

CONFIGURATIONS

| Physics | Control | Thompson | Noah | YSU | YSU-Noah |
|---|---|---|---|---|---|
| Microphysics | Simple Ice[a] | Thompson[b] | Simple Ice | Simple Ice | Simple Ice |
| Land-Surface Model | Thermal Dif.[c] | Thermal Dif. | Noah LSM[c] | Thermal Dif. | Noah LSM |
| PBL | Mellor-Yamada[d] | Mellor-Yamada | Mellor-Yamada | Yonsei Univ.[e] | Yonsei Univ. |

[a]Hong et al. 2004; [b]Thompson et al. 2006; [c]Skamarok et al. 2005; [d]Janjic 2002; [e]Hong & Dudhia 2003.

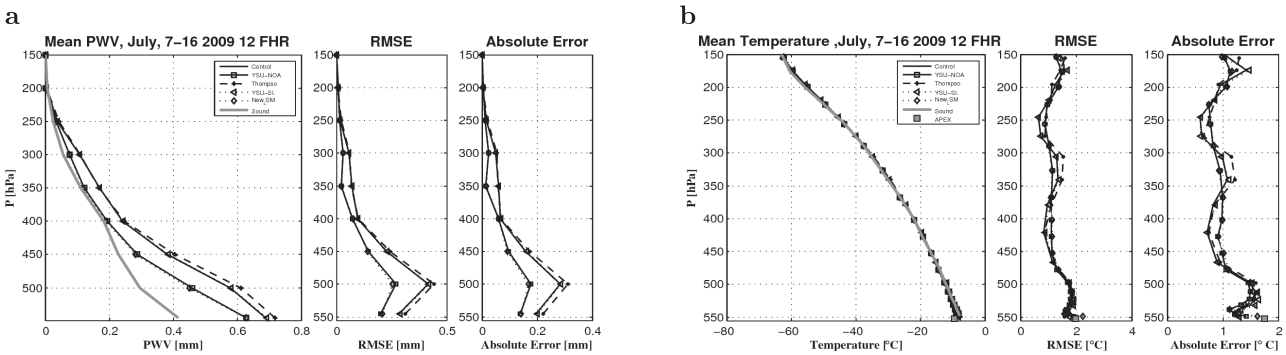


Fig. 1. Mean vertical profiles of (a) PWV [mm] and (b) temperature [°C] from 7 to 16 July 2009 at 12 forecast hour (FH).

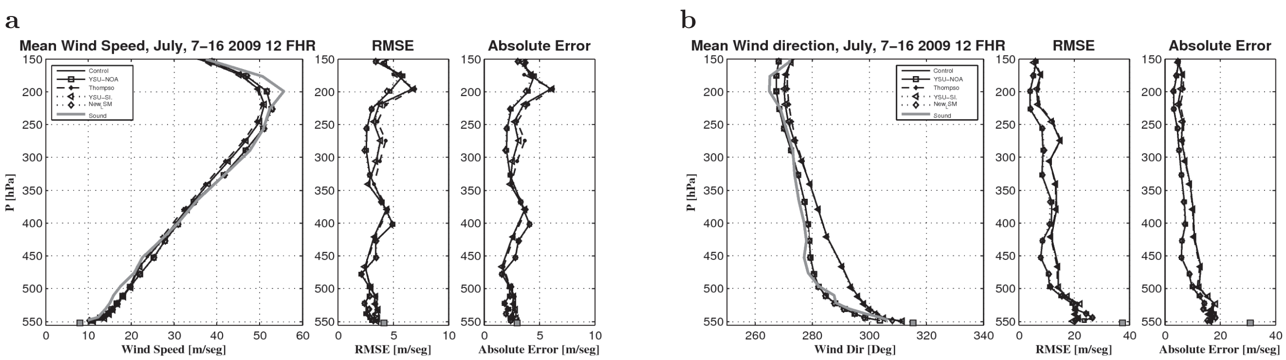


Fig. 2. Mean vertical profiles of (a) wind speed [m/s] and (b) wind direction [Deg] from 7 to 16 July 2009 at 12 forecast hour (FH).

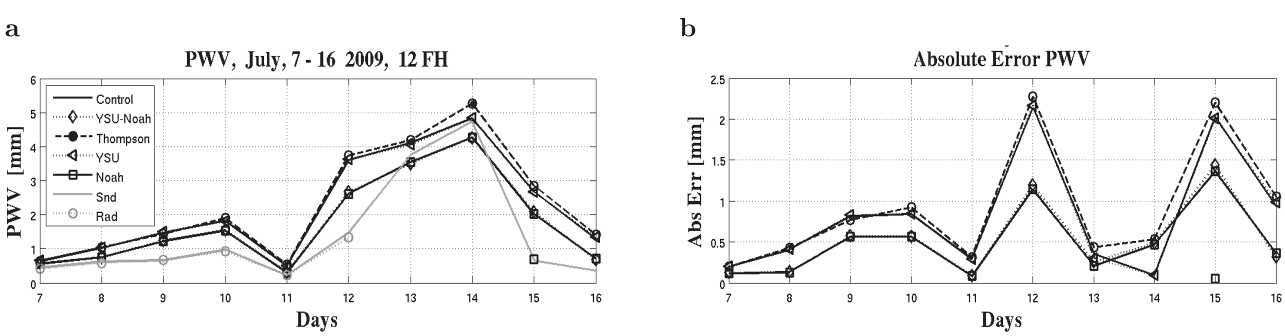


Fig. 3. Time series of (a) average PWV [mm] and (b) PWV Absolute Error [mm] at 12 forecast hour (FH) for all WRF configurations.

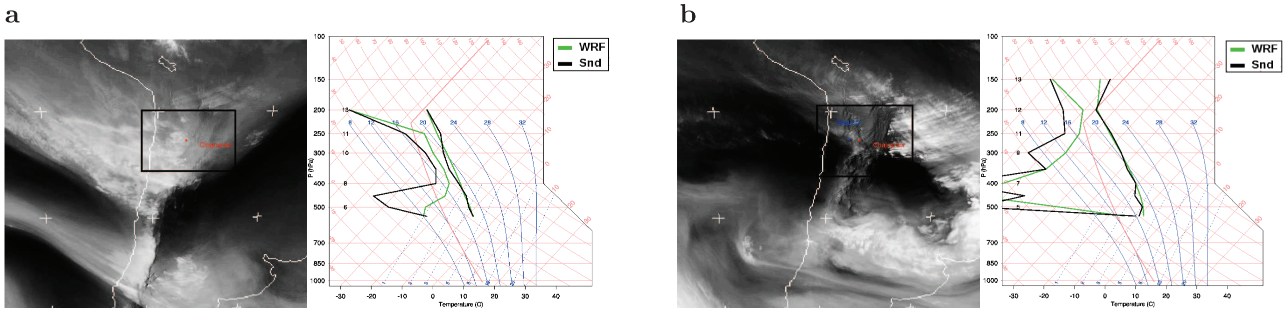


Fig. 4. Synoptic analysis. (a) GOES water vapor satellite image and Skew-T diagram of WRF simulations and radiosondes over APEX (located at 5.1 km of height) for 12 July 2009, (b) Same as (a) but for day 15 July 2009 over Sequitor, located at 2 km of height.

front and convergence became stronger at the surface. Cumulus clouds formed associated to this system, which were well simulated by the model. The water vapor mixing ratio profile from the radiosonde showed a very dry shallow layer near 450 hPa (below cloud base) that was not reproduced by any model configuration (Figure 4a). That was the main cause of PWV error in simulations of that day. The GFS model, the FNL analysis and NCEP reanalysis for this day show even more humidity at this level (450 hPa) than WRF. All this suggest that such errors can be due to lack of information in initial and boundary conditions or due to very local processes that need larger vertical resolutions to be simulated.

In 15 July, the radiosonde was deployed over Sequitor base site at 2 km of height. PWV was calculated from radiosonde data integrating the humidity profile from 5 km up to the top of the atmosphere. It was compared with PWV simulated at APEX. This day the satellite image showed isolated clouds over Sequitor while an overcast sky was present at APEX. Thus, it is possible that the radiosonde data did not catch the real atmospheric conditions over APEX site. The comparison between the simulated PWV at Sequitor and that calculated from the radiosonde showed an absolute error of only 0.05 mm in Noah configuration (Figure 4b). In other words, the model reproduced very well the observations at this place. Mid-clouds were present in the simulation at APEX site in agreement with the satellite image, causing the increase of PWV with regard to Sequitor base site.

## 4. CONCLUSIONS

The WRF model does a very good job forecasting the weather over the Chajnantor region. Configurations that use the Noah Land surface Model predict much better the vertical profiles of atmospheric properties, particularly the PWV and water vapor mixing ratio over the region. There are not significant differences between the two microphysics schemes analyzed.

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