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WRF SURFACE AND UPPER AIR VALIDATION OVER CENTRAL CHILE DURING LA NIÑA-EL NIÑO TRANSITION

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Abstract: Pacific Ocean suffers El Niño-La Niña sea surface oscillations which influences regional meteorological variables as surface temperature, wind fields and the diurnal development of the planetary boundary layer (PBL). In this work, we used WRF in order to evaluate its performance during the transition from weak La Niña to moderate El Niño phenomena, against surface observations and upper air measurements. Surface 2-m temperature was better described during moderate El Niño than weak La Niña event for selected settings. 10-m wind surface have not highlighted any influence. Upper air WRF validation was well described using PBL height estimations from LIDAR observations for comparison. Also, upper air WRF validation was considered against PBL height estimations based in bulk Richardson number from synoptic rawinsonde observations; however, these synoptic rawinsonde measurements usually failed in the estimation of the PBL height.

Key words: *WRF model validation, Niño-Niña, surface, LIDAR and rawinsonde data*

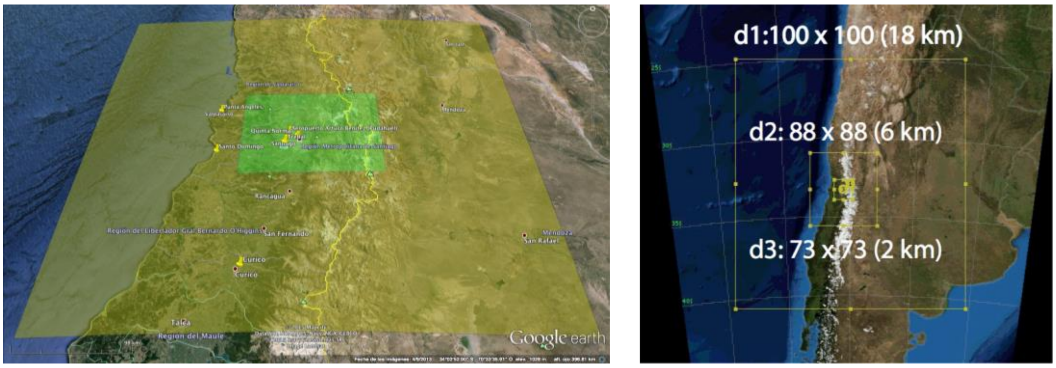
INTRODUCTION

It is well known that air quality models require high quality mass consistent meteorological fields from prognostic meteorological models. While these meteorological models have demonstrated increasing forecast skill over North America and Western Europe, few studies have focused on model validation in the Southern Cone of South America (Falvey and Garreaud 2002; Saide et al., 2011). Furthermore, this region suffers sea surface temperature (SST) oscillations due to El Niño and La Niña phenomena, producing changes in the surface weather conditions over Central Chile. In addition, this Southern mid-latitude location is affected by synoptic subsidence of subtropical Pacific anticyclone, limiting the vertical development of the planetary boundary layer height (PBLH) and promoting air pollution episodes (Garreaud et al., 2002; Saide et al., 2011).

In this work, we used Weather Research Forecast Model v3.6 (WRF) in order to evaluate its performance during the transition from weak La Niña to moderate El Niño phenomena, against surface observations and upper air measurements. Upper air WRF validation is focused in the PBL and model results are compared to estimated PBLH values from either synoptic rawinsonde or LIDAR ceilometer datasets.

STUDY AREA AND EVALUATION PERIOD

The study area covers 150x150 km^2 over Central Chile, around Santiago de Chile (33º 27'S 70º40'W), centered in the Metropolitan Region inside the Central Valley, surrounded on the east by the Andes Mountains with altitudes over 4000 asl-m, on the west by the Coastal Range over 1500 asl-m, and hilly chains partially blocking the north and south faces (Figure 1a). In this work, we apply the WRF meteorological model for an annual 2009 simulation using three telescoping one-way nested grids (Figure 1b) with a maximum 2x2 km^2 horizontal resolution in the innermost grid.



(a) (b)

Figure 1. Study area: (a) Location and physical geography of the D2 and D3 WRF simulation domains, also with the location of the meteorological surface stations and the upper-air site at Santo Domingo; (b) WRF nested domains.

About the WRF model settings selected, they include: Kain-Fritsch cumulus scheme (outer and medium domain), WSM 3-class microphysics scheme, RRTM longwave and Dudhia shortwave radiation schemes, and a 5-layer soil model. About PBL physics, Yonsei University-Pleim-Chang (YSU) scheme was applied. NCEP reanalysis fields supplied initial and boundary conditions.

About the study period, the beginning of 2009 marked the end of a weak La Niña event that transitioned into a moderate El Niño event by the last quarter of 2009 (Table 1).

Table 1. Sea surface temperature, 3 months running mean (Huang et al., 2015).

	DJF	**JFM**	**FMA**	**MAM**	**AMJ**	**MJJ**	**JJA**	**JAS**	**ASO**	**SON**	**OND**	**NDJ**
2009	-0.8	-0.7	-0.4	-0.1	0.2	0.4	**0.5**	**0.6**	**0.7**	**1.0**	**1.2**	**1.3**

For model validation, we applied the DS-3505 global surface hourly observational database along 2009 year in order to compare wind speed and temperature over six stations: two stations are located along the coast (D-F) and the remaining four stations (A,B,C,E) are located in Central Valley surrounded by complex terrain composed by the Andes Mountains to the East and Chilean Coastal Range to the West (Figure 1a). Surface validation performance was based on the criteria reported by Emery et al. (2001).

Upper air validation was focused in 1-12 June period against rawinsonde (as its available dataset) and in 1-30 June period (against ceilometer dataset), as during this period national air quality government authority warned Santiago de Chile citizens about air pollution risks due to strong atmospheric stability.

To validate upper air model performance, two different approaches were considered: (a) Observations from Santo Domingo synoptic rawinsonde launched twice daily near the coast (Figure 1a: D site) were used to estimate PBLH by means of the bulk Richardson number (Holtslag and van Ulden, 1983; González et al., 2015); this approach is very feasible, as almost every National Meteorological Office provides these data. (b) Estimation of PBLH from an algorithm based on aerosol concentration measurements provided by a ceilometer installed at inner Santiago de Chile; these PBLH estimations were supplied by Muñoz et al. (2010).

RESULTS

During the first quarter of 2009 the transition from weak La Niña to moderate El Niño event was observed (Table 1). This phenomenon has an impact in the 2-m temperature surface WRF performance (Table 2): systematic, random and gross errors are usually lower during El Niño than La Niña event. Also, YSU PBL scheme produces higher sensible heat flux than other schemes during nighttime, which can result in an increase in 2-m temperature (Kleczek et al., 2014). In addition, this systematic error can be influenced by the thermal 5-layer thermal diffusion (TD) soil model, which also increases the sensible heat flux compared to the Noah parametrization (Kleczek et al., 2014); this effect is noted on the surface stations. Particularly, coastal observations presented higher bias, reflecting the overestimation of the heat transfer by coupling YSU-TD, with a higher deviation along cold sea surface episodes, i.e., at the beginning of 2009 with the final weak La Niña. Surface stations located far from sea breeze effect are better described by this model configuration. About inner/inland sites results, they changed from overestimation to underestimation; negative bias is in agreement with previous results from Kleczek et al. (2014).

Table 2. Statistics for 2-m temperature: blue cells corresponds to January-June and red cells to July-December

Station	BIAS (ºC)	Gross Error	IOA (ºC)	RMSE (ºC)	BIAS (ºC)	Gross Error	IOA (ºC)	RMSE (ºC)
A	1.73	3.87	0.53	4.69	1.43	4.57	0.81	5.30
B	1.57	2.83	0.92	3.68	-0.75	2.39	0.93	3.04
C	0.85	2.14	0.95	2.82	-1.22	2.11	0.95	2.74
D	2.70	2.92	0.81	3.47	1.89	2.25	0.85	2.80
E	1.02	2.88	0.90	3.65	-0.06	2.11	0.94	2.67
F	1.97	2.49	0.61	2.98	1.09	2.08	0.65	2.56

10-m wind speed is generally overestimated independently of the PBL scheme used, as WRF trends to force non-local synoptic patterns instead of local effects. On the other hand, YSU scheme usually produces slightly lower wind speed during daytime; at the opposite, after sunset higher values are predicted. Against coastal observations higher positive is achieved bias due to more influence of oversea geostrophic winds on the computation of inland winds. There is no clear pattern about the influence of La Niña-El Niño on the prediction of 10-m wind speed, highlighting the capability of WRF to properly represent both events.

Table 3. Statistics for 10-m wind speed: blue cells corresponds to January-June and red cells to July-December

Station	BIAS (m s^{-1})	Gross Error	IOA (m s^{-1})	RMSE (m s^{-1})	BIAS (m s^{-1})	Gross Error	IOA (m s^{-1})	RMSE (m s^{-1})
A	0.63	1.46	0.44	1.94	0.53	1.67	0.61	2.06
B	-0.35	1.19	0.83	1.58	-0.51	1.44	0.69	1.96
C	0.86	1.00	0.77	1.19	0.65	0.92	0.69	1.14
D	1.11	1.48	0.74	1.89	0.93	1.50	0.80	1.93
E	-0.54	1.18	0.74	1.45	-0.81	1.30	0.68	1.65
F	2.44	3.00	0.51	3.69	2.99	3.47	0.59	4.19

About upper air WRF validation, the PBLH WRF parameter was extracted at the two specific locations where either rawinsonde (Figure 3) or ceilometer (Figure 4) were launched/located. For the rawinsonde selected episode (1-12 June) the maximum PBL height occurs at 1500 LT over both locations, and it never exceeds 500 m. Coastal PBL height dynamics are more unstable before sunrise and after sunset due to sea breeze influence. On average, it is noted the very low PBL height during winter over the Chilean central zone, no matter onshore or inland location.

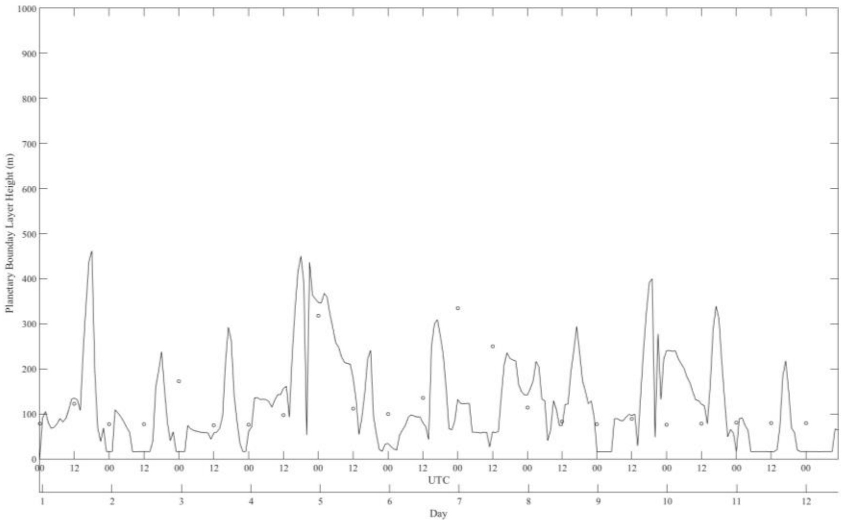


Figure 3. Evolution of the planetary boundary layer height along 1-12 June: (-) WRF, (○) rawinsonde

In this work, the available rawinsonde data do not represent properly the daily fluctuations and the diurnal development of the PBL height: this fact points out the low frequency of these measurements in the PBL (just 3-4 levels), as this rawinsonde is focused on synoptic patterns rather than the physics of the lowest layer. However, this approach of using synoptic rawinsonde to estimate PBL height could be feasible if the location presents a more convective behavior, as convection increases the PBL height and more upper air observations are included in this layer.

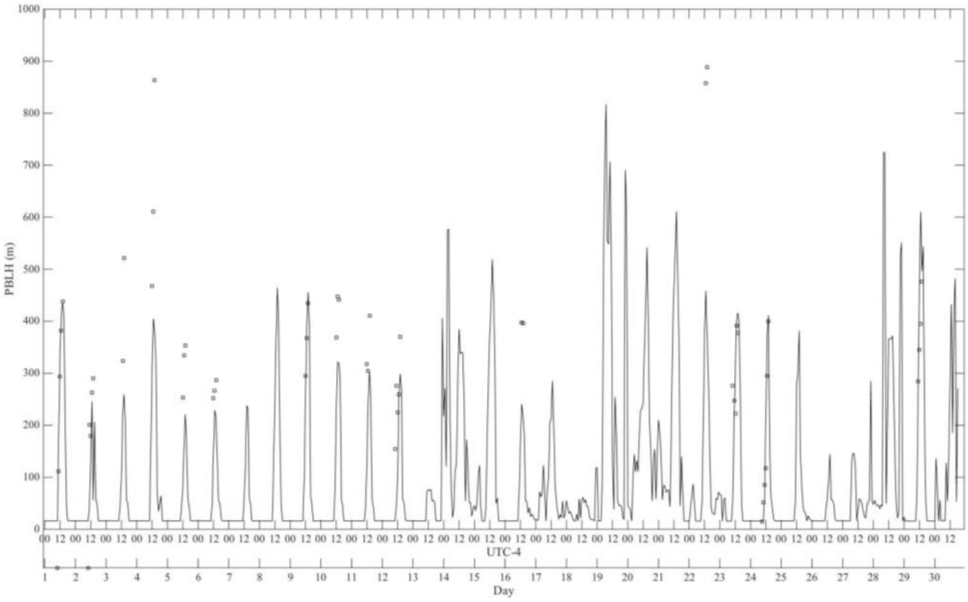


Figure 4. Evolution of the planetary boundary layer height along June 2009: (-) WRF, (□) ceilometer

In contrast with rawinsonde observations, ceilometer dataset provides a good representation of the diurnal dynamic development of the PBLH along June 2009 (Figure 4): At 1100 LT, mixing starts to increase, until it reaches its maximum at 1500 LT. The dynamic diurnal cycle predicted by WRF in inner Santiago de Chile is in agreement with ceilometer data. On some days the WRF model underestimates PBLH, also following the 2-m temperature underestimation during wintertime, lower heat transfer is predicted by WRF, affecting both parameters

CONCLUSIONS

Both ENSO (El Niño Southern Oscillation) and topographic conditions of Central Chile provide a singular influence to the meteorological conditions over this region; which also affect to the PBL structure. In this work, WRF model validation at PBL over Central Chile was done during the El Niño-La Niña transition period, covering the whole 2009 year. About surface temperature, a positive bias in coastal model results was observed, especially during cold sea surface episodes along La Niña period; this result can be related to the overestimation of surface heat flux using YSU PBL scheme and 5-layer thermal diffusion soil model, combined to the sea breeze effect. In fact, inland sites model results show an underestimation of surface temperature. Better results were achieved for surface wind speed, with similar statistics in both El Niño and La Niña periods.

Specific conditions over Central Chile are favorable to low PBL height periods, producing poor air quality events over Santiago de Chile. Therefore, validation of PBL height calculated by WRF model was done along June 2009 period when air quality warnings were announced in that city. PBL height estimations from LIDAR observations are comparable to WRF model predictions, showing the capability of this model to represent this PBL parameter; only some differences arise when surface temperature bias is higher. Also, PBL estimations from synoptic rawinsonde datasets were done but, because of the low number of observations at the PBL, these estimations are not realistic. As synoptic rawinsondes are launched everyday all over the world, it should be highly recommended to increase these rawinsondes vertical resolution at the lowest layer, so they can be applied not only as synoptic observations, but also as PBL observations closely related to poor air quality episodes.

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