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A COMPARISON OF DIFFERENT WRF-CALMET SIMULATIONS AGAINST SURFACE AND PBL RAWINSONDE DATA

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Abstract: It is well-known that air quality modeling requires accurate and detailed meteorological modeling, depending on the scale of the problem. Because of that, significant efforts were done in the improvement and validation of high resolution meteorological models. In this process, comparison of model results against measurements is a typical issue; however, most of those comparisons are mainly based in surface measurements, although the significant effect of aloft meteorological processes in air pollutants dispersion is well-known.
In this work, CALMET diagnostic model is nested to WRF model simulations (3 km horizontal resolution) over a complex terrain and coastal domain at NW of Spain, covering 100x100 km^2, during three different periods when primary pollutants glc peaks were detected. NCEP reanalysis are applied as initial and boundary conditions.
After checking different WRF PBL schemes, using Yong Sei University-Pleim-Chang (YSU) scheme simulation as the best WRF result, different CALMET horizontal resolutions are applied over the 100x100 km^2 simulation domain: 1 km, 0.5 km, and 0.2 km. CALMET simulations PBL depths are quite similar, and better than WRF results. With the 0.5 km simulation grid, different CALMET meteorological inputs using the best WRF result and/or surface and upper-air measurements are tested. The lowest RMSE surface data from CALMET results are obtained using the best WRF result combined to surface measurements as input data.

Key words: *CALMET, WRF model validation and intercomparison, rawinsonde data.*

INTRODUCTION

The management of air quality requires previous knowledge of atmospheric processes and pollution. While, the interpretation of the spatial and temporal evolution of air pollution requires extensive and detailed weather information, as both are strongly related. Although the measurements obtained by weather stations, surface and upper, provide a significant basis for driving meteorological studies, their biggest limitations are the lack of stations in every location and time (including upper air) and the need to know in detail the evolution of atmospheric phenomena. Accurate meteorological models allow covering these faults.

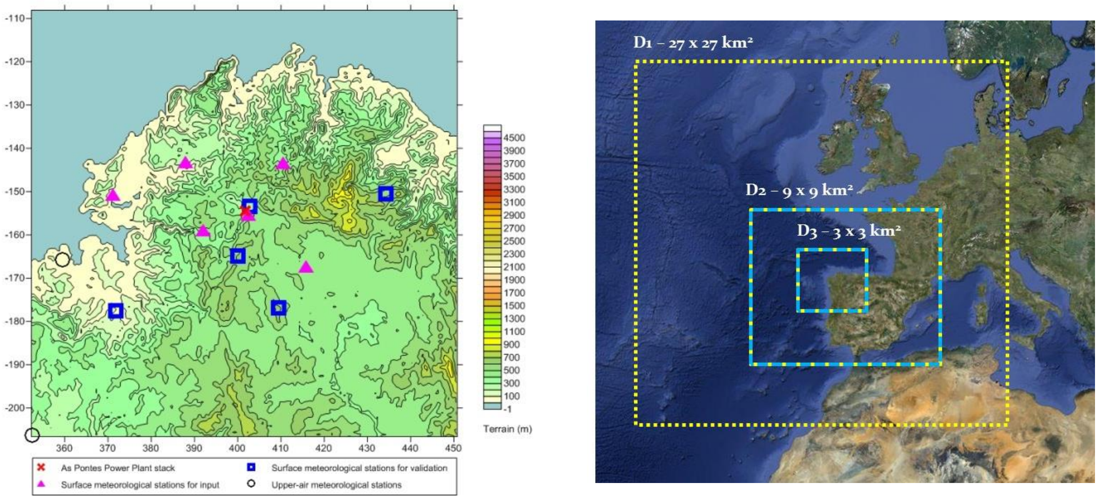
There are a large number of possible configurations to be chosen by model users to obtain a meteorological model suited to the characteristics of the region and the phenomena being studied. Therefore, there is no universal model configuration that can be applied to every region and every process, as the model must be validated against measurements to determine the degree of accuracy of the simulation results and to obtain a suitable model configuration (Hernández-Ceballos et al., 2010). Particularly, Ames et al (2002) emphasizes the significance of meteorological model validation related to CALMET model configuration, as it can strongly influence the results of the CALPUFF dispersion model.

Previous examples in meteorological models evaluation include statistics and methods selection. Willmott (1981) pointed out the advantages of using the RMSE to evaluate meteorological models; against other statistical parameters due to either overestimation of large errors or masking small ones. More recently, Snyder et al. (2007) applied a bayesian statistical method to validate RegCM3 model, and Cao et al. (2012) applied artificial neural networks. However, many meteorological models evaluations are still based in statistical parameters as RMSE, BIAS, etc (Emery et al., 2001; Chang and Hanna, 2004).

In this work, CALMET diagnostic model nested to WRF model simulations is evaluated by comparison to both surface and upper air measurements, along specific periods. PBL depth and surface data are considered.

STUDY AREA AND EVALUATION PERIODS

Galicia occupies the extreme northwest corner of the Iberian Peninsula, between 42° and 44° N and 7° and 9°30' W. The study area around As Pontes Power Plant (Fig. 1a), Northern Galicia in Northwestern Iberian Peninsula, is centred at As Pontes valley, covering the roughly E-W oriented lowlands around the River Eume with the following surrounding geographic features: to the East, the Serra da Carba and the Serra do Xistral, which reaches an altitude of 1000 asl-m; to the north, a series of hill ranges running roughly N-S from the coast, with maximum altitudes of 550-750 asl-m; to the West, low coastal hills (< 200 asl-m) bordering the Atlantic coast; to the South, the Serra de Queixeiro and Serra da Loba, with maximum altitudes of 750-850 asl-m; and to the SE, interacting with the river Eume via the gap between the Serra da Carba and the Serra da Loba, the high plain of Terra Chá. Therefore, it is a complex terrain, with several granitic mountains, valleys and coastal line mixed in the same environment.



(a) (b)

Figure 1. (a) Location (UTM coordinates) and physical geography of the CALMET simulation domain inside the D3 domain (Northwestern Galicia), with the location of meteorological surface and upper-air sites. (b) WRF nested domains, with D3 containing the CALMET simulation domain.

Three 3-days significant SO_2 episodes in this region are selected, following double criteria: hourly maximum SO_2 ground level concentration (glc) exceeding 170 μg/m^3 and synoptic representativeness, as typical weather conditions for SO_2 episodes in the Northwestern Iberian Peninsula. Selected Periods cover: P1, from 13 July 2005 to 15 July 2005; P2, from 1 June 2006 to 3 June 2006; and P3, from 9 July 2009 to 11 July 2006. All of them are anticyclonic and stable periods, typical conditions in the synoptic pattern High Pressure over Atlantic and Europe (HPAE) (Saavedra et al., 2012a).

METEOROLOGICAL MODELING

In this study, the mesoscale model WRF is coupled with the diagnostic model CALMET (WRF/CALMET system). This system is run on an hour-to-hour basis, first by using WRF to obtain a mesoscale meteorological field as a first guess field, and then using the CALMET model to adjust the meteorological fields considering the local influence of high-resolution terrain and land use data in the study area.

WRF v.3.2 model (Skamarock et al., 2008) is configured with 30 layers in the vertical direction and 3 levels of one-way nested domains (Fig. 1b) to reach a horizontal grid resolution of 3 km over the study area. The vertical grid sizes increased gradually with height with the lowest level being at 10 m above the ground. The model top pressure was located at 100 hPa. Apart from the different planetary boundary layer (PBL) schemes tested, model settings are Kain-Fritsch scheme for cumulus parameterization (for 27 and 9 km domains only), the WSM3-class microphysics scheme, the RRTM longwave and Dudhia shortwave radiation, and the 5-layer soil model (Dudhia, 1996). NCEP-GFS analysis data (1º horizontal resolution) are used as initial and boundary conditions every three hours. Neither surface nor upper-air observations are used. Elevation and land cover data are provided by the United States Geological Survey (USGS, 2008). WRF model is initialized as a ‘‘cold start’’ at 0000 UTC each day and run for 72 h, updating the boundary conditions every six hours and recording data every hour. No time as model spin-up is considered. The output frequency of the WRF model is set to 1 h. After testing four different PBL schemes, Yong Sei University-Pleim-Chang (YSU) scheme (Hong and Lim, 2006) is selected because of their better results (Saavedra et al., 2012b; Souto et al., 2013).

WRF results at 3x3 km^2 horizontal resolution are applied as input to CALMET model (Scire et al., 2000), in order to improve complex terrain and coastal influences. Vertical layers applied in CALMET simulations are (top-faces): 20, 40, 79, 176, 290, 439, 640, 880, 1180, 1580, 2062, 2453, 3354 and 4162 agl-m.

Table 1. RMSE from CALMET simulations against surface meteorological sites data, wind speed and temperature.

Simulations		**RMSE, wind speed ($m \cdot s^{-1}$)**			**RMSE, temperature (ºC)**		
	CALMET meteorological inputs and grids	**P1**	**P2**	**P3**	**P1**	**P2**	**P3**
Group 1 (against 11 sites)							
Best WRF	-	1.574	2.582	1.968	3.635	1.879	2.522
Cm-1/3km	WRF results only, 1 km grid resolution	1.495	2.550	1.946	3.753	2.305	3.092
Cm-0.5/3km	WRF results only, 0.5 km grid resolution	1.498	2.510	1.919	3.755	2.293	3.083
Cm-0.2/3km	WRF results only, 0.2 km grid resolution	1.499	2.527	1.914	3.763	2.285	3.081
Group 2 (against 5 sites)							
Cm(S+U)	Data from 11 (all) surface and 2 upper-air sites	0.048	0.061	0.054	0.650	0.050	0.732
Cm(W+S6)	WRF results and 6 surface sites	0.493	0.610	0.682	3.480	1.944	2.687
Cm(Sw+Uw)	WRF results (as measurements), 6 surface and two upper-air sites	1.463	2.245	2.250	3.577	3.374	2.825
Cm(S6+U)	Data from 6 surface and 2 upper-air sites	1.412	2.491	2.622	1.416	2.870	2.369

RESULTS

Seven different CALMET simulations are done (Table 1), sorted in two groups, depending on the meteorological input applied: Group 1, using only the best WRF results as input, and different CALMET horizontal resolutions; and Group 2, using also meteorological measurements, but keeping a 0.5 km^2 CALMET horizontal resolution.

Observational dataset includes hourly average observations from 11 monitoring stations, and two rawinsondes located in NW Iberian Peninsula (Fig. 1a). Surface stations have been selected as much representative as possible based on the characteristics of observations sites. When only 6 surface sites measurements are applied as input data, the other 5 sites measurements are applied for model testing. Upper-air observations are collected from two rawinsondes (Fig. 1a), EOAS-Santiago (MeteoGalicia, Regional Met Office) and A Coruña (AEMET, Spanish Met Office), alternatively launched every 6 hours. The following meteorological parameters are evaluated: PBL depth, surface temperature and wind speed.

About surface evaluation, Table 1 shows the root mean square error (RMSE) modelled vs. measured for the different WRF and CALMET simulations. Group 1 and Cm(S+U) simulations are evaluated against 11 (all) sites; Group 2 simulations are evaluated against 5 sites not applied in those simulations.

Group 1 simulations provide similar surface performance, showing that CALMET cannot improve WRF results without measurements. Of course, the lowest RMSE are obtained in Cm(S+U) simulation, as it is tested against the surface sites which are used as input data. About the other Group 2 simulations, a significant improvement respect to WRF results is obtained using WRF results and 6 surface sites data (Cm(WRF+S6)), even better than using surface and upper-air measurements (Cm(6S+U)): WRF simulations provide better upper-air information than 2 rawinsondes launched every 6 hours.

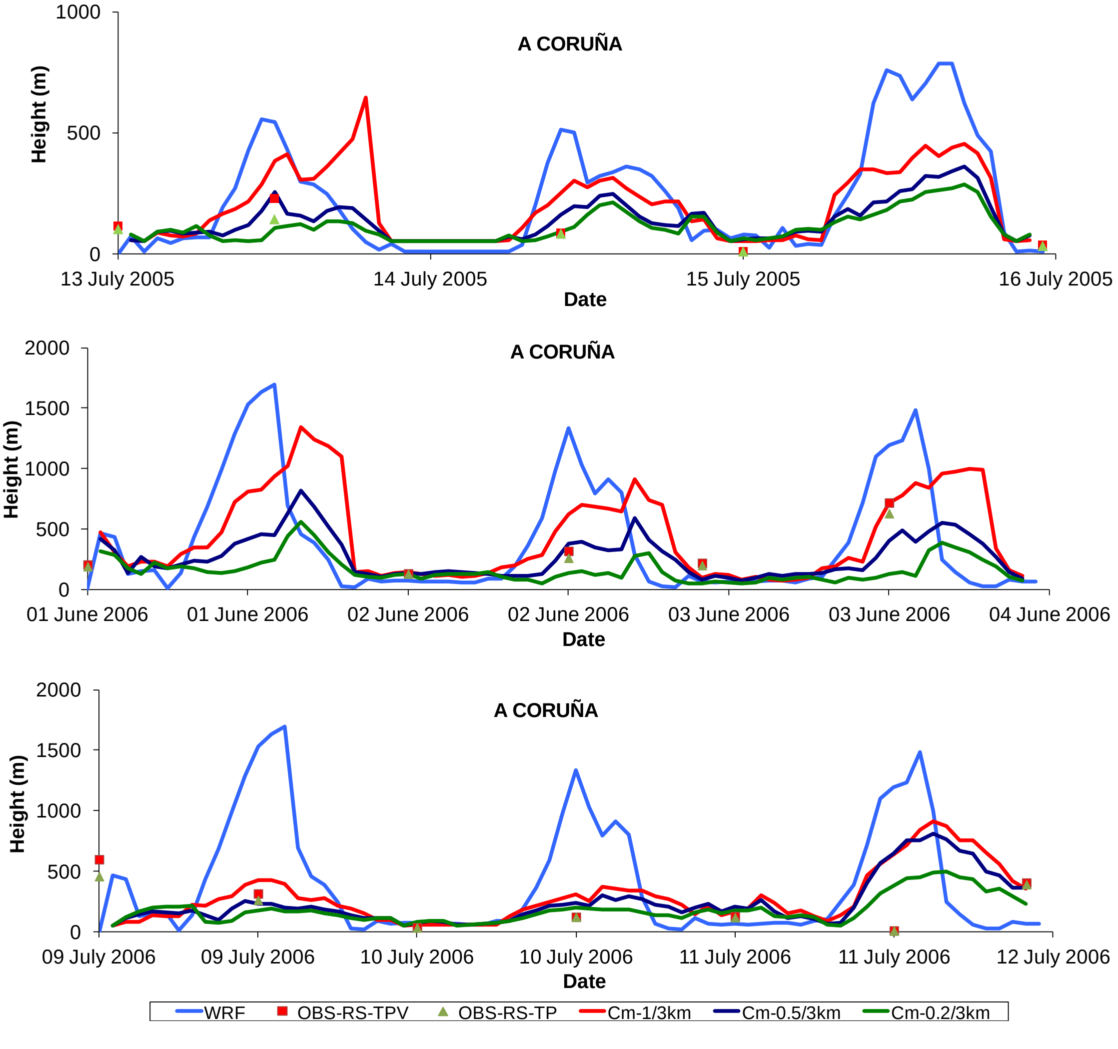


Figure 2. PBL depth time series over A Coruña (at 00Z and 12Z every date) modelled by WRF model (YSU PBL scheme) and different CALMET model resolutions (lines) and estimated from the A Coruña rawinsonde data (dots). PBL depth estimated using observed virtual potential temperature (OBS-RS-TPV), and using observed potential temperature (OBS-RS-TP) (Vogelezang et al., 1996).

About upper-air evaluation, PBL depth, both modelled (Group 1 simulations) and estimated from rawinsonde data are compared. CALMET PBL depth is modelled as follows: in land, using Holtslag and van Ulden (1986), and overwater using a profile technique, considering air-sea temperature difference (Scire et al., 2000). PBL depth estimation follows the critical bulk Richardson number method (Vogelezang et al., 1996) in dry atmosphere (as a function of potential temperature). A critical Richardson number of 0.25 is applied. A Coruña CALMET PBL depth results (Fig. 2) using different horizontal resolutions are quite similar, but significantly better than WRF results; EOAS-Santiago PBL depth comparison is similar. Both 0.5x0.5 km^2 and 0.2x0.2 km^2 resolutions provide a good agreement to the estimated PBL depth.

CONCLUSIONS

Seven different CALMET simulations along three different periods over a coastal and complex terrain Atlantic domain were done, using both WRF results and surface and upper-air measurements. Simulations results were compared to estimated PBL depths (from upper-air data) and surface wind and temperature. PBL depths obtained by CALMET model are similar, and better than WRF PBL depths. The best surface results were obtained by CALMET with WRF results and surface measurements as input dataset, as the best option to obtain meteorological fields for CALPUFF modelling; also adding more surface sites data.

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