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Evaluation of modeled wind field for dispersion modeling

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ABSTRACT

This study compares MM5 and WRF modeled upper air and surface wind speed and direction with observations from two standard meteorological stations locat;ed in areas characterized by either flat or complex terrain. Additionally, we evaluate the boundary layer height calculated by AERMET VIEW Upper Estimator. The upper air wind speed predictions of MM5 (but not of WRF) met all the acceptance criteria. In contrast, WRF surface wind predictions were mostly in better agreement with the observations than those of MM5, with a clear advantage for the 12 km grid resolution over the 3 km grid resolution. Modeled wind fields over complex terrain were less accurate than over flat terrain. Based on these results we conclude that in the absence of measured on-site meteorological data, WRF surface wind field predictions are expected to provide more reliable pollutant dispersion estimations and to propagate the estimation uncertainties to a lesser extent than MM5 surface wind field predictions, in particular for flat terrain scenarios.

1. Introduction

Oftentimes, one of the problems that must be overcome when assessing the impact of emissions from industrial plants on the environment is the lack of in-situ meteorological observations. Moreover, even if the surface wind field is known, it may not be sufficient for assessing dispersion, since upper air data are required for building the vertical wind profile and for estimating the mixing layer height. This problem can be circumvented using modeled meteorological data. Namely, if reliable surface measurements are missing it is possible to estimate the wind field using meteorological models with nested grid capacity. The latter accounts for the local topography and for (some) land cover features. Such models include the NCAR MM5 (5th-generation Mesoscale Model) and the WRF (The Weather Research and Forecasting) — two of the most widely used prognostic meteorological models. When using such models to acquire the wind field, e.g. for estimating pollutant dispersion, the wind data are obtained by defining a pseudo-meteorological station at the location where the meteorological records are missing. Several evaluation studies of the MM5 and WRF mesoscale meteorological models against point meteorological measurements have been reported (Durante et al., 2012; Balzarini et al., 2012; Carvalho et al., 2006; NPS-CIRA, 2004). Specifically, Liu and Warner (2004) reported that WRF forecasts the wind speed and direction in the upper troposphere better than MM5 but that MM5 generates more accurate forecasts at the surface and the lower troposphere. In contrast, NPS-CIRA (2004) reported that the MM5 upper air average wind speed over either flat or complex terrain was quite close to the measured average wind speed, with only slight under-prediction. A similar disagreement is found between reported underestimation by 4–5% of MM5 surface wind speed for offshore platforms (Durante et al., 2012) and MM5 over-prediction of surface wind speeds over land and coastal regions (Zhang et al., 2011; Carvalho et al., 2006). Posada et al. (2013) compared MM5 modeled wind field and radiosonde data for Madrid, Spain, and found good model performance (in terms of solely the wind speed) during winter precipitation events. Likewise, Madala et al. (2014) found that WRF captured the characteristic variations of surface meteorological variables, such as the air temperature, relative humidity, wind field, vertical wind profile, equivalent potential temperature and surface fluxes. Using a set of acceptable model performance criteria (Emery and Tai, 2001), wind speed bias of 0.5 m/s, wind direction mean bias of 10°, a root mean square error (RMSE) of 2.0 m/s for the wind speed, and some other performance indicators were reported for MM5 meteorological predictions (URS Corporation, 2008). Interestingly, MM5 performed better when using the 36 km or the 12 km grid resolutions than with the 4 km grid (URS Corporation, 2008; Zhang et al., 2011). Likewise, running WRF simulations with a 5 km grid resolution did not improve, in general, the model performance when compared to using a 15 km grid (Balzarini et al., 2012). Yet, most studies that examined different grids (from 36 km to 3 km) did not evaluate systematically the accuracy of the results vs. observations (Durante et al., 2012; NPS-CIRA, 2004), and in other cases the comparisons were inconclusive. For example, Kochanski et al. (2013) reported that WRF simulations overestimated the vertical wind speed component and underestimated the horizontal wind speed at heights >10 m a.g.l. whereas other studies (e.g. Balzarini et al., 2012) found no systematic tendency of WRF towards

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underestimation or overestimation of the surface wind speed. Moreover, to our best knowledge, a quantitative evaluation of the predicted wind direction over a long period has never been reported.

In locations where upper air measurements are not available as input for dispersion modeling, the mixing height is oftentimes calculated by the AERMET VIEW Upper Estimator. The latter calculates the heights of the convective and of the mechanically-generated boundary layers based on Thomson (1992), with the mixing height being their sum. MM5 predictions of the mixing height were studied by Ferrero et al. (2011). Comparison between predicted and observed convective boundary layer height has been performed by Thé et al. (2001), who found that the model over-predicted by ~50%. Here we compare the Beit Dagan radiosonde upper air observations, from which the mixing layer height can be derived, with the sum of the convective and the mechanically-generated boundary layers, predicted by the AERMET VIEW Upper Estimator.

In spite of the Near East regional sensitivity to climate changes and desertification as well as the rich dynamics of common synoptic patterns, regional WRF evaluation has been reported only for the wet season precipitation forecasts (Rostkier-Edelstein et al., 2013; Givati et al., 2012) and for the maximum and minimum wind speeds in two one-month periods (Lynn, 2007). Whereas the day-to-day variation of WRF predicted daily maximum wind speeds was satisfactory, the minimum daily wind speed forecast was rather poor (Lynn, 2007). Moreover, particle wet deposition is generally small in regions characterized by a very dry weather, such as the study area in this work. The high seasonal and year-to-year meteorological variability suggest that evaluation of meteorological model predictions is crucial, especially if modeled wind fields are used later for estimating emission dispersion and ambient pollutant concentrations, as is oftentimes the case when environmental impact assessments (EIAs) are performed as part of an application for permit for establishing a new factory or business.

In this study we evaluate modeled wind fields for both flat and complex terrain conditions. Specifically, upper air wind speed (MM5 and WRF) and mixing height (AERMET VIEW Upper Estimator) predictions are compared to radiosonde data, and MM5 and WRF surface wind field predictions are compared to meteorological observations.

2. Methods

2.1. Upper air comparisons

The Israel Meteorological Service (IMS) collects twice a day upper air data (up to 5500 m a.s.l.) in Beit Dagan, including the scalar average wind speed, which is obtained from measurements at various heights within the mixing layer. Upper air wind speed observations were lognormally distributed with a mode at 4–5 m/s (Fig. 1). We compared the representative upper wind speed, derived from measurements of the daily radiosonde launches at Beit Dagan throughout the year of 2011, with the upper air wind speed predictions of MM5 and WRF. Specifically, the modeled characteristic upper air wind speed was derived from wind profiles obtained by MM5 (version 3.6, 12 km resolution) and by WRF (version 3.5.1, 12 km and 3 km resolutions). The configuration of the meteorological models is presented in Table 1. It is noteworthy that we did not run MM5 on a resolution finer than 12 km, since it was reported to perform better at the 12 km resolution than at the 4 km resolution (URS Corporation, 2008; Zhang et al., 2011). The comparison was performed for (a) the whole year of 2011, (b) the different seasons of that year, and (c) time periods within this year that were characterized by low (<2 m/s), intermediate (2–8 m/s), and high (>8 m/s) upper air wind speeds. Furthermore, AERMET VIEW Upper Estimator predictions of the boundary layer height were compared to the measured mixing height, derived from the 2011 radiosonde launches at Beit Dagan. Only 48% of measurements was valid for the latter comparisons, and about 52% of the wind speed measurements could be used to derive the observed scalar average wind speed.

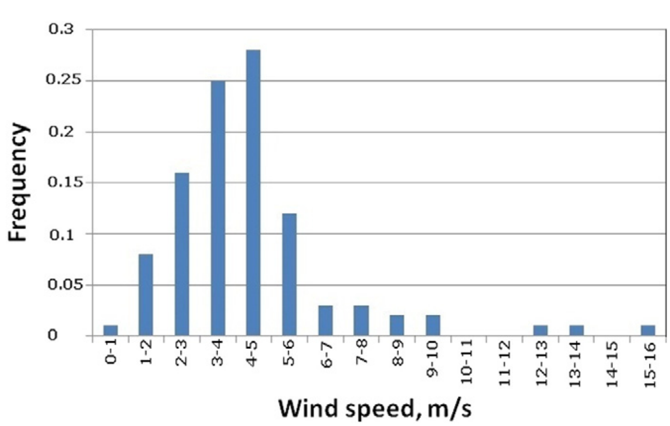

Fig. 1. Wind speed distribution in the upper air for the whole year of 2011 as measured by radiosonde launches in Beit Dagan, Israel.

Table 1
Configuration of the meteorological models.

Model	WRF	MM5
Model code	WRF model version 3.5.1	MM5 model version 3.6
Horizontal grid mesh	48 km/12 km/3 km (81 × 81 cells at each grid)	108 km/36 km/12 km (23 × 23/31 × 31/31 × 31 cells)
Vertical grid mesh	28 layers	18 layers
Grid interaction	Two-way nesting	Two-way nesting
Initialization	NCEP CFSR reanalysis	NCEP CFSR reanalysis
Boundary conditions	NCEP CFSR reanalysis	NCEP CFSR reanalysis
Microphysics	WSM 3-class simple ice	Simple ice/Dudhia
Cumulus scheme	Kain–Fritsch (48 km/12 km/3 km grids)	Kain–Fritsch (108 km/36 km/12 km grids)
Planetary boundary layer	YSU	MRF
Longwave radiation	RRTM	RRTM
Shortwave radiation	Dudhia	NA
Vegetation data	USGS (24 category scheme)	USGS (24 category scheme)
Land surface model	Unified NOAH	Five-layer soil model/Dudhia
Shallow convection	None	None
Sea surface temperature	Do not update SST	Standard (invariant)
Thermal roughness	Default	Default
Snow cover effects	None	None
4D data assimilation	None	FDDA
Integration time step	240 s	300 s
Platform	Linux cluster	Linux cluster

2.2. Surface meteorological data

Evaluation of MM5 (12 km resolution) and WRF (both 12 km and 3 km resolutions) wind speed and direction at the ground, and of the surface temperature estimates was performed against surface meteorological measurements from the year of 2011 for the (a) whole year, (b) four seasons, and (c) low, intermediate and high surface wind speeds. The observations were obtained from the Beit Dagan meteorological station (32.007 N, 34.814 E, 35 m a.s.l, 20 m a.g.l), which is operated by the Israel Meteorological Service. The station is located at the center of Israel's flat coastal plains, about 7 km from the Mediterranean Sea (Fig. 2). The measurements reveal that Beit Dagan does not experience a predominant wind direction but mostly evenly distributed winds, which result from the station's location in open flat terrain. A further comparison of the surface wind field was performed using data collected at the Zova meteorological station (31.787 N, 35.124 E, 730 m a.s.l, 10 m a.g.l), which is about 35 km to the SE from Beit