Using windprofiler data in time and frequency domain for the evaluation of meteorological drivers employed in chemistry transport modelling

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ABSTRACT

Meteorological fields are required as indispensable input for air quality models. But they can be a source of significant errors which contribute to uncertainties in simulations of the atmospheric distribution of chemical species and aerosols. Within the COST728 action a study has been initiated, which takes advantage of hourly available high quality wind profile measurements from profiling radars to assess whether several regional-scale meteorology models widely in use for air pollution studies are properly simulating the spatial - i.e. vertical - and temporal features imbedded in the observations.

The shown examples here just serve to illustrate the way the profile comparison has been set up. A detailed discussion of the results and an enhanced profile structure evaluation will be reported in an upcoming publication.

1. INTRODUCTION

Three-dimensional air quality modelling systems (AQMS) are being applied by responsible agencies for air quality management decisions and for the development of air quality standards. Hence, a high quality of the AQMS themselves is required [1]. Uncertainties in air quality model predictions can arise from various sources within the system, which usually consist of an emission model or data-base, a meteorological model and a chemistry transport model (CTM). In so-called online-models the meteorological and chemistry transport models are merged and can interact bi-directionally. Off-line models often employ an interface module to couple the meteorological fields to the CTM.

Meteorological fields can be a source of significant errors which contribute to uncertainties in simulations of the atmospheric distribution of chemical species and aerosols [2]. Therefore, the evaluation of the quality of meteorological simulations used for chemistry transport studies is indispensable. Especially in complex meteorological situations the resulting concentrations of pollutants can vary a lot among different model systems as it is indicated in figure 1, which shows as an example the comparison of observed and modelled sulphate concentrations during a high PM10 episode in late winter 2003 over Germany. The deviations of model concentration from the observed ones and among the model concentrations was largest when the meteorological situation was dominated by a blocking high pressure system causing a slow down or even retreat of incoming fronts. Starting with about day 66 the situation turned to the meteorologically simpler case - a quasi steady westerly flow. The associated observed low sulphate concentrations were in general much better captured by the different models.

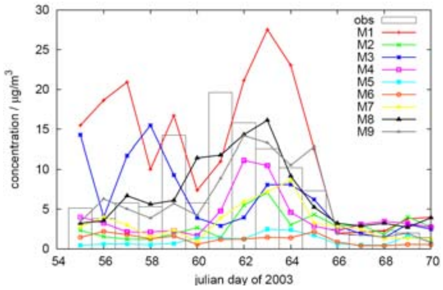

Figure: 1: *Daily* averages of o*bserved (columns) and modelled (symbols connected by lines) sulphate concentrations from 24.02.2003 to 11.03.2003 for Melpitz, Germany.*

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Wind velocity and wind direction are parameters of fundamental relevance for atmospheric dispersion and thus for chemistry transport modelling. The models in use should reproduce, beside mean quantities, the variability of wind on the relevant spatial and time scales. Besides surface winds upper level wind should be considered for evaluation studies as well, since they are less influenced by small scale geographical details and therefore better characterize the overall mesoscale transport aspects. In this study we use vertical wind profiles derived from VHF or UHF radars (wind profilers) for three different sites as observational "truth" to assess the performance of several meteorological drivers applied in air pollution studies.

2. MODELS AND WIND PROFILERS.

Several mesoscale meteorological models in use for chemical transport studies are taking part in this comparison exercise, which is organised under the umbrella of the COST 728 action. The models are applied in configurations (resolution, boundary conditions, assimilation and nudging) as they are typically operated by the participating institutions. Model runs with different set ups of MM5, WRF, COSMO and GEM, with grid resolutions between 6 km and 54 km have been considered. Additionally two meteorological drivers derived from analysis data are taking part in this evaluation.

Wind observations employed in this study are hourly wind profiler data for the entire year 2000 at three European stations of the CWINDE wind profiler network [3]: Camborne/United Kingdom, Cabauw/ The Netherlands and Lindenberg/Germany. In 2000 the windprofiler network was in an early stage of operation, so only a few segments of considerable length without missing data were available, i.e. for undistorted spectral analysis. For the special time period from 24.03.2003 to 11.03.2003 additionally data from the Lindenberg boundary profiler were used.

3. Comparison of model winds with observations

We start this section by presenting some results from a comparison of a GKSS MM5 run for an episode in spring 2000. A multi-model comparison of winds with profiler data for a meteorological complex situation follows under 3.2.

3.1 Episode spring 2000

At GKSS long term chemistry transport model runs are performed with the goal to provide estimates of trends in the PAH distribution over Europe [4]. A quite coarse grid resolution had to be chosen for computing cost reasons. Several tests were performed to evaluate the sufficiency of the meteorological data used for the simulations.

Mean vertical wind profiles derived from wind profiler data at three stations for the entire year 2000 were compared to respective model profiles obtained from the MM5 model runs at GKSS using a model resolution of 54 km. The comparison showed in general good agreement for the mean of both wind components and a high correlation, the results are reported in [5].

However, a closer look at individual time series reveals, that the hourly model data from the 54 km grid resolution runs is much smoother compared to the observations, although the model data series consists of time step snap shots at the hour, while the windprofiler data represent an average over 20 to 30 minutes. Figure 2 presents an example of such time series showing the observed and modelled U-wind component at a height of about 910 m over the Camborne area. Overall the model wind follows the observations quite well, no systematic differences are obvious. The standard deviations of the two series amounting to 7.99 ms^{-1} (obs.) and 7.91 ms^{-1} (MM5) show an acceptable agreement. But from figure 2 it is evident that the observational data contains much more variability on short time scales.

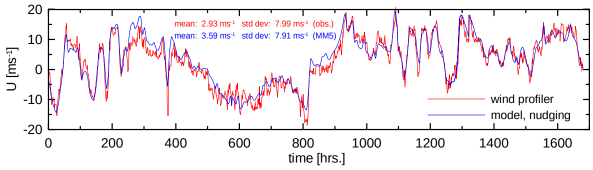


Figure 2: *Hourly time series of the U-wind component at a height of about 910 m as measured by the wind profiler at Camborne, UK, (red) and as computed with MM5 (54 km grid resolution; full nudging; blue) for days 100 to 169 of the year 2000.*

The respective maximum entropy power spectrum of model wind time series shows a strong attenuation at higher frequencies (shorter periods) when compared to that derived from the observations (figure 3). The model power spectrum starts at a period of about 20 hours to roll off with a much steeper slope indicating that intra-day fluctuations are not adequately resolved by the MM5 runs with a grid resolution of 54 km. The same behaviour of the model power spectra has been found for other locations and altitudes (not shown here).

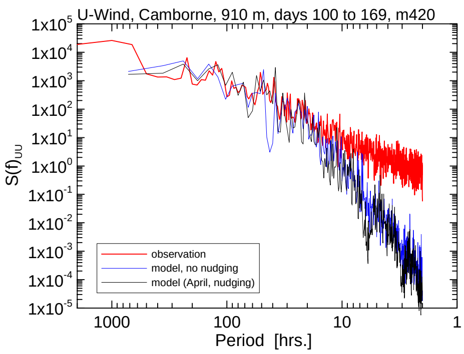


Figure 3: *ME-power spectra of the U-wind component at an altitude of 910 m computed from wind profiler data at Camborne, UK, (red) and respective MM5 results with 54 km grid resolution (full nudging; black, no-nudging: blue) for days 100 to 169 of the year 2000.*

The dips in the model spectra evident in figure 3 (they do not occur at other locations) at the periods 6 hours and 3 hours are related to the nudging of wind and other data from the ERA 40 reanalysis, as the comparison of spectra from a run with nudging and one without nudging clearly indicates. Overall it can be stated that the wind velocities from the simulation are of sufficient quality for our purposes. But if locally induced circulations with a daily cycle (e.g. see-breeze effect in coastal areas) or meteorological situations with strong intra-day fluctuations dominate in the region of interest a much higher grid resolution needs to be chosen. Spectra for the location Cabauw, NL, for which model runs with higher grid resolutions are available, suggest a grid resolution of about 6 km to initiate wind fluctuations on the intra-day time scale.

3.2 Episode Spring 2003

This section focuses on a high PM10 episode (24.02.2003 to 11.03.2003) over Germany, which was marked by complex meteorology. A first evaluation of this episode with focus on chemistry near the surface has been published by Stern et al. 2008 [6]. The authors provide a description of the overall meteorological situation. In the frame of COST 728 we extent this study by looking into vertical profiles of meteorological quantities and by incorporating additional models.

Figure 4 shows for the entire episode as an example a comparison between modelled (selected models) and observed wind velocity at an altitude of about 500 m over Lindenberg. The strong variability of the wind speed during the period is in general followed by the models, but also systematic deviations can be seen (i.e. some models tend to underestimate velocity).

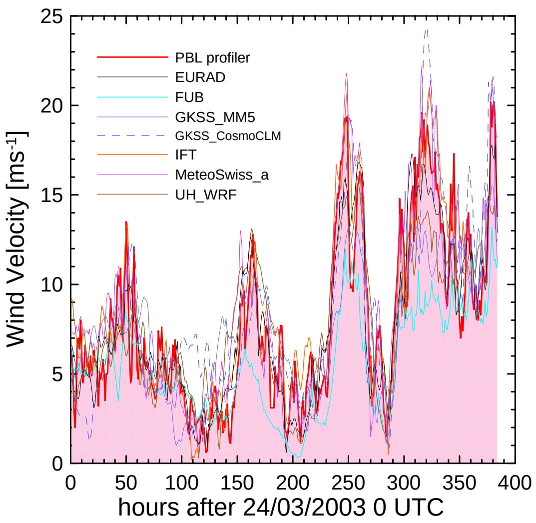


Figure 4: *Time series of wind velocity as measured by the Lindenberg pbl-profiler at about 500 m altitude together with results from selected models.*

Maximum entropy spectra of the wind velocity time series displayed in figure 4 can be seen in figure 5. Most models match the location of the central spectral peak of the measurements, indicating that the general variability (timing) has been captured, but there are also deviations indicating a partial phase shift, which has been quantified by cross spectral analysis (not shown here). Most model-spectra roll of much steeper at the high frequency end of the spectrum compared to the observation. This indicates that fluctuations on the order of a few hours (intra day) are not well represented. In general the models with higher spatial resolutions – as can be expected - come closer to the observed variability. The model run with a 6 km grid spacing follows the observed variability quite close.

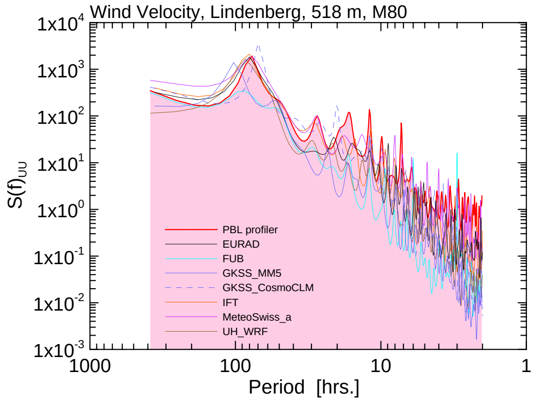


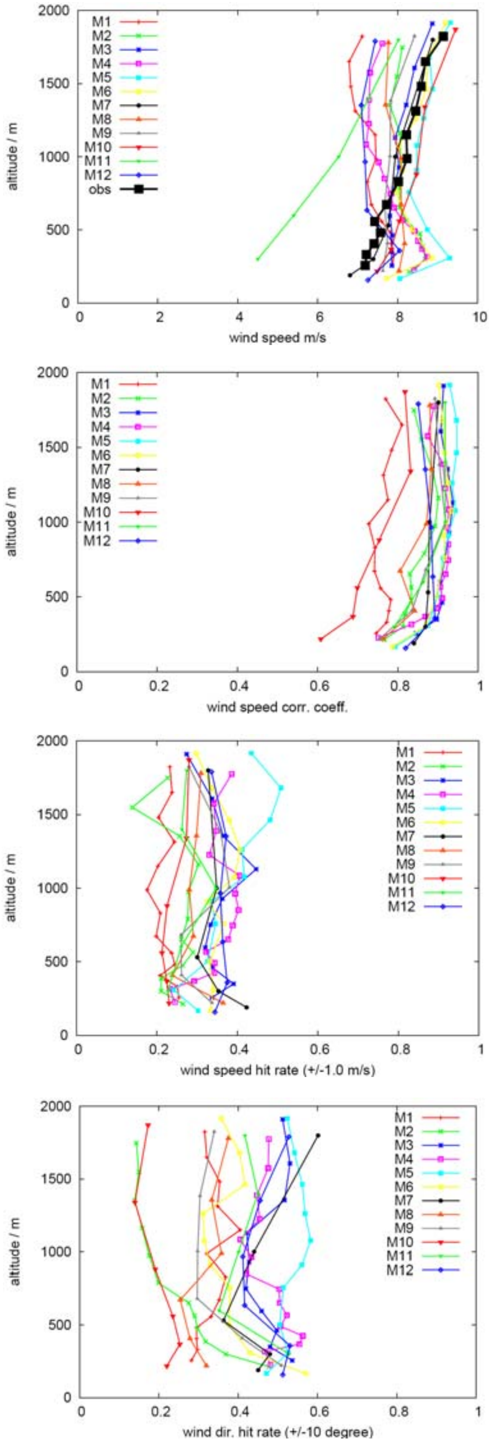
Figure 5: *ME-power spectra of the time series displayed in figure 4.*

Height dependent behaviour, agreements, phase shifts and other deviations at one location can be visually assessed by comparisons of time height cross-sections. A more systematic evaluation of the model performances can be derived by using statistical measures as quality indicators [7]. We evaluated several statistical measures at all available model layers for the entire suite of participating models, two are shown below. The average vertical profiles of wind velocity are displayed in figure 6a. It can be seen that almost all models overestimate wind velocity below approximately 500 m and underestimate velocity above 1 km. The increase of wind speed with altitude and shape of the profile is not adequately reproduced by most of the models.

The correlation coefficients derived for the whole time series is typically high, this is indicated by values between 0.8 and 0.9 (figure 6b). The entire hit rates with respect to an allowed deviation of 1m/s for the hourly values are small and fall between 0.2 and 0.4 (figure 6c).

Wind direction is of course a parameter of utmost importance for regional transport studies, it characterizes entire dispersion situations, i.e. near the source regions. In figure 6d the hit rate for wind direction with an allowance of 20 degrees centred around the observed direction is shown. The spread among the model results is larger than that for wind speed hit rates, some model systems show higher hit rates between 0.4 and 0.6 while other do not show values larger than 0.2.

As stated above, a detailed evaluation and discussion of the comparison results can not be presented here. It would need to incorporate the different set ups of the modelling systems with respect to data assimilation, nudging procedures etc. Those results will be reported in an upcoming dedicated publication.



a) b) c) d)

Figure 6: *Vertical profiles of the mean wind velocity for the period from 24.02.2003 to 11.03.2003 obtained from the PBL windprofiler at Lindenberg and related model results (a). Correlation coefficients for wind velocity and hit rate for wind velocity (± 1 ms-1) (c) and wind direction (± 10°) (d) with respect to the observations.*

4. CONCLUSIONS

Wind profiling radars are very useful for the evaluation of meteorological models incorporated in air quality modelling systems. They allow for the assessment of the quality of modelled wind velocities and wind directions at various altitude levels. Compared to radiosonde data, which often has been used for this purpose, wind profiler observations have the advantage of much higher time resolution (at least hourly data) and that they represent quasi-local profiles. The examples presented here illustrate the potential. Several deficiencies in model systems or their set-up could be identified. I.e. the availability of hourly data allows the identification of regionally induced wind systems, which have a large relevance in the context of dispersion studies.

From the practical point of view, the model evaluation community would certainly welcome a common reporting scheme of the profiler data from the European stations. A unified data format, missing data-handling procedures and data quality reporting would be very helpful and probably lead to an increased use of this valuable data by modellers.

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