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COMPARING THE INFLUENCE OF INPUT METEOROLOGICAL DATASET AND LOCAL DISPERSION MODEL CHOICE ON REGULATORY MODELLING OUTPUTS

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Abstract: Regulatory dispersion modellers increasingly use meteorological data from Numerical Weather Prediction (NWP) models, due to diminishing availability of local meteorological observations and improved resolution, accuracy and availability of NWP data. However, few studies investigate the influence of NWP input meteorological datasets on local dispersion modelling. A recent UK Atmospheric Dispersion Modelling Liaison Committee project compared outputs from ADMS and AERMOD using observed and NWP meteorological datasets. NWP data was obtained from two models, each at two horizontal grid resolutions: the UK Met Office's Unified Model (UM) at 1.5 and 10 km; and the Weather Research and Forecasting (WRF) model at 1 and 9 km. Wind speed and direction, temperature and cloud cover were extracted from NWP and supplied to the local dispersion model, consistent with observed data variables. Idealised near-ground and elevated sources were defined, representing intensive agriculture and industrial processes respectively. Dispersion modelling was undertaken at four UK meteorological measurement locations: one flat terrain, one coastal and two complex terrain. Ground-level receptor output grids were specified radially from the source locations, up to 1 km from the near-ground source and 5 km from the elevated source. Maximum values and locations of: annual average; 98th percentile hourly average; and maximum hourly average concentrations were compared for each combination of input meteorological dataset and local model. Sensitivity to input meteorological data was quantified using the range of model outputs obtained with observed and four different NWP datasets, normalised by the corresponding value obtained with observed meteorology. ADMS and AERMOD demonstrated low sensitivity (≤ 0.18) to input meteorology types for maximum annual average and 98th percentile hourly concentrations in flat terrain. Increased sensitivity was found for sources in complex terrain and maximum hourly concentrations. For most outputs, larger concentration differences were found between ADMS and AERMOD using observed meteorology compared to using different meteorological datasets in the same local model.

Key words: dispersion, meteorology, ADMS, AERMOD, sensitivity

INTRODUCTION

Dispersion models are used for regulatory planning and assessment studies of a wide range of pollution sources. There is variation in the modelling approaches recommended in guidance from different national regulators, with some prescribing a specific model and input data sources (e.g. Germany, TA-Luft 2021) while others provide broad guidance but leave more room for professional judgement (e.g. England, EA/Defra 2014). In the UK, local dispersion models ADMS (Carruthers et al., 1994) and AERMOD (Cimorelli et al., 2004) are both widely used for regulatory studies of industrial sources.

Local dispersion models rely on input meteorological (met) data to define the atmospheric conditions for dispersion. Both ADMS and AERMOD were originally developed to use observed met data, as this was readily available and more accurate than outputs from early meteorological models. More recently, there has been an increase in the accuracy and availability of modelled met data, alongside a decline in the availability of high quality measured met data. In the UK, the number of met measurement sites with data available via the MIDAS Open research archive (Met Office, 2019) since 1980 peaked in 1994 and 1995 at 740, but fell to 396 by 2019. Hence there can be difficulties with finding locally representative observed met data for dispersion modelling studies and an increasing interest in using modelled met data.

Modelled met data for local dispersion modelling can be derived from Numerical Weather Prediction (NWP) models run at a range of grid scales. NWP models such as Weather Research and Forecasting (WRF, Skamarock et al. 2021), and the Unified Model (UM, Walters et al., 2019) often have differing configuration options suitable for modelling at global, continental or regional scales. For example, convection processes associated with locally intense precipitation events occur at km scale and must be parameterised for coarser grid scales (typically 10 km or greater). NWP models often incorporate ('assimilate') measurement data in order to improve initial conditions and/or limit the divergence of modelled solutions from real conditions.

There is a need to explore the quantitative impacts of the choice of input met data on dispersion model outputs, for a range of source and site characteristics. The present study started by comparing met model datasets to measurements at multiple UK locations, then quantified the sensitivity of ADMS and AERMOD dispersion model outputs for idealised sources with varying observed and modelled input met datasets. Study methodology and results are described below, followed by a discussion and key conclusions.

METHODOLOGY

Four met measurement locations around Great Britain were selected for the dispersion modelling investigations. They included examples of flat terrain, coastal and complex terrain conditions as shown in Table 1. The example sources for dispersion modelling were placed at the location of the met measurement site. The following subsections describe the met datasets and the modelling approach.

Meteorological datasets

Routine hourly met measurement data for wind speed, wind direction, temperature, cloud cover and precipitation were obtained from the MIDAS Open archive (Met Office, 2019) for each site for the study year of 2019. Typical measurement uncertainty values for each parameter were identified from World Meteorological Organisation (WMO) guidelines (WMO, 2018).

Modelled met data were obtained from two models: WRF version 4.3.3 run by Air Pollution Services (APS), at 1, 3 and 9 km grid scales (only 1 and 9 km were used for dispersion testing); and UM version 7.0 run by the UK Met Office, at 1.5 and 10 km grid scales (Bush et al., 2020 and Walters et al., 2019 respectively). The 10 km grid scale UM is a global model configuration, which is archived at 3-hourly temporal resolution; all of the other datasets are regional modelling configurations and have hourly temporal resolution. APS applied the 'CONUS' suite of WRF configuration options, with boundary conditions for the outermost domain obtained from the ECMWF ERA5 reanalysis (Hersbach et al. 2020).

Met data was extracted from the UM into ADMS input format using the Numerical Atmospheric-dispersion Modelling Environment (Jones et al. 2007) version 8.3 met pre-processor, this applies spatial interpolation to the required location for all variables and temporal interpolation to most variables in the 3-hourly archive data. For the WRF data, APS used the meteorological extraction utility from CERC's coupled modelling system (Hood et al., 2018) for most variables, with custom Python code for cloud cover and precipitation. This approach does not include spatial interpolation. All extracted datasets included values of wind speed, wind direction, temperature, cloud cover and precipitation, consistent with the observed variables.

Dispersion modelling

Dispersion modelling was implemented with ADMS version 5.9.0.1 (pre-release version of ADMS 6, Carruthers et al., 1994) and AERMOD version 22112 (with AERMET 22112, Cimorelli et al., 2004). The ADMS and AERMOD model configurations and inputs were as consistent as possible, allowing for some differences in available input options.

Idealised elevated and near-ground source properties were defined, representing a large industrial facility and an intensive agriculture activity respectively. The elevated source had diameter 1.8 m, height 90 m, exit velocity 18 m s^{-1} and exit temperature 140 °C. The near-ground source had diameter 0.72 m, height 5.5 m, exit velocity 2.8 m s^{-1} and exit temperature set to the maximum of 17.4 °C and the ambient temperature at each hour (to avoid plumes denser than ambient air).

Radial grids of output points were defined with an angular spacing of 30° and covering a radius of 1 km from the near-ground source and 5 km from the elevated source. The radial spacing is variable, finest close to the near-ground source (10 m) and coarsest beyond 1 km from the elevated source (200 m).

RESULTS

The mean bias of wind speed for each modelled dataset compared to observations is shown in Table 1 for each site. Many of the values are within the typical measurement uncertainty of ±0.5 m s^{-1}. There is a wider range of values for the two complex terrain sites than for the two simpler sites.

Table 1. Summary of sites used in dispersion modelling study, with name, type, latitude (Lat), longitude (Lon), observed annual average wind speed and modelled wind speed mean bias from the four NWP datasets.

Site name	Site type	Lat (°)	Lon (°)	Observed average wind speed (ms^{-1})	Modelled wind speed mean bias (ms^{-1})			
					WRF 1 km	WRF 9 km	UM 1.5 km	UM 10 km
Waddington	Flat terrain	53.175	-0.522	4.84	-0.15	-0.53	-0.67	-0.69
Leuchars	Coastal	56.377	-2.861	4.69	-0.11	-0.10	-0.51	-0.30
Drumalbin	Complex terrain	55.627	-3.735	5.32	-0.73	-0.95	-1.20	-1.33
Sennybridge	Complex terrain	52.063	-3.613	3.47	1.46	0.76	0.24	0.11

The maximum annual average concentrations calculated by ADMS and AERMOD with differing input met datasets are shown in Figure 1 for the near-ground source and elevated source at each site. Table 2 presents the relative variation in spatial maximum values of the different metrics, i.e. annual average and high percentiles of hourly average concentrations. These are calculated separately from ADMS and AERMOD outputs with observed and four NWP datasets: WRF at 1 and 9 km grid resolution; and UM at 1.5 and 10 km grid resolution. The sensitivity of model outputs to the choice of input met dataset generally increases for sites of greater complexity and for high percentile outputs. However, the differences between ADMS and AERMOD outputs are comparable to or larger than the variation due to input met datasets for most combinations of source, site and output metric.

Table 2. Summary of sensitivity of ADMS and AERMOD spatial maximum value of annual average concentration (AAve), 98th percentile of hourly average concentration (P98), or maximum hourly average concentration (P100) to varying input met datasets. Sensitivity calculated the range of model results obtained with observed met and the four tested NWP met datasets, normalised by the corresponding value obtained with observed met data. This is compared with the difference between AERMOD and ADMS, when both use observed met (AERMOD–ADMS)/(0.5*(ADMS+AERMOD)). Text colours indicate sensitivity category: **Low** < 0.2; **Medium** 0.2 – 0.4; **High** 0.4 – 1.0; Very High > 1.0.

Source type	Site	ADMS 6 sensitivity			AERMOD sensitivity			AERMOD – ADMS 6		
		AAve	P98	P100	AAve	P98	P100	AAve	P98	P100
Near-ground	Waddington	0.16	0.02	0.22	0.16	0.05	0.14	0.24	0.30	0.40
	Leuchars	0.26	0.02	0.20	0.20	0.02	0.26	0.19	0.28	0.47
	Drumalbin	0.25	0.02	0.09	0.26	0.06	0.67	0.37	0.37	1.26
	Sennybridge	0.19	0.26	0.11	0.14	0.06	0.39	-0.25	-0.19	-0.49
Elevated	Waddington	0.18	0.11	0.32	0.18	0.16	1.06	-0.15	0.07	-0.70
	Leuchars	0.13	0.31	0.62	0.15	0.31	0.51	-0.21	-0.05	-0.52
	Drumalbin	0.38	0.08	0.26	0.29	0.20	0.34	-0.18	-0.13	1.67
	Sennybridge	0.15	0.18	0.23	1.02	0.81	0.27	0.64	0.59	1.64

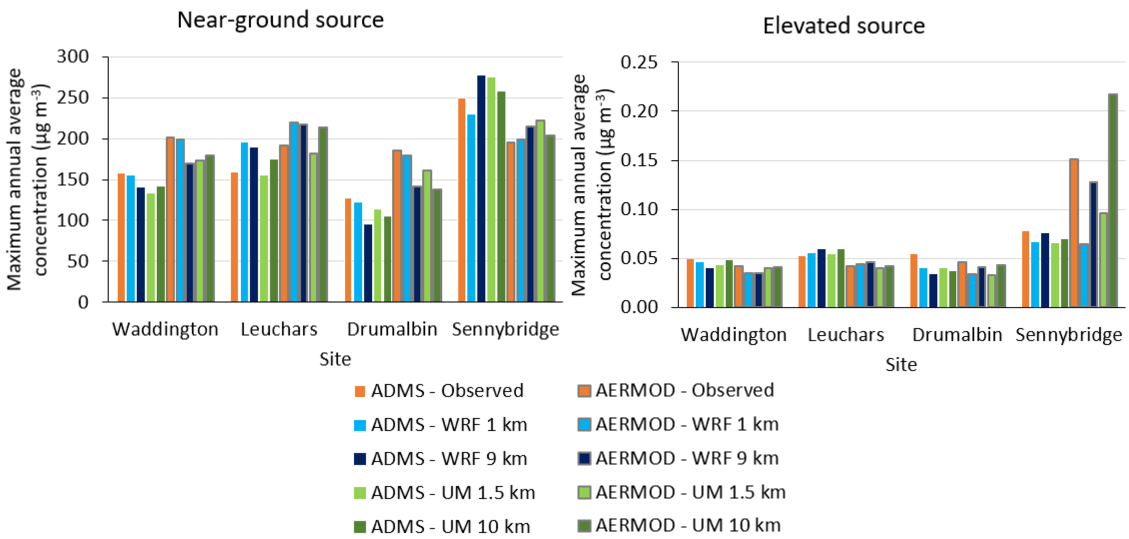

Figure 1. Maximum annual average concentrations (µg m^{-3}) modelled using ADMS (bars without border) and AERMOD (bars with border), with observed and four modelled input met datasets at four sites (indicated by the bar colour). Left panel: concentrations from near-ground source; Right panel: concentrations from elevated source.

DISCUSSION AND CONCLUSIONS

This study quantified the relative influence of using different observed and NWP met datasets for local dispersion modelling, compared to the use of the same observed met in ADMS or AERMOD. The differences between dispersion outputs with observed and a range of NWP met data are smallest for annual average concentrations and increase for high percentiles or maximum values of hourly concentrations, indicating greater uncertainty in these highest values. However, there was no clear trend in dispersion model outputs related to the NWP model grid size within the range tested (1 – 10 km). High quality NWP met data appears to be an adequate substitute for observed met data in local dispersion modelling, where locally representative observations are not available.

The general trend for differences in predicted maximum annual average concentration from ADMS and AERMOD is different for near-ground and elevated sources, indicating that differences in representing initial plume rise and vertical plume spread may account for some of the differences in behaviour (Carruthers et al., 2009). Differences in the handling of plume dispersion in complex terrain (Carruthers et al., 2011) also lead to greater differences between ADMS and AERMOD at these sites.

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