

# High resolution meteorological modelling of wind field in a coastal, mountainous, and industrial complex

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**Abstract:** The need for continued improvement of air quality is reflected in the UK's current failure to meet a number of European air quality standards, which could result in annual penalties amounting to £100s of millions. The Port Talbot industrial complex is one of such cases. Great challenges are encountered in understanding the causes for the frequent breaches of air quality standard in this area. The scientific objective of the studentship is to develop a verified methodology of applying the comprehensive three-dimensional meteorological model, the Weather Research & Forecasting Model (WRF), at an unprecedentedly high spatial resolution (250 m) in order to test thoroughly the capabilities of capturing the local wind systems as a means of analysing pollution sources in a functionally, topographically and meteorologically complex situation. Specifically, the student will: (1) identify the synoptic meteorological conditions under which air pollution concentrations measured at monitoring locations are high; (2) carry out high spatial resolution WRF simulations, and test the model's predictions against wind data already being gathered at about ten locations in the area; (3) analyse the characteristics of wind systems focusing on spatial variability of wind and boundary layer depth, land/sea circulation, and the impact on transport of pollutants; and (4) use the modelling results together with emissions data to infer the local contributions to pollutant concentration and to suggest measures which might be used to reduce pollution levels. Anticipated achievements and impacts are: (i) a well trained researcher with multi-disciplinary expertise and skills in the areas of weather/climate modelling, local weather systems, and air pollution transport and dispersion, (ii) a new methodology for determining the potential sources contributing locally to pollution levels, and providing a guide for new sites of weather stations, and (iii) leading to better protection of human and environmental health and more equitable environmental regulation.

**Background** The Port Talbot industrial complex is a 7 km long site comprising steelworks and associated industries, located on the coastal strip between the Swansea bay and a large mountain ridge dissected by river valleys (see Fig.1 (c)). Great challenges are encountered in understanding the causes for the frequent breaches of air quality standard, particularly for PM<sub>10</sub>, in this area. One of major challenges is the complex wind system which is influenced not only by synoptic conditions, but also by land/sea interaction, topography, and industrial settings (Cai & Steyn, 2000). For example, the land/mountain/sea circulation, under certain synoptic conditions, may become a dominant system which is favourable to accumulation of pollutants. However, there is no previous scientific investigation into this type of sub-km scale meteorology in such a coastal, mountainous, and industrial environment in association with local air quality. We recently carried out a successful pilot study in which we used a regional meteorological model, Weather Research & Forecasting Model (WRF), to examine the air movements across the Bay area. Using principle component and cluster analysis, the study identified two sets of meteorological scenarios associated with high PM<sub>10</sub> levels at a monitoring site. The preliminary results of WRF applied to these two scenarios at an unprecedentedly high spatial resolution of 250 m demonstrated its potential as a tool for better understanding the complicated spatial pattern of wind in the region (Fig. 1 (a) & (b)) and so for identifying the origins and source strengths of locally emitted pollutants arriving at monitoring locations.

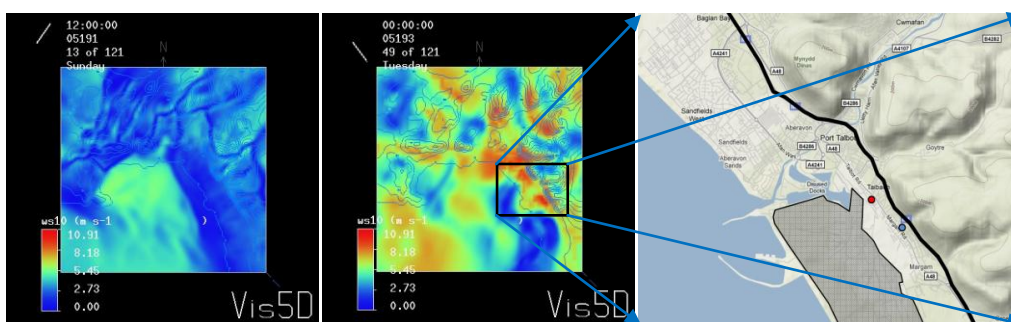


Fig. 1 (a) & (b) The WRF output of wind speed (at 10 m) for the Swansea Bay area; (c) Port Talbot town with M4 (black line), the main industrial area (grey zone), and two air quality stations (blue and red dots).

**Objectives** The scientific objective of the studentship is to develop a verified methodology of applying the comprehensive meteorological model, WRF, at an unprecedentedly high spatial resolution (250 m) in order

to test thoroughly the model's capabilities of capturing the local wind systems as a means of carrying out analysis of pollution sources in a functionally, topographically and meteorologically complex situation. Specifically, the student will:

1. use principle component and cluster analysis to identify the synoptic meteorological conditions under which air pollution concentrations measured at monitoring locations are high;
2. for each of these synoptic conditions, carry out a high spatial resolution WRF simulation, and test the model's predictions against wind data at about ten locations in the area;
3. analyse the characteristics of wind systems focusing on spatial variability of wind and boundary layer depth, land/sea circulation, and the impact on transport of pollutants; and
4. use the modelling results together with emissions data to infer the local contributions to pollutant concentration and to suggest measures which might be used to reduce pollution levels.

**Methodology** A synoptic climatological methodology is first utilised in which principal component analysis and cluster analysis are used to derive synoptic air mass types based on surface observational data. These air mass types are then analysed in relation to pollution levels in order to identify the typical synoptic conditions favourable to high PM<sub>10</sub> concentrations. The WRF Model will be configured with 5 nested domains, with grid resolutions of 36, 12, 3, 1 and 0.25 km. The outmost domain covers the whole British Isles. The finest domain covers the Swansea Bay and the Port Talbot area (see the figures) and this configuration represents a unique sub-km resolution modelling study for a coastal, mountainous, and industrial complex. The CEH Land Cover data (accessible through NERC) and Geomatics Group's LIDAR data (accessible through the CASE partner) and will be used to derive the landuse data needed in WRF. The initial and boundary conditions were taken from the Global Forecast System (GFS). The model results will be validated against available data measured at Mumbles Head (Met Office's site) and Port Talbot area (~10 sites). After validation, a thorough examination of the 3D, time-varying wind fields will be conducted using graphical tools, VIS5D and GRADS. The coastal boundary layer height will be diagnosed using the method in Batchvarova et al. (1999). Trajectory analysis based on the method proposed by Cai et al. (2000) will be used to examine the transport of pollutants in the bay area. The computation will be conducted on University's High-Performance Computing cluster.

**Anticipated achievements and impacts** (1) A well trained researcher with multi-disciplinary expertise and skills in the areas of weather/climate modelling, local weather systems, and air pollution transport and dispersion. (2) An enhanced ability to determine the movement of pollutants in regions of complex coastal environment and industrial activity at high spatial and temporal resolution. (3) A new and comprehensive tool for determining the spatial pattern of wind, giving a better understanding of potential sources contributing locally to pollution levels, **and** providing a guide for new sites of weather stations. (4) Leading to better protection of human and environmental health and more equitable environmental regulation.

**Training** Apart from receiving generic training from the University's programme, the student will be trained in air pollution analysis and meteorological modelling. The placement with the Environment Agency (EA) will provide an opportunity for the student to take part in data-collecting activities and develop an understanding of how scientific evidence is applied to operational and policy decision-making. EA have a good working relationship with the businesses on the site, and are seen by them as a trusted partner with whom they are willing to share unpublished data, including site activity and meteorological data. Through EA the student will also have a link with the Port Talbot PM<sub>10</sub> data group. Thus the student will appreciate the broader social, political and economic context in which scientific evidence is used to underpin environmental regulation. They will have the opportunity to develop not only as an environmental scientist, but as one whose technical and scientific outputs will be sufficiently developed as to be of immediate relevance to efforts to improve the environment. On a practical note, working closely with a key end-user of the proposed research will enable its rapid uptake and dissemination into operational use.

## References

- Batchvarova, E., X.-M. Cai, S.-E. Gryning, D.G. Steyn, 1999: Modelling internal boundary layer development in a region with complex coastline. *Boundary-Layer Meteorology*, **90**, 1-20.
- Cai, X.-M. and D.G. Steyn, 2000: Modelling study of sea breezes in a complex coastal environment, *Atmos. Env.*, **34**, 2873-2885.
- Cai, X.-M., R.A.S. Hourston and D.G. Steyn, 2000: A Numerical Study of Meteorological Conditions during PACIFIC '93, *Atmos. & Ocean*, **38**, 457-479.