Institution: University of Manchester

Unit of Assessment: UoA 7 Earth Systems and Environmental Sciences

Title of case study: Improving weather and climate forecasting

1. Summary of the impact

Our research since 1993 has led directly to demonstrable improvements in the physical representation of atmospheric particulates in the suite of Met Office numerical weather prediction (NWP) and climate models. These models have had enormous reach and significance across the REF period in both public sector and commercial Met Office activities. Our measurements impact directly on the model prediction of air quality, extreme pollution events (for fire brigade, police and public agencies), visibility, cloud cover, rainfall, and snowfall (for defence and the public weather service, commercial aviation, utilities, road and rail sectors).

2. Underpinning research

Key researchers:

Professor Thomas Choularton (1993-date)

Professor Hugh Coe (1997-date)

Dr James Allan (2001-date; Senior Research Fellow)

Dr Paul Connolly, (2006-date; Senior Lecturer)

Dr Keith Bower, (1993-date; Senior Research Fellow)

Professor Martin Gallagher (1993-date)

Work between 1993 and 1997 on the transport and dry deposition of aerosol particles (1) was developed to consider wet deposition of atmospheric particulate by rainfall and snowfall in complex topography and direct cloud water deposition to the ground, resulting in their parameterisation for incorporation into large scale models. These processes are critical to understanding particulate transportation and deposition patterns and rates.

We have made significant contributions over the last decade to understanding particle properties that control of atmospheric visibility. Centre for Atmospheric Science (CAS) scientists led development of data analysis methodologies (2) underpinning Aerosol Mass Spectrometer (AMS) use in quantifying particle composition. This led to development of one of the first airborne AMS instruments being installed on the UK FAAM research aircraft, and its subsequent use to quantify atmospheric aerosol composition around the world (6) with airborne AMS measurements used to test visibility prediction in an operational weather forecasting model (3). Our direct measurements revealed that the aerosol was a complex mixture of organic, sulphate and nitrate with a very different water content to the ammonium sulphate previously assumed in the model (6). This directly led to development of a new UK emission inventory. Use of our data in a new parameterisation of hygroscopic growth including all constituents in an operational forecast model has led to significant improvements in model predictive skill.

Knowledge of the size distribution of snow in clouds is crucial to accurate precipitation forecasting. This is significant in the formation of surface snowfall events and, since most rain falling in mid-latitudes is initiated as snow, is crucial to the quantitative forecasting of rainfall. CAS led a consortium under the Clouds Water Vapour and Climate initiative funded by NERC to use radar and airborne in-situ microphysical measurements to investigate physics of snowfall generation in frontal clouds (4). This led to an improved understanding of the physics responsible for the origin of the snow crystals, their properties and growth resulting in new parameterisations of the snow size distribution (5). This affects the properties of the clouds and how effectively they generate precipitation as both rain and snow.

3. References to the research

(Key references are 1,3 and 5). The research has been published in leading international journals and have each led to invited international presentations.

1. Gallagher, MW; Beswick, KM; Duyzer, J; et al., Measurements of aerosol fluxes to Speulder forest using a micrometeorological technique, Atmospheric Environment, 31, 3, 359-373, 1997, doi:10.1016/S1352-2310(96)00057-X, 79 Web of Science (WoS) citations.

2. Allan J, Jimenez J, Williams P, Alfarra M, Bower K, Jayne J, Coe H, Worsnop D., Quantitative sampling using an Aerodyne aerosol mass spectrometer - 1. Techniques of data interpretation and error analysis, Journal of Geophysical Research-Atmospheres, 108(D3), 2003, doi:10.1029/2002jd002358, 199 WoS citations.

3. Haywood J, Bush M, Abel S, Claxton B, Coe H, Crosier J, Harrison M, Macpherson B, Naylor M, Osborne S., Prediction of visibility and aerosol within the operational Met Office Unified Model. II: Validation of model performance using observational data, Quarterly Journal of the Royal Meteorological Society, 134, 636, 1817-1832, 2008, doi:10.1002/qj.275, 12 WoS citations.

4. Field, P. R., Hogan, R. J., Brown, P. R. A., Illingworth, A. J., Choularton, T. W., Kaye P. H., Hirst, E. and Greenaway, R., Simultaneous radar and aircraft observations of mixed phase cloud at the 100m scale, Quarterly Journal of the Royal Meteorological Society, 130(600), 1877-1904, 2004, doi:10.1256/qj.03.102, 25 WoS citations.

5. Field, P. R., Hogan, R. J., Brown, P. R. A., Choularton, T. W. et al., Parameterisation of ice-particle size distributions for mid-latitude stratiform cloud, Quarterly Journal of the Royal Meteorological Society, 131, 609, 1997-2017; 2005, doi:10.1256/qj.04.134, 62 WoS citations.

6. Jimenez, J.L., et al. Evolution of Organic Aerosols in the Atmosphere. Science, 2009; 326(5959): 1525-1529, doi:10.1126/science.1180353. Pub. Dec 11, 2009, 421 WoS citations

4. Details of the impact

Context

Forecasting by the original Met Office's NAME model of the transport and deposition of particulate material is crucial to the modelling of natural and man-made chemical releases, and nuclear accidents. Without accurate representation of particle loss to the surface accurate prediction is impossible. The Met Office has national responsibility to provide specialist advice about the atmospheric dispersion of chemicals and pollutants. NAME is used to provide predictions of release incidents, for example the Fukushima nuclear plant failure after tsunami damage in 2011, and is used to provide pollutant deposition maps across the UK for DEFRA.

Low visibility, snowfall and rainfall impact on road, rail, marine and airborne transport. Improved prediction of low-visibility events is valuable in safety and economic terms. For example, winter-time fogs cause flight cancellations due requiring increased spacing between take-off and landing slots. To provide such prediction the Met Office has developed a simple visibility diagnostic that is computationally efficient for use in operational forecasting, routinely used in the transport sector.

Accurate short-range numerical weather prediction forecasts and climatological climate projections of cloud-cover and precipitation are central to the Met Office core mission. Inaccurate forecasts of stratocumulus cloud cover have a large effect on short range surface temperature forecasts, which are important to many customers for Met Office models. They are also of great importance to the climate system due to radiative effects and potential feedback mechanisms in a perturbed climate. Boundary layer clouds are also one of the largest uncertainties in current climate models, owing to both physical processes and aerosol indirect effects.

Pathways to Impact

Enhanced wet, dry and cloud deposition parameterisations were developed from our research on UK wet deposition, taken up by the Met Office and included in the operational NAME model. Verified as efficient and effective, they have been at the heart of NAME since the 1990s

(Corroborative statement A, below; p302, “Choularton's group measured and provided suitable rates for use in the NAME model…Representative coefficients …were measured …in extensive field and modelling experiments carried out by T. Choularton's team at UMIST”).

NERC and the Met Office jointly support the UK research aircraft from which airborne aerosol measurement research is largely delivered by NERC-funded Manchester scientists. Through the shared facility, Manchester aerosol and cloud physics research has been closely linked to Met Office providing considerable synergy for many years. By aligning these activities with Met Office model development and testing objectives we have used our data to directly test the products in the Met Office operational model and improve the process descriptions in it.

In response to Manchester’s novel measurements of aerosol composition around the UK, the Met Office implemented a new emission source inventory and used it to show that the revised predicted aerosol has a significant effect on the visibility prediction in the model. This tool was tested and shown to operationally robust and is now providing significantly improved visibility forecasts compared to the previous model.

Reach and Significance

The Met Office is the national weather service provide for the UK and services the needs of Government in the areas of Defence, Government Services and the Public Weather Service. It received £172m in revenue from Government for these activities and is measured annually on its ability to meet service targets for its products. Forecasts of rain and snowfall are core Met Office model products and Manchester has worked closely with the Met Office to ensure that model improvements are tested against measured data and strategically developed from such observations. Manchester’s relationship with the Met Office has been developed over the last decade to be the main provider of airborne cloud and aerosol measurements to the Met Office for this task. Implementation of Met Office model development into the operational products has led to significant improvement in predictive skill over this period and this in turn has allowed the Met Office to drive growth in commercial revenue in 2011/12 by 6% to £33m, largely in the Commercial Aviation, Utilities, Road and Rail sectors (statement B). This revenue can be used as an indication of the worth of the operational products to the commercial end-user. Furthermore, the worth of Public Service Weather forecasting to the UK economy was independently estimated to be £634m in 2007 (statement C) and is not foreseen to have reduced across the REF period.

Manchester research in atmospheric particulate measurements have directly fed Met Office models in all relevant processes at all relevant scales. In each of the cases detailed below our input has made a major contribution to the development of parameterisations within the relevant Met Office model and has been evaluated as improving the model performance and representation of the underlying physical process beyond the previous process treatment. As emphasised by our corroborating Met Office project partners, the improvement in model skill attributable to any single process improvement is impossible to quantify owing to model complexity. However, rigorous stability and accuracy criteria are applied before adoption of any process description in Met Office models and each of the following have been widely adopted in the appropriate scale of model.

Impact from the development of the NAME model

The research contributed to the development of the original Met Office's forecasting tool NAME. NAME is used to model a wide range of UK and European scale atmospheric dispersion events including chemical and radiological releases, pathogen dispersion, greenhouse gas emissions and air pollution trend analyses. Customers of the information include Fire Brigade, Police, Health Protection Agency, Health Protection, Scotland Environment Agency Scottish, Environment Protection Agency, Food Standards Agency (statement D)

Impact of improved Visibility and Precipitation forecasts

In collaboration with the Met Office, CAS have produced a description of the snow size distribution and hence improved the parameterisation within the 1.5 km resolution operational NWP model. This new model has produced improvements in the forecast skill for snowfall and precipitation issued to a wide range of public and private sectors. In recent tests (statement E) this new model has been delivered skill scores 30% better than the North Atlantic European model and also significantly better than the UK4 model (statement F). These improvements in forecasting, routinely available to the UK population of 70 million, are of major benefit across a wide range of activities and public and private sectors. For example the cost of the snow to the UK economy was estimate at £500M per day in January 2013 (statement G) and improved forecast skill enhances mitigation strategies to offset these costs.

The CAS airborne aerosol measurements (described in the pathway) contributed to testing and improvement of the predictive capability of atmospheric visibility in the Met Office Operational 1.5 km and 4 km resolution NWP models, used since 2008 (statement H). Thus they have been able to provide visibility forecasts that are based on the most up to date assessments of chemical composition of the aerosol for a host of public and private sectors such as military low flying aircraft operations, search and rescue, aviation, fisheries, sea freight, coastguard, mountaineering, hiking and other recreational activities (statement B). One of the stated targets reported annually by the Met Office is the accuracy of the Terminal Airfield Forecasts (TAFs), which are made available to both civil and military airfields. The improvements to the visibility model over recent years have meant this performance target has been consistently met.

5. Sources to corroborate the impact

A. Development and validation of a pollutant dispersion and deposition model for meso- and regional scales. R&D Technical Report P302 Alison Malcolm, Roy Maryon and Helen Webster, UKMO Copyright Environment Agency 1999, http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/str-p302-e-e.pdf

B. Met Office Annual Report and Accounts 2012/13, http://www.metoffice.gov.uk/media/pdf/n/e/Annual_Report-web.pdf

C. The Public Weather Service's Contribution to the UK economy, http://www.metoffice.gov.uk/media/pdf/h/o/PWSCG_benefits_report.pdf

D. The Met Office dispersion Model, http://www.metoffice.gov.uk/research/modelling-systems/dispersion-model

E. Lean, H.W et. al., 2011. Experiences with a 1.5 km version of the Met Office Unified Model for short range forecasting 91st Annual Meeting of the American Meteorological Society, Seattle (https://ams.confex.com/ams/91Annual/webprogram/Manuscript/Paper177409/AMS_Seattle_Extabs.pdf)

F. Letter from Cloud Scale Modelling Manager: responsible in the UK Met Office for the Cloud Modelling Group, highlighting data provided and the contribution to cloud microphysical parameterisations used in the operational 1.5 km model.

G. Cost of snow to UK Economy http://news.sky.com/story/1039900/snow-costs-uk-economy-500m-a-day

H. Letter from Research Fellow and Aerosol Research Manager: confirming our role in providing input to the UK Met Office model visibility forecasts in the UK Operational 1.5 and 4 km Models.