Novel trajectory-based approach for evaluation of climate models against aerosol observations in a Lagrangian framework

Daniel Partridge, Peter Tunved, Zak Kipling,
Hamish Struthers, Joao Teixeira

16th AeroCom workshop, October 10th, 2017
FMI, Helsinki , Finland

UNIVERSITY OF EXETER
College of Engineering, Mathematics and Physical Sciences

Constraining Arctic Forcing Uncertainty

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-1120, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 10 February 2017
© Author(s) 2017. CC-BY 3.0 License.

Atmospheric Chemistry and Physics
Open Access
Discussions
EGU

Aerosols at the Poles: An AeroCom Phase II multi-model evaluation

Maria Sand[1], Bjørn H. Samset[1], Yves Balkanski[2], Susanne Bauer[3], Nicolas Bellouin[4], Terje K. Berntsen[1,5], Huisheng Bian[6], Mian Chin[7], Thomas Diehl[8], Richard Easter[9], Steven J. Ghan[9], Trond Iversen[10], Alf Kirkevåg[10], Jean-François Lamarque[11], Guangxing Lin[9], Xiaohong Liu[12], Gan Luo[14], Gunnar Myhre[1], Twan van Noije[14], Joyce E. Penner[19], Michael Schulz[10], Øyvind Seland[10], Ragnhild B. Skeie[1], Philip Stier[15], Toshihiko Takemura[16], Kostas Tsigaridis[3], Fangqun Yu[13], Kai Zhang[17,9], Hua Zhang[18]

[1]Center for International Climate and Environmental Research – Oslo (CICERO), Oslo, Norway
[2]Laboratoire des Sciences du Climat et de l'Environnement, CEA-CNRS-UVSQ, Gif-sur-Yvette, France
[3]NASA Goddard Institute for Space Studies and Columbia Earth Institute, New York, NY, USA
[4]Department of Meteorology, University of Reading, Reading, UK
[5]Department of Geosciences, University of Oslo, Oslo, Norway

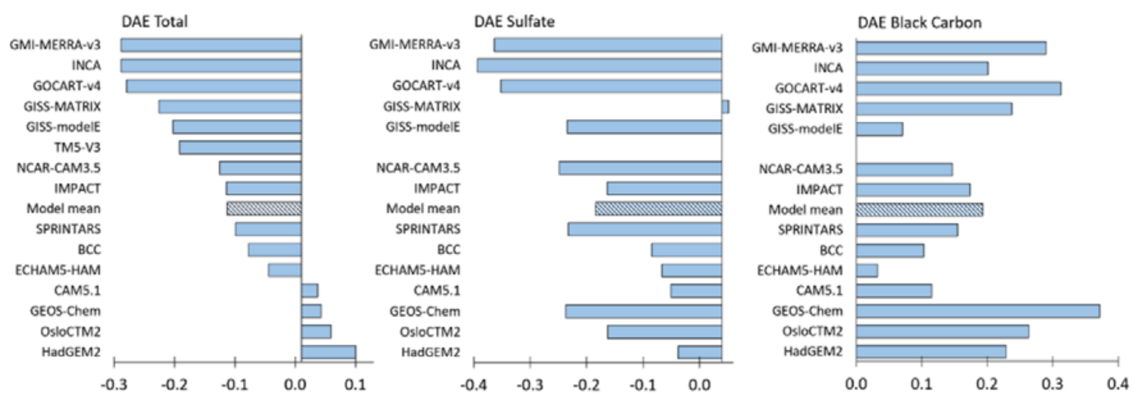


Figure 14: Arctic annual mean DAE (in W m^{-2}) for the AeroCom phase II models, TOTAL (left), sulfate (middle), BC FF (right). The striped bar is the model mean. TM5-V3 have reported total only.

Recommendations to improve understanding of Arctic aerosols and reduce the uncertainties:

- Sensitivity tests on removal processes/resolution during transport.
- Updated emission inventories (missing sources).
- Model evaluation (AOD) against local observations.

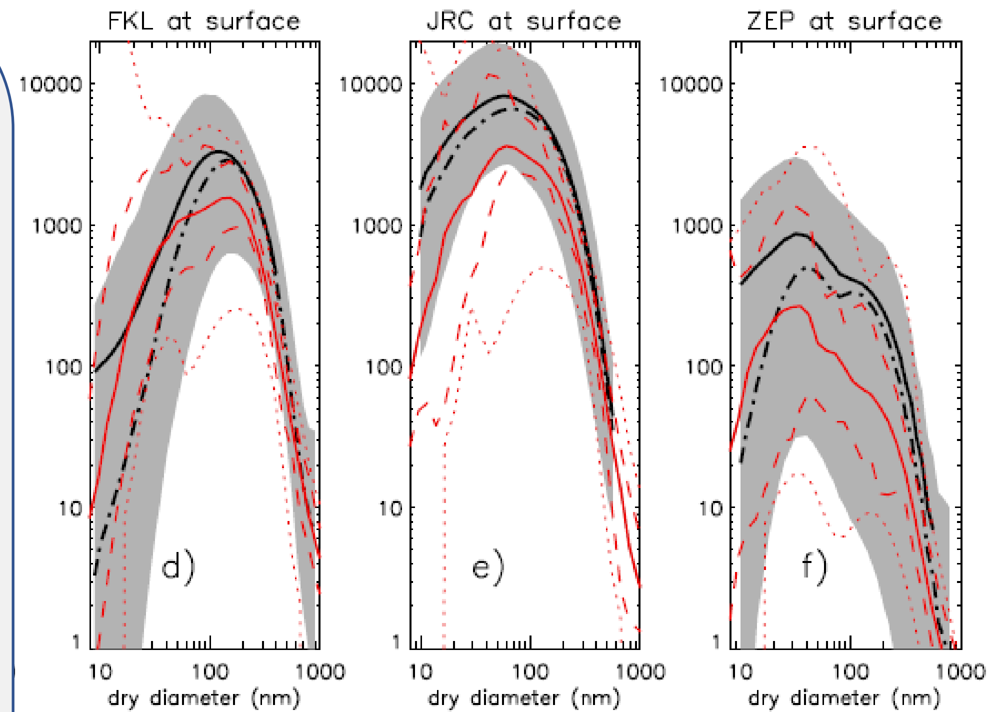
Evaluation of GCM representation of aerosol properties

Commonly applied methods

Provides:

- ✓ Easy interpretation
- ✓ Evaluation of model aerosol climatology
- ✓ Highlights regions of major discrepancy for model improvement
- ✓ Efficient to produce

To...
sulfate aerosol mass concentrations (µg S m^{-3}) from lowest model level (HadGem3-UKCA).



Mann et al., 2014, ACP: Summer multi-model mean simulated size distributions versus DMPS/SMPS measurements.

Evaluation of GCM representation of aerosol properties

One step further …

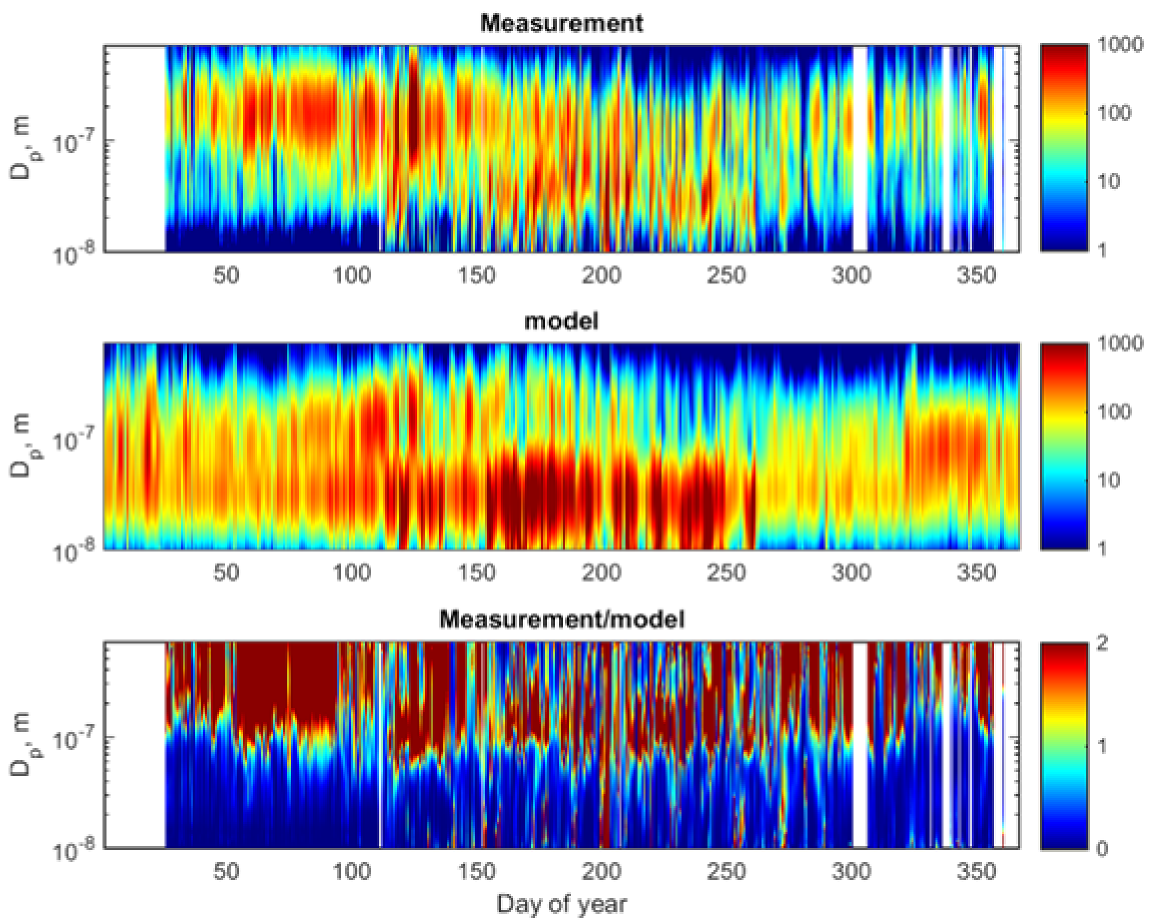
Co-locate model output to observations at target measurement station:

- Spatially
- Temporally (3hr resolution)
- Instrumentation size grid

Provides:

✓ Easy interpretation

✓ Time resolved information of discrepancies.



Partridge et al., 2016 (in-prep). ECHAM-HAM simulated aerosol size distribution versus Zeppelin DMPS/SMPS measurements (2006).

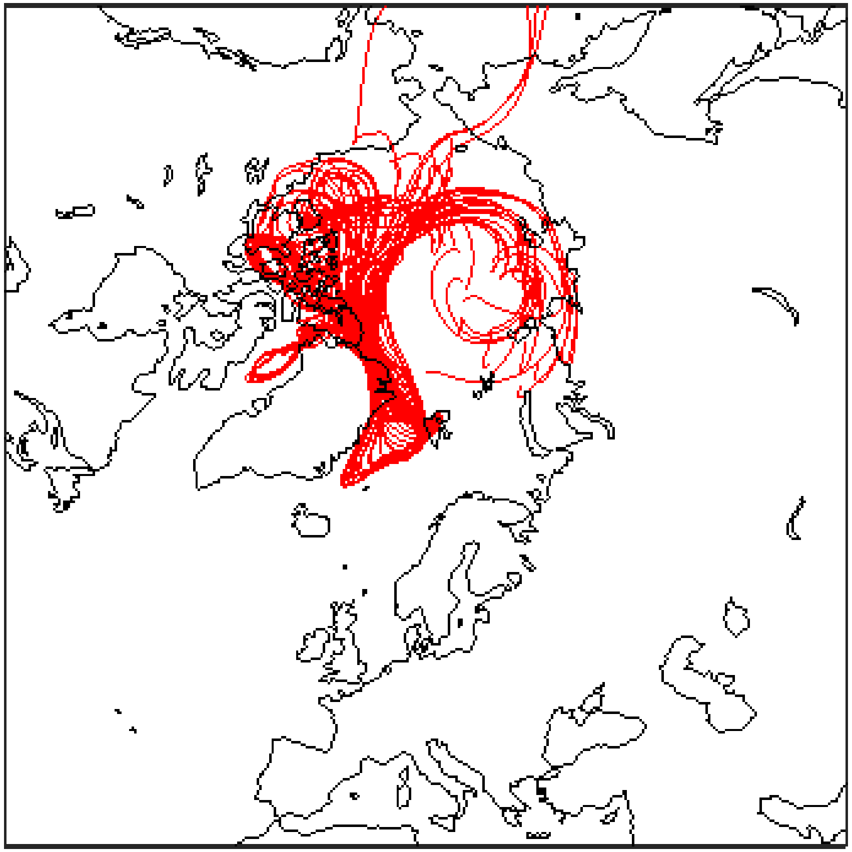
Evaluation of GCM representation of aerosols + transport/sources/sinks using a trajectory framework

STEP 1: Evaluation of GCM transport representation using Lagrangian air mass trajectories (HYSPLIT4)

Run GCM over observation time period. Convert GCM meteorological output to HYSPLIT format (ARL).

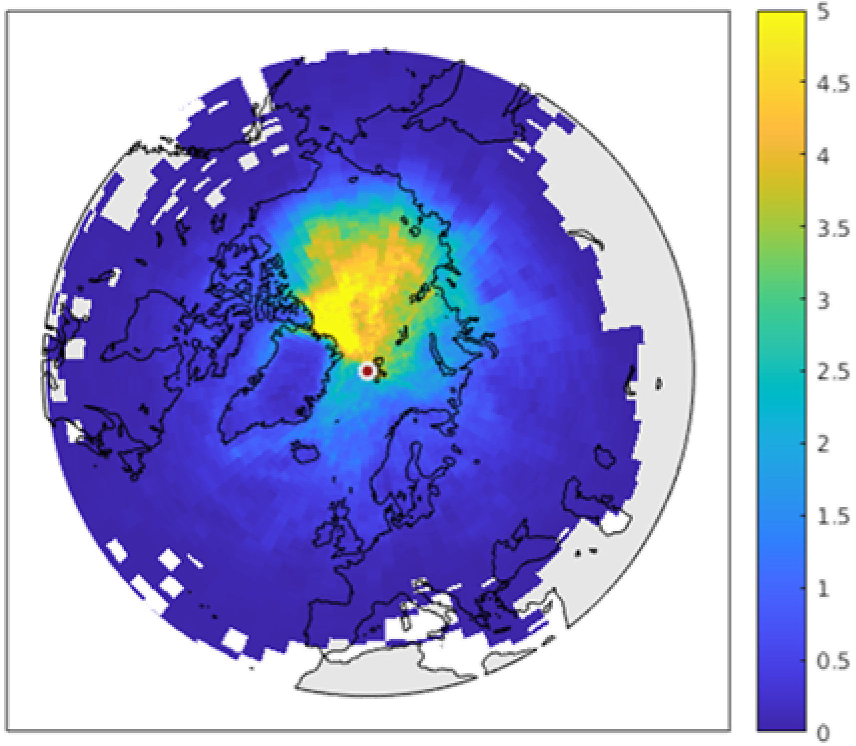
Calculate trajectories on model data (nudged /free running)

Calculate trajectories on re-analysis data (e.g. GDAS)

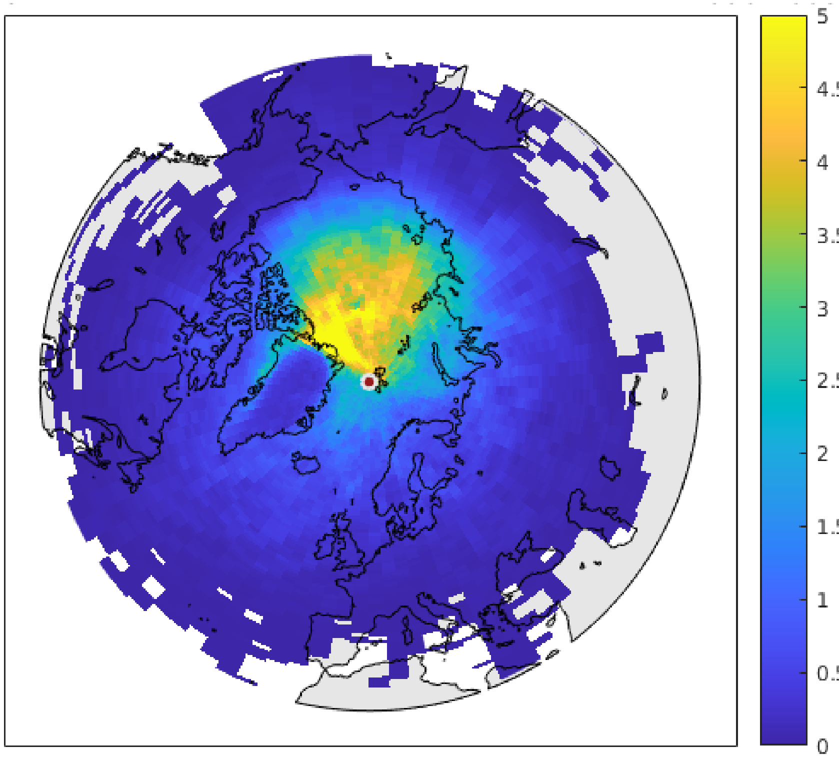


Proof of concept: Mt Zeppelin transport climatology on reanalysis and GCM data using HYSPLIT4 trajectory model

ERA-Interim Reanalysis wind fields

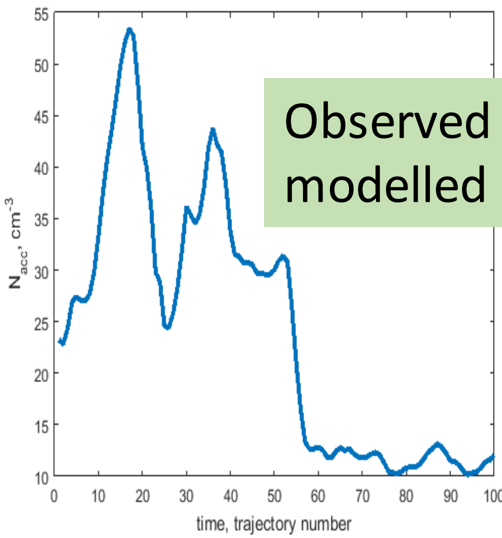


ECHAM-HAM nudged to ERA-Interim



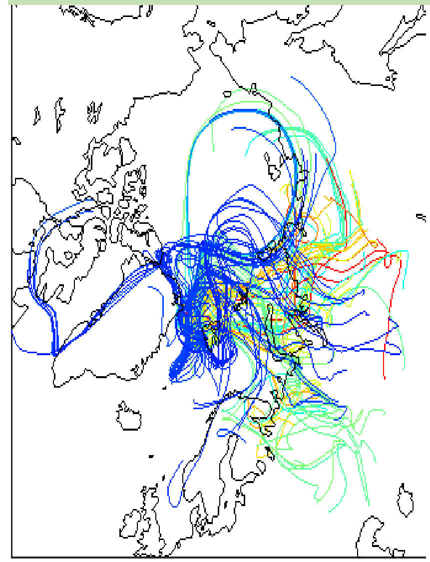
- **Percentage of trajectories crossing each grid. 2006-2009, one trajectory every three hours (ca 10000 trajectories per plot).**
- **Successfully transformed GCM meteorological output onto required HYSPLIT format**

STEP 2: Linking aerosol source areas to observed concentrations at receptor station (Zeppelin, Arctic)

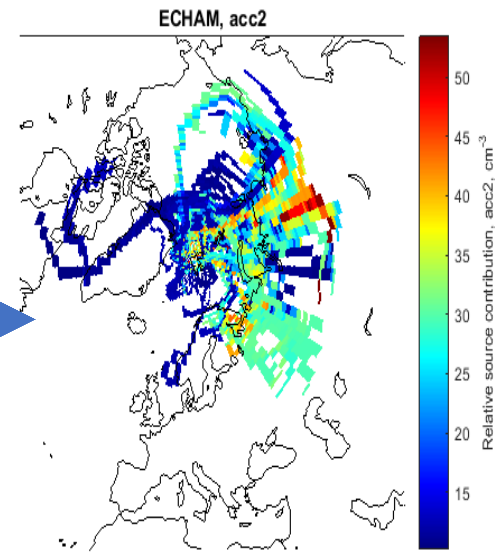


Observed or modelled data

Each trajectory endpoint is assigned a value corresponding to observed concentration

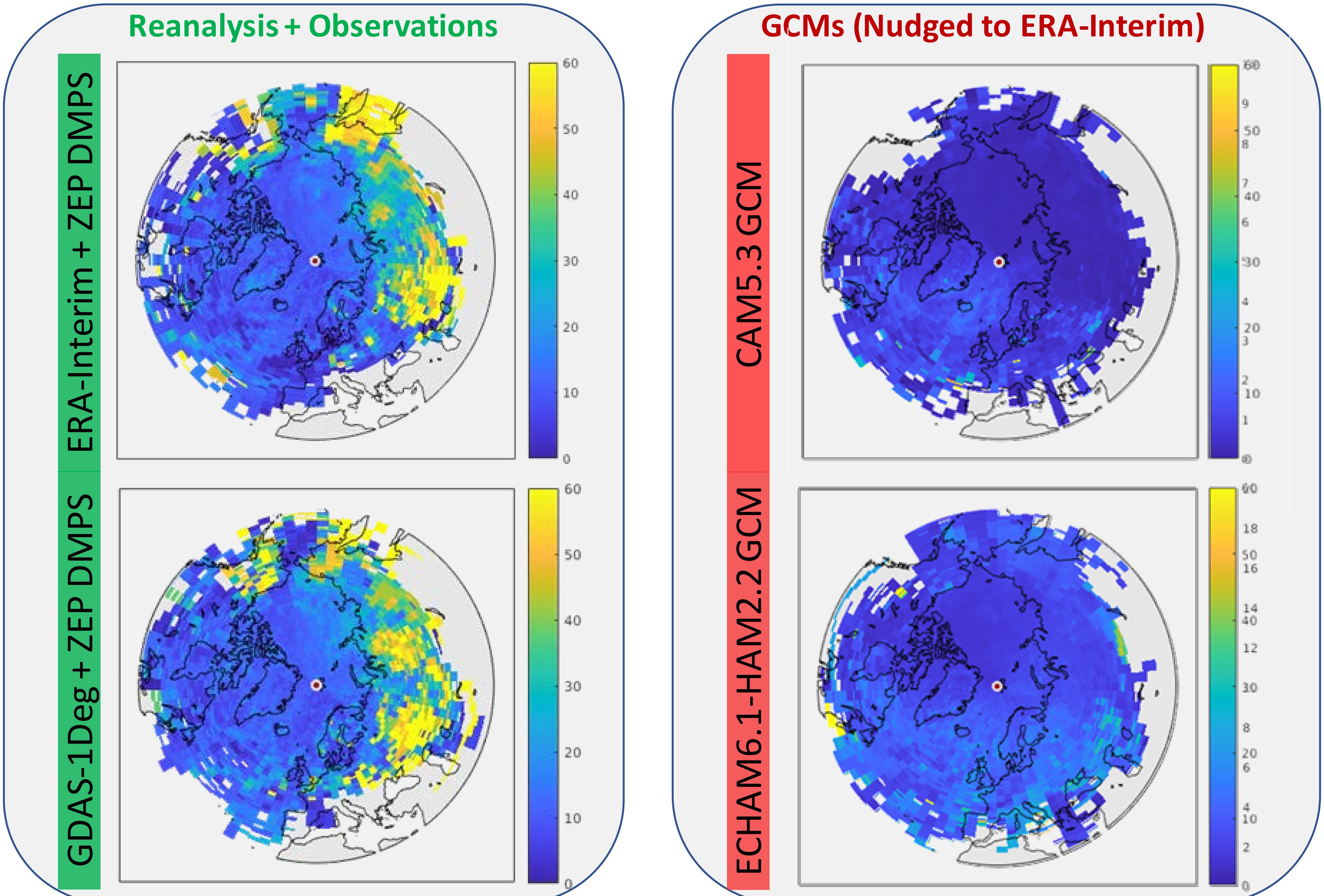


The average value for each grid point is calculated, revealing potential source regions



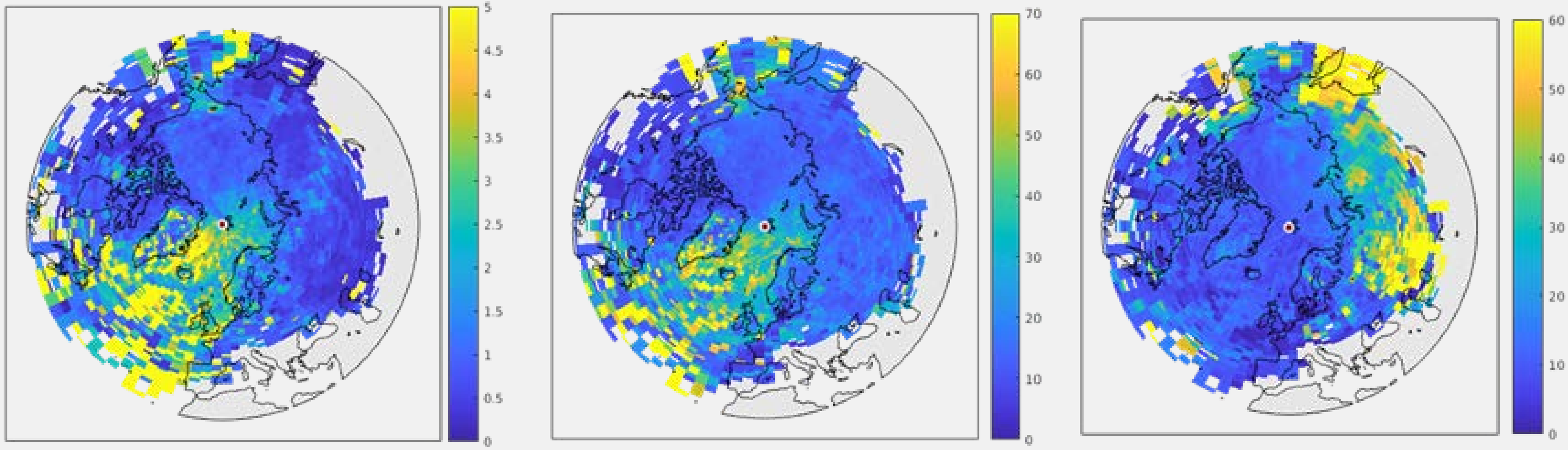
- Measured/modelled quantity extracted from the data with hourly resolution.
- For every measured/modelled value, a trajectory is calculated

Relative source contribution of aerosol particle conc.: $N(D_p{=}250{:}630nm)\ cm^{-3}$ [2006-2009] to Svalbard



ERA-Interim + ZEP DMPS, 2006:2009

Nuc: N(D_p=10:20nm) cm^{-3} | **Aitken: N(D_p=20:70nm) cm^{-3}** | **Accum1: N(D_p=70:250nm) cm^{-3}**



Advantage of this framework is that it allows for an apparent potential source analysis using real observations versus GCM simulated output.

- Facilitates tracing the aerosol evolution during transport to investigate the role of sources, dynamical processes and sinks on the aerosol properties in the model.

- Pinpoint where, why and when the models underperform in their representation of aerosol properties for efficient improvement.

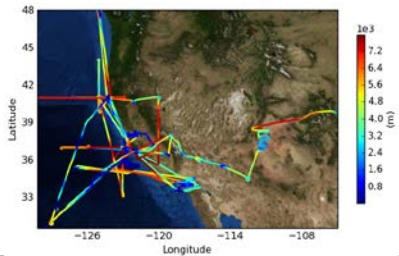
AeroCom Aerosol GCM Trajectory Experiment

- Are the models capable of reproducing observed flow patterns in the atmosphere and hence the role of aerosol emissions, processes and timescales? Evaluate influence of transport via nudged/free-running simulations against ERA5 reanalysis.

- How do the different models represent source-receptor relationships for simulated aerosol properties? How does this compare to experimentally derived relationships, for e.g. BC, sea salt measurements?

- What is the role of sink mechanisms for aerosols in the different models, e.g. precipitation?

Community Intercomparison Suite



❖ No model development required, only post-processing of model output into required format.

❖ Extend the evaluation framework to a larger group of GCMs and measurement stations within the ACTRIS measurement framework having long-term continuous aerosol data.

❖ One GCM simulation at high temporal resolution (3hr) provides data for repeating analysis for any station. (Diagnostics required: 3D wind fields, surface meteorology, aerosol lognormal parameters (N1, R1, GSD1, MMRSS etc.).

AeroCom Trajectory Data submission

localhost/trajectories/

UNIVERSITY OF EXETER

BACK TRAJECTORY DATABASE

HOME DATABASE LOG OUT NEW STATION REQUEST CONTACT Logged in as: dw

Welcome to the back trajectory database site

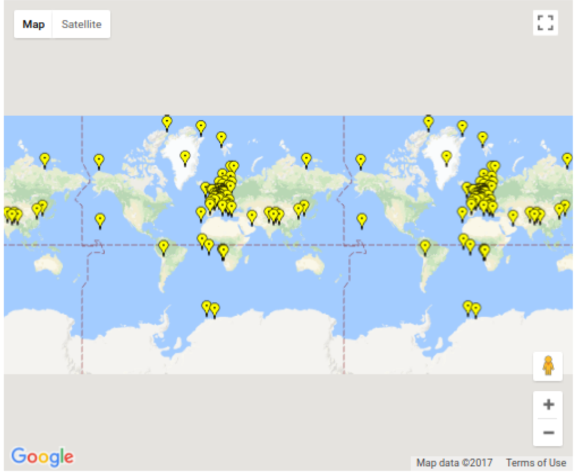
This website generates pre-calculated back trajectories using the HYSPLIT trajectory model (Hybrid Single Particle Lagrangian Integrated Trajectory Model) for both reanalysis data and general circulation models (GCMs) in support of the AeroCom Aerosol GCM Trajectory Experiment.

Rationale

Aerosols are important components of the climate system; however, the impact of aerosols on climate remains is highly uncertain due to the limited understanding of processes governing atmospheric aerosol sources and sinks. Historically, trajectory models have been used to study role of transport in a Lagrangian framework and investigate source-receptor relationships and atmospheric processes for experimental data using meteorological fields from reanalysis data. However, GCMs provide the same output necessary for trajectory calculations to examine source and transport dependence of any simulated atmospheric constituent at any location for which we have corresponding observations.

Accordingly, applying trajectory calculations to the meteorological fields from reanalysis and GCM data for the same location and time-period (i.e. in a synchronised manner) facilitates a highly transparent means for evaluating the dependence of discrepancies between models and observations as a function of aerosol source/sink pathways during transport to a measurement station.

Currently, back-trajectories are provided for three GCMs (ECHAM6.1-HAM2.2; CAM5.3; HadGEM3-UKCA) as well as two reanalysis products for comparison (GDAS one-degree; ERA-Interim. Please sea model description for more details.

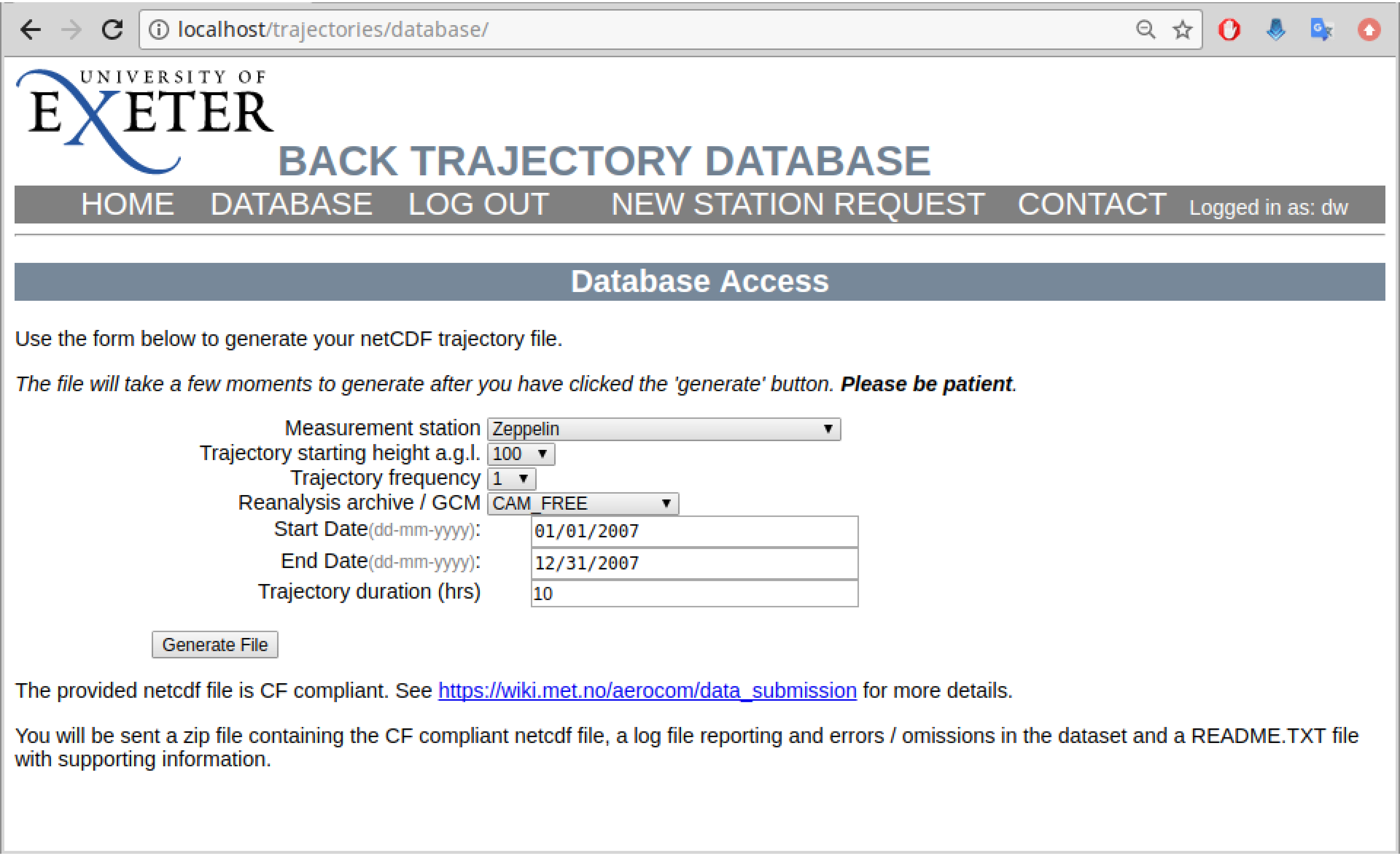


Locations of measurement stations for which back-trajectories have been calculated (Database). Stations within the Aerosols, Clouds, and Trace gases Research InfraStructure Network ACTRIS having long term measurements of aerosol size distribution have been selected as well as certain AERONET (AErosol RObotic NETwork) stations. Requests can be made for trajectories to be calculated for new stations not found on this map.

HYSPLIT calculated trajectories based on archive data may be distributed without permission (see http://ready.arl.noaa.gov/HYSPLIT_agreement.php). We are extremely grateful to NOAA for making HYSPLIT available to produce back trajectories in an open way. We ask that you cite HYSPLIT if used in published work.

Daniel Partridge
Lecturer in Atmospheric Science
CEMPS
University of Exeter

AeroCom Trajectory Data submission



localhost/trajectories/database/

UNIVERSITY OF EXETER

BACK TRAJECTORY DATABASE

HOME DATABASE LOG OUT NEW STATION REQUEST CONTACT Logged in as: dw

Database Access

Use the form below to generate your netCDF trajectory file.

The file will take a few moments to generate after you have clicked the 'generate' button. ***Please be patient***.

Measurement station	Zeppelin
Trajectory starting height a.g.l.	100
Trajectory frequency	1
Reanalysis archive / GCM	CAM_FREE
Start Date(dd-mm-yyyy):	01/01/2007
End Date(dd-mm-yyyy):	12/31/2007
Trajectory duration (hrs)	10

Generate File

The provided netcdf file is CF compliant. See https://wiki.met.no/aerocom/data_submission for more details.

You will be sent a zip file containing the CF compliant netcdf file, a log file reporting and errors / omissions in the dataset and a README.TXT file with supporting information.

Current Participants

- ✓ NorESM: Annica Ekman: Stockholm University; Hamish Struthers: NSC
- ✓ CAM: Hailong Wang; Steve Ghan: PNNL
- ✓ HadGEM: Daniel Partridge; Florent Malavelle; Jim Haywood: University of Exeter, UK Met Office
- ✓ ECHAM-HAM: Philip Stier: University of Oxford; Ulrike Lohmann: ETH

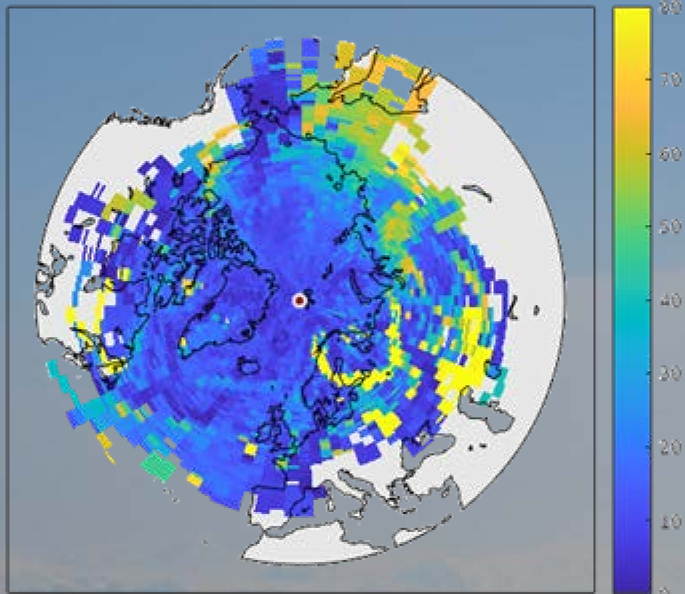
Interested in participating?

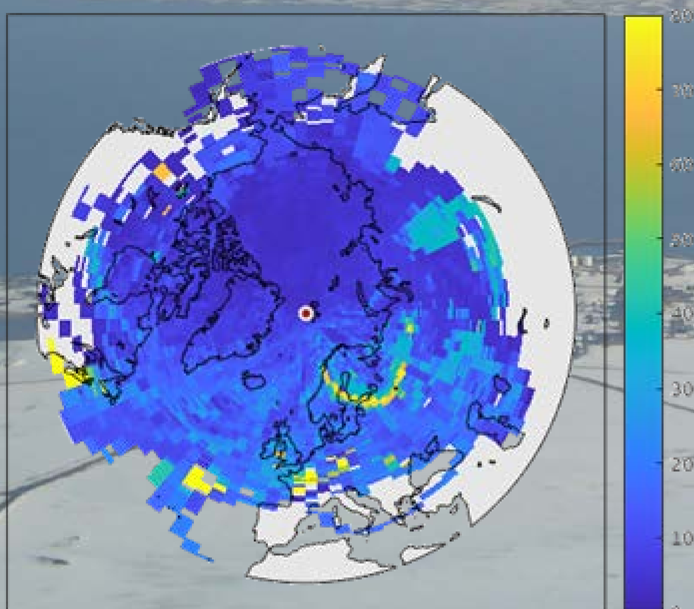
Contact me for a copy of the documentation:

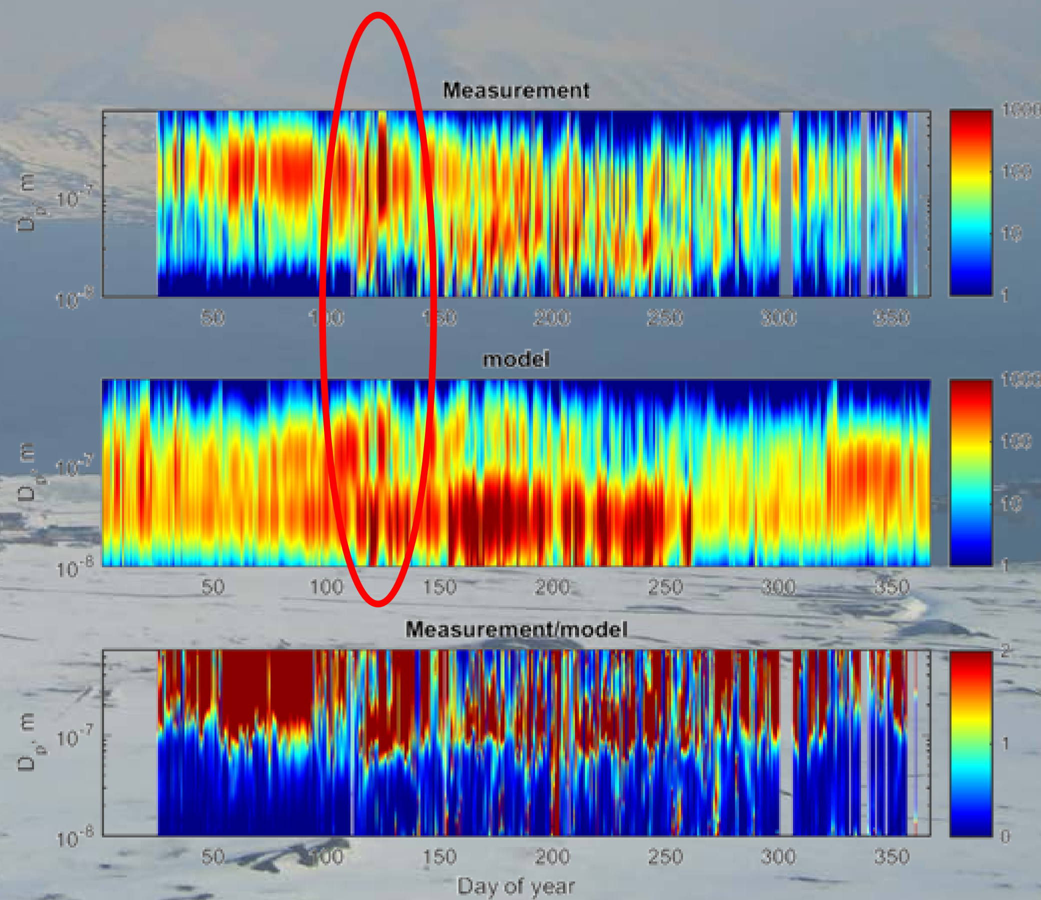
d.g.partridge@exeter.ac.uk

View from Zeppelin mountain, May 2nd 2006:

Aerosol sources: record 2006 agricultural forest fires in Eastern Europe.

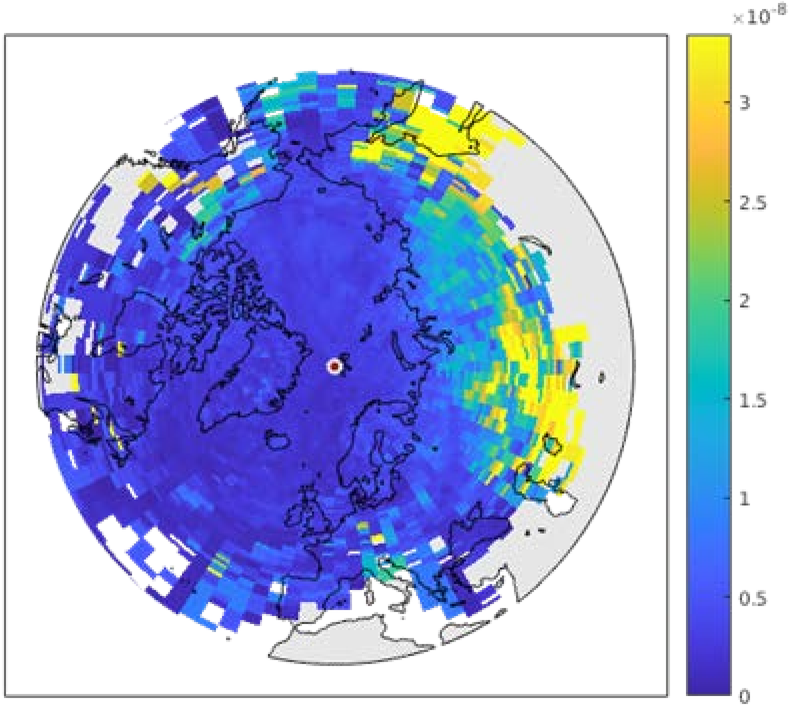




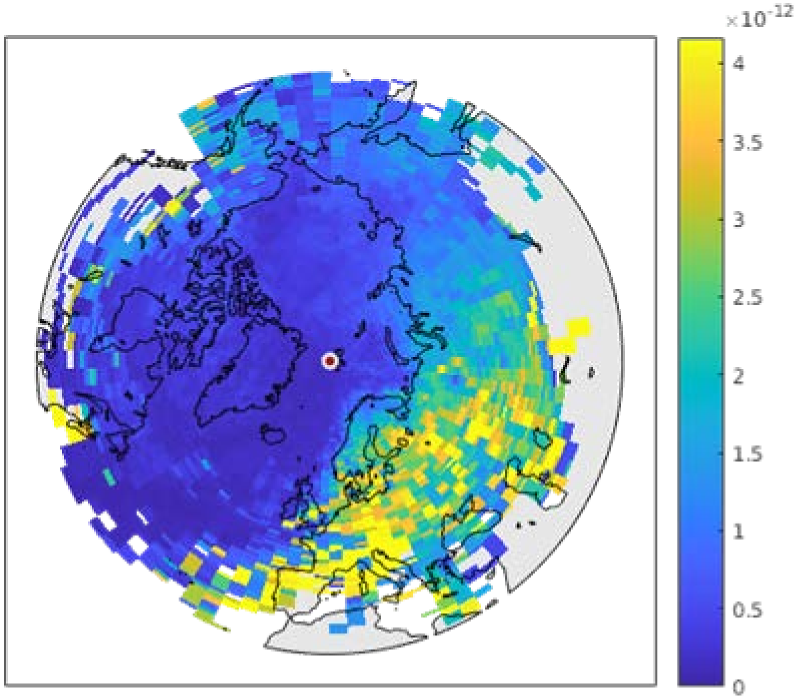


Sources of BC to Zeppelin, Svalbard

ERA-Interim Reanalysis wind fields + PSAP BC measurements



ECHAM-HAM nudged to ERA-Interim

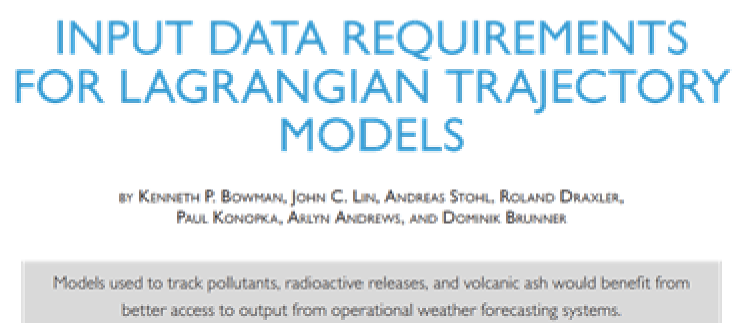


Conversion requirements

- Converting to grid-point horizontal winds for spectral and/or vorticity-divergence formulations.
- Re-gridding to a consistent uniform grid for those using staggered, Gaussian or irregular grids.
- Converting from NetCDF to GRIB unless native GRIB output is supported.
- Getting the correct hybrid coefficients into the GRIB file to describe the vertical coordinate.
- Ensuring the GRIB parameters used are correctly matched to those expected by grib2arl.
- Ensuring the units for these parameters are consistent with those expected by grib2arl.

ARL Packed Data Format Overview

Consists of a series of fixed length records, one for each meteorological variable. The records are arranged in time series, with surface fields followed by upper air fields. Each record contains a ascii header that provides information about the date, time, variable, and packing constants. This is followed by the packed binary data, one byte per grid point.



INPUT DATA REQUIREMENTS FOR LAGRANGIAN TRAJECTORY MODELS

by Kenneth P. Bowman, John C. Lin, Andreas Stohl, Roland Draxler, Paul Konopka, Arlyn Andrews, and Dominik Brunner

Models used to track pollutants, radioactive releases, and volcanic ash would benefit from better access to output from operational weather forecasting systems.