UNIFIED MODEL INTERCOMPARISONS FOR VOLCANIC ASH TRANSPORT MODELING

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Abstract: Our group is pursuing a volcanic ash transport model intercomparison study (VATMIS) to rigorously evaluate the relative performance of several Atmospheric Transport Models (ATM's) on the atmospheric transport of volcanic ash from selected case studies. These intercomparisons require the definition of standard output formats for producing results in a common framework. In our work, we define the common format and develop a set of tools to evaluate the data, allowing for side-by-side comparisons on a level playing field. Though the intercomparison tools we develop have widespread applicability to a number of ATM activities, we demonstrate their utility in the realm of volcanic ash transport modeling. In this presentation, we use the Alaska Mount Spurr eruption of 1992 as a case study, employing HYSPLIT, FLEXPART and PUFF with common meteorological forcing data, and with release and intrinsic-model set-ups as similar as possible. This case study will allow us to test the deployment of our intercomparison tools and refine as necessary.

Key words: *particle dispersion, volcanic ash, model intercomparison, HYSPLIT, FLEXPART, PUFF, Mount Spurr*

INTRODUCTION

Numerous models are in use for the exploration and prediction of atmospheric dispersion processes, each with their own internal assumptions and, more importantly for the purpose of this work, their own output representations. It is often desirable to evaluate these differing model outputs from a common perspective, and in conjunction with related data such as observed fallout and meteorological fields. In operational settings, particularly those involving emergency response, it is helpful to view the relevant fields from different sources in a common framework so as to rapidly discern important differences. In research, development and educational environments, the ability to present such differences in a common framework allows for objective evaluations. In addition to comparing different models, it is also desirable to compare different configurations of the same models.

In order to pursue our own operational and research needs, we are developing a process for casting native model outputs and related data into a common post-processing environment. This approach is dependent on casting all data into a relatively simple standard ASCII file format, and building a suite of post-processing tools. Other modeling systems, such as WRF and HYSPLIT, have adopted this paradigm of focusing software development on a robust set of programs that operate on a standard input format, depending on the construction of conversion routines for getting data from native to standard format. In this way, the post-processing software is isolated from changes in model outputs and readily accepts new models as long as they can be converted to the standard format.

The approach is best suited for sparse, gridded-data in a lat-lon coordinate system, such as that found in modeling plume-like features. As a first test and demonstration, we pursue the initial stages of a Volcanic Ash Transport Model Intercomparison Study (VATMIS) of the August 1992 Mount Spurr eruption in Alaska. The initial emphasis of this work is to set up the software processing environment to support a qualitative multi-model investigation of the event.

METHODS

The key to our processing disparate model outputs into a common framework is the definition of a common intermediate output format used by a suite of post-processing tools (Figure 1). Our vision is that any model output and other supporting data to be processed through this framework will be supplied with a routine for conversion to the standard data format. Currently we have implemented (with much help from model developers) conversion programs for HYSPLIT (Draxler and Hess, 1998; Draxler 1999), FLEXPART (Stohl et al. 2005), and PUFF (Peterson, 2006).

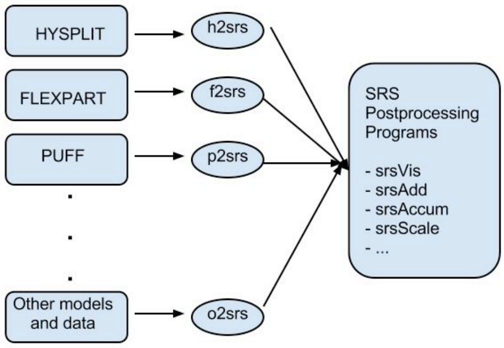

Figure 1. SRS-based postprocessing system

The standard data format adopted for our processing is based directly on the so-called Source Receptor Sensitivity (SRS) matrix format (Wotawa et al.,2003, Seibert et al, 2004), used up to now primarily for storing source-receptor sensitivities resulting from backwards simulations of FLEXPART. The format is simple and intuitive, with a single SRS file (Figure 2) storing a time series of two-dimensional rectangular lat-lon oriented sensitivities. It has evolved to where it can be used to represent global or regional sensitivities for forward and backward simulations. SRS files are text, for easy editing when necessary, and for ease in quick viewing. Files begin with a header consisting of release location and times, followed by time series information, and finally information for the rectangular lat-lon coordinate domain. The remainder of the file consists of time-series 4-tuples of latitude, longitude, timestep and sensitivity value. Timesteps are negative for forward simulation and positive for backward (this convention follows from the original, in which backwards simulations were the norm, and hence positive values).

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-152.20  61.30 19920819 01  19920819 04  0.13E+16   29   1   1 0.05 0.05 "XXX00"
-172.00   51.00  801  401
 61.40 -152.35   -1  0.1152397E-07
 61.45 -152.35   -1  0.4221232E-08
 61.35 -152.30   -1  0.2384217E-07
 61.40 -152.30   -1  0.5392899E-06
 61.45 -152.30   -1  0.1494994E-06
 61.30 -152.25   -1  0.3057000E-07
 61.35 -152.25   -1  0.4190307E-05
 61.40 -152.25   -1  0.2968699E-05
 61.45 -152.25   -1  0.2684802E-06
 61.30 -152.20   -1  0.2359612E-04
        .
        .
        .
 55.50 -132.85  -29  0.2447198E-07
 55.55 -132.85  -29  0.2232424E-07
 55.60 -132.85  -29  0.1426538E-07
 55.65 -132.85  -29  0.1646655E-07
 55.70 -132.85  -29  0.4463321E-08
 55.40 -132.80  -29  0.9045308E-10
 55.45 -132.80  -29  0.4526813E-09
 55.50 -132.80  -29  0.9063139E-09
 55.55 -132.80  -29  0.6351120E-09
 55.60 -132.80  -29  0.3634799E-09
 55.65 -132.80  -29  0.9092497E-10
```

Figure 2. SRS sample file format

Although originally developed to represent backwards sensitivities, the same format can be used to represent any lat-lon gridded time series on a two-dimensional surface. Concentration and deposition fields can also be stored this way. Given that each SRS file represents a single two-dimensional time series for a single state variable, model outputs with multiple levels and species will have one SRS file for each level-species combination to be processed. Hence, a ten-species, ten-level native output will be represented with one hundred SRS files. Although this may seem excessive, programs developed to process these files can easily handle such numbers. We have created programs to add an arbitrary number of SRS files together, allowing us to create single SRS files consisting of the sum of all levels, or the sum of all species, or even both. Additionally, we can convert an SRS file in which the data at each timestep is a snapshot, into a new file that represents the data in cumulative form. We plan also to use this SRS format to store spatial observations, such as satellite images and fallout maps, so that these, too, can be integrated into a unified postprocessing system. Finally, this post-processing system is by no means restricted to LPDMs - we expect to process WRFChem outputs also, in the near future.

TEST CASE

This work was inspired by the Hekla 2000 Benchmark Document (Bonadonna et al., 2011) from the Ash Dispersal Forecast and Civil Aviation Workshop in Geneva, Switzerland, 18-20 October 2010. Also coming from this workshop was a companion document, Model Definition Document (http://www.unige.ch/sciences/terre/mineral/CERG/Workshop/results/Model-Document-Geneva10.pdf)

The Hekla 2000 Benchmark Document had an objective of investigating the state of Volcanic Ash Transport and Dispersal Models (VATDM), using a single benchmark case (26 Feb 2000 Hekla eruption) with different VATDM's. The primary metrics for comparison were concentration contours at different flight levels and different times, plus vertical concentration profiles. An additional comparison of ground deposit load was provided. Models used were ASH3D, ATHAM, FALL3D, FLEXPART, HYSPLIT, JMA, MLDP0, MOCAGE, NAME, PUFF, TEPHRA2 and VOL-CALPUFF. The document was organised in a way to facilitate side by side comparisons of the models, but the model runs were performed independently by different groups with different projections and graphical representations, making it in some cases difficult to compare objectively.

We have chosen to pursue a similar study, of the August 1992 Mount Spurr eruption in Alaska, as a first evaluation of the post-processing system, using FLEXPART, HYSPLIT and PUFF as modeling platforms. The models are set up as similarly as possible, all driven by the CFSR 0.5 degree global reanalysis (Saha et al., 2010). The initial runs were performed with HYSPLIT and FLEXPART using ten categories (bins) of volcanic ash size, and ten vertical levels (Webley et al., 2009) This represents a reasonably complex implementation of air dispersion models, which we can use to fully test our SRS conversion programs. The PUFF model is currently being explored in this same context.

After running the HYSPLIT and FLEXPART cases, native output was converted to SRS format files for select vertical levels and species (bins) for concentrations and depositions. In the case of native HYSPLIT output, deposition is written per interval, and another SRS program was written to convert this to cumulative. Once in SRS format, our SRS visualisation program is employed to plot the data in common frames of reference. Additionally, similar visualisation routines that interface with grib-api are used to plot the meteorological fields (Figure 3 and Figure 4).

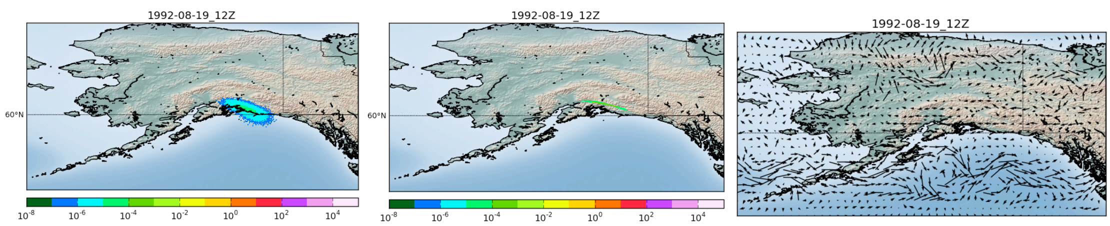

Figure 3. 5000m Species 5 concentration (kg m^{-3}). FLEXPART left, HYSPLIT right. 850mb winds right.

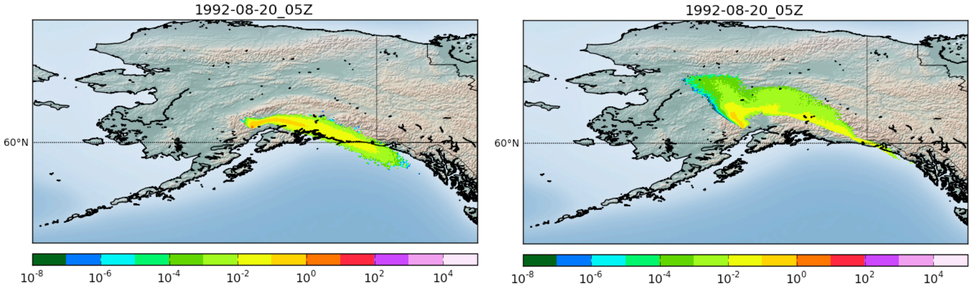

Figure 4. Species 5 cumulative deposition (kg m^{-2}). FLEXPART left, HYSPLIT right.

The differences in HYSPLIT and FLEXPART outputs were worrisome at first, but we recognised that this was a complex model setup, and that maybe we should not necessarily expect close agreement with a single species on a specific model output level. We performed another set of simple runs (this time adding the PUFF model) using a single SO_2 species with a single, integrated model level, performed the same transformations to SRS output and visualisation, and observed closer matches in output (Figure 5 and Figure 6). Please note that the PUFF model run is still preliminary, with some uncertainties about how we set it up, but the output was included here to demonstrate how it fits into the postprocessing framework with the other models.

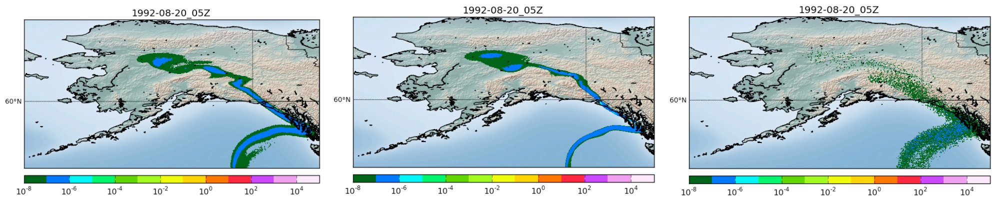

Figure 5. SO2 total column concentration (kg m^{-3}). FLEXPART left, HYSPLIT middle, PUFF right.

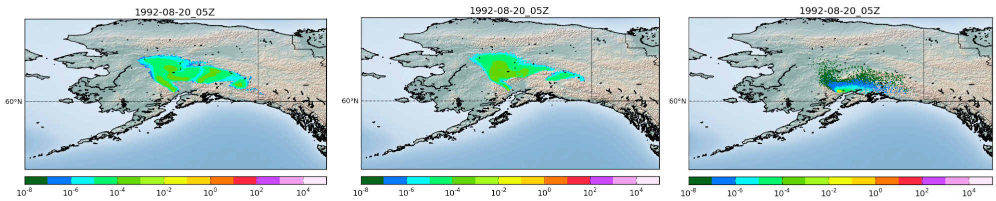

Figure 6. SO2 cumulative deposition (kg m^{-2}). FLEXPART left, HYSPLIT center, PUFF right.

SUMMARY AND FUTURE DIRECTION

The primary emphasis at this early stage is to test and refine the processes for model intercomparison. The basic process has been implemented and tested and shows great promise in bringing together the results of various models, along with observational data, for comparison in a common framework. The SRS post processing tools (and some of the data-to-SRS utilities) are all Python based, using numpy, matplotlib and basemap as a powerful and flexible foundation. Further work in the unified post processing system includes the addition of more data-to-SRS conversion routines and SRS processing programs. Future SRS processing programs include those that create station time series, and those that combine SRS files from a stack of vertical levels to produce vertical cross sections and point profiles. The current tools support qualitative comparisons, but, with a standard SRS format as input, we plan to add a suite of quantitative tools for more objective grid-to-grid and temporal comparisons between models and observations.

The Mount Spurr eruption was chosen as a test case because of recent attempts to intercompare volcanic ash models and its high visibility. Although the current emphasis continues to be development of the intercomparison tools, we are aiming for a rigorous model intercomparison of this case, as a demonstration of this system's value. In the bigger picture, this approach has wide-ranging applicability to virtually any dispersion environment in which native formats can be logically converted to an SRS-like format. Although volcanic ash, radionuclide transport, wildfire emissions and air quality are logical extensions, one can easily picture other domains, such as oceanic transport of debris from tsunamis as experienced in March 2011 at Fukushima, Japan. We expect this post processing system to be valuable in operational situations where numerous models and ensemble collections of models are run in emergency response environments, requiring quick and meaningful evaluation of numerous inputs.

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