

Unified Model Intercomparisons for Volcanic Ash Transport Modeling

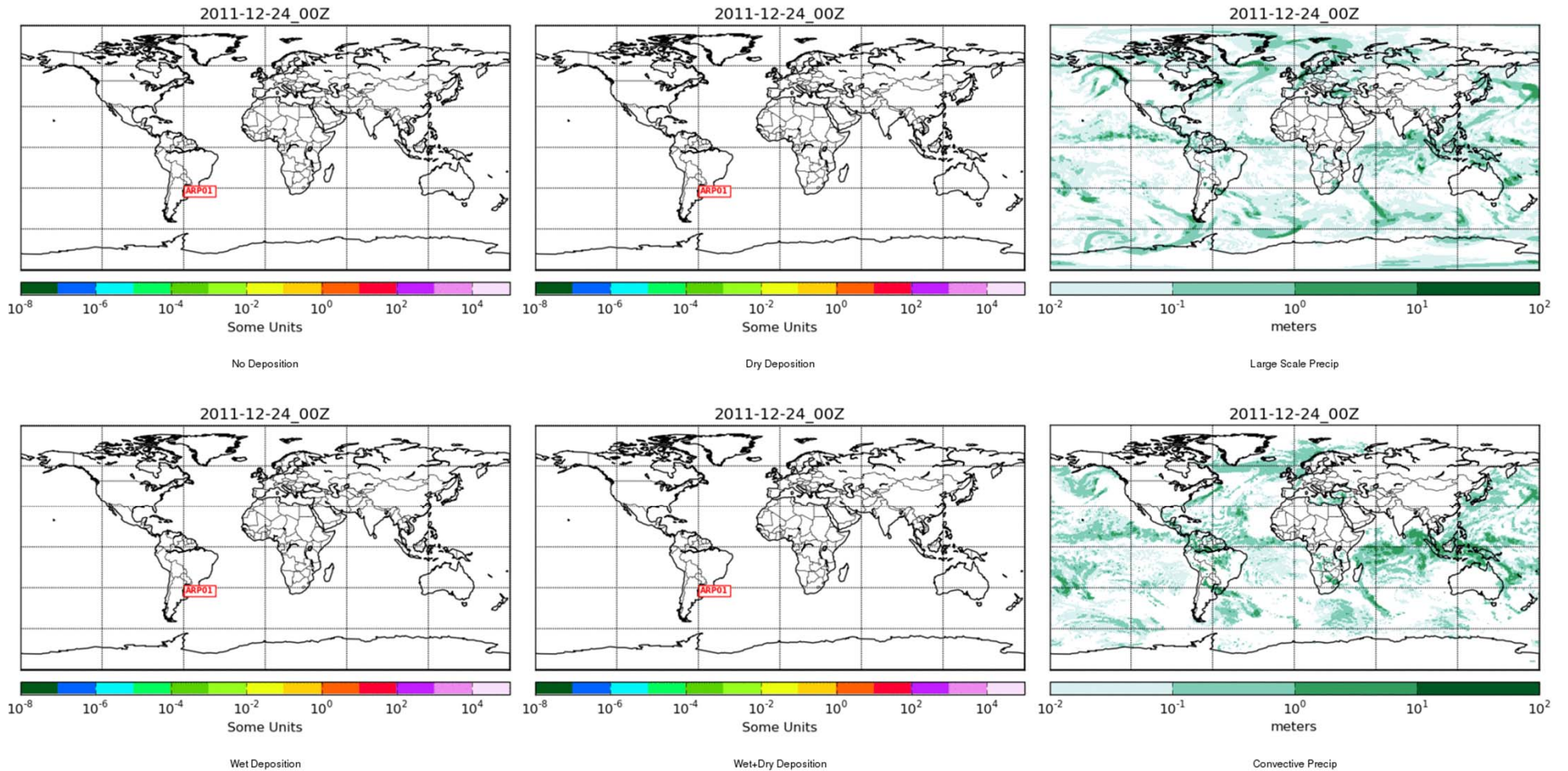
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Barbara Stunder⁴

¹Arctic Region Supercomputing Center, University of Alaska Fairbanks,
Fairbanks, Alaska USA

²Central Institute for Meteorology and Geodynamics, Vienna, Austria

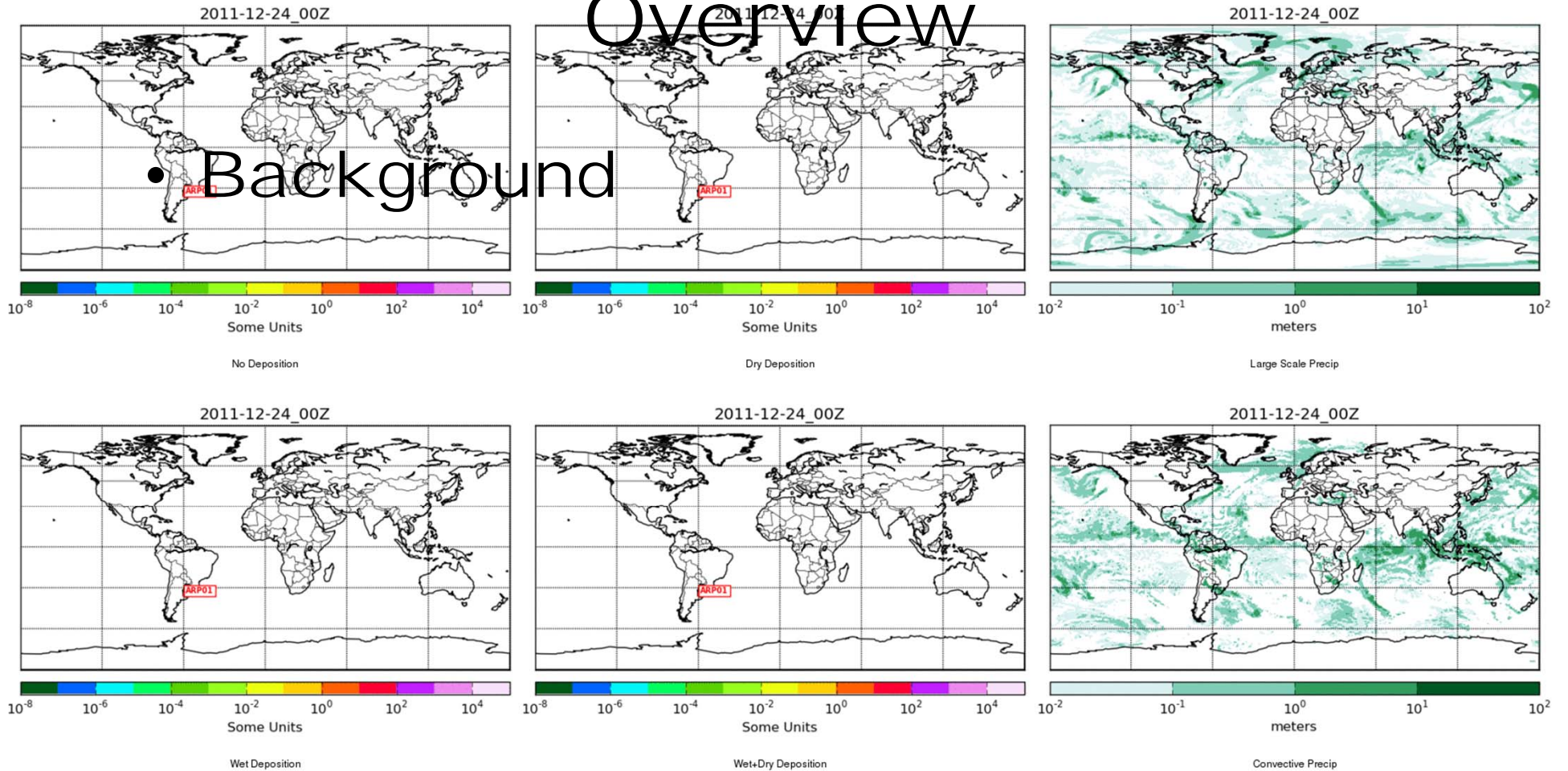
³Geophysical Institute, University of Alaska Fairbanks, Fairbanks, USA

⁴NOAA Office of Oceanic and Atmospheric Research, Air Resources
Laboratory, College Park, Maryland USA



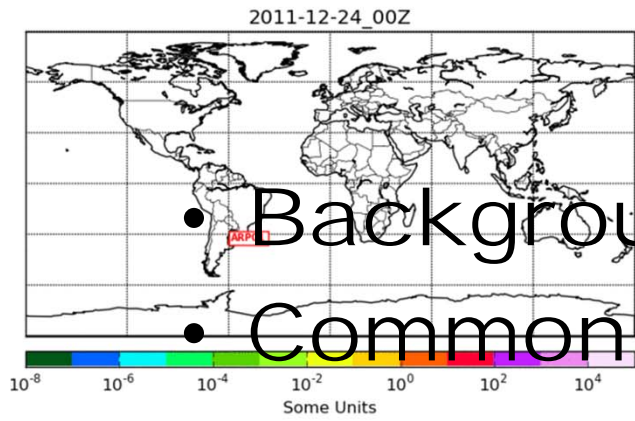
Overview

- Background

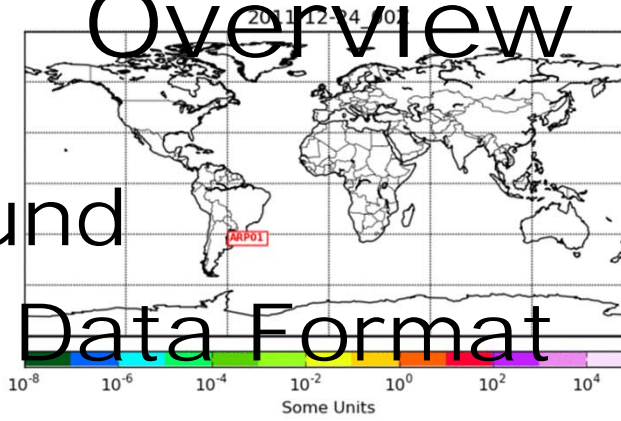


Overview

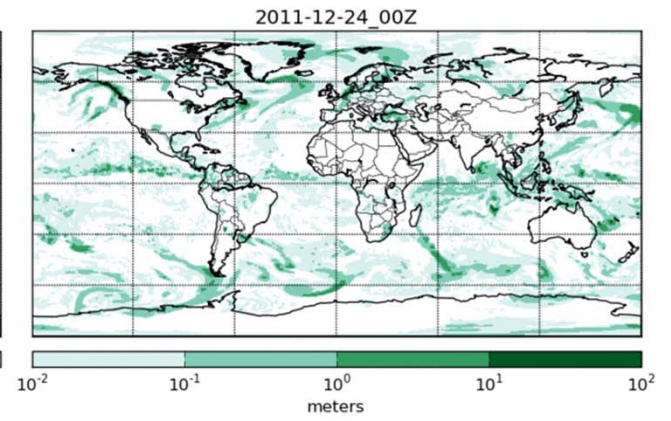
- Background
- Common Data Format



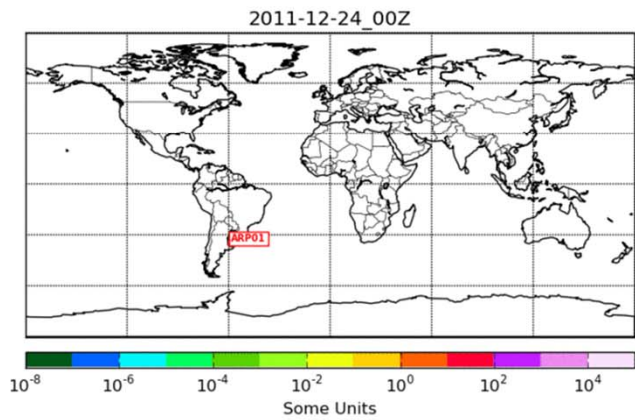
No Deposition



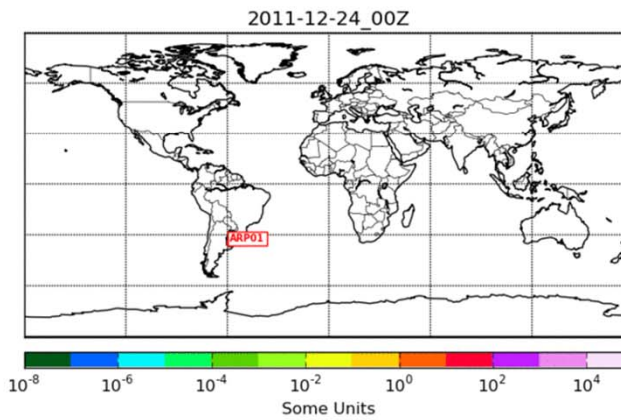
Dry Deposition



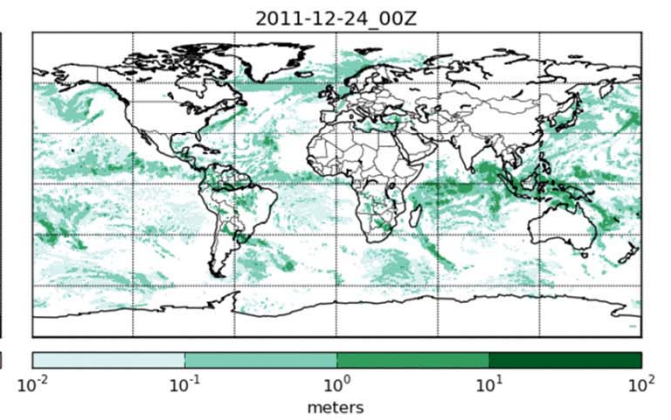
Large Scale Precip



Wet Deposition



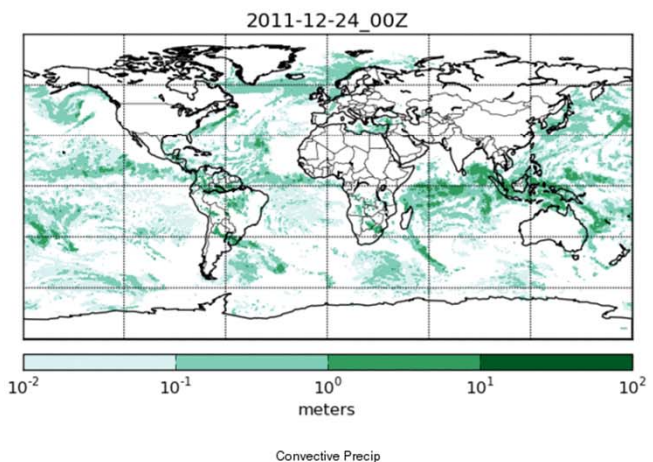
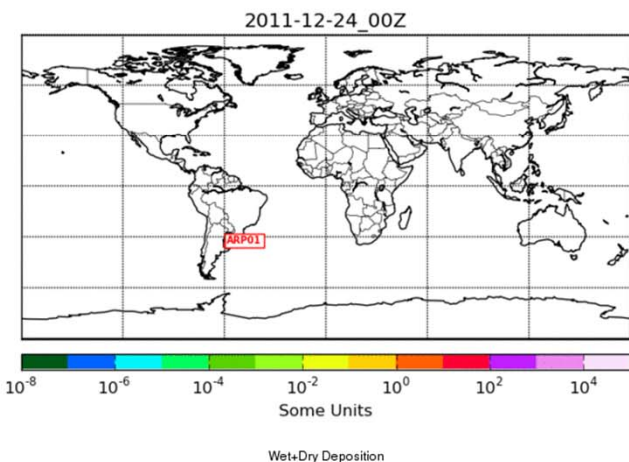
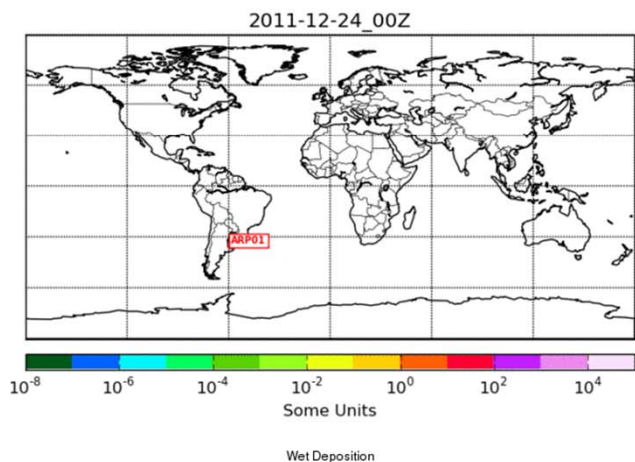
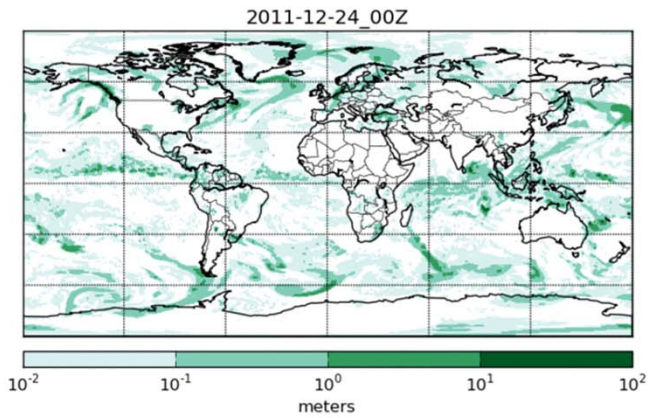
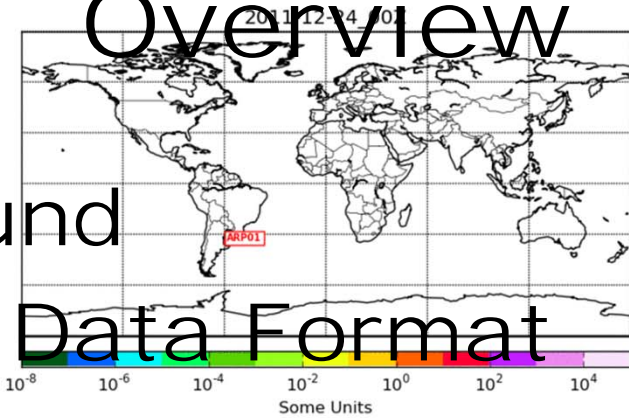
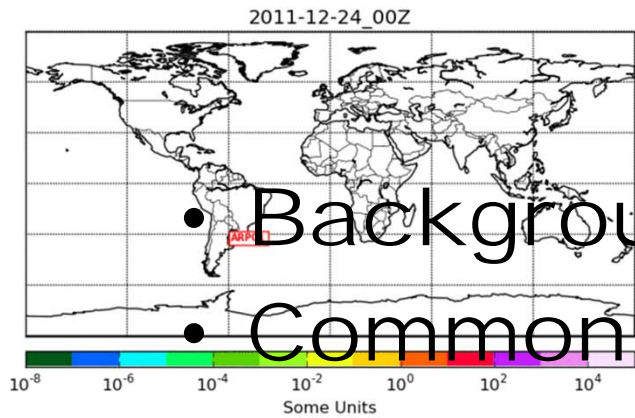
Wet+Dry Deposition



Convective Precip

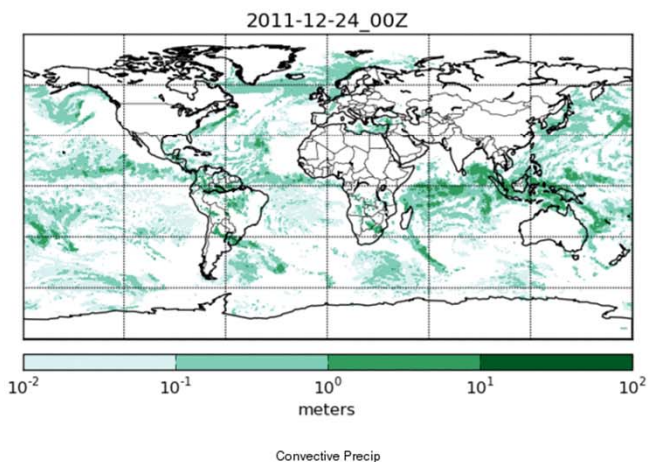
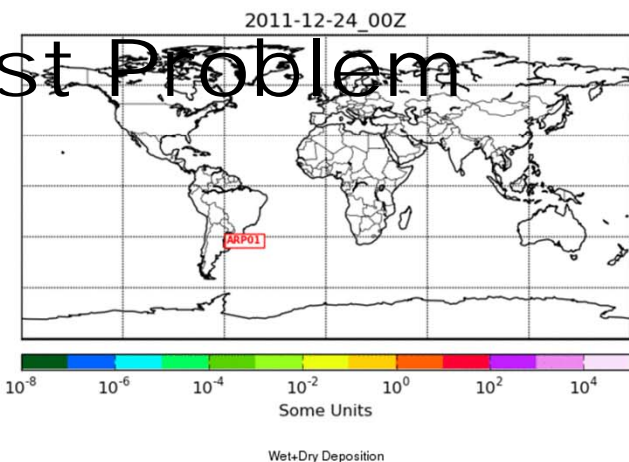
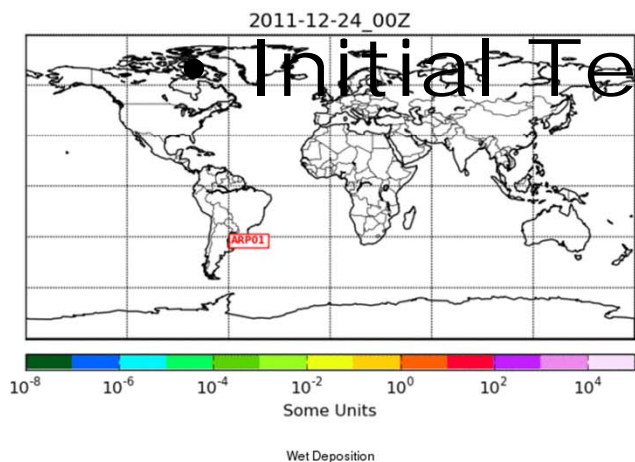
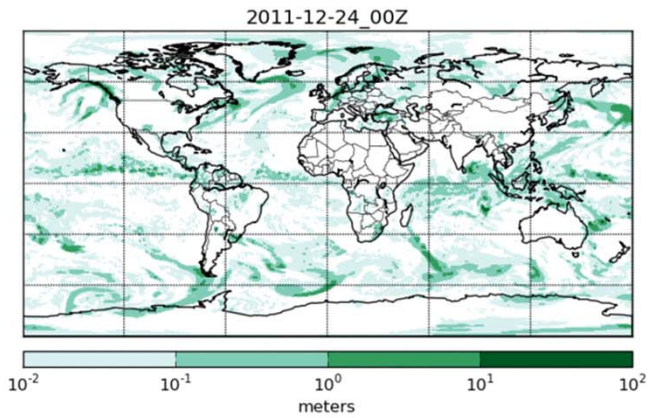
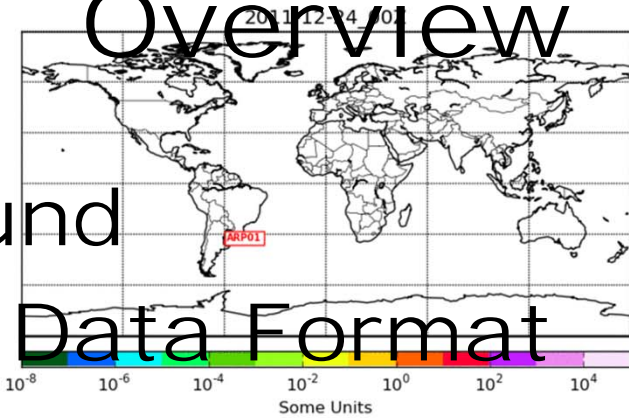
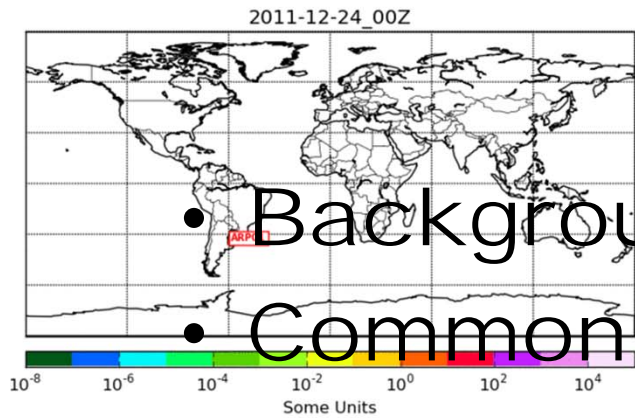
Overview

- Background
- Common Data Format
- SRS-format Processing



Overview

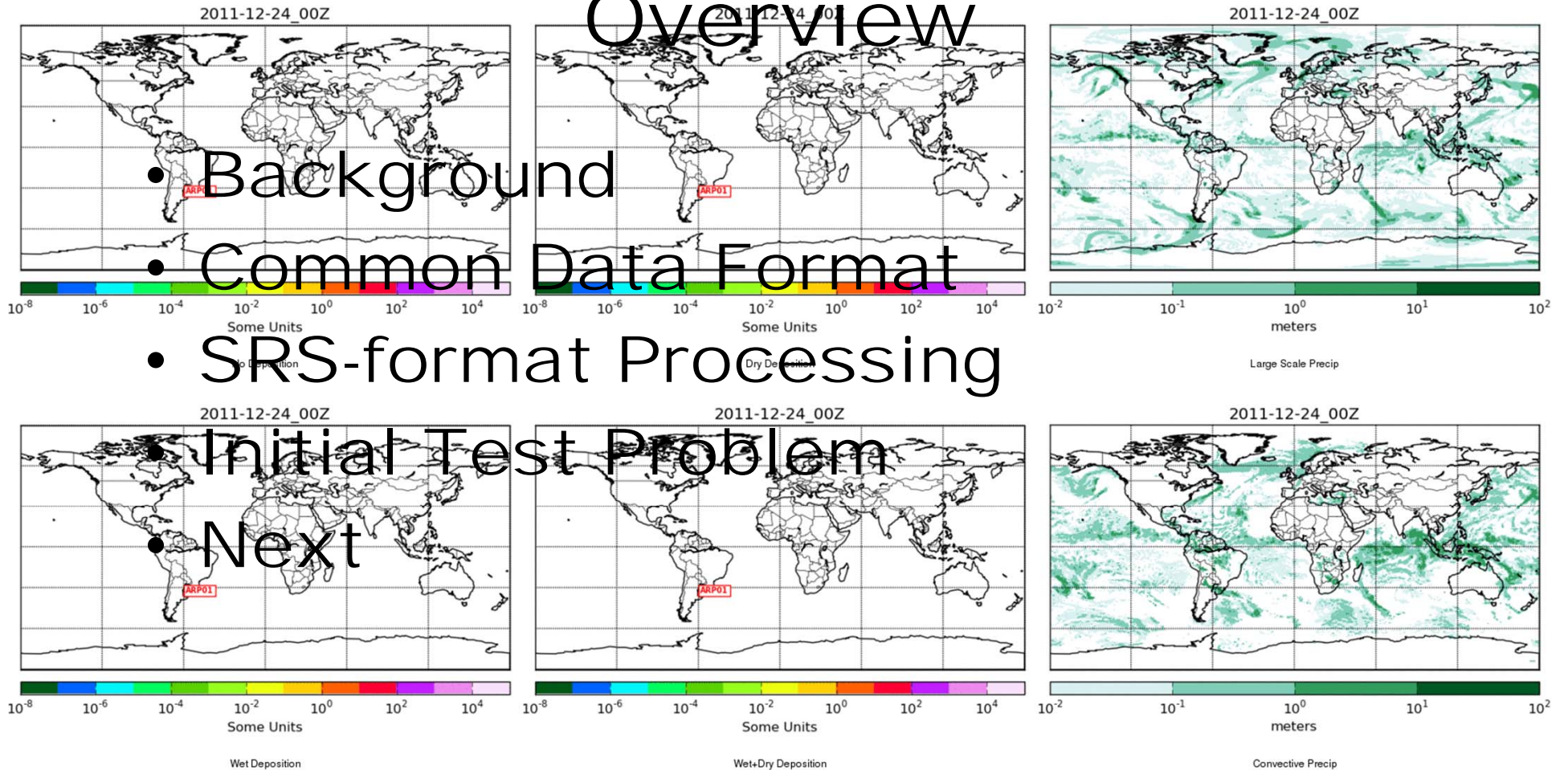
- Background
- Common Data Format
- SRS-format Processing



Overview

- Background
- Common Data Format
- SRS-format Processing

- Initial Test Problem
- Next



Acknowledgements

- John Burkhart, Norwegian Institute for Air Research (NILU)
- Roland Draxler, NOAA Air Resources Laboratory
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- Ramona Stefanescu, Mechanical and Aerospace Engineering Department, SUNY Buffalo
- Others

Hekla 2000 Benchmark Document



Ash Dispersal Forecast and Civil Aviation Workshop
Geneva, Switzerland, 18-20 October 2010
Hekla 2000 Benchmark Document

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¹⁰Meteorological Research Institute, JMA, Japan

¹¹NOAA Air Resources Laboratory, USA

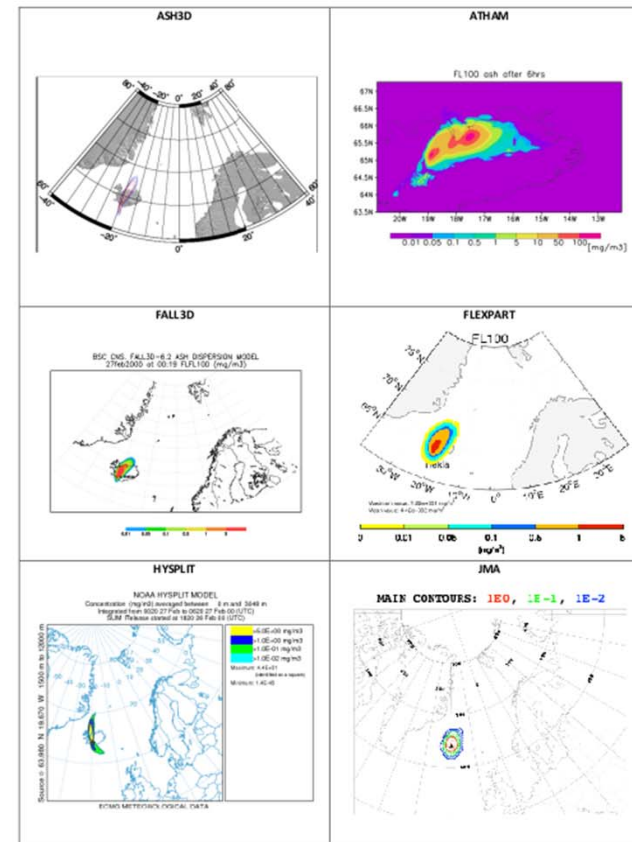
¹²Geophysical Institute, University of Alaska Fairbanks, USA

Citation: Bonadonna, C, Folch, A, Loughlin, S, Puempel, H (2011), "Ash Dispersal Forecast and Civil Aviation Workshop - Model Benchmark Document," <https://vhub.org/resources/505>

Concentration Comparisons

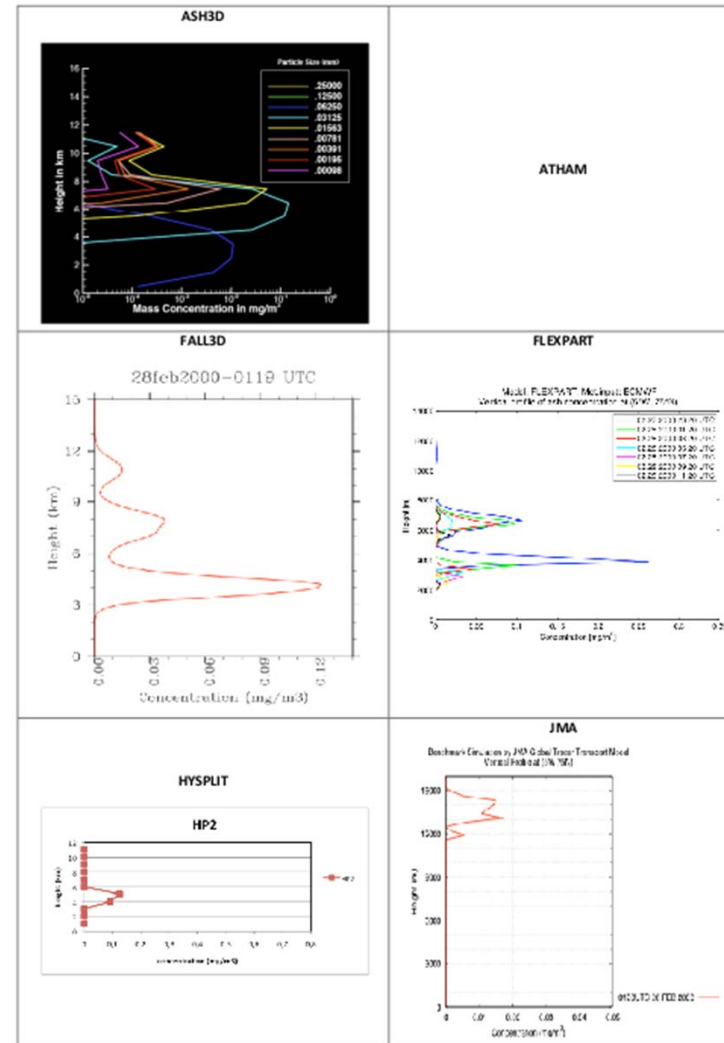


Plate 1.a
Concentration contours at FL100 (27 FEB 2000, 00:20UTC, 6h).



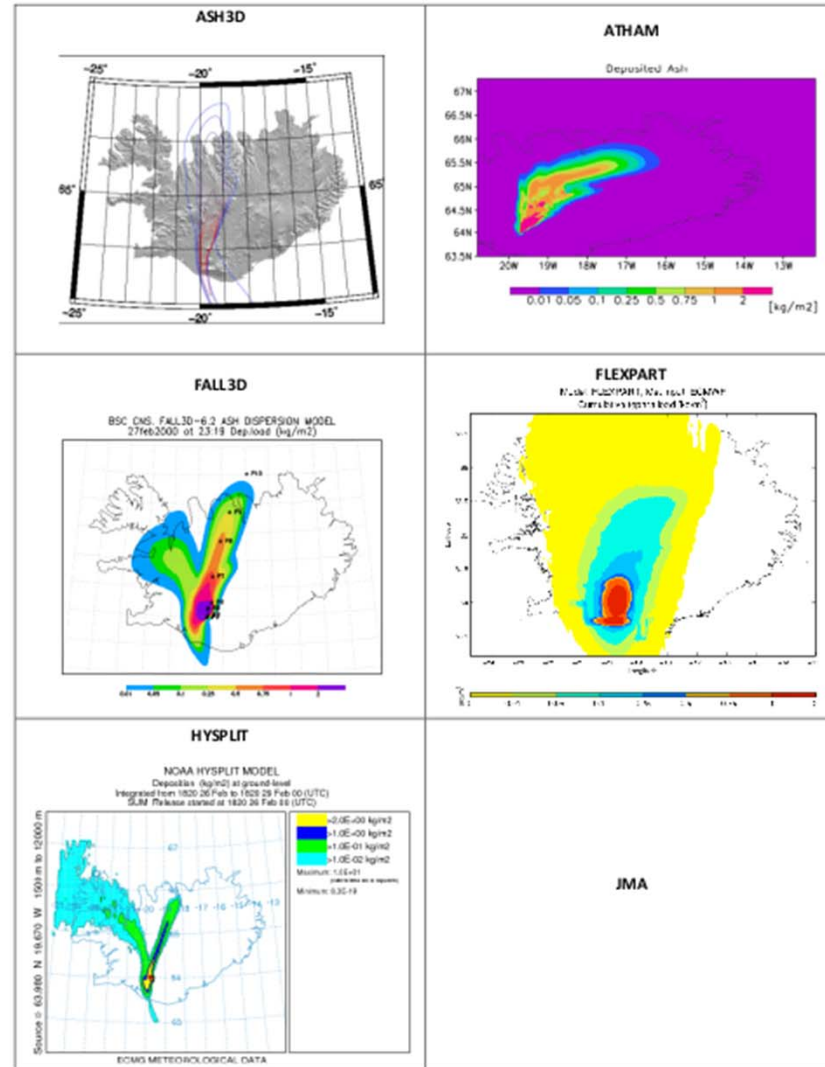
Vertical profile comparisons

Plate 7.b
Vertical concentration profile (28 FEB 2000, 01:20UTC, 31h).



Ground deposit load

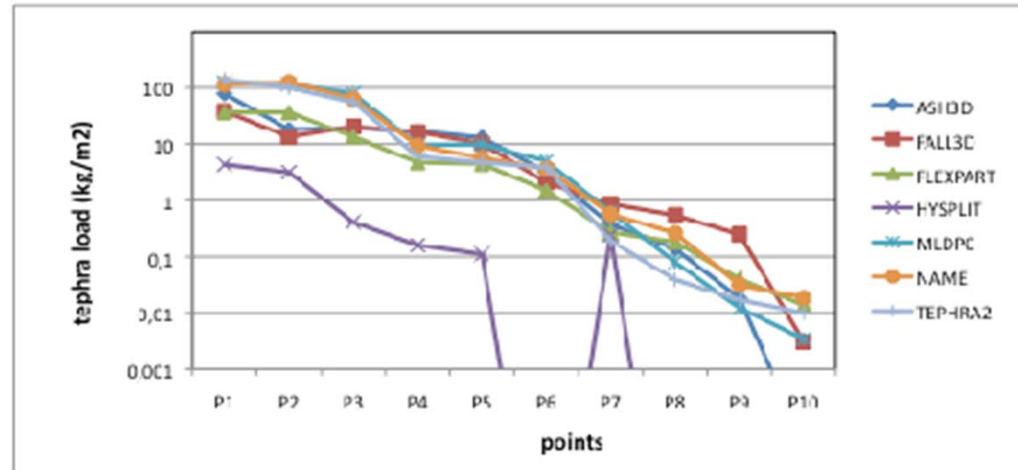
Plate 8.
Ground deposit load.



Ground deposit load

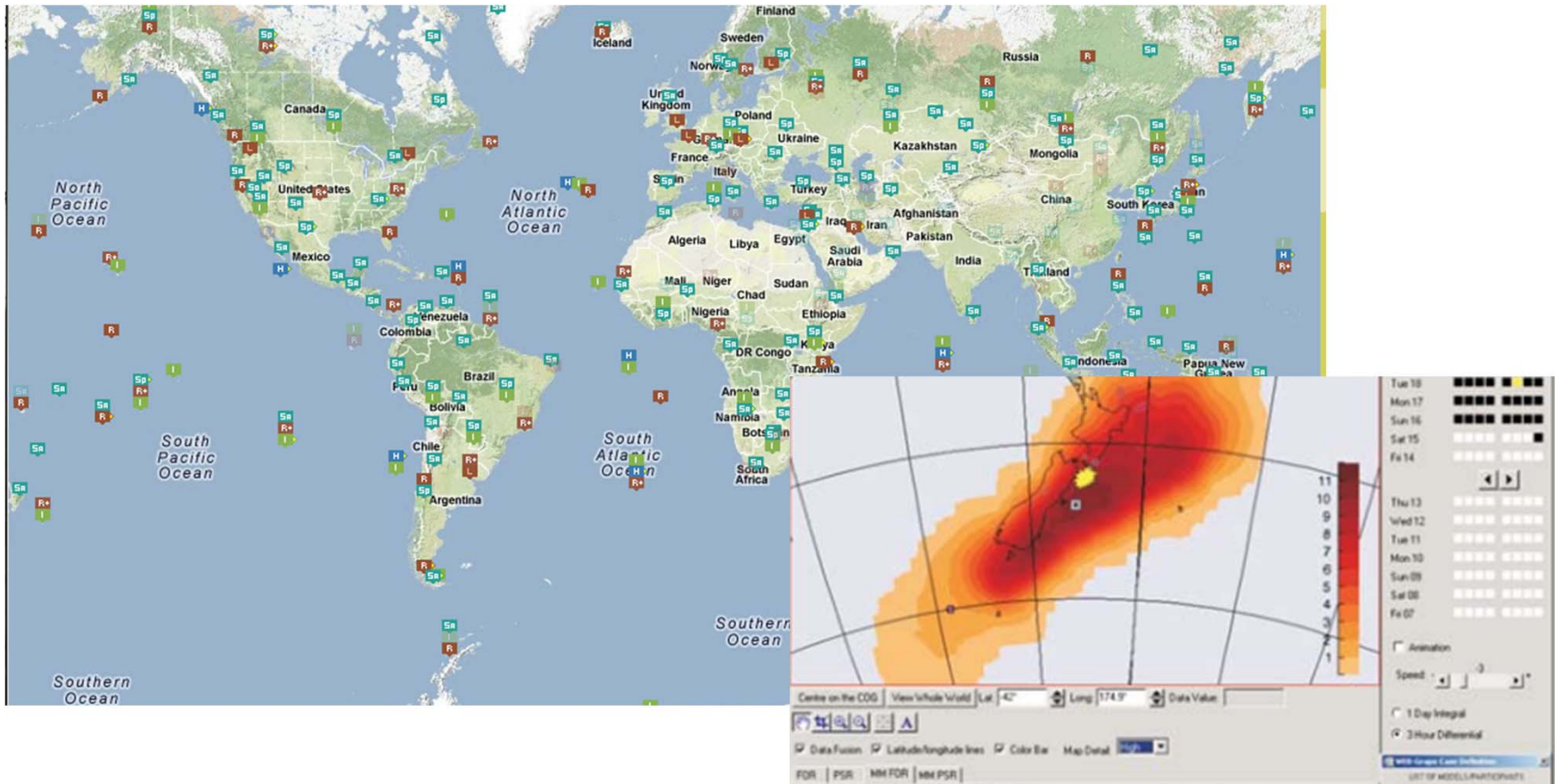
Plate 9.

Ground deposit load at different distances from the vent.

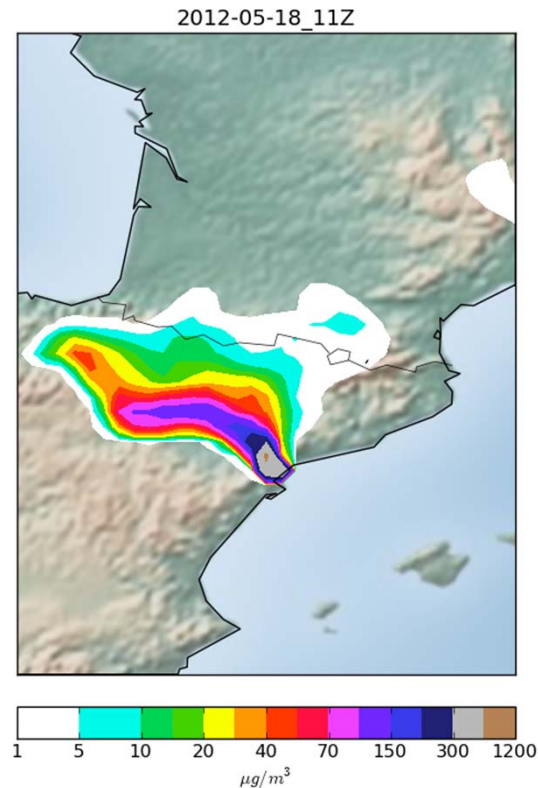


UTM			
X (m)	Y (m)	Z (m)	Distance from source (km)
565532	7096993	1453	2.25
566435	7097879	1162	3.5
567915	7102424	485	7.84
566851	7112630	257	17.08
567586	7115674	258	20.19
574124	7126200	516	30.07
574247	7176994	588	81.77
587095	7249537	188	155.37
602785	7306504	135	214.05
633250	7382744	24	294.89

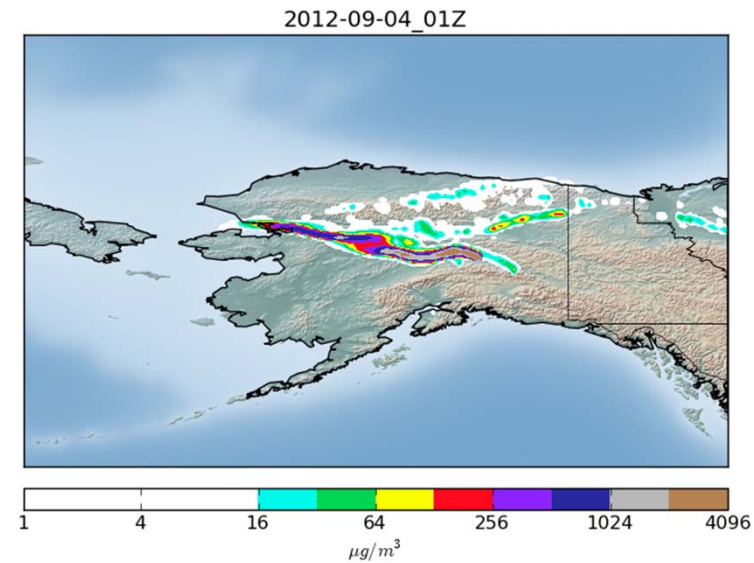
Origins of this work - Comprehensive Test Ban Treaty Organisation (CTBTO)



Origins of this work - Prototype Operational Wildfire Smoke Modeling



Catalonia

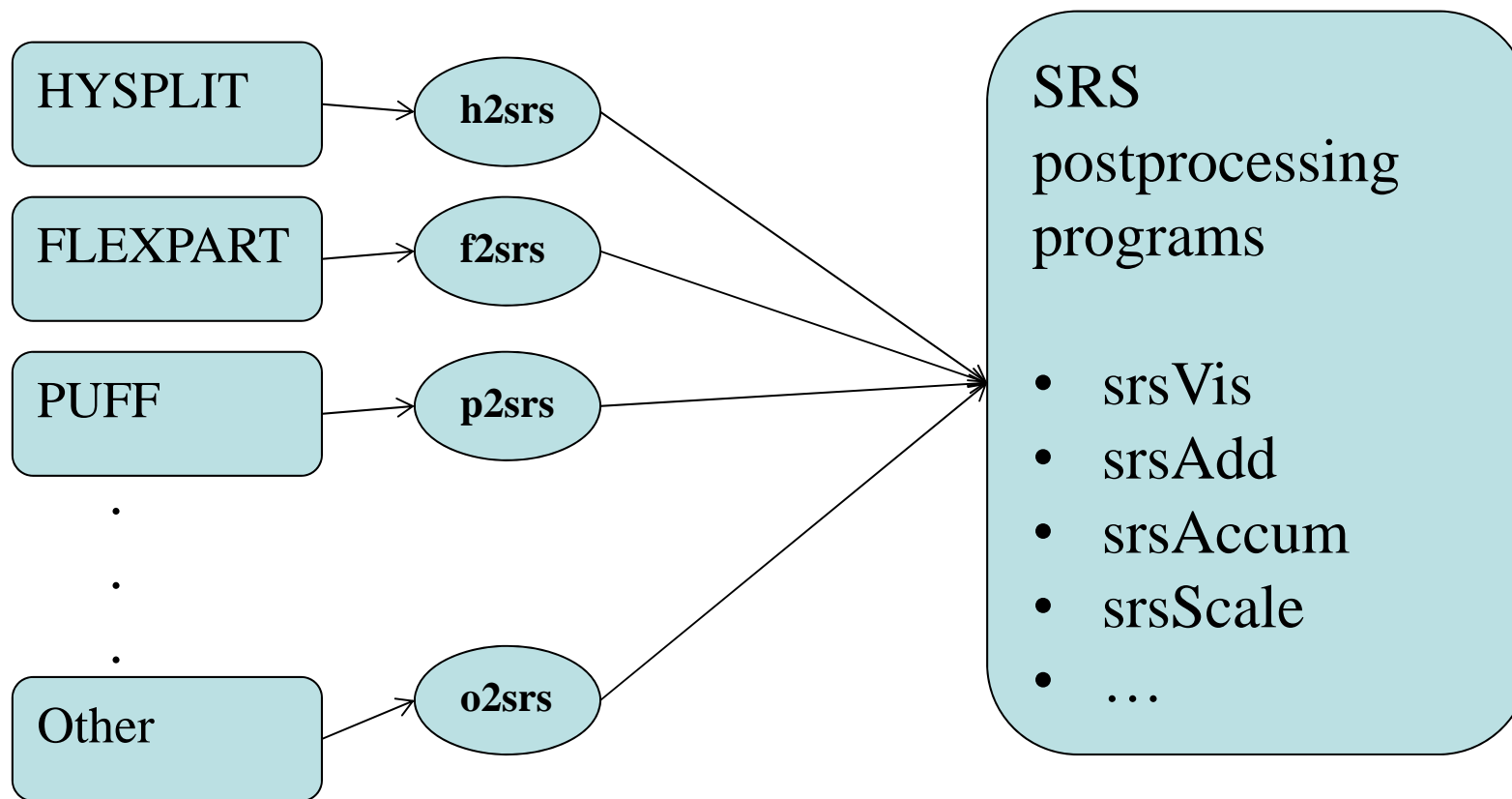


Alaska

Our goals

- Run models on equal footing
- Display/evaluate results in common framework
- Comparison tools based on single data format
- Research and operational applications

Single intermediate data format



The common data format – Requirements

- Simple format
- Easy to understand and manipulate
- Suitable for wide range of outputs
– forward, backward, regional, global
- Efficient storage

The common data format – Source Receptor Sensitivity (SRS)

```

-152.20 61.30 19920819 01 19920819 04 1.51E+09 28 1 1 0.05 0.05 "ERU_000001"
-172.00 51.00 801 401
61.35 -152.00 -1 3.2000000E+01
61.65 -151.95 -3 8.2758456E-07
61.70 -151.95 -3 7.2541312E-07
61.60 -151.90 -3 1.0454189E-04
61.65 -151.90 -3 1.7524986E-04
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61.55 -151.85 -3 1.1887410E-04
61.60 -151.85 -3 2.0116019E-03
61.65 -151.85 -3 9.5033952E-04
61.55 -151.80 -3 1.0933746E-04
61.60 -151.80 -3 6.1254893E-04
61.50 -151.75 -3 5.0170982E-04
61.55 -151.75 -3 1.8973760E-03
61.60 -151.75 -3 1.7860175E-03
61.65 -151.75 -3 3.9825128E-05
61.50 -151.70 -3 3.4984728E-05
61.55 -151.70 -3 9.8084730E-04
61.60 -151.70 -3 1.2435511E-03
61.65 -151.70 -3 1.5727941E-03
.
.
.
55.95 -136.05 -28 6.8677573E-09
56.00 -136.05 -28 8.6501250E-09
56.15 -136.05 -28 3.0768225E-07
56.20 -136.05 -28 8.3457519E-07
56.10 -136.00 -28 2.0645113E-07
56.15 -136.00 -28 4.3991047E-08
56.10 -135.95 -28 6.9917006E-07
56.15 -135.95 -28 1.4898067E-07

```

SRS Files

- Each SRS file stores a time series of a single entity on a 2D horizontal slice
- Simple model with one species and two levels would have one SRS file for each level
- Output with ten species on ten levels results in 100 “basic” SRS files, plus more for depositions
- But... once in SRS format, various SRS-specific tools add, combine, etc. to create more complex, condensed 2d horizontal slice time series
 - Add levels
 - Add species
 - Add levels and species
 - Create cumulative 2d time series
 - Future – create vertical profiles, point time series, etc.
- The key is having all model output in common format for consistent processing

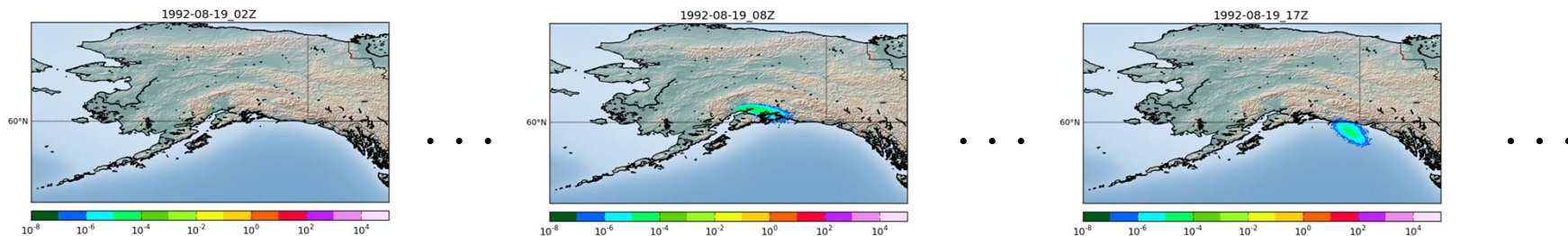

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-152.20 61.30 19920819 01 19920819 04 1.51E+09 28 1 1 0.05 0.05 "ERU_000001"
-172.00 51.00 801 401
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61.65 -151.95 -3 8.2758456E-07
61.70 -151.95 -3 7.2541312E-07
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```

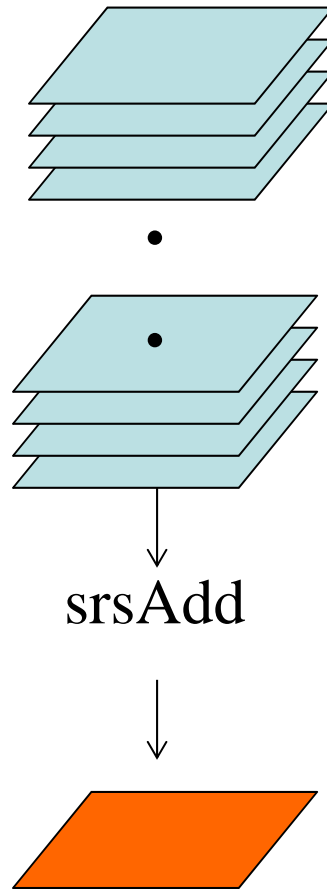
SRS Files

- Each file is a timeseries of a 2D horizontal lat/lon slice



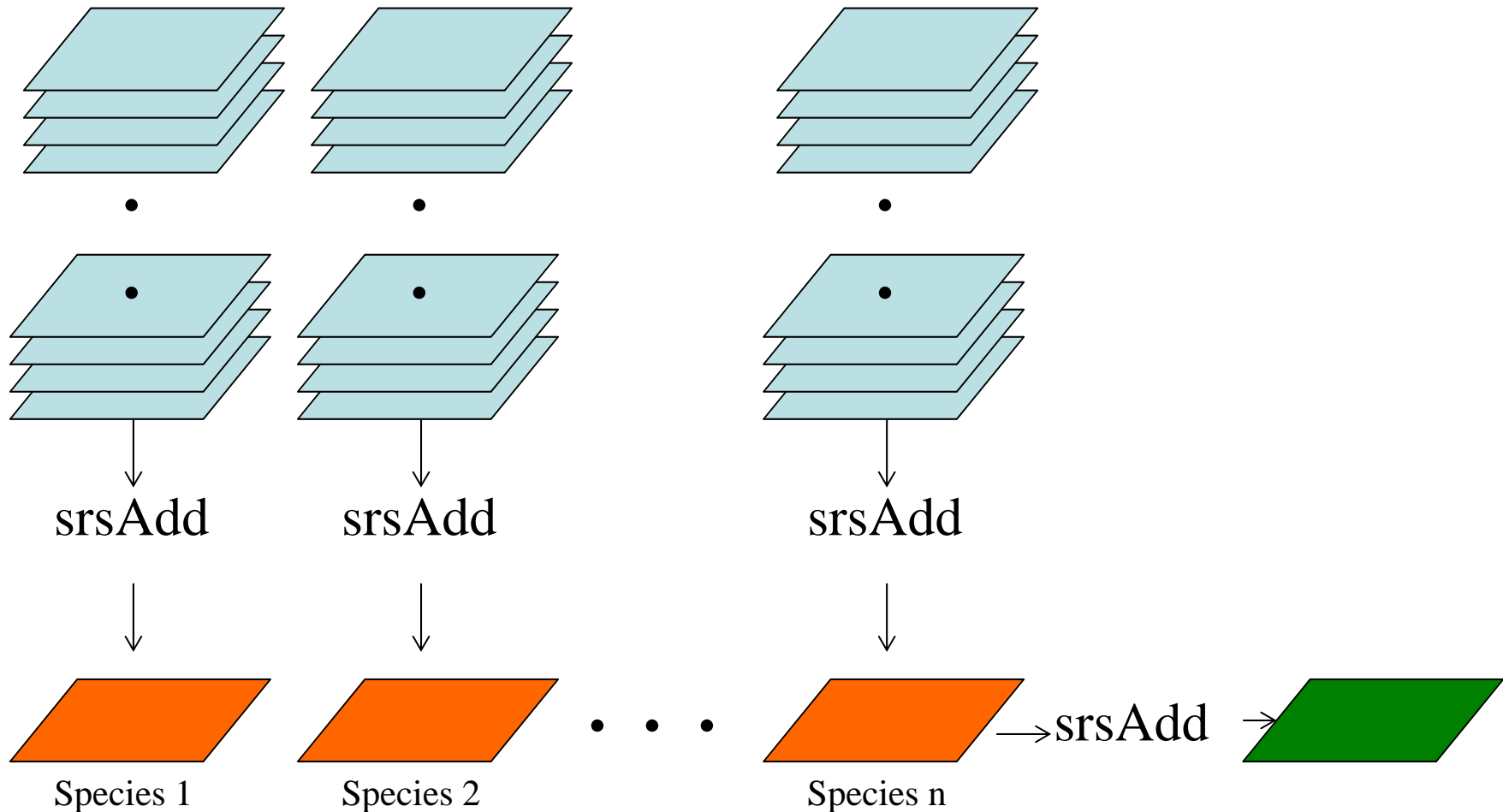
FLEXPART August 1992 Mount Spurr eruption – Species 5, Level 4

Adding vertical levels for integrated column values

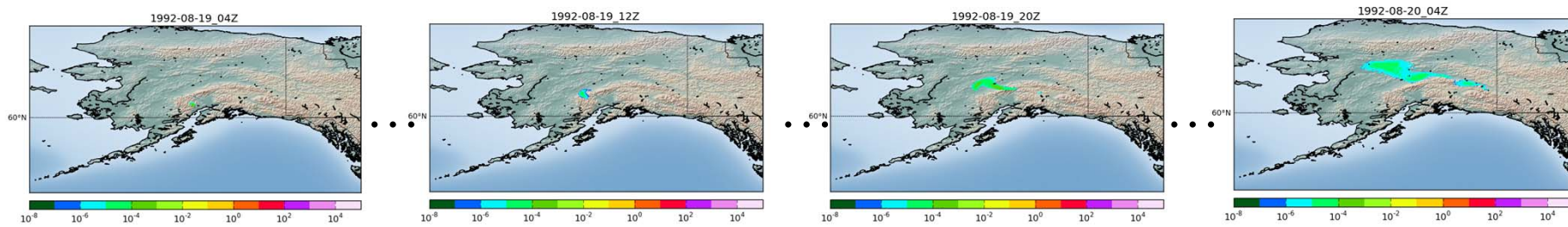




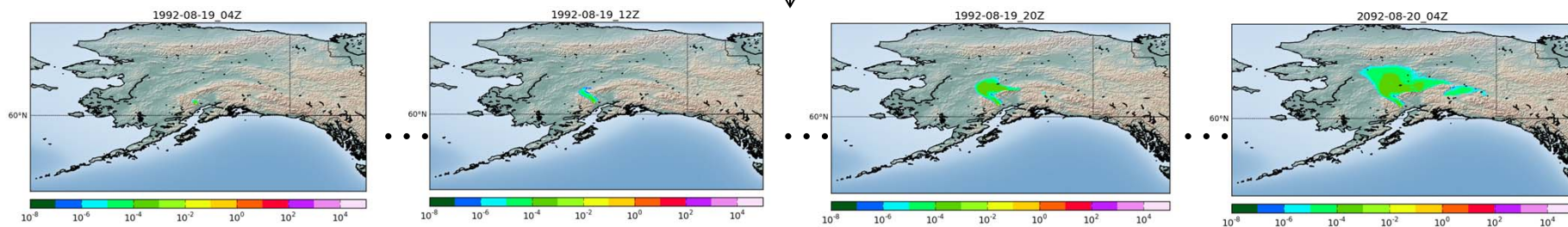
Adding multiple species in vertical levels for total integrated mass values



HYSPLIT writes time-averaged deposition output:

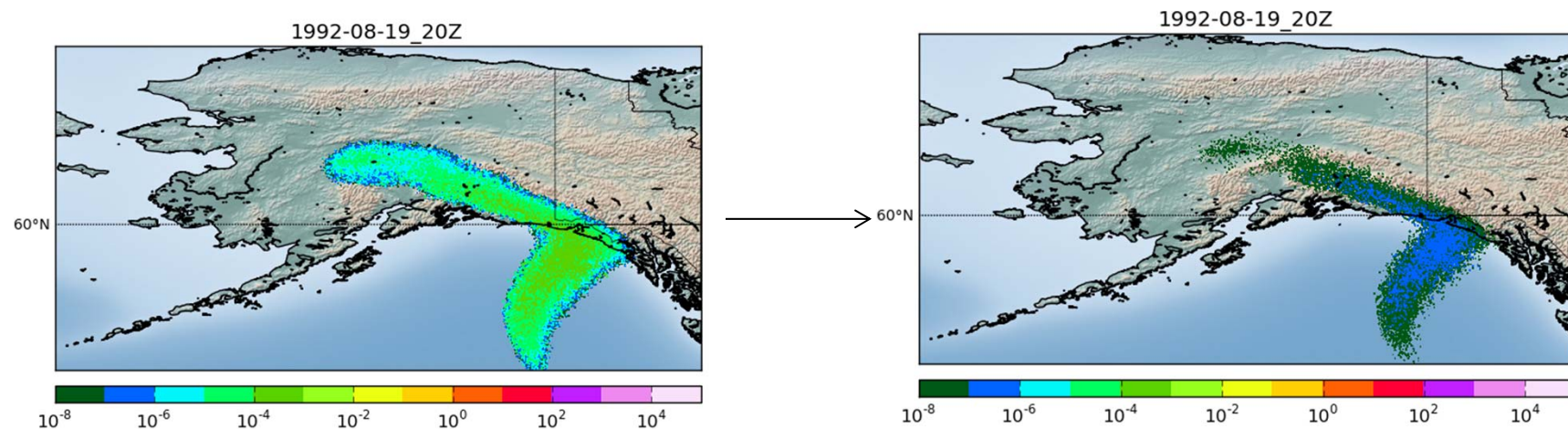


srsAccum re-arranges the SRS time series to accumulated output:



srsScale

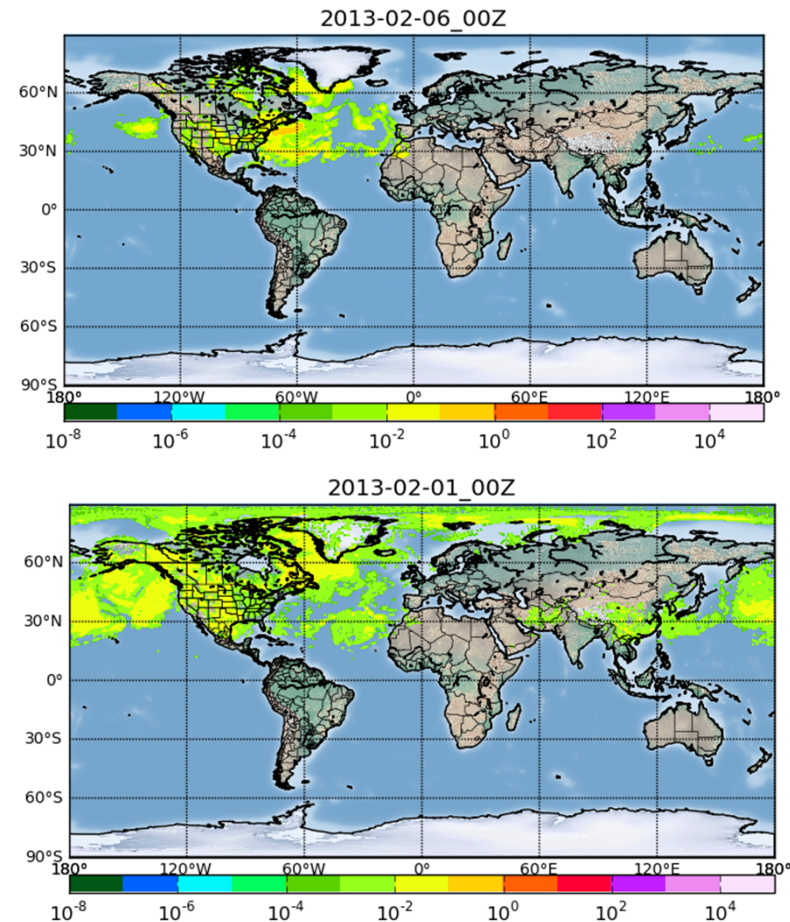
- Useful for unit changes, global adjustments, etc.



srsScale 1.0E-3

Storage of SRS Files

- ASCII (makes editing easier)
- Sparse format
- Efficient for typical plume features
- Easily gzipped, and our utilities work naturally with zipped or unzipped SRS files



Primary tasks for implementation

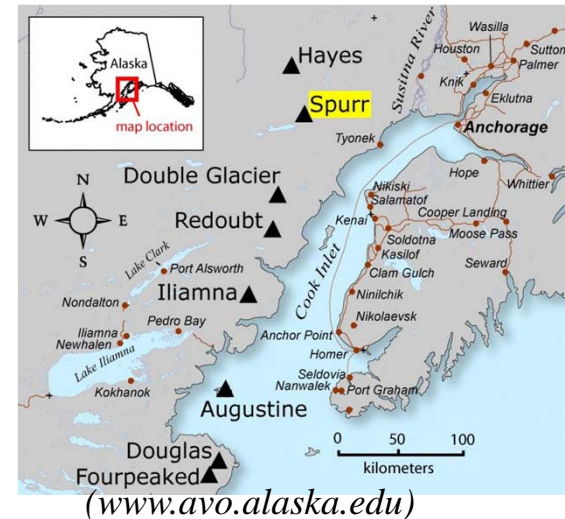
- Visualisation and evaluation tools that use SRS format as input
- Conversion routines from native model output to SRS format

Test Case and Strategy

- Find a data-complicated case with multiple species and vertical levels
- Take one event that we understand, have data for, and meet certain criteria
 - Affected air space
 - In vicinity of populated area plus airport
 - Complex topography
 - Multiscale

Mt Spurr, August 1992

- Location/time description
 - Start: 00:42 UTC 1992-08-19
 - End: 04:10 UTC 1992-08-19
 - Total duration: 3.5 hours
 - Max plume height: about 14km
 - Location: -152.2539 61.2989
 - Summit: 3374m MSL



- Ash
 - Density 2.6E03 kg/m³
 - Total mass emitted: 3.35E10 kg
 - Mass flow rate: 2.72E6 kg/s
 - 10 size classes (from 3 to 1536 μm) and fractions of each

Size (μm)	Percent	Mass (kg)	Emission rate (kg/h)
3	4.5	1.51E+09	4.31E+08
6	5.3	1.78E+09	5.07E+08
12	8.1	2.71E+09	7.75E+08
24	10.9	3.65E+09	1.04E+09
48	11.7	3.92E+09	1.12E+09
96	23.2	7.77E+09	2.22E+09
192	5.9	1.98E+09	5.65E+08
384	4.2	1.41E+09	4.02E+08
768	5.5	1.84E+09	5.26E+08

Methods

- Primary emphasis at early stage is to test and refine the processes for model intercomparison
- Find input data that works with all models – not easy
- Set up models in identical ways – not easy
- Run models to generate output in native format
- Convert native outputs to the standard SRS format for fields of interest, process and combine as necessary
- Produce visuals with software tools based on the SRS format inputs



Common Input Data

- January 1979 – December 2010
- 0.5 degree GRIB 2
- 6 hourly

NCEP CLIMATE FORECAST SYSTEM REANALYSIS (CFSR)

The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) was completed over the 31-year period of 1979 to 2009 in January 2010. The CFSR was designed and executed as a global, high resolution, coupled atmosphere-ocean-land surface-sea ice system to provide the best estimate of the state of these coupled domains over this period. The current CFSR will be extended as an operational, real time product into the future.

The CFSR relative to most, if not all, previous reanalyses include (1) coupling of atmosphere and ocean during the generation of the 6 hour guess field, (2) an interactive sea-ice model, and (3) assimilation of satellite radiances by the Grid-point Statistical Interpolation scheme over the entire period. The CFSR global atmosphere resolution is ~38 km (T382) with 64 levels extending from the surface to 0.26 hPa. The global ocean is 0.25° at the equator, extending to a global 0.5° beyond the tropics, with 40 levels to a depth of 4737m. The global land surface model has 4 soil levels and the global sea ice model has 3 levels. The CFSR atmospheric model contains observed variations in carbon dioxide (CO₂) over the 1979-2009 period, together with changes in aerosols and other trace gases and solar variations. With these variable parameters, the analyzed state will include estimates of changes in the Earth system climate due to these factors.

All available conventional and satellite observations were included in the CFSR. Satellite observations were used in radiance form and were bias corrected with "spin up" runs at full resolution, taking into account variable CO₂ concentrations. This procedure enabled smooth transitions of the climate record due to evolutionary changes in the satellite observing system.

CFSR atmospheric, oceanic and land surface output products are available at an hourly time resolution and 0.5° horizontal resolution. This reanalysis will serve many purposes, including providing the basis for most of NCEP Climate Prediction Center's operational climate products by defining the mean states of the atmosphere, ocean, land surface and sea ice over the next 30-year climate normal (1981-2010); provide initial conditions for historical forecasts required to calibrate operational NCEP climate forecasts (from week 2 to 9 months); and provide estimates and diagnoses of the earth's climate state, over the satellite data period, for community climate research.

Preliminary analysis of the CFSR output indicates a product far superior in most respects to the reanalysis of the mid-1990s. The previous NCEP reanalyses have been one of the most used NCEP products in history; there is every reason to believe the CFSR will supersede these older products both in scope and quality, because it is higher in time and space resolution, covers the atmosphere, ocean, sea ice and land, and was executed in a coupled mode with a more modern assimilation system and forecast model.

For additional information about the CFSR, please visit: <http://cfs.ncep.noaa.gov/cfsr>.

Component CFSR datasets in the CISL RDA:

- ds093.0: NCEP Climate Forecast System Reanalysis (CFSR) 6-hourly Products, January 1979 to December 2010
- ds093.1: NCEP Climate Forecast System Reanalysis (CFSR) Selected Hourly Time-Series Products, January 1979 to December 2010
- ds093.2: NCEP Climate Forecast System Reanalysis (CFSR) Monthly Products, January 1979 to December 2010

Beginning on January 1, 2011, CFSR has been extended by NCEP's Climate Forecast System Version 2 (CFSV2) operational model. Until the operational CFS is changed, it continues to be the identical model that was used to create CFSR. Therefore, until it is changed, the data produced by CFSV2 can be considered as a seamless extension to CFSR, except that the resolution of the surface and flux fields was increased from the 0.3-degree resolution in CFSR to approximately 0.2-degrees in CFSV2.

For additional information about CFSV2, please visit: <http://csl.ncep.noaa.gov>.

Component CFSV2 datasets in the CISL RDA:

- ds094.0: NCEP Climate Forecast System Version 2 (CFSV2) 6-hourly Products
- ds094.1: NCEP Climate Forecast System Version 2 (CFSV2) Selected Hourly Time-Series Products
- ds094.2: NCEP Climate Forecast System Version 2 (CFSV2) Monthly Products

The Research Data Archive is managed by the Data Support Section of the Computational and Information Systems Laboratory at the National Center for Atmospheric Research in Boulder, Colorado. NCAR is sponsored by the National Science Foundation.

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<http://rda.ucar.edu/pub/cfsr.html>



CFSR Data Selection



NCEP Climate Forecast System Reanalysis (CFSR) 6-hourly Products, January 1979 to December 2010
ds093.0

For assistance, contact [Bob Dattore](#) (303-497-1825).

Description

Data Access

Documentation

Get a Subset

A subset is a partial selection of the records from each data file. Make selections from the following options to request a subset of data that matches your selections (you will then have further opportunity to refine your subset), and then click the "Continue" button below.

Can I submit requests without going through this interface? [↗](#)

Temporal (Valid Time) Selection: 1979-01-01 00:00 to 2011-01-01 03:00

Parameter Selection: (selecting no parameters has the same effect as selecting all parameters)

Parameter presets:

- 5-wave geopotential height
- 5-wave geopotential height anomaly
- Absolute vorticity
- Aerodynamic conductance
- Albedo
- Best (4 layer) lifted index
- Canopy water evaporation
- Categorical freezing rain (yes=1; no=0)
- Categorical ice pellets (yes=1; no=0)
- Categorical rain (yes=1; no=0)
- Categorical snow (yes=1; no=0)
- Ozone vertical diffusion
- Parcel lifted index (to 500 mb)
- Planetary boundary layer height
- Plant canopy surface water
- Potential evaporation rate
- Potential temperature
- Potential vorticity
- Precipitable water
- Precipitation rate
- Pressure
- Pressure reduced to MSL

**FLEXPART
and
WRF
presets**

Ingesting CFSR

- Retrieve FLEXPART presets (GHT, U, V, W, T, RH – doesn't have precip, but can probably be added in)
- FLEXPART
 - Straightforward. Read in directly like GFS
- HYSPLIT
 - Convert to ARL format using HYSPLIT tool *api2arl*
 - Needs to be compiled against ECMWF grib-api
 - Doesn't seem to work with grib-api v9+
- PUFF-UAF
 - *cnvgrib* from GRIB2 to GRIB1
 - *gribtonc* from GRIB1 to netCDF

Setting up

- All model runs are computed on a global grid
- Need to understand specifics of model to set up emissions and various run-time parameters. Try to do as consistently as possible
- Each model has its own way of defining the output grid, and it's been possible to do this consistently with FLEXPART, HYSPLIT and PUFF-UAF

Execution

- FLEXPART – serial execution (FLEXPART-WRF supports parallel)
- HYSPLIT – often took us up to 20 times longer than FLEXPART, but supports MPI execution (we are in correspondence with HYSPLIT group about performance)
- PUFF – serial execution, very quick (so far, results are preliminary)

Output to SRS Format - general process

- Inventory data availability, projections, directions, nesting, etc.
- Write SRS header information
- For each timestep, and specified level, species, etc, find lat, lon, value of positive entries and write this, plus timestep number, to SRS file

```
-152.20 61.30 19920819 01 19920819 04 1.51E+09 28 1 1 0.05 0.05 "ERU_000001"  
-172.00 51.00 801 401  
61.35 -152.00 -1 3.2000000E+01  
61.65 -151.95 -3 8.2758456E-07  
61.70 -151.95 -3 7.2541312E-07  
61.60 -151.90 -3 1.0454189E-04  
61.65 -151.90 -3 1.7524986E-04  
61.70 -151.90 -3 4.6090435E-06  
61.55 -151.85 -3 1.1887410E-04  
61.60 -151.85 -3 2.0116019E-03  
61.65 -151.85 -3 9.5033952E-04  
61.55 -151.80 -3 1.0933746E-04  
61.60 -151.80 -3 6.1254893E-04  
61.50 -151.75 -3 5.0170982E-04  
61.55 -151.75 -3 1.8973760E-03  
61.60 -151.75 -3 1.7860175E-03  
61.65 -151.75 -3 3.9825128E-05  
61.50 -151.70 -3 3.4984728E-05  
61.55 -151.70 -3 9.8084730E-04  
61.60 -151.70 -3 1.2435511E-03  
61.65 -151.70 -3 1.5727941E-03  
.  
.  
55.95 -136.05 -28 6.8677573E-09  
56.00 -136.05 -28 8.6501250E-09  
56.15 -136.05 -28 3.0768225E-07  
56.20 -136.05 -28 8.3457519E-07  
56.10 -136.00 -28 2.0645113E-07  
56.15 -136.00 -28 4.3991047E-08  
56.10 -135.95 -28 6.9917006E-07  
56.15 -135.95 -28 1.4898067E-07
```

Output to SRS format

- FLEXPART
 - Binary header file plus binary timestep files in a complex, sparse format
 - Need to consider multiple species, levels, depositions, forwards, backwards, nested
 - Currently using the evolving *pflexible* to extract necessary fields and then create SRS file for specified level, species, etc.
 - Have created *flexout2srsm.py* to deal with most of this

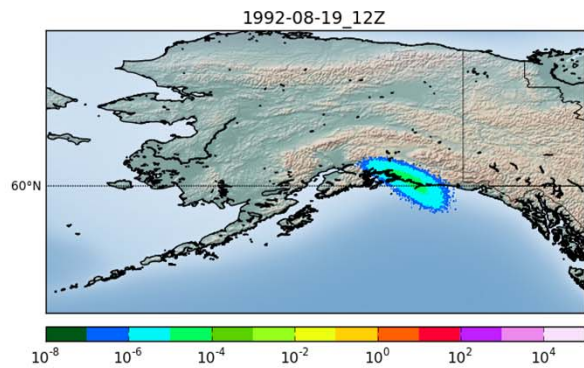
Output to SRS format

- HYSPLIT
 - Header and all timestep values in a single binary file.
 - Need to consider multiple species, levels, depositions, forwards, backwards, nested
 - Have modified HYSPLIT Fortran programs *conc2ctbt* and *conc2asc* to create a much more general and SRS-oriented *conc2srs* (should be part of HYSPLIT distro now)

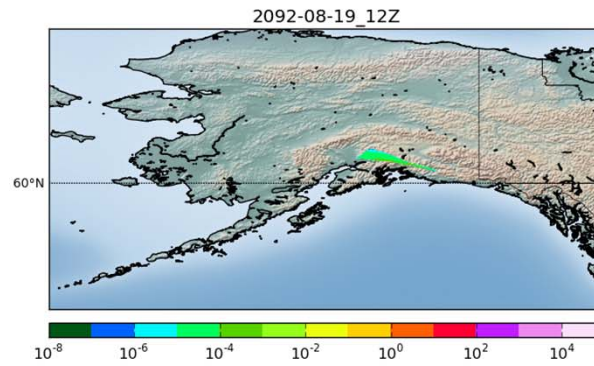
Output to SRS format

- PUFF
 - Header and all timestep values in a single netCDF file. When PUFF is run this format needs to be specified.
 - Need to consider multiple species, levels, fallout, etc.
 - Have created a crude *puff2srs.py* to generate the SRS file from netCDF output.

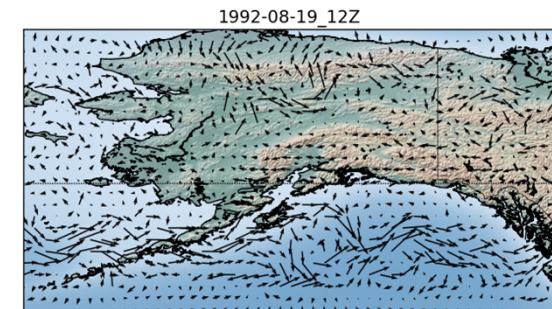
Snapshot of Species 5 Concentration and Winds, 5000m MSL



FLEXPART

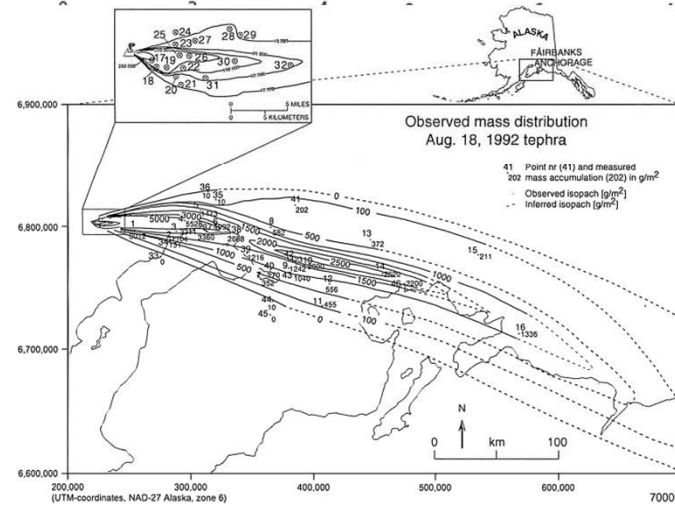
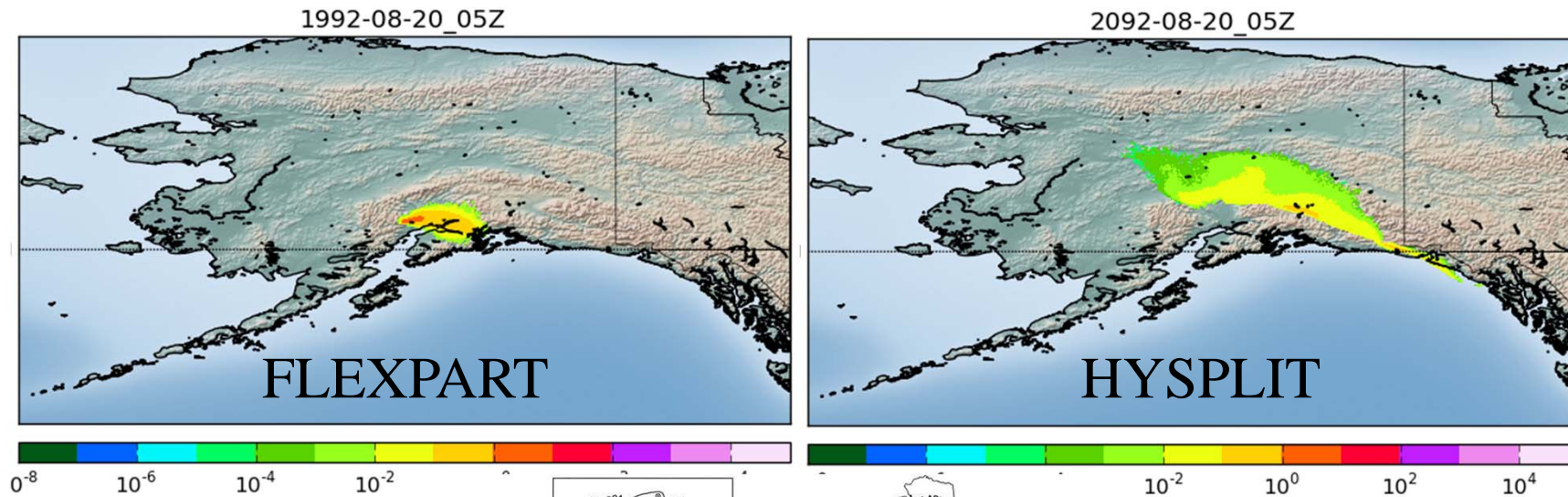


HYSPLIT



Meteorology

Deposition (Fallout) of Species 5

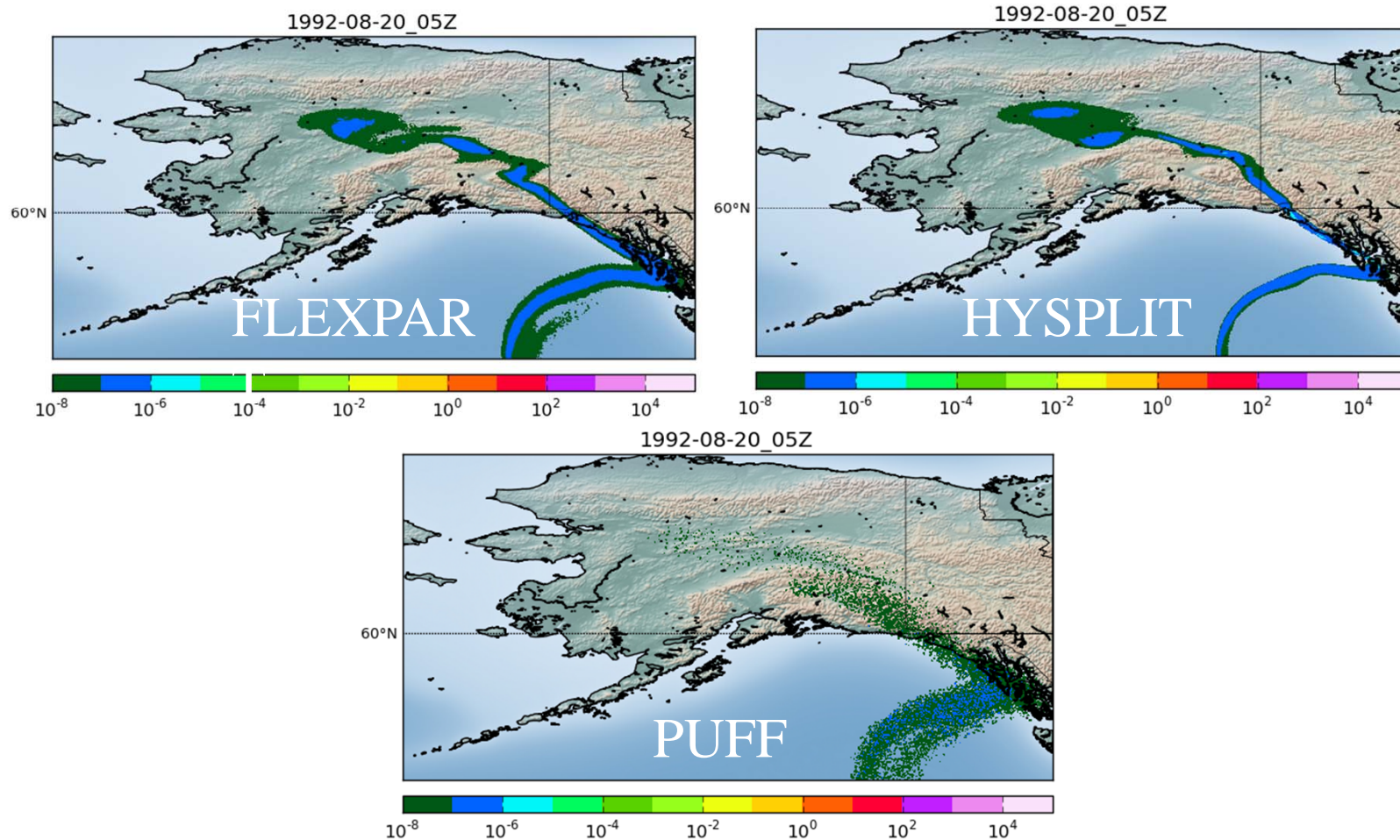


Todo: Convert
observed fields to
SRS format and
incorporate in the
system

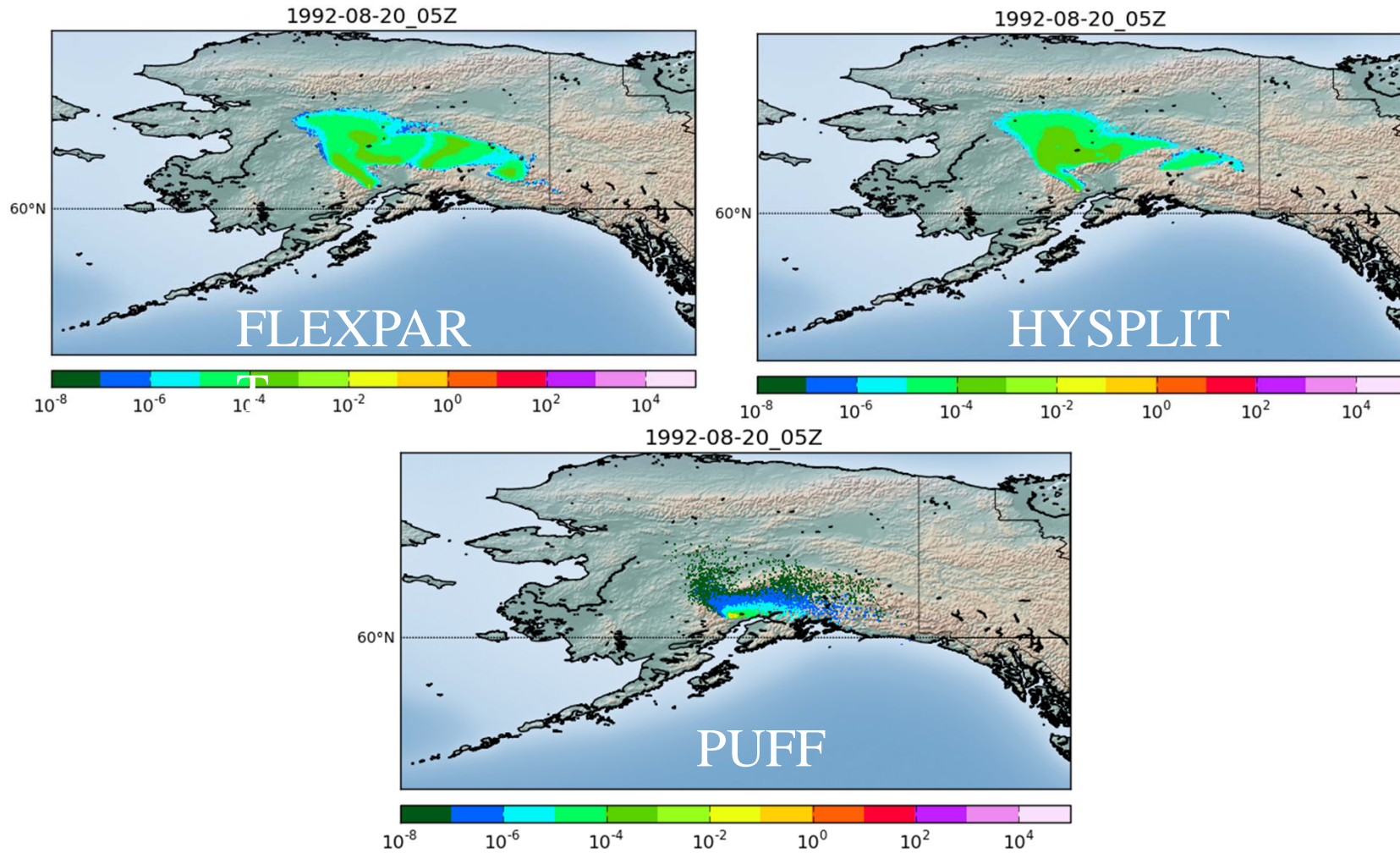


Arctic Region Supercomputing Center

Simple SO₂ Case – total integrated column concentration



Simple SO2 case – cumulative deposition



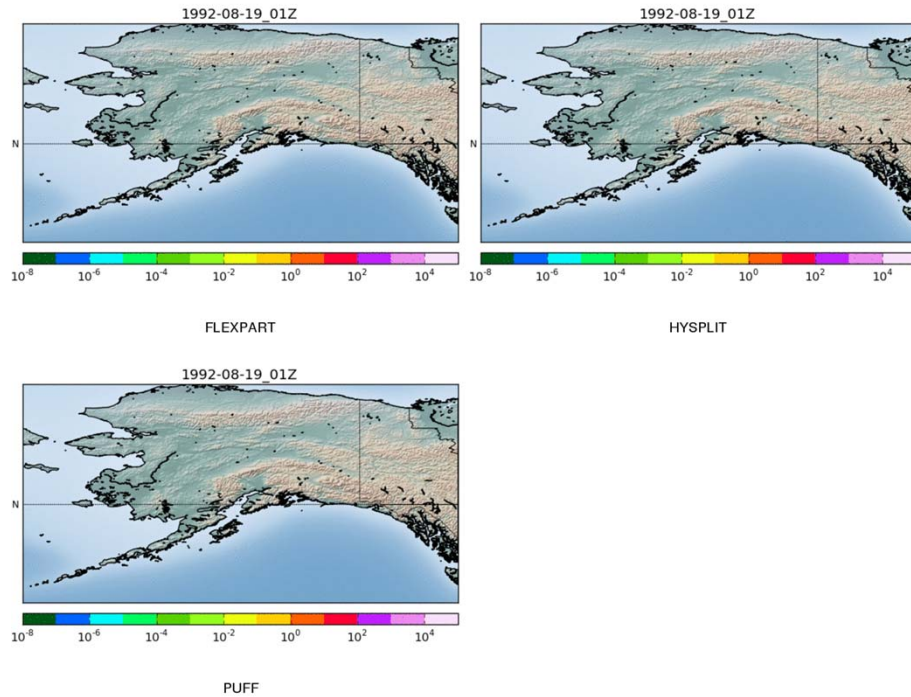
Closing Thoughts

- A lot can be automated, but there are many degrees of freedom to consider
- The user of these tools needs to understand what's in the model output
 - E.g. HYSPLIT requires that you run with a model level 0 to get deposition, and doesn't differentiate between wet and dry, and outputs by timestep, not cumulatively

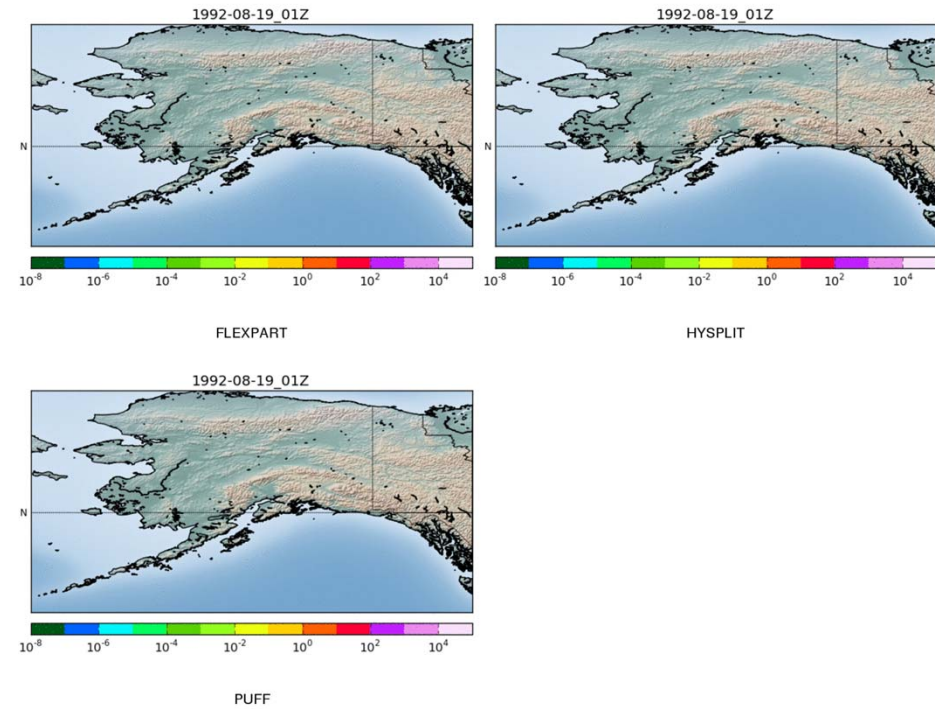
Next

- FLEXPART-WRF, WRFChem, other models
- Bigger picture – operational, ensembles, emergency response
- Add more visuals (vertical cross sections and profiles)
- Add quantitative evaluation and intercomparison. Grid to grid and temporal
- Package in a more user-friendly way
- Seek funding to drive all this!

The Vision – facilitating multi-model and multi-configuration comparisons



Multi-model Concentration



Multi-model Fallout