# Unified Model Intercomparisons for Volcanic Ash Transport Modeling

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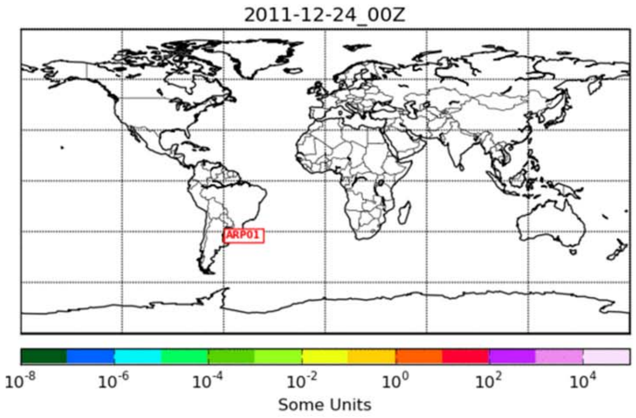
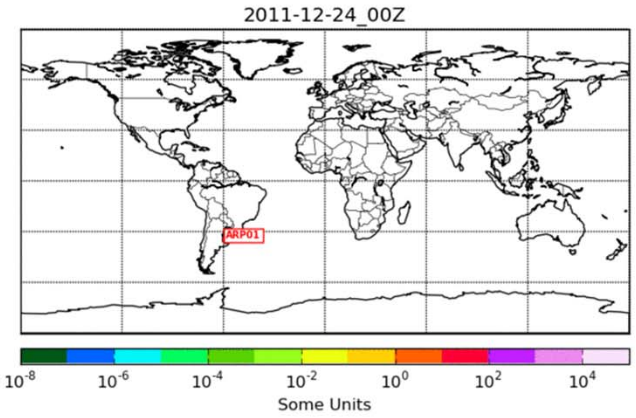
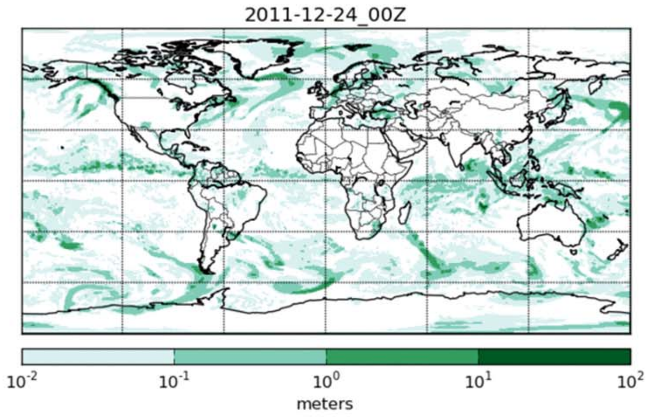


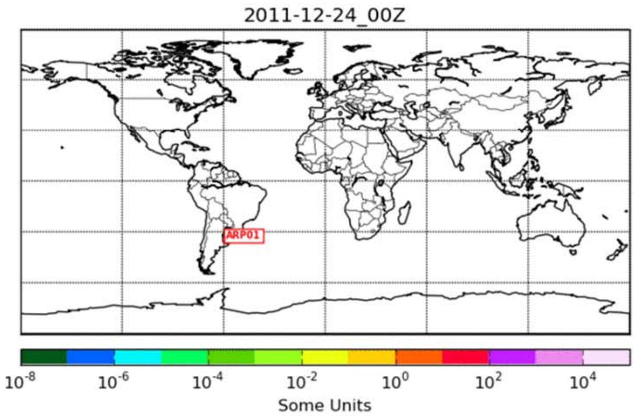

No Deposition



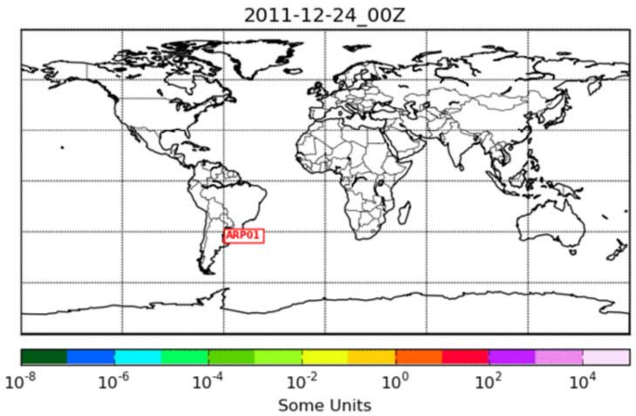

Dry Deposition



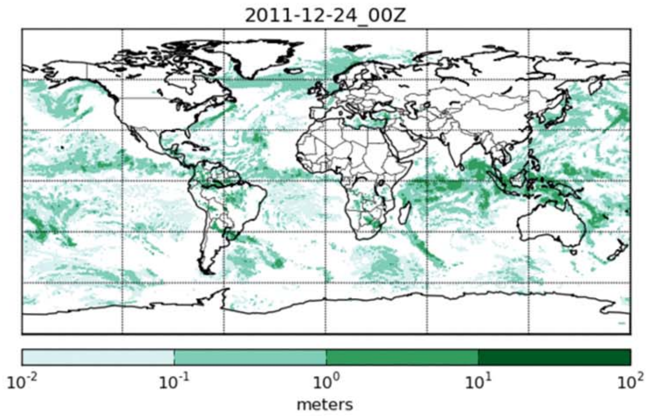

Large Scale Precip




Wet Deposition



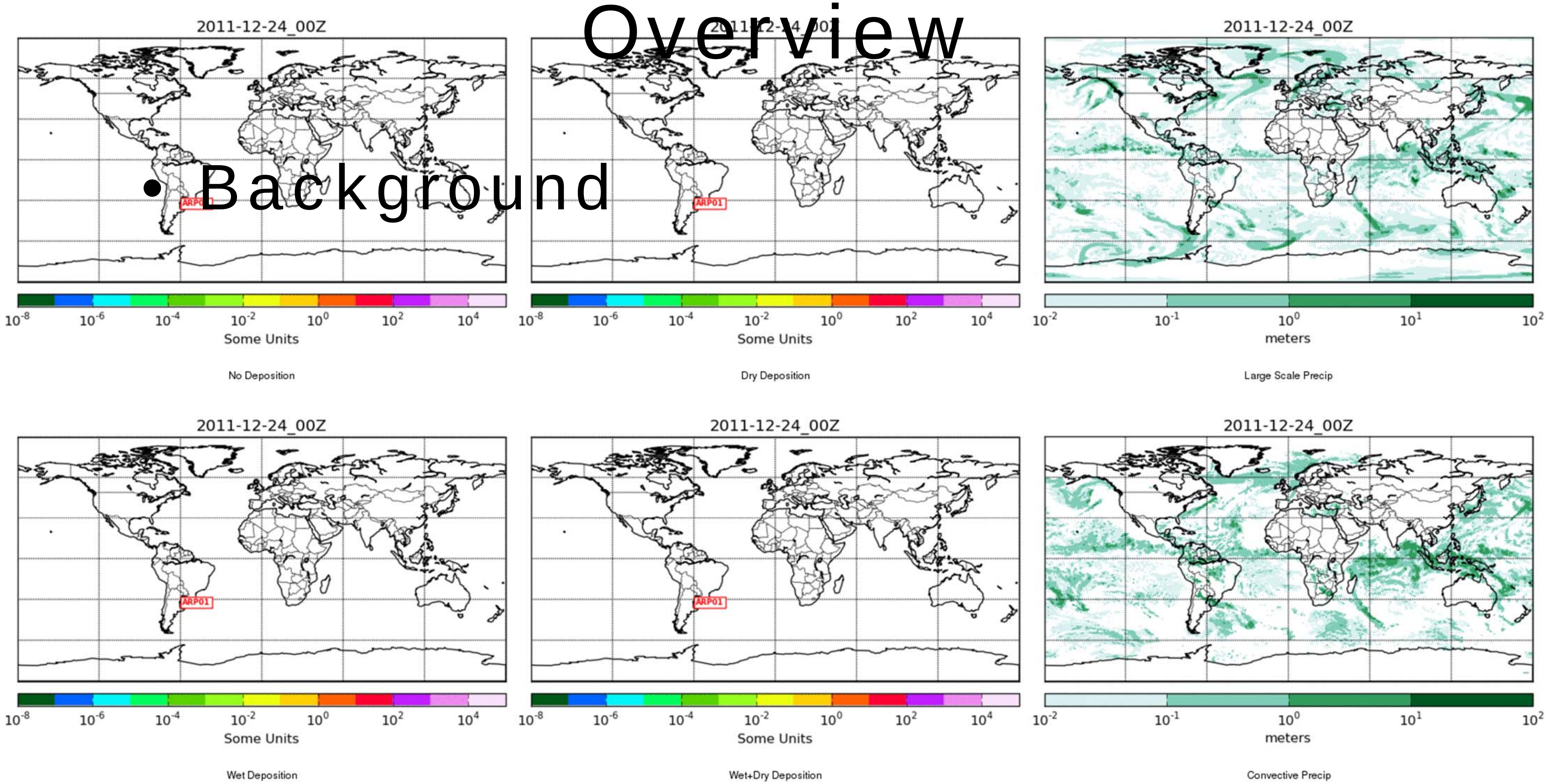

Wet+Dry Deposition




Convective Precip

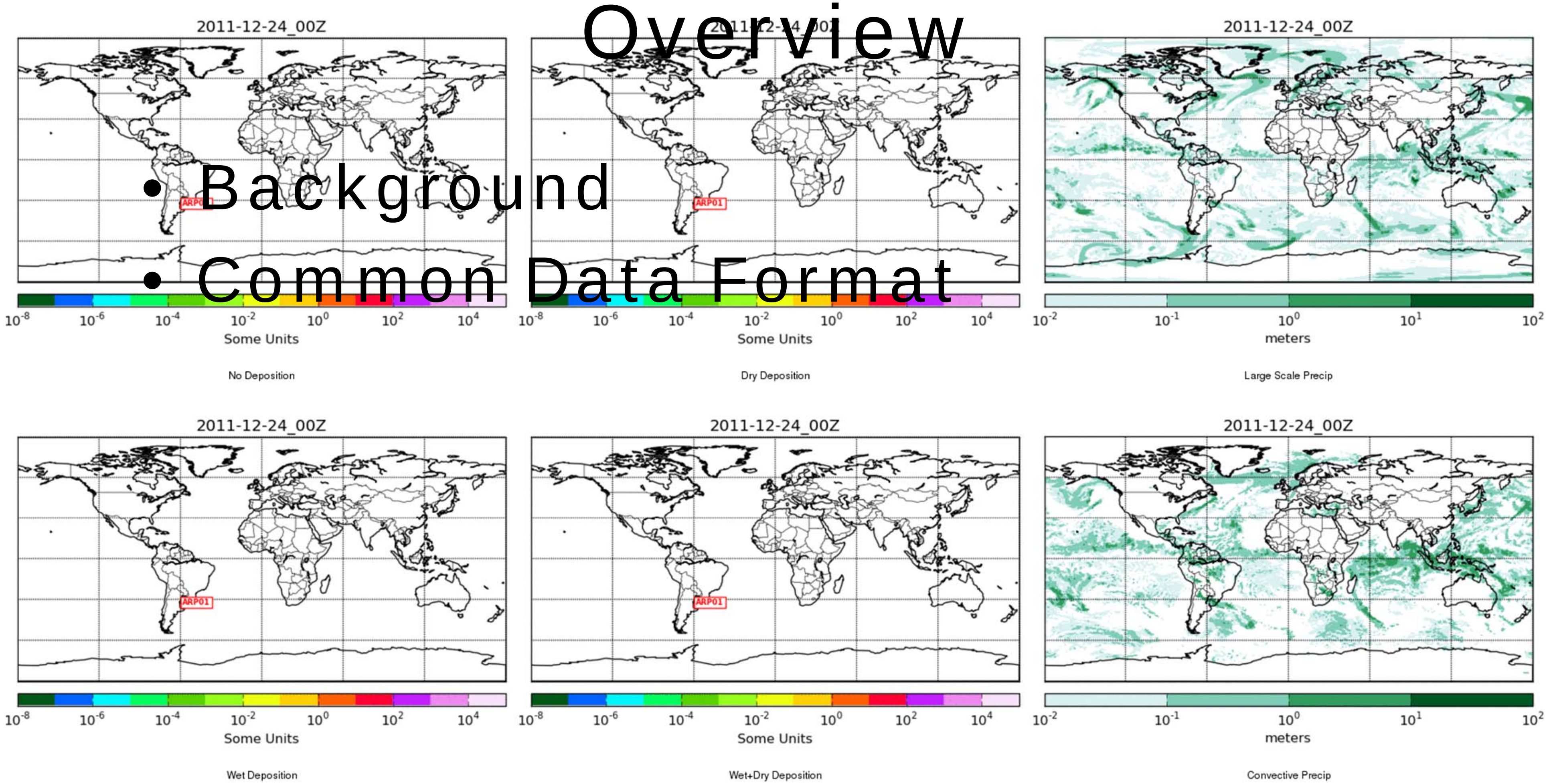
# Overview

- Background



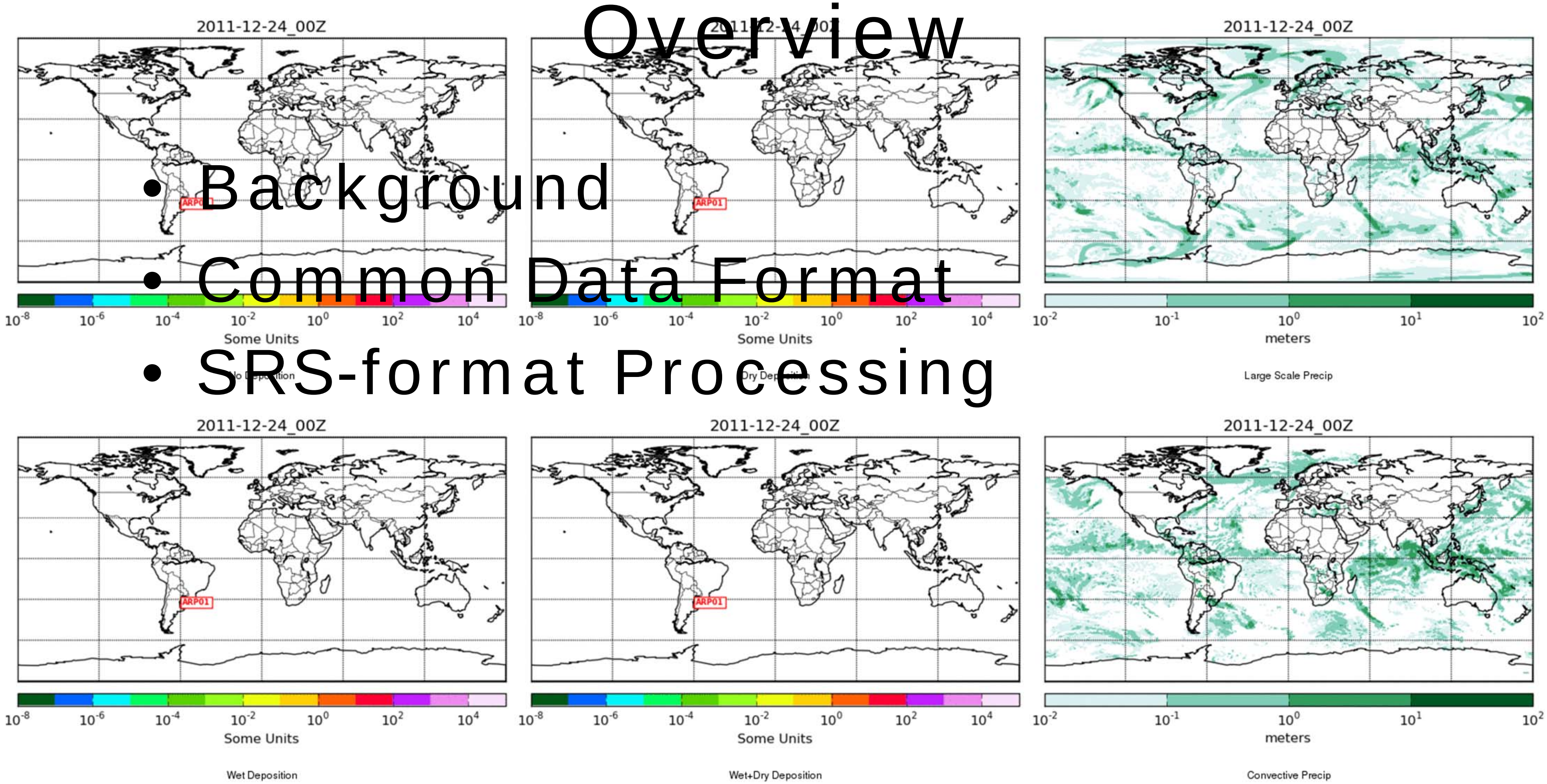
# Overview

- Background
- Common Data Format



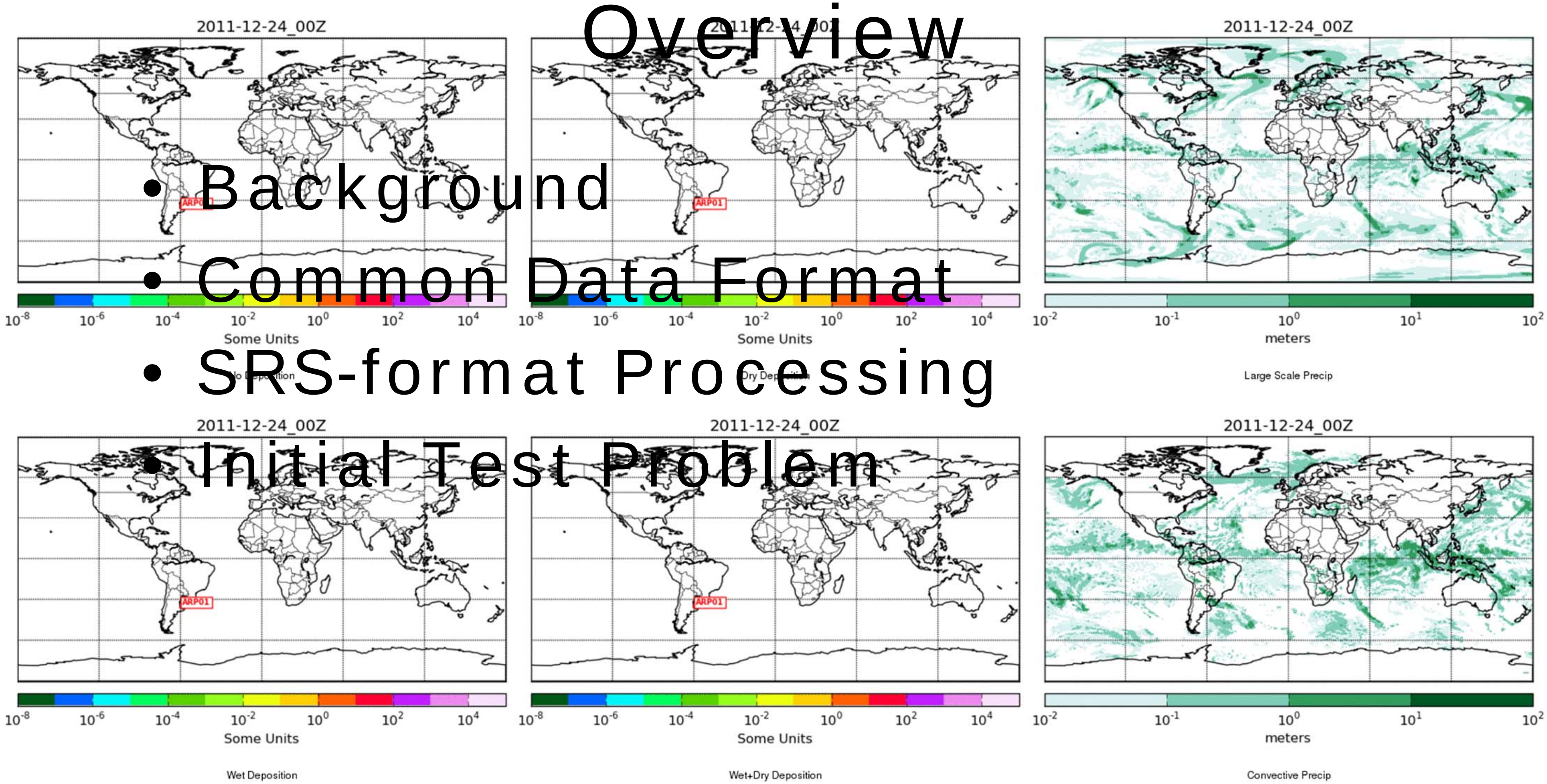
# Overview

- Background
- Common Data Format
- SRS-format Processing



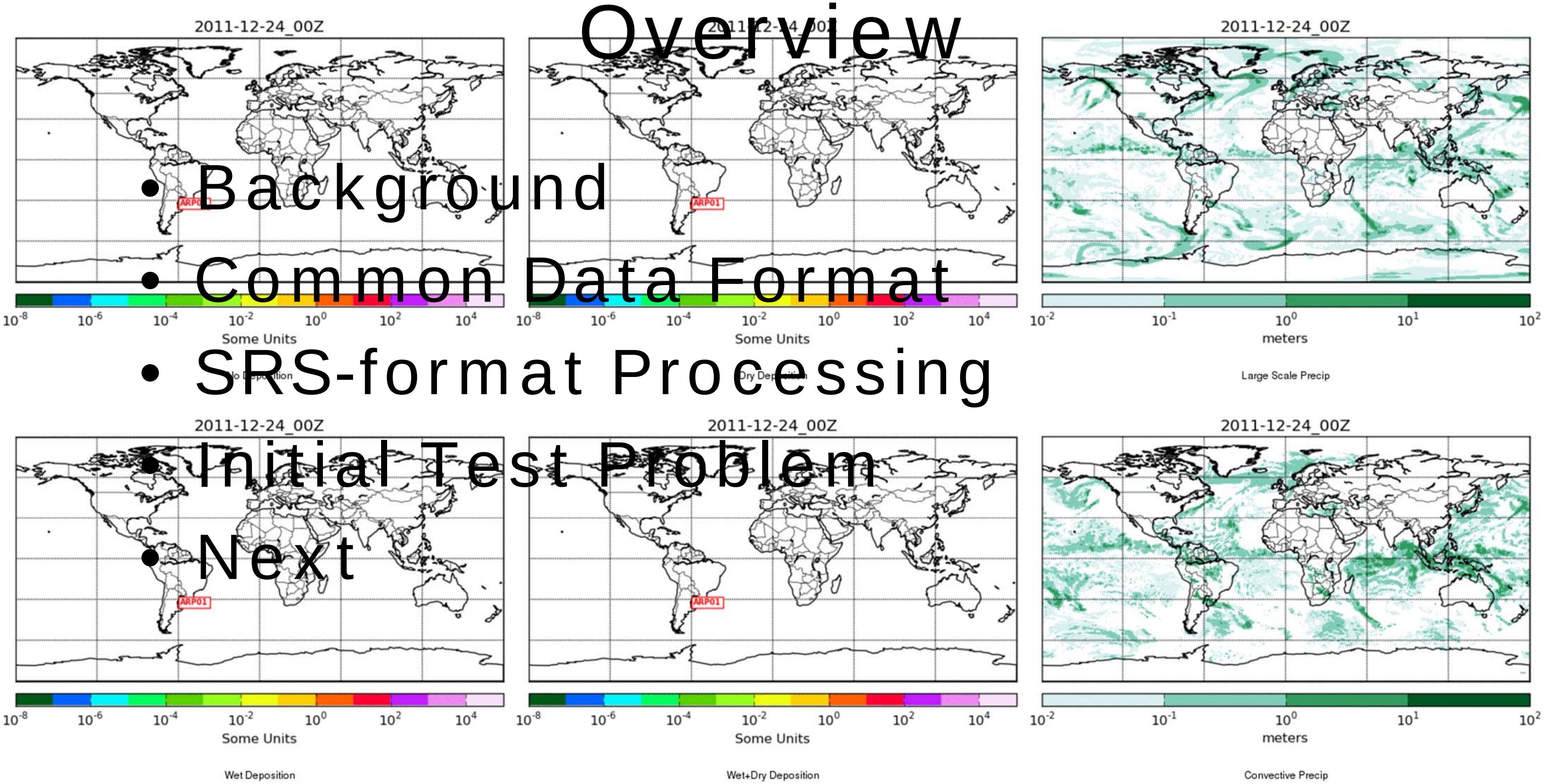
# Overview

- Background
- Common Data Format
- SRS-format Processing
- Initial Test Problem



# 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
- Jerome Brioude, NOAA ESRL Chemical Sciences Division
- Monika Krysta, Comprehensive Test Ban Treaty Organisation (CTBTO)
- Ramona Stefanescu, Mechanical and Aerospace Engineering Department, SUNY Buffalo
- Others

# Hekla 2000 Benchmark Document

UNIVERSITÉ DE GENÈVE FACULTÉ DES SCIENCES

IAVCEI

**Ash Dispersal Forecast and Civil Aviation Workshop**

*Geneva, Switzerland, 18-20 October 2010*

**Hekla 2000 Benchmark Document**

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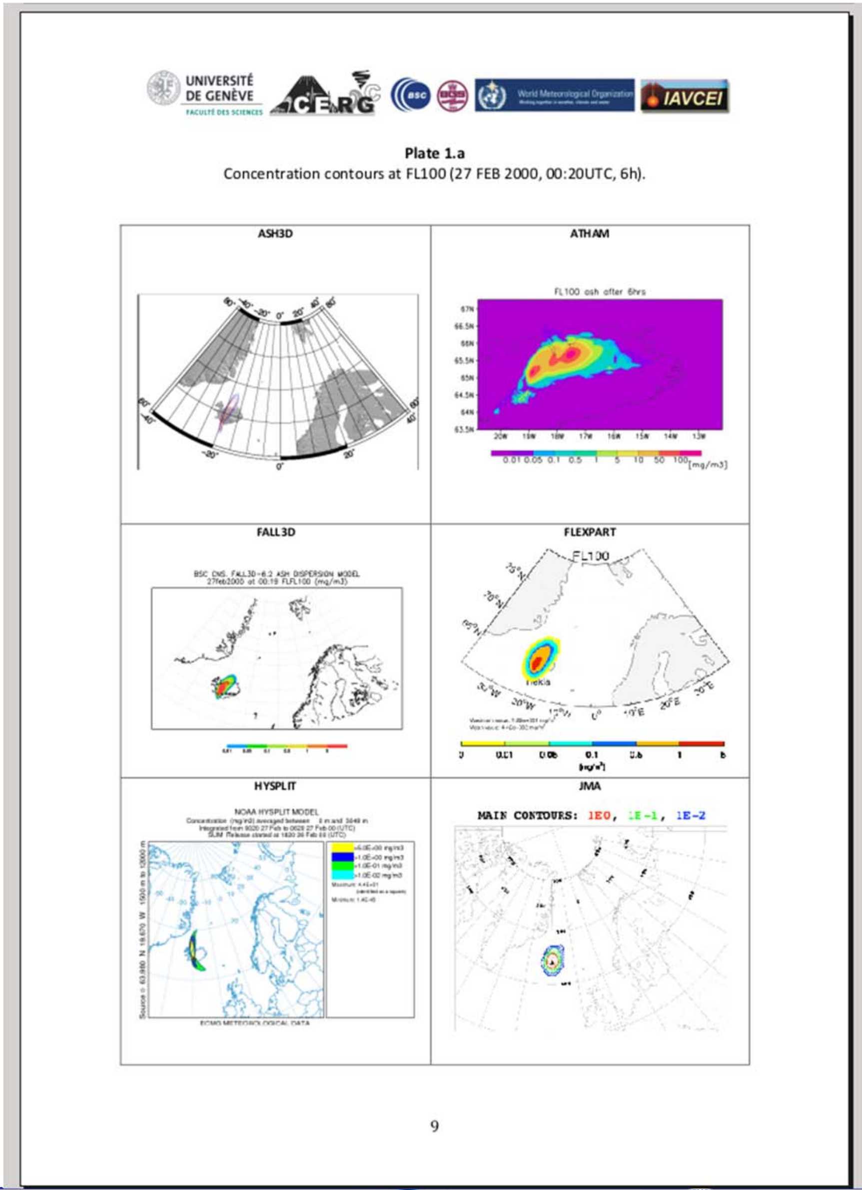
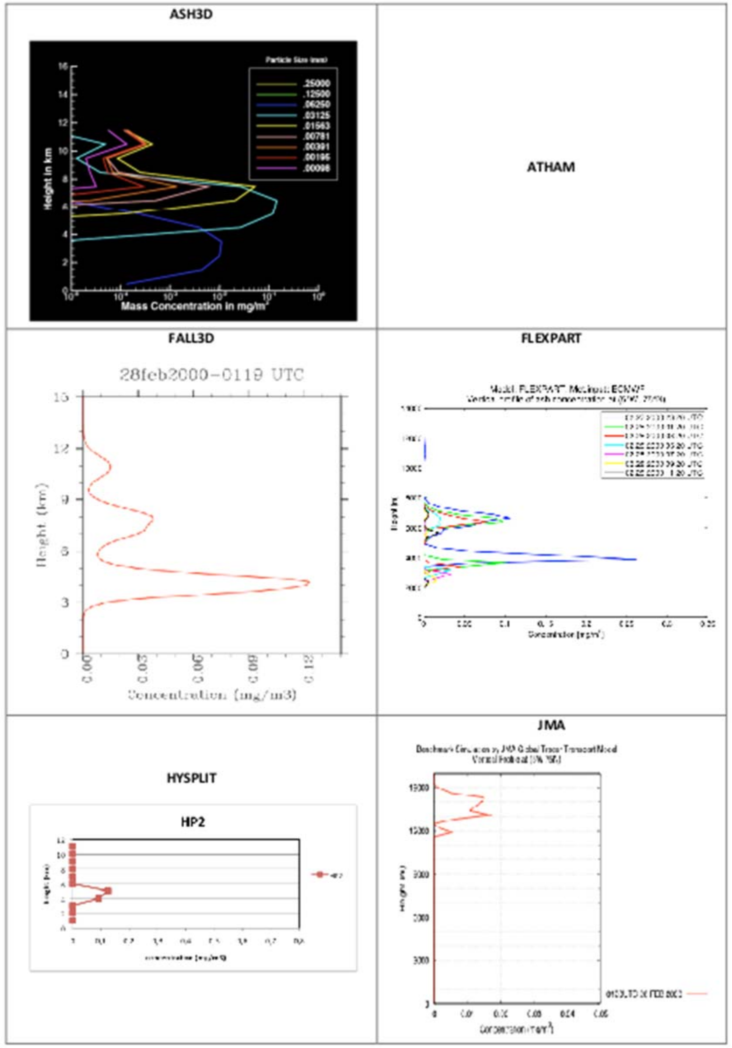
# Concentration Comparisons



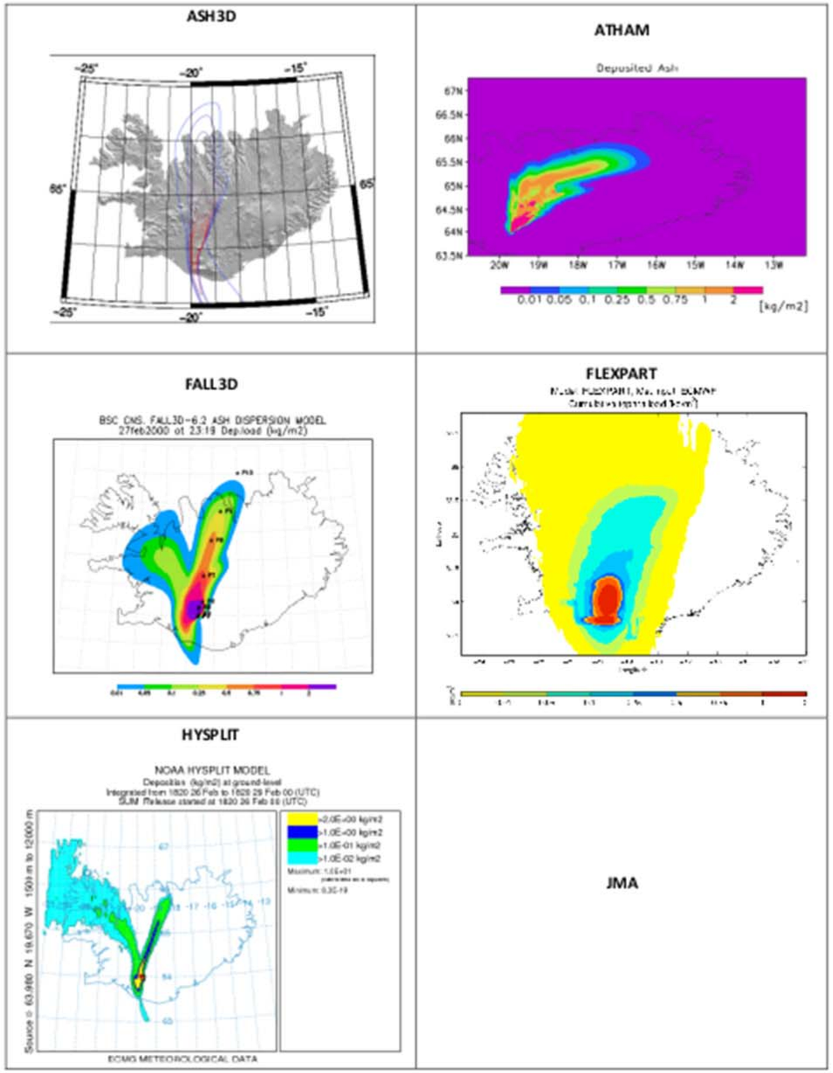
# Vertical profile comparisons

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



# Ground deposit load

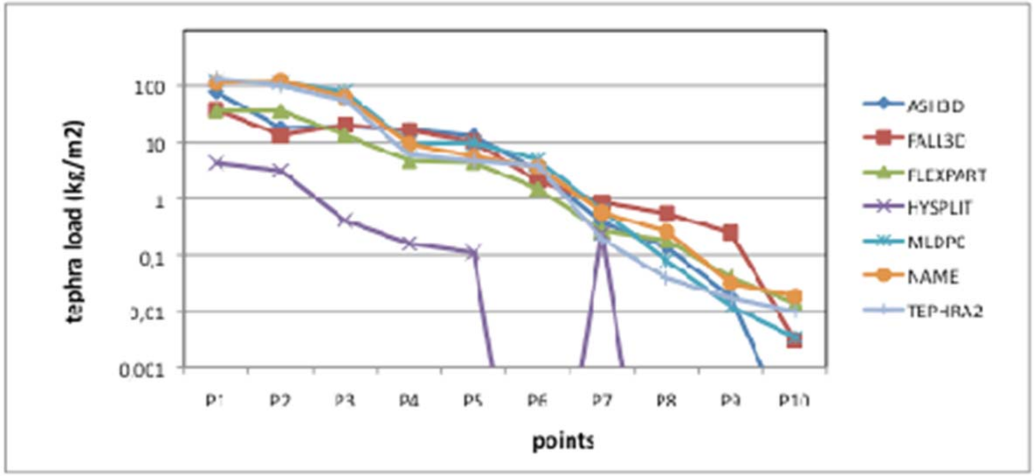
**Plate 8.**
Ground deposit load.



# Ground deposit load

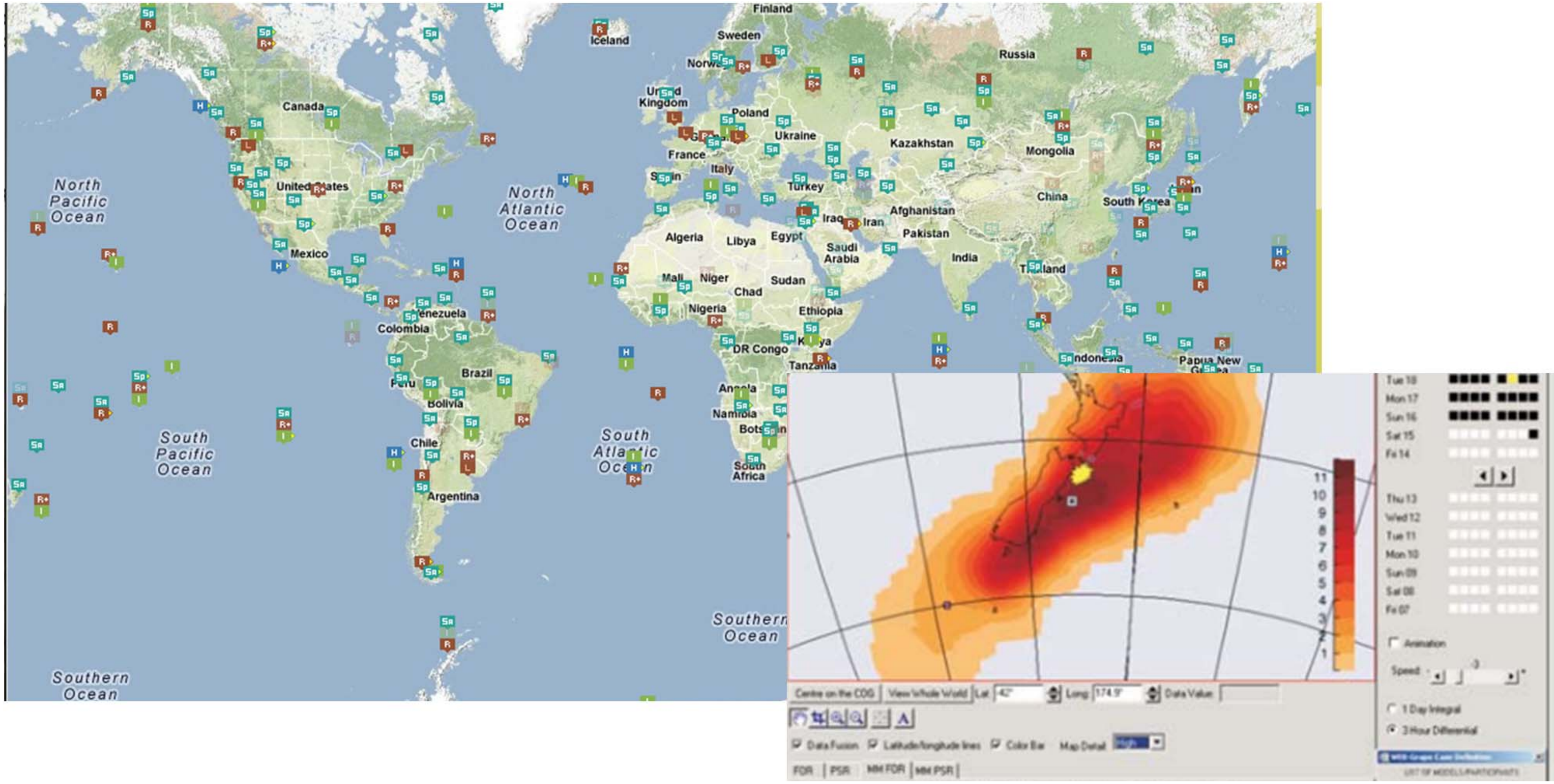
**Plate 9.**

Ground deposit load at different distances from the vent.

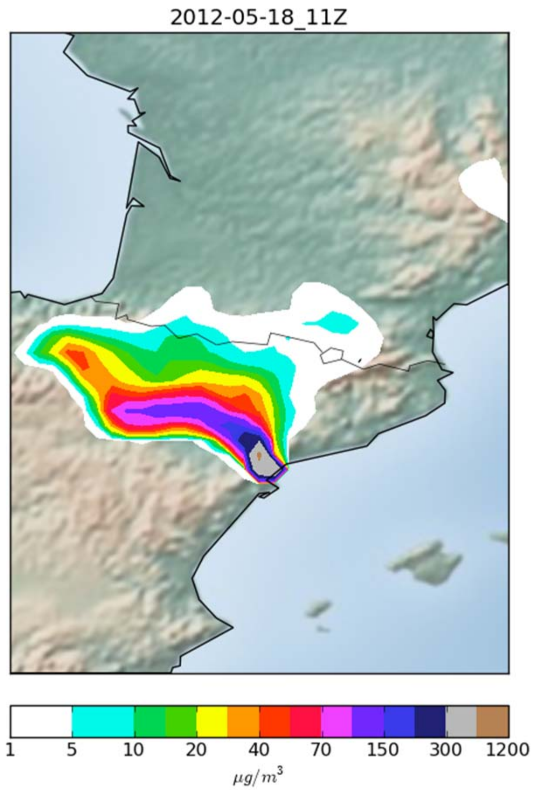



| UTM | | | |
|---|---|---|---|
| X ($m$) | Y ($m$) | Z ($m$) | Distance from source ($km$) |
| 565532 | 7096993 | 1453 | 2.25 |
| 566435 | 7097879 | 1162 | 3.5 |
| 567915 | 7102424 | 485 | 7.84 |
| 566851 | 7112630 | 257 | 17.08 |
| 567586 | 7115674 | 258 | 20.19 |
| 574124 | 7126200 | 516 | 30.07 |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

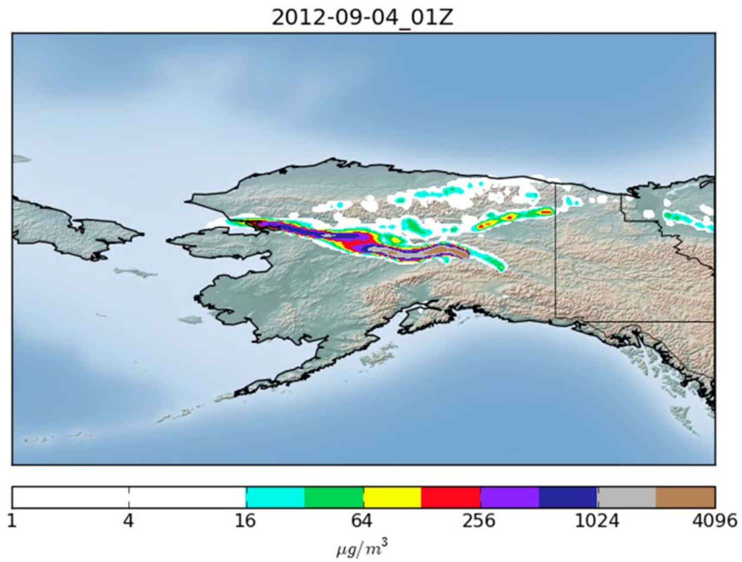
# Origins of this work - Comprehensive Test Ban Treaty Organisation (CTBTO)



# Origins of this work - Prototype Operational Wildfire Smoke Modeling




Catalonia

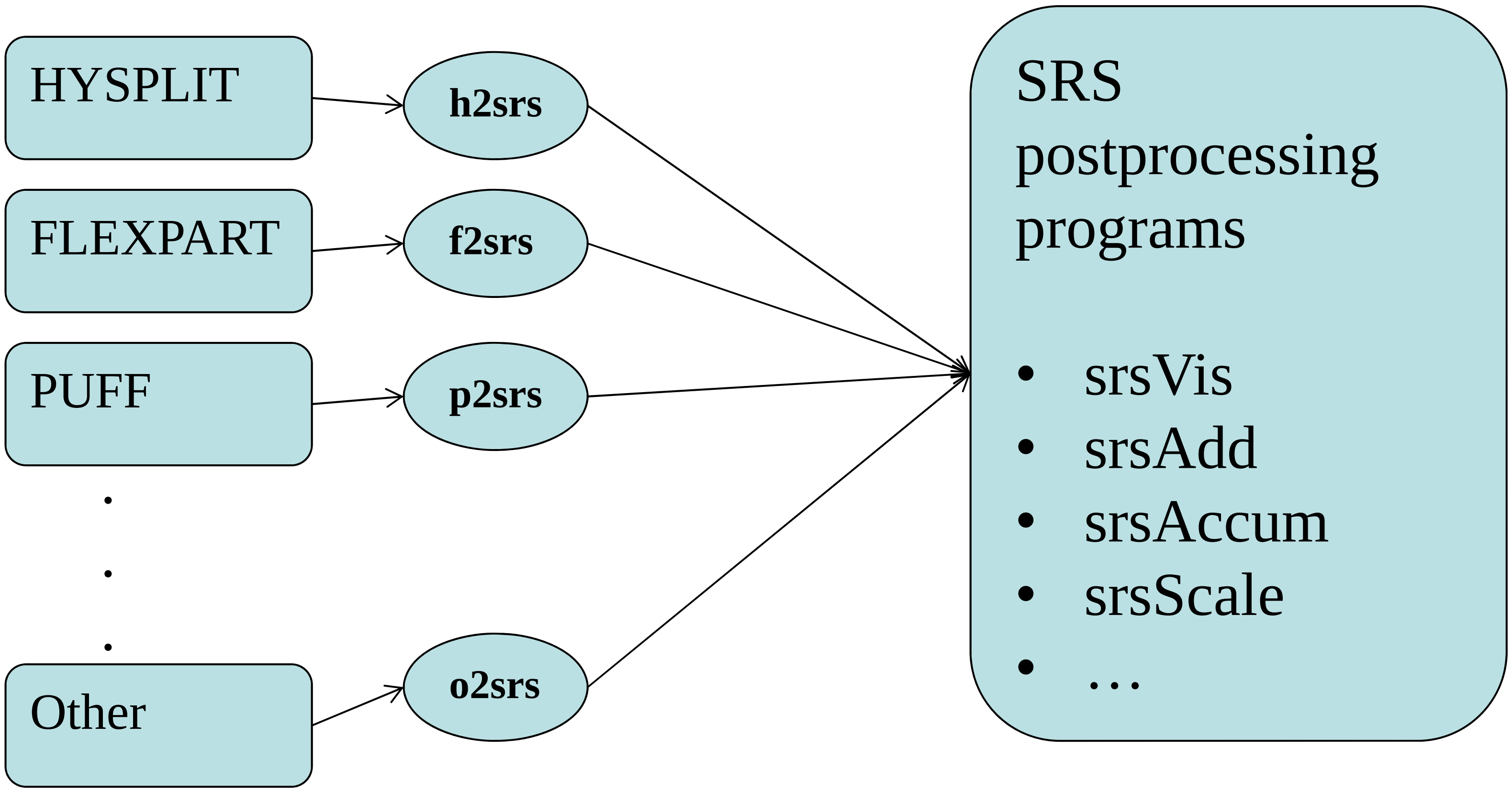



Alaska

# 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
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
```

# 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

# SRS Files

```
-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
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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
```
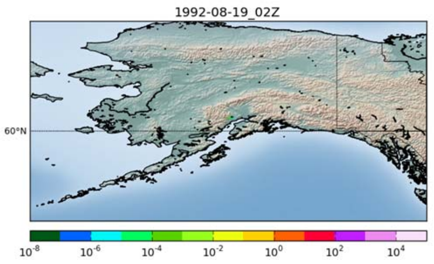

- Each file is a timeseries of a 2D horizontal lat/lon slice

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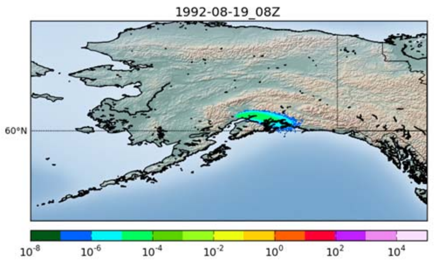


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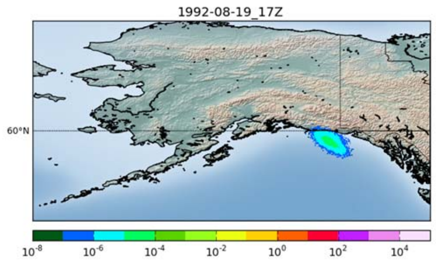
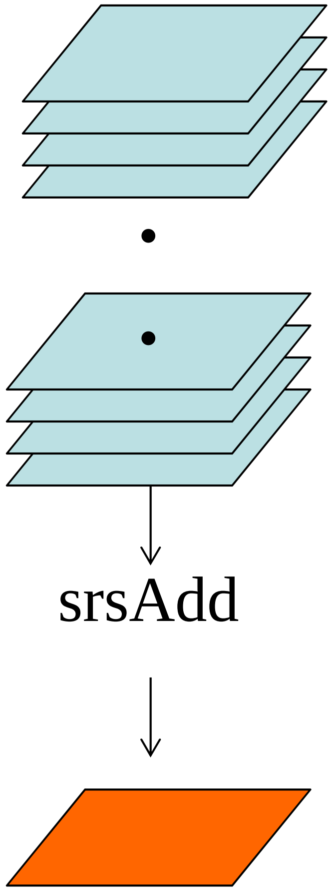


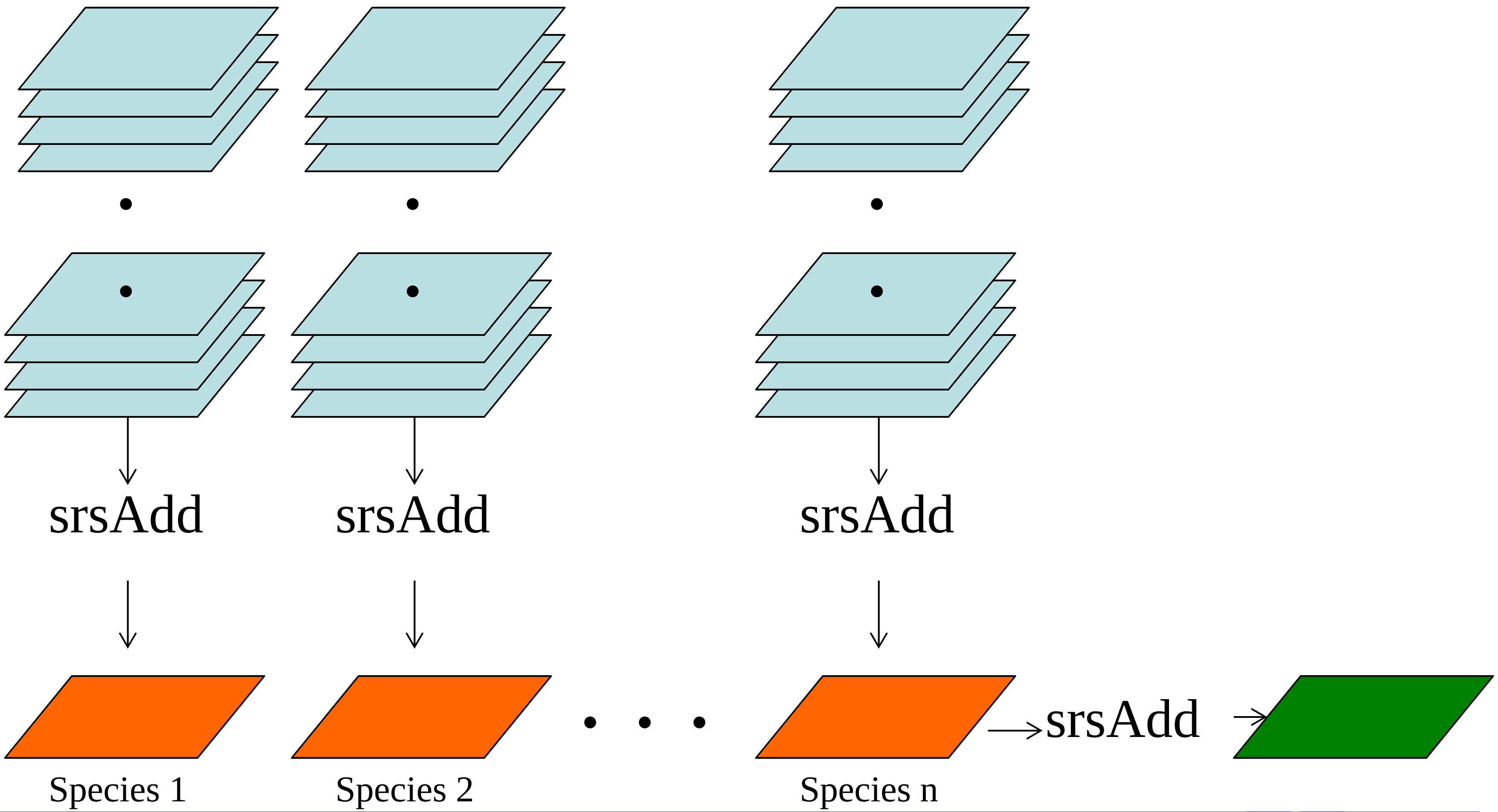

. . .

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

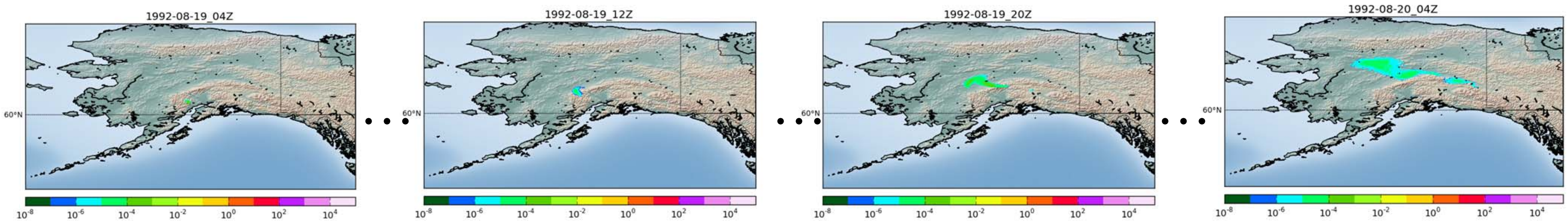
# Adding vertical levels for integrated column values



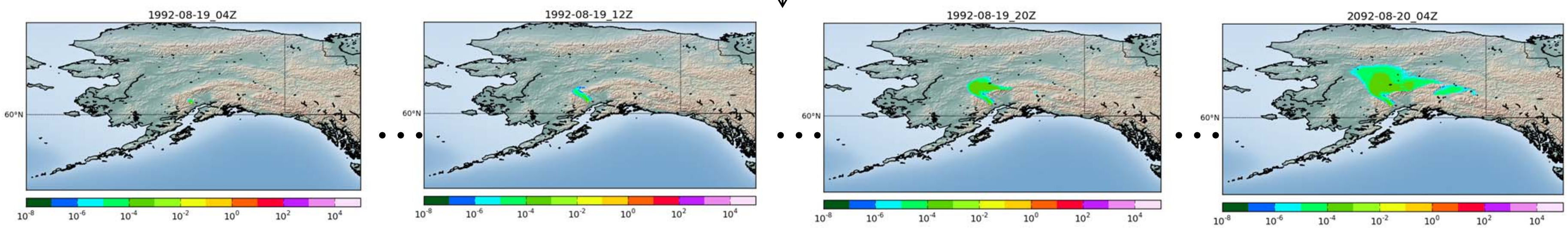
# Adding multiple species in vertical levels for total integrated mass values



# HYSPLIT writes time-averaged deposition ouput:

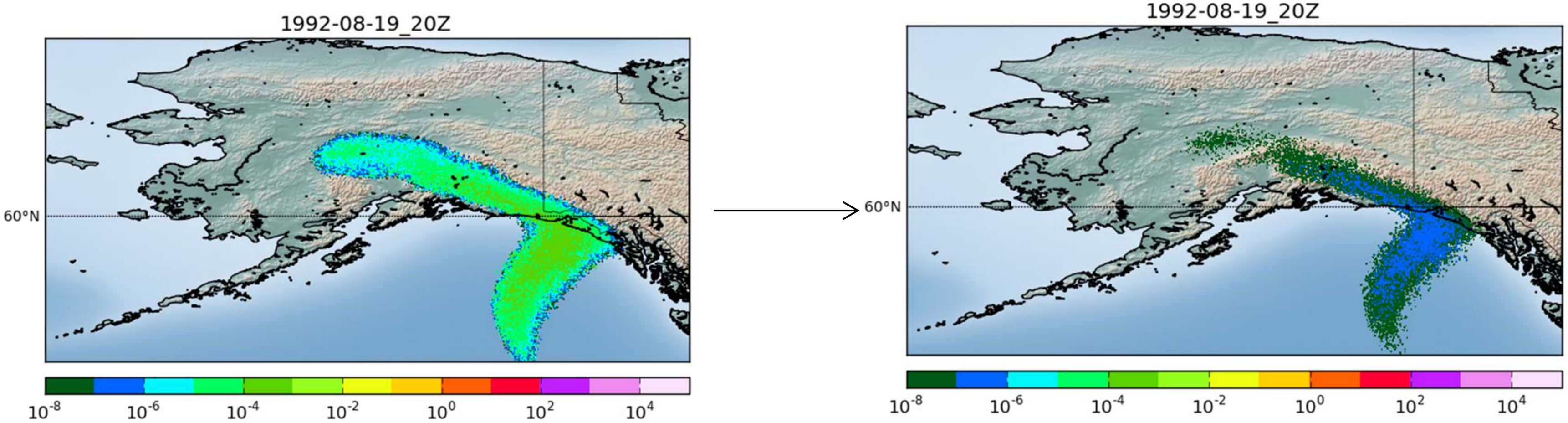



# *srsAccum* re-arranges the SRS time series to accumulated ouput:



# srsScale

- Useful for unit changes, global adjustments, etc.




*srsScale 1.0E-3*

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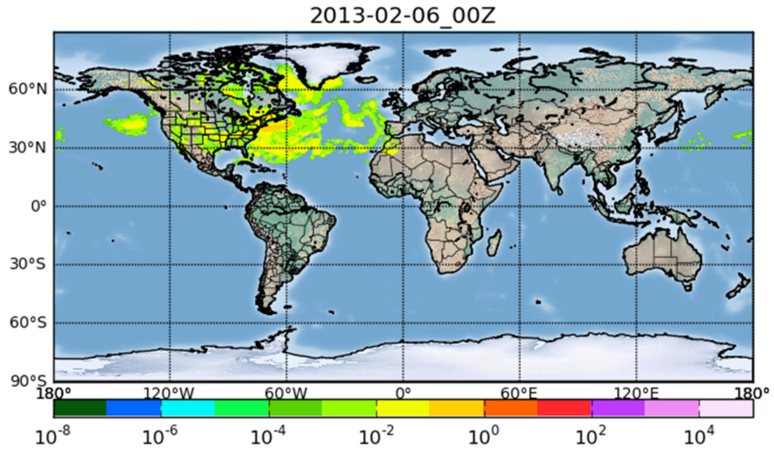
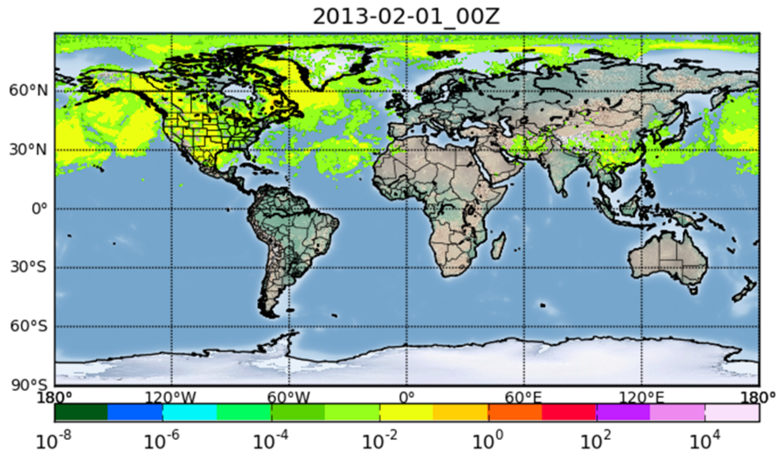
# Storage of SRS Files

- 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

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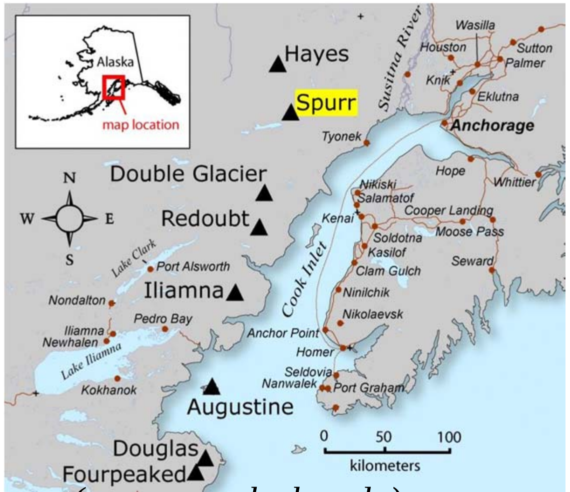
# Mt Spurr, August 1992

- 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/m$^3$
  - 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



(www.avo.alaska.edu)

| Size (um) | Percent | Mass (kg) | Emission rate (kg/h) |
|---|---|---|---|
| 3 | 4.5 | 1.51E+09 | 4.31E+0 |
| 6 | 5.3 | 1.78E+09 | 5.07E+0 |
| 12 | 8.1 | 2.71E+09 | 7.75E+0 |
| 24 | 10.9 | 3.65E+09 | 1.04E+0 |
| 48 | 11.7 | 3.92E+09 | 1.12E+0 |
| 96 | 23.2 | 7.77E+09 | 2.22E+0 |
| 192 | 5.9 | 1.98E+09 | 5.65E+0 |
| 384 | 4.2 | 1.41E+09 | 4.02E+0 |
| 768 | 5.5 | 1.84E+09 | 5.26E+0 |

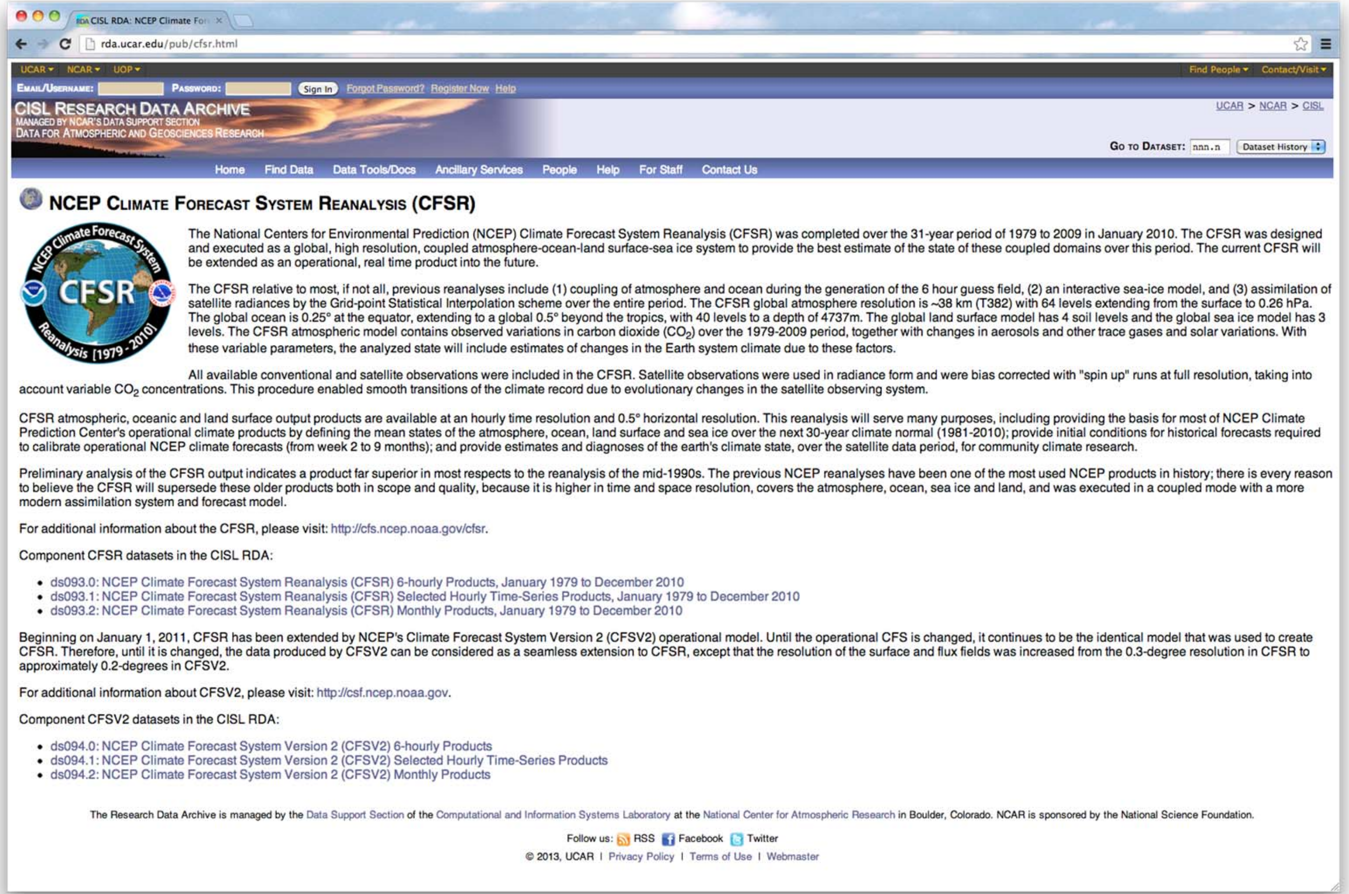
ZAMG Zentralanstalt für Meteorologie und Geodynamik
UNIVERSITY OF ALASKA FAIRBANKS
NOAA

# 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

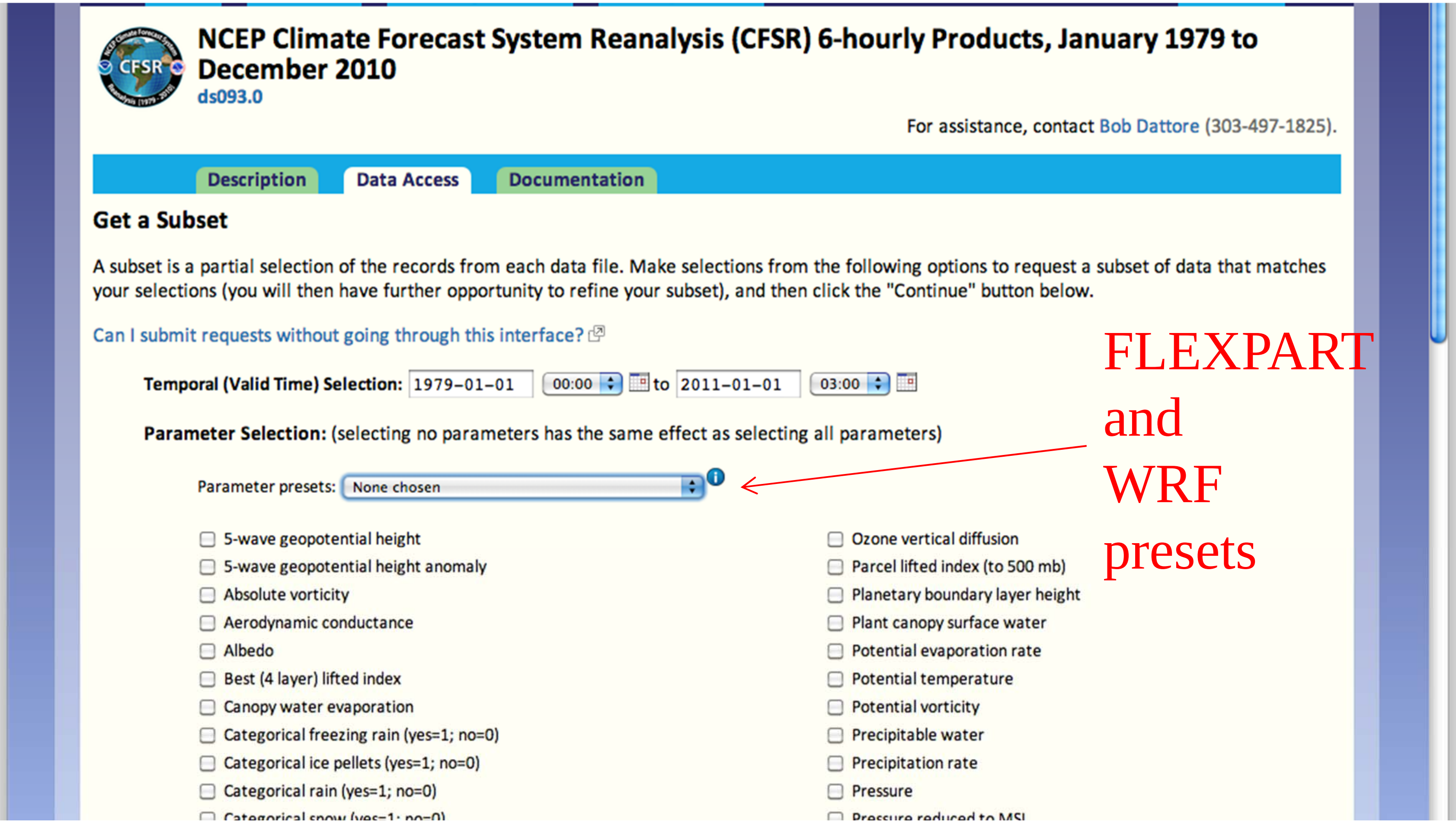
# Common Input Data

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




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: None chosen

- 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)

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# 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
```

ZAMG Zentralanstalt für Meteorologie und Geodynamik

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# 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

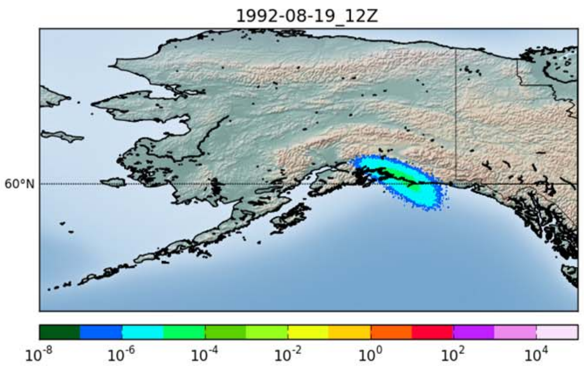
- HYSPLIT
  - Header and all timestep values in a single binary file.
  - Need to consider multiple species, levels, depositions, forwards, backwards, nested
  - Have modified HYSPLIT Fortran programs *conc2ctbt* and *conc2asc* to create a much more general and SRS-oriented *conc2srs* (should be part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

# Output to SRS format

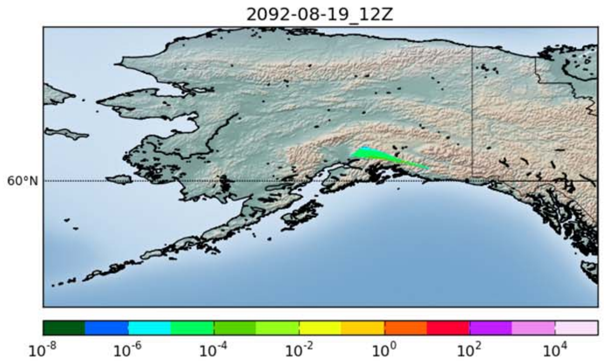
- PUFF
  - Header and all timestep values in a single netCDF file. When PUFF is run this format needs to be specified.
  - Need to consider multiple species, levels, fallout, etc.
  - Have created a crude *puff2srs.py* to generate the SRS file from netCDF output.

Arctic Region Supercomputing Center

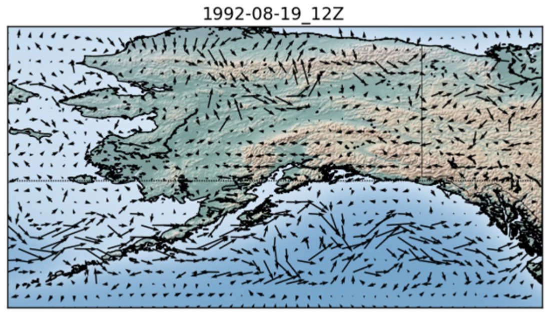
# Snapshot of Species 5 Concentration and Winds, 5000m MSL




FLEXPART

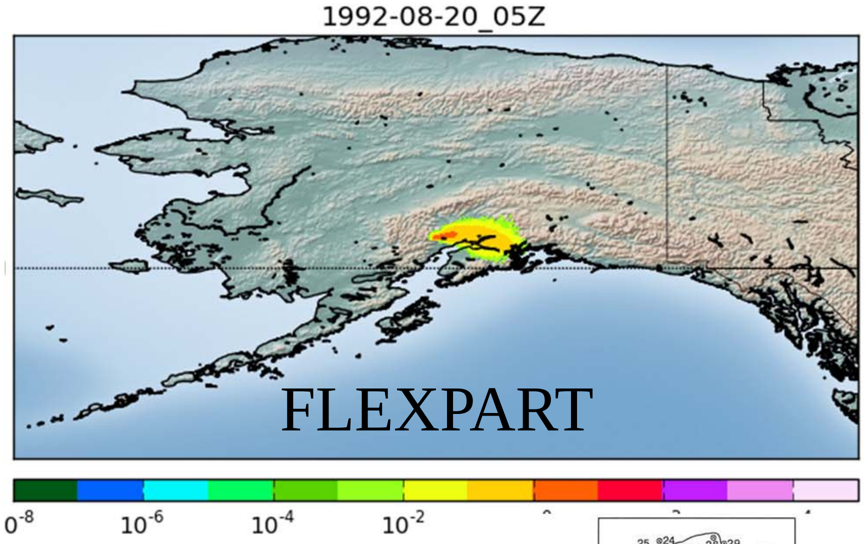


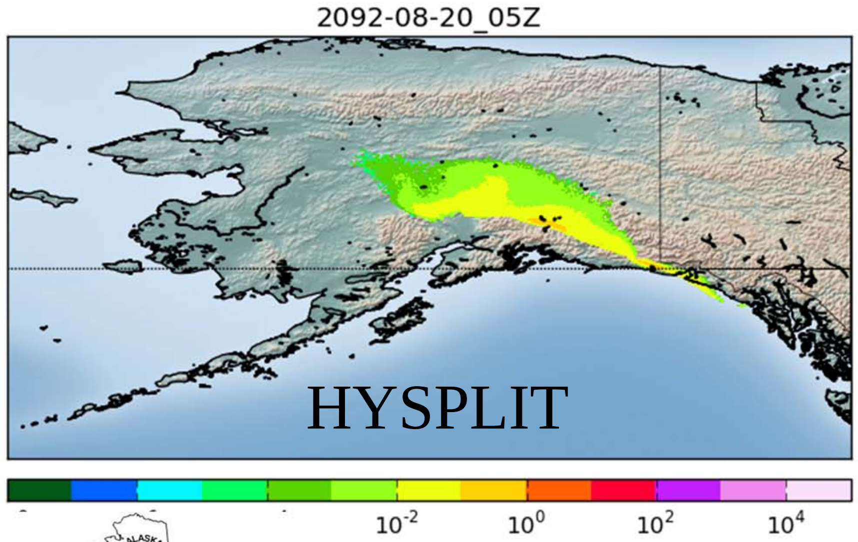

HYSPLIT

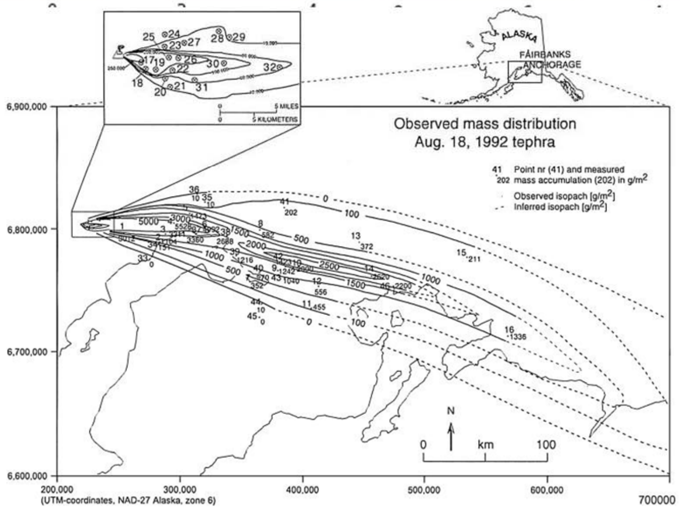



Meteorology

# Deposition (Fallout) of Species 5

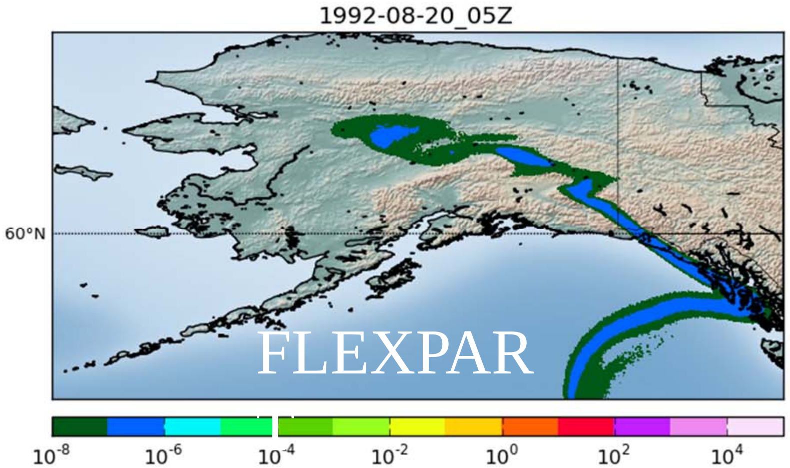


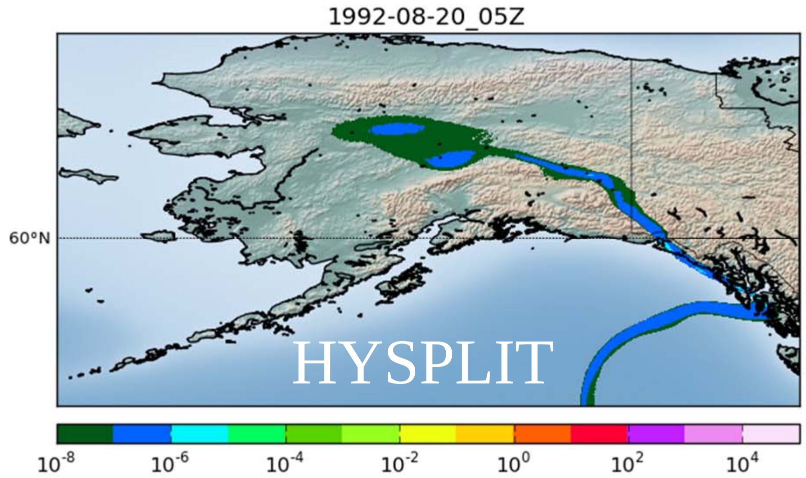



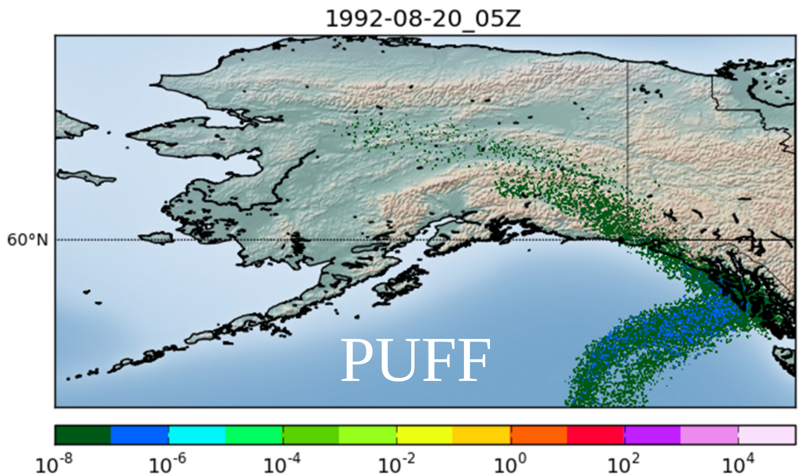




Todo: Convert observed fields to SRS format and incorporate in the system

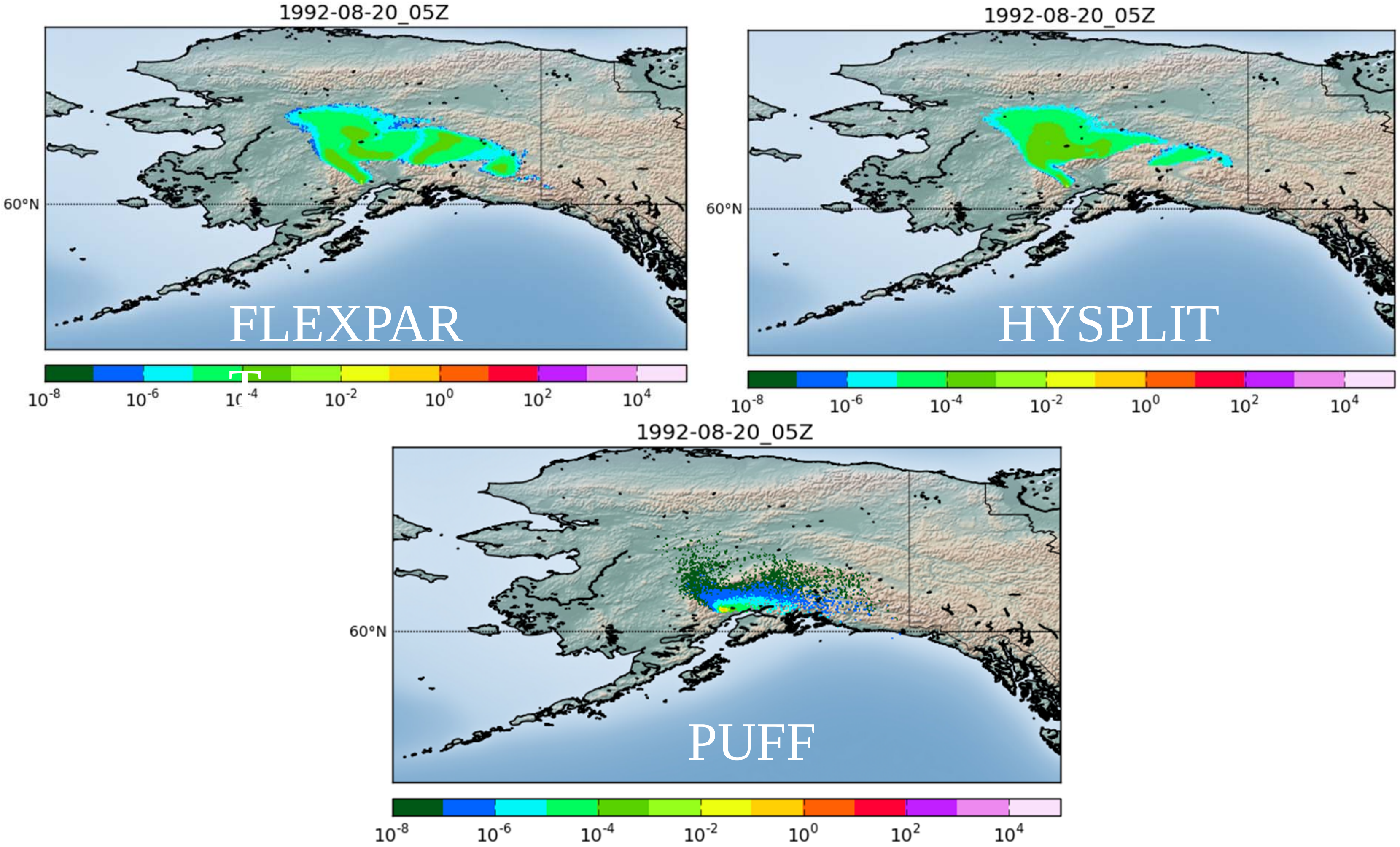
# Simple SO2 Case – total integrated column concentration



# Simple SO2 case – cumulative deposition



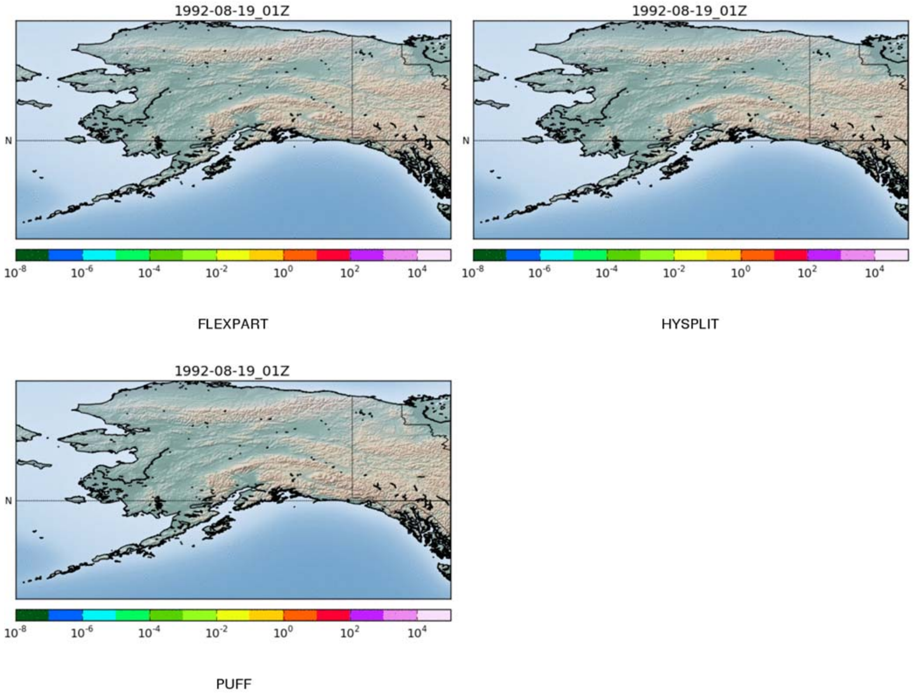
# Closing Thoughts

- 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

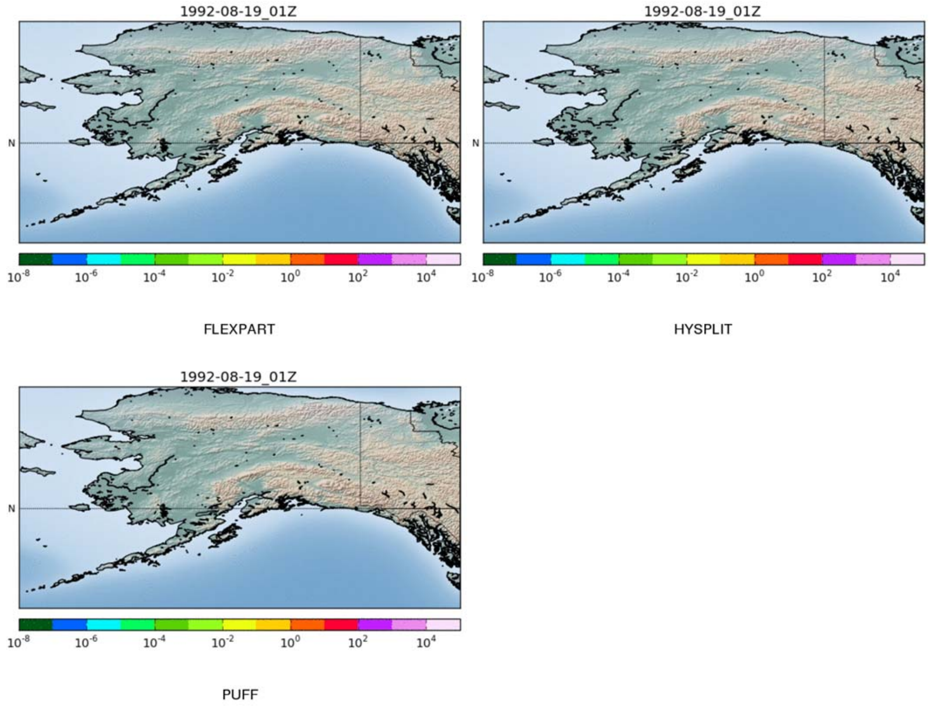
# Next

- 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