HYSPLIT volcanic ash dispersion modeling R&D, NOAA NWS NCEP operations, and transfer to operations

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NOAA = U.S National Oceanic and Atmospheric Administration
OAR = Office of Oceanic and Atmospheric Research
NESDIS = National Environmental Satellite, Data, and Information Service
NWS = National Weather Service
NCEP = National Centers for Environmental Prediction

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Outline

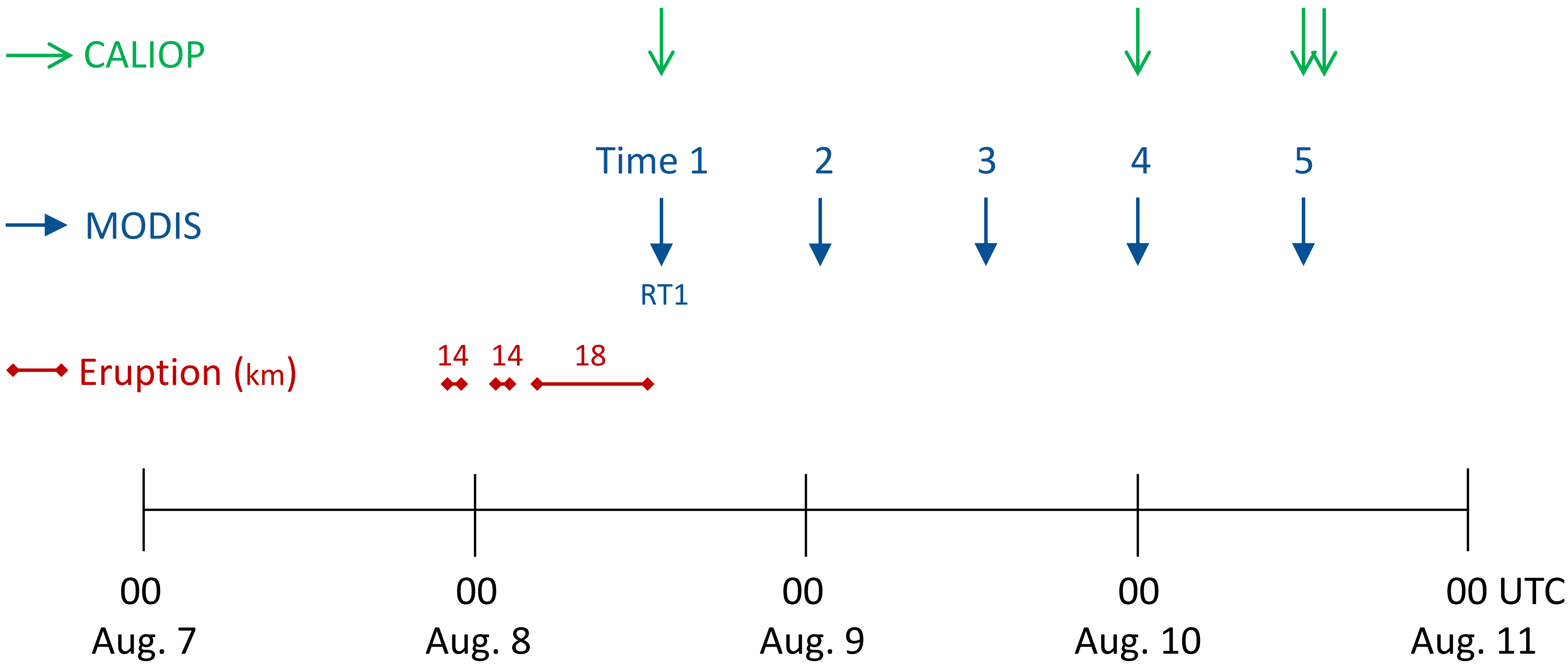
- Recent research**
  - Using satellite retrievals to improve forecasts and to guide model development
  - Inverse modeling

- What is NCEP* operations?
- Research to operations (R2O)

*The HYSPLIT transport and dispersion model is run by NCEP in support of the U.S. VAACs

**Some of this research was in response to requirements and funding by the Federal Aviation Administration (FAA). The views expressed are those of the authors and do not necessarily represent the official policy or position of the FAA.

Case study: Kasatochi, Alaska, August, 2008



HYSPLIT model configuration

- NOAA NCEP Global Data Assimilation System (GDAS) meteorology - 1 degree latitude-longitude, 3-hourly
- Source terms

  (1) Initialize at vent, linear and cylindrical source
    - 4 particle size bins
    - Unit source

  (2) Initialize model with Time 1 satellite retrieval
    - Mass loading
    - Effective radius
    - Retrieved top height, 2.5 km layer depth

Compare model results of different source terms against retrievals at later times

GDAS = Global Data Assimilation System

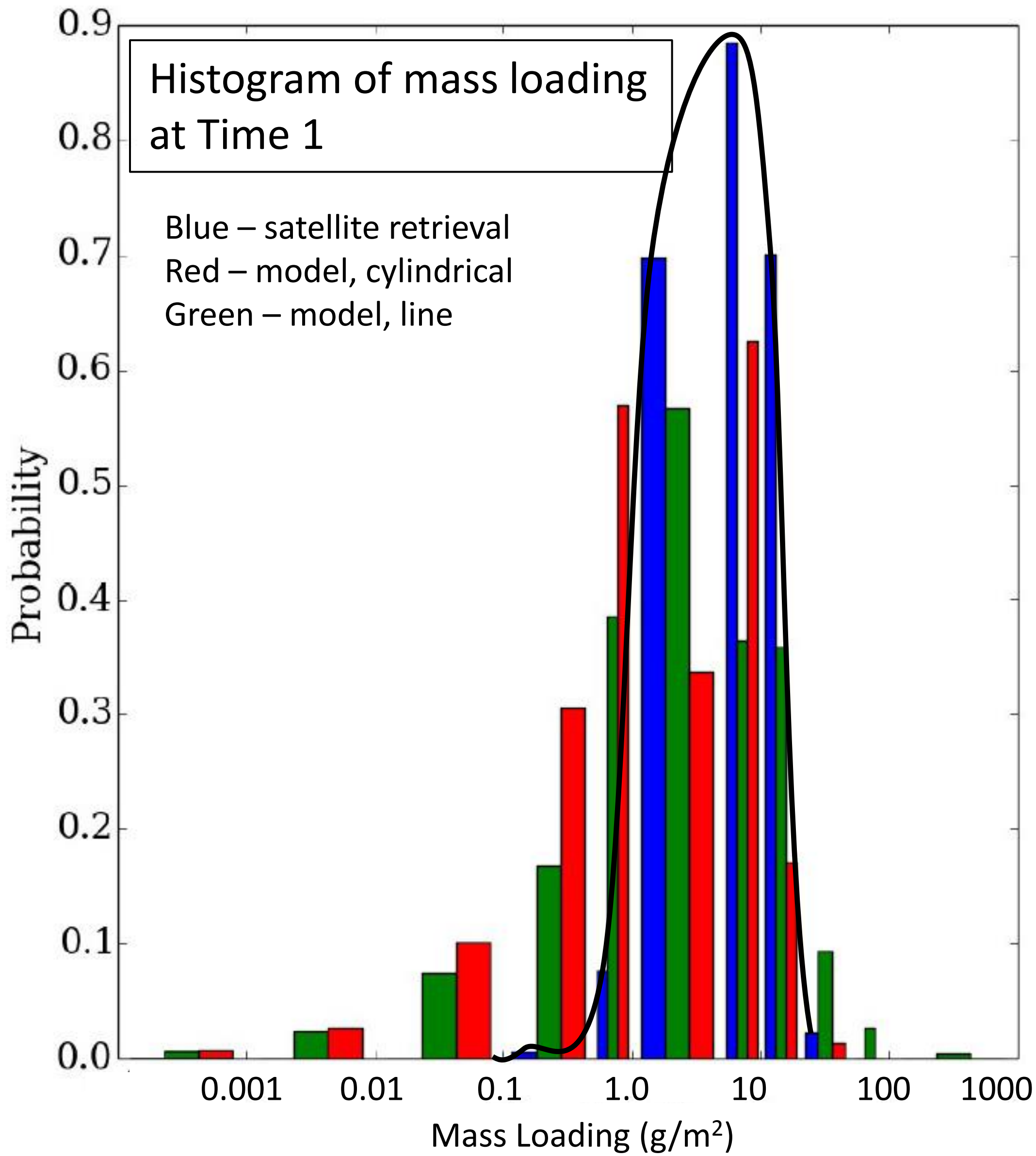
How to account for our use of a unit source?

Need to have an estimate of the mass eruption rate (MER)

With MER=1.0x10^{11} g/hour, its distribution (red, green) generally matches the satellite retrievals*

This MER is about 2 orders of magnitude less than the emipirical algorithm (Mastin et al, 2009)

*Satellite retrievals do not detect very small mass loadings.

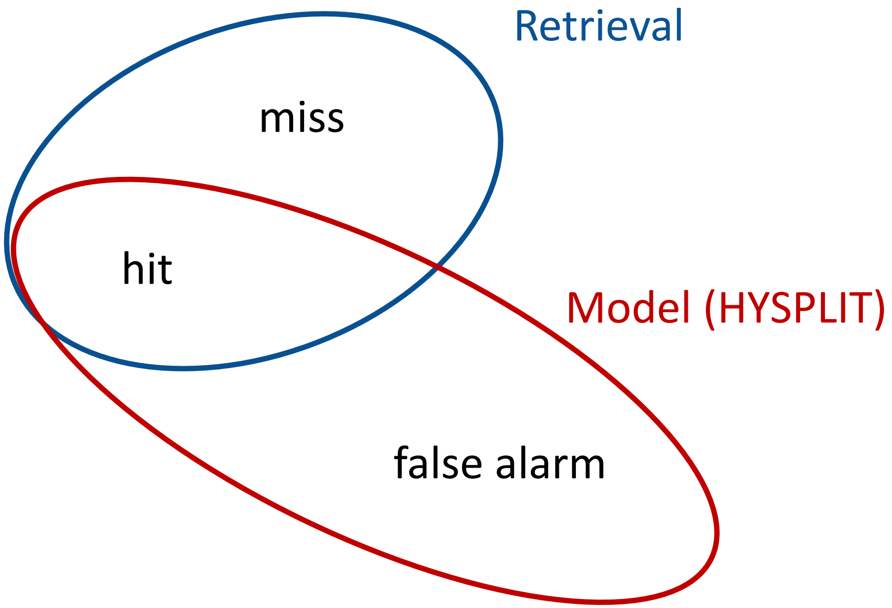


Verification statistics

Retrieval = hit + miss
Model = hit + false alarm
Overlap = hit
Total = hit + miss + false alarm

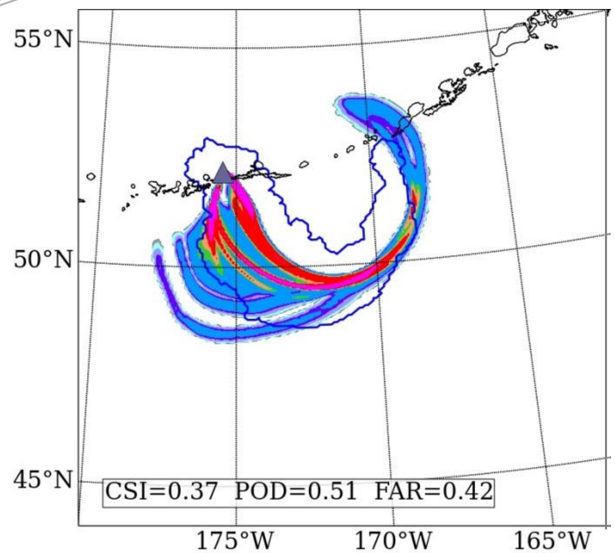
CSI = overlap / total 0.0 to 1.0
POD = overlap / retrieval 0.0 to 1.0
FAR = false alarm / model 0.0 to 1.0

Threshold = 0.1 g/m^2
but otherwise statistics are binary (yes/no)
and independent of mass loading value.



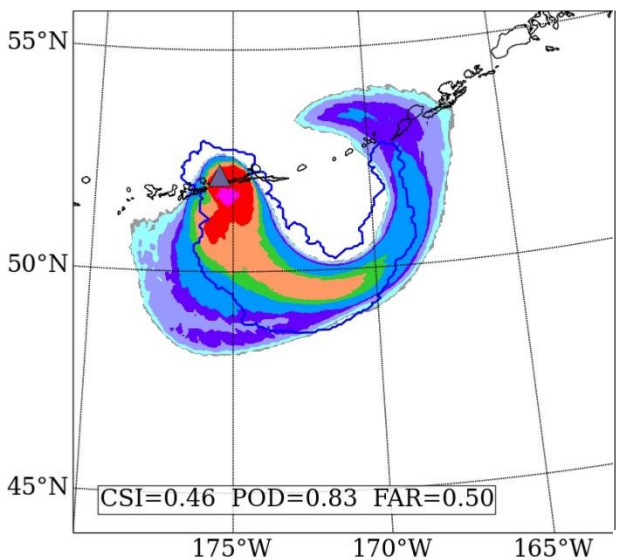
CSI = Critical success index
POD = Probability of detection
FAR = False alarm ratio

Mass loading (g/m²) valid at Time 1

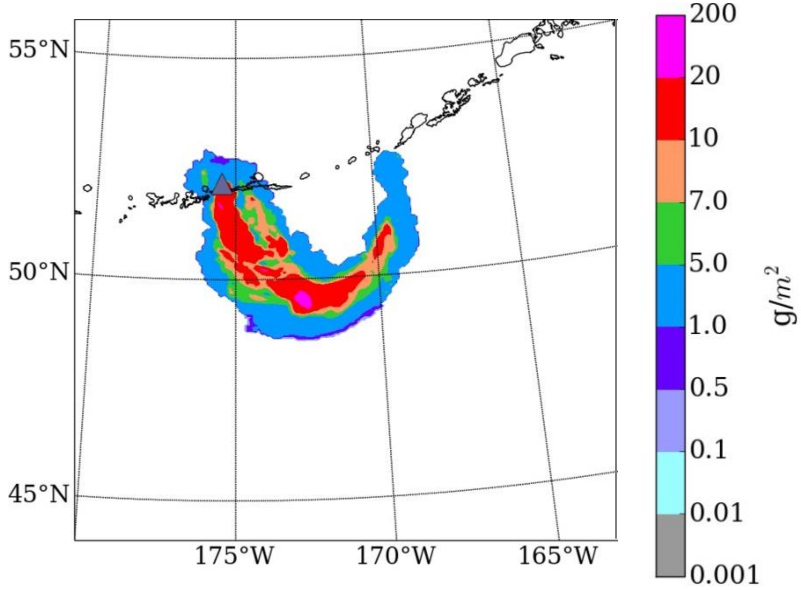


Line source initialized at vent.

Cylindrical source initialized at vent.

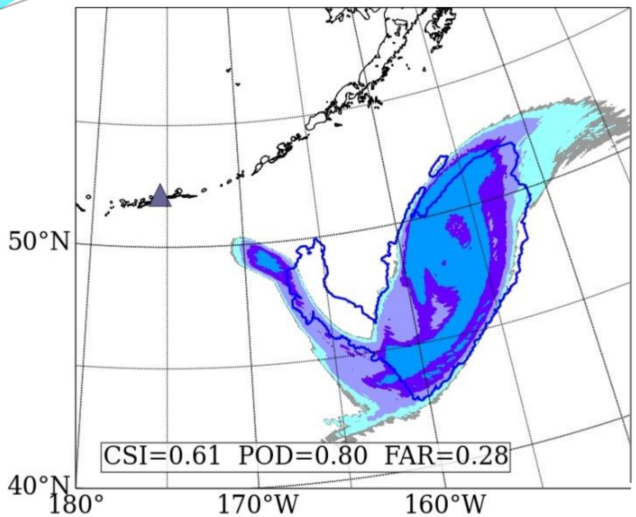


Satellite retrieval



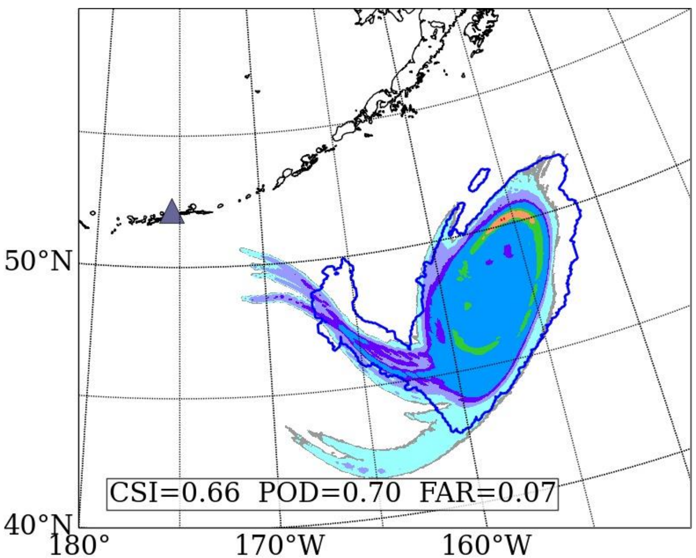
Color bar applies to all.
Solid line is retrieval footprint (plots on left).

Mass loading (g/m^2) valid at Time 4

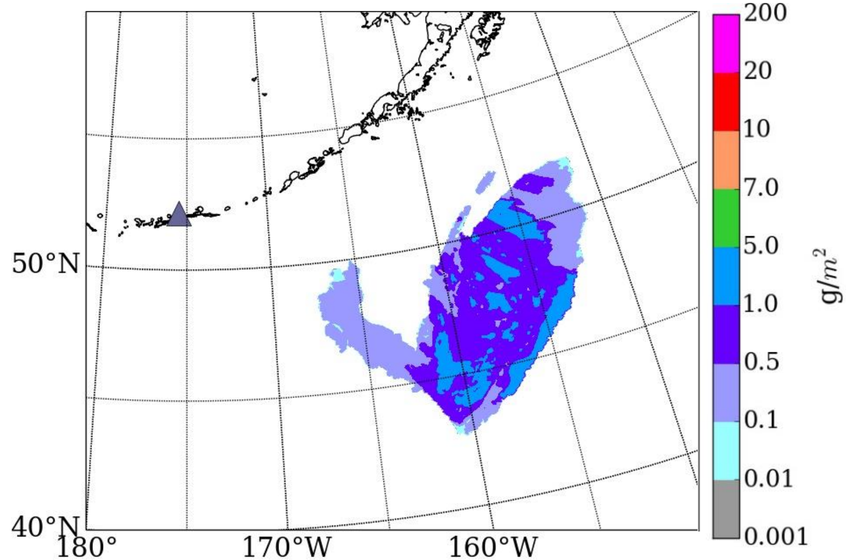


Cylindrical source initialized at vent.

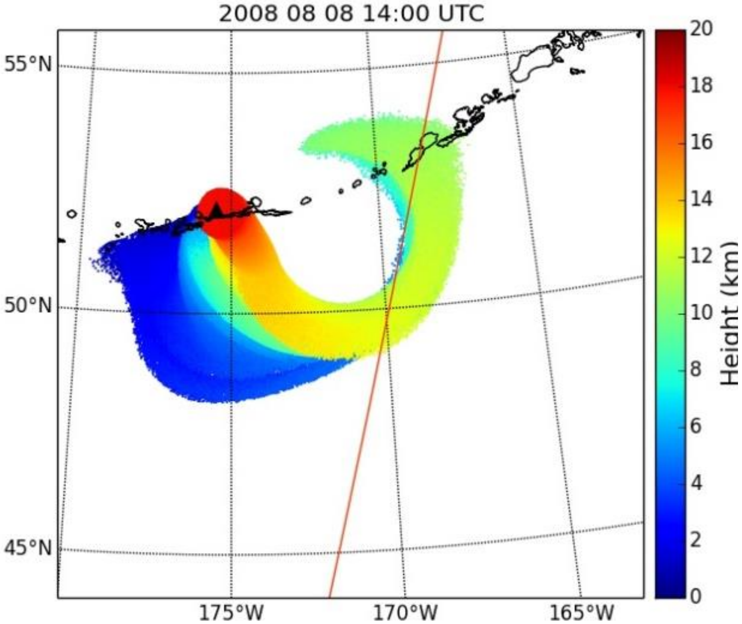
Initialized from satellite retrieval at Time 1.

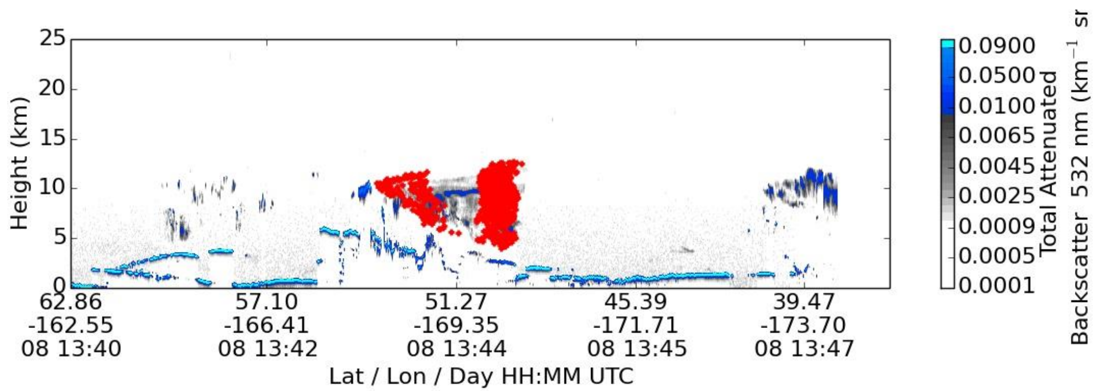


Satellite retrieval



Height of ash at Time 1





Cylindrical initialization, model particle positions color-coded by height.

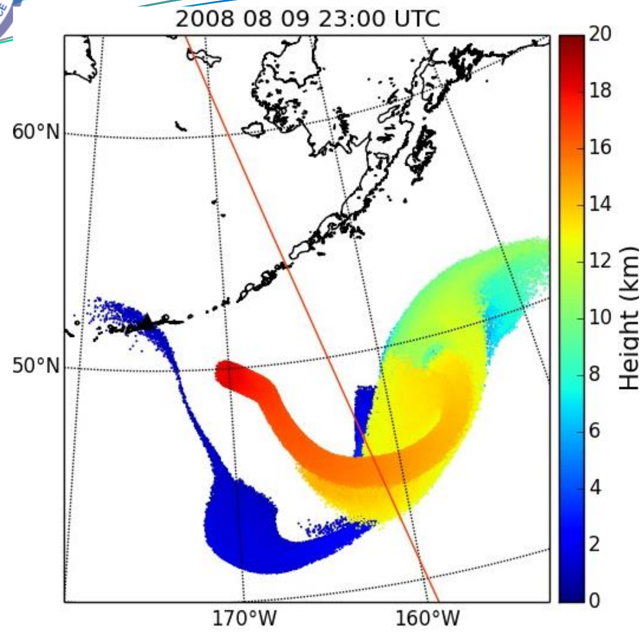
Model particle positions (red) and CALIOP backscatter

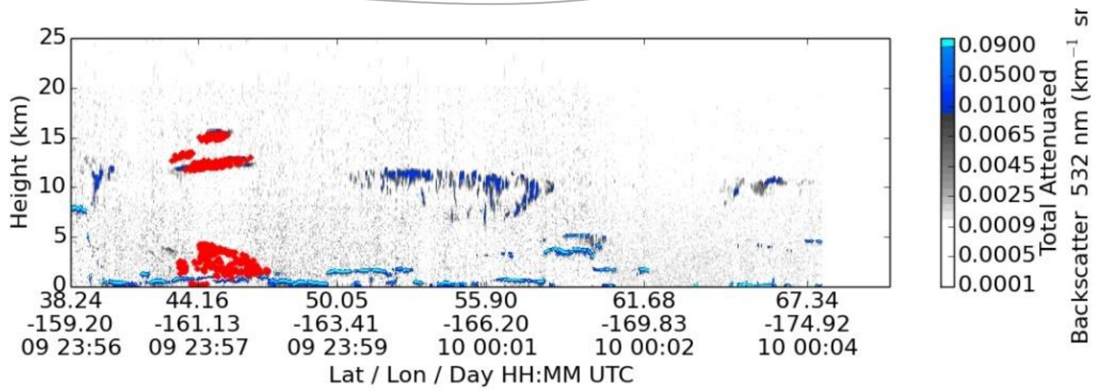
Orange solid line = track of CALIOP

The lidar data was obtained from the NASA Langely Research Center Atmospheric Science Data Center.

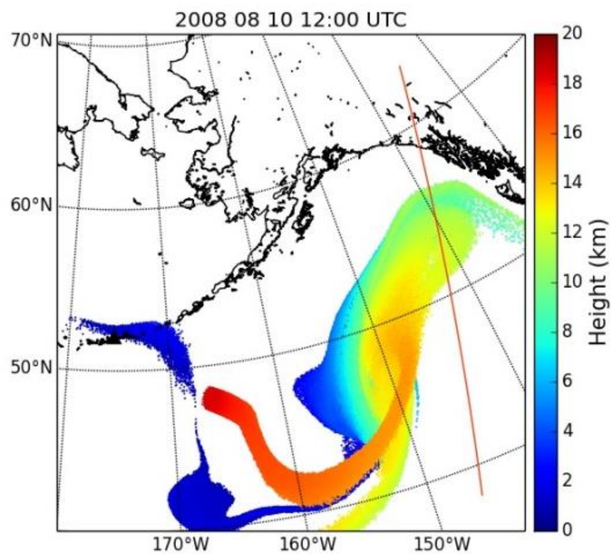
Height of ash at Times 4 and 5

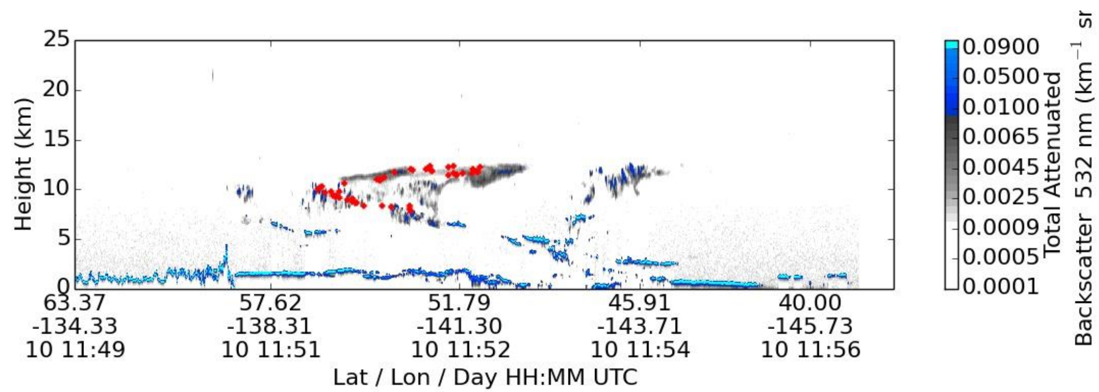
Time 4





Time 5

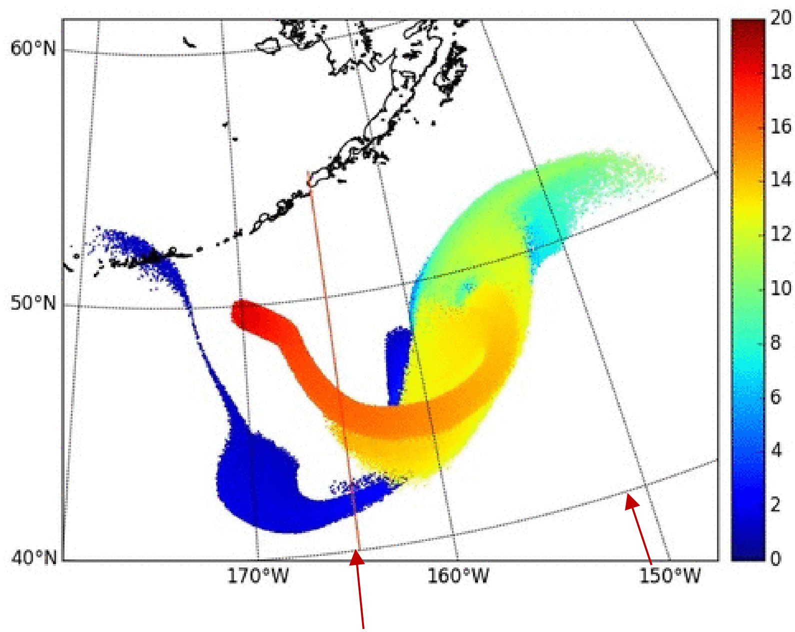




The lidar data was obtained from the NASA Langely Research Center Atmospheric Science Data Center.

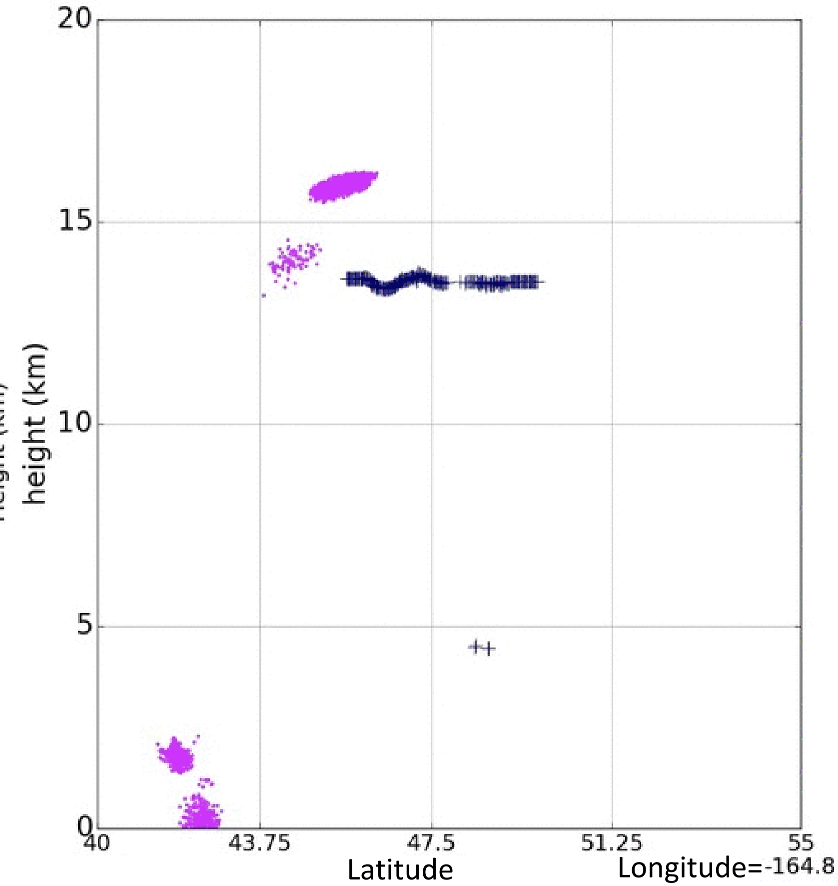
Cylindrical initialization

Vertical plume structure at Time 4



Cylindrical initialization at vent.

Model particle positions color-coded by height.



Vertical cross-section along red line on plot at left.

Model particle positions (magenta).

Satellite-retrieved top heights (black).

Loop from 165 to 151 degrees longitude.

HYSPLIT Inverse Modeling

Given: Areas of ash and no ash

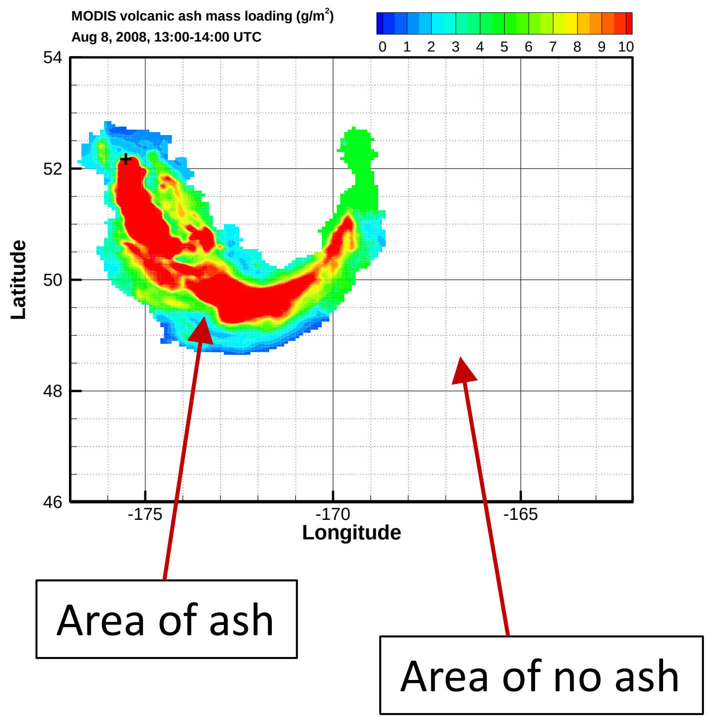
And: Unit source dispersion patterns with time from known volcano

Determine: The mass eruption rate as a function of height and time.

In other words, what source will best match this satellite result?

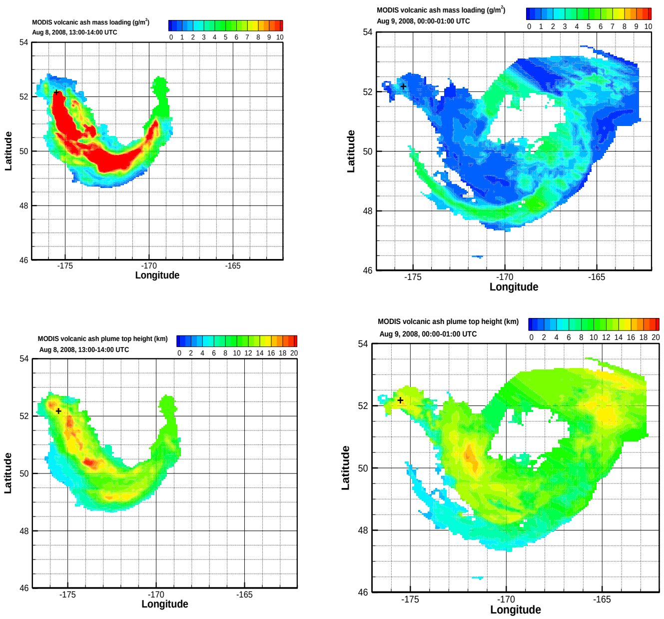
Why? Operationally, a forecaster should be able to improve the forecast by re-running the dispersion case with this new source term.

Satellite retrieval mass loading



HYSPLIT Inverse Modeling

- An independent HYSPLIT simulation at each time segment (t), at each possible release height (k) is run with unit source;
- A *Transfer Coefficient Matrix (TCM)* is then built to correspond with the available satellite mass loading observations. Mass loadings are obtained by integrating from surface to ash cloud top or for a fixed cloud depth;
- Source terms are solved by minimizing a cost function built to measure the differences between model simulations and observations, following a general 4D-variational data assimilation approach.



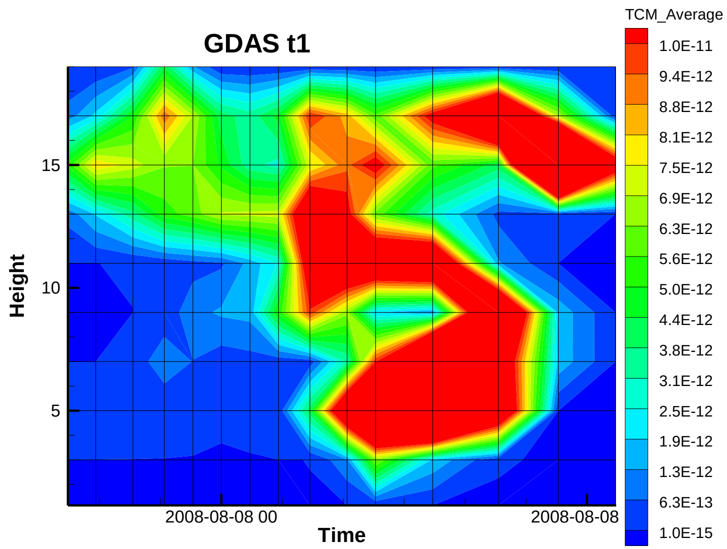
Volcanic ash mass loading at point (i, j), time s
model *satellite*

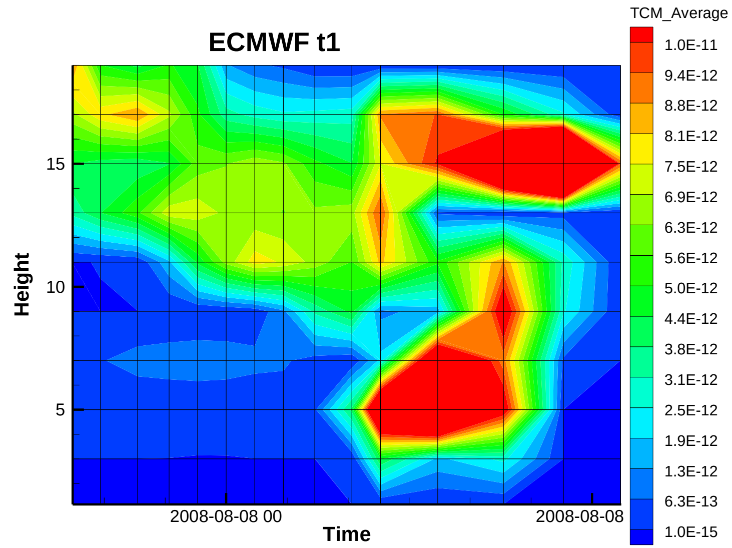
Source term
Unknown *background*

$$\mathcal{F} = \frac{1}{2}\sum_{t=1}^{T}\sum_{k=1}^{K}\frac{(q_{kt}-q_{kt}^{b})^2}{\sigma_{kt}^2} + \frac{1}{2}\sum_{s=1}^{S}\sum_{i=1}^{I}\sum_{j=1}^{J}\frac{(l_{ijs}^{m}-l_{ijs}^{o})^2}{\epsilon_{ijs}^2} + \mathcal{F}_{other}$$

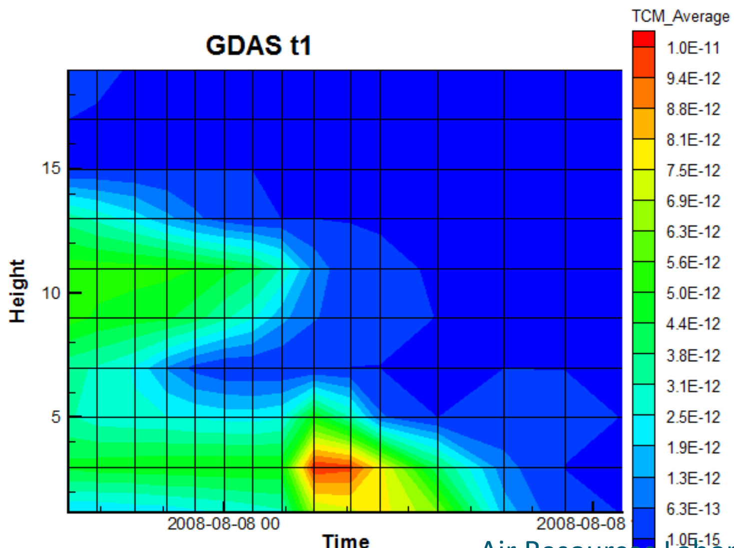
HYSPLIT Inverse Modeling

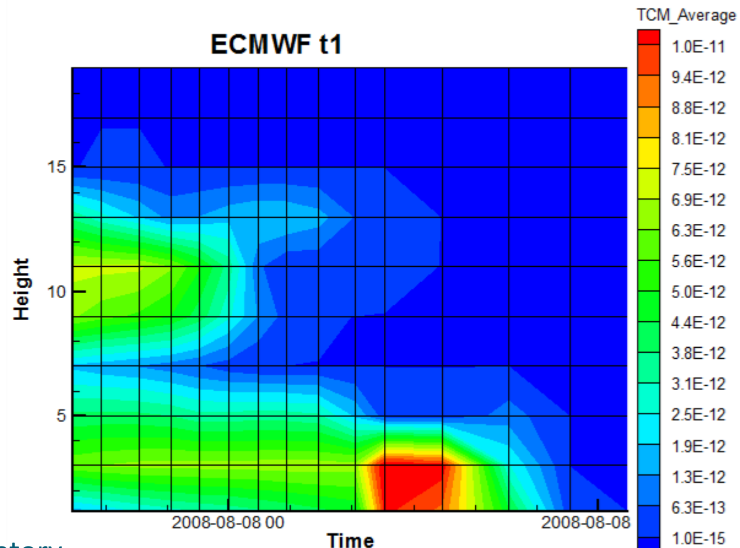
Using "ash" areas





Using "no ash" areas





Summary of this research on Kasatochi, 2008 …

- Quantitative source term to reduce some of the uncertainty in the model results
  - At vent
    - MER algorithm (Mastin, 2009) and an estimate of fine ash fraction will likely give uncertain results without any mass adjustment from satellite retrievals
    - Cylindrical source initialization tended to be better than linear source
    - Inverse modeling shows promise but needs to be tested with more eruptions
  - Downwind
    - Initializing HYSPLIT from satellite-retrieved-products and assuming an ash cloud thickness gave roughly comparable results as the cylindrical source initialized at the vent

- HYSPLIT was able to simulate the height and thickness of the ash cloud layer(s) reasonably well compared to lidar data

- The HYSPLIT top heights agreed reasonably well with retrieved top heights, although HYSPLIT also showed a very complex vertical structure in parts of the ash cloud

For more on this work, see the poster by Crawford et al.

More on dispersion model verification

Above binary (yes/no) statistics are for mass loadings above some threshold.

Draxler (2006) developed a “rank” score to compare point-to-point concentration values.

- Correlation coefficient
  (scatter)
- Fractional bias
- CSI (aka Figure of Merit in Space or Threat Score)
  (spatial coverage)
- Kolmogorov-Smirnov Parameter
  (unpaired cumulative distribution)

Satellite Retrieval at 2008 08 08 13:40 UTC
Model output one hour average 2008 08 08 13 - 14 UTC
GDAS 1degree

96098 Unaveraged data points for processing
0.28 Correlation coefficient (P=99%)
66.75 Root mean square error
13.27 Average bias [(C-M)/N]
1.24 Fractional bias [2B/(C+M)]
51.94 False Alarm Rate [fa/(fa+hit)]
54.98 Probability of Detection [hit/(hit+miss)]
34.48 Threat Score [hit/(fa+hit+miss)]

14.48 Measured 95-th percentile
11.80 Measured 90-th percentile
6.24 Measured 75-th percentile
2.43 Measured 50-th percentile

69.77 Calculated 95-th percentile
43.13 Calculated 90-th percentile
14.19 Calculated 75-th percentile
0.95 Calculated 50-th percentile

19.00 Kolmogorov-Smirnov Parameter

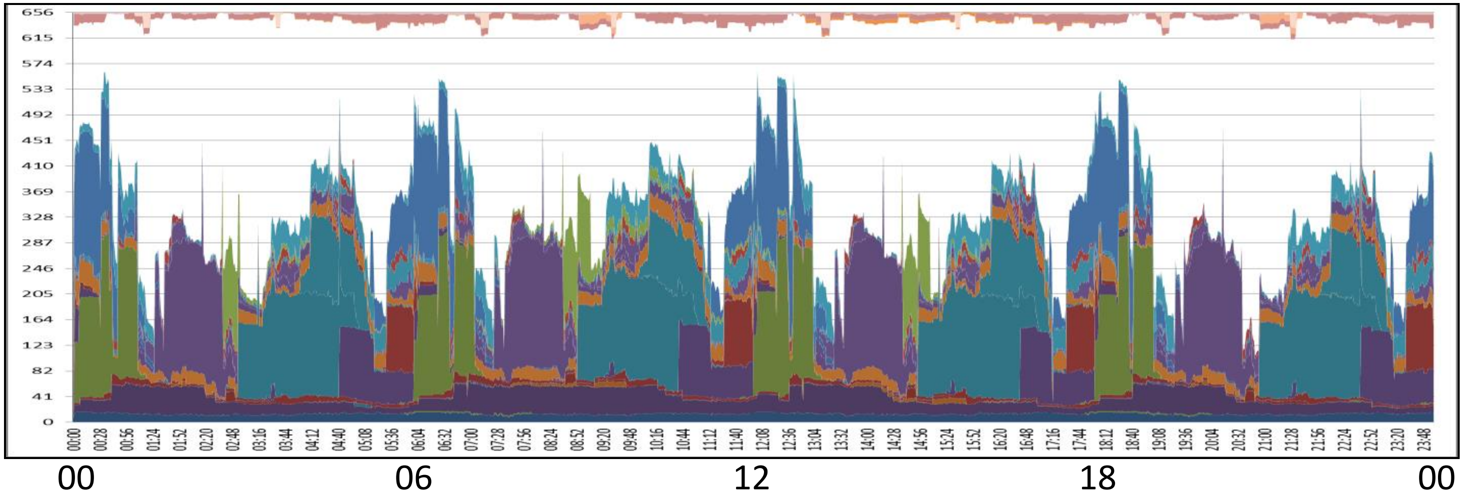
1.61 Final rank (C,FB,FMS,KSP)

Example stats from Kasatochi
Valid 14 UTC August 8, 2008

Draxler, 2006: The use of global and mesoscale meteorological model data to predict the transport and dispersion of tracer plumes over Washington, D.C. Wea. Forecasting, 21, 383–394, doi:10.1175/WAF926.1.

What is NOAA NCEP operations?

- Numerical weather prediction (NWP) models, data assimilation, other models (hurricane, storm surge, ocean, climate, HYSPLIT, etc.), dissemination, etc.
- Operations computer heavily used
- Operates 24/7, backed up, people on-call, etc.
- Goal: Deliver all products with no more than fifteen minute variability from day to day
- Developers must use, and keep up with changes to, NCEP operational hardware, software, and coding standards (no MATLAB, IDL; avoid netCDF; etc.)
- New products need to be requirements, not requests
- My office, NOAA ARL, is <u>not</u> operations



NCEP operations - volcanic ash capability

Traditional run:

- Operator enters volcano name, eruption height, start date/time and duration
- Runs HYSPLIT with unit source
- VAAC forecaster looks at “ash reduction level” cases to choose which one, if any, to issue.
  - The choice is based on a comparison to satellite imagery.
  - The default is based on a reference eruption, but the ash reduction levels give options, up to three orders of magnitude difference, in output concentration.
- VAAC forecaster issues the VAA (observation and forecast)

Available features:

- Turn off wet deposition
- Effective area source
- Initialize with model particle positions from earlier HYSPLIT run, entering new eruption height if different (time-varying height or successive puffs)
- Initialize from earlier run, but with modified particle positions (horizontally translated, or exclude part of ash cloud)

How to transfer our research into NCEP operations

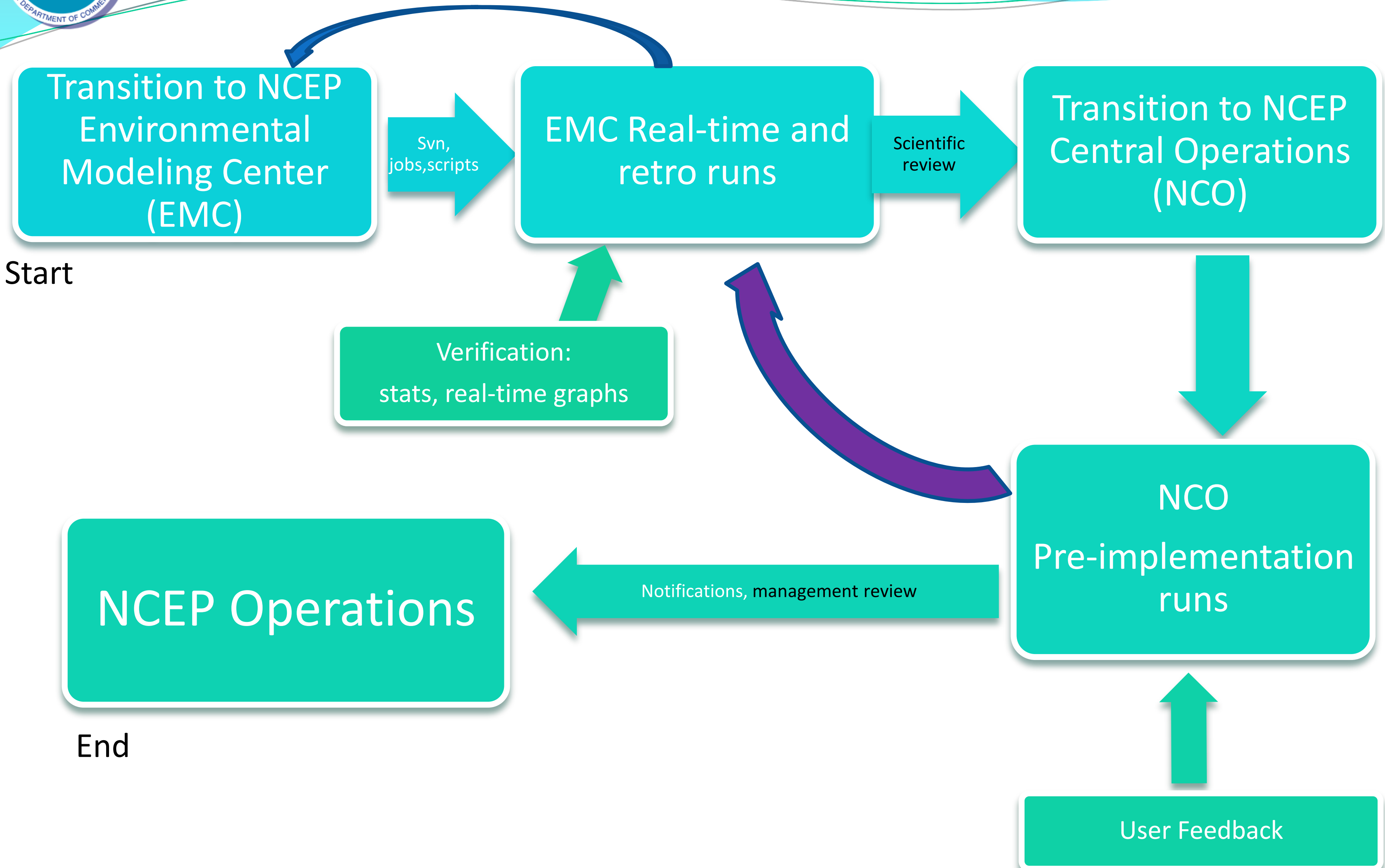
(1) Decide what is needed (convince ourselves this is beneficial)
– if a new product is needed, develop it

(2) Get it working on the “development” NCEP computer

(3) Get preliminary approval from NCEP management.

Then…

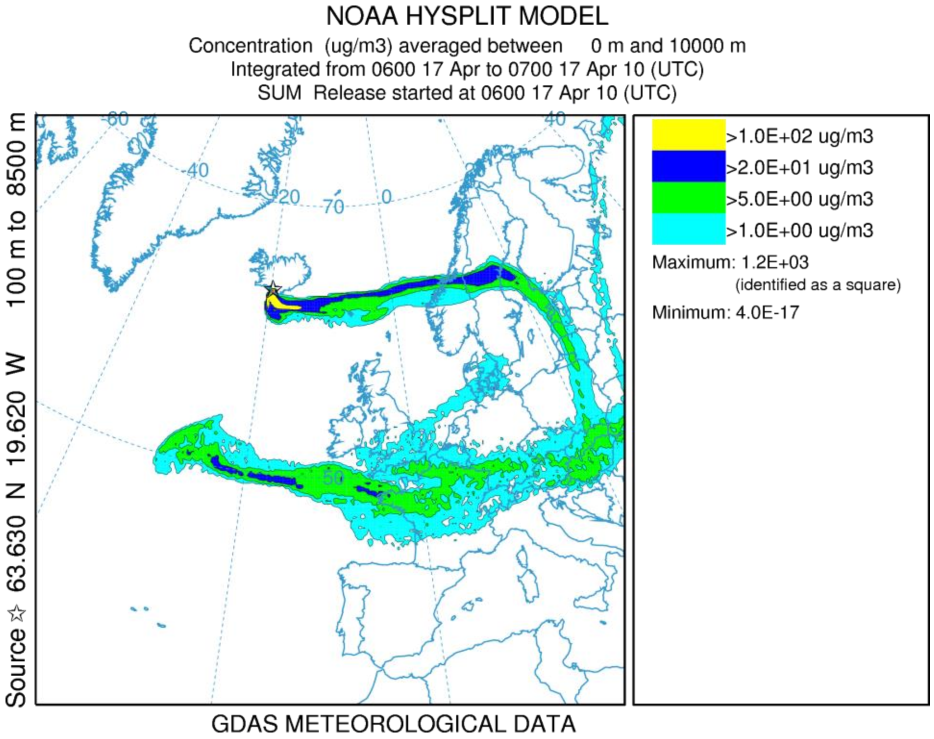
Transition to Ops Process (~6 months)



Summary – Research to Operations (R2O) at NCEP

- From the R&D perspective, it is hard to get volcanic ash upgrades or new products into operations because of the detailed/lengthy process to transfer R2O
- But, once it has been transferred, then the customers will receive the products because NCEP required rigorous testing and evaluation, systems are fully backed-up, etc.

Thank you…



NOAA HYSPLIT MODEL
Concentration (ug/m3) averaged between 0 m and 10000 m
Integrated from 0600 17 Apr to 0700 17 Apr 10 (UTC)
SUM Release started at 0600 17 Apr 10 (UTC)
Source ☆ 63.630 N 19.620 W 100 m to 8500 m
>1.0E+02 ug/m3
>2.0E+01 ug/m3
>5.0E+00 ug/m3
>1.0E+00 ug/m3
Maximum: 1.2E+03
(identified as a square)
Minimum: 4.0E-17
GDAS METEOROLOGICAL DATA

Extras

Data Archive of Tracer Experiments and Meteorology (DATEM)

http://www.arl.noaa.gov/DATEM.php

Near ground-level releases of tracer gases

Experiment	Number of tracer releases	Sampler distance from release	Meteorology
ACURATE (March, 1982-Sept. 1983)	near-continuous	300 - 1100 km	NARR
ANATEX_GGW (1987)	33 (every 2.5 days)	500 - 3000 km	NARR
ANATEX_STC (1987)	33 (every 2.5 days)	500 – 2000 km	NARR
ASCOT (1980)	10	~10 km	WRF
CAPTEX (1983)	6	300 – 1100 km	WRF and NARR
ETEX	1	200 – 1500 km	Reanalysis
INEL74 (Jan- May, 1974)	near-continuous	~1200-1800 km	Reanalysis
METREX_8h_MDVA (Nov 83 – Dec 84)	~ 275	< 50 km	MM5
METREX_8h_MtVernon (Nov 83 – Dec 84)	~ 275	< 50 km	MM5
OKC80 (1980)	2	100, 600 km	NARR
SRP76 (March 1975 – Sept. 1977)	near-continuous	< 150 km	Reanalysis

Volcanic ash evaluation

Soufriere Hills, 2010, Montserrat, West Indies

- Statistical comparison against satellite-based mass loadings show no significant differences.

	V7.3.2	V7.4.0
Correlation Coefficient	0.33	0.36
Fractional Bias	0.25	0.24
Figure of Merit in Space	48.15	48.15
KSP*	26.00	24.00
Rank	2.21	2.25

Example slide from presentation to NCEP

The "rank" score is based on the correlation coefficient, fractional bias, Figure of Merit in Space, and a measure of the cumulative concentration distribution. Rank varies from 0.0 to 4.0 (best). Differences of 0.1 or less are not significant. Tracer experiment information available at http://www.arl.noaa.gov/DATEM.php

KSP = Kolmogorov-Smirnov Parameter