Volcanic Ash Forecasting

Dispersion Model Initialization

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WMO-IUGG VASAG/7
Vancouver, WA
August 21-23, 2017

St. Augustine Volcano 2006
Image courtesy of AVO/USGS. Photographer: McGimsey, Game

Outline

- Describe current NOAA operational initialization and possible future initialization
- Summarize our research on model initialization
    - “data insertion”
    - inverse modeling

INITIALIZATION
Forecaster determines initialization
(height of plume and duration of eruption)

(large uncertainty in empirical relationship between plume height and mass eruption rate)

↓

HYSPLIT

Default threshold based on eruption height (from historical analysis)

↓

OUTPUT

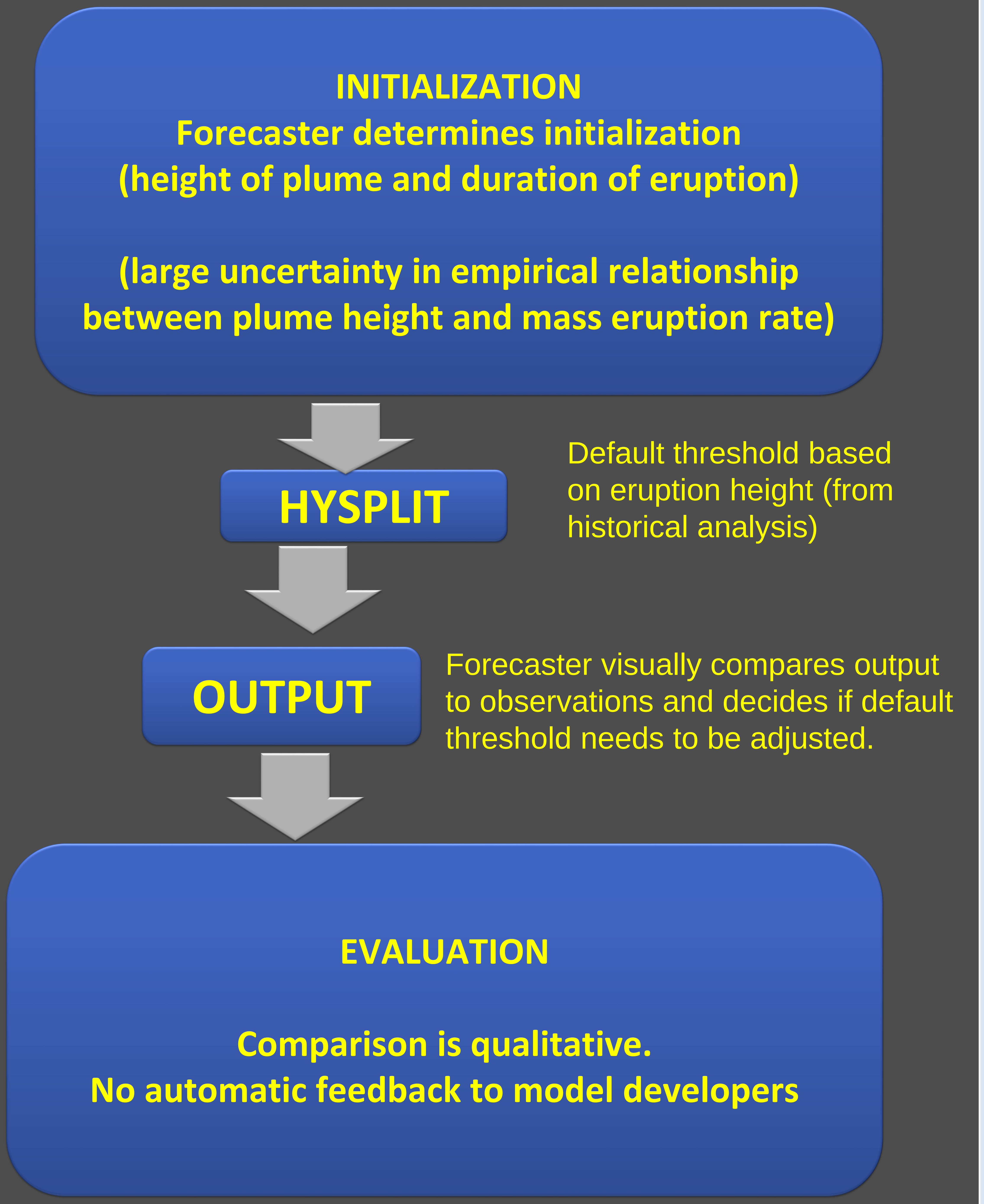
Forecaster visually compares output to observations and decides if default threshold needs to be adjusted.

↓

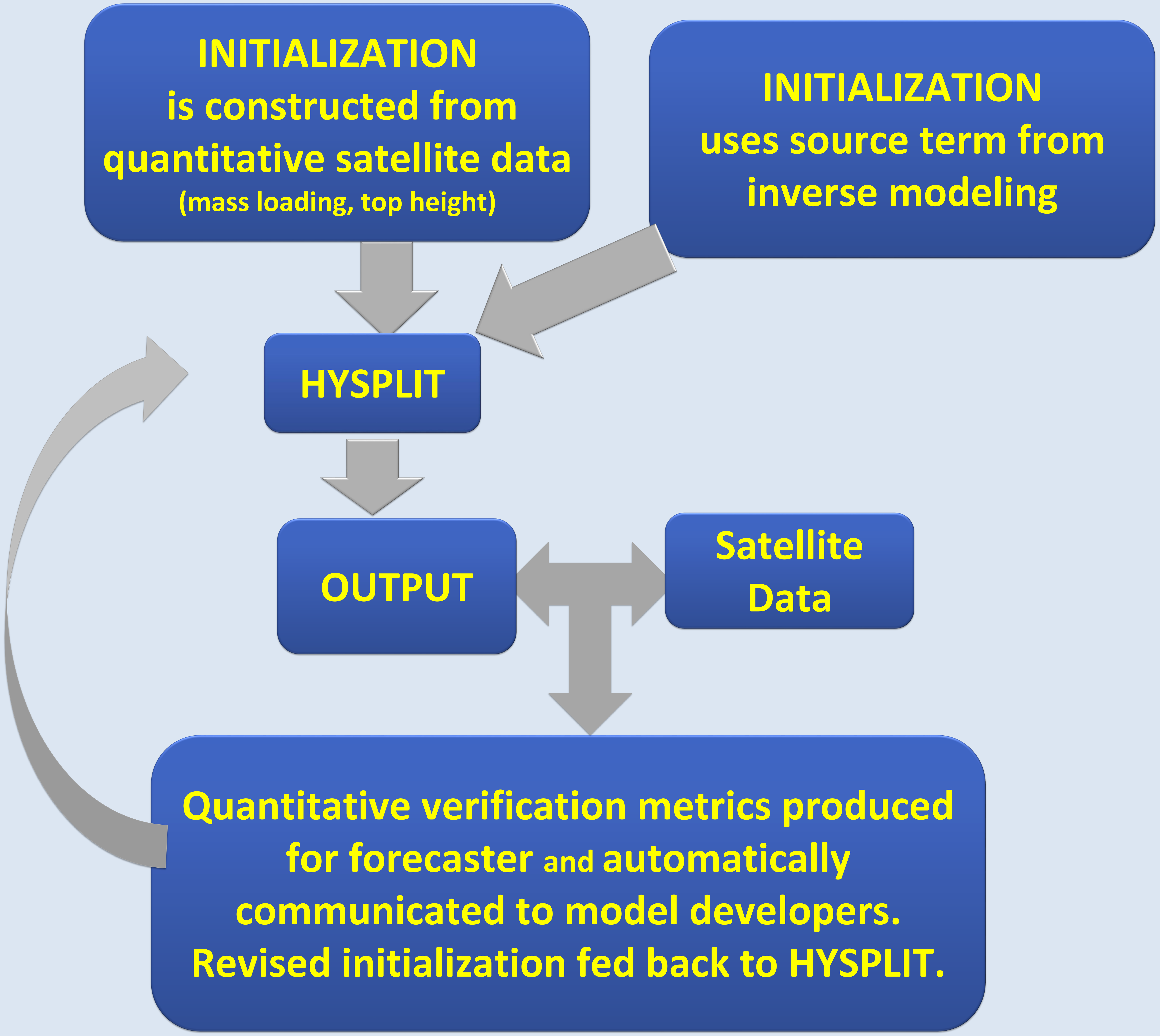
EVALUATION

Comparison is qualitative.
No automatic feedback to model developers

Current flow of information



Current flow of information



Possible future flows of information
with reduced uncertainty in initialization (source term)

Case study: Kasatochi, Alaska, August, 2008

CALIOP
LIDAR instrument

Time 1 | 2 | 3 | 4 | 5

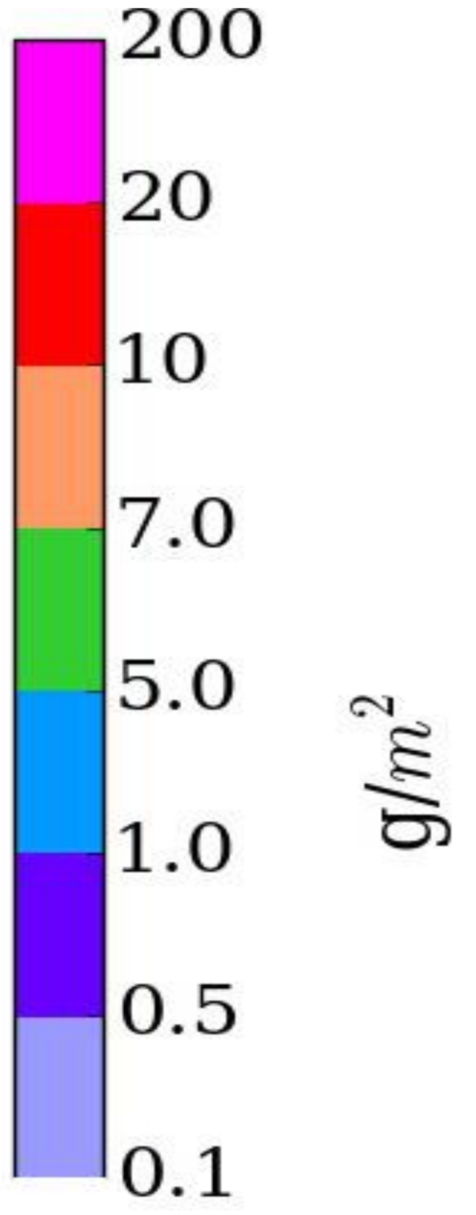
MODIS
Passive IR

RT1

Eruption (km)

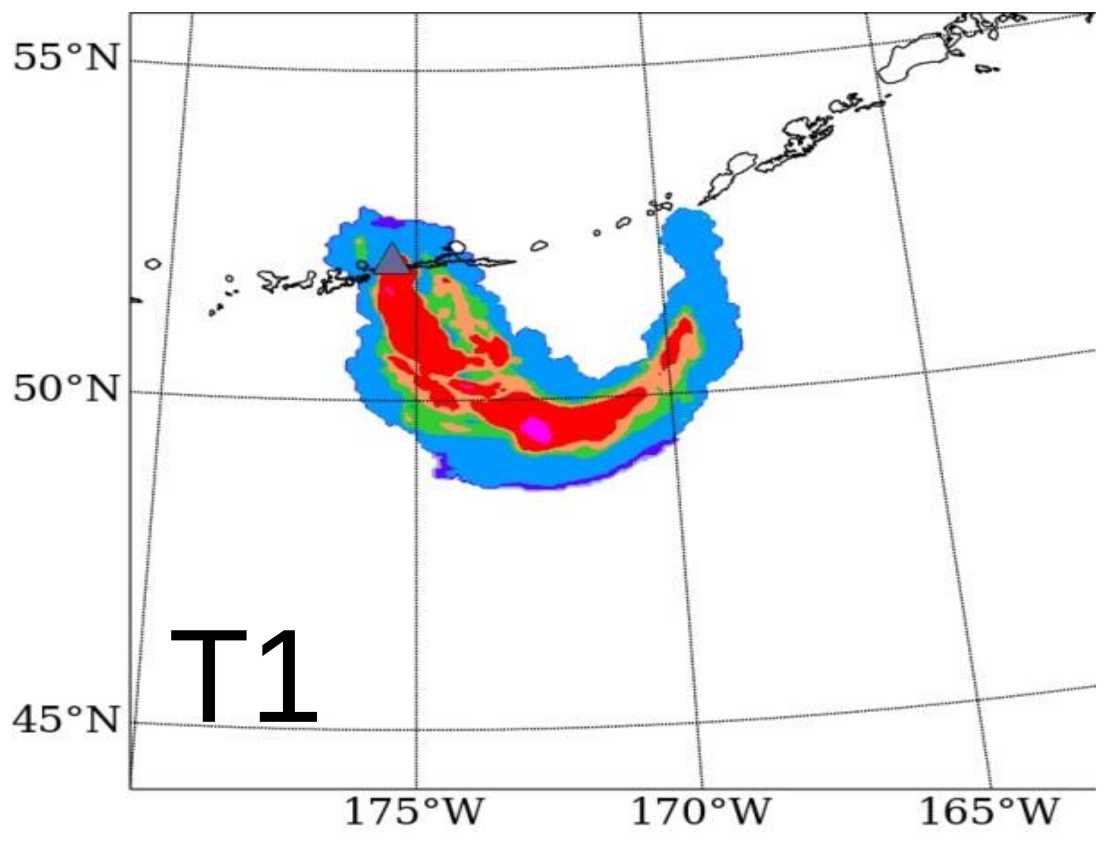
14 E1 | 14 E2 | 18 E3

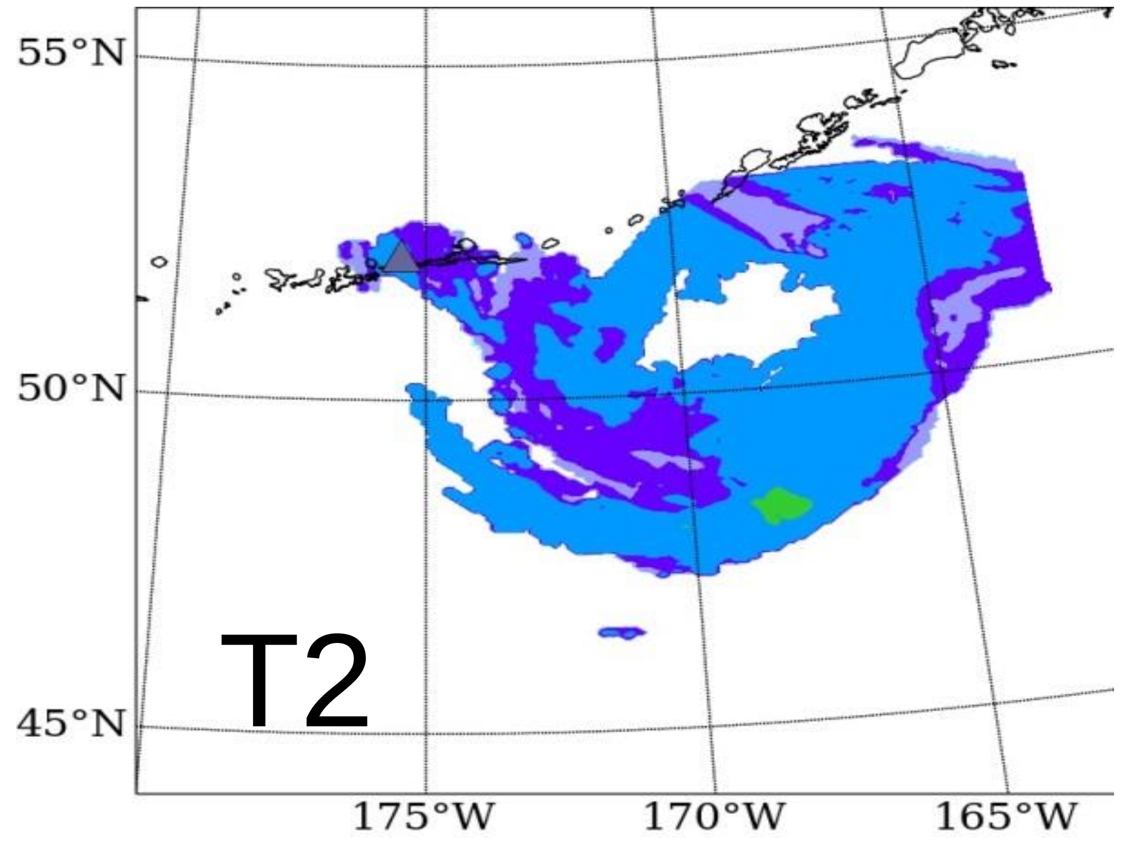
00 Aug. 7 | 00 Aug. 8 | 00 Aug. 9 | 00 Aug. 10 | 00 Aug 11

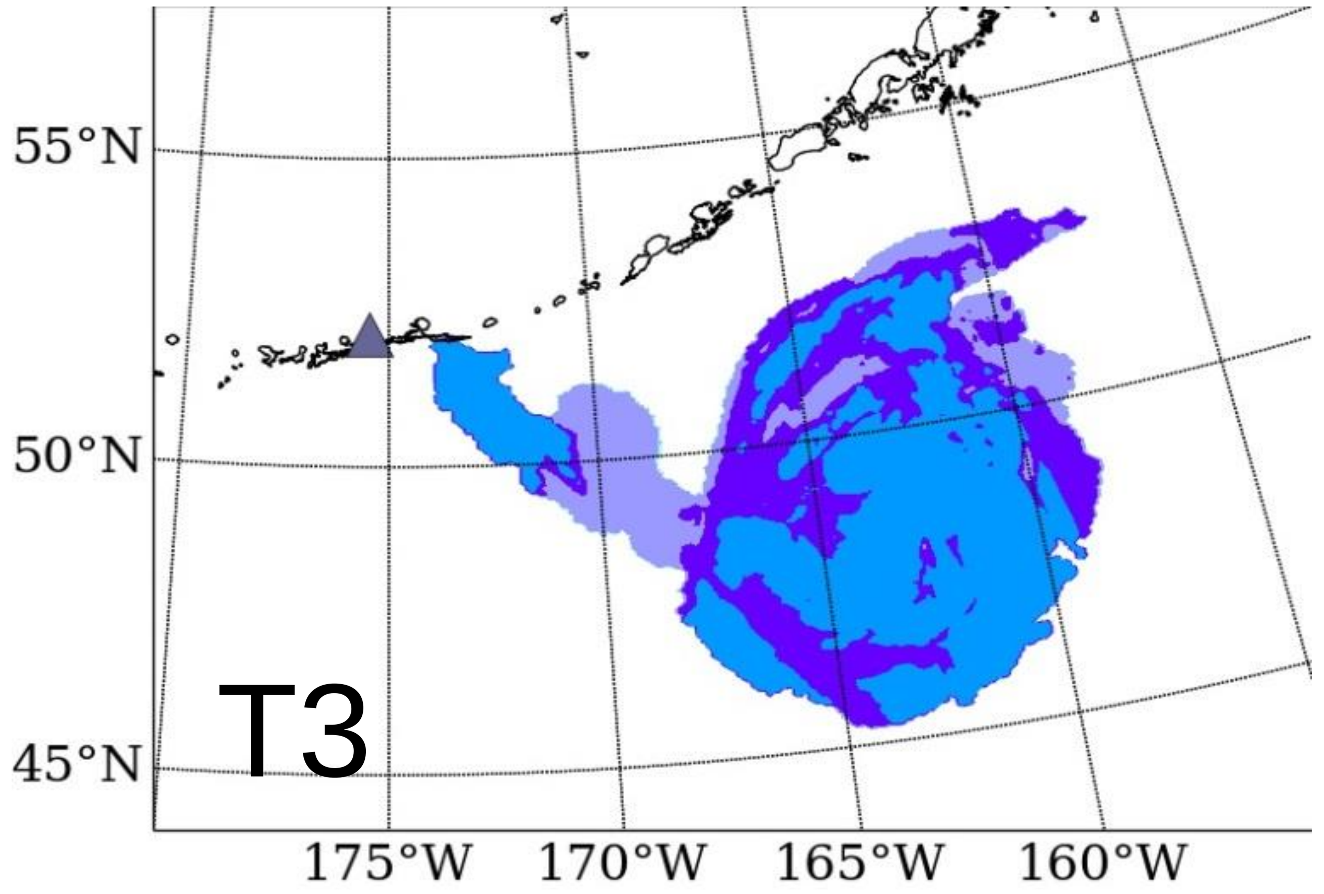


Hot Start / Data Insertion / Downwind initialization

Passive IR satellite retrievals of column mass loading of ash





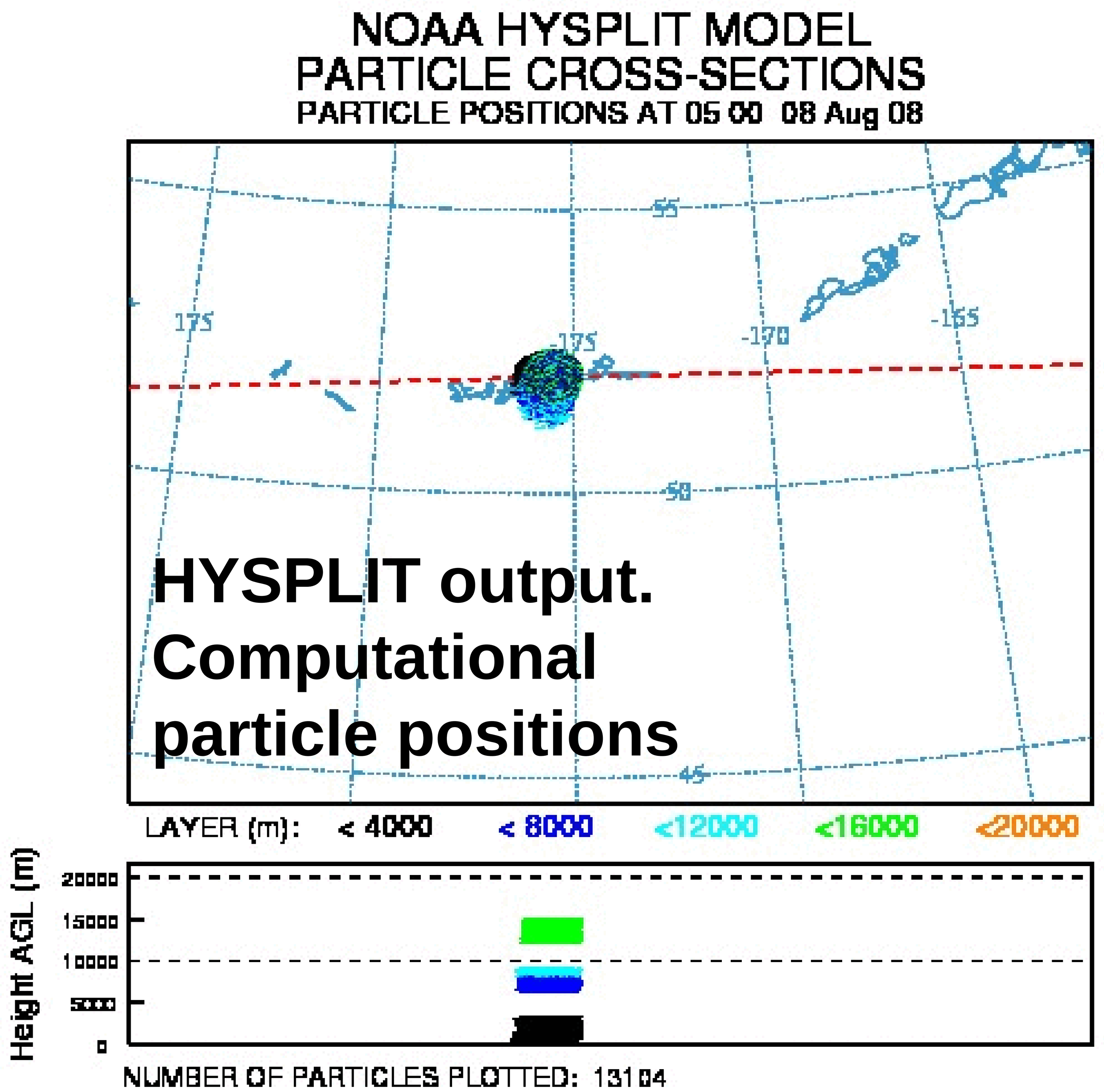


Cylindrical Source Term
08/08 04:00 UTC

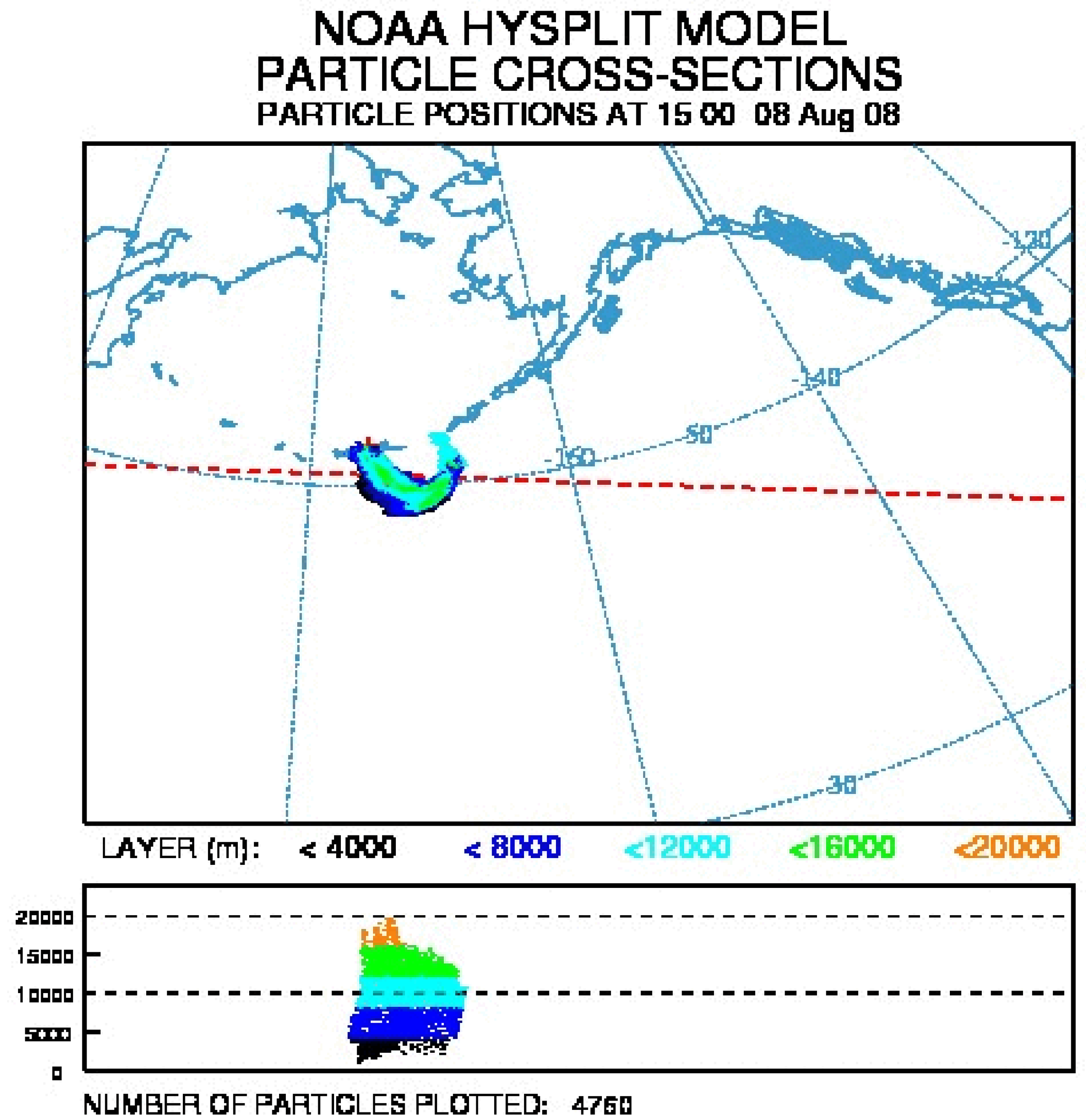
Source term RT1
08/08 14:00 UTC

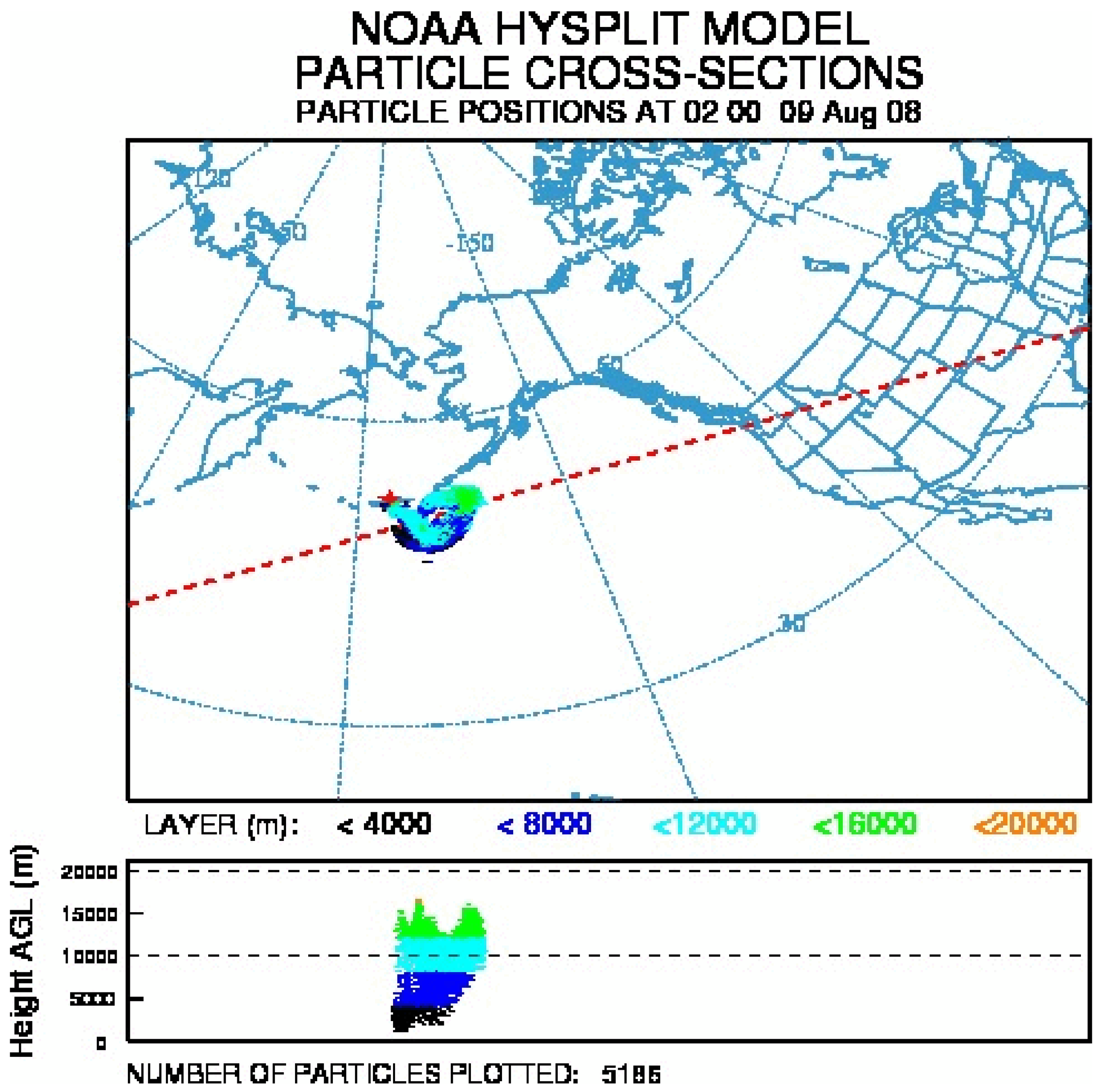
Source term RT2
08/09 01:00 UTC

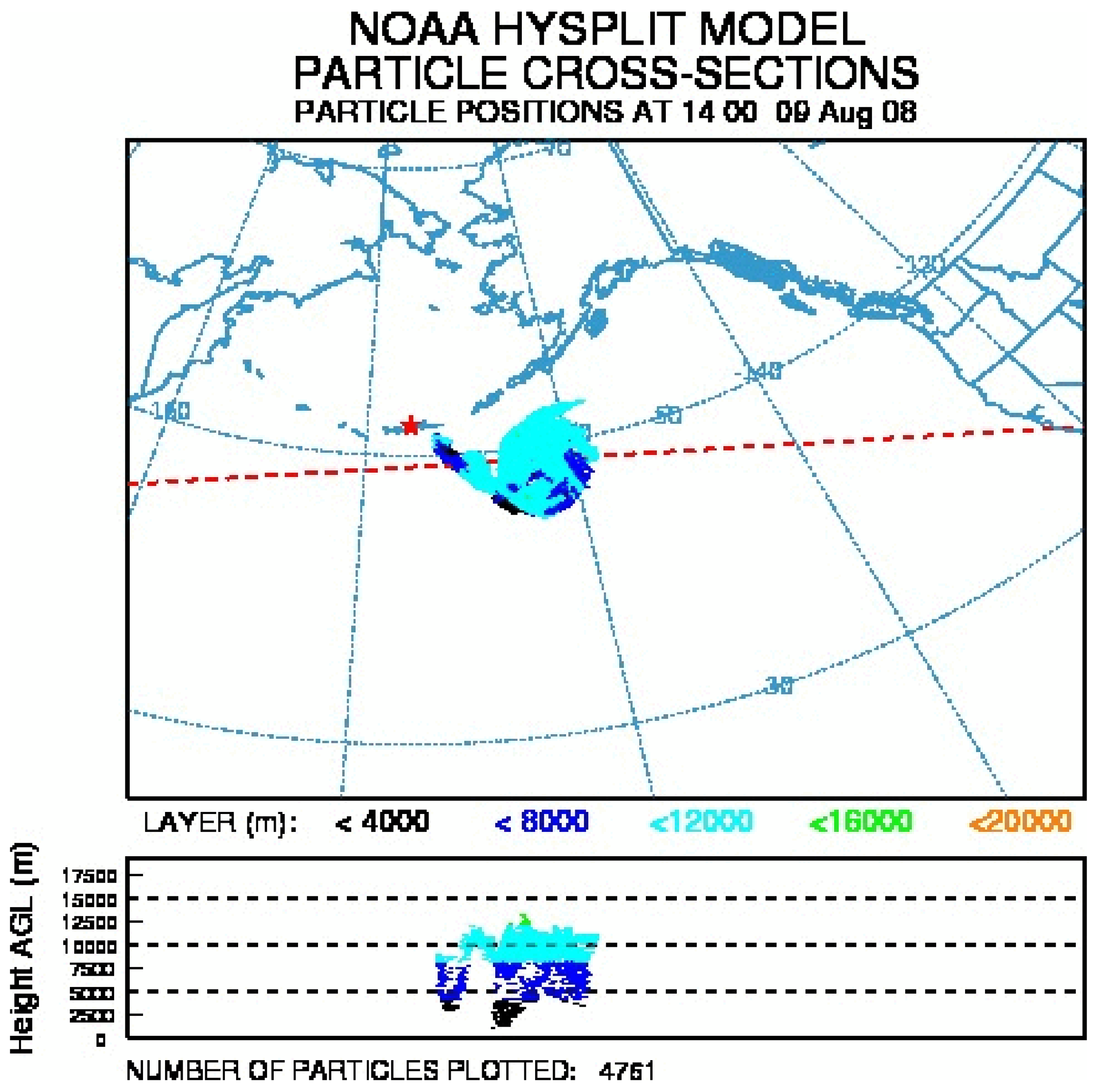
Source term RT3
08/09 13:00 UTC



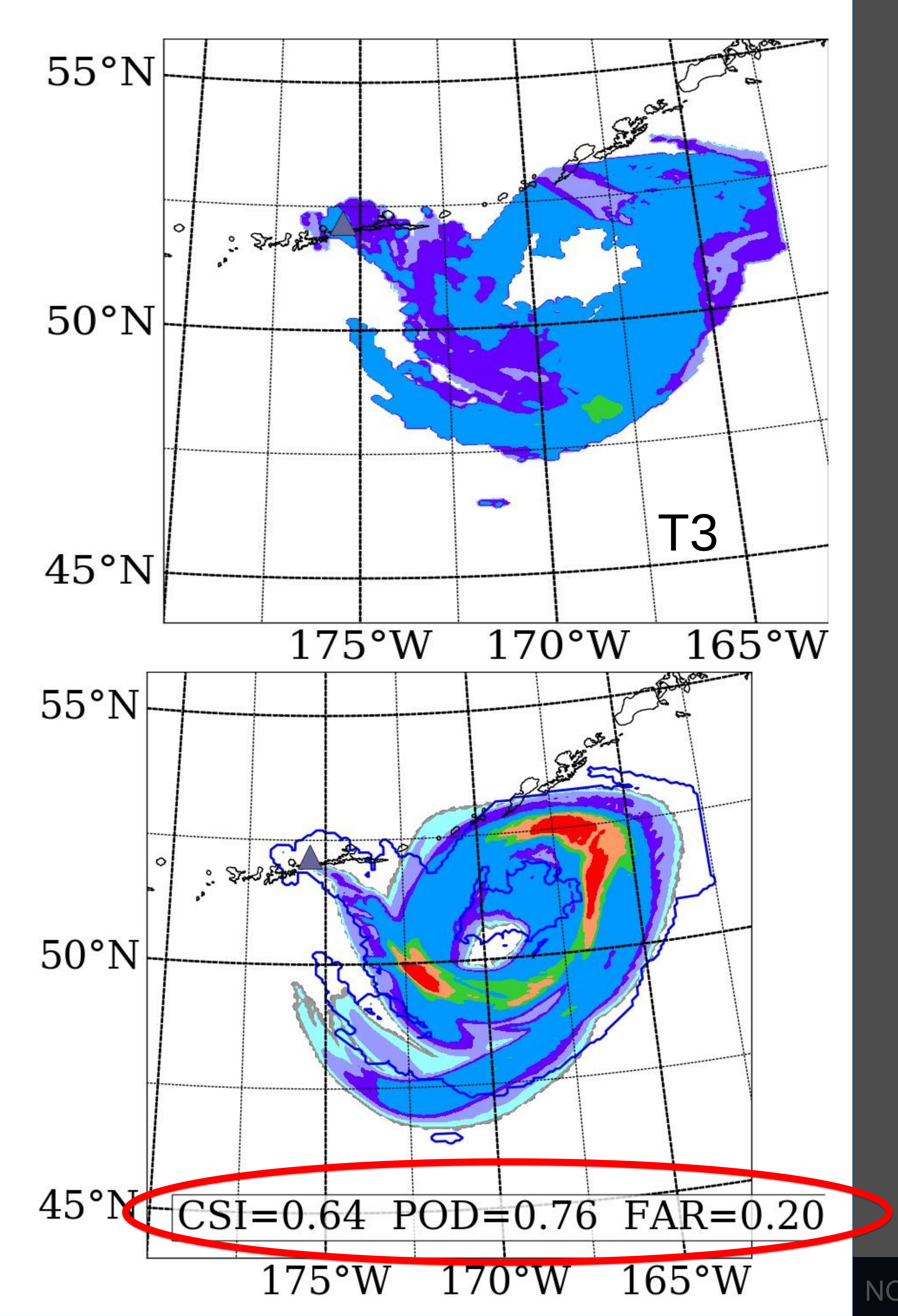
HYSPLIT output. Computational particle positions







Crawford, et al., (2016) Initializing HYSPLIT with satellite observations of volcanic ash: A case study of the 2008 Kasatochi eruption *J. of Geophysical Research: Atmospheres,* 121, p 10,786, doi:10.1002/2016D024779



Critical Success Index $$CSI = \frac{A}{A+B+C}$$

Probability of Detection $$POD = \frac{A}{A+C}$$

False Alarm Ratio $$FAR = \frac{B}{A+B}$$

		Observed Yes	Observed No
Modeled	Yes	A	B
	No	C	D

KSP – Kolmogorov Smirnov Parameter. The largest difference between the two CDF’s of the mass loading.

Data Insertion / Down wind initializations performed well

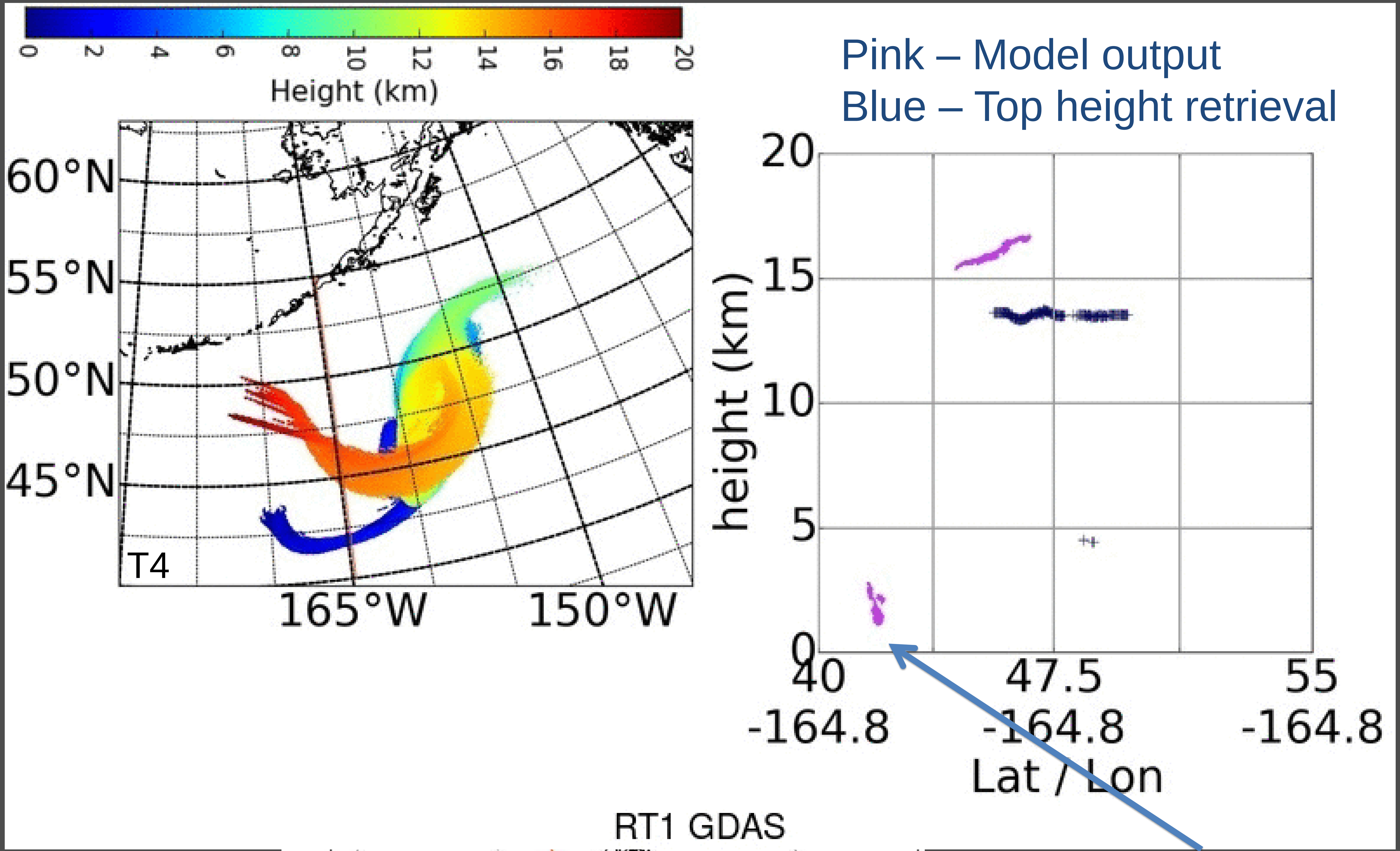
Using earliest retrieval produced better forecasts overall.

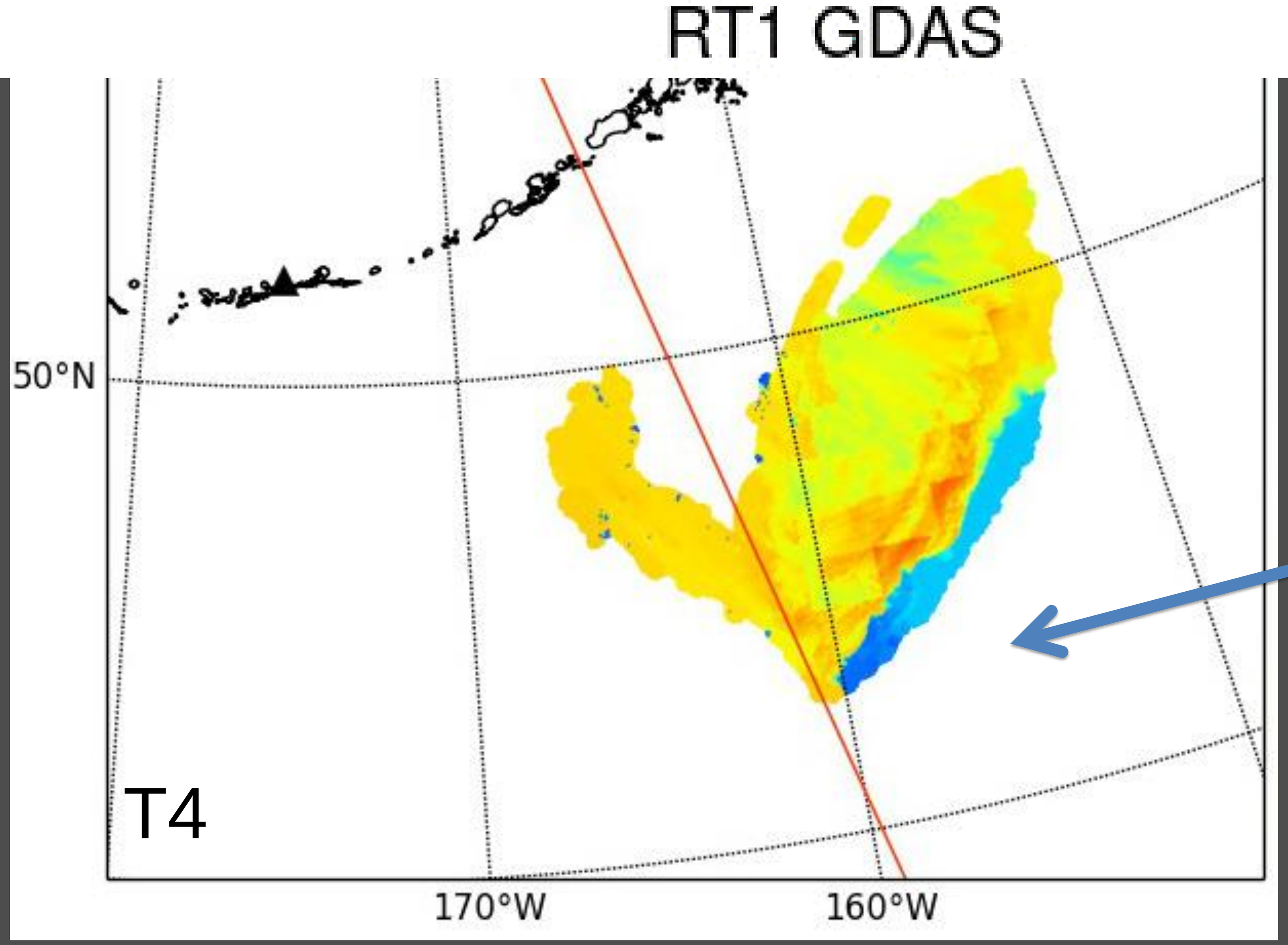
Model initialized with passive IR retrieval at 08/08/2008 14 UTC. RT1

Output shown at 08/10/2008 00 UTC (T4)

Model output agrees well with passive IR retrievals of top height and space based lidar data.

The ash cloud develops into a complex three dimensional structure.





Patchiness of the passive IR height retrieval may reflect the layered nature of the ash cloud.

Inverse modeling

Unknown emissions terms are obtained by searching for the emissions that would create model predictions which best match observations.

Motivation

- **Produce better long term forecasts by creating a more accurate initialization.**

Applications

- Fukushima nuclear accident
- **Volcanic ash**
- Wildfire smoke
- Methane and CO_2 sources
- Finding release locations

OUTLINE

- Technique used to search for emissions terms.
- Determine how well model output produced with an emission matches observations.
- What observations should be used?

Tianfeng Chai, et al., (2017) Improving volcanic ash predictions with the HYSPLIT dispersion model by assimilating MODIS satellite retrievals
Atmos. Chem. Phys., 17, p1-15 doi:10.5194/acp-17-1-2017

Searching for emission terms

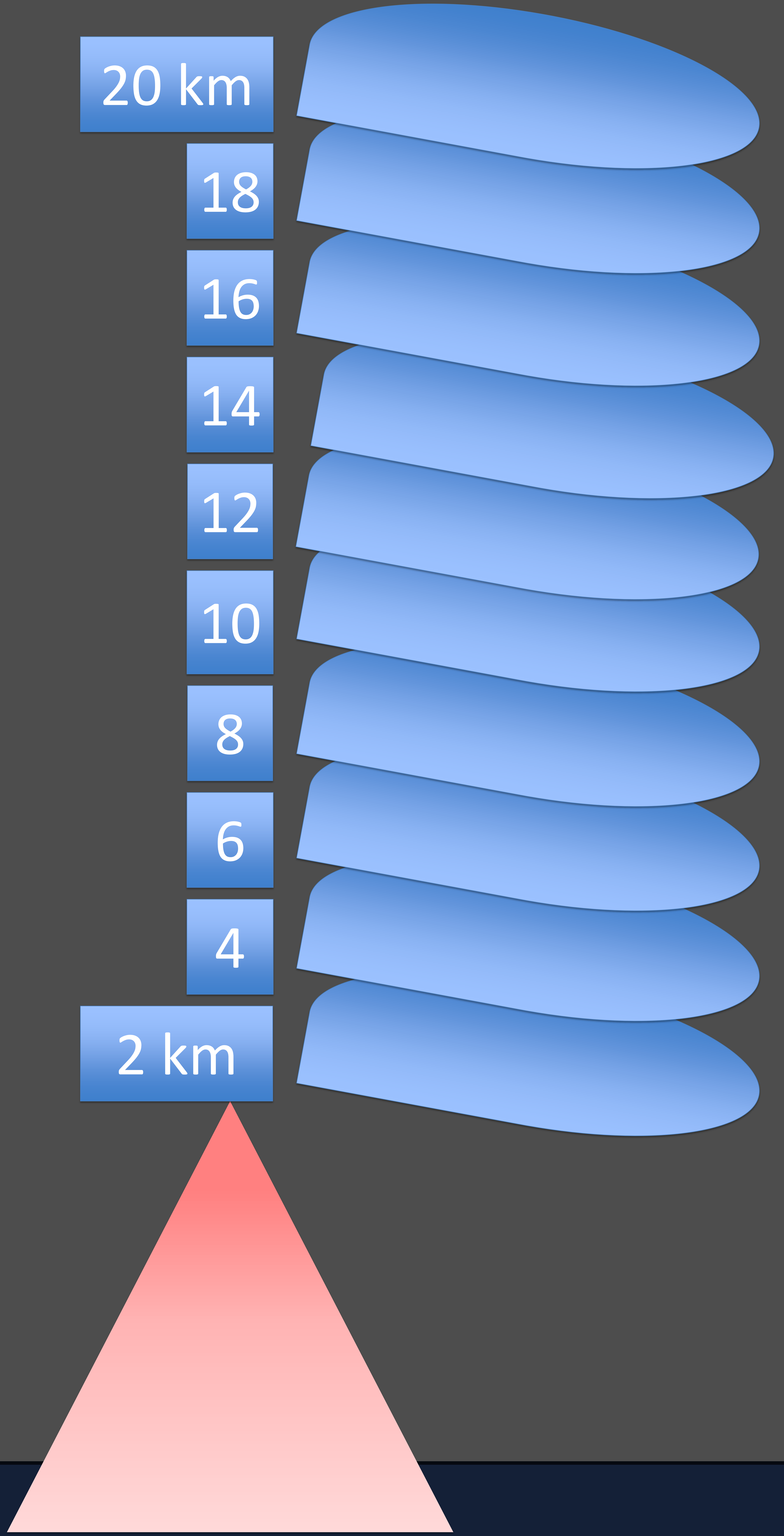
– determine positions and times of likely emissions

HYSPLIT RUNS For Inversion Algorithm

290 HYSPLIT Simulations

Unit emission for every hour from 19:00 UTC on 7 August to 23:00 UTC on 8 August 2008. (29 time periods)

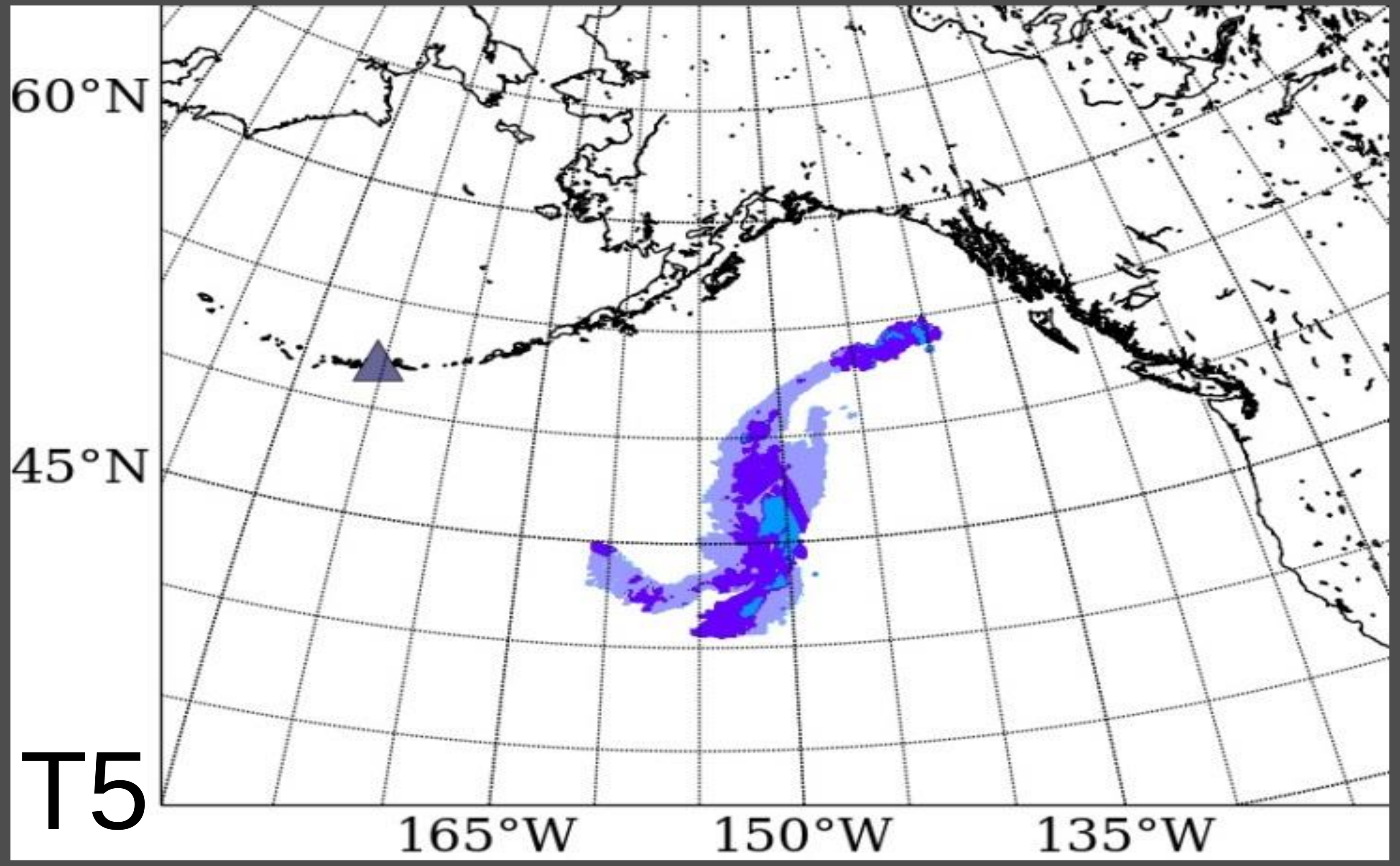
Particles released over 2 km increments from vent to 20 km. (10 runs per time period)

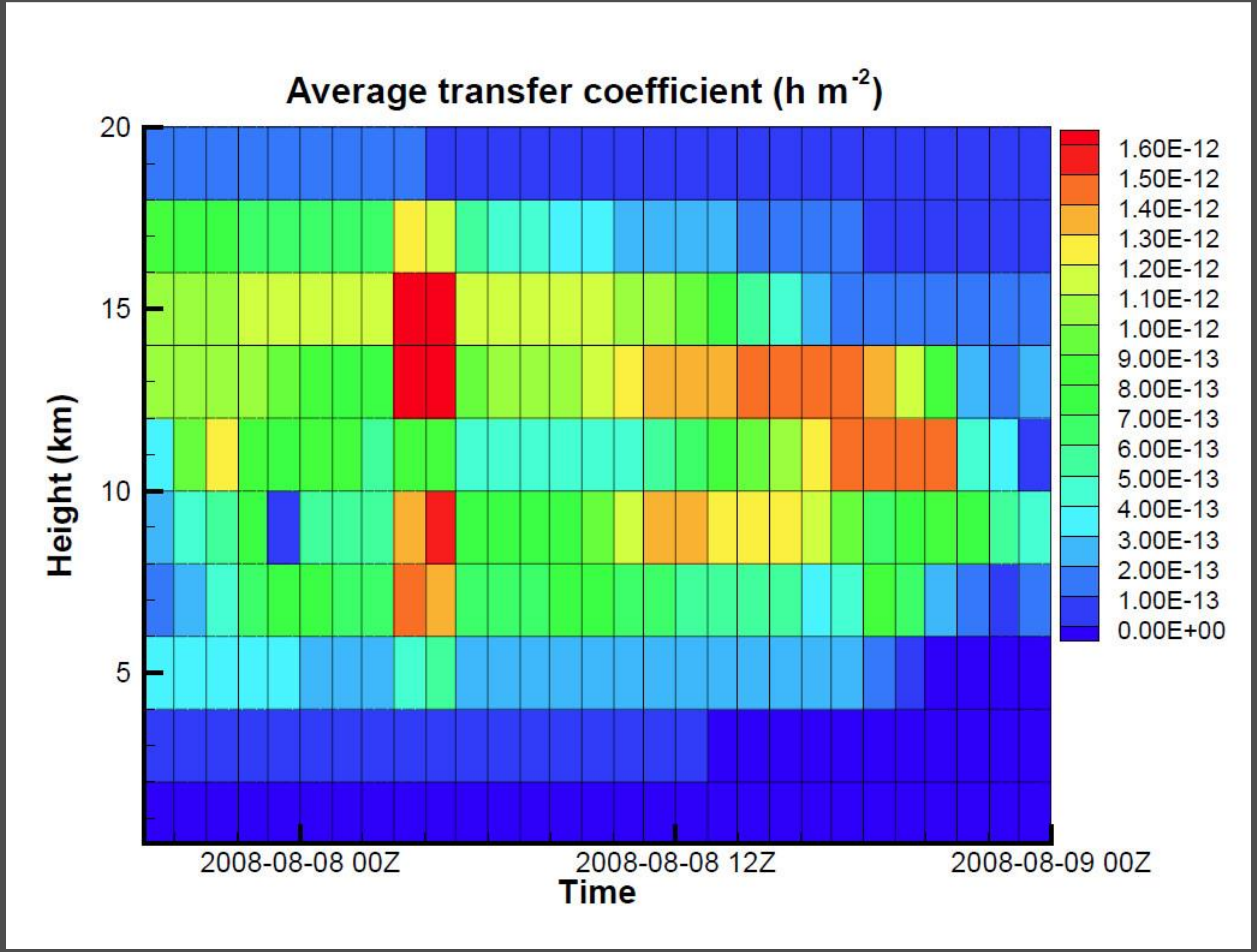


At time T5, assuming ash extends from observed top to surface.

Which HYSPLIT runs produce ash that coincides with observed ash?

Average over all observations containing ash (shows 290 boxes).

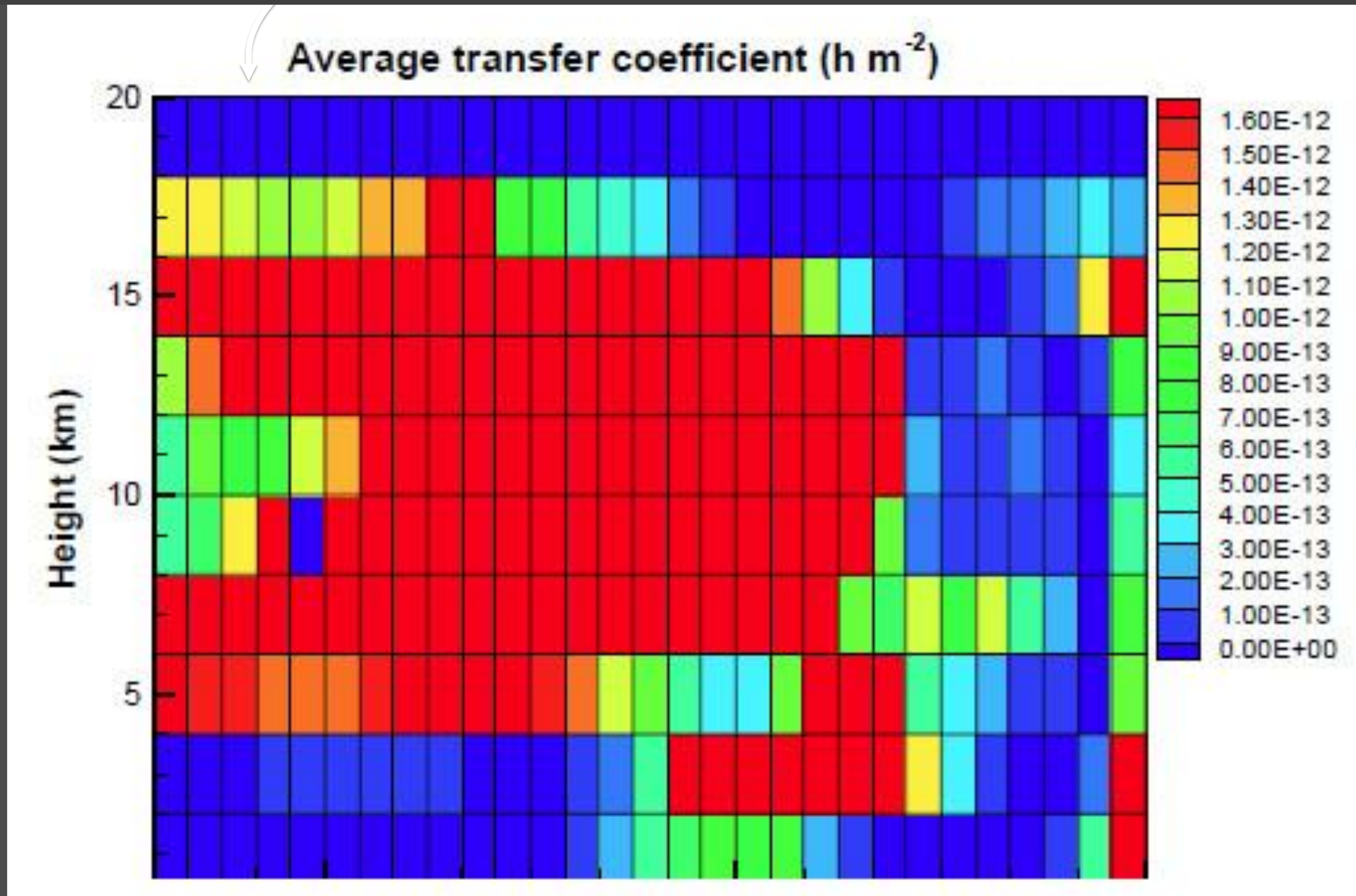




Which observations to use? Ash present …

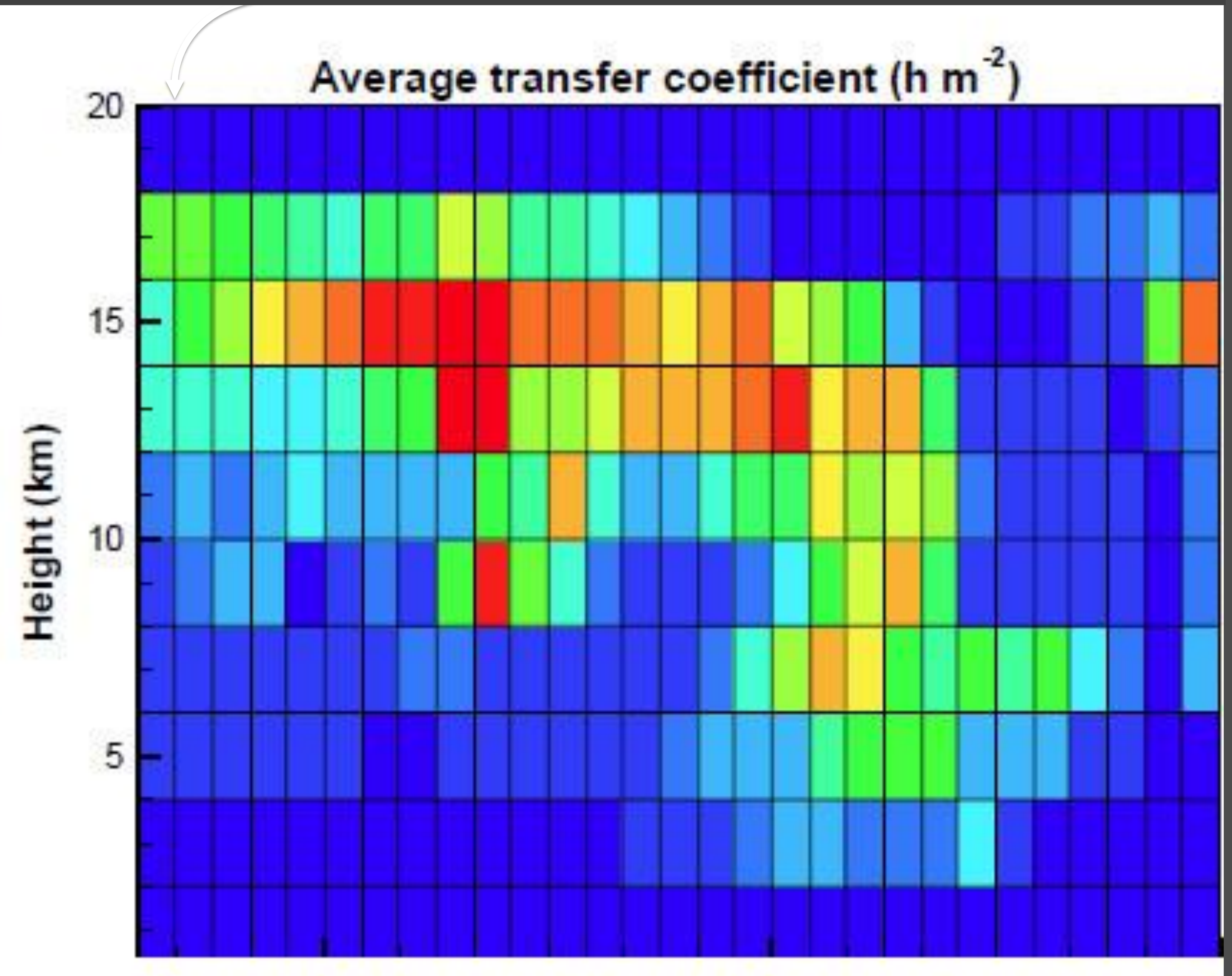
Need to assume a vertical structure.

from surface to observed cloud top



T2

in layer of observed cloud top only,



T2

or also in layers above and below cloud top

As newer observations become available should older observations be discarded?

Should clear sky observations be taken into account? Areas of no ash horizontally and above cloud top.

Create cost function

Measure how well observations agree with model output.

Take into account errors in observations

May take into account other restrictions (e.g. smoothness of emissions)

C^0_n – observations

x^b_i - first guess emission rates.

Create Cost Function

$$F = \frac{1}{2}\sum_i^{290}\frac{(x_i - x^b{}_i)^2}{\sigma_i{}^2} + \frac{1}{2}\sum_n^{Y}\frac{(c^h{}_n - c^o{}_n)^2}{\epsilon_n}$$

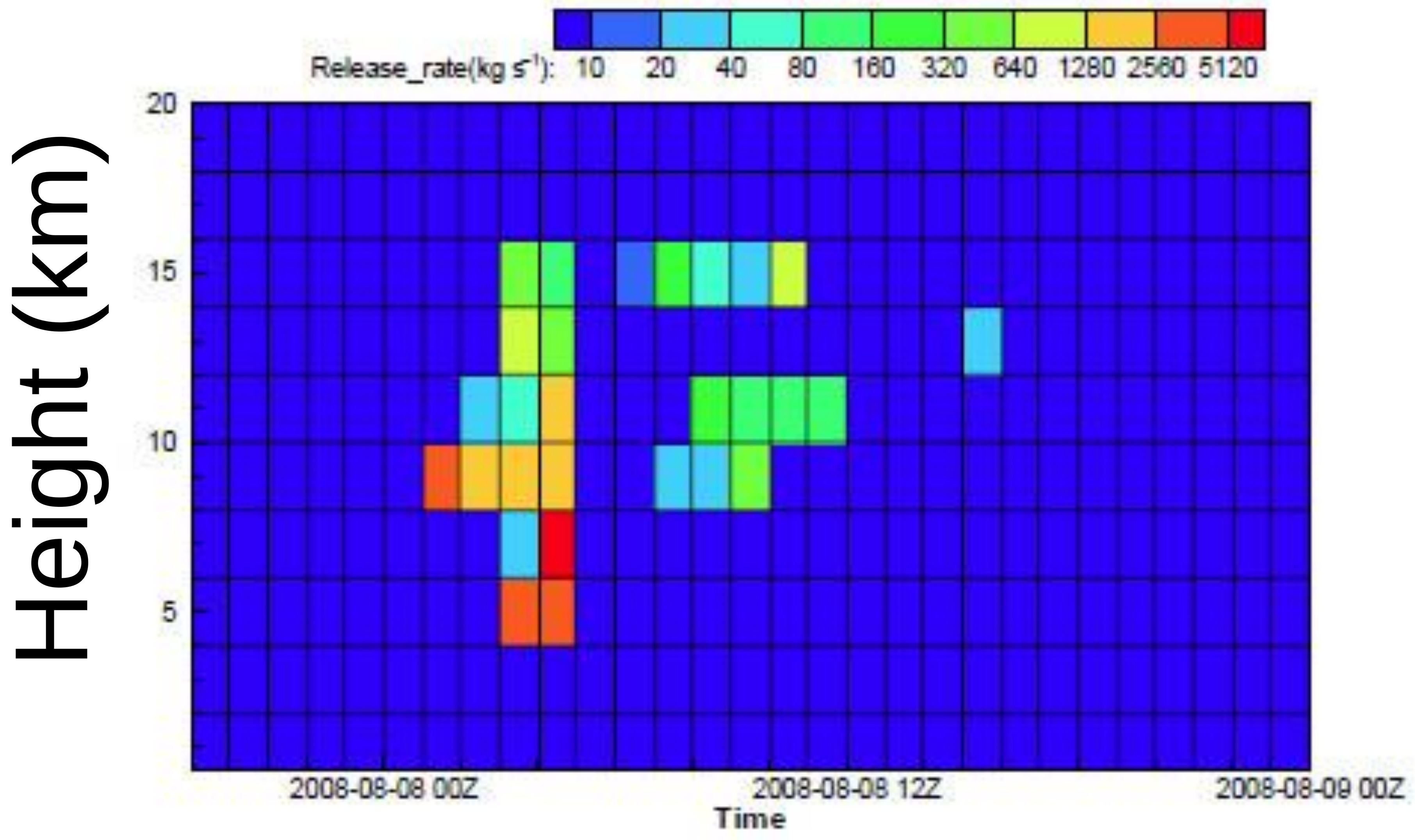
$C^h_n = M_{n1}x_1 + M_{n2}x_2 + M_{n3}x_3 + \ldots.\ M_{n\,290}x_{290}$

Since emissions are not well known, make this large so penalty for diverging from first guess emission is small.

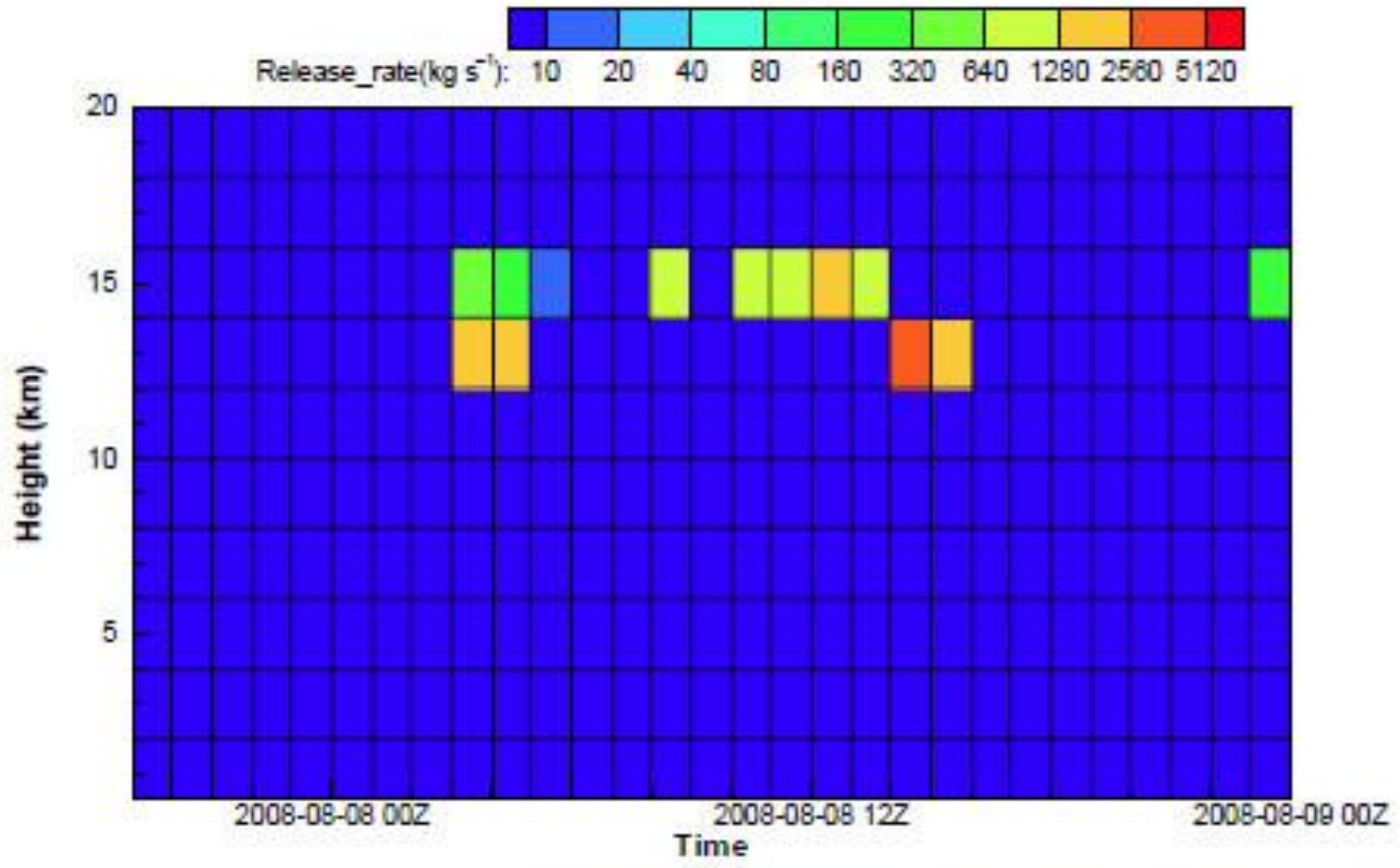
Minimize cost function to find emission terms $x_1 \ldots.\ x_{290}$.

Results – emission strength vs time and height

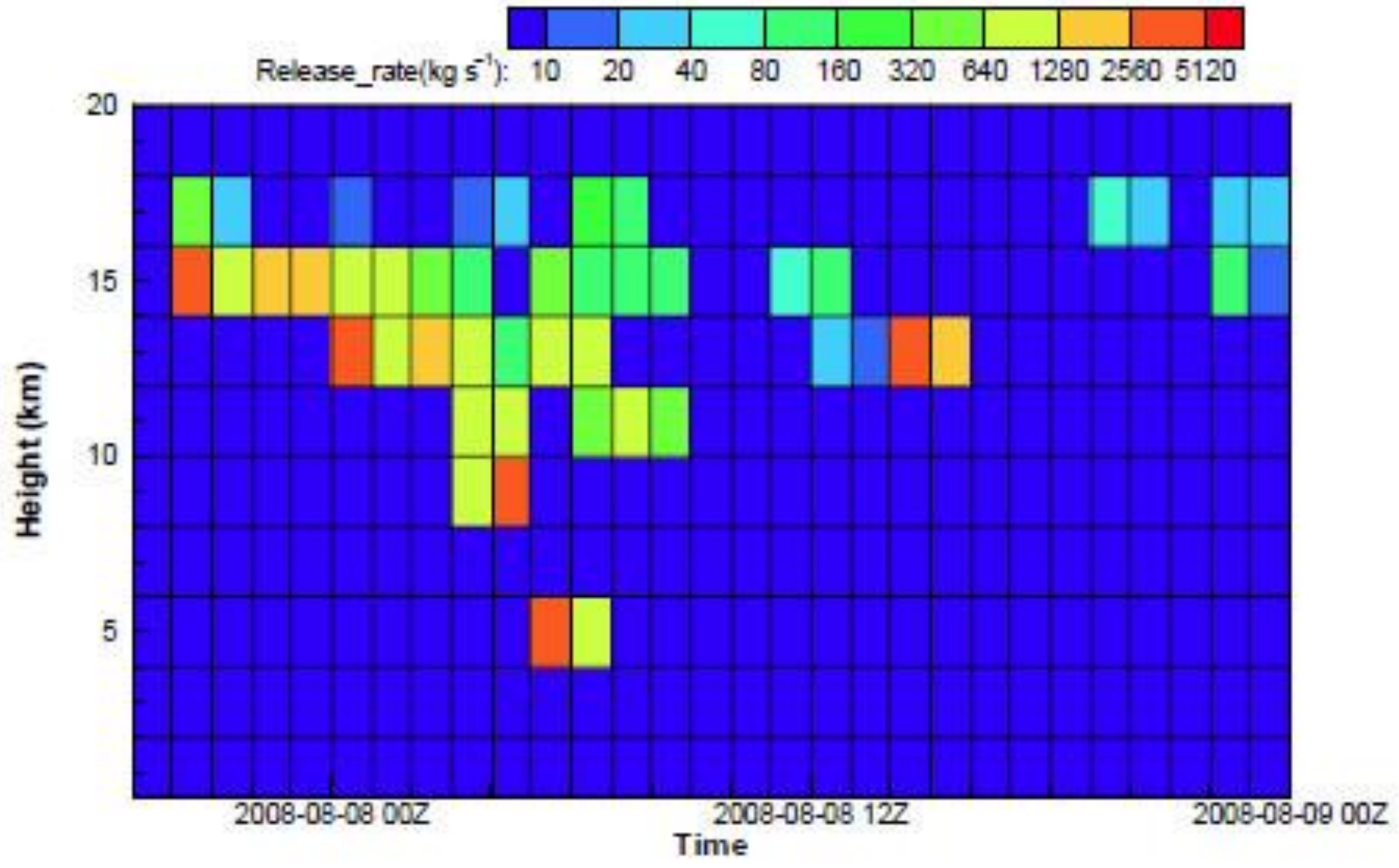
Different assumptions about vertical structure of ash cloud results in different emissions estimates.



Surface to observed cloud top



Singer layer where observed cloud top resides



Three layers centered around observed cloud top

For Kasatochi, 2008,

- data insertion was a relatively simple way to assimilate satellite retrievals, and obtain a good model simulation, and
- inverse modeling was used to obtain estimates of the quantitative emissions with time and height.

Both require assumptions about the ash cloud thickness.

We plan to continue work with both of these, and on verification metrics.

Knowns:
C^0_{nm} – observation at location m and time n.
q^b_{ikt} - first guess of emission rate at location i, height k and time period t.

Uknowns:
Emission rates q_{ikt} at location i, height k and time period t.

For this application, i, the location is known

Pick a q_{ikt} and use it to calculate C^h_{nm} (Model output at location m and time n) (the modeled mass loadings at location m and time n).

Calculate Cost Function

$$\mathcal{F} = \frac{1}{2}\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{i=1}^{I}\frac{(q_{ikt} - q^b_{ikt})^2}{\sigma^2_{ikt}} + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{M}\frac{(c^h_{nm} - c^o_{nm})^2}{\epsilon^2_{nm}}$$

Make this large so penalty for diverging from first guess emission is small.v

Pick a new q_{jkt} and use it and the TCM to calculate C^h_{nm} (the modeled mass loadings at location m and time n).

Hysplit output at location m and time n.

Calculate cost function again and see which one produces lower value.