

Aerosol Products for Atmospheric Transport Modeling Applications; A path forward

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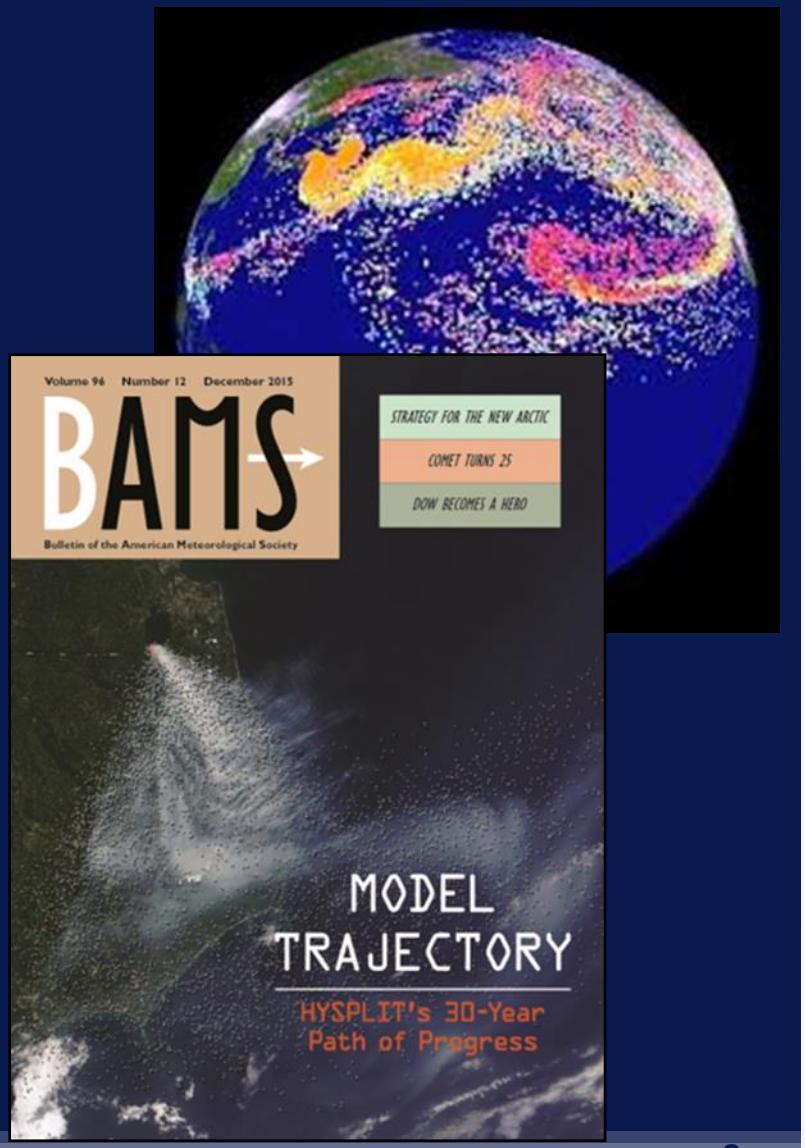
The accidental or intentional release of hazardous materials to the atmosphere (chemical, biological, nuclear agents, volcanic ash, smoke, dust) can have significant health, safety, national security, economic, and ecological implications.

Goals

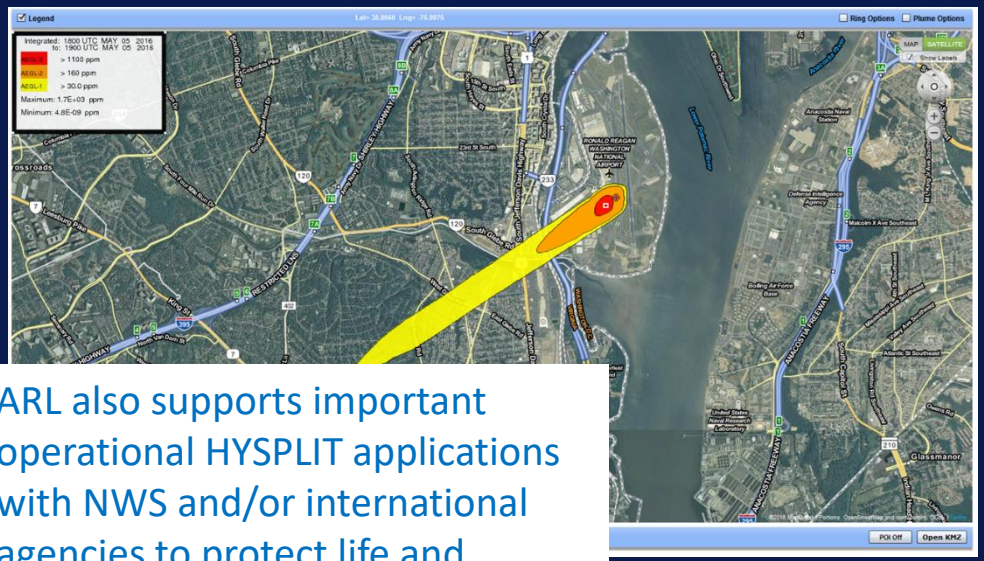
- Understand atmospheric transport and dispersion processes to improve the model quality.
- Assess the simulation uncertainties and applicability.
- Transition dispersion model products (Research to operations/applications/services) to NOAA and other agencies and organizations.

HYSPLIT

- We are the developers of the state-of-the-art HYSPLIT atmospheric transport and dispersion model.
- Operational and research grade dispersion products
- 4,100+ formally registered users from US and overseas (government, private sector, and academia) who require ability to use forecast data and/or the source code
- Extensive additional use by others
- ***READY*** HYSPLIT web site usage:
  - Average 70,000+ simulations/month
  - 1,200,000+ in 2017
  - Meteograms in READY: ~10,000/day
- ***HYSPLIT peer literature reference***:
  - 800+ references to Draxler and Hess, 1998. Source: Web of Science
  - 650+ references to HYSPLIT BAMS Stein et al, 2015 (published in December, 2015)



Operational uses



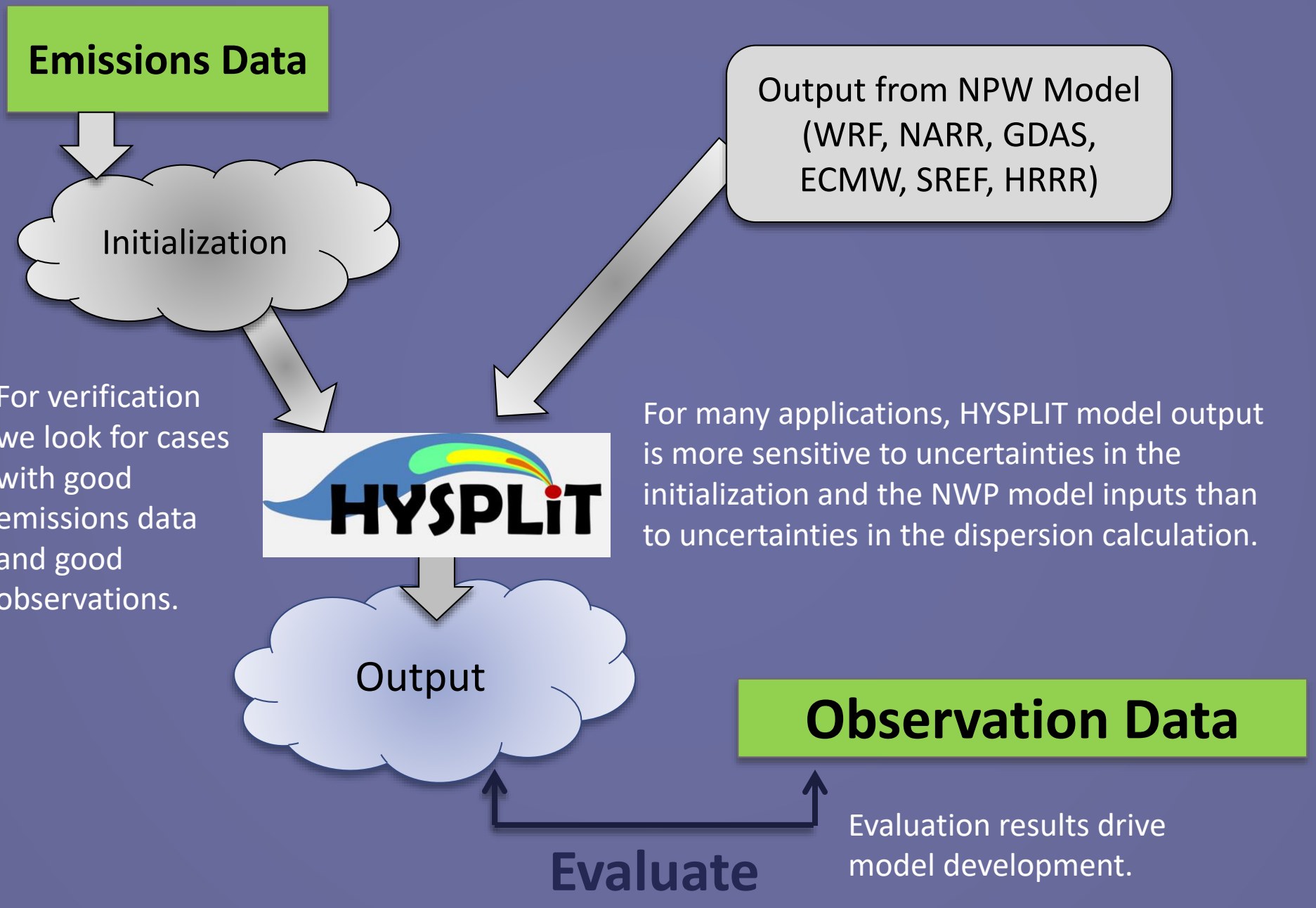
- HYSPLIT used operationally by the Weather Forecast Offices to forecast transport and dispersion of **hazardous materials from industrial accidents**, to protect life and property

ARL also supports important operational HYSPLIT applications with NWS and/or international agencies to protect life and property in the event of:

- Nuclear accidents
- Wildfires
- Clandestine nuclear activities (Comprehensive Test Ban Treaty Organization)
- Volcanic eruptions



MODELS NEED DATA



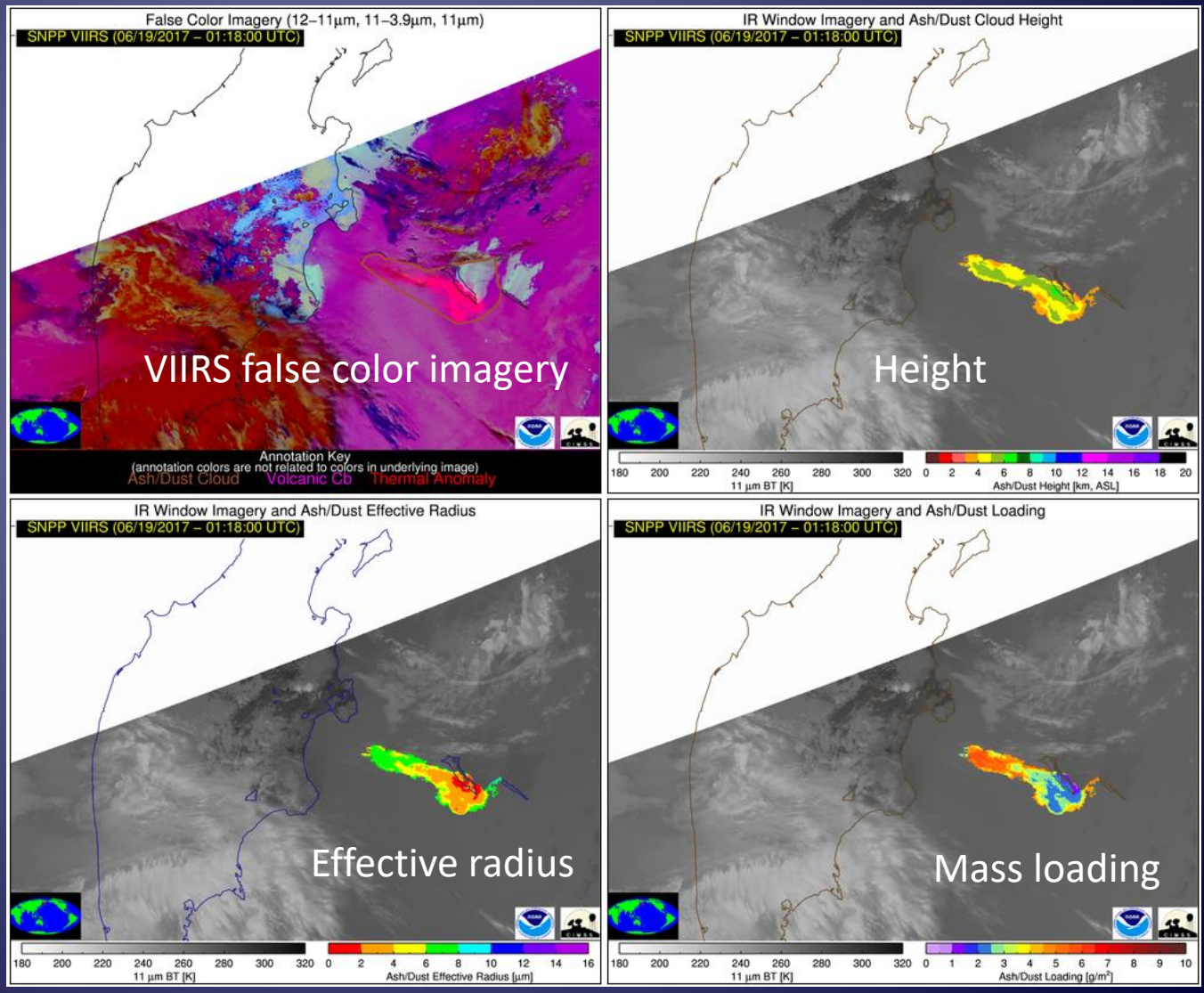
Volcanic Clouds (ash and SO_2)

- Utilize new sources of information
  - Satellite data
- Reduce uncertainty in initialization (source term)
  - Data insertion
  - Inversion algorithms
- produce probabilistic output
- Quantitative verification metrics
- Automate



VOLcanic Cloud Analysis Tookit (VOLCAT): An "enterprise information system" is a scientific software package that transforms large volumes of satellite (using all relevant GEO and LEO satellites, *including S-NPP*) and non-satellite data into, application specific, actionable information.

VOLCAT volcanic eruption products derived from a SNPP overpass on June 19, 2017 at 01:18 UTC shows the volcanic ash cloud generated by a short but powerful eruption of Shiveluch in Kamchatka.



Steps to using satellite products in HYSPLIT

Identify product which is potentially useful.

Transfer the product from where it lives to where we can work with it.

Transform the satellite product into a format which can be ingested into HYSPLIT or compared to HYSPLIT model output.

Understand satellite product data limitations and uncertainties.

Devise, revise, and evaluate methods for using the data.

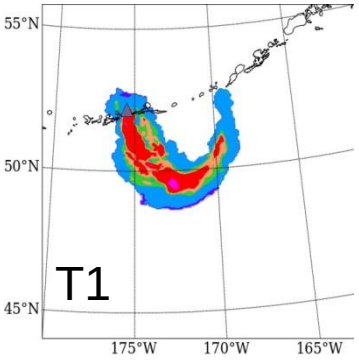
Less time on this

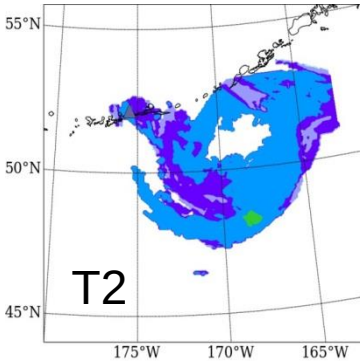
More time on this!

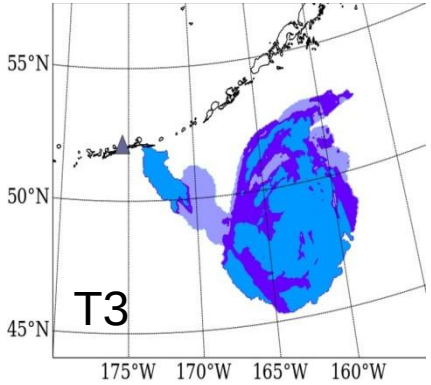
An enterprise information system allows users to spend more time using the data.

Data Insertion

Passive IR satellite retrievals of column mass loading of ash





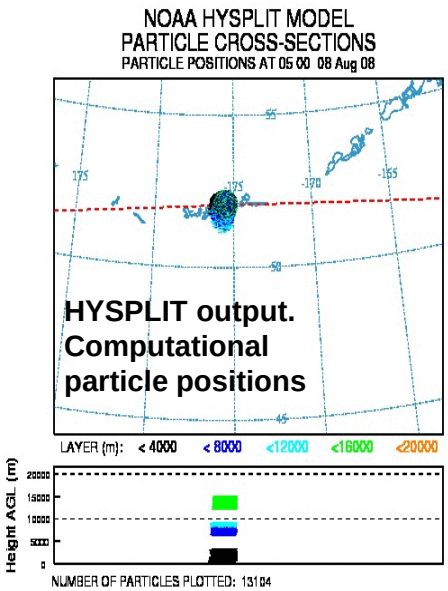


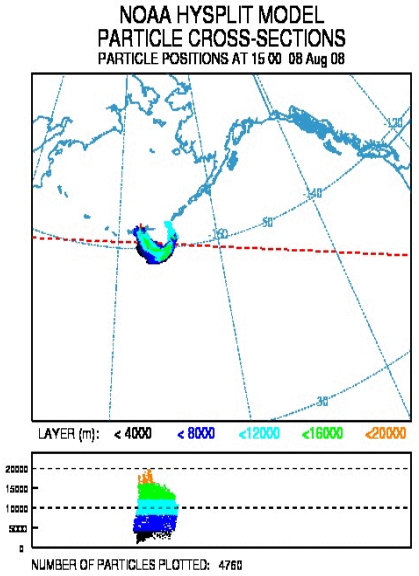
Cylindrical Source Term
08/08 04:00 UTC

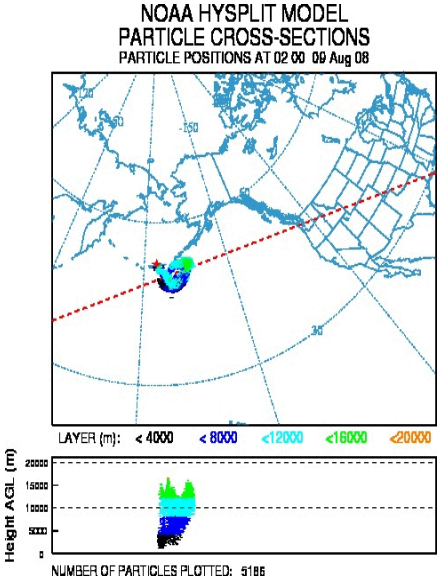
Source term RT1
08/08 14:00 UTC

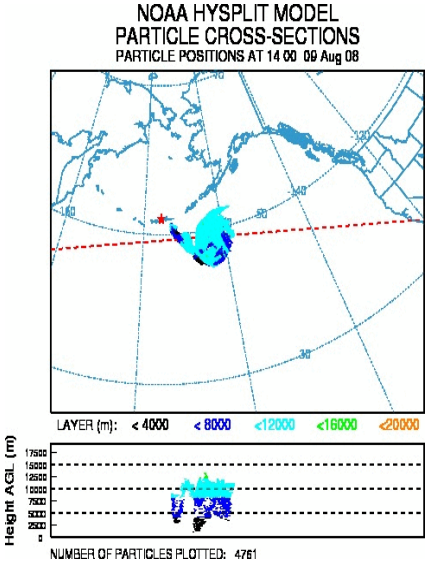
Source term RT2
08/09 01:00 UTC

Source term RT3
08/09 13:00 UTC









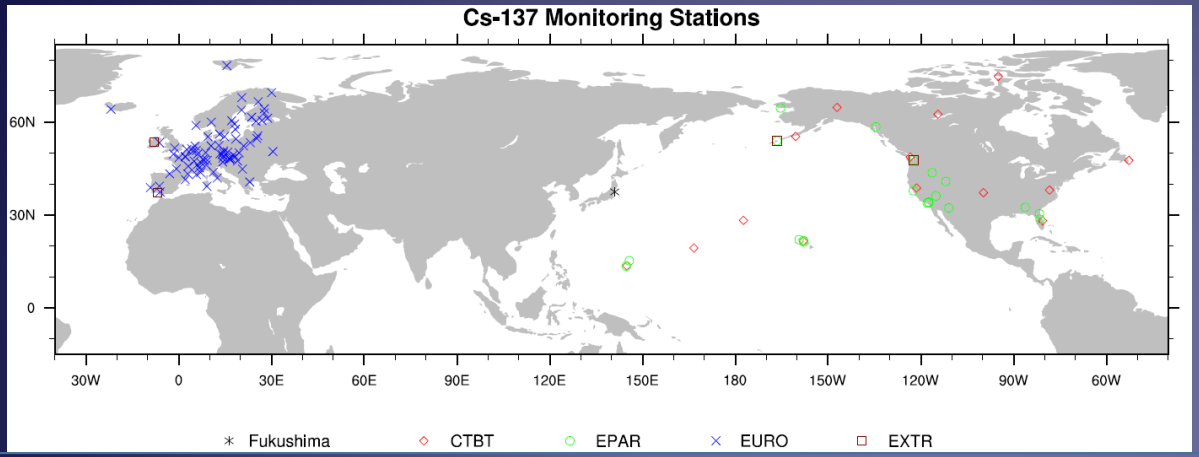
Crawford, et al., (2016) Initializing HYSPLIT with satellite observations of volcanic ash: A case study of the 2008 Kasatochi eruption *J. of Geophysical Research: Atmospheres,* 121, p 10,786, doi:10.1002/2016D024779

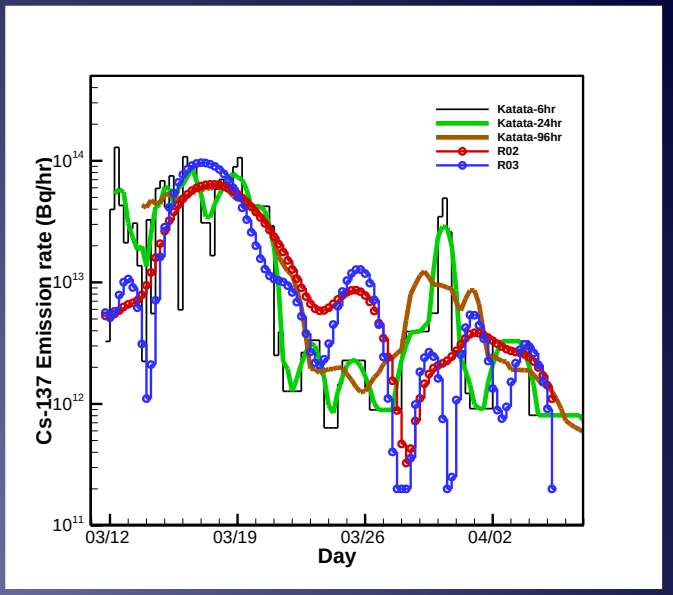
Inverse modeling

- Infer information about sources (strength, location, temporal variation/trends, vertical distribution)
- Applications:
  - Comprehensive Test Ban Treaty Organization
  - Greenhouse gas sources monitoring and verification
  - Volcanoes
  - Nuclear accidents

HYSPLIT inverse modeling

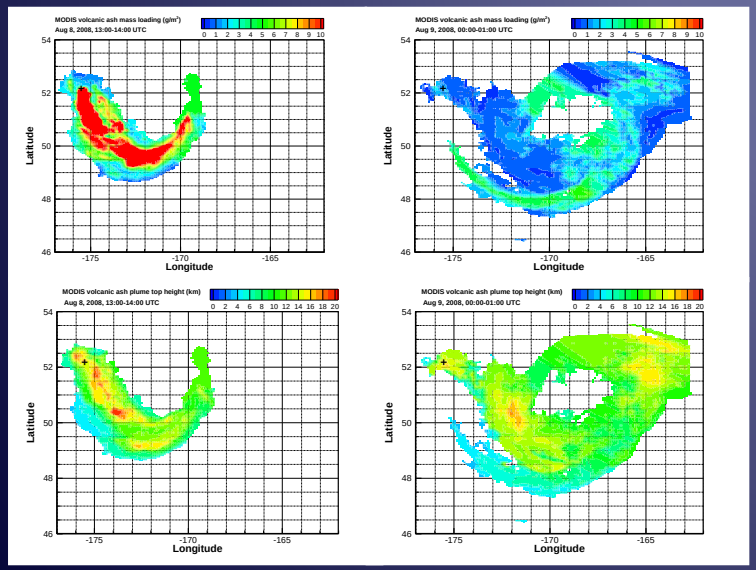
1. Fukushima source term estimation

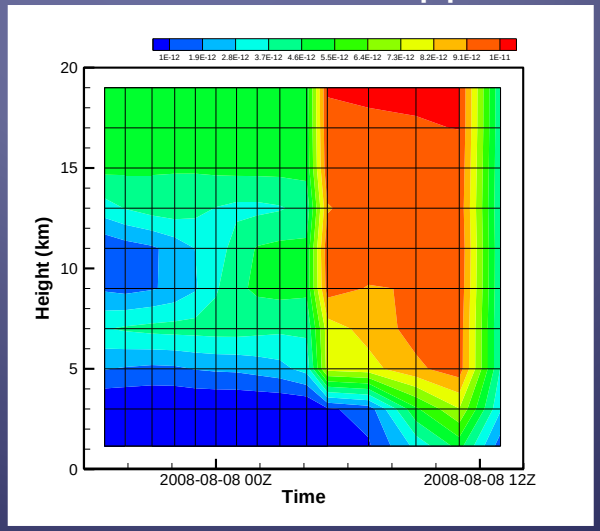




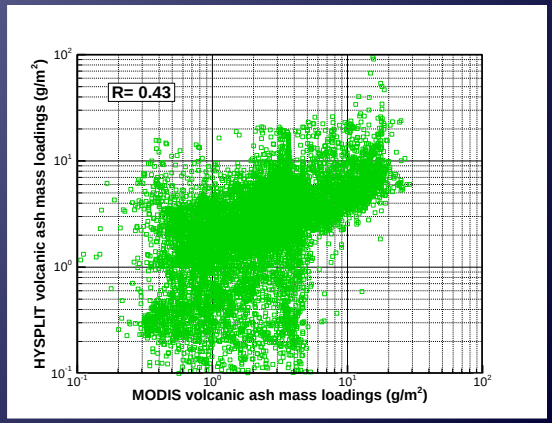
Ref: Source term estimation using air concentration measurements and a Lagrangian dispersion model–Experiments with pseudo and real cesium-137, T Chai, R Draxler, A Stein – Atmos. Environ., 2015

2. Volcanic ash application - Kasatochi eruption





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.

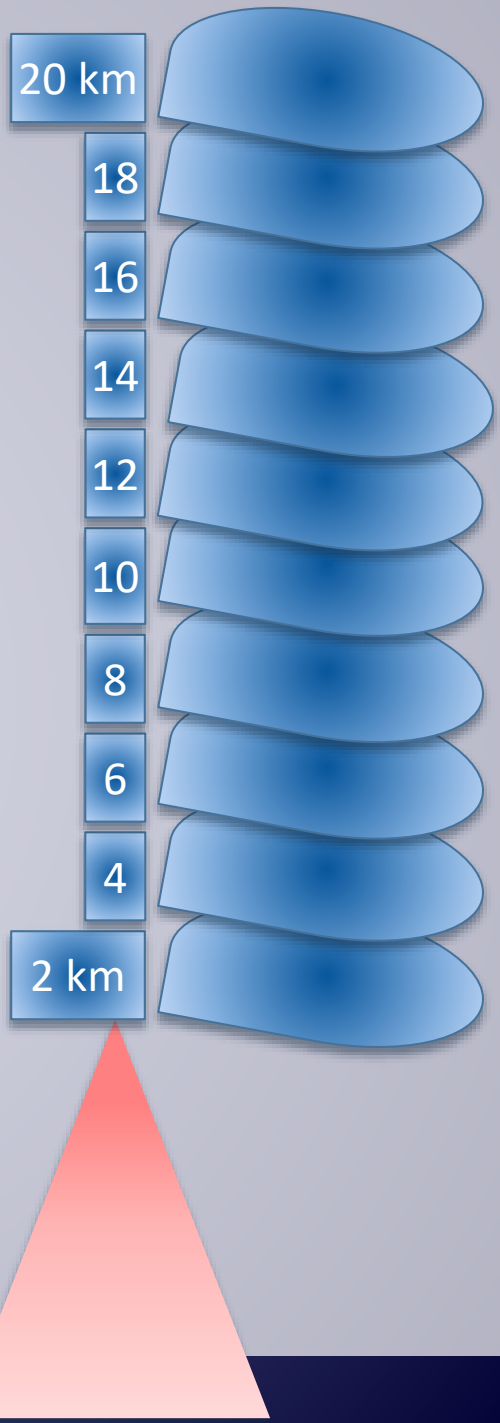
1 – determine positions and times of likely emissions.

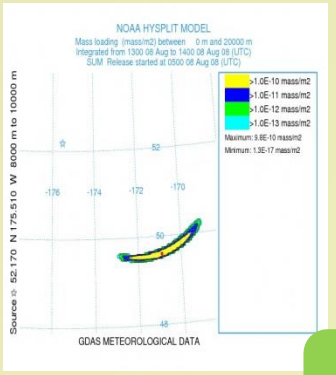
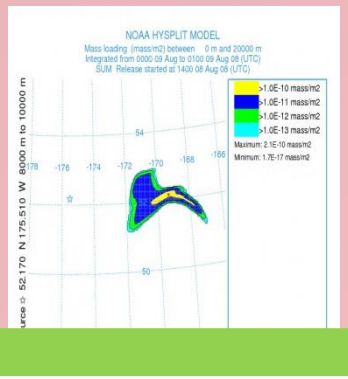
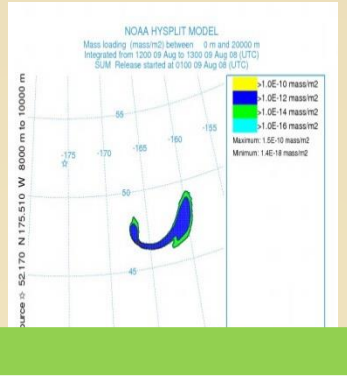
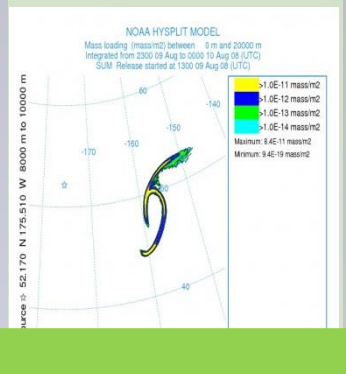
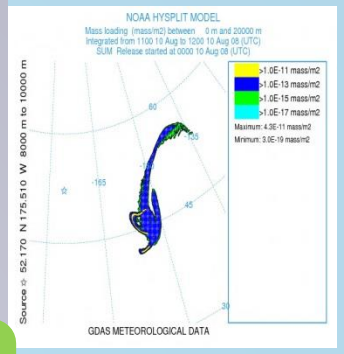
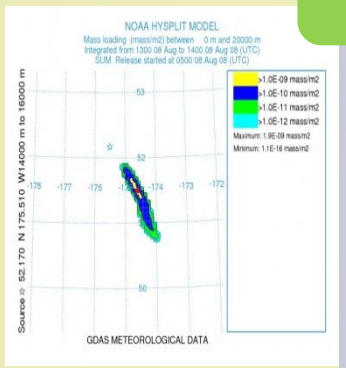
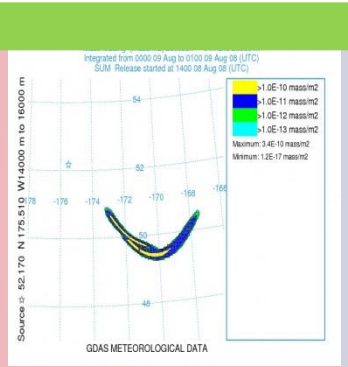
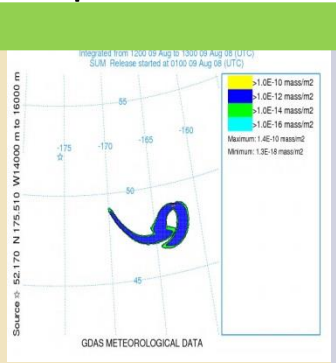
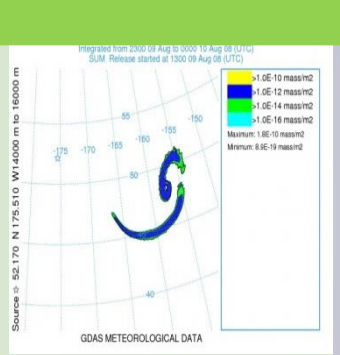
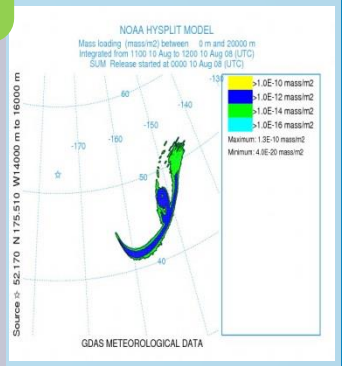
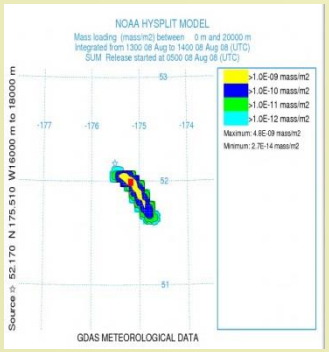
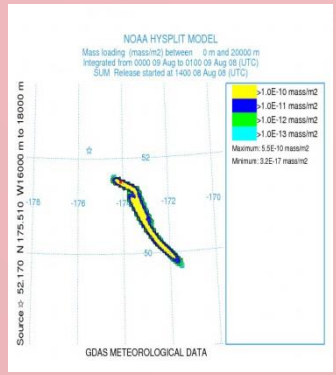
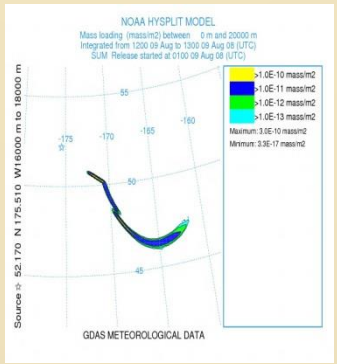
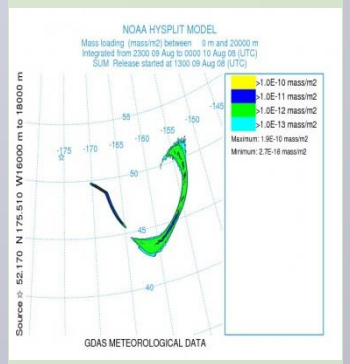
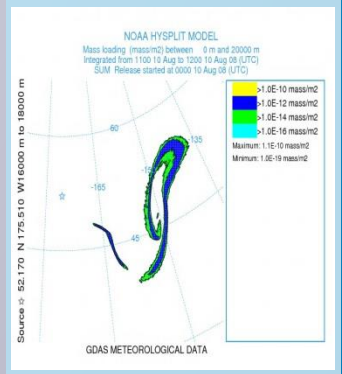
HYSPLIT RUNS For Inversion Algorithm

290 HYSPLIT Simulations

Unit emission for every hour

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



	T1	T2	T3	T4	T5
8-10 km 5-6 UTC					
14-16 km 5-6 UTC					
16-18 km 5-6 UTC					

3 of the 290 runs (output shown at 5 time periods)

2 – Decide on observations
3 – Create TCM

Transfer Coefficient Matrix

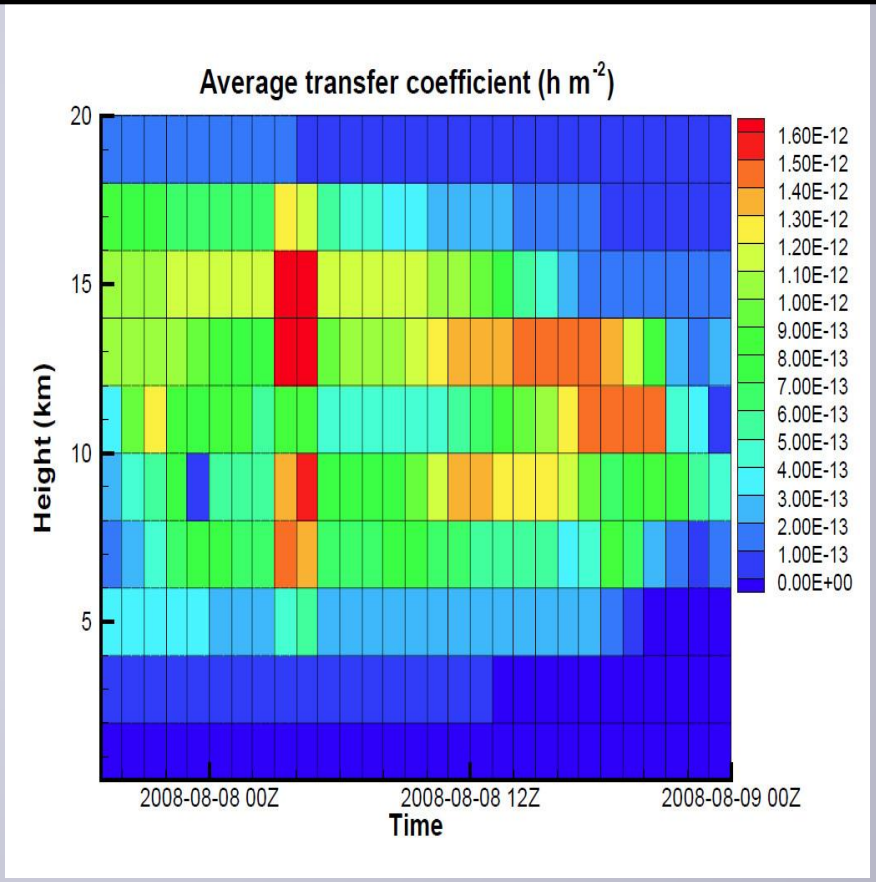
Which HYSPLIT runs produce ash which coincides with observed ash?

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

290 columns for each HYSPLIT run

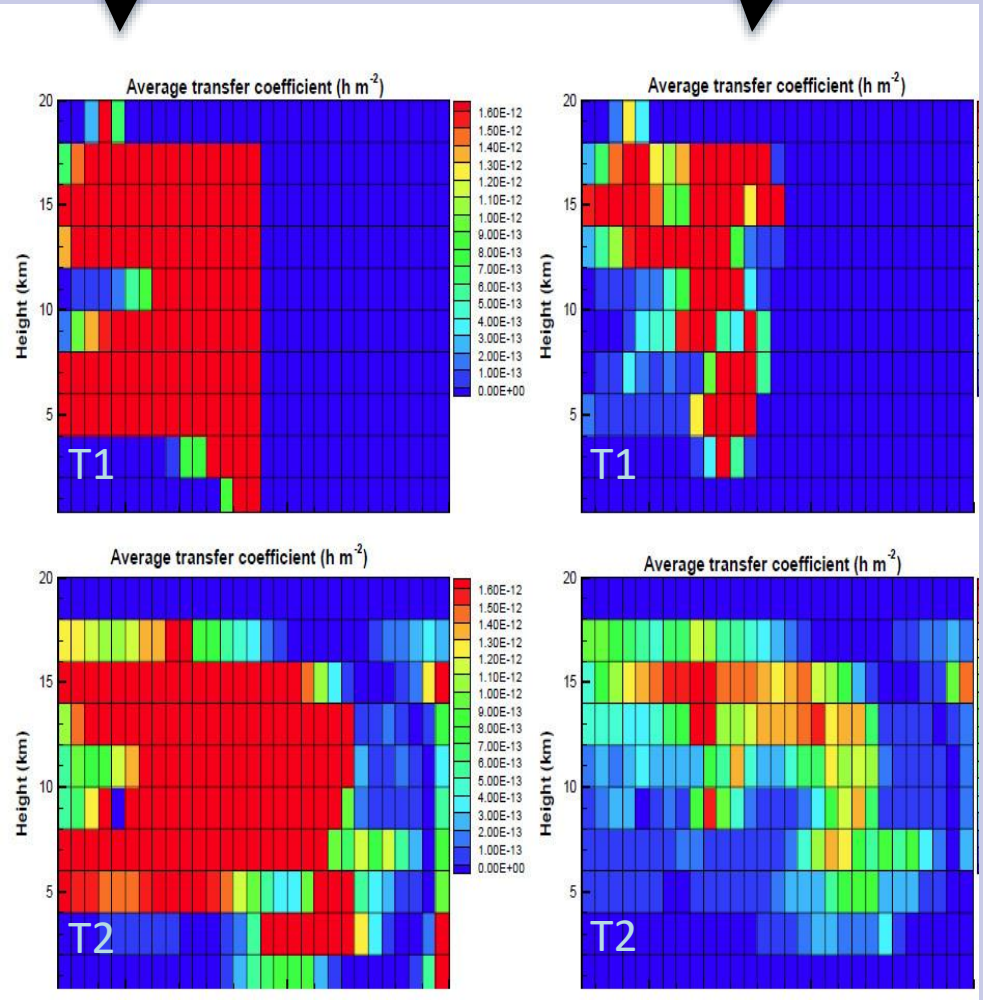
Y number of observation points / times

Mass/m² from HYSPLIT run at observation point / time.



Model results at
An observation point $C^h_1 = M_{1\,1}x_1 + M_{1\,2}x_2 + M_{1\,3}x_3 + \ldots M_{1\,290}x_{290}$ Where x_N are the unknown emissions

Which observations to use?



Assumptions about vertical structure of observations?

- Ash present from surface to observed cloud top
- Ash present only in layer of observed cloud top
- Ash present in layer of observed cloud top and also layer above and layer below

Observations at how many times should be used?

As newer observations become available should older observations be discarded?

Should clear sky observations be taken into account?

Areas where no ash is observed

Area above the observed cloud top

How to Search for emissions?

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.

Cost Function

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

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

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

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

Some conclusions

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

However predictions made with the different emissions estimates all show decent skill.

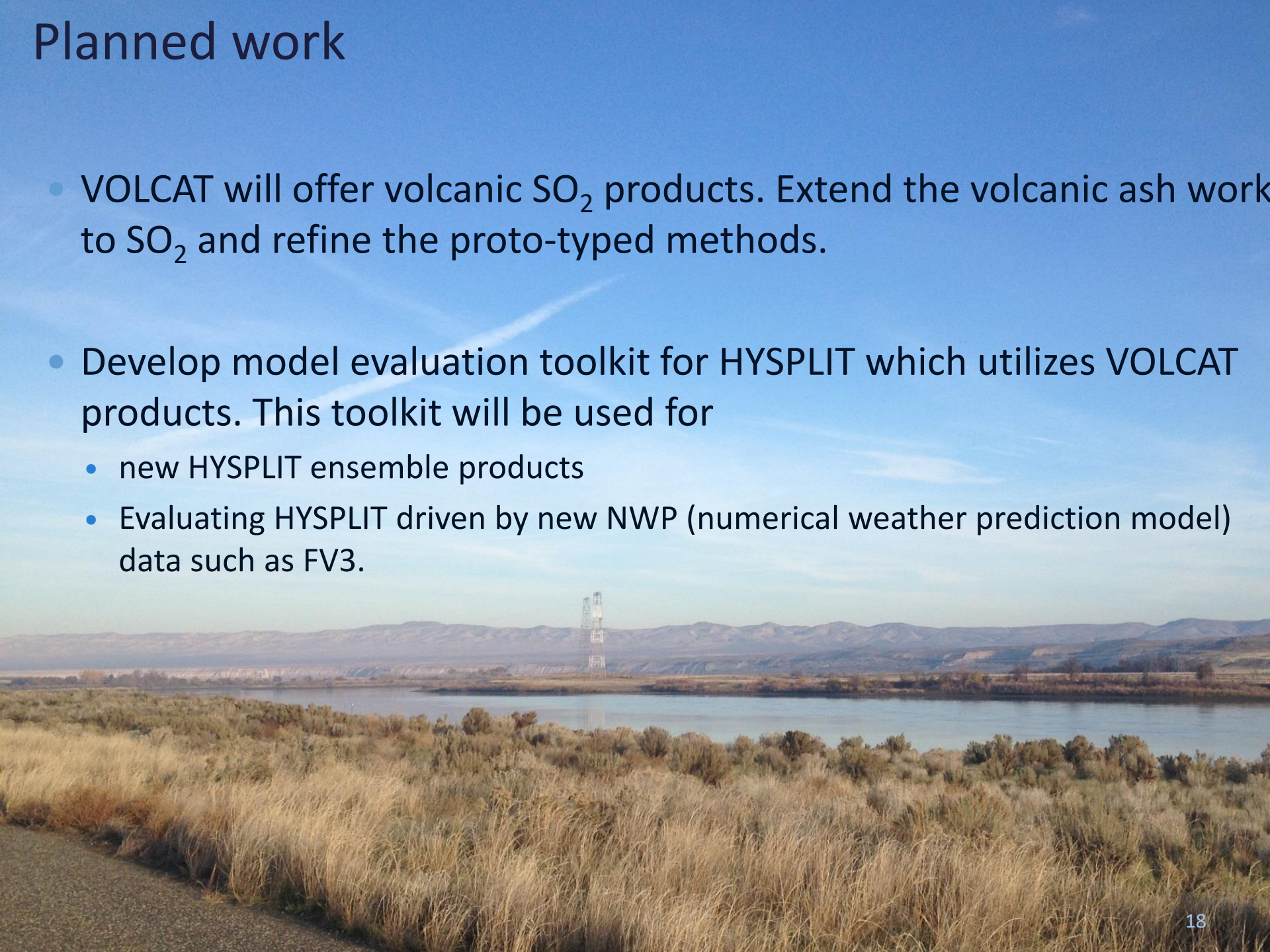
Enforcing zero mass loading in ash-free regions does not create emission estimates which improve model skill.

Assimilating observations from multiple time periods is beneficial.

Planned work

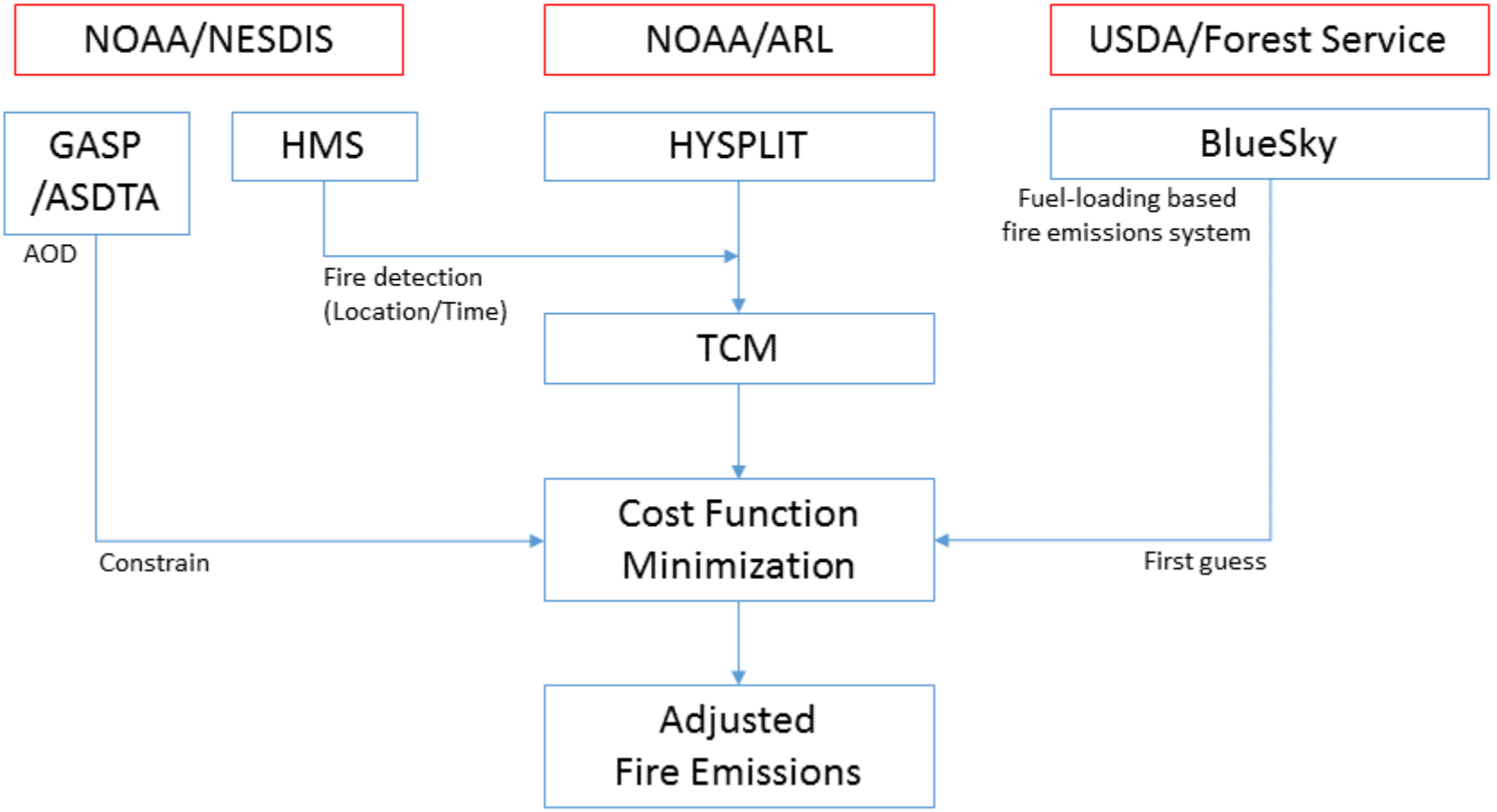
- VOLCAT will offer volcanic SO_2 products. Extend the volcanic ash work to SO_2 and refine the proto-typed methods.

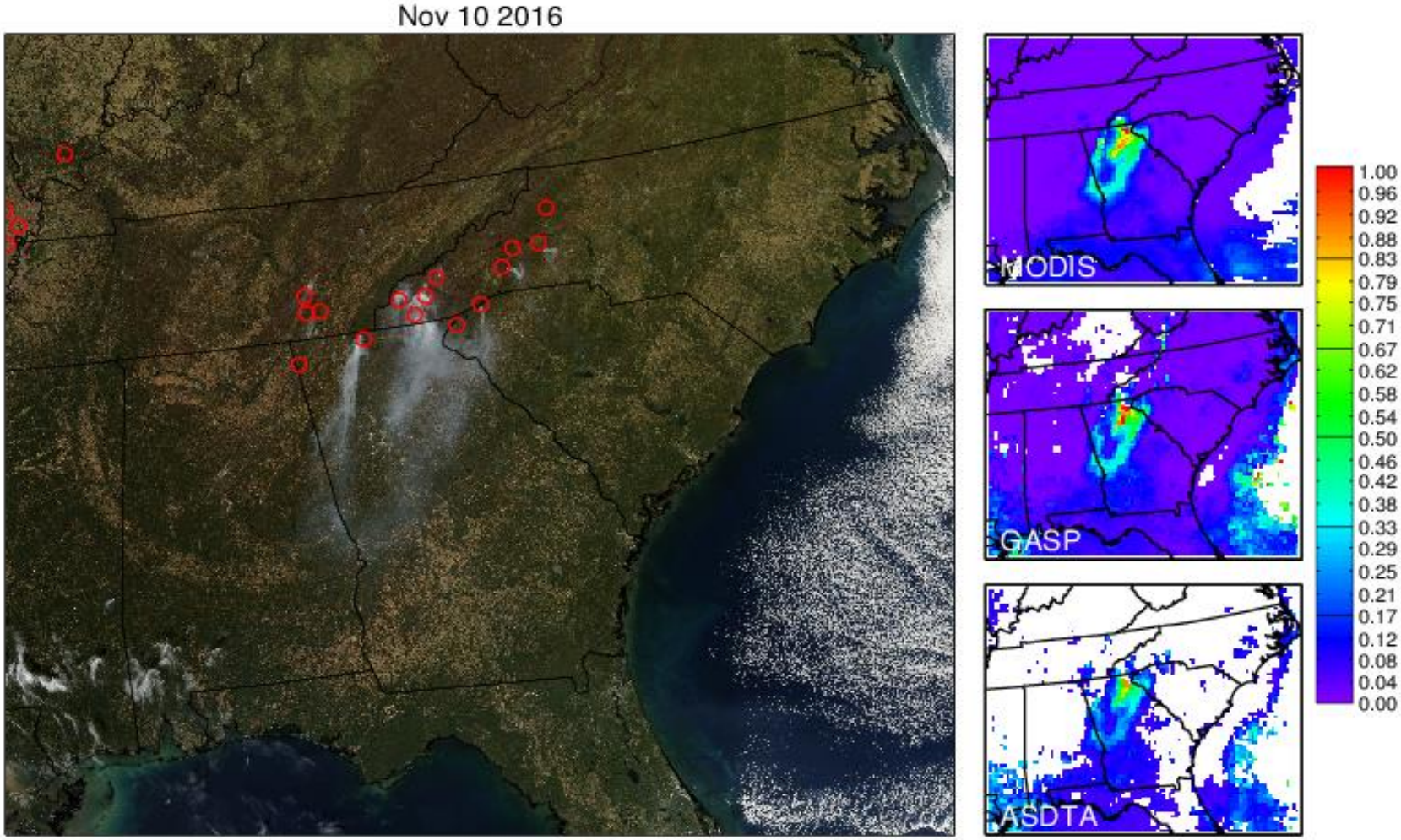
- Develop model evaluation toolkit for HYSPLIT which utilizes VOLCAT products. This toolkit will be used for
  - new HYSPLIT ensemble products
  - Evaluating HYSPLIT driven by new NWP (numerical weather prediction model) data such as FV3.



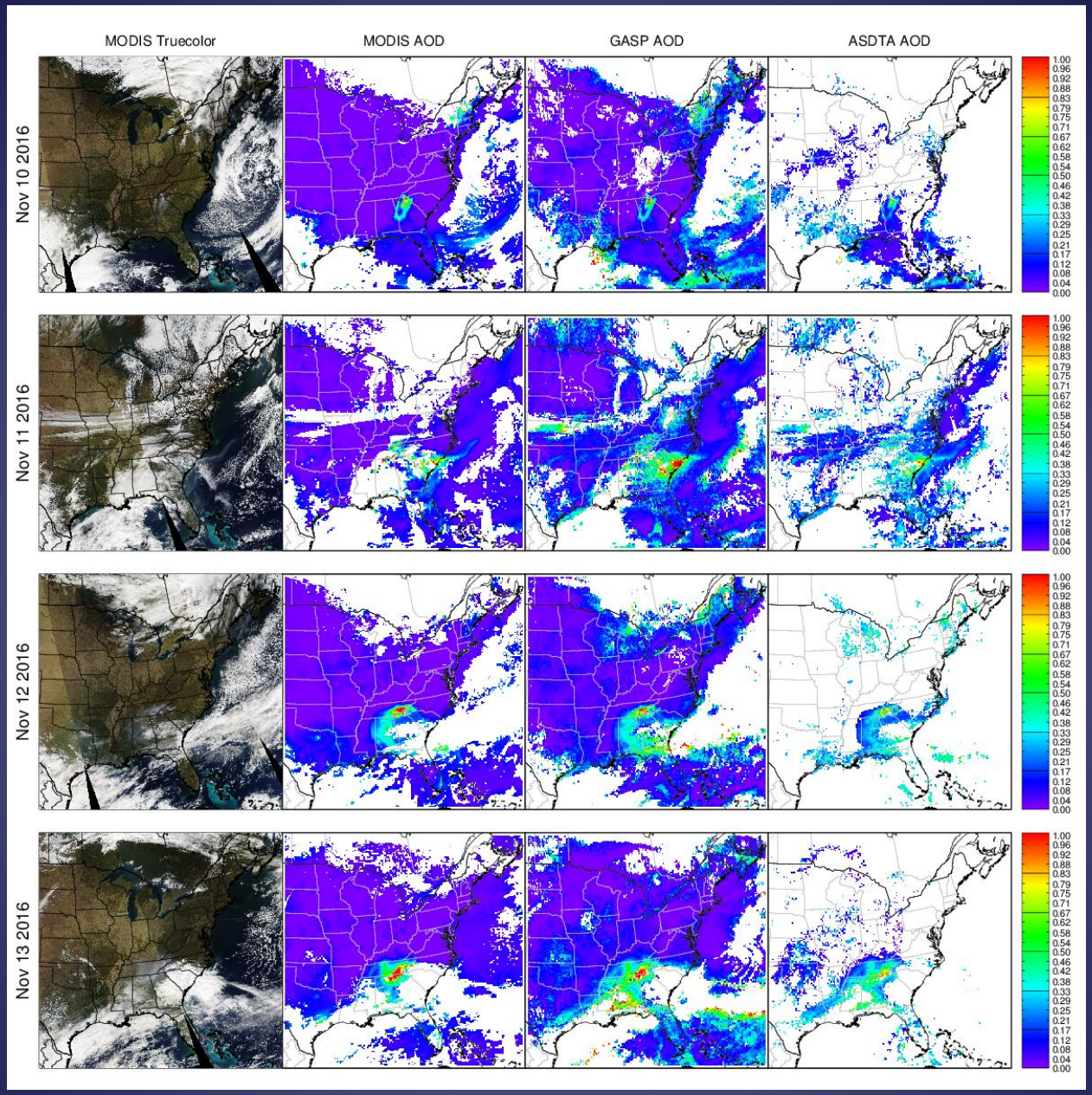
Thanks!!

HYSPLIT-based Emissions Inverse Modeling System (HEIMS-fire)

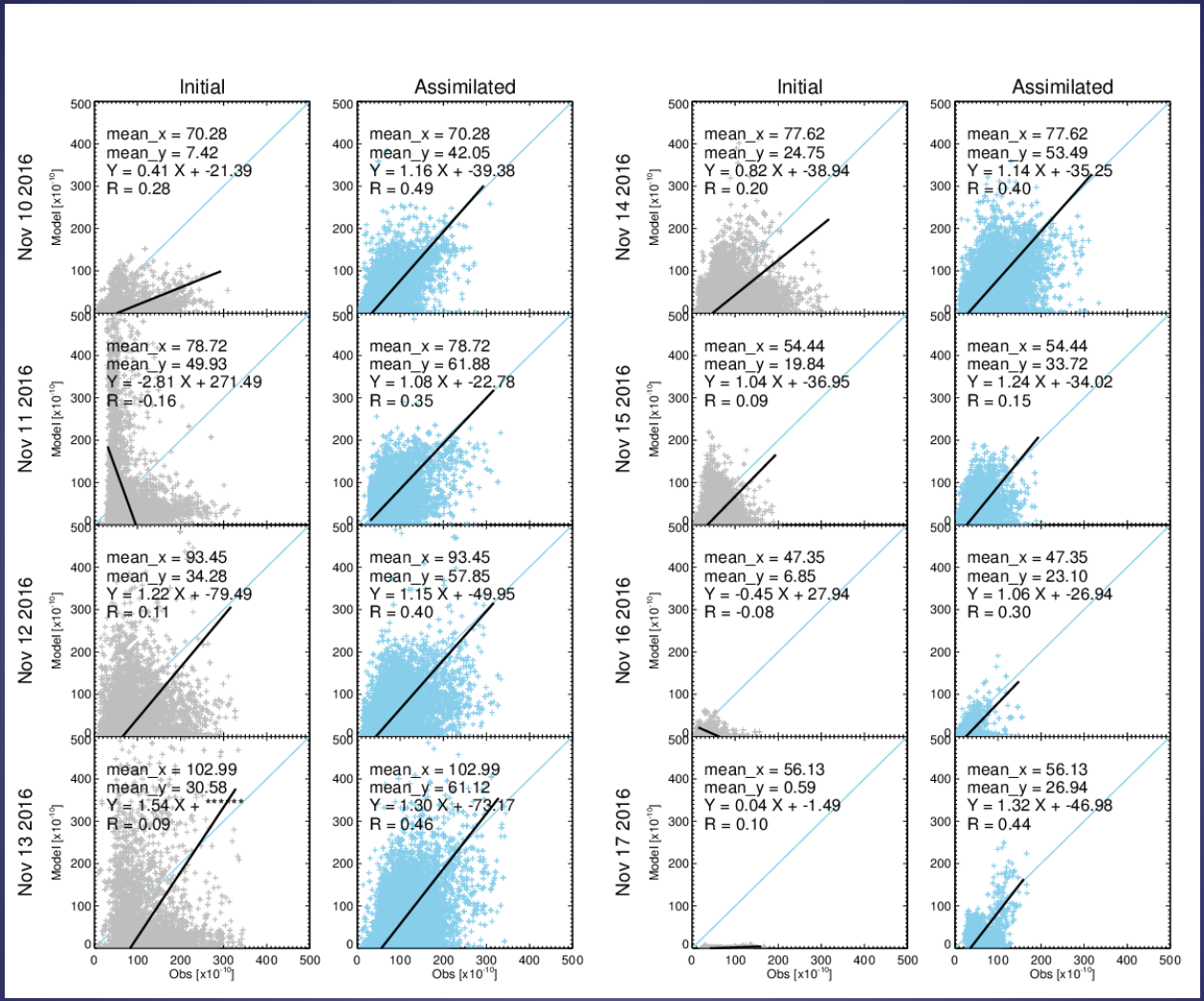




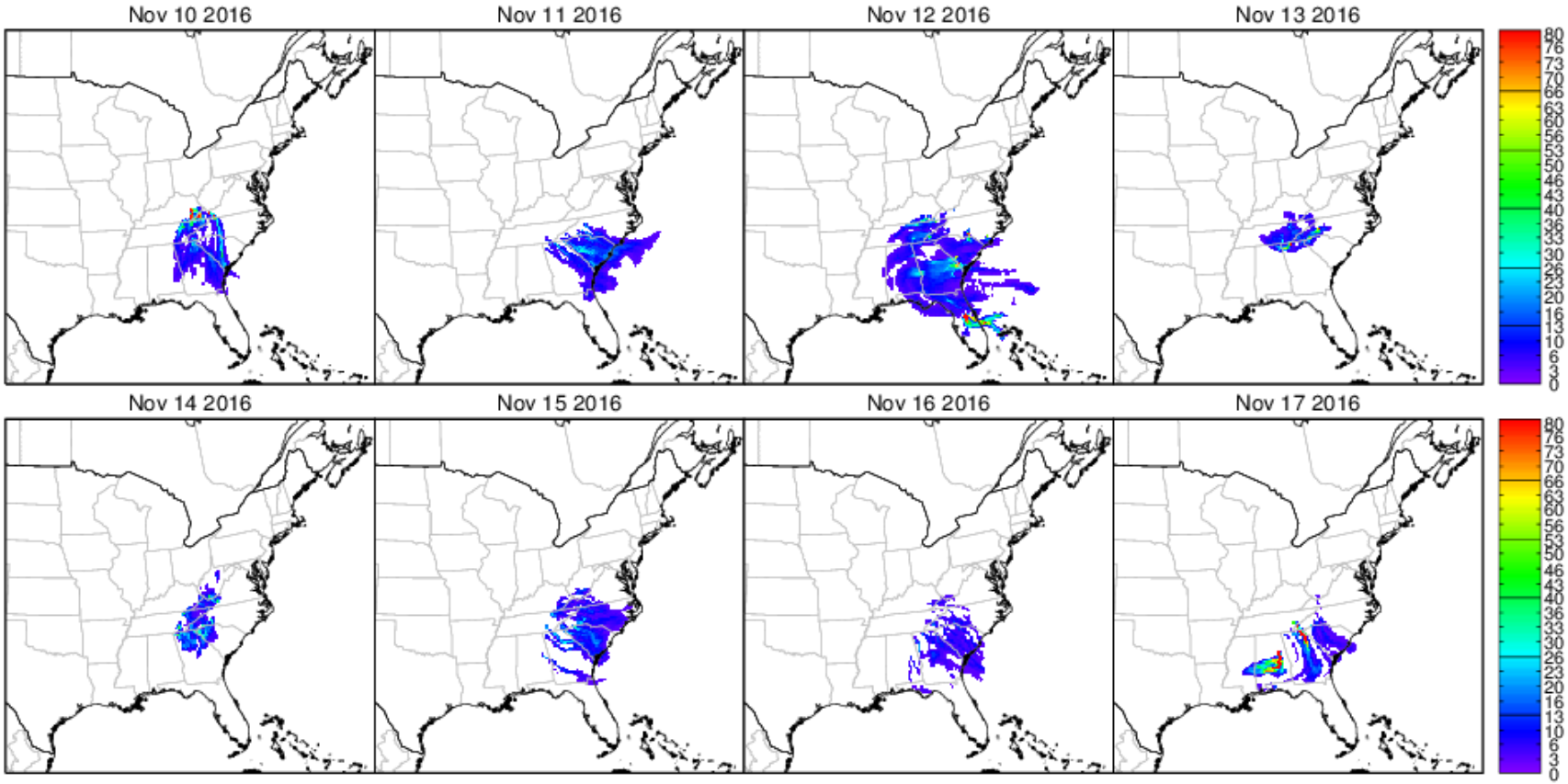
Observed fire events in southeastern US on November 10, 2016. MODIS truecolor image is shown in left panel, and MODIS, GASP, ASDTA aerosol optical depths are shown in right panel. Red circles indicate locations of wildfires detected by HMS.



Observed wildfire events for the study during November 10-17, 2016. MODIS truecolor images, MODIS AOD, GASP AOD, and ASDTA AOD are shown.



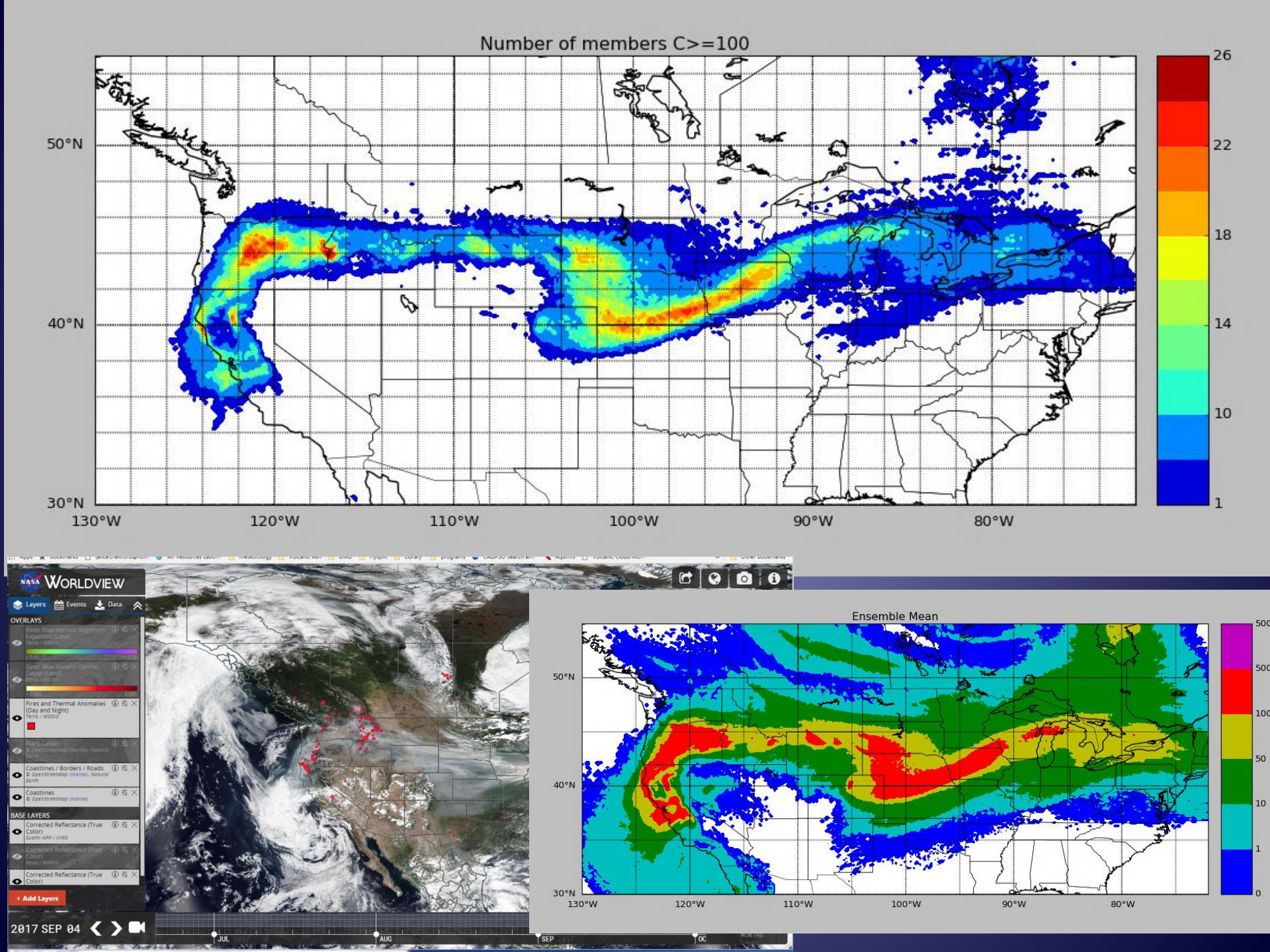
Scatter plot comparison between initial and assimilated particulate matter column concentrations using adjusted fire emissions during November 10-17, 2016



Spatial distributions of reconstructed fire particulate matter column concentrations using assimilated wildfire emissions.

		Nov. 10	Nov. 11	Nov. 12	Nov. 13	Nov. 14	Nov. 15	Nov. 16	Nov. 17
	Observation	70.28	78.72	93.45	102.99	77.62	54.44	47.35	56.13
mean	Initial	7.42	49.93	34.28	30.58	24.75	19.84	6.85	0.59
	Assimilated	42.05	61.88	57.85	61.12	53.49	33.72	23.10	26.94
RMSE	Initial	73.34	118.20	93.68	11.53	69.63	46.56	50.49	61.22
	Assimilated	51.43	46.50	68.14	72.44	51.87	39.28	40.61	43.69
Slope	Initial	0.41	-2.81	1.22	1.54	0.82	1.04	-0.45	0.04
	Assimilated	1.16	1.08	1.15	1.30	1.14	1.24	1.06	1.32
R	Initial	0.28	-0.16	0.11	0.09	0.2	0.09	-0.08	0.1
	Assimilated	0.49	0.35	0.40	0.46	0.4	0.15	0.3	0.44

Statistics of modeled smoke particulate column air masses using initial and assimilated fire emissions (unit: $x10^{-10}$ kg)

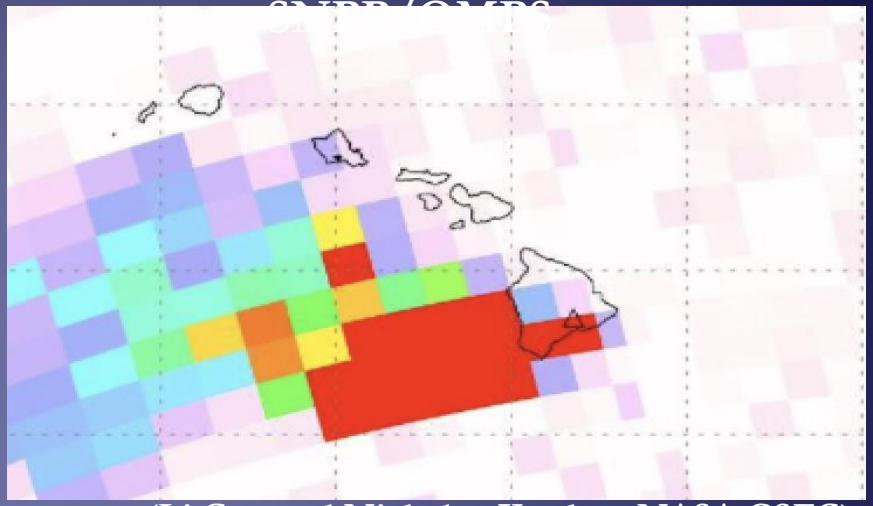

Number of members C>=100
50°N
40°N
30°N
130°W
120°W
110°W
100°W
90°W
80°W
26
22
18
14
10
1
NASA WORLDVIEW
Layers
Events
Data
OVERLAYS
Deep Blue Aerosol Angstrom Exponent (Land)
Deep Blue Aerosol Optical Depth (Land)
Fires and Thermal Anomalies (Day and Night)
Terra / MODIS
Place Labels
Coastlines / Borders / Roads
Coastlines
BASE LAYERS
Corrected Reflectance (True Color)
Suomi NPP / VIIRS
Aqua / MODIS
+ Add Layers
2017 SEP 04
JUL
AUG
SEP
Ensemble Mean
50°N
40°N
30°N
130°W
120°W
110°W
100°W
90°W
80°W
500
500
100
50
10
1
0

SO_2 Forecasting from Kilauea Eruption

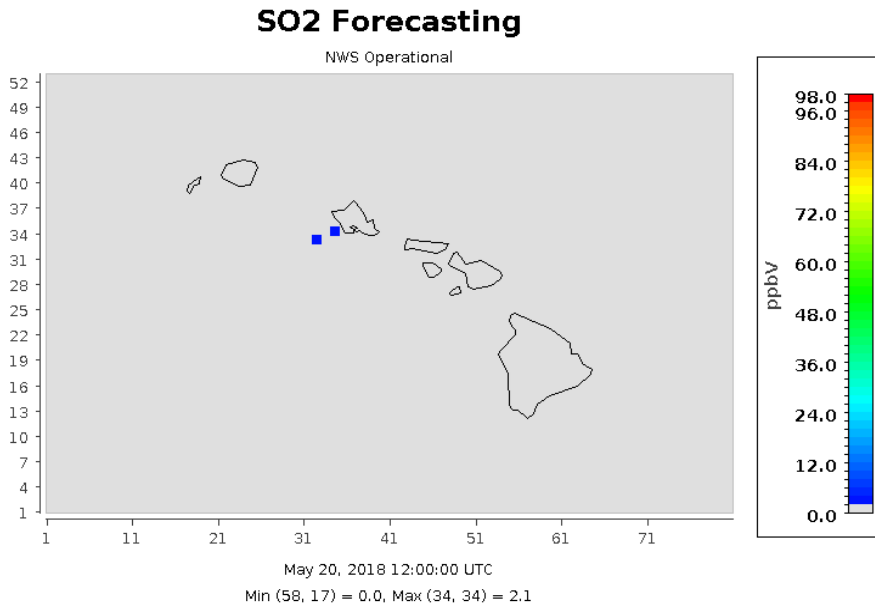
(Daniel Tong, OAR/ARL)

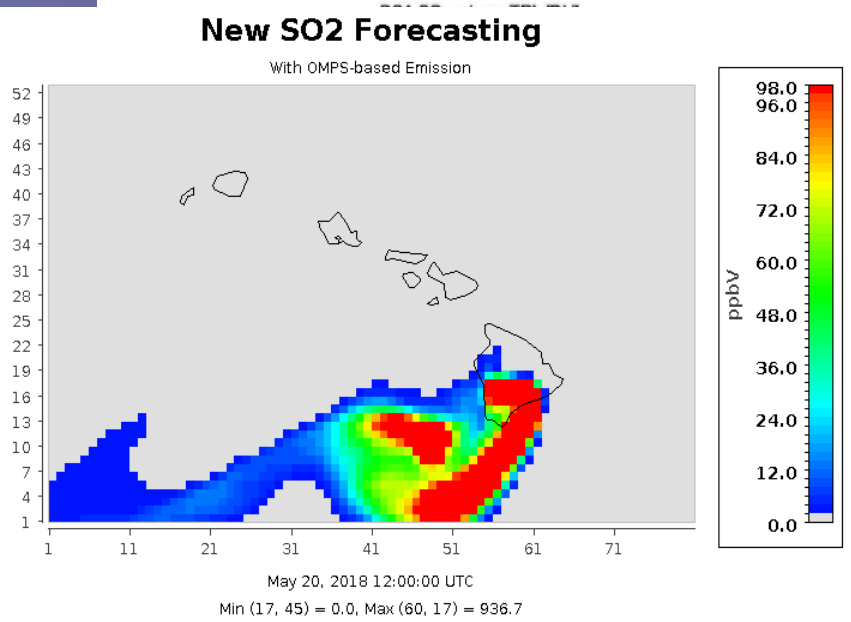


(REUTERS/Terray Sylvester)



(Li Can and Nickolay Krotkov, NASA GSFC)





QUESTIONS