Volcano Applications and Emergency Response

Presenter: **Alice Crawford**

Other Team Members: **Allison Ring, Tianfeng Chai, Barbara Stunder, Binyu Wang, Sonny Zinn, Hyun-Cheol Kim, Christopher Loughner, Fantine Ngan, Mark Cohen**

NOAA Air Resources Laboratory

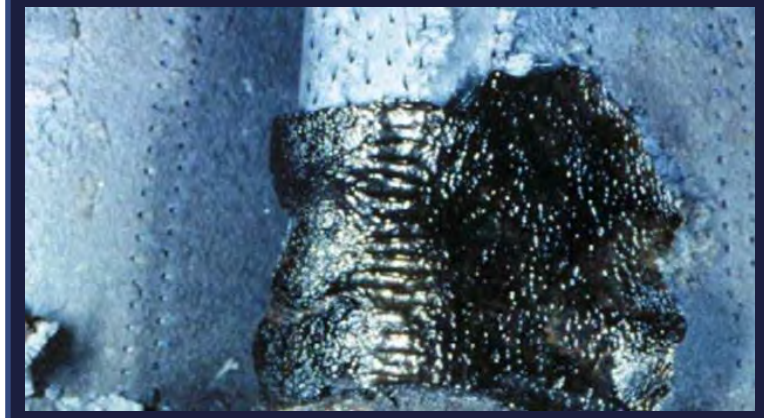
March 2022

Modeling of Volcanic Emissions

Climate and Weather Impacts

1991 eruption of Mount Pinatubo (USGS)

Aviation Hazards



Ash deposits inside jet engine that encountered ash cloud from Redoubt Volcano on 15 December 1989.

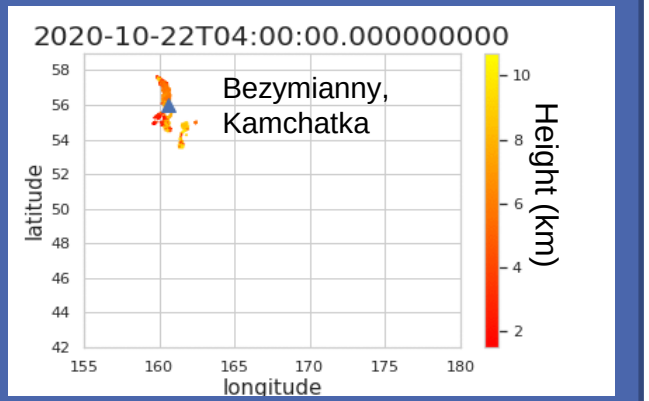
U.S. Geological Survey

Infrastructure Hazards

U.S. Geological Survey

Human Health Hazards

Tracer of opportunity



HYSPLIT simulation

Relevance to OAR Strategic Goals

Make forecasts better

Improve accuracy, precision, and efficiency of forecasts and predictions to save lives and property and support a vibrant economy.

- Design tools and processes to forecast high-impact weather, water, climate, ocean, and ecosystem events
- Transition science that meets users' current and future needs
- Develop interdisciplinary Earth system models

Raikoke eruption, June 2019
Picture taken from International Space Station (CNN)

Hazard Assessments

What is the maximum airborne ash concentration that might exist at Hanford after a volcanic event with recurrence intervals of 2,500 and 10,000 years?

Hanford site: 9 nuclear reactors and 5 large plutonium processing plants. (now decommissioned)

Project Scope

- Estimate ash amounts at Hanford, WA if Mount St. Helens erupts
- Estimates needed for design criteria for the waste treatment and immobilization plant being constructed at Hanford, WA
- Both ash deposition (ashfall) and ash resuspension considered

Collaboration between

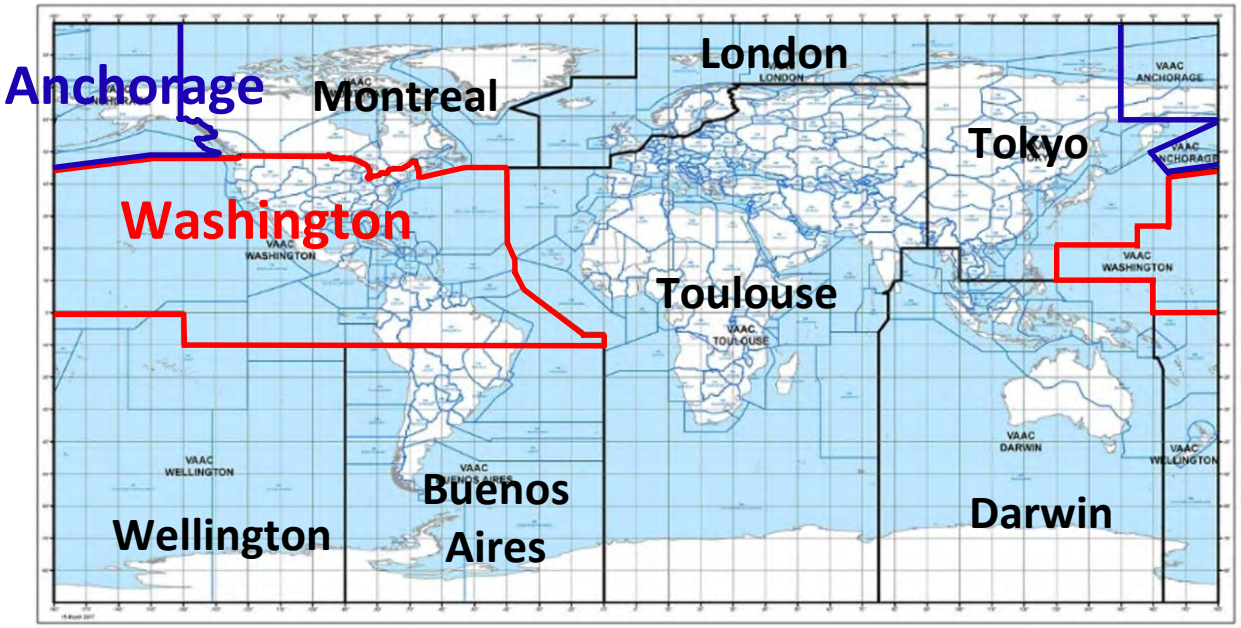
- Department of Energy, Office of River Protection (DOE ORP)
- United States Geological Service (USGS)
- Desert Research Institute (DRI)
- NOAA Air Resources Laboratory (ARL)

Project completed in 2018

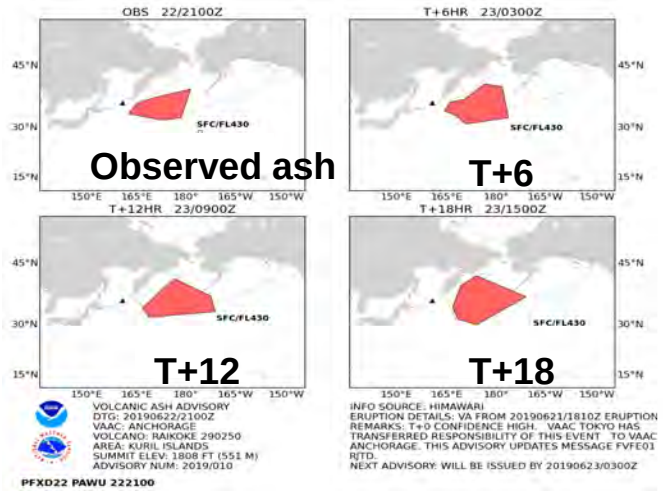
- 3 peer reviewed reports and 1 peer-reviewed article by DRI, USGS, and ARL.
- Development of ash resuspension modeling capability

Volcanic Ash Advisory Centers for Aircraft Safety

- ARL provides modeling support to NOAA's Volcanic Ash Advisory Centers, VAACs
- Quantitative Volcanic Ash (QVA) Standards and Recommended Practices (SARPs) for significant ash clouds was endorsed by the International Civil Aviation, ICAO, Meteorological Panel (METP) in June 2021
- After approval by Air Navigation Commission (ANC) and comment period, the provisions will be introduced as an initial operating capability in Amendment 81 to Annex 3
- QVA SARPS include providing gridded information on ensemble relative frequency of exceedances of specified concentration levels of volcanic ash



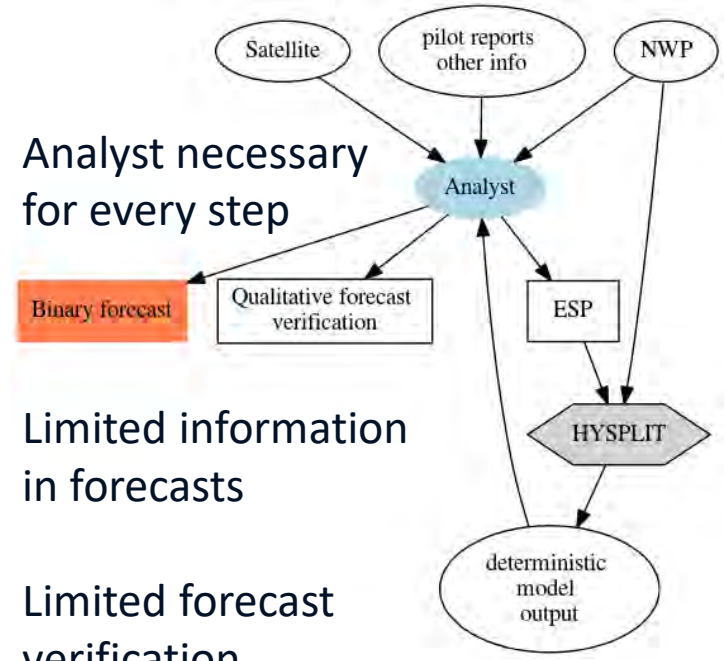
Washington VAAC: https://www.ospo.noaa.gov/Products/atmosphere/vaac/



The current Volcanic Ash Advisory (VAA) is a text and graphical product. https://www.ssd.noaa.gov/VAAC/messages.html
Areas of discernable ash at 0, 6, 12, 18 hours are indicated by a polygon.

Volcanic Ash Advisory Center Enhancements

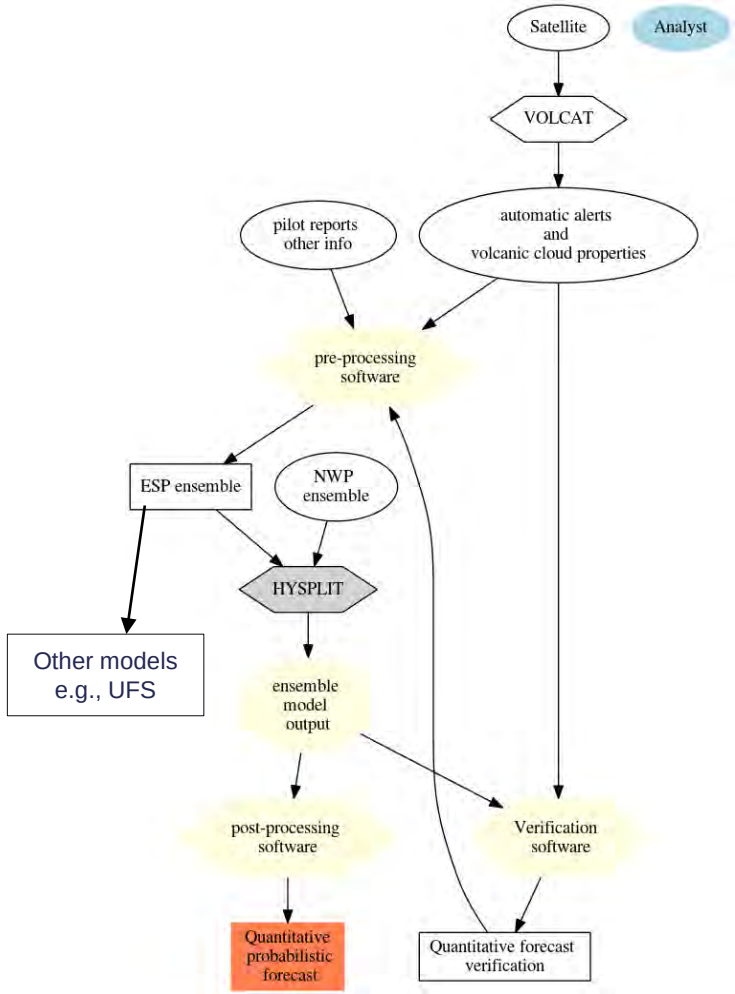
Current Workflow



ESP = Eruption Source Parameters, e.g., Plume height, eruption duration, mass eruption rate

NWP = output from numerical weather prediction model

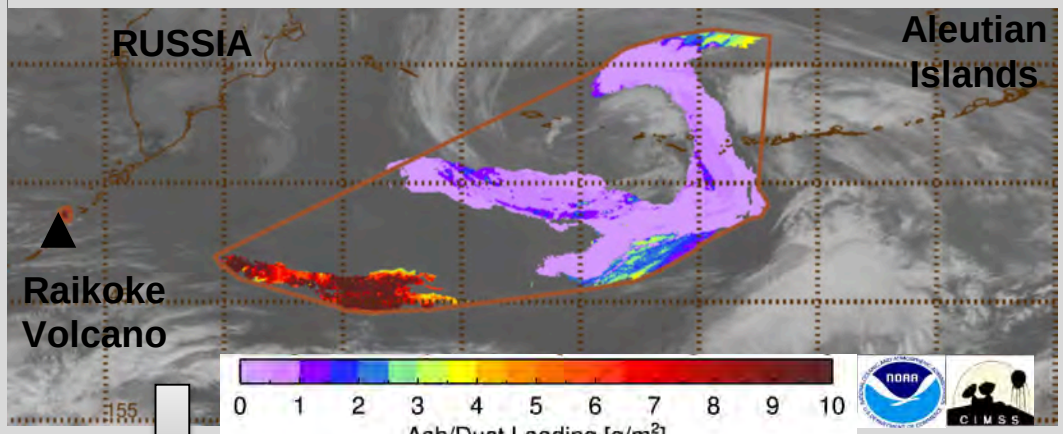
Future Workflow



- Analyst oversees steps; data can be inserted at as many points as needed.
- Data insertion and inverse algorithms create eruption source parameters.
- Time- and height-resolved emissions from inversion can be provided to NWP models.
- More information in forecasts. Forecasts communicate inherent uncertainty.
- Routine forecast verification

Data Insertion and Time-Lagged Ensemble

VOLcanic Cloud Analysis Toolkit VOLCAT
06/23/2019 at 03:00 UTC (Himawari-8)

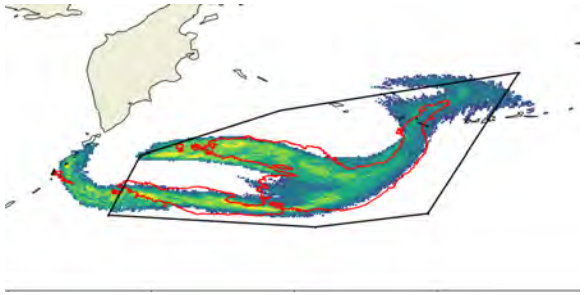


Source Term: initial position and amount of volcanic ash mass

Numerical Weather Prediction (NWP) meteorology fields

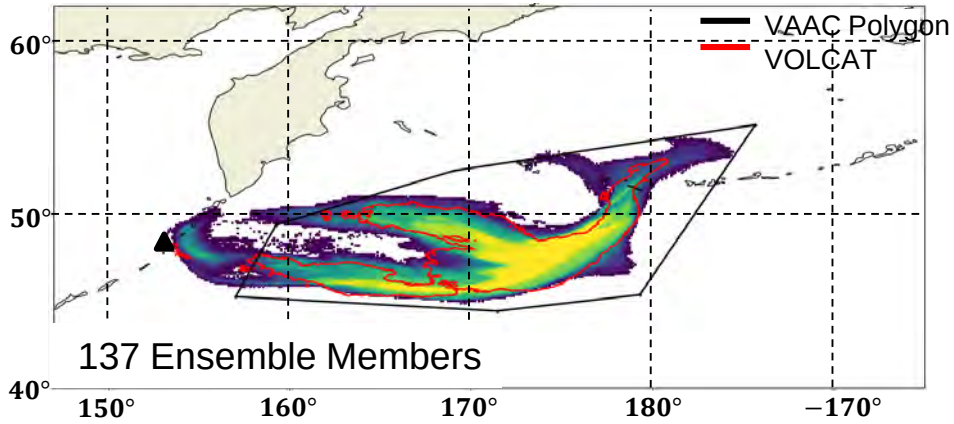
HYSPLIT AIR RESOURCES LAB

Run created for every satellite retrieval (every 10 minutes)

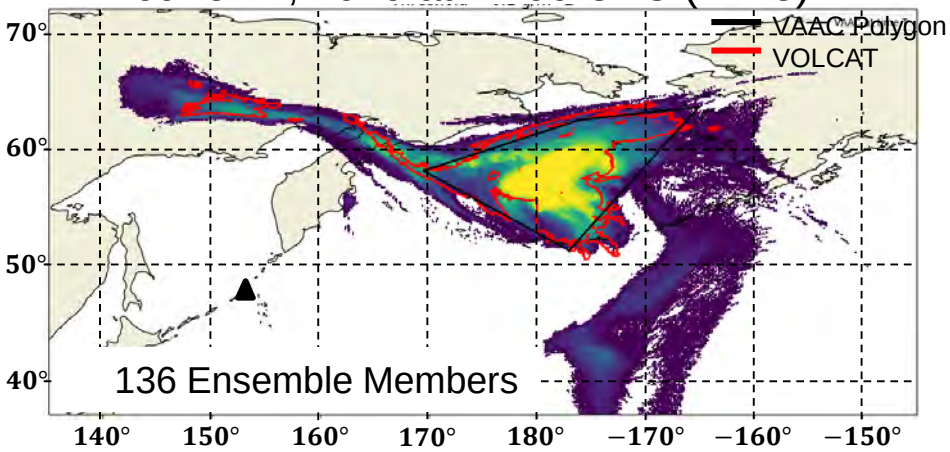


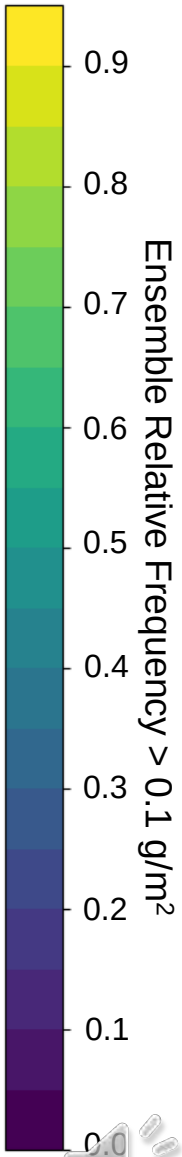
Combine Runs to create time-lagged ensemble

June 22, 2019 at 21:00 UTC (T+27)



June 24, 2019 at 21:00 UTC (T+75)





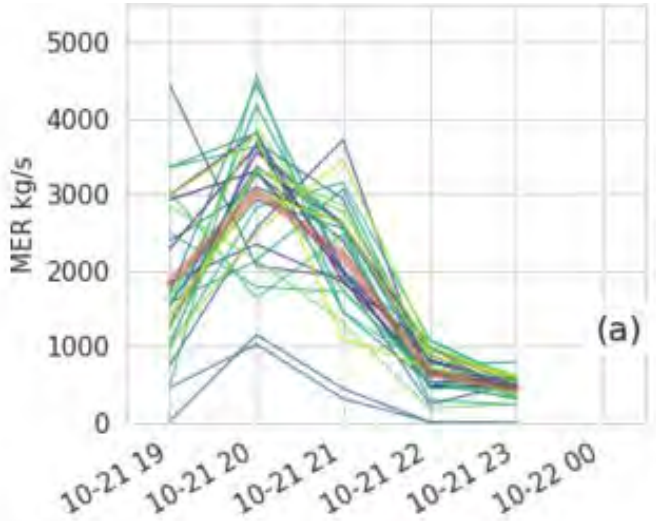
Inversion Algorithm with Ensemble Meteorology

Medium sized eruption of Bezymianny in Kamchatka in October of 2020.

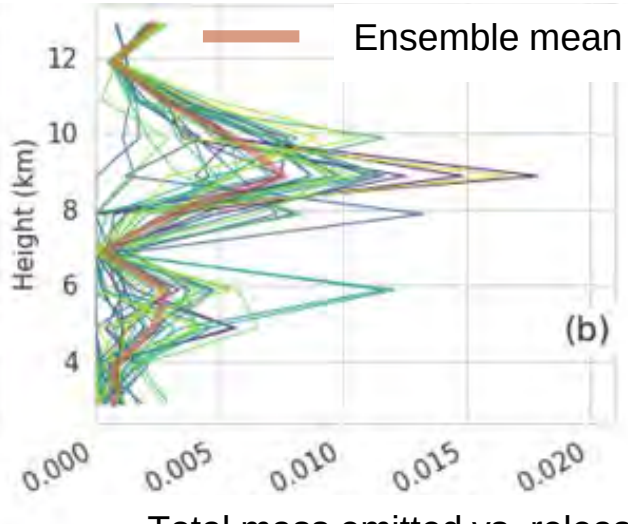
Two hours of VOLcanic Cloud Analysis Toolkit (VOLCAT) volcanic ash mass loadings (available every 10 minutes) are assimilated to generate **ash emission estimates** with 1 hour temporal resolution and 1 km vertical resolution that have the best match between HYSPLIT simulations and VOLCAT observations. (VOLCAT: https://volcano.ssec.wisc.edu/)

Probabilistic emissions estimates may be provided to weather and climate models.

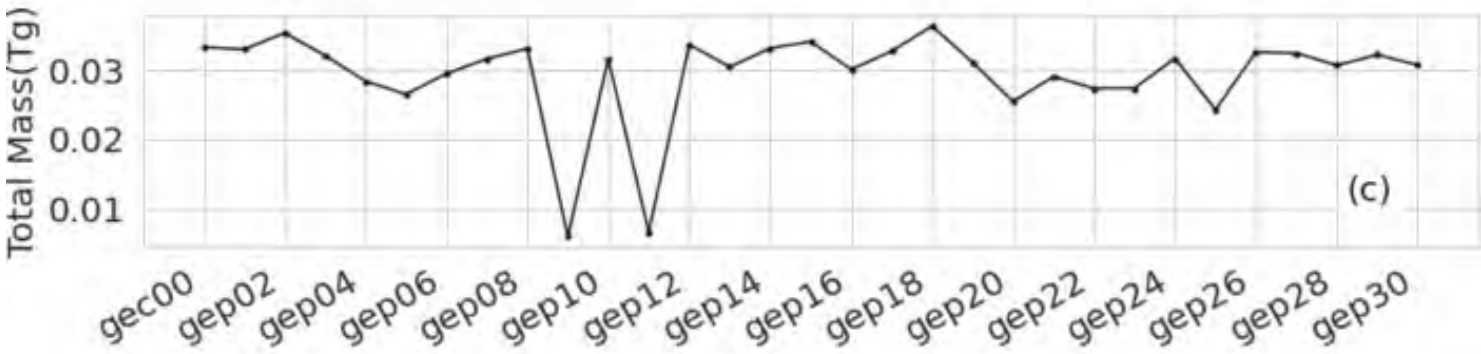
Reference: Chai, T., Crawford, A., Stunder, B., Pavolonis, M. J., Draxler, R., and Stein, A.: Improving volcanic ash predictions with the HYSPLIT dispersion model by assimilating MODIS satellite retrievals, *Atmos. Chem. Phys.*, 17, 2865-2879, https://doi.org/10.5194/acp-17-2865-2017, 2017.



Mass eruption rate (kg/s) vs. time for each ensemble member

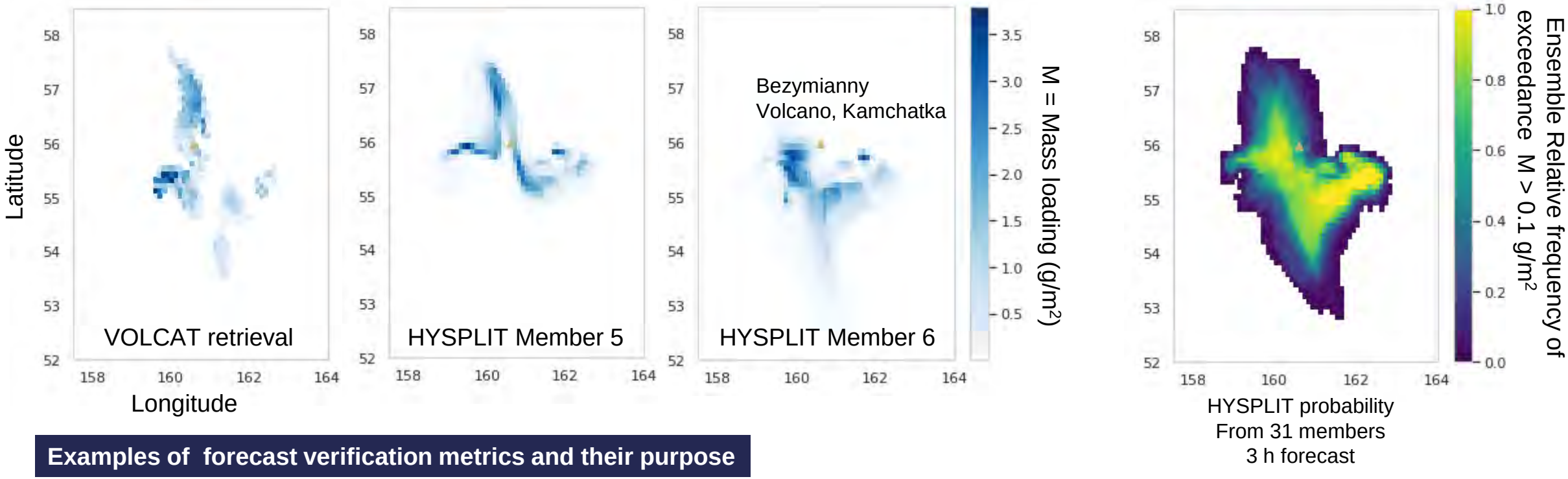


Total mass emitted vs. release height for each ensemble member



Total mass emitted based on VOLCAT inversions using each of the 31 members of the Global Ensemble Forecast System (GEFS)

Evaluation of Probabilistic Ash Forecasts



Examples of forecast verification metrics and their purpose

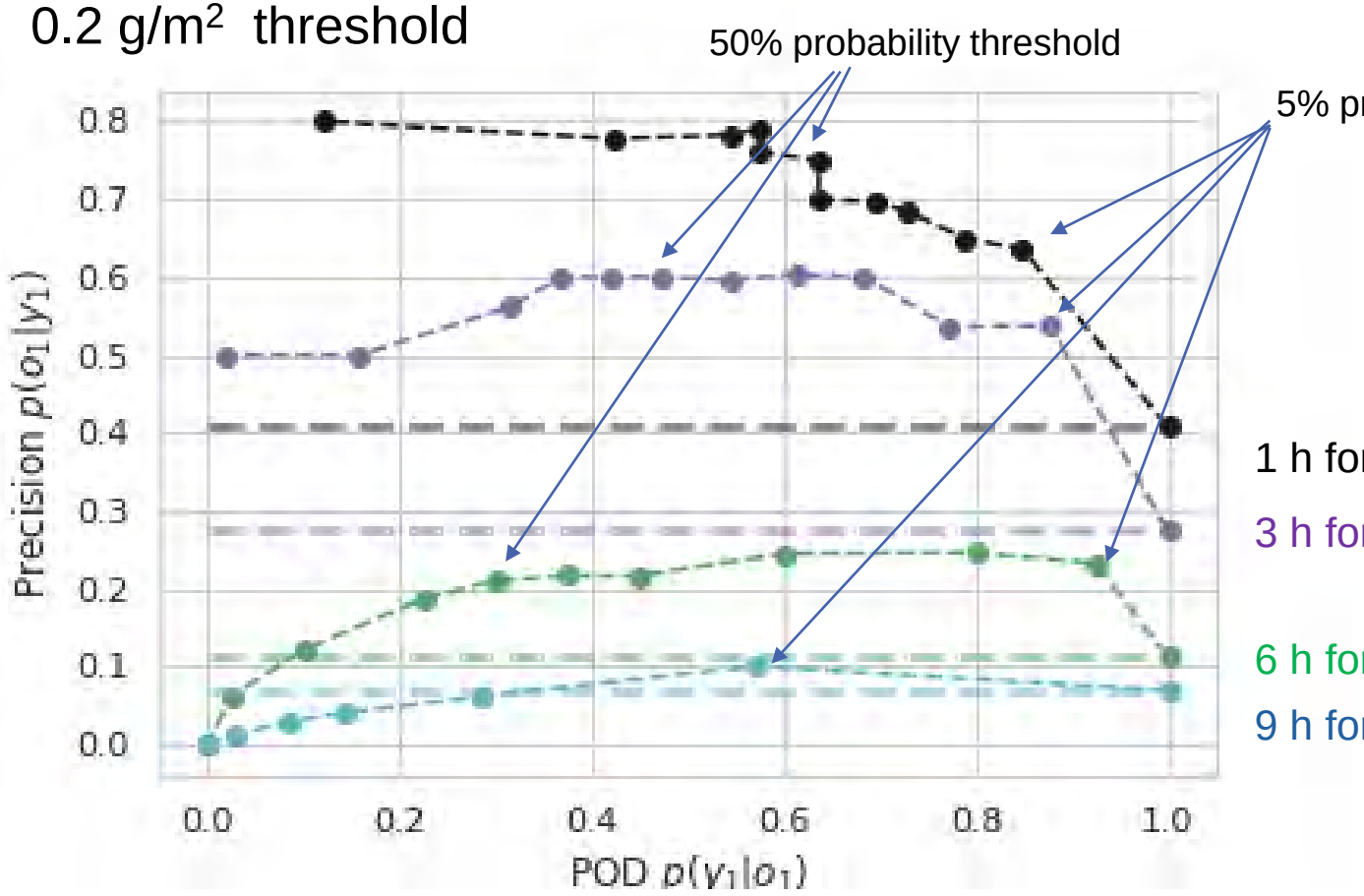
- **Reliability Diagrams:** Are the probabilities well calibrated, e.g., does the ensemble-estimated probabilities represent the actual probabilities?
- **Rank histograms:** Does the ensemble satisfy the consistency condition, e.g., is the observation consistent with the ensemble?
- **Fractional Skill Score (FSS) and neighborhood ensemble probability (NEP):** What is the model's relative skill as a function of spatial resolution?
- **Precision Recall Curve (PRC):** For choosing appropriate probability thresholds for risk-based approaches. Useful for imbalanced datasets.

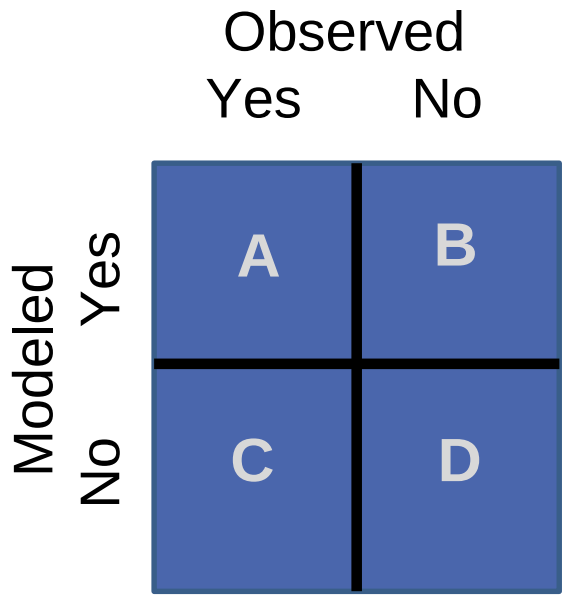
Evaluation of Probabilistic Ash Forecasts

Precision Recall Curve

0.3 degree spatial resolution

0.2 g/m^2 threshold





O_1 = observation above threshold

y_1 = model above threshold

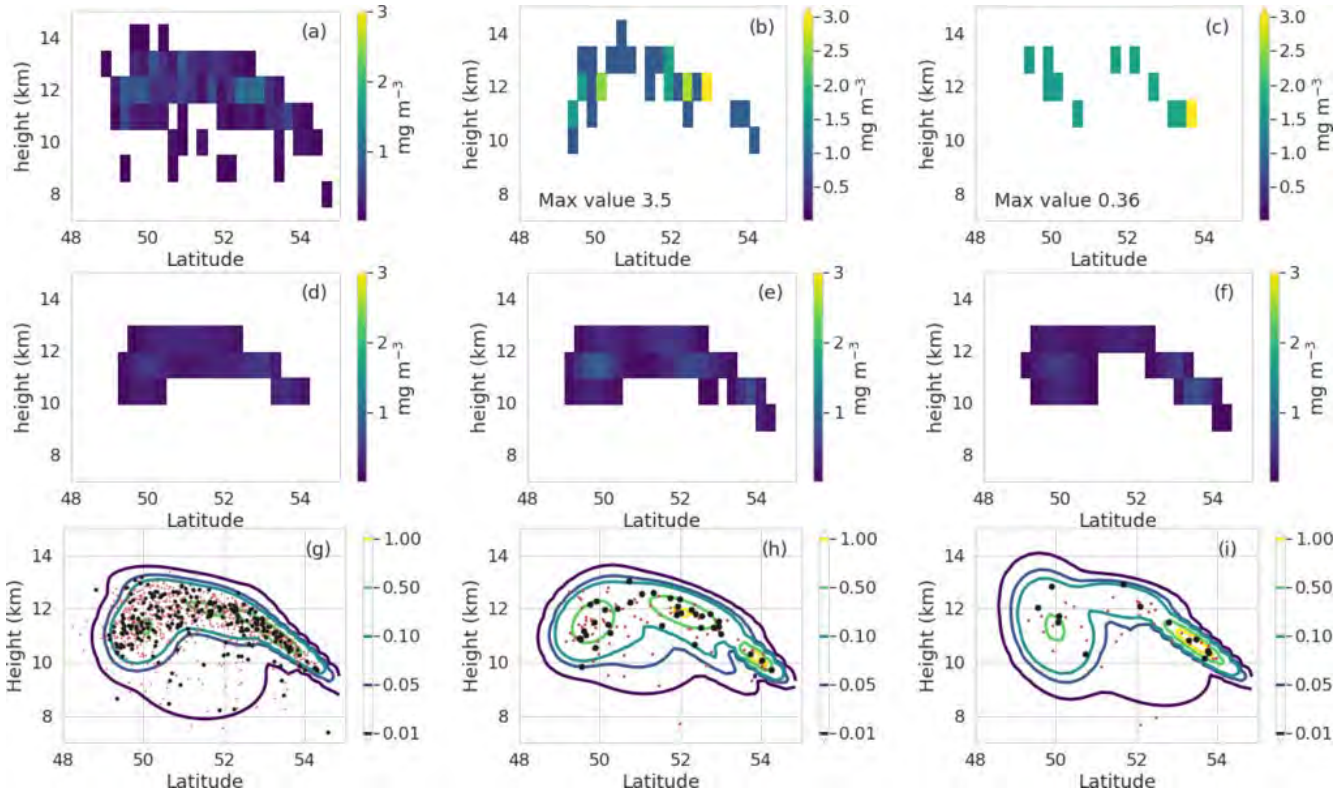
POD = probability of detection = a/(a+c)

Precision = a/(a+b)

Innovative Modeling Methods

Use of a Gaussian Mixture Model can reduce the number of computational particles that are needed in a simulation, identify features, and reduce file sizes.

500,000 particles **50,000 particles** **25,000 particles**



Vertical slice through edge of distal ash cloud

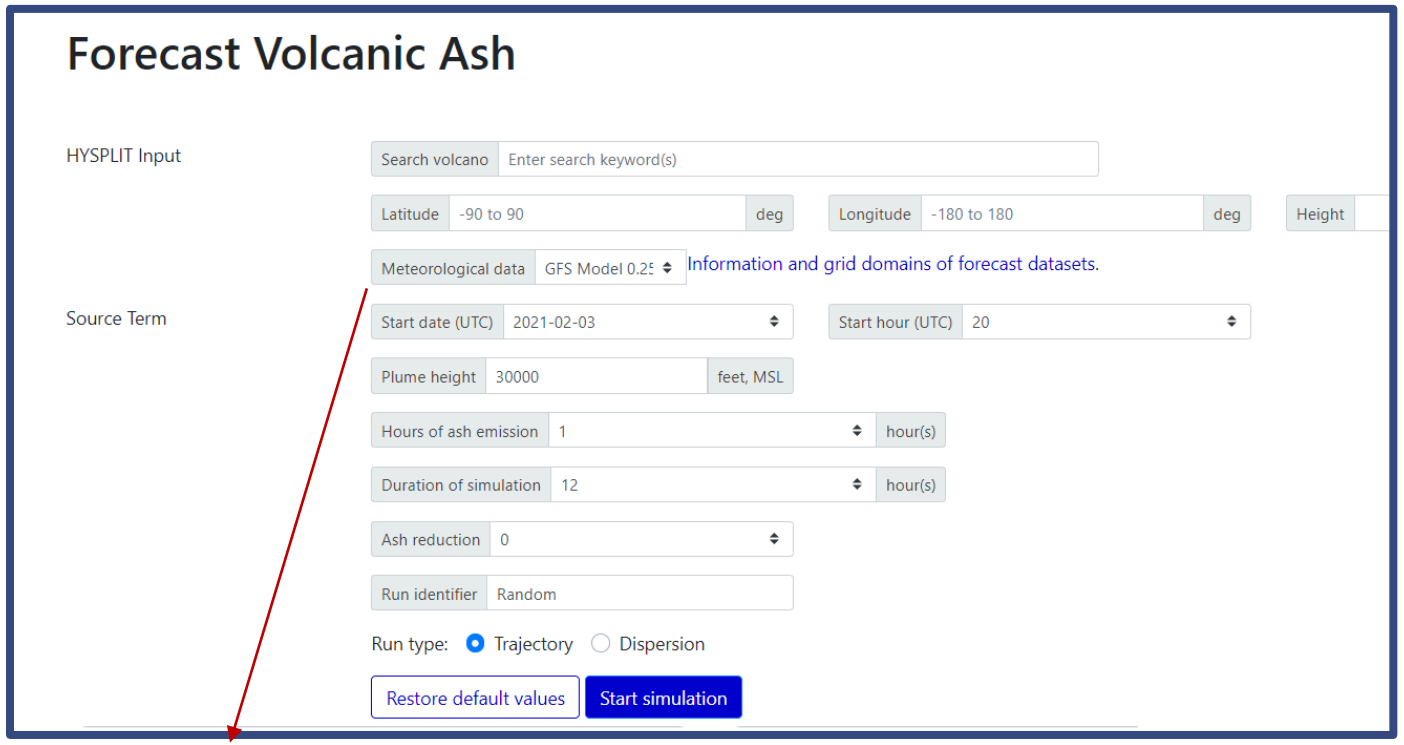
Current histogram method

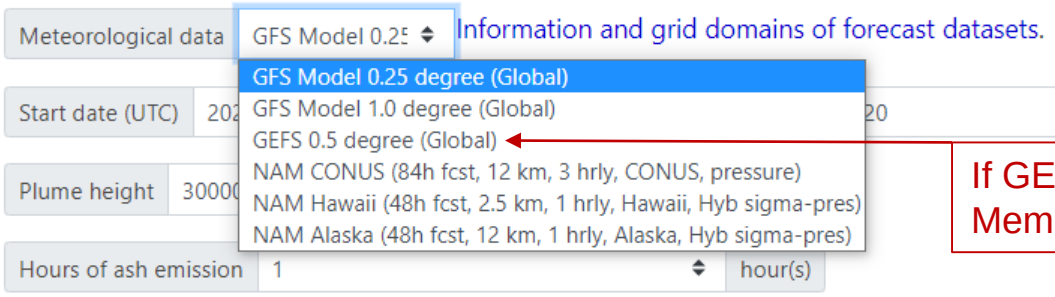
New Gaussian Mixture Model method
Concentrations can be estimated accurately with less particles.

Particle view

A. Crawford (2020). The Use of Gaussian Mixture Models with Atmospheric Lagrangian Particle Dispersion Models for Density Estimation and Feature Identification. *Atmosphere*, 11, 1369. doi:10.3390/atmos11121369

Web Application for Dispersion Ensembles





Joint Technology Transfer Initiative project in conjunction with operational partner National Weather Service, NWS, Environmental Modeling Center, EMC

Dispersion ensembles for volcanic ash using GEFS meteorology progressed from readiness level, RL5 to RL8. Expected to be operational, RL9, in Fall 2022.

Demonstration on ARL web server: **https://apps.arl.noaa.gov/hysplitash/**

If GEFS is chosen, then HYSPLIT is run for each Member of the GEFS and ensemble output is produced.

HYSPLIT runs triggered by VOLCAT alerts

ARL Home > READY > Transport & Dispersion Modeling > Volcanic Ash > Run the HYSPLIT Volcanic Ash Model > Forecast Volcanic Ash

Volcanic Ash

HYSPLIT trajectory and dispersion runs are generated in response to alerts produced by the volcanic cloud monitoring system (VOLCAT)

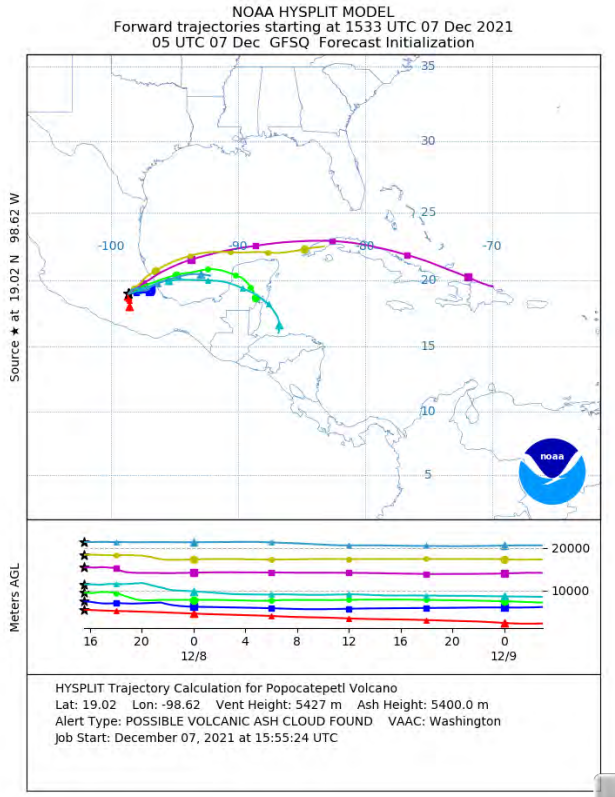
Choose a volcano:
Popocatepetl

VOLCAT Alerts and corresponding HYSPLIT trajectory and dispersion runs for the last 48 hours

Trajectory and dispersion runs are generated when an alert is received

	Date and Time (UTC):	Alert Type	Location (lat, lon)	Nearby Volcanoes	VAAC Region	HYSPLIT Trajectories	HYSPLIT Dispersion
Alert 0	12/07/2021 at 15:33 UTC	ash	19.02, -98.62	Popocatepetl | Iztaccihuatl | Papayo | Chichinautzin | Malinche, La	Washington	• png	• 3hrs • 6hrs
Alert 1	12/07/2021 at 15:13 UTC	ash	19.02, -98.62	Popocatepetl | Iztaccihuatl | Papayo | Chichinautzin | Malinche, La	Washington	• png	• 3hrs • 6hrs
Alert 2	12/07/2021 at 14:43 UTC	ash	19.02, -98.62	Popocatepetl | Iztaccihuatl | Papayo | Chichinautzin | Malinche, La	Washington	• png	• 3hrs • 6hrs
							• 3hrs

Joint Polar Satellite System (JPSS) project with NESDIS to incorporate satellite retrievals into modeling system.



https://www.ready.noaa.gov/hysplitash-bin/autoash.py

Publications

2020 A. Crawford. The Use of Gaussian Mixture Models with Atmospheric Lagrangian Particle Dispersion Models for Density Estimation and Feature Identification. *Atmosphere*, 11, 1369 (doi:10.3390/atmos11121369)

2020 Y.H. Tang, D. Q. Tong , K. Yang, P. Lee, B. Baker, A. Crawford, W. Luke, A. Stein, P. C. Campbell, A. Ring, J. Flynn, Y.X. Wang, J. McQueen, L. Pan, J. P. Huang, and I. Stajner. Air quality impacts of the 2018 Mt. Kilauea Volcano eruption in Hawaii: A regional chemical transport model study with satellite-constrained emissions. *Atmos. Env.*, 237 (doi:10.1016/j.atmosenv.2020.117648)

2019 B. Stunder, A. Crawford, J. Kibler, N. Eckstein, and J. Osiensky. Research and Operations: Perspective on Quantitative Ash Products. Information paper presented at the Meteorological Panel (METP) Working group on meteorological information and service development (WG-MISD) volcanic ash sulfphur dioxide (VASD) work stream meeting on 20 November 2019.

2019 V. Etyemezian, J. A. Gillies, L. G. Mastin, A. Crawford, R. Hasson, A. R. Van Eaton, and G. Nikolich. Laboratory Experiments of volcanic ash resuspension by wind. *J. Geophys. Res. Atmos*., 124 (doi:10.1029/2018JD030076)

2018 A. Crawford, C. Loughner, and A. Stein. Modeled Concentrations of volcanic ash due to resuspension at Hanford: final report. AFP-NOAA-REPORT-03, Revision 0.

2017 T. Chai, A. Crawford, B. J. B. Stunder, M. J. Pavolonis, R. Draxler, and A. Stein. Improving volcanic ash predictions with the HYSPLIT dispersion model by assimilating MODIS satellite retrievals, *Atmos. Chem. Phys*, 17 (doi:10.5194/acp-17-2865-2017)

2016 Crawford, A. M., Stunder, B. J. B., Ngan, F., and Pavolonis, M. J. (2016), Initializing HYSPLIT with satellite observations of volcanic ash: A case study of the 2008 Kasatochi eruption, *J. Geophys. Res. Atmos.*, 121, 10,786-10,803 (doi:10.1002/2016JD024779)

Selected Presentations

2020 Off the Grid: The use of Gaussian mixture models with Lagrangian transport and dispersion models for density estimation and feature identification. *Alice Crawford. (*AGU Fall meeting)

2020 A Comparison of Meteorological Deterministic and Ensemble Inputs to HYSPLIT For Volcanic Ash Transport in Small to Moderate Sized Eruptions. *Eric Roy, Alice Crawford, Barbara Stunder and Binyu Wang (*AGU Fall meeting)

2020 Development and Evaluation of a Volcanic Ash Ensemble Forecasting System Using the NOAA HYSPLIT Model. *Binyu Wang, Barbara Stunder, Jeffrey McQueen, Alice Crawford, Allison Ring, et al. (*AGU Fall meeting)

2020 Exploring Volcanic Ash Forecasting Techniques Using HYSPLIT and VOLCAT Observations. *Allison Ring, Alice Crawford, Tianfeng Chai, Justin Sieglaff and Michael Pavolonis Sr.* (AGU Fall meeting)

2020 Application of a novel ensemble mean technique to probabilistic forecasting of volcanic ash transport using HYSPLIT. *Jorge Eduardo Guerra and Alice Crawford. (*AGU Fall meeting)

2020 Volcanic Ash Forecast Verification Using HYSPLIT and Satellite Ash Observations Identified by VOLCAT. *Allison Ring, Alice Crawford, Barbara Stunder, Justin Sieglaff, and Michael Pavolonis.* (AMS January Meeting)

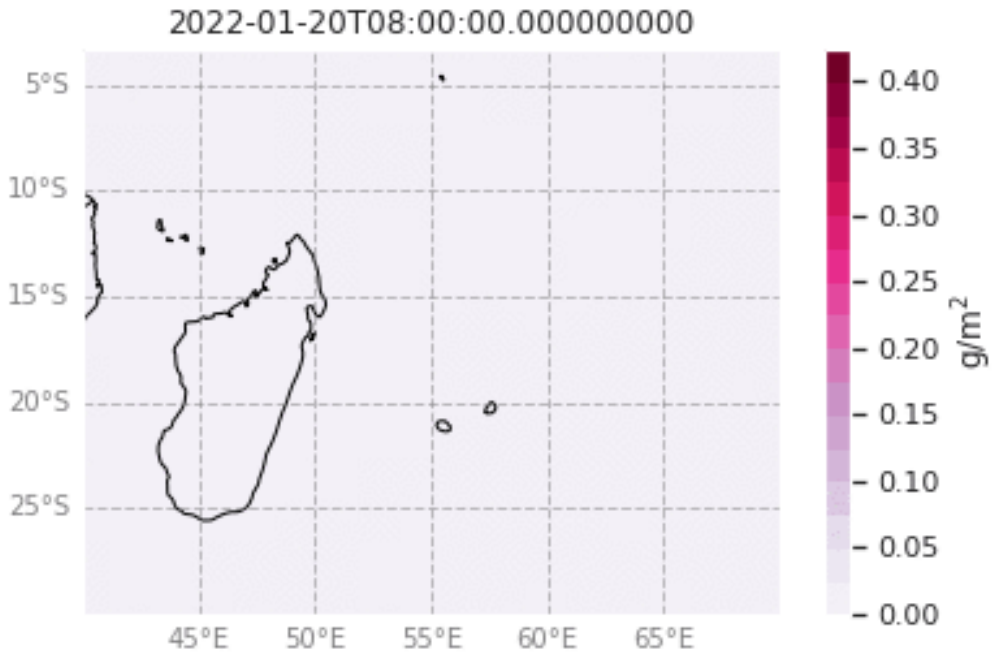
2018 Modeling Concentrations of Resuspended Volcanic Ash. *Alice Crawford, Christopher Loughner, and Ariel Stein.* (AGU Fall meeting)

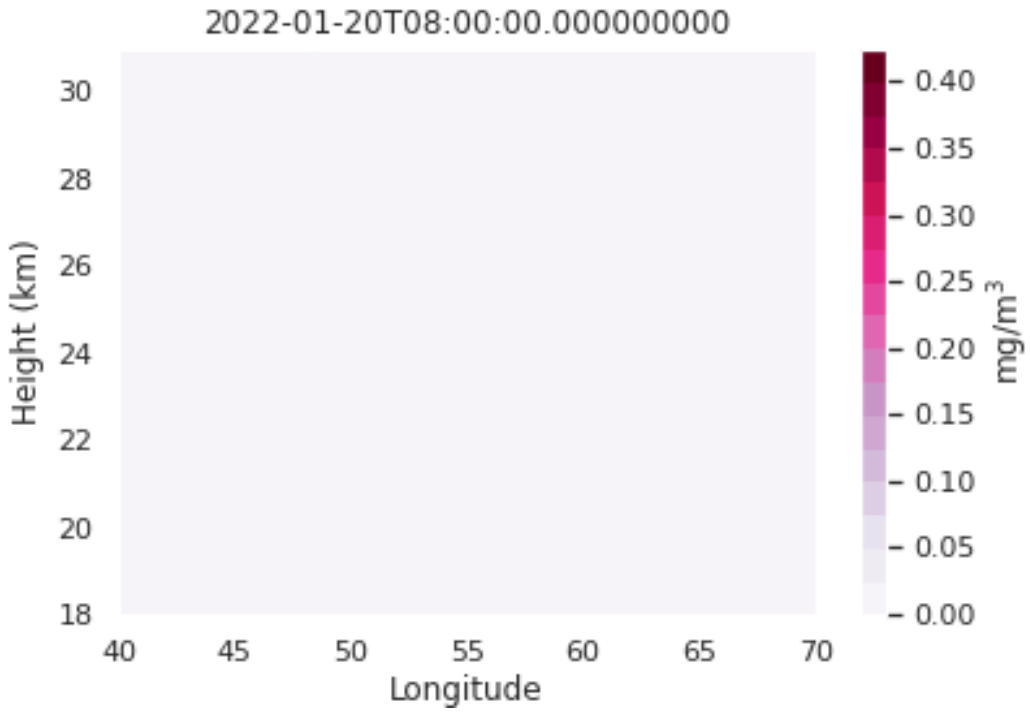
2017 Data assimilation and inverse modeling with HYSPLIT Lagrangian dispersion model and satellite data - Applications to volcanic ash and wildfire smoke predictions. *Tianfeng Chai.* (NOAA Satellite Conference, City College of New York)

Future Plans

- Continue to support development and transition to operations of probabilistic ash forecasting capabilities which meet the needs of the aviation sector.
- Produce time and height resolved emissions of volcanic ash and SO_2 using observations and inversion algorithms which can be utilized in UFS and other modeling systems.
- Model volcanic SO_2 and ash as a *Tracer of Opportunity* to assess and revise turbulence parameterizations in the upper troposphere / lower stratosphere (e.g., in support of NOAA's Earth Radiation Budget Initiative)
- Explore innovative modeling methods to improve computational efficiency and improve forecasts.

HYSPLIT modeling of SO_2 from the Hunga Tonga eruption (Jan 15, 2022)





Shows SO_2 cloud approaching Madagascar to support NOAA team making downwind measurements of the volcanic emissions in the vicinity of Reunion Island (Simulations using GFS 0.25-degree meteorology)