The HYSPLIT model- Tracing its evolution and path to success
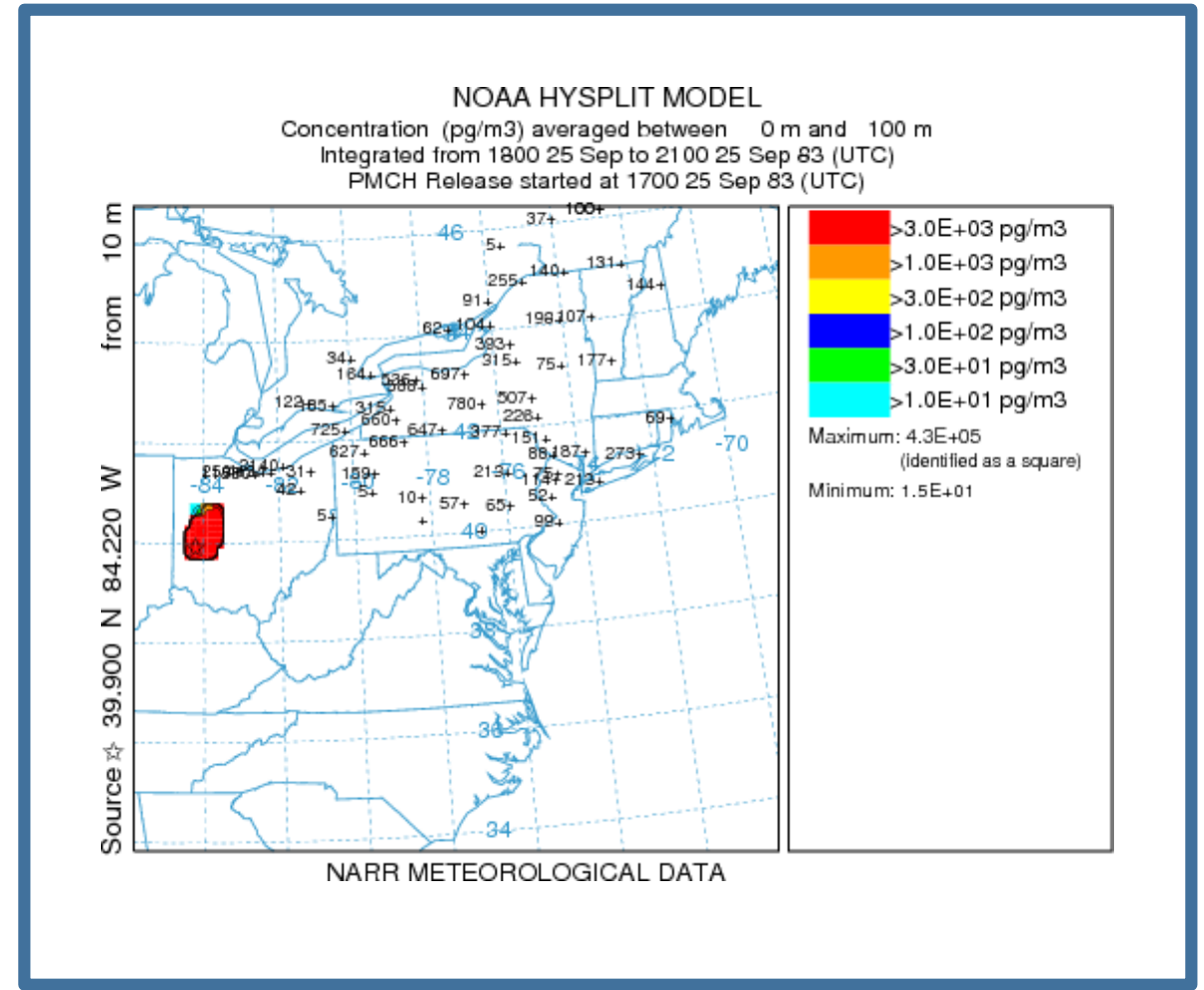
Dr. Alice Crawford

Air Resources Laboratory, NOAA,
College Park, MD USA

Tianfeng Chai, Mark Cohen, Miguel Cahuich,
HyunCheol Kim, Christopher Loughner,
Fantine Ngan, Bavand Sadeghi, Sonny Zinn,
Ariel Stein, Roland Draxler, Glenn Rolph,
Barbara Stunder

alice.crawford@noaa.gov

Where are we now? How is HYSPLIT used

Operations

application areas that have been transitioned to operations at NOAA

Volcanic Ash

Radiological release

Chemical release

Dust

Smoke

Screen shot from AP video shown in Washington Post, [What's known about the toxic plume from the Ohio train derailment], Justine McDaniel, Feb 15, 2023.

Quasi-operational application areas

Locust swarms (ARL web application)

Volcanic Smog (University of Hawaii)

Smoke modeling, prescribed burn planning (US forest service)

Greenhouse gasses

READY and HYSPLIT distributions

Research

Citation report generated by web of science using search for HYSPLIT (all fields)

4,178 publications found
27% from the U.S.
73% from 120 different countries/regions across all continents.

 topics include aerosols, mercury, volcano, bio-aerosols (pathogens), biological control (insects), allergy (pollen), forest fires, Pcbs, Pahs, CS-137, groundwater, clouds, microplastics

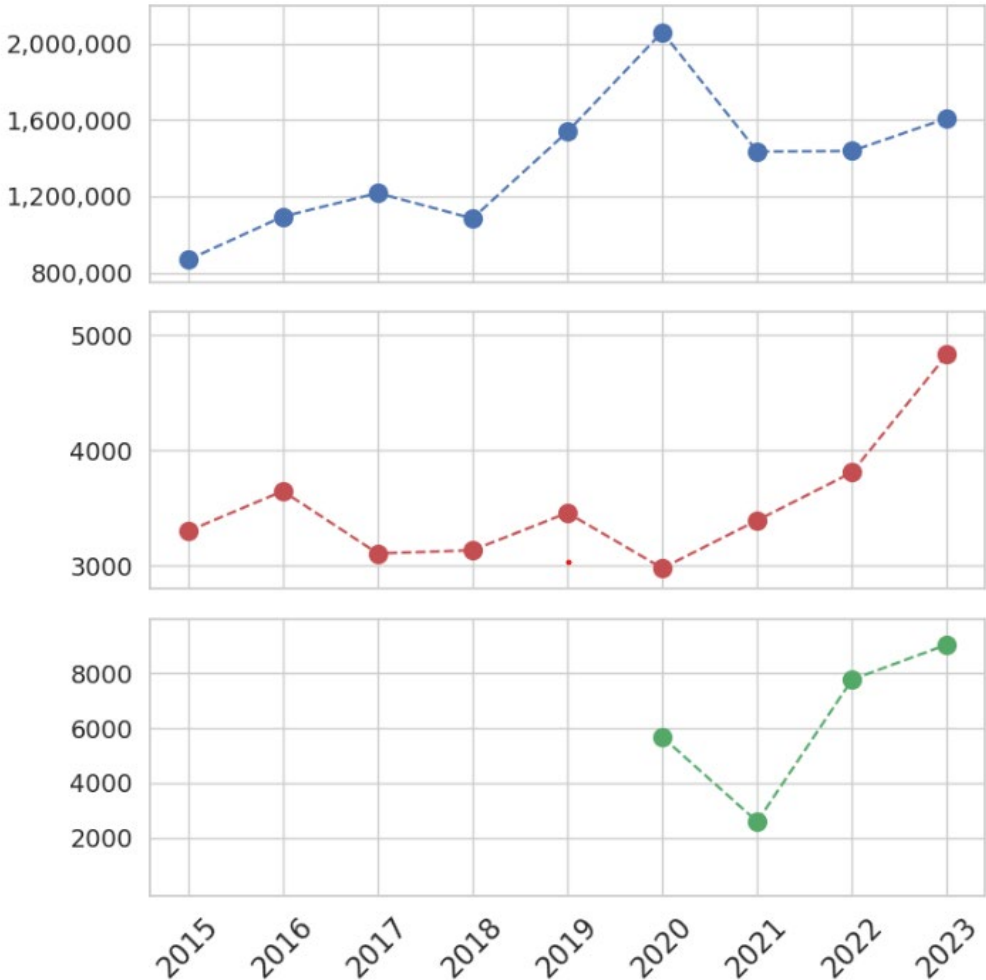| Citations in Web of Science	
51,683 citations	All HYSPLIT publications
3,568 citations	Stein et al. 2015: *Bull. Amer. Meteor. Soc.*, **96**, 2059-2077
2,526 citations	Draxler et. al. 1998
943 citations	Rolph et al 2017: *Environmental Modelling & Software*, **95**, 210-228

Where are we now? HYSPLIT by the Numbers

Simulations performed on READY web application by the public and registered users

Simulations performed on the Web Operations Center by NWS Weather Forecasting Offices

Simulations performed on the locust forecasting web application

+ many more simulations carried out by users who download the model to their local computers

3387 Registered HYSPLIT users (special access to the model)

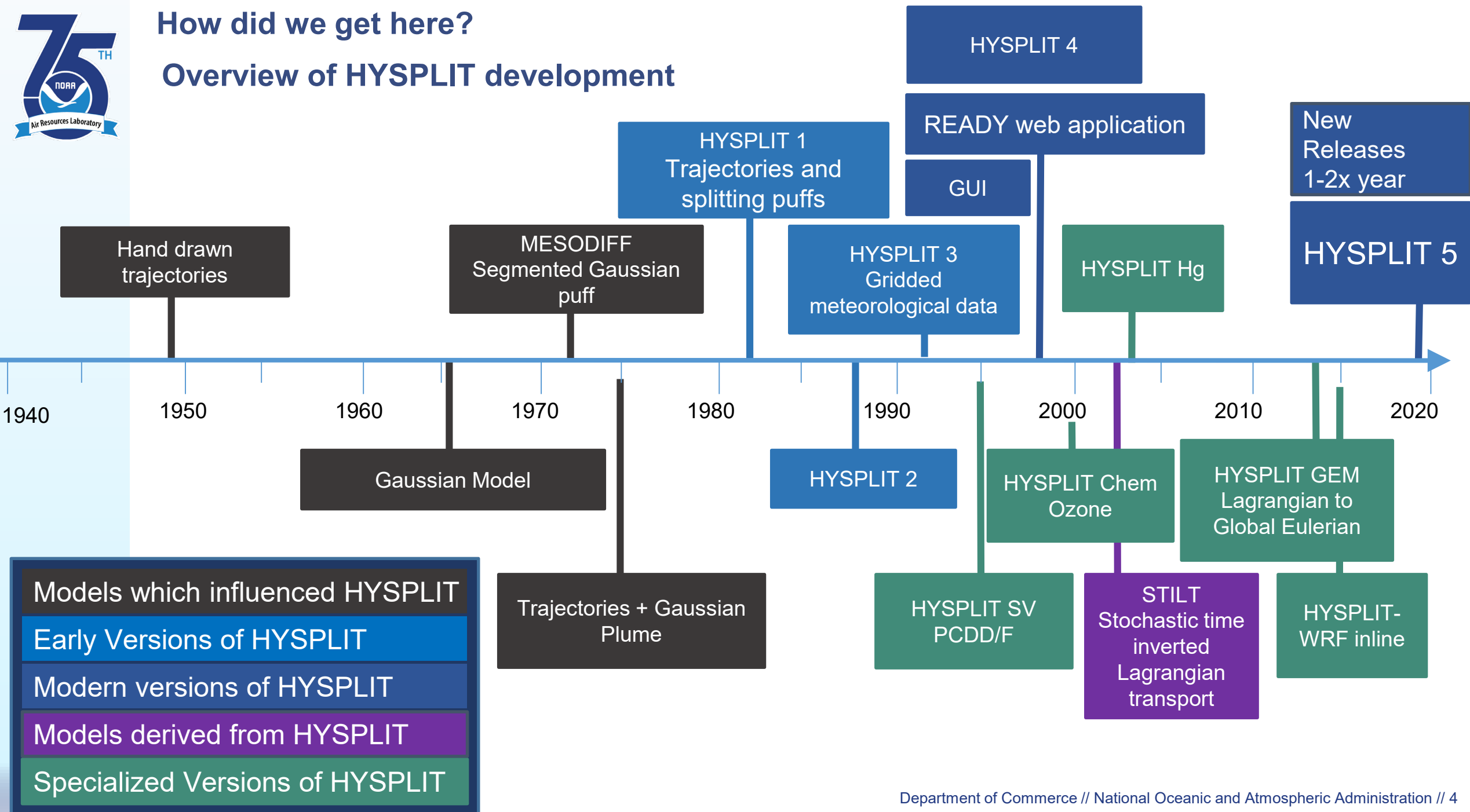5737 HYSPLIT Forum users

8474 HYSPLIT Forum questions
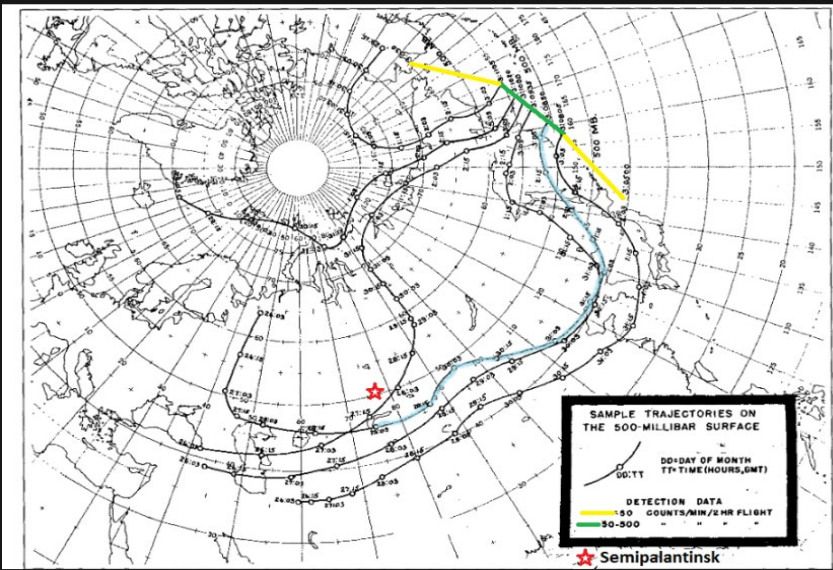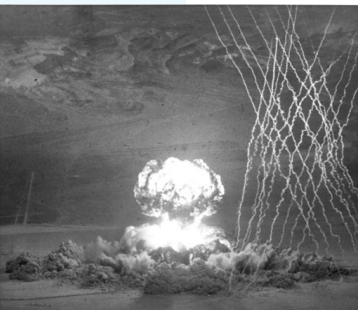
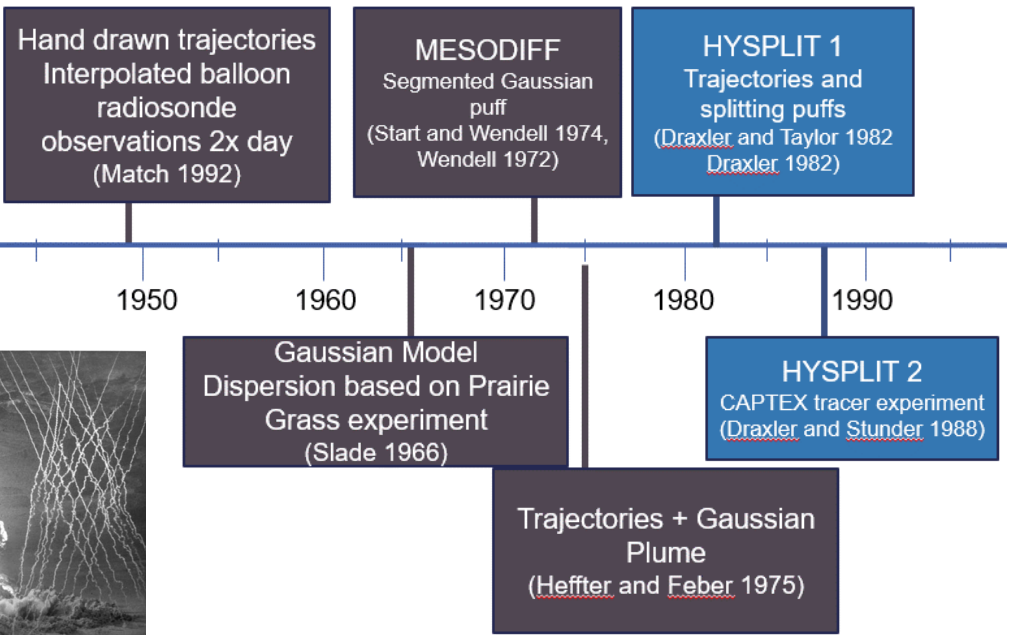1000+ Workshop Attendees 2018-2022
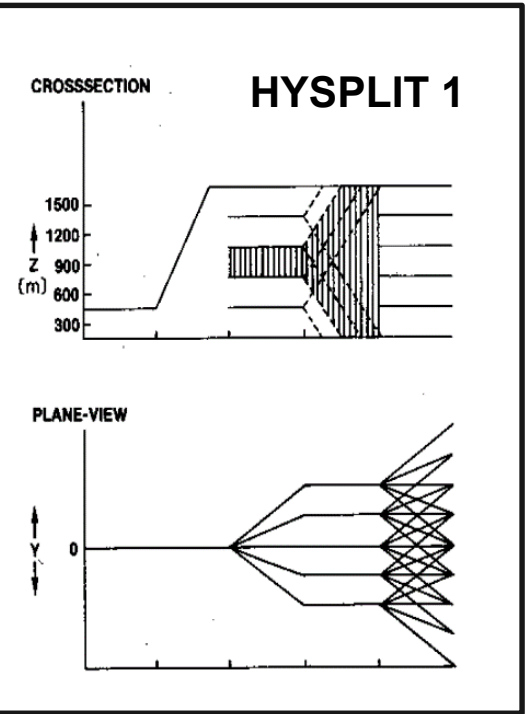
How did we get here?
Overview of HYSPLIT development

HYSPLIT 4

READY web application

New Releases 1-2x year

HYSPLIT 1
Trajectories and splitting puffs

GUI

Hand drawn trajectories

MESODIFF
Segmented Gaussian puff

HYSPLIT 3
Gridded meteorological data

HYSPLIT Hg

HYSPLIT 5

1940   1950   1960   1970   1980   1990   2000   2010   2020

Gaussian Model

HYSPLIT 2

HYSPLIT Chem Ozone

HYSPLIT GEM
Lagrangian to Global Eulerian

Models which influenced HYSPLIT

Early Versions of HYSPLIT

Modern versions of HYSPLIT

Models derived from HYSPLIT

Specialized Versions of HYSPLIT

Trajectories + Gaussian Plume

HYSPLIT SV
PCDD/F

STILT
Stochastic time inverted Lagrangian transport

HYSPLIT-WRF inline

Early development

Hand drawn trajectories
Interpolated balloon radiosonde observations 2x day
(Match 1992)

MESODIFF
Segmented Gaussian puff
(Start and Wendell 1974, Wendell 1972)

HYSPLIT 1
Trajectories and splitting puffs
(Draxler and Taylor 1982 Draxler 1982)

1950　1960　1970　1980　1990

Gaussian Model
Dispersion based on Prairie Grass experiment
(Slade 1966)

HYSPLIT 2
CAPTEX tracer experiment
(Draxler and Stunder 1988)

Trajectories + Gaussian Plume
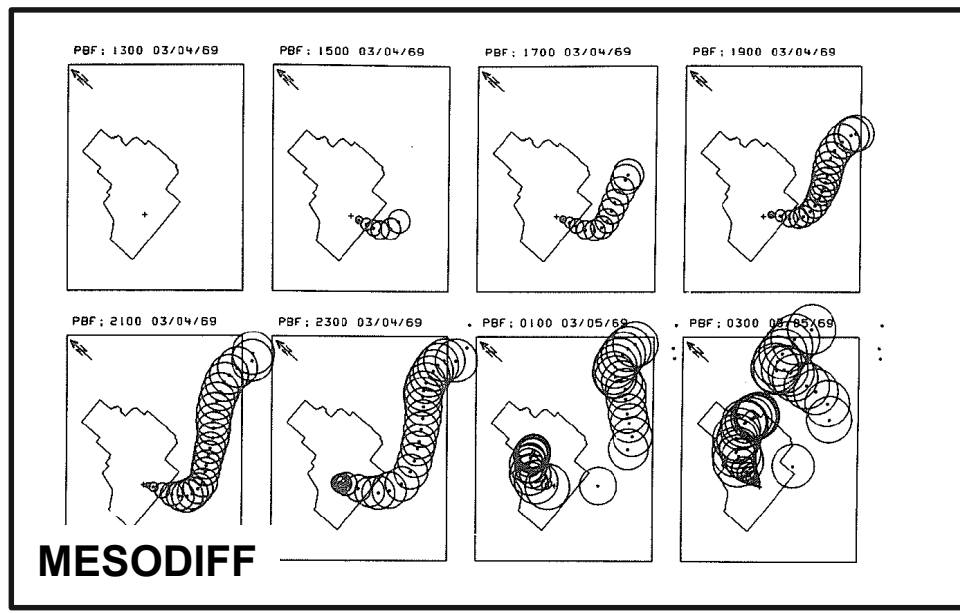(Heffter and Feber 1975)

HYSPLIT 1

Application Areas
- Radiological releases forecasting and source determination
- Planning for tracer experiments to understand boundary layer processes

Key Developments
- Use of local or rawinsonde data
- Modeling of turbulent dispersion

Hand drawn trajectories

Finding the site of the first soviet nuclear test in 1949
Machta (1992) BAMS

Figure 1 The location of the first detection of debris from Joe-1 near Kamchatka, with backward trajectories from six parts of the flight leg on 3 September 1949 at 500 mb. The figure is reproduced unchanged from 1949.

SAMPLE TRAJECTORIES ON THE 500-MILLIBAR SURFACE

★ Semipalantinsk

MESODIFF

Tracer Experiments Conducted by ARL

Wide range of spatial scales in **ARL tracer experiments**, ranging from sub-kilometer to synoptic scale
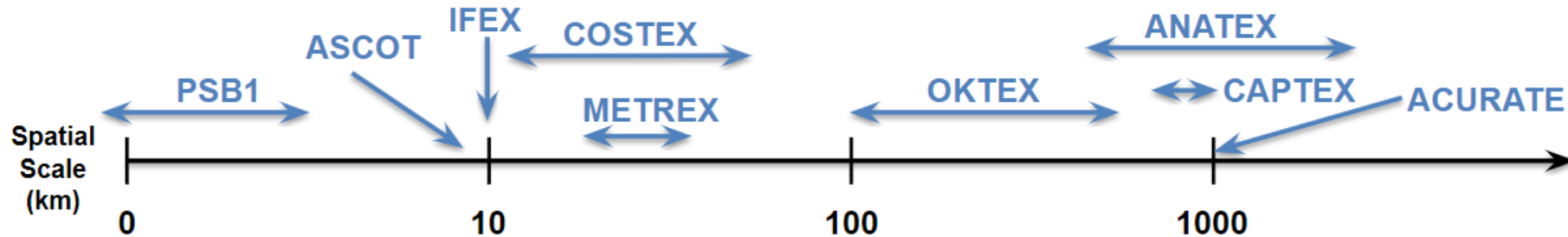
DATEM Data Archive of Tracer Experiments and Meteorology
Available to the public since the early 2000s.
https://www.arl.noaa.gov/hysplit/datem-tracer-evaluation/datem/
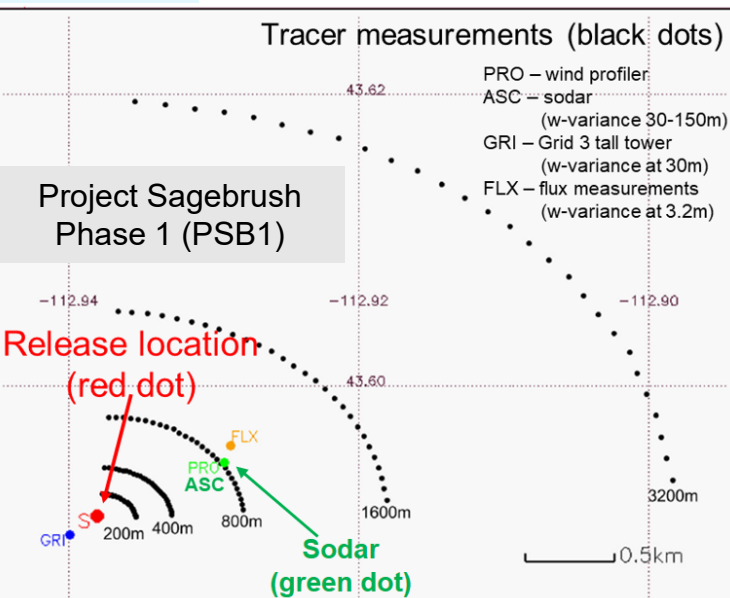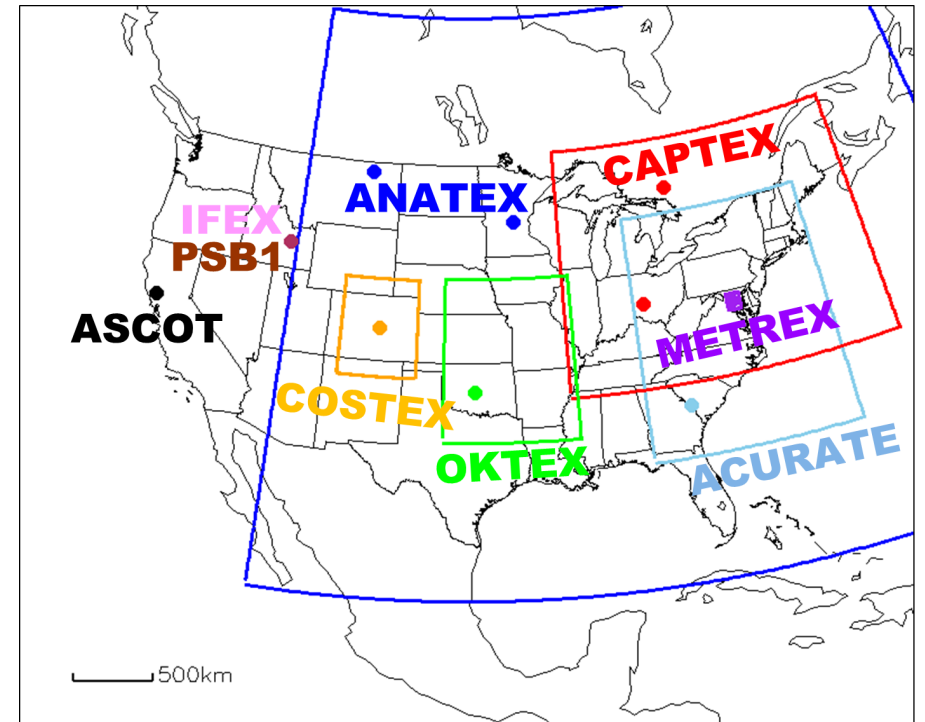
DATEM benefits the dispersion modeling community

- Data and evaluation tools

- Sensitivity studies

- Model intercomparisons

- Model benchmarking

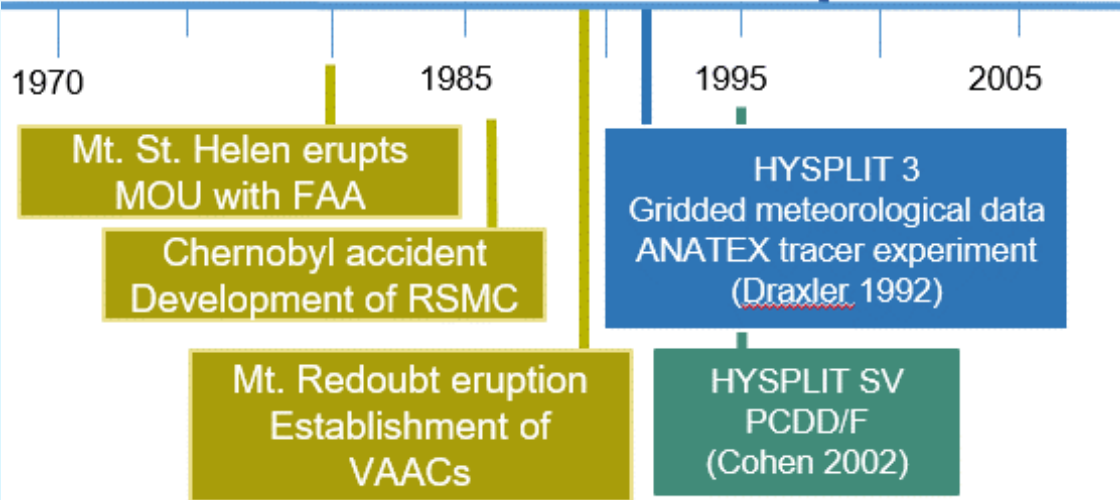# The emergence of modern HYSPLIT

Mount St. Helens erupting in 1980
USGS photographic library

HYSPLIT 4
Trajectories, puffs, particles.
Coupling to meteorological models.
(Draxler and Hess 1998)

GUI

READY web application
(Rolph et. al. 2017)

Main Application Areas
Radiological releases, tracer experiments, volcanic emissions, semi-volatile pollutants

Key Developments:
Linear chemistry
User Interfaces
Coupling to Meteorological Models

1970   1985   1995   2005

Mt. St. Helen erupts
MOU with FAA

Chernobyl accident
Development of RSMC

Mt. Redoubt eruption
Establishment of VAACs

HYSPLIT 3
Gridded meteorological data
ANATEX tracer experiment
(Draxler 1992)

HYSPLIT SV
PCDD/F
(Cohen 2002)

BMRC REGIONAL METEOROLOGY GROUP
DEPOSITION FROM 00Z 27 APR TO 12Z 30 APR (UTC)
12Z 25 APR CHNB FORECAST INITIALIZATION

GROUND-LEVEL DEPOSITION (Bq/M2)

| 1.0E+04 | 1.0E-02 | 1.0E+00 | >0.0 |
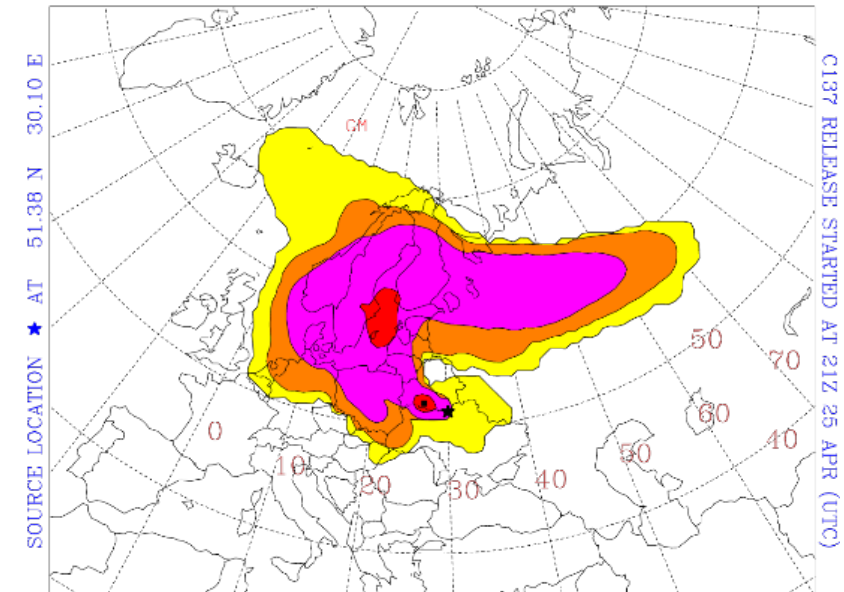
Emergency Response
Chernobyl ^{137}Cs Deposition

Draxler and Hess, 1998
Australian Meteorological Magazine

MOU – memorandum of understanding
FAA – Federal Aviation Administration
RSMC – Regional Specialized Meteorological Center
VAAC – Volcanic Ash Advisory Center

Decision Support
Real-time Environmental Applications and Display sYstem
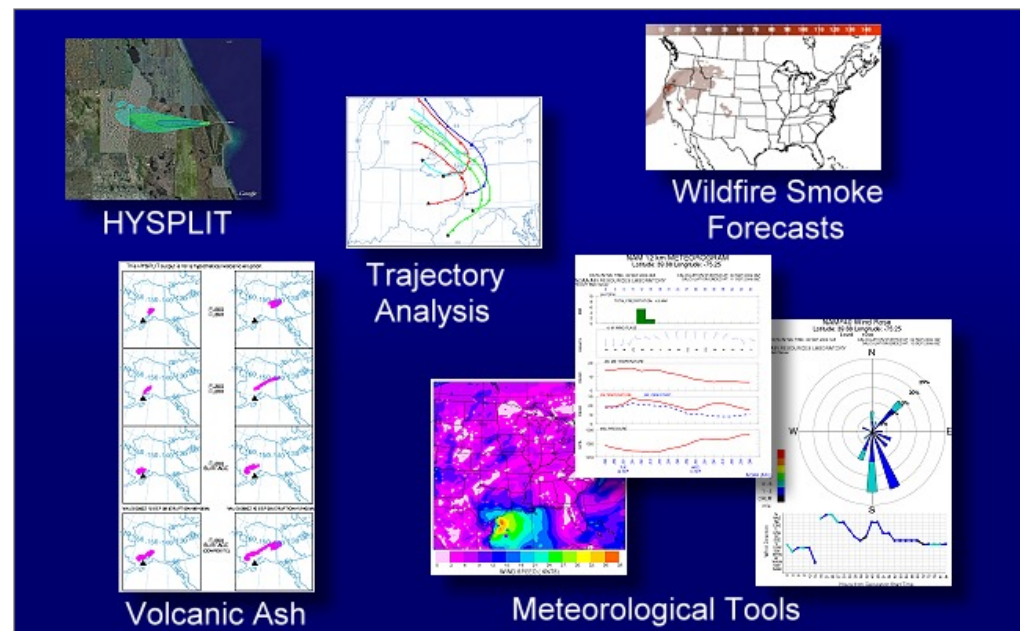
- 1997 Interactive web site first made publicly available

- Other U.S. federal agencies needed to run HYSPLIT remotely and display graphical results. However, retrieving graphical products through the client's firewall was problematic.

- Continuously updated with new capabilities

- 2007 An operational web application was created for the Weather Forecasting Offices to run HYSPLIT for emergency response.

- https://www.ready.noaa.gov/index.php

- https://www.ready.noaa.gov/READYnews.php

Coupling to Numerical Weather Prediction (NWP) Models

Flexibility and Ease of Use

Coupling with all NOAA models including global ensemble forecast system (GEFS, 31 members) and high resolution ensemble forecast (HREF, 10 members)

Archive of meteorological datasets available for download

Creation of WRF dataset specifically for dispersion applications (Ngan et. al. 2017, A Long-Term WRF Meteorological Archive for Dispersion Simulations: Application to Controlled Tracer Experiments)

Software for coupling with almost any NWP model (e.g. WRF, ERA5, MERRA2)

Capability to run with multiple nested input metdata grids
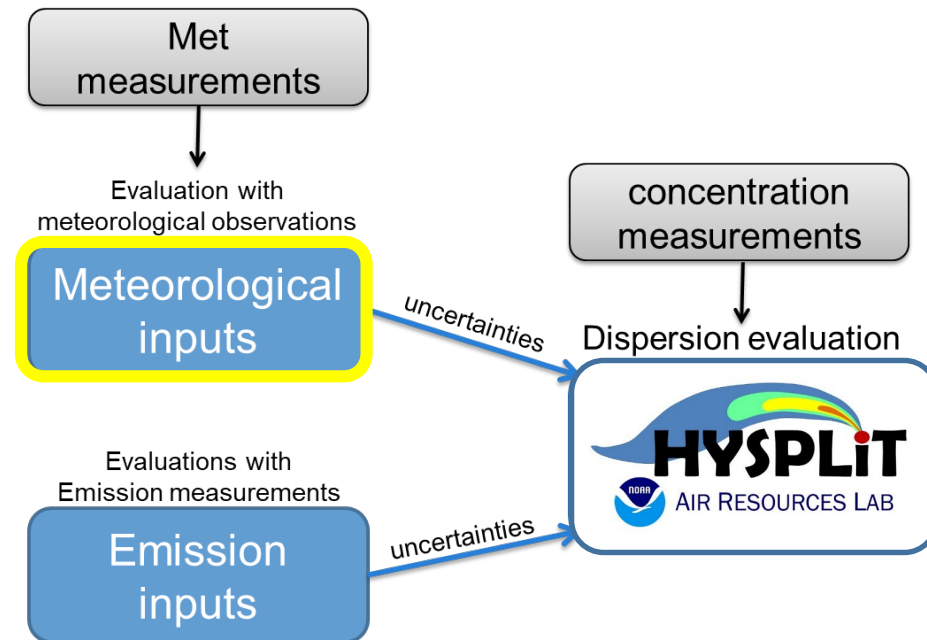
The rapid expansion of HYSPLIT

Key Developments:
- Transitioned smoke forecasting to NWS operations in 2007
- Use of satellite observations and UAS (uncrewed aircraft systems)
- Method for specifying complex emissions scenarios
- Emphasis on source-receptor framework and inversions
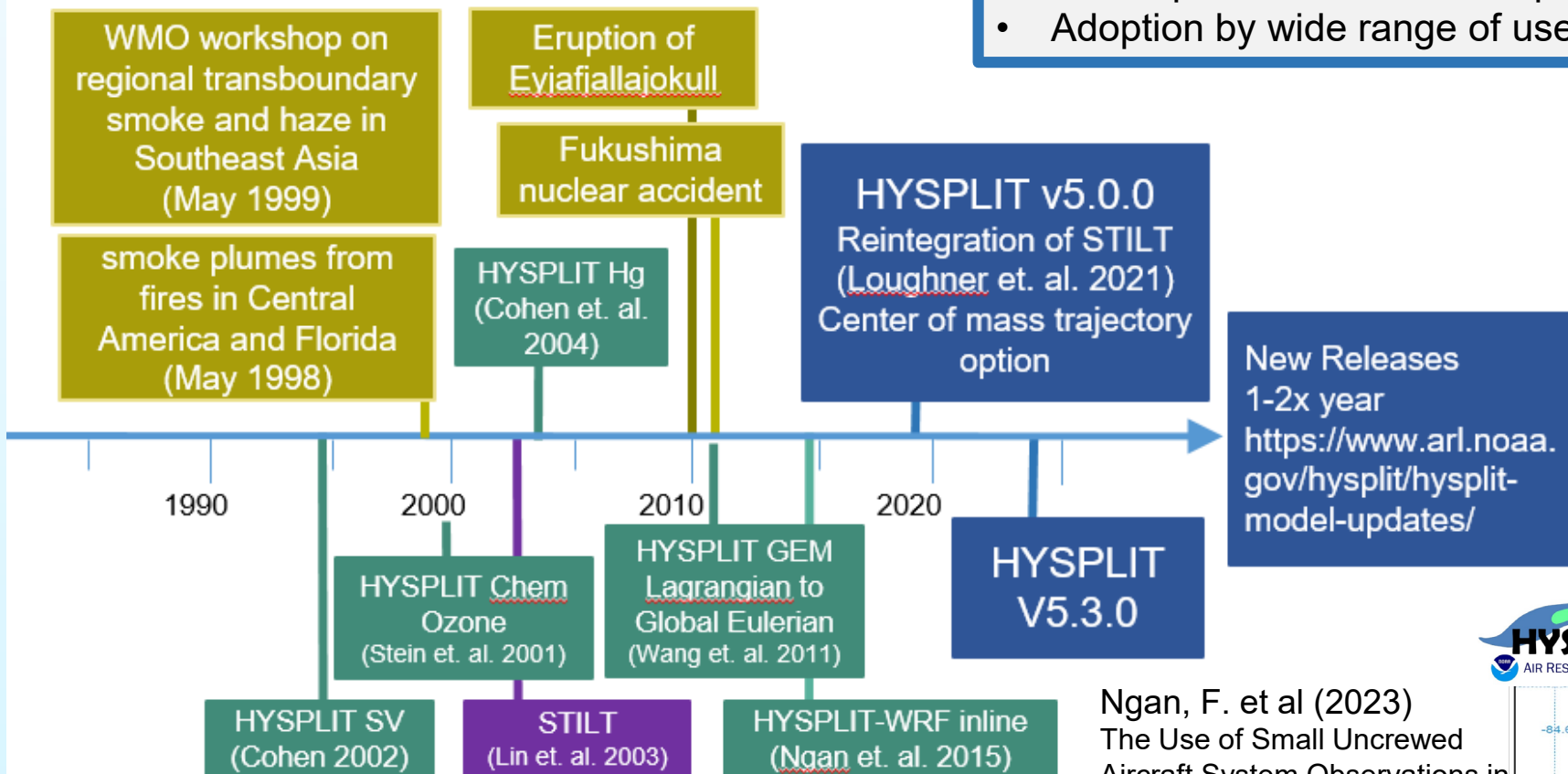- Development of ensembles/probabilistic output
- Adoption by wide range of users world-wide

Rapid expansion of Application Areas
Radiological releases, tracer experiments, field campaigns, volcanic emissions, wildfire smoke, dust, prescribed burns, mercury, insects (e.g. locusts), pathogens, precipitation, chemicals, microplastics, greenhouse gasses.

WMO workshop on regional transboundary smoke and haze in Southeast Asia (May 1999)

Eruption of Eyjafjallajokull

Fukushima nuclear accident

HYSPLIT v5.0.0 Reintegration of STILT (Loughner et. al. 2021) Center of mass trajectory option

smoke plumes from fires in Central America and Florida (May 1998)

HYSPLIT Hg (Cohen et. al. 2004)

New Releases 1-2x year https://www.arl.noaa.gov/hysplit/hysplit-model-updates/

1990   2000   2010   2020

HYSPLIT Chem Ozone (Stein et. al. 2001)

HYSPLIT GEM Lagrangian to Global Eulerian (Wang et. al. 2011)

HYSPLIT V5.3.0

HYSPLIT SV (Cohen 2002)

STILT (Lin et. al. 2003)

HYSPLIT-WRF inline (Ngan et. al. 2015)

Ngan, F. et al (2023)
The Use of Small Uncrewed Aircraft System Observations in Meteorological and Dispersion Modeling. *Journal of Applied Meteorology and Climatology*

WRF — Release location — 10 km

sUAS nudged WRF — 10 km
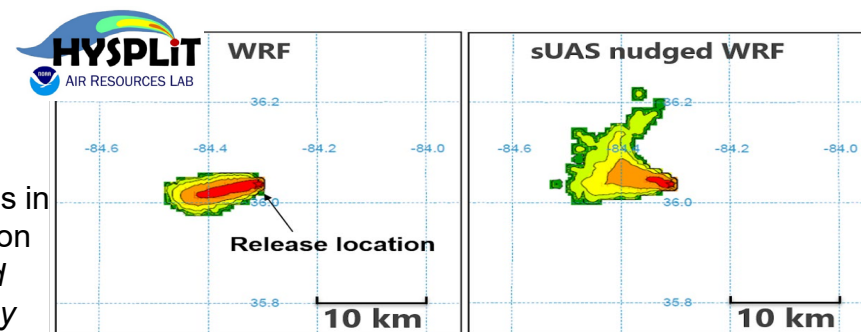
Commitment to Open Science: An Example

Detailed Source-Attribution for the Atmospheric Transport and Deposition of Dioxin and Mercury to the Great Lakes

- Policy-relevant analysis : Connecting individual sources with deposition of toxic chemicals to sensitive ecosystems
- To reduce toxic impacts, need to know where the impacts are coming from

Chicago Tribune
— ONLINE EDITION —

http://www.chicagotribune.com/services/site/premium/interceptlogin.register

Nearby coal plants said to harm lake
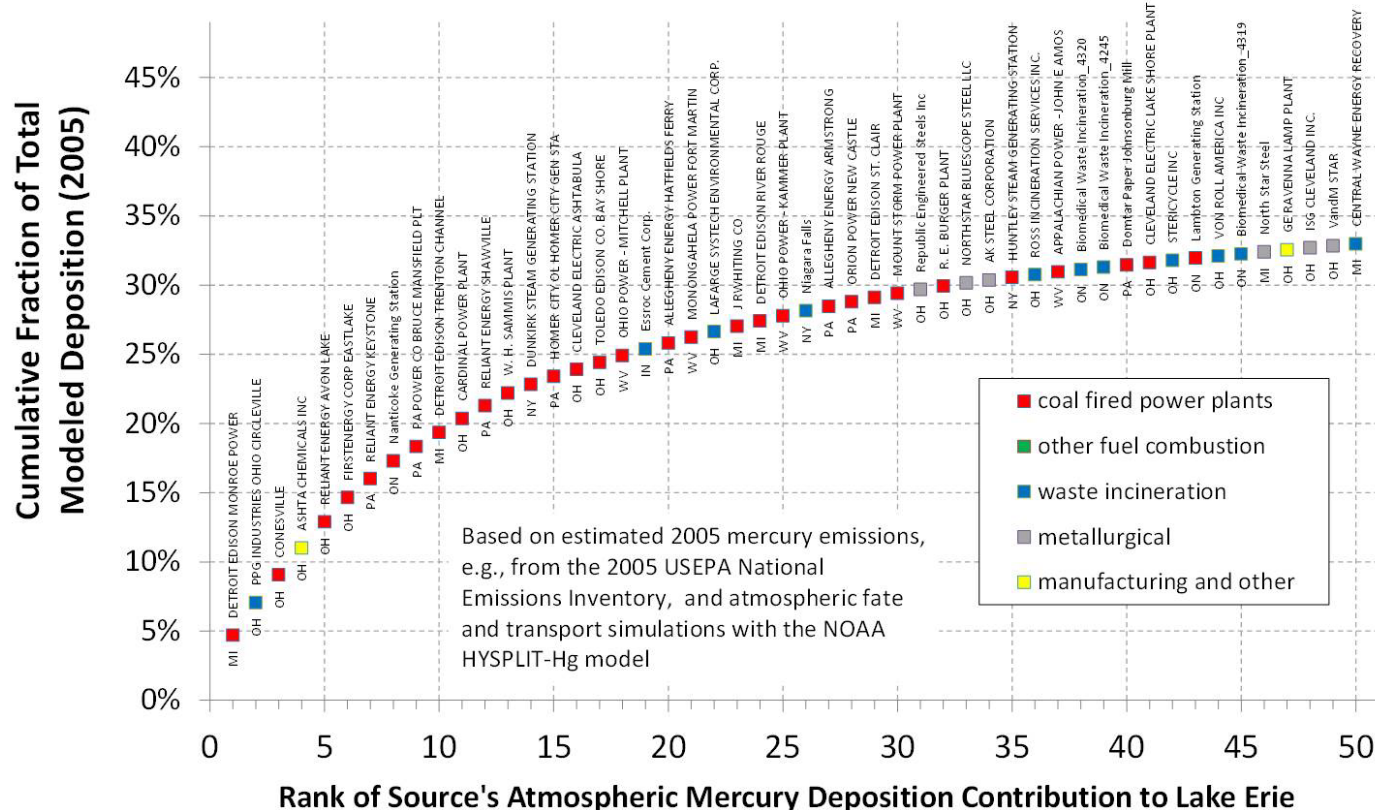
By Michael Hawthorne
Tribune staff reporter

September 19, 2005

Contradicting a key part of the Bush administration's environmental policy, a new federal study estimates most of the mercury falling into Lake Michigan comes from smokestacks close to the shoreline.

Sixteen of the top 25 sources of mercury dropped into the lake are coal-fired power plants, according to the study by the National Oceanic and Atmospheric Administration (NOAA). Some of the toxic metal comes from as far away as Nevada and Texas, the study found, but most blows toward the lake from coal plants and factories in Illinois, Wisconsin, Michigan and Indiana.

Top 50 Atmospheric Deposition Contributors to Lake Erie

Based on estimated 2005 mercury emissions, e.g., from the 2005 USEPA National Emissions Inventory, and atmospheric fate and transport simulations with the NOAA HYSPLIT-Hg model

Legend:
- coal fired power plants (red)
- other fuel combustion (green)
- waste incineration (blue)
- metallurgical (gray)
- manufacturing and other (yellow)

Publications by Cohen et. al. in 1995, 2002, 2004, 2016, plus 2007 Report to Congress

"Open Science is the principle and practice of making research products and processes available to all, while respecting diverse cultures, maintaining security and privacy, and fostering collaborations, reproducibility, and equity" https://www.science.gov/

Where are we going? Overarching Goals

➢ **Maintain and develop state of the art atmospheric transport and dispersion modeling system**

- Model evaluation

- Model improvement through improved inputs, physics, parameterizations, performance and more.

➢ **Develop and support best practices and methods for model applications**

- Transition modeling tools to operational environments at NOAA and at external partners

- Support model users in their application of the model and interpretation of model results

- Be leaders in the wider transport and dispersion modeling communities through research, publications, conferences, committees, collaborations
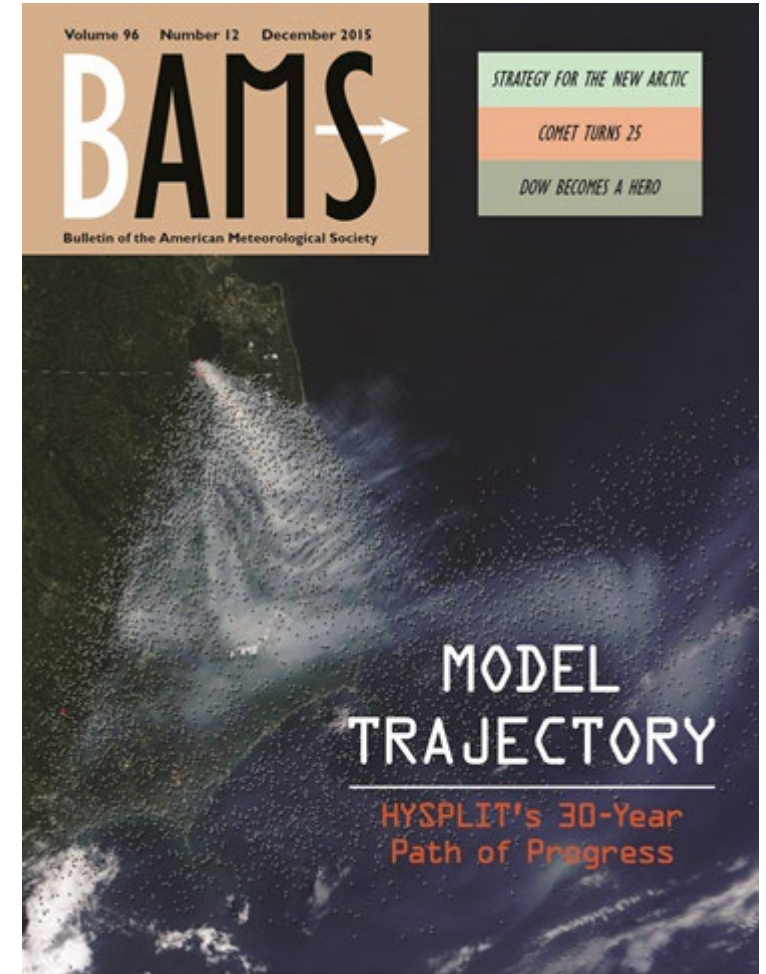
Collaborations (a sampling)

Questions?