NOAA's Air Resources Laboratory's aerosol modeling capabilities

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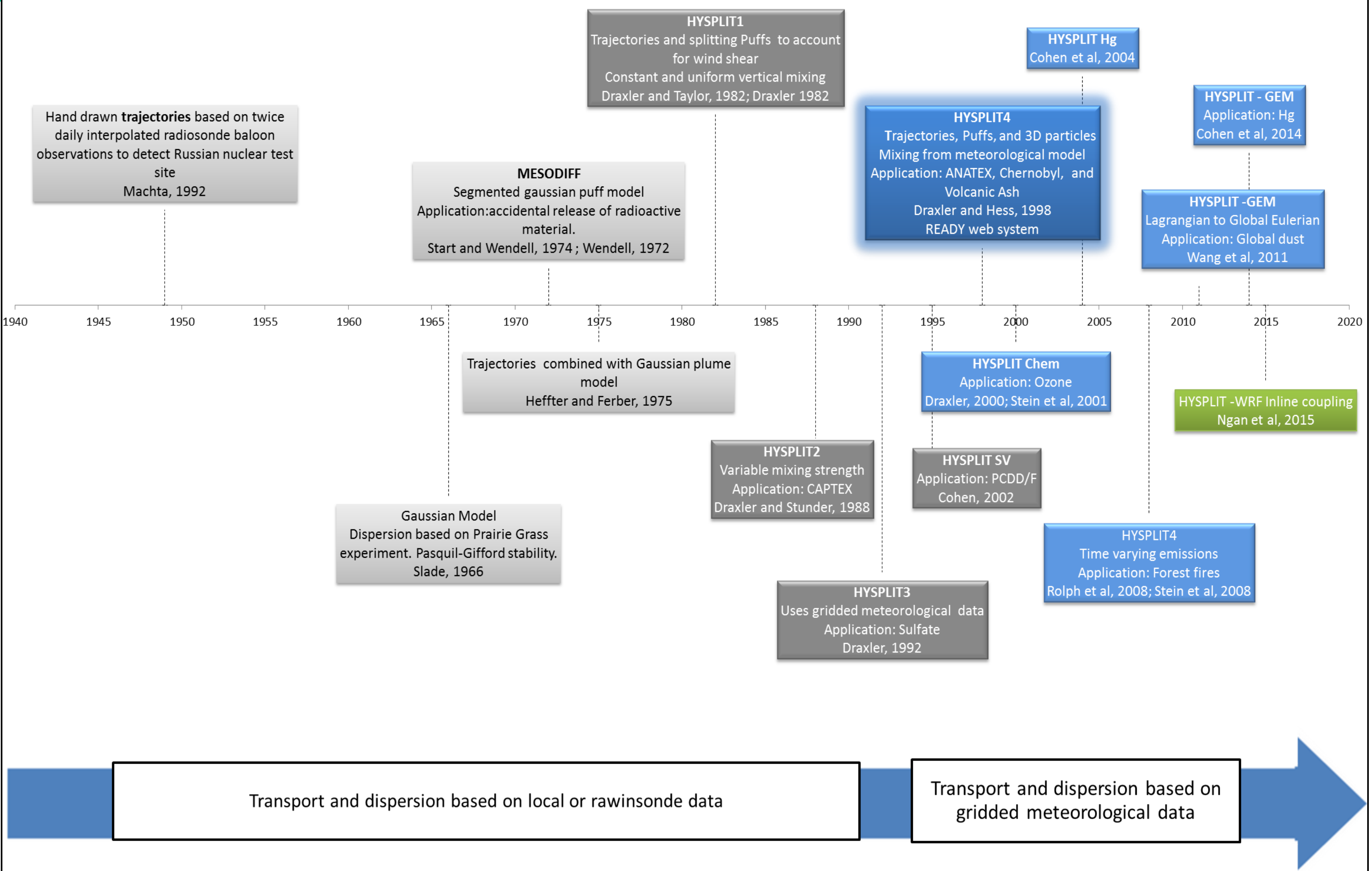
9 June 2015
Nineteenth Annual George Mason University Conference on Atmospheric Transport and Dispersion Modeling

History of the HYSPLIT model



NOAA's HYSPLIT atmospheric transport and dispersion modeling system. Stein et al, 2015 Bulletin of the American Meteorological Society 2015 ; e-View doi: http://dx.doi.org/10.1175/BAMS-D-14-00110.1

Hand drawn trajectories: 1949

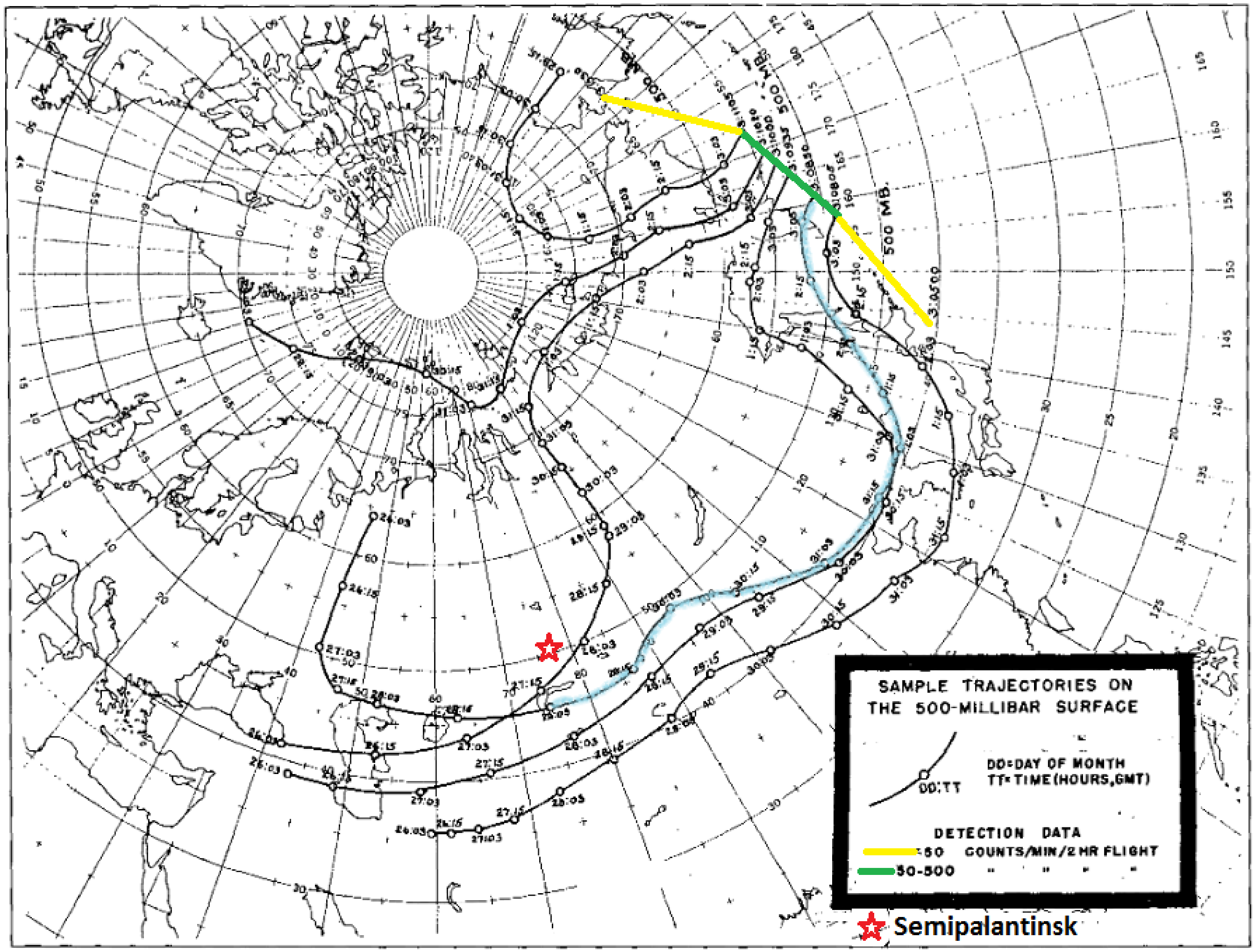
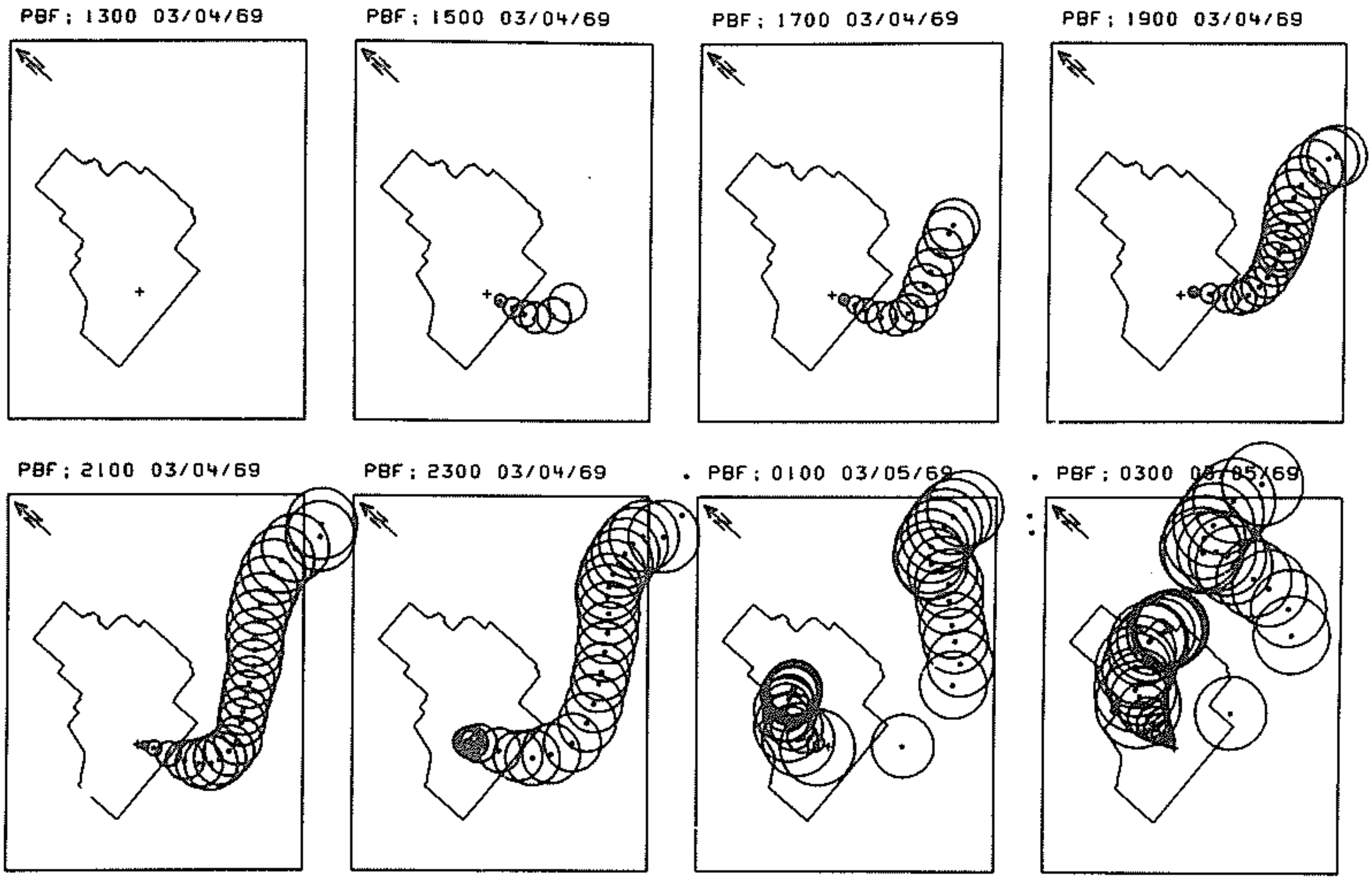


FIG. 1. The location of the first detection of debris from Joe-1 near Kamchatka, with backward trajectories from six parts of the flight leg on 3 September 1949 at 500 mb. The figure is reproduced unchanged from 1949.

Machta, 1992 *BAMS*

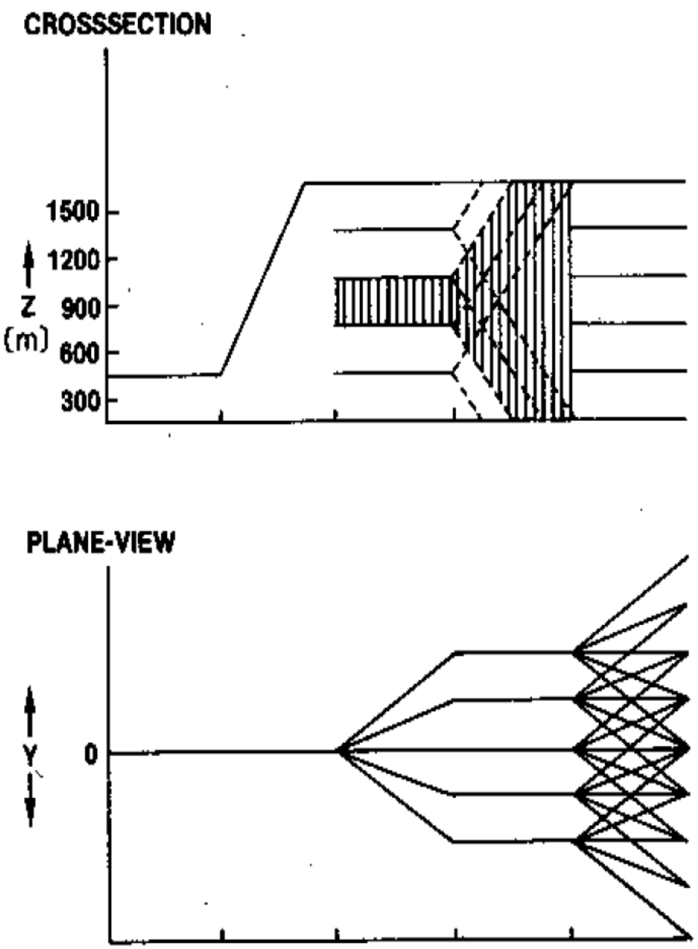
Calculated Trajectories with Dispersion MESODIFF



Start and Wendell, 1974

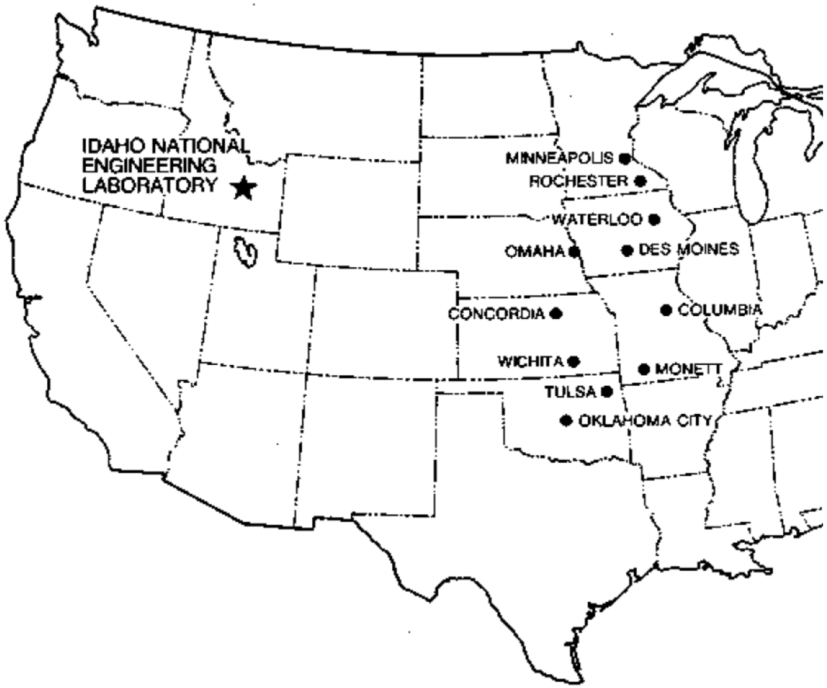
Model (no name) with Puff Splitting: HYSPLIT1

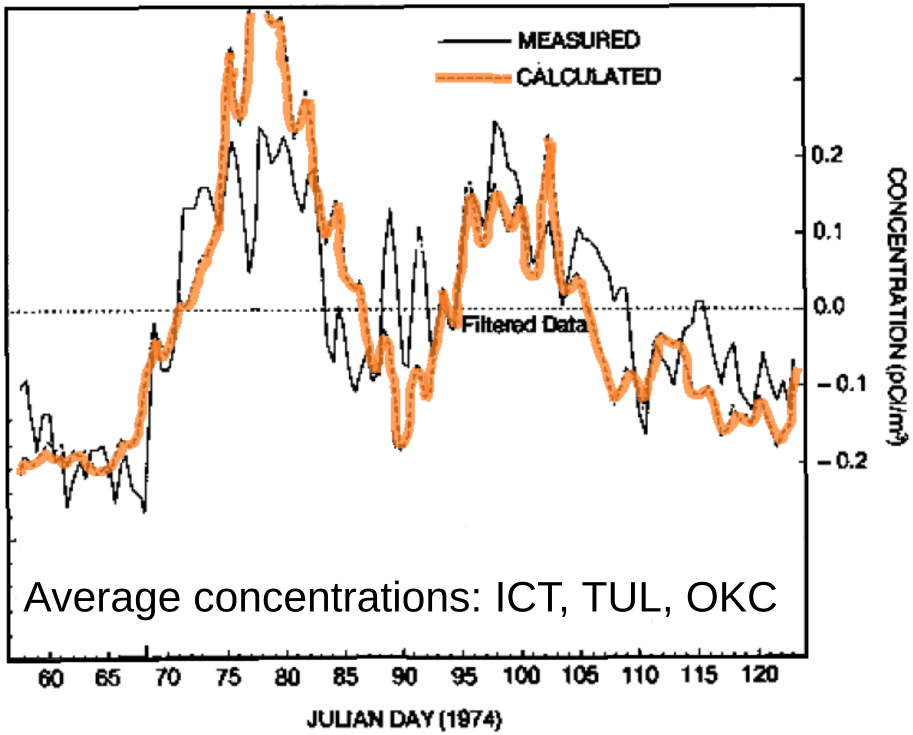
- Segmented pollutant puffs released near the surface and trajectories were followed for several days
- Transport calculated from wind observations based on rawinsonde data (not interpolated) taken twice daily
- No vertical mixing assumed at night and complete mixing over the planetary boundary layer (PBL) during the day
- Nocturnal wind shear modeled by vertically splitting the puffs that extended throughout the PBL into 300m sub-puffs during the nighttime transport phase of the calculation



HYSPLIT1: 1500 km Verification

- Kr-85 released to the atmosphere and sampled at multiple locations in the Midwestern U.S. during a two-month field experiment
- Northern sampling sites showed evidence of local sources
- Southern sites (ICT, TUL,OKC) are well correlated with emissions from INEL

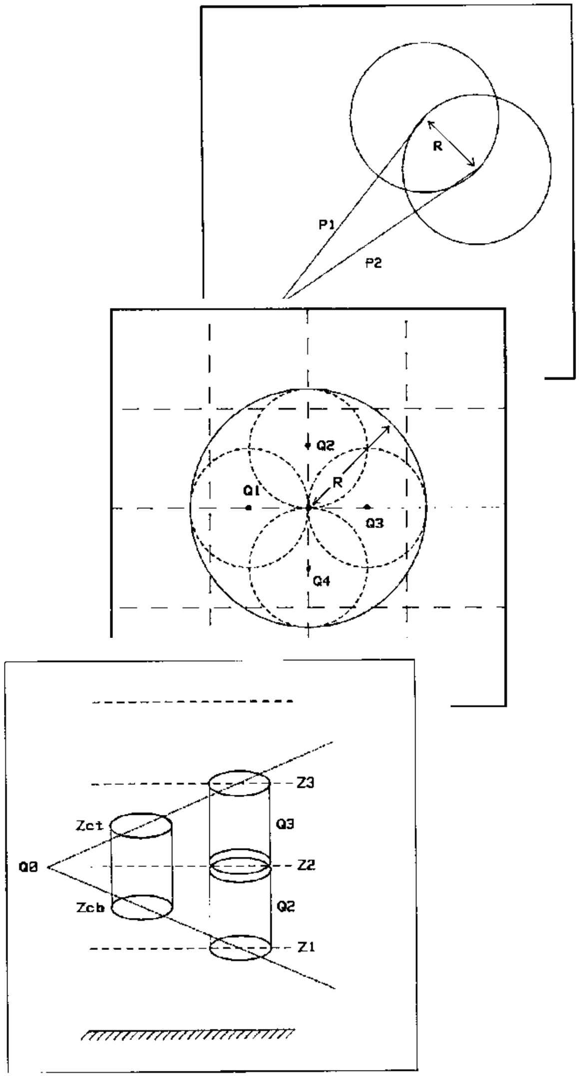




Draxler, 1982 *Atmospheric Environment*

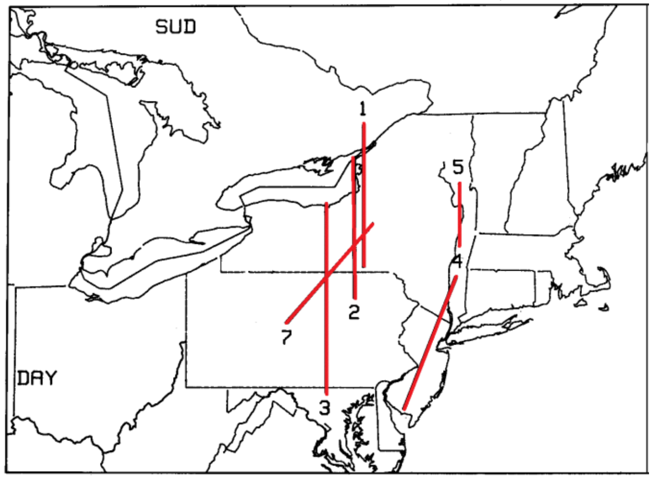
HYSPLIT2: Continuous Puff Splitting and Merging

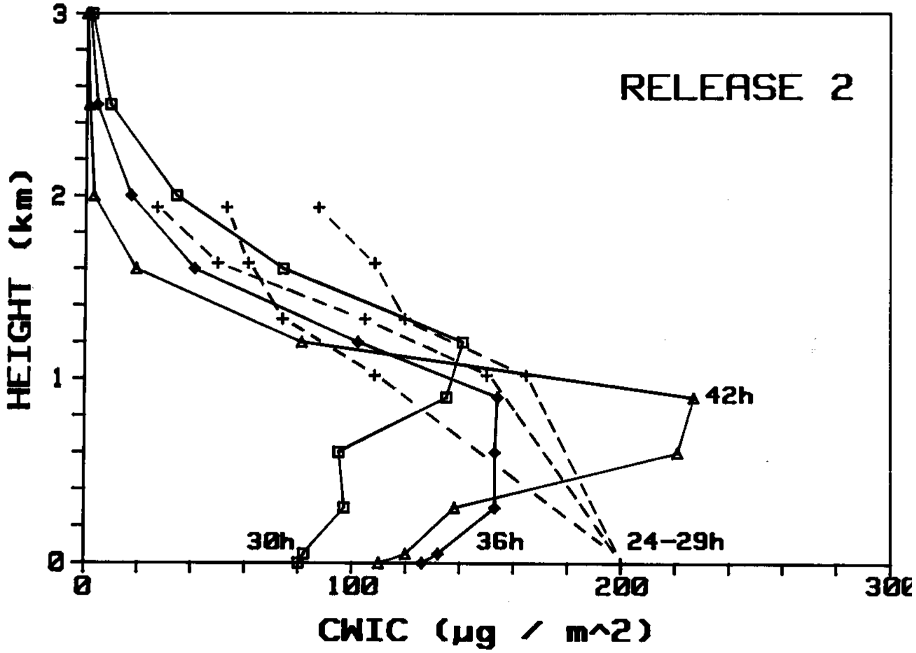
- Use of interpolated rawinsonde or any other available measured data to estimate vertical mixing coefficients that varied in space and time
- Mixing coefficients were derived from Monin-Obukhov length, friction velocity, and surface friction potential temperature
- Rather than arbitrary stable-unstable puff splitting algorithm, puffs could split at any time when their size exceed the spatial resolution of the meteorological data (vertical or horizontal)
- Puffs are merged when the distance between them is less than their radius

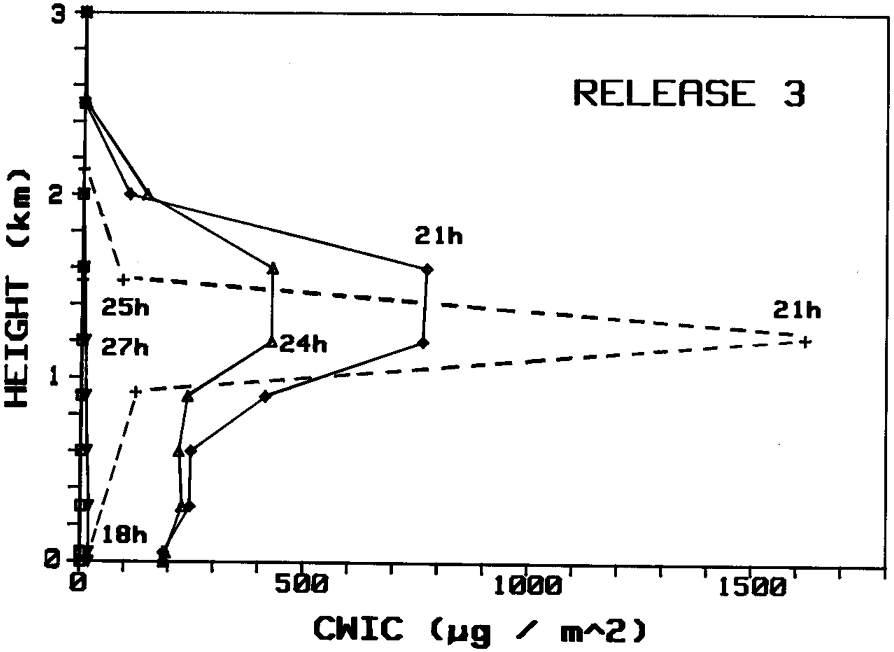


HYSPLIT 2 test: CAPTEX

- The rawinsonde based HYSPLIT calculations were able to capture the gross vertical plume structure in a well mixed (#2) environment and a case with greater vertical stability (#3)
- Aircraft paths for each release shown at right
- Measured (dashed) and model (solid) cross-wind integrated concentrations (CWIC) are shown below

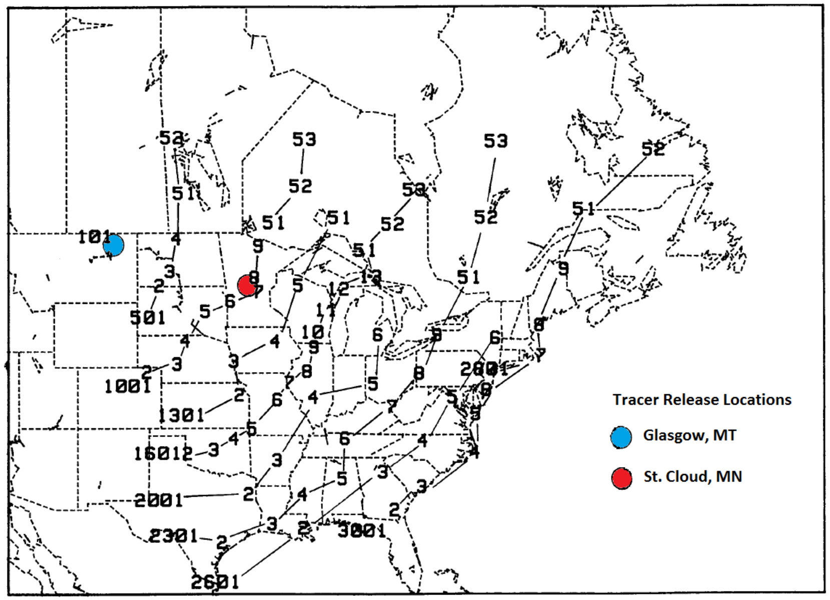


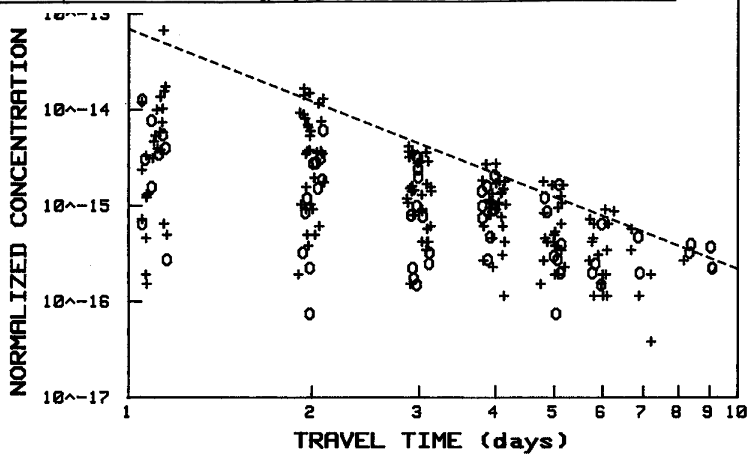




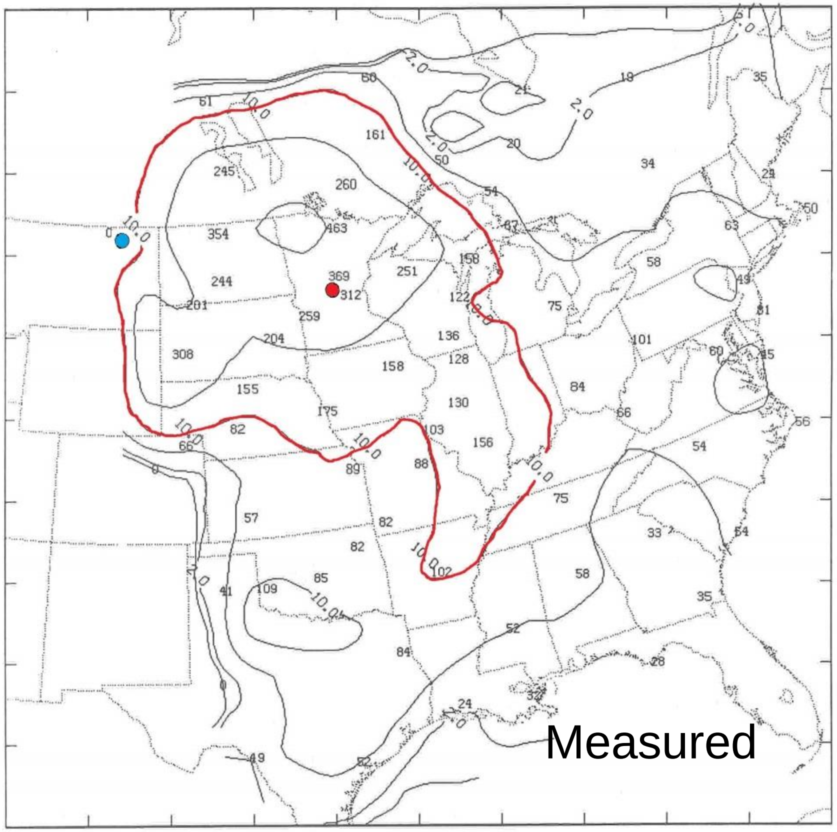
HYSPLIT3: Gridded Meteorological Data

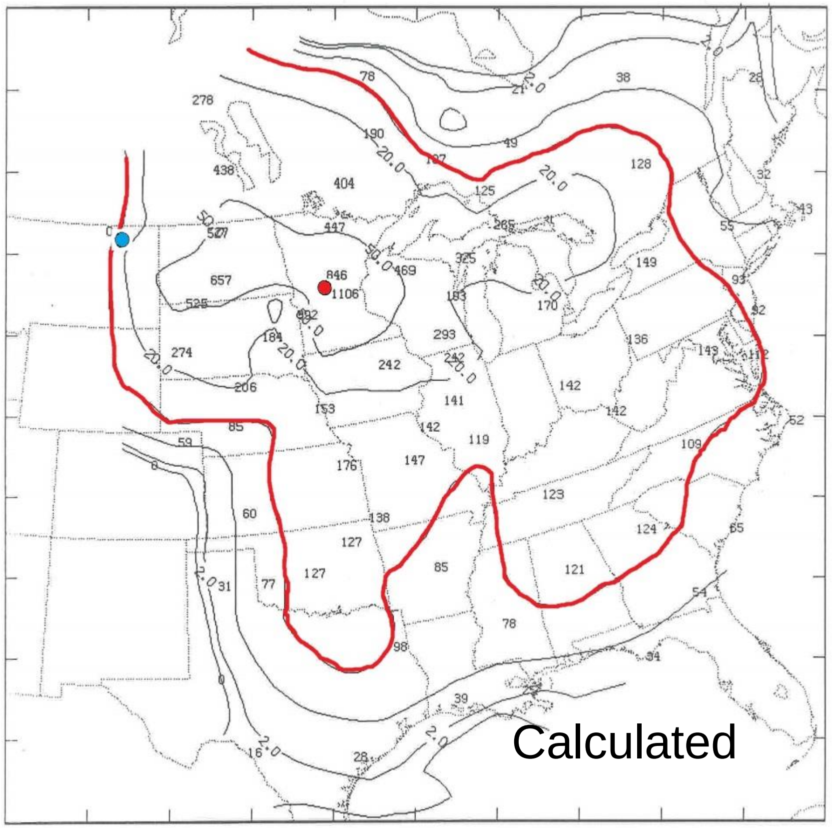
- Similar to HYSPLIT2, the calculation followed cylindrical puffs that grow in time along a trajectory and split when they reach the meteorological grid size.
- However, HYSPLIT3 was designed to utilize gridded meteorological model outputs such as from the Nested Grid Model (NGM)
- Most of the initial development and testing was conducted using data from the Across North America Tracer Experiment (ANATEX) and the NGM
- The NGM was re-run for ANATEX to create a data archive at 2 hour intervals at a resolution of 90 km, a challenging data storage problem for the PC's 20 MB internal disk drive





HYSPLIT3: Three-Month Average PFT Concentration



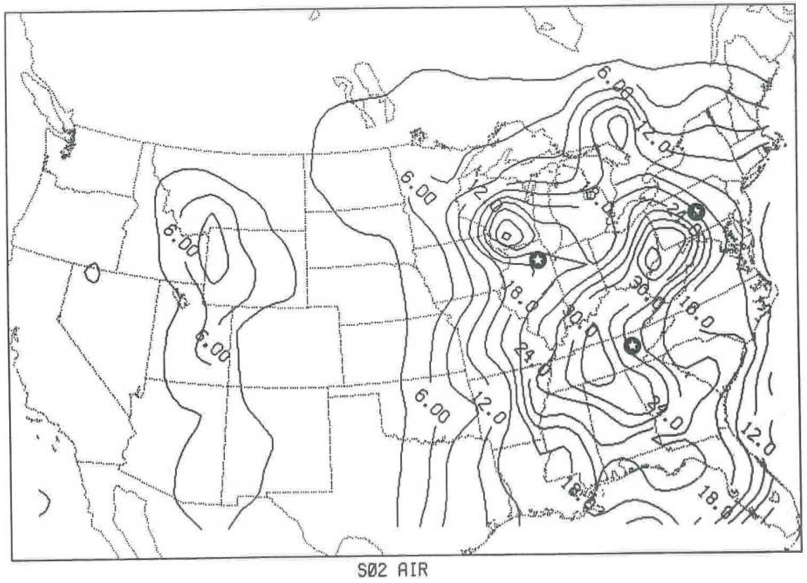


- Calculations using NGM meteorology showed about a factor of two over-prediction for the January-March (1987) average.
- Most bias due to over-prediction at STC; cause unknown.

HYSPLIT3: Linear Chemistry

- Chemical formation and deposition of sulfate was incorporated into HYSPLIT3 in a first attempt to include a chemical module into the system.
- The application incorporated gas- and aqueous-phase oxidation of sulfur dioxide, and dry and wet removal of SO_2 and aerosol SO_4^{2-}.
- Chemical transformations occurred within each Lagrangian puff without any interaction with other puffs.
- NGM predicted precipitation was used for all removal and chemical conversion calculations.

Sulfur dioxide air concentrations



Rolph *et al*, 1992 *Atmospheric Environment*

HYSPLIT 4: Including 3D Particle Dispersion

- Includes an automated method of simultaneously using multiple meteorological grids such that the computation always uses the finest spatial resolution available at the time and location of the puff
- Pre-processors were developed for many different meteorological models (WRF, RAMS, MM5, ECMWF) to convert data to the ARL format, in addition to the archives of existing NOAA models
- Multiple parameterizations to estimate the stability from gradients of meteorological variables
- Multiple options to convert stability into dispersion values (diffusivity profiles, turbulent kinetic energy, velocity variance)
- Modeling the turbulent particle motion directly (3D) or the change in the statistic of the particle distribution (puffs)
- Different Lagrangian representations: 3D particles, Top Hat or Gaussian puffs, or combinations of the previous two: puffs with a planar mass having vertical particle characteristics
- **Version 4 of HYSPLIT has been the basis for the construction of essentially all model applications for the last 15 years**

HYSPLIT4: Evolution since 1998

- Wilson non-homogeneous turbulence correction
- Modified Gaussian random number scheme
- Backward dispersion option (Footprints)
- Integrated meteorological grid ensemble options
- Turbulence ensemble by varying random number seed
- The use of Turbulent Kinetic Energy (TKE) if available
- Pre-computed random numbers
- Variable Lagrangian time scale (stable or unstable)
- CAPE enhanced vertical mixing
- Enhanced precision for certain meteorological fields
- Embedded Eulerian model for pollutant background

HYSPLIT4: Current Applications

- **Model Evaluation**
  - Data Archive of Tracer Experiments and Meteorology
- **Emergency Response**
  - Radiological releases
  - Improvised nuclear devices
  - Volcanic eruptions
- **Air Quality**
  - Fire smoke
  - Wind-blown dust

Model Evaluation

Data Archive of Tracer Experiments and Meteorology

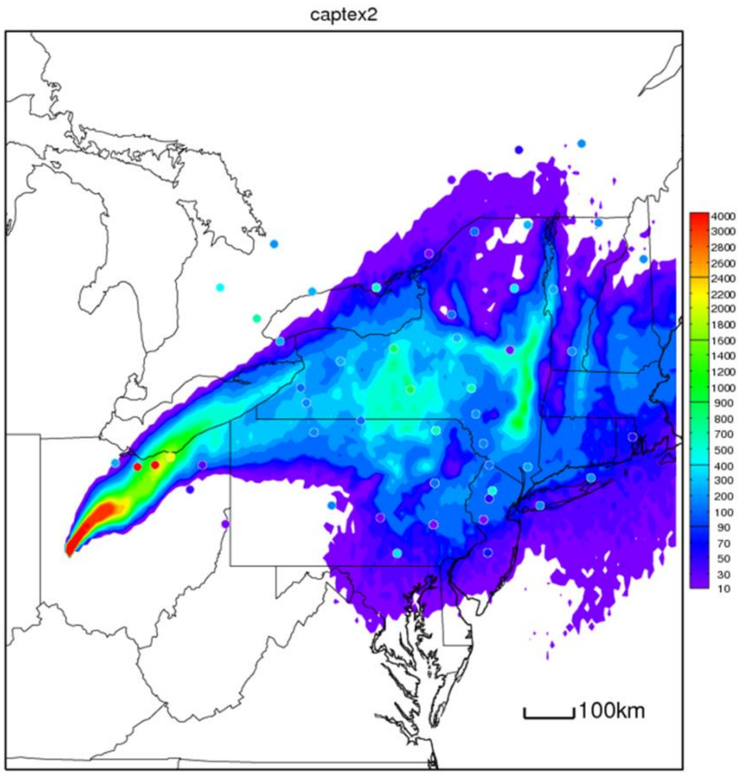
- **Approach**
  - North American Regional Reanalysis (NARR) and several with WRF runs
  - Common statistical evaluation protocols
- **Accomplishments**
  - Web access to run HYSPLIT for each experiment
  - Standardized model change testing in conjunction with version control

- **Cross Appalachian Tracer Experiment (CAPTEX)** Dayton, OH, and Sudbury, ONT, Sep., Oct., 1983
- **Atlantic Coast Unique Regional Atmospheric Tracer Experiment (ACURATE),** Savannah River Plant, SC, Spring 1982 – Summer 1983
- **Across North America Tracer Experiment (ANATEX)**, Glasgow, MT, and St. Cloud, MN, January through March 1987
- **Oklahoma Tracer Experiment**, Norman, OK, July, 08 1980
- **Metropolitan Tracer Experiment (METREX)** , Washington, DC, January – December 1984
- **European Tracer Experiment (ETEX)**, Rennes, France, October 23, 1994
- **Savannah River Plant Experiment** , Aiken, SC, Aug. 1975 through Sep. 1977
- **Atmospheric Studies in Complex Terrain (ASCOT)** , California, September 12-25, 1980
- **Colorado Springs Tracer Experiment (COSTEX)**, October 18, 21, 23, 2010

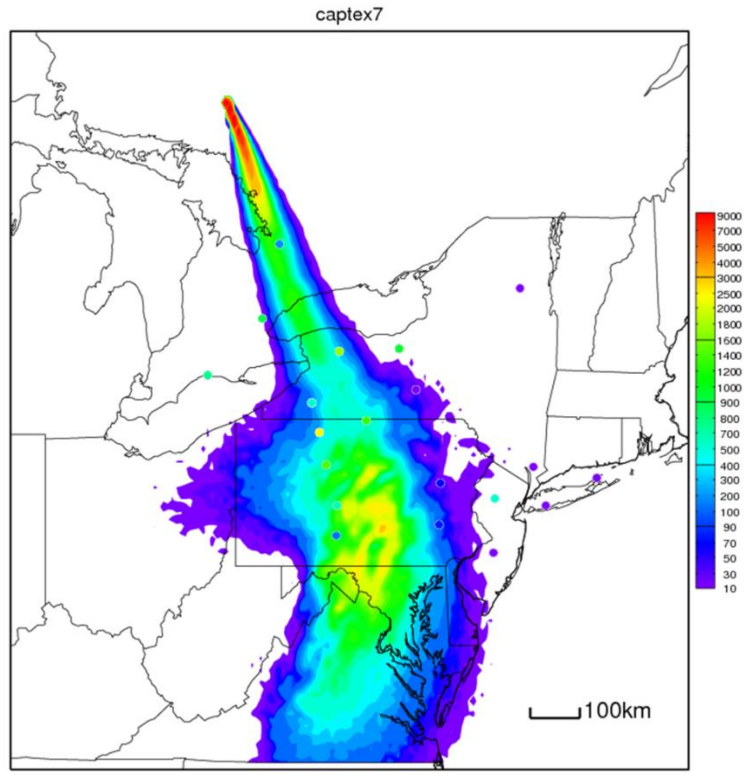
Model Evaluation

CAPTEX Average Concentration from HYSPLIT

Release #2



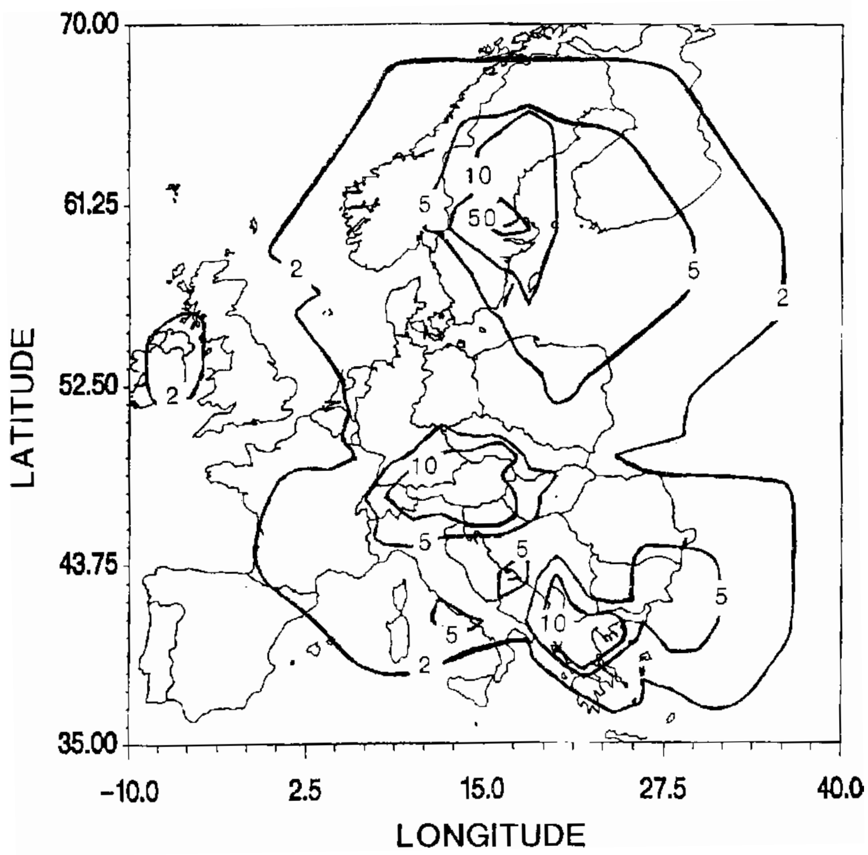
Release #7



Emergency Response

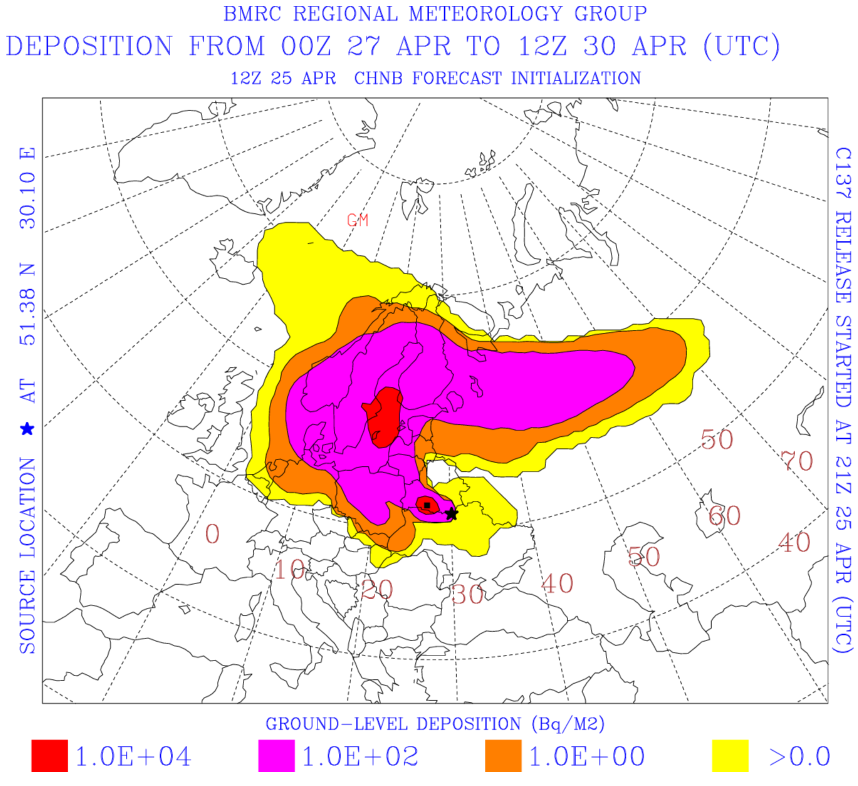
Chernobyl ^{137}Cs Deposition

ATMES Report



Draxler and Hess, 1998

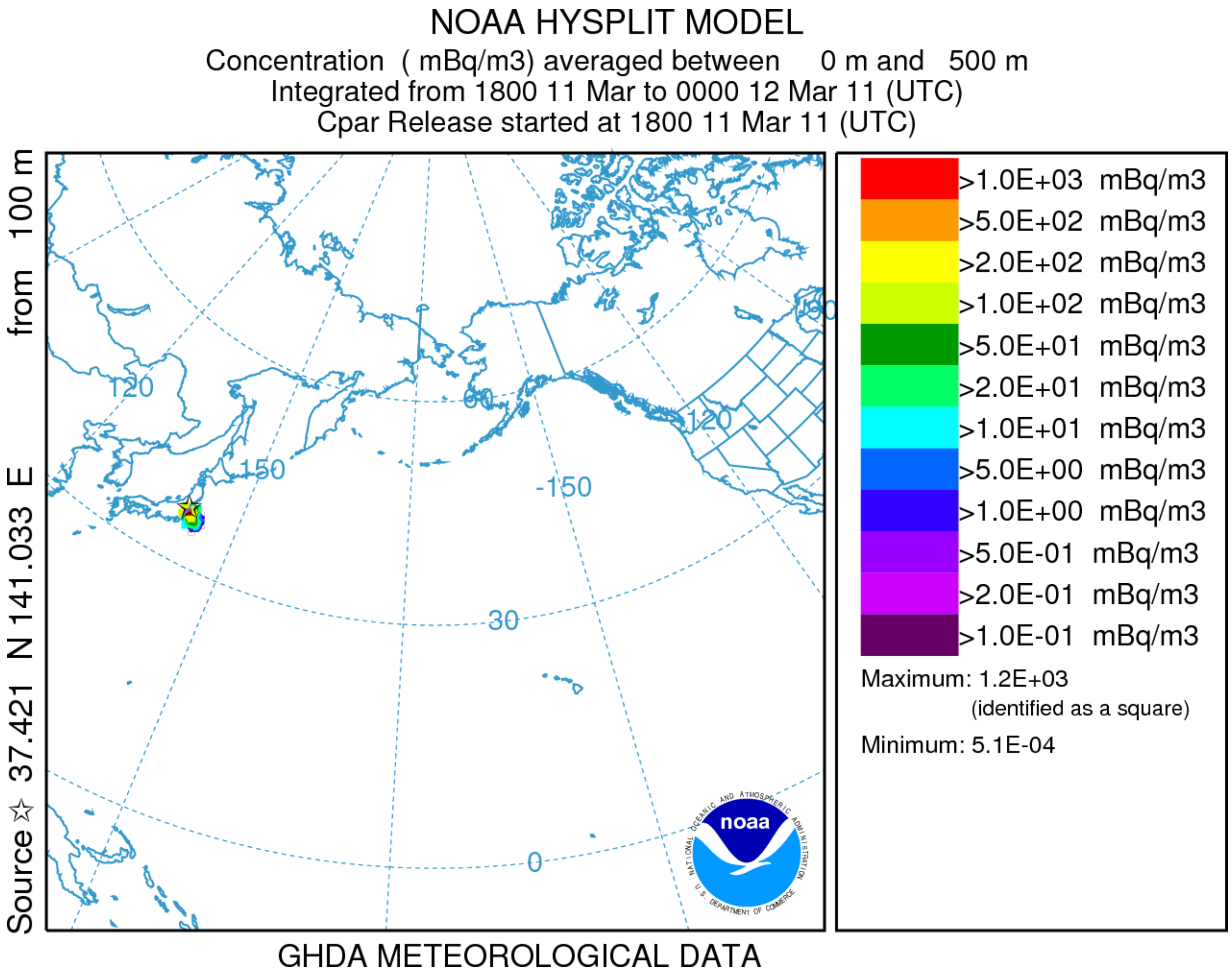
Australian Meteorological Magazine



Emergency Response

Fukushima Global Simulation

- Cs-137 air concentrations
- 100,000 particles per hour
- 0.5 degree NOAA GDAS meteorological data
- http://ready.arl.noaa.gov/READY_fdnpp.php



Emergency Response

Improvised Nuclear Devices

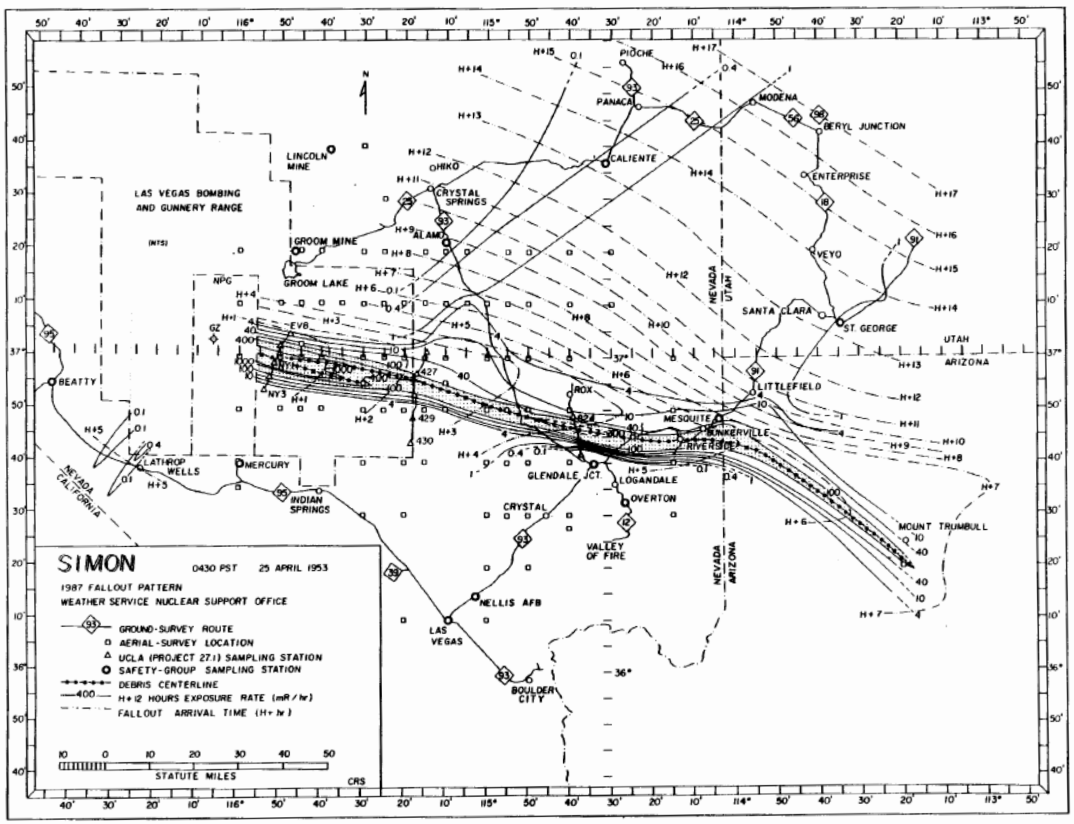
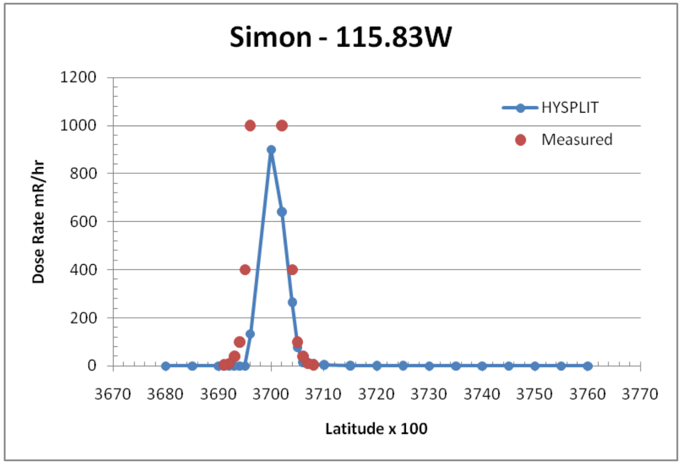


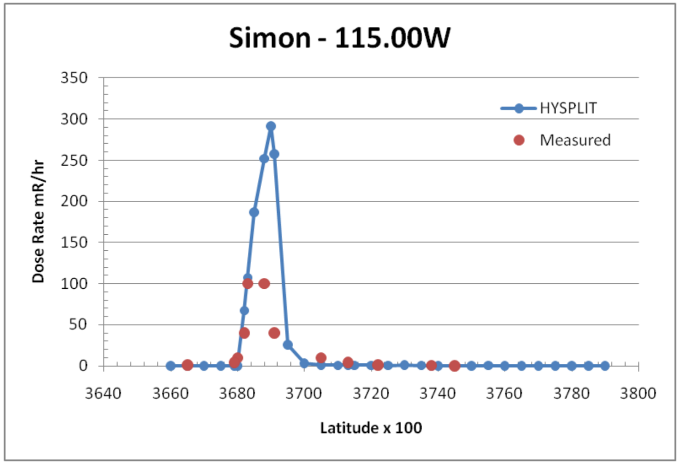
Figure 5.8. The WSNSO 1987 SIMON Fallout Pattern.

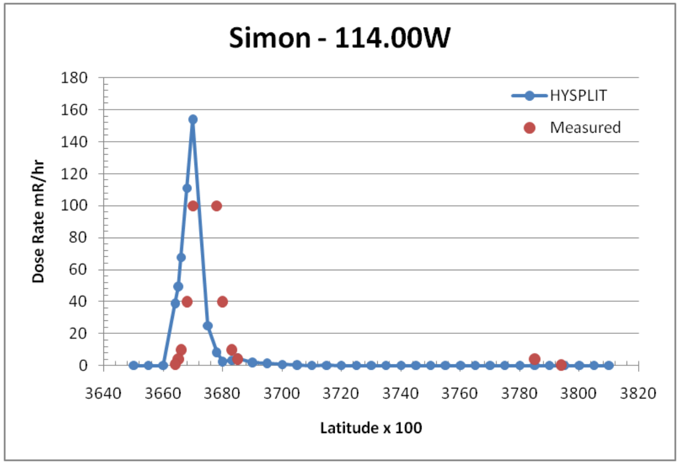
- **Backgroud**
  - ARL participated in early atmospheric testing
- **Approaches**
  - Dose based upon fission yields
  - 212 species considered
  - Partitioned between gas and 60 particle size bins
  - Activity distribution with height based upon yield
  - Time-decayed dose post-processing
  - WRF model for meteorology

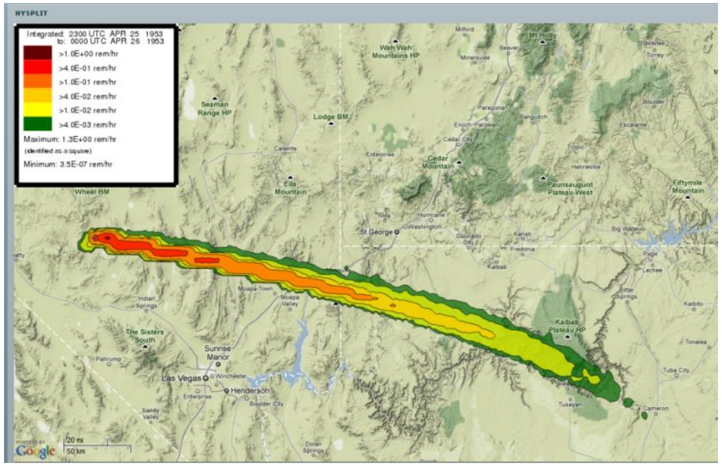
Emergency Response

Improvised Nuclear Devices



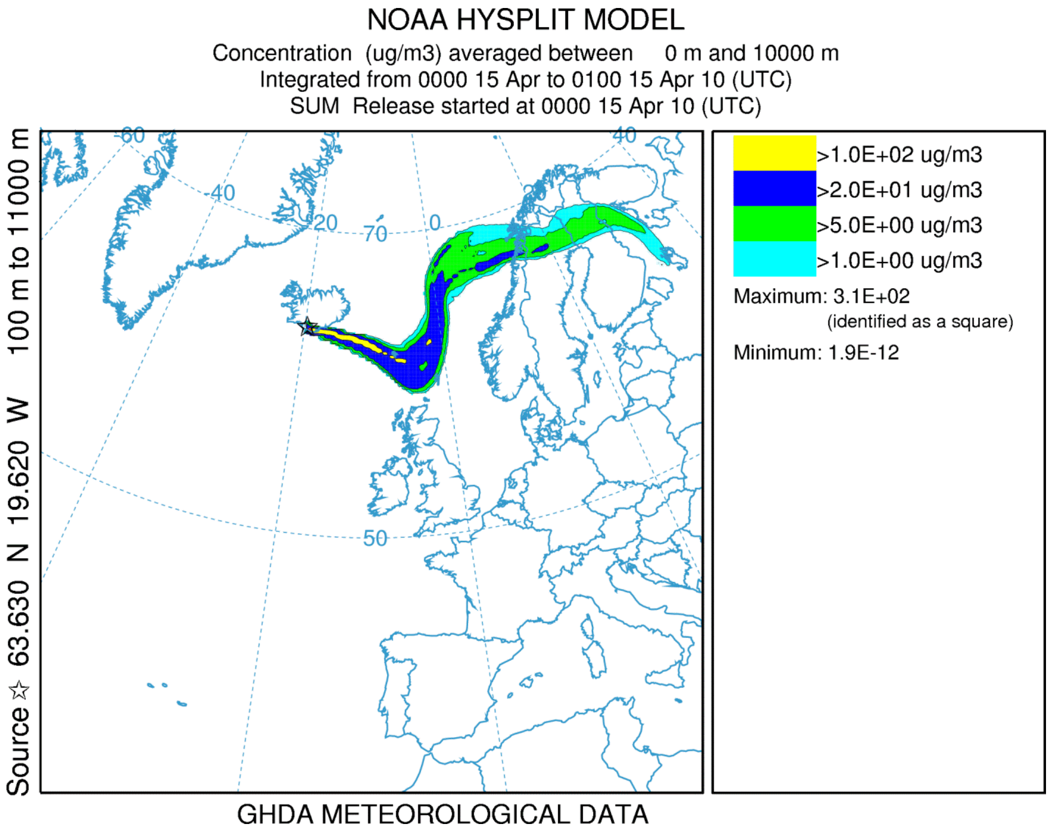






Emergency Response

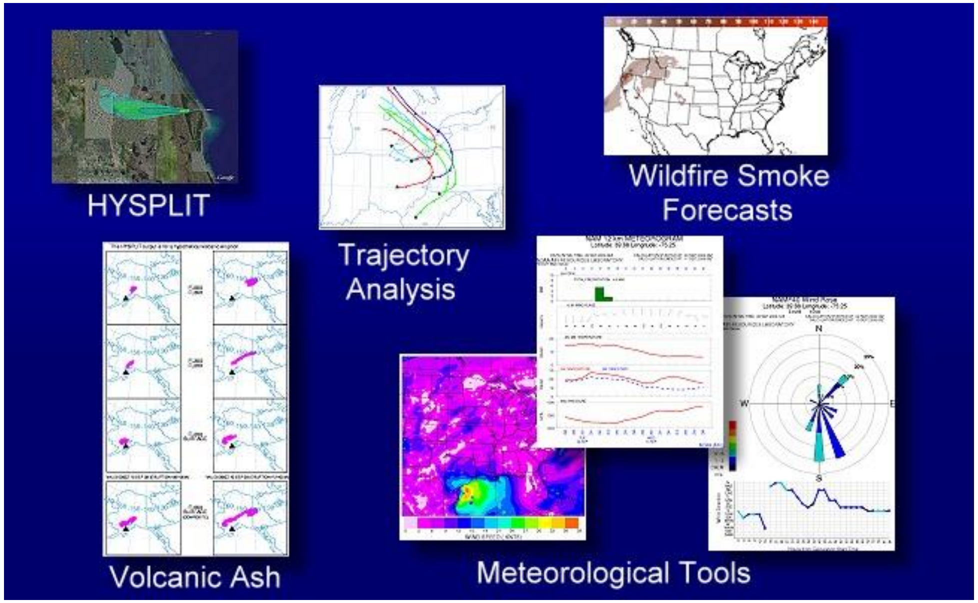
Volcanic Eruptions



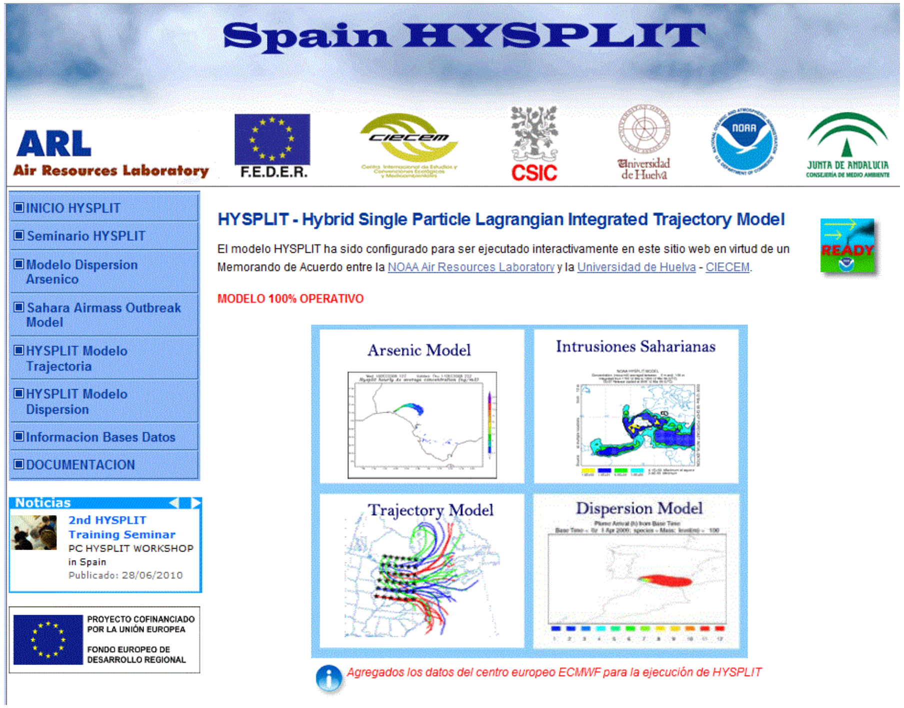
- **Background**
  - Mt. St. Helens – forecast trajectories to the USGS
  - Mt. Redoubt – KLM encounter
- **Approaches**
  - Source term uncertainty (mass, particle size, height)
  - Quantitative air concentration
- **Applications**
  - Primary customer is the Washington Volcanic Ash Advisory Center (NCEP and NESDIS)
  - HYSPLIT installed in Australia, Argentina, and AFWA

Decision Support

Real-time Environmental Applications and Display sYstem



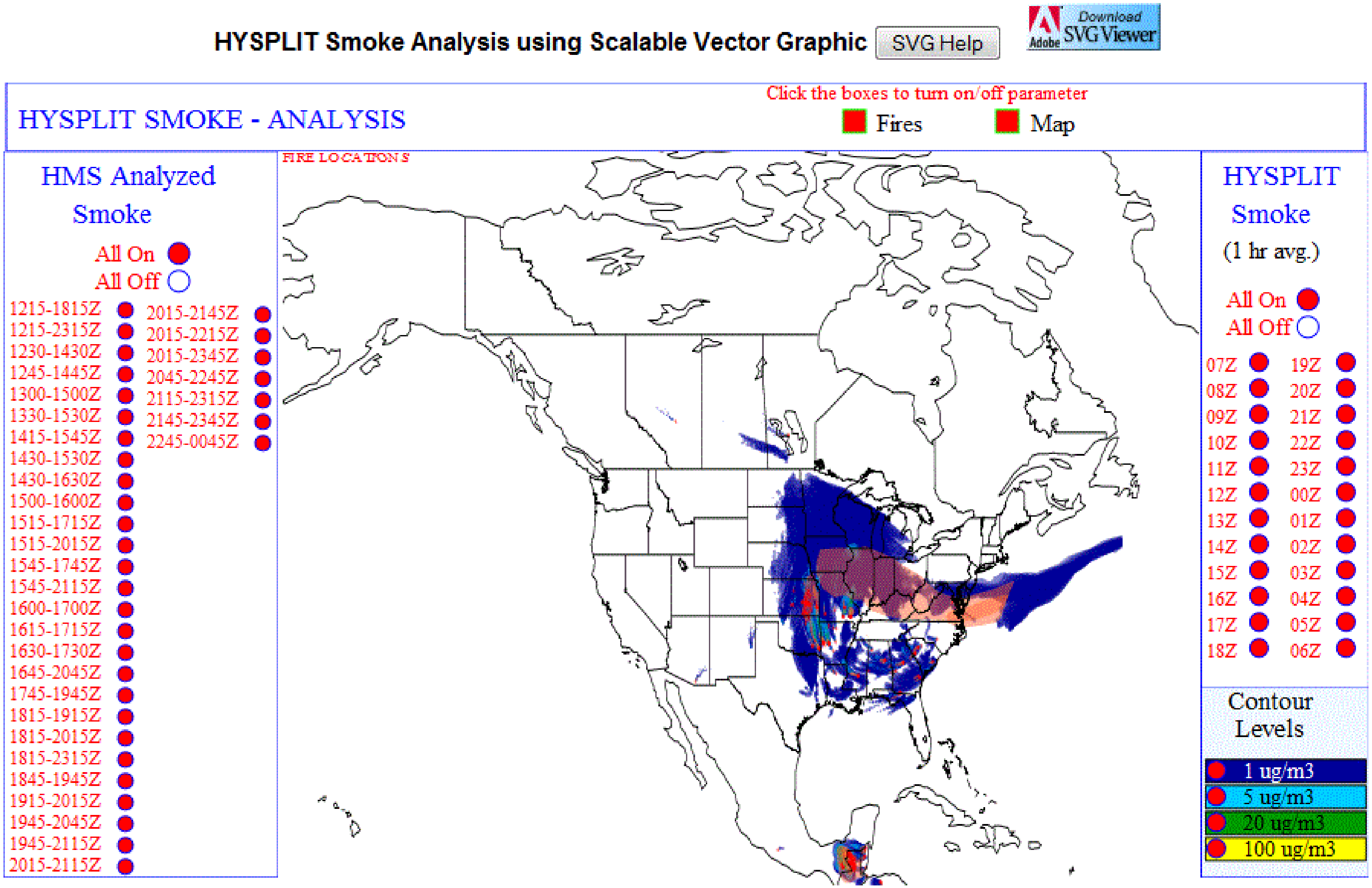
- **Public Web Interface**
  - 80,000 unregistered user runs on average per month
  - Mirror and backup capabilities (only one in Spain)



- **Training**
  - Participants from US and international governments, private industry, and academia
  - Web Forum with more than 1,000 participants
  - COMET

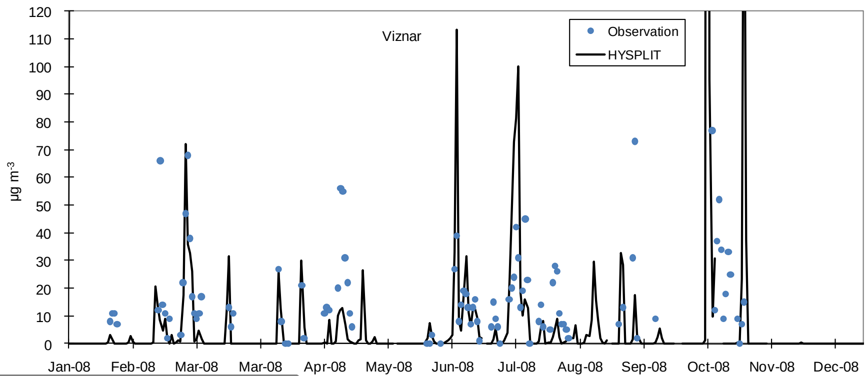
Air Quality

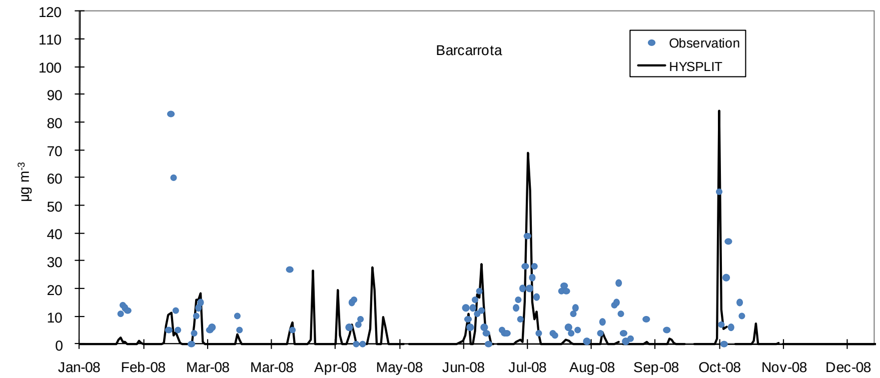
Fire Smoke

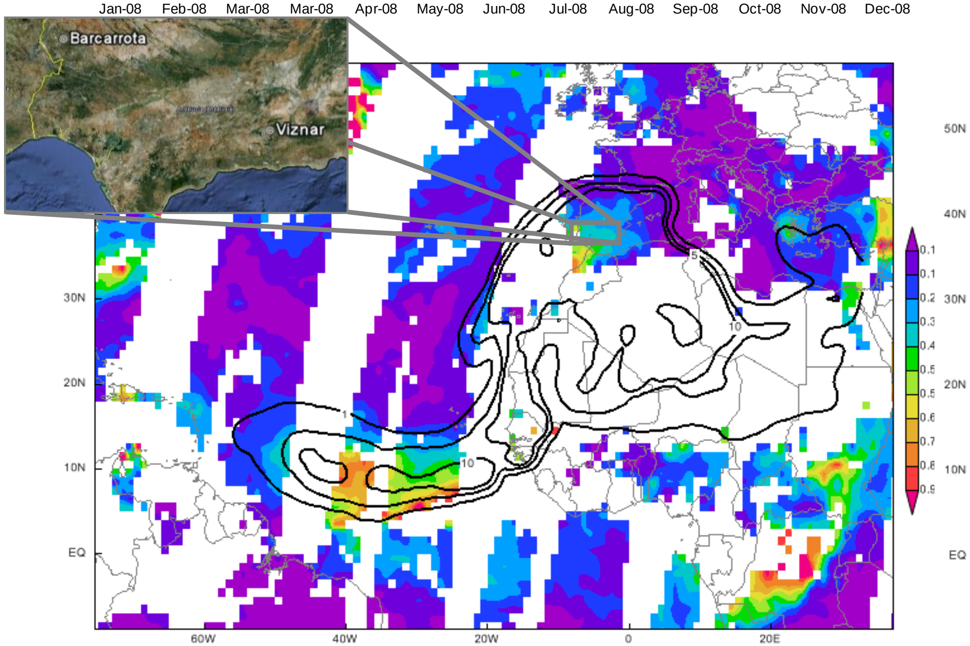


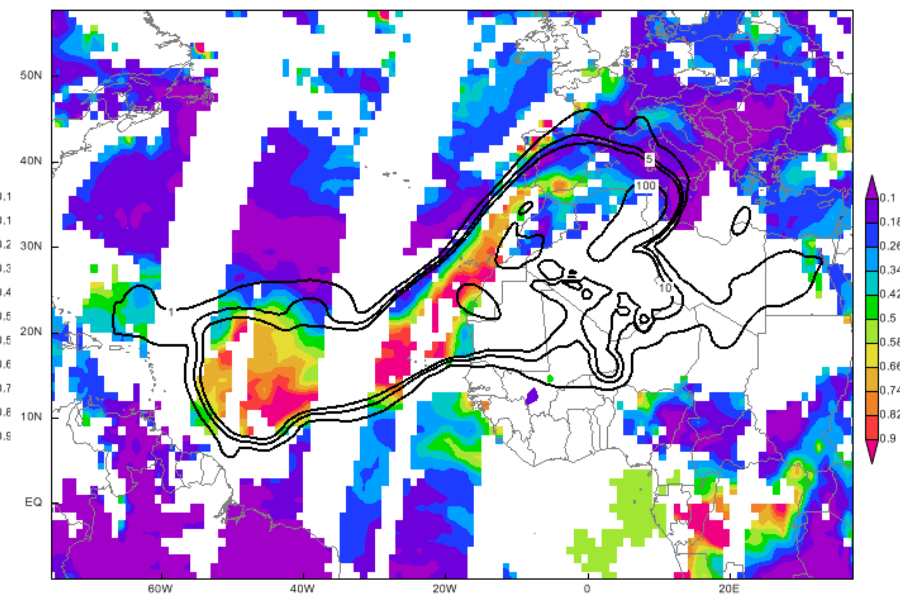
Air Quality

Dust from North Africa









Part of a Memorandum of Agreement with the University of Huelva, Spain

Will the United States see another "Dust Bowl" soon?

Daniel Tong (CICS/UMD and GMU)
Contributed by Julian Wang (NOAA) and Dongchul Kim (NASA)

- **The 1930s Dust Bowl (severe drought and poor land management);**

- **Observations revealed rapid intensification of dust storm activity in the western US;**

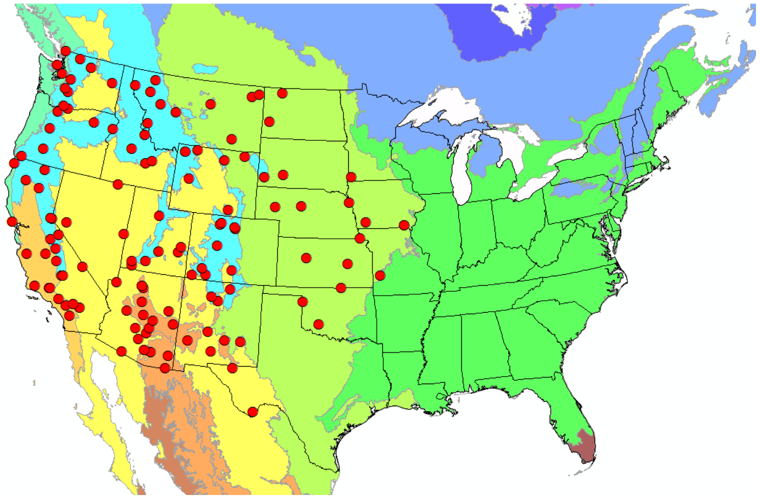
- **The Center for Diseases Control and Prevention (CDC) has reported a sharp increase in valley fever (*Coccidioidomycosis*).**

- **The confluence of drier subtropics expanded by precipitation shift, greater evaporation, less snow/ice, and earlier spring powered by warming collectively amplifies the effects of natural climatic variations to intensify seasonal or decade-long droughts, leading to future "Dust Bowl" in the Americas (*Romm, Science, 2011)*.**

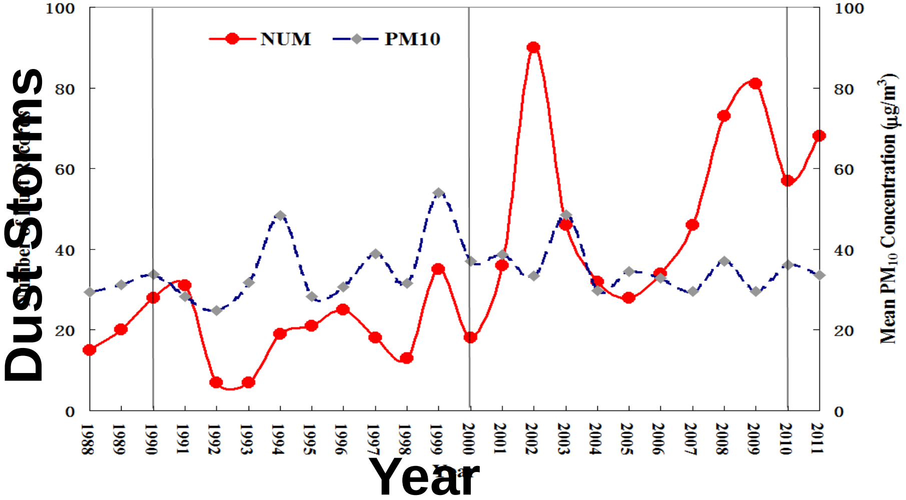
Dust Trend and Valley Fever

- Rapid increase in dust storm activity;

Ground Monitors

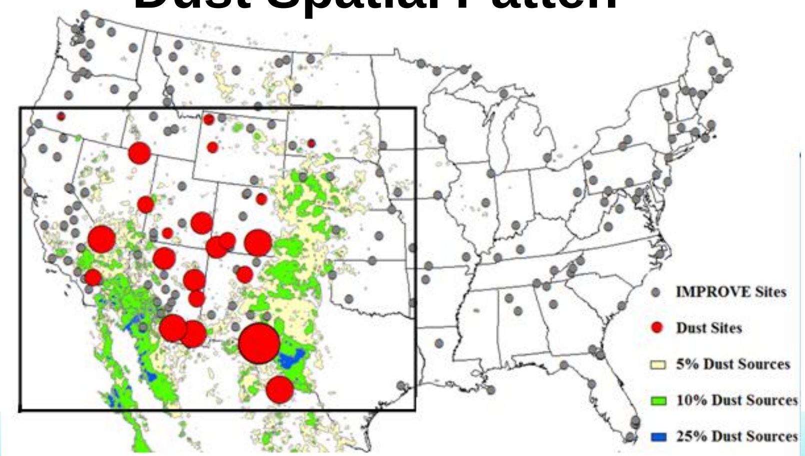


Dust Climatology



- The dust trend is correlated with the Valley Fever incidences;

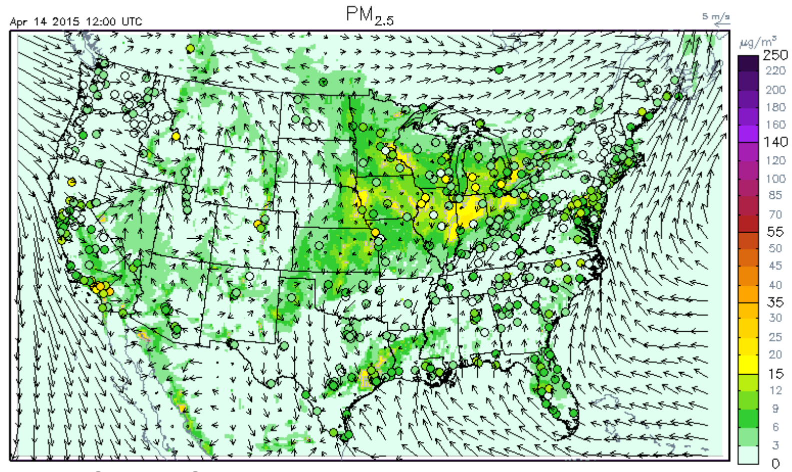
Dust Spatial Patten



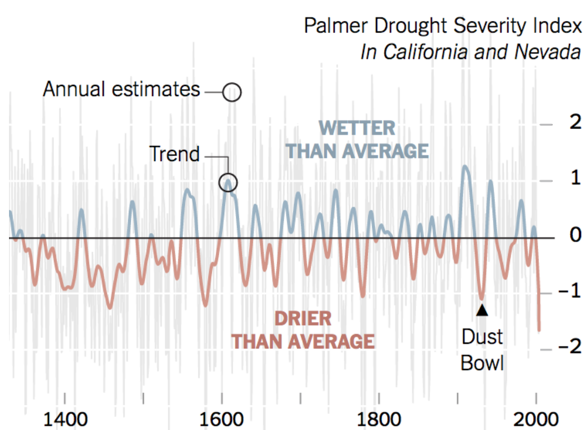
Valley Fever Cases

Building "Dust Bowl" Prediction Capability

- Short-term dust forecasting capability (Tong et al., 2015);



- Long-term dust storm projection;



- Reproduce observed dust variability;
- Assimilate satellite data;
- Identify key climate drivers;

The profound socioeconomic impacts of another Dust Bowl can easily justify investment in building dust bowl prediction capability.

Inline versus Offline

Comparison of inline and offline approaches

	Inline HYSPLIT	Offline HYSPLIT
Source of met. input	WRF-ARW	Varying met. data (WRF, MM5, NARR, etc); Need conversion programs for each
Met. input frequency	The meteorology is used at WRF’s time step, which could be seconds. No temporal interpolation .	WRF’s output (hourly or in minute intervals) interpolated to the HYSPLIT time step.
Vertical grid	Using WRF’s terrain-following hydrostatic vertical coordinate. No vertical interpolation.	A terrain-following coordinate using a equation between height & model level; then interpolating data to HYSPLIT’s layers
Horizontal grid	Following WRF’s grid configuration.	Same as the meteorological data grid.
Disk usage	Dispersion output and WRF output based on users’ request.	Large cost of data storage if high temporal resolution data are needed.
Multiple simulations	Requires repeating the meteorological simulation.	Only one meteorological simulation is required.

Inline coupling of WRF-HYSPLIT: model development and evaluation using tracer experiments. Ngan et al, 2015, Journal of Applied Meteorology and Climatology 2015 ; e-View doi: http://dx.doi.org/10.1175/JAMC-D-14-0247.1