HYSPLIT Nuclear Applications and Emergence Response

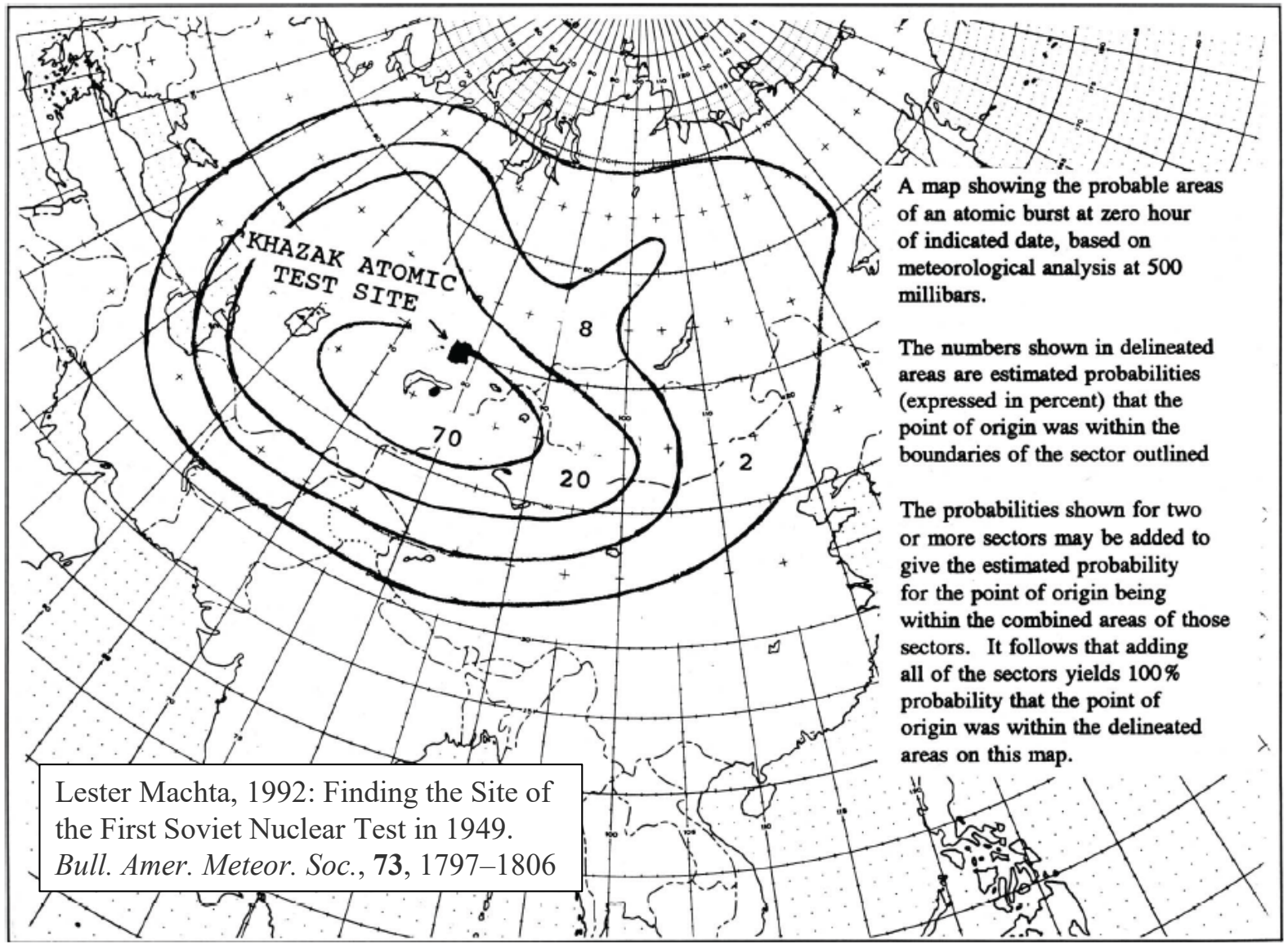
Tianfeng Chai, Mark Cohen, Sonny Zinn, Alice Crawford, HyunCheol Kim, Fong Ngan, Ariel Stein, Roland Draxler, Glenn Rolph, Barbara Stunder, Jerome Heffter

Air Resources Laboratory, NOAA,
College Park, MD USA

104th AMS Annual Meeting, 28 January to 1 February 2024, Baltimore, Maryland
12th Symposium on the Weather, Water, and Climate Enterprise
Linking Earth and Sky: 75 Years of Weather and Climate Research in the NOAA Air Resources Laboratory

Finding the first Soviet Nuclear Test Site in 1949

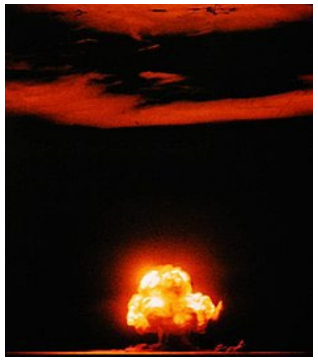
- The *Special Projects Section* of the U.S. Weather Bureau was established in 1948
- 1st major task: Find the first Russian nuclear test site Using back-trajectories from aircraft measurements of radioactivity
- The estimated and actual location was ~5% of the trajectory distance, much smaller than the typical ~20%
- *Special Projects Section* became the NOAA Air Resources Laboratory (ARL)



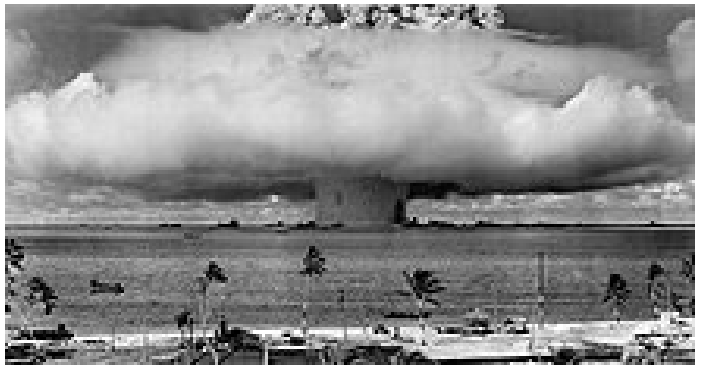
Lester Machta, 1992: Finding the Site of the First Soviet Nuclear Test in 1949. *Bull. Amer. Meteor. Soc.*, **73**, 1797–1806

FIG. 4. The probability of the nuclear test taking place somewhere in the indicated areas if the time of the explosion was 0100 UTC 29 August 1949. This figure is based on an identical map prepared in September 1949 for 0300 UTC by the Weather Bureau, but the isolines have been shifted by 2 h using 500-mb winds. The solid rectangle, added later, locates the Khazak Test Site where Joe-1 took place. The dot to its south, the center of the 70% ellipse area, is the most likely calculated position of the test site.

ARL Nuclear Testing Fallout Predictions

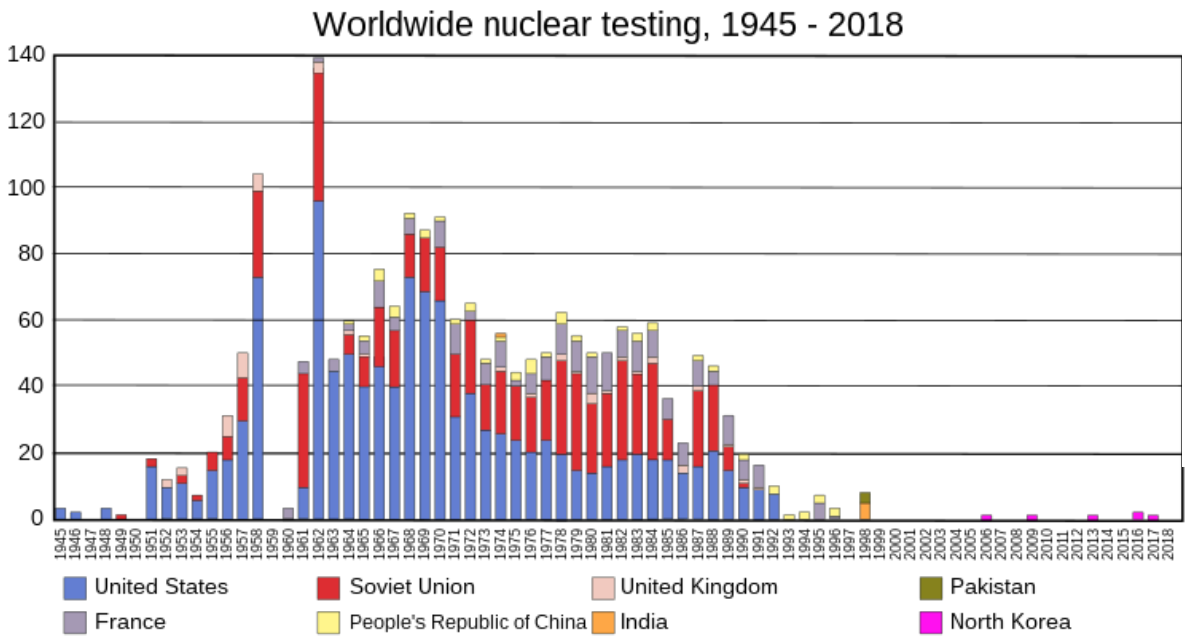


Trinity test, 1945



“Baker Shot”, at Bikini Atoll, 1946

Castle Bravo test, 1954



https://en.wikipedia.org/wiki/Nuclear_weapons_testing

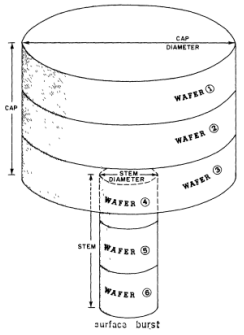
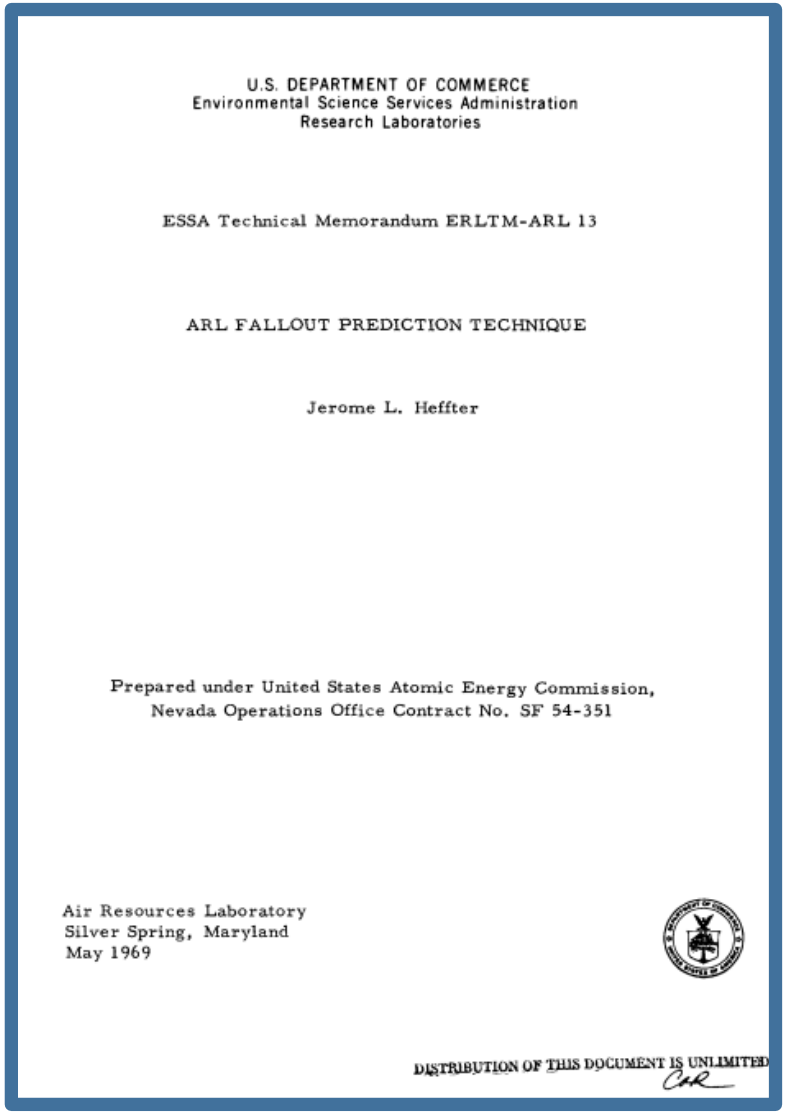


Figure 2. Six wafers of equal thickness comprising a typical mushroom-shaped stabilized nuclear cloud.

Modeling of a typical mushroom-shaped nuclear cloud (Heffter, 1969)



U.S. DEPARTMENT OF COMMERCE
Environmental Science Services Administration
Research Laboratories

ESSA Technical Memorandum ERLTM-ARL 13

ARL FALLOUT PREDICTION TECHNIQUE

Jerome L. Heffter

Prepared under United States Atomic Energy Commission,
Nevada Operations Office Contract No. SF 54-351

Air Resources Laboratory
Silver Spring, Maryland
May 1969

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HYSPLIT Model Development

HYSPLIT has been under development at NOAA ARL for 75 years, but it first began being called “HYSPLIT” about 40 years ago

Hand drawn trajectories

MESODIFF Segmented Gaussian puff

HYSPLIT 1 Trajectories and splitting puffs

HYSPLIT 3 Gridded meteorological data

HYSPLIT Hg

HYSPLIT 4

HYSPLIT 5

1940 1950 1960 1970 1980 1990 2000 2010 2020

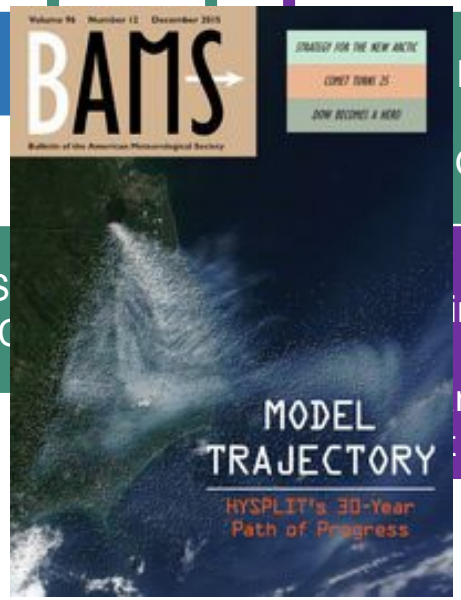
Gaussian Model

Trajectories + Gaussian Plume

HYSPLIT 2

HYSPLIT GEM Lagrangian to Global Eulerian

HYSPLIT-WRF inline



Models which influenced HYSPLIT

Early Versions of HYSPLIT

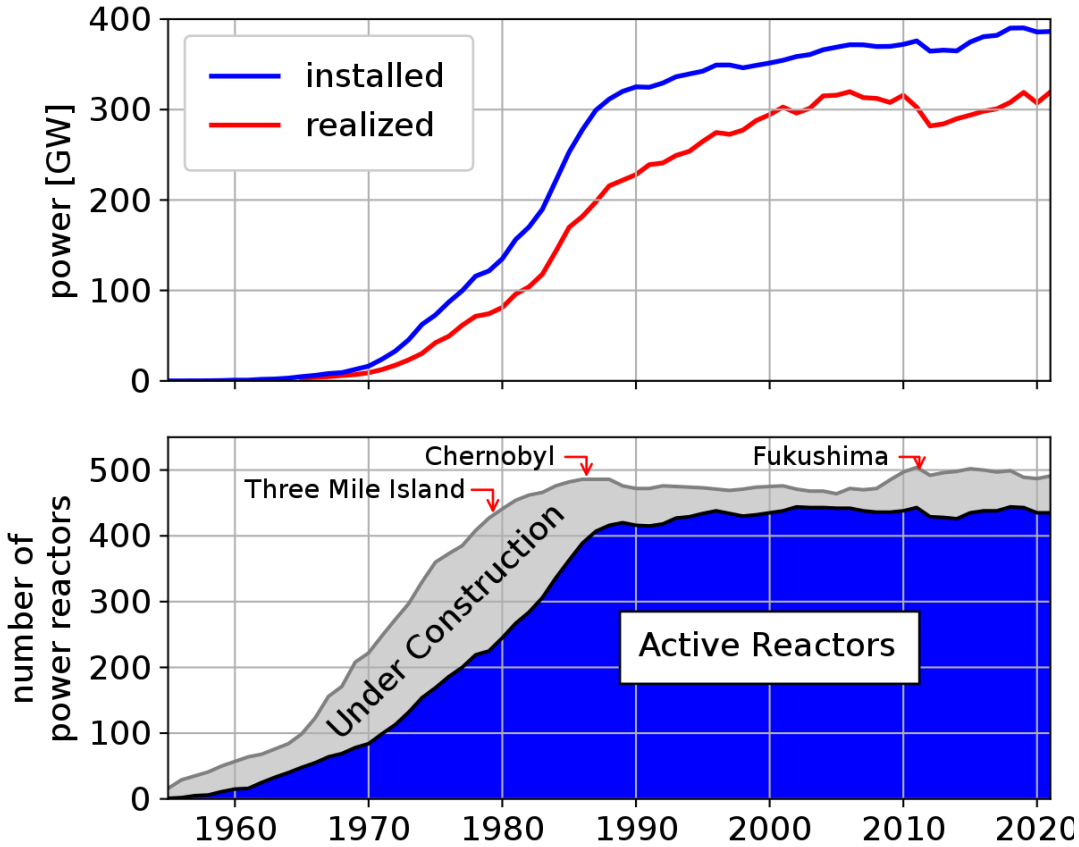
Modern versions of HYSPLIT

Models derived from HYSPLIT

Specialized Versions of HYSPLIT

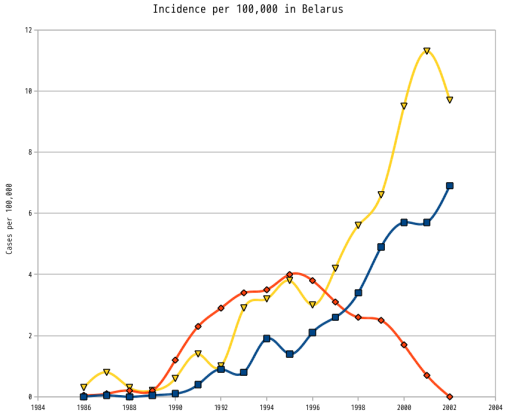
“The HYSPLIT model- Tracing its evolution and path to success” by Alice Crawford, adapted from Stein et al. (2015)

Nuclear Power Plants And Accidents



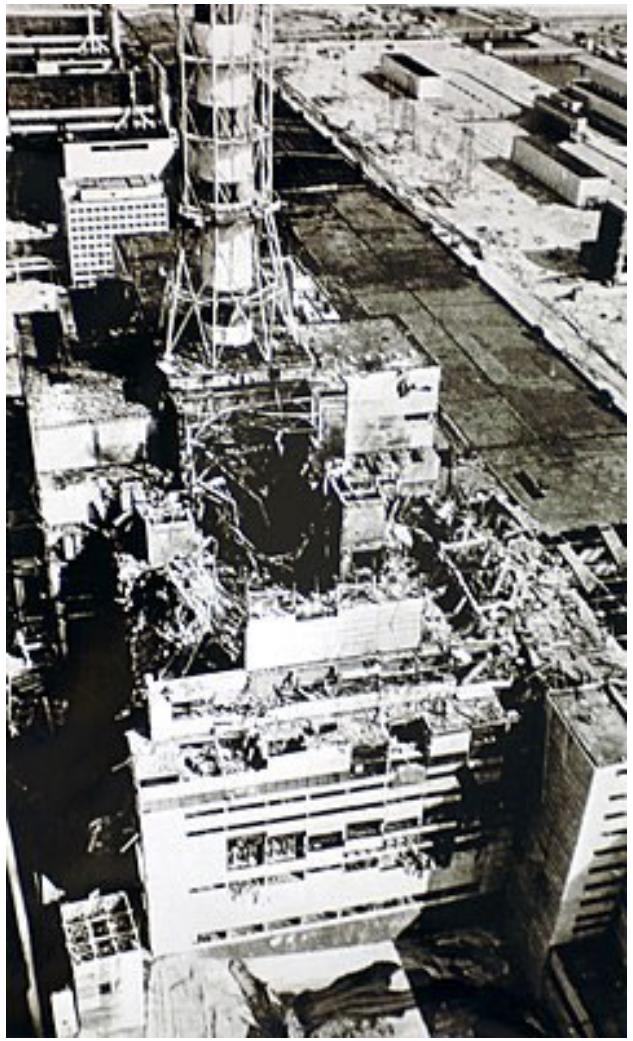
Number of generating and under construction civilian fission-electric reactors, over the period 1960 to 2021. https://en.wikipedia.org/wiki/History_of_nuclear_power

Three Mile Island (PA, USA) Accident on March 28, 1979. https://en.wikipedia.org/wiki/Three_Mile_Island_accident

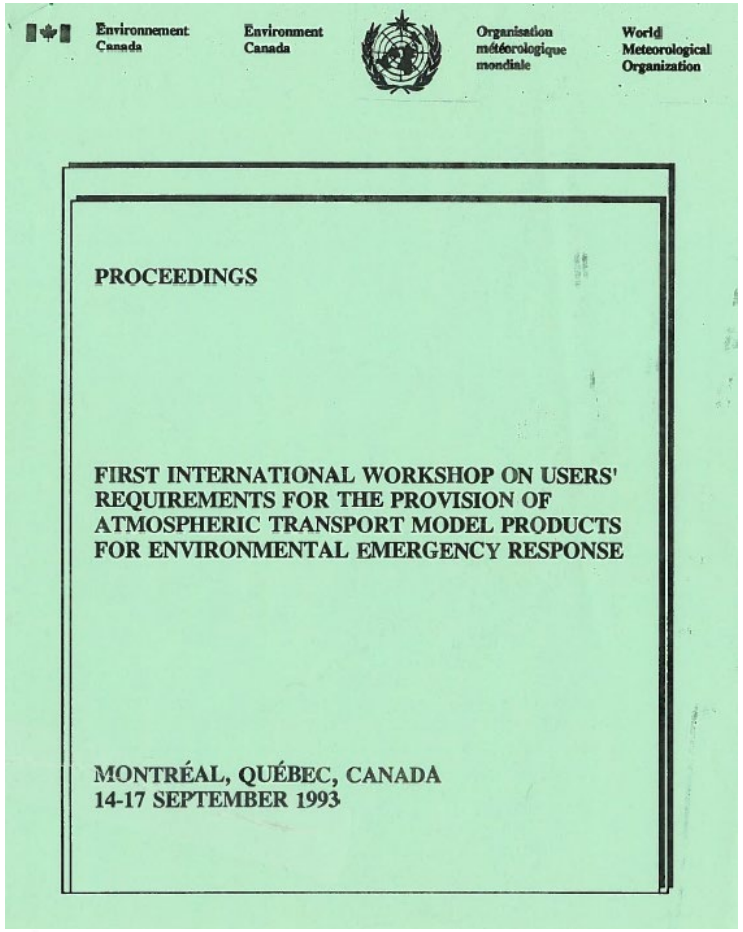


Thyroid cancer incidence in Belarus. Ages 19-34 (yellow), 15-18 (blue), 0-14 (red). https://en.wikipedia.org/wiki/Chernobyl_disaster

Chernobyl Disaster



World Meteorological Organization (WMO)'s Regional Specialized Meteorological Centers (RSMC) for Nuclear Emergency Response



Environnement Canada | Environment Canada | Organisation météorologique mondiale | World Meteorological Organization

PROCEEDINGS

FIRST INTERNATIONAL WORKSHOP ON USERS' REQUIREMENTS FOR THE PROVISION OF ATMOSPHERIC TRANSPORT MODEL PRODUCTS FOR ENVIRONMENTAL EMERGENCY RESPONSE

MONTRÉAL, QUÉBEC, CANADA
14-17 SEPTEMBER 1993

UNITED STATES OF AMERICA

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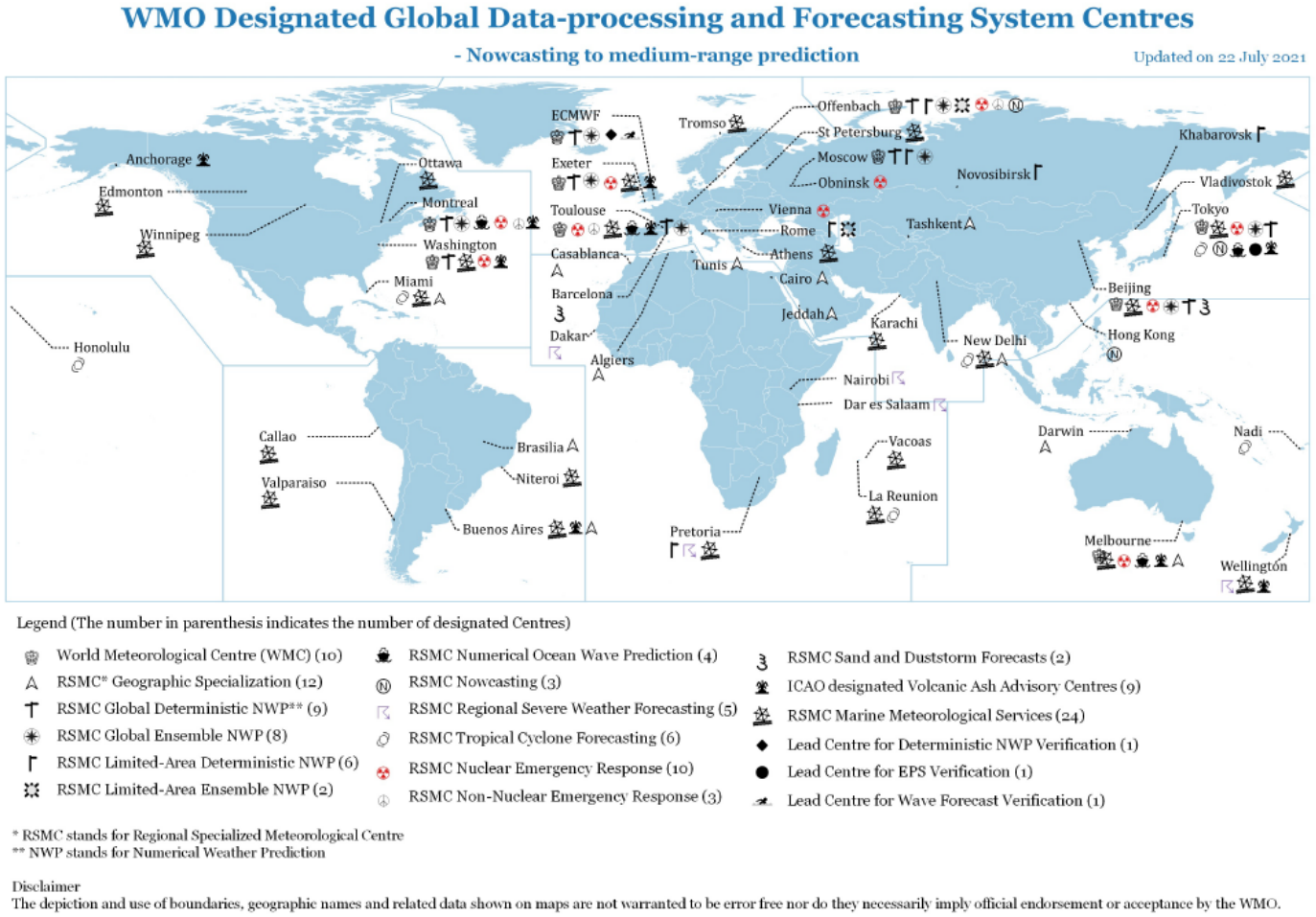


ARL, together with NOAA NWS NCEP, are designated by the WMO as the Washington Regional Specialized Meteorological Centre (RSMC) for nuclear emergency responses, beginning in 1993 and formalized in 2007.

RSMC Emergency Response Activities

REGIONAL SPECIALIZED METEOROLOGICAL CENTER (RSMC)

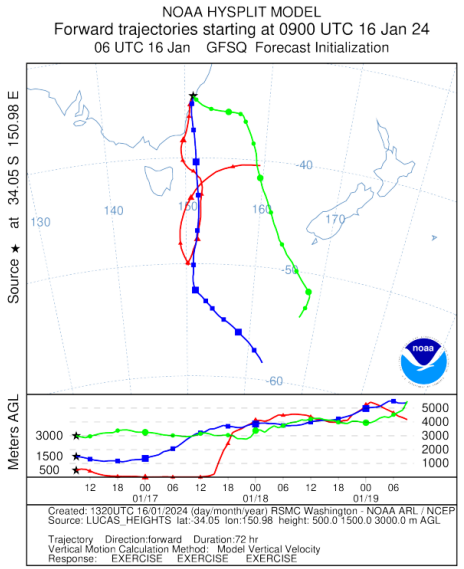
TRANSPORT MODEL PRODUCTS

The following are current (as of the date indicated in the table) operational RSMC products as established by **The World Meteorological Organization (WMO)** for the provision of transport model products for environmental emergency response. To view a product click on the text link or click on one or more checkboxes and then click on the **Request checked boxes** button at the bottom of the form. Details on the model products can be found in **WMO/TD-No. 778**. The lead RSMCs are highlighted in yellow shading. To ensure the latest update, refresh/reload your browser.

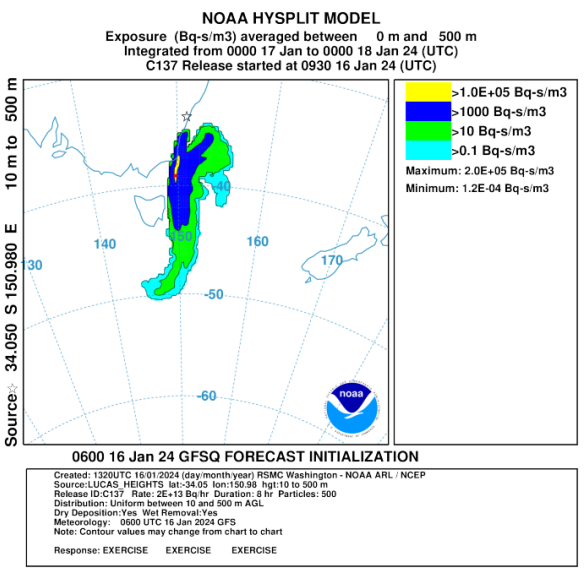
For all (current and past) model results, click on the link titled, "**All Products**" in the first column of each RSMC. "**No archive**" is displayed if no additional products are available.

RSMC TIME OF MODEL RUN (YYYYMMDDCC_HHMM)	MODEL PARAMETERS	JOINT STATEMENT	VIEW PRODUCTS	TRAJECTORIES	TIME PERIOD 1 +24 HRS	TIME PERIOD 2 +48 HRS	TIME PERIOD 3 +72 HRS
Washington Unavailable All Products	Cover (Postscript)	Region III/IV	Check All Uncheck All	Trajectories (traj.txt)	Exposure Deposition	Exposure Deposition	Exposure Deposition
Montréal Unavailable All Products	Cover (Postscript)	Region III/IV	Check All Uncheck All	Trajectories (traj.txt)	Exposure Deposition	Exposure Deposition	Exposure Deposition
Melbourne Unavailable All Products	Cover (Postscript)	Region V	Check All Uncheck All	Trajectories (traj.txt)	Exposure Deposition	Exposure Deposition	Exposure Deposition
Exeter Unavailable All Products	Cover (Postscript)	Region I/VI	Check All Uncheck All	Trajectories (traj.txt)	Exposure Deposition	Exposure Deposition	Exposure Deposition
Toulouse Unavailable All Products	Cover (Postscript)	Region I/VI	Check All Uncheck All	Trajectories (traj.txt)	Exposure Deposition	Exposure Deposition	Exposure Deposition

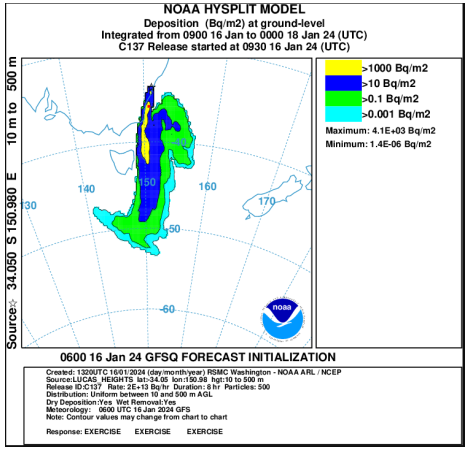
Trajectories



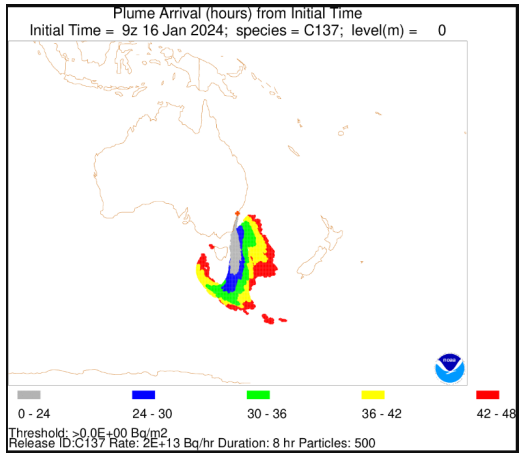
Exposure



Depositions

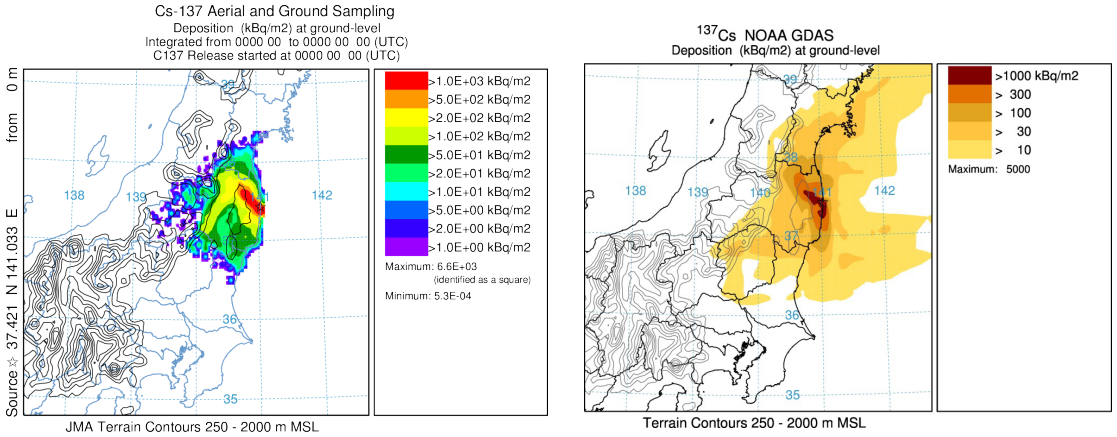


Time of Arrival

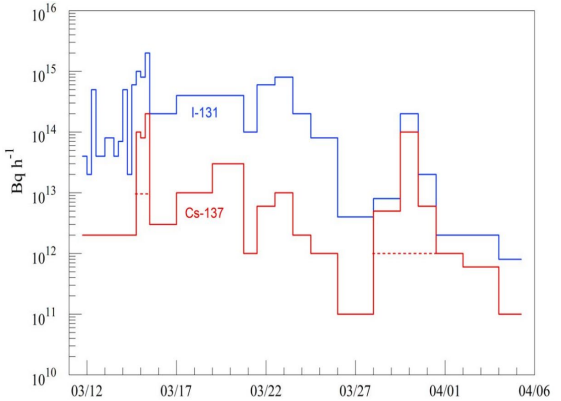


Fukushima Nuclear Accident - HYSPLIT modeling

HYSPLIT Cs-137 local deposition verification



Unit 3 after the explosion on 15 March, 2011



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, D05107, doi:10.1029/2011JD017205, 2012

Journal of Environmental Radioactivity 139 (2015) 172–184

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

World Meteorological Organization's model simulations of the radionuclide dispersion and deposition from the Fukushima Daiichi nuclear power plant accident☆

Roland Draxler[a,*], Dèlia Arnold[e], Masamichi Chino[g], Stefano Galmarini[f], Matthew Hort[b], Andrew Jones[b], Susan Leadbetter[b], Alain Malo[c], Christian Maurer[e], Glenn Rolph[a], Kazuo Saito[d], René Servranckx[c], Toshiki Shimbori[d], Efisio Solazzo[f], Gerhard Wotawa[e]

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[d] Japan Meteorological Agency, Ibaraki, Japan
[e] Zentralanstalt für Meteorologie und Geodynamik, Vienna, Austria
[f] European Commission, Joint Research Centre, Ispra, Italy
[g] Japan Atomic Energy Agency, Ibaraki, Japan

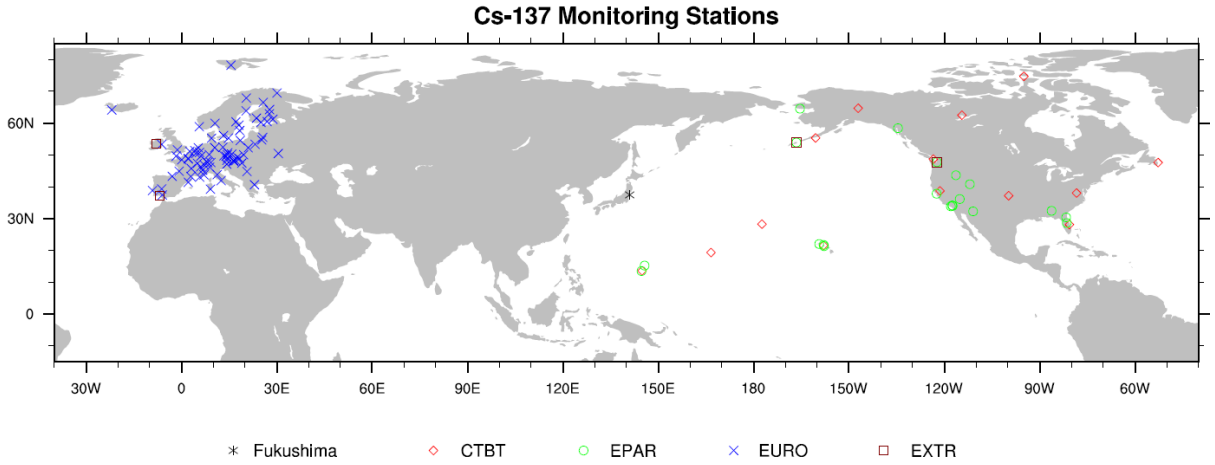
Evaluation of the Transfer Coefficient Matrix (TCM) approach to model the atmospheric radionuclide air concentrations from Fukushima

Roland R. Draxler[1] and Glenn D. Rolph[1]

Received 21 November 2011; revised 6 January 2012; accepted 9 January 2012; published 6 March 2012.

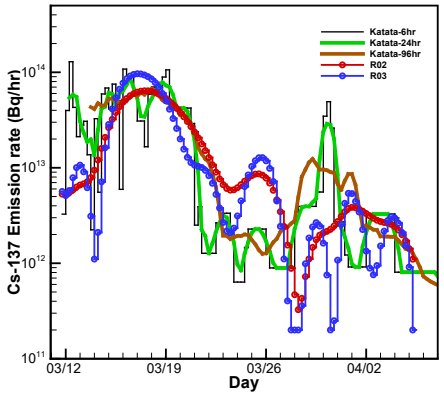
[1] A procedure is developed and tested to provide operational plume forecasts in real-time by continuously updating the previous day's simulations as new meteorological data become available. Simulations are divided into smaller time segments and each segment is continued as an independent calculation using a unit source emission. Multiple computational species are tracked at the same time to represent different classes of radionuclides, each with different dry and wet deposition characteristics. When quantitative air concentration results are required, the unit source calculations are multiplied by the appropriate temporally varying emission rates and decay factors for the radionuclide species involved. Air concentrations for multiple emission scenarios can easily be created

TCM Approach For Source Term Estimation



Transfer Coefficient Matrix (TCM)

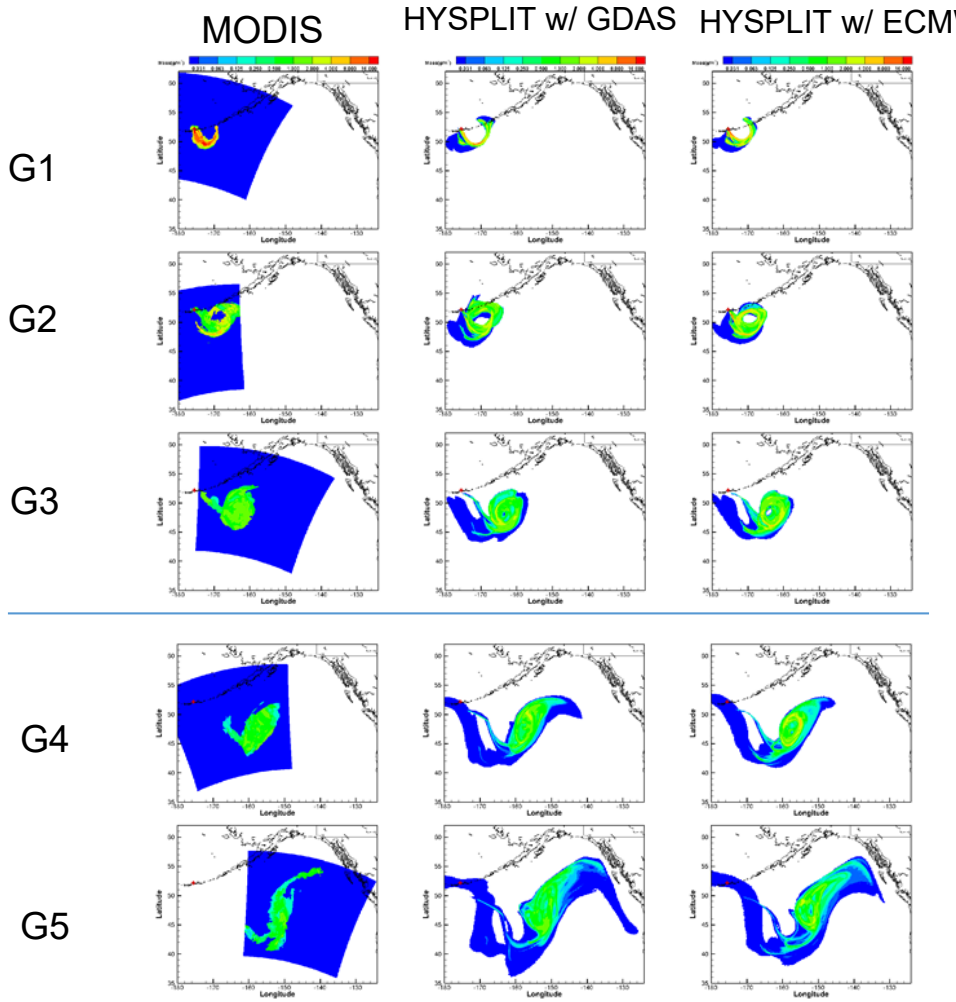
$$\begin{pmatrix} c_1^h \\ c_2^h \\ \vdots \\ c_M^h \end{pmatrix} = \begin{pmatrix} H_{1,1} & H_{1,2} & \cdots & H_{1,N} \\ H_{2,1} & H_{2,2} & \cdots & H_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ H_{M,1} & H_{M,2} & \cdots & H_{M,N} \end{pmatrix} \begin{pmatrix} q_1 \\ q_2 \\ \vdots \\ q_N \end{pmatrix}$$



$$\mathcal{F} = \frac{1}{2}\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{i=1}^{I}\frac{(q_{ikt} - q_{ikt}^b)^2}{\sigma_{ikt}^2} + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{M}\frac{(c_{nm}^h - c_{nm}^o)^2}{\epsilon_{nm}^2} + \mathcal{F}_{other}$$

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

Volcanic Ash Application- Kasatochi eruption

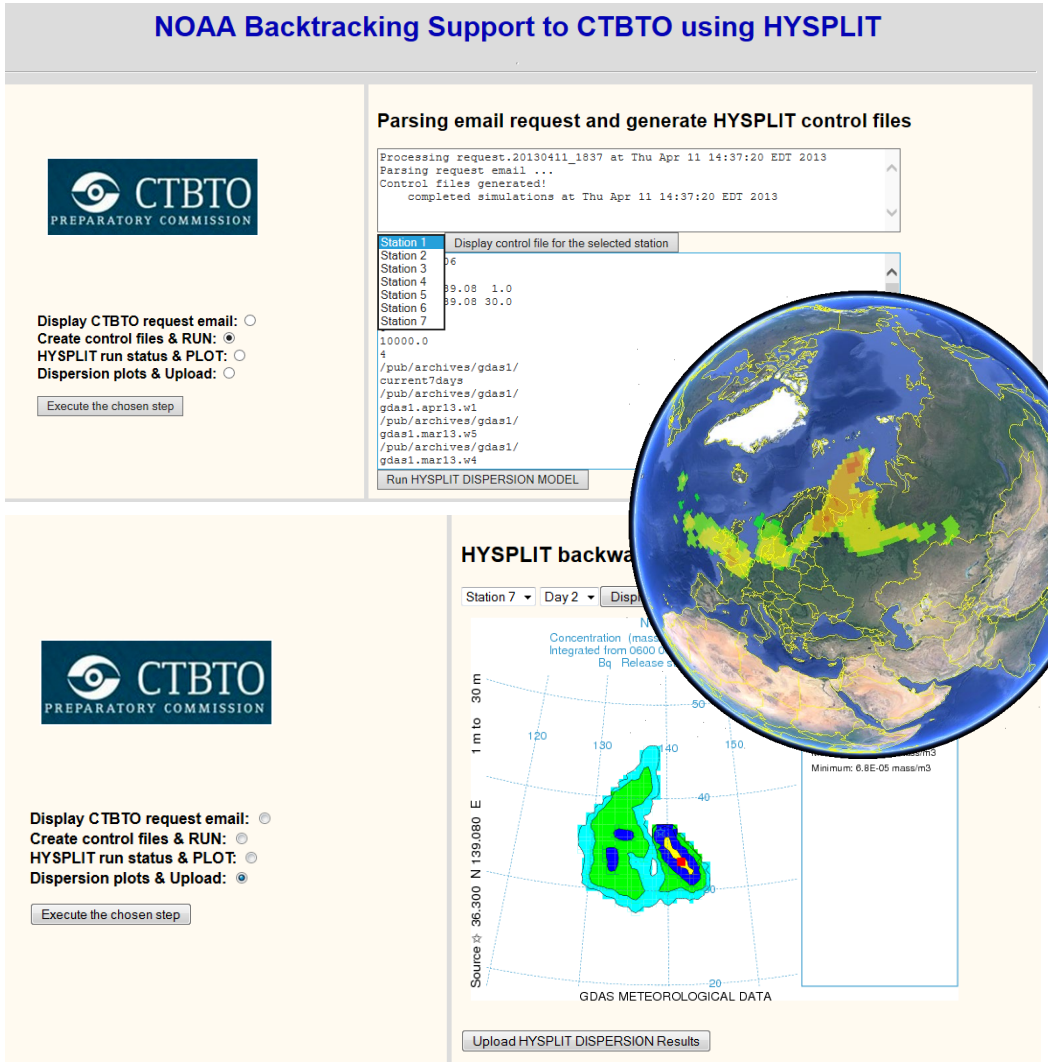


Improving volcanic ash predictions with the HYSPLIT dispersion model by assimilating MODIS satellite retrievals, Atmos. Chem. Phys., Chai, T. et al., 17, 2865-2879, 2017.

NOAA Backtracking Support to Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) Using HYSPLIT

- In case of anomalous radionuclide measurements, CTBTO Executive Secretary and the Secretary General of WMO, the CTBTO Provisional Technical Secretariat (PTS) will request ATM computations from WMO Centres in near-real-time
- Supporting centers will provide model results to CTBTO within 24 hours.

ARL developed HYSPLIT-based software operational since 2014



Forecasts For Potential Ukraine Accidents

A TCM forecasting system has been running at NOAA ARL since March 2022

NOAA
Air Resources Laboratory

ARL Home > READY > Transport & Dispersion Modeling > HYSPLIT > HYSPLIT Dispersion Model

Select source location

A list of currently available automated HYSPLIT simulations is provided below.

- **Zaporizhzhia_UA (H0003):** 47.5083, 34.5844
- **Yuzhnoukrainsk_UA (H0005):** 47.8167, 31.2167
- **Rivne_UA (H0006):** 51.3278, 25.8917
- **Khmelnytskyi_UA (H0007):** 50.3014, 26.6498
- **Chernobyl_UA (H0008):** 51.3892, 30.0994

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NOAA
Air Resources Laboratory

ARL Home > READY > Transport & Dispersion Modeling > HYSPLIT > HYSPLIT Dispersion Model

HYSPLIT Model Results for H0003
(LAT: 47.5083 LON: 34.5844)

00 UTC HYSPLIT Runs for 20240125

MORE RESULTS	GIF Plots	PostScript Plots	PDF Plots	Google Earth
Exposure	.gif	.ps	.pdf	.kmz
Exposure Time-of-Arrival	.gif	.ps	.pdf	.kmz
Deposition	.gif	.ps	.pdf	.kmz
Deposition Time-of-Arrival	.gif	.ps	.pdf	.kmz
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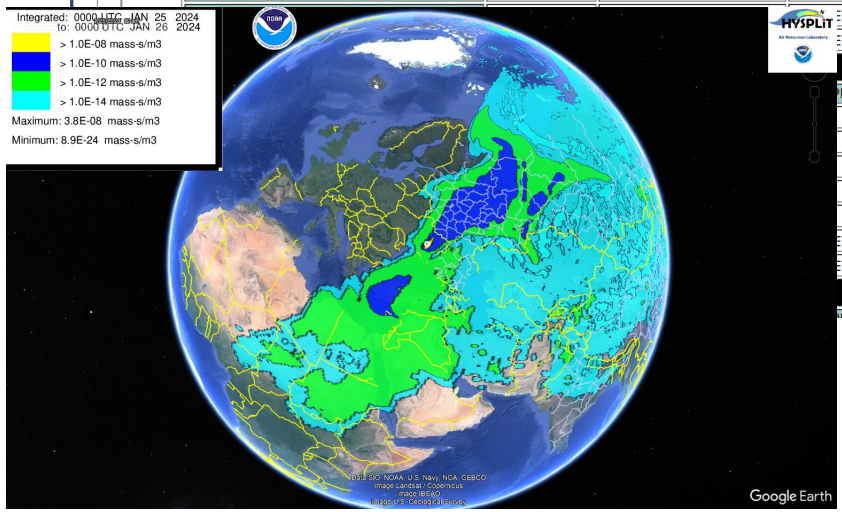
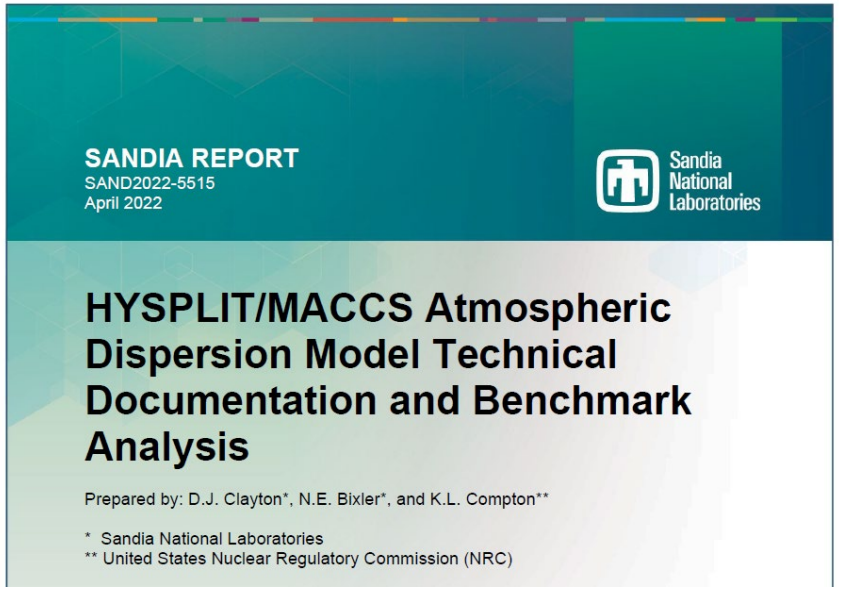
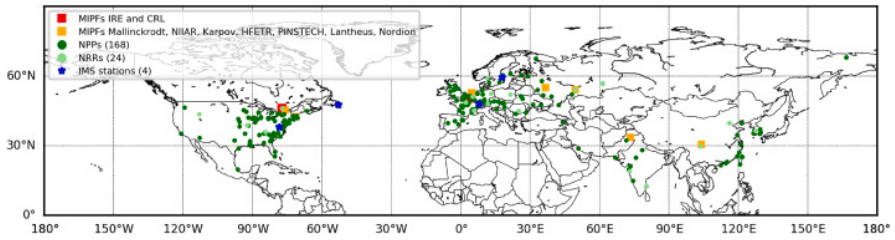


Collaborations

- Working with other national agencies for nuclear emergency preparedness and response
  - Working with Sandia National Lab and US Nuclear Regulatory Commission (NRC), integrated HYSPLIT dispersion model into its MELCOR Accident Consequence Coe System (MACCS) in 2022
  - Assisting Air Force Technical Applications Center (AFTAC)
  - Collaborating with US EPA for a nuclear inverse modeling system
- Participated in three international challenges to model the long-range transport of radionuclides
- Participated in the 1st Nuclear Explosion Signal Screening Open Inter-Comparison Exercise 2021
- Assisting many researchers in their nuclear applications using the HYSPLIT model



Overview of the locations of different emitters and the four selected International Monitoring System (IMS) stations of the Third ATM-Challenge



Summary

History

- ARL was originally created for nuclear-related tasks
- The nuclear fallout prediction techniques developed at ARL prompted the HYSPLIT development
- ARL was instrumental in the initiation of the WMO RSMC nuclear emergency response activities

Operations

- ARL continuously support the RSMC Washington activities since 1993, and has been actively engaged in the future development, such as providing guidelines for future TCM implementation
- ARL has successfully implemented NOAA Backtracking support to Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) application using HYSPLIT (ongoing on-demand operation since 2014)

Research and other activities

- ARL has been actively participated in the radionuclide transport and dispersion modeling studies
- Capabilities built for nuclear applications have been extended to other applications (such as TCM approach and inverse modeling for volcanic ash forecasting)
- ARL has built a quasi-operation system for potential Ukraine nuclear accidents using TCM approach
- ARL has been assisting many others to apply HYSPLIT in their various nuclear-related applications

Thanks for your attention!

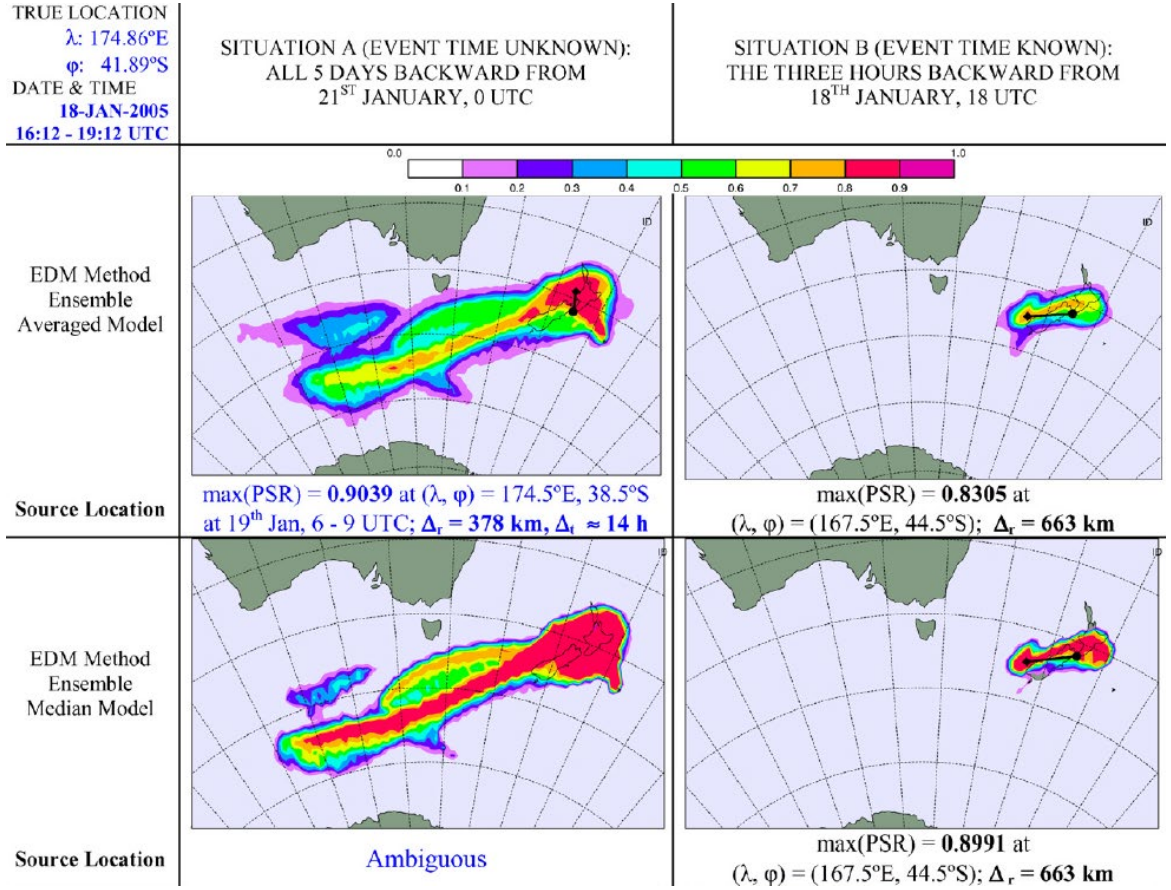
Questions?

Global backtracking of anthropogenic radionuclides

Table 1
Participants and model systems involved in this backward EDM study

Institute/role	LPDM information				Meteorological inpu
	Name	Primary reference	Mode	Thousands of particles released per RN sample	NWP system
Air Force Tech. Appl. Center/NDC USA	HYSPLIT Version 4.6	Draxler and Hess (1998)	3D-part.	200	NCEP GFS
Bureau of Met. Australia/WMO RSMC Melbourne	HYSPLIT Version 4.7	Draxler and Hess (1998)	3D-part.	20–30	NMOC GASP
Canadian Met. Centre/ WMO RSMC Montréal	MLPD0 Global	D'Amours et al. (2004)	3D-part.	144–288	CMC S—GDAFS
China Met. Administration/WMO RSMC Beijing	HYSPLIT Version 4.6	Draxler and Hess (1998)	part.-puff	0.5	NCEP GDAS
Commissariat à l'énergie atomique/NDC France	HYSPLIT Version 4.6	Draxler and Hess (1998)	3D-part.	50	NCEP GDAS
CTBTO PTS/ International Data Centre	FLEXPART Version 5.1	Stohl et al. (1998)	3D-part.	240	ECMWF 4DVAR
Deutscher Wetterdienst/ WMO RTH Offenbach	GME-LPDM Version 2.1	Glaab et al. (1998)	3D-part.	50–500	DWD GME
FFERC of Roshydromet/WMO RSMC Obninsk	STADIUM Version 2		3D-part.	50	SMA
Japan Meteorol. Agency/WMO RSMC Tokyo	JMA Model	Iwasaki et al. (1998)	3D- part.	100	JMA GSM
NOAA Air Res. Laboratory/WMO RSMC Washington	HYSPLIT Version 4.6	Draxler and Hess (1998)	part.-puff	0.5–5	NCEP GDAS
UK Met. Office/WMO RSMC Exeter	NAME Version 8.12	Ryall and Maryon (1998)	3D-part.	240	UK MO, GUM
University of Natural Resources (BOKU) & Zentralanstalt f. Met.	FLEXPART Version 5.0	Stohl et al. (1998)	3D-part.	100	ECMWF4DVAR

A. Becker et al. / Atmospheric Environment 41 (2007) 4520–4534



PSR: Possible Source Region. The actual and the predicted event locations are shown as black dot and diamond.