Overview of NARAC Modeling During the Response to the Fukushima Dai-ichi Nuclear Power Plant Emergency

International Workshop on Source Term Estimation Methods for Estimating the Atmospheric Radiation Release from the Fukushima Daiichi Nuclear Power Plant

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DOE/NNSA Response to Fukushima Dai-ichi

- DOE/NNSA mission: Assess the consequences of releases from the Fukushima Dai-ichi Nuclear Power Plant
- DOE/NNSA deployed personnel and home teams
  - Predictive modeling
  - Air/ground monitoring and sample collection
  - Laboratory sample analysis
  - Dose assessment
  - Data interpretation

DOE/NNSA Response to Fukushima Dai-ichi

- March 11, 2011
  - Nuclear Incidence Response Team **(NIT)** stood up and begins 24/7 operations
  - National Atmospheric Release Advisory Center **(NARAC)** stood up to provide atmospheric modeling projections
  - Consequence Management Home Team **(CMHT)** stood up to support data collection and analysis efforts
  - Radiation Emergency Assistance Center/Training Site **(REAC/TS)** in Oak Ridge, TN stood up to provide medical advice and assistance
  - DOE/NNSA Consequence Management expertise provided for the U.S. Agency for International Development (U.S. AID) Disaster Assistance Response Team **(DART)** in Tokyo
  - NNSA Administrator offered assistance of NA-42 Aerial Measuring System **(AMS)** assets to the Government of Japan, U.S. Military, and the U.S. Embassy
- March 14, 2011. Decision to deploy a Consequence Management Response Team **(CMRT)** and Radiological Assistance Program **(RAP)** personnel to Japan

National Atmospheric Release Advisory Center (NARAC)

NARAC → **Capabilities**

Provides real-time predictions of atmospheric transport of radioactivity from a nuclear accident or incident

Plume model predictions

- Airborne or Ground Contamination
- Dose
- Protective Action Guidelines

Access to world-wide weather data and geographical information

- Observed & forecast weather data
- Terrain & land surface
- Maps
- Population

Real-time access to NARAC models

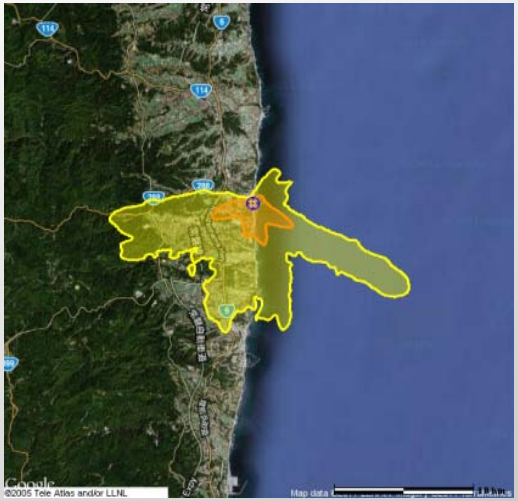
- Unclassified (Internet / Web) and classified communications
- Standalone simple plume models

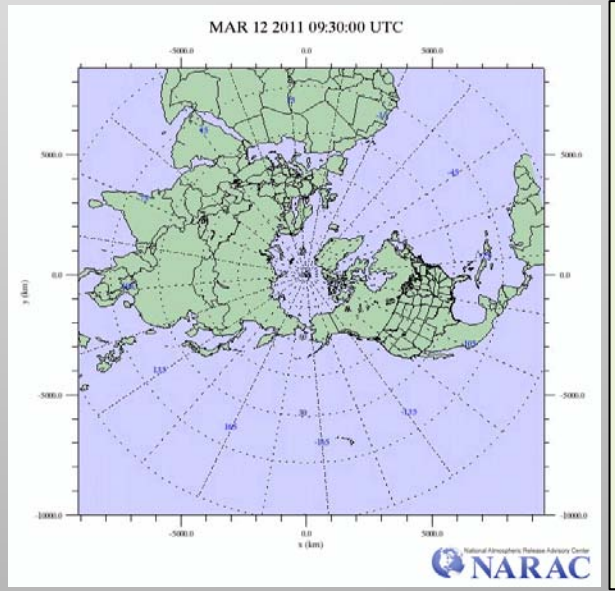
24x7 scientific & technical support

NARAC Supported A Variety of Requests During the Fukushima Response

- Regular forecasts to support mission planning and situational awareness
- Wide range of hypothetical scenarios to inform federal considerations on actions to protect US citizens in Japan (in collaboration with White House OSTP, NRC, DOE/CMHT)
- Predictions of possible arrival times and dose in US territories
- Model refinement and source term estimation based on field data

Example of 1 (yellow) and 5 (orange) rem (Total Effective Dose over March 12-26) for hypothetical scenario



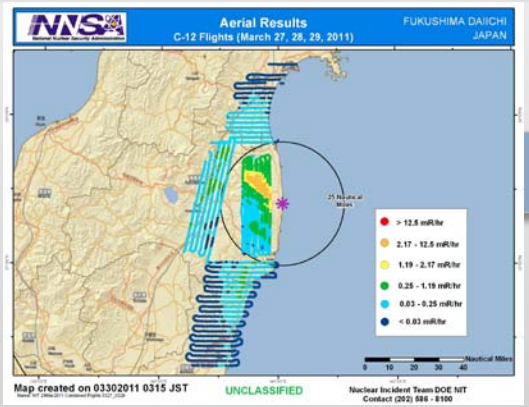


Particle animation of hypothetical unit release illustrates complexity of trans-Pacific dispersion (color coding shows different 24-hr release periods

NARAC Conducted Initial Model Refinement as Part of Its Response Activities

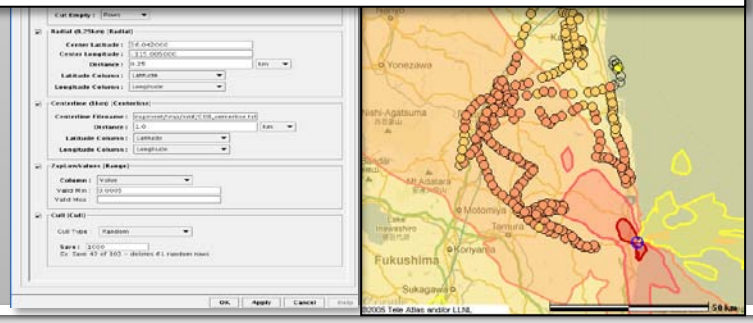
Initial Model Predictions Guide Measurement Surveys

Measurement surveys and sensor data, e.g., DOE AMS, DOE, DoD, and Japan field data

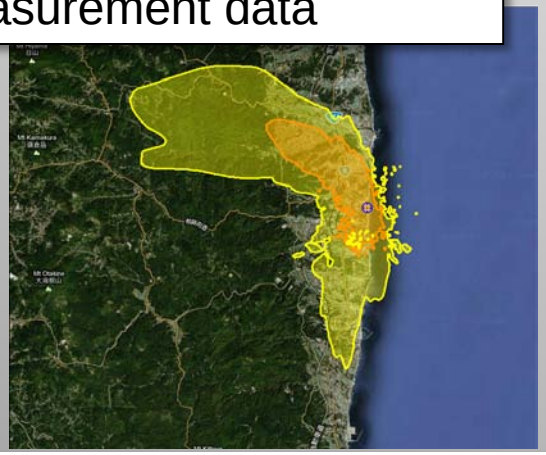


Measurement Data transferred electronically to LLNL/NARAC

Software used to help select, filter and statistically compare measurements and predictions

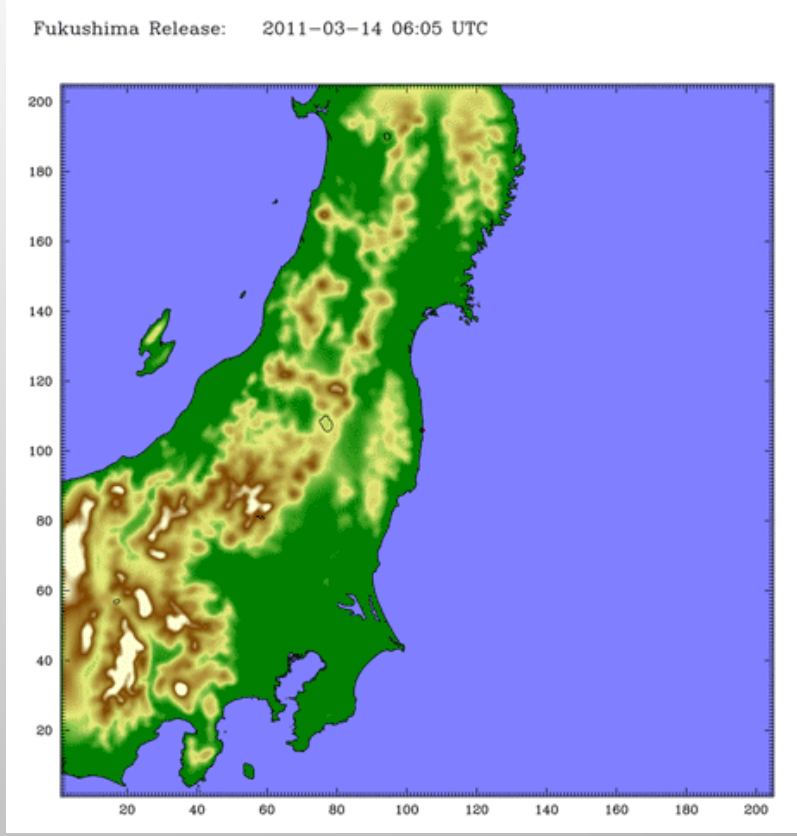


Updated predictions using measurement data



Rapidly Changing Meteorological Conditions Presented a Significant Modeling Challenge

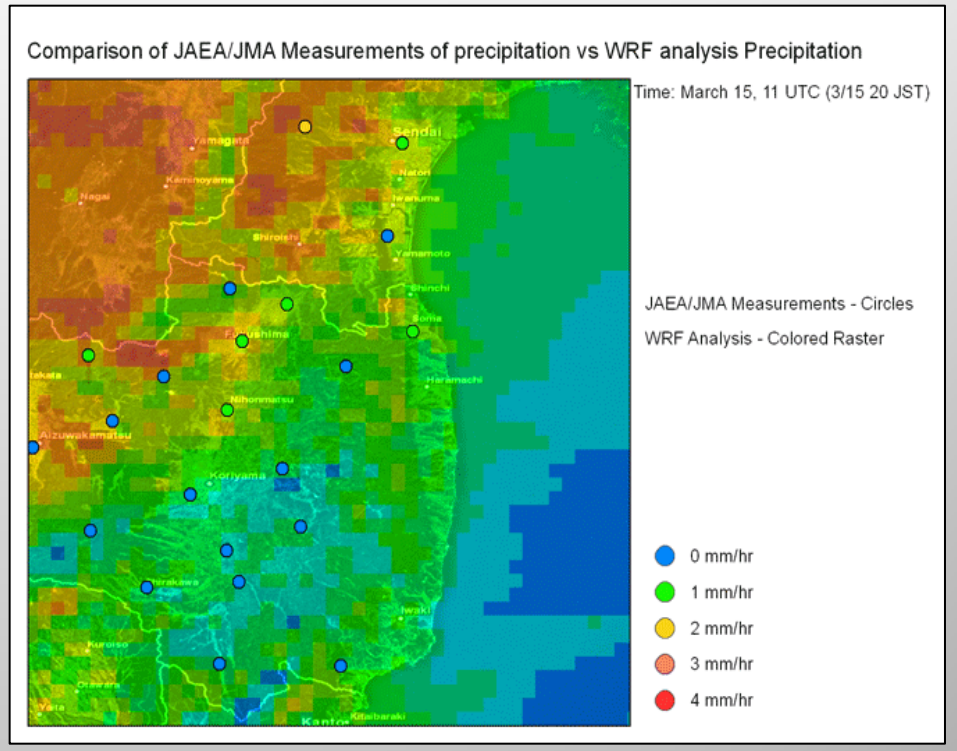
- Winds primarily off-shore until March 14 – March 16 when winds rotated clockwise (primary focus of NARAC reconstruction analyses)
- Winds remained primarily off-shore until March 21 (confirmed by other investigators)
- Initial forecasts captured overall pattern of winds and occurrence of precipitation
- Subsequent higher resolution (3-km) FDDA simulations provided increased accuracy in modeling the timing of the wind shifts and precipitation patterns



Particle animation for hypothetical constant release rate
(March 14 00 UTC - March 16 00 UTC)

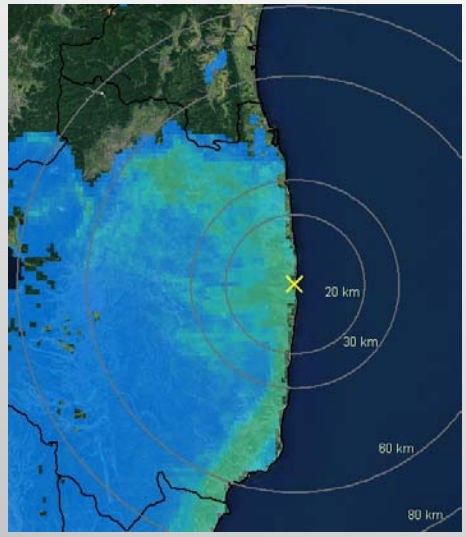
WRF FDDA Simulations Were Use to Develop Spatially and Temporally Varying Precipitation Fields

- Precipitation occurred episodically
- In-cloud and below-cloud scavenging can significantly impact plume transport and deposition patterns
- NARAC simulations investigated
  - Uniform grid-wide (potentially time-varying) precipitation based on Japanese meteorological observations
  - WRF FDDA spatially and temporally varying precipitation
- Comparisons of time series of measured and WRF-modeled precipitation rates (not shown) show good agreement for stations located near Tokyo and Fukushima City

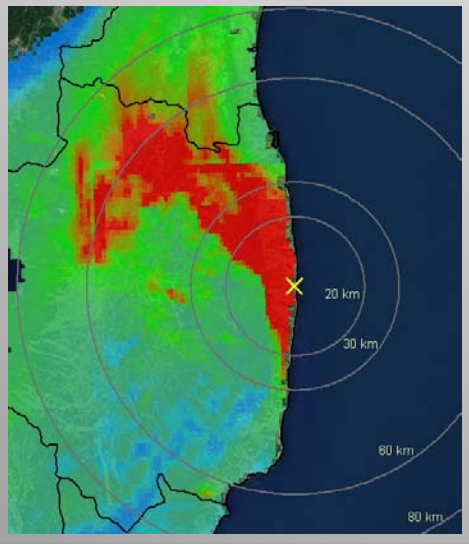


Animation of WRF-predicted precipitation rates overlaid with Japanese precipitation data (data only reported to the nearest 1 mm/hr)

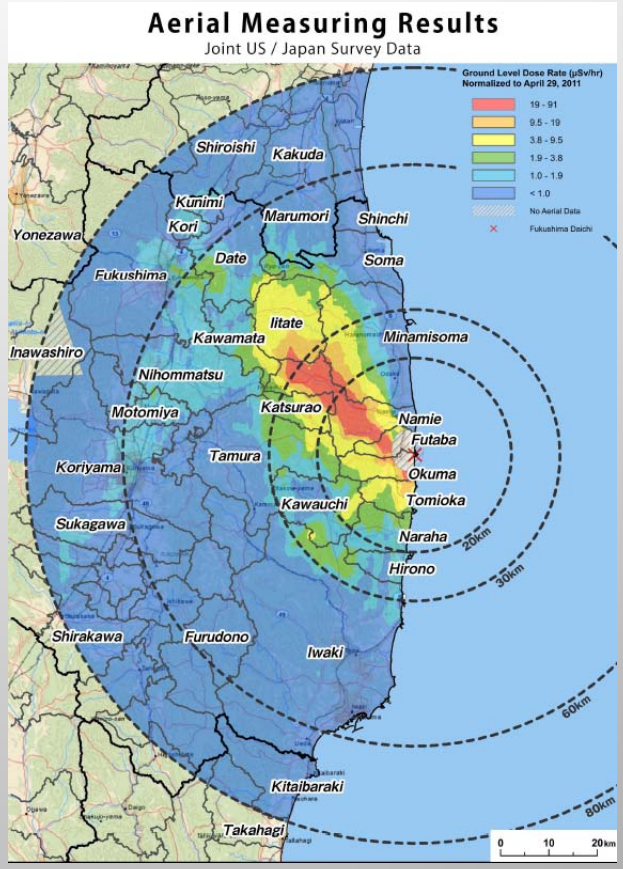
Precipitation Scavenging Appears to be Key in Reconstructing the Fukushima Releases



FLEXPART predicted relative deposition pattern using WRF-generated winds and a constant release rate, but no precipitation



FLEXPART deposition pattern for same WRF-generated winds and constant release rate with spatially and temporally-varying precipitation

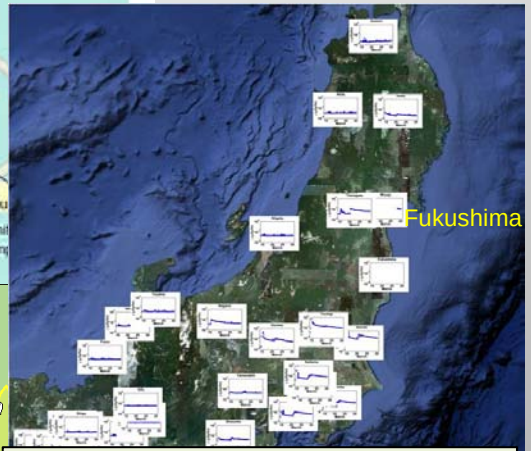


Aerial Measuring Survey analyzed dose rate data

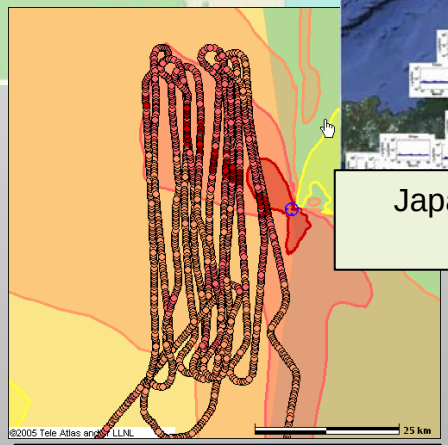
A Variety of Radiological Data From Japan Was Used in Reconstruction of the Release

- On-site plant radiological measurements (gaps due to off-line period following earthquake/tsunami and during March 15 site evacuation)
- Dose rate time series from Japanese MEXT radiological monitoring stations (most only available post March 15 0900 UTC)
- System for Prediction of Environmental Emergency Dose Information (SPEEDI)
- DOE Aerial Measuring Survey (AMS) collection beginning March 17-18
- DOE / DoD ground monitoring data
- Limited radiological monitoring data available for off-shore wind periods

Plant monitoring locations



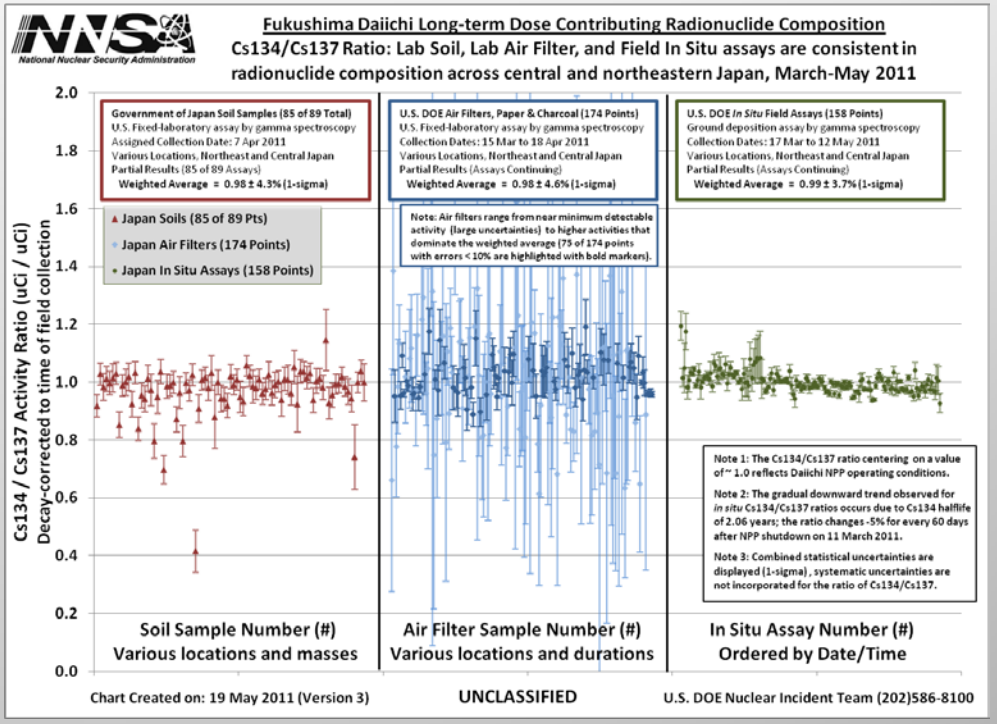
Japanese MEXT prefectural monitoring data



AMS data overlaid on NARAC analysis

NARAC Focused On Dose Rate Data and Dose Reconstruction

- Focus on key radionuclide contributors to dose
  - I-131, I-132, Te-132, Cs-134, Cs-137, Xe-133
- Relative activity ratios determined *a priori* of based on DOE spectral analysis
- Refinements made as additional radionuclide data became available



Example: Cs-134/Cs-137 ratio from laboratory analysis of soil, air filter, and *in situ* field assays

Source Reconstruction Based on Optimization of Overall Fit of Model and Data Paired in Space and Time

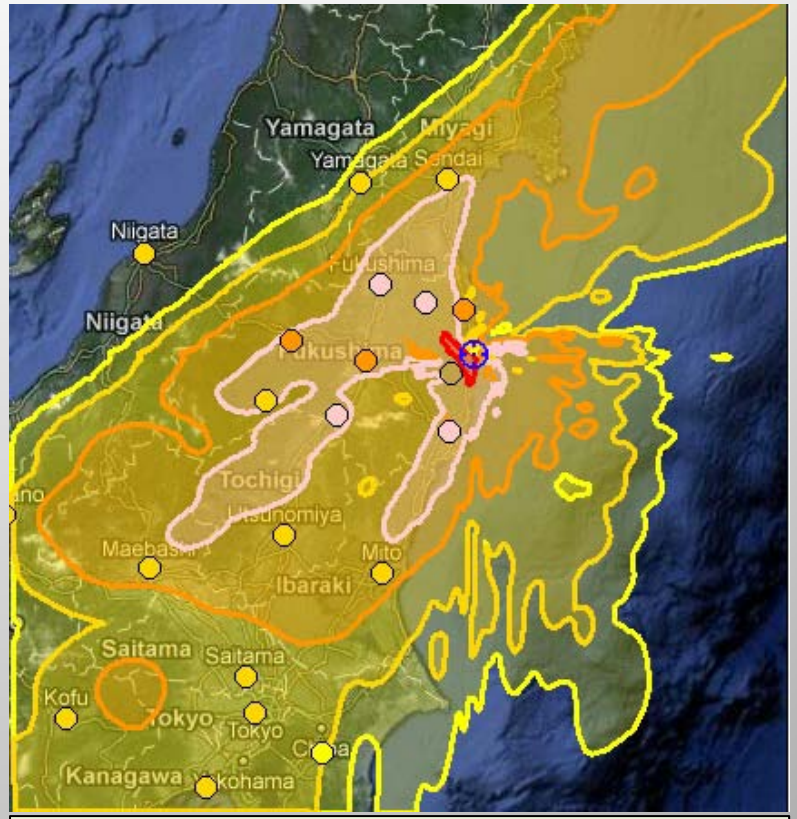
- Data imported in a variety of formats for importing measurement data (e.g., XML, Excel, CSV, ASCII text/table)
- Graphical displays for displaying and comparing measurement data with plume model predictions (geospatial and time series representations, text-based output, scatter plots, Google Earth overlays)
- Rapid selection, grouping, and editing of measurement data for analyses (e.g., geospatial inclusion/exclusion zones, centerline-located data, measurement sampling, minimum/maximum data ranges, streamlined capabilities for fast turnaround)
- Identification and removal of measurement outliers using Pierce and Gould data rejection method
- Statistical comparison of measurements and predictions using measurement-to-model ratio statistics (e.g., percentage of values with factor R, bias, etc.)
- GUI-based post-processing capabilities to linearly scale predicted source term quantities

NARAC Conducted a Range of Source Reconstruction Analyses During the Response

- Input assumptions and data often determined by availability of information at the time the simulation was performed
- Limited information available regarding reactor and spent fuel pool conditions
- Time-varying releases from multiple sources treated as one combined source
- Focus on critical period from March 14-16
- Meteorological analyses developed from:
  - Local meteorological data provided by Japanese stations
  - Numerical weather prediction forecasts and Four Dimensional Data Assimilation (FDDA) simulations at 1, 3, 5, and 15-km resolutions
- Limited investigation of sensitivity to input assumptions

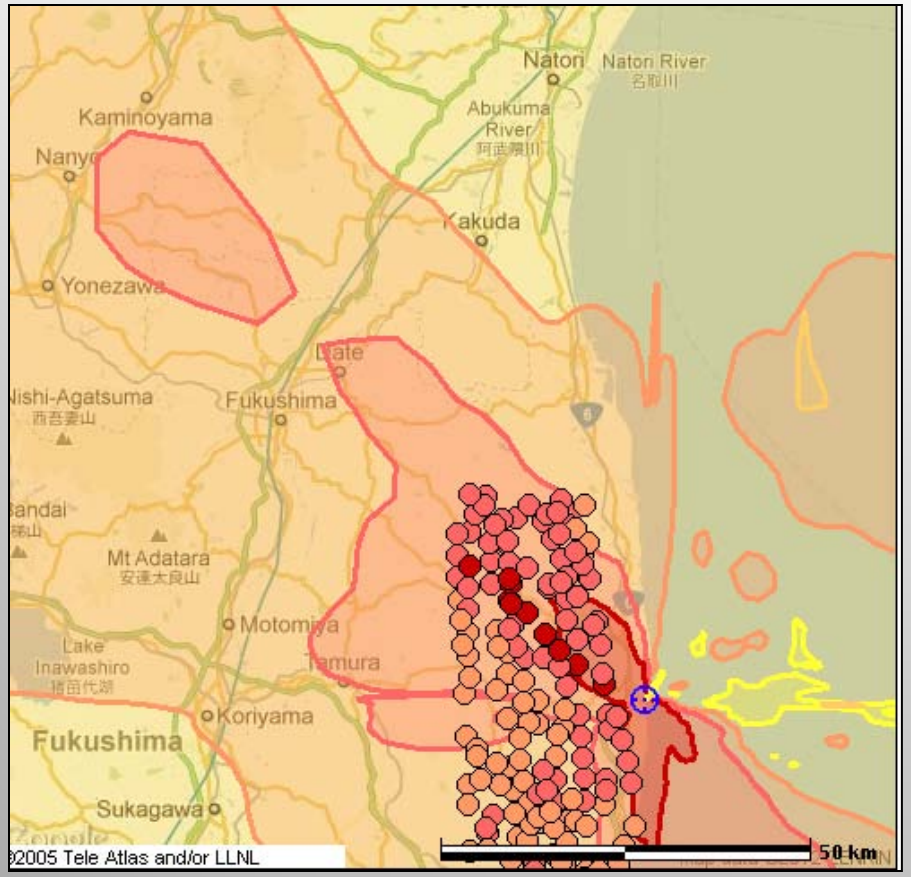
Example of NARAC Source Reconstruction Based on Japanese MEXT Dose Rate Data

- March 14-16 period
- NARAC ADAPT/LOD simulation
  - WRF 3-km FDDA meteorology
  - Radionuclide mix: Cs-134, Cs-137, I-131, I-132, Te-132, Xe-133 in relative activity ratios 1:1:20:20:20:100
  - Uniform release rate
- MEXT dose rate data assumed to include both air immersion and ground-shine
- Good agreement with AMS data collected on March 18 (not shown), which was not used in the reconstruction

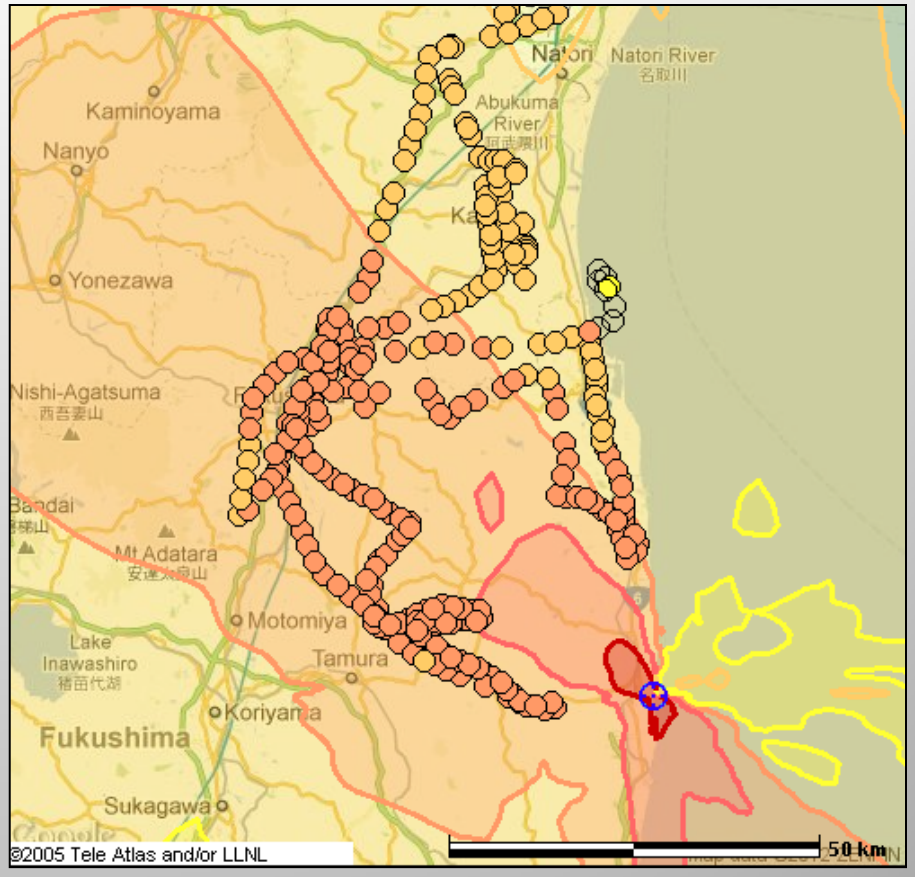


NARAC model result contours compared to MEXT data (circles color coded in the same manner as the contours)

NARAC ADAPT/LODI Simulations Compared to Aerial Measuring System (AMS) Data



NARAC modeled dose rate levels overlaid with March 18 AMS data. Meteorology based on Japanese weather observations



NARAC modeled dose rate levels overlaid with March 26 AMS data (data not used in source estimation process).

A Range of Emission Rates Were Found to Be Consistent with Dose Rate Data

- A range of emission rates were found to be consistent with the available dose-rate data, within model and measurement uncertainties
- Source term estimates were sensitive to
  - Source term input assumptions (e.g., time-varying vs. constant emission rates, assumed radionuclide mix and activity ratios, release characteristics, reactor conditions)
  - Choice of meteorology (e.g., observational data vs. WRF FDDA fields)
  - Selection of the radiological data (e.g., AMS, MEXT) to preferentially match in the model refinement process
  - Precipitation
- NARAC source estimates for the March 14-16 period consistent with other published estimates within expected uncertainties inherent in physics models, source estimation methods, and data (Chino et al. 2011; GOJ 2011a, 2011b, and 2011c; Stohl et al. 2011)
- Source estimates for off-shore-wind times are significantly more speculative as Japanese radiological measurement data are generally unavailable for these periods, requiring the use of sparser and longer-range measurements and model calculations.

After Action Process Identified Future Work to Address Remaining Questions and Refine Release Estimates

- Utilize the complete set of Japanese (e.g., 550000+ data records in DOE database) and global radiological data sets (e.g., Japan data, sample and spectral analyses, Comprehensive Test Ban Treaty Organization, EPA RadNET, and U.S. nuclear power plant data) to conduct a comprehensive source term analysis
- Use nuclear reactor expert analyses and measurement data to improve / constrain source term estimates and refine radionuclide mix
- Improve modeling to more accurately simulate complex meteorological conditions and dispersions, including precipitation scavenging
- Investigate the use of ensemble forecasts to develop probabilistic arrival times and impact estimates for both regional (e.g. Japan) and long-range (e.g., trans-Pacific) cases
- Develop better understanding of the interplay between and sensitivity of source estimates to meteorological conditions and release characteristics (e.g., release height, radionuclide mix, particle size distribution)
- Determine to what degree multiple release events can be distinguished via time-varying radionuclide signatures and/or reactor analyses
- Determine to what degree data constrains release rates during off-shore flow periods
- Adapt, develop, and evaluate multiple source reconstruction approaches (inversion, optimization, predictor-corrector, Bayesian inference stochastic sampling)

Acknowledgements

- NARAC Operations Scientists, Customer Support, System Administrators, Systems Team – plume modeling, CMweb support, 24/7 systems support, tool updates
- RSL/SNL/LANL/LLNL CMHT – monitoring data; health physics support
- CMHT Laboratory Team – sample analysis
- Radiological Triage – Spectral analysis for isotopic mix
- DOE HQ Nuclear Incident Team – Management, coordination and prioritization of Interagency and White House tasking
- NRC – reactor and spent fuel source term analyses

DOE/NNSA Principal Deputy Administrator Neile Miller (in yellow) with the NARAC team.

National Atmospheric Release Advisory Center

NARAC

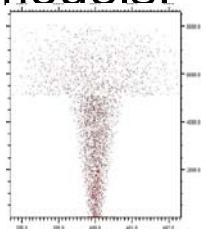
Web: narac.llnl.gov
Email: narac@llnl.gov

Lawrence Livermore National Laboratory

NARAC Modeling System Predicts Consequences of Radiological/Nuclear Incidents

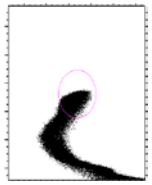
IND source models:

- LLNL *KDFOC*
- LLNL *LWAC*
- ORNL *ORIGEN*



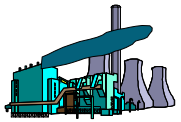
RDD Source models:

- SNL *Source Term Calculator*
- SNL *PUFF*



Nuclear power and fuel sources:

- NRC *RASCAL*

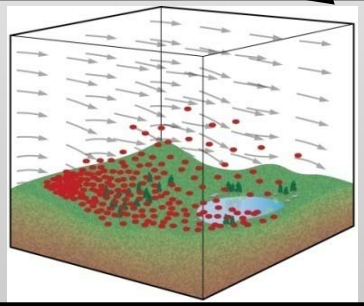


Fire source model:

- LLNL

3-D Atmospheric Dispersion and Fallout models:

LLNL *ADAPT/LODI*



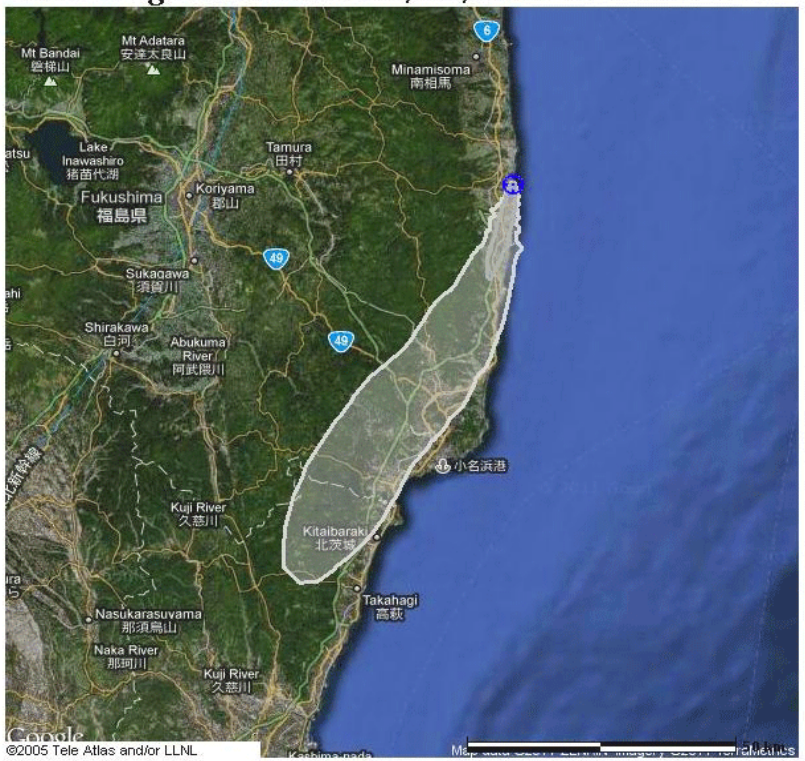
- Airborne and fallout contamination and dose predictions for worker and public protection
- Affected population and casualty estimates

Sandia National Laboratories

OAK RIDGE National Laboratory

NARAC Provided Regular Forecasts to Support Mission Planning and Model Analysis

- Up to thrice-daily forecasts of hourly relative air concentrations to inform field operations, monitoring, and emergency planning
- Tabular summaries of wind speed and direction, atmospheric stability, and precipitation for selected locations
- 5-km forecasts generated using Weather Research and Forecast (WRF) model, driven by NOAA global GFS model output
  - Regular checks for consistency with NOAA HYSPLIT forecasts
  - Comparisons against available Japanese meteorological data



Daily weather forecasting for mission planning (hypothetical hourly plume to illustrate predicted shifts in wind direction)

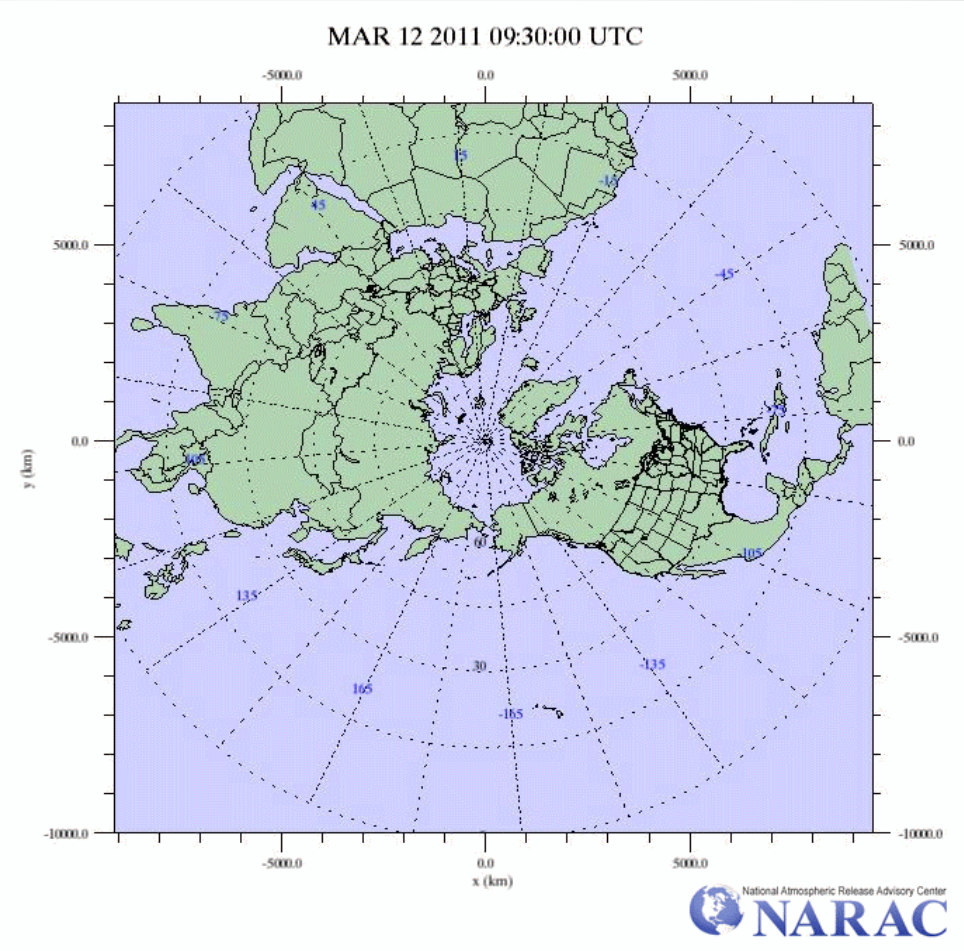
DOE/NARAC Worked Closely with the NRC to Estimate Impacts for a Wide Range of Hypothetical Scenarios

- Predictions of arrival times and protective action areas for sheltering / evacuation, relocation, iodine administration, and worker protection to inform emergency planning
- Analyses based on a range of hypothetical scenario source terms provided by the Nuclear Regulatory Commission (NRC)
  - RASCAL and MELCOR modeling
  - Separate and combined impacts for reactor cores and spent fuel
- Use of a variety of meteorological conditions, including real-world weather and artificial conditions to target
- NARAC predictions conducted and distributed by DOE subject to White House, direction

Example of predicted protective action areas for hypothetical scenario (Total Effective Dose over March 12-26)

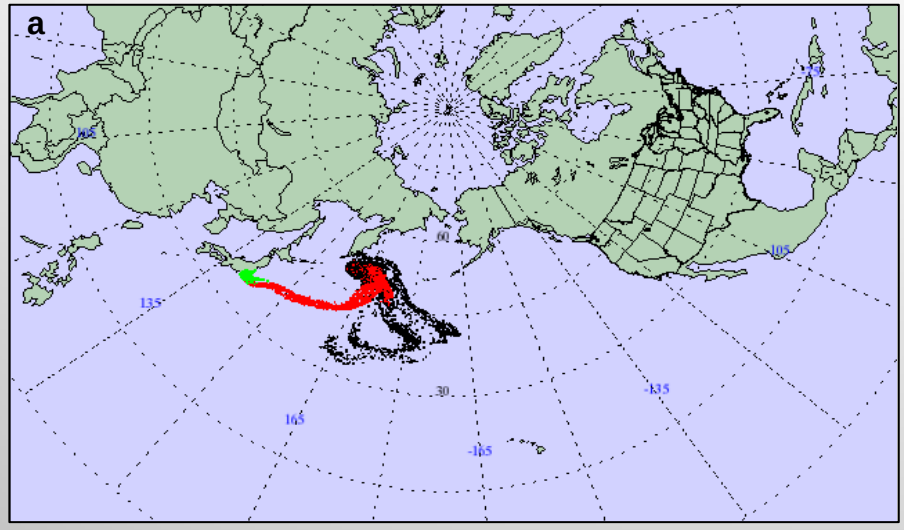
DOE/NARAC Provided Predictions of Possible Arrival Times and Dose in US Territories

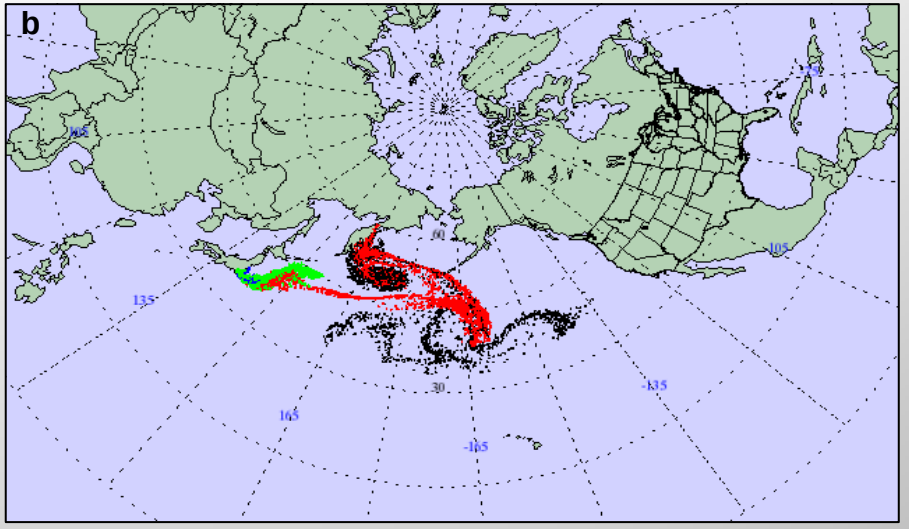
- NARAC estimated arrival times and radiation dose for selected locations in the US using:
  - NOAA GFS 0.5 degree meteorological forecasts and analyses
  - NRC source term analyses
  - DOE Consequence Management Home Team (CMHT) dose conversion analyses
- Derived from simulations using nominal 12/24-hour unit release rates, scaled by NRC source quantities and CMHT dose conversion values
- Predictions consistent with detected plume arrival times and low levels of radiation

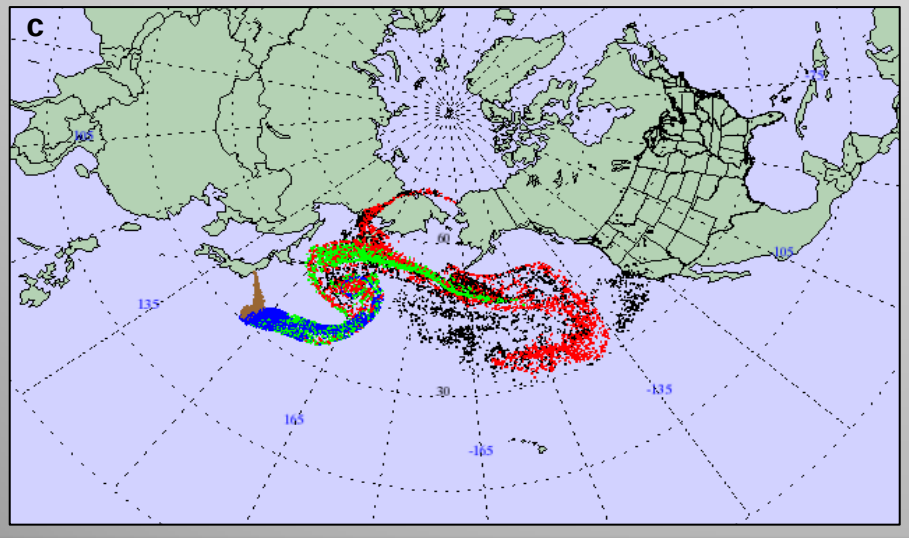


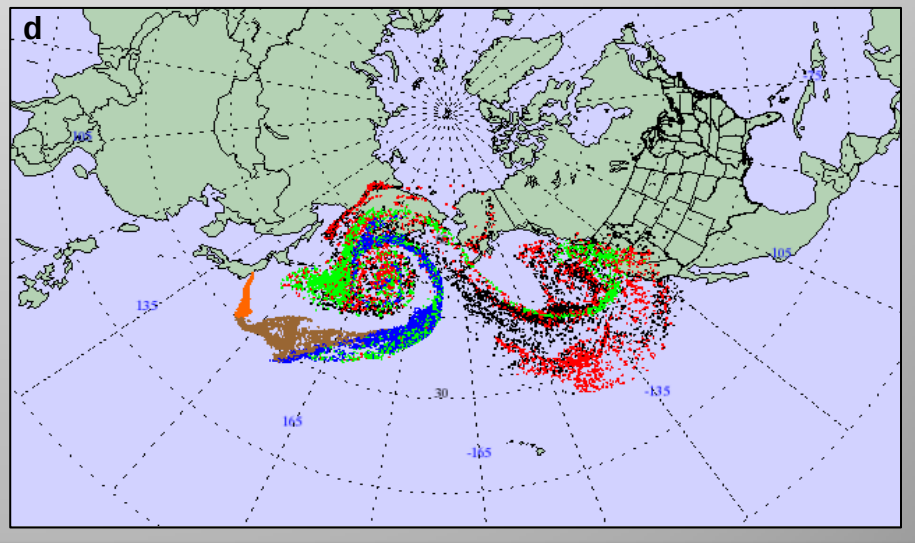
Particle animation of hypothetical unit release illustrates complexity of trans-Pacific dispersion

DOE/NARAC Provided Predictions of Possible Arrival Times and Dose in US Territories

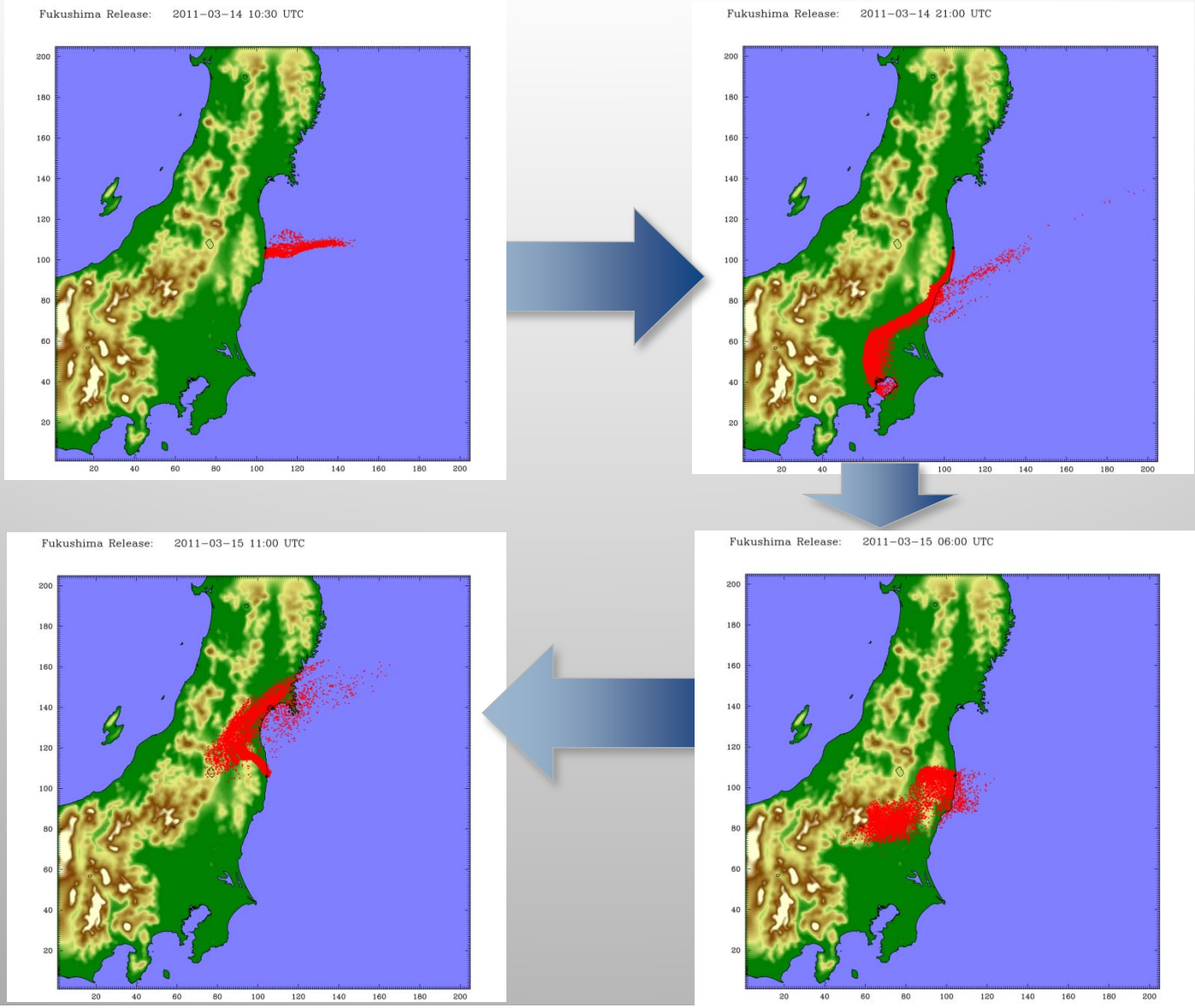




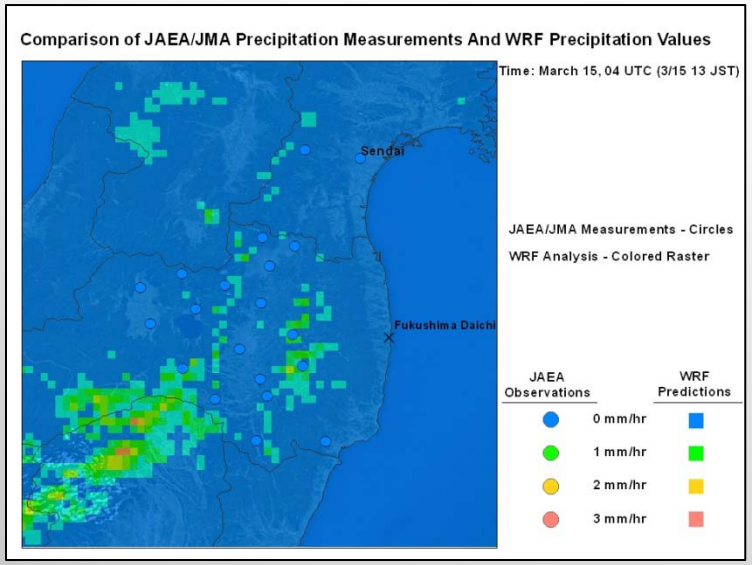


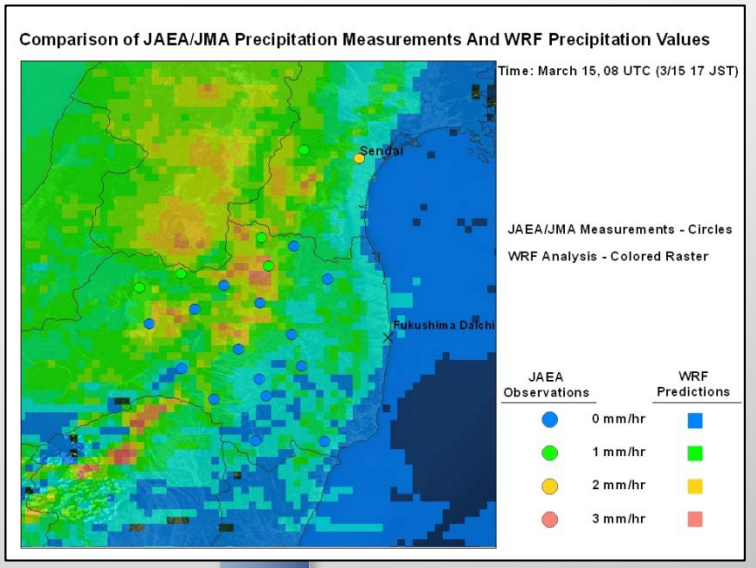


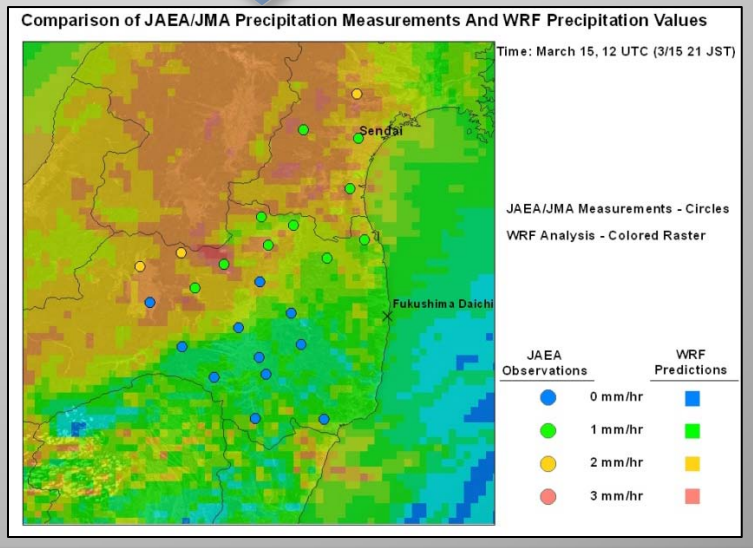
Time Series Extracted from Particle Animation

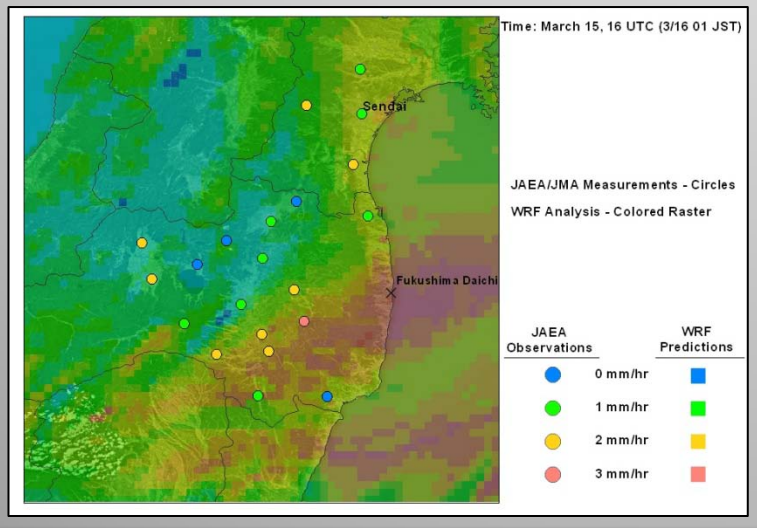


Time Series Extracted from WRF Precipitation Animation









Episodic Rainfall Occurred Throughout the Release Period (Measurements at Two Cities)