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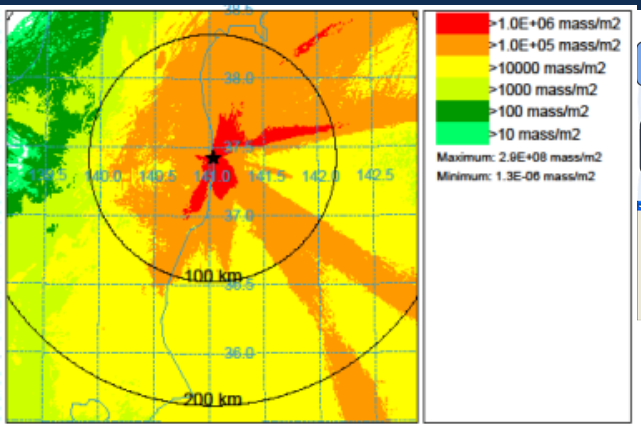

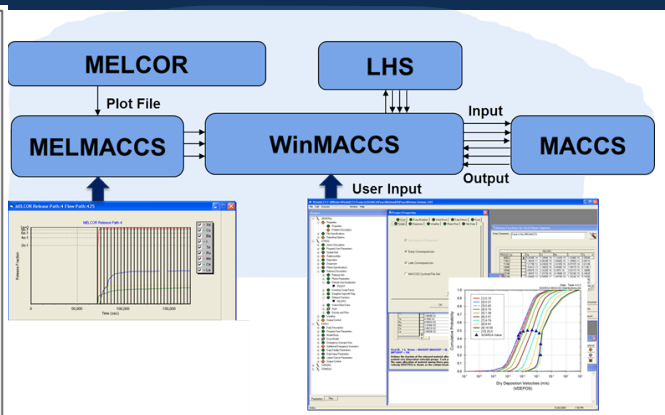

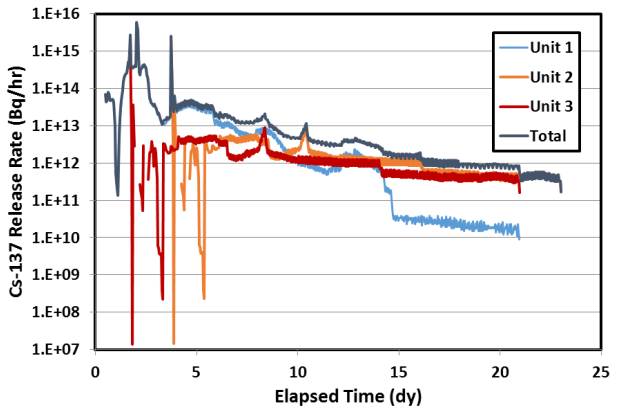

Preliminary Atmospheric Transport and Land Contamination Results for Fukushima Daiichi Units 1, 2, & 3

Nathan E. Bixler and Daniel J. Clayton

Sandia National Laboratories

Presented at the 8th IMUG Meeting, September 15-16,2016

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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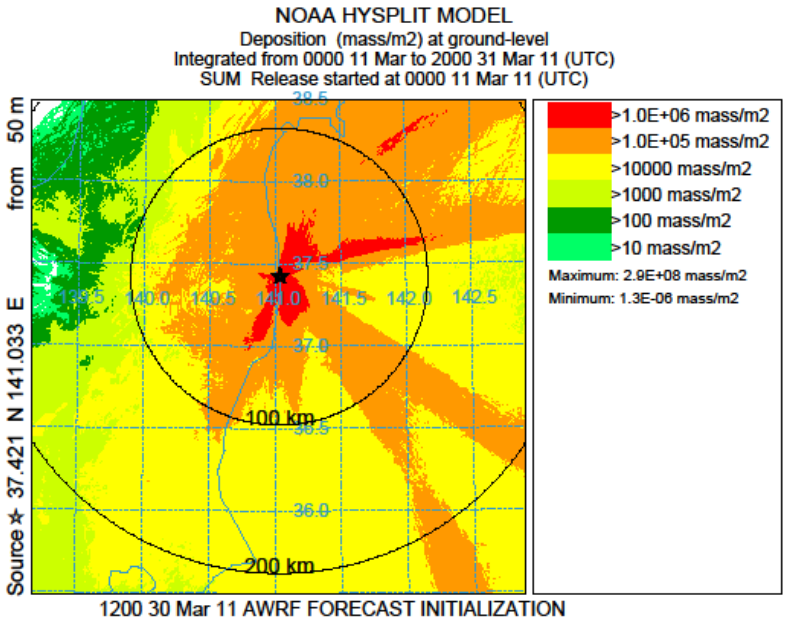
Overview

- Objectives
- Source terms
- Atmospheric transport and dispersion
- Deposition observations and predictions
- Summary
- Future work



Objectives of Atmospheric Transport Analysis

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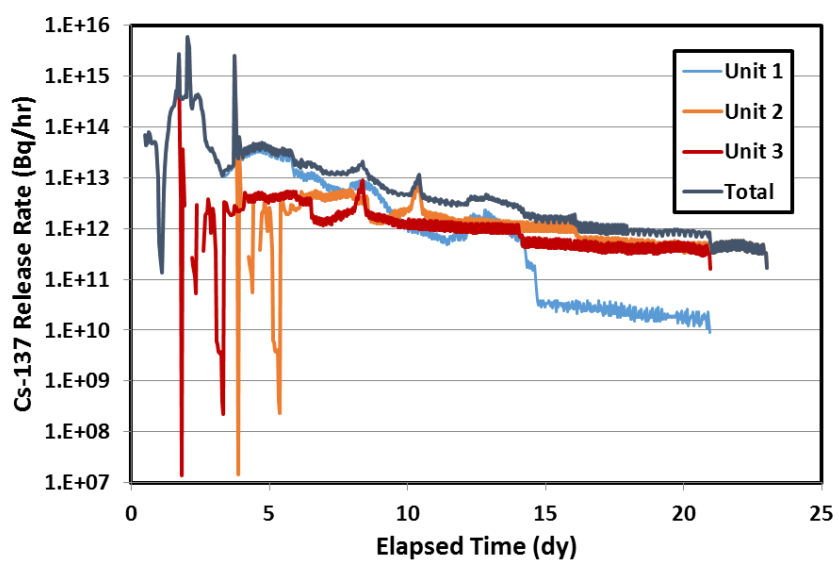
- Reasonably replicate ground deposition pattern based on MELCOR source terms
  - Major focus on deposition toward the northwest
  - Lesser focus on deposition in other areas
  - Focus initially on Cs-137
- Provide guidance in release timing and magnitude for MELCOR analysts
- Benchmark models against real data
  - HYSPLIT particle tracking model (current work)
  - Gaussian plume segment model (future work)

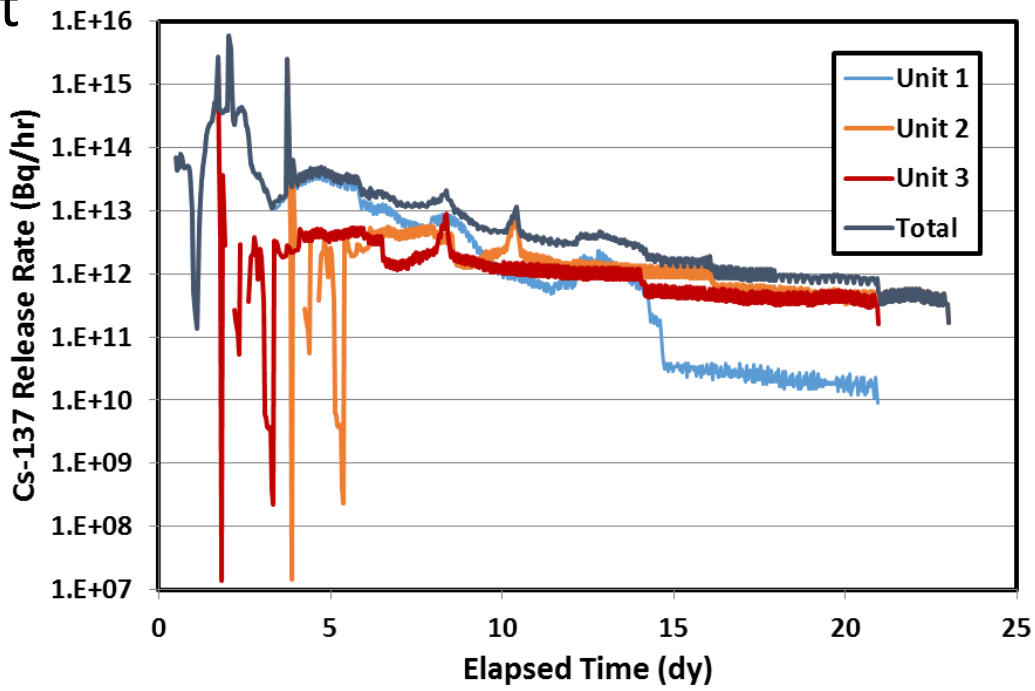
Preliminary MELCOR Release Calculations

- MELCOR calculations have been extended to 21 days
- Initial MELCOR analyses performed for Units 1 & 3
- Unit 2 currently modeled as delayed (49 hr) release from Unit 3
- Releases do not account for attenuation by reactor buildings (possibly factor of 2 or more)
- Currently working on better model for Unit 3

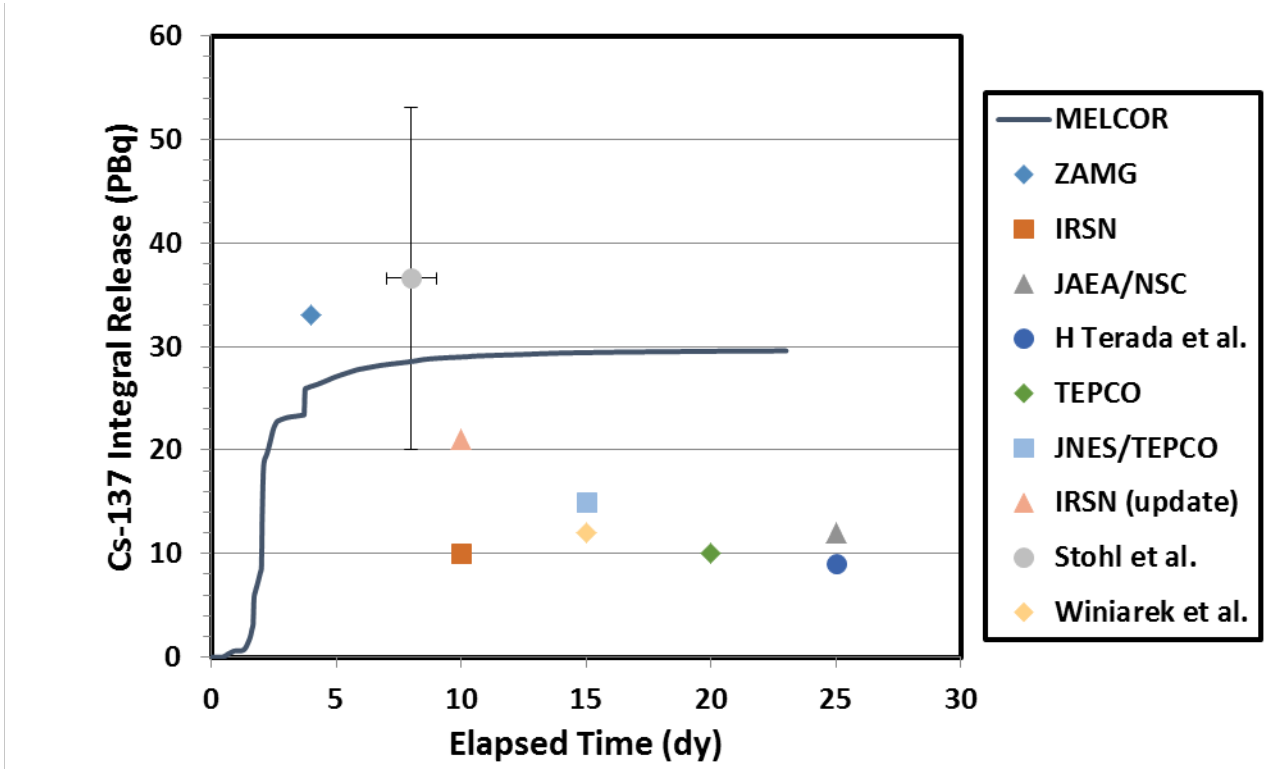


Observations on MELCOR Estimated Releases

- Unit 1 dominates release through day 7
- Unit 2 is the most important release after day 9 except for short period around day 13
- Major release spikes occur at
  - 41 hours (U3)
  - 49-50 hours (U1)
  - 90 hours (U2)
- Total release is about
  - 29 PBq Cs-137
  - 27 PBq Cs-134



Integral Release Estimates



- MELCOR total Cs-137 release is in the upper end of range
- Accounting for attenuation by reactor buildings will potentially align MELCOR release with most other estimates

Aspects of Calculating Atmospheric Transport and Dispersion

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- Meteorological data
  - Gridded, 3D, transient wind fields are required for high fidelity ATD models
  - Data are usually generated by a weather forecasting model (WRF, MM5, etc.)
  - Methods are used to ensure forecasts remain true to weather observations (nudging, running short-duration forecasts, etc.)
  - Resolution (from 0.5 degree to a few km grid spacing) is very important to the results
- ATD model
  - Best models construct air and ground concentrations by tracking a large number of Lagrangian particles (each particle represents ~10^{15} aerosol particles)
  - Concentration is constructed from the integral of mass (or activity) of particles residing in a grid cell over a time interval
  - A key aspect is treatment of deposition, wet and dry

Key Uncertainties – Source Term and Weather

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- Source term
  - Most source terms to date are reconstructed from dose and concentration measurements
    - Depend on accuracy of measurements
    - Depend on accuracy of atmospheric transport and dispersion (ATD) models
  - MELCOR source term used in this presentation is the first attempt to evaluate ground deposition based purely on an accident analysis
    - Uncertainties in accident progression drive uncertainties in source term
    - However, coupled ST/ATD analysis may help reduce uncertainties in accident progression
- Weather
  - Gridded 3D weather data have inherent uncertainties that depend on
    - Resolution of grid
    - Underlying models for sub-grid scale phenomena

Key Uncertainties – ATD Model

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- ATD Model
  - Numerical process of constructing particle trajectories is very accurate
  - Modeling of turbulent fluctuations from mean wind velocities introduces uncertainties
    - Treatment of turbulent intensity information from meteorological data
    - Temporal correlation of turbulent velocities
  - Dry deposition
    - Representation of aerosol size distribution
    - Dependence of deposition velocities on aerosol properties, wind speed, surface boundary layers, and surface roughness
  - Wet deposition
    - Treatment of capture of aerosol particles by falling raindrops or snowflakes (dominated by impaction and interception)
    - Treatment of interaction of aerosols with moisture droplets inside clouds (contributions from electrophoresis, diffusion, turbulence, etc.)

Approaches for Evaluating Release

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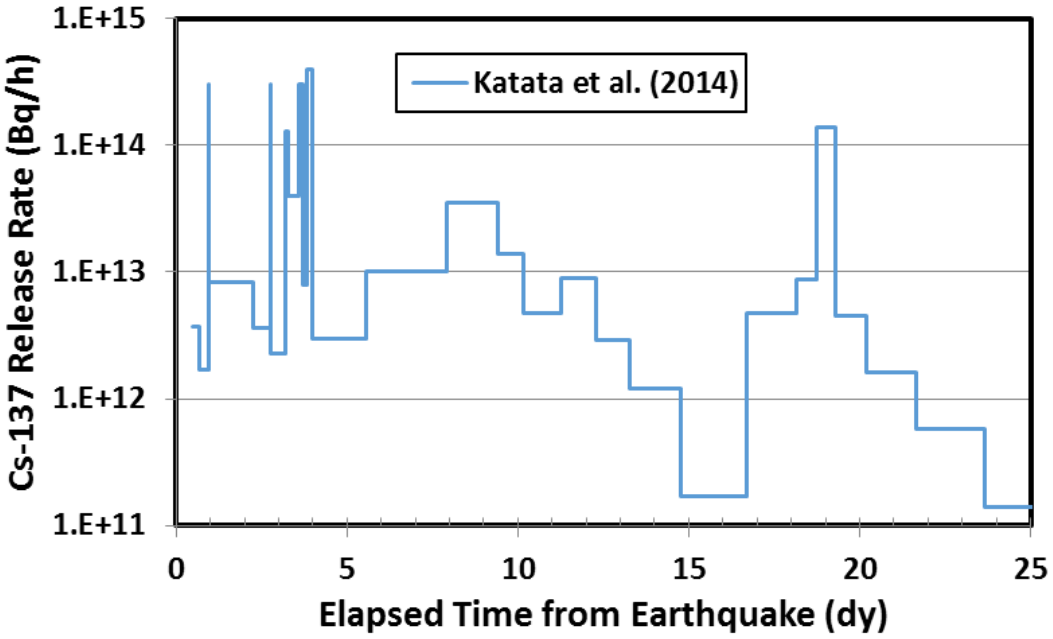
- Reverse calculations
  - Infer release rates from ratio of measured to estimated dose measurements and air concentrations
- Inverse calculations
  - Reconstruct source term based on observed dose and concentration measurements
- Forward calculations
  - Start with source term and estimate air and ground concentrations
  - Tends to be an iterative process but can lead to more fundamental understanding

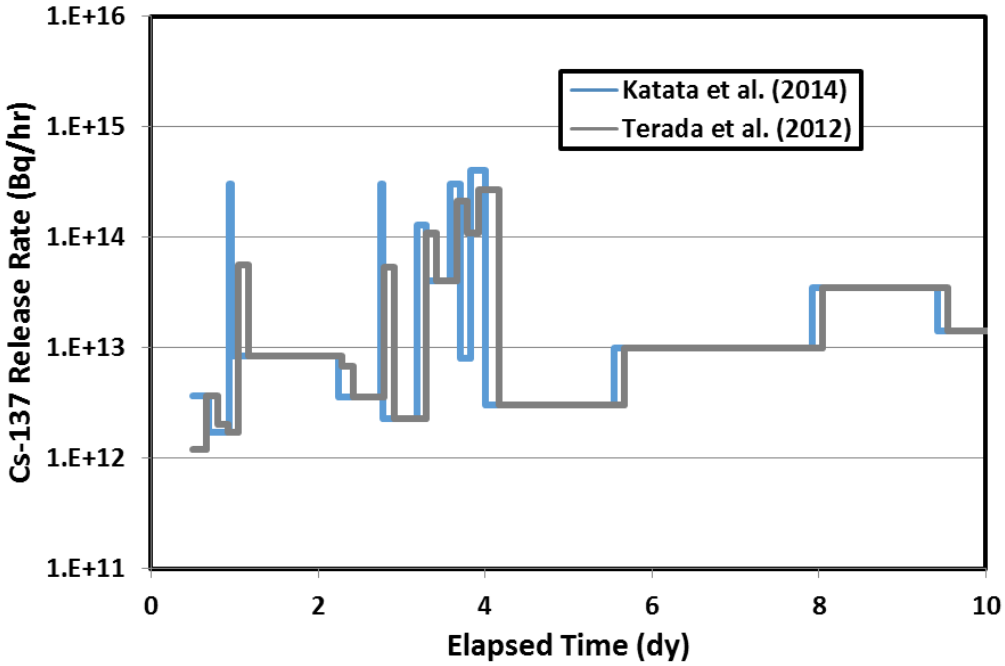
Reverse Calculation by Katata, et al.

- One of the more widely cited source terms – used as reference in following slides
- Based on
  - Measurements nearby and at Japanese monitoring stations
  - SPEEDI (MM5 and GEARN) to estimate atmospheric dispersion with 1 km^2 resolution
- Uncertainty in source term from several sources
  - Weather data
  - Deposition models
  - Dispersion model
  - Measurement errors



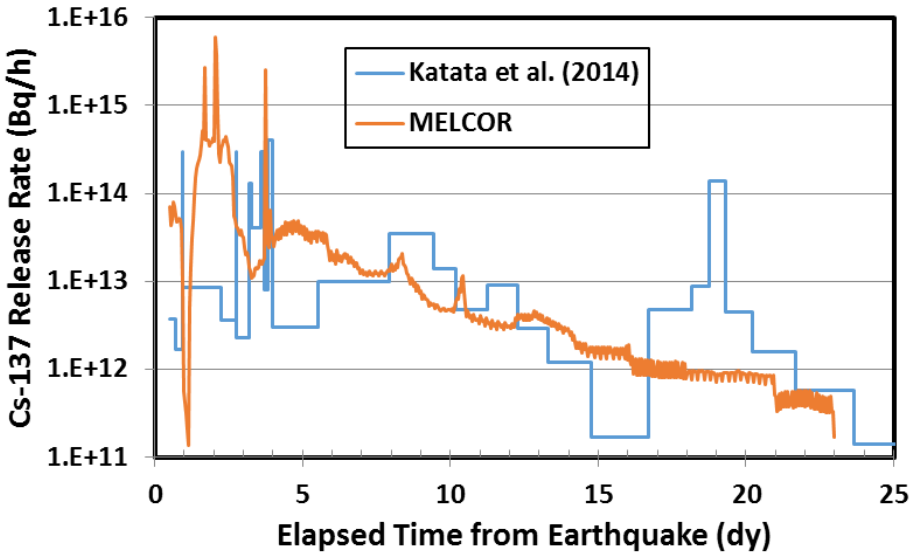
Comparison: Katata and Terada

- Both based on reverse calculations
- Comparison indicates uncertainties in source term
  - 2.5 hour difference in timing
  - Differences in release rates within first 5 days
- Other comparisons shown at last BSAF Meeting by Mathieu et al. indicate larger uncertainties



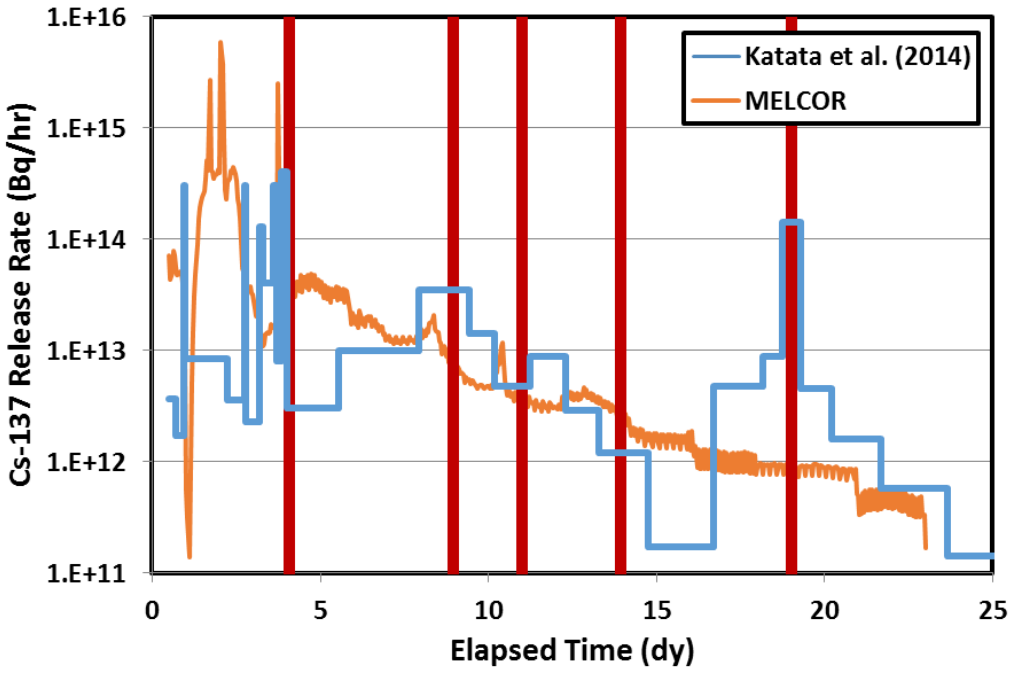
Comparison: Preliminary MELCOR Results with Katata et al.

- MELCOR predictions agree reasonably well with source term from Katata et al.
- Early release period – first 5 days
  - MELCOR estimates large releases from Unit 1 during first three days
  - Katata et al. estimate a series of release during days 3 and 4
  - MELCOR predicts one large spike around day 4
- Intermediate release period – days 5 through 17
  - Trends are very similar
- Late release period – days 17 through 21+
  - Katata et al. report a large period of release peaking on day 19



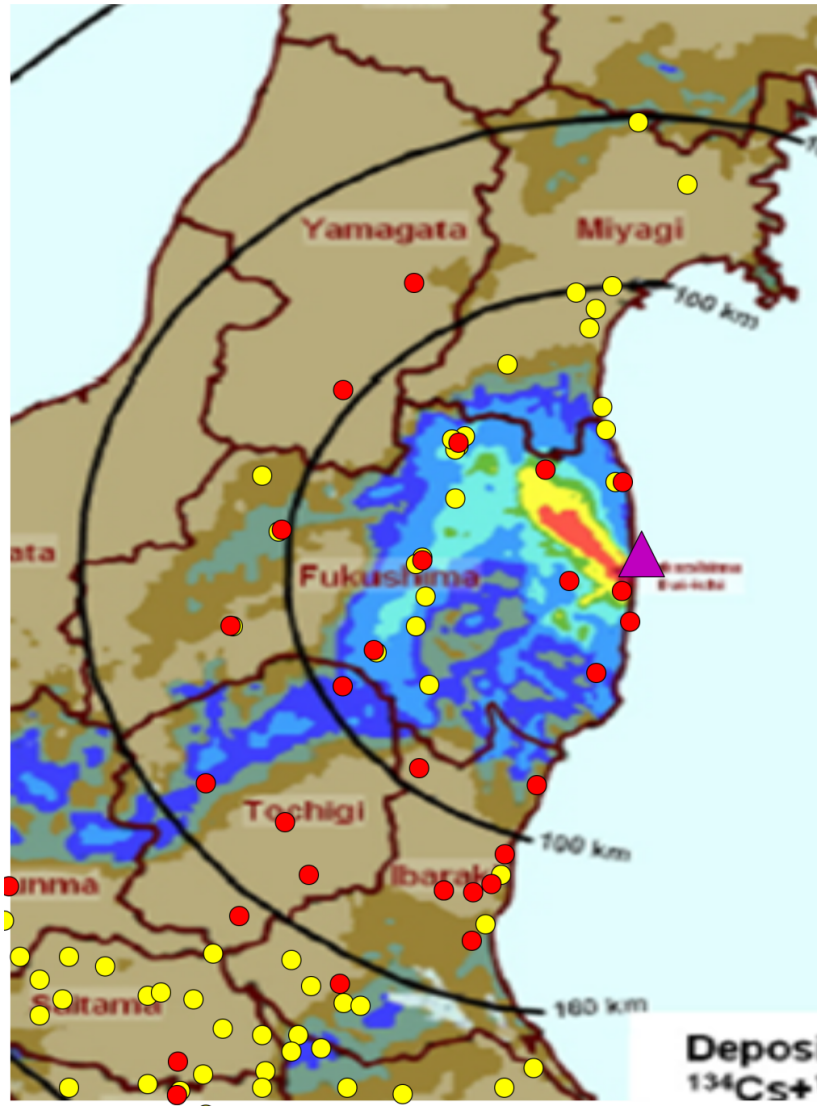
Key Release Times

- Key times when wind blows to NW (vertical red lines on plot)
  - 98 hours (4.1 dy), March 15
  - 215 hours (9 dy), March 20
  - 264 hours (11 dy), March 22
  - 334 hours (13.9 dy), March 24
  - 456 hours (19 dy), March 30



Observed Deposition

- Significant contamination out to about 75 km in all directions
- Largest contamination level to the NW



Predicted Deposition for Two Source Terms

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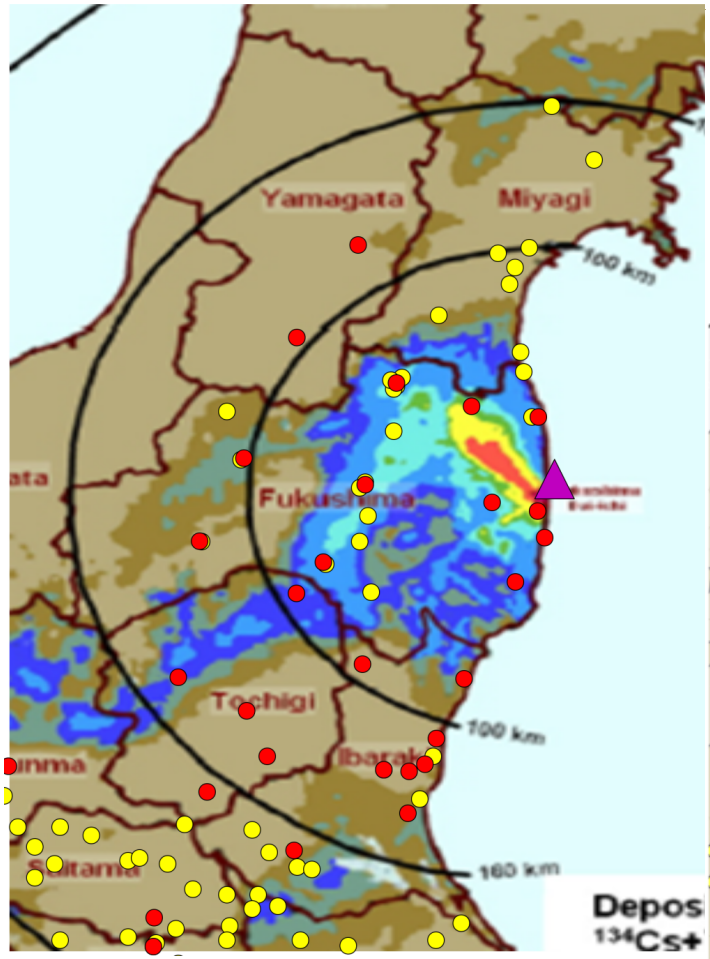
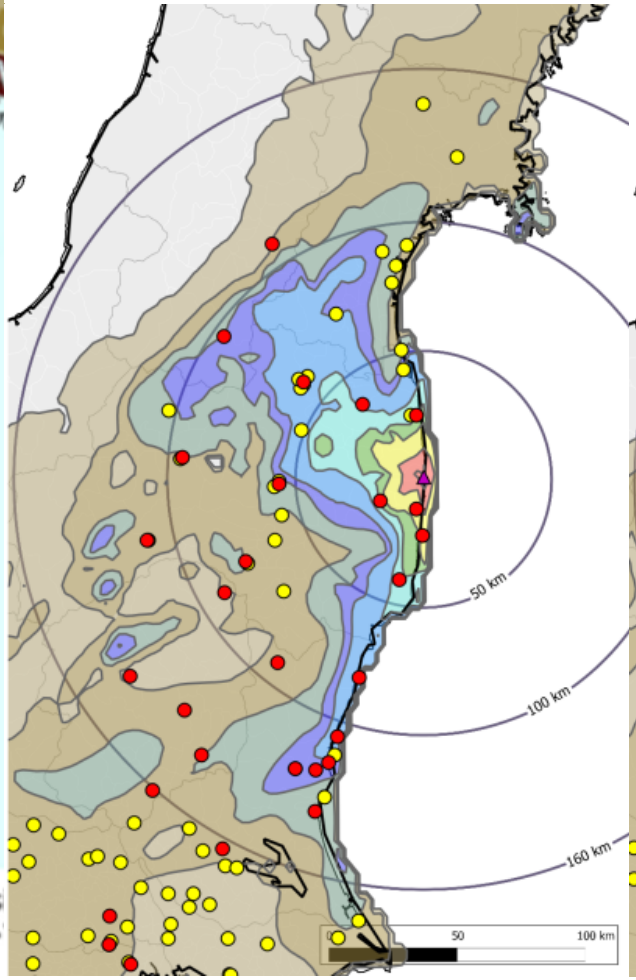
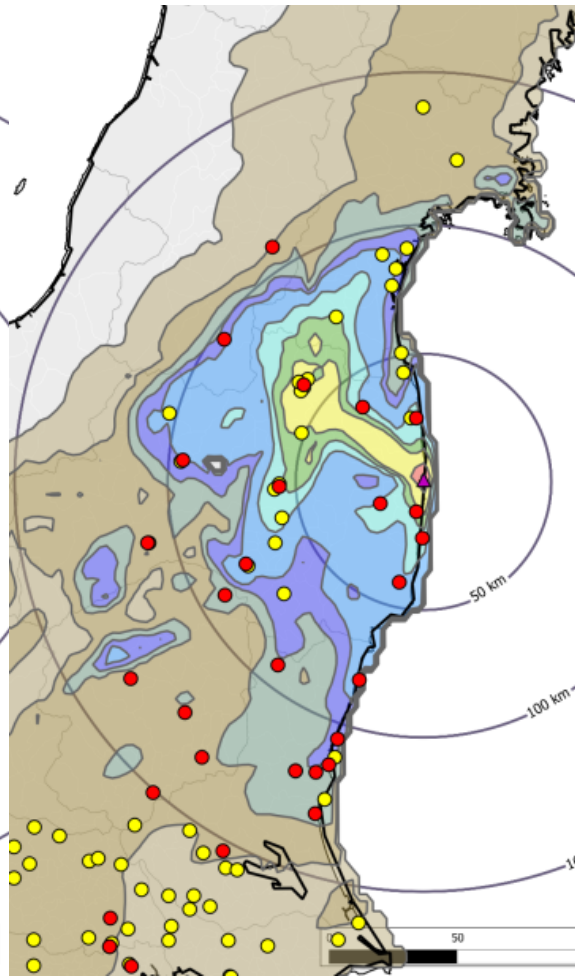
Katata et al.

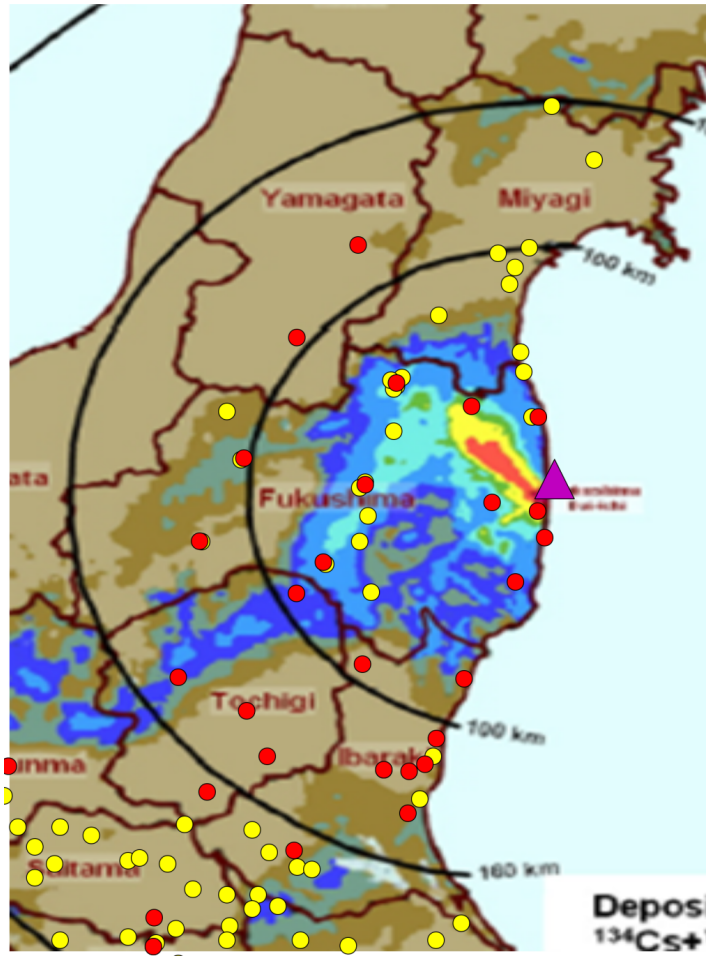
Terada et al.

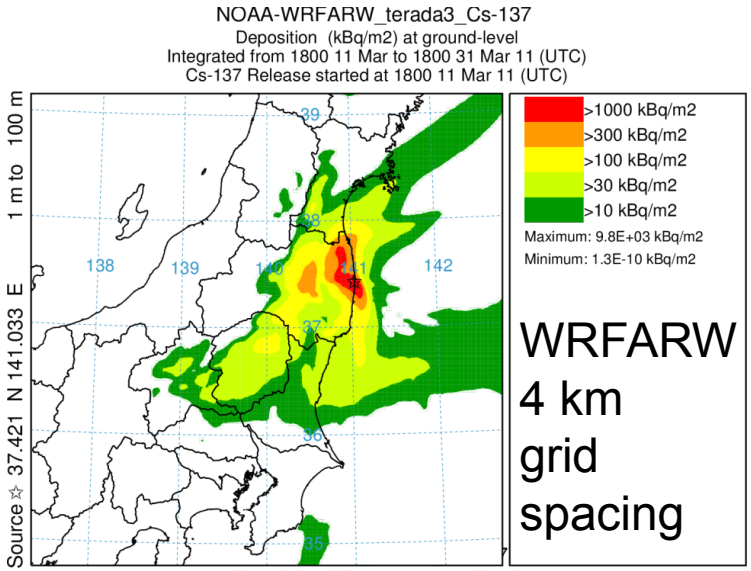


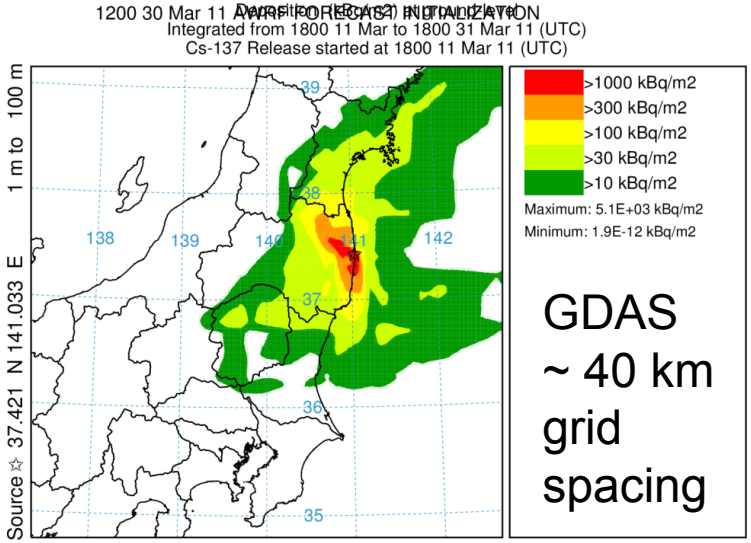




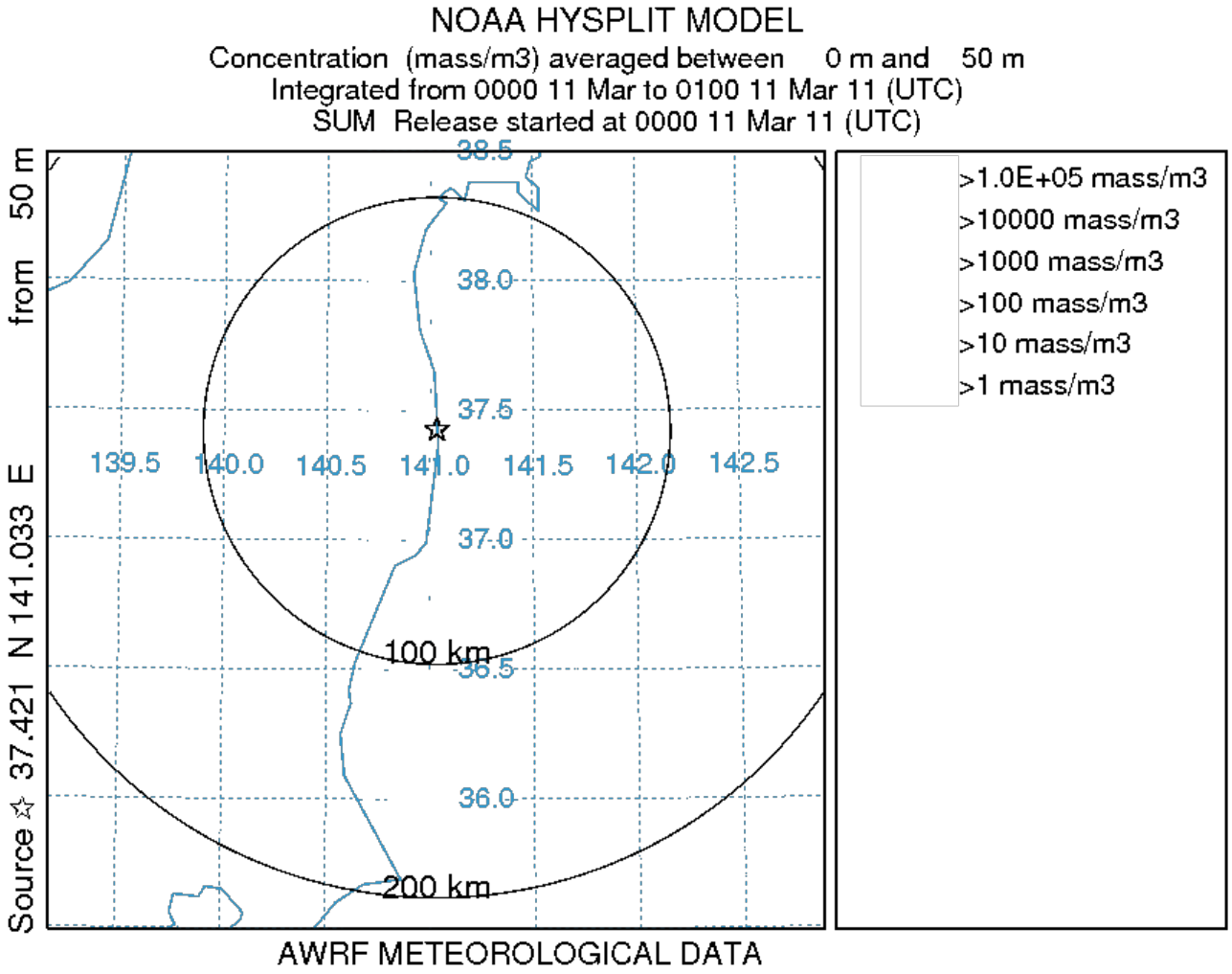
Predicted Deposition for Two Meteorological Data Sets (Terada)



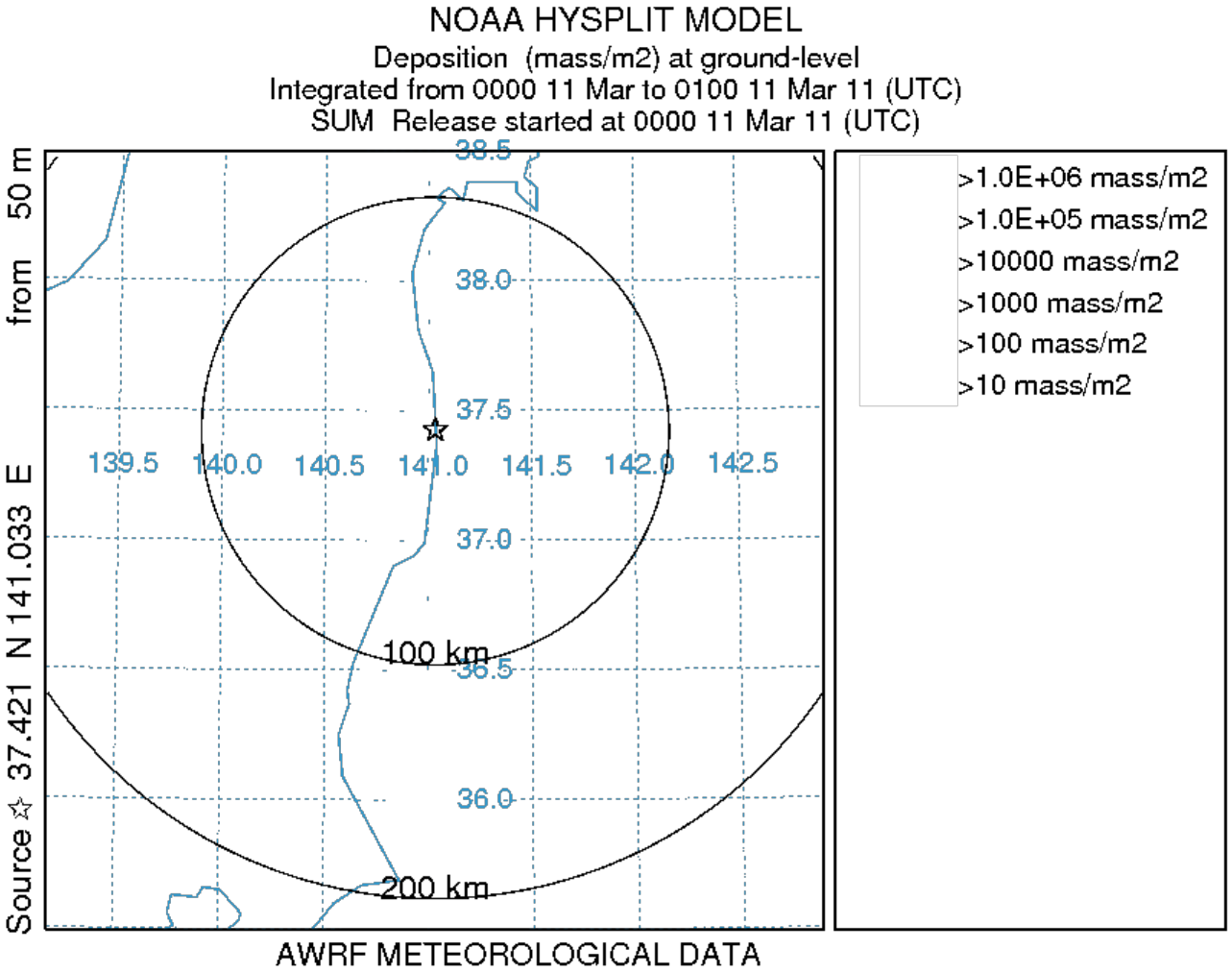




Predicted Air Concentrations Based on MELCOR Source Term



Predicted Deposition Based on MELCOR Source Term



Summary

- Recent MELCOR data has provided a preliminary source term for evaluation
  - Extended to 21 days for Units 1 & 3
  - Unit 3 currently used as surrogate for Unit 2
- MELCOR source term is comparable to other estimates
  - Integral releases are at the upper end of the spectrum
  - Signature has many features in common with Katata et al. (2014)
  - Some key differences remain to be studied
- ATD modeling
  - Preliminary ATD modeling demonstrates capability to model accident and consequences from beginning to end
  - Preliminary results exhibit some of the observed features but demonstrate need for further refinement

Future Work

- MELCOR Source Term
  - Complete Unit 2 analysis
  - Generate reactor building models
  - Evaluate critical release timings
- Atmospheric Transport
  - Evaluate several meteorological datasets
  - Evaluate updated MELCOR source terms
- General
  - Create BSAF WG for atmospheric transport analysis
  - Share meteorological data among BSAF WG
  - Share source-term data among BSAF WG