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Current Status and Future Directions in the Use of High-Resolution Atmospheric Models for Support of T&E

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Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 2005		2. REPORT TYPE		3. DATES COVERED 00-00-2005 to 00-00-2005	
4. TITLE AND SUBTITLE Current Status and Future Directions in the Use of High-Resolution Atmospheric Models for Support of T&E				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Dugway Proving Ground,Dugway,UT,84022-5000				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES Modeling and Simulation Conference, 2005 Dec 12-15, Las Cruces, NM					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 28	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Weather Forecasting as a High Performance Computing problem

- *The world's first electronic computer (ENIAC*) was developed by “Army Ordnance” (Aberdeen Proving Ground) to compute World War II ballistic firing tables.*

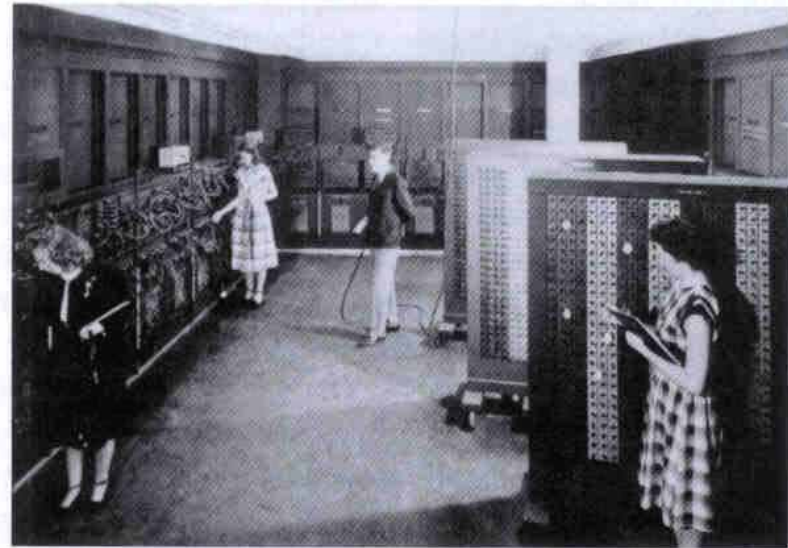


Figure 3: The ENIAC computer in 1948. The operators are changing the plug-in wiring. (PLATZMAN, 1979).

- *In addition to ballistics, the ENIAC's fields of application included **weather prediction**...*

*Electronic Numerical Integrator And Computer

More recent indicators of weather's dominant role as a user of high-performance computing

- 1952 - Princeton's Institute for Advanced Study developed first general-purpose computer; the primary intended use was weather prediction and research
- 1977 - The National Center for Atmospheric Research was Cray Research's first official customer with the Cray 1A
- 2000 – Europe's three fastest super computers were dedicated to weather forecasting
- 2005 – 10-20 of the top-100 super computers in the world are utilized primarily for operational weather forecasting or weather research

Why Numerical Weather Prediction is Computationally Intensive

- Nonlinear, nonhomogeneous, partial differential equations that describe fluid dynamics and thermodynamics of the atmosphere must be solved with high-order numerical techniques
- Physics of atmospheric turbulence, radiation, chemistry and cloud/precipitation processes are complex
- Soil, vegetation, ocean processes are part of model
- Because of the numerics, a doubling of the resolution in horizontal and vertical requires a 16-fold increase in the computing power required for the same area

History of ATEC Four-Dimensional Weather (4DWX) Program

- Situation in 1995 – Unmet needs of Army test range forecasters
 - range-scale model products,
 - a modern data archival system, and
 - better graphical displays of data and model products
- 1996-present – ATEC and the National Center for Atmospheric Research have partnered on the development of one of the highest-resolution operational weather-prediction systems in the world

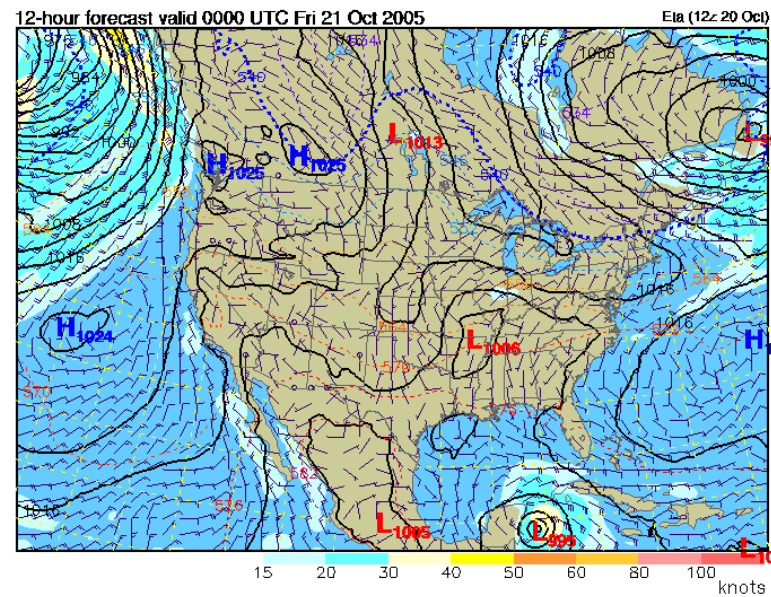
Paradigms of the ATEC 4DWX Program

- Partnership and close collaboration between ATEC meteorologists and system developers
- Rapid prototyping and deployment of new capabilities – concept to operations in 3-6 months
- Frequent upgrades/releases – system is NOT static

An example – Standard versus 4DWX model forecasts

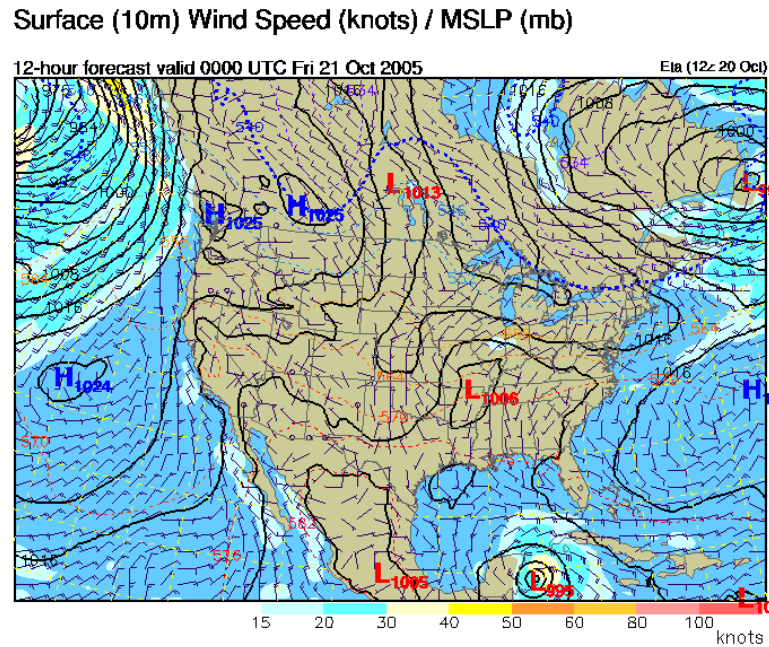
Standard model forecast from
National Weather Service

Surface (10m) Wind Speed (knots) / MSLP (mb)

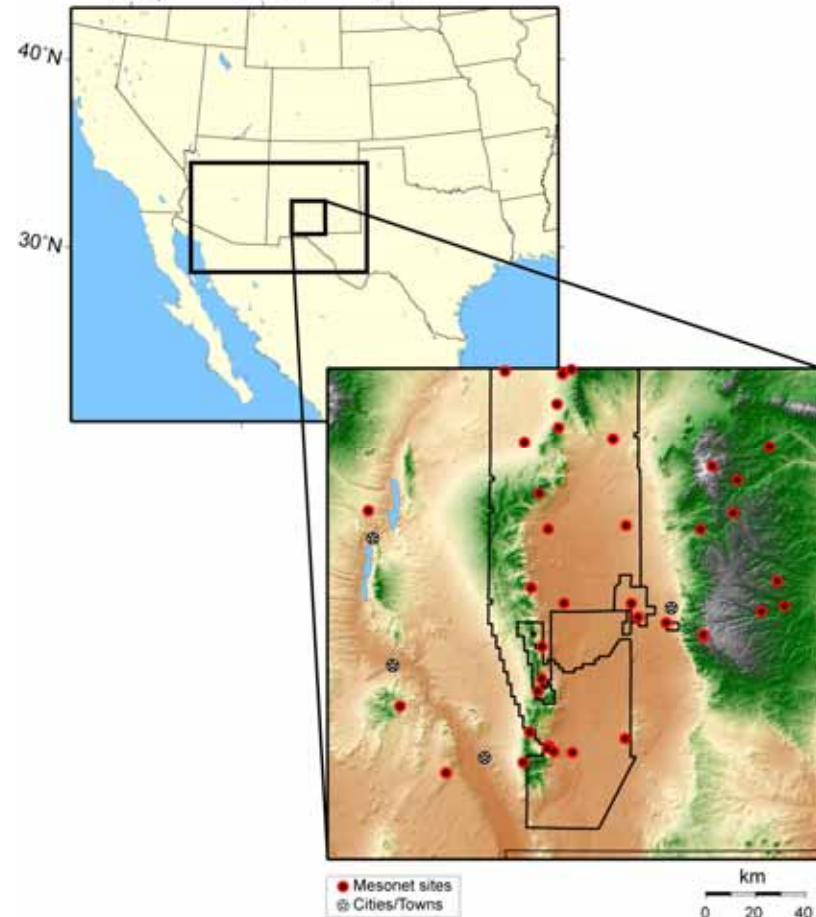


For example - model forecasts

Standard model forecast from National Weather Service



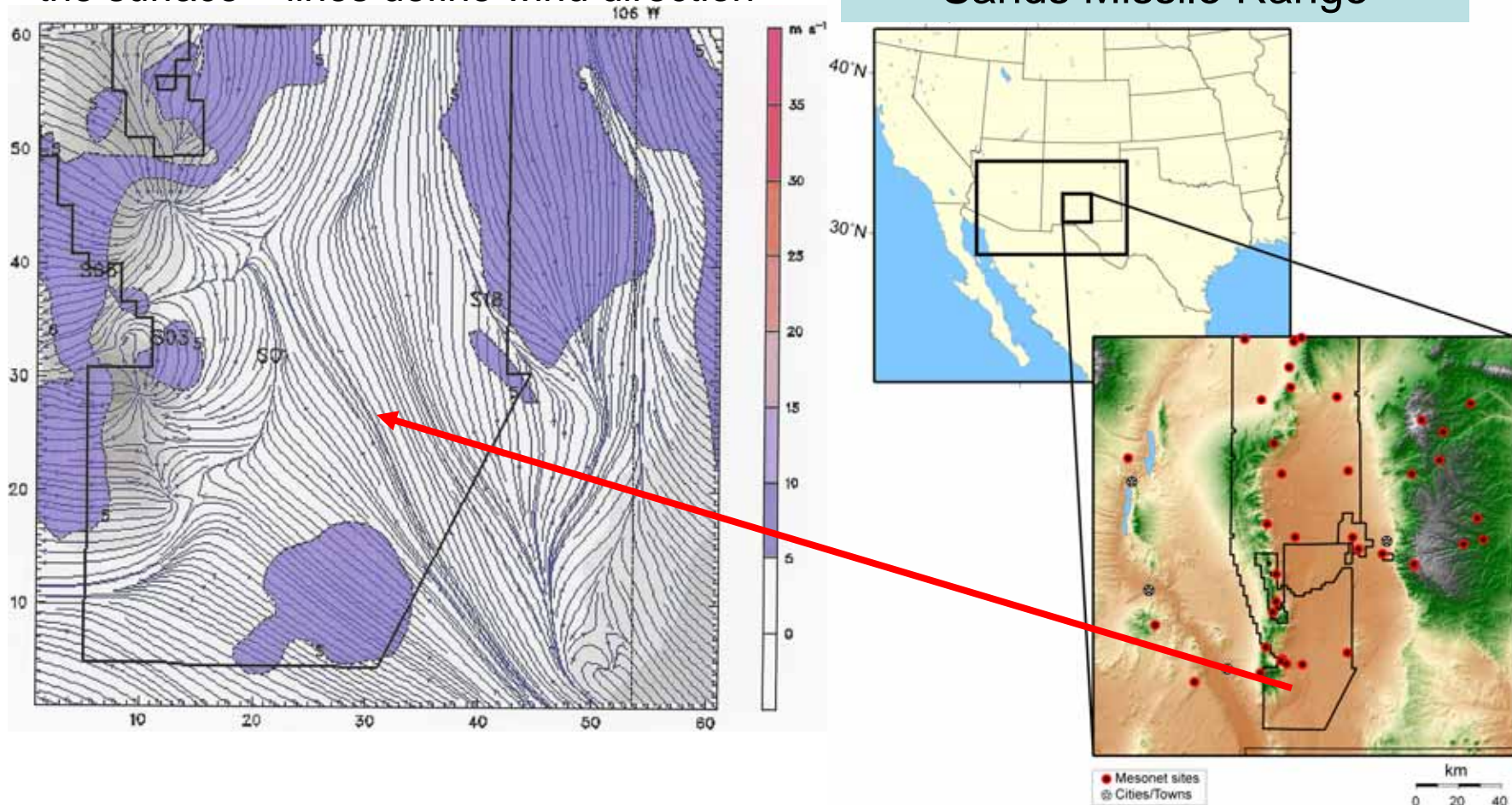
Current 4DWX model computational area for White Sands Missile Range



For example - model forecasts

Complex forecast wind-flow pattern near the surface – lines define wind direction

Current 4DWX model computational area for White Sands Missile Range



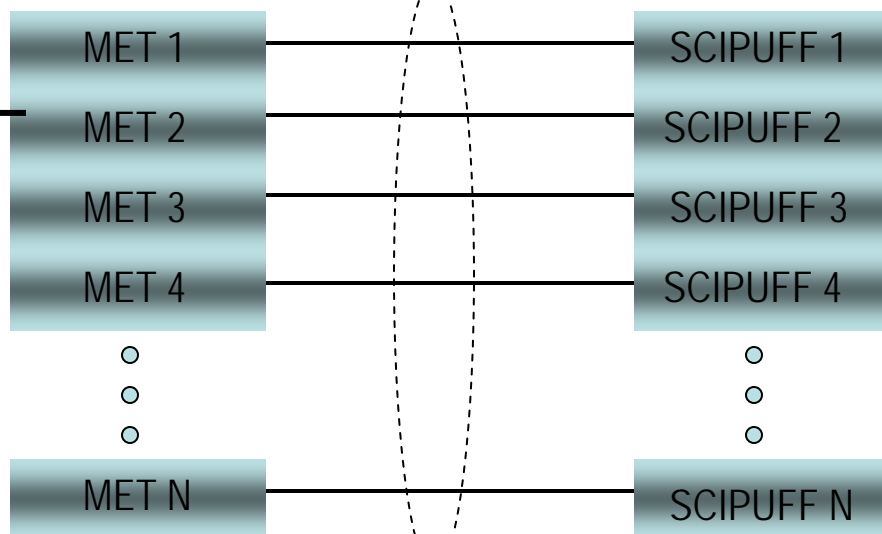
Why haven't standard products been able to serve ATEC's weather needs?

- Test ranges have specialized weather needs – e.g., boundary layer winds
- Models need to be especially high resolution because of nearby complex topographic and coastal forcing
- Weather models need to be closely coupled to special-applications models – transport and diffusion, parachute drift, sound propagation

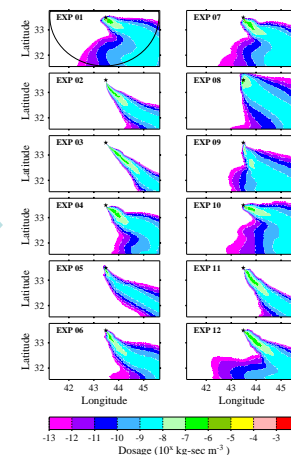
New High-Performance Computing Requirements for ATEC 4DWX System -- EXISTING EFFORTS --

- **Ensemble prediction** – multiple parallel model runs provide probabilistic forecasts to T&E customers
- **4DWX On The MOVE** – graphical interface to weather model allows support of world-wide operational and virtual testing by non-experts
- **Global Climatological Analysis Tool** – constructs high-resolution analyses of regional climate for long-range test planning, at ranges or worldwide
- **FCS/VPG Support** – 4DWX model provides very-high-resolution atmospheric environment for virtual testing

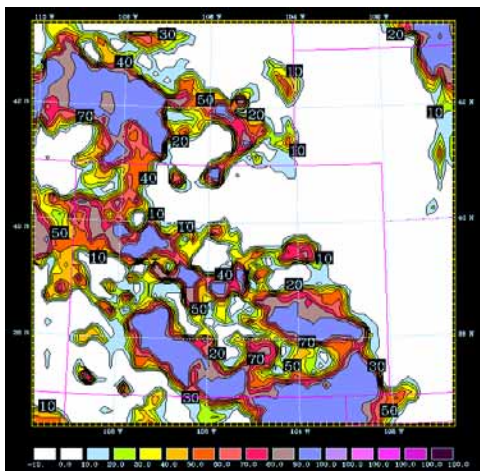
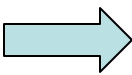
ATEC Ensemble Prediction



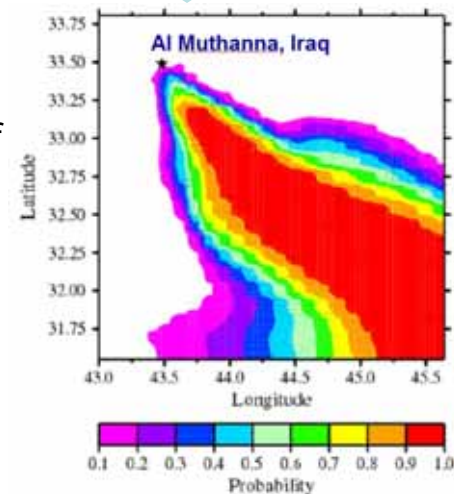
Plume ensemble output



Met. ensemble output:
probability of
winds > 5 m/s over
Colorado



Probability of
dosage
exceedance



ATEC 4DWX On The Move

- Graphical interface is used to deploy operational weather modeling system
- Used to support special missions that are not covered by stationary range weather-modeling systems
- Example – WSMR support of missile launches in Hawaii

The Graphical Interface: for quickly configuring and running the 4DWX forecast system

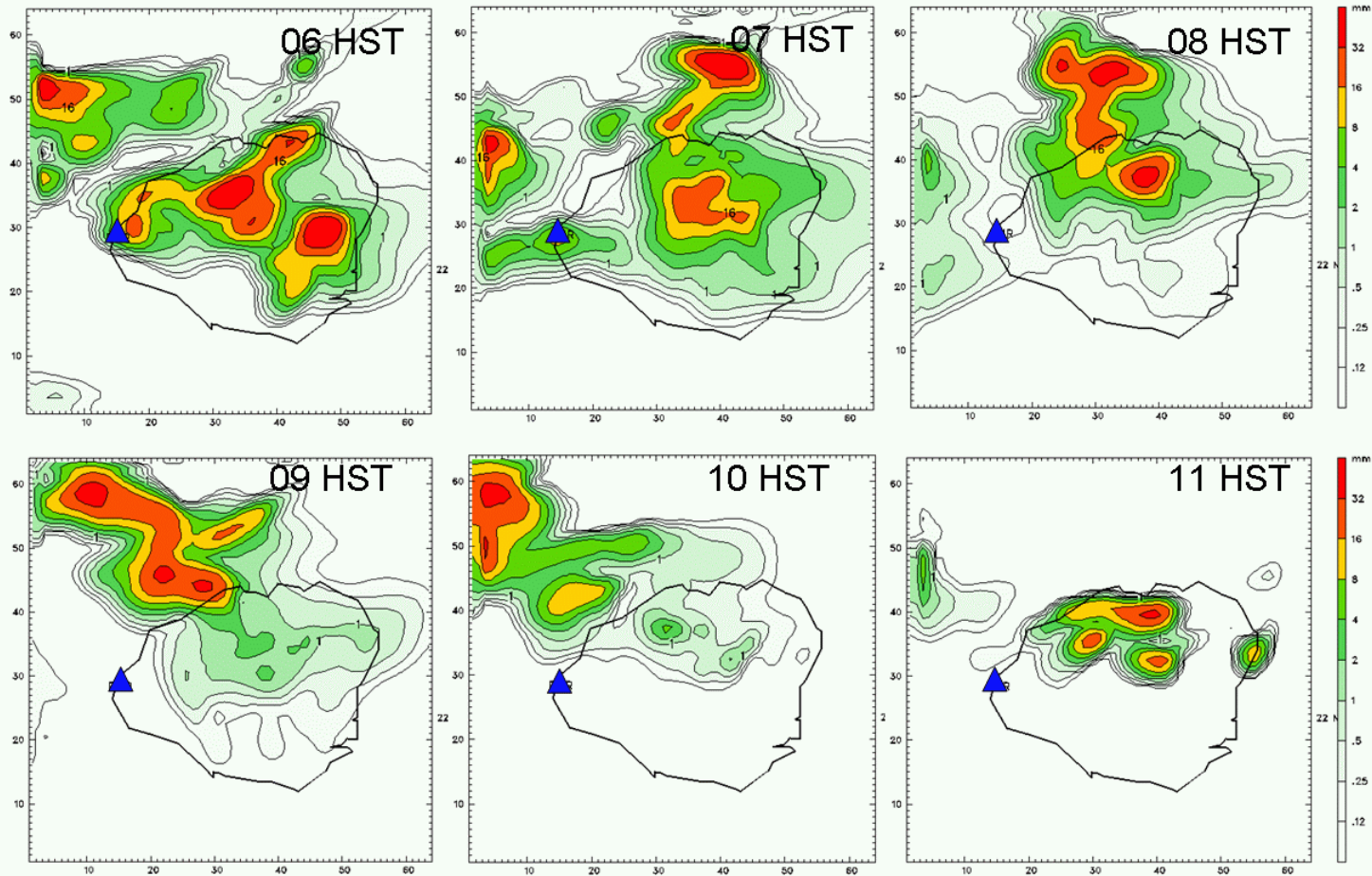
The screenshot displays the web interface for the ClimoFDDA system, specifically the 'Location Setup' page. The interface is organized into several sections:

- Navigation Menu:** Home, Job Manager, New Job, Search Job, My Jobs.
- Breadcrumb:** CLAT: ClimoFDDA Job 12 > Config Setup > Location Setup > MMS Setup > Timeline Setup.
- Page Title:** ClimoFDDA.
- Section:** Location Setup.
- Map Tools:** A panel on the left of the map with instructions: 'To Navigate (1) Select a tool and click on the map, or (2) Click a tool.' Tools include: Update map, Return to Full Extents, Zoom Factor, Zoom In More, Zoom Out More, Recenter the Map, Save map, and Draw domain on map.
- Map:** A satellite-style map of Hawaii with 'HAWAII' and 'UNITED STATES' labels. Below the map, the coordinates are: Latitude: 22.293 N, Longitude: 159.626 W.
- Key Map:** A small world map with the instruction: 'Click the keymap to recenter the map.'
- Map Services:** A section with checkboxes for 'Base Map Layers': World Satellite Imagery (checked), World Base Map, and Country Boundaries.
- Map Utilities:** A section titled 'Zoom to Boundaries' with input fields for Latitude and Longitude. The current values are NW: 22.307, -159.79; SE: 21.79, -159.20. Below these are the labels 'Current boundaries are shown.' and an 'Update' button.
- Domain size and centroid:** A section with a 'Domain size' dropdown set to '100x100km' and a 'Zoom Domain' button. The 'Domain centroid' section shows Latitude: 22.040 and Longitude: -159.499, with the note 'Current coordinates (map center) are shown.'
- Quick View:** A section with a dropdown menu labeled 'Select a location'.
- Footer:** A button labeled 'Add to configuration'.

The situation in the early morning of 2 Feb 2005

- Mission: Rocket launch scheduled for 0800-1100 HST.
- Weather conditions at 0200 HST:
 - Persistent moist unstable flow over Kauai causing widespread thunderstorms.
 - Most of Kauai under a Flash Flood Warning.
- Situation looked highly unfavorable for a launch, but model was predicting a break in the rain between 0900 and 1100 HST.

The ATEC-model forecast from the previous evening:
Heavy rain until about 0830 HST, followed by rapid clearing



(PMRF station is marked as blue triangles)

Case of Feb. 2 2005



Later that Morning (02 Feb 2005)

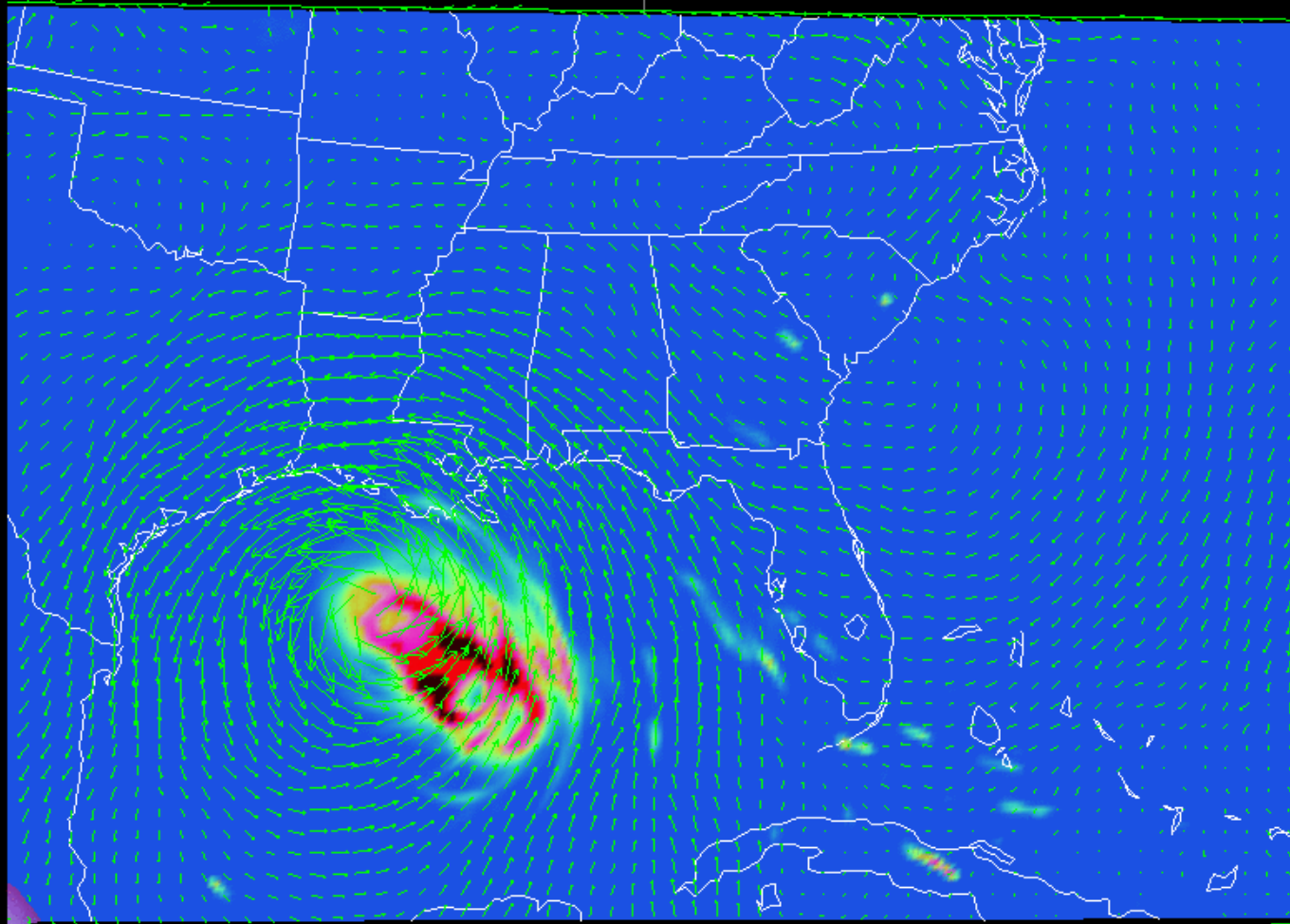
- 0600 HST: Little improvement in observed weather conditions.
- 0830 HST: National Weather Service radar indicated a break in the thunderstorm activity.
- 0900 HST: Rain ends and skies clear, as forecast by the model.
- **Rocket successfully launched.**

ATEC 4DWX On The Move – A National Asset

Supporting the Department of Homeland Security's
forecast of the impact of Hurricane Rita on
the National infrastructure

14:00:00
23 Sep 2005
1 of 57
Friday

N



Colors –
storm total
precipitation

Surface winds and accumulated rain (Magenta: > 150 mm; red: > 250 mm; black > 350 mm)

Vis5D

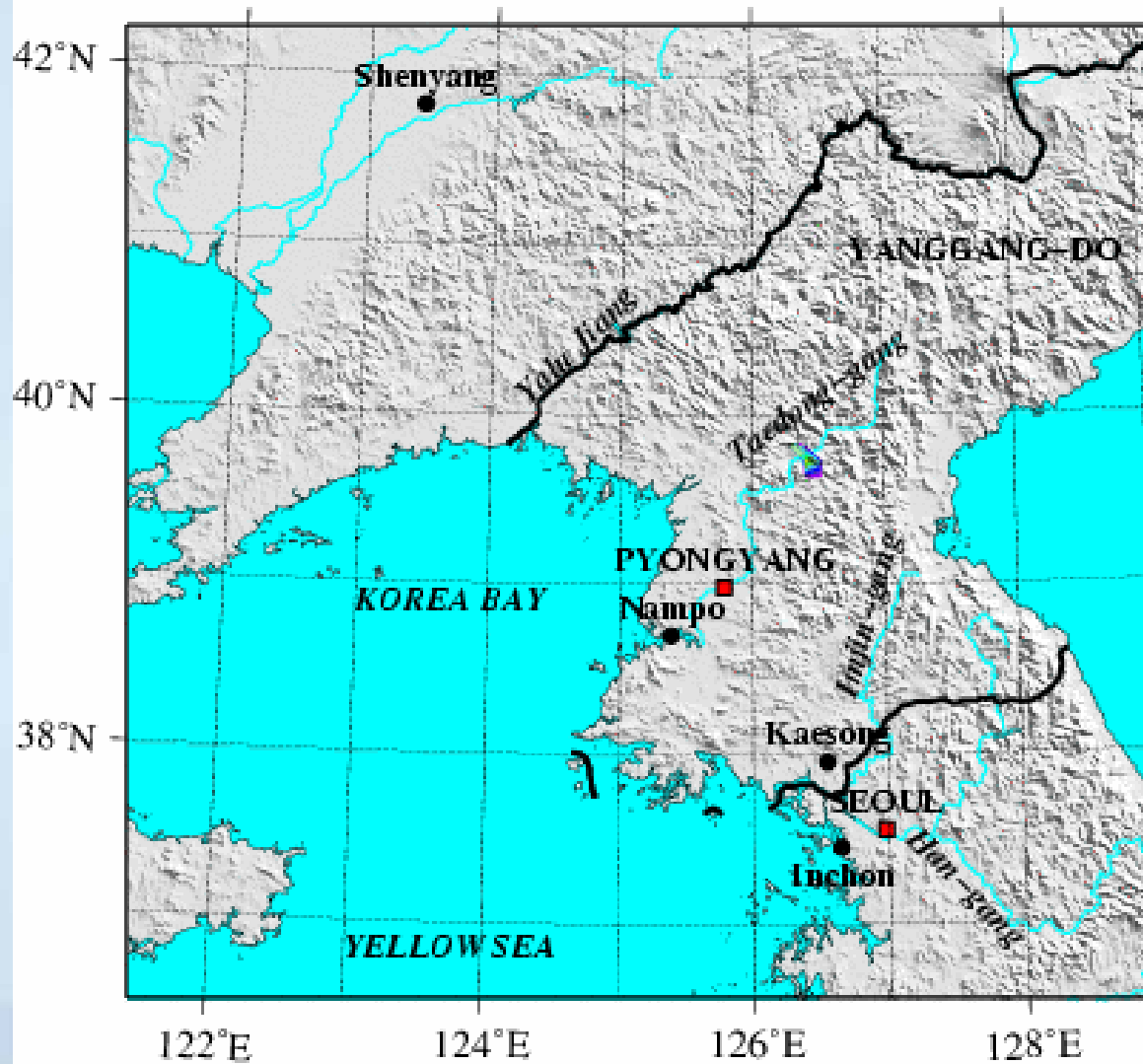
Global Climatological Analysis Tool

- Model is run for decades-long historical period to “downscale” available global climatological analyses
- The resulting high-resolution climatology of winds, temperature, etc. can be used for long range test planning
- The system can be used for range T&E or operational testing worldwide
- National Ground Intelligence Center now uses this system operationally; it will soon be deployed to ATEC ranges.

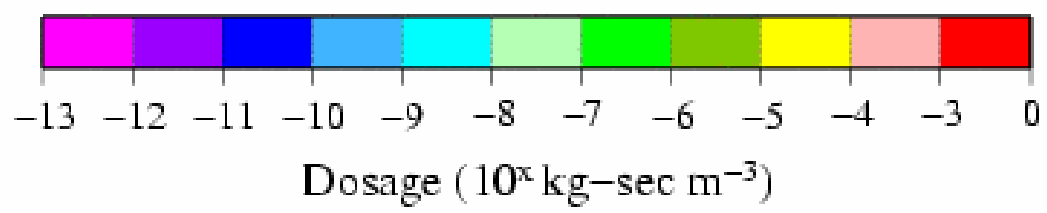
Example Of Application of Global Climatological Analysis Tool

What is the typical pattern of atmospheric transport of hazardous material over the Korean Peninsula in March?

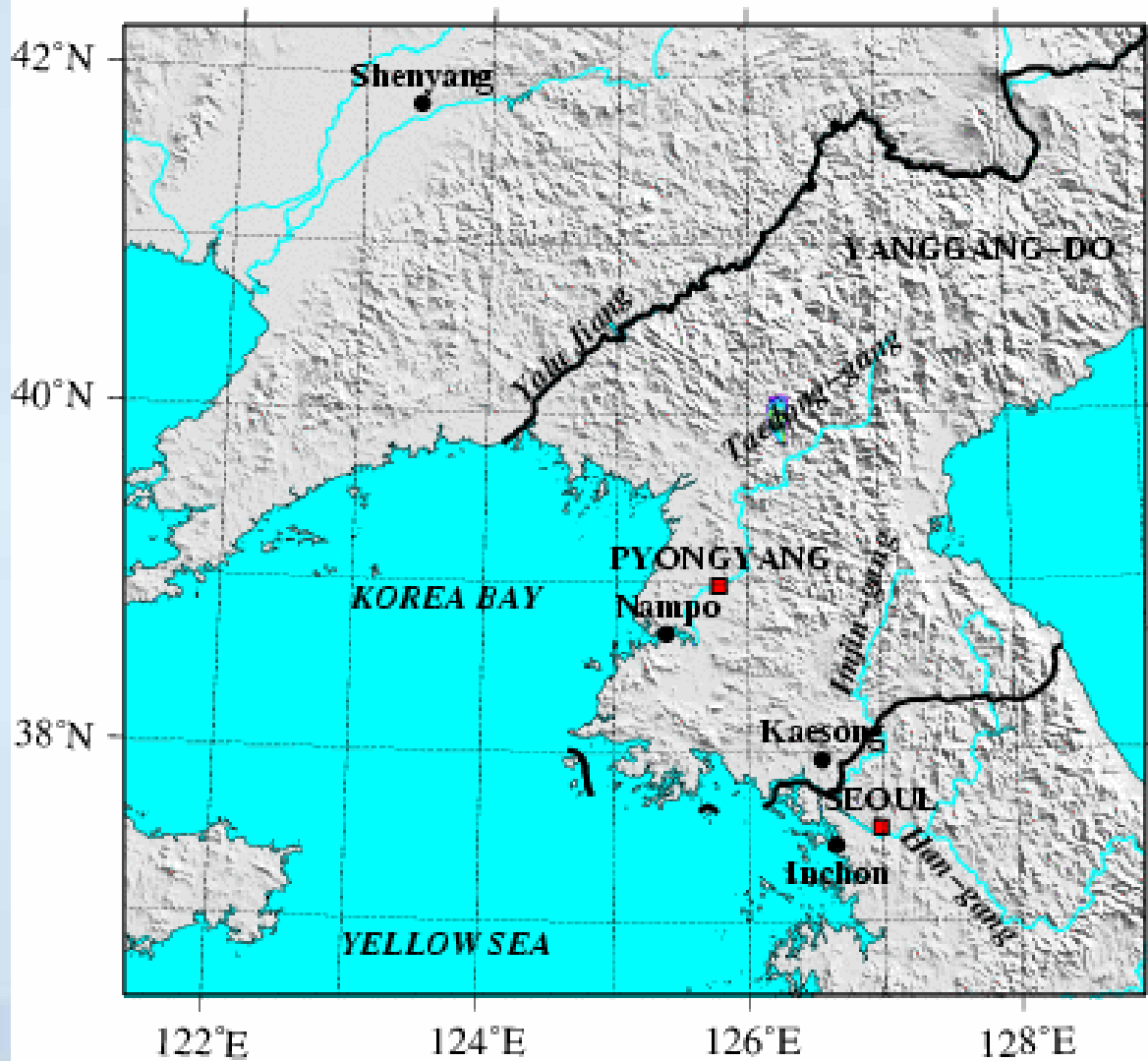
GB 03/15/1987 13:00 GMT



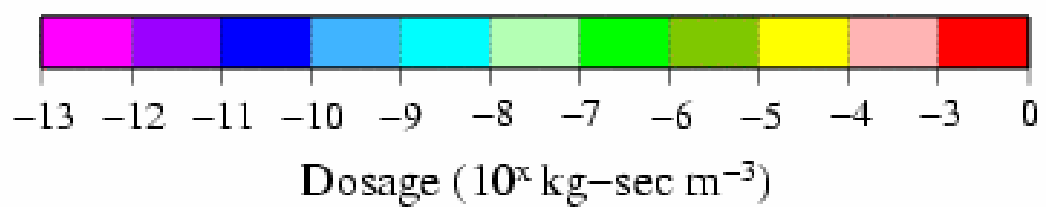
Day 1



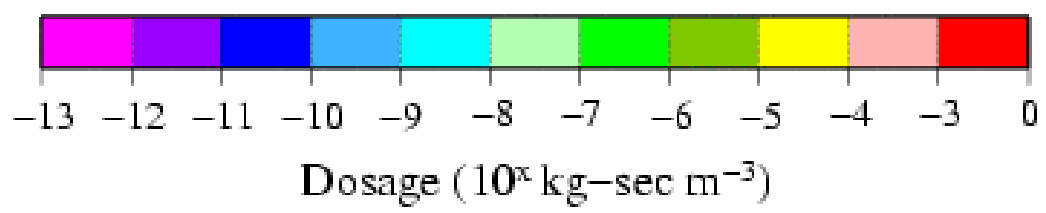
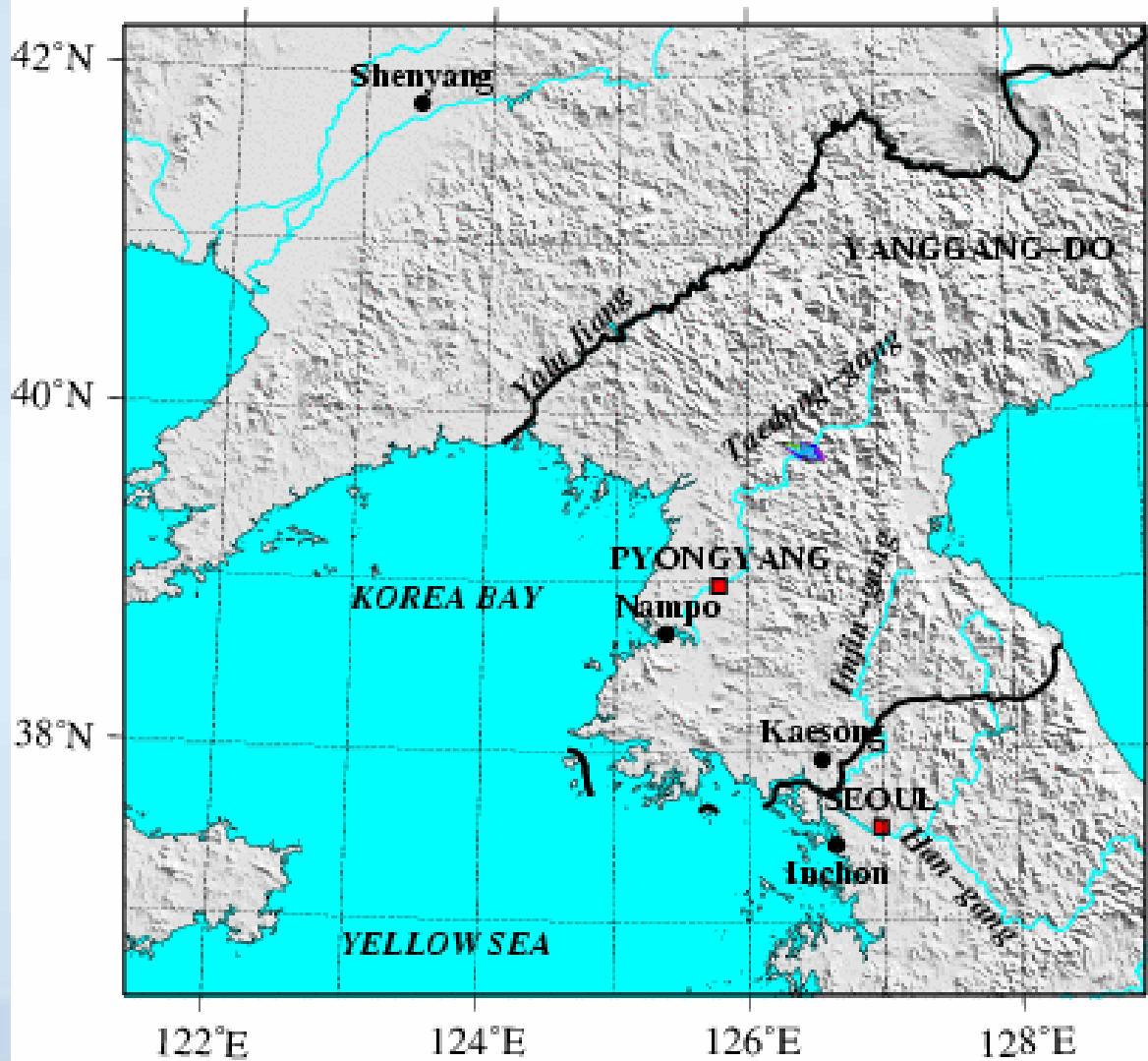
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Day 2



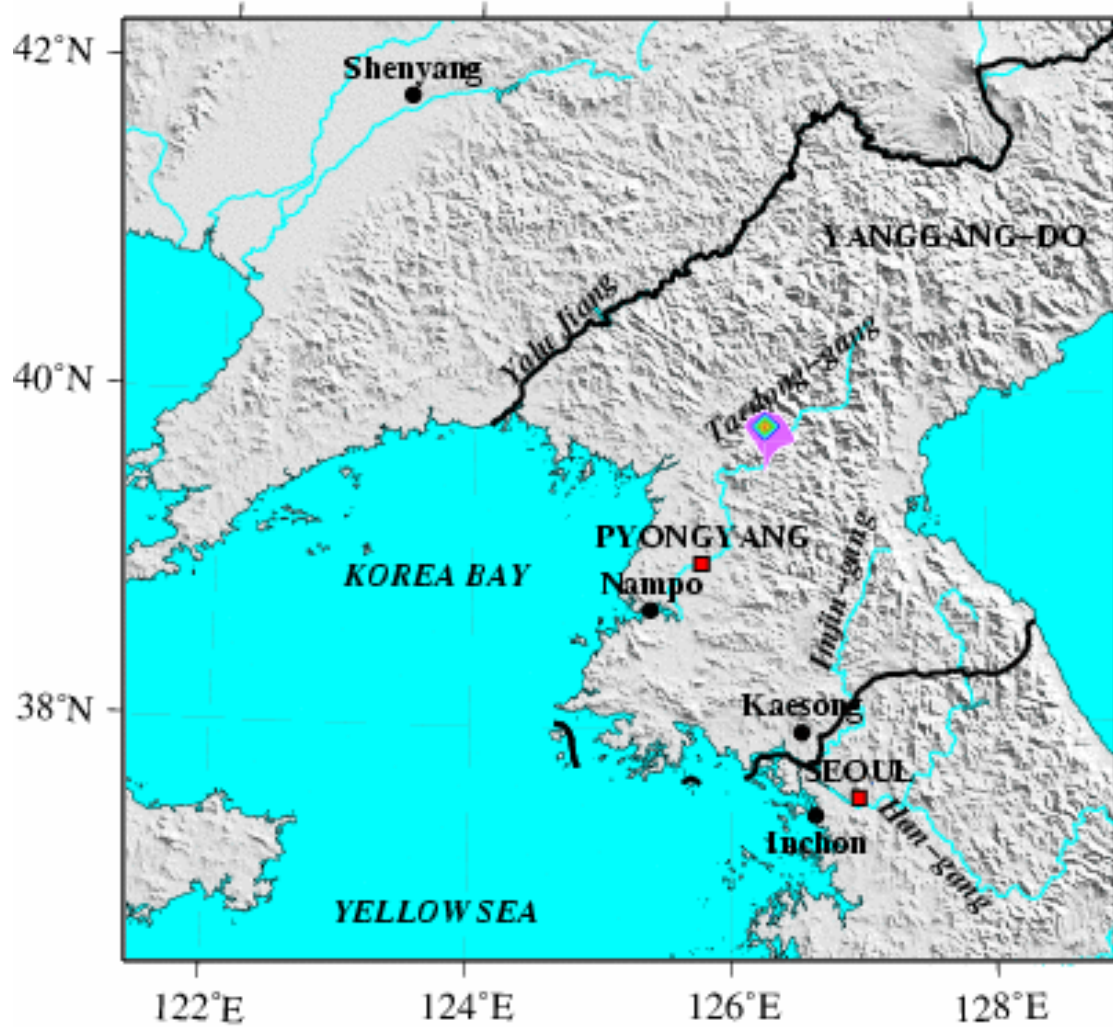
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Day 3
etc.

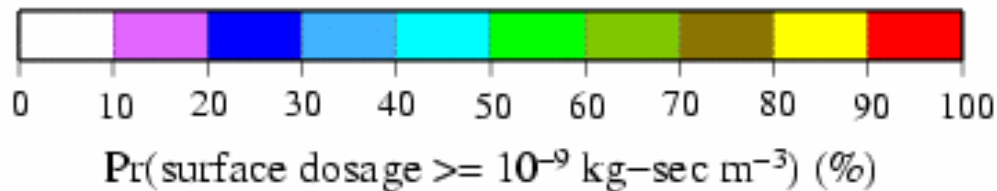
GB

03/15 13:00 GMT



Probability of
Exceeding a
Dosage
Threshold

Based on an
ensemble from
large number of
case days in
March

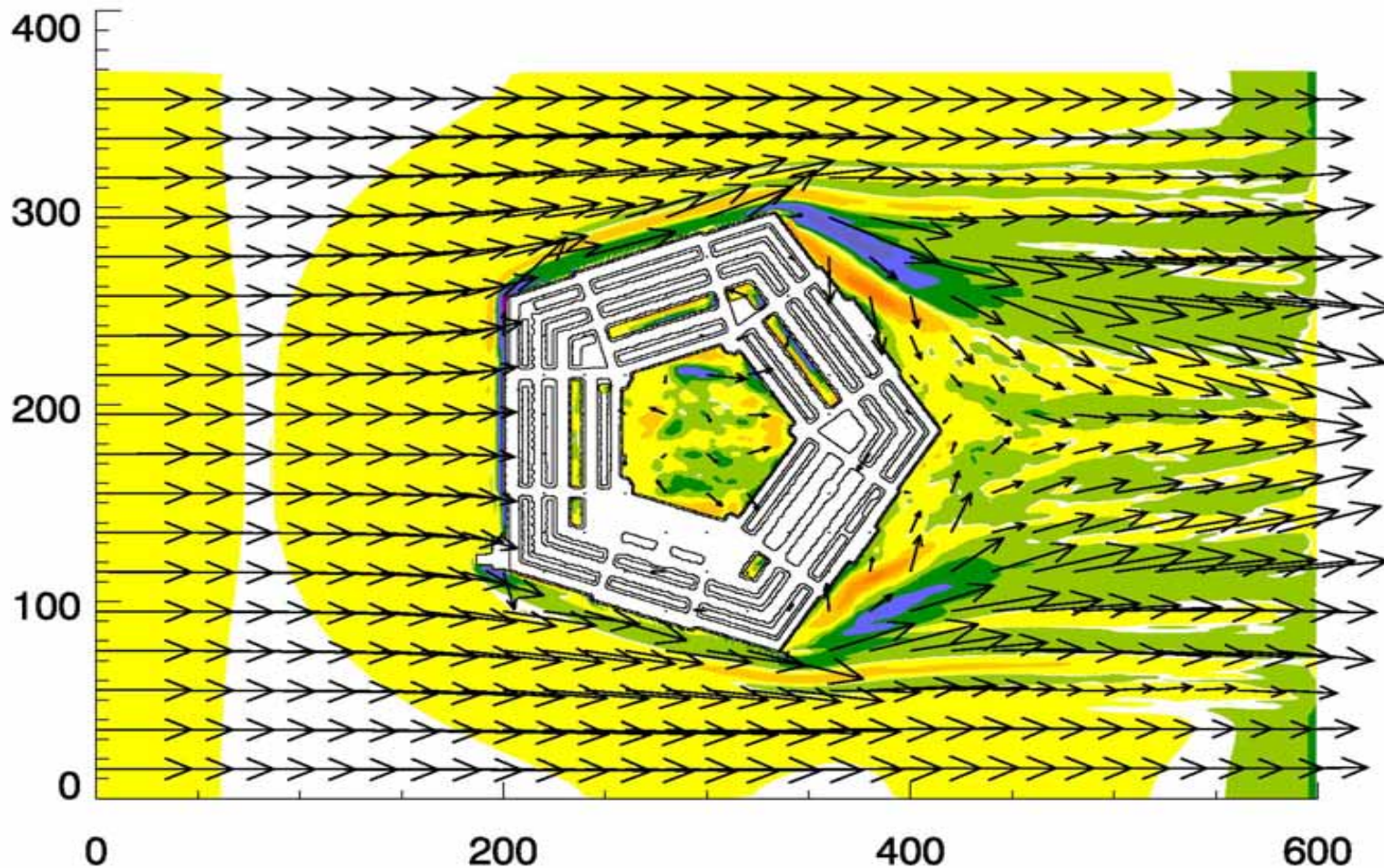


A New Extremely Computationally Intensive Direction for T&E Modeling

- Building-aware computational fluid dynamics models
- Application – Actual and virtual testing in urban settings
- Computationally intensive because grid increments must be about 2 meters to resolve building and street-canyon effects

Example – Modeled wind flow around the Pentagon

$W z = 5$ neutral mean



Summary of New Computationally Intensive Atmospheric Modeling in Support of T&E

- Ensemble prediction is providing probabilistic information to customers
- High-resolution atmospheric forecast systems can be deployed worldwide for operational testing
- Model-based very-high-resolution climatologies can be generated worldwide for long-range test planning
- FCS/VPG is beneficiary of high-resolution modeling and climatological-analysis capability
- ATEC 4DWX model is being coupled to building-aware urban models