The Advancement of Weather Forecasting from an Art to a Science: Today's Prediction Capability of Extreme Weather, Short-term Climate and Water Events

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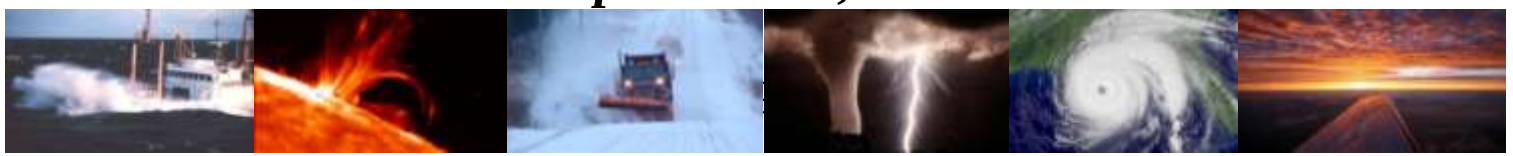
Annual Conference of the Prognostics and Health Management Society
Minneapolis, MN
September 26, 2012



Outline

- "The Weatherman is not a Moron"
- Recent Examples of Predicting Extreme Events
- The Transformation of Weather Prediction from an Art to a Science
- Essential Components of Numerical Predictions
- The Future is Now: Extending Prediction Capabilities into Decision Support Services
- Summary

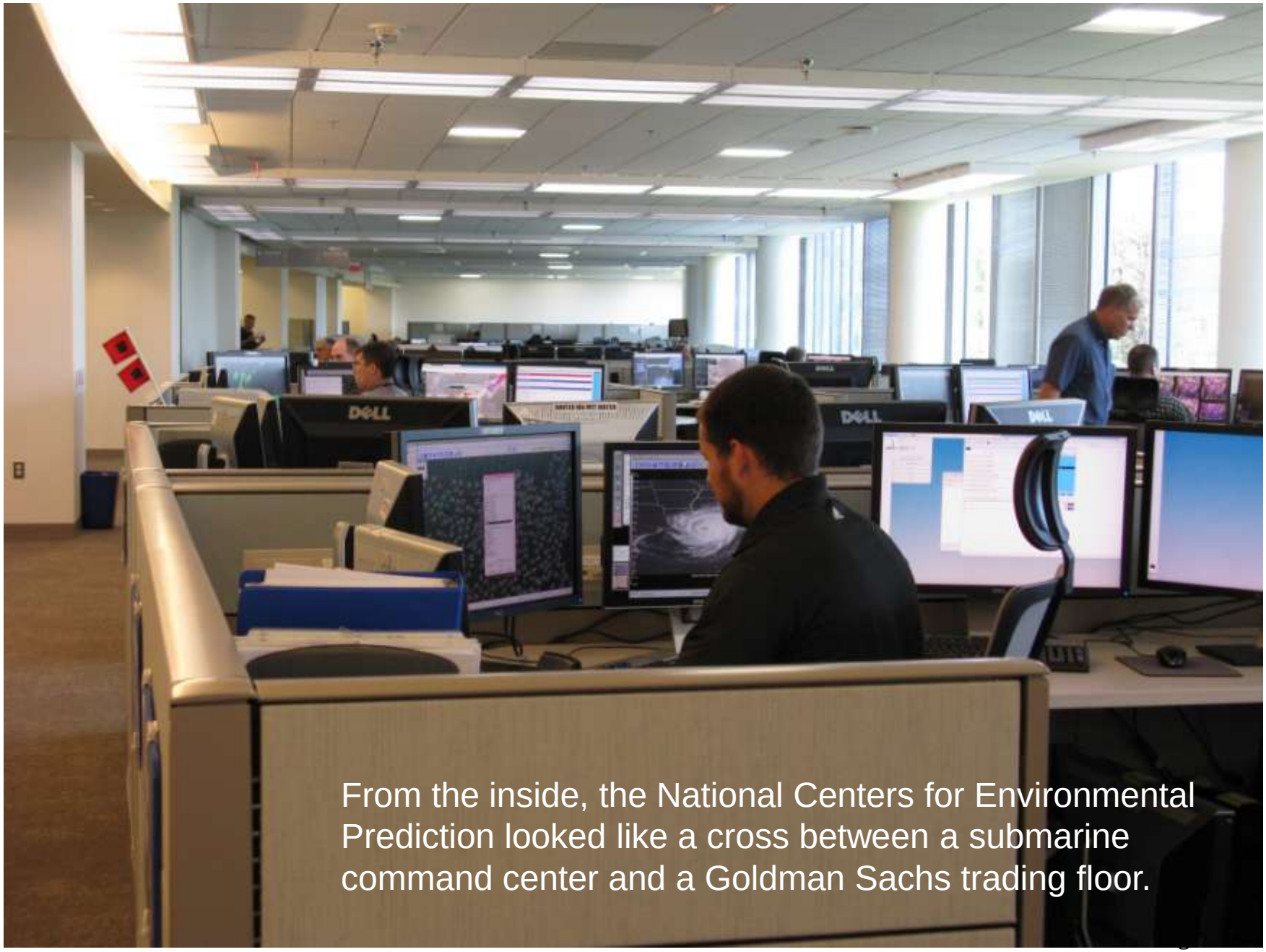
The New York Times
September 9, 2012

IN THE HOCUS POCUS REALM OF PREDICTING THE FUTURE, WEATHER FORECASTING STANDS OUT AS AN AREA OF GENUINE, MEASURABLE PROGRESS. YOUR OWN EXPERIENCE MAY DIFFER. **BY NATE SILVER**

THE WEATHERMAN IS NOT A MORON

“The Weatherman is not a Moron”

- Weather prediction has progressed when most other predictions have failed
- Progress can be “measured”/verified in a quantitative way
- Prediction capabilities include uncertainty and have already been integrated into key decision support



Quoted from “The Weatherman is not a Moron” New York Times Magazine, September 9, 2012

Recent Examples of Predicting Extreme Events

Rapidly Developing Pacific Storm: Not Predicted

13-14 November 1981

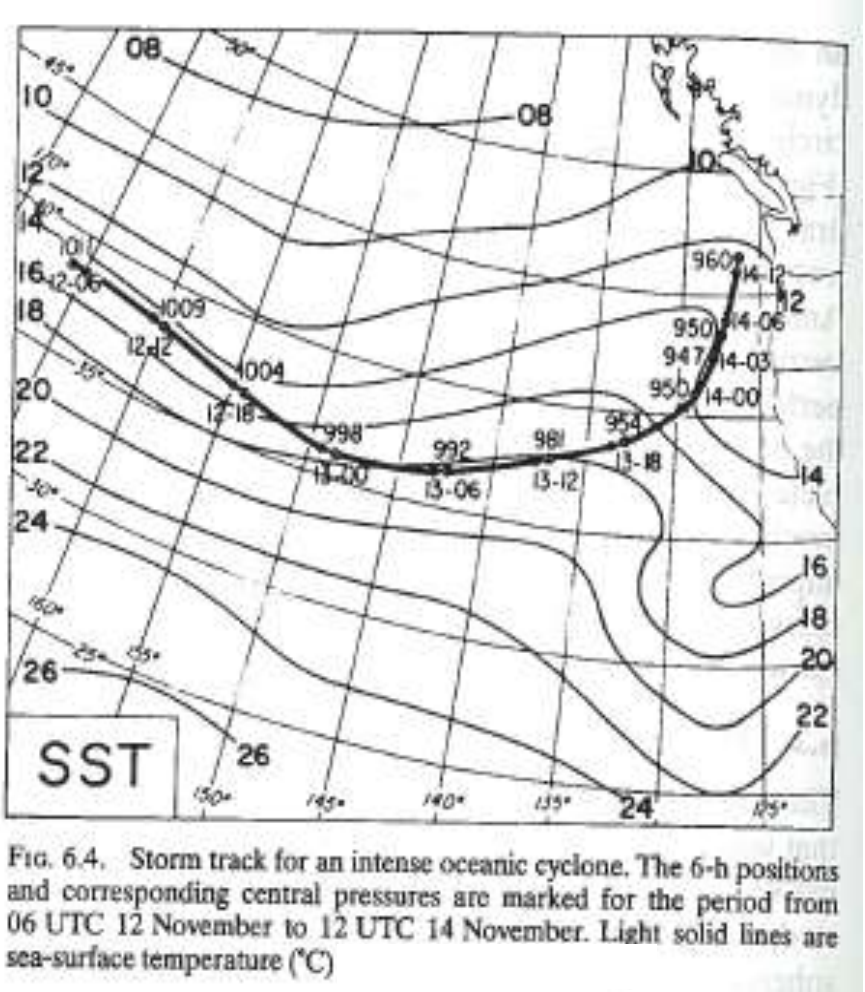


FIG. 6.4. Storm track for an intense oceanic cyclone. The 6-h positions and corresponding central pressures are marked for the period from 06 UTC 12 November to 12 UTC 14 November. Light solid lines are sea-surface temperature (°C)

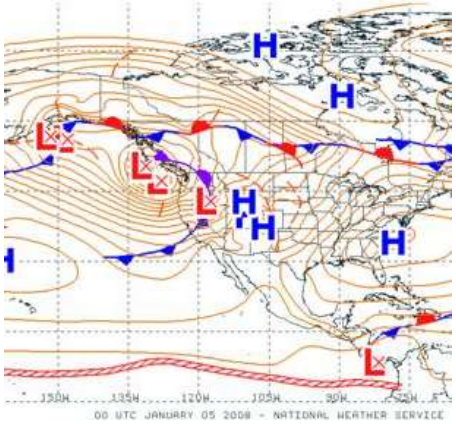
Reed and Albright, MWR, 1986

FIG. 10. GOES-W visible image 2215 GMT 13 November 1981.

January 3-7, 2008
West Coast Rain/Snow Event

- Snowfall in CA mountains of up to 10 feet.
- Many locations with multiple feet of snow.
- Localized flooding caused by heavy rains at lower elevations
- Rainfall amounts 2-10 inches.

00Z 5 January, 2008



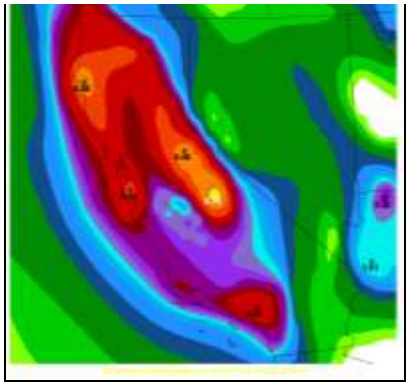
3 Weeks Prior to Event

MJO Update: issued by Climate Prediction Center
December 24, 2007
"Some *potential exists for a heavy precipitation event* tied to tropical convection by week 3 … along *the west coast of the US* "

6 Days Prior to Event

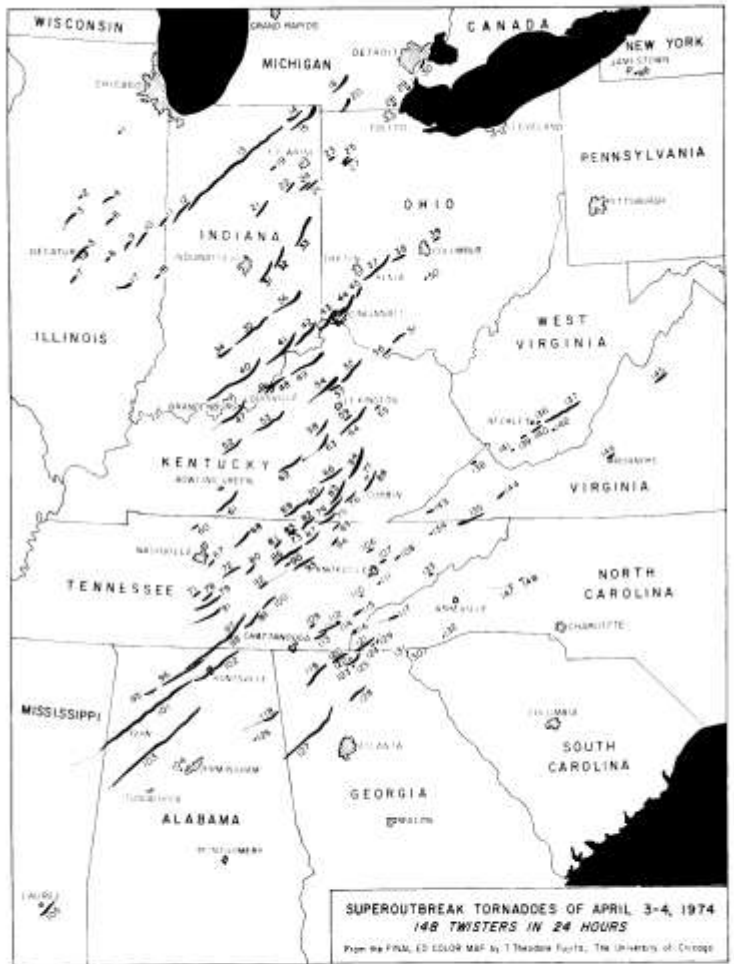
Hazards Assessment
Issued December 28, 2009

4 Days Prior to Event



HPC 48-h QPF ending 00Z 6 Jan
Issued 00Z 1 Jan
Day 4-5 forecast

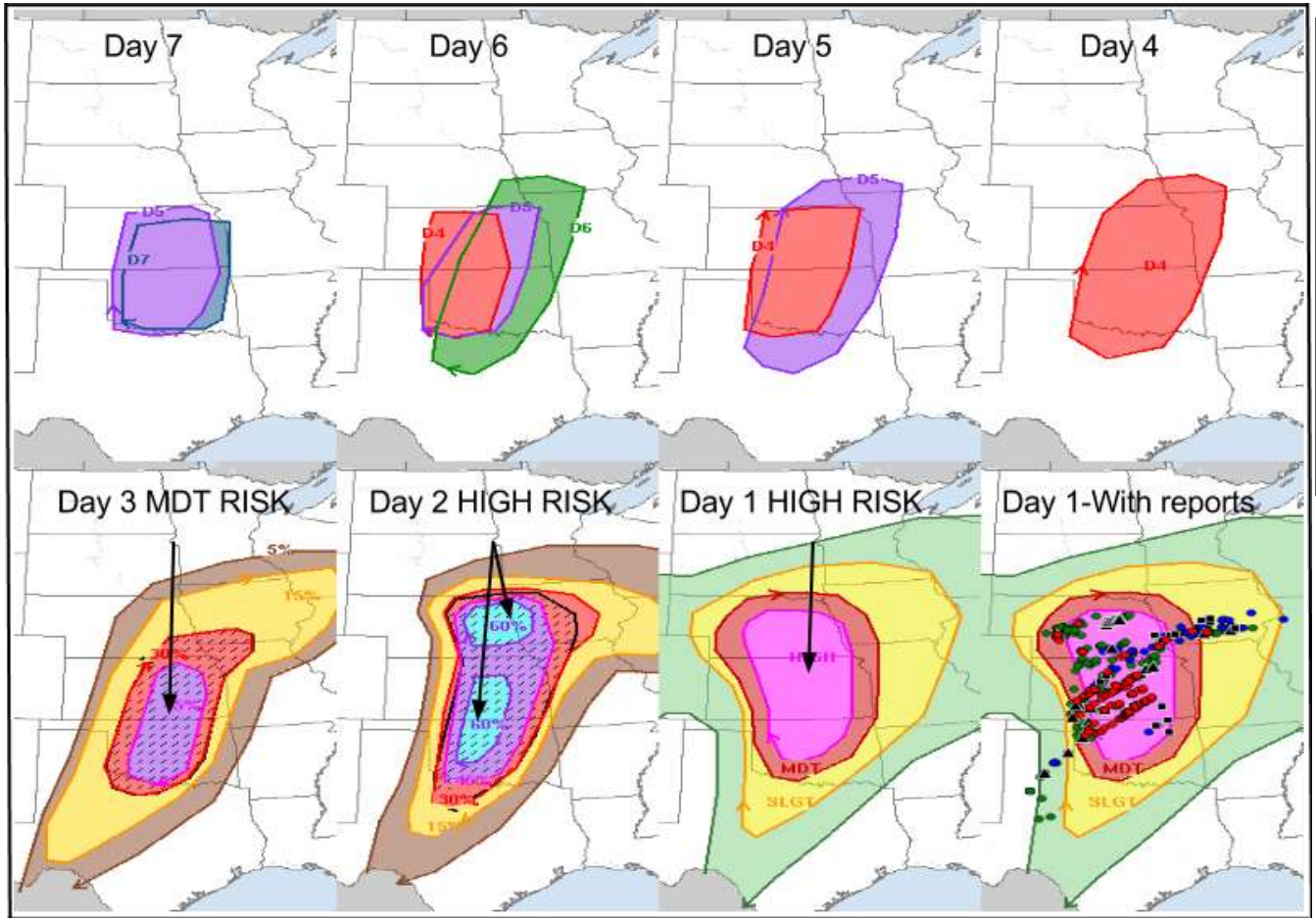
April 3-4, 1974 Super Outbreak



Tornado Tracks
12Z April 3 – 12Z April 4, 1974

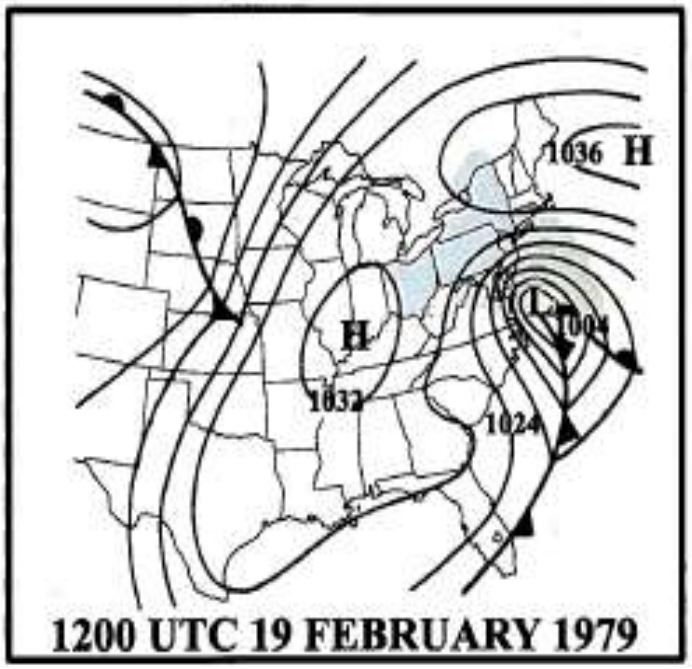
- One of the deadliest tornado outbreaks in the 20th Century (330 fatalities)
- Involved over one-quarter of the country
  - 148 tornadoes in 13 states
- Potential for severe weather was recognized only the afternoon before event
- Magnitude of event not realized until evening news – April 3

14 April 2012 Great Plains Outbreak



- **60 Tornadoes (1 EF4, 3 EF3 & 3 EF2)**
- **6 Fatalities in Woodward, OK near midnight**
- **Outlook first issued 7 days in advance; Moderate Risk 3 days in advance; High Risk 2 days in advance (only 2nd time)**
- **Preliminary NWS average warning lead time (Tornadoes) : 20.1 minutes.**

Presidents' Day Storm 18-20 February, 1979



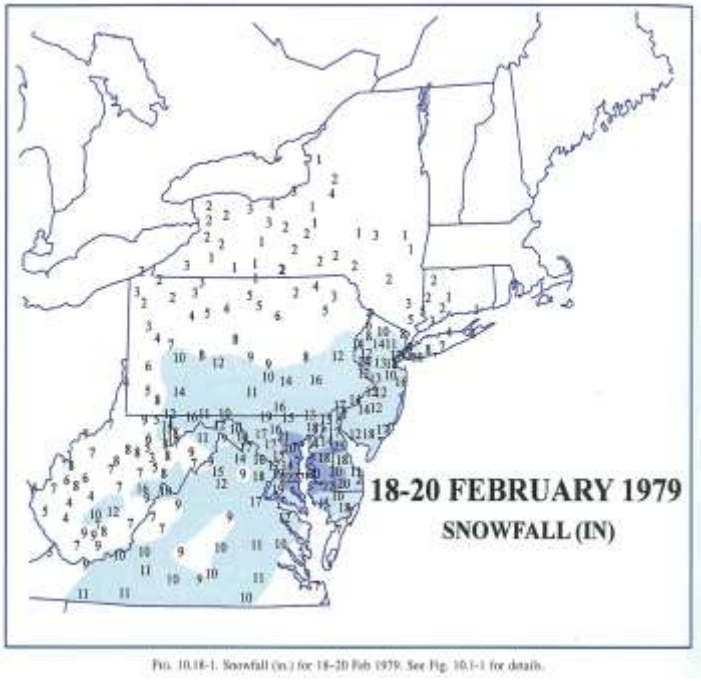


FIG. 10.18-1. Snowfall (in.) for 18–20 Feb 1979. See Fig. 10.1-1 for details.

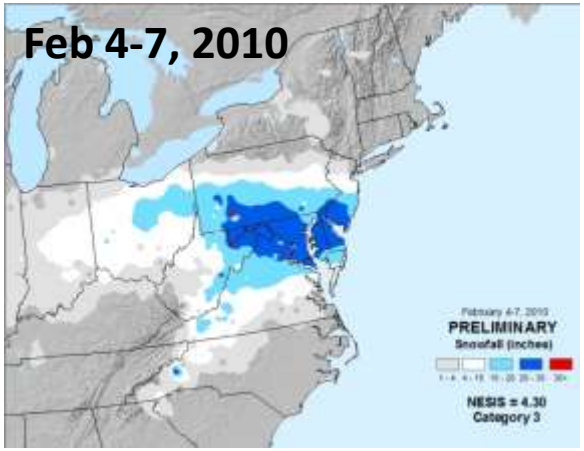
1830Z 19 Feb 1979

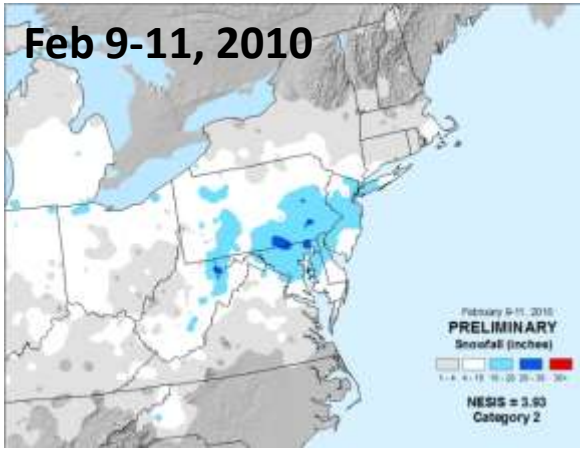
- 22 inches of snow buries Washington D.C. area
- Rapid cyclogenesis off the coast
- Not predicted even hours in advance

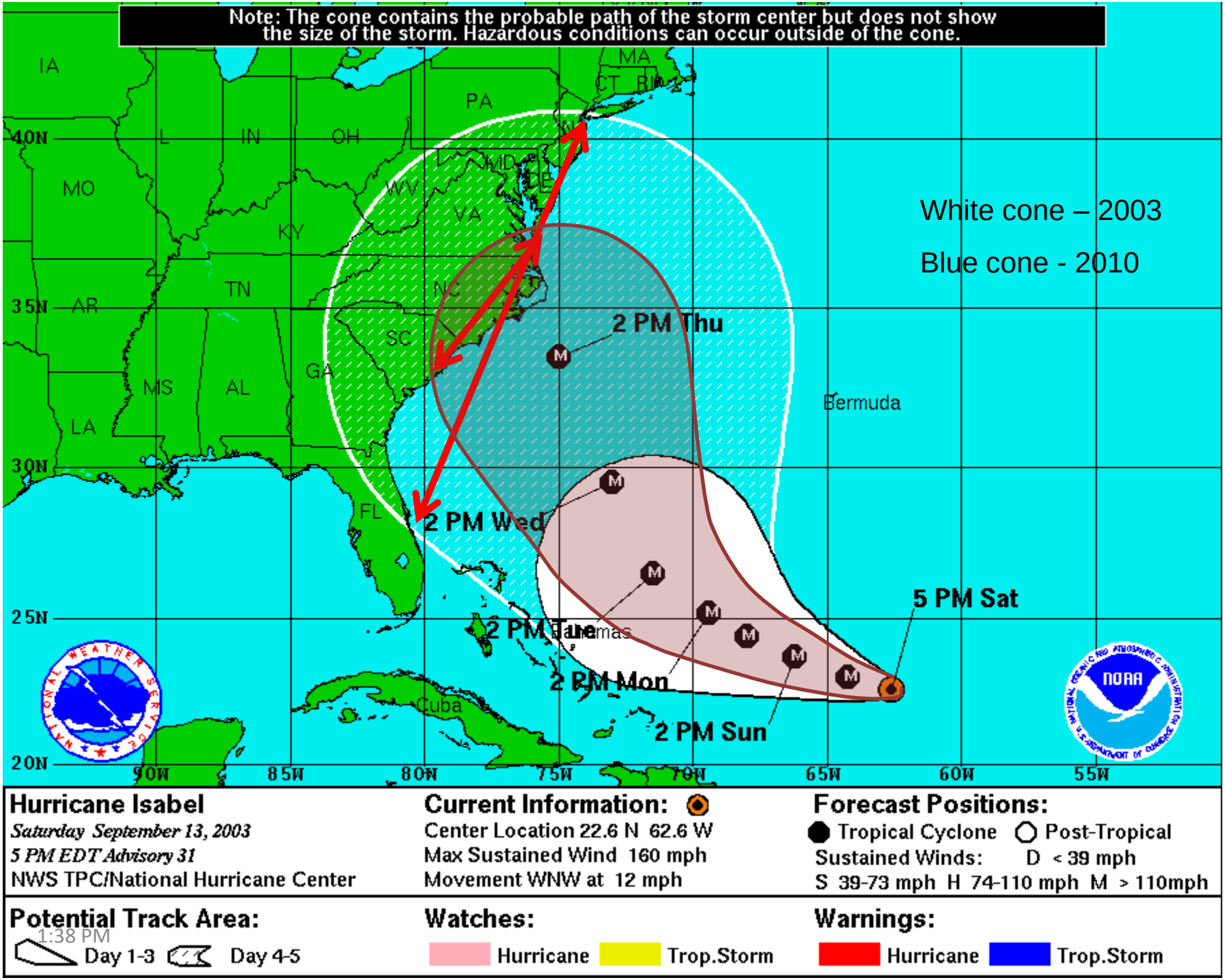
February 4-11, 2010: "Snowmageddon"

- February 4-7, 2010: massive winter storm paralyzes mid-Atlantic region
  - Locations in Maryland, Pennsylvania, Virginia, and West Virginia recorded more than 30 inches of snow.
  - Washington DC's two-day total of 17.8 inches ranked as the fourth highest total storm amount in history.
  - Philadelphia's 28.5 inches ranked as the second highest amount
  - Baltimore's 24.8 inches ranked as its third highest storm total amount
- Strong blizzard during February 9-11 affects same areas still digging out from earlier storm.
  - Produced as much as 14 inches in the D.C. area, 20 inches in Baltimore, 17 inches in New Jersey, more than 27 inches in Pennsylvania, and 24 inches in northern Maryland.

- Storm system predicted 7+ days in advance; potential for heavy snow 3-5 days in advance
- States implement COOP plans, airlines cancel flights, retail industry pre-stocks shelves







Hurricane Isabel
Saturday September 13, 2003
5 PM EDT Advisory 31
NWS TPC/National Hurricane Center

Current Information:
Center Location 22.6 N 62.6 W
Max Sustained Wind 160 mph
Movement WNW at 12 mph

Forecast Positions:
Tropical Cyclone Post-Tropical
Sustained Winds: D < 39 mph
S 39-73 mph H 74-110 mph M > 110mph

Potential Track Area:
Day 1-3 Day 4-5

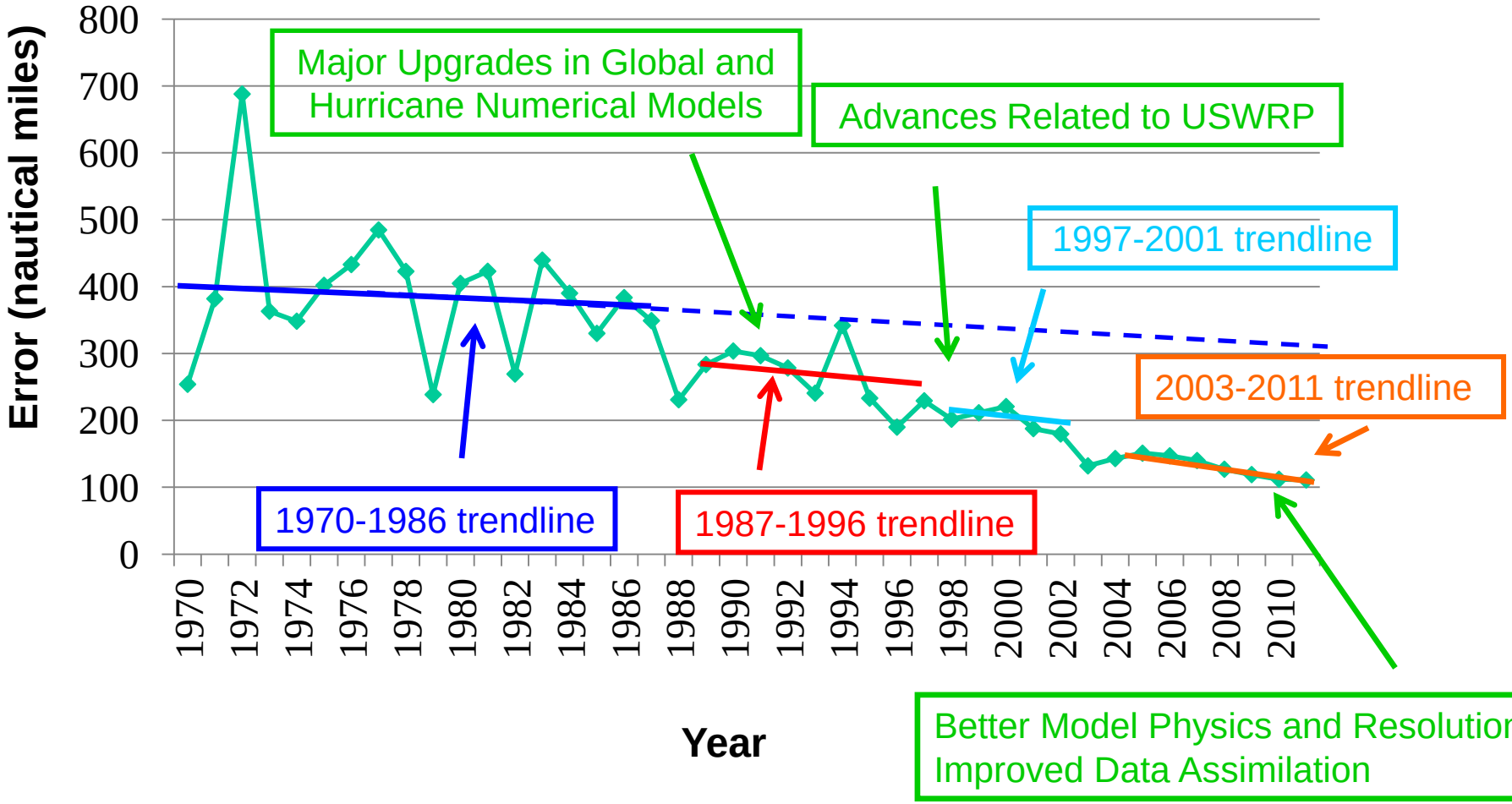
Watches:
Hurricane Trop.Storm

Warnings:
Hurricane Trop.Storm

1:38 PM

Hurricane Prediction Skill

National Hurricane Center
Atlantic 72 Hr Track Forecast Errors

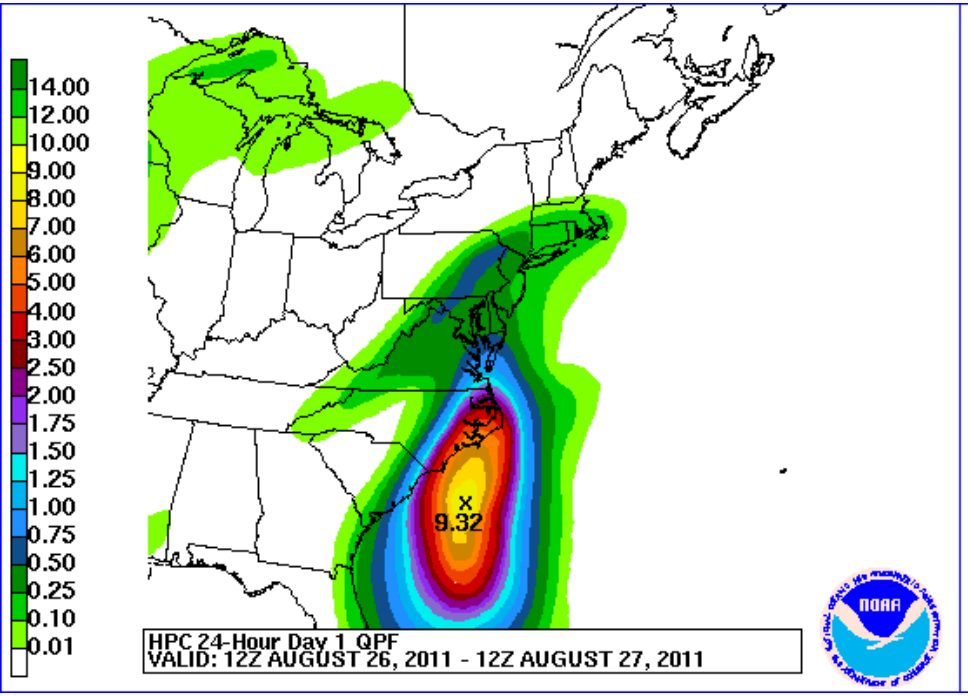


Hurricane Irene Track Forecast

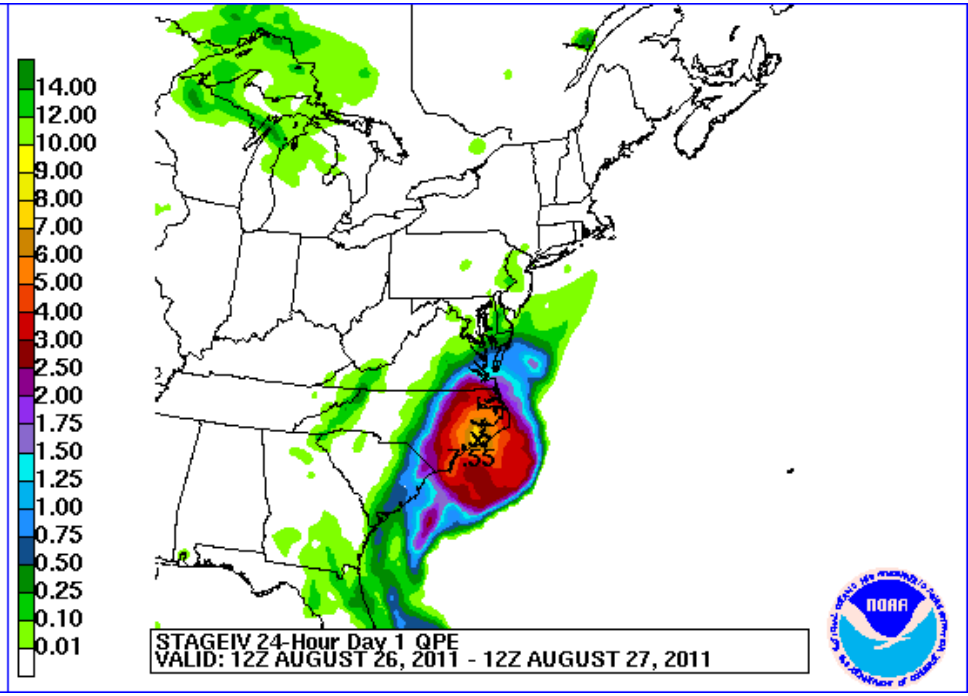
August 20, 2011 – August 27, 2011

Hurricane Irene Precipitation

Precipitation Forecast Loop



Precipitation Verification Loop

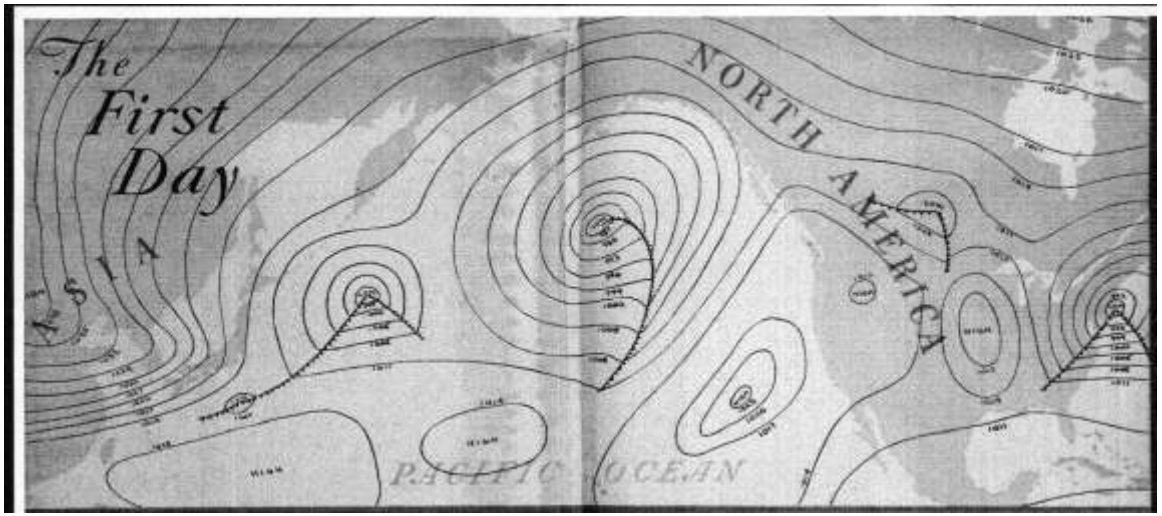


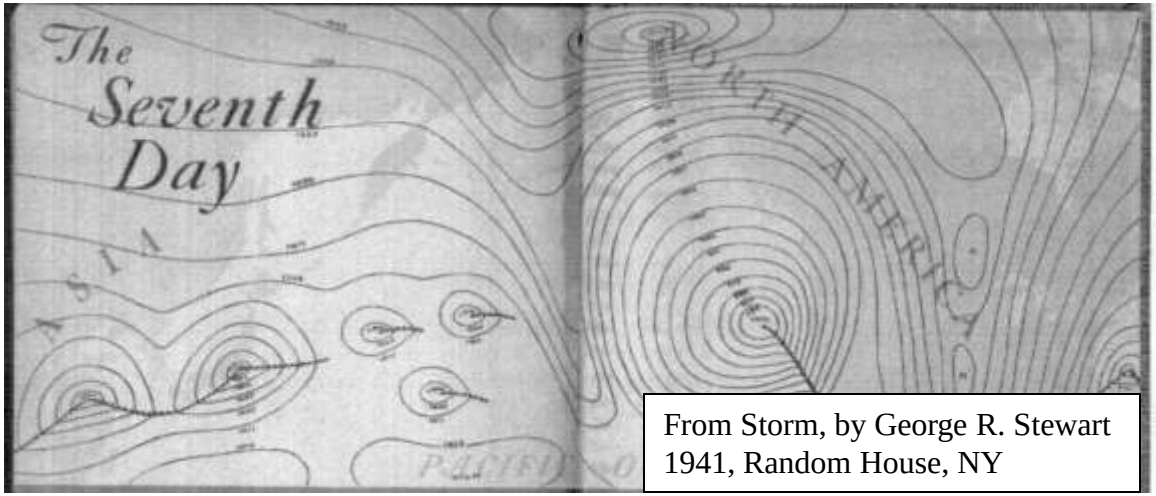
August 26 – 29, 2011

Background: The Transformation of Weather Prediction from an Art to a Science

Forecasting in the ‘30s, ‘40s, ’50s

When Forecasting was an “Art”





From Storm, by George R. Stewart
1941, Random House, NY

Data

- Surface – every six hours
- Regional to global extent

Forecast Process

- Subjective – based on analogs, experience
- Manually intensive
- Based on data from one level

Today's Forecast Process

Data

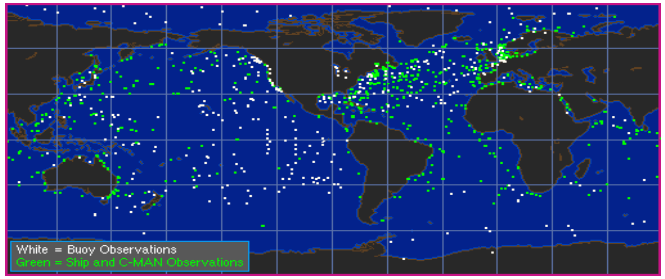
- Multi-faceted
- Increasingly remotely-sensed

Forecast Process

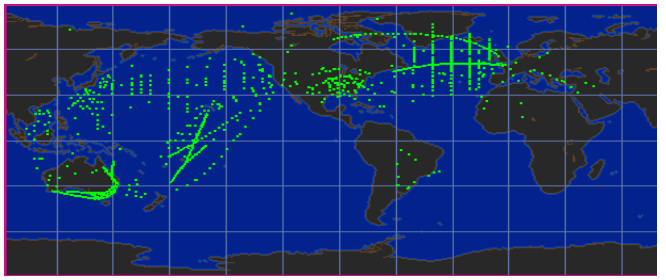
- Objective
- Based on numerical models
- Initialized with a "cube" of data
- Forecast made out to week 2

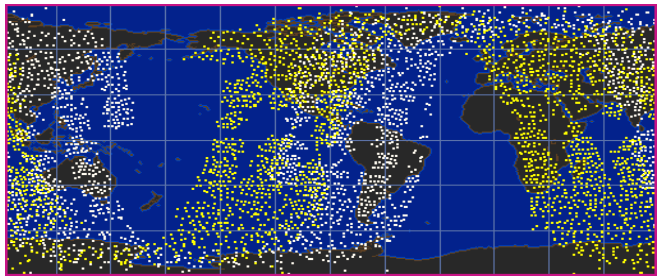
Ongoing Opportunities

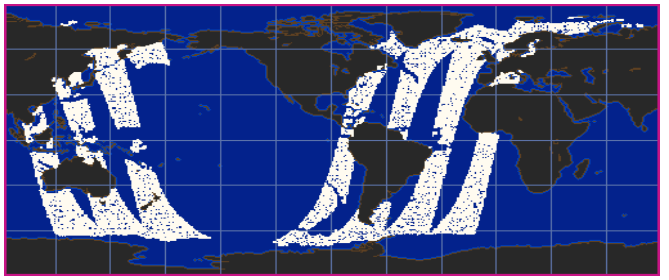
- Public-Private
- Earth System Model approach
- Assimilation of satellite data

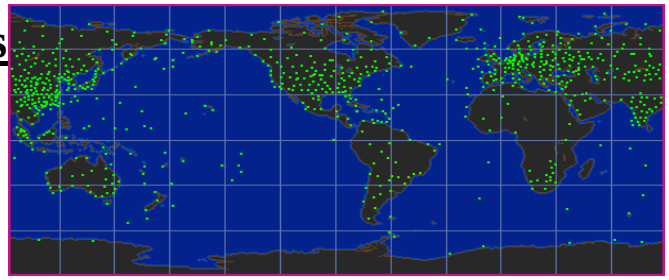


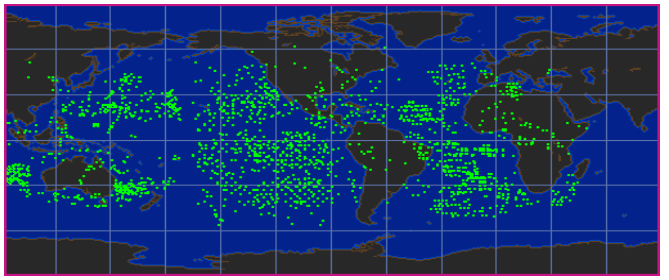
Marine Obs -- 12 Hour Total


12Z Aircraft Wind/Temp Reports


12Z Satellite Temp/Hum Soundings


12Z Satellite Ocean/Surface Winds


12Z Global Rawinsondes


12Z DMSP Microwave Precipitable Water/Sfc Winds

The Essential Components of the Numerical Prediction Enterprise

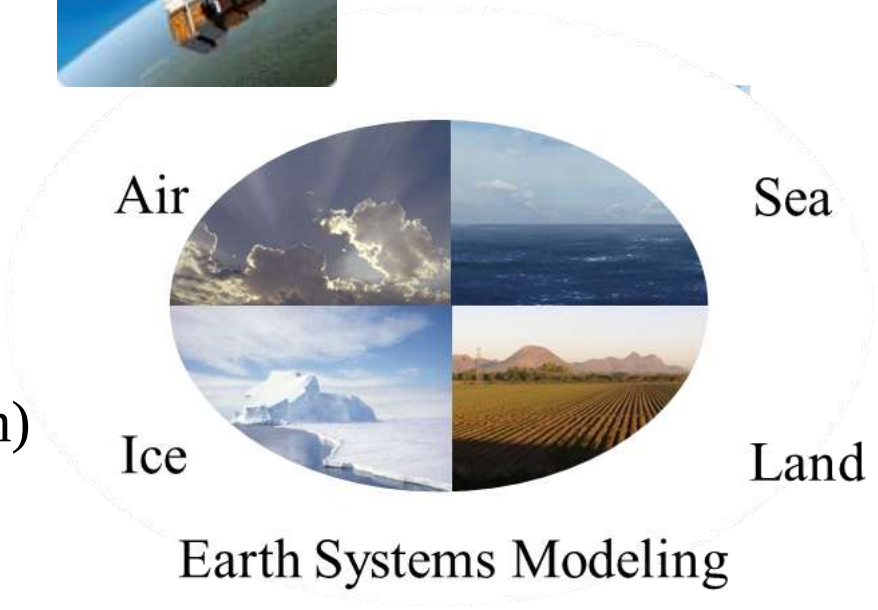
Everything you read, see or hear about weather, climate and ocean forecasts is based on NCEP numerical prediction models

Three Essential Components of the Numerical Prediction Enterprise

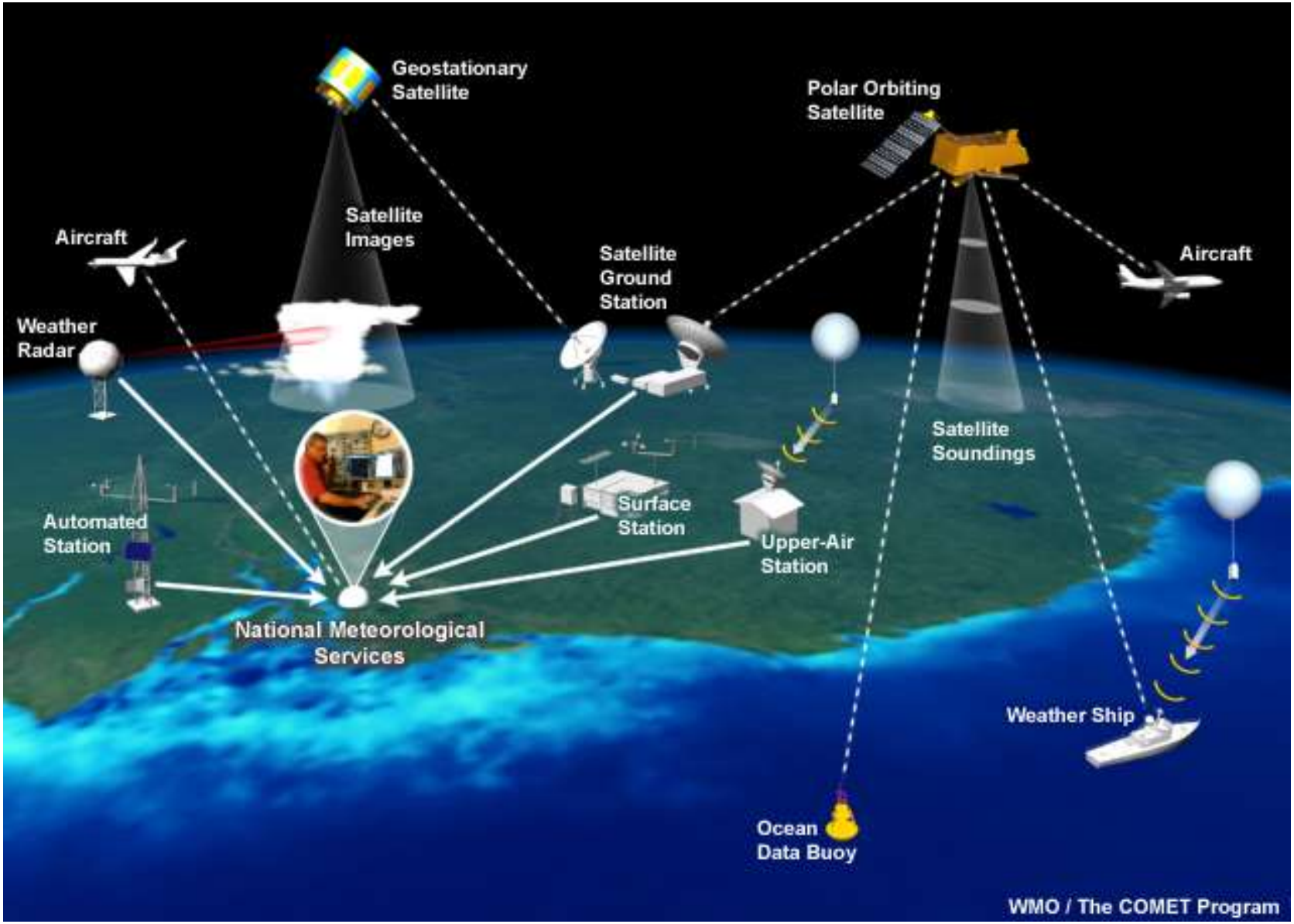
- Global Observing System
- Computers (supercomputers, work stations)
- Data Assimilation & Modeling/Science

Three Essential Components of Today's Operational Numerical Prediction Enterprise

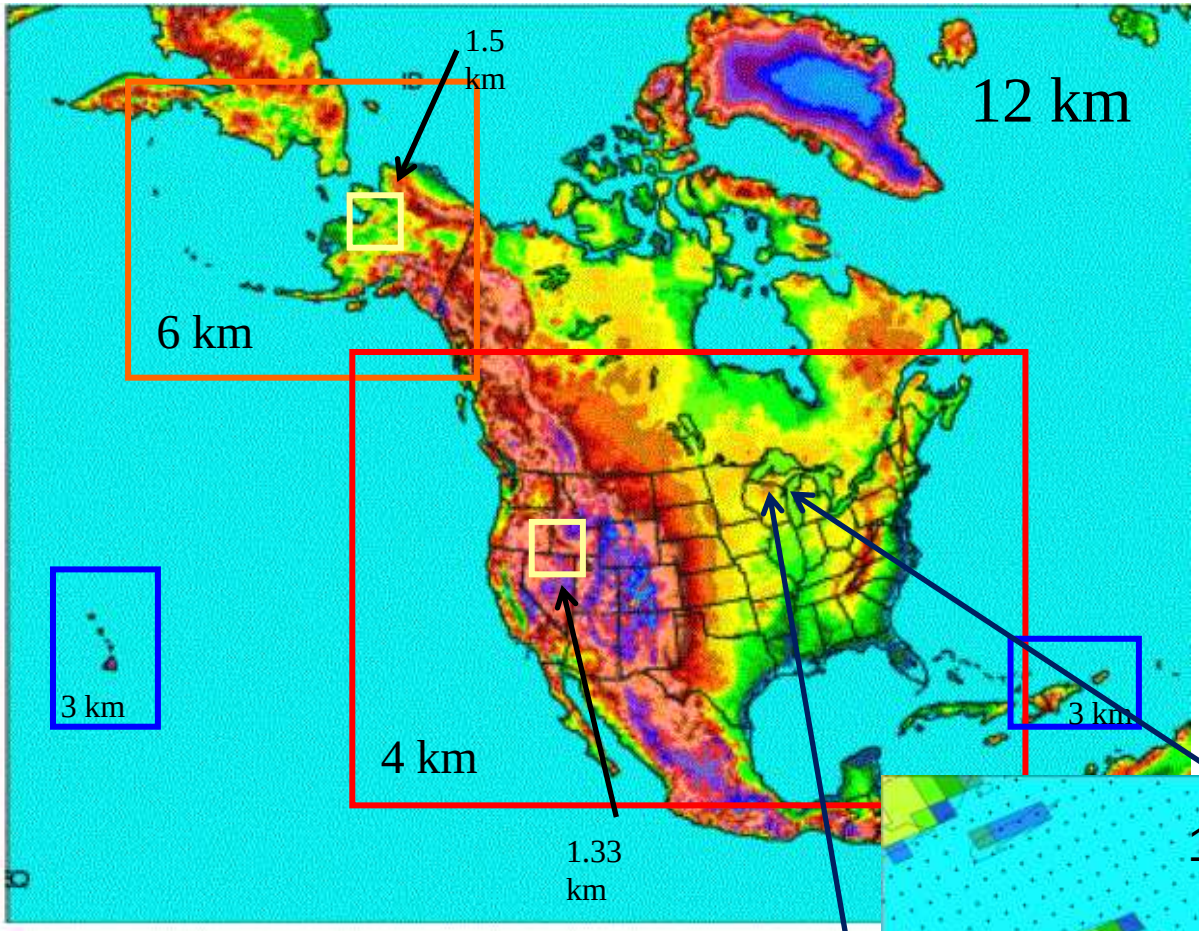
- Observations
  - ~2 billion/day
  - 99.9% remotely sensed, mostly satellites
- Model
  - Earth System model; coupled
  - Global resolution (27km)
  - North American resolution (4km)
- Computer
  - 2012
    - Primary/backup15 minute switchover
    - 73 trillion calc/sec – IBM Power 6
  - 2013
    - 146 trillion calc/sec – IBM iDataPlex Intel/Linux



Global Observing Critical for Successful Numerical Weather Prediction

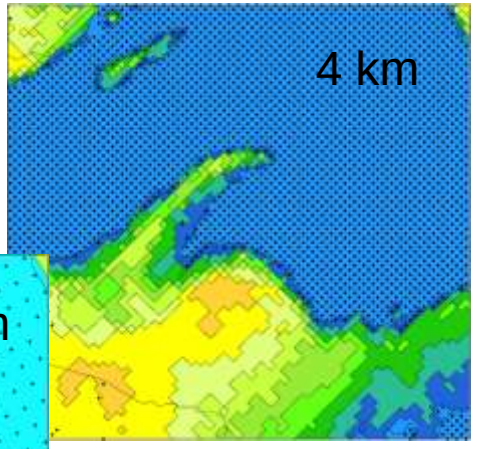


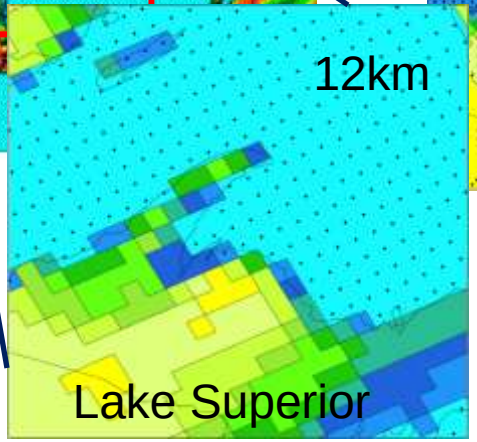
Nonhydrostatic Multiscale Model (NMM-B)



Regional Domain (12 km)
– 84 hrs
Embedded Mesoscale
(6, 4 & 3 km)
– 60 hrs
Incident Directed-[Fire Wx]
(1.5 & 1.33 km)
– 36 hrs

Lake Superior





Model Production Suite

We are Now Running “Earth System” Prediction Models

Atmosphere

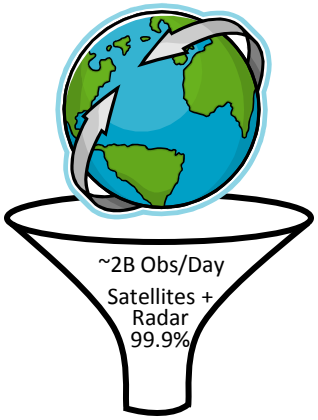
Ocean

Cryosphere

Land

- Predictions Driven by Global Observing Systems
- Real-time operations require world’s largest computers
- BIOLOGY/CHEMISTRY NOW BEING INCLUDED

NOAA's Model Production Suite



Global Data Assimilation

Global Forecast System

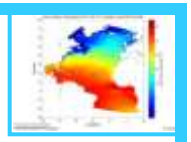
Climate Forecast System
GFS MOM4
NOAH Sea Ice

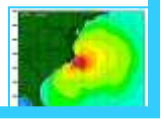
Hurricane
GFDL
HWRF

Coupled

Oceans
HYCOM

WaveWatch III

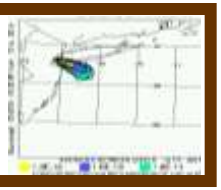




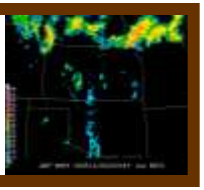
NOS – OFS
- Great Lakes
- Northern Gulf of Mexico
  Bays
- Chesapeake
- Tampa
- Delaware

Regional DA | **Regional NAM**
WRF NMM

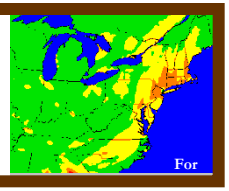
Dispersion
ARL/HYSPLIT



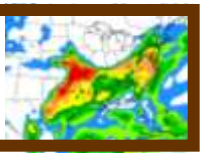
Severe Weather
WRF NMM/ARW
Workstation WRF



Air Quality
NAM/CMAQ



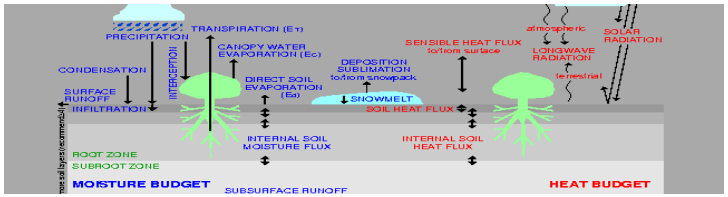
Rapid Refresh for Aviation



Space Weather
ENLIL

North American Ensemble Forecast System
GFS, Canadian Global Model

Regional DA | **Short-Range Ensemble Forecast**
WRF: ARW, NMM
ETA, RSM

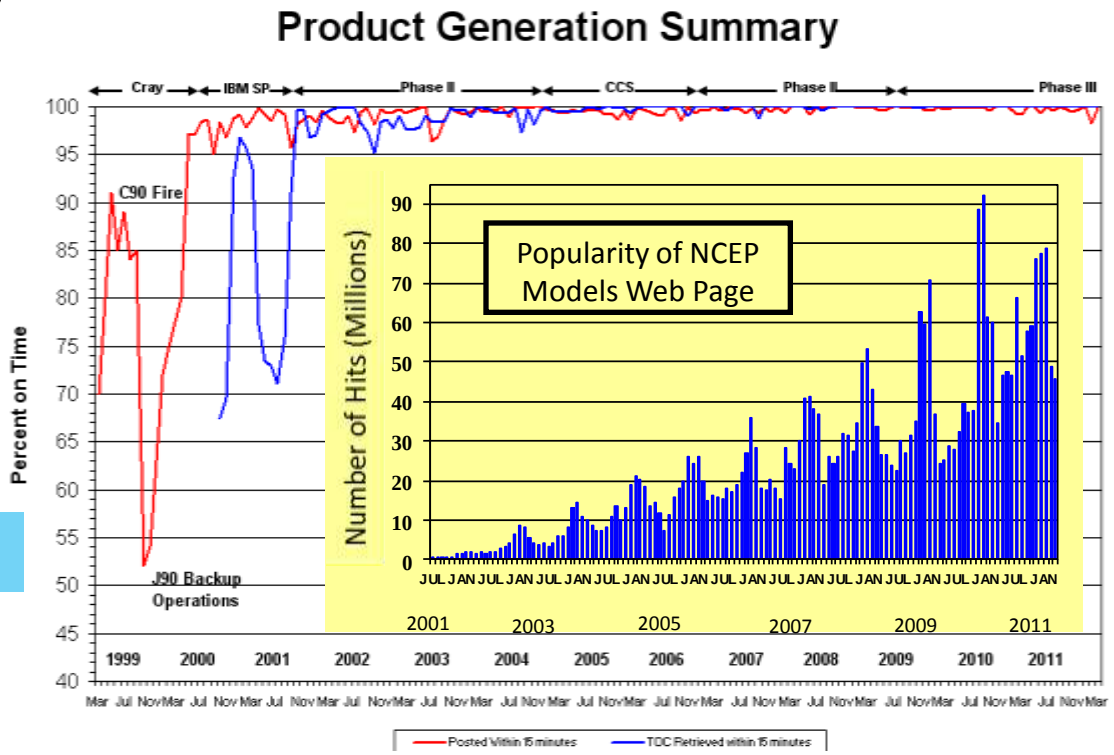


NOAH Land Surface Model

Computing Capability

"reliable, timely and accurate"

- Current computers
  - IBM Power6
  - 73.1 trillion calculations/sec
  - 2 billion observations/day
  - 27.8 million model fields/day
  - Primary: Gaithersburg, MD
  - Backup: Fairmont, WV
  - Guaranteed switchover in 15 minutes
- Next generation computer: by Oct 2013
  - IBM iDataPlex Intel/Linux
  - 143 trillion calc/sec
  - Primary: Reston, VA
  - Backup: Orlando, FL



Web access to models as they run on the CCS

The Future is Now!
Extending Prediction Capabilities into Decision Support Services

- Need to Quantify Uncertainty
- Introduction of Ensemble Forecasting

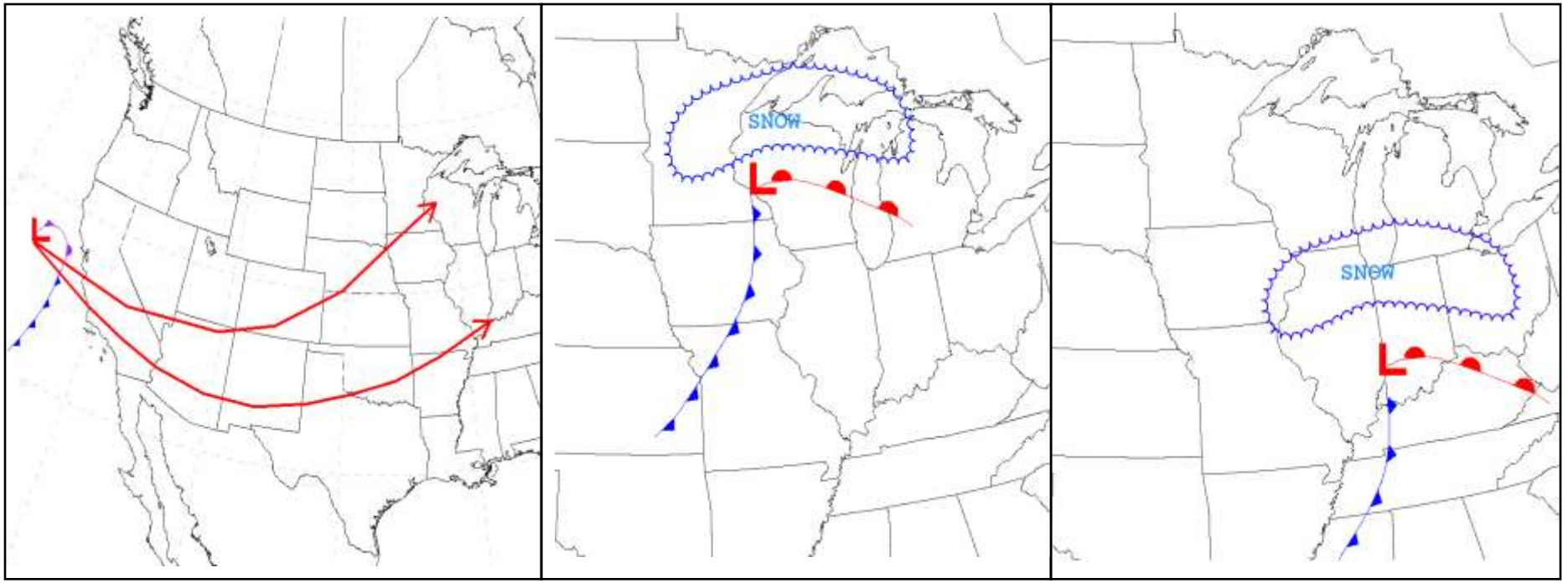
Numerical Weather Models (NWP) and Ensemble Systems

Weather forecasting: It's impossible to be certain all of the time!

- Numerical weather models...
  - All forecasts contain errors (either in physics or initial analysis) that increase with time
  - Doubling time of small initial errors ~1 to 2 days
  - Maximum large-scale (synoptic) predictability ~10 to 14 days
- Ensembles…
  - A collection of models providing information on a range of plausible forecasts, statistical measures of confidence, and extend predictability
  - Ensemble Model runs provide a range or "envelope" of solutions
  - The spread of solutions can be used to provide probabilities or "confidence" limits for any forecasts

The Forecaster's Dilemma

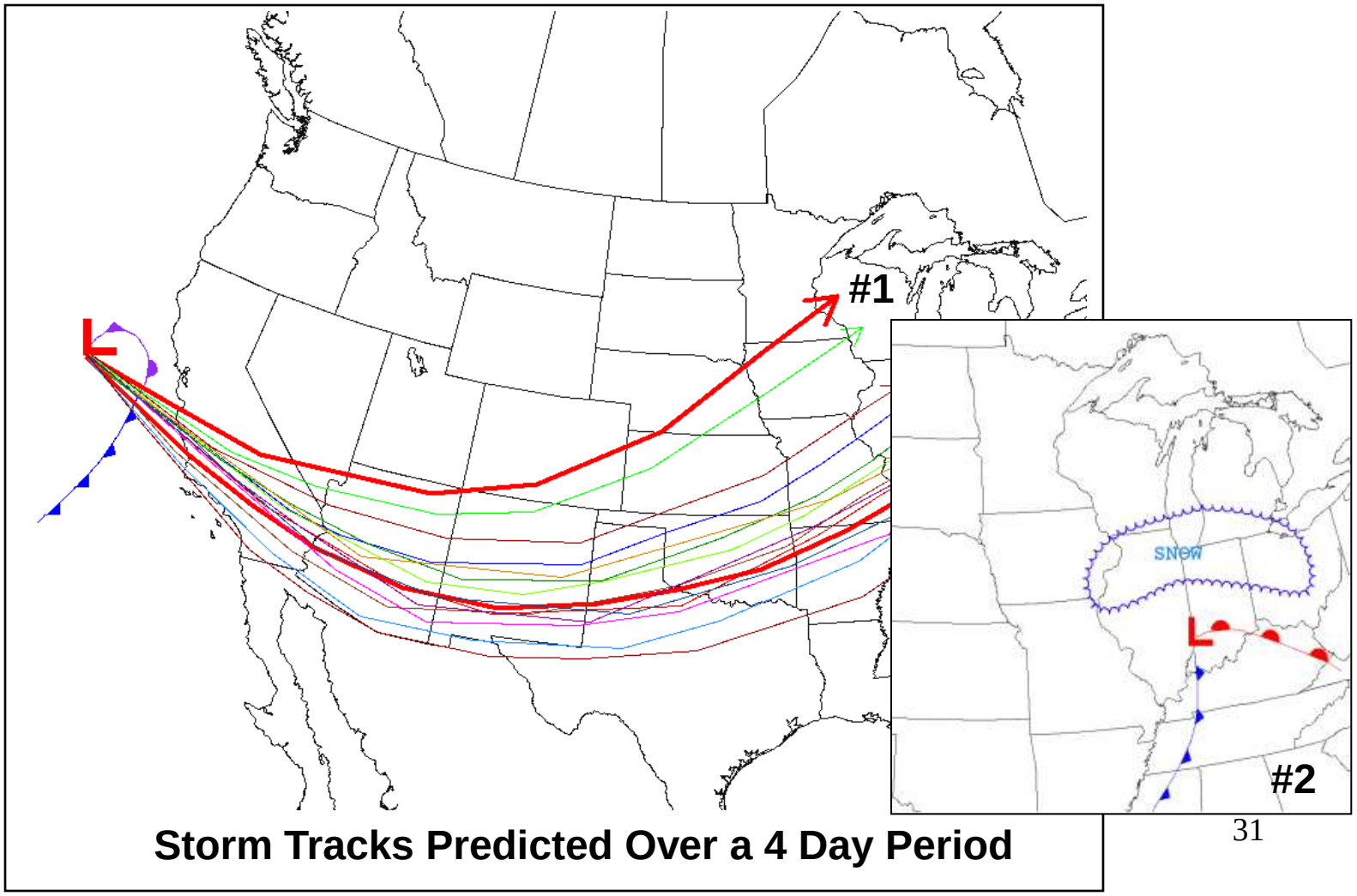
Initialization | Forecast Possibility #1 | Forecast Possibility #2



Today **Four Days Later**

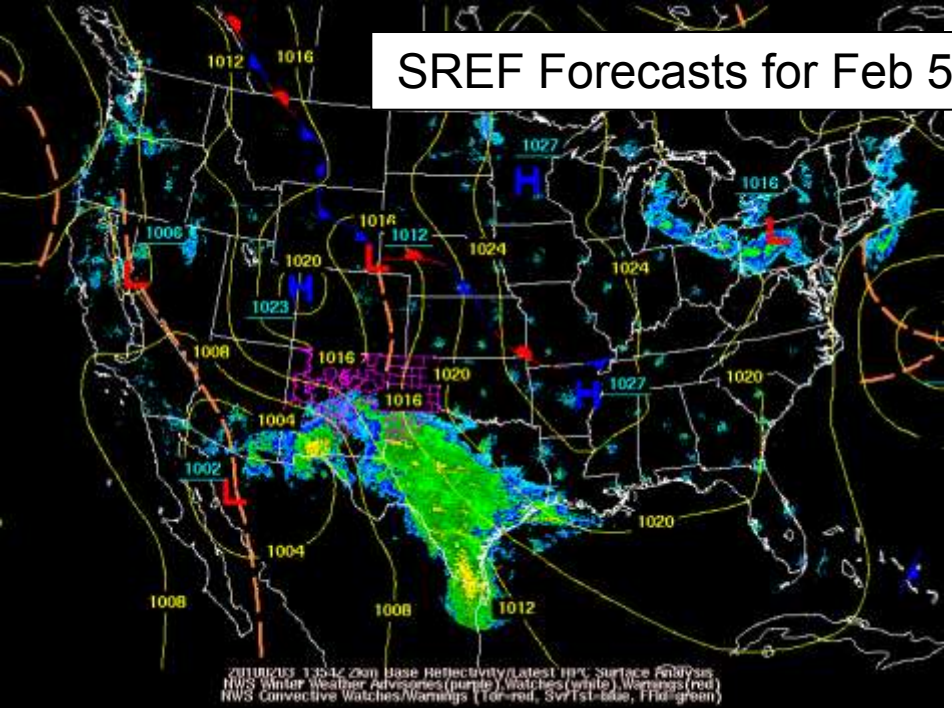
An Ensemble of Possibilities

Ensembles provide an envelope of solutions (and probable "best solutions") representing possible storm tracks, storm intensity and precipitation amount/type

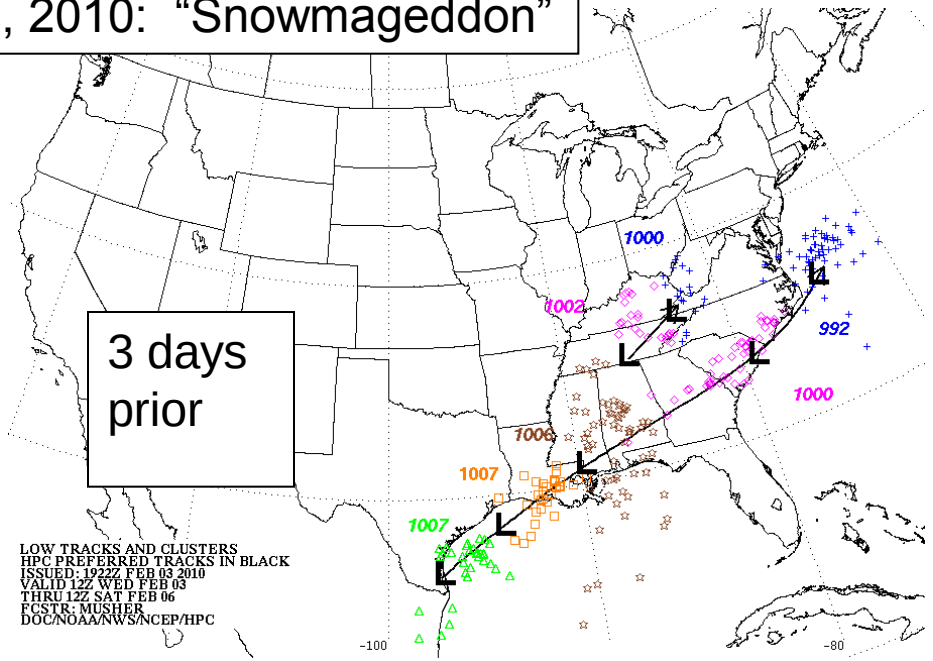


Storm Tracks Predicted Over a 4 Day Period

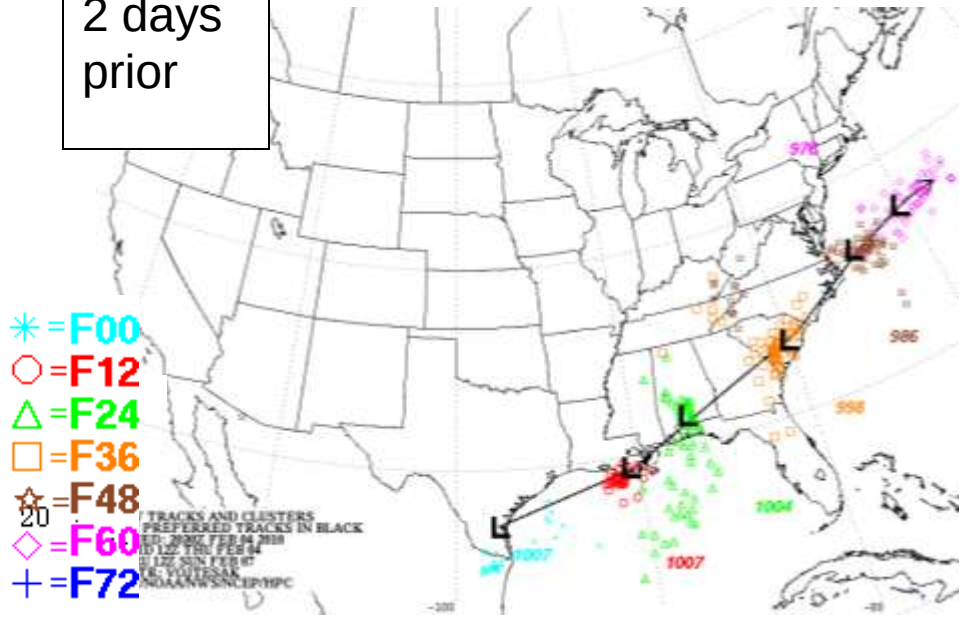
SREF Forecasts for Feb 5, 2010: "Snowmageddon"



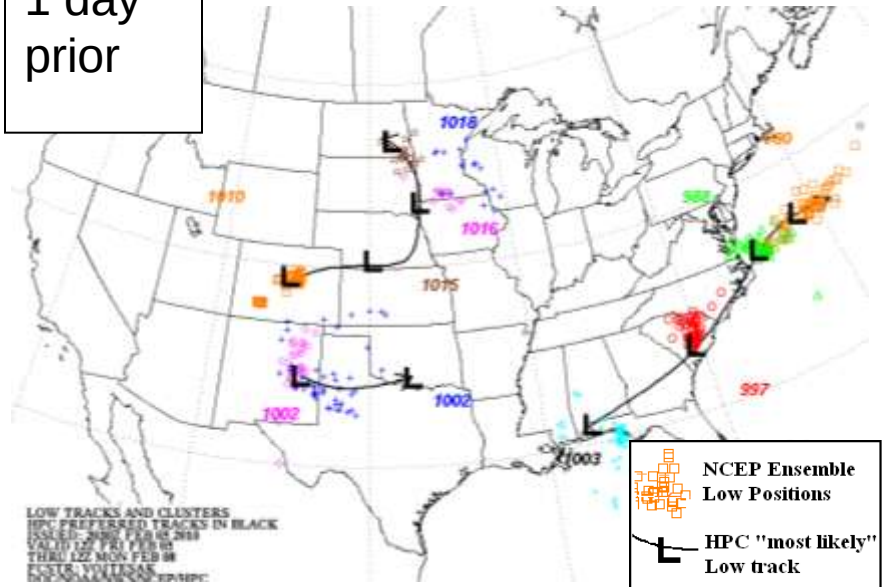
3 days prior



2 days prior



1 day prior



Impacts

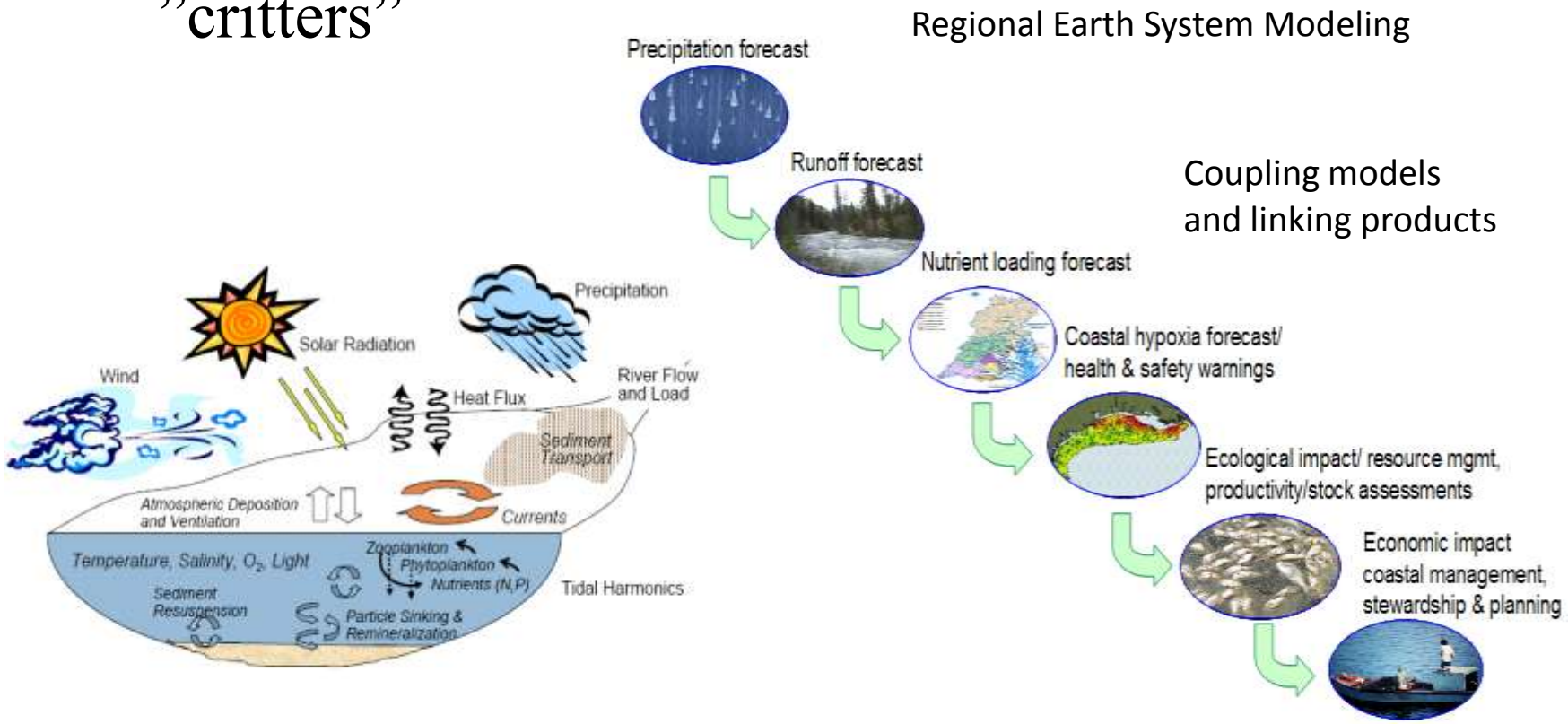
"Snowmageddon"

- States declare emergency days before snow
- Airlines cancel thousands of flights at least a day in advance
- Stores adjust to optimize retail sales entire week before the storm
  - Low to no impact on GNP[1]
- Federal disaster declared; facilitates snow removal, and faster recovery!

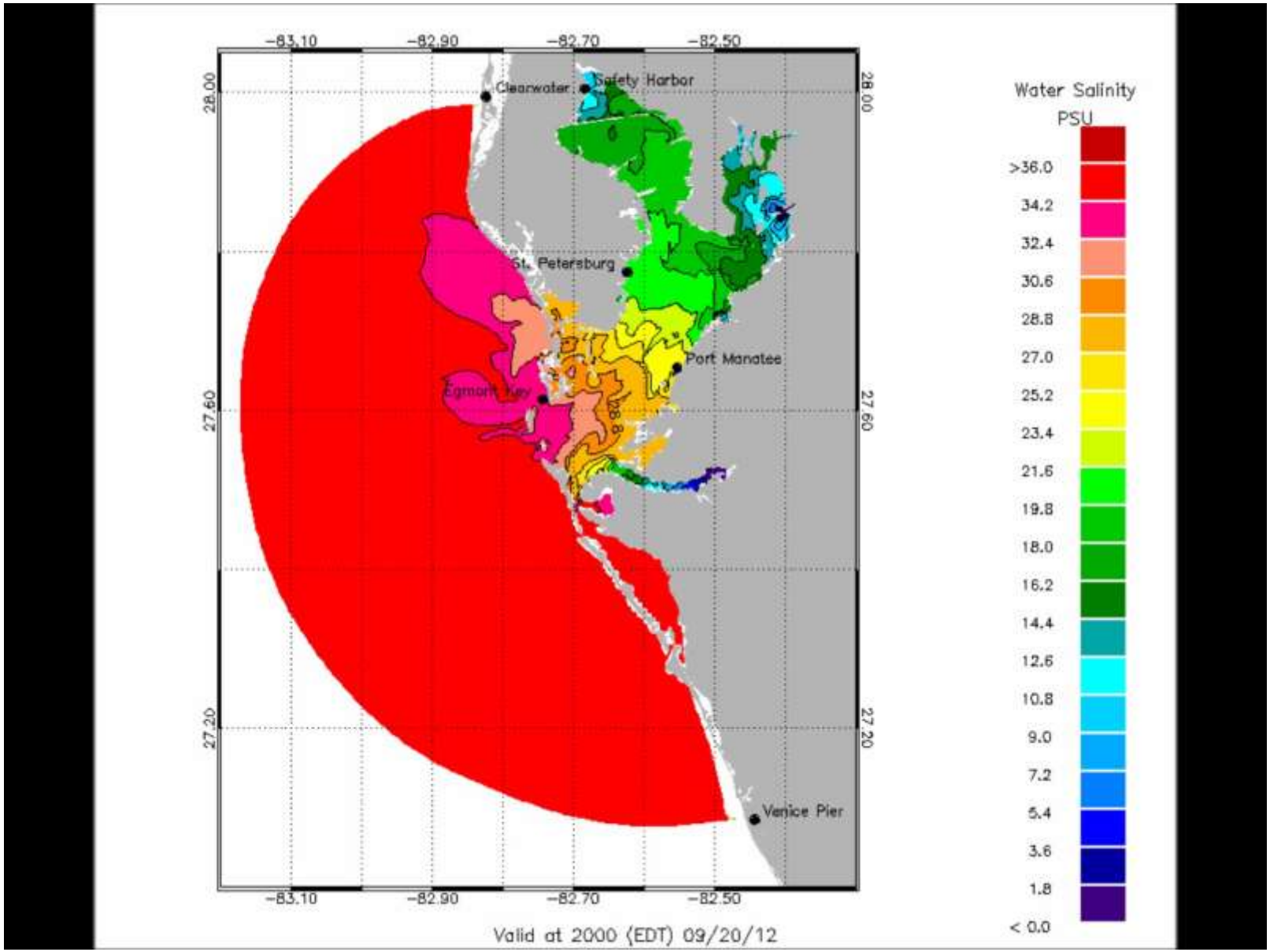
[1]Some studies (Liscio Reports from 1993-1996) show that major NE snowstorms in the 1990s negatively impacted economic indices for months after the event, including GNP.

Extending Prediction Models into Nontraditional Areas

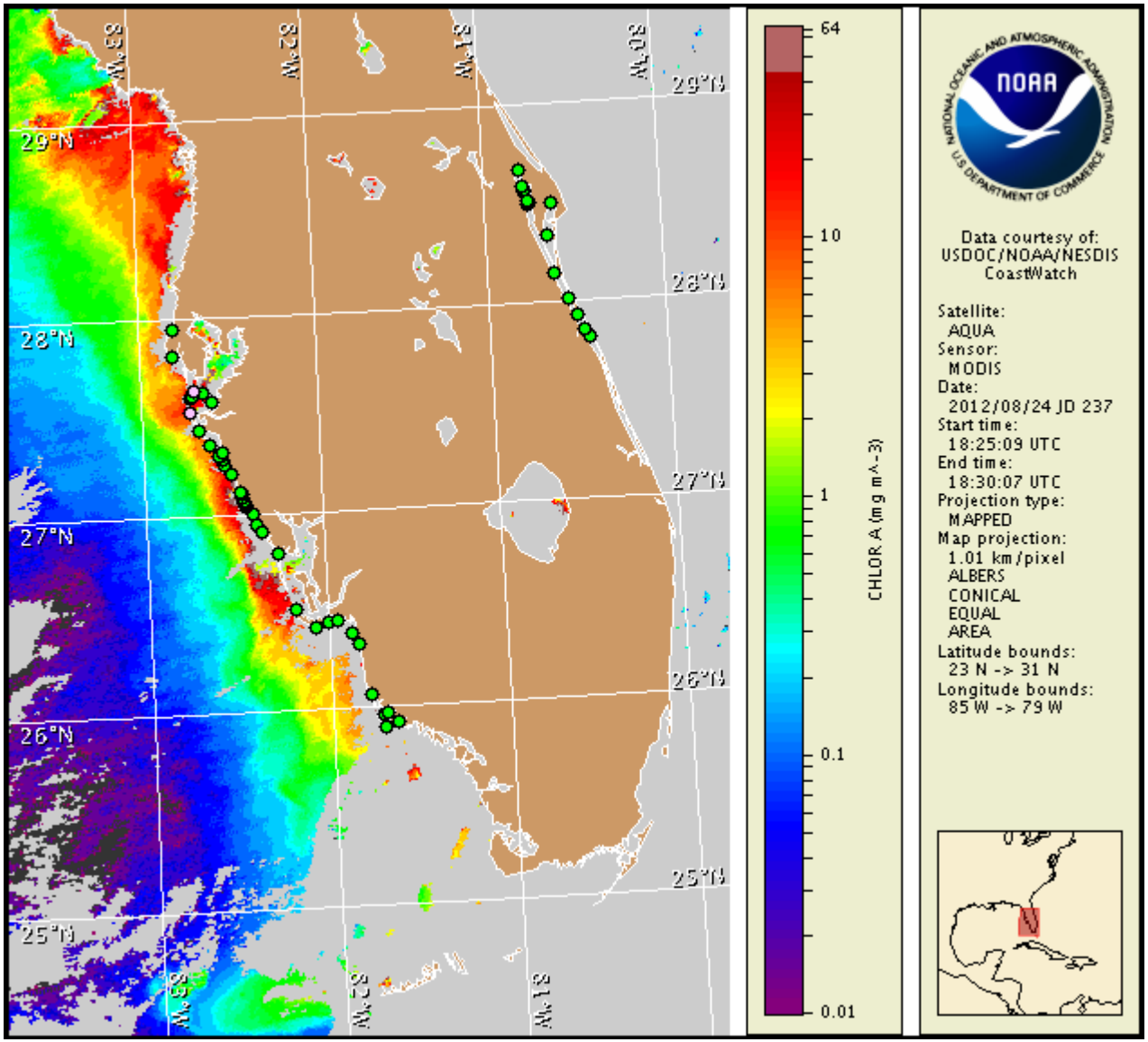
- Coupled Models: Atmosphere – Ocean – Land → provide opportunities for ecosystem prediction: beach/water quality, health, ”critters”



Surface Water Salinity Forecast Guidance
Tampa Bay Operational Forecast System



NOAA Harmful Algal Bloom Operational Forecast System



Satellite chlorophyll image with possible HAB areas shown by red polygon(s).

Gulf of Mexico Harmful Algal Bloom Bulletin

Region: Southwest Florida

Monday, 27 August 2012

NOAA Ocean Service

NOAA Satellite and Information Service

NOAA National Weather Service

Relies on satellite imagery, field observations, models, public health reports and buoy data to assess and predict bloom conditions, location and movements.

Summary

- Weather forecasting has made a revolutionary change in the past 50 years
  - One of the top intellectual achievements of the 20th century
- 4 main components of the modern forecast process
  - Global observations -- Numerical models/service
  - Super computers -- Highly educated forecasters
- Can now routinely predict weather/extreme events days to a week (plus) in advance
- Linking forecasts to decision-making across a wide spectrum of users and decision makers
  - Big challenges remain – quantifying uncertainty being one of them
- Transforming weather forecasts to "impact-based forecasts" for Decision Support Services → especially emergency management community
- Need to approach from an interdisciplinary perspective, physical and social scientists
- Expand prediction into non-traditional areas: air/water quality, ecosystems, health vectors – based on an interdisciplinary Earth System approach

THANK YOU

Appendix

Predicting Health Vectors

Malaria Field Program in Niger

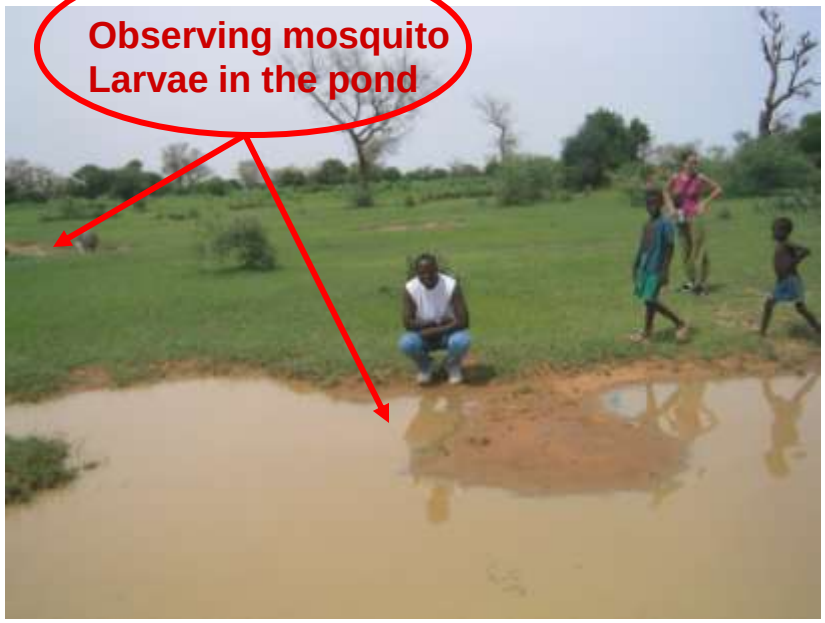
Malaria Field Campaign in Niger

Pond near Banizoumbou

CDC Light trap

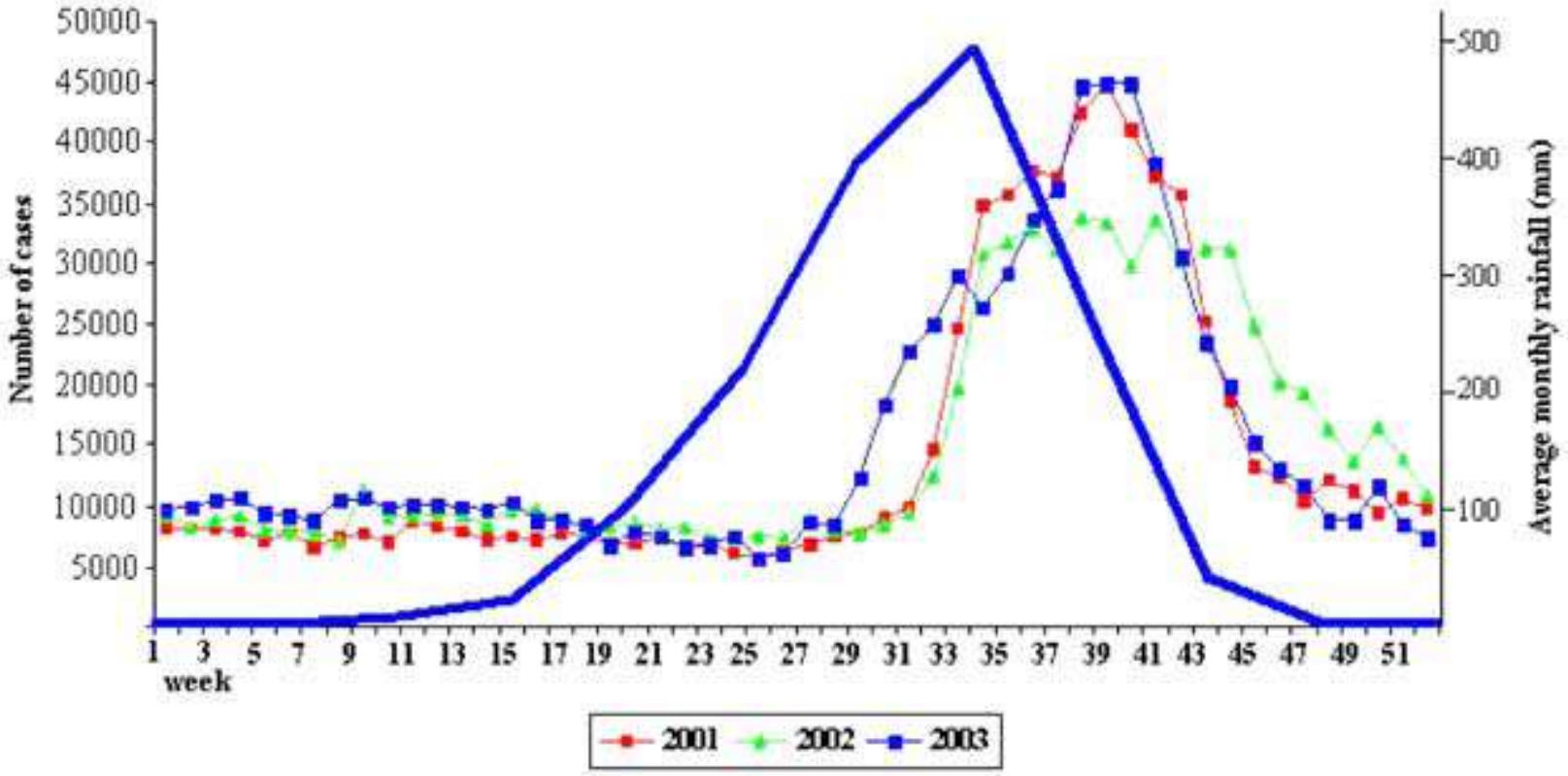
Well in Zindarou

Observing mosquito Larvae in the pond



Rainfall and Malaria

Weekly Cases in Niger from 2001 to 2003

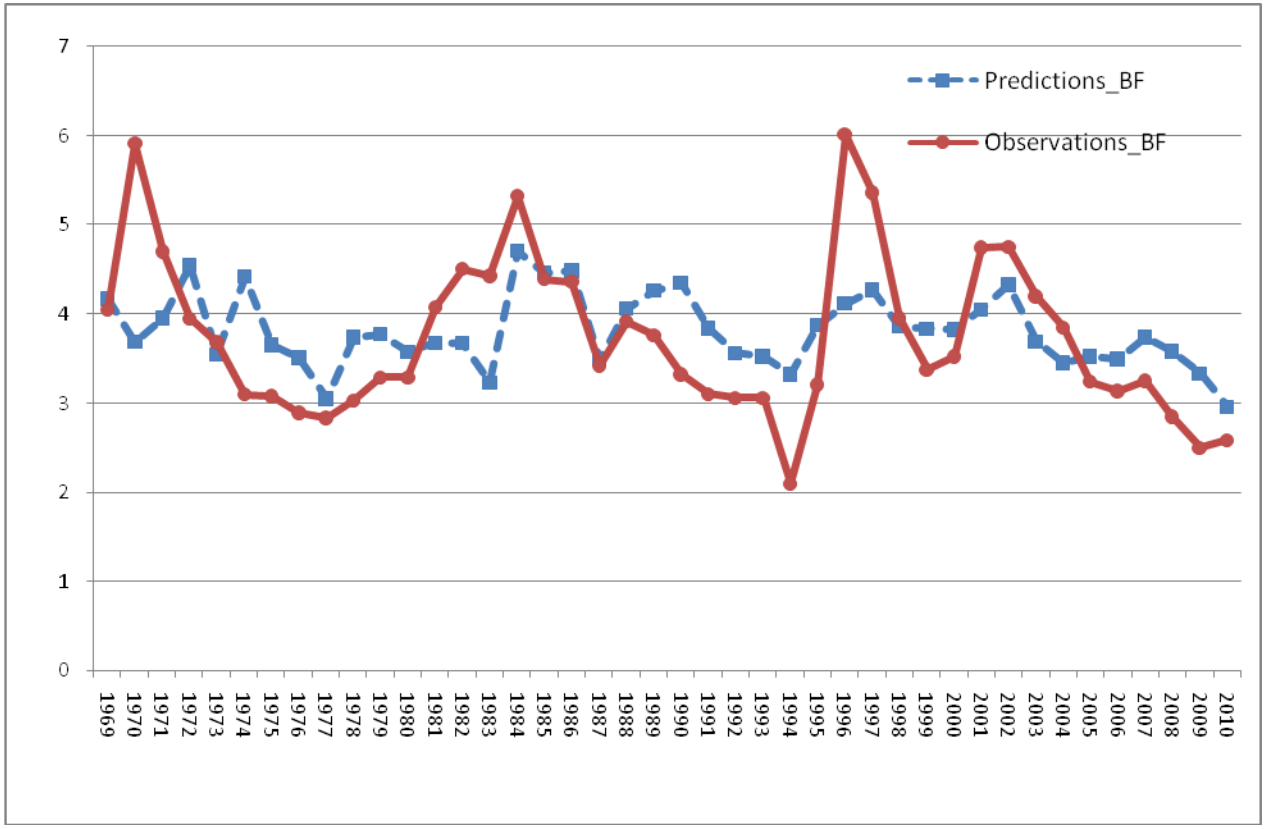


Solid blue: GPCP Precipitation

Predicting Meningitis in Burkina Faso

NCEP Reanalysis employed to develop a meningitis prediction system in Burkina Faso

Meningitis Incidence Rate
in logarithmic form - Case of Burkina Faso
Base Period: 1968-2005



Yaka et al., 2008

Relationships between high impact weather and outbreaks of cholera

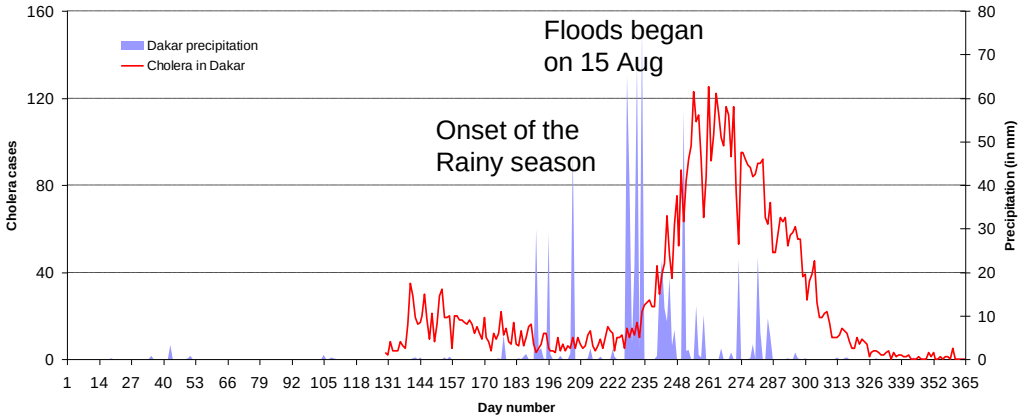
Linkages between environmental parameters and cholera outbreaks
Understand influence of weather and climate on cholera outbreaks
Develop early warning systems for water borne disease outbreaks
WHO; WMO; National Health Institutions; National Met & Hydrologic Services

There is now strong evidence that climate variability has a major influence on the cycles of cholera outbreaks.

Studies have shown that cholera has a marked seasonality associated with the rainfall season, especially in coastal countries.

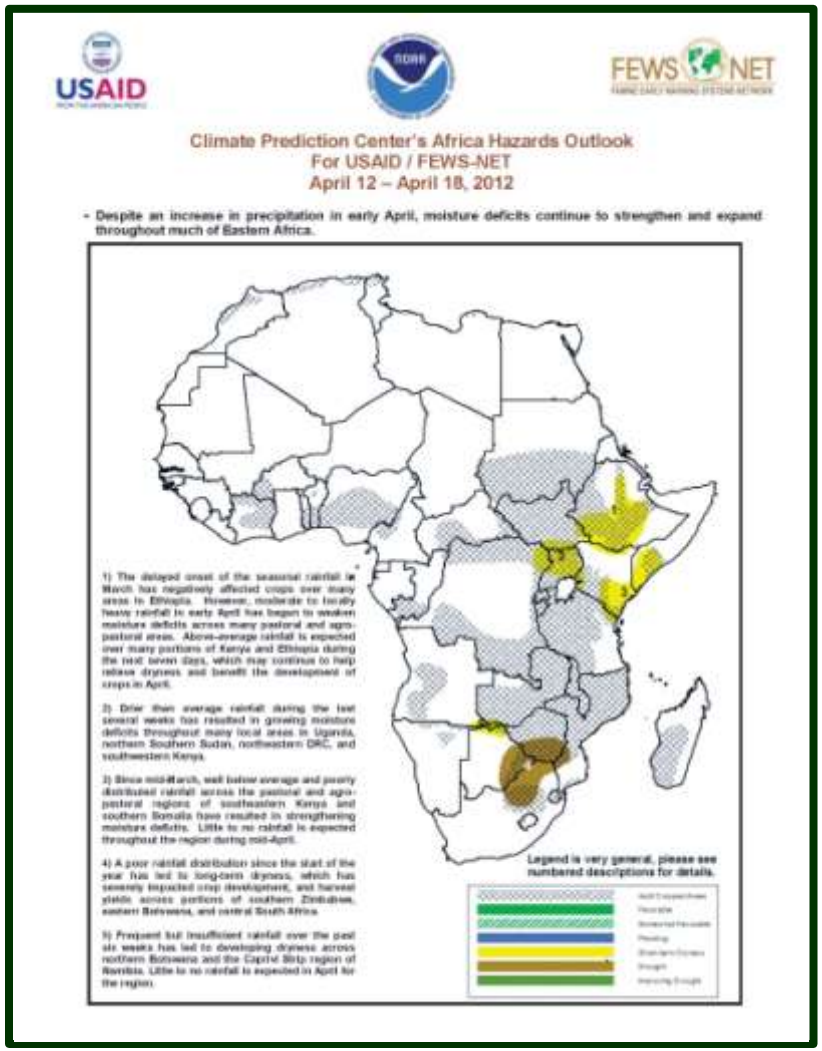
The peak of epidemic outbreaks are preceded by an increase in sea surface temperature and rainfall.

2005 Cholera outbreak and Precipitation in Dakar, Senegal



Drought and Food Security Planning

Weekly Climate Risk Bulletins



- Objective: Support USAID/Food for Peace
- Facilitate decision making on issues related to food security.
- Enable USAID for other risk management strategies, such as humanitarian relief efforts

http://www.cpc.ncep.noaa.gov/products/fews/africa_hazard.pdf

Weekly Weather Summary and Outlook For Darfur Humanitarian Relief Effort