Meteorology and High-Performance Cyberinfrastructure: *Applications in the Extreme*

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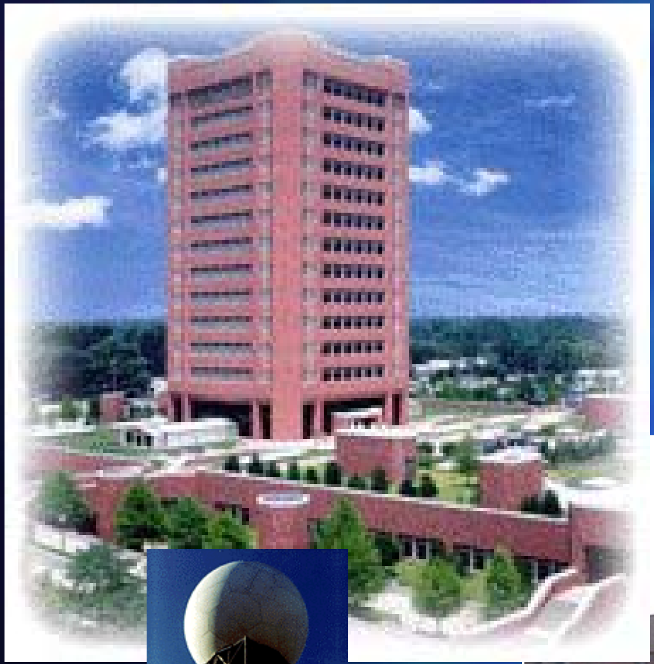
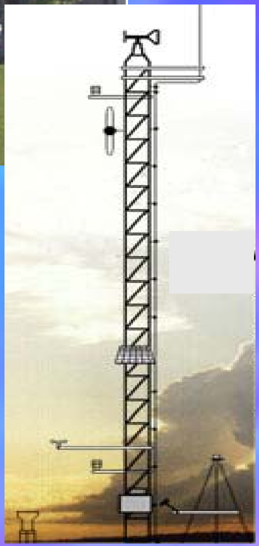
School of Meteorology
Center for Analysis and Prediction of Storms
University of Oklahoma

OSCER Symposium

Friday, 13 September 2002

The Oklahoma Weather Center



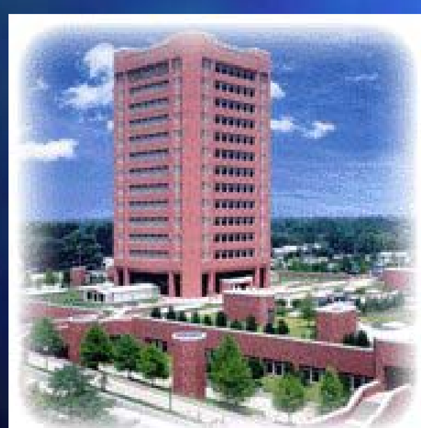


The Oklahoma Weather Center

- A unique confederation of 11 Federal, State, and University of Oklahoma entities
- Employs over 600 professionals – largest group of operational, research and academic meteorologists in the nation
- Over $0.5 billion in infrastructure
- Yearly research expenditures of $65 M
- Injects over $120 M annually into OK economy
- Develops much of the technology used operationally within the NWS

the university of OKLAHOMA

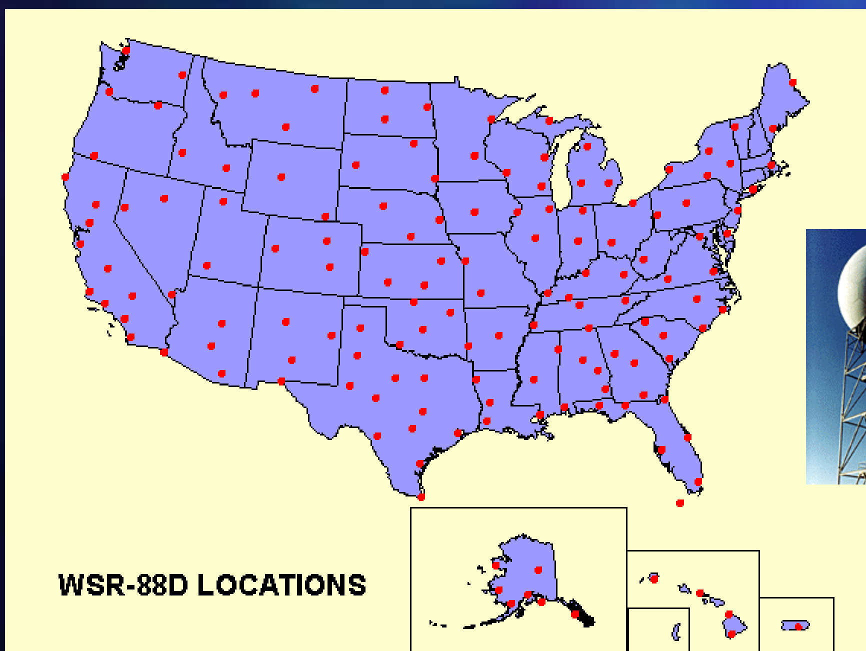
- School of Meteorology (SoM)
- Center for Analysis and Prediction of Storms (CAPS)
- Oklahoma Climatological Survey (OCS)
- Cooperate Institute for Mesoscale Meteorological Studies (CIMMS)
- Environmental Verification and Analysis Center (EVAC)
- International Center for Natural Hazard and Disaster Research (ICNHDR)



- National Severe Storms Laboratory (NSSL)
- Storm Prediction Center (SPC)
- National Weather Service Forecast Office
- NEXRAD Operational Support Facility
- Warning Decision Training Branch

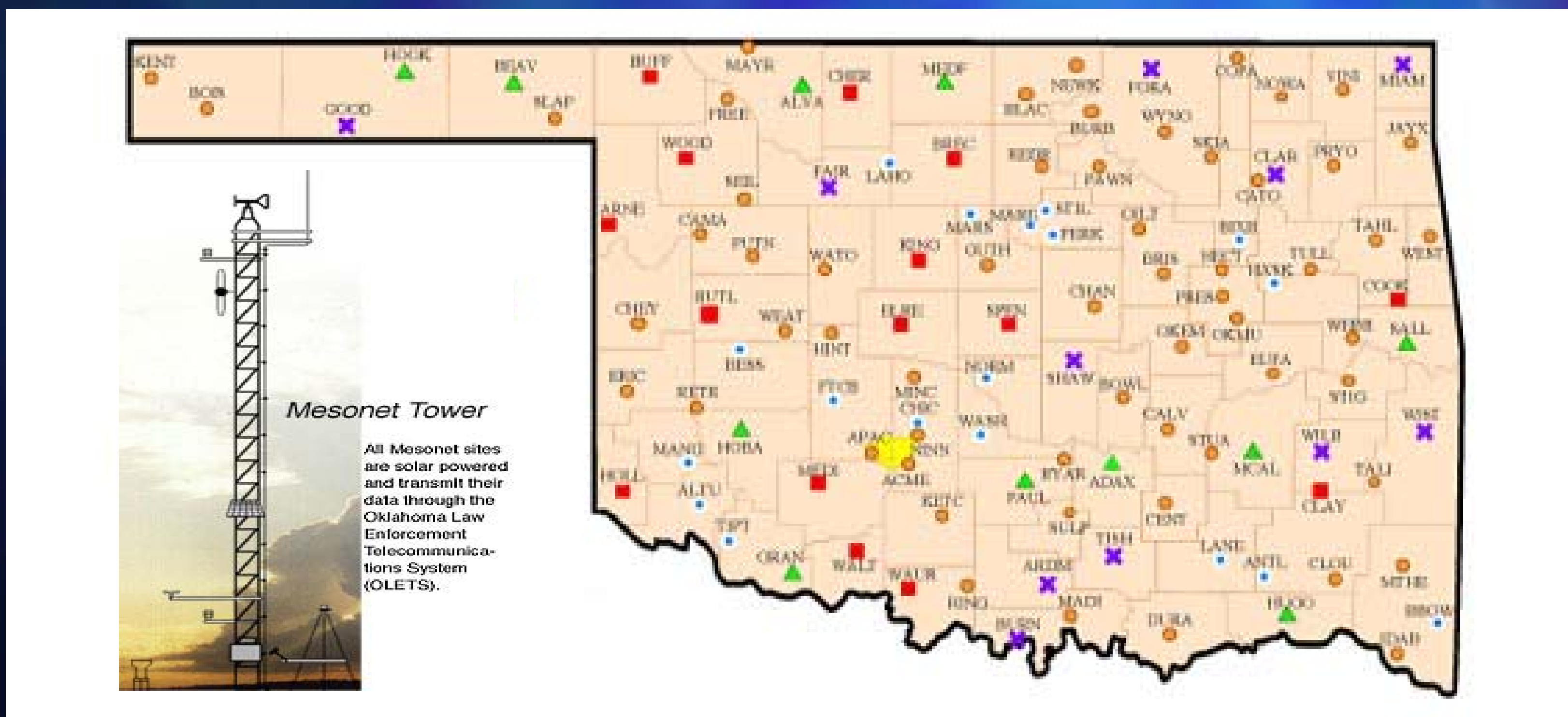
Major Achievements

- <u>Pioneered</u> Doppler weather radar technology



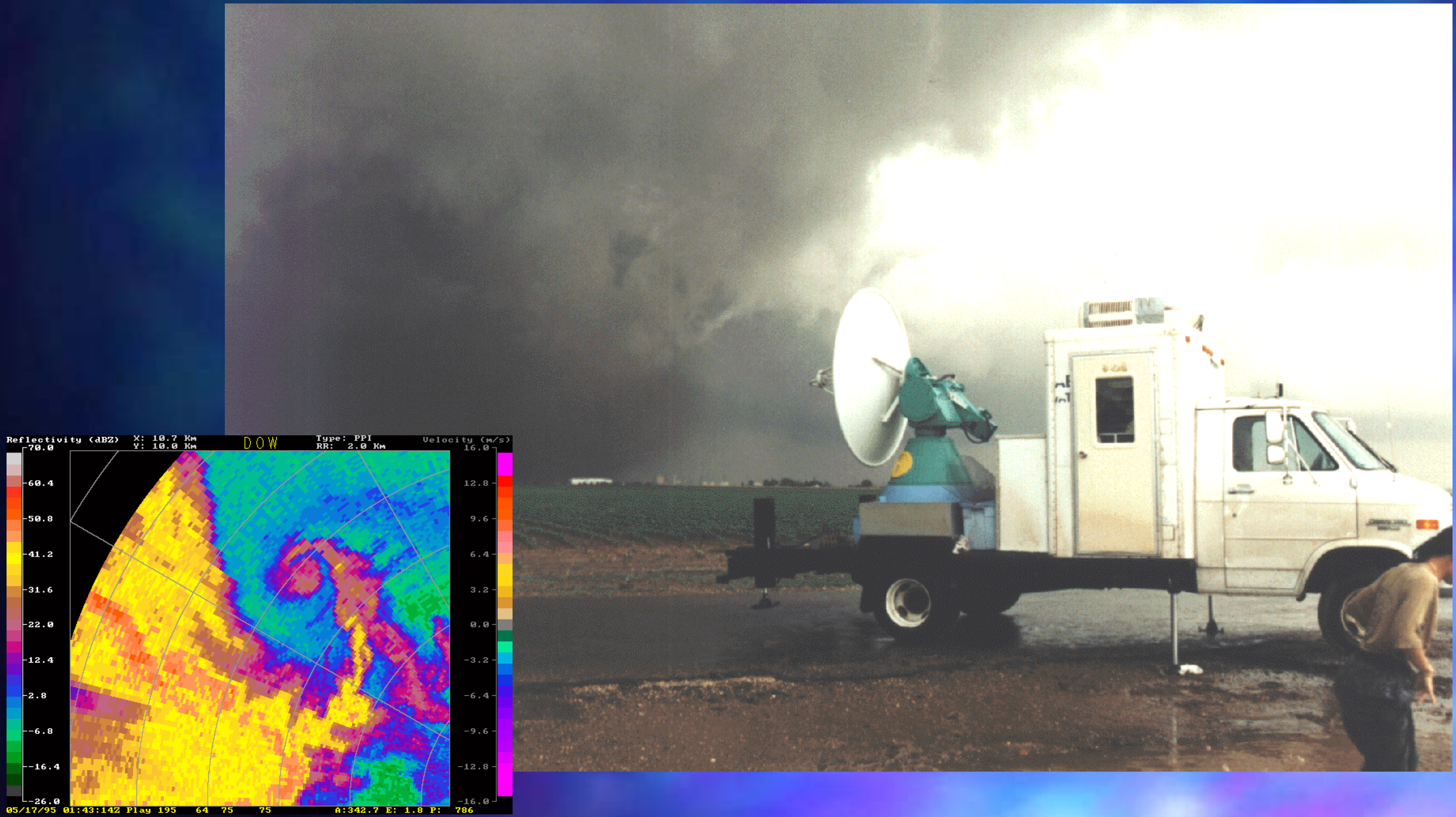
Major Achievements

- Created the <u>nation's first</u> high-density State-wide surface observation network – the Oklahoma Mesonet



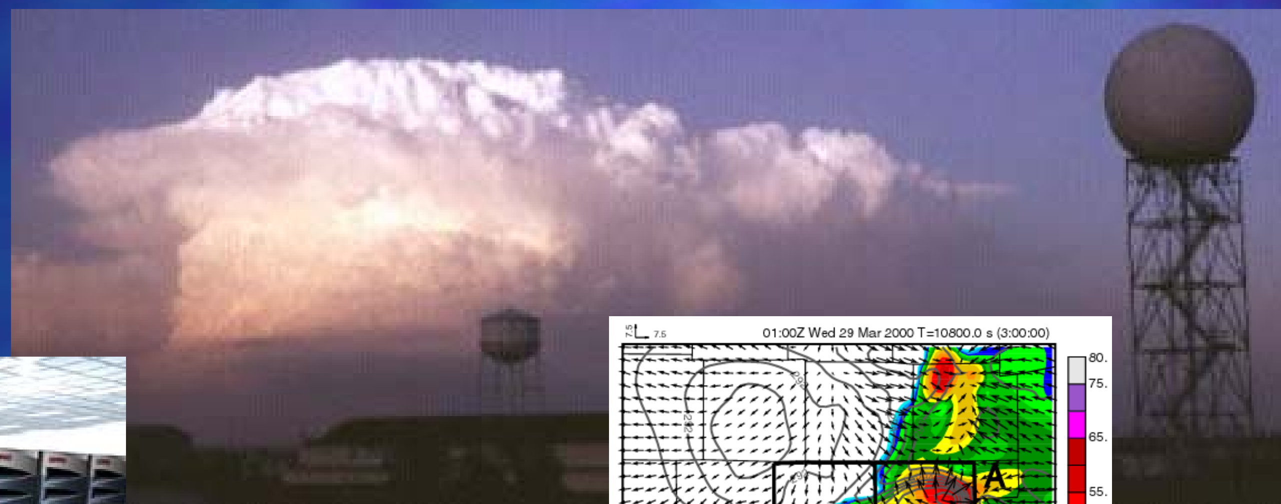
Major Achievements

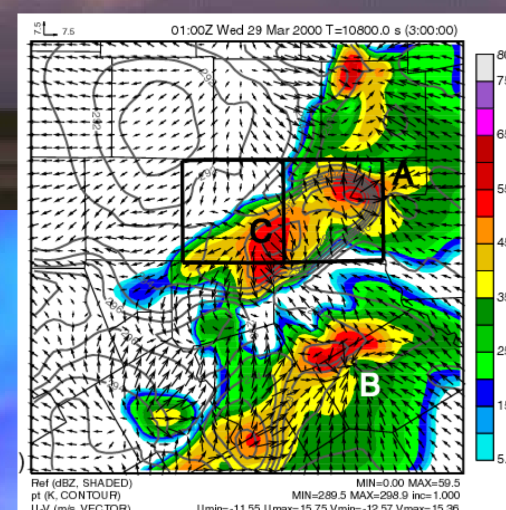
- Developed the <u>world's first</u> ground-based mobile Doppler radar (Doppler on Wheels); recorded <u>highest wind speeds on Earth</u> (318 mph) during Moore, Oklahoma F5 tornado on 3 May 1999



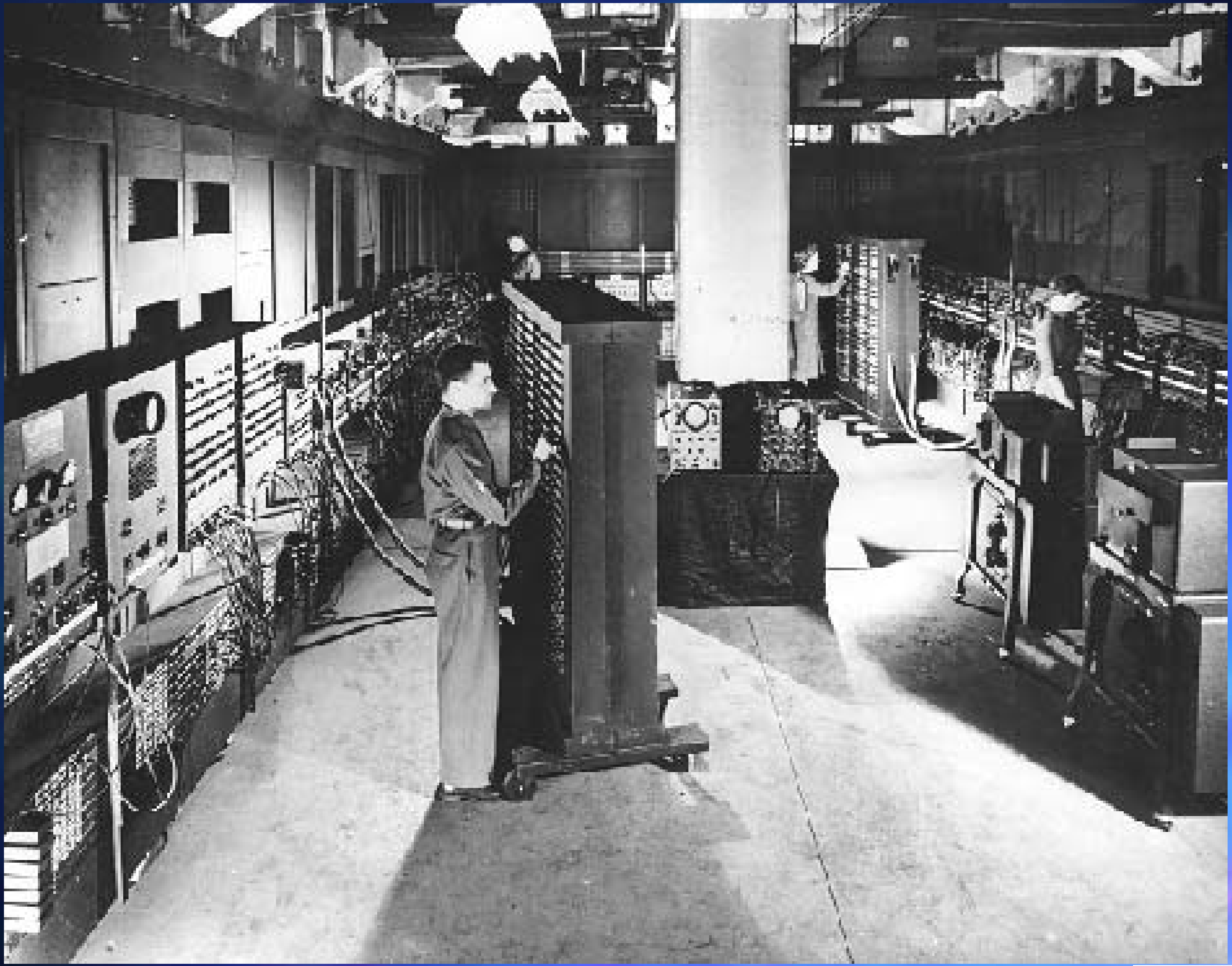
Major Achievements

- Created the <u>world's first</u> computer-based forecast system designed specifically for intense, local storms – now used operationally by American Airlines, FAA, Kennedy Space Center, and others





In the Beginning… ENIAC



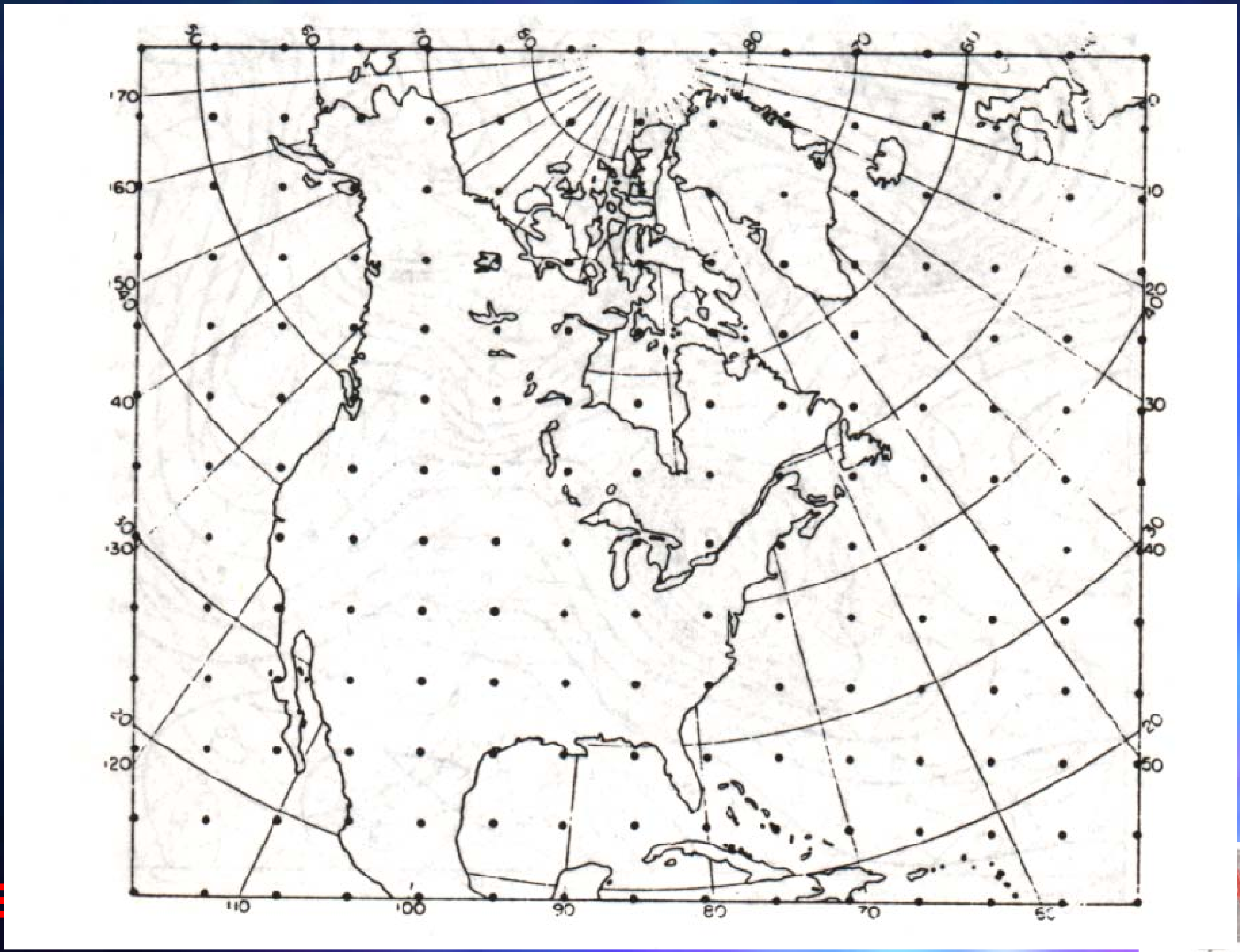
ENIAC Versus Today

- **Weighed 30 tons**
- **Had 18,000 vacuum tubes, 1,500 relays thousands of resistors, capacitors, inductors**
- **Peak speed of 5000 adds/second and 300 multiplies/sec**
- **A 1.2 GHz Pentium IV processor is 500,000 times faster than the ENIAC**
- **A desktop PC with 1 Gbyte of RAM can store 5 million times as much data as the ENIAC**

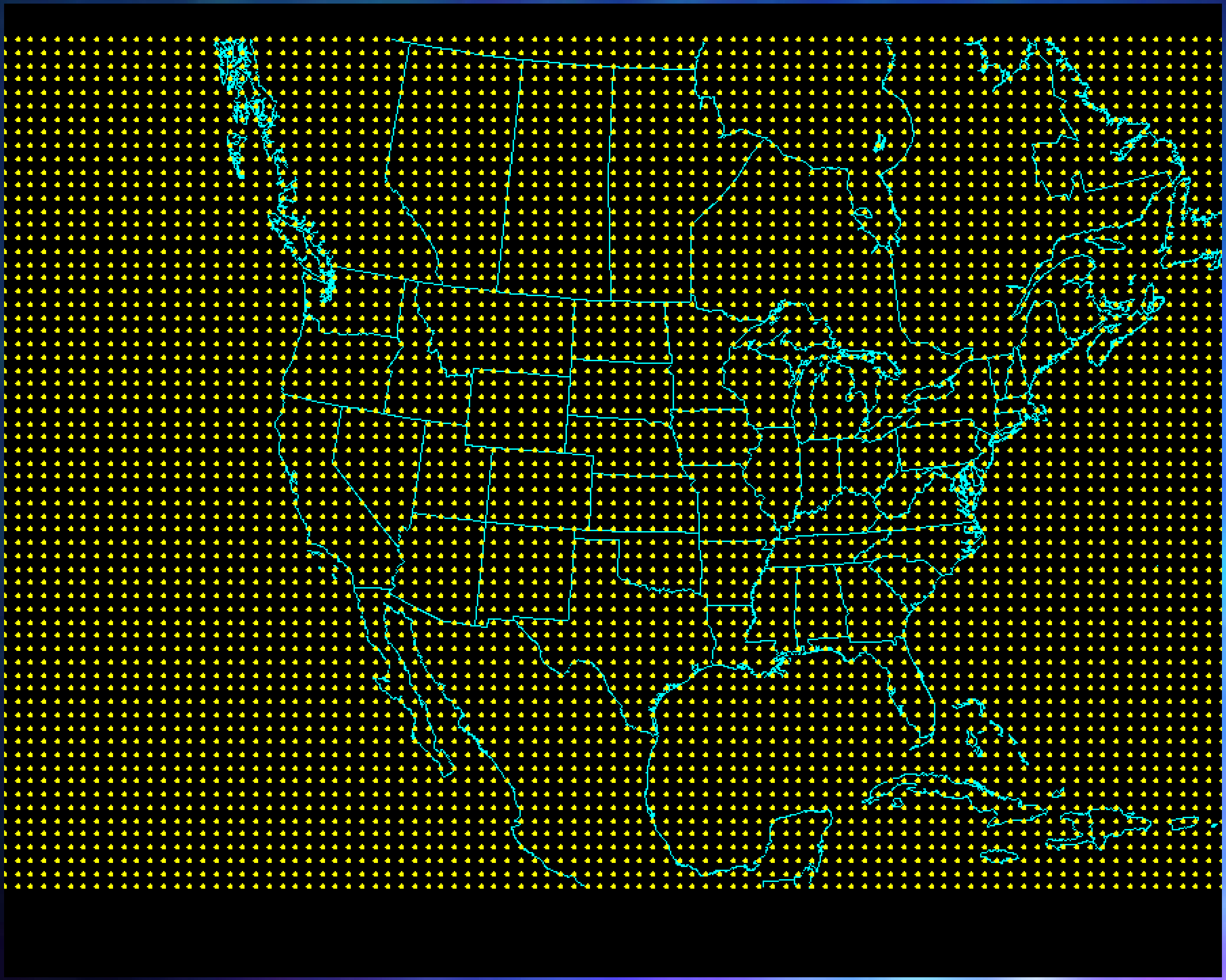
Charney, Fjortoft, and von Neumann (1950)

- Numerically integrated one equation at one level in the atmosphere
- 24 hour forecast

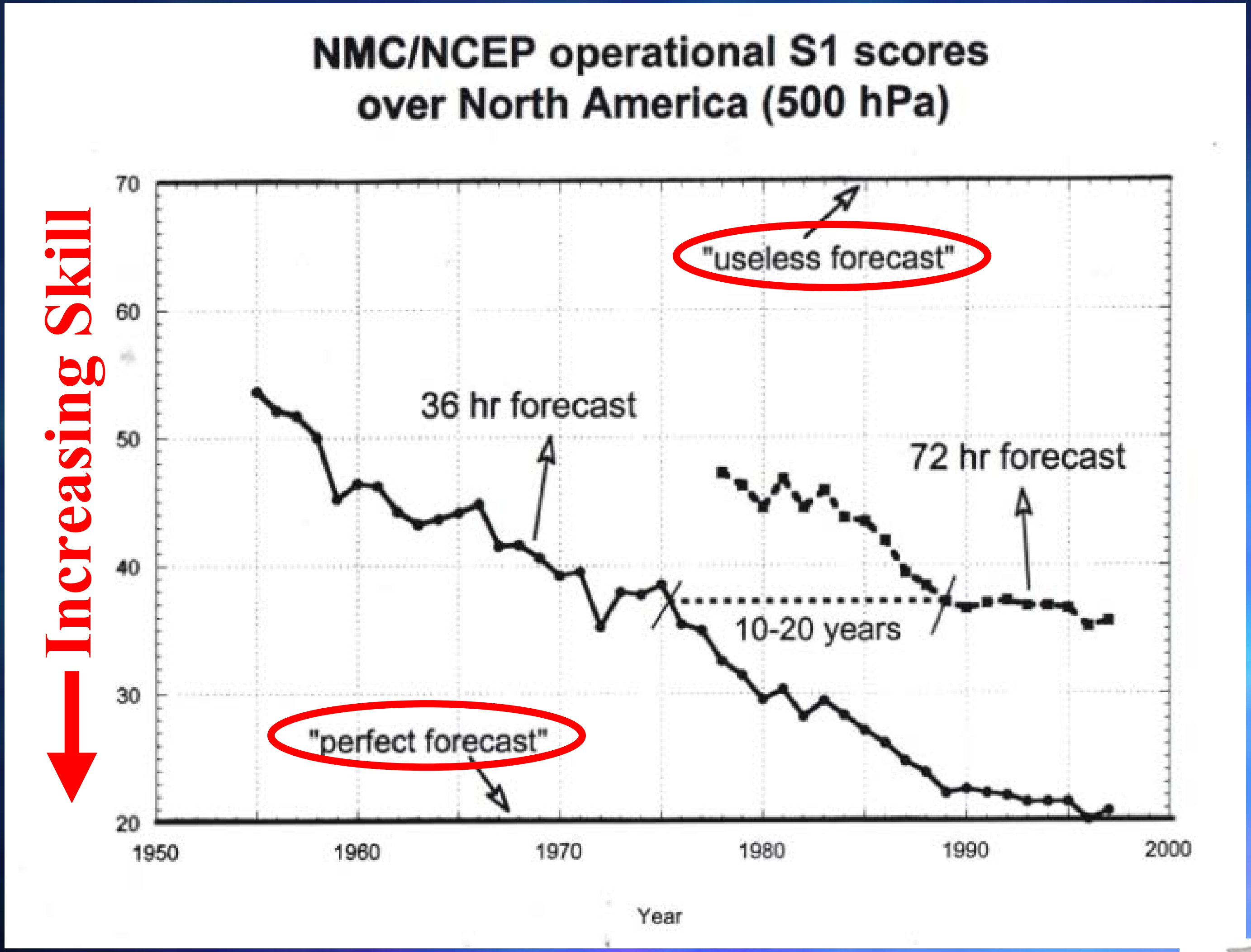
The 1950 Grid – Prediction Started at the Large Scale…736 km grid spacing



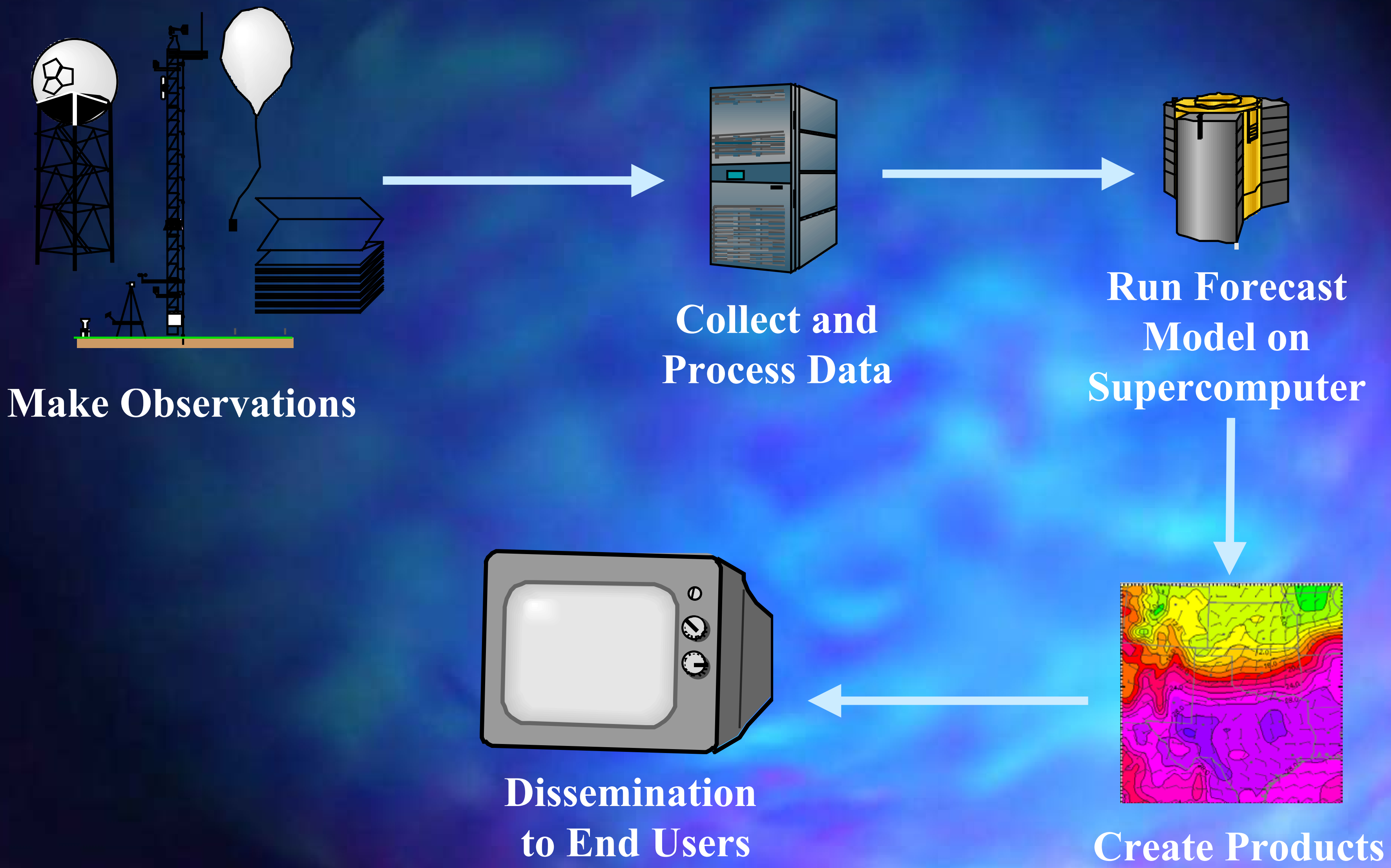
…And Grid Spacing Has Been Decreasing Ever Since



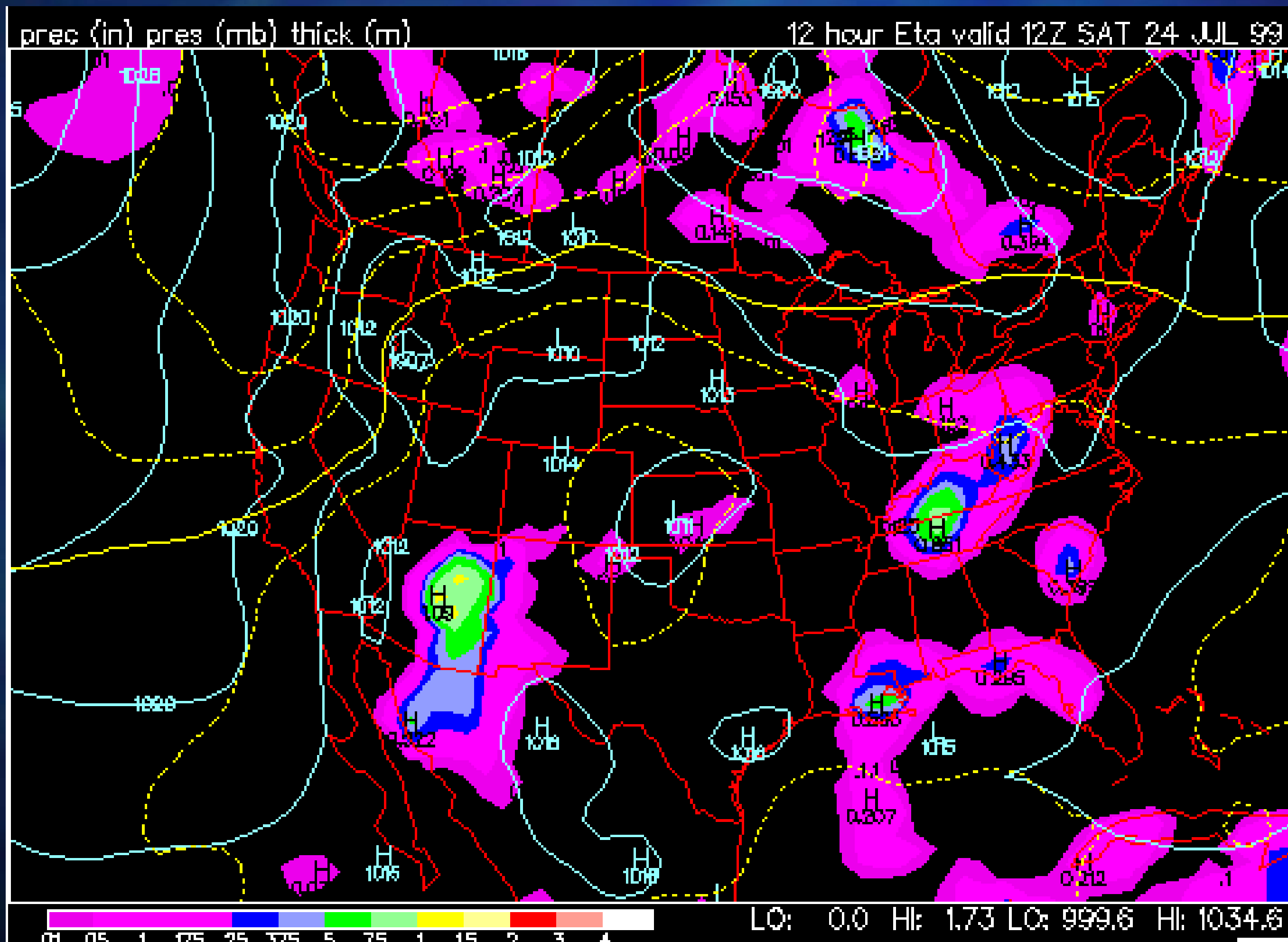
Trends in Computer Model Forecast Skill



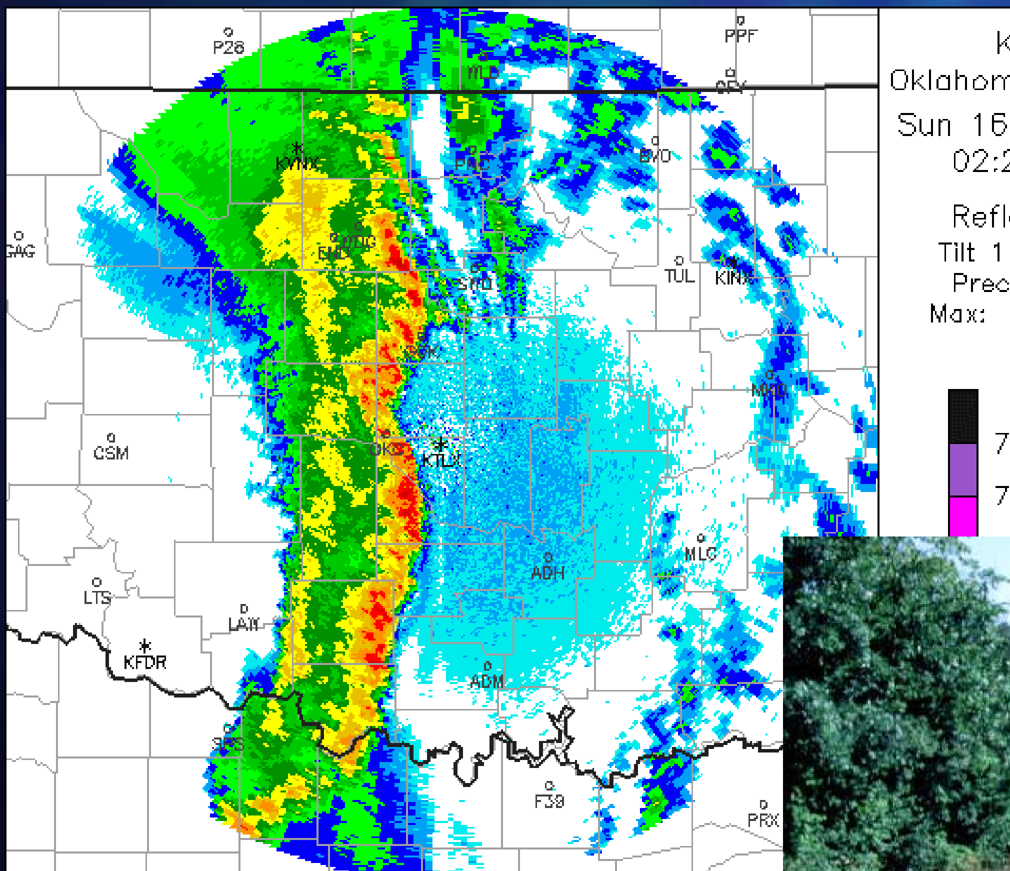
Numerical Weather Prediction



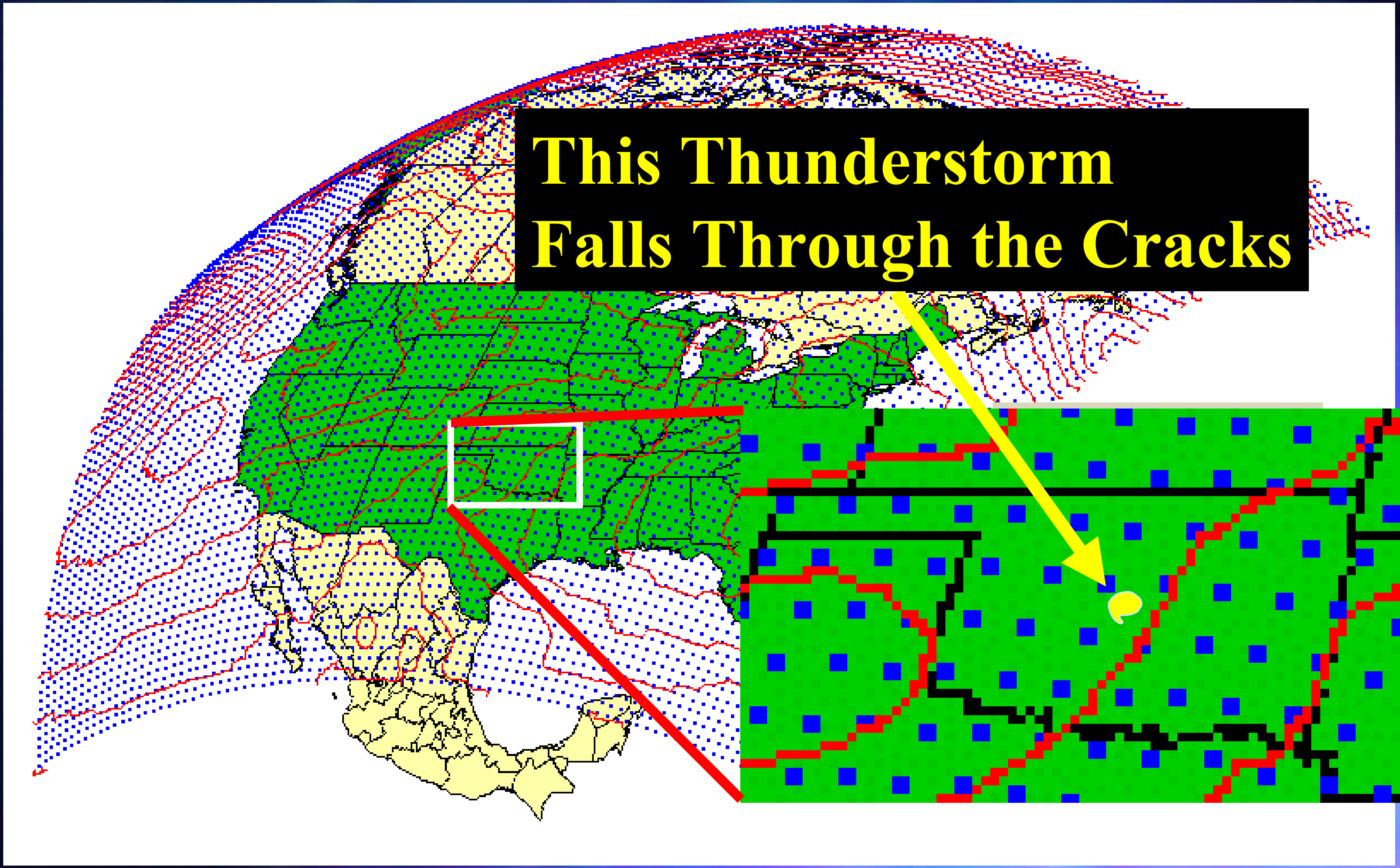
What Do Operational Forecast Models Currently Predict?



What Causes the Real Problems?



Why the Lack of Detail?



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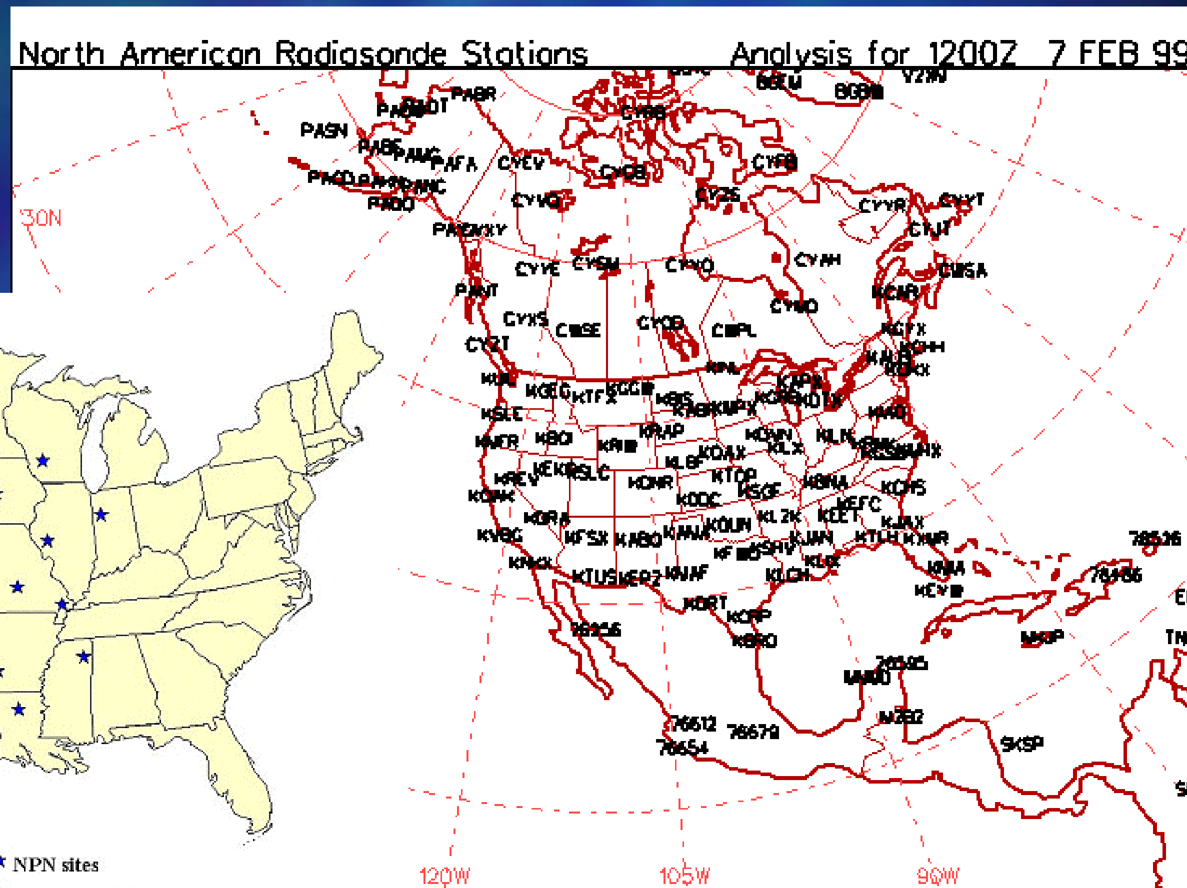
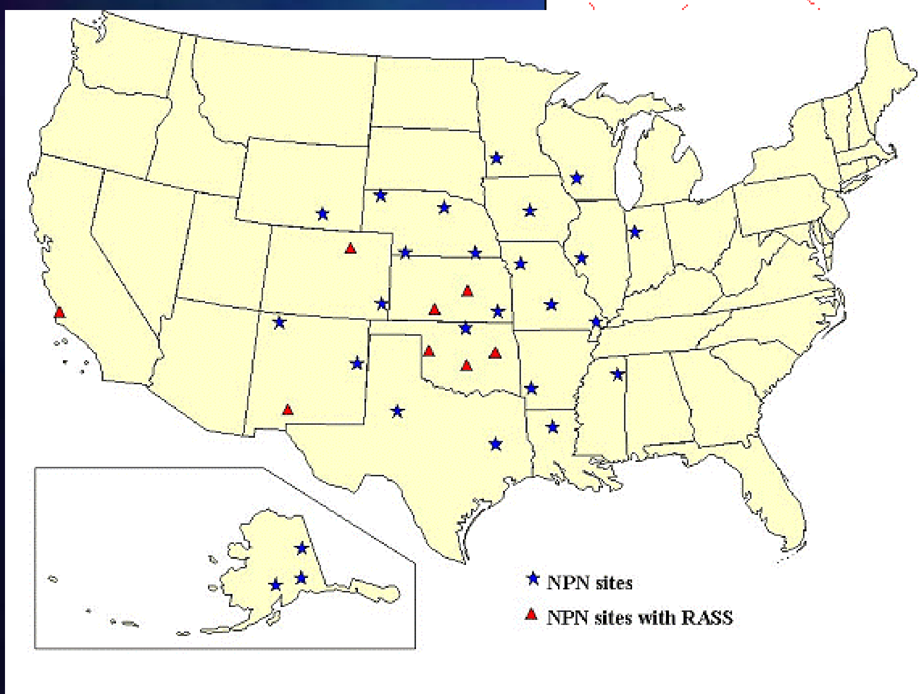
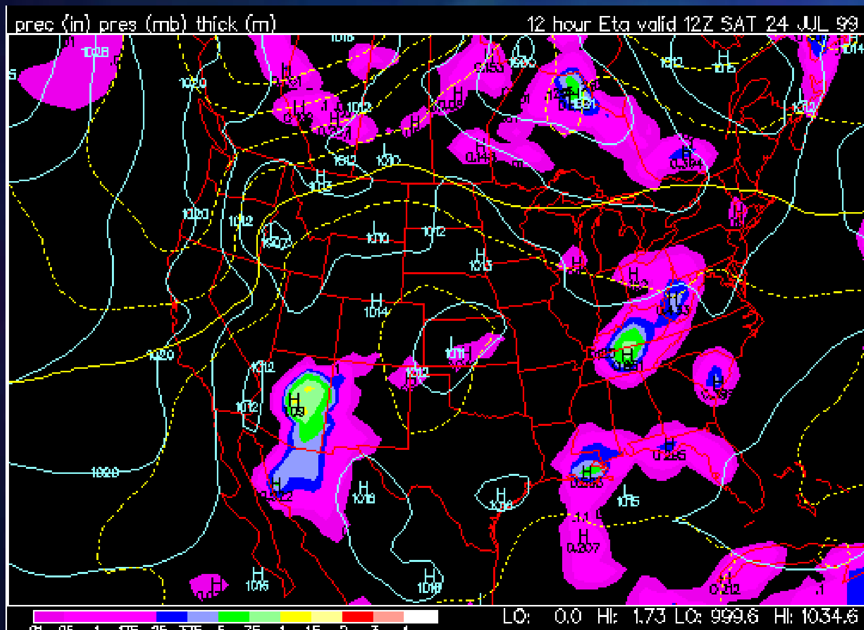


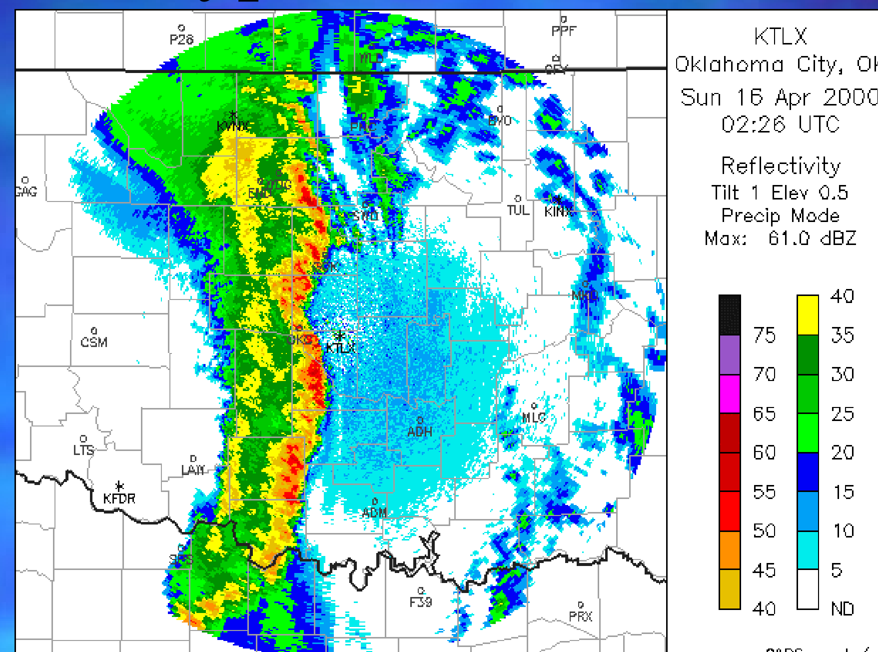


The Foundational Question in 1989



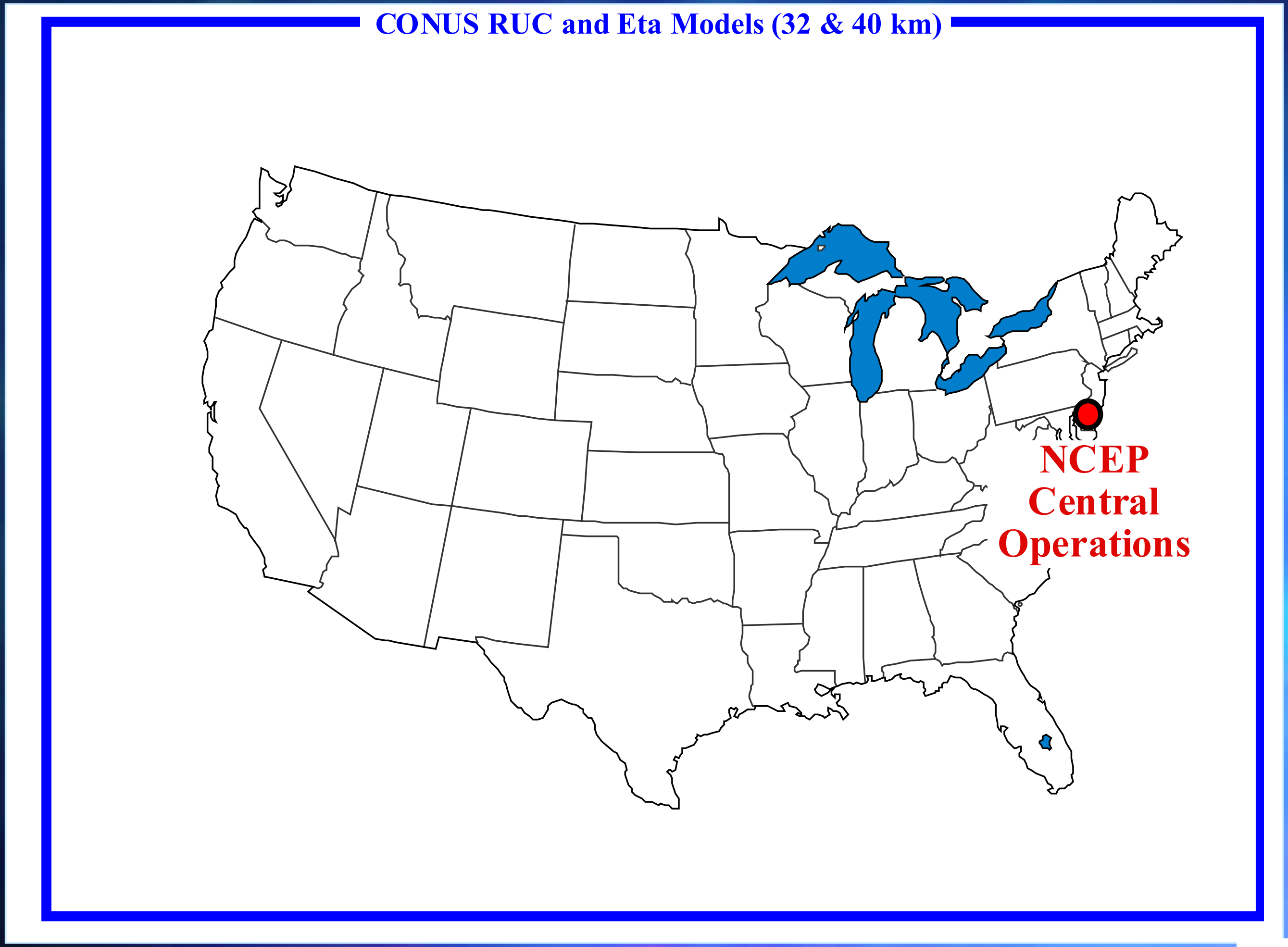
Can computer forecast model technology. . .

. . . explicitly predict this type of weather?

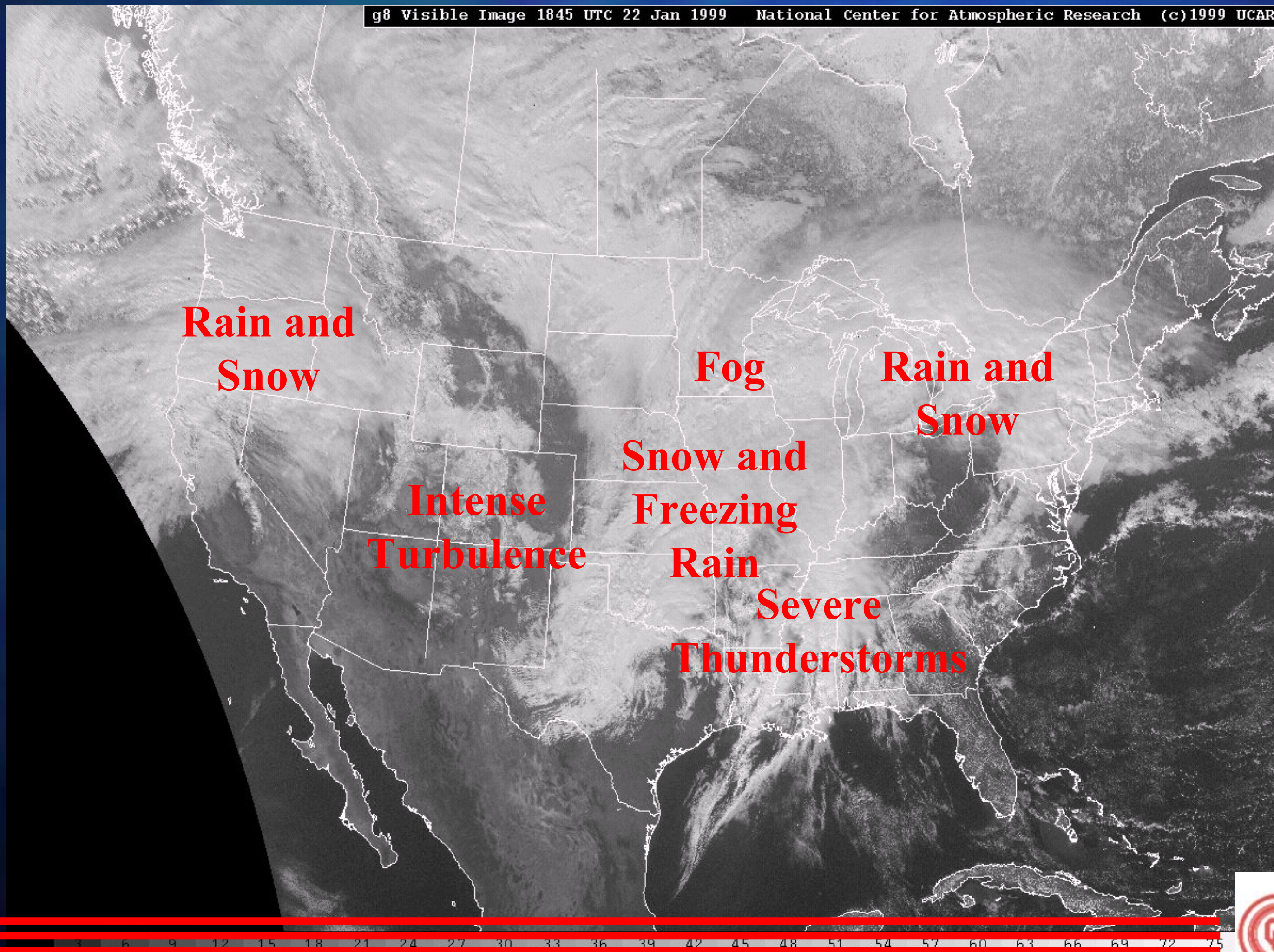


Center for Analysis and Prediction of Storms

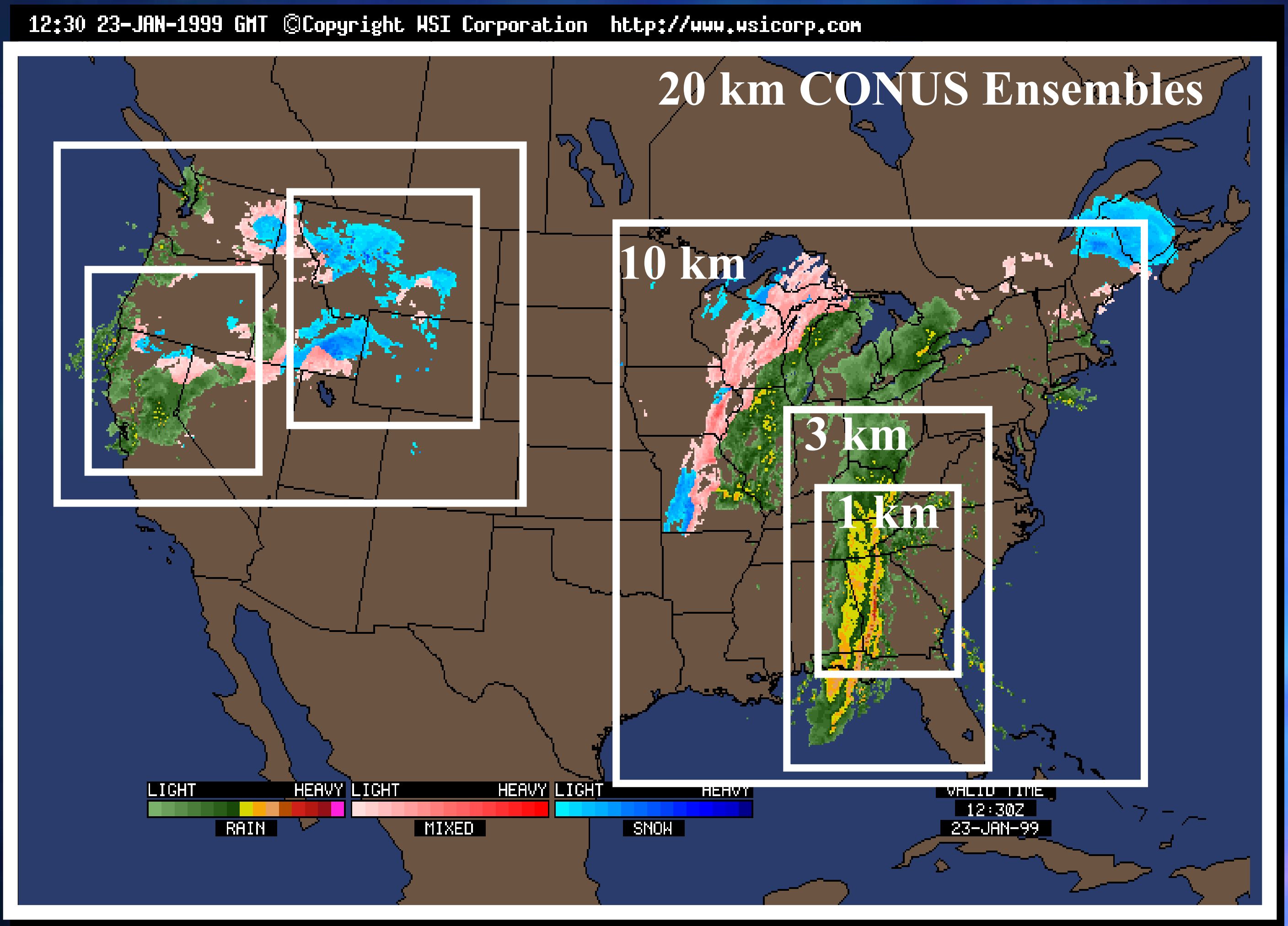
Present NWS Operations



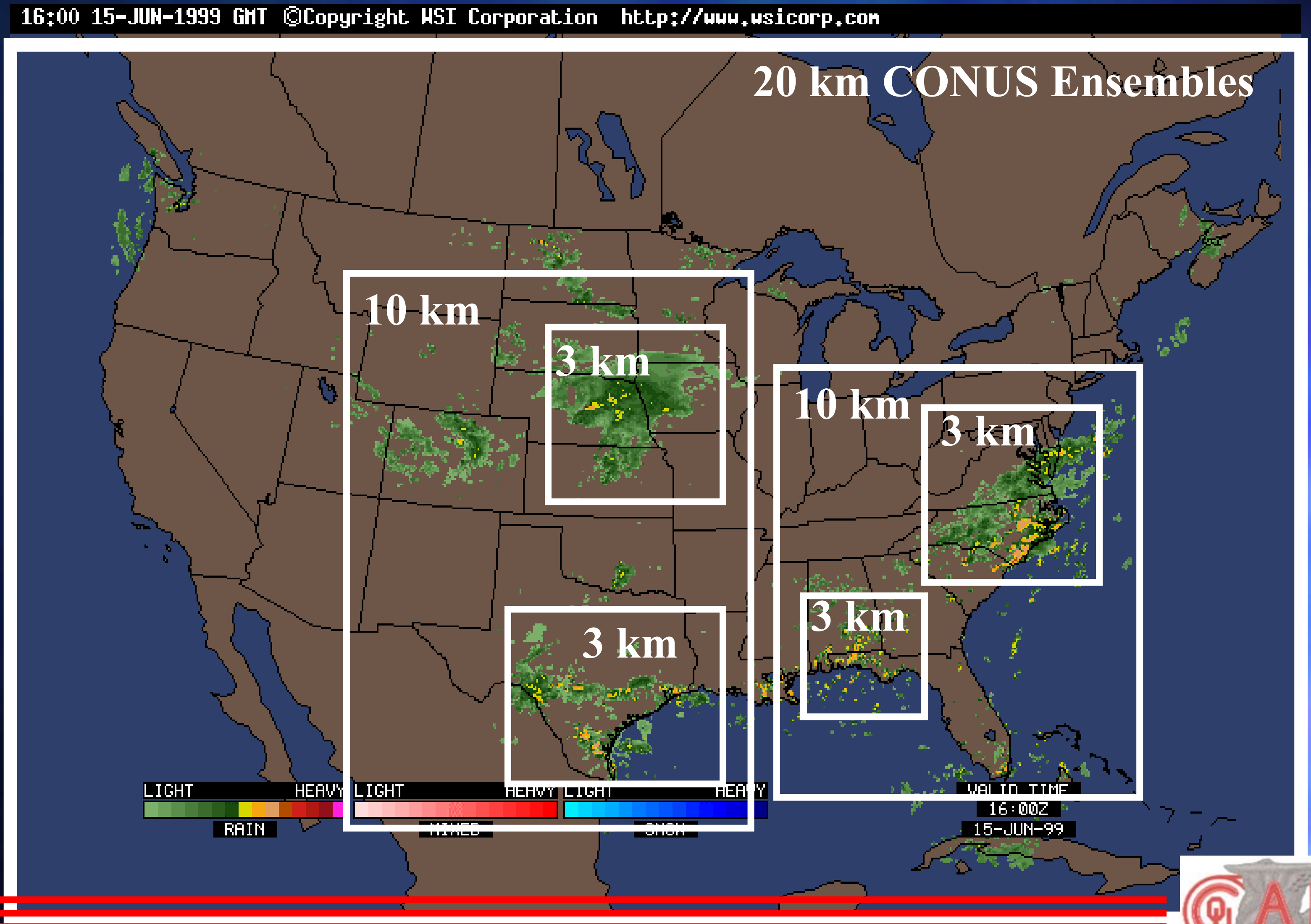
Small-Scale Weather is LOCAL and heterogeneous!



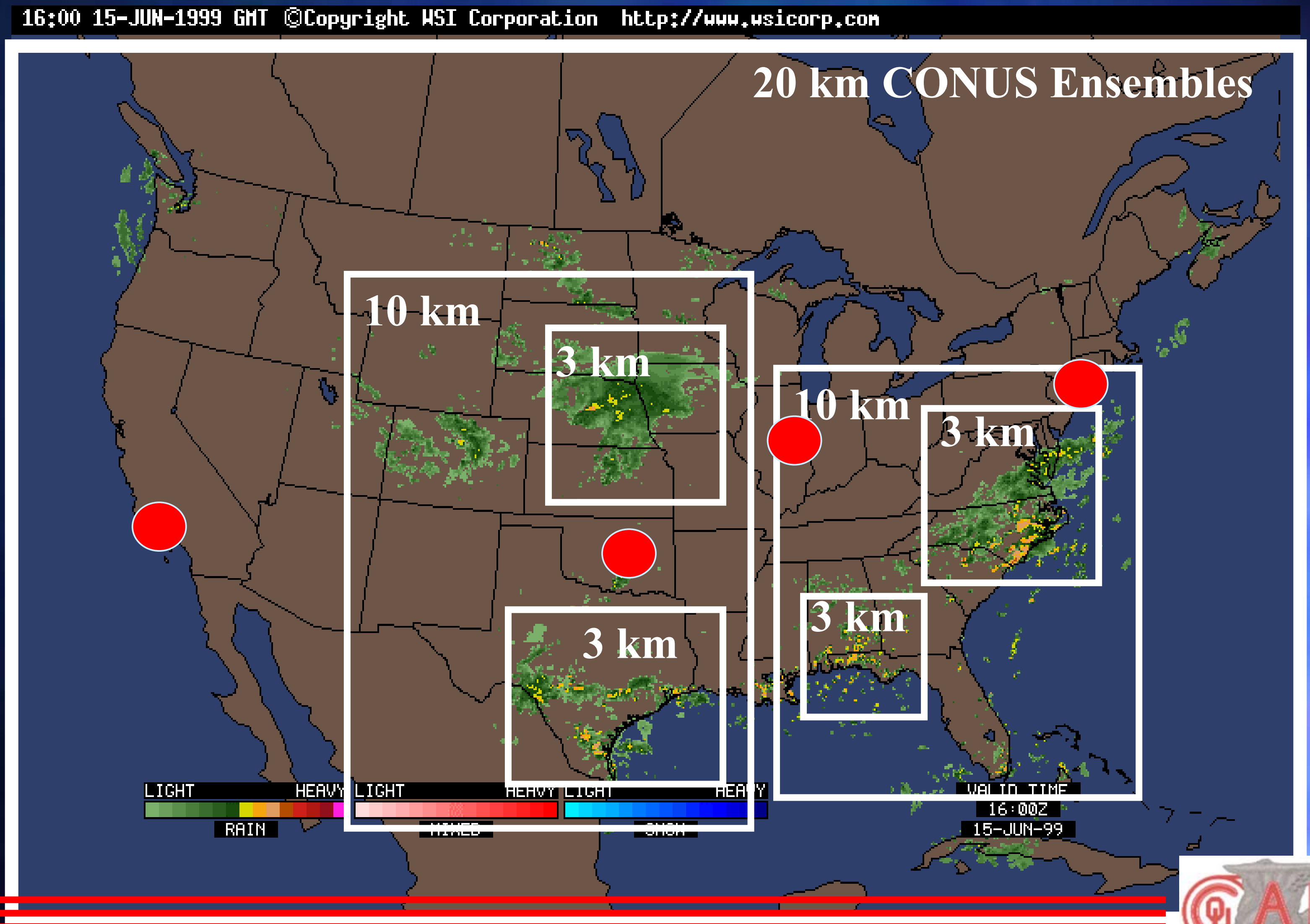
A Dynamic Environment (time = t)



A Dynamic Environment (time = t+6 hours)



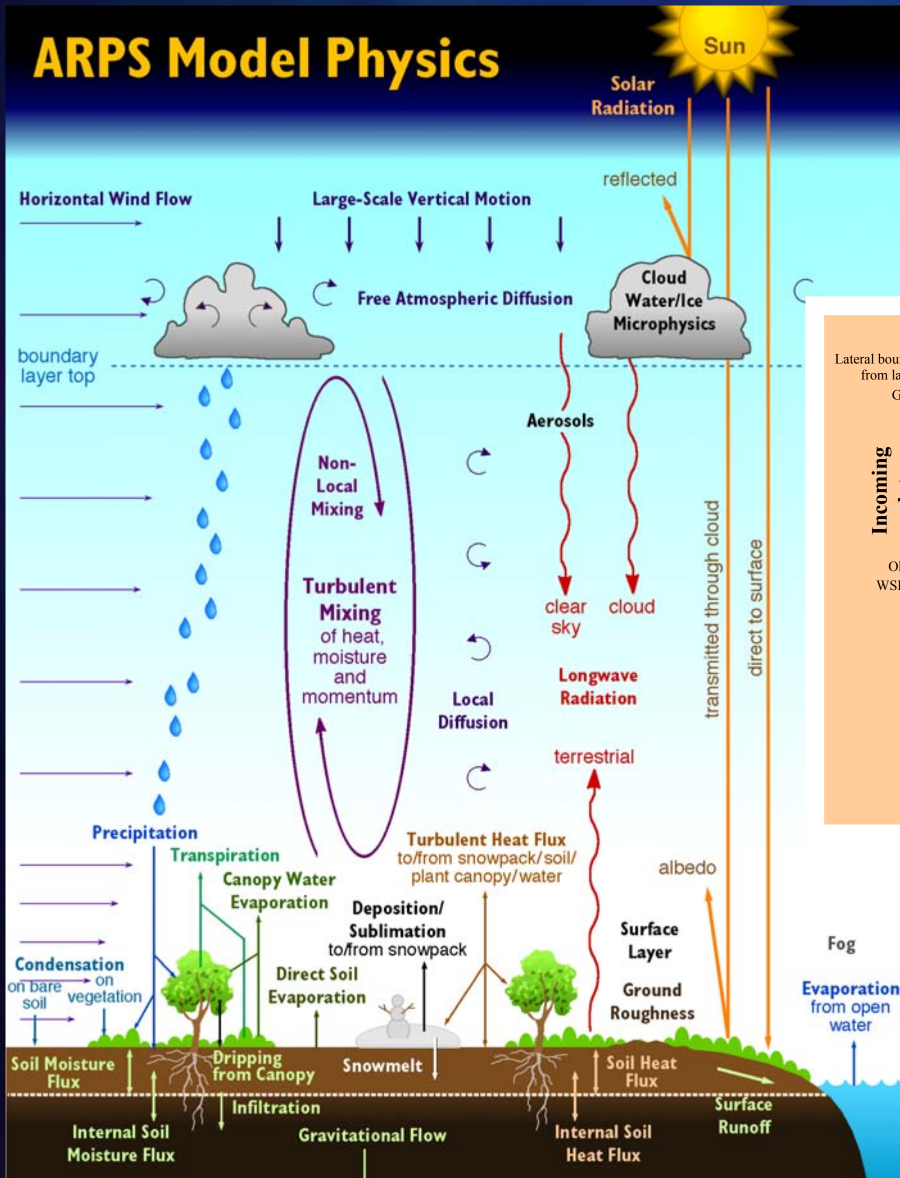
Distributed Computing: The "Grid"

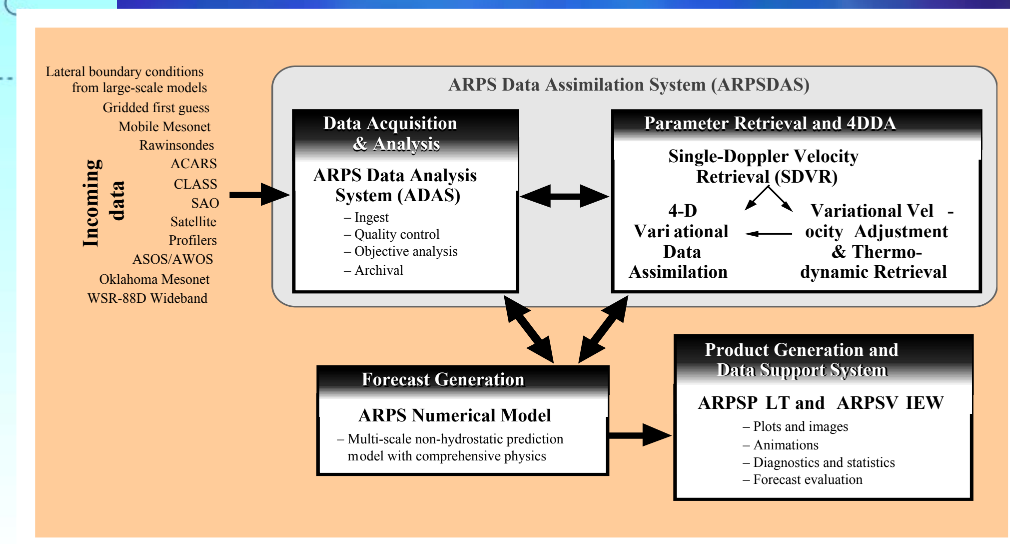


Three Key Ingredients for Storm-Scale Prediction

- #1 -- A computer forecast system that accurately represents complex <u>physical processes</u> and operates <u>efficiently</u> on parallel computers

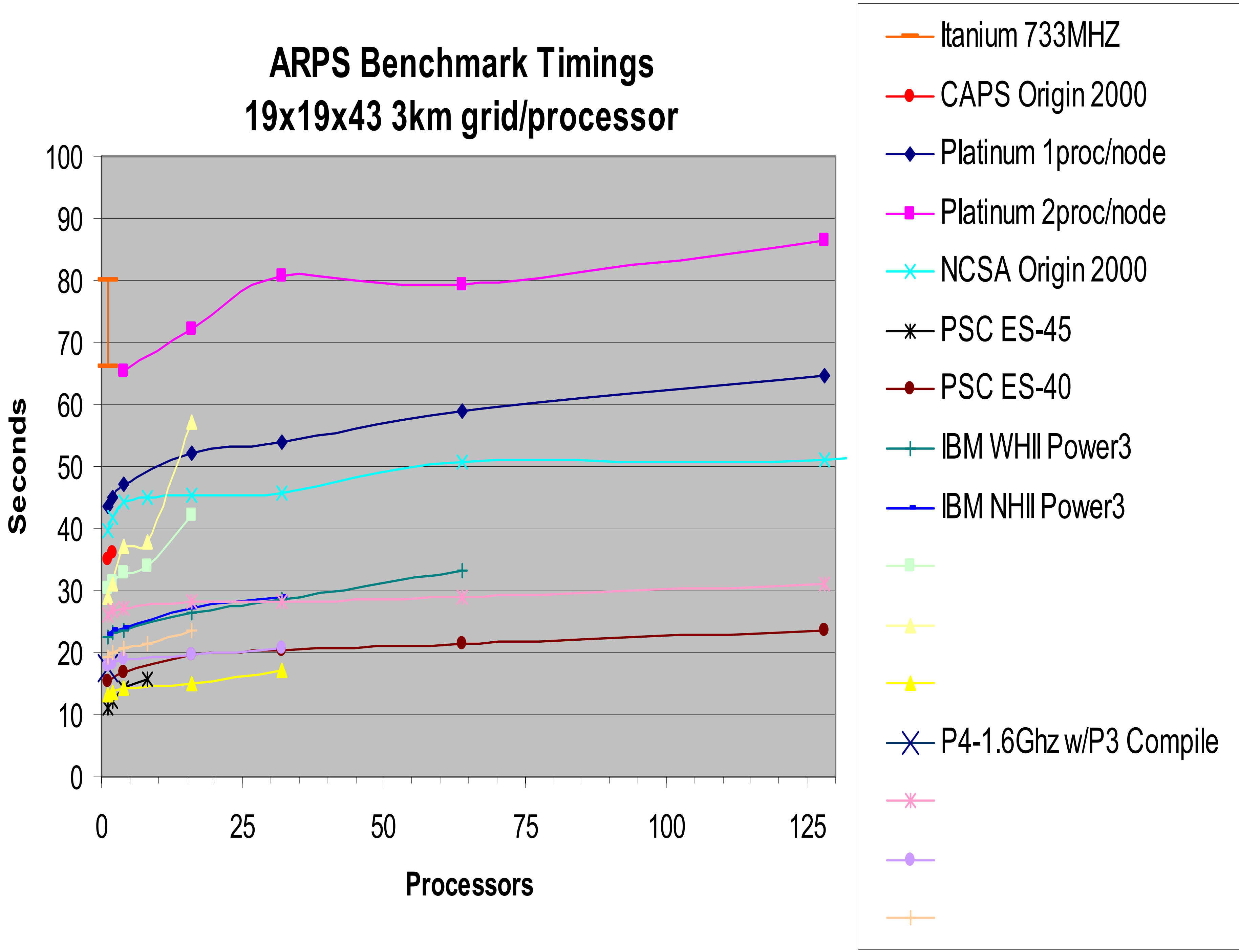
Advanced Regional Prediction System (ARPS)

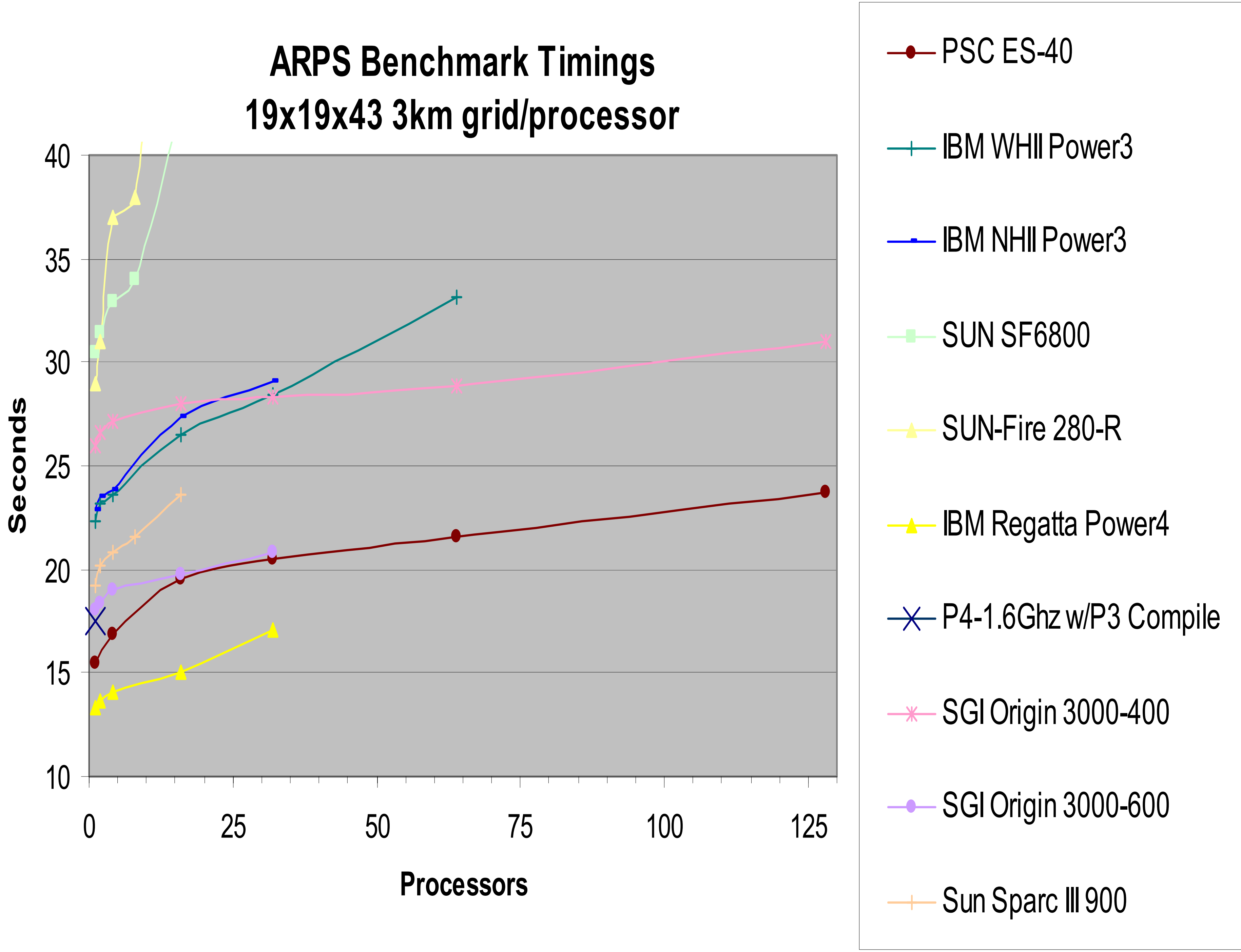




The ARPS

- Cartesian grid-point code (600,000 lines of Fortran-90) developed new beginning in 1992
- Uses 2-D domain decomposition and MPI/Open-MP
- Emphasis given to portability, scalability, parallelism, adaptability
- Solves 12-15 nonlinear PDEs; 10^{11} equations per forecast
- Has has been run on dozens of machines ranging from Laptops to the CM-200 to a 1024 node Cray T3E to Alpha and Linux Clusters

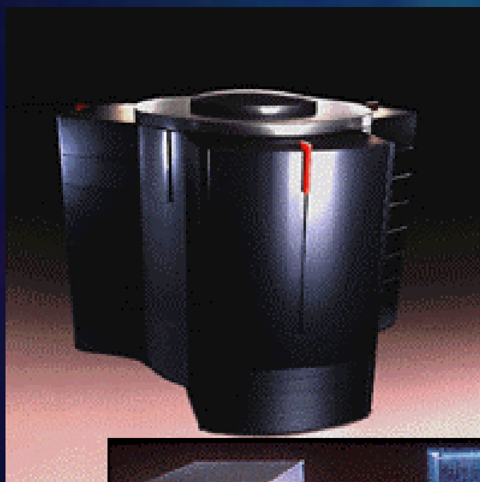

ARPS Benchmark Timings
19x19x43 3km grid/processor
Seconds
Processors
100
90
80
70
60
50
40
30
20
10
0
0
25
50
75
100
125
Itanium 733MHZ
CAPS Origin 2000
Platinum 1proc/node
Platinum 2proc/node
NCSA Origin 2000
PSC ES-45
PSC ES-40
IBM WHII Power3
IBM NHII Power3
P4-1.6Ghz w/P3 Compile

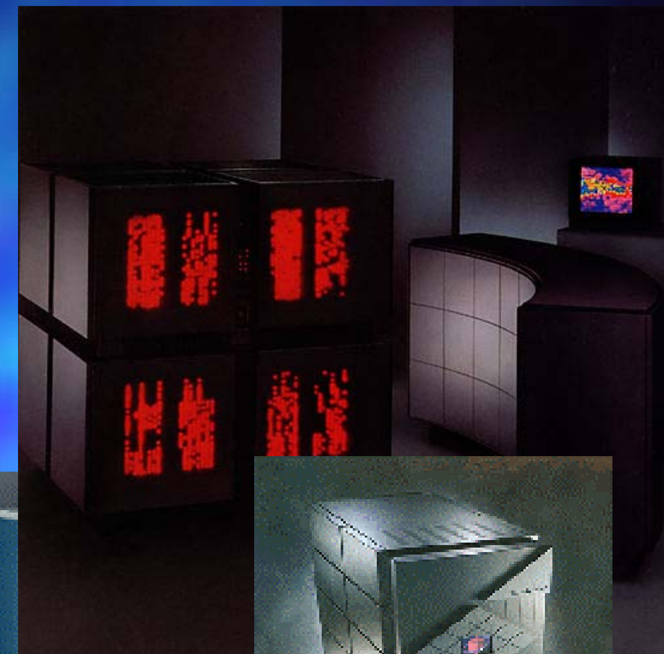
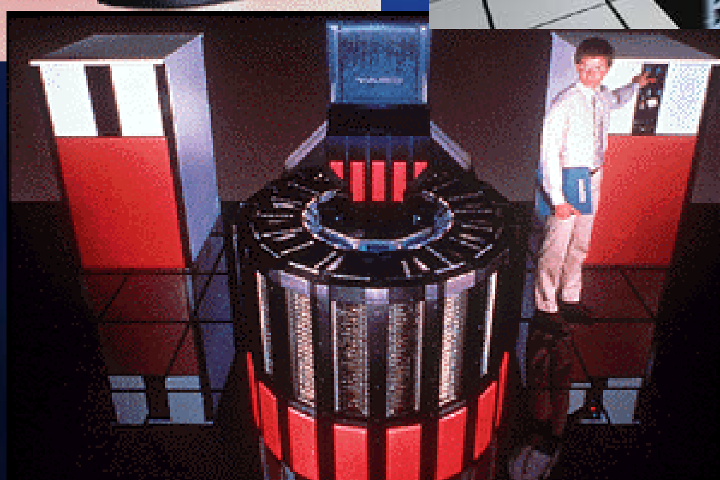
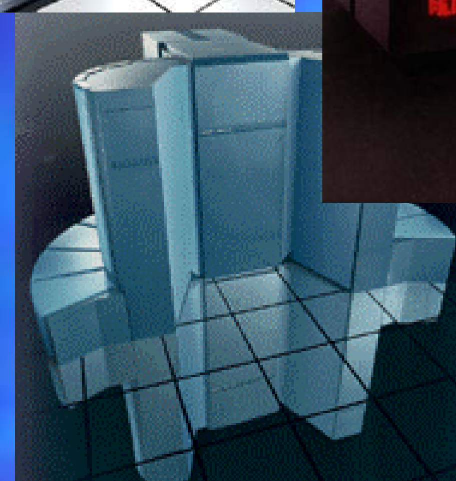
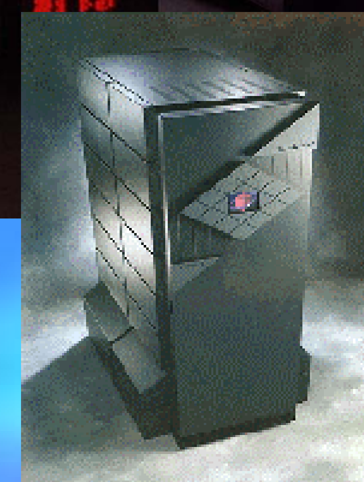


ARPS Benchmark Timings
19x19x43 3km grid/processor
Seconds
Processors
40
35
30
25
20
15
10
0
25
50
75
100
125
PSC ES-40
IBM WHII Power3
IBM NHII Power3
SUN SF6800
SUN-Fire 280-R
IBM Regatta Power4
P4-1.6Ghz w/P3 Compile
SGI Origin 3000-400
SGI Origin 3000-600
Sun Sparc III 900

Three Key Ingredients for Storm-Scale Prediction

- #2 -- Sufficient computing power to accommodate high spatial resolution and produce a forecast at least **10x the speed of the weather**



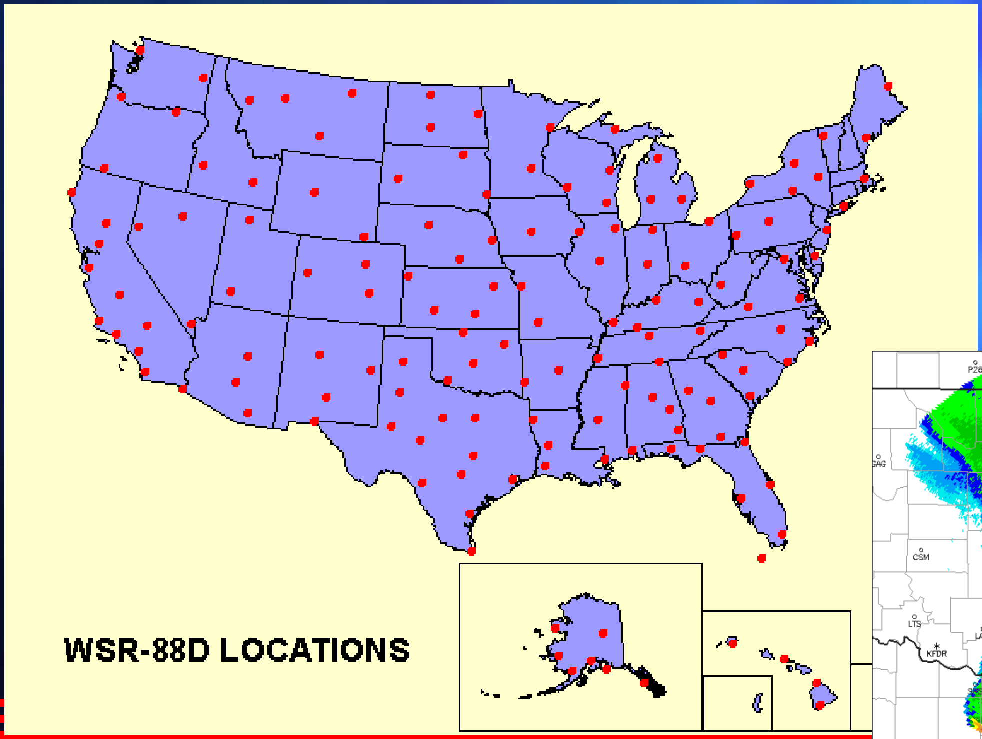





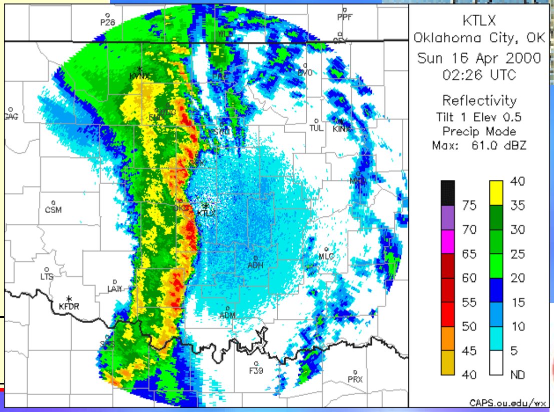
The Need for Teraflops

- Must fit the prediction model to the observations (data assimilation/retrieval)
  - About 50-100 times as expensive as the forecast
- Must use high spatial resolution
  - 1-3 km resolution in sufficiently large domains
- Must quantify forecast uncertainty (ensembles)
  - May need 20-30 forecasts to produce an ensemble each forecast cycle
- Requirements: 10-100 TFLOPS <u>sustained</u>; 0.5 TB memory; 20 TB storage

Three Key Ingredients for Storm-Scale Prediction

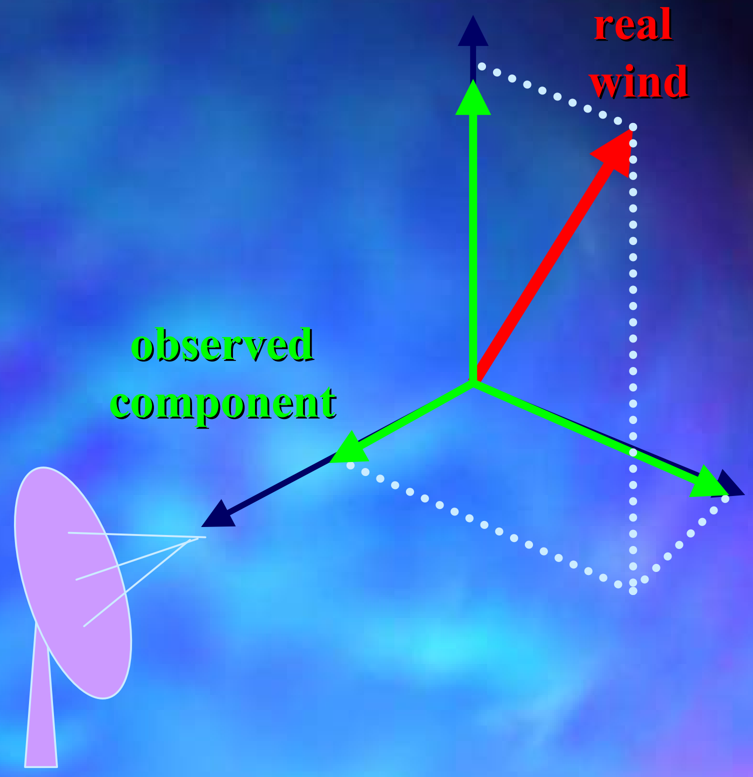
- #3 -- Observations of sufficiently high time/space resolution



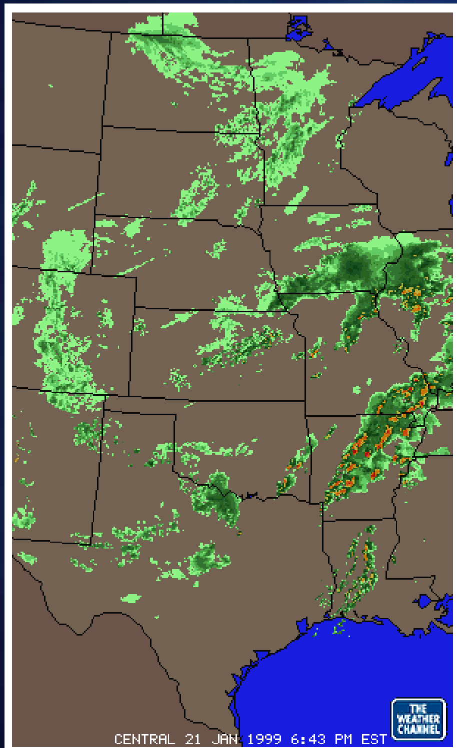


The Challenge of Using Doppler Radar Data in Numerical Weather Prediction

- The radar observes ...
  - one (radial) wind component
  - precipitation intensity
- We need ...
  - 3 wind components
  - temperature
  - humidity
  - pressure
  - water substance (6-10 fields)
- CAPS was created to explore solutions to this "retrieval" problem and apply them to storm-scale numerical prediction

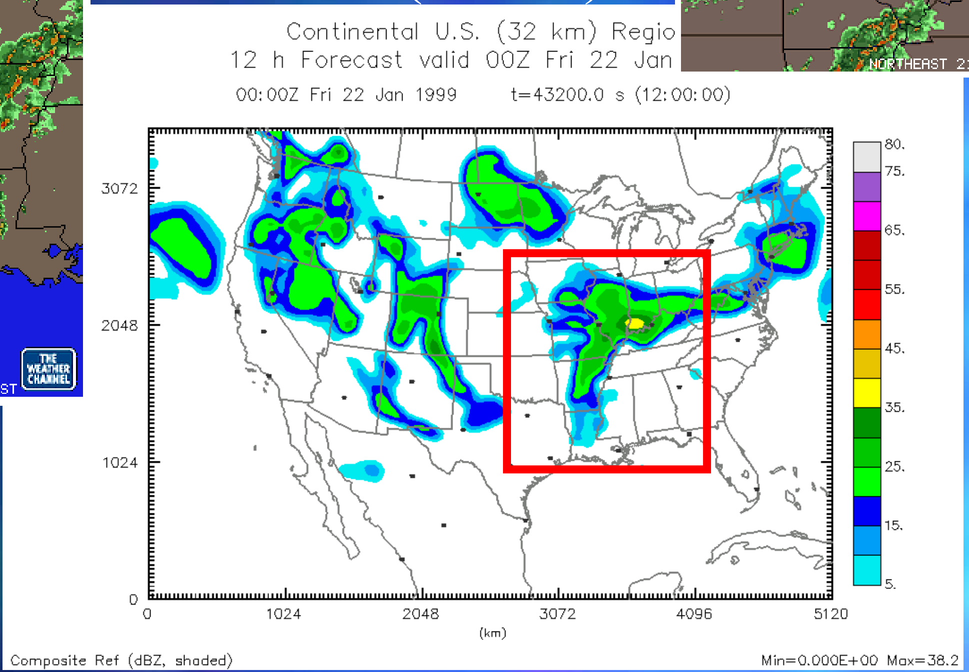


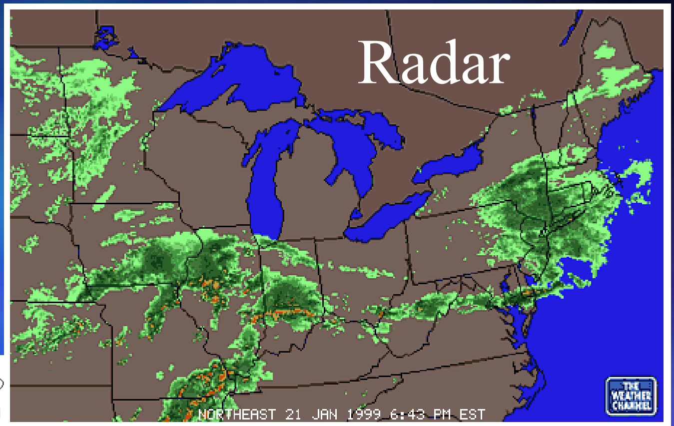
The Impact of Regional/Local Prediction



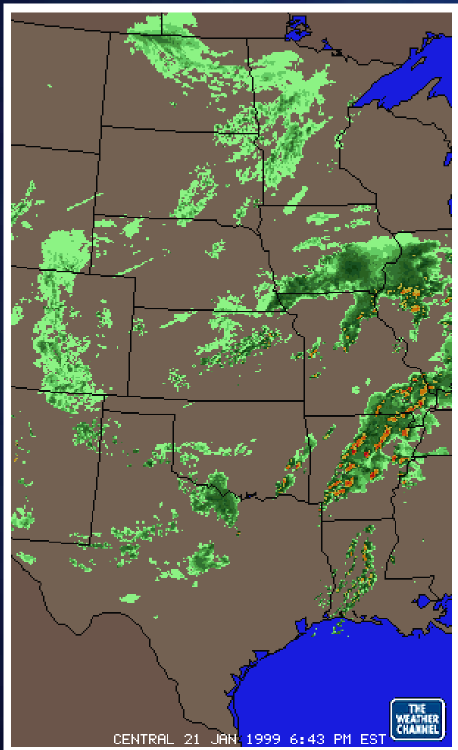
Radar (Tornadoes in Arkansas)

CAPS 12-hour Forecast (32 km)



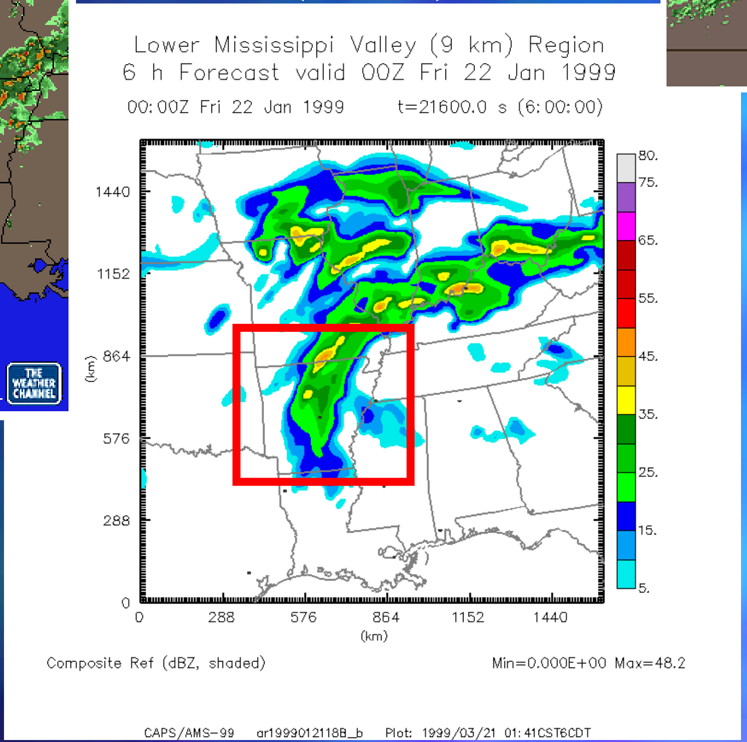


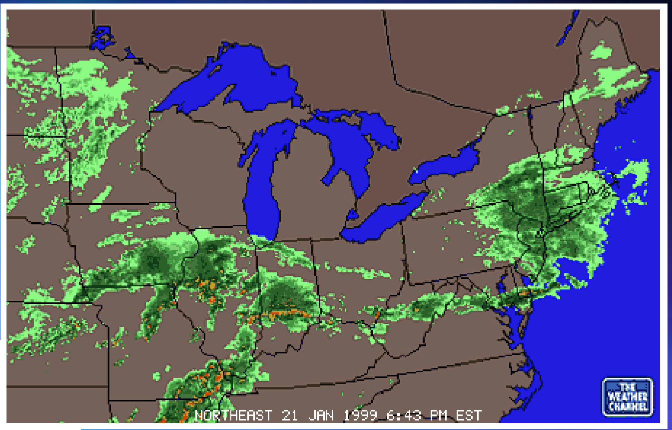
The Impact of Regional/Local Prediction



Radar (Tornadoes in Arkansas)

CAPS 6-hour Regional Forecast (9 km)

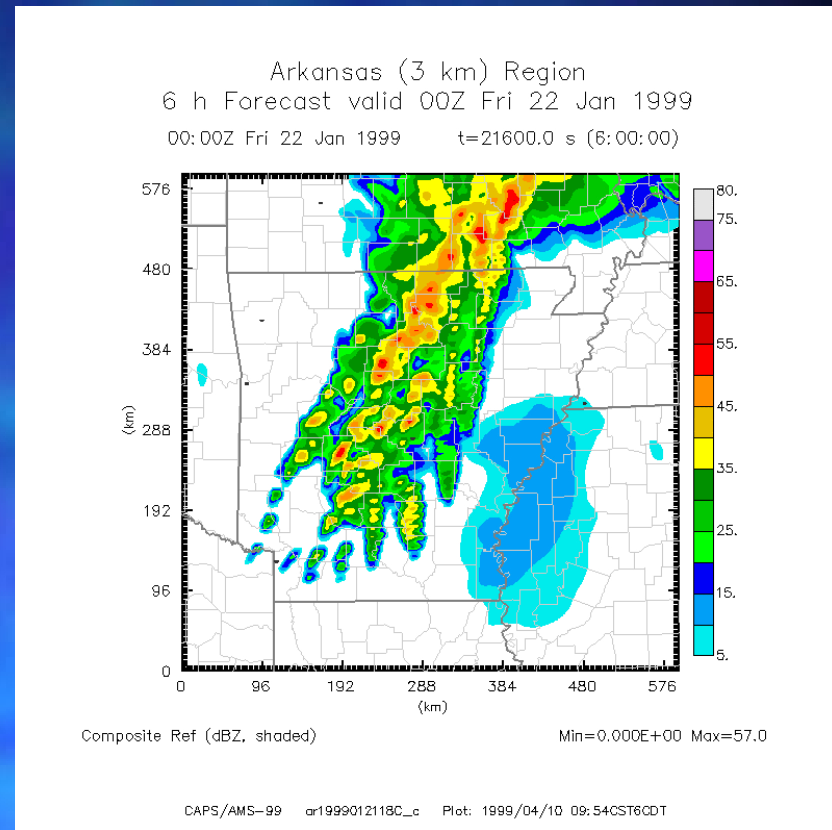




Radar

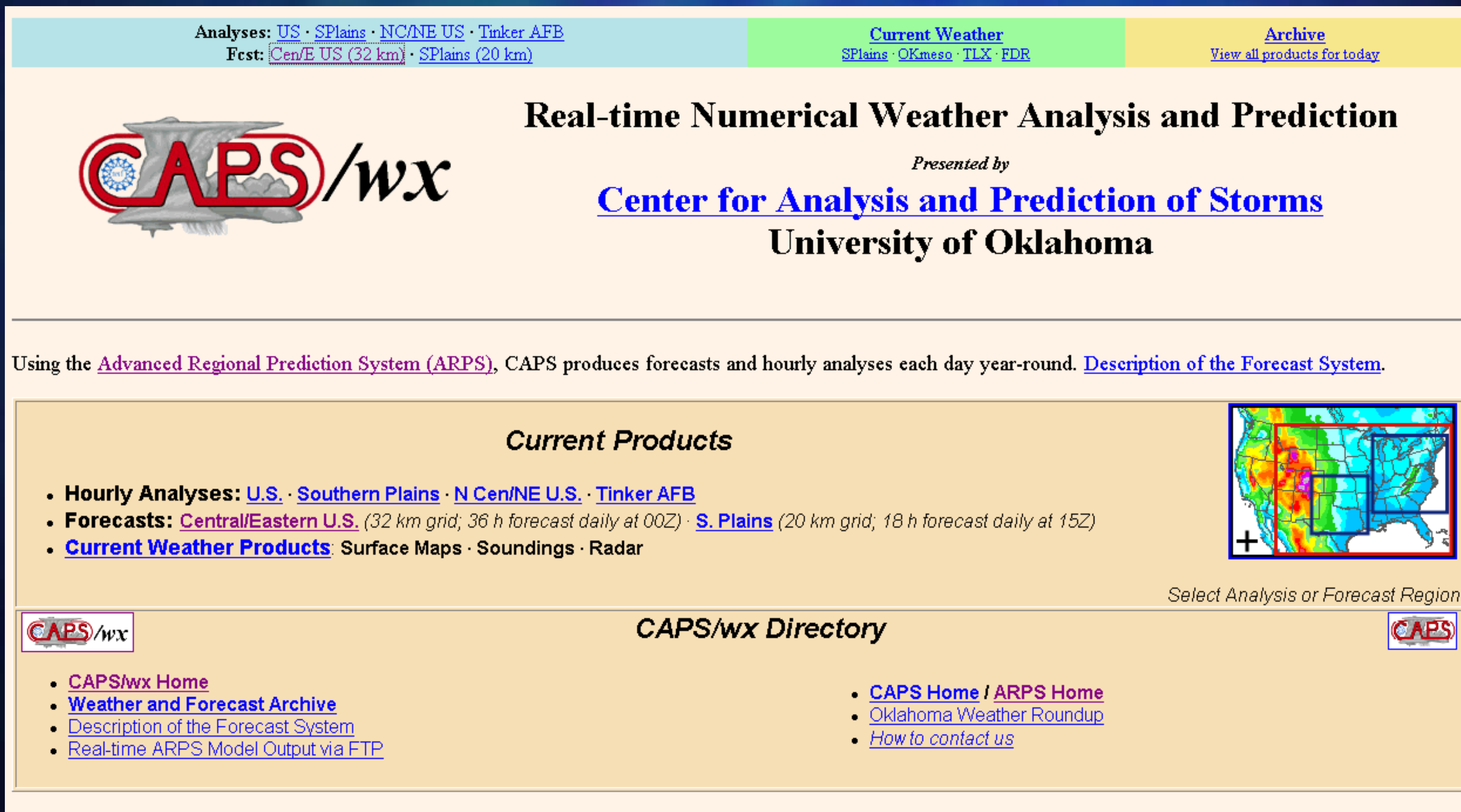
The Impact of Regional/Local Prediction

Radar



CAPS 6-hour Local Forecast (3 km)

Real Time Forecasts



Analyses: US · SPlains · NC/NE US · Tinker AFB
Fcst: Cen/E US (32 km) · SPlains (20 km)

Current Weather
SPlains · OKmeso · TLX · FDR

Archive
View all products for today

CAPS/wx

Real-time Numerical Weather Analysis and Prediction

Presented by

Center for Analysis and Prediction of Storms
University of Oklahoma

Using the Advanced Regional Prediction System (ARPS), CAPS produces forecasts and hourly analyses each day year-round. Description of the Forecast System.

Current Products

- **Hourly Analyses:** U.S. · Southern Plains · N Cen/NE U.S. · Tinker AFB
- **Forecasts:** Central/Eastern U.S. *(32 km grid; 36 h forecast daily at 00Z)* · S. Plains *(20 km grid; 18 h forecast daily at 15Z)*
- **Current Weather Products**: Surface Maps · Soundings · Radar

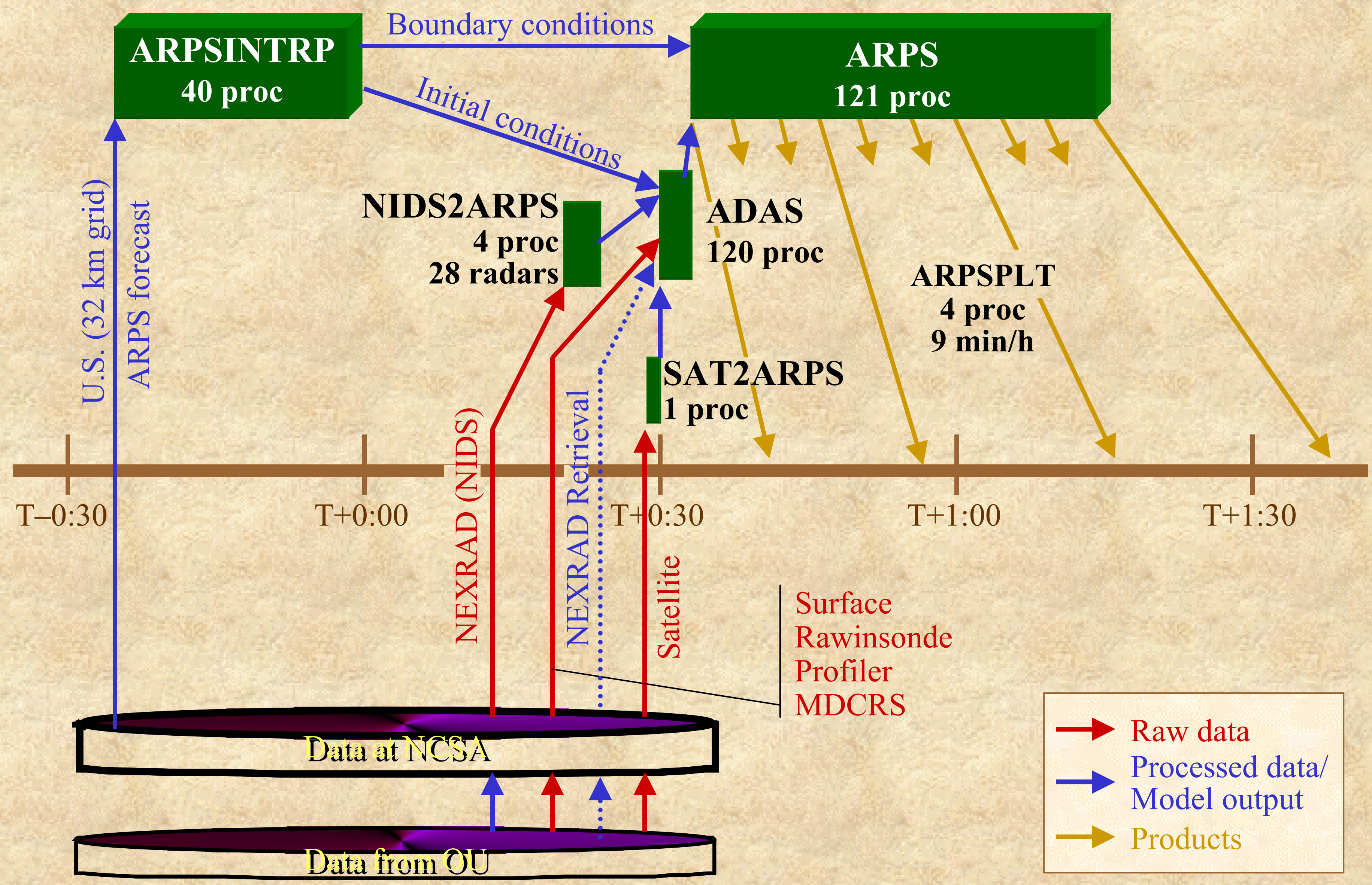
Select Analysis or Forecast Region

CAPS/wx Directory

- CAPS/wx Home
- Weather and Forecast Archive
- Description of the Forecast System
- Real-time ARPS Model Output via FTP
- CAPS Home / ARPS Home
- Oklahoma Weather Roundup
- *How to contact us*

Data and Process Flow Timeline

AMS-99 • Southern Plains (9 km) grid • 9 h forecast



OU Supercomputing Center for Education and Research

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The OU Supercomputing Center for Education & Research helps undergraduates, grad students, faculty and staff to learn and use supercomputing in their science and engineering.

Latest News

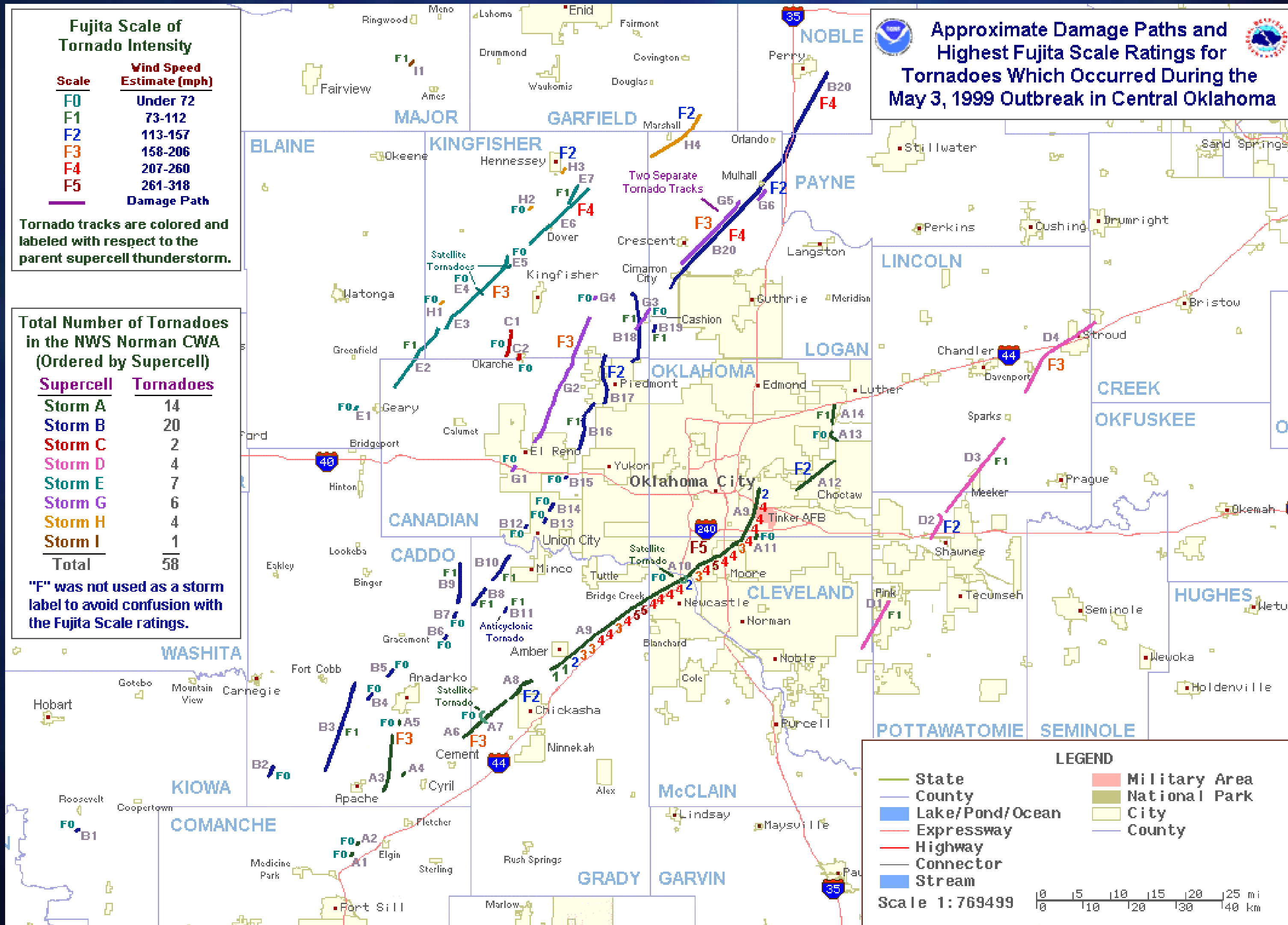
July 18 2002:	OU's Channel 22 "University Profile" series now has a video about OSCER (15 MB WMV) by Kevin Blake & Heather Finstuen
June 15 2002:	Read about OSCER in the Norman Transcript
May 13 2002:	A/C roof units installed [OU Daily] [Norman Transcript]
May 10 2002:	Visit from IBM VP for HPC Sales Peter Ungaro (next to last row of pictures)
May 6 - 9 2002:	Visit from Aspen Systems Inc for Xeon cluster installation
May 6 2002:	Xeon cluster delivered
April 2 - 5 2002:	IBM FAStT500 delivered
April 2 2002:	IBM Regatta delivered
March 29 2002:	IBM Regatta and FAStT500 ordered
March 4 2002:	Xeon Cluster ordered from Aspen
December 7 2001:	OU Board of Regents approves supercomputers
August 31 2001:	First Supercomputing in Plain English workshop
August 31 2001:	OSCER founded as a division of the Department of Information Technology

THE UNIVERSITY OF OKLAHOMA One of America's 100 Best College Buys

Vice President for Research University of Oklahoma

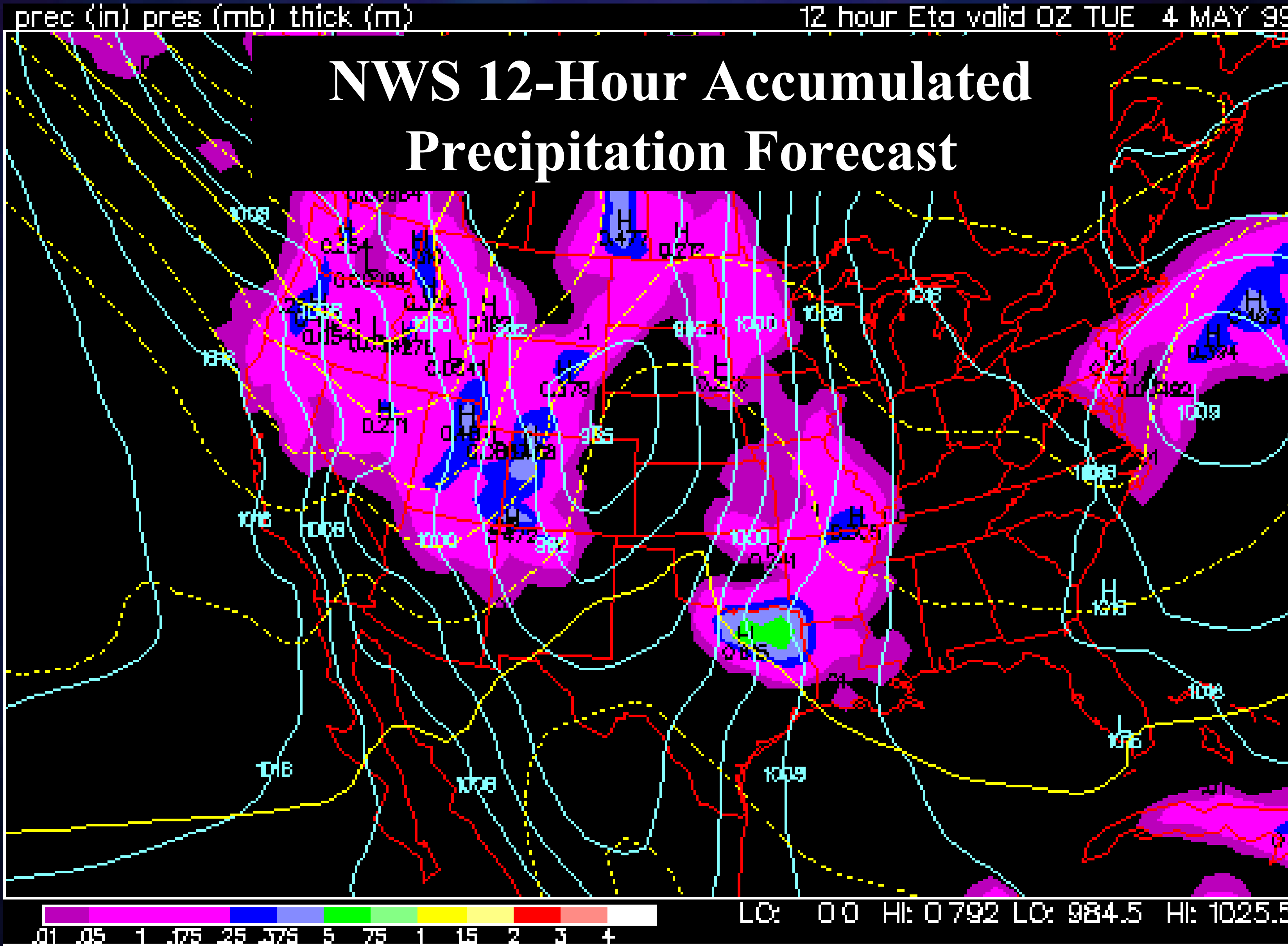
3 May 1999 Oklahoma Tornado Outbreak

May 3 Tornado Tracks/Intensity

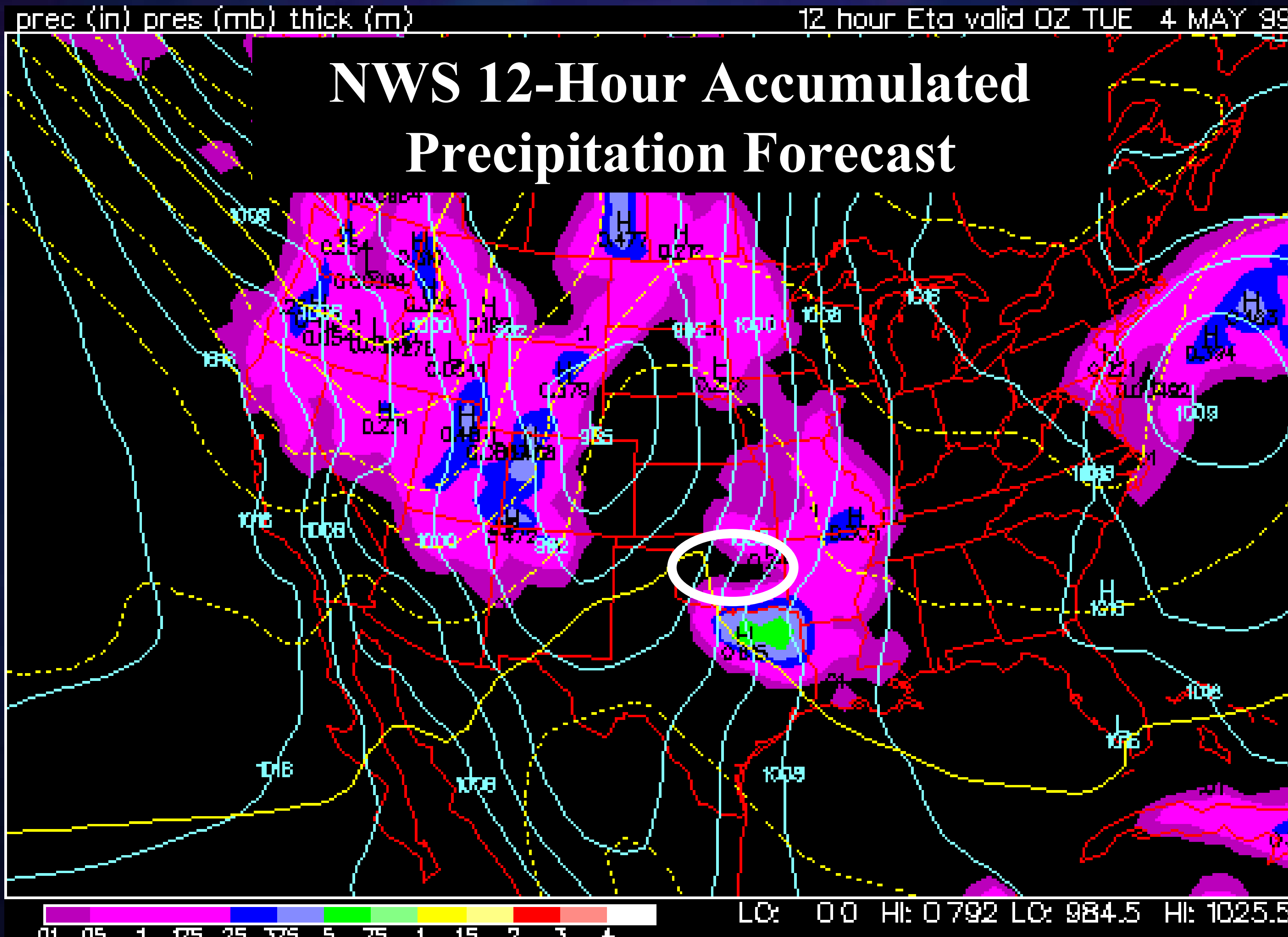


Courtesy Oklahoma City Area National Weather Service Forecast Office

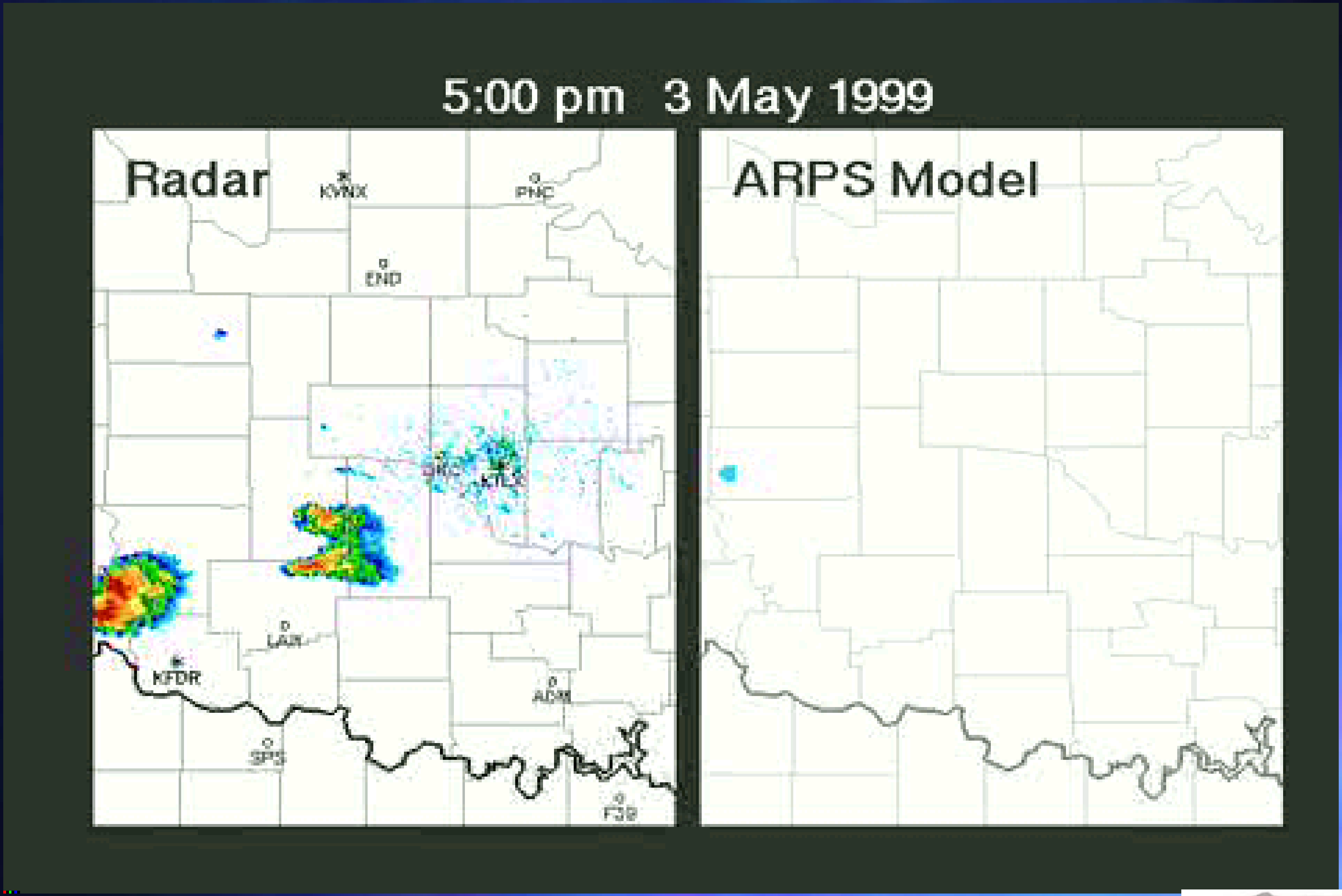
NWS 12-Hour Accumulated Precipitation Forecast



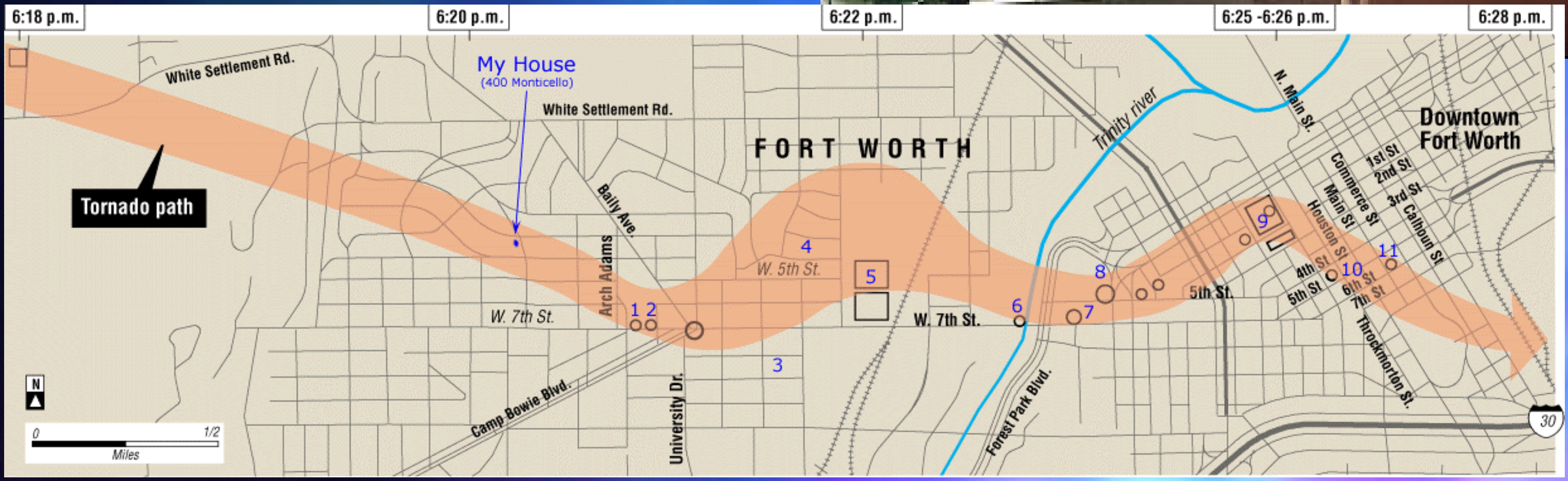
NWS 12-Hour Accumulated Precipitation Forecast



CAPS Numerical Forecasts of the May 3 Tornadic Storms

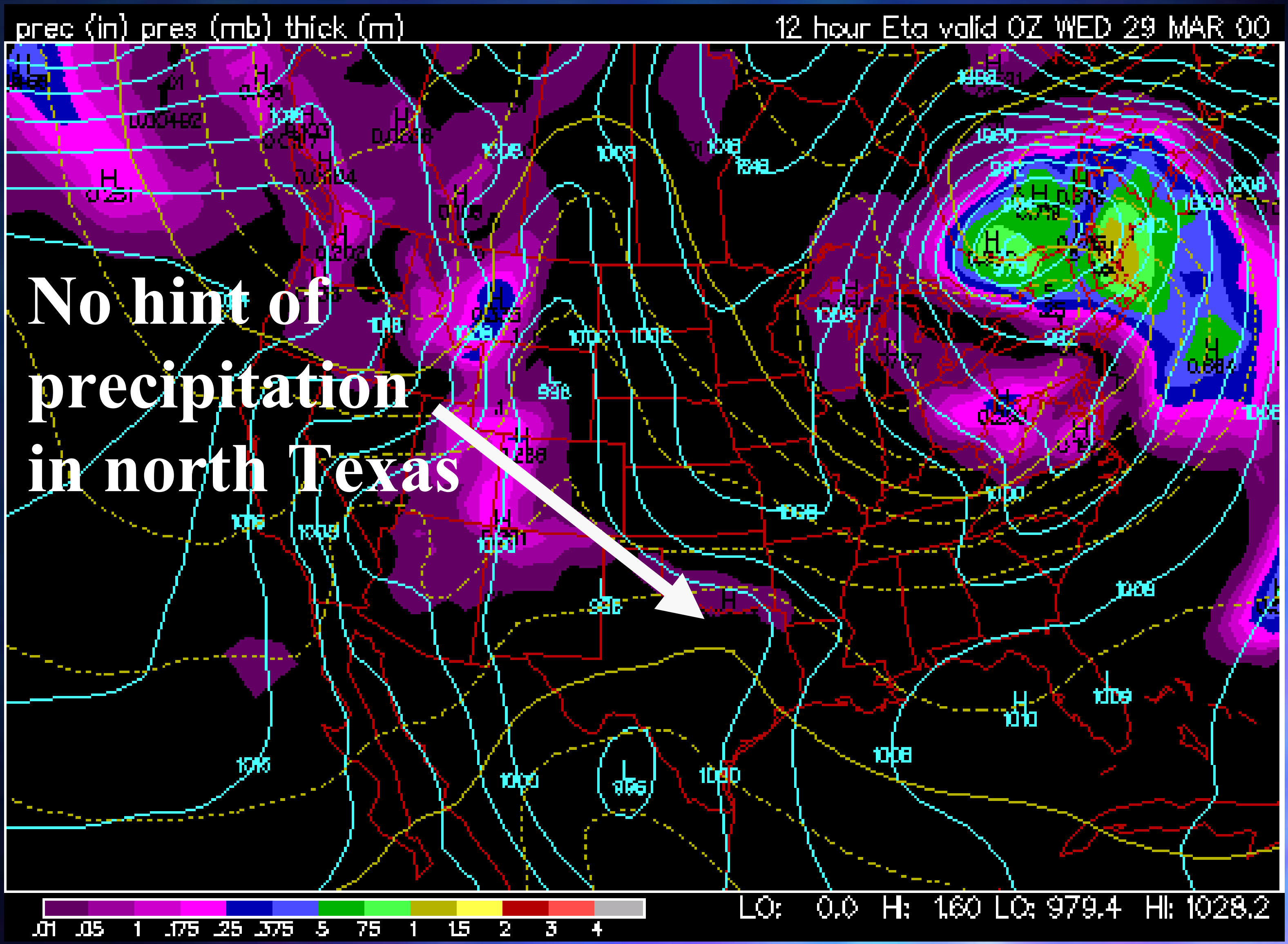


March 28, 2000 Fort Worth Tornado



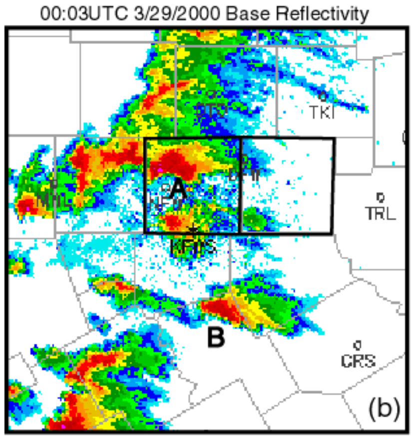
Fort Worth Tornadic Storm on TV Radar

NWS 12-hr NWS Forecast (32 km resolution) Valid 6 pm CDT (shading indicates 12-hr accumulated precipitation)

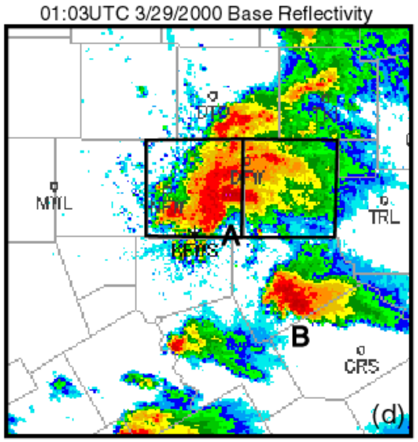


KFWS Radar Observations

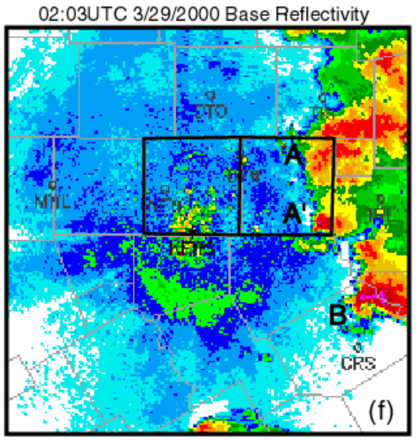
(6 pm)



(7 pm)



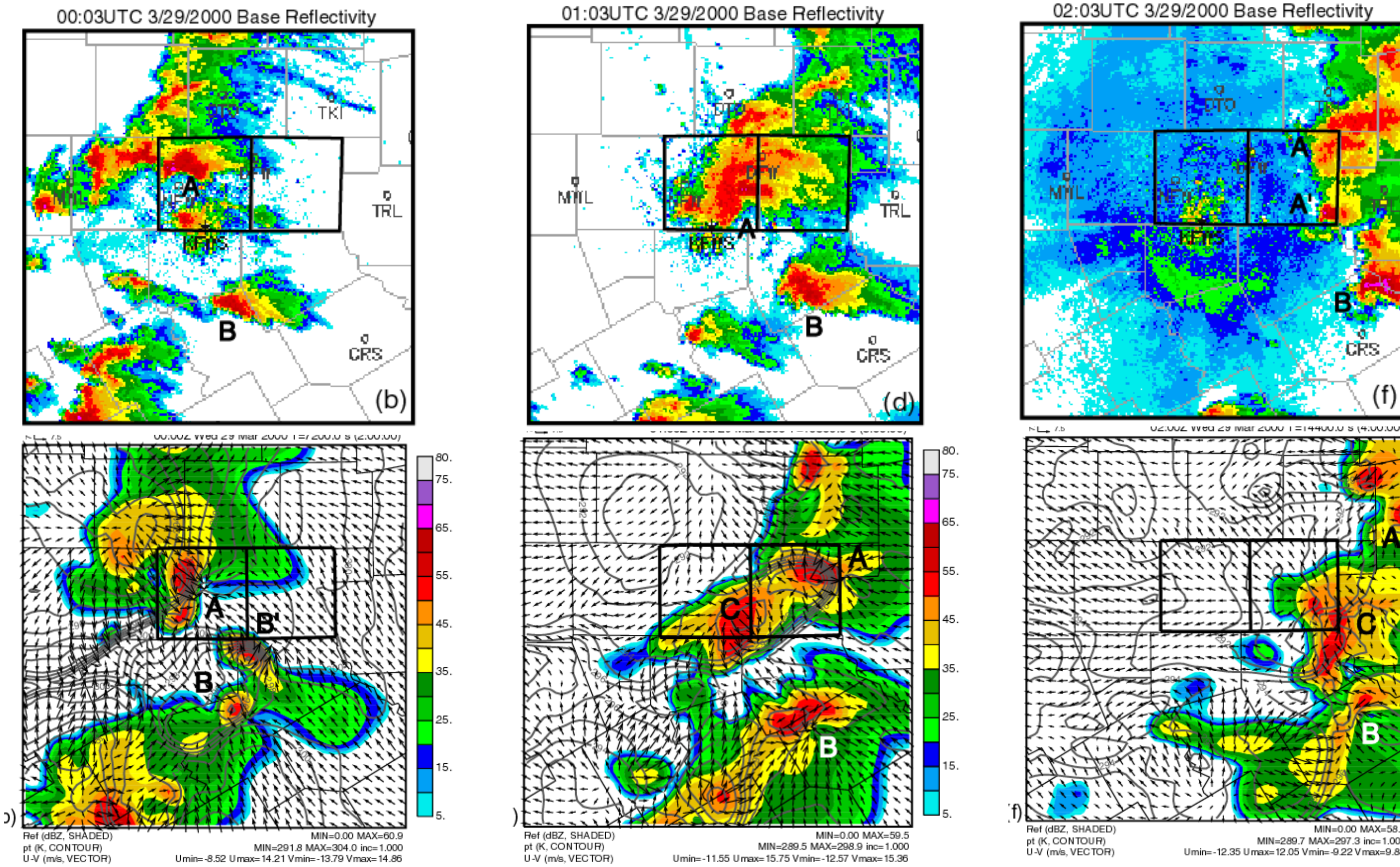
(8 pm)



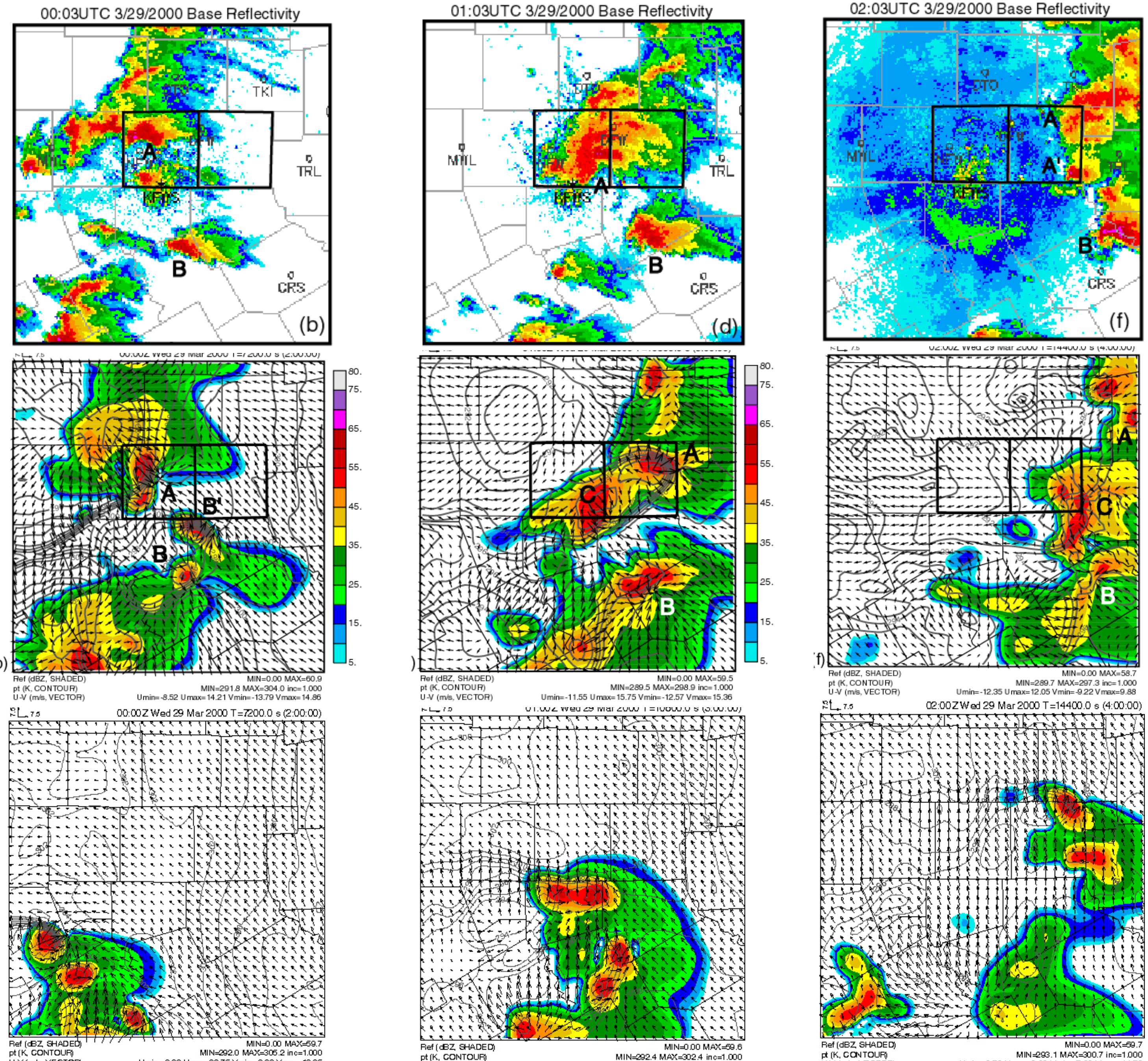
2 hrs (6 pm) | 3 hrs (7 pm) | 4 hrs (8 pm)

KFWS Radar Observations

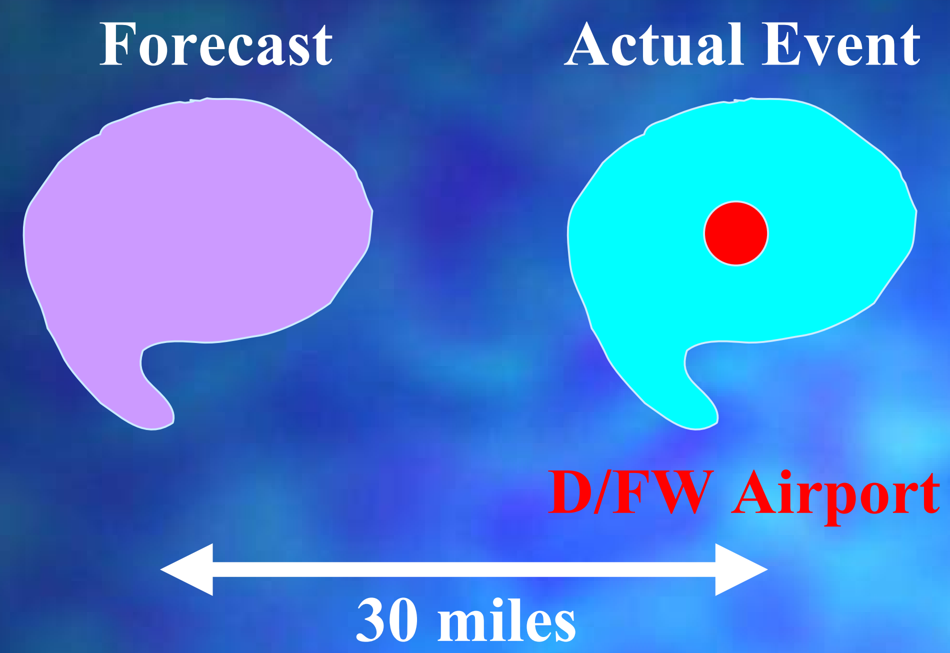
ARPS 3 km Forecast <u>With</u> Radar Data



	2 hrs (6 pm)	3 hrs (7 pm)	4 hrs (8 pm)
KFWS Radar Observations			
ARPS 3 km Forecast **With** Radar Data			
ARPS 3 km Forecast **Without** Radar Data			

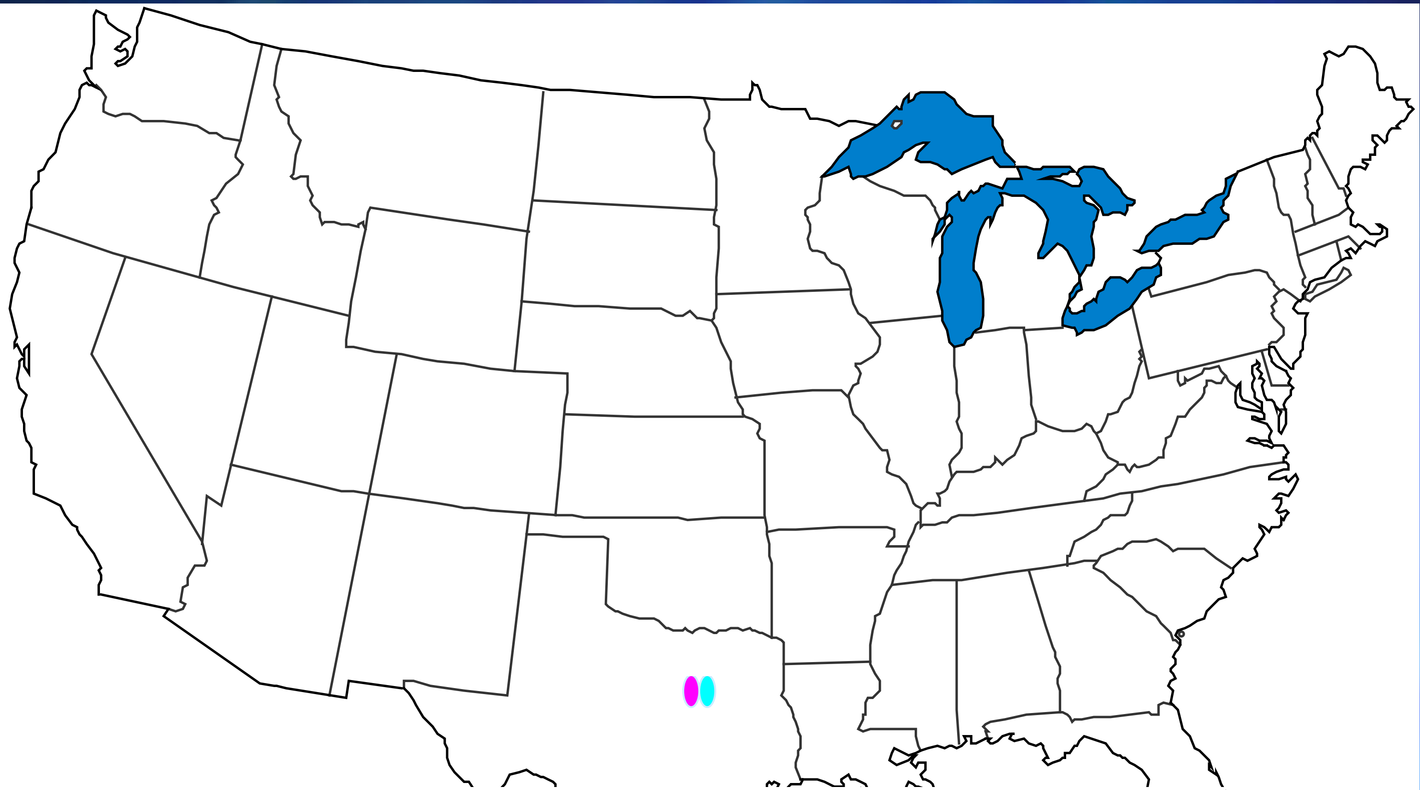


How Good are the Forecasts??



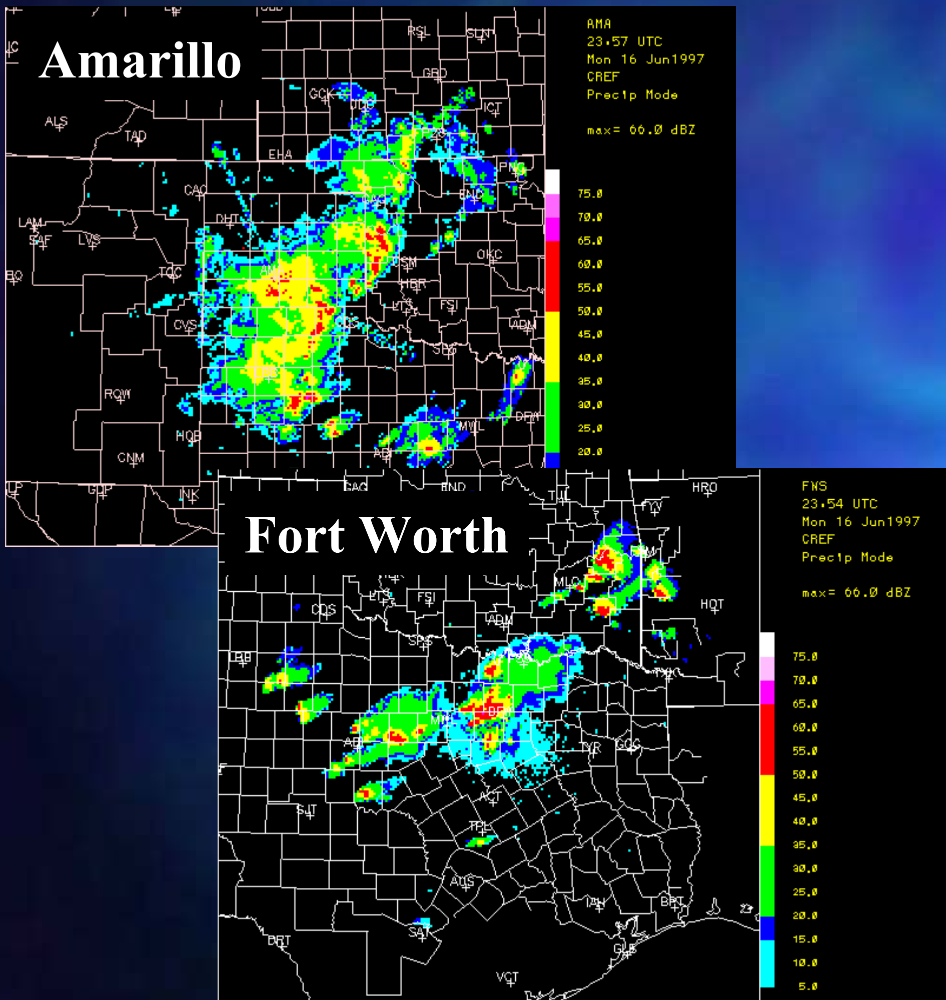
A perfectly predicted storm having a position error of 30 miles may be a terrible forecast on the scale of a single airport

How Good Are the Forecasts??

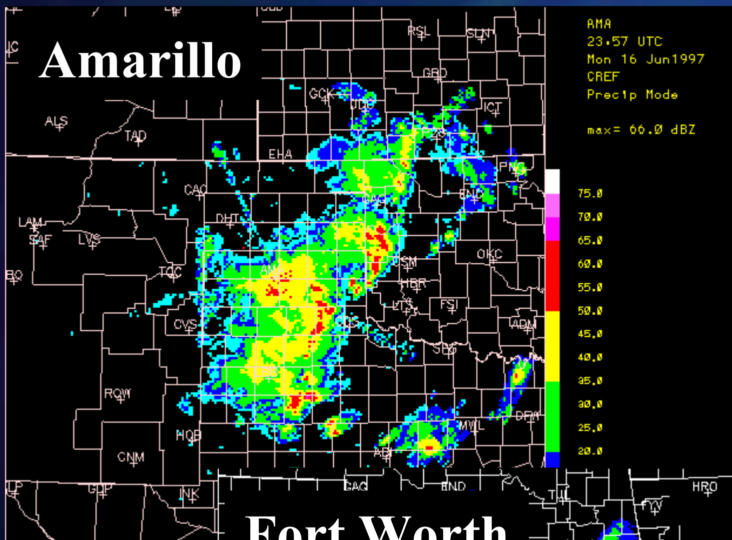


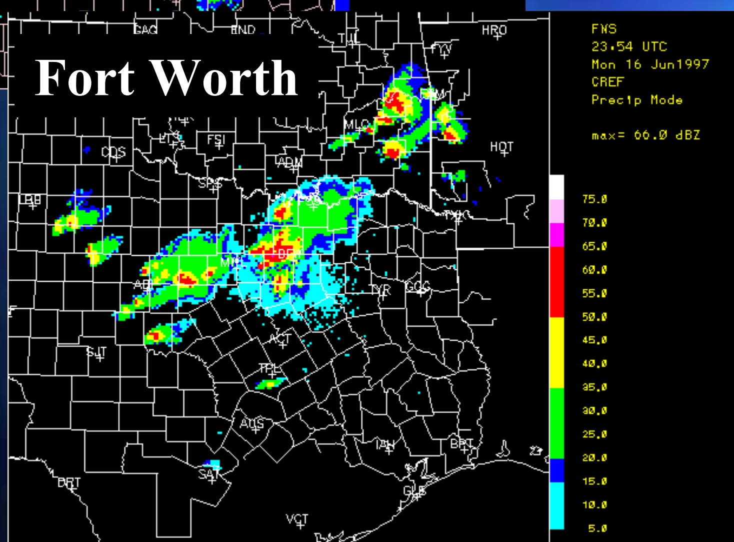
This same forecast would, on a larger scale, be viewed as exceptionally accurate

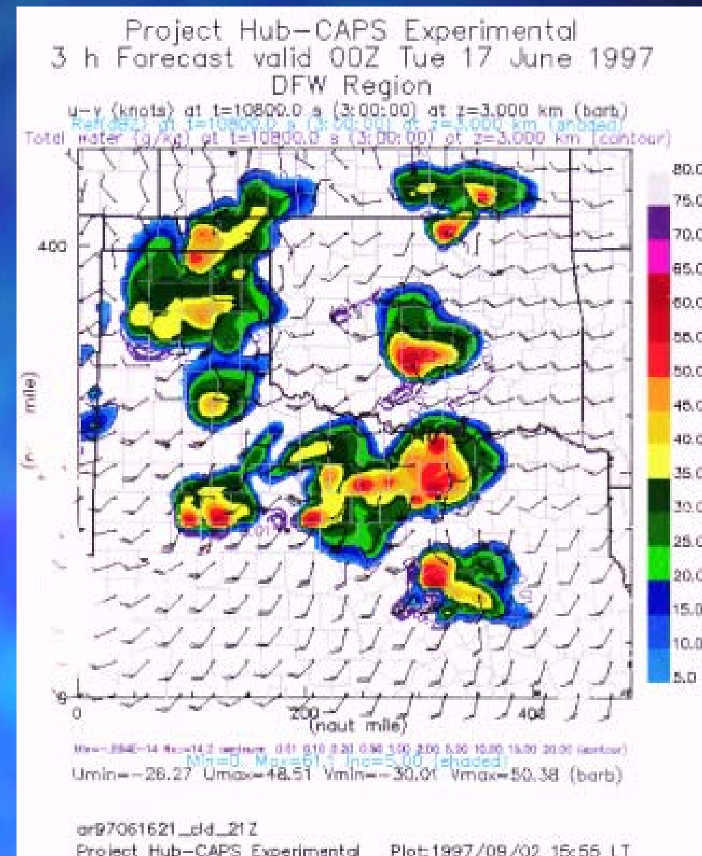
Pinning Your Forecast on a Single Model Run???



Pinning Your Forecast on a Single Model Run???

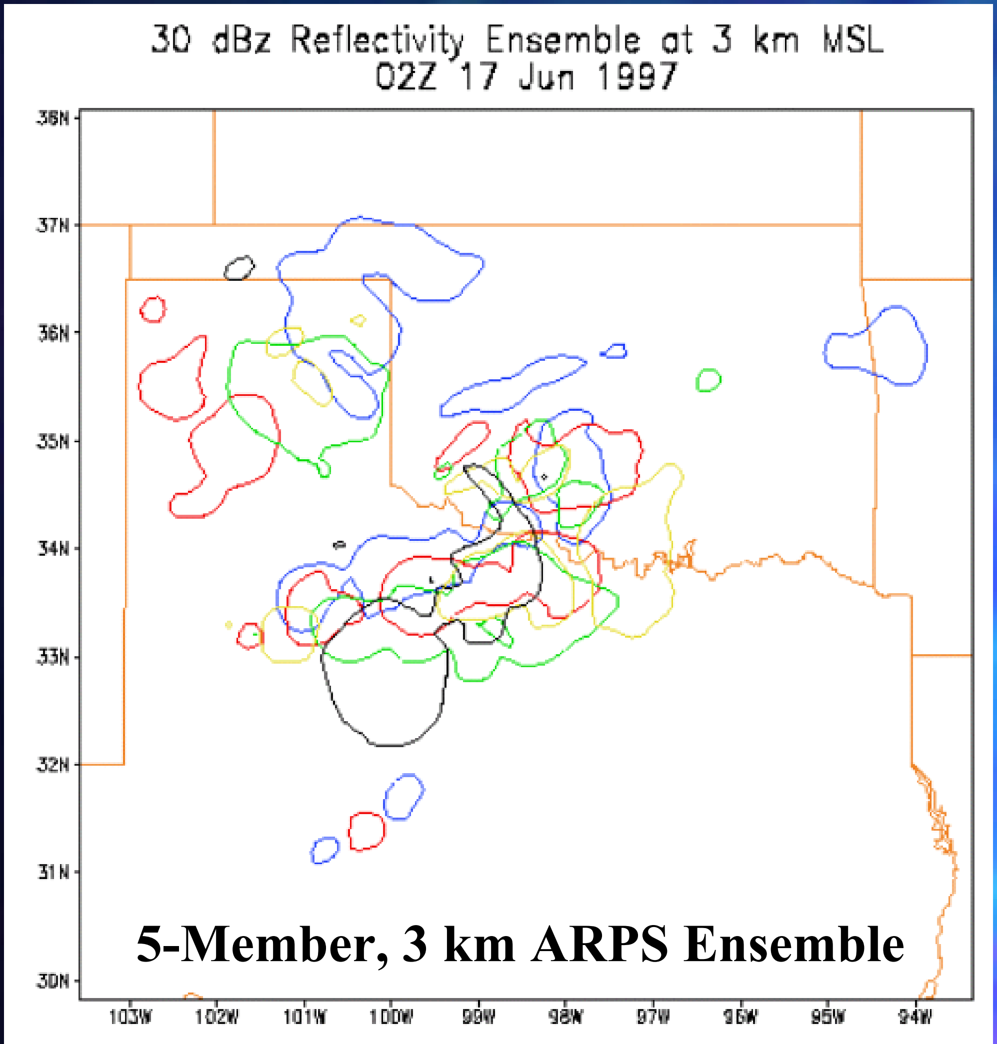


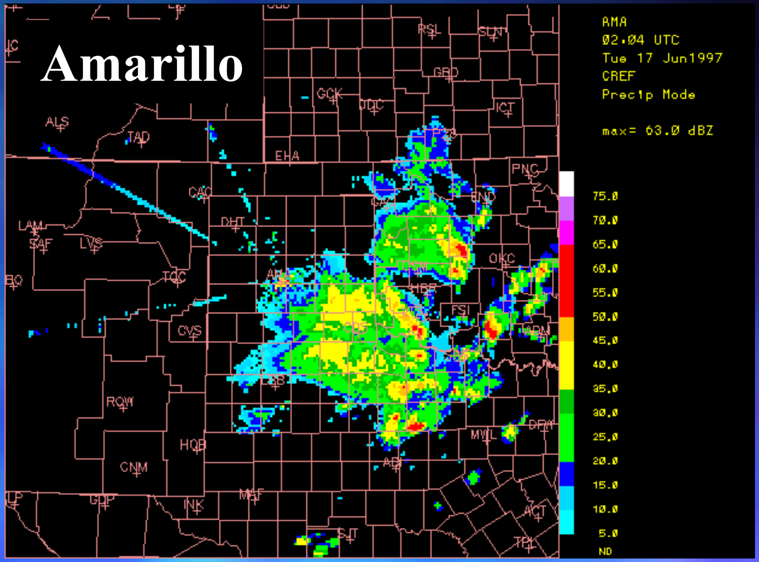


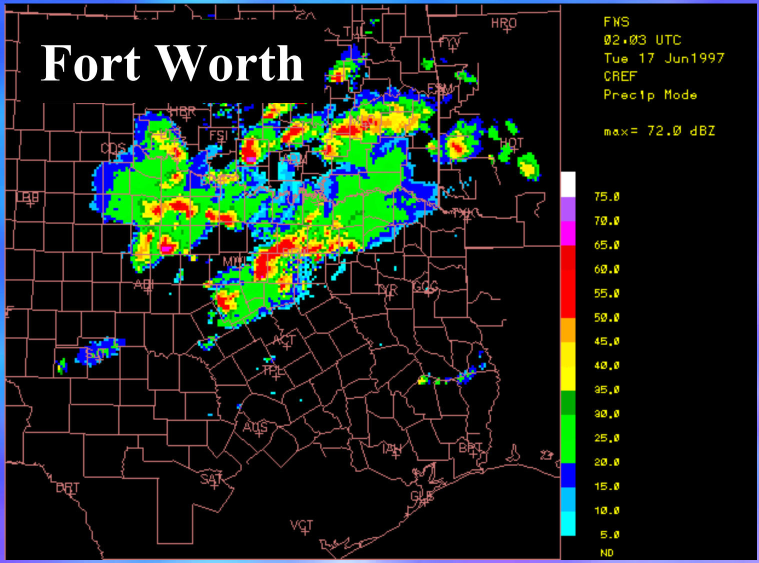


3 km ARPS Forecast Valid 00Z Monday, 16 June 1997

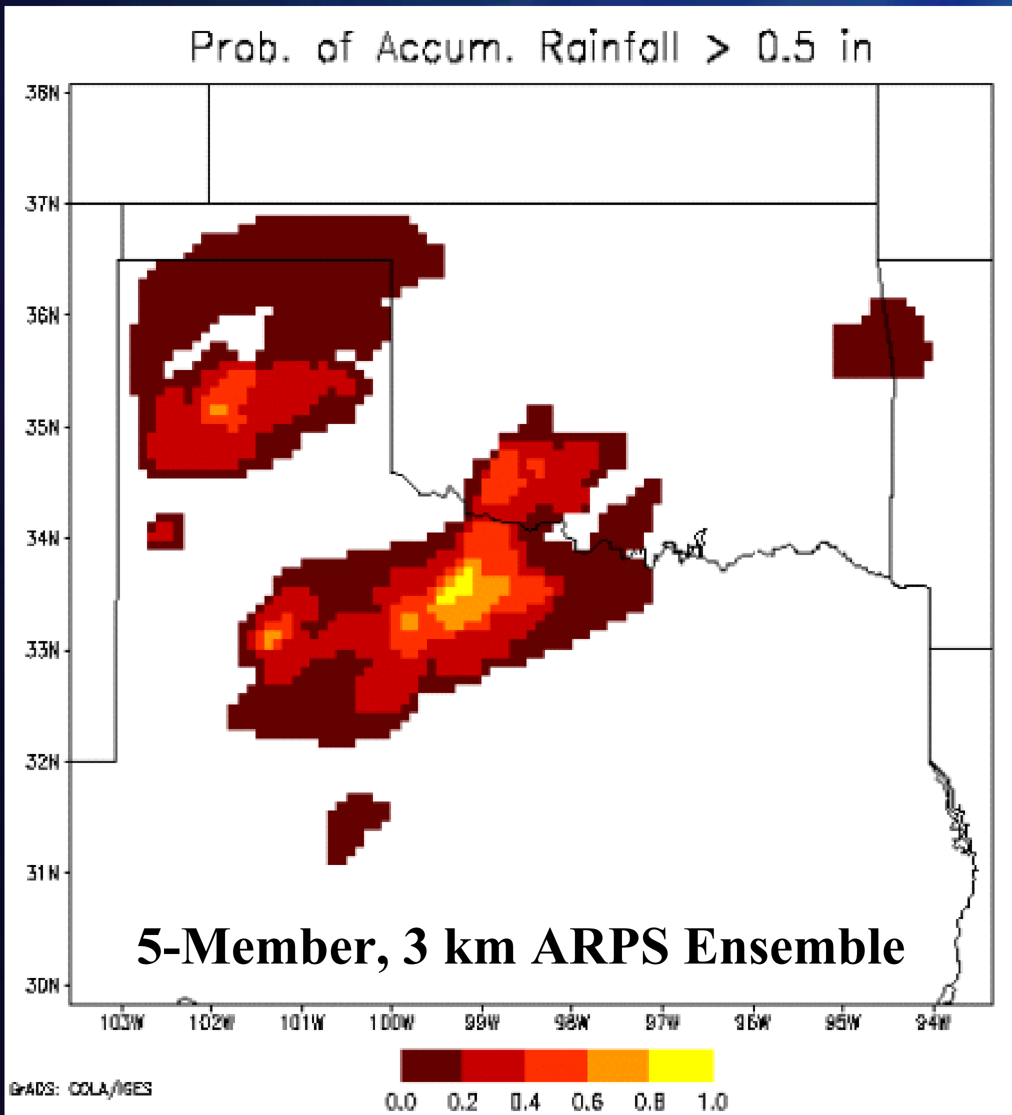
Storm-Scale Ensembles in Action

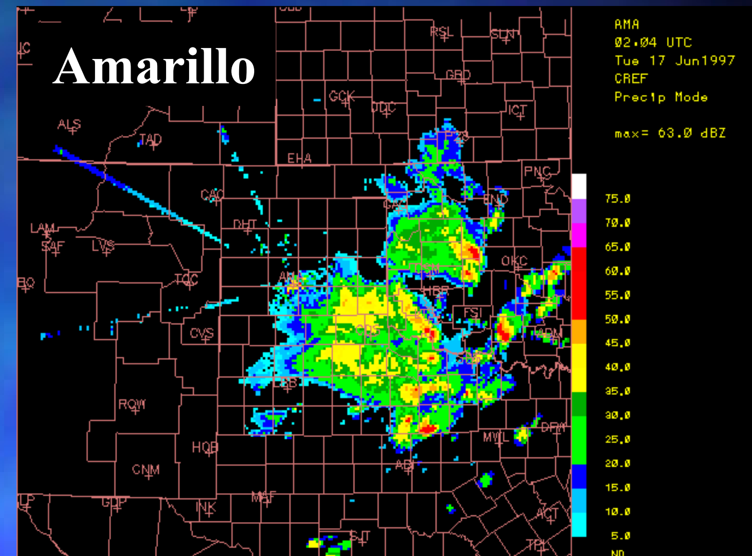


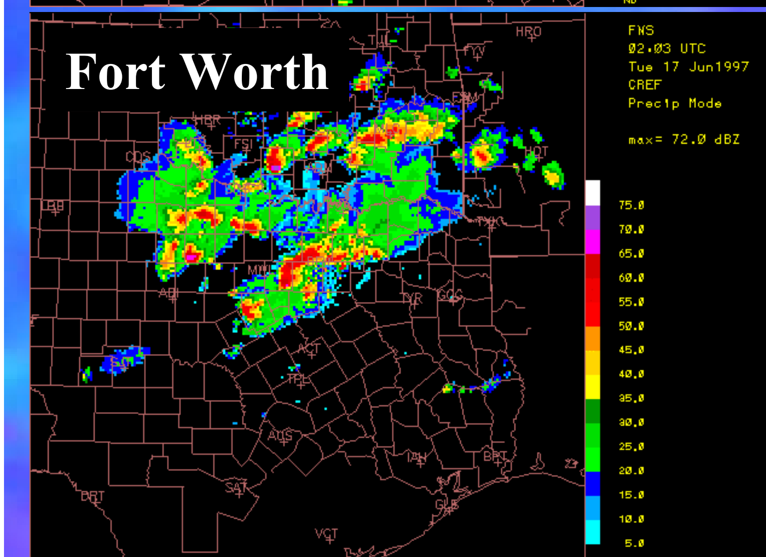




Storm-Scale Ensembles in Action







The Private Sector Enters the NWP Game

WEATHER CENTRAL, INC

The world leader in weather systems and services since 1974

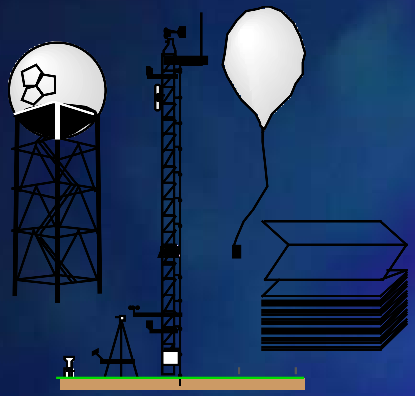
5725 Tokay Boulevard Madison, Wisconsin 53719
Phone - 608-274-5789

WDT

Weather Decision Technologies, Inc.

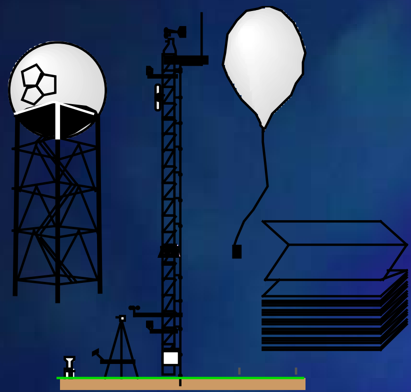
WSI

Traditional Methodology

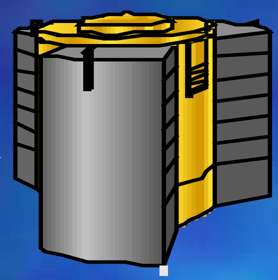


Raw Data Collection
& Dissemination (NWS)

Traditional Methodology

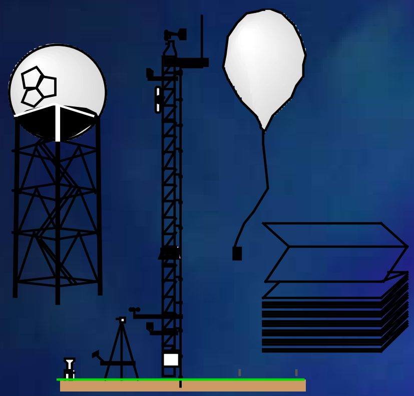


Raw Data Collection
& Dissemination (NWS)

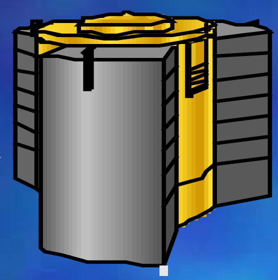


Computer
Forecast Models (NWS)

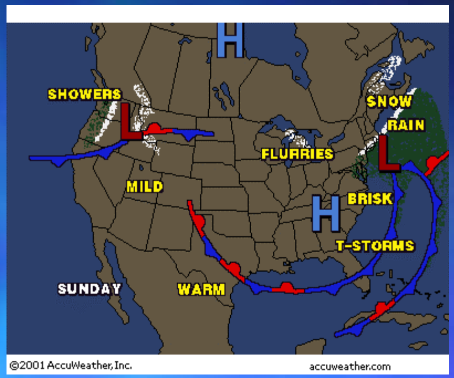
Traditional Methodology



Raw Data Collection
& Dissemination (NWS)

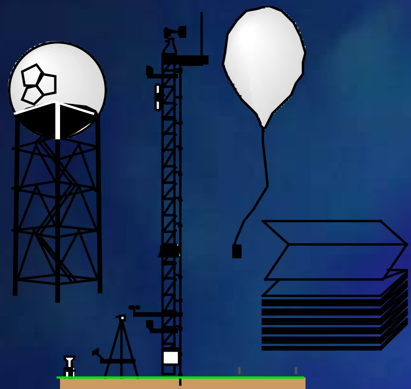


Computer
Forecast Models (NWS)

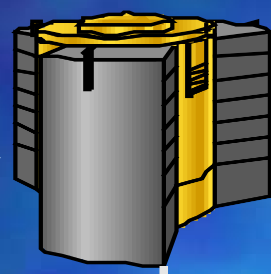


Data/Products (NWS)

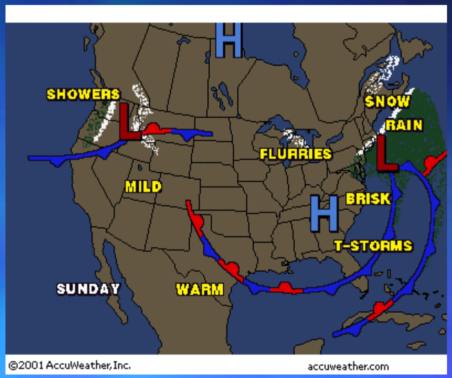
Traditional Methodology



Raw Data Collection
& Dissemination (NWS)



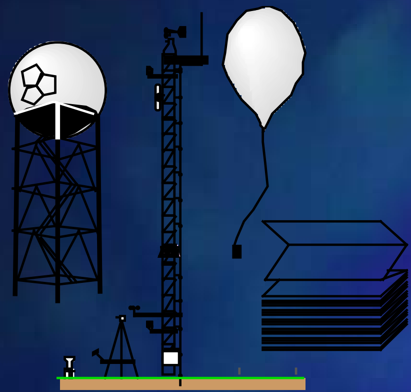
Computer
Forecast Models (NWS)



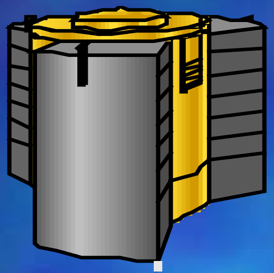
Data/Products (NWS)

Analysis, Advice Based
on NWS Information

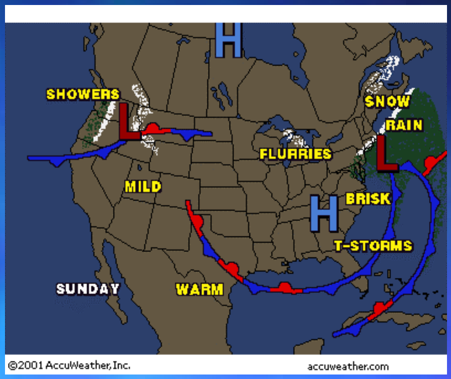
Traditional Methodology



Raw Data Collection
& Dissemination (NWS)



Computer
Forecast Models (NWS)

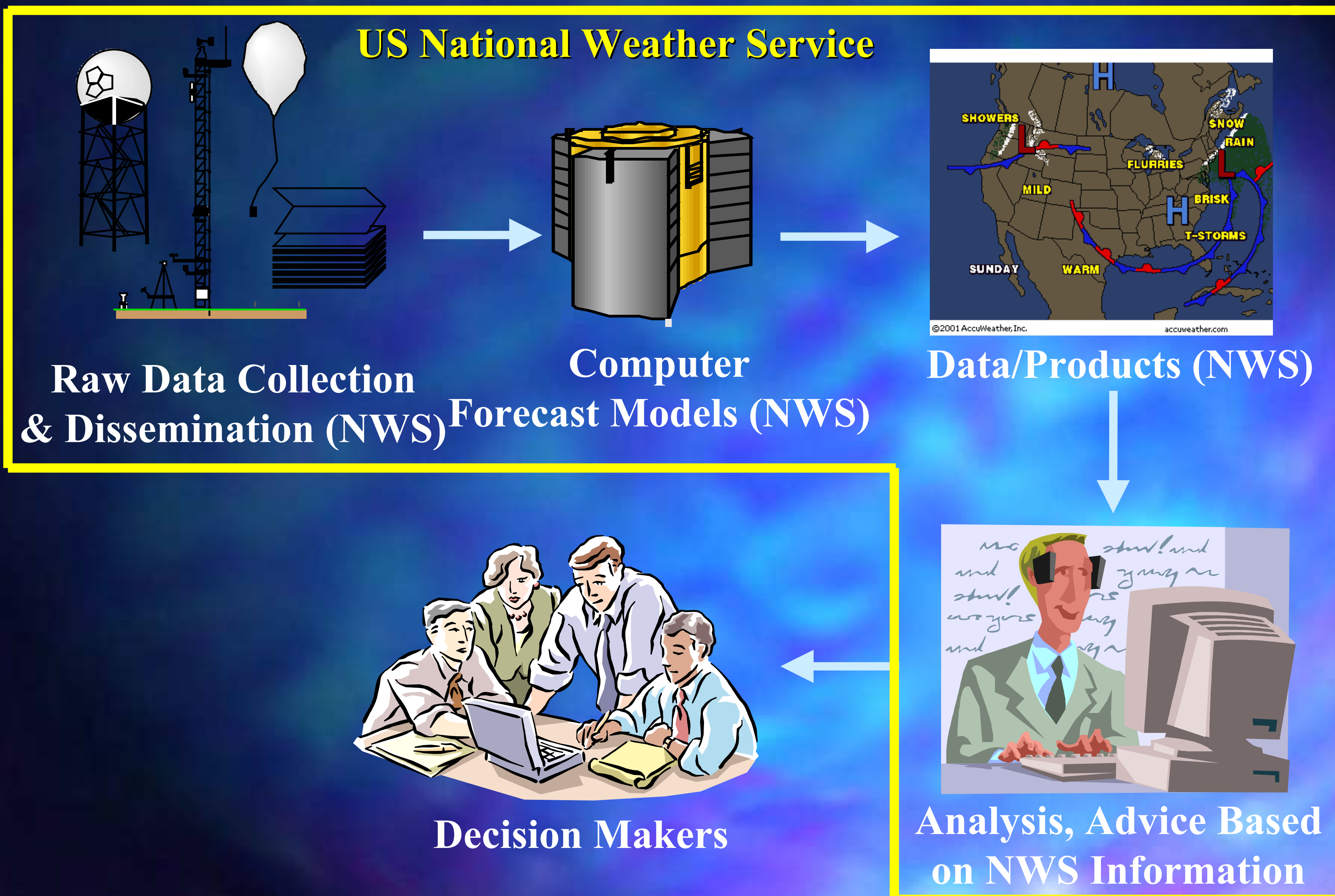


Data/Products (NWS)

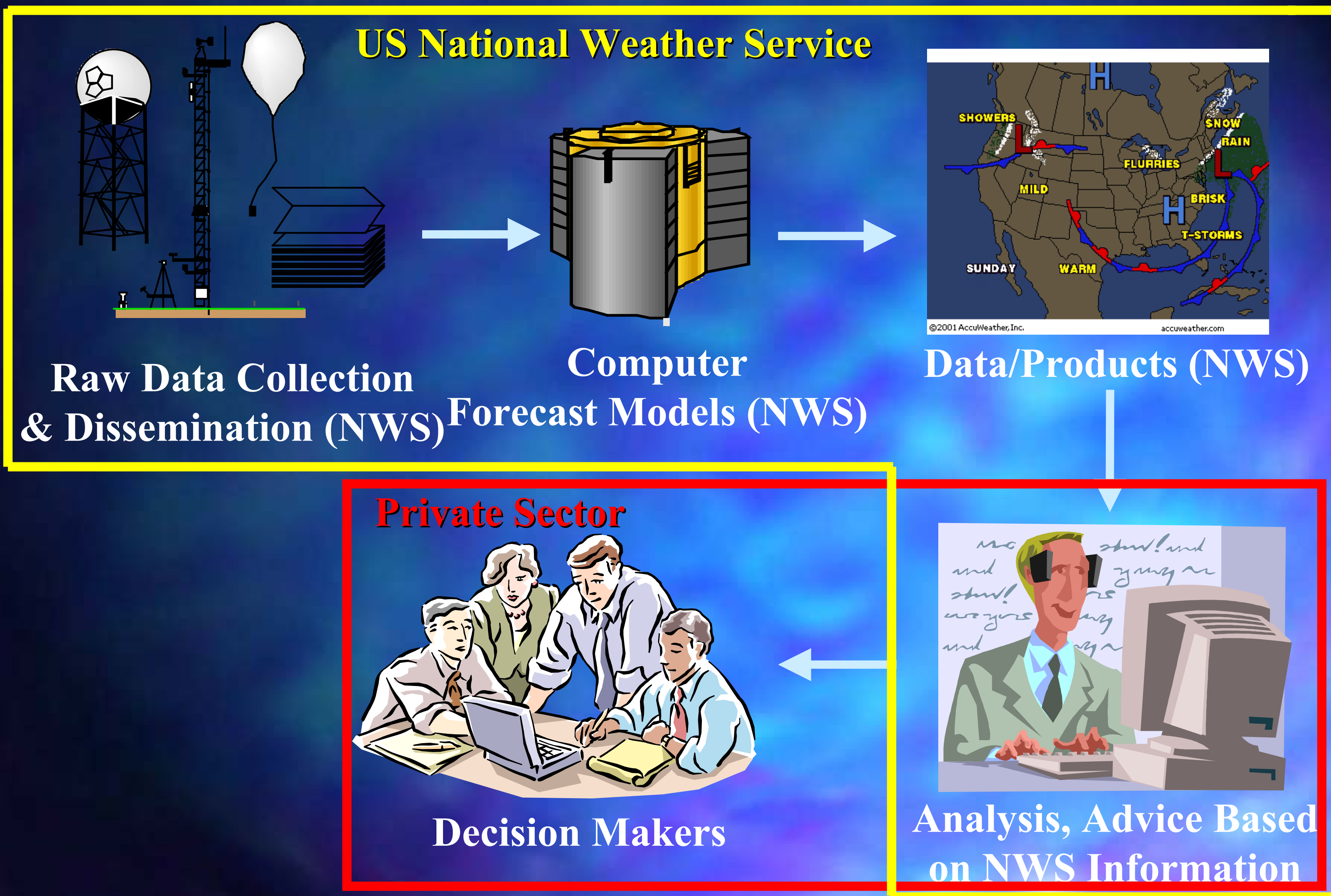
Analysis, Advice Based
on NWS Information

Decision Makers

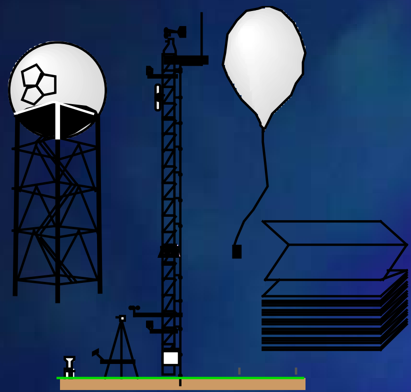
Traditional Methodology



Traditional Methodology

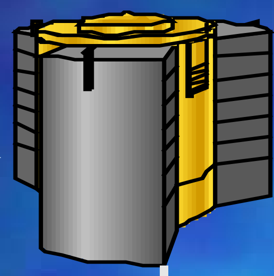


The New Landscape

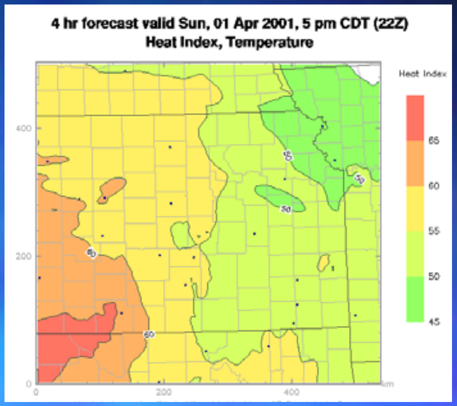


Raw Data Collection & Dissemination (NWS)

Private Sector



Customized Computer Forecast Models/Decision Support Tools

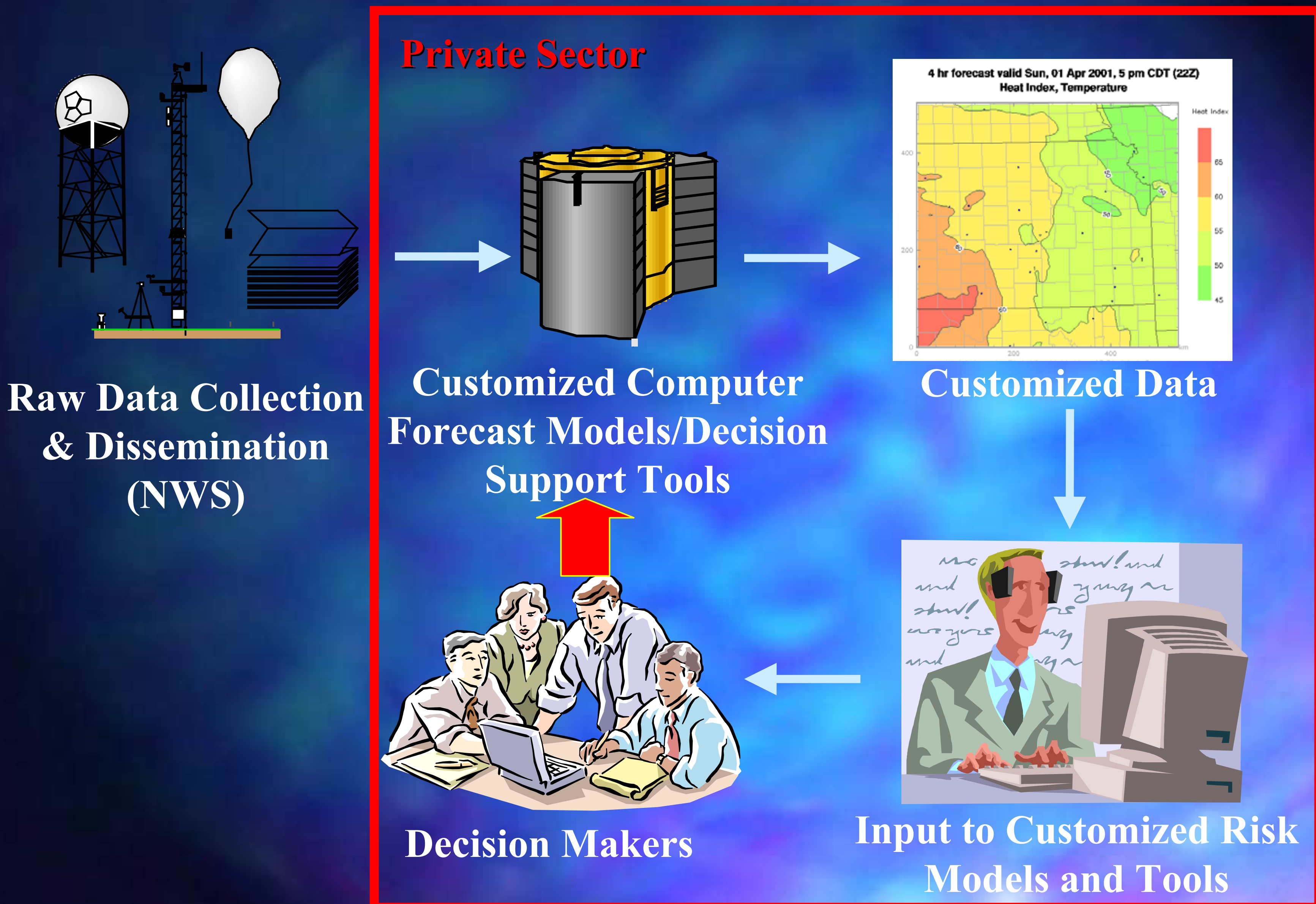


Customized Data

Input to Customized Risk Models and Tools

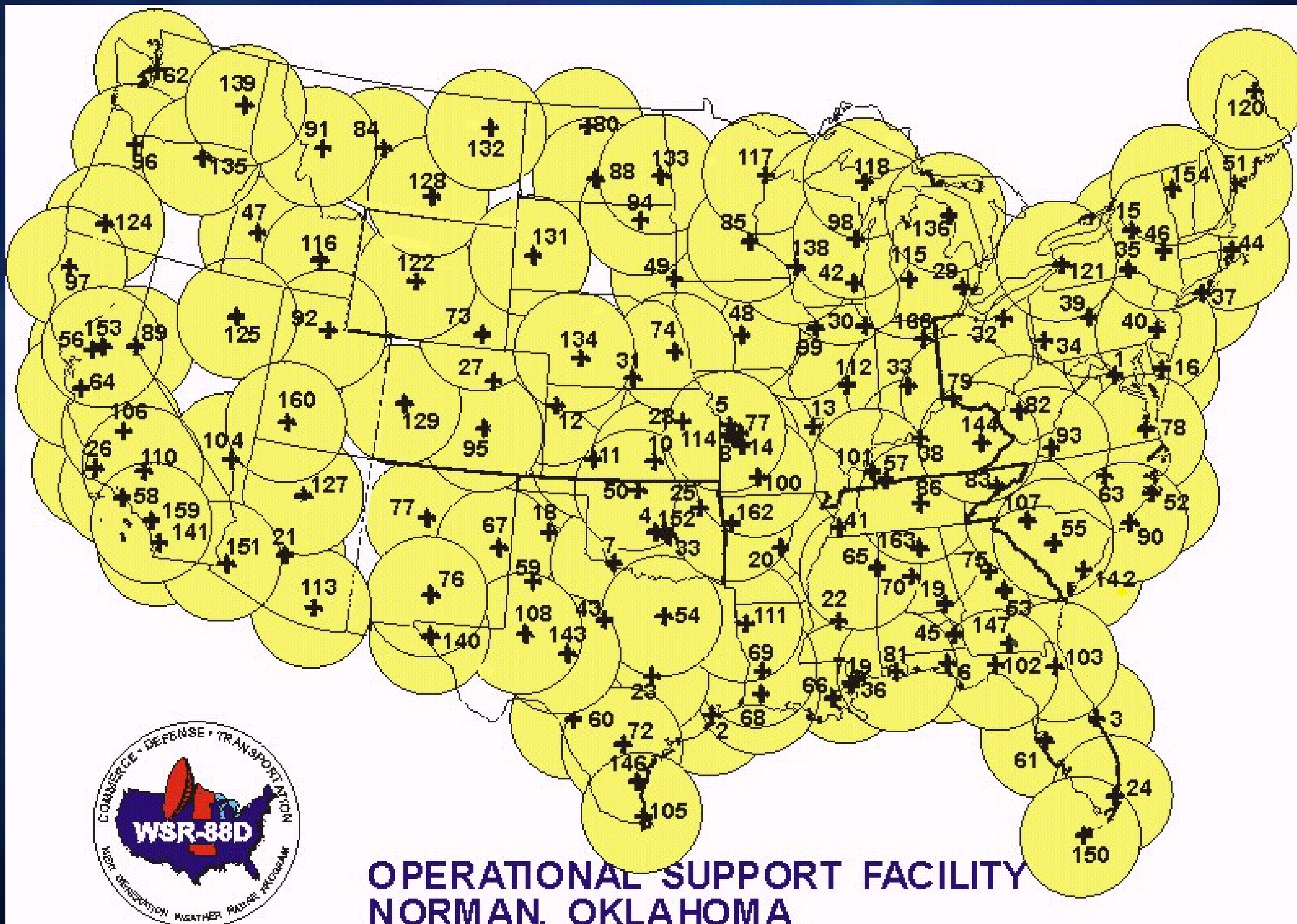
Decision Makers

The New Landscape

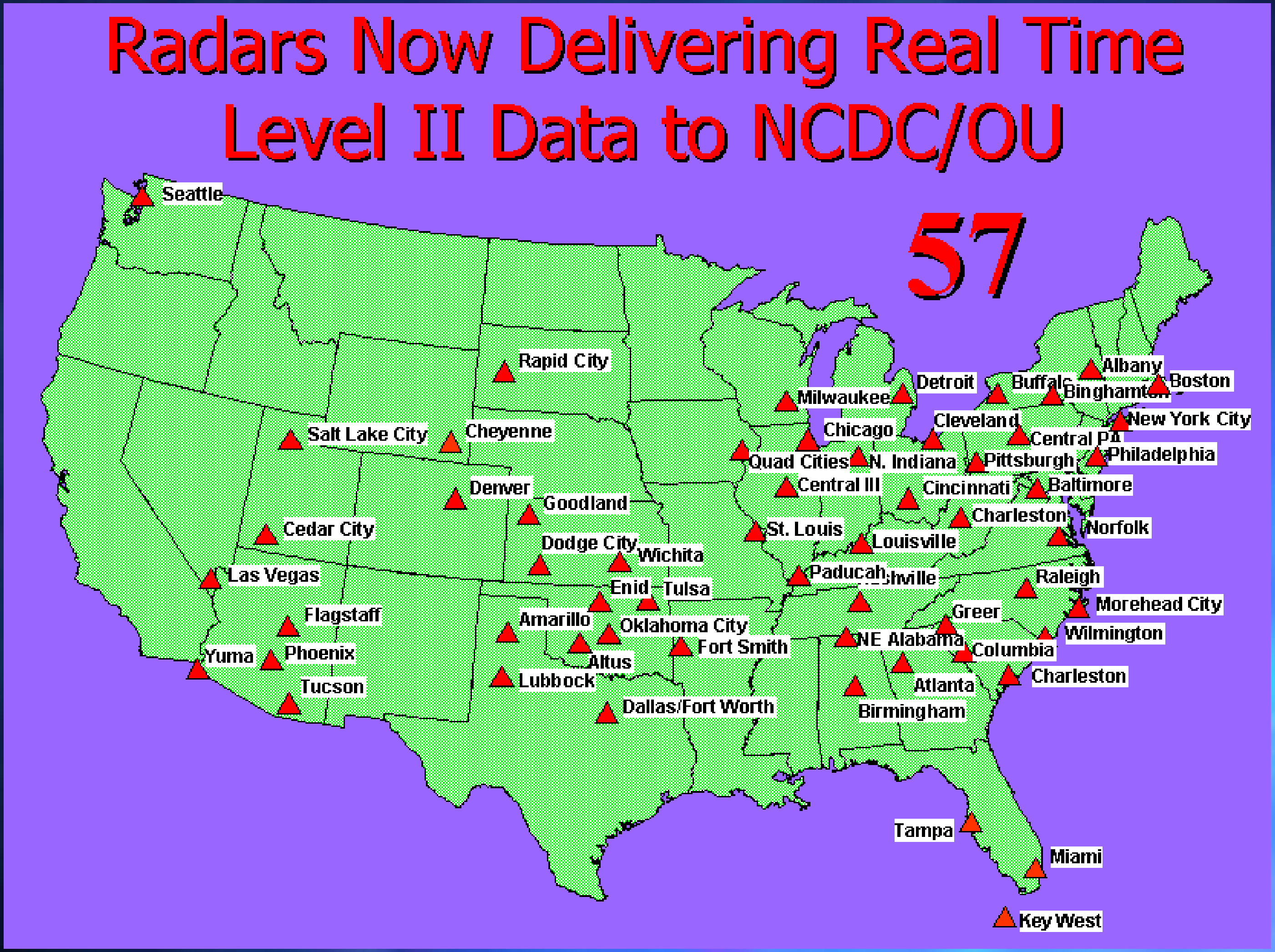


Other Information Technology Activities at

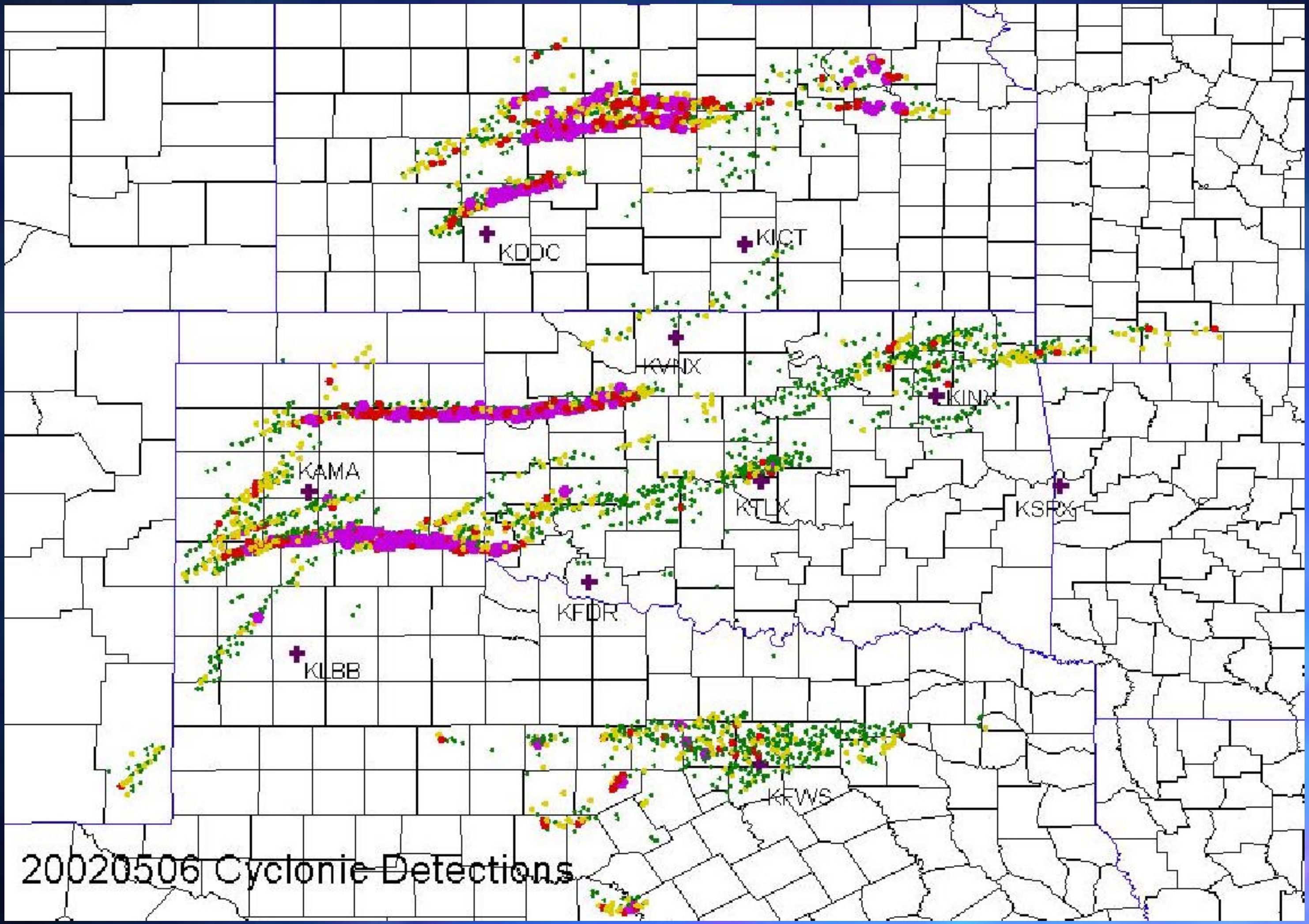
NEXRAD Radar Network



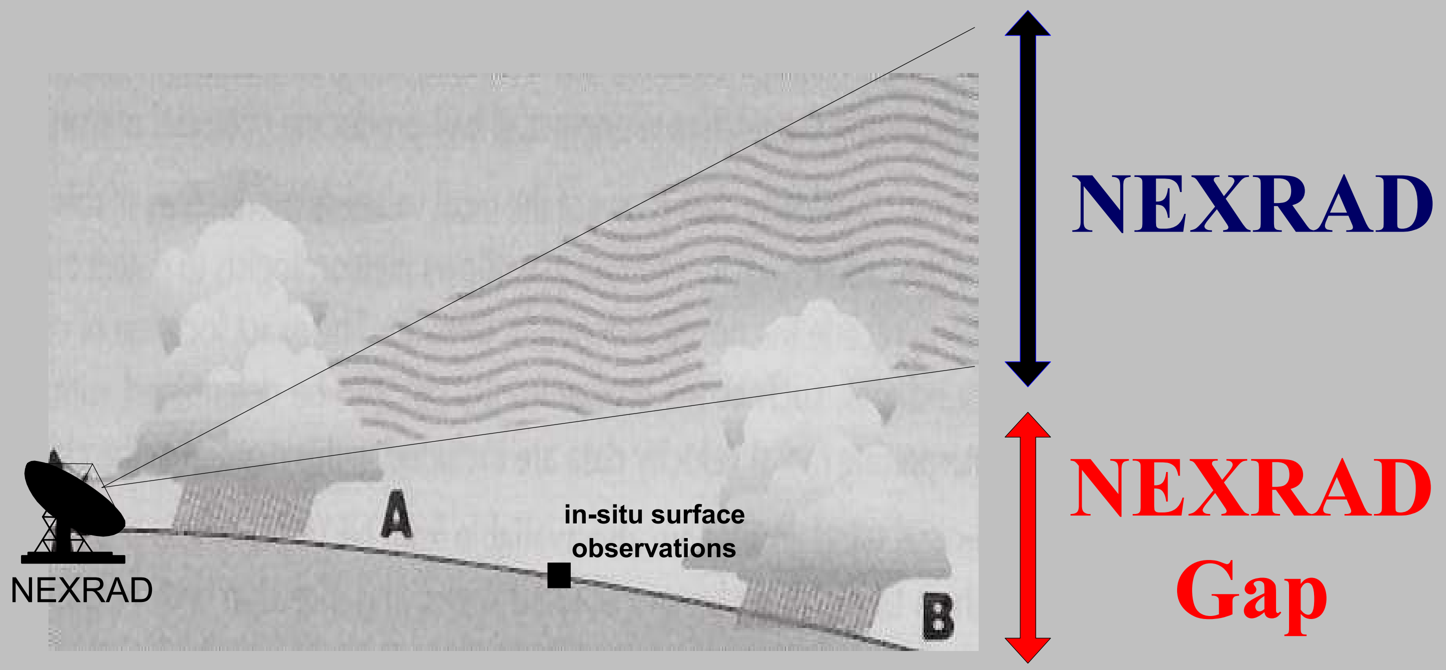
Ingesting NEXRAD Radar Data via the Internet



Mesocyclone Climatologies → Medium ITR Grant

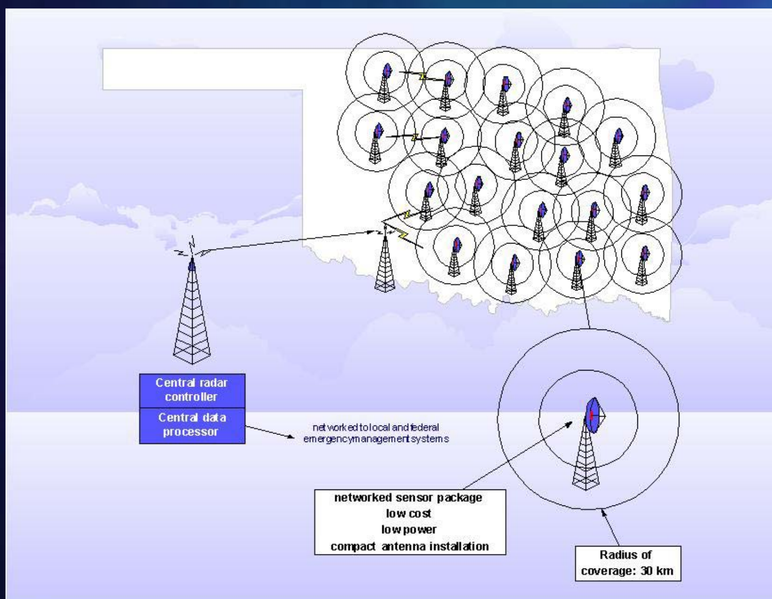


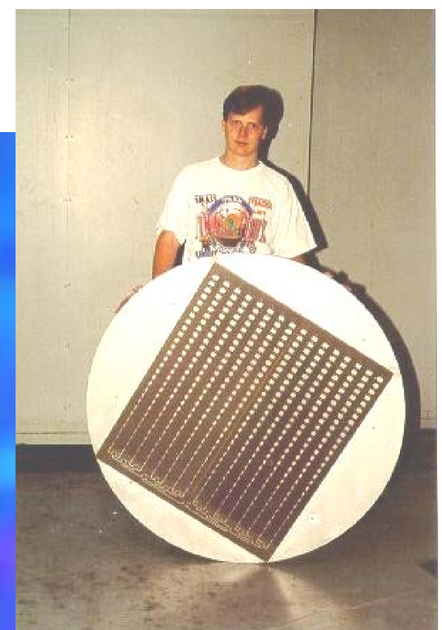
Courtesy Thomas Jones and Kevin McGrath, University of Oklahoma

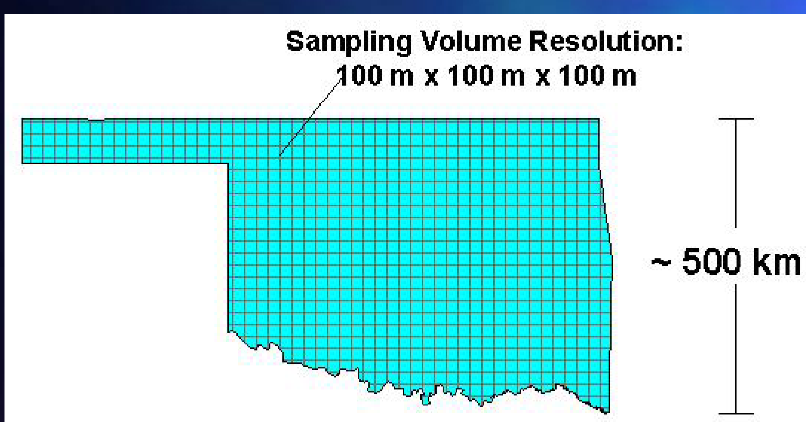


NEXRAD
in-situ surface observations
A
B
NEXRAD
NEXRAD Gap

Center for Adaptive Sampling of the Atmosphere (CASA) – NSF ERC Proposal

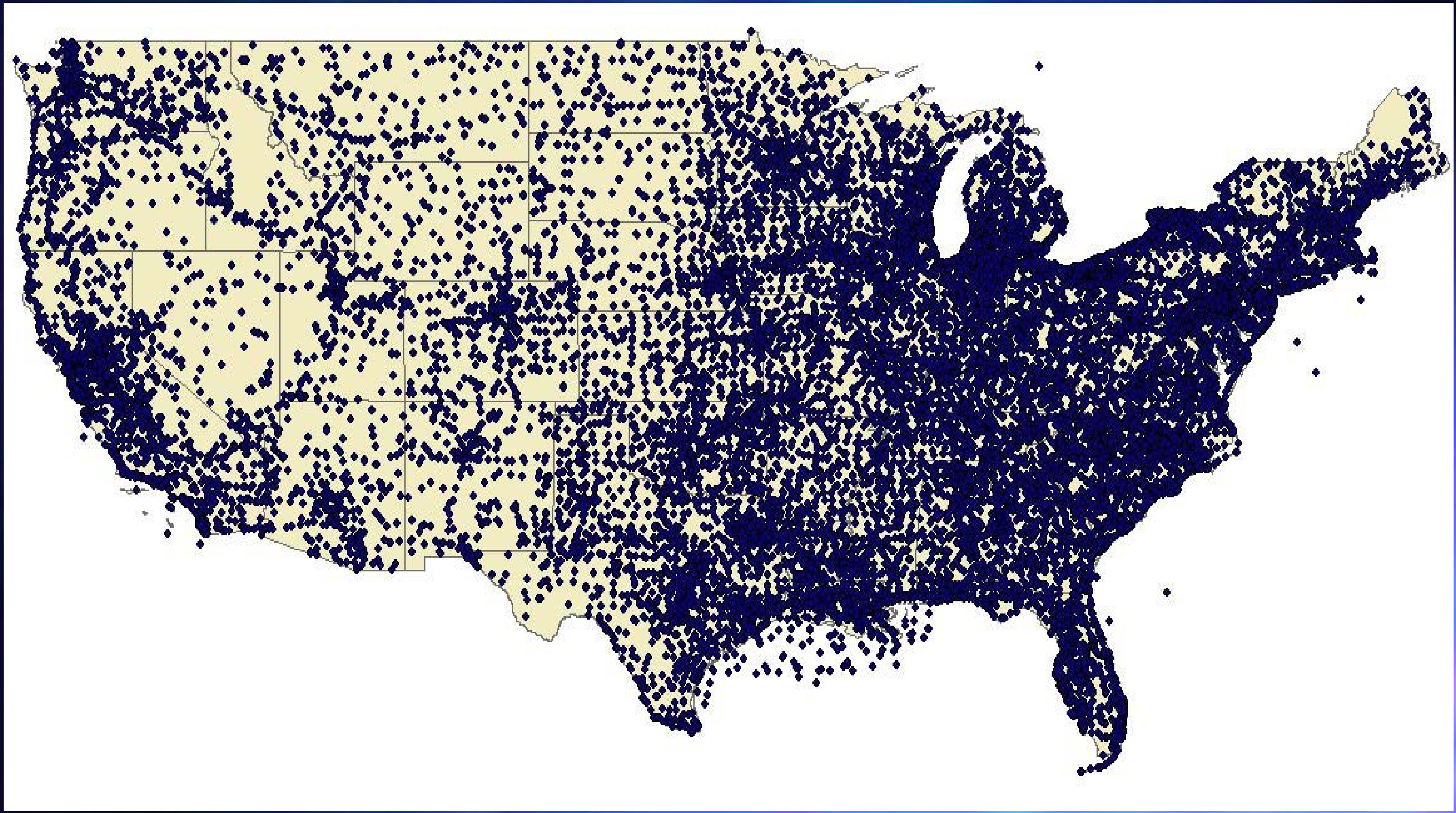






Concept: Prof. D. McLaughlin, U of Massachusetts

FCC Cellular Database -- 20,455 sites



Data Handling Requirements

Per Pixel Data storage: 10 bytes per observation

Assume sensor nodes update each minute.

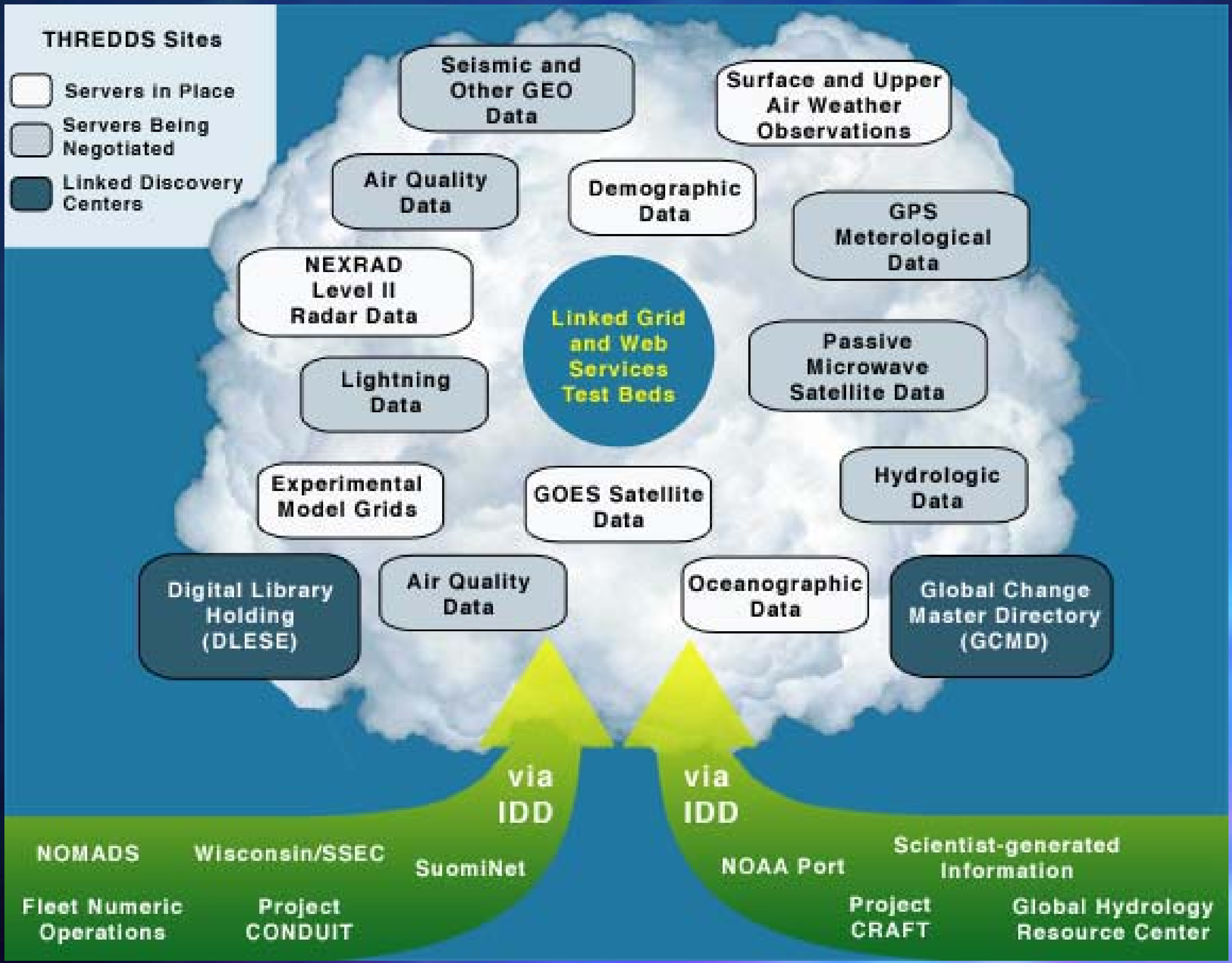
Total Data Volume

- Regional Network: 25 Gbytes per observation; **26 Tbytes per day**
- Nation-wide Network: 900 Gbytes per observation; **1.3 Pbytes per day**

Dealing with the Flood of Information

- Generating it
- Moving it
- Analyzing (mining) it
- Storing it
- Finding it
- Accessing it
- Combining it
- As scientists and engineers, we spend well over 50% of our time dealing with the logistics of information

Linked Environments for Atmospheric Discovery (LEAD) – NSF Large ITR Proposal



Linked Environments for Atmospheric Discovery (LEAD) – NSF Large ITR Proposal