Hydrologic Ensemble Prediction: Challenges and Opportunities

John Schaake
(with lots of help from others including:
Roberto Buizza, Martyn Clark, Peter Krahe,
Tom Hamill, Robert Hartman, Chuck Howard,
Pedro Restrepo, D.J. Seo, Jutta Thielen,
Zoltan Toth, Eric Wood, HEPEX SSG)

Joint COST Action 731 Workshop and NetFAM Workshop on

Uncertainty in High-Resolution Meteorological and Hydrological Models

Vilnius, Lithuania

April 27, 2006

Some Questions for the Workshop

Why are Ensemble Forecasts Needed?

How should ensemble weather forecasts be used in hydrological forecasting?

How can uncertainties in hydrological models, model parameters and hydrological initial conditions be represented in hydrological ensemble prediction?

What is the relative role of initial conditions and meteorological forecast skill in hydrological uncertainty? How does this vary with season and climate?

What processes and tools are needed for forecasters to control the operation of a hydrological ensemble forecast system?

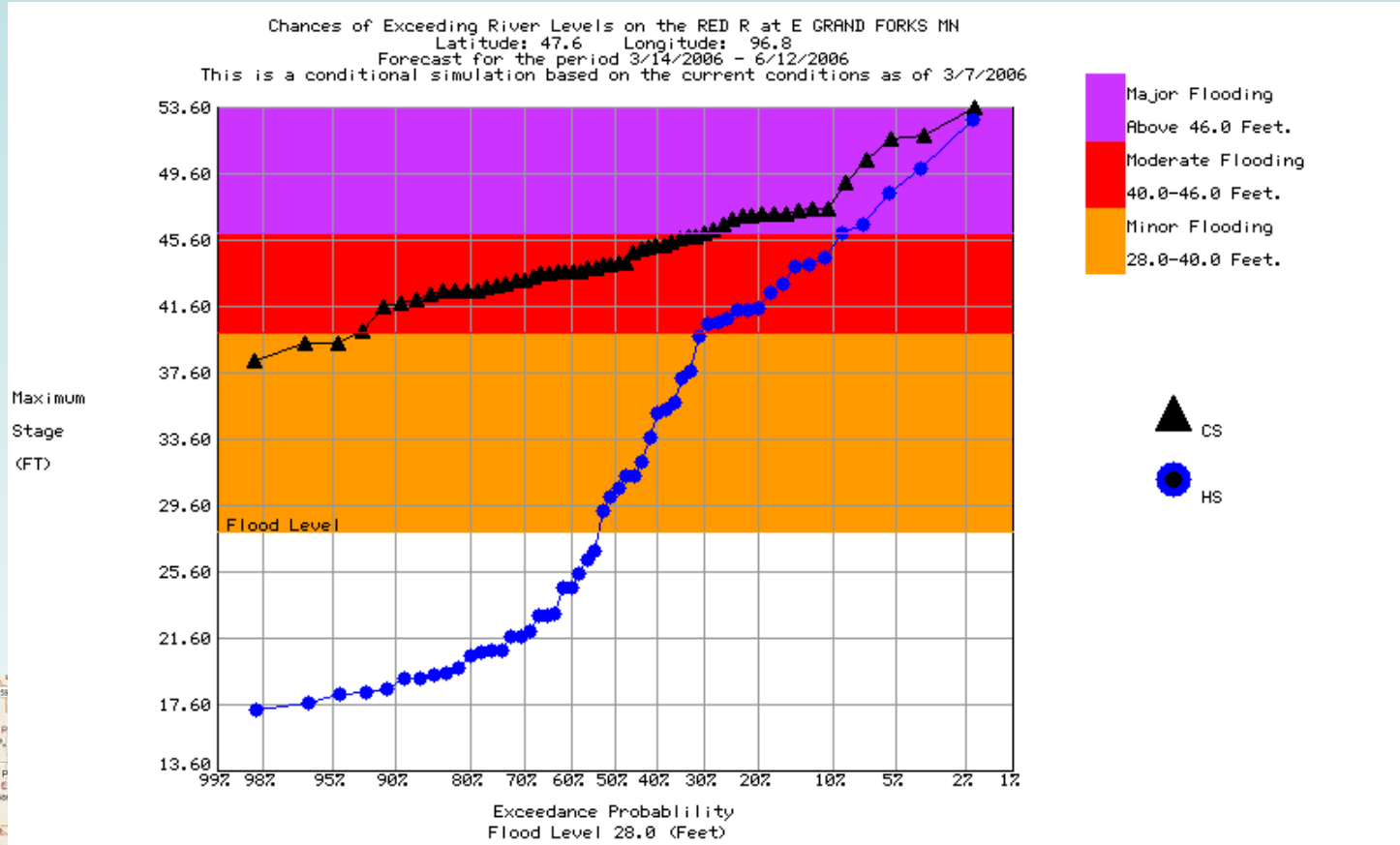
What is the role of a human forecaster in ensemble prediction?

How can hydrological ensemble forecasts be verified, also for big events, and what can be done to gain confidence that a given forecast system is reliable?

How should uncertainty be communicated to decision makers and to the public?

What interaction is needed between forecasters and users?

Why are Ensemble Forecasts Needed?



Impacts

Collapse

60.0	Top of levee constructed by Corps of Engineers for City of Grand Forks.
54.4	Record flood level. 22 April 1997 (from floodmarks).
53.0	TOP OF RAILS ON BNSF RR BRIDGE OVER THE RED RIVER
50.1	WATER ON GATEWAY DRIVE AT THE KENNEDY BRIDGE
50.0	RAILROAD BRIDGES BECOME INOPERATIVE
49.9	TOP ELEVATION OF P.L. 99 EMERGENCY DIKE IN EAST GRAND FORKS
48.7	WATER ON DEMERS AVE AT THE SORLIE BRIDGE
48.0	TOP ELEVATION OF P.L. 99 DIKE IN RIVERSIDE PARK AREA
47.5	WATER ON GATEWAY DRIVE AT THE ENGLISH COULEE
46.0	Major Flood Stage. Begin road closure on Sorlie Bridge (DeMers Av).
45.0	Begin road closure to Riverside Park. WATER ON MILL ROAD AT THE ENGLISH COULEE
44.9	AGRICULTURAL DAMAGE BEGINS AT RIVER MILE 271-296. WATER ON EAST GRAND FORKS APPROACH TO POINT BRIDGE.
43.7	CLOSE MILL ROAD AT ENGLISH COULEE BRIDGE.
42.2	WATER ON LEWIS BLVD AT THE KENNEDY BRIDGE
42.0	Begin road closure to Riverside Park.
41.0	Close flood gates on English Coulee and activate pump station.
40.0	Moderate Flood Stage. Extensive flooding in greenway for Grand Forks.
38.0	Begin closing flood gates in Grand Forks and activate strom water pumping stations.
34.0	East Grand Forks Water problems at HWY 2 abd 4th St underpass.
33.0	Agricultural Flooding between Oslo and Grand Forks (Tab F) AGRICULTURAL DAMAGE BEGINS AT RIVER MILE 271 - 296
28.0	Flood Warning Stage (minor). Bankfull Stage

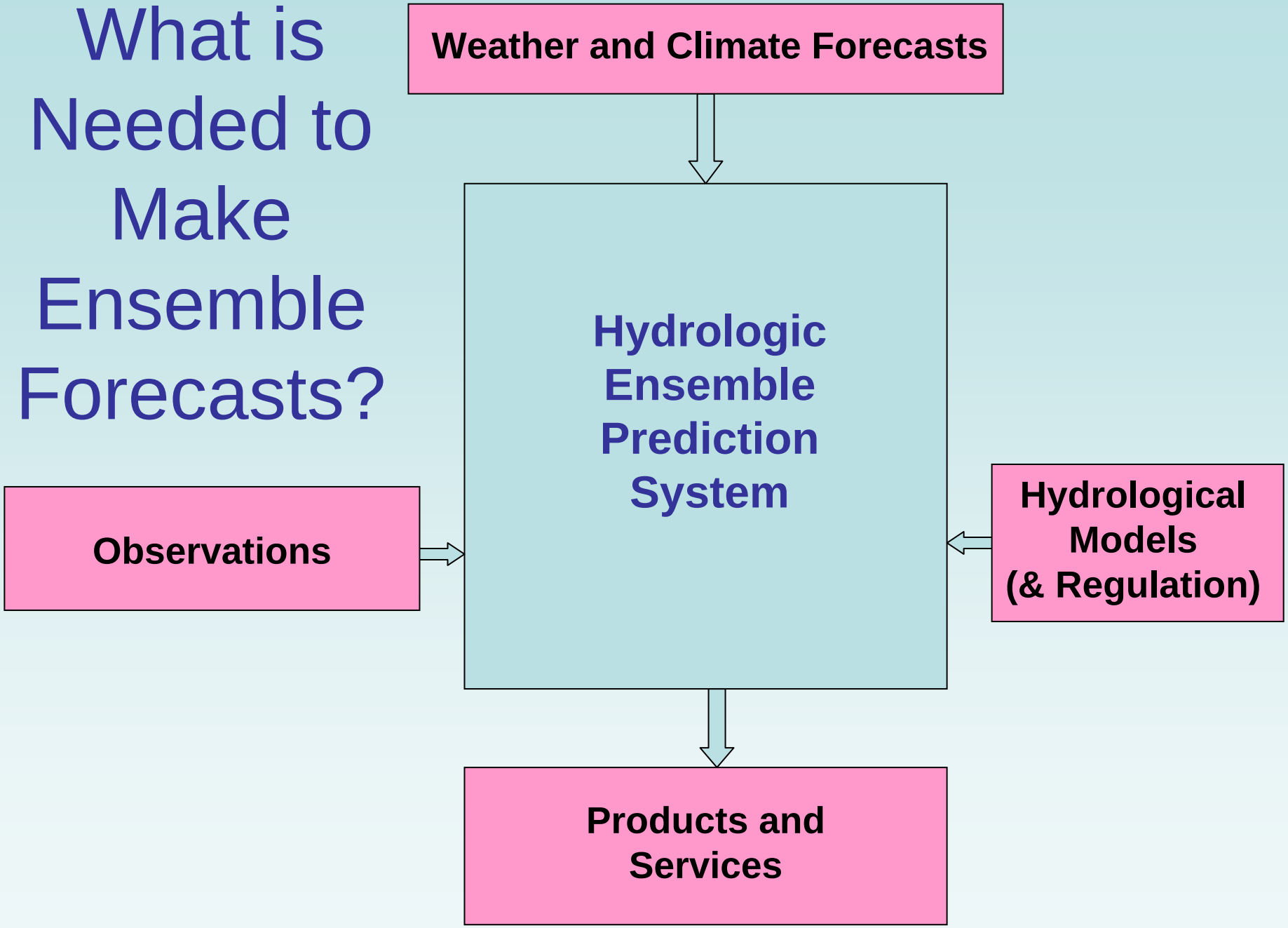
Other Data Sources:
U.S. Geological Survey (USGS) Data and Site Info for East Grand Forks

Collaborative Agencies

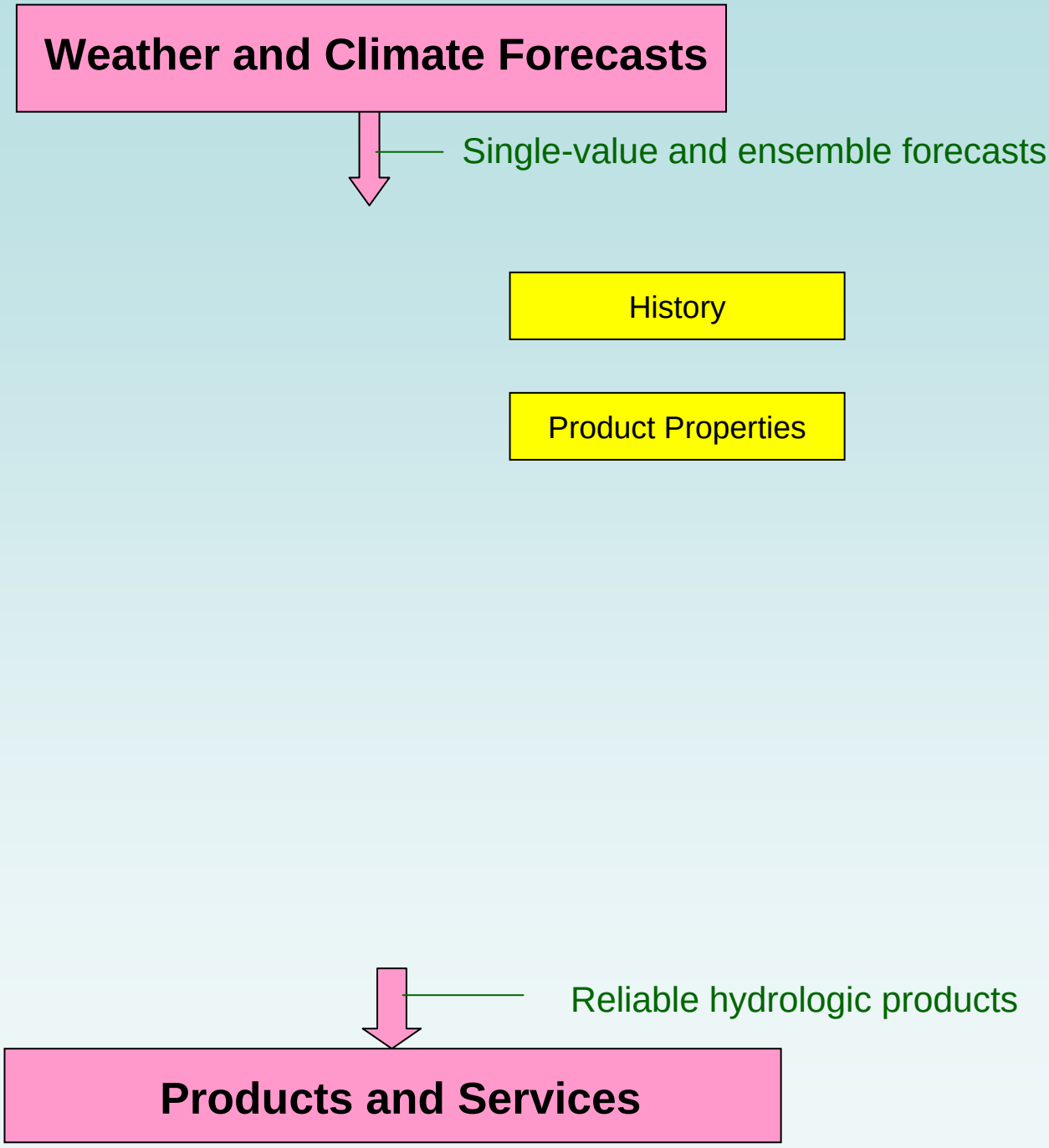
Collapse

The National Weather Service prepares its forecasts and other services in collaboration with agencies like the US

What is Needed to Make Ensemble Forecasts?



Elements of a Hydrologic Ensemble Prediction System



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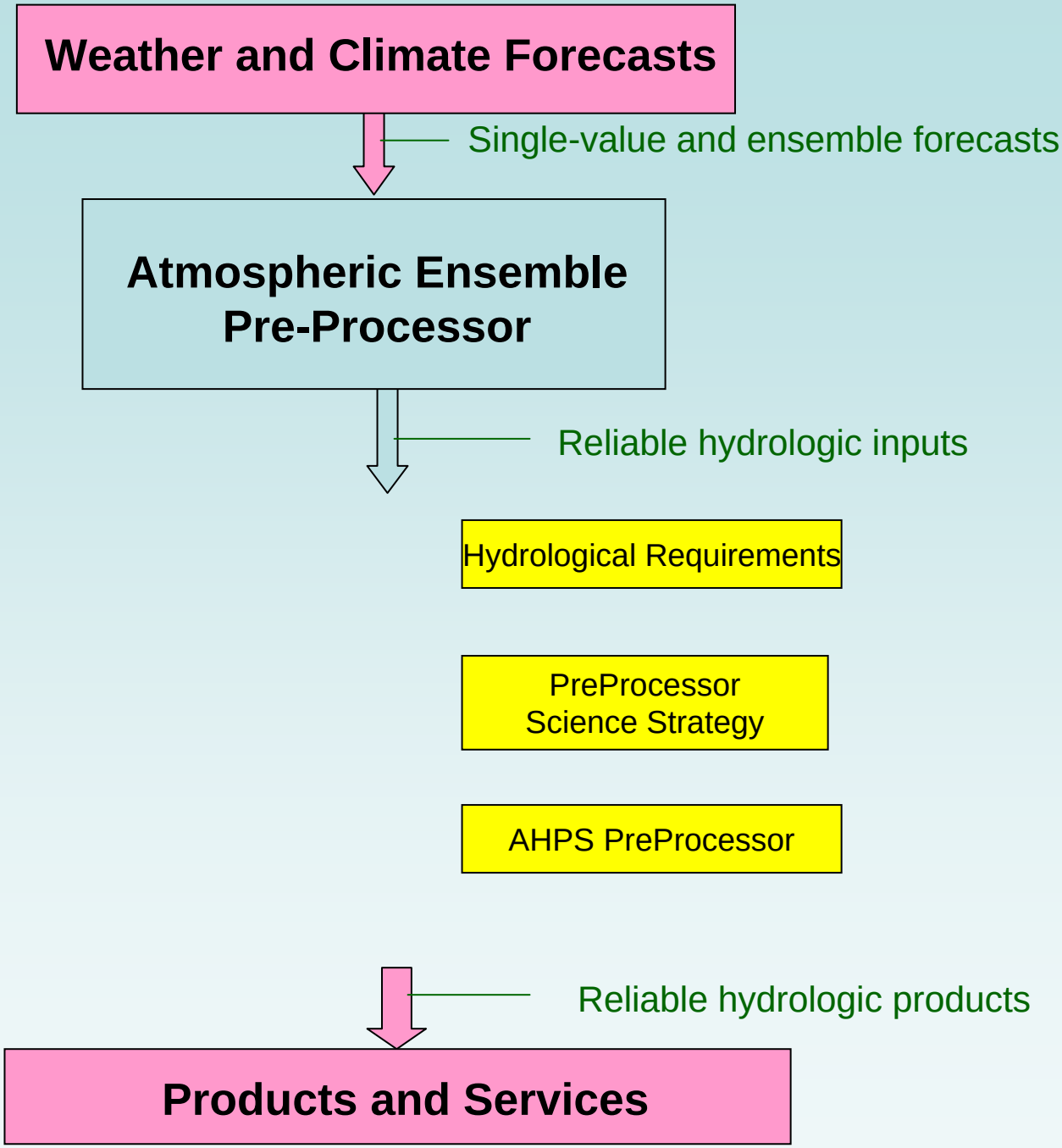

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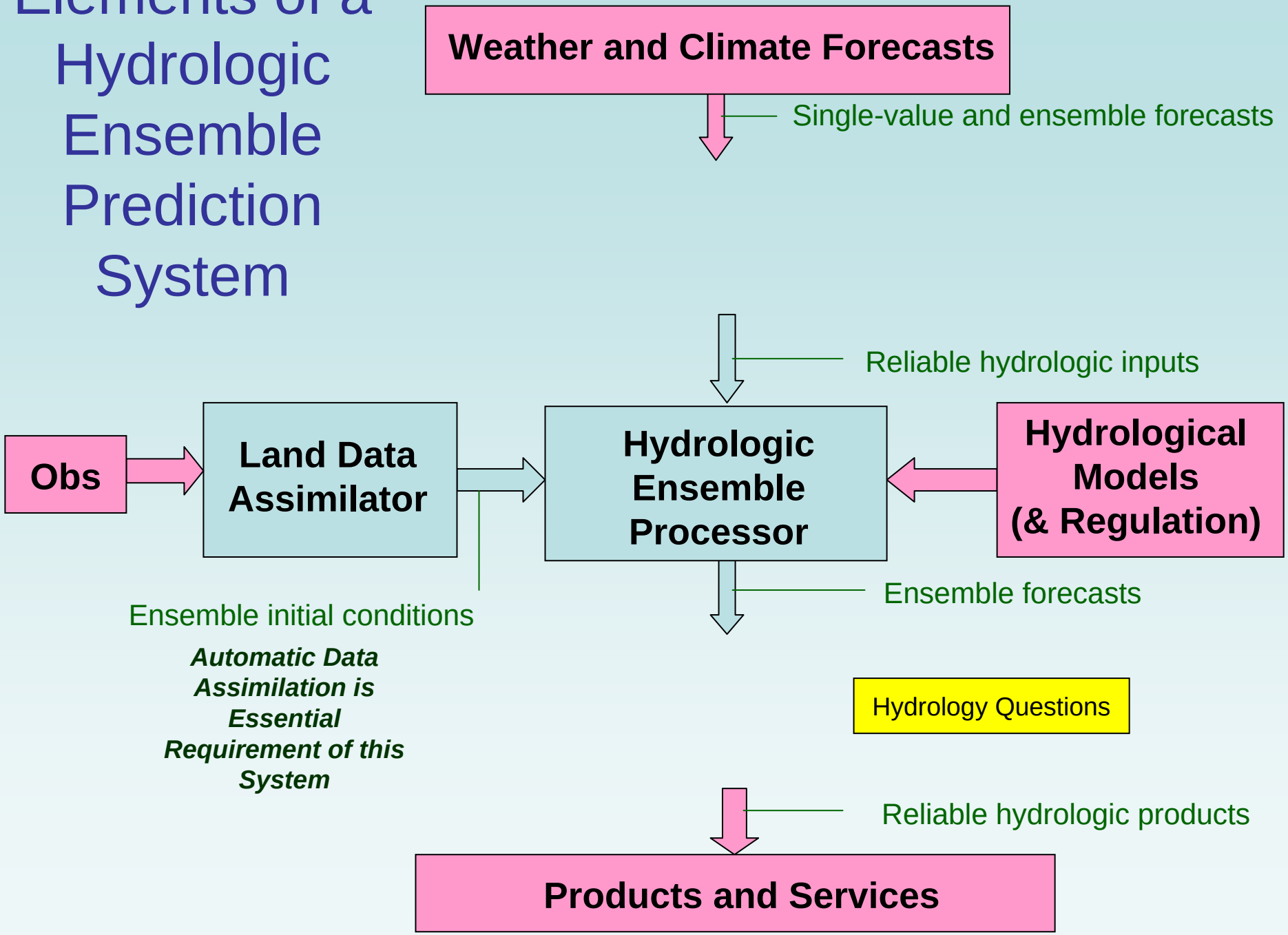

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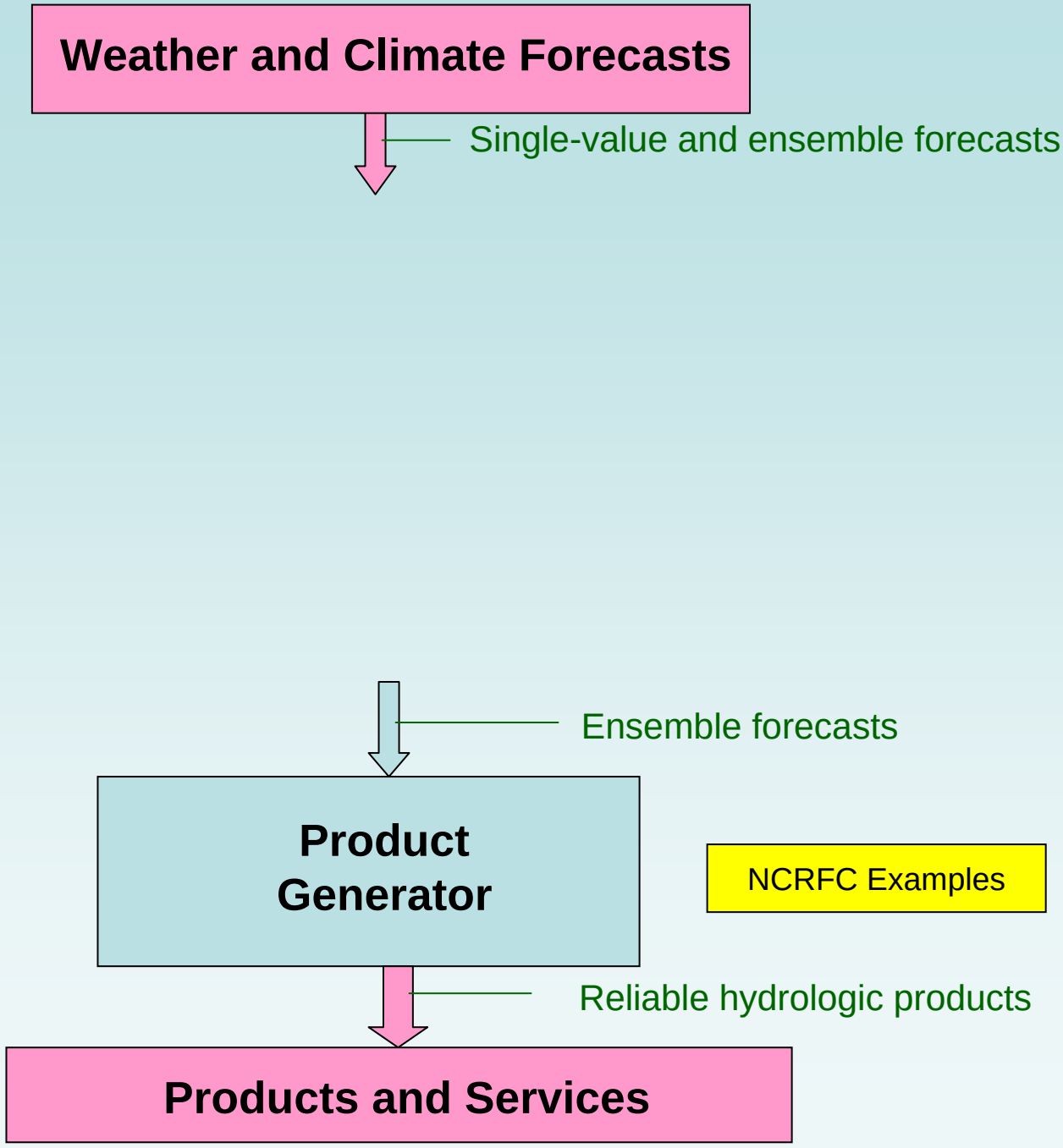
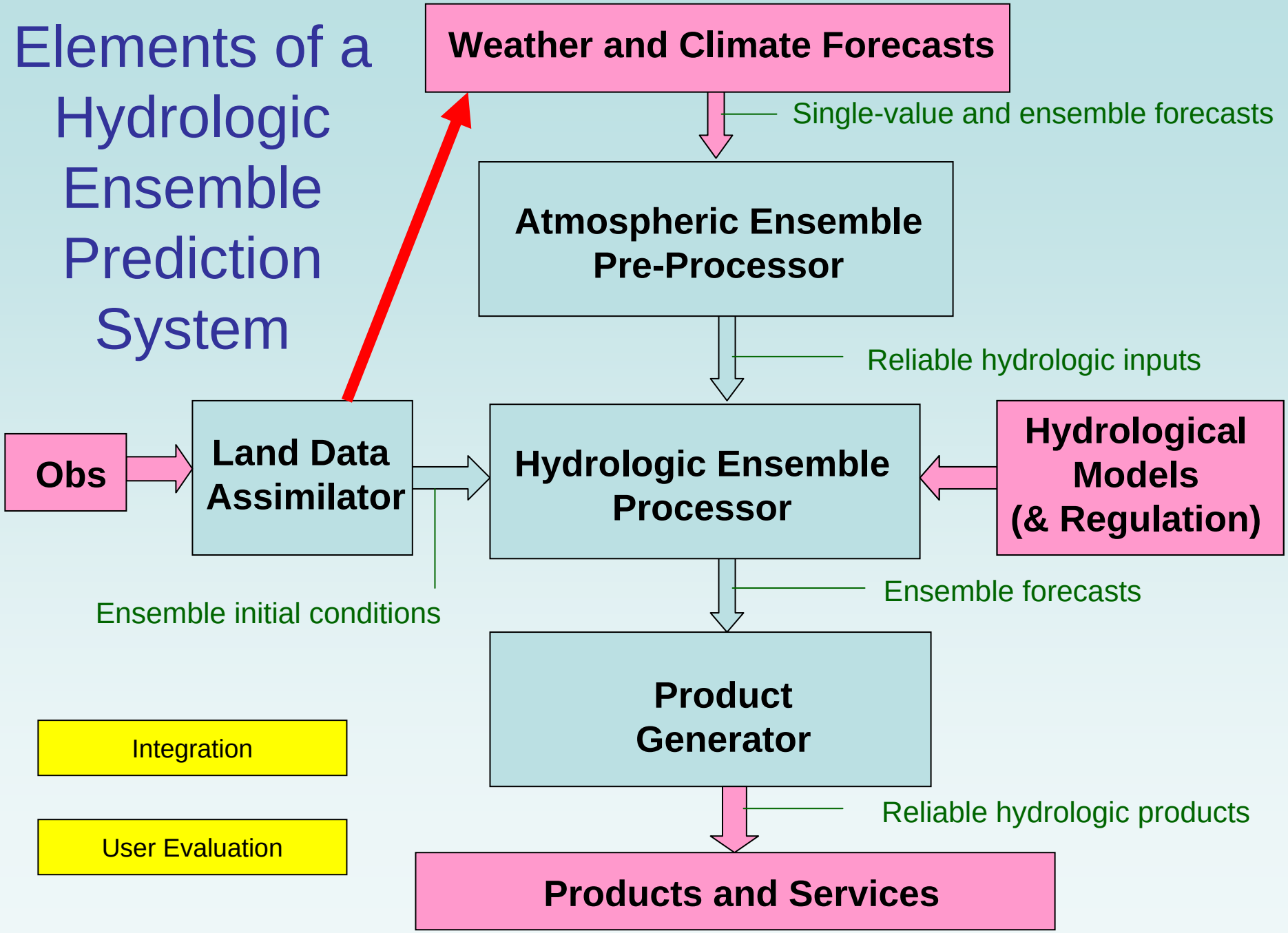


Elements of a Hydrologic Ensemble Prediction System



Hydrological Ensemble Prediction Experiment (HEPEX)

HEPEX aims to demonstrate how to produce reliable hydrological ensemble forecasts that can be used with confidence to make decisions for emergency management, water resources management and the environment

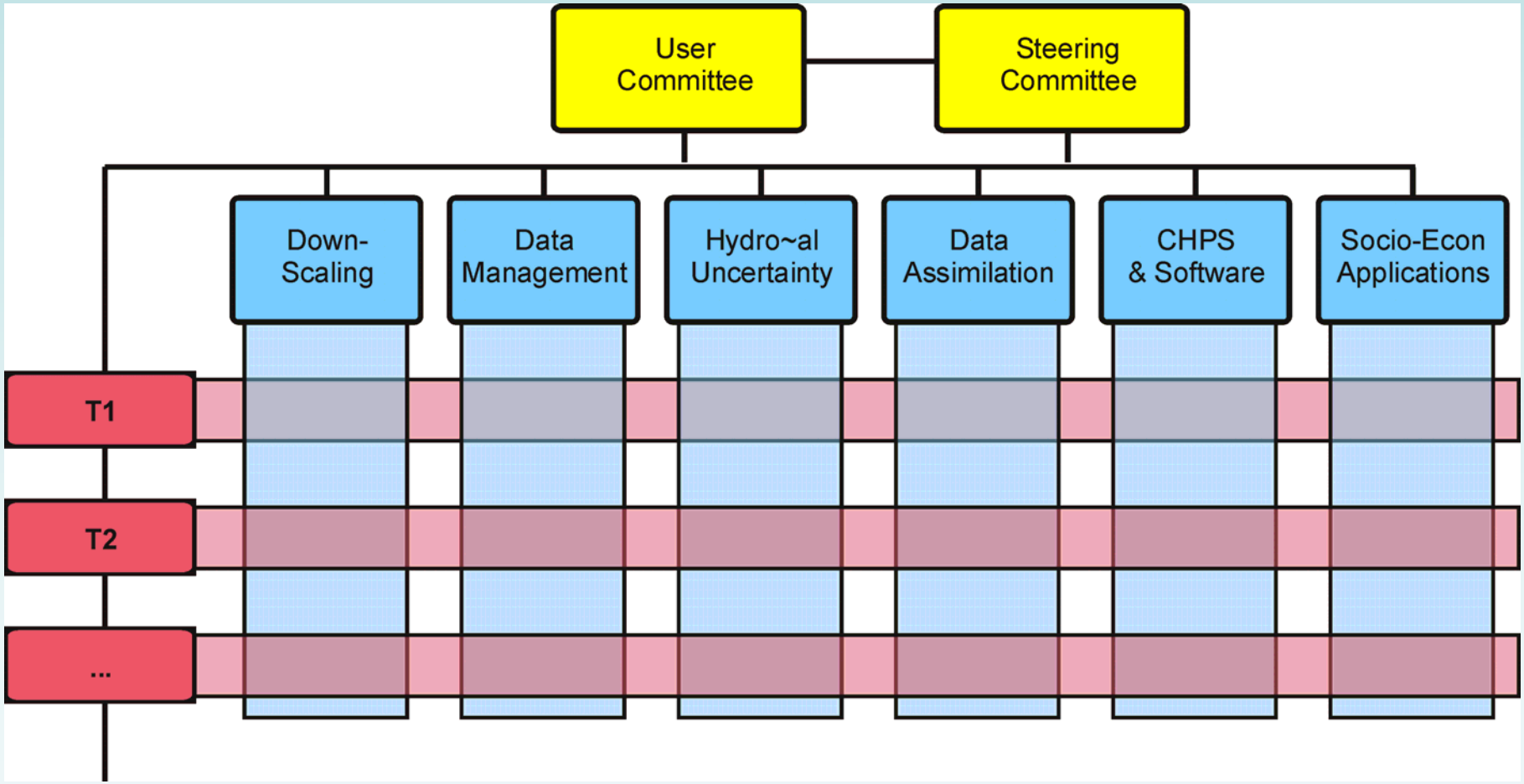
Initial Workshop

- ECMWF - March 8-10, 2004
- 80 Participants
- 16 Countries
- Users [NY Power, BC Hydro, Quebec Hydro, EDF (France), Mekorot (Israel), WMIG (Canada), CddHoward (Canada), SMHI (Sweden), BGF (Germany), …]
- Meteorologists
- Hydrologists

Three Basic Elements of HEPEX

- Testbed Projects
- Supporting Data Sets
- Components of the Community Hydrologic Prediction System (CHPS)

HEPEX Organization



3. TIGGE

TIGGE (the THORPEX Interactive Grand Global Ensemble) is a framework for international collaboration in development and testing of ensemble prediction systems.

TIGGE could lead to:

- An enhanced international collaboration between operational centres and universities
- A deeper understanding of the contribution of observation, initial and model uncertainties to forecast error, and the design of more valuable ensemble systems
- The developments of new methods of combining ensembles from different sources and of correcting for systematic errors (biases, spread over-/under-estimation)

Thank You

HEPEX Workshop
Boulder – July 19-22, 2005

Properties of Existing Products

- Heterogeniety — Implications
- Assessment — Problems
- Model Bias — Examples
- Skill and reliability of probabilities — Examples
- Scale dependency — Examples

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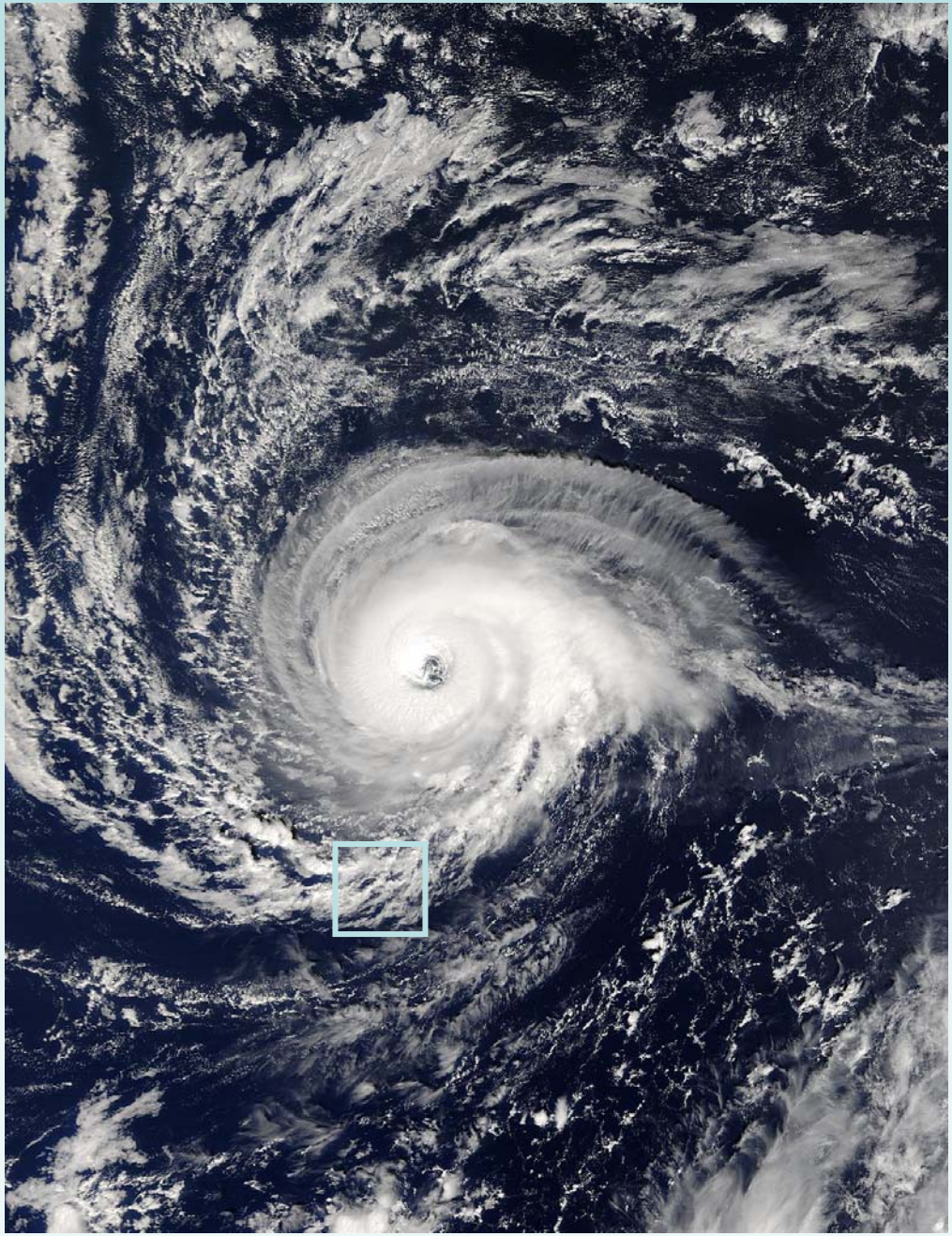

Source: MODIS

“ ”

Much of the weather occurs at scales smaller than those resolved by the weather forecast model. Model must treat, or “parameterize” the effects of the sub-gridscale on the resolved scale.

Tom Hamill

Next

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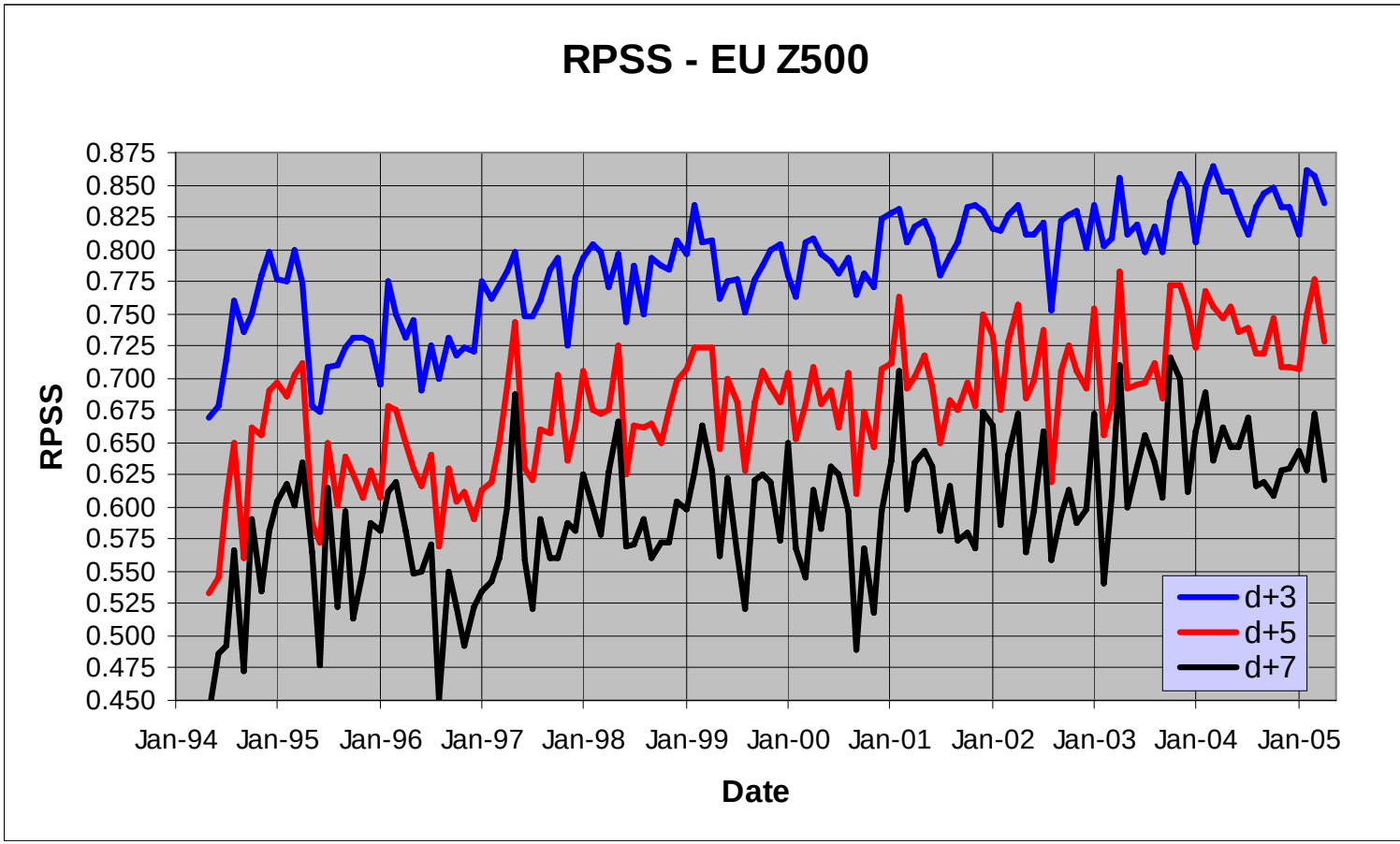
1. The EPS performance has been continuously increasing

Improvements over Europe have been slightly smaller, as can be detected by comparing the time evolution of the RPPS for 500 hPa geopotential height predictions over Europe (left) and NH (previous slide).



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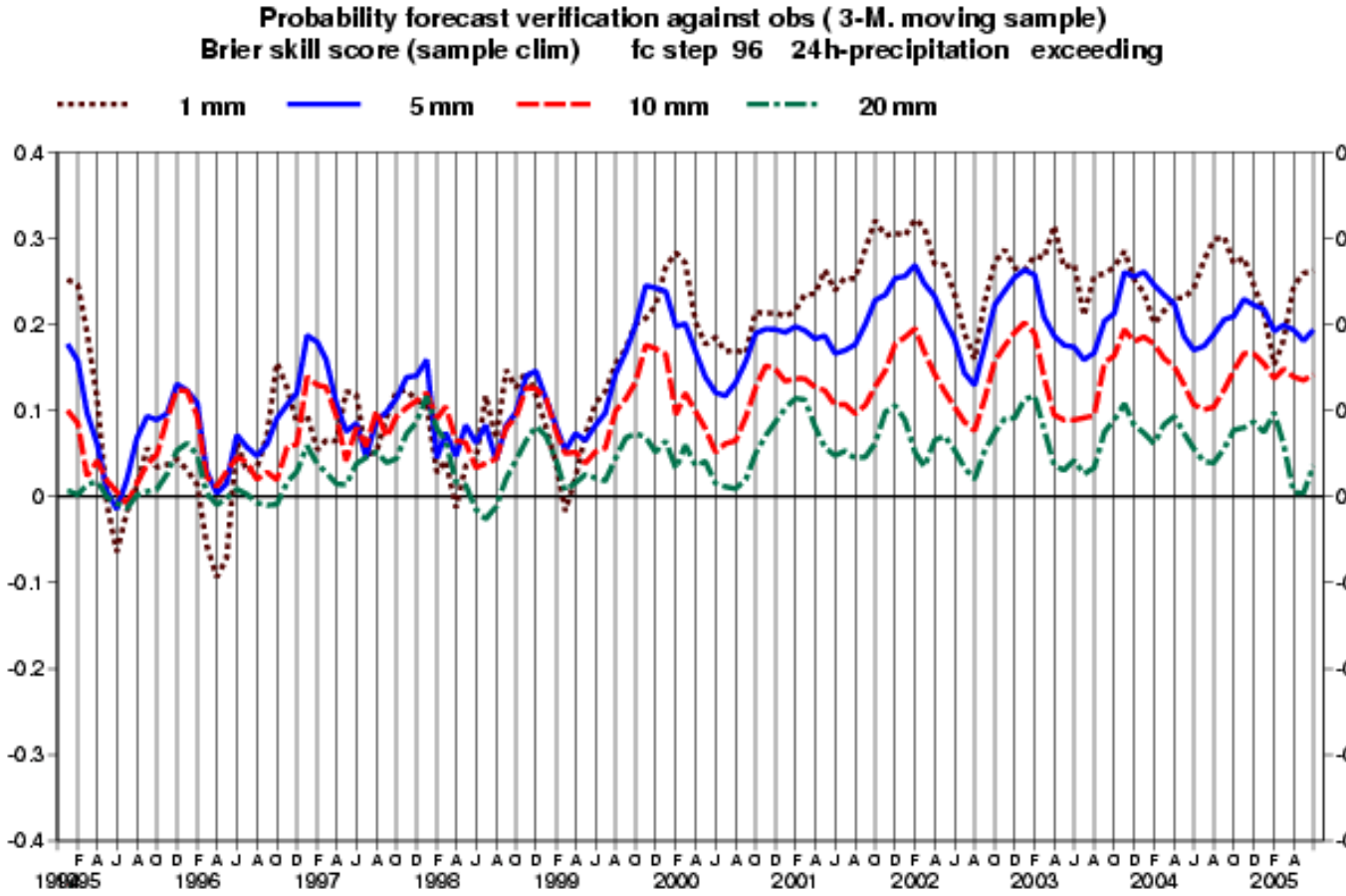
1. Trends in BSS for d+4 probabilistic precipitation prediction

EPS probabilistic predictions of precipitation over the NH between d+3 and d+4 have improved following the introduction of stochastic physics (Oct 1998) and the system upgrade from TL159 to TL255 in Nov 2000.



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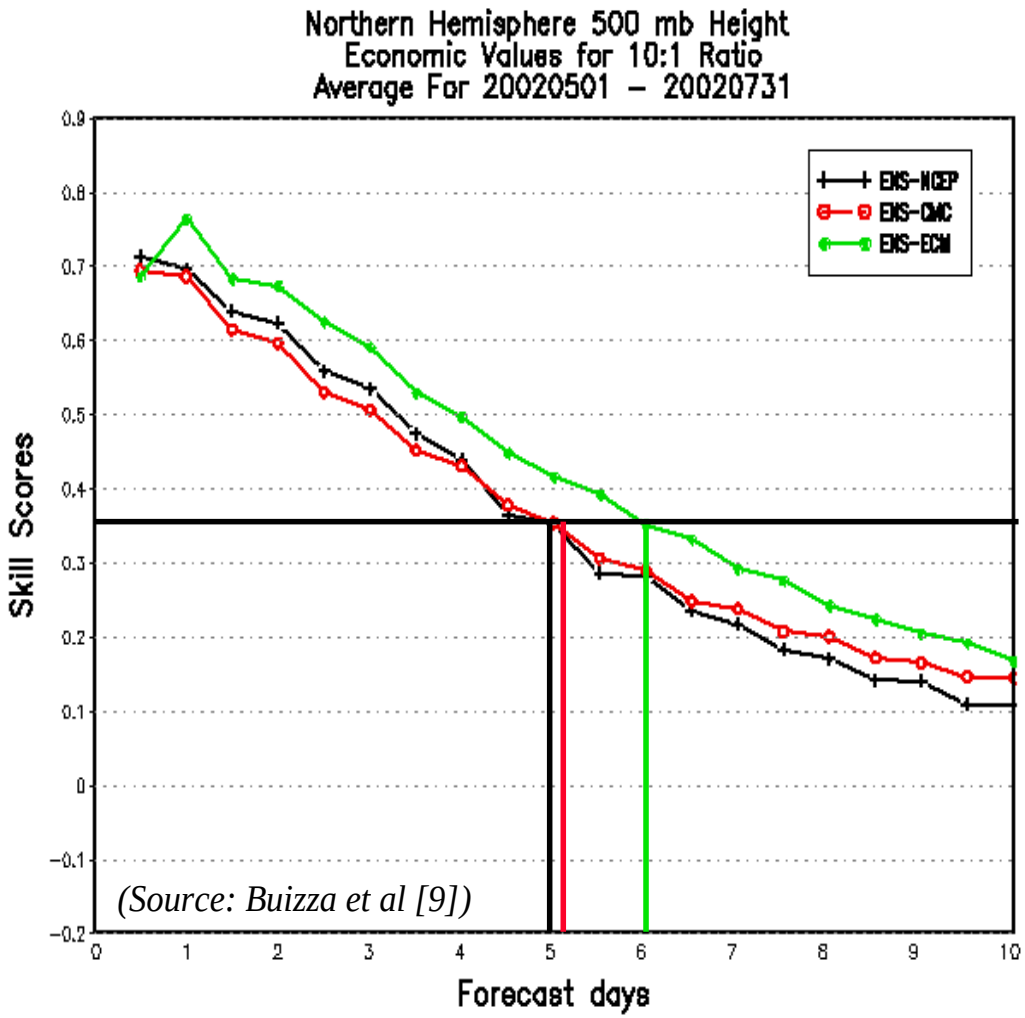
1. Comparison of the ECMWF, MSC and NCEP EPSs (JJA02)

Recent studies *[2,9]* have shown that, accordingly to many accuracy measures, the ECMWF EPS can be considered the most accurate single-model ensemble system.

This is shown, e.g., by the comparison of the EV* of 10-member ensembles based on the ECMWF, MSC (Meteorological Service of Canada) and NCEP (National Centers for Environmental Predictions) EPSs *[9]* (Z500 over NH).

* EV, the potential economic value, is the reduction of the mean expenses with respect to the reduction that can be achieved by using a perfect forecast *[4,16]*.

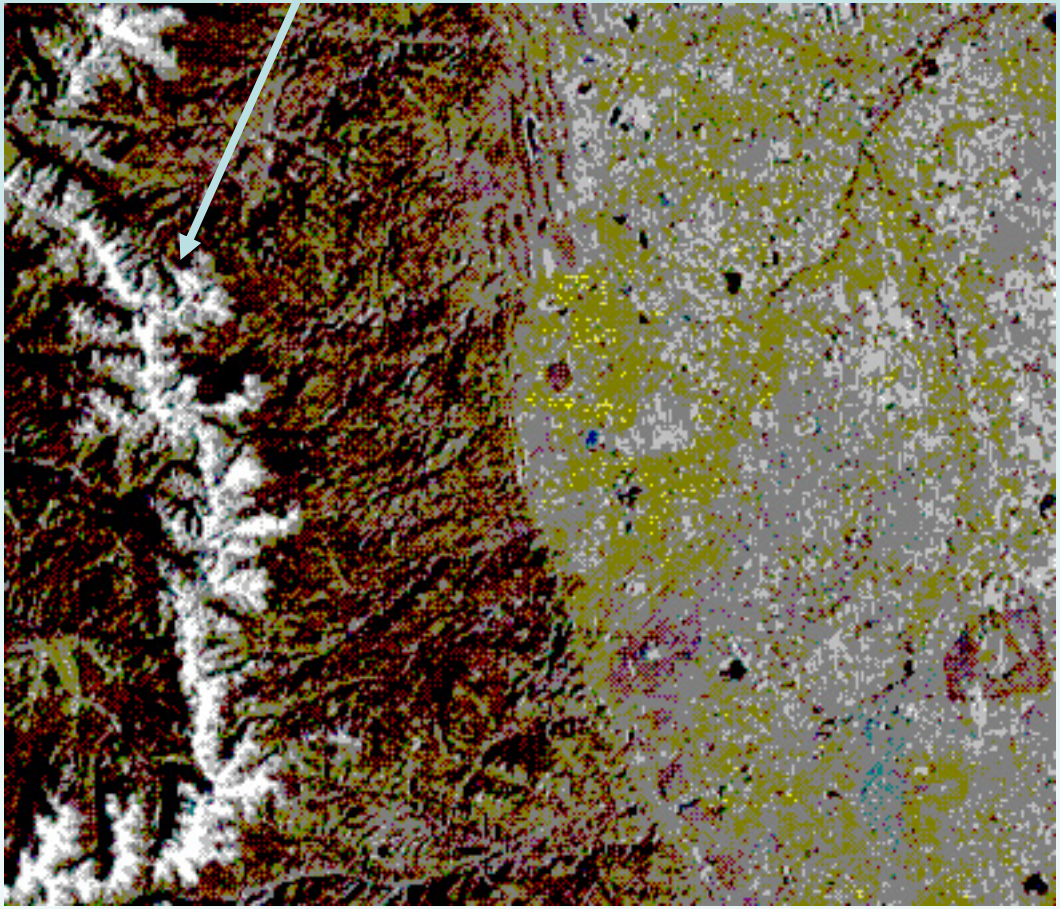


(Source: Buizza et al [9])

A lot happens inside a grid box

Tom Hammil, CDC

Rocky Mountains



Approximate size of one grid box in NCEP ensemble system

Denver

Next

Source: accessmaps.com

Questions

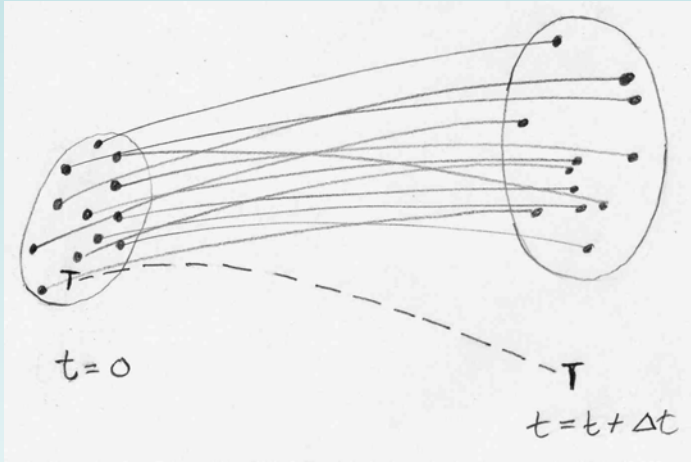
- Can we accurately forecast the evolution of the pdf of the grid-box average weather?
- How do we downscale from a grid-box average to a particular river basin or sub-area?

Return

Typical problems with current generation ensemble forecasts

- Would like to maximize pdf sharpness subject to calibration. But:

Tom Hammil, CDC



- Ensemble forecasts are biased
  - Ensemble mean different (systematic model error; improve the model or post-process to correct errors)
  - Ensemble spread less than it ought to be (better initial conditions, higher-res forecasts, incorporating stochastic effects).

Next

Forecast Input Requirements

- For each sub-basin and time step
- For all lead times 1hr to 1yr
- Ensemble inputs include:
  - Precipitation
  - Temperature
  - Potential evaporation
  - Freezing level
- Verification

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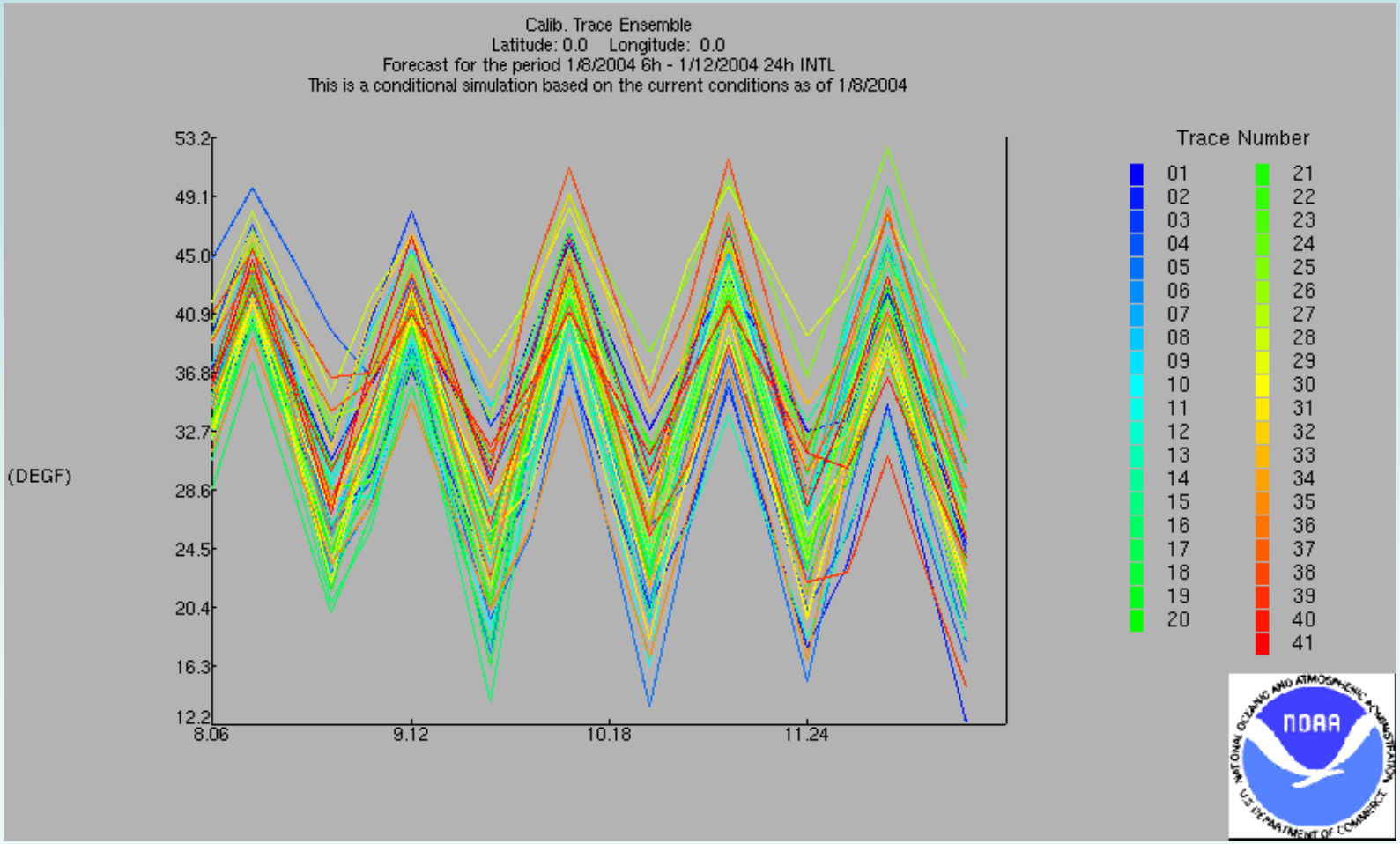
Ensemble Temperature Forecast



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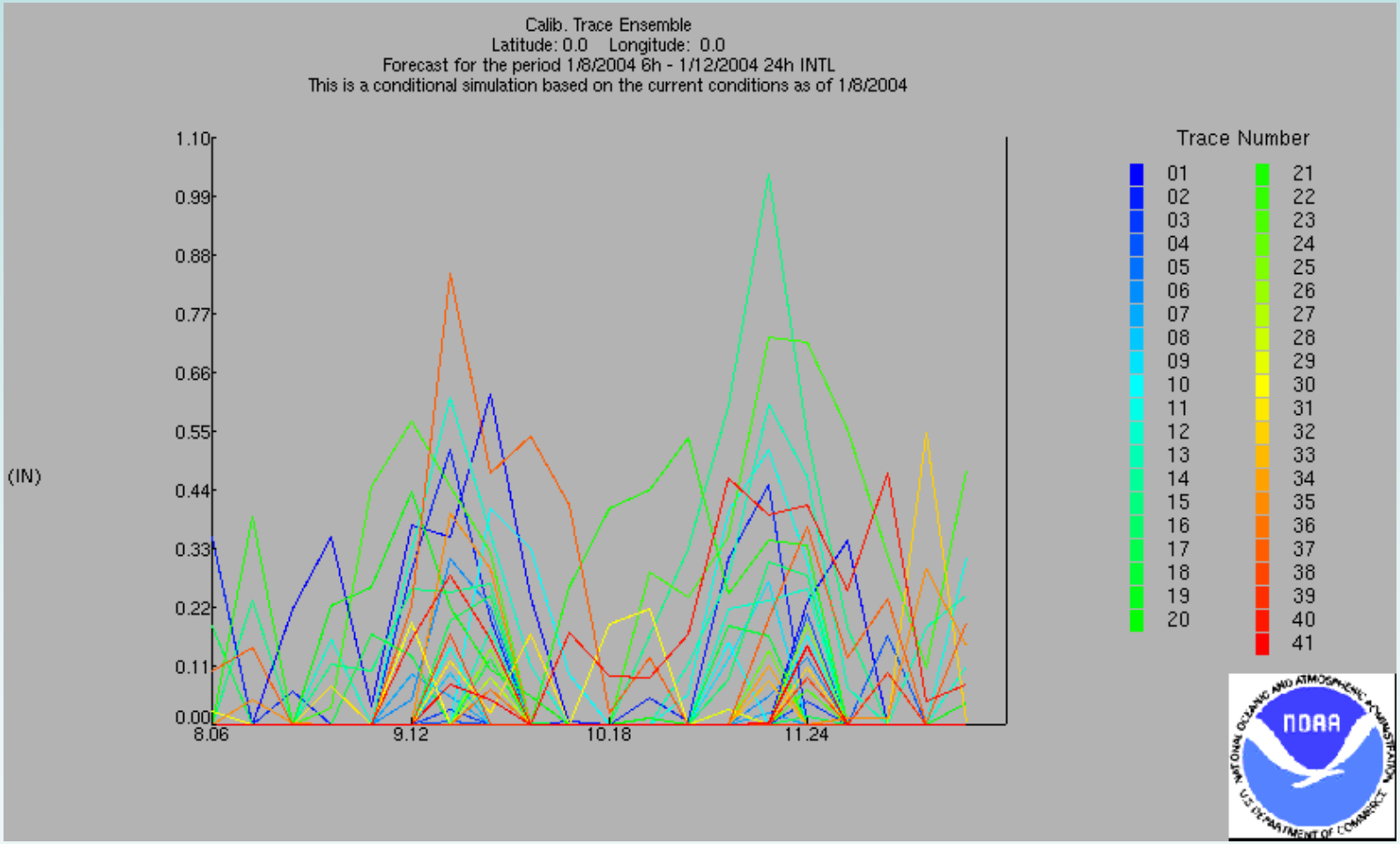
Ensemble Precipitation Forecast



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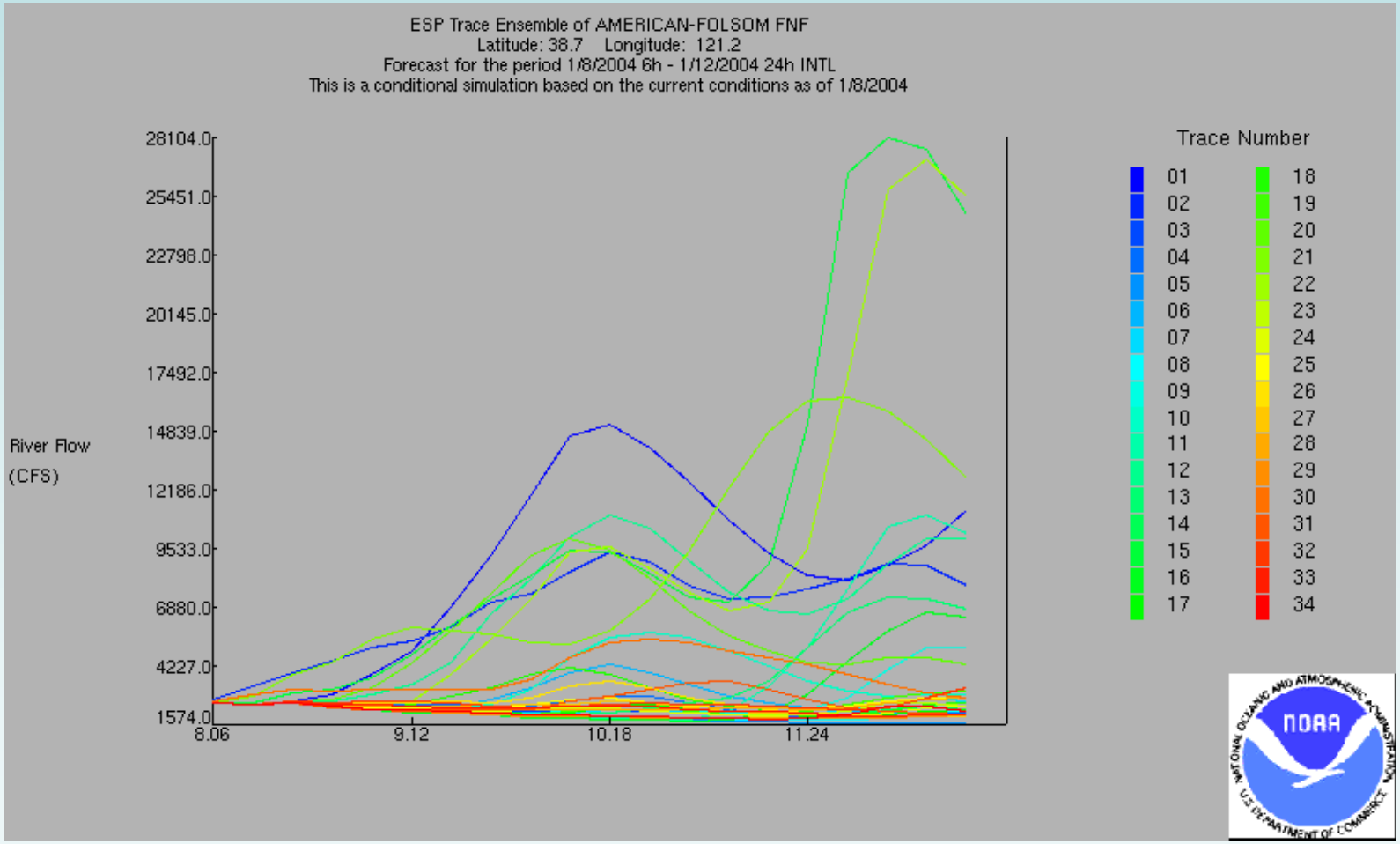
Ensemble Streamflow Forecast



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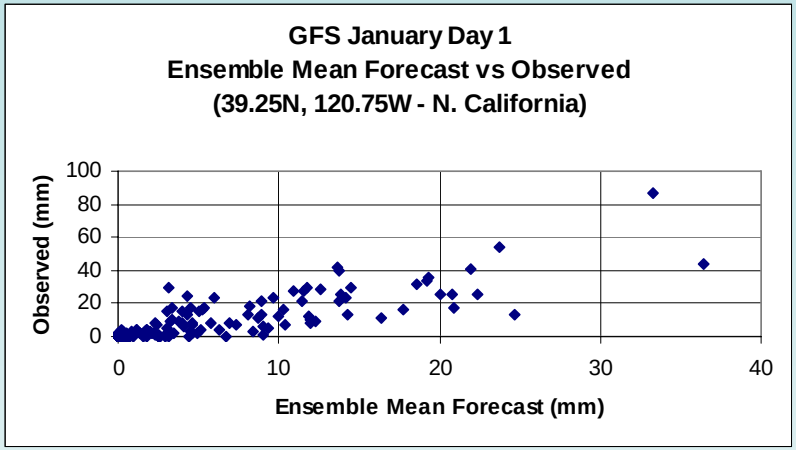
Immediate AHPS Ensemble Precipitation Goals

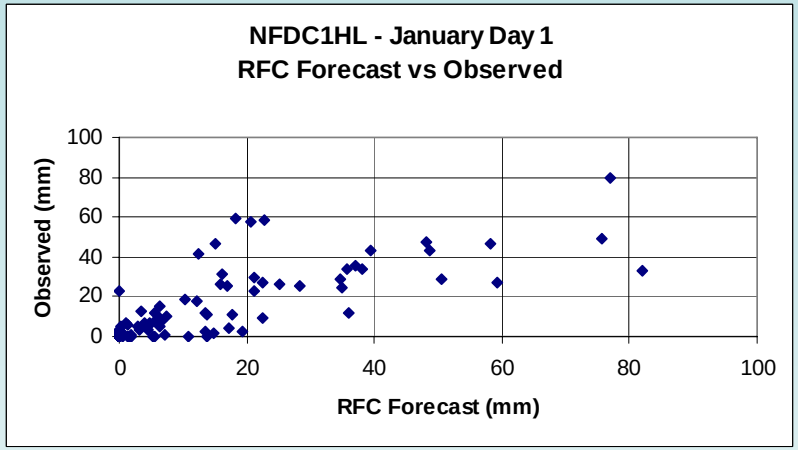
- Create short & medium term precipitation ensembles for input to hydrologic models at basin scale.
- Use existing HPC deterministic forecasts (after modification by RFC HAS forecasters) (i.e. Maintain role of human forecaster for short-term forecasts). Add confidence Factor?
- Use GFS fixed ensemble mean forecasts up to 14 days (to extend lead time and improve preprocessor parameters)

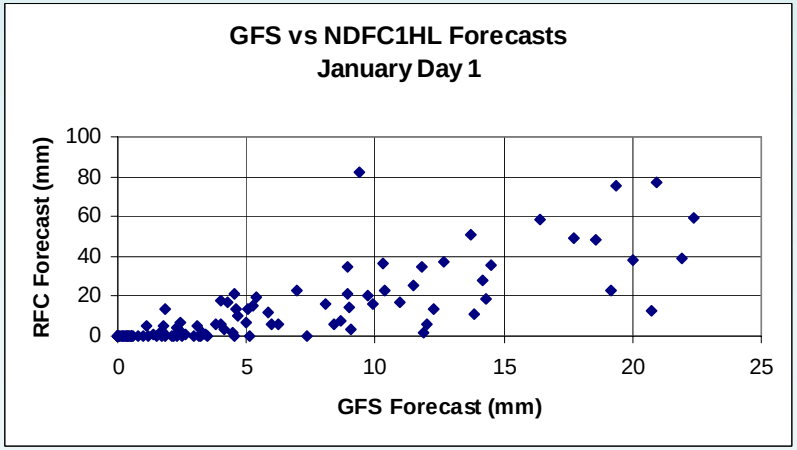
AHPS PreProcessor Performance Objectives

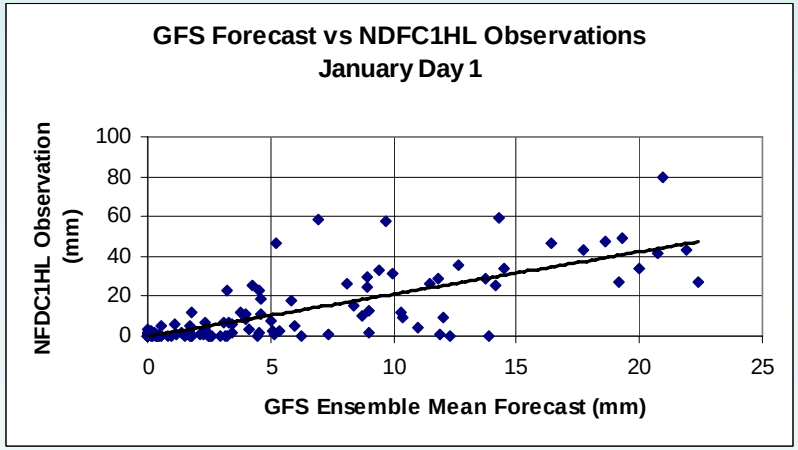
- Preserve skill of the single-value forecasts (at all space and time scales)
- Remove forecast biases
- Produce reliable probabilities
- Account for space/time scale dependency
- Simple, efficient and robust

Precipitation Forecasts and Observations California – January Day 1









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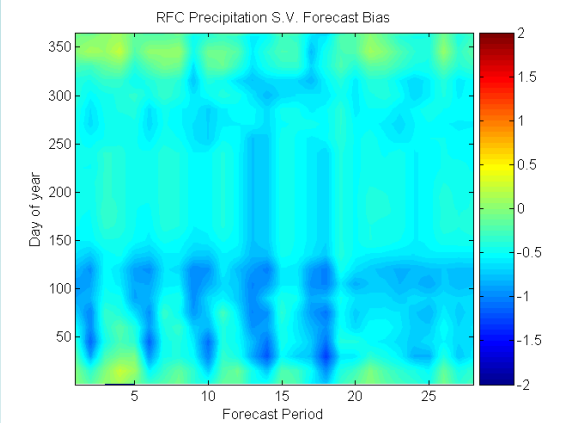
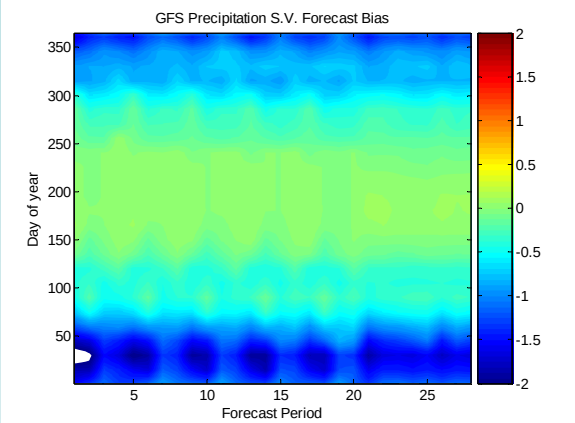
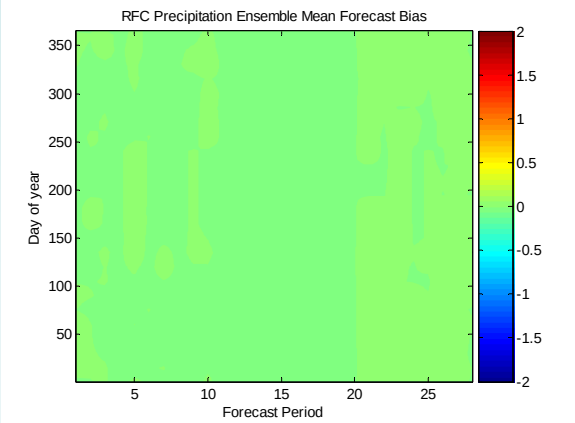
Bias – nfdc1huf Precipitation

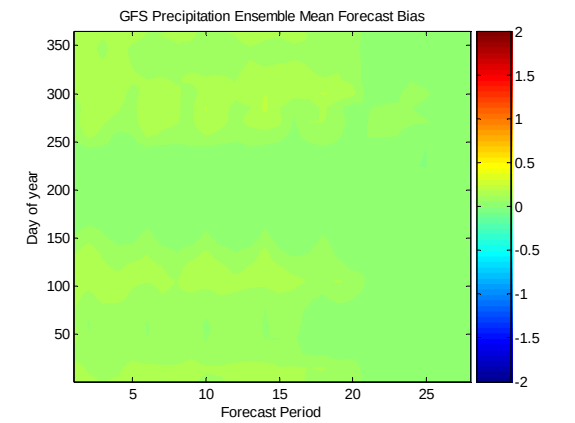
Raw Forecasts





Ensemble Mean





RFC Forecasts

GFS Forecasts

Next

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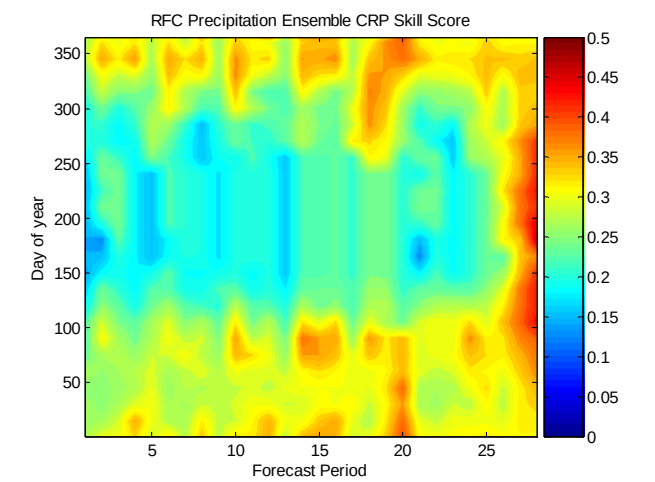
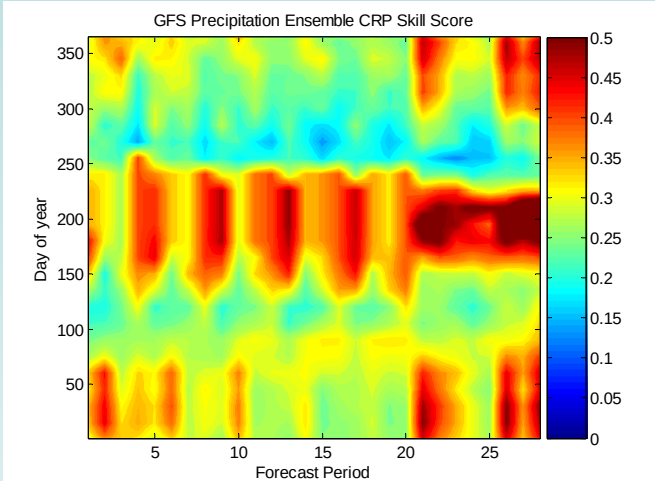
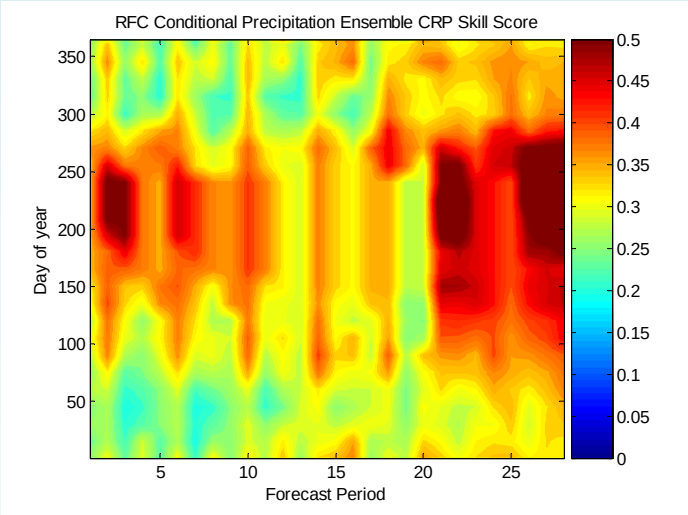
Continuous Rank Probability Skill Score – nfdc1huf Precipitation

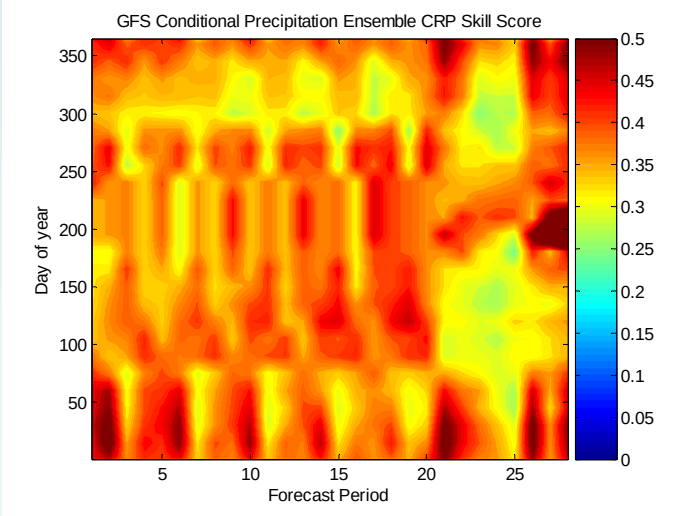
All Events





Wet Events





RFC Forecasts

GFS Forecasts

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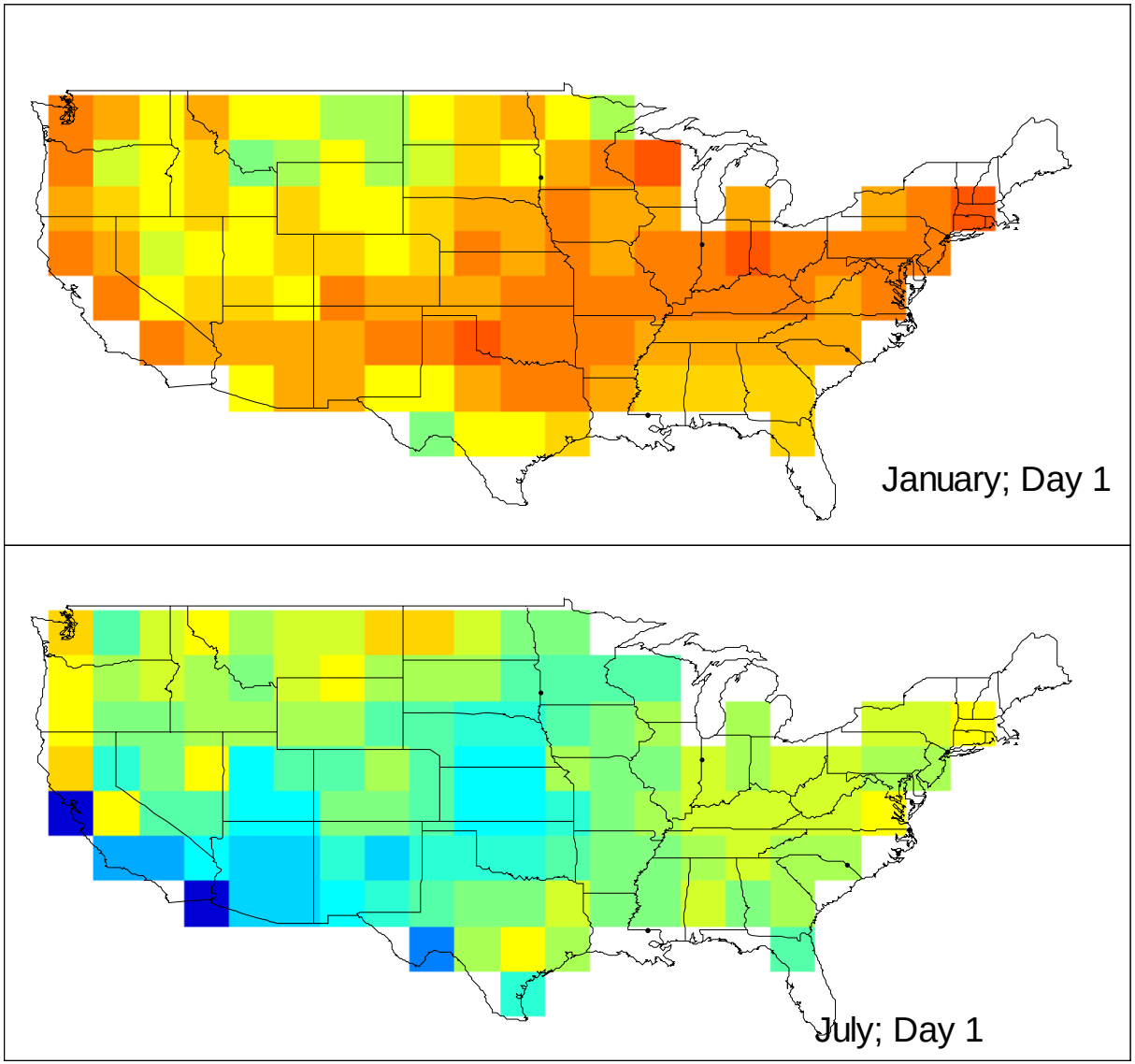
Corr. coeff. between ensemble mean forecast and observed precipitation



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AHPS PreProcessor Science Strategy

- Develop basic capability using existing “single-value” forecasts and observations
- Apply to specific RFC Sub-basin areas using limited RFC and HPC archives of QPF
- Expand to gridded regions – include mult-scale properties
- Develop general Bayesian approach to using GFS ensemble forecasts
- Other approaches (e.g. analogs)?

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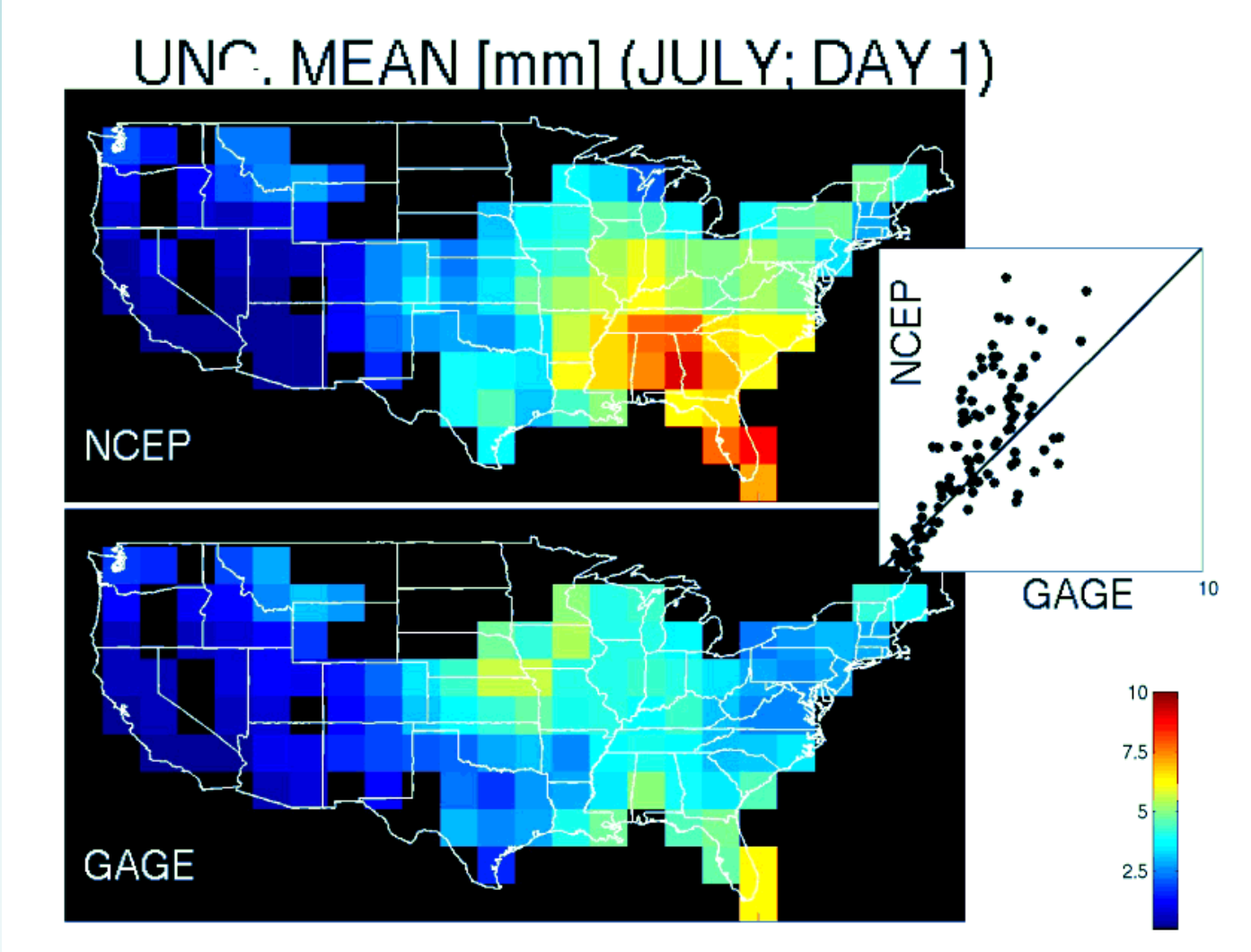
NCEP Global Ensemble Forecasts



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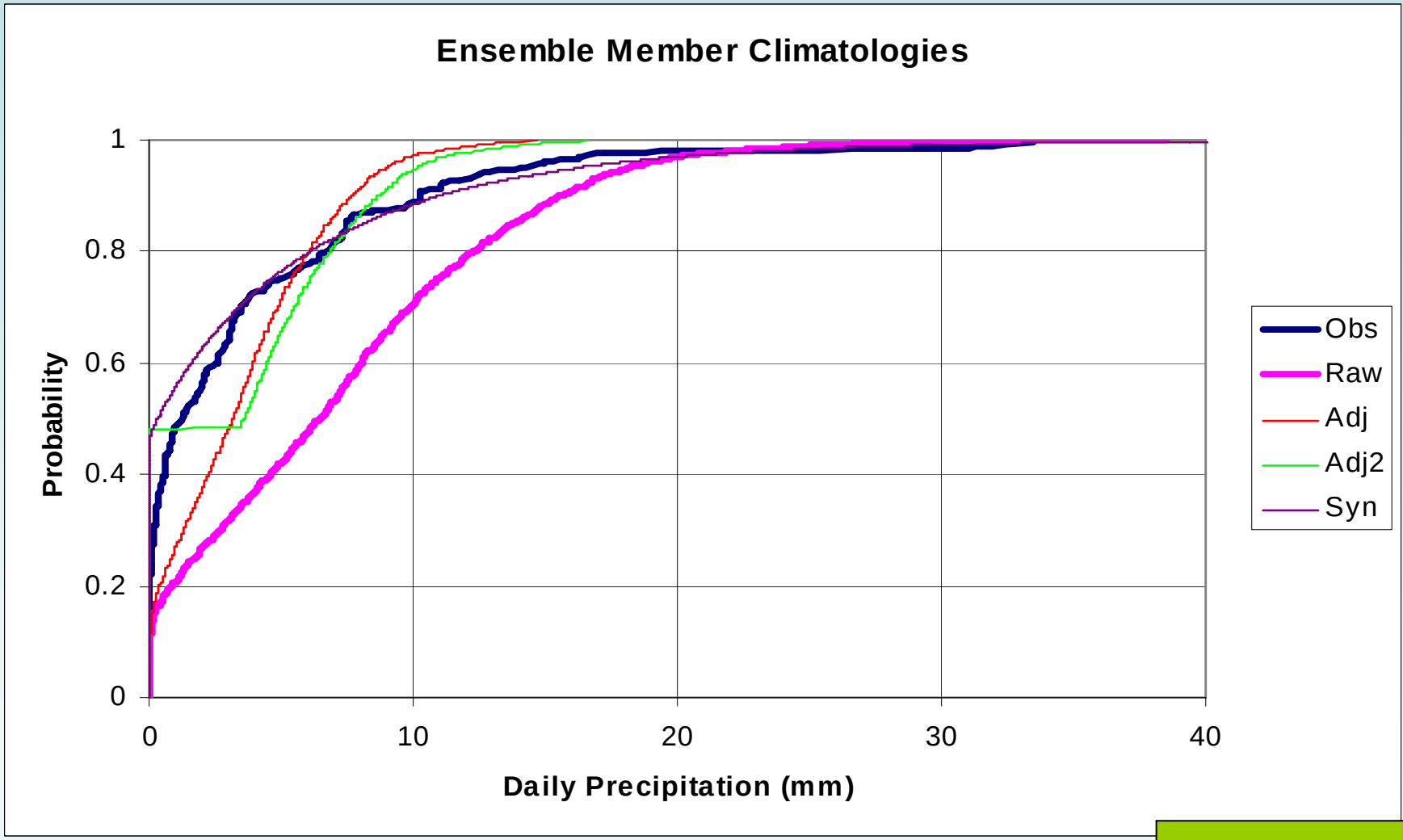
Cumulative Distributions of Adjusted Ensemble Members



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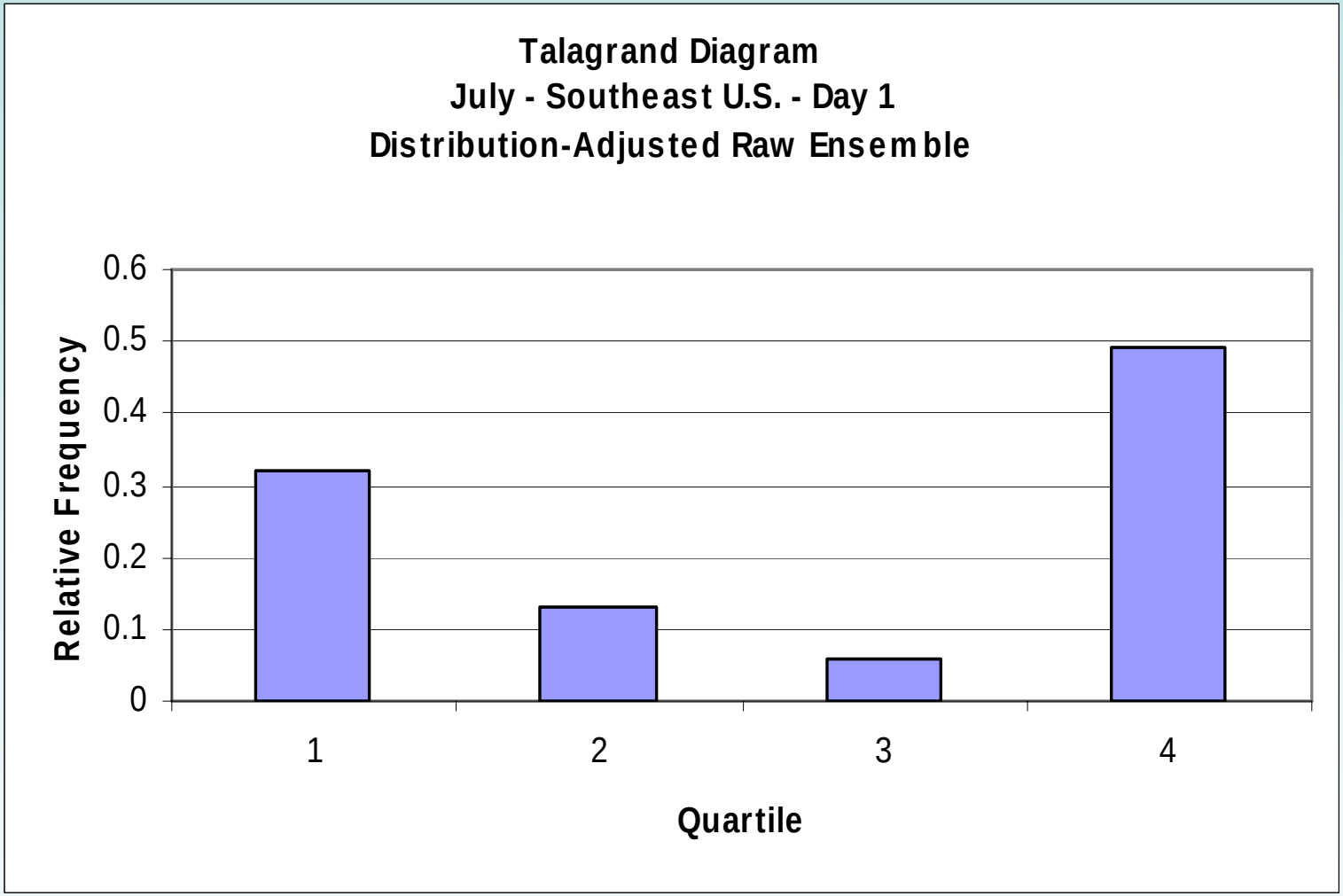
Uncertainty Analysis of Global Ensemble Precipitation Forecasts



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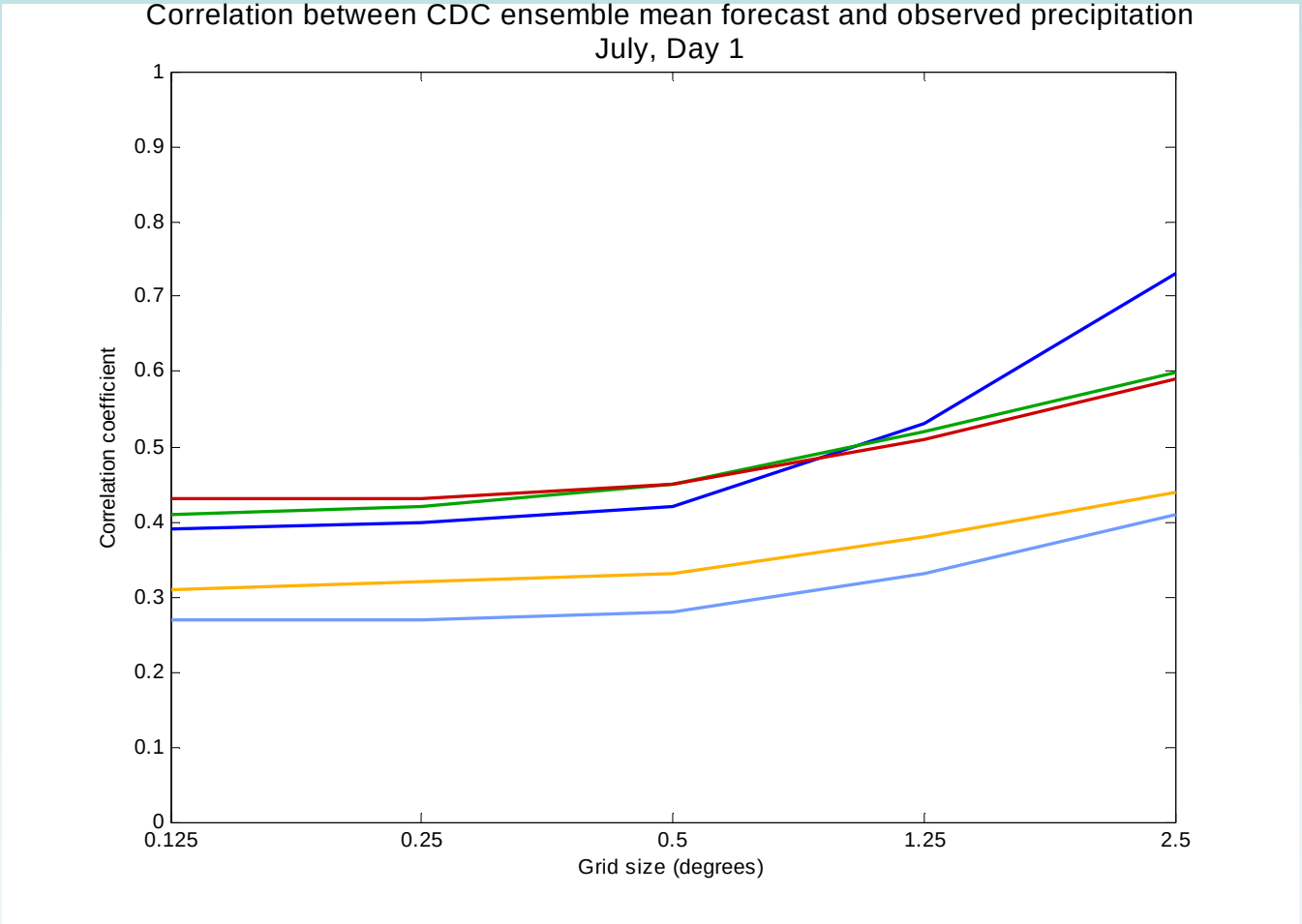
Effect of Spatial Scale on 24hr Forecast Skill (July – 5 locations)



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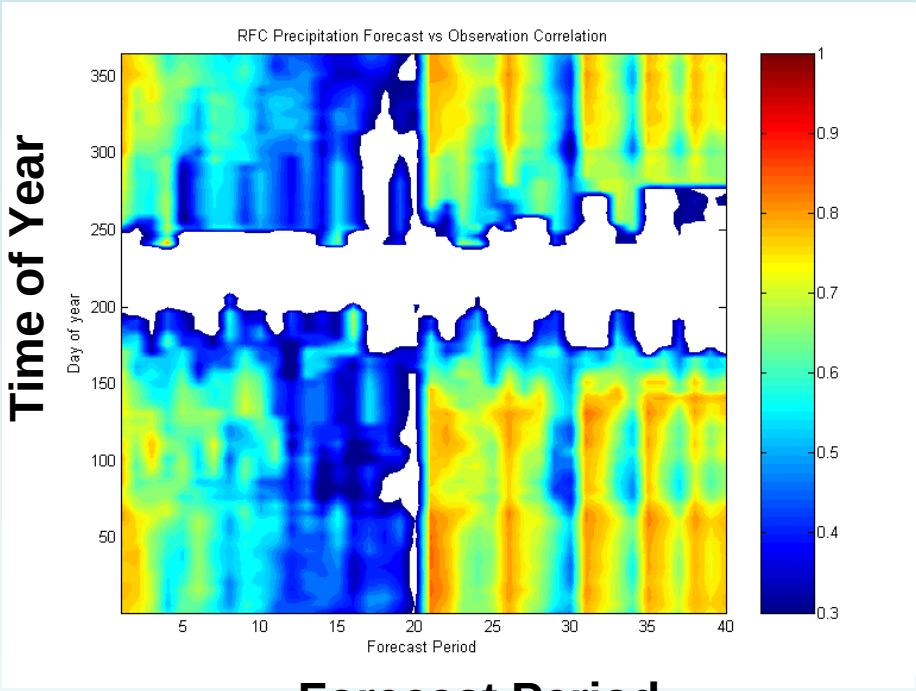
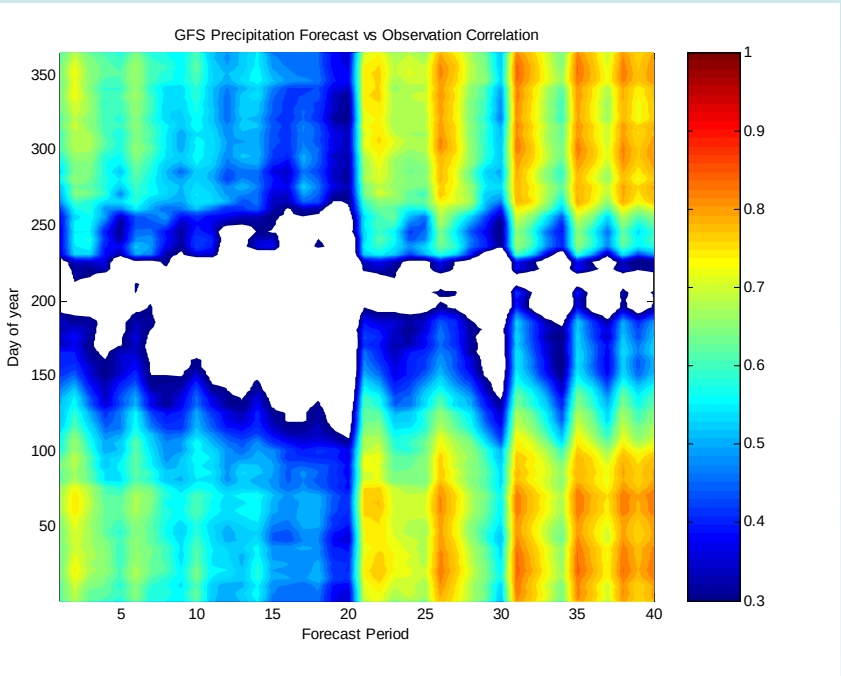
Correlation Coefficient
Precipitation Forecast vs Observation
North Fork American River

RFC Forecasts



Forecast Period

GFS Forecasts



Forecast Period

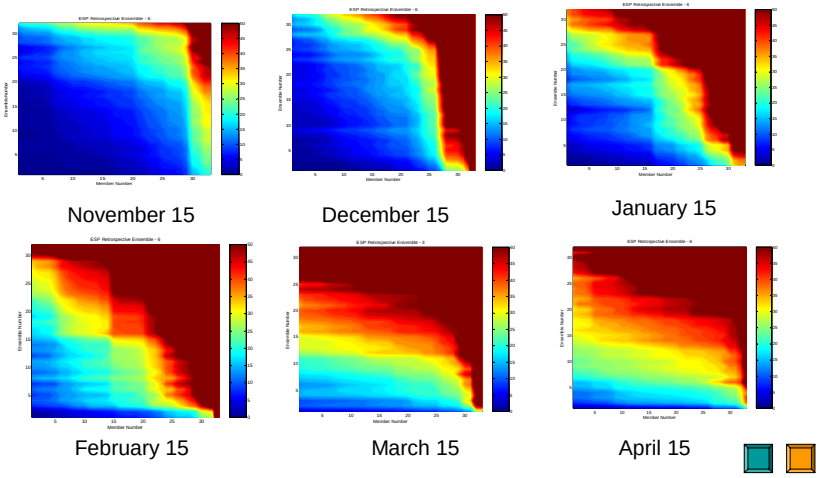
Return

Hydrologic Model Uncertainty Issues

- What are the sources of uncertainty in hydrological models? How are they linked?
- What are the implications of hydrological models being imperfect representations of real hydrological systems?
- How can uncertainties in hydrological models, model parameters and hydrological initial conditions be represented in hydrological ensemble prediction?
- What is relative role of initial conditions and meteorological forcing?

Relative Importance of Initial Conditions vs Precipitation North Fork American River, CA

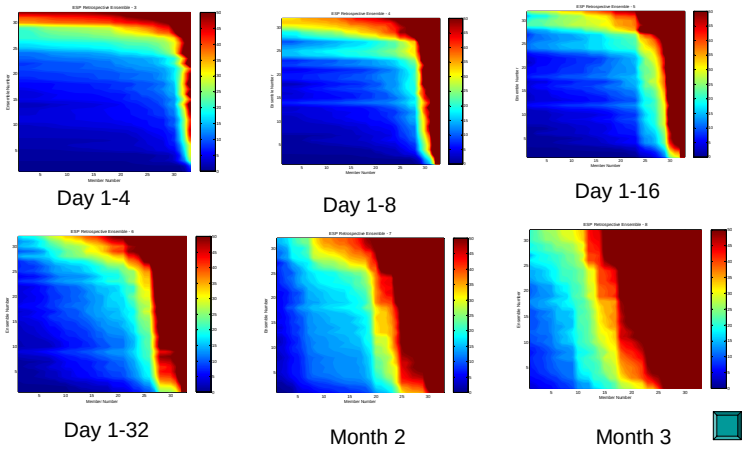
Effect of Initial Conditions vs Forcing for 1-Month Forecast North Fork American River



November 15 | December 15 | January 15

February 15 | March 15 | April 15

Effect of Initial Conditions vs Forcing for December 15 Forecasts North Fork American River



Day 1-4 | Day 1-8 | Day 1-16

Day 1-32 | Month 2 | Month 3

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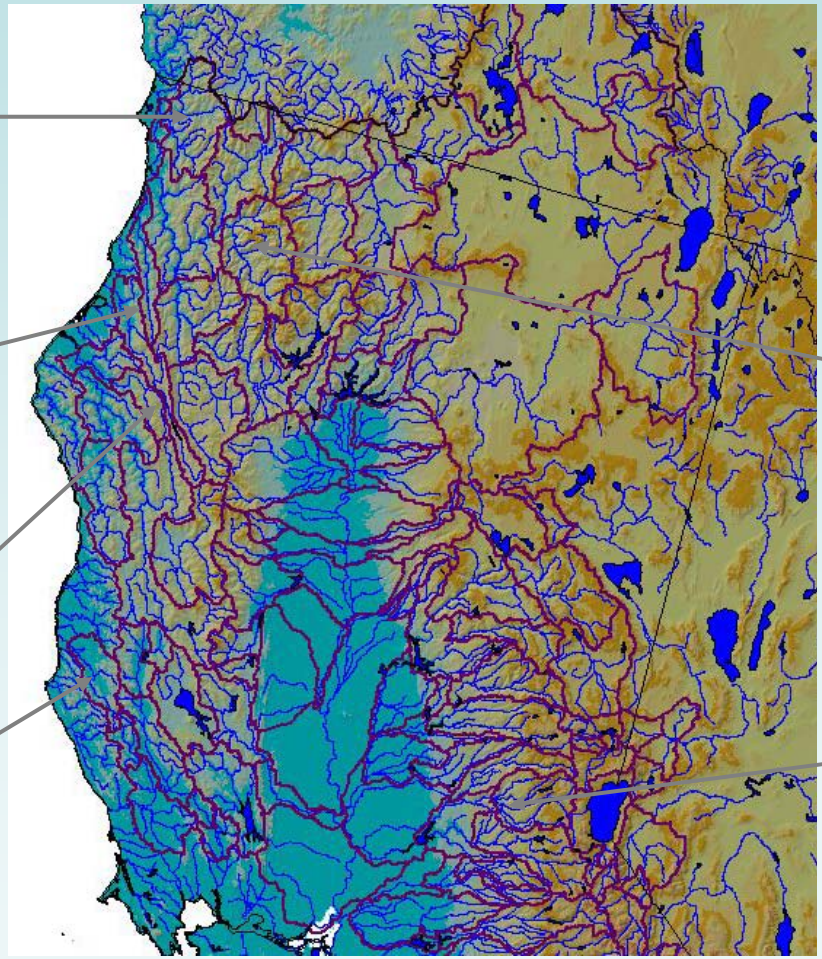
Short-term Ensemble Prototype



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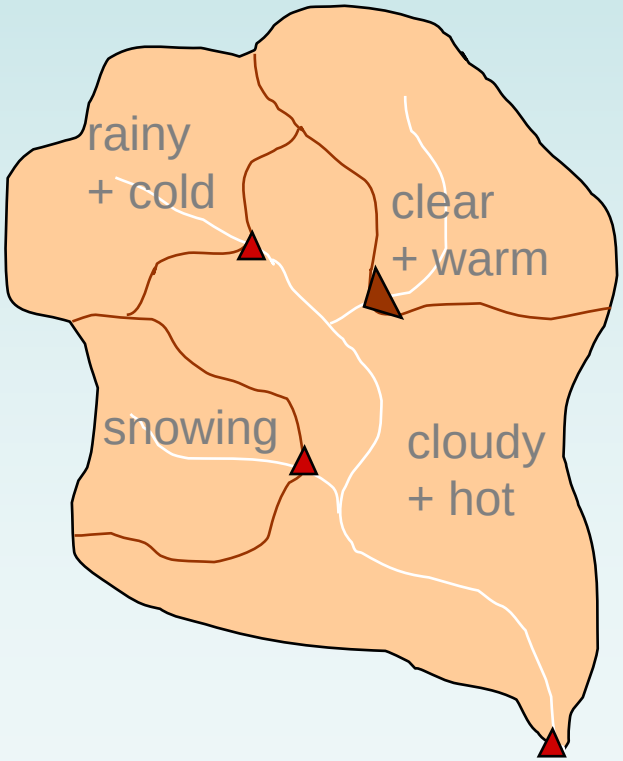
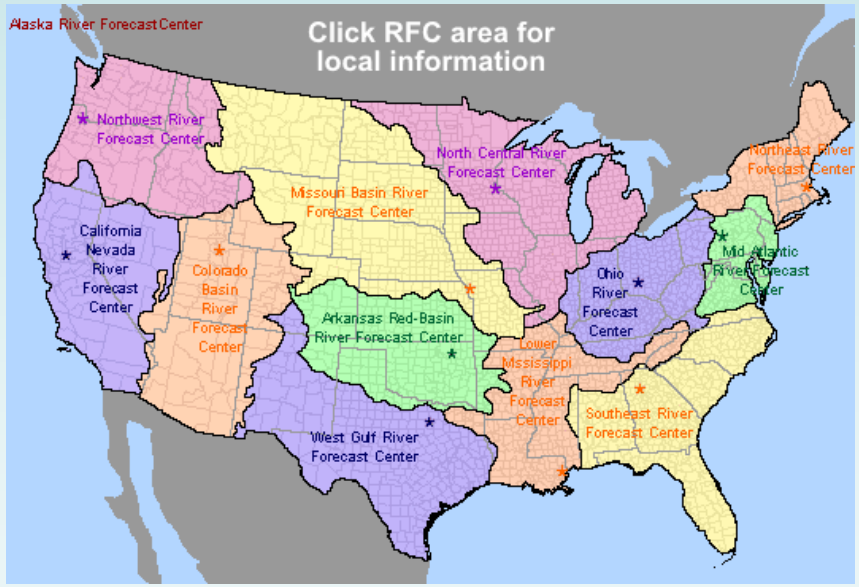
Ensemble Challenges

- Maintain spatial and temporal relationships across very large areas





Irrational outcomes

Next

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Forecaster Role

- Include forecaster skill in short-term inputs (QPF, temperature, etc.)

- Forecasters add value to short-term QPF.
  - HPC adds value to models
  - RFC adds value to HPC

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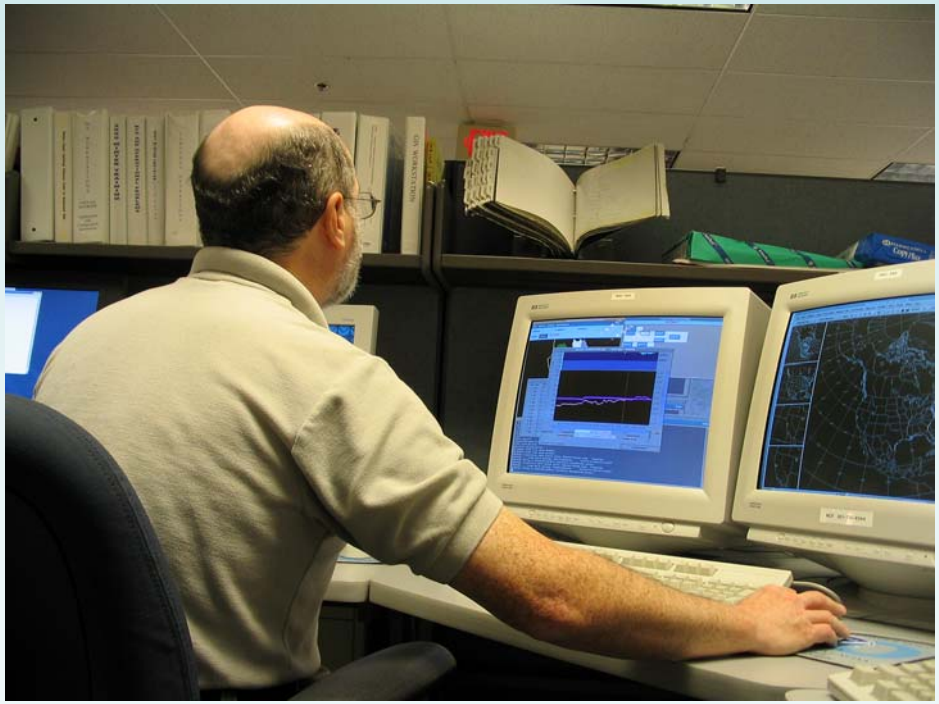
Forecaster Role

- Include forecaster guidance of hydrologic model operation



- Hydrologic models require on-going tuning
- Forecasters commonly adjust or influence raw model output

Next

Return

Verification

- Must be able to measure performance of every element in the system
- Need probabilistic measures
- Must be useful to forecasters and model developers

Return

HEPEX Testbed Projects

- Canada – Great Lakes
- Europe
  - EU-JRC Ispra, Pan-European Flood, Po River
- Brazil
- U.S.
  - SE U.S.
  - Western U.S.
- Bangladesh
- PreProcessing / Statistical Downscaling
- Hydrologic Uncertainty / Data Assimilation

Return

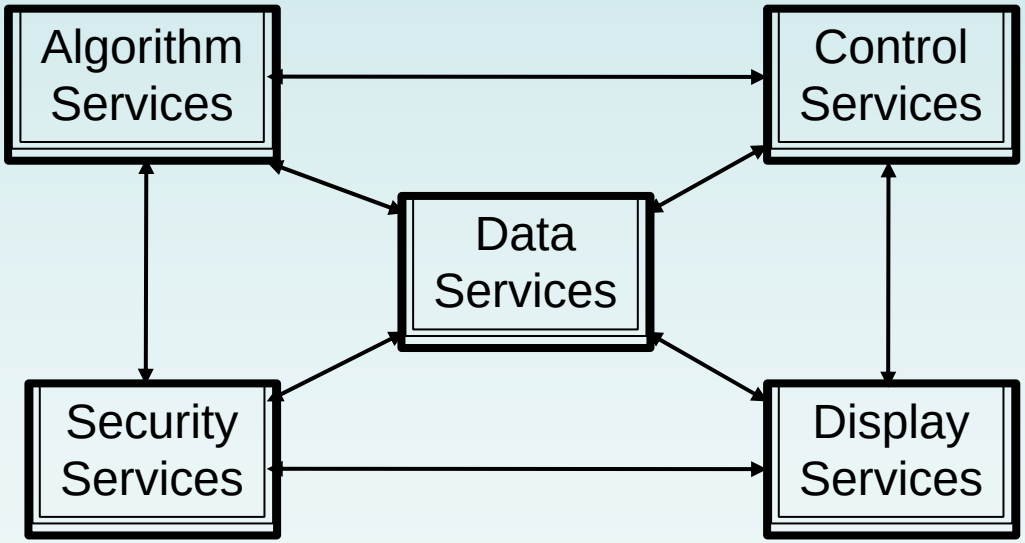
Supporting Data Sets
(Under Construction)

- GFS Fixed Ensemble (1979 – present)
  - Temperature and Precipitation
  - Selected Regions
- Precipitation and Temperature Analyses
  - Selected Regions
  - Multi-scale
- Hydrological Basins
  - Forcing
  - Basin characteristics
  - Streamflow
  - Snow, soil moisture, satellite, etc
- TIGGE Ensembles
- CPC Products (for US)
- Other? (e.g. ECMWF, CMS, etc.)

Return

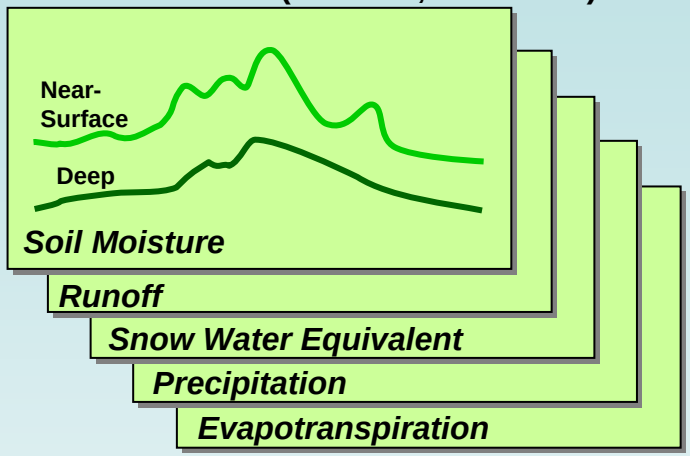
Community Hydrologic Prediction System (CHPS)

Federal agencies
State, regional, and local cooperators
Universities
Private sector
International organizations

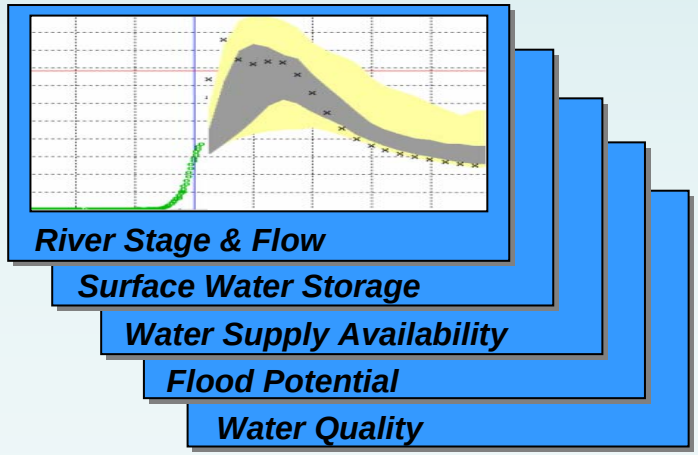


Hydrology XML Consortium
http://www.weather.gov/oh/hydroxc/index.html

Point Information (Stations, Grid Cells)



Vector Information (River Segments)



Return

AHPS Outreach
Customer Satisfaction Survey

CFI GROUP WORLDWIDE
ANN ARBOR
ATLANTA
BUENOS AIRES
KUALA LUMPUR
LONDON
MADRID
MELBOURNE
MILAN
PARIS
PORTO ALEGRE
SEOUL
SHANGHAI
STOCKHOLM

National Weather Service
Hydrologic Services Program

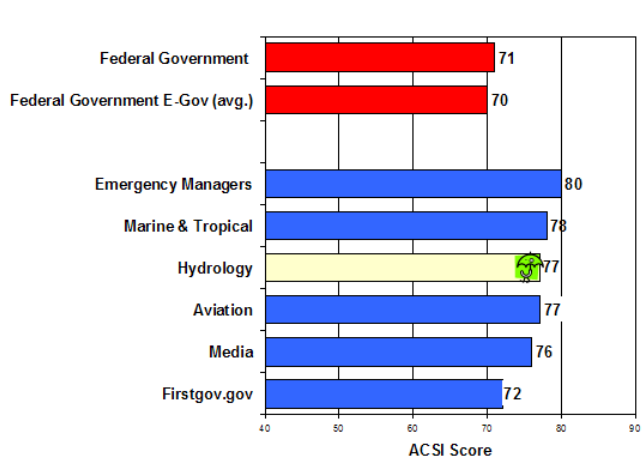
Customer Satisfaction Results

October 28, 2004

CFI Group
Claes Fornell International

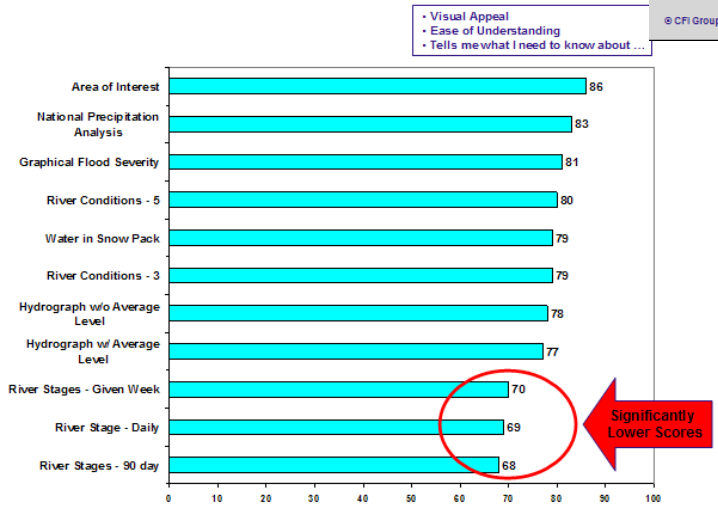
FEDERAL CONSULTING GROUP

Hydrology Receives High Marks
Similar to other NWS scores; above Fed Gov ACSI



9

Overall Scores for Graphics
Based on average of 3 questions



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Next

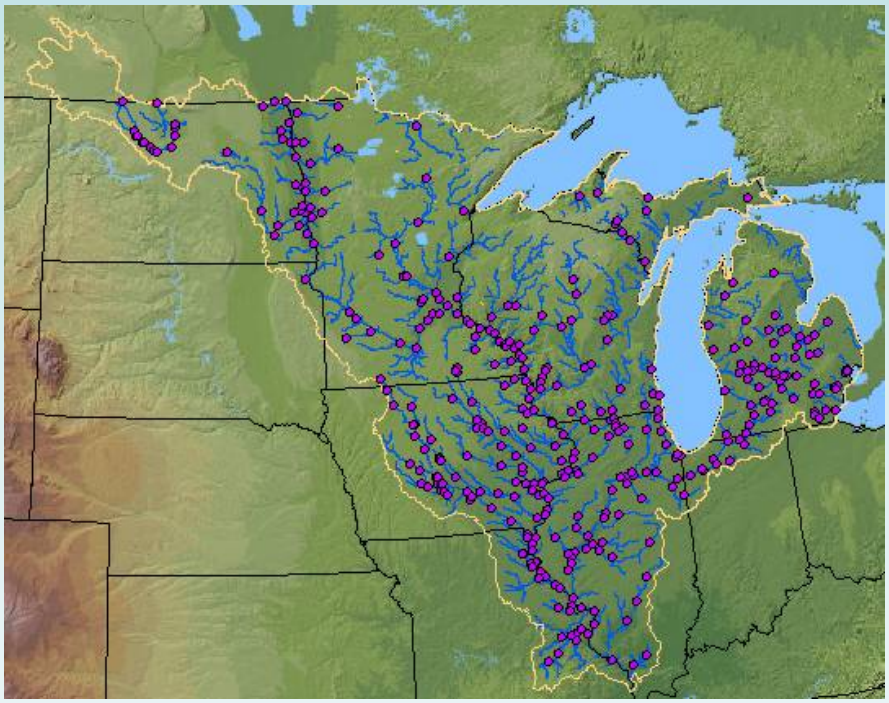
Return

Forecaster – User Roles

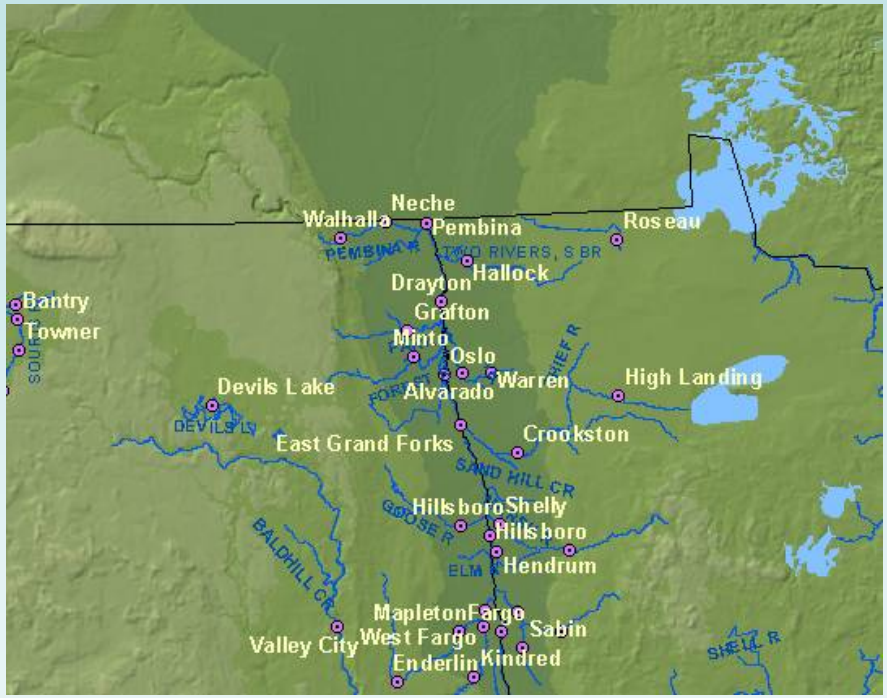
- Potential users know what hydrologic ensemble predictions can do for them.
- Forecast developers know what users need
- Users and forecasters work together to develop forecast products
- Real-time Interaction is Essential

Return

North Central River Forecast Center (NCRFC)



Forecast Area



Red River of the North

Next

Return

National Weather Service Advanced Hydrologic Prediction Service - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back Search Favorites

Address http://www.crh.noaa.gov/ahps2/river.php?wfo=fgf&wfoid=18766&riverid=204483&view=1%2C1%2C1%2C1%2C1%2C1&pt%5B%5D=144057&allpoints=142070%2C143611%2C144057

Google grand forks flooding Search 44 blocked Check Look for Map AutoFill Options grand forks flooding

Home News Organization Search Search

Red River of the North

Choose a Location

Return to:
Red River of the North Point Selection Page

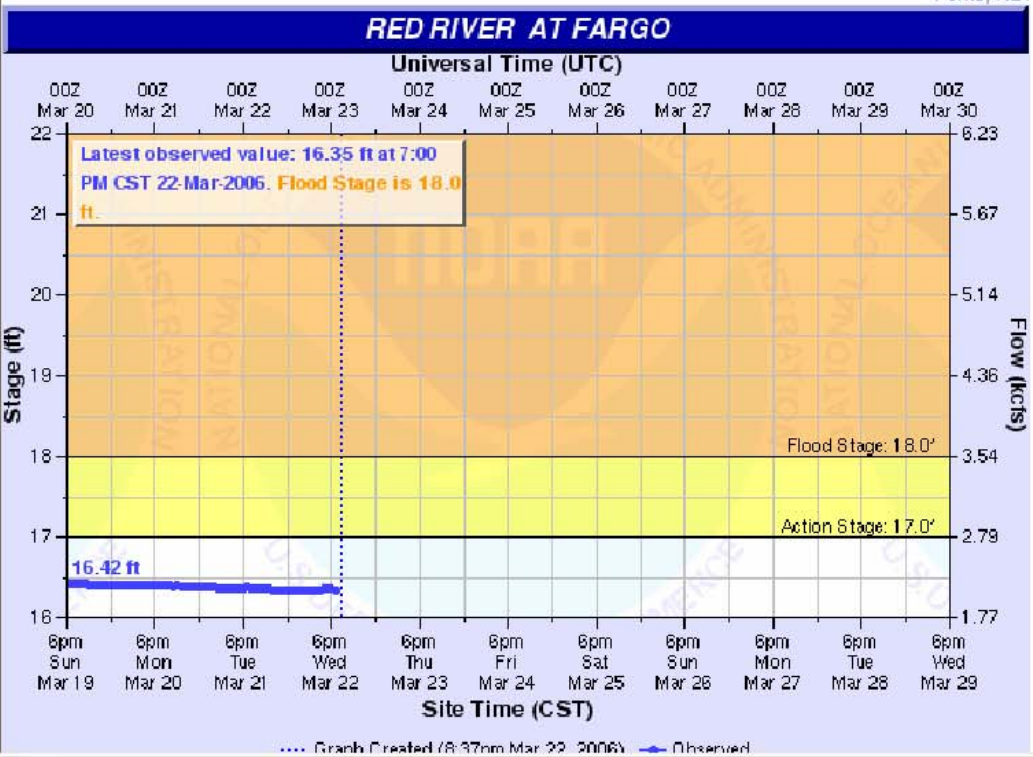
Important Note:
Book-marking page saves current search criteria

at Fargo

Flood Stage: 18 Feet
Latest Stage: 16.35 ft at 01:00 UTC 03/23 01:00

Current Warnings/Statements/Advisories:
None currently.

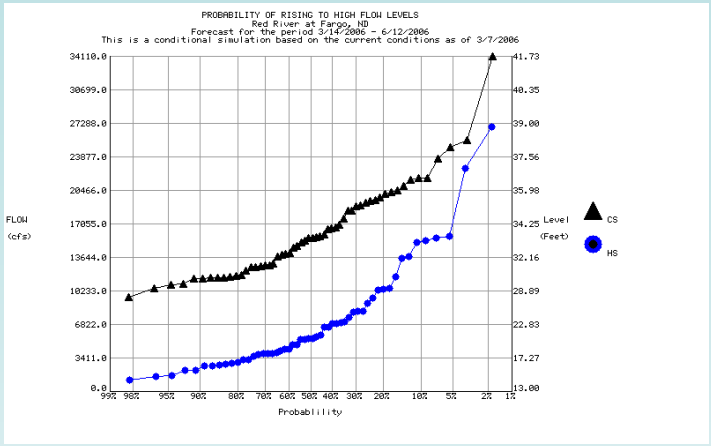
Complete information about the Red River of the North at Fargo available from NWS Eastern North Dakota/Grand Forks, ND.



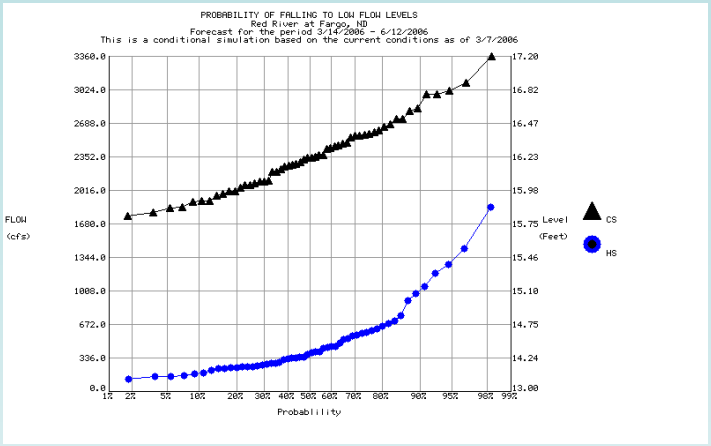
Internet

start Inbox f... TextPad... 2 Micr... 2 Micr... Laplink ... Search ... National... Map - Mi... Google 9:44 PM

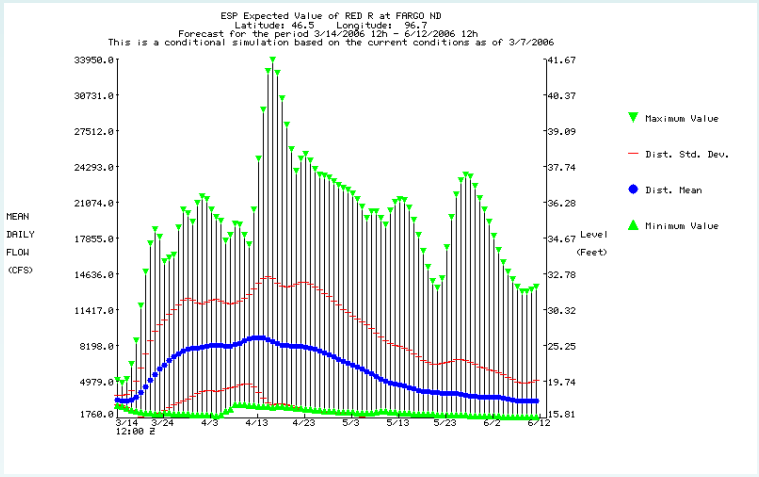
Probability Forecasts for Red River at Fargo, ND



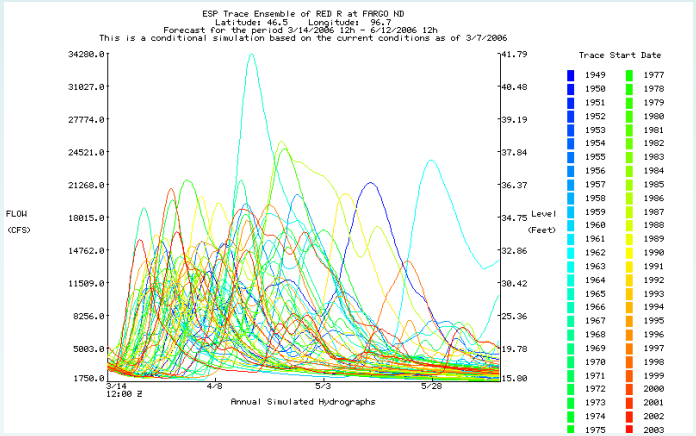
90-day Maximum Flow



90-day Minimum Flow

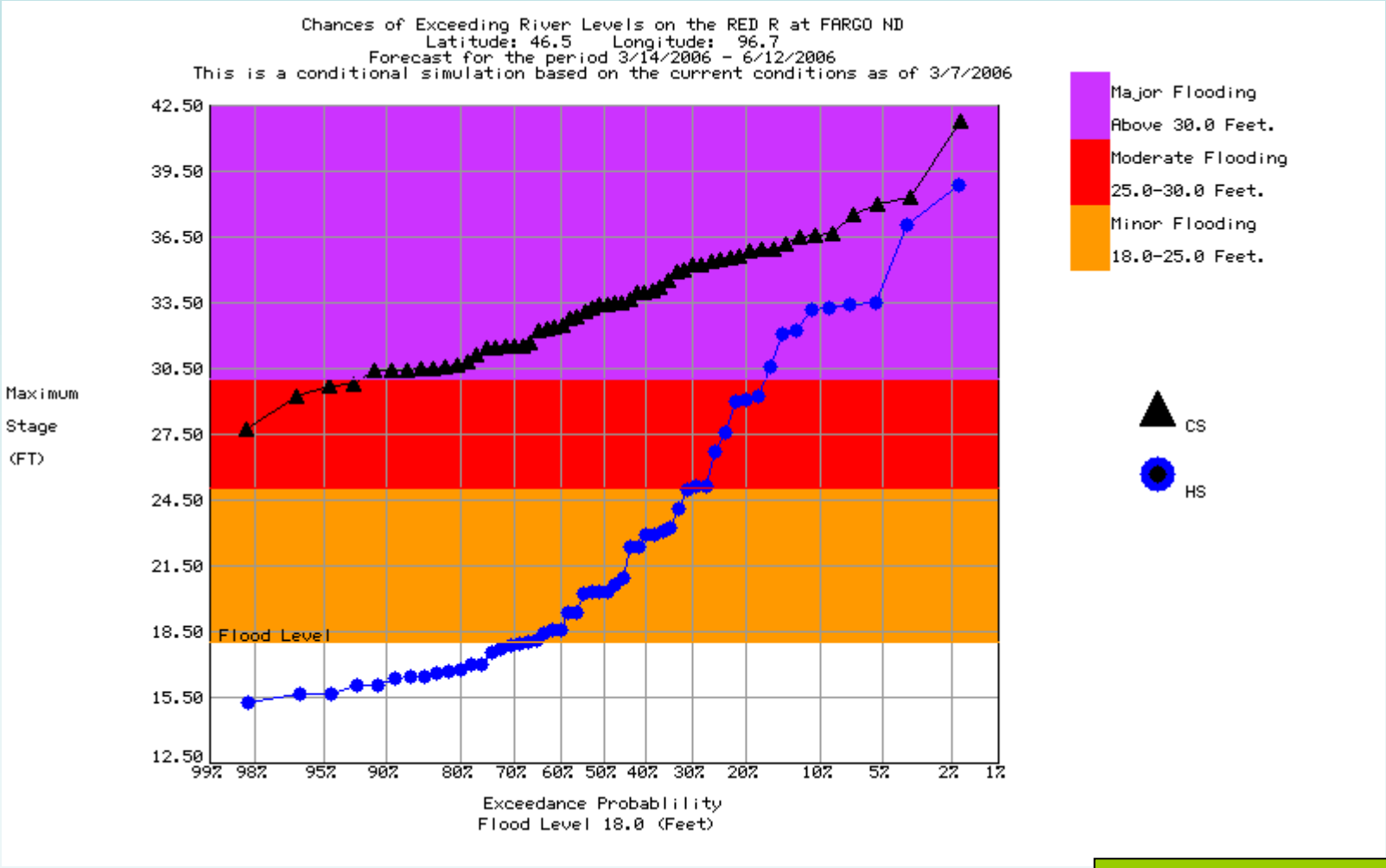


Expected Value Plot



Ensemble Traces

Stage Exceedance Forecast for Fargo



Return