

# Ensemble River Routing Forecast Forced by GEFS Runoff Output: A Development Plan and Preliminary Experiments

*Dingchen Hou\**, *Zoltan Toth*,  
*Kenneth Mitchell and Helin Wei\**

Environmental Modeling Center/NCEP/NOAA  
5200 Auth Road Camp Springs, MD 20746  
\* SAIC at EMC/NCEP/NOAA

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# Motivation

## Background:

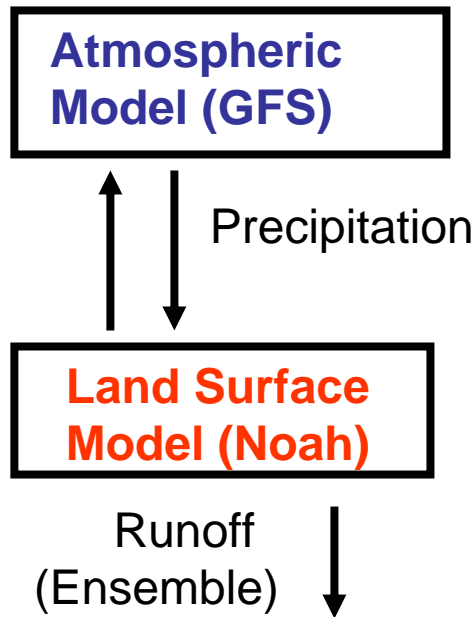
- Development in Land Surface component of NWP systems made it possible to include stream flow in NWP (Mitchell et al, 2004).
- River routing experiment in data assimilation mode revealed potential benefit of river flow forecast in NWP (Lohmann et al, 2004).
- Existence of uncertainty in initial conditions, model structure and forcing needs to be considered with an ensemble approach.

## Purpose:

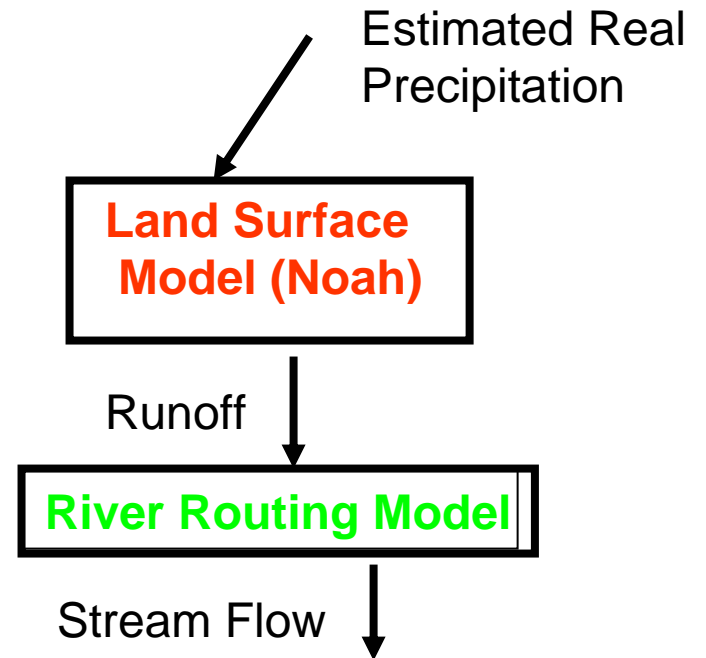
- Demonstrate feasibility of gridded river routing in operational GEFS.
- Establish optimal configuration for river routing.
- Develop suitable strategy to account for uncertainties.
- Develop suitable methods of post processing and generating final products.
- Evaluate the model output of stream flow.

# Current NCEP Routines (No Stream Flow Forecast)

Operational GEFS real time  
Forecast (Ensemble)

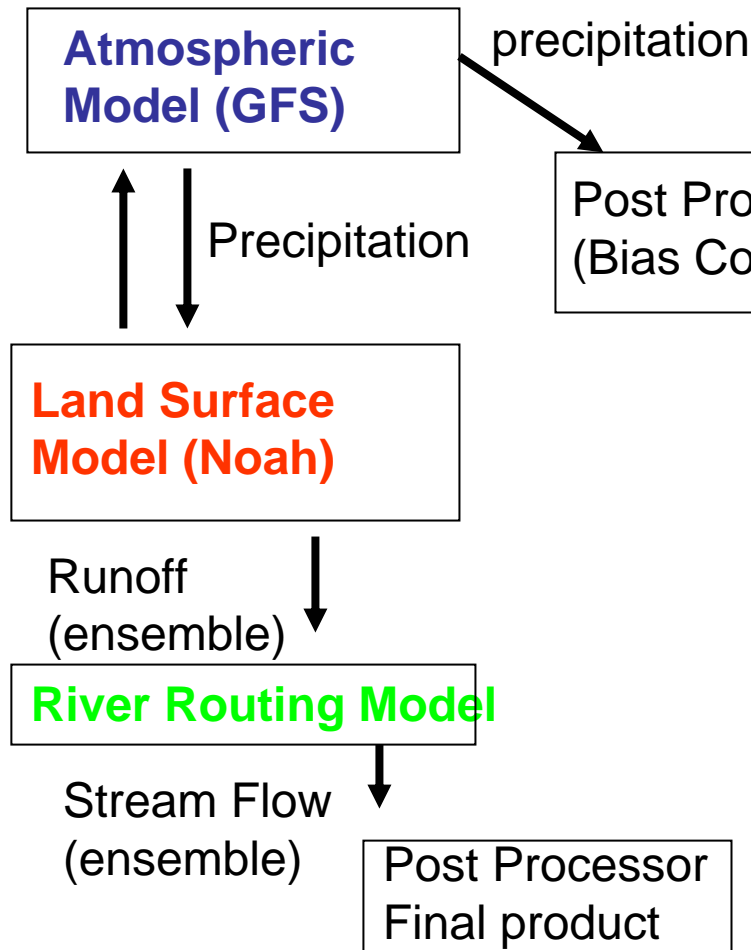


NLDAS quasi-real time  
Analysis (Single)

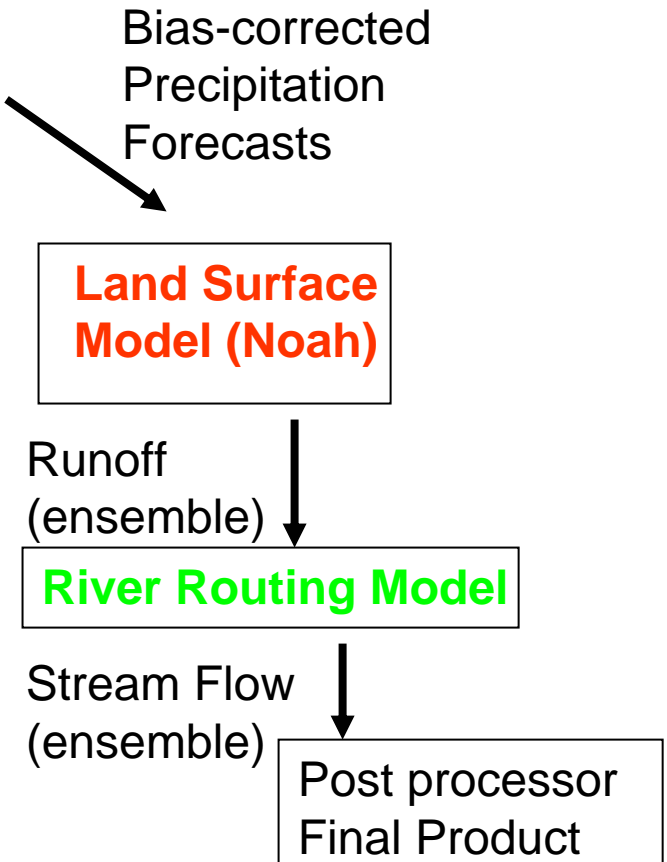


# Ensemble Stream Flow Forecast Two Possible Approaches

**A)**



**B)**



# Configuration

## Design of Preliminary Experiment (Approach A)

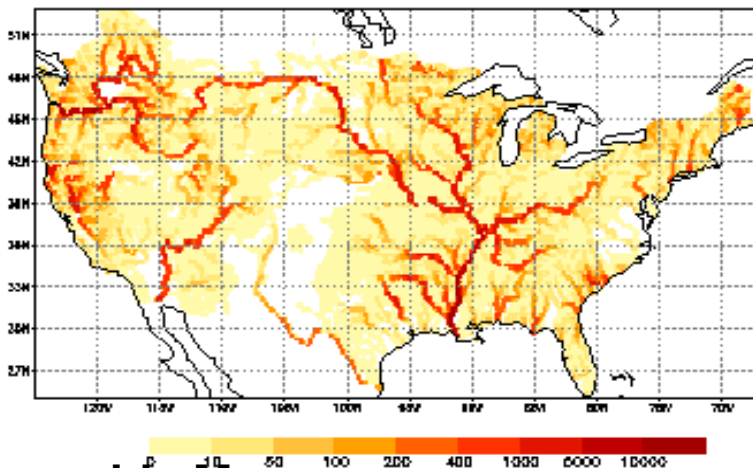
- **River Routing Model:** linear program, distributed approach, same as used in NLDAS (Lohmann et al., 1998, 2004).
- **CONUS domain**, 1/8 degree grid size (same as NLDAS).
- **River Flow Direction Mask:** A D8 model, river stream in each grid point is discharged to 1 of the eight main directions (Lohmann, et al, 2004).
- **Forcing:** Runoff from global ensemble forecasts (GEFS) and the high resolution control forecast (GFS).
- **Uncertainty** considered in river routing: only in the forcing.
- **Warming up period:** A dry start on Jan. 1<sup>st</sup> 2006 and a wetting up (warming up) period of 3 months
- **Evaluation:** For this preliminary test, using river routing products generated by the same model forced by NLDAS runoff, which is generated from observed precipitation (denoted as analysis). Observation will be used in the follow up study.

# An example of Stream Flow Forecast

Forced by GFS, GEFS Forecast and NLDAS Product  
Forecast Starting at 00Z, April 1<sup>st</sup>, 2006. Lead time 15 days

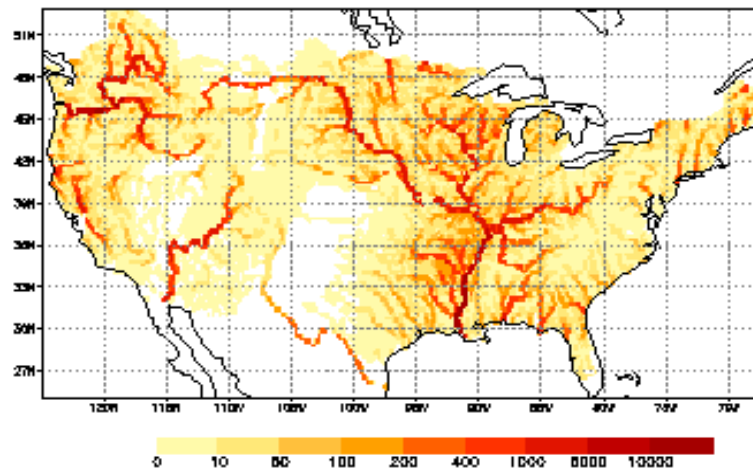
## GFS High Res. control

STREAM FLOW: GFS 360hr fcst from 20060401



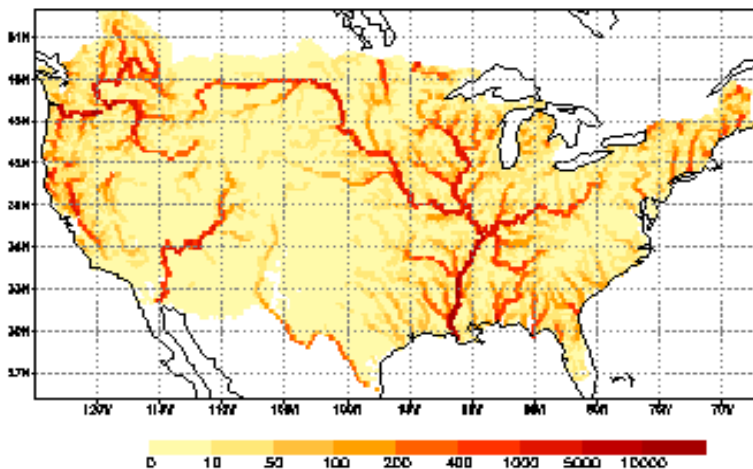
## Ensemble Control

STREAM FLOW: CTL 360hr fcst from 20060401



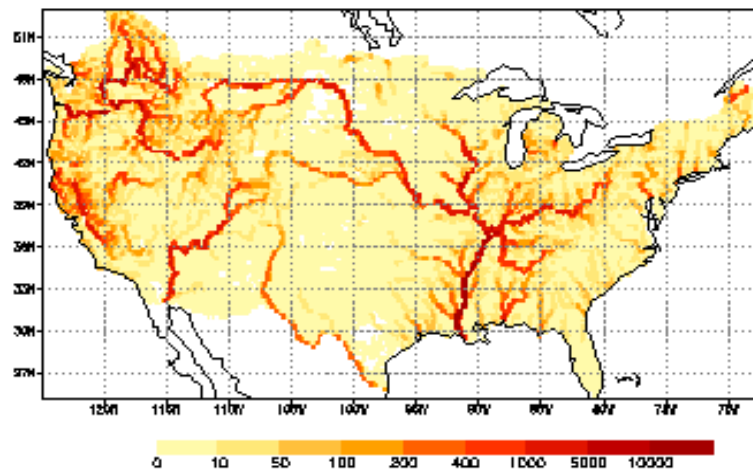
## Ensemble Mean

STREAM FLOW: ENS. MEAN 360hr fcst from 20060401



## Analysis (NLDAS)

STREAM FLOW: NLDAS 360hr fcst from 20060401



# An example of Stream Flow Forecast

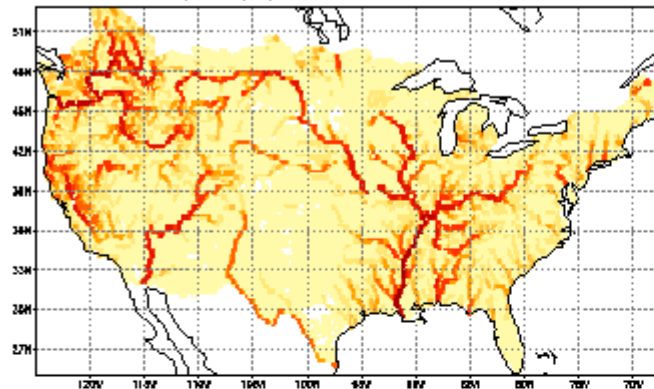
Stream Flow forced by NLDAS Product and Ensemble Mean Forecast

Error of Ensemble Mean and Ensemble Spread

Forecast Starting at 00Z, April 1<sup>st</sup>, 2006. lead time 12 days

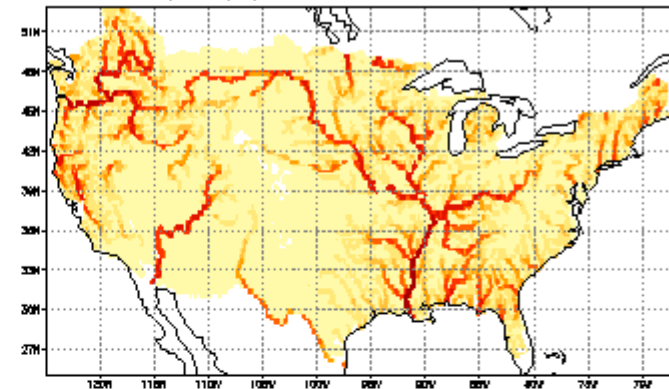
## Analysis (NLDAS)

STREAMFLOW (m<sup>3</sup>/s): NLDAS 288hr fcst from 20060401



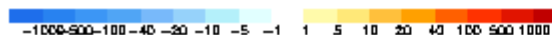
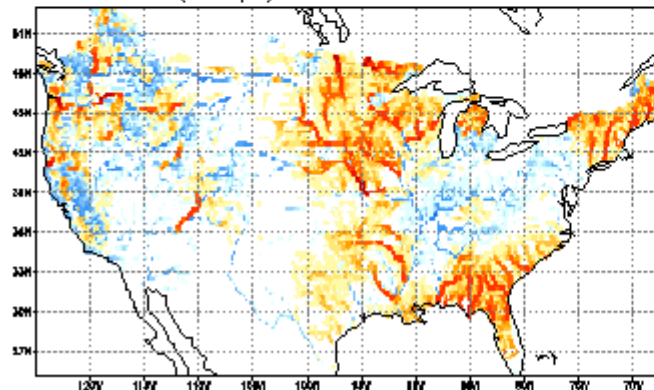
## Ensemble Mean

STREAMFLOW (m<sup>3</sup>/s): ENS. MEAN 288hr fcst from 20060401



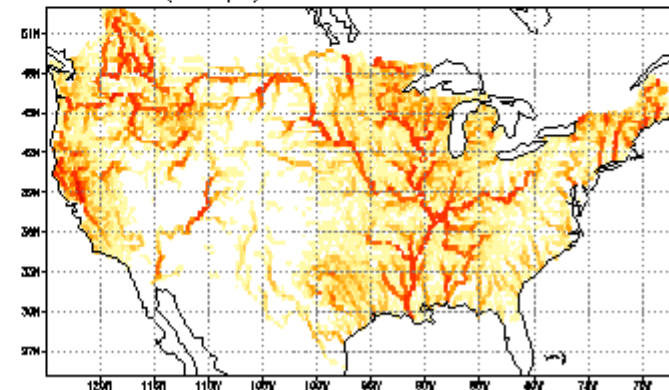
## Error=Ens. Mean-NLDAS

STREAMFLOW (m<sup>3</sup>/s): ERROR 288hr fcst from 20060401



## Ensemble Spread

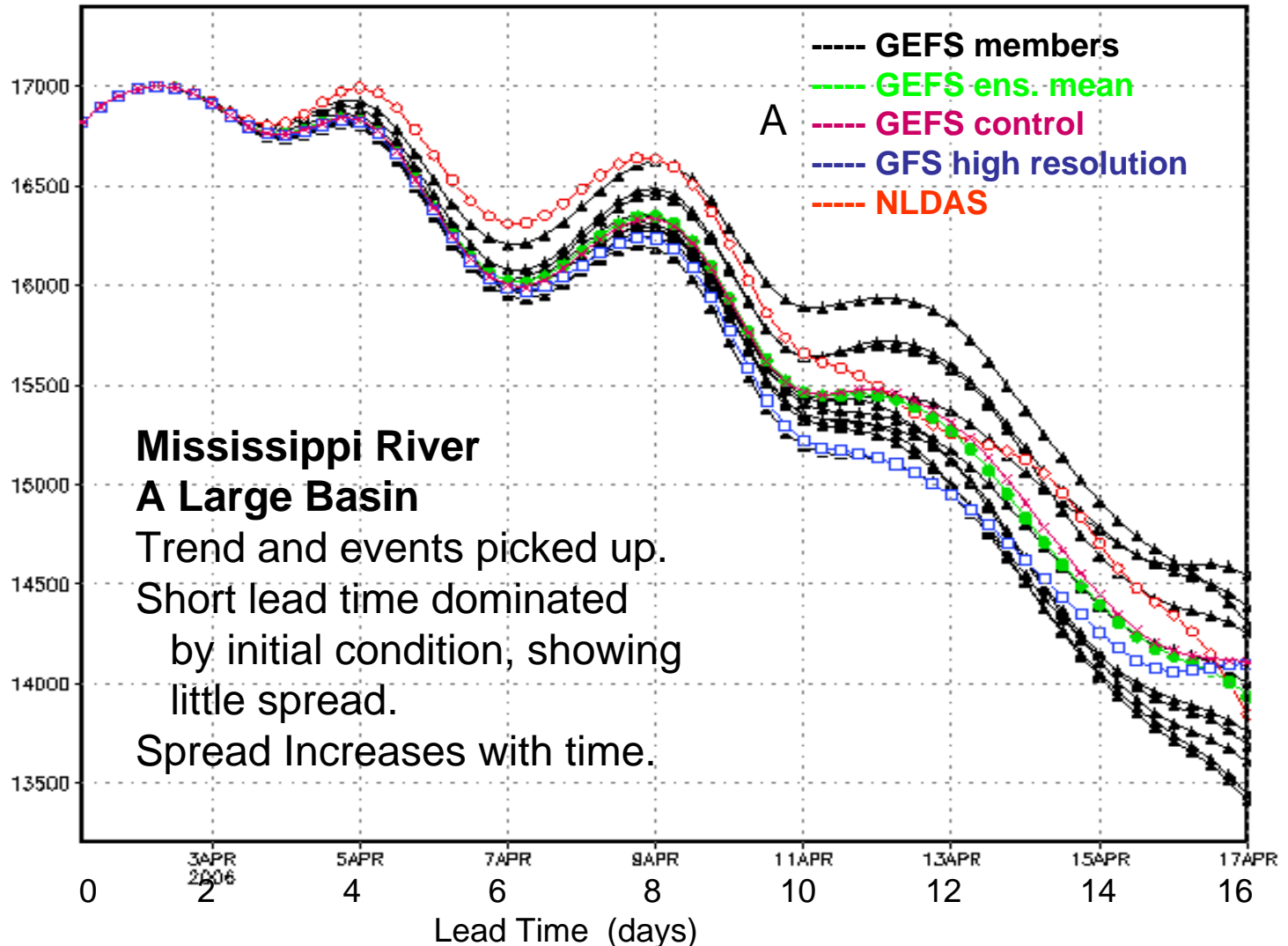
STREAMFLOW (m<sup>3</sup>/s): ENS. SPRD 288hr fcst from 20060401



# An Example of Stream Flow Forecast (Lower Mississippi)

Forced by GFS, GEFS Forecast and NLDAS Product  
Forecast Starting at 00Z, April 1<sup>st</sup>, 2006. Lead time 0-16 days

STREAMFLOW (m<sup>3</sup>/s) ensemble fcst from 20060401

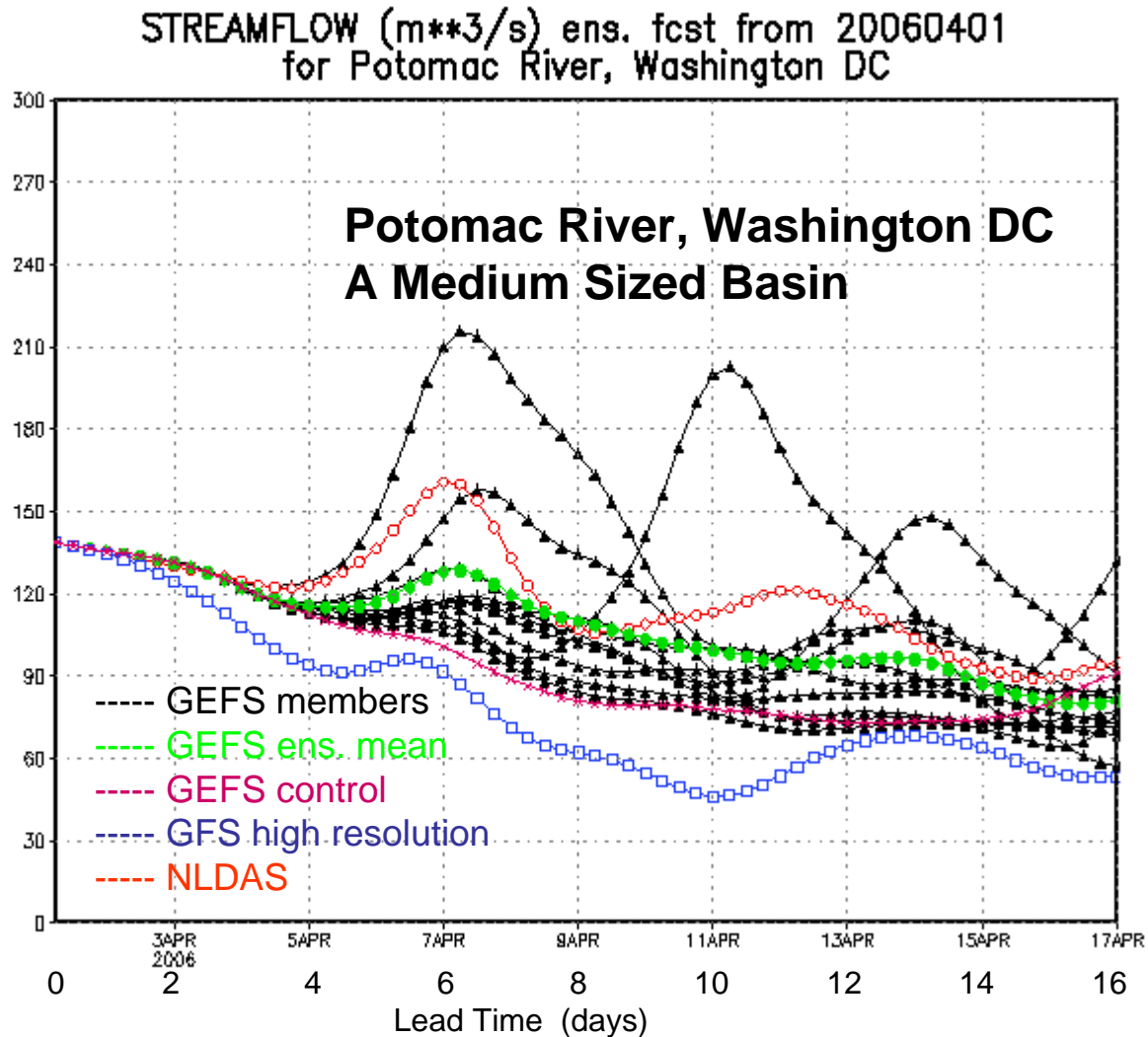


# An Example of Stream Flow Forecast

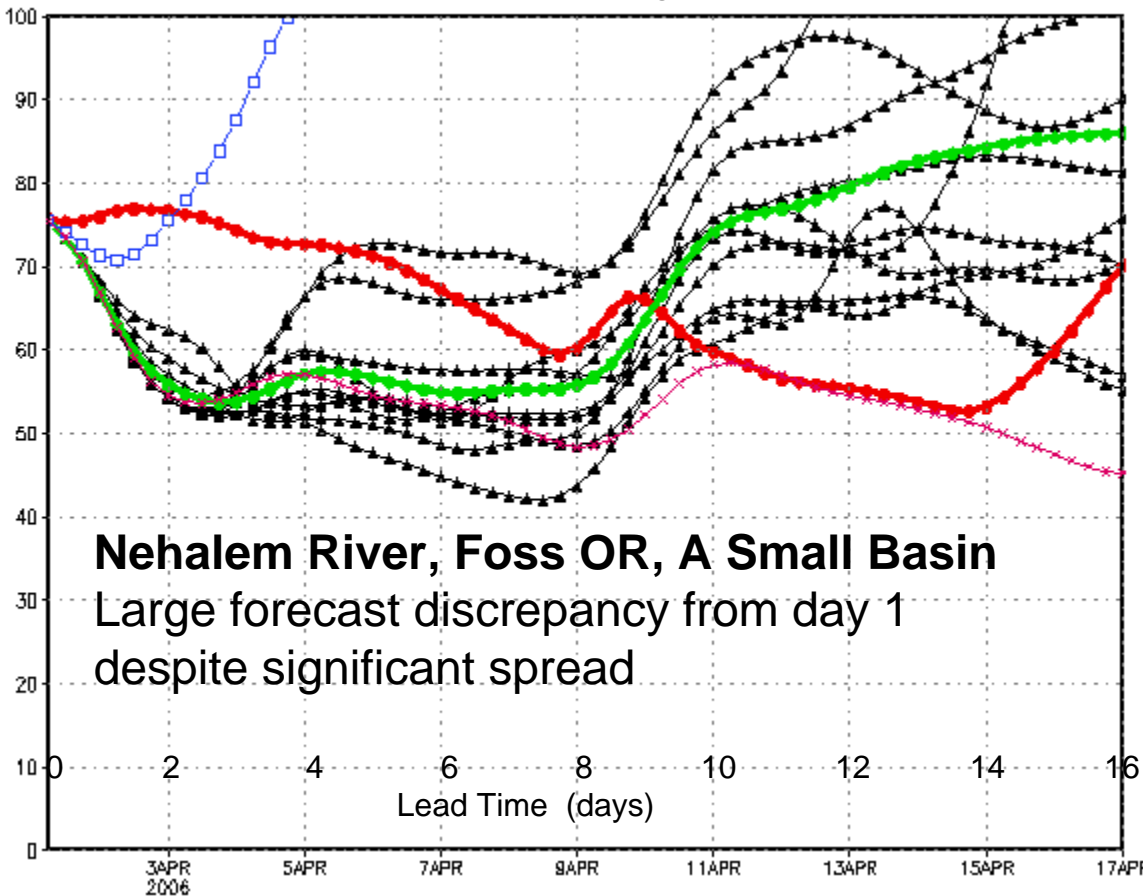
Forced by GFS, GEFS Forecast and NLDAS Product  
Forecast Starting at 00Z, April 1<sup>st</sup>, 2006. Lead time 0-16 days

Single forecast showing major deficit.

Non-linear evolution of ensemble members help to improve base flow forecast and catch major flood events.



STREAMFLOW (m<sup>3</sup>/s) ens. fcst from 20060401  
for Nehalem River, Foss OR

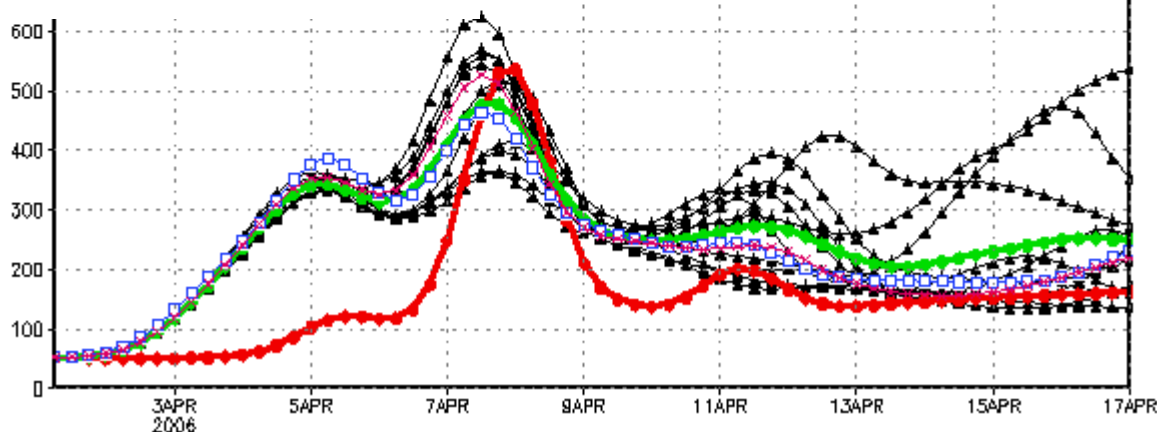
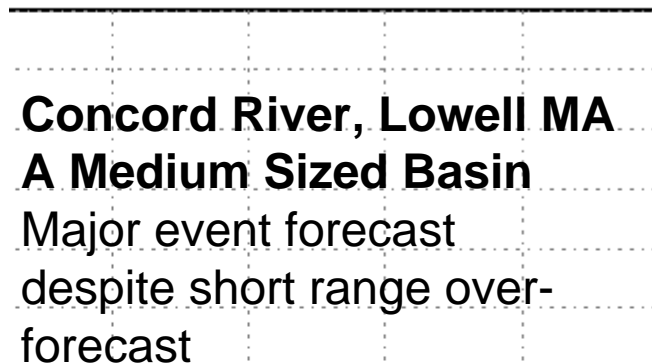


- GEFS members
- GEFS ens. mean
- GEFS control
- GFS high resolution
- NLDAS

**Possible causes of deficit**

- Exclusion of uncertainty in initial “surface water”
- Bias of precipitation forecast
- Lack of spread in precip. fcst.

STREAMFLOW (m<sup>3</sup>/s) ens. fcst from 20060401  
- Concord River, Lowell MA



# Another Example (initiated May 4<sup>th</sup>, 2006)

Stream Flow forced by NLDAS Product and Ensemble Mean Forecast  
Error of Ensemble Mean and Ensemble Spread  
Forecast Starting at 00Z, May 4th, 2006. lead time 12 days

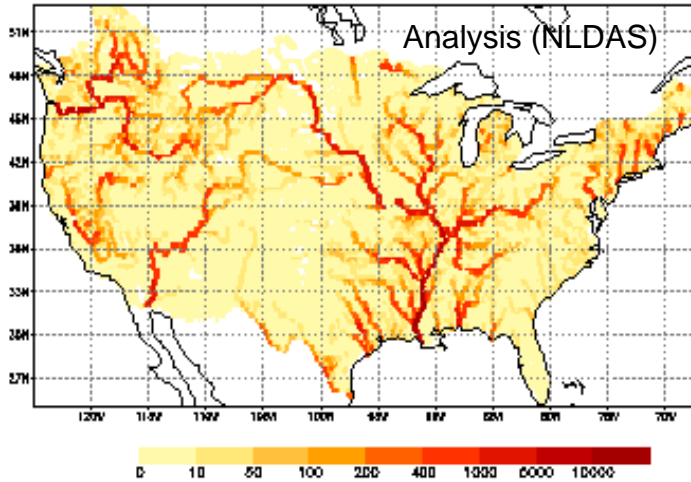
**Note:**  
**New England Flood**

Regions of  
over-forecasting  
And under-forecasting

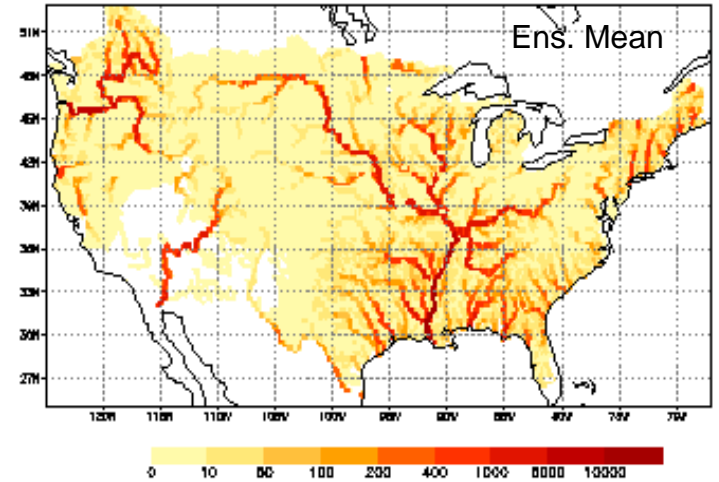
Systematic Error

Significant  
Spread  
(comparable to  
Error)

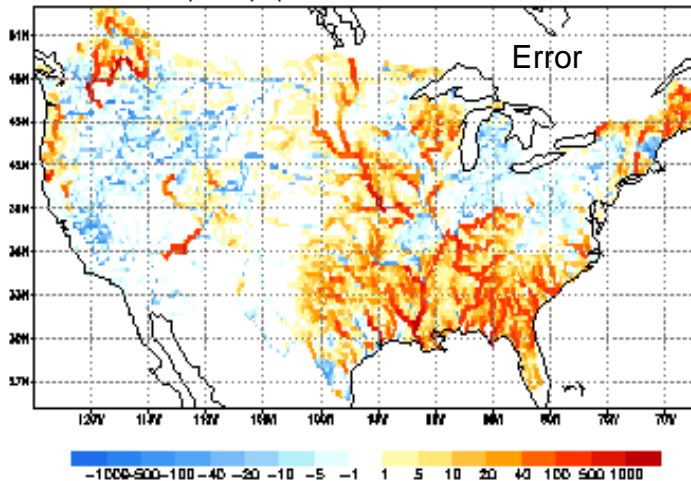
STREAMFLOW (m<sup>3</sup>/s): NLDAS 288hr fcast from 20060504



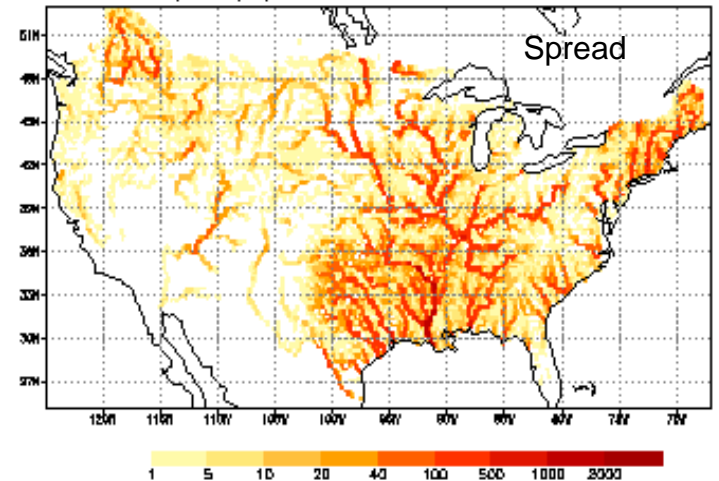
STREAMFLOW (m<sup>3</sup>/s): ENS. MEAN 288hr fcast from 20060504



STREAMFLOW (m<sup>3</sup>/s): ERROR 288hr fcast from 20060504



STREAMFLOW (m<sup>3</sup>/s): ENS. SPRD 288hr fcast from 20060504



**Mississippi, River  
Vicksburg, MS  
The Large Basin**

**May 4<sup>th</sup> case**

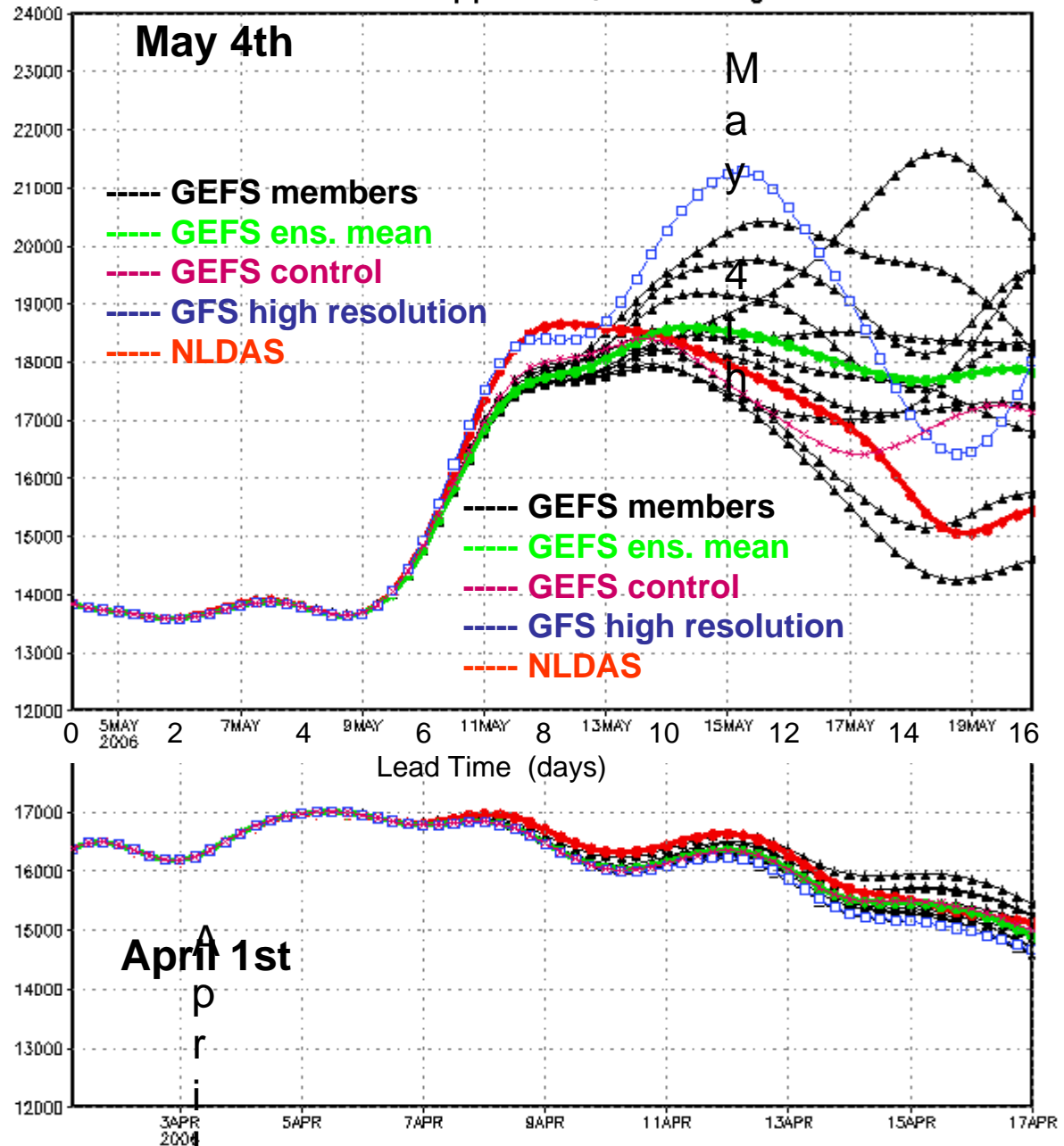
A major mid-range event well simulated

Significant spread in extended range

**April 1<sup>st</sup> case**

With out a major event,  
all simulations are  
similar and spread is  
small.

STREAMFLOW (m\*\*3/s) ens. fcst from 20060504  
for Mississippi River, Vicksburg MS



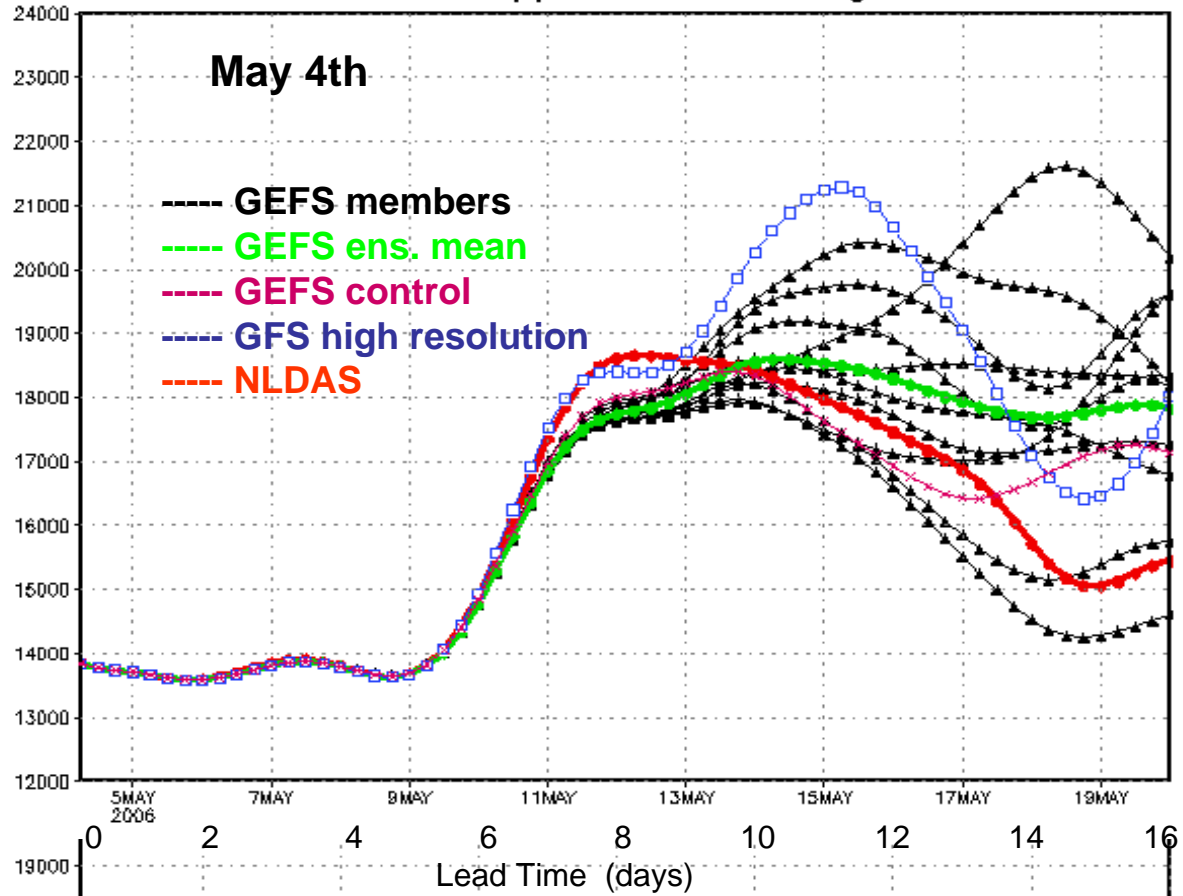
STREAMFLOW (m<sup>3</sup>/s) ens. fcst from 20060504  
for Mississippi River, Vicksburg MS

Mississippi, River  
Vicksburg, MS  
The Large Basin

**May 4th case**

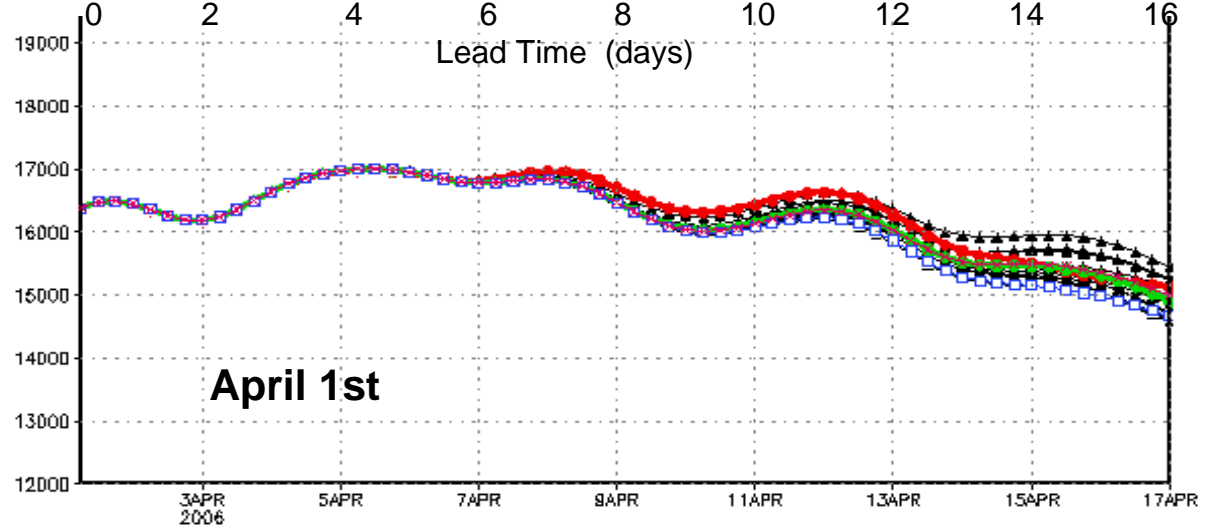
A major mid-range event  
well simulated

Significant spread in  
extended range



**April 1st case**

With out a major event,  
all simulations are similar  
and spread is small.

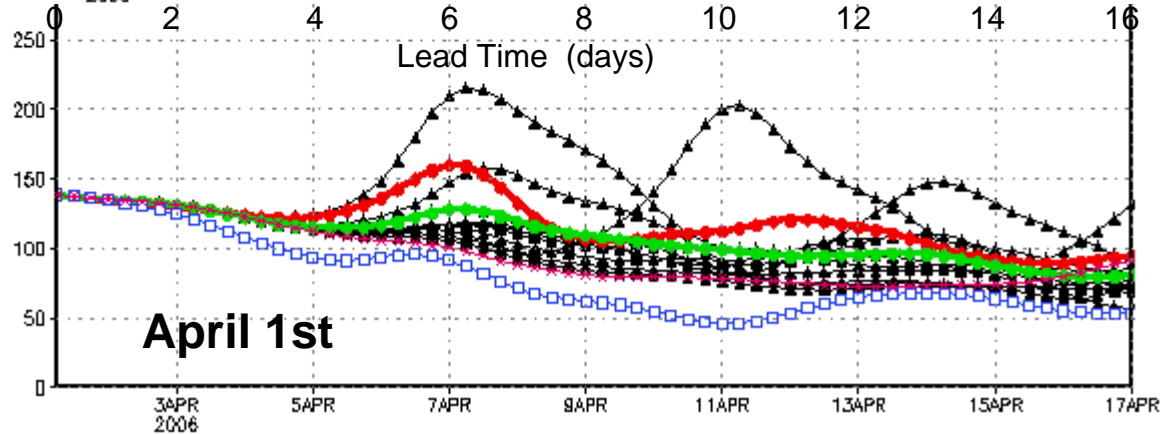
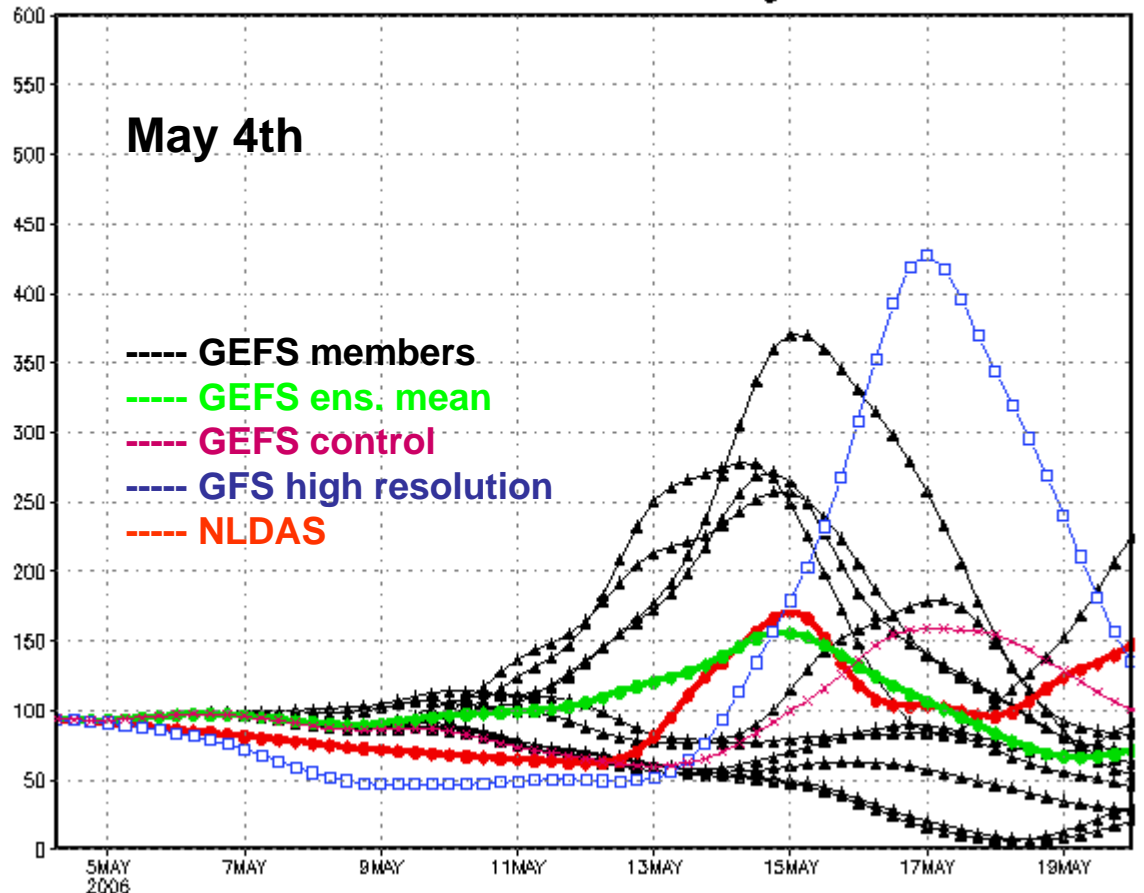


STREAMFLOW (m<sup>3</sup>/s) ens. fcst from 20060504  
for Potomac River, Washington DC

Potomac River  
A Medium sized basin

In both cases

Non-linear feature  
contributes to better forecast  
of a major event in terms of  
time and amplitude.

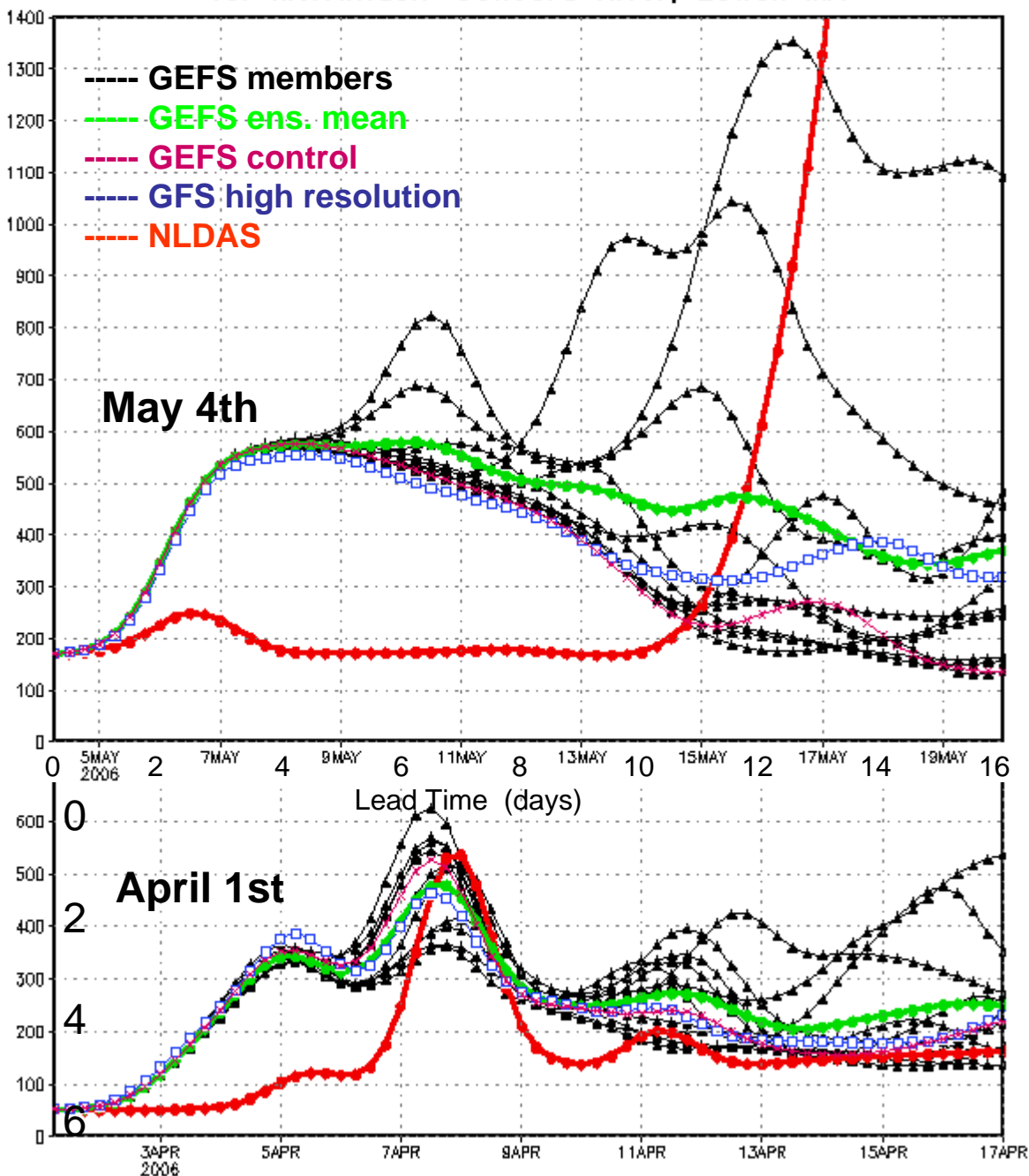


# Merrimack-Concord River Lowell, MA A Medium Sized Basin

## Mid-May Flood Event

Compared with the Mid-April event, the Mid-May event is harder for the model to simulate. Nevertheless, the ensemble shows some skills with some of its members stretch to catch the analysis with various amplitude and timing.

STREAMFLOW (m<sup>3</sup>/s) ens. fcst from 20060504  
for Merrimack-Concord River, Lowell MA



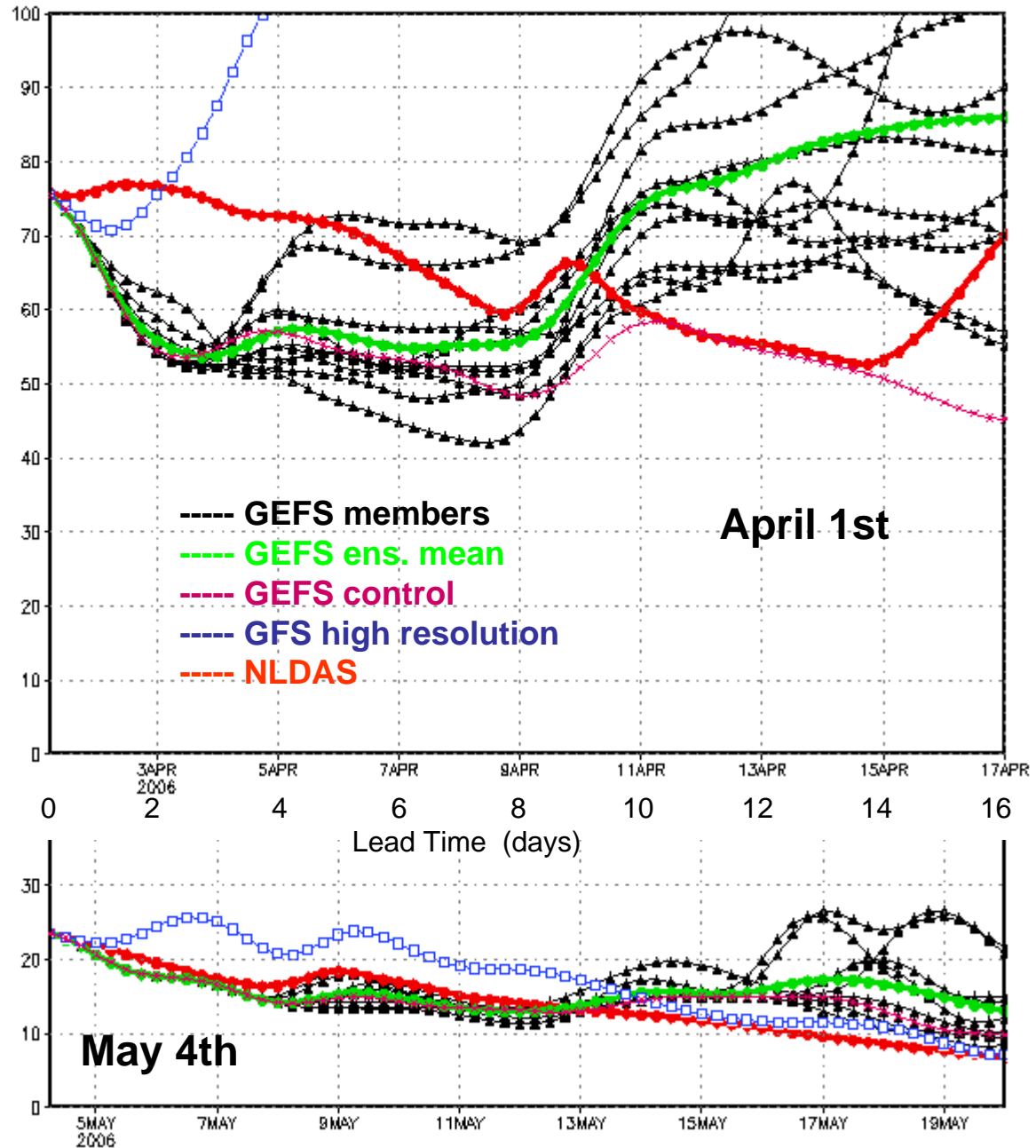
STREAMFLOW (m<sup>3</sup>/s) ens. fcst from 20060401  
for Nehalem River, Foss OR

**Nehalem River, FOSS OR  
A Small Basin**

A challenge for the models

**Possible causes of  
The short range  
forecast deficit**

- Exclusion of uncertainty in initial “surface water”
- Bias of precipitation forecast
- Lack of spread in precip. fcst.



# Preliminary Results

Although rigorous verification and more extensive experiments are necessary for any concrete conclusion, the following preliminary results are encouraging:

- The stream flow forecasts forced by GFS/GEFS runoff output are comparable to the analysis (NLDAS).
- Compared with single forecasts (higher or lower resolution), the ensemble mean provides more realistic (closer to NLDAS) geographic distribution of stream flow.
- The ensemble system has clear advantage with the non-linear temporal evolution of its members helping to pick up significant flood events.
- With longer lead times, the ensemble has significant spread to provide additional information, especially for medium and large basins.
- Although the ensemble spread increases significantly with lead time, the ensemble members may still fail to embrace the analysis. This suggests that uncertainty in initial conditions and model structure need to be considered.

# Further Development

## General Strategy

- Cooperation with HEPEX, NAEFS and THORPEX.
- Facilitate probabilistic forecast.

## Configuration

- Expand to global domain (Initially at 0.5 degree resolution).
- Simplified lumped approach.

## Bias Correction

- To the precipitation for better input runoff.
- To the stream flow output for better product.
- Generate a hind-cast data set for a better estimate of bias.

## Representation of Uncertainties

- Uncertainty associated with the initial state of “surface water”.
- Uncertainty associated with the river routing model itself.

## Evaluation

- Consider the effects of human control and water management.
- Quantitative evaluation with rigorous statistics.

# REAL-TIME GENERATION OF HIND-CAST DATASET?

- When computing facilities are upgraded (2007 at NCEP)
  - Forgo increasing resolution/membership
  - Instead generate hind-cast “ensemble”
- Arrangement
  - Running land surface data assimilation (NLDAS) for the past 25 years
  - Generate control forecast from re-analysis initial conditions
    - Initialized from 30 days ahead of current date
      - For each year in re-analysis dataset (25-50 yrs)
  - Additional cost is 2-3 times current ensemble configuration - *DOABLE*
- Bias correction methodology
  - Same as currently (Kalman Filter type algorithm), except
    - Estimate climate mean bias as mean of difference between
      - Re-analysis & hind-cast forecast (+/-30 days x 25 yrs = 1,500 sample)
        - » Use centrally weighted recursive filter to save on disc storage requirements
    - Combine regime dependent Kalman filter + climate mean bias estimates
      - More weight on Kalman filter at short
      - More weight on climate mean estimate at long leads
  - Explore possible regime dependent corrections at long lead
    - Save & use entire sample of 1,500 using hind-casts in research
- Discard 30+ day old hind-cast data
  - Implement DA/model upgrades at wish
    - Generate regime dependent & climate mean bias statistics during
      - ~30-day parallel testing prior to operational implementation

# REAL-TIME GENERATION OF HIND-CAST DATASET?

