IBM T. J. Watson Research Center

Estimating high-resolution near-surface forecast uncertainty to support optimization of resources

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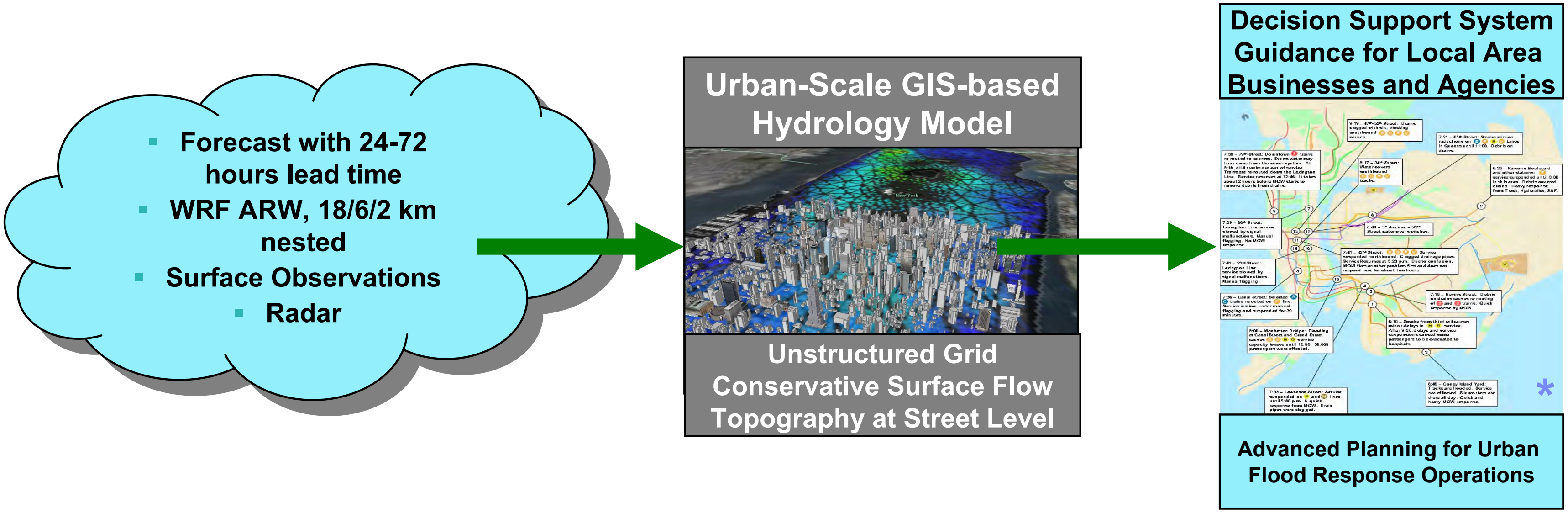
Outline

- Overview and motivation
- Approach
- Example results
- Conclusions and future work

Decision Support System for Operational Resource Management



*Major Subway Flooding Incidents on September 8, 2004. "August 8, 2007: Storm Report." Metropolitan Transportation Authority, 9/20/2007, page 21.

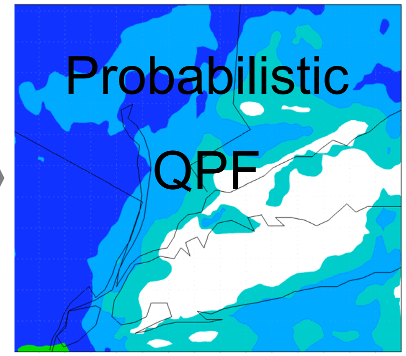
- **Adequate response to urban flood can be provided based on forecast with 48/72 hour lead time**
- **At this timescale uncertainties become very important for DSS system**
- **An assessment of rainfall uncertainties (QPF) and the knowledge about result reliability are needed**
- **Application: flash floods in New York City**
- **Preliminary assessment uses soil moisture as the land surface variable subject to initialization errors**

Hillside Ave Flooding. Same source, page 23.

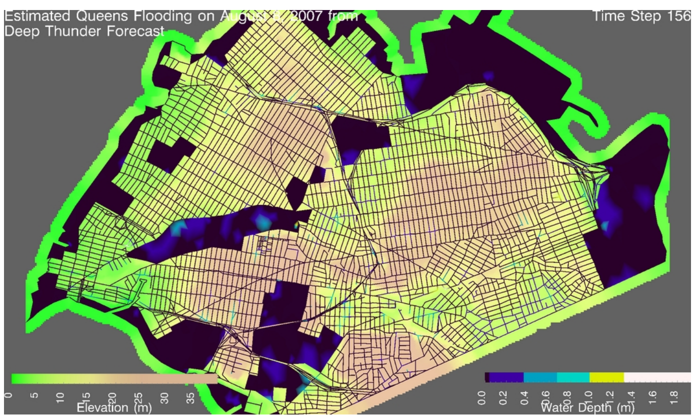
Workflow

Uncertainty assessment

Perturbed Soil Moisture → WRF 72 hrs lead time → Probabilistic QPF



Urban Hydrology



- Spatial and temporal uncertainties in rainfall patterns propagate further and contribute to overall uncertainties of flash flood forecasts
- There are also additional sources of uncertainties within Urban Hydrology model (model parameters, flood routing, etc.)
- Probabilistic hydrological simulations at urban scale become inputs to the decision support system

Observations

- **Real-time AWS/WeatherBug data at 5 minute intervals**
- **Observations from more than 400 surface stations in tri-state area:**
  - **Rainfall**
  - **Temperature**
  - **Relative humidity**
  - **Surface winds**
- **WRF/Noah land surface model:**
  - **<u>Soil moisture</u>**
  - **Vegetation type and fraction**
  - **Albedo, skin temperature etc.**

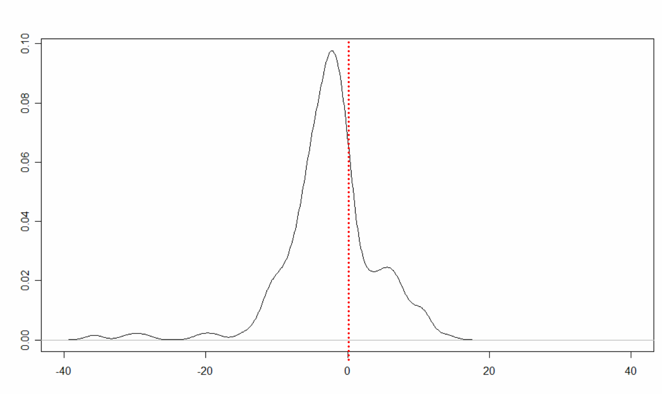
- **Spatial distribution of soil moisture is estimated from observed accumulated rainfall**
- **Comparison with the WRF inputs from default databases provides information on the distribution of errors**
- **PDF of errors for a particular initialization time is used to compute weighted average of ensemble members**

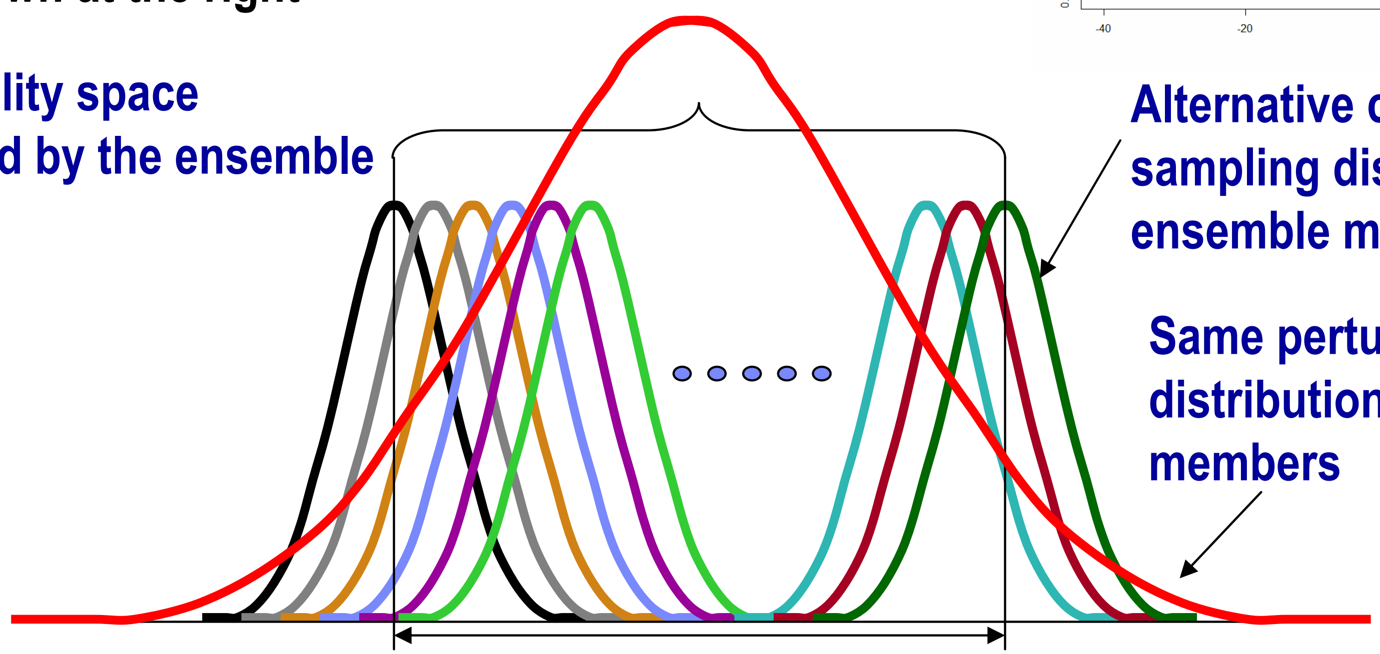
Mixed Gaussian Model for Ensemble Generation

- **Alternative scenario to stochastic perturbations sampling for each ensemble member is to cover variability space with a limited size of ensemble:**

  $\mathcal{N}_i(\mu,\sigma)$ ***where μ varies and σ is the same for all ensemble members***

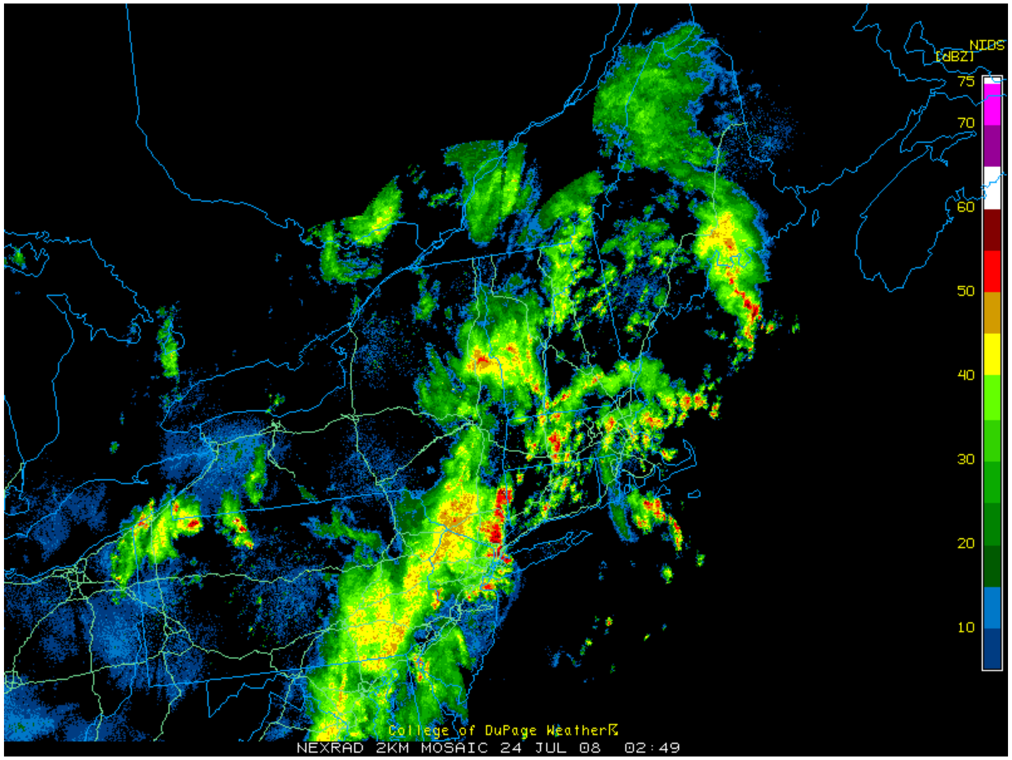
- **Initial distribution of soil moisture errors is shown at the right**





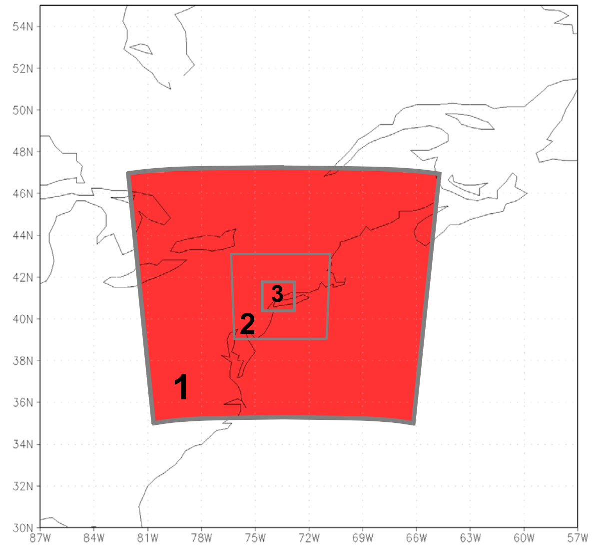
Heavy Rain and Severe Weather event on July 24, 2008

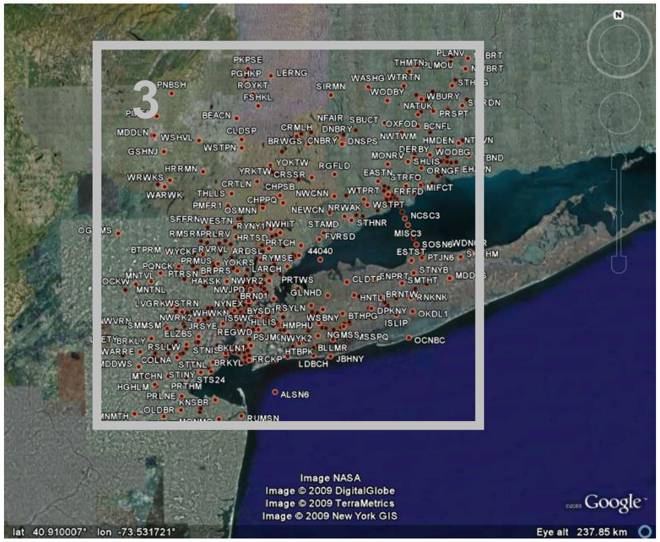
- National Weather Service, Upton, NY – 12:05 AM EDT, WED. JUL. 23, 2008
  - Potential for heavy rainfall
  - Scattered convection through this evening could produce brief downpours with localized urban/poor drainage flooding mainly north and west of New York City
  - Full summer greenup will allow to absorb at least an inch or two without encountering significant widespread
  - QPF amounts of between two and three inches in a 30 hour period from Wednesday afternoon through Thursday
  - Likely result in at least moderate flooding problems for poor drainage in urban areas
  - Very hard to time individual convective elements
- National Weather Service, Upton, NY – 2:31 AM EDT, THU. JUL. 24, 2008
  - Several inches of rainfall is expected overnight with widespread flash flooding



Simulation Model Domain

- **WRF/ARW with 3D-Var data assimilation (v.2.2)**
- **Domain:**
  - **Nested grid: 18/6/2 km (76x76x42)**
  - **Centered at 41°N, 74°W**
  - **42 vertical levels**
- **Microphysics: WSM 5-class scheme**
- **Cumulus parameterization: Grell-Devenyi Ensemble**
- **Radiation: Longwave – RRTM, Shortwave – Goddard**
- **Boundary layer: YSU scheme**
- **Noah LSM and land surface characteristics from WRF data sets**
- **Initial and Boundary conditions:**
  - **NAM (12 km)**
  - **SST RTG (0.5 deg)**
- **Surface observations: AWS/WeatherBug data**

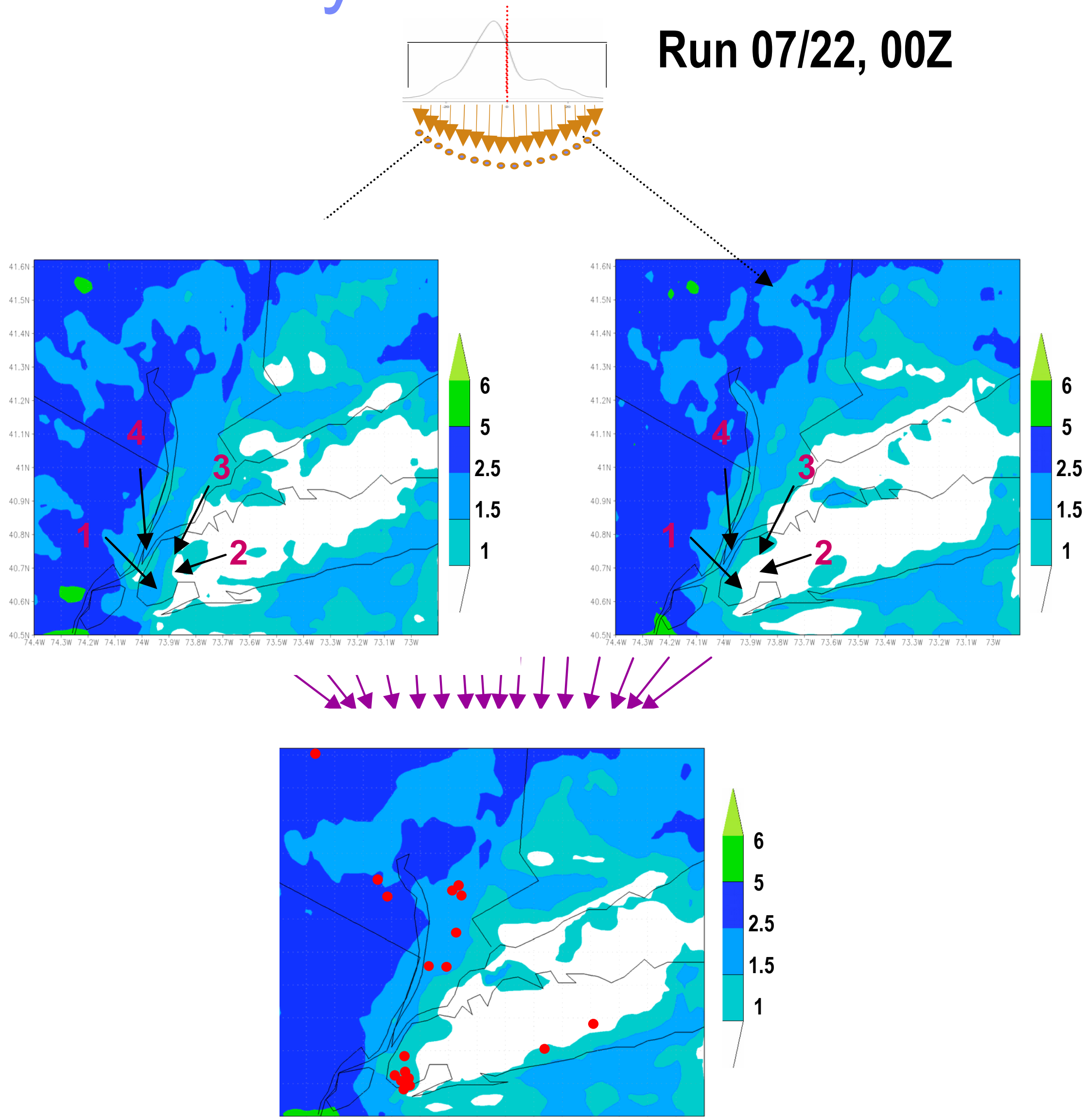




Ensemble Results and Uncertainty Estimates

- Spatial distribution of accumulated precipitation (in inches) by July 24, 2008, 12Z (60 hours) is shown for two ensemble members: $\mathcal{N}(-20\%, 10\%)$ and $\mathcal{N}(+20\%, 10\%)$. Size of ensemble – 8 members.
- Rainfall accumulation in urban areas at Brooklyn[1], Queens[2], La Guardia airport[3], lower Manhattan[4], for example, are different.
- Ensemble Average accumulated precipitation agrees with observations at the sites where rainfall exceeded 1".
- Forecast uncertainty is estimated based on ensemble variance.
- Forecast and uncertainty estimates are used in Decision Support System for risk analysis.

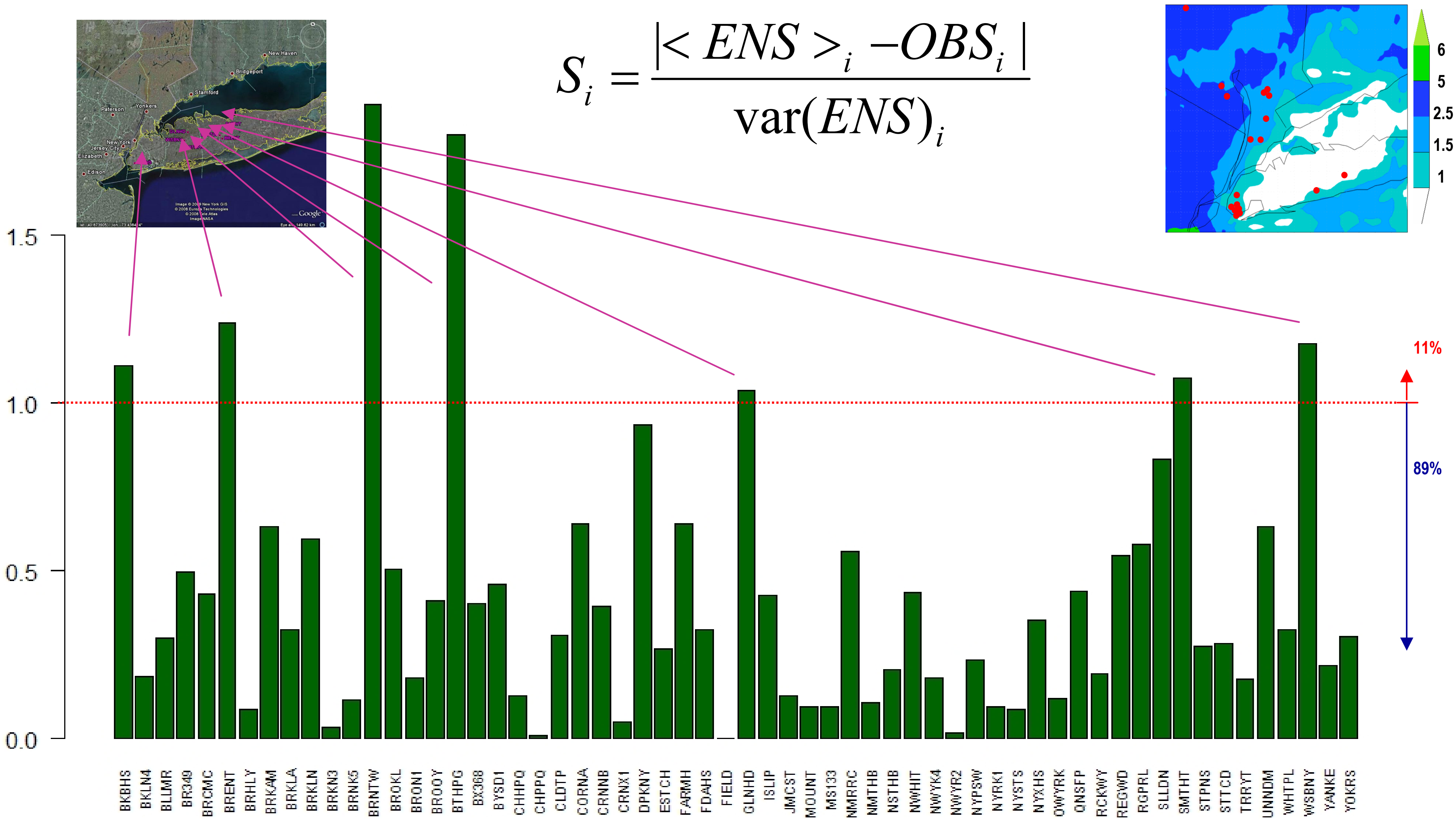
Run 07/22, 00Z



Ensemble Average

Fraction of Forecast Error Linked to Uncertainties in Soil Moisture

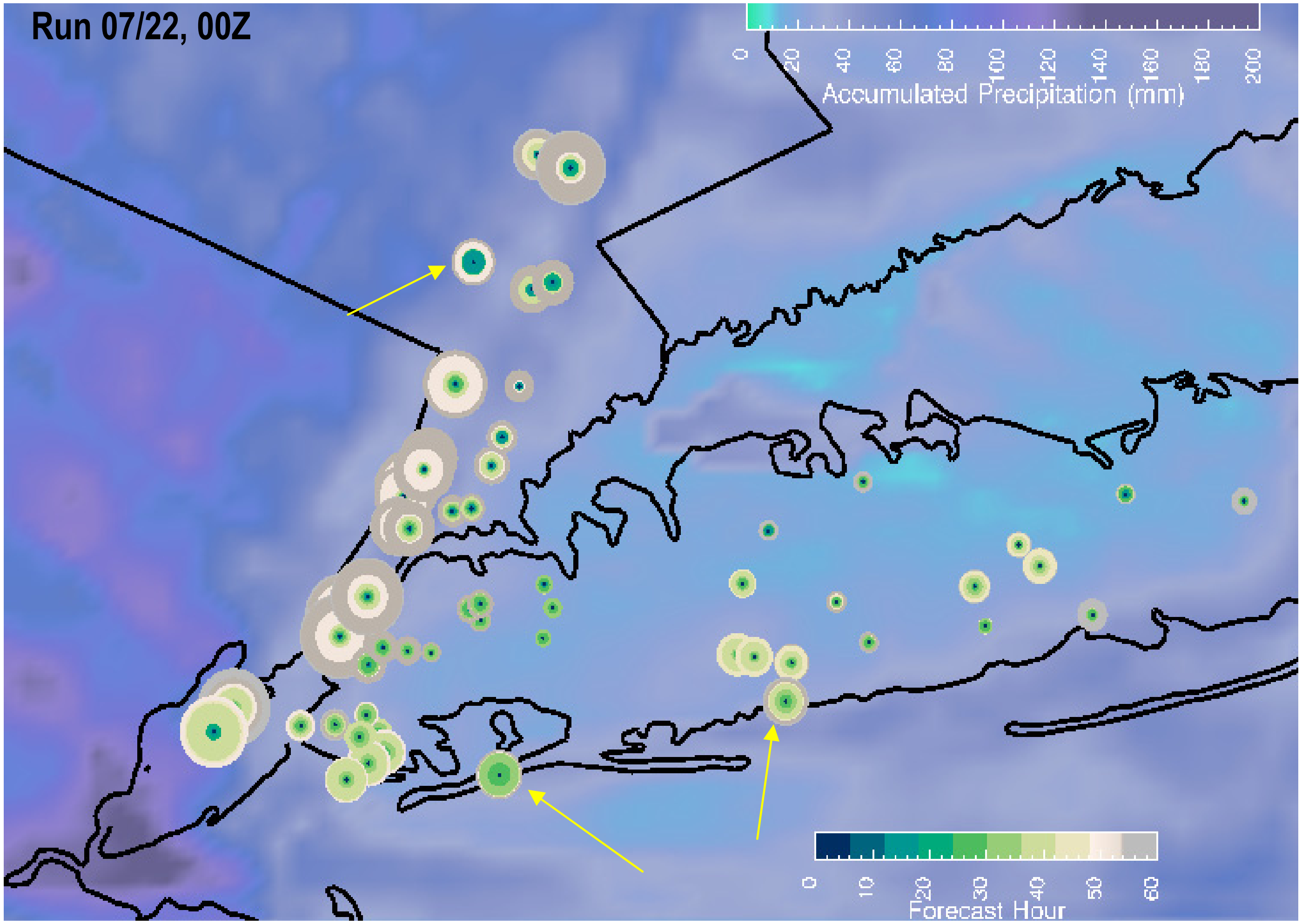
$$S_i = \frac{|< ENS >_i - OBS_i|}{\mathrm{var}(ENS)_i}$$



Ratio of the forecast error and uncertainty for each site

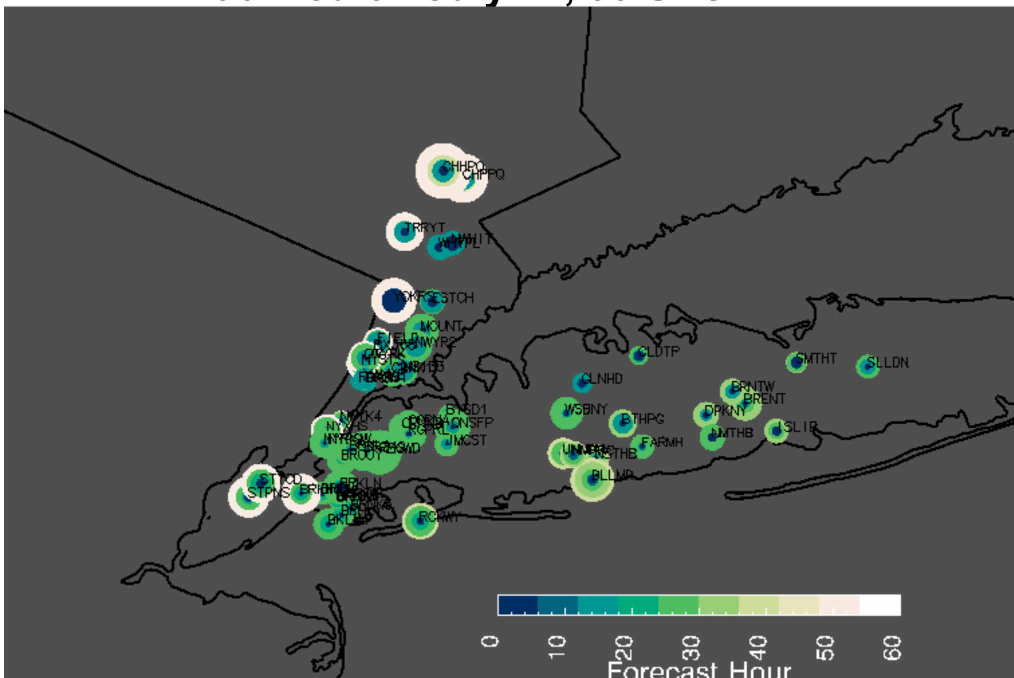
Temporal Evolution of Rainfall Uncertainties: Accumulated Precipitation

- **Time of the event is between July 23, 2008, 20:00 UTC and July 24, 2008, 4:00 UTC (44 – 52 hrs)**
- **Overlay of accumulated rainfall forecast (60 hrs) and uncertainty estimates for run initialized at 07/22, 00Z shows geographical location of the sites with with high uncertainty in the magnitude of the accumulated rainfall**
- **Larger intensity uncertainties in an earlier hour are related to temporal uncertainties (different rainfall onset time)**
- **Sites marked with yellow arrows have higher forecast uncertainty at earlier hour**

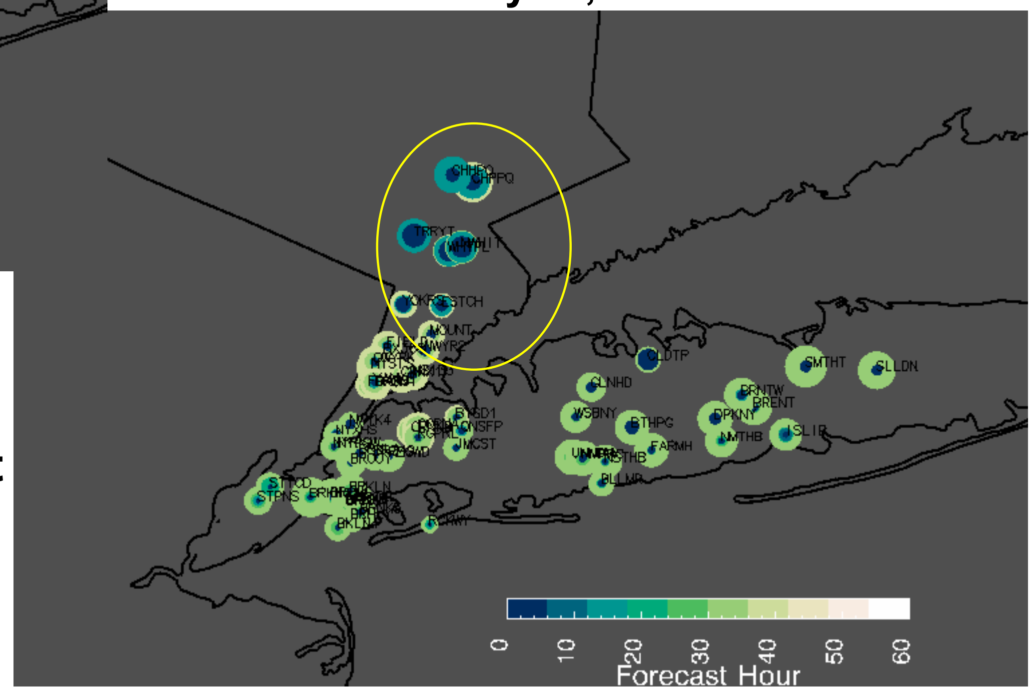


Temporal Evolution of Forecast Uncertainties: Surface Winds and Temperature

- **Surface Winds for run initialized on July 22, 00 UTC**



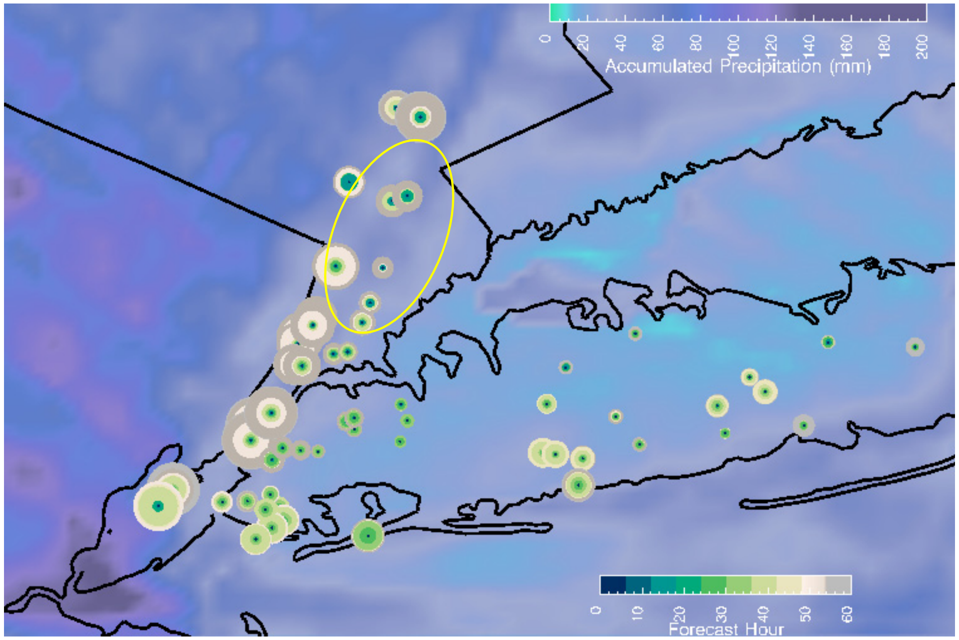
- **Surface Temperature for run initialized on July 22, 00 UTC**



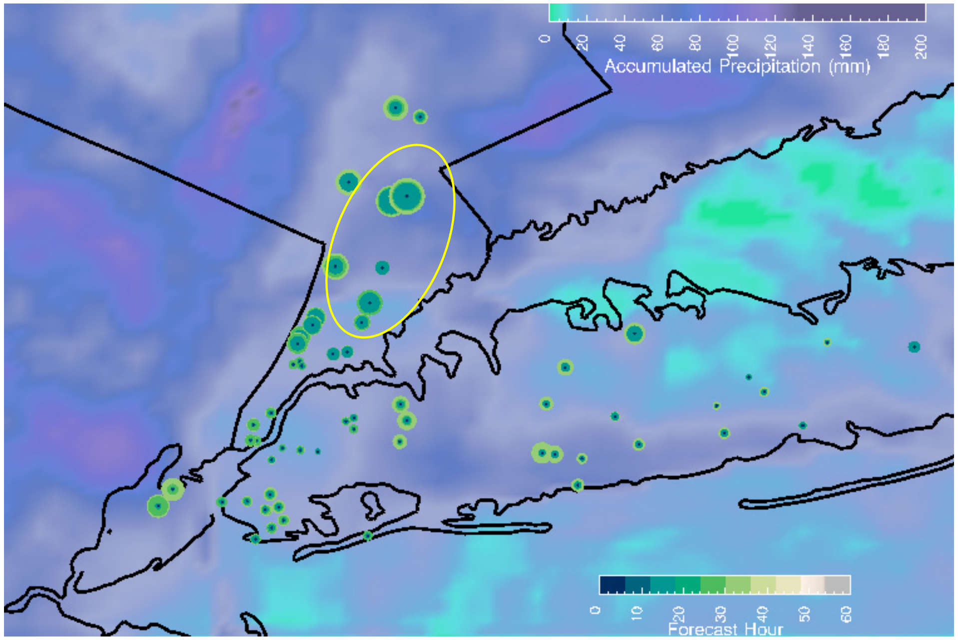
- **Sites can be virtually divided into clusters with some common underlying feature related to the source of uncertainties**
- **Time of maximum wind uncertainties is different at different clusters**
- **For temperature uncertainties, a cluster of sites in Northern Westchester County have larger uncertainty at the earlier time prior to the rainfall event**

Temporal Evolution of Forecast Uncertainties: Comparison between two operational runs

Run 07/22, 00Z



Run 07/23, 00Z



- **When it becomes available, ensemble from a later run initialized at 07/23, 00Z, is compared with the original ensemble**
- **Sites within the yellow circle have higher forecast uncertainty at earlier hour for run 07/23, 00Z, while final rainfall accumulation in the circled area is about the same for both runs**

Conclusions

- 72 hour high resolution ensemble forecasting is desirable for providing guidance on oncoming flooding events for local businesses
- Generating ensemble perturbations using mixed Gaussian model with adjusted weighting of ensemble members can provide sufficient coverage of the variability space for a relatively limited number of ensemble members
- Forecast error at about 90% of sites can be related to soil moisture initialization uncertainties
- Analysis of temporal evolution of ensemble variance gives an estimate to temporal uncertainties in rainfall onset time
- Uncertainties are smaller for temperature and the largest for accumulated rainfall

Future Work

- **Spatial covariance of uncertainties for a larger set of land surface characteristics**
- **Examination of other variability sampling techniques and comparison with the mixed Gaussian model approach**
- **Operational implementation of model output calibration based on weighted ensemble averaging**