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

- Forecast with 24-72 hours lead time
- WRF ARW, 18/6/2 km nested
- Surface Observations
- Radar

Urban-Scale GIS-based Hydrology Model

Unstructured Grid Conservative Surface Flow
Topography at Street Level

Decision Support System Guidance for Local Area Businesses and Agencies

- Advanced Planning for Urban Flood Response Operations

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.
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:
  - Soil moisture
  - 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:

\[ \mathcal{N}(\mu, \sigma) \text{ where } \mu \text{ varies and } \sigma \text{ is the same for all ensemble members} \]

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

Variability space covered by the ensemble

Soil Moisture Initialization Error

Alternative choice: perturbation sampling distribution for an ensemble member

Same perturbation sampling distribution for all ensemble members
Heavy Rain and Severe Weather event on July 24, 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

  - 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: \( \mu(-20\%,10\%) \) and \( \mu(+20\%,10\%) \). 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.
Fraction of Forecast Error Linked to Uncertainties in Soil Moisture

\[ S_i = \frac{\langle ENS \rangle_i - OBS_i}{\text{var}(ENS)_i} \]
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 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

- 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