Experimental Seasonal Hydrologic Prediction System

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Hydrologic Model-based Prediction Approach

- Land Surface Model
- Ensemble of Atmospheric Forcings
- Runoff
- Soil Moisture
- Snow
- Evaporation

Initial conditions

Ensemble Hydrologic Prediction

Ensemble of Hydrologic Forecasts

Reservoir Storage

Spin-up Period

Observed Meteorology

Forecast Period

Cumulative flow (cfs days)

Princeton Seasonal Hydrologic Prediction System

Seasonal Climate Forecasts from Dynamical Climate Models

- Observed Forcing Climatology
- Bayesian Merging

Forcing Generation

- Atmospheric Ensemble Pre-Processor

Hydrologic Initial Conditions

- Pre-Forecast Processor

VIC

- Hydrologic Ensemble Processor

Predicted Hydrologic Conditions

Product Generator

Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model

Grid Cell Vegetation Coverage

Variable Infiltration Curve
Challenges in Using Seasonal Climate Forecast

- Climate models tend to have their own climatology which is different from the real climate, causing bias in precipitation and temperature fields → Bias Correction
- Disparity in spatial scales between the resolved scales in climate models and the spatial scales needed in hydrologic applications. → Spatial downscaling
- To create realistic daily atmospheric forcing for the hydrologic forecast system from the monthly information provided by the climate models. → Temporal downscaling
Bayesian Merging of Information

\[ p(\theta | y) = \frac{p(\theta, y)}{p(y)} = \frac{p(\theta)}{p(y)} \times p(y | \theta) \]

- Posterior
- Prior
- Likelihood function

1/8th degree scale variable
Variable at GCM scale and above

Bayes Theorem
Seasonal Hydrological Prediction System

• **Bayesian Merging**
  – Likelihood function builds the correlation between variables across different spatial scales.
  – GCM forecast information comes from larger spatial scales and longer temporal scales with increase in lead time to ensure that only useful (skillful) information is brought in.

• **Spatial downscaling**
  – Spatial downscaling is achieved via Bayesian merging and resampling of historical data.

• **Temporal downscaling**
  – Resampling and scaling daily atmospheric forcing from historical data to match forecasts from the posterior distribution.
  – Conditional resampling based on similarity between anomalies in the historical fields and the mean of the posterior distribution (K-NN approach).
Forecast Methods Implemented:

- CFS
- CFS+DEMETER
- CPC
- ESP

http://hydrology.princeton.edu/forecast
Evaluation with Hindcasts
Evaluation with Hindcasts

- **Three forecast methods** (starting from the same IC)
  - **Climatological Forecast (ESP)**
    - Randomly select 20 years from historical data as atmospheric forcing
  - **Single NWP-based Bayesian Merging (CFS)**
    - 1 climate model, 15 ensemble members
    - Conditional resampling historical data
  - **Multiple NWP-based Bayesian Merging (CFS+DEMETER)**
    - 8 climate models, total 78 ensemble members
    - Conditional resampling historical data

- **Hindcasts over the Ohio River basin**
  - 19 year hindcasts for comprehensive evaluation
  - A few examples
  - Comprehensive evaluations
Soil Moisture: 198805 Forecast

Total Column Soil Moisture (mm) Mean Percentile (Init: 198805)


Observations

Climatological Forecast

CFS-based Forecast

Multi-model Forecast

Lead time
Streamflow Forecasts

- Observed climatology from the USGS
- Observations from USGS
- Offline simulation is obtained with VIC driven by observed meteorology
- CFS: Only CFS forecast is used in the merging and downscaling.
- CFS+DEMETER: Seasonal forecasts from 8 climate models are used in the merging and downscaling.
- ESP: Random selection of historical forcing
Ranked Probability Score (RPS)

RPS: 0 ~ 1
With 0 being the perfect forecast
19 years of hindcasts
3 tercels, below normal, normal and above normal with probability of 1/3 each.

CFS
CFS+DEMETER
ESP
Forecasting of Drought (soil moisture quantiles)
2007-03 Forecast made 2007-01 (3 month)

Narrow inter-quartile ensemble spread
High Confidence

Wide inter-quartile ensemble spread
Low Confidence

Soil Moisture Quantiles

Prediction of the Area in Drought for 2007

Exceedence Probability for streamflow (relative to 25% threshold)

Forecasts

Predictions of 2007 Hydrologic Drought

Future Work

Need to develop the following enhancements:

• Incorporate the CPC “official outlook” seasonal forecasts;
• Incorporate Multiple land Surface Models (Noah, SAC, VIC, CLM) as well as water reservoir storage in the river routing scheme;
• Develop a post-processor to remove hydrologic model bias in the hydrologic forecast products;
• Assimilate observed river discharges to improve the initial conditions of soil moisture;
• Develop approaches to assess whether the ensembles capture the total uncertainty of the forecasts products, and related verification statistics
• Improve extreme event prediction, including characterizing extreme events.
Future Work

- Downscaling
- Ensemble QPE
- Initial Conditions
- Product Generation
- Parameter Estimation
- Hydrologic Uncertainty
- Post-Processing