Seasonal Hydrological Forecasting for Drought Early Warning
(and forecasting on other time scales)

Justin Sheffield
University of Southampton, Princeton University
Princeton Climate Analytics
Why Forecasting of Climate, Hydrology, or Water Resources?

What is it?
• Forecasting climate, availability of water, or extreme events (droughts, floods) over the next weeks, months or years

Why is it important?
• Decisions can be made that could saves lives, increases income, reduces losses, increases productivity, …
• Water resources management can be improved or optimized
• Flood warnings, drought early warning
How can we possibly forecast something so far in the future?

- Forecasting relies on the inertia in the climate system (the tendency for aspects of the system to persist in a certain state) and teleconnections between these states and the variable of interest (e.g. streamflow at a certain location).
- These sources of predictability can be the ocean temperature, soil moisture, snow pack, ..., each persists at different time scales.
Forecasting, Predictions and Projections

Some definitions

- **Forecasting**: making an estimate of what will happen in the future (exact or deterministic)
- **Prediction**: making an estimate of what might happen in the future (inexact or probabilistic)
- **Projections**: making an estimate of a plausible future (inexact)

Deterministic versus probabilistic

- **Deterministic** process is exactly defined, e.g. it will rain next week
- **Probabilistic** process captures the uncertainty, e.g. 30% change of rain
Two Main Types of Forecasting

- **Statistical**:  
  - pros (easy to use; based on real data; simple)  
  - cons (empirical so no direct physical basis; may be associative; assumes stationarity)

- **Dynamical** (physically-based model):  
  - pros (physical basis, can be used for attribution)  
  - cons (complex; skill dependent on model; challenged by chaos of climate systems)
Time Scales of Forecasts

- **Short-term forecasts** (~1 week) based on weather model forecasts, such as those you see on the TV weather forecast.
- **Sub-seasonal** or inter-seasonal forecasts (2 weeks to 3 months) based on medium range weather models or seasonal climate models.
- **Seasonal** forecasts (3-6 months) based seasonal climate models.
- **Long-range** forecasts (1 year) based seasonal climate models.
- **Decadal** Forecasts (1-10 years) based decadal climate models.

<table>
<thead>
<tr>
<th>Time Scale</th>
<th>Duration</th>
</tr>
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<tbody>
<tr>
<td>Short-Term</td>
<td>2 weeks</td>
</tr>
<tr>
<td>Seasonal</td>
<td>3-6 months</td>
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<tr>
<td>Long Range</td>
<td>1 year</td>
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<tr>
<td>Decadal</td>
<td>5-10 years</td>
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</tbody>
</table>
Examples of How Forecasts Can be Used

- Flood forecasts can provide alerts to communities
- Streamflow forecasts for energy management – hydropower, thermoelectric plants
- Reservoir management
  - A reservoir can release (save) water if a flood (drought) is forecast
- Agriculture
  - Crop yield forecasting helps manage food storage and food security
  - Agricultural water use can be optimized – irrigation can be scheduled
  - When and what to plant for optimal yield
  - Whether to cover crops against frost
- Recreation summer/winter (open a ski resort early or late)
- Transport (optimize routes and modes of transport)
- Retail planning
  - stock up on umbrellas, winter coats, summer wear
- Long-term planning
  - Buy commodities, stockpile, …
  - Invest in a vineyard?
What is forecast verification?
Forecast verification is the process of assessing the quality of a forecast. The forecast is compared, or verified, against a corresponding observation of what actually occurred.

The verification can be qualitative ("does it look right?") or quantitative ("how accurate was it?"). In either case it should give you information about the nature of the forecast errors.

Why verify?
The three most important reasons to verify forecasts are:
• to monitor forecast quality - how accurate are the forecasts and are they improving over time?
• to improve forecast quality - the first step toward getting better is discovering what you're doing wrong.
• to compare the quality of different forecast systems - to what extent does one forecast system give better forecasts than another, and in what ways is that system better?

There are MANY ways to verify a forecast

Hydrologic Monitoring and Prediction System

- Real-time Weather
- Initial Conditions
- Land surface (hydrology) models
- River Discharge
- Drought Index
- Water Management

Kms scale
Daily time step
Hydrologic Monitoring and Prediction System

- Multiple GCM Ensemble Forecast
- Obs. Climatology
- Climate indices Teleconnection

GCM resolution

Large scale

Merging Downscaling (Ta, P)

Real-time Weather

Kms scale Daily time step

“Weather” Generator (Ensembles)

Land surface (hydrology) models

(Ensemble) Drought Index

(Ensemble) River Discharge

Water Management

Initial Conditions
Two Time Scales in the FDM

- **Climate Forcing Data**
  - Reanalysis, Gridded Obs., Remote Sensing
  - Remote Sensing, Global Weather Models
  - Weather Forecast Models
  - Seasonal Climate Models

- **Downscaling and Merging Methods**
  - Merging, Downscaling, Bias Correction
  - Merging, Downscaling, Bias Correction
  - Downscaling, Bias Correction
  - Bayesian Merging and Downscaling

- **Hydrological and Other Impact Models**
  - VIC Land Surface Hydrologic Model
  - Agricultural models and other impact models

- **Flood and Drought Products and Other Sectoral Impacts**
  - Historic Events, Trends and Variability, Mechanisms
  - Hydrologic Monitoring and Flood and Drought Tracking
  - 7-day Forecasts of Floods
  - Seasonal Forecasts of Drought Development/Recovery

- **Timeline**
  - 1950: HISTORIC RECONSTRUCTIONS
  - 2008: REAL-TIME MONITORING
  - Now: SHORT-TERM FORECASTS
  - Now + 7 days: SEASONAL FORECASTS
  - Now + 9 mo.

Sheffield et al. (2014), BAMS
Seasonal Climate Forecast Models: North American Multi-Model Ensemble (NMME)

NMME is a coordinated set of climate model seasonal forecasts

- **Phase 1 (NMME-1) is used in the AFDM**
- Monthly forecasts out to 9 months
- Models = NCAR/CCSM3, GFDL/CM2.1, IRI/ECHAMA, IRI/ECHAMF, NASA/GMAO
- Hindcasts for 1980-2010; realtime forecasts from 2011

- The AFDM is being updated with **Phase 2 (NMME-2)**
- Daily temporal resolution
- Multiple meteorological variables

All freely available at https://www.earthsystemgrid.org/search.html?Project=NMME
Seasonal SPI-3 (6 month) forecast
Multi-model ensemble, initialized at the start of March 2018
Example of Drought Forecasts from NMME-1
SPI6 for MAMJJA, 2011 & 2012
SPI6: Prior 3-month (MAM) observation with the current (JJA) 3-month forecast

2011

OBS/CPC
GFDL/CM2.1
IRI/ECHAMF
IRI/ECHAMF
NASA/GMAO
NCEP/CFSv2
NMME

2012

OBS/CPC
GFDL/CM2.1
IRI/ECHAMF
IRI/ECHAMF
NASA/GMAO
NCEP/CFSv2
NMME
Example of Drought Forecasts from NMME-1
SPI6 for MAMJJA, 2011 & 2012

SPI6: Prior 3-month (MAM) observation with the current (JJA) 3-month forecast
Regional Example:
Horn of Africa Drought 2010-2011

Monitoring the propagation of the drought

Seasonal forecasts (based on CFS model only)

(a) Average Soil Moisture (40°-52E, 3°-12N)

(b) Area in Drought (40°-52E, 3°-12N)
Summary of Seasonal Forecast Skill from NMME-1 over African Regions for Precipitation and Soil Moisture

Soil moisture

SPI6

SPI6 – Soil Moisture

Soil moisture skill > SPI at start to mid growing season

NMME-2 Sub-Seasonal Forecasts

Start of the rainy season with ~2 month lead time

White areas are where signal (skill of forecast) to noise (variability in observed start of the season) ratio is small
Linking to Sub-Seasonal Hydrological Forecasts

NMME-2 forecasts driving hydrological model with ~2 month lead time

Example forecast (lon = 5.5, lat= 11.5, year=1997)

Frac of annual max flow (–)

Month

Start of the flow season
Timing of peak flow
Multi-Model Merging provides greater skill for sub-seasonal forecasts

Three NMME-2 seasonal forecast models driving a hydrological model

(Mississippi River, USA)

Weighted mean based on error covariance
Evaluation of forecast skill of monthly precipitation from three NMME-2 seasonal forecast models.
NMME-2 **Weighted Multi-Model** Skill for Precipitation and Temperature Forecasts – Lake Chad Basin
Linking to Agricultural Production

Modeled rain-fed maize yield (kg/ha) as a function of planting date

- Yields for varieties of maize
- Calculated using DSSAT physically based crop model
- As a function of planting date for different historic years

How can forecasts of the start of the growing season and water availability be used in decision making?

Different planting dates
Short-Term Weather and Hydrological Forecasting

- The AFDM and regional systems include short-term forecasts (7 days), which have the potential to contribute to flood early warning and other extreme events (extreme precipitation, heat and cold waves, frost).

- The forecasts are driven by weather climate model forecasts from the US Global Ensemble Forecast System (GEFS), which provides 20 ensemble forecasts every 6-hours out to 15 days.

- The FDM bias-corrects and downscales the forecasts of precipitation and temperature and uses these to drive the hydrological model to produce an ensemble of hydrological forecasts.

![Short-term weather and water forecasts](image1)

- Extreme heat and flash drought
- Frost damage
- Flooding
- UV damage
Streamflow monitoring and forecasting for Cyclone Idai

Initial flooding: 2019-03-06 to 2019-03-13
Streamflow monitoring and forecasting for Cyclone Idai

Peak flooding: 2019-03-12 to 2019-03-19

Forecast: initialized on 2019-03-06

Monitoring

Discharge Ratio w.r.t. Mean

FORECAST
Verif Time: 2019-03-12
Init Time: 2019-03-12
Ensemble: 01

REANALYSIS
Verif Time: 2019-03-12
Forecast Skill for River Flooding from Cyclone Idai

Example of forecast skill and ensemble spread for the peak flooding on the Pungwe River, 11 March – 5 April

Modeled (Observed rainfall)
Modeled (GEFS forecast rainfall)
Forecast Skill for River Flooding from Cyclone Idai

Example of forecast skill and ensemble spread for the peak flooding on the Pungwe River, 11 March – 5 April
Any questions?