# Seasonal Hydrological Forecasting for Drought Early Warning

(and forecasting on other time scales)

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# Why Forecasting of Climate, Hydrology, or Water Resources?

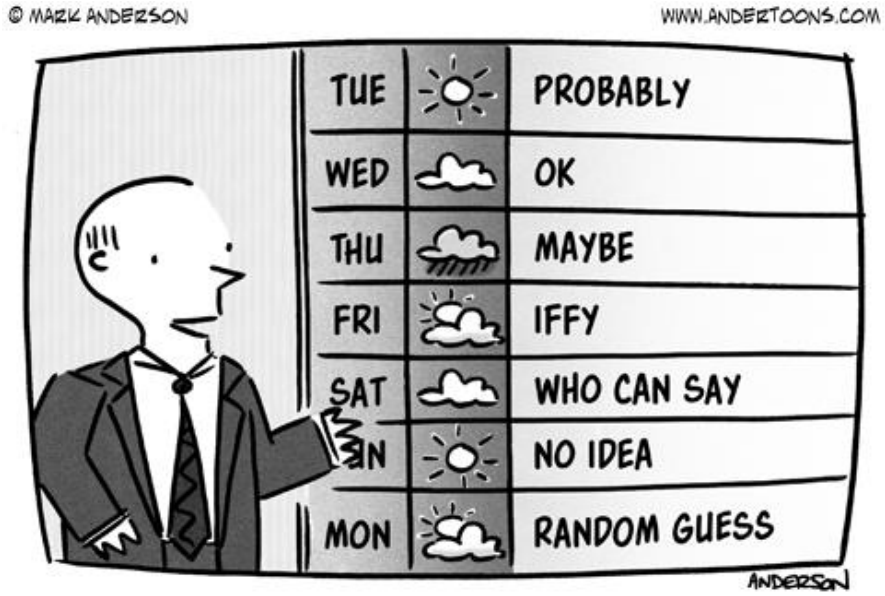
What is it?

- 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?



"And now the 7-day forecast…"

- 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 locations).
- 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

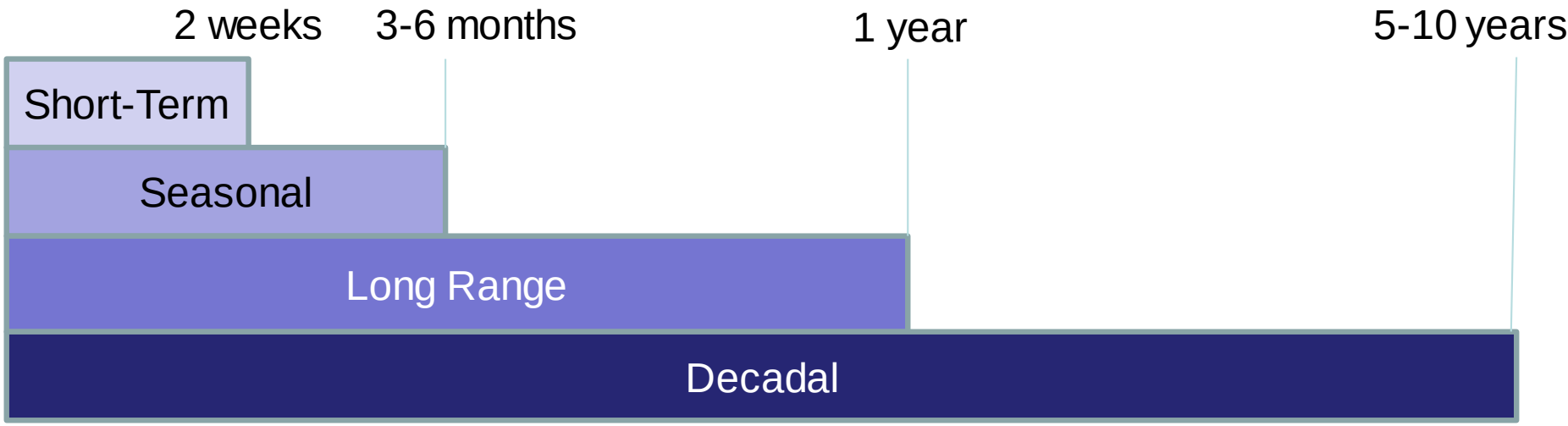
# Two Main Types of Forecasting

- 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



# 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?

# Forecast Verification

**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.

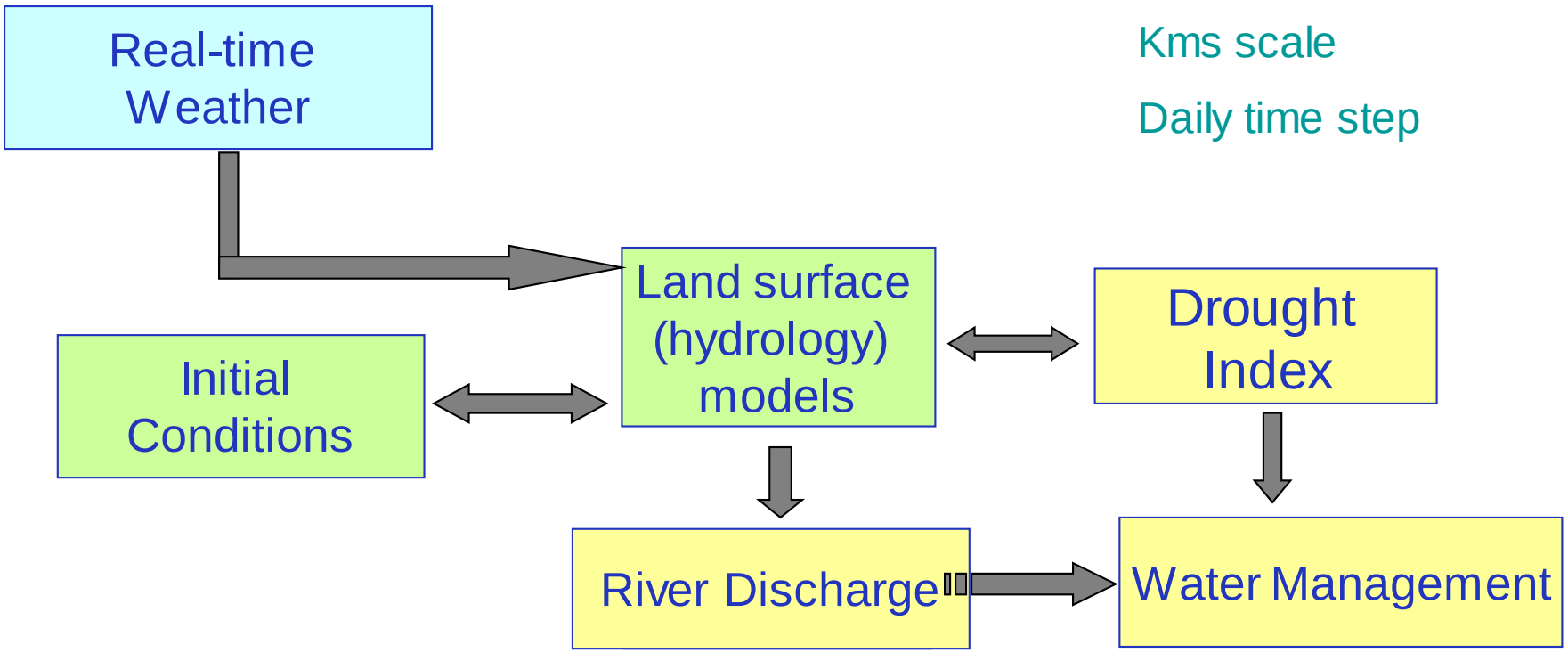
The verification can be qualitative ("does it look right?") or quantitative ("how accurate was it?"). In either case it should give you information about the nature of the forecast errors.

**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?

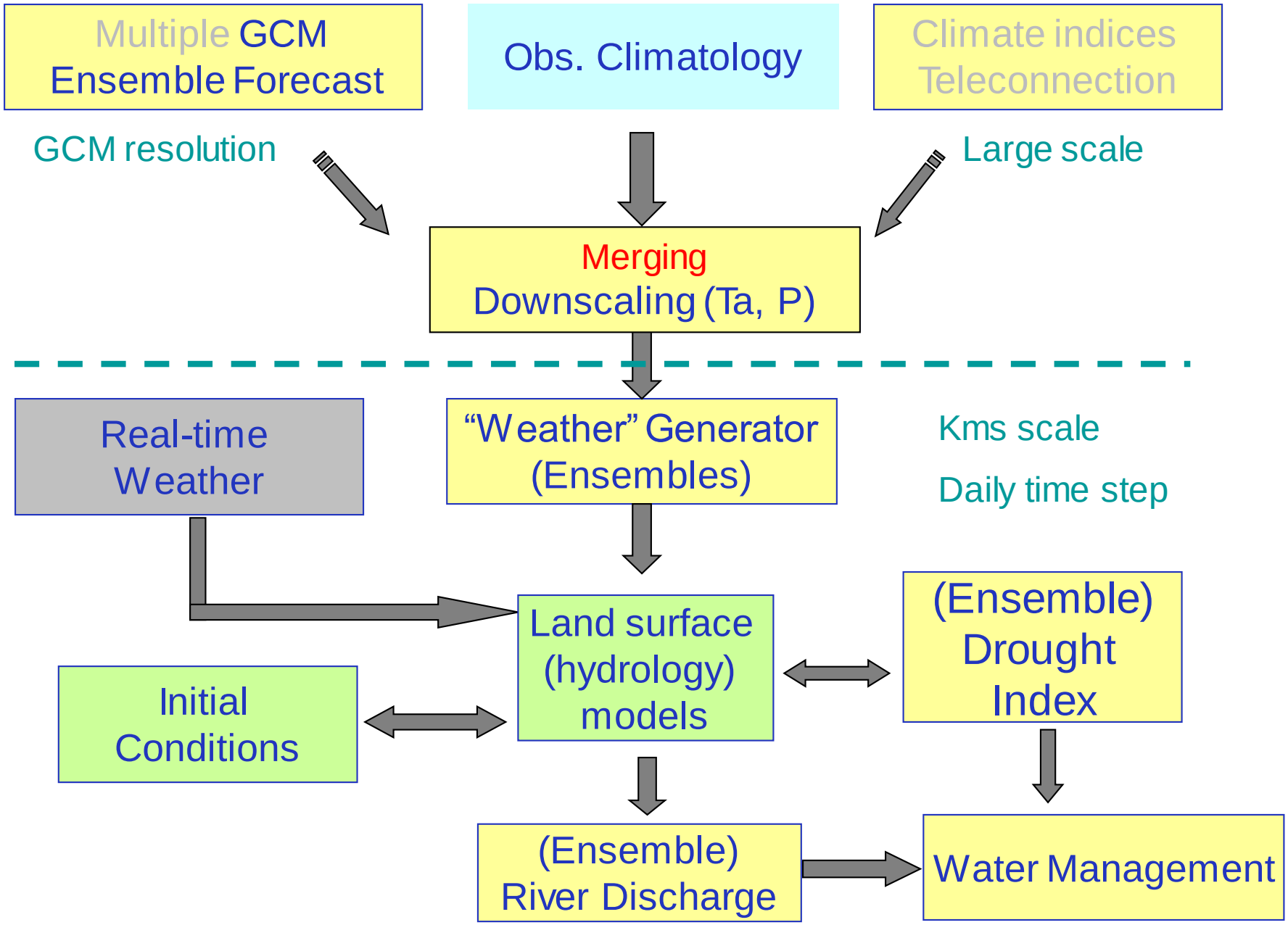
There are **MANY** ways to verify a forecast

https://www.cawcr.gov.au/projects/verification/#Standard_verification_methods

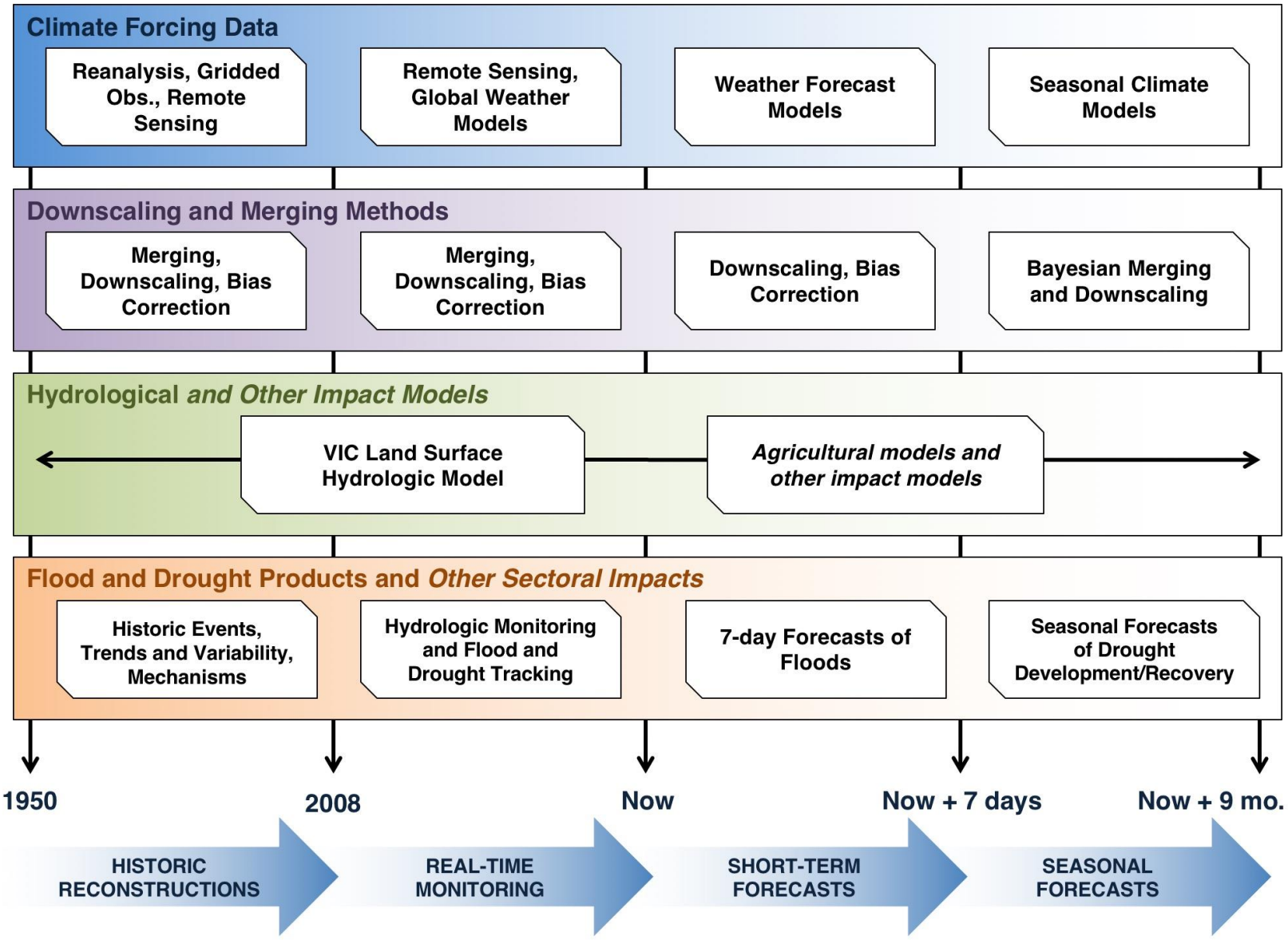
# Hydrologic Monitoring and Prediction System



# Hydrologic Monitoring and Prediction System



# Two Time Scales in the FDM



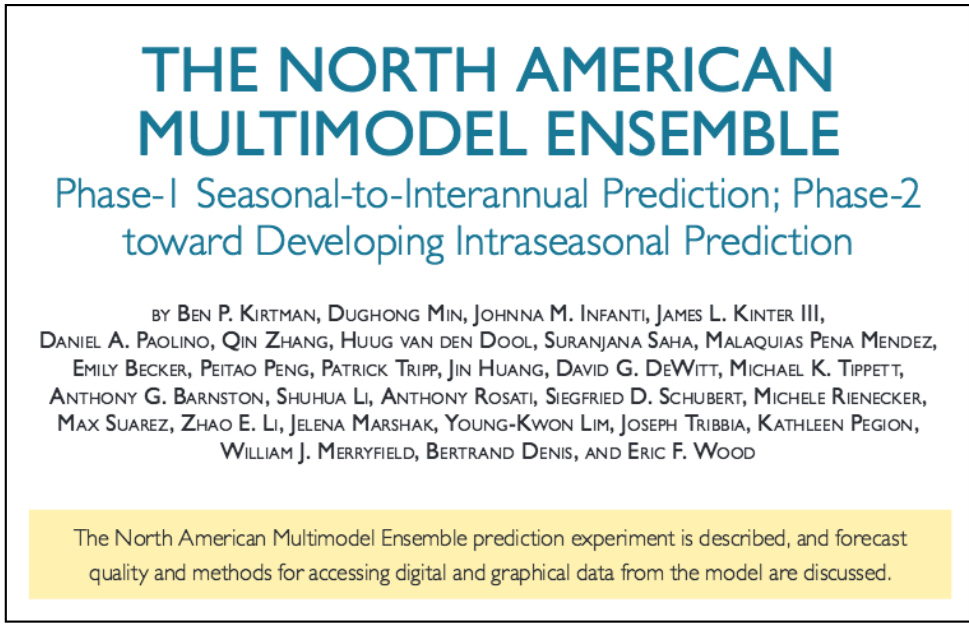

Sheffield et al. (2014), BAMS

# 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
- Models = NCAR/CCSM4, NOAA/CFSV2, CanCM3, CanCM4, GFDL/FLORB-01, NASA/GEOS-5



THE NORTH AMERICAN MULTIMODEL ENSEMBLE

Phase-1 Seasonal-to-Interannual Prediction; Phase-2 toward Developing Intraseasonal Prediction

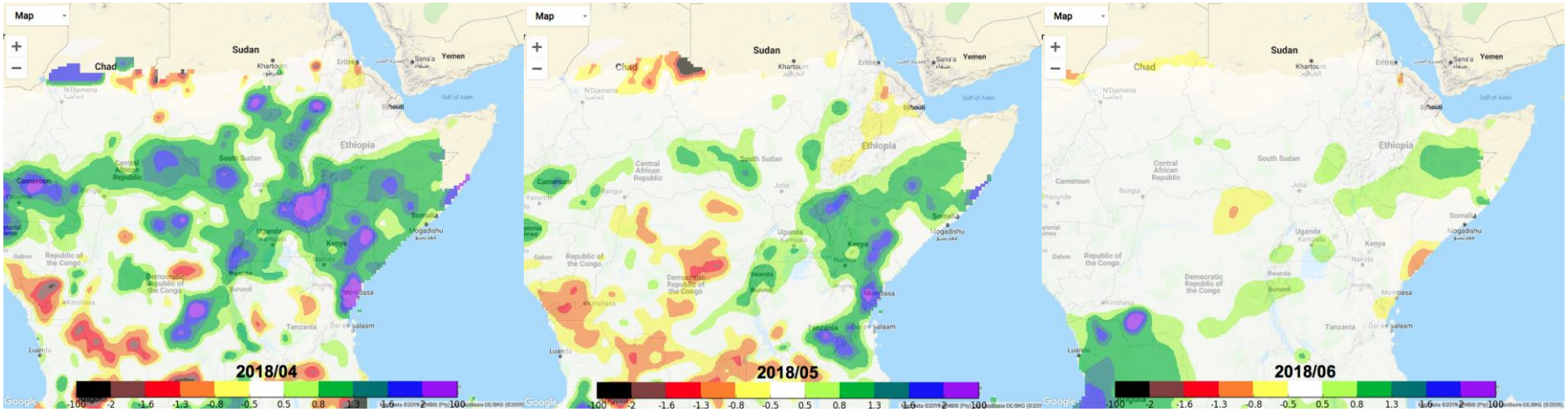
BY BEN P. KIRTMAN, DUGHONG MIN, JOHNNA M. INFANTI, JAMES L. KINTER III, DANIEL A. PAOLINO, QIN ZHANG, HUUG VAN DEN DOOL, SURANJANA SAHA, MALAQUIAS PENA MENDEZ, EMILY BECKER, PEITAO PENG, PATRICK TRIPP, JIN HUANG, DAVID G. DEWITT, MICHAEL K. TIPPETT, ANTHONY G. BARNSTON, SHUHUA LI, ANTHONY ROSATI, SIEGFRIED D. SCHUBERT, MICHELE RIENECKER, MAX SUAREZ, ZHAO E. LI, JELENA MARSHAK, YOUNG-KWON LIM, JOSEPH TRIBBIA, KATHLEEN PEGION, WILLIAM J. MERRYFIELD, BERTRAND DENIS, AND ERIC F. WOOD

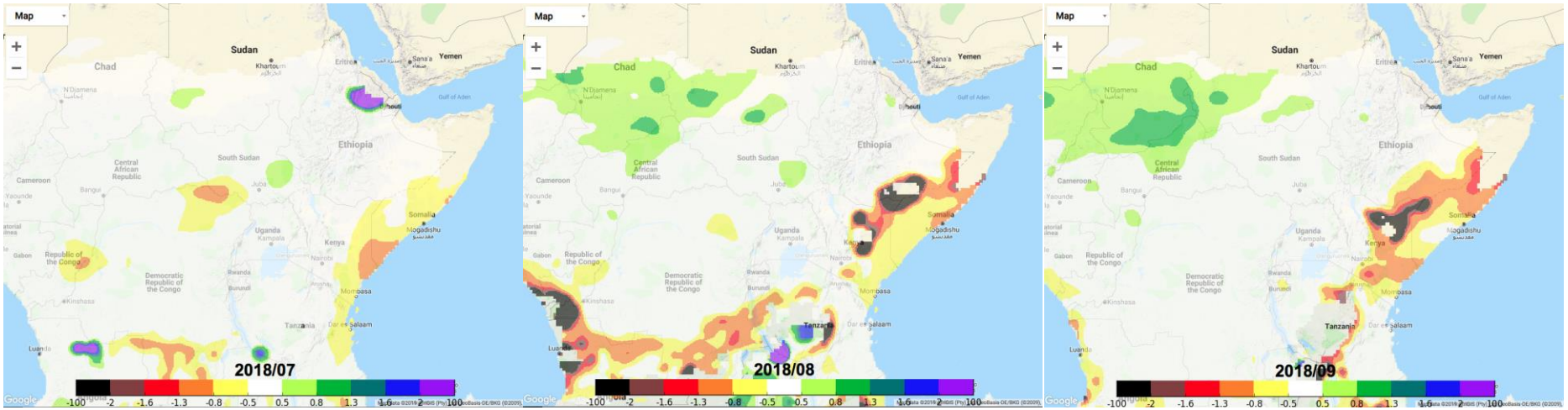
The North American Multimodel Ensemble prediction experiment is described, and forecast quality and methods for accessing digital and graphical data from the model are discussed.

All freely available at https://www.earthsystemgrid.org/search.html?Project=NMME

# Seasonal SPI-3 (6 month) forecast

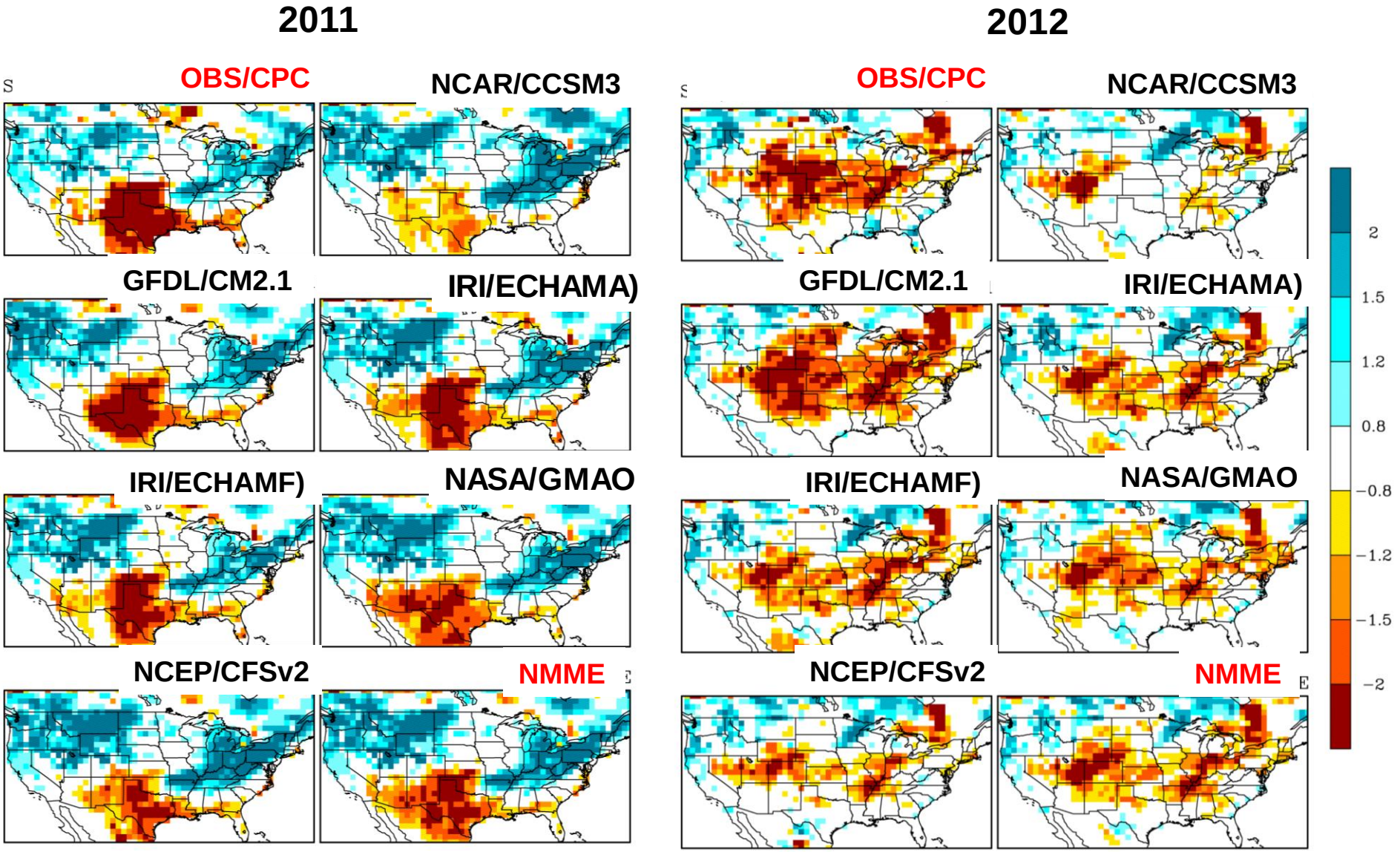
Multi-model ensemble, initialized at the start of March 2018



# 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



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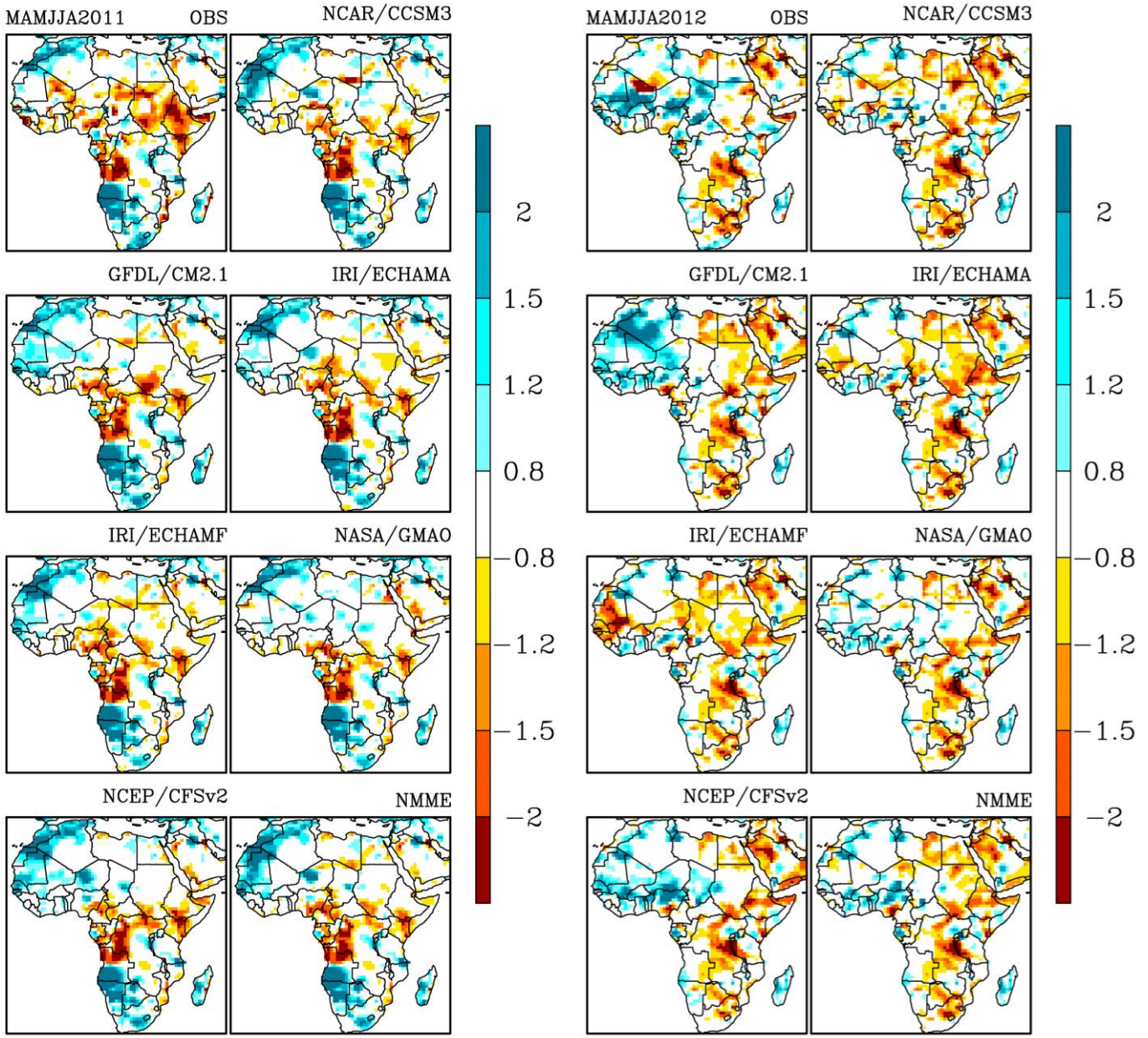
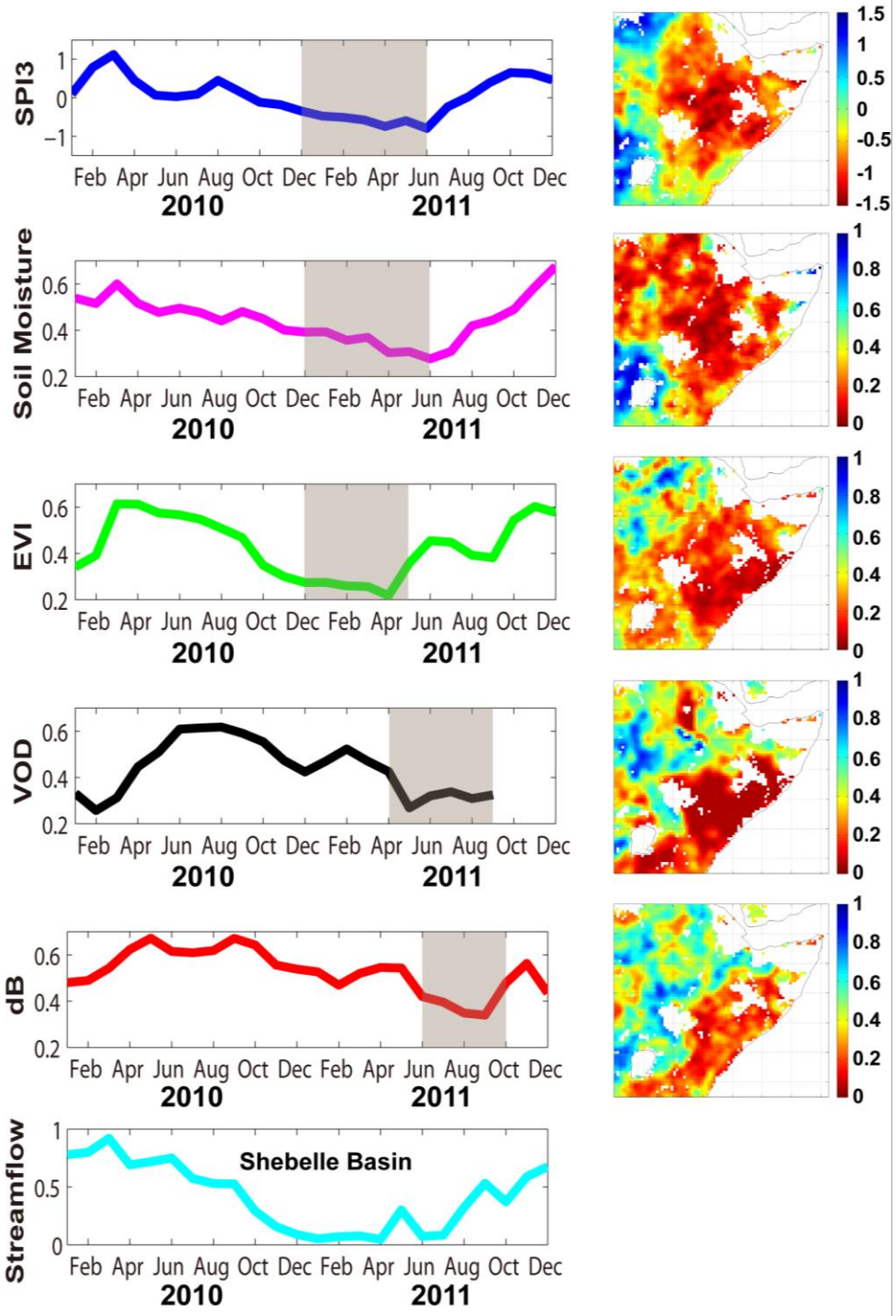
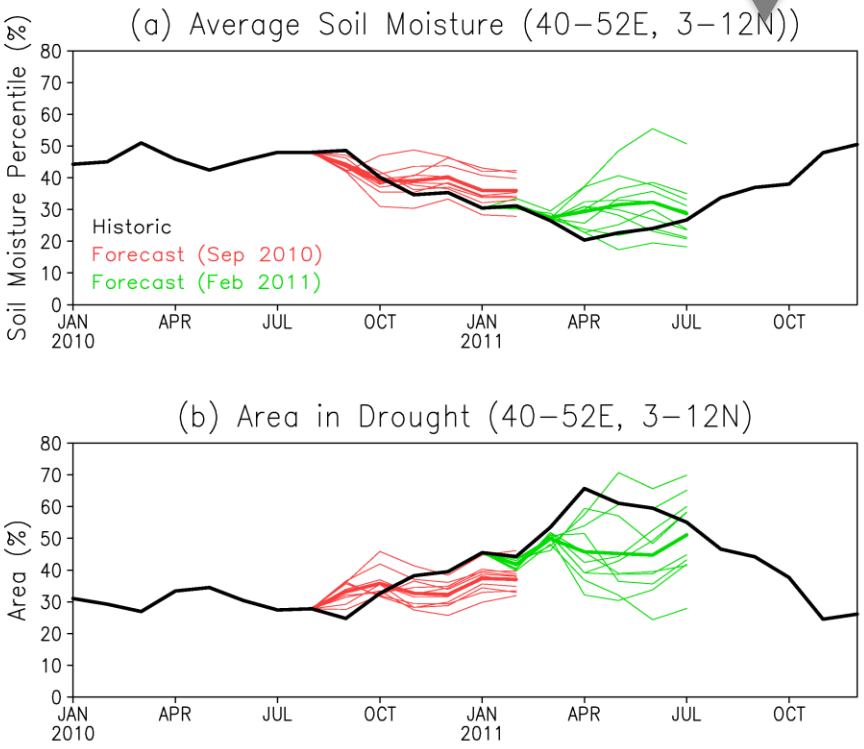


# Regional Example: Horn of Africa Drought 2010-2011



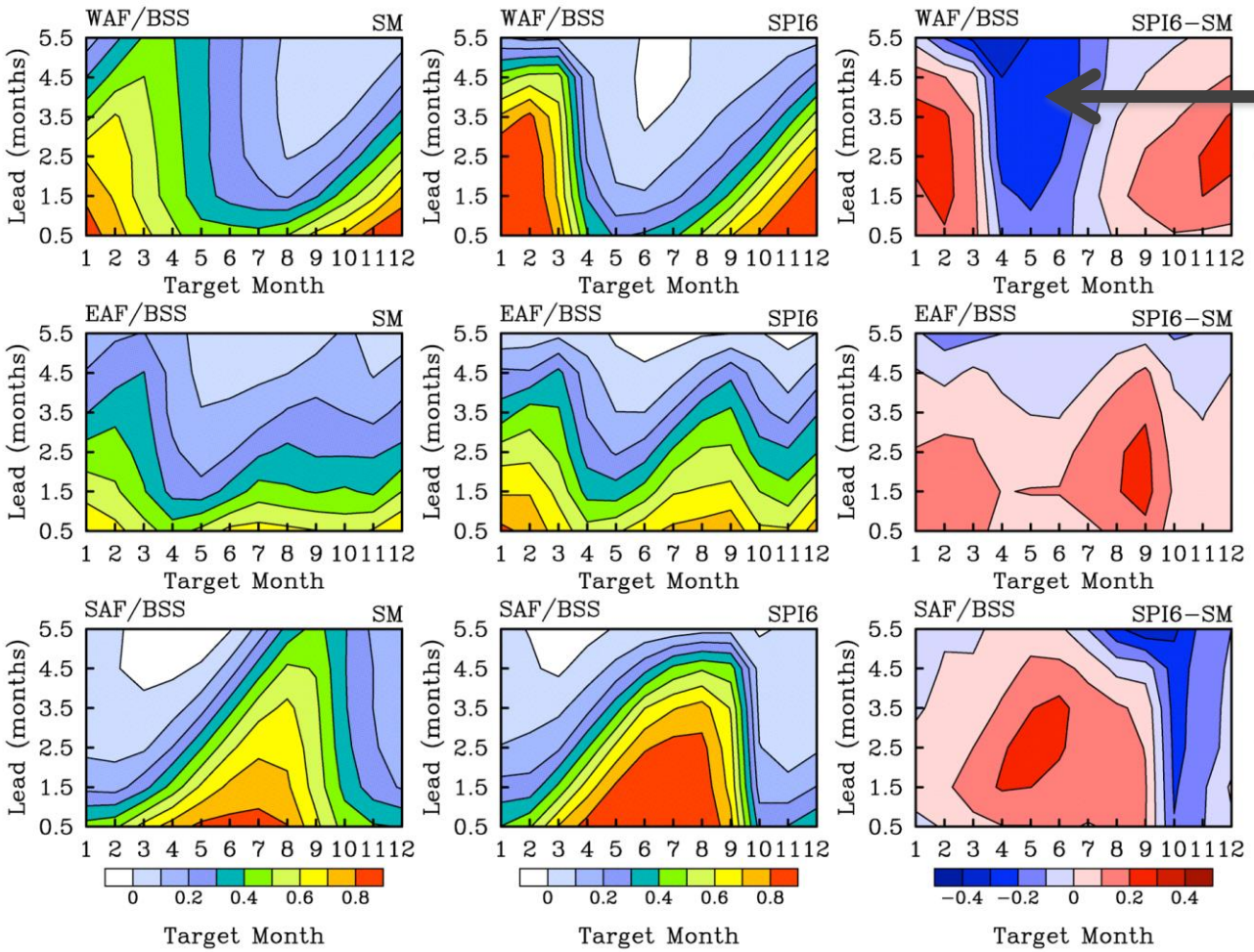

Monitoring the propagation of the drought

Seasonal forecasts (based on CFS model only)

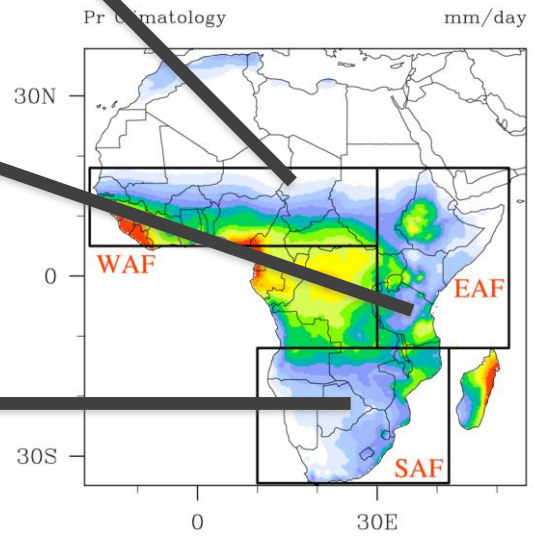


# Summary of Seasonal Forecast Skill from NMME-1 over African Regions for Precipitation and Soil Moisture

Soil moisture | SPI6 | SPI6 – Soil Moisture



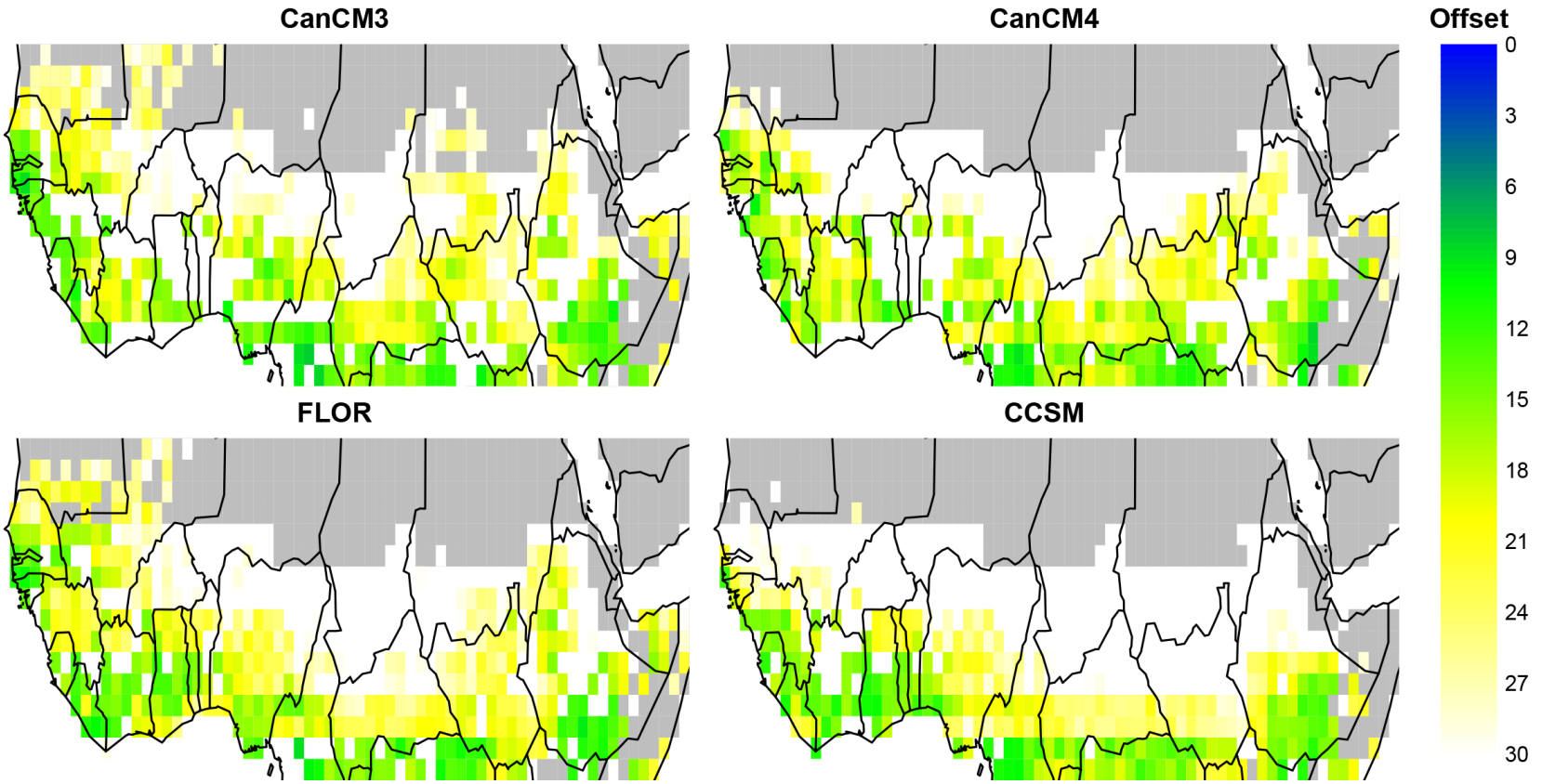

Soil moisture skill > SPI at start to mid growing season




Yuan, Y., E. F. Wood, N. W. Chaney, J. Sheffield, J. Kam, M. Liang, and K. Guan, 2013: Probabilistic Seasonal Forecasting of African Drought by Dynamical Models. *J. Hydrometeor., 14 (6), 1706-1720.*

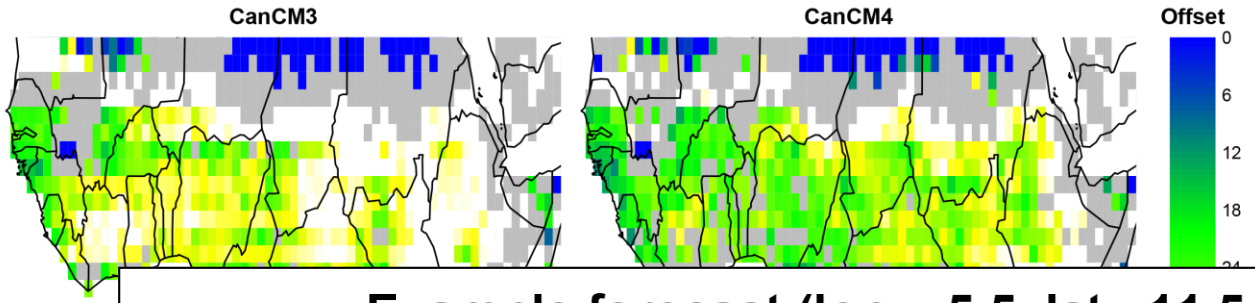
# NMME-2 Sub-Seasonal Forecasts

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

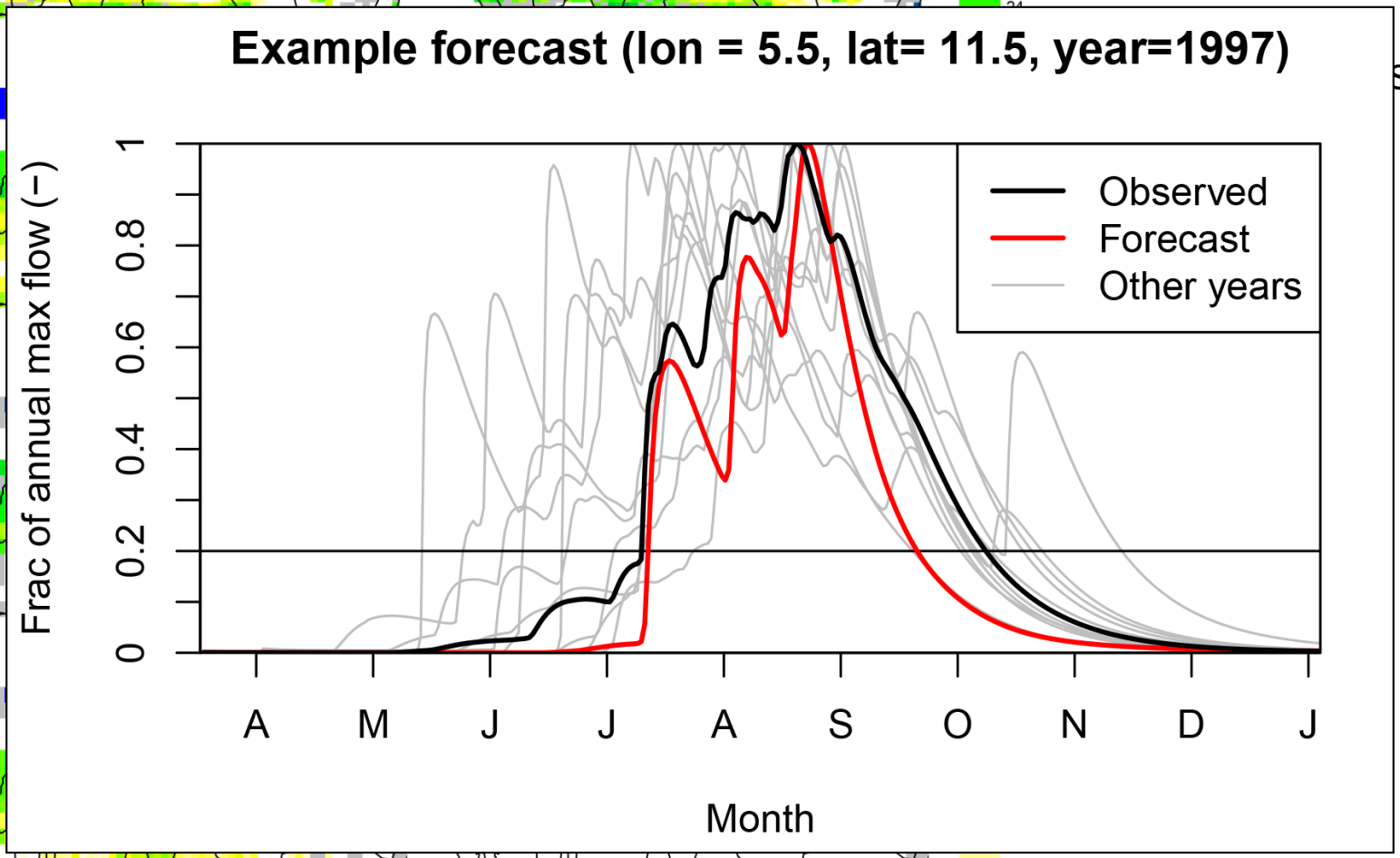
# Linking to Sub-Seasonal Hydrological Forecast




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

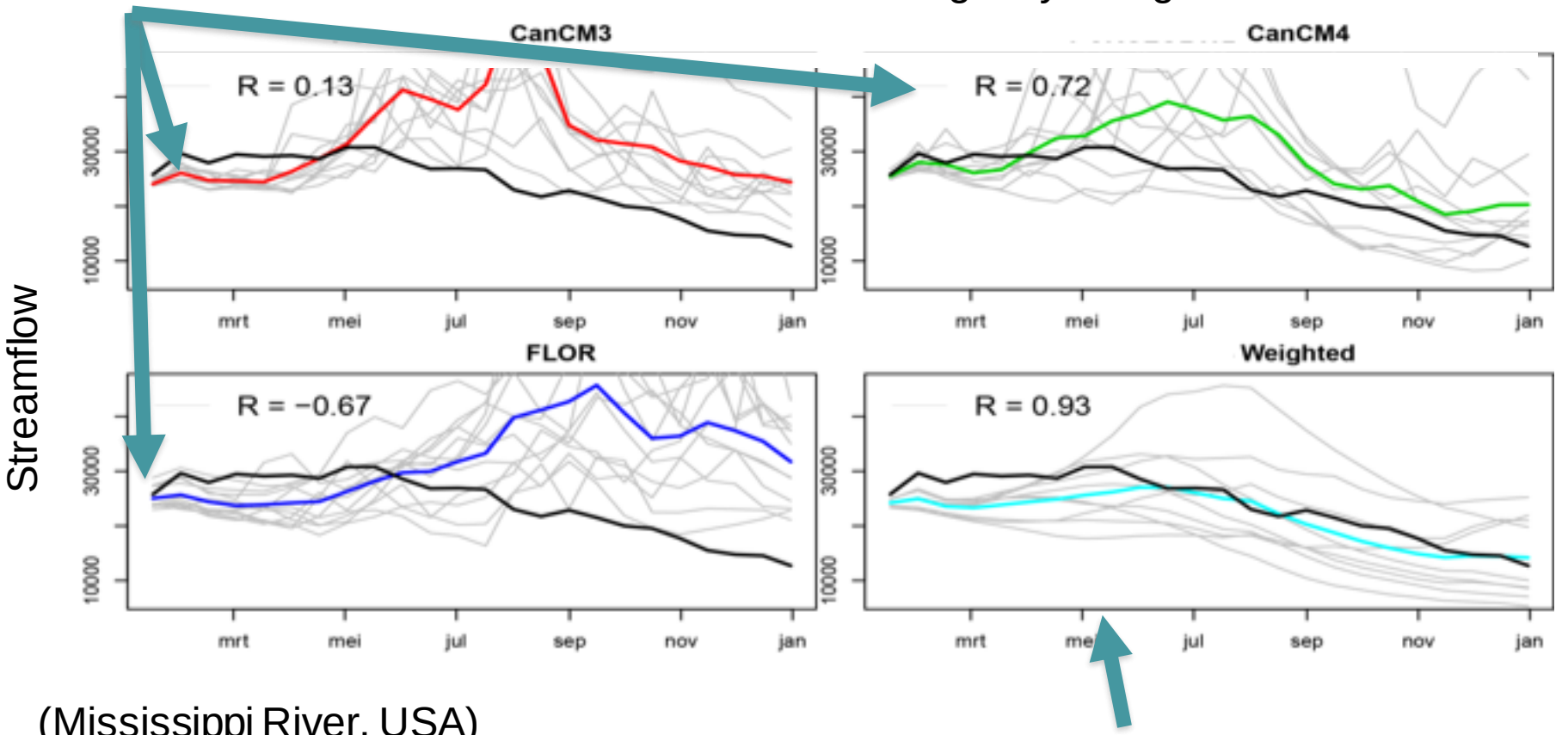
season

flow



# Multi-Model Merging provides greater skill for sub-seasonal forecasts

Three NMME-2 seasonal forecast models driving a hydrological model

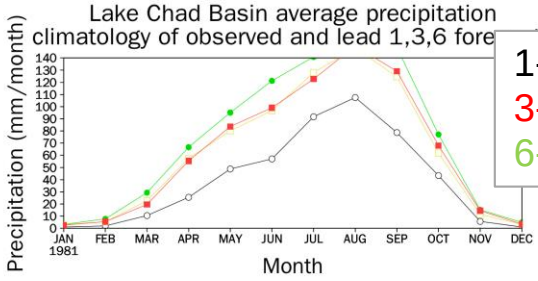


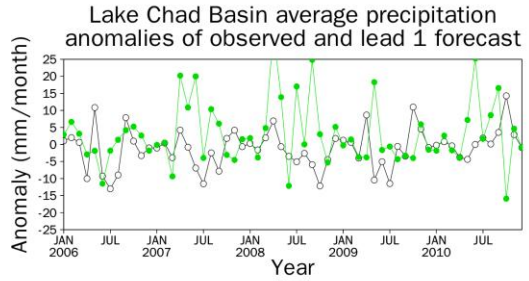

(Mississippi River, USA)

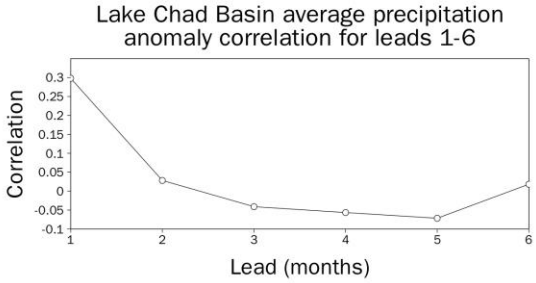
Weighted mean based on error covariance

# NMME-2 Model Skill for Sub-Seasonal Precipitation Forecasts – Lake Chad Basin

## CanCM3

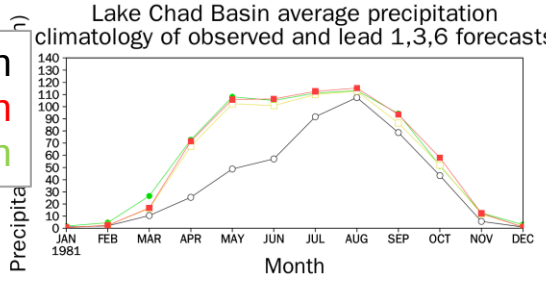


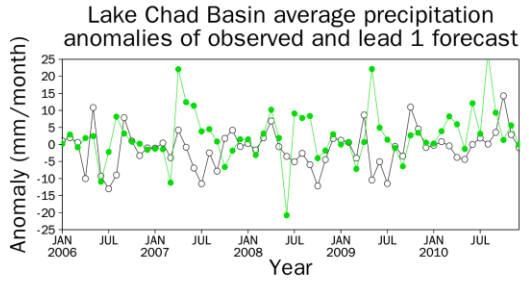



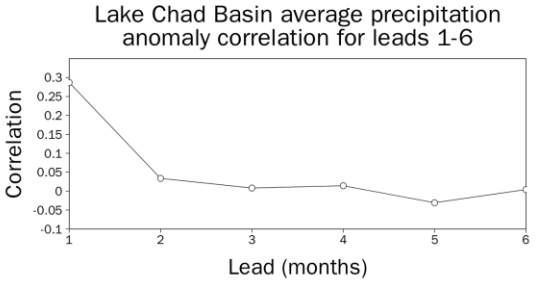




1-month
3-month
6-month

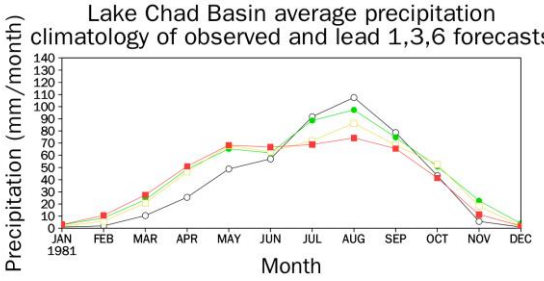
## CanCM4

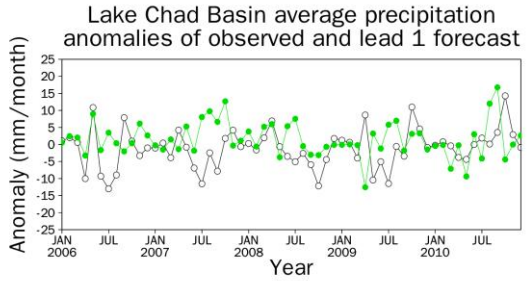


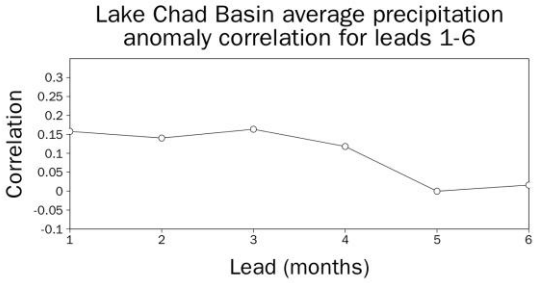




## GFDL-FLOR

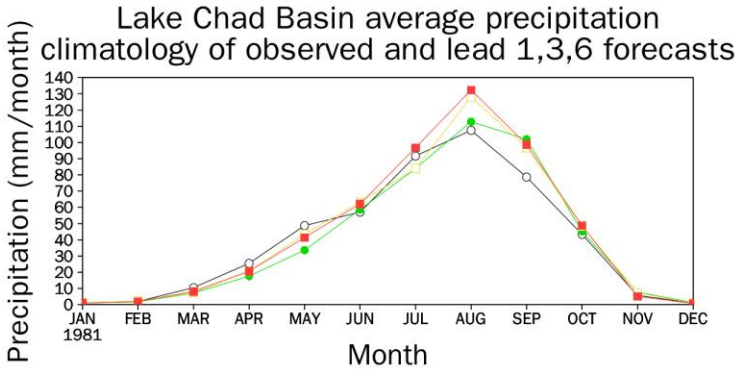


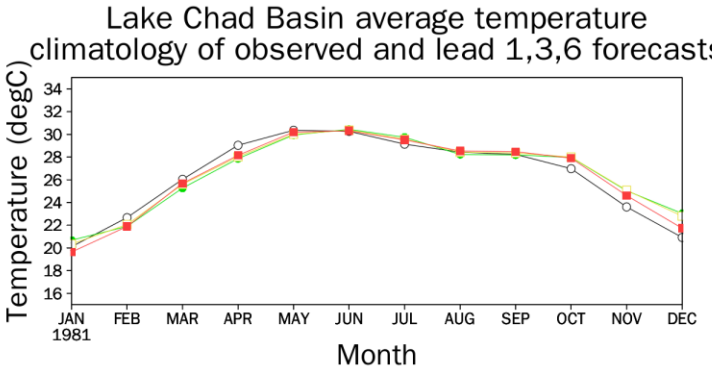



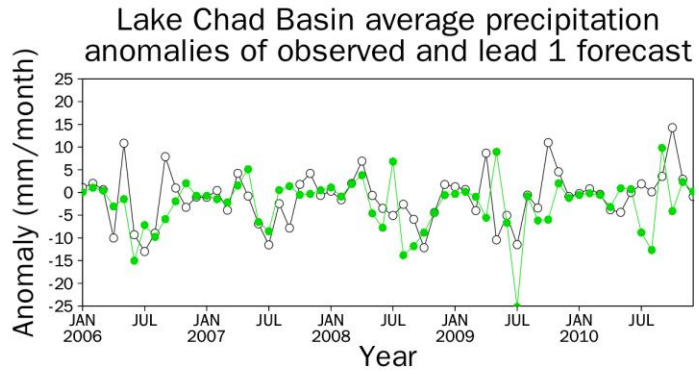



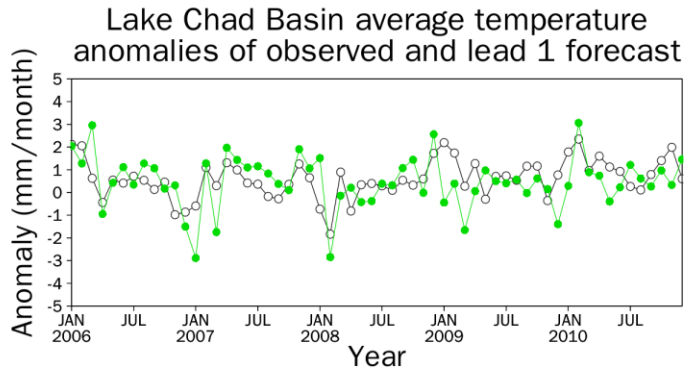

Evaluation of forecast skill of monthly precipitation from three NMME-2 seasonal forecast models

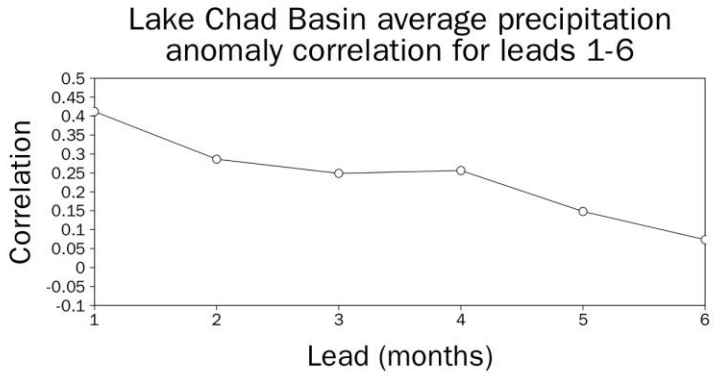
# NMME-2 Weighted Multi-Model Skill for Precipitation and Temperature Forecasts – Lake Chad Basin

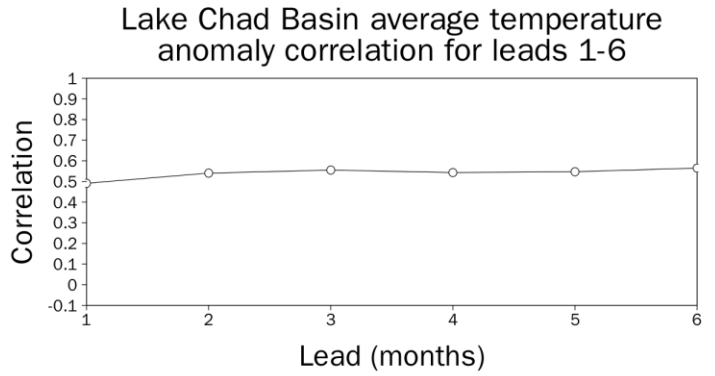


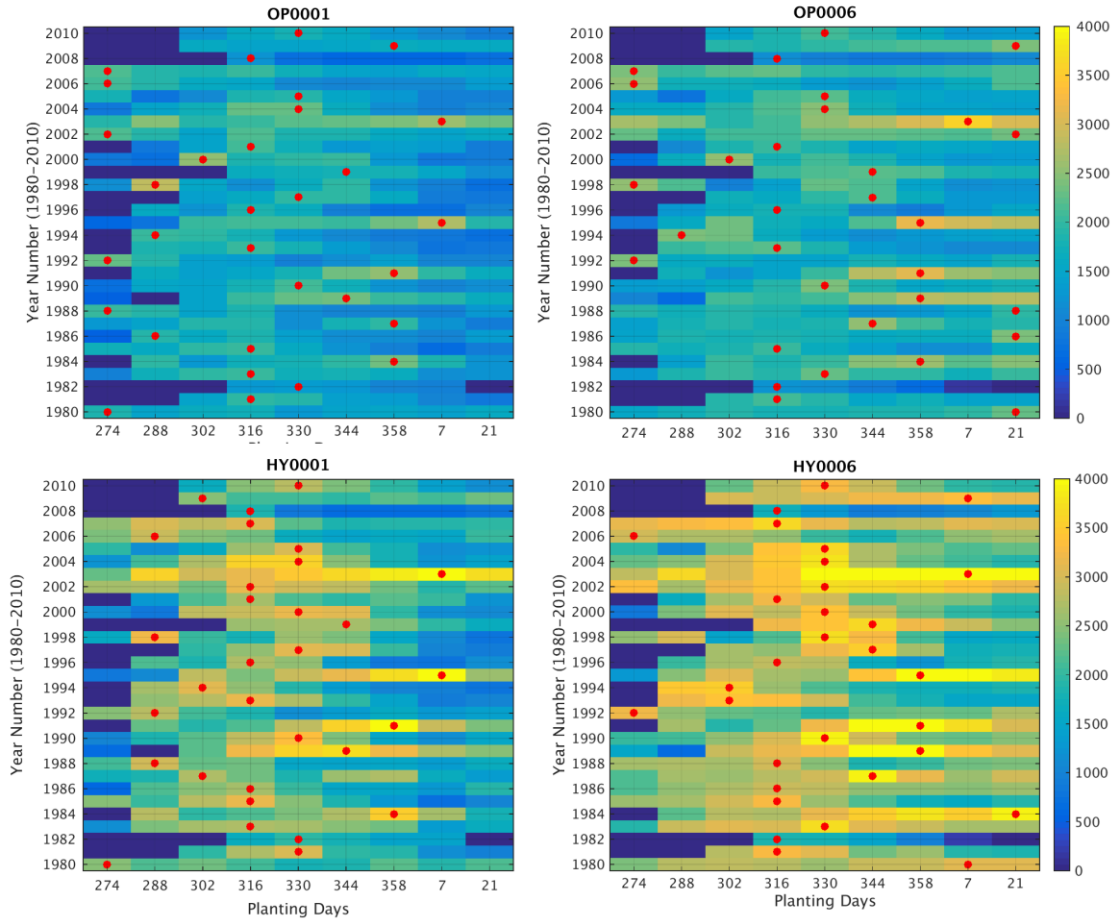



# Linking to Agricultural Production

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

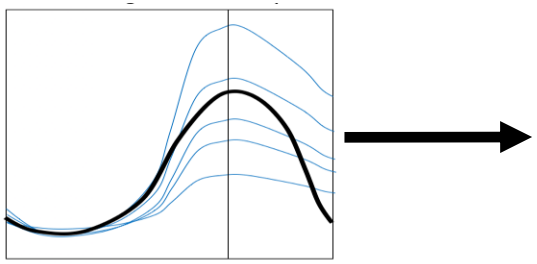
How can forecasts of the start of the growing season and water availability be used in decision making?

# 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

Extreme heat and flash drought

Frost damage

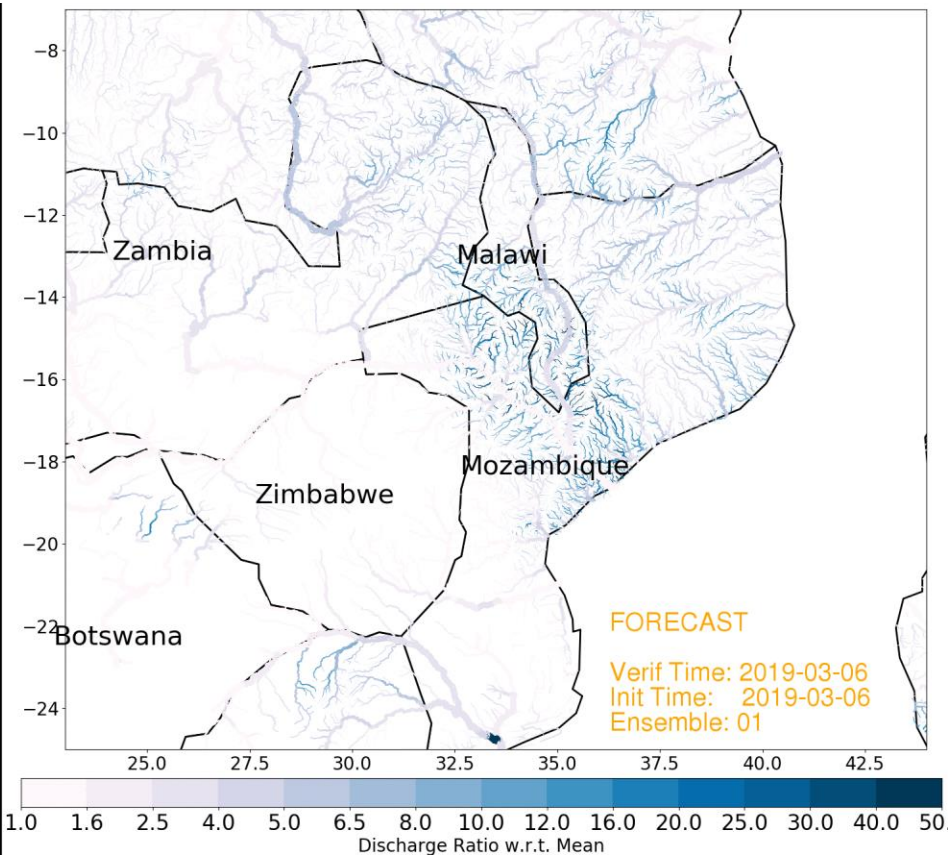
Flooding

UV damage

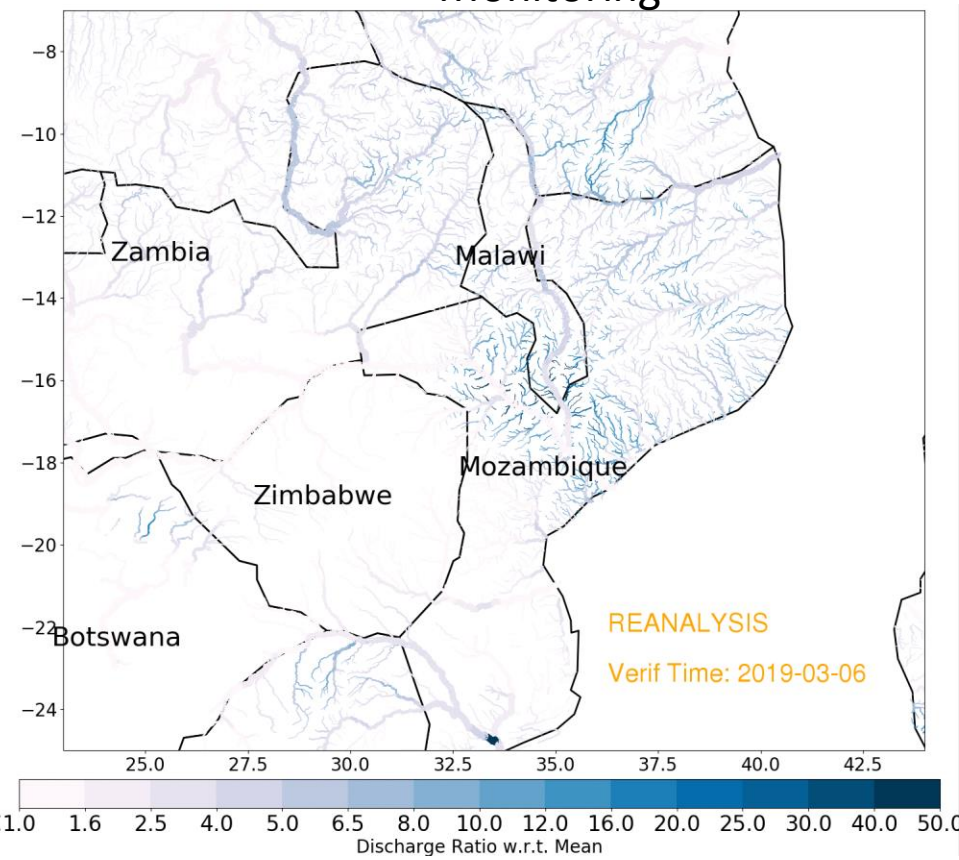
# Streamflow monitoring and forecasting for Cyclone Idai

**Initial flooding: 2019-03-06 to 2019-03-13**

Forecast: initialized on 2019-03-06



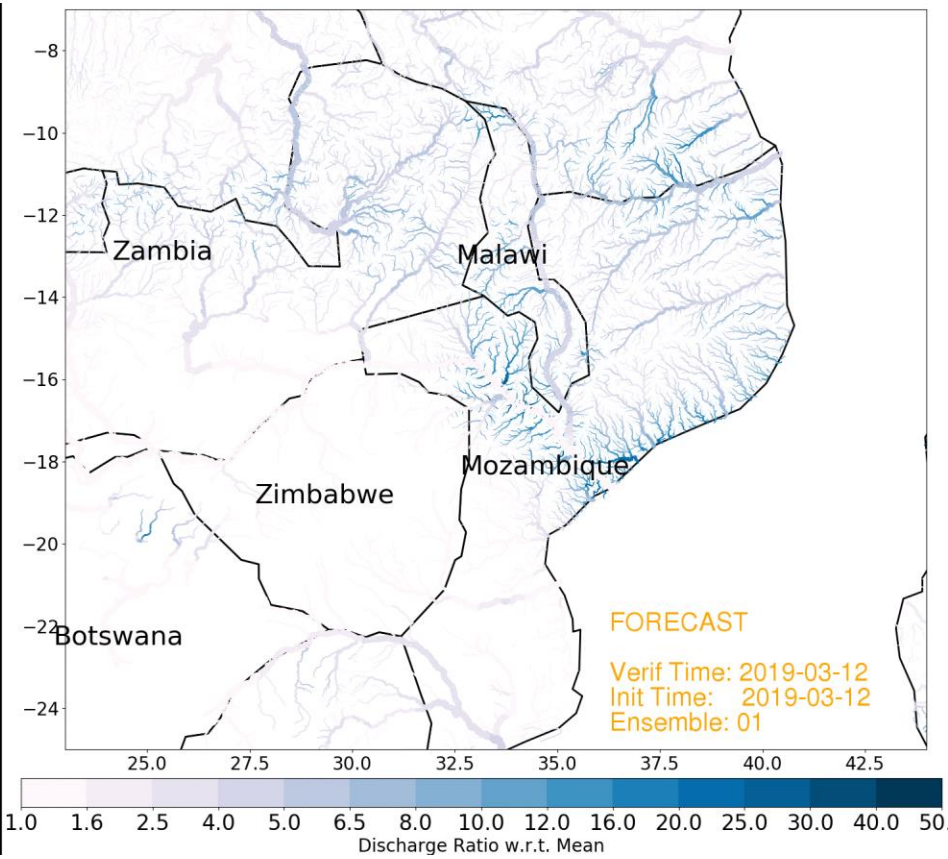

Monitoring



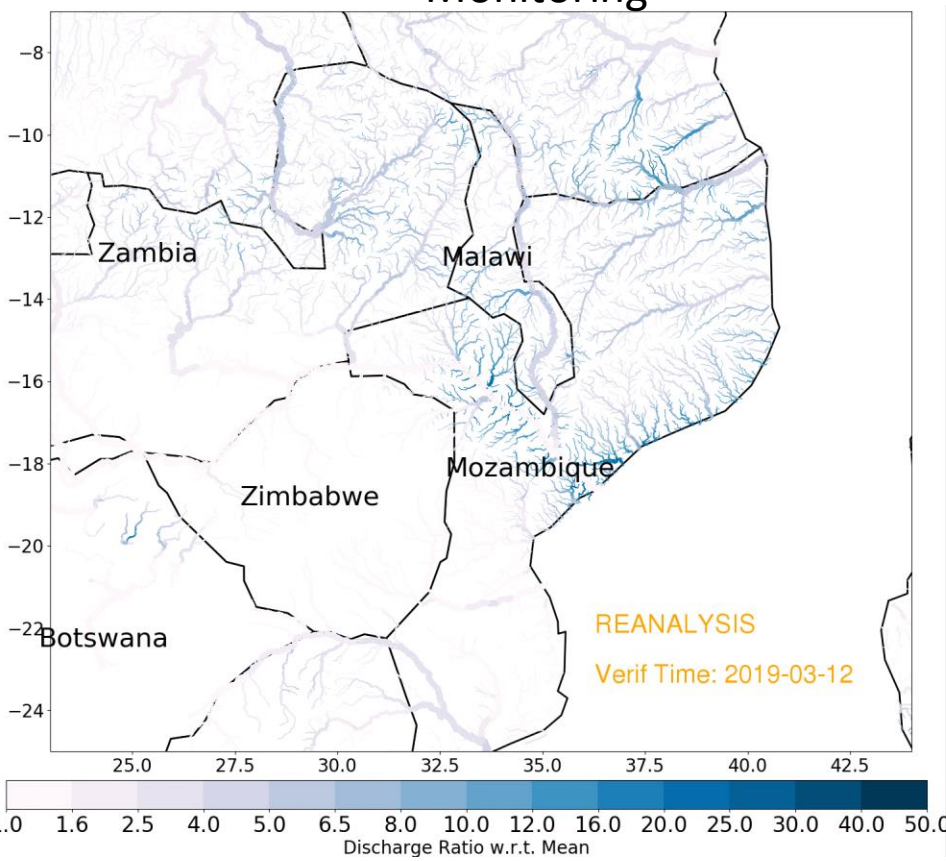
# Streamflow monitoring and forecasting for Cyclone Idai

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

Forecast: initialized on 2019-03-06

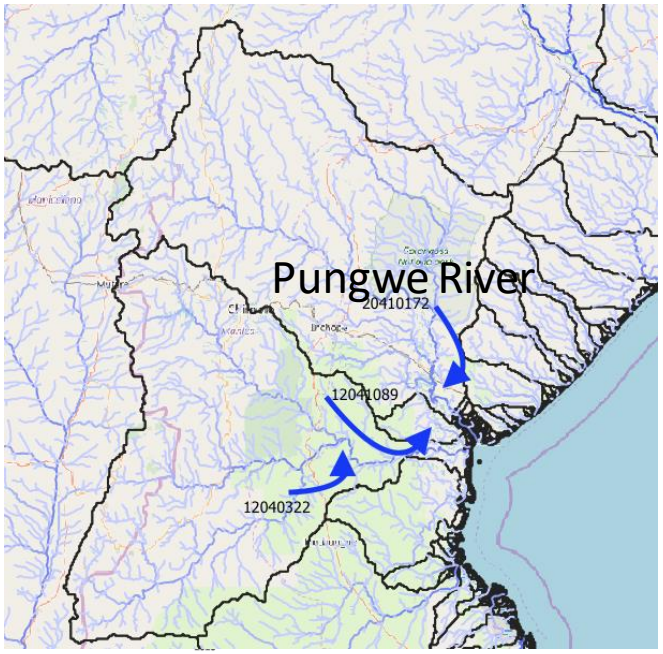


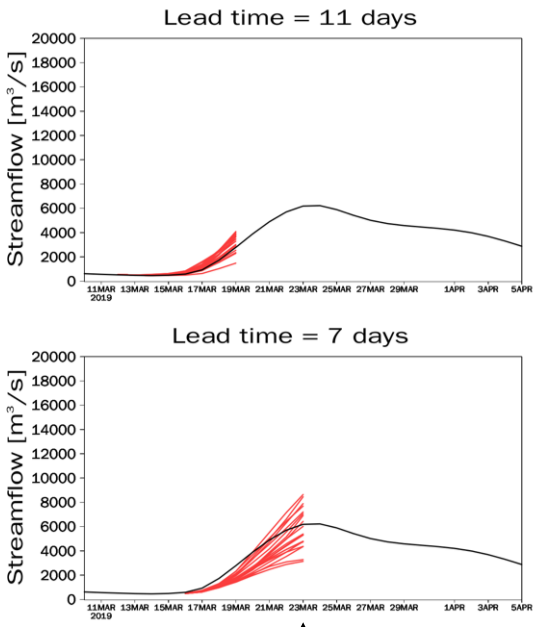

Monitoring

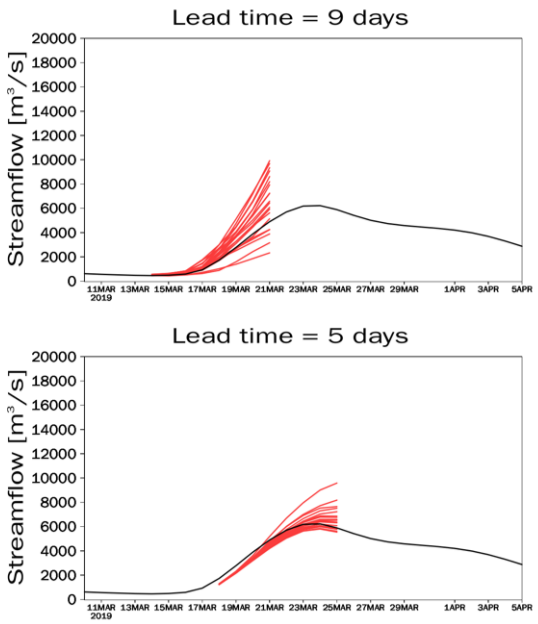


# Forecast Skill for River Flooding from Cyclone Idai

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










Peak flow

Modeled (Observed rainfall)
Modeled (GEFS forecast rainfall)

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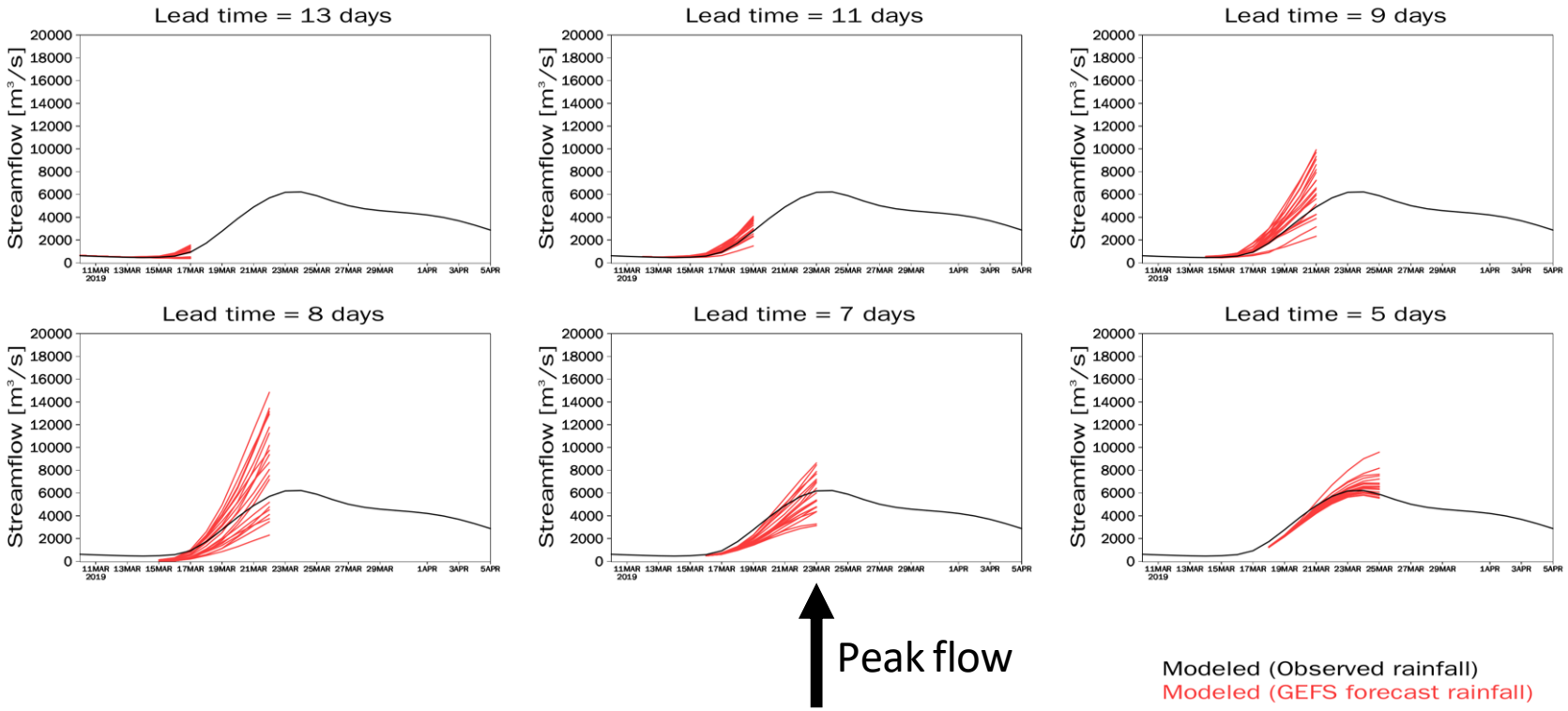

Any questions?