

# Optimizing Reservoir Operations for Hydropower Production in Africa

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**UCLA**



# Optimizing Reservoir Operations for Hydropower Production in Africa



## Motivation

- Low energy production



800 million people



45 million people

- Sub-optimal energy production (as low as 30% of design)

# Optimizing Reservoir Operations for Hydropower Production in Africa



## VISION

To support decision makers in making **optimal reservoir planning decisions** on a seasonal scale with a goal to increase amount of energy produced.

## OBJECTIVES

- Decision Support System with
- Optimization tool
  - Hydrologic forecast
  - Seasonal Climate forecast

## DOMAIN

East Africa, Gibe basin

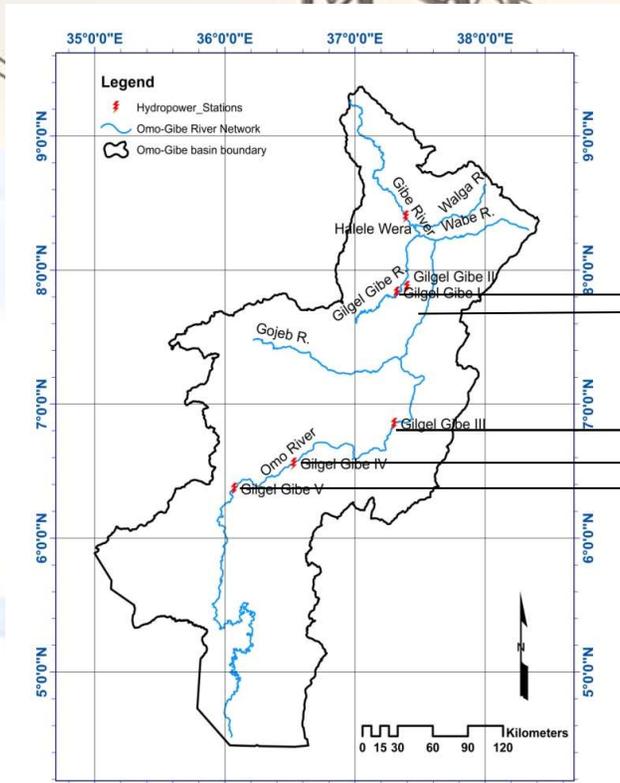
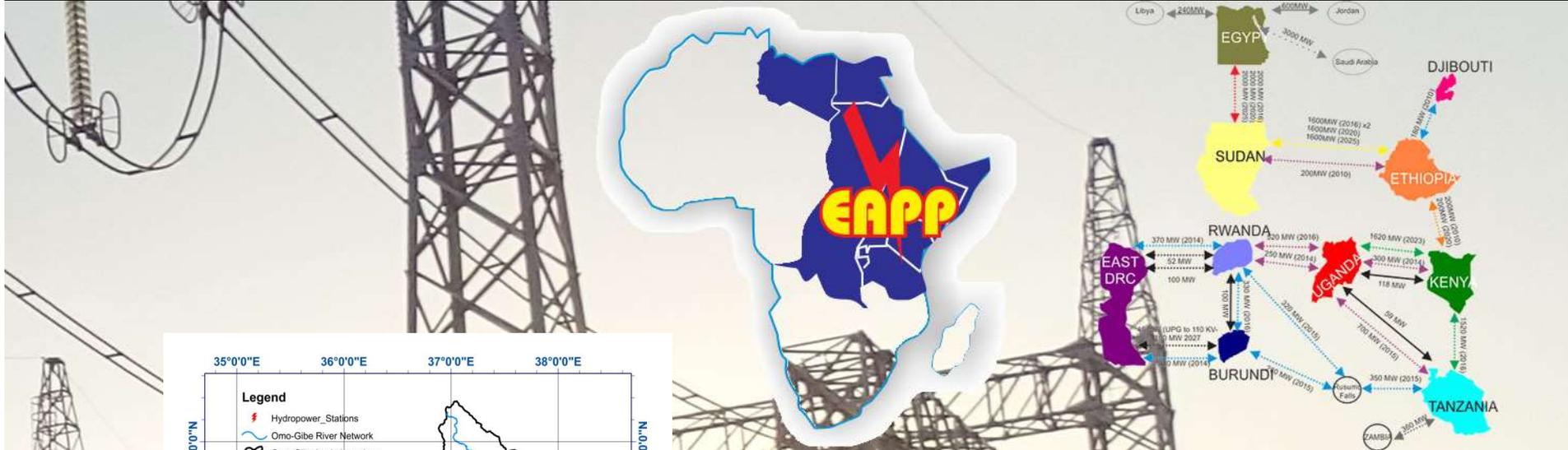
## DECISION MAKERS

Ethiopian Electric Power, Water Works Construction Corporation, & Sectors engaged in water management

## DECISIONS TARGETED

Reservoir planning

# Geographic Domain



## Gibe I (2004)

Installed Capacity - 210MW  
Max Storage - 840 Mm<sup>3</sup>

## Gibe II (2010)

Installed Capacity - 420 MW  
Max Storage - 0.15 Mm<sup>3</sup>

## Gibe III (2015)

Installed Capacity - 1870 MW  
Max Storage - 13700 Mm<sup>3</sup>

## Gibe IV (Planned)

Installed Capacity - 1450 MW

## Gibe V (Planned)

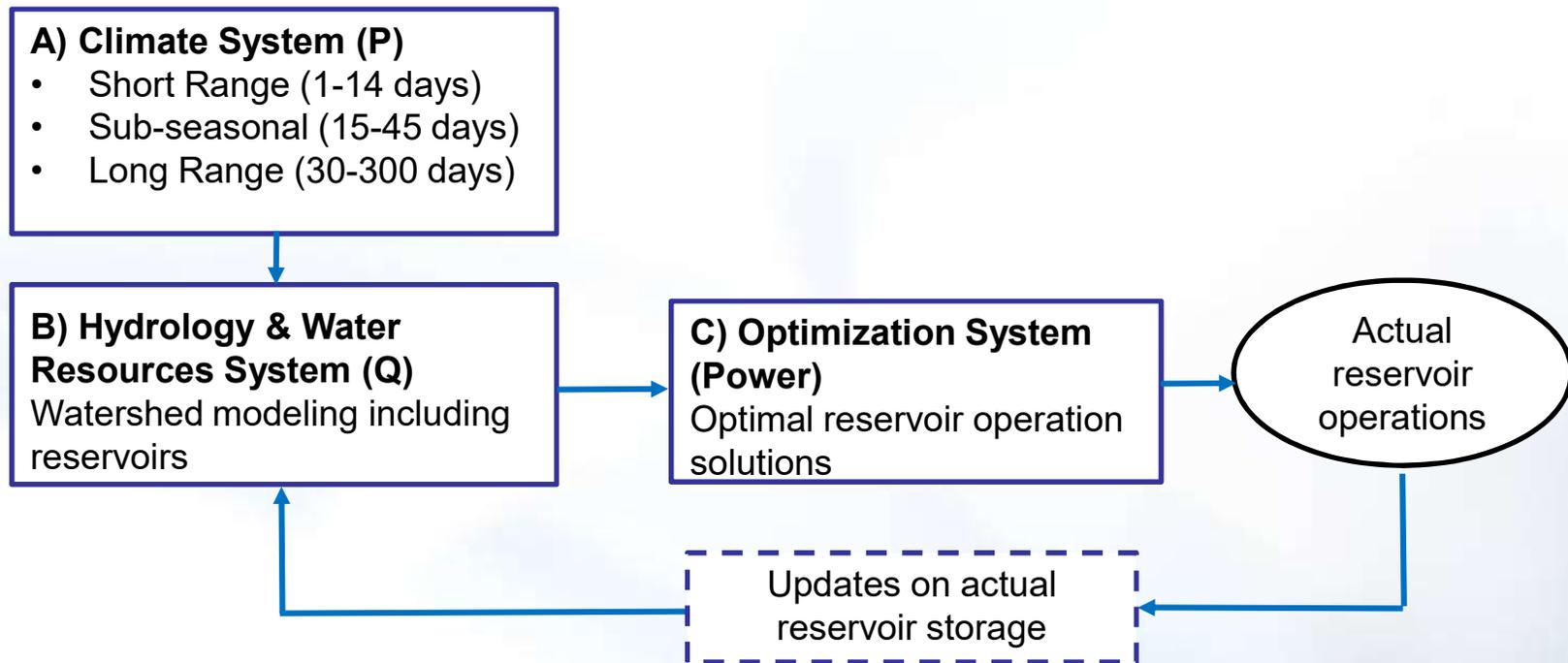
Installed Capacity - 600 MW

## Test Catchment - Omo Gibe Basin

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## Approach – Decision Support System

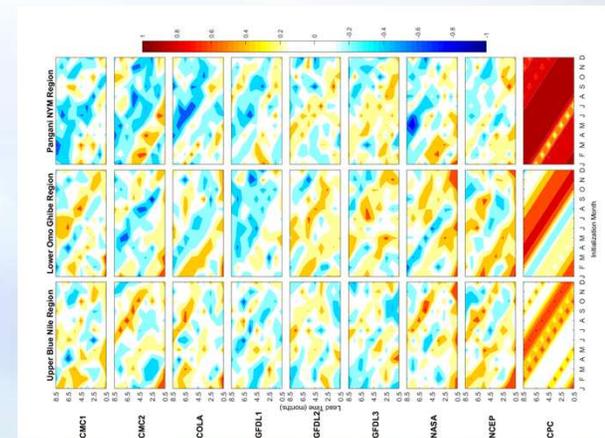
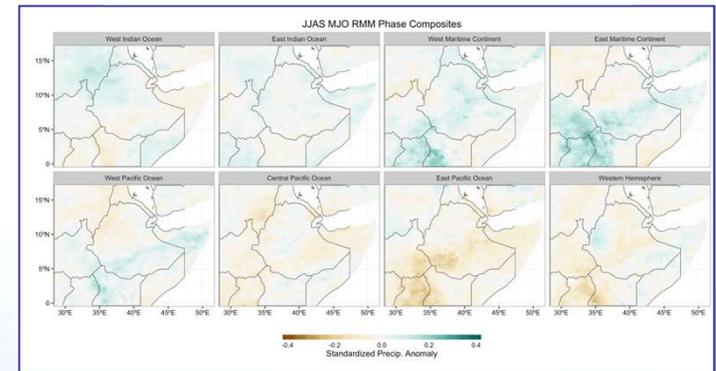
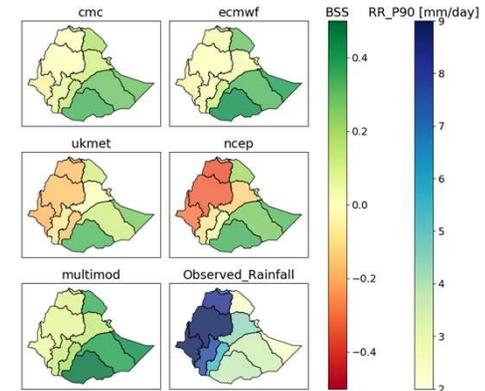


# Multi-model Multi-Timescale Rainfall Forecasts



## Methodology:

- **Short Range** – Multi-model ensemble derived from 8 global centers combined using quantile regression (QR)
- **Sub-seasonal Range** – NOAA CFS 4-member ensemble + Madden-Julian Oscillation
- **Seasonal Range** – Multi-model ensemble derived from NMME forecasts combined with SST indicators.

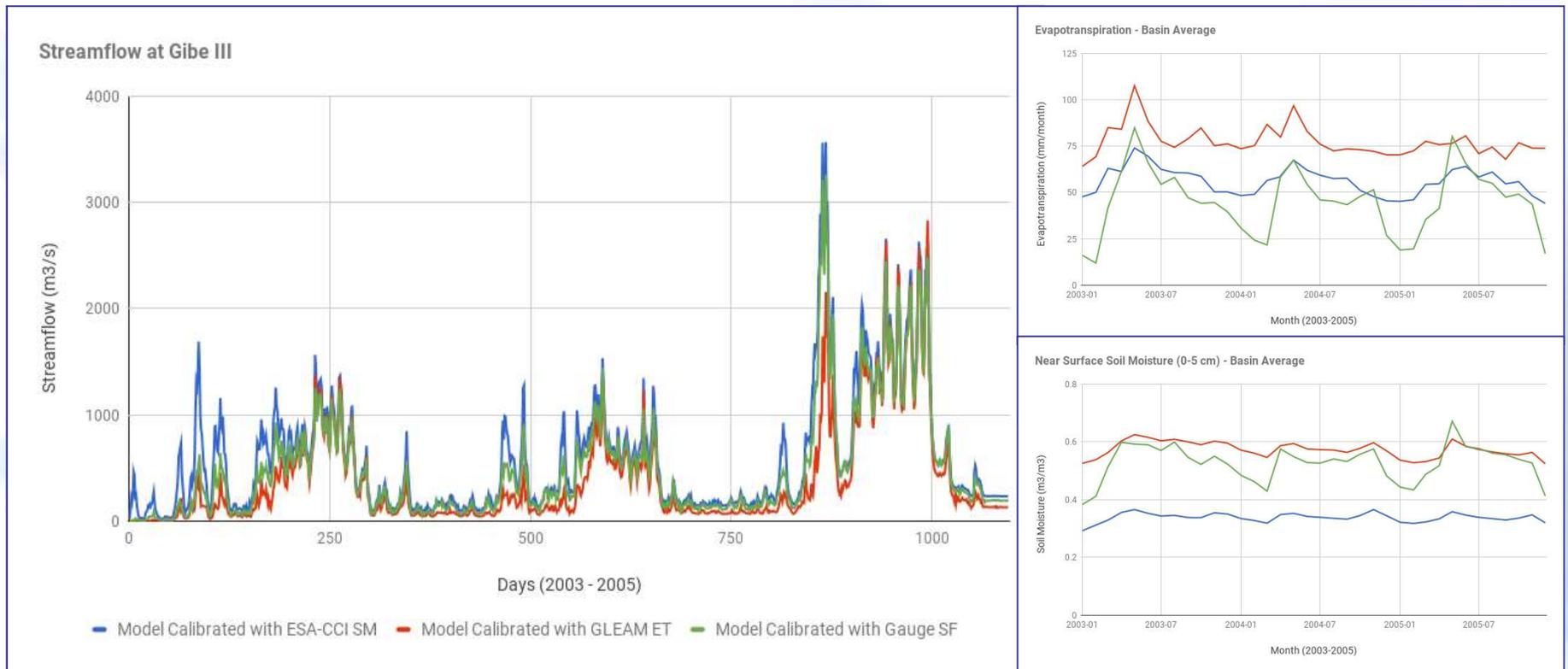


# Hydrologic Forecasts at Multi-Timescales



## Methodology:

- **Noah-MP** – Land Surface Model, driven by NASA's LIS
- **Calibration** – using satellite ET and soil moisture
- **Input** – Improved rainfall forecast
- **Output** – Hydrologic forecast

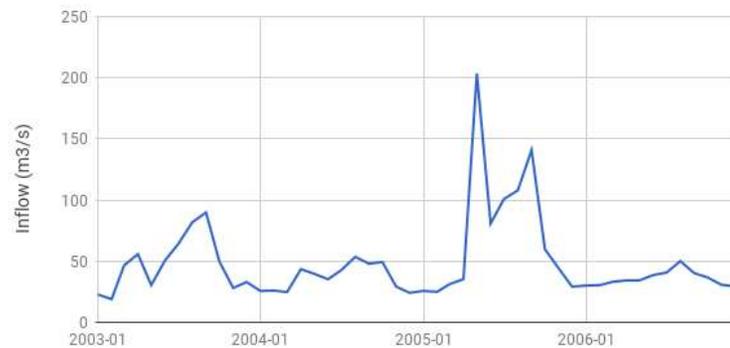


# Optimal Reservoir Operation Solutions

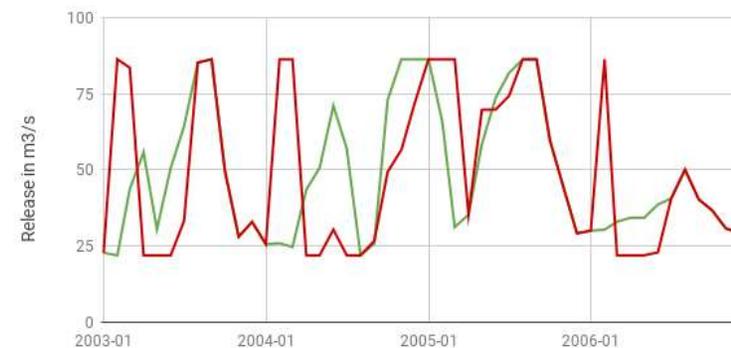


## Preliminary Results – Gibe I

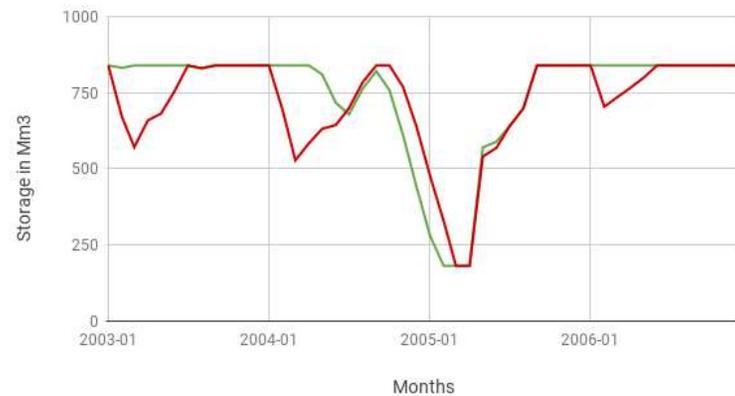
Inflow Into Gibe I



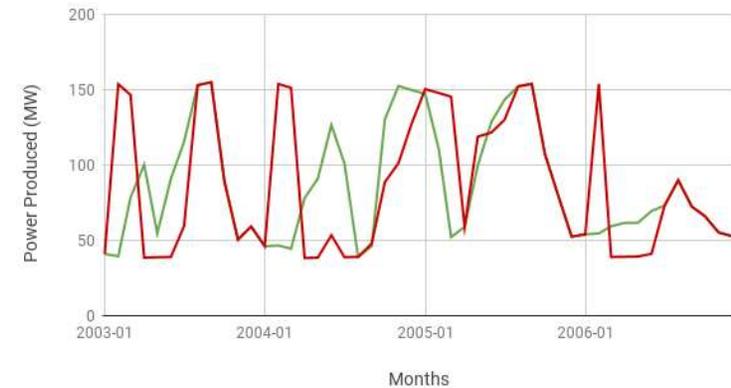
Release From Gibe I



Storage of Gibe I



Power Production in Gibe I



 Optimized for maximum power production  
 Optimized for actual demand



## Comparison with “Business-As-Usual”

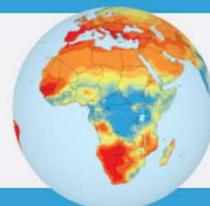
| Years | Gibe I - Observed (GWh) (Actual Power Produced) | Gibe I - Modeled (GWh) (Optimized for Maximum Power) | Percentage Change in Power Production (%) |
|-------|---|--|---|
| 2005  | 788   | 940  | +19                                       |

# Transition – User-friendly DSS



## EAST AFRICA CATCHMENT RAINFALL

NASA-UCLA Reservoir Operations for Hydropower Production in Africa



NCAR  
UCAR

Downloads

region

accumulation  
length

date

model

Home Ethiopia East Africa

Select from the options below to display precipitation forecasts or observed products.

### 1. SELECT OBSERVED OR FORECAST DATA

- Forecasts
- Recent Observations

### 2. SELECT AN AVERAGING PERIOD

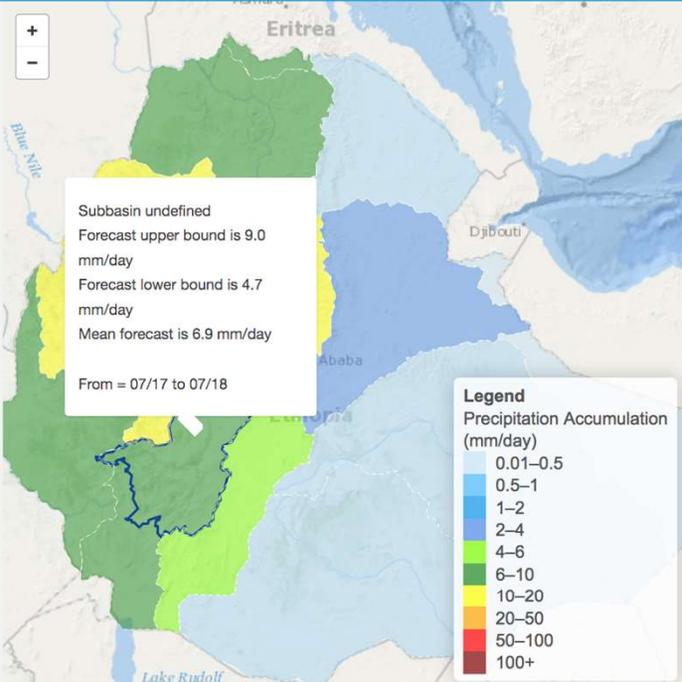
24 Hour

### 3. SELECT THE RAINFALL DATE TO DISPLAY

2017-07-17 00Z to 2017-07-18 00Z

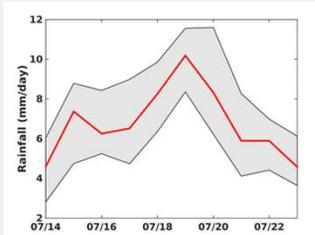
### 4. SELECT A MODEL OR OBSERVED PRODUCT TO DISPLAY

European (ECMWF)



Leaflet | Tiles © Esri – Sources: GEBCO, NOAA, CHS, OSU, UNH, CSUMB, National Geographic, DeLorme, NAVTEQ, and Esri  
Click on a watershed above to view time series.  
The map above displays a forecast average from 2017/07/17 00Z to 2017/07/18 00Z.  
This forecast was initialized on 2017/07/14 00Z and is a 24 hour average

Download data from graph



Precipitation (mm/day) from most recent available TIGGE forecast. The red line represents the median of all forecast ensemble members. The upper black line shows the 90th percentile ensemble member, and the lower black line shows the 10th percentile ensemble member. Water levels above or below these bounds each have a 10% probability of occurrence.

Time series



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ETHIOPIAN ELECTRIC POWER



# Transition - Training of Stakeholders



## Participants:

- (1) Ethiopian Electric Power
- (2) Ethiopian Construction Works
- (3) National Meteorological Agency
- (4) Irrigation Bureaus

- Workshop I: Satellite Remote Sensing, Basic Data Analysis tools
- Workshop II: Climate Forecasting
- Workshop III: Hydrologic Forecasting, Optimization (Hydroterm)

## NCAR Visit:

Ethiopian Construction Works Corp.





## **Next Steps**

- Collaborating with SERVIR to run operational components of the forecasting system  
(<https://climateserv.servirglobal.net>)
- Final Integration of the DSS components
- Trial application of DSS to operation
- Sustainable DSS implementation by end-users

# ***Optimizing Reservoir Operations for Hydropower Production in Africa***



## **Publications**

**Broman, D., et al.: Spatial and Temporal Variability of East African Kiremt Season Precipitation and Large-Scale Teleconnections, JGR, 2018.**

**Boehnert, J., et al.: Communicating Water Resource and Flood Risk in East Africa and South Asia, EOS, 2018.**

**Stellingwerf, S., et al.: Investigation of Bias and Skill in East African Medium-Range Rainfall Forecasts for Hydrologic Applications, JGR. 2018.**

**Hopson, T., et al.: Reliable Ensemble Rainfall Forecasts with Informative Skill-Spread Information, MWR, 2018.**

**Koppa, A., et al. A Validation Framework for Remotely Sensed Precipitation and Evapotranspiration Without the Use of Ground-Based Measurements, Water Resources Research, 2018.**

**Gebremichael, M., et al.: Uncertainty analysis of seasonal climate forecasts in East Africa, J. Hydromet., 2018.**



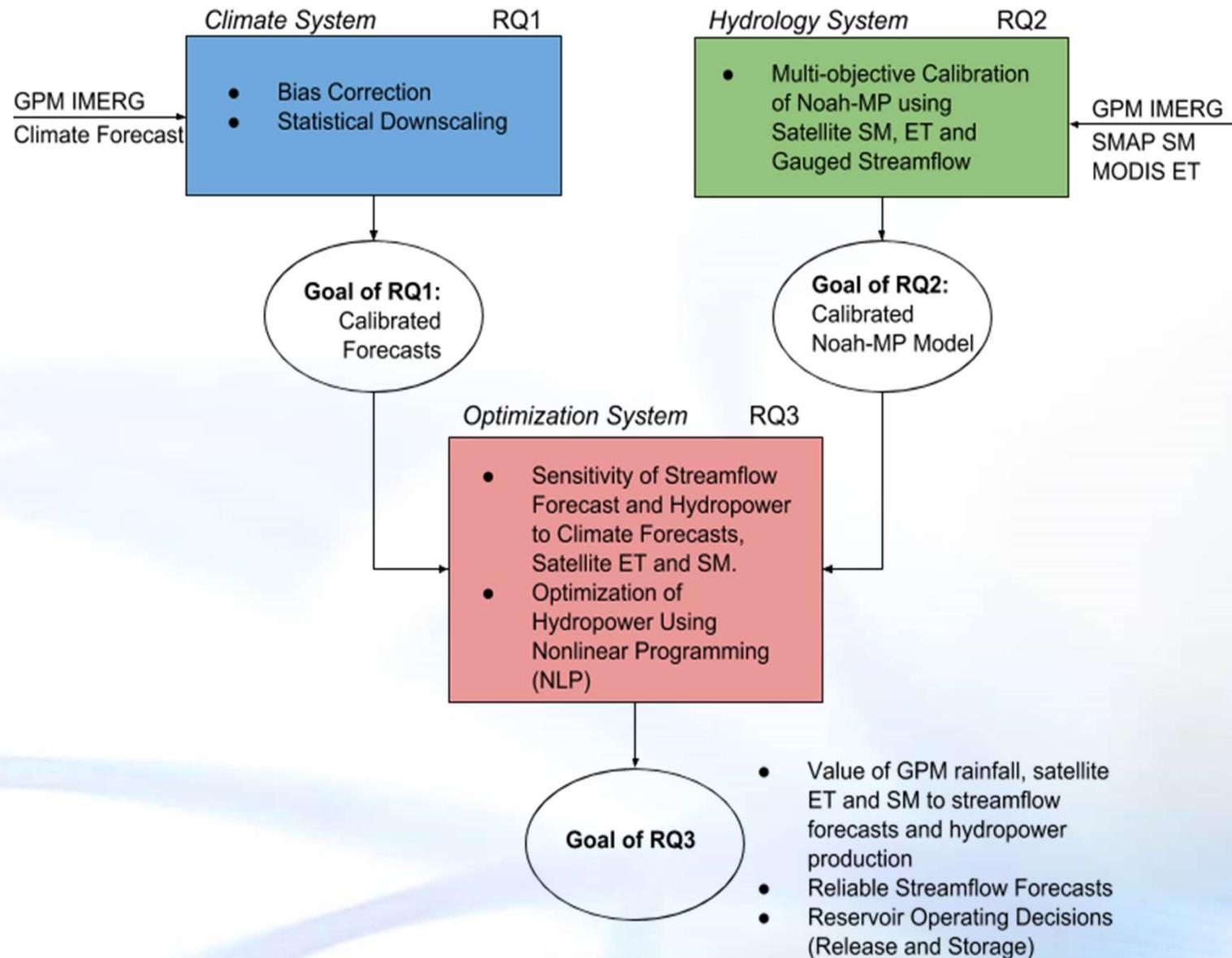
*Gibe III – tallest dam in Africa*

# Thank You



## Backup Slides

# Optimizing Reservoir Operations for Hydropower Production in Africa



# Optimizing Reservoir Operations for Hydropower Production in Africa



## Approach - Long Range or Seasonal Forecasting

### NMME Seasonal Hindcasts and Forecasts

| Acronym | Centre      | Model               | Hindcast period | Ensemble size | Lead times (months) |
|---------|-------------|---------------------|-----------------|---------------|---------------------|
| NCEP    | NOAA-NCEP   | NCEP-CSFv2          | 1982-2010       | 24            | 0.5-9.5             |
| GFDL1   | NOAA-GFDL   | GFDL-CM2.1-aer04    | 1982-2010       | 10            | 0.5-11.5            |
| GFDL2   | NOAA-GFDL   | GFDL-CM2.5-FLOR-A06 | 1982-2010       | 12            | 0.5-11.5            |
| GFDL3   | NOAA-GFDL   | GFDL-CM2.5-FLOR-B01 | 1982-2010       | 12            | 0.5-11.5            |
| NCAR    | NCAR-UM     | COLA-RSMAS-CCSM4    | 1982-2010       | 10            | 0.5-11.5            |
| NASA    | NASA        | NASA-GMAO-062012    | 1981-2010       | 12            | 0.5-8.5             |
| CMC1    | Canadian MC | CMC1-CanCM3         | 1981-2010       | 10            | 0.5-11.5            |
| CMC2    | Canadian MC | CMC2-CanCM4         | 1981-2010       | 10            | 0.5-11.5            |

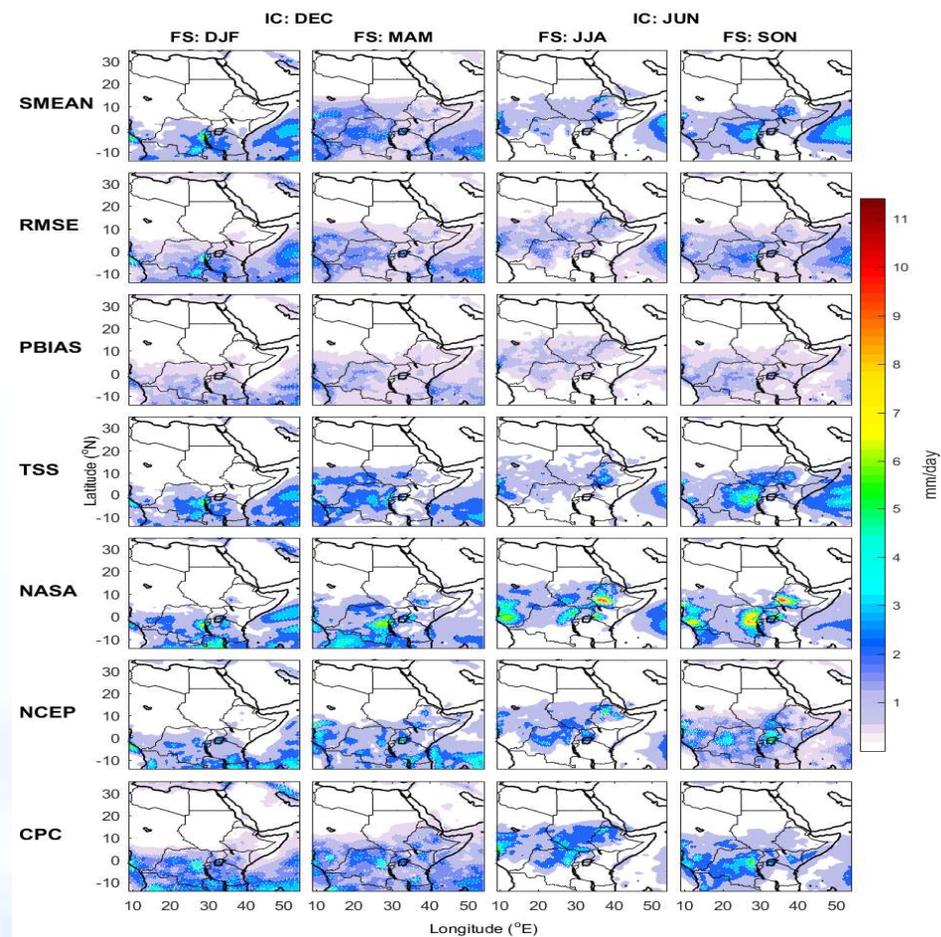
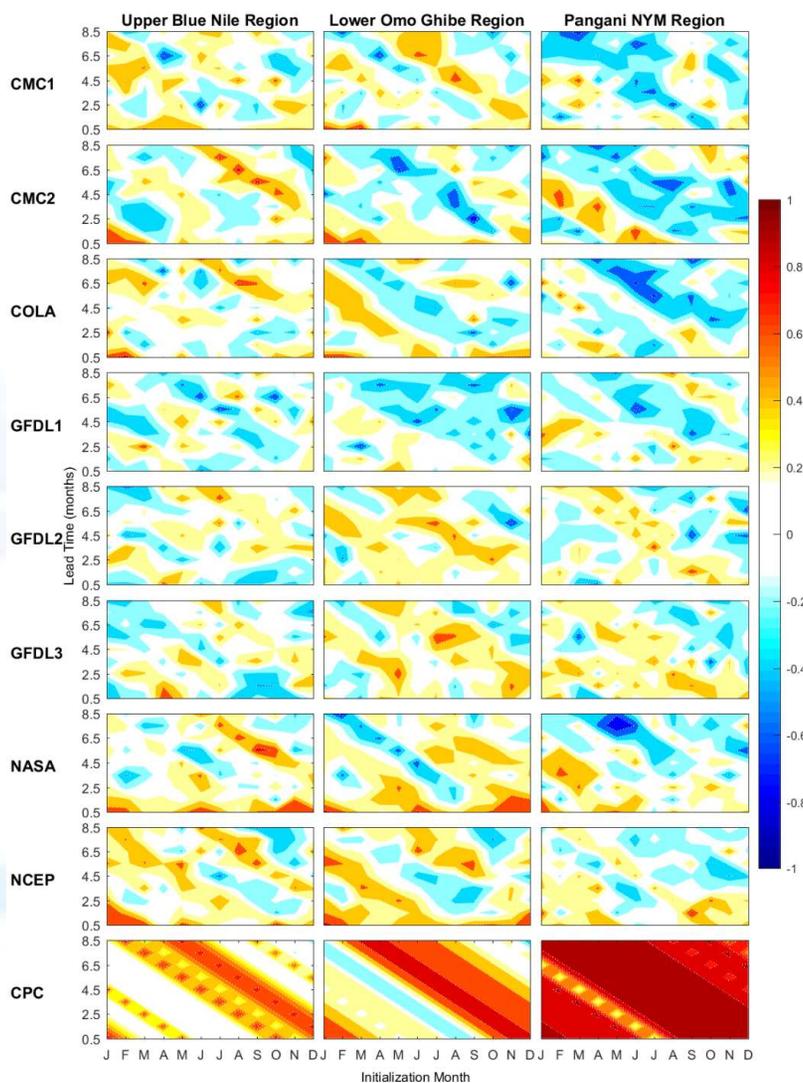
8 NMME models, 12 monthly initializations, and 0.5-8.5 month lead times during 1998-2010 are considered

# Seasonal Forecast



## Regional Summary: Correlation

## Combined Forecast: RMSE

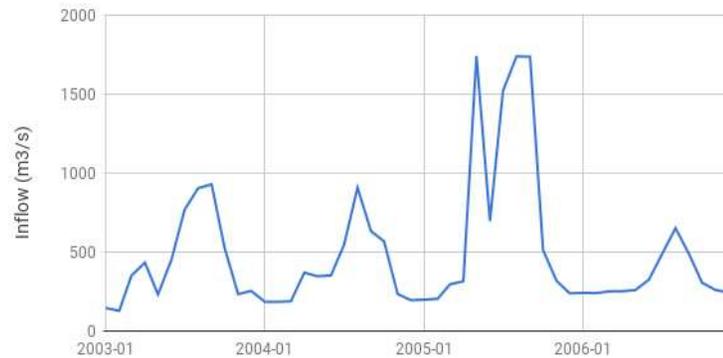


# Optimal Reservoir Operation Solutions

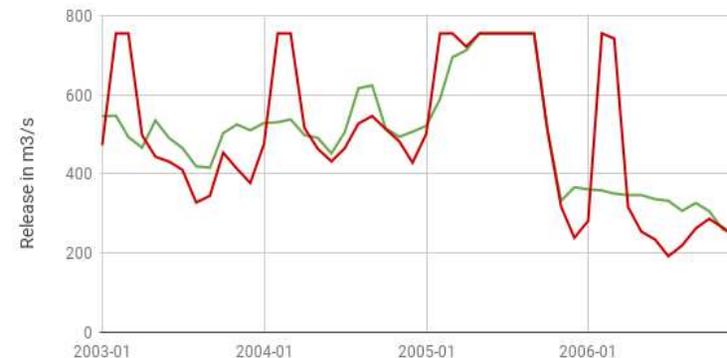


## Preliminary Results – Gibe III

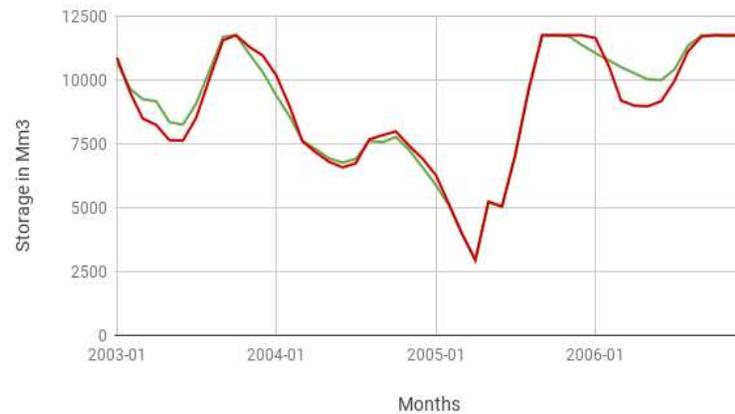
Inflow Into Gibe III



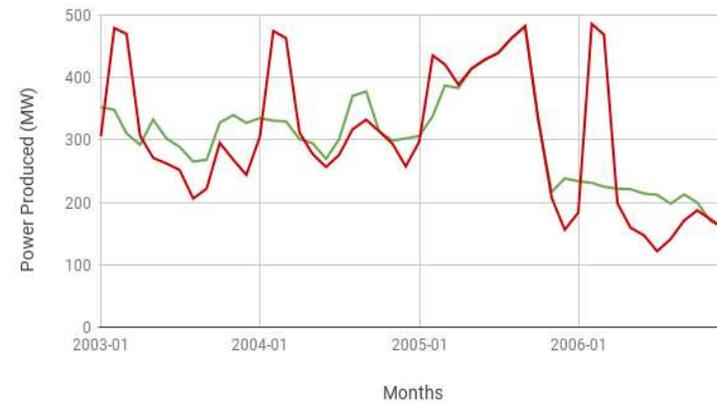
Release From Gibe III



Storage of Gibe III



Power Production in Gibe III



- Optimized for maximum power production
- Optimized for monthly demand