Optimizing Reservoir Operations for Hydropower Production in Africa through the Use of Remote Sensing Data and Seasonal Climate Forecasts

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WATER CHALLENGES

WATER SECURITY

- Unmet demand
- Tightly interrelated with food, energy, and environment
- Global change (climate change, population growth) catalyze the water security challenge

PRESSURE POINTS & OPPORTUNITIES

- Big data (management of various kinds and formats of conventional and unconventional data from different disciplines and sources)
- Advanced analytical capabilities that can generate insights
- Improved Technology and Infrastructure
    - Nontraditional supplies (wastewater recycling)
- Sustainable Planning and Management
    - Water use efficiency

SMART WATER MANAGEMENT SYSTEM

The system has three pillars:

1. Water intelligence system - comprehensive data portal with analytical and data visualization capabilities
2. Innovative water technology and infrastructure
3. Smart solutions for sustainable planning and management

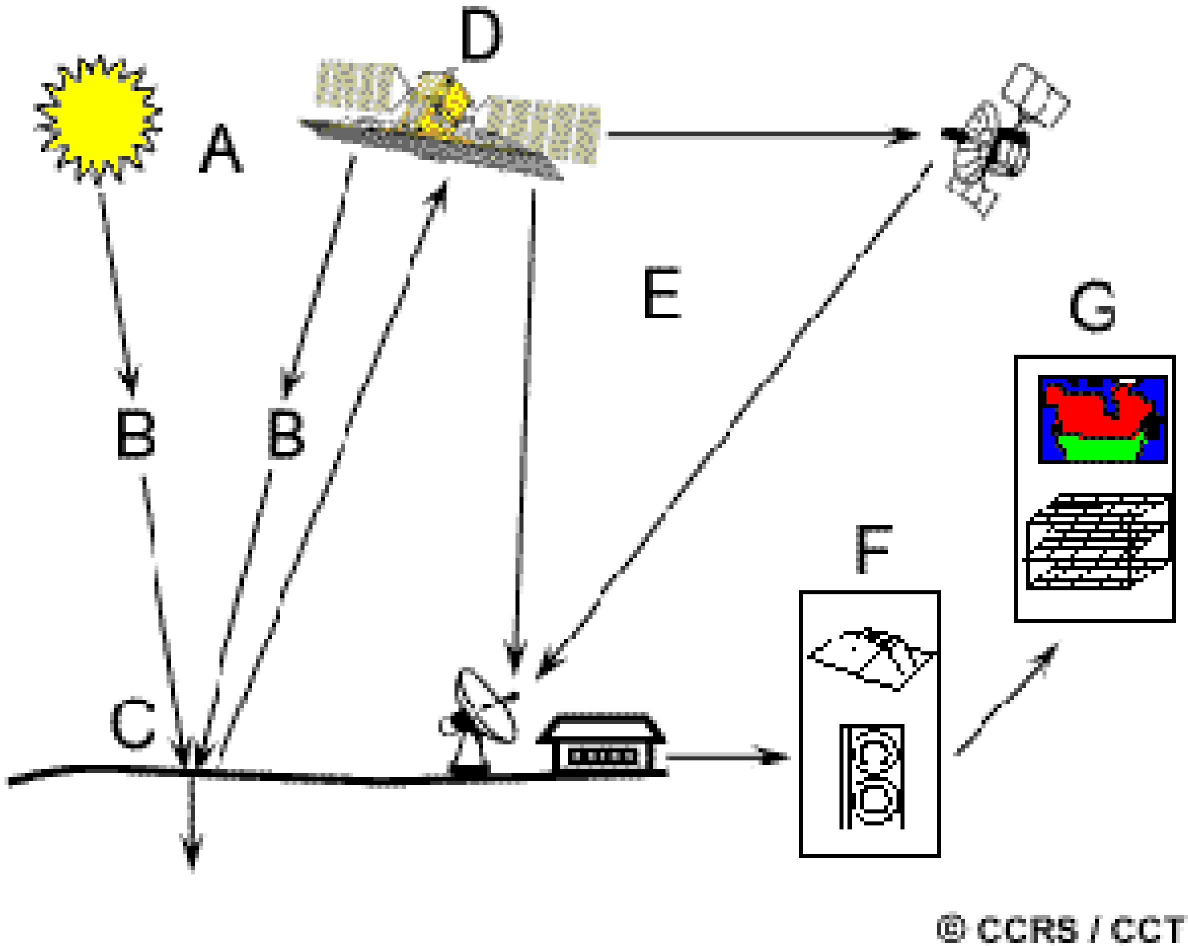
Paradigm Shift:

Satellite Remote Sensing
of Hydrologic Science

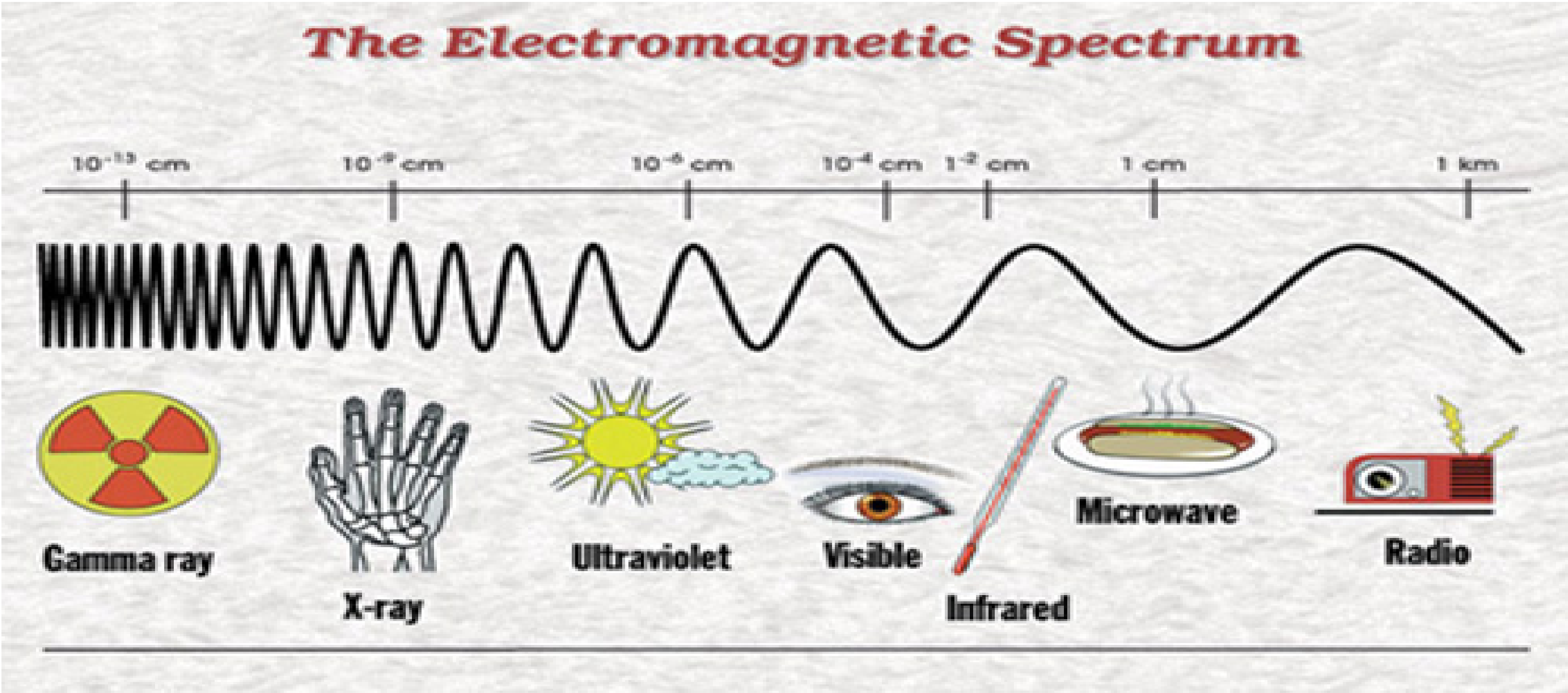
Satellite Remote Sensing of Hydrology

- Fundamentals of Remote Sensing
- Spectrum
- Geostationary vs polar-orbiting satellites
- Active vs passive sensors

Fundamentals



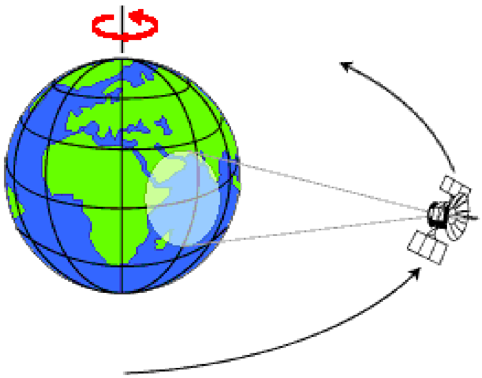
Electromagnetic Spectrum

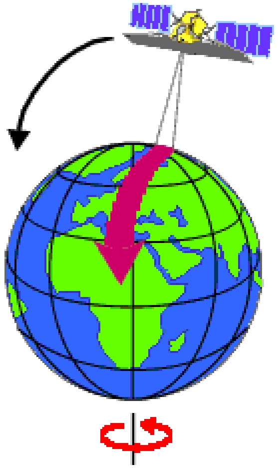


Most Useful Regions:

- Visible and Infrared Remote Sensing
- Thermal Infrared
- Microwave

Geostationary vs Polar-Orbiting





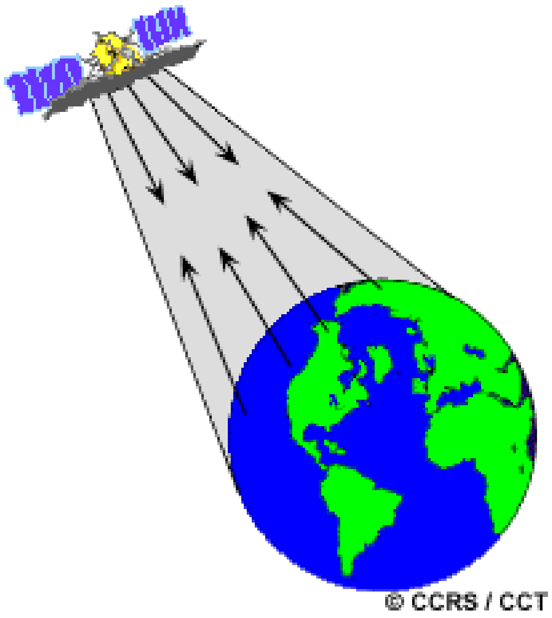
Geostationary

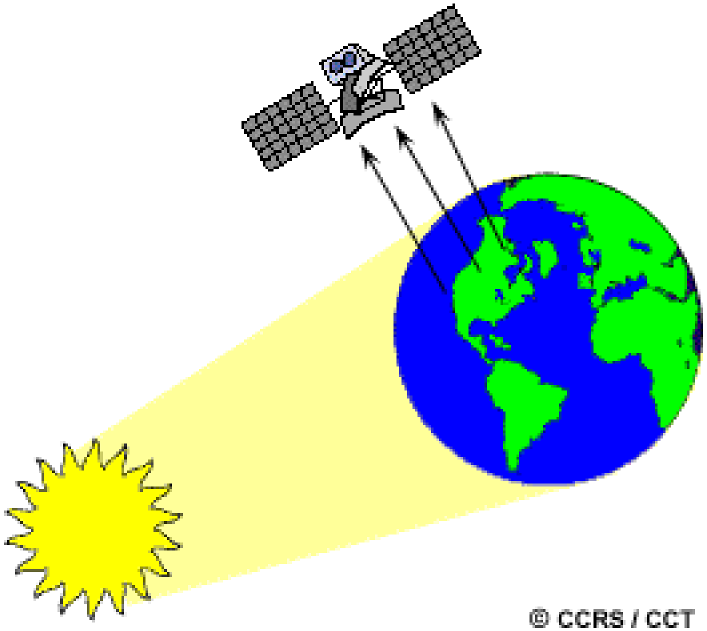
- ~ 40,000 km altitude
- Fixed relative to the Earth

Polar-Orbiting

- < 500 km altitude
- Move North-south

Active vs Passive Sensors



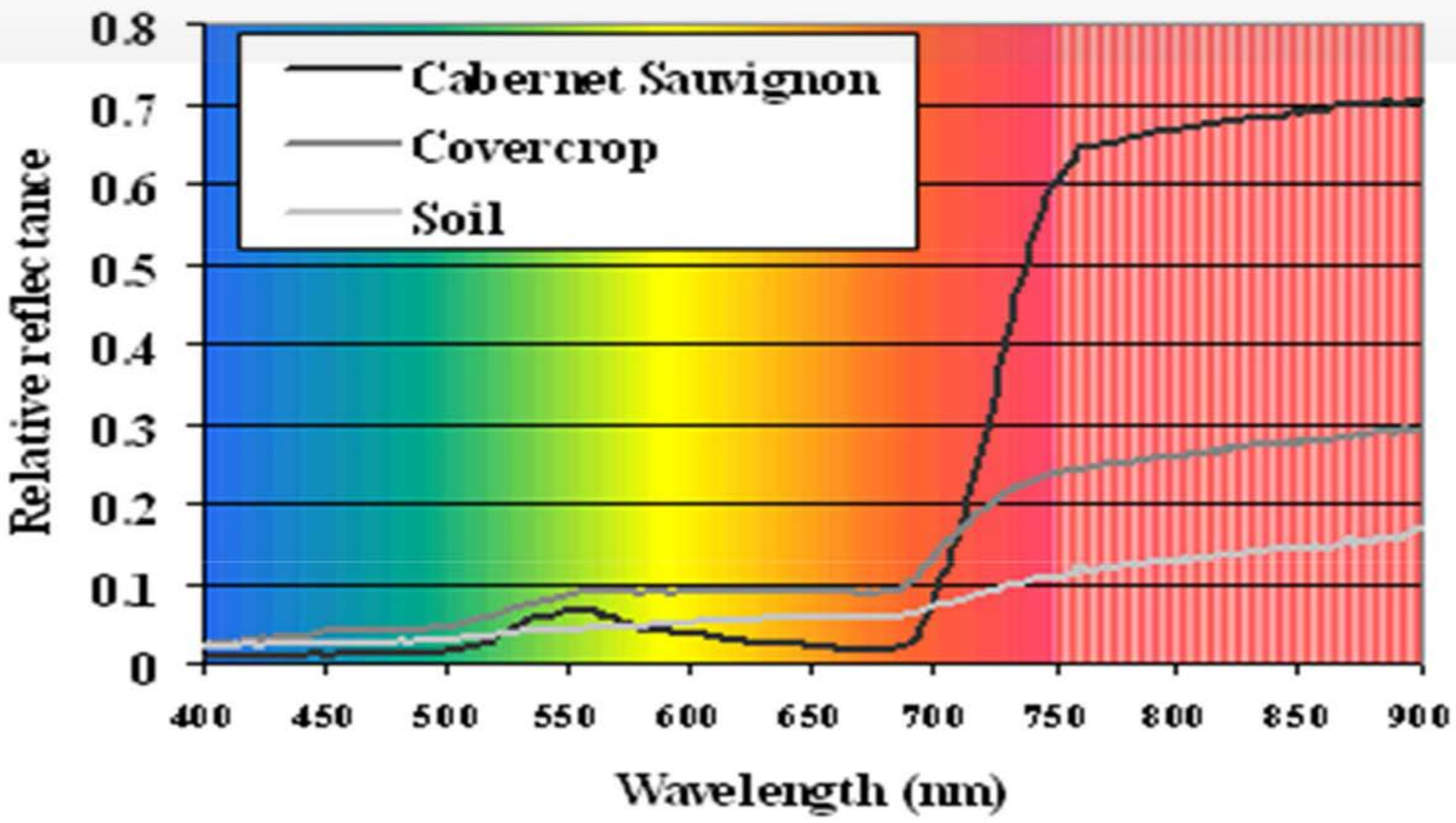


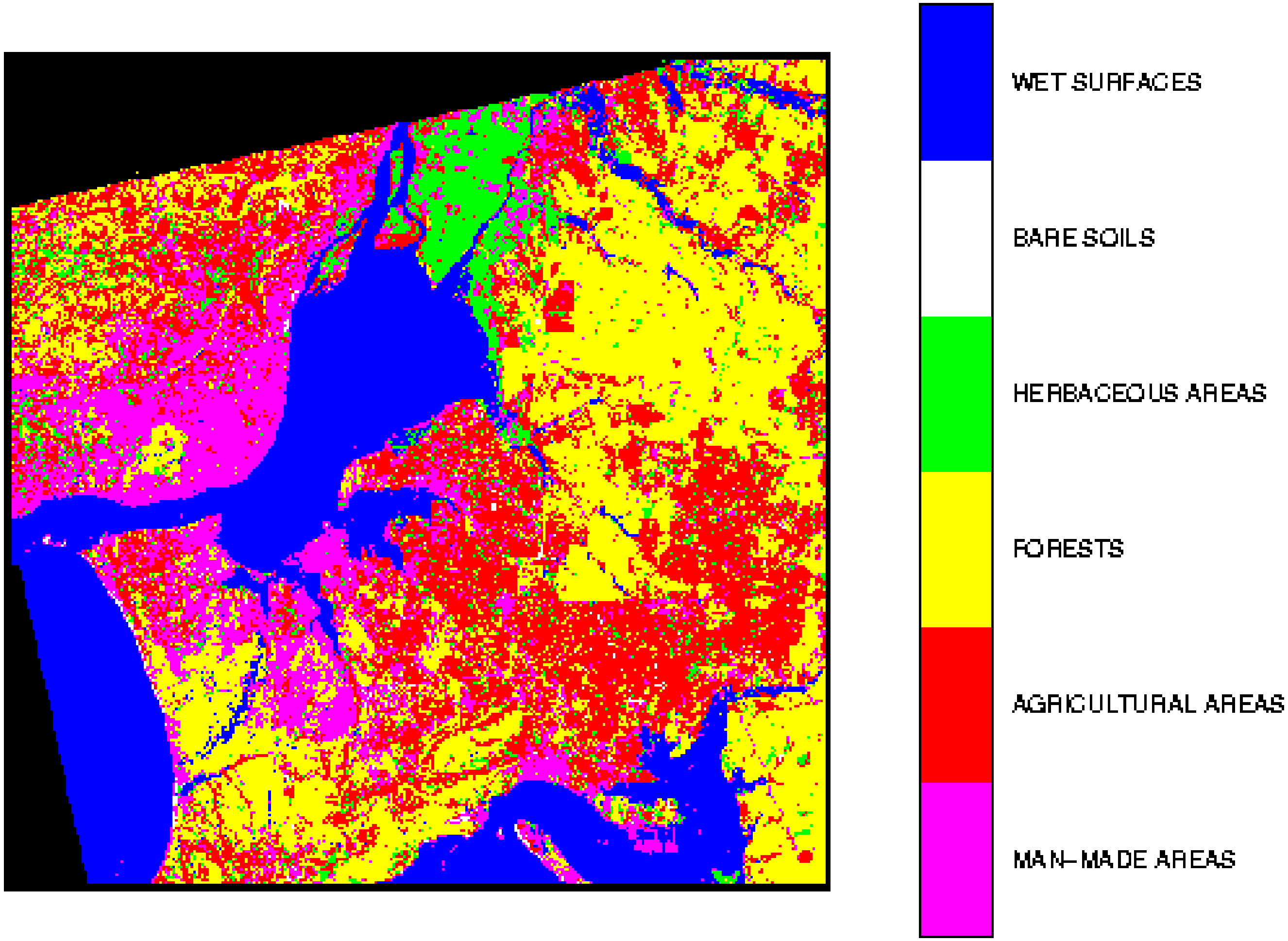
Active Sensors

Passive Sensors

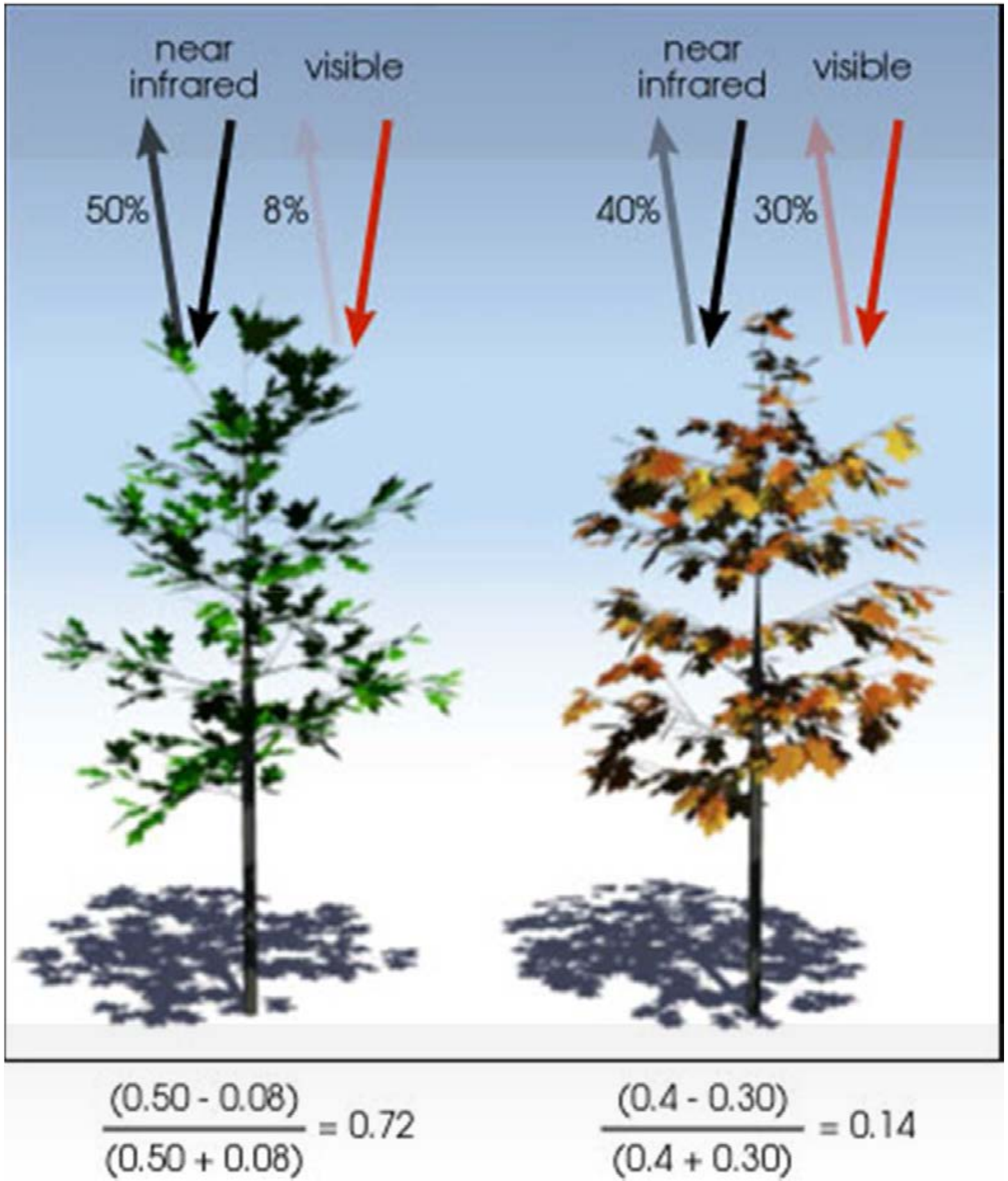
Examples of Applications in Hydrology

Visible and Near Infrared Applications




WET SURFACES
BARE SOILS
HERBACEOUS AREAS
FORESTS
AGRICULTURAL AREAS
MAN-MADE AREAS

Normalized Difference Vegetation Index



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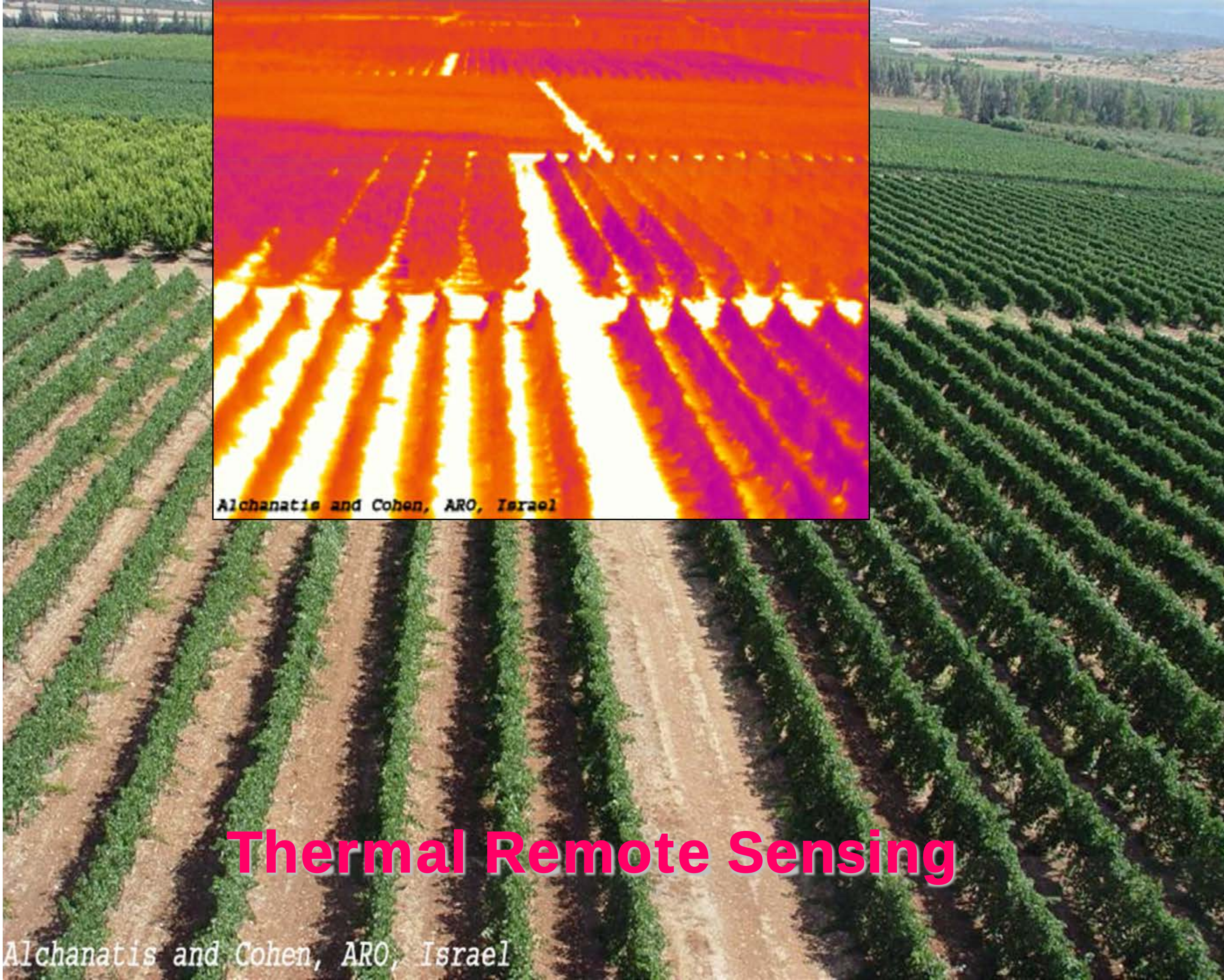
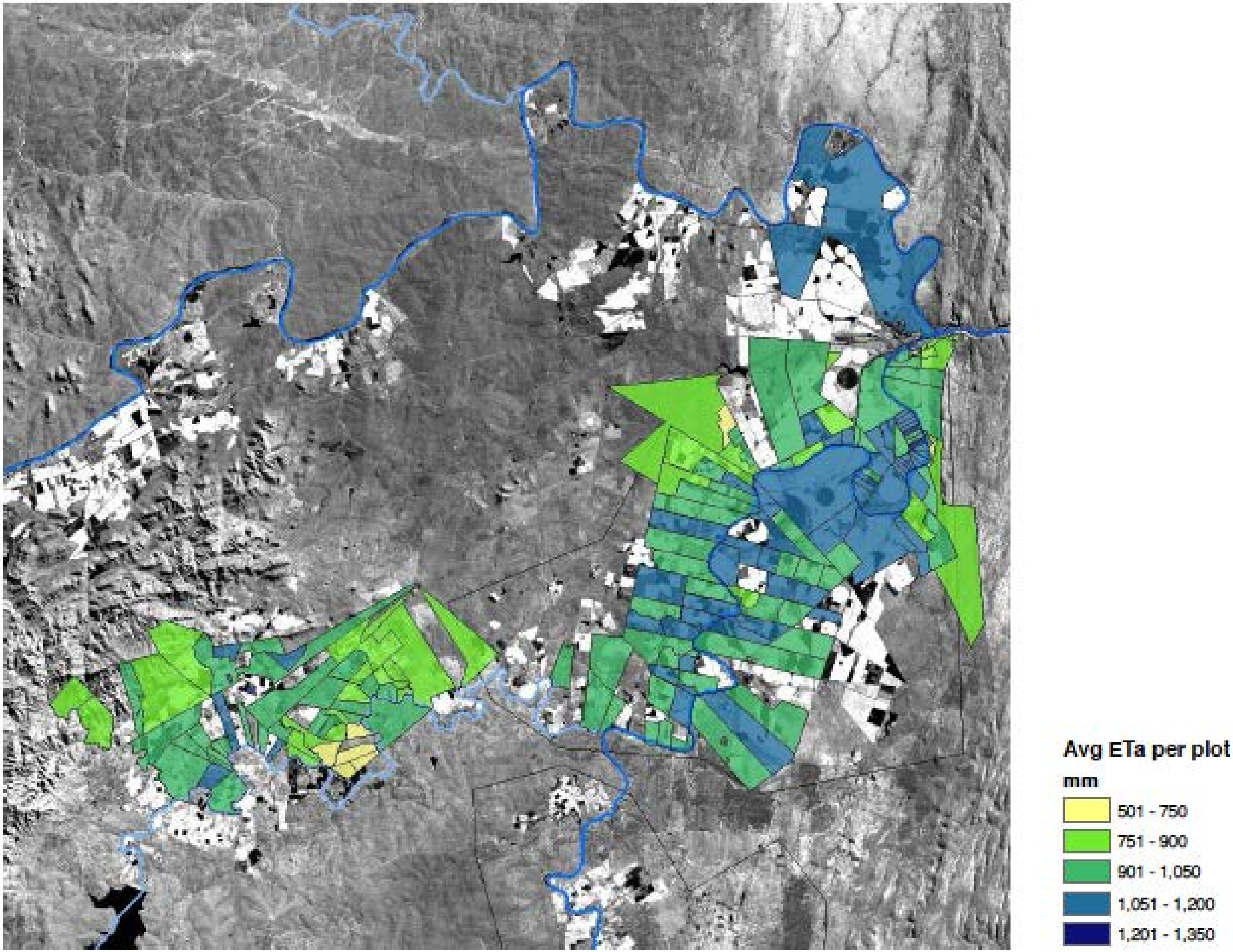


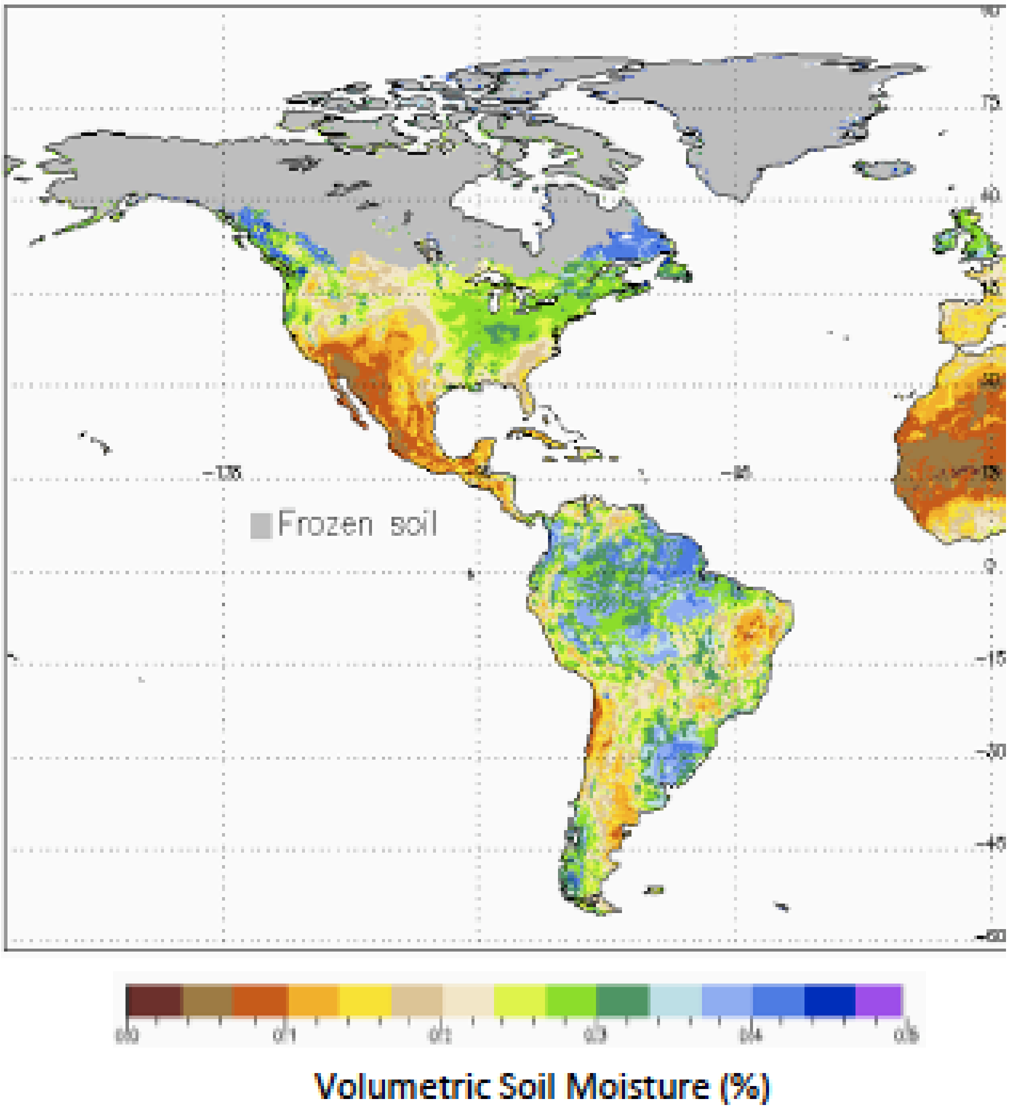
Thermal Remote Sensing

Water Use

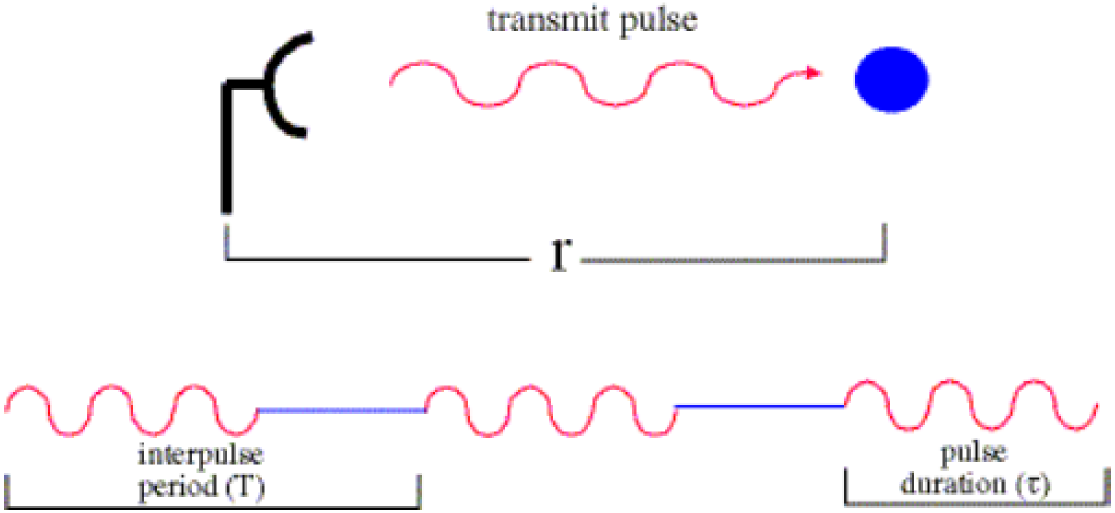


Avg ETa per plot
mm
501 - 750
751 - 900
901 - 1,050
1,051 - 1,200
1,201 - 1,350

Microwave: Soil Moisture Product

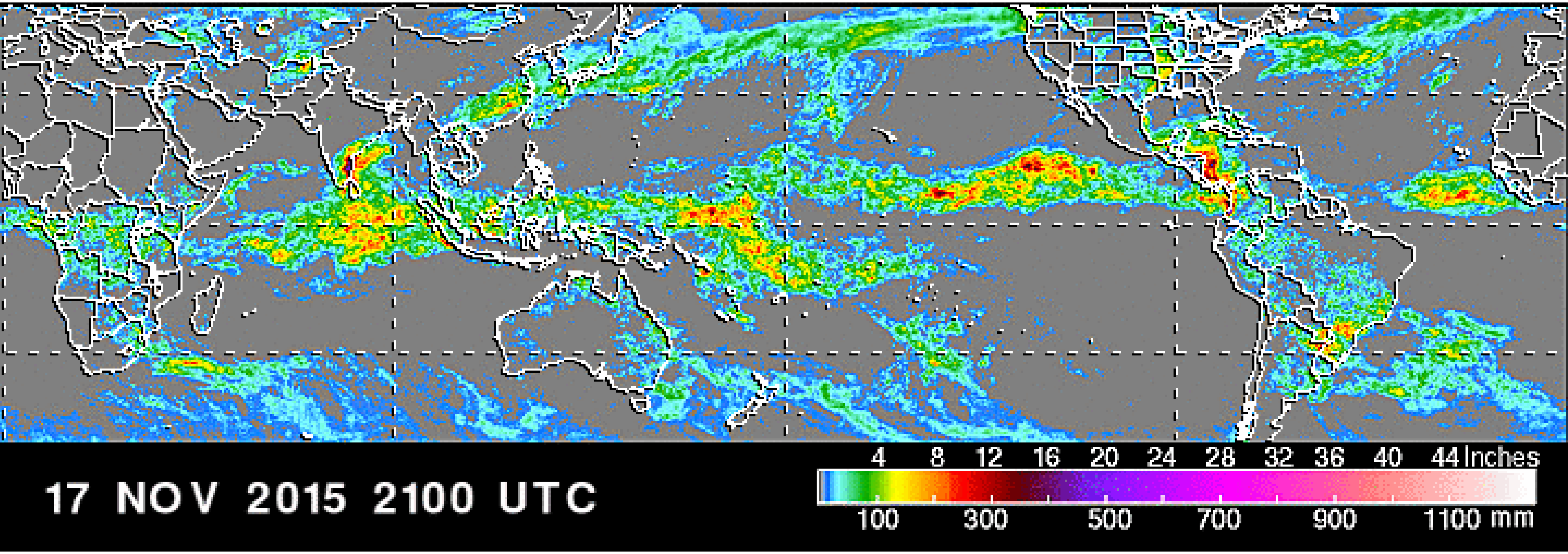


- Assimilate SMAP data into a state-of-the-art land surface model to derive global estimates of root-zone moisture.
- Would use L1C Radiometer, Level 3 High Resolution Radar Soil Moisture, and Level 3 Freeze/Thaw.
- Global output would represent 3 hour intervals at 9 km resolution with 7-day latency.



Weather Radar

Microwave: Precipitation



Societal Benefits of Rainfall Data

Extreme Events and Disasters

- Landslides
- Floods
- Tropical cyclones
- Re-insurance

Water Resources and Agriculture

- Famine Early Warning System
- Drought
- Water Resource management
- Agriculture

Weather, Climate & Land Surface Modeling

- Numerical Weather Prediction
- Land System Modeling
- Global ClimateModeling

Public Health and Ecology

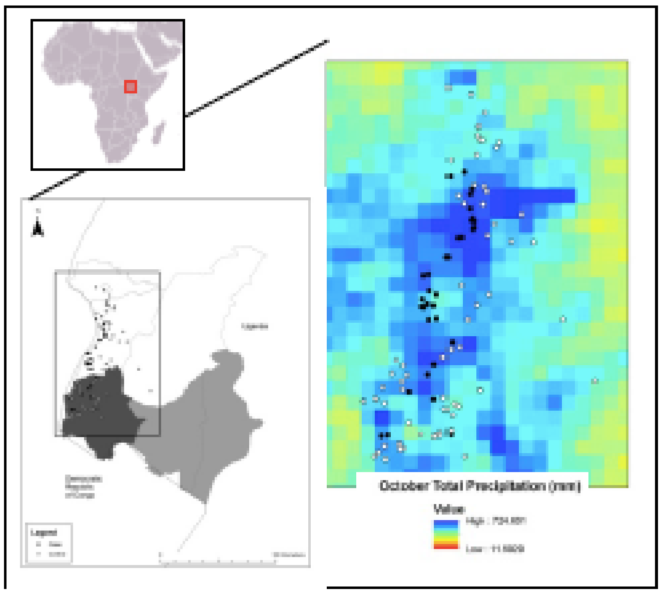
- Disease tracking
- Animal migration
- Food Security

Courtesy: Dalia Kirschbaum, *GPM Applications Science Lead*

TRMM Data Are Used in Disease Tracking

TRMM data has been used to estimate and trace the source areas of vector and river-borne diseases around the world. GPM will enable higher resolution evaluation of these disease source areas.

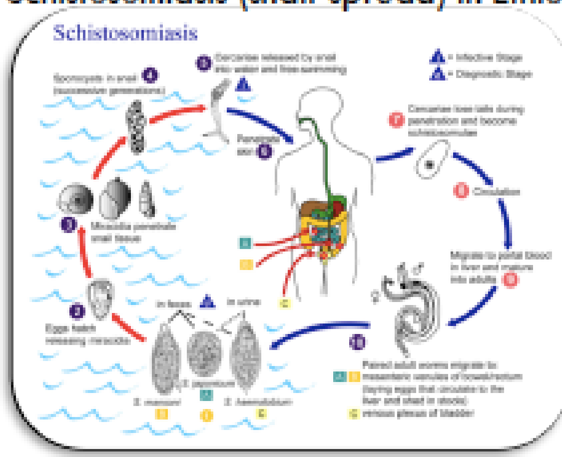
Observed Plague Cases in Uganda



Cases are associated with wetter, cooler regions

Monaghan et al. 2012; MacMillan et al., 2012

Schistosomiasis (snail-spread) in Ethiopia



Courtesy of Bitew and Gebremichael

Studies have found a relationship between TRMM rain and the onset of this disease in local populations due to contact with snails in irrigation channels

Courtesy: Dalia Kirschbaum, *GPM Applications Science Lead*

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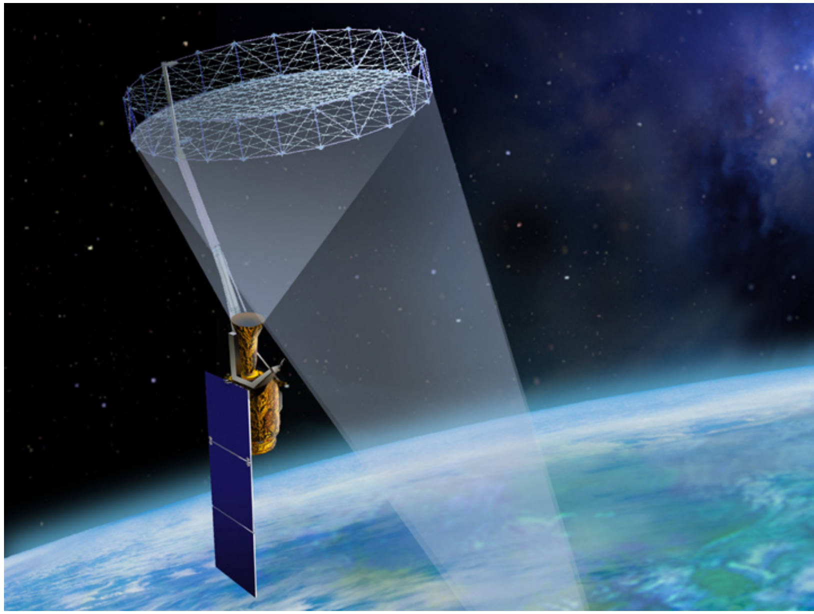
Some New Satellite Missions

GPM

SMAP



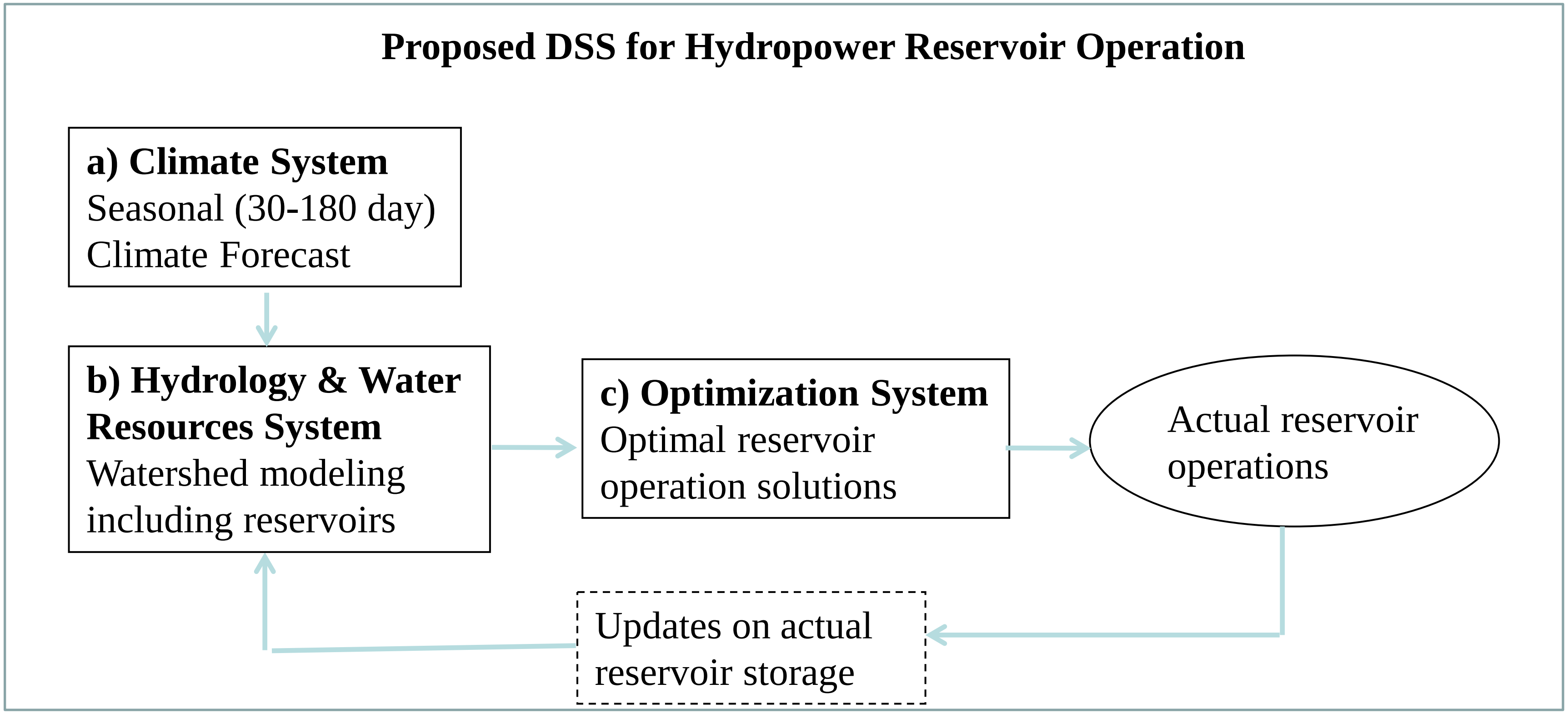
Outlook of Power in Africa

- More than 30 African countries experience power shortages and regular interruptions in service, leading many to rely on very costly leased generating plants as an emergency stopgap.
- Majority of energy comes from hydropower, yet existing hydropower systems in Africa perform far below their optimal potential, in some cases as low as 30% of design capacity.
- New hydropower dam developments are proliferating.
- East Africa Power Pool (EAPP) recently established to enhance the interconnected hydropower system operation and coordination capabilities.
- President Obama's Power Africa Initiative will provide funding and technical support amounting to $26B over the next 10 years adding extra 30GW to the total generated power capacity to the continent.

Objectives

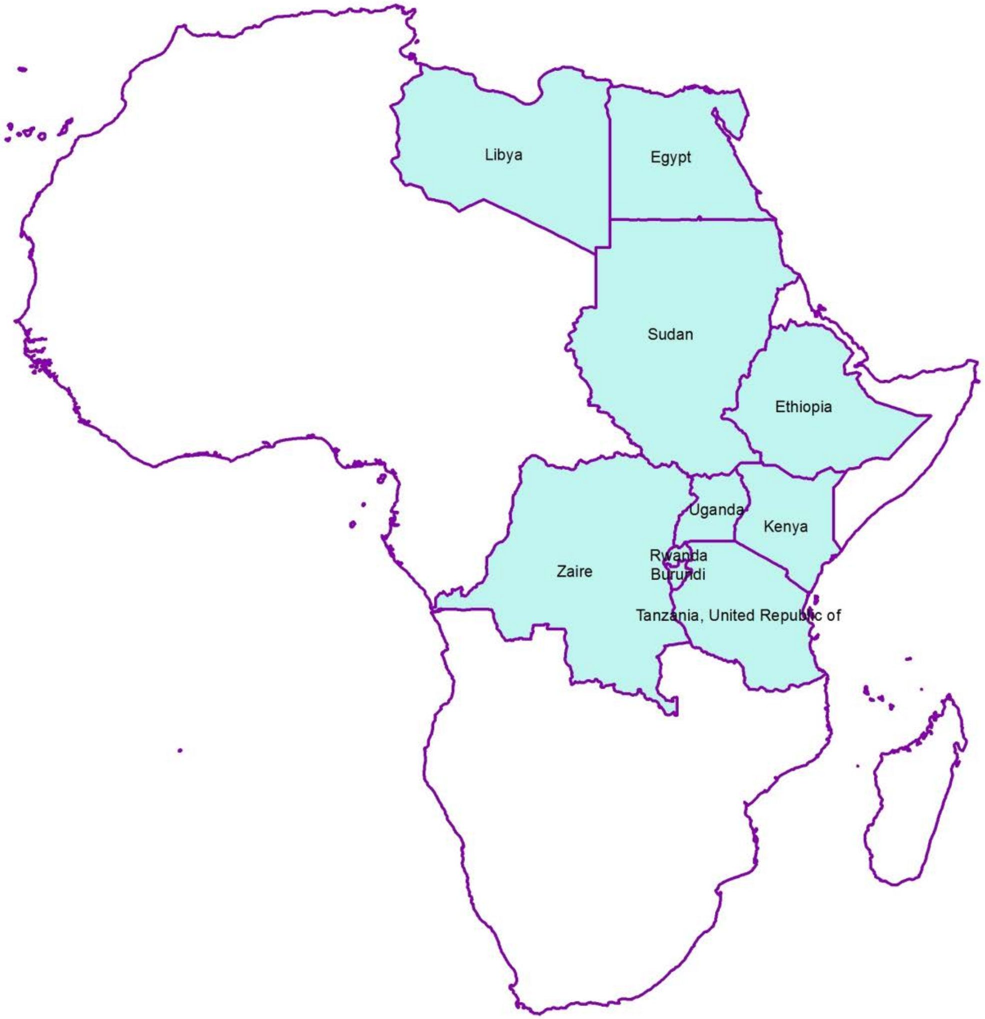
- Utilize remote sensing data and seasonal climate forecasts in a Decision Support System (DSS) to:
  - optimize and achieve reliable seasonal reservoir operations for hydropower production
  - improve performance of hydropower systems in Sub-Saharan Africa

Main Components of DSS



Domain

- East Africa Power Pool (10 countries and 3 will join soon)
- Blue Nile and Omo-Ghibe basins in Ethiopia
- Pangani basin in Tanzania (Nyumba ya Mungu reservoir)



Approach

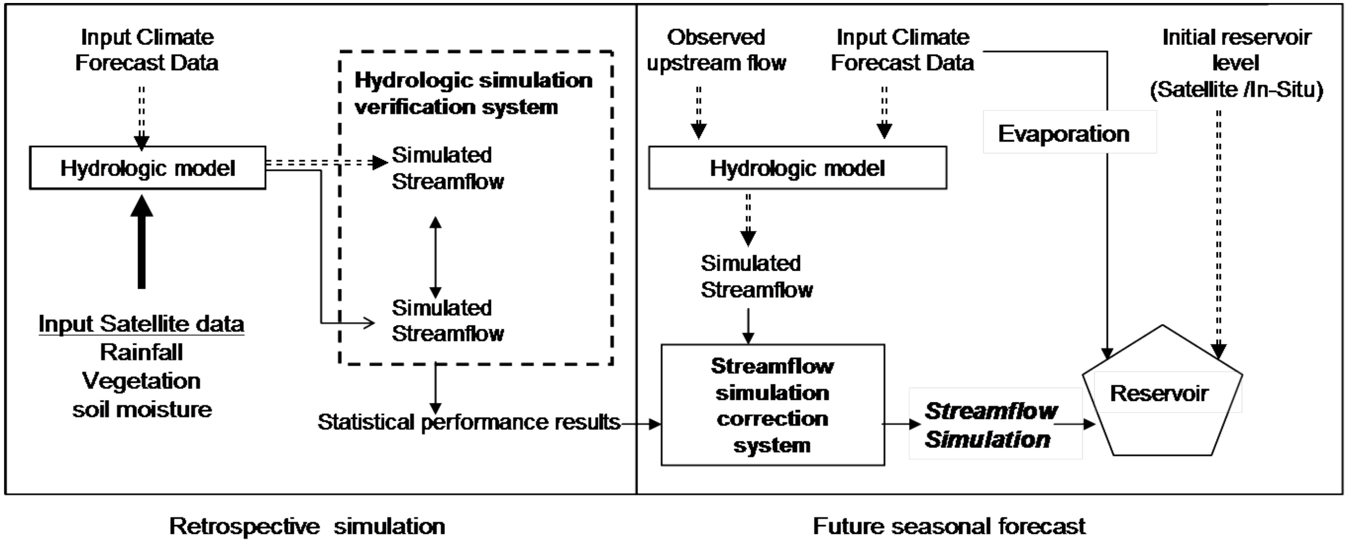
Area 1: Climate System

- Statistical and dynamical forecasts to improve Seasonal climate forecasting
- Tailoring of seasonal climate forecasts for seasonal river flow applications

Approach

Area 2: Hydrology and Water Resource System

- Aimed at using the available satellite remote sensing observations (rainfall, soil moisture, evapotranspiration, vegetation index and Leaf Area Index) in conjunction with the seasonal climate forecasts to simulate seasonal streamflow flowing into the reservoir.



Approach

Area 3: Optimization System

- Nonlinear programming formulation for hydropower production
- Objective function is minimizing loss of the stored potential energy. The constraint set includes energy demand, turbine capacity, flow continuity, maximum storage variation, minimum and maximum storages, minimum and maximum power releases, and bounds on non-power release.

Approach

Area 4: DSS Software

- DSS software that :
  - automates the entire process (i.e. downloads data from the ftp sites, runs the models, applies statistical models) to produce results
  - provides options to simulate the system with special operation rules defined by the user
  - has a very powerful visualization tool
  - a Graphical User Interface (GUI) to manipulate the input data, run outputs, and generate maps, graphs and tables.

AREA 1: CLIMATE SYSTEM: Seasonal Forecasts

Two major initiatives and sources:

1. North America Multi-Model Ensemble (NMME) seasonal forecast (with global product)
   - Phase-1: Seasonal-to-Interannual Prediction
   - Phase-2: Intraseasonal Prediction

2. International Multi-Model Ensemble (IMME) seasonal forecast
   - European Seasonal-to-Interannual Prediction (EuroSIP) in collaboration with NCEP

NMME Seasonal Hindcasts and Forecasts

Centre	Model	Hindcast period	Ensemble size	Lead times (months)
NOAA-NCEP	NCEP-CSFv2	1982-2010	24	0.5-9.5
NOAA-GFDL	GFDL-CM2.1	1982-2010	10	0.5-11.5
NOAA-GFDL	GFDL-CM2.1-aer04	1982-2010	10	0.5-11.5
NOAA-GFDL	GFDL-CM2.5-FLOR-A06	1982-2010	12	0.5-11.5
NOAA-GFDL	GFDL-CM2.5-FLOR-B01	1982-2010	12	0.5-11.5
NCAR-UM	COLA-RSMAS-CCSM3	1982-2010	6	0.5-11.5
NCAR-UM	COLA-RSMAS-CCSM4	1982-2010	10	0.5-11.5
NASA	NASA-GMAO	1981-2010	10	0.5-8.5
NASA	NASA-GMAO-062012	1981-2010	12	0.5-8.5
Canadian MC	CMC1-CanCM3	1981-2010	10	0.5-11.5
Canadian MC	CMC2-CanCM4	1981-2010	10	0.5-11.5

Seasonal Analysis Questions

- What are the accuracies and skills of different forecasts in the study region?
  - What are the weights of different forecasts in the multi-model ensemble forecast estimation for the region?
  - What are effective error correction methods in relation to the satellite products?
  - Satellite versus forecast products?

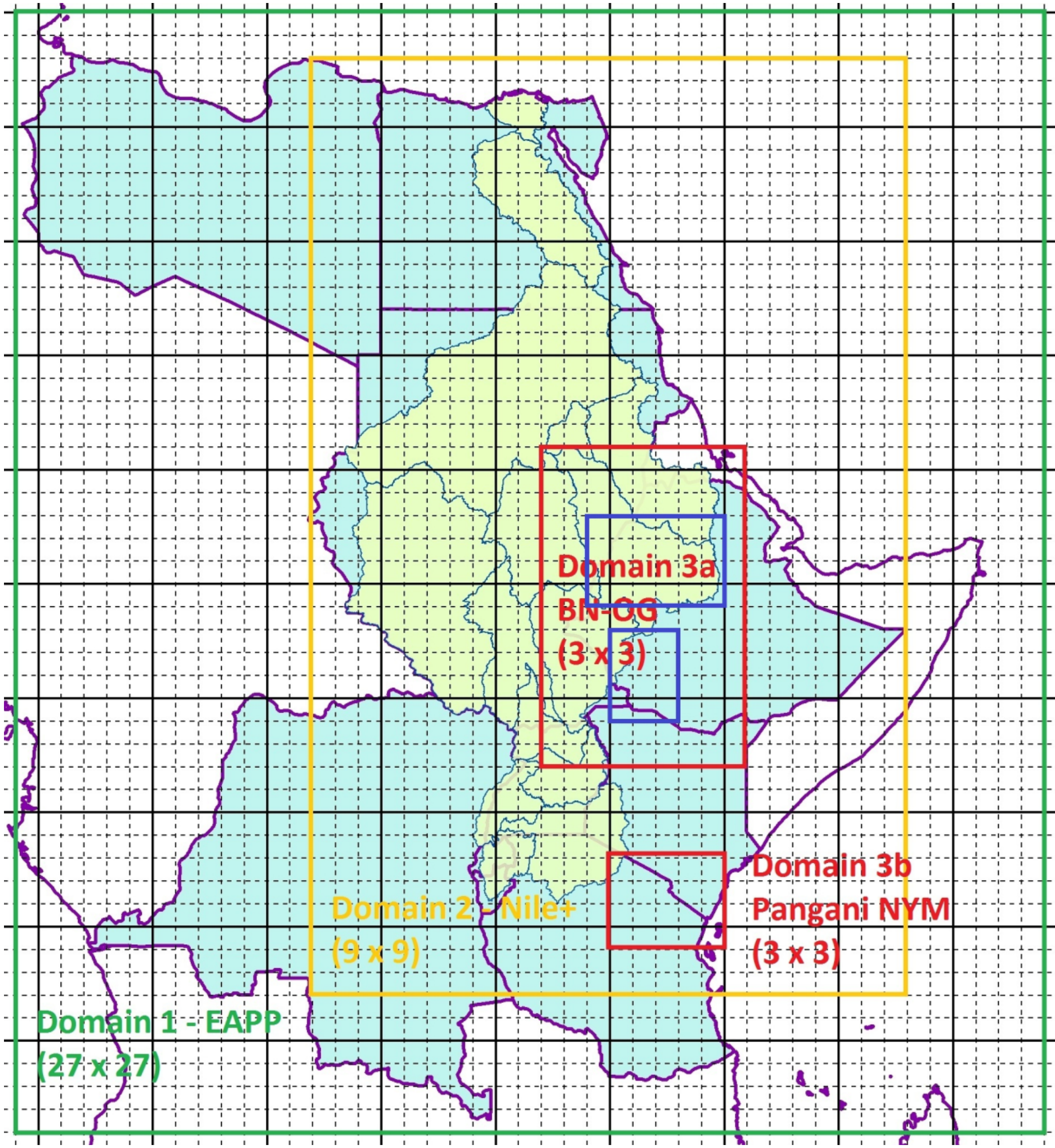
- Does the spatial resolution of the NMME forecasts sufficient enough for the intended DSS applications?
  - What are the best downscaling options?

Comparison – Forecast Validation

- Validation datasets:
  - TRMM merged rainfall (***TRMM-3B43v7***)
  - CPC Unified rain gauge & CMAP (***CPC-CMAP-UGD***)
  - GHCN and CAMS temperature (***GHCN-CAMS***)
  - Experimental networks of rain gauges

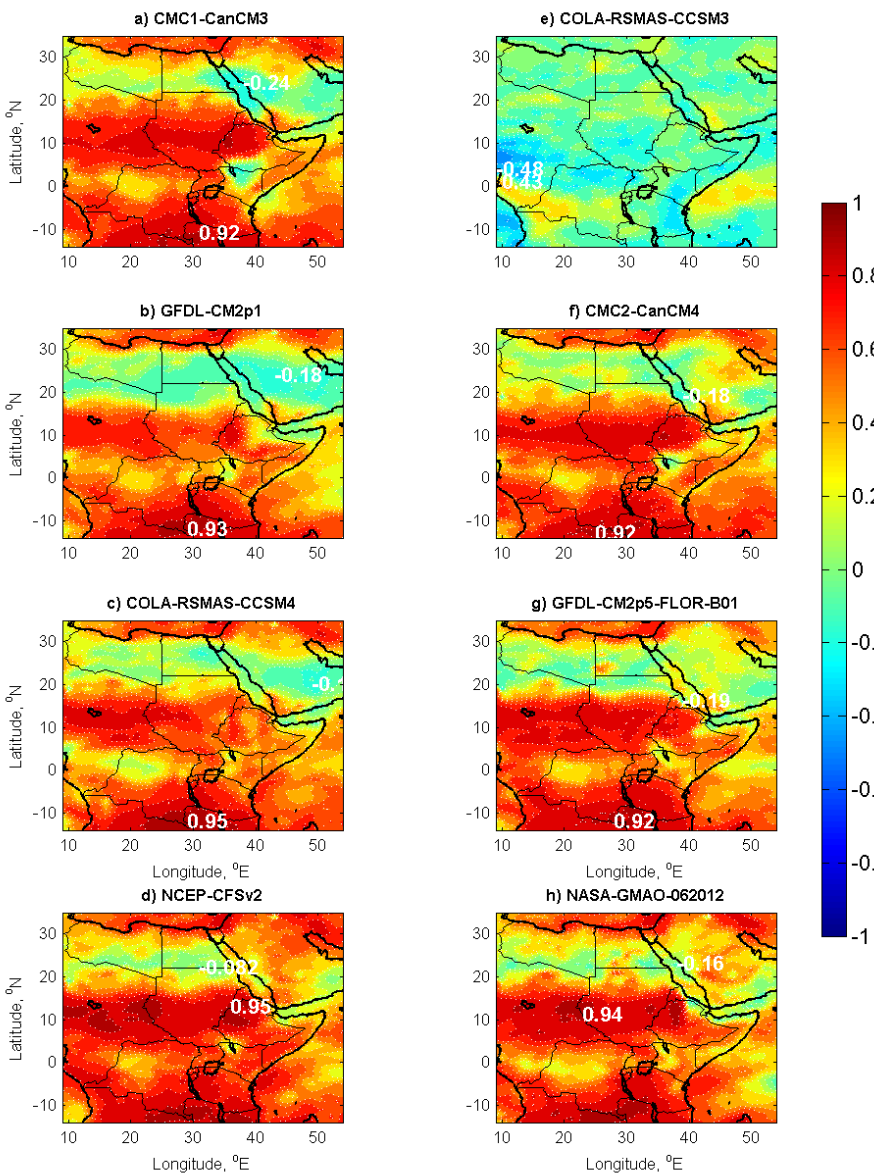
Validation Domains

- Blue Nile – Omo Ghibe (BNOG) region in Ethiopia
- Pangani NYM (PNYM) reservoirs in Tanzania
- Upper Blue Nile Basin (UBNB) region
- Lower Omo Ghibe Basin (LOGB) region

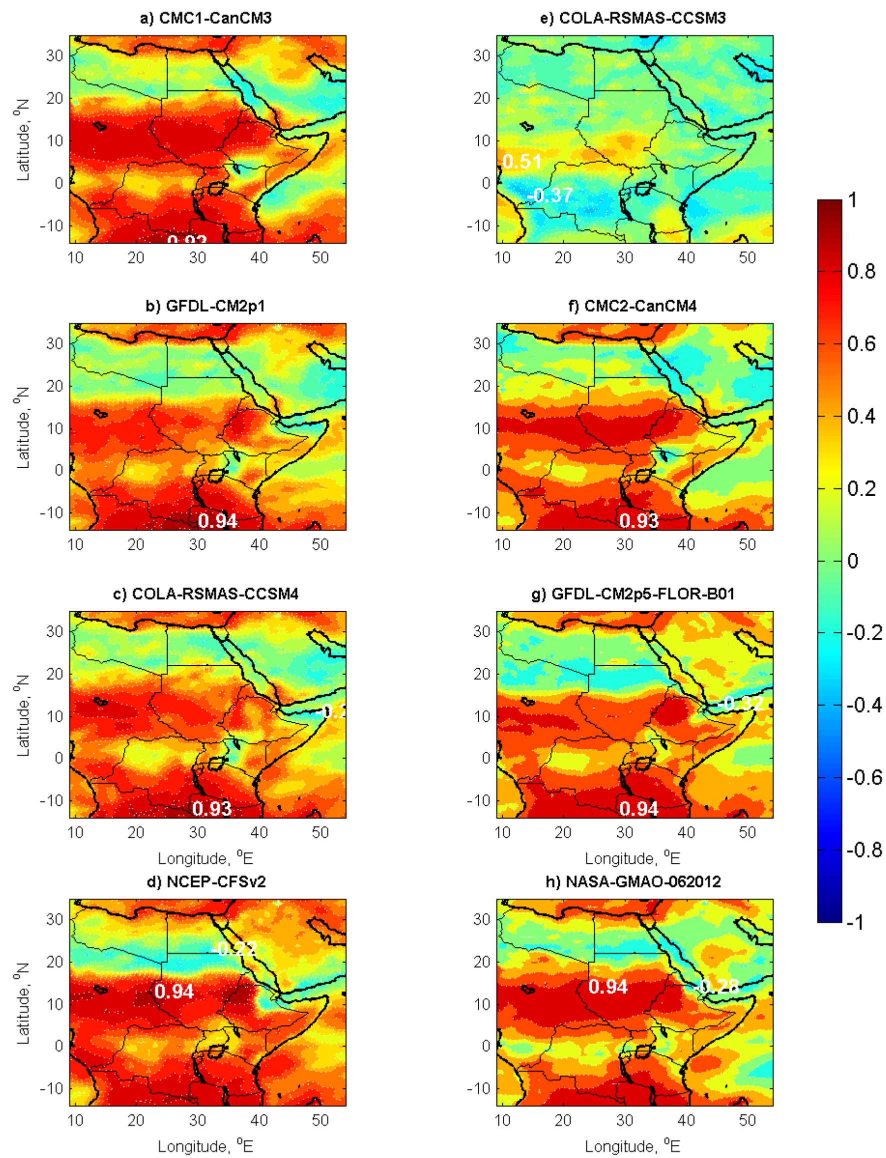


Correlation Coefficient with TRMM-3B43v7 for:

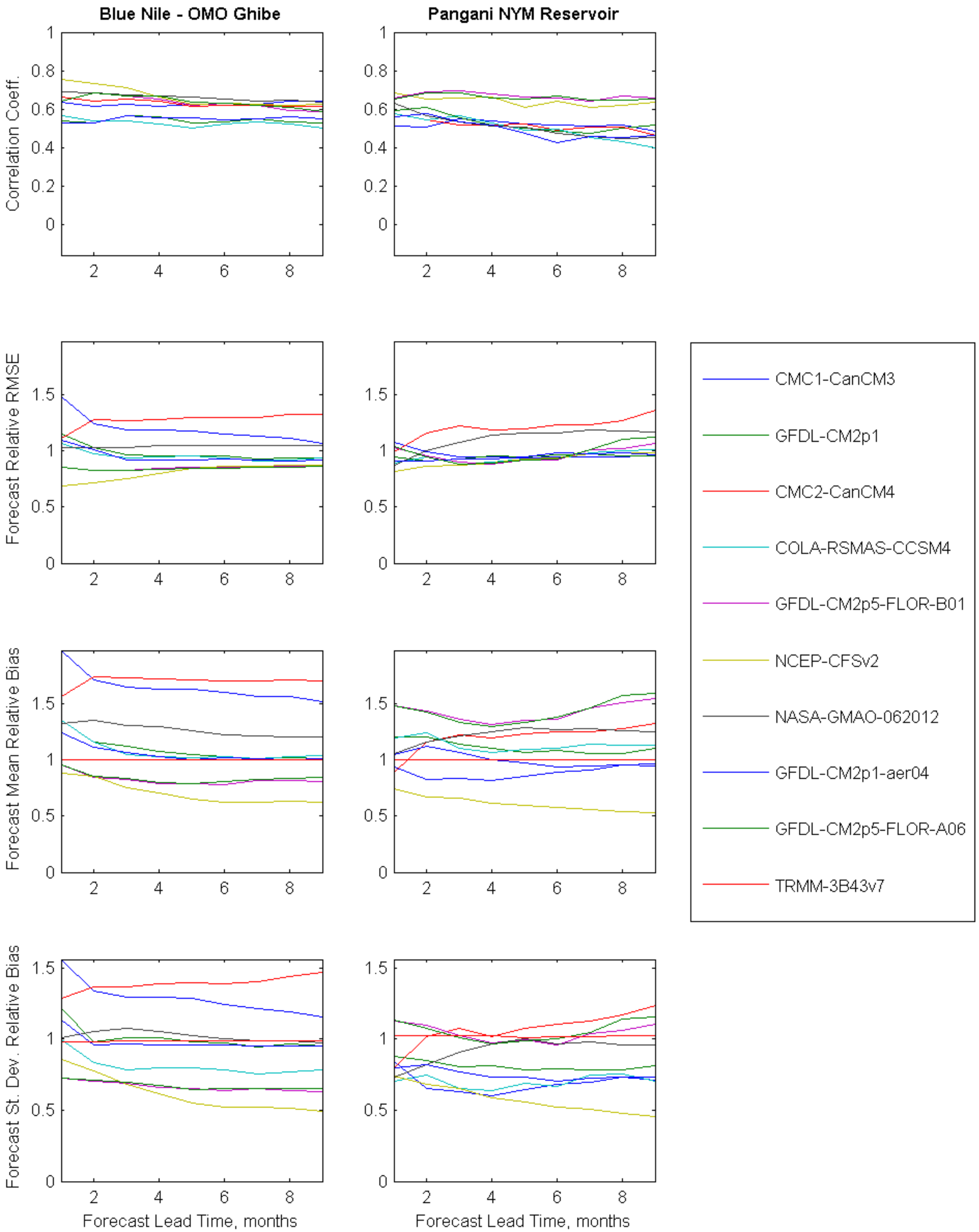
1-month lead



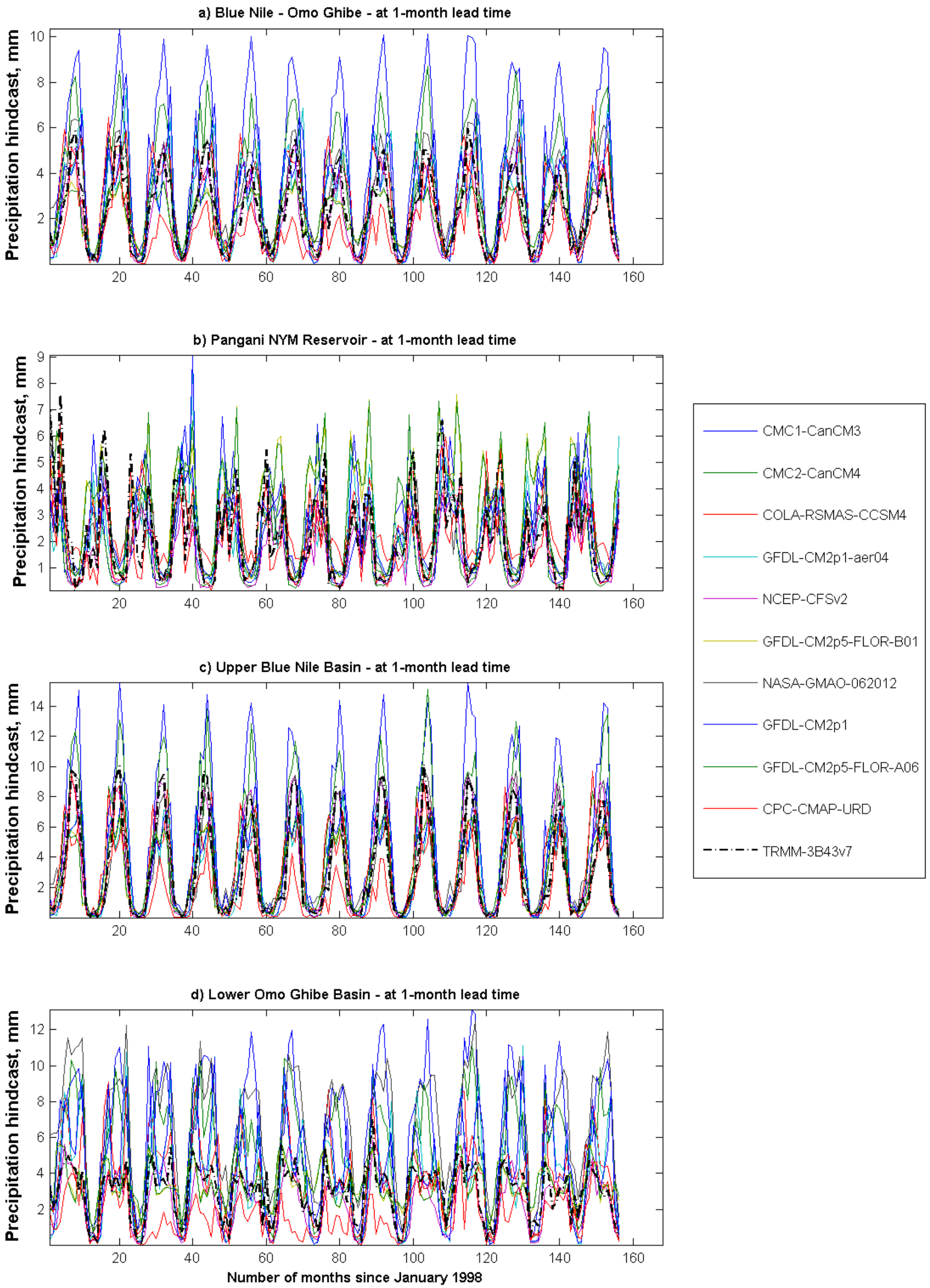
6-month lead

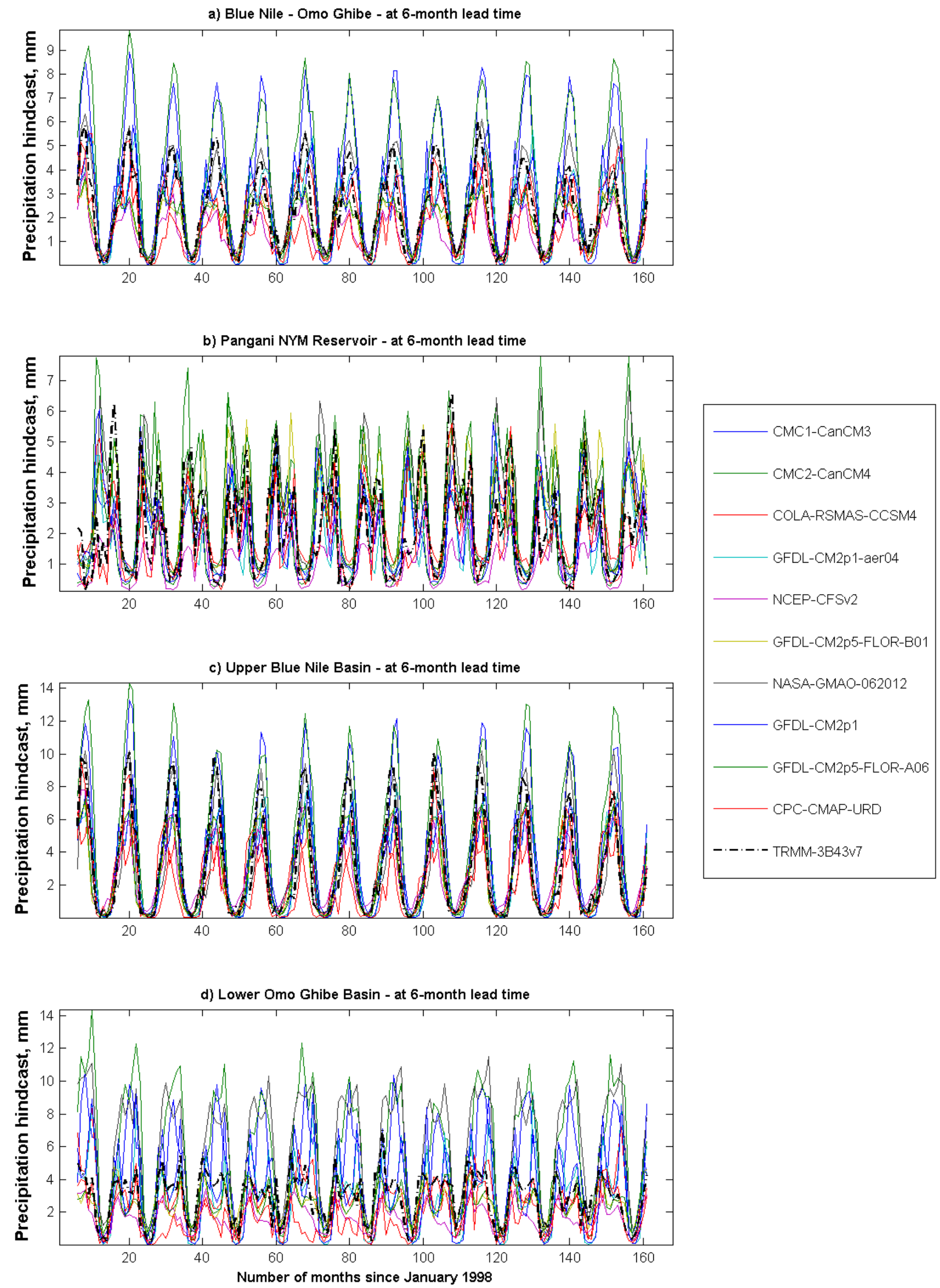


Performance of the Seasonal Forecast Models for the case study domains

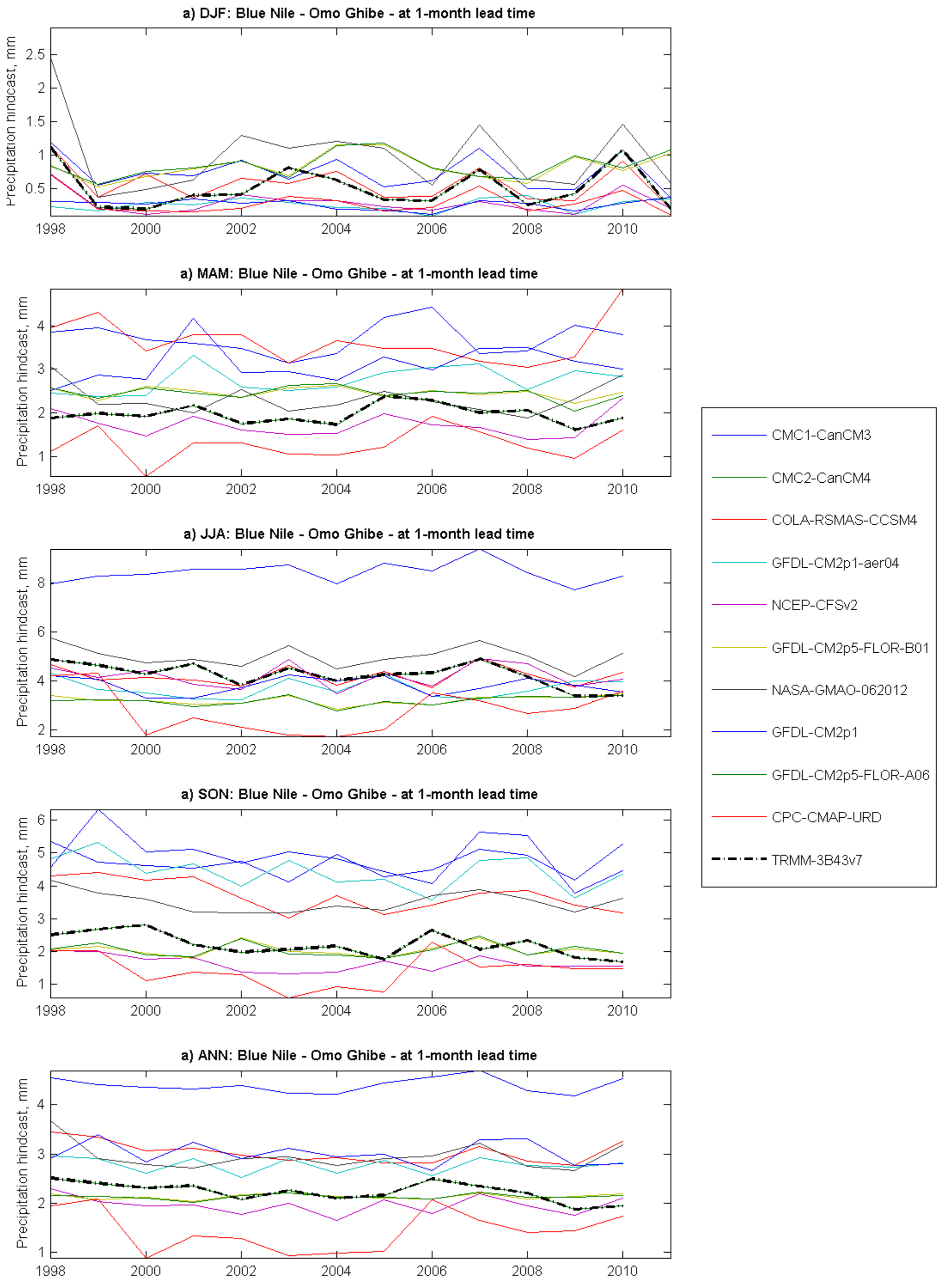


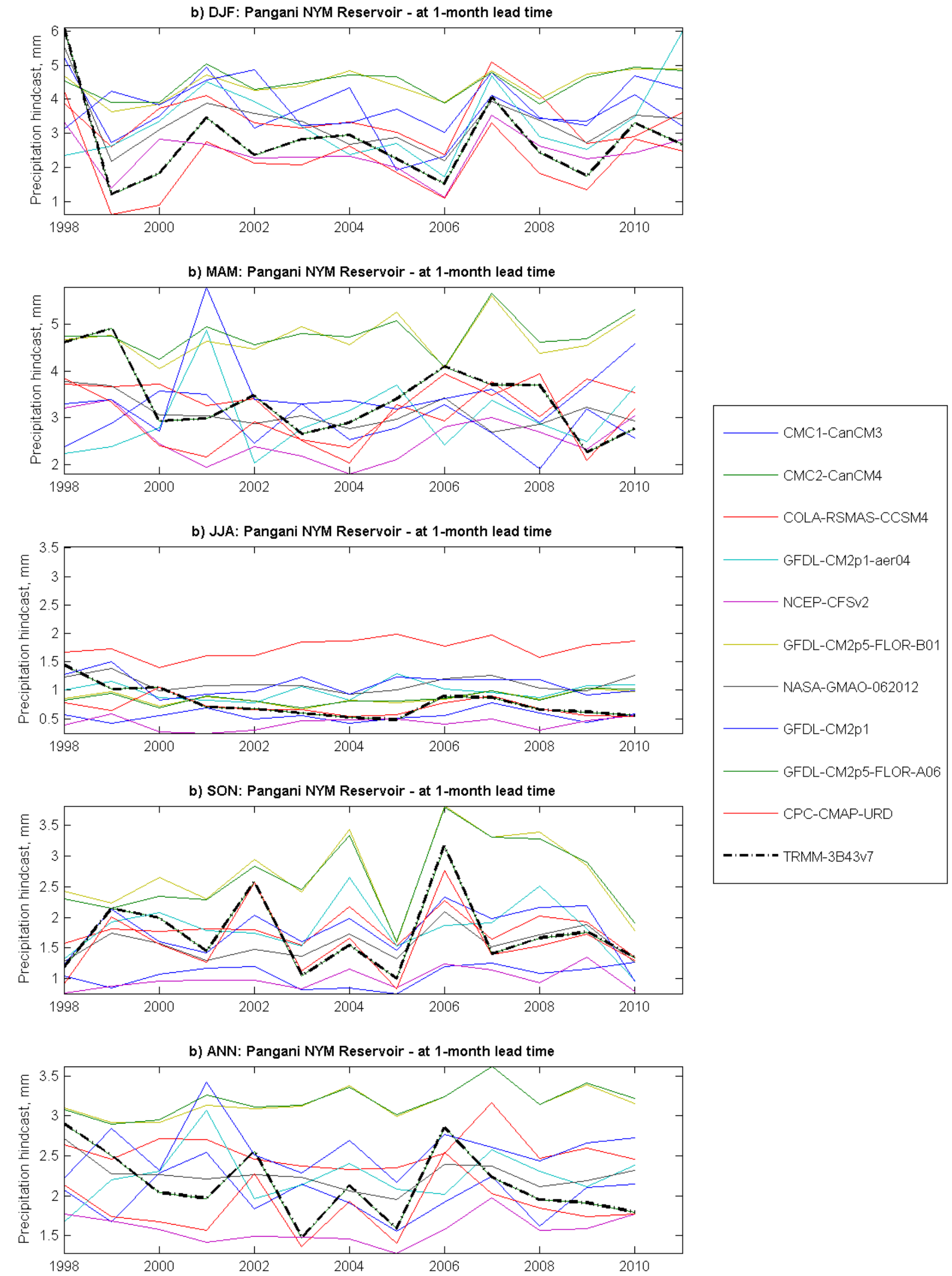
Monthly NMME forecasts and RS estimates:



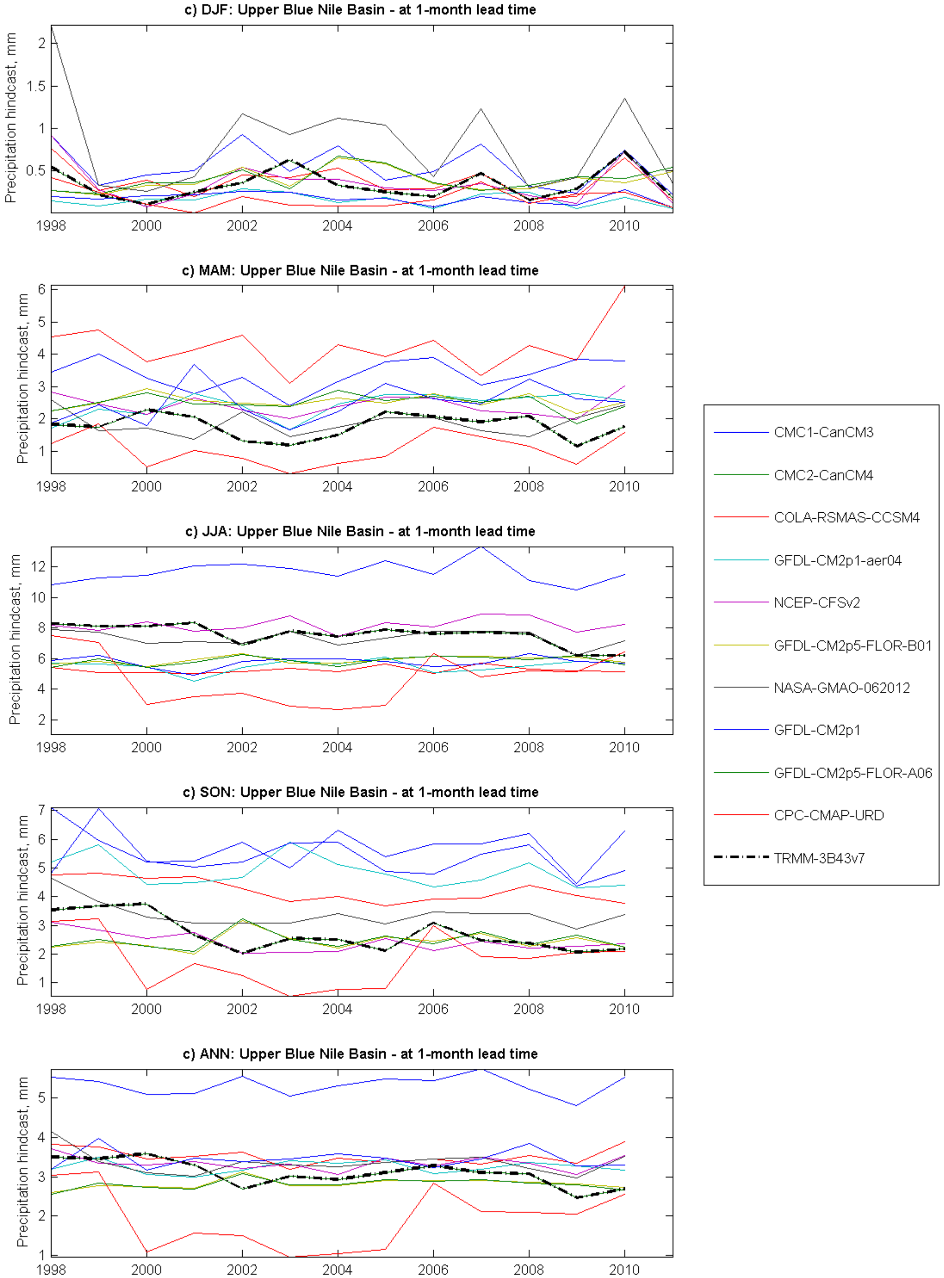


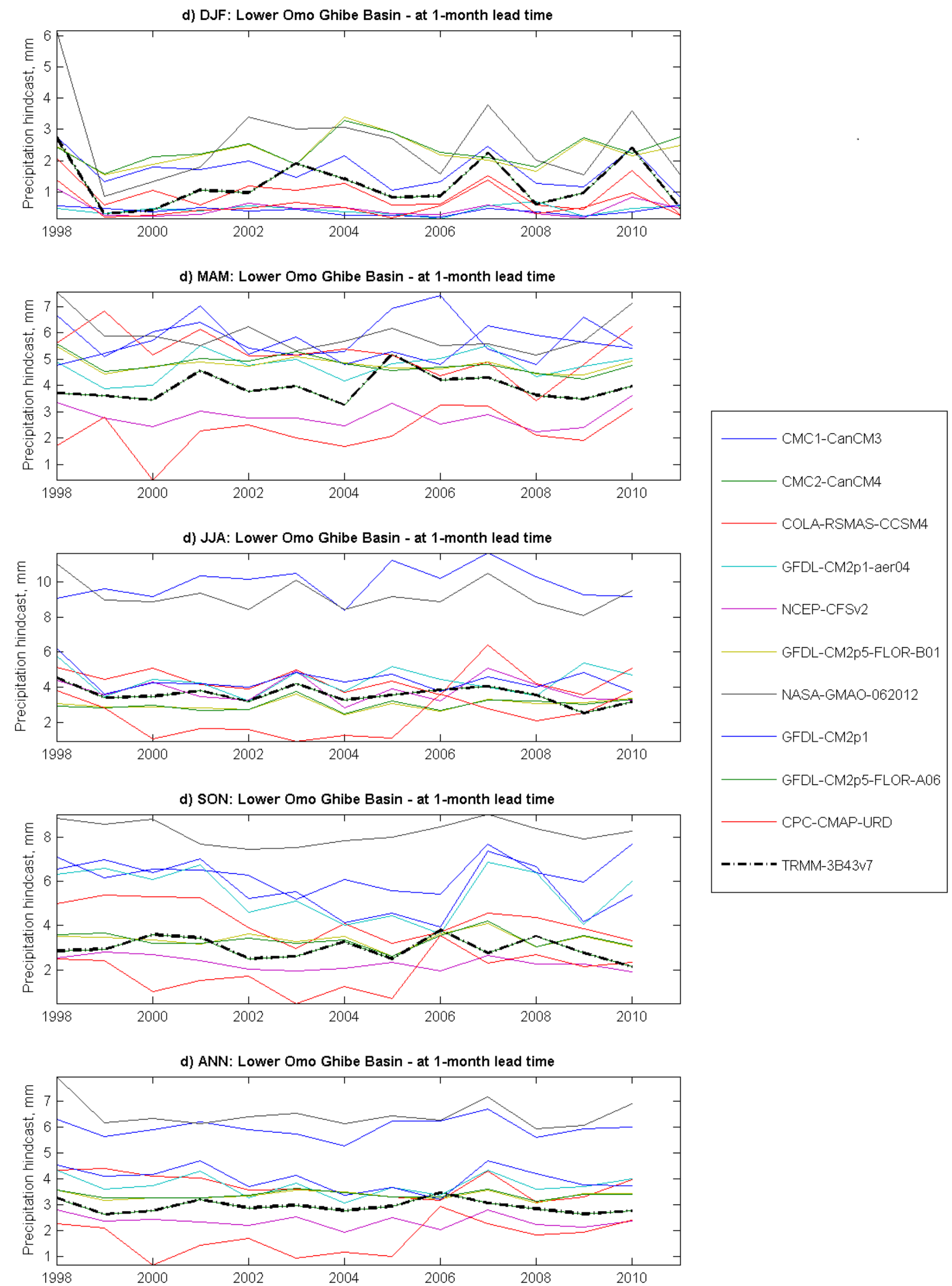
Blue Nile–Omo Ghibe vs Pangani NYM regions





Upper Blue Nile Basin vs Lower Omo Ghibe Basin





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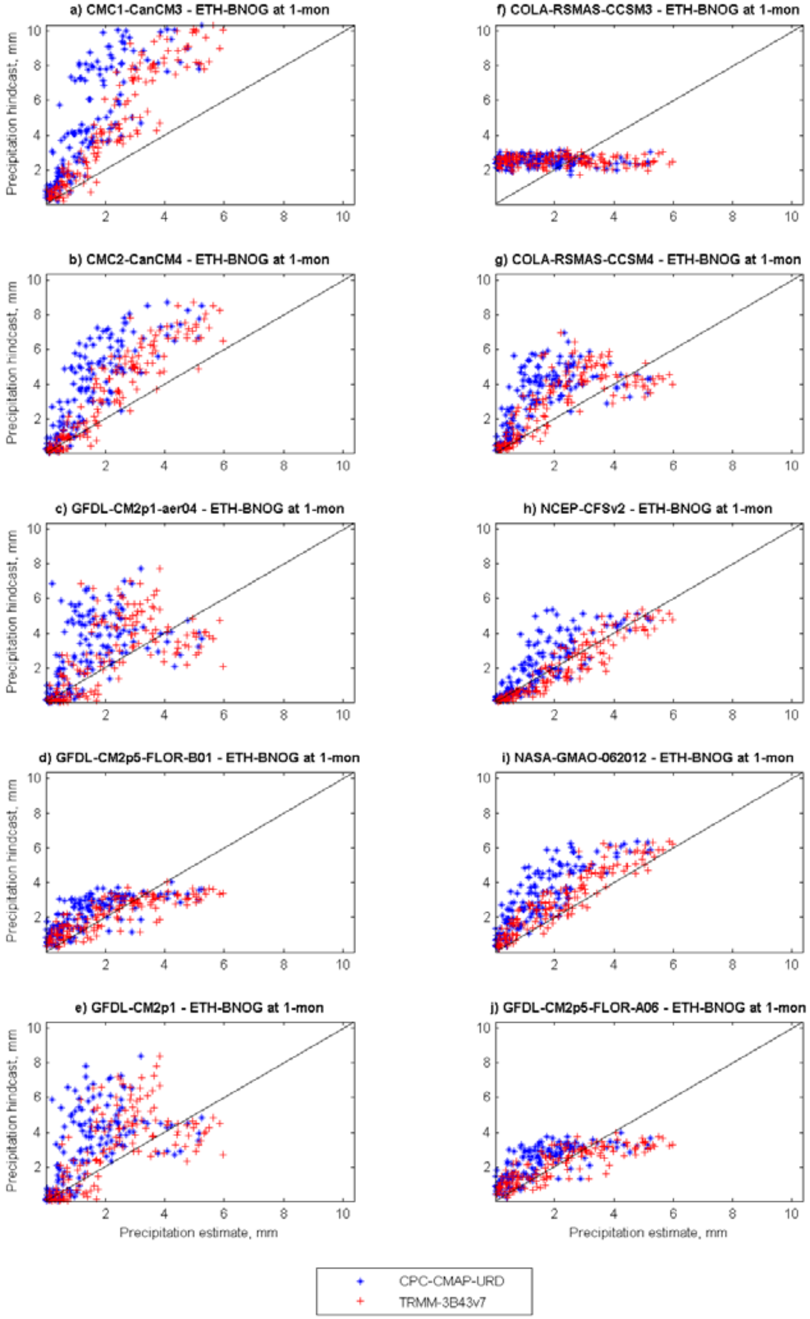

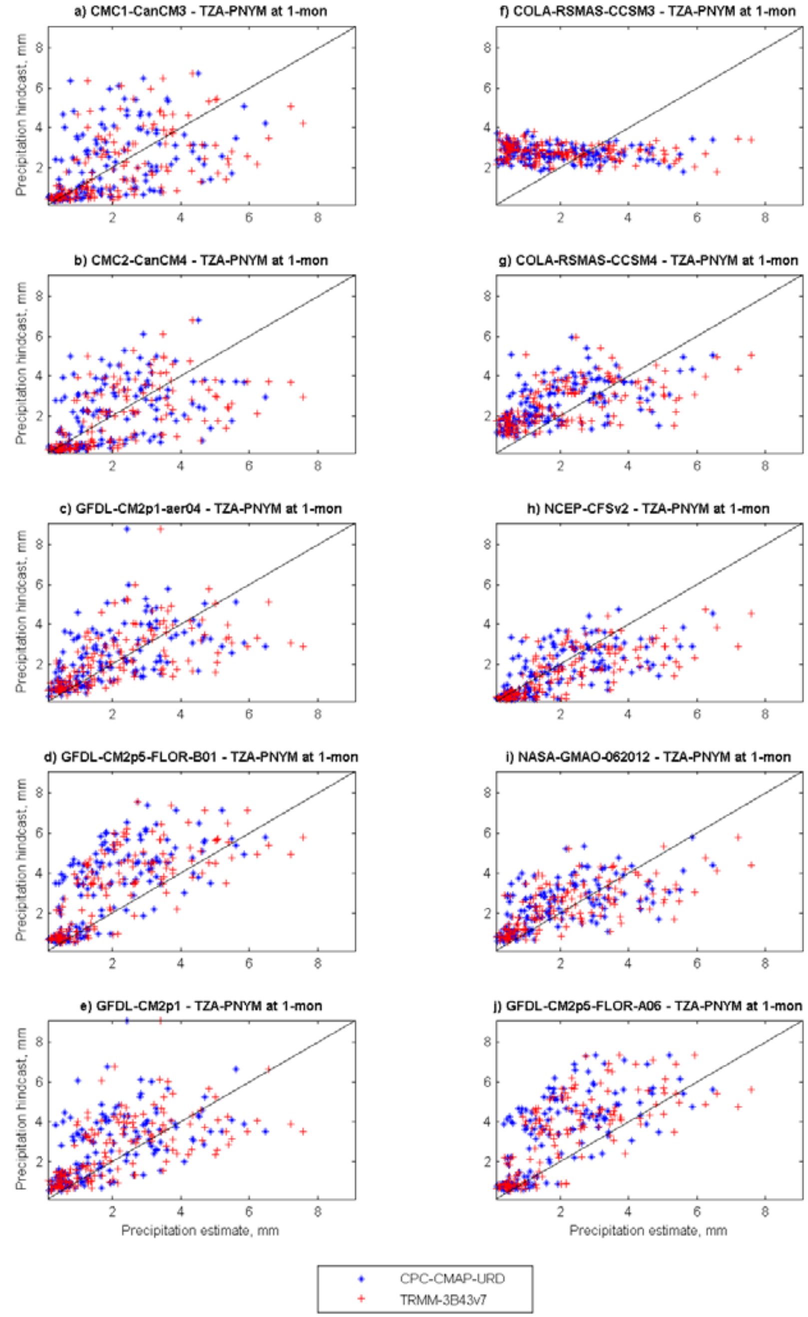

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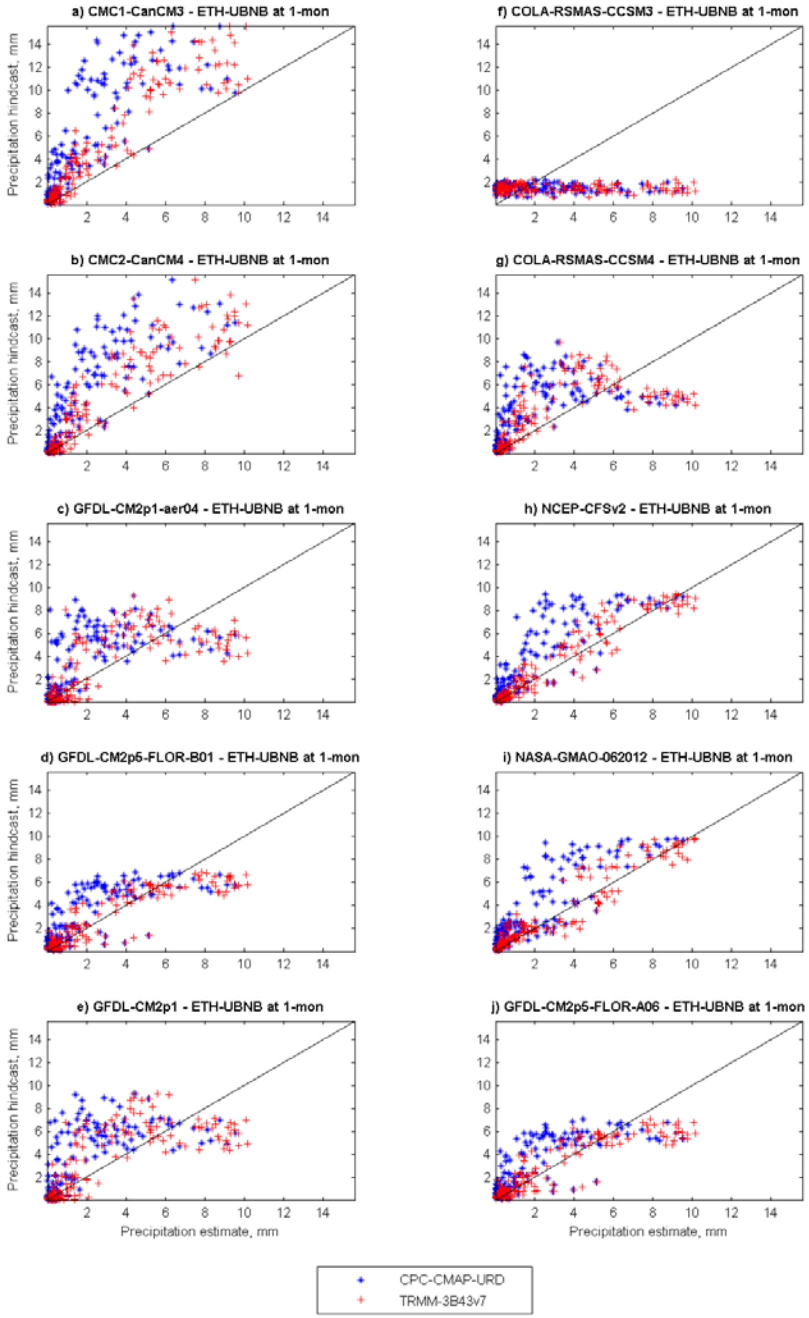

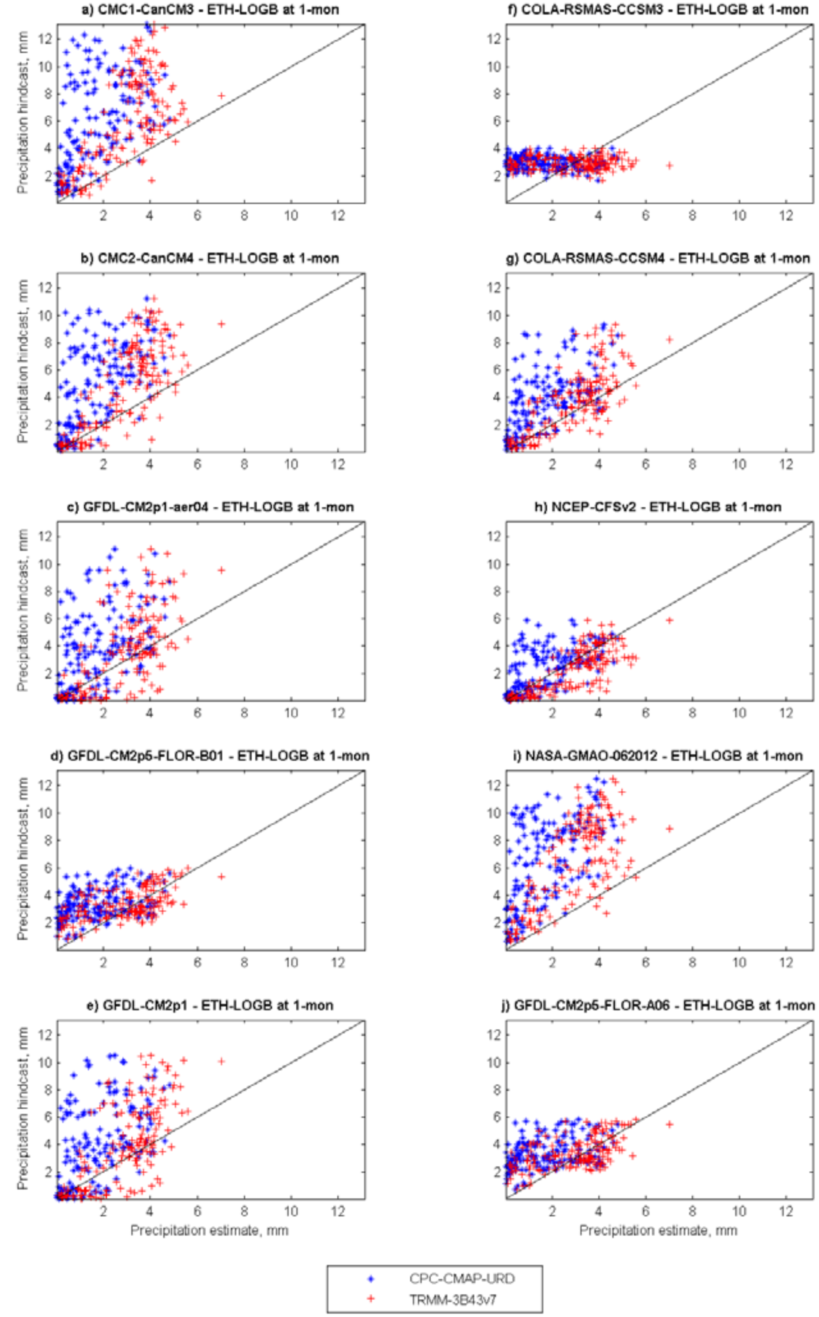

Conclusions

- Satellite remote sensing plays a critical role in hydrology. Application, research and education in Africa should use this source of information.

- We are developing a new application for the use of satellite remote sensing to increase the hydropower production in Africa.

Acknowledgement

NASA ROSES Applied Sciences Program – Water Resources Application.