Satellite-Based Rainfall Monitoring: The TAMSAT Experience in Africa

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Courssurl’utilisation des produitssatellitaires aux applications agro météorologques, 5-9 Mai 2014, Ouagadougou, Burkina Faso

6 May 2014

TAMSAT* Research Group

TAMSAT = **T**ropical **A**pplications of **M**eteorology using **SAT**ellite data and ground-based observations

- Dr Emily Black, *TAMSAT Group Leader*
- Dr Ros Cornforth, *Innovations Leader / AfClix Director*
- Prof Richard Allan, *Professor in Climate Science*
- Dr Elena Tarnavsky, *Post-doctoral Research Scientist*
- Dr Ross Maidment, *Post-doctoral Research Assistant*
- Dr Marc Stringer, *Scientific Computing Expert*
- Matthew Young, 3rd year *PhD Student*
- George Dugdale, *TAMSAT Founder/Visiting Research Fellow*

Overview

- Importance of and Requirements for Rainfall Monitoring
- Approaches
  - Ground-based gauge observations
  - Gauge-calibrated satellite-based estimates
- The TAMSAT method for rainfall estimation and operational products
- Skill and Reliability
  - Validation: operational and case studies
  - Inter-comparisons with other rainfall products
- Applications
  - Drought monitoring
  - Weather Index-based Insurance: drought and flood
  - Hydrology and land surface modelling

Importance

- Rainfall affects a wide range of human activities:
  - **Agriculture**: anticipate yield shortfalls, select crop variety according to season start and length, determine irrigation needs, predict likely harvest, advise commodity trading, forecast crop prices
  - **Famine early warning**: anticipate famine (drought during the wet season → crop failure →famine) and assist national governments and international aid organisations in meeting food provision needs
  - **Hydrology**: predict river flows, plan hydropower generation, mitigate against floods, plan water harvesting activities, anticipate shortfalls in the availability of fresh water, estimate ground-water recharge
  - **Soil erosion, sedimentation, crusting**: heavy rainfall (along with poor soil quality, lack of vegetation cover, and topography) can cause erosion, reservoir sedimentation, and soil crusting
  - **Pest and disease monitoring**: anticipate pest (locust) and disease (malaria, dengue fever) outbreaks and ID outbreak areas →help reduce time and effort for pest and disease control through focusing on outbreak areas when outbreaks are likely to occur

Requirements

- Either too little or too much rainfall can be a problem
  → monitoring rainfall occurrence and amount
- What is too little or too much rainfall?
  → need both real-time information and a long-term record
- However, rainfall is difficult to measure:
  - Intermittent variable
  - High spatial and temporal variability, and
  - Inadequate density of ground-based observations from rain gauges for spatially contiguous rainfall monitoring
- Rainfall estimates need to be:
  - Comparable (internally consistent) over space and time,
  - Reliable (skillful/robust) spatially and temporally,
  - Available in real time and over the long term, and
  - Accessible at low cost

Approaches

- Ground-based gauge observations: 19^{th} century to present
- Ground-based weather radar: invented in 19^{th} Century, in operational use since 1940s, virtually non-existent in Africa
- Satellite-based observations:
  - Vanguard (1959) ~9 days
  - TIROS (1960) ~78 days
  - Geostationary:
    ATS (1960), SMS (1970s), GOES (1970s), Meteosat (1980s)
  - (Near) Polar-orbiting:
    NOAA (1970s), TRMM (1997), QuikSCAT (1999), Metop-A (2006)
  - Most recent →GPM constellation, launched Feb 2014, orbits at approx. 407 km distance (designed to succeed TRMM)

Approaches 2

- Ground-based gauge observations

PROS	CONS
Comparability Rainfall amounts can be compared over space and time, provided standardised gauges are used; in case of differing gauge designs, use correction factors.	**Point-based measurement** Rain gauges measure rainfall at a point and reliable aerial observations are difficult to obtain as rainfall can vary greatly over short distances.
Long-term observations In many places rain gauge observations date back to over 100 years.	**Gauge distribution** Gauges are read daily thus, located in easily accessible places; gauge distribution may not be representative of regionally variable rainfall.
Simplicity Inexpensive, simple to manufacture and use, and easy to maintain instruments.	**Measurement error** Observers report amount of rainfall into the gauge, which can differ substantially from actual rainfall (e.g. wind losses, evaporation, side-wetting, splashing, inappropriate siting, etc); room for error in the transcription of gauge measurements.
	Time delay Typically read at 6:00 a.m. for previous day's rain observation, but weeks to months can elapse before data are assembled into useful datasets; telemetered gauges are increasingly affordable, but still expensive to install in many locations, more difficult to maintain, prone to signal failures and vandalism.

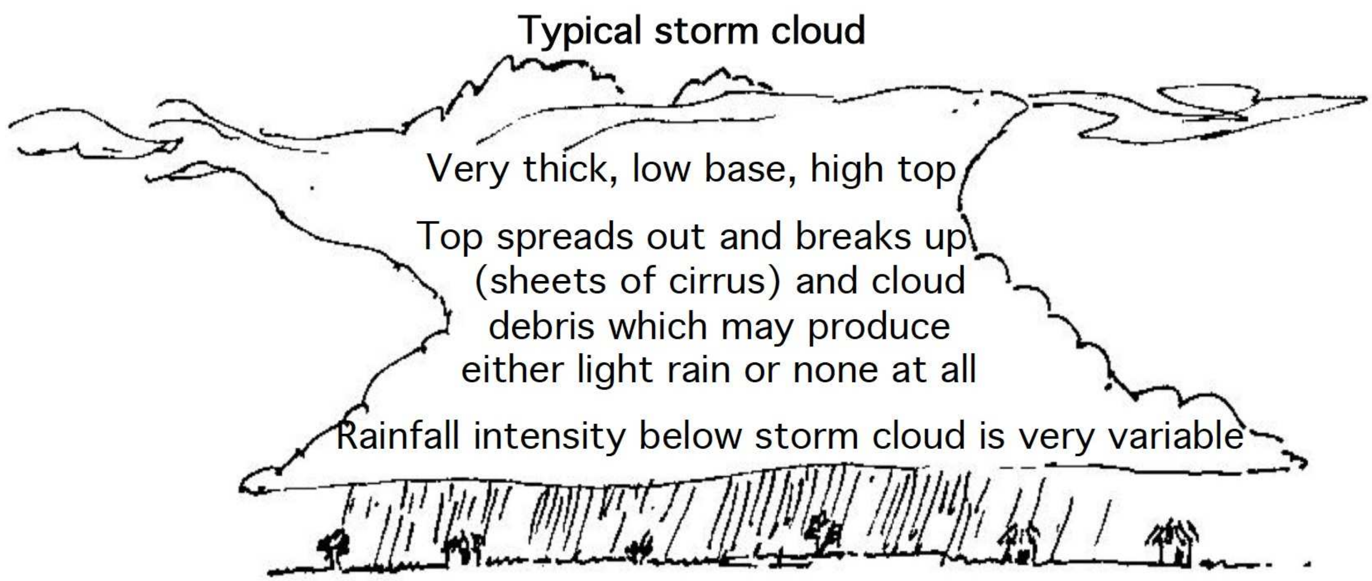
Approaches 3

- Gauge-calibrated satellite-based products

PROS	CONS
Comparability Rainfall amounts can be compared over space and time, provided a consistent approach is used for rainfall retrieval.	**Reliability** The approach for rainfall retrieval is indirect and thus, rainfall estimates may not be equally reliable in all cases and over all areas; hence, reliability is contingent on the interpretation of a skilled specialist and gauge data input for calibration.
Long-term observations Satellites have now been in orbit for around 30 years.	**Calibration** Rainfall estimation is reliant on calibration against ground-based observation and thus, satellite approaches still require incorporation of observations from rain gauges.
Real time availability Imagery are available in near-real time, typically within an hour or so from acquisition.	
Reliable area estimates Images cover large areas and represent aerial rainfall better than gauge observations.	
Cost Imagery from a wide range of satellite-borne instruments are now available to national meteorological agencies (NMA) and other non-profit users free of charge.	

The TAMSAT Method

- Atmospheric T decreases with height in the troposphere, depending on weather and air moisture content
- Lower T, lower IR emissions and vice versa
  →IR can help to estimate cloud top T
- Storm clouds are cold, -40° to -80℃; cirrus clouds are also very cold lower, stratiform or inactive cumulus clouds' T = 0-20℃
  → IR can ID storm (cold) clouds though confused with cirrus

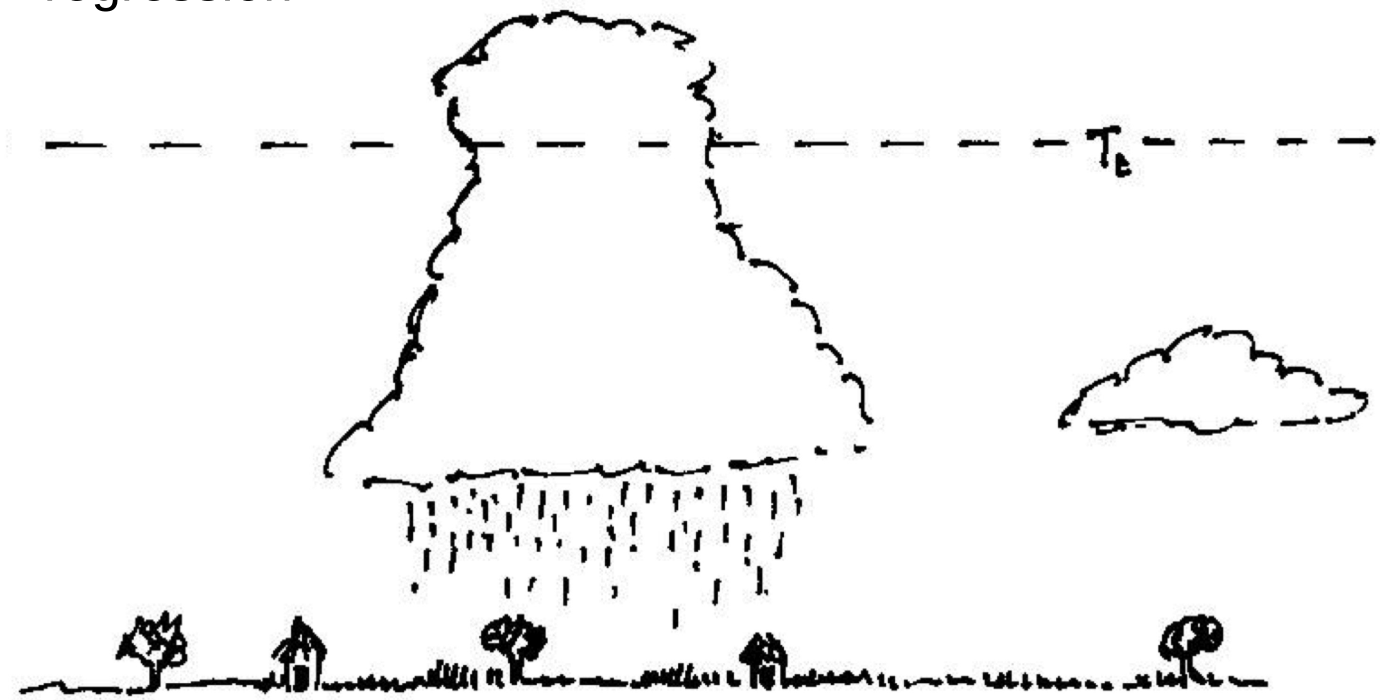


The TAMSAT Method 2

- Data input: Meteosat TIR (10.8 µm) imagery
- Calculate Cold Cloud Duration (CCD) that is the length of time cloud top is colder than threshold temperature T_t for each pixel
- Estimate rain amount as Rainfall [mm] = a0 + a1 CCD [hrs] with T_t, a_0, a_1 calibrated against historical gauge observations
- Calibration parameters vary in space (regions) & time (months)

The TAMSAT Method 3

- Rainfall is mainly from convective storm clouds
- Clouds (above a certain height) with tops colder than T_t are raining
- Cloud top height H_t can be identified by its T in the IR imagery
- Rainfall amount can be calculated from CCD as compared with ground-based observations from rain gauges through linear regression

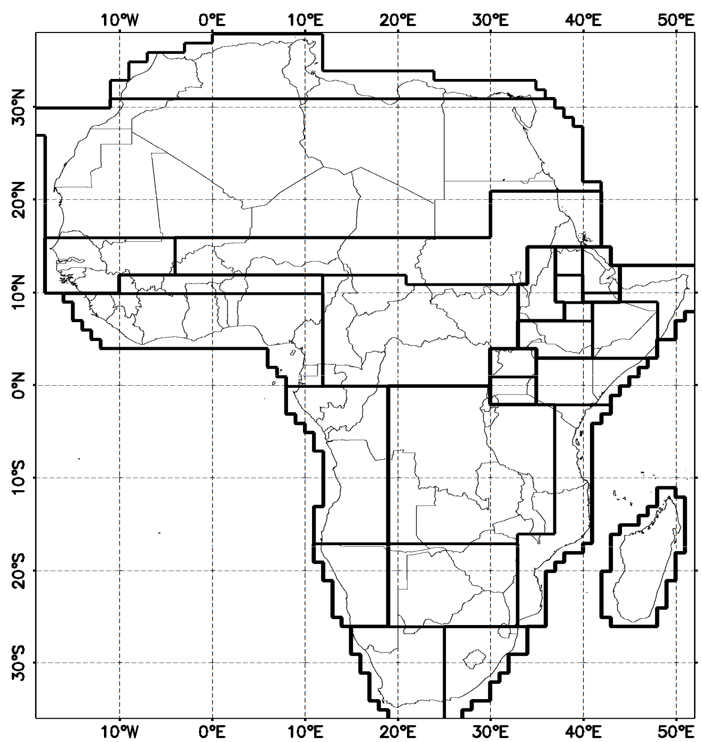


The TAMSAT Method 4

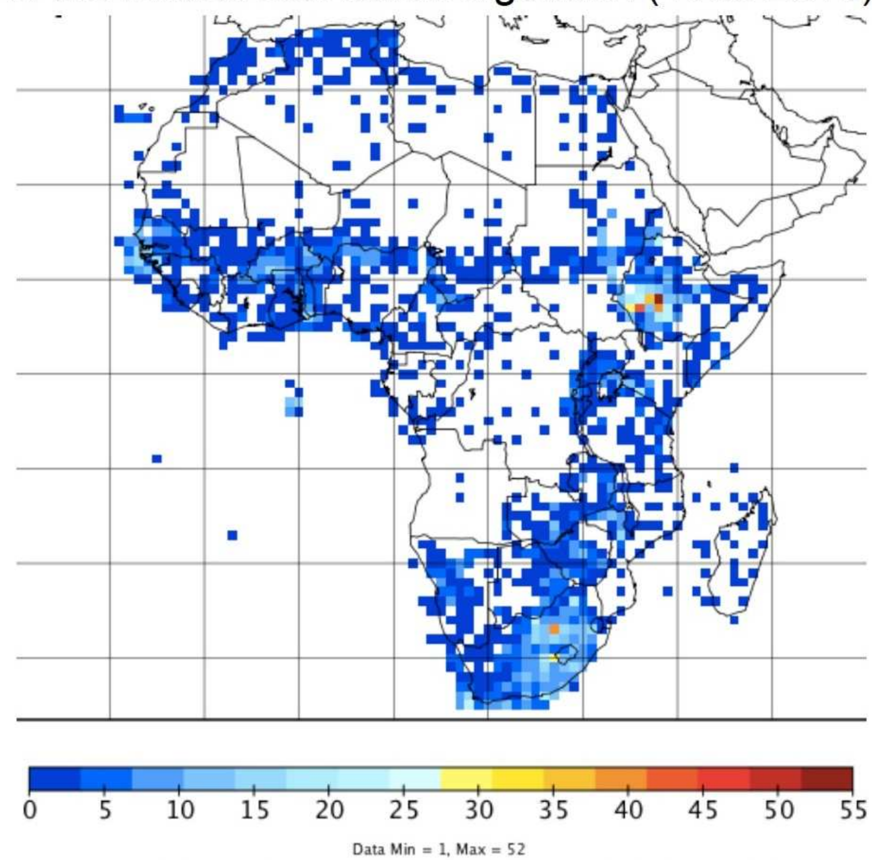
ADVANTAGES	LIMITATIONS
Local expertise. Many African NMAs are equipped to receive Meteosat SEVIRI data and personnel have the required training.	**Warm rain effect.** Non-raining clouds are distinguished from raining clouds based on their cloud-top temperature. Coastal or mountainous areas may experience rainfall from clouds that are not high enough to register as cold in TIR imagery. → rainfall would occur but not appear as rainfall estimate
Simple. The TIR-based approach for rainfall estimation calibrated against gauge observations is simple to implement and use operationally.	**Non-raining cirrus clouds.** Cirrus clouds are high and appear as very cold in TIR imagery, indicating rainfall, but are not deep enough for rainfall to develop.
Frequent. The frequency of observations (15 min) is suitable for operational monitoring.	**Local rainfall variations.** Rainfall intensity varies beneath a typical convective cloud (wide base), while TIR imagery shows the top of the cloud. → rainfall estimates are not precise at the pixel level at a particular time.
Available. TIR imagery are available in real time and over the long term from the early 1980s.	Tends to **underestimate high rainfall**, partly due to the calibration toward drought monitoring using the median rainfall event (i.e. the rain event most likely to occur).
Accessible. Rainfall estimates and derived products are in the public domain.	
Reliable. Reliable dekadal totals and aerial averages.	

The TAMSAT Method 5

Calibration zones: e.g. May



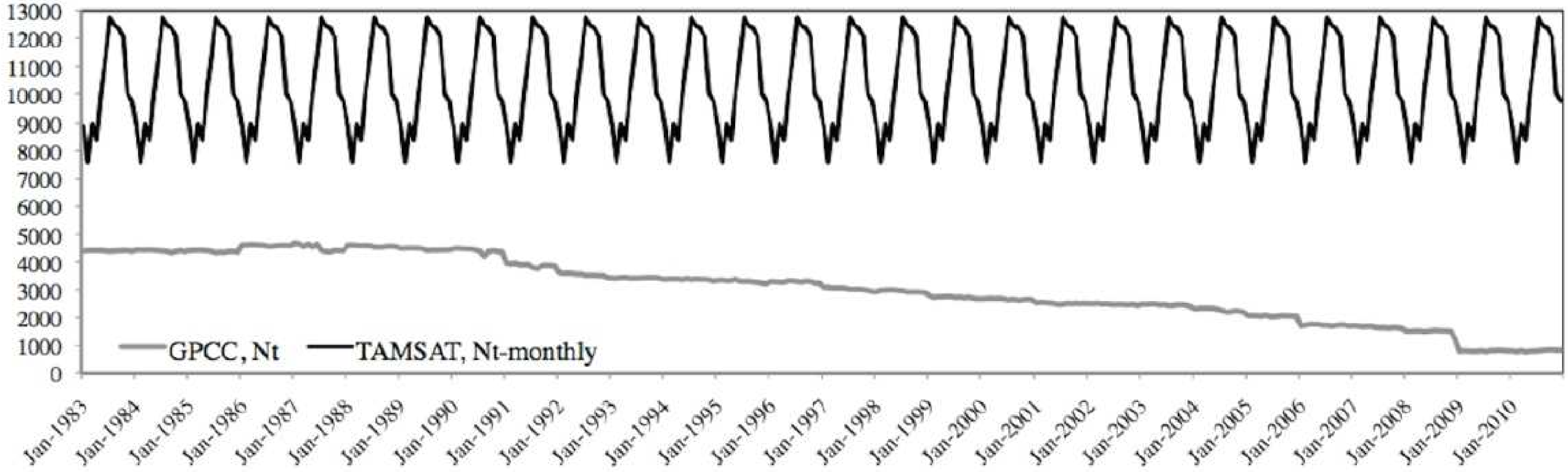
New, proprietary TAMSAT rain gauge archive for spatially-contiguous monthly calibrations of the rainfall estimation algorithm (1983-2010)



Legend: number of gauges within 0.5-deg grid cell

The TAMSAT Method 6

- Number of gauge records for a monthly varying, climatology-based calibration (TAMSAT $N_{t\text{-}monthly}$)* as compared with time-varying gauge input (e.g. GPCC N_t)
(*) TAMSAT's calibrations vary monthly but not interannually

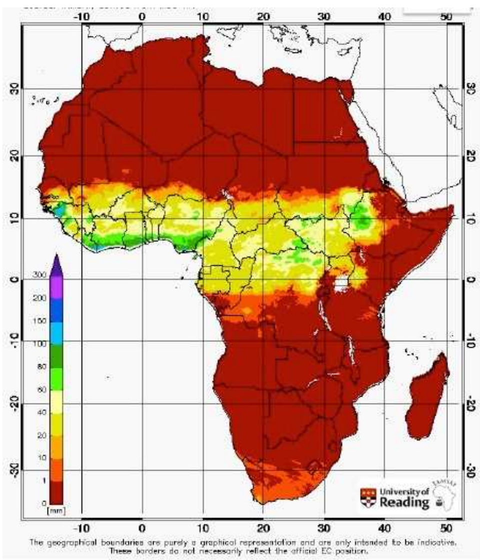


The TAMSAT Rainfall Products

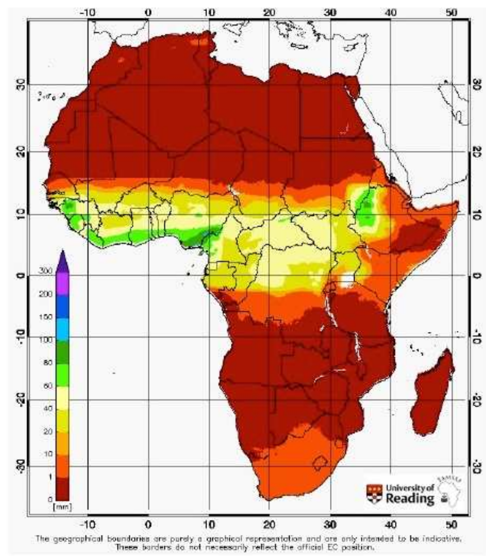
Dissemination channels:

-TAMSAT's web site: http://www.met.reading.ac.uk/~tamsat/data/ *all products, including daily

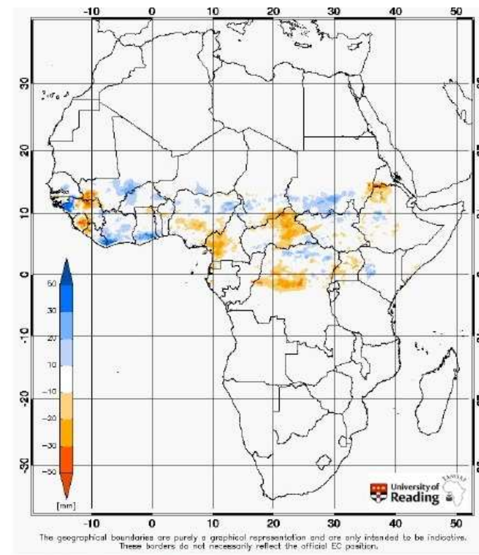
-GEONETCast data broadcasting: http://navigator.eumetsat.int/discovery/Start/Explore/Quick.do



Total rainfall
(1983-present):
- Dekadal (10-daily)
- Monthly
- Seasonal



30-year Climatology
(1983-2012):
- Dekadal (10-daily)
- Monthly
- Seasonal

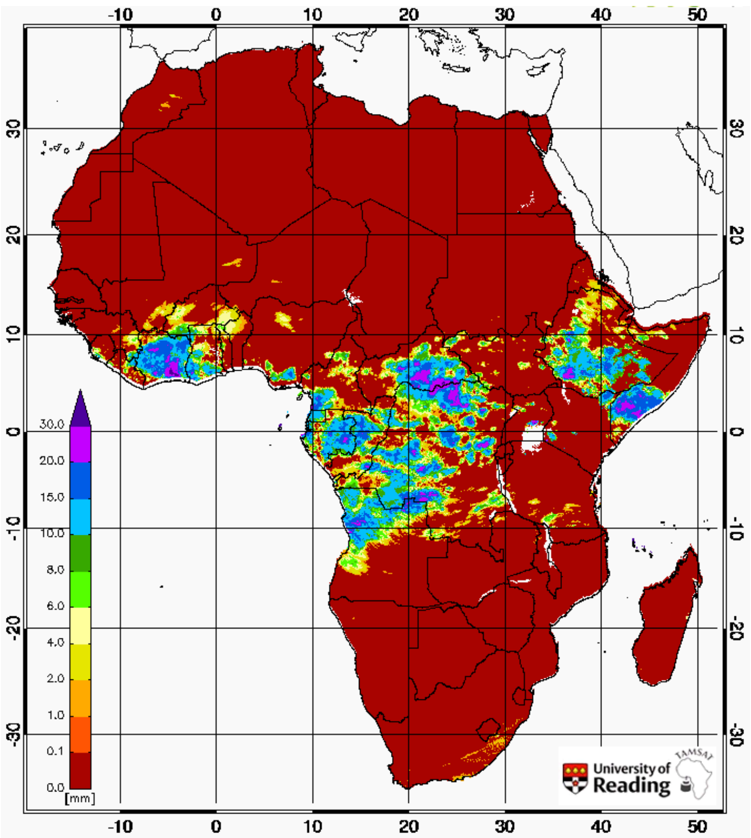


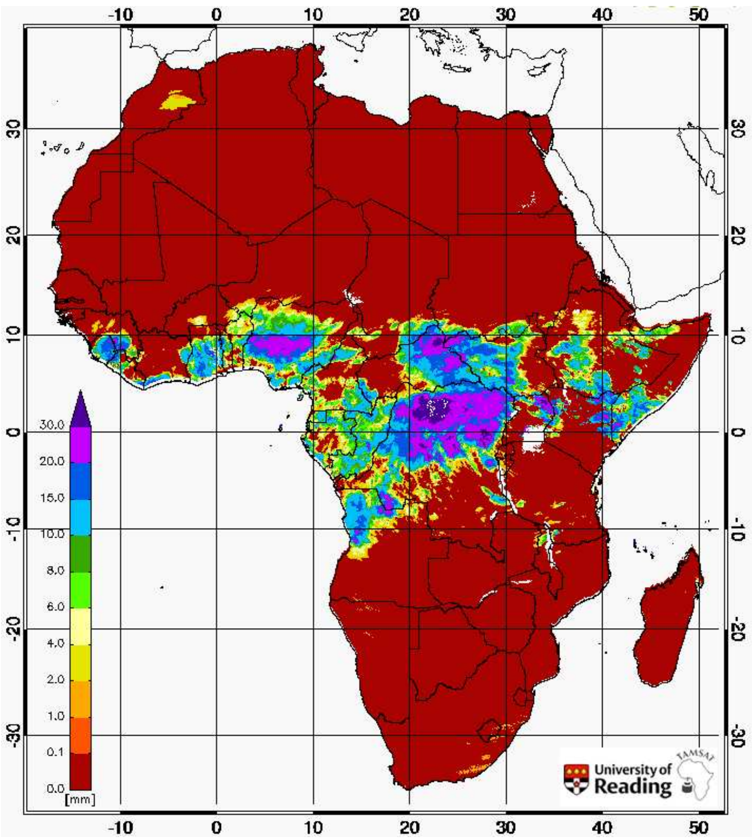
Rainfall anomaly
(1983-present):
-Dekadal (10-daily)
- Monthly
- Seasonal

First African near-real time and long-term product for operational rainfall monitoring

The TAMSAT Rainfall Products 2

- NEW: Daily Rainfall Estimates
  Users' Guide to the TAMSAT Daily Rainfall Estimates is available at:
  http://www.met.reading.ac.uk/~tamsat/cgi-bin/data/rfe.cgi





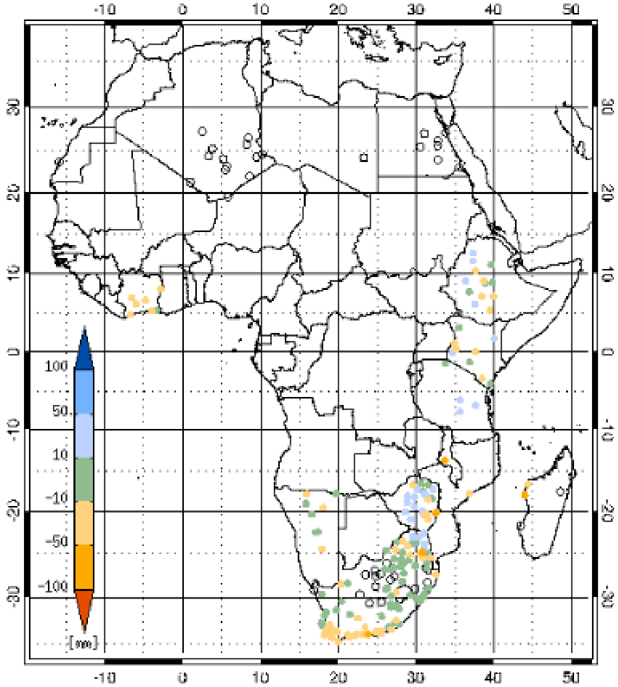
Skill and Reliability

- Operational validation: comparison of the 10-daily TAMSAT rainfall estimates with independent GTS gauge data (i.e. data that have not been used in calibrating the rainfall estimation algorithm)
  - Pixel-to-point comparison (rainfall over a pixel compared with rainfall at a point within the pixel's footprint)
  - Systematic overview of performance in near-real time
  - Provides a comprehensive set of skill measures
  - Covers the time period from Jan 2011 to present

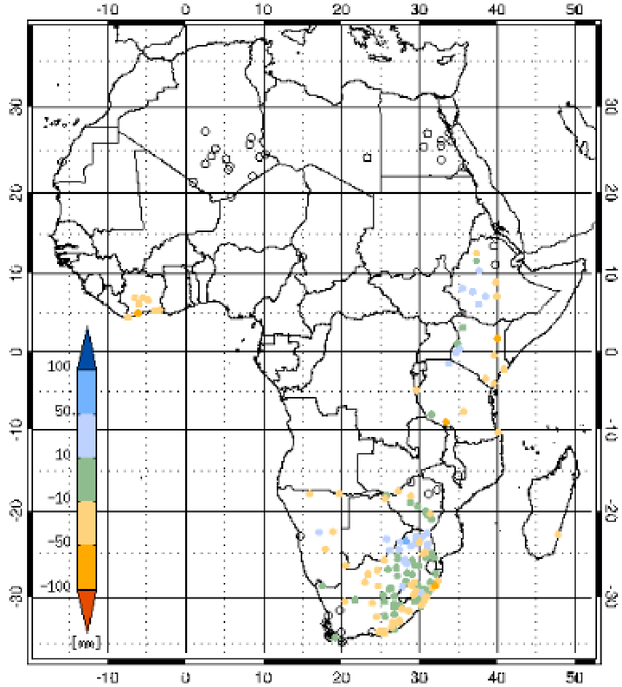
Detailed Guide to validation reports is available at:

http://www.met.reading.ac.uk/~tamsat/data/rfe_val.html

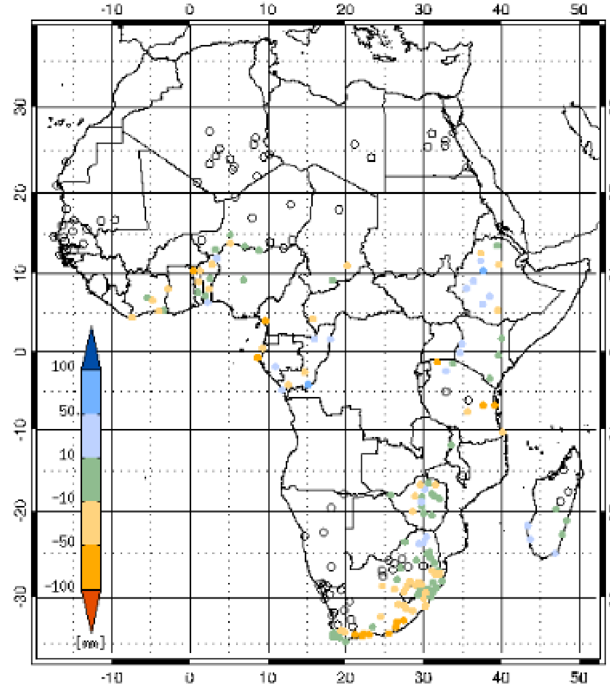
(TAMSAT – gauge) for Year 2014 Month 4 Dekad 1



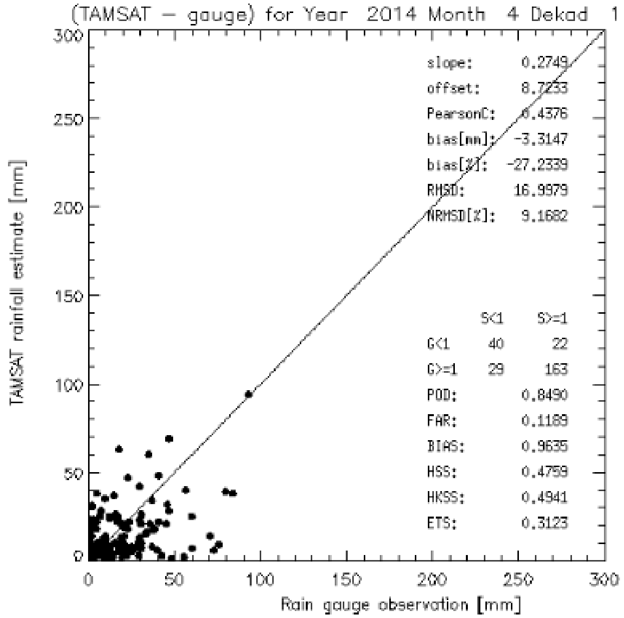
(TAMSAT – gauge) for Year 2014 Month 4 Dekad 2



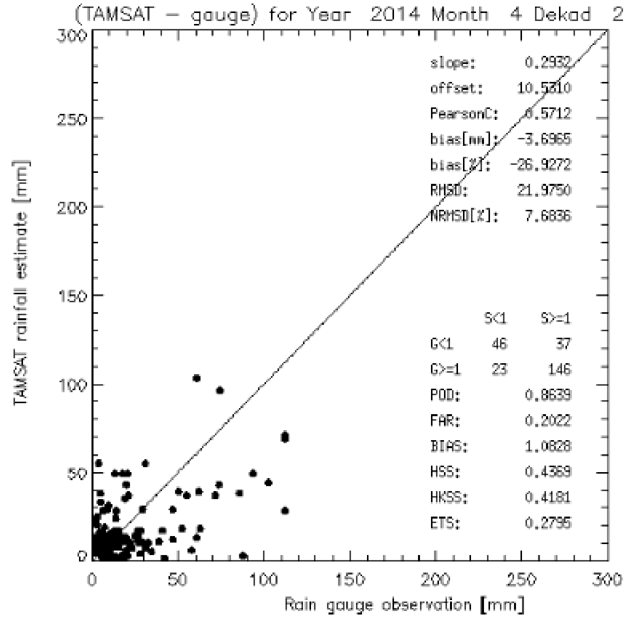
(TAMSAT – gauge) for Year 2014 Month 4 Dekad 3



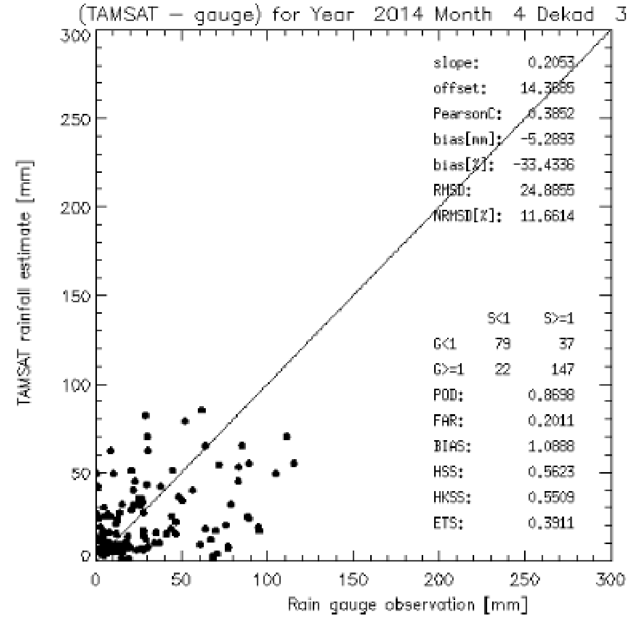
(TAMSAT – gauge) for Year 2014 Month 4 Dekad 1



(TAMSAT – gauge) for Year 2014 Month 4 Dekad 2

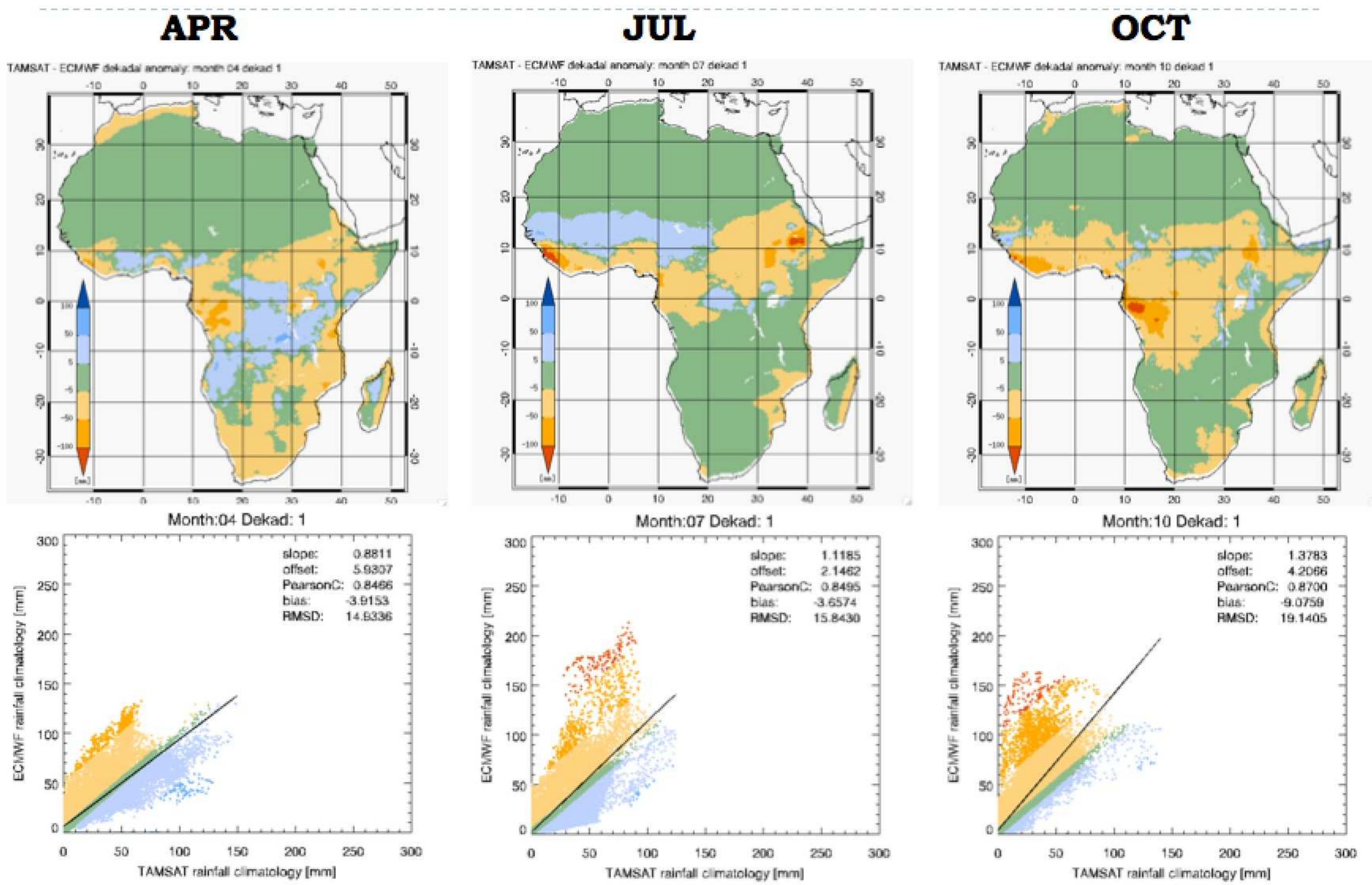


(TAMSAT – gauge) for Year 2014 Month 4 Dekad 3



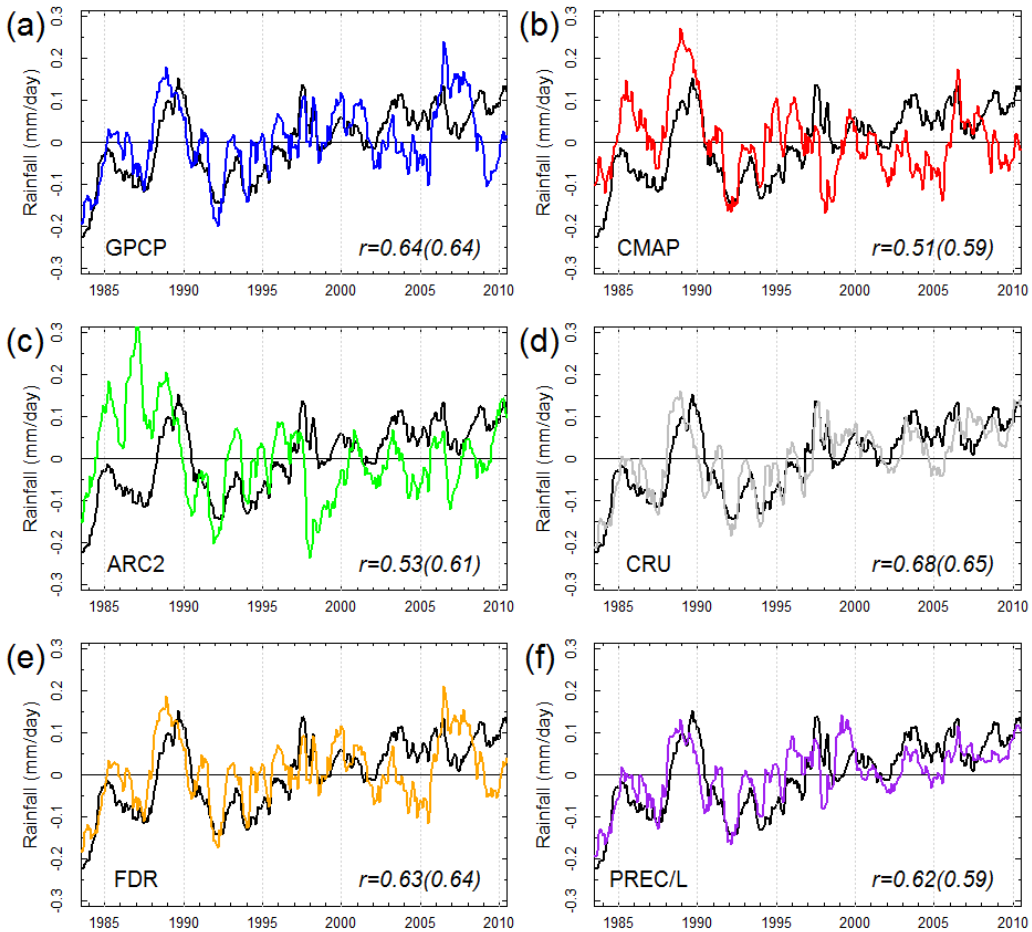
Skill and Reliability 2

- Inter-comparison: TAMSAT & ERA-interim 10-daily rainfall climatology (2000-2007) at 0.25° lat-lon grid



Skill and Reliability 3

- Inter-comparison: TAMSAT & other rainfall products (GPCP, CMAP, ARC2, CRU, GPCC FDR, PREC/L), [*Maidment, 2014*]



Applications

- Drought monitoring – e.g. JRC Drought Bulletin, Namibia

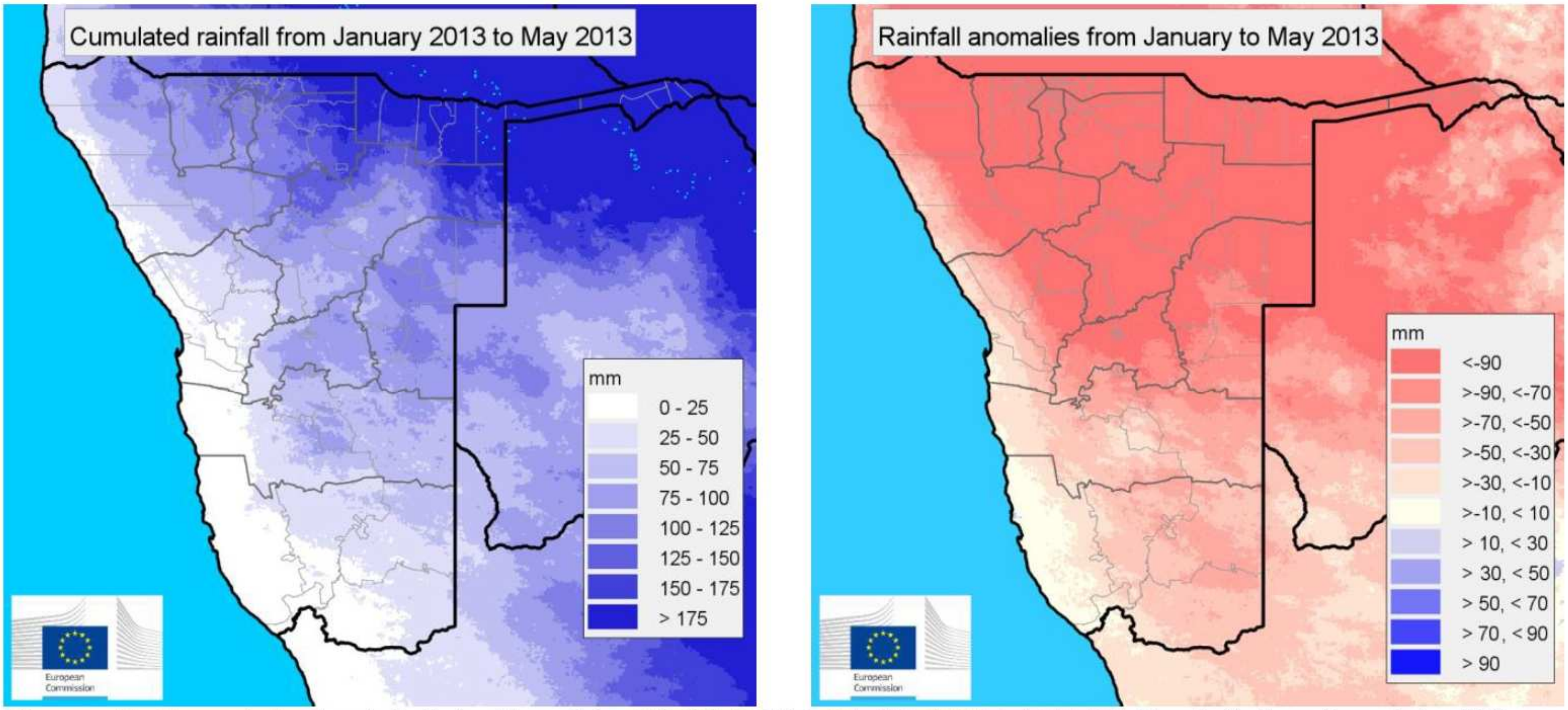
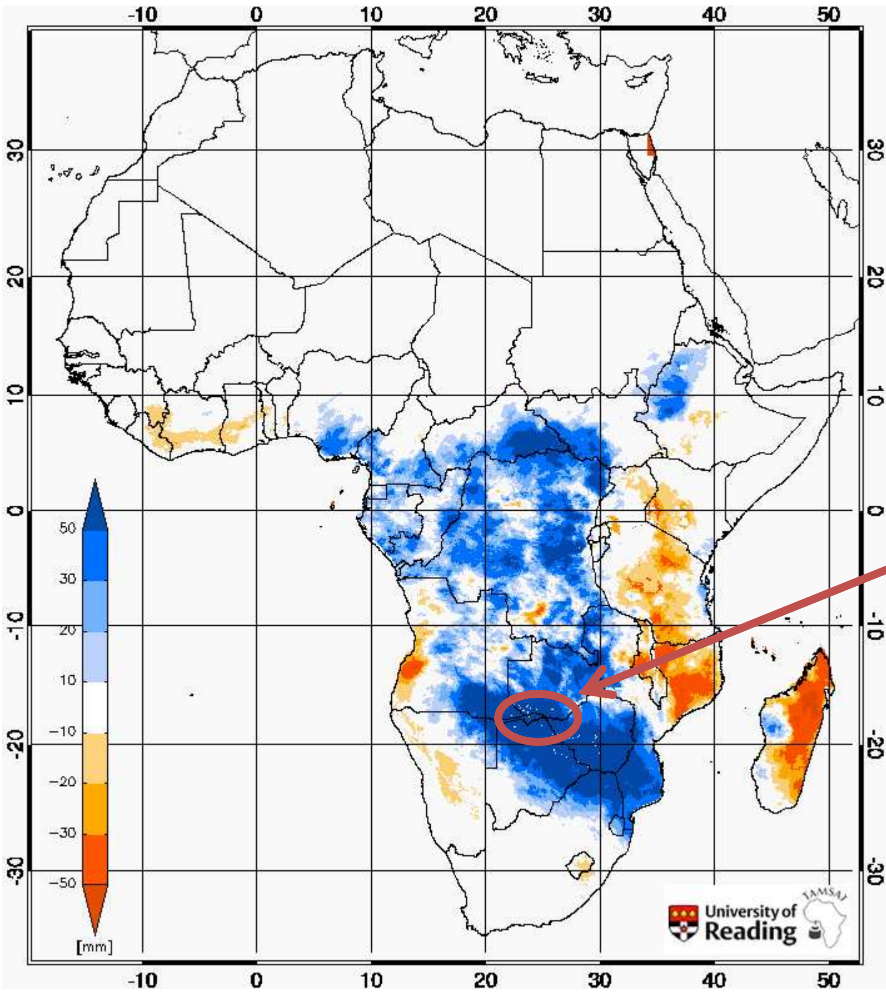


Figure 3. Cumulated rainfall in Namibia 01.01.2013-31.05.2013 (TAMSAT rainfall estimate); difference between this cumulated rainfall and the long term average cumulate (TAMSAT, 1983-2012).

Applications 2

- …and flood monitoring – e.g. floods in Namibia, March 2014



Namibia: Heavy Rains Flood Villages

BY GEORGE SANZILA, 17 MARCH 2014

Makolonga/Linyanti — Following heavy rainfall in the Zambezi Region the two constituencies of Sibbinda and Linyanti have experienced flooding for the first time in decades which has forced hundreds of people from their homes.

Villages in areas such as Makolonga, Mazoba, Sibbinda and Linyanti have been submerged by rainwaters for more than a week, with the situation said to be exacerbated by underground water that is spewing out from below the surface due to a fairly shallow water table.

At Mbozi village in the Makolonga area more than 15 households have been made homeless with a dozen having relocated to dry areas, while some have chosen to stay put to guard their possessions. Just a few kilometres further west 18 villages are reportedly affected with some homesteads having already succumbed to floodwaters and collapsed.

Some roads leading to villages have been completely cut off by the rainwater.

At Linyanti the interior of homes have been heavily flooded. Floors and furniture have been spoiled, plus food such as drought relief maize received by the villagers.

RELATED TOPICS

Namibia

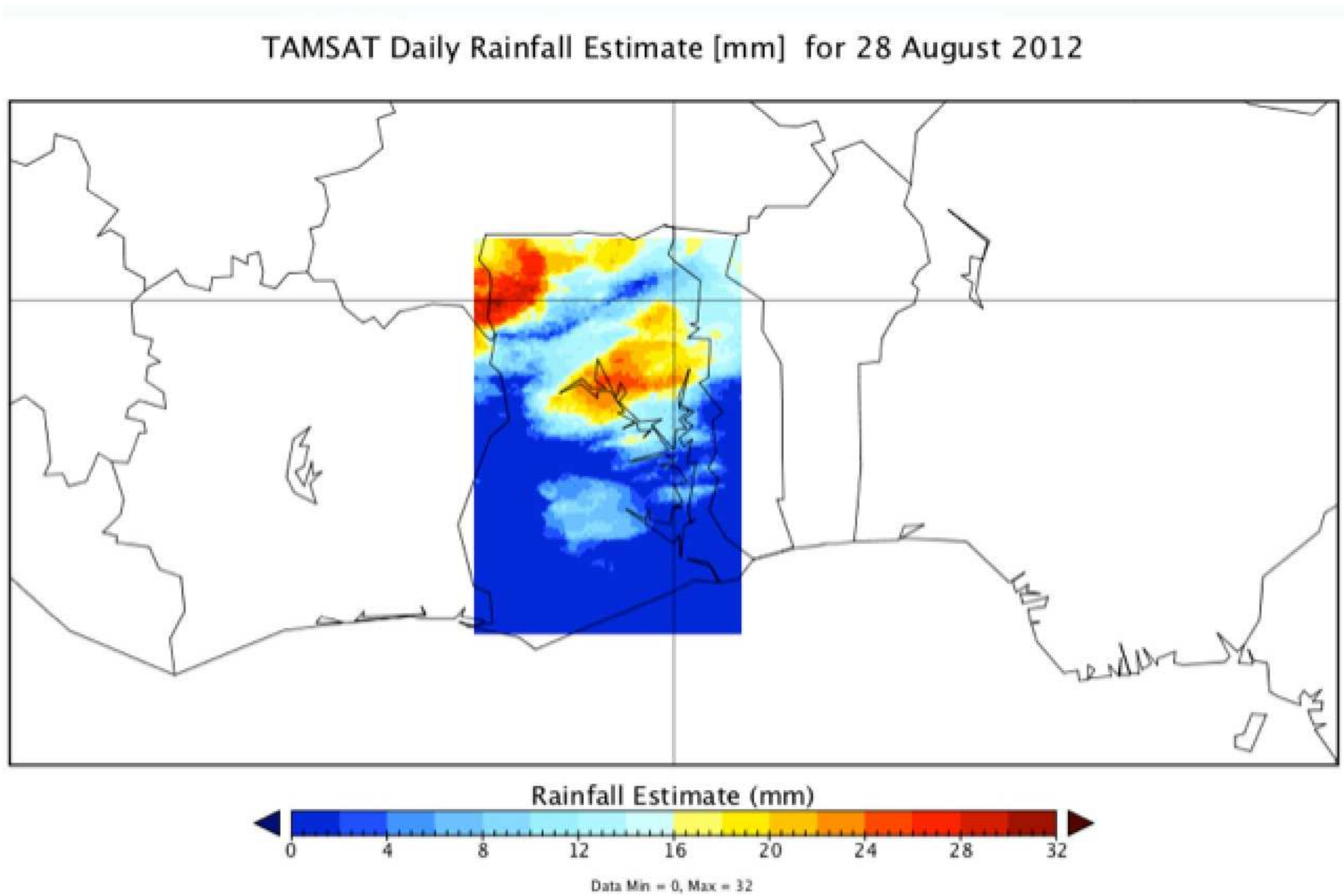
- Namibia: African Stars Go Second

Climate

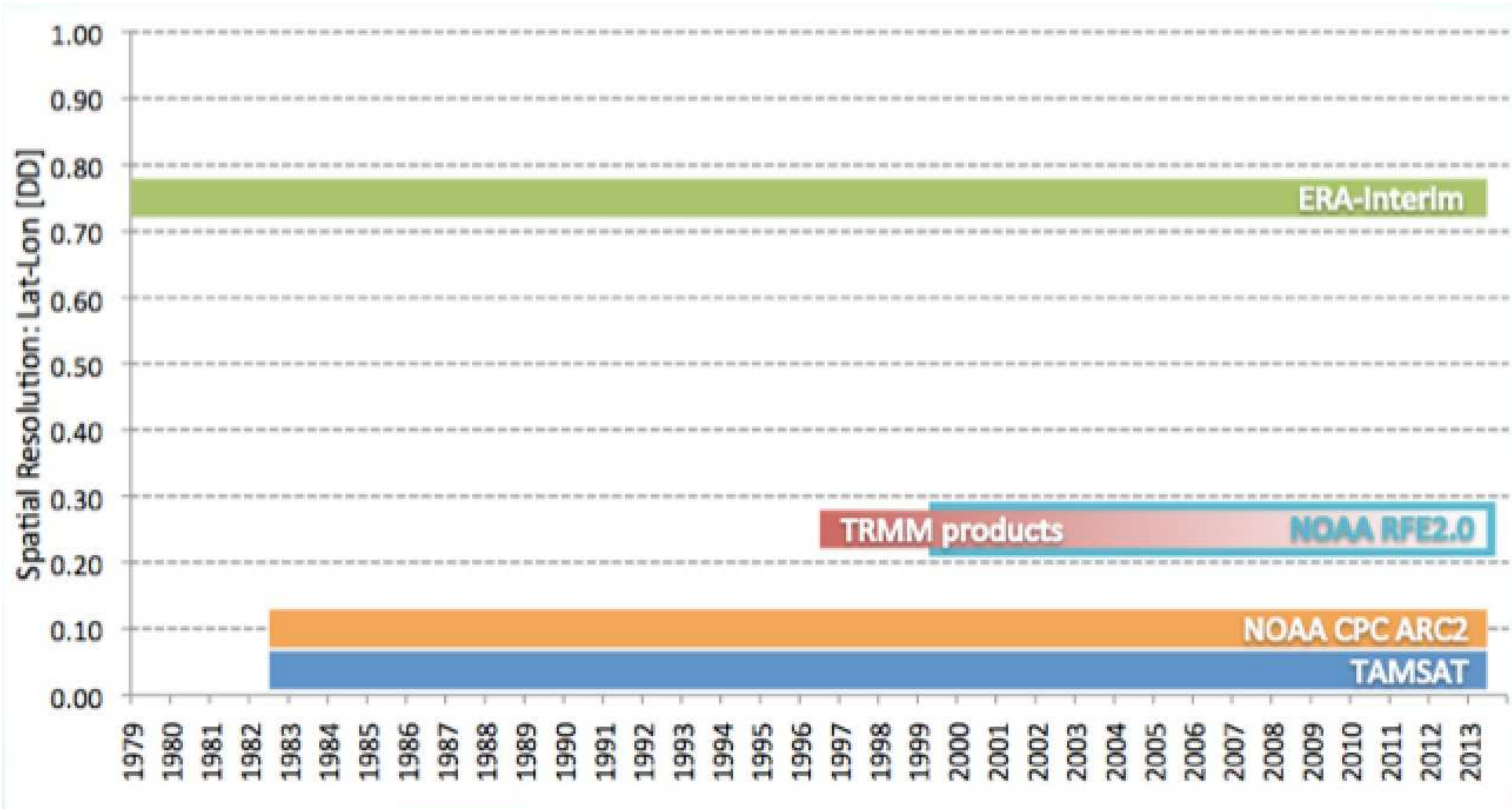
- Africa: UN Climate Chief Urges Greater Suppo...

Applications 3

- Weather Index-based Insurance (WII): development of diagnostics for drought and flood insurance, Ghana



Applications 4



TAMSAT => TIR + gauges (GTS & a proprietary TAMSAT archive)

NOAA CPC ARC2 => 3-hourly GPI (Meteosat archive & NOAA's Meteosat data feed) + gauges (GTS)

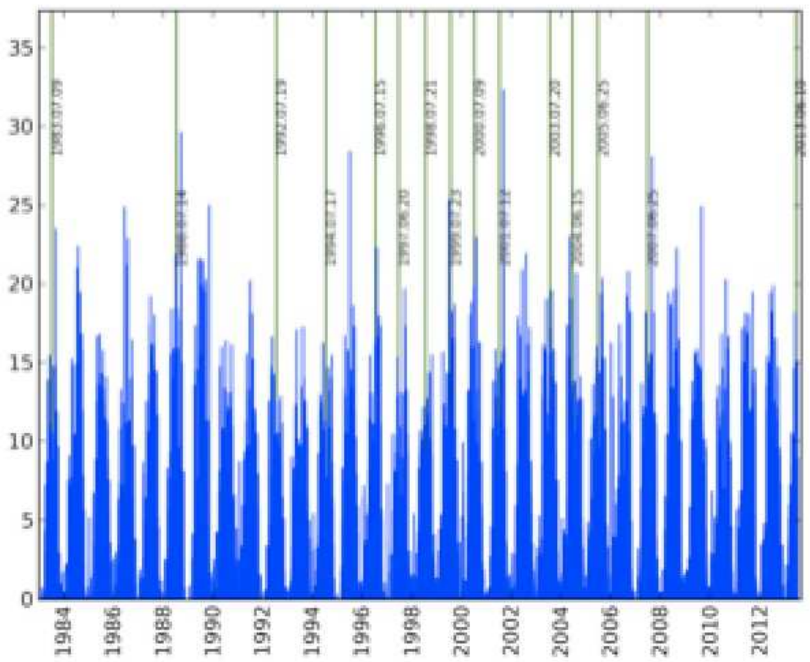
RFE2.0 => SSM/I + AMSU-B + 0.5-hourly GPI + gauges (GTS)

Applications 5

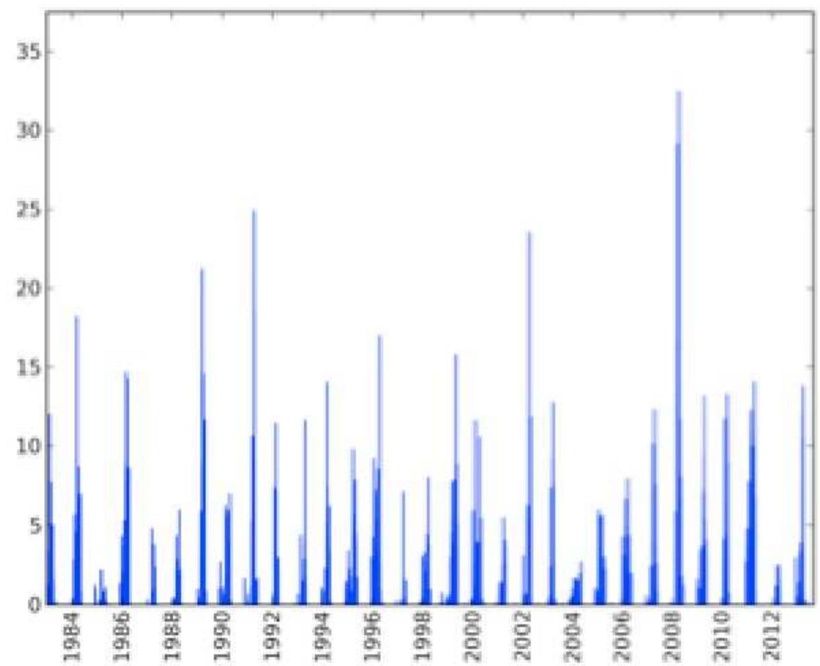
Dry spell length

- WII partial payout @ 12-16 days with rain < 2.5 mm
- WII 100% payout @ 34 days with rain < 2.5 mm

TAMSAT - mean DAILY rainfall estimate (RFE) over Ghana (3W-1E, 5S-11N)



ARC2 - mean DAILY rainfall estimate (RFE) over Ghana (3W-1E, 5S-11N)

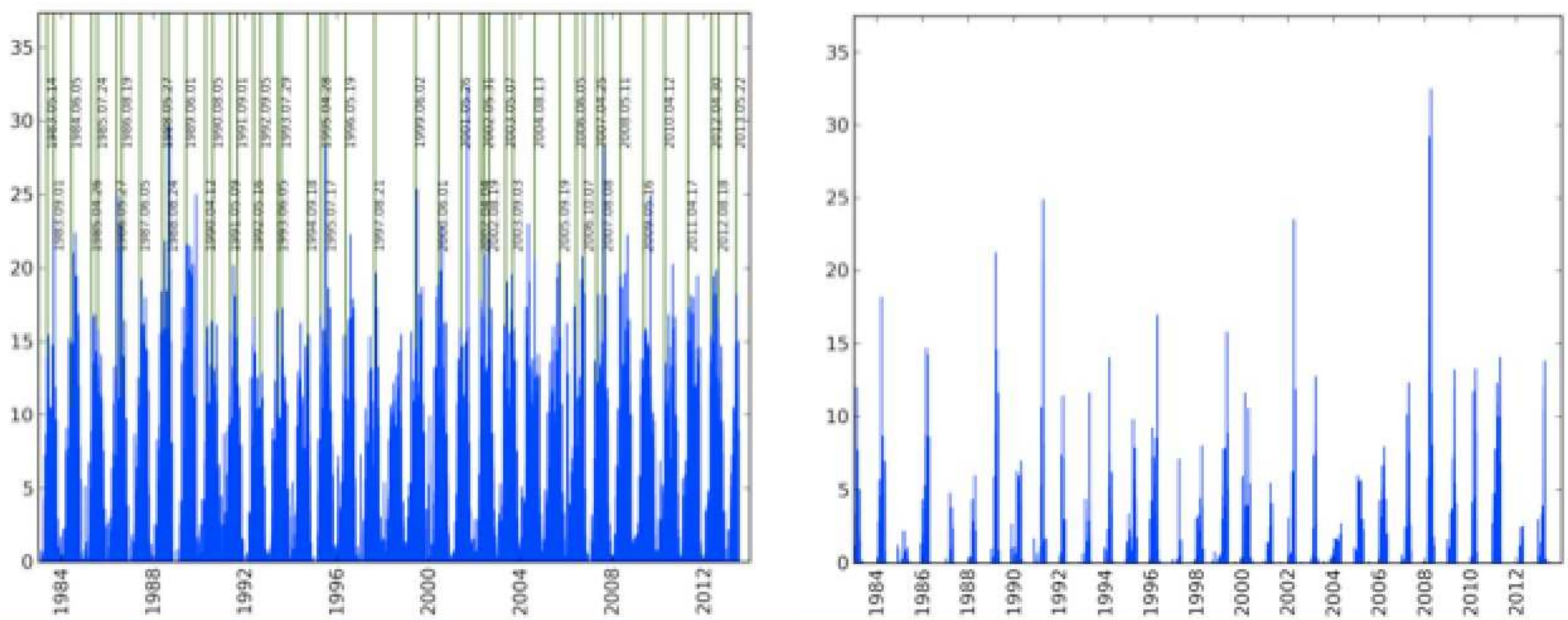


Applications 6

Start of season (SOS)

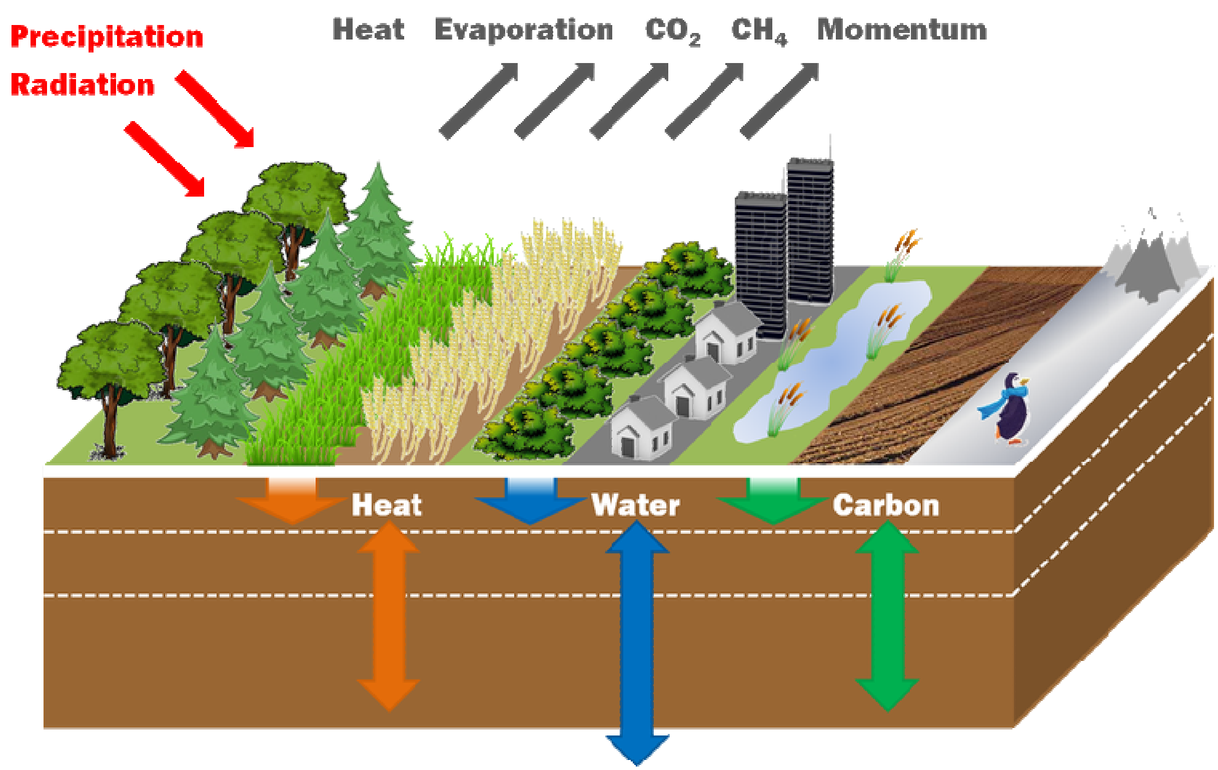
- Rain > 25 mm over 5 consecutive days
- Day 1 + 2 more days of the 5 days are wet (rain > 1 mm)
- For the next 30 days, no more than 7 days are dry

TAMSAT - mean DAILY rainfall estimate (RFE) over Ghana (3W-1E, 5S-11N) ARC2 - mean DAILY rainfall estimate (RFE) over Ghana (3W-1E, 5S-11N)



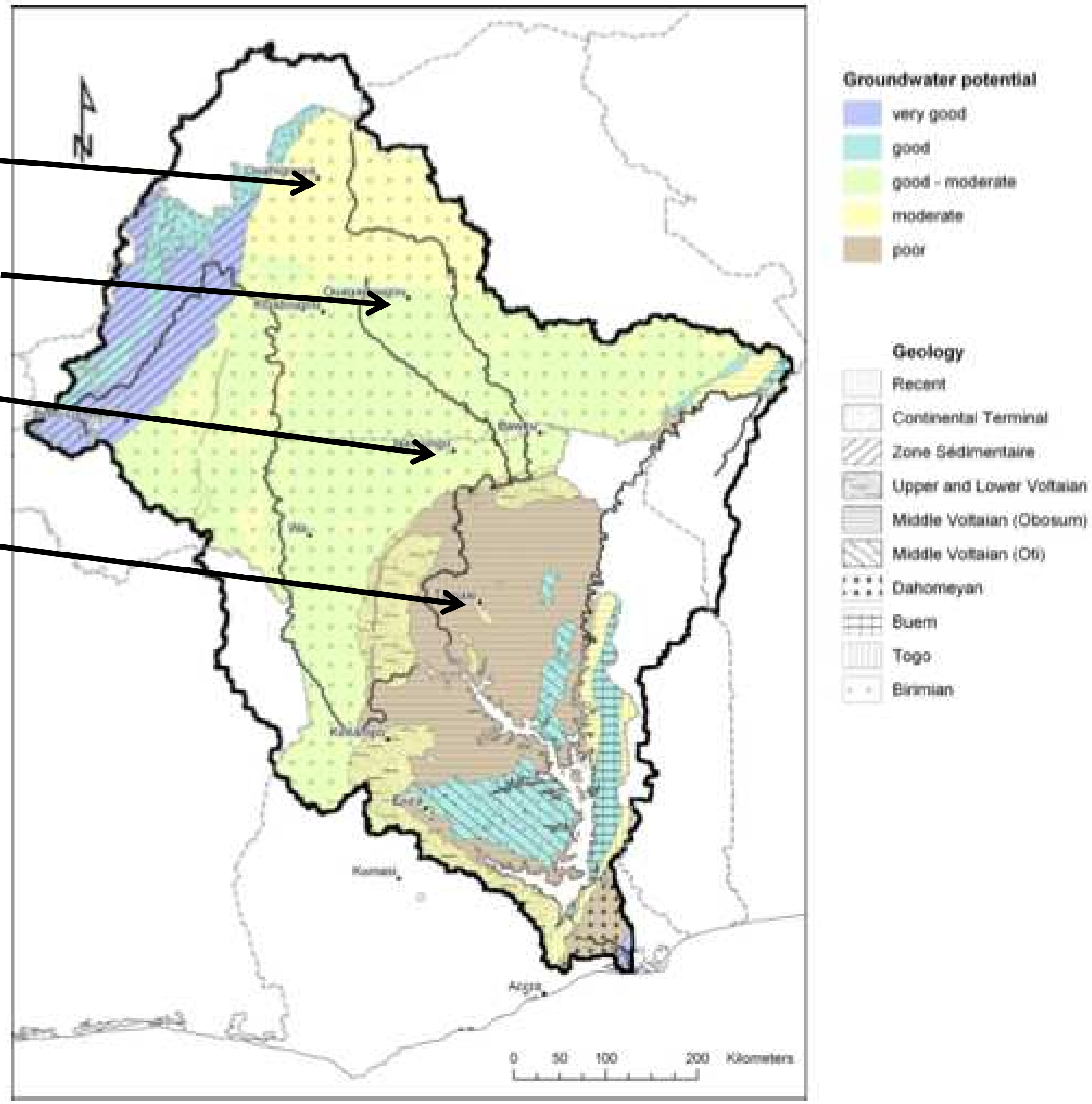
Applications 7

- Hydrology and land surface process modelling: JULES in the Volta River Basin with meteorological forcing from station data disaggregated from daily to hourly temporal resolution and using TRMM 3B42 rainfall

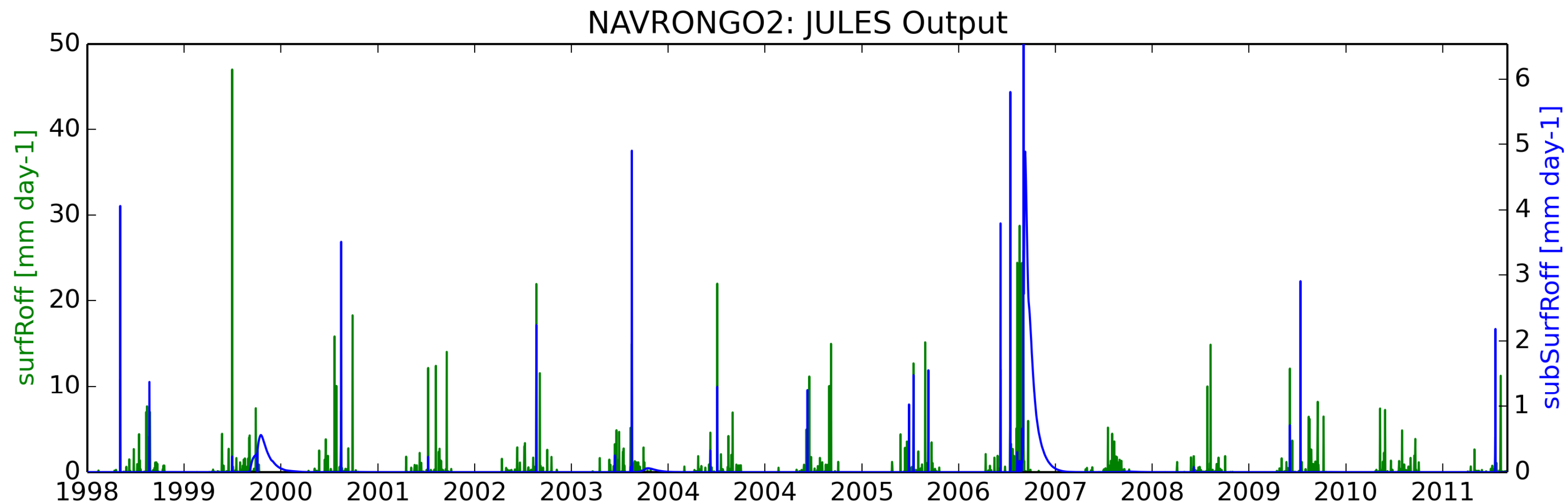


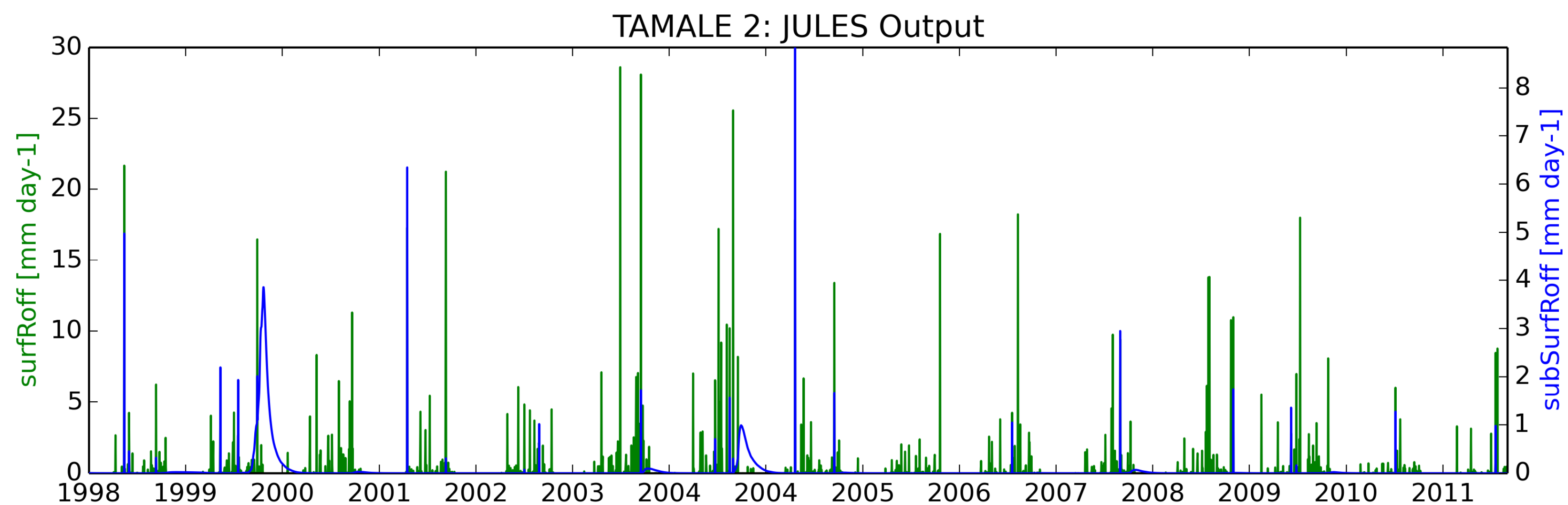
Applications 8

- Ouahigouya
- Ouagadougou
- Navrongo
- Tamale

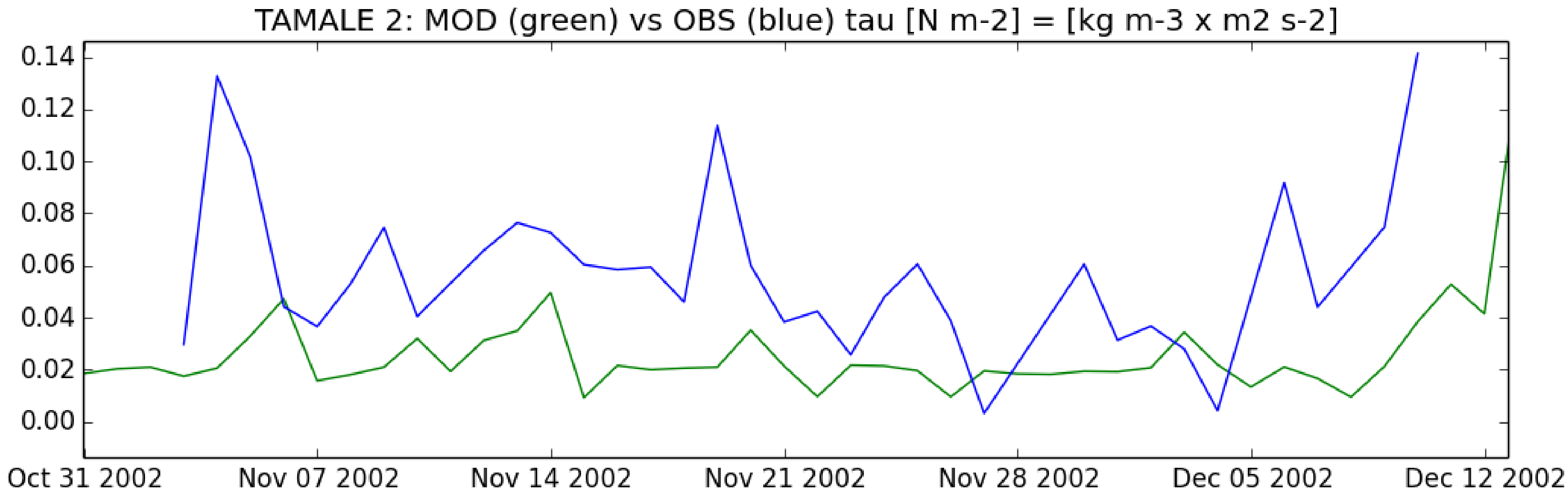


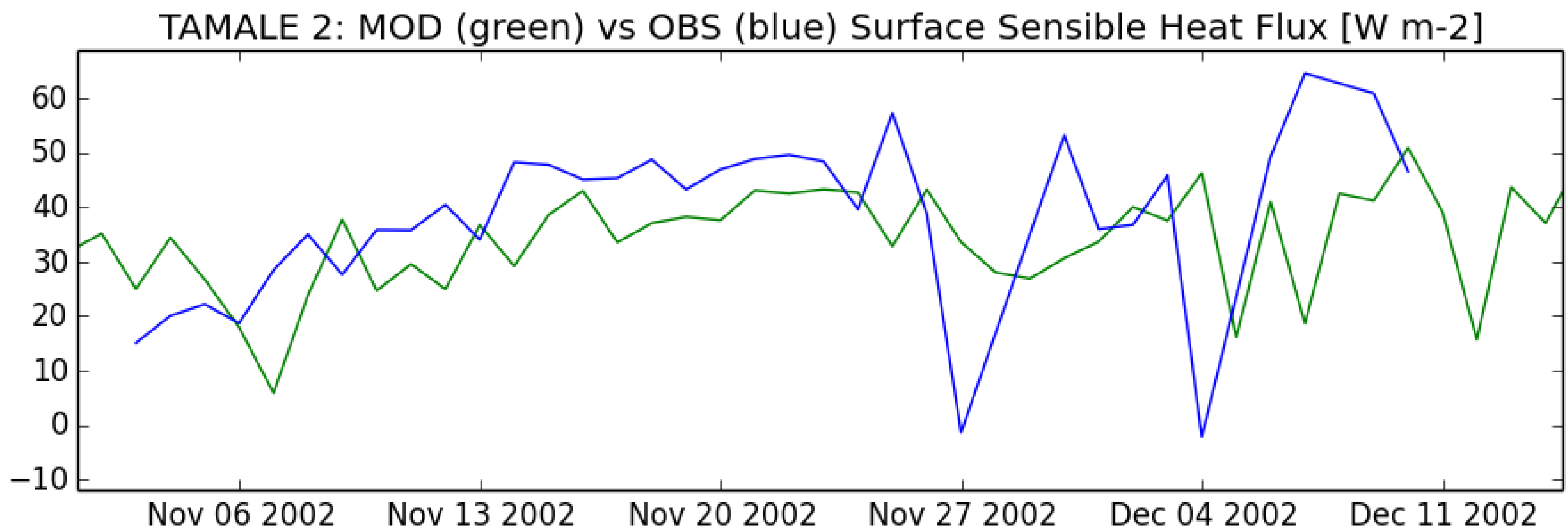
Applications 9





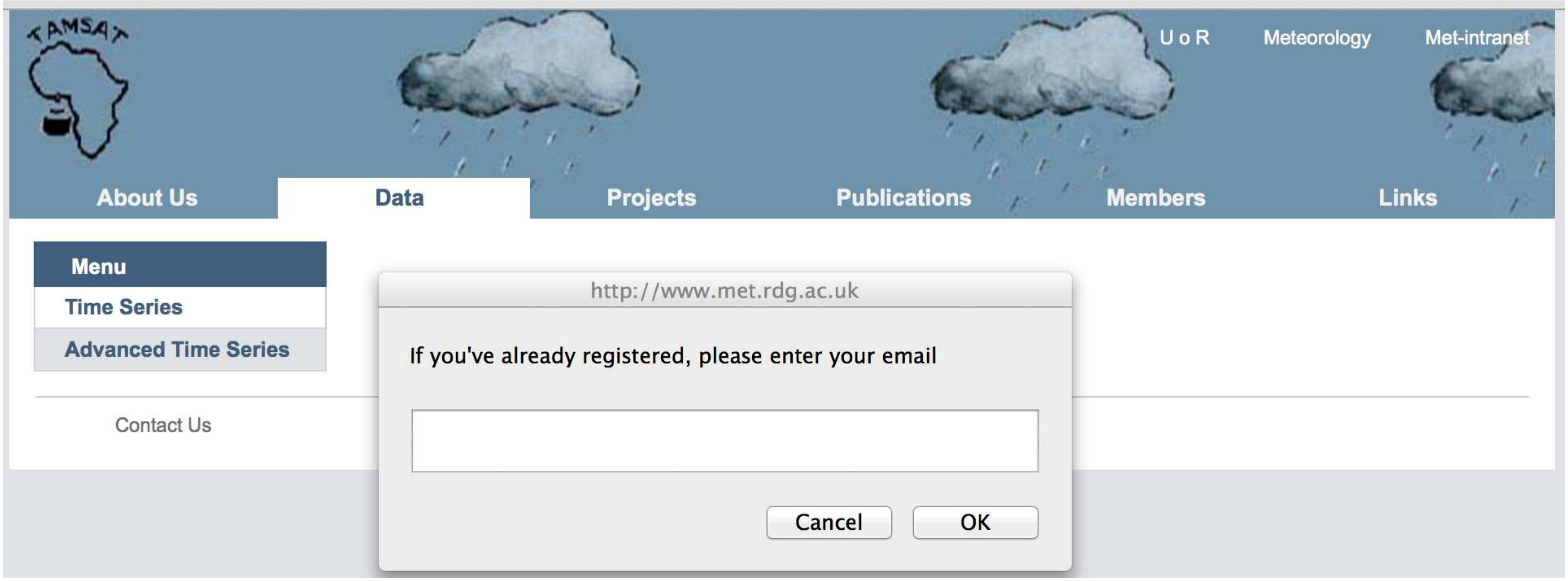
Applications 10



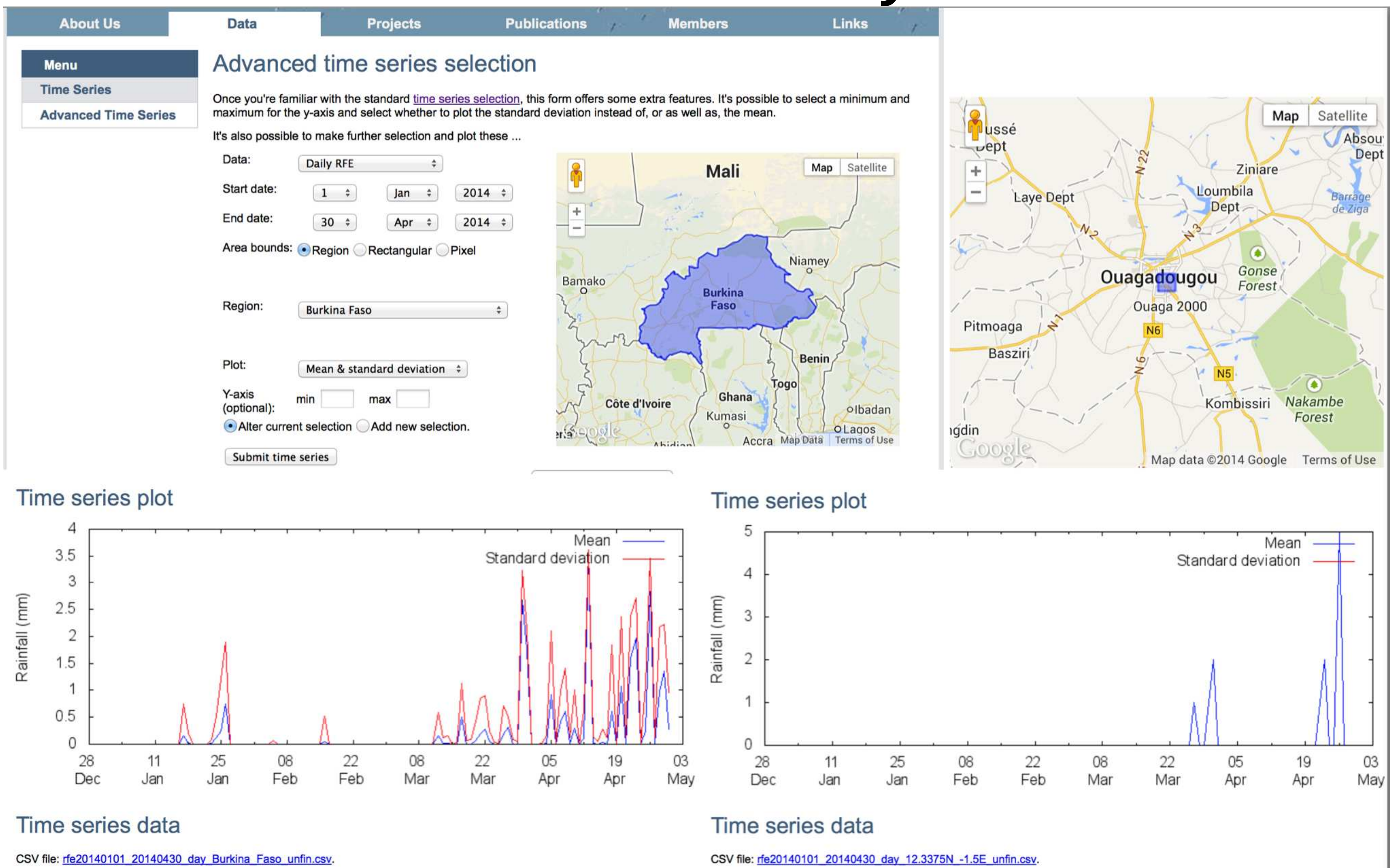


Visualization/Data Analysis tools

- SPIRITS (JRC)
- ILWIS Open (University of Twente)
- TAMSAT Data Visualizer – to be released in Summer 2014
  http://www.met.rdg.ac.uk/~tamsat/cgi-bin/time_series/time_series.cgi



Visualization/Data Analysis tools 2



Visualization/Data Analysis tools 3

Advanced time series selection

Once you're familiar with the standard time series selection, this form offers some extra features. It's possible to select a minimum and maximum for the y-axis and select whether to plot the standard deviation instead of, or as well as, the mean.

It's also possible to make further selection and plot these ...

Selection 1)

Data: Daily RFE

Start date: 1 Jan 2014

End date: 1 Apr 2014

Area bounds: Region Rectangular Pixel

Region: Burkina Faso

Plot: Mean

Y-axis (optional): min max

Alter current selection Remove selection.

Selection 2)

Data: Daily RFE

Start date: 1 Jan 2014

End date: 1 Apr 2014

Area bounds: Region Rectangular Pixel

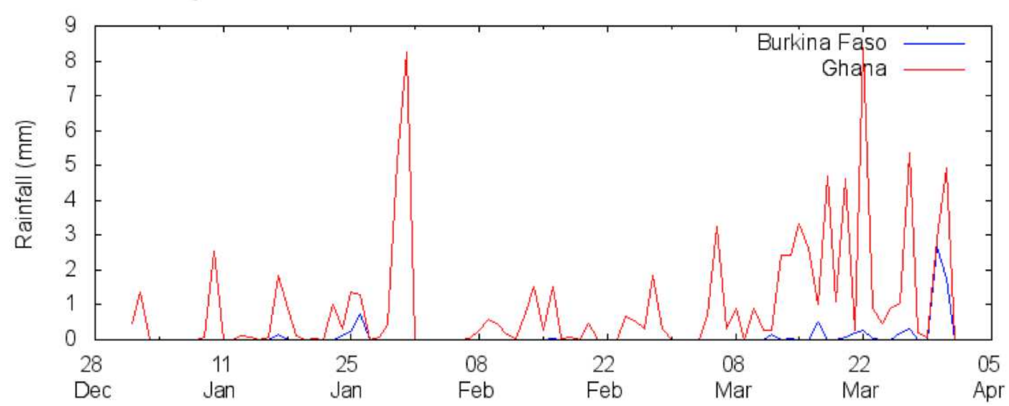
Region: Ghana

Plot: Mean

Y-axis (optional): min max

Alter current selection Add new selection.

Time series plot



Thank You!

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Post

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