Near Real Time Flood Water Mapping and Modeling

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NASA GSFC Office of Applied Sciences

May 29, 2013

Flood Mapping

Satellite Data Sources for Flood Mapping

- NASA data is free and publicly available
  - **MODIS on Aqua and Terra satellites (250m, revisit 2X daily)**
  - ASTER on Terra (15 m, revisit 16 days)
  - ALI and Hyperion on EO-1 (30 m, 3-4 day revisit)
  - Landsat 7 (30 m, 16 day revisit, scan line corrector issue)
  - Landsat 8 data to be available on Thursday at 1:00 Eastern Time (30 m, 16 day revisit)
- Other data sources available for purchase
  - Radar (RADARSAT, Terra SAR-X, ..)
  - Optical (SPOT, IKONOS, Quicksat, ..)

MODIS

- Terra Launch date, December 18, 1999
- Aqua Launch date, May 4, 2002
- ***MODIS LANCE system now providing***

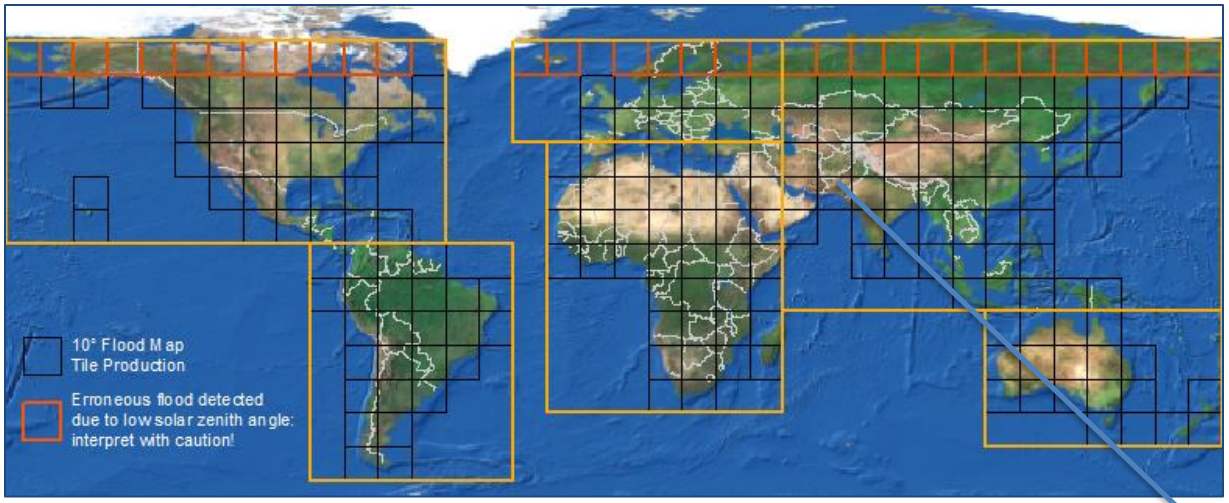
lvl 1 and 2 products within 2.5 hours of observation

- Follow-on sensor launched Oct. 28, 2011 (VIIRS on Suomi/ NPP)

SPECIFICATIONS

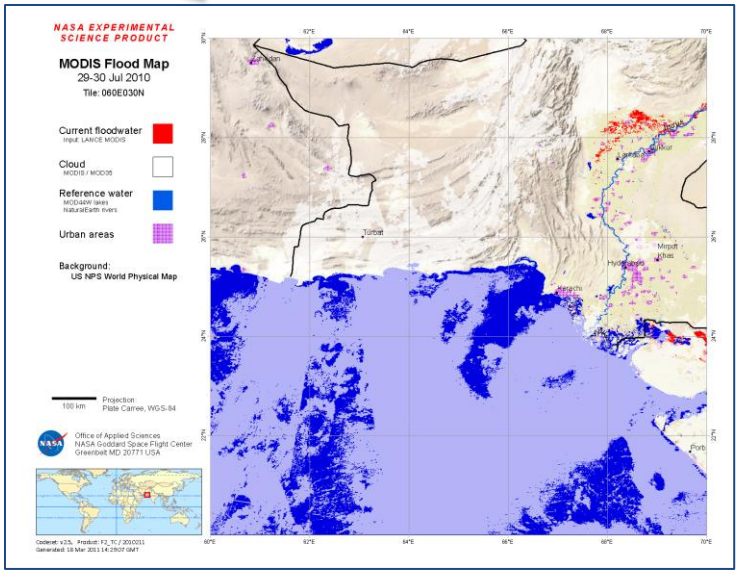
Orbit:	705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dimensions:	2330 km (cross track) by 10 km (along track at nadir)
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size:	1.0 x 1.6 x 1.0 m
Weight:	228.7 kg
Power:	162.5 W (single orbit average)
Data Rate:	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)
Design Life:	6 years

Experimental Global Near Real Time Surface Water Extent and Flood Extent Maps



http://oas.gsfc.nasa.gov/floodmap/

July 2010 Flooding in Pakistan



Dartmouth Observatory: http://floodobservatory.colorado.edu/LanceModis.html

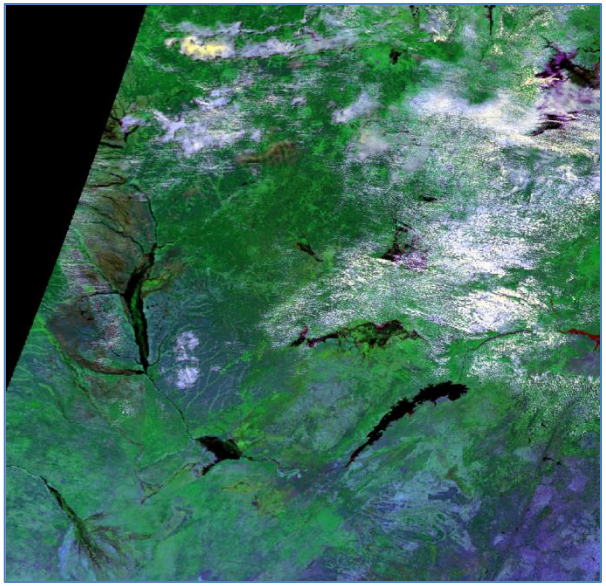
MODIS Images

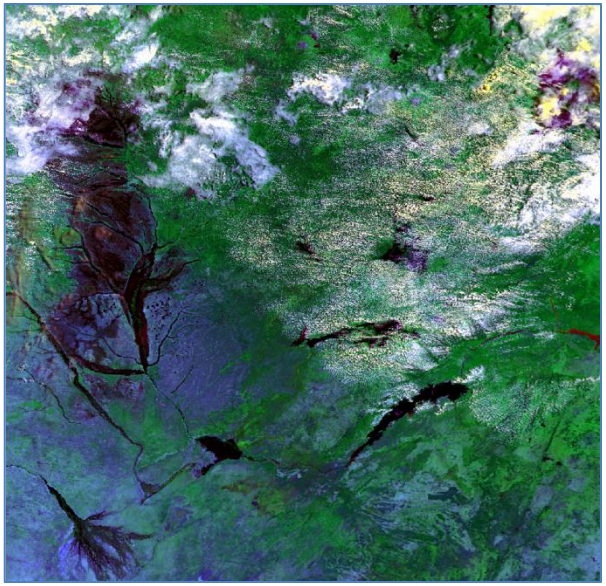
Terra | Aqua

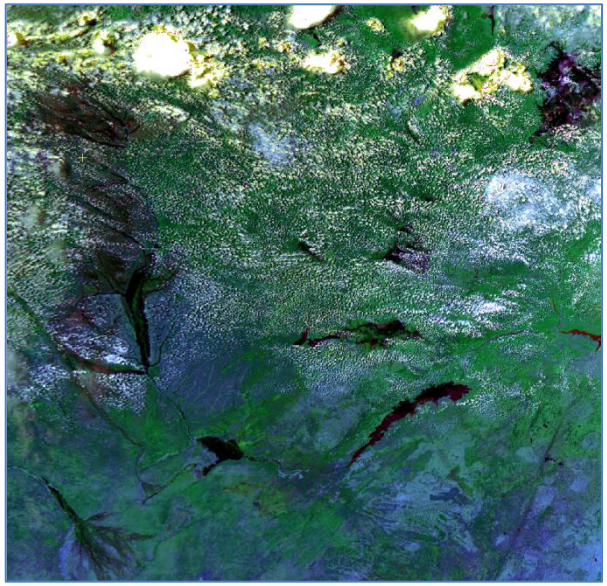
March 24, 2009

Tile h20 v10
Okavango Delta –
Lake Kariba

March 25, 2009

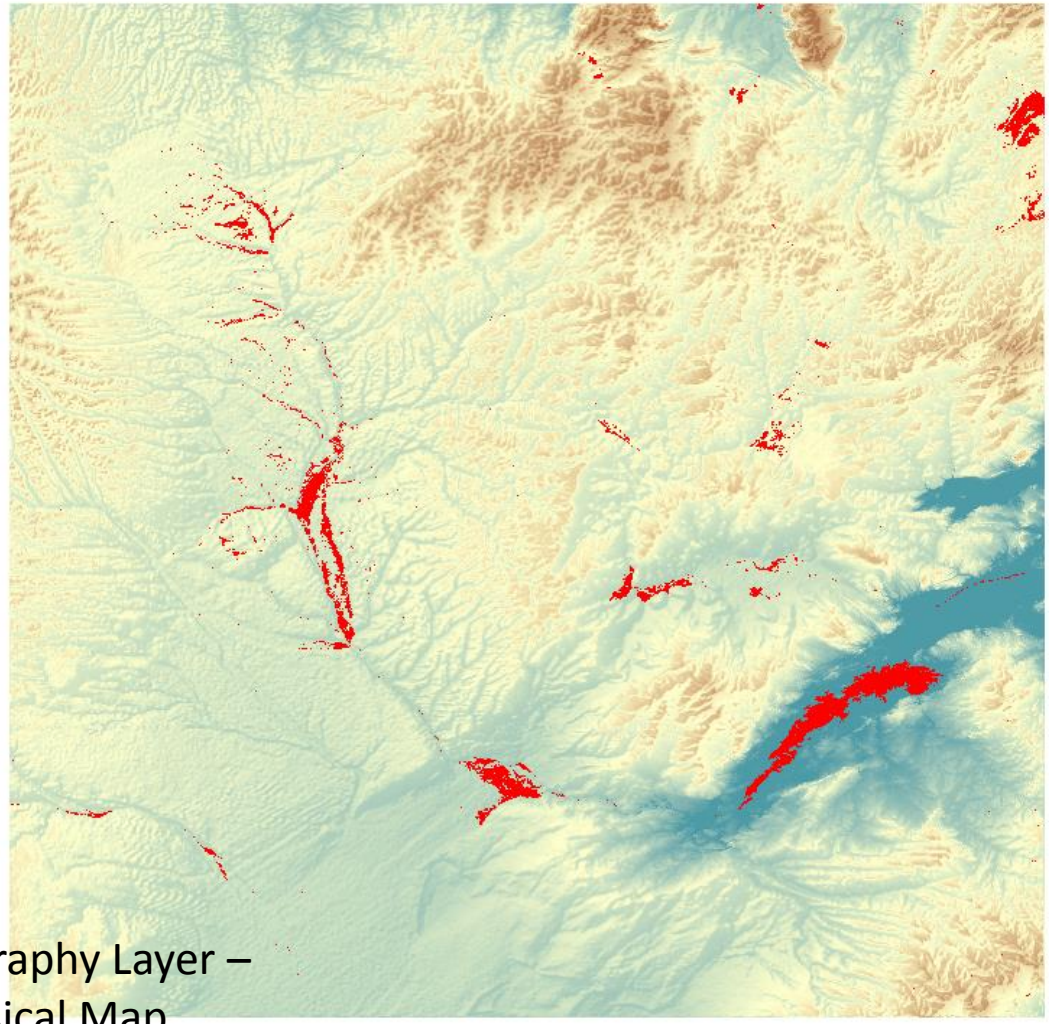






Surface Water from MODIS Bands 1 and 2

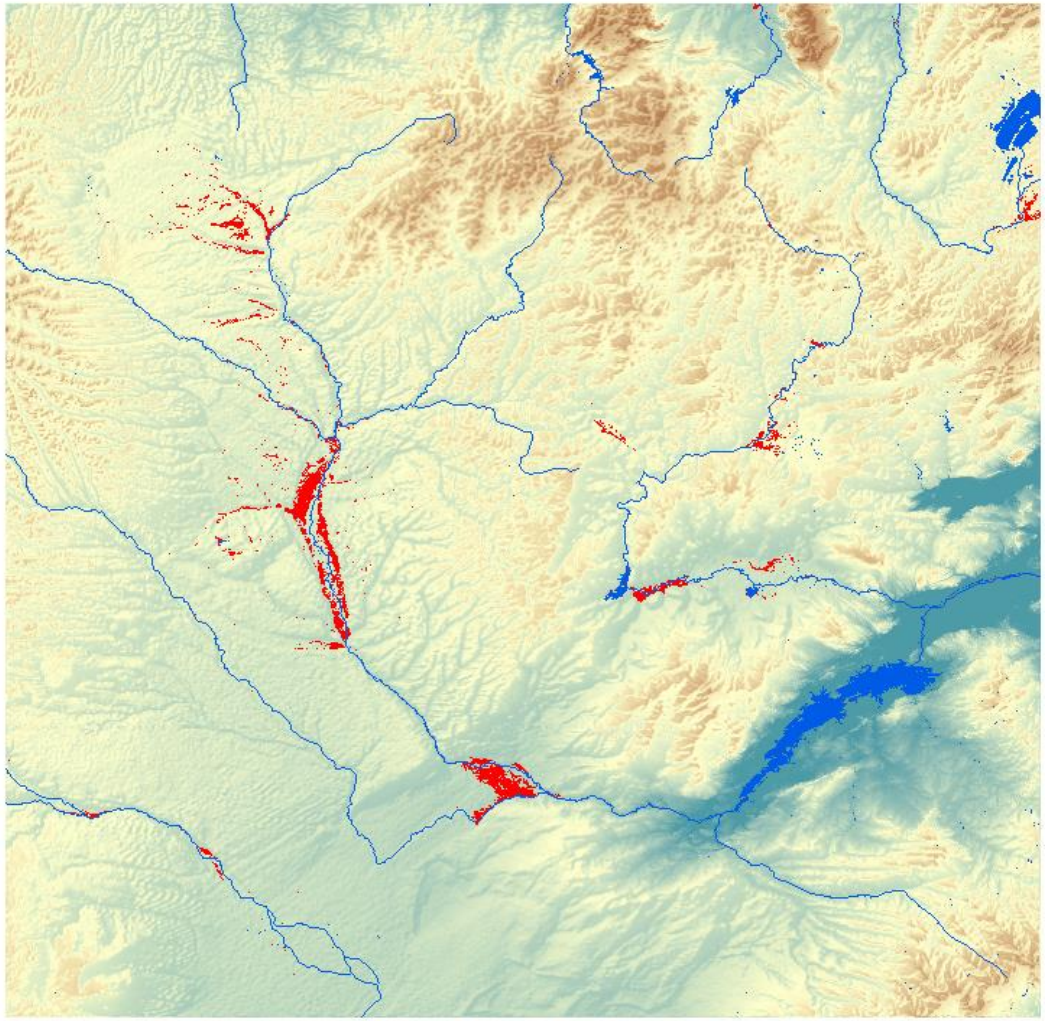
Dartmouth
Flood Observatory
Algorithm



Background Topography Layer –
US NPS World Physical Map

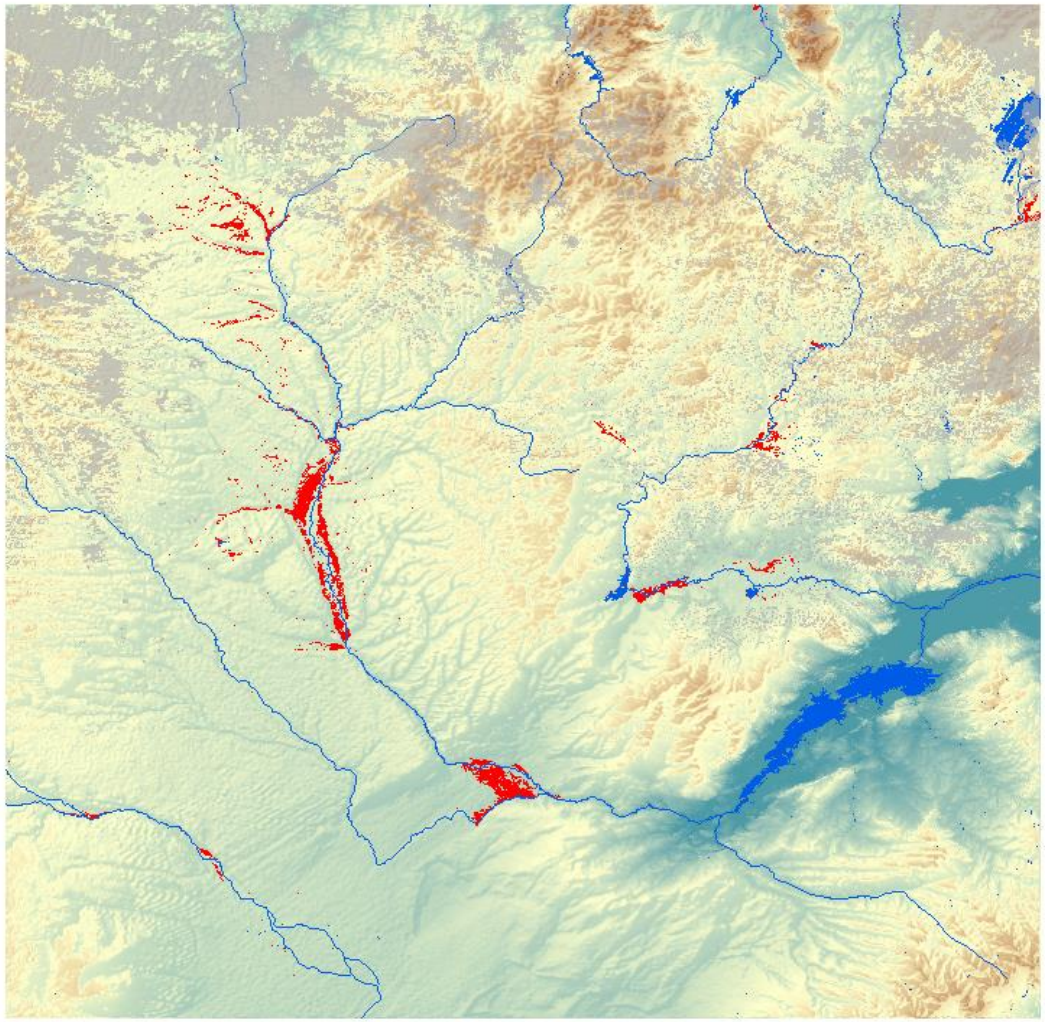
Reference water overlay: lakes & rivers
Remaining red = potentially flooded areas

MOD44W
overlay

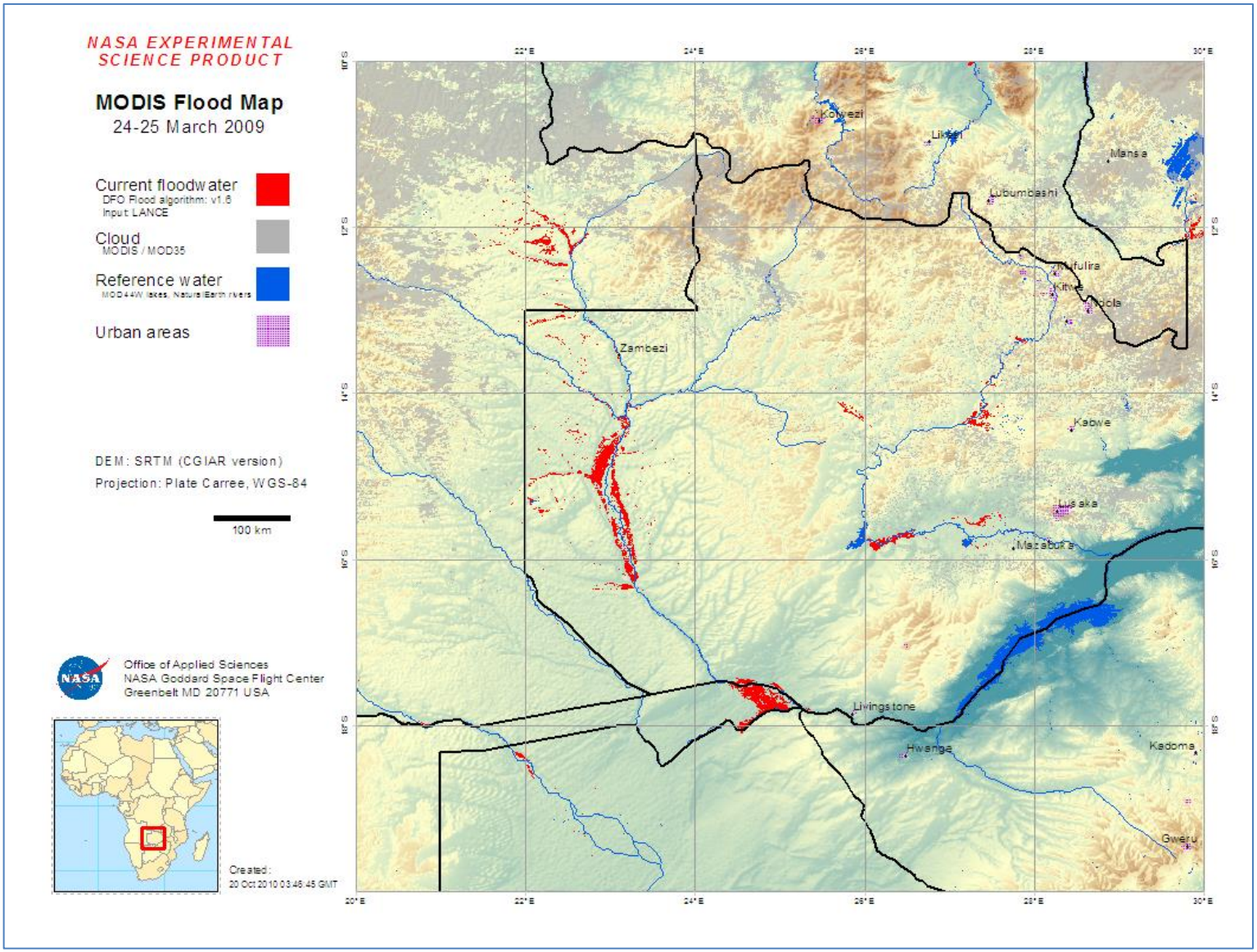


Cloud areas masked

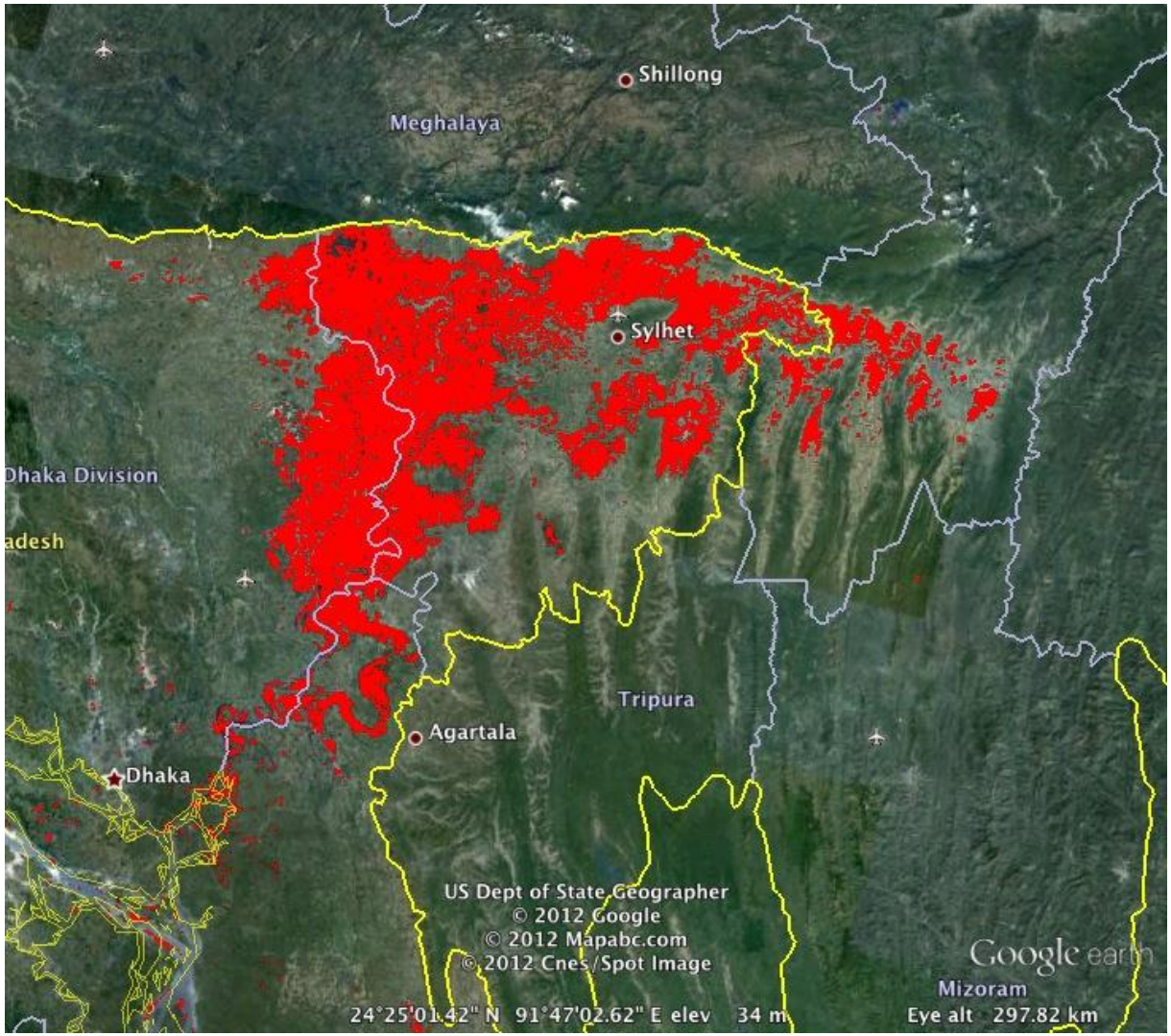
MOD35
Cloud product



Annotations for published product



View in Google Earth



July 2012 Flooding in Assam, India

MODIS Flood Products

- MODIS Flood Map (MFM) – png
- MODIS Flood Water (MFW) – shapefile, KMZ
- MODIS Surface Water (MSW) – shapefile, KMZ
- MODIS Water Product (MWP) – geotiff; combines both MFW and MSW)

  Raster product provided with the following pixel values:

  0 : Insufficient data to make water determination (cloudy, missing images, swath gaps, or bad data values).

  1 : No water detected.

  2 : Water detected AND coinciding with reference water (e.g., not flood).

  3 : Water detected, beyond reference water, so may be flood

- README (for all products) – pdf, txt

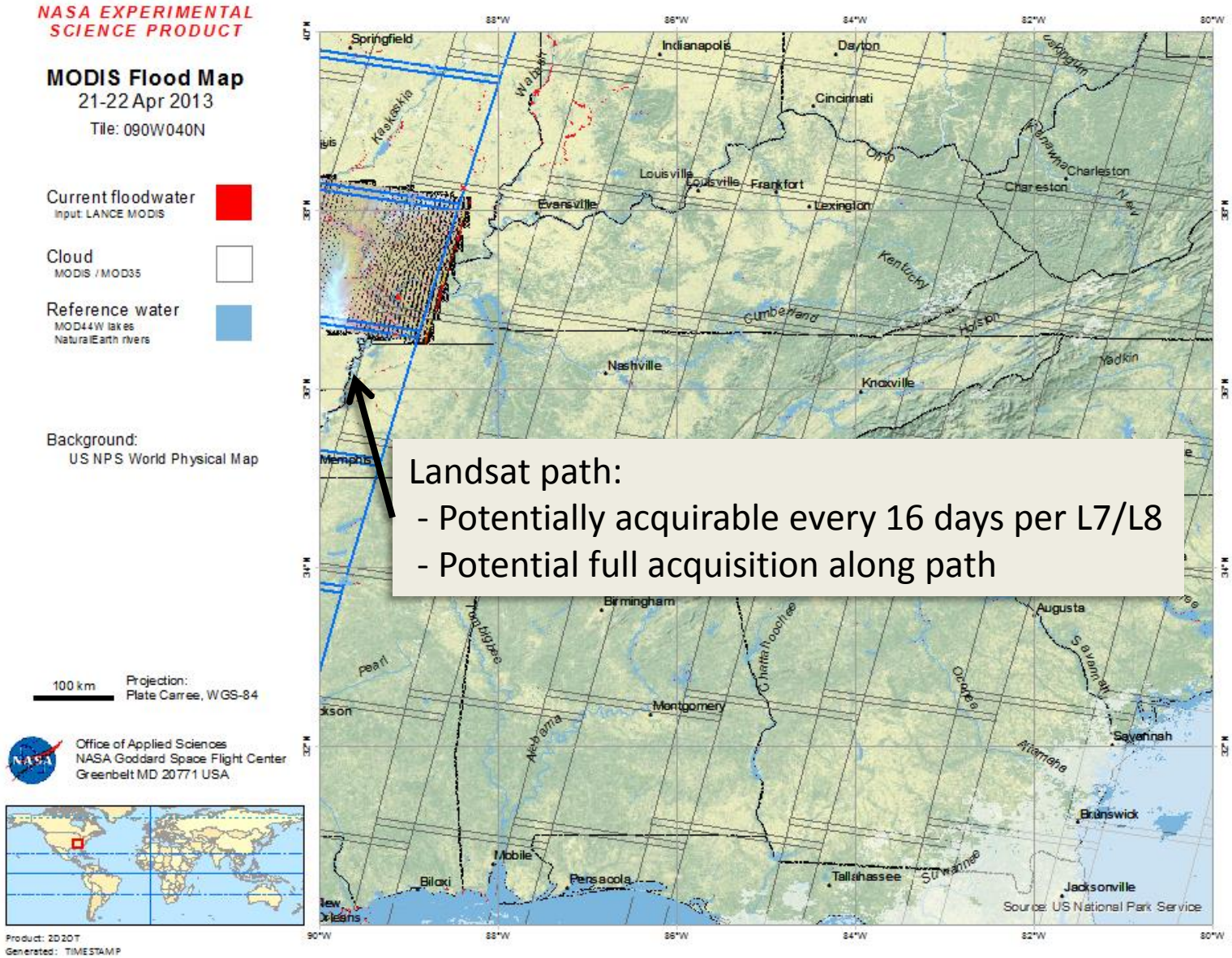
MODIS Flood Products

- 2 day composites: 2 water detects required (out of 4 images) – method of cloud shadow masking

- (new) 3 day composites: 3 water detects required (out of 6 images) – method of cloud shadow masking

- 1 day composites: On demand, 1 water detect required (out of 2 images)– experimental geometry based cloud shadow mask

MODIS Flood Map April 21 with Landsat image & path/row grid



MODIS Water Extent on Landsat 7 Image

NASA EXPERIMENTAL SCIENCE PRODUCT

MODIS Flood Map

21-22 Apr 2013

Tile: 090W040N

Current floodwater
Input: LANCE MODIS

Cloud
MODIS / MOD35

Reference water
MOD44W lakes
NaturalEarth rivers

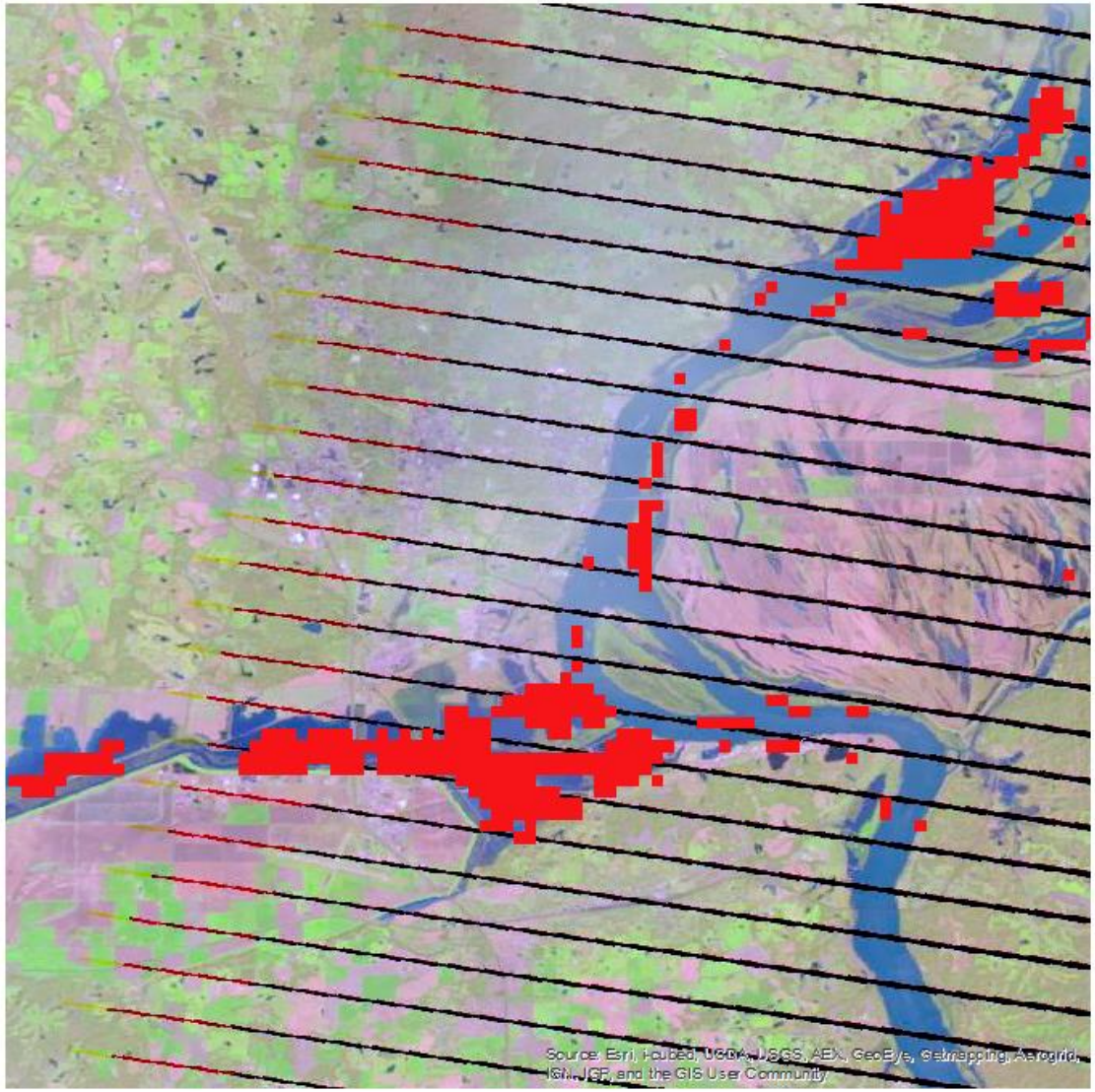
Background:
US NPS World Physical Map

1 km

Projection:
Plate Carree, WGS-84

Office of Applied Sciences
NASA Goddard Space Flight Center
Greenbelt MD 20771 USA

Product: 2D2DT
Generated: TIMESTAMP



Landsat Water Extent Map

NASA EXPERIMENTAL SCIENCE PRODUCT

~~MODIS Flood Map~~

21-22 Apr 2013

Tile: 090W040N

Landsat Water

Cloud
MODIS / MOD35

Reference water
MOD44W lakes
NaturalEarth rivers

Background:
US NPS World Physical Map

1 km

Projection:
Plate Carree, WGS-84

Office of Applied Sciences
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Product: 2D20T
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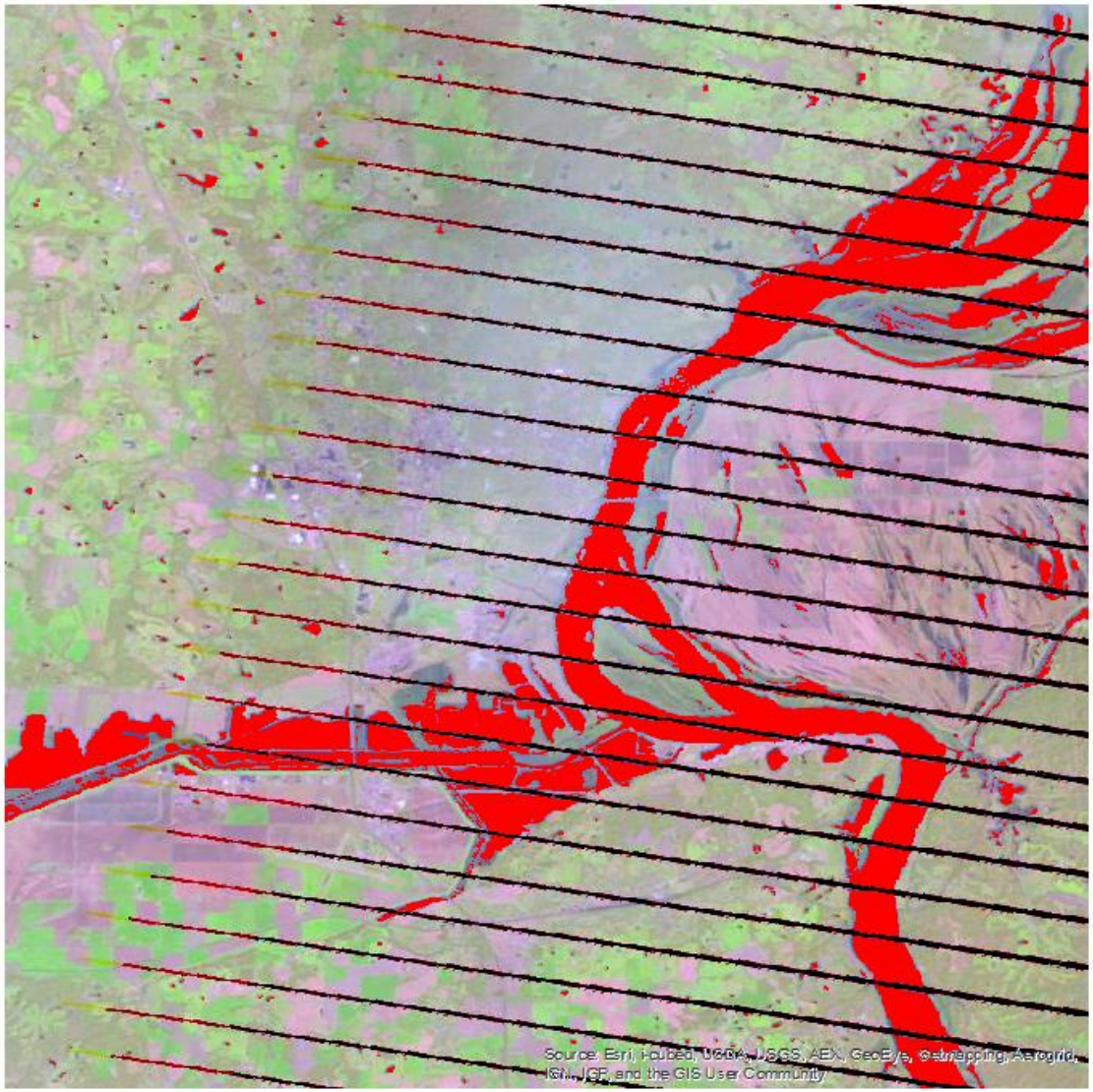
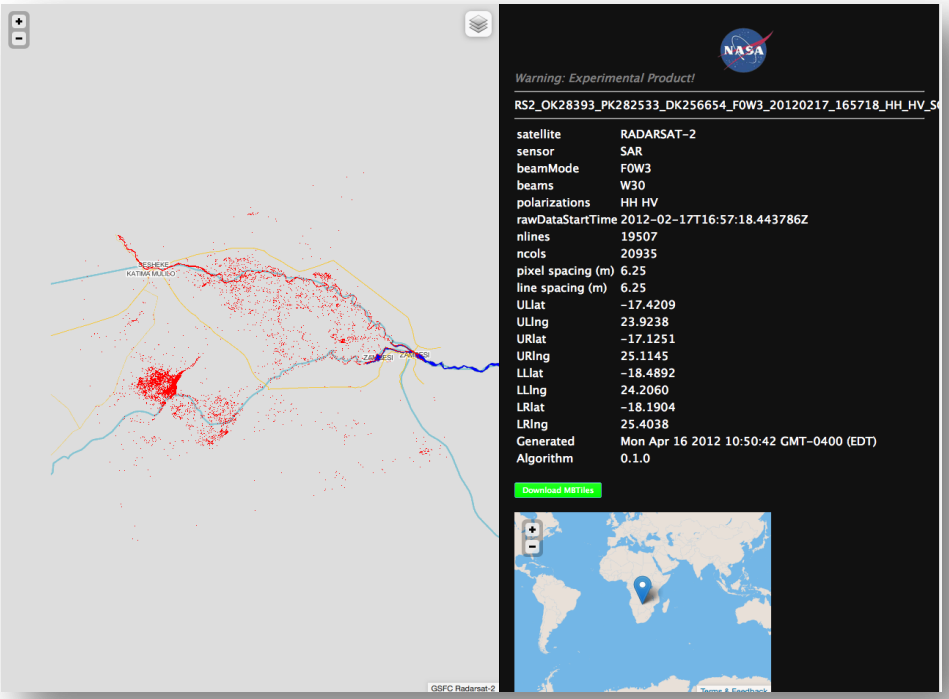


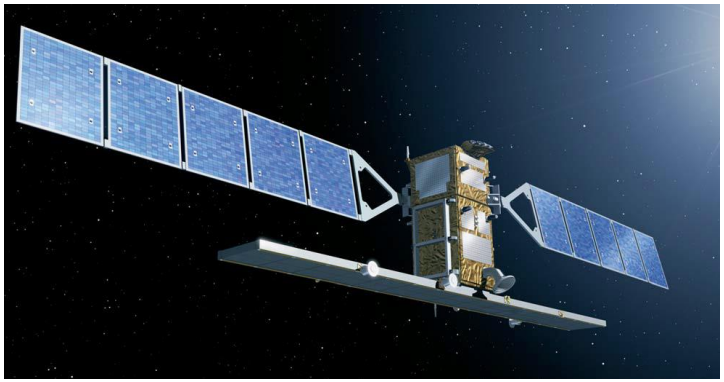
Radar Flood Mapping

- Partnership with CSA under CEOS/ GEO flood pilot projects
  - CSA has provided 400 free tasking requests for RADARSAT 2
  - Approx. 160 tasking requests to date in 2 pilot regions
  - Maximum resolution: 3m
  - Project includes training and capacity building for use of radar data in partner areas through CEOS project (CSA and other funding)



Prototype Automated RARDARSAT 2 Flood Map: April, 2012 Flooding in Namibia

Looking Forward to:
ESA Sentinel 1 Radar Mission



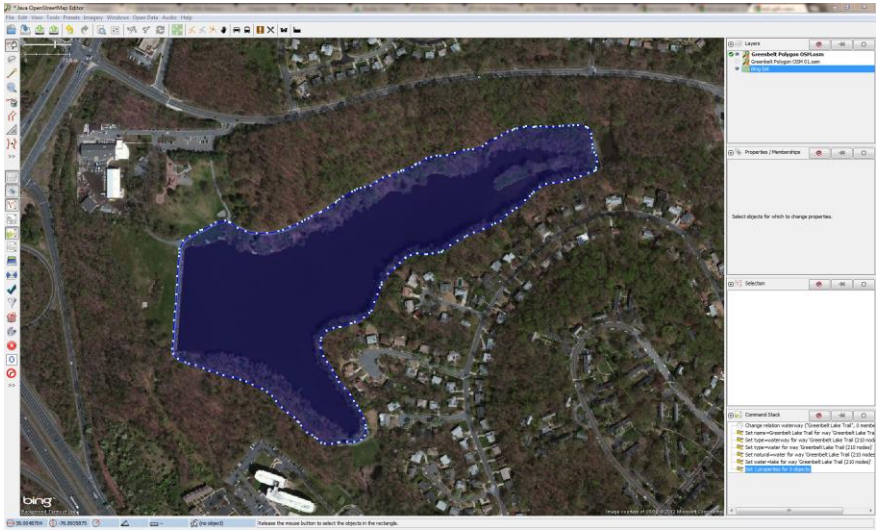
Expected Launch: 2013
Expected Free and Open Data Policy

- C-Band Radar
- Six day orbital repeat
- Near real time delivery of data within an hour after reception by the ground station
- Four standard operational modes, designed for interoperability with other systems:
  - Strip Map Mode, 80 km swath and 5 x 5 m spatial resolution;
  - Interferometric Wide Swath Mode, 250 km swath, 5 x 20 m spatial resolution
  - Extra-wide Swath Mode, 400 km swath and 25 x 100 m spatial resolution
  - Wave Mode, low data rate and 5 x 20 m spatial resolution. Sampled images of 20 x 20 km at 100 km intervals along the orbit.

http://www.esa.int/esapub/bulletin/bulletin131/bul131a_attema.pdf

In-situ Measurements of Water Extent to Enhance Satellite Data
Waterpedia Project: Collaboration with Open Street Map

P.I. : Dan Mandl, NASA GSFC



GSFC Lake & Greenbelt Lake – Students Taking GPS Points

Left: Neil Shah, Summer Intern, Univ. of Md College Park, major Aerospace Engineering, Middle: Chris Flatley, summer intern, Virginia Tech, major Computer Engineering

Joshua Bronston, Navajo Tech College GSFC Coop student – Pursuing Masters in Computer Engineering

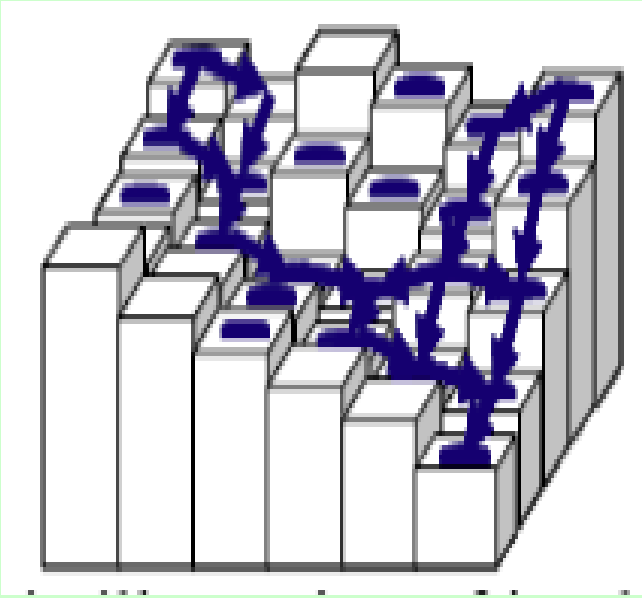
Flood Mapping Next Steps

- Process historical flood maps for MODIS record
- MODIS validation/ incorporate lessons learned
- Transition MODIS flood mapping to operations – Pacific Disaster Center
- Fully automate RADAR flood mapping (for Caribbean, MENA TBD)
- Landsat Flood Maps (for Caribbean, MENA TBD)
- Investigate merged products
- Waterpedia

Flood Modeling

NASA/ OU CREST Cell-based Water Balance Model

Cell-to-Cell Flow Routing



Storage = (Precip. — ET) + (Inflow – Outflow) - Infiltration

Step I: Rainfall-infiltration Partitioning (Distributed and Time-variant)

Step 2: Flow Routing using Macro-scale Cell-to-Cell Algorithm

Step 3: Flood Inundation Mapping

CREST Flood Model Inputs

Precipitation = TRMM TMPA-RT product

- **0.25 degree resolution product**
- 0.10 degree “IMERG” product under development at NASA GSFC
- Evaluation using rain guage measurements

Digital Elevation Model (and derived products) = SRTM Hydrosheds product

- **1 km product**
- 90 m = highest resolution hydrologically corrected product available
- 250 m resampled product
  - Computational requirements for calibration
  - Direct Comparison with MODIS flood maps
- Evaluation using Landsat imagery of rivers

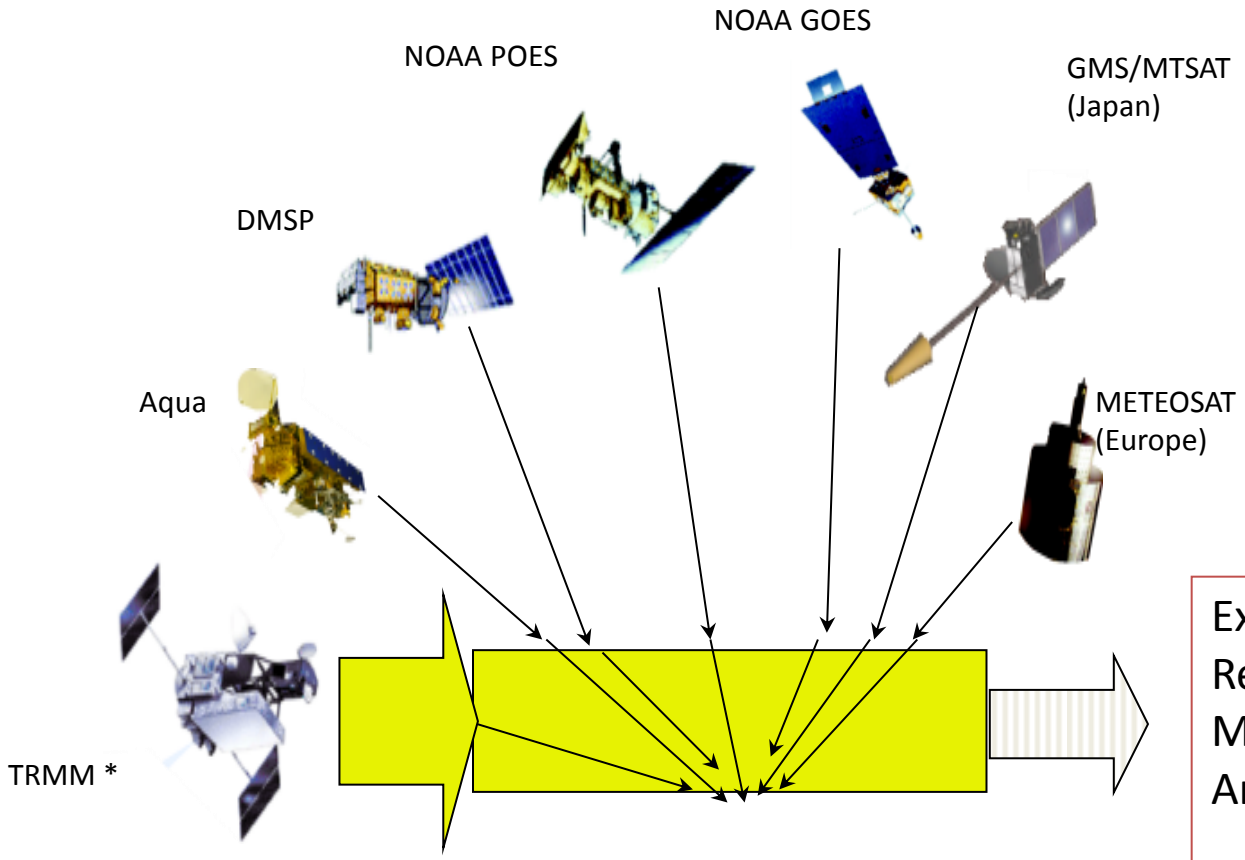
Evapotranspiration = FEWSNET Climatology product

- **0.25 degree monthly historical average**
- Investigating use of ALEXI model data, daily NRT FEWSNET product
- In-situ Measurements?

Stream gauge data for calibration and validation !

PRECIPITATION

Key Model Input - NASA Near Real Time *Rainfall Measurements*



Experimental Near Real-Time TRMM Multi-Satellite Precipitation Analysis (TMPA-RT)

* TRMM used to calibrated all other satellites

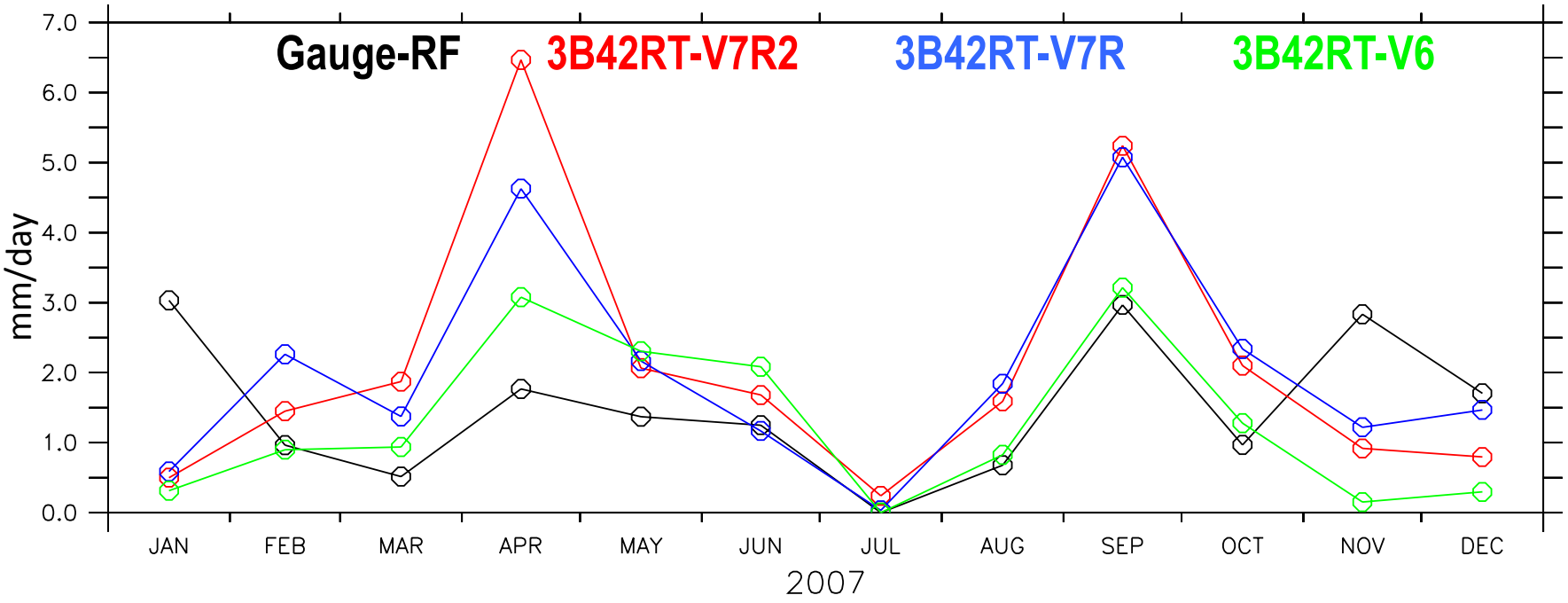
From: Hong, Adler

Global Precipitation Measurement (GPM) Mission to Launch February 2014

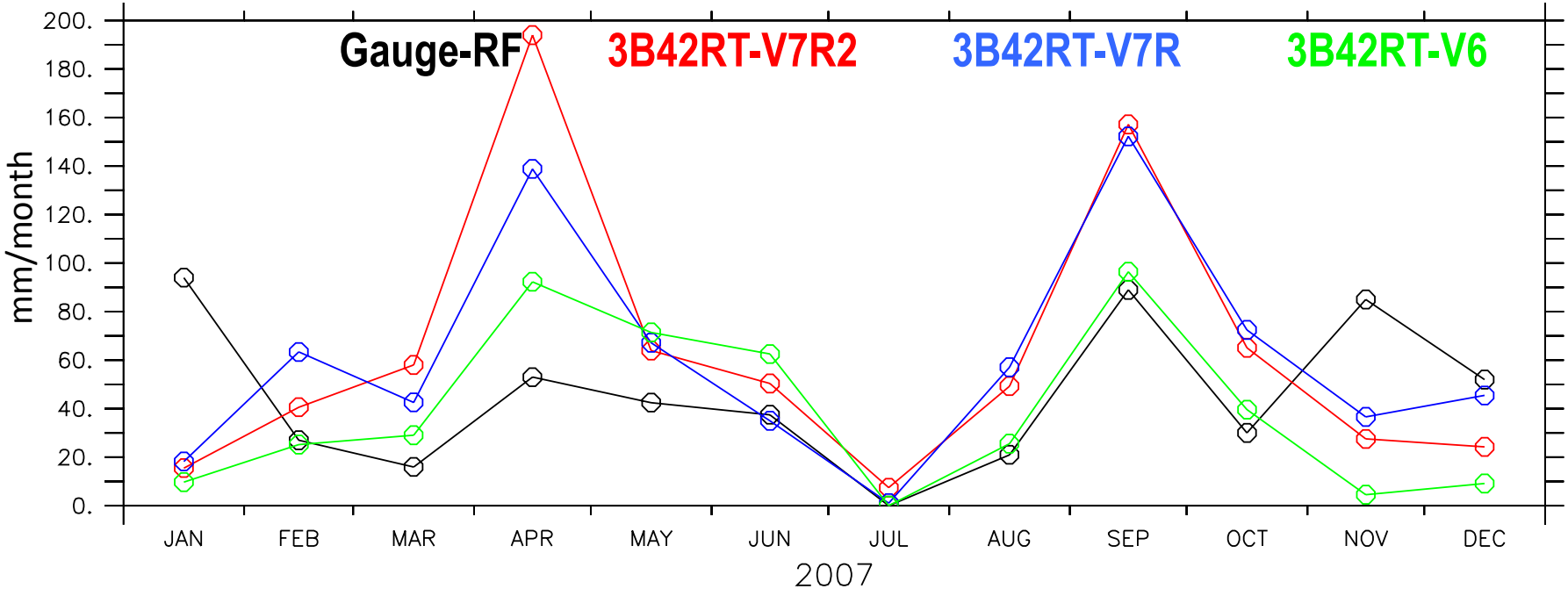
TUNISIA Rainfall and Statistics
TMPA vs Rain-Gauge
(daily and Monthly)

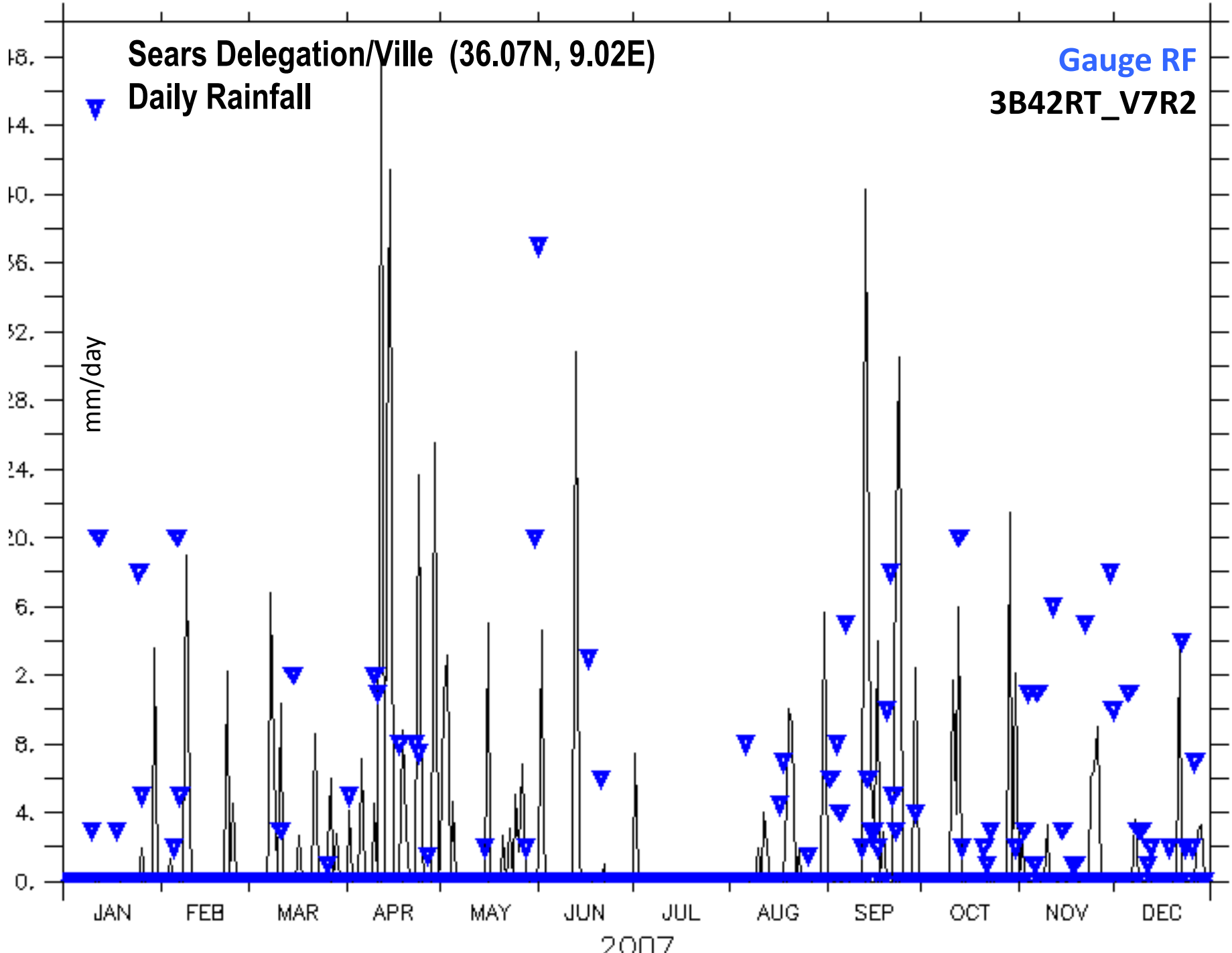
Note: Rain Gauge data (1 year)
TMPA: 2000-2012 (Latest 3B42RT-V7R2)

Monthly Rainfall (mm/day), SERS DELIGATION (36.07N, 9.02E)



Monthly accumulated Rainfall (mm/month), SERS DELIGATION (36.07N, 9.02E)




Sears Delegation/Ville (36.07N, 9.02E)
Daily Rainfall
Gauge RF
3B42RT_V7R2
mm/day
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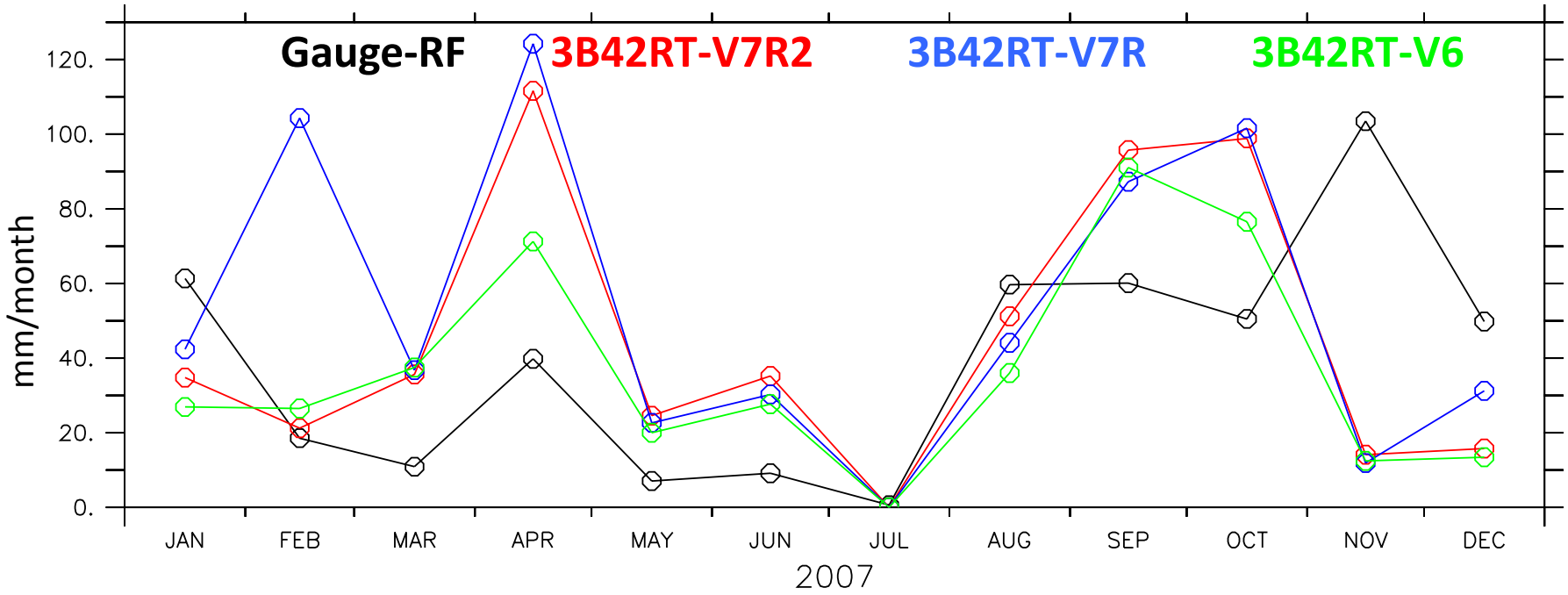
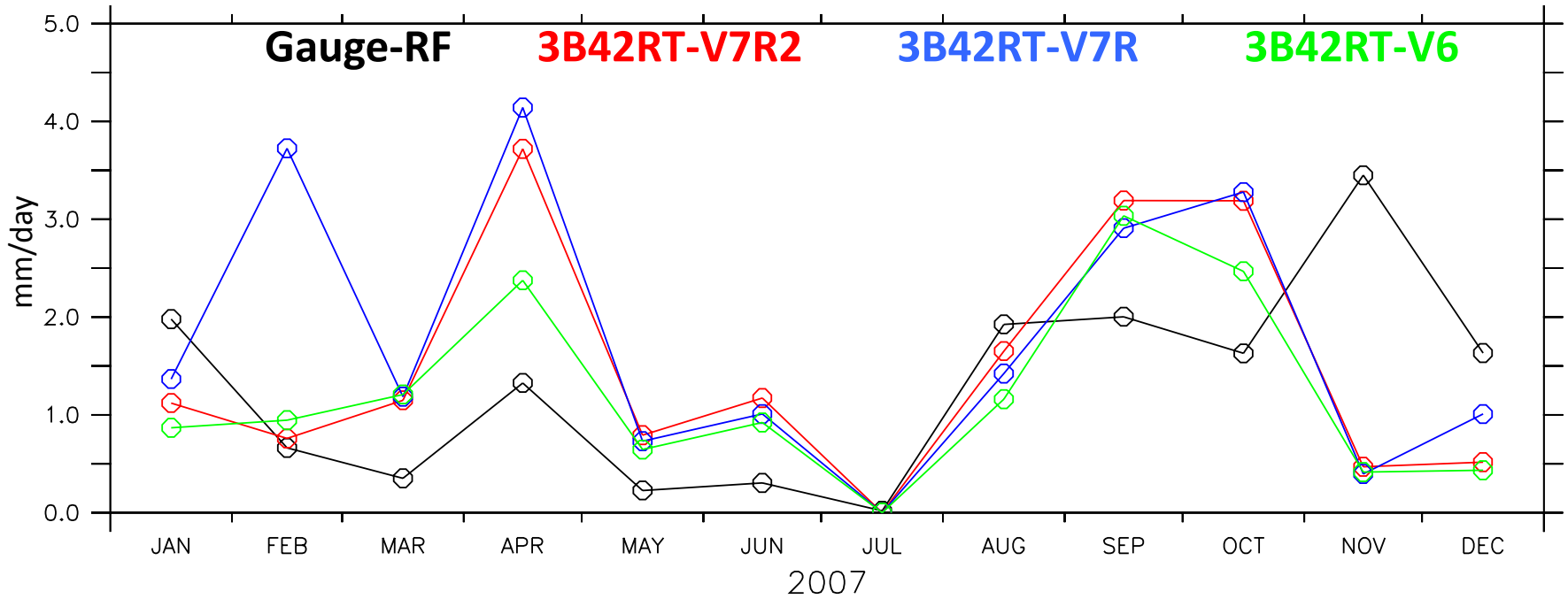
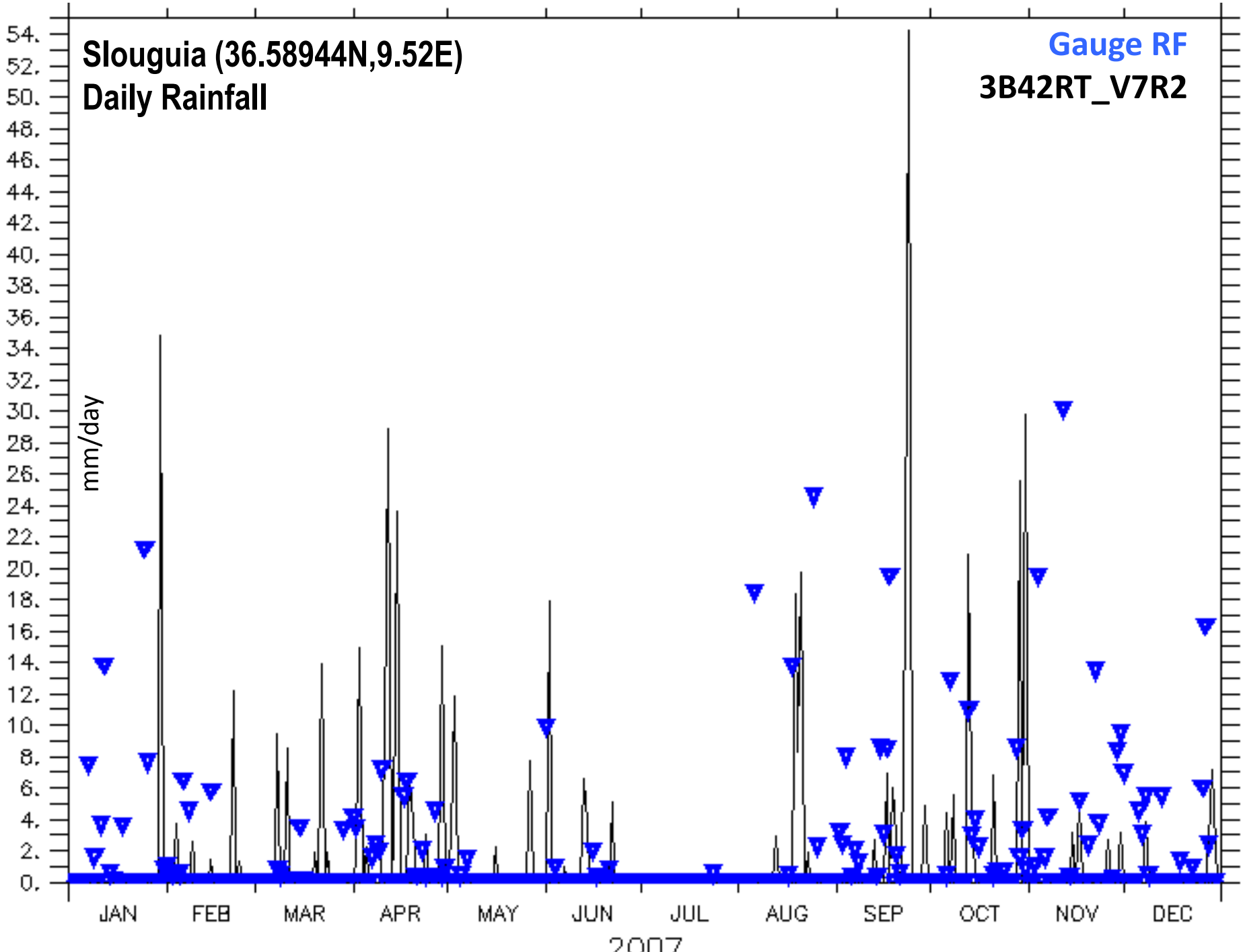
2007

Monthly accumulated Rainfall (mm/month), SLOUGUIA (36.58944N, 9.52E)



Monthly Rainfall (mm/day), SLOUGUIA (36.58944N, 9.52E)




Slouguia (36.58944N,9.52E)
Daily Rainfall
Gauge RF
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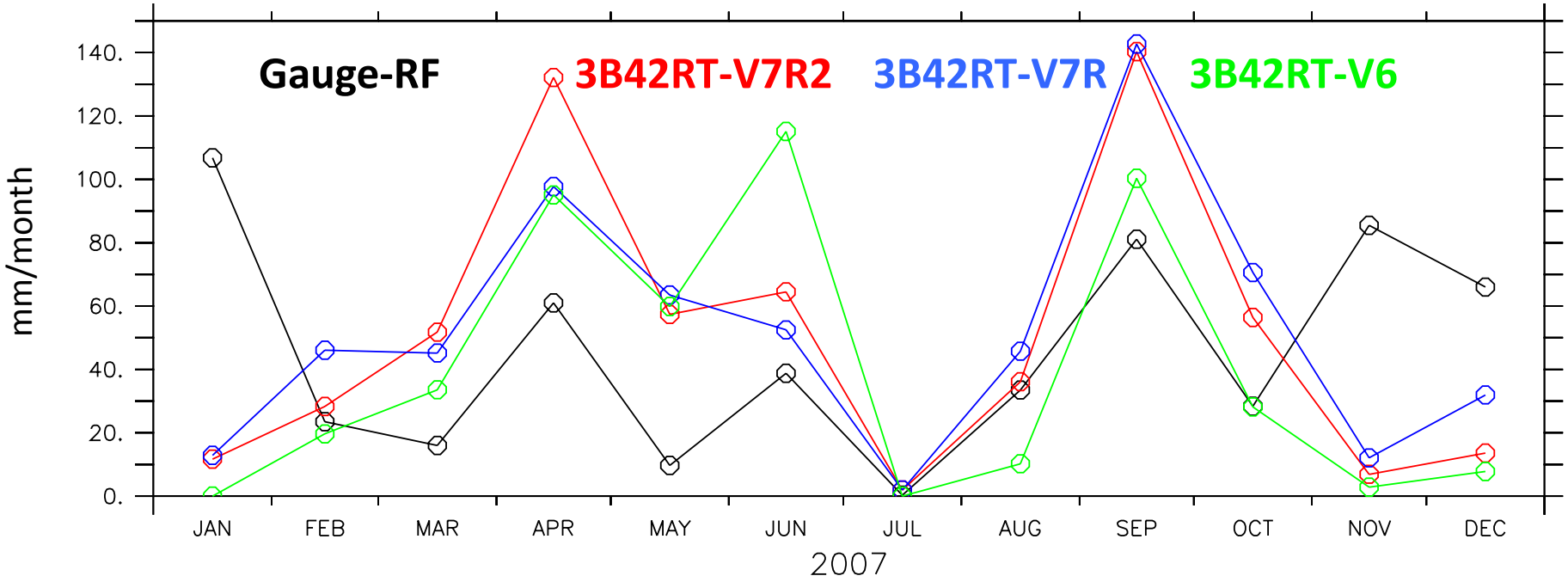
Monthly accumulated Rainfall (mm/month), Djebel Kbouch PF (3622306N, 8.899445E)



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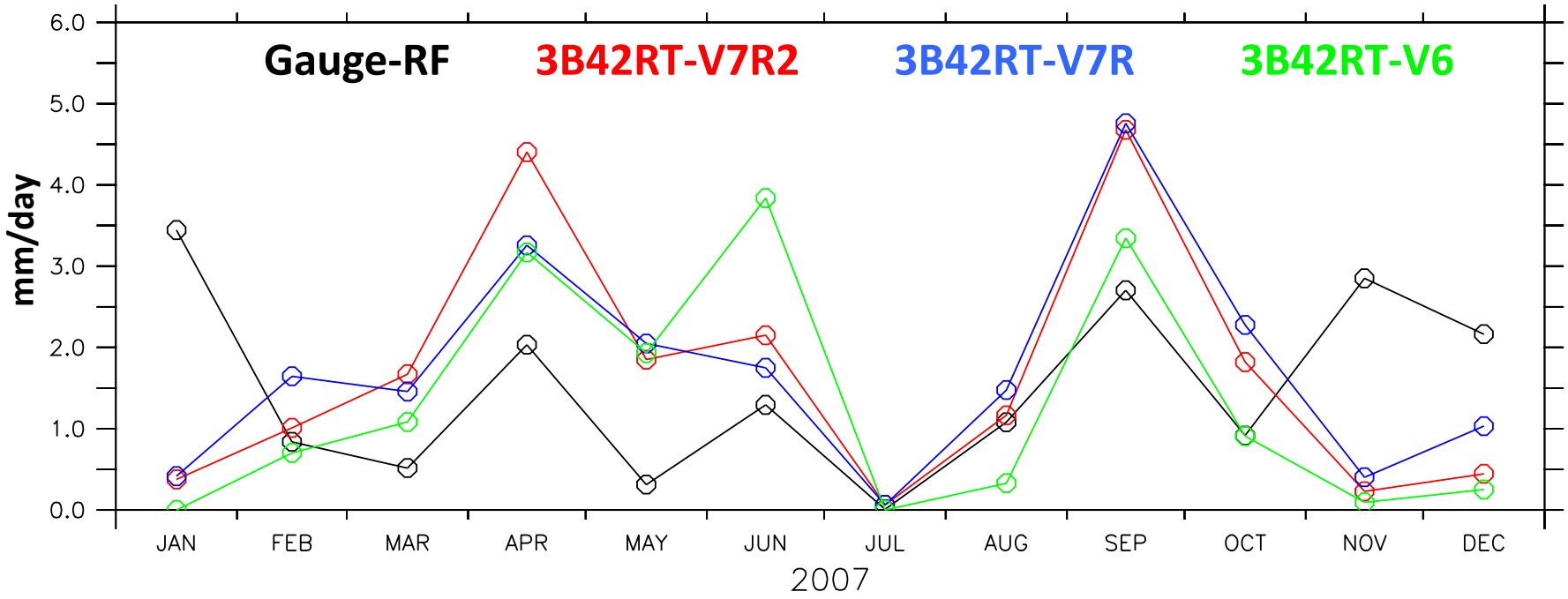

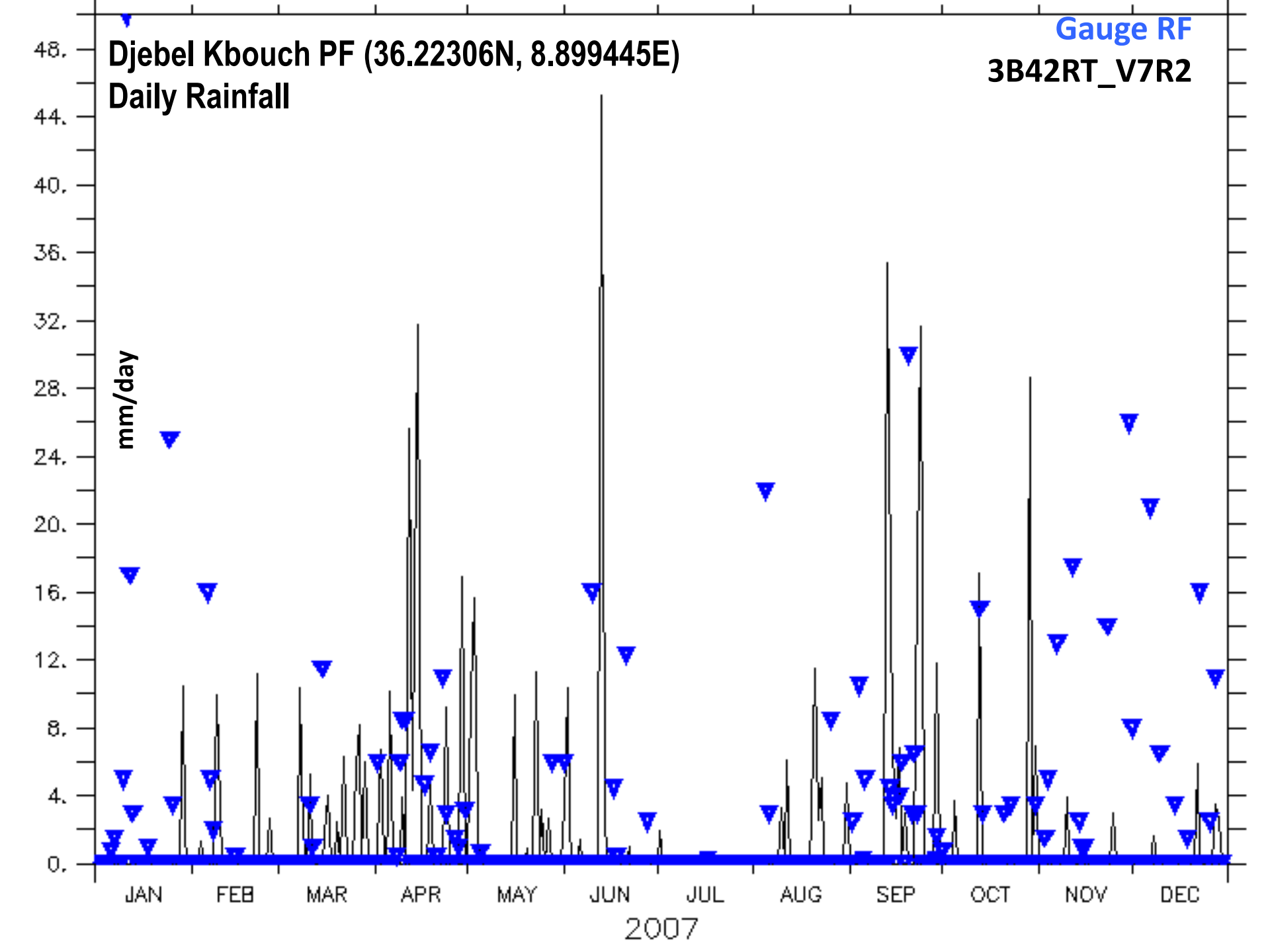
Djebel Kbouch PF (36.22306N, 8.899445E)
Daily Rainfall
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mm/day
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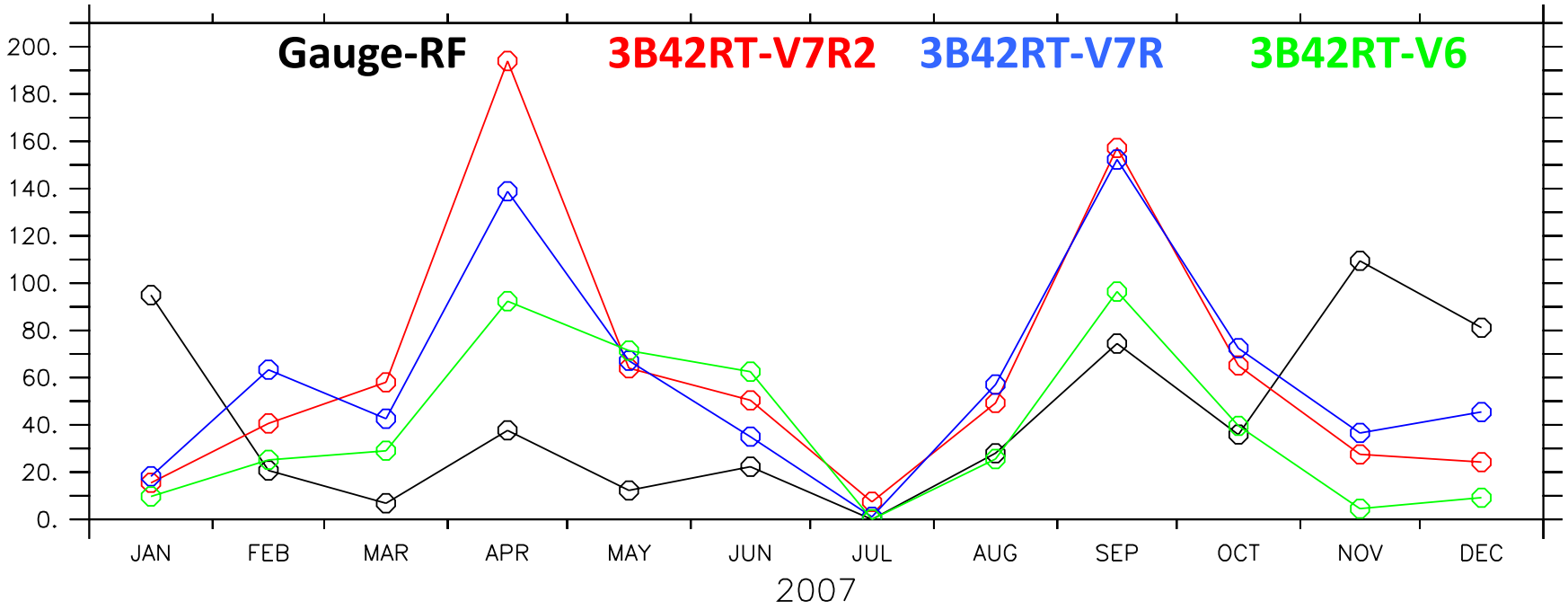
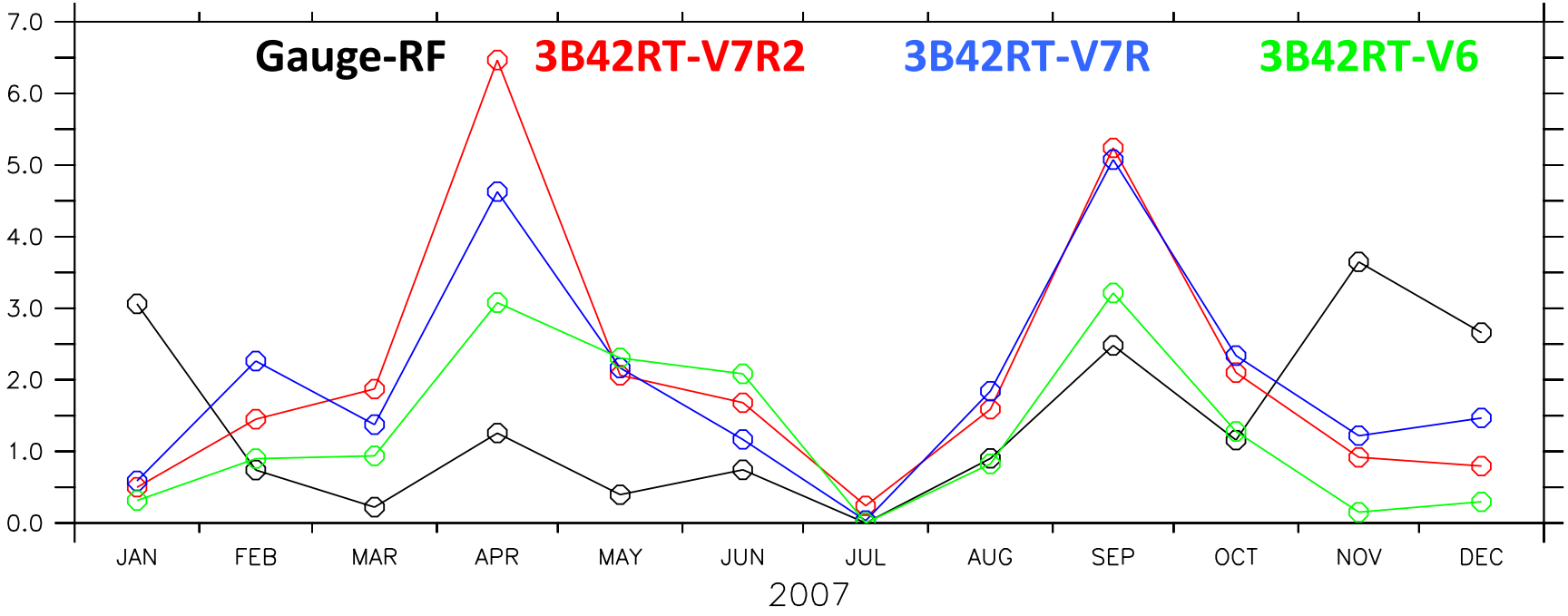
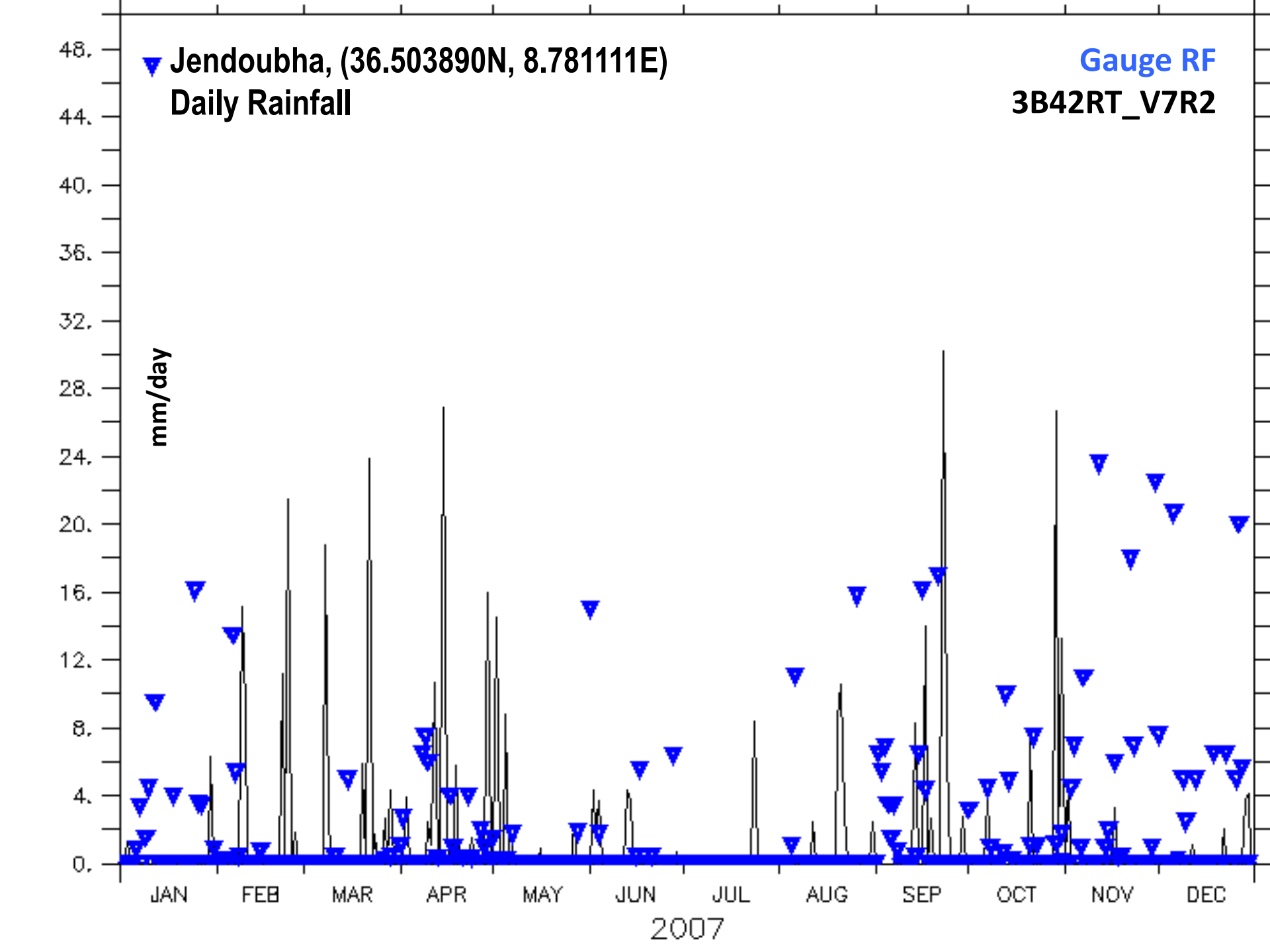
Monthly accumulated Rainfall (mm/month), Jendoubha, (36.503890N, 8.781111E)



Monthly Rainfall (mm/day), Jendoubha, (36.503890N, 8.781111E




Jendoubha, (36.503890N, 8.781111E)
Daily Rainfall
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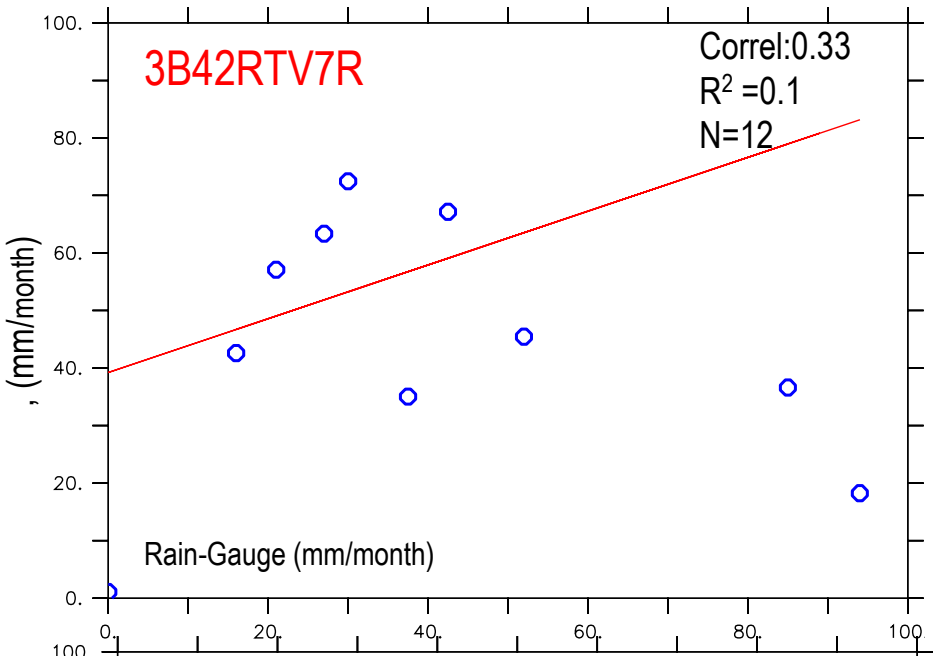
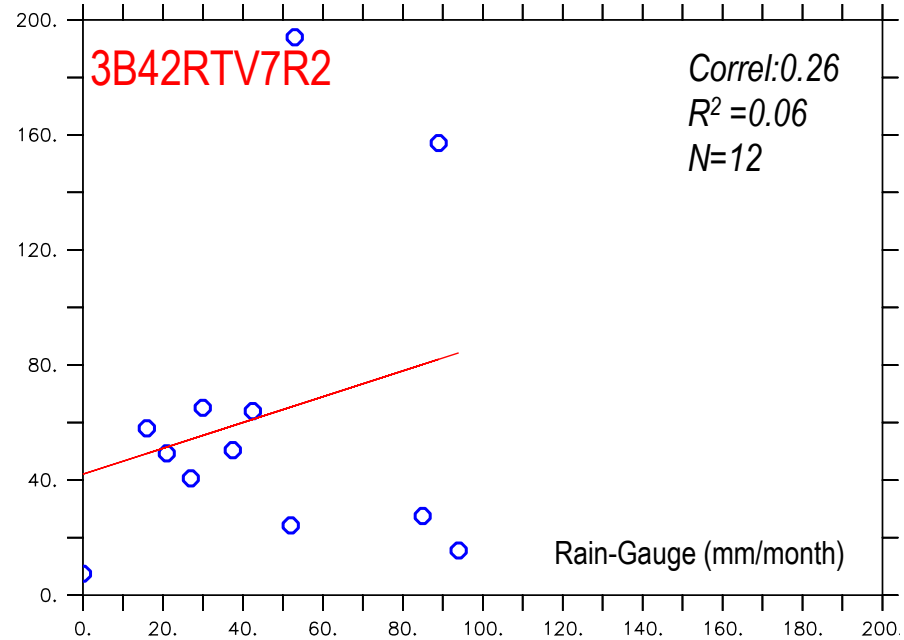
2007

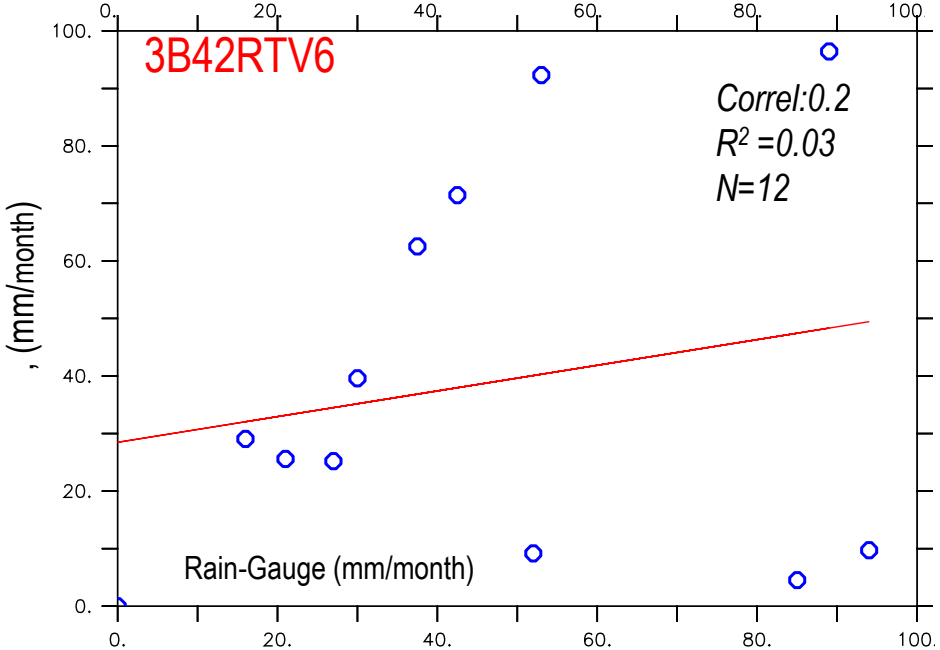
Monthly Mean (mm/day) Rainfall Statistics for Tunisia (TMPA versus Rain-Gauge)

SLOUGUIA	Mean	Max	Min	SD	cv(%)	Corr. TMPA vs. Gauge (2007)	Corr. TMPA vs Gauge (2007 except winter, March-Sep)
3B42RT_V7R2	1.48	3.72	0	1.22	82.5	0.22	0.76
3B42RT_V7R	1.76	4.14	0	1.38	78.1	0.08	0.68
3B42RT_V6	1.21	3.04	0	0.93	77.3	0.21	0.77
Guage	1.29	3.45	0.02	1.01	78.3		
DJEBEL							
3B42RT_V7R2	1.65	4.68	0.063	1.52	91.66	0.13	0.91
3B42RT_V7R	1.71	4.75	0.063	1.31	76.21	0.11	0.90
3B42RT_V6	1.30	3.83	0	1.41	108.27	0.03	0.72
Guage	1.51	3.45	0.009	1.10	72.83		
JENDOUBHA							
3B42RT_V7R2	1.15	2.37	0.24	0.84	73.04	0.07	0.84
3B42RT_V7R	1.32	4.11	0.34	1.05	77.7	0.05	0.81
3B42RT_V6	1.12	2.76	0	0.89	80.2	0.02	0.85
Guage	1.43	3.64	0	1.21	84.08		
SERS DELIGATION							
Gauge	1.50	3.03	0	0.99	66.28		
3B42RT_V7R2	2.08	6.46	0.24	1.88	90.62	0.26	0.81
3B42RT_V7R	2.01	5.07	0.03	1.49	73.99	0.33	0.90
3B42RT_V6	1.28	3.21	0	1.13	87.85	0.21	0.92

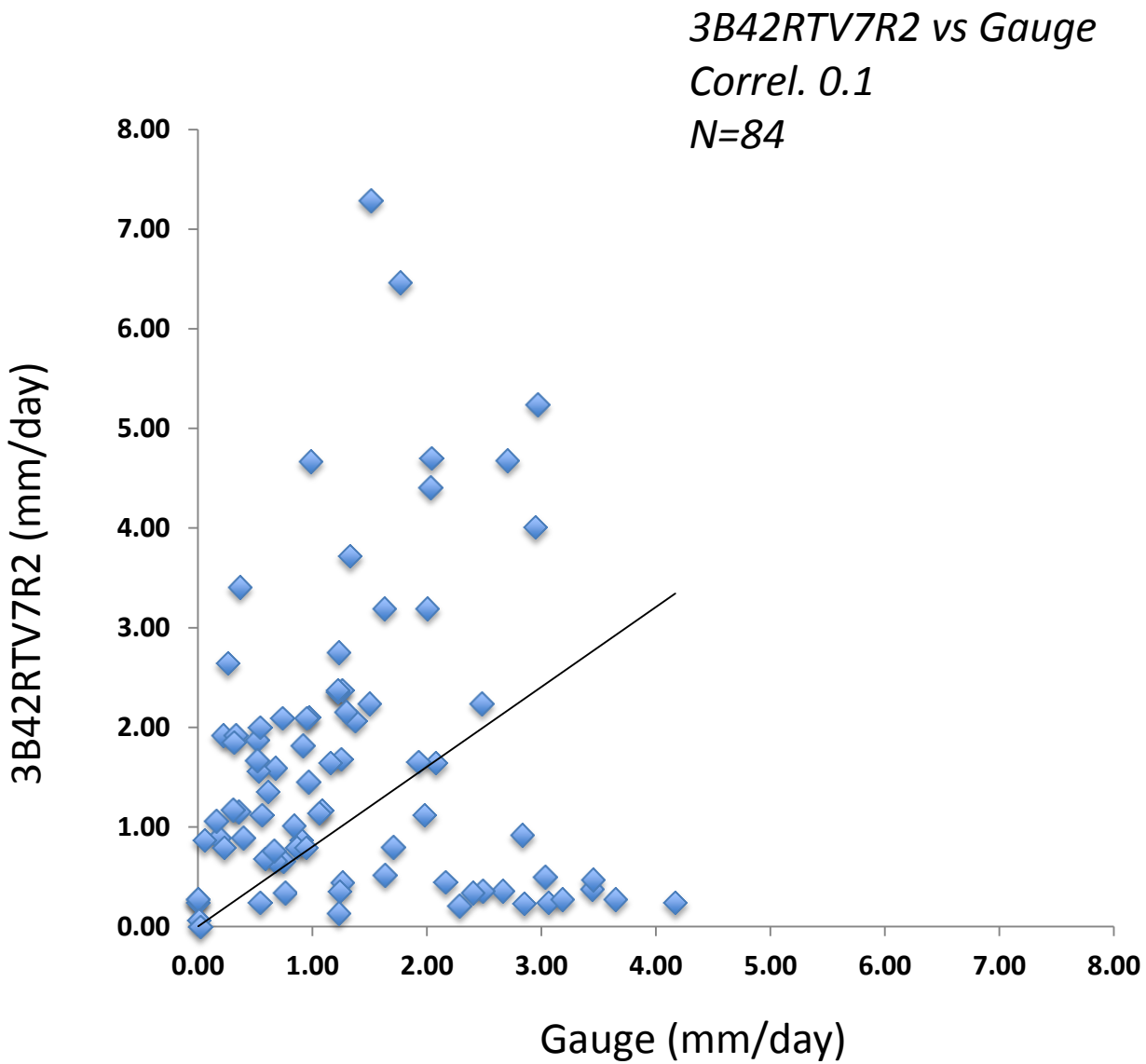
Sers Deligation: Regression (2007) TMPA versus Rain-Gauge





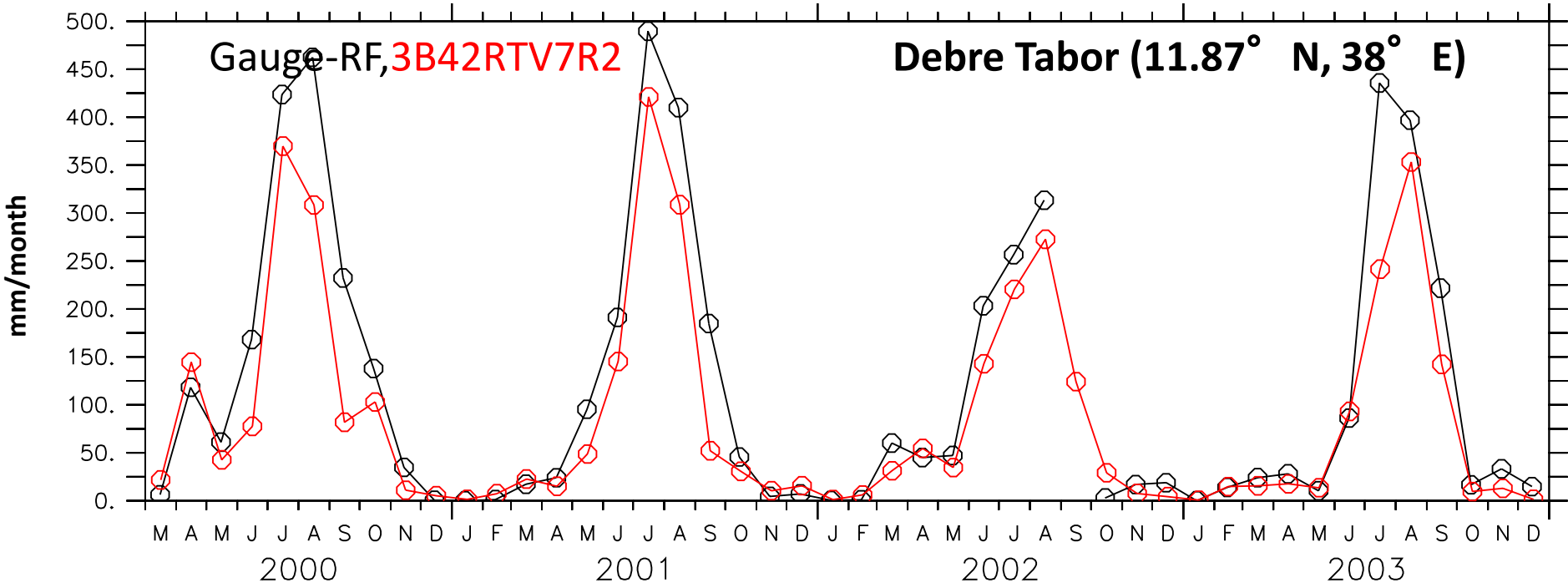


Monthly Mean Rainfall (mm/day): Medjerda Basin Stations, Tunisna)

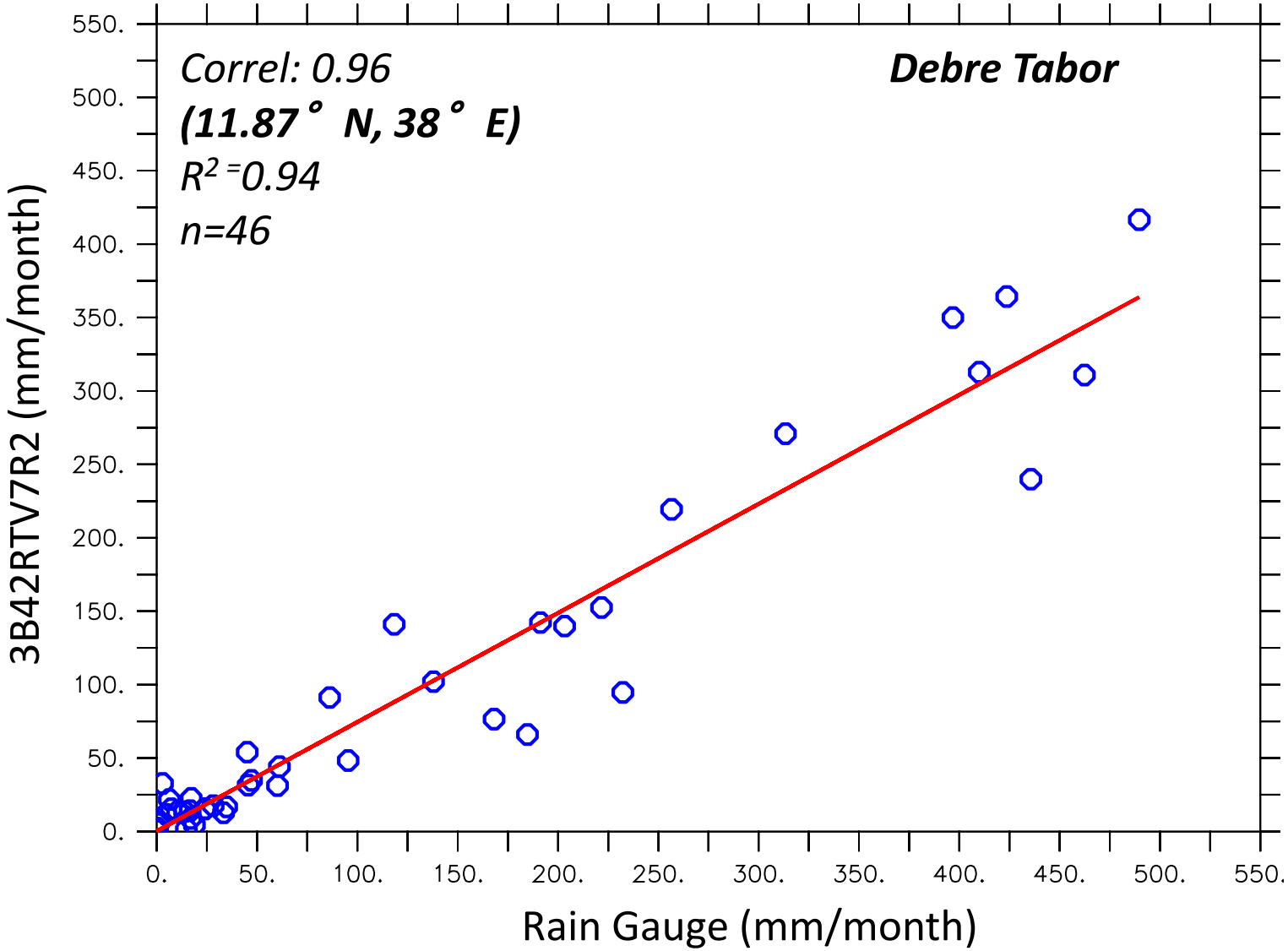


Check the differences
TMPA Performances over the Blue Nile

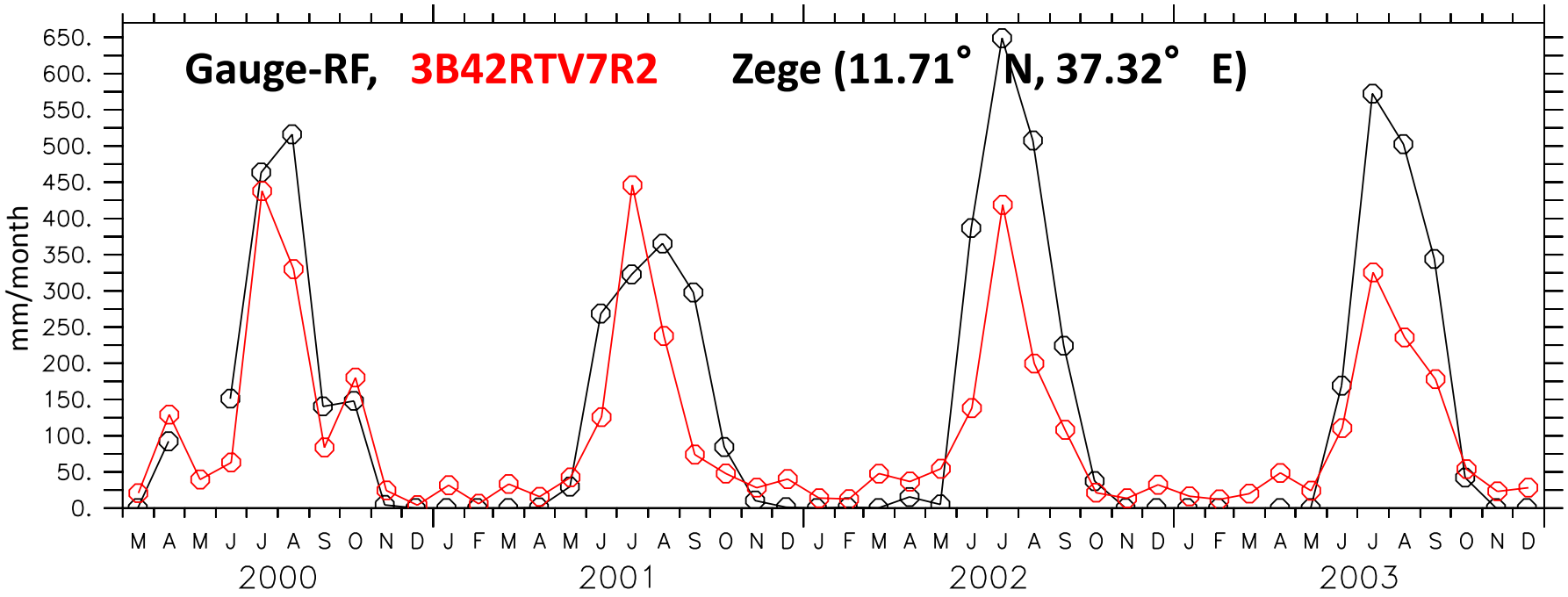
Blue Nile, Debre Tabor (11.87° N, 38° E)



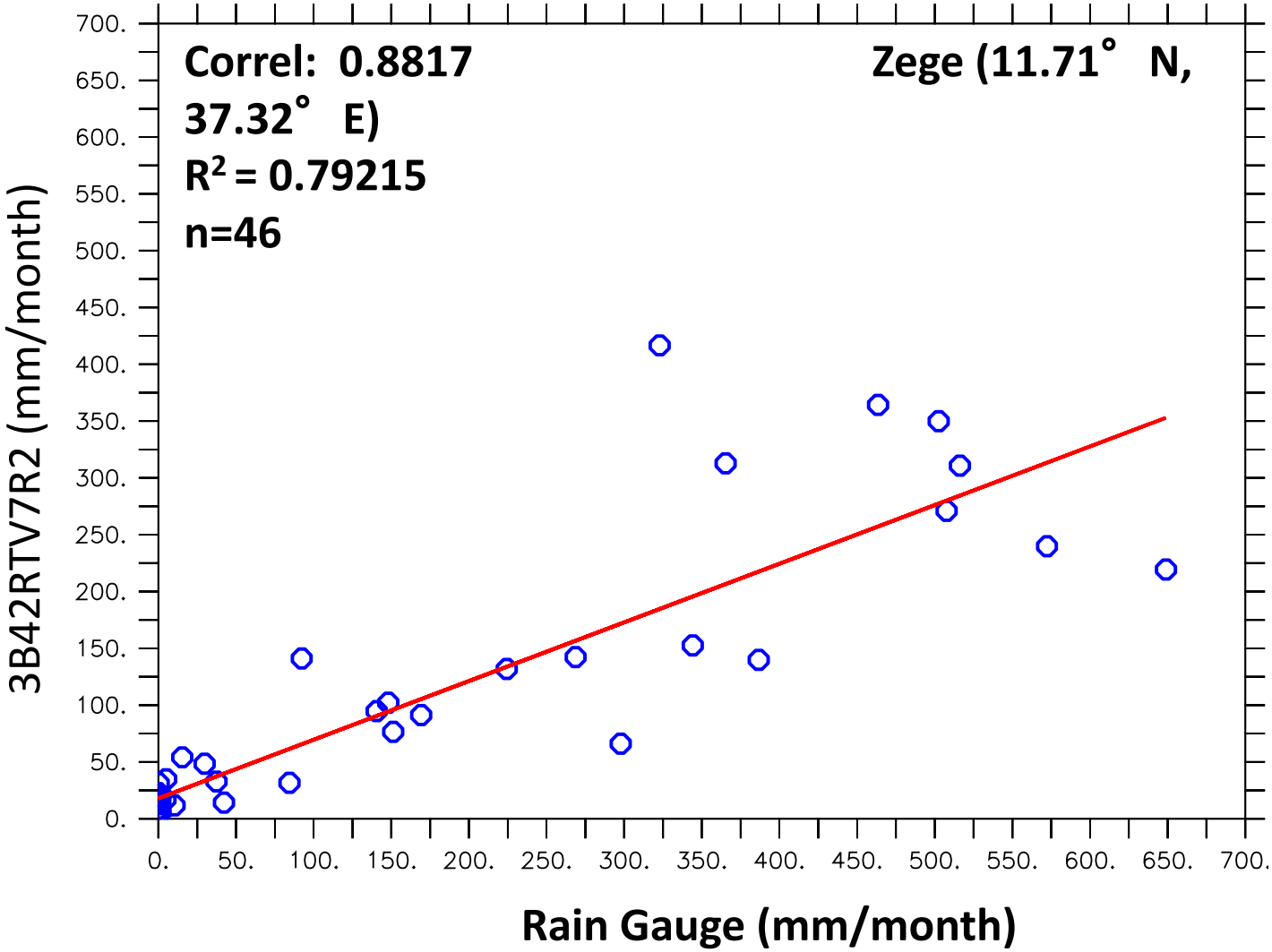
Blue Nile, Debre Tabor (11.87° N, 38° E)



Blue Nile, Zege (11.71° N, 37.32° E)



Blue Nile, Zege (11.71°N, 37.32°E)



- Pingping Xie1 and An-Yuan Xiong2

- “A conceptual model for constructing high-resolution gauge-satellite merged precipitation analyses “

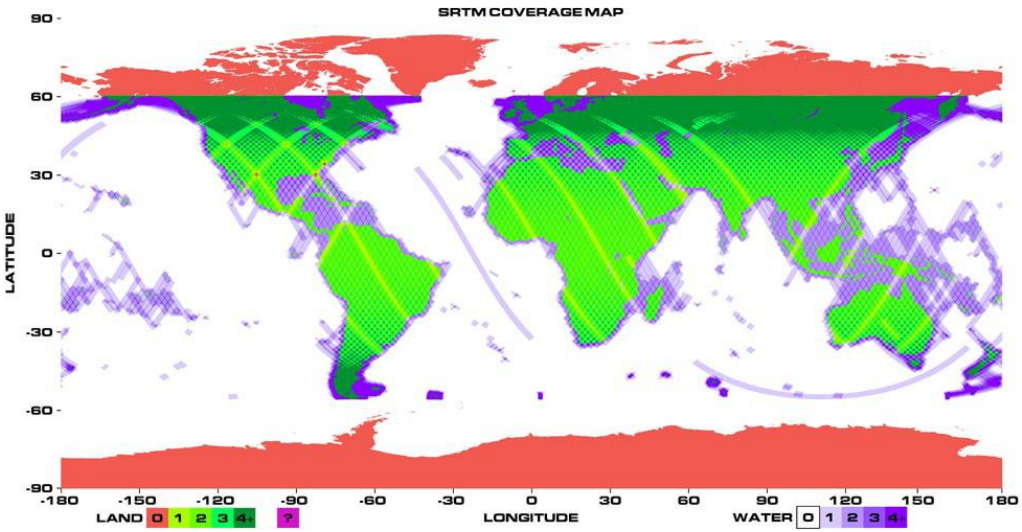
- Received 15 April 2011; revised 15 August 2011; accepted 16 August 2011; published 8 November 2011. JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, D21106, doi:10.1029/2011JD016118, 2011

Digital Elevation Models And Dams

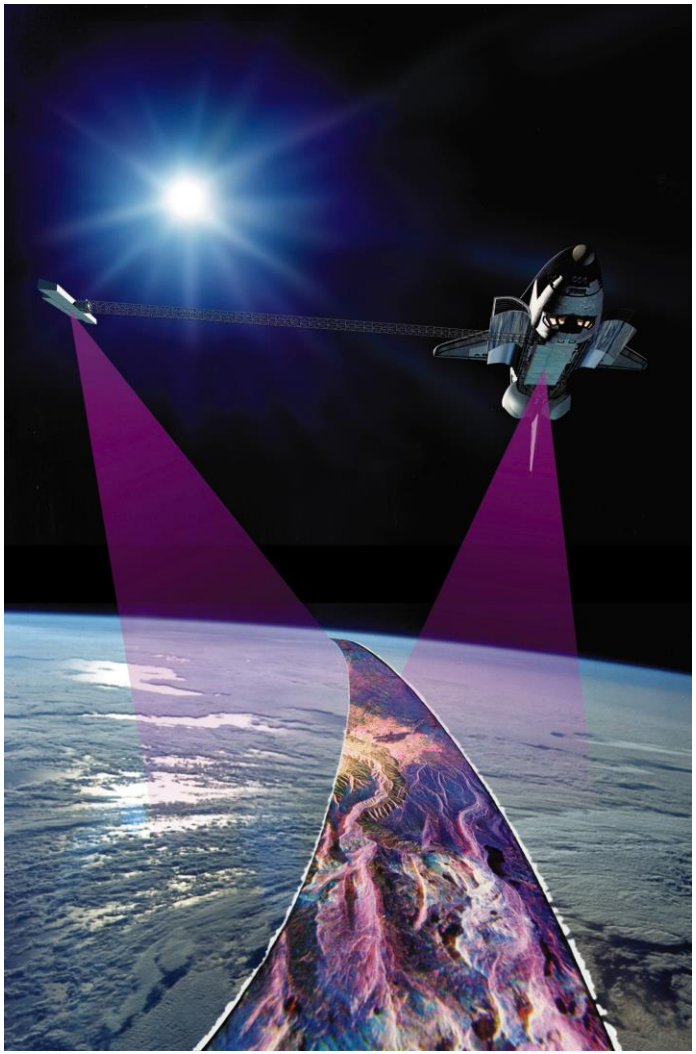
Shuttle Radar Topography Mission - (SRTM)

Measurements: gridded elevation data of 80% of the Earth's surface

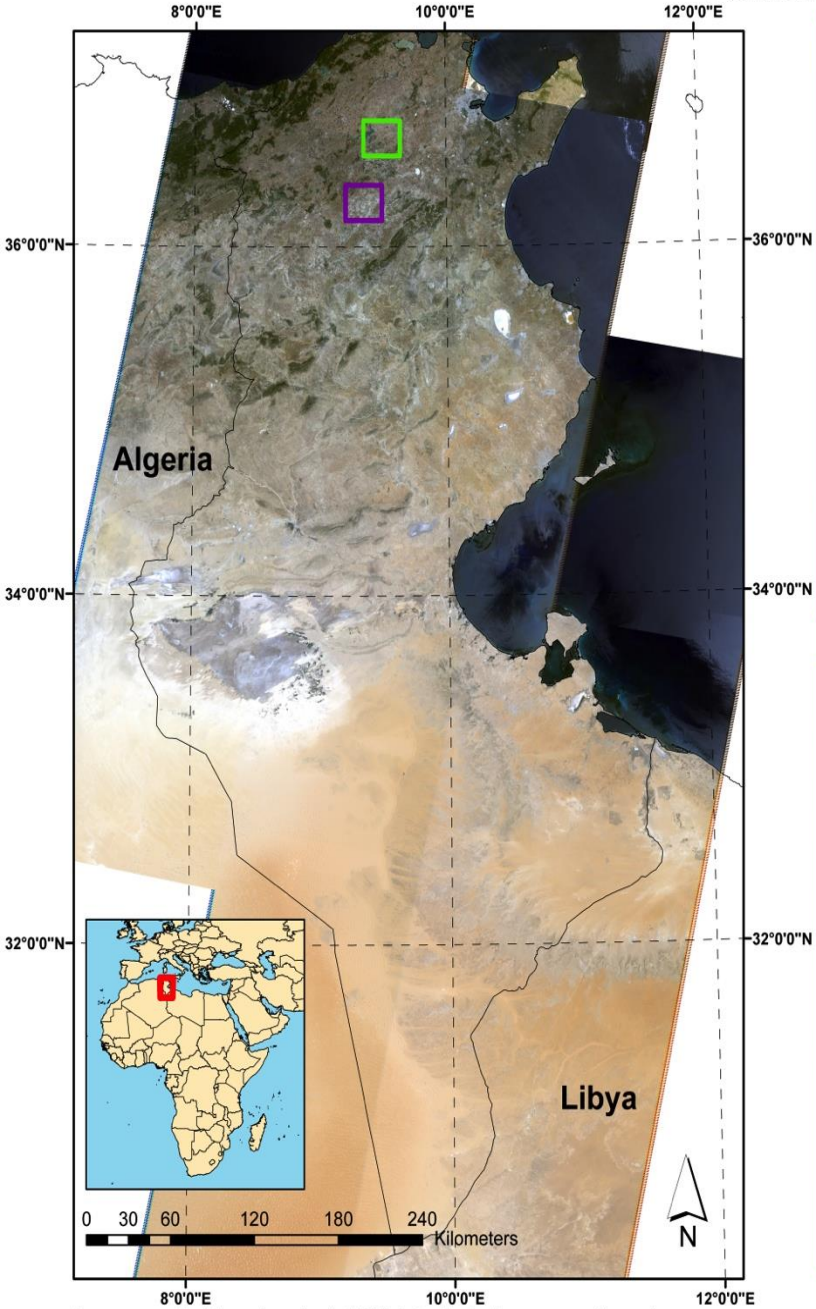
- 30m – 90m spatial resolution



Most land surfaces between 60 degrees north latitude and 54 degrees south latitude.



Tunisia Flow Accumulation



HydroSHEDS Con 90m FAC

HydroSHEDS Con 250m FAC

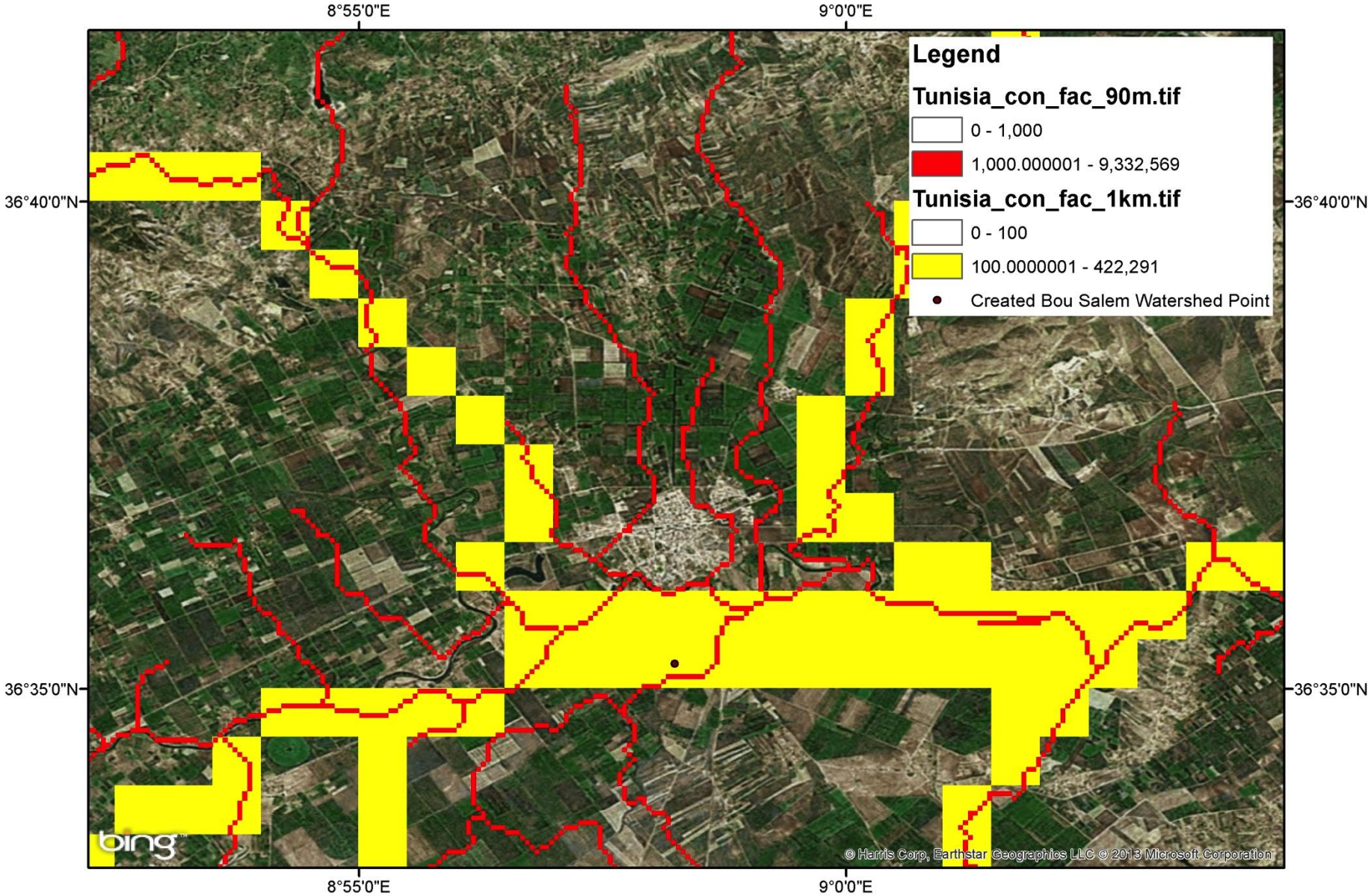
HydroSHEDS Con 90m FAC

HydroSHEDS Con 250m FAC

Image created from Landsat 5 TM data includes scenes from June 2003 and June of 2011. Thematic mapper bands 3, 2, and 1 are displayed as red, green, and blue colors, respectively.

Map Created By: Katherine Melocik
Date Created: 11/08/2012
Data Sources: ESRI, NASA

Flow Accumulation Discontinuity

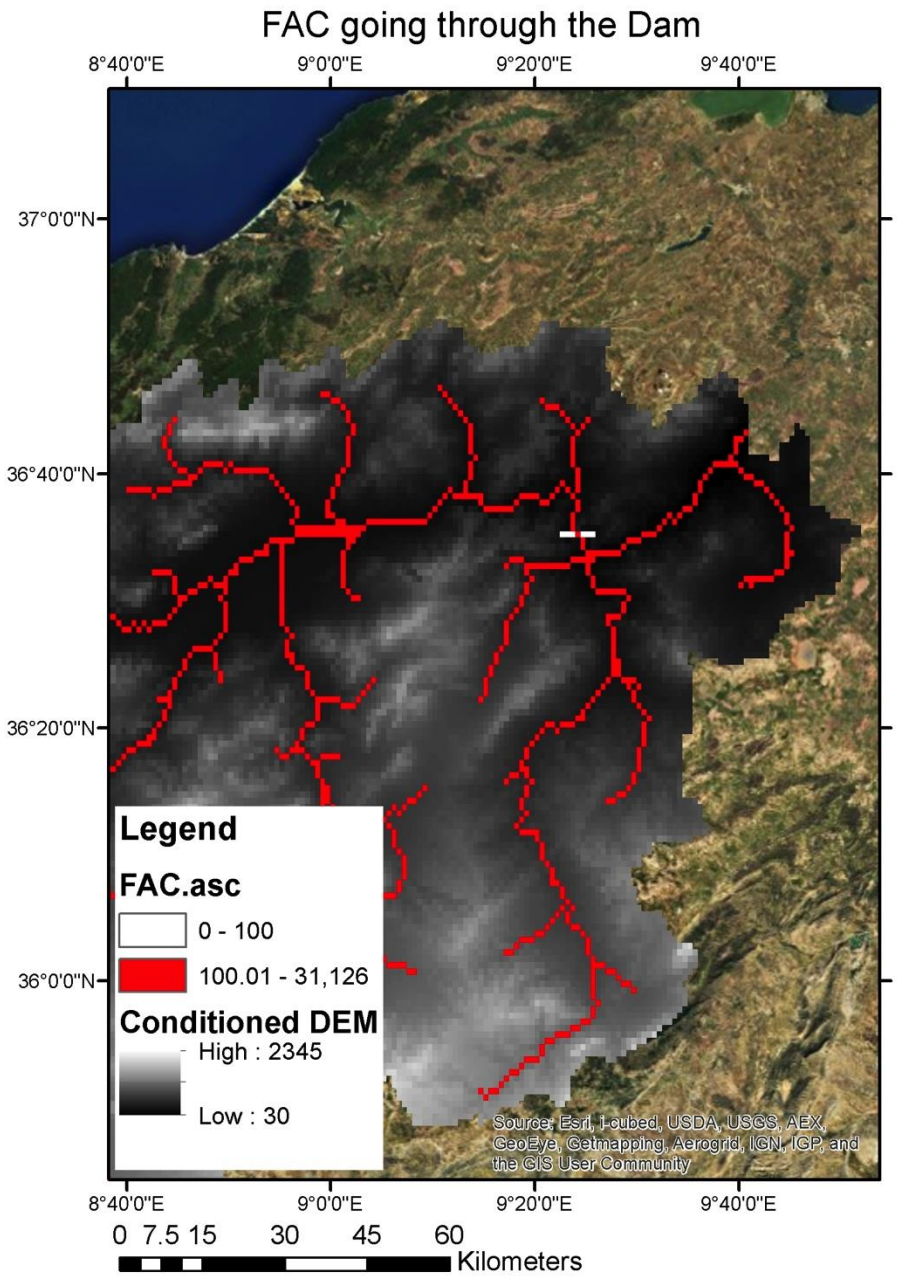


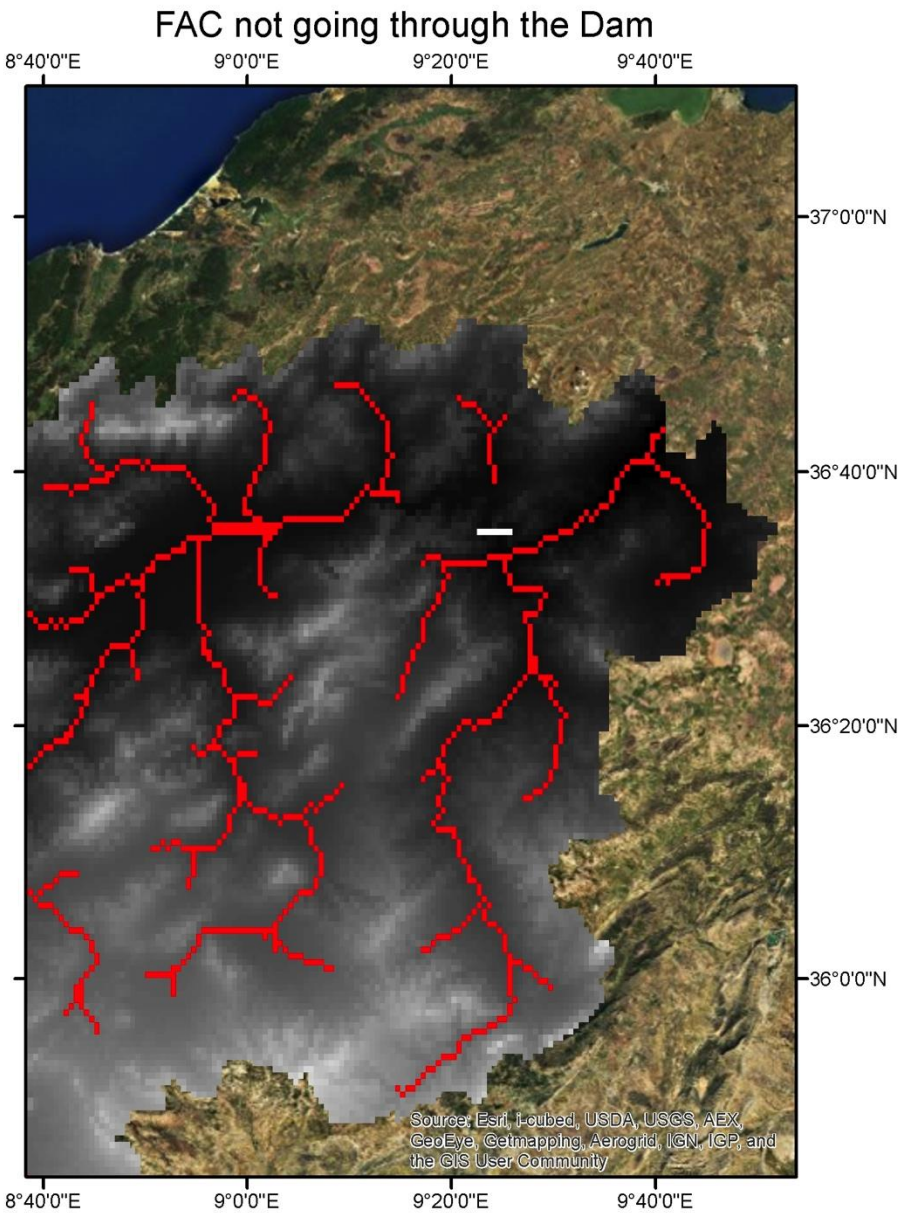
0 0.5 1 2 3 4 Miles

N

Map Created By: Katherine Melocik
Date Created: 05/24/2013
Data Sources: ESRI, NASA

Sidi Salem Dam Modification with/without FAC Broken

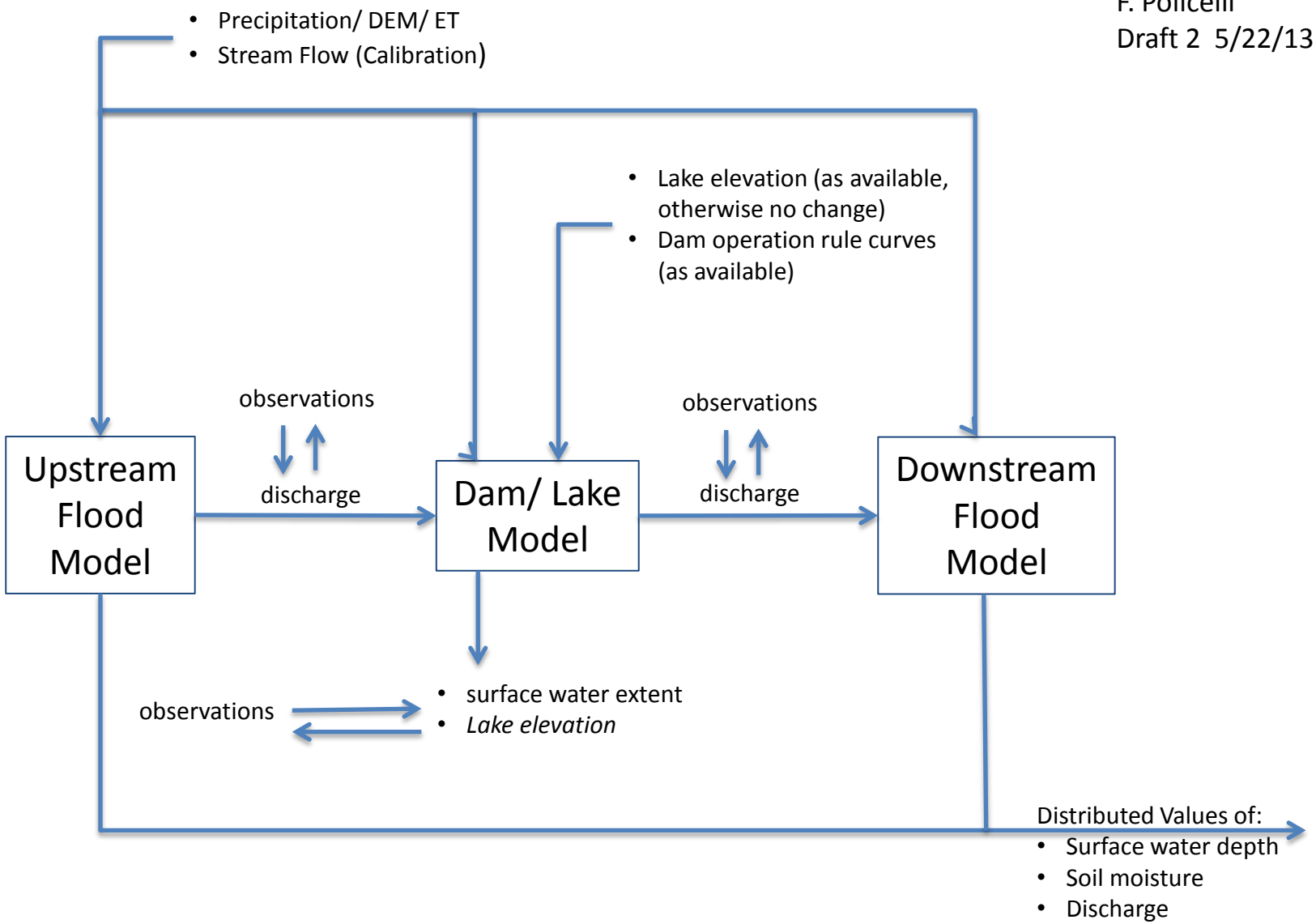




Map Created By: Katherine Melocik
Date Created: 5/1/2013
Data Sources: ESRI, NASA

Note: DEM is from USGS HydroSHEDS Conditioned Product, which is NOT sink filled. However, the DEM has to be filled in order to produce the FAC.

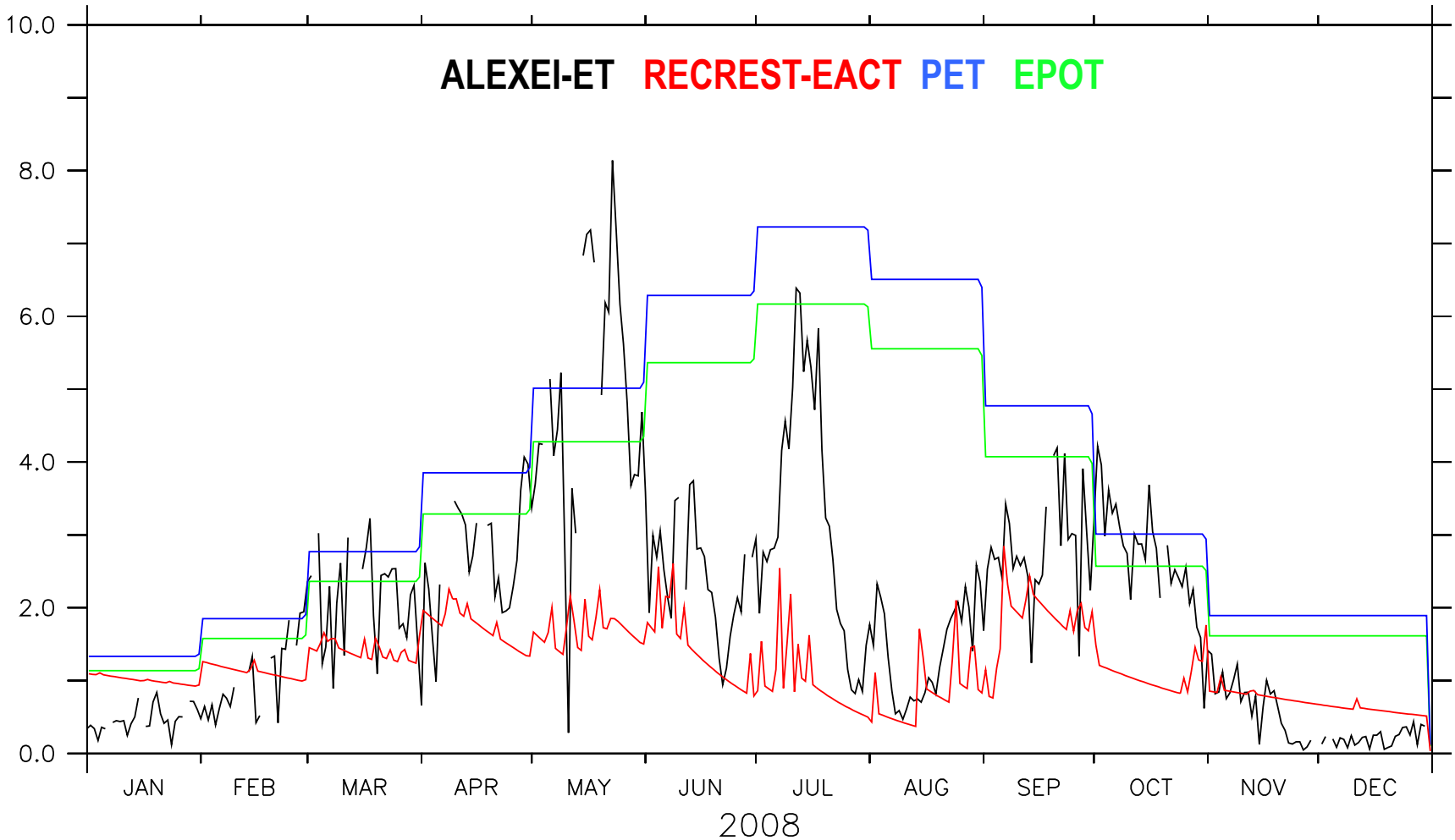
Flood Model
Dams Concept
F. Policelli
Draft 2 5/22/13



EVAPOTRANSPIRATION

1. Daily Evapotranspiration based on ALEXEI and RECREST for Tunisia (Medjerda Basin)

SERS DELIGATION (36.07N, 9.02E)



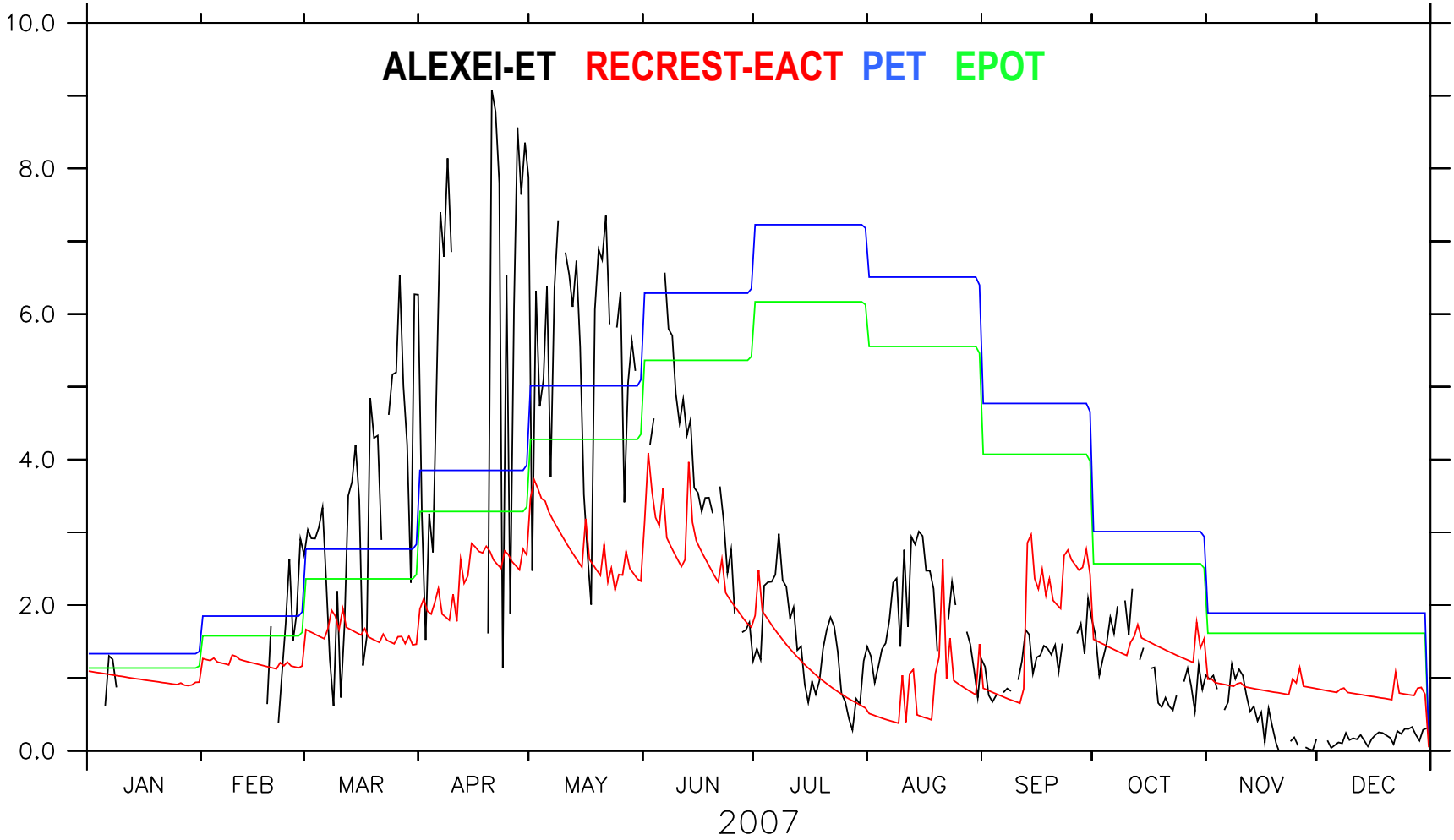
RECREST model-ETs:

PET (input to RECREST model)

EPOT=PET*KE KE: conversion factor for PET to local Actual ET

EACT :simulated AET

SERS DELIGATION (36.07N, 9.02E)



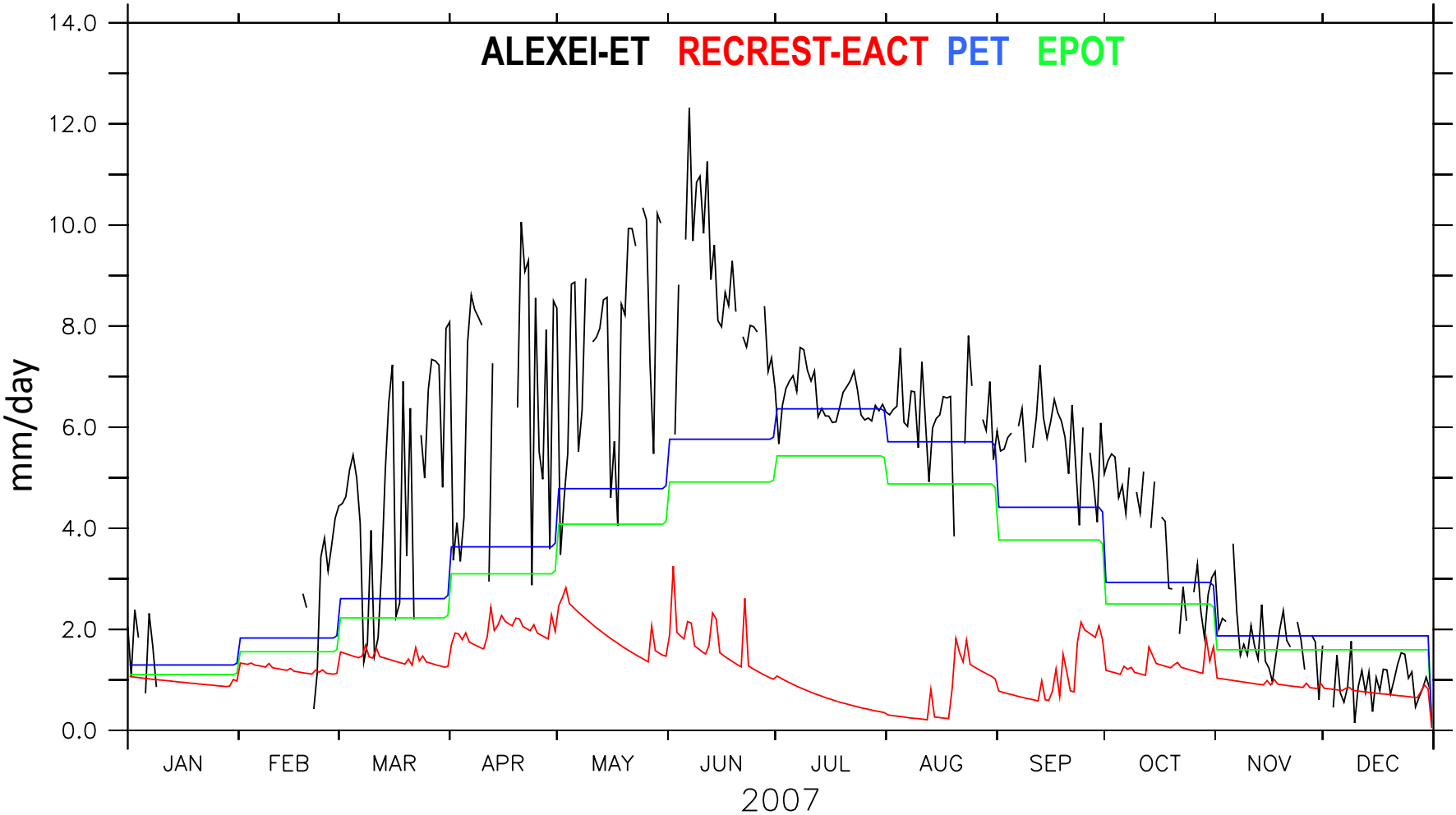
RECREST model-ETs:

PET (input to the RECREST model)

EPOT=PET*KE KE: conversion factor for PET to local Actual ET

EACT :simulated AET

EL HERRI (9.676° E,36.72° N), TUNISIA



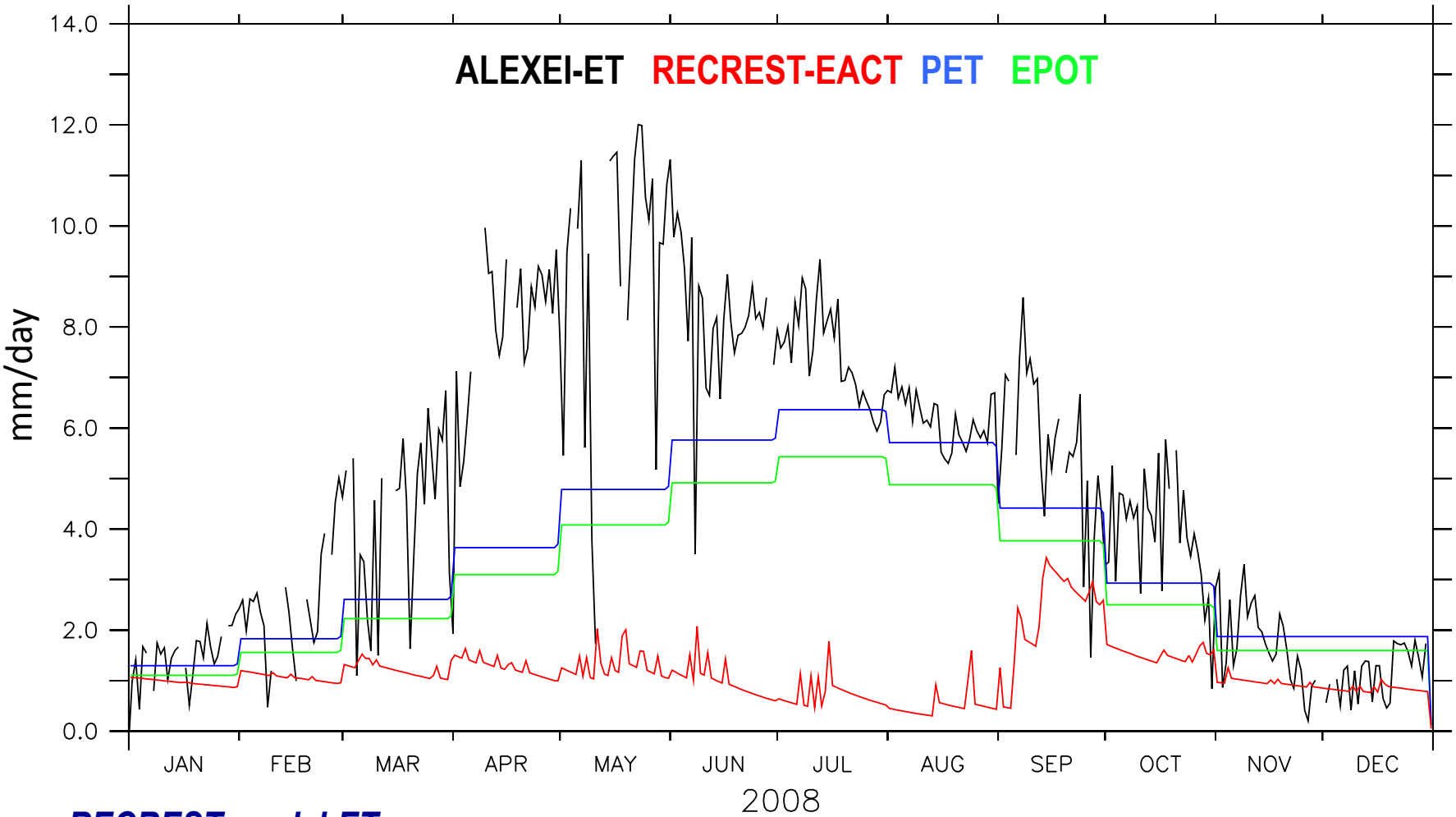
RECREST model-ETs:

PET (input to the RECREST model)

EPOT=PET*KE KE: conversion factor for PET to local Actual ET

EACT :simulated AET

EL HERRI (9.676° E,36.72° N), TUNISIA



RECREST model-ETs:

PET (input to the RECREST model)

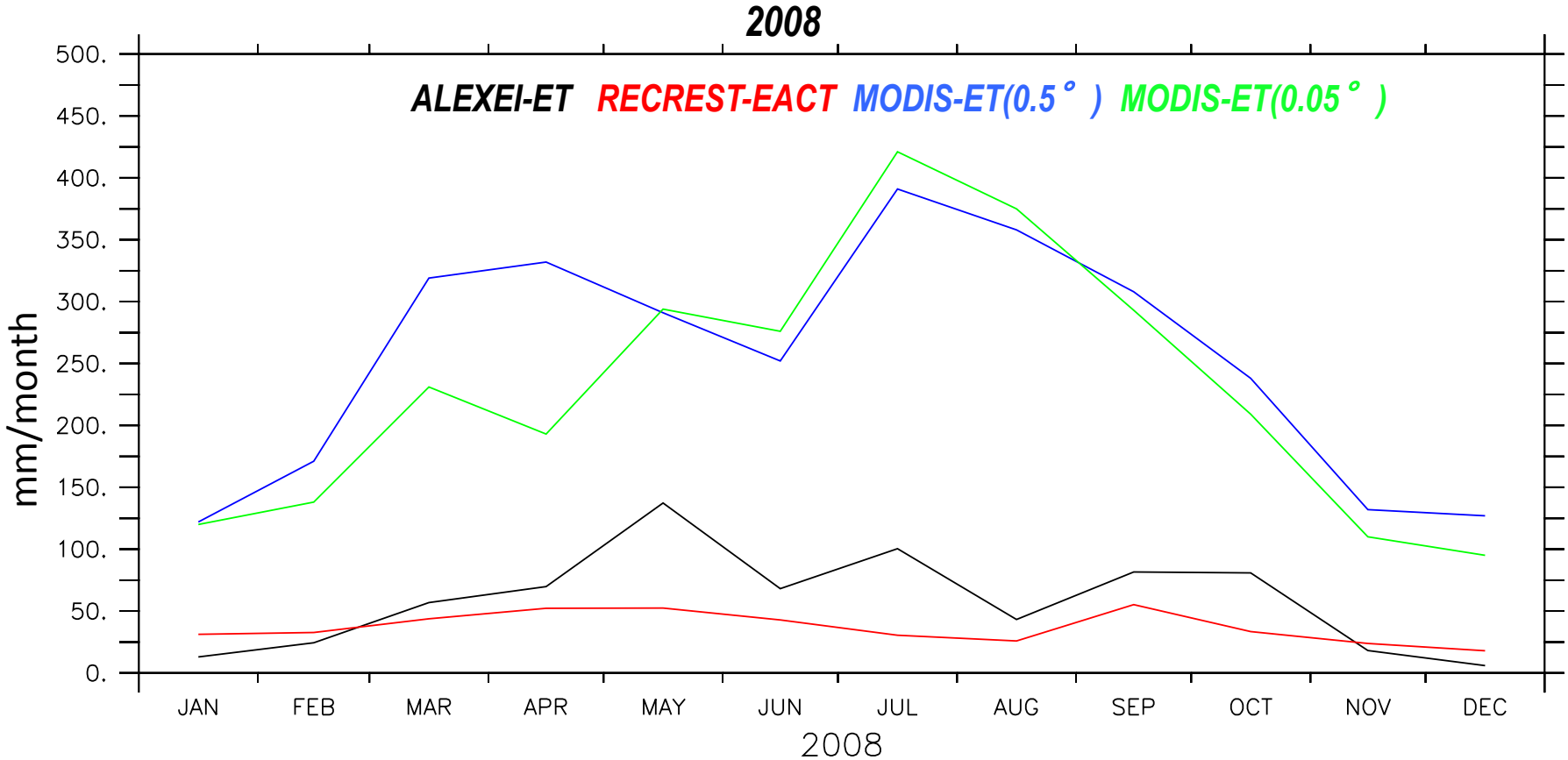
EPOT=PET*KE KE: conversion factor for PET to local Actual ET

EACT :simulated AET

2. Monthly Evapotranspiration based on MODIS, ALEXEI and RECREST for Tunisia (Medjerda Basin)

Monthly accumulated ET based on ALEXEI, MODIS and RECREST MODEL

SERS DELIGATION (36.07N, 9.02E)



MODIS (MOD16), 0.05 and 0.5 Degree , monthly accumulated ET

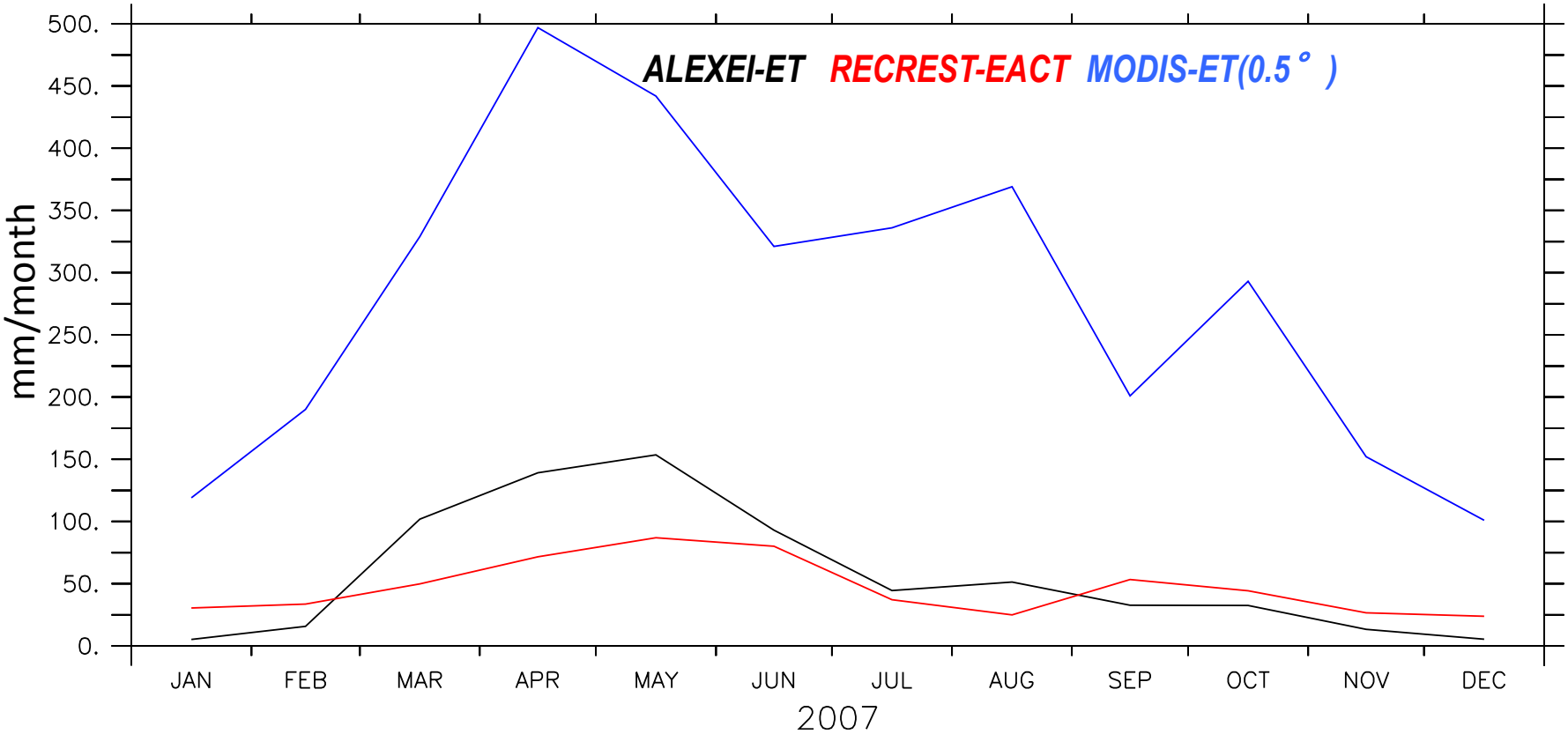
RECREST-EACT, monthly accumulated based on simulated 3hr'ly-actual ET

ALEXEI monthly accumulated based on daily ET

Monthly accumulated ET based on ALEXEI, MODIS and RECREST MODEL

SERS DELIGATION (36.07N, 9.02E)

2007



MODIS (MOD16), 0.5 Degree , monthly accumulated ET

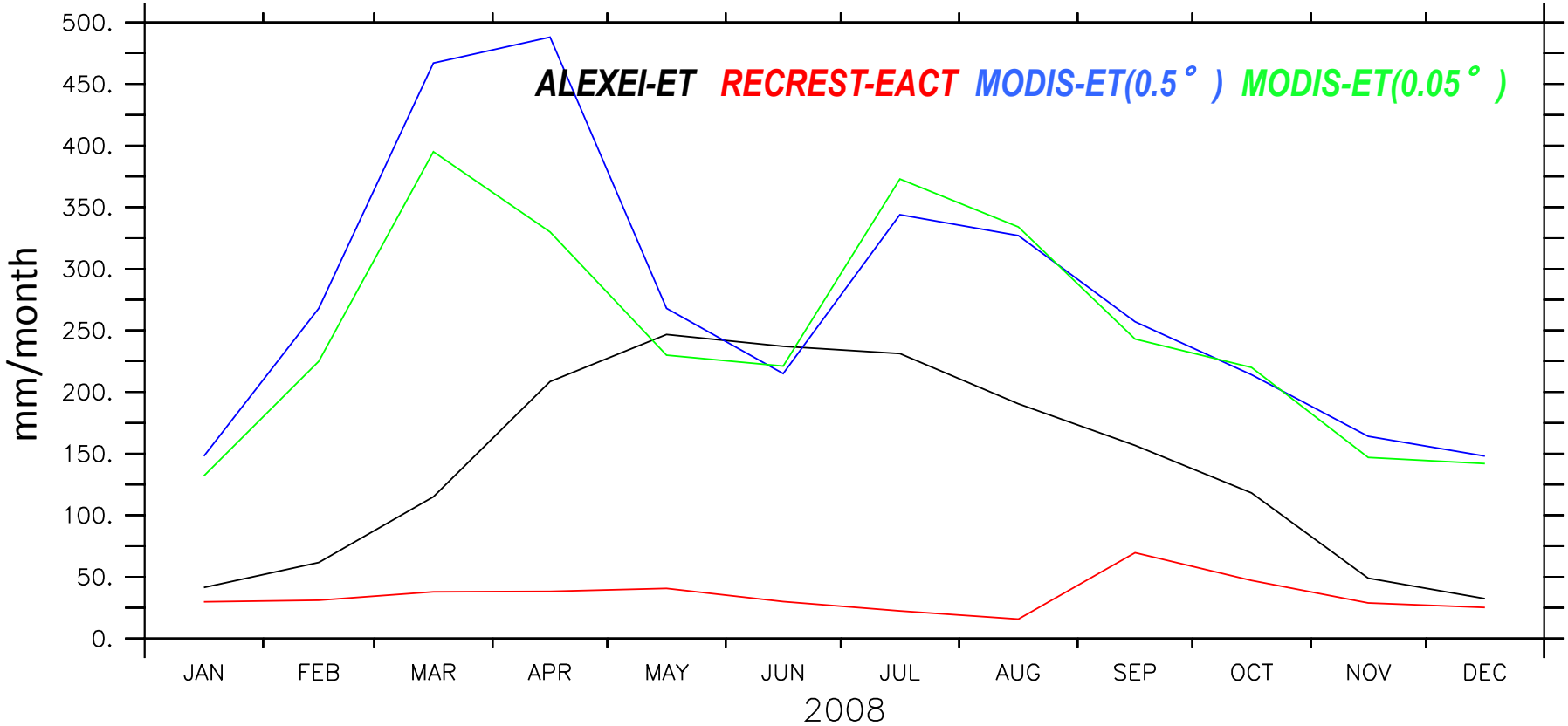
RECREST-EACT, monthly accumulated based on simulated 3hr'ly-actual ET

ALEXEI monthly accumulated based on daily ET

Monthly accumulated ET based on ALEXEI, MODIS and RECREST MODEL

El Herri (36.72N, 9.676E)

2008



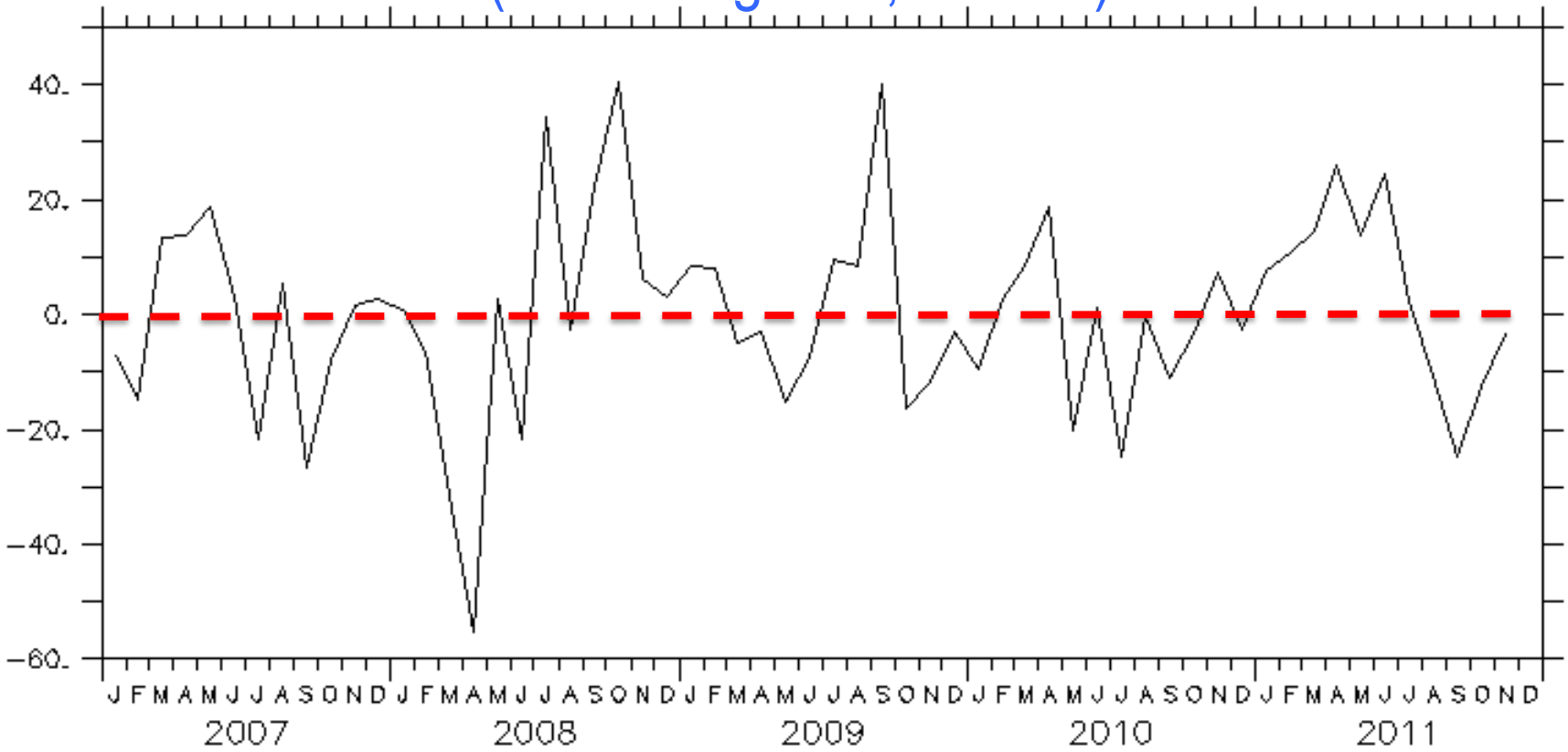
MODIS (MOD16), 0.05 and 0.5 Degree , monthly accumulated ET

RECREST-EACT, monthly accumulated based on simulated 3hr'ly-actual ET

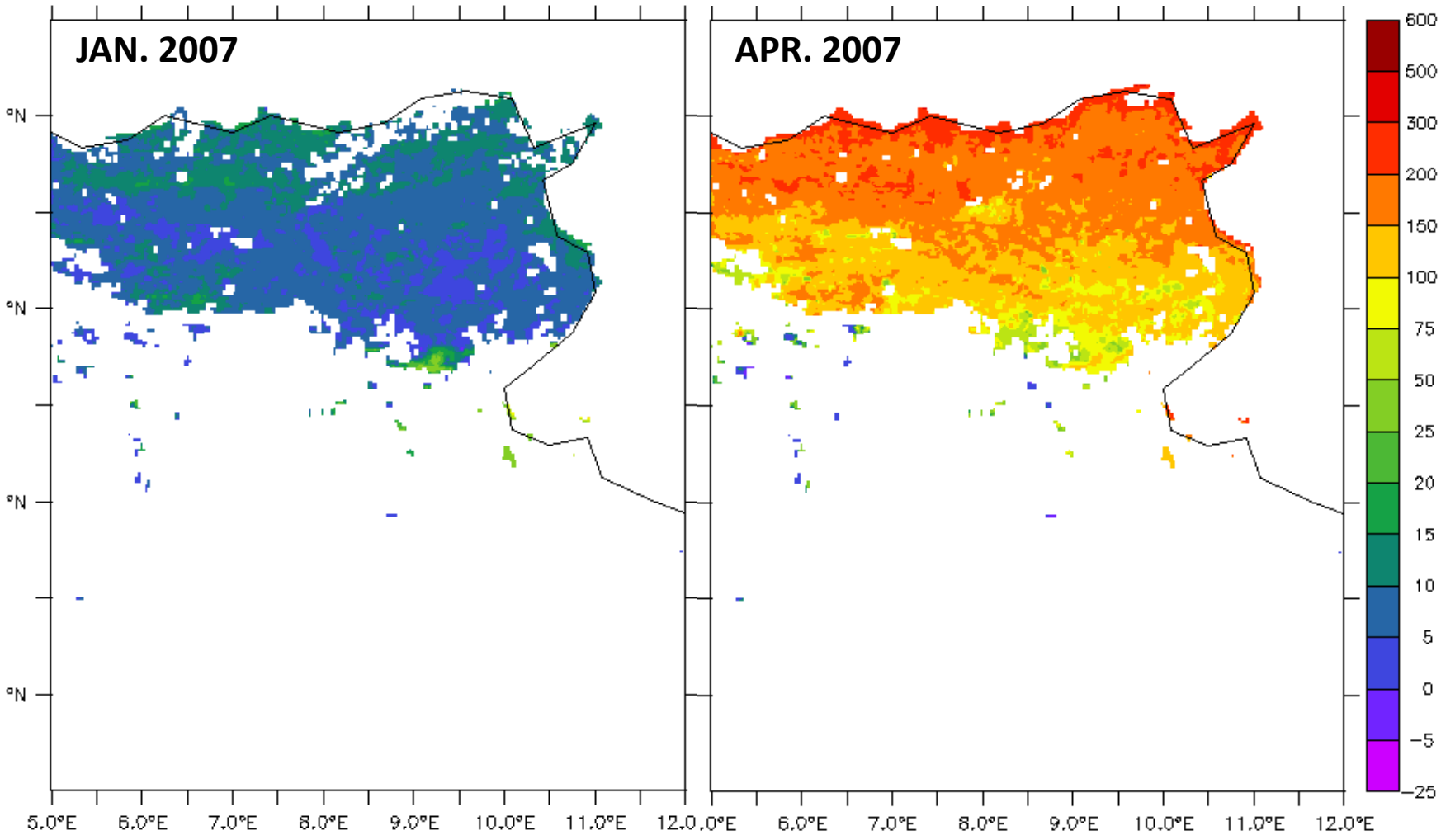
ALEXEI monthly accumulated based on daily ET

3. ALEXEI VS MODIS Spatial distribution for TUNISIA

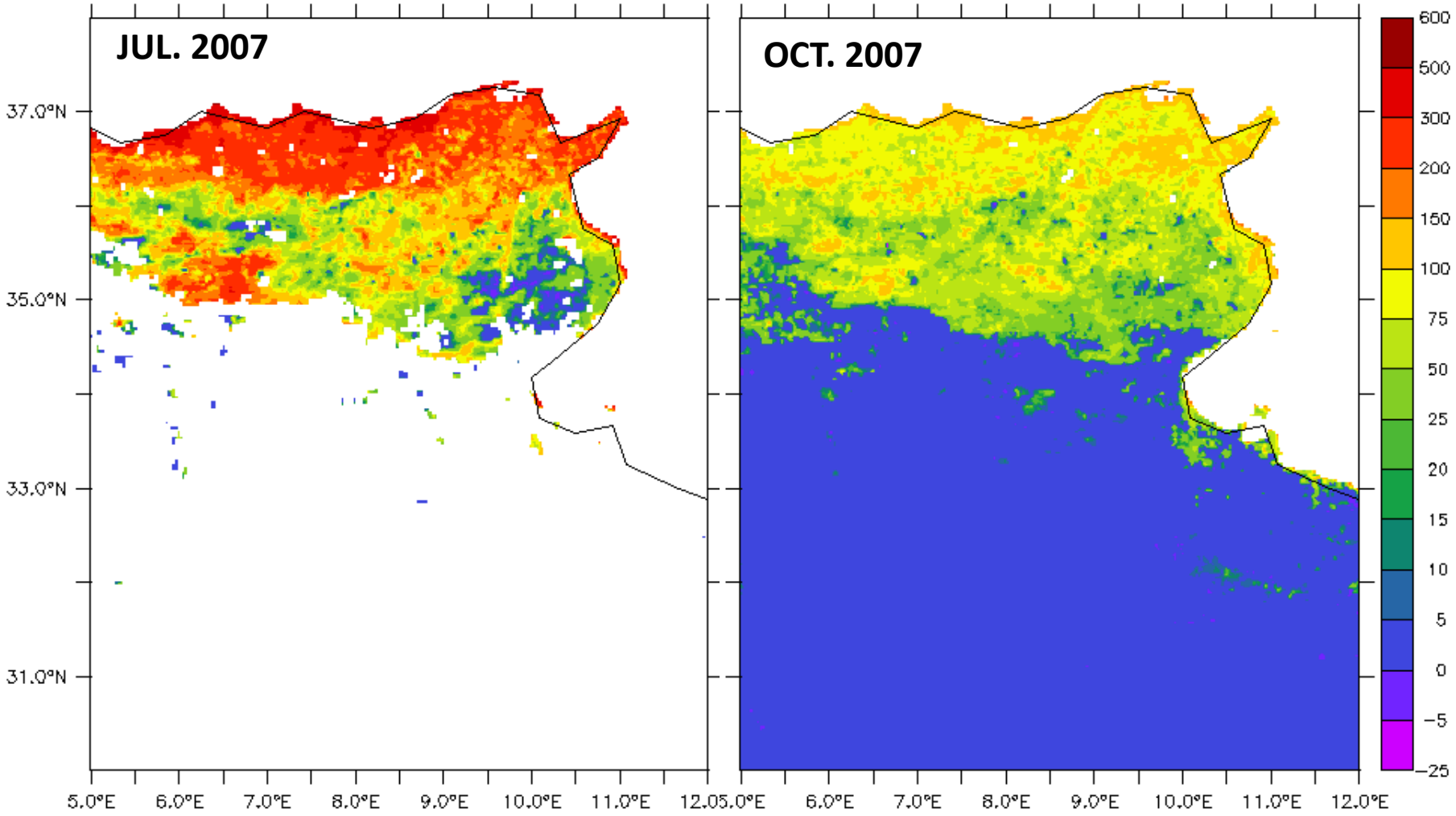
ALEXEI Monthly accumulated ET (mm/month) Anomaly from Mean monthly ET for 2007-2011 (Sers Deligation, Tunisia)



Seasonal ET (mm/month) –ALEXEI TUNISA



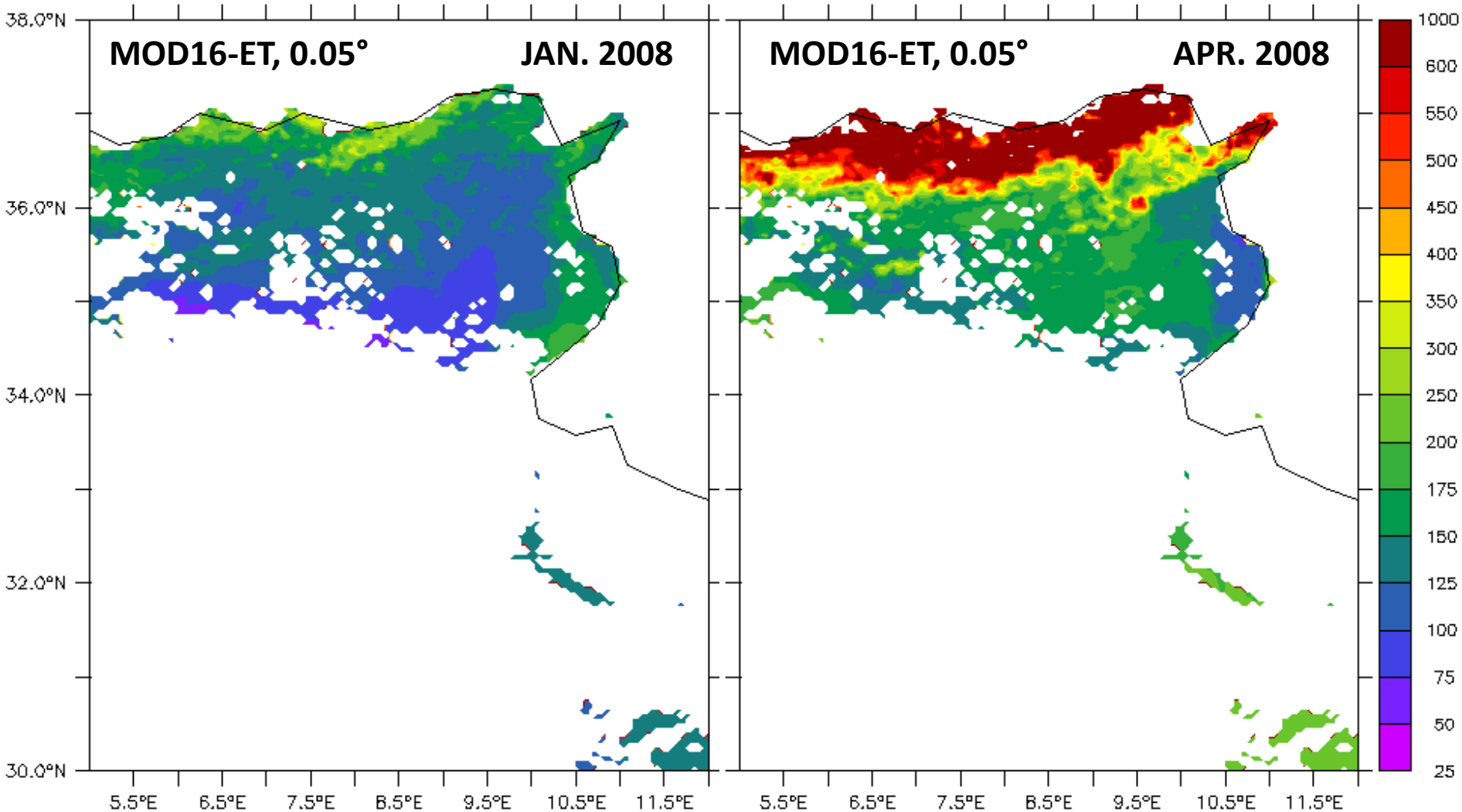
Seasonal ET (mm/month) –ALEXEI TUNISA



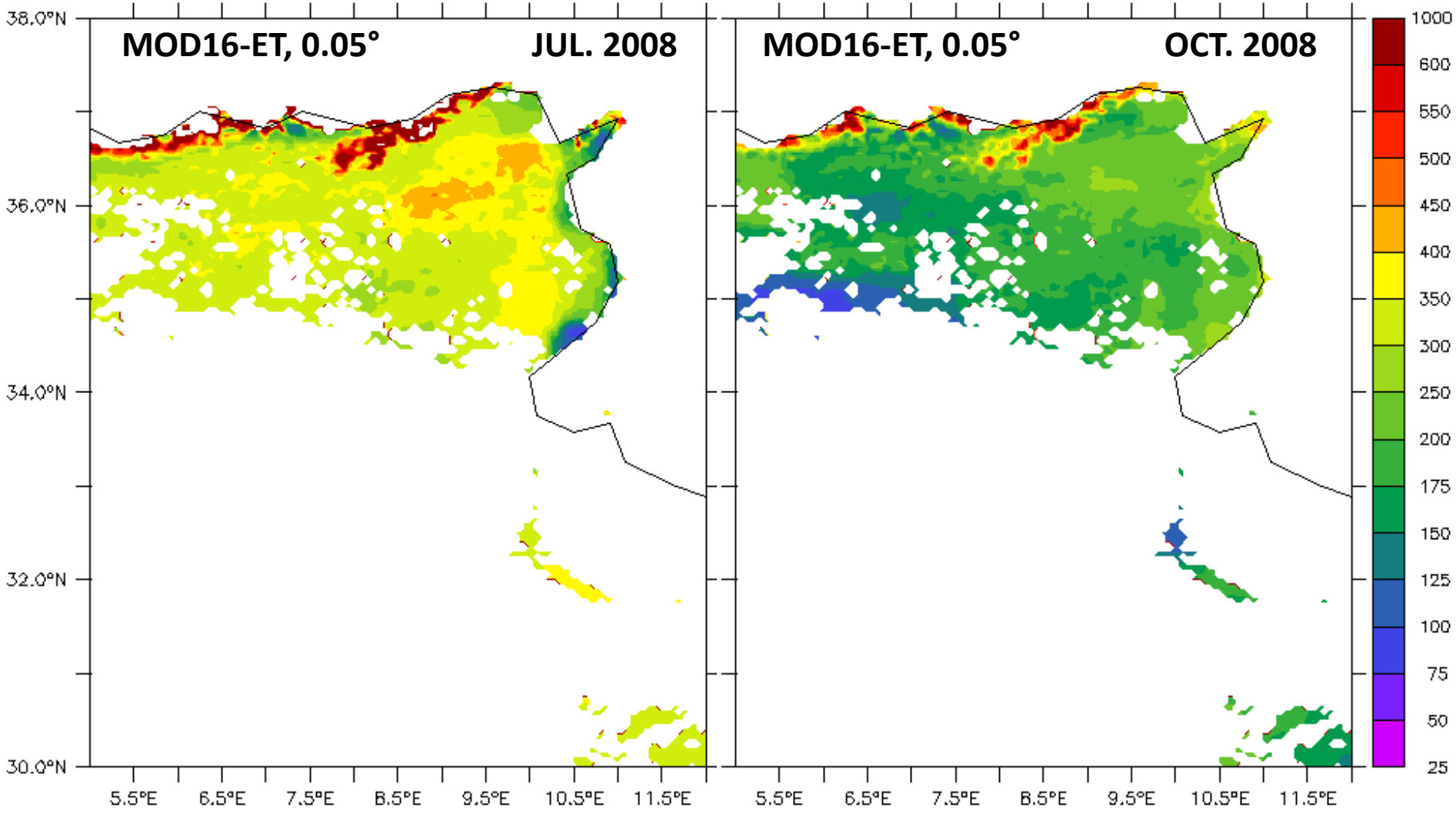
ET-PLOTS-SET II

1. 2D Plots: MODIS-MOD16A2 ET 0.05 DEGREE

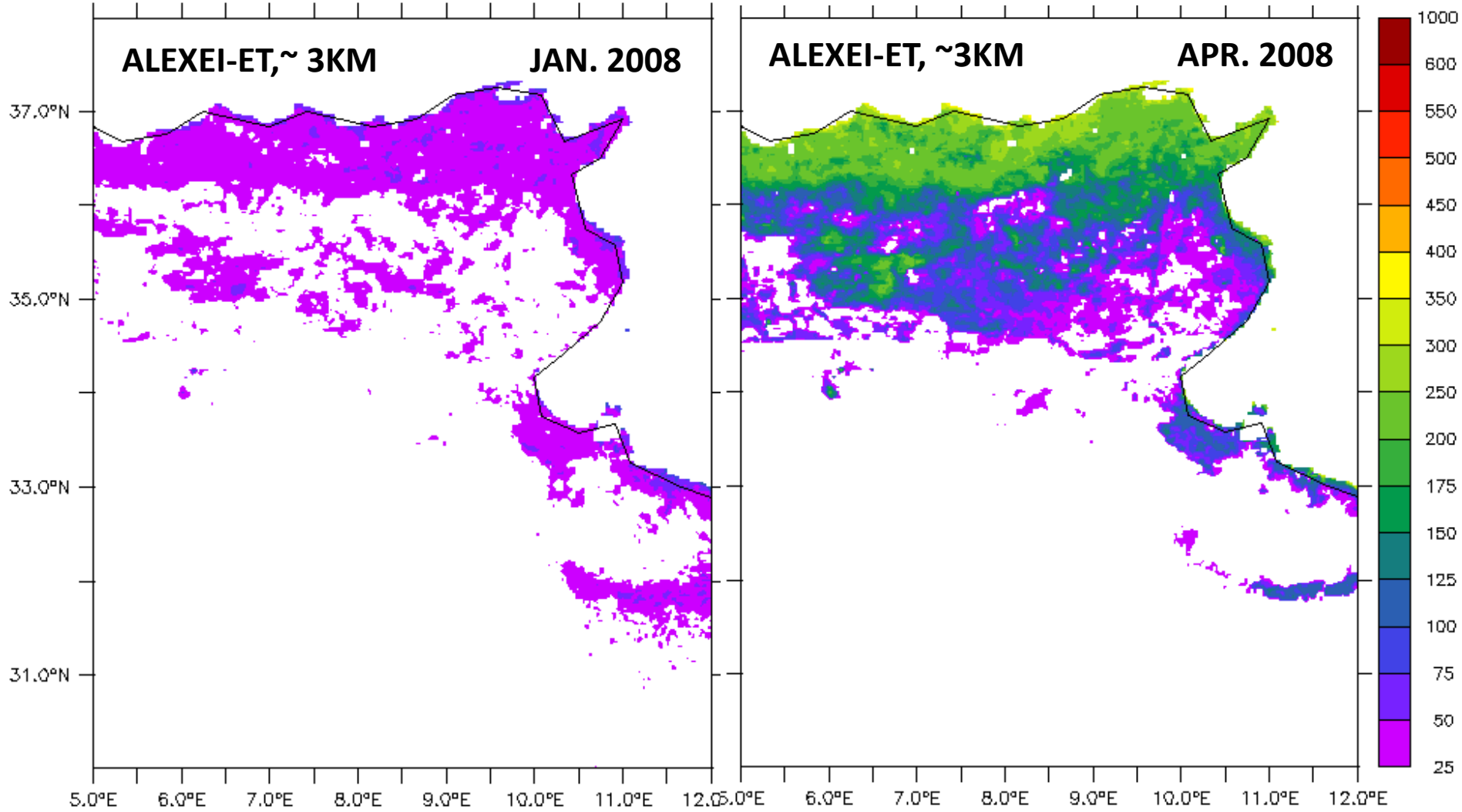
MODIS-ET (~5km) in mm/month, TUNISIA

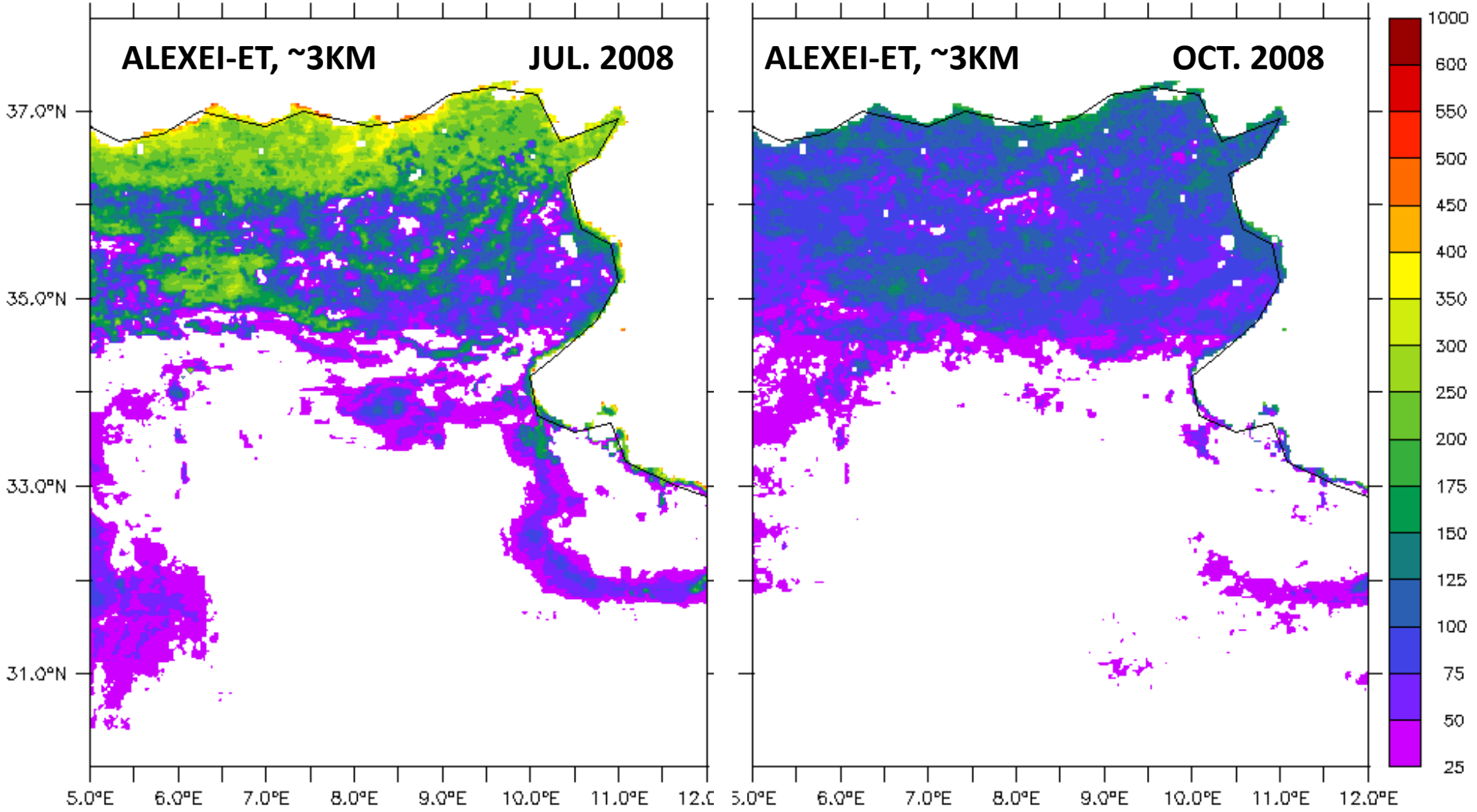


MODIS-ET (~5km) in mm/month, TUNISIA

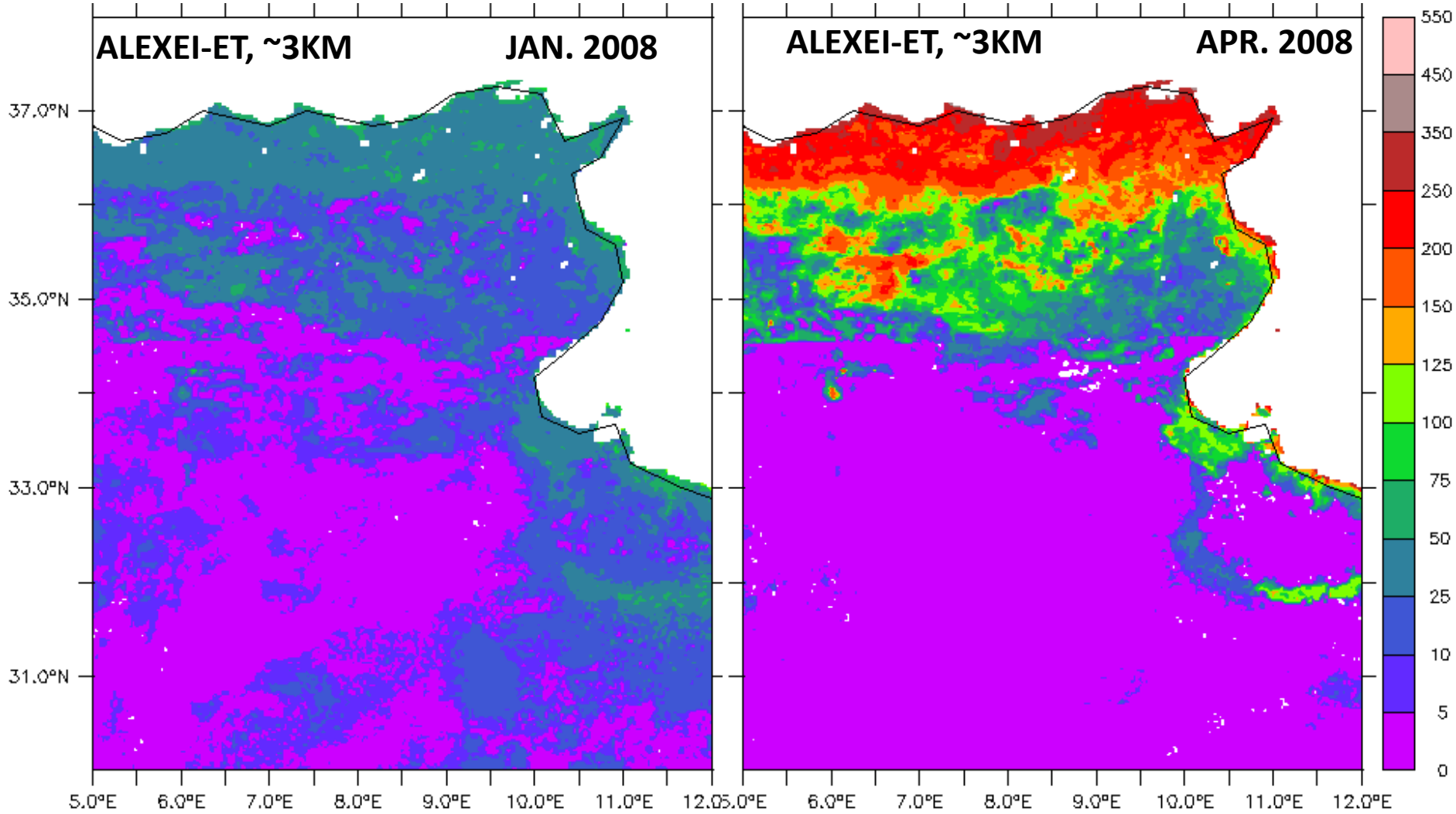


2. 2D Plots: ALEXEI MONTHLY PLOTS:
(Same coloring scale as MODIS plots above)


ALEXEI-ET,~ 3KM
JAN. 2008
ALEXEI-ET, ~3KM
APR. 2008
37.0°N
35.0°N
33.0°N
31.0°N
5.0°E
6.0°E
7.0°E
8.0°E
9.0°E
10.0°E
11.0°E
12.0°E
1000
600
550
500
450
400
350
300
250
200
175
150
125
100
75
50
25


ALEXEI-ET, ~3KM
JUL. 2008
ALEXEI-ET, ~3KM
OCT. 2008
37.0°N
35.0°N
33.0°N
31.0°N
5.0°E
6.0°E
7.0°E
8.0°E
9.0°E
10.0°E
11.0°E
12.0°E
1000
600
550
500
450
400
350
300
250
200
175
150
125
100
75
50
25

3. 2D Plots: ALEXEI MONTHLY PLOTS:
(coloring scale to get spatial distribution features)


ALEXEI-ET, ~3KM
JAN. 2008
ALEXEI-ET, ~3KM
APR. 2008
37.0°N
35.0°N
33.0°N
31.0°N
5.0°E
6.0°E
7.0°E
8.0°E
9.0°E
10.0°E
11.0°E
12.0°E
550
450
350
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75
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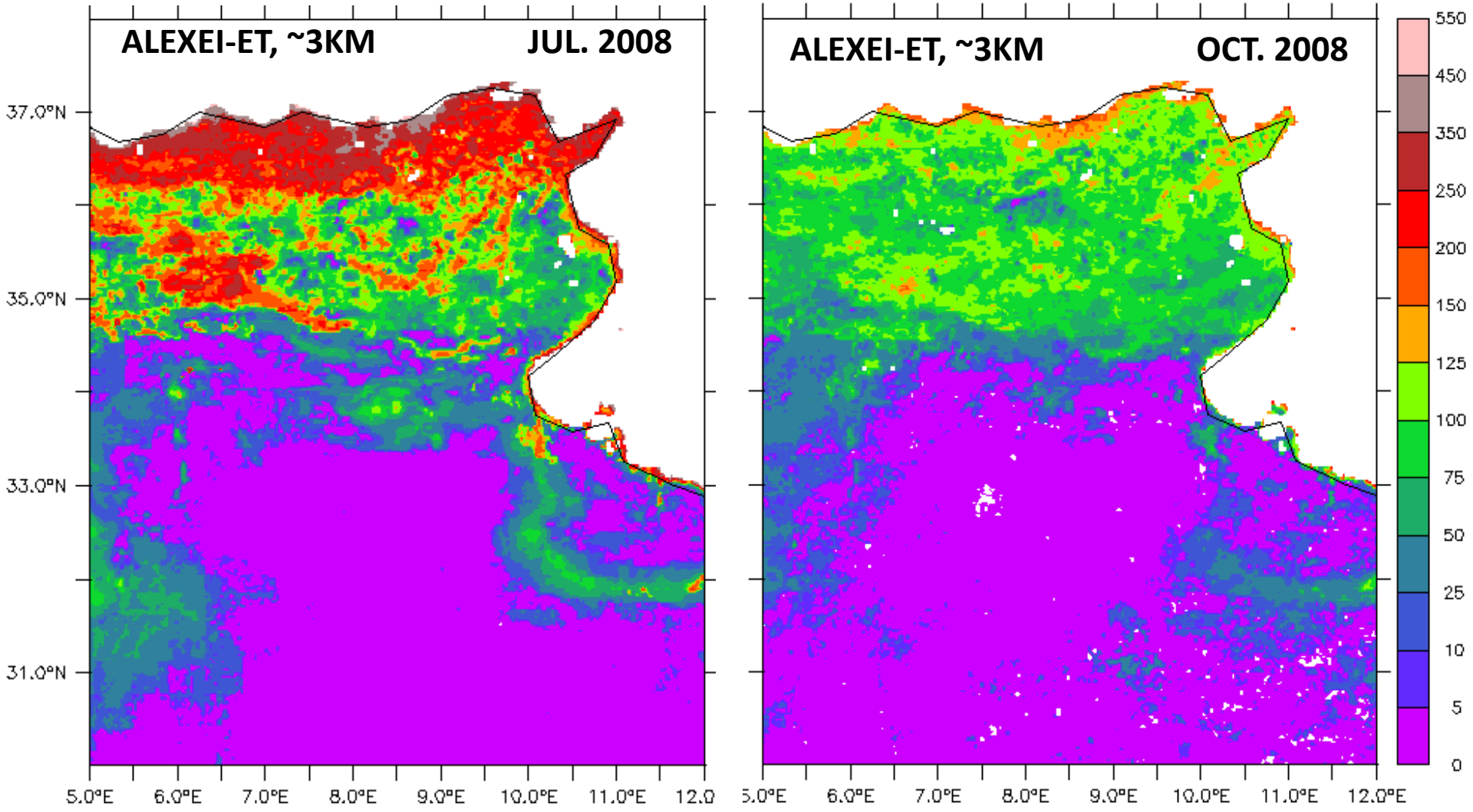
25
10
5
0


ALEXEI-ET, ~3KM
JUL. 2008
ALEXEI-ET, ~3KM
OCT. 2008
37.0°N
35.0°N
33.0°N
31.0°N
5.0°E
6.0°E
7.0°E
8.0°E
9.0°E
10.0°E
11.0°E
12.0
550
450
350
250
200
150
125
100
75
50
25
10
5
0

Recent Model Results

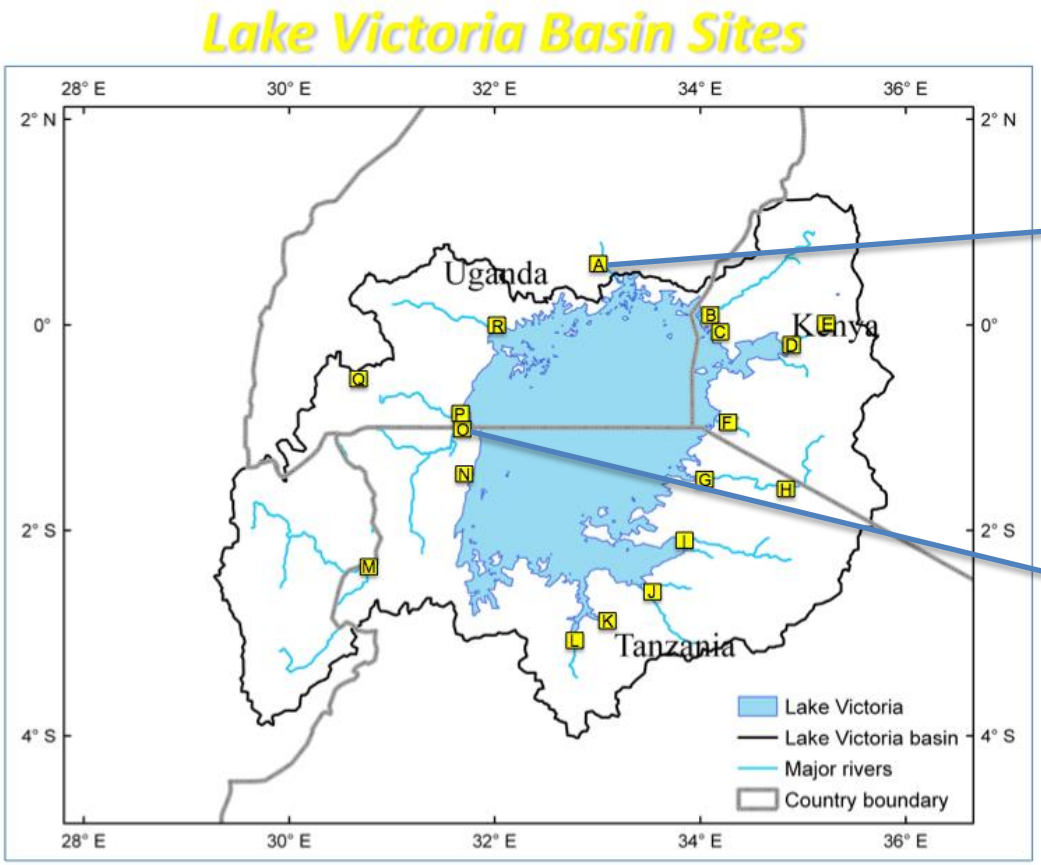
Calibration Runs (CREST 2.0), Statistics
1 km resolution, 3 hourly model simulations
Compared with daily stream flow data
2007 Tunisia

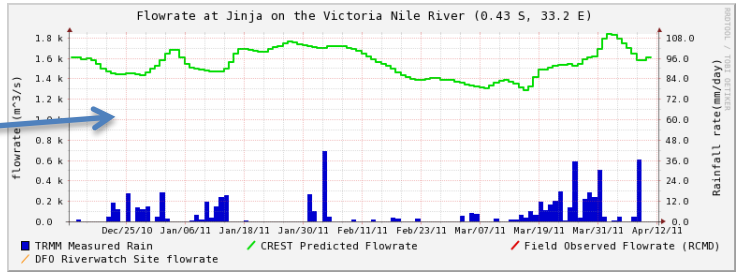
Station	NSCE	BIAS(%)	CC
SLOUGUIA	0.216851	4.342463	0.467323
EL HERRI	0.275675	7.64221	0.532392,
MELLEGUE	0.149283	-53.679114	0.418566
PONT ROUTE	0.044236	-75.609874	0.235299

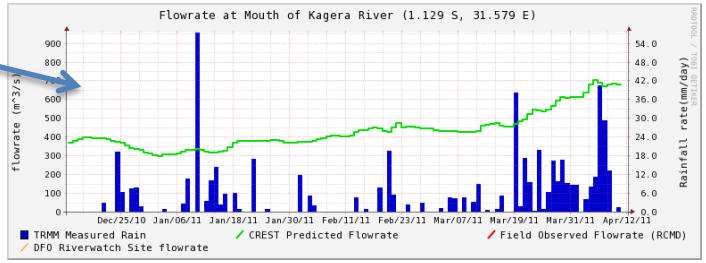
Calibration Runs (CREST 2.0), Statistics
3 hourly model simulations
Compared with daily stream flow data
2007 Tunisia

Station	NSCE (1km, daily)	NSCE (90m , daily)
EL HERRI	0.2757	TBD
Bou Salem	In work	-0.65 after 1 iteration

Lake Victoria Basin Flood Modeling







SERVIR-Africa Project

Flood Modeling Challenges (1 of 2)

- Precipitation data accuracy and spatial resolution
  - Need rain gauge data to evaluate satellite data
  - New Retrieval Algorithms being developed for GPM mission (IMERG)
  - Combine NRT rain gauge and satellite data ?!
- Elevation data accuracy
  - Quantify DEM errors in partnership with member countries
  - Evaluate effect of DEM errors in partnership with member countries
  - If needed – investigate methods to improve DEMS
- Elevation data spatial resolution
  - Currently using 1 km spatial resolution
  - Concern about model limitations at higher resolution – need to investigate this
- Evapotranspiration data accuracy
  - In-situ data needed to evaluate accuracy
  - Model currently uses a monthly climatology product based on FEWSNET data. NASA is investigating model sensitivity and other data sources (ALEXI and MODIS)

Flood Modeling Challenges (2 of 2)

- Dams/ hydrological infrastructure
  - Not included in current flood model
  - Area of Applied Research with member countries
- Snowmelt is not included in current model
- Member nations will need precipitation forecasts from national Met Offices
- Require stream gauge data for calibration and evaluation !
- Calibration is computationally expensive
  - NASA has developed a Parallel processing approach to calibration
  - For large areas/ high resolution, super-computing assets are needed

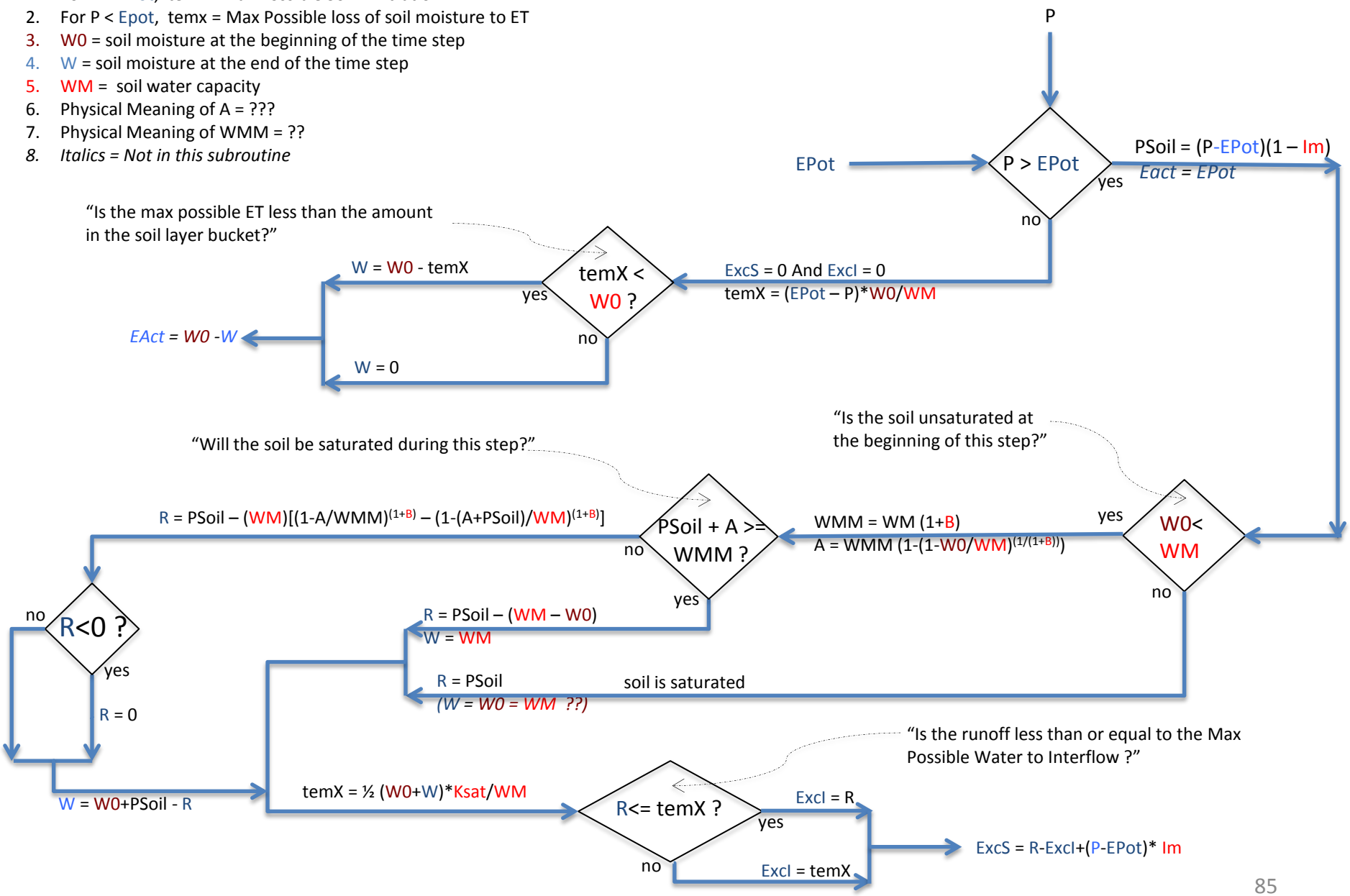
- Examine additional flood models ?!
  - Global Flood Monitoring System (not currently calibrated)
  - EF-5/ CREST (modified version of CREST)

CREST DETAILS

CREST Model 2.0 Subroutine CREST_RunoffGen

Notes

1. For P > EPot, temx =Max Possible Soil Infiltration
2. For P < Epot, temx = Max Possible loss of soil moisture to ET
3. W0 = soil moisture at the beginning of the time step
4. W = soil moisture at the end of the time step
5. WM = soil water capacity
6. Physical Meaning of A = ???
7. Physical Meaning of WMM = ??
8. *Italics = Not in this subroutine*



CREST Model V 2.0 Hydrological Parameters

"Initial Conditions"

1. **W0** - initial value of soil moisture = a percentage of the WM and should therefore vary between 0 – 100 (?)
2. **SS0** - initial value of overland reservoir
3. **SI0** - initial value of interflow reservoir

"Physical Parameters"

4. **Ksat** – saturated soil hydraulic conductivity
5. **RainFact** - the multiplier on the precipitation field
6. **WM** –soil water capacity depth (Areal mean for given cell)
7. **B** - the exponent of the variable infiltration curve
8. **IM** - Impervious area ratio.
9. **KE** – The factor to convert the PET and local actual ET
10. **coeM** - overland runoff velocity coefficient

"Conceptual Parameters"

11. **expM** - overland flow speed exponent
12. **coeR** - multiplier used to convert overland flow speed to channel flow speed
13. **coeS** - multiplier used to convert overland flow speed to interflow flow speed
14. **KS** - overland reservoir discharge parameter
15. **KI** - interflow reservoir discharge multiplier

"Adjustment Parameter"

16. **AreaFact** - multiplier that modifies the area of grid cells

CREST MODEL V 2.0 Input and Output Variables

Inputs

- **Rain =** Rainfall
- **DEM =** Digital Elevation Model
- **FAC** = ArcGIS(DEM) – Flow Accumulation Map = upstream drainage area for a given cell
- **FDR**= = ArcGIS (DEM) – Flow Direction Map = flow direction for a given cell
- **PET** = Potential Evapotranspiration
- **Robs –** Observed stream flow rate

Outputs

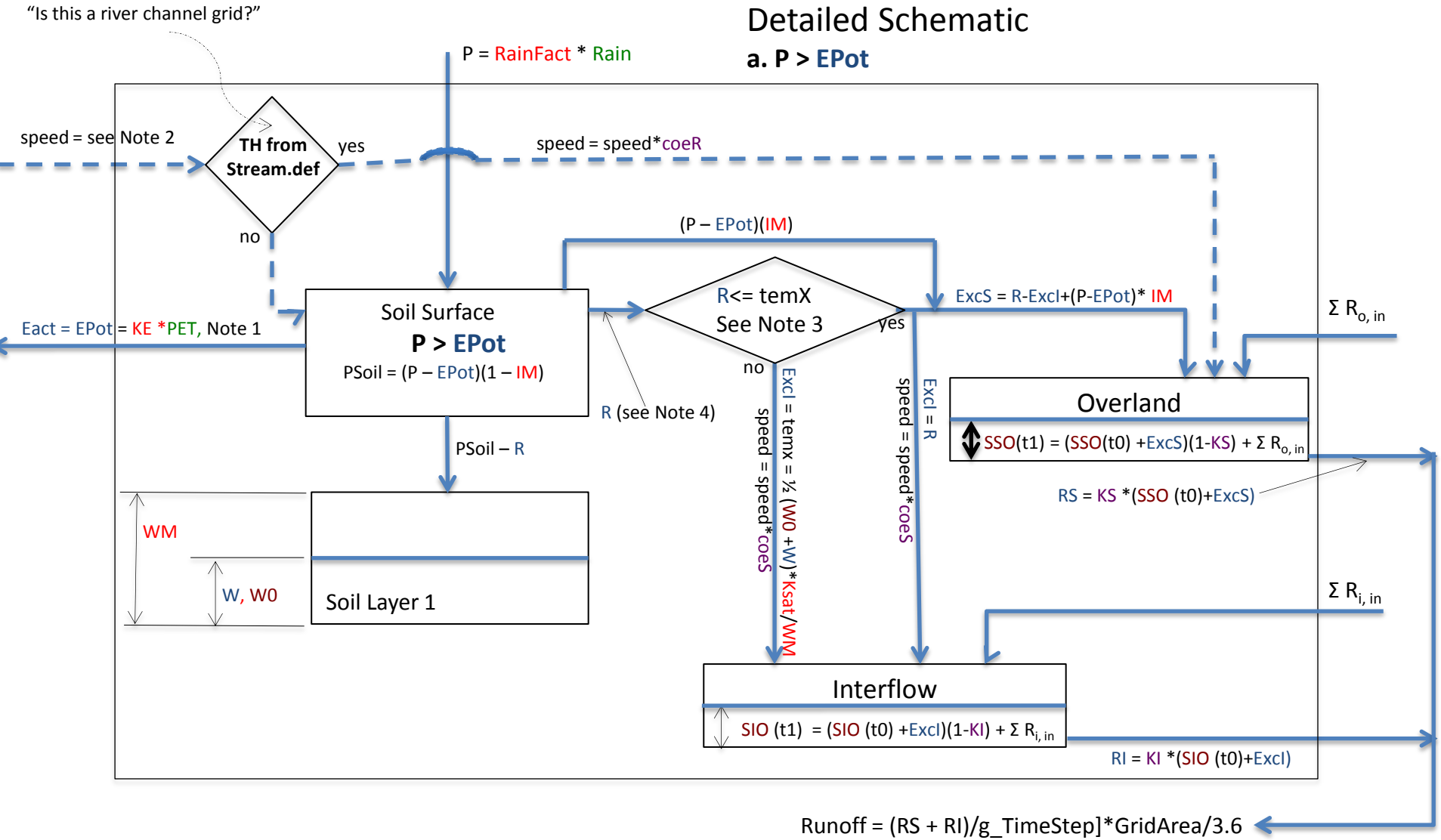
- **Rain** – input precipitation; unit is mm (for a cell for a 3 hour time step)
- **PET –** Input PET
- **EPot =** PET*KE
- **EAct** - depth of simulated actual evapotranspiration; unit is mm (for a cell for a 3 hour time step)
- **W –** depth of water filling the pore space bucket
- **SM** - depth of water filling the pore space bucket; unit is mm (for a cell for a 3 hour time step)
- *Fix this* **R** - depth of overland reservoir; unit is mm (for a cell for a 3 hour time step)
- **ExcS** - depth of surface excess rain; unit is mm (for a cell for a 3 hour time step)
- **ExcI** - depth of interflow excess rain; unit is mm (for a cell for a 3 hour time step)
- **RS** – Surface Runoff, simulated discharge of each grid cell; unit is m^3/s.
- **RI** – Interflow Runoff

Internal Variables

- P =RainFact * Rain
- WMM
- A
- temX

Detailed Schematic

a. P > EPot



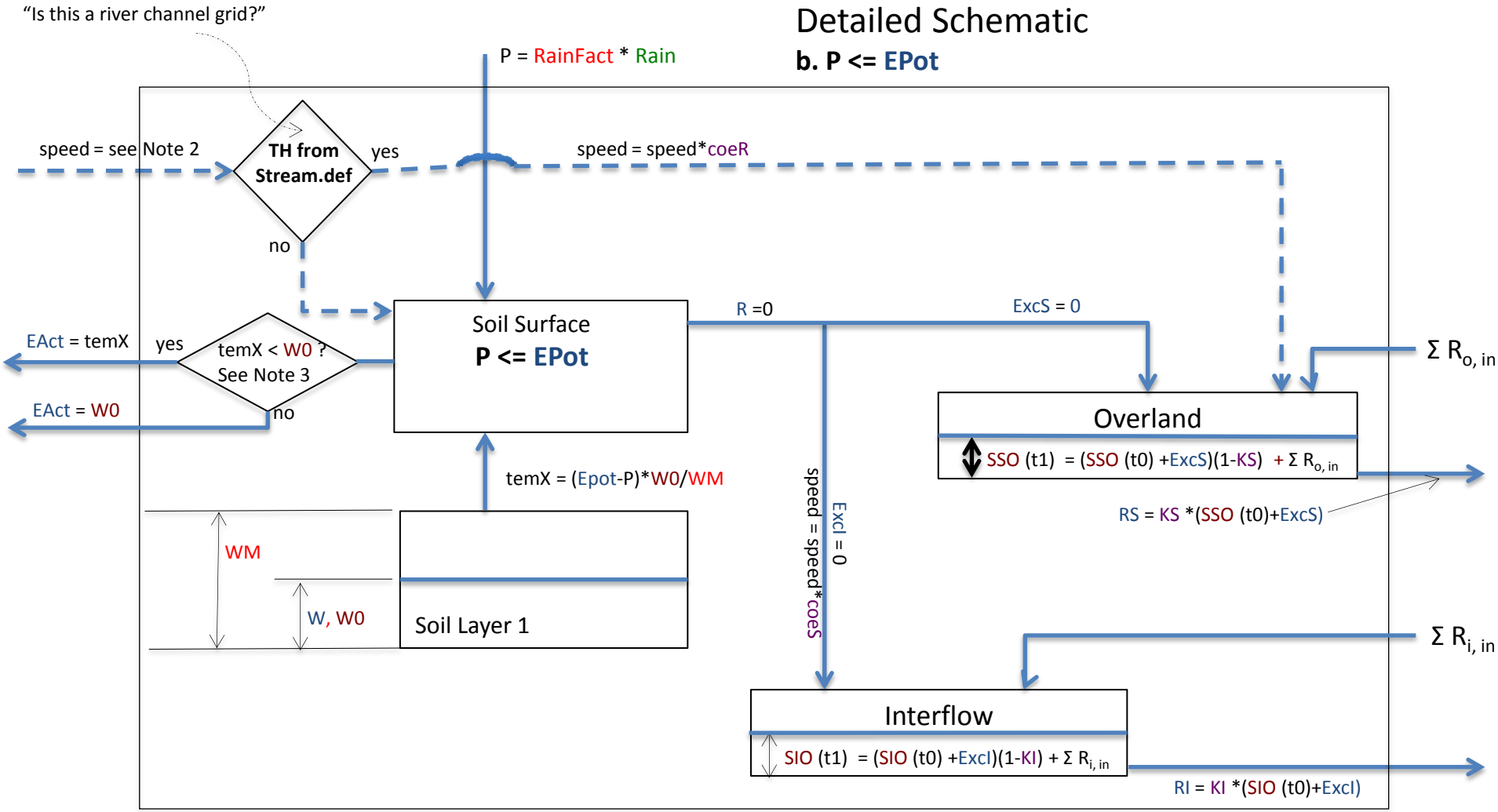
Notes

1. If (P>EPot) then EAct = EPot, else EAct = W0-W
2. Speed = coeM (SpeedVegLocal +SpeedVegNext)/2 *(gDEM-gDEM(NextCell)/Length)^expM; default values: SpeedVegLocal = SpeedVegNext = 0.5
3. temX = Max Possible Water to Interflow = ½ (W0 +W)*Ksat/WM
4. If soil is initially saturated, R = Psoil; W = W0
   If soil is saturated during the timestep, R = Psoil – (WM – W0); W = WM
   If soil is not saturated, R = PSoil – (WM)[(1-A/WMM)$^{(1+B)}$ – (1-(A+PSoil)/WM)$^{(1+B)}$]; W = W0 +Psoil –R
5. WMM = WM(1+B)
6. A = WMM (1-(1-W0/WM)$^{(1/(1+B))}$)

Dark Red = Initial Condition
Red = Physical Parameter
Purple = Conceptual Parameter
Green = Input Variable
Blue = Output Variable

Detailed Schematic

b. P <= EPot



Notes

1. If (P>EPot) then EAct = EPot, else EAct = W0-W
2. Speed = coeM (SpeedVegLocal +SpeedVegNext)/2 *(gDEM-gDEM(NextCell)/Length)^expM; default values: SpeedVegLocal = SpeedVegNext = 0.5
3. temX = Max Possible Evapotranspiration= (Epot-P)*W0/WM

Dark Red = Initial Condition
Red = Physical Parameter
Purple = Conceptual Parameter
Green = Input Variable
Blue = Output Variable

Resolution/Time Step (example from Nile Model)

- To limit water movement to 1 cell per time step, model only stream reaches with:

$V <= \Delta X/\Delta t$

ΔX = spatial resolution of DEM

Δt = time step of model

For ΔX = 1 km, Δt = 3 hours

➔ $V <= 0.1$ m/s

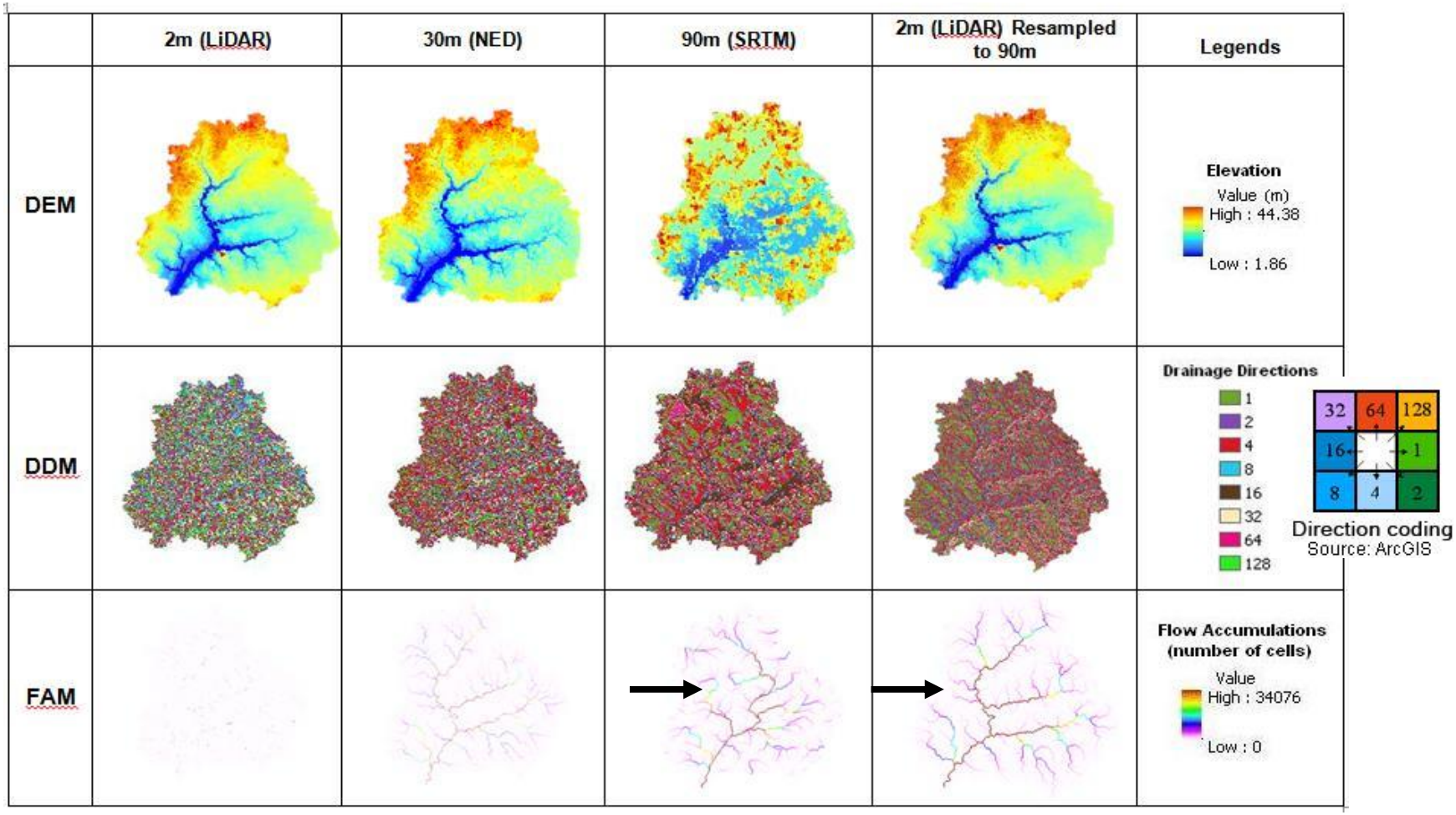
➔ V = 2.4 – 260 m/s for calibration period

For ΔX = 90 m, Δt = 3 hours

➔ $V <= 0.008$ m/s

➔ V = 0. 06 – 692 m/s for calibration period

HI Resolution DEMs - Discussion



Back-up Charts

MODIS Flood Mapping Challenges

MODIS data advantages

- 2 daylight acquisitions/ day
- 250m spatial resolution

MODIS data limitations

- 250m spatial resolution
- cloud cover
- dense vegetation

Cloud shadow and Terrain shadow often mis-identified as water (spectrally similar)

- Developing monthly terrain shadow mask
  DEM: 30m ASTER DEM resampled to 250m

- Testing geometry-based cloud shadow mask
  MOD35 Cloud Detection, MOD06 Cloud Height

Region	Governorate	Date
Grand Tunis	Tunis Ariana Ben Arous Manouba	30/10/2011
Zaghouan	Zaghouan	30/10/2011
El Batan	Manouba	02/11/2011
Mjez El-Bab	BEJA	30/10/2011
Redayef	GAFSA	23/09/2009
Sabalet Ben Ammar (North-West of Tunis)	Ariana	14/10/2007
Grand Tunis	Tunis Ariana Ben Arous Manouba	13/10/2007
Grand Tunis, Zaghouan, Nabeul Other zones in coastline	Tunis Ariana Ben Arous Manouba Zaghouan Nabeul	17-23/09/2003
	Jendouba Béja Manouba Bizerte	January 2003

Dear Fritz,

Please find attached the file with the most important flood events in Tunisia since 2003.

Best regards,
Sinan Bacha