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ASSIMILATION OF REMOTE SENSING-DERIVED FLOOD EXTENT AND SOIL MOISTURE DATA INTO COUPLED HYDROLOGICAL-HYDRAULIC MODELS

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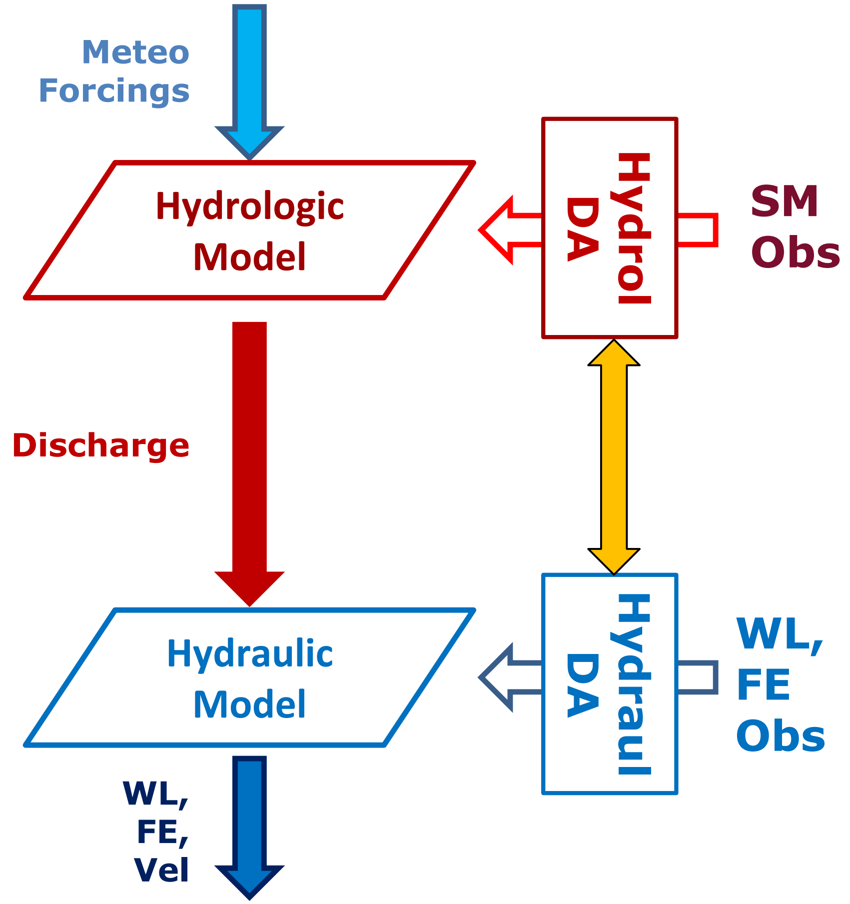
Research questions:

- How to combine remote sensing derived soil moisture and flood extent data with hydrologic-hydraulic models for improved streamflow predictions?
- What is the respective merit of soil moisture and flood extent data assimilation for streamflow predictions?

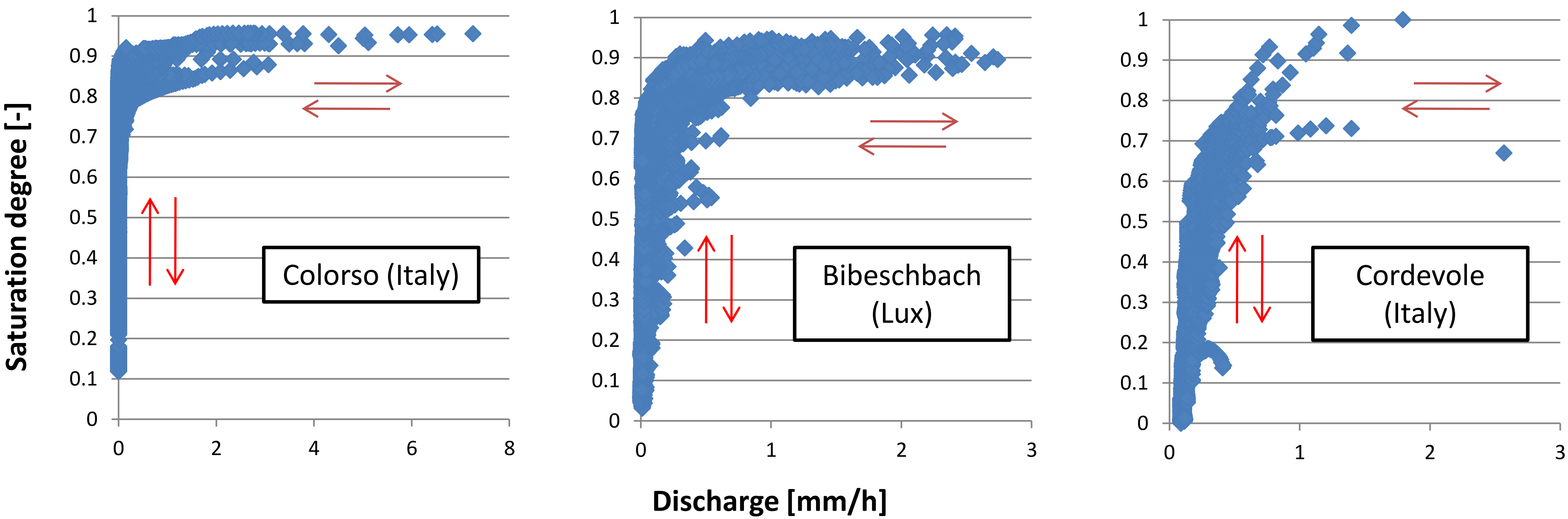
- Hydrological and Hydraulic models represent different physical processes and take advantage of different types of observations.

- Different sensors are available and provide complementary information

- <u>Hypothesis: </u>assimilation of both data sets provides advantages for streamflow predictions



Rationale:

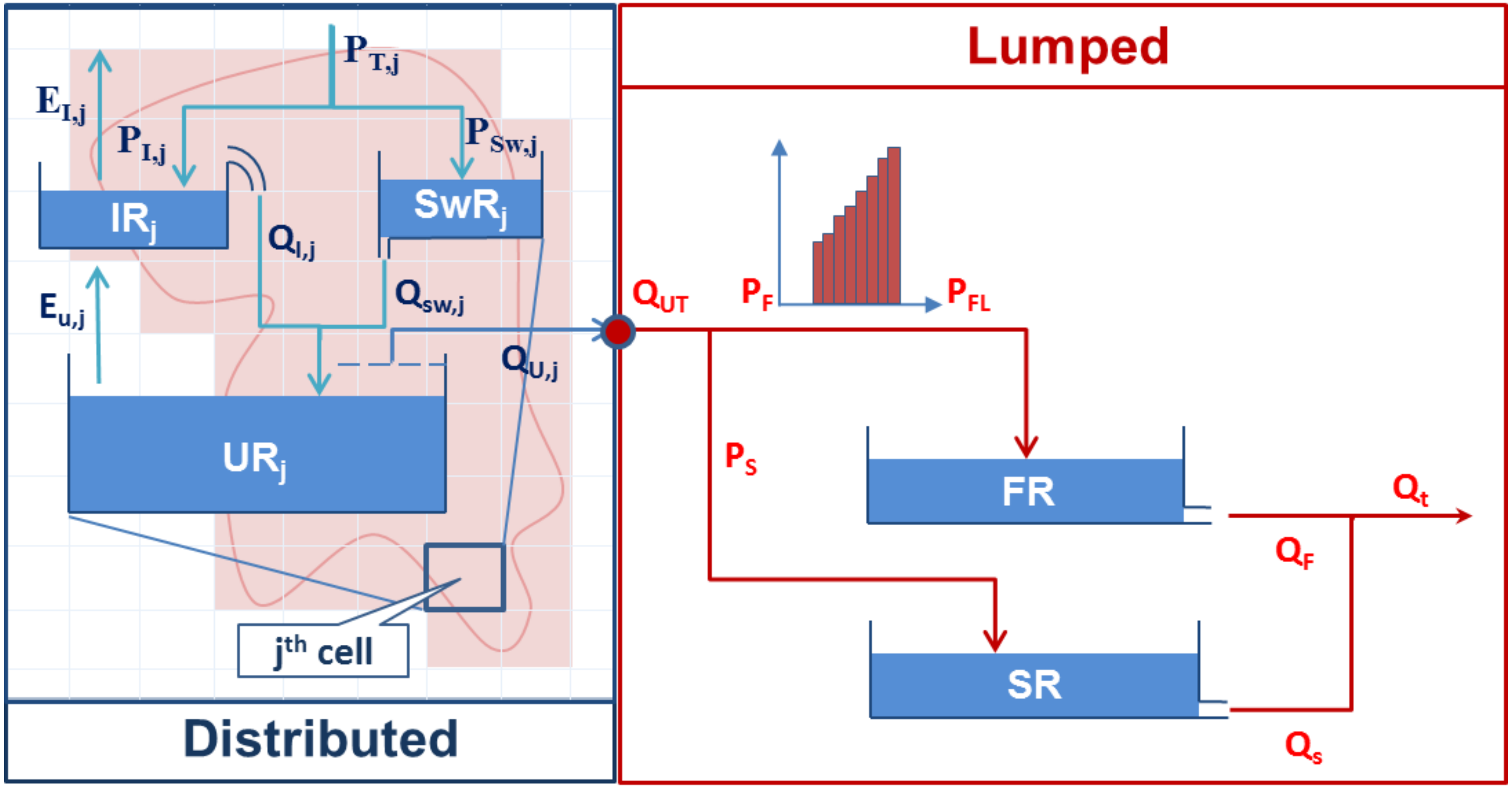


- Initiation of fast runoff is a threshold process that occurs when soil moisture rises above a critical threshold
- Soil moisture and water level variability are inversely correlated: potentially soil moisture and water level (or flood extent) observations are highly complementary

Matgen et al., HP, 2012

1. Setup of model cascade
2. Ensemble generation
3. Satellite data processing
4. Assimilation

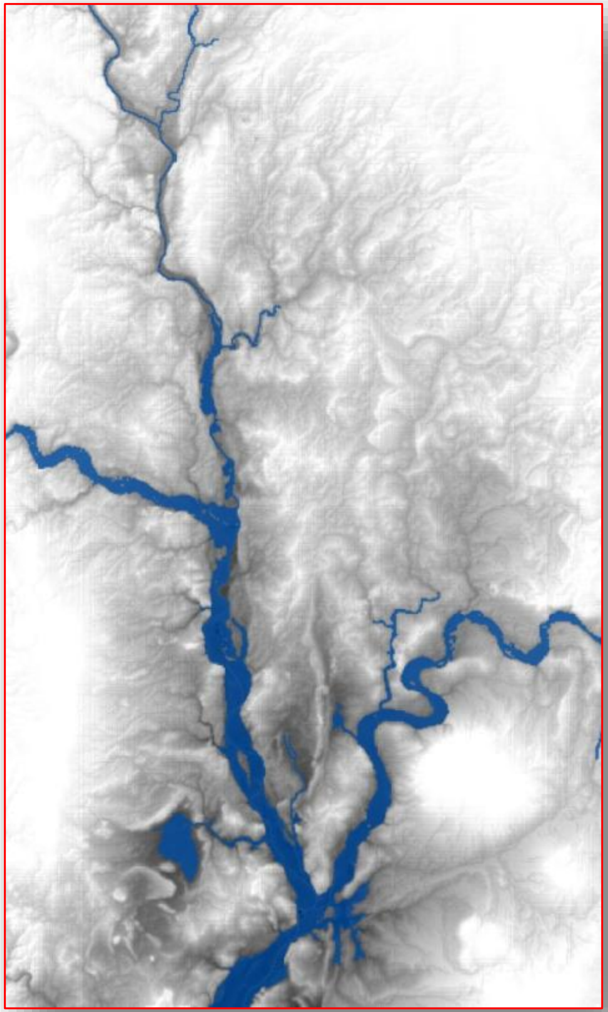
The model was set up using the SuperFlex (Fenicia et al., WRR, 2010) framework



- Model structure can be adapted to catchment properties and satellite data characteristics
- Calibration performed on the basis of in situ measurements or SM satellite observations

LISFLOOD-FP SubGrid

- Designed for modelling flood flows in larger catchments.
- Uses DEM file as geometry.
- Models 1D- 2D dimensional flows or fully 2D dimensional flows.
- Calibration performed on the basis of in situ measurements or satellite observations



Precipitation

↓

Hydrol Mod

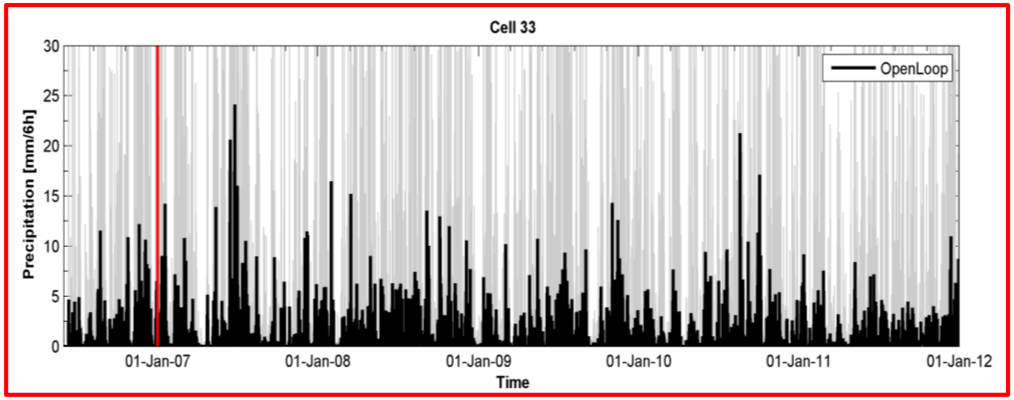
SWI

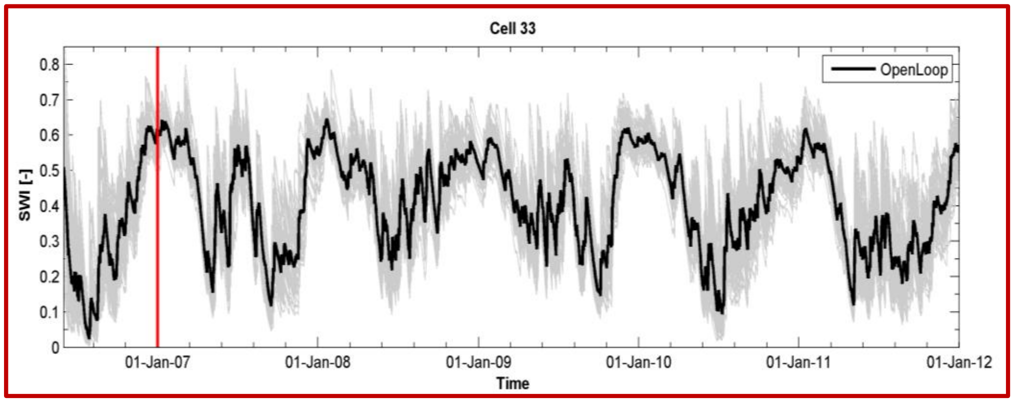
Discharge

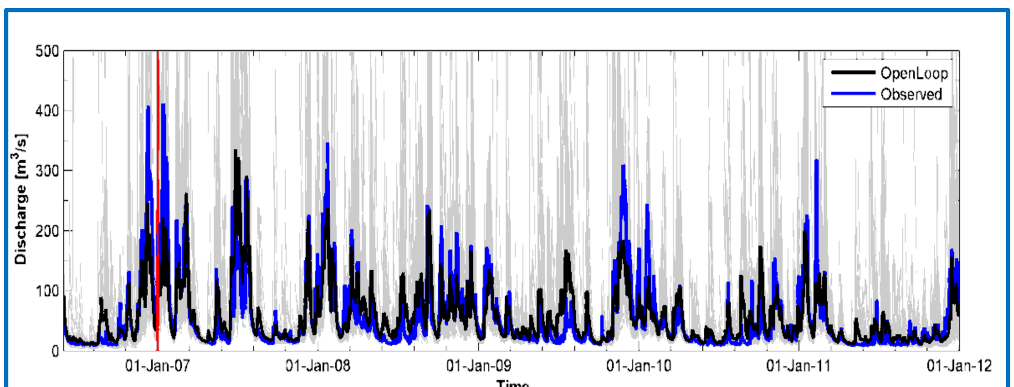
↓

Hydraul Mod

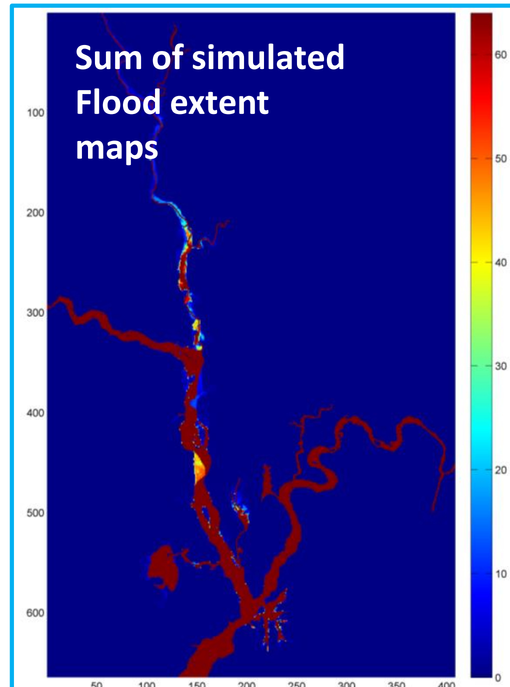
Flood Extents







- 64 Particles
- Multiplicative Error randomly generated from lognormal distribution
- Ensemble of Discharge validated by the Ensemble Verification Measure of De Lannoy et al. (2006)



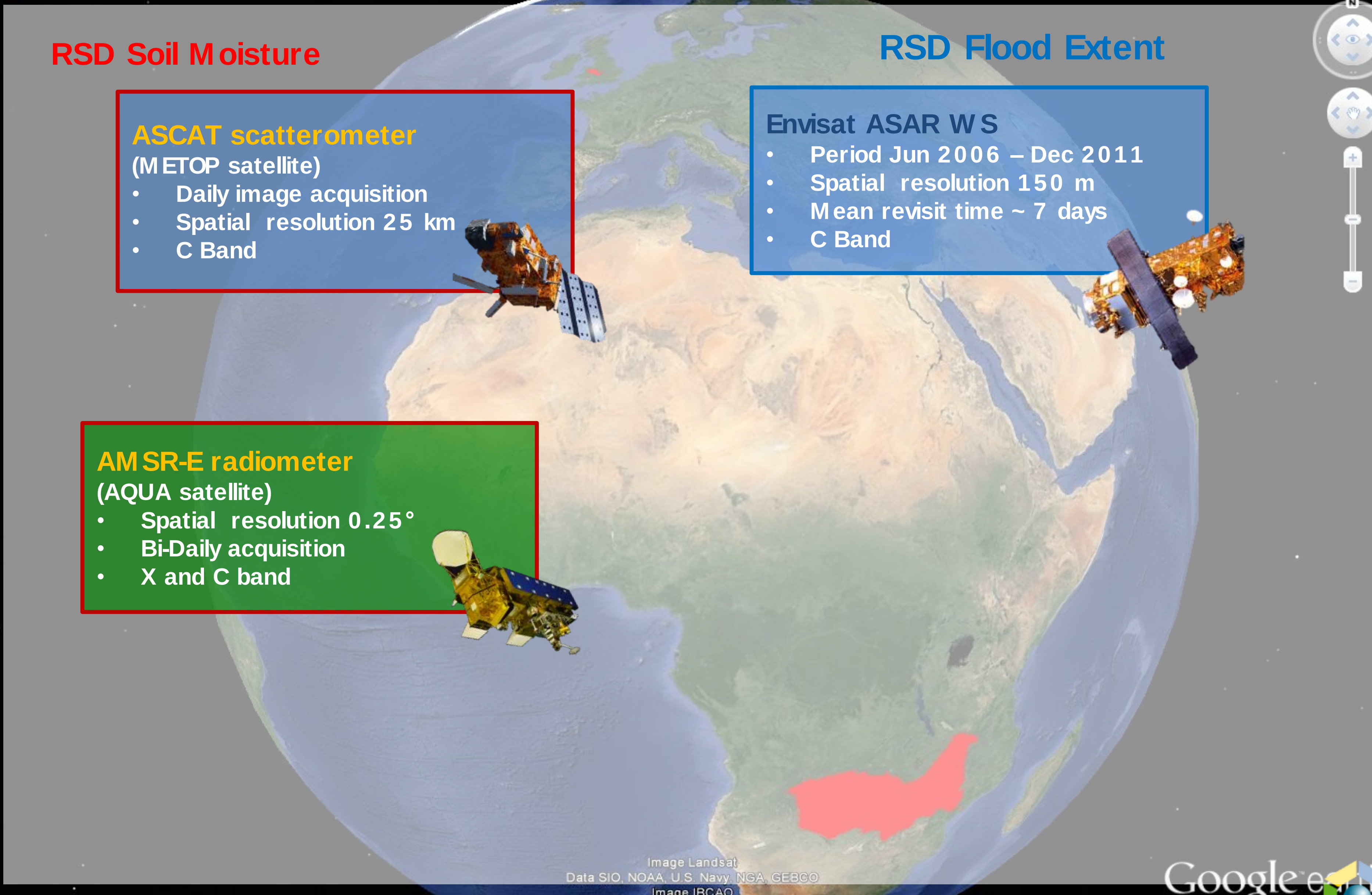
RSD Soil Moisture

ASCAT scatterometer
(METOP satellite)
- Daily image acquisition
- Spatial resolution 25 km
- C Band

AMSR-E radiometer
(AQUA satellite)
- Spatial resolution 0.25°
- Bi-Daily acquisition
- X and C band

RSD Flood Extent

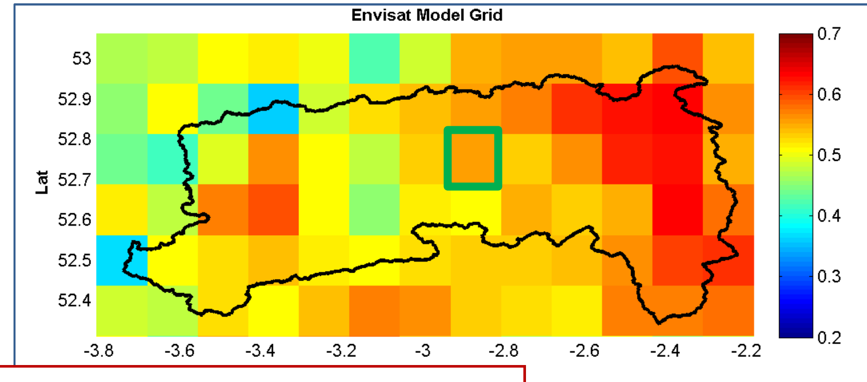
Envisat ASAR WS
- Period Jun 2006 – Dec 2011
- Spatial resolution 150 m
- Mean revisit time ~ 7 days
- C Band

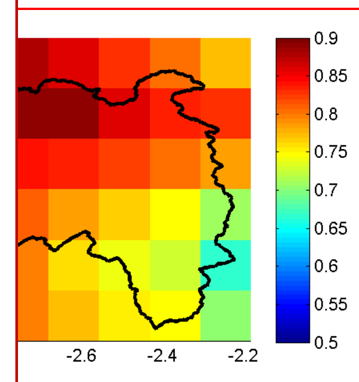


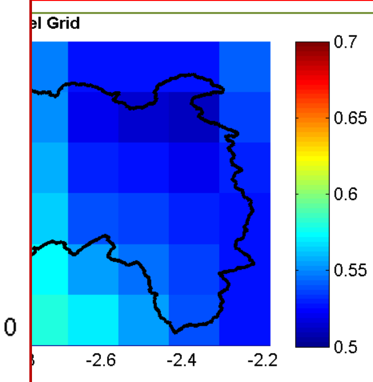
RSD Soil Moisture processing

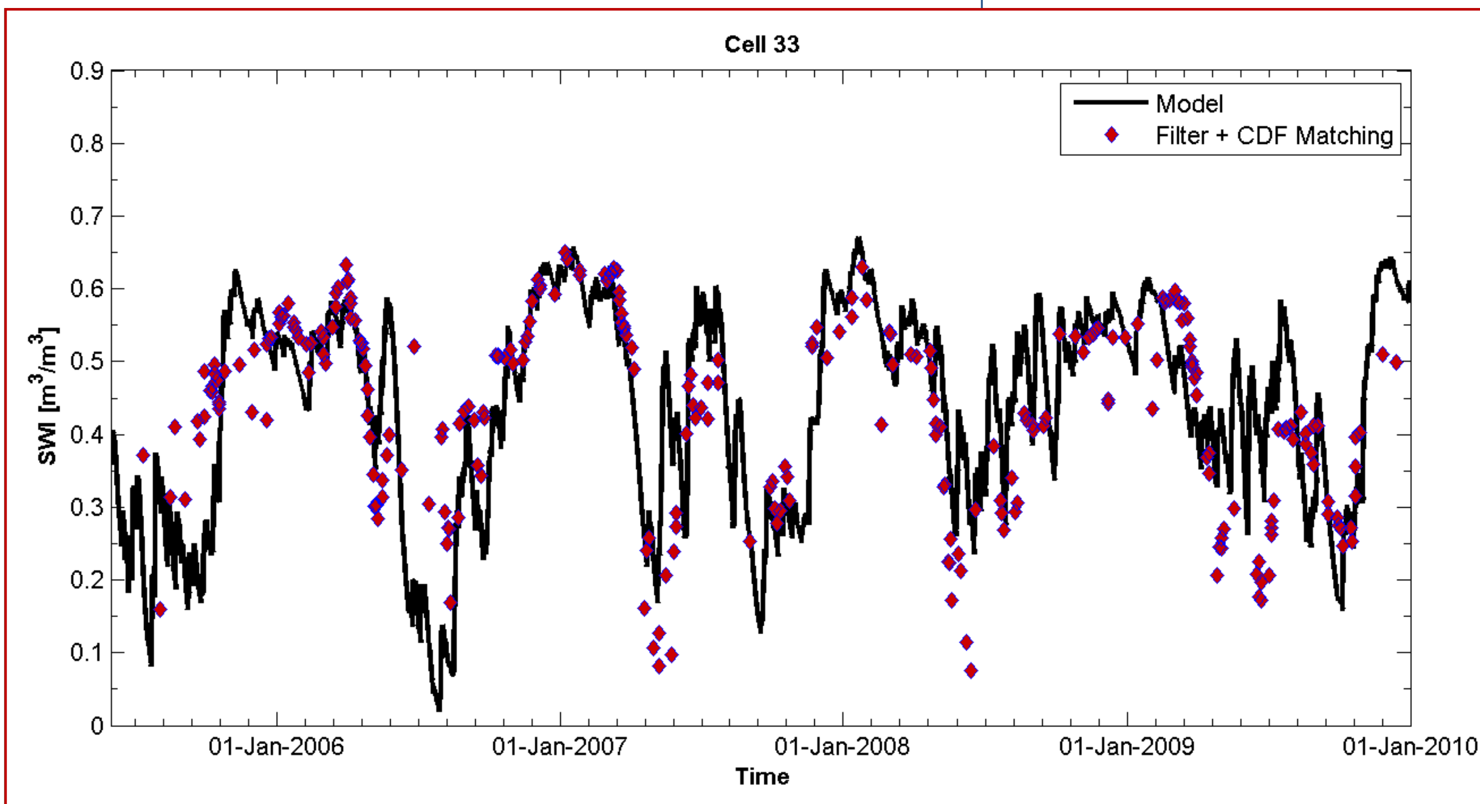
- Snow Masking
- Upscale or Downscale to Model Grid
- From surface to Root Zone
- CDF Matching

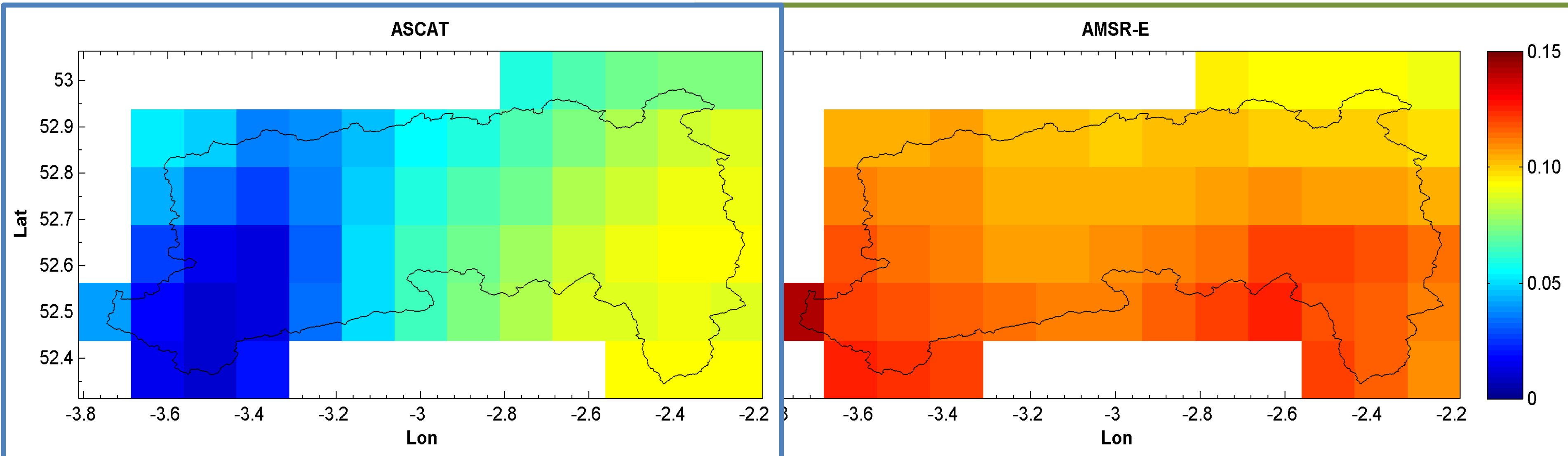
Envisat 0.0042°









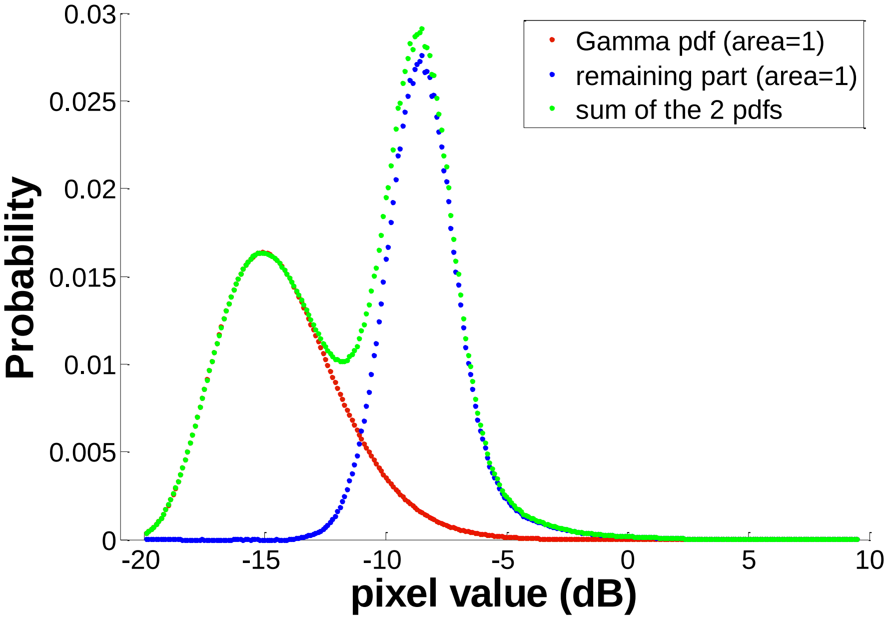


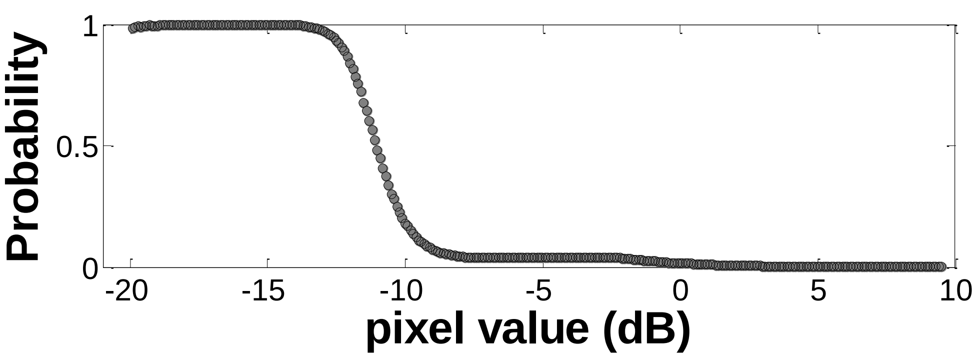
For all satellite products the open loop mean was assumed as reference

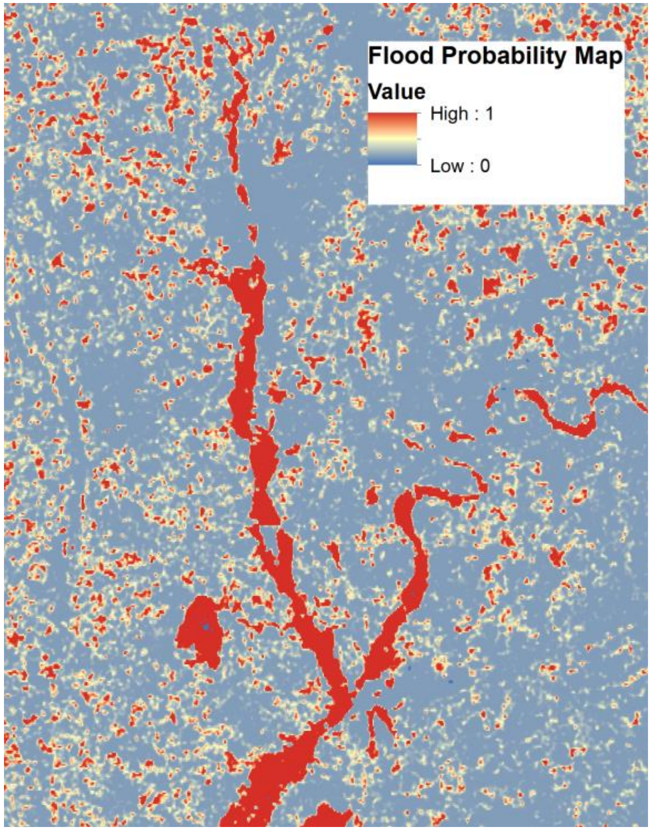
The following triplet was considered:

Model-AMSRE-Ascat (Ascat and AMSRE error parameterization)

Probability of a pixel to be flooded knowing its backscatter



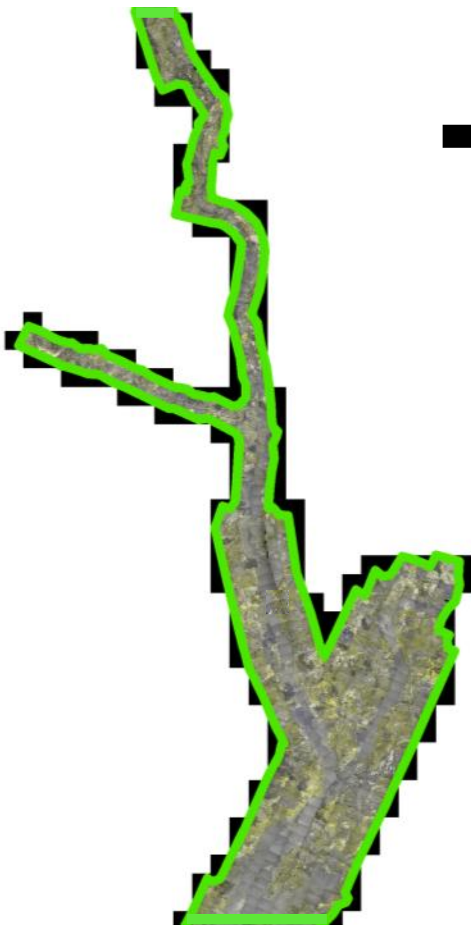




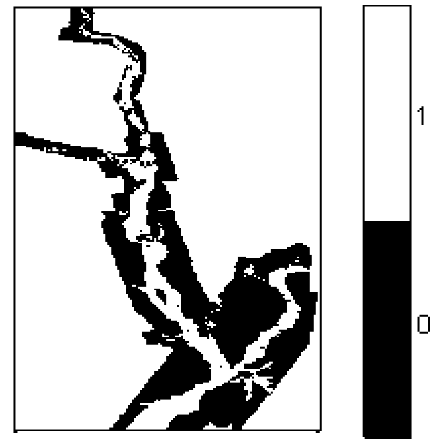
$$p(w|\sigma^0) = \frac{p(\sigma^0|w)p(w)}{p(\sigma^0|w)p(w) + p(\sigma^0|d)p(d)}$$

Giustarini et al., IEEE TGRS, 2013

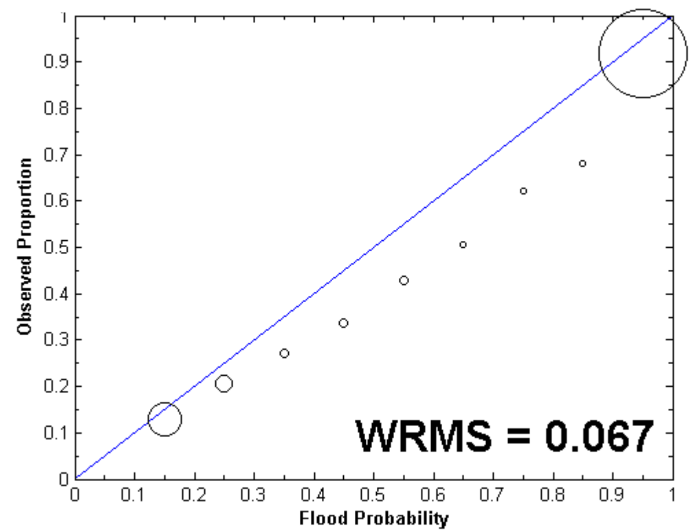
Evaluation of results



Aerial photography (flood event on River Severn)

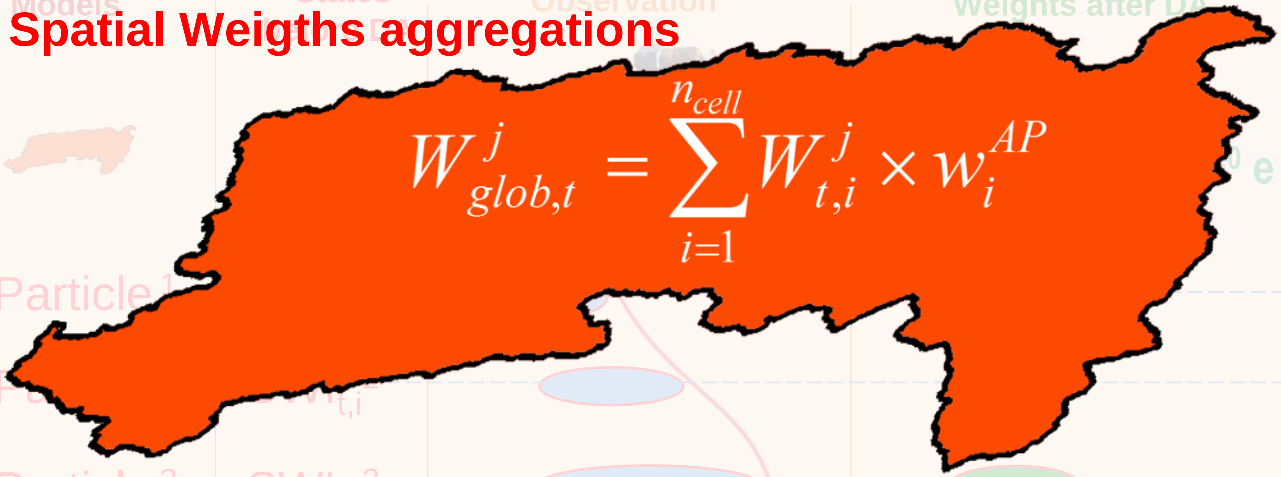


Flood extent obtained through photo-interpretation



Reliability diagram

Spatial Weigths aggregations



$$W^{j}_{glob,t} = \sum_{i=1}^{n_{cell}} W^{j}_{t,i} \times w_i^{AP}$$

Weigthed mean

$$Q_t = \left(\sum_{j=1}^{nPart} W_{glob,t}{}^{j} \times Q_{t,j} \right) / \sum_{j=1}^{nPart} W_{glob,t}{}^{j}$$

Particle Filter

Assumption : binomial likelihood pdf $p(k,n \mid \Theta) = \binom{k}{n} \Theta^k (1-\Theta)^{n-k}$

k = # successes
n = # trials

$MOD_{t,i}$

1	0	1
0	1	1
1	0	0

$$w_{1,1}^{t,i} = \Theta_{1,1}$$ Simulated Water pixel

$$w_{3,3}^{t,i} = 1 - \Theta_{3,3}$$ Simulated Dry pixel

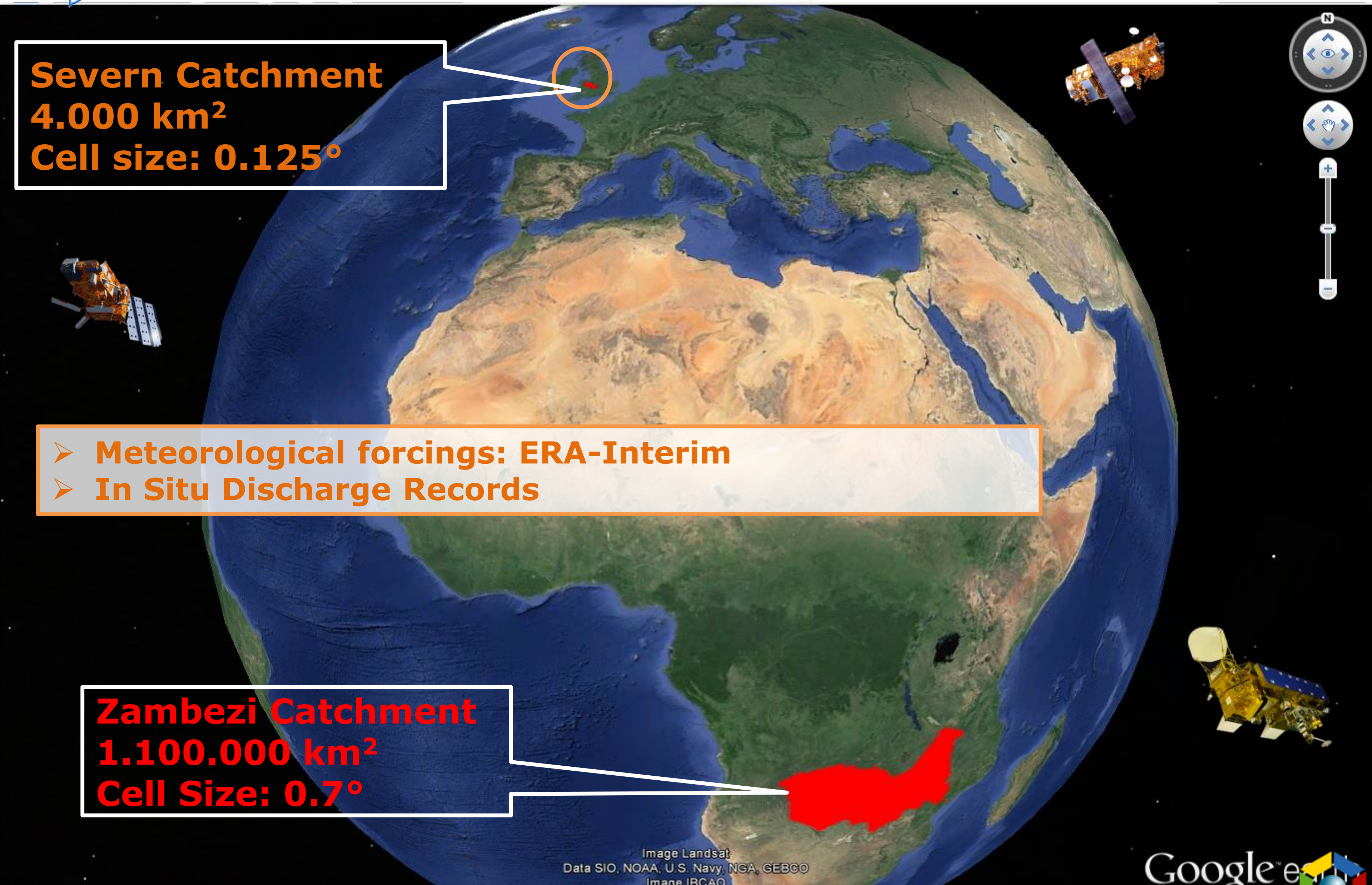
Satellite observation

$\Theta_{1,1}$	$\Theta_{1,2}$	$\Theta_{1,3}$
$\Theta_{2,1}$	$\Theta_{2,2}$	$\Theta_{2,3}$
$\Theta_{3,1}$	$\Theta_{3,2}$	$\Theta_{3,3}$

$w_{1,1}^{t,i}$	$w_{1,2}^{t,i}$	$w_{1,3}^{t,1}$
$w_{2,1}^{t,i}$	$w_{2,2}^{t,i}$	$w_{2,3}^{t,i}$
$w_{3,1}^{t,i}$	$w_{3,2}^{t,i}$	$w_{3,3}^{t,i}$

Spatial Weights aggregations

$$W^{i,t} = \sum_{j,k} w_{j,k}^{i,t}$$

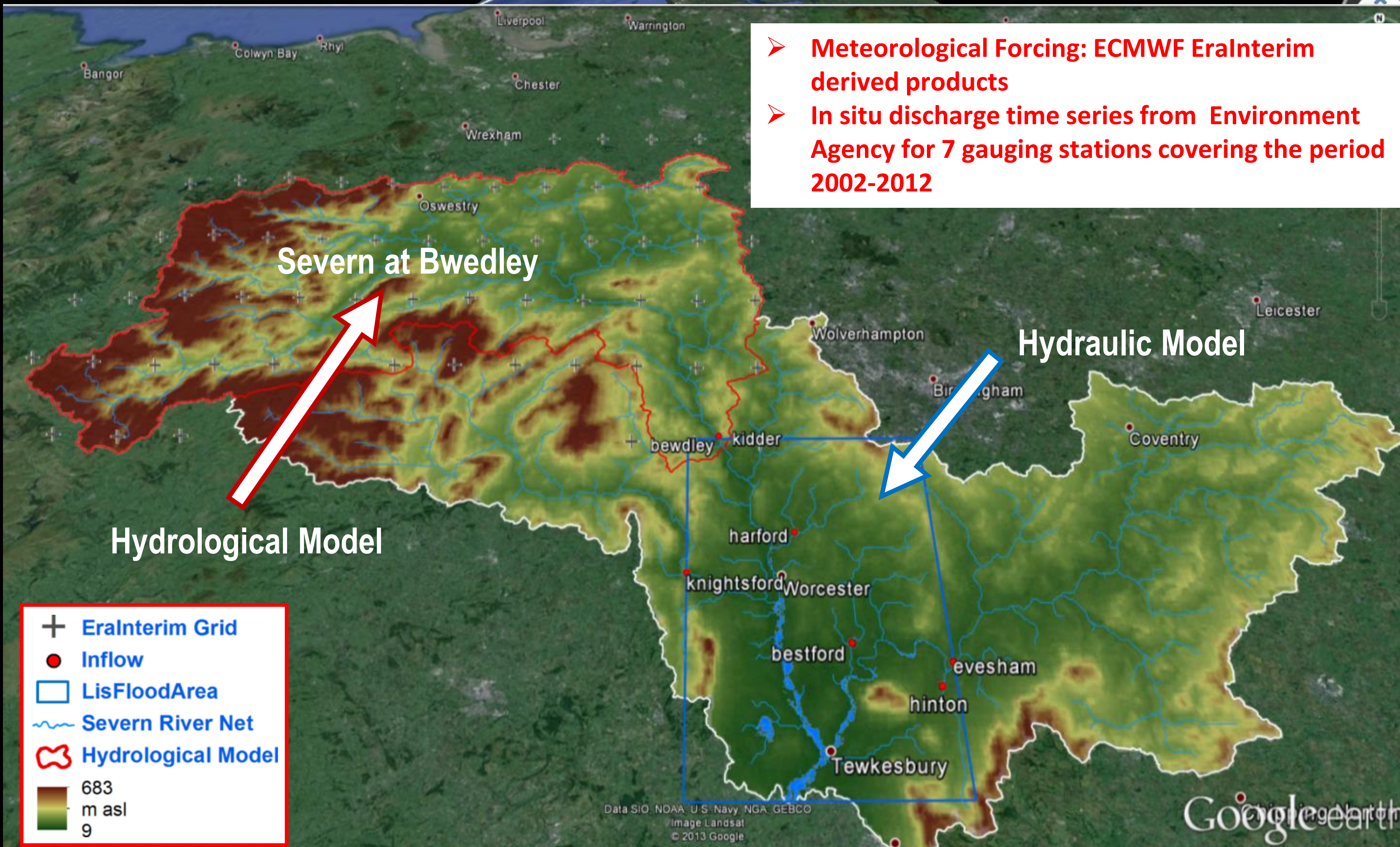


Severn Catchment
4.000 km²
Cell size: 0.125°

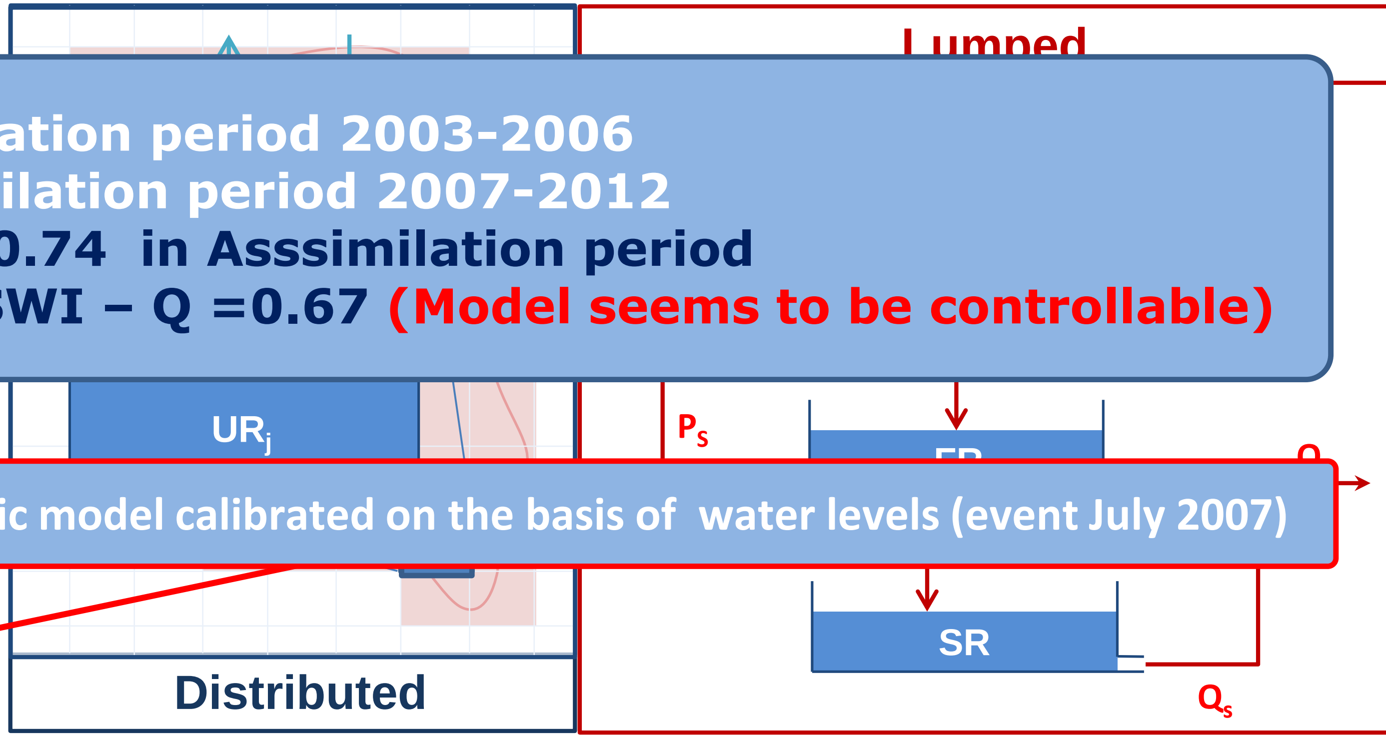
- **Meteorological forcings: ERA-Interim**
- **In Situ Discharge Records**

Zambezi Catchment
1.100.000 km²
Cell Size: 0.7°

- Meteorological Forcing: ECMWF EraInterim derived products
- In situ discharge time series from Environment Agency for 7 gauging stations covering the period 2002-2012



Hydrologic Model Scheme



- Calibration period 2003-2006
- Assimilation period 2007-2012
- NS = 0.74 in Asssimilation period
- Corr SWI – Q =0.67 **(Model seems to be controllable)**

- Hydraulic model calibrated on the basis of water levels (event July 2007)

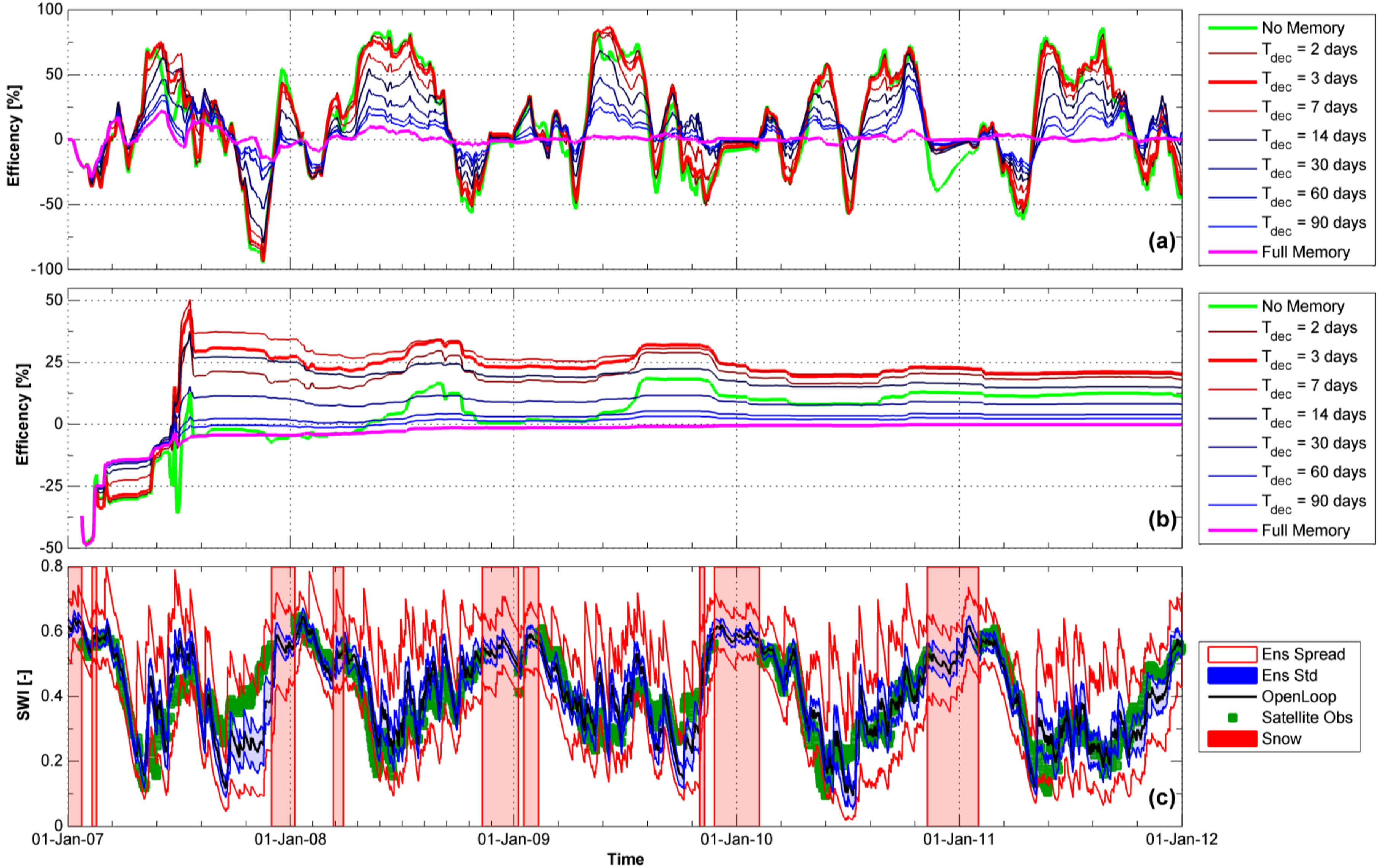
Cell size
0.125° x 0.125°

4 Reservoirs and 10 parameters to calibrate

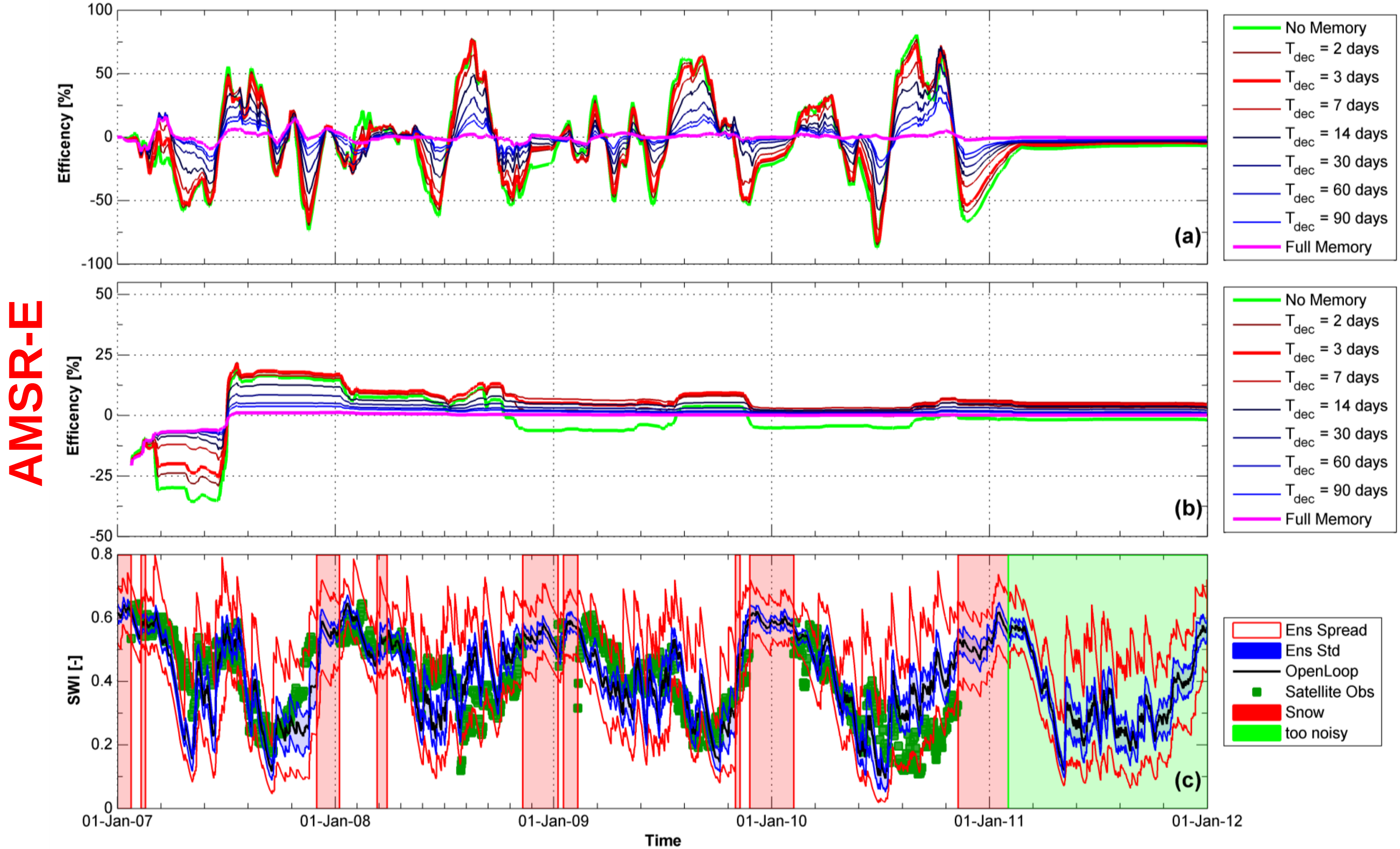
Meteorological forcings (Precipitation and Temperature):

- ECMWF ERA Interim derived products with 6h time resolution;
- Precipitation spatially distributed;
- Evapotranspiration was computed using Hamon formula and lumped values of ERA Interim temperatures

ASCAT

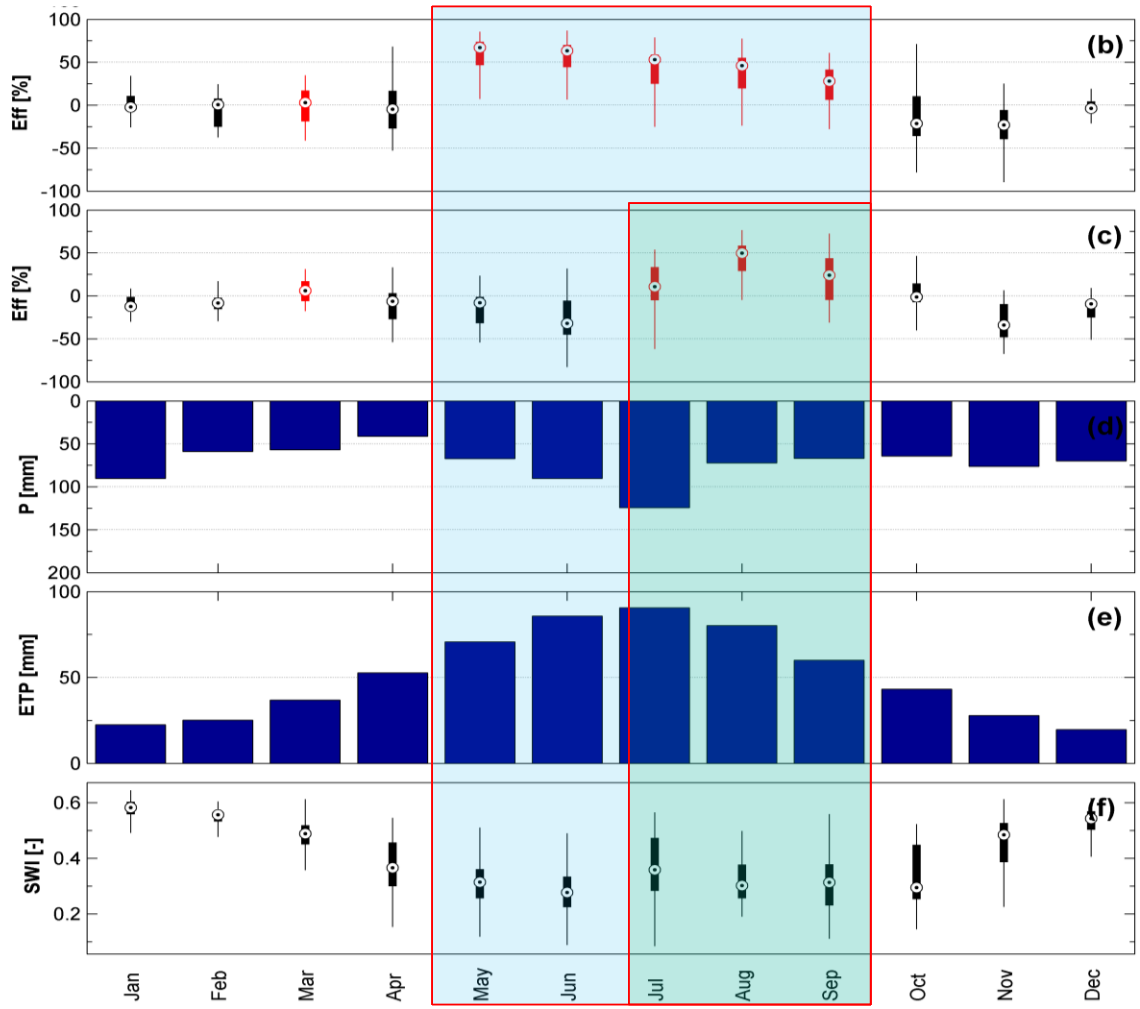

100
50
0
-50
-100
Efficency [%]
(a)
No Memory
T_{dec} = 2 days
T_{dec} = 3 days
T_{dec} = 7 days
T_{dec} = 14 days
T_{dec} = 30 days
T_{dec} = 60 days
T_{dec} = 90 days
Full Memory
50
25
0
-25
-50
Efficency [%]
(b)
No Memory
T_{dec} = 2 days
T_{dec} = 3 days
T_{dec} = 7 days
T_{dec} = 14 days
T_{dec} = 30 days
T_{dec} = 60 days
T_{dec} = 90 days
Full Memory
0.8
0.6
0.4
0.2
0
SWI [-]
(c)
Ens Spread
Ens Std
OpenLoop
Satellite Obs
Snow
01-Jan-07
01-Jan-08
01-Jan-09
01-Jan-10
01-Jan-11
01-Jan-12
Time

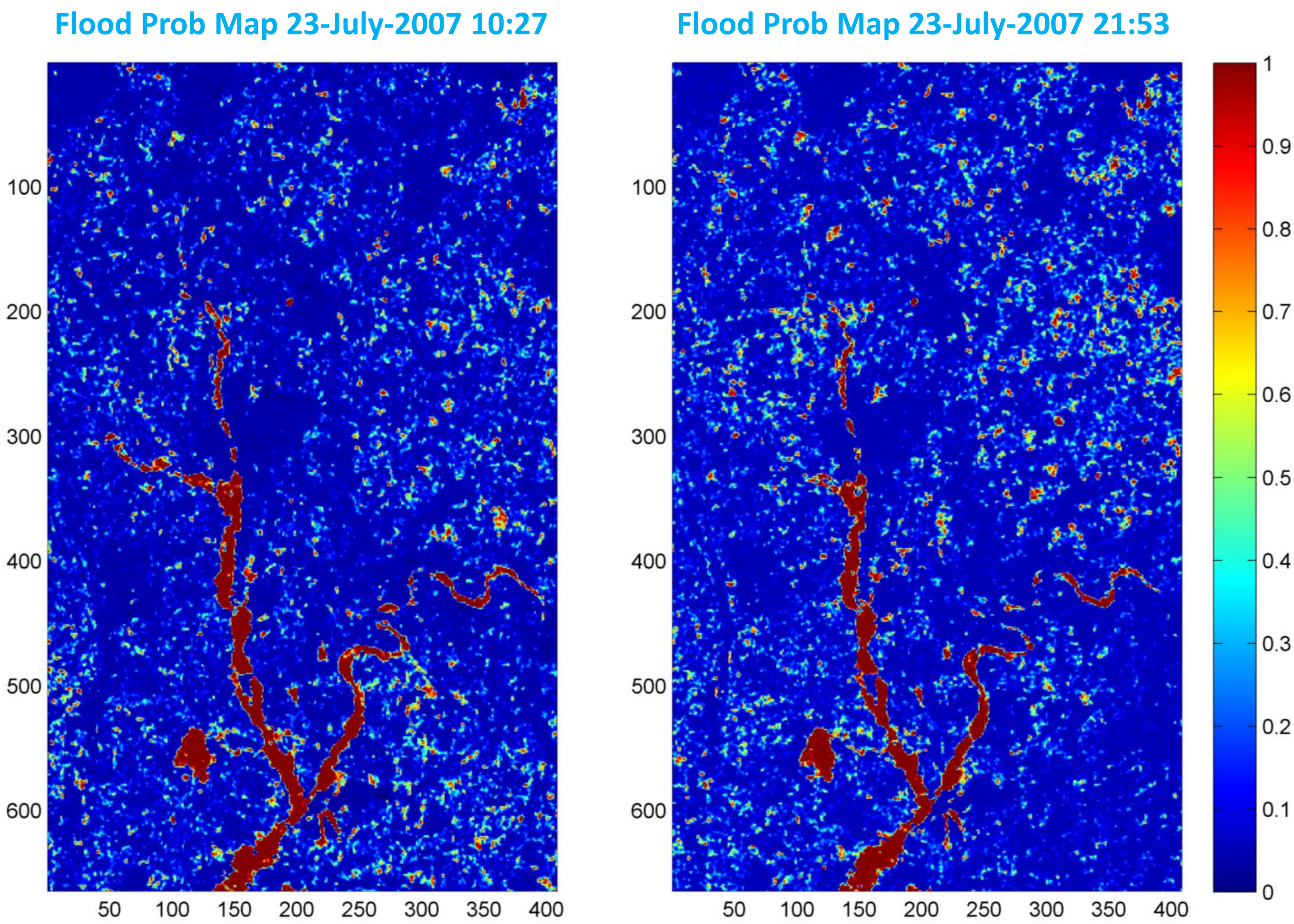
SM Assimilation: AMSR-E



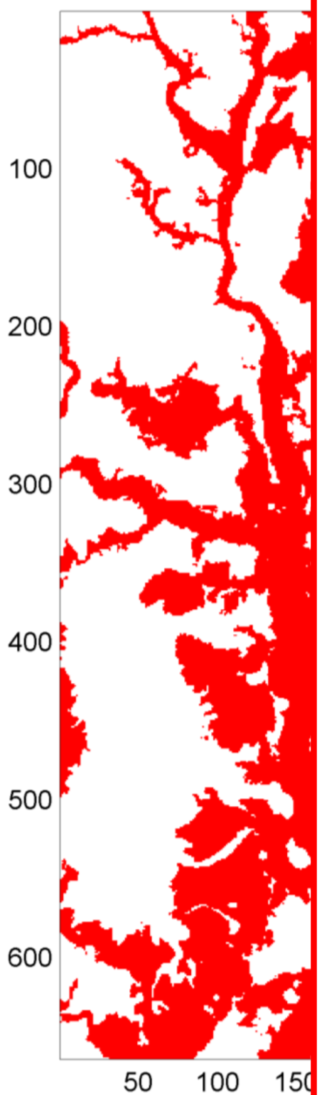
Ascat

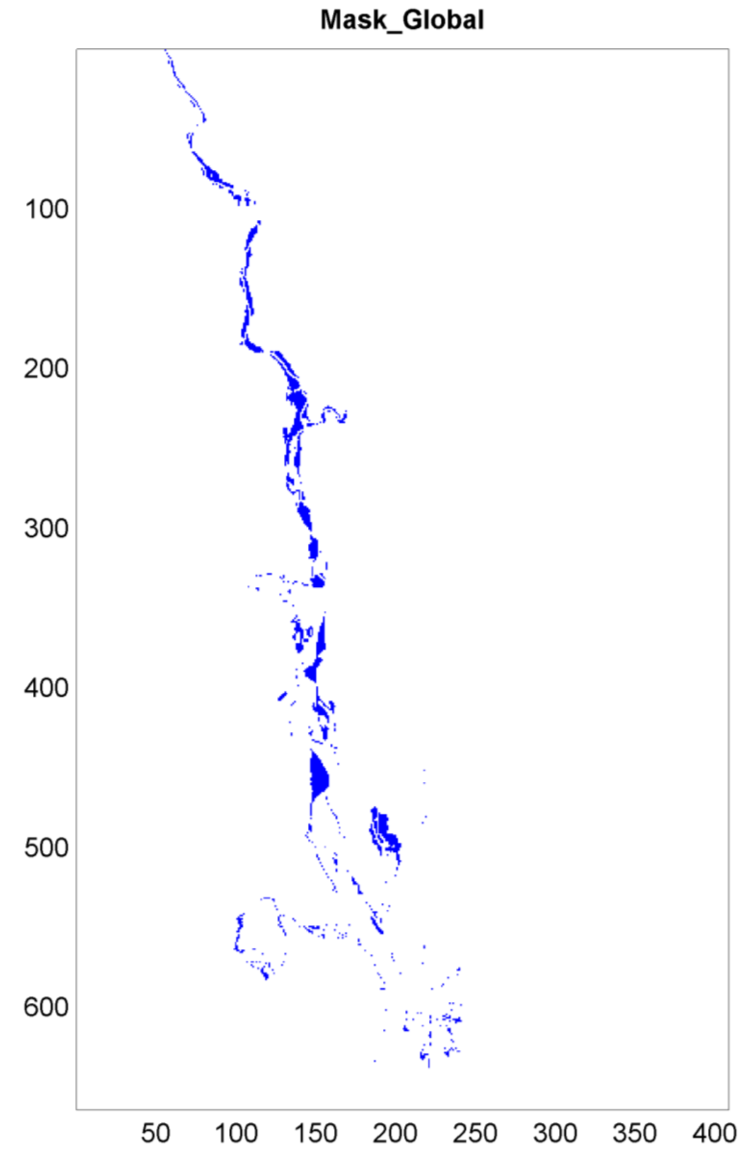
AMSR-E


(b)
(c)
(d)
(e)
(f)
Eff [%]
Eff [%]
P [mm]
ETP [mm]
SWI [-]
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

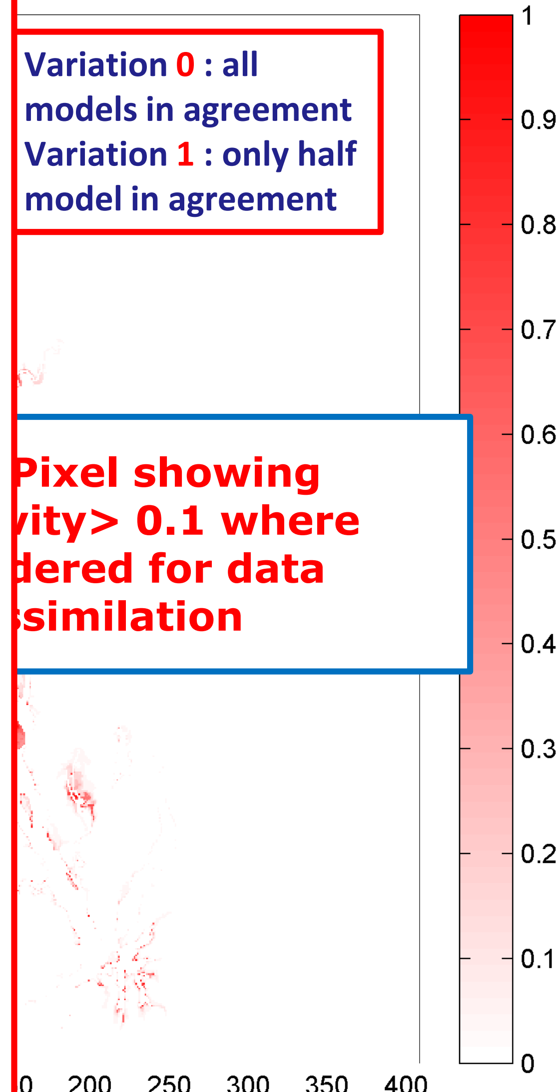

Flood Prob Map 23-July-2007 10:27
Flood Prob Map 23-July-2007 21:53
100
200
300
400
500
600
50
100
150
200
250
300
350
400
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

DEM Information





Sensitivity Index

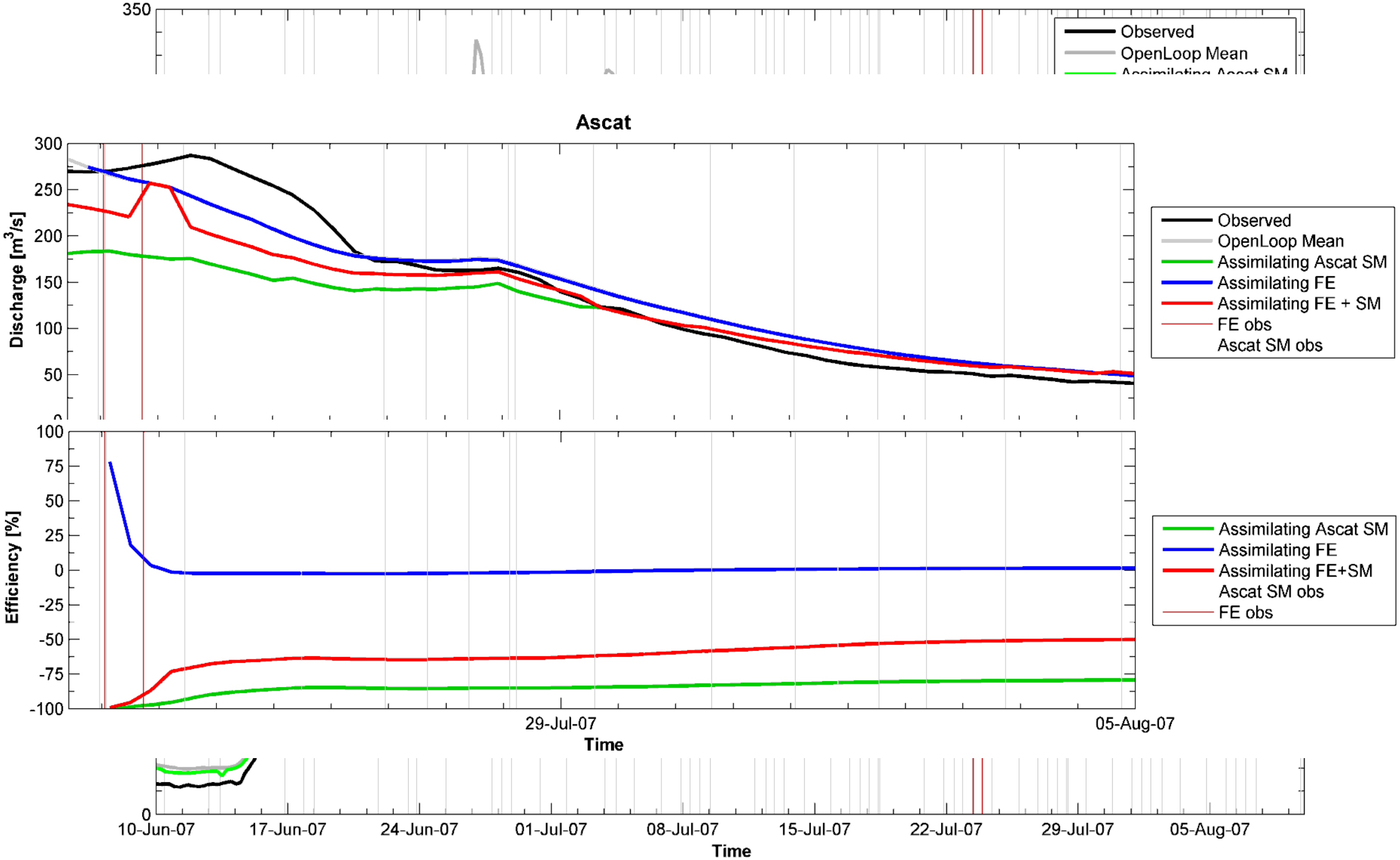


Variation 0 : all models in agreement
Variation 1 : only half model in agreement

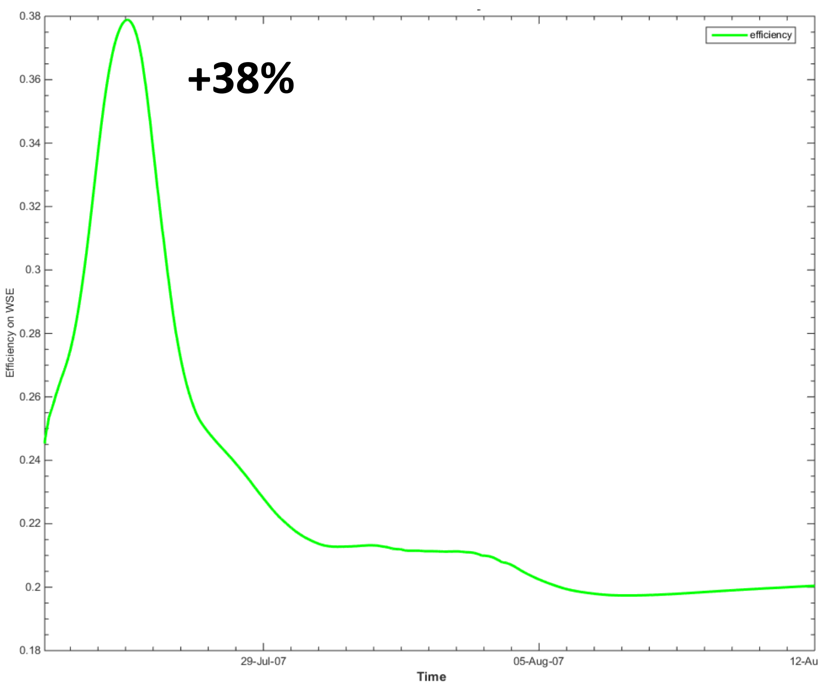
Pixel showing
vity> 0.1 where
dered for data
ssimilation

Bewdley (upstream boundary)

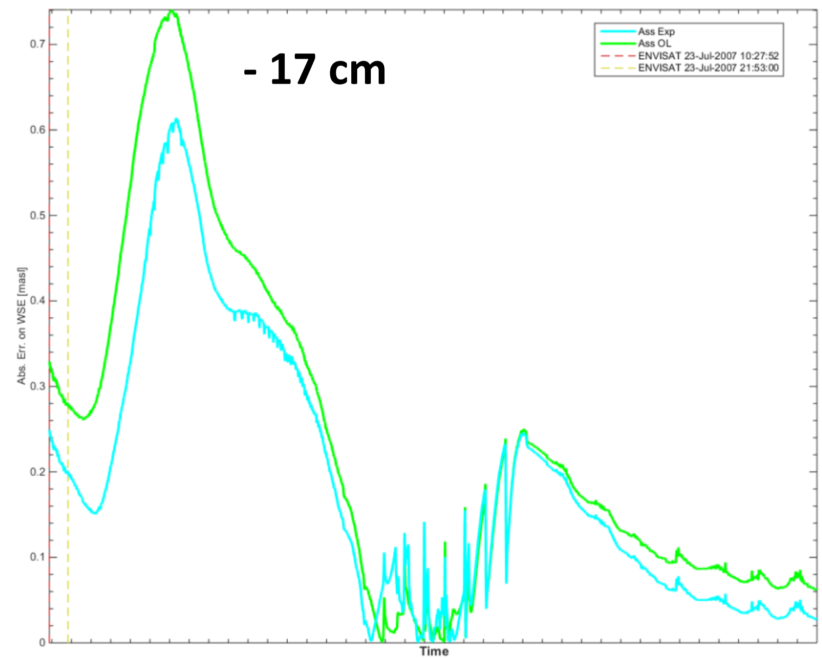
ENVISAT FE + Ascat SM



Saxons Lode (intermediate gauge)

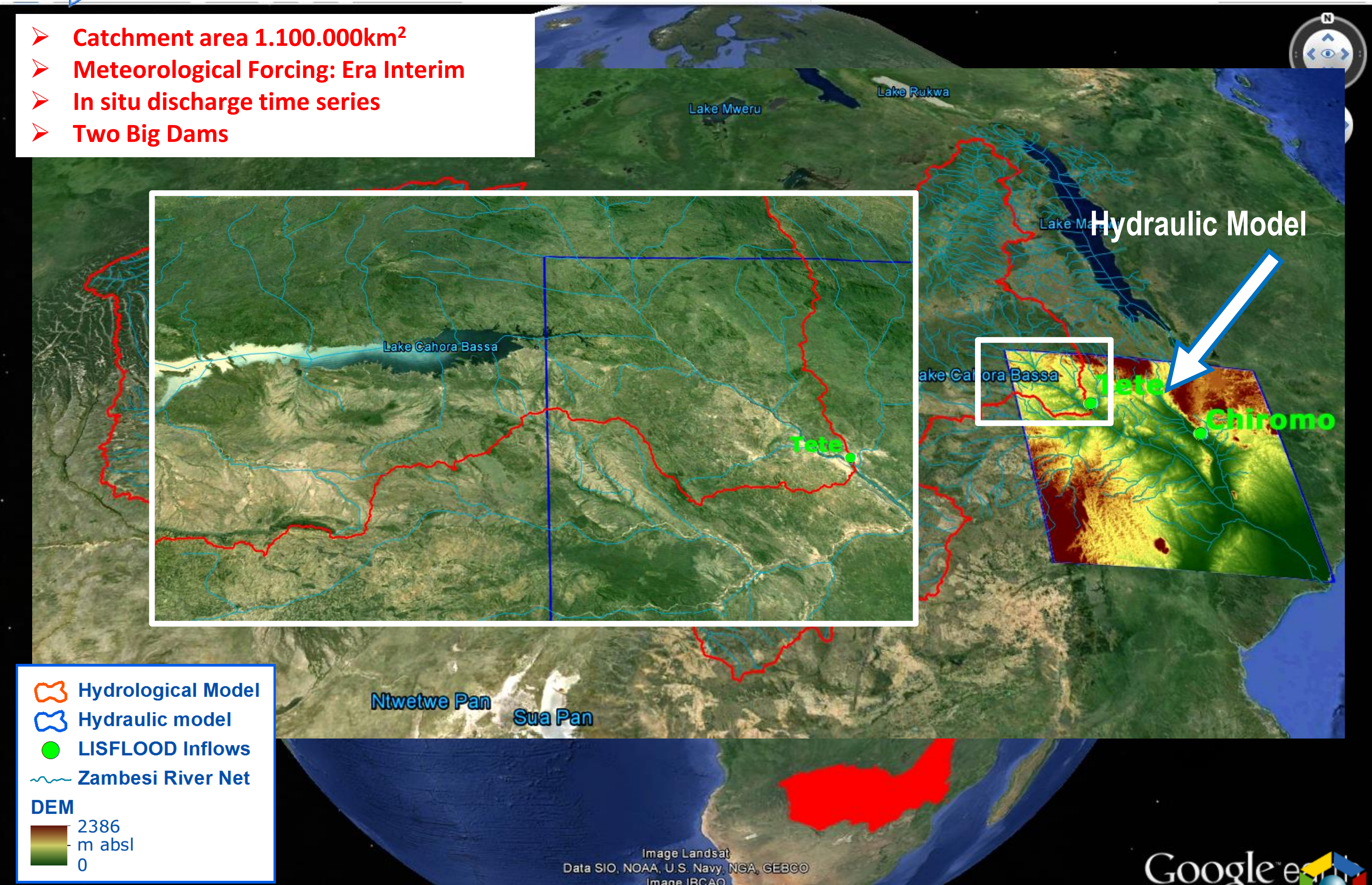


Efficiency on water elevation



Absolute error on water elevation

- Catchment area 1.100.000km^2
- Meteorological Forcing: Era Interim
- In situ discharge time series
- Two Big Dams

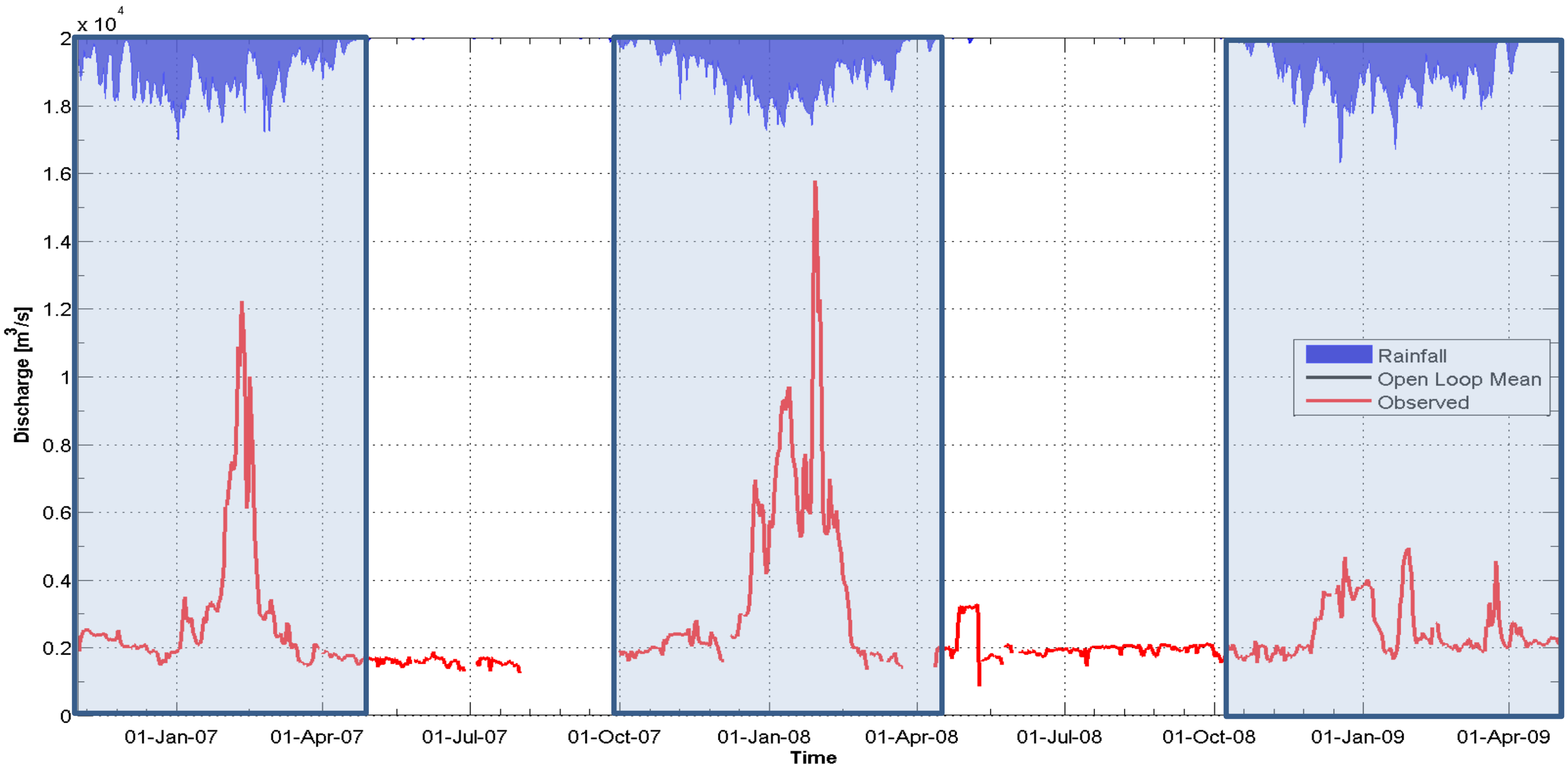


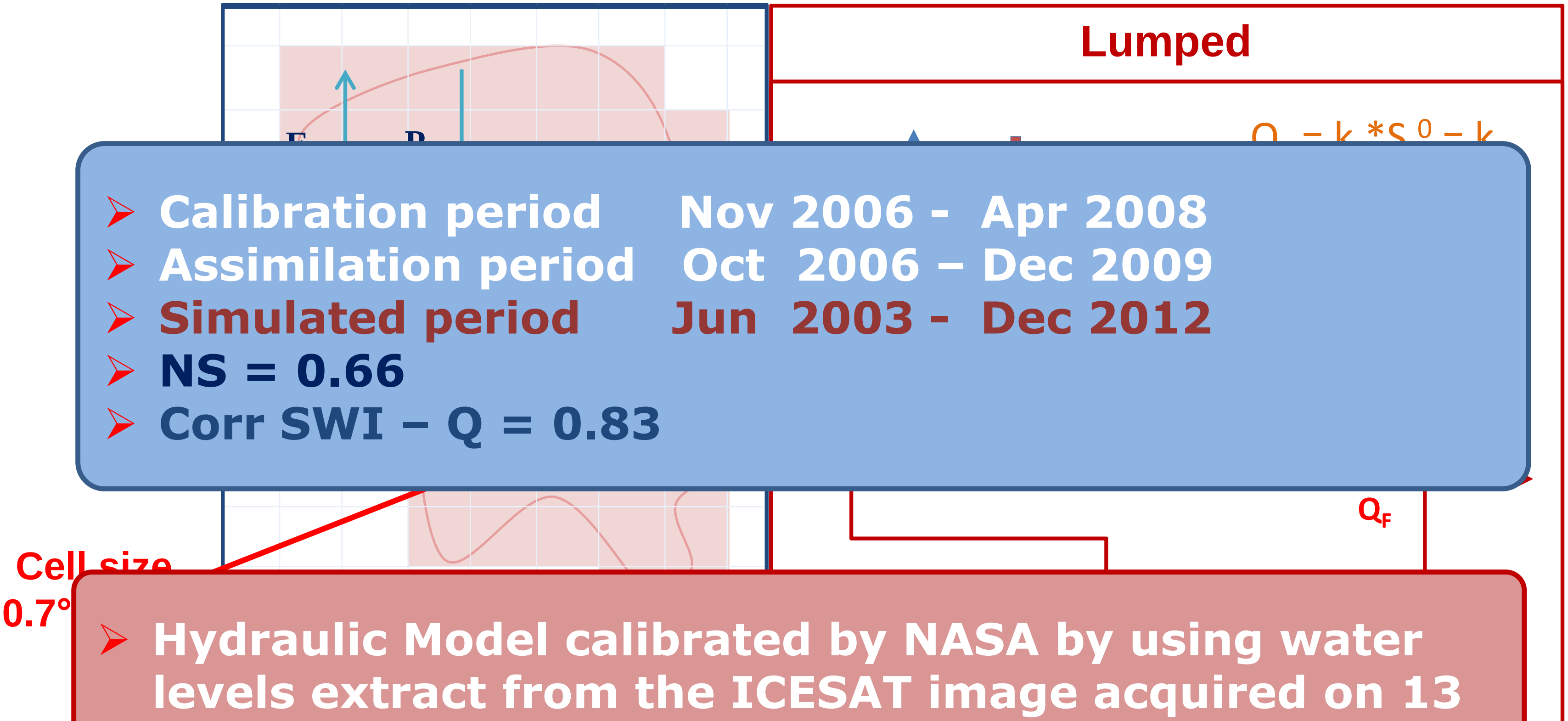
Rain Season from October to April

Effects Cahora Bassa Dam

Near constant base flow during the dry period

Different response during floods





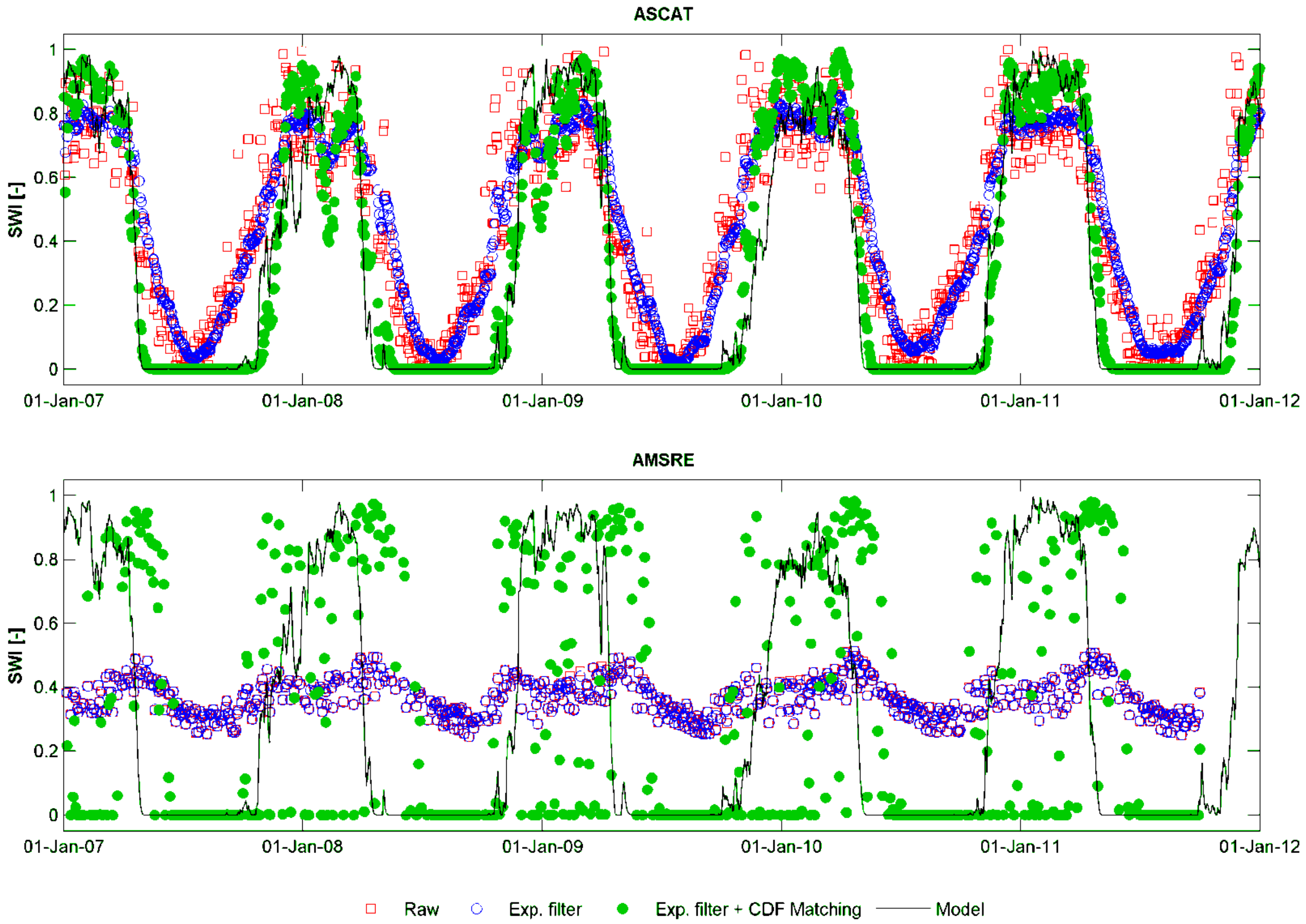
- Calibration period Nov 2006 - Apr 2008
- Assimilation period Oct 2006 – Dec 2009
- Simulated period Jun 2003 - Dec 2012
- **NS = 0.66**
- Corr SWI – Q = 0.83

- Hydraulic Model calibrated by NASA by using water levels extract from the ICESAT image acquired on 13 March 2007

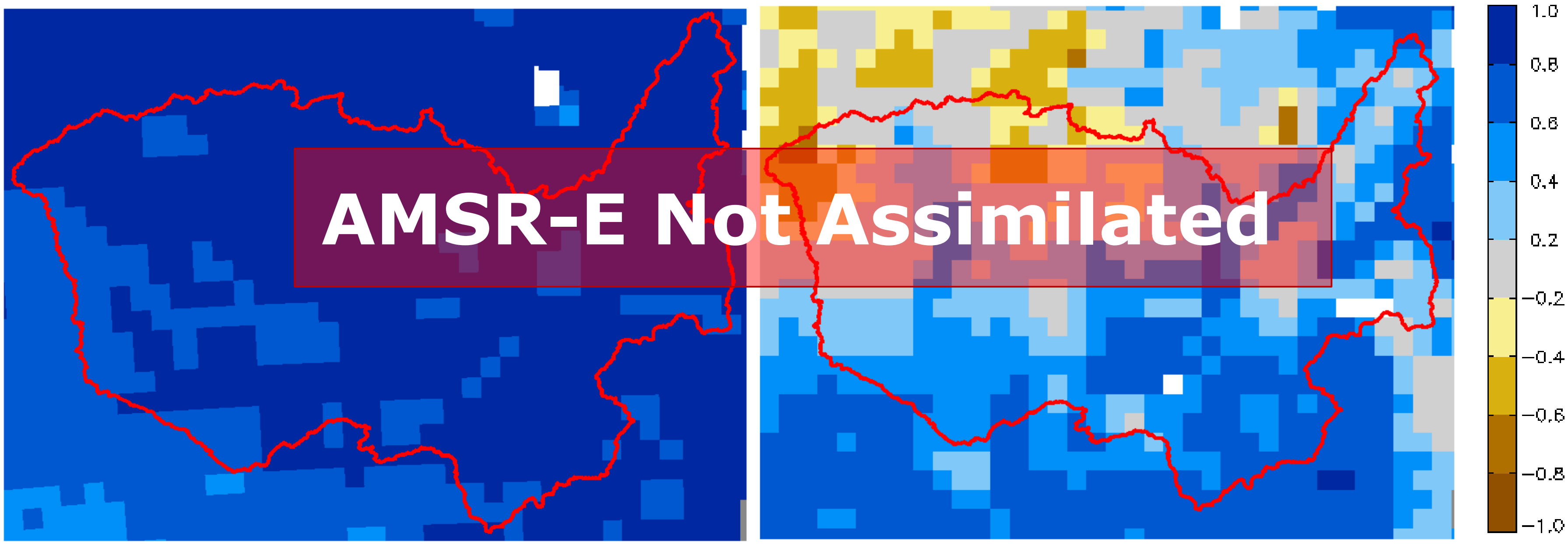
Meteorological forcings (Precipitation and Temperature):

- ERA Interim total precipitation and temperature
- 1 day time resolution;
- Evapotranspiration was computed using Hamon

Remote sensing-derived soil moisture



AMSR-E Climatology



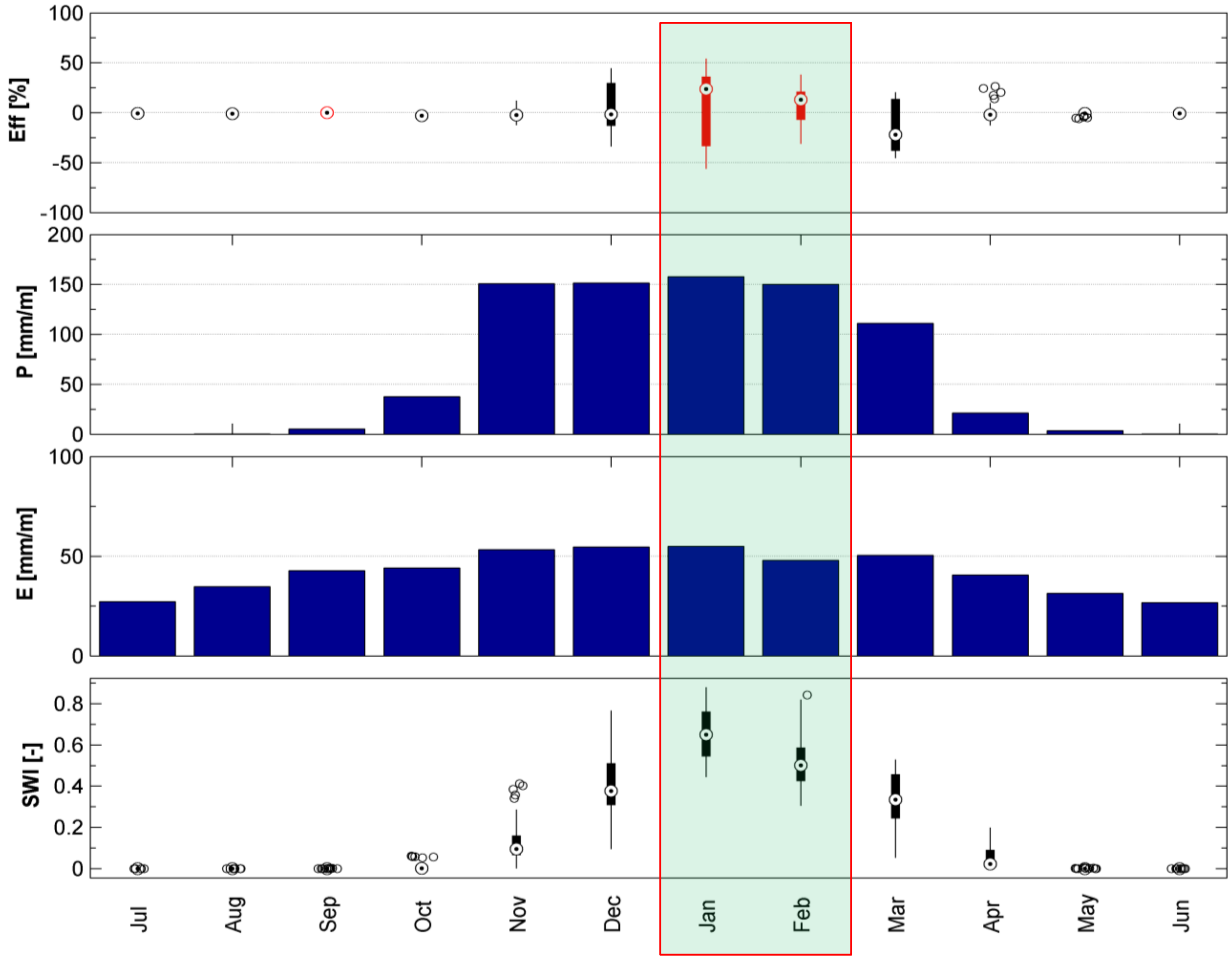
Correlation ASCAT Era Interim **Correlation AMSR-E Era Interim**

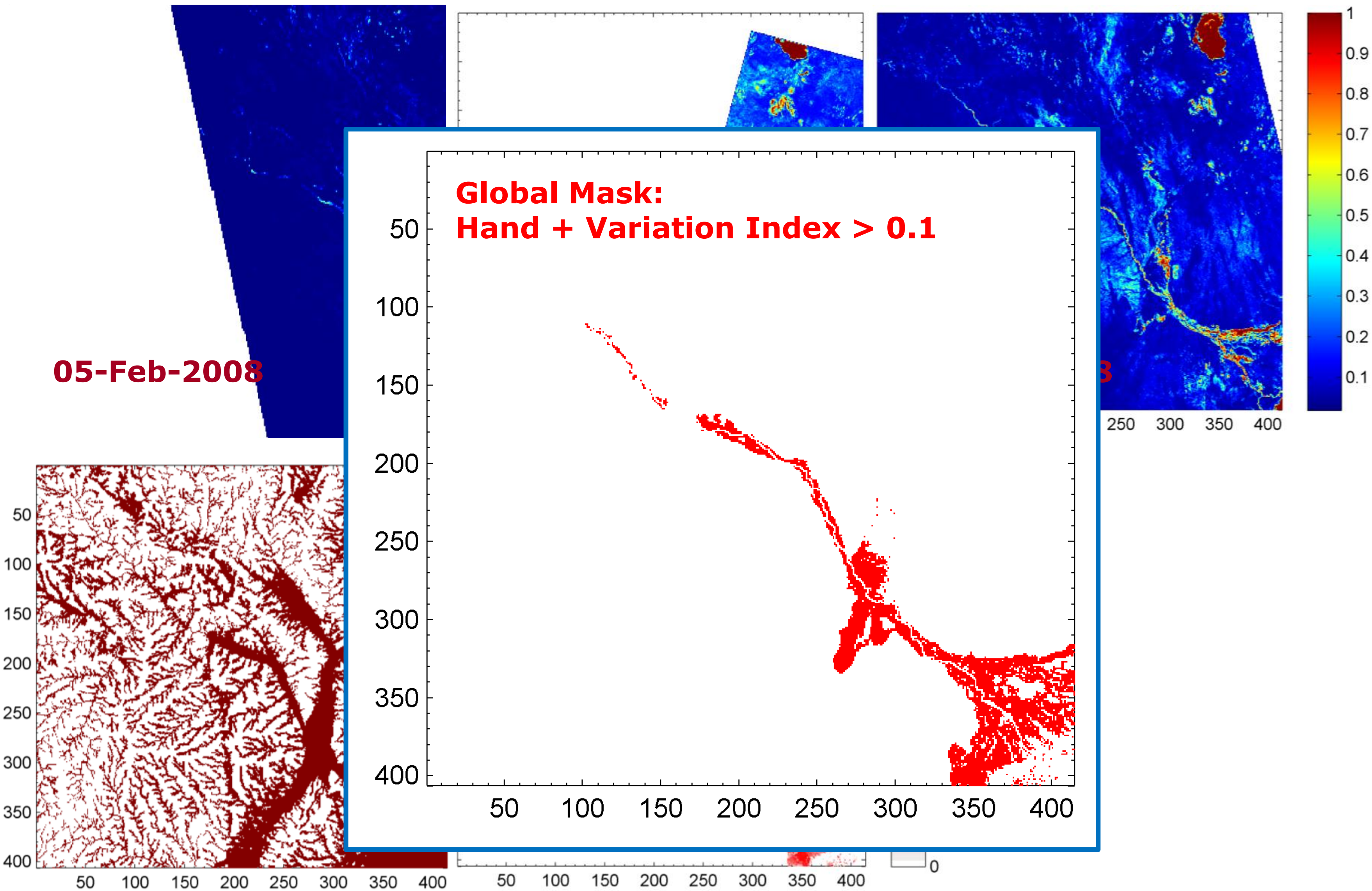
Source: Dorigo et al., HESS 2010

ASCAT


ASCAT
70
35
0
-35
-70
Efficency [%]
No Memory
T_{dec} = 2 days
T_{dec} = 3 days
T_{dec} = 7 days
T_{dec} = 14 days
T_{dec} = 30 days
T_{dec} = 60 days
T_{dec} = 90 days
Full Memory
SWI [-]
1
0.75
0.5
0.25
Ens Spread
Ens Std
OpenLoop
Satellite Obs
Dry Mask
01-Jan-07
01-Apr-07
01-Jul-07
01-Oct-07
01-Jan-08
01-Apr-08
01-Jul-08
01-Oct-08
01-Jan-09
01-Apr-09
Time

ASCAT

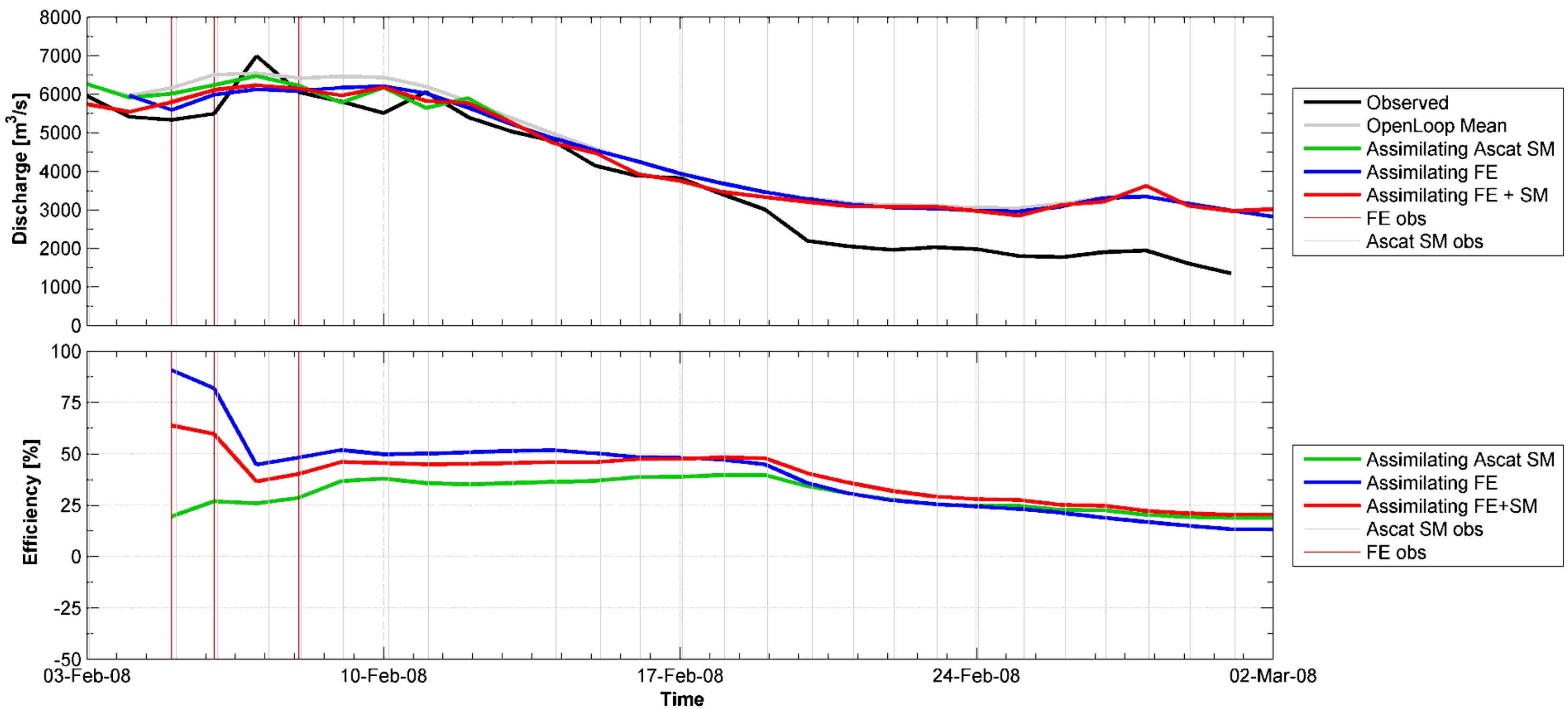

Eff [%]
100
50
0
-50
-100
P [mm/m]
200
150
100
50
0
E [mm/m]
100
50
0
SWI [-]
0.8
0.6
0.4
0.2
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun



Hand Mask 15 m

Variation Index

ENVISAT FE & ASCAT SM



- The assimilation of RSD soil moisture products improves discharge predictions in specific time periods ("wet and warm").
- The efficiency further depends on the satellite product, filter settings and the climatology of the catchment.
- The assimilation of FE outperforms SM data assimilation during storm events (when soils are saturated).
- RSD FE and SM provide complementary information for discharge predictions and a combination of both data sets is advantageous.

On practically all levels improvements are necessary and possible:

- Improve parameterisation of observing errors (e.g. autocorrelation structure, temporal and spatial variability)
- Further improve commensurability between models and data (necessary to fit model structures to characteristics of satellite data)
- Reduce existing time delay between data acquisition and higher level data dissemination (e.g. by developing fully automatic processing chains)
- Improvement of data assimilation schemes (e.g. feedbacks between models)
- Test with additional data: Sentinel-1, Cosmo Skymed, TerraSAR-X, Radarsat, ALOS, SMOS, SMAP
- Continue testing approach in contrasting regions across the Earth with multiple models