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

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

**Purpose**

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

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

RSD Soil Moisture

**Method**

**Results**

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

RSD Flood Extent
snow masking
- Modis Snow Product 8 day aggregated
- AMSRE 0.25°
- Envisat 0.0042°
- Upscale or Downscale to Model Grid
- From surface to Root Zone
- CDF Matching
The triple collocation method (Draper et al., RSE 2013) allows parameterizing the error considering a triplet of unbiased and independent datasets. Parameterization is possible if one dataset is assumed as reference. 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)  

Reliability diagram

Flood extent obtained through photo-interpretation

WRMS = 0.067
Spatial Weights aggregations

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

Weighted mean

\[ Q_{t} = \left( \sum_{j=1}^{n_{Part}} W^{j}_{glob,t} \times Q_{t,j} \right) / \sum_{j=1}^{n_{Part}} W^{j}_{glob,t} \]
Assumption: binomial likelihood pdf \( p(k, n \mid \Theta) = \binom{n}{k} \Theta^k (1 - \Theta)^{n-k} \)

\[
\begin{array}{ccc}
\Theta_{1,1} & \Theta_{1,2} & \Theta_{1,3} \\
\Theta_{2,1} & \Theta_{2,2} & \Theta_{2,3} \\
\Theta_{3,1} & \Theta_{3,2} & \Theta_{3,3} \\
\end{array}
\]

MOD\(_{t,i}\)

\[
\begin{array}{ccc}
1 & 0 & 1 \\
0 & 1 & 1 \\
1 & 0 & 0 \\
\end{array}
\]

\[
W_{t,i} = \begin{cases} \Theta_{1,1} & \text{Simulated Water pixel} \\
1 - \Theta_{3,3} & \text{Simulated Dry pixel} \\
\end{cases}
\]

Spatial Weights aggregations

\[
W_{i,t} = \sum_{j,k} W_{j,k}
\]
Severn Catchment
4,000 km²
Cell size: 0.125°

Zambezi Catchment
1,100,000 km²
Cell Size: 0.7°

- Meteorological forcings: ERA-Interim
- In Situ Discharge Records
Meteorological Forcing: ECMWF EraInterim derived products

In situ discharge time series from Environment Agency for 7 gauging stations covering the period 2002-2012
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

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

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

4 Reservoirs and 10 parameters to calibrate
Conclusions

Purpose

Case Study

Method

Model Sensitivity Index

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

Only Pixel showing sensitivity > 0.1 where considered for data assimilation
Bewdley (upstream boundary)
Saxons Lode (intermediate gauge)

Efficiency on water elevation

Absolute error on water elevation

+38%

- 17 cm
- Catchment area 1.100.000km²
- 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
Meteorological forcings (Precipitation and Temperature):

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

Calibration period: Nov 2006 - Apr 2008
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
Remote sensing-derived soil moisture
AMSR-E Climatology

Correlation ASCAT Era Interim

Correlation AMSR-E Era Interim

Source: Dorigo et al., HESS 2010
ASCAT

[Graph showing seasonal variation in Eff, P, E, and SWI]
Global Mask: Hand + Variation Index > 0.1
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