On the use of radar altimetry and its integration with other satellite sensors for river discharge estimation and forecasting

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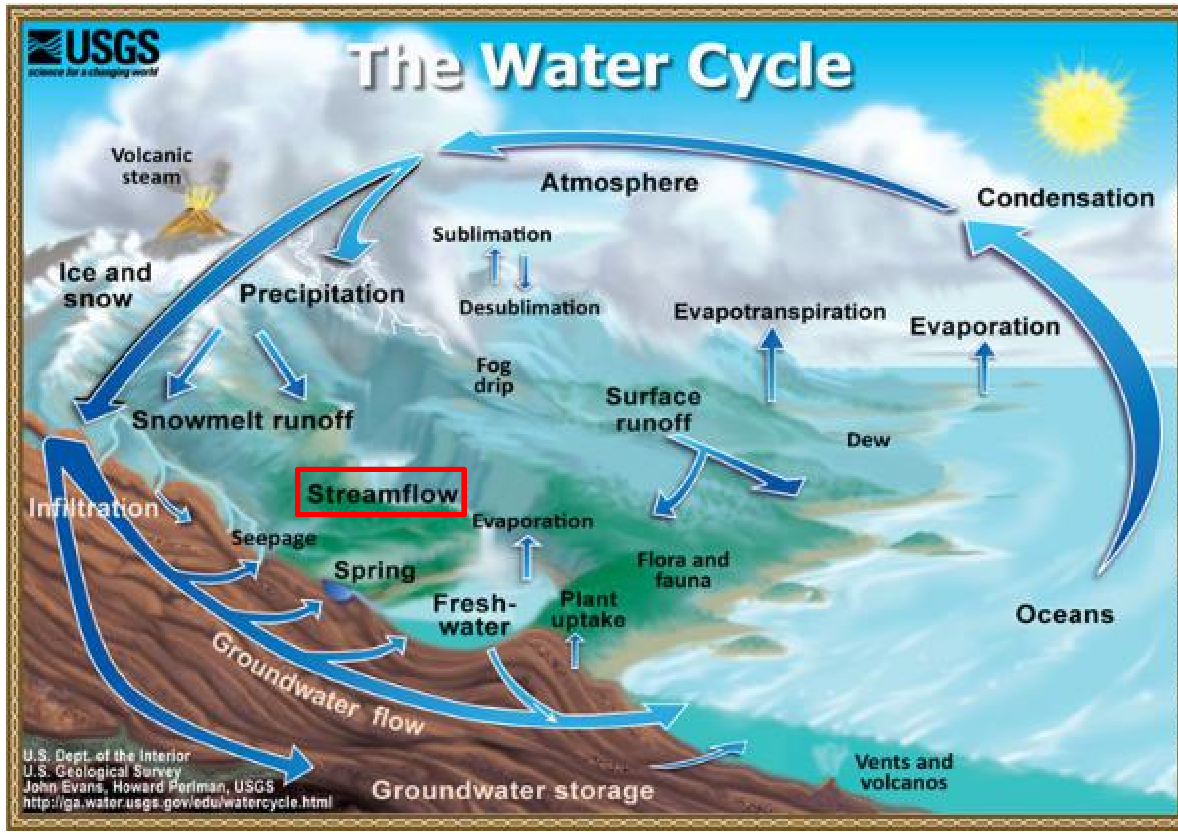
*Presented by **Jérôme Benveniste***

WHY DISCHARGE?

River discharge is one of the ECVs selected by GCOS as an important variable both as an **indicator** and **driver** of the climate system:-

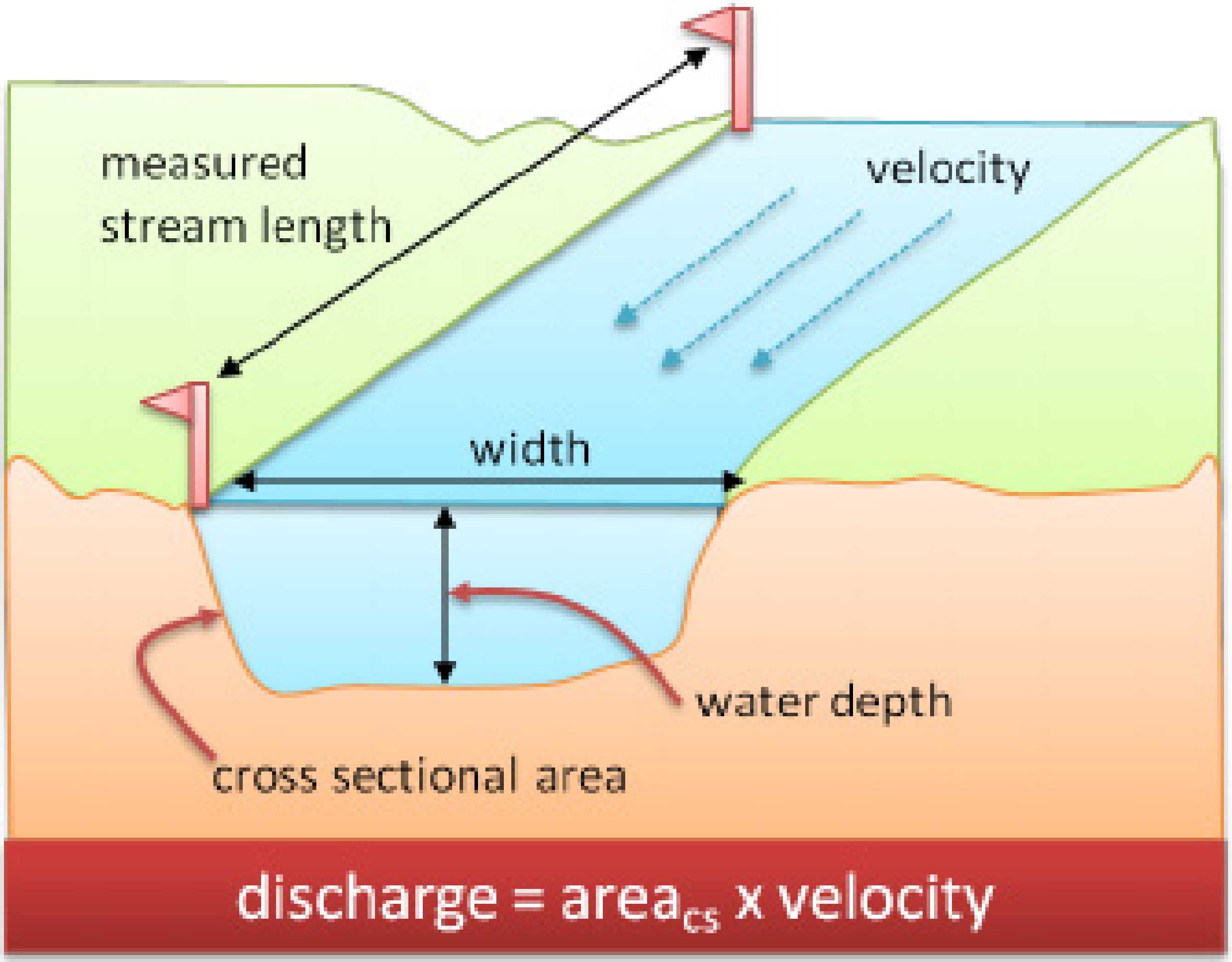
- **Indicator**: reflects changes in precipitation and evapotranspiration
- **Driver**: Significantly affecting ocean salinity and thermohaline circulation.
- Key variable in the water cycle
- Essential for water resources management (incl. coping with floods and droughts)
- Necessary for the flood prediction (hydraulic risk)
- Help in identifying and adapting potential effects of climate change.



RIVER DISCHARGE DEFINITION AND MEASUREMENTS

River discharge is a measure of the volume of water flowing through a river channel cross-section per unit of time.

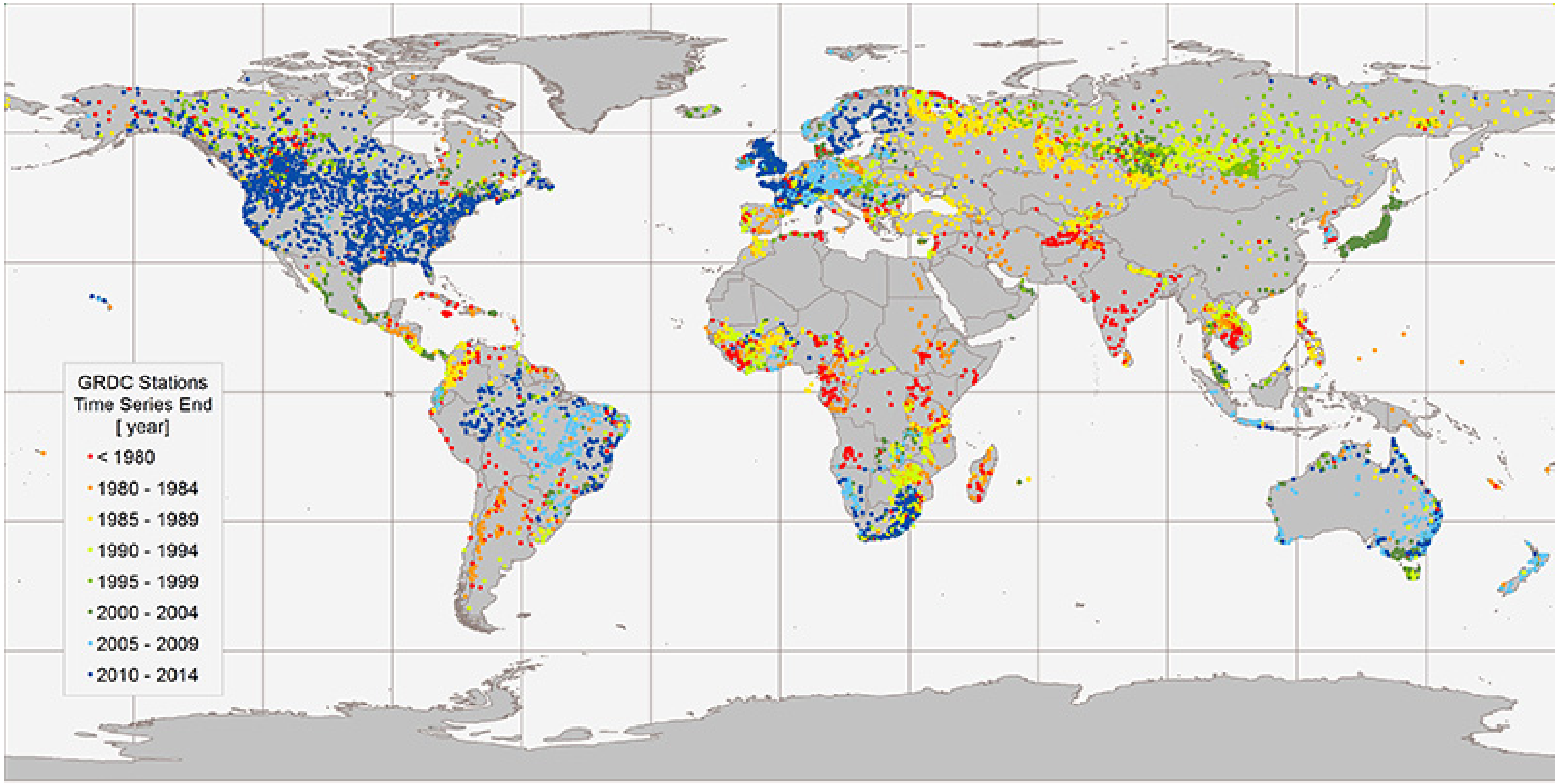
It can also be expressed as the flow velocity times the cross-sectional flow area.



Its estimation is not direct and, traditionally, it consists of in-situ measurements of water flow velocity vertical profiles and depth, at different measuring points across the river and the water level.

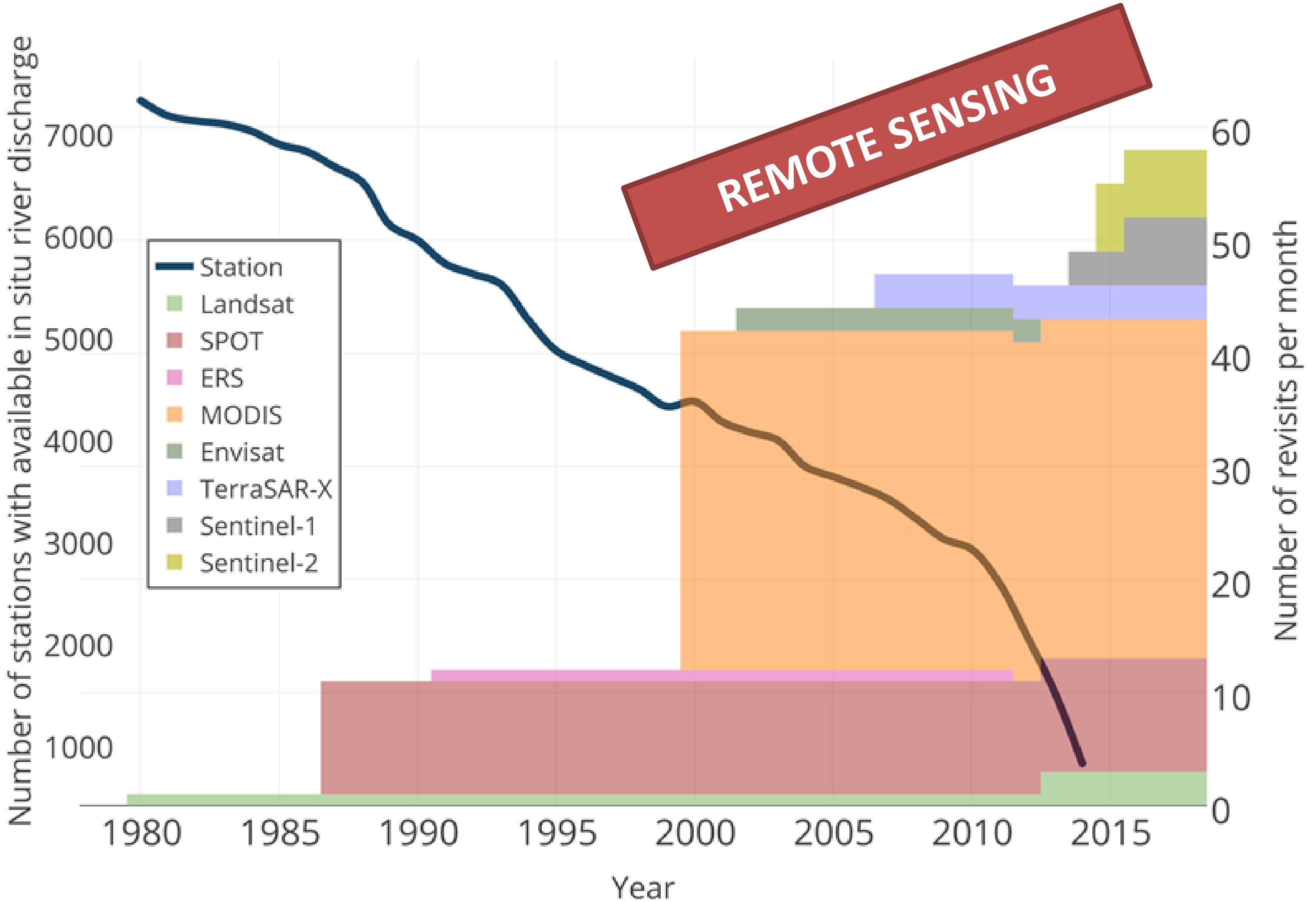
RIVER DISCHARGE FROM THE TRADITIONAL MONITORING NETWORK

- Not representative of the global water flow
- High costs of installation and maintenance
- Not uniformly distributed in the world
- Inaccessibility of many remote areas
- Problems of data sharing among neighbouring countries
- Reduction of hydrometric stations



8962 stations with monthly data discharge data, including data derived from daily data (Status: 20 December 2013)
Koblenz: Global Runoff Data Centre, 2014.

RIVER DISCHARGE FROM THE TRADITIONAL MONITORING NETWORK



Change in the number of stations with available in-situ river discharge according to Global Runoff Data Center (GRDC) together with satellite observation during last three decades (Elmi, 2015)

RIVER DISCHARGE FROM REMOTE SENSING

SENSORS

- Altimeter
- Passive microwave
- Optical

APPROACHES

- Hydraulic models
- Rating curve

RIVER DISCHARGE FROM ALTIMETRY

SENSORS

- **Altimeter**
- Passive microwave
- Optical

APPROACHES

- **Hydraulic models**
- Rating curve

Simplest hydraulic model
(steady, uniform flow)

Gleason & Smith 2014 PNAS
Bjerklie et al. 2003 JoH
Negrel et al. 2011 HESS
Garambois & Monnier 2015 AWR

Simple hydraulic model
(steady flow)

Durand et al. 2014 JoH
Tarpanelli et al. 2013 RS

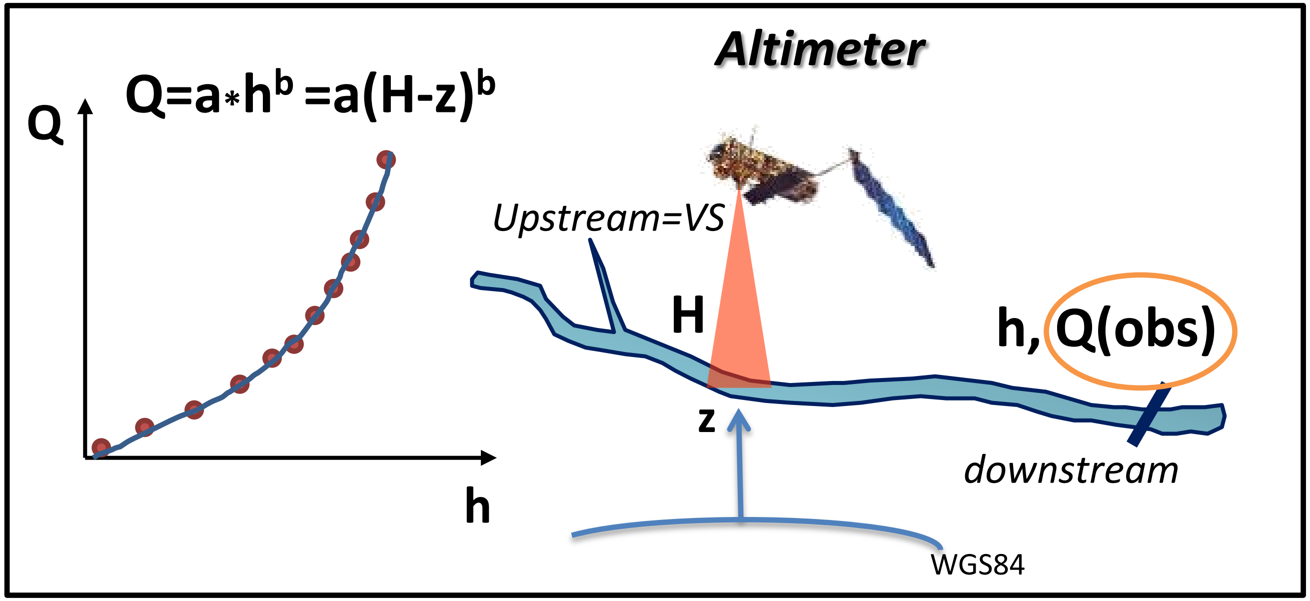
Complex hydraulic models
(unsteady flow)

Yan et al. 2014 JHE
Domeneghetti et al. 2015 HyP
Domeneghetti et al. 2013 RSE

RIVER DISCHARGE FROM ALTIMETRY

SENSORS
- **Altimeter**
- Passive microwave
- Optical

APPROACHES
- Hydraulic models
- **Rating curve**



LARGE RIVERS	SAT	STUDY
Ob'	T/P	Kouraev et al. 2004, RSE
Amazon	T/P	Zakharova et al. 2006, CRG
Brahmaputra	T/P	Papa et al. 2010, JGR
Ganga	ERS-2	
Brahmaputra	JASON-2	Papa et al. 2012, JGR
Ganga		
Chad	T/P	Coe et Birkett, 2004, WRR
Zambesi	ENVISAT	Michailovsky et al. 2012, HESS

RIVER DISCHARGE FROM ALTIMETRY

SENSORS

Altimeter

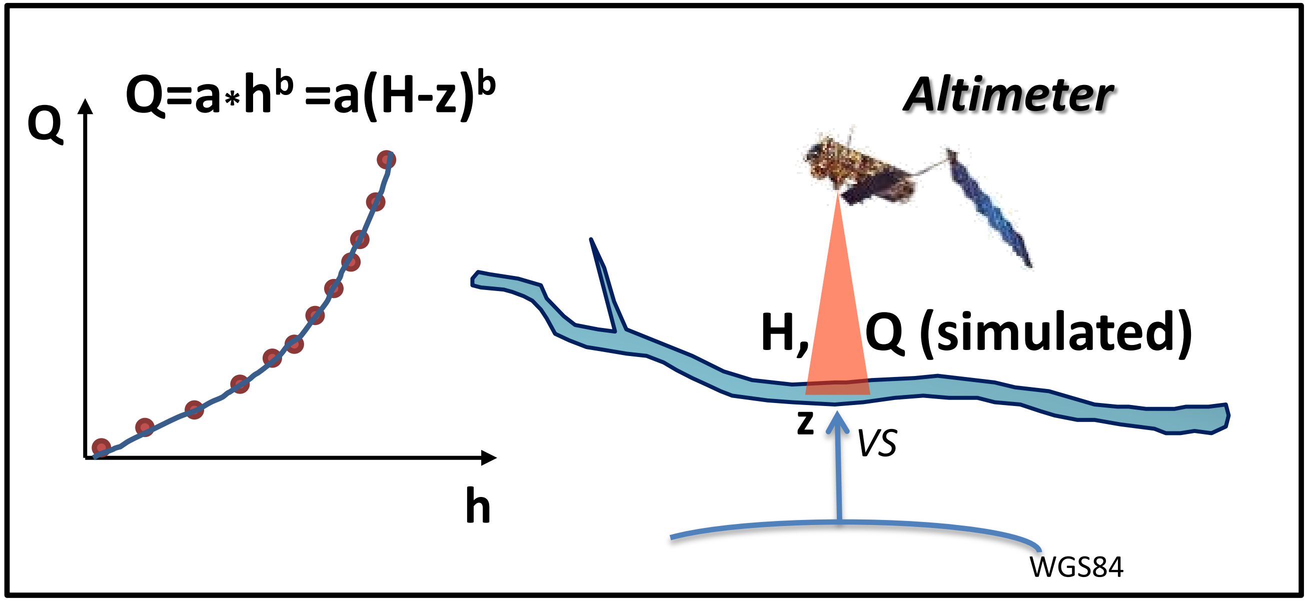
Passive microwave

Optical

APPROACHES

Hydraulic models

Rating curve



RIVER	SAT	Study
Negro	T/P ENVISAT	Leon et al. 2006, JoH
Branco	ENVISAT	Getirana et al. 2009, JoH
Branco	ENVISAT	Getirana et al. 2013, JoH
Amazon	ENVISAT JASON-2	Paris et al. 2016, WRR

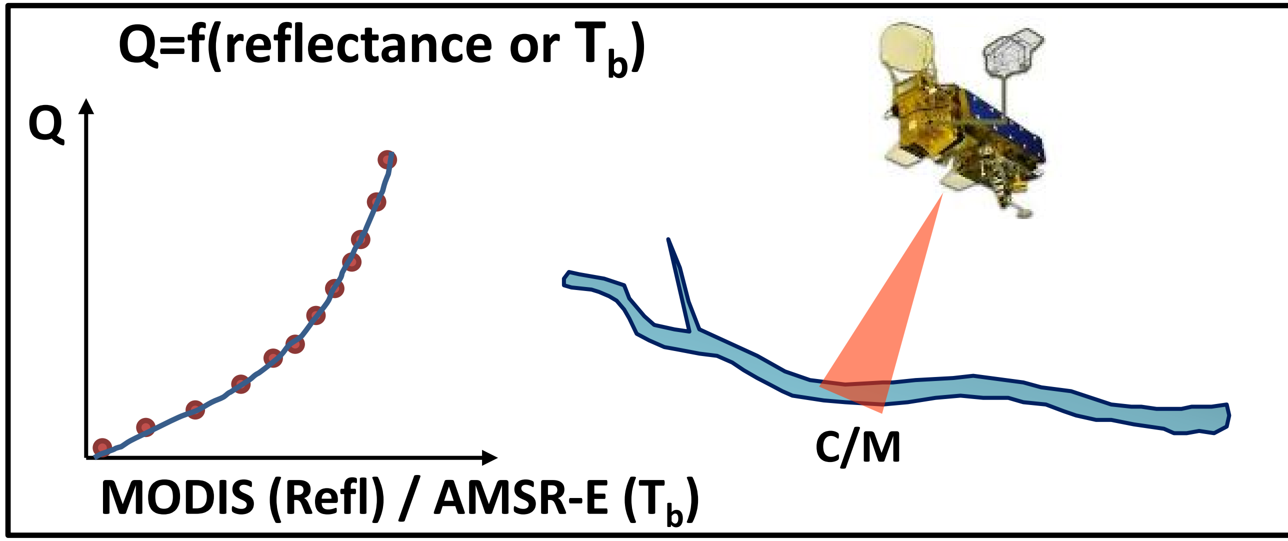
RIVER DISCHARGE FROM OPTICAL AND PASSIVE MICROWAVE

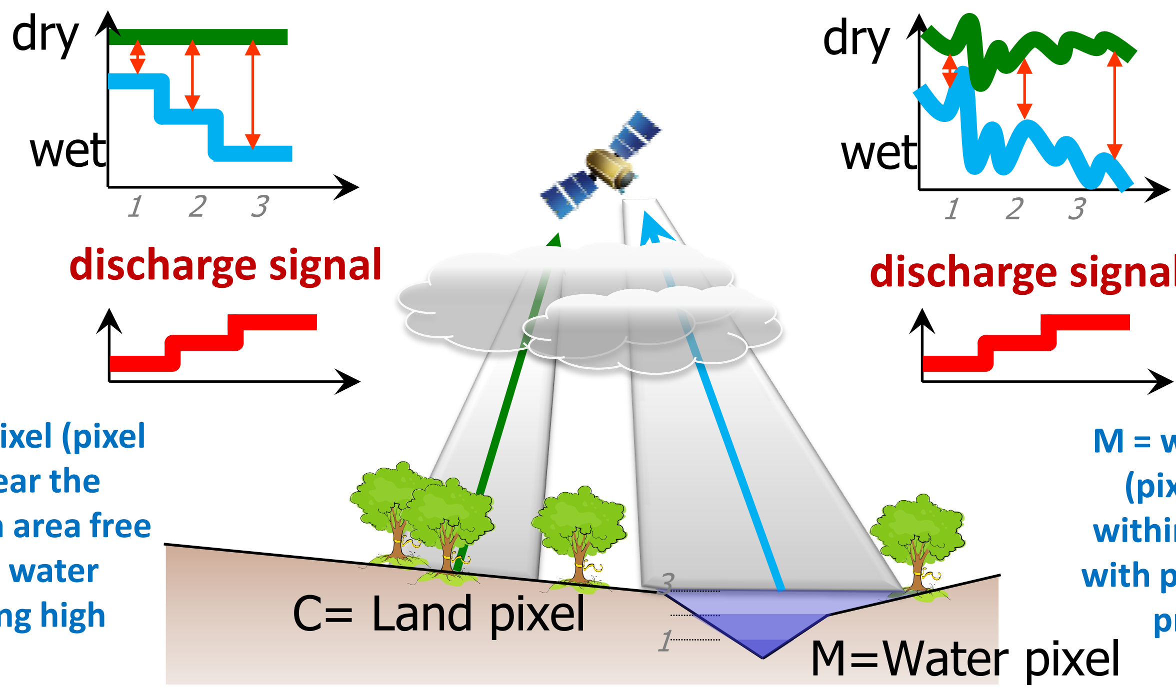
SENSORS

- Altimeter
- Passive microwave
- Optical

APPROACHES

- Hydraulic models
- Rating curve





C = land pixel (pixel located near the river in an area free of surface water even during high floods)

M = water pixel (pixel located within the river with permanent presence of water)

RIVER DISCHARGE FROM AMSR-E

SENSORS

Altimeter

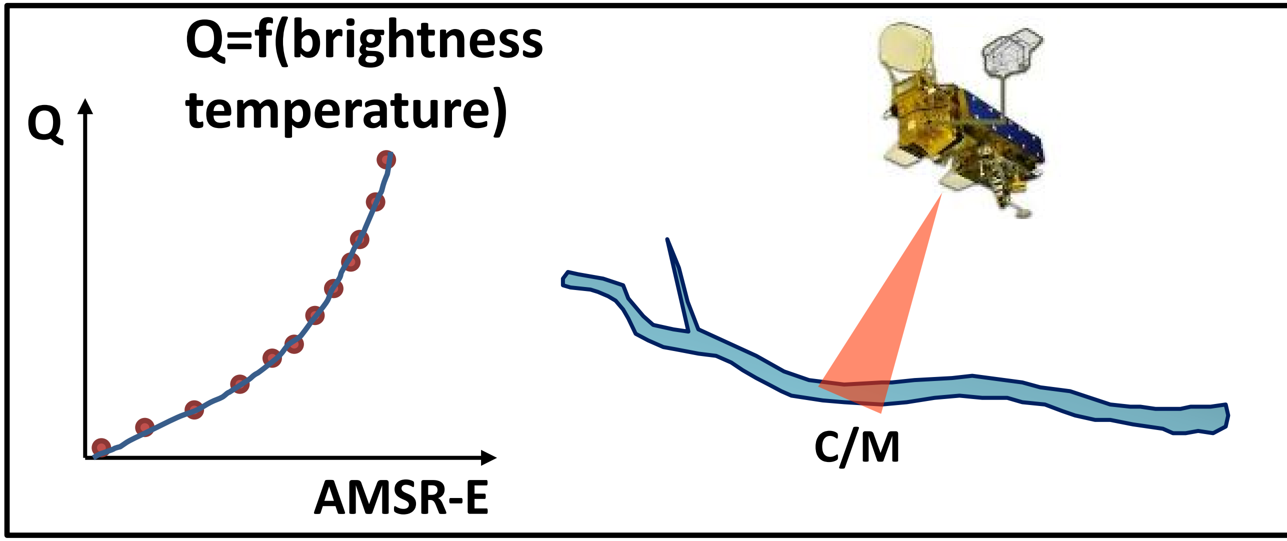
Passive microwave

Optical

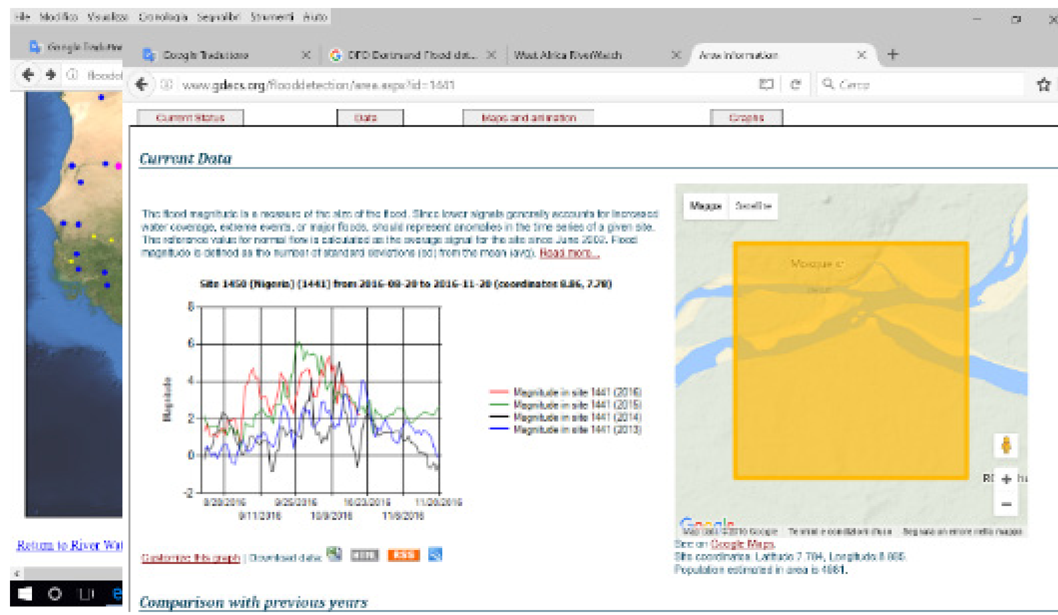
APPROACHES

Hydraulic models

Rating curve



Brakenridge et al., 2007, WRR



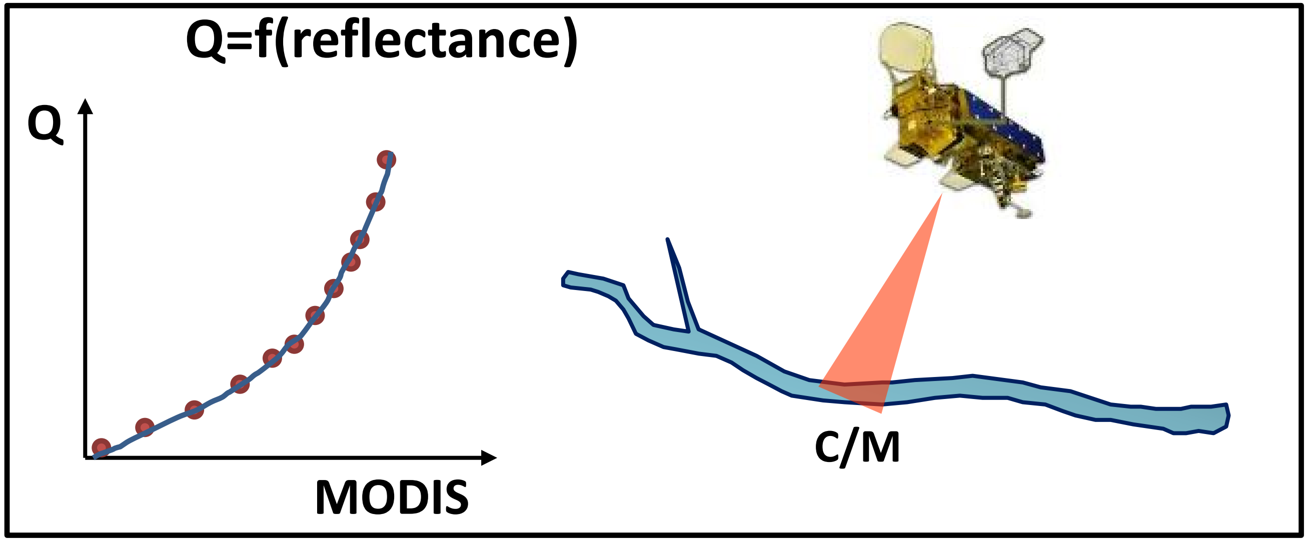
Global Flood Detection System – DFO

http://www.dartmouth.edu/~floods

RIVER DISCHARGE FROM MODIS

SENSORS
- Altimeter
- Passive microwave
- **Optical**

APPROACHES
- Hydraulic models
- **Rating curve**



VanDijk et al. 2016 WRR

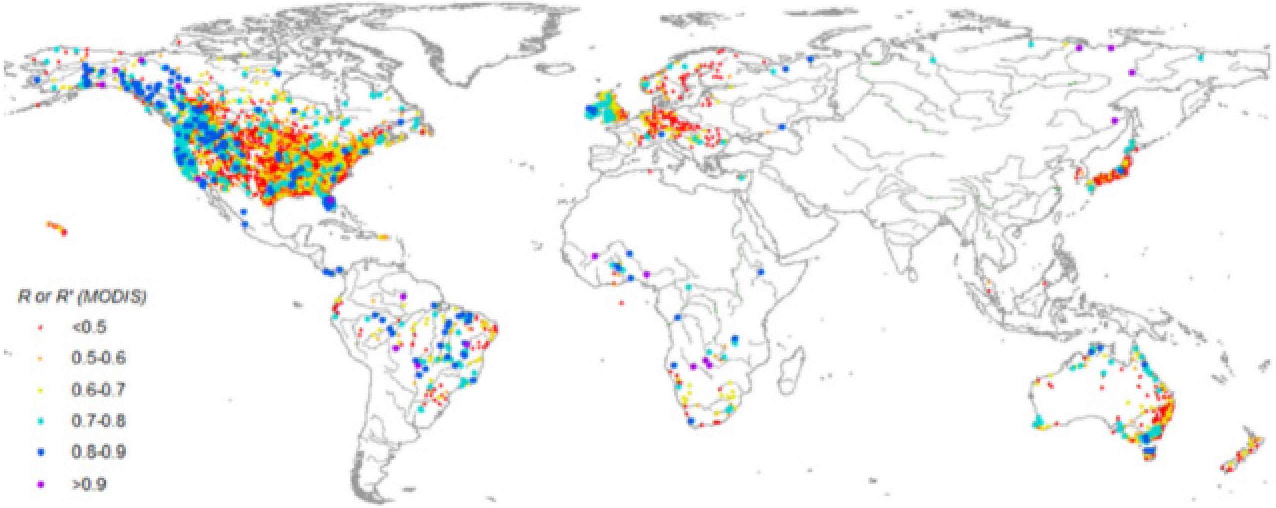
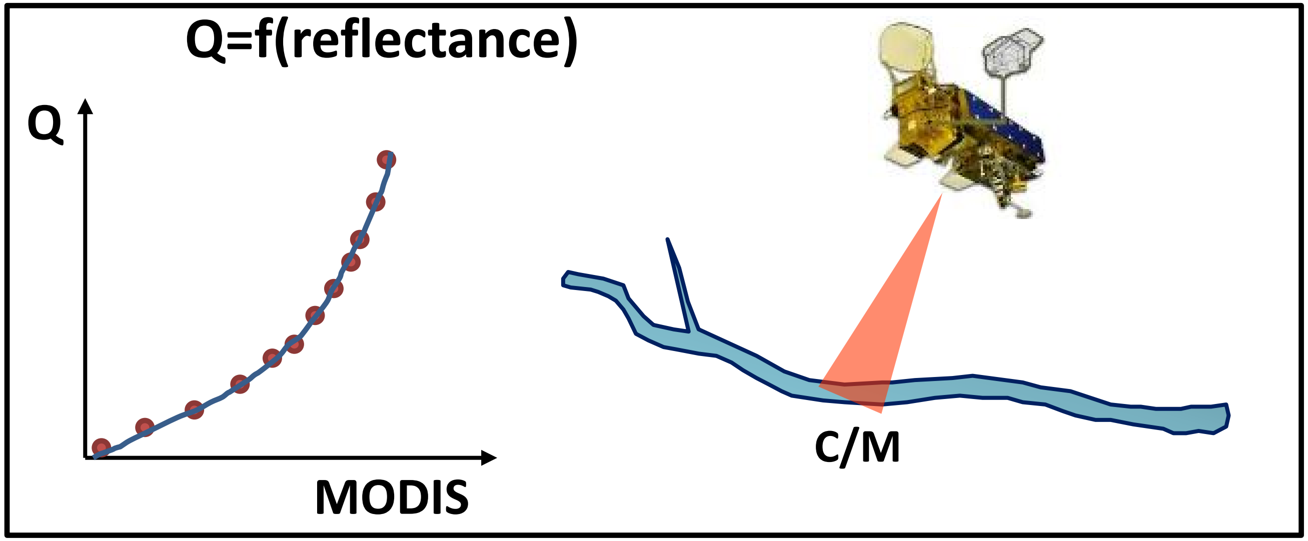


Figure 3. MODIS-based river remote sensing evaluated against monthly average station discharge observations, expressed as the greater of parametric (R) and non-parametric (R') correlation coefficient in validation.

RIVER DISCHARGE FROM MODIS

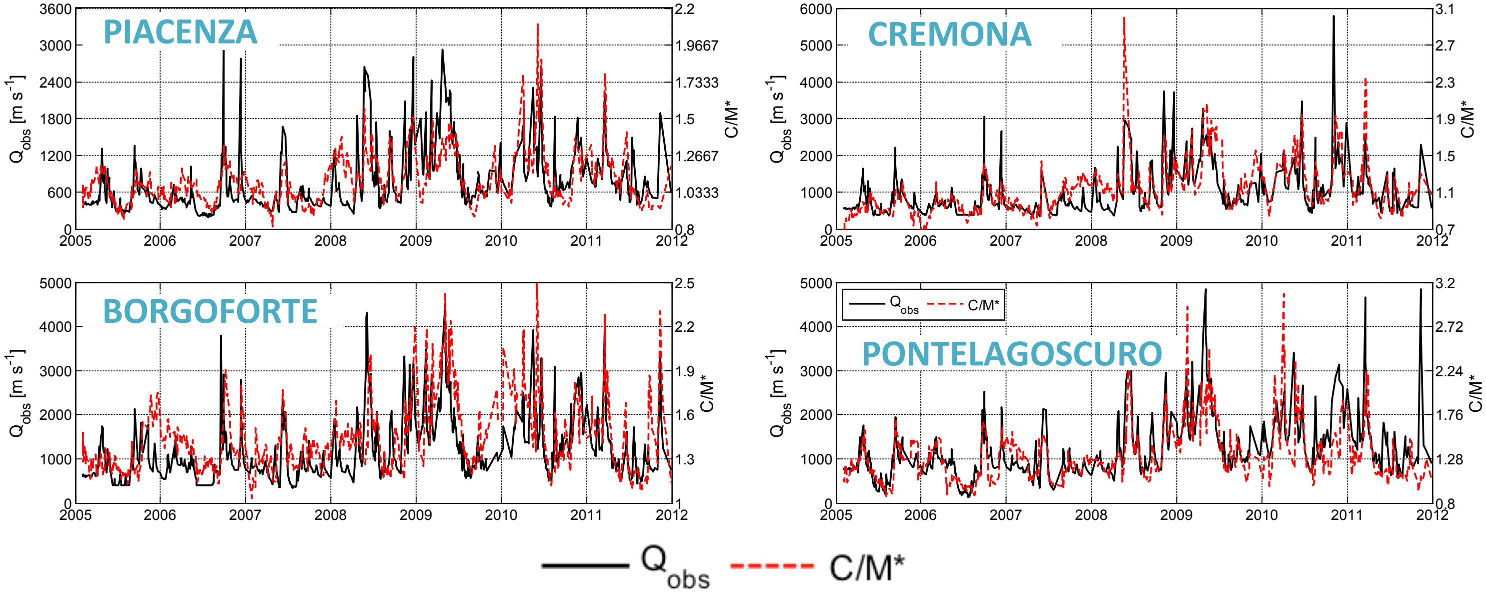
SENSORS
- Altimeter
- Passive microwave
- **Optical**

APPROACHES
- Hydraulic models
- **Rating curve**



Tarpanelli et al. 2013 RSE

Po:



Po
Danube
Duero
Tiber

RIVER DISCHARGE FROM ALTIMETER + RADIOMETER

SENSORS

Altimeter

Passive microwave

Optical

APPROACHES

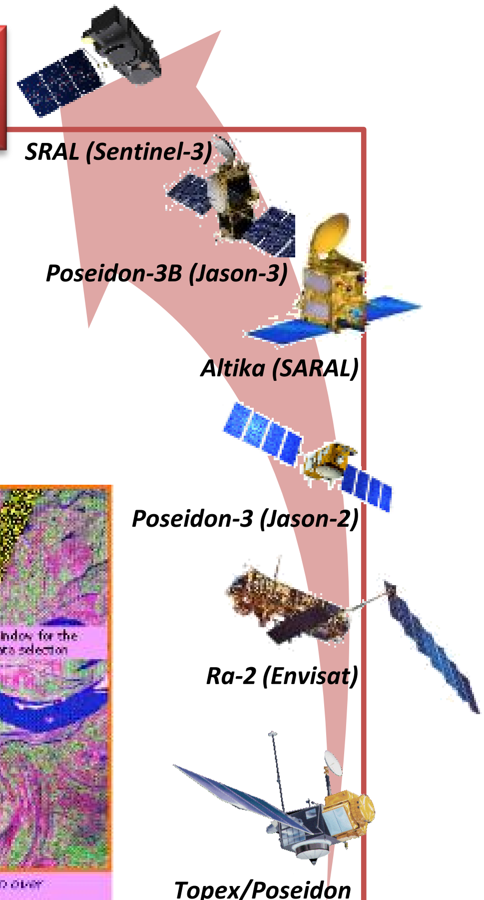
Hydraulic models

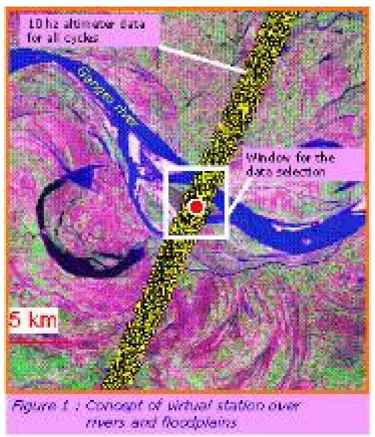
Rating curve

RADAR ALTIMETER

Temporal resolution:

10-35 days





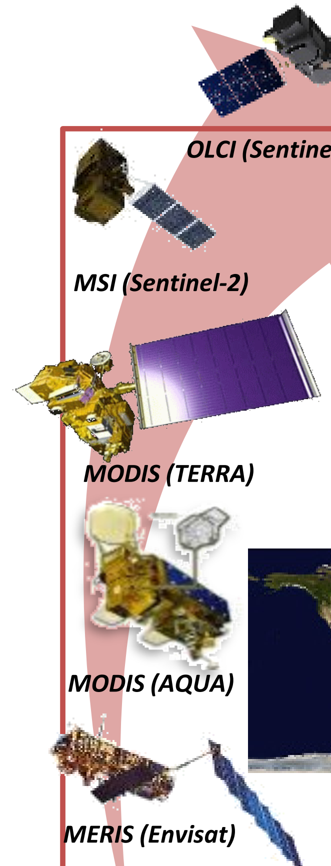
OPTICAL

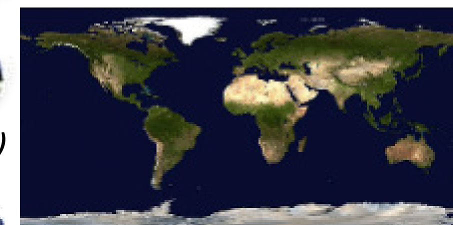
Spatial resolution:

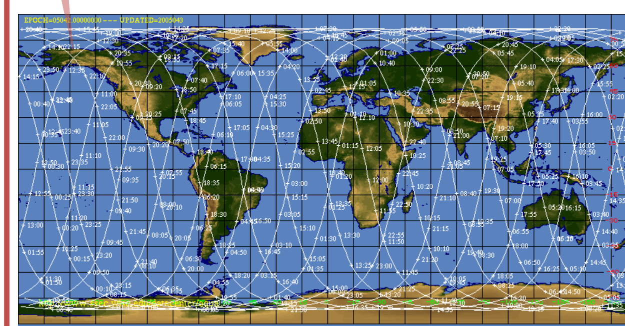
10-350 m

Temporal resolution:

1-10 days







RIVER DISCHARGE FROM ALTIMETER + RADIOMETER

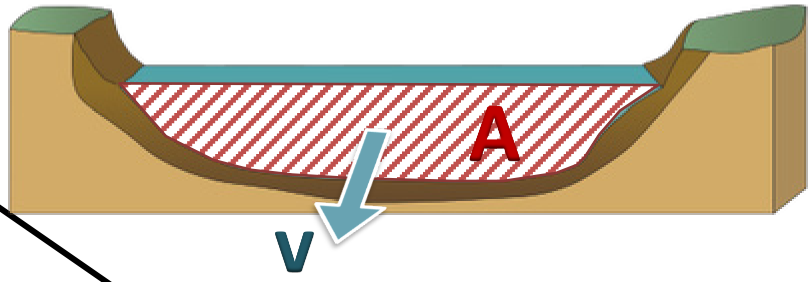
SENSORS

- Altimeter
- Passive microwave
- Optical

APPROACHES

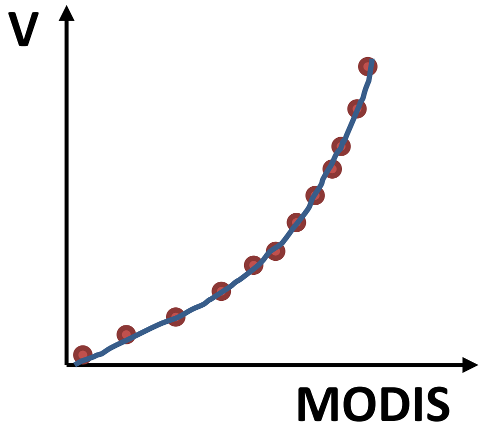
- Hydraulic models
- Rating curve

$$Q = v \cdot A$$



Flow velocity derived by MODIS

(Tarpanelli et al., 2013 - Remote Sensing of Environment)



Flow Area

A=f(water level, geometry)

derived by radar altimetry observation

Known (Topographic survey)

unknown

(Moramarco et al., 2013 – Journal of Hydrology)

RIVER DISCHARGE FROM ALTIMETER + RADIOMETER

SENSORS

Altimeter

Passive microwave

Optical

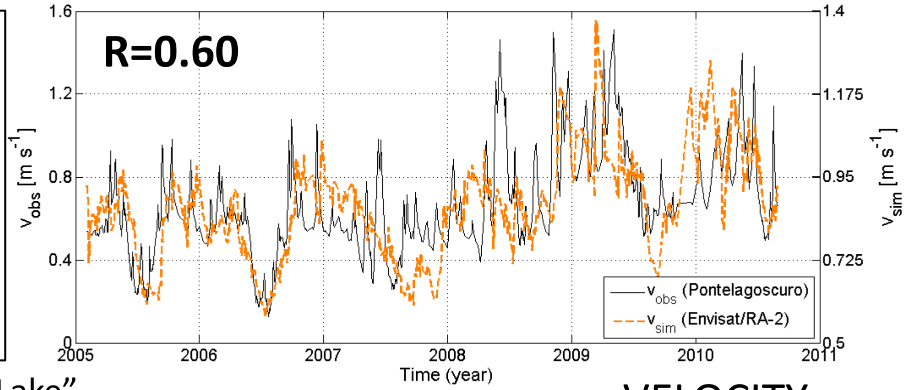
APPROACHES

Hydraulic models

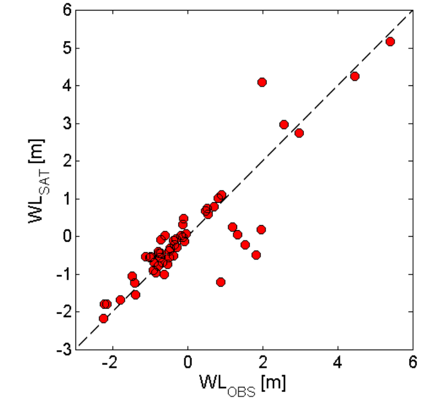
Rating curve

MODIS+ENVISAT

"river&Lake"



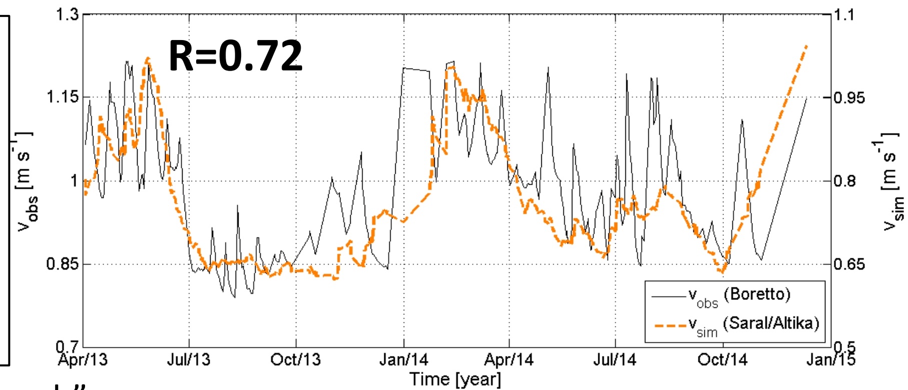
VELOCITY

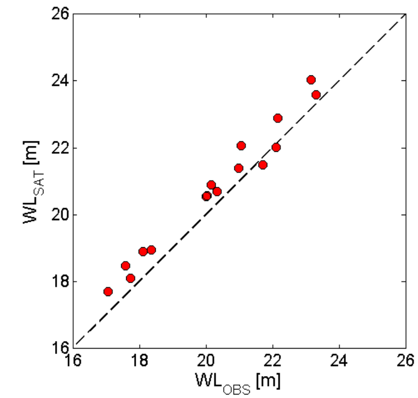


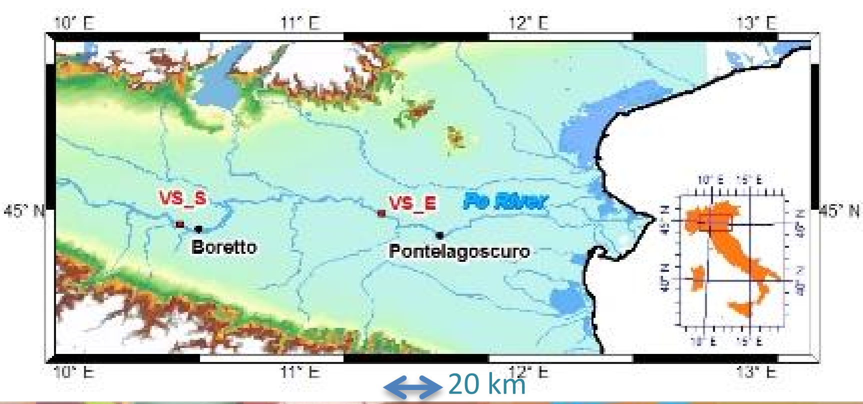
WATER LEVEL

MODIS+SARAL

"Hydroweb"







WL ERRORS	ENVISAT PONTELAGOSCURO	SARAL BORETTO
R	0.89	0.99
RMSE [m]	0.70	0.61
RRMSE [%]	15	3

RIVER DISCHARGE FROM ALTIMETER + RADIOMETER

SENSORS

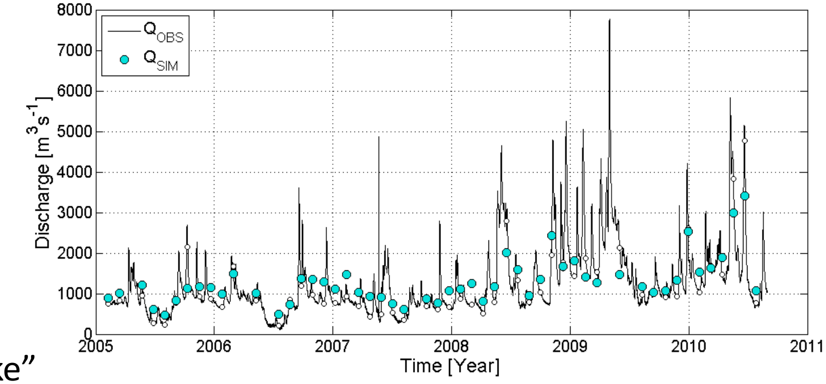
- Altimeter
- Passive microwave
- Optical

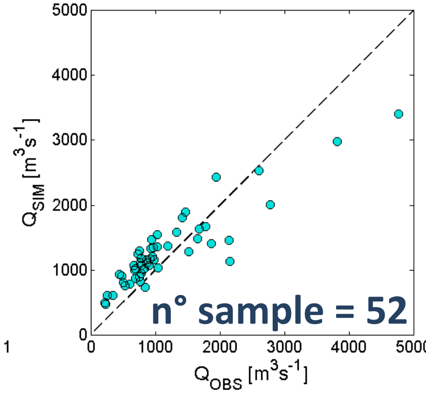
APPROACHES

- Hydraulic models
- Rating curve

MODIS+ENV
ISAT

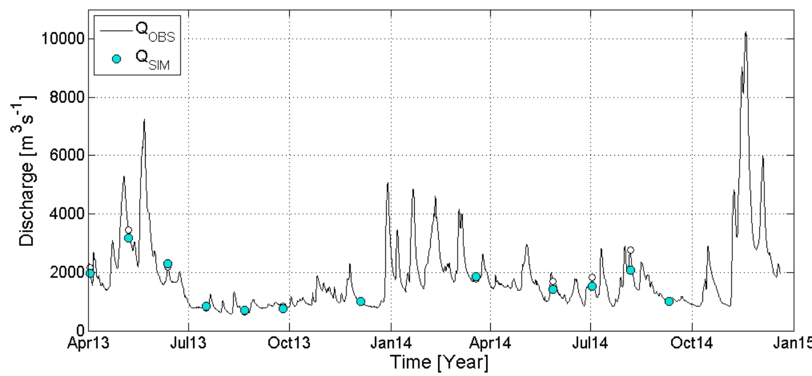
"river&Lake"

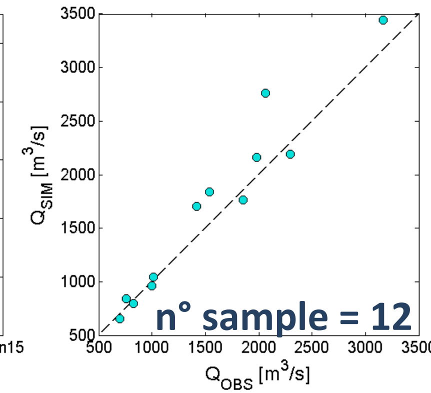


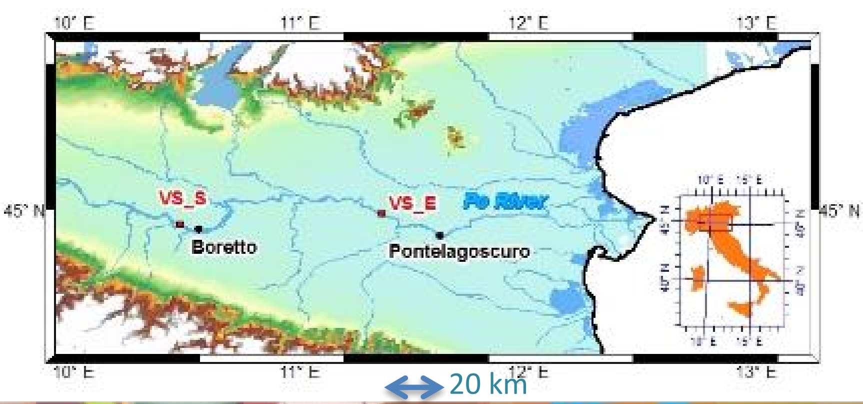


MODIS+SAR
AL

"Hydroweb"







Q ERRORS	ENVISAT PONTELAGOSCURO	SARAL BORETTO
R	0.91	0.97
RMSE [m^3/s]	423	258
RRMSE [%]	36	15

RIVER DISCHARGE FROM ALTIMETER + RADIOMETER

SENSORS

Altimeter

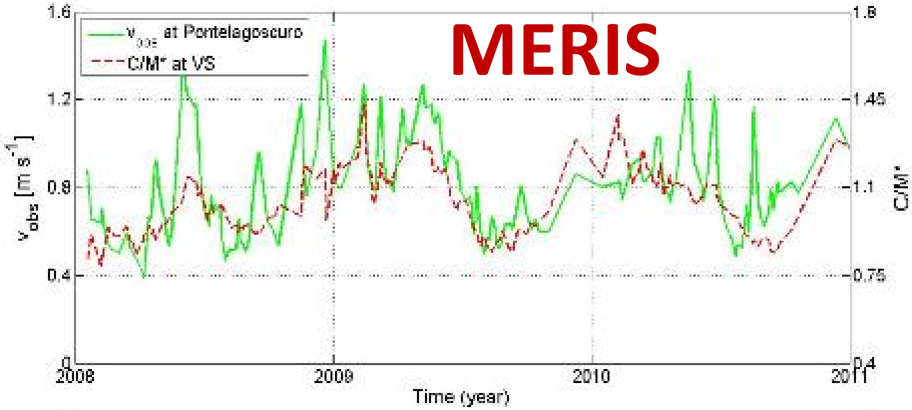
Passive microwave

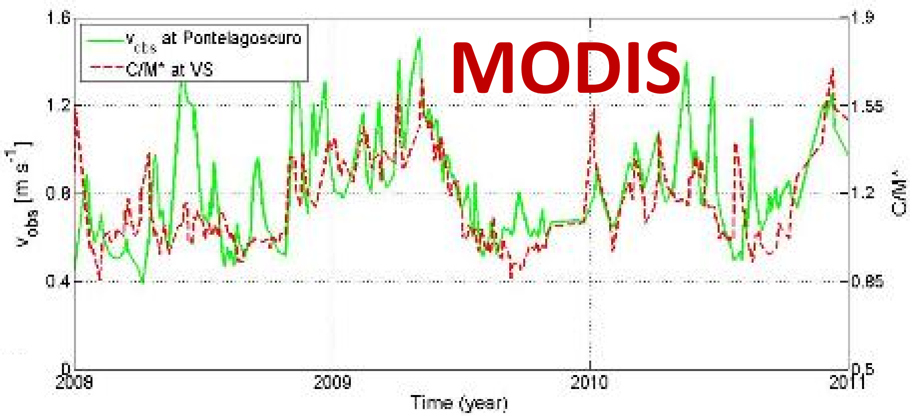
Optical

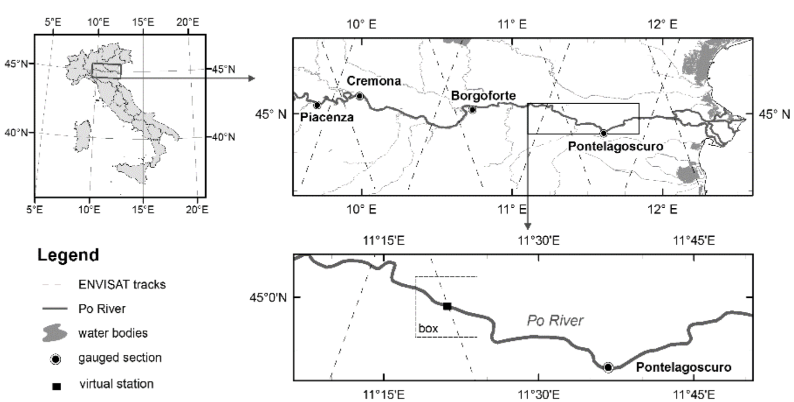
APPROACHES

Hydraulic models

Rating curve







RIVER DISCHARGE FROM ALTIMETER + RADIOMETER

SENSORS

Altimeter

Passive microwave

Optical

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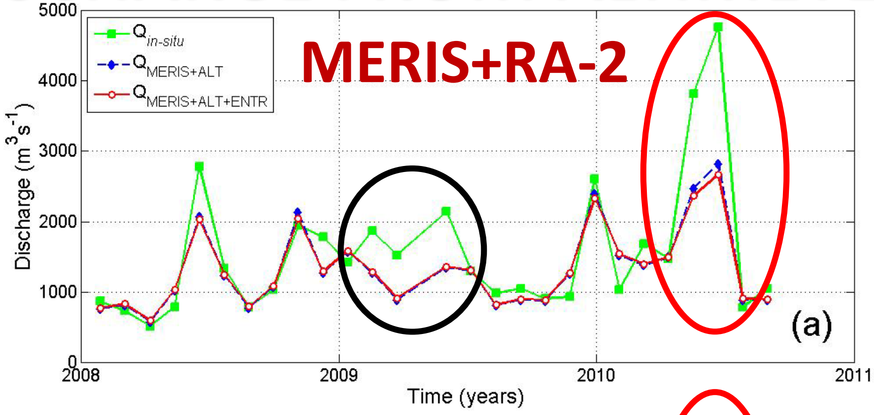
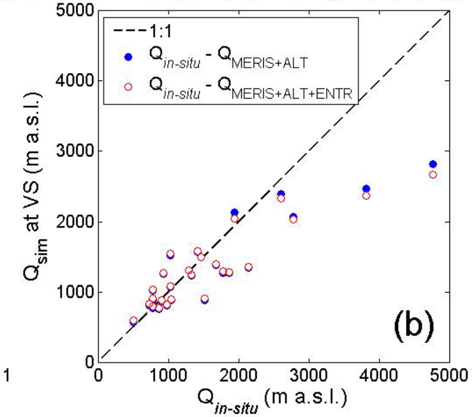
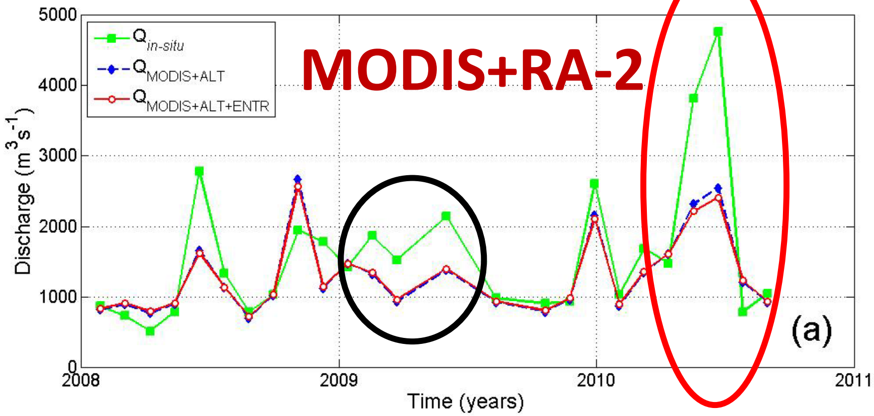
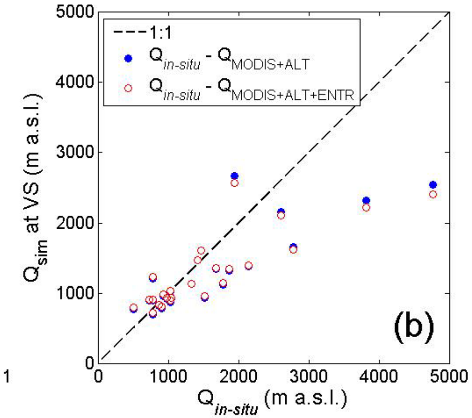
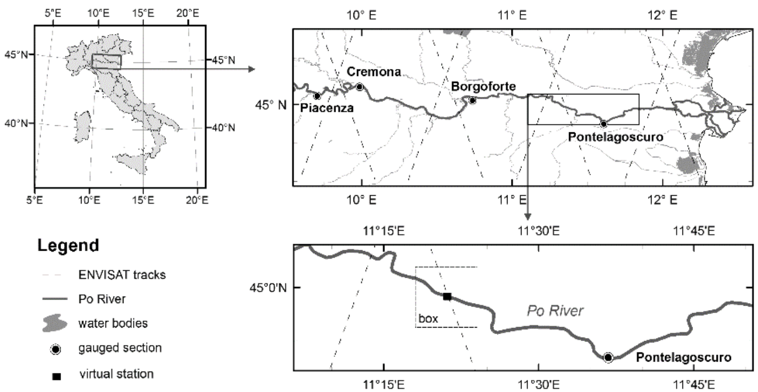
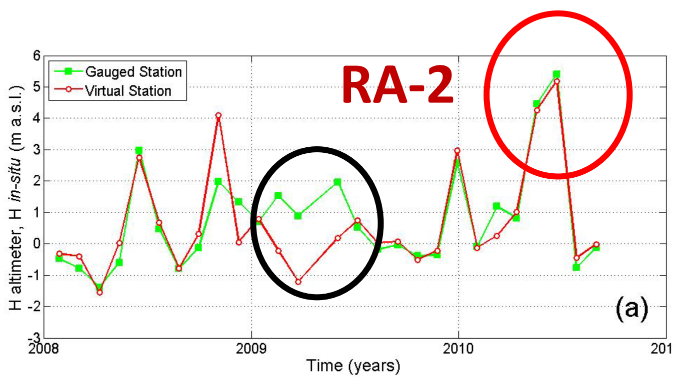












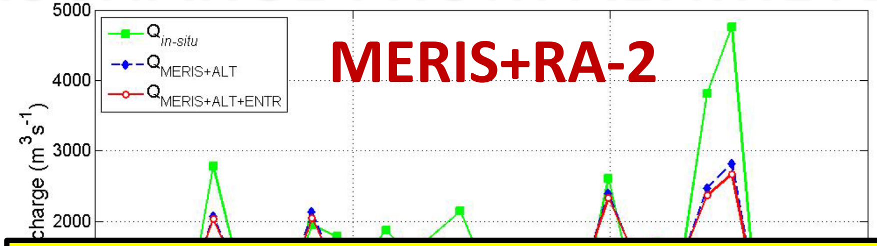
RIVER DISCHARGE FROM ALTIMETER + RADIOMETER

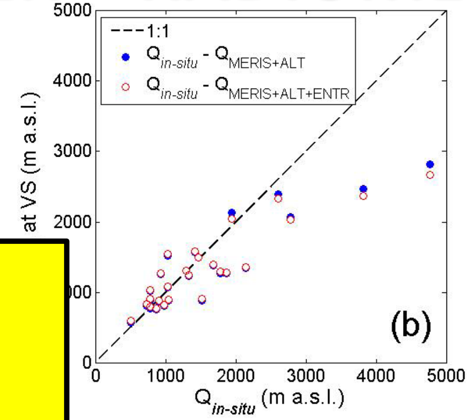
SENSORS

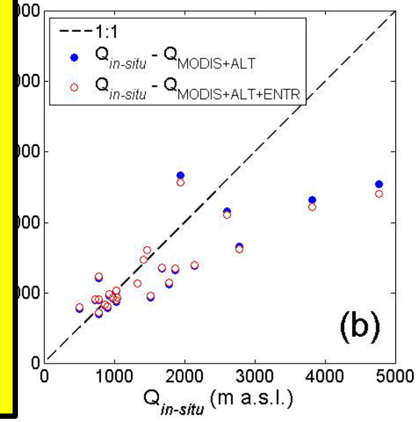
- Altimeter
- Passive microwave
- Optical

APPROACHES

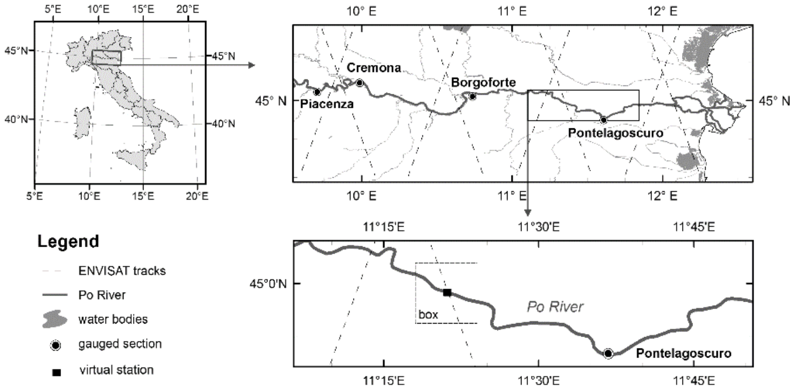
- Hydraulic models
- Rating curve







MERIS + RA-2: SIMULTANEOUS MEASUREMENTS! Potential application of OLCI and SRAL (SENTINEL-3)



Q ERRORS	MODIS+RA-2 PONTELAGOSCURO	MERIS+RA-2 PONTELAGOSCURO
R	0.56	0.60
NS	0.58	0.67
RRMSE [%]	41 %	36 %

RIVER DISCHARGE FORECASTING FROM ALTIMETER + RADIOMETER

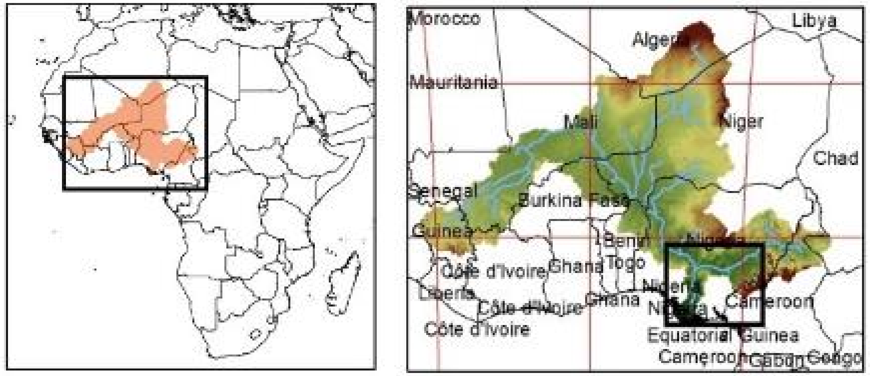
SENSORS

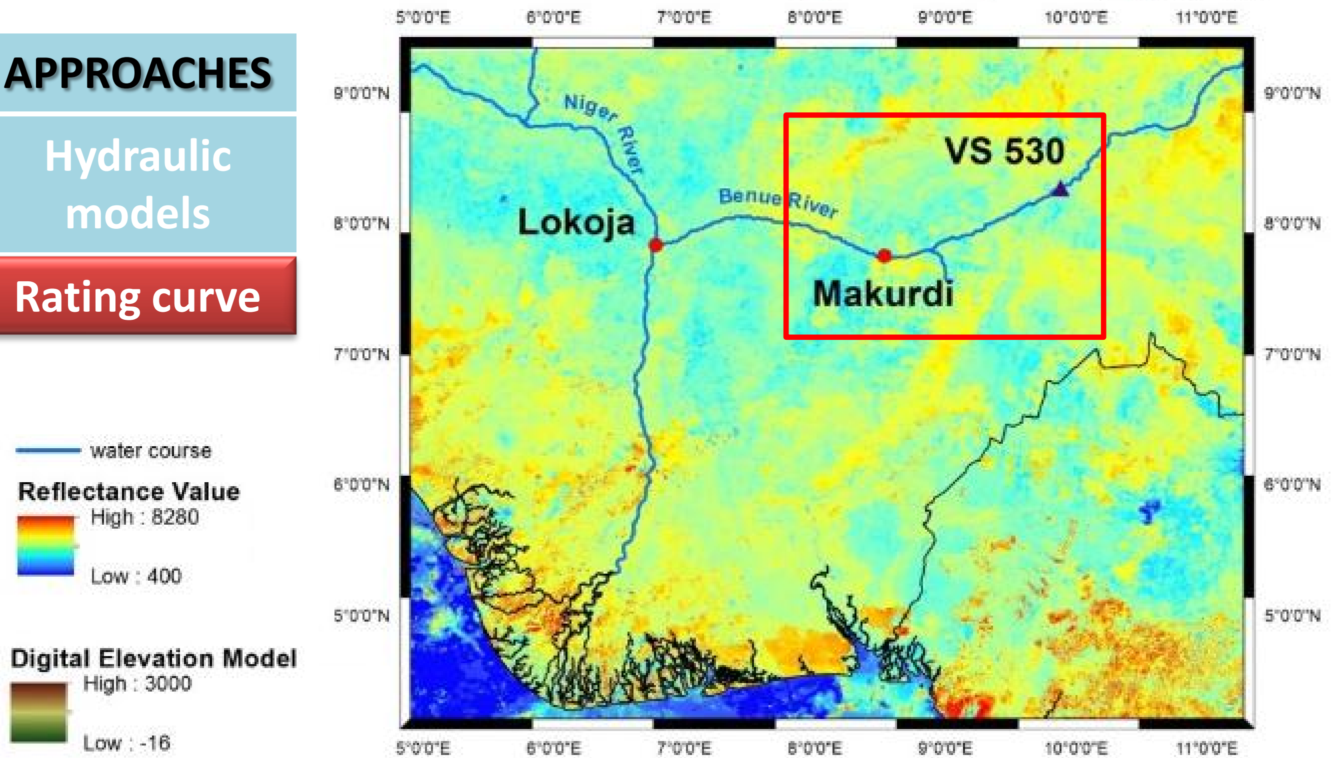
- Altimeter
- Passive microwave
- Optical

APPROACHES

- Hydraulic models
- Rating curve

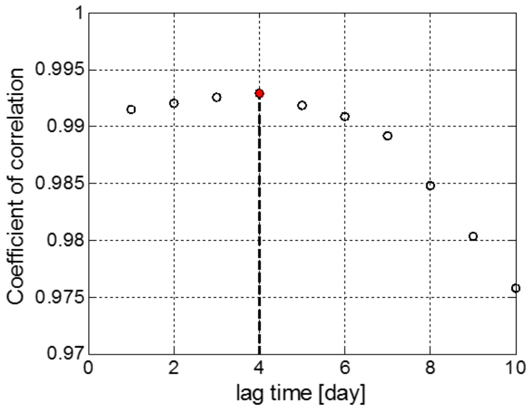
MODIS+RC => Discharge / RA-2+RC => Discharge





River discharge forecast at Makurdi (Benue river) by using separately MODIS and ENVISAT altimetry data at VS 530

Lead time: 4 days

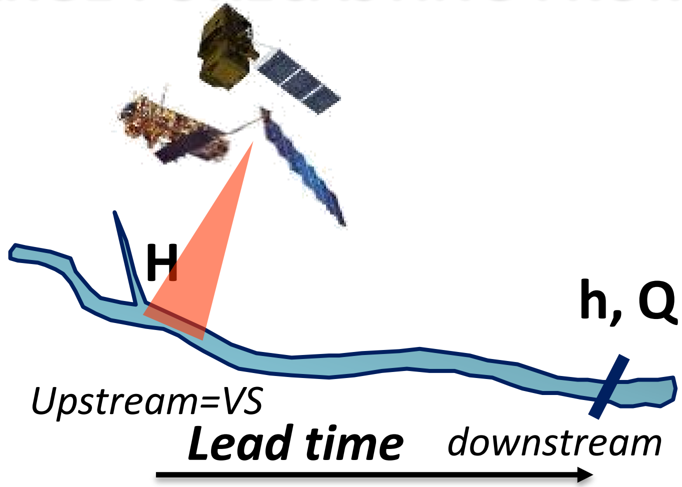


(Tarpanelli et al., 2016 RSE, under review)

RIVER DISCHARGE FORECASTING FROM ALTIMETER + RADIOMETER

SENSORS

- Altimeter
- Passive microwave
- Optical



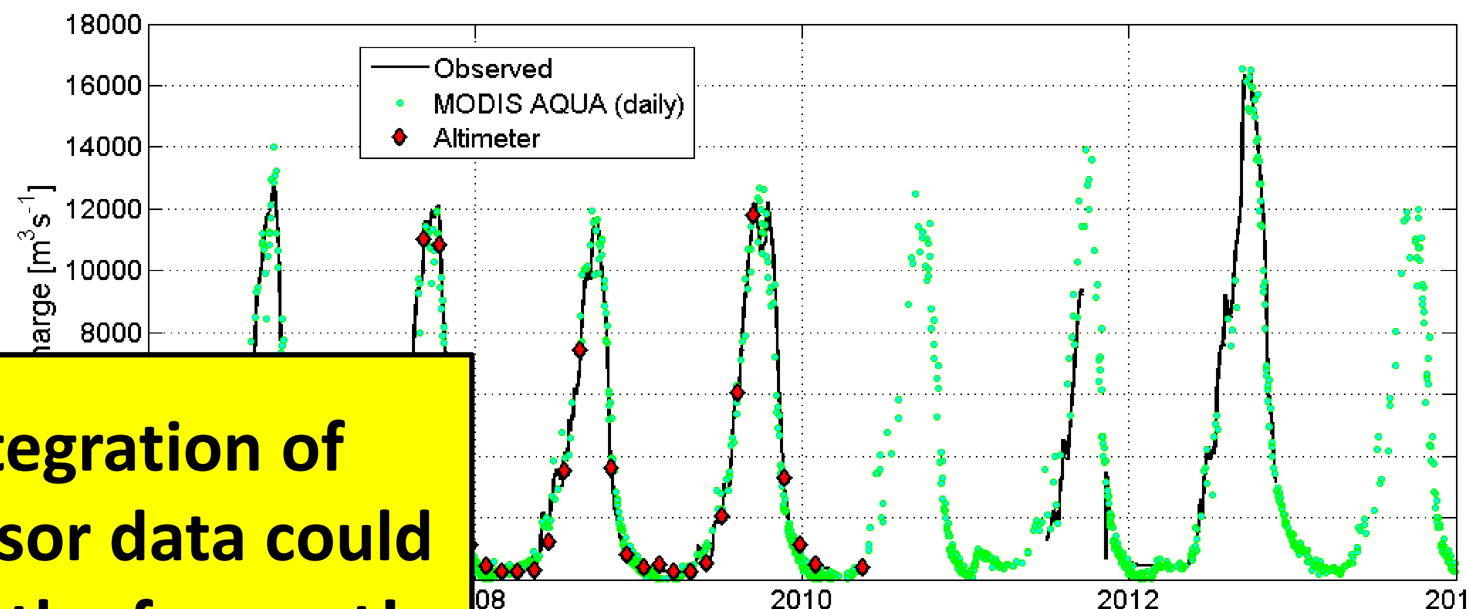
Product	r	PC	N°
ENVISAT/RA-2	0.995	0.99	40
MODIS DAILY	0.991	0.53	854
MODIS 8-DAY	0.988	0.83	237

Persistence Coeff:

$$PC = 1 - \frac{\sum_1^T \left(Q_{obs}^t - Q_{sim}^t\right)^2}{\sum_1^T \left(Q_{obs}^t - Q_{obs}^{t-TL}\right)^2}$$

APPROACHES

- Hydraulic models
- Rating curve



The integration of multi-sensor data could improve the forecast!

(Tarpanelli et al., 2016 RSE, under review)

CONCLUSIONS

1) Altimetry is a valid technique for hydrological/hydraulic applications, such as river discharge estimation of large rivers.

1) Optical and passive microwave sensors are able to estimate the variation of river discharge also in small rivers (e.g. Po).

1) The integration of different sensors represents an added value to the information derived from single sensor data and widens the possibilities of increasing the accuracy of river discharge estimates.

   The integration can be:

   - using all available satellite altimetry missions together (densification);
   - using all available satellite altimetry missions and imaging data (optical and passive microwave sensors)

Evaluation of the use of satellite sensors for the most important hydrological applications requiring RIVER DISCHARGE

While the temporal resolution of radar altimetry prevents its use on the forecasting activities and for water resources management for small basins, the optical sensors could give a better support for the evaluation of extreme events.

Altimetry can be used for the climate change evaluations, whereas actually less studies have addressed this topic for optical sensors.

	ALTIMETRY			OPTICAL/PASSIVE MICROWAVE		
	FORECASTING OF EXTREME EVENTS	WATER RESOURCES MANAGEMENT	CLIMATE CHANGE	FORECASTING OF EXTREME EVENTS	WATER RESOURCES MANAGEMENT	CLIMATE CHANGE
Small-medium basins						X
Large basins						X

 = Fit for purpose  = Needs more R&D  = Does not work X = Not well studied

ROADMAP FOR USING SATELLITE DATA IN HYDROLOGICAL APPLICATIONS

QUESTIONS	ANSWER	SOLUTION
Are we able to estimate Q from satellite at ungauged location?	Not completely. Most of the models or algorithms rely on *in-situ* observations	Improving hydraulic laws tailored to the use of satellite observations (water level, slope, width)
Can we use satellite altimetry (including SWOT) for hydrological application in medium sized basins?	No, due to not sufficient temporal resolution (daily or sub-daily measurements required)	Multi-mission approach, specifically merging with optical images
Are satellite observations used for operational hydrological purposes?	No, the use is still in the infancy state	Data assimilation (as in other communities, e.g. Meteorology, Oceanography)
Can we rely on satellites to produce long and global time-series of River Discharge?	Yes, but not done yet	R&D study required (e.g. within CCI+)

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THANK YOU FOR YOUR ATTENTION