→ MEASUREMENTS AND OBSERVATIONS IN THE 21st CENTURY CONFERENCE

New perspectives for river discharge monitoring by leveraging ground and satellite observations

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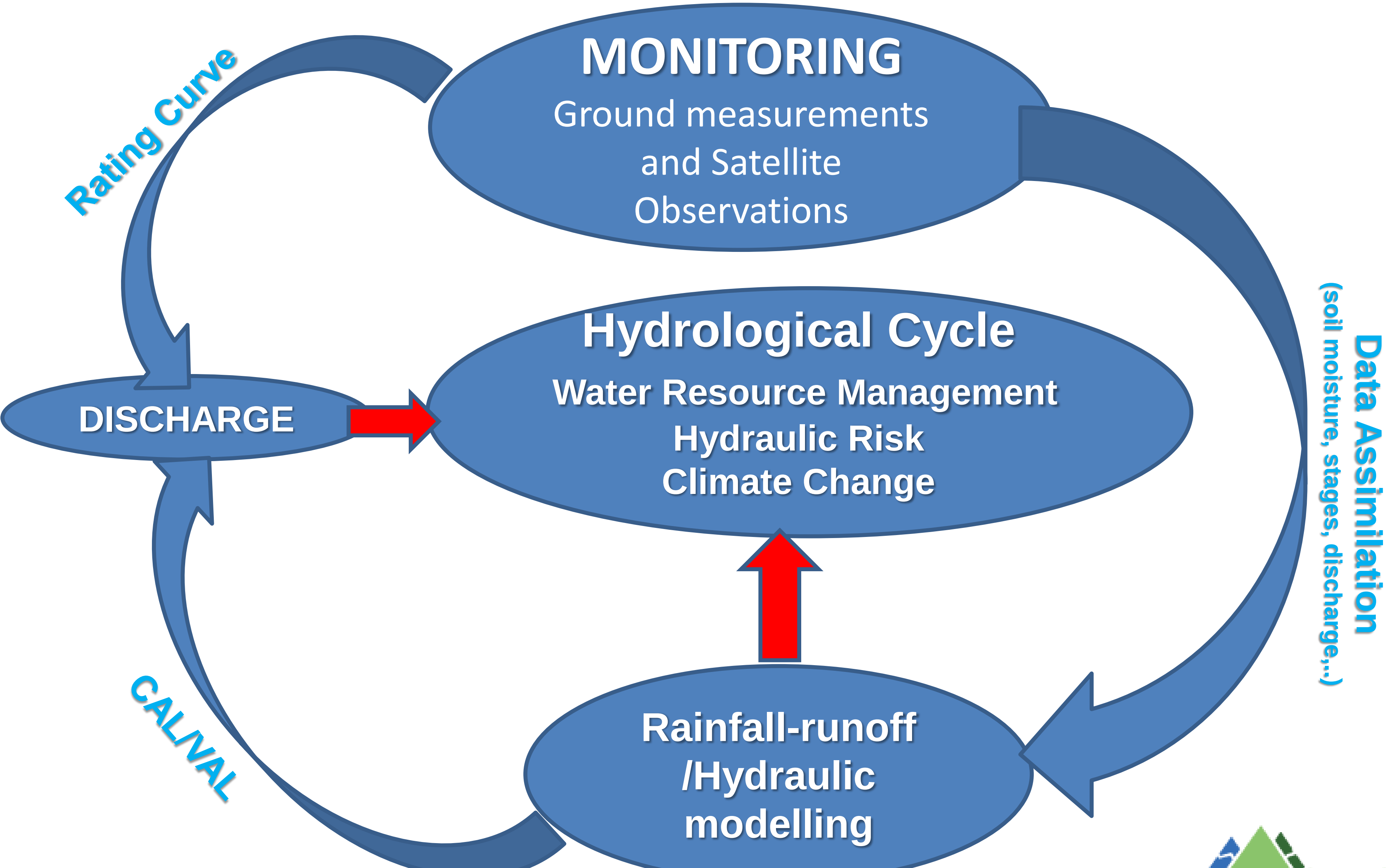
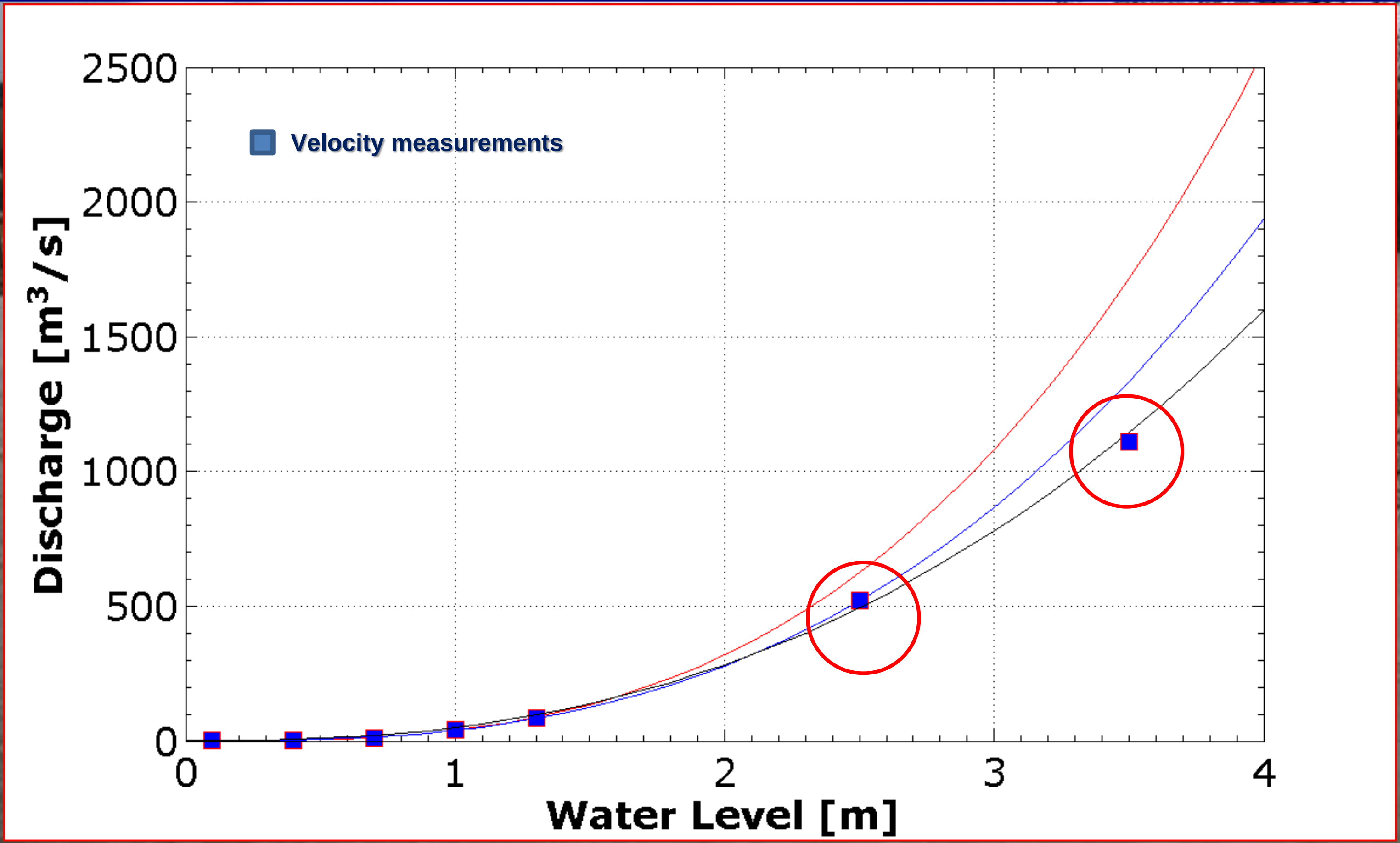
21 November 2016 | ESA–ESRIN | Frascati, Rome (Italy)


MONITORING
Ground measurements
and Satellite
Observations
Rating Curve
DISCHARGE
Hydrological Cycle
Water Resource Management
Hydraulic Risk
Climate Change
Data Assimilation
(soil moisture, stages, discharge,..)
CAL/VAL
Rainfall-runoff
/Hydraulic
modelling

Can one carry out flow velocity measurements and estimate the discharge?



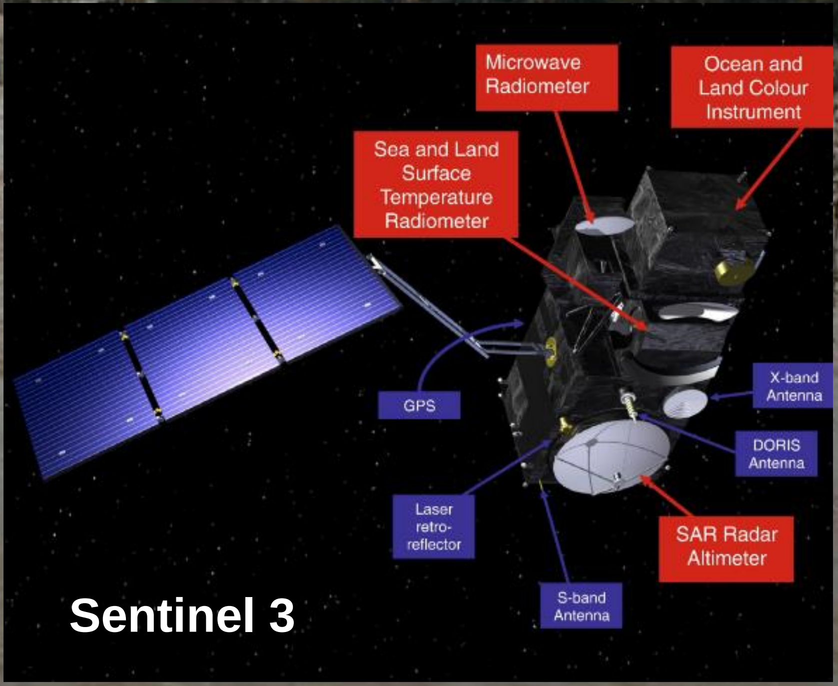
Flood November 2005: Tiber River – Ponte San Giovanni

Can one carry out flow velocity measurements and estimate the discharge?

No Bridges – No Sensors

Need to exploit new technolgy for ground and satellite observations

Drone - UAV



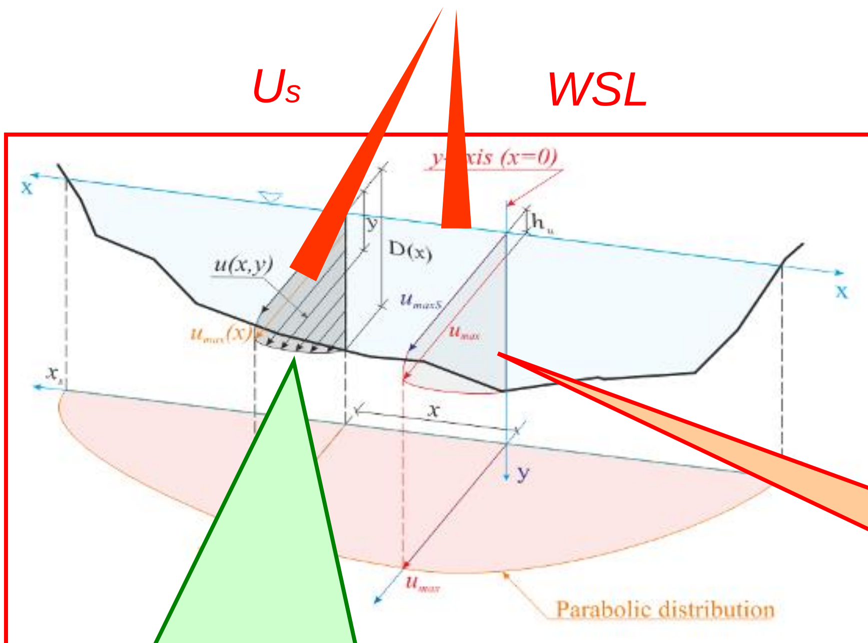
Sentinel 3

Flood November 2005: Tiber River – Ponte San Giovanni

A prototype of radar-drone system for measuring the surface flow velocity at river sites and discharge estimation (SWARMNET Project - MIUR)

Recently, a growin… the use of Unmanned …) for topographic applic… and considering their capability UVA may be of a considerable interest for the hydrological monitoring and in particular for streamflow measurements.

Specifically, UVA may give information in terms of Us and WSL of priority to estimate discharge by Entropy model.



Two-dimensional velocity distribution (Moramarco et al. 2004):

$$u = \frac{u_{\max_v}}{M} \ln\left[1 + \left(e^M - 1\right)\frac{D-y}{D-h}\exp\left(1 - \frac{D-y}{D-h}\right)\right]$$

u_{max} estimation:

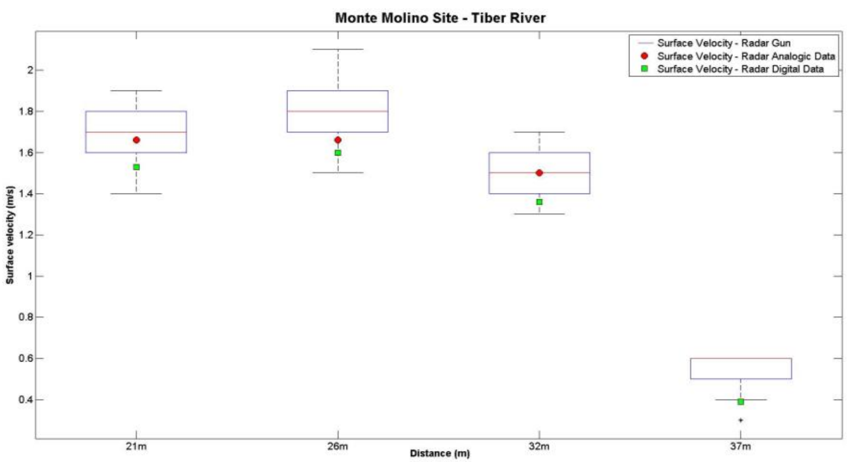
$$u_{\max} = \frac{u_{\max_v}}{\frac{1}{M}\ln\left[1 + \left(e^M - 1\right)\frac{D}{D-h}\exp\left(1 - \frac{D}{D-h}\right)\right]}$$

Us: Surface flow velocity

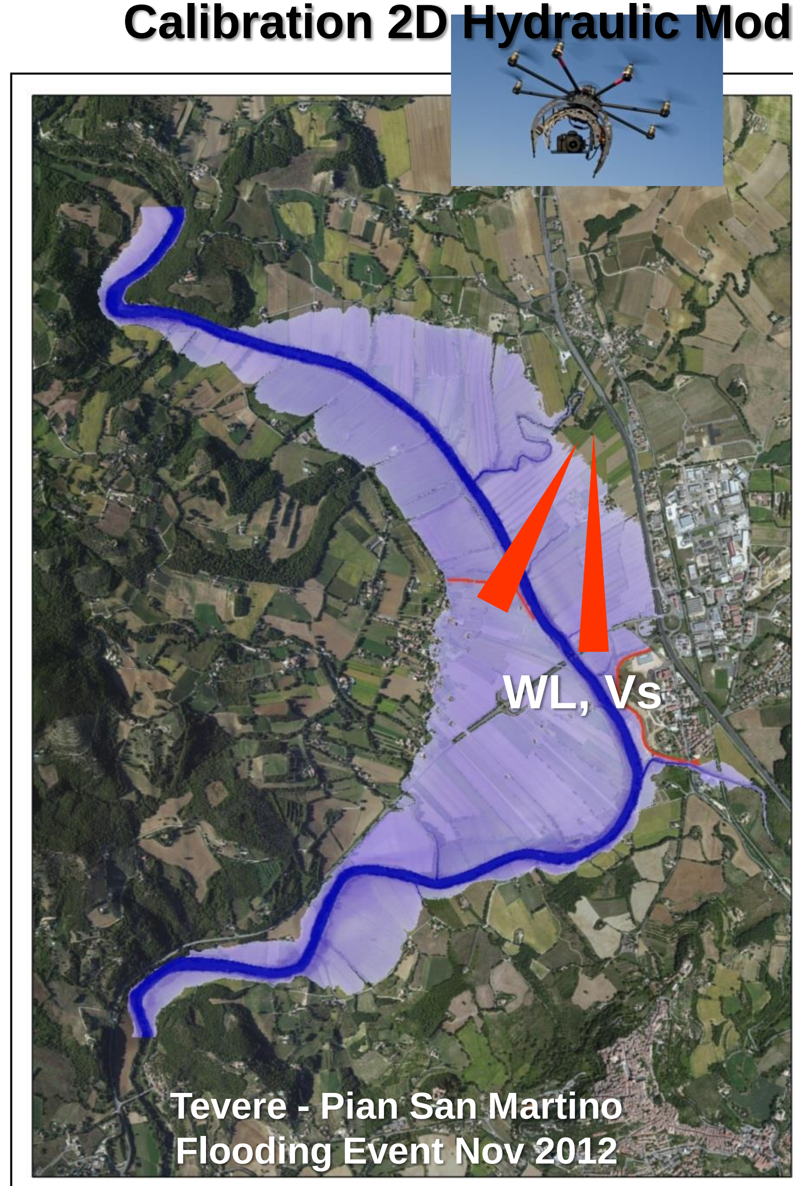
WSL: Water Surface Level

GROUND OBSERVATIONS

DRONE: Experimental Radar Sensor



Calibration 2D Hydraulic Model

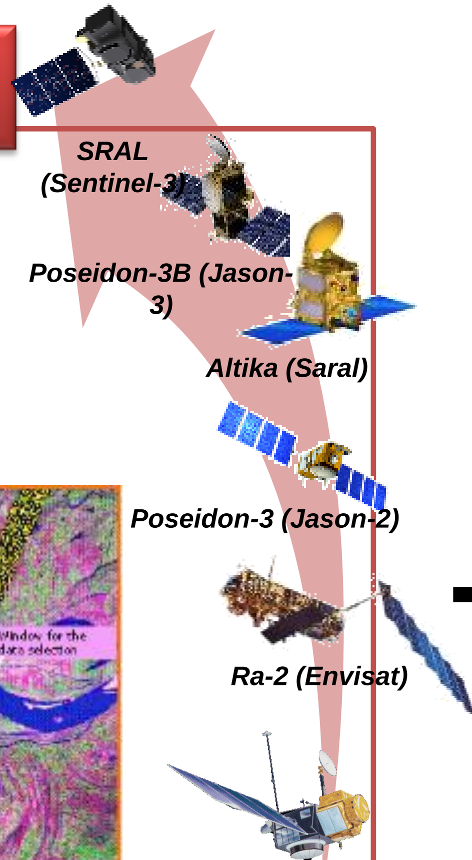


RIVER DISCHARGE FROM SATELLITE OBSERVATIONS

RADAR ALTIMETER

Temporal resolution:

10-35 days



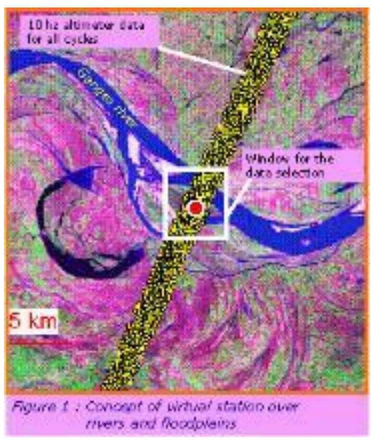
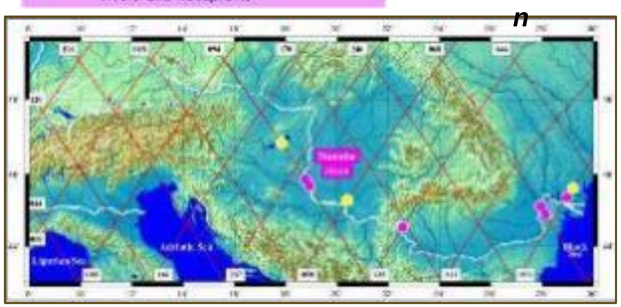


Figure 1 : Concept of virtual station over rivers and floodplains



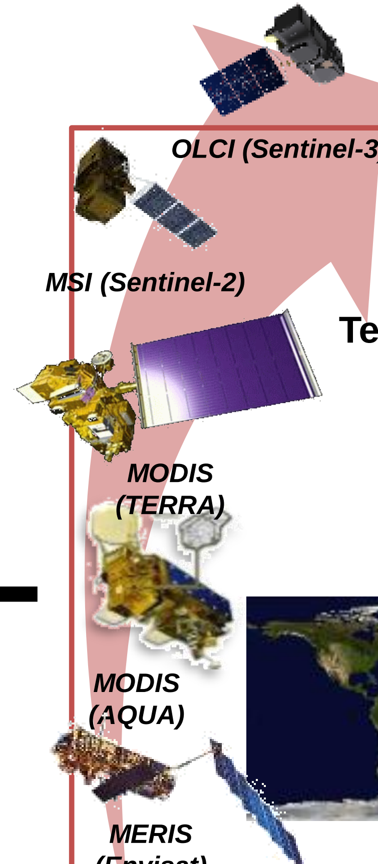
+

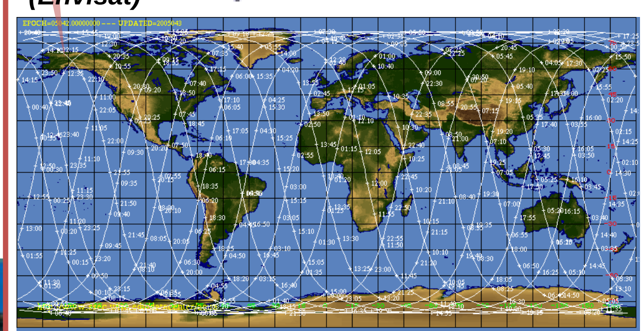
RADIOMETER

Spatial resolution:
250-350 m

Temporal resolution:

1-10 days





Discharge Monitoring by Satellite

The SWOT and SENTINEL missions:
River monitoring at global scale

Water Surface Elevation

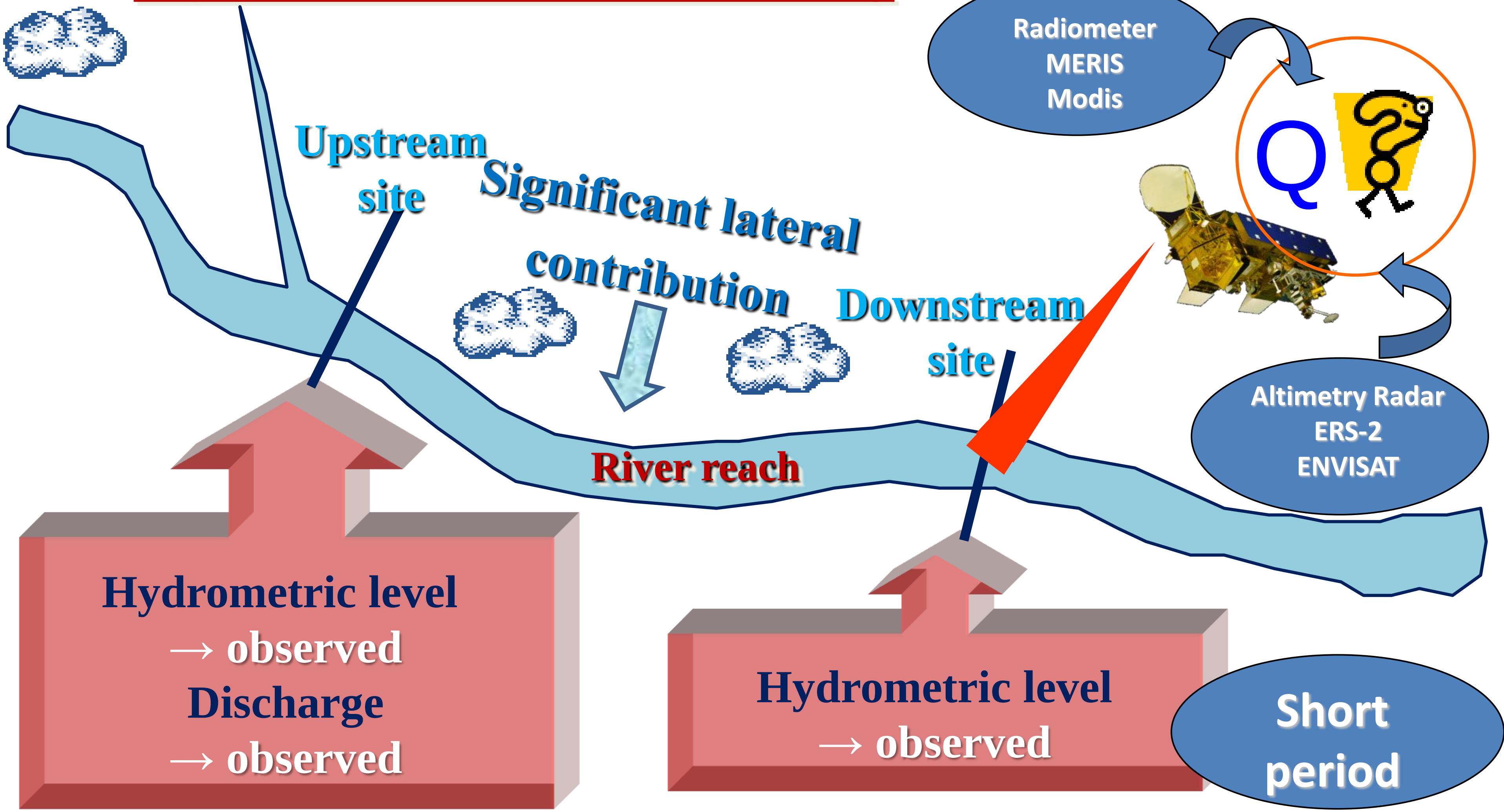
(ALTIMETER)

Water Surface Velocity

(MODIS - MERIS)

Discharge Assessment

Hydrometric Monitoring



BENEFIT USING ALTIMETRY PRODUCT

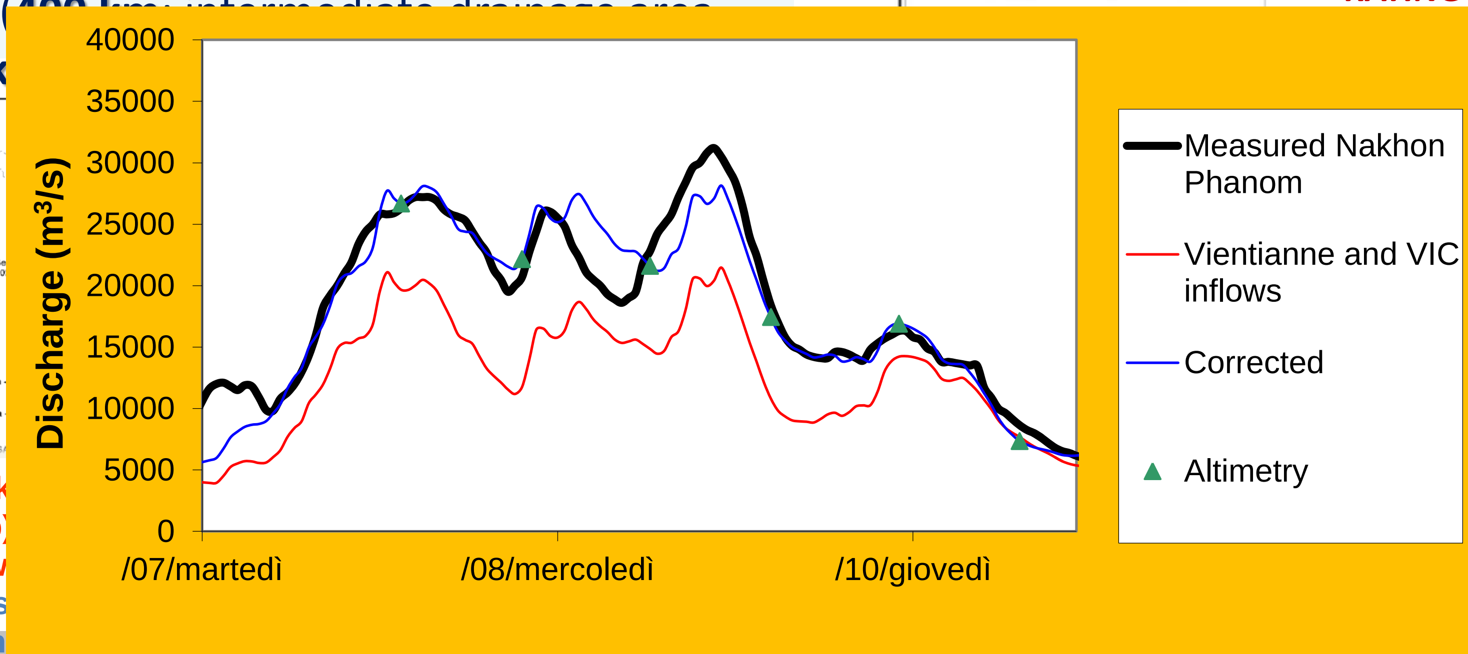
Relating Qu– WL(Alt)_downstream

Birkinshaw et al. (2010) used altimetry water levels on the Mekong River (Southeastern A... sed by Moramarco & Si... al. (2005), named as **Ratin**

$$Q_d(t) = \alpha \frac{A_d(t)}{A_u(t - T_L)} Q_u(t - T_L) + \beta = \alpha X + \beta$$

Without using rainfall data

Mekong River: reach bounded by two gauged sections (400 km; intermediate drainage area **300000 k**



RATING CURVE

(Alt-RCM)

Birkinshaw, S.J., O'Donnell, G.M., Moore, P., Kilsby, C.G., Fowler H.J., & Berry, P.A.M., Using satellite altimetry data to augment flow estimation techniques on the Mekong River, Hydrol. Process., 2010, 24, 3811-3825

Remote Sens. **2013**, *5*, 4145-4162; doi:10.3390/rs5094145

OPEN ACCESS

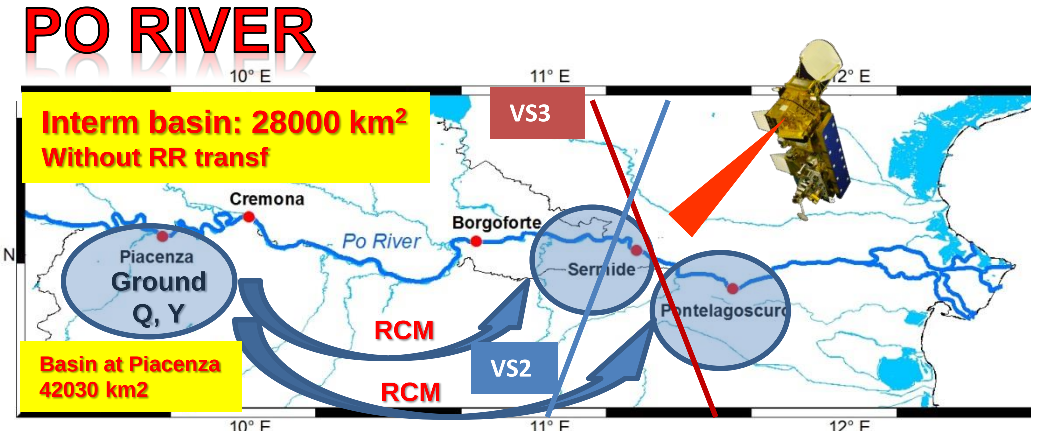
Remote Sensing

River Discharge Estimation by Using Altimetry Data and Simplified Flood Routing Modeling

Angelica Tarpanelli *, Silvia Barbetta, Luca Brocca and Tommaso Moramarco

BENEFIT USING ALTIMETRY PRODUCT

PO RIVER



Empirical discharge formulation (Bjerklie, 2003 JoH)

$$Q = c_1 \cdot W^a \cdot Y^b \cdot S^d$$

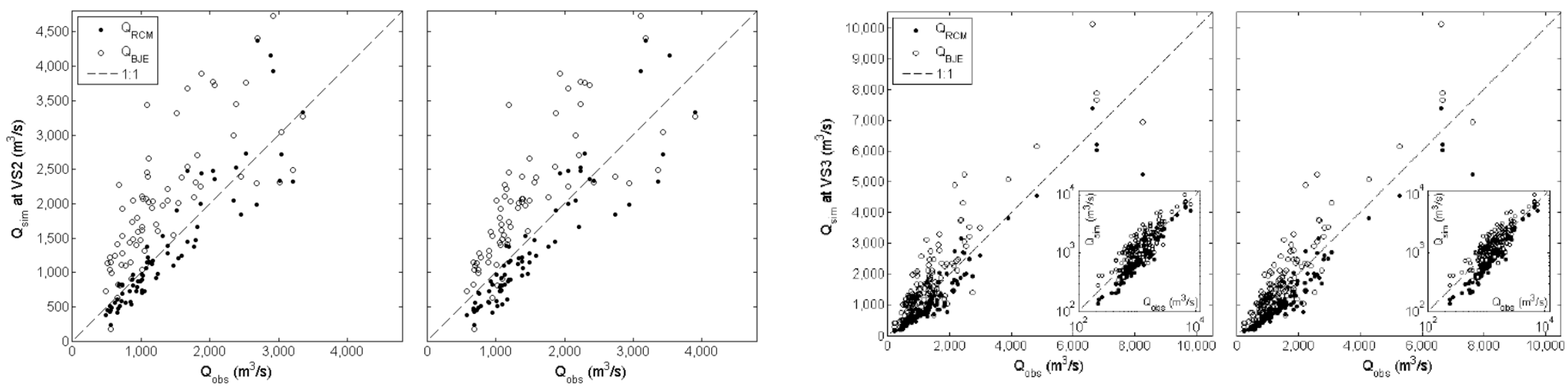
Discharge — Surface top width — Depth of the equivalent rectangular section — channel slope

$$Q_{BJE} = 7.22 \cdot W^{1.02} \cdot Y^{1.74} \cdot S^{0.35}$$

Parameters calibrated and validated using 1012 discharge measurements in 102 rivers in the United States and New Zealand

Bjerklie, D.M., Dingman, S.L., Vorosmarty, C.J., Bolster, C.H., Congalton, R.G., 2003. Evaluating the potential for measuring river discharge from space. *Journal of Hydrology*, 278,

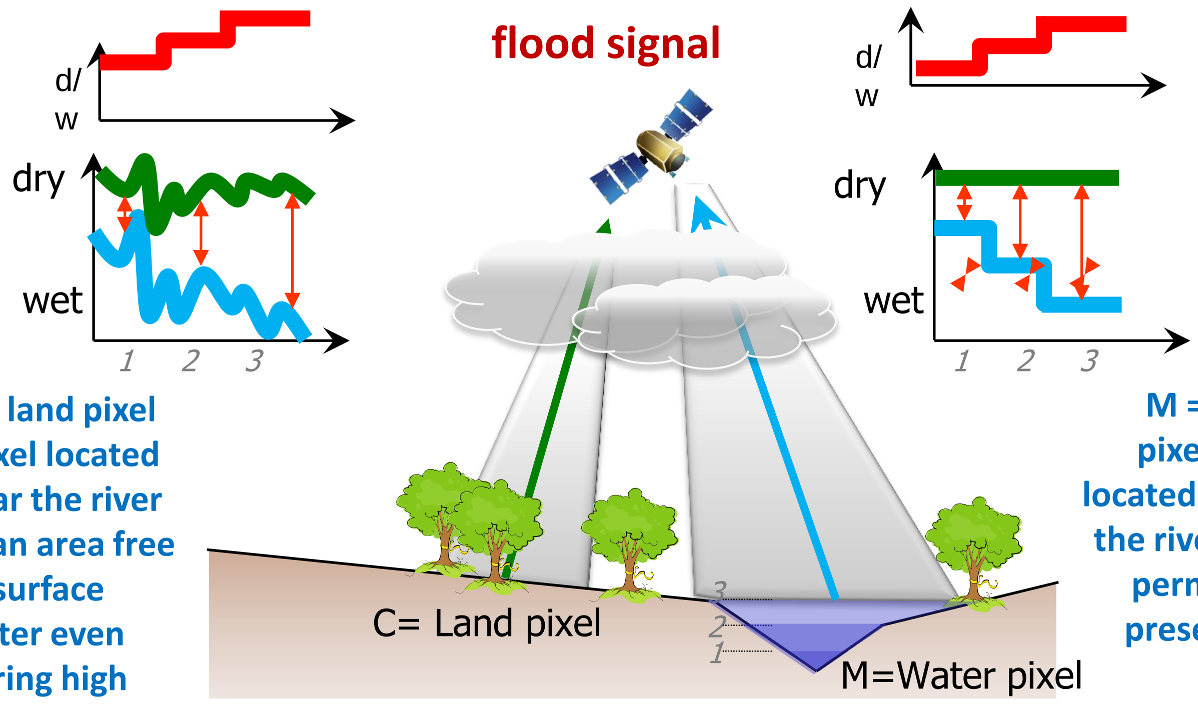
Satellite	Pontelagoscuro RCM RMSE ($m^3 \cdot s^{-1}$)	RRMSE (%)	NS (-)	RE (%)	BJ03 RMSE ($m^3 \cdot s^{-1}$)	RRMSE (%)	NS (-)	RE (%)
VS2 (ERS-2)	405	26.9	0.73	−12.1	834	55.3	−0.14	38.3
VS3 (ERS-2 and ENVISAT)	497	33.3	0.82	−25.8	670	44.9	0.66	20.6
VS3 (ERS-2)	526	31.2	0.82	−22.3	794	47.0	0.60	21.3
VS3 (ENVISAT)	467	35.7	0.80	−30.1	527	40.3	0.74	19.8



Sermide **Pontelagoscuro** **Sermide** **Pontelagoscuro**

BENEFIT USING RADIOMETER PRODUCTS

Flow Velocity by MODIS data



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)

C/M increases with the presence of water and, hence, of discharge

BENEFIT USING RADIOMETER PRODUCTS

Remote Sensing of Environment 136 (2013) 47–55

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

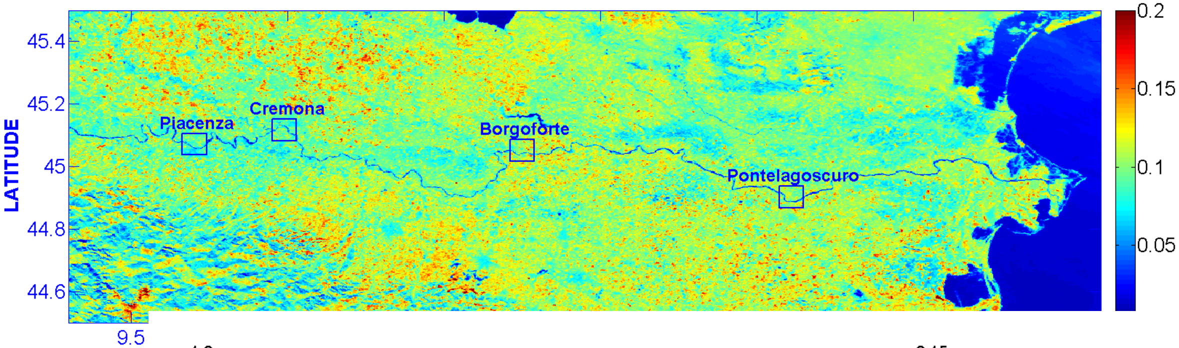
journal homepage: www.elsevier.com/locate/rse

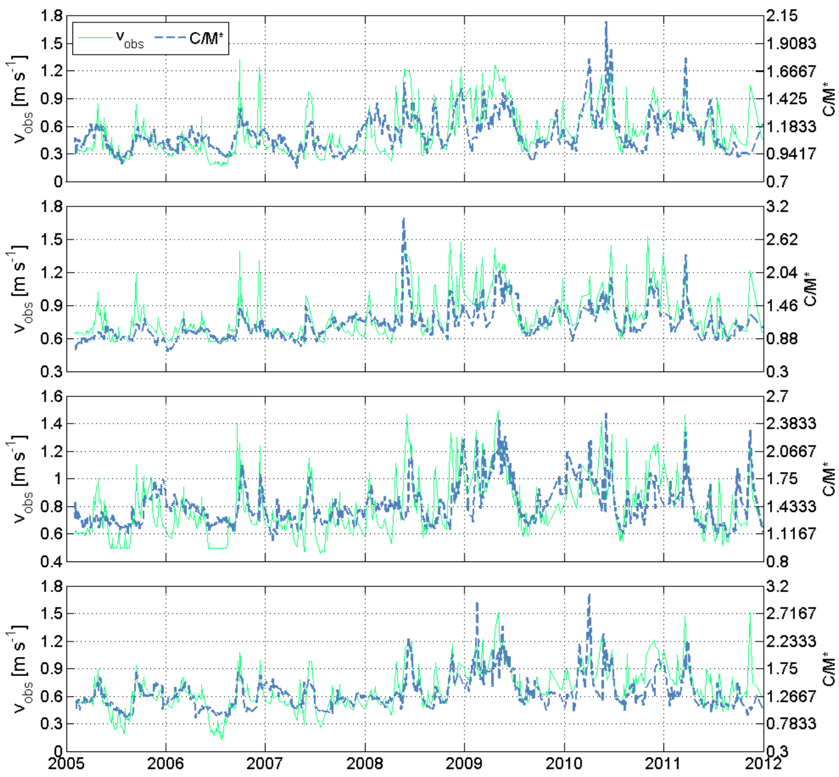
Toward the estimation of river discharge variations using MODIS data in ungauged basins

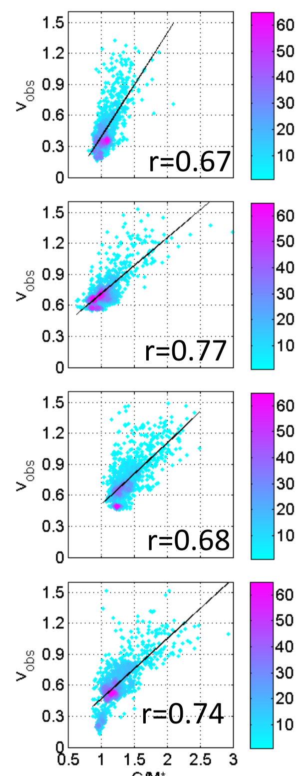
Angelica Tarpanelli [a,*], Luca Brocca [a], Teodosio Lacava [b], Florisa Melone [a], Tommaso Moramarco [a], Mariapia Faruolo [b], Nicola Pergola [b], Valerio Tramutoli [c]

PO RIVER BASIN

AQUA- MODIS Reflectance value of Channel 2 (10-Feb-2005 10:10)







Piacenza

Cremona

Borgoforte

Pontelagoscuro

BENEFIT USING RADIOMETER PRODUCTS

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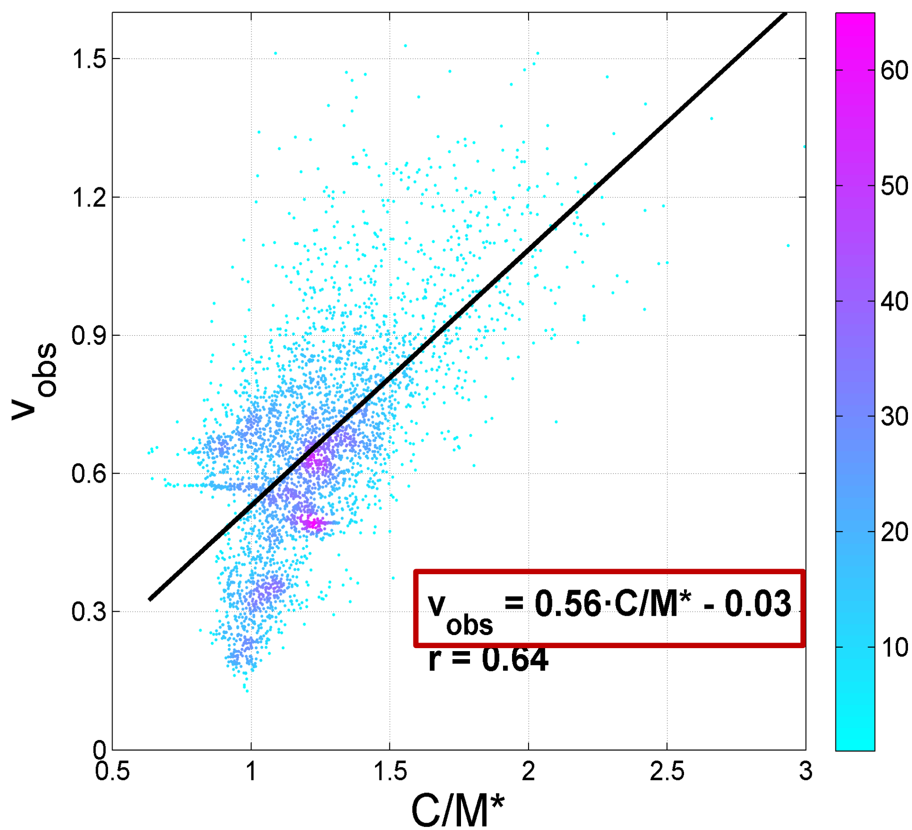
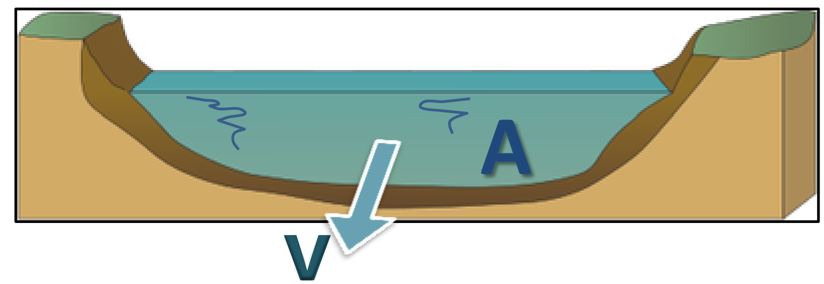
PO RIVER BASIN

Identification of a regional relationship between C/M* and v





$$Q = v \cdot A$$

$$A = f(h)$$

1) h in-situ with actual river section

2) h altimetry with actual river section

3) h altimetry with Entropy river section

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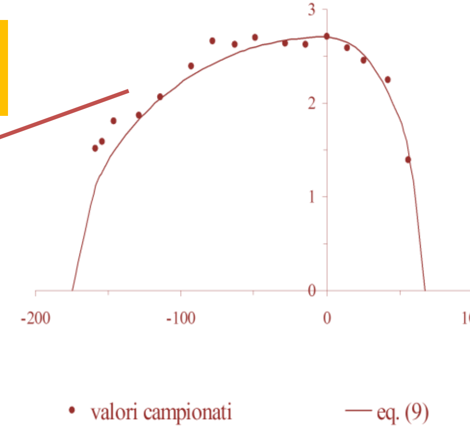
Journal of Hydrology
journal homepage: www.elsevier.com/locate/jhydrol
ELSEVIER

An entropy-based method for determining the flow depth distribution in natural channels

Tommaso Moramarco [a,*], Giovanni Corato [b], Florisa Melone [a], Vijay P. Singh [c,d]

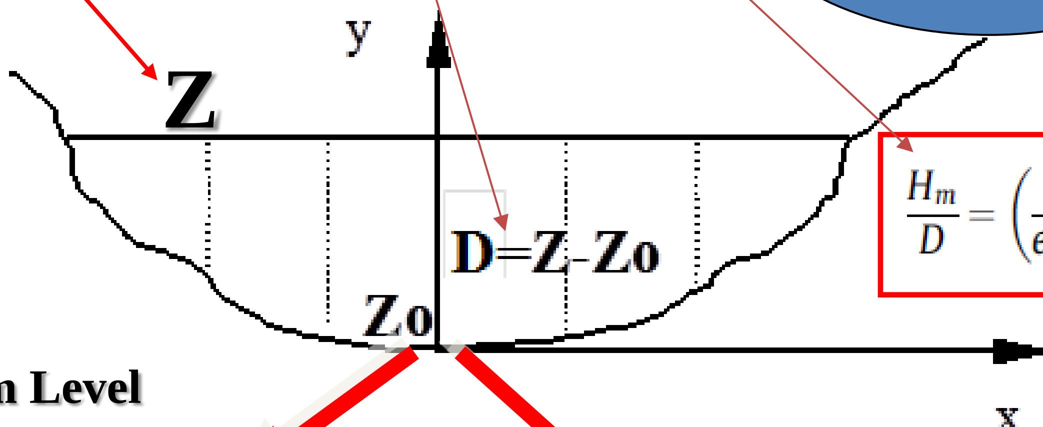
Entropic Model for Bathymetry



Ground Observations

$$h(x) = \frac{D}{W} ln\left[\frac{e^{W}-1}{u_{\max} S} u_s(x) + 1\right]$$

$$\frac{H_m}{D} = \left(\frac{e^W}{e^W - 1} - \frac{1}{W}\right) = \Theta(W)$$



Z_0 Channel Bottom Level

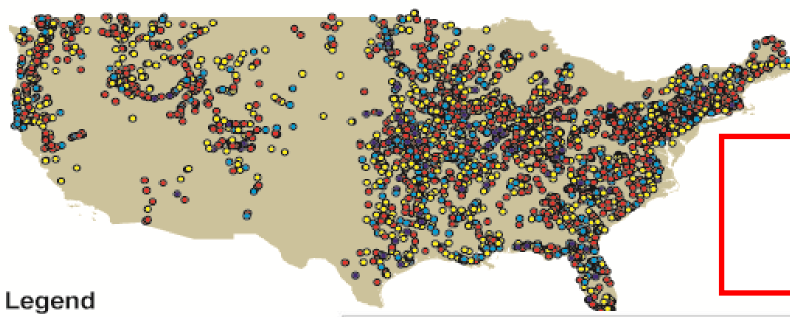
1) Zo Known

2) Zo Unknown

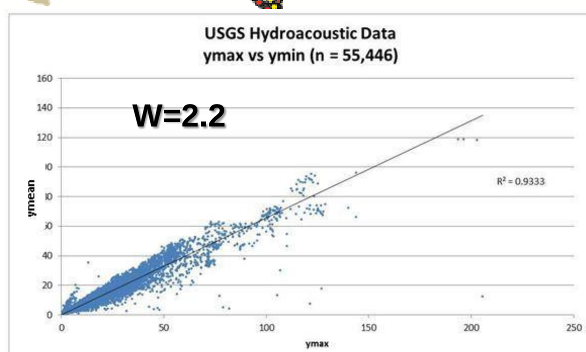
SWOT Project (USGS – IRD(Fr) - IRPI – WS(Ca))

USGS Discharge Measurement Data

N = 17224	stream_wdth	xsec_area	mean_vel	max_vel	mean_depth	max_depth	meas_q	Ymax/Ymean	Vmax/Vmean	W/Ymean
MEAN	403.40	7083.58	2.41	6.19	9.18	13.76	23146.25	1.56	3.02	51.77
MAX	8580.00	340000.00	10.80	76.75	95.20	143.95	1435932.57	16.28	73.10	608.03
MIN	100.00	88.47	0.50	0.50	0.84	1.31	61.48	1.00	1.00	5.37
STDEV	511.64	21814.56	1.48	4.23	9.50	14.03	86793.35	0.33	2.76	42.89
CV	1.27	3.08	0.61	0.68	1.03	1.02	3.75	0.21	0.91	0.83



$$\frac{H_m}{D} = \left(\frac{e^W}{e^W - 1} - \frac{1}{W}\right) = \Theta(W)$$



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Entropic Model for Bathymetry

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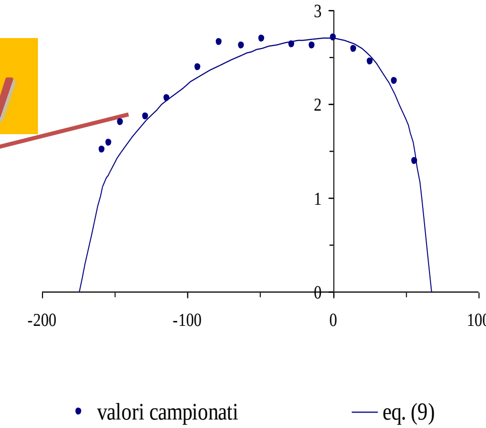
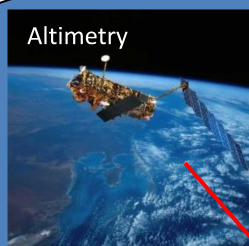
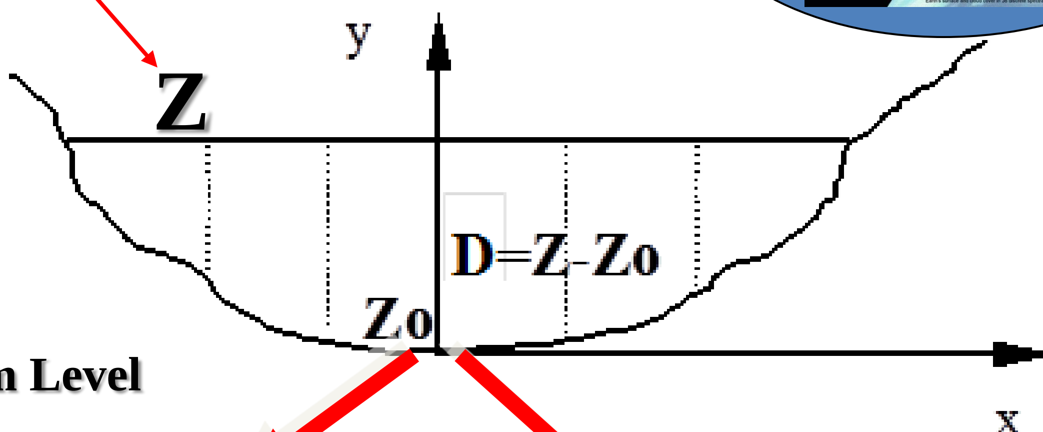


Satellite Observations





Zo Channel Bottom Level

1) Zo Known

2) Zo Unknown

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Entropic Model for Bathymetry

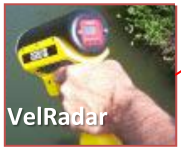
Zo (Channel Bottom Level) - Known

An entropy-based method for determining the flow depth distribution in natural channels

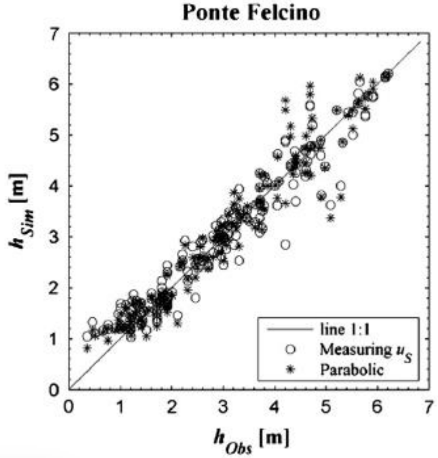
Tommaso Moramarco [a,*], Giovanni Corato [b], Florisa Melone [a], Vijay P. Singh [c,d]

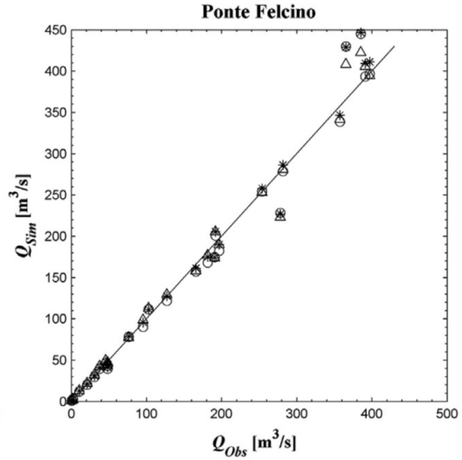
Ground Data

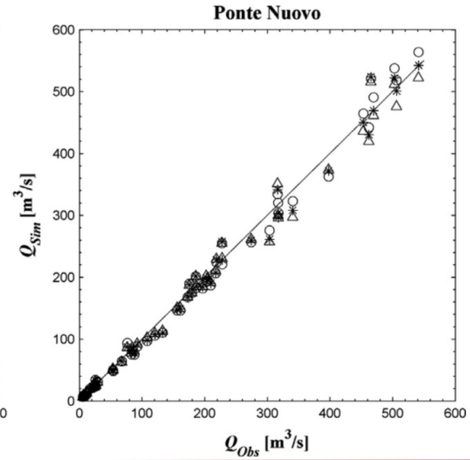
+



$$h(x)=\frac{D}{W}\ln\left[\frac{e^{W}-1}{u_{\max S}}u_s(x)+1\right]$$





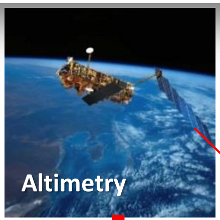


IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING 1

Coupling MODIS and Radar Altimetry Data for Discharge Estimation in Poorly Gauged River Basins

Angelica Tarpanelli, Luca Brocca, Silvia Barbetta, Mariapia Faruolo, Teodosio Lacava, *Member, IEEE*, and Tommaso Moramarco

Satellite Observations



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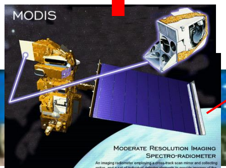
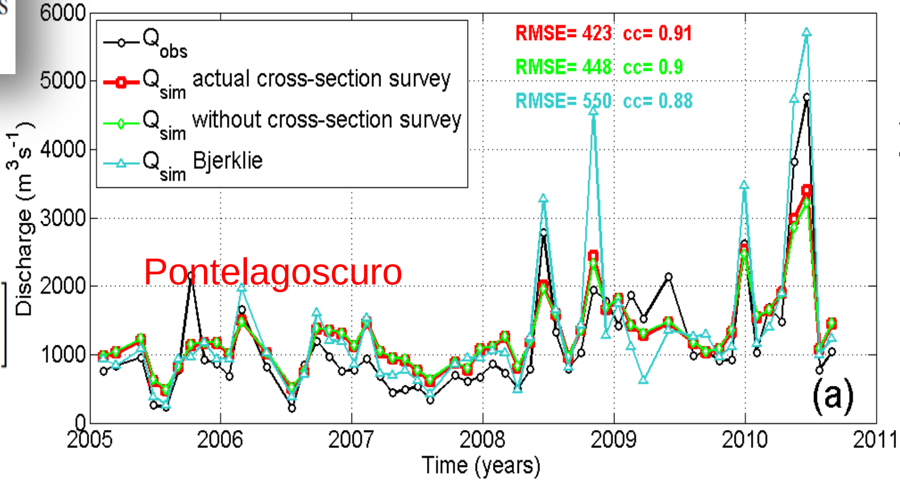
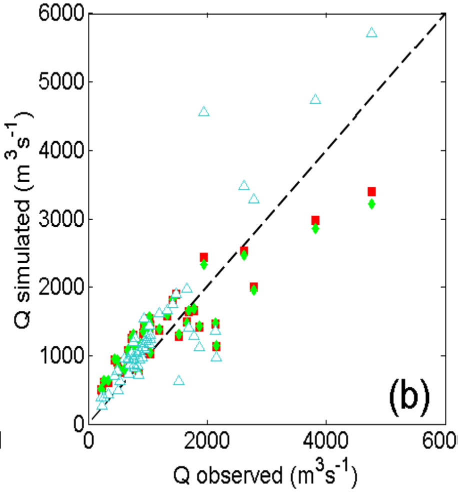


$$h(x)=\frac{D}{W}\ln\left[\frac{e^{W}-1}{u_{\max S}}u_s(x)+1\right]$$





METHOD

Zo (Channel Bottom Level) - Unknown

Target: Estimate max flow depth, D

$$u_{\max|oss} = \frac{\sqrt{gD_m S_f}}{k} ln\left(\frac{1}{\exp(-aD_m)}\right) = \frac{u_{oss}}{\emptyset(M)}$$

(Moramarco and Singh, JHE, 2010)

K (von Karman=0.41)

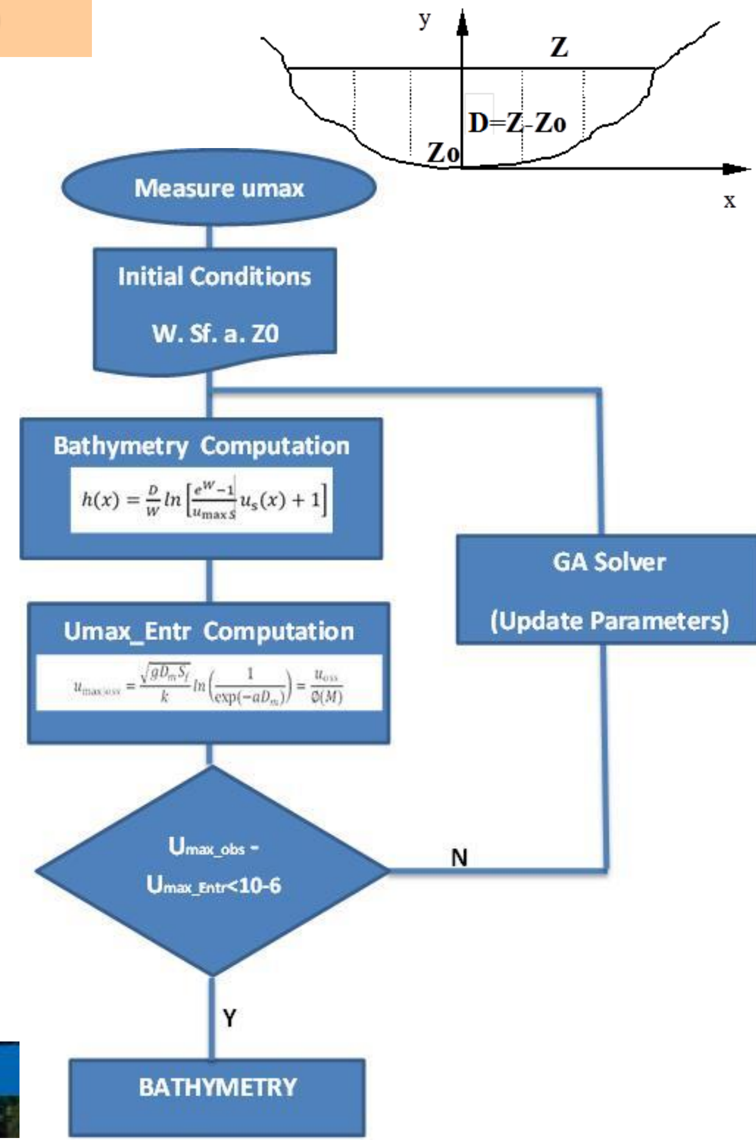
$\emptyset(M)$ Entropy = 0.65

a: parameter. *yo=exp(-aDm): location v=0*

Sf: hydraulic gradient

Dm: Mean flow depth by Entropy law F(W,*Z0*) $h(x) = \frac{D}{W} ln\left[\frac{e^{W}-1}{u_{\max S}} u_s(x) + 1\right]$

Parameter Estimation (a, Sf, W, Zo)
GA solver (Palisade Corporation, 2013)



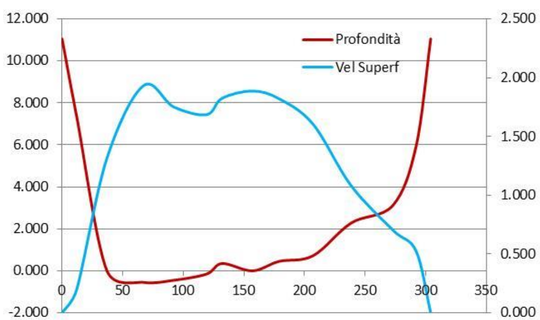
Case Study

Zo Unknown

Ground Observations

6 velocity measurements
Ponte Nuovo

FIUME TEVERE - Ponte Nuovo				
Data	A_obs	Q_obs	V_max_sup	V_mean
22/10/1992	204.070	340.510	2.400	1.669
04/03/1997	76.380	38.750	0.730	0.507
03/06/1997	278.160	506.380	2.660	1.820
29/11/1999	80.320	54.070	1.000	0.673
16/12/1999	290.910	438.280	2.580	1.507
07/11/2000	150.550	227.720	2.320	1.513



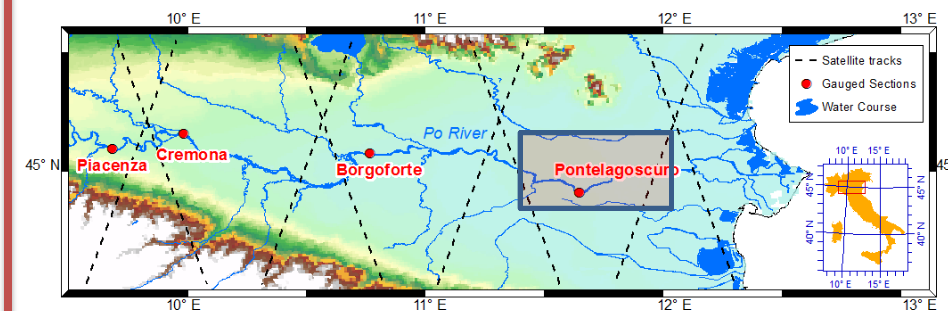
Surface Velocity:

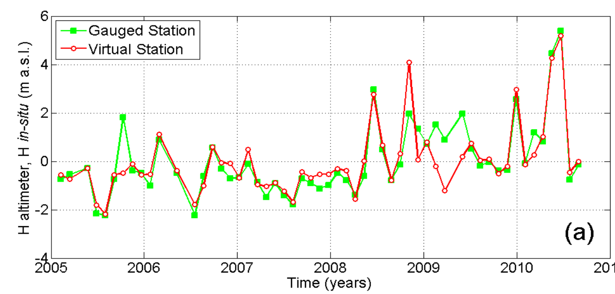
1) Observed
2) Parabolic Distr
(Moramarco et al. 2004)

Satellite Observations

MODIS 2005-2010
Envisat 2005-2010

Pontelagoscuro (70000 km²)





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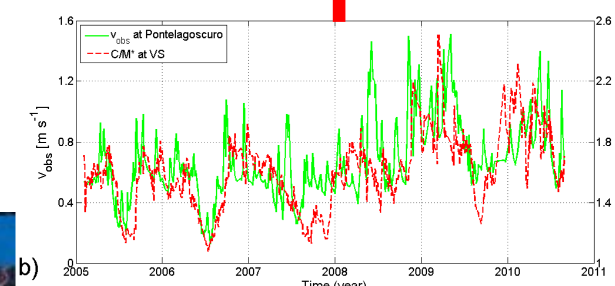
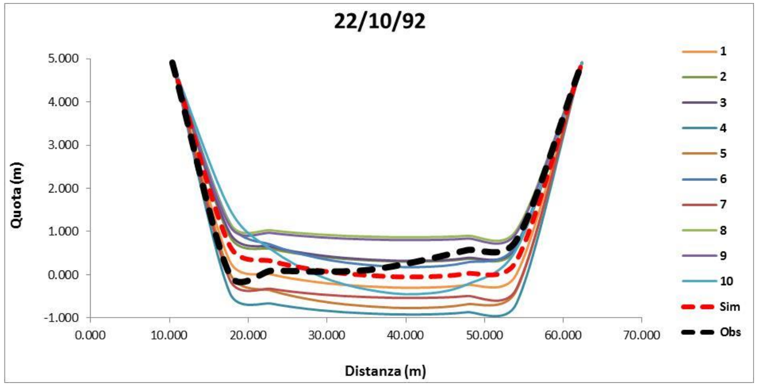


Range of parameters

W=2.1 (USGS)	Pnuovo e Pontelagoscuro
1.2<Wini=7.5<15	Pnuovo e Pontelagoscuro
0.001<Sfini=2x10^{-3}<0.003	Pnuovo
0.0001<Sfini=2x10^{-4}<0.0003	Pontelagoscuro
0.5<a(yo)ini=0.75<1	Pnuovo e Pontelagoscuro
-5< Z0ini = Halt/2<Halt -1	Pnuovo e Pontelagoscuro

Sensitivity to Initial Conditions

10 random realizations – Average Cross-Section

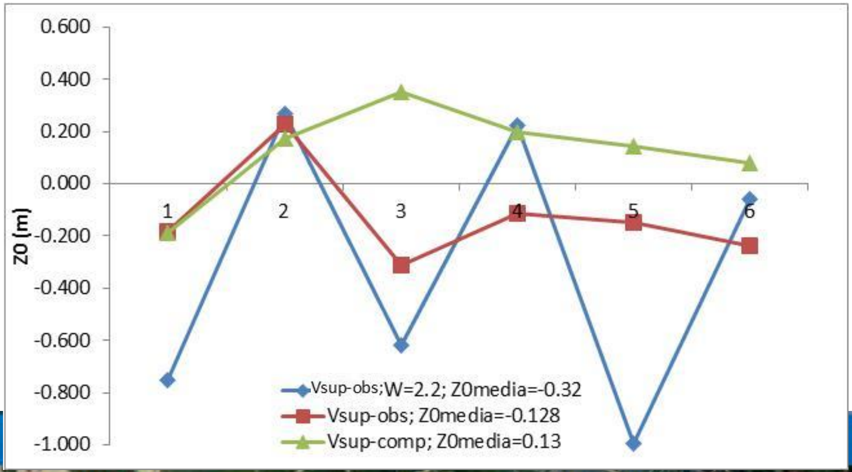


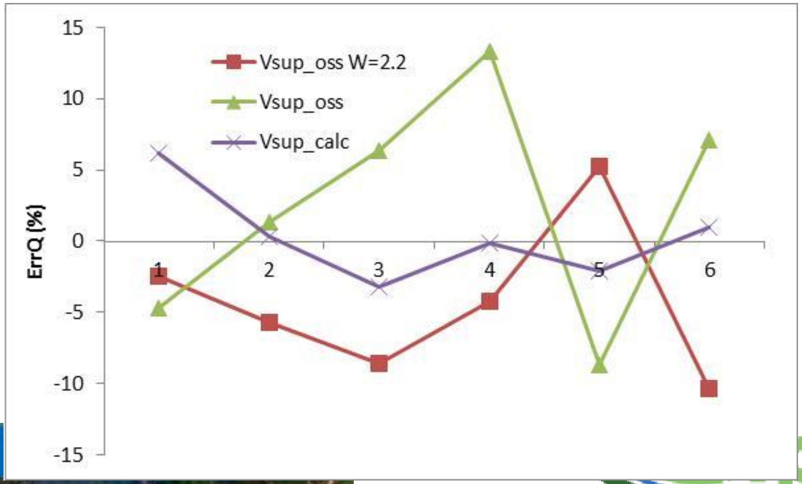
RESULTS

Field Data

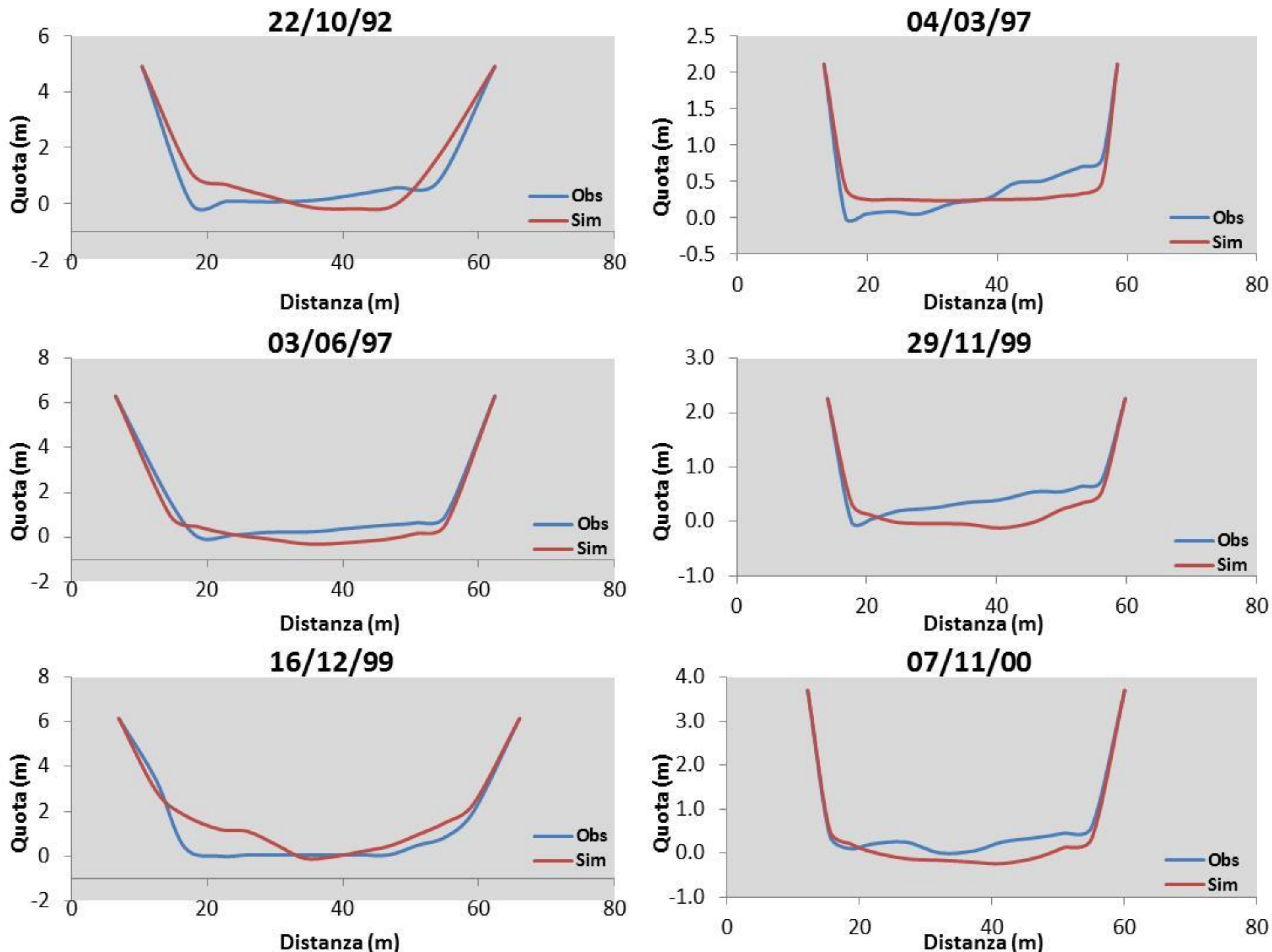
Ponte Nuovo

	Average values		
	W	Yo	S0
Vsup_Obs	2.2	0.01352	0.0015
Vsup_Obs	5.147	0.02130	0.0016
Vsup_Calc	6.398	0.01940	0.0015

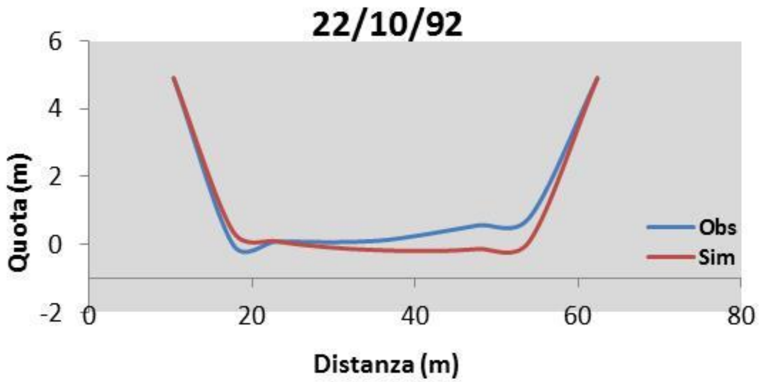


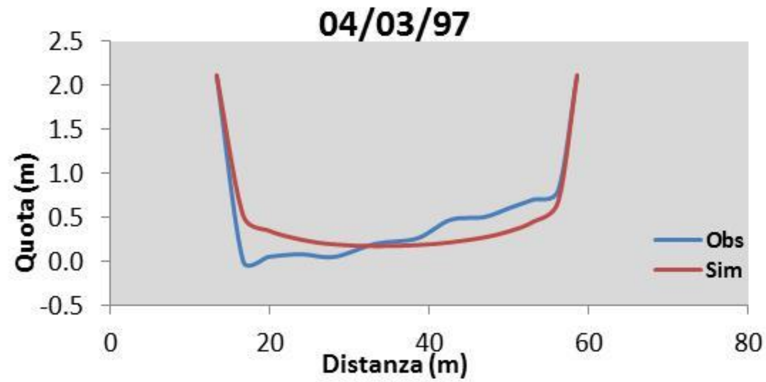


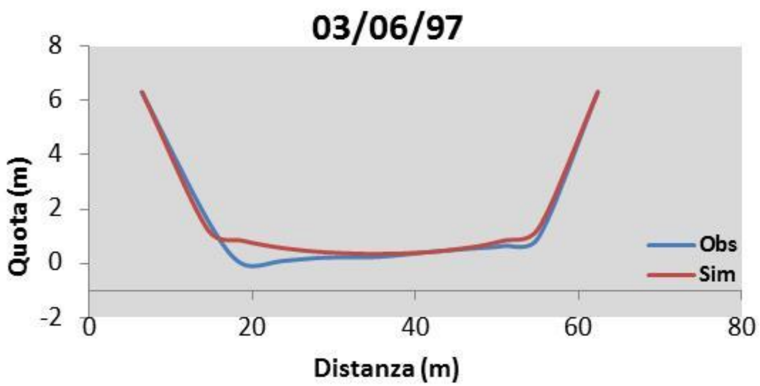
Ponte Nuovo – Observed Surface Velocities

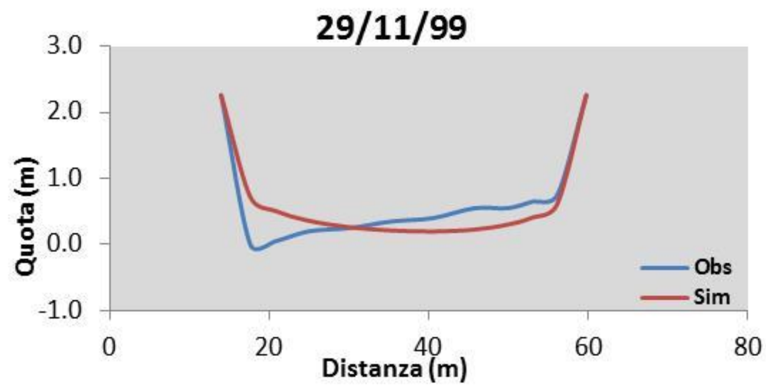


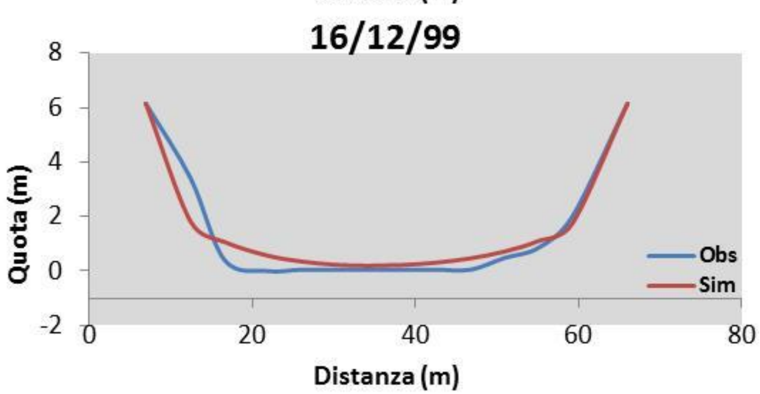
Ponte Nuovo – Parabolic Surface Velocities

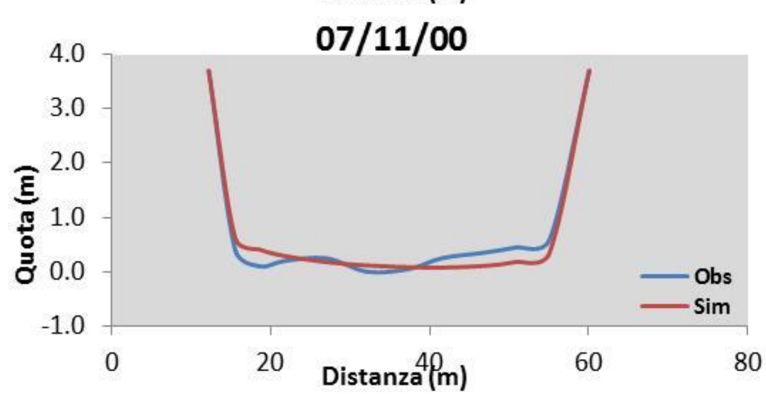






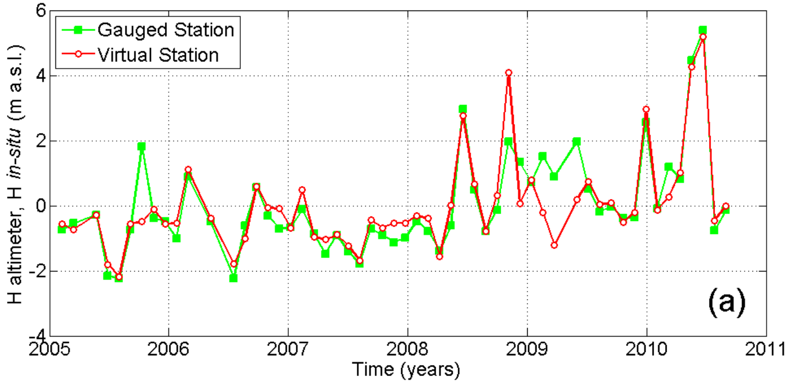


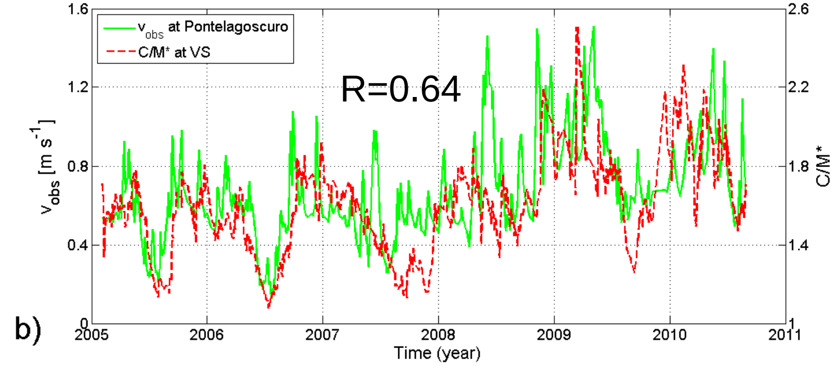


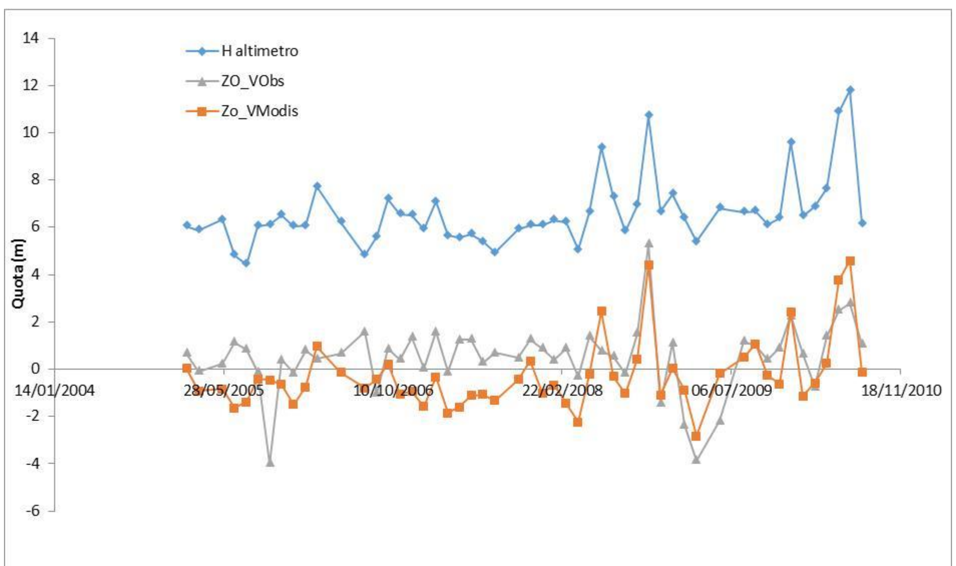


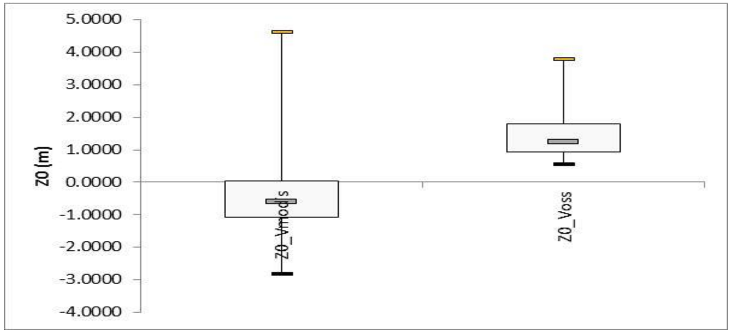
Satellite Observations

Pontelagoscuro









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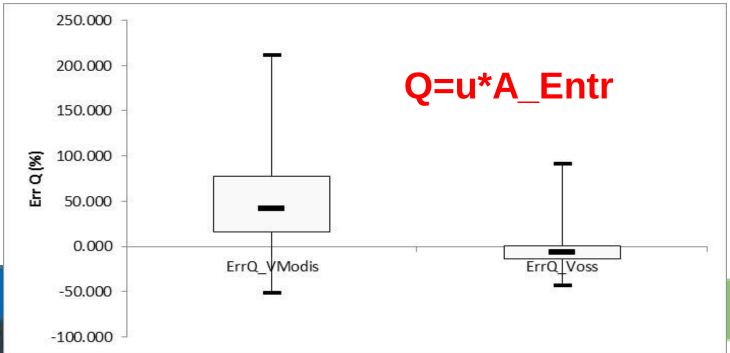

Conclusions

- Discharge for high flood can be assessed by leveraging ground and satellite observations in terms of stage and maximum surface velocity.

- The capability of Radiometers (MODIS, MERIS) to estimate mean flow velocity can be efficiently employed together with Altimeter for discharge assessment. These aspects may be of particular interest for Sentinel 3 and SWOT missions for which significant improvements are expected in terms of vertical accuracy and spatial and temporal resolution.

- The analysis showed the potential of satellite data for estimation of the discharge in river sites where only the survey of the cross section is needed.

- The entropy model would allow to overcome the need of river cross section topographical data as well. Analyses are on going in different river sites in cooperation with USGS

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THANK YOU