ESA - MOST Dragon 2 Programme
中国科技部-欧洲空间局合作 "龙计划"二期

2011 DRAGON 2 SYMPOSIUM
"龙计划"二期2011年学术研讨会

Land Surface Temperature from satellite data and distributed hydrological model to assess water resources availability in the upper Yangtze basin

(ID 5281)

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POLITECNICO DI MILANO

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Thanks to Castelletti & Mora

Revised version of the project (2010): OBJECTIVES and DELIVERABLES

Objectives:

1. Implementation of **hydrological water balance model** for water resources assessing

2. **Soil moisture monitoring** using remote sensing thermal and microwave data in comparison to hydrological model

3. **Wetlands dynamics** and biological ecological resources monitoring using remote sensing data (Lakes, middle Yangtze basin)

4. **Floods watch** with **remote sensing** and **hydrological model**”

Deliverables:

- Evapotranspiration maps and relative soil moisture
- Discharge and flow duration curves at different river cross sections

Time Table of the project

	2010												2011												2012			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1.Development of hydrological water balance model for water resources assessing																												
2. Soil moisture monitoring assimilating remote sensing thermal and microwave data, into hydrological model,																												
3. Wetlands dynamics and biological ecological resources monitoring using remote sensing data																												
4. Floods watch with remote sensing and hydrological model																												
5. Web interface for soil moisture monitoring and water resources management in “quasi real time”.																												

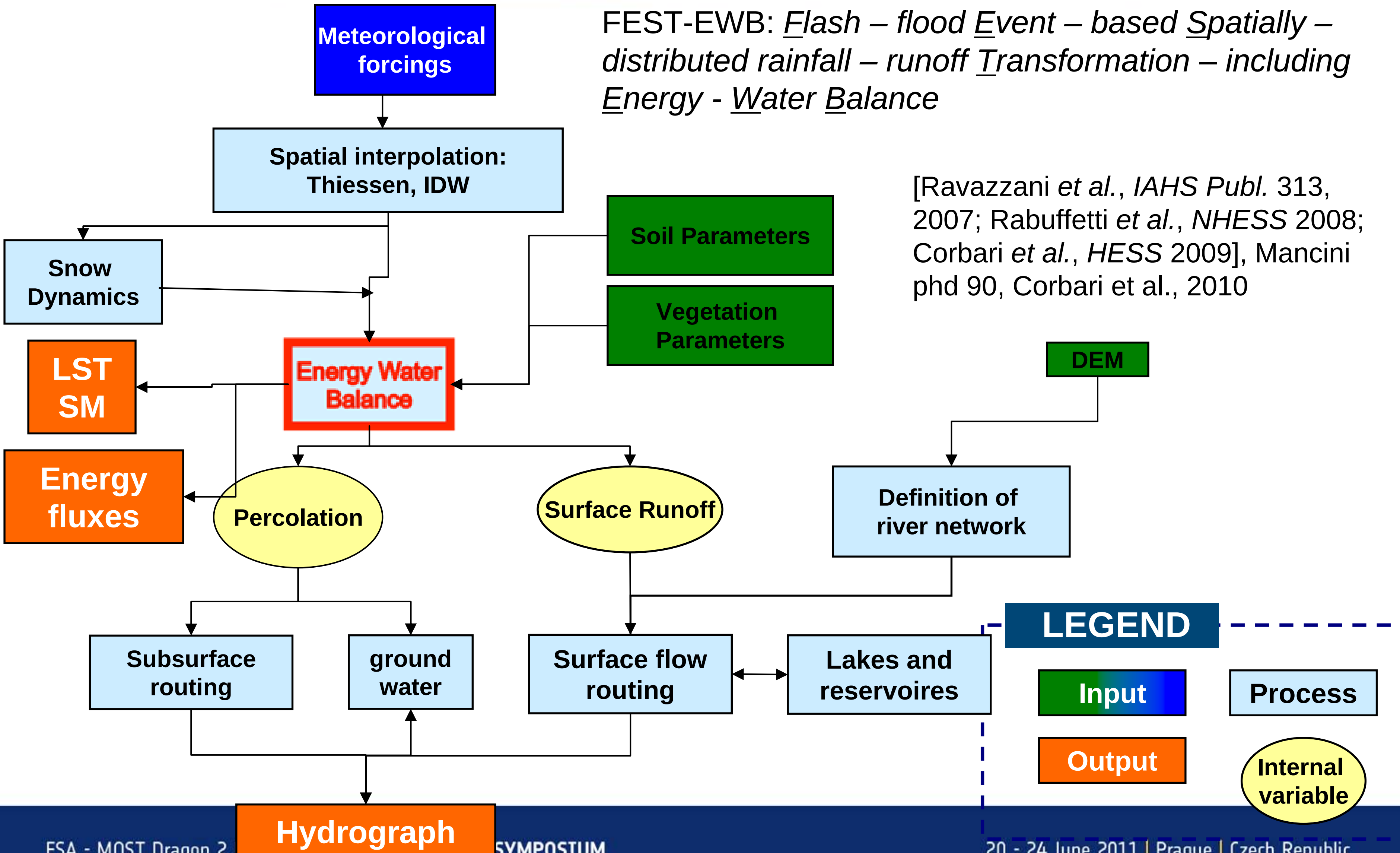
(grey)	model development and satellite data analysis
(yellow)	operative period

June 2011

FEST-EWB – distributed hydrological model by POLIMI → settings for Yangtze river basin

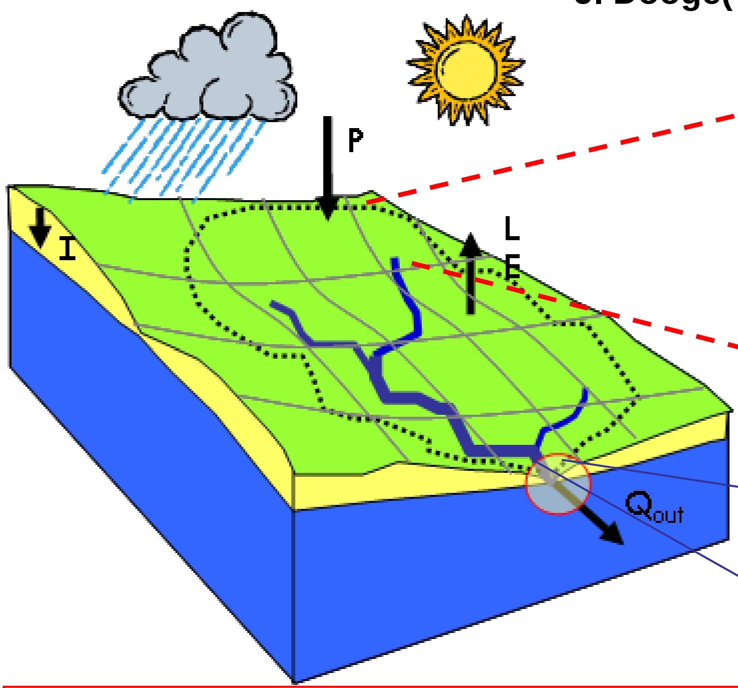
FEST-EWB: *F̲lash – flood E̲vent – based S̲patially – distributed rainfall – runoff T̲ransformation – including E̲nergy - W̲ater B̲alance*

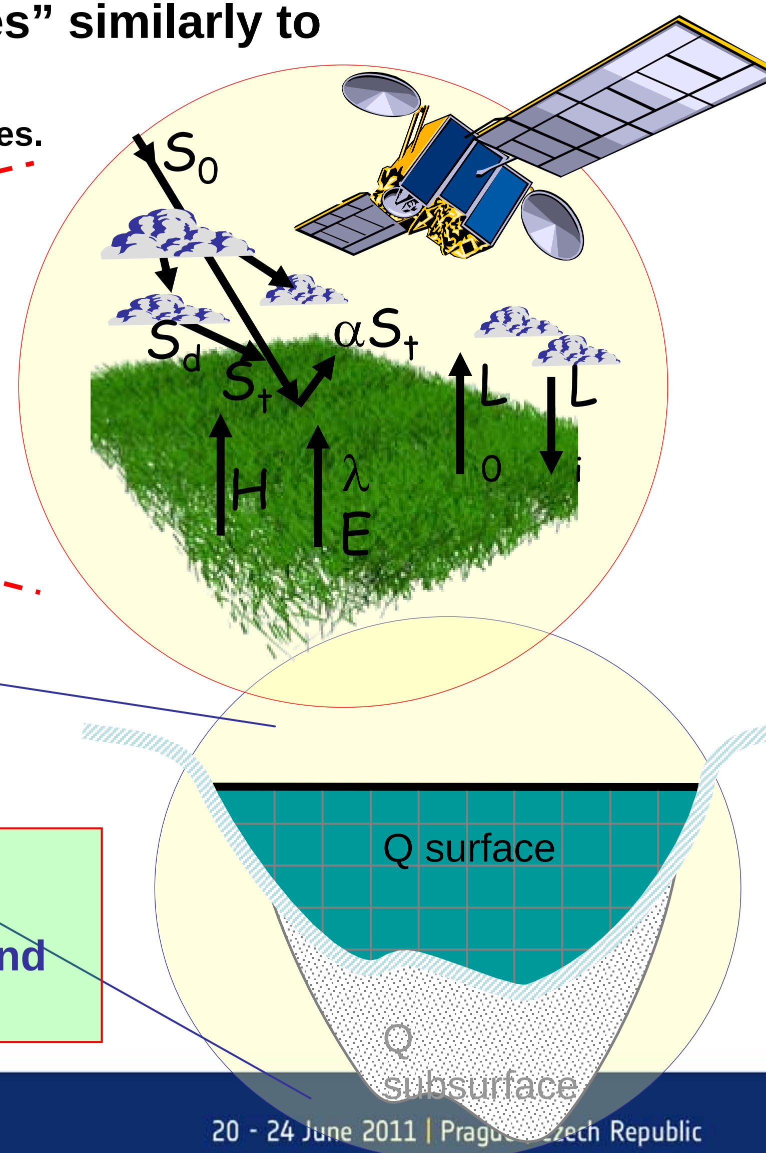
[Ravazzani *et al.*, *IAHS Publ.* 313, 2007; Rabuffetti *et al.*, *NHESS* 2008; Corbari *et al.*, *HESS* 2009], Mancini phd 90, Corbari et al., 2010



Is it reasonable to use evaporation flux “measures” similarly to discharge measurements?

J. Dooge(1972), internal variables.





Open problems :

1) Congruency between radiometric measurements and termodynamic equilibrium temperature

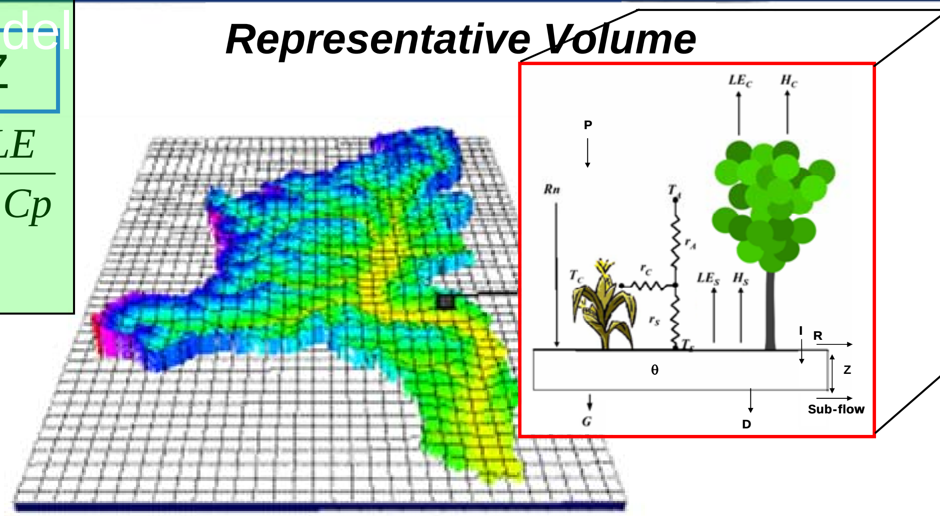
Distributed hydrological model for Remote sensing Interaction: continuous soil moisture update with energy balance base on LST equilibrium temperature model

Soil water balance

$$P_{tot}=R+ET_{eff}+D+(\theta_{t+1}-\theta_t)*Z$$

Energy balance

$$Rn-G-H-LE=\frac{dS}{dt} \qquad ETeff=\frac{LE}{\rho Cp}$$

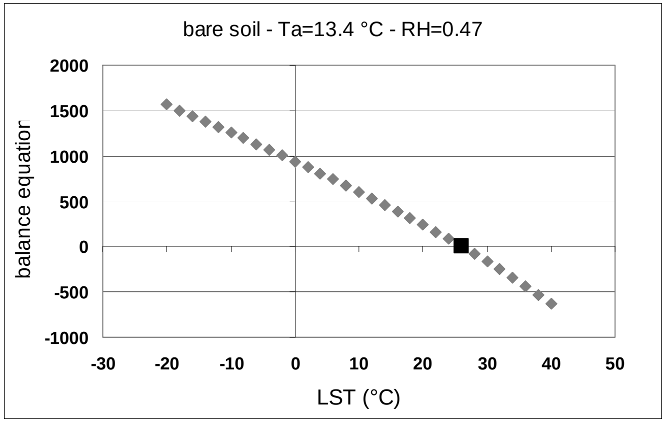


Finding an equilibrium temperature which is reppresentative of the heterogeneity of the termodynamic exchanges

$$RET=\int_V T(T_{canopy},T_{soil})\,dxdydz$$

$$f_t(RET)=R_n(RET)-H(RET)-\lambda ET(RET)-G(RET)=0$$

$$f(RET)=0 \longrightarrow Soil\ moisture\ (RET)$$



Corbari et al (2010) HYP, RSE subm.

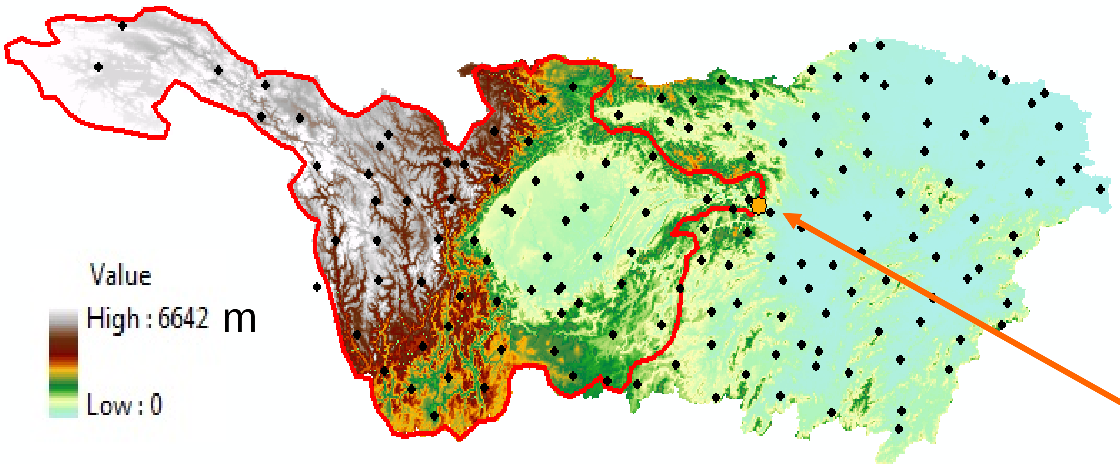
$$LEv+LEs=\lambda E=\left[\frac{f_v}{(r_a+r_c)}+\frac{(1-f_v)}{(r_{as}+r_s)}\right]\frac{\rho_a c_p}{\gamma}\left(e^*(T_s)-e_a\right)$$

Upper Yangtze river basin: DEM and meteorological data

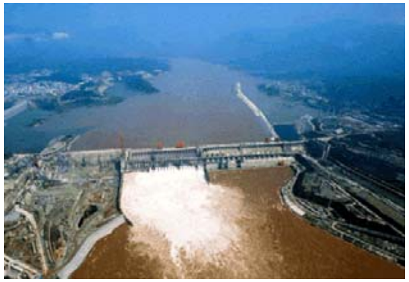
158 meteorological station
(density= 0.02%)
2000-2010

http://www.ncdc.noaa.gov/oa/ncdc.html

Daily data:
Air temperature
Rainfall
Air relative humidity
Incoming shortwave radiation
Wind speed



(Three Gorges Damn)

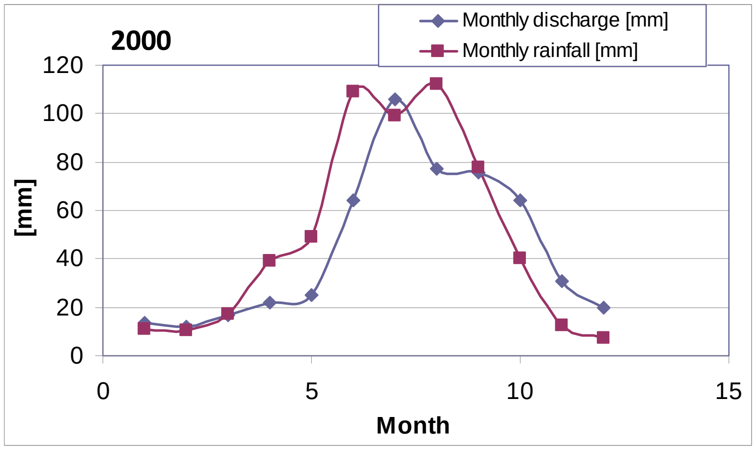


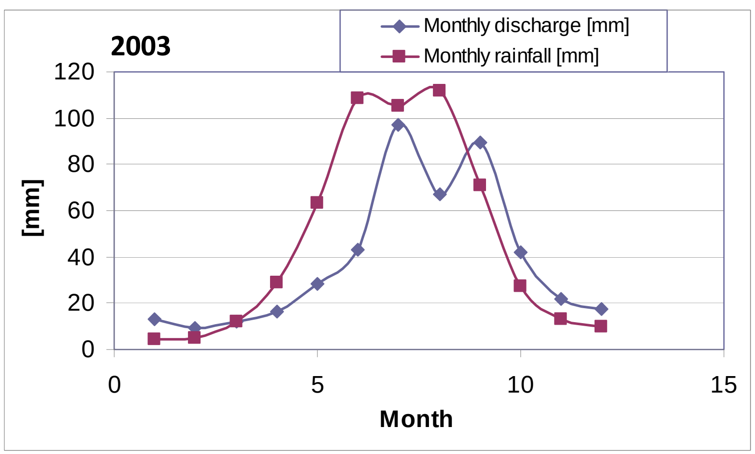
Daily discharge
Yichang (30.66 N, 111.23 E)
2000-2004 →
before three gorges dam construction

- Area: 1005500 km^2
- Main lenght river: 2400 km
- Average Discharge: 13242 m^3/s
- Cumulated annual rainfall: 816 mm

http://www.bafg.de/cln_007/nn_293894/GRDC

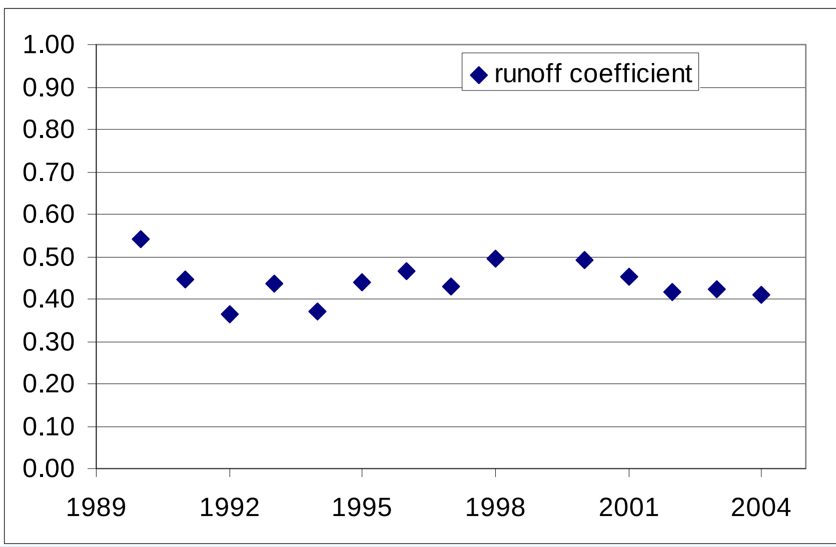
Upper Yangtze river basin hydrological characterization: river network definition and Rainfall and Discharge regimes





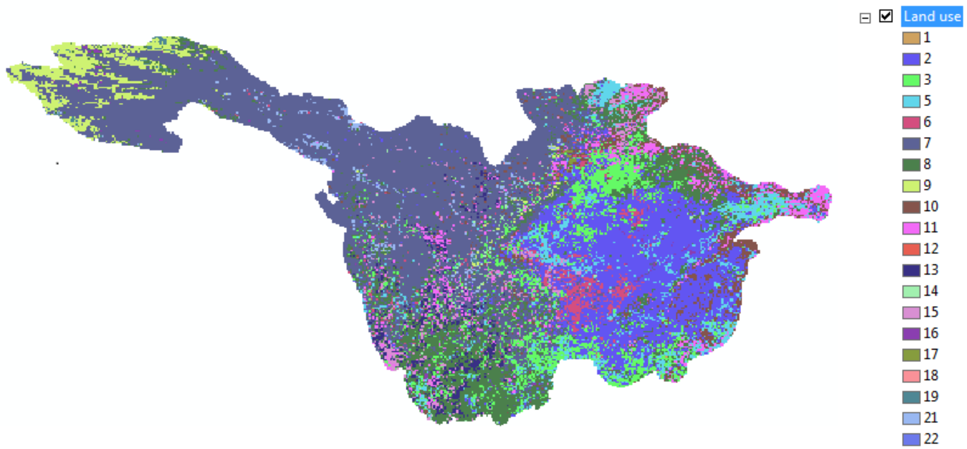
River network Area Threshold : 400 km^2

Runoff coefficient = discharge/rainfall



Upper Yangtze river basin hydrological characterization: pixel maximum storage

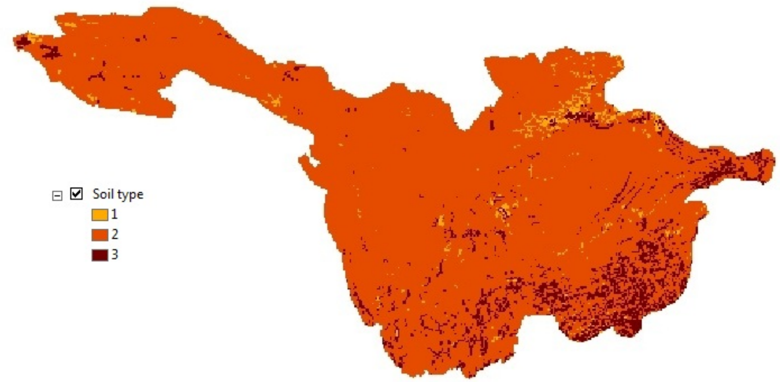
<u>Land cover</u>: Envisat's Medium Resolution Imaging Spectrometer (**MERIS**) instrument. ESA GLOB COVER 2009



1	Urban and built-up land
2	**Dryland cropland and pasture**
3	**Irrigated cropland and pasture**
5	Cropland/grassland mosaic
6	Cropland/woodland mosaic
7	**Grassland**
8	**Shrubland**

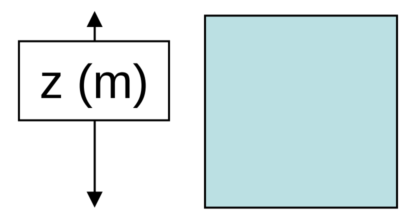
Soil Type

http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/c

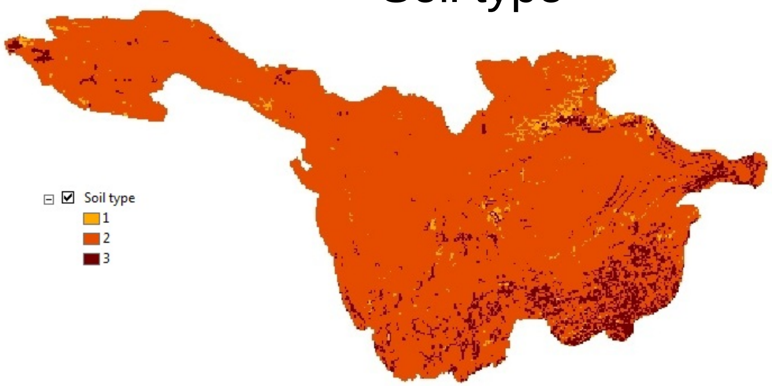


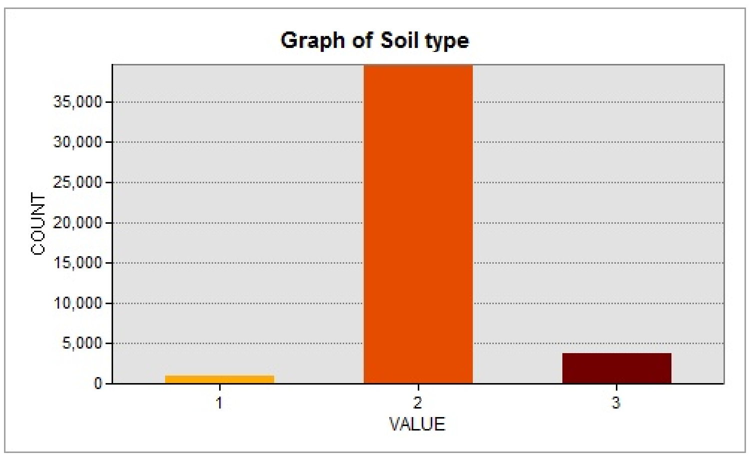
Pixel max water storage

$$z = \frac{S(CN_1)}{soil\ \ porosity}$$



Soil type





1	Sand
2	Sandy clay loam
3	Clay

Handbook of hydrology

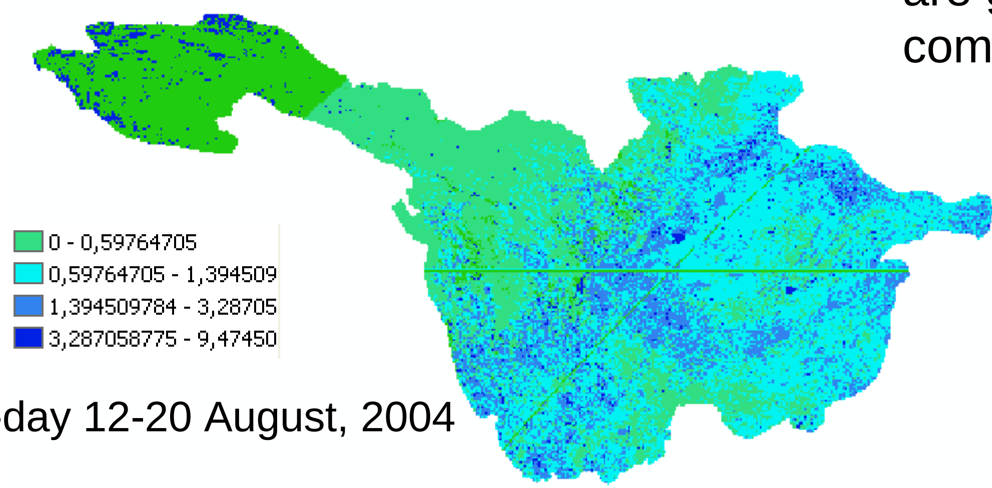
TABLE 5.3.2 Water-Retention Properties Classified by Soil Texture

Texture class	Sample size	Total porosity ϕ, cm³/cm³	Residual water content θ_r, cm³/cm³	Effective porosity ϕ_e, cm³/cm³	Bubbling pressure h_b Geometric,† mean, cm	Pore-size distribution λ Arithmetic mean	Water retained at −33 kPa, cm³/cm³	Water retained at −1500 kPa, cm³/cm³
Sand	762	0.437* (0.374–0.500)	0.020 (0.001–0.039)	0.417 (0.354–0.480)	7.26 (1.36–38.74)	0.694 (0.298–1.090)	0.091 (0.018–0.164)	0.033 (0.007–0.059)
Loamy sand	338	0.437 (0.368–0.506)	0.035 (0.003–0.067)	0.401 (0.329–0.473)	8.69 (1.80–41.85)	0.553 (0.234–0.872)	0.125 (0.060–0.190)	0.055 (0.019–0.091)
Sandy loam	666	0.453 (0.351–0.555)	0.041 (−0.024–0.106)	0.412 (0.283–0.541)	14.66 (3.45–62.24)	0.378 (0.140–0.616)	0.207 (0.126–0.288)	0.095 (0.031–0.159)
Loam	383	0.463 (0.375–0.551)	0.027 (−0.020–0.074)	0.434 (0.334–0.534)	11.15 (1.63–76.40)	0.252 (0.086–0.418)	0.270 (0.195–0.345)	0.117 (0.069–0.165)
Silt loam	1206	0.501 (0.420–0.582)	0.015 (−0.028–0.058)	0.486 (0.394–0.578)	20.76 (3.58–120.4)	0.234 (0.105–0.363)	0.330 (0.258–0.402)	0.133 (0.078–0.188)
Sandy clay loam	498	0.398 (0.332–0.464)	0.068 (−0.001–0.137)	0.330 (0.235–0.425)	28.08 (5.57–141.5)	0.319 (0.079–0.559)	0.255 (0.186–0.324)	0.148 (0.085–0.211)
Clay loam	366	0.464 (0.409–0.519)	0.075 (−0.024–0.174)	0.390 (0.279–0.501)	25.89 (5.80–115.7)	0.242 (0.070–0.414)	0.318 (0.250–0.386)	0.197 (0.115–0.279)
Silty clay loam	689	0.471 (0.418–0.524)	0.040 (−0.038–0.118)	0.432 (0.347–0.517)	32.56 (6.68–158.7)	0.177 (0.039–0.315)	0.366 (0.304–0.428)	0.208 (0.138–0.278)
Sandy clay	45	0.430 (0.370–0.490)	0.109 (0.013–0.205)	0.321 (0.207–0.435)	29.17 (4.96–171.6)	0.223 (0.048–0.398)	0.339 (0.245–0.433)	0.239 (0.162–0.316)
Silty clay	127	0.479 (0.425–0.533)	0.056 (−0.024–0.136)	0.423 (0.334–0.512)	34.19 (7.04–166.2)	0.150 (0.040–0.260)	0.387 (0.332–0.442)	0.250 (0.193–0.307)
Clay	291	0.475 (0.427–0.523)	0.090 (−0.015–0.195)	0.385 (0.269–0.501)	37.30 (7.43–187.2)	0.165 (0.037–0.293)	0.396 (0.326–0.466)	0.272 (0.208–0.336)

Saturated conductivity
Wilting point
Field capacity
Residual water content
Brooks and Corey index

http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/c

Leaf area index

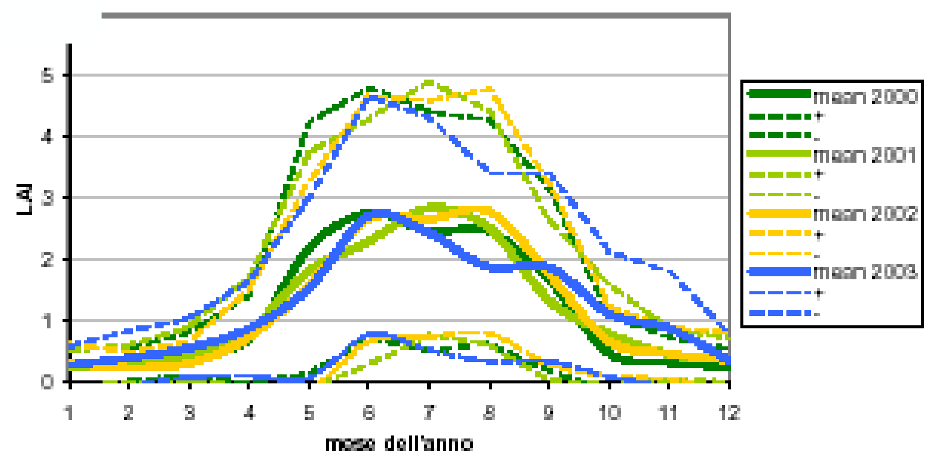


8-day 12-20 August, 2004

LAI 1-km **MODIS LAI** used products are generated over an 8-days compositing period

The link with Evapotranspiration

$$rc = \frac{Minimum\ \ stomata\ \ resis\tan ce}{LAI} \quad [\sec^{-1}]$$



Meteorological ground observations: from daily to hourly data for remote sensing LST comparison

Methods tested in the Upper Po river basin where hourly data are available

Air temperature (method 1)

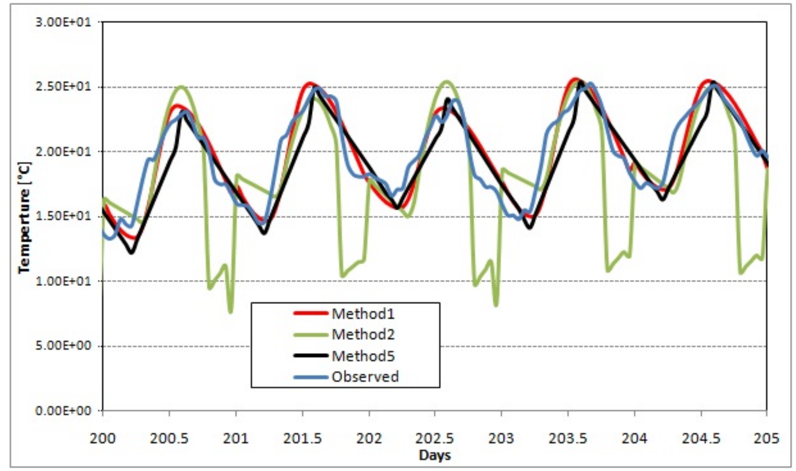
For $0 \leq H < RISE$ *and* $14{:}00h < H \leq 2400h$

$T(H)=T_{ave}+AMP(\cos(pH'/10.0+RISE)))$

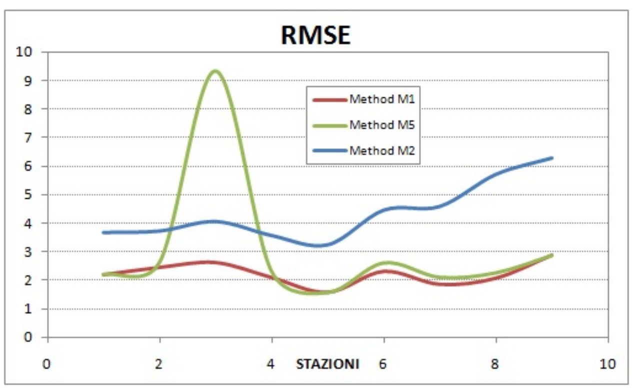
For $RISE \leq H \leq 14{:}00h$

$T(H)=T_{ave}-AMP(\cos(p(H-RISE)/(14-RISE)))$

RISE=Time of Sunrise [h]
T(H)= Temperature at any hour
H'=H+10 if H<RISE
H'=14 if H>14:00h
$T_{ave}=(T_{min}+T_{max})/2$
$AMP=(T_{max}-T_{min})/2$



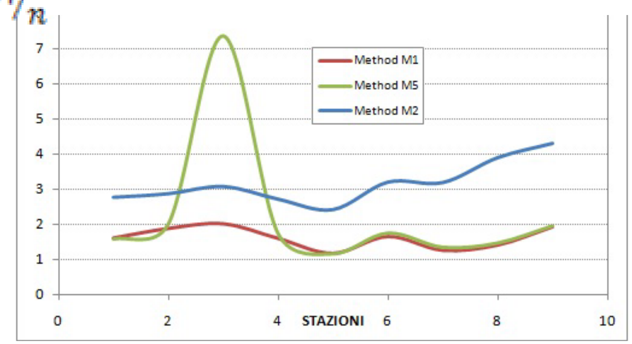
$$RMSE(\hat{\theta}) = \left[\sum_{i=1}^{n} (\hat{\theta}_i - \theta_i)/_n\right]^{1/2}$$



RMSE=2.3°C

$$ME(\hat{\theta}) = \sum_{i=1}^{n} |\hat{\theta}_i - \theta_i|/_n$$

ME=1.7°C



Accuracy of hourly air temperatures calculated from daily minima and maxima. Reicosky et al. 2000

Meteorological ground observations: from daily to hourly data for remote sensing LST comparison

Methods tested in the Upper Po river basin where hourly data are available

Incoming shortwave radiation (Method 4)

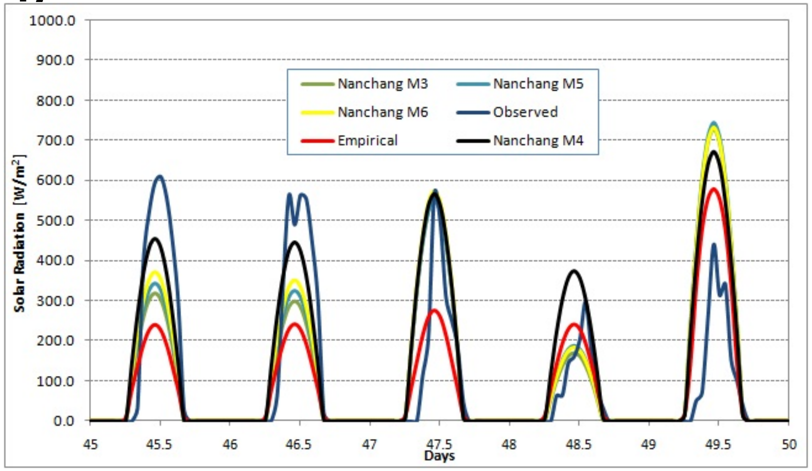
$R_G = R_E a_0 (T_{Dif})^{0,5}$

R_G is daily actual global radiation [MJ/m^2]

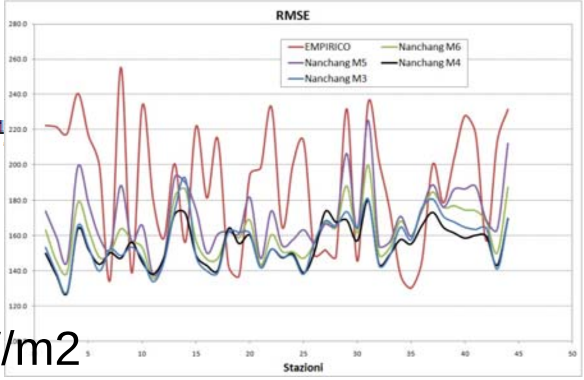
R_E is daily extra atmosphere global solar radiation [MJ/m^2]

a_0 =0,153

T_{Dif} is daily temperature difference [℃]

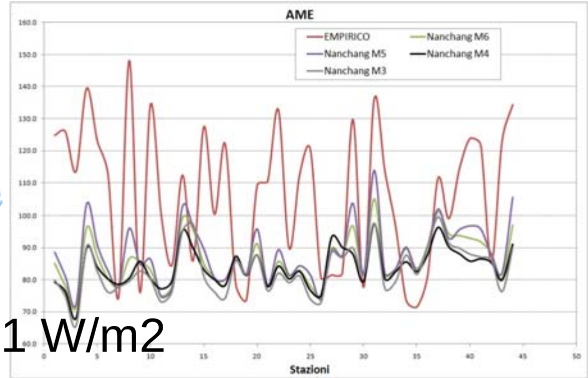


$$RMSE(\hat{\theta}) = \left[\sum_{i=1}^{n} (\hat{\theta}_i - \theta_i)/_n\right]^{1}$$



RMSE=153.8 W/m2

$$AME(\hat{\theta}) = \sum_{i=1}^{n} |\hat{\theta}_i - \theta_i|/_n$$



Mean Error=83.1 W/m2

Accuracy of hourly air temperatures calculated from daily minima and maxima. Reicosky et al. 2000

Meteorological ground observations: from daily to hourly data for remote sensing LST comparison

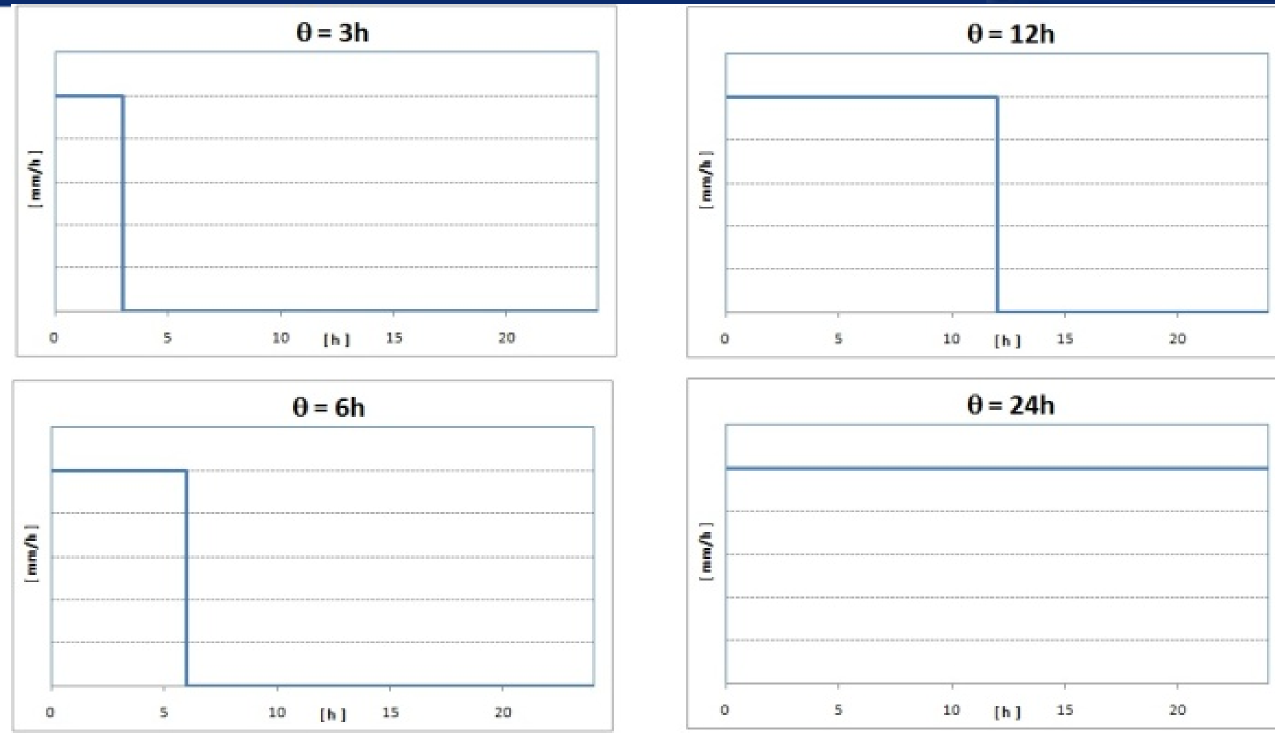
Precipitation

Available cumulative daily rainfall

and relative duration
[3 – 6 – 12 – 24] h

↓

Constant intensity for
assigned duration



Relative air humidity

Wind velocity

→ Average daily value

FEST-EWB model calibration 2000-2004

MODEL spatial resolution = 5 x 5 km
Model EWB temporal resolution = 1h
Channel routing temporal resolution =0.25 h

1. **Snow model calibration**: comparison between snow area coverage from MODIS and FEST-EWB

2. **Land surface temperature** comparison among FEST-EWB model, MODIS & AATSR

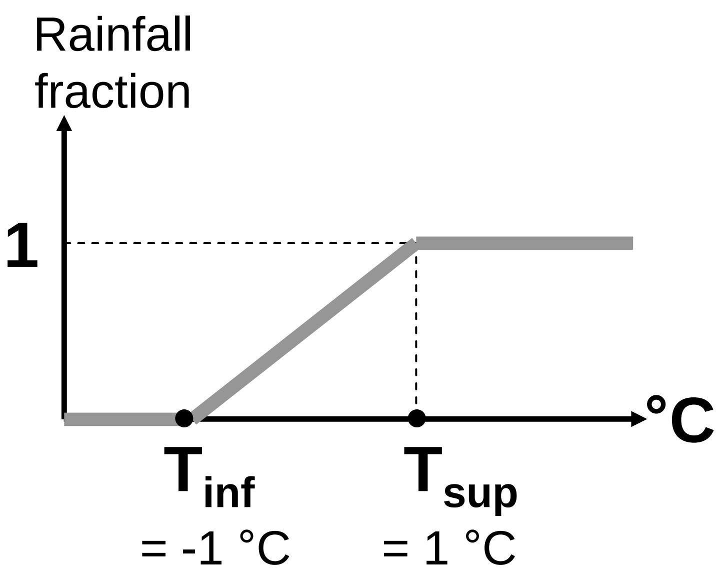
Outputs

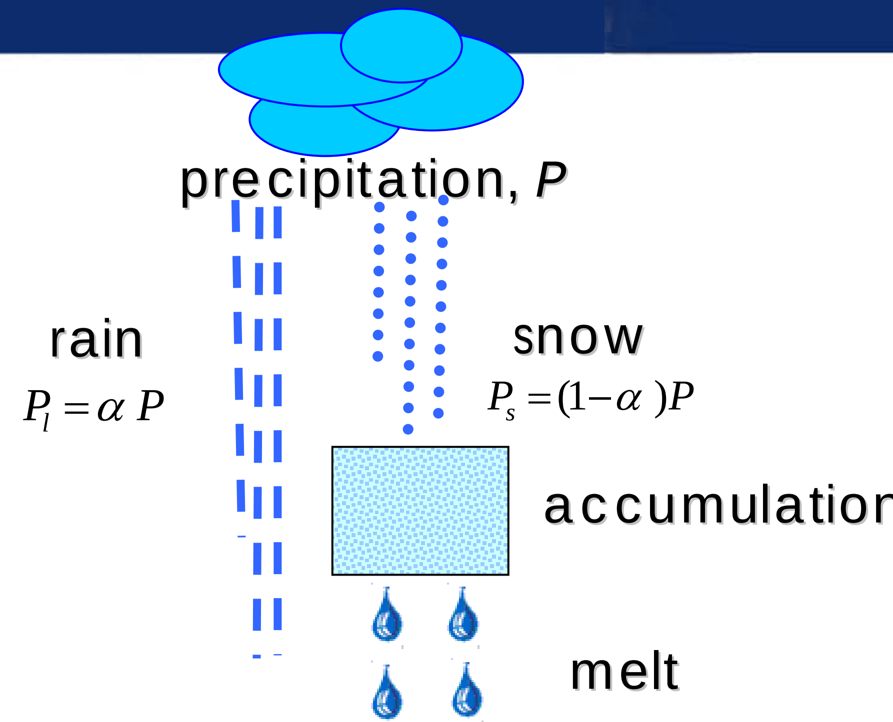
1. LAND SURFACE TEMPERATURE maps
2. Evapotranspiration maps
3. Discharge and flow duration curves at river cross sections

FEST-EWB snow dynamic

ACCUMULATION: Precipitation partitioning

$$
\begin{cases}
\alpha = 0 & \Leftrightarrow T_a \le T_{inf} \\
\alpha = \dfrac{T_{air}(t) - T_{inf}}{T_{sup} - T_{inf}} & \Leftrightarrow T_{inf} < T_a < T_{sup} \\
\alpha = 1 & \Leftrightarrow T_a > T_{sup}
\end{cases}
$$





MELTING

$$SnowMelt = C_m (T_a - T_b)$$

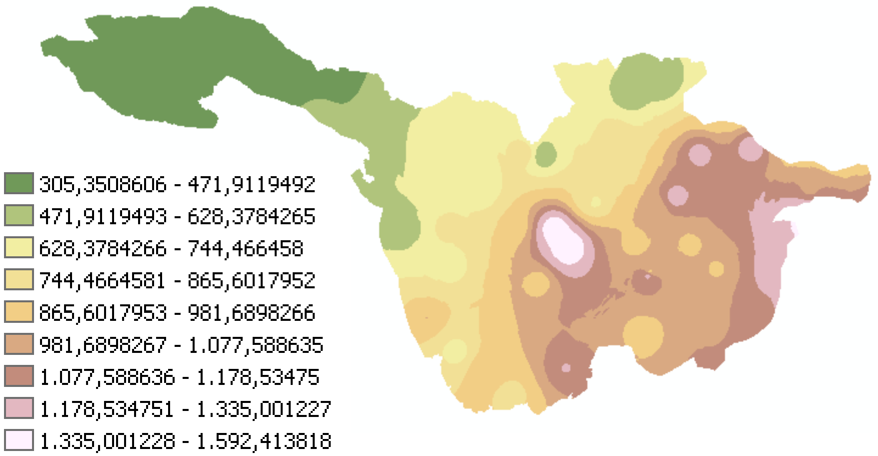
T_a = air temperature

T_b = threshold temperature = 0 °C

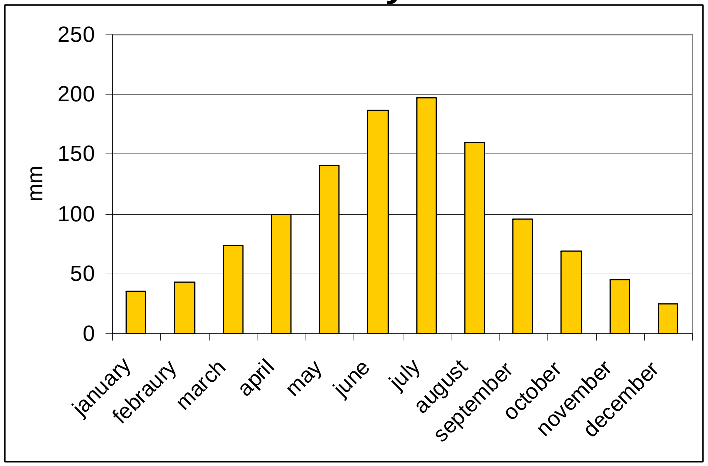
C_m = melt coefficient = 4.5 [m/(s °C)]

Upper Yangtze river basin: rainfall and snow spatial and temporal distribution

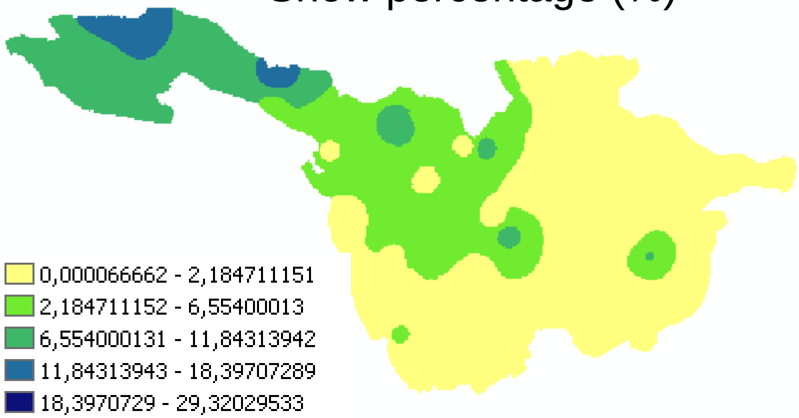
Mean Annual precipitation (mm) [2000-2010]



Rainfall mean monthly values



Snow percentage (%)



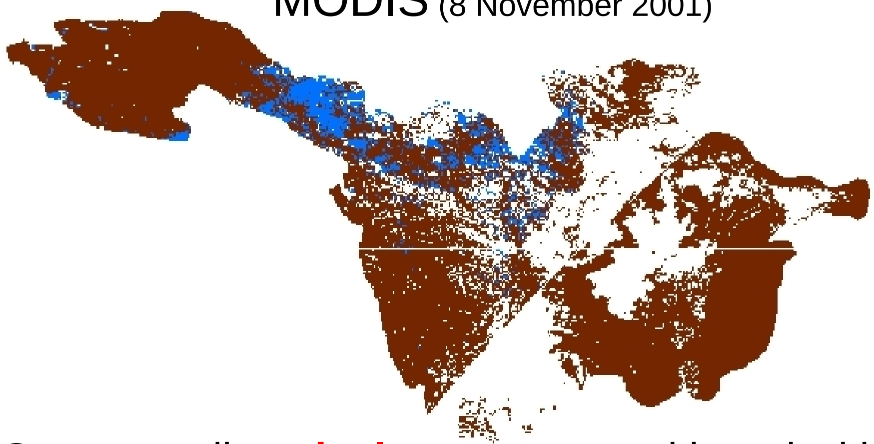
FEST-EWB snow model calibration

MODIS *(Moderate Resolution Imaging Spectroradiometer) on board Terra and Aqua satellite*

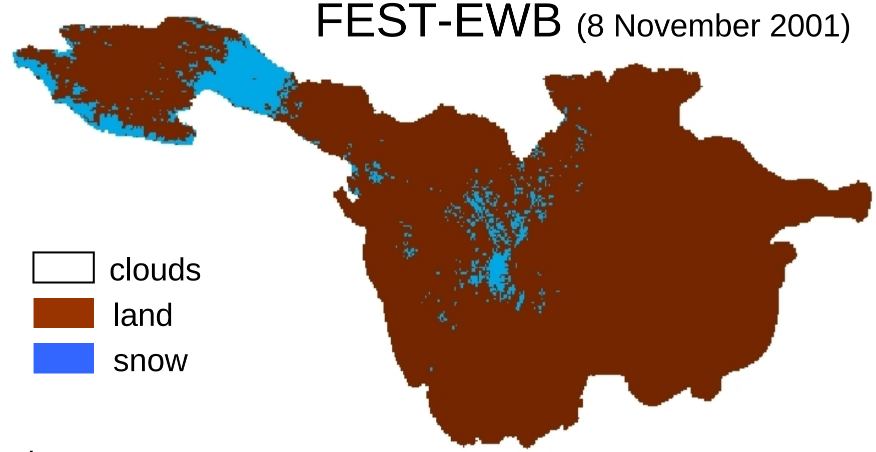
- Years : 2000-2004
- Months : from September to April
- **Number of images: 50**

Upper Yangtze river basin: comparison between MODIS and FEST-EWB snow area coverage

MODIS (8 November 2001)



FEST-EWB (8 November 2001)



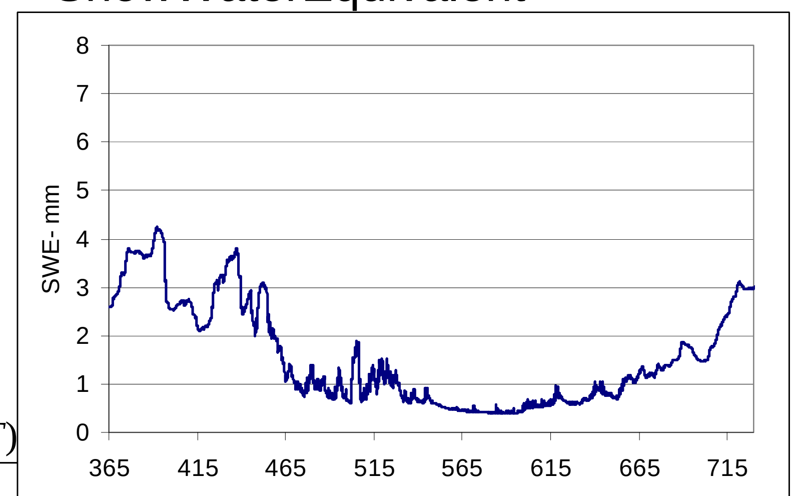
Correspondigs **pixel percentage** with and without snow

TOTALE		FEST No Snow	FEST Snow
MODIS	No Snow	95.5	0.4
MODIS	Snow	0.6	3.5

CPI=0.98

$$CPI = \frac{correctsnow(MODIS\&FEST) + correctnosnow(MODIS\&FEST)}{n° \ total \ pixels}$$

SnowWaterEquivalent



Jan 2001 Dec 2001

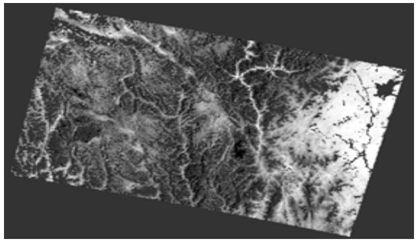
Land surface temperature from remote sensing: AATSR and MODIS data

AATSR ENVISAT Gridded Surface Temperature (ATS_NR__2P)

- Spatial coverage: 90 N , 90 S , 180 W , 180 E
- Data type: optical/multi spectral radiometry low/medium resolution
- Resolution: resampled 1 km x 1km along track

IMAGES:

- Months: from July 2002 to December 2004
- **Number of images: 150**



Georeferencing [BEAM Program]

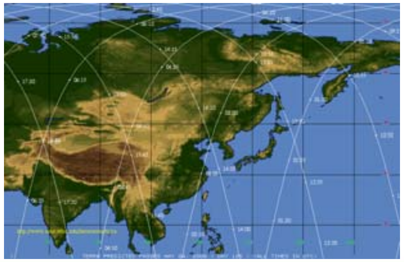
Envisat images are insufficient to cover the period of interest

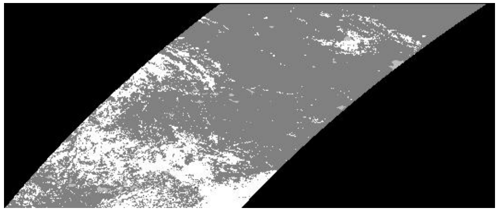
↓

Completed with **MODIS**/*Terra LST daily L3 global 1km sin grid v004*

IMAGES:

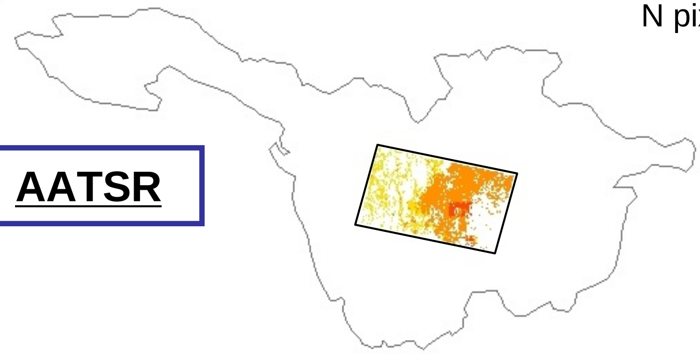
- Years : 2000-2004
- Months : from January to December
- **Number of images: 300**

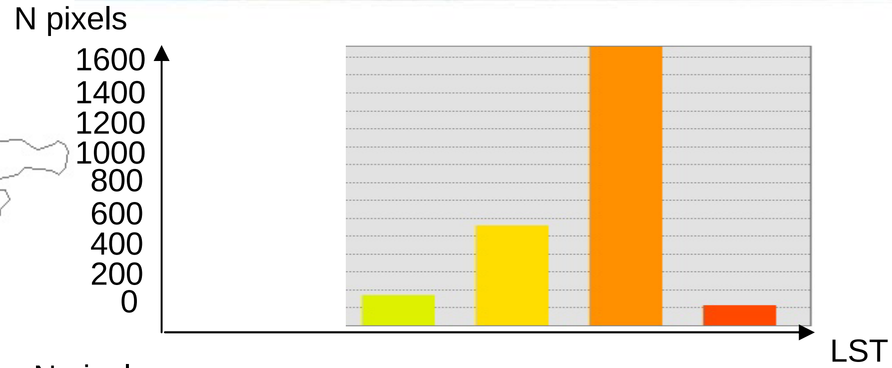


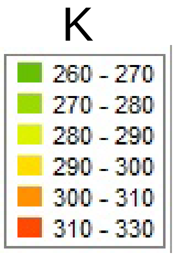


Comparison between LST from MODIS and AATSR and RET (18 August 02 -11:12am) - DAY

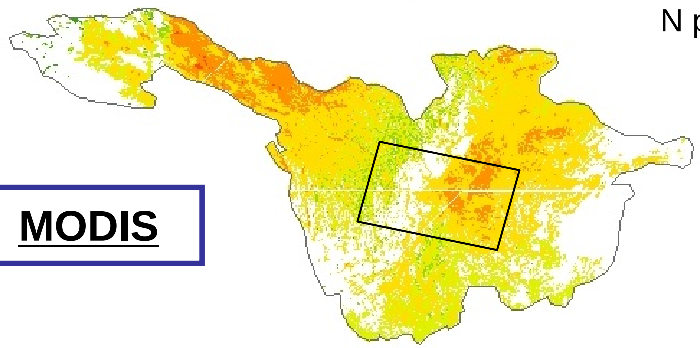
AATSR

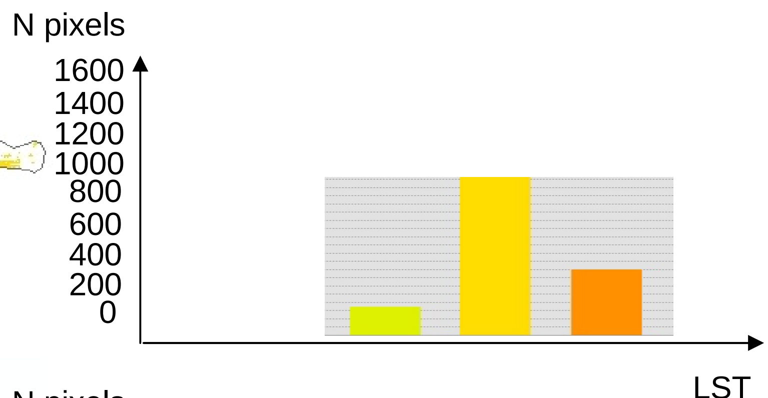




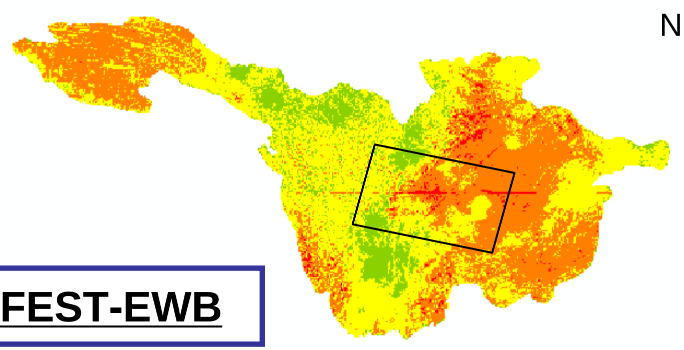


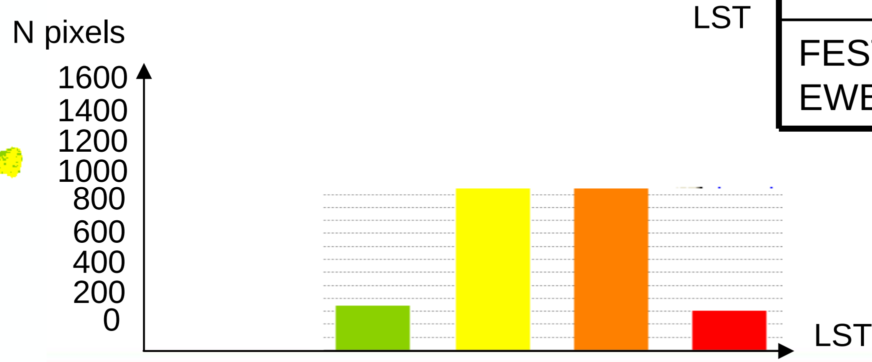
MODIS





FEST-EWB





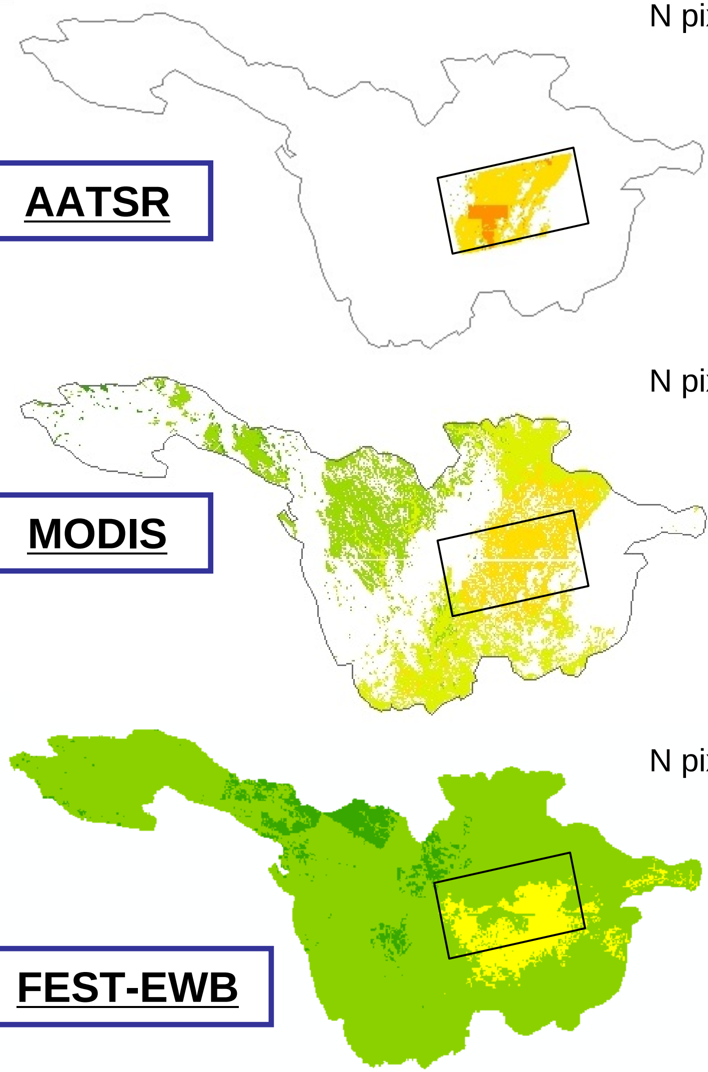
	Mean LST (°C)	St. Dev. (°C)
AATSR	28.1	6.0
MODIS	24.1	4.5
FEST-EWB	26.1	5.1

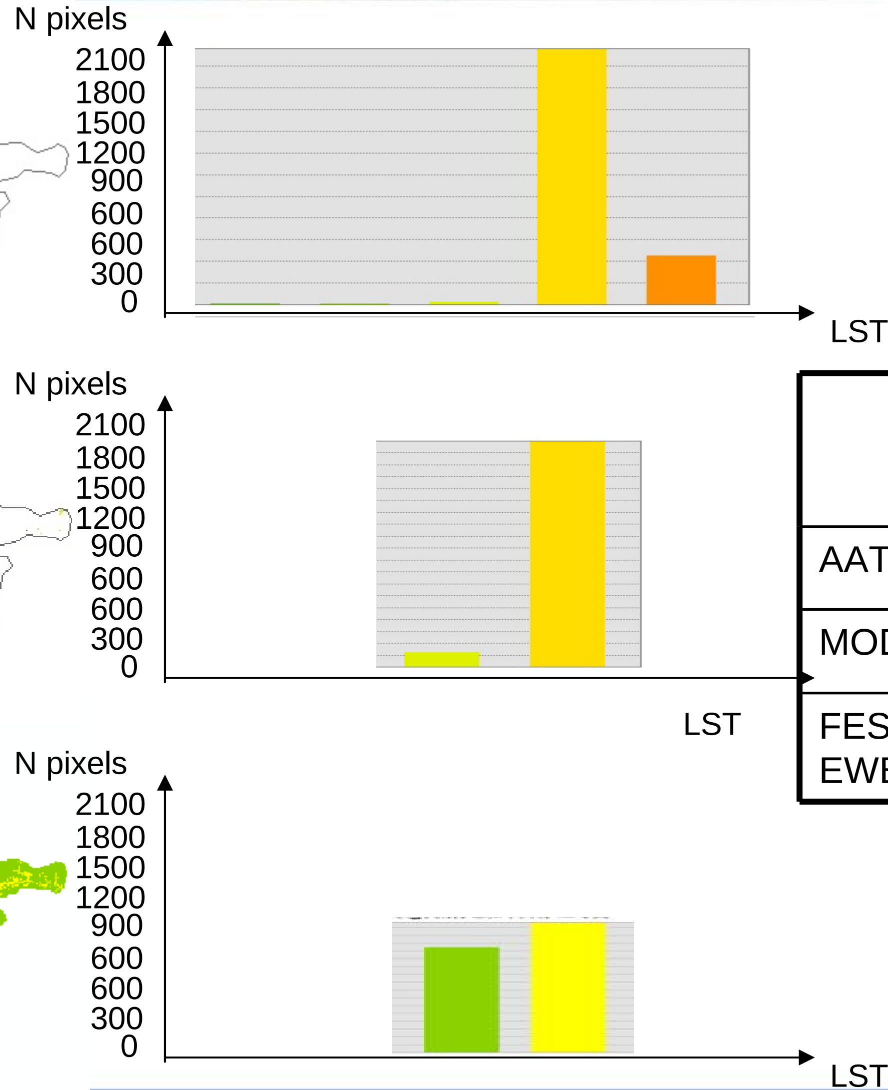
Comparison between LST from MODIS and AATSR and RET (18 August 02 -11 pm) - NIGHT

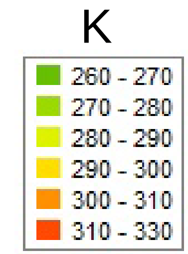
AATSR

MODIS

FEST-EWB



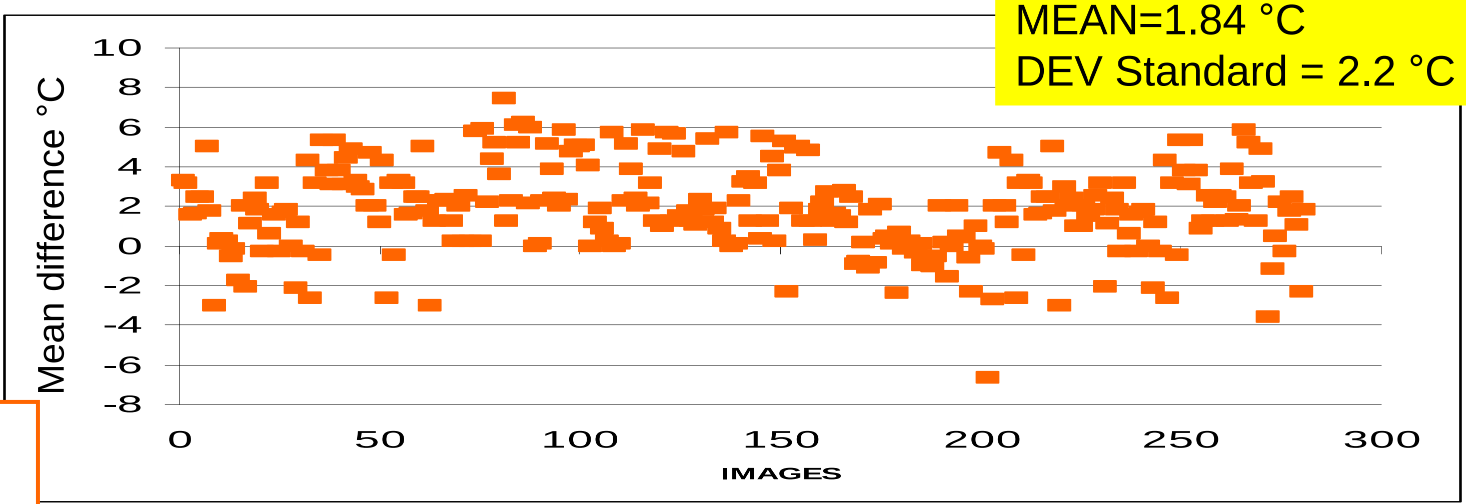




	Mean LST (°C)	St. Dev. (°C)
AATSR	24.3	3.5
MODIS	19.8	1.8
FEST-EWB	19.1	1.0

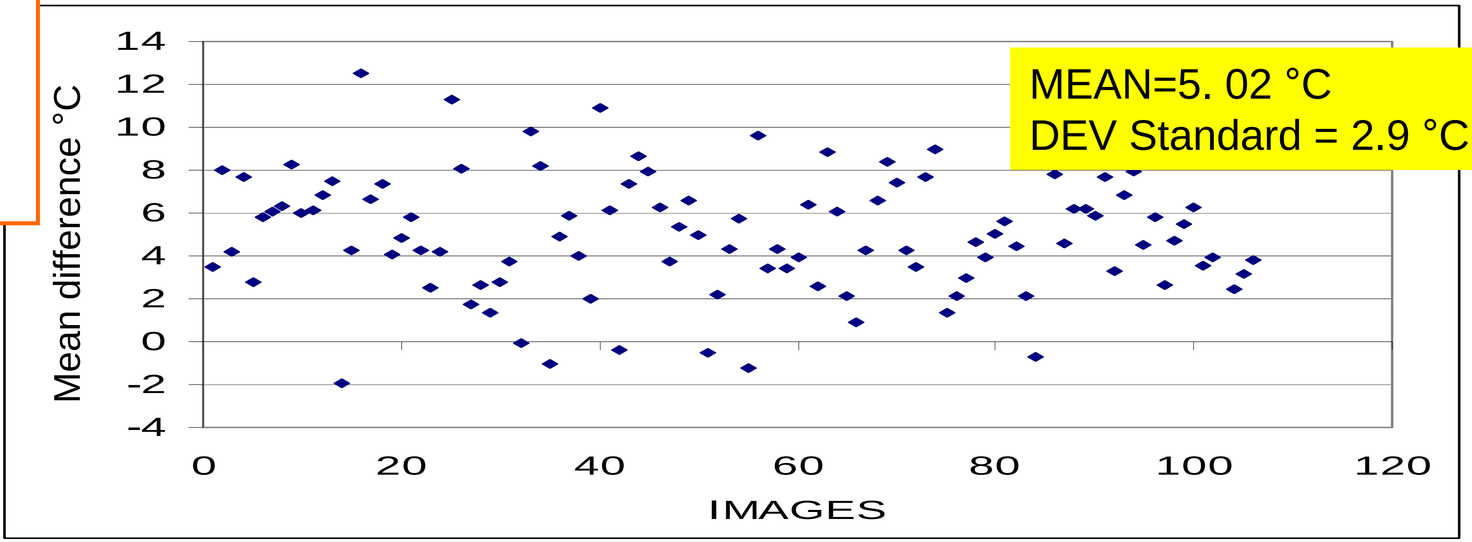
Comparison between LST from MODIS and AATSR and RET (2000-2004)

Difference between FEST-EWB LST and **MODIS** (**2000-2004**)



MEAN=1.84 °C
DEV Standard = 2.2 °C

Model RET are on average 1.8 °C higher then MODIS LST, and 5 °C higher respect to **AATSR.**

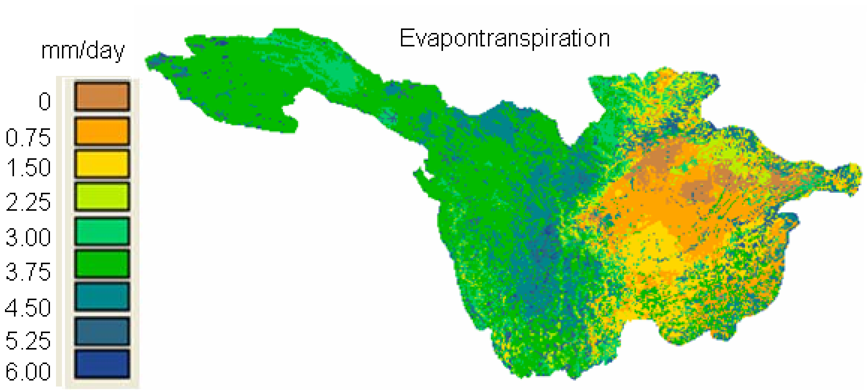


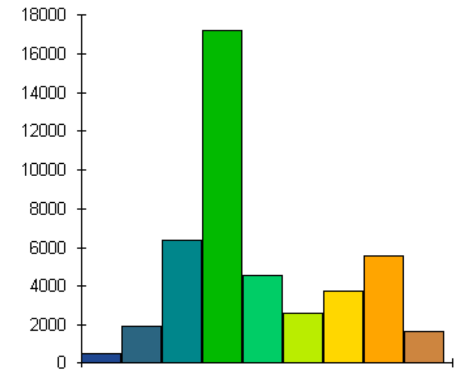
MEAN=5. 02 °C
DEV Standard = 2.9 °C

Difference between FEST-EWB LST and **AATSR**(**2002-2004**)

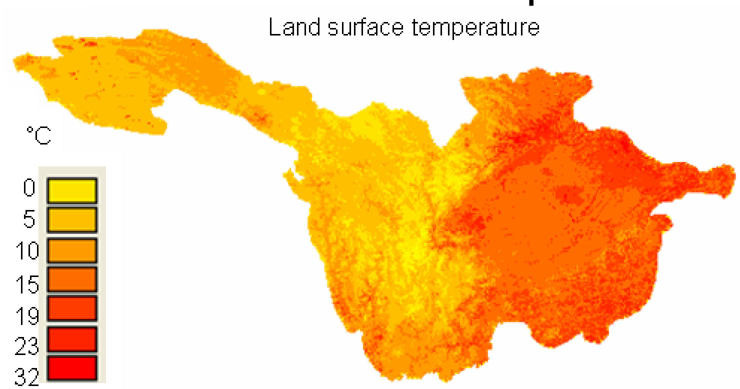
Comparison between RET and evapotranspiration from FEST-EWB

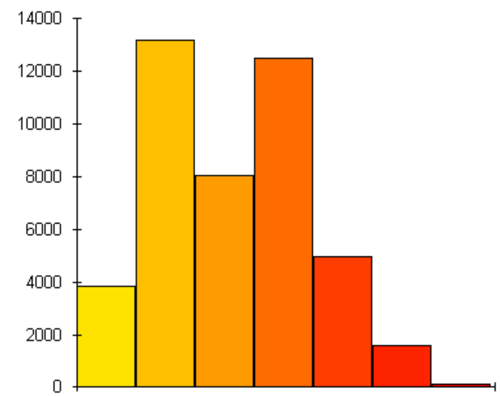
Evapotranspiration



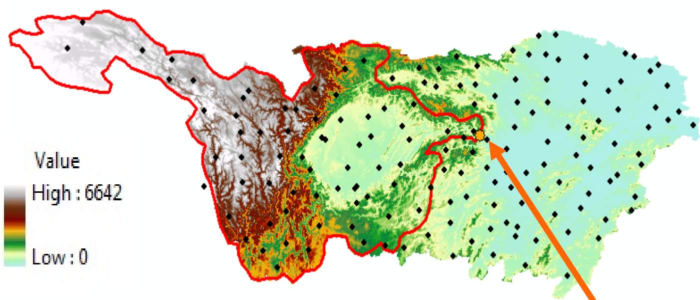


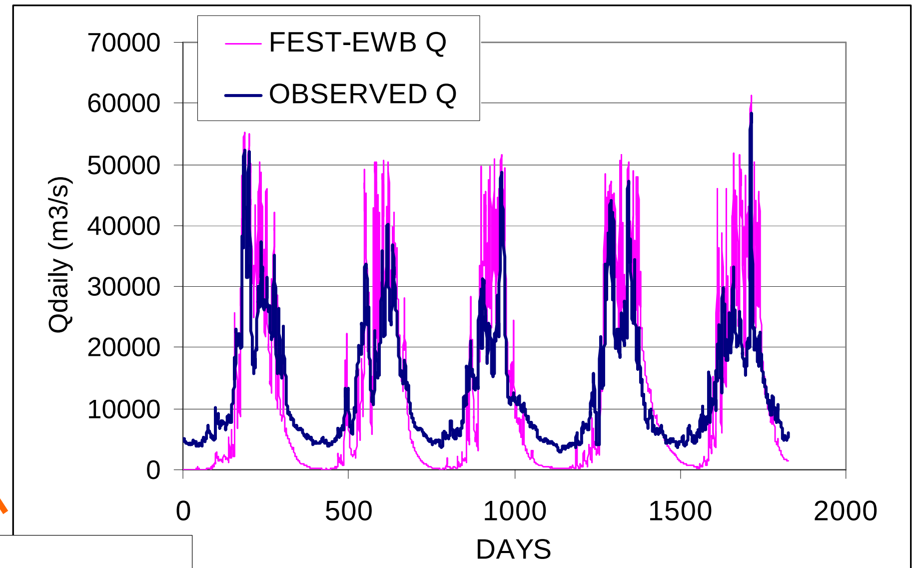
Land surface temperature



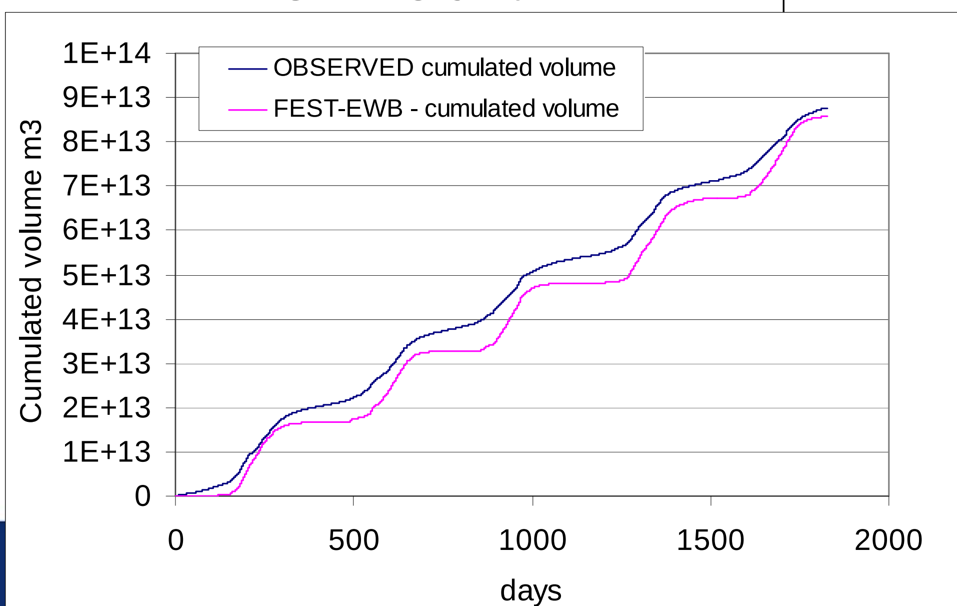


Discharge and volume control: CONTINUOUS SIMULATION at Yichang





ERROR -18.9 %



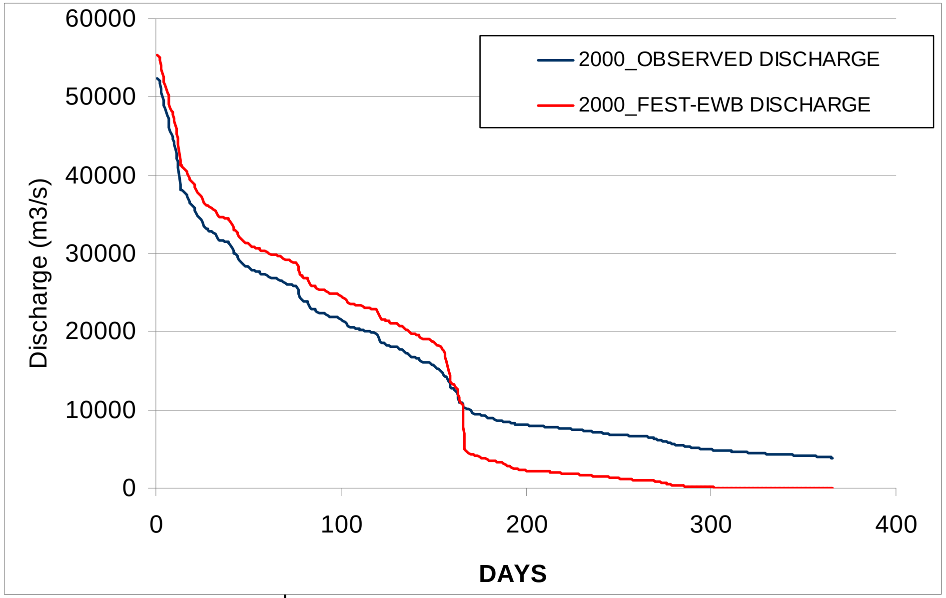
Daily discharge
Yichang
2000-2004 →
before three gorges dam construction

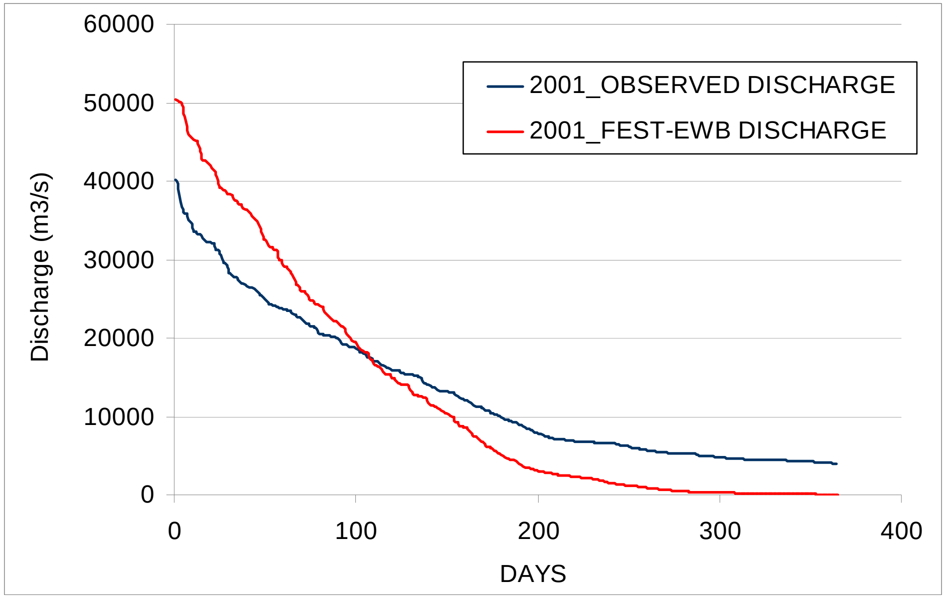
RMSE 83.3 m³/s
NASH 0.61

$$\eta = 1 - \frac{\sum_{j=1}^{n_t} \left(Q_{m,j} - Q_{o,j}\right)^2}{\sum_{j=1}^{n_t} \left(Q_{o,j} - \overline{Q_o}\right)^2}$$

Flow duration curves at Yichang for water resources management

for hydropower and agricultural potential use for river cross section of interest.





Some problems ON baseflow

ONGOING CALIBRATION

CONCLUSIONS… “working in progress”

Land surface temperature and evapotranspiration fluxes estimates from satellite data can be a promising tool to be used in synergy with traditional discharge measurements for improving mass fluxes at river basin scale: a step forward the quantification of the “internal variables” of the hydrological model (Dooge 1972) .

Next year activity:

1. distributed maps of evapotranspiration from the hydrological model and satellite thermal infrared
2. continuous soil moisture updating for flood forecast and irrigation time management, eventually SMOS data comparison.
3. Flow duration curve in different river cross sections
4. Wetlands dynamics modelling and interaction with ID5264 (Hervè Yèsou)
5. Interaction with Drought Monitoring and Hydrology projects

Recent papers **(http://geoserver.iar.polimi.it)**