Evapotranspiration estimates from an energy-water balance model and satellite Land Surface Temperature over the desertic Heihe River basin in China

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1. Introduction

The objective of the presentation is the estimate of evapotranspiration (ET) using a distributed hydrological model (FEST-EWB, [1]) which is calibrated employing satellite-sensed Land Surface Temperature (LST) over the Heihe River basin.

The FEST-EWB calibration is performed in an innovative way: not with a single measurement for the whole basin, but with a pixel-by-pixel approach. This means that parameters are updated according to the error found within each and every cell, thus allowing for a "distributed calibration". The procedure involves 67 test dates throughout year 2012, using LST data obtained from the MODIS instrument (product MOD11A1) aboard satellite Terra, at a 1km spatial resolution.

From the calibrated model, estimates of energy (latent heat) and mass (evapotranspiration) fluxes are obtained. First, these results are compared with the data gathered by two eddy covariance stations found in the agricultural area of the basin. The overall agreement between the estimated and measured data is good, as certified by numerous statistical indexes.

Then, the ET estimates are compared with global ET products: the Chinese ETMonitor [2], MERRA2, ERA-Interim, GLDAS2 and GLEAM. A considerable variability emerges, as a consequence of the different foundational model hypotheses.

All the results are also filtered according to the pixels' land cover type, looking for trends.

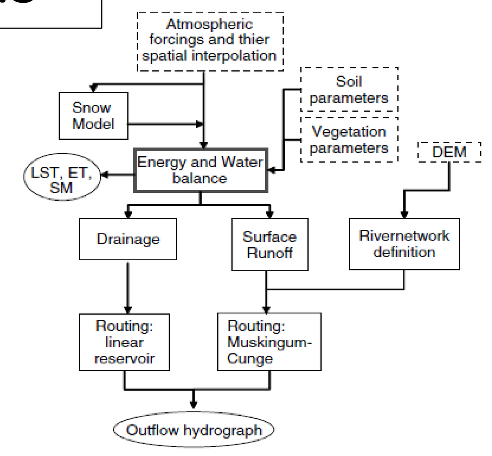
2a. Materials

- **Daman eddy-covariance station** is located within the cultivated croplands, (38.86°N, 100.37°E), and its data are available every half-hour from 25-May-12 to 15-Sep-12.
- **Yingke eddy-covariance station** is located within the cultivated croplands (38.89°N, 100.36°E), and its data are available every half-hour from 04-Jun-12 to 17-Sep-12
- **Evapotraspiration products** are organized as follows

Dataset	Spatial resolution	One image every..
ERA-Interim	0.125° x 0.125°	3 hours
ETMonitor	0.01° x 0.01°	1 day
GLDAS2	1° x 1°	3 hours
GLEAM	0.25° x 0.25°	1 day
MERRA2	0.625° x 0.5°	1 hour

2b. Methods

The **FEST-EWB** distributed hydrological model [1] closes the water and energy balances pixel-by-pixel, computing the superficial runoff and routing the water through the hydrological network.

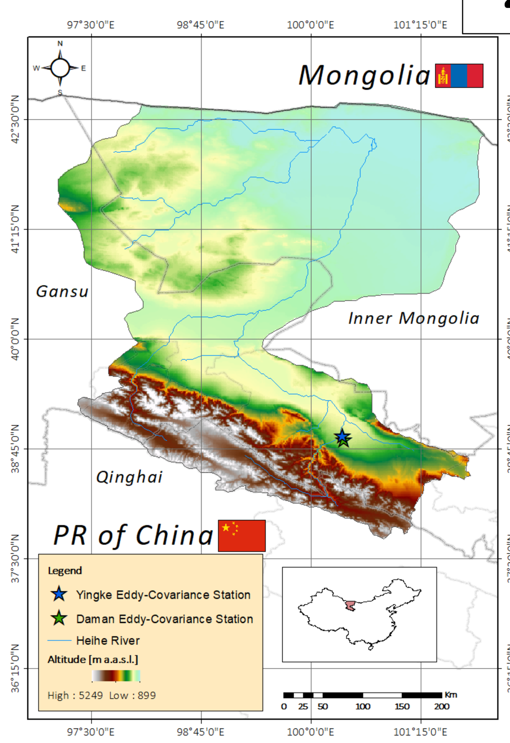


$$\begin{cases} \frac{\partial SM}{\partial t} = \frac{P - R - PE - ET}{dz}, & \textit{mass balance} \\ Rn - G - (Hs + Hc) - (LEs + LEc) = \frac{\Delta W}{\Delta t}, & \textit{energy balance} \end{cases}$$

The **distributed calibration** process involves 67 test dates chosen during year 2012 by selecting values of cloud cover lower than 5%. The proposed calibration variables are the Brooks-Corey Index (**bc**), the soil depth (**d**), the hydraulic conductivity at saturation (k_{sat}) and the minimum stomatal resistance (rs_{min}).

Other parameters too have been taken into consideration, in particular when dealing with the desertic area, like initial soil moisture condition (SM_O) and soil thermal conductivity (g_{therm}).

2c. Case Study



The Heihe River Basin (HRB) is a vast (152'606 km^2) heterogeneous area, with high mountains (up to 5249m), cultivated oases and a vast desertic plateau.

The main land use categories are:

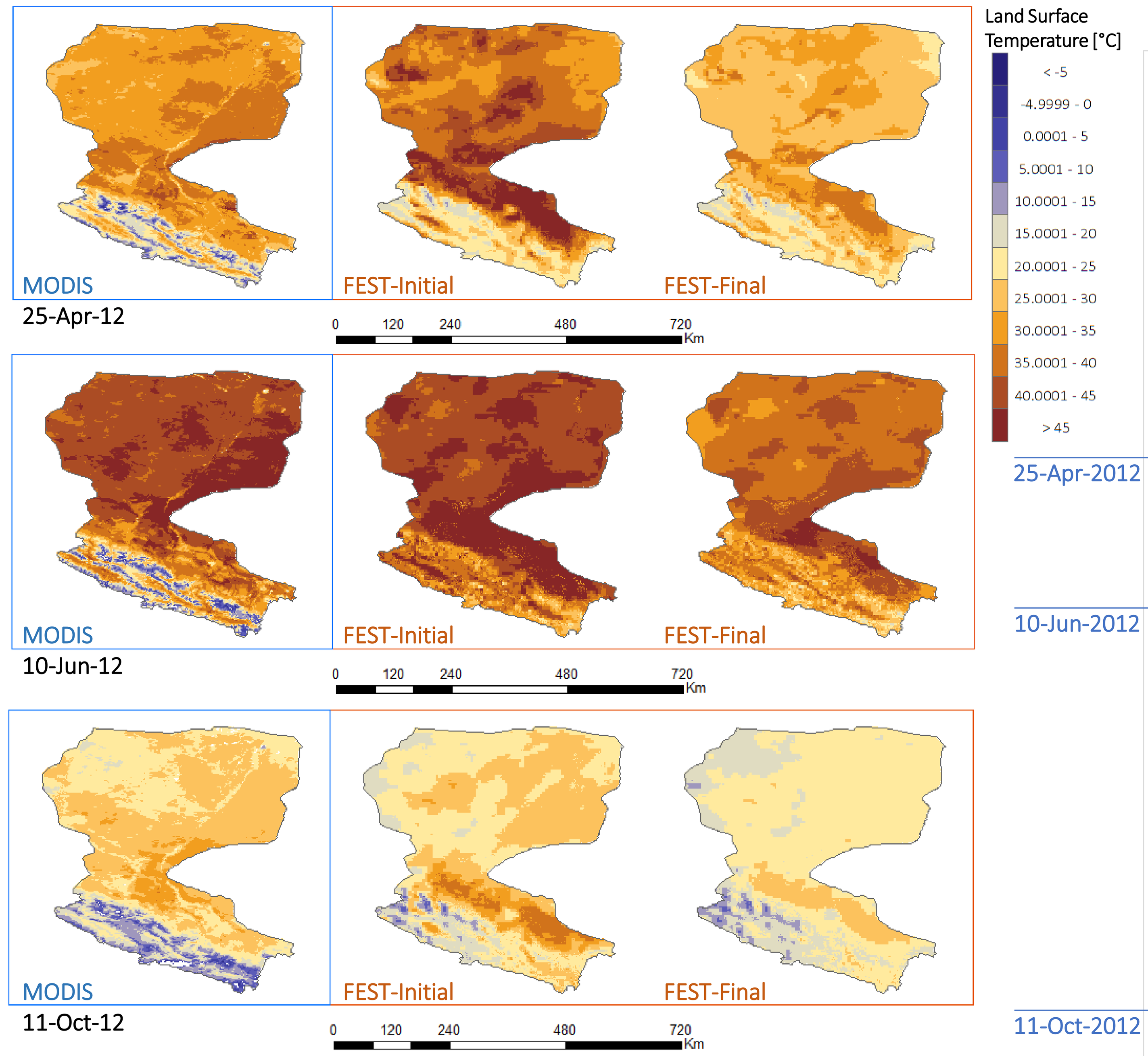
- Cultivated croplands (3.2%)
- Wild vegetation with low-stem shrubs (27.2%)
- Desertic or sparsely vegetated area (66.1%)
- Other (artificial/mixed vegetation/snow/ice/water): 3.5%

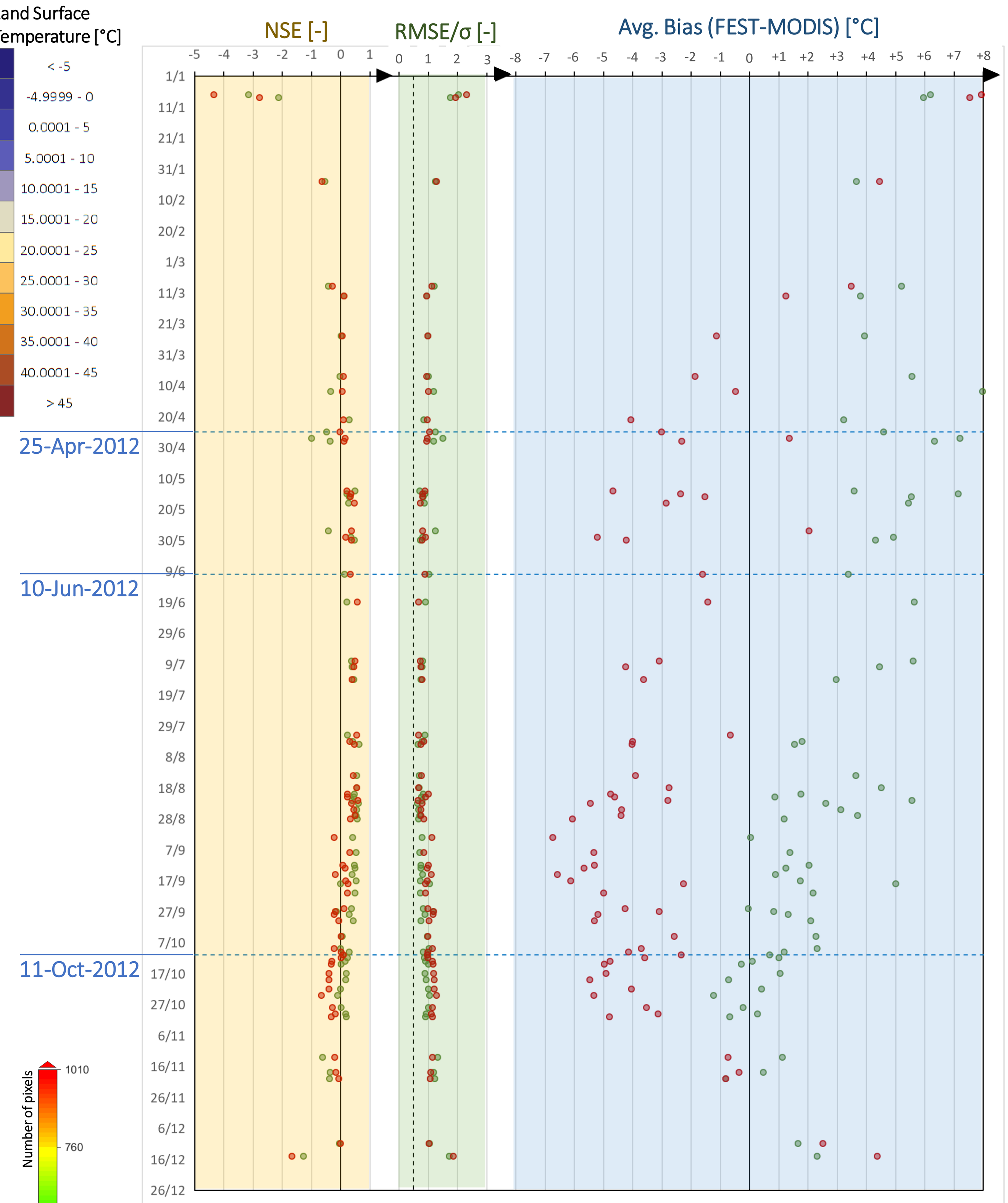
Two eddy-covariance stations (Daman and Yingke) are placed within the cultivated area, and allow for a direct test of the latent heat fluxes.

MODIS images are available over the area with 1km spatial resolution, everyday at *circa* 12:00 local time.

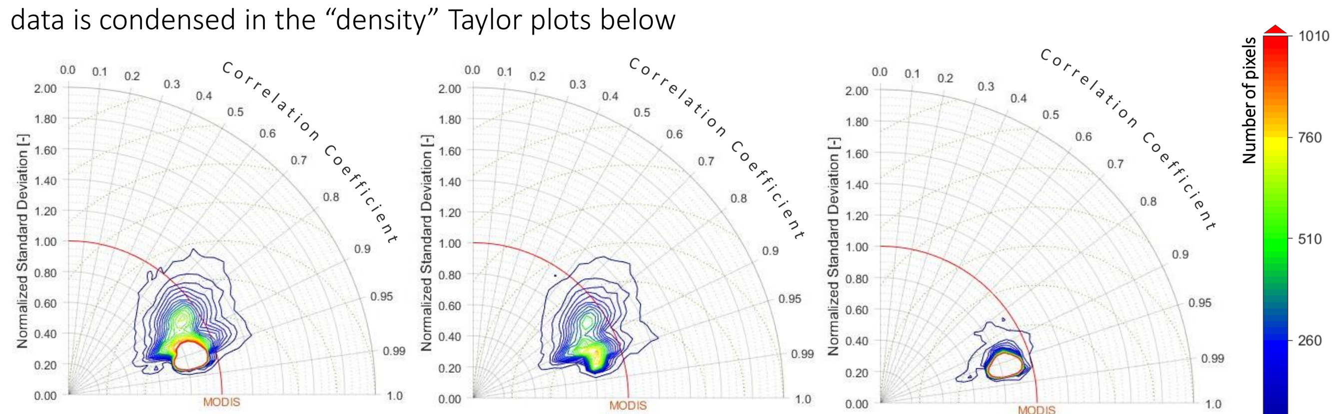
4a. Model Calibration Results

Parameter configurations	Parameter Variations						Calibration statistics (FEST v. MODIS)			
	Brooks-Corey index (bc)	Min. Stomatal Resistance (rs_{min})	Hydraulic conductivity (k_{sat})	Soil depth (d)	Initial Soil Moisture condition (SM_O)	Soil Thermal Conductivity (g_{therm})	Avg. RMSE	Avg. RMSE/σ	Average Bias (FEST-MODIS)	Avg. Nash-Sutcliffe Efficiency (NSE)
Initial	0.10 ÷ 0.33	0 ÷ 500	103.7 ÷ 4104 m/d	2.5 ÷ 73.5 cm	30 m³/m³	2.88 W/(mK)	7.7°C	2.96	+2.88°C	+0.067
Final	0.03 ÷ 0.16	0 ÷ 125	2.48 ÷ 307.8 m/d	2.5 ÷ 73.5 cm (10cm in desert)	30 m³/m³ (1 m³/m³ in desert)	2.88 W/(mK) (8 W/(mK) in desert)	8.1°C	3.01	-2.69°C	-0.039





By analysing the calibration result pixel-by-pixel, the adaptation of FEST-EWB results to MODIS data is condensed in the "density" Taylor plots below

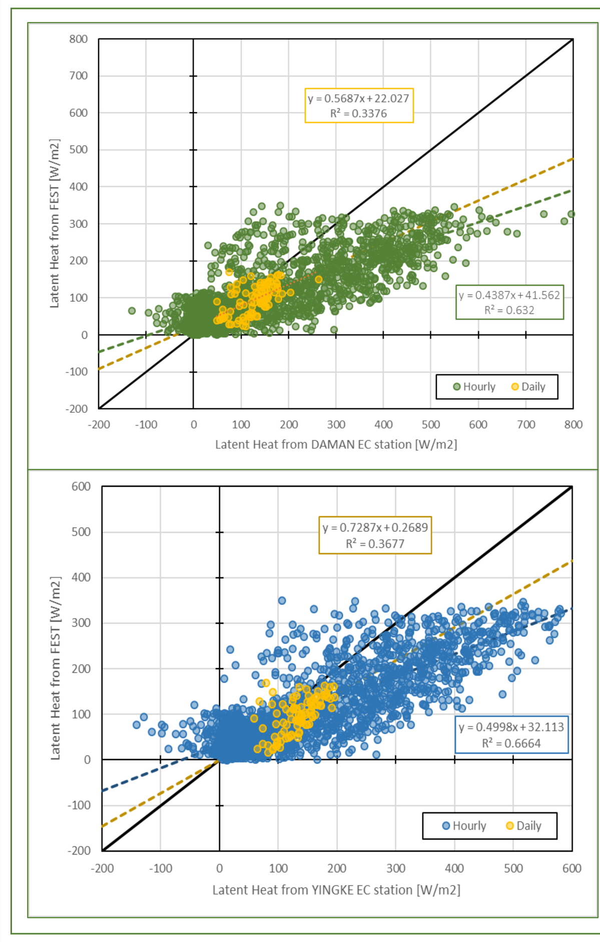


Avg. statistics	Whole basin	*Fields*	Shrubland	Desert
$RMSD/\sigma_{obs}$	0.387	*0.451*	0.510	0.324
$\sigma_{mod}/\sigma_{obs}$	0.863	*0.952*	0.882	0.848
$\bar{\rho}$	0.920	*0.894*	0.859	0.951

(data from the "Fields" category are not shown in the plots on the left)

4b. Model Validation & Evapotranspiration Comparison

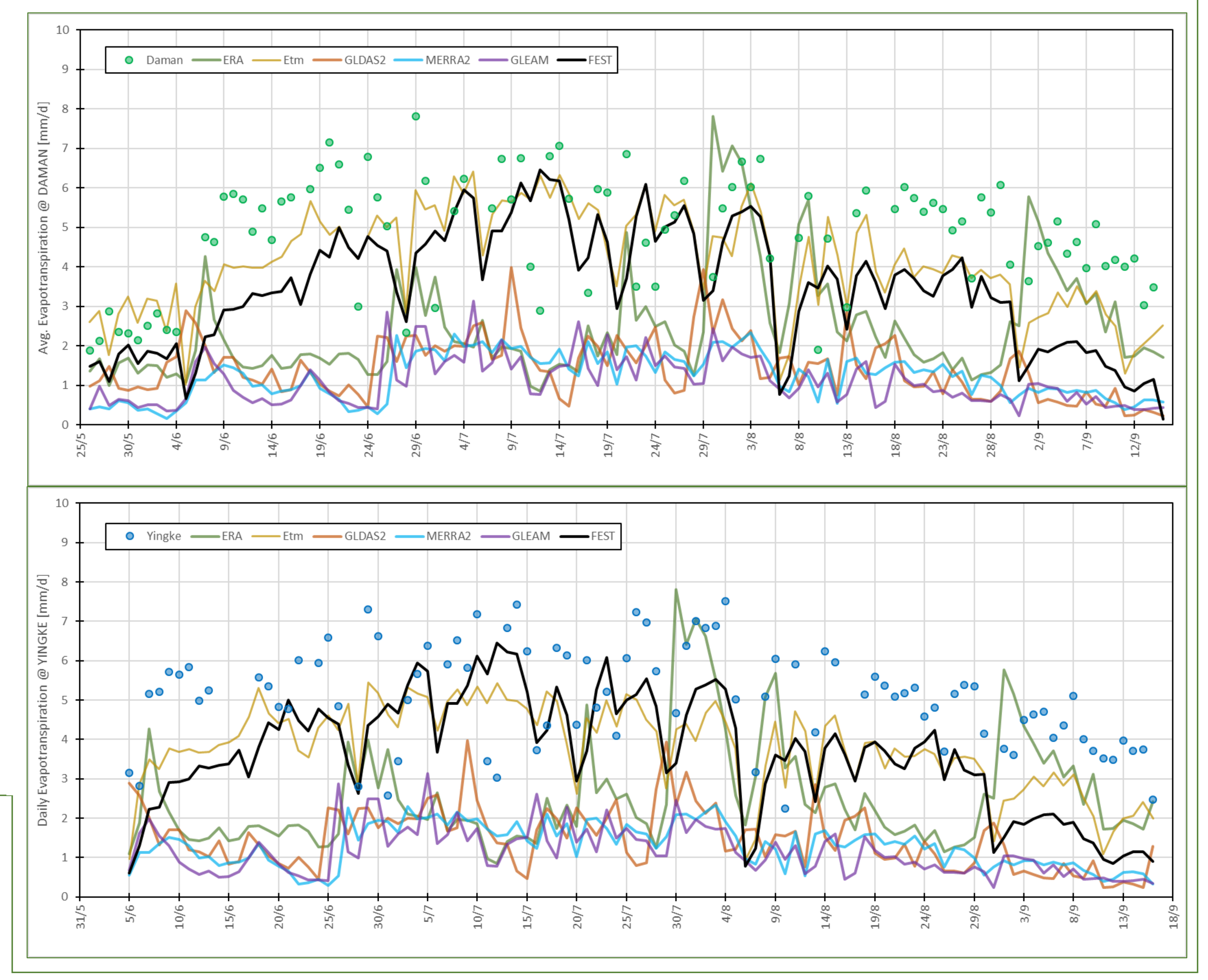
Models performances with EC data



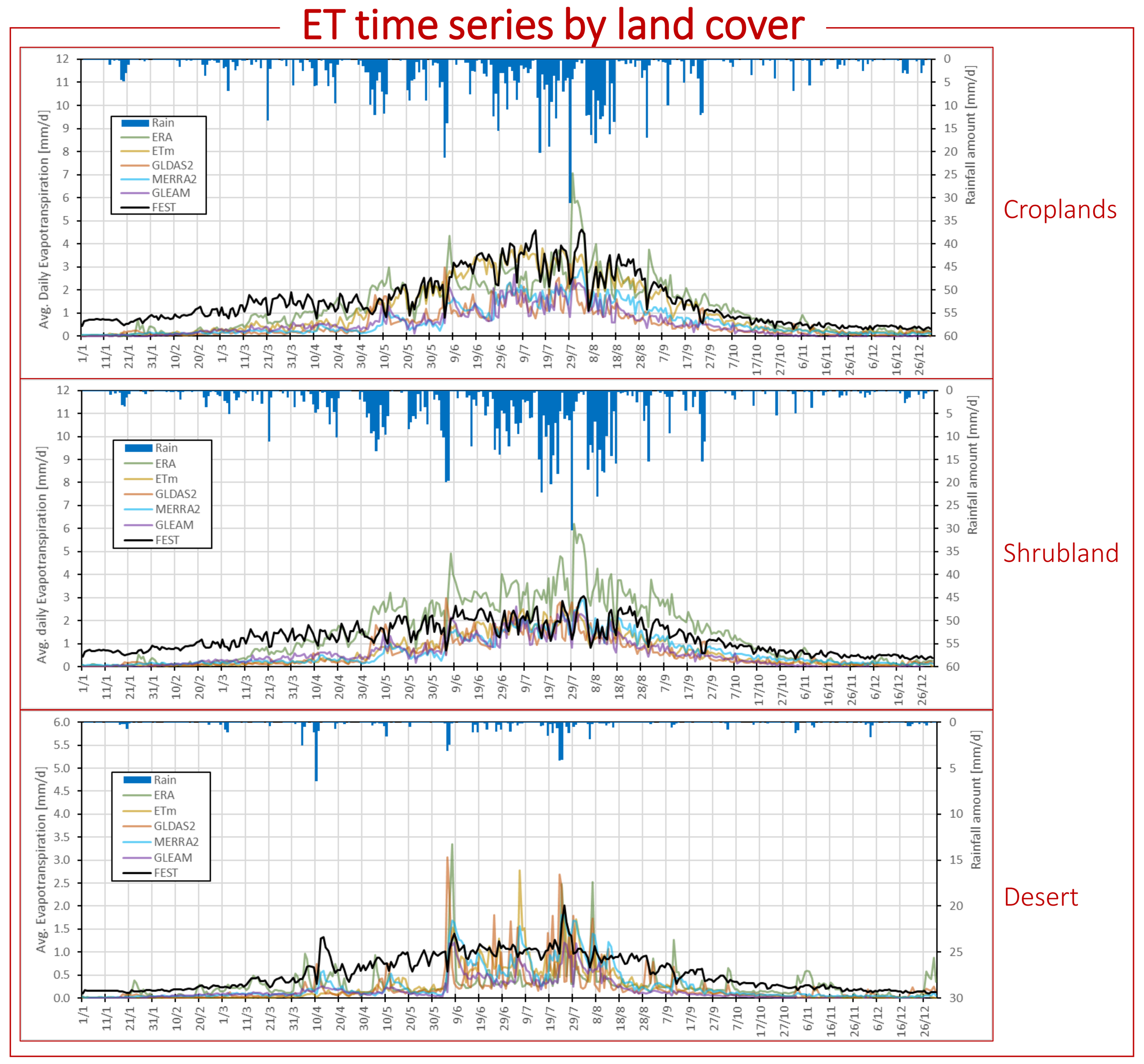
The model has been validated first against the latent heat (**Xle**) data retrieved from two eddy-covariance stations placed in the cultivated area of the basin. For each station, both the hourly matches and the daily aggregations are plotted, in order to "validate" the latter for the daily comparison with the Re-Analysis models. Globally, the model tends to underestimate the latent heat fluxes.

By looking at the daily values, the model is also compared with an ET-dedicated model (ETMonitor) and four Re-Analysis products (ERA, GLDAS2, MERRA2, GLEAM).

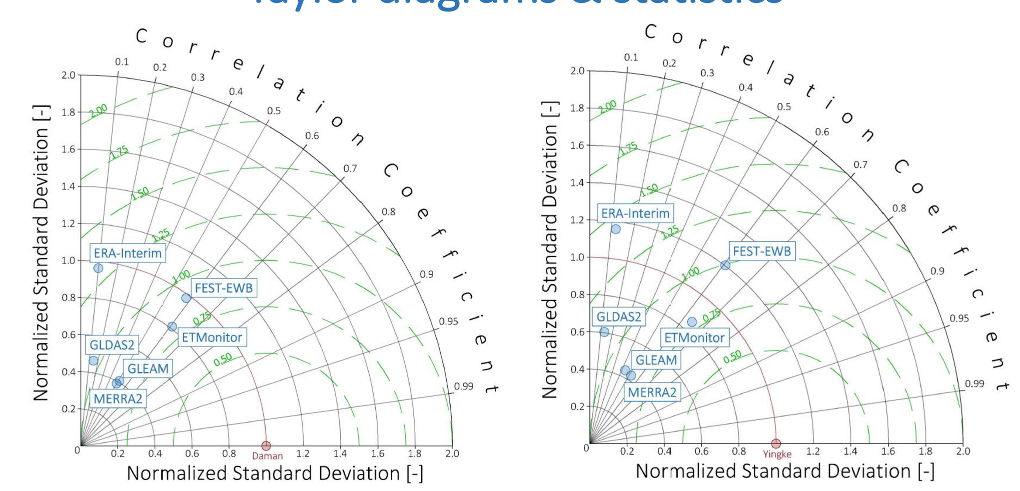
While ERA behaves more erratically, the other Re-Analyses are quite clustered around lower values than detected from the EC station, surely affected by their coarser spatial scale, which smooths out the pixel-level singularities.



ET time series by land cover



Taylor diagrams & statistics



	Daman			Yingke		
	$RMSD/\sigma_o$	σ_{mod}/σ_o	ρ	$RMSD/\sigma_o$	σ_{mod}/σ_o	ρ
ERA-Interim	1.314	0.963	0.099	1.429	1.159	0.121
ETMonitor	0.815	0.811	0.609	0.790	0.853	0.644
GLDAS2	1.035	0.464	0.148	1.093	0.604	0.130
GLEAM	0.861	0.408	0.512	0.898	0.491	0.437
MERRA2	0.870	0.388	0.499	0.855	0.427	0.519
FEST-EWB	**0.901**	**0.979**	**0.581**	**0.990**	**1.202**	**0.606**

Conclusions

The calibration procedure has allowed to correct the model's behaviour, fixing a general temperature overestimation which, as a consequence, boosted the evapotranspiration to out-of-scale values. The pixel-by-pixel fitness shown in the Taylor plots points out the particular homogeneity of the desert area. In the validation against EC data, the FEST-EWB performance is good, considering the difference in scale between the data. In the comparison against other models, the good accuracy of FEST-EWB is further highlighted, with only ETMonitor able to obtain comparable results.

References & Acknowledgements

[1] C Corbari, G Ravazzani, M Mancini (2011) – *A distributed thermodynamic model for energy and mass balance computation: FEST-EWB* – Hydrological Processes, 25, 1443-1452 (2011)
[2] G Hu, L Jia (2015) – *Monitoring of Evapotranspiration in a Semi-Arid Inland River Basin by Combining Microwave and Optical Remote Sensing Observations* – Remote Sensing, 7, 3056-3087 (2015)

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