Combining satellite data and land model outputs to advance in the estimation of land surface fluxes

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Outline

1. Motivation: global land heat fluxes
2. Satellite observations and land model fluxes
3. Linking satellite data and land fluxes
4. Evaluation of the satellite-driven fluxes
5. Suggestions for MSG and METOP-A data

LandFlux

The **LandFlux** Initiative of the GEWEX Radiation Panel (GRP):

- Objectives:

  to develop the needed capabilities to produce a **global, multi-decadal** surface turbulent flux data product.

- Agenda:

  1st workshop in Toulouse, May 2007.
  2nd workshop scheduled end of 2008.

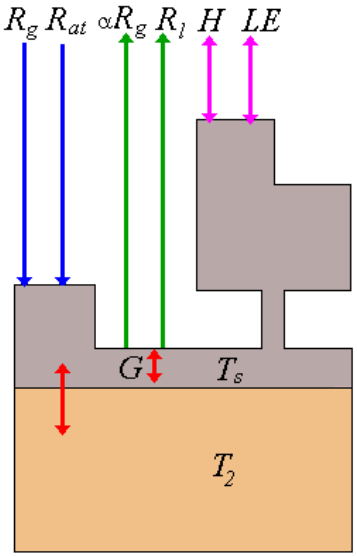
(http://grp.giss.nasa.gov/landflux.html)

Land Surface Models

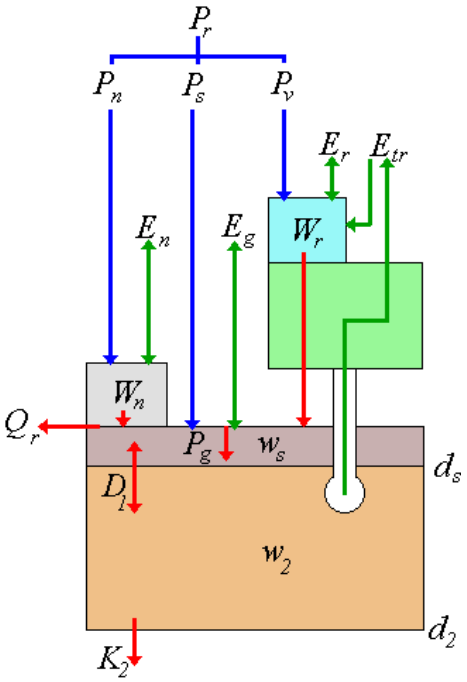
• Sources of global land fluxes? Sophisticated coupled/off-line SAVT schemes with some surface parameters derived from remote sensing data (e.g LAI, FVC), many others from approximate relationships with vegetation, soil type or climate regime.

e.g.

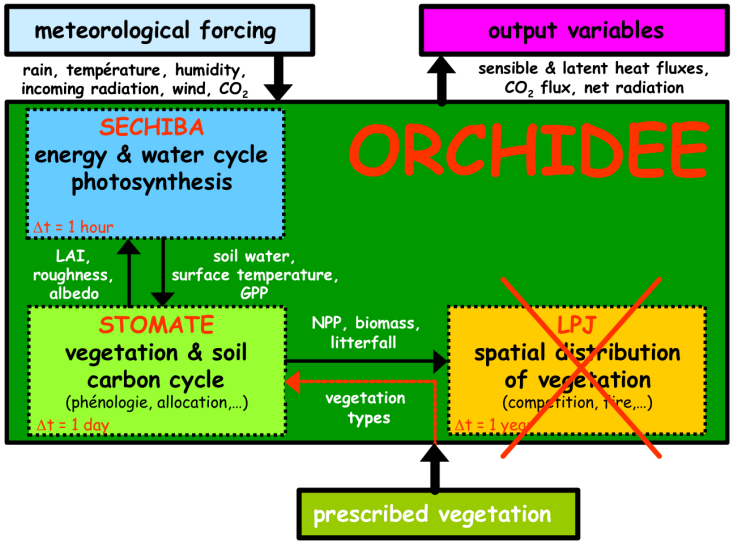
Energy/Fluxes



Hydrology



Global biospheric model ORCHIDEE



(Courtesy of the ISBA team)

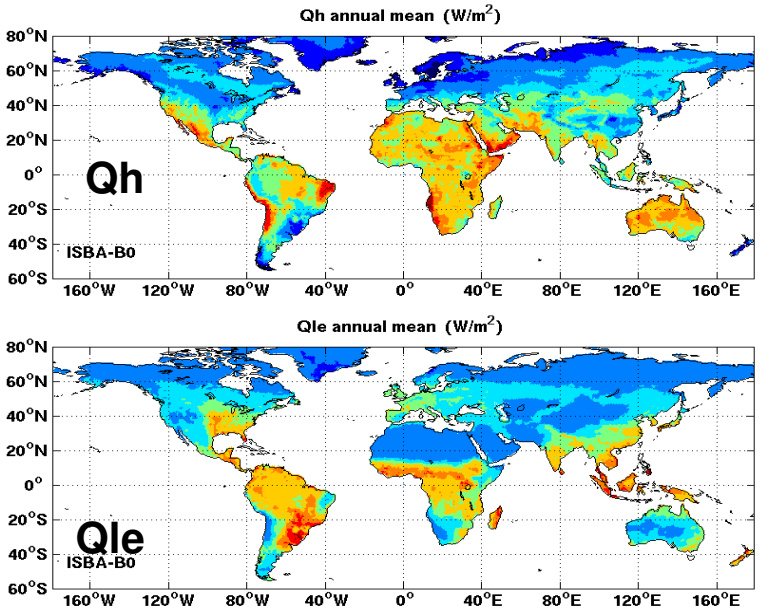
(Courtesy of the ORCHIDEE team)

Challenges

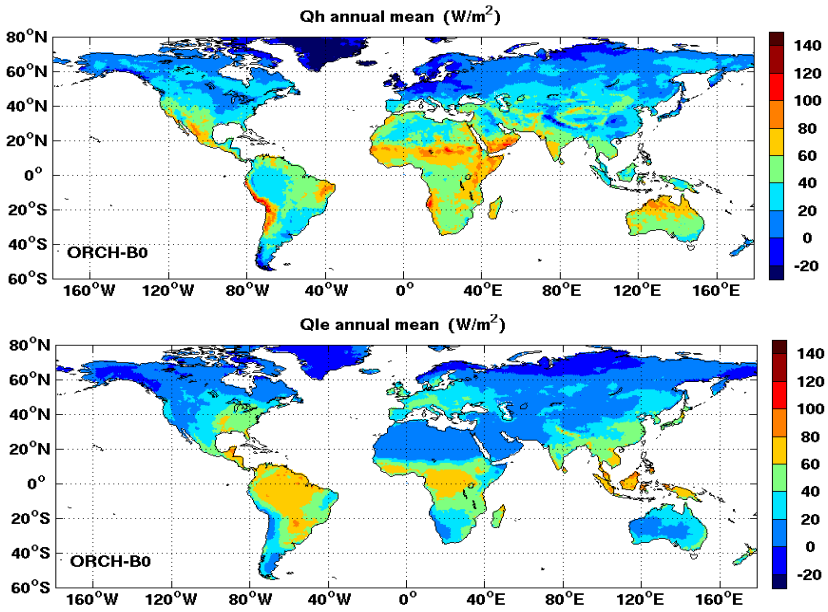
• Not easy to calibrate/tune the comprehensive parameterizations of the LSMs when doing the transition from the local/regional to the global scale. This results in differences in the land fluxes.

e.g. 1993 annual mean fluxes from two off-line models with similar forcing GSWP-2 B0 baseline run

ISBA



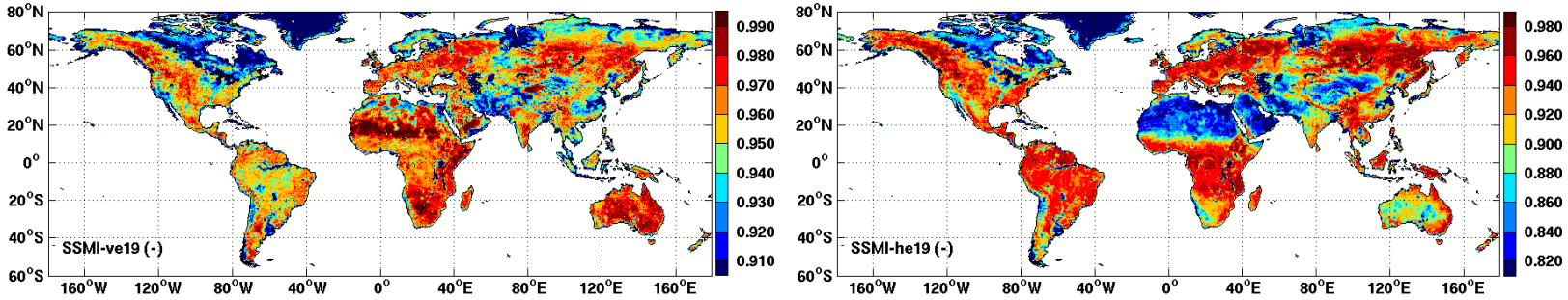
ORCHIDEE



Satellite data

• How can we help? There is **satellite data** with temporal and spatial resolutions compatible with surface models and with expected sensitivity to the land fluxes due to their proven sensitivity to surface properties.

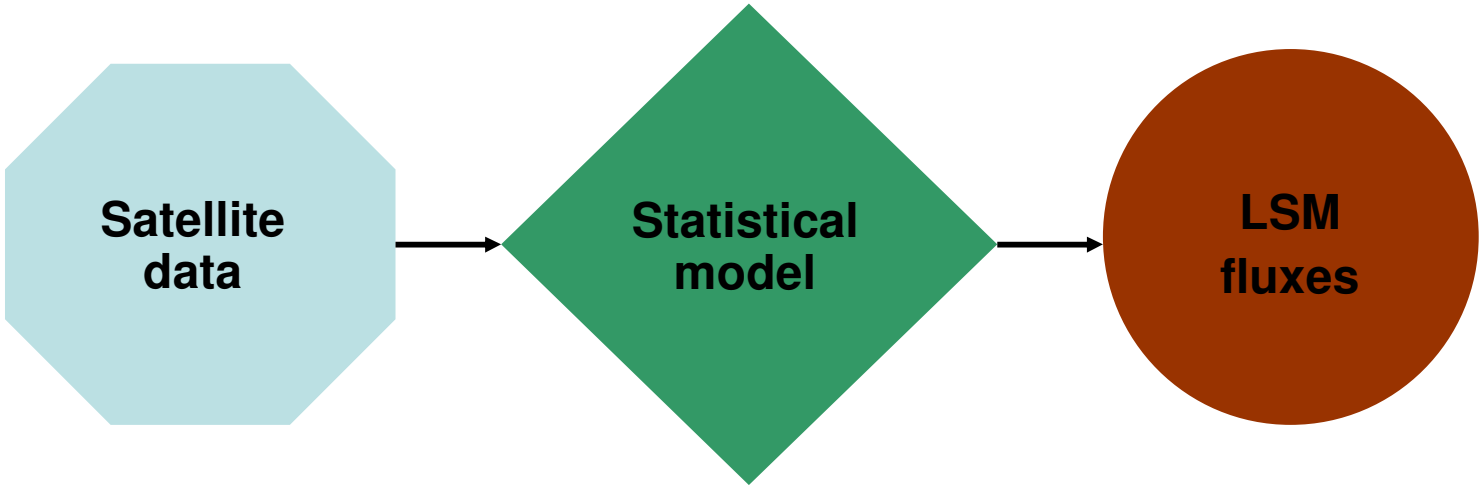
e.g. monthly means of SSM/I emissivities at 19 GHz



• Some of these data are presently **not exploited** in the calibration/ development of the land model parameterizations, as there is so far no easy way to integrate these data into the models.

Statistical model

• Our **proposal**: to link the satellite data with the land fluxes through a statistical model**.**



• The relation between observational data and fluxes is not prescribed, but derived from the **statistical analysis** of a global dataset of coincident satellite observations and land model fluxes.

Satellite observations

A suite of **satellite observations** selected based on:

- suspected sensitivity to the heat fluxes
- availability over the globe
- spatial resolution compatible with climate analysis
- temporal coverage of at least a decade

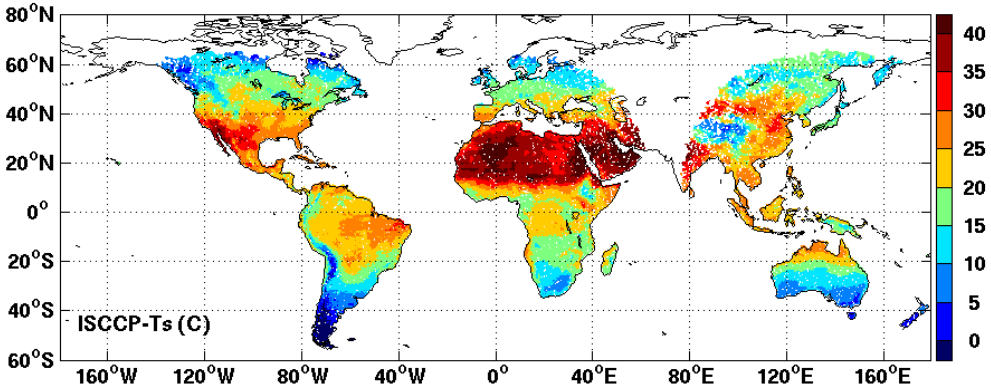
Selection:

- ISCCP thermal infrared land **skin temperature**
  [mean value and the amplitude of the diurnal cycle]
- SSM/I microwave **emissivities**
  [vert/hor polarized at 19, 37 and 85 GHz]
- ERS microwave radar **backscattering**
  [at 20° and 45° incident angles]
- AVHRR **reflectances**
  [visible and near-infrared]
- surface **radiation** product from ISCCP data
  [short and long-wave net radiation]

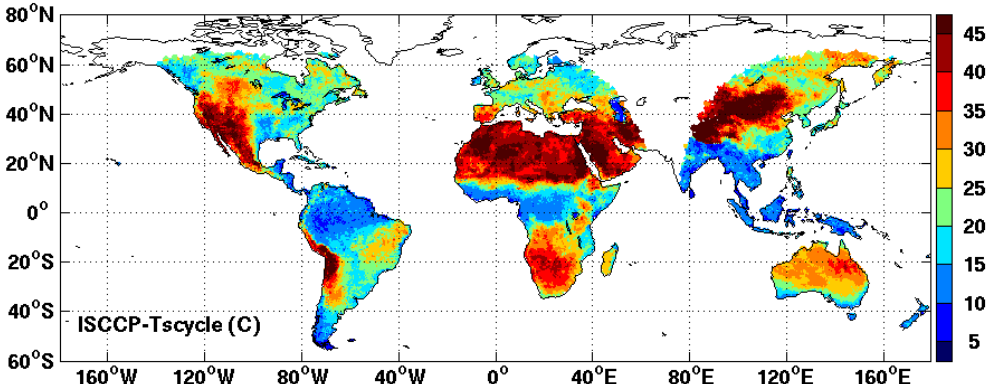
Satellite observations

• Examples of monthly mean values for June 93

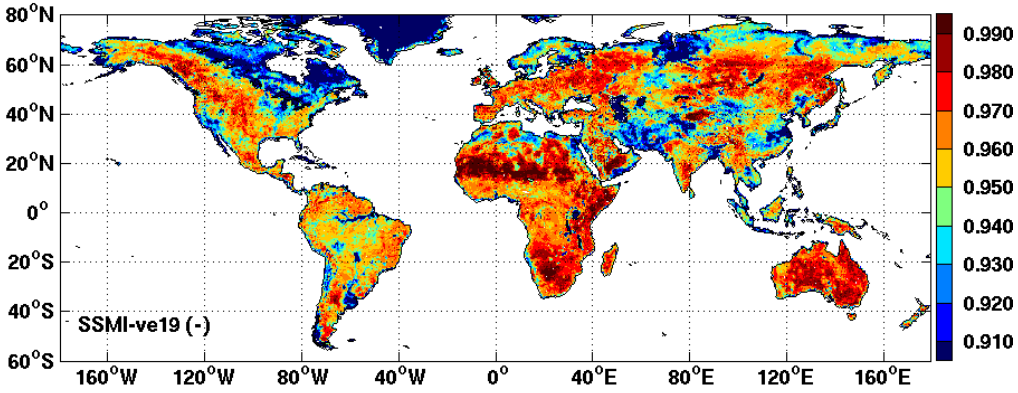
ISCCP **skin temperature**



skin temperature **diurnal cycle**



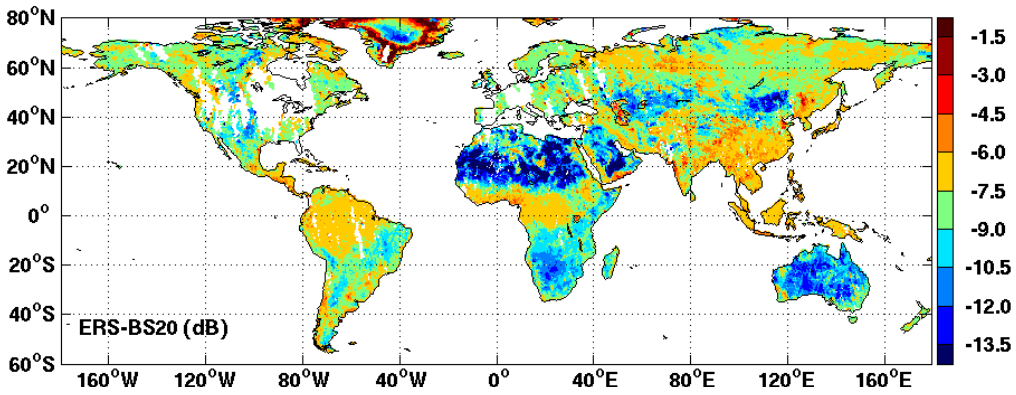
SSM/I vert-pol **emissivity** at 19 GHz



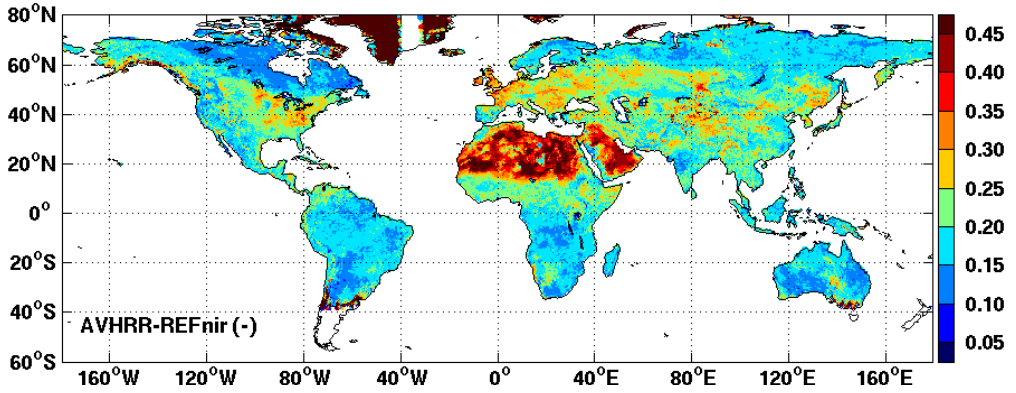
Satellite observations

• Examples of monthly mean values for June 93

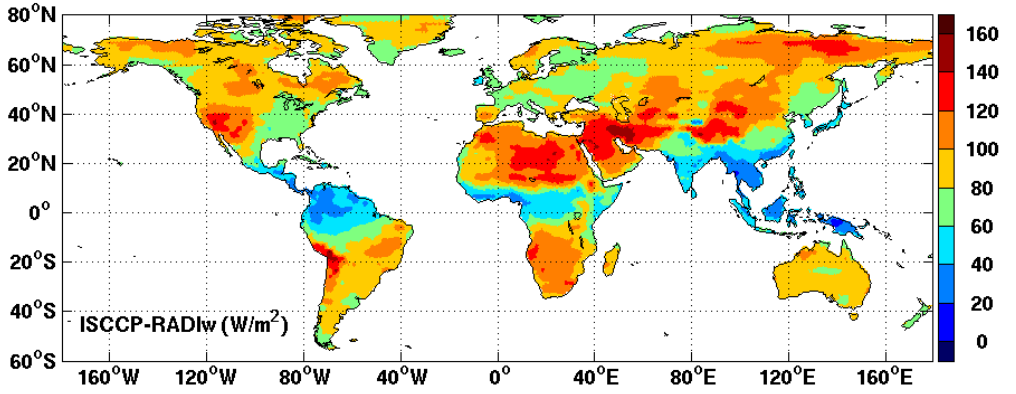
ERS **backscattering** at 20°



AVHRR near-IR **reflectance**



long-wave **net radiation**



Land heat fluxes

As in situ flux measurements are very sparse in space and time, fluxes from **LSMs** are adopted as the most reliable estimates of land heat fluxes at a global scale.

Selection:

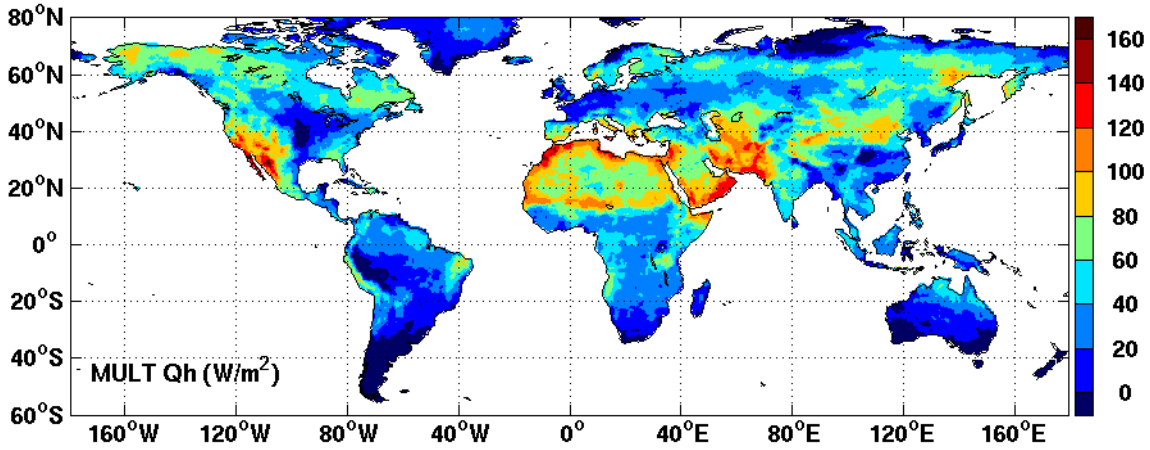
- **GSWP-2** Global Soil Wetness Project exercise
  - 15 LSMs driven in off-line mode using global meteorological forcing inputs in 1986-1995.
  - using fluxes from a **multi-model** analysis (average across the individual models) and two French participating models (**ISBA** and **ORCHIDEE**)

- **NCEP/NCAR** reanalysis
  - 50 years record by a frozen global data assimilation system with a couple land-atmosphere scheme.

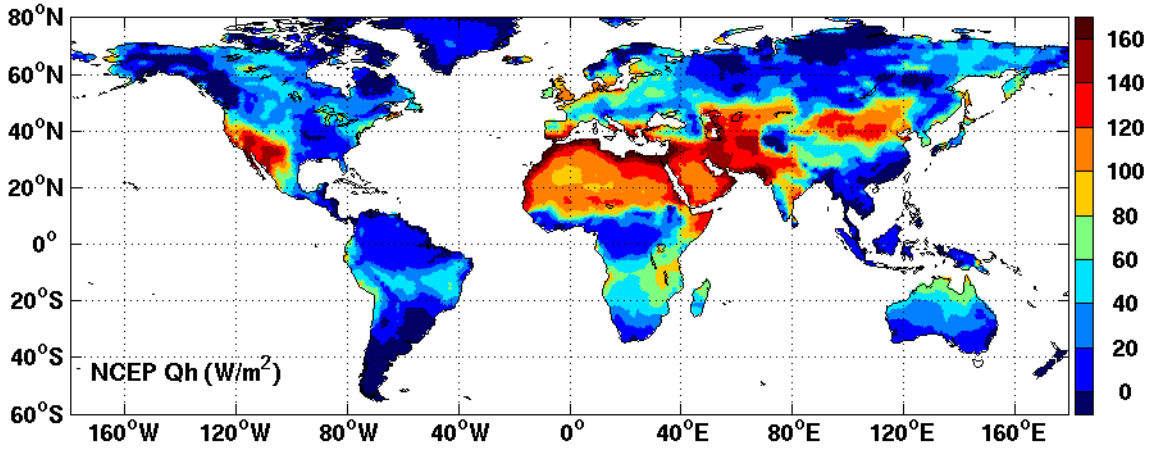
Land heat fluxes

• Examples of monthly mean **sensible fluxes** for June 93

GSWP **multi-model**



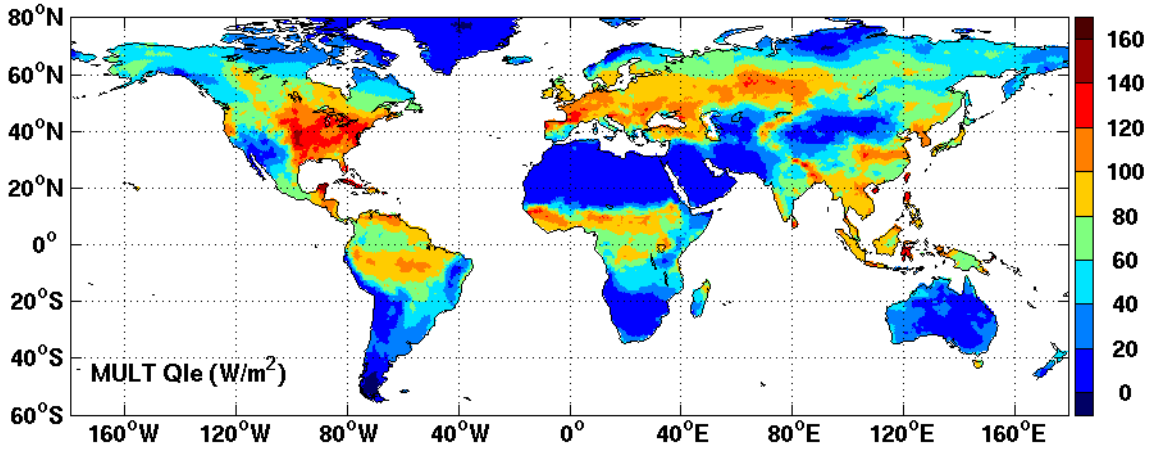
NCEP **reanalysis**



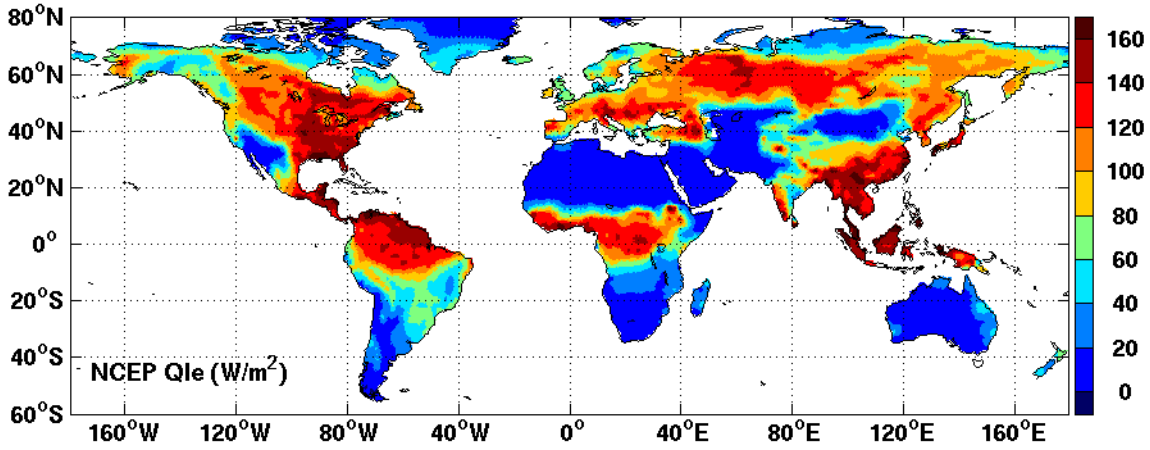
Land heat fluxes

• Examples of monthly mean **latent fluxes** for June 93

GSWP **multi-model**



NCEP **reanalysis**



Data processing

• **1993-1995** time period considered, data averaged into monthly means.

• **monthly means** judge adequate for a first exercise and in line with the objective of deriving a global multi-decadal monthly land heat flux climatology.

• shorter times possible (depending on satellite temporal resolution).

• satellite observations and LSM fluxes re-gridded in to a **0.25ºx0.25º equal area grid** at the equator (~770 km^2), only for snow-free pixels.

Linking satellite data and LSM fluxes

• satellite observations and each of the LSMs are related through a separate **statistical model** based on **neural networks**.

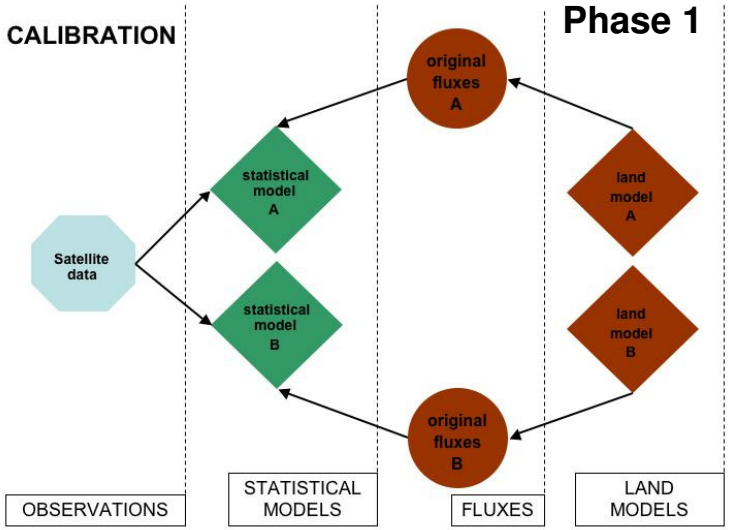
• statistical predictors has already been used, but a **global application** has not been tried before.

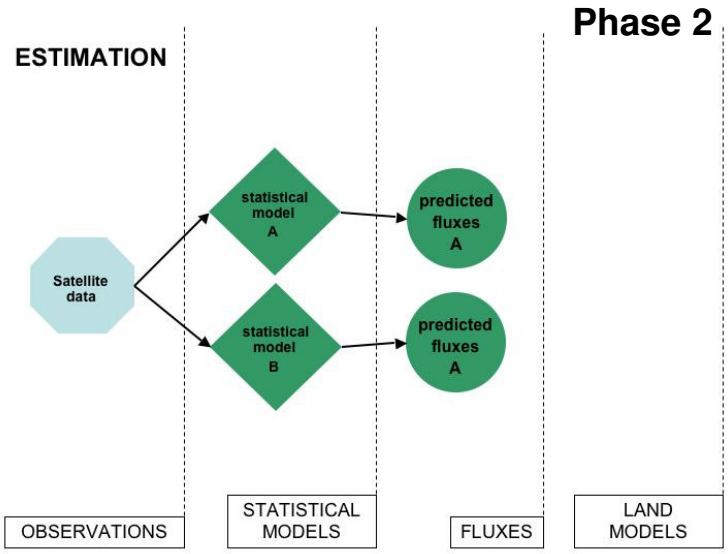
• note that this is **not** an **absolute** flux **retrieval** scheme, as each statistical model will inverse the satellite data based on the global fluxes prescribed by each individual LSM.

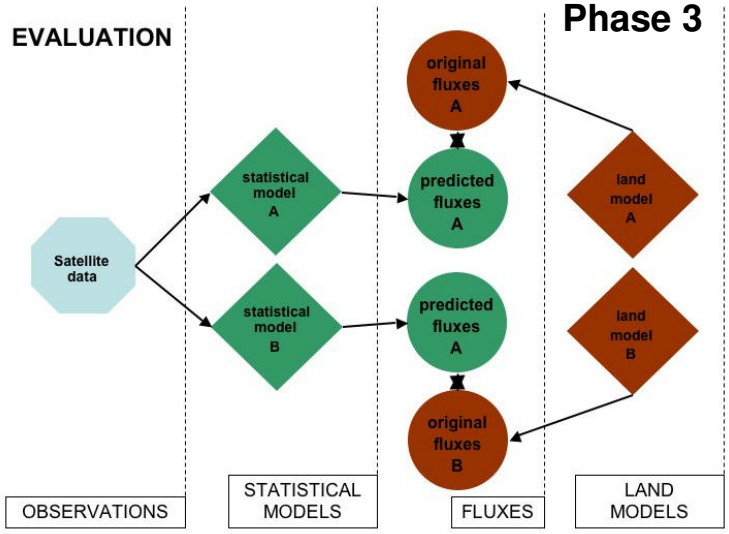
• the statistical model is **calibrated** with data from Feb-May-Aug-Nov 93 and then used to estimate fluxes from Jan-93 to Dec-95.

Using the statistical model

1. Motivation
2. Satellite and fluxes
3. Linking satellite and fluxes
4. Fluxes evaluation
5. MSG and METOP-A







Evaluation of the satellite-driven fluxes

- **Global errors**

- correlations of **0.8-0.9** and RMSE of ~ **25 W/m²** when using all satellite data.

- there is **redundancy** in the information provided by the satellite data, specially for the latent fluxes.

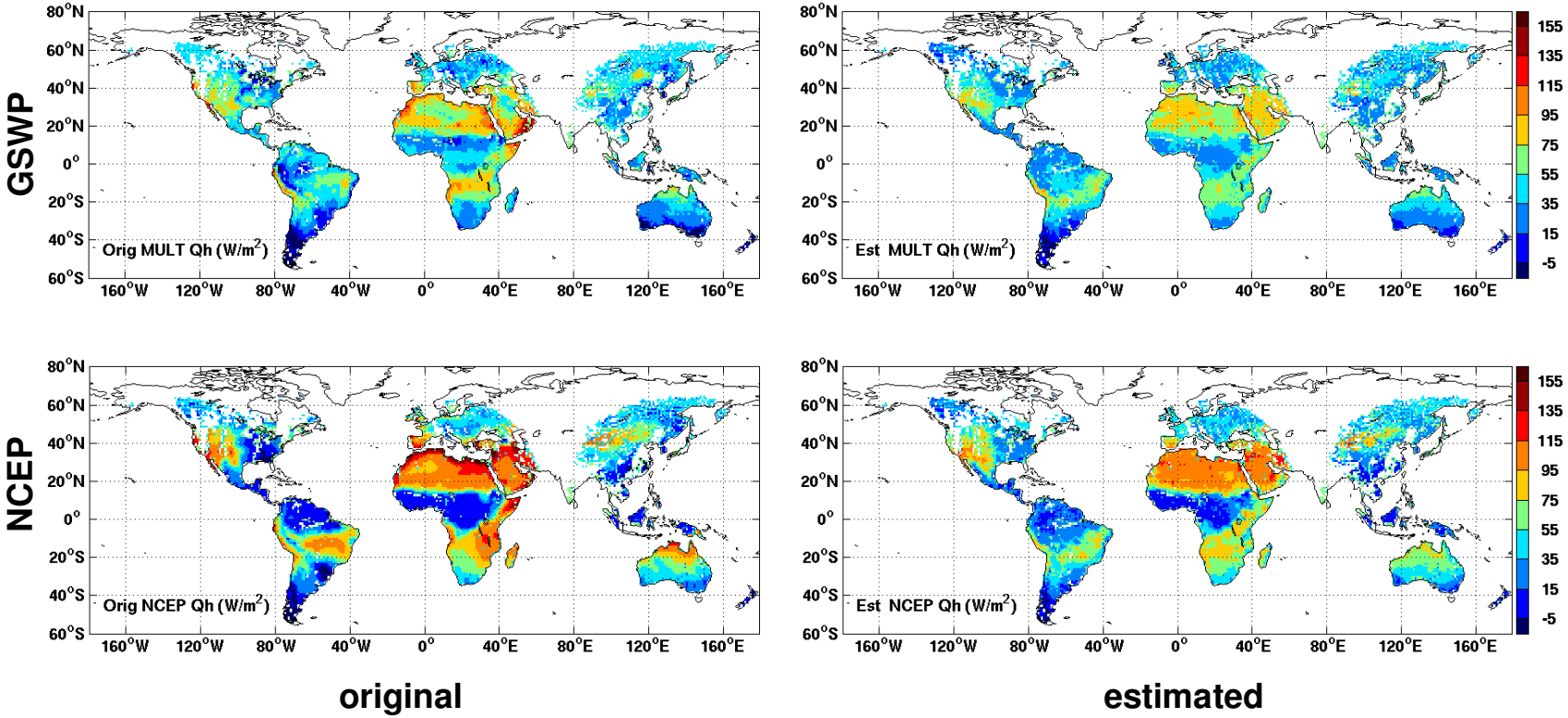
Table 2. Correlation coefficients and RMS Errors for a non-linear estimation between different combinations of individual groups of satellite-derived variables and the sensible and latent fluxes. 'All Groups' means with all the satellite variables listed in Table 1. 'No variable X' means all variables but the variable X. The RMS errors are given in W/m^2 and as a percentage of the mean flux (in brackets).

	Correlation		RMS	
Satellite products	GSWP	NCEP	GSWP	NCEP
			Sensible flux	
All groups	0.83	0.84	16.7(36.0)	23.5(42.4)
No Emissivity	0.78	0.80	18.7(40.2)	26.0(46.9)
No Backscatter	0.79	0.81	18.5(39.7)	25.8(46.5)
No Reflectance	0.78	0.80	18.7(40.0)	26.0(47.0)
No Skin Temperature	0.69	0.75	21.9(47.0)	29.1(52.5)
No Diurnal Cycle	0.73	0.78	20.5(44.0)	27.2(49.2)
No Net Radiation	0.79	0.81	18.4(39.6)	25.5(46.1)
			Latent flux	
All groups	0.92	0.92	14.2(30.5)	22.0(39.7)
No Emissivity	0.88	0.87	17.0(36.6)	27.1(48.9)
No Backscatter	0.88	0.87	17.0(36.3)	27.3(49.2)
No Reflectance	0.86	0.87	18.5(39.7)	27.6(49.9)
No Skin Temperature	0.87	0.87	17.9(38.5)	27.5(49.7)
No Diurnal Cycle	0.88	0.88	16.8(36.2)	27.0(48.7)
No Net Radiation	0.89	0.89	16.5(35.4)	25.8(46.7)

Evaluation of the satellite-driven fluxes

- Comparing **geographical patterns**

e.g. GSWP-mult and NCEP **sensible** fluxes in August 1995



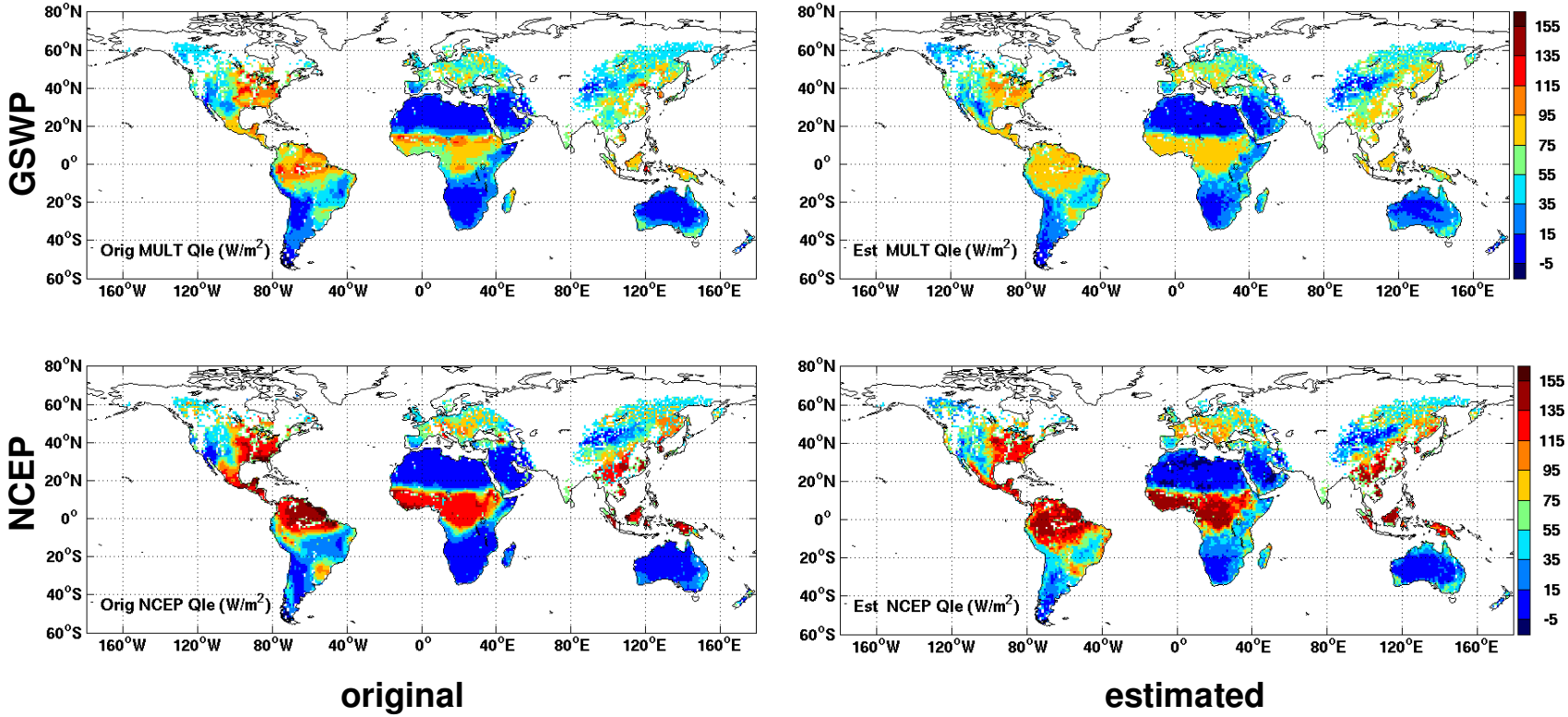
original **estimated**

- estimated fluxes capture well the regional variations associated to different climate and vegetation regimes.

Evaluation of the satellite-driven fluxes

- Comparing **geographical patterns**

e.g. GSWP-mult and NCEP **latent** fluxes in August 1995



original **estimated**

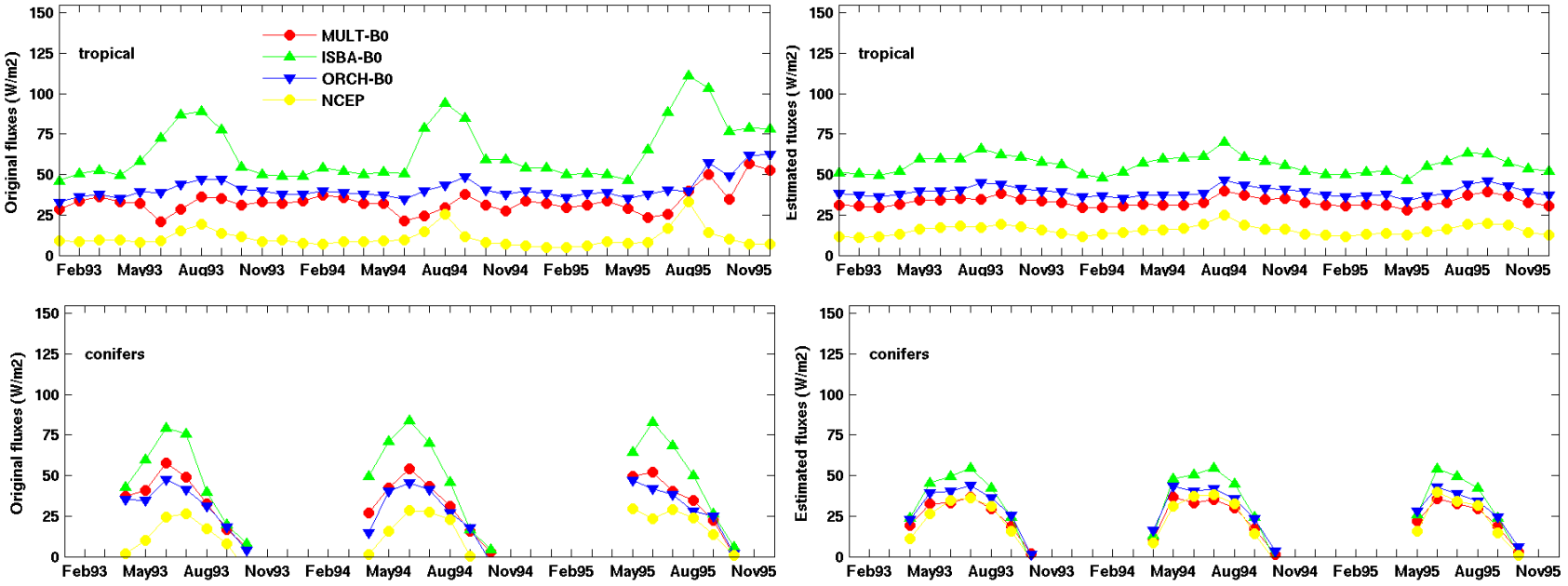
- the global differences between the different land models are kept in the estimated fluxes as expected, the statistical models cannot remove global biases.

Evaluation of the satellite-driven fluxes

- Comparing **temporal patterns**

Type	Continent	Latitude	Longitude
tropical	South America	-10 0	-70 -50
conifers	Asia	50 60	100 140

e.g. zonally averaged **sensible** fluxes in 1993-1995



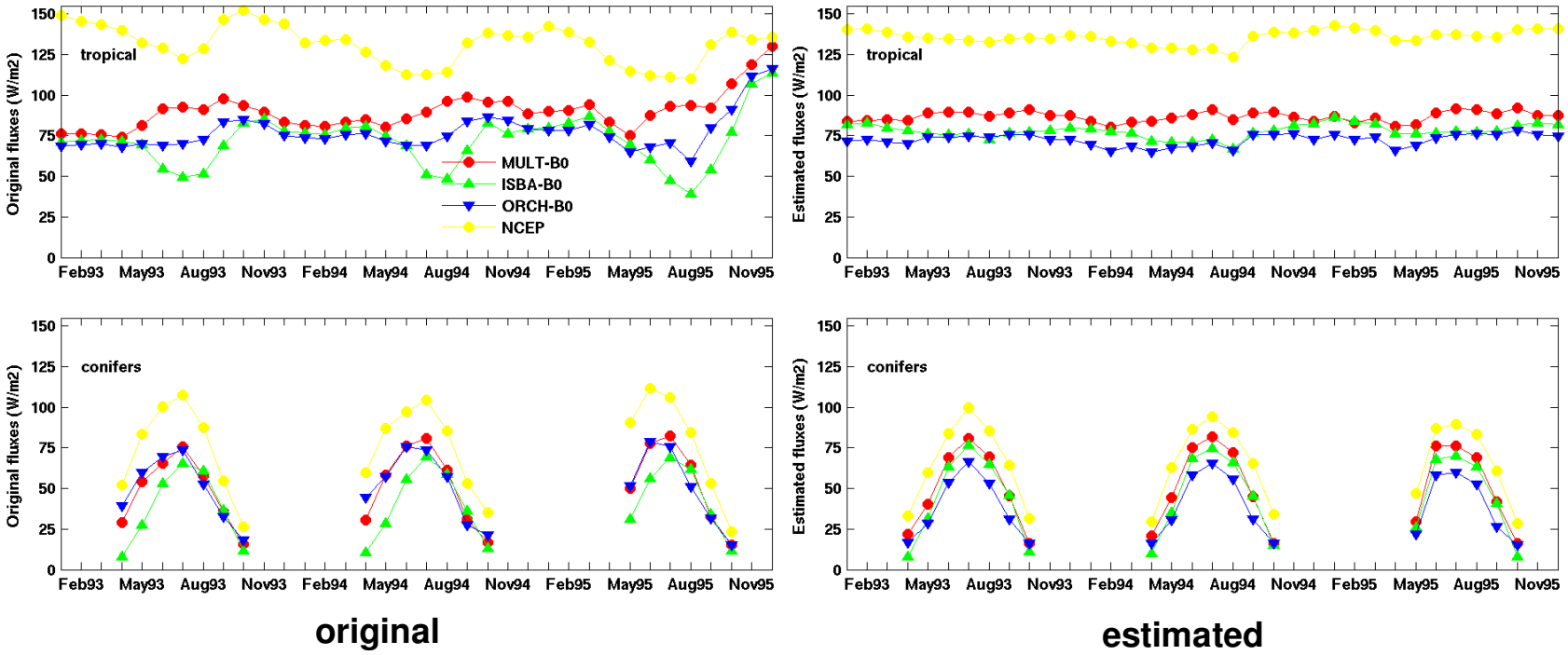
original **estimated**

- temporal patterns are also captured in the estimated fluxes. Some attempts to “correct” fluxes can be observed (e.g. summer ISBA fluxes)

Evaluation of the satellite-driven fluxes

• Comparing **temporal patterns**

e.g. zonally averaged **latent** fluxes in 1993-1995



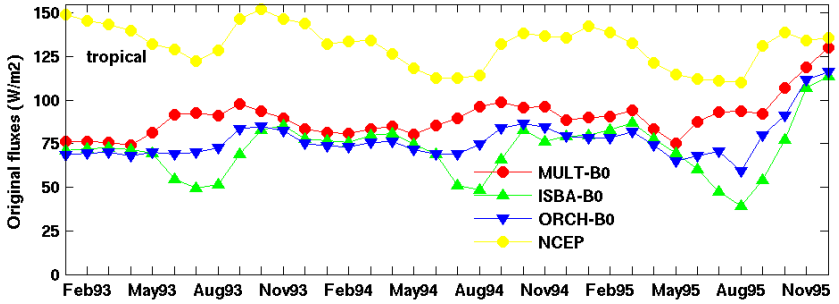
original **estimated**

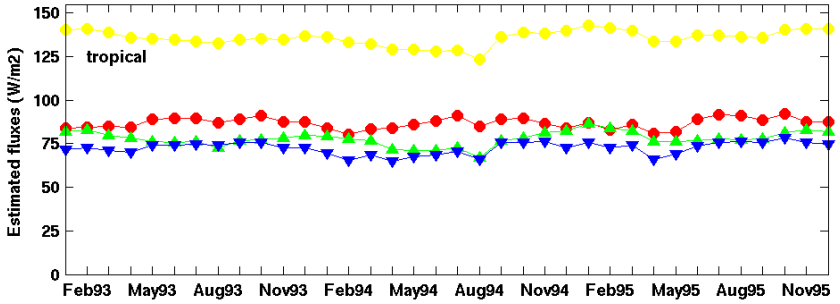
• large fluxes at the end of 1995 “corrected” in the estimated fluxes (fluxes anomaly due an anomaly in GSWP radiative forcing).

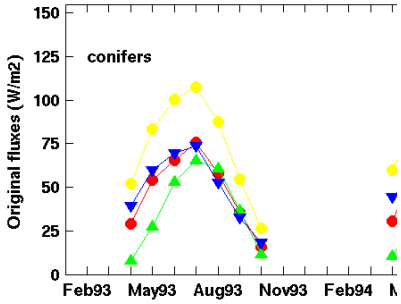
Evaluation of the satellite-driven fluxes

- Comparing **temporal patterns**

e.g. zonally averaged **latent** fluxes in 1993-1995







orig

- large fl
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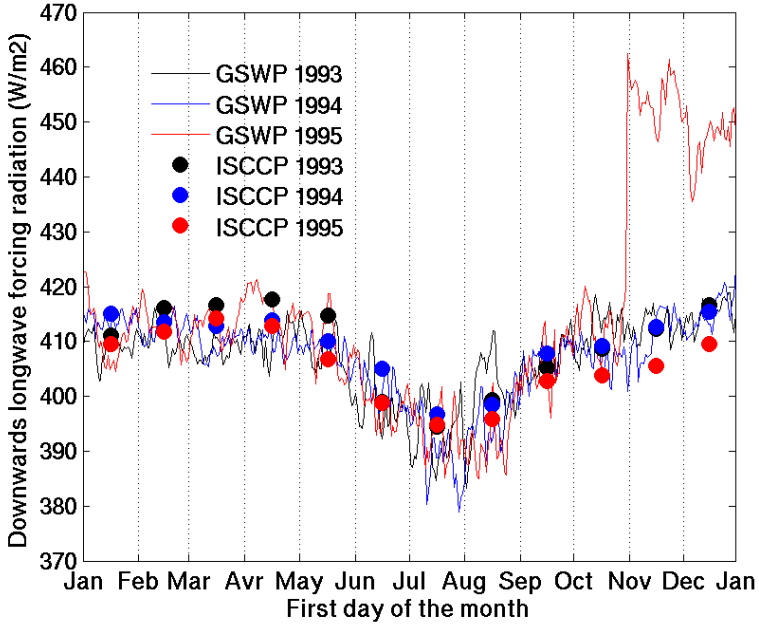

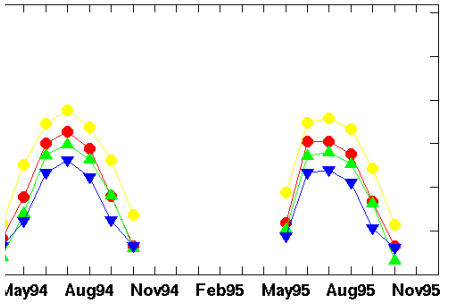

imated

timated fluxes
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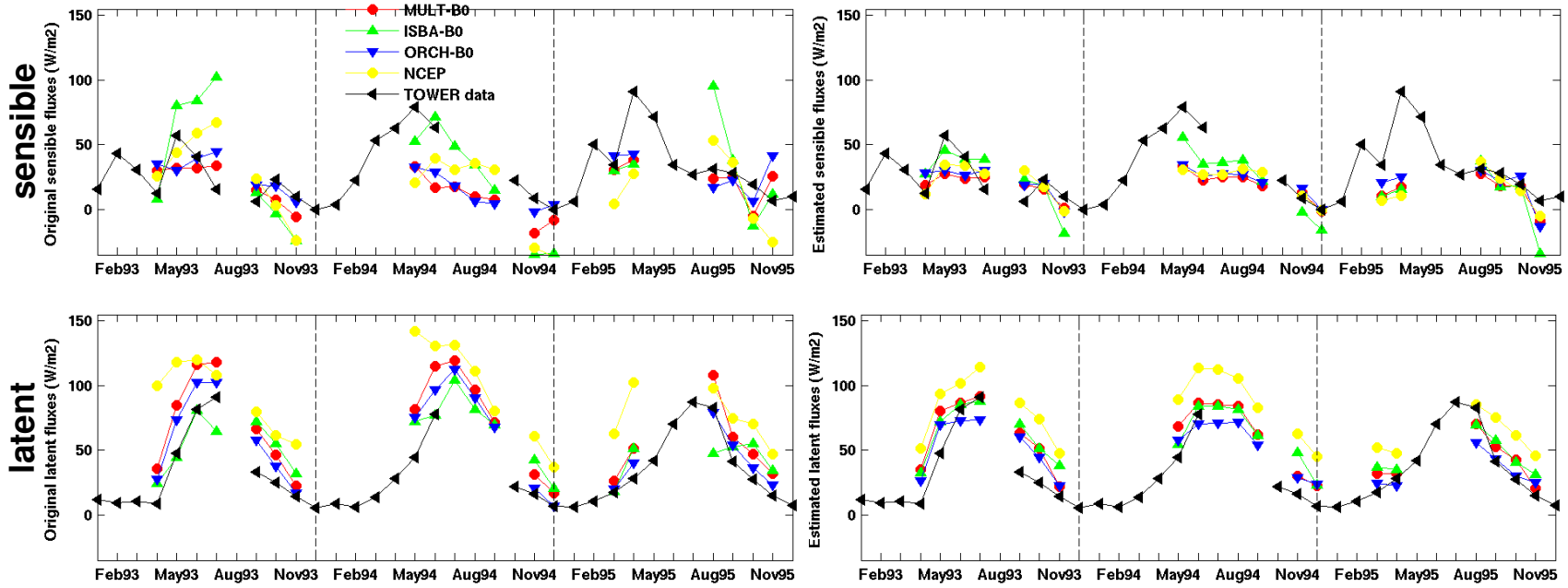
Evaluation of the satellite-driven fluxes

- Comparing with **tower fluxes**

averaged fluxes in 2°x2° box around **Harvard Forest** [72°W-42°N]



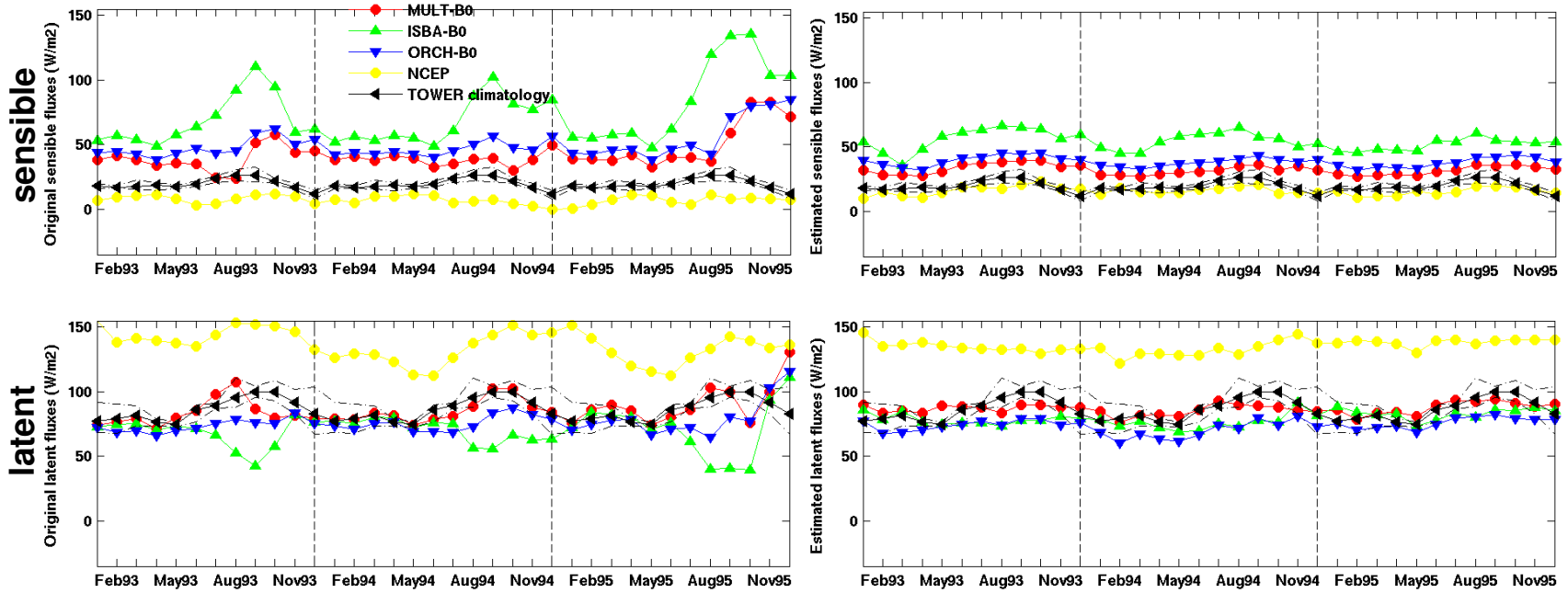
original **estimated**

- less spread in estimated fluxes, but no conclusions can be derived from just one case.

Evaluation of the satellite-driven fluxes

• Comparing with **annual tower climatologies** [2002-2006]

averaged fluxes in 2°x2° box around **Tapajos Forest** [54°W-3°S]



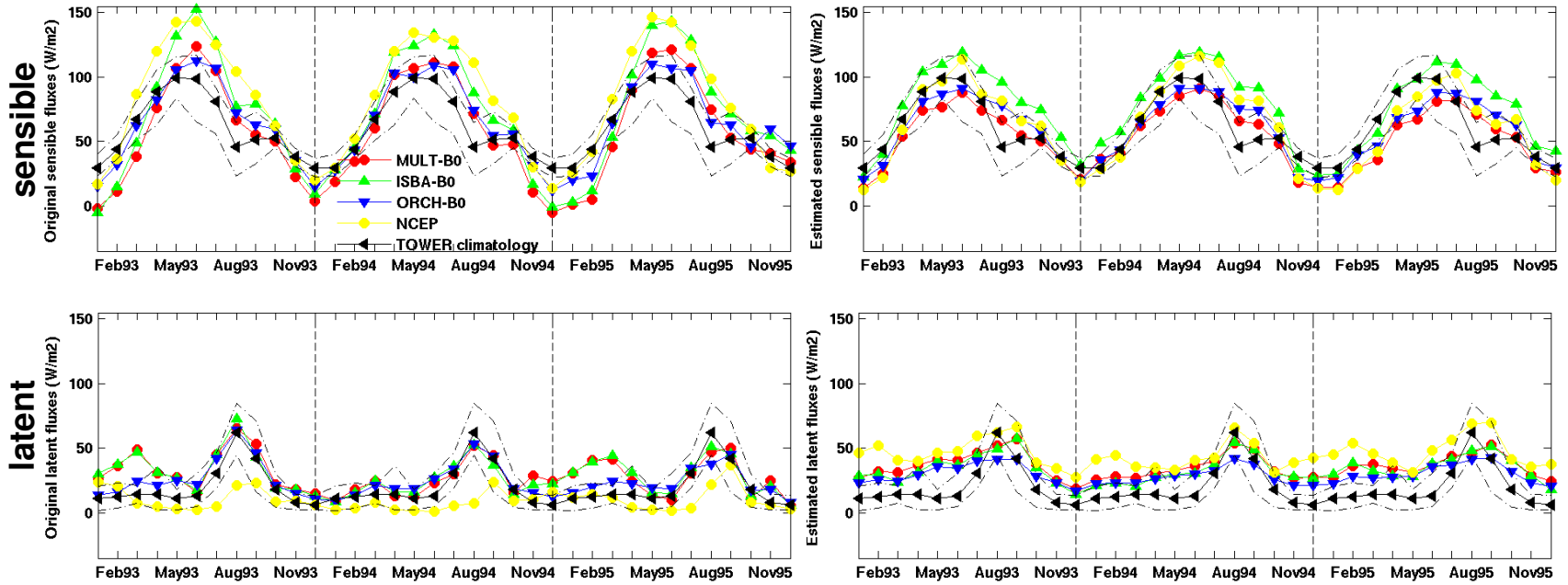
original **estimated**

• extending the comparison by using annual climatologies built by averaging the tower fluxes in the 2002-2006 period.

Evaluation of the satellite-driven fluxes

• Comparing with **annual tower climatologies** [2002-2006]

averaged fluxes in 2°x2° box around **Kendall grassland** [110°W-32°N]



original **estimated**

• estimated sensible fluxes agreeing better here, latent fluxes worst? Difficult to judge from a few examples, attempting a systematic comparison with climatologies from all AmeriFlux stations.

Evaluation of the satellite-driven fluxes

• Comparing with **annual tower climatologies** [2002-2006]

systematic comparison with **76 AmeriFlux stations**

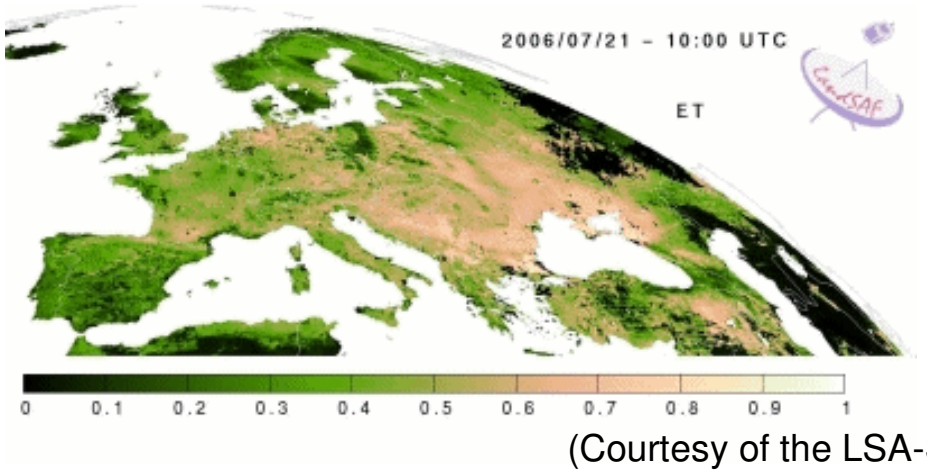
	Correlation		RMSE(%)	
	LSM	SM	LSM	SM
	Sensible flux			
MULT	0.66	0.68	66.3	59.1
ISBA	0.64	0.68	78.5	68.0
ORCH	0.70	0.67	51.8	52.8
NCEP	0.73	0.67	66.7	58.5
	Latent flux			
MULT	0.77	0.78	56.8	46.9
ISBA	0.70	0.71	58.0	55.0
ORCH	0.82	0.79	40.4	47.8
NCEP	0.76	0.75	72.0	64.4

Table 6. Comparison of the fluxes from the multi-model, ISBA, ORCHIDEE, and NCEP models with tower fluxes. The table corresponds to a comparison with a 2000-2006 annual climatology from AmeriFlux data LSM refers to the original model fluxes, SM to the fluxes estimated by each corresponding statistical model. The correlation between model and tower fluxes is given, together with the RMS of the differences between model and tower fluxes, expressed as percentage of the tower fluxes. See the text for more details.

• **similar errors** when comparing the original and estimated fluxes with the annual tower
• comparison **not conclusive** as in this mid-latitude environments is where the land model fluxes do not show the largest differences.

Applications with MSG and METOP-A data

• the same methodology could be used to statistically analyzed the relationship between the LSA-SAF evapo-transpiration estimates produced with MSG data and the Metop-A observations with sensitivity to the heat fluxes.



(Courtesy of the LSA-SAF team)

e.g.

(1) to link monthly means of LSA-SAF ET and Metop-A observations for the available 2007-2008 period, and

(2) to then study the local or temporal deviations of the ET produced by the statistical models to reveal potential modeling or data problems and possible areas of improvement.

Applications with MSG and METOP-A data

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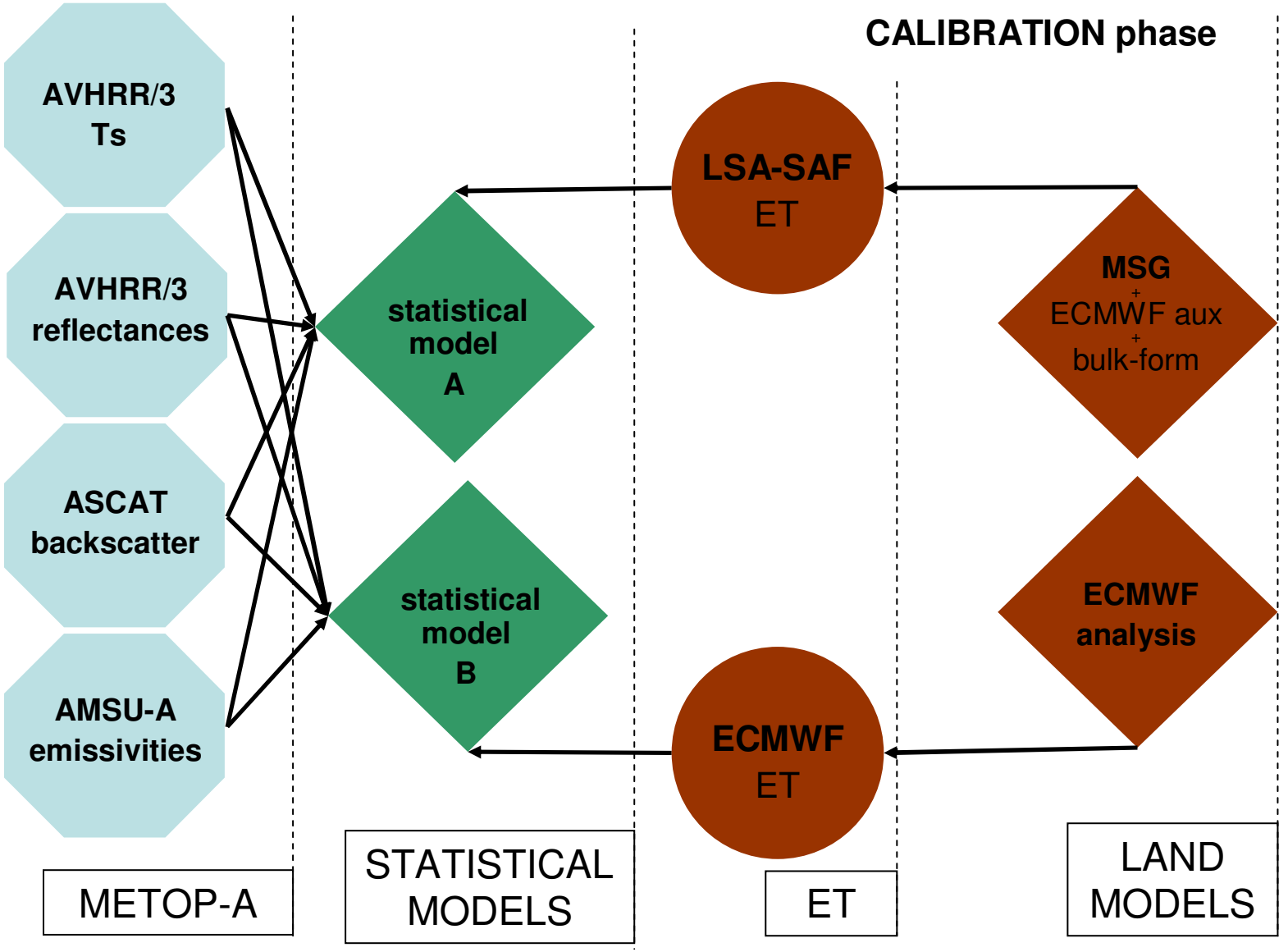
2. Satellite and fluxes
3. Linking satellite and fluxes
4. Fluxes evaluation
5. MSG and METOP-A



Applications with MSG and METOP-A data

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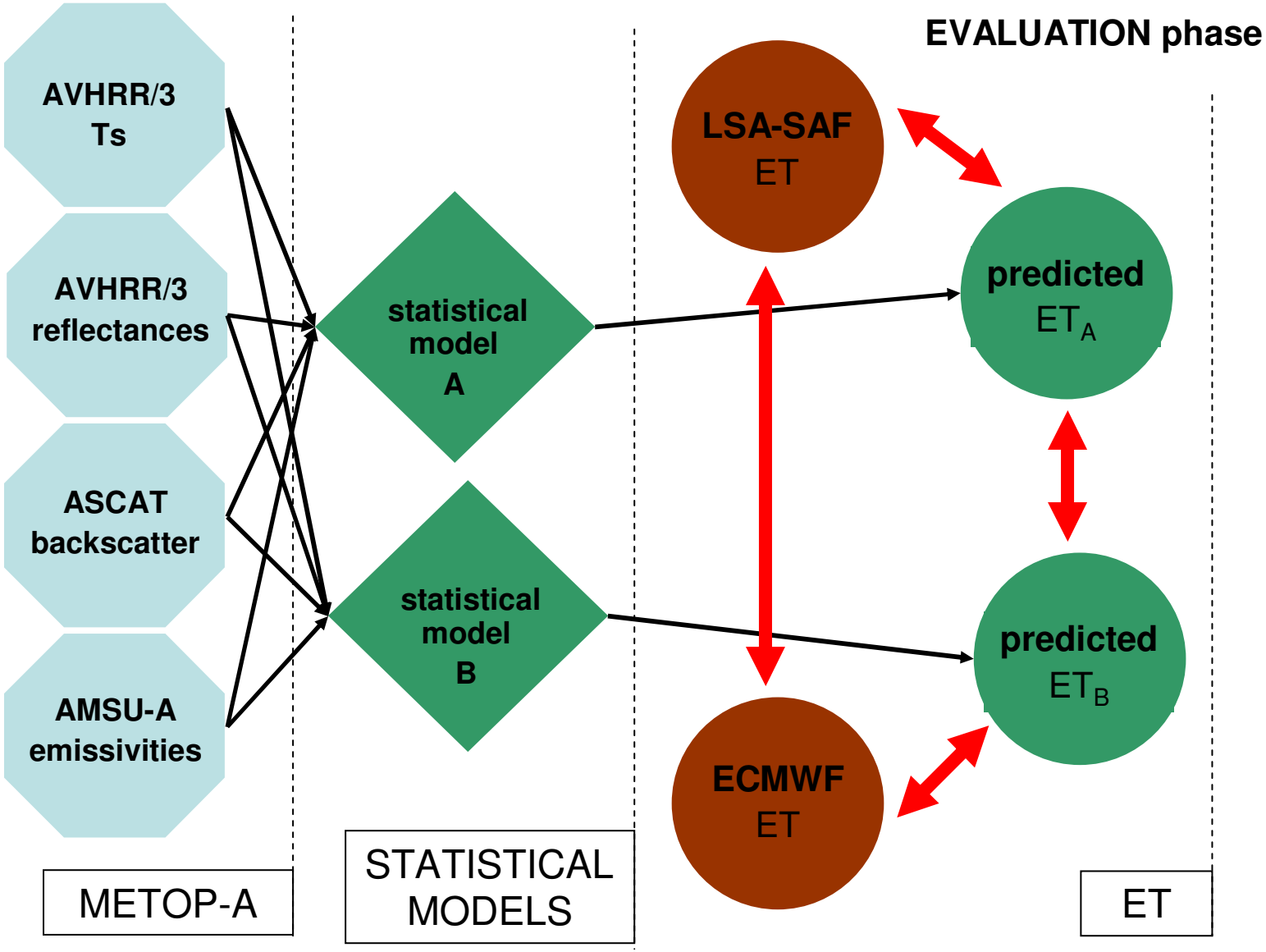


Summary

• Statistical models linking satellite data and fluxes are capable of reproducing the land model fluxes with theoretical RMSE of ~25 W/m^2, proving the the satellite data contain relevant information for flux estimation.

• The statistical models cannot remove global biases in the land model fluxes, but they can do it locally helped by the satellite information for those regions where there is a departure from the global relationship.

• The statistical models cannot be used to derive independent land fluxes from satellite data, but it can be regarded as a method to combine satellite data and land model outputs maximizing relational consistency, and a pragmatic step forward in the search of methods to derive global land heat fluxes.

Summary

- More details in:

  Jimenez, C., C. Prigent, and F. Aires, Towards an estimation of global land heat fluxes from multi-satellite observations, J.Geophys. Res., under review.

  [http://aramis.obspm.fr/~jimenez/]

- A similar approach to estimate soil moisture:

  Aires, F., C. Prigent, and W. Rossow, Sensitivity of satellite microwave and infrared observations to soil moisture at a global scale: 2. Global statistical relationships, J.832 Geophys. Res., 110, D11103, doi:10.1029/2004JD005094, 2005.

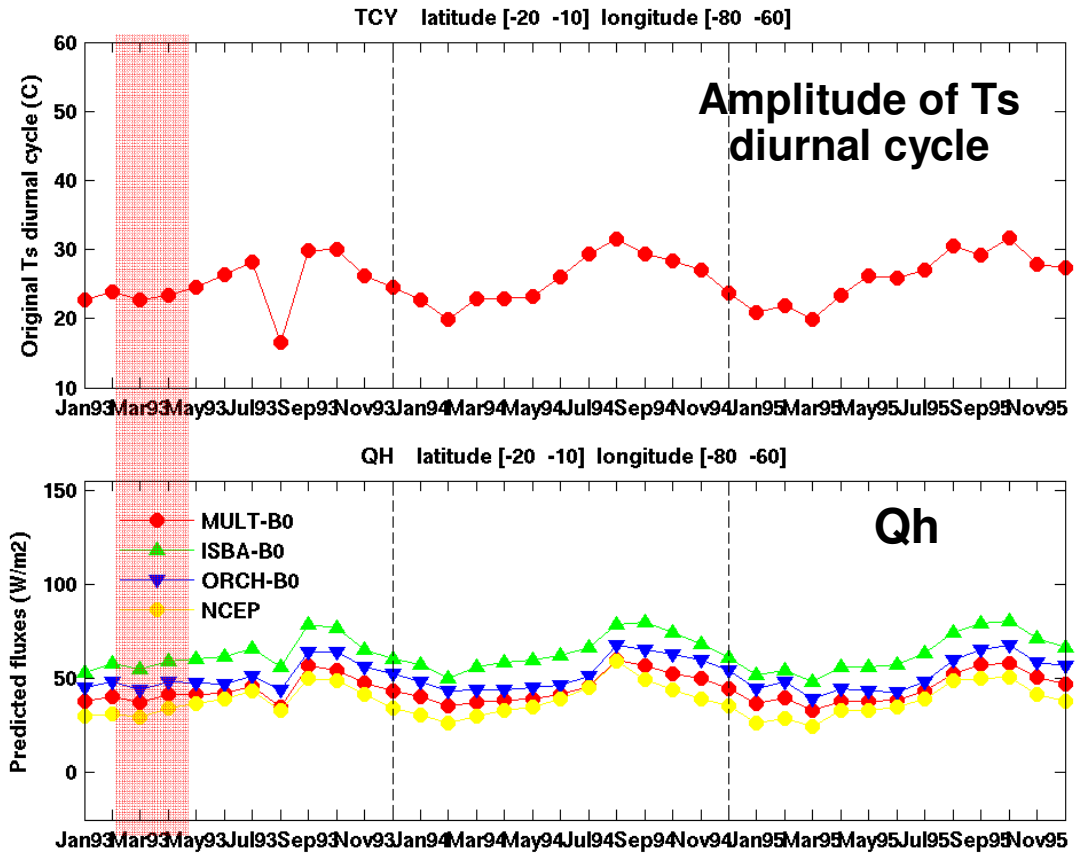
- About this type of methodology:

  Aires, F., and C. Prigent, Toward a new generation of satellite surface products?, J.Geophys. Res., 111, D22S10, 10.1029/2006JD007,362, 2006.823.

Template

BACKUP SLIDES

- The predicted fluxes depend on the "**quality**" of the modeled **fluxes,** but also of the **satellite** data.



e.g. zonal mean fluxes in S. America [20°S-10°S, 80°E-60°E]

Satellite data sensitivity to land heat fluxes

- correlations of **0.8-0.9** and RMSE of ~ **25 W/m²** when using all satellite data
  [e.g. Wang et al., 2007 30-40 W/m²]

- there is **redundancy** in the information provided by the satellite data, specially for the latent fluxes

- net **radiation** is a more elaborated satellite product, **not included** in the remaining tests to have fluxes driven only by the more direct satellite products

Table 2. Correlation coefficients and RMS Errors for a non-linear estimation between different combinations of individual groups of satellite-derived variables and the sensible and latent fluxes. 'All Groups' means with all the satellite variables listed in Table 1. 'No variable X' means all variables but the variable X. The RMS errors are given in W/m² and as a percentage of the mean flux (in brackets).

	Correlation		RMS	
Satellite products	GSWP	NCEP	GSWP	NCEP
			Sensible flux	
All groups	0.83	0.84	16.7(36.0)	23.5(42.4)
No Emissivity	0.78	0.80	18.7(40.2)	26.0(46.9)
No Backscatter	0.79	0.81	18.5(39.7)	25.8(46.5)
No Reflectance	0.78	0.80	18.7(40.0)	26.0(47.0)
No Skin Temperature	0.69	0.75	21.9(47.0)	29.1(52.5)
No Diurnal Cycle	0.73	0.78	20.5(44.0)	27.2(49.2)
No Net Radiation	0.79	0.81	18.4(39.6)	25.5(46.1)
			Latent flux	
All groups	0.92	0.92	14.2(30.5)	22.0(39.7)
No Emissivity	0.88	0.87	17.0(36.6)	27.1(48.9)
No Backscatter	0.88	0.87	17.0(36.3)	27.3(49.2)
No Reflectance	0.86	0.87	18.5(39.7)	27.6(49.9)
No Skin Temperature	0.87	0.87	17.9(38.5)	27.5(49.7)
No Diurnal Cycle	0.88	0.88	16.8(36.2)	27.0(48.7)
No Net Radiation	0.89	0.89	16.5(35.4)	25.8(46.7)

Satellite data sensitivity to land heat fluxes

- **Sensible fluxes** are more correlated to the net radiation and the surface skin temper. and its diurnal cycle amplitude.

- **Latent fluxes** are more correlated to the net radiation, the AVHRR reflectances and the MW emisivities.

Table 1. Correlation coefficients and RMS errors for a non-linear estimation between individual groups of satellite-derived variables (SSM/I emissivity, ERS backscatter, AVHRR reflectance, and ISCCP skin temperature, amplitude of its diurnal cycle and net radiation) and the sensible and latent fluxes (GSWP multi-model analysis and NCEP reanalysis). The RMS errors are given in W/m^2 and as a percentage of the mean flux (in brackets).

	Correlation		RMS	
Satellite products	GSWP	NCEP	GSWP	NCEP
			Sensible flux	
Emissivity	0.44	0.61	27.1(58.1)	34.9(63.0)
Backscatter	0.32	0.52	28.6(61.3)	37.5(67.7)
Reflectance	0.42	0.59	27.4(58.8)	35.4(63.8)
Skin Temperature	0.64	0.63	23.0(49.5)	34.1(61.6)
Diurnal Cycle	0.59	0.71	24.4(52.3)	30.8(55.5)
Net Radiation	0.69	0.70	21.8(46.8)	31.5(56.9)
			Latent flux	
Emissivity	0.80	0.83	21.6(46.2)	31.5(56.9)
Backscatter	0.70	0.75	25.6(55.0)	36.7(66.2)
Reflectance	0.82	0.79	20.2(43.4)	34.5(62.4)
Skin Temperature	0.48	0.48	31.5(67.7)	49.3(89.1)
Diurnal Cycle	0.72	0.76	24.9(53.4)	36.2(65.3)
Net Radiation	0.82	0.84	20.6(44.3)	29.5(53.4)

Satellite data sensitivity to land heat fluxes

• Comparing the fluxes estimated from the statistical model driven by the satellite-data and the original LSM fluxes is used to analyze the **sensitivity** of the satellite observations to the land fluxes.

What's expected?

(a) Rn = Qh + Qle + Qg

Net radiation, Sensible, Latent, Ground heat flux

(b) Qh = cp Ch x (Ts - Ta)

Surface, Air temperature

(c) Qle = L Cle x (Ms - Ma)

Surface, Air moisture

Evaluation of the satellite-driven fluxes

- **Global errors**

- correlations of **0.8-0.9** and RMSE of ~ **25 W/m²** when using all satellite data
  [e.g. Wang et al., 2007 30-40 W/m²]

- there is **redundancy** in the information provided by the satellite data, specially for the latent fluxes

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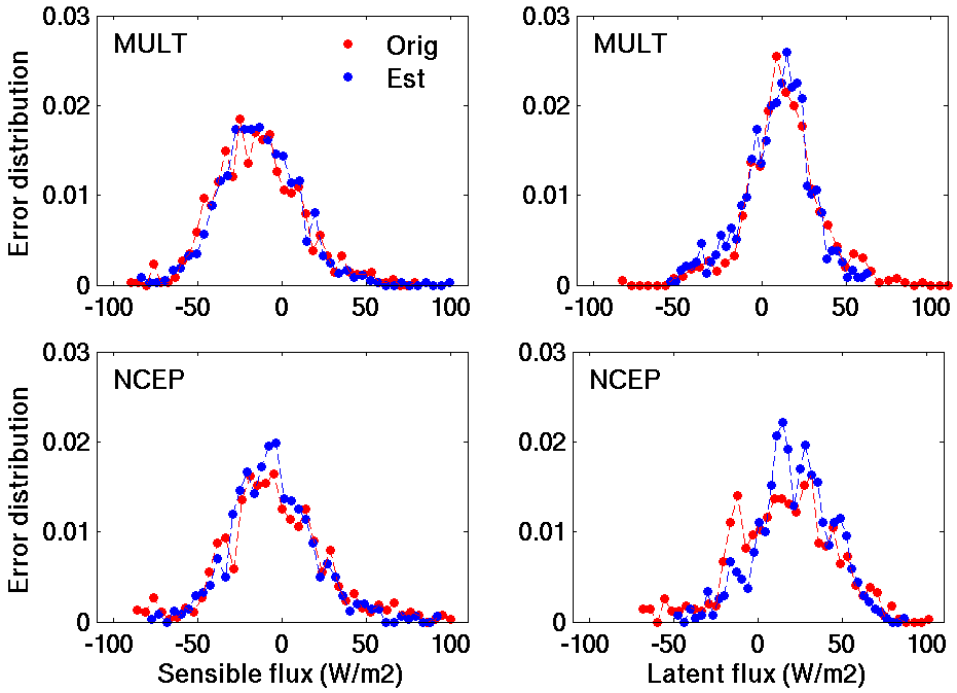
Evaluation of the satellite-driven fluxes

• Comparing with **annual tower climatologies** [2002-2006]

systematic comparison with **76 AmeriFlux stations**



• **similar errors** when comparing the original and estimated fluxes with the annual tower

• comparison **not conclusive** as it cannot be extended to other geographical areas where the land model fluxes show larger differences.