Using microwave emissivities for the estimation of global land surface heat fluxes

Carlos Jimenez[1], Catherine Prigent[1], Filipe Aires[2]

[1]LERMA, Observatoire de Paris, France
[2]LMD, IPSL, Université Paris VI, France

Laboratoire d'Étude du Rayonnement et de la Matière en Astrophysique

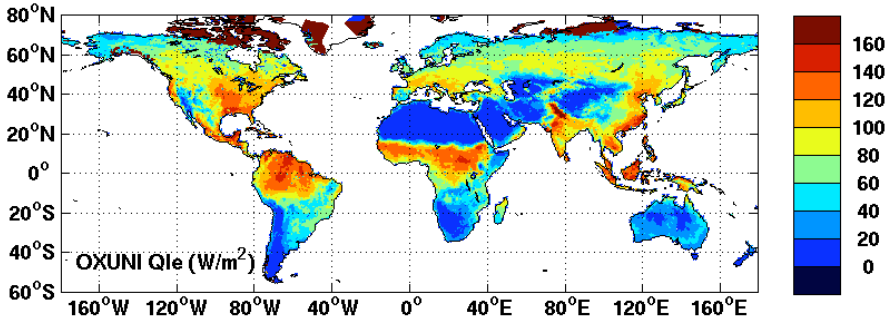
Motivation

• Estimating land **surface heat fluxes** is challenging as the fluxes do not have a unique signature that can be remotely or directly detected. Some **possibilities**:

[e.g. monthly latent fluxes August 93]

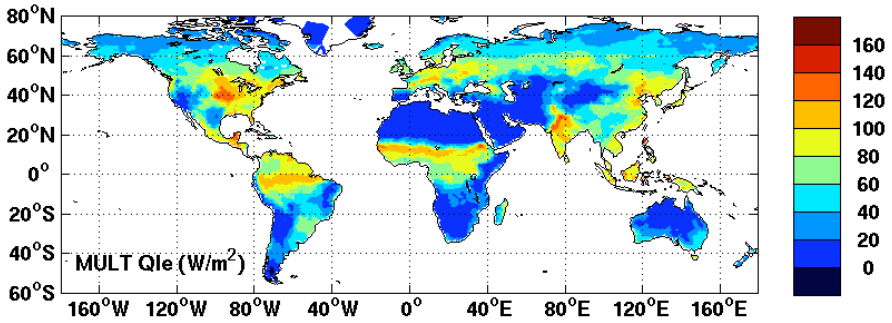
(a) using observations to infer the properties of the atmosphere and surface needed to derive the fluxes by **physically** based **formulations**

e.g. (Fisher J., 2007, Rem. Sens.Envir.)



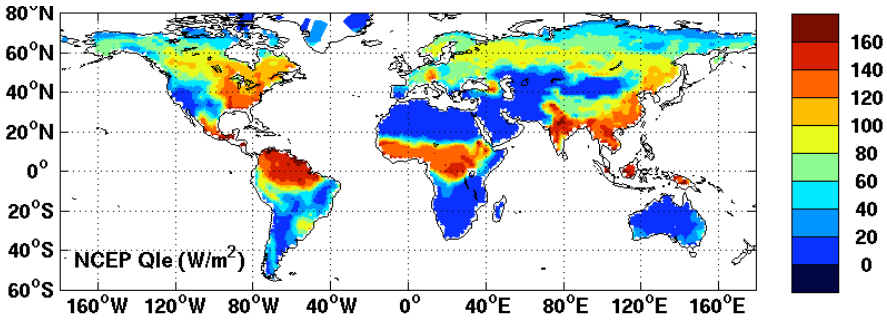
(b) using observations to **force** 'complex' **land surface model**, e.g GSWP-2

(Dirmeyer P. (2006), BAMS)



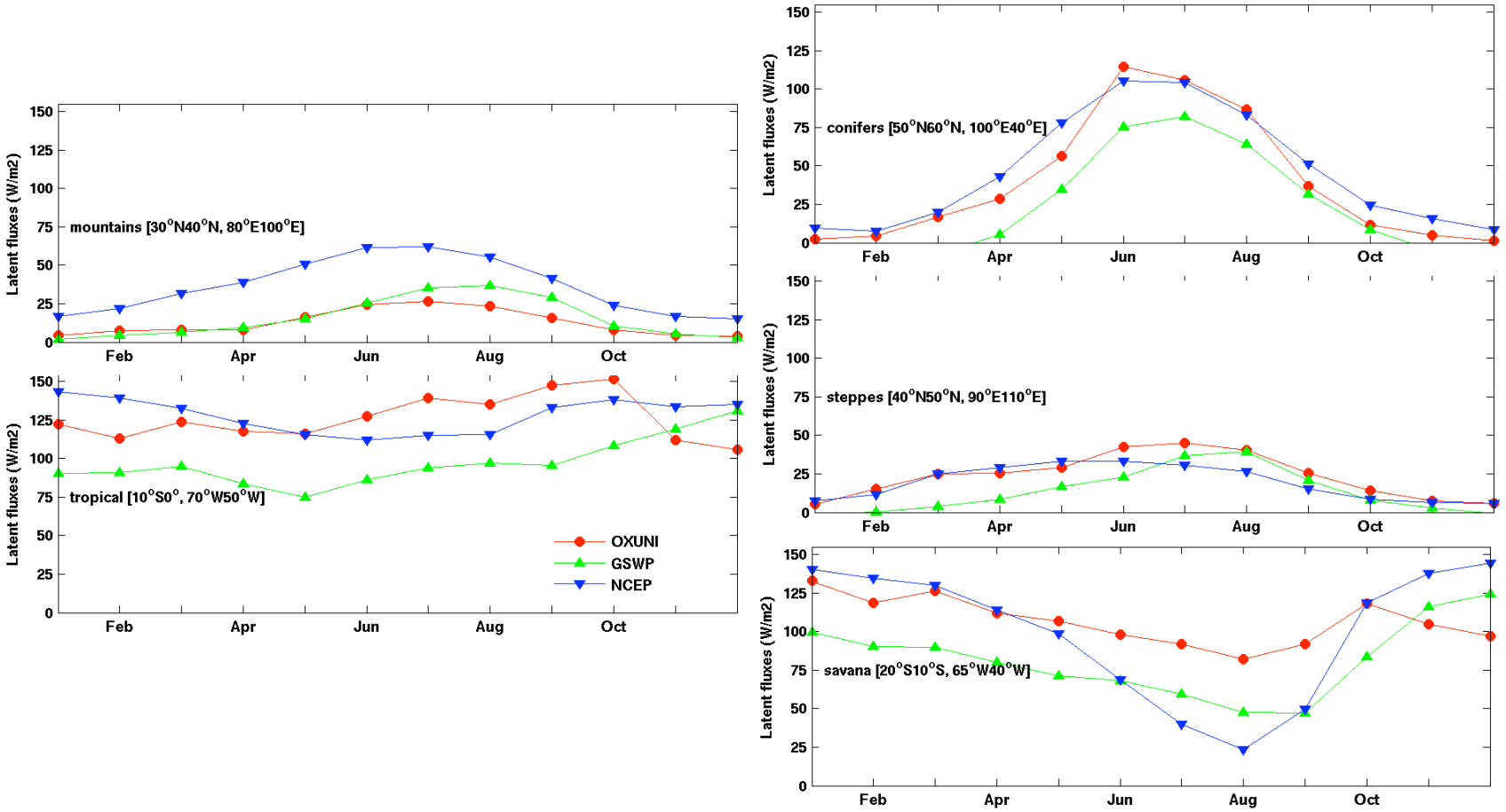
(c) **assimilating** observations into a coupled land-atmosphere model e.g NCEP reanalysis

(Kalnay. E. (1996), BAMS)



Motivation

e.g. latent flux **annual climatologies** (1993-1995) for different ecosystems



• a large spread of values is observed when comparing the existing global estimates of land surface heat fluxes.

Motivation

• Several global data analysis activities are conducted in the frame of **GEWEX** to complete the description of the energy and water cycle.

• Most products are now being worked on (clouds, aerosols, radiative fluxes, precipitation, ocean surface turbulent fluxes, water vapour, temperature, and ozone) apart from the **land surface heat fluxes**.

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 in Melbourne, Aug 2009.

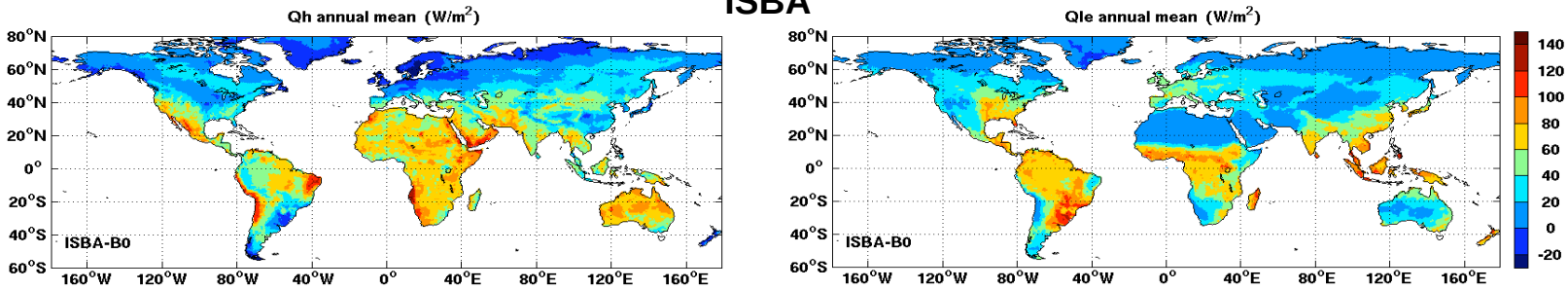
(http://www.gewex.org/projects-GRP.htm)

Estimating fluxes: land surface models

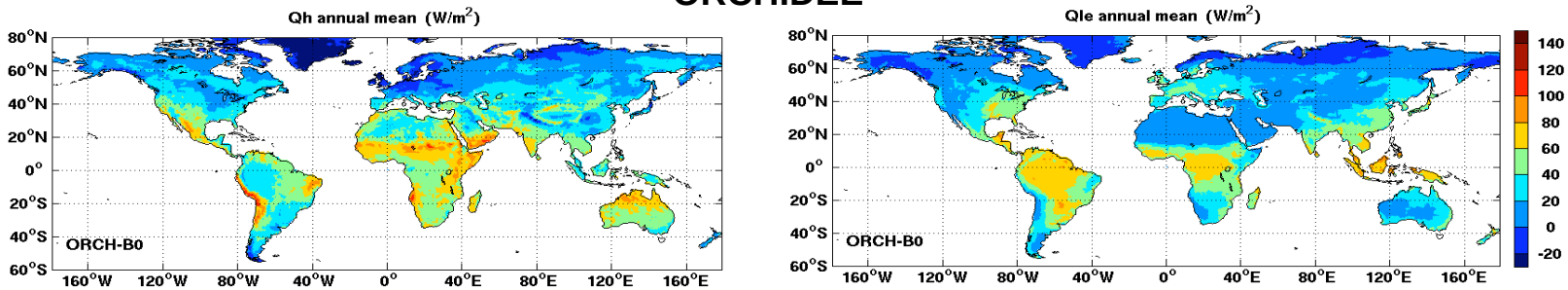
• Most global heat flux estimates are coming from coupled/off-line **SAVT** schemes with some surface parameters derived from remote sensing data (e.g LAI), many others from approximate relationships with vegetation, soil type or climate regime.

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

ISBA



ORCHIDEE



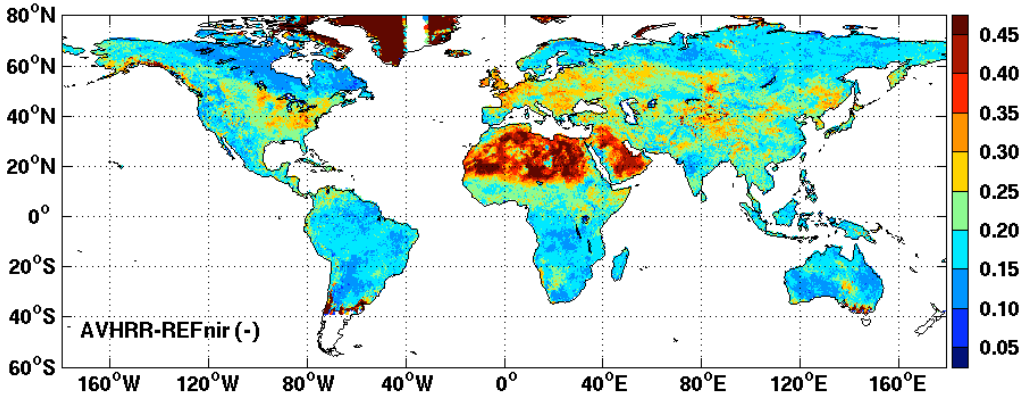
• Not easy to **calibrate/tune** the comprehensive parameterizations of the land models when doing the transition from the **local/regional to the global** scale.

Estimating fluxes: satellite observations

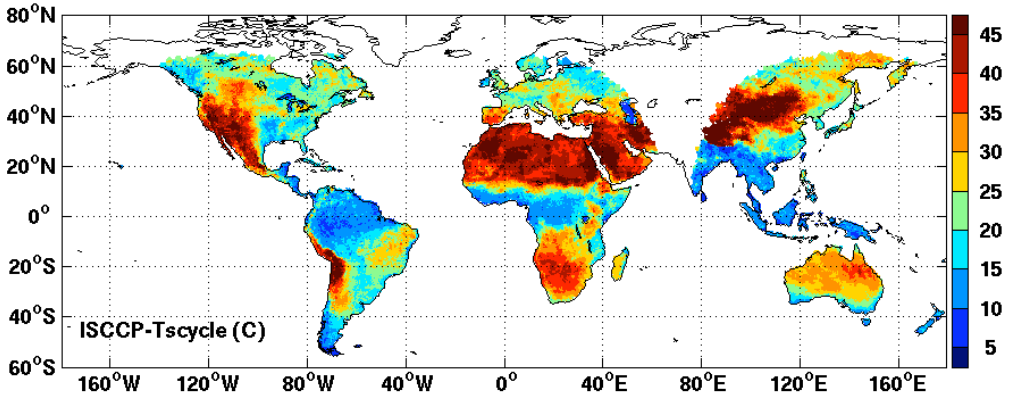
• There is **satellite data** with temporal and spatial resolutions compatible with surface models and with expected sensitivity to the land fluxes.

e.g. monthly mean values for June 93

AVHRR **reflectances** [visible and near-IR]



ISCCP **skin temperature** [diurnal cycle, thermal infrared]
[Aires et al. (2004), JGR]

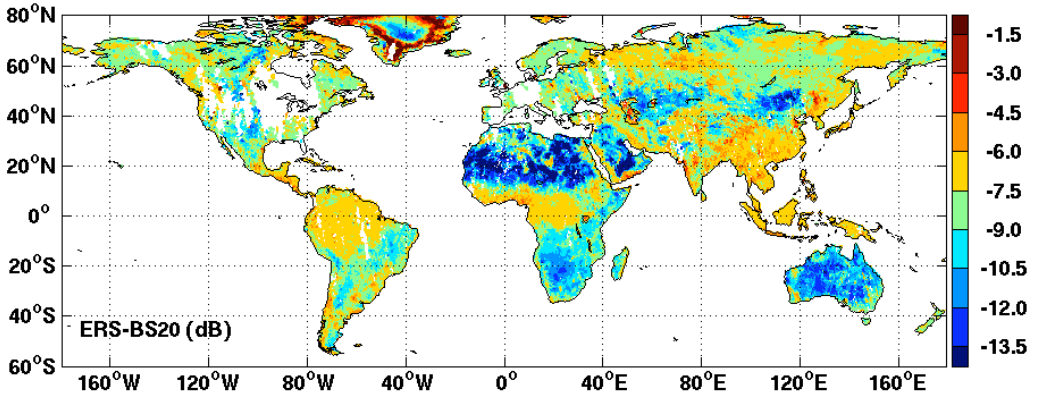


Estimating fluxes: satellite observations

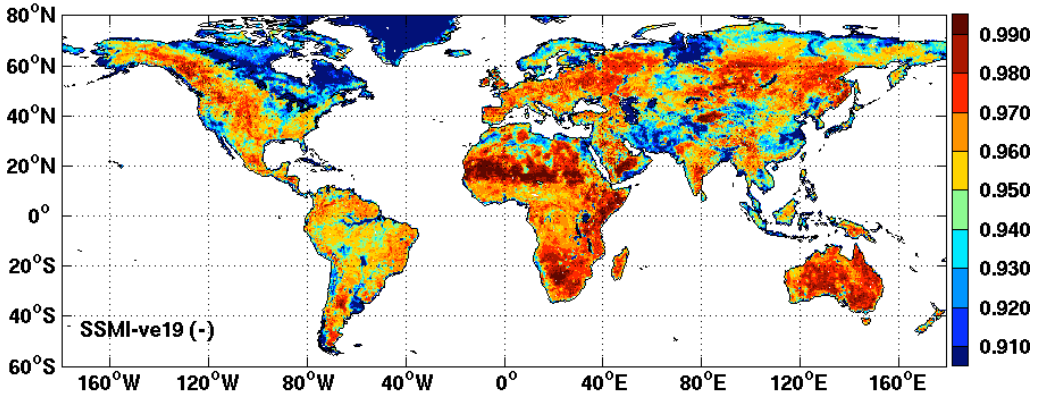
• There is **satellite data** with temporal and spatial resolutions compatible with surface models and with expected sensitivity to the land fluxes.

e.g. monthly mean values for June 93

ERS **backscattering**
(active microwave)



SSM/I **emissivities**
[passive microwave]
[Prigent et al. (2006), BAMS]



		AVHRR	ISCCP	ERS	SSMI
global correlation with NCEP latent fluxes	**R**	0.79	0.76	0.75	0.83

Combining observations and model fluxes

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

• Our **proposal**: to use an statistical model to provide the mapping between the observations and the land fluxes.

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

Combining observations and model fluxes

Example

Applying the statistical modeling with a suite of coincident:

Satellite observations:

- 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 **backscattering** [at 20° and 45° incident angles]
- AVHRR **reflectances** [visible and near-infrared].

Global fluxes:

- **GSWP-2** Global Soil Wetness Project exercise
  - 15 LSMs driven in off-line mode using global meteorological forcing 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 frozen global data assimilation system with a couple land-atmosphere scheme.

[monthly means in 1993-1995, 0.25º x 0.25º]

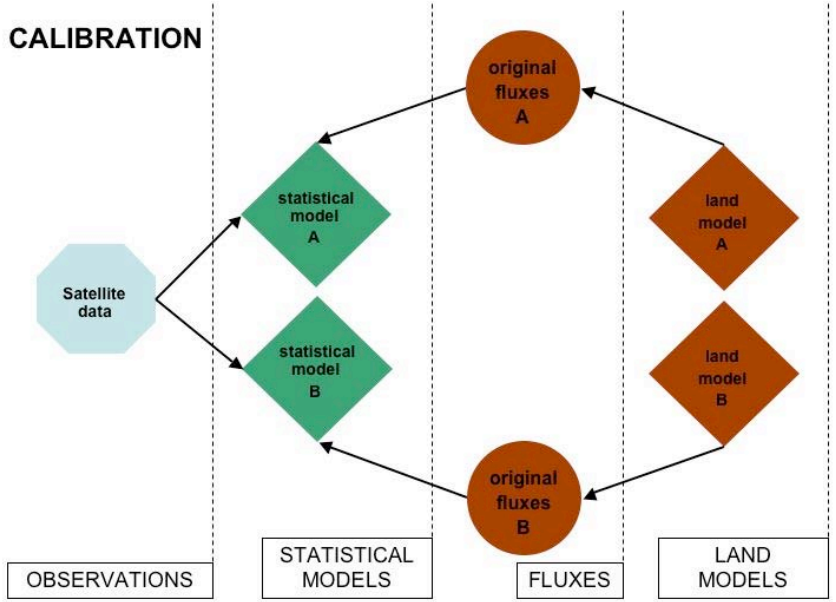
[Jimenez et al. (2009), JGR]

Methodology

Phase 1

The statistical models learn the global relationships between observations and fluxes.

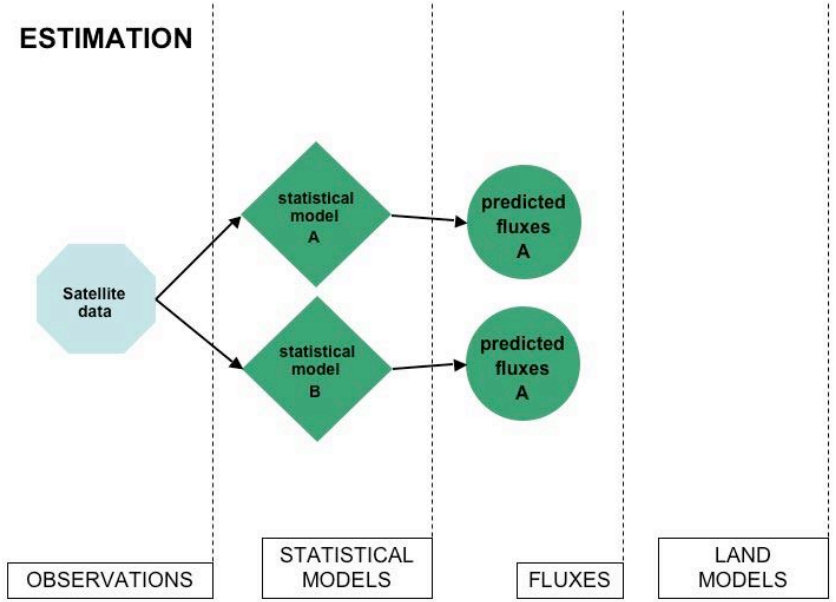
[e.g. calibrating with Feb-May-Aug-Nov 93]



Phase 2

The statistical models map the observations into fluxes using the learned global relationships.

[estimating fluxes for rest of 93-95]



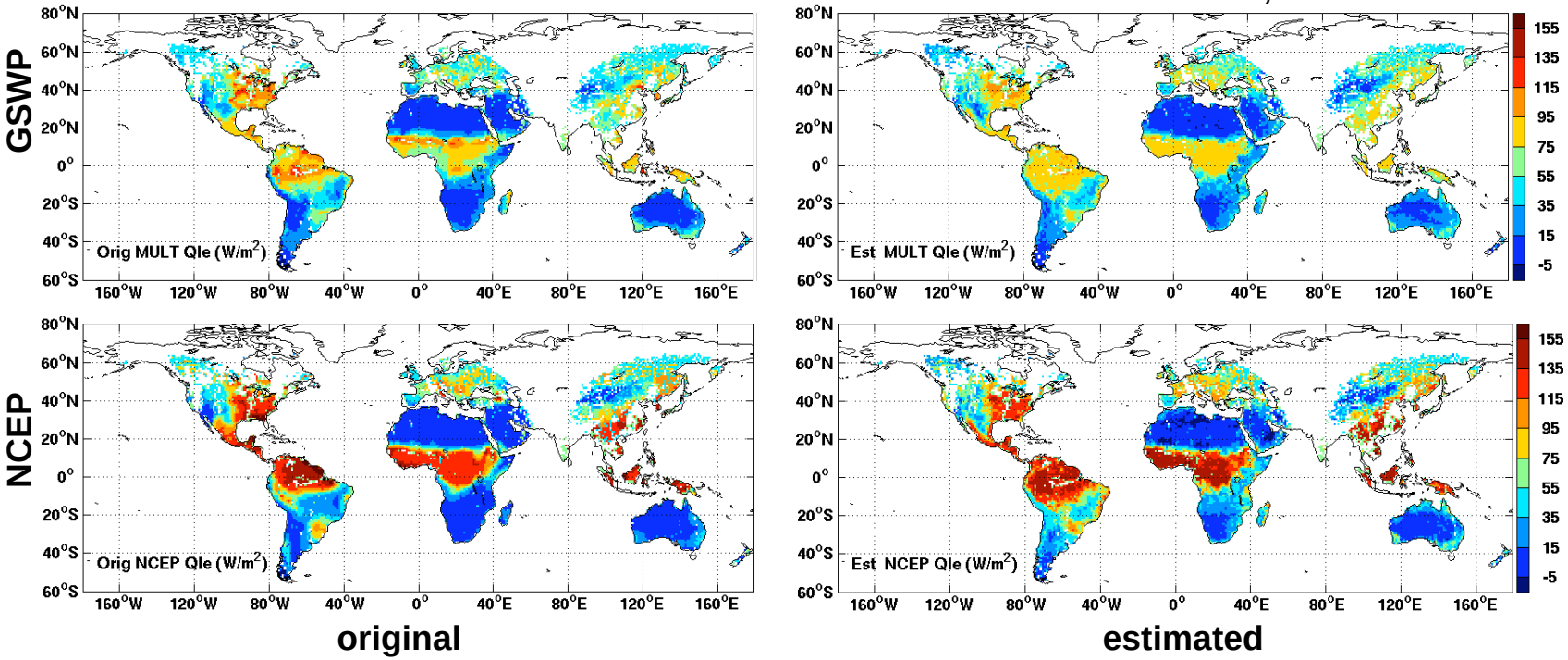
Applications

- **Producing land heat fluxes**

  - the **observation-driven fluxes** are a new product combining the information from the observations and the land surface model.

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

r ~ **0.9,** RMSE ~ **25 W/m²**

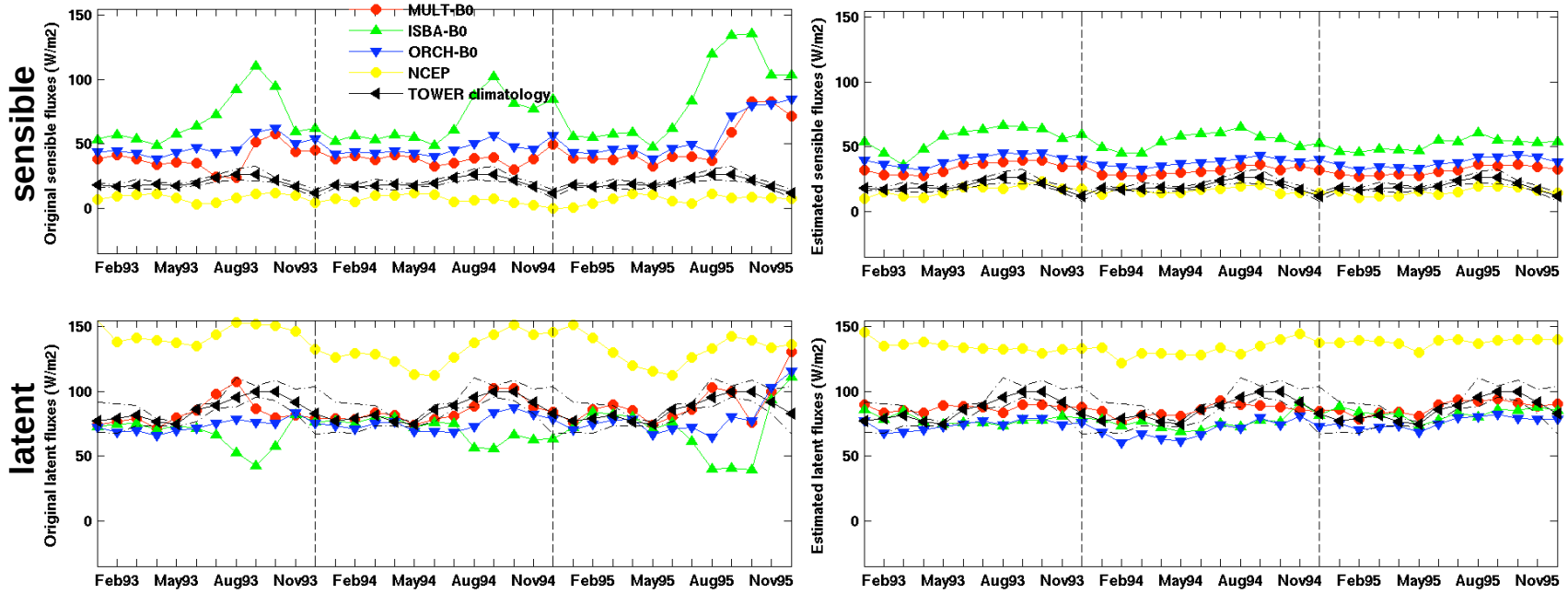


- Is the new product merging observations and land model outputs a **better estimate**? Global evaluation/validation of heat fluxes remains very challenging.

- **Model development**

  - for specific regions and times there may be no consistency between the LSM fluxes and the statistical model fluxes: this can be used to diagnose **potentially anomalous LSM fluxes.**

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



original **estimated**

- in this example the estimated fluxes seem to partition more according with the expected fluxes that some of the original fluxes.

- **Model development**

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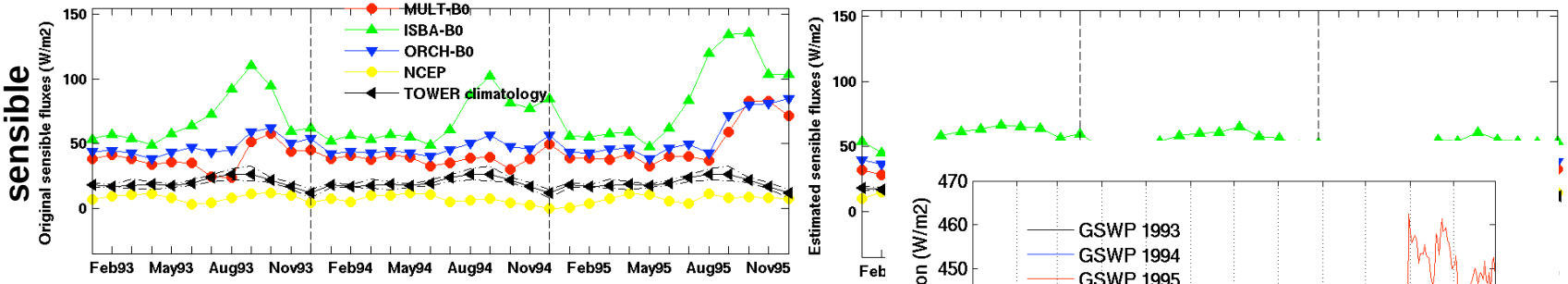
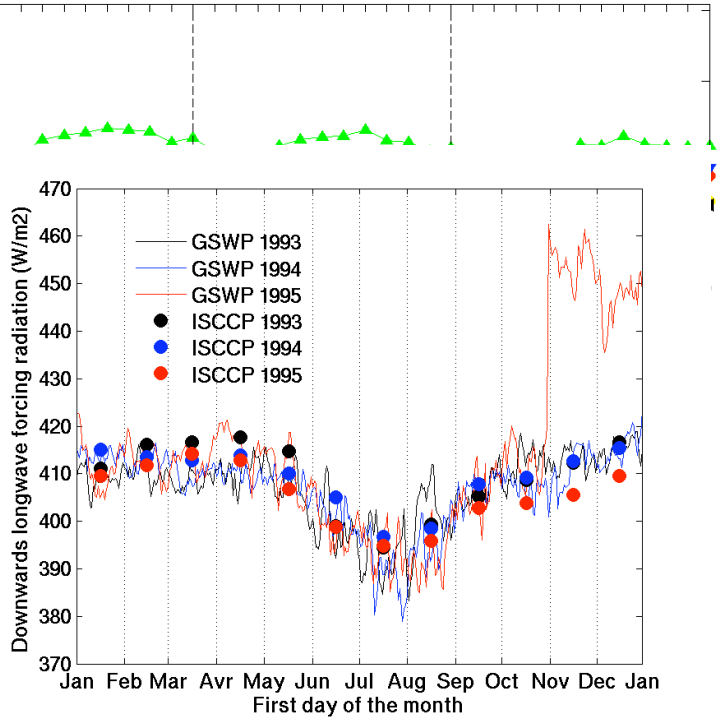


original



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

- **caution** when interpreting the differences, as they can also be related to **problems** with the observational **data** or the statistical **model**.

Applications

- **Assimilation**

  - the observations mapped into state variables by the statistical model could be integrated into the LSM by standard variational **assimilation schemes.**

Cost function to combine information from the observations and the LSM:

$$J(x_0) = \frac{1}{2}(x_0 - {x_0}^b)^T \boldsymbol{B}^{-1}(x_0 - {x_0}^b)$$

background term

$$+ \frac{1}{2}\sum_{i=0}^{n}(x(t_i) - {x_i}^r)^T \boldsymbol{R}_i(x(t_i))^{-1}(x(t_i) - {x_i}^r)$$

LSM satellite-derived statistical model error

  - there exist techniques to calculate $\boldsymbol{R_i}$ and give more weights to the statistical model predictions when there are more reliable.

[Aires (2004), JGR]

  - as the statistical model was calibrated with the LSM outputs, we force **consistency** between **LSM** and **satellite-derived state variables** and minimize problems trying to assimilate exogenous inputs (bias correction, pdf matching, ….)

Summary

- ✓ **Microwave emissivities** can be a significant source of information at the time and spatial resolutions required for the production of a global climatology of land surface heat fluxes.

- ✓ We propose an **statistical analysis** to globally map a dataset of multi-frequency observations (including the emissivities) into land surface model (LSM) heat fluxes.

- ✓ The **satelite-driven fluxes** can be considered as a new product that merges information from the observations and the LSMs.

- ✓ The methodology can also be used for:

  - **model development** as discrepancies between the original LSM state variable and the satellite-driven variable can potentially identify LSM problems.

  - including satellite observations into **assimilation** schemes minimizing the problems related to assimilating exogenous inputs.

Summary

- **For further details:**

[Jimenez, C., C. Prigent, and F. Aires, Toward an estimation of global land surface heat fluxes from multisatellite observations, J. Geophys. Res., 114, D06305, 2009.]

[Aires, F., and C. Prigent, Toward a new generation of satellite surface products?, J. Geophys. Res., 111, D22S10, doi:10.1029/2006JD007362, 2006.]

[Prigent, C., F. Aires, and W. B. Rossow, Land surface microwave emissivities over the globe for a decade, Bul. Amer. Meteorol. Soc., doi:10.1175/BAMS-87-11-1573, 1573-1584, 2006.]

[Aires, F., C. Prigent, W. B. Rossow, Temporal interpolation of global surface skin temperature diurnal cycle over land under clear and cloudy conditions, J. of Geophy. Research, 109, D06214, doi:10.1029/2003JD003527, 2004.]

[Aires, F., Neural network uncertainty assessment using Bayesian statistics with application to remote sensing: 1. Network weights, J. of Geophy. Research, D10303, doi:10.1029/2003JD004173, 2004.]

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