Structural spatial error in turbulent Energy fluxes.

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Objectives

Part 1: TIEOHF

- Study spatial and temporal covariances in turbulent heat flux product biases (against ICOADS ref)
- Develop structural error patterns
  - annual mean, seasonal cycle
- Quantify structural error v random errors on regional basis
  - Structural (correlated) + Regional (uncorrelated)

Part 2: "CAGE-like" study => CLIVAR CONCEPT-Heat

- Use structural error patterns in closing Global and Regional heat (and water) budgets extending NASA Energy and Water cycle Study: CLIVAR CONCEPT-Heat
  - L'Ecuyer et al (2015), Rodell et al. (2015)

Data

HOAPS
SeaFlux
IFREMER
OAFlux
JOfuro

Turbulent fluxes (Latent/Sensible) over Oceans
PI: Abderrahim Bentamy
Bentamy et. al. (2017) Rem. Sens. Env.

One of the main tasks of OceanHeatFlux project is to assemble a large set of flux related data, including existing flux data collections, relevant inputs for flux calculation and validation data. A significant effort is also dedicated to the homogenization of these data to ease their combination and intercomparison.

This section summarizes the type and list of datasets assembled by OHF project.

A complete online detailed product catalogue and how to access the data is described on this page.

Reference flux dataset

The reference dataset includes the major existing collections of turbulent flux estimation. They have been homogenized so they are now all converted into the same format and conventions (NetCDF), and provided on the same spatial (1/4 degree) and temporal (daily) resolution, over the same 1999-2009 period.

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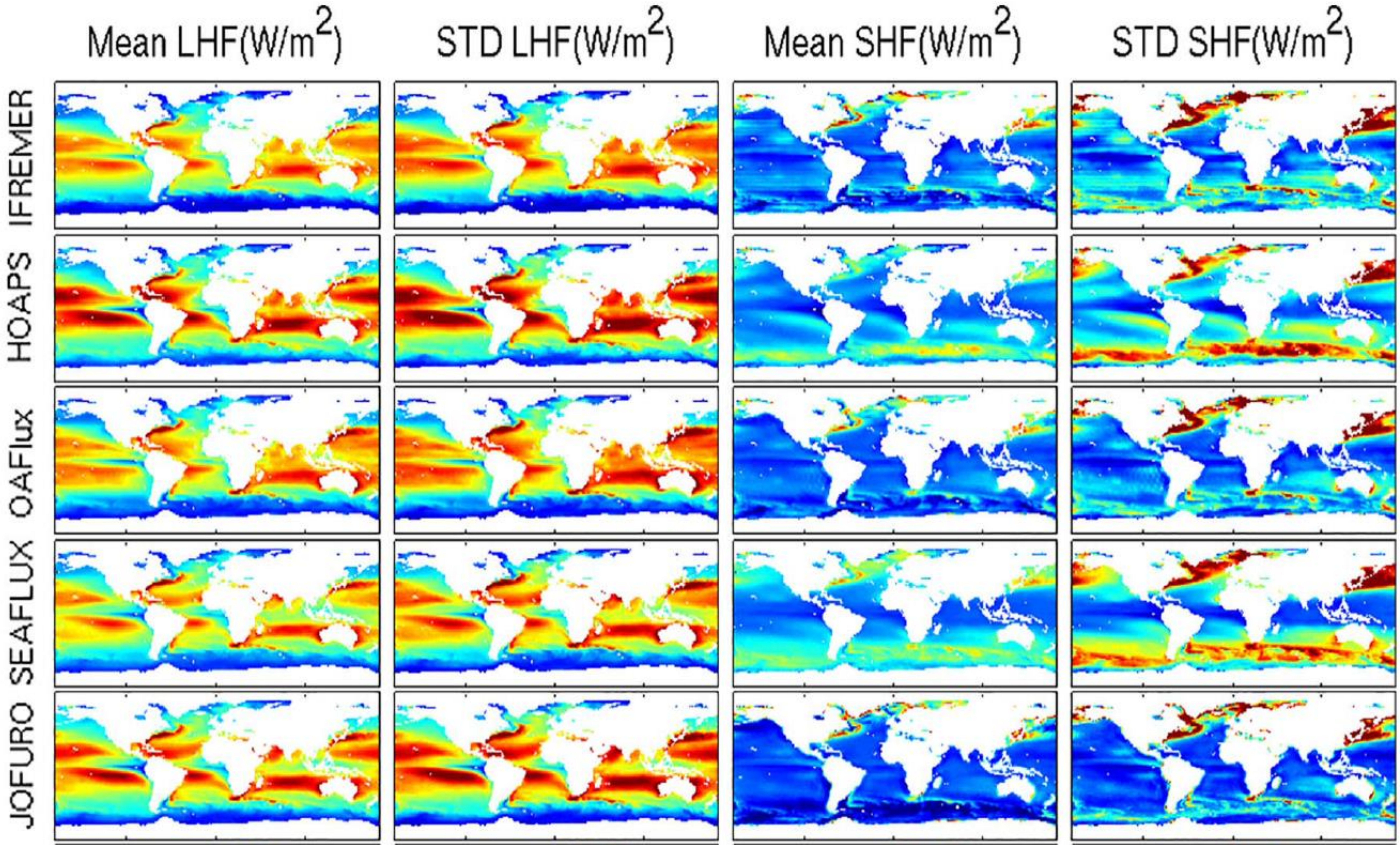
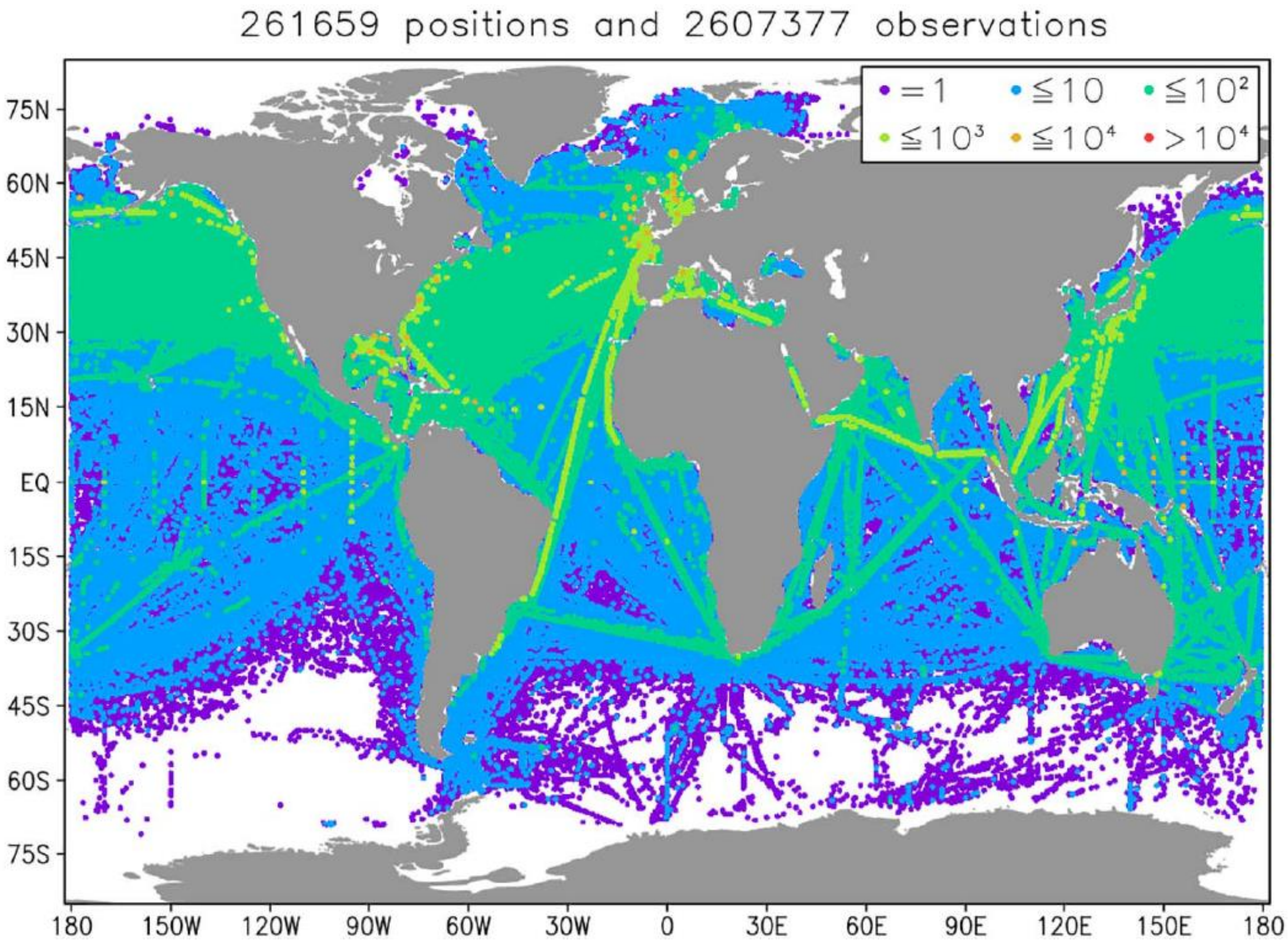
Product mean and stds (EO only!)



ICOADS data 2000-2007



Very Large areas with < 10 samples

Bentamy et al (2017)

Bias assessments against ICOADS

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Multiplicative α, and Additive β bias

No explicit spatial variation in α, β.

A. Bentamy et al. *Remote Sensing of Environment 201 (2017) 196–218*

$$y = \alpha x + \beta$$

Table 2

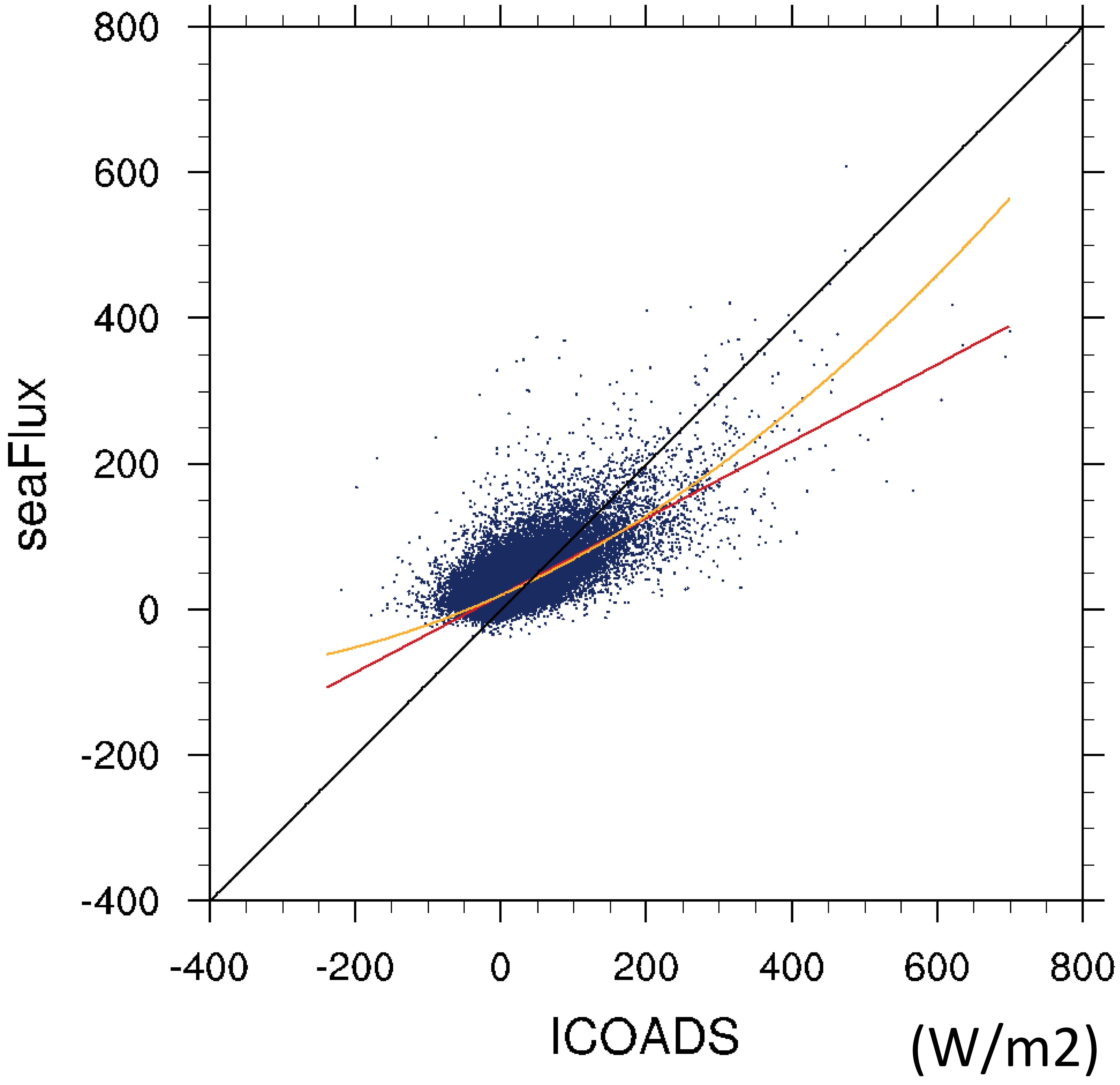
Performance (common signal, SNR, and noise) and nowcast calibration (additive and multiplicative bias) metrics for collocations of sensible and latent heat flux of ICOADS observations and eight global products and their ensemble. Only the ICOADS performance metrics are given as these data are taken to be calibrated already (Eq. (1)). All product metrics employ collocations *from even years only* between 2000 and 2007 (odd year averages are retained for validation and are qualitatively the same; not shown). Pairs of numbers refer to pre- and post-calibration (i.e., only nowcast error and bias vary). Signal and noise (as standard deviations) and additive bias are in W/m^2 and SNR (Gruber et al., 2016) is in dB. Results in bold are related to the lowest SNR values.

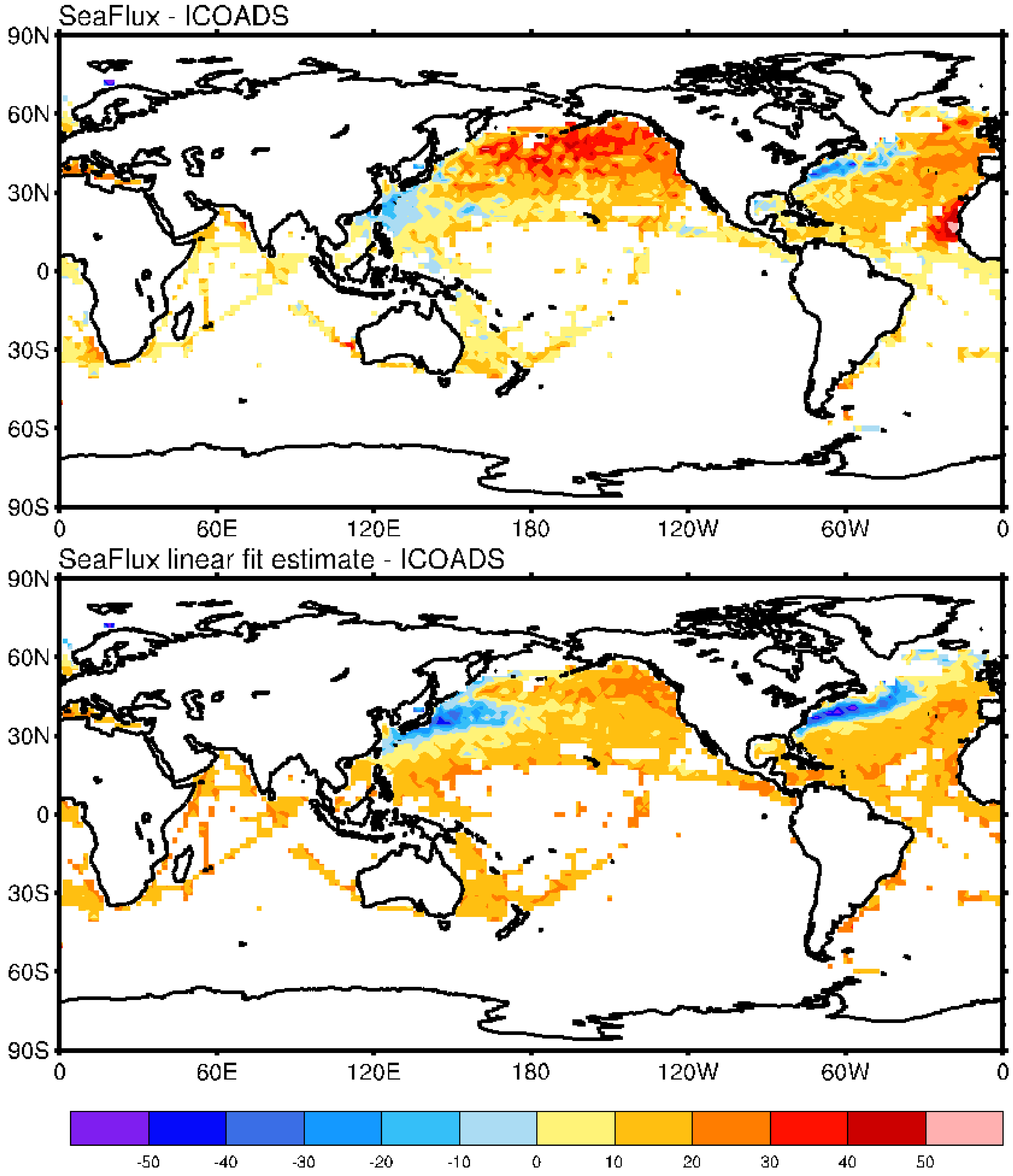
Product	Common Signal	Common SNR	ICOADS Noise	Product Noise	Product Bias Addit	Product Bias Multi
Sensible heat flux						
CFSR	2.58	− 18.18	20.94	15.28/20.94	4.89/0.00	0.73/1.00
ERA	**4.96**	**− 12.36**	**20.57**	**14.42/20.57**	**9.42/0.00**	**0.70/1.00**
HOAPS	**5.46**	**− 11.66**	**20.89**	**16.13/20.89**	**7.71/− 0.00**	**0.77/1.00**
Ifremer	0.94	− 26.99	20.91	17.26/20.91	5.81/− 0.00	0.83/1.00
J-Ofuro	**5.45**	**− 11.51**	**20.53**	**13.90/20.53**	**5.50/0.00**	**0.68/1.00**
Merra	3.08	− 16.69	21.07	12.03/21.07	7.33/− 0.00	0.57/1.00
OAFlux	1.89	− 20.94	21.05	14.55/21.05	6.30/− 0.00	0.69/1.00
SeaFlux	3.52	− 15.57	21.12	14.99/21.12	12.00/− 0.00	0.71/1.00
Ensemble	2.11	− 19.96	21.01	13.98/21.01	6.93/0.00	0.67/1.00
Latent heat flux						
CFSR	18.24	− 11.88	71.61	62.20/71.61	27.76/0.00	0.87/1.00
ERA	11.47	− 16.10	73.18	61.72/73.18	30.31/0.00	0.84/1.00
HOAPS	**25.35**	**− 8.74**	**69.35**	**64.47/69.35**	**13.84/0.00**	**0.93/1.00**
Ifremer	16.08	− 12.88	70.87	48.24/70.87	28.73/0.00	0.68/1.00
J-Ofuro	17.34	− 12.36	71.90	61.95/71.90	21.04/0.00	0.86/1.00
Merra	**43.81**	**− 2.62**	**59.23**	**42.99/59.23**	**26.70/0.00**	**0.73/1.00**
OAFlux	19.05	− 11.51	71.71	55.37/71.71	26.15/0.00	0.77/1.00
SeaFlux	17.02	− 12.53	71.97	55.35/71.97	23.86/0.00	0.77/1.00
Ensemble	**25.64**	**− 8.62**	**69.15**	**52.97/69.15**	**28.22/0.00**	**0.77/1.00**

Seaflux Sensible Heat flux bias
vs
Linear fit bias

2° x 2° bins

(2001 DJF)





RMSE (linear fit) = 24.4

RMSE (quadratic fit) = 24.6

RMSE (1:1) = 34.0

Spatially integrated

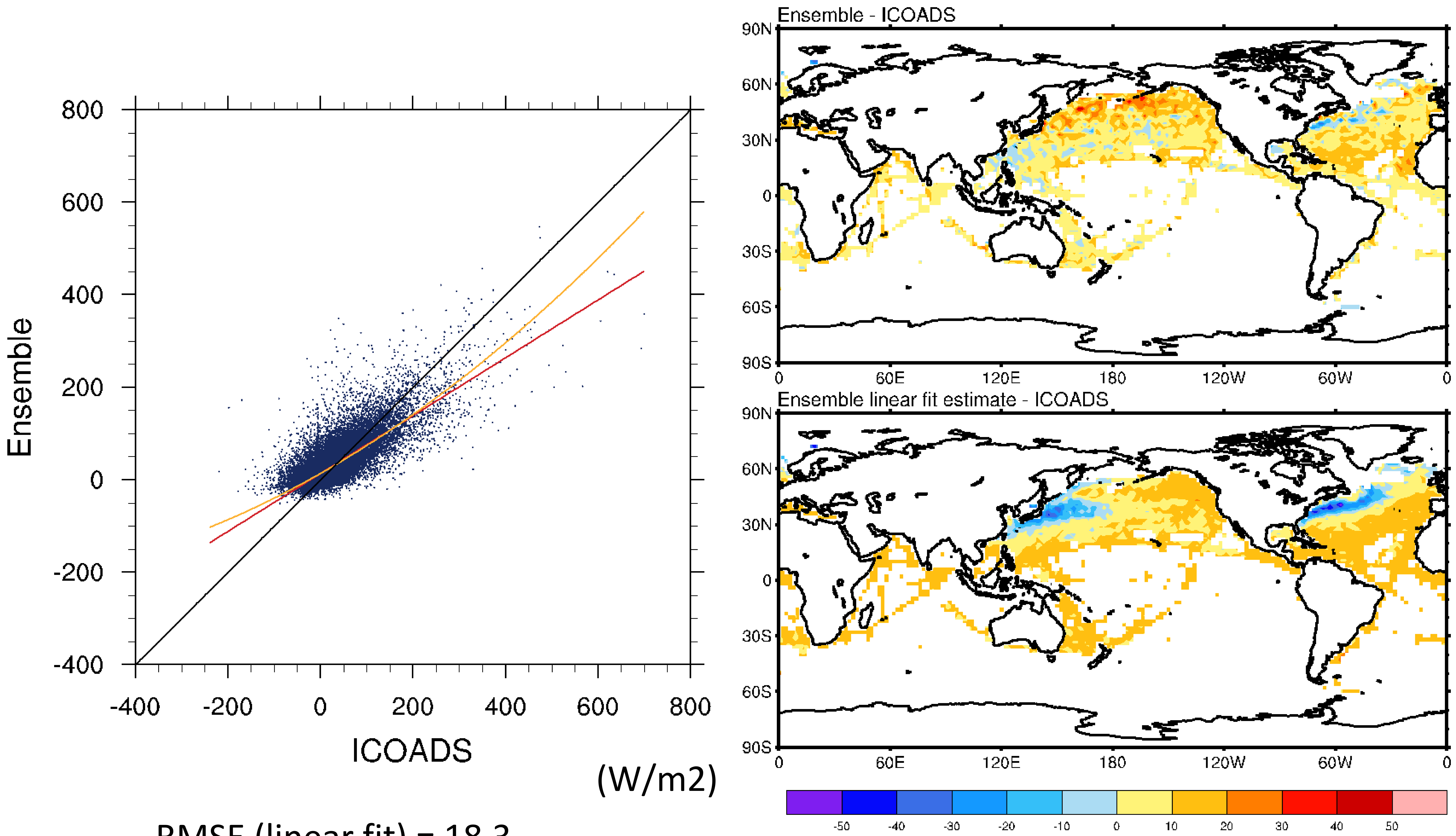
RMSE(1:1) = 16.0

RMSE(linear) = 18.1

Ensemble = HOAPS+SeaFlux
+OAFlux+Ifremer+JOfuro

Ensemble SH bias
vs
Ensemble Linear fit estimate bias

(2001 DJF)



(W/m2)

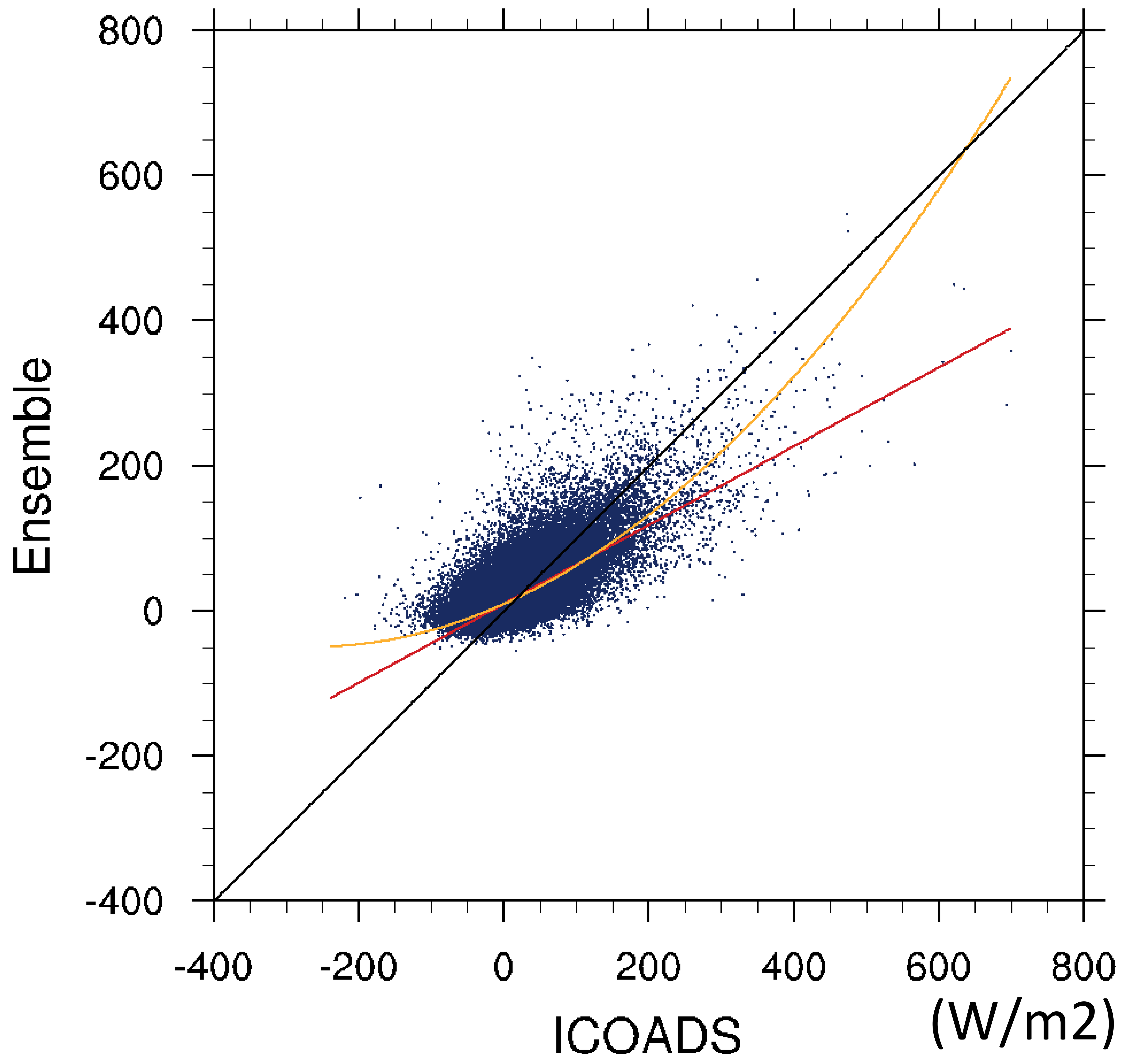
RMSE (linear fit) = 18.3
RMSE (quadratic fit) = 18.5
RMSE (1:1) = 29.0

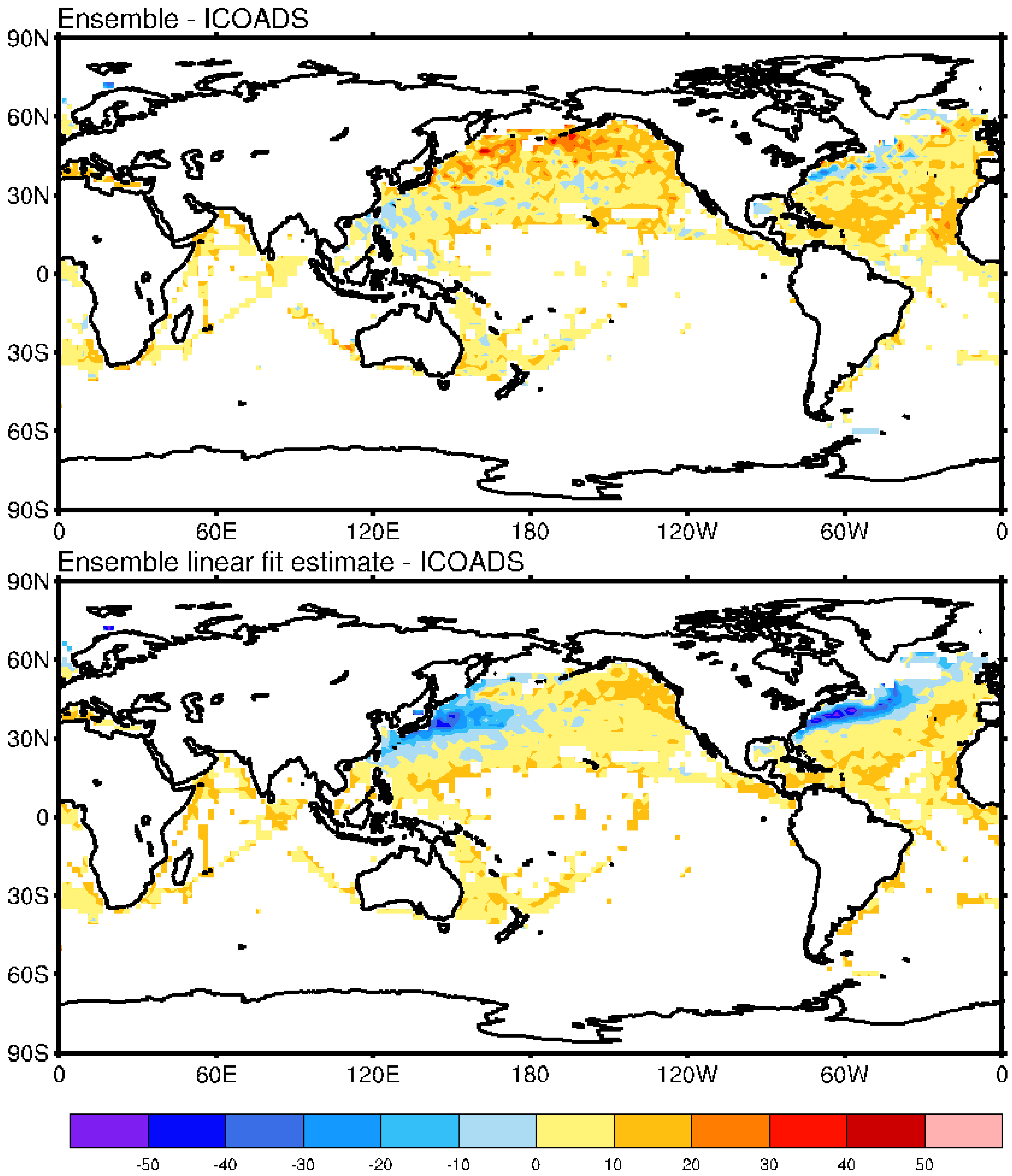
Spatially integrated
RMSE(1:1) = 10.8
RMSE(linear) = 13.1

Ensemble SH bias

vs (2001 all season)

Ensemble Linear fit estimate bias





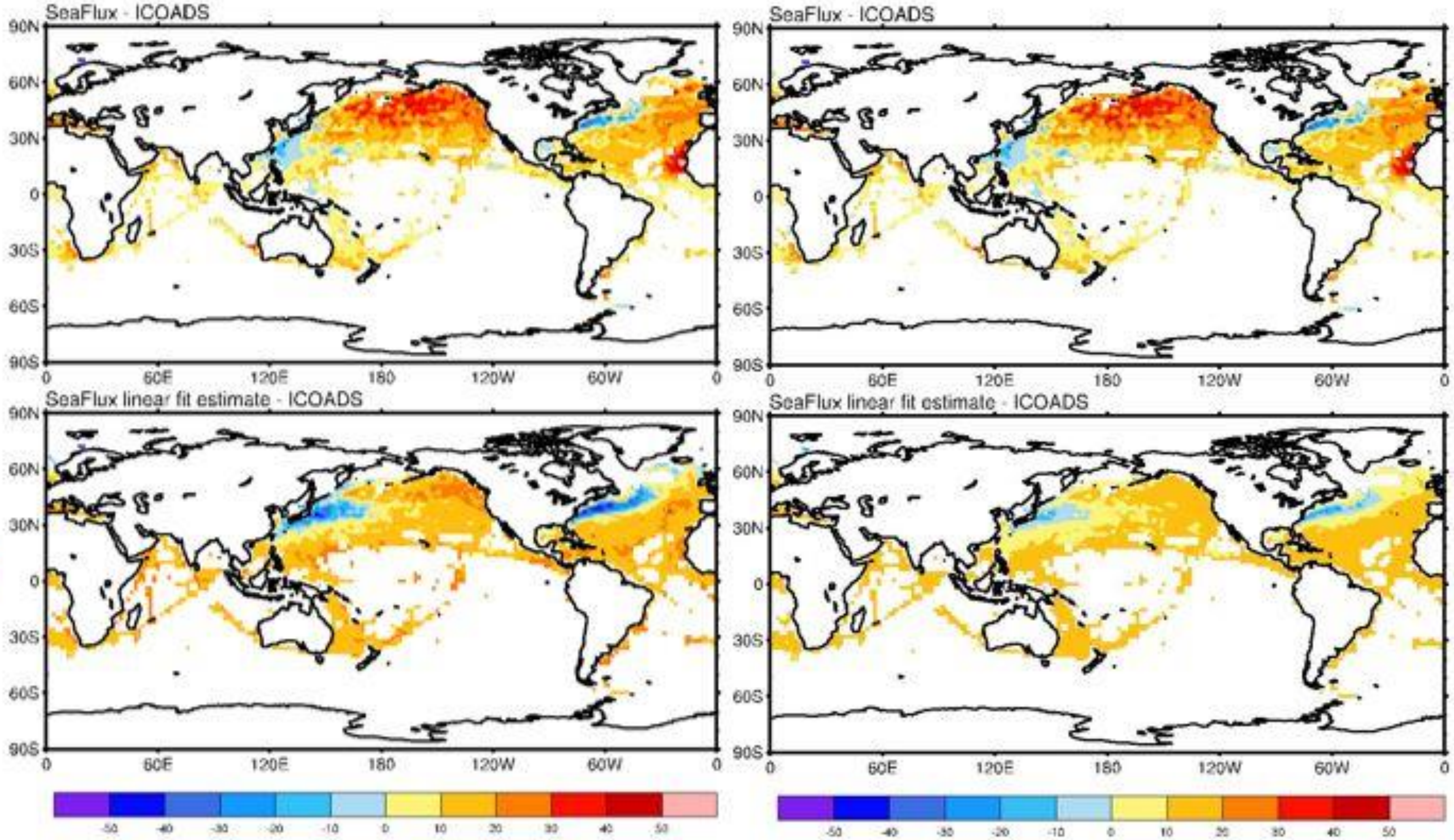
RMSE (linear fit) = 15.6
RMSE (quadratic fit) = 15.9
RMSE (1:1) = 22.8

Spatially integrated
RMSE(1:1) = 10.8
RMSE(linear) = 11.4

(2001 DJF)

Seaflux bias
vs
Linear fit bias

Linear fit based on all data in DJF 2001



Linear fit with "homogeneous" data density

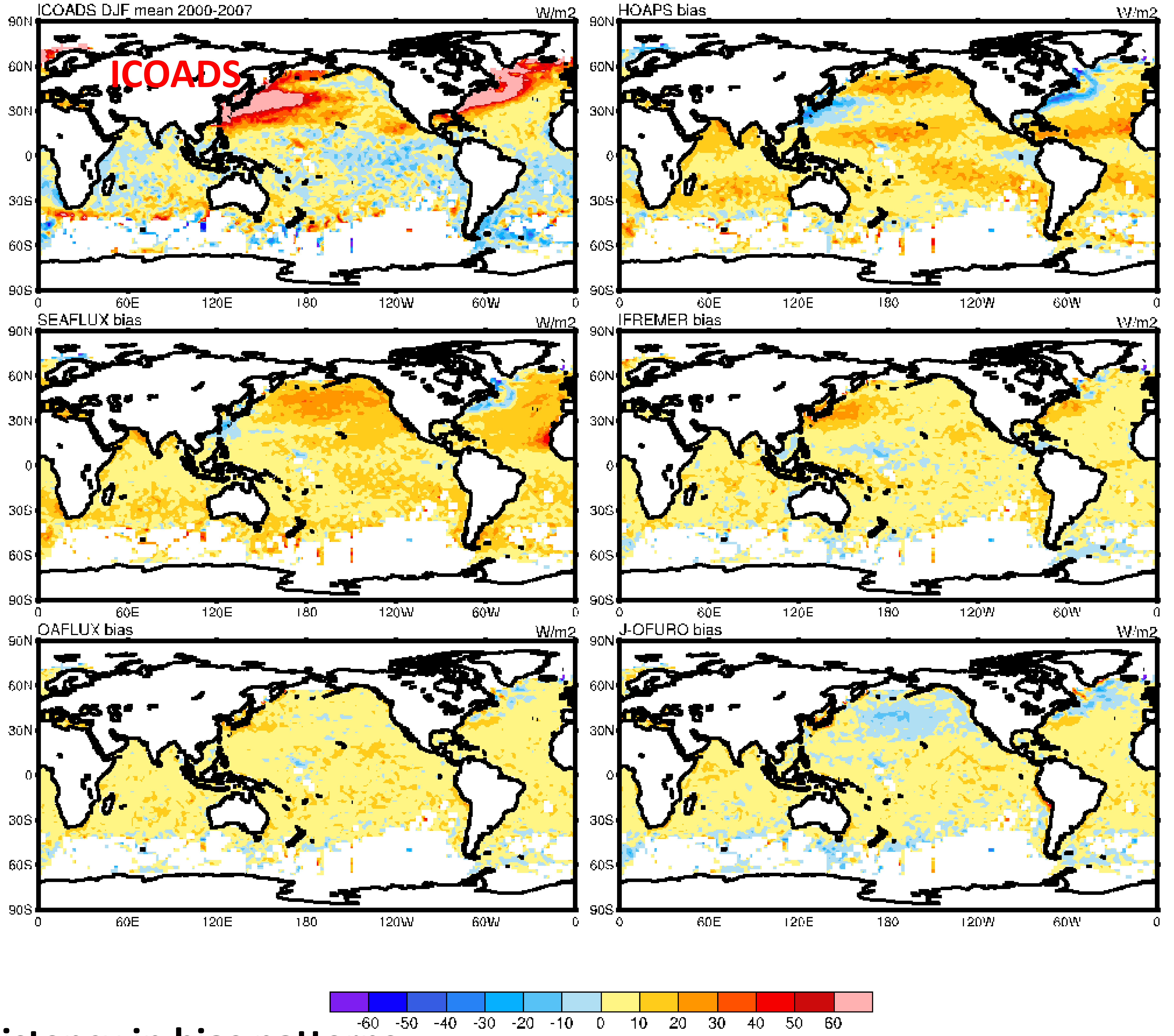
Spatially integrated
RMSE(1:1) = 16.0
RMSE(linear) = 18.1

Spatially integrated
<u>RMSE(linear) = 12.1</u>

We conclude about the Linear bias scaling

- Does it reduce spatial variability of bias error? No?
- Does it reduce seasonal variability of bias errors? Still being assessed
- More diagnostics needed
- Try different approaches to reducing spatial correlations within the biases!!

2000-2007 DJF SH_bias (Daily matches; 8 DJF seasons, 2°x 2° bin means)



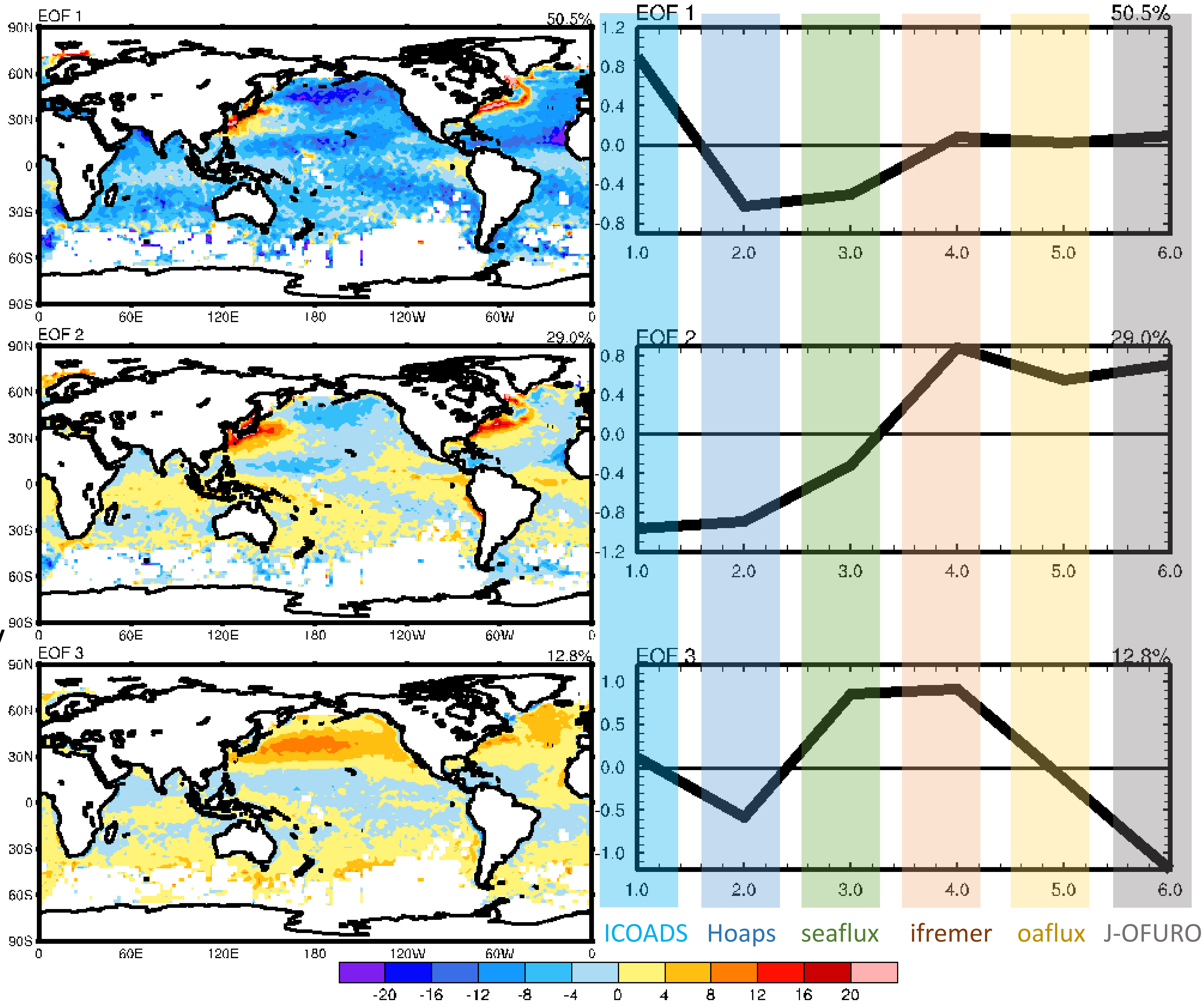
Some consistency in bias patterns

Cannot be confident offset pattern is "bias": Undersampling in time and space

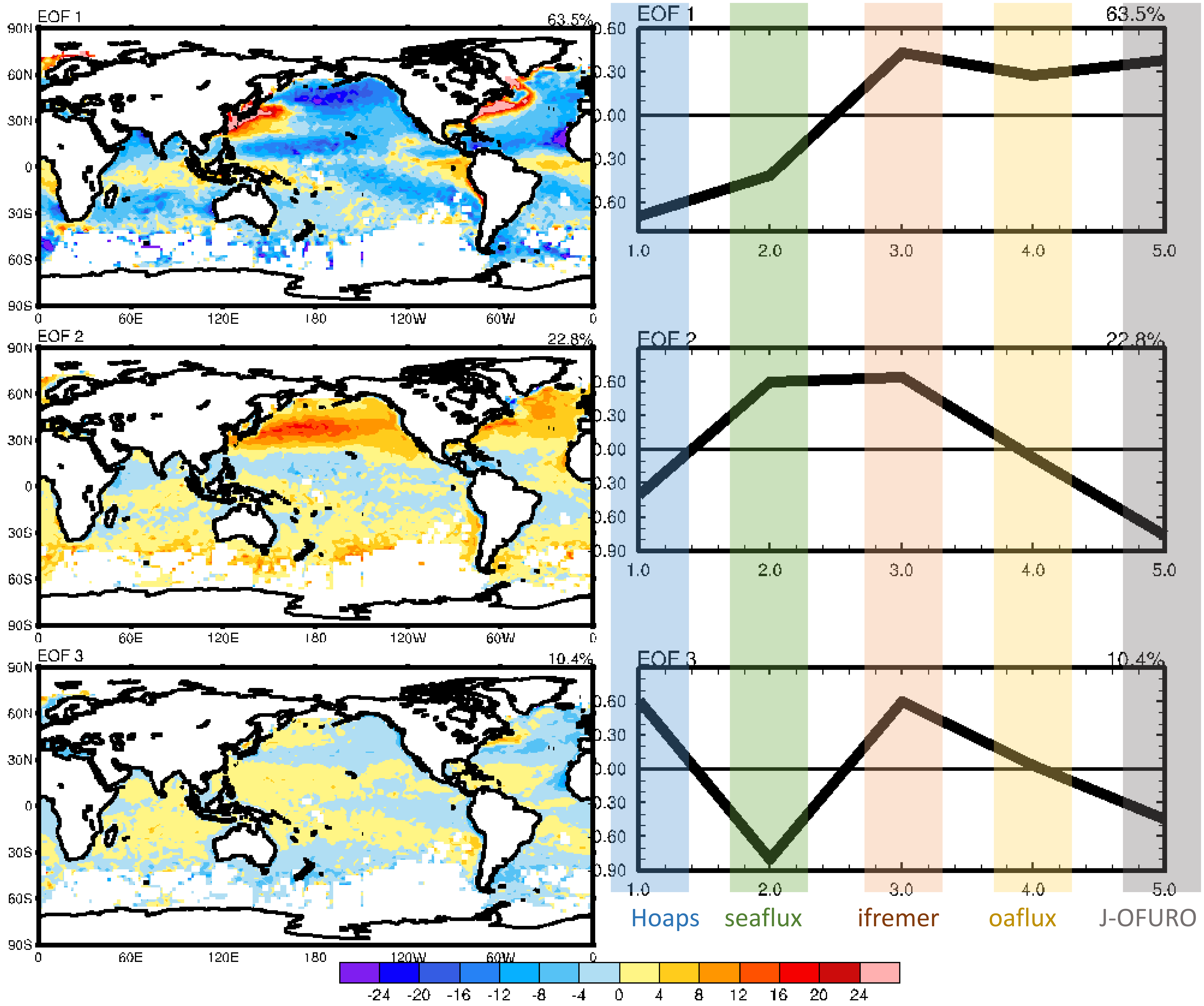
EOFs of the SH Flux DJF (ICOADS + Products)

1st EOF
= Mean
Bias
v ICOADS

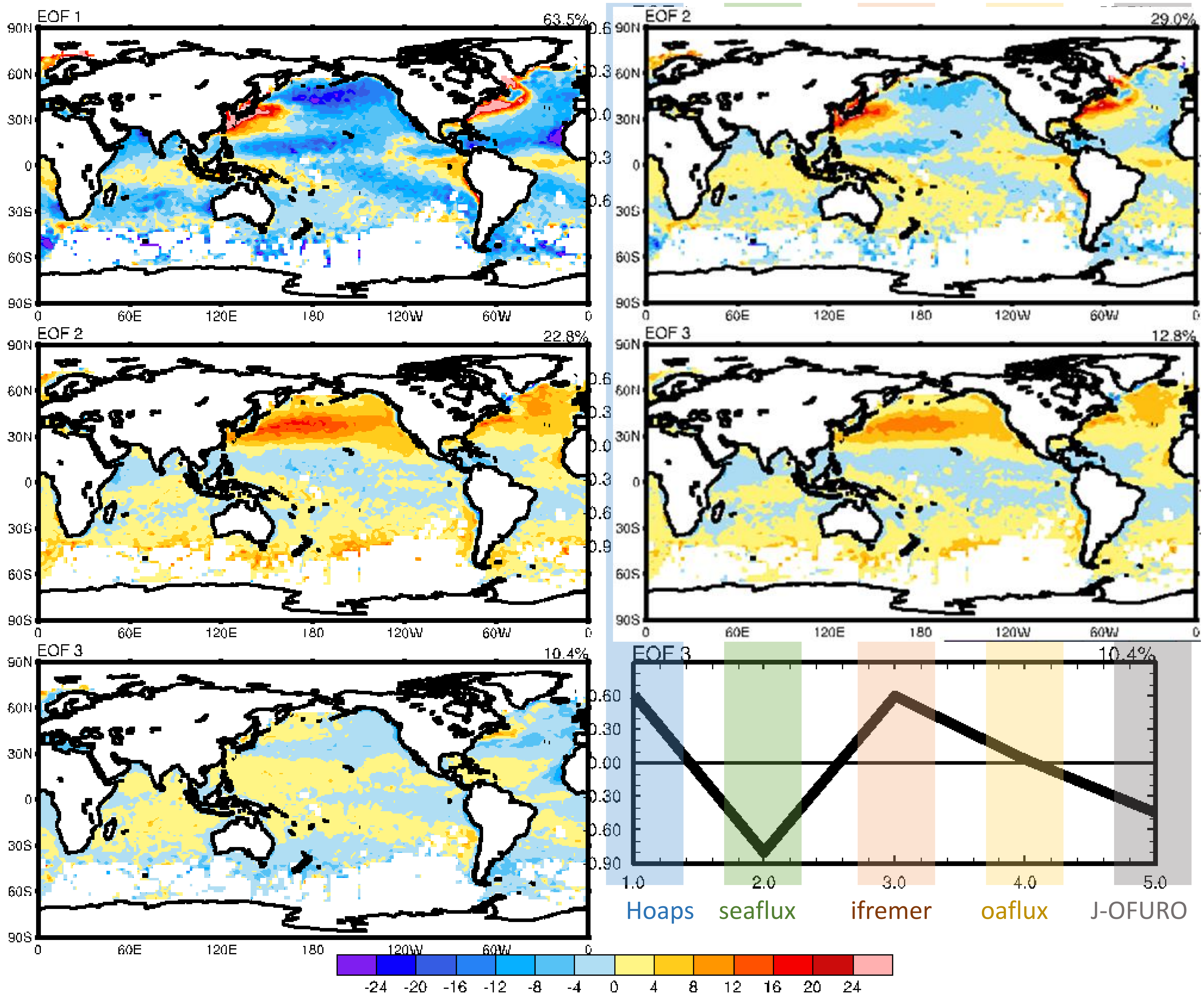
Variability
between
products



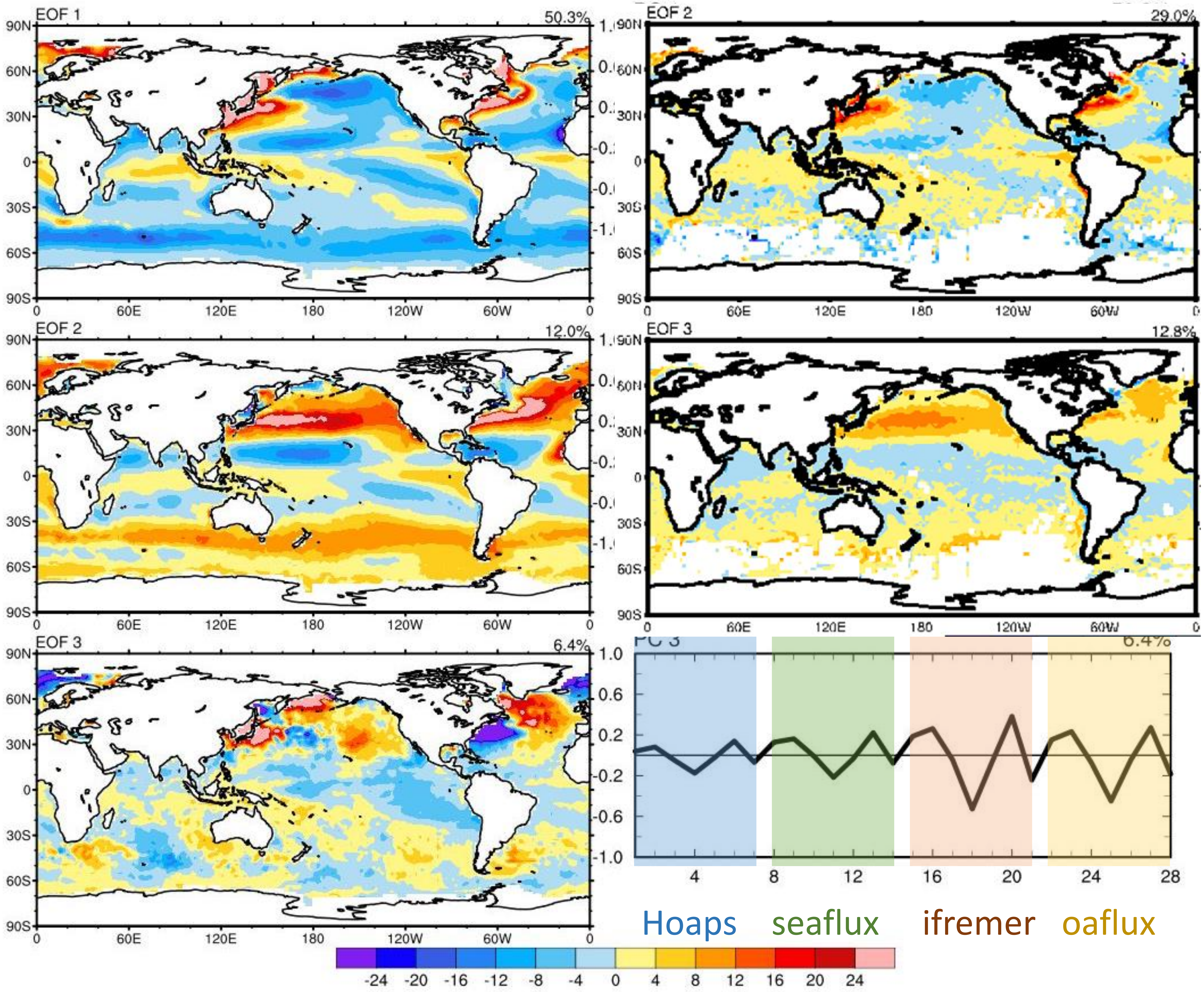
EOFs of DJF SH_bias against ICOADS



EOFs of DJF SH_bias against ICOADS



Inter-product EOFs SH DJF for 7 years (2001-2007 inc)



Structural error patterns

- 1st EOF pattern => bias offset of products from ICOADS
- 2-3 EOF patterns => structural variability between flux products
- These EOF patterns are more representative of true bias and capture the correlated variability in that bias, than the ICOADS differences alone which are largely undersampled.
- Next step: quantifying Structural v "Random" regional errors
- Project ICOADS mean differences onto EOF patterns (note this now done and it does reduce spatially correlated bias greatly)

PART 2 CLIVAR research focus CONCEPT-HEAT:

Consistency between planetary energy balance and ocean heat storage

An overall goal is to **bring together different climate research communities** all concerned with the energy flows in the Earth system to advance on the **understanding of the uncertainties through physical budget constraints**:

- Atmospheric radiation
- Ocean Heat Content
- Earth's surface fluxes
- Climate variability and change
- Data assimilation & operational services (R&D)
- Climate projection
- Global sea level

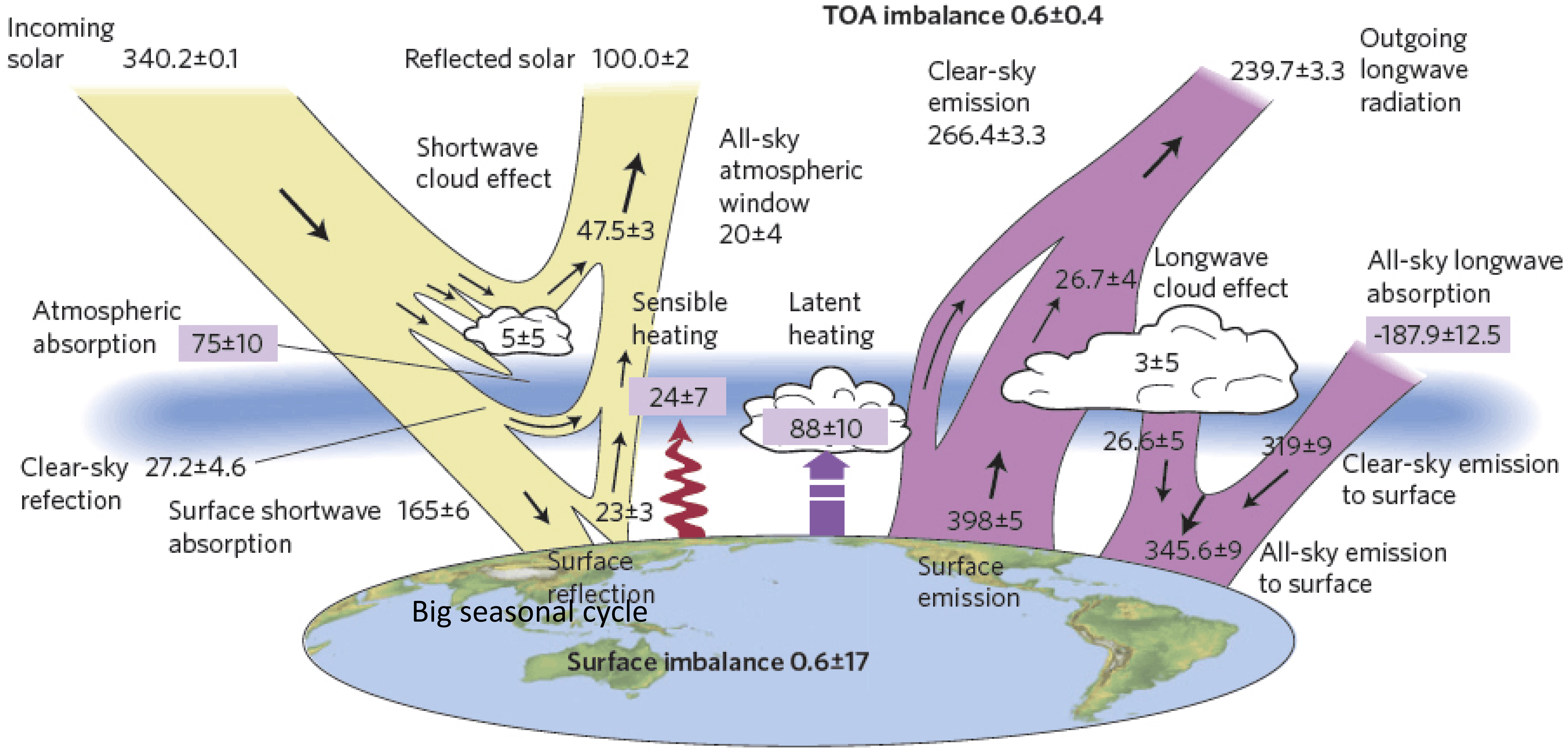
Remote sensing	In situ	Reanalysis systems	Numerical model

Global Heat Budget

Four components

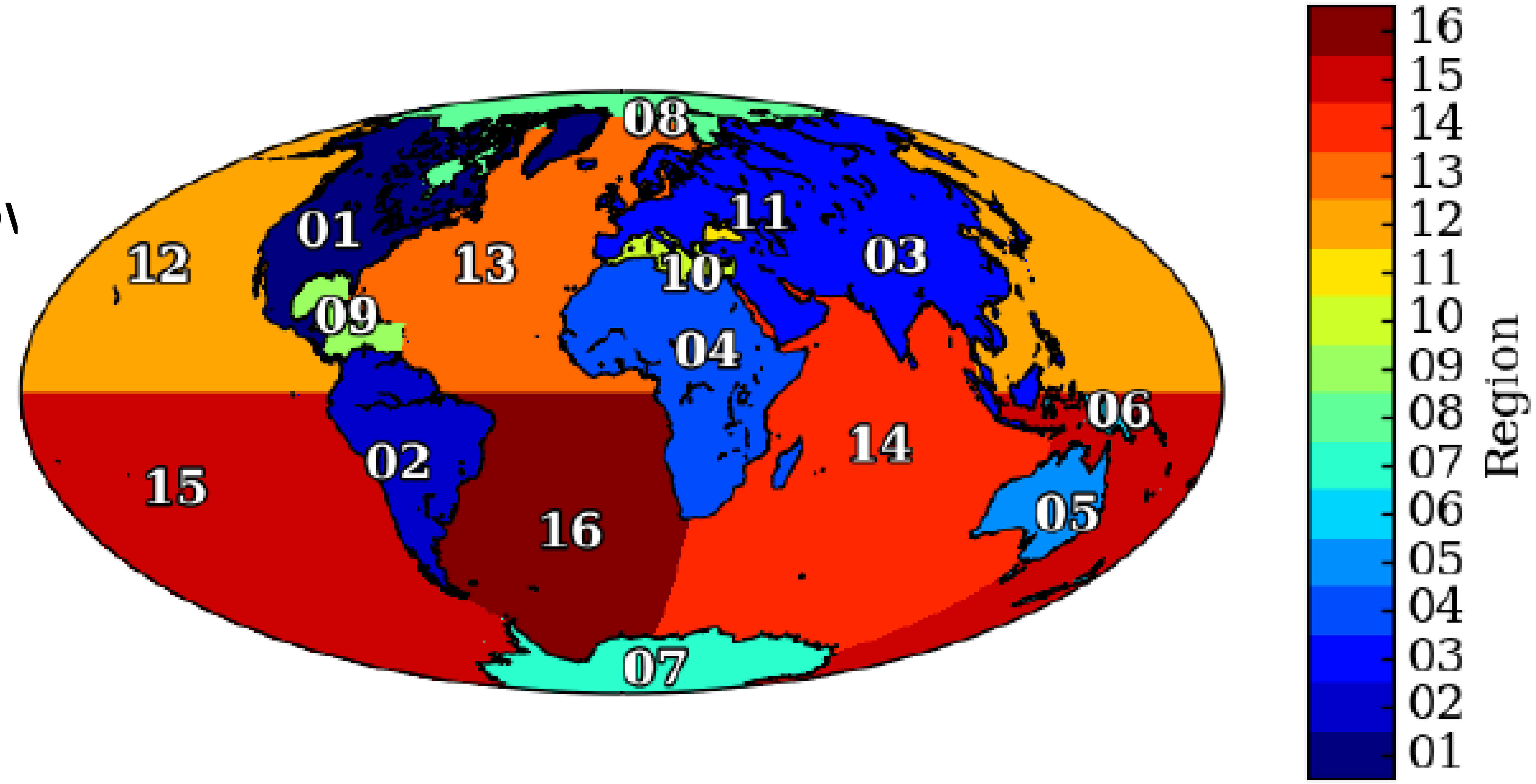
- sensible heat flux from air-sea temperature difference;
- latent heat flux associated with evaporation;
- incoming short-wave radiation from the sun;
- long-wave radiation from the atmosphere and ocean.

Global air-sea heat flux (W/m2):

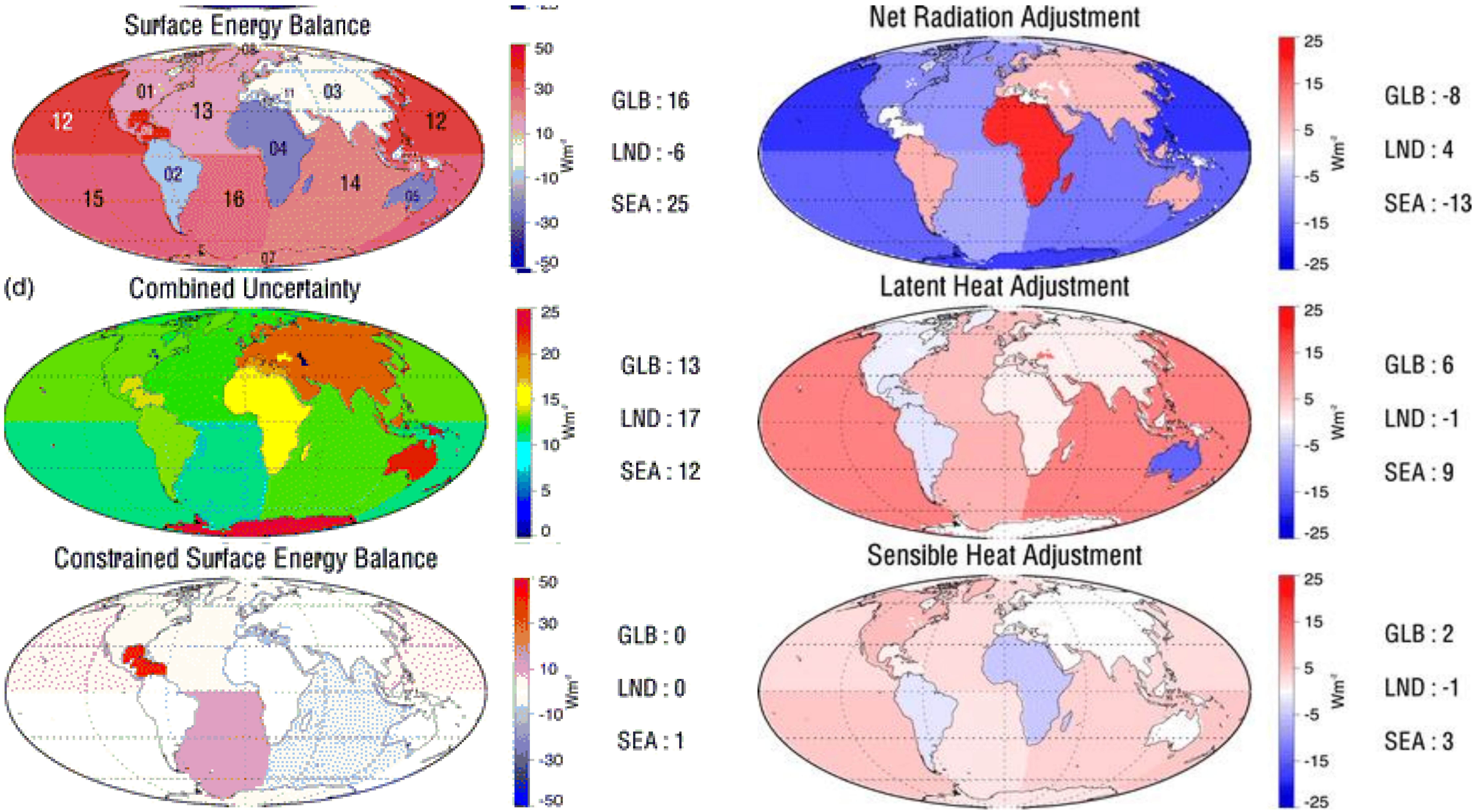


NASA NEWS

- NASA NEWS energy and water budget study : L'Ecuyer et al (2015), Rodell et al (2015)
  - 16 regions: 7 Land, 9 Ocean (Low resolution)
  - 9 vertical energy fluxes : TOA(3 radn.); Surface(4 radn., Latent, Sensible)
  - 2 vertical water fluxes : Surface (EvapT, Precip)
  - 1 horizontal water flux : Atm. convergence (Merra) or Runoff
  - Constrained energy flux into land, Total ocean energy from Argo.
- Study period 2000-2010

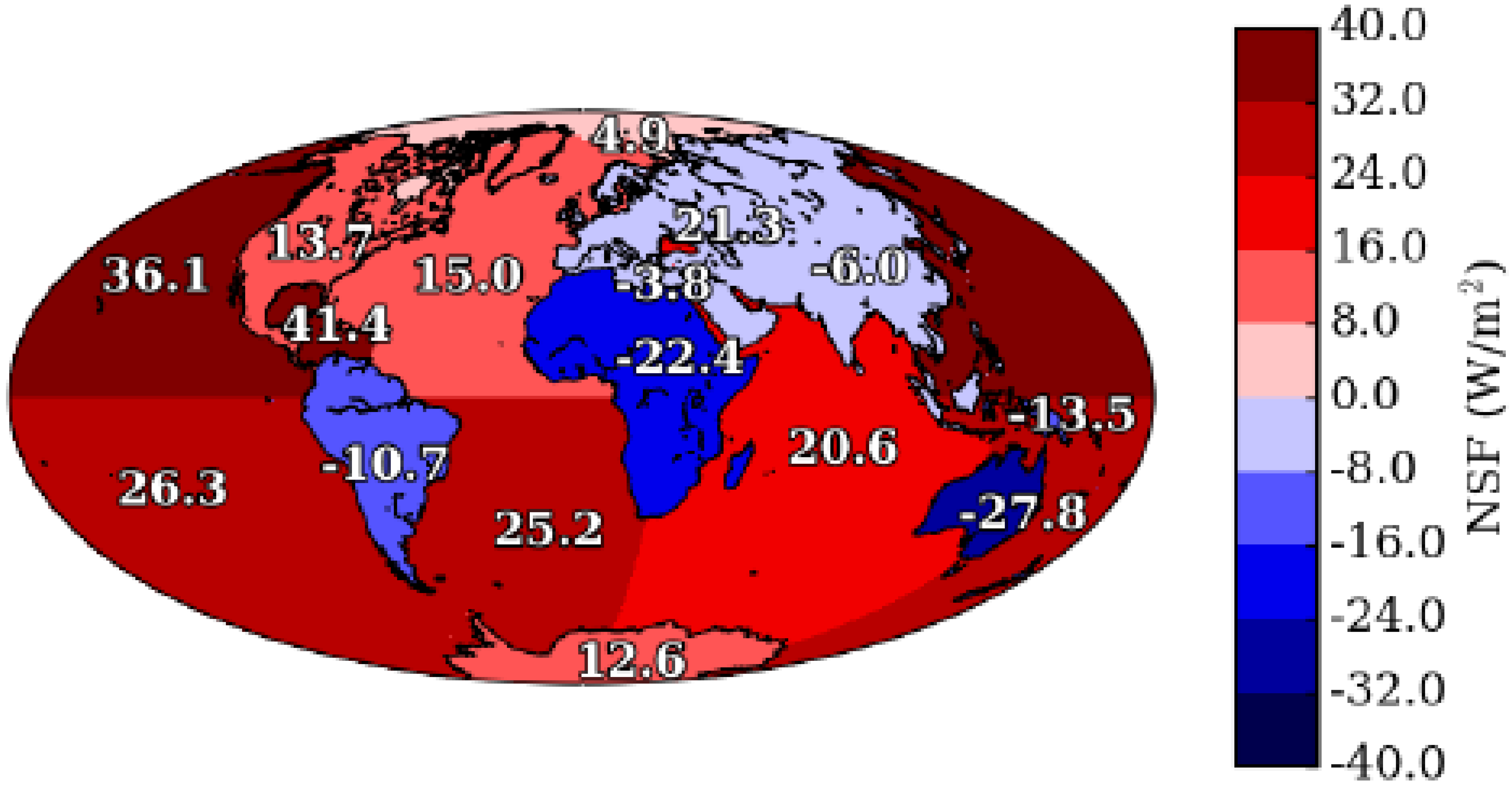


L’Ecuyer et al (2015) Solution

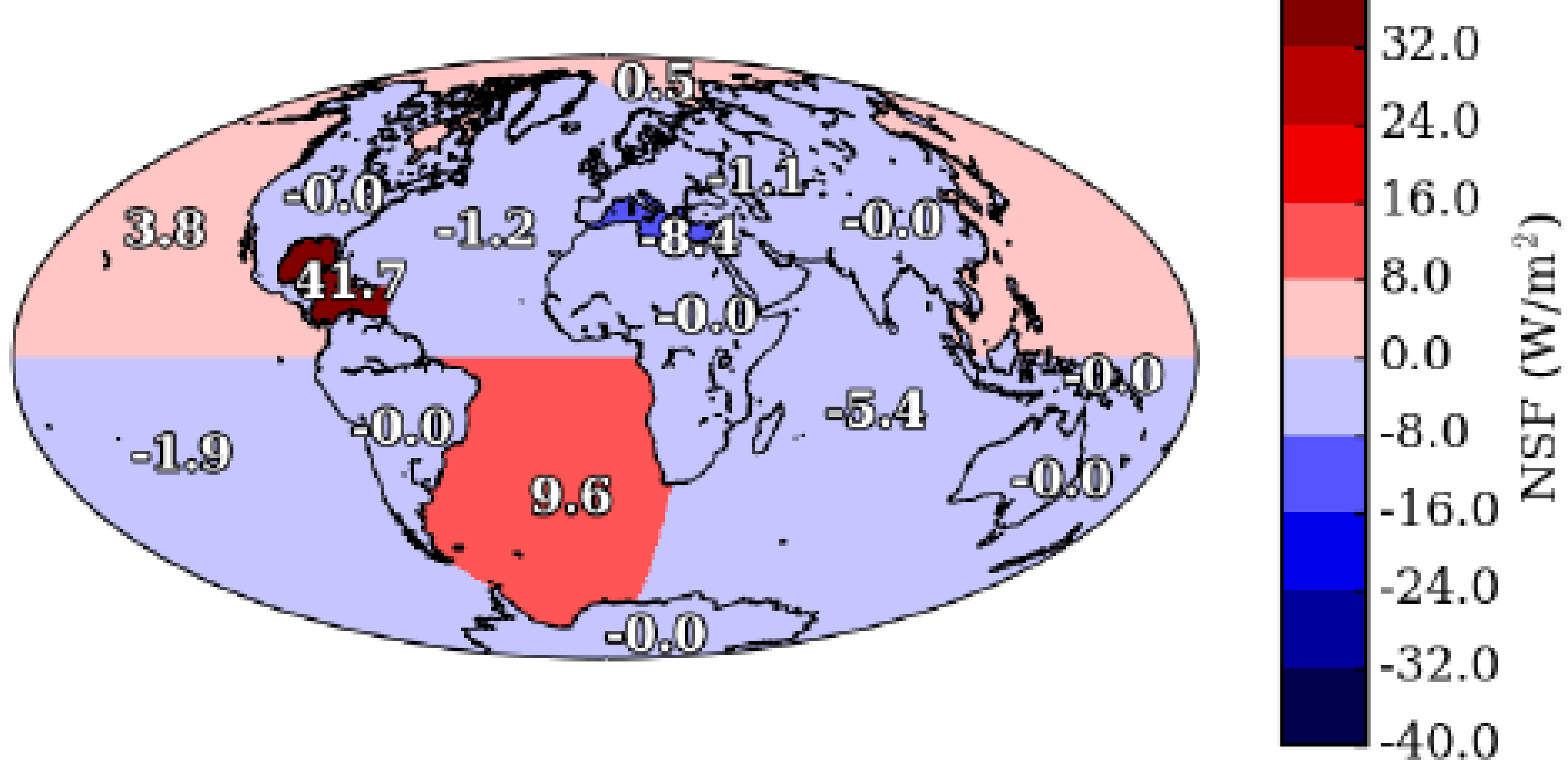


Constrained Flux adjustment

Initial total surface flux



Final total surface flux
(spatially uncorrelated flux errors)

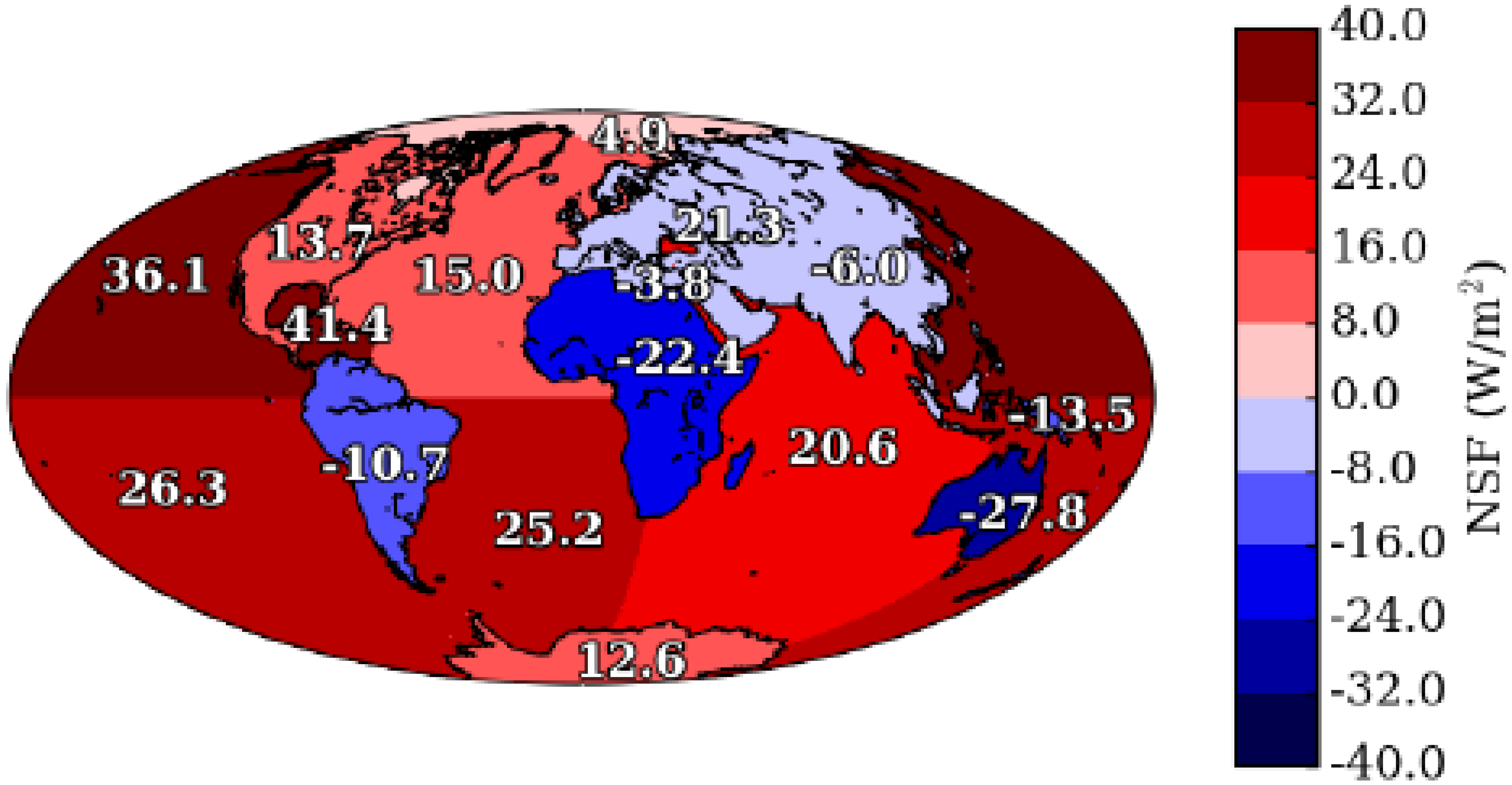


All flux errors assumed uncorrelated

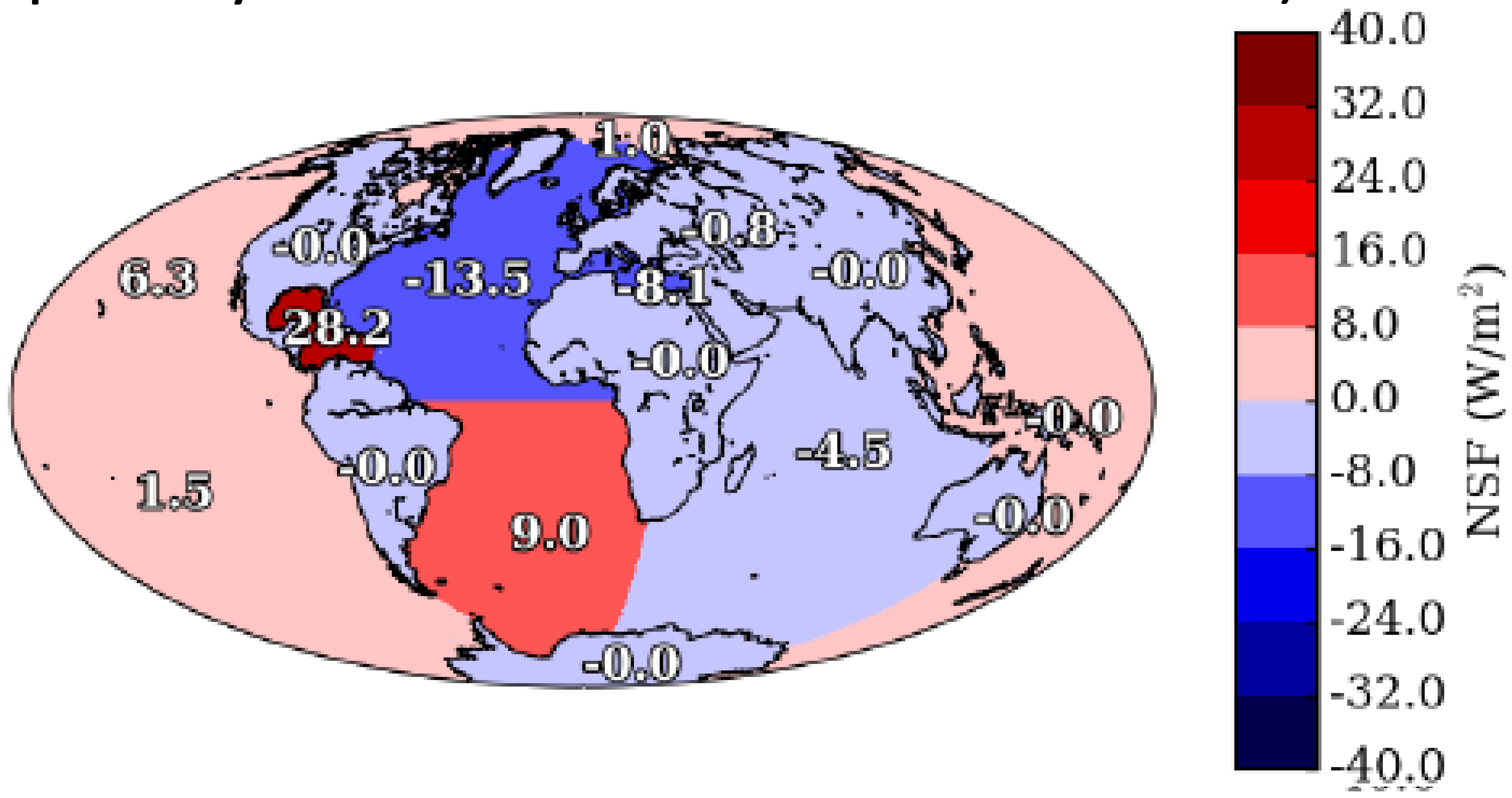
Not realistic!
Structural errors in Flux products spatially correlated across regions!

Constrained Flux adjustment

Initial total surface flux



Final total surface flux
(spatially correlated turbulent flux errors)



All flux errors assumed uncorrelated

Not realistic!

Structural errors in Flux products spatially correlated across regions!

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TABLE 1. Data sources and associated documentation.

Parameter	Dataset	Relevant satellite inputs	References
Radiative fluxes	SRB	CERES, AVHRR	Gupta et al. (1999)
4 semi-independent products	ISCCP-FD	AVHRR	Zhang et al. (2004)
	2B-FLXHR-lidar	*CloudSat*, *CALIPSO*	Henderson et al. (2013)
	C3M	MODIS, AMSR-E, CERES, *CloudSat*, *CALIPSO*, MODIS	Kato et al. (2010); Kato et al. (2011)
Ocean turbulent heat fluxes 1 product + errors	SeaFlux	SSM/I	Curry et al. (2004); Clayson et al. (2015, manuscript submitted to *Int. J. Climatol.*)
Land turbulent heat fluxes	Princeton ET	AIRS, CERES, MODIS, AVHRR	Vinukollu et al. (2011)
3 semi-independent products	MERRA	Numerous	Rienecker et al. (2011); Bosilovich et al. (2011)
	GLDAS	SSM/I, SSMIS, GOES-IR, TOVS, AIRS, TRMM, MODIS, AVHRR	Rodell et al. (2004b)
Atmospheric latent heating 1 product + errors	GPCP v.2.2	SSM/I, SSMIS, GOES-IR, TOVS, AIRS	Adler et al. (2003); Huffman et al. (2009)

Energy Budget datasets L’Ecuyer et al (2015)

Conclusions

- We can now seek to develop improved models of spatially correlated structural error in EO products.
- Potential to apply to:-
  - **Ocean Turbulent fluxes**
  - **Surface Radiative fluxes**
  - **Land turbulent fluxes?**
  - **Precipitation ?**
- Seasonal structural errors => Full monthly-interannual
- This will allow **Novel and much improved Global-Regional "CAGE" budgets** (Energy/Water budget) to be derived from the latest EO Observation products
- Beyond? Link in Carbon cycle?: Land and Ocean? Needs meeting to coordinate physical and carbon communities to consider possibilities