Reconstruction of interdecadal variability of air-sea interaction in the Atlantic 1880-2004: links to atmospheric circulation patterns

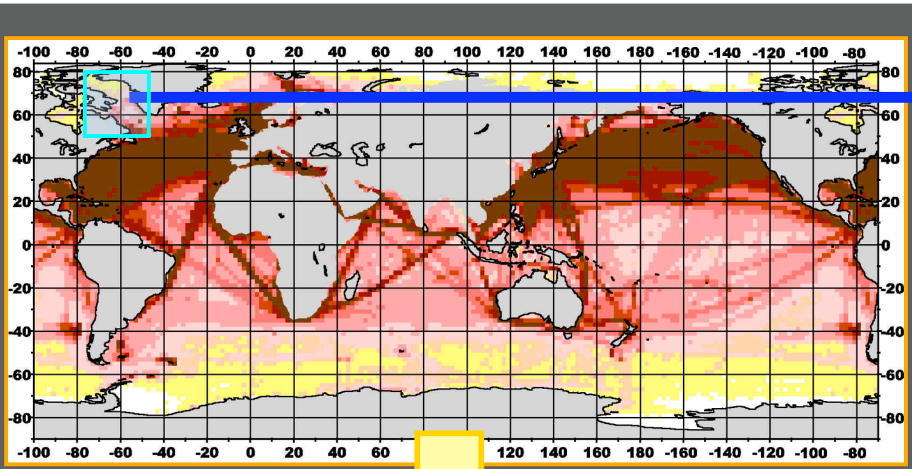
Sergey Gulev, Konstantin Belyaev, Thomas Jung, Eberhard Ruprecht

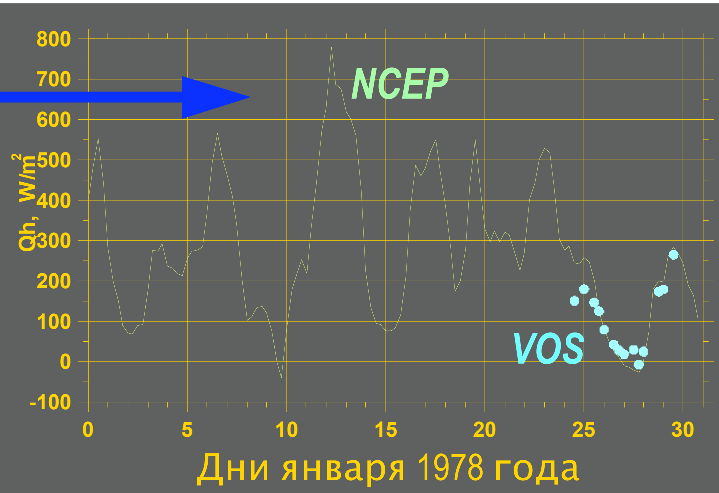
Outline:

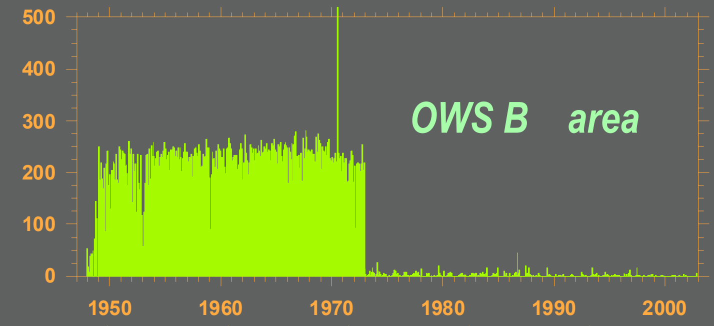
- Introduction: Uncertainties of surface flux fields : importance of sampling errors
- A way to account for sampling uncertainty and to minimize it: using modified FT-distribution (2eWPDF)
- Homogenized 100-yr flux time series in the North Atlantic from VOS (ICOADS)
- Surface heat fluxes and the NA variability patterns
- Conclusions

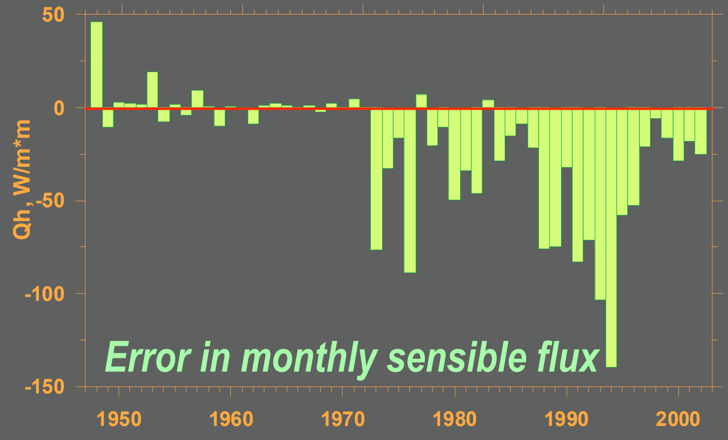
CLIMAR-3, Gdynia, 6-9 May 2008

The nature of sampling bias in air-sea fluxes





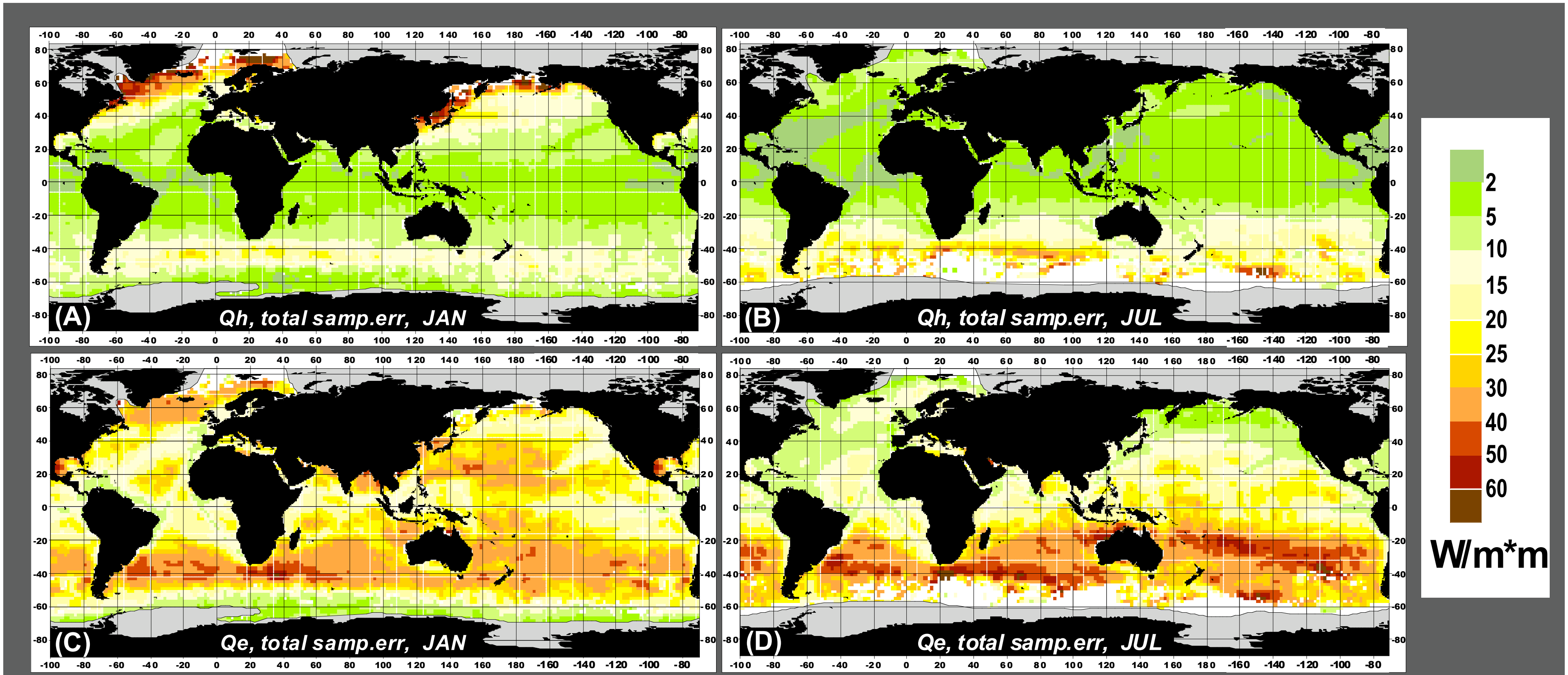


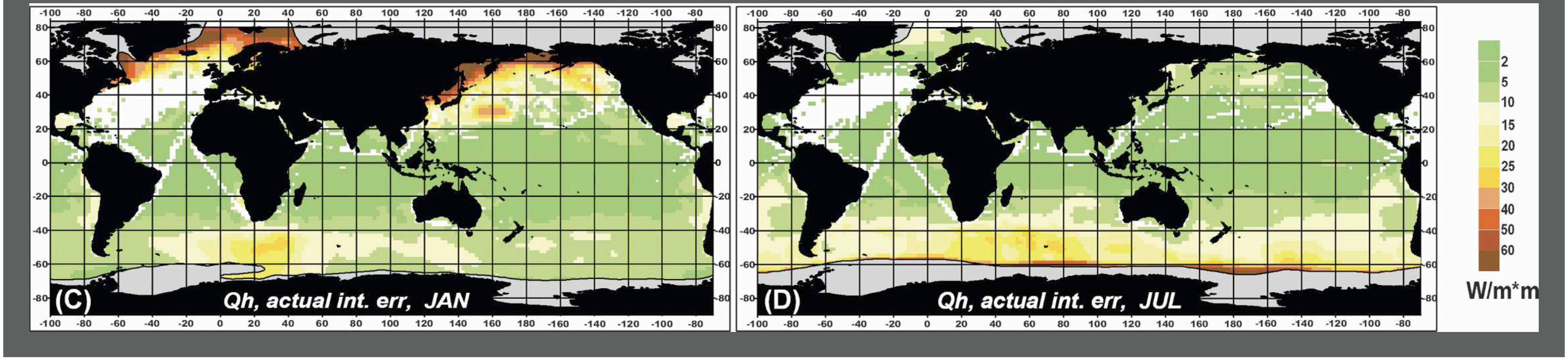


“VOS-like” re-sampling of NWP in order to quantify sampling bias

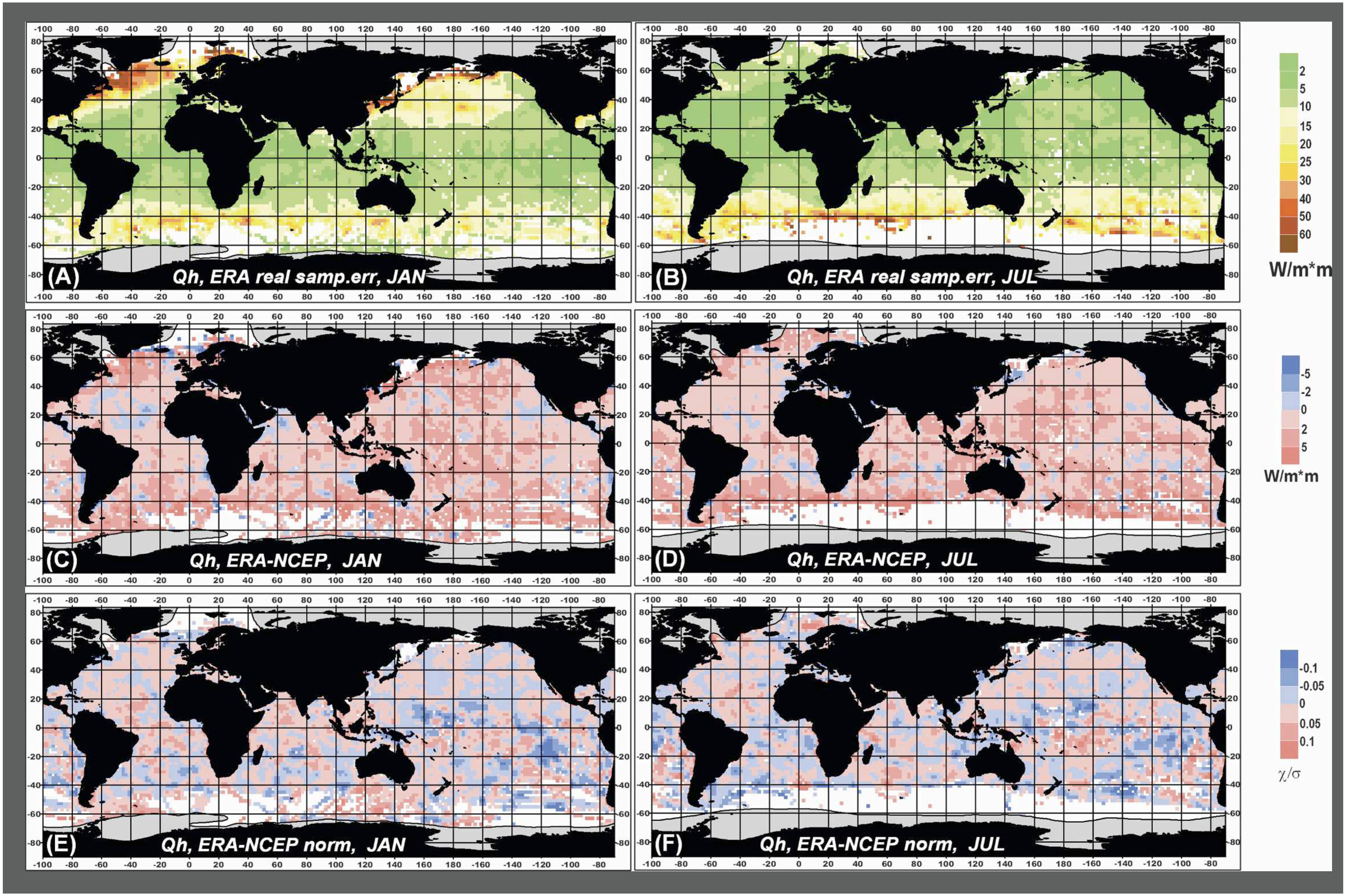
Gulev et al., 2007a,b *J. Climate*

Magnitude of sampling error

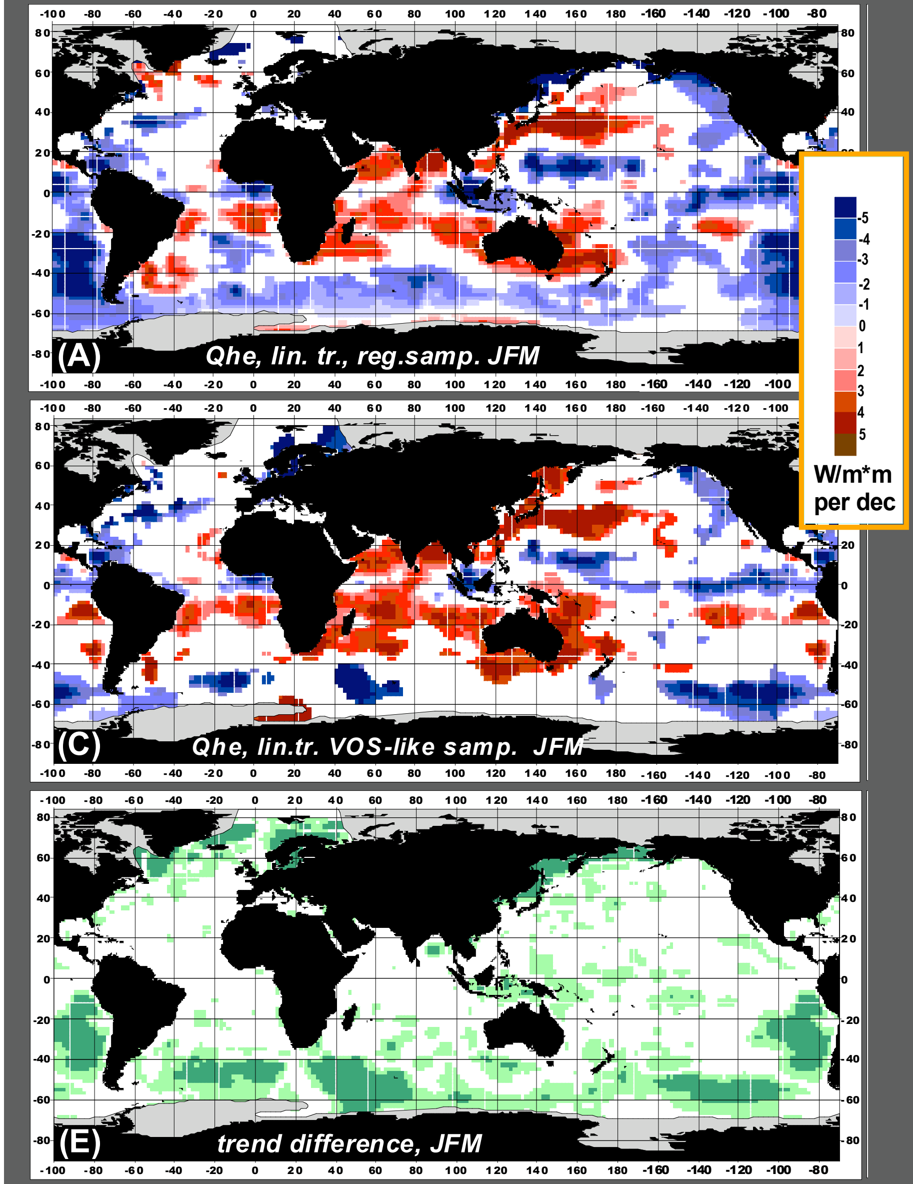




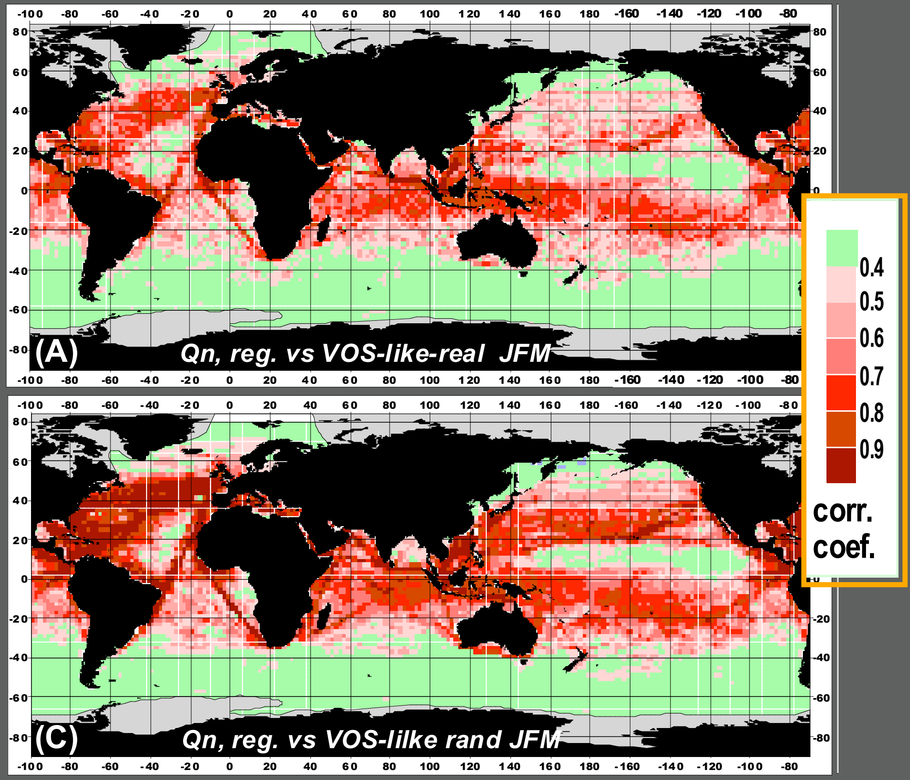
Sampling errors from different NWP



Sampling affecting trends and interannual variabilioty in surface fluxes

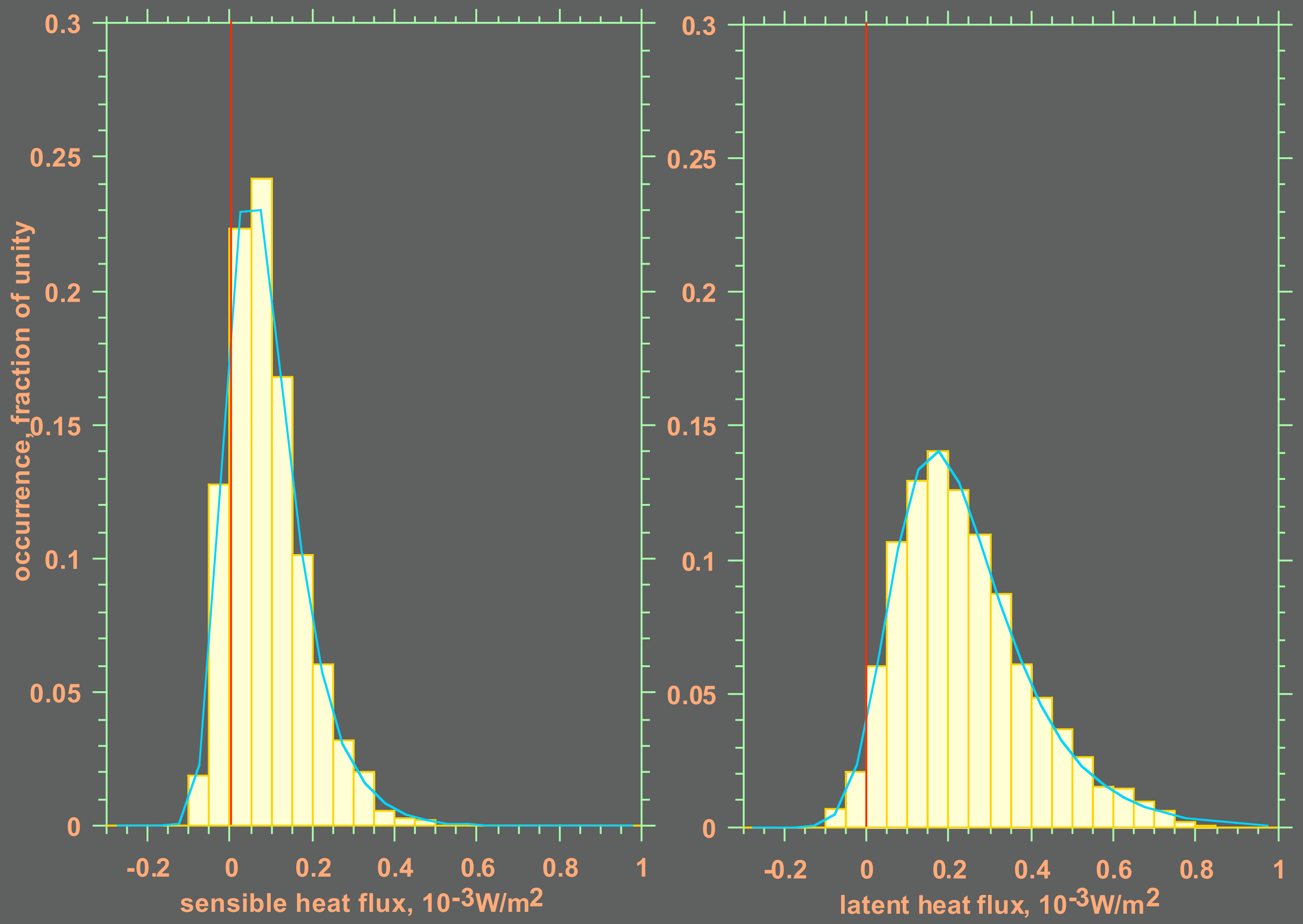


- Changing trend sign in subpolar NA
- No consistency in interannual variability



How to overcome sampling error?

Although it is clear how to quantify sampling error,
it is unclear how to minimize it → PDF is needed



Modified FT-distribution (2ePDF)

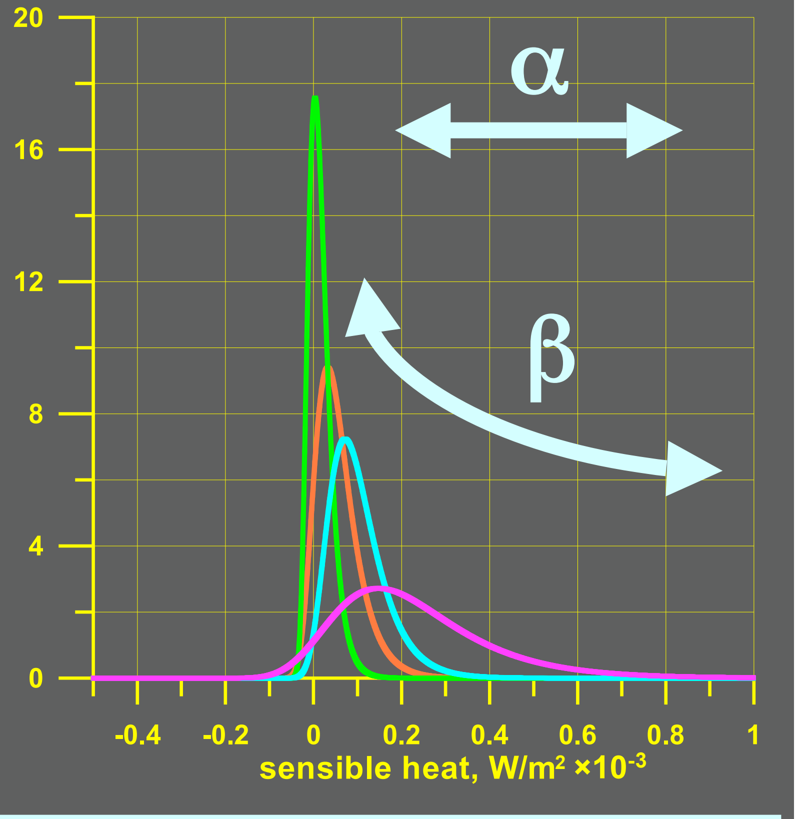
PDF: $$P(x) = -(\alpha \cdot \beta) \cdot e^{\beta x} \cdot e^{-\alpha \cdot e^{\beta x}}, \quad \alpha > 0, \beta < 0$$

Mean, variance, modal value:

$$\bar{x} = \int_{-\infty}^{\infty} P(x) \cdot x\,dx = \frac{C + \ln \alpha}{-\beta}$$

$$\operatorname{var} x = \int_{-\infty}^{\infty} P(x) \cdot x^2\,dx - \bar{x}^2 = \frac{\pi^2}{6\beta^2}$$

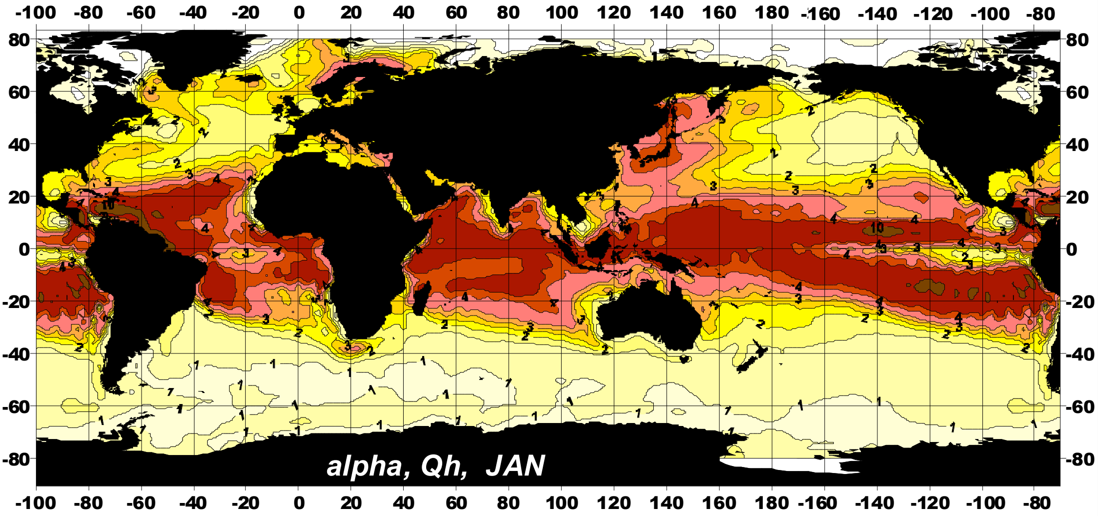
$$\bar{x}_{\mathrm{mod}} = \frac{\ln(1/\alpha)}{\beta}$$

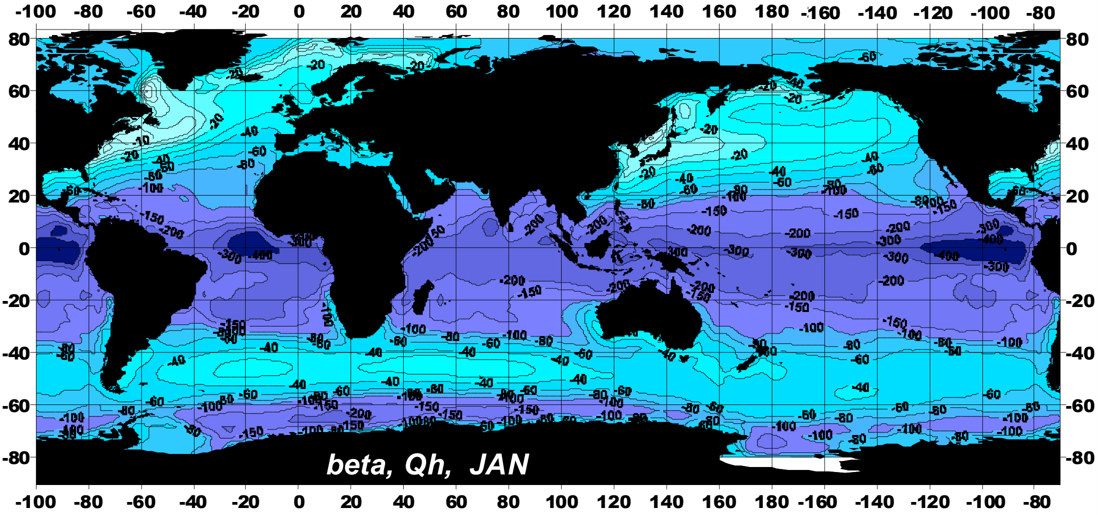


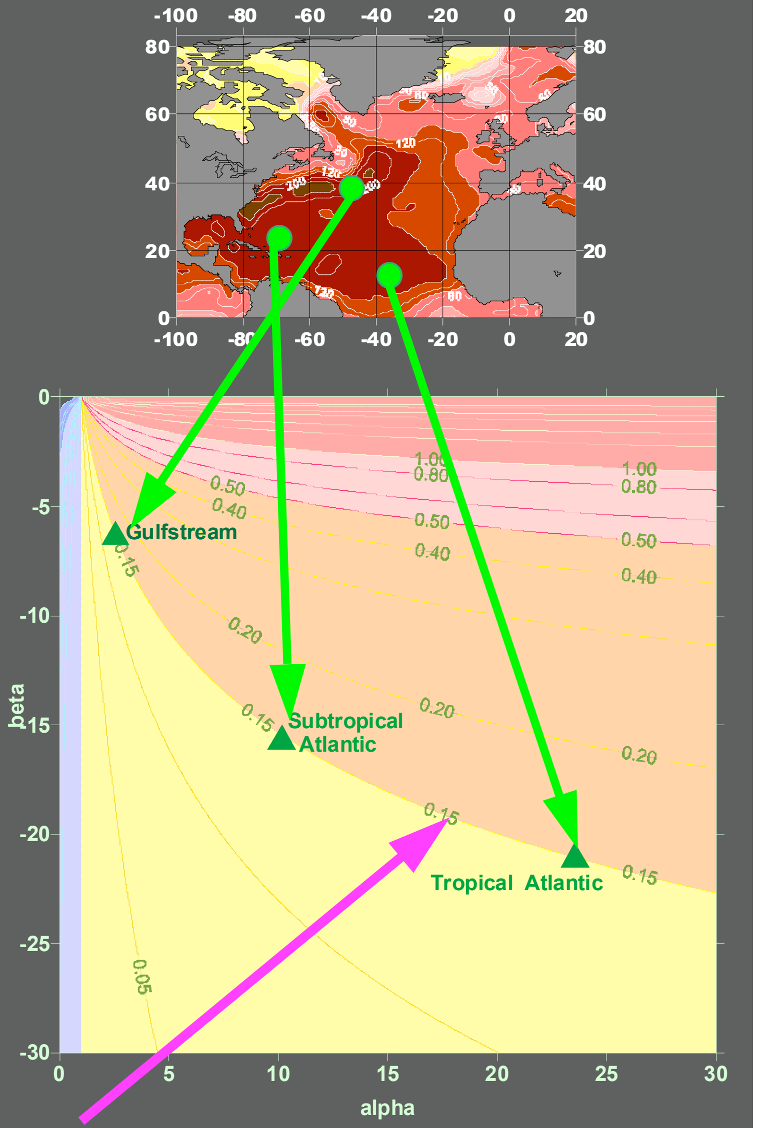
$$\frac{n}{\beta} + \sum_{i=1}^{n} x_i - n \bigg/ \sum_{i=1}^{n} e^{\beta x_i} \cdot \sum_{i=1}^{n} x_i e^{\beta x_i} = 0; \qquad \alpha = n \bigg/ \sum_{i=1}^{n} e^{\beta x_i}$$

Parameter estimation:

Accounting for different statistical properties of qualitatively similar fluxes





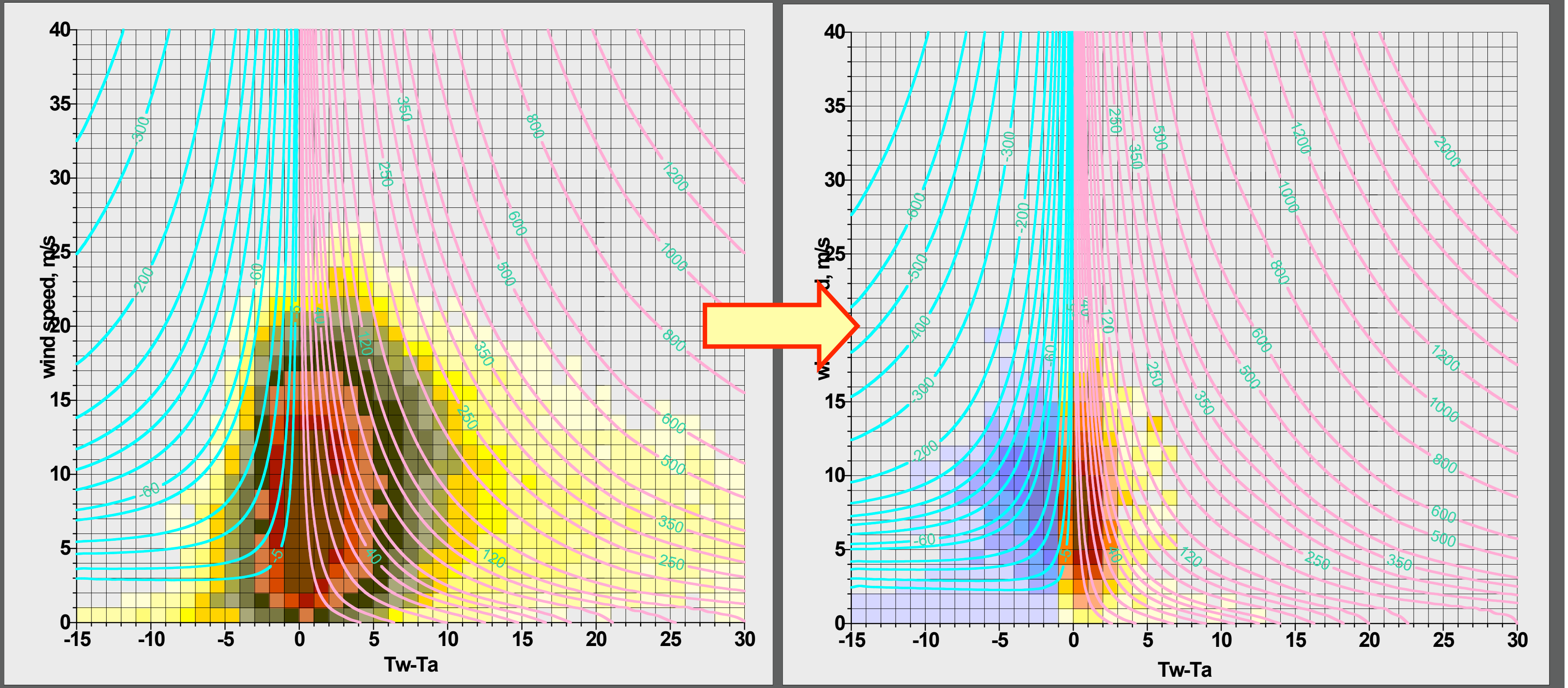


Fluxes in W/m^2×10^{-3}

2D-case: Weibull + 2ePDF

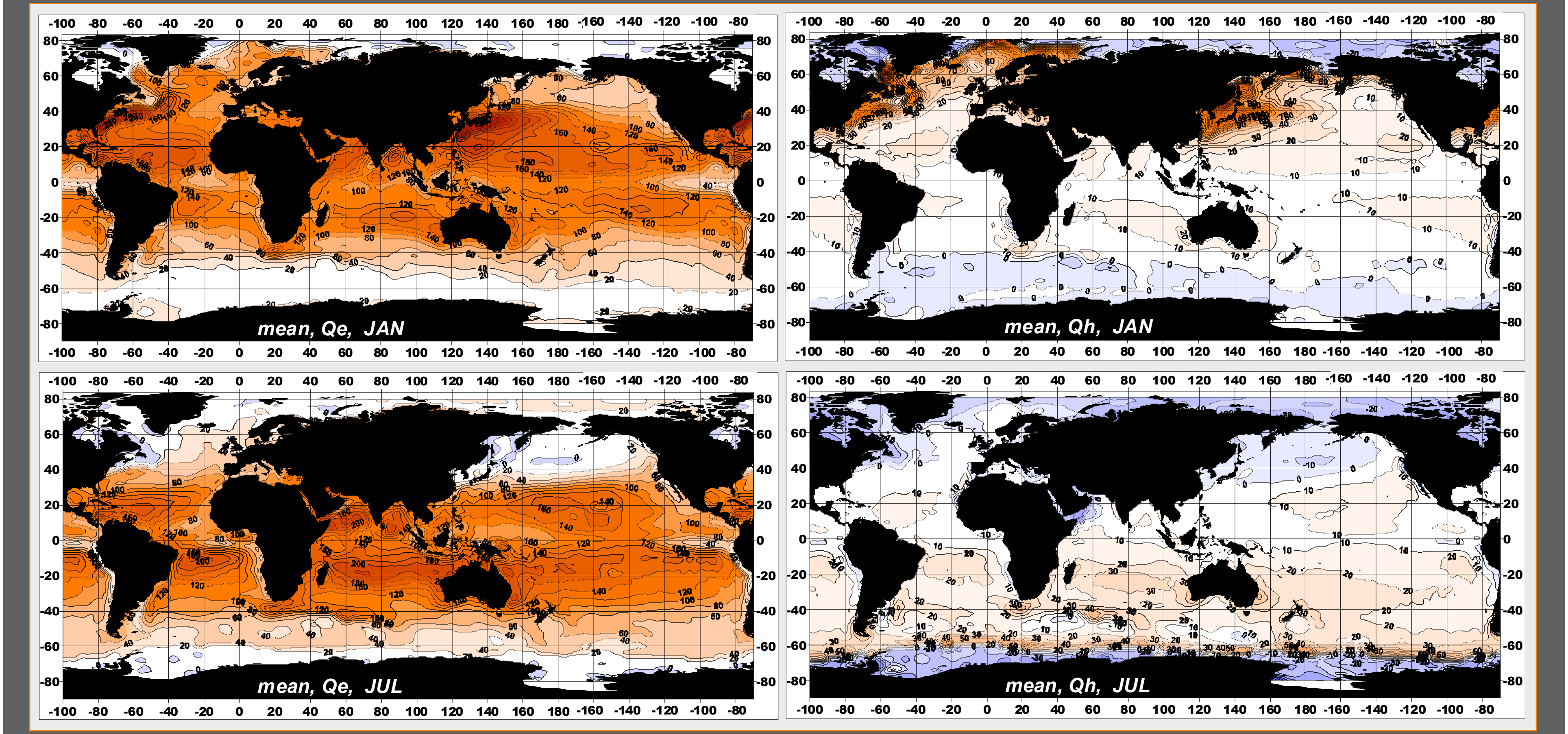
$$P(V\,|\,\delta T)\cdot P(\delta T)=\frac{\alpha_V}{\beta_V}\left(\frac{V}{\beta_V}\right)^{\alpha_V-1}\cdot e^{-\left(\frac{V}{\beta_V}\right)^{\alpha_V}}\cdot(\alpha_T\cdot\beta_T)\cdot e^{\beta_T\,\delta T}\cdot e^{-\alpha_T\cdot e^{\beta_T\delta T}}$$

WIND - Weibull PDF

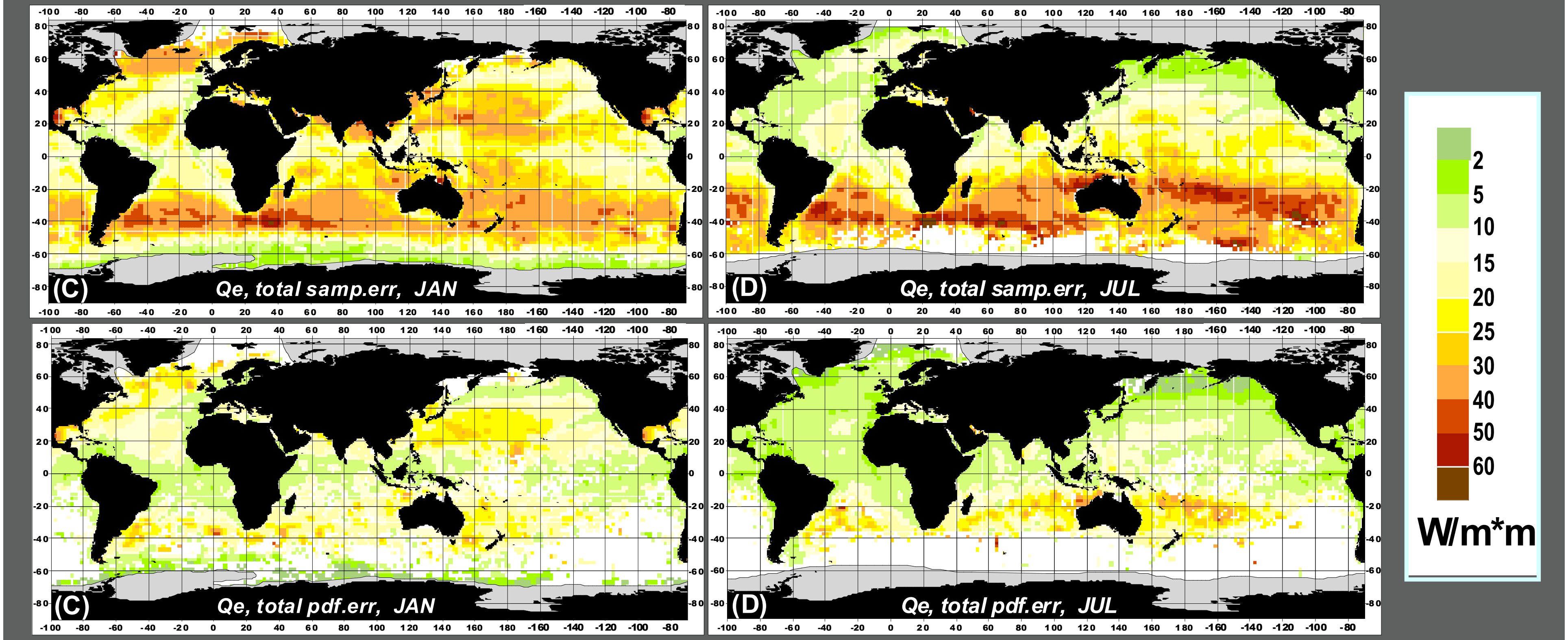


SST-T_{air} -2ePDF

New climatology of turbulent fluxes



Minimization of sampling error



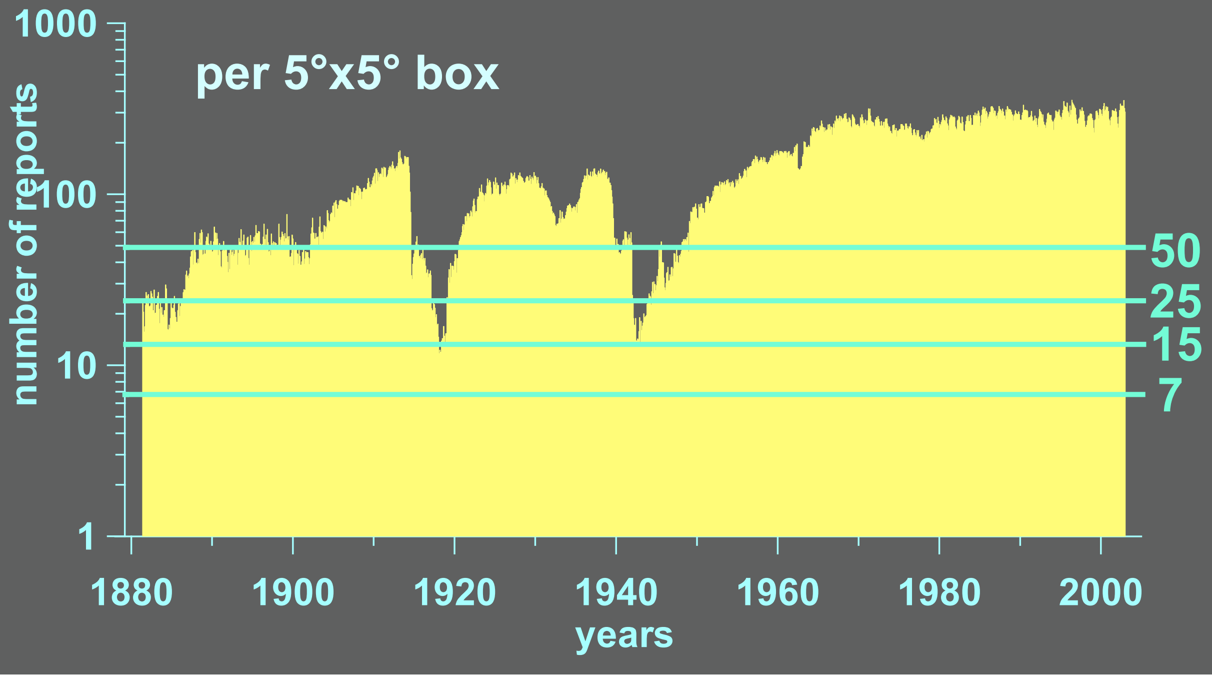
Application of 2eWPDF reduces the sampling uncertainty in 2-10 times (7 times on average)

Task: To derive homogeneous time series of turbulent fluxes in the North Atlantic

What means "homogeneous"?

- Sampling in 1960s+ should be as bad as before WW2
- Impact of parameterizations should be minimized
- Impact of changes in obs. practices should be minimized

The fluxes will not be correct, but variability might be reliable



MC-sub-sampling for *n*=7,15,25,50 per 5°x5° box

Technology of the reconstruction

Parameterizations:

- COARE-3.0 (with some simplifications)

Parameters:

- Wind – Beaufort only, WMO1100 => to Lindau (1995) scale (not after 1986)
- SST – buckets only, no engine intakes (not after 1986)
- Air temperature – all
- Relative humidity – multi-regression reconstruction

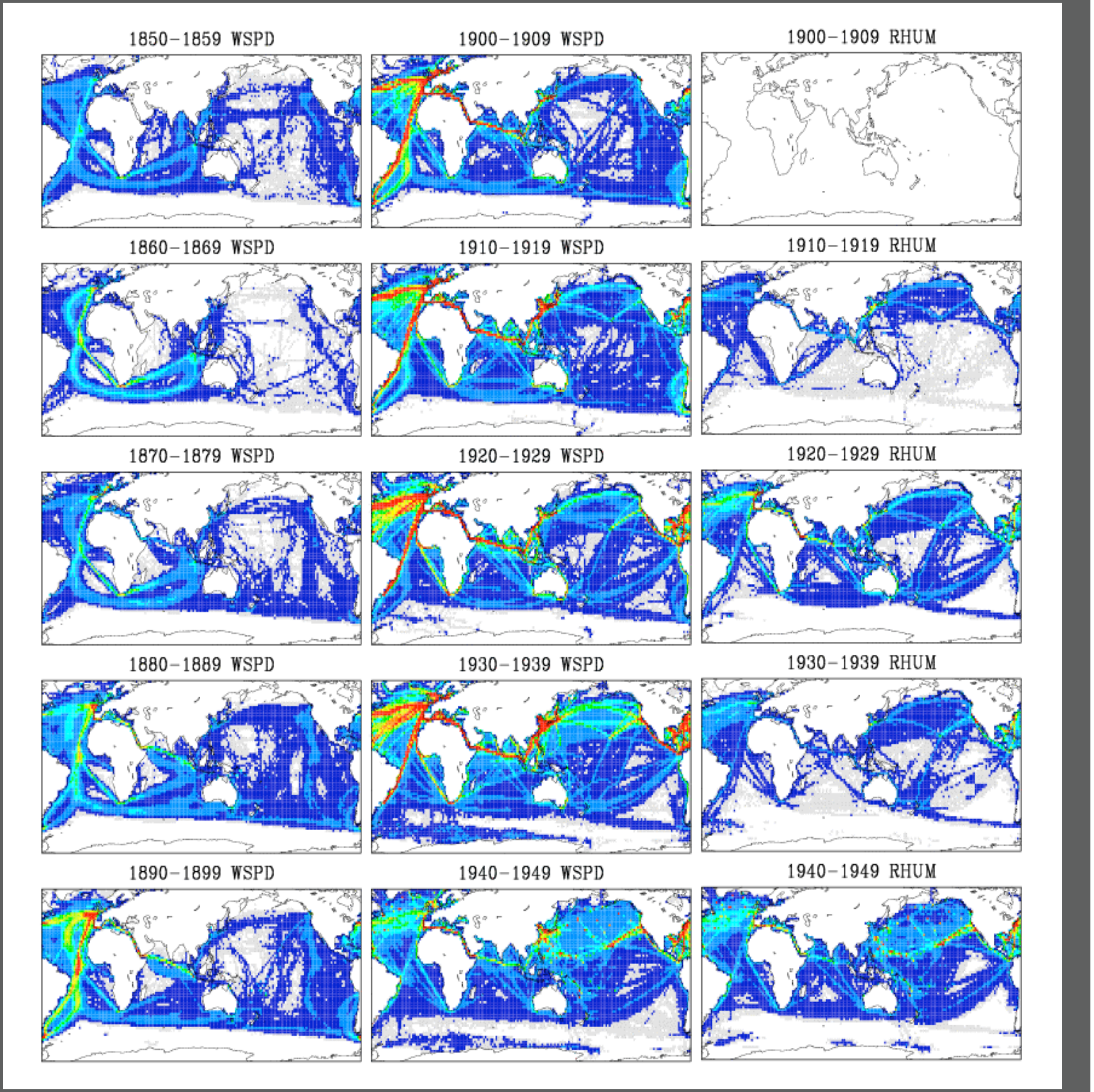
Production – iterative run for every month:

- 1st guess - 2eWPDF derivation of monthly statistics for 10º boxes south of 40ºN and for gerrymander cells north of 40ºN
- 2eWPDF computation for 5ºx5º boxes, if the PDF does not fit at 95% level, use the 1st guess
- then – repeat the procedure again

Reconstruction of humidity

Sampling of humidity:

- ☐ no humidity before 1910
- ☐ humidity is sparse before 1950

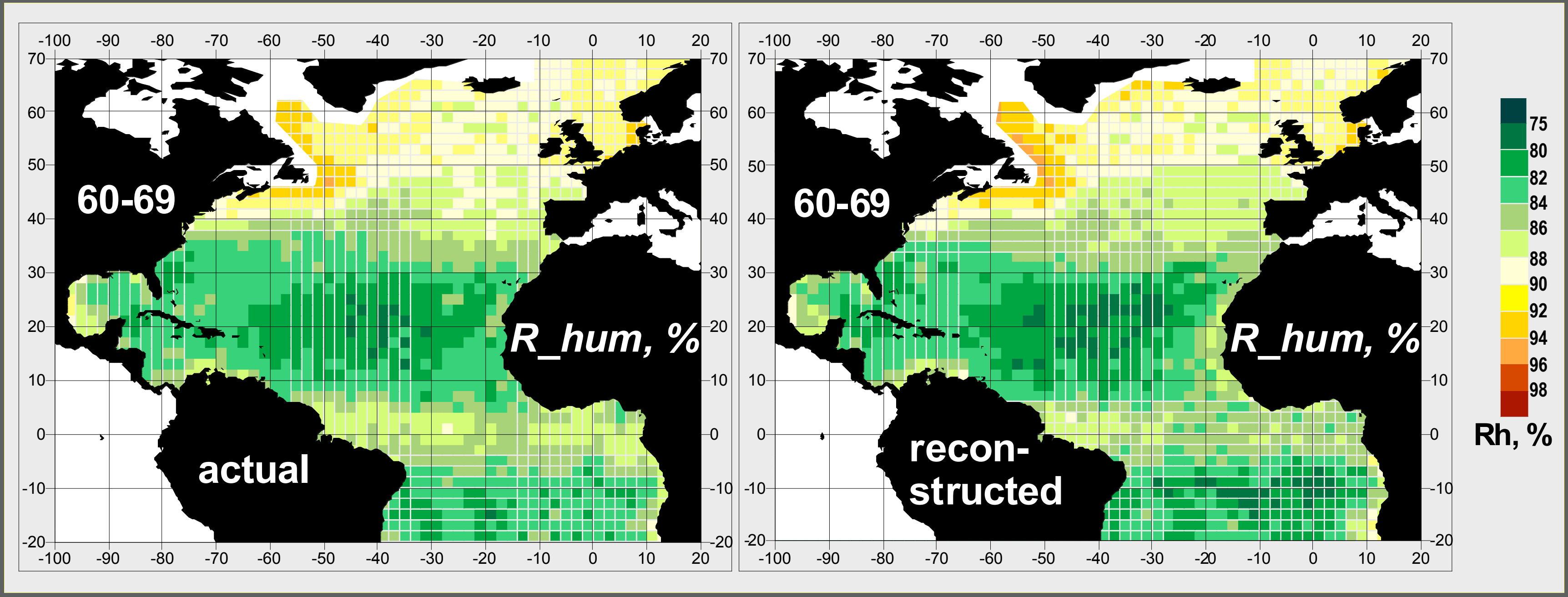


Woodruff et al. 2005

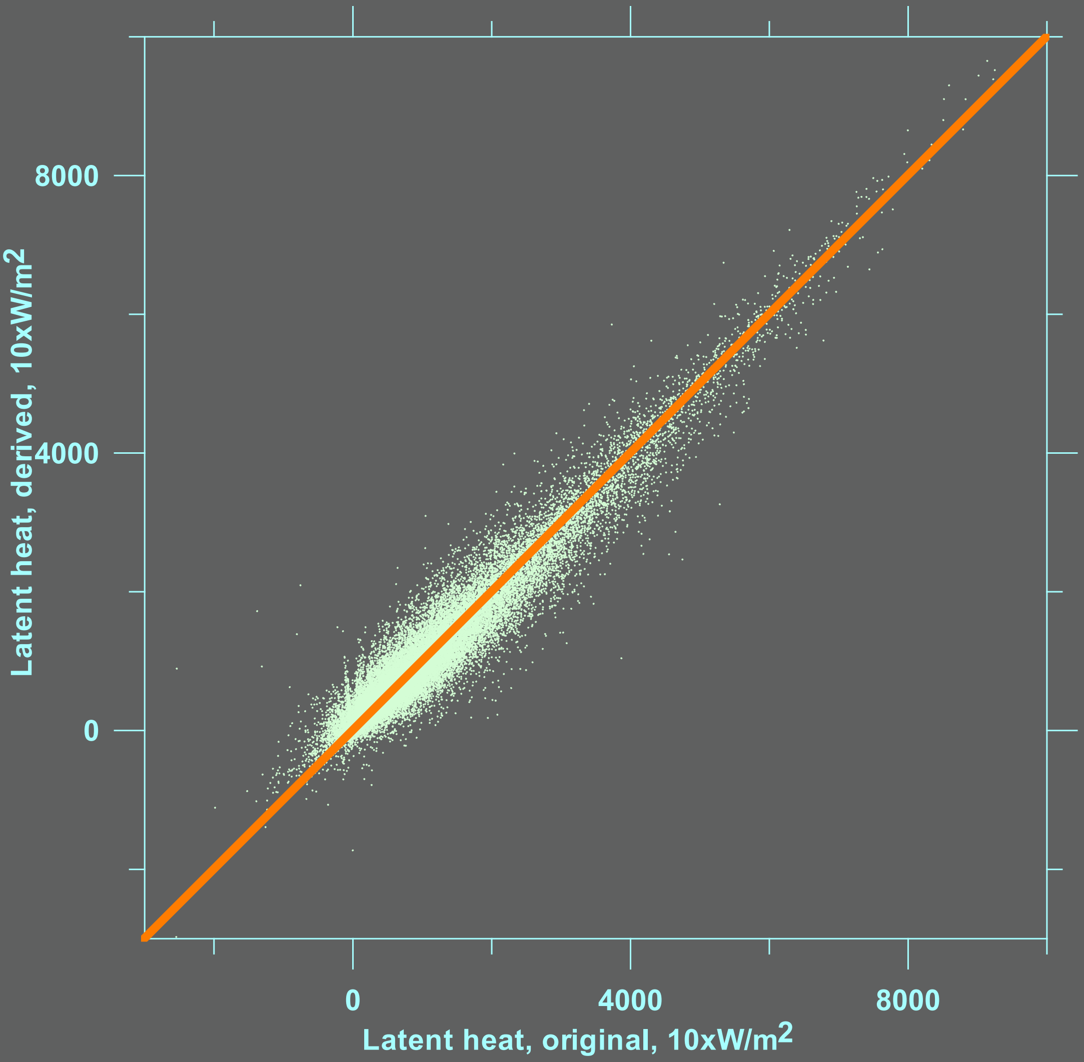
Reconstruction of relative humidity

Strategy:

- Statistical multiregression approach (not a neural network yet) for the decade of 1960s
- Deviations from seasonal climatology are considered
- Exponential functions + polynomials for Ta, V, SLP
- Done locally, for every month and every box



Effect of humidity in latent heat flux

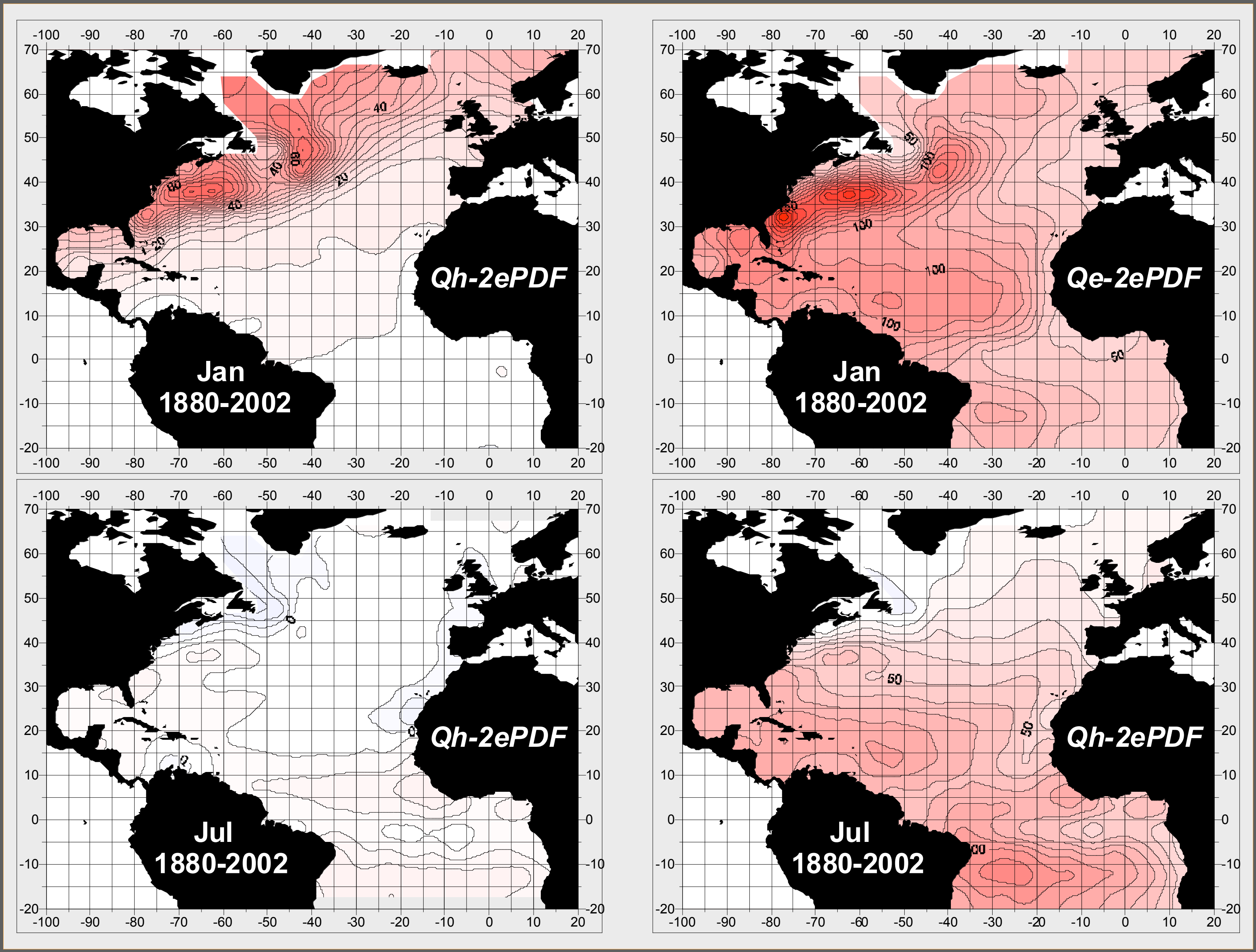


RMS = 7 W/m^2

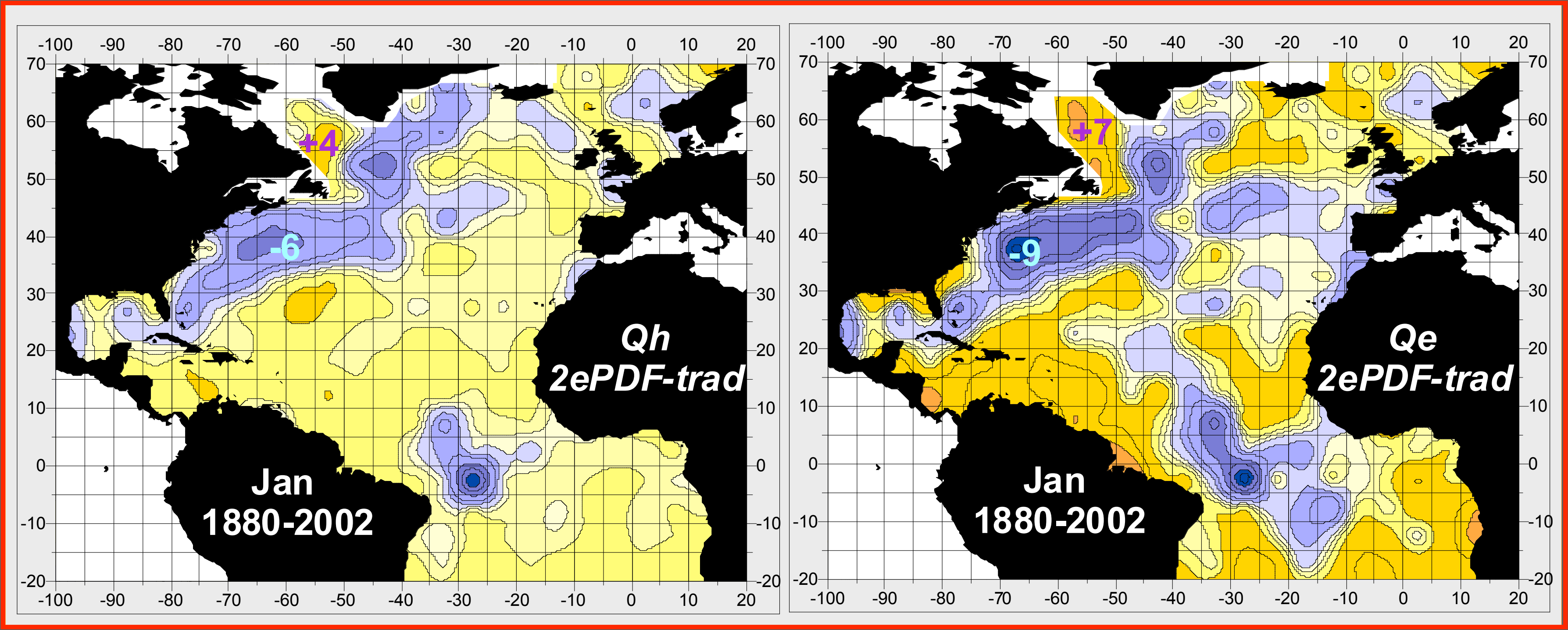
Slope = 0.996

Intercept = +1.4 W/m^2

125-yr (1980-2004) climatology



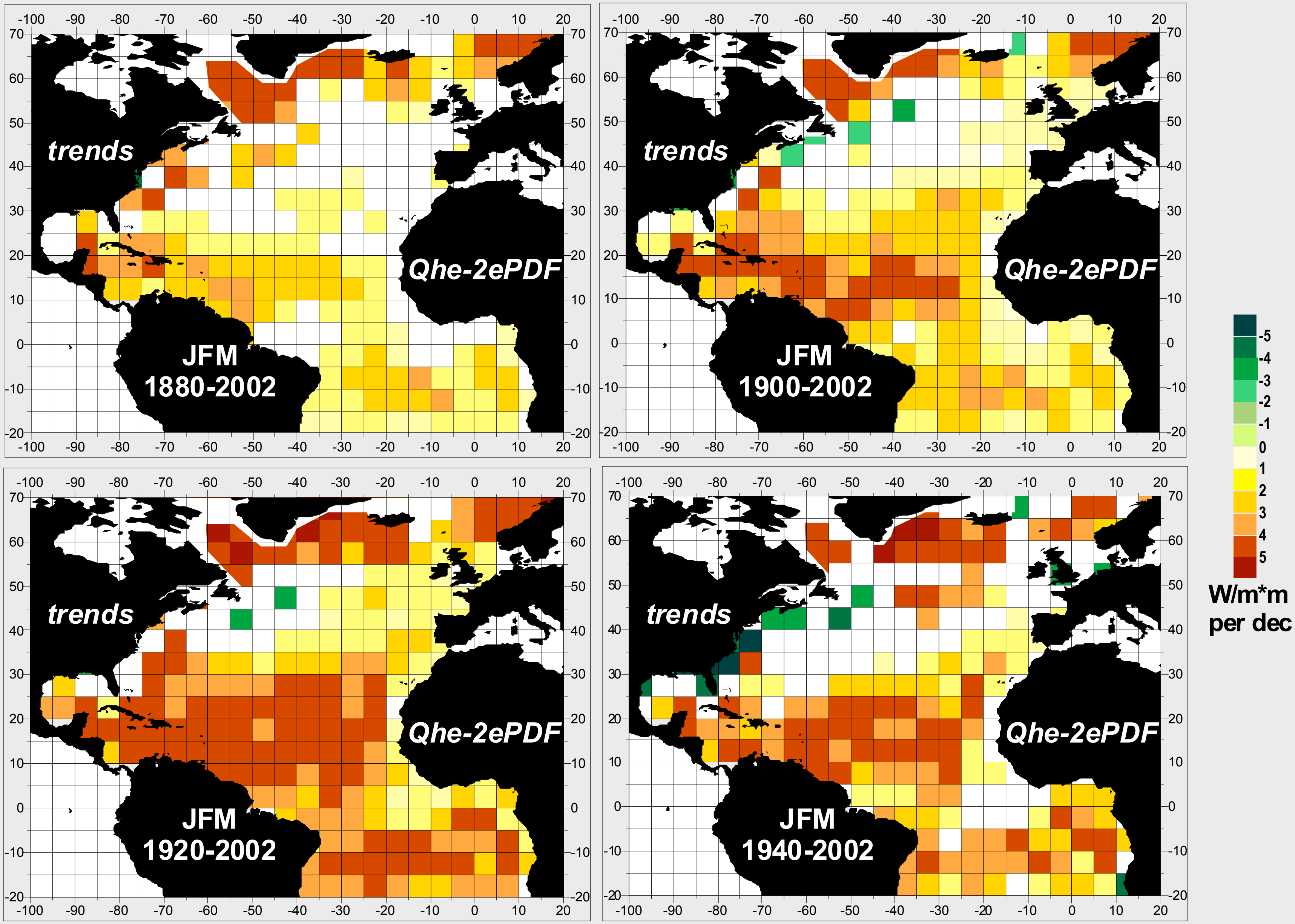
How it is different from the raw averaging?



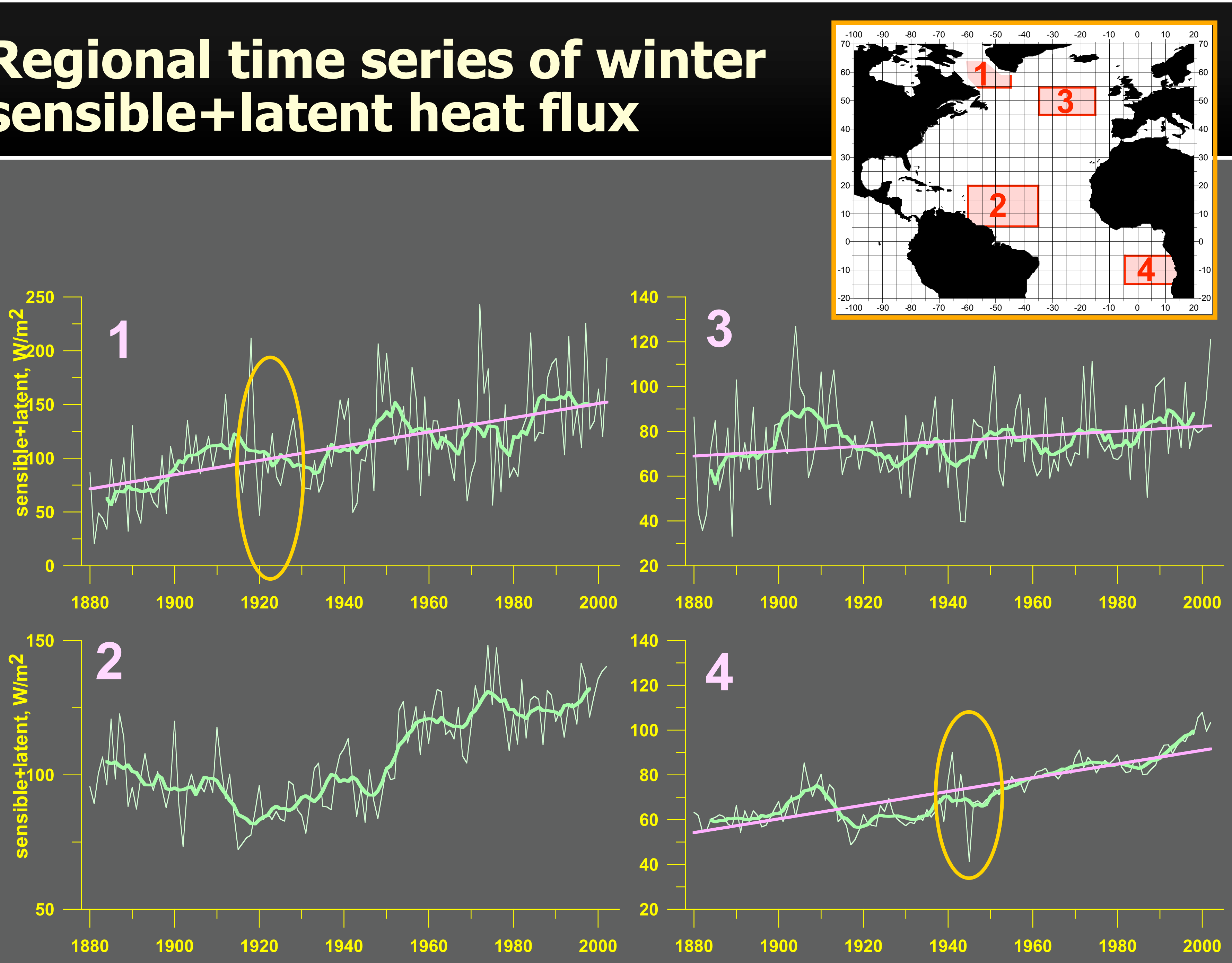
Differences
“2eWPDF-derived minus traditionally averaged”
fluxes:

Sampling effect is clearly visible

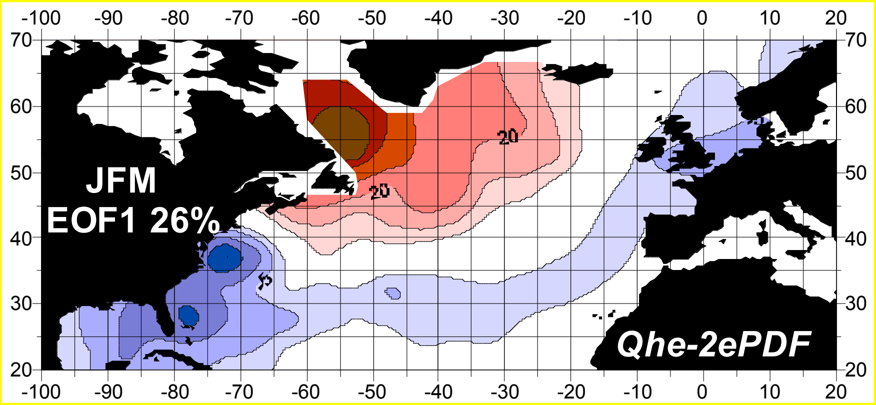
Winter linear trends

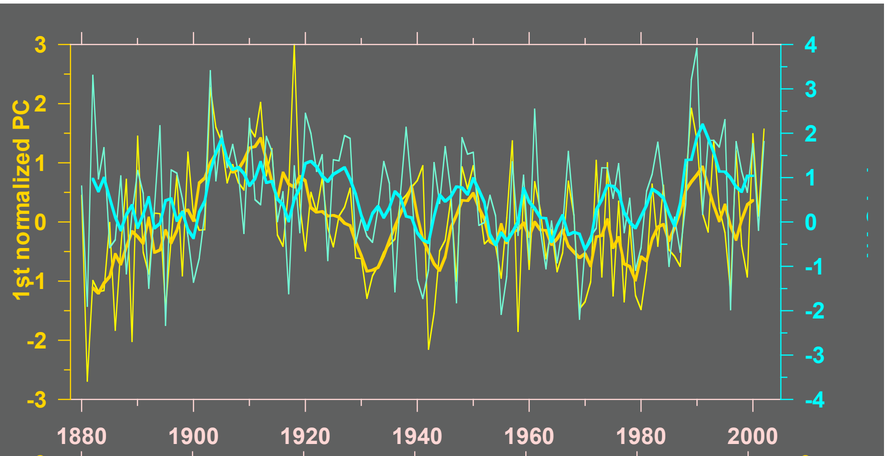


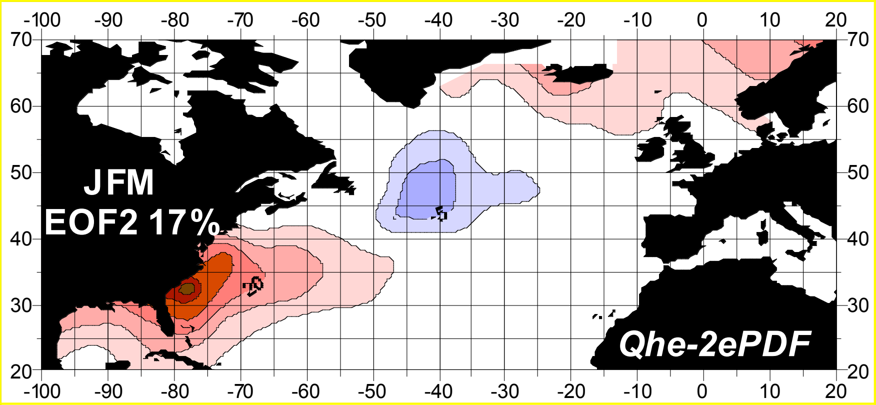
Regional time series of winter sensible+latent heat flux

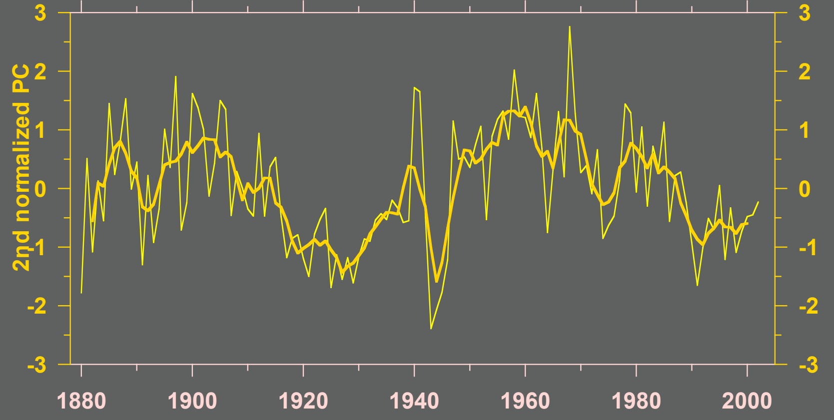


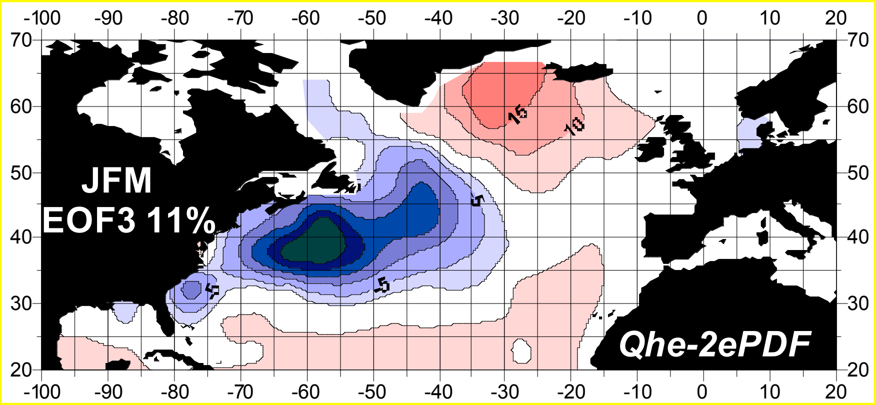
Winter (JFM) EOFs of sensible+latent flux

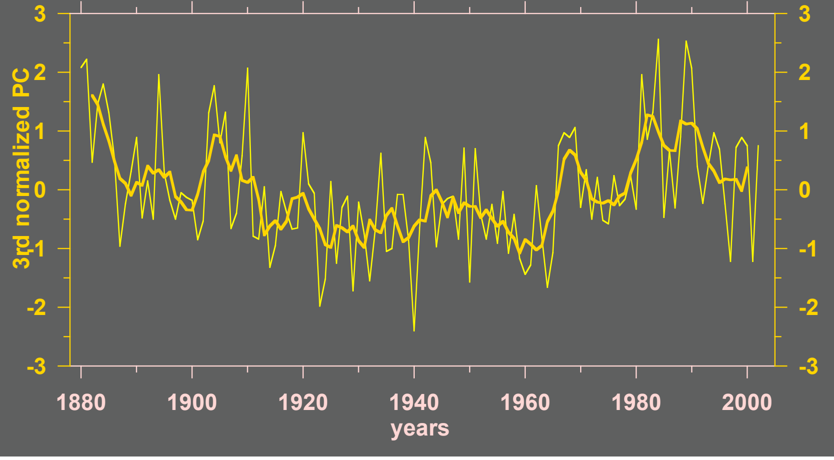






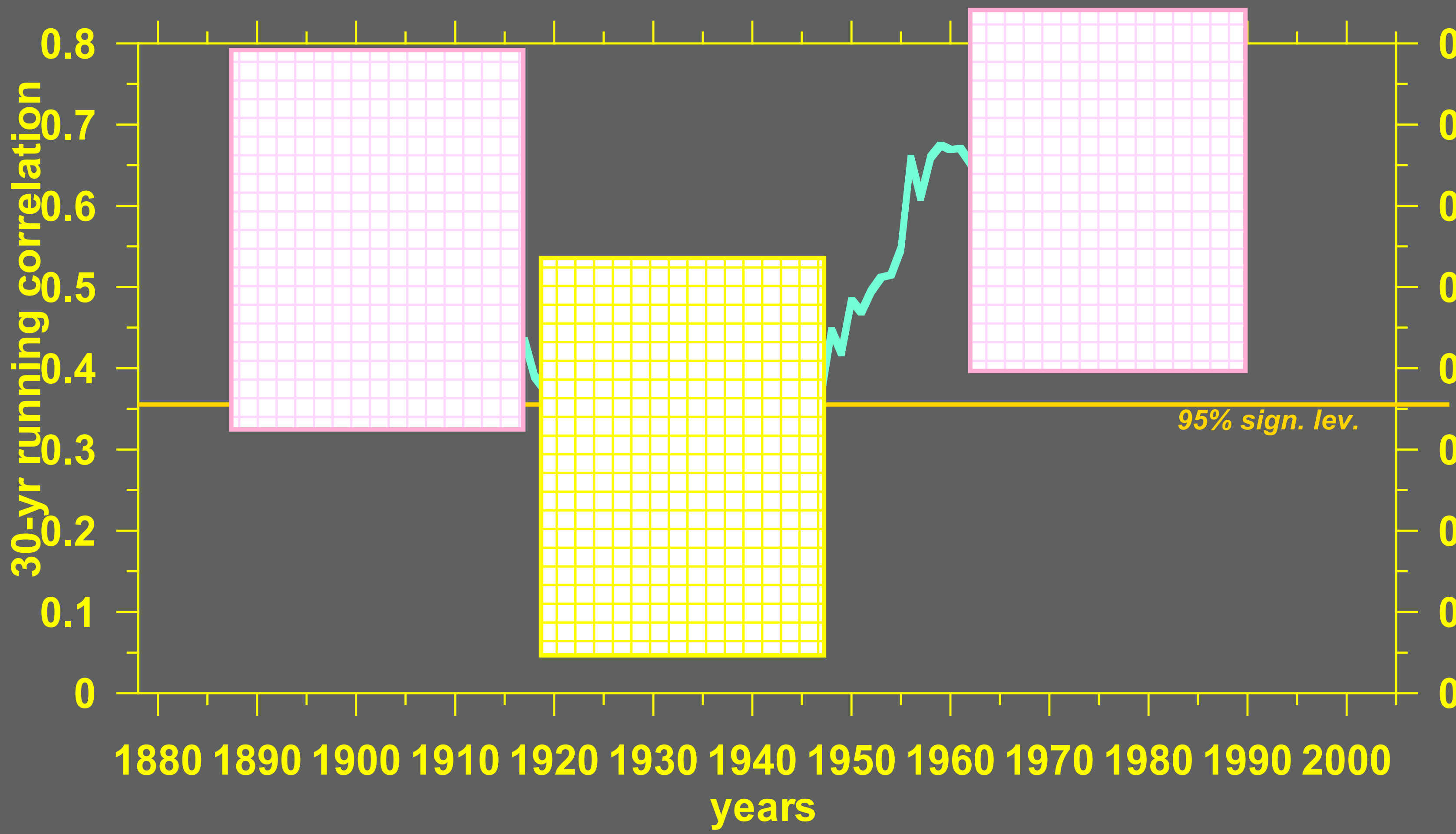




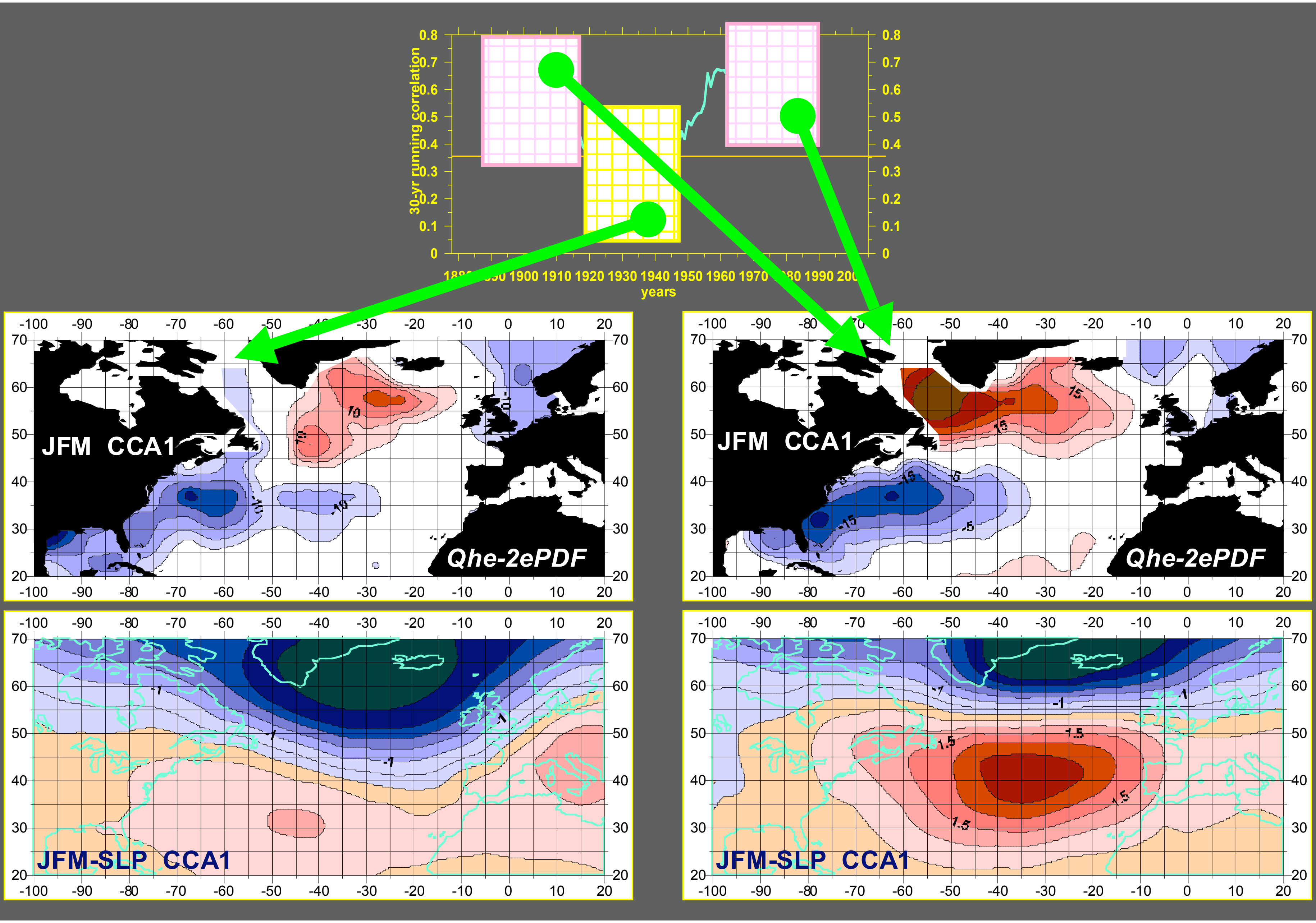


Link of the leading mode of turbulent fluxes to NAO

30-yr running correlation changes over time considerably



Canonical correlation of the heat fluxes with HadSLP for different periods



Conclusions

- 2eW-PDF allows for the minimization of sampling biases in turbulent fluxes from 2 to 7 times and Allows for the development of long-term homogeneous flux time series
- 5-degree 125-yr homogeneous time series of turbulent fluxes (1880-2004) were derived – multi-decadal variability is visible
- During 1915/20 – 1950/55 winter surface turbulent fluxes are loosely connected with NAO, being closely related to NAO during the decades before and after this period

Special thanks

Steve Worley, DSS, NCAR, Boulder
Scott Woodruff, CDC, NOAA, Boulder

for many years of reliable feedback in ICOADS data management

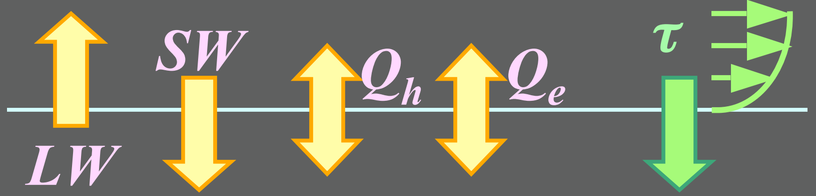
VOS-based ocean-atmosphere fluxes

Measurements and variable corrections:

SST, T_a, q, SLP, V, cloud cover, wave heghts and periods

Parameterizations:

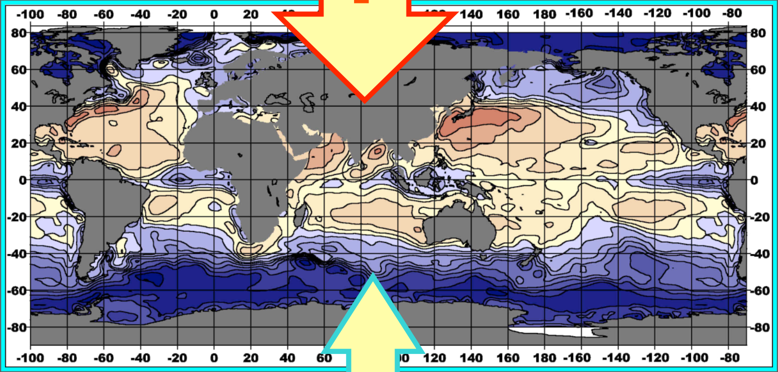
$$
\begin{aligned}
LW &= \varepsilon\sigma SST^4 F_{lw}(Cn, T_a, e_z),\\
SW &= Q_o F_{sw}(C_n, T_a, e_z, h_o)(1-\alpha),\\
Q_h &= C_p C_t \rho (SST - T_a\gamma)V,\\
Q_e &= L C_e \rho (0.622/P)(e_o - e_z)V,\\
H &= SW - LW - Q_h - Q_e\\
\tau &= \rho C_v (V, h_w) V^2
\end{aligned}
$$



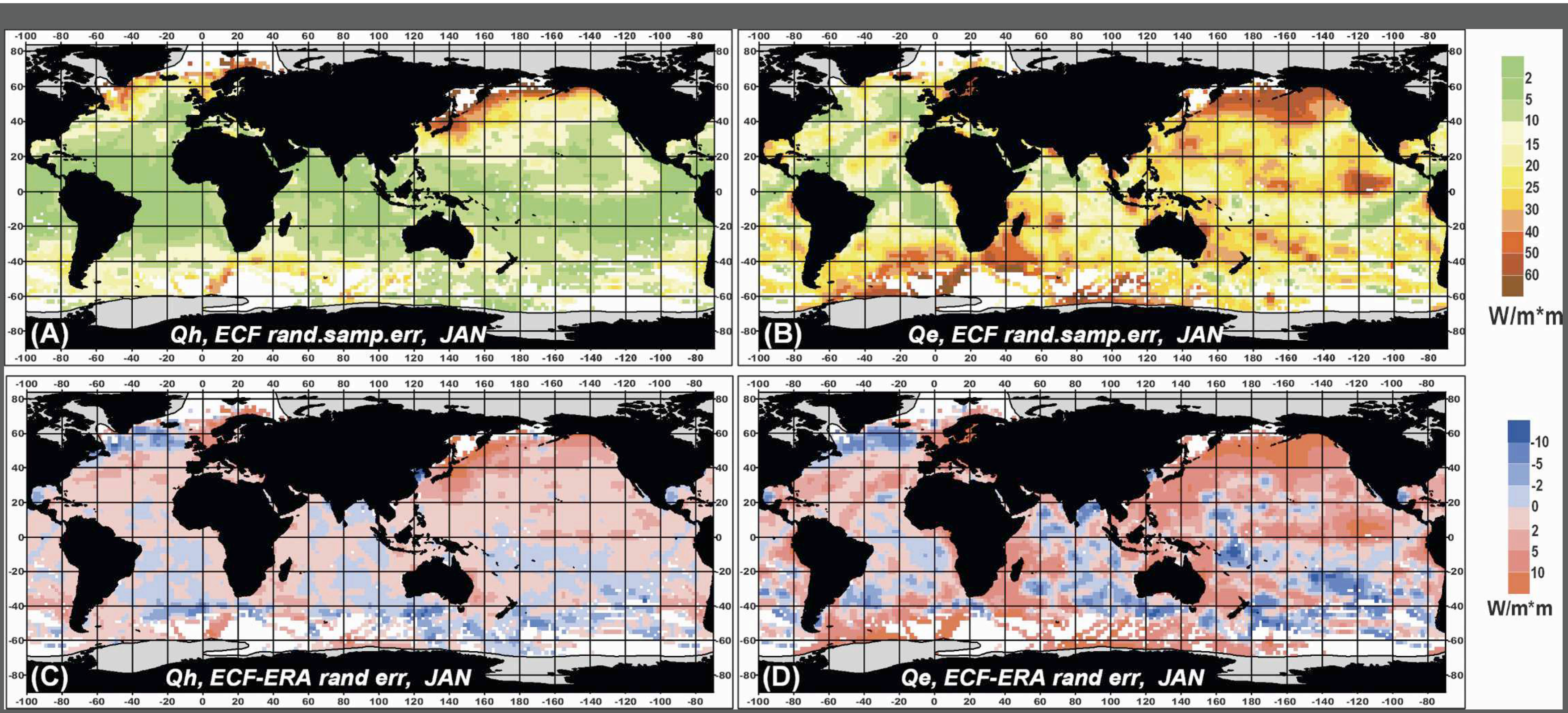
Objective analysis and averaging:

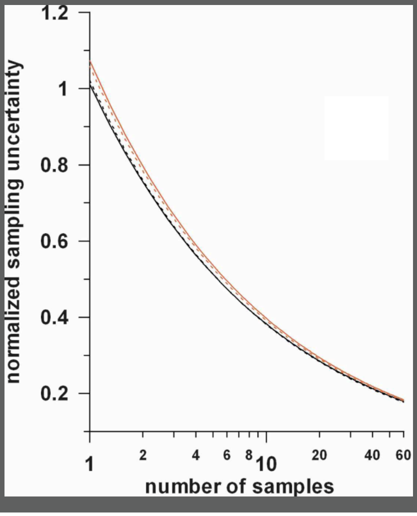
Global air-sea flux fields

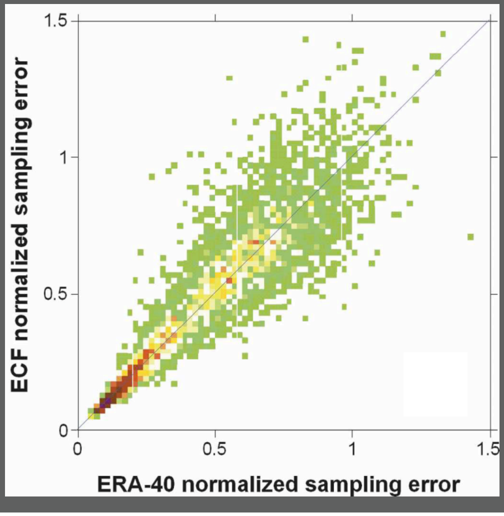
?



Sampling errors from different NWP

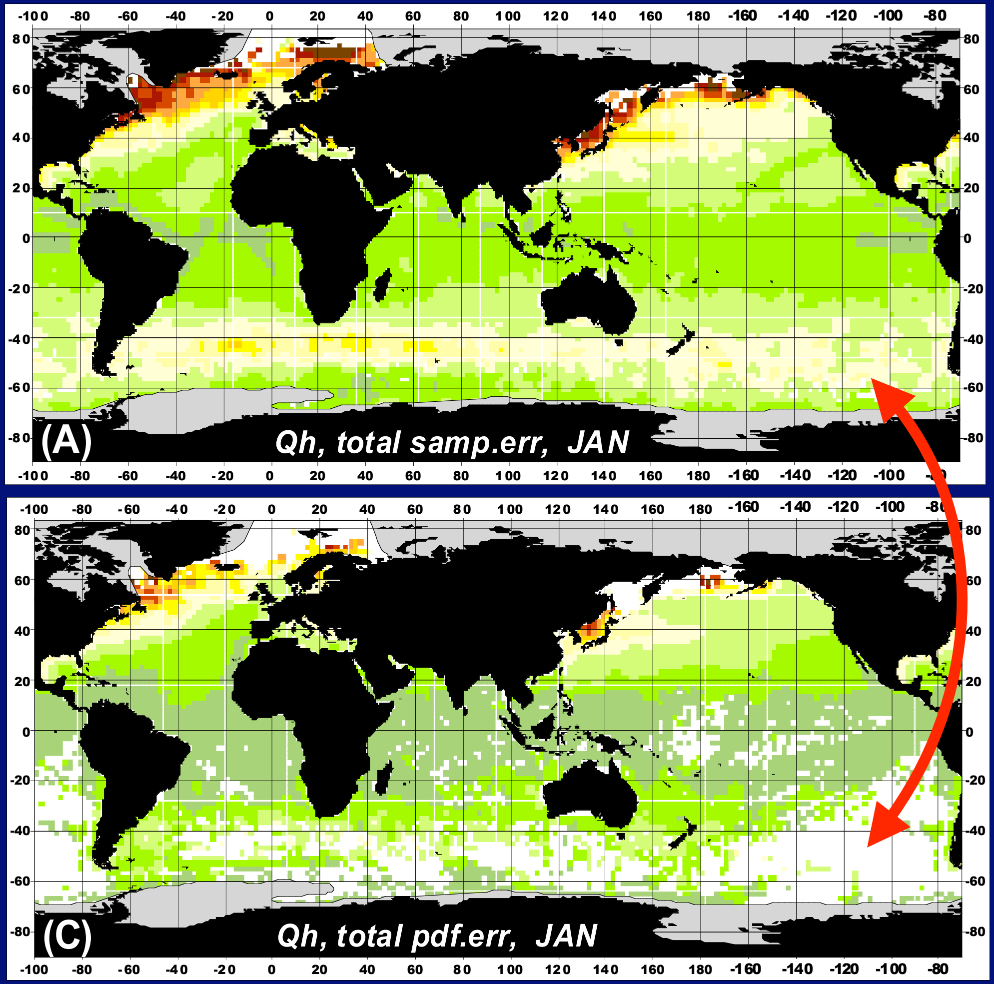


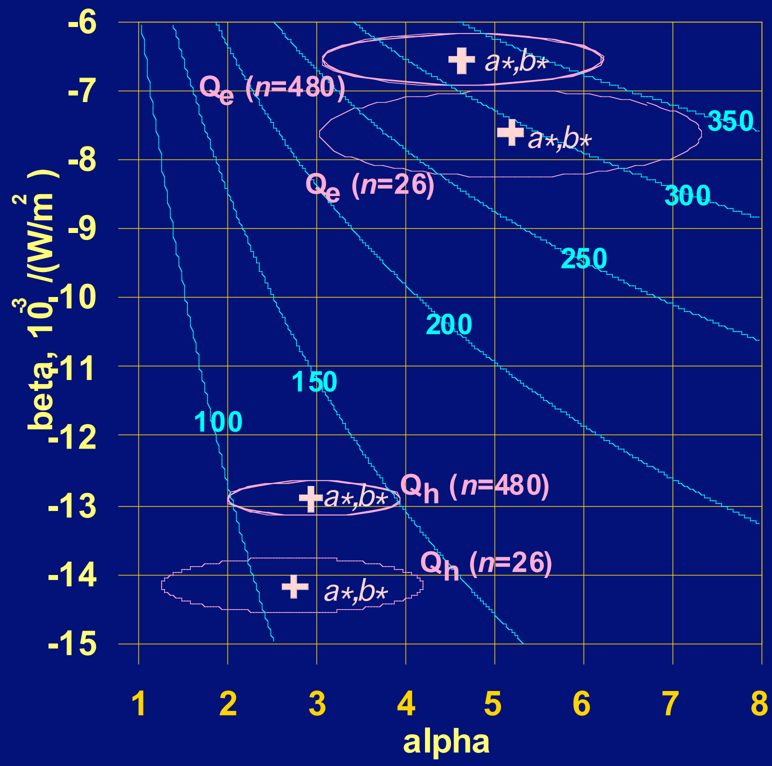




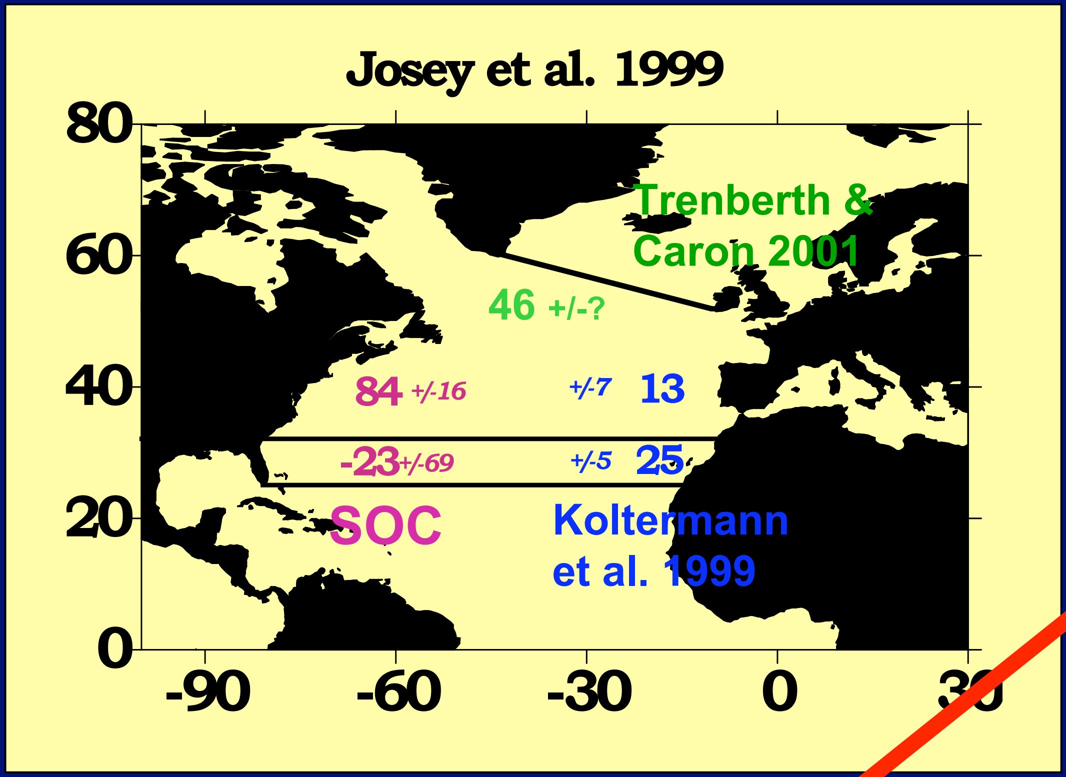
Actual values may be different, but when scaled with *std* sapling error is practically equal, when derived from different NWP

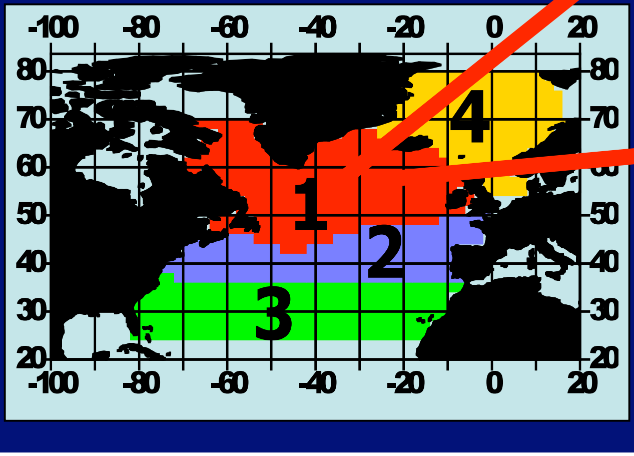
$$\frac{(\alpha-\alpha_*)^2}{\sigma_1^2}-\frac{2\rho}{\sigma_1\sigma_2}(\alpha-\alpha_*)(\beta-\beta_*)+\frac{(\beta-\beta_*)^2}{\sigma_2^2}=6(1-\rho^2)$$





Estimating regionally integrated heat flux using 2e PDF





Uncertainty in the integrated sensible+latent flux

VOS-like sampling:

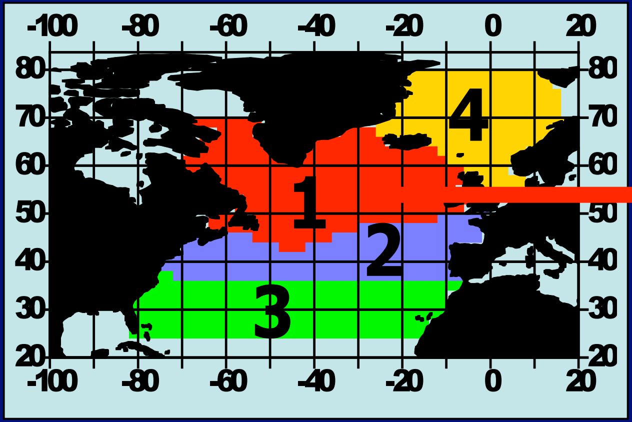
$\Delta = 0.67 * 10^{14}$ W

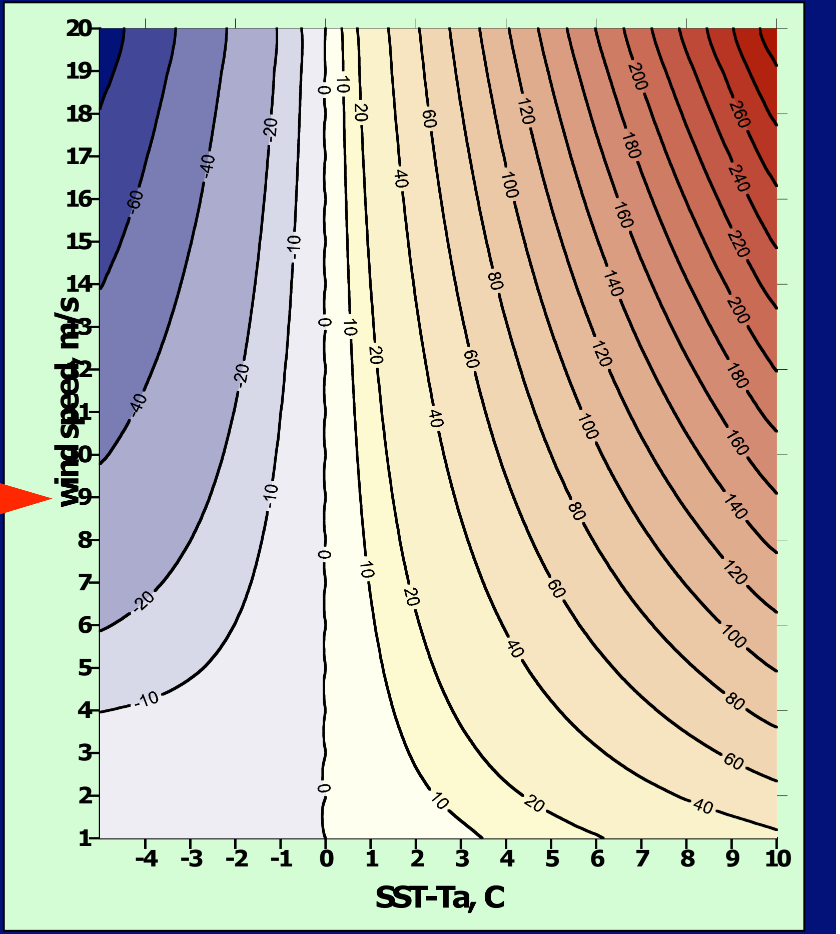
2e-PDF - reconstruction:

$\Delta = 0.23 * 10^{14}$ W

Regional balances: a new domain for integration

$$Q_h = C_p \cdot \rho \cdot C_t(\delta T, V) \cdot \delta T \cdot V$$

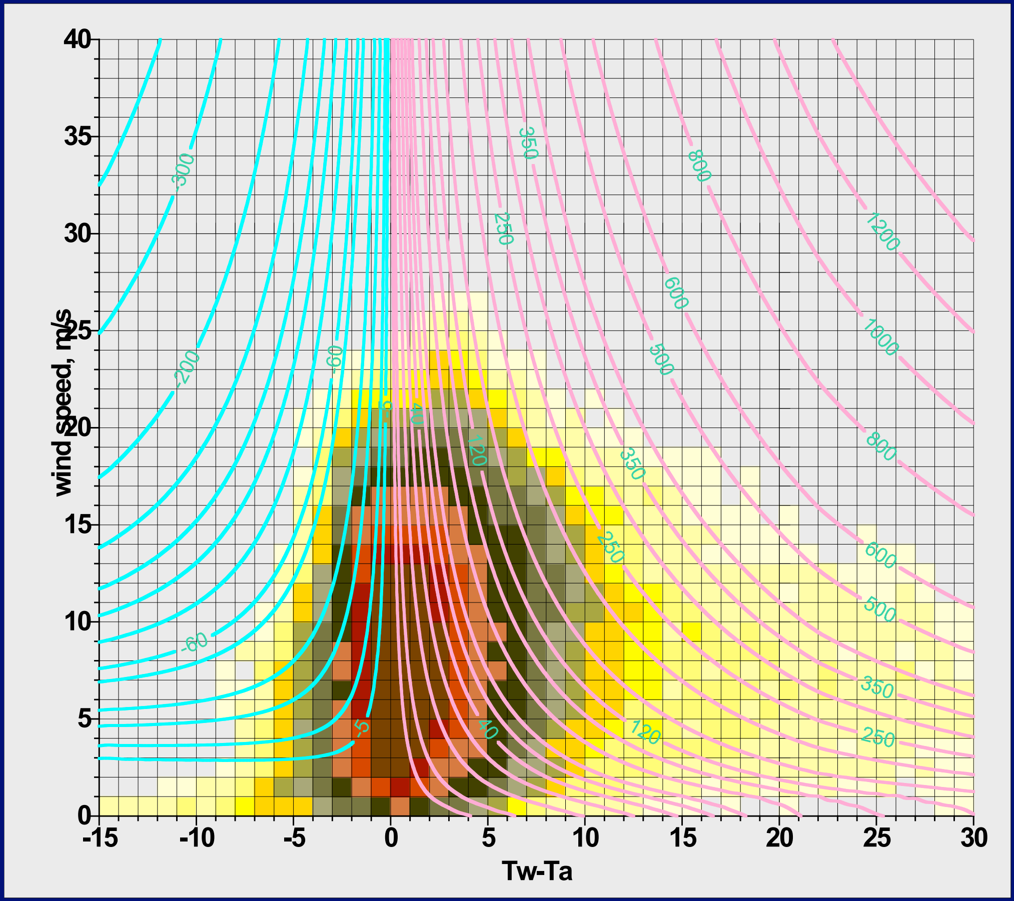




$$Q_\Sigma = \int_t dt \int_S Q\,dS = \int_V dV \int_{\delta T} Q\,d(\delta T)$$

2-dimensional double-exponential-Weibull (2eW) PDF

WIND - Weibull PDF



SST-Tair -2ePDF

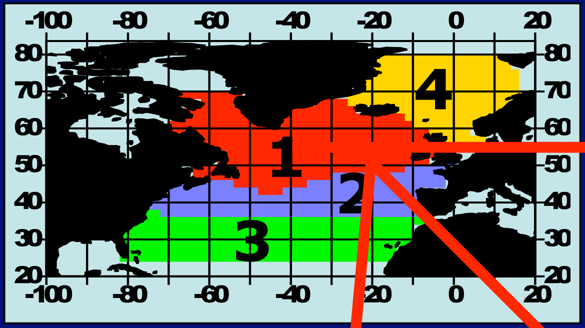
$$P(V\,|\,\delta T)\cdot P(\delta T) =$$

$$= F(\alpha_V, \beta_V, \alpha_{\delta T}, \beta_{\delta T}) =$$

$$= \frac{\alpha_V}{\beta_V}\left(\frac{V}{\beta_V}\right)^{\alpha_V - 1} \cdot e^{-\left(\frac{VT}{\beta_V}\right)^{\alpha_V}} \cdot$$

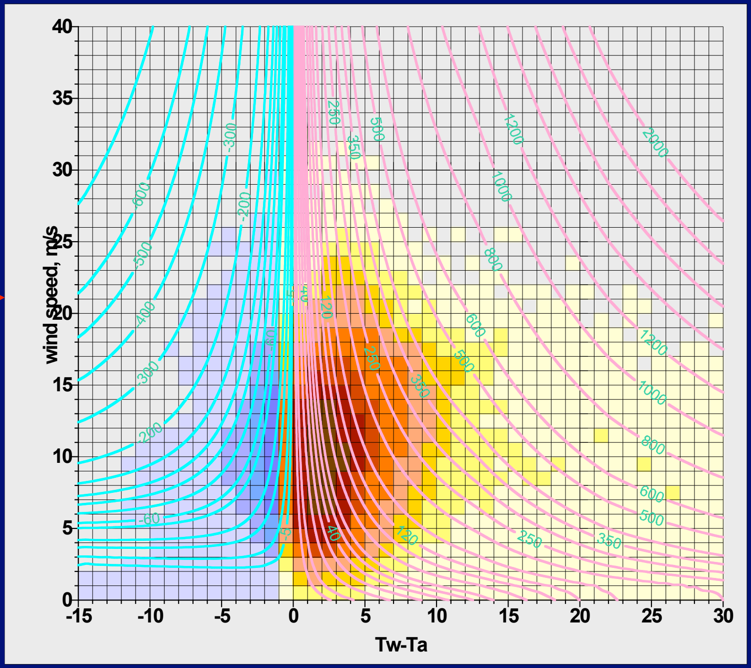
$$\cdot(\alpha_T \cdot \beta_T)\cdot e^{\beta_T\,\delta T} \cdot e^{-\alpha_T \cdot e^{\beta_T \delta T}}$$

2D-distributions of turbulent fluxes



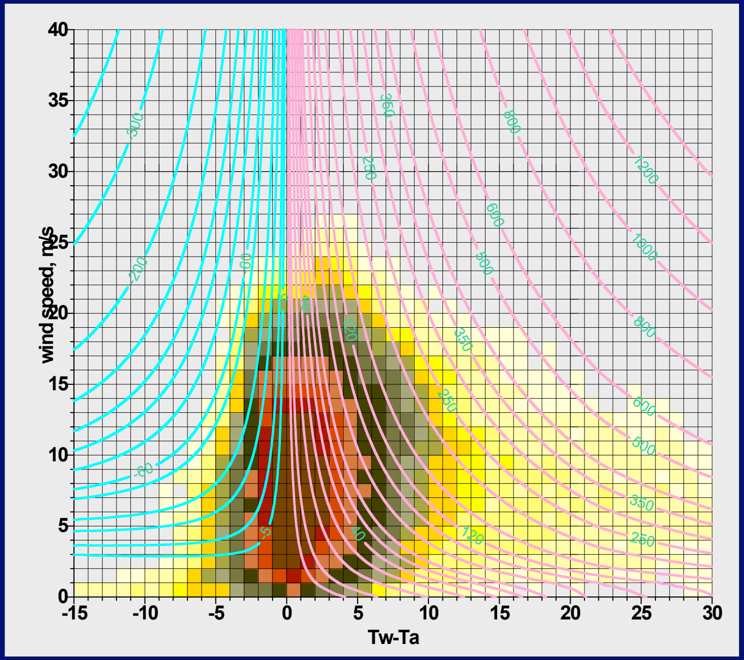
Fluxes accumulated over $\delta T, V$ -classes

Qe

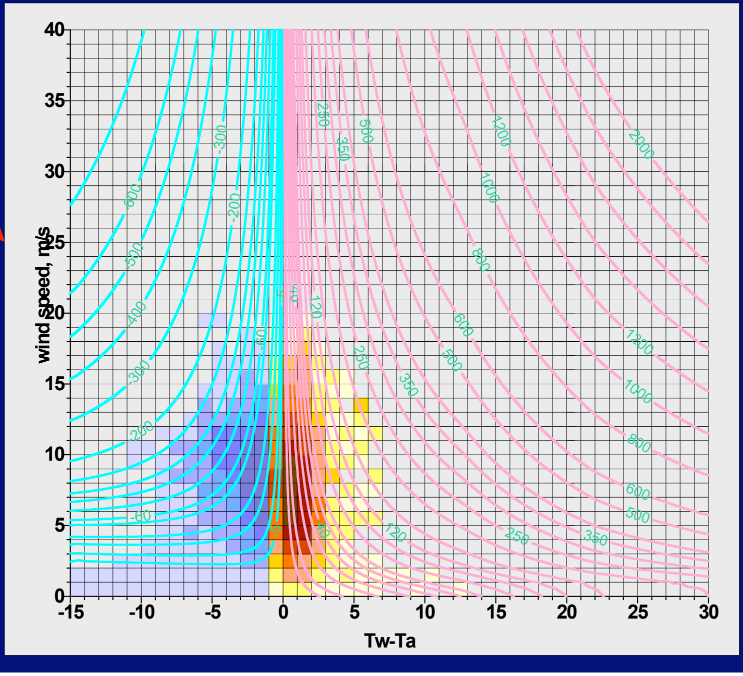


10^{11} W

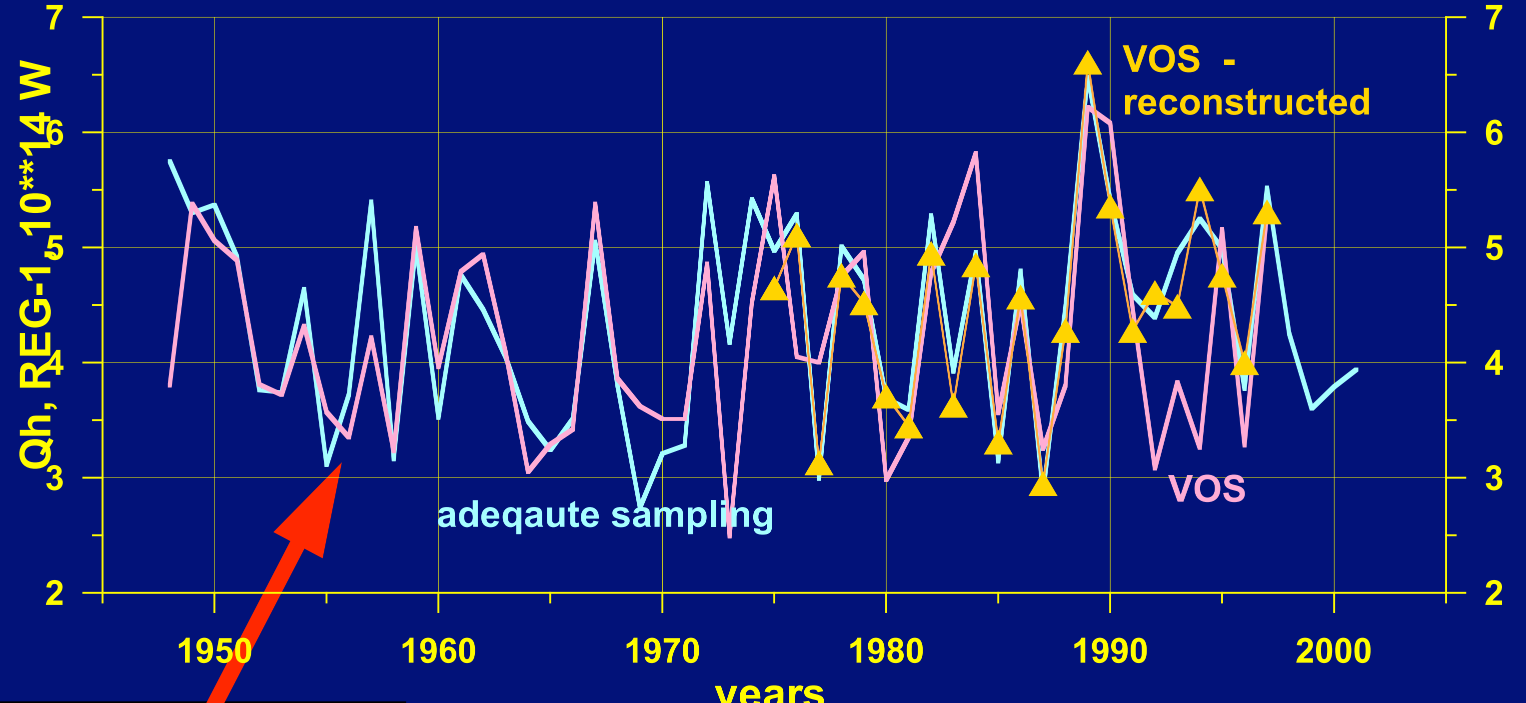
2D- PDF of sensible flux

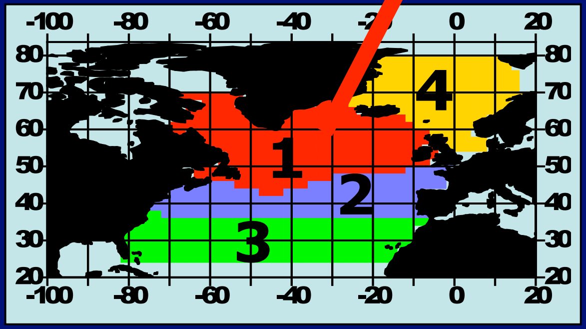


Qh



Estimating regionally integrated heat flux using two dimensional 2e-Weibull PDF





VOS-like sampling:

$\Delta = 0.67*10^{14}$ W

2D-2eW-PDF - reconstruction:

$\Delta = 0.11*10^{14}$ W

2e-PDF - reconstruction:

$\Delta = 0.23*10^{14}$ W