SAMPLING ERRORS IN VOS-BASED SEA-AIR FLUX CLIMATOLOGIES

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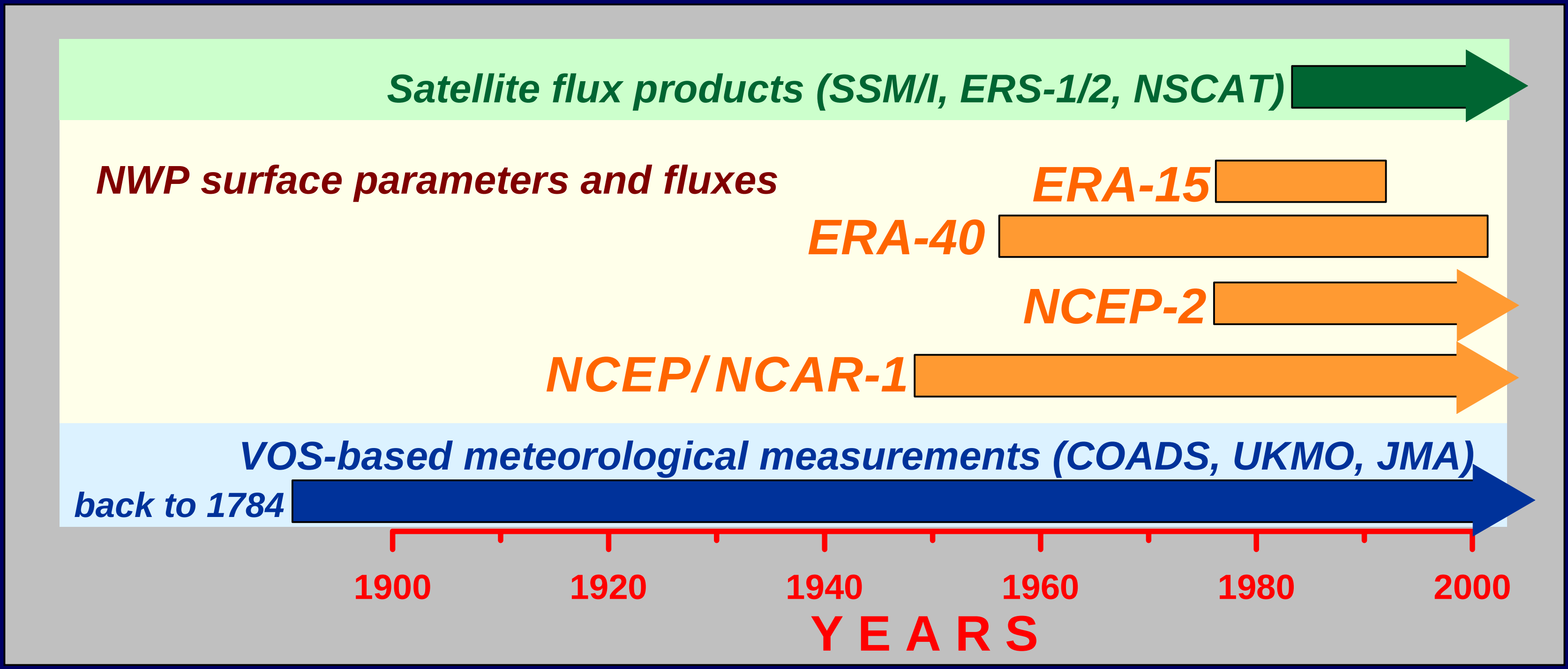
Outline:

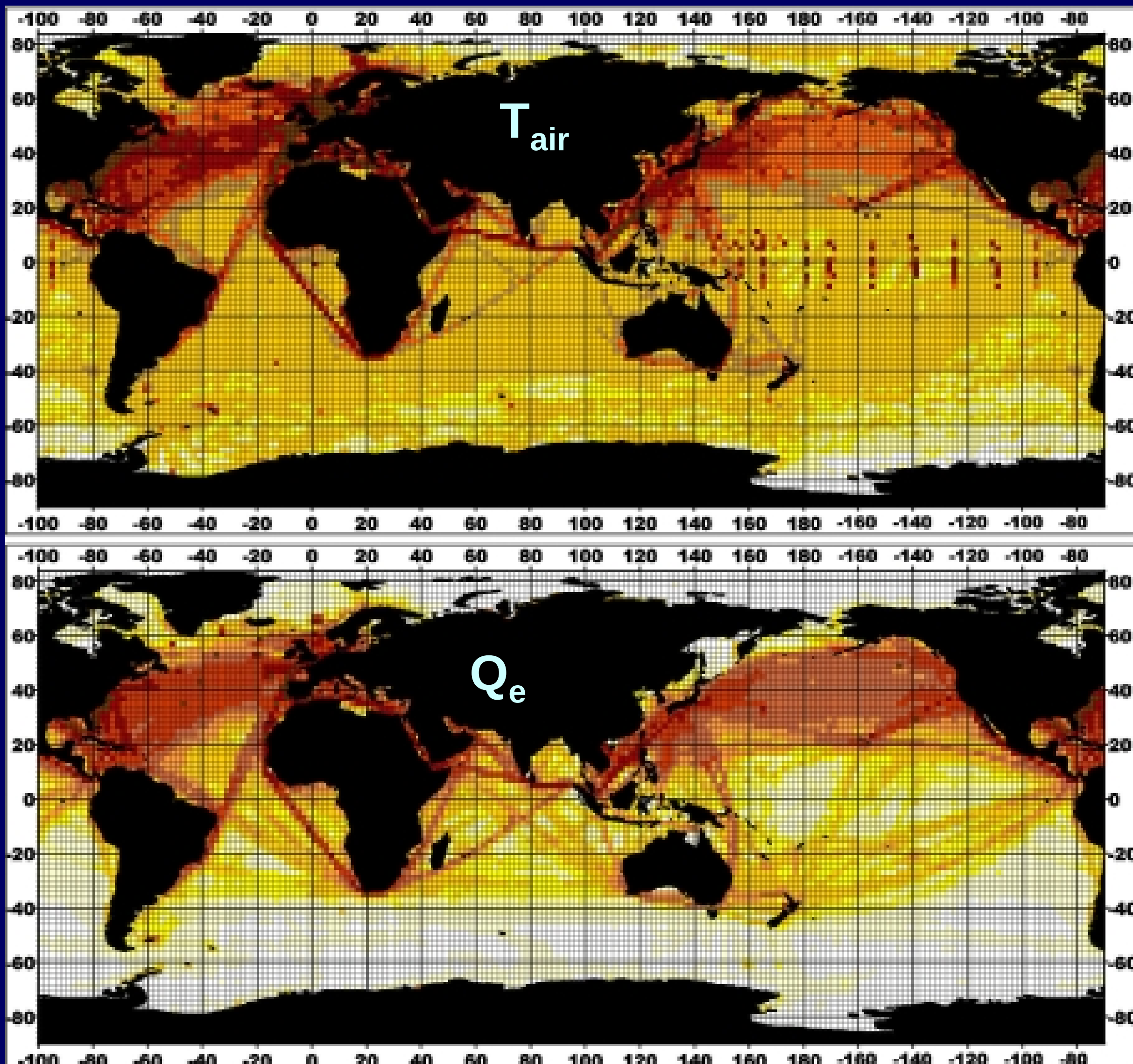
- Background: the nature of sampling bias in surface flux-related variables and fluxes
- Estimation of random and non-random sampling biases in the VOS fluxes using NWP products
- Impact of sampling on climate means, regional balances and variability patterns
- Minimization of sampling biases: a parametric approach
- Discussion & Conclusions

Sources of the global- and basin-scale flux field products:

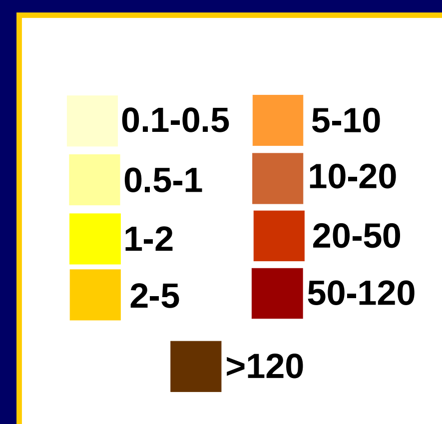
Although satellite and NWP flux products have been largely improved over the last years, VOS-based flux fields still have the longest continuity, providing surface marine measurements already for 150 years



Sampling/averaging problem in VOS fluxes

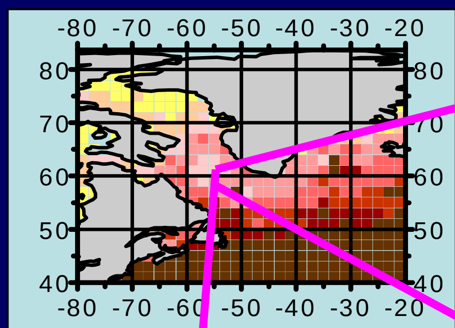


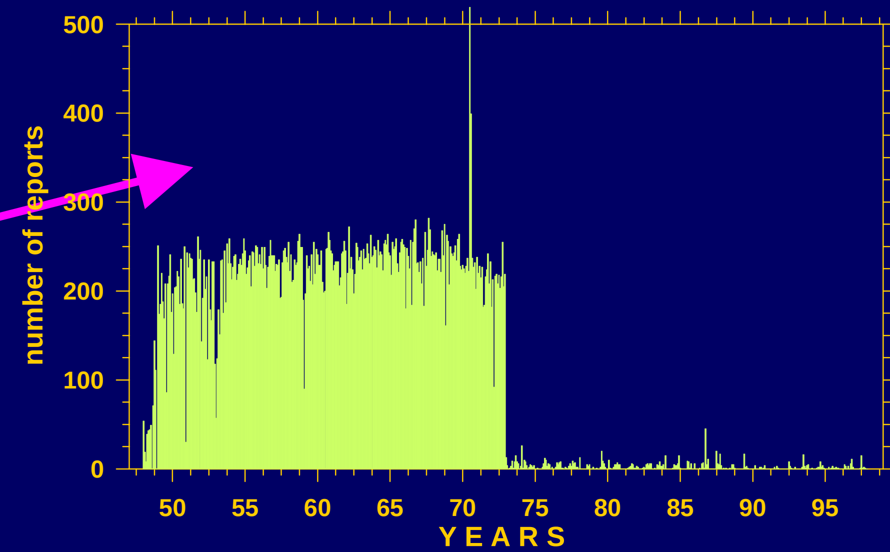
Marine meteorological observations are typically characterized by a strong spatial and temporal inhomogeneity of the number of samples

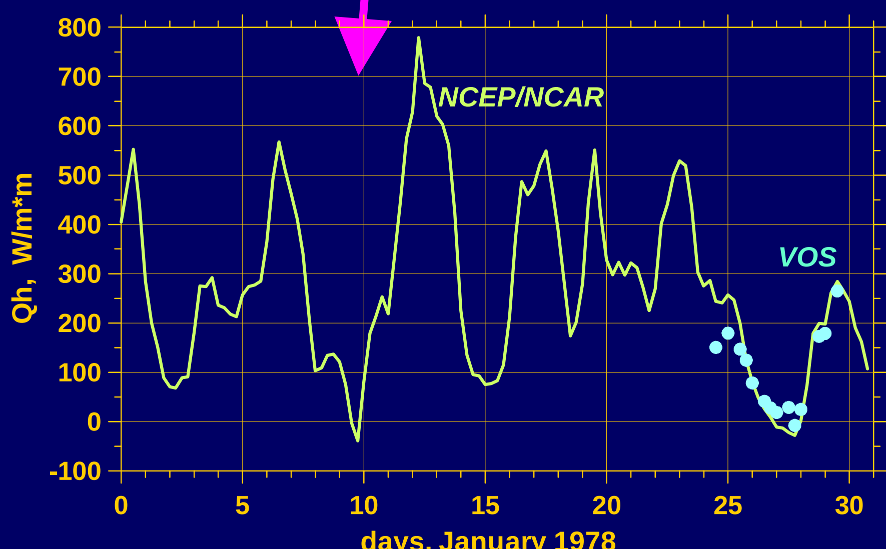


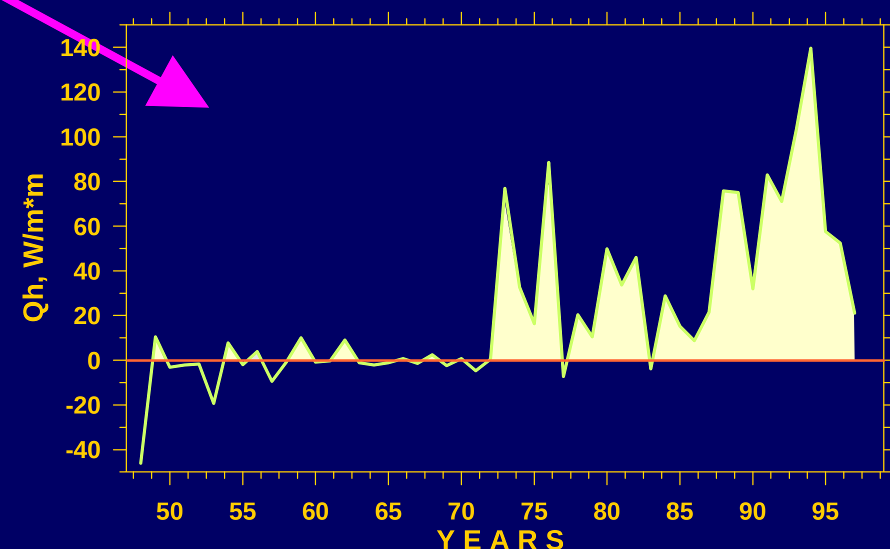
Nature of sampling bias in VOS fluxes

Example: Labrador Sea









Sampling biases:

Random sampling error is the represenativeness error, associated with the actual number of samples used to derive monthly mean:

$$\varepsilon_r = \Sigma(\text{actual}|_{rand}) - \Sigma(\text{true})$$

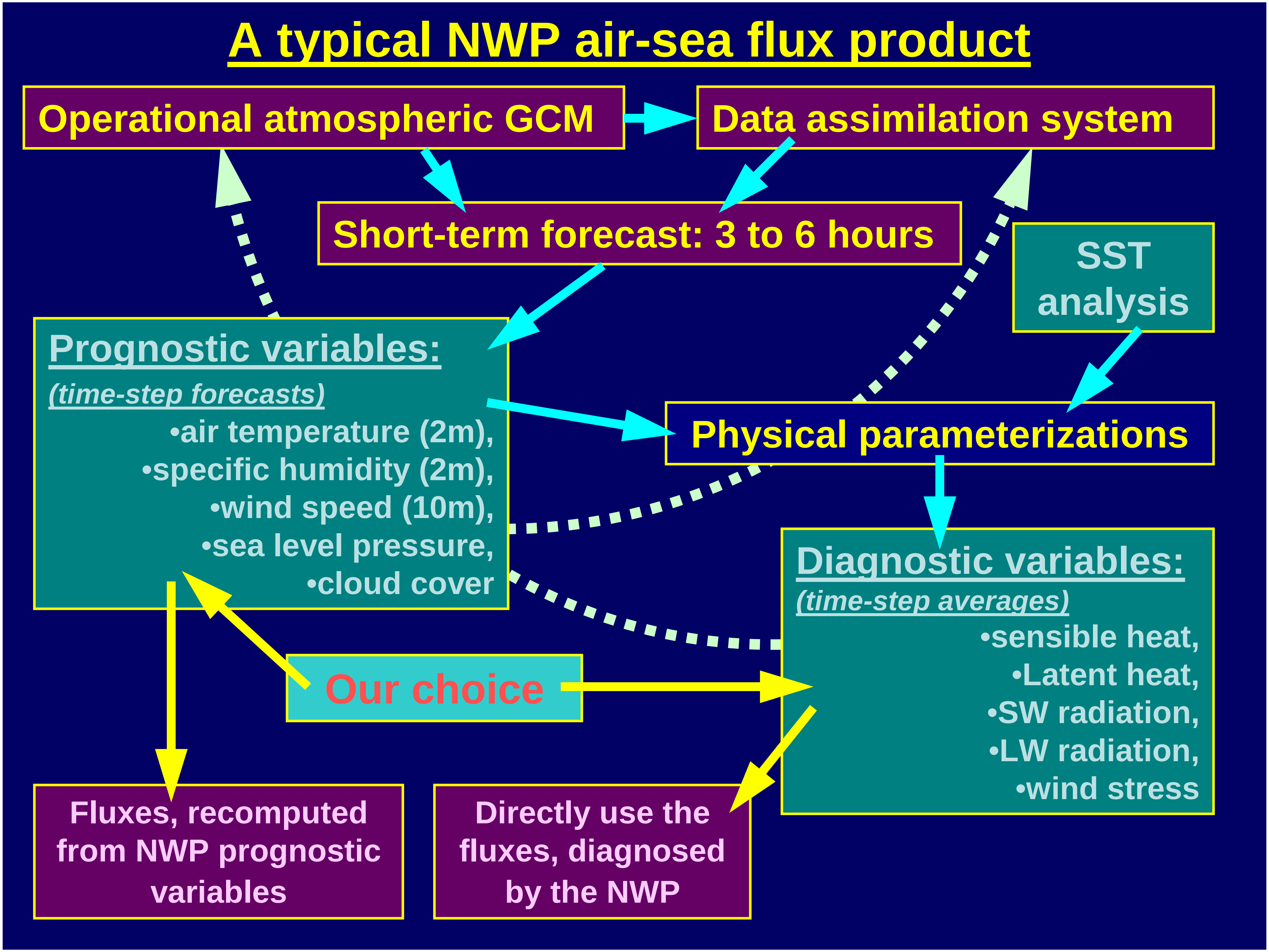
Fair weather bias is the non-random error, associated with the actual conditions under which the observations were sampled:

$$\varepsilon_f = \Sigma(\text{actual}|_{cond}) - \Sigma(\text{true})$$

Interpolation bias results from the interpolation in the unsampled locations:

$$\varepsilon_i = f(\Psi),$$

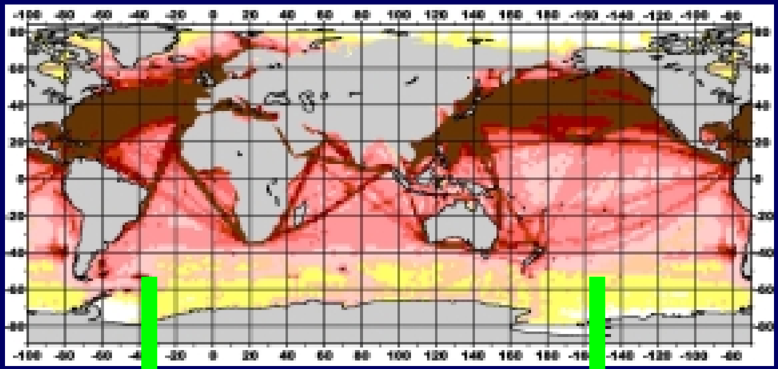
where Ψ is interpolation operator.



A typical NWP air-sea flux product
Operational atmospheric GCM
Data assimilation system
Short-term forecast: 3 to 6 hours
SST analysis
Prognostic variables:
(time-step forecasts)
•air temperature (2m),
•specific humidity (2m),
•wind speed (10m),
•sea level pressure,
•cloud cover
Physical parameterizations
Diagnostic variables:
(time-step averages)
•sensible heat,
•Latent heat,
•SW radiation,
•LW radiation,
•wind stress
Our choice
Fluxes, recomputed from NWP prognostic variables
Directly use the fluxes, diagnosed by the NWP

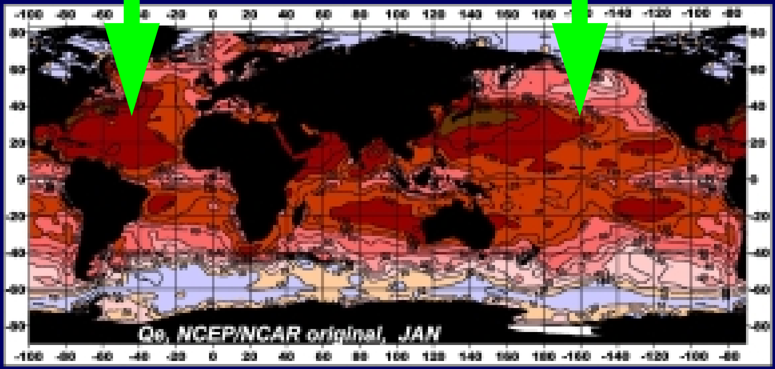
Use of NWP fluxes for quantifying sampling biases

Despite potentially high biases in the magnitude of fluxes, reanalyses provide reliable representation of synoptic variability and homogeneous and adequate sampling. This allows for the use of reanalyses for estimating sampling errors.



Random sampling error ← **Random VOS-like sub-sampling**

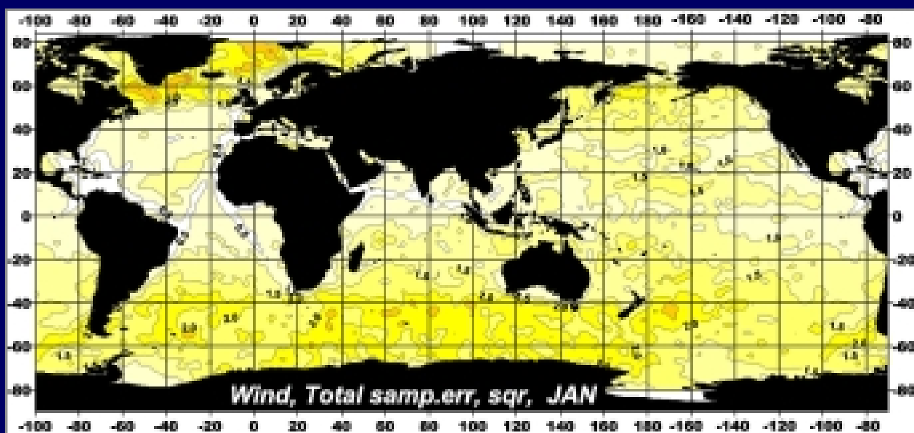
Real-time VOS-like sub-sampling → **Total sampling error** → **Fair weather bias**

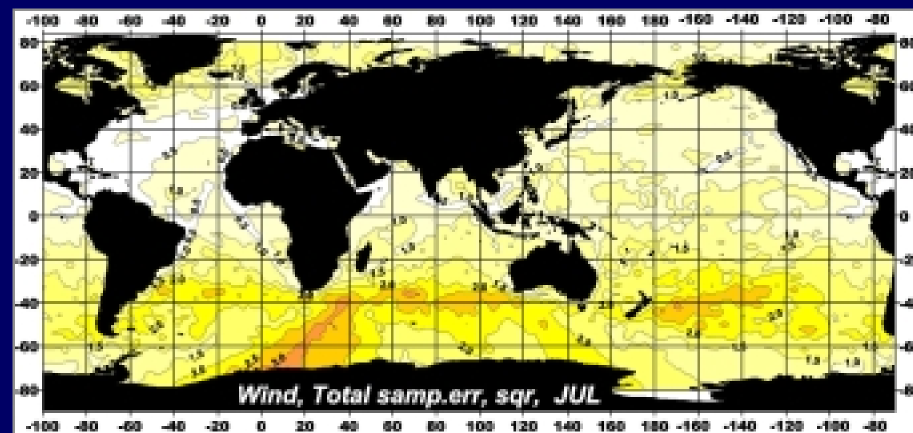


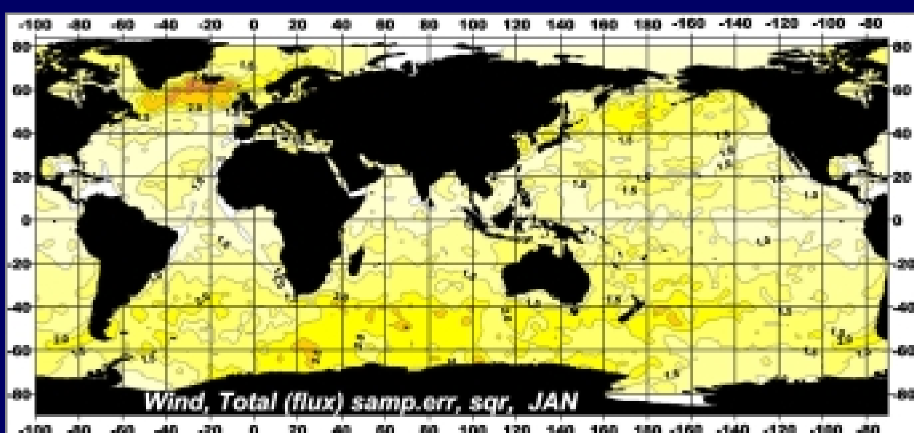
Sampling errors in individual variables:

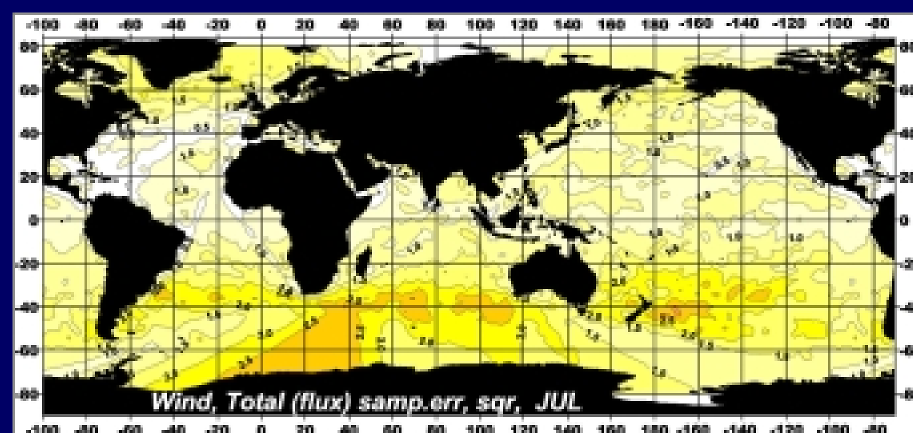
"Parameter sampling error": based on the number of observations of particular variable.

"Flux sampling error": based on the number of observations containing all variables required for the corrections and flux computations.





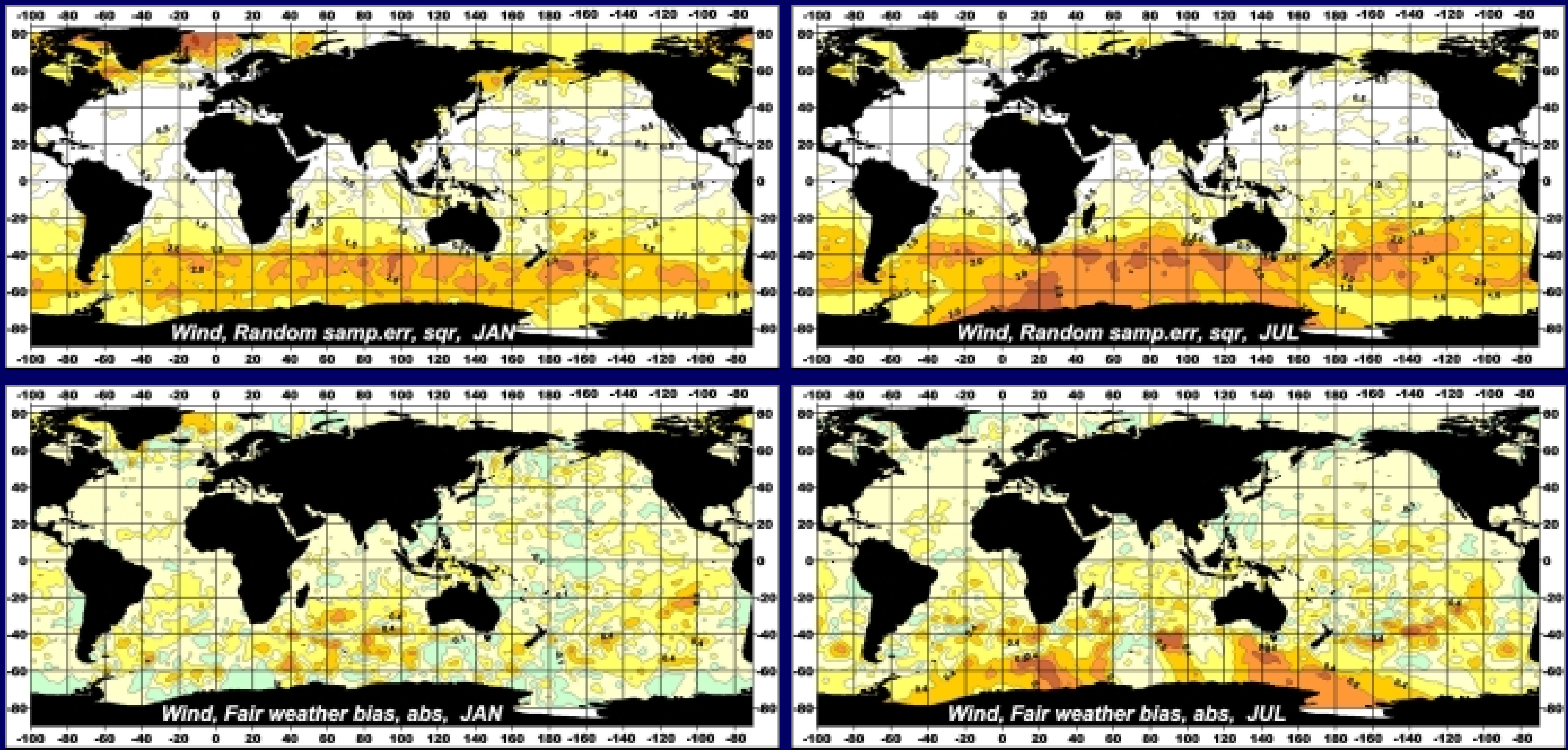




Sampling errors in individual variables:

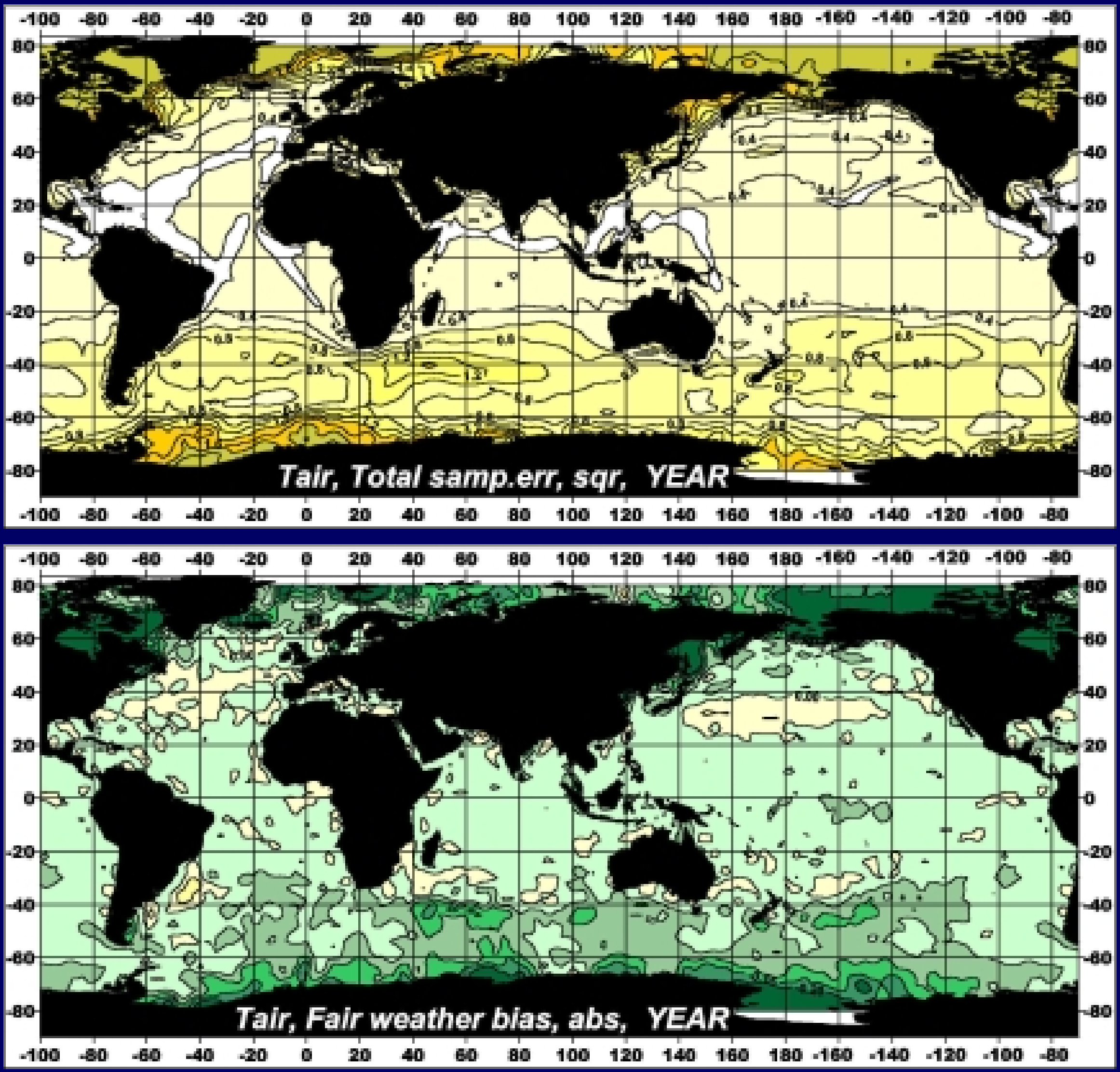
"Random sampling error": random selection of the number of VOS observations, averaging over 20 runs.

"Fair weather bias": elimination of random error from the total sampling uncertainty by sub-sampling in well sampled regions.

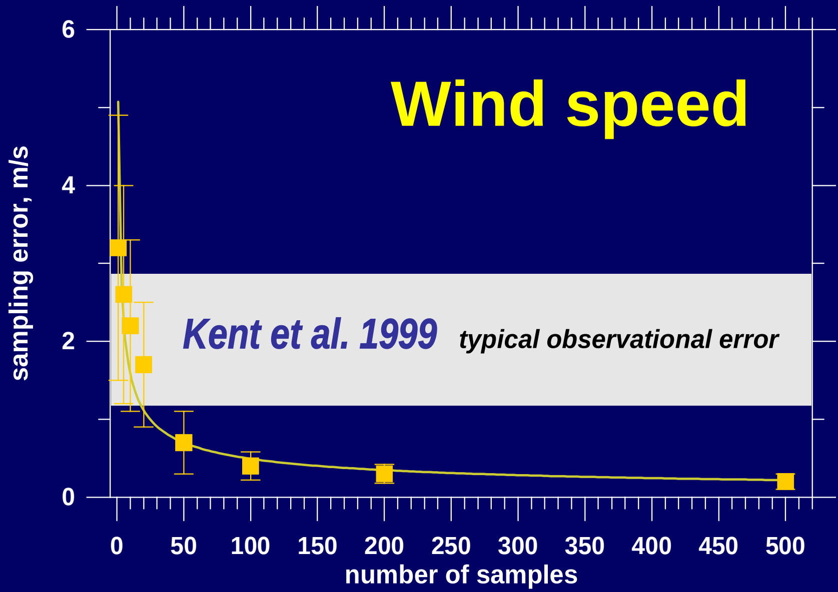


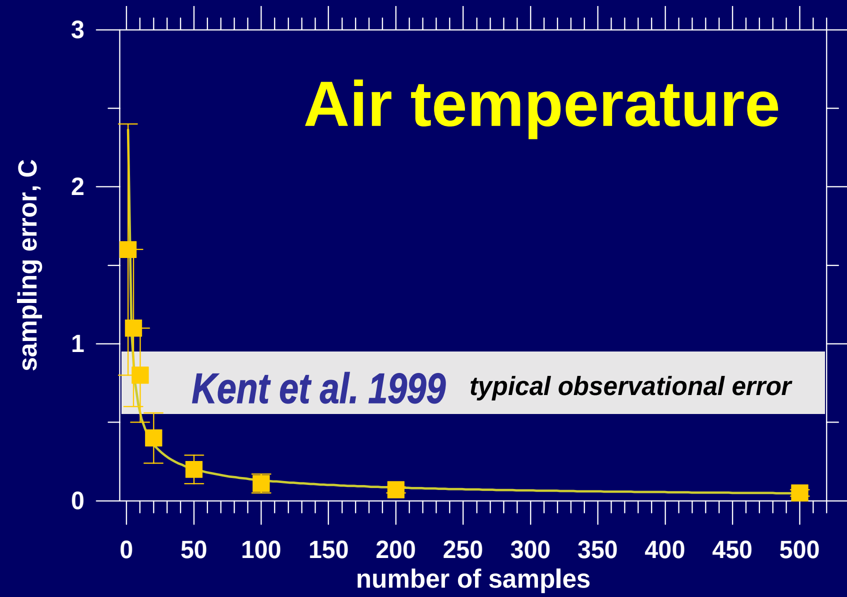
Sampling errors in individual variables:

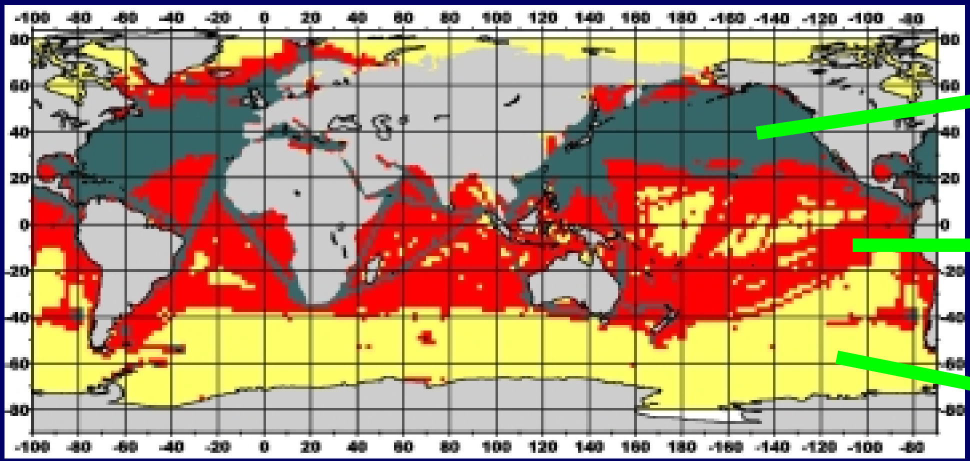
Air temperature



Sampling errors in individual variables: dependence on the number of samples





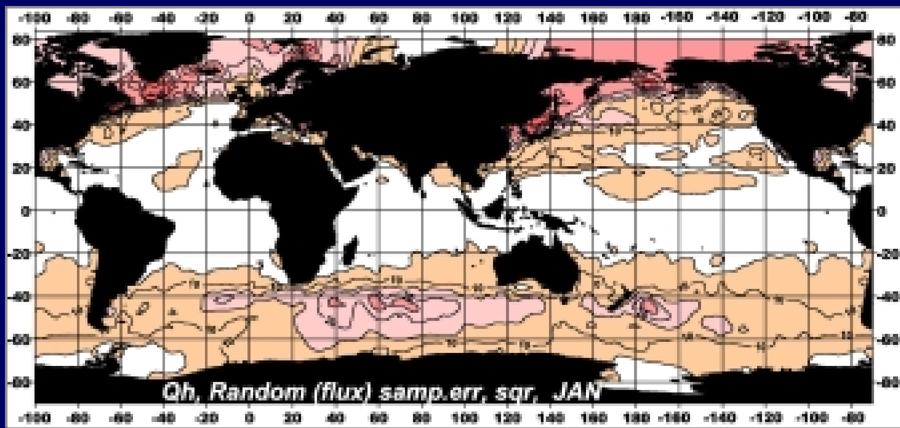


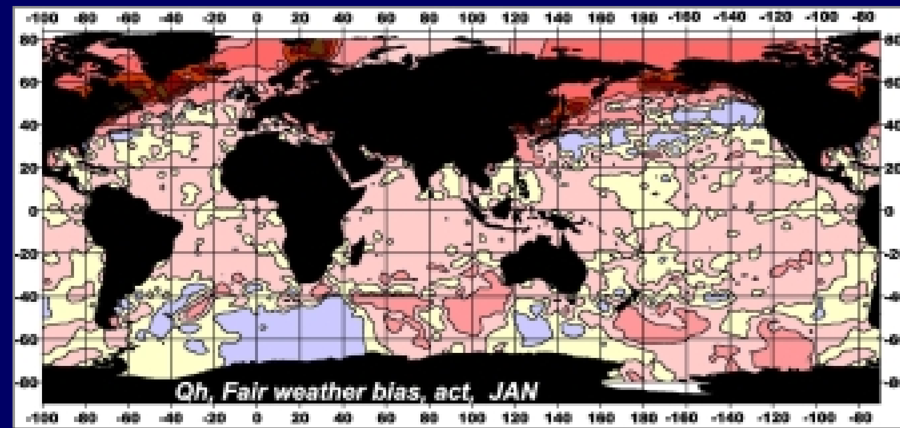
Sampling error < obs. error

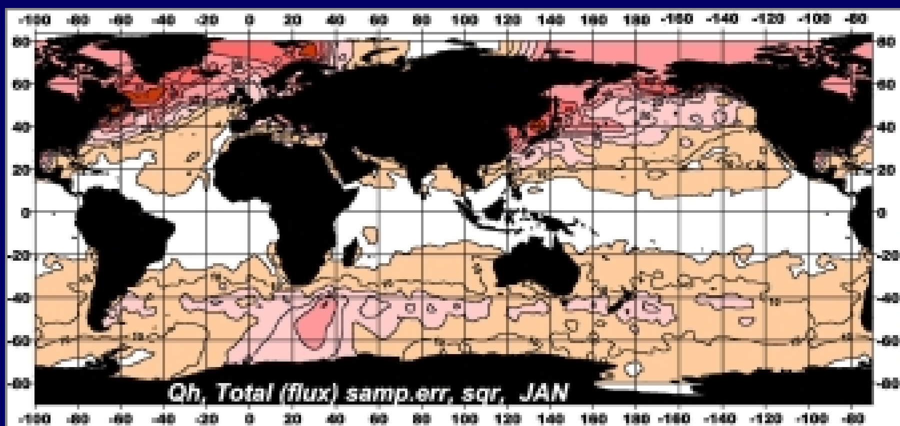
Sampling error ≈ obs. error

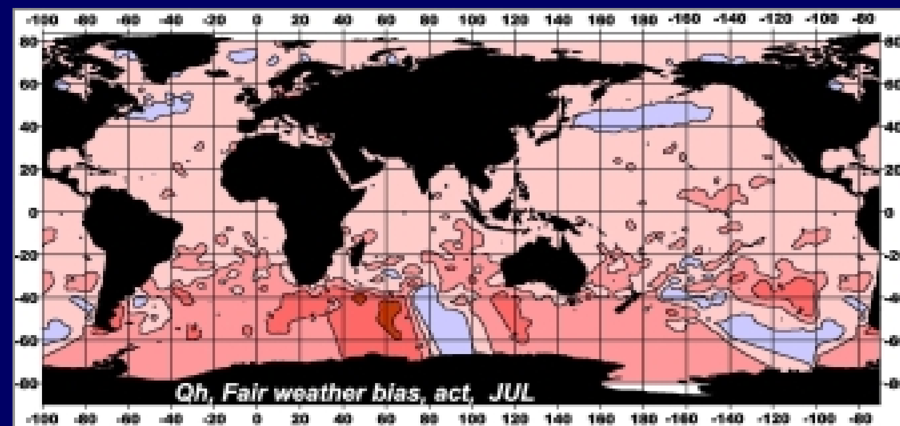
Sampling error > obs. error

Sampling errors in fluxes:





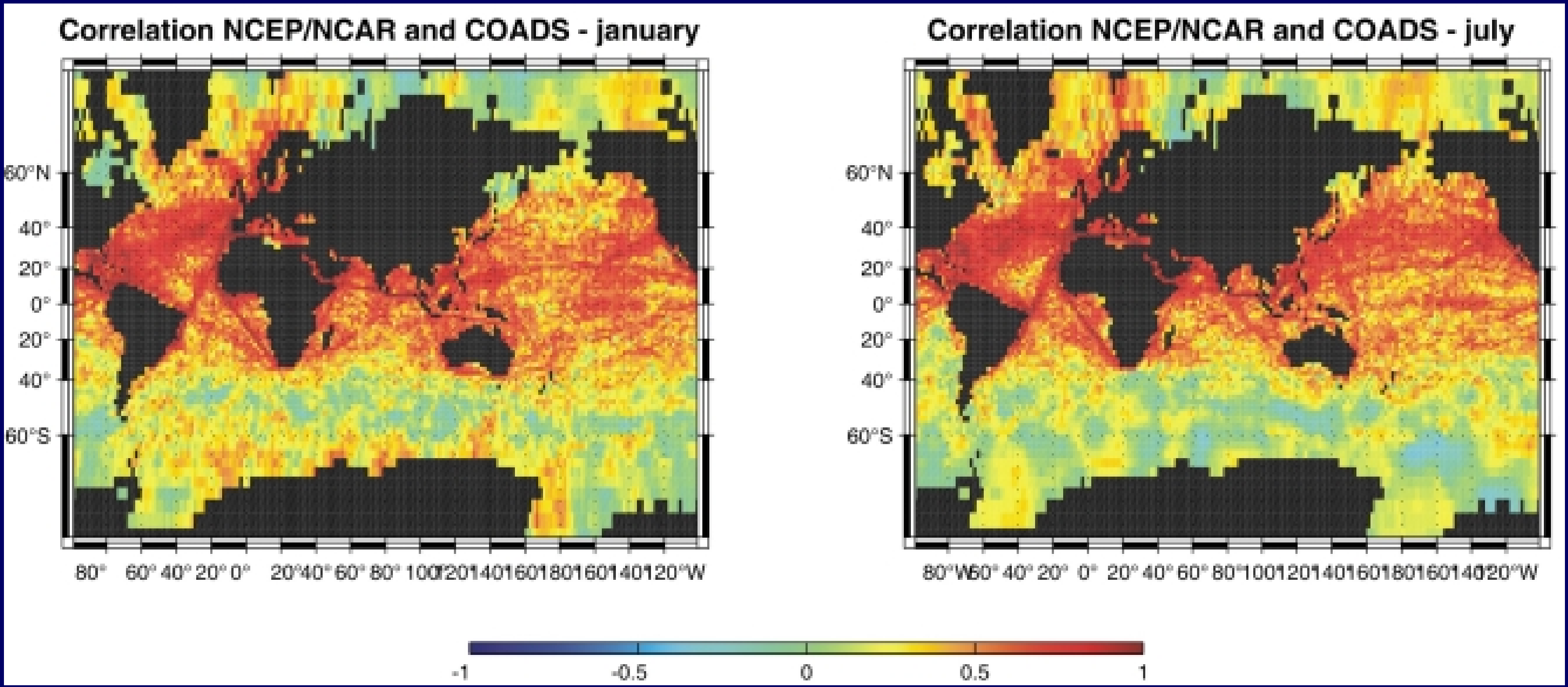




Fair weather biases tend to underestimate fluxes, especially in poorly sampled locations

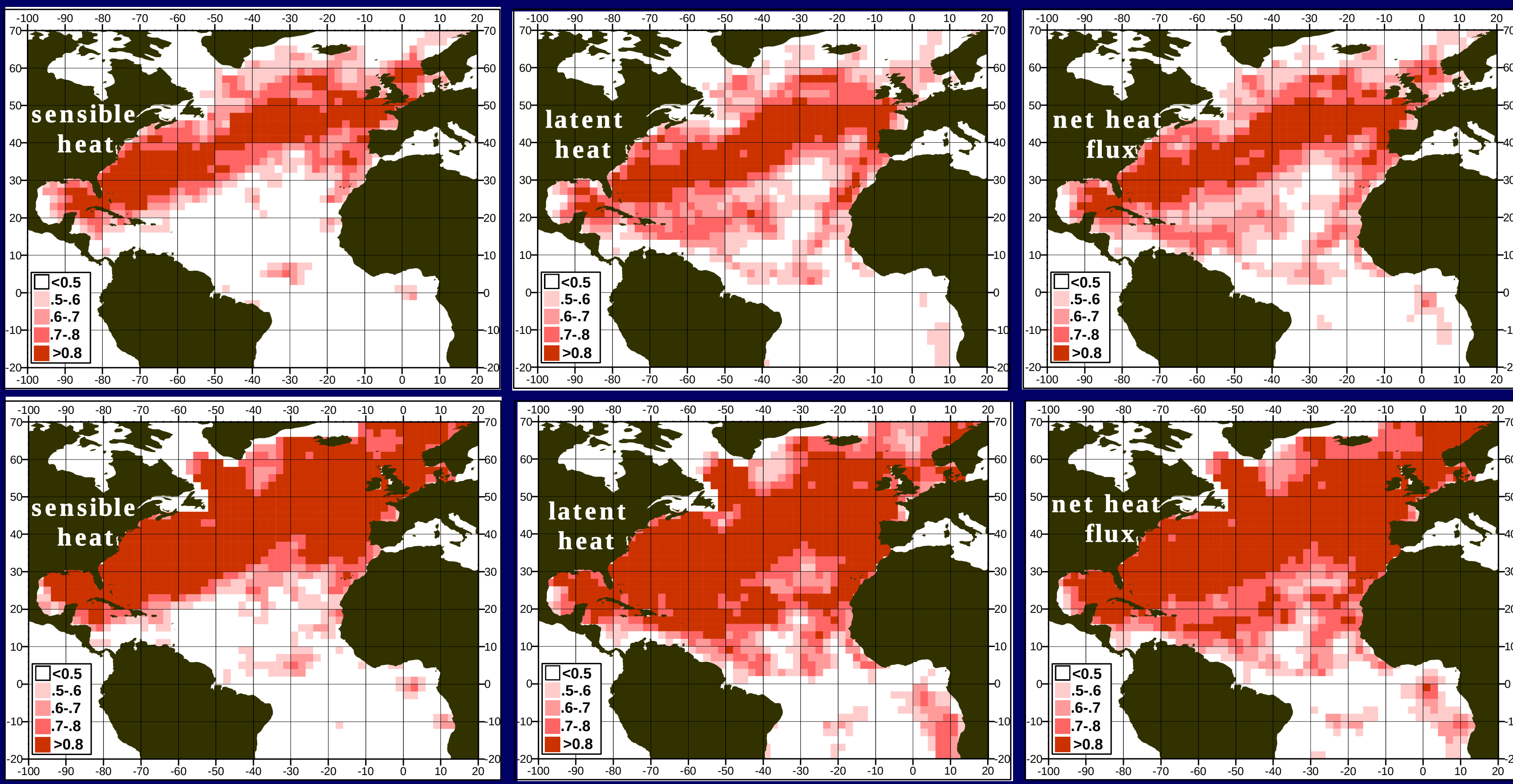
Sampling errors in fluxes: impact on variability

Total cloud cover



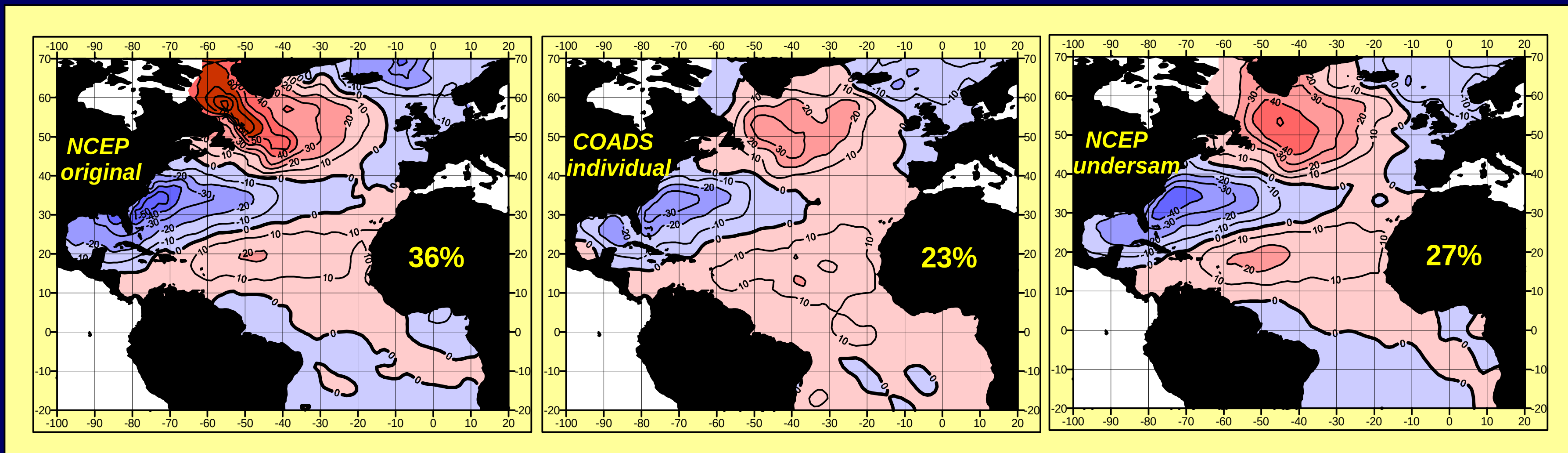
Sampling errors in fluxes: impact on variability in fluxes

Correlation of VOS fluxes with NWP

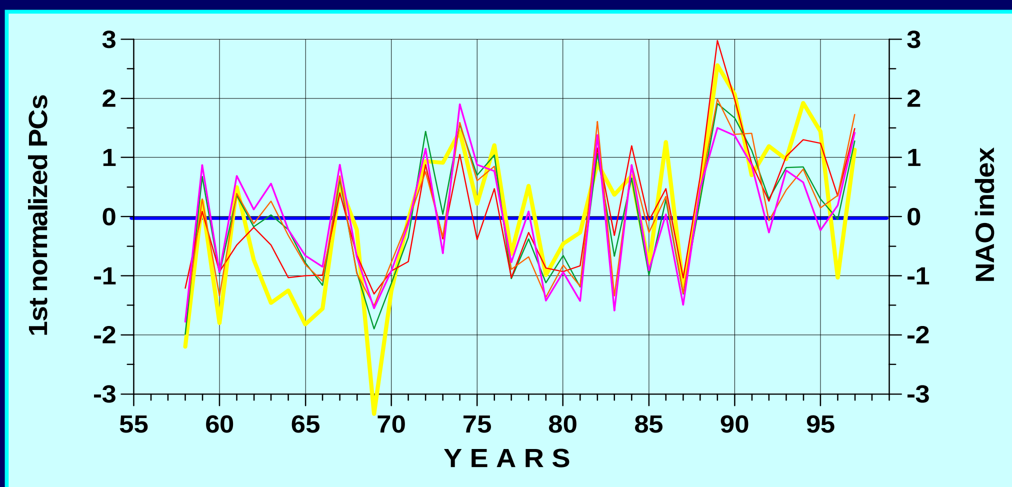


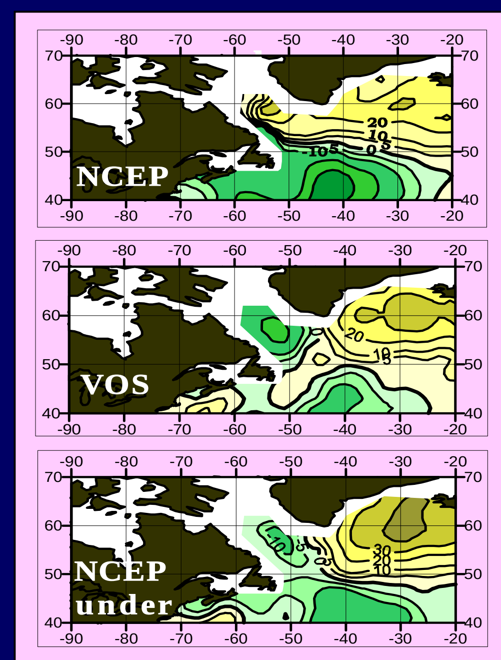
Correlation of VOS fluxes with VOS-like sampled NWP

Sampling impact on variability patterns



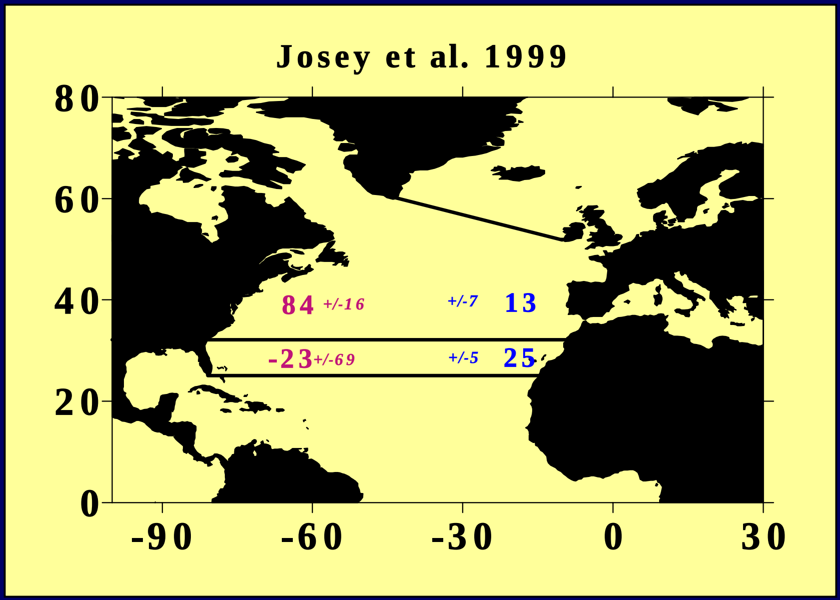
EOF-1

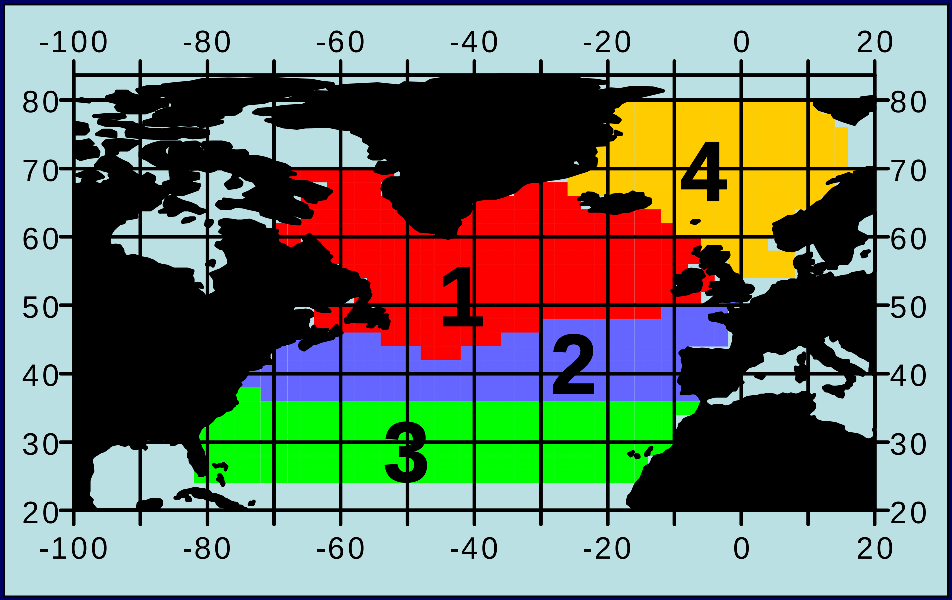




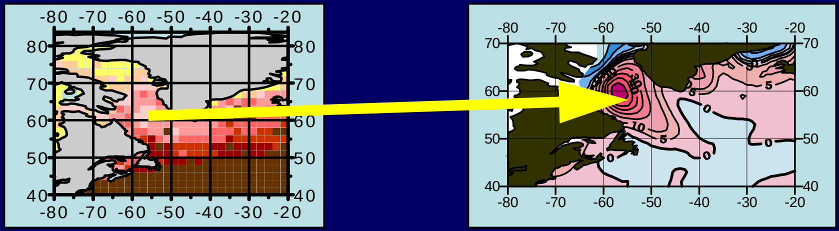
EOF-2

Regional balances: how to overcome the sampling bias





Regionally integrated surface flux



$$Q_{\Sigma} = \int_t dt \int_S Q dS$$

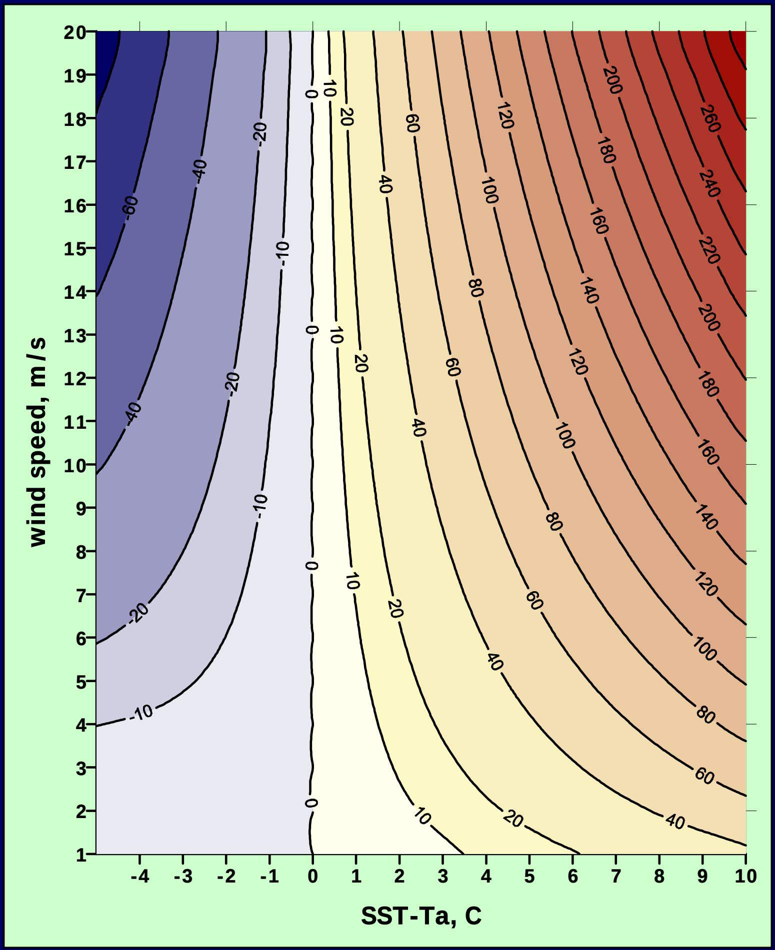
$$\xi(Q_{\Sigma}) = \int_t dt \int_S \xi(Q) dS$$

Changing the integration domain: geography to the parameter space

Bulk formulae:

$$Qh = Cp \cdot \rho \cdot Ct(\delta T, V) \cdot \delta T \cdot V$$

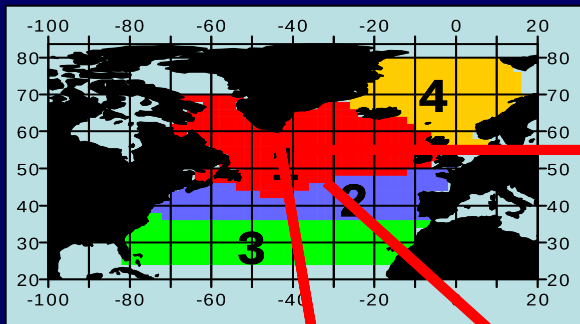
$$Q_\Sigma = \int_t dt \int_S Q\,dS = \int_V dV \int_{\delta T} Q\,d(\delta T)$$



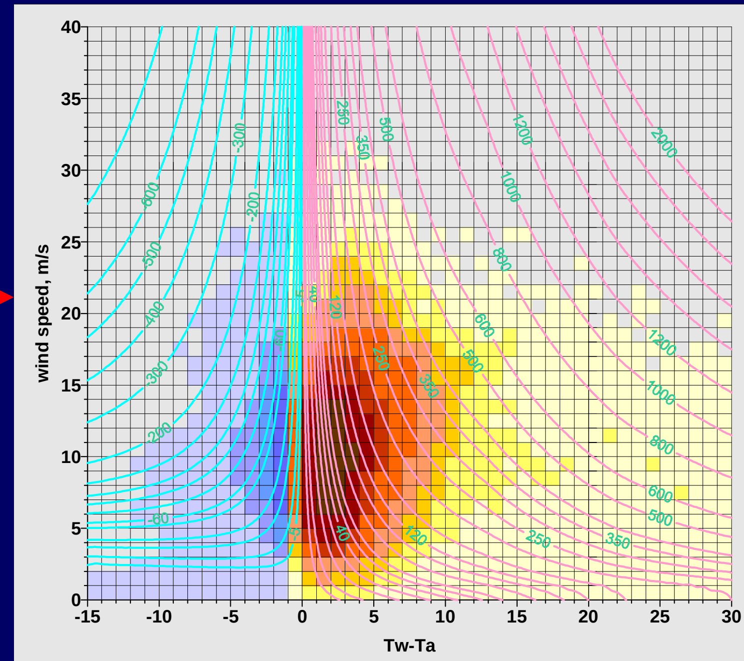
For a given region and time period integration over latitude and longitude can be replaced by integration in the $\delta T, V$ -plane

2D-distributions of turbulent fluxes

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

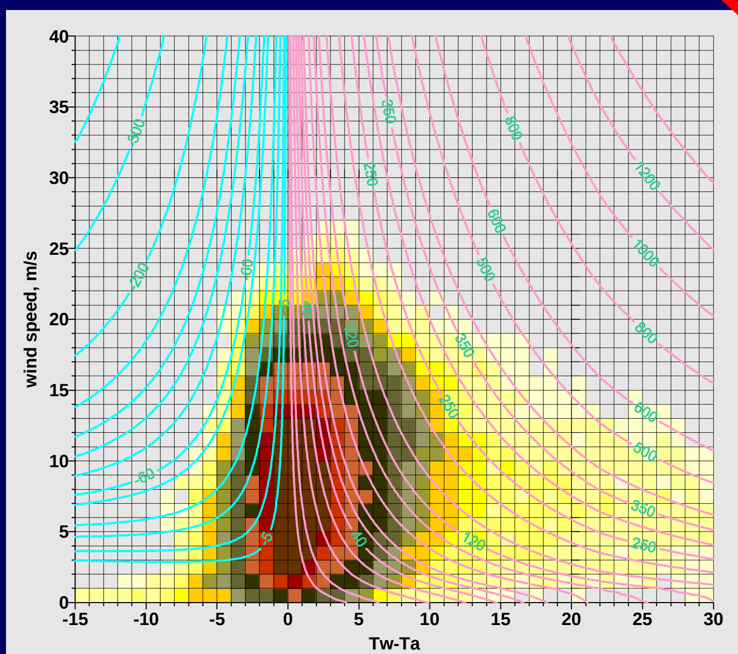


Qe

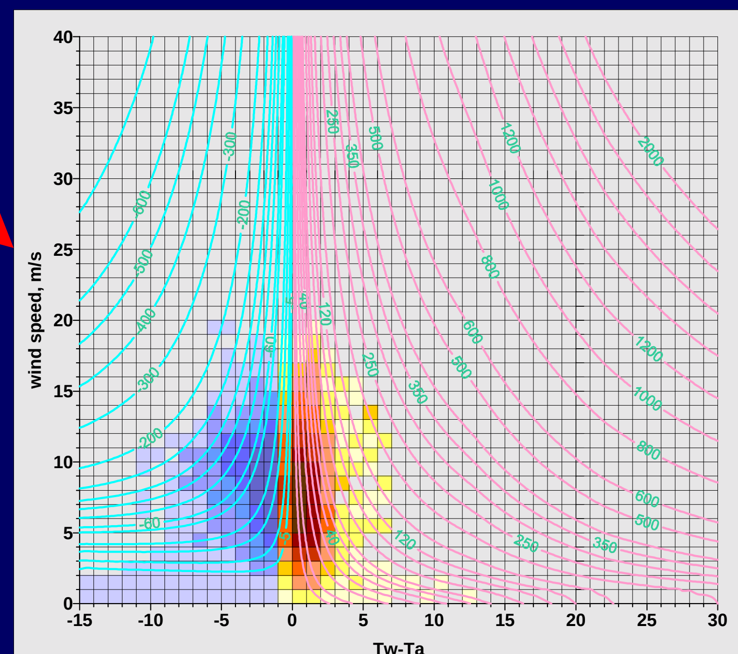


10^{11} W

2D- PDF of sensible flux

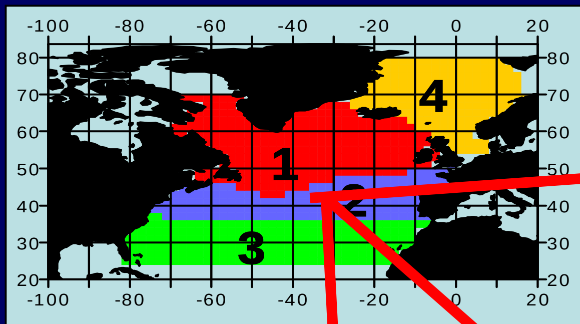


Qh



2D-distributions of turbulent fluxes

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



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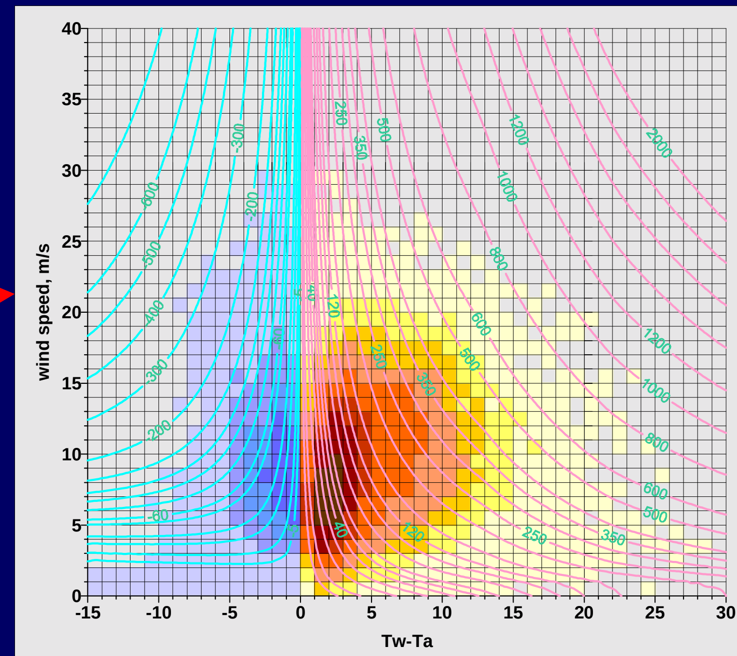
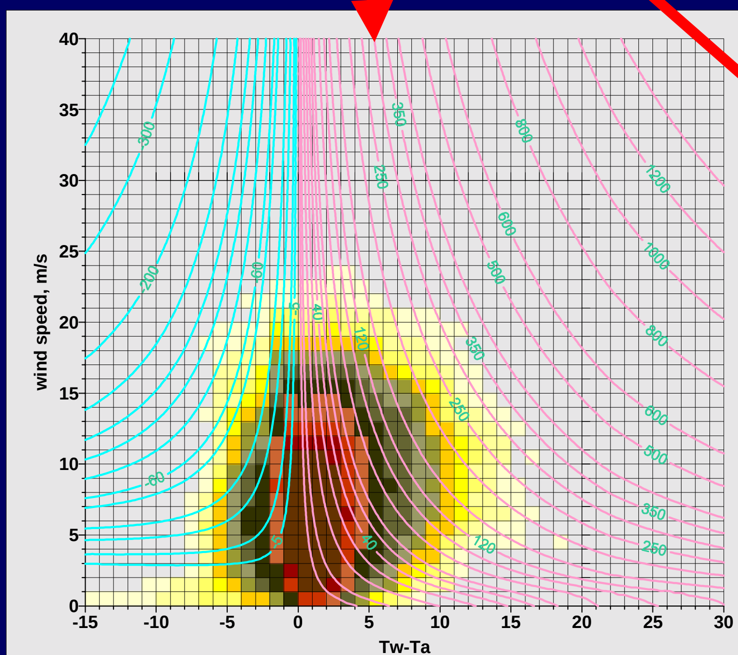


10^{11} W



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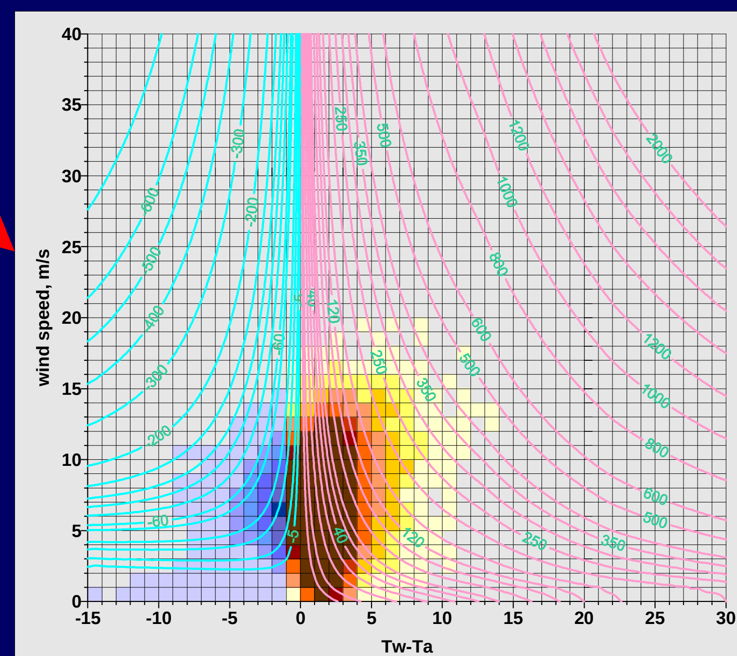
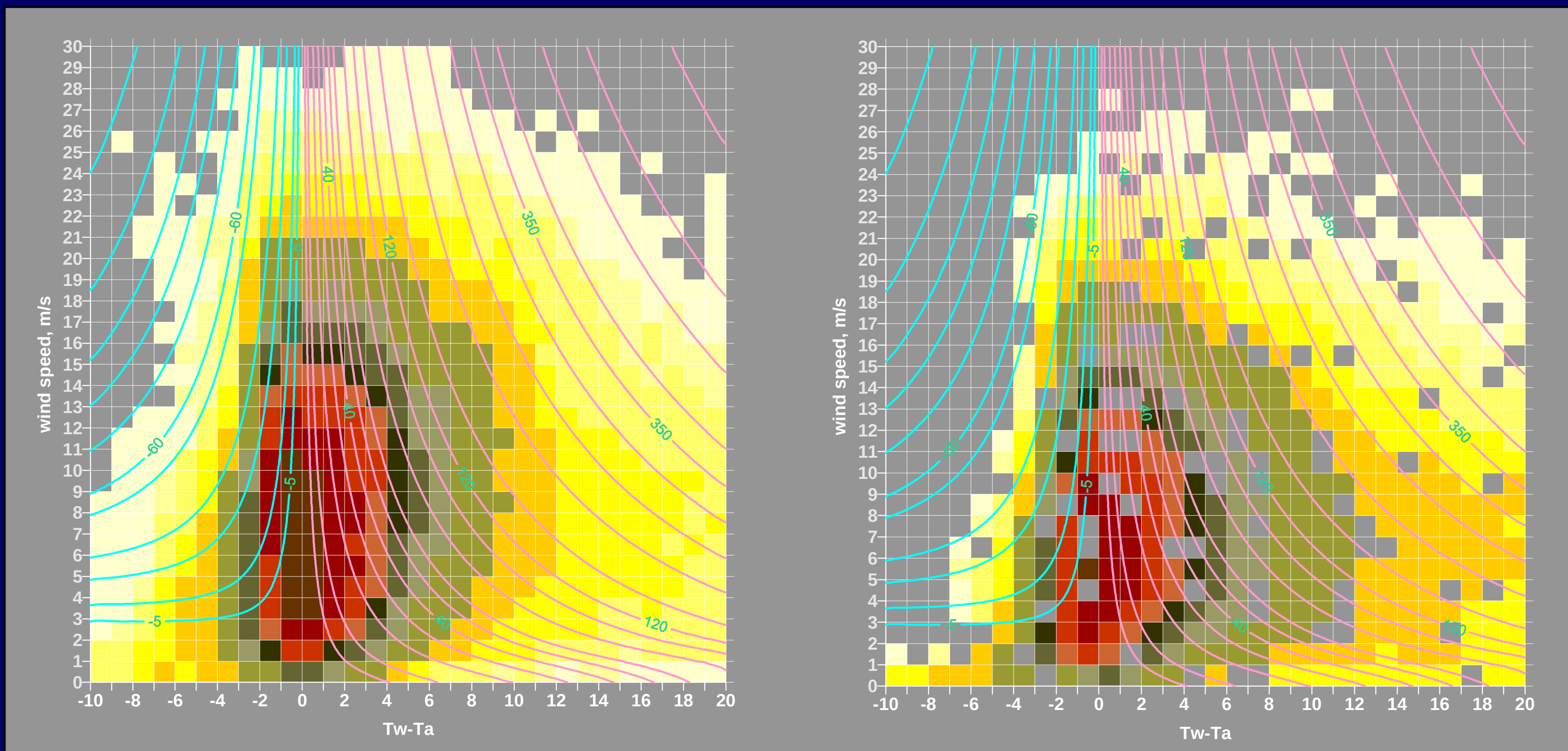


2D-distributions of turbulent fluxes

NCEP/NCAR Reanalysis: adequate sampling

VOS fluxes: inadequate sampling



Fitting 2D VOS and NWP PDFs:

The joint probability distribution of δT and V :

$$P(\delta T) = \sum_r P(\delta T | V) P(V)$$

$$P(\delta T|V) = f_{\delta t} / \delta T, \quad P(V) = f_v / V,$$

$$f_{\delta t} = \frac{1}{\sqrt{2\pi(1-\rho^2)\sigma_{\delta t}}} \exp\left\{ \frac{-1}{2(1-\rho^2)\sigma_{\delta t}^2} \left[\delta t - \mu_{\delta t} - \rho \frac{\sigma_\delta}{\sigma_v} (v - \mu_v) \right]^2 \right\},$$

$$f_v = \frac{1}{\sqrt{2\pi\sigma_v}} \exp\left[\frac{-(v-\mu_v)^2}{2\sigma_v^2} \right] \left\{ 1 - \frac{c_v}{6} \left[\frac{3(v-\mu_v)}{\sigma_v} - \left(\frac{(v-\mu_v)}{\sigma_v} \right)^3 \right] \right\},$$

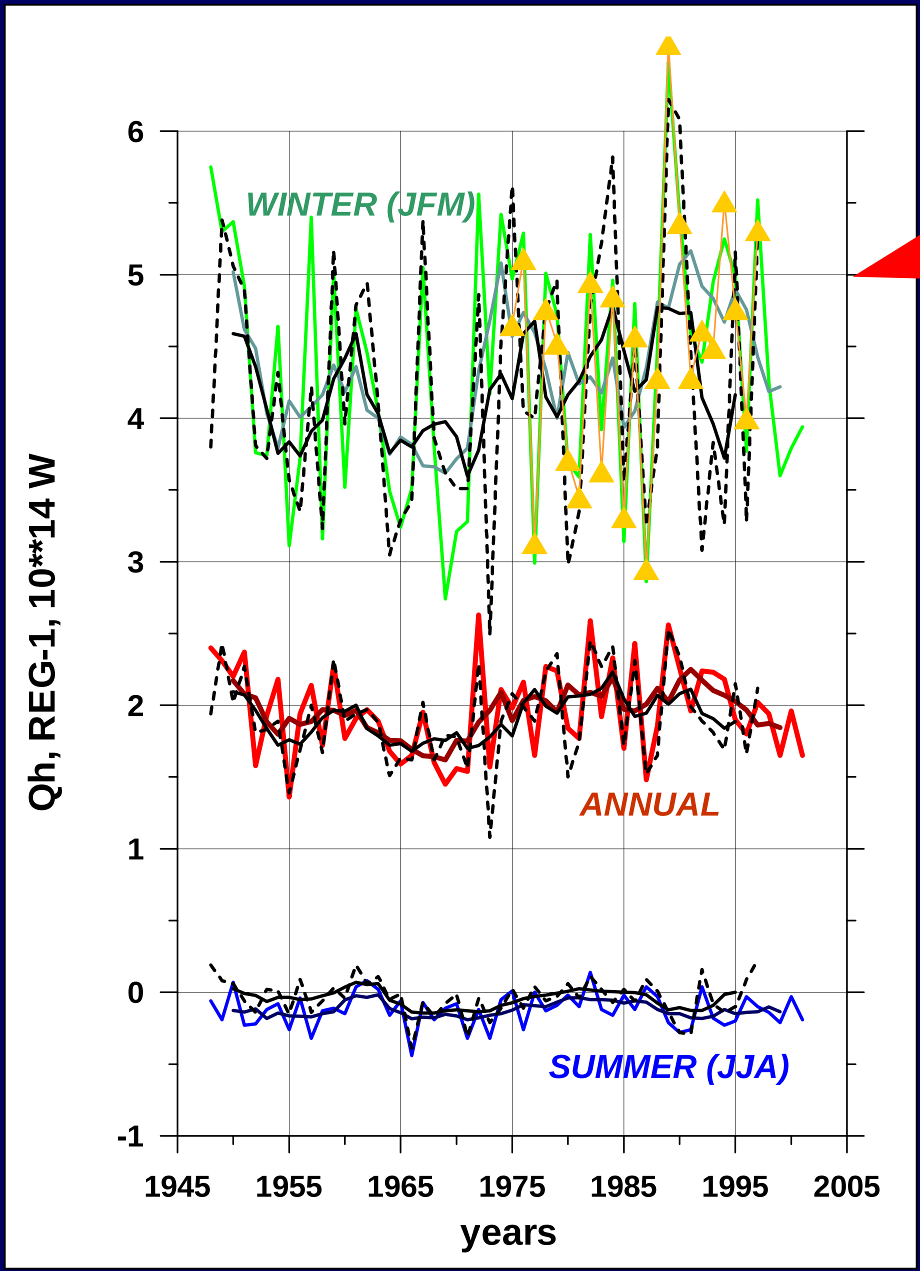
$$\delta t = \ln(|\delta T|), \quad v = \ln(V).$$

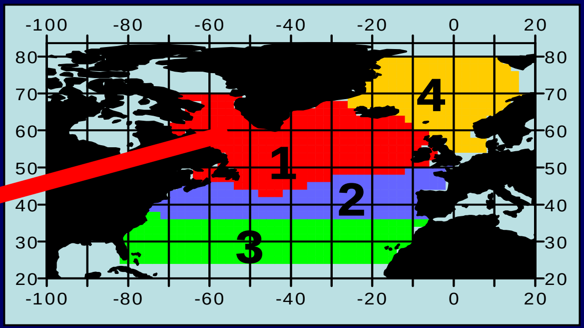
where μ stays for means and σ - for standard deviations, while ρ is correlation coefficient and C is skewness. The transformation function for the 2D PDFs for VOS and NWP:

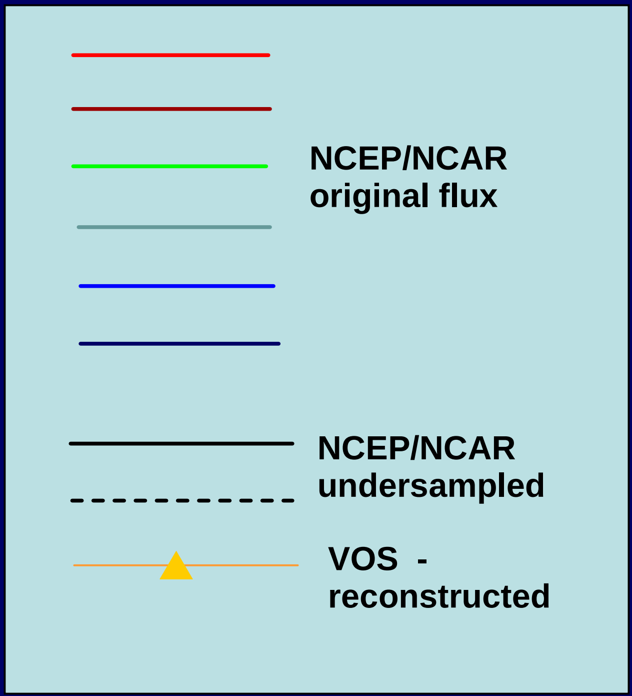
$$P(\delta T|V)_{VOS} = \Psi\left[P(\delta T|V)_{NWP} \right],$$

$$\Psi = f(\mu_{\delta t}, \mu_v, \sigma_{\delta t}, \sigma_v, \rho)$$

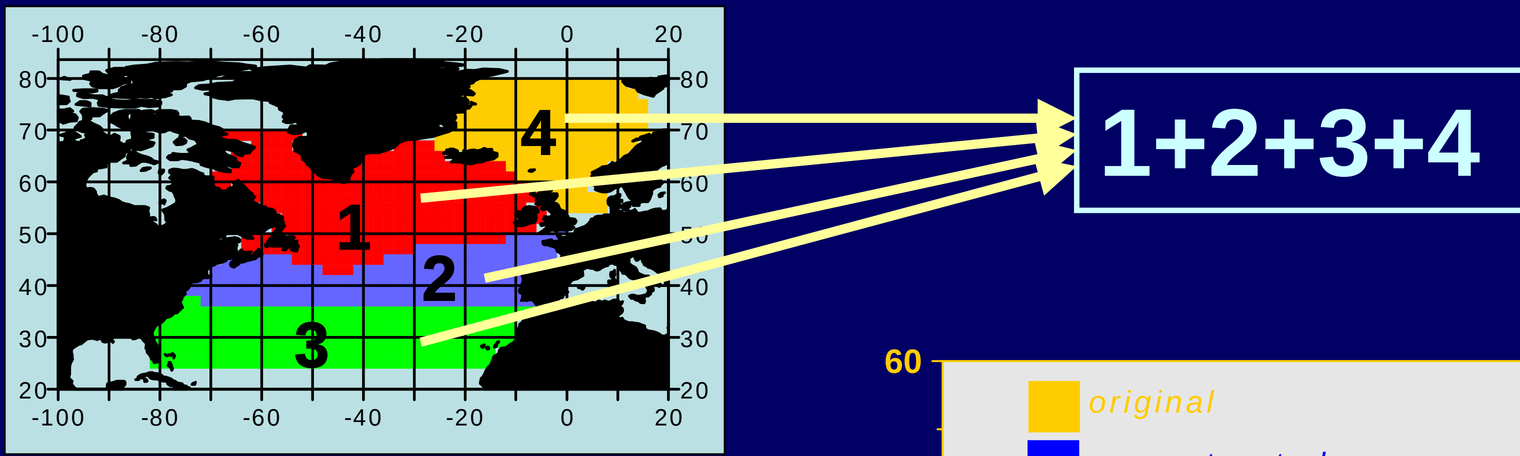
Estimating regionally integrated heat flux:

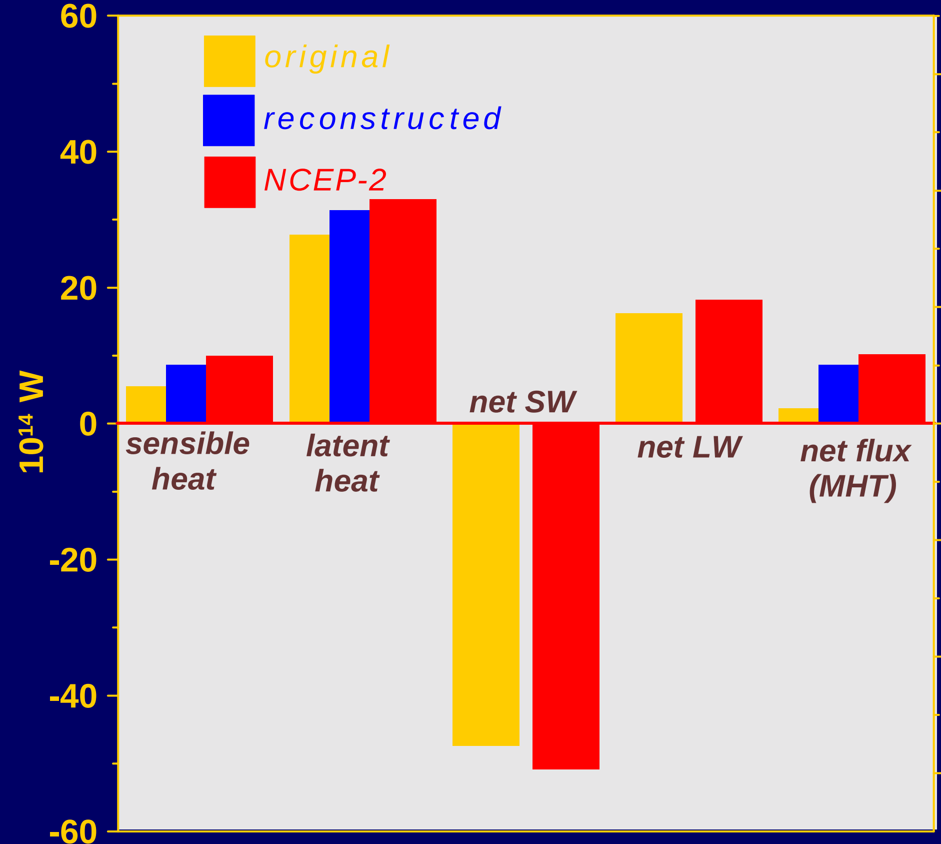






Estimating MHT at 20N:





MHT at 20N:

0.22 PW (original VOS)

SOC: 0.34PW

0.87 PW (reconstructed VOS)

1.02 PW (NCEP-2)

Conclusions:

Sampling errors in individual VOS variables are comparable to the random observational errors and may be higher in the Southern Ocean and poorly sampled regions of the Northern Hemisphere oceans.

Sampling errors in VOS surface fluxes are locally large and may amount to 50-200 W/m^2 in poorly sampled regions of the Labrador Sea and Southern Ocean.

Sampling biases seriously affect the variability patterns in poorly sampled regions.

Use of parametric approach largely improves reliability of basin-scale balances in the VOS fluxes. However, it does not help to improve the flux field itself.

VOS fluxes still have a future!