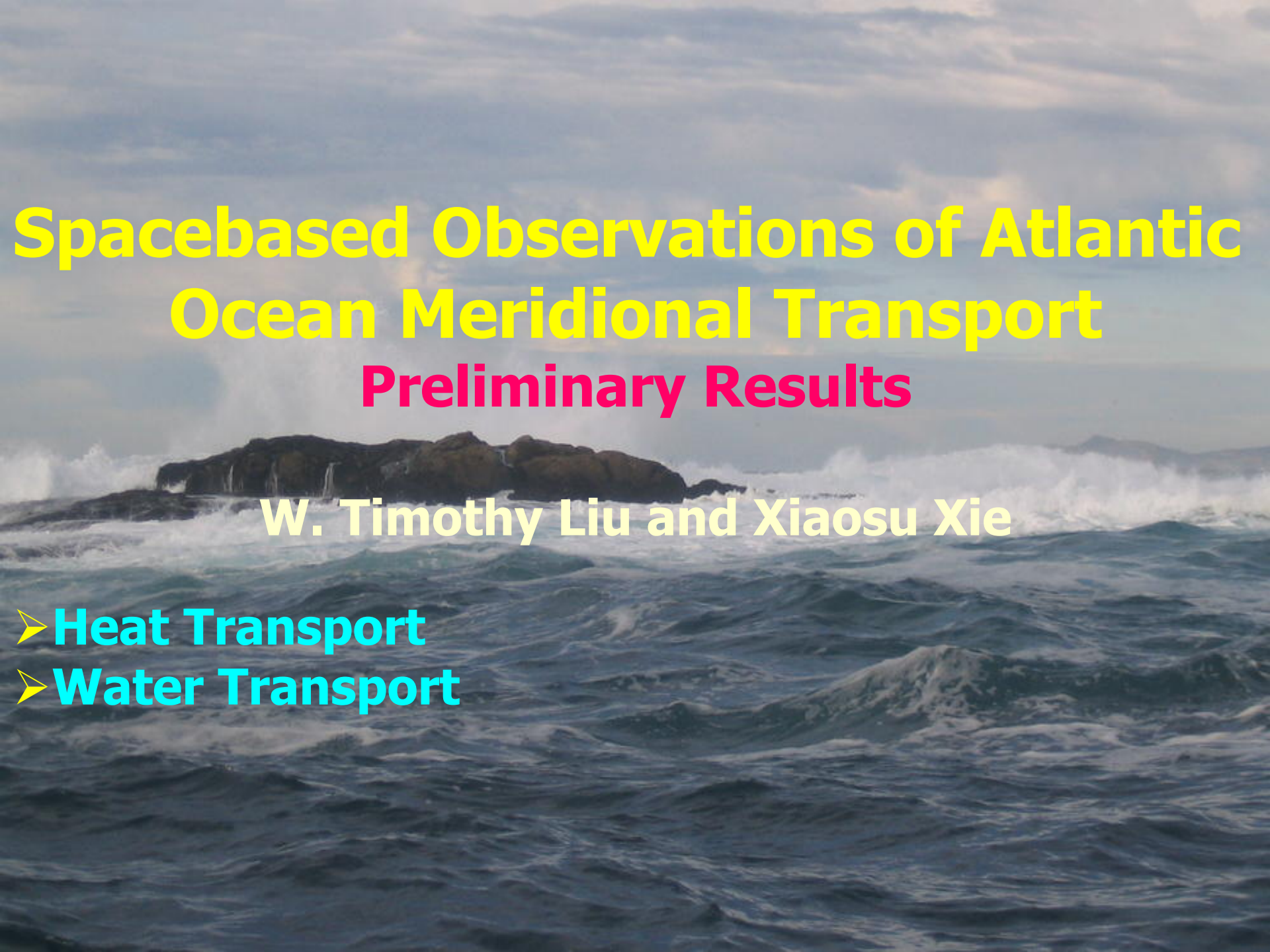


Spacebased Observations of Atlantic Ocean Meridional Transport

Preliminary Results

W. Timothy Liu and Xiaosu Xie

- Heat Transport
- Water Transport

WORLD CLIMATE PROGRAMME

RESEARCH • APPLICATION • IMPACT • DATA

W. Timothy Liu

WORLD CLIMATE RESEARCH PROGRAMME

REPORT OF THE JSC/CCCO

'CAGE' EXPERIMENT: A FEASIBILITY STUDY

WCP - 22
MAY 1982

WCRP

INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

WORLD METEOROLOGICAL ORGANIZATION

Meridional Heat Transport (MHT)

Conservation of heat

$$\frac{\partial H}{\partial t} + \nabla \cdot \zeta = SW - LW - LH - SH$$

By Green's theorem

$$MHT(\theta) = \int_{\theta}^{\theta_o} \int_{x_1}^{x_2} \left(\frac{\partial H}{\partial t} - SW + LW + LH + SH\right) dx dy$$

H: Heat content

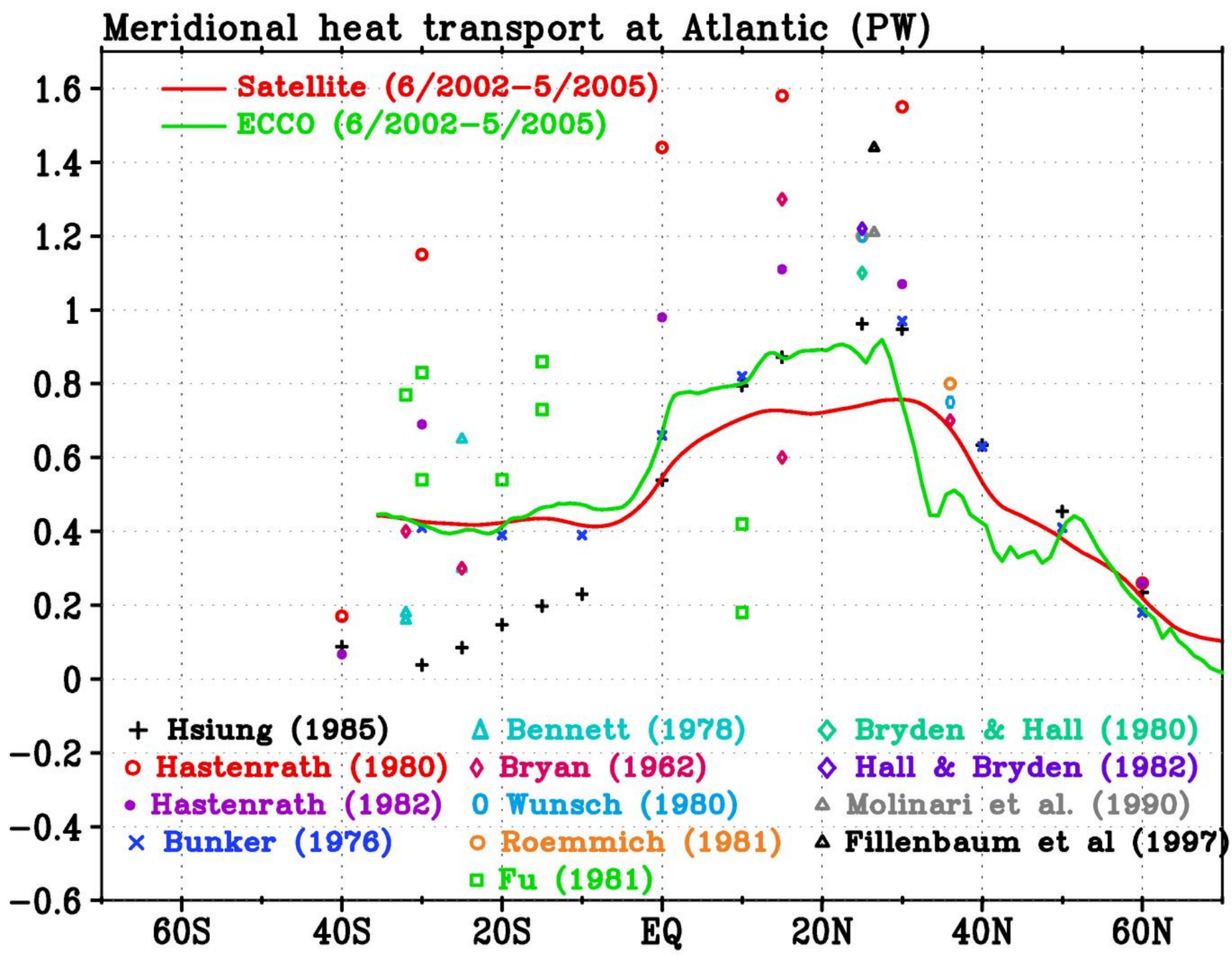
ζ: Horizontal heat flux

SW: Short wave radiation

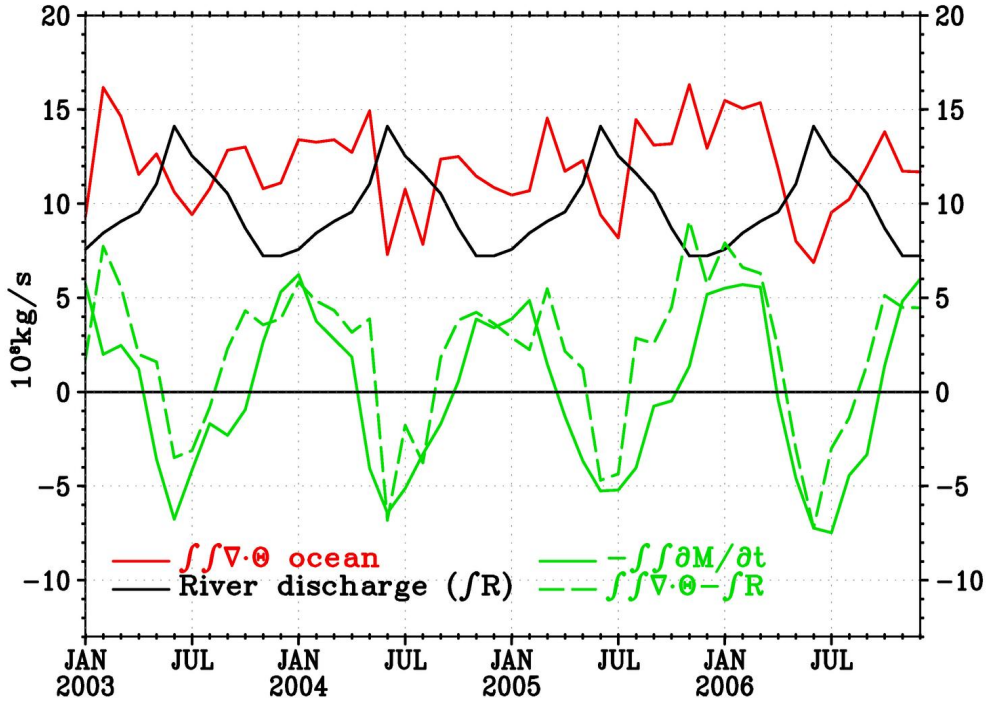
LW: Long wave radiation

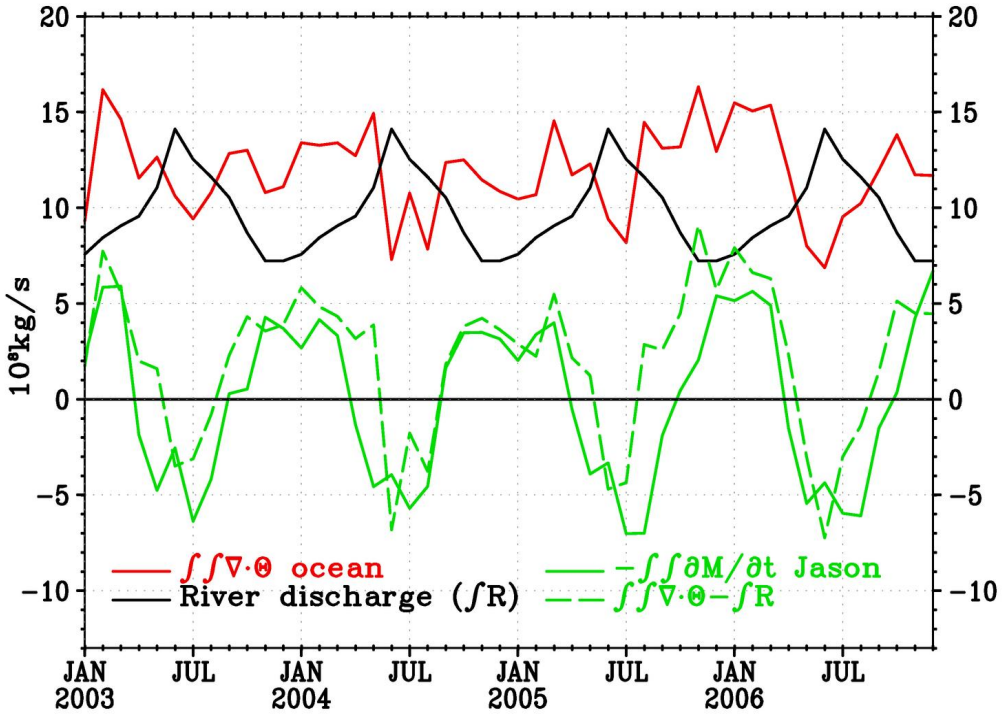
LH: Latent heat

SH: Sensible heat


Meridional heat transport at Atlantic (PW)
Satellite (6/2002–5/2005)
ECCO (6/2002–5/2005)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
60S
40S
20S
EQ
20N
40N
60N
Hsiung (1985)
Hastenrath (1980)
Hastenrath (1982)
Bunker (1976)
Bennett (1978)
Bryan (1962)
Wunsch (1980)
Roemmich (1981)
Fu (1981)
Bryden & Hall (1980)
Hall & Bryden (1982)
Molinari et al. (1990)
Fillenbaum et al (1997)

- **H can be derived from Argo**
- **Coverage is not sufficient**
- **Space-observation may be a solution**





Red - divergence of water vapor transport integrated over depth of the atmosphere

Black - sum of climatological river discharge across all coastline

Green - loss rate of water stored in all oceans from GRACE

---- difference between fresh water flux and river input

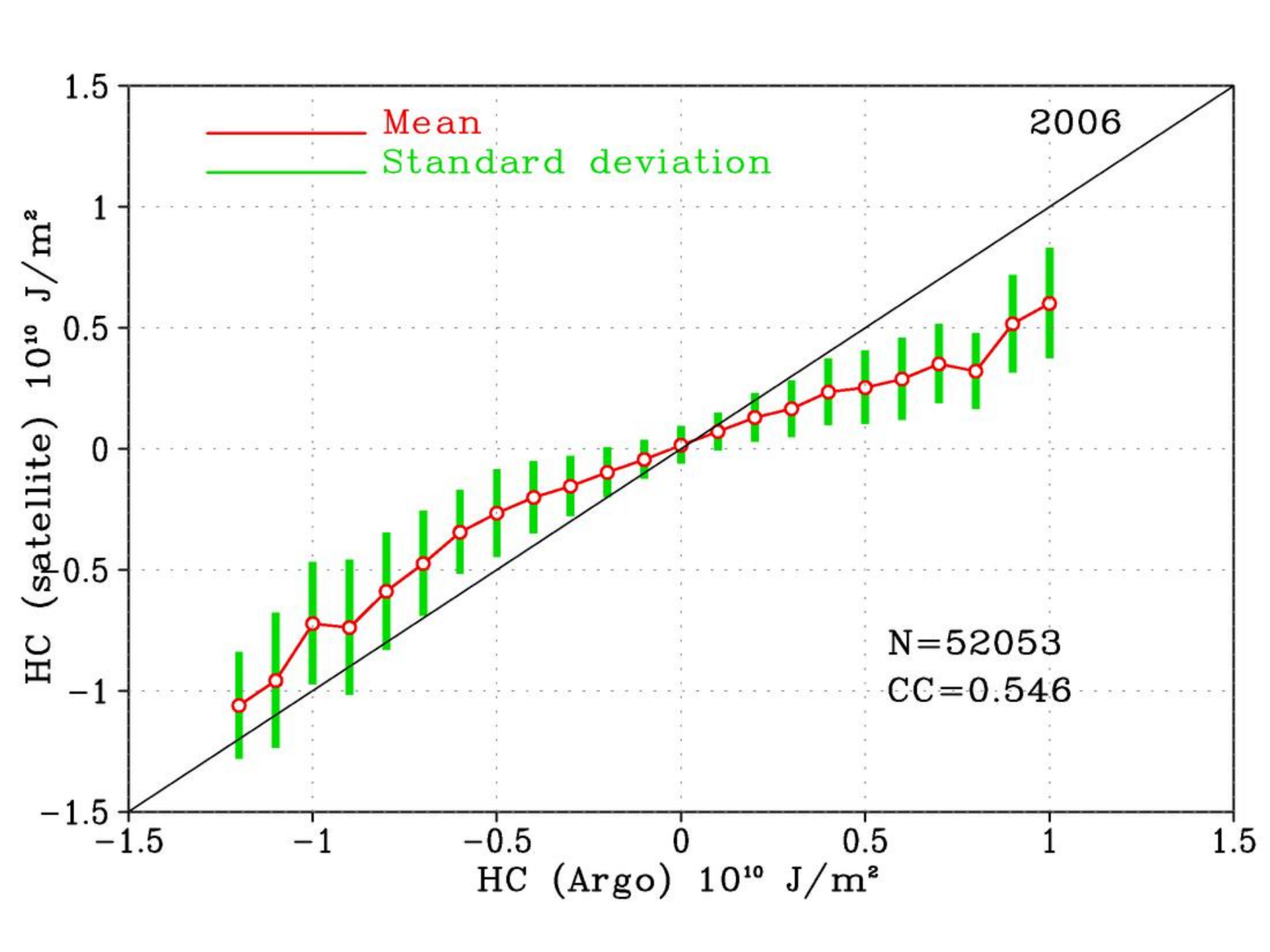
Green - subtracting climatological steric change from altimeter

$$\eta = \frac{P_a - P_b}{g\,\rho_0} + \frac{<\rho>}{\rho_0}$$

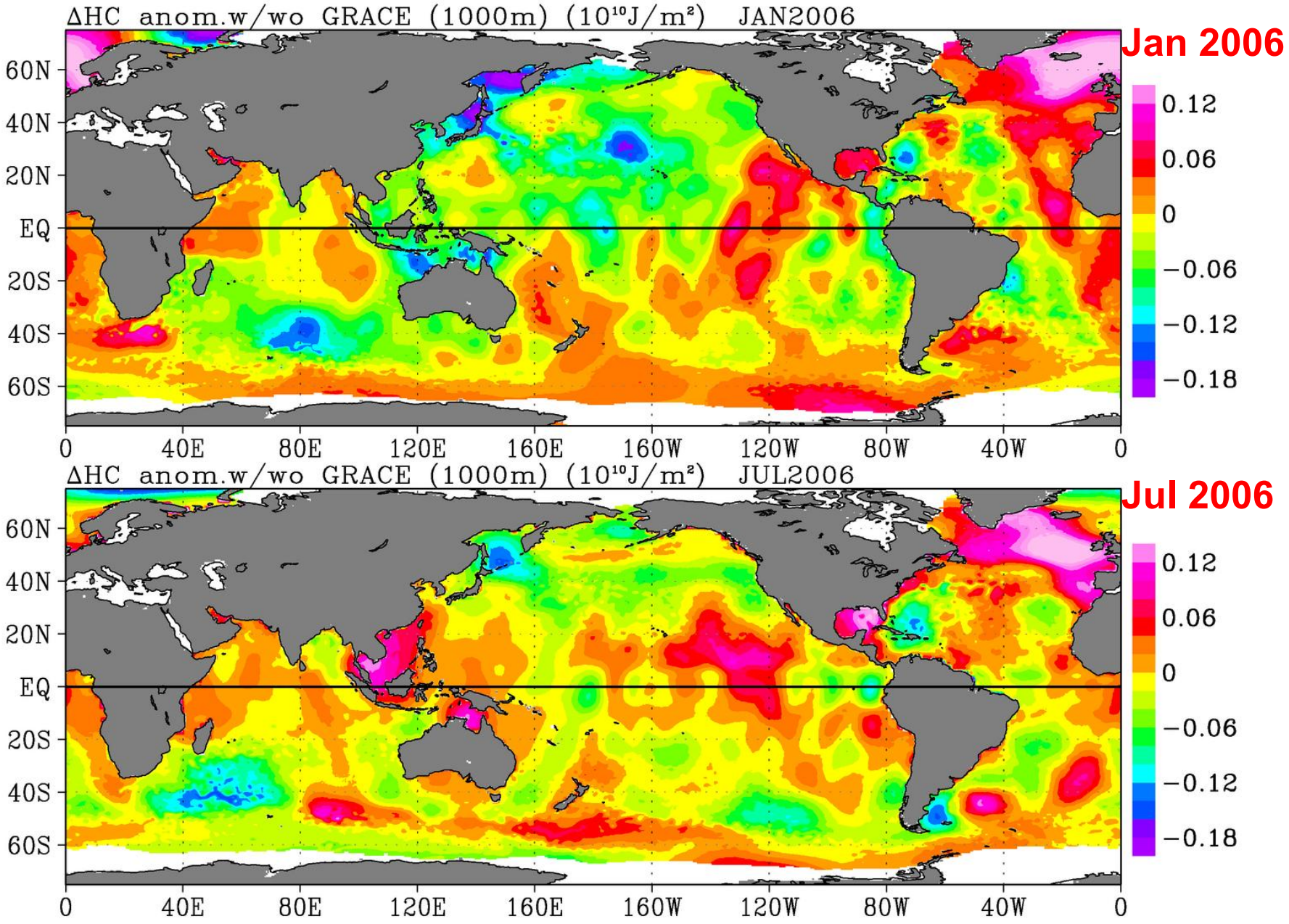
Sea level | Mass change | Steric change

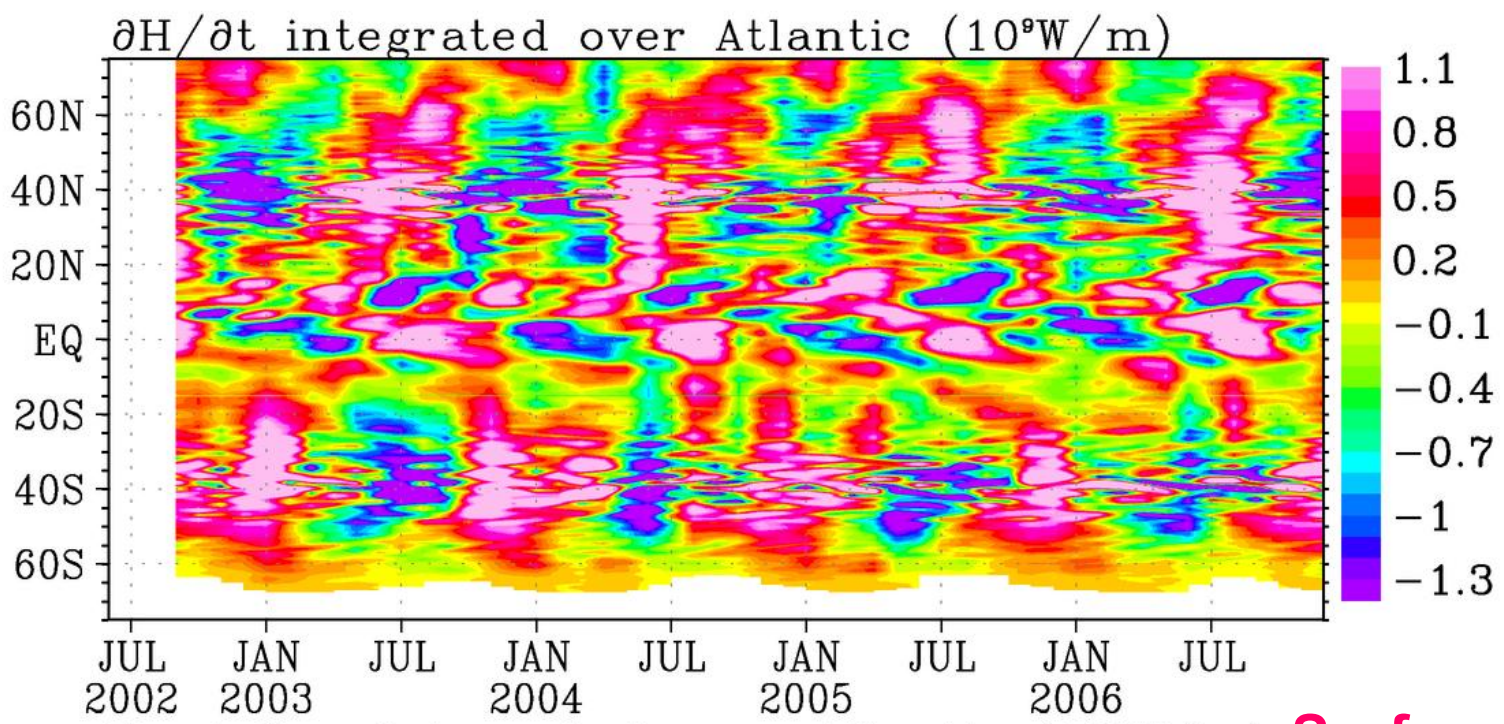
$$H' = \frac{c_p\,\rho_0}{\alpha}\eta'_s$$

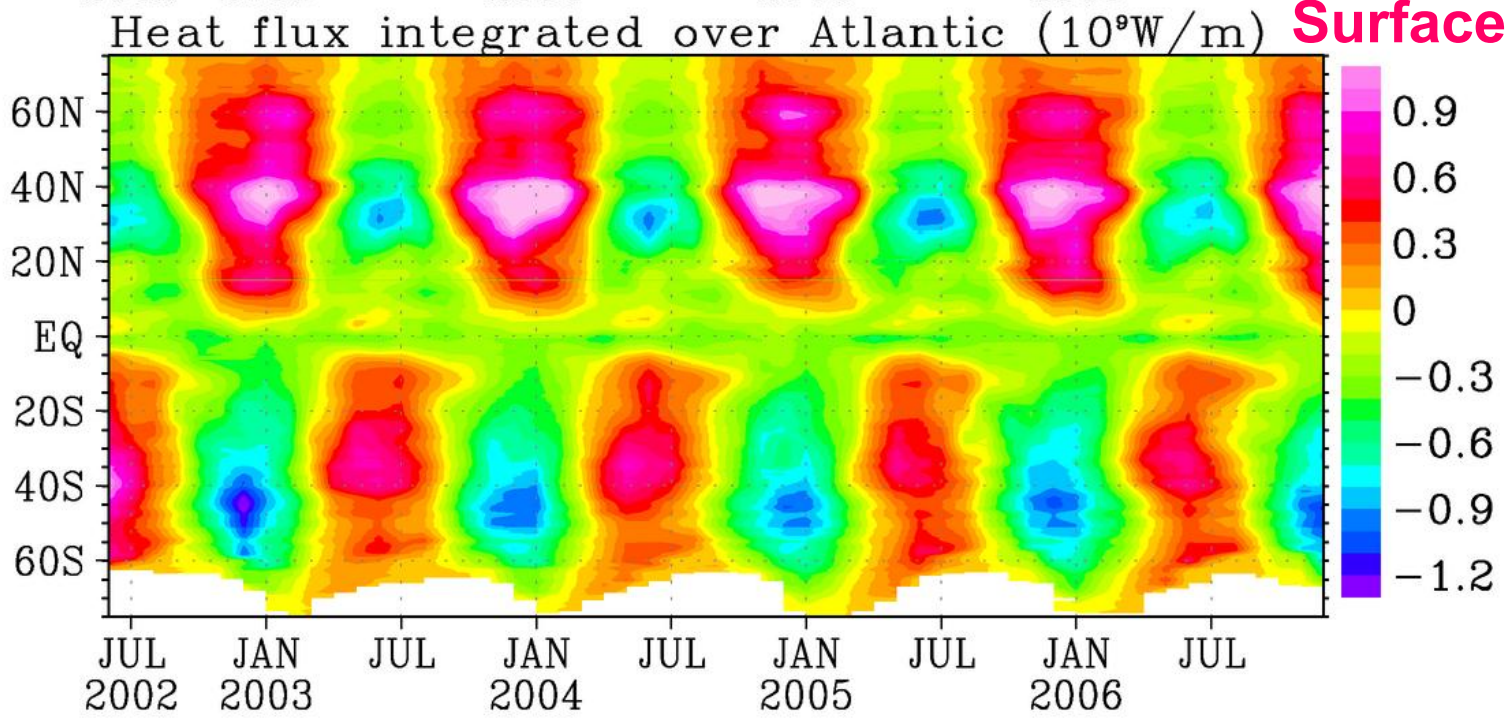
α- Thermal expansion coefficient


Mean
Standard deviation
2006
N=52053
CC=0.546
HC (satellite) 10¹⁰ J/m²
HC (Argo) 10¹⁰ J/m²
1.5
1
0.5
0
−0.5
−1
−1.5

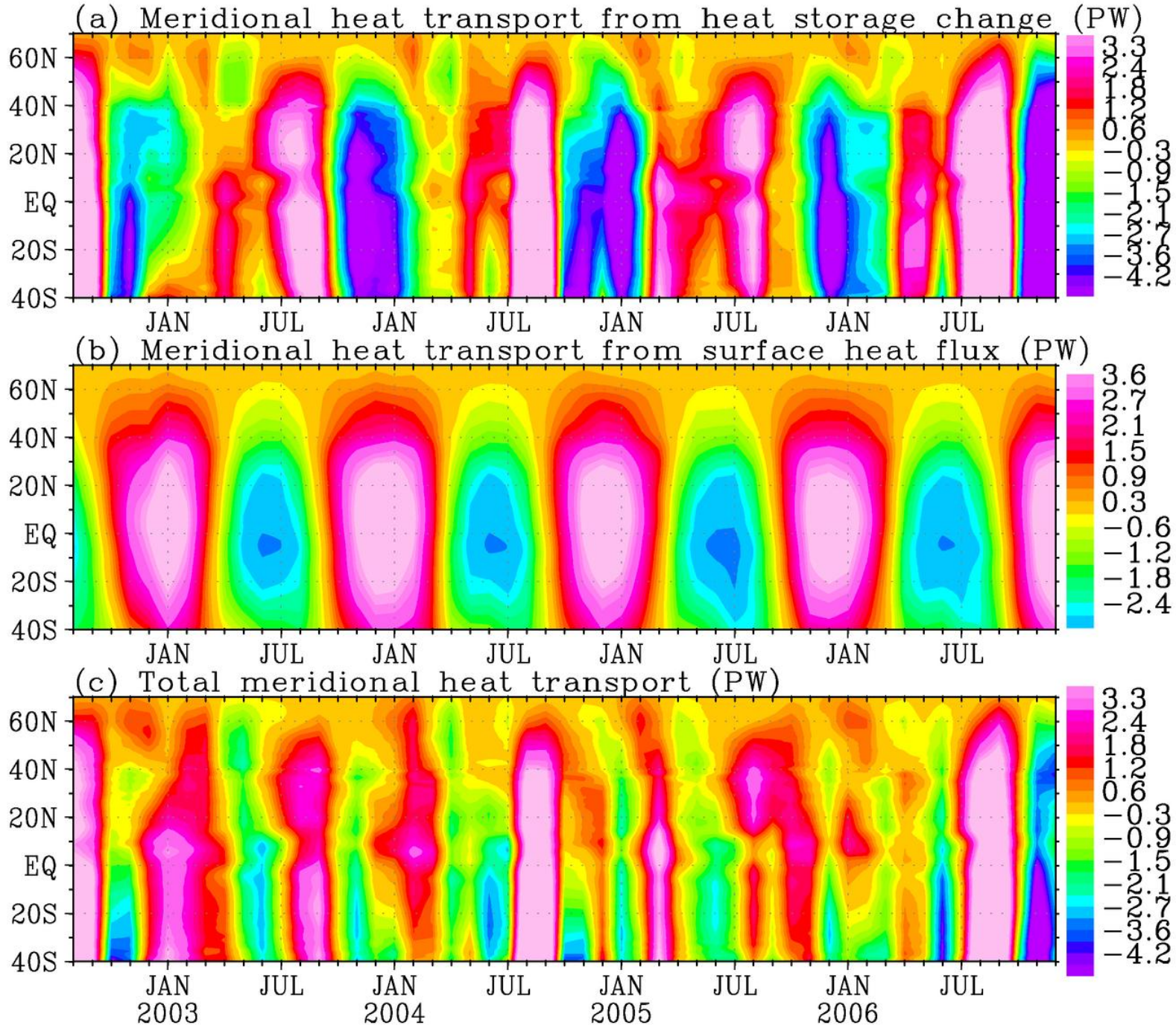
Impact of GRACE in deriving heat content







Surface Heat Loss



MHT from heat storage change (Statistic-al model)

MHT from surface heat flux

Total MHT at Atlantic

Meridional Water Transport (MWT)

Conservation of water mass

$$\frac{\partial M}{\partial t} + \nabla \cdot \psi = P - E$$

By Green's theorem

$$MWT(\theta) = \int_{\theta}^{\theta_o} \int_{x_1}^{x_2} \left(\frac{\partial M}{\partial t} + E - P - R\right) dx dy$$

Ekman water transport

$$EWT(\theta) = \int_{x_1}^{x_2} -\frac{\tau_x}{\rho f} dx$$

P: Precipitation

E: Evaporation

Ψ: Horizontal mass flux

R: River discharge

τ_x: Zonal stress

HYDROLOGIC BALANCE

$$\frac{\partial W}{\partial t} + \nabla \bullet \Theta = E - P$$

$$\Theta = \frac{1}{g}\int_0^{p0} qU\mathbf{d}p$$

$$W = \frac{1}{g}\int_0^{p0} q\mathbf{d}p$$

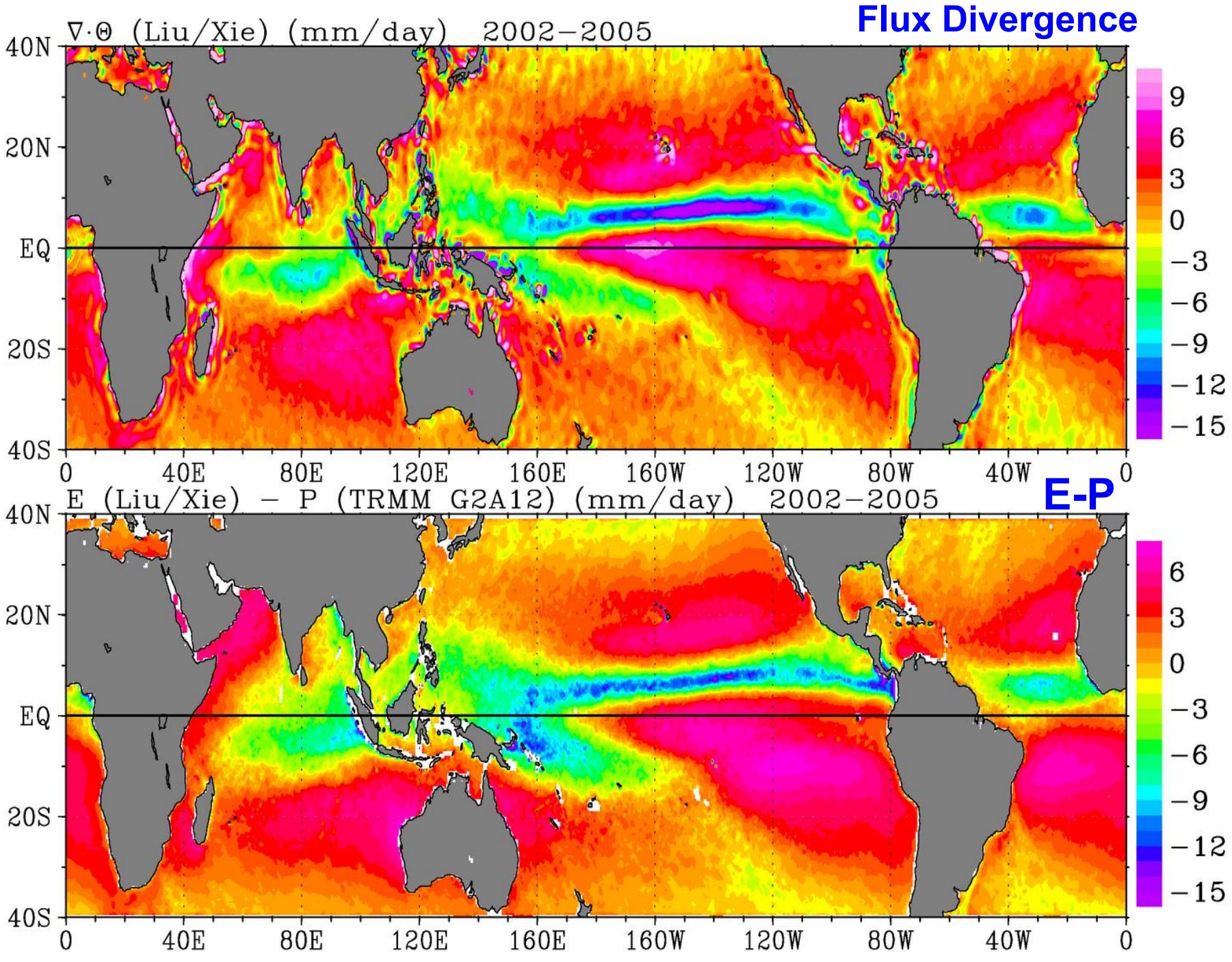
$$\Theta = \mathbf{Ue}\ W$$

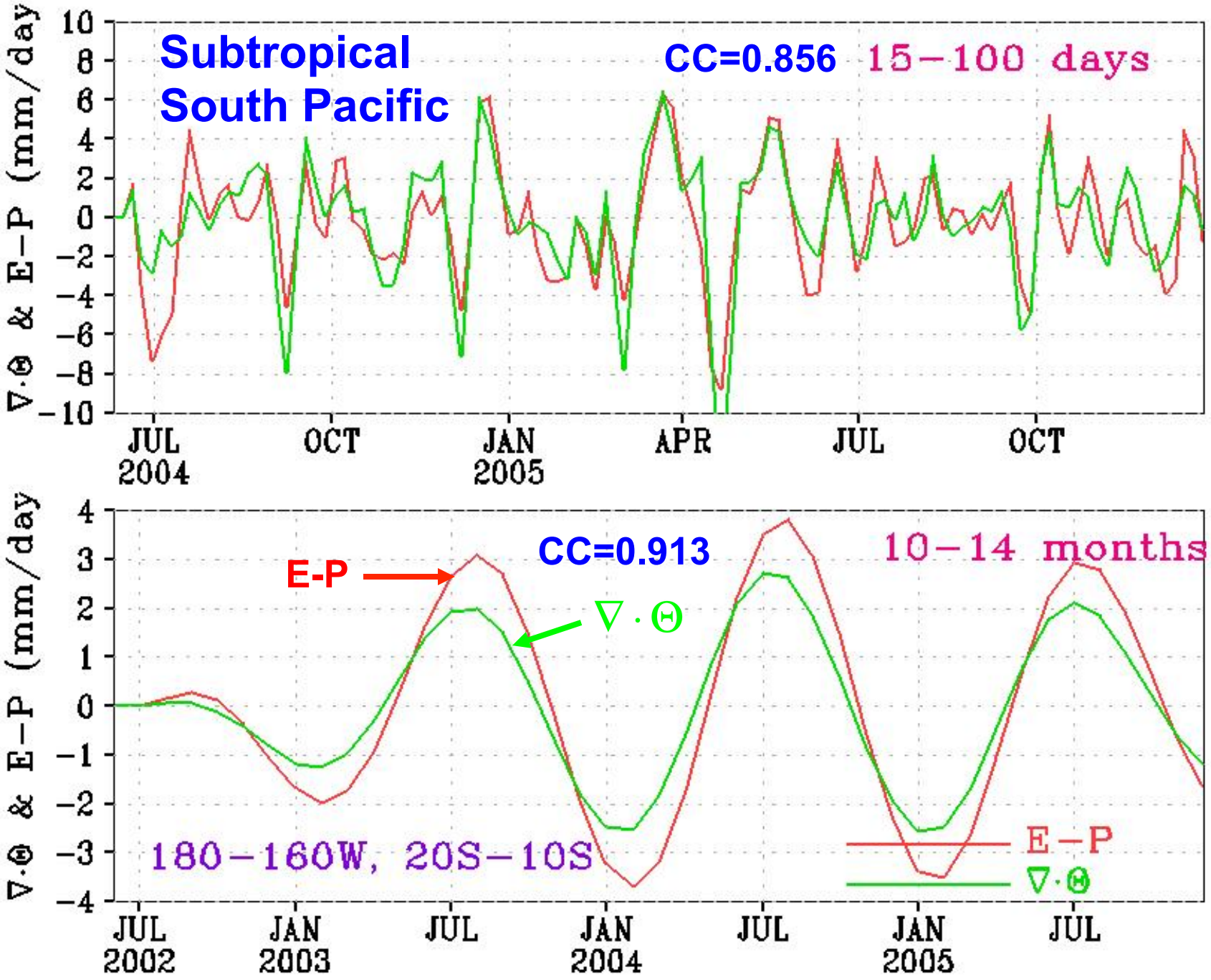
Ue=f(Us) **Liu (1993)-polynomial**

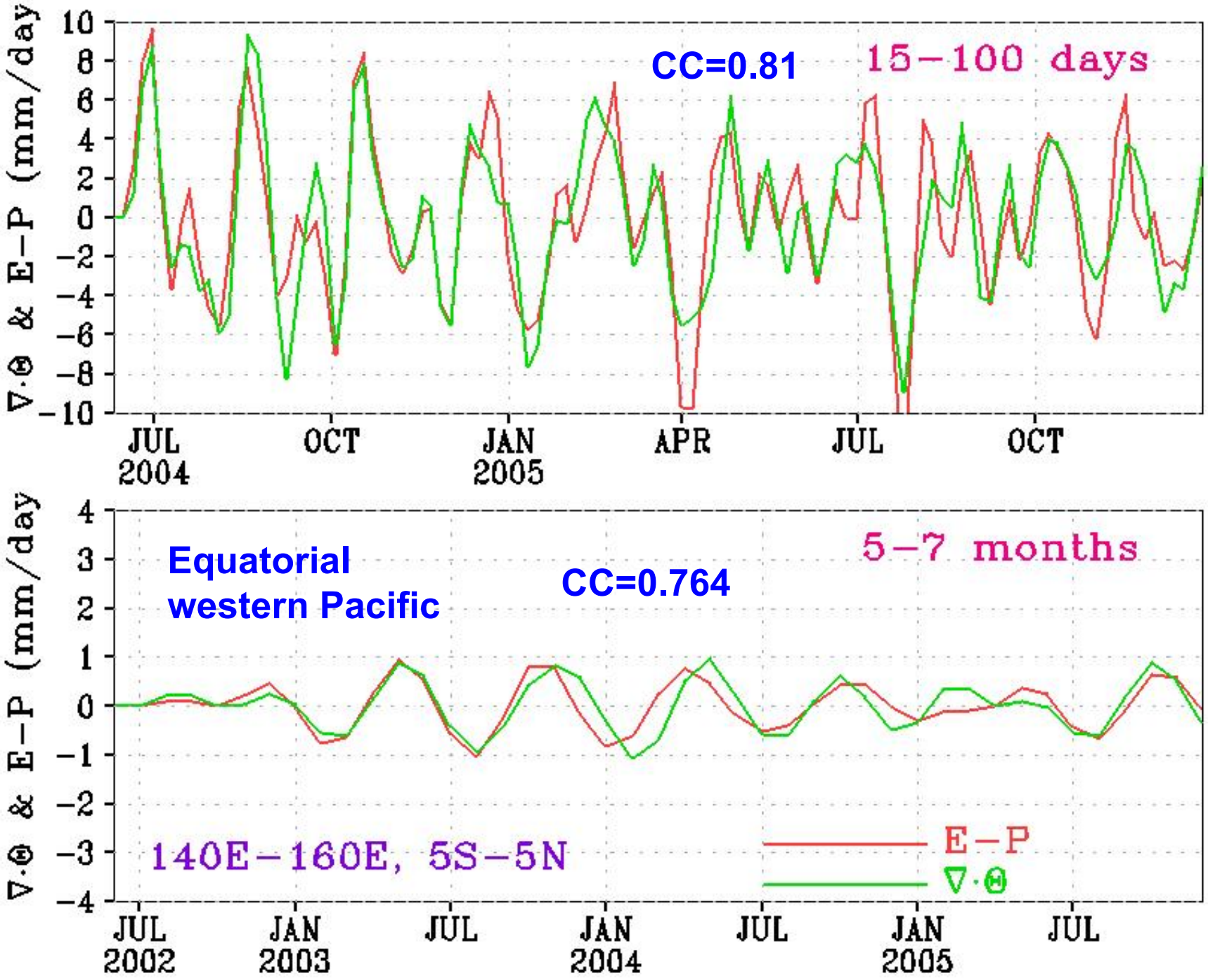
Liu & Tang (2005) - Neural Network

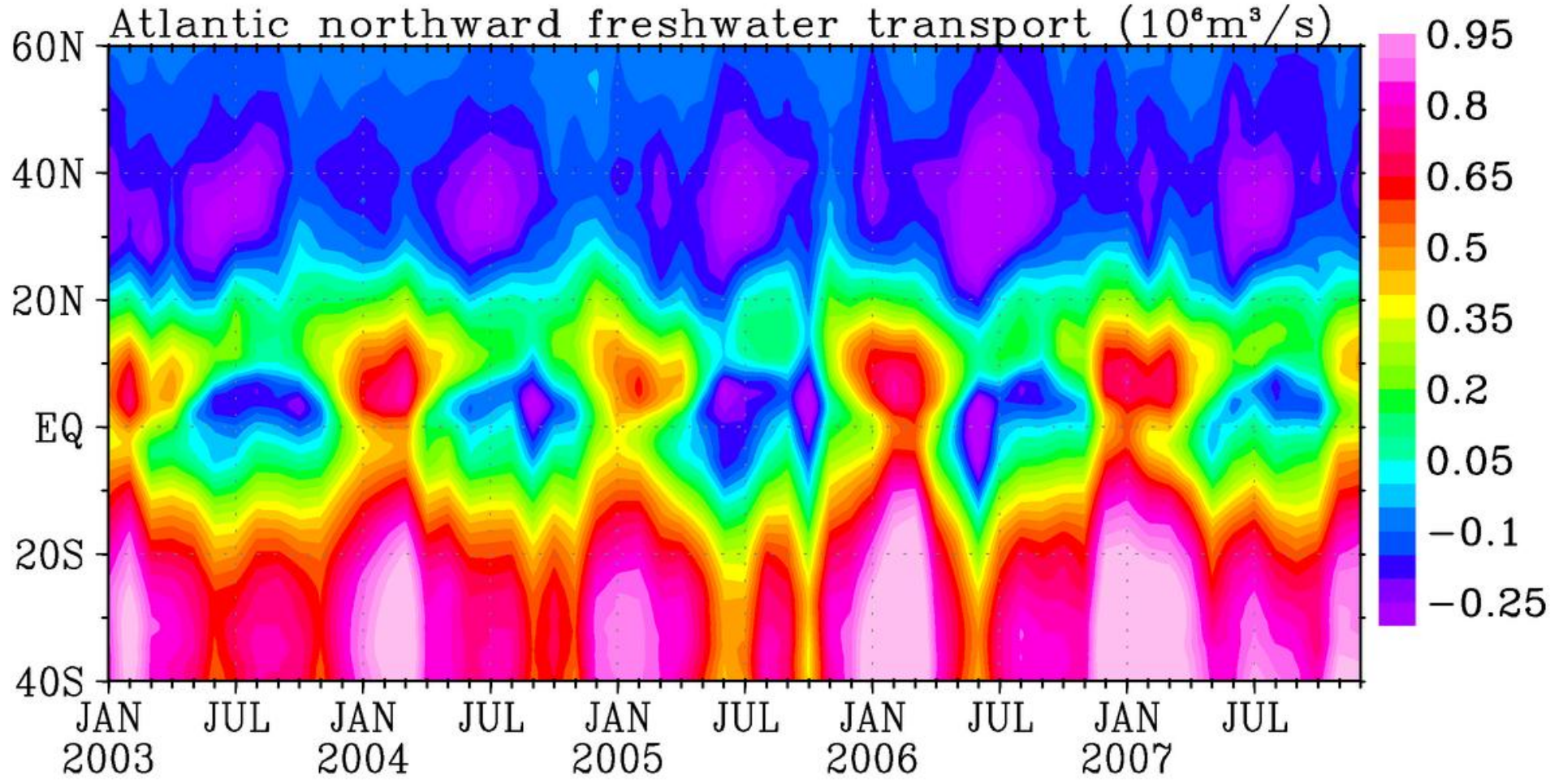
Ue = U_{850mb} **Heta & Mitsuta (1993)**

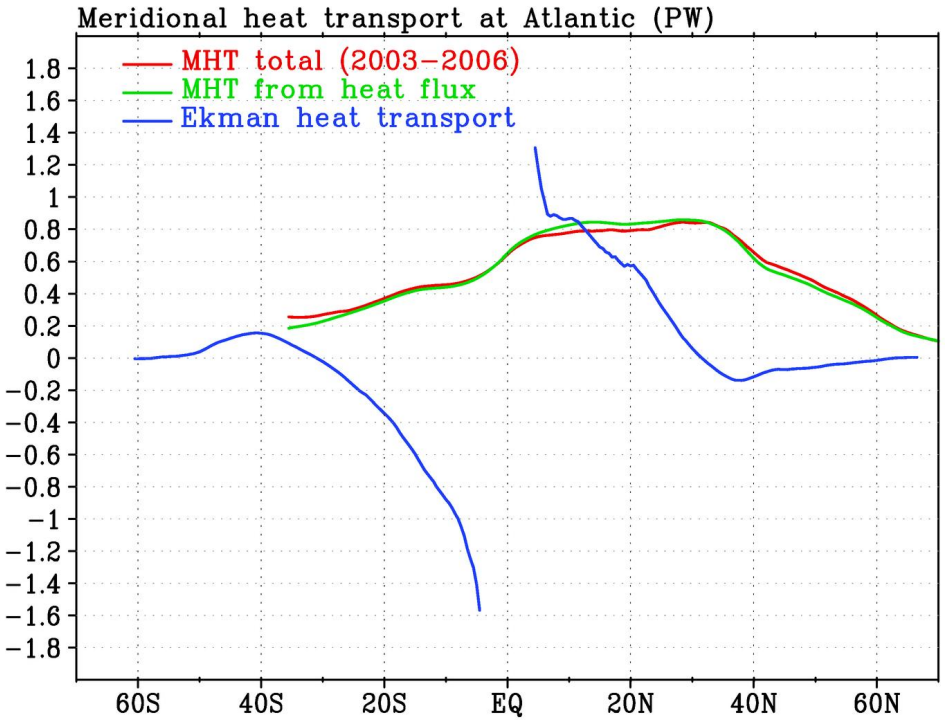
Both Us & U_{850mb} **Xie et al. (2007) - SVR**


Flux Divergence
∇·Θ (Liu/Xie) (mm/day) 2002–2005
40N
20N
EQ
20S
40S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
9
6
3
0
−3
−6
−9
−12
−15
E (Liu/Xie) − P (TRMM G2A12) (mm/day) 2002–2005
E-P
40N
20N
EQ
20S
40S
0
40E
80E
120E
160E
160W
120W
80W
40W
0
6
3
0
−3
−6
−9
−12
−15


Subtropical
South Pacific
CC=0.856
15–100 days
∇·Θ & E–P (mm/day)
10
8
6
4
2
0
−2
−4
−6
−8
−10
JUL
2004
OCT
JAN
2005
APR
JUL
OCT
E-P
CC=0.913
10–14 months
∇·Θ
180–160W, 20S–10S
E–P
∇·Θ
4
3
2
1
0
−1
−2
−3
−4
JUL
2002
JAN
2003
JUL
JAN
2004
JUL
JAN
2005
JUL


CC=0.81
15–100 days
∇·Θ & E–P (mm/day
10
8
6
4
2
0
–2
–4
–6
–8
–10
JUL
2004
OCT
JAN
2005
APR
JUL
OCT
Equatorial
western Pacific
CC=0.764
5–7 months
4
3
2
1
0
–1
–2
–3
–4
140E–160E, 5S–5N
E–P
∇·Θ
JUL
2002
JAN
2003
JUL
JAN
2004
JUL
JAN
2005
JUL

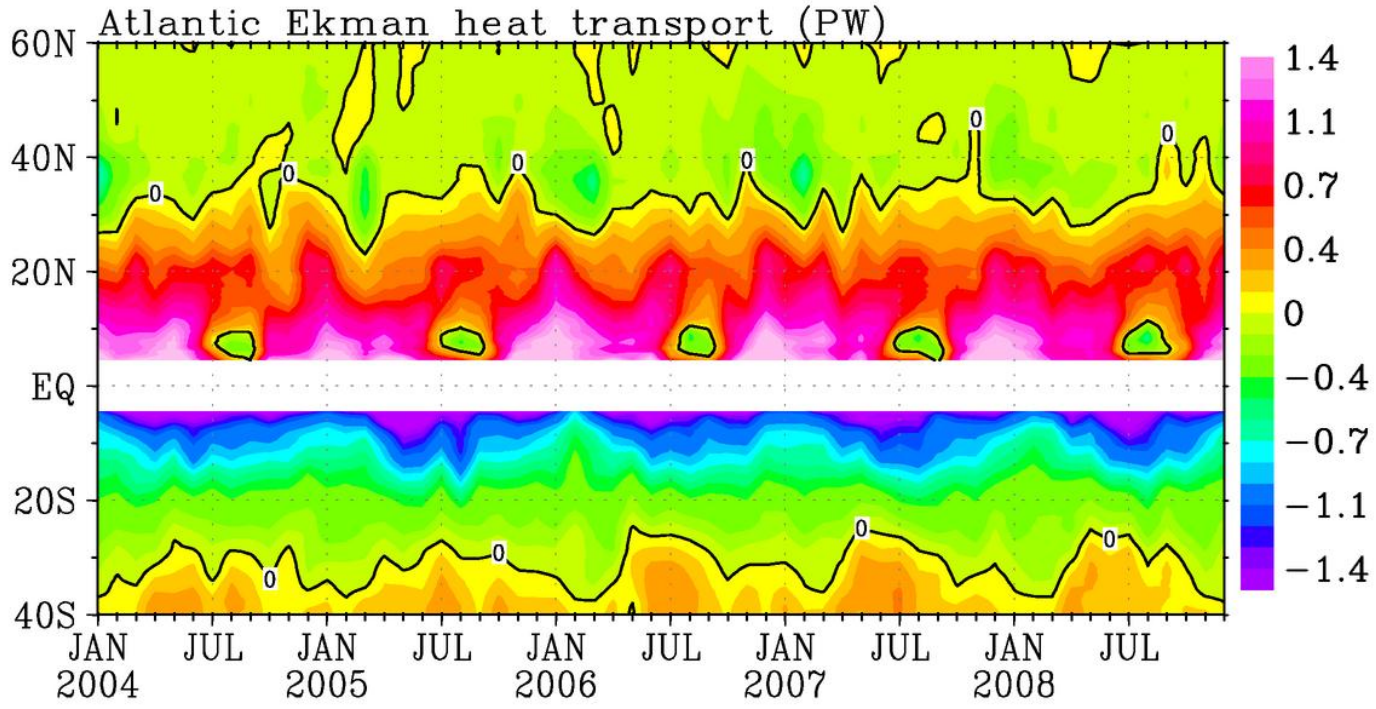

Atlantic northward freshwater transport (10⁶m³/s)
60N
40N
20N
EQ
20S
40S
JAN
2003
JUL
JAN
2004
JUL
JAN
2005
JUL
JAN
2006
JUL
JAN
2007
JUL
0.95
0.8
0.65
0.5
0.35
0.2
0.05
−0.1
−0.25



$$EHT(\theta) = -c_p \int_{x_1}^{x_2} \frac{\tau_x}{f}(T_e - \overline{T})dx$$

T_e: Potential temp. of Ekman layer

$\overline{T}$: Mean potential temp. of the water column



Summary

- Spacebased data provide almost continuous spatial and temporal coverages for a decade
- Reality checks are needed
- What is the relation between surface Ekman transport in the total meridional transport

backup

Ocean Balance

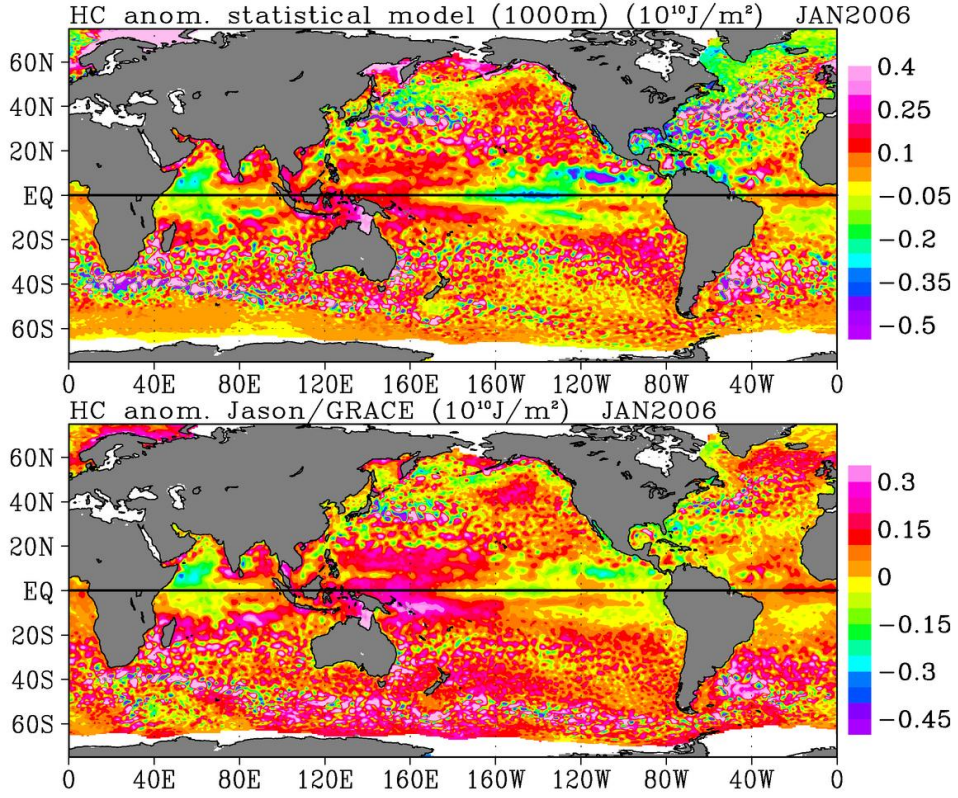
$$\iint \frac{\partial M}{\partial t} = \int R - \iint \nabla \cdot \Theta$$

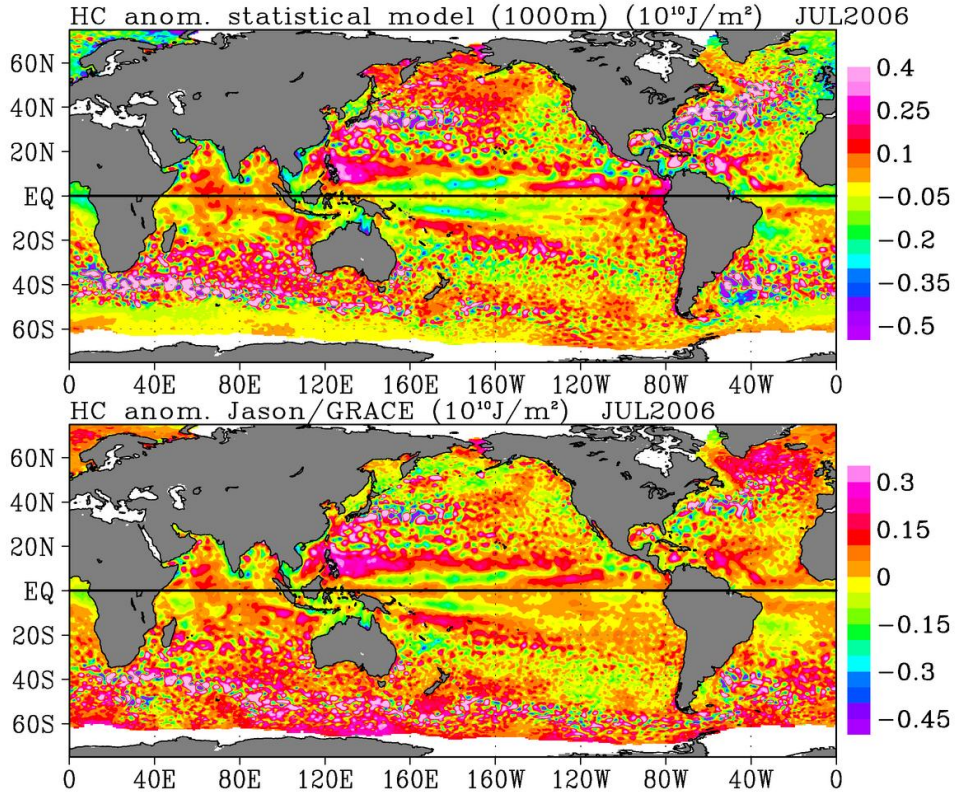
M could come from GRACE
or subtracting climatological steric change from altimeter

HC Jan 2006

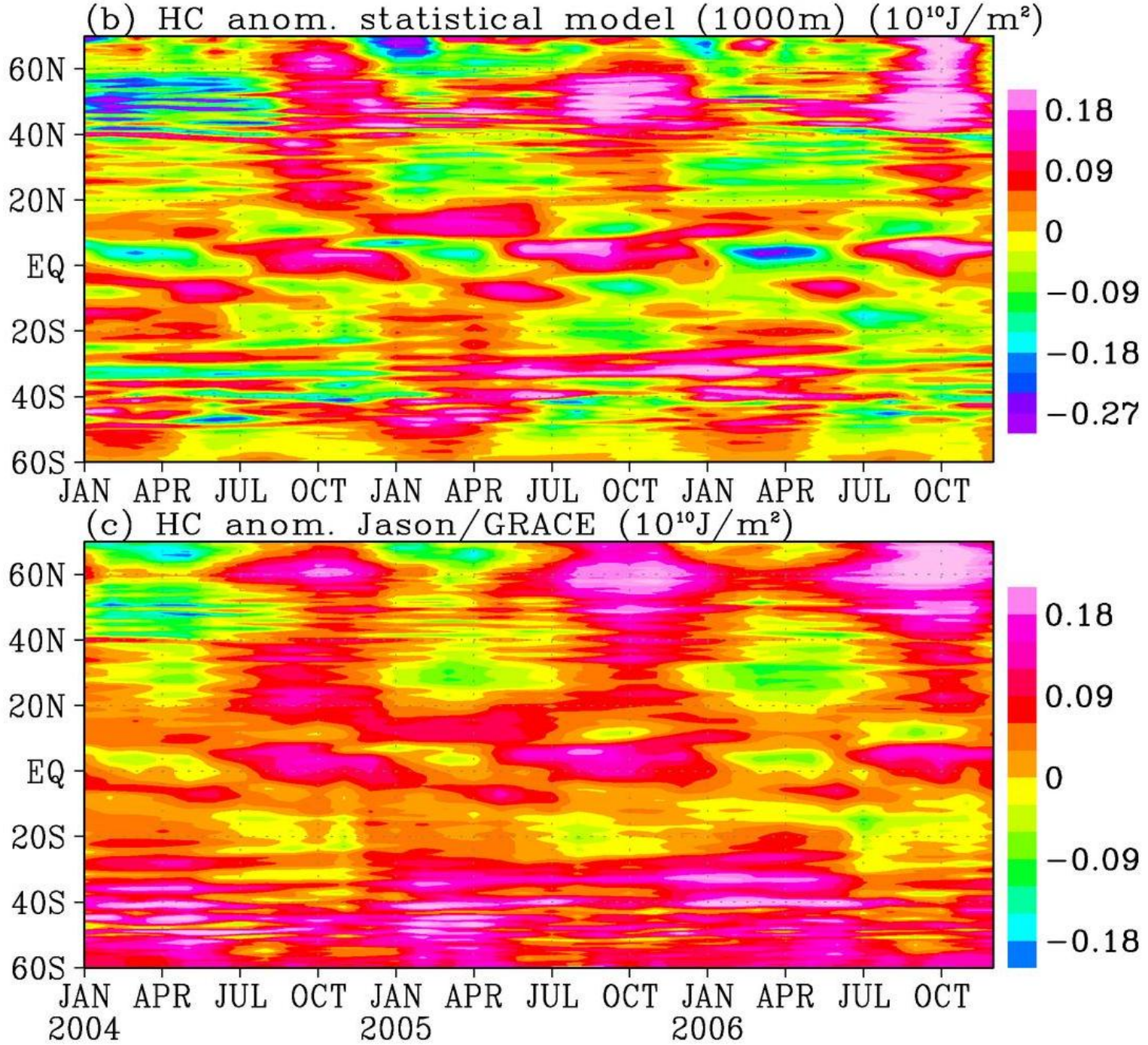
Statistical model

HC Jul 2006





Jason/GRACE


(b) HC anom. statistical model (1000m) (10¹⁰J/m²)
60N
40N
20N
EQ
20S
40S
60S
JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT
0.18
0.09
0
−0.09
−0.18
−0.27
(c) HC anom. Jason/GRACE (10¹⁰J/m²)
60N
40N
20N
EQ
20S
40S
60S
JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT
2004
2005
2006
0.18
0.09
0
−0.09
−0.18

Thermal expansion coeff. from Argo