Ekman Transport and Depth-integrated Ocean Meridional Transport

Preliminary Results

W. Timothy Liu and Xiaosu Xie

- Heat Transport
- Water Transport
- Long Term Variability

Ekman water transport

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

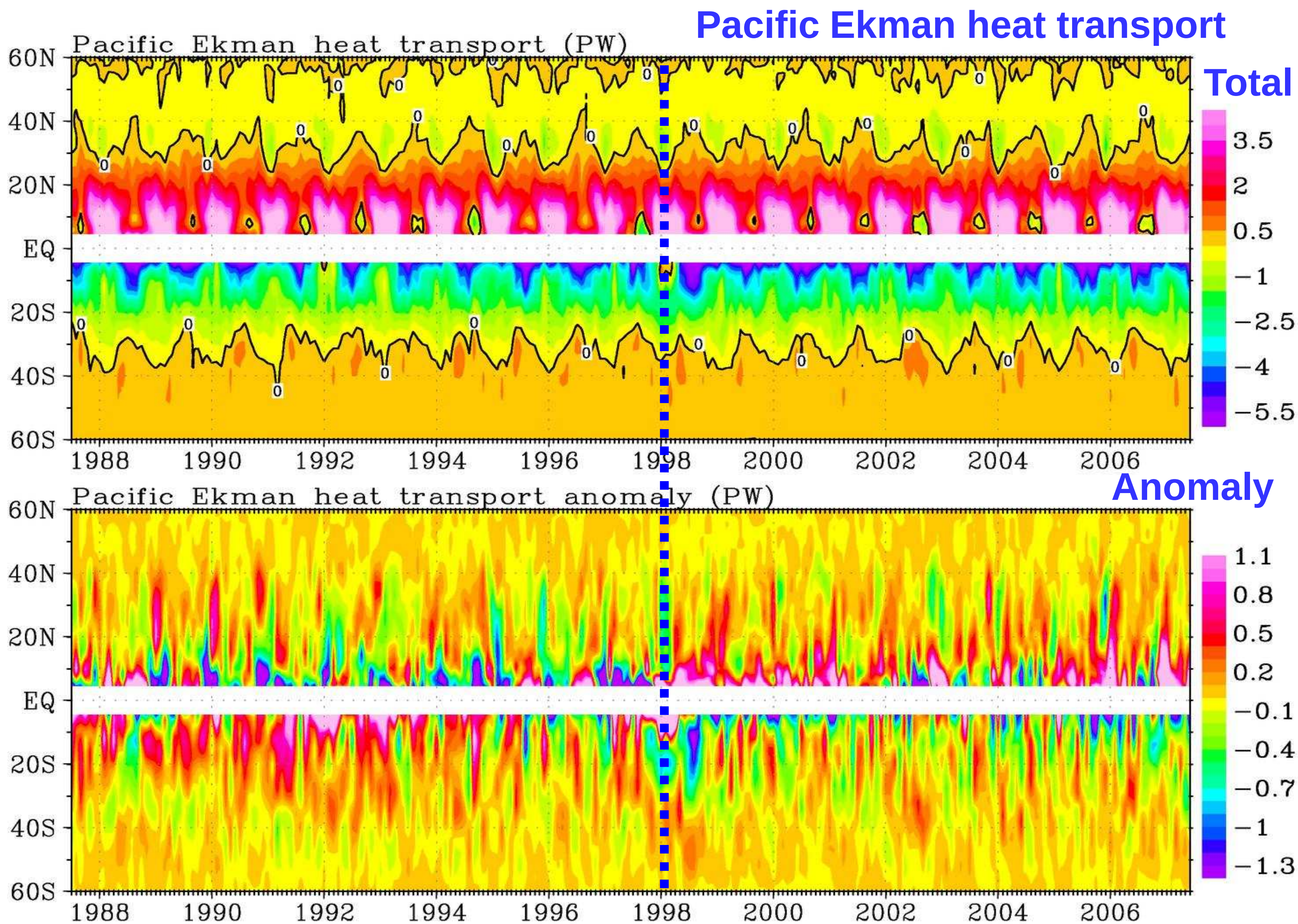
τ_x: Zonal stress
Te: Potential temp. of Ekman layer
$\overline{T}$: Mean potential temp. of the water column

Ekman heat transport

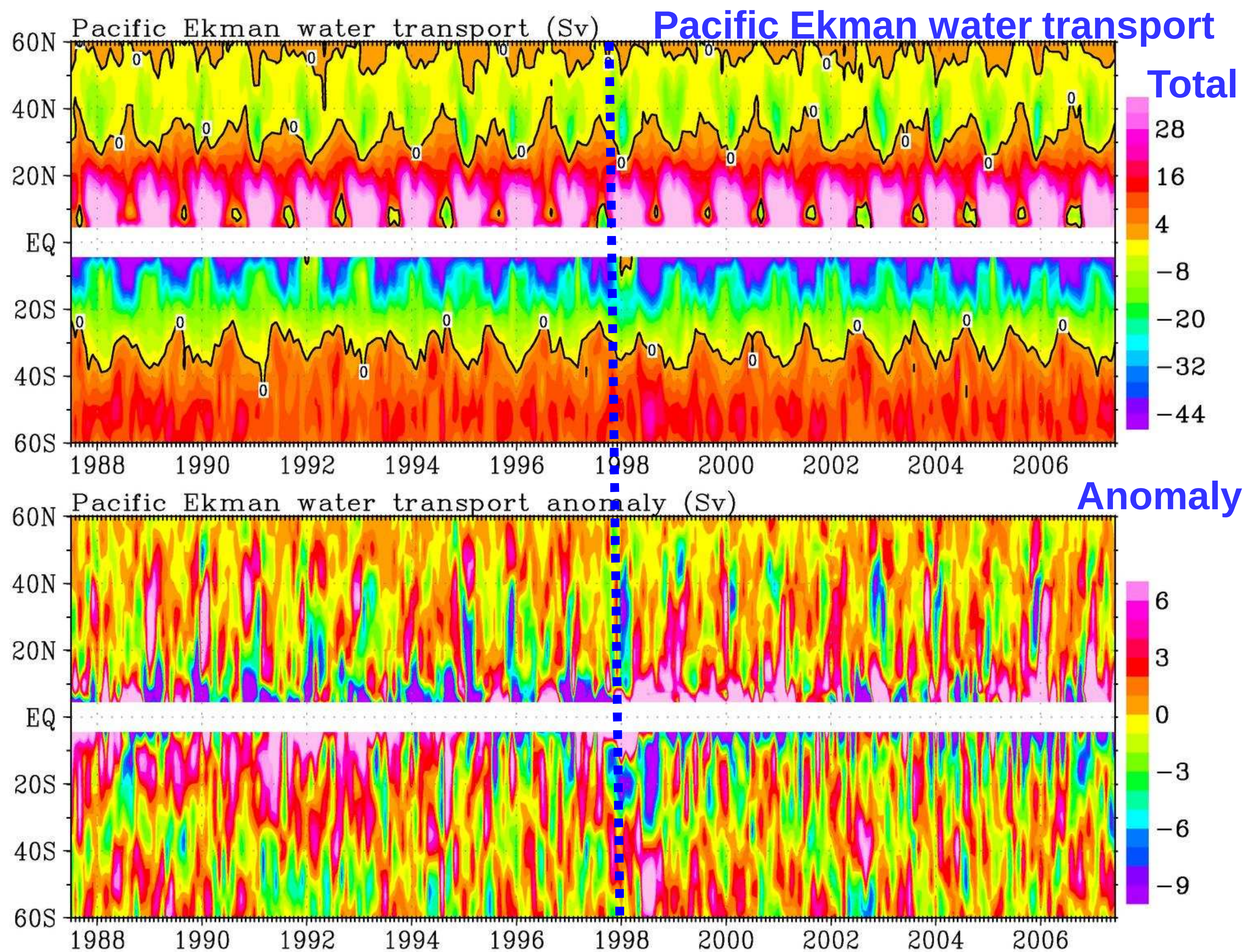
$$\mathrm{EHT}(\theta) = -c_p \int_{x_1}^{x_2} \frac{\tau_x}{f} (T_e - \overline{T}) dx$$

Sato, Polito, & Liu, 2002: GRL, 29(17)

Sprintall & Liu, 2005: Oceanography, 18(4)



Intensification of poleward Ekman heat transport since 1998 in the tropics



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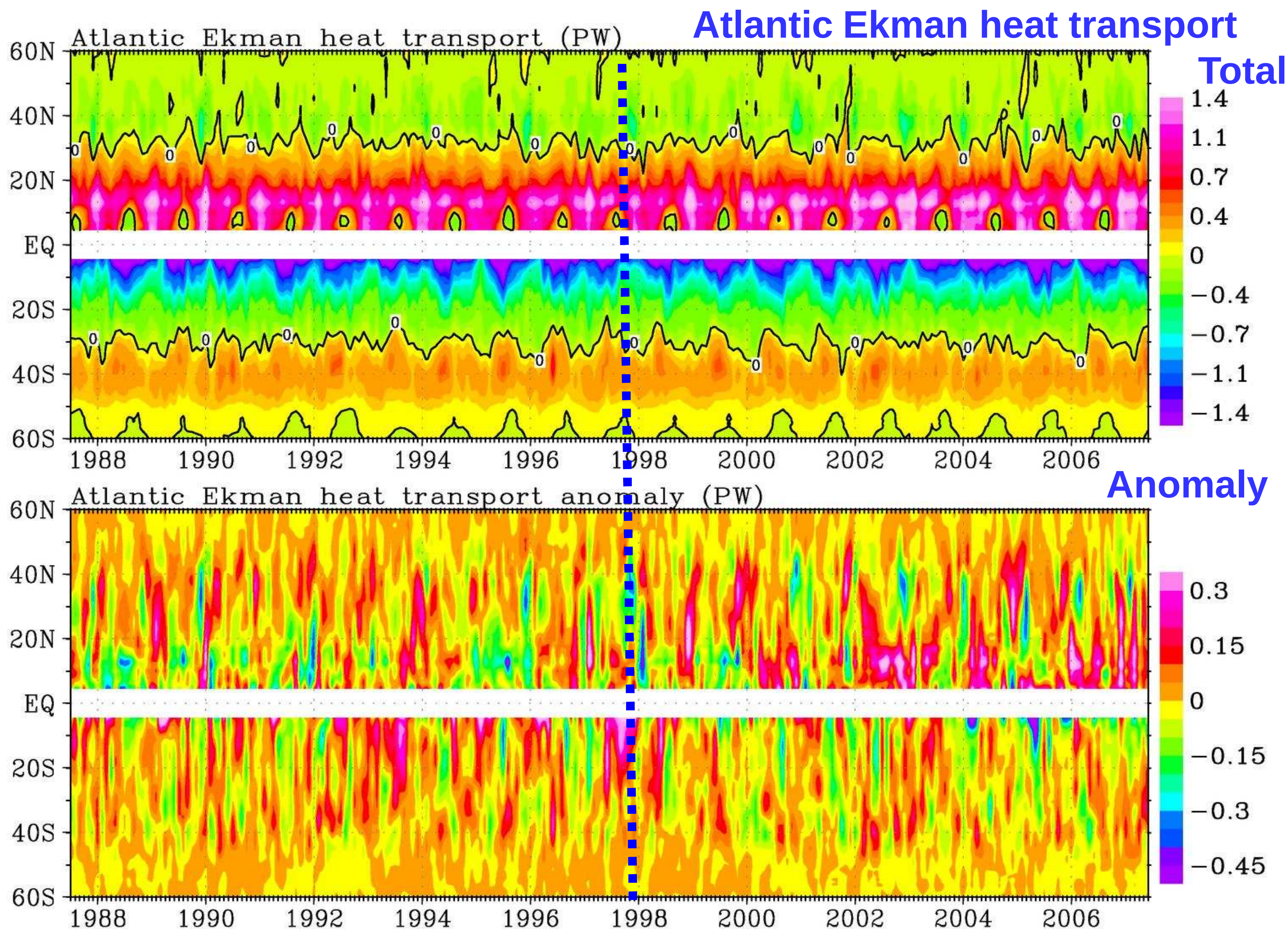
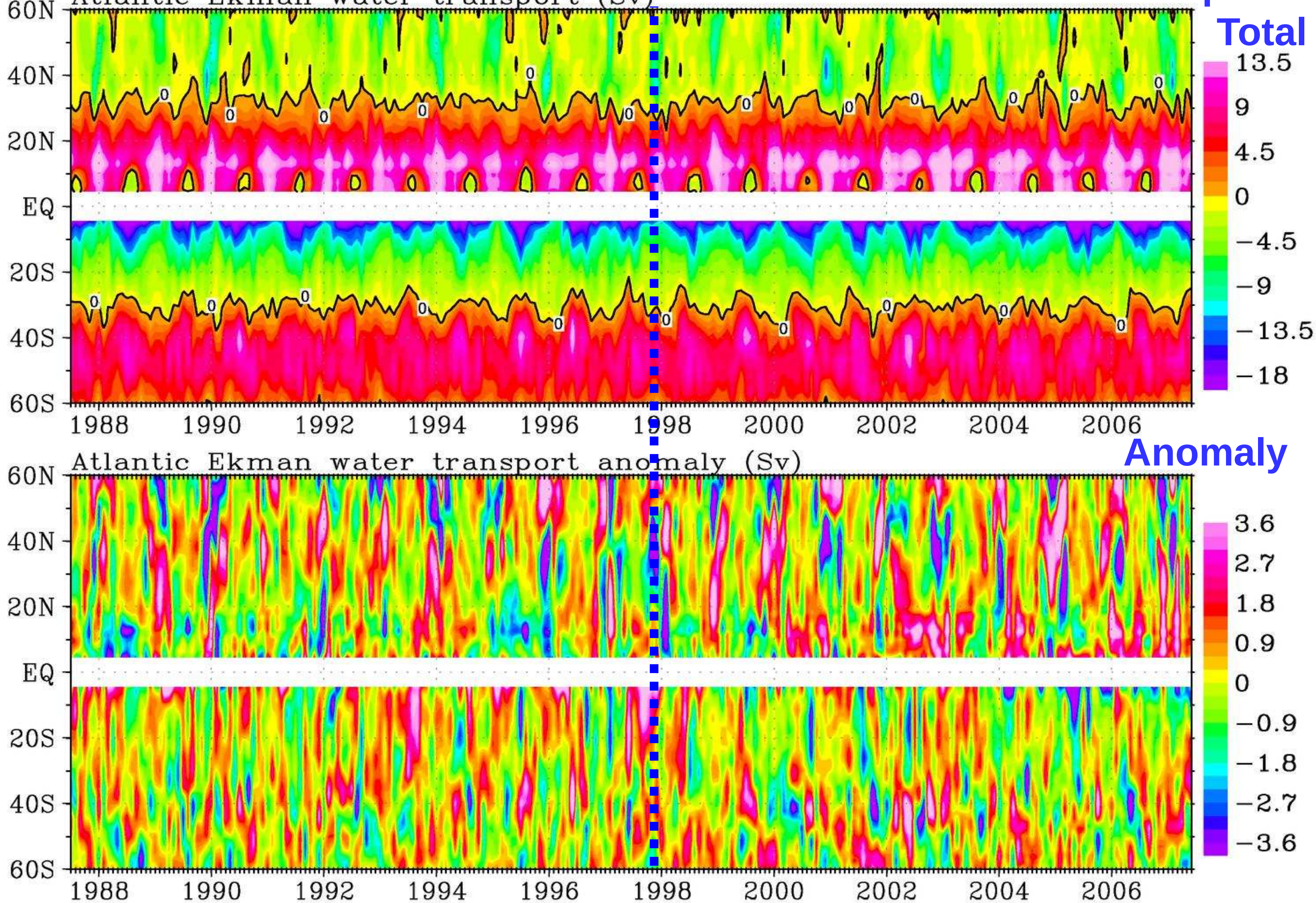
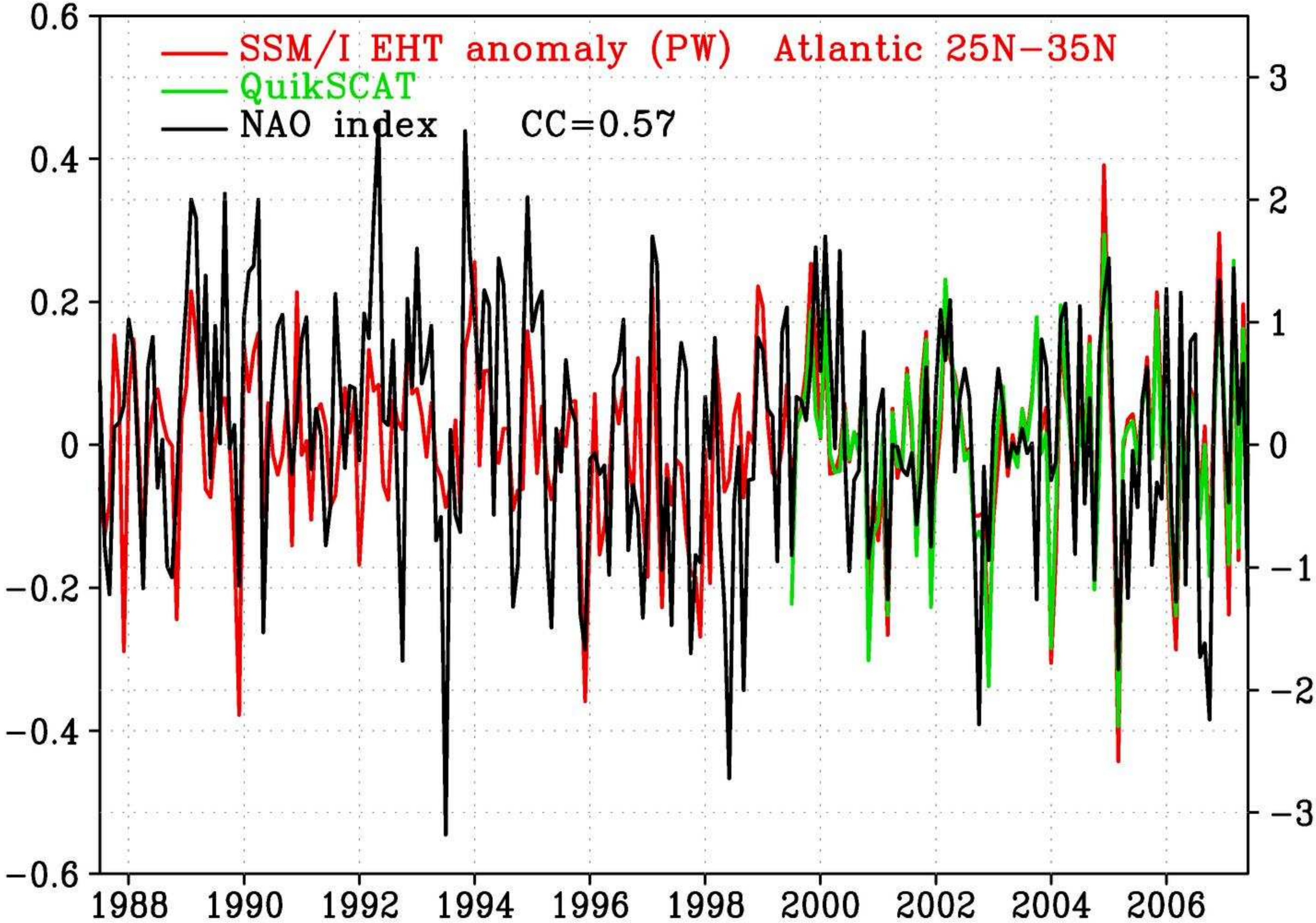


Intensification of poleward Ekman heat transport since 1998 in the tropics

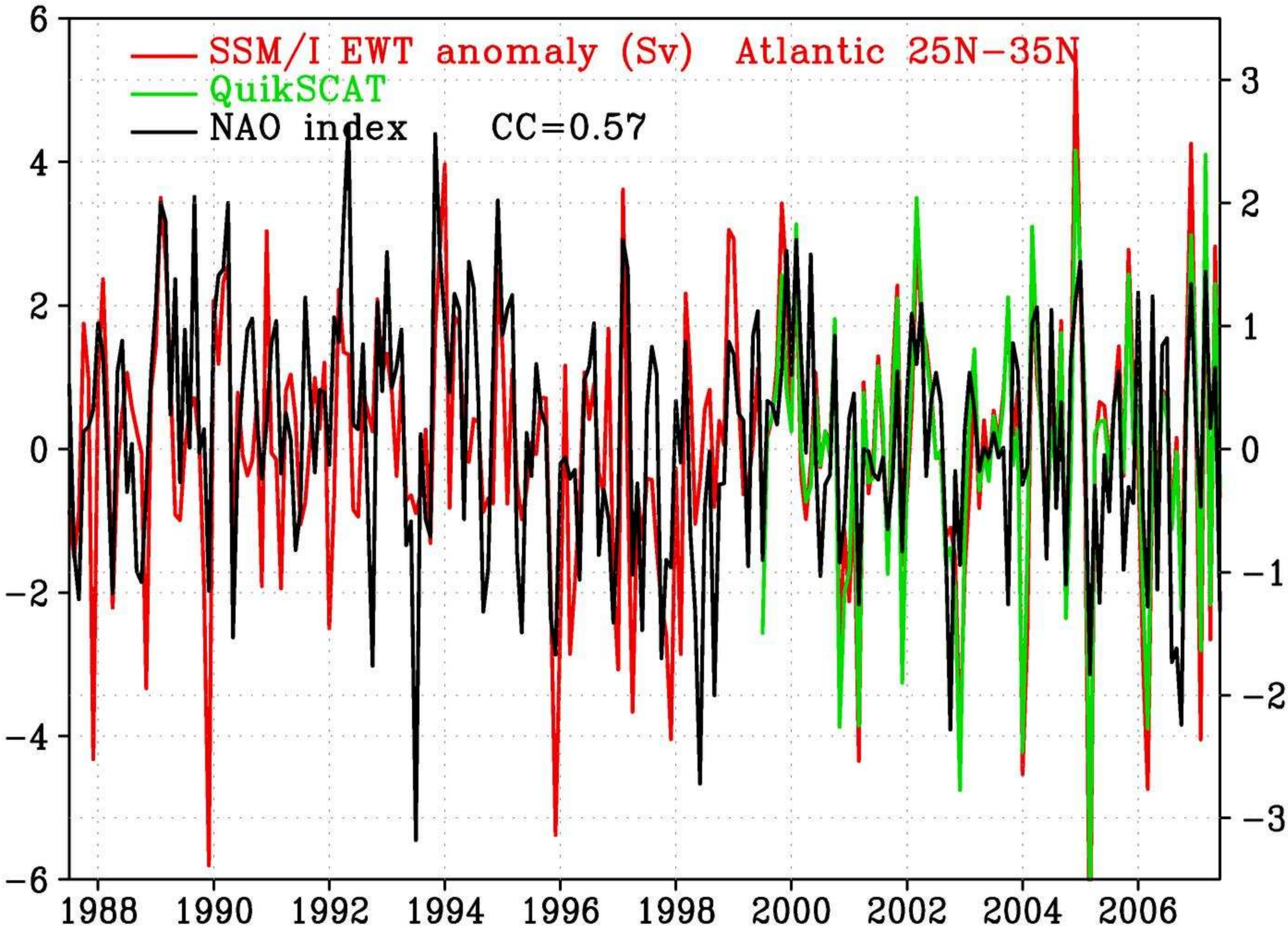
Atlantic Ekman water transport



Intensification of poleward Ekman water transport from 1998 in the tropics



Ekman heat transport in the subtropical Atlantic is correlated with NAO



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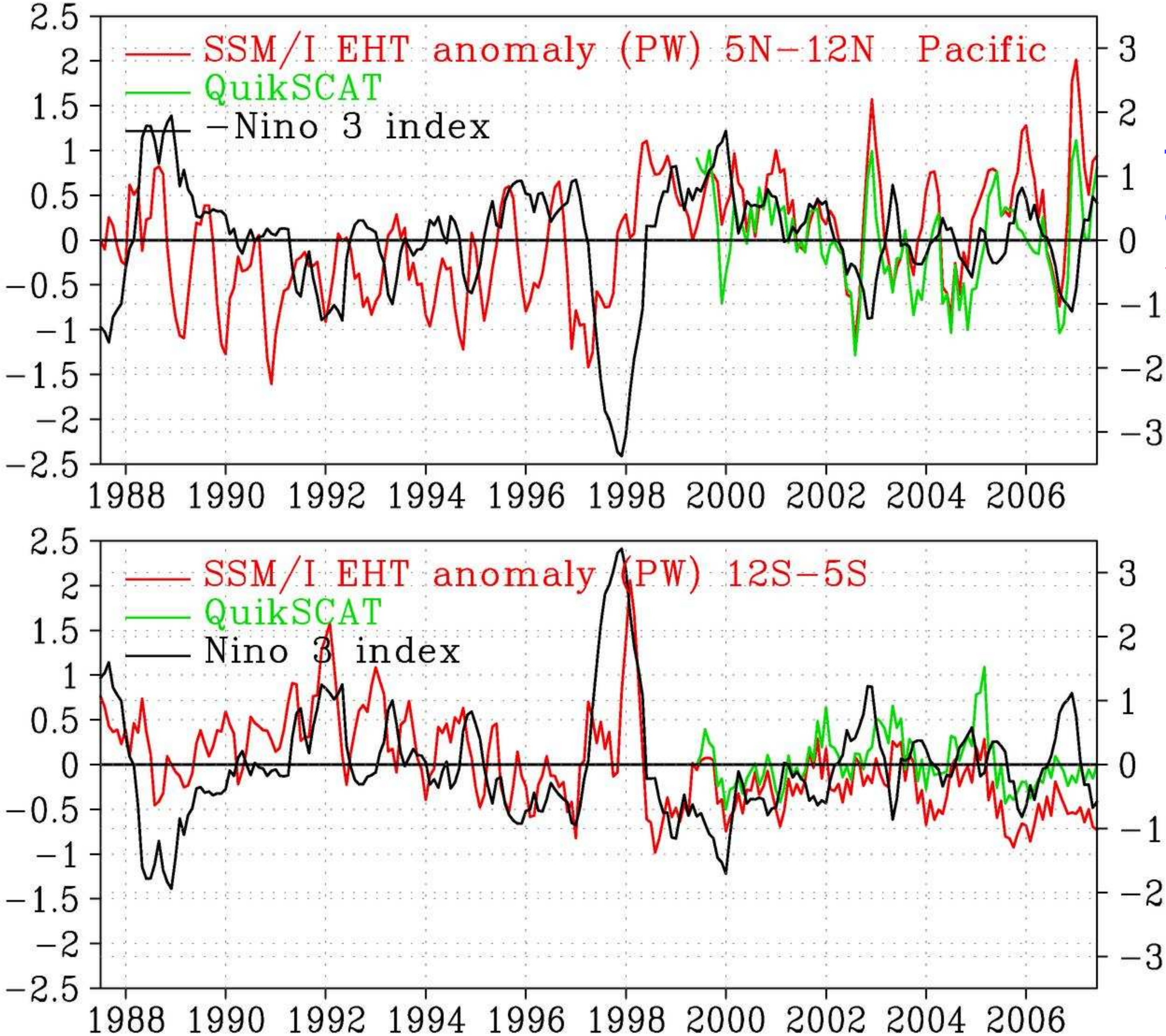
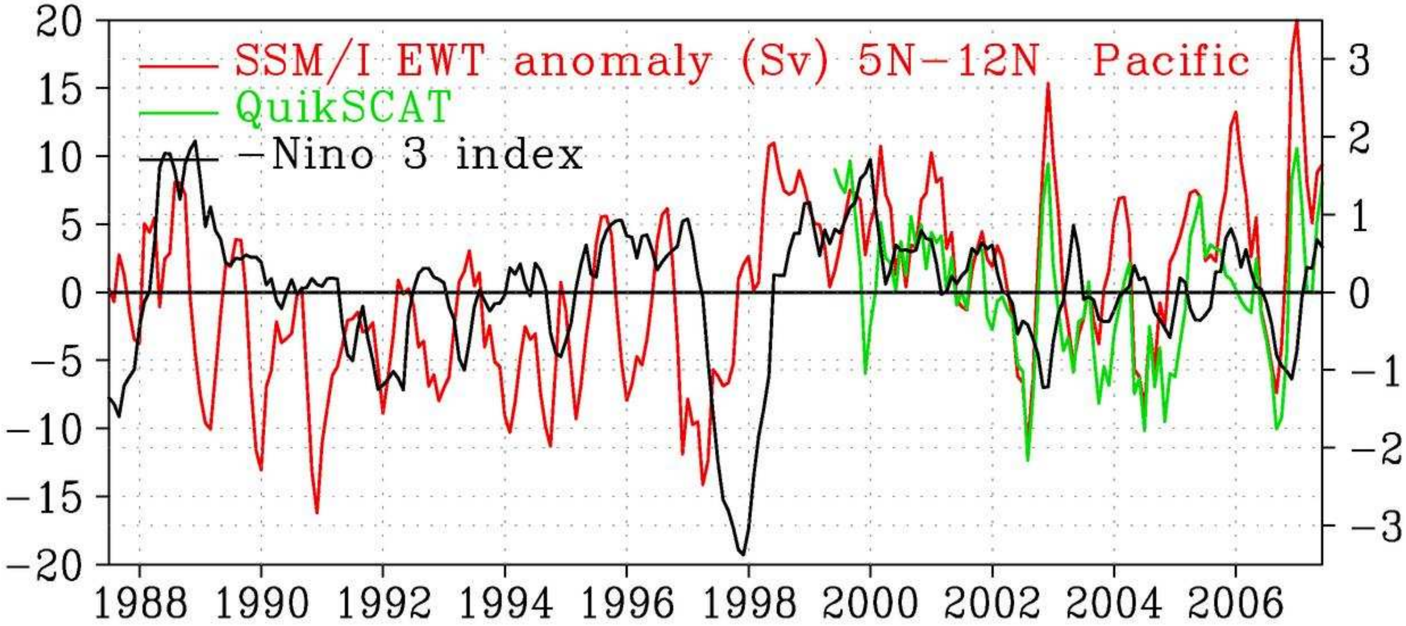
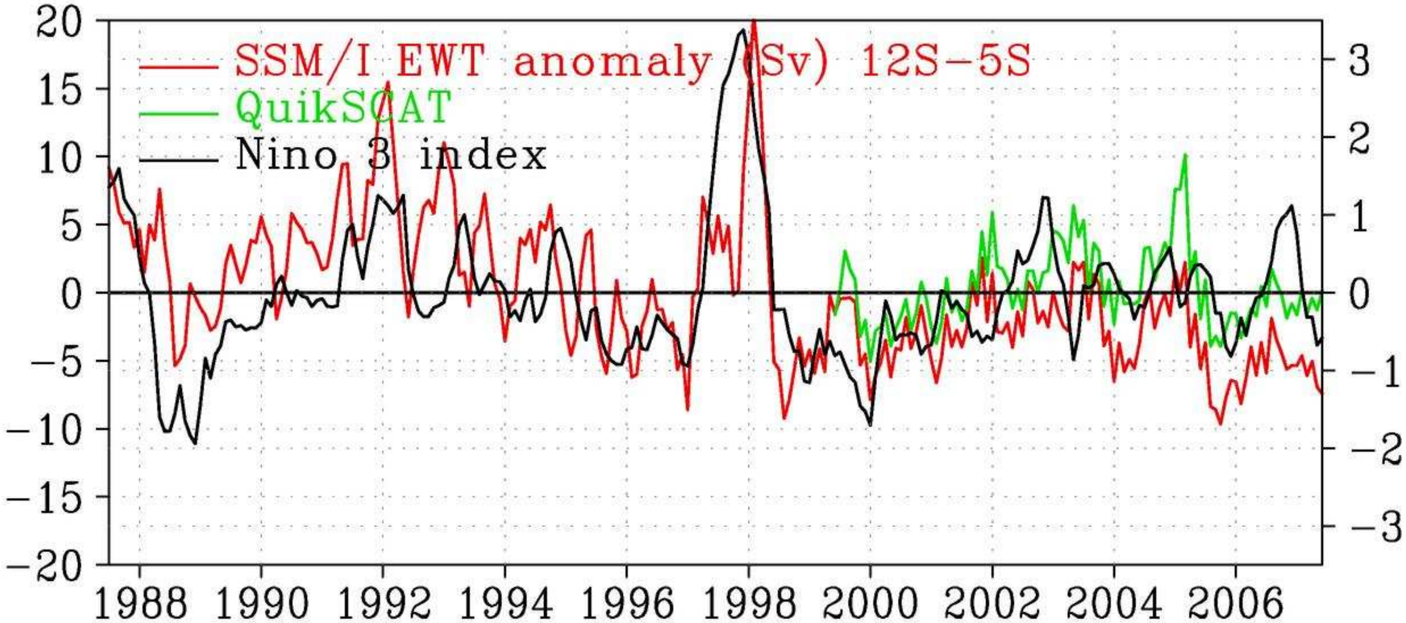


Ekman heat transport anomaly 5N-12N
SSM/I
QuikSCAT

5S-12S



Ekman water transport anomaly 5N-12N
SSM/I
QuikSCAT



5S-12S

Impact of ENSO on Ekman water transport in the equatorial Pacific

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 Water Transport (MWT)

Conservation of water mass

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

By Green's theorem

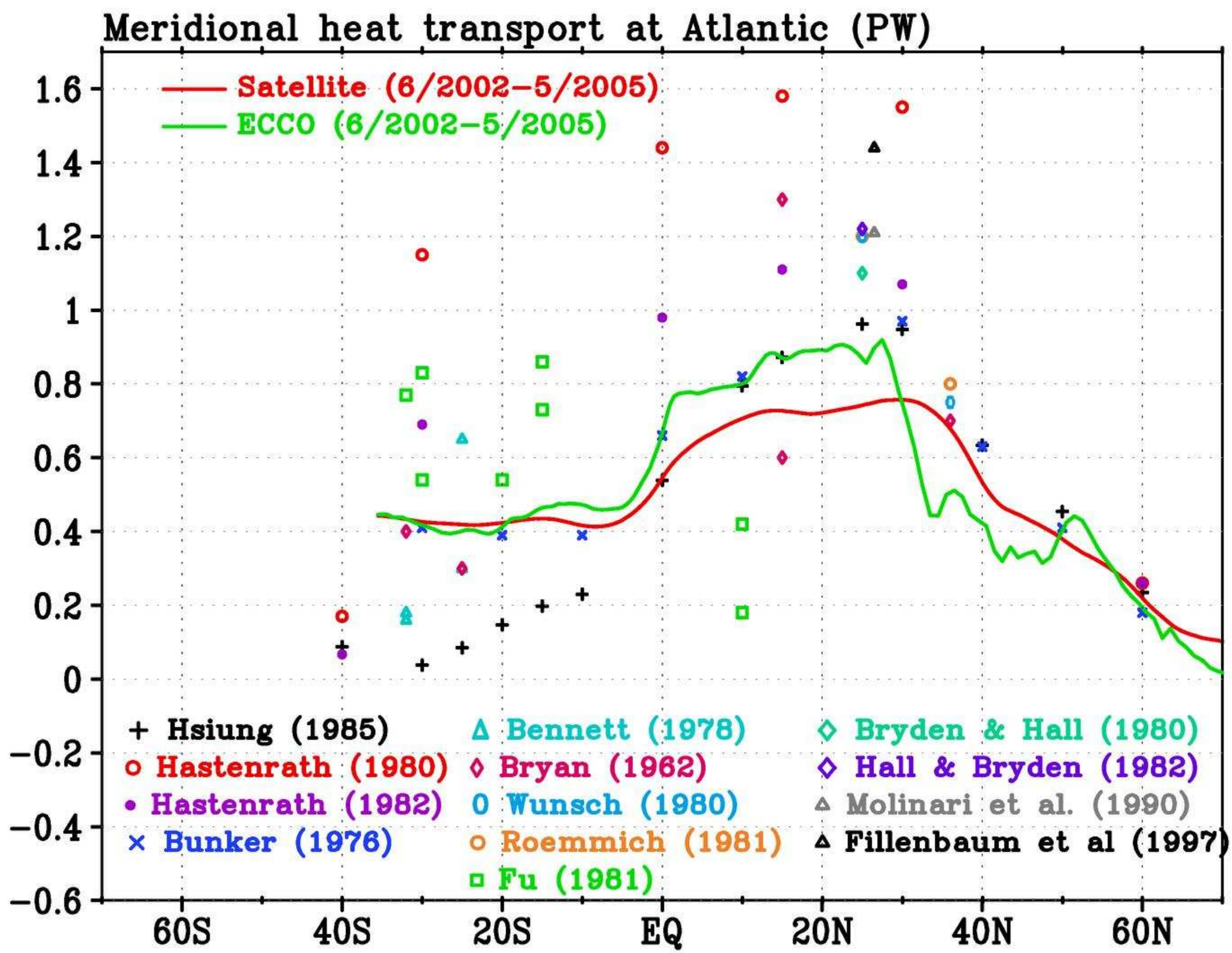
$$MWT(\theta) = \int_{\theta}^{\theta_o} \int_{x_1}^{x_2} (\frac{\partial M}{\partial t} + E - P - R) dxdy$$

P: Precipitation

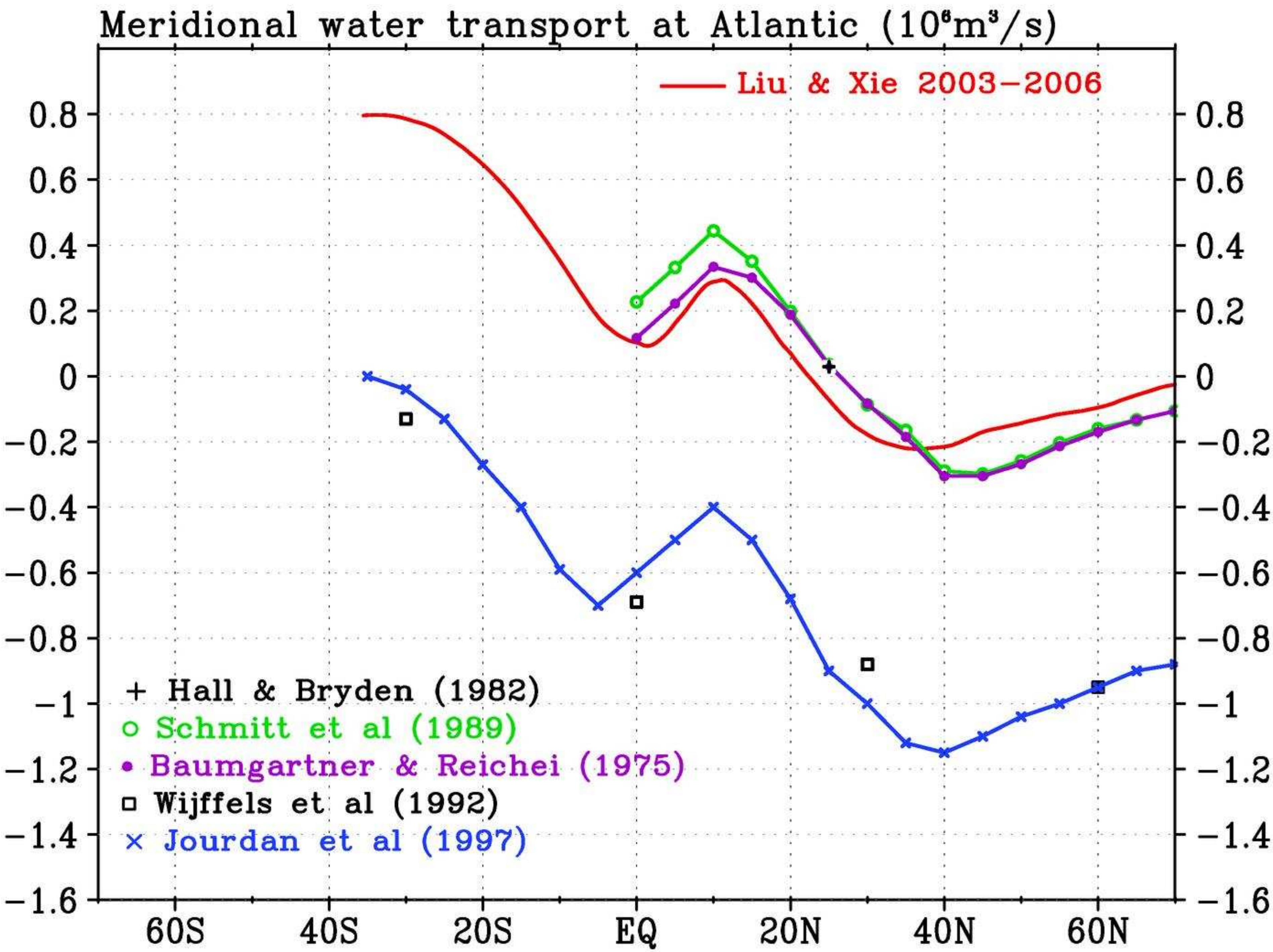
E: Evaporation

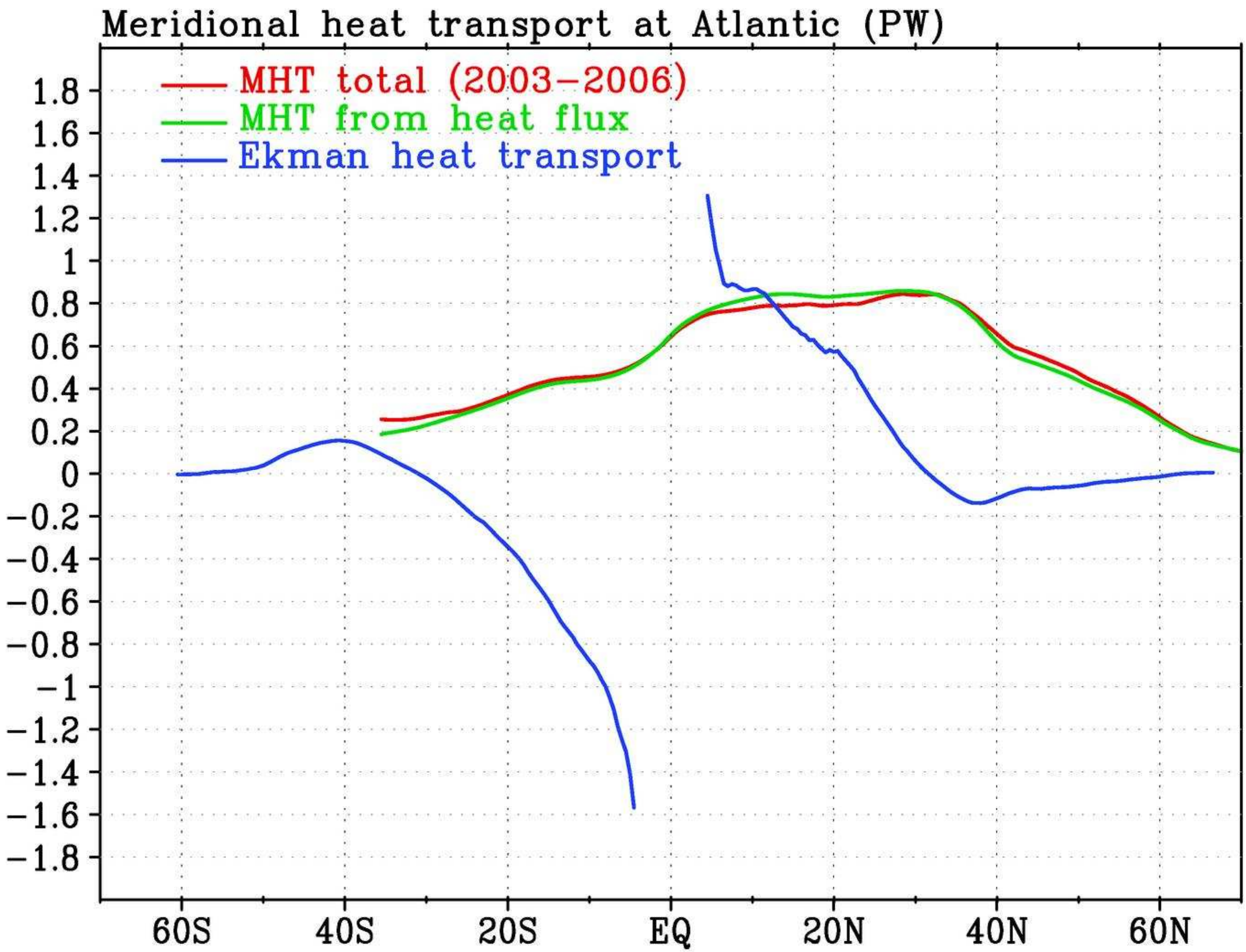
Ψ: Horizontal mass flux

R: River discharge

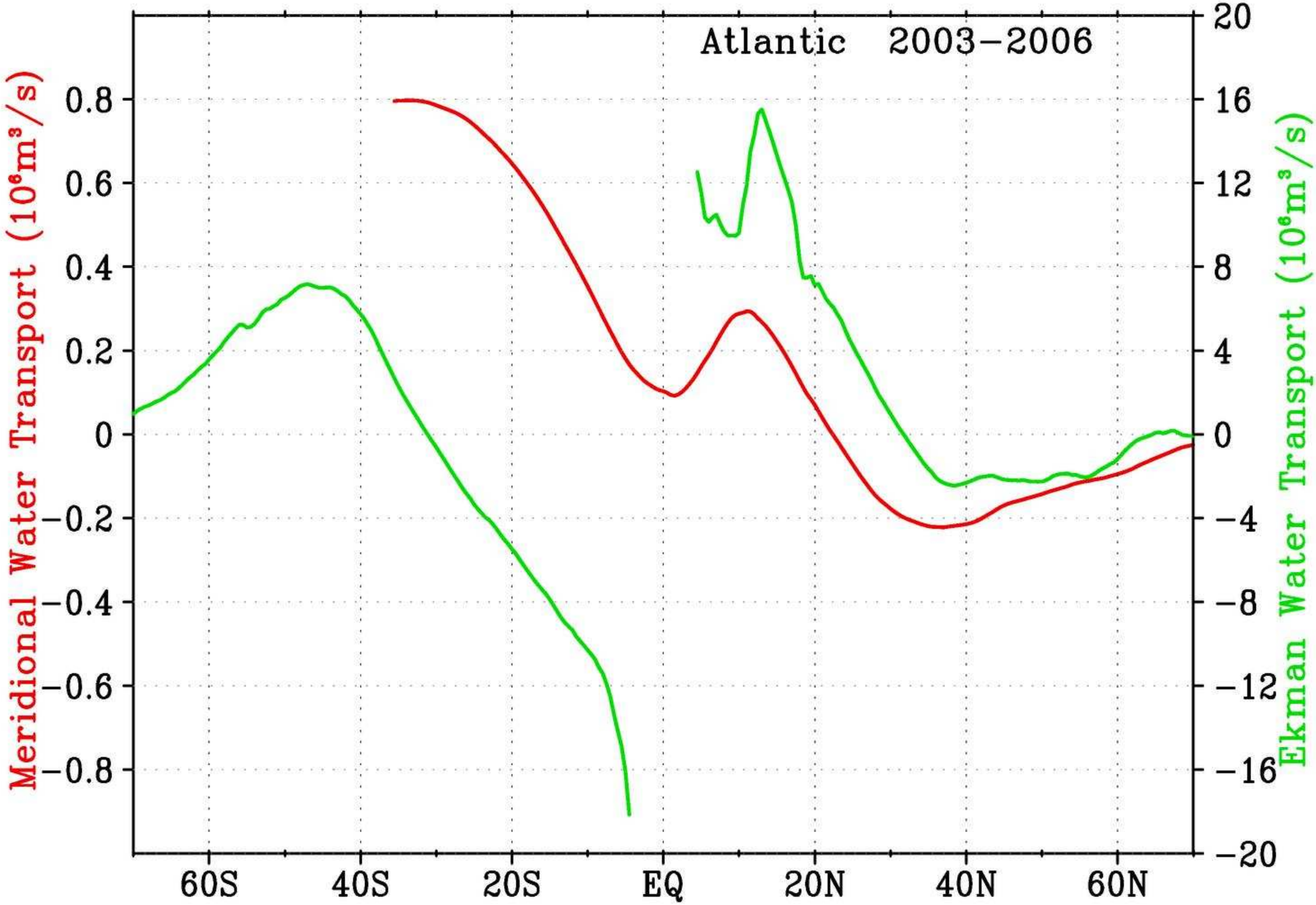


Meridional heat transport at Atlantic (PW)
Satellite (6/2002-5/2005)
ECCO (6/2002-5/2005)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
60S
40S
20S
EQ
20N
40N
60N
Hsiung (1985)
Hastenrath (1980)
Hastenrath (1982)
Bunker (1976)
Bennett (1978)
Bryan (1962)
Wunsch (1980)
Roemmich (1981)
Fu (1981)
Bryden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

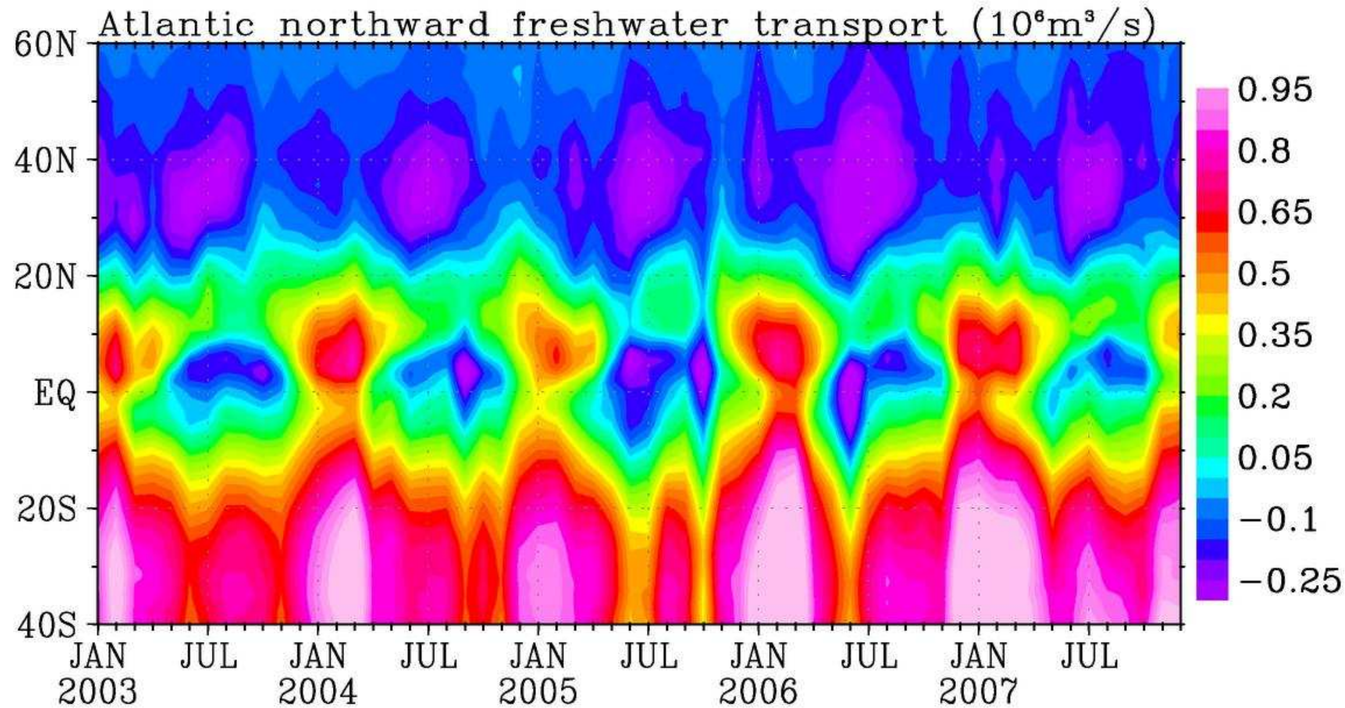

Meridional water transport at Atlantic (10⁶m³/s)
Liu & Xie 2003–2006
+ Hall & Bryden (1982)
○ Schmitt et al (1989)
• Baumgartner & Reichei (1975)
□ Wijffels et al (1992)
× Jourdan et al (1997)
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
−1.6
60S
40S
20S
EQ
20N
40N
60N



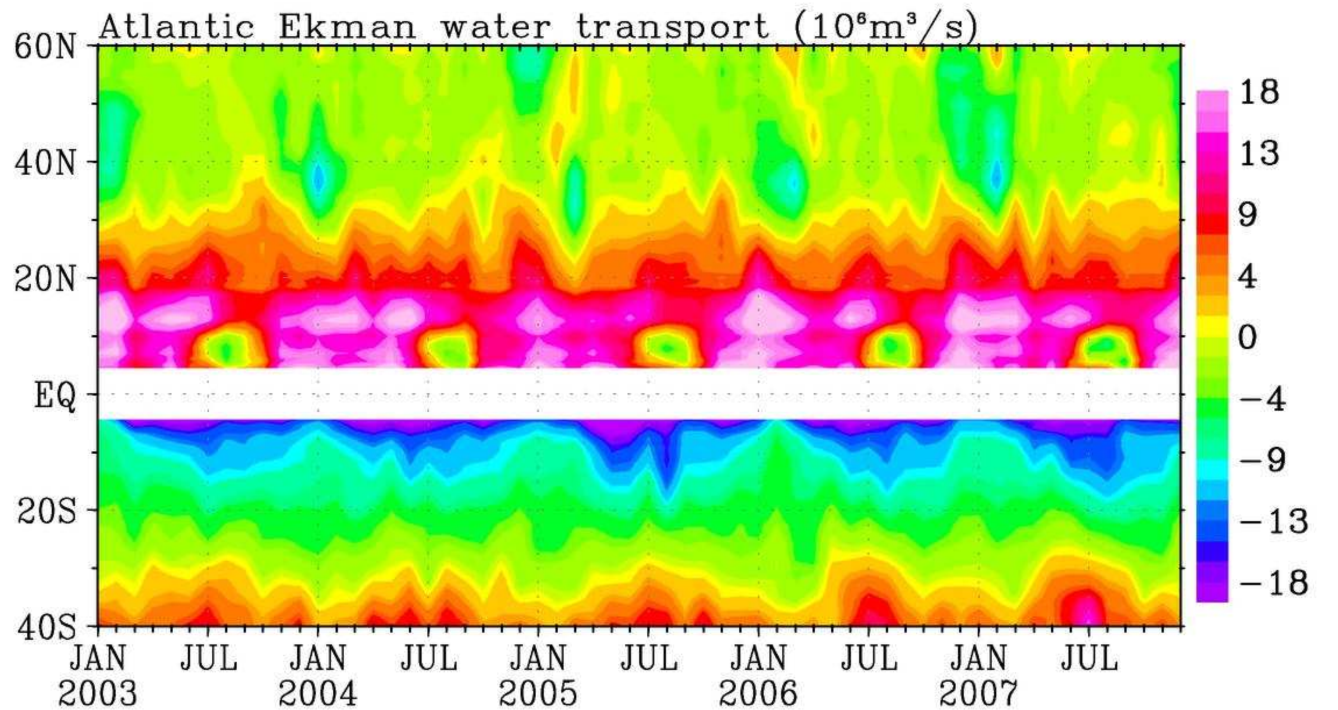
Meridional heat transport at Atlantic (PW)
MHT total (2003-2006)
MHT from heat flux
Ekman heat transport
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
−1.6
−1.8
60S
40S
20S
EQ
20N
40N
60N



Atlantic 2003–2006
Meridional Water Transport ($10^6m^3/s$)
Ekman Water Transport ($10^6m^3/s$)
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
20
16
12
8
4
0
−4
−8
−12
−16
−20
60S
40S
20S
EQ
20N
40N
60N



Atlantic total northward water transport



Atlantic Ekman water transport

Peak poleward transport in winter in the tropics

Summary

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

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

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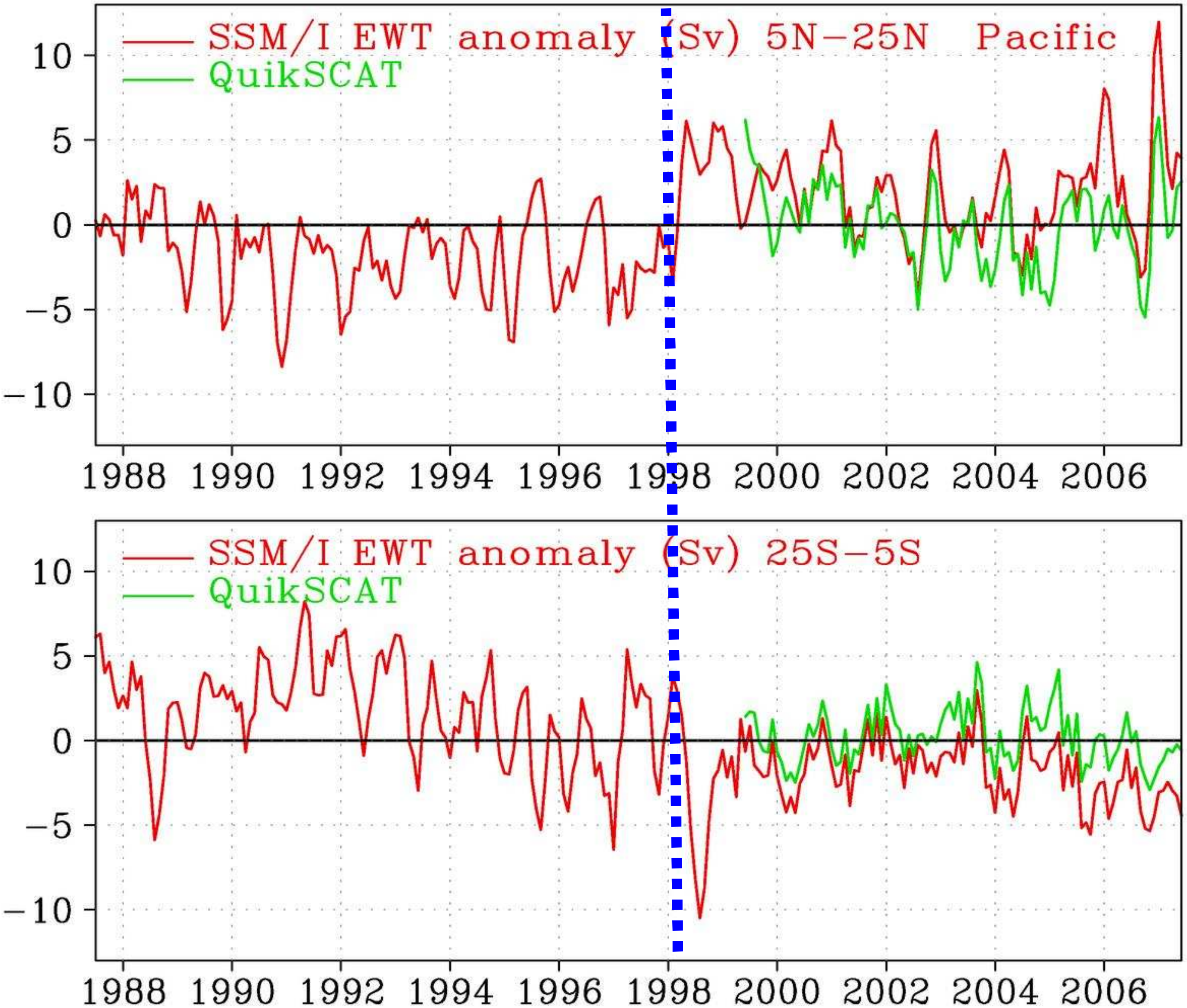
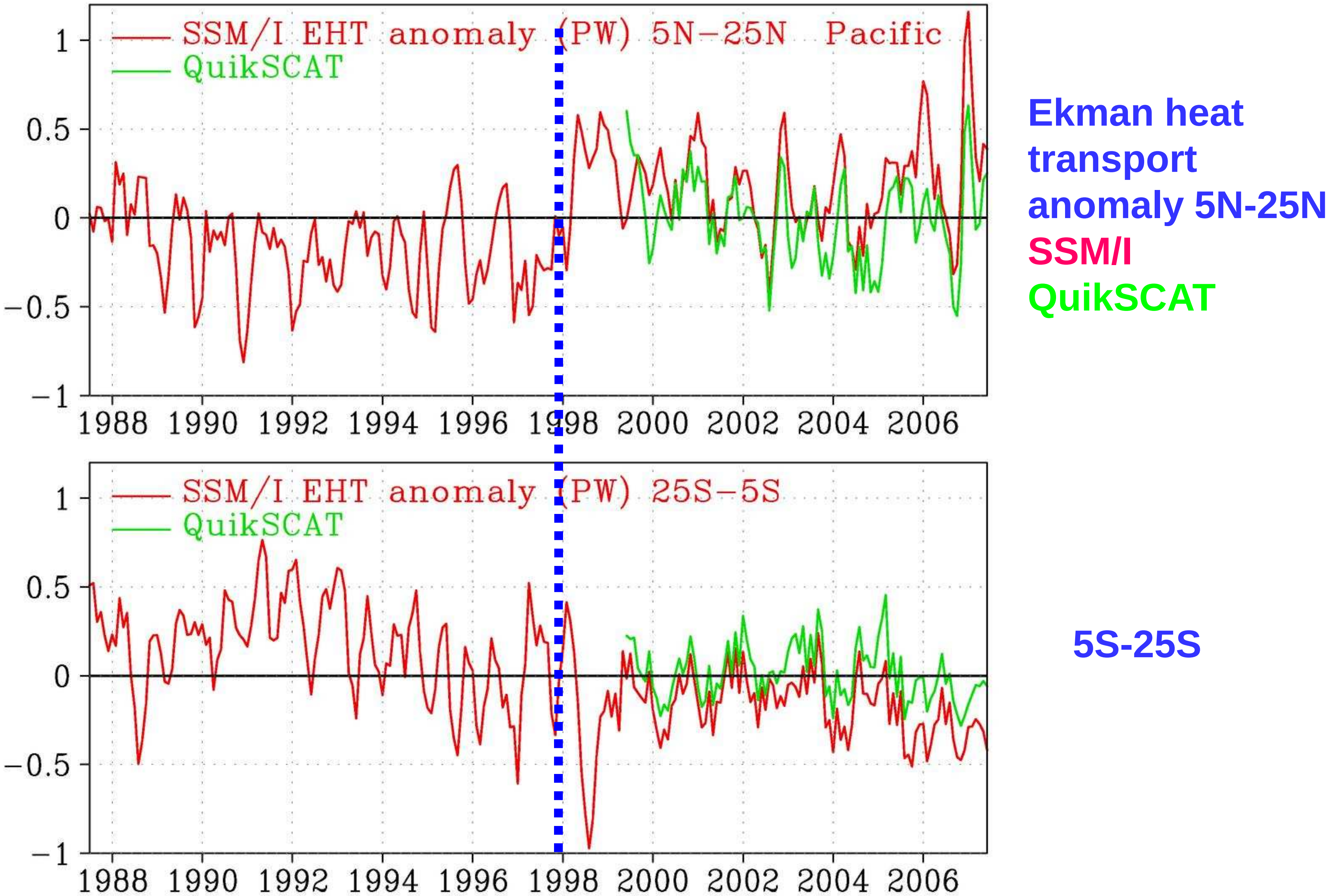


Ekman water transport anomaly 5N-25N
SSM/I
QuikSCAT

5S-25S

Intensification of poleward Ekman water transport from 1998 in the tropical Pacific



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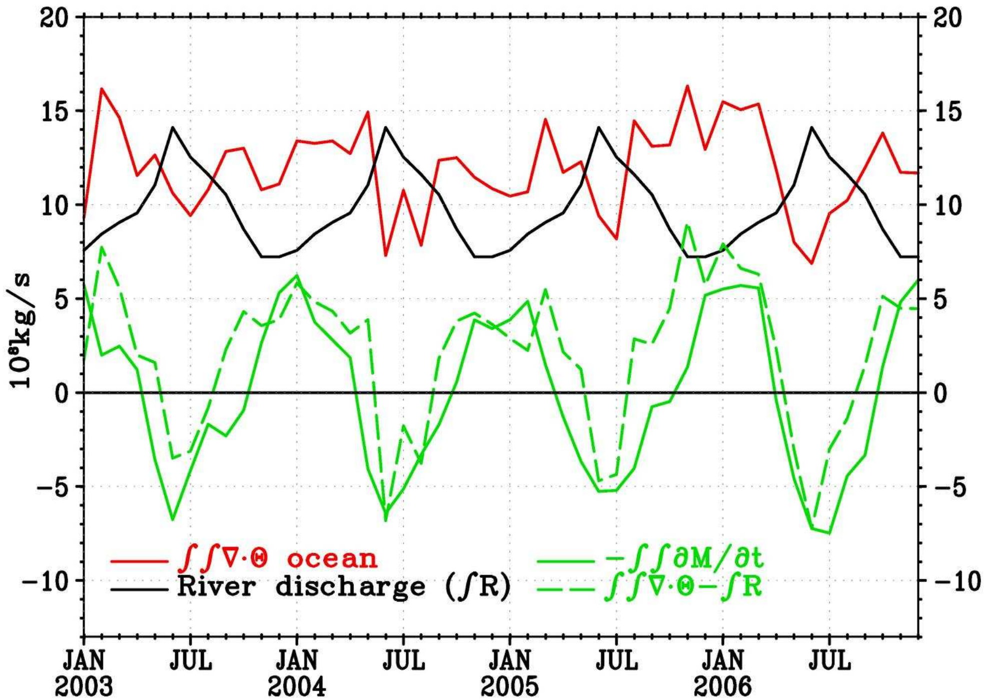
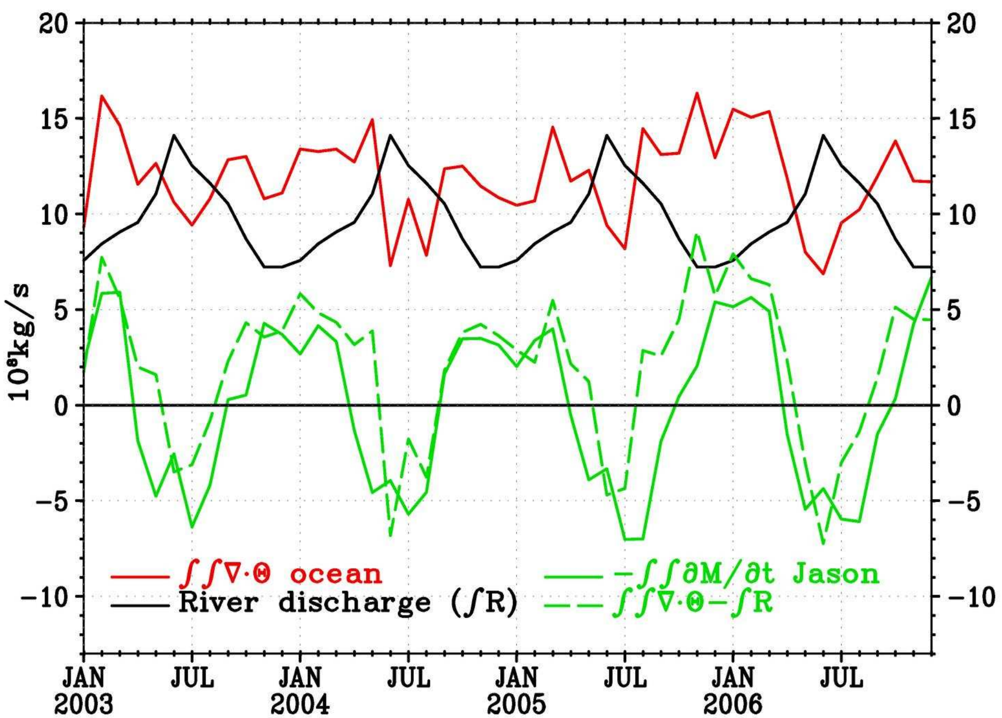


Red - divergence of water vapor transport integrated over depth of the atmosphere

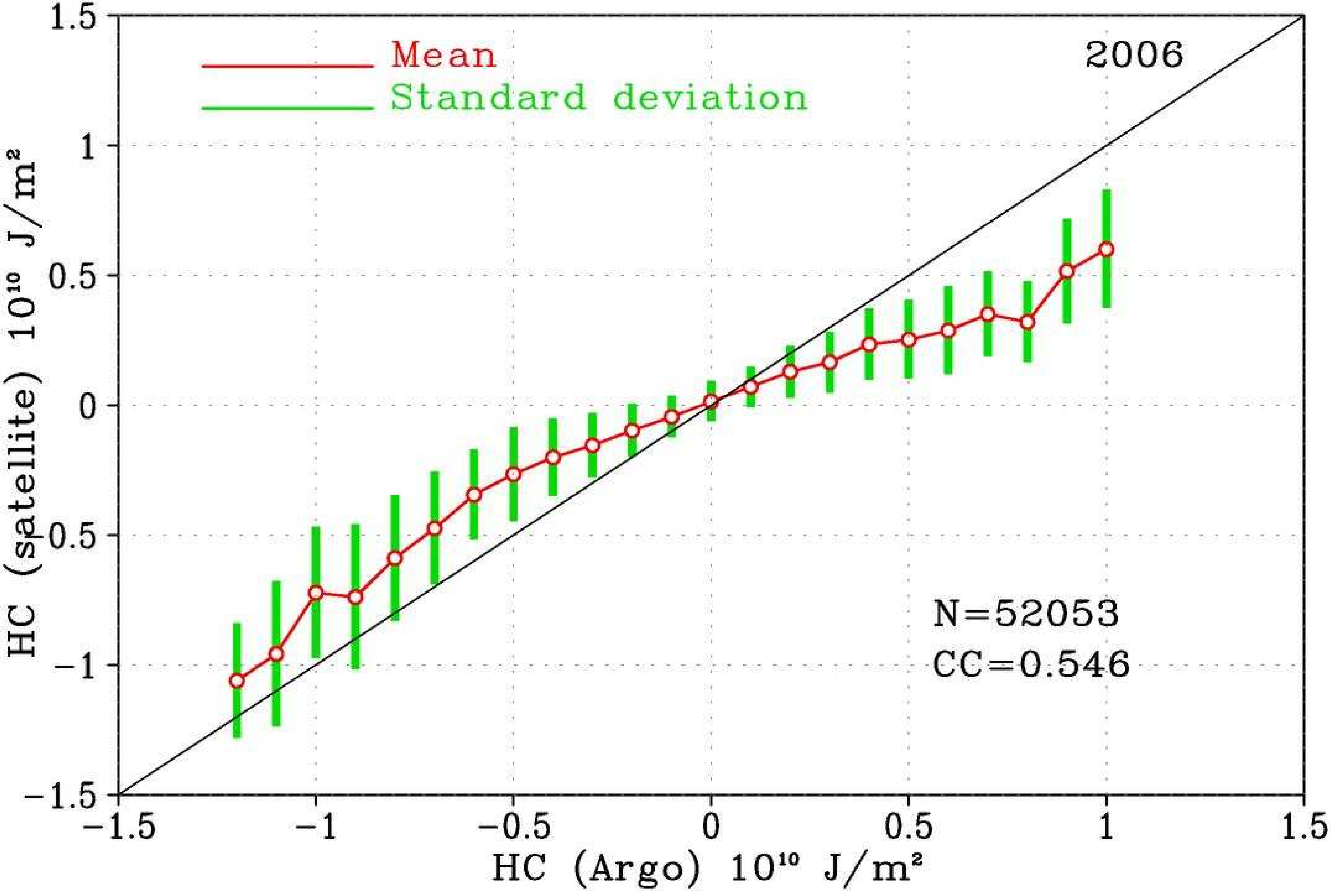
Black - sum of climatological river discharge across all coastline

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


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
−1.5
−1
−0.5
0
0.5
1
1.5

HYDROLOGIC BALANCE

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

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

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

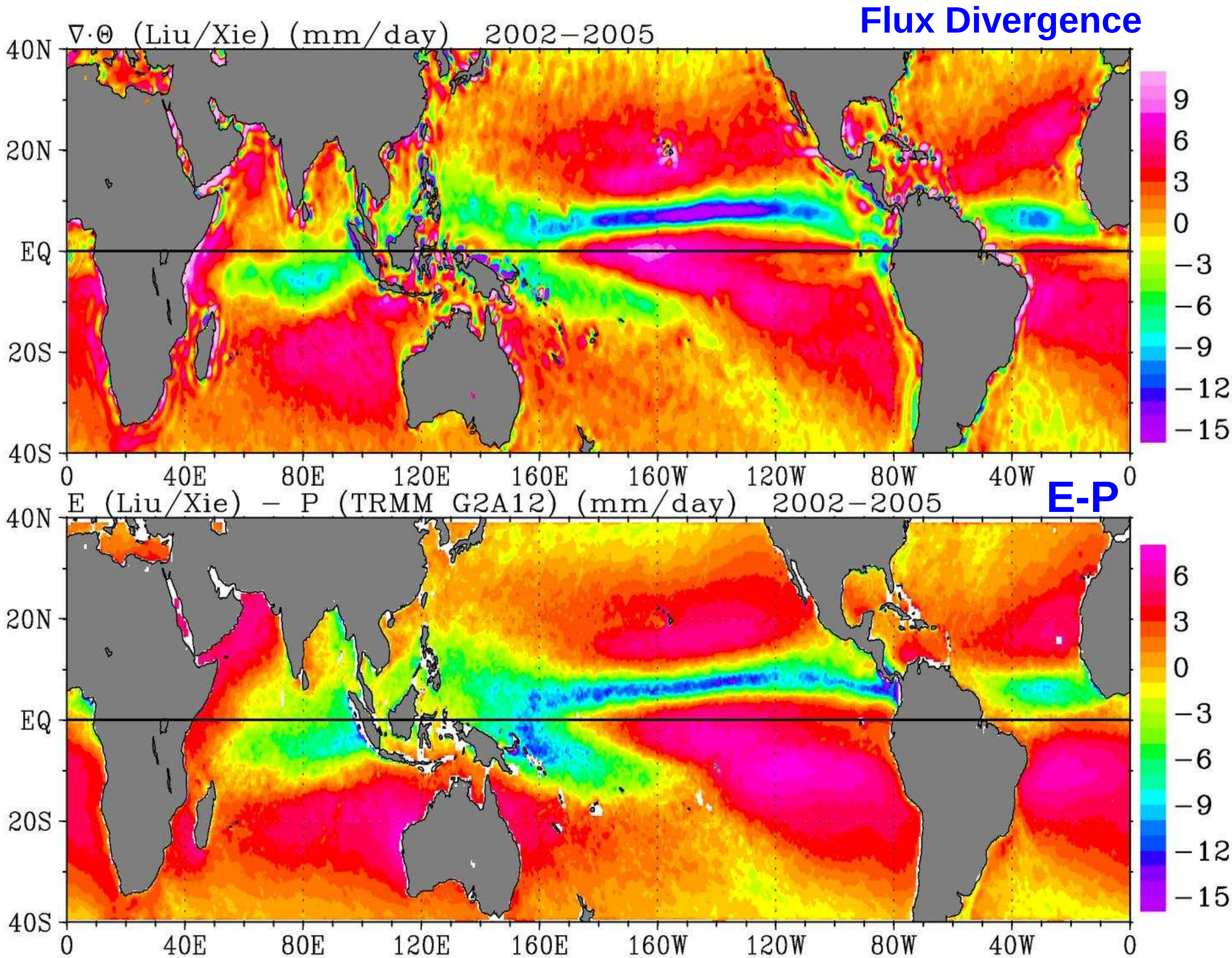
$$\Theta = \mathbf{Ue}\ W$$

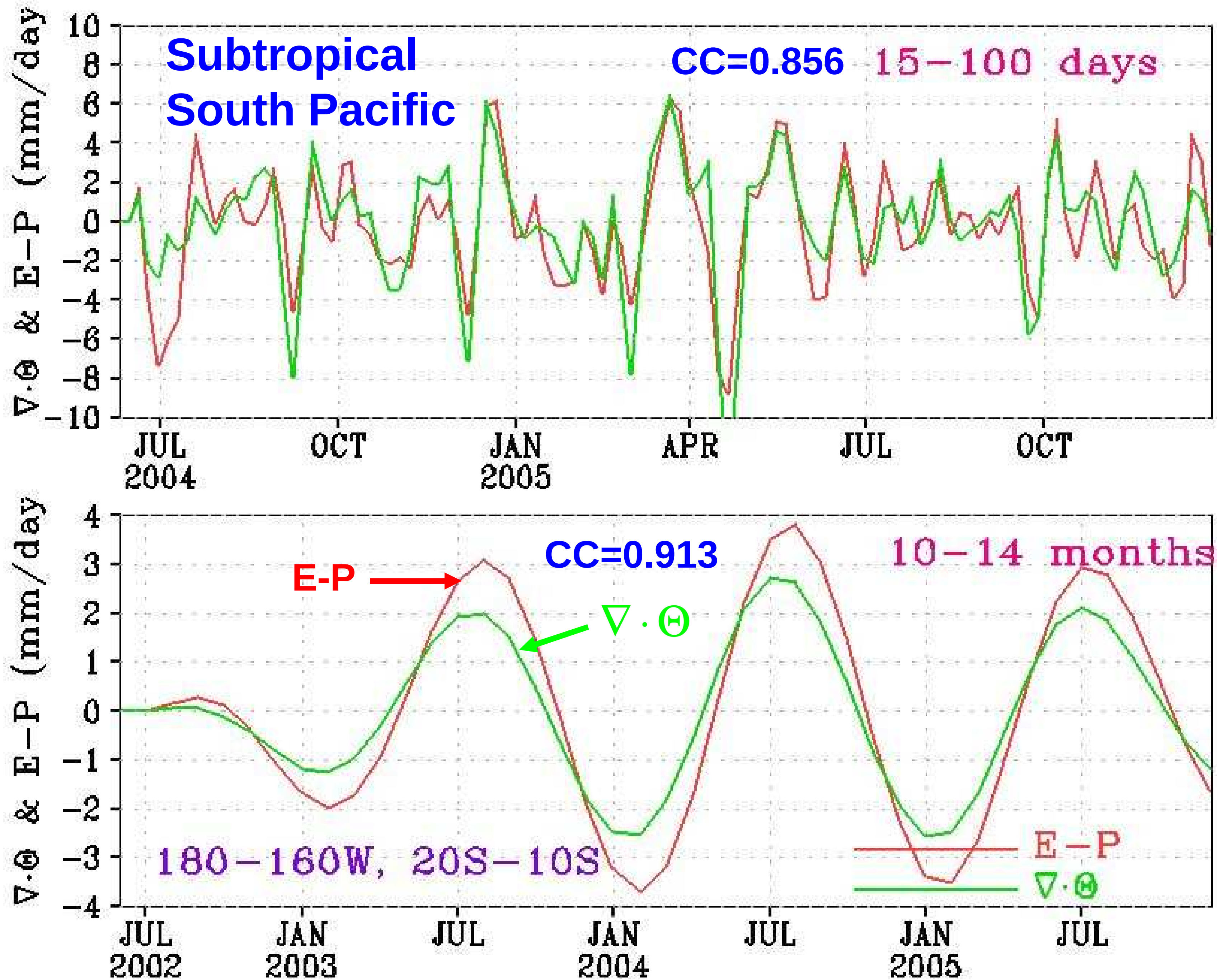
Ue=f(Us) **Liu (1993)-polynomial**

Liu & Tang (2005) - Neural Network

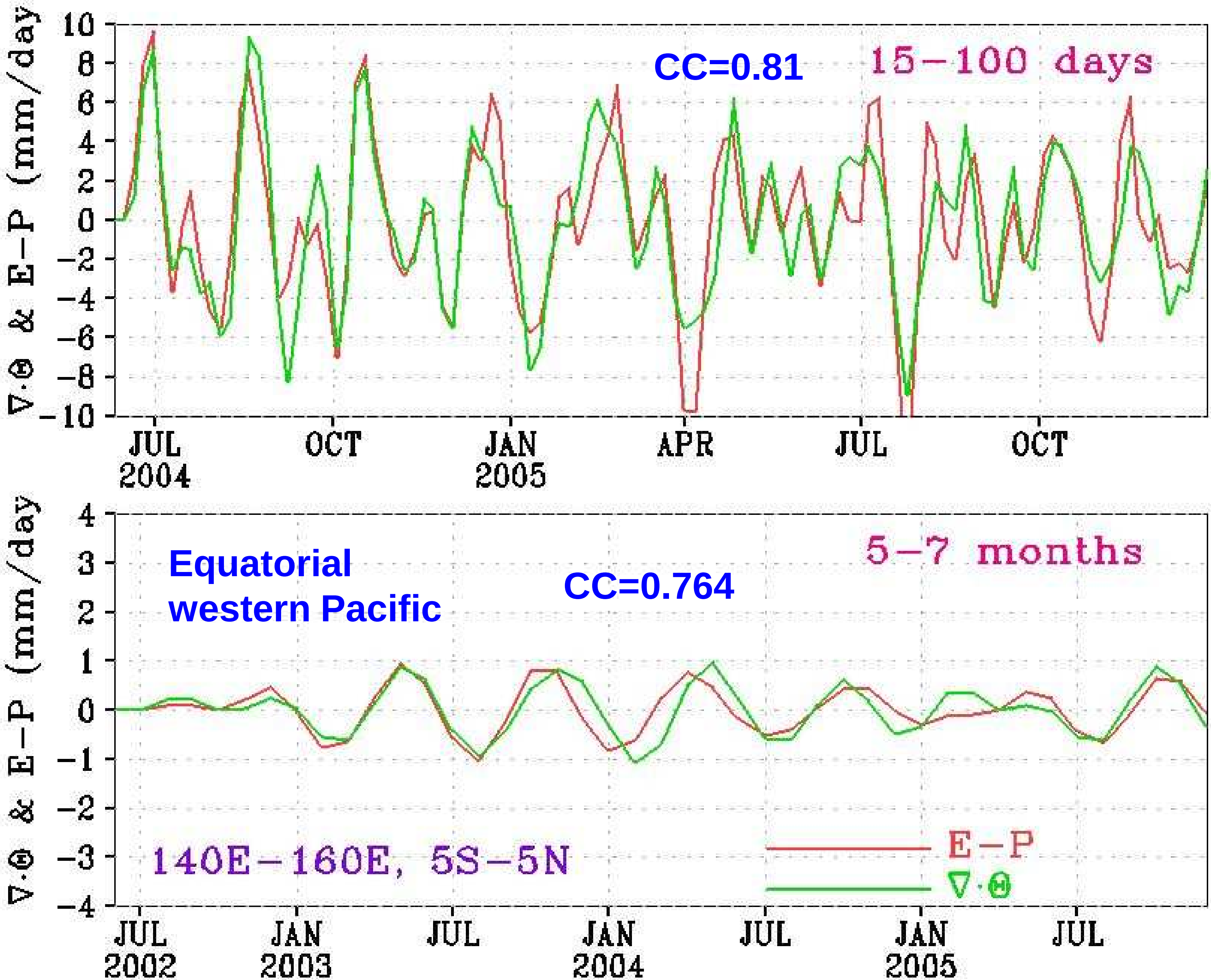
Ue = U_{850mb} **Heta & Mitsuta (1993)**

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-P
E (Liu/Xie) − P (TRMM G2A12) (mm/day) 2002–2005
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)
JUL
2004
OCT
JAN
2005
APR
JUL
OCT
E-P
CC=0.913
10−14 months
∇ · Θ
180−160W, 20S−10S
E−P
∇·Θ
JUL
2002
JAN
2003
JUL
JAN
2004
JUL
JAN
2005
JUL



CC=0.81
15−100 days
∇·Θ & E−P (mm/day)
JUL 2004
OCT
JAN 2005
APR
JUL
OCT
Equatorial western Pacific
CC=0.764
5−7 months
140E−160E, 5S−5N
E−P
∇·Θ
JUL 2002
JAN 2003
JUL
JAN 2004
JUL
JAN 2005
JUL