Ocean-atmosphere Fresh Water Flux in Global Hydrological Balance

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- Two Way to Estimate
- Validation with Rawinsonde
- Atmospheric Water Balance
- Ocean Mass Balance
- Continental Mass Balance
- Sea Level Balance
- Salinity Balance
- Meridional Transport

Importance of Water Cycle

- Critical to existence of human life
- Essential to weather and climate
- Tightly coupled with energy cycle
- Heat storage with high heat capacity and latent heat form clouds and affect radiative balance

HYDROLOGIC BALANCE

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

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

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

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

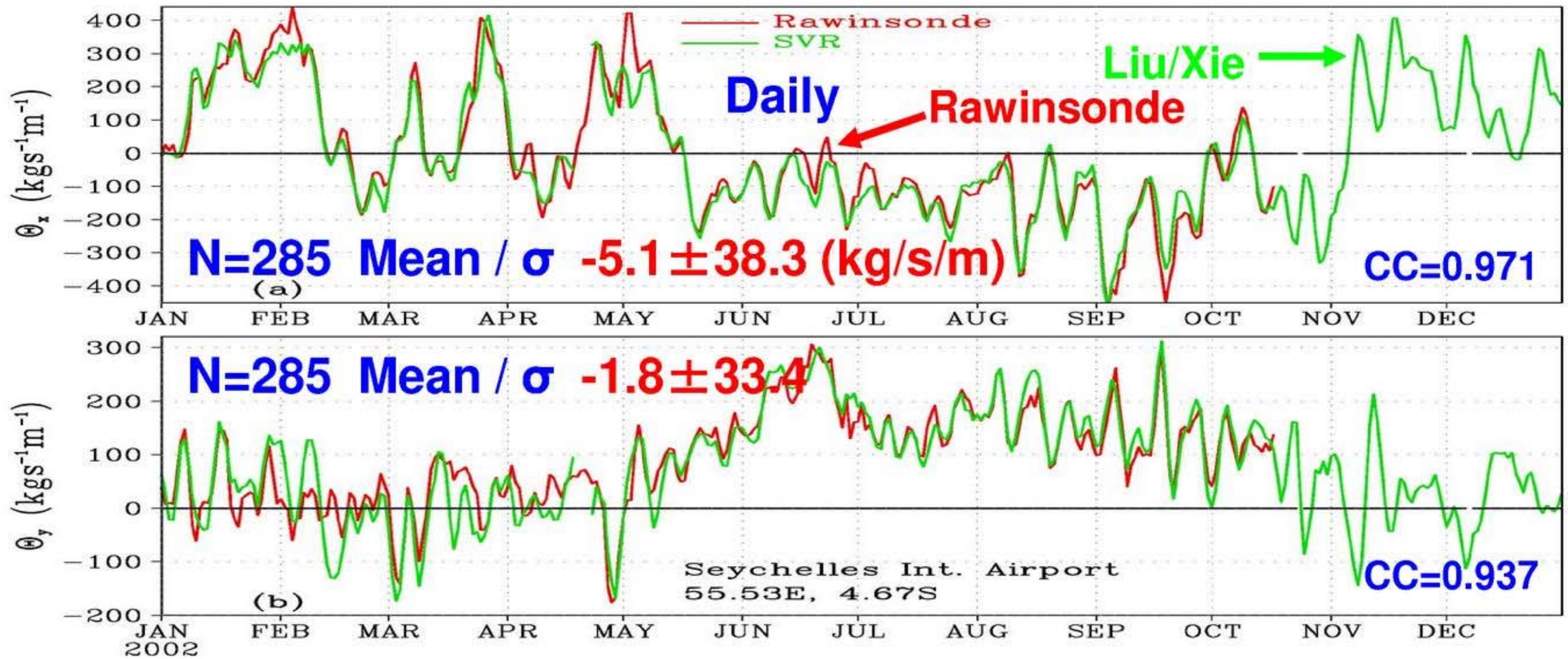
Θ is equivalent to column water vapor W advected by Ue.
Ue is the depth-averaged wind weighted by humidity
We use SVR to relate Ue to wind at two levels:
1. U_N: scatterometer surface wind stress
2. U_{850mb}: cloud drift wind (free-stream wind)

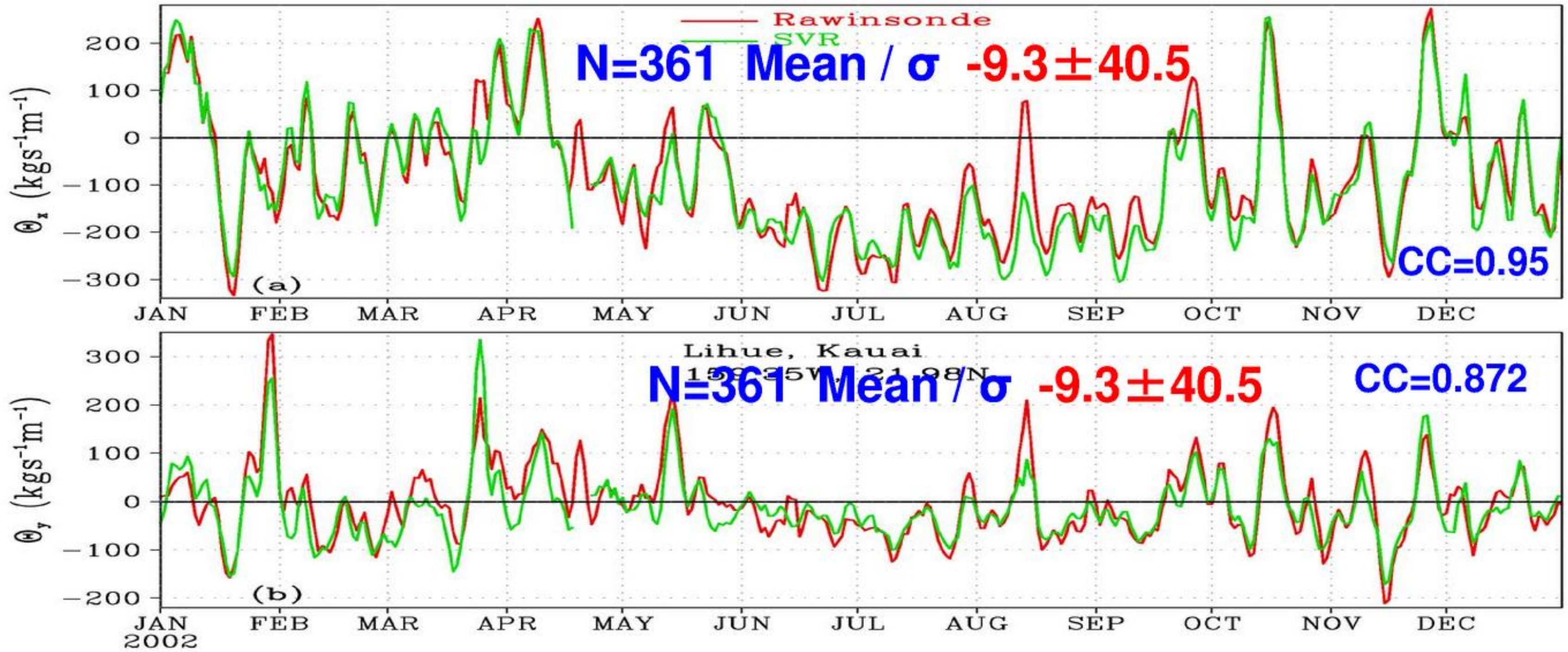
Two ways of estimating air-sea water flux- can they be reconciled?

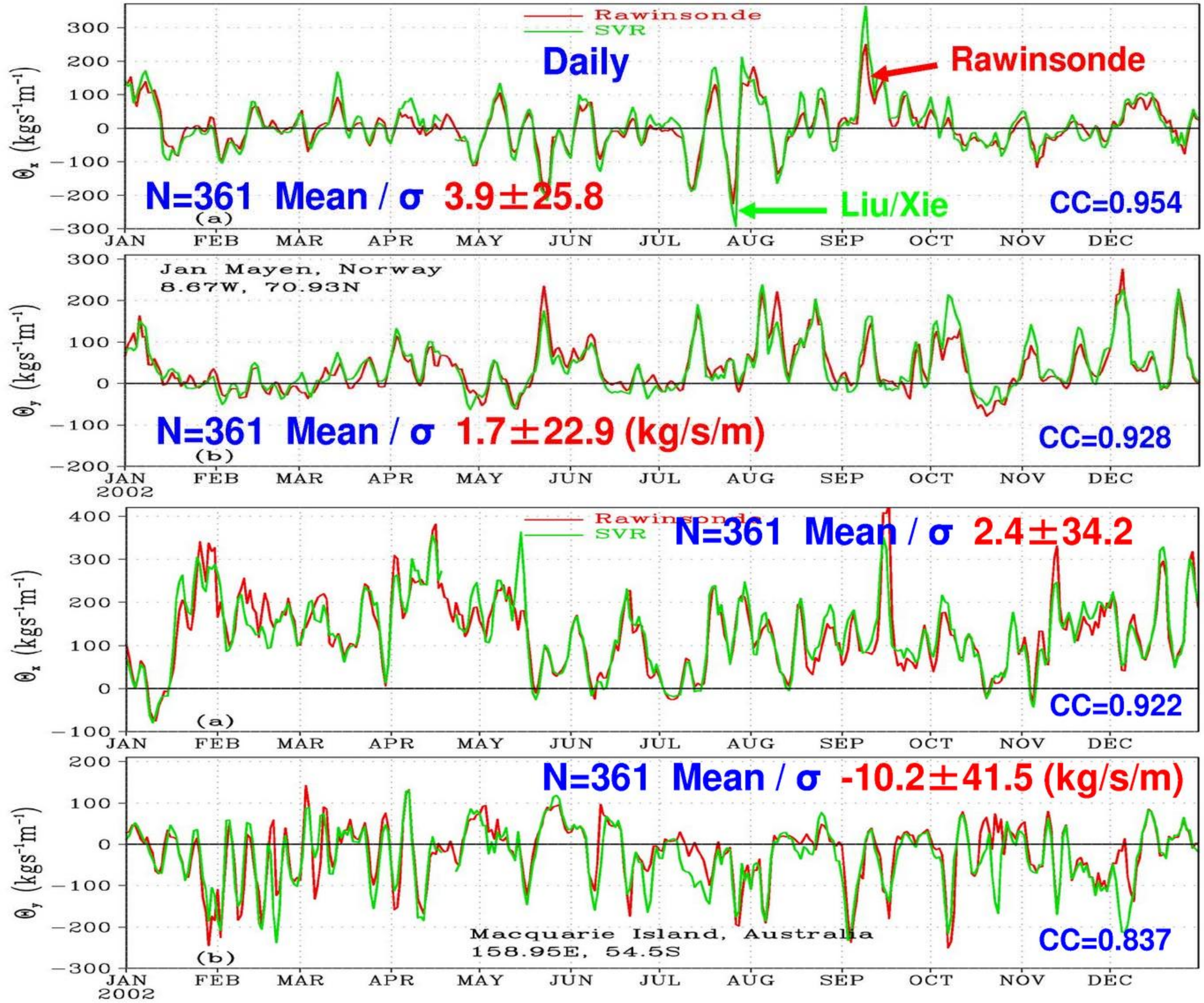
- Evaporation is transported by turbulence. At small scale of turbulence, factors of atmospheric circulations, such as, Coriolis force, pressure gradient force, baroclincity, cloud entrainment, are not important

- All these factors are important in the divergence of moisture transport integrated through atmos. depth

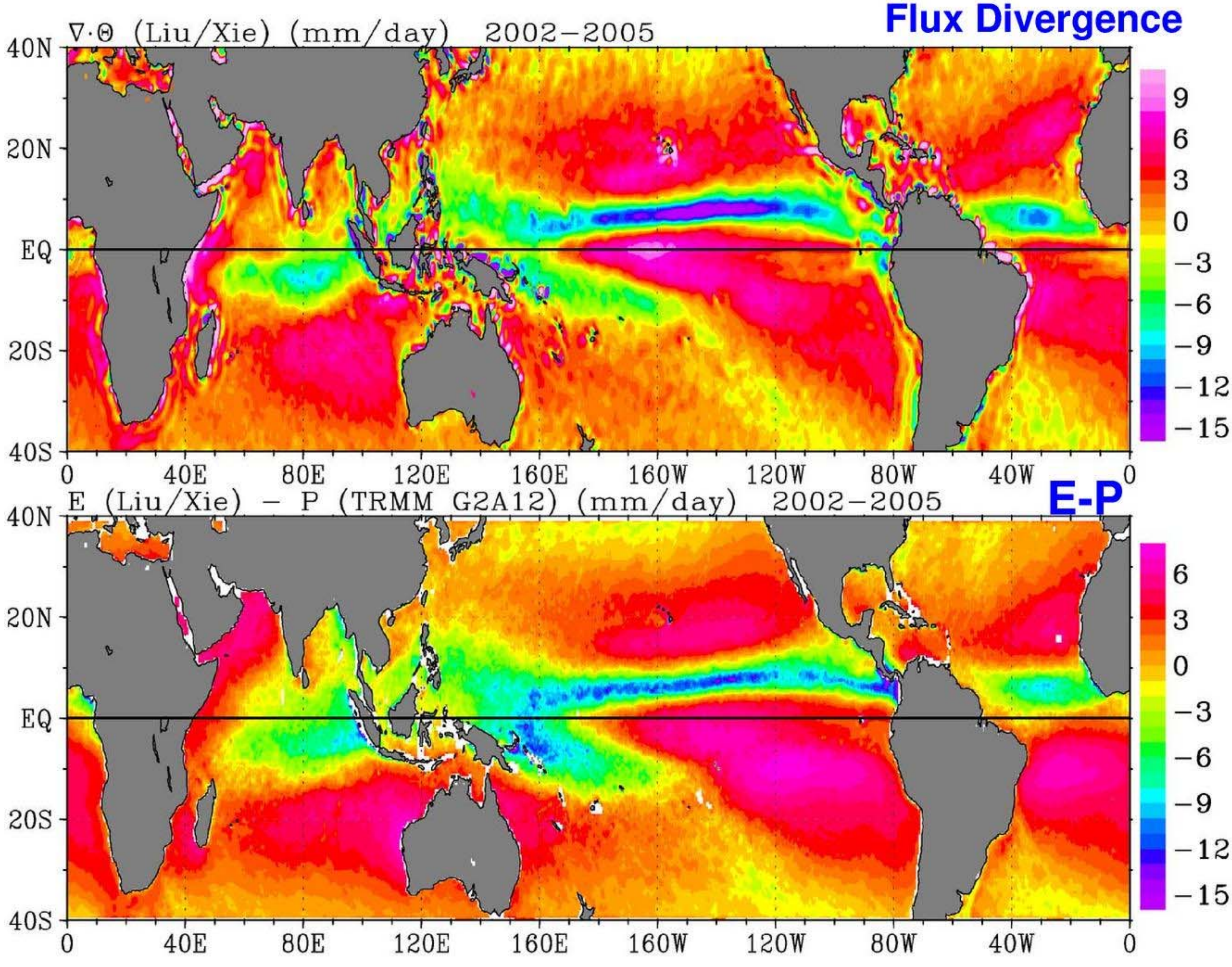
- Bulk parameterization was first used as a zero order approximation of what we wanted from what we had, bulk measuements. We hided our ignorance or incapability in the coefficient and we need to understand its limit


Rawinsonde
SVR
Liu/Xie
Daily
Rawinsonde
N=285 Mean / σ -5.1±38.3 (kg/s/m)
CC=0.971
(a)
N=285 Mean / σ -1.8±33.4
Seychelles Int. Airport
55.53E, 4.67S
CC=0.937
(b)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2002

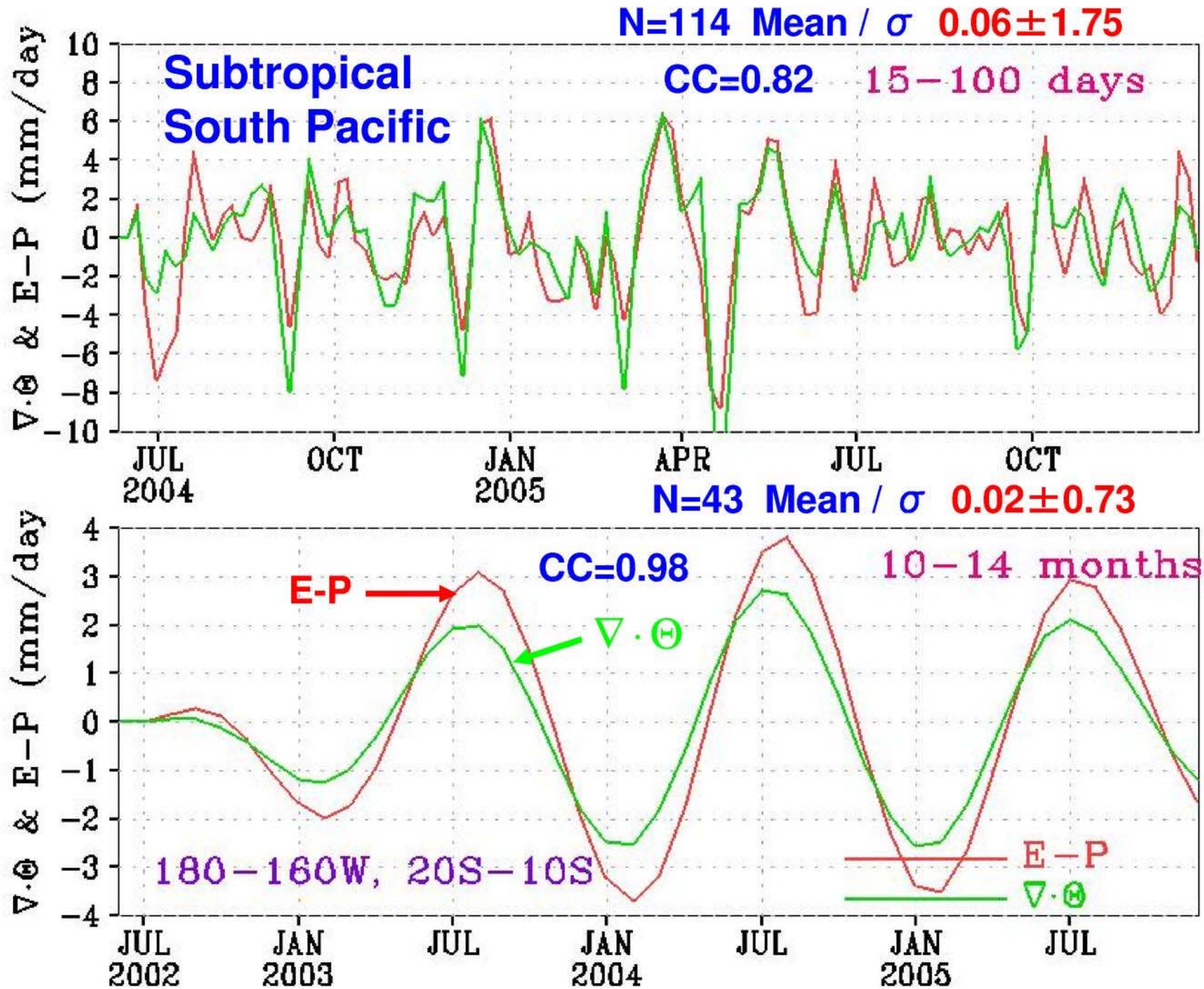

Rawinsonde
SVR
N=361 Mean / σ -9.3±40.5
CC=0.95
(a)
Lihue, Kauai
N=361 Mean / σ -9.3±40.5
CC=0.872
(b)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2002



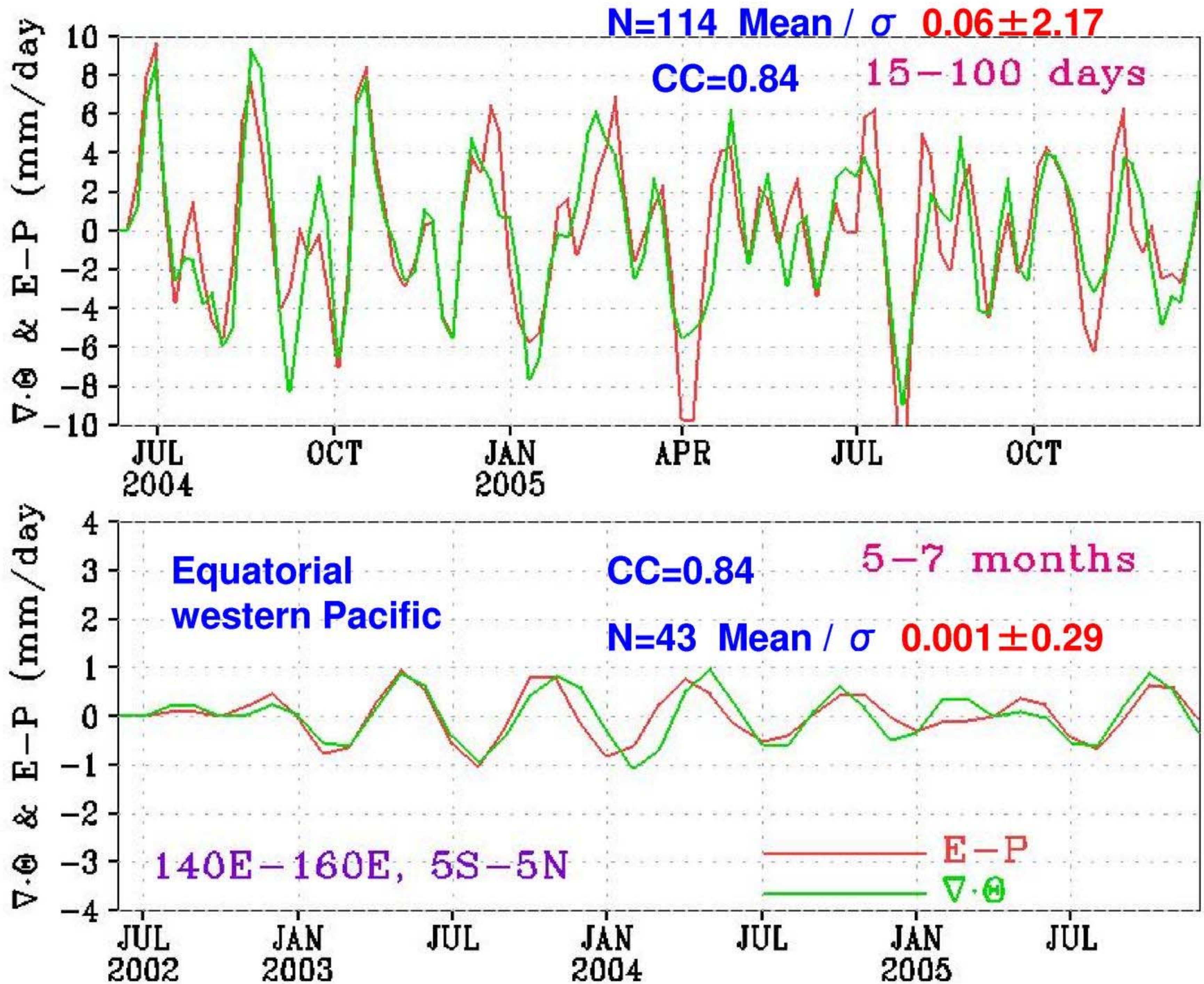
Rawinsonde
SVR
Daily
Rawinsonde
N=361 Mean / σ 3.9±25.8
Liu/Xie
CC=0.954
(a)
Jan Mayen, Norway
8.67W, 70.93N
N=361 Mean / σ 1.7±22.9 (kg/s/m)
CC=0.928
(b)
2002
Rawinsonde
SVR
N=361 Mean / σ 2.4±34.2
CC=0.922
(a)
N=361 Mean / σ -10.2±41.5 (kg/s/m)
Macquarie Island, Australia
158.95E, 54.5S
CC=0.837
(b)
2002



N=82589 Mean / standard deviation -0.06±0.81 (mm/day)

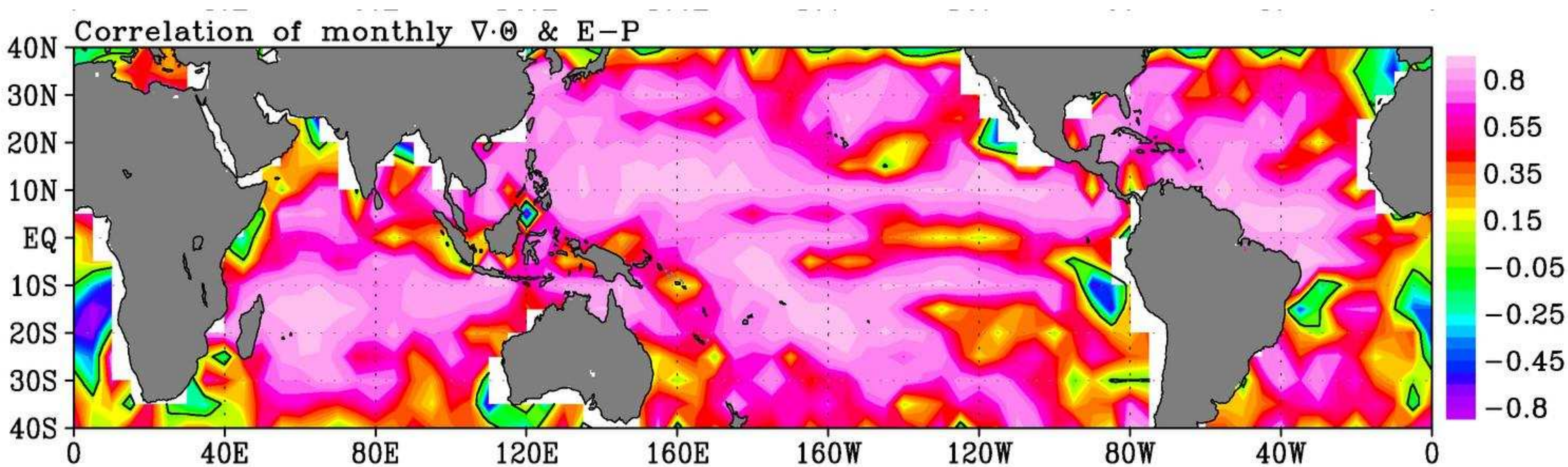


N=114 Mean / σ 0.06±1.75
Subtropical
South Pacific
CC=0.82
15-100 days
∇·Θ & E-P (mm/day)
JUL 2004
OCT
JAN 2005
APR
JUL
OCT
N=43 Mean / σ 0.02±0.73
CC=0.98
10-14 months
E-P
∇·Θ
180-160W, 20S-10S
E-P
∇·Θ
JUL 2002
JAN 2003
JUL
JAN 2004
JUL
JAN 2005
JUL

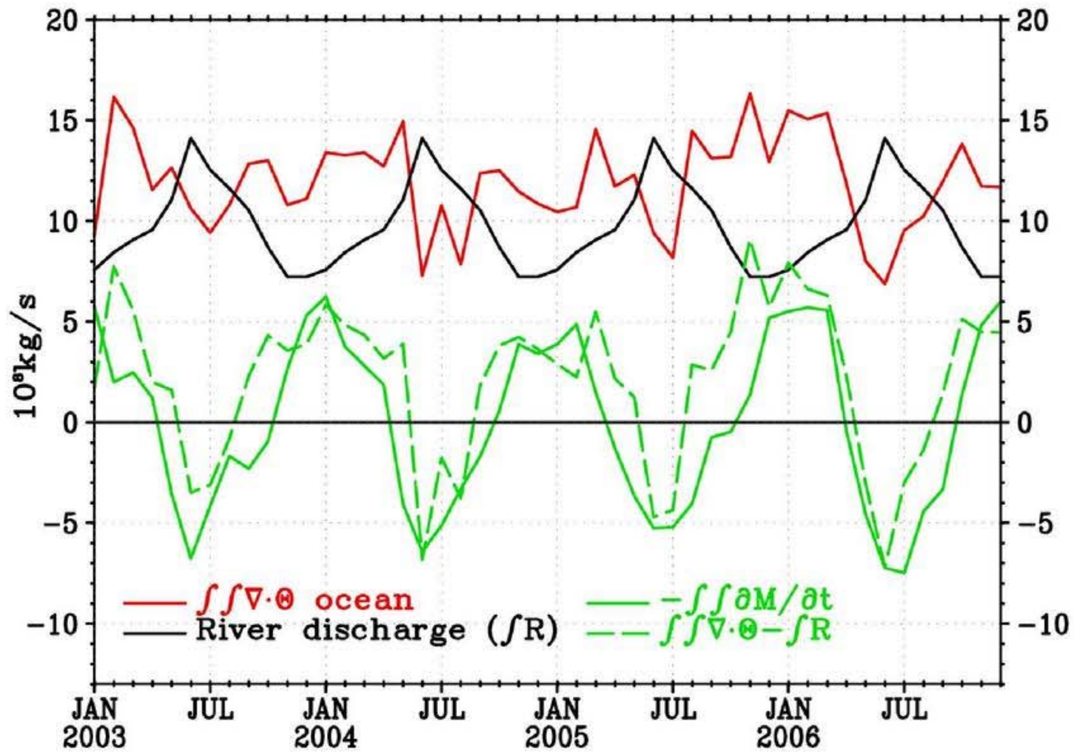


N=114 Mean / σ 0.06±2.17
CC=0.84
15−100 days
∇·Θ & E−P (mm/day)
JUL 2004
OCT
JAN 2005
APR
JUL
OCT
Equatorial western Pacific
CC=0.84
5−7 months
N=43 Mean / σ 0.001±0.29
140E−160E, 5S−5N
E−P
∇·Θ
JUL 2002
JAN 2003
JUL
JAN 2004
JUL
JAN 2005
JUL

Correlation of $\nabla \cdot \Theta$ and E-P



Global Ocean Water Balance



Mean / standard deviation

2.14±2.62 (10^8kg/s) 20%

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

GRACE Dai/Trenberth Liu/Xie

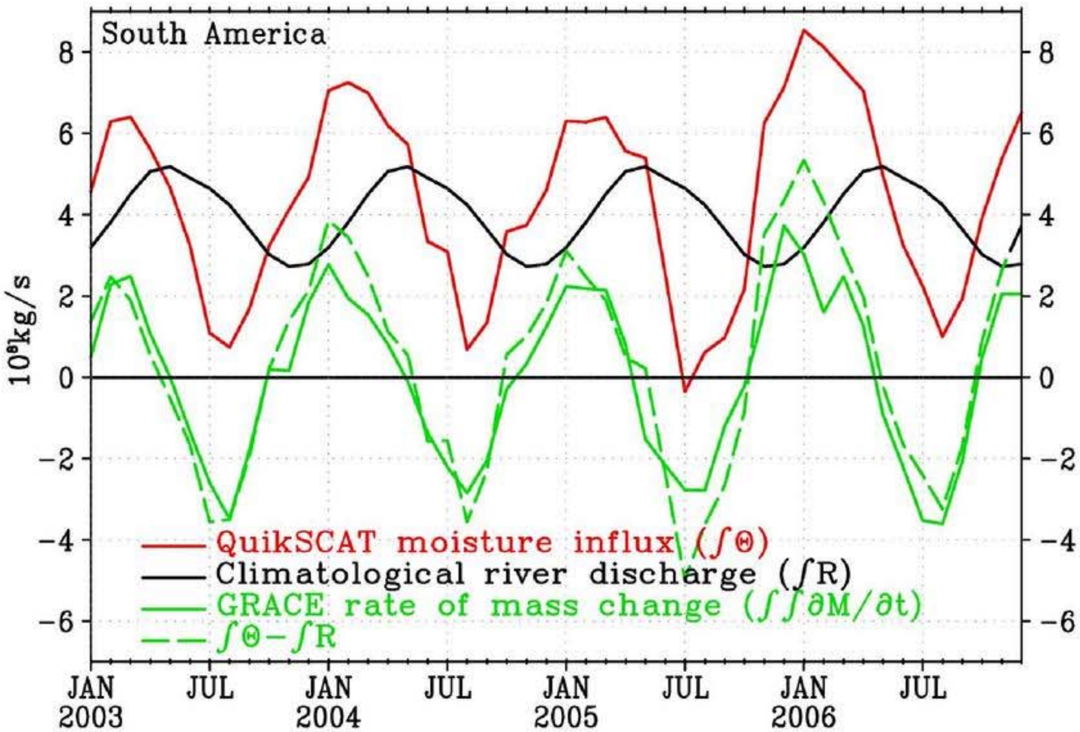
$$\iint (E-P) = \int \Theta = \iint \nabla \cdot \Theta$$

Four-year means in cm/yr

div of water transport

Liu (2010)	10.6
Hilburn	21.9
E-P	
Merra (2008)	10.6
NEWS	10
Budyko (1974)	12
River discharge	
Dai (2002)	8.6

Water Balance over South America



Mean / standard deviation

0.36±0.93 (10^8kg/s) 13%

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

GRACE **Liu/Xie** **Dai/Trenberth**

$$\iint (P-E) = \int \Theta$$

Four-year means in cm/yr

Moisture into continent

Liu	76.1
Hilburn	154.5

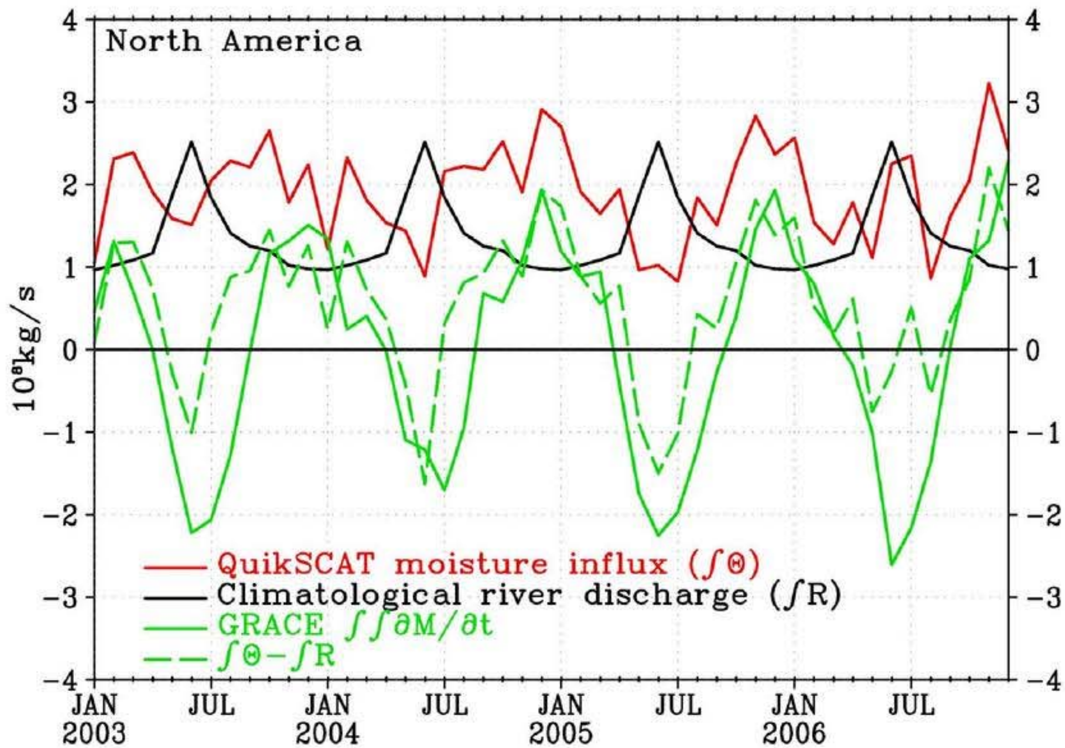
P-E

NEWS	61.3
Budyko (1974)	73

River discharge

Dai (2002)	69.2

Water Balance over North America



Mean / standard deviation

1.92 ± 1.31 (10^8kg/s) 17%

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

GRACE **Liu/Xie** **Dai/Trenberth**

$$\iint (P-E) = \int \Theta$$

Four-year Means in cm/yr

Moisture into continent

Liu 28.9

Hilburn -5.9

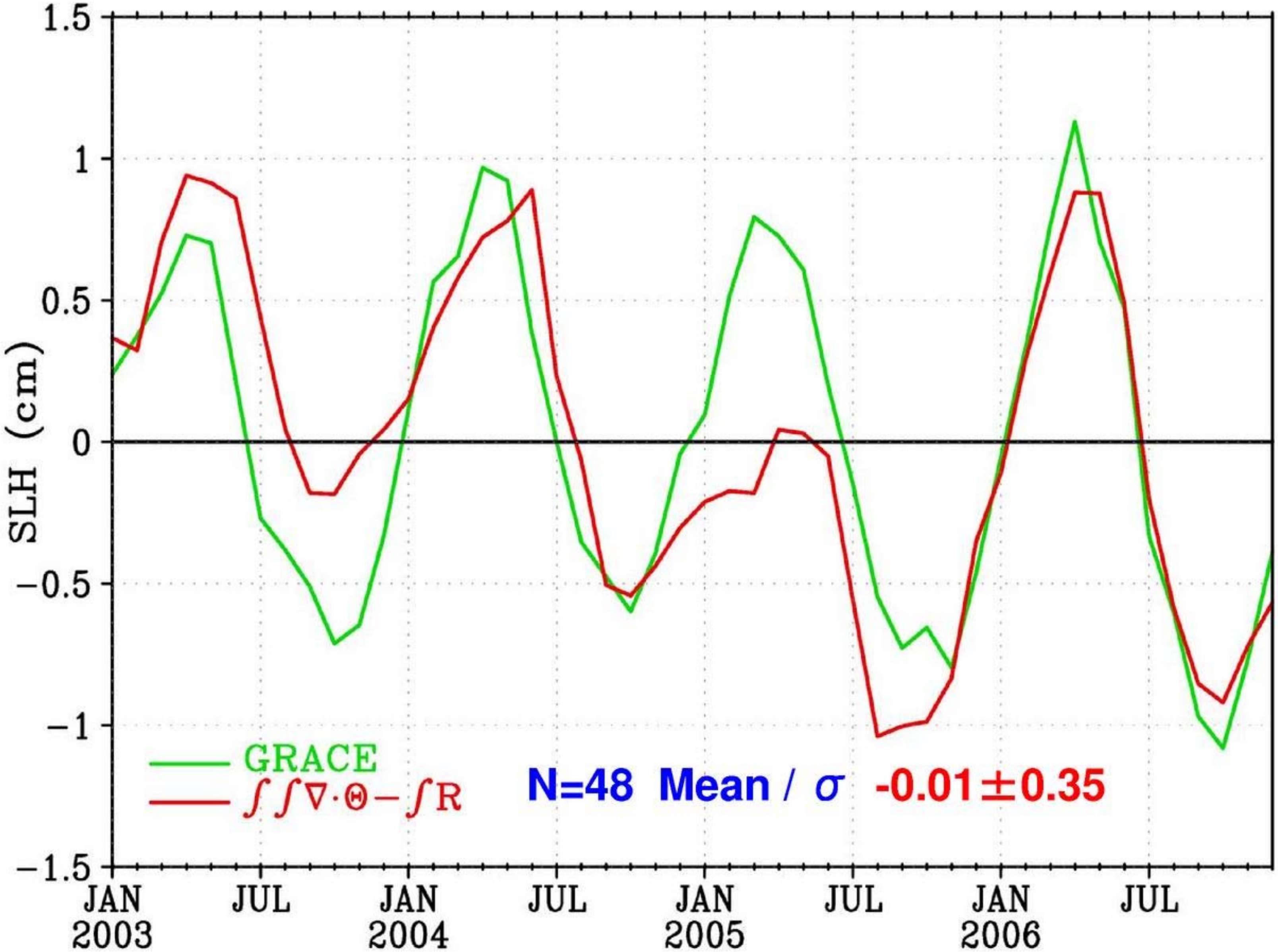
P-E

NEWS 20.9

Budyko (1974) 34

River Discharge

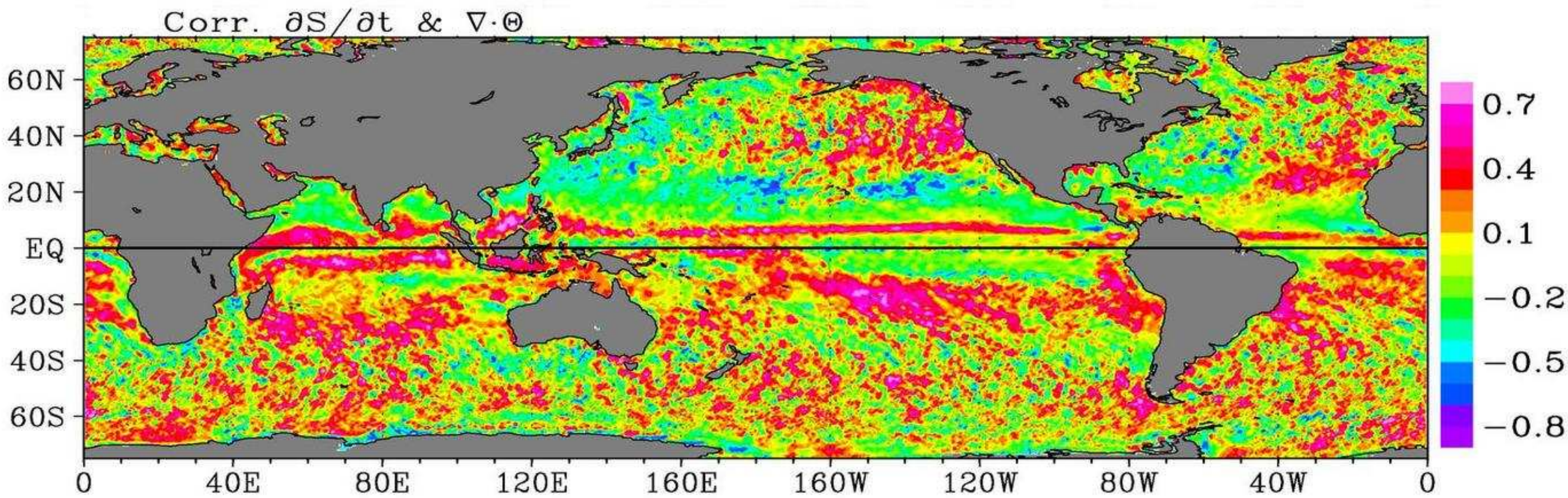
Dai (2002) 20.5

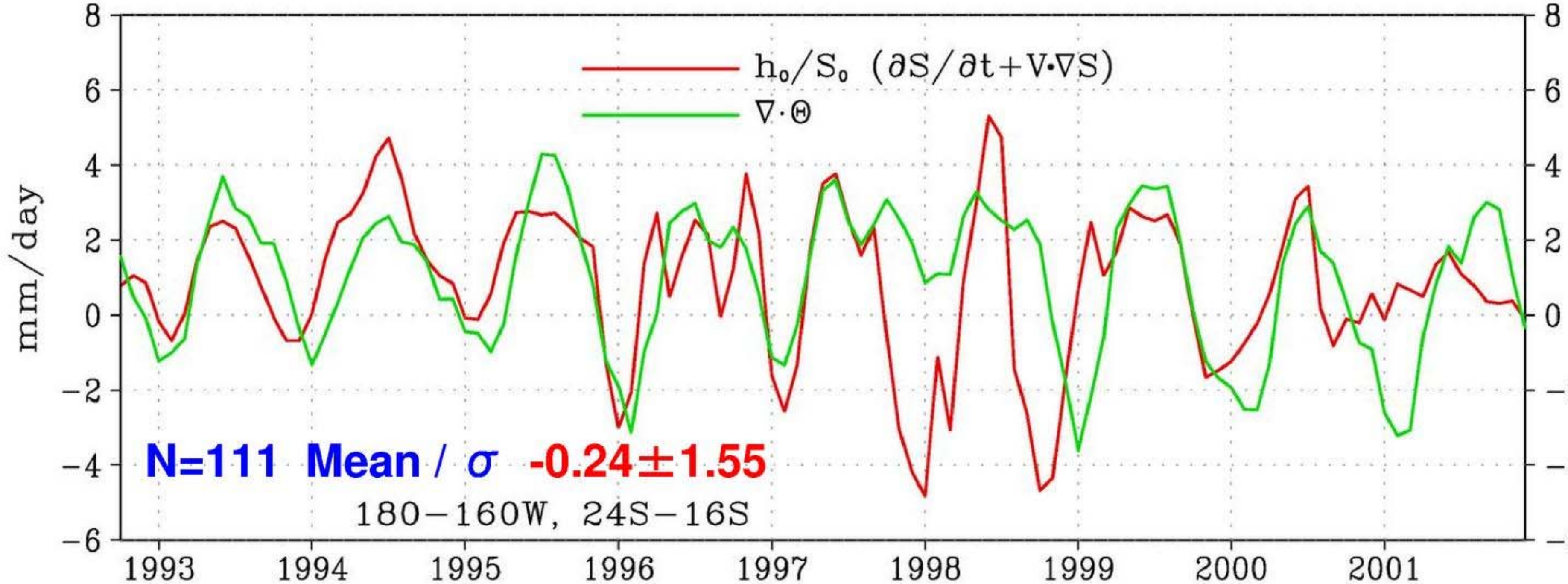


Sea level variation calculated from GRACE & moisture transport

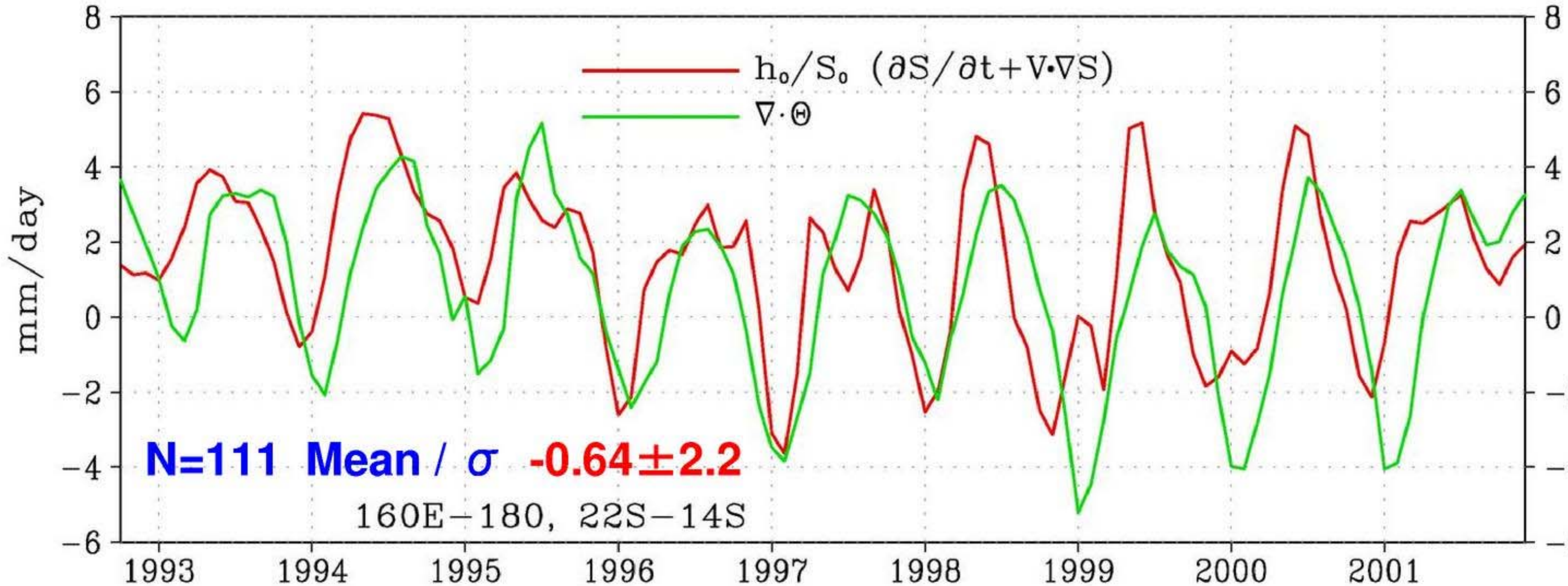
Water and Salinity Balance

$$E - P = \frac{h_0}{S_0}\left(\frac{\partial S}{\partial t} + V \cdot \nabla S\right)$$





h₀/S₀ (∂S/∂t+V•∇S)
∇·Θ
mm/day
N=111 Mean / σ -0.24±1.55
180−160W, 24S−16S
1993
1994
1995
1996
1997
1998
1999
2000
2001



h₀/S₀ (∂S/∂t+V•∇S)
∇·Θ
mm/day
N=111 Mean / σ -0.64±2.2
160E−180, 22S−14S
1993
1994
1995
1996
1997
1998
1999
2000
2001

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

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

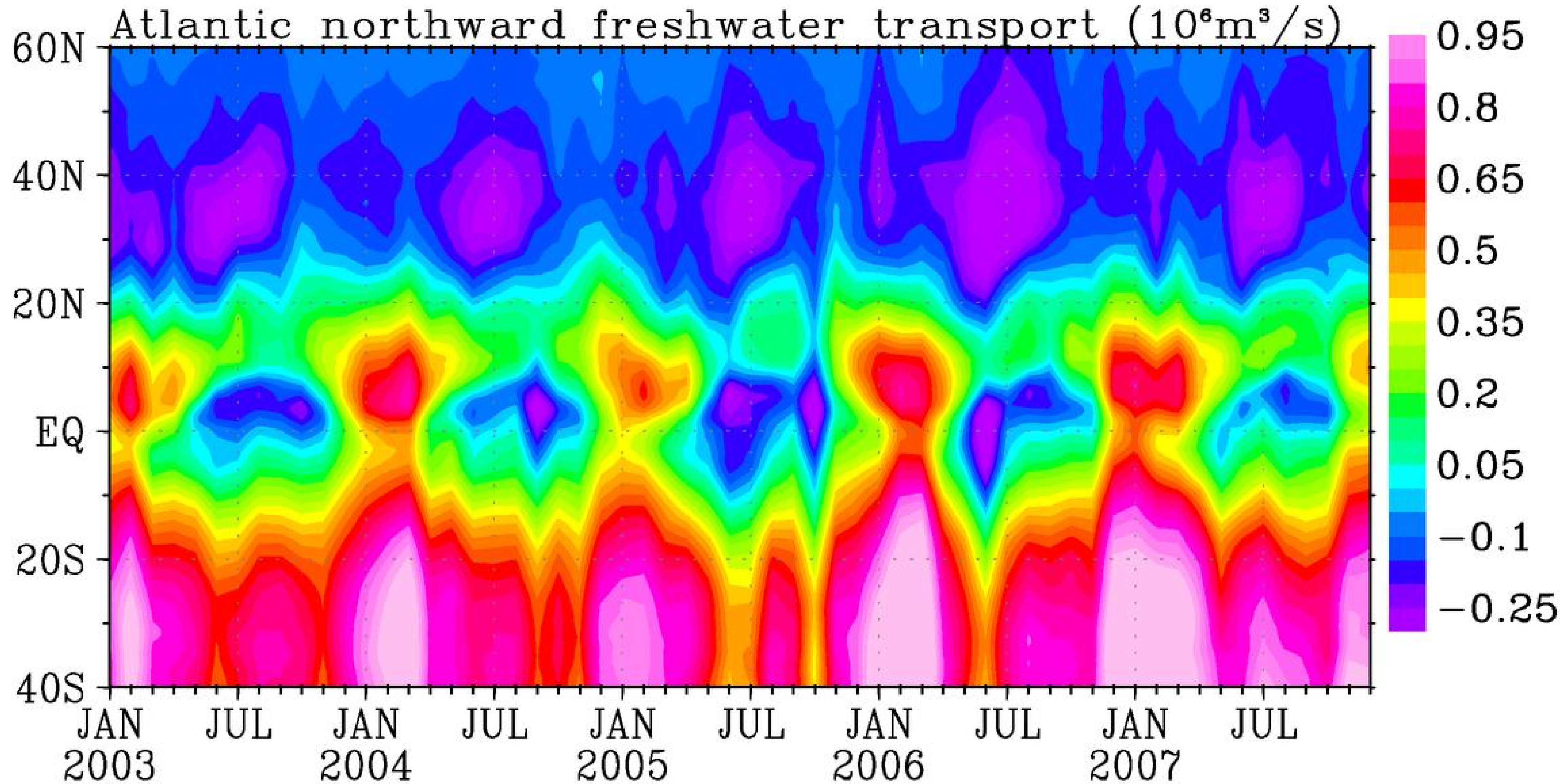
P: Precipitation

E: Evaporation

Ψ: Horizontal mass flux

R: River discharge

τ_x: Zonal stress



Atlantic northward freshwater transport ($10^6 m^3/s$)
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