An Evaluation of Reanalysis Transports between Ocean and Land

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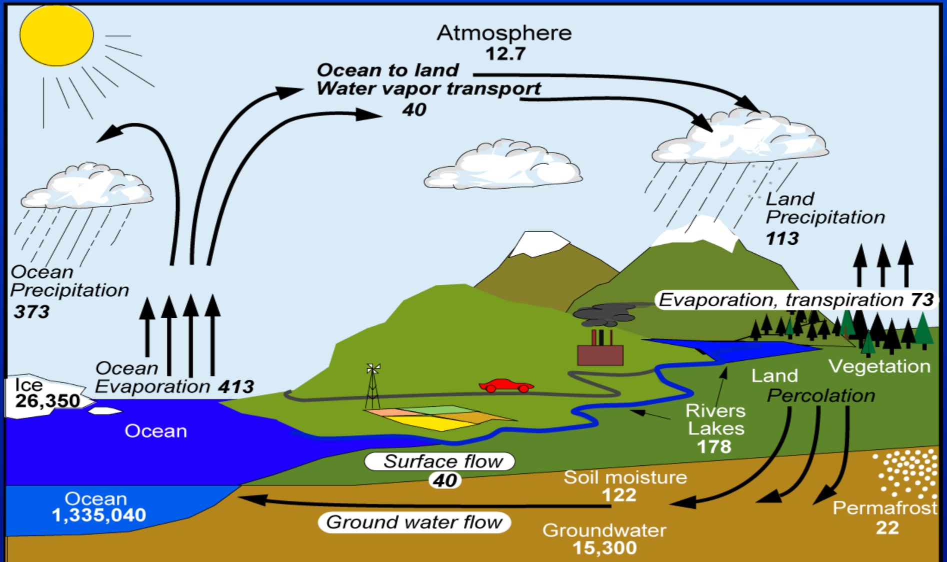
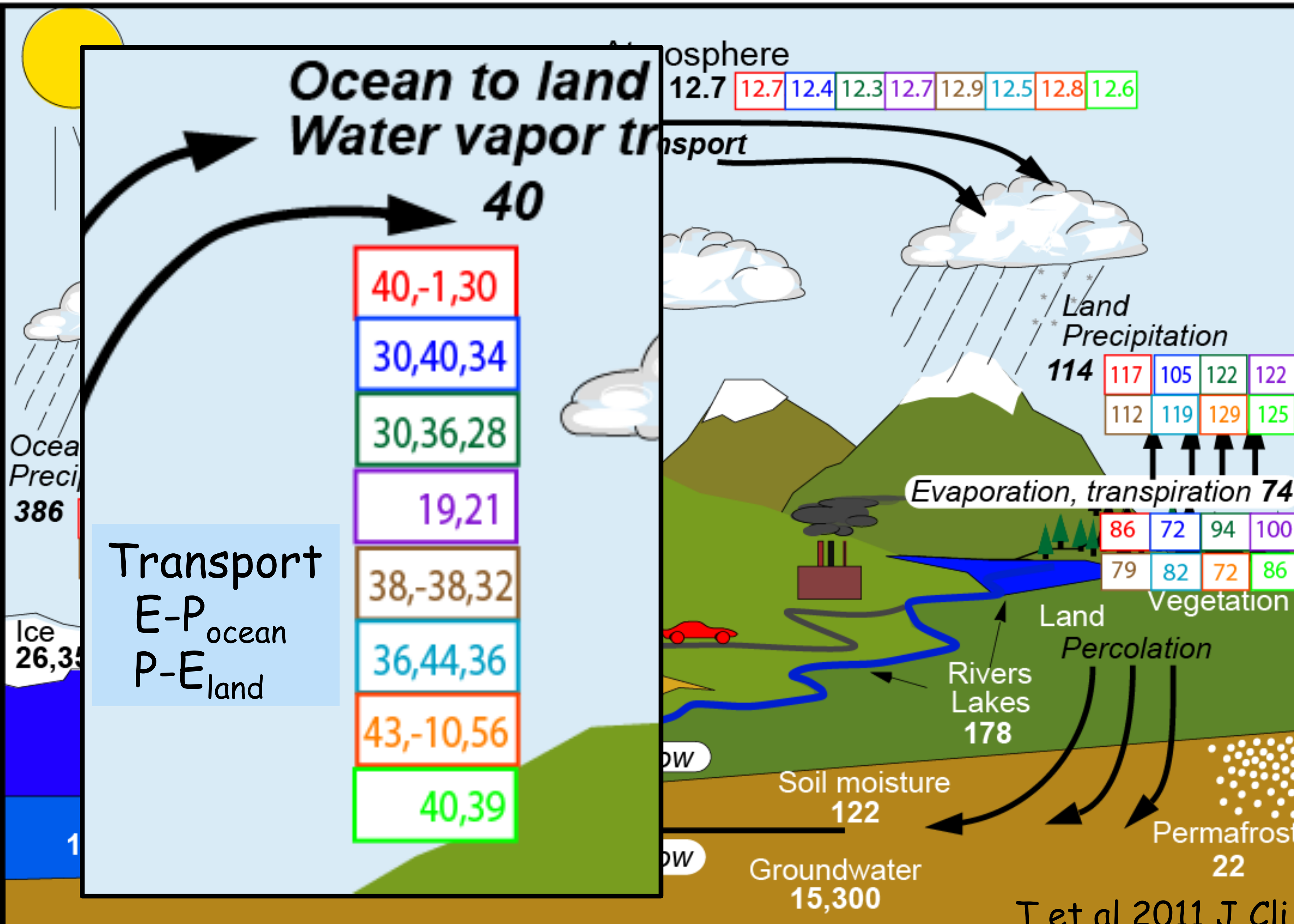
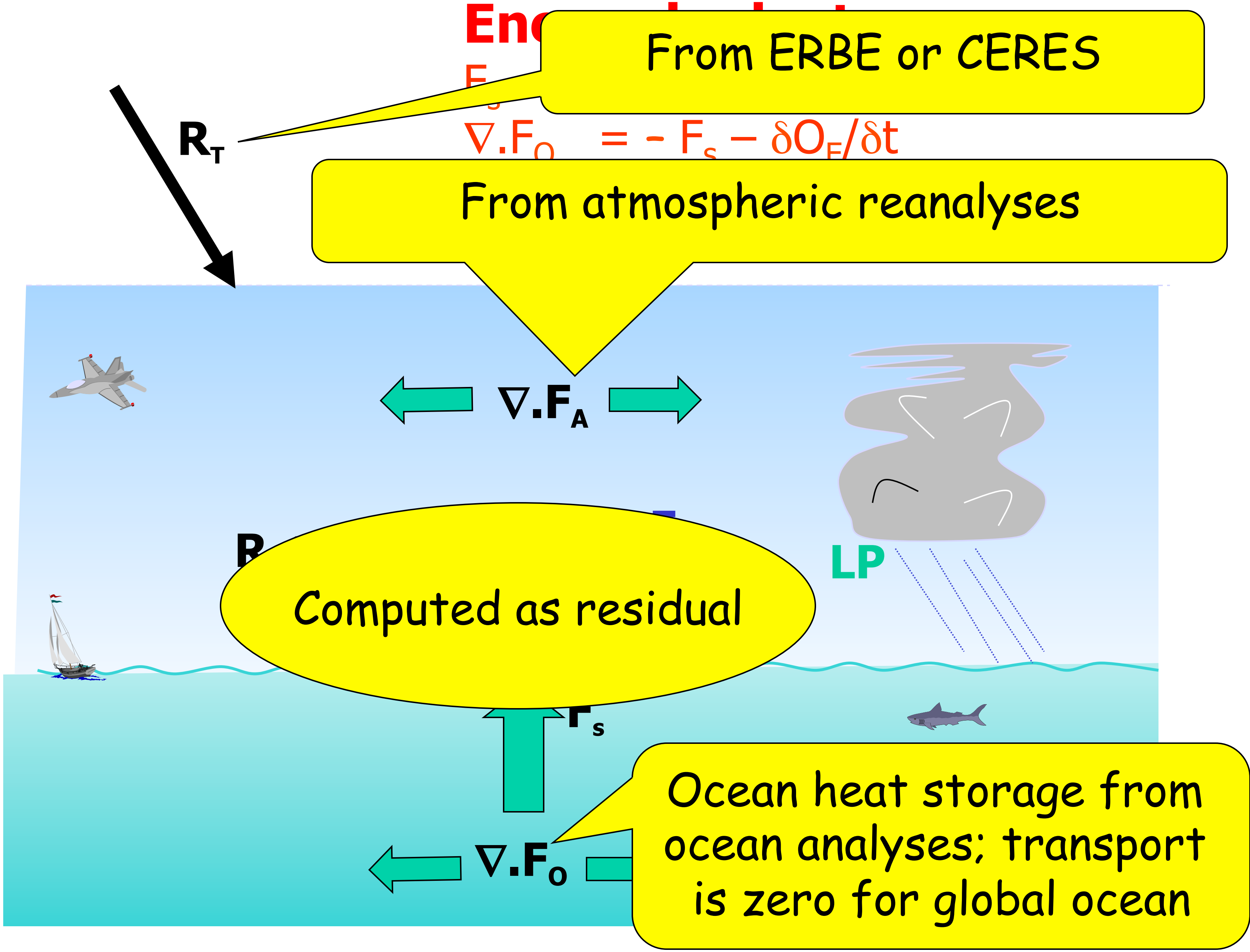


Hydrological Cycle: 2002-08

MERRA JRA R1 R2
ERA-40* ERA-I CFSR C20R

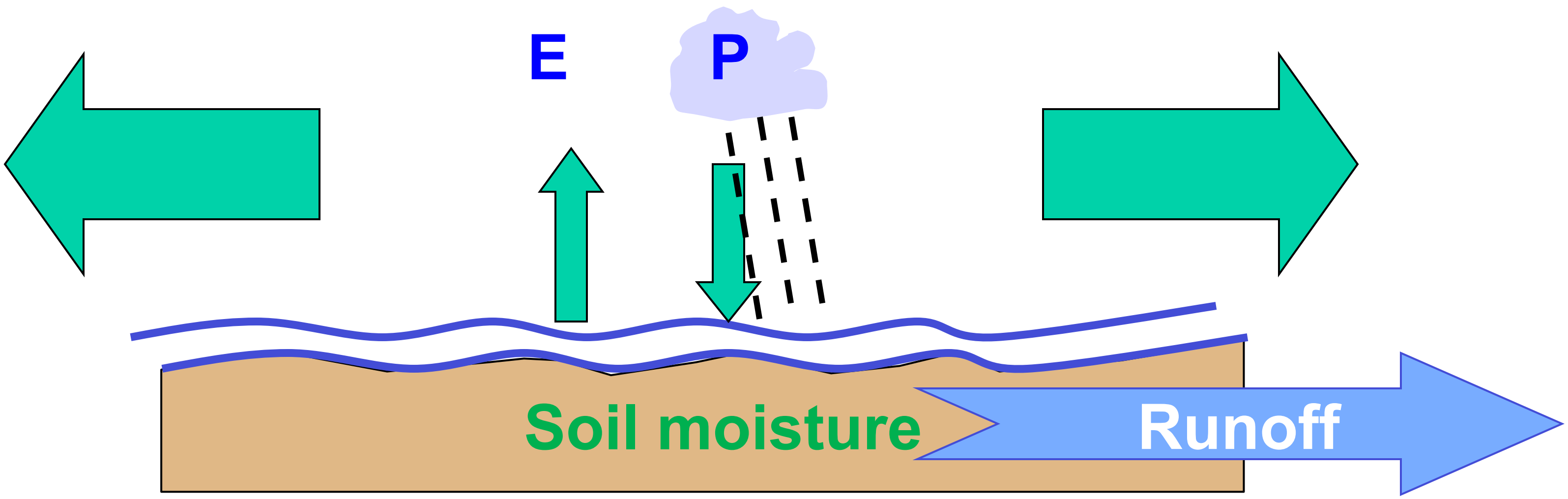


Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges *1990s



En
F
∇.FO = - Fs – δOE/δt
From ERBE or CERES
RT
From atmospheric reanalyses
∇.FA
R
LP
Computed as residual
Fs
∇.FO
Ocean heat storage from ocean analyses; transport is zero for global ocean

Divergence of atmospheric moisture is balanced by E-P



Surface moisture budget

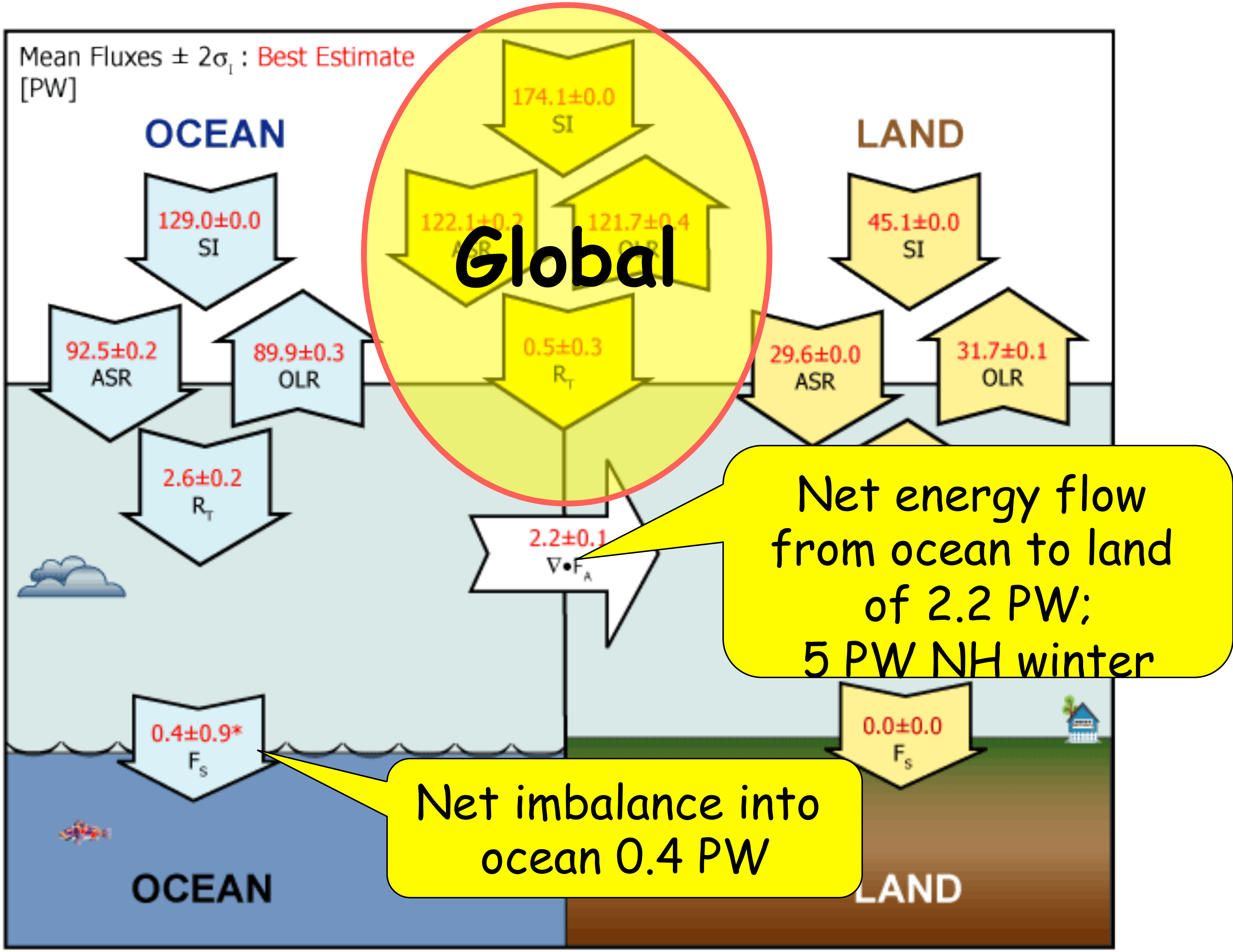
Divergence of surface moisture
= runoff
is balanced by **E-P**
or change in storage

Atmospheric moisture budget

$dS/dt = P - E - R$; $P - E = -dW/dt - \mathrm{div}\mathbf{Q}$

GRACE (→ dS/dt)

Dai et al 2009 (→ R)

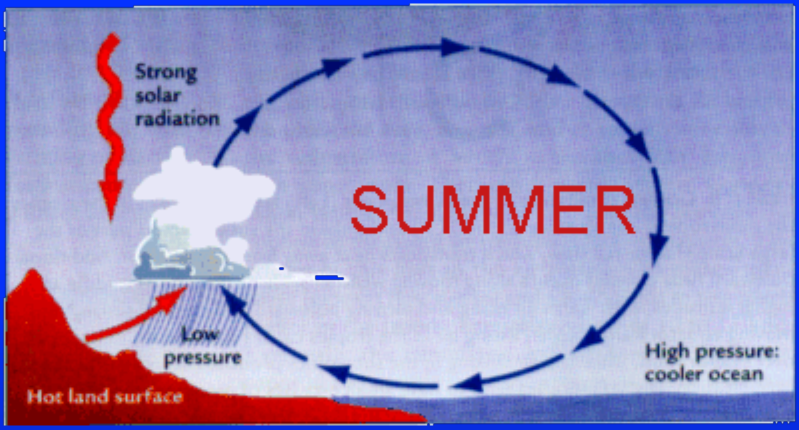


CERES period March 2000 to 2005 Fasullo and Trenberth 2008

Transport of energy from ocean to land

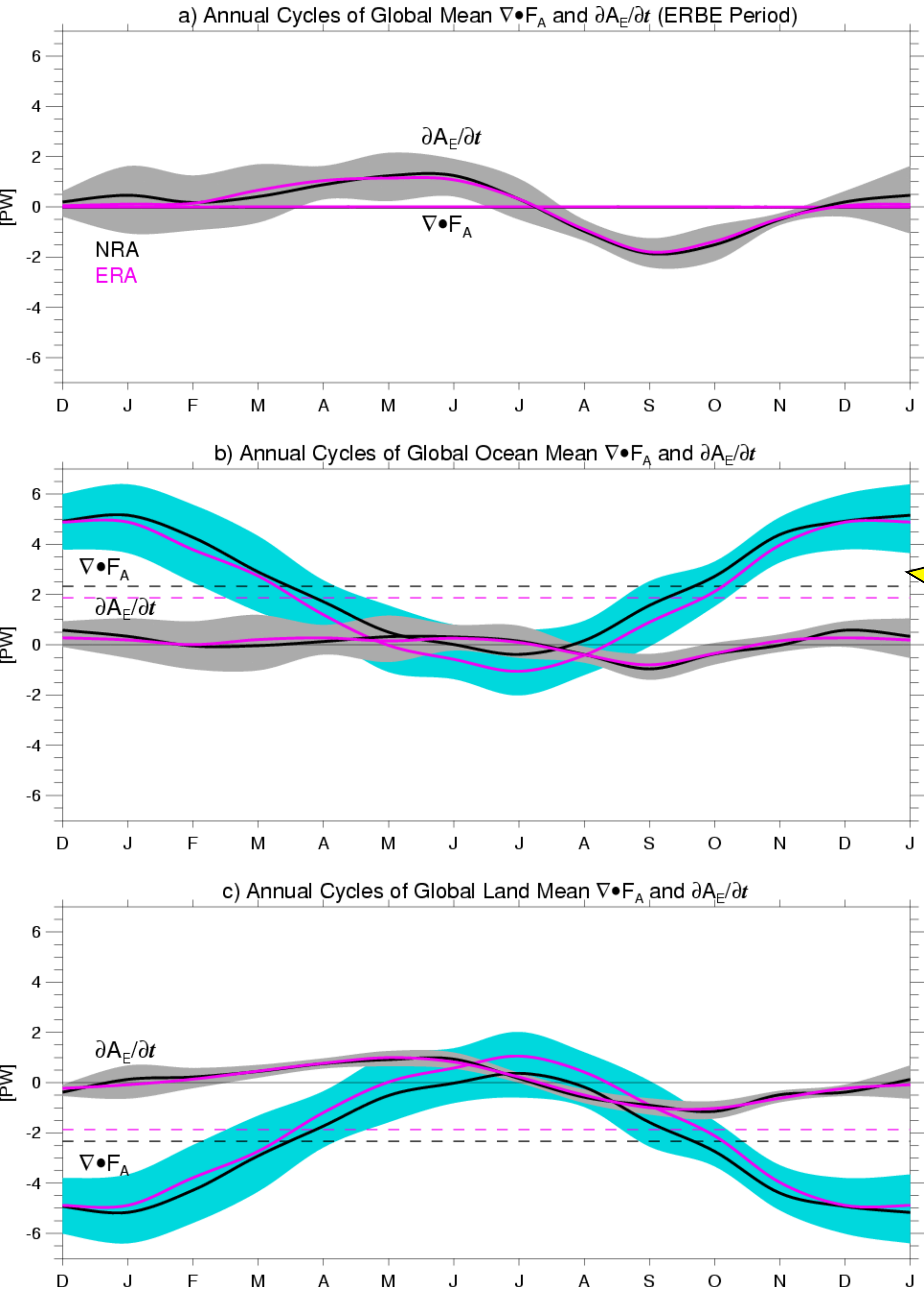
1) NH winter: strong westerlies transport heat and moisture from ocean to land: maritime vs continental climates

2) Summer Monsoons: transport moisture from ocean to land but transport heat (DSE) from land to ocean as part of monsoon overturning => large compensation



3) Overall there must be a transport of moisture from ocean to land as part of the hydrological cycle

4) Land is warmer in summer but cooler in winter: expect large annual cycle in DSE transports



Atmospheric total energy divergence ($\nabla \cdot F_A$) and tendency ($\delta A_E/\delta t$)

Global

globa

globa

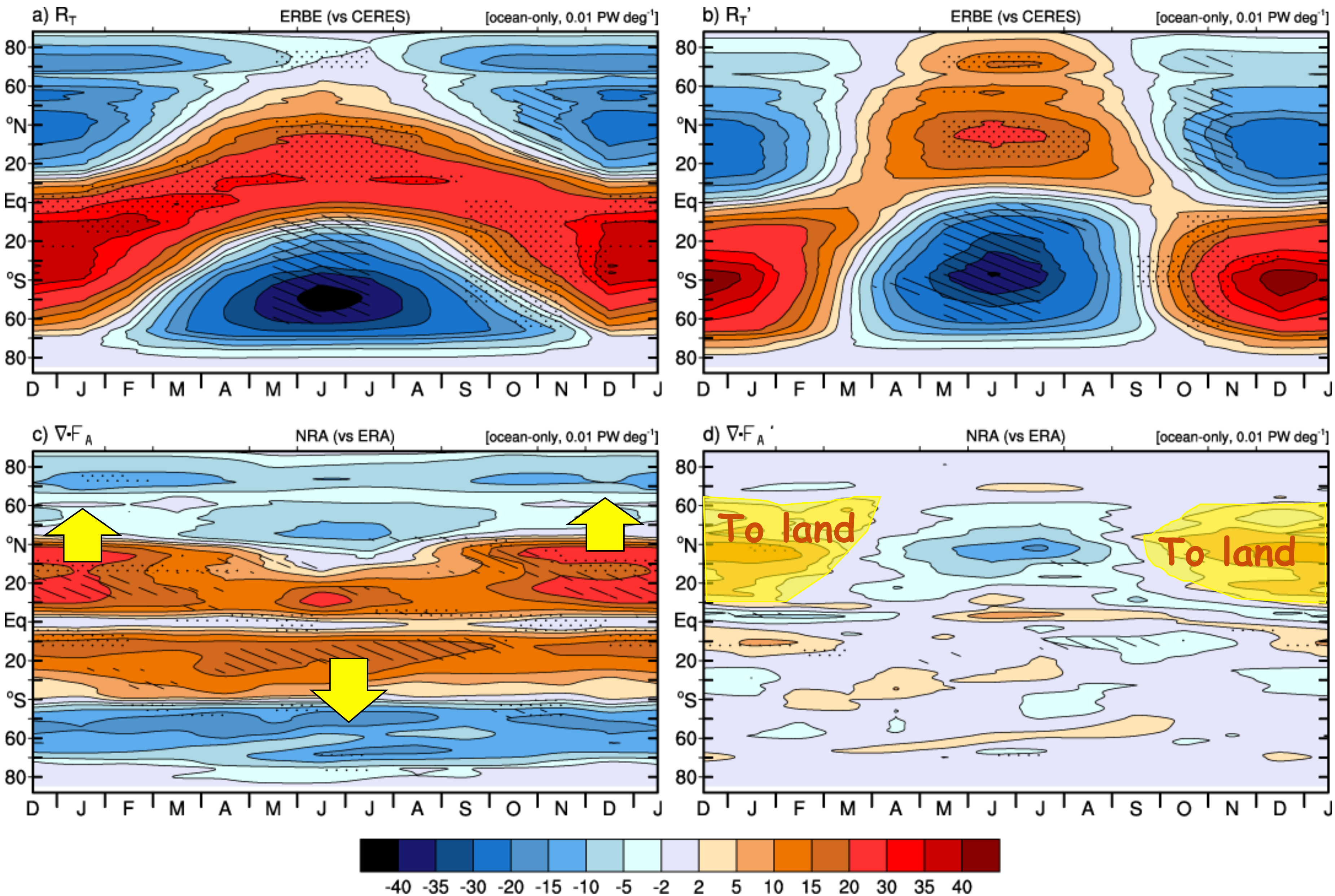
Main ocean to land energy transport is in NH in northern winter

Sign reverses in summer

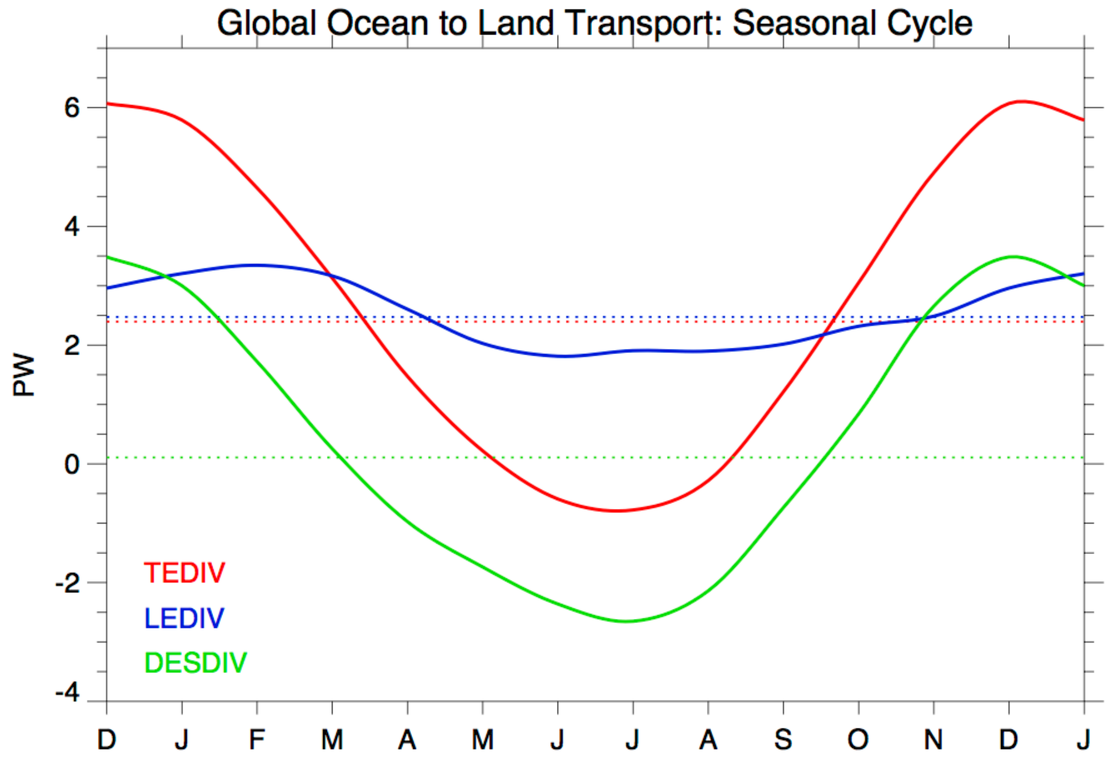
Global =0

Fasullo and Trenberth 2008

Ocean only



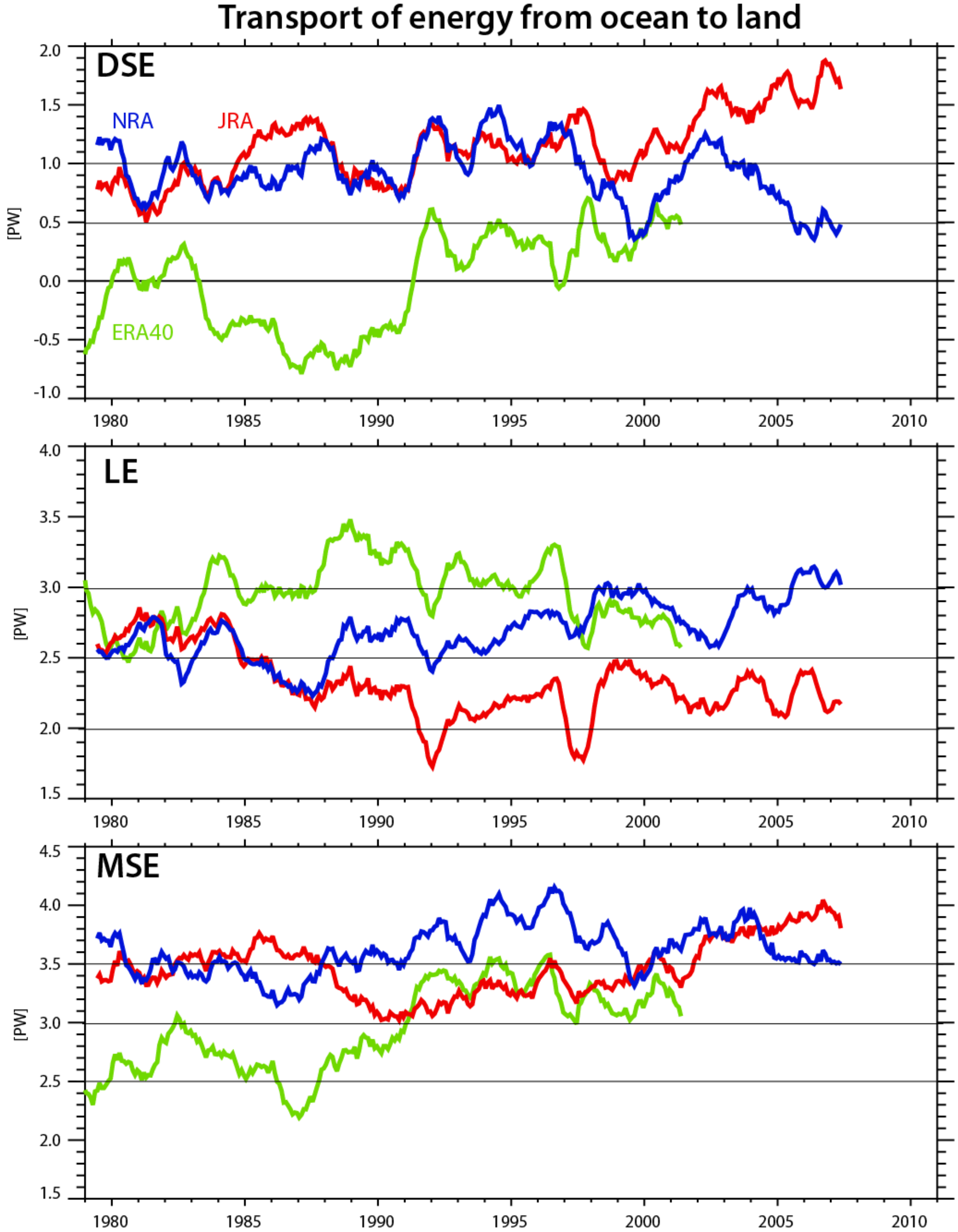
Fasullo and Trenberth 2008



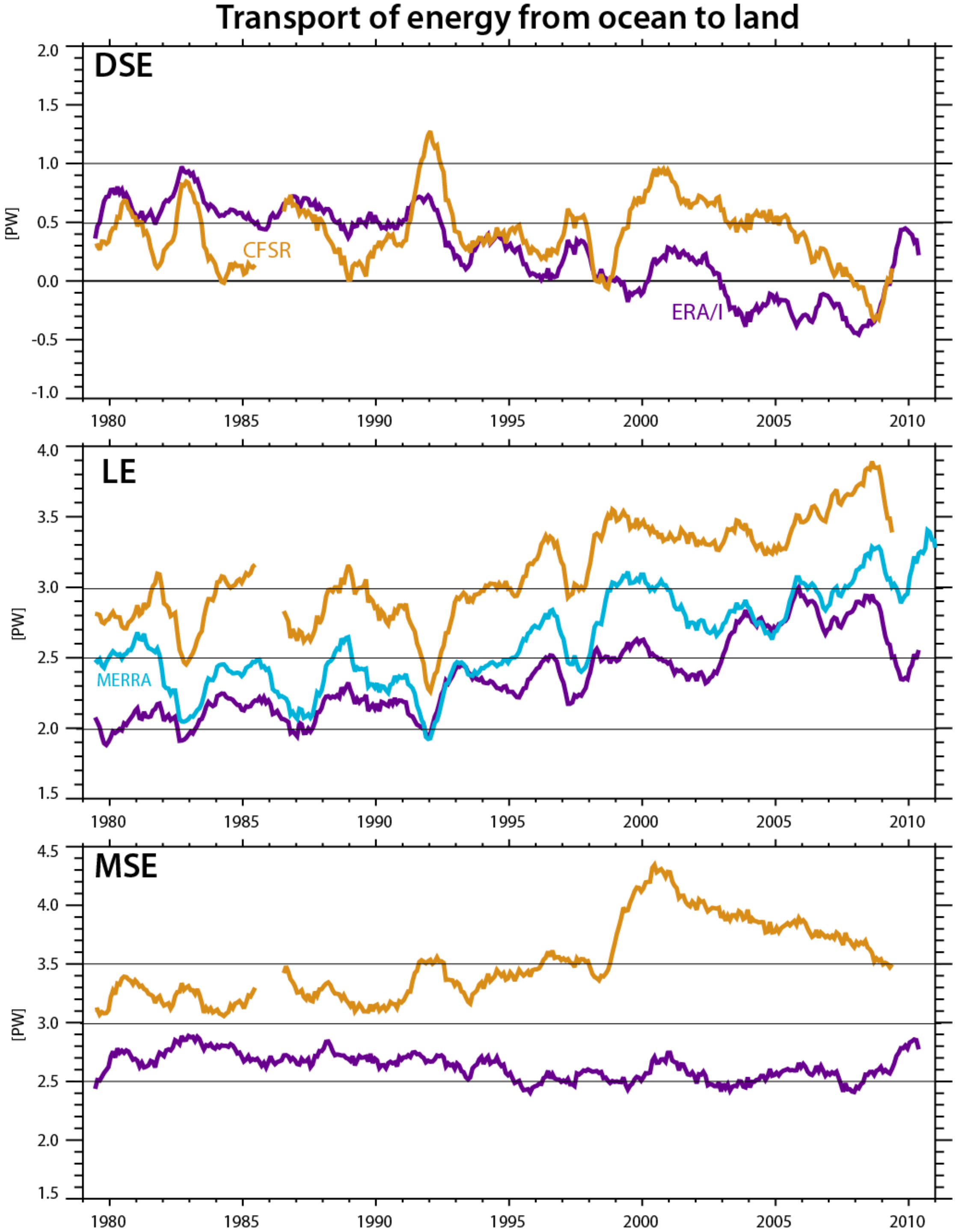
ERA-I
1989-2010

Annual cycle

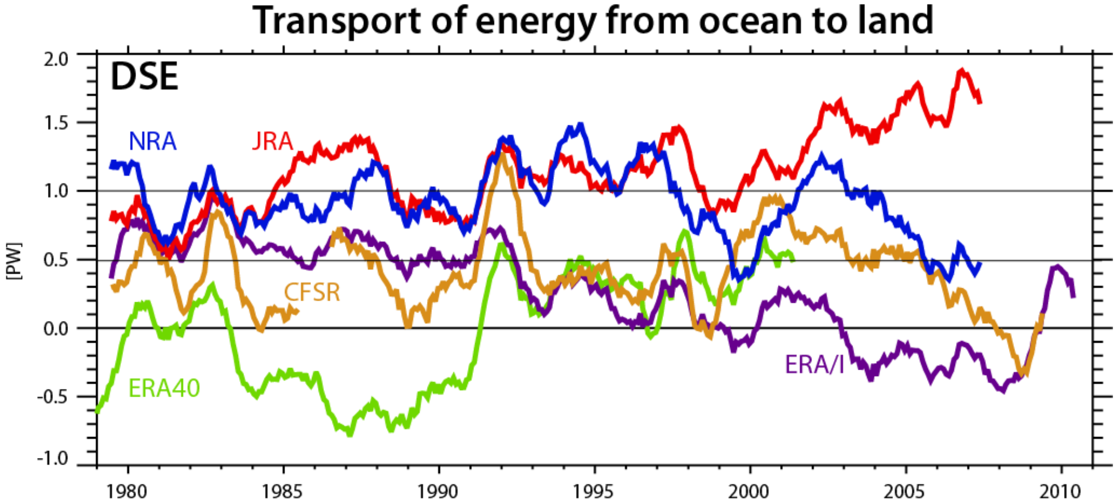
- Hydrological cycle ensures moisture transport to land year round.
- Large annual cycle in DSE; net close to zero.
- Large annual cycle in total (includes KE) but net comes from moisture.



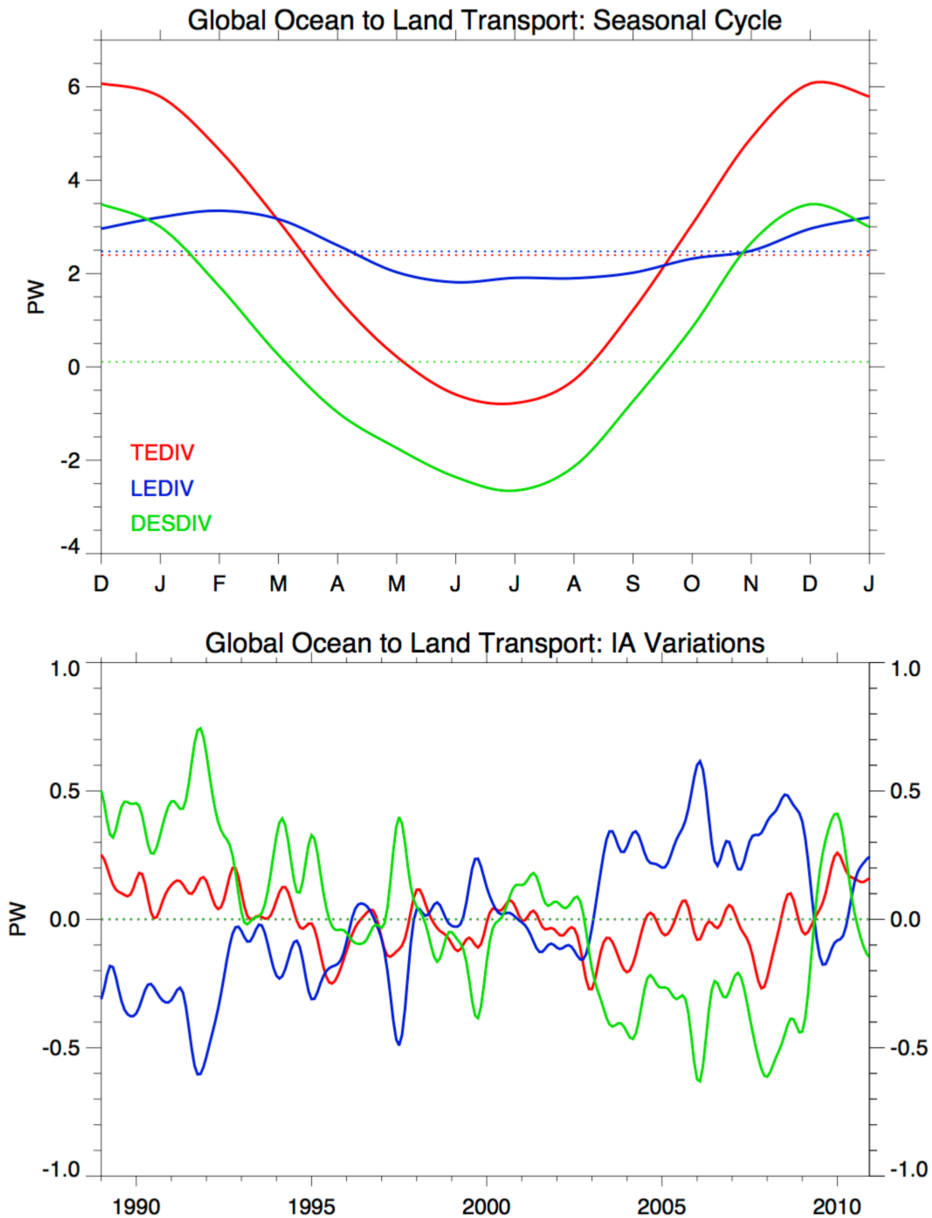
12-month running means



Upward trend:
Increased
water vapor



Net DSE transport to land?

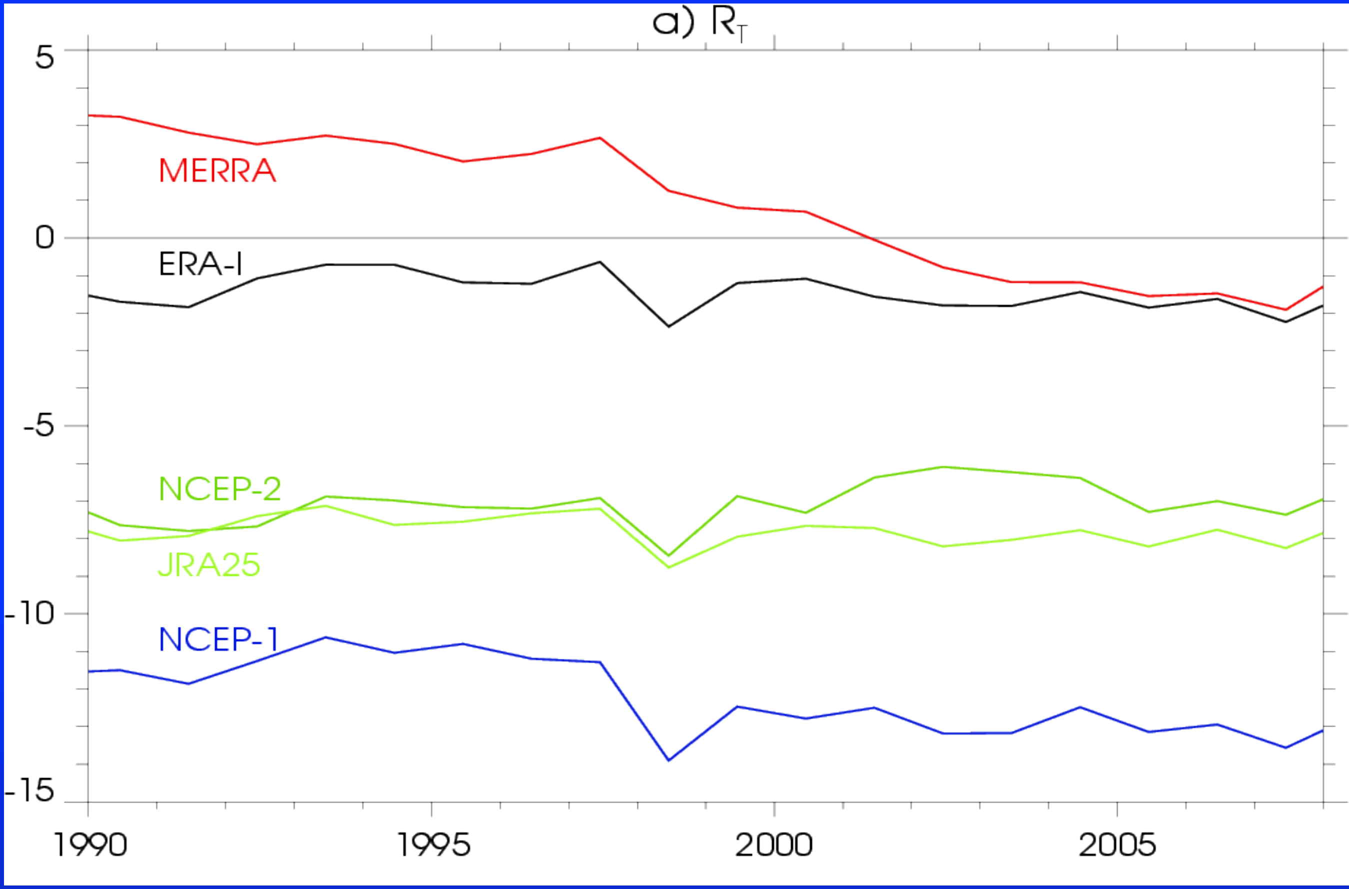


ERA-I
1989-2010

Annual cycle

Variations:
Large compensation between DSE and LE; typical of tropics

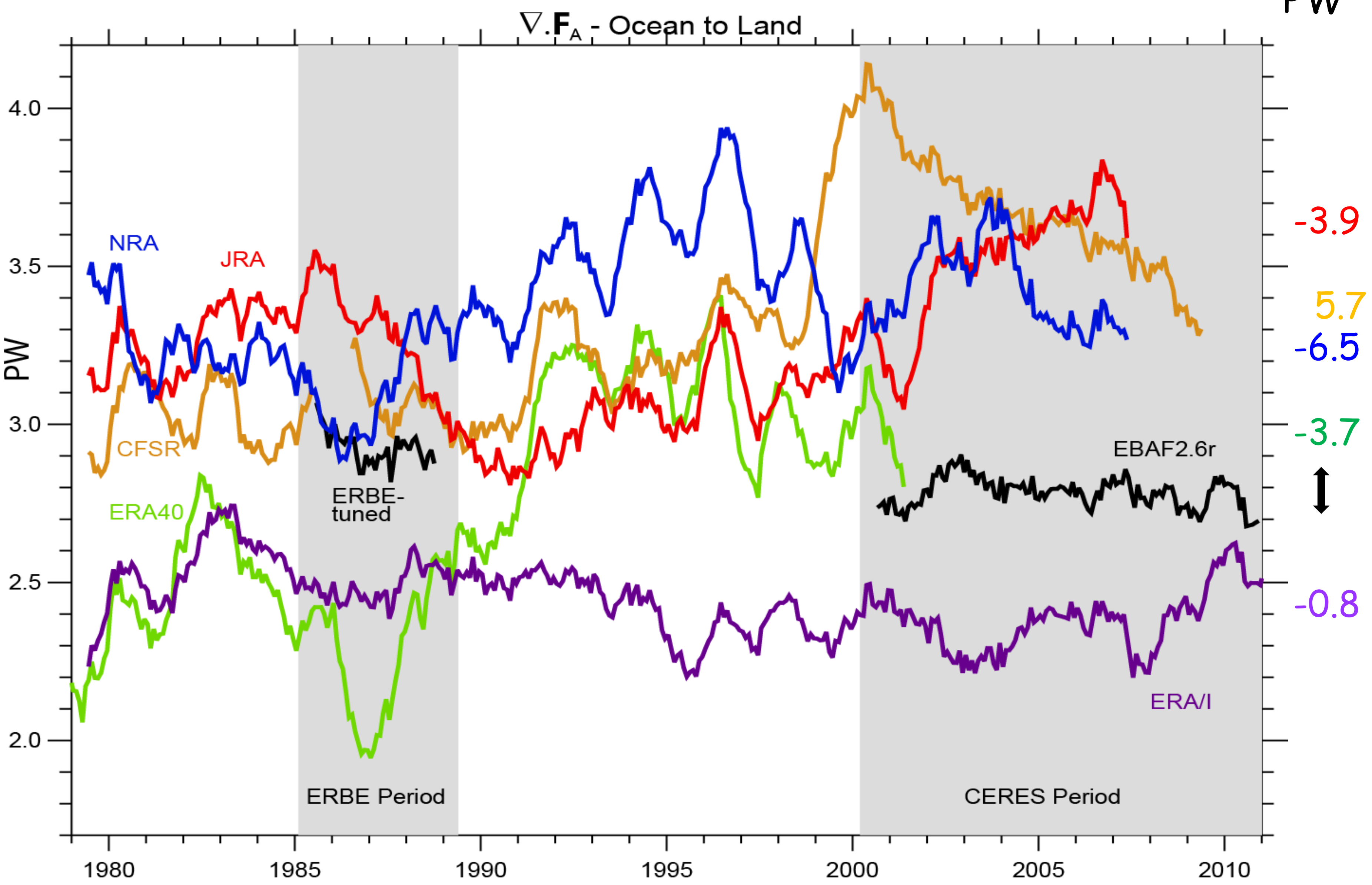
TOA Net Radiation



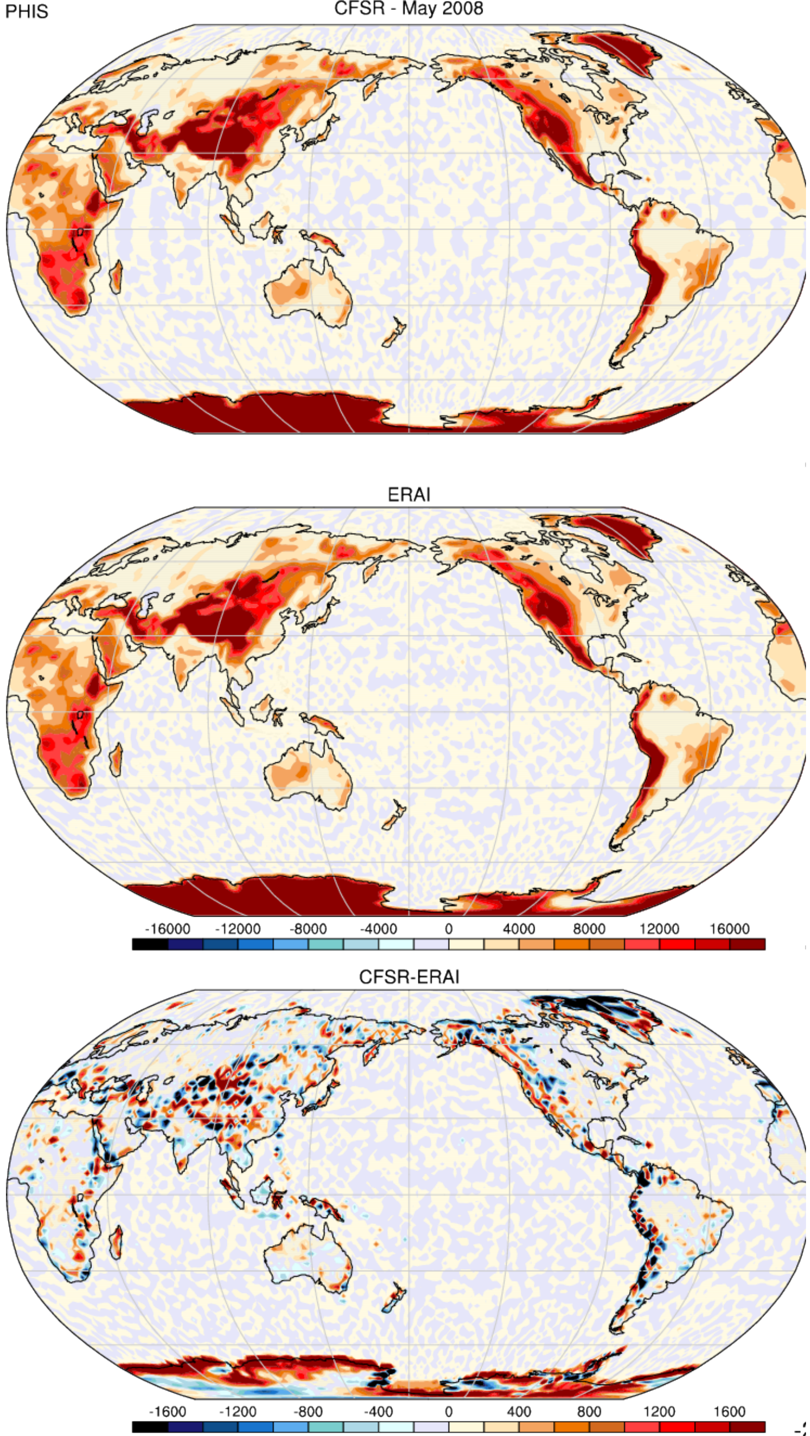
Reanalyses: TOA 1990-2008

Trenberth et al 2009:
0.9 W m^{-2} for 2000s

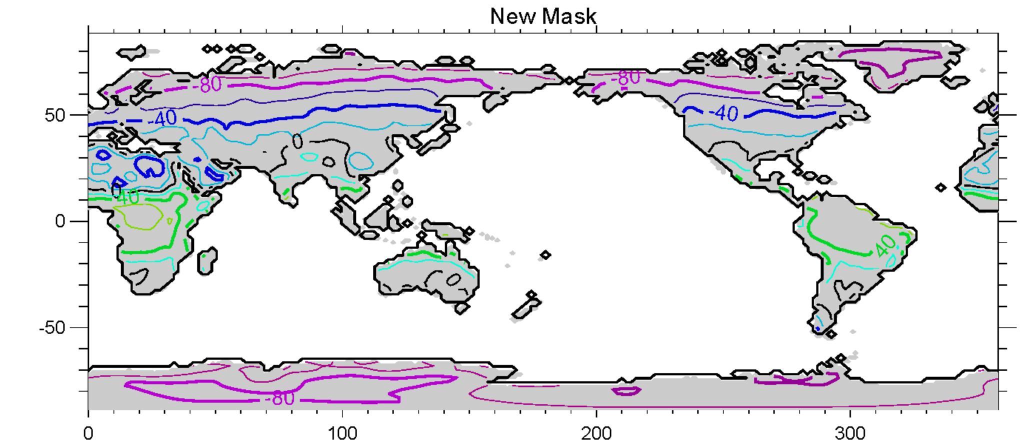
Transport of energy: Ocean to land

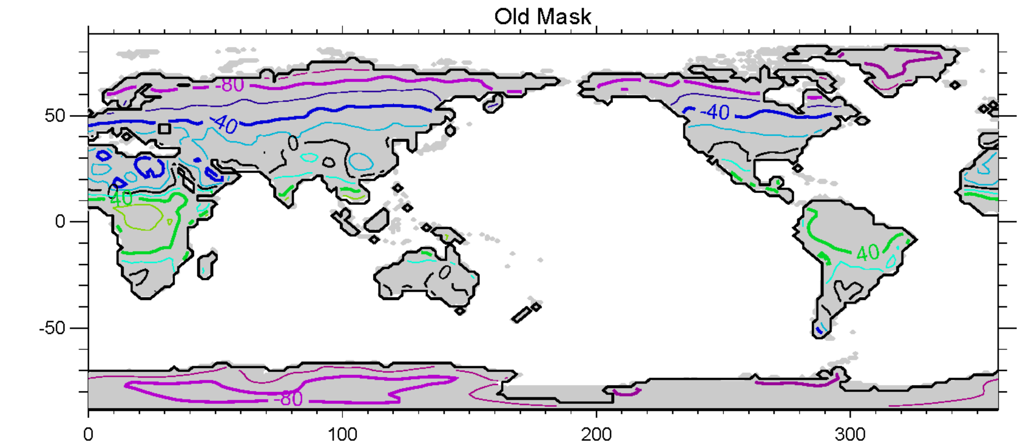


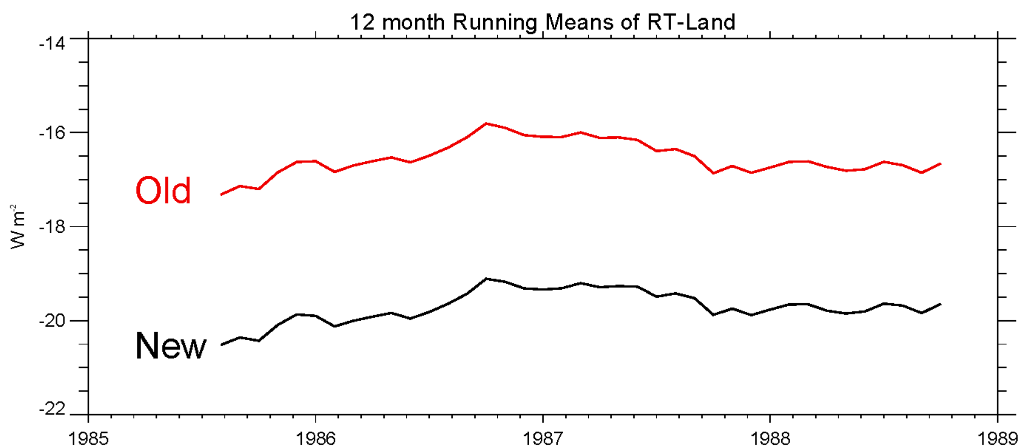
Why are transports ocean to land so different?



1) Resolution: land edge
2) Topography
3) Definition: ice shelves, lakes, marginal seas
4) Partially filled grid squares
5) Divergence fields are inherently noisy and must be smoothed, blurring lines.
6) Moisture and precip fields remain different.





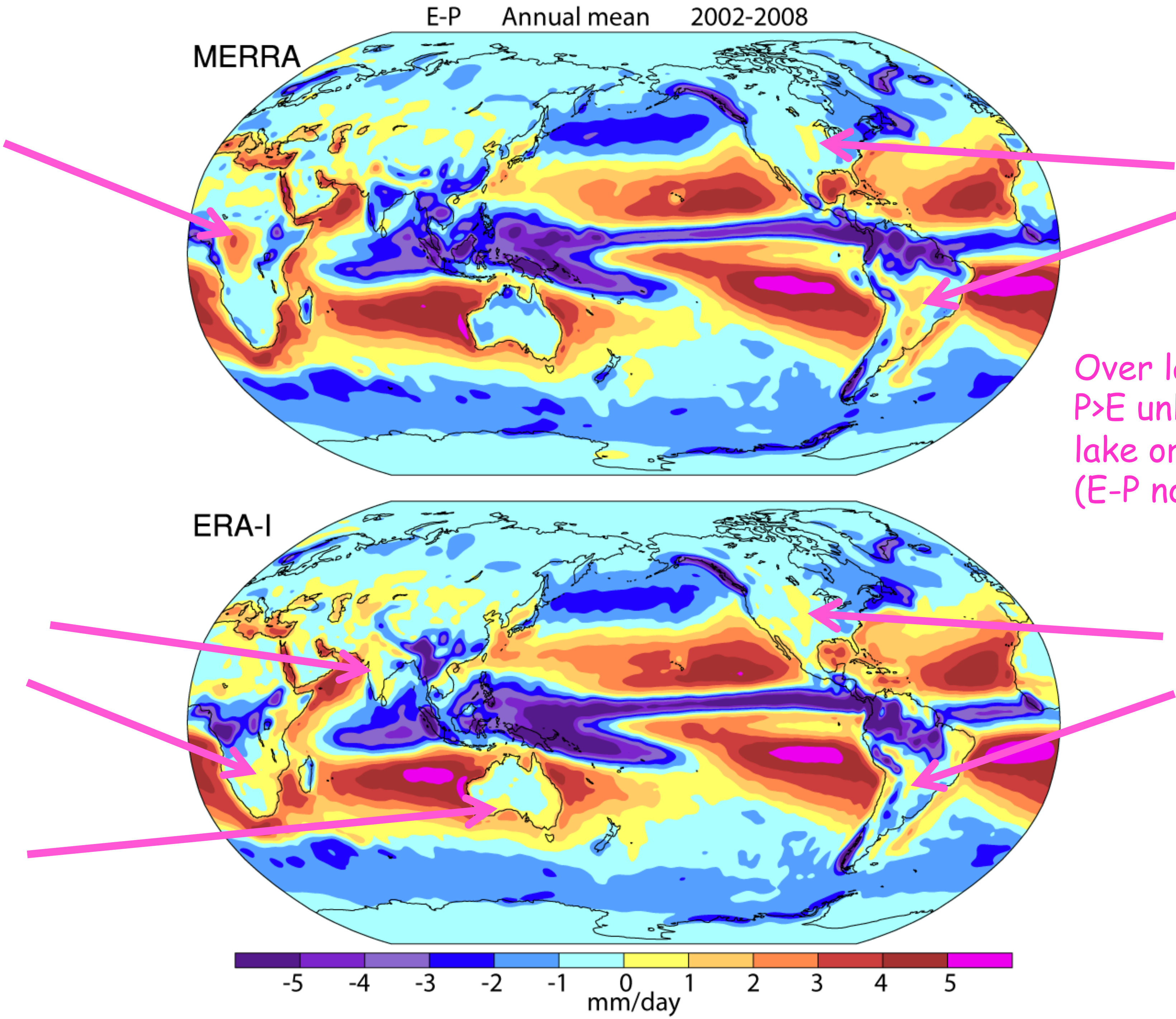


ERBE R_T

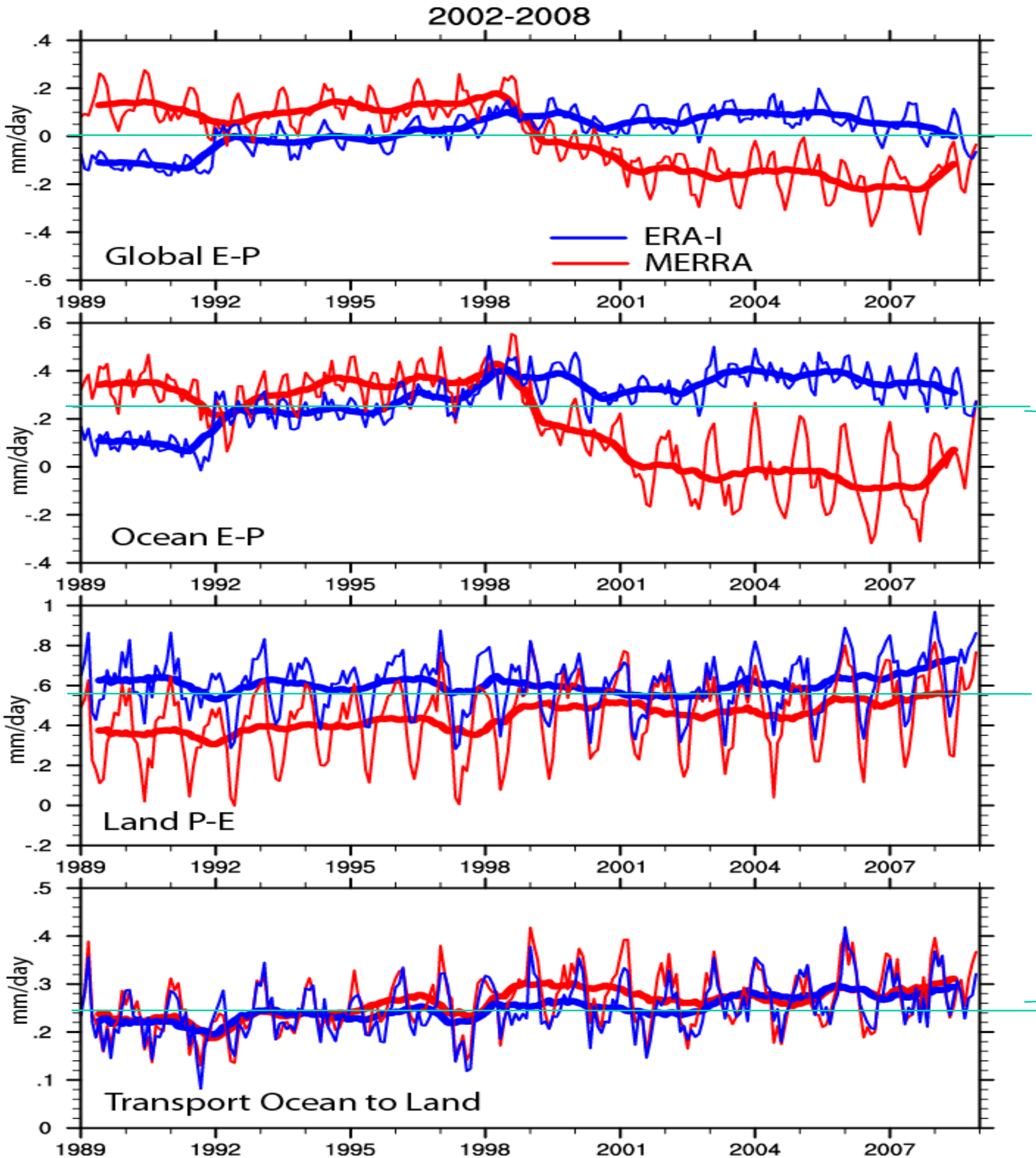
Effects of changes in land mask T63

Excluded small islands, ice shelves

Mean diff ~3 W m^{-2}
~0.45 PW



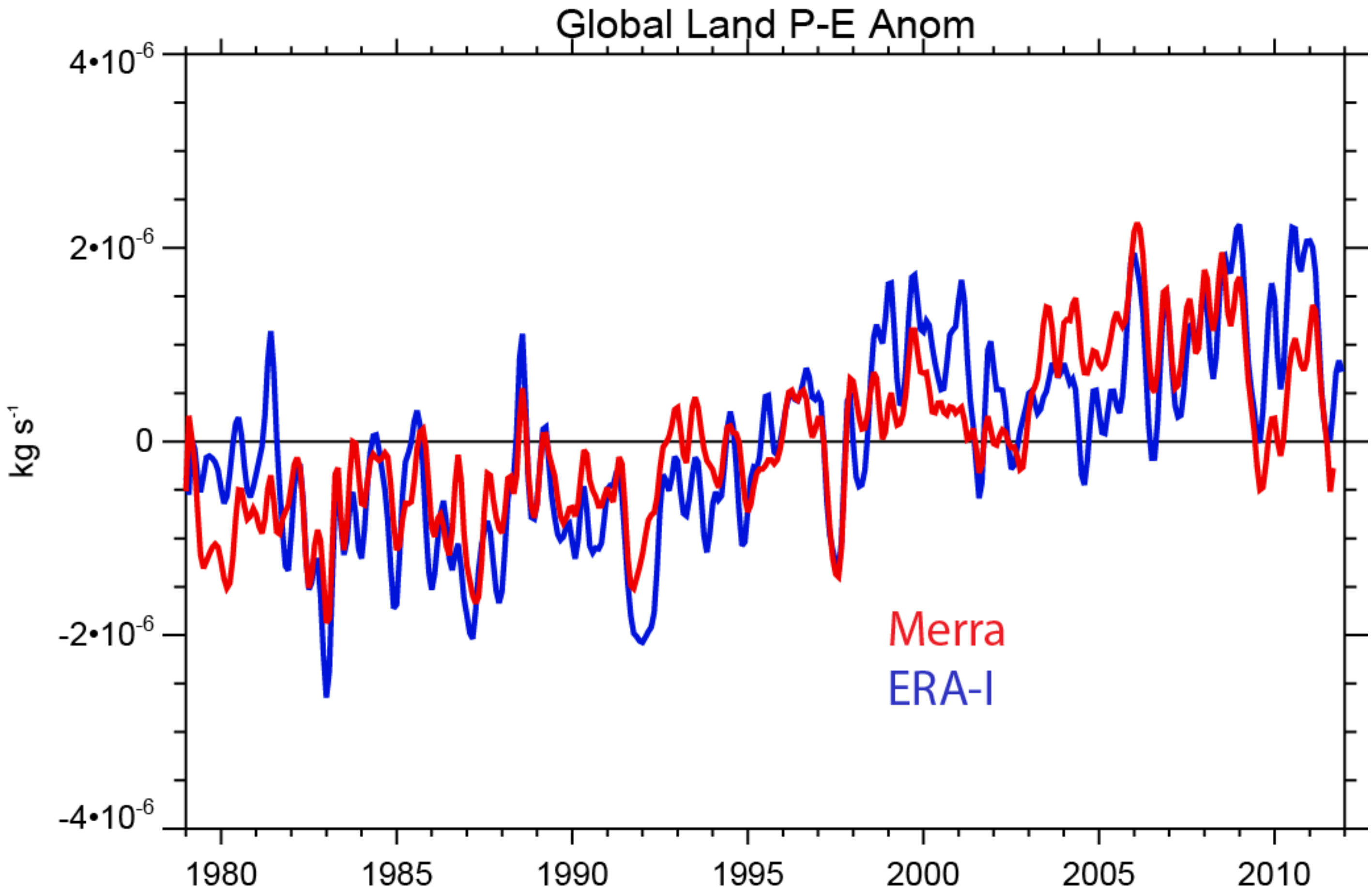
Over land:
P>E unless
lake or river
(E-P not +ve)



For mean E-P

Ocean = -Land

Global = 0

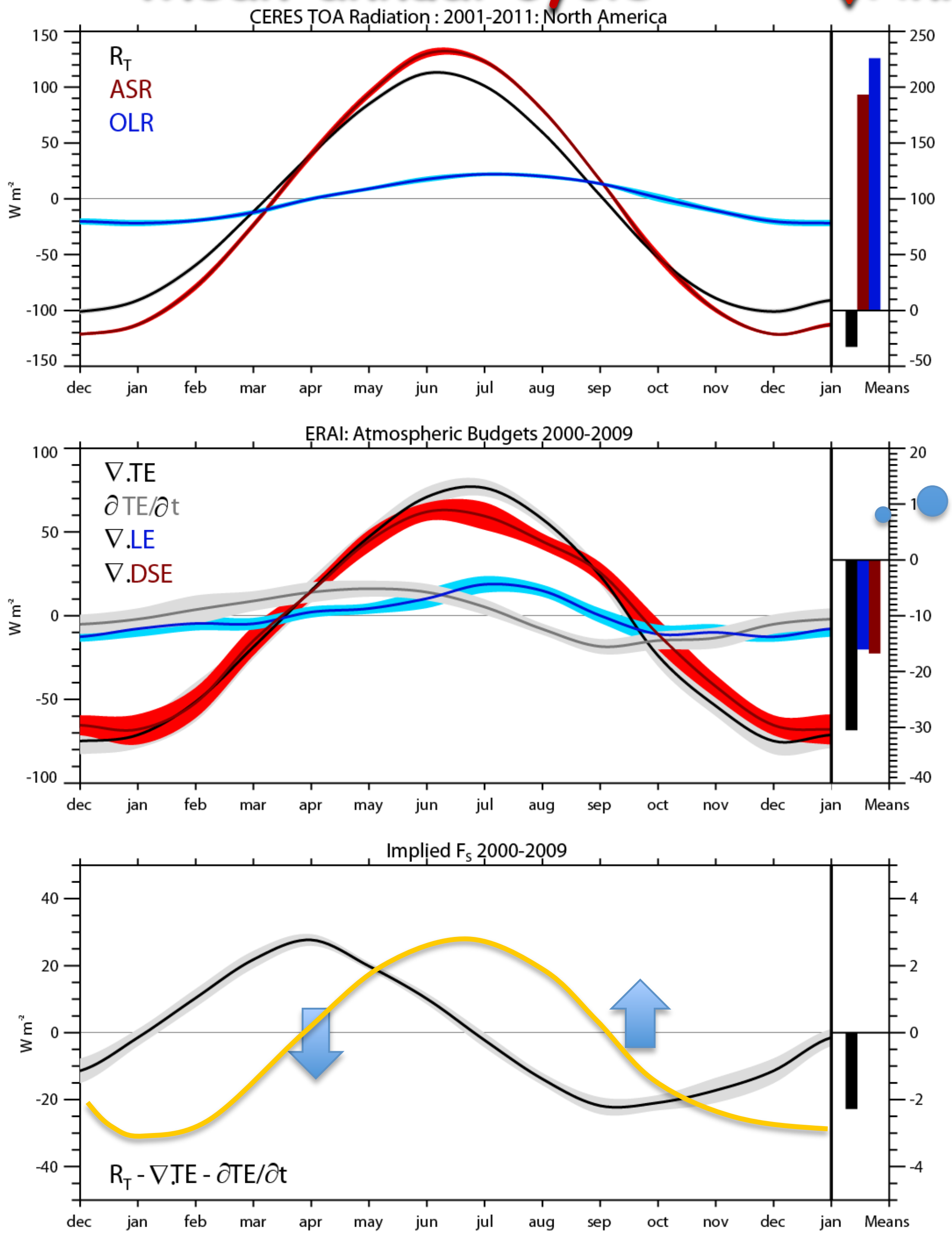

Global Land P-E Anom
4•10^{-6}
2•10^{-6}
0
-2•10^{-6}
-4•10^{-6}
kg s^{-1}
1980
1985
1990
1995
2000
2005
2010
Merra
ERA-I

Merra
ERA-I

Regional energy and water budgets

1 sigma error bars included based on interannual variability

Mean annual cycle ⇓**Annual means**



Regional energy balance

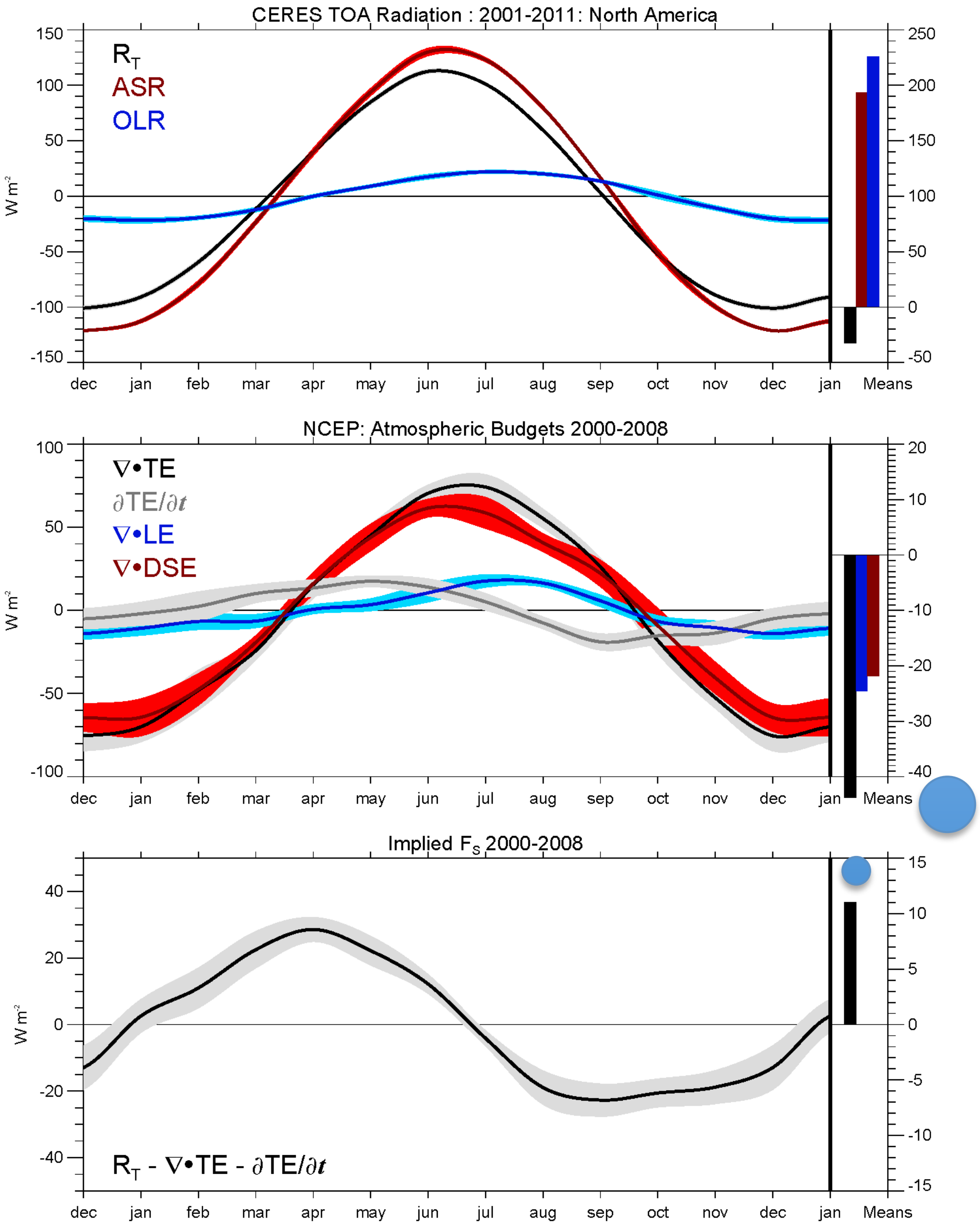
Annual means

ERA-I

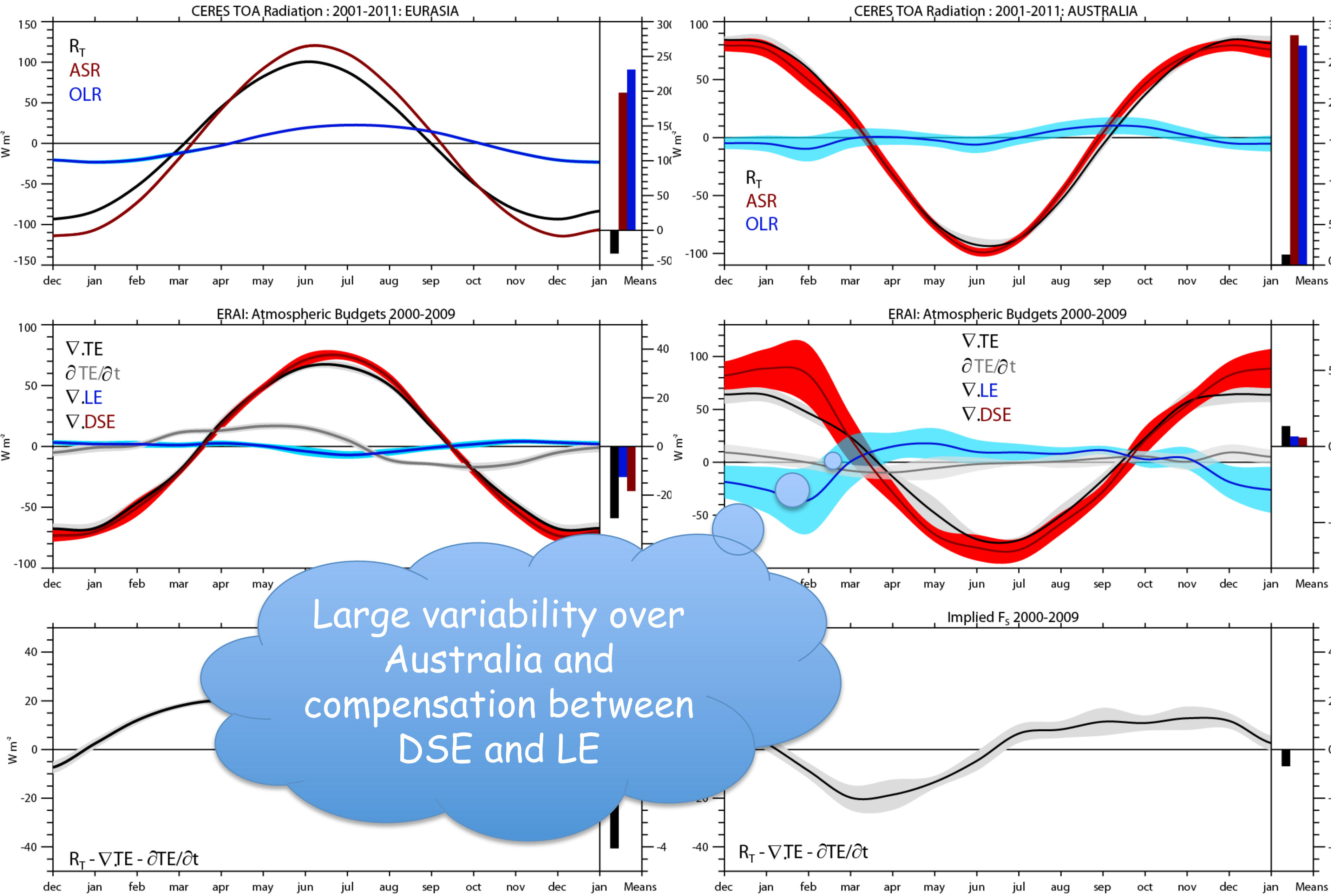
Net imbalance as implied surface flux down.

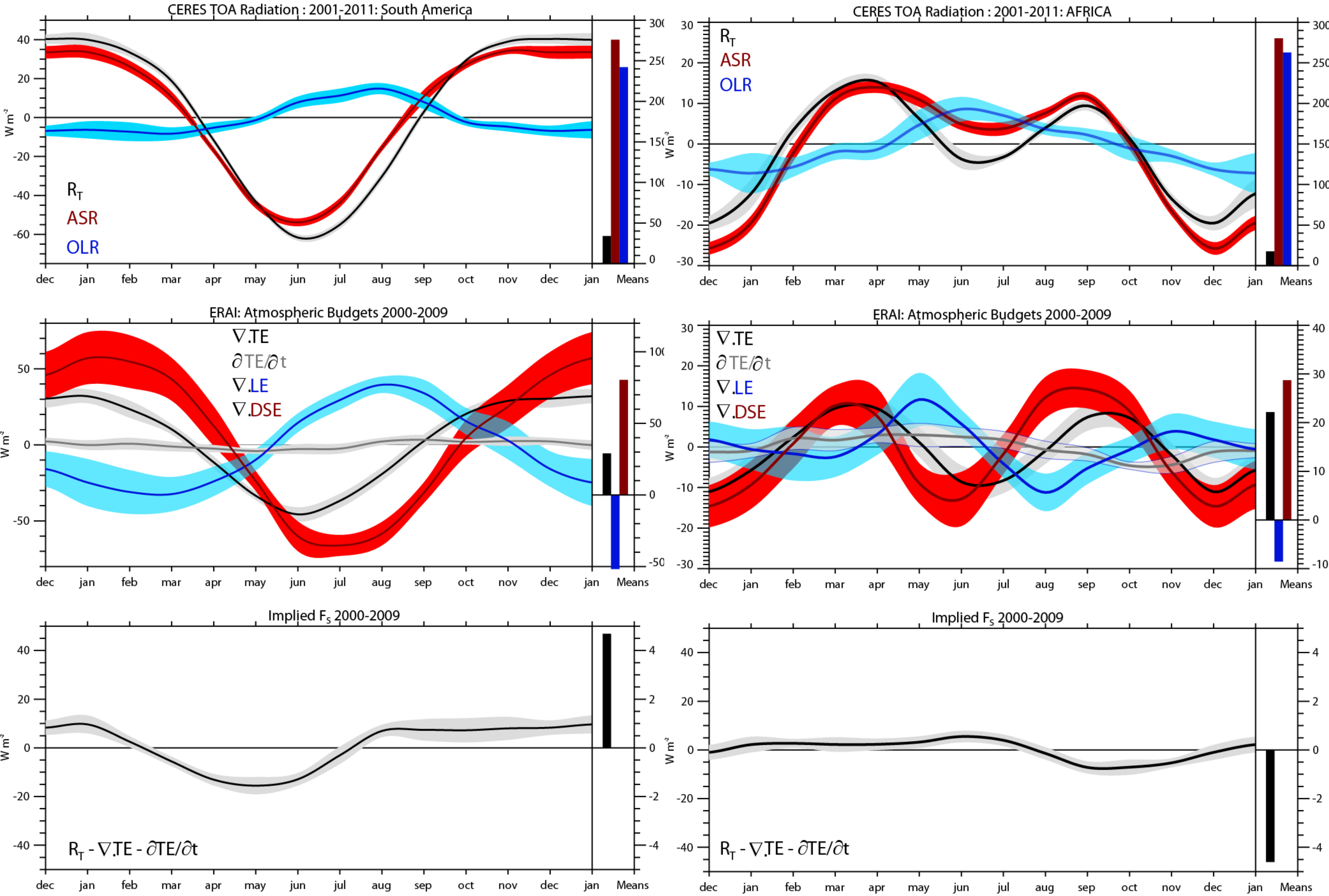
Annual cycle of imbalance => storage?

Implied soil T min in Jan and max in July

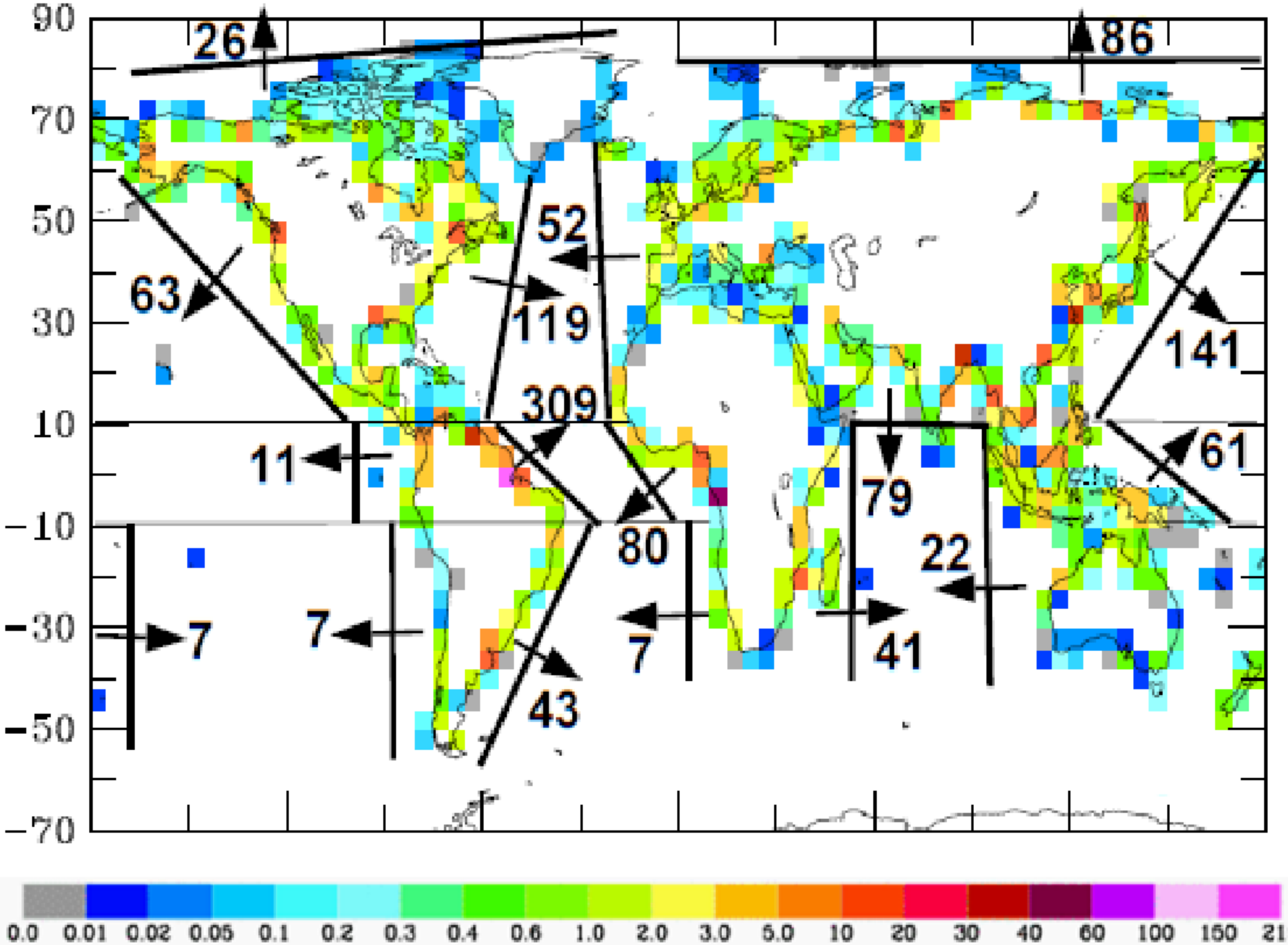


Using NCEP R1: much larger imbalance


CERES TOA Radiation : 2001-2011: EURASIA
CERES TOA Radiation : 2001-2011: AUSTRALIA
R_T
ASR
OLR
ERAI: Atmospheric Budgets 2000-2009
∇.TE
∂TE/∂t
∇.LE
∇.DSE
Implied F_S 2000-2009
R_T - ∇.TE - ∂TE/∂t
W m⁻²
dec jan feb mar apr may jun jul aug sep oct nov dec jan Means
Large variability over Australia and compensation between DSE and LE


CERES TOA Radiation : 2001-2011: South America
CERES TOA Radiation : 2001-2011: AFRICA
R_T
ASR
OLR
ERAI: Atmospheric Budgets 2000-2009
∇.TE
∂TE/∂t
∇.LE
∇.DSE
Implied F_S 2000-2009
R_T - ∇.TE - ∂TE/∂t
W m^{-2}
dec jan feb mar apr may jun jul aug sep oct nov dec jan Means

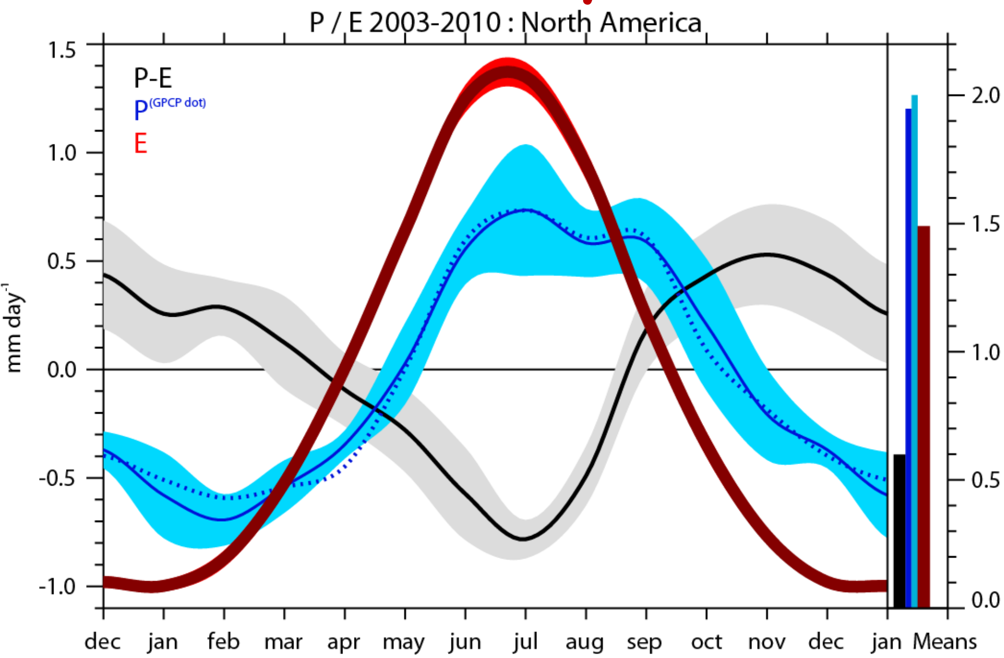
Land runoff



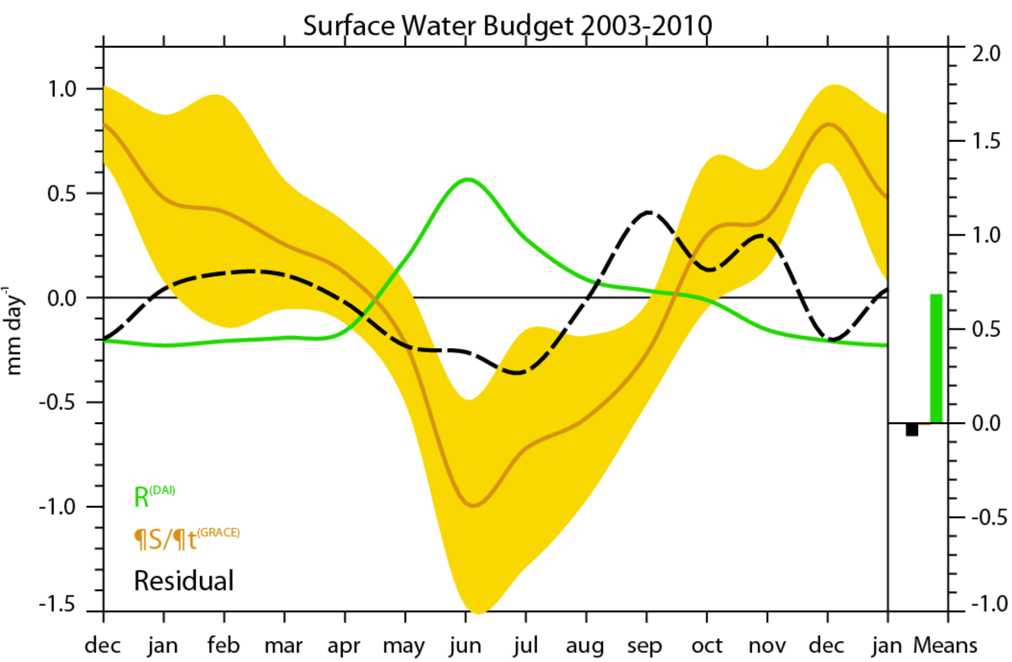
Discharge: 10^3 m^3/s from each 4° lat x5° lon coast

Dai and Trenberth 2002; 2009

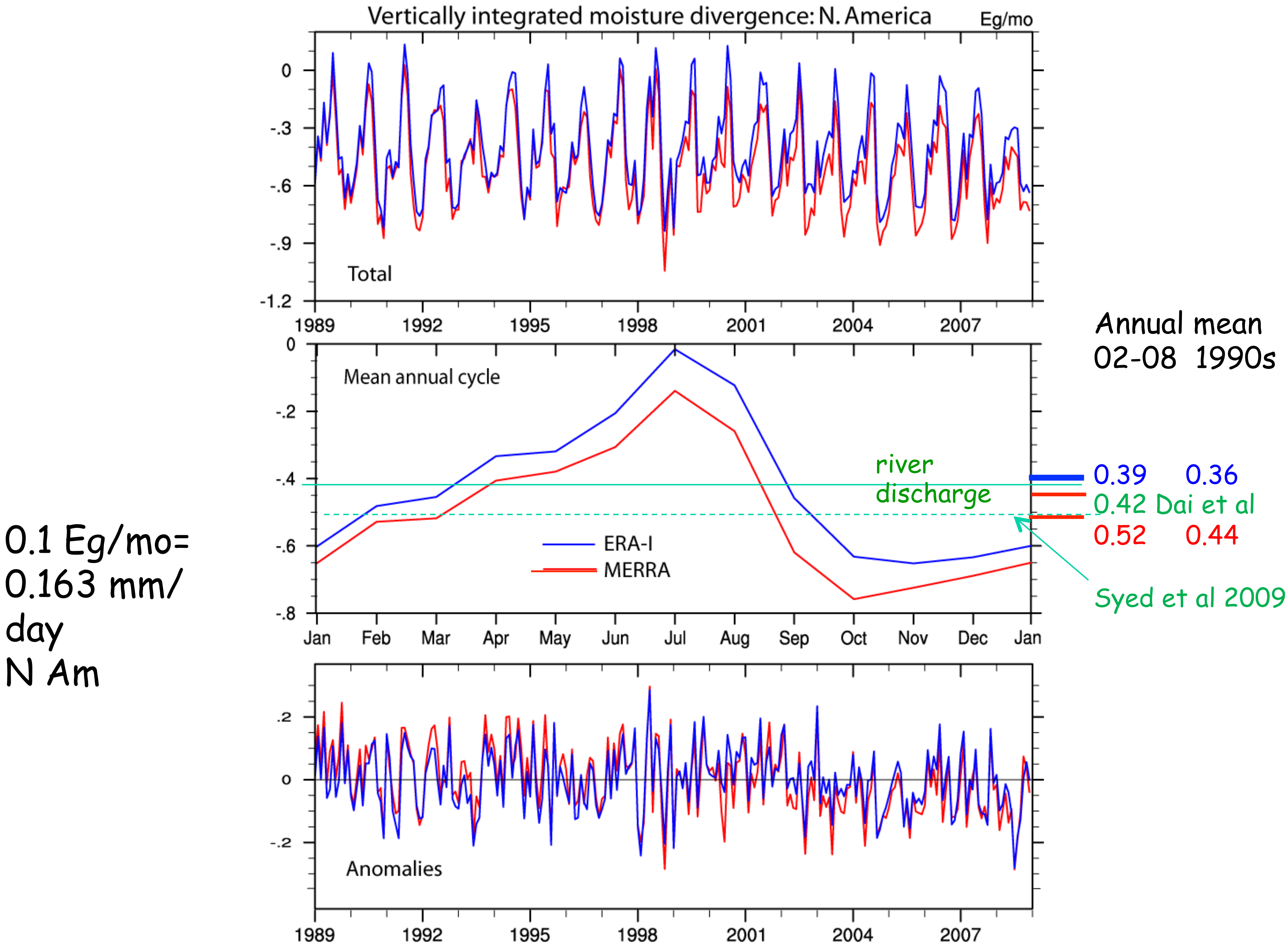
Mean annual cycle ⇓Annual means



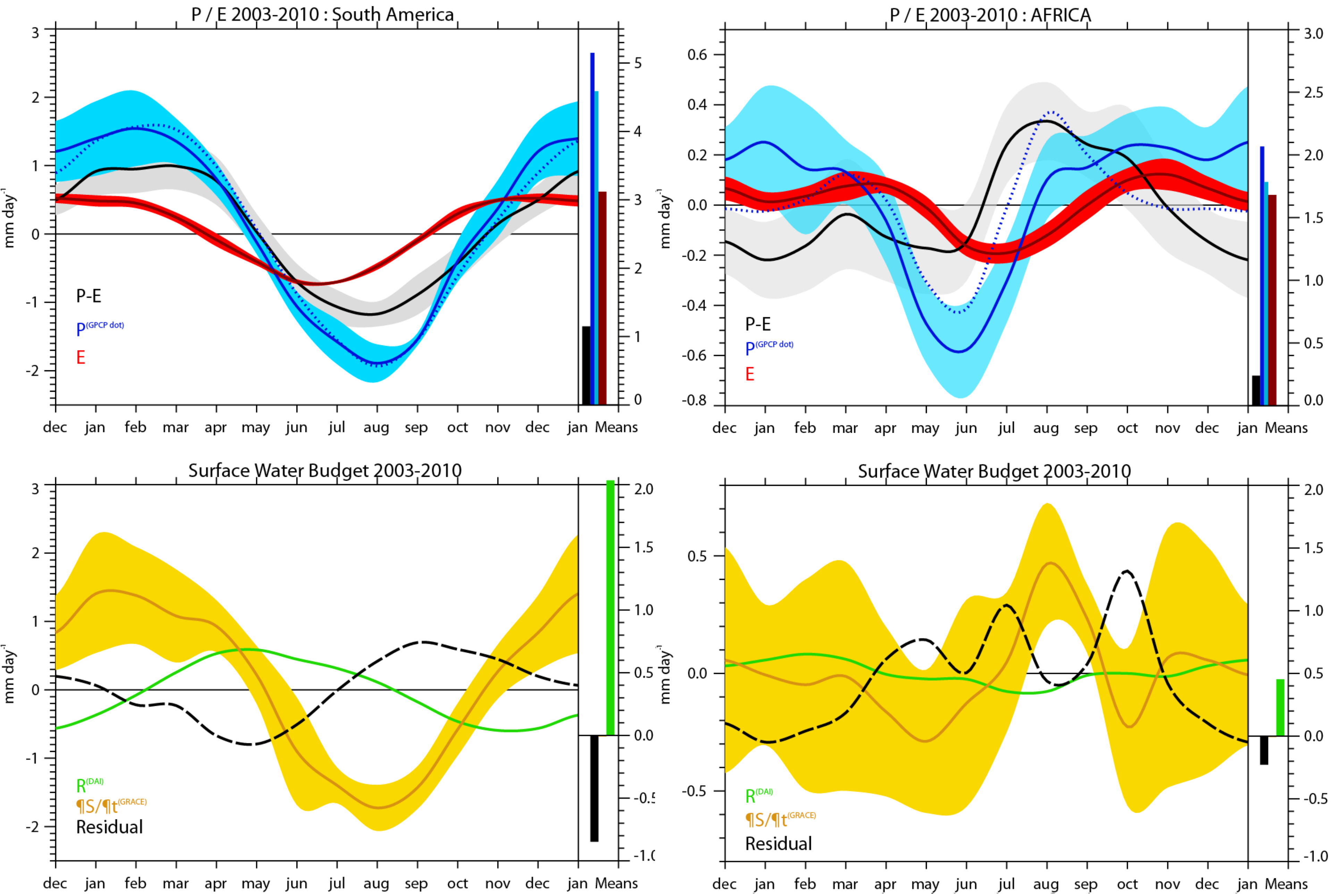
ERA-I
E model
P model P^{GPCP} (dashed)
P-E budget



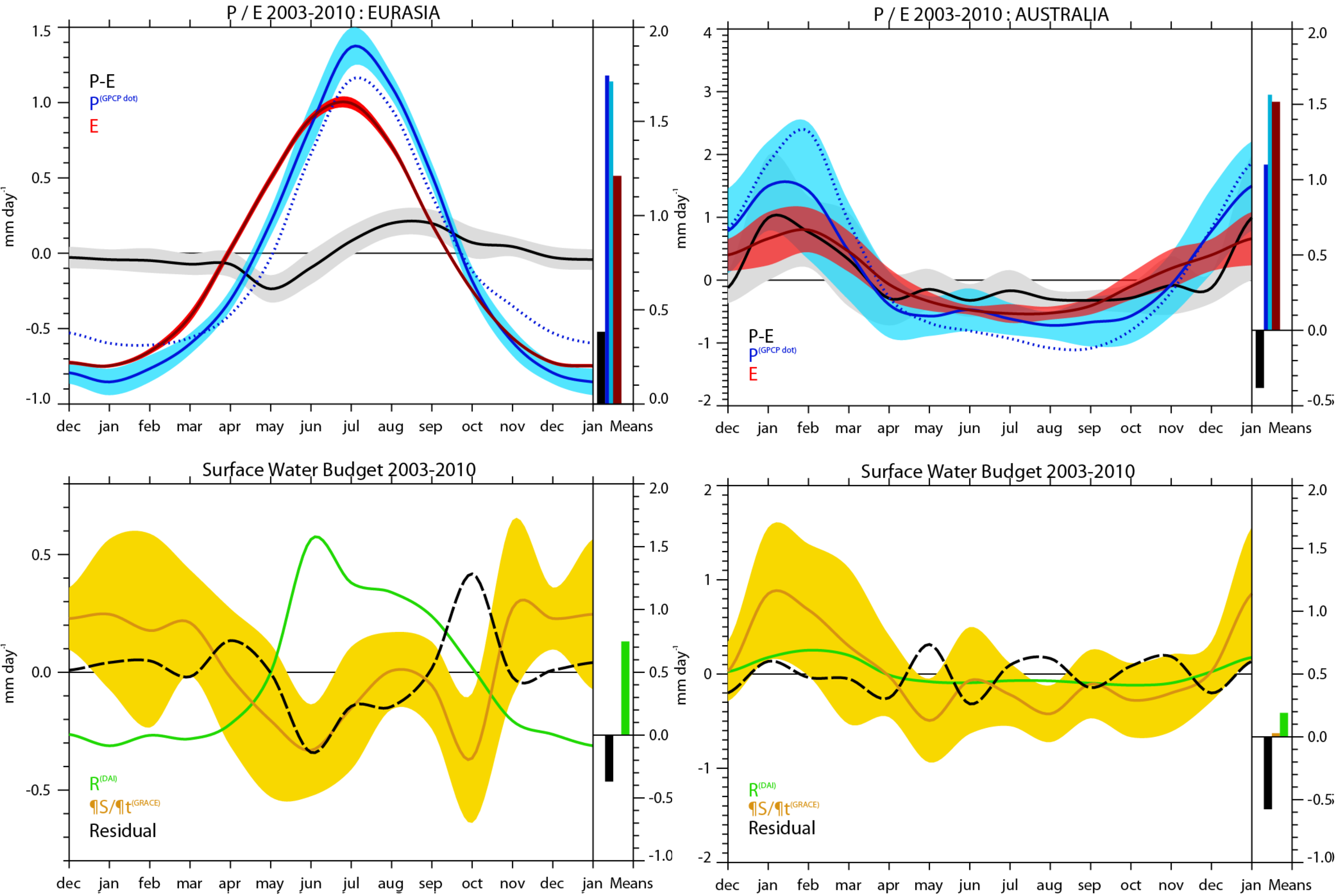
ΔStorage GRACE
Runoff Dai et al
Residual =P-E - R



Vertically integrated moisture divergence: N. America
Eg/mo
0
-.3
-.6
-.9
-1.2
Total
1989
1992
1995
1998
2001
2004
2007
0
-.2
-.4
-.6
-.8
Mean annual cycle
ERA-I
MERRA
river
discharge
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
.2
0
-.2
Anomalies
1989
1992
1995
1998
2001
2004
2007
Annual mean
02-08 1990s
0.39 0.36
0.42 Dai et al
0.52 0.44
Syed et al 2009
0.1 Eg/mo=
0.163 mm/
day
N Am



E too large, P too small, and/or R too large


P / E 2003-2010 : EURASIA
P-E
P(GPCP dot)
E
mm day-1
Means
dec jan feb mar apr may jun jul aug sep oct nov dec jan
P / E 2003-2010 : AUSTRALIA
P-E
P(GPCP dot)
E
mm day-1
Means
dec jan feb mar apr may jun jul aug sep oct nov dec jan
Surface Water Budget 2003-2010
R(DAI)
¶S/¶t(GRACE)
Residual
mm day-1
Means
dec jan feb mar apr may jun jul aug sep oct nov dec jan
Surface Water Budget 2003-2010
R(DAI)
¶S/¶t(GRACE)
Residual
mm day-1
Means
dec jan feb mar apr may jun jul aug sep oct nov dec jan

Implications

Reanalyses

- Ocean E is generally too large, and P is too large except for MERRA
- The low value of P-E over land is consistent with the view that E is too large and P occurs prematurely, so that the role of advection from afar is too low.
- The lifetime of moisture is too short in models.
- The moisture budget provides better estimates and more stable estimates of E-P than model fluxes or E and P.

Concluding remarks

- Regional budgets depend very sensitively on the definition of the domain.
- This is especially so for large contrasts, such as land-ocean boundaries.
- There are large differences in basic fields across reanalyses: land/sea mask, topography, as well as with resolution
- There remain large differences among reanalyses
- Reanalyses do not produce a consistent record in time to allow low frequency variability or trends to be documented well: with a few exceptions: sfc T?
- There are substantial improvements in some reanalyses, notably ERA-I.
- We can and must do better.