Interannual Variations in Atmospheric Energy and Moisture Budgets

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Goal

- Analyze interannual variations in atmospheric energy and moisture budgets from reanalysis & observation-based datasets during past 12 years.
- Stratify data according to large-scale domains corresponding to ascending and descending branches of Hadley Circulation.
- How do interannual variations in atmospheric radiation, precipitation, sensible heat and dry static energy divergence co-vary in different circulation regimes?

Data Used

- ERA-Interim monthly reanalysis data

- CERES EBAF Ed2.7 TOA and SFC radiation (March 2000-March 2012).

- GPCP V2.2 precipitation

Dry Static Energy Budget

- On annual mean time-scale:

$$R_a + LP + S = H$$

R_a = net atmospheric radiation (=$R_{toa} - R_{sfc}$)
P = precipitation rate
L = Latent heat of vaporization
S = Surface sensible heat flux
H = Vertical integral of divergence of dry static and kinetic energy.

$$H = \boldsymbol{\nabla}.\frac{1}{g}\int_0^{p_s}(s+k)\boldsymbol{v}dp$$

where $s=c_p T + gz$ is the dry static energy and k is kinetic energy.

Moist Static Energy Budget

$$R_a + LE + S = M$$

R_a = Net atmospheric radiation (=R_{toa} – R_{sfc})
E = Evaporation rate
L = Latent heat of vaporization
S = Surface sensible heat flux
M = Vertical integral of divergence of moist static and kinetic energy.

$$M = \boldsymbol{\nabla}.\frac{1}{g}\int_0^{p_s}(h+k)\boldsymbol{v}dp$$

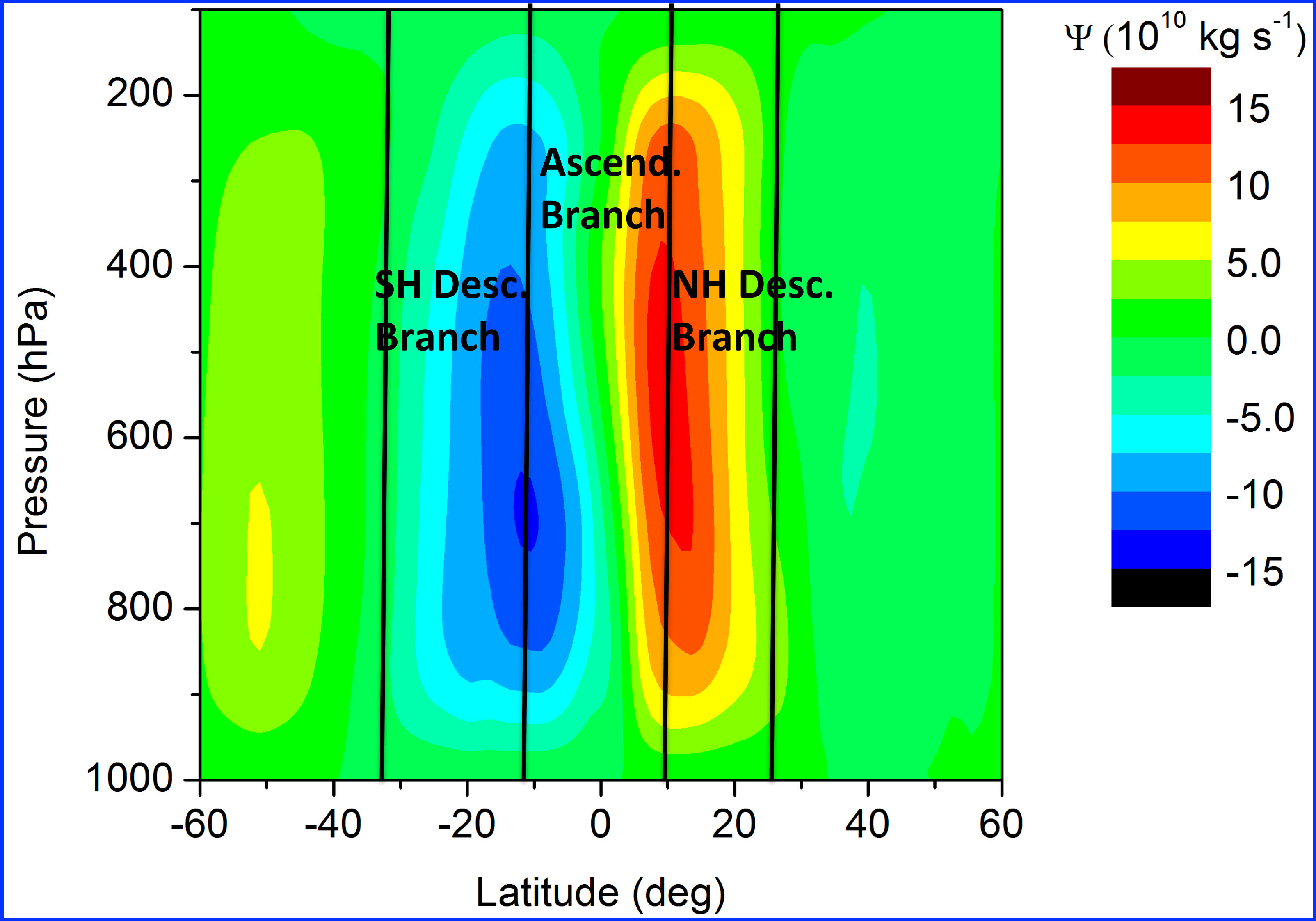
where h = s + Lq is the moist static energy and k is kinetic energy.

Moisture Budget

- From difference between DSE and MSE budgets:

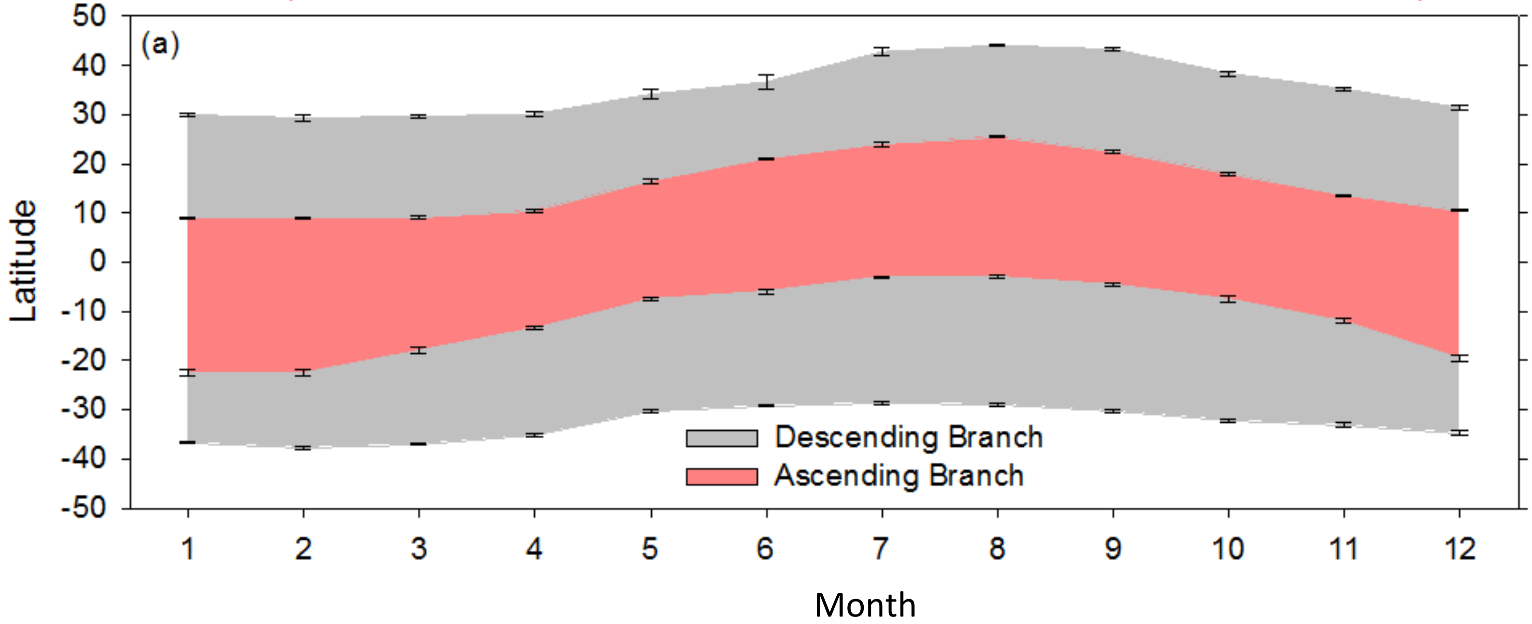
$$L(P-E) = H - M = -\boldsymbol{\nabla}.\frac{1}{g}\int_0^{p_s}(Lq)\boldsymbol{v}dp$$

Analysis Domains: 3 Branches of Hadley Ciculation

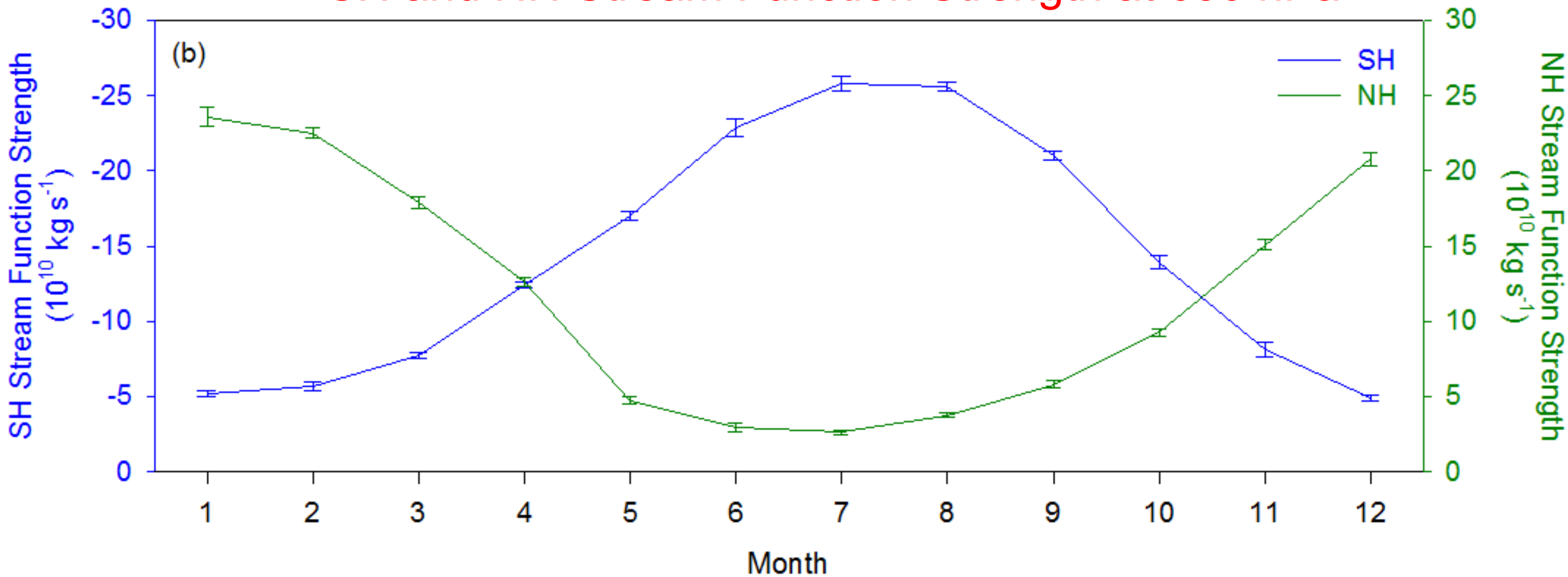


- Evaluate time variation in ATM energy budget within 3 branches of Hadley Circulation.
- The averaging domains change with season (follow large-scale circulation).

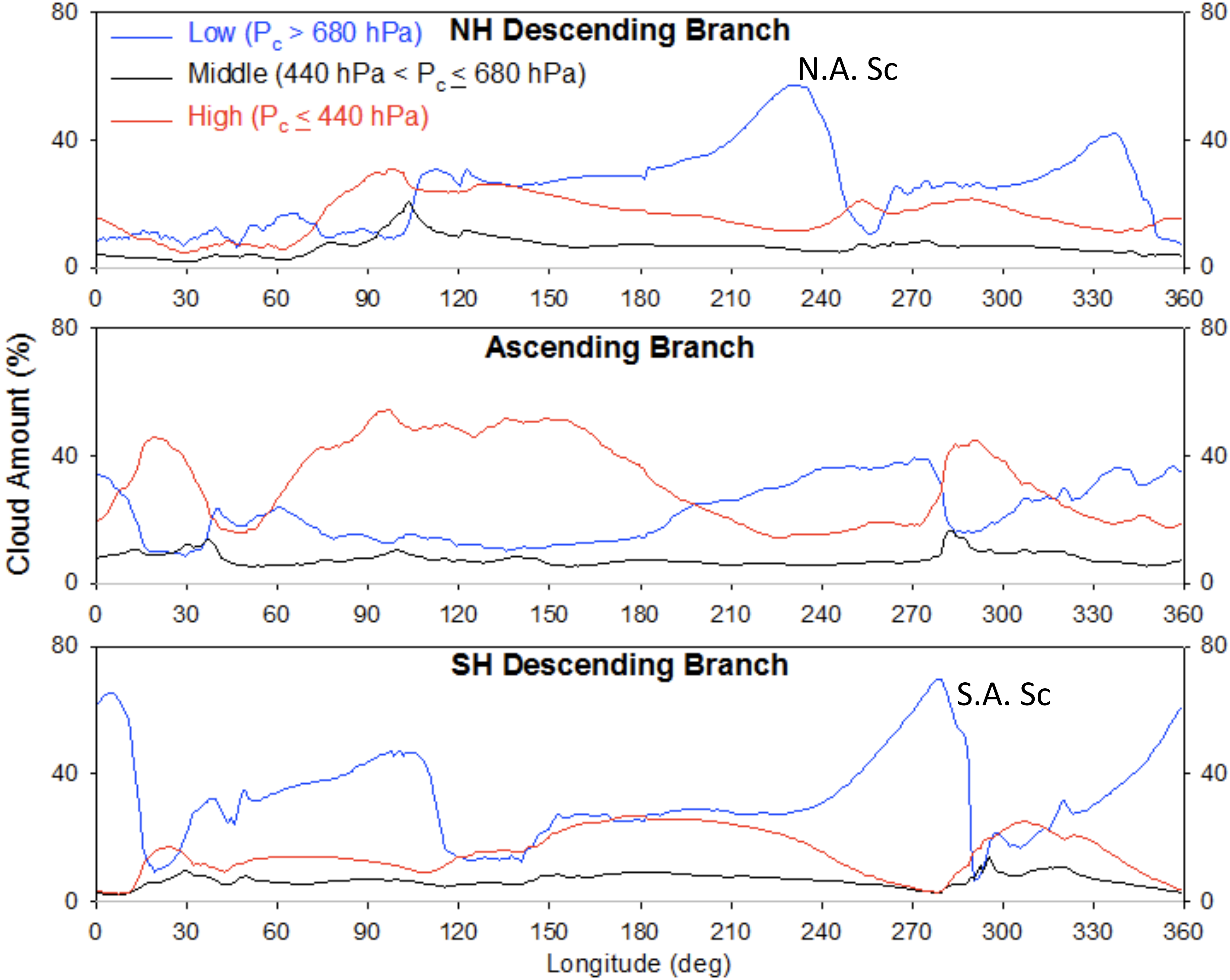
Annual cycle of Latitudinal Boundaries of 3 Branches of Hadley Circulation



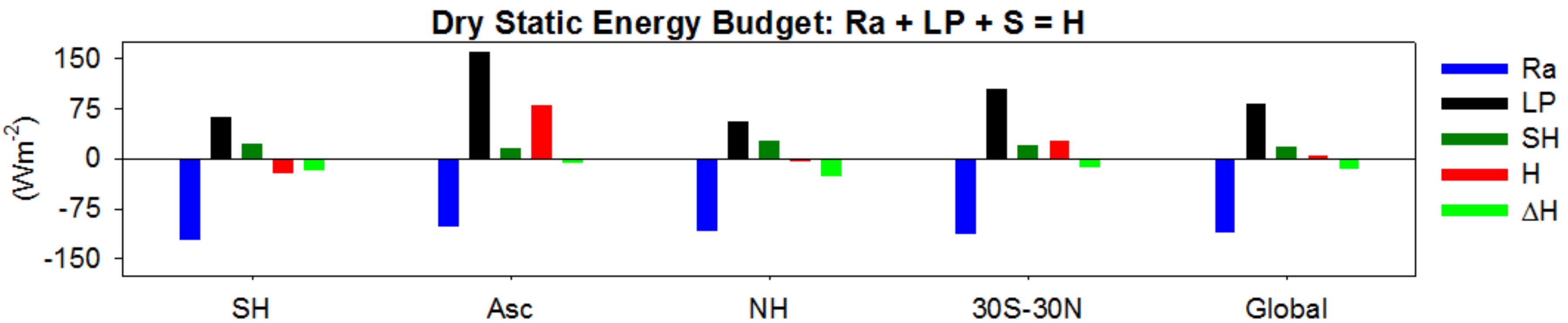
SH and NH Stream Function Strength at 650 hPa



Mean Cloud Fraction (MODIS)

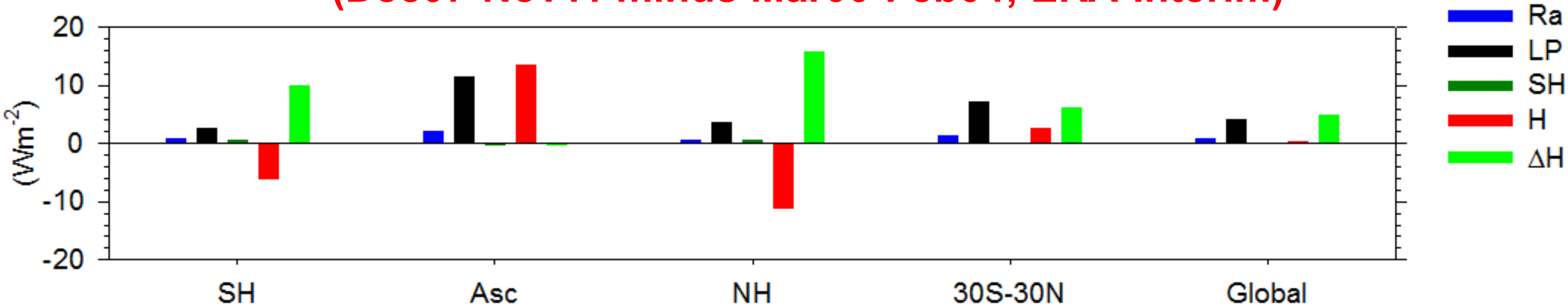


Dry Static Energy Budget
(March 2000 – February 2010; ERA-Interim)



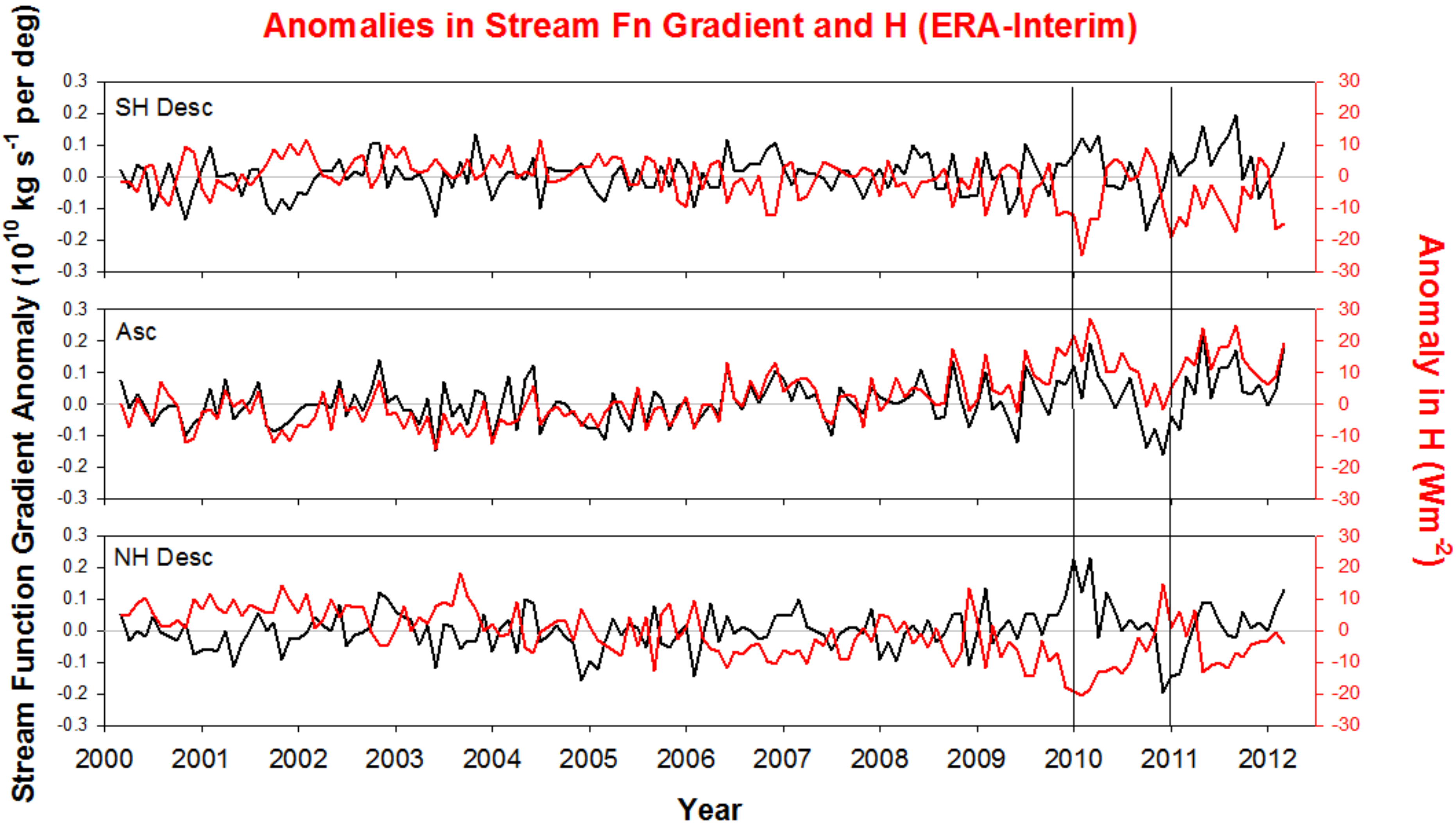
- Asc Branc: Latent heating > Radiative cooling => Divergence of DSE (H > 0)
- Desc Branches: Radiative cooling > Latent heating => Convergence of DSE (H < 0)

Change in Dry Static Energy Budget
(Dec07-Nov11 minus Mar00-Feb04; ERA-Interim)

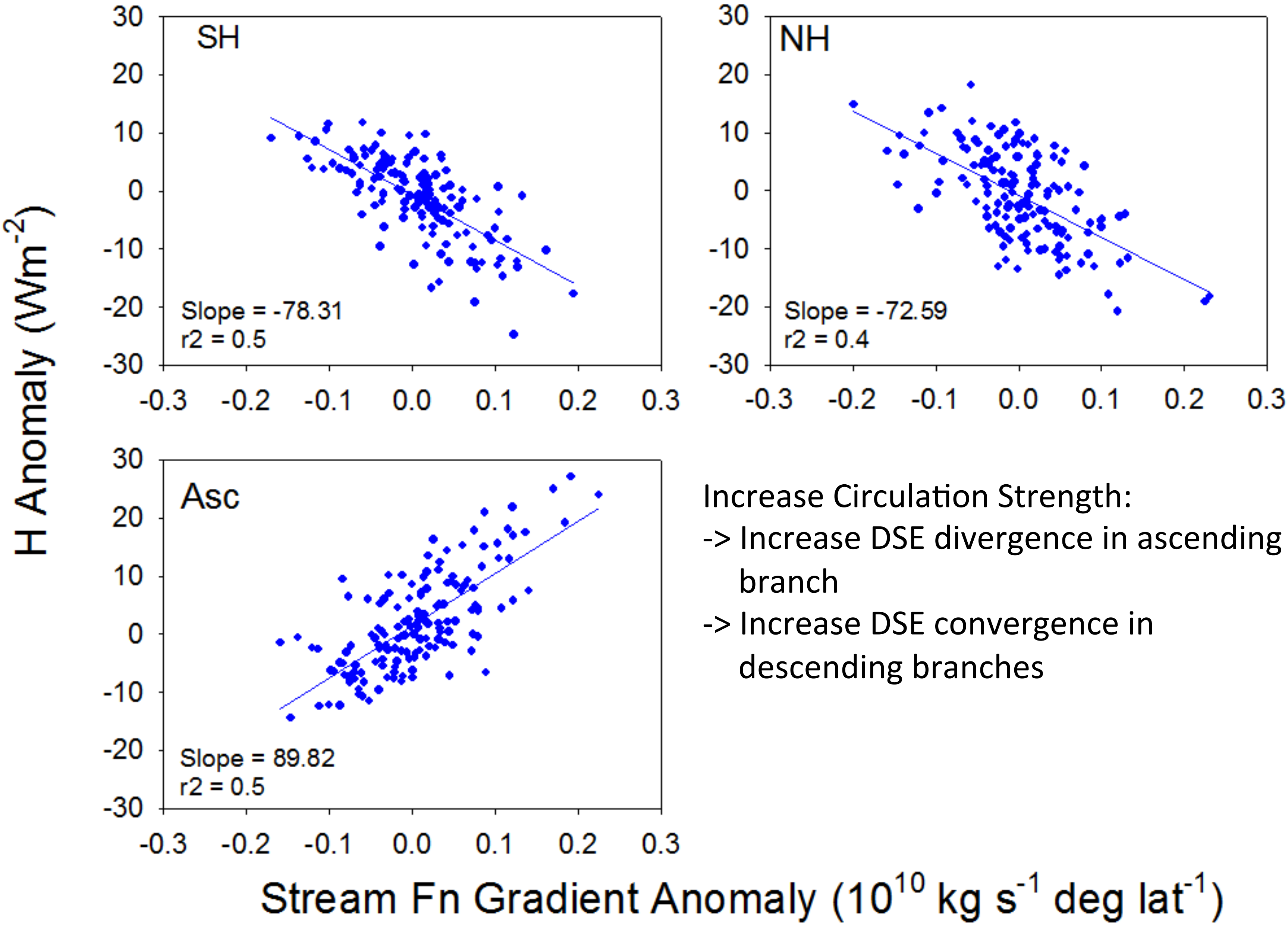


- Increase in precipitation everywhere, especially ascending branch.
- Large increase in H in ascending branch; large decrease in H in descending branches.
  => Increase in circulation strength?

Relationship with Hadley Circulation Strength



DSE Divergence vs Strength of Hadley Circulation

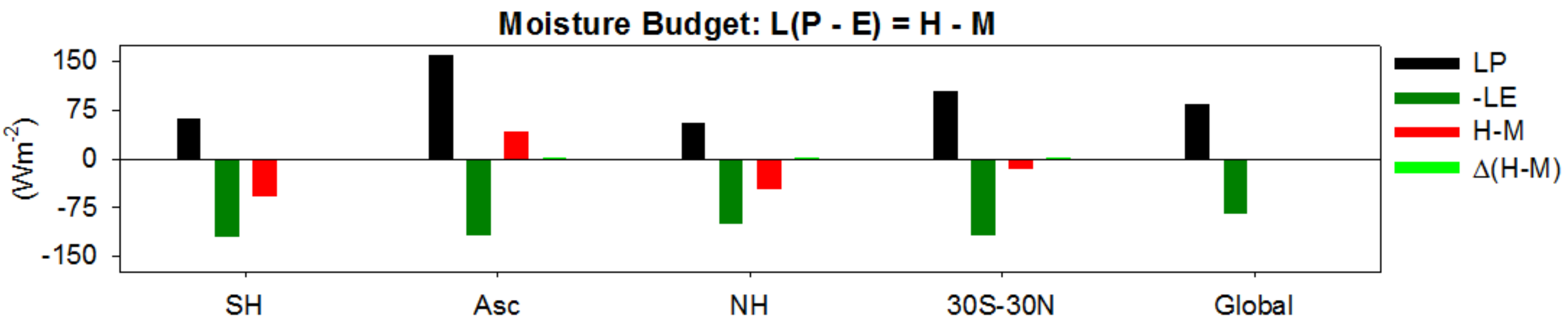


Increase Circulation Strength:

-> Increase DSE divergence in ascending branch

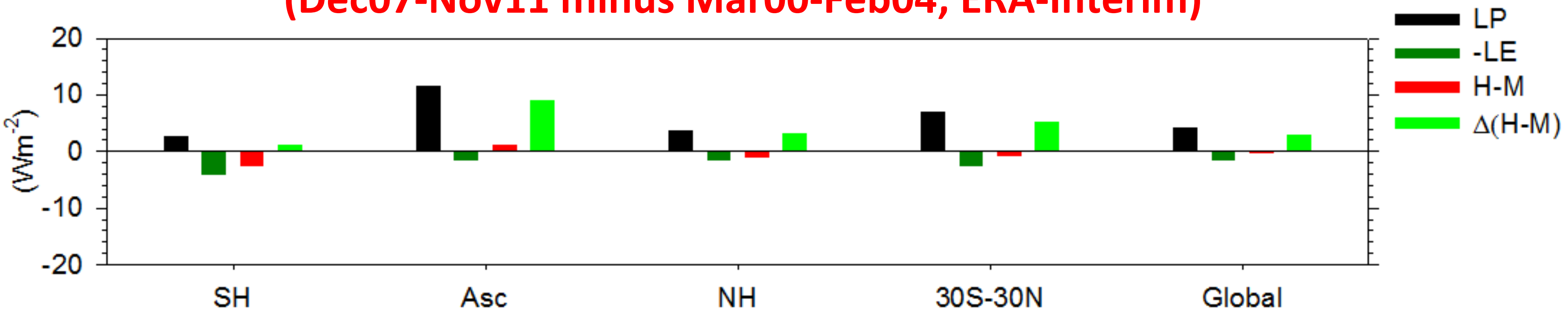
-> Increase DSE convergence in descending branches

Moisture Budget
(March 2000 – February 2010; ERA-Interim)

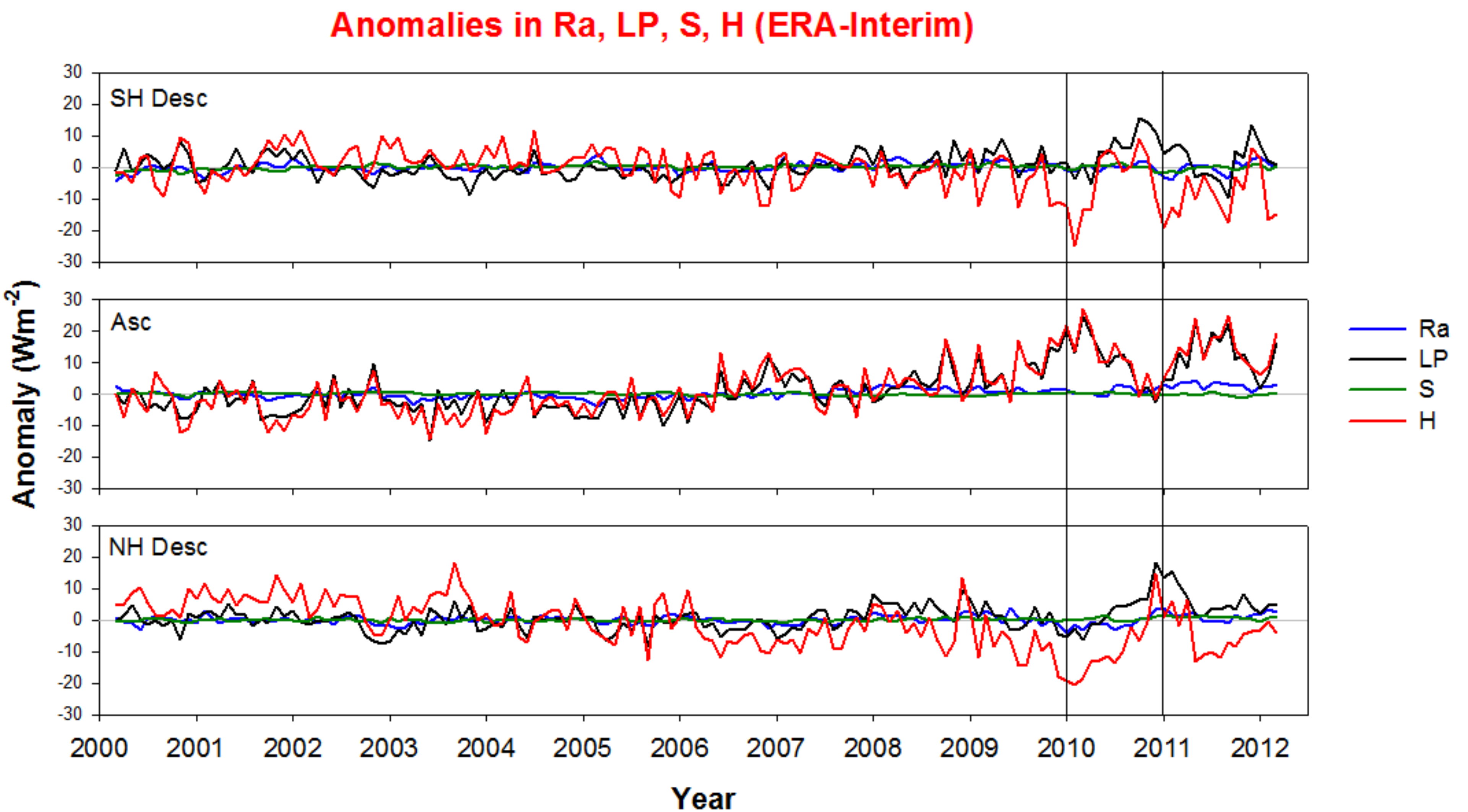


- Asc Branc: LP > LE => Moisture Convergence (H-M > 0)
- Desc Branches: LE > LP => Moisture Divergence (H-M < 0)

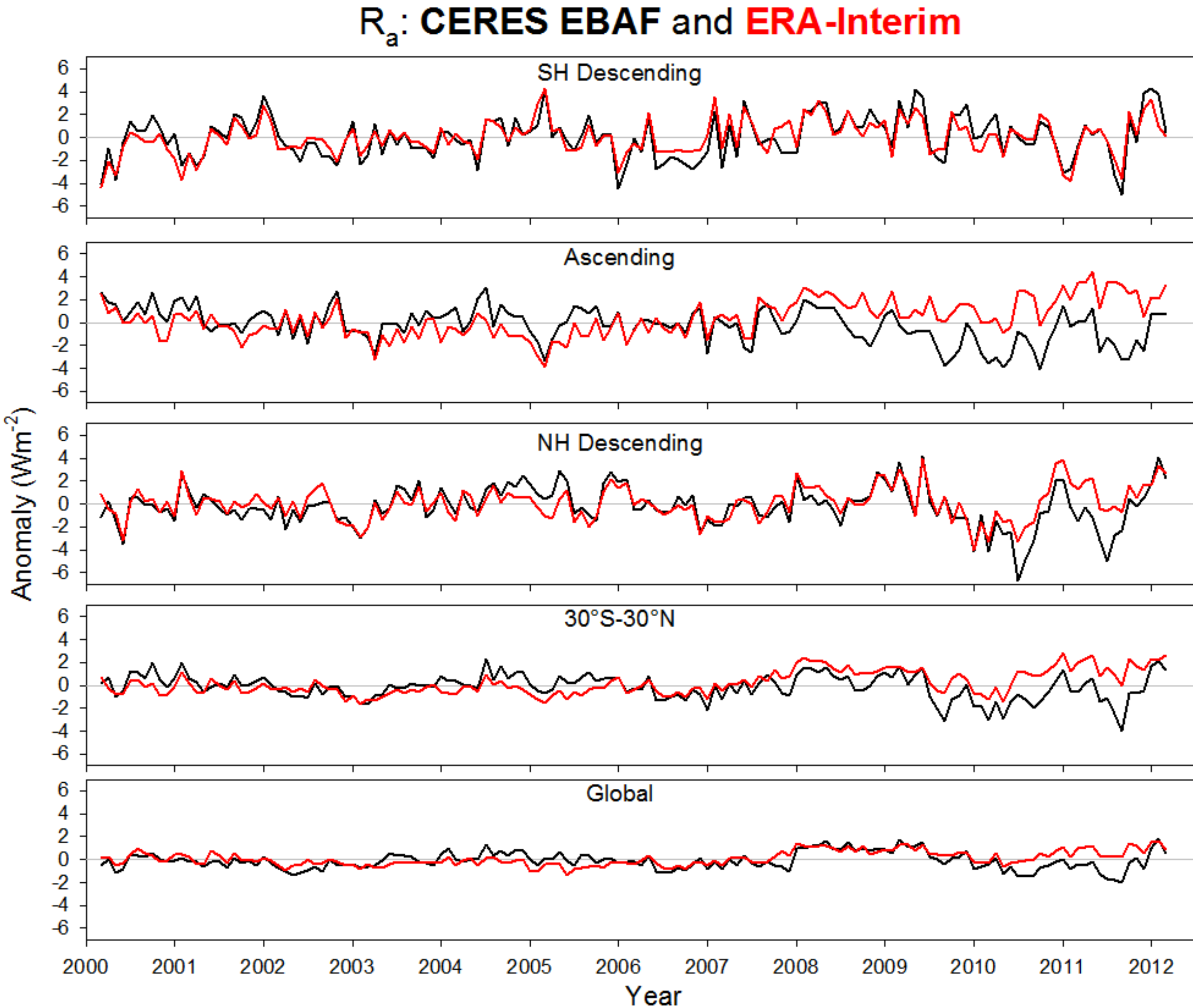
Change in Moisture
(Dec07-Nov11 minus Mar00-Feb04; ERA-Interim)



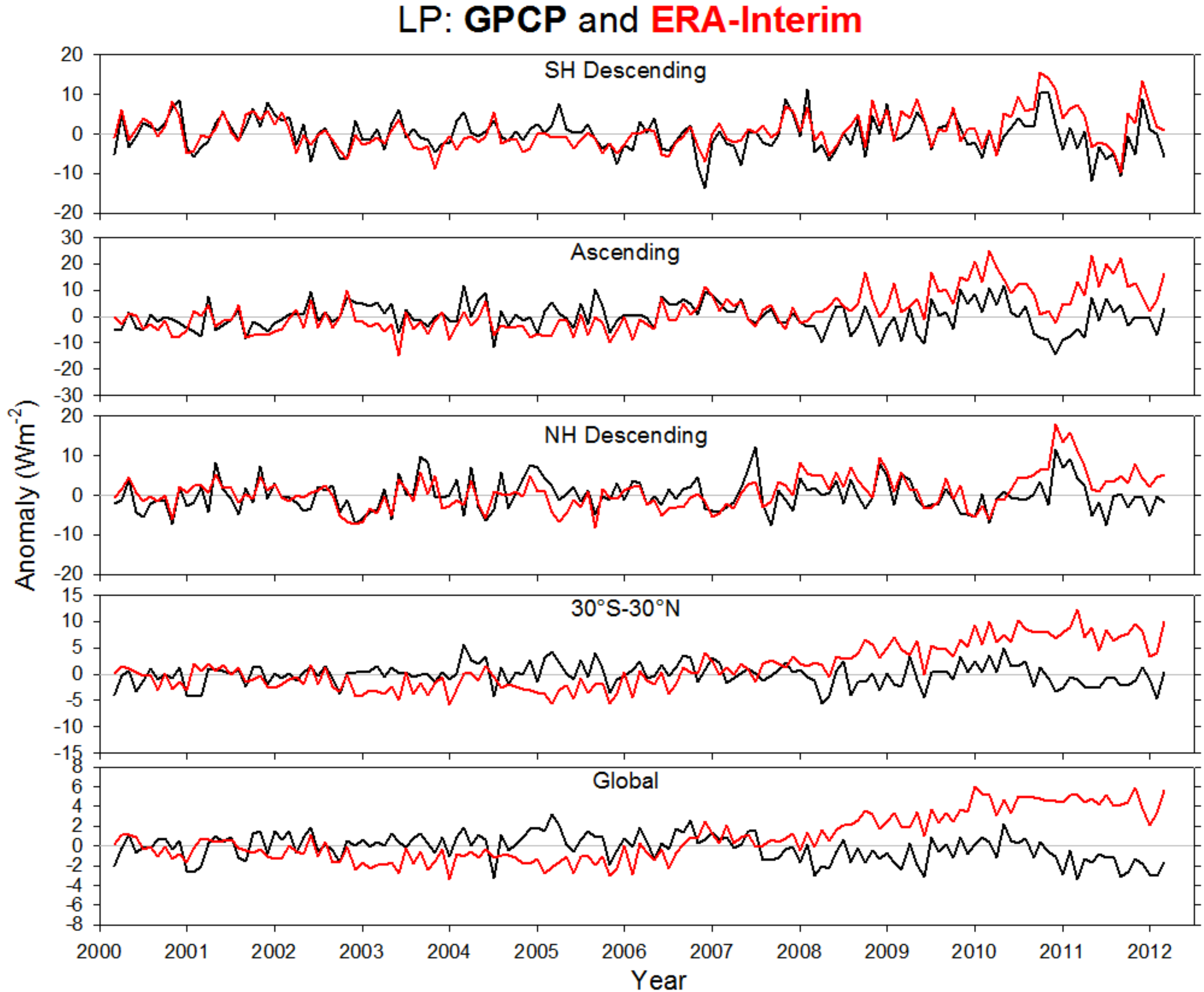
- Increase in LP not balanced by increase in LE and/or moisture convergence/divergence.
- Large imbalance in moisture budget during latter portion of record.



Anomalies in Ra, LP, S, H (ERA-Interim)
SH Desc
Asc
NH Desc
Anomaly (Wm-2)
Year
Ra
LP
S
H
30
20
10
0
-10
-20
-30
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012

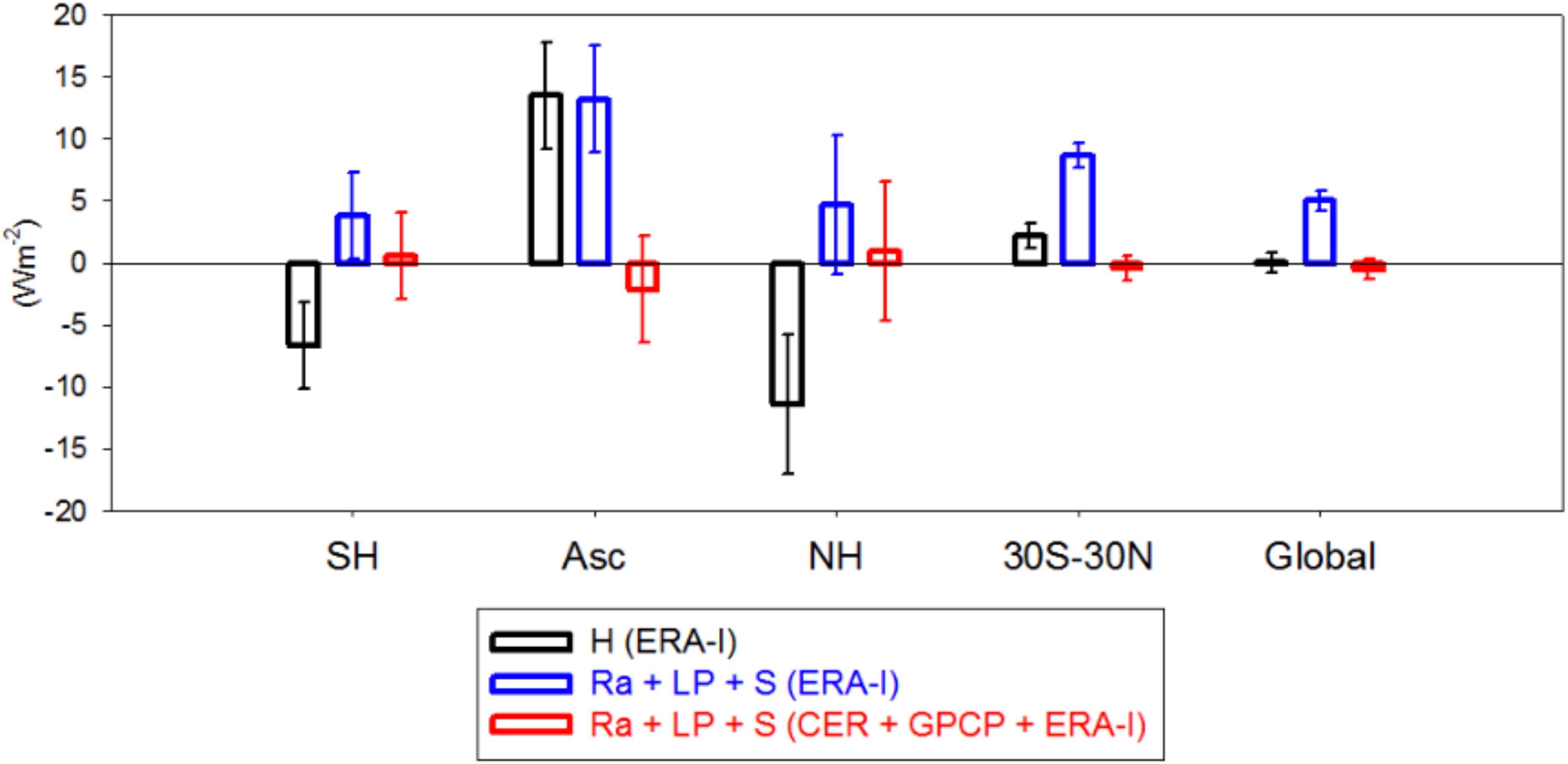


Rₐ: CERES EBAF and ERA-Interim
SH Descending
Ascending
NH Descending
30°S-30°N
Global
Anomaly (Wm⁻²)
6
4
2
0
-2
-4
-6
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year



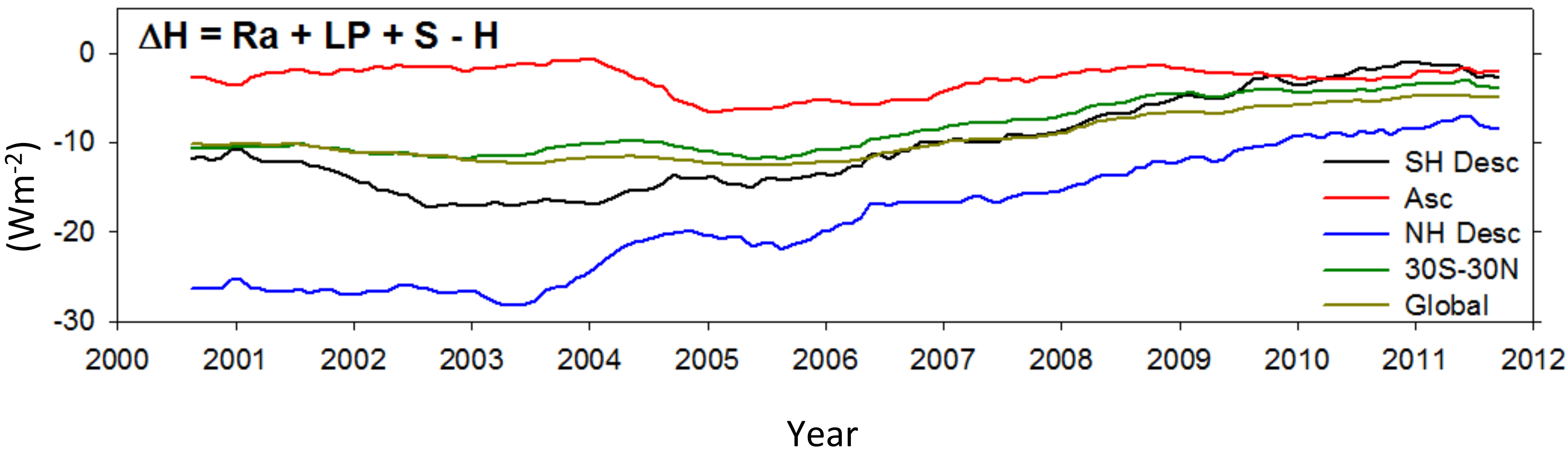
LP: GPCP and ERA-Interim
SH Descending
Ascending
NH Descending
30°S-30°N
Global
Anomaly (Wm-2)
Year
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012

Change in H
(Dec07-Nov11 minus Mar00-Feb04)



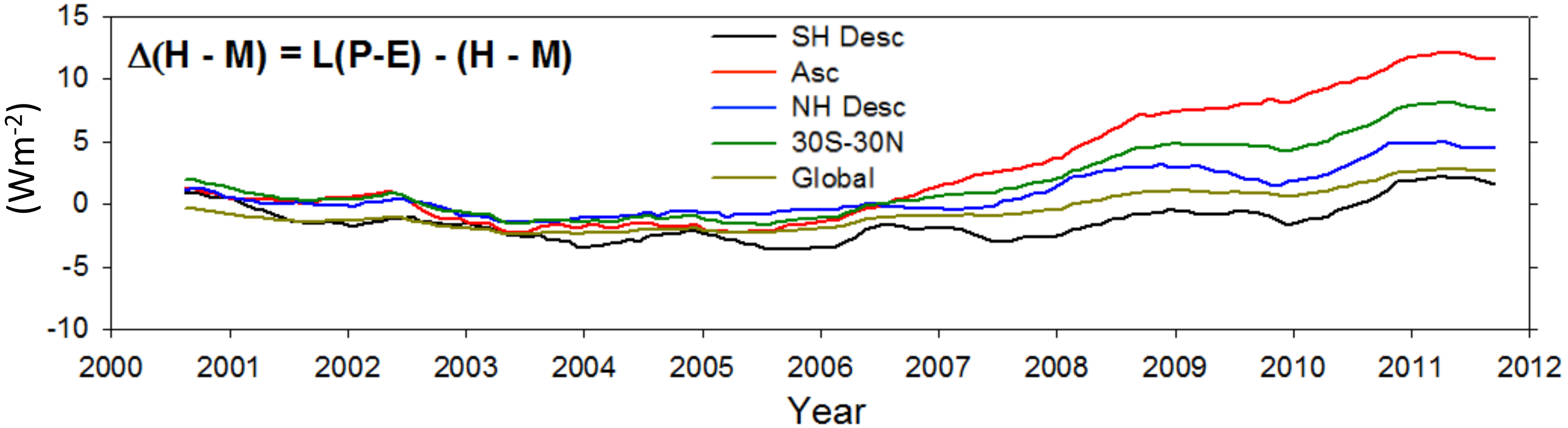
- Observations (CERES+GPCP) show no significant change in H (circulation strength) during past decade.

Time Variation in Dry Static Energy Imbalance (ERA-Interim)



- Near zero ΔH in ascending branch due to balance between LP and H throughout record.
- Large increase in convergence of DSE (H < 0) in subsidence branches reduces ΔH during latter part of record.

Time Variation in Moisture Imbalance (ERA-Interim)

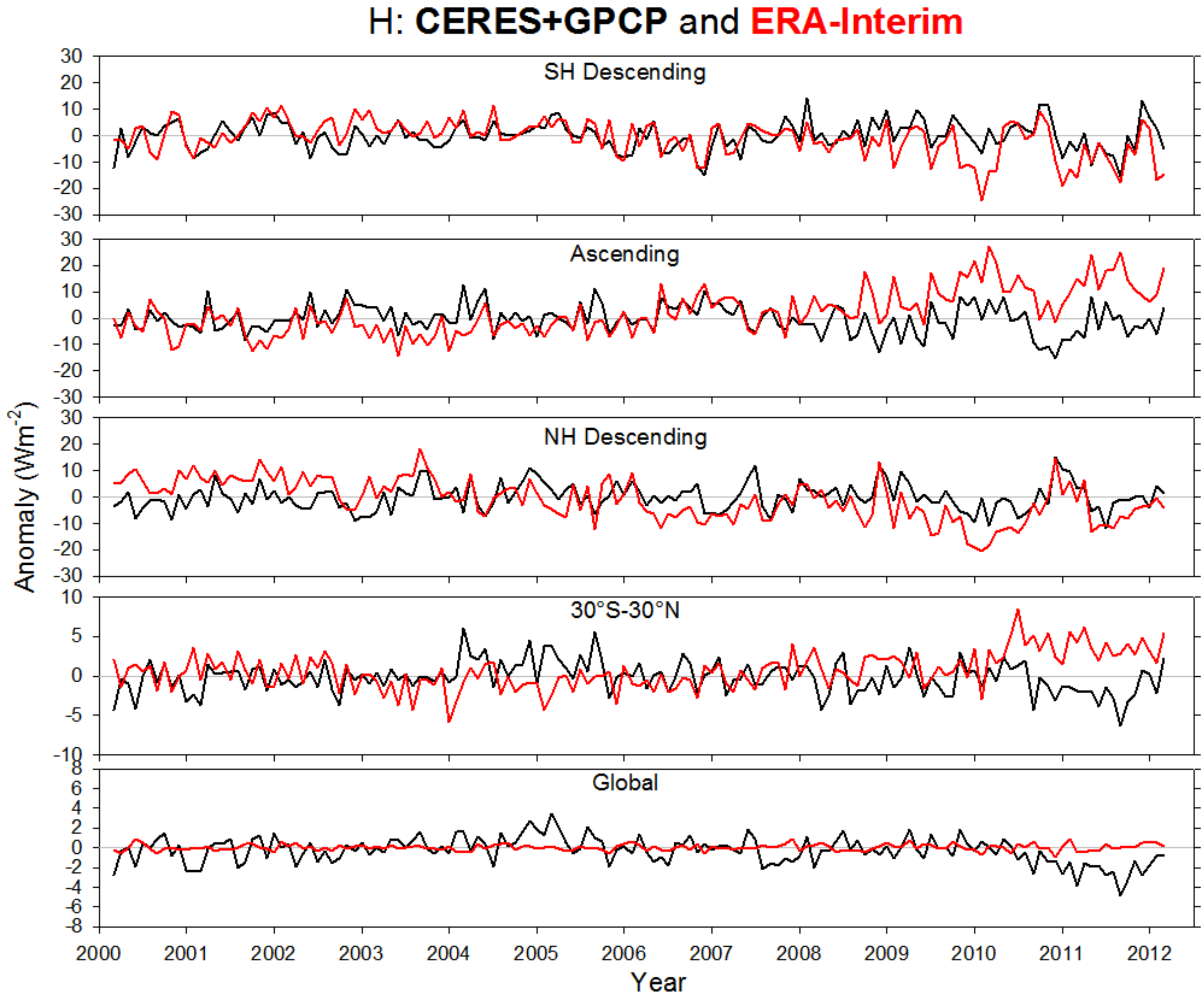


- While atmospheric energy imbalance becomes smaller during latter part of the record, moisture imbalance gets larger due to precipitation increase.

Summary

- Atmospheric energy budget:
  - Asc Branc: Latent heating > Radiative cooling => Divergence of DSE (H > 0).
  - Desc Branches: Radiative cooling > Latent heating => Convergence of DSE (H < 0).
- H correlated with strength of Hadley circulation (r ~ 0.7).
- ERA-Interim shows marked increase in precipitation after 2009, especially in ascending branch of Hadley circulation.
  - This is accompanied by large increase in H in ascending branch & large decrease in descending branch.

  ⇒ Increase in circulation strength?
- H determined as residual (Ra+LP+S) from observations (CERES, GPCP) does not show a significant change during CERES period.
- ERA-I record also shows huge temporal swings in ATM energy & moisture imbalances, which depend upon circulation regime.
- Suggests there are spurious drifts in P and H in ERA-I (input changes?).


H: CERES+GPCP and ERA-Interim
SH Descending
Ascending
NH Descending
30°S-30°N
Global
Anomaly (Wm^{-2})
Year
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012