Land-Atmosphere Interaction: Part II

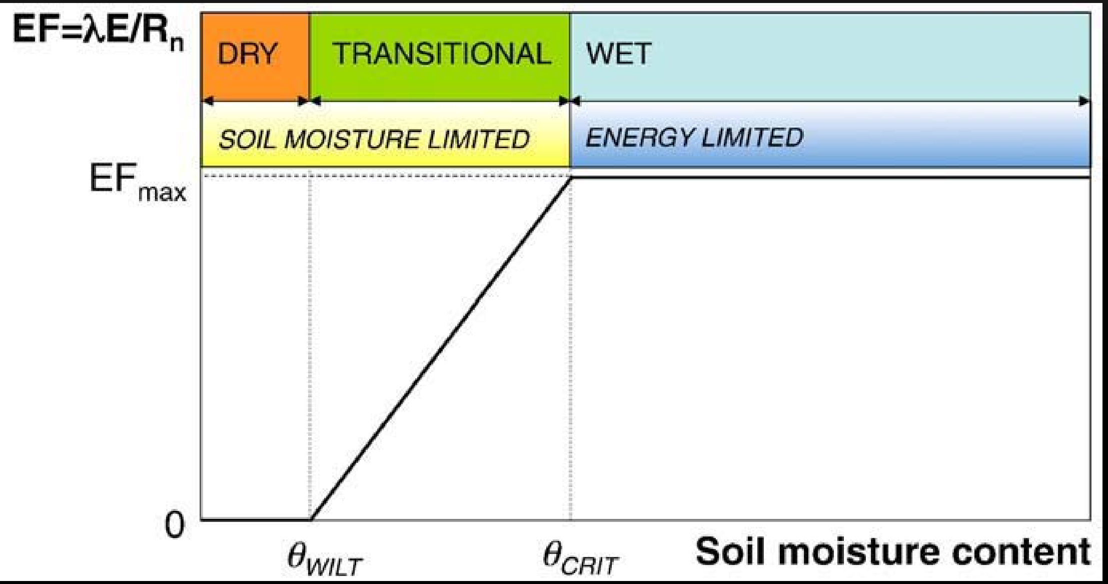
Outline

- Definition of soil moisture
- Land water budget
- Land energy budget
- Land-atmosphere interaction

Land-Atmosphere Interaction

- Evapotranspiration (latent heat flux) from land is both a water flux and an energy flux, and soil moisture is both a water and energy storage.
- The land energy and water balances are coupled through the evapotranspiration term (E, λE). Thus soil moisture plays a key role both in the water and energy cycles
- Other impacts: soil moisture-albedo feedback; soil moisture interaction with biochemical cycle; non-local impacts of soil moisture (via changes in large-scale circulation or moisture advection)
- *Does this mean soil moisture is an important constrain on evapotranspiration in all climate regimes?*
  - The answer is no. Soil moisture is the main controlling factor for evapotranspiration only in some regions.

How do you expect evapotranspiration to vary with soil moisture?



EF (the evaporative fraction) is the ratio of LH to Rn, and EFmax its maximal value.

Three climate/soil moisture regimes

- Wet: Above a given critical soil moisture value θ_{CRIT}, evapotranspiration is independent of the soil moisture content.
- Dry: Under θ_{WILT}, no evapotranspiration takes place anymore
- Transitional: Between θ_{CRIT} and θ_{WILT}, evapotranspiration increases with soil moisture.

Two main evapotranspiration regimes

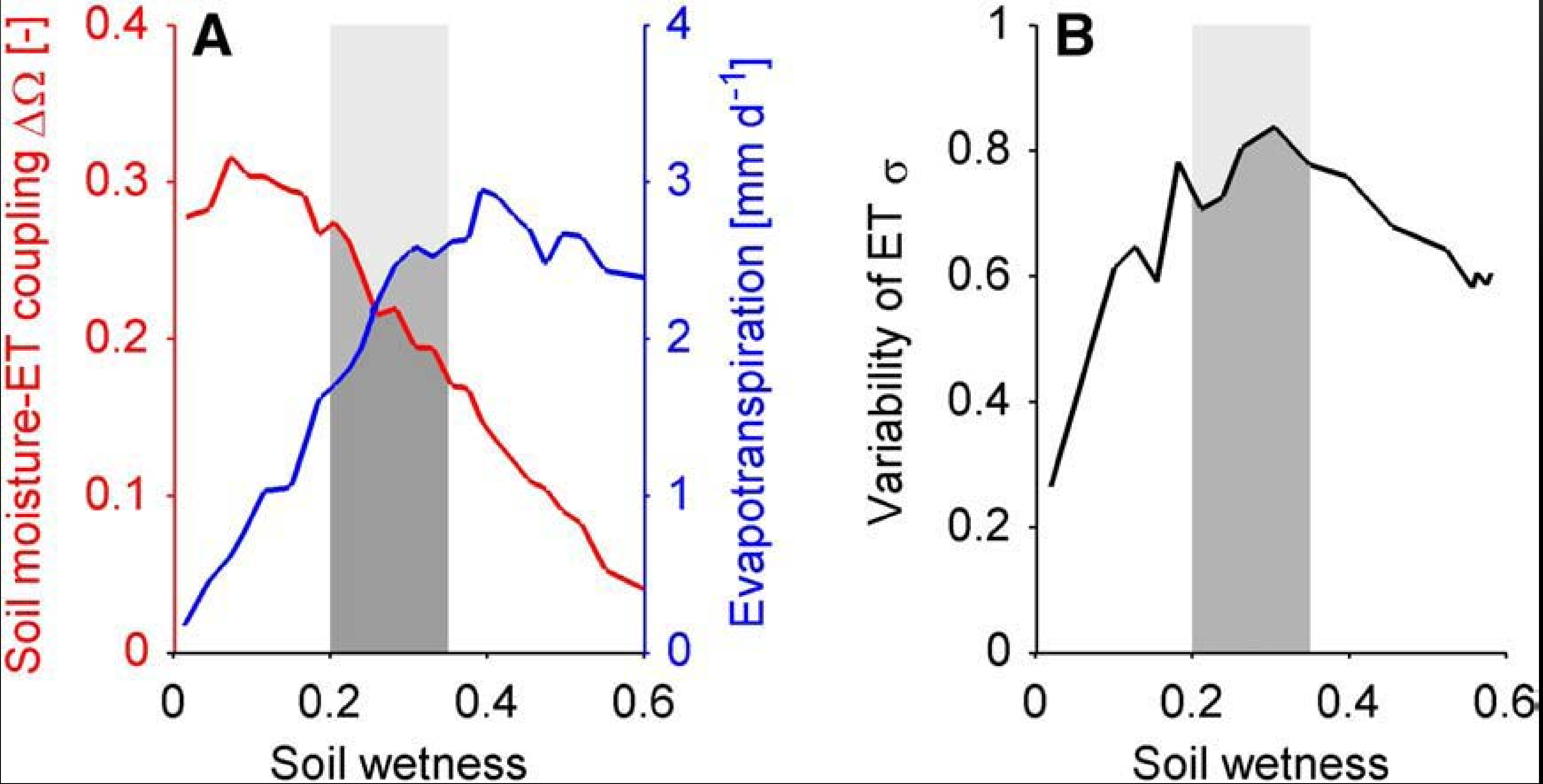
- The soil moisture-limited evapotranspiration regime: below θ_{CRIT}, soil moisture content provides a first-order constraint on evapotranspiration.
- In the energy-limited evapotranspiration regime ($\theta>\theta_{CRIT}$), evaporative fraction has reached its maximum and ET is independent of the soil moisture content.

Seneviratne et al. 2010

Three climate/soil moisture regimes:

- Three climate/soil moisture regimes can be defined, related to the impact of soil moisture on evapotranspiration variability
  - dry ($\theta<\theta_{WILT}$) climate regime (no evaporation)
  - Wet ($\theta>\theta_{CRIT}$) climate regime
  - transitional climate regime ($\theta_{WILT}\leq\theta\leq\theta_{CRIT}$)
- Only in the transitional climate regime soil moisture strongly constrains evapotranspiration variability and thus results feedbacks to the atmosphere.
- Strong soil moisture–climate coupling requires: D
  - a strong dependency of evapotranspiration on soil moisture and
  - large mean evapotranspiration so there are appreciable impacts on the atmosphere.

Coupling of soil moisture and evapotranspiration in GLACE simulations



- In dry regime, evapotranspiration is strongly controlled by soil moisture (red line in left panel), but its absolute value (blue line) and variations (right panel) are too small to impact climate variability.
- In wet regime, the evapotranspiration (blue line) is large, but is not controlled by soil moisture, thus soil moisture has little impact on evapotranspiration (red line).
- Only in transitional regime between dry and wet climates are both conditions met for strong soil moisture–climate coupling: a strong dependency of evapotranspiration on soil moisture and large mean evapotranspiration

Seneviratne et al. 2010

Examples

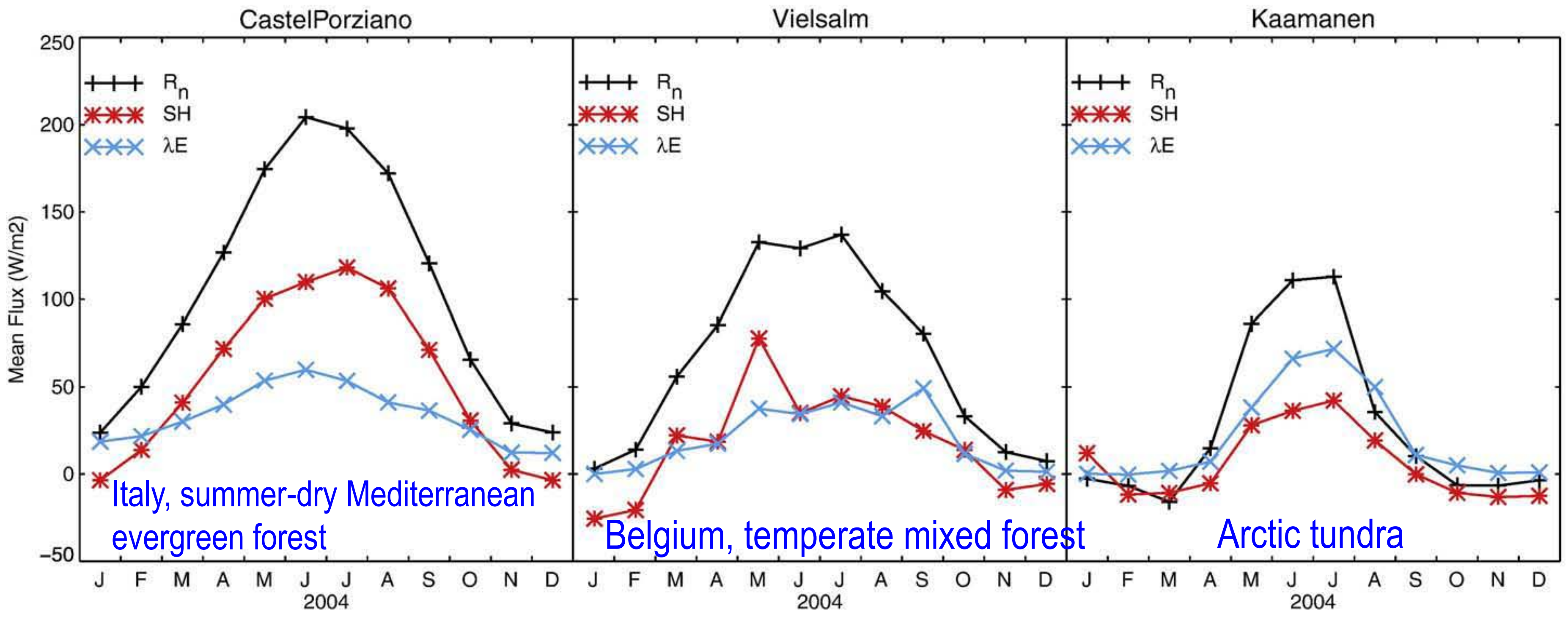


Fig. 7. Monthly net radiation (R_n), latent heat flux (λE) and sensible heat flux (SH) during 2004 at three CarboEurope flux tower sites covering a wide range of climate zones: Castelporziano, Italy (summer-dry Mediterranean evergreen forest, Reichstein et al., 2002); Vielsalm, Belgium (temperate mixed forest, Aubinet et al., 2001); and Kaamanen, Finland (Arctic tundra, Aurela et al., 2002). [Figure adapted from Seneviratne and Stöckli, 2008].

- This analysis shows how drivers of evapotranspiration vary with climate regimes. Soil moisture is the limiting factor in the Mediterranean site (left), while at the arctic tundra site the low evapotranspiration is due to energy (radiation) limitation and the short growing season length (right).

Seneviratne et al. 2010

Soil moisture–temperature coupling

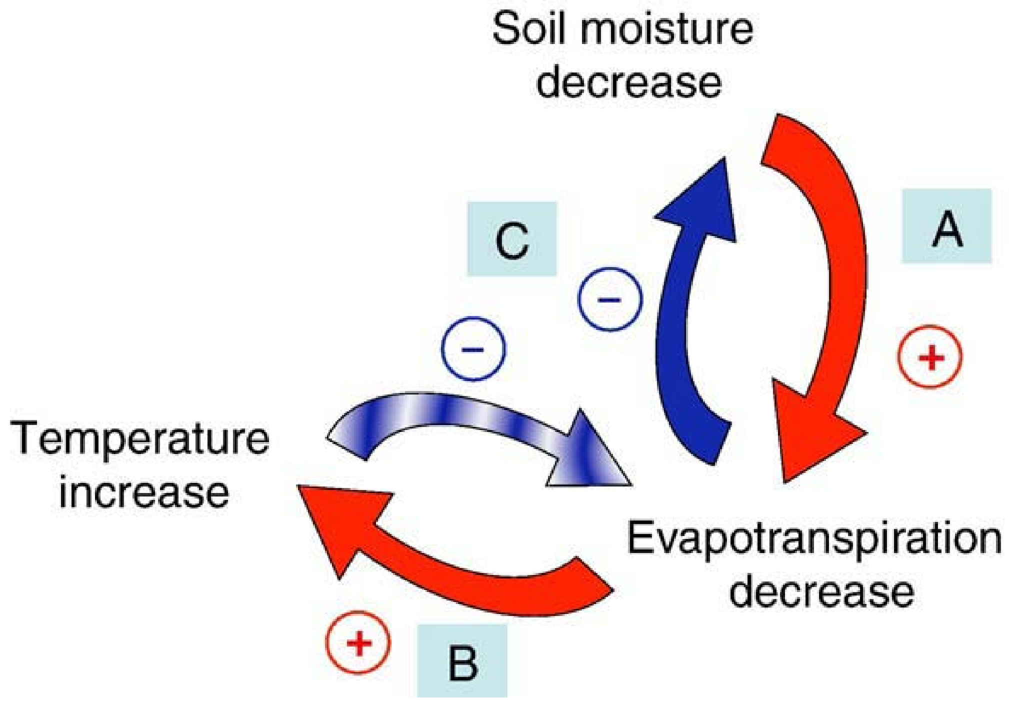


Fig. 9. Processes contributing to soil moisture–temperature coupling and feedback loop. Positive arrows (red) indicate processes that lead to a drying/warming in response to a negative soil moisture anomaly and blue arrows denote potential negative feedbacks (the hatched blue arrow indicates the tendency for enhanced temperature to lead to more evaporative demand; if this results in an increase of evapotranspiration, this in turn leads to a further drying of the soil and thus to a positive feedback loop). Note that possible links to the radiation (clouds and water vapour) are not included. and that the displayed relationships similarly apply for positive soil moisture anomalies (leading to negative temperature anomalies). (A), (B) and (C) refer to the different steps of the feedback loop (see text for details).

- A: reduced soil moisture anomalies → decreased evapotranspiration
- B: decreased evapotranspiration → an increase in air temperature
- C: Increased temperature → a higher vapor pressure deficit and evaporative demand → a potential increase in evapotranspiration and a further decrease in soil moisture.

Seneviratne et al. 2010

Soil moisture–precipitation coupling

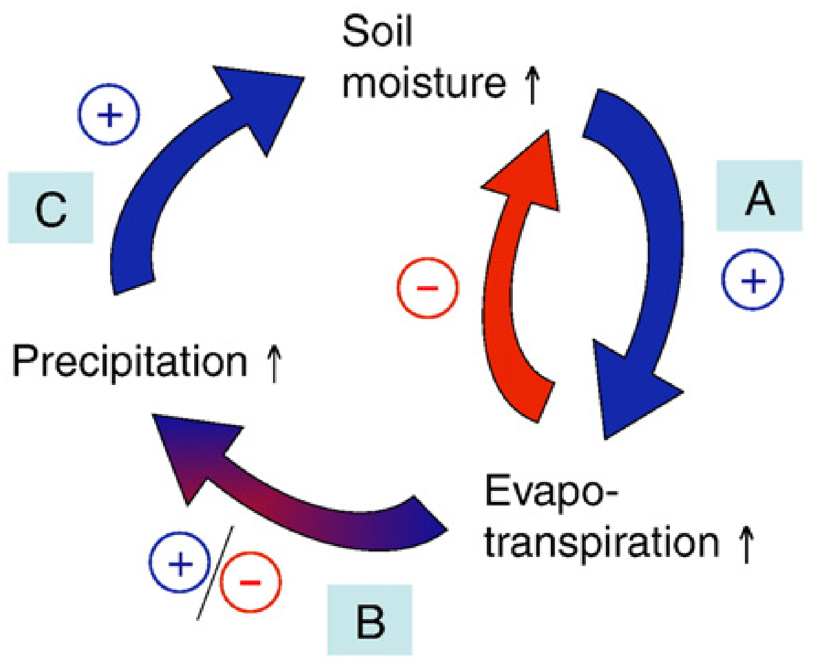


Fig. 10. Processes contributing to soil moisture–precipitation coupling and feedback loop Positive arrows (blue) indicate processes leading to a positive soil moisture-precipitation feedback (wetting for positive soil moisture anomaly, drying for negative soil moisture anomaly), the negative arrow (red) indicates a potential negative feedback damping the original soil moisture anomaly, and the red-blue arrow indicates the existence of both positive and negative feedbacks between evapotranspiration and precipitation anomalies. (A), (B) and (C) refer to the different steps of the feedback loop (see text for details).

C: precipitation → increases soil moisture

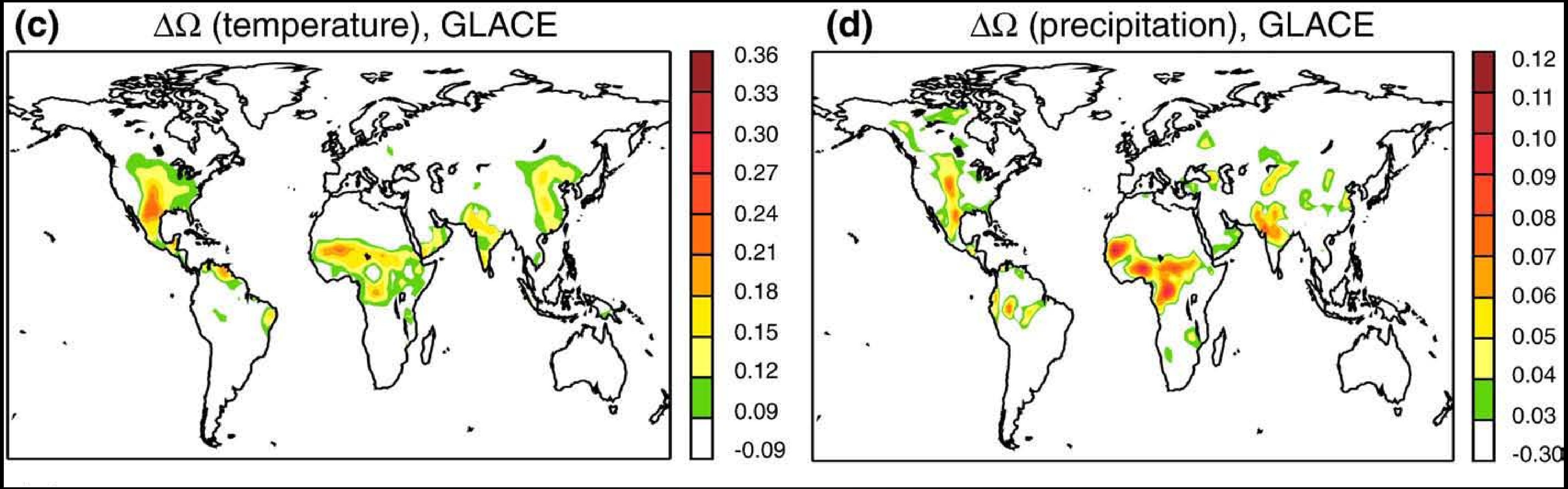
A+: higher soil moisture → higher evapotranspiration (in the transition zone)

A-: increasing evapotranspiration → reduce the available soil moisture.

B: the most uncertain link: higher evapotranspiration leading to higher precipitation, but under specific conditions convective instability and/or cloud formation may be stronger over dry soils

Seneviratne et al. 2010

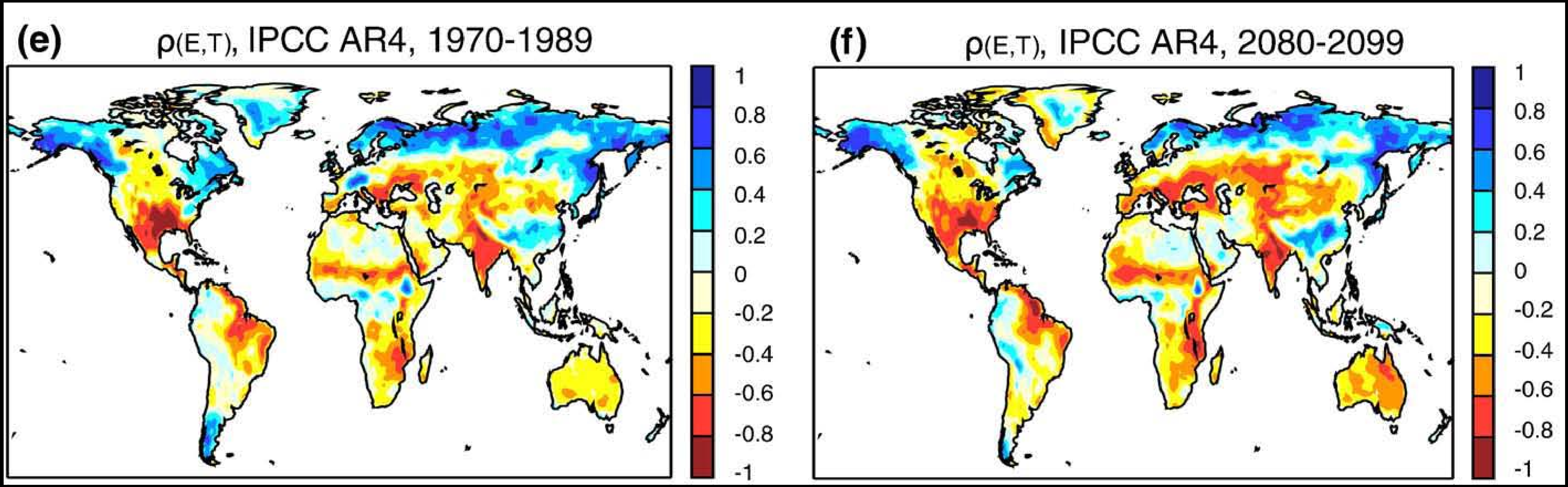
Geographical hot spots of land–atmosphere coupling: Estimations of the soil moisture–temperature (left) and soil moisture–precipitation (right) coupling



The GLACE experiment (Koster et al., 2004) investigated land–atmosphere coupling characteristics of 12 Atmospheric General Circulation Models (AGCMs)

Seneviratne et al. 2010

Estimations of soil moisture–temperature coupling in the context of climate change



- There is a a northward shift of climate regimes in the Northern Hemisphere; coupling also becomes stronger in some regions
- Soil moisture-climate interaction may amplify climate variability or change

Seneviratne et al. 2010

References

- Koster, R. D., M. J. Suarez, and M. Heiser. 2000. Variance and predictability of precipitation at seasonal-to-interannual timescales. Journal of Hydrometeorology 1:26–46.
- Koster, R. D., S. P. P. Mahanama, T. J. Yamada, G. Balsamo, A. A. Berg, M. Boisserie, P. A. Dirmeyer, F. J. Doblas-Reyes, G. Drewitt, C. T. Gordon, Z. Guo, J.-H. Jeong, D. M. Lawrence, W.-S. Lee, Z. Li, L. Luo, S. Malyshev, W. J. Merryfield, S. I. Seneviratne, T. Stanelle, B. J. J. M. van den Hurk, F. Vitart, and E. F. Wood. 2010. Contribution of land surface initialization to subseasonal forecast skill: First results from a multi-model experiment. Geophysical Research Letters 37:L02402, doi:10.1029/2009GL041677.
- Seneviratne, S.I., T. Corti, E.L. Davin, M. Hirschi, E.B. Jaeger, I. Lehner, B. Orlowsky, and A.J. Teuling. 2010. Investigating soil moisture-climate interactions in a changing climate: A review. Earth-Science Reviews 99, 3-4:125-161, doi:10.1016/j.earscirev.2010.02.004
- Teng, H., G.W. Branstator, H. Wang, G.A. Meehl, and W.M. Washington, 2013: Probability of US heat waves affected by a subseasonal planetary wave pattern. Nature Geoscience, 6, 1056-1061, DOI: 10.1038/ngeo1988.
- NAS report: "*Assessment of Intraseasonal to Interannual Climate Prediction and Predictability* ", Section 2.3