Land-Atmosphere Interaction: Part I

Outline

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

Why are we interested in soil moisture?

- The water stored on land is a key variable controlling numerous processes and feedback loops within the climate system and is of major relevance to the water and energy cycles.
- Soil moisture is a source of water for the atmosphere through evapotranspiration, which includes plant transpiration and bare soil evaporation. Evapotranspiration is a major component of the continental water cycle, and it returns as much as 60% of the whole land precipitation back to the atmosphere (e.g. Oki and Kanae, 2006).
- Evapotranspiration is also an important energy flux, and land evapotranspiration uses up more than 50% of the total solar energy absorbed by land surfaces (Trenberth et al., 2009).
- Soil moisture has important impacts on climate processes, including air temperature, boundary-layer stability and in some instances on precipitation.

Definition: Volumetric Soil Moisture

- Soil moisture is usually defined as the water contained in the unsaturated soil zone

$$\theta = \left(\frac{volume\ of\ water\ in\ V}{V}\right)$$

- The definition is applicable on multiple scales, from a few cubic centimeters to several cubic kilometers, depending on the measurement method or research application.

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Definition: saturation ratio

- Saturation ratio

$$\theta_s = \frac{\theta}{\theta_{SAT}}$$

where θ_{SAT} is saturation soil moisture content (also water-holding capacity). Saturation ratio varies between 0 (no soil moisture) and 1 (full saturation).

- Soil moisture index (SMI): The maximum volume of water available to plants is the field capacity (θ_{FC}) minus the permanent wilting point (θ_{WILT})

$$SMI = \frac{\theta - \theta_{WILT}}{\theta_{FC} - \theta_{WILT}}$$

The SMI is a measure of soil moisture content as the ratio of the total storage available to plants (varying between 0 and 1)

*Above the field capacity, water cannot be held against gravitational drainage, and below the wilting point, the water is held too strongly by the soil matrix and is not accessible to plants.

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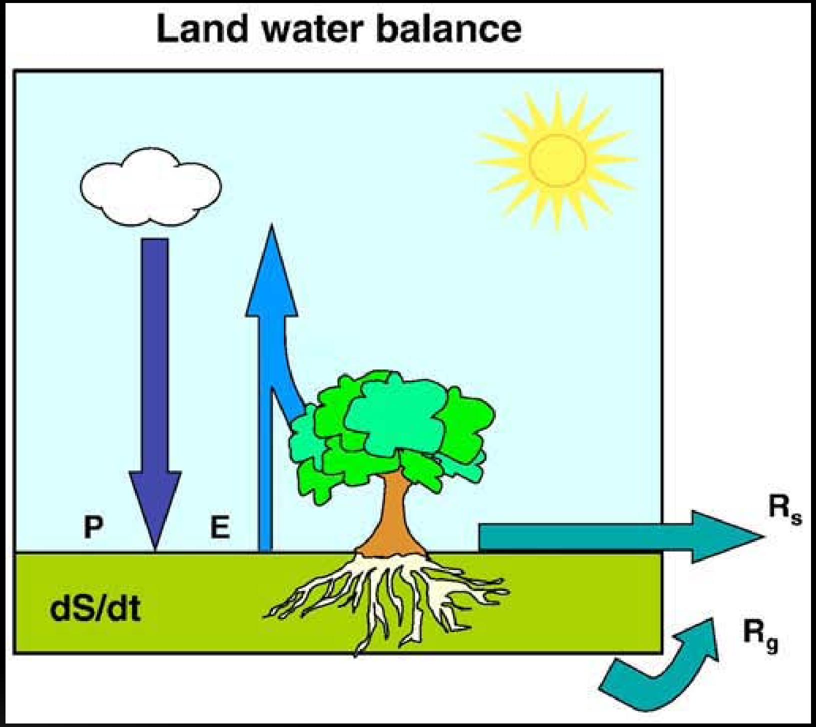
Land Water Budget Equation

- The land water balance for a surface soil layer without considering lateral exchange between adjacent soil volumes can be written as:

$$\frac{dS}{dt} = P - E - R_s - R_g$$

- where dS/dt is the change of water content within the given layer, P is the precipitation, E is the evapotranspiration, Rs is the surface runoff, and Rg is the drainage.

Can you describe the water budget for a soil layer based on the figure below?



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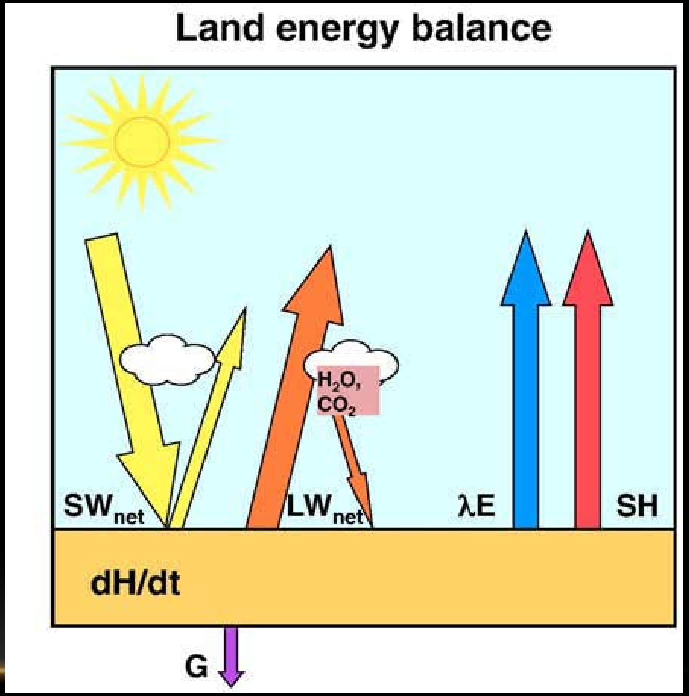
Land Energy Budget Equation

- The land energy balance for the surface soil layer can be expressed as:

$$\frac{dH}{dt} = R_n - \lambda E - SH - G$$

- dH/dt is the change of energy within the considered surface soil layer including temperature change and phase changes associated with soil freezing/melting or snow melt.
- Rn is the net radiation, including LW and SW
- λE is the latent heat flux; λ is the specific latent heat of evaporation
- SH is the sensible heat flux,
- G is the ground heat flux to deeper layers

Can you describe the energy budget for a soil layer based on the figure below?



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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