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Evaporation in the global water cycle

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Summary

Land-surface evaporation is a key component in the water and energy cycles that dominates the interactions among the Earth surface and atmosphere. Nowadays, understanding its global magnitude and variability remains an existing challenge for hydrologists and climatologists, as noted in **Chapter 1**. Contemporary developments in the field of satellite remote sensing of the Earth provide the opportunity to reduce the uncertainty in our estimates of global evaporation. This thesis presents a new methodology dedicated to derive global fields of evaporation by combining atmospheric and environmental satellite-based observations. Results are validated using in situ data, evaluated against other methodologies, and analysed at different levels. Conclusions bring new insights into the process of land-surface evaporation and the importance of the different components of the flux (i.e. transpiration, soil evaporation, interception loss and snow and ice sublimation) within the global water cycle.

Chapter 2 describes the new methodology, named GLEAM (Global Land-surface Evaporation: the Amsterdam Methodology). GLEAM combines global imagery of most of the meteorological and environmental variables that are relevant for the evaporation process. These are variables that, unlike evaporation, can be observed or derived from satellites in a relatively straightforward manner. The core of the methodology is a modification of the Priestley and Taylor (1972) equation; potential evaporation estimates are translated into actual evaporation using a multiplicative (stress) factor. This factor accounts for the control of land surface over the rates of transpiration and soil evaporation, and depends on the vegetation water content and the soil moisture conditions in the root zone. Rainfall interception loss, transpiration, soil evaporation and snow sublimation are derived separately.

Different validation activities of the methodology are undergone. Model estimates of soil moisture at different depths are compared to in situ observations. This comparison suggests that the assimilation of satellite-based soil moisture contributes to improving the final estimates of soil moisture. Evaporation fields are successfully validated using the data from 43 FLUXNET meteorological towers. A high correlation coefficient with ground measurements is found both at daily ($R = 0.83$) and at monthly ($R = 0.90$) time-scales.

Chapter 3 describes what represents the first successful attempt towards the global representation of rainfall interception loss based on satellite data.

The methodology is an adaptation of the most broadly used scheme to estimate interception loss at local and regional scales over the last 30 years: Gash's analytical model (Gash, 1979; Valente, 1997). For its integration in GLEAM, Gash's analytical model is driven by global satellite-based precipitation. Other satellite-derived inputs that allow the application at the global scale are the fraction of tall canopy cover and the lightning frequency climatology (which is used as a proxy for rainfall intensity). Gash's model state variables – such as the canopy storage capacity or the evaporation rate under saturated conditions – are set to constant. These constant values are calculated as an average of a sample of measurements from previous applications of Gash's analytical model at the regional scale.

GLEAM estimates of interception loss are validated against measurements from 42 previous field studies over different forest ecosystems. Results of this validation show a strong correlation with in situ data ($R = 0.86$) and a negligible bias. Daily global maps of rainfall interception loss are presented for the first time.

Chapter 4 investigates the applicability of the triple collocation (TC) statistical technique to calculate the error structure of GLEAM evaporation estimates. The TC technique is first validated by applying it to characterize the error of three different estimates of soil moisture at a pixel scale: one single station, a remotely-sensed estimate and a land surface model. This validation is done in four watersheds of dense observational networks. Due to the density and quality of the soil moisture observations, the watershed average can be considered the best possible estimate of soil moisture at the pixel scale. Then the TC-estimated errors can be validated against the calculated errors relative to this watershed average.

Once validated, TC is applied to calculate the error of three global land-surface evaporation products: GLEAM, MERRA and the Princeton University product by Sheffield et al. (2010). The estimated global distribution of the errors of GLEAM is analysed in detail and subsequently compared to the analogous maps of the other two products. FLUXNET observations are used in an attempt to validate the resulting fields of errors. Despite the inconclusive results of this final validation, GLEAM seems to perform better than the other two products in 69% of the world's land surface. The superior performance of GLEAM is suggested by both the TC-estimated errors and the errors resulting from the straight comparison to in situ data.

Chapter 5 describes the results of the global application of the methodology. After having explained, validated and evaluated GLEAM in previous chapters, here, GLEAM is applied to study the global magnitude and variability of land-surface evaporation. Firstly, the potential of the methodology to estimate volumes of water available for runoff over a large region and a long period is tested. Estimates of $P - E$ are compared to river discharge measurements showing the skill of GLEAM to partition precipitation into evaporation and runoff. Then the partitioning of precipitation over the different continents and biomes is studied globally. Special attention is paid to the different contribution of each component of land-surface evaporation to the total flux. Seasonal distributions of the main components of the global water cycle are analysed with focus on the control of land-surface conditions over these distributions. The relationships between evaporation and its drivers are studied and precipitation is recognised as an important factor determining the volumes of evaporation over forests. The influence of precipitation is more important under conditions of low net radiation when interception can be the largest contributor to the evaporative flux.

Within GLEAM, variables are combined in an approach that minimises the load of modelling to make the final output rely in the quality and value of the satellite observations. As indicated in **Chapter 6**, this sets GLEAM as a rather simple and general tool that is easy to use for global studies of the water and energy cycles. Its applicability at regional scale relies on the use of better resolution input data, and the possibility to extend the model to account for processes like runoff or advection that can be determining at watershed scale. Despite the fact that there is still some room for improvement, current results suggest that GLEAM's estimates are realistic. A first version of the GLEAM datasets is presently available online. It includes daily global maps from 1984 to 2007 of transpiration, interception loss, soil evaporation, sublimation, surface soil moisture, root-zone soil moisture and stress conditions for evaporation. These datasets are currently being used for a wide range of applications and at different research centres.