Social-Ecological Dimensions of Terrestrial Moisture Recycling

Stockholm Resilience Centre — Research for Biosphere Stewardship and Innovation | Stockholm University

Colorado State University | TU Delft

CMMAP Summer Meeting, 2015

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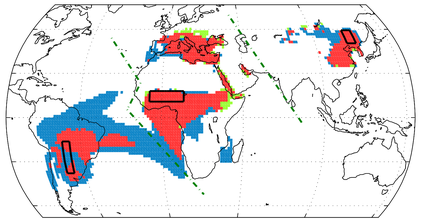
1. Variability in space and time

PURPOSE
Determine whether and how precipitationsheds varied a lot (or a little) in space and time

METHOD
Backtrack the sources of precipitation for three locations globally, and use frequency of contribution and EOF analysis to quantify variability.

RESULT
A core region of evaporation contribution that occurs every year was found to be relatively stable for most precipitationsheds. The precipitationsheds for three regions were found to have low variation in space and time, with the primary mode of variation as an expansion and contraction of evaporation sources (1st EOF), versus an oscillation back and forth (2nd EOF).

Composite of core precipitationsheds for La Plata, Western Sahel and Northern China



ERA–I only | MERRA only | ERA–I & MERRA

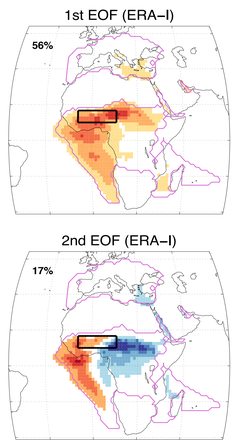


Fig. 6. Comparison of first and second EOFs for the Western Sa
The magenta line indicates the 5mm growing season^{-1} precipi
number in the upper left corner indicates the amount of variance
season^{-1} for the sake of clarity in the figure

2. Using an ecosystem services approach

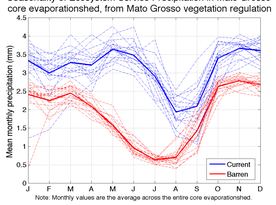
PURPOSE
Integrate terrestrial moisture recycling into an Ecosystem Services framework, to be used in discussions of land-use policy

METHOD
Compare moisture recycling between current vegetation and bare-soil, to identify the "added value" of vegetation for evaporation flows, globally.

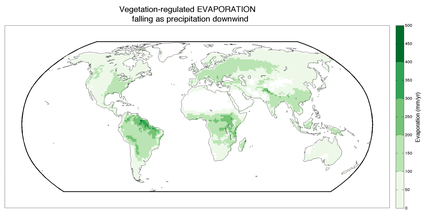
$$E_{C,track} - E_{B,track} = S_E$$
$$P_{C,track} - P_{B,track} = S_P$$

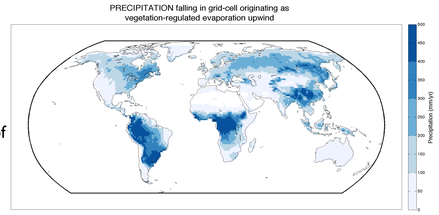
RESULT
The sources and sinks of terrestrial moisture recycling ecosystem services are identified (located on the windward and leeward sides of continents, respectively), and a transparent metric for inclusion in ecosystem services inventories is developed. A case study in Brazil reveals the seasonal differences in ecosystem service provision, depending on vegetation, and we further overlay our findings with existing spatial archetypes of ecosystem services.

Seasonality of Ecosystem Service Precipitation in Mato Grosso core evaporationshed, from Mato Grosso vegetation regulation

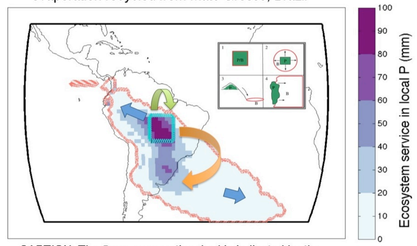


Note: Monthly values are the average across the entire core evaporationshed.





Vegetation-regulated Precipitation provided by evaporation recycled from Mato Grosso, Brazil



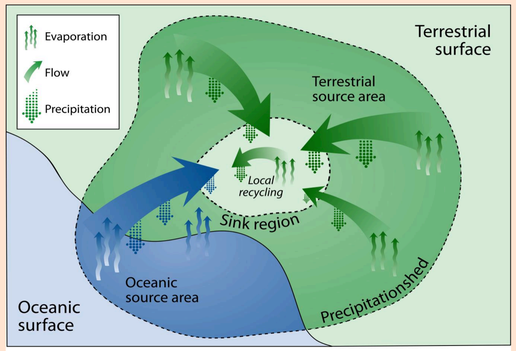
CAPTION: The 5mm evaporationshed is indicated by the red-colored boundary, and the Mato Grosso, Brazil source region is indicated by the cyan-colored line

What are social-ecological systems?

Social Ecological Systems (SES) are complex interacting systems that contain internal variables with multiple subsystems and multiple scales of organization. "The different parts of an SES are relatively separable but interact to produce outcomes at the SES level, which in turn feed back to affect these subsystems and their components, as well other larger or smaller SESs."

Ostrom, E. (2009) A General Framework for Analyzing Sustainability of Social-Ecological Systems. Science. 325, 419 DOI: 10.1126/science.1172133

What is terrestrial moisture recycling?



Terrestrial moisture recycling refers to the atmospheric branch of the water cycle that occurs on land. Essentially, water that evaporates from land surfaces, travels through the atmosphere, and falls back as precipitation somewhere on land is considered terrestrial moisture recycling.

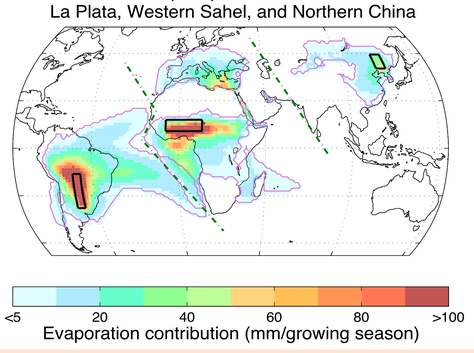
It is useful to explore moisture recycling using SES, since humans can impact and are impacted by modifications to terrestrial (i.e. land) surfaces.

What is a precipitationshed?

For a given region, e.g. the state of Colorado, it is possible to identify the locations that contributed moisture that eventually falls as precipitation in the state.

The **precipitationshed** is the spatial boundary that encompasses the land and ocean surfaces that contribute moisture to a specific location.

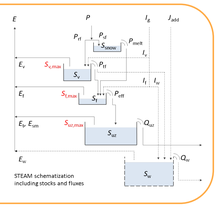
ERA–I precipitationsheds for La Plata, Western Sahel, and Northern China



Modeling Approach

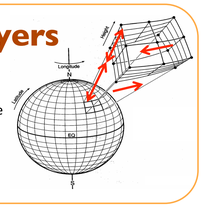
STEAM

ERA-Interim climate data forces STEAM, which simulates terrestrial moisture partitioning, and changes the evaporation fluxes to the atmosphere..



WAM-2layers

...these altered evaporation fluxes are fed into WAM-2layers influencing the moisture budget of the atmosphere, leading to precipitation changes downwind...



FUNDING

This research was funded primarily by a grant from Vetenskapsrådet (Sweden) with additional support from Colorado State University, and TU Delft.

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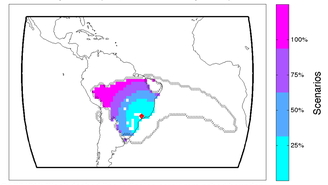
Keys, P. W., van der Ent, R. J., Gordon, L. J., Hoff, H., Nikoli, R., and Savenije, H. H. G.: Analyzing precipitationsheds to understand the vulnerability of rainfall dependent regions, Biogeosciences, 9, 733-746, doi:10.5194/bg-9-733-2012, 2012

Keys, P.W., Barnes, E.A., van der Ent, R.J., and Gordon, L.J. (2014). Variability of moisture recycling using a precipitationshed framework. Hydrology and Earth System Sciences. 18, 3937–3950. doi:10.5194/hess-18-3937-2014

Keys, P.W., Wang-Erlandsson, L. and Gordon, L.J. (*in preparation*). Terrestrial Moisture Recycling as an Ecosystem Service.

3. Land-use change and moisture recycling

Map of "forested" areas to convert to grasslands or croplands (in SP 1mm core pshed)



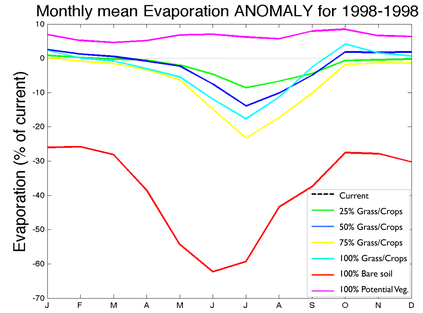
CAPTION: Black dashed line indicates core 1mm pshed boundary and the red dot indicates location of Sao Paulo

PURPOSE
Identify the extent to which different scenarios of land-use change can impact rainfall in Sao Paulo, Brazil

METHOD
Perform six land-use scenarios in Sao Paulo's precipitationshed, using realistic change (deforestation replaced by mosaic grass and cropland), and two extreme scenarios (potential natural vegetation, and bare soil).

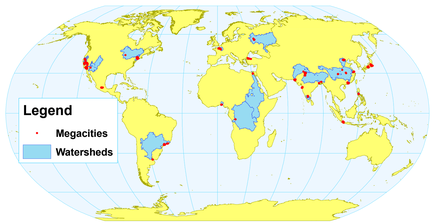
RESULT
We find that the realistic Grass/Crop scenarios produce decreased evaporation in Sao Paulo's precipitationshed, and that there is a pronounced deficit during the dry season, likely indicating the importance of forests for providing sustaining dry season transpiration.

Monthly mean Evaporation ANOMALY for 1998-1998



4. Megacities and moisture recycling

Surface Water Dependent Megacities



PURPOSE
Determine whether precipitationsheds of urban areas vary with well-known modes of climate variability (e.g. ENSO)

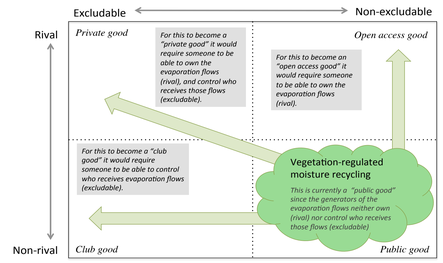
METHOD
Identify the precipitationsheds for 26 megacities globally (that are dependent on surface water). Then, correlate the annual precipitationshed evaporation anomalies with climate modes.

RESULT
Depending on the location on the planet, different precipitationsheds are correlated with different anomalies. Strong correlations are found between particularly dry or wet years and particularly strong climate modes.

5. Moisture recycling governance

PURPOSE
Since society has the potential to influence and modify terrestrial moisture recycling, we identify the institutional structures & best suited for governing moisture recycling phenomena.

METHOD
Review existing forms of water and resource governance, and develop criteria for evaluating suitability



[EXPECTED] RESULTS
We use multiple approaches, including economic classification of the service (see figure), as well as comparative water governance analysis.

The most suitable structures and processes are likely to be related to non-binding, trans-boundary resource treaties, that are additive to existing agreements, rather than standalone governance mechanisms.