How trees water our planet: forests, rain and the future

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Water

Essential for life and everything we care about
Food security, health, industry, environment and productivity

- 2/3 global population suffer scarcity for >1 month of the year
- Half a billion already face year round scarcity

Global water scarcity
Global water cycle (flows in 1000 km$^3$ yr$^{-1}$)

- Ocean to land: 40
- Land Precipitation: 113
- Evaporation, transpiration: 73
- Surface flow: 40
- Ground water flow

Adapted from, Trenberth et al. 2007. J. Hydromet. 8: 758-769
Figure 2. Annual average precipitation $P$ and evaporation $E$ over continental areas (1999–2008).

Figure 3. Average continental precipitation recycling ratio $\rho_c$ (1999–2008).
Forests
Source of atmospheric moisture
Deforestation implicated in
Less cloud
Less reliable rain (Sahel, West Africa, Cameroon, Central Amazonia, India)

Estimate: vapor from land reduced by ~ 5% by land cover change (Sterling et al. 2013).
Borneo cover 1973 to 2010 (Gaveau et al. 2014)

Mean daily precipitation from APHRODITE (63 stations)

Watersheds by % forest cover change versus % precipitation change.

From McAlpine et al. submitted

Numbers are selected watersheds.
Forests and evaporation

- Closed tropical forests evaporate 1-2 m/yr
- ~10 x low vegetation, ~2 x open water
- High leaf area, canopy height and roughness
Forests are special
Soil infiltration and storage
Deep roots
Stem storage
Interception
Aerosols

Mexican cave

S. America coast p.m.
Annual rain by distance inland in three forested (A, B, C) and six nonforest regions (D, E, F, G, H, I)

Data from Makarieva & Gorshkov (2007).
Temperature explanation

Warm air rises cooler sea
Dry air
Moist air
Rising cooling condensing raining
Warmer land

Warm air rises
Text books:

- 1686 Edmond Halley’s theory for Trade Winds
- 1735 George Hadley’s theory (Earth's rotation)
- Later … cells …

A major roadblock

Stevens & Bony 2013. What are climate models missing? Science 340, 1053-1054

Rainfall over land is largely determined by ‘unresolved processes’ … this is the ‘main limitation in current representations of the climate system’ and ‘a major roadblock to progress in climate science’
Still a major roadblock

Marotzke et al. (2017) Climate research must sharpen its view. Nature Climate Change 7:89-91

“The global water cycle … remains one of the least understood natural cycles. Hence, the predictions of this cycle in a changing climate are amongst the most uncertain.”
Problems

‘Cold Amazon paradox’
Model runoff is $\frac{1}{2}$ Amazon’s observed
  e.g. Hagemann et al. 2011, J. Hydrometeor, 12, 556–578
Also ocean-land contrast is wrong
Cold Amazon Paradox

Monthly rain and temp °C
Amazon: green-lines
Ocean: blue-lines.

Mean data values 1978-2013 re National Centers for Environmental Prediction–National Center for Atmospheric Research reanalysis (at ref 1000 hPa)
Do forests attract rain?

- Some believe forests attract rain
- Most experts disagree
But …

Anastassia Makarieva
Victor Gorshkov

Good physics, e.g.,

Vapour to liquid/solid

• Condensation

• Fewer gas molecules

Ideal gas law

\[ PV = nRT \]
Prediction

Areas with highest evaporation develop lowest pressure
draw in air and moisture … positive feedback

Warm oceans

Forests
Condensation winds

From Sheil & Murdiyarso (2009)
Bioscience, 59: 341-347
a) Dry air (pinkish)
b) Water vapour accumulates more rapidly over forest (bluish)
c) Condensation begins in the saturated air
d) Condensation lowers local pressure drawing in air from ocean

Based on data and ideas in Makarieva et al. (2014) J. Hydrometeorology, 15, 411-426
Evidence

Difference in mean pressure between rainy and rainless days at 0000, 1200, and 1800 in regions A, B, and C. Per station, the first three bars denote the wet season and next three denote the dry season. Dots indicate differences at 0.01 probability (t test).

See Makarieva et al. 2014. J. Hydrometeorology, 15, 411-426
Evidence

Rainfall declines into interiors … but not over forest
Resolves cold Amazon paradox and runoff shortfall
Hour by hour relation of pressure, wind direction & rain

Distance effect disappears over boreal forest in winter
Forest loss and rain reliability
Weak Amazon monsoon
Monsoons v local moisture
Power estimates for global circulation
Hurricanes velocity profiles
Implications 1: risks

Continuous cover maintains interior rain
Switching possible
Implications 2: opportunities
Supply-focused interventions
Greening deserts
New regional value
Research
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