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

Douglas Sheil
Norwegian University of Life Sciences

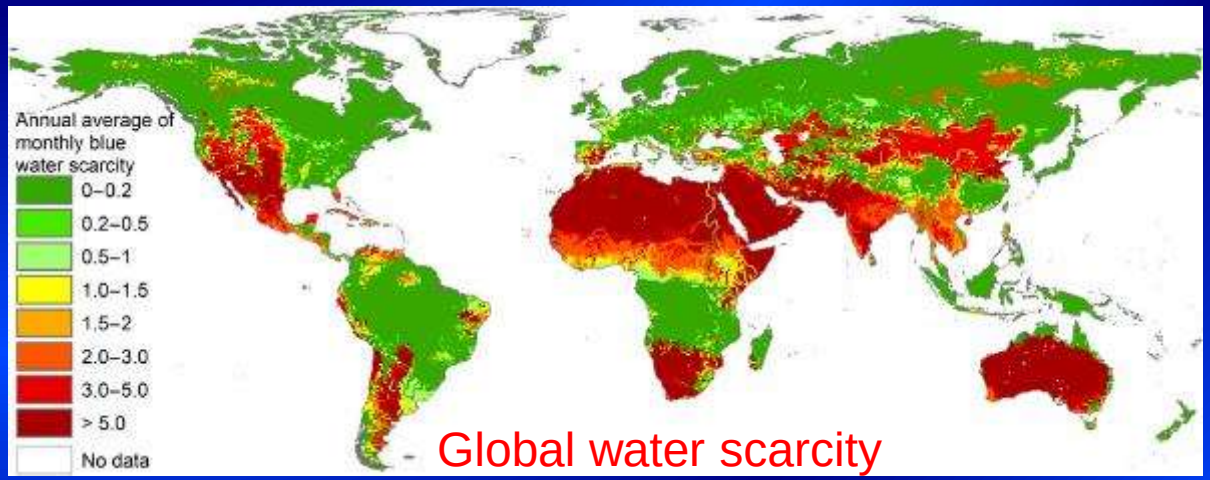
Norwegian University of Life Sciences

Water

Essential for life and everything we care about

Food security, health, industry, environment and productivity

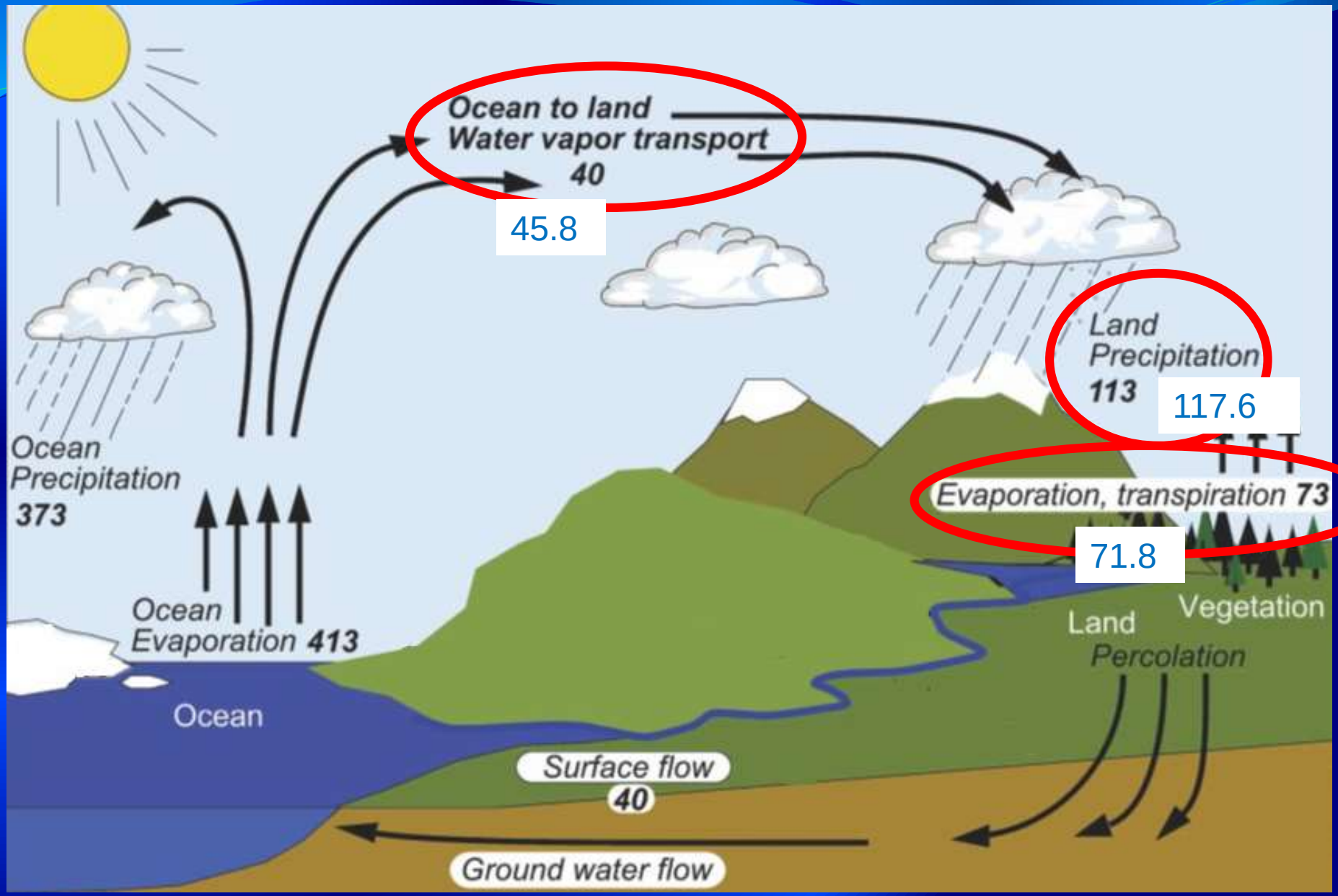
- 2/3 global population suffer scarcity for >1 month of the year
- Half a billion already face year round scarcity



Global water scarcity

Mekonnen & Hoekstra, 2016. *Sci. Adv.*, 2: e1500323

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



Adapted from, Trenberth *et al.* 2007. *J. Hydromet.* 8: 758-769
Schneider *et al.* 2017. *Atmosphere*, 8, 52.

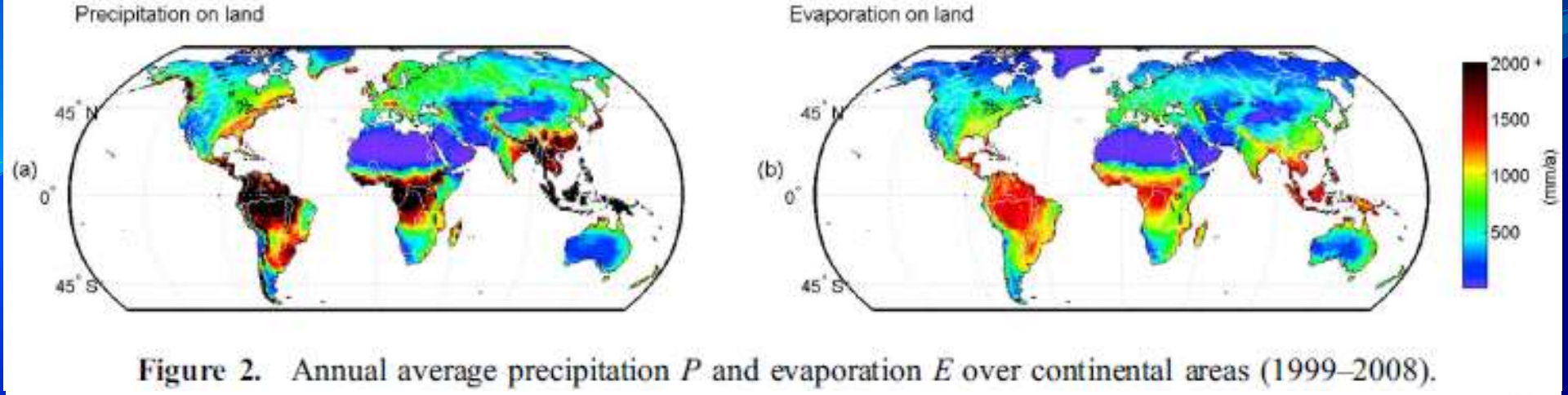


Figure 2. Annual average precipitation P and evaporation E over continental areas (1999–2008).

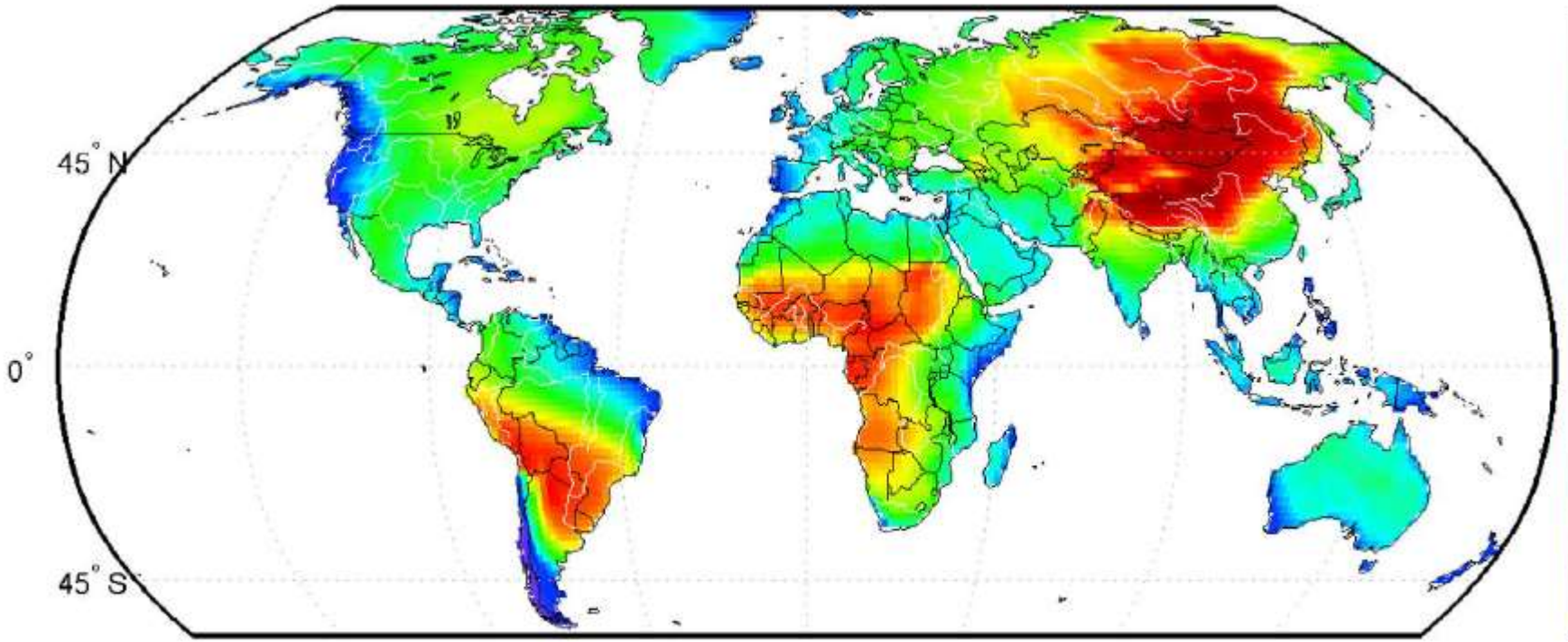


Figure 3. Average continental precipitation recycling ratio ρ_c (1999–2008).

van der Ent, R.J. et al. 2010. *Water Resour. Res*. 46 (9): 1944-7973

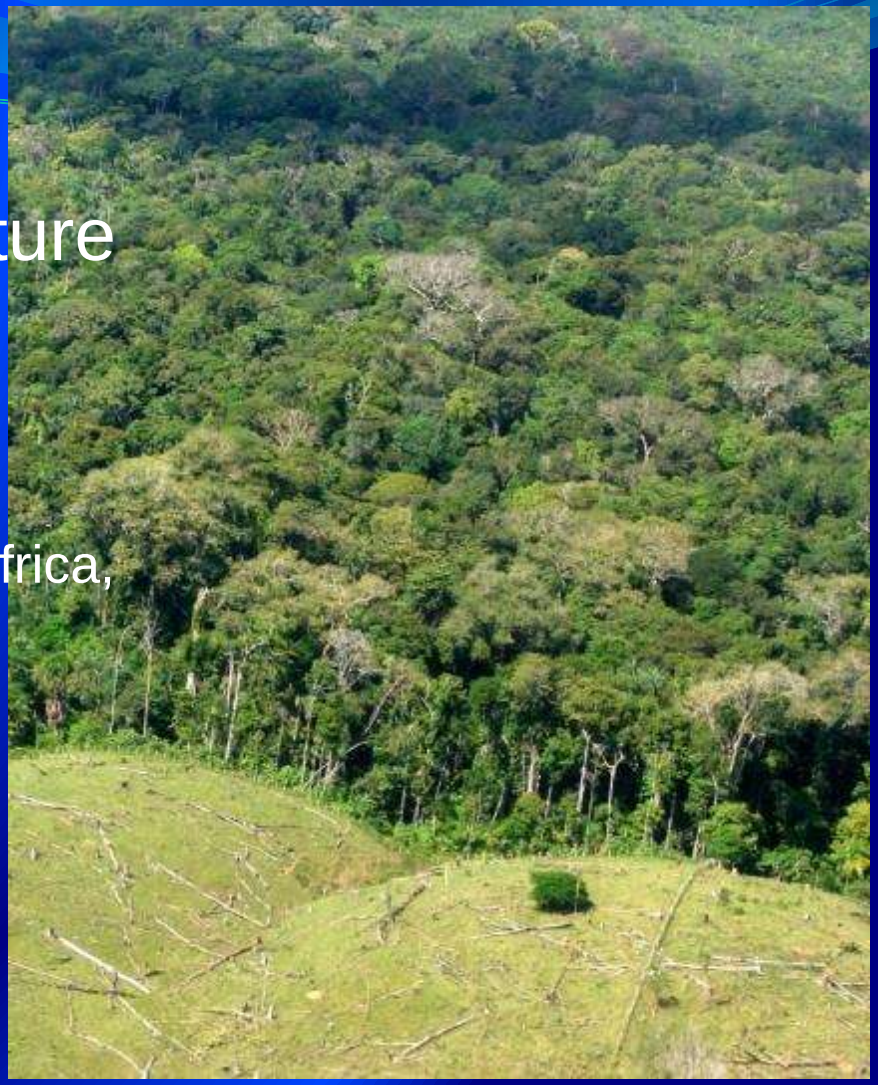
Forests

Source of atmospheric moisture

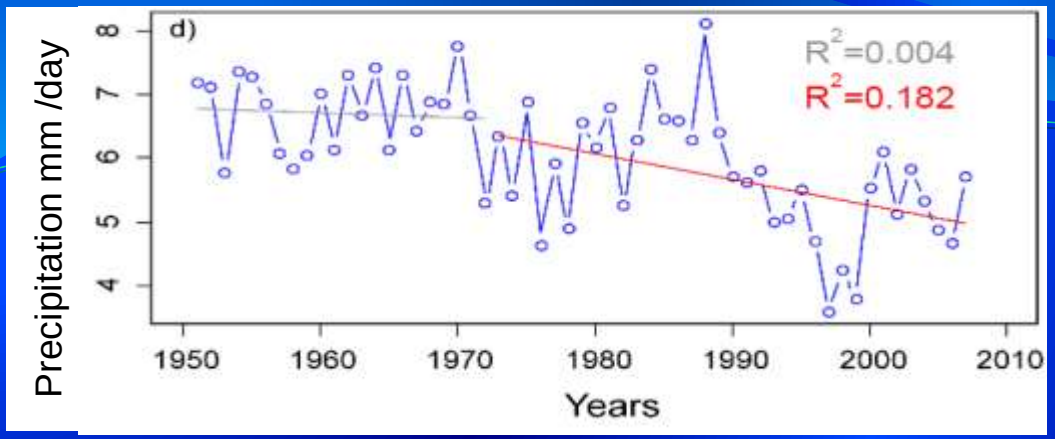
Deforestation implicated in

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).

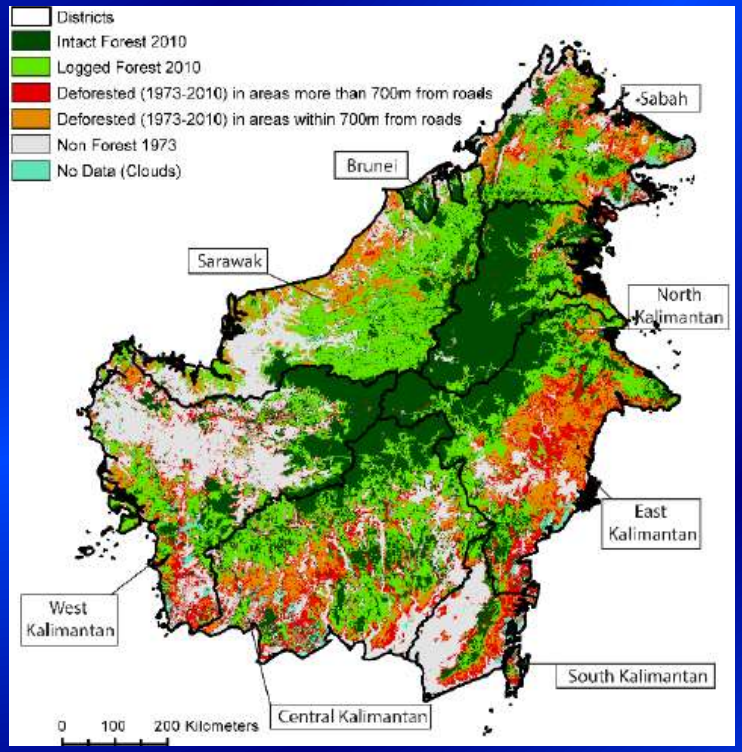


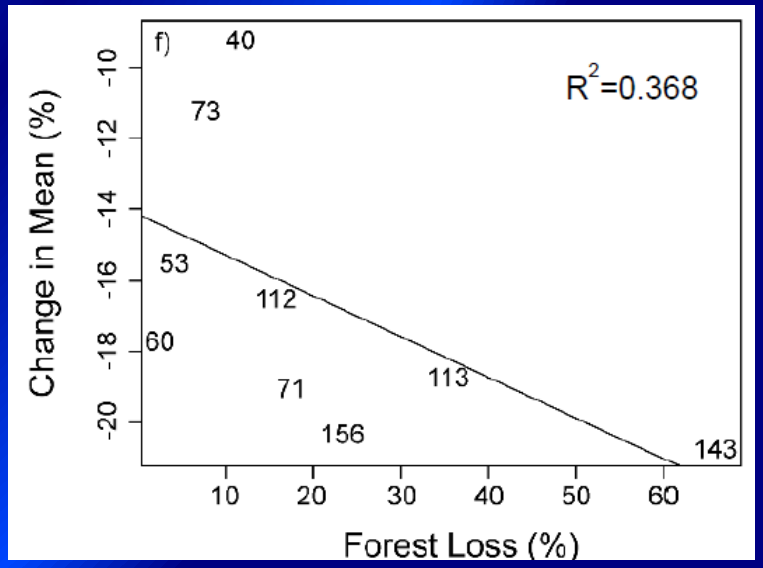
Borneo cover 1973 to 2010 (Gaveau *et al* 2014)

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

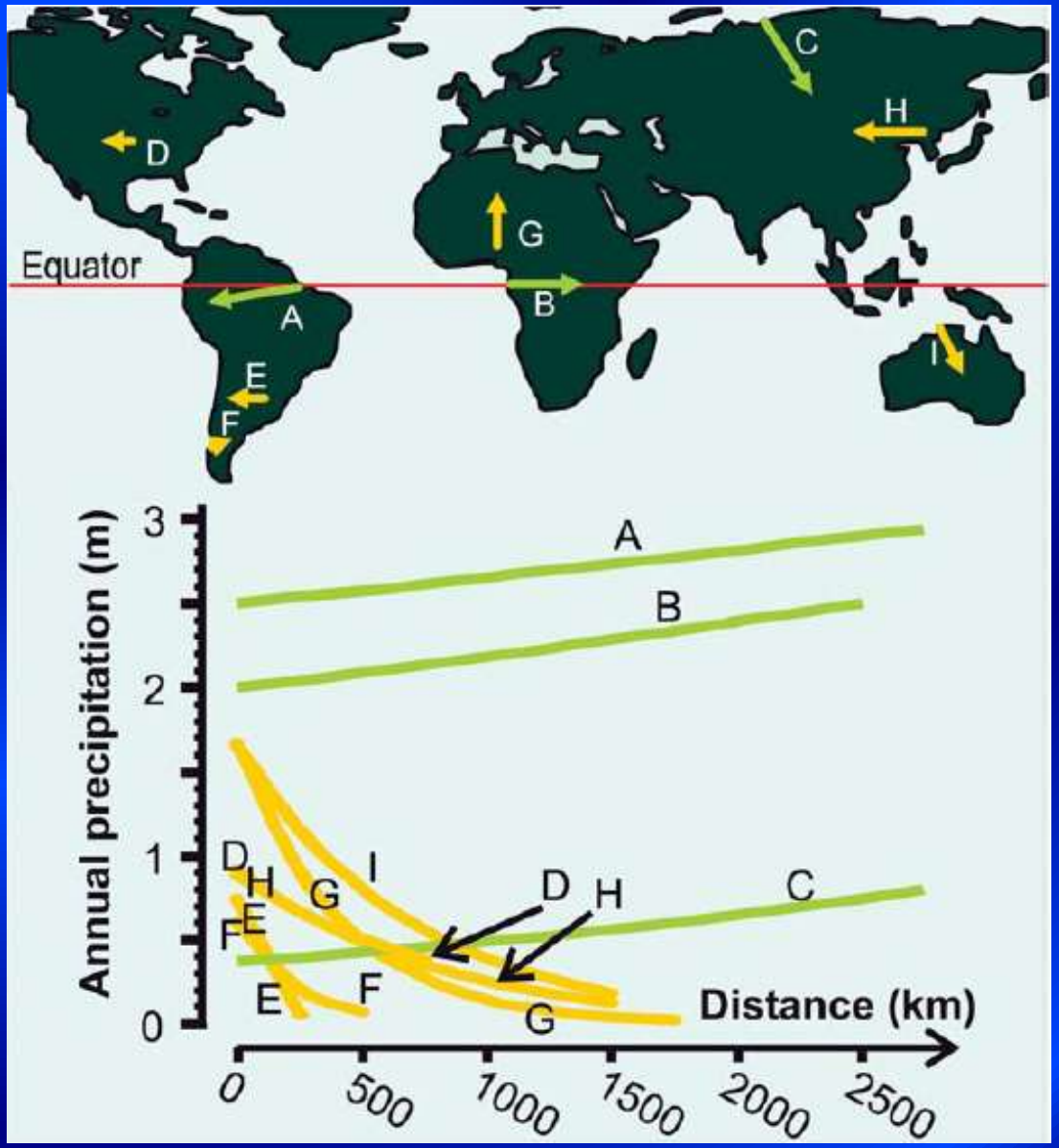
Interception

Aerosols

Mexican cave

S. America coast p.m.

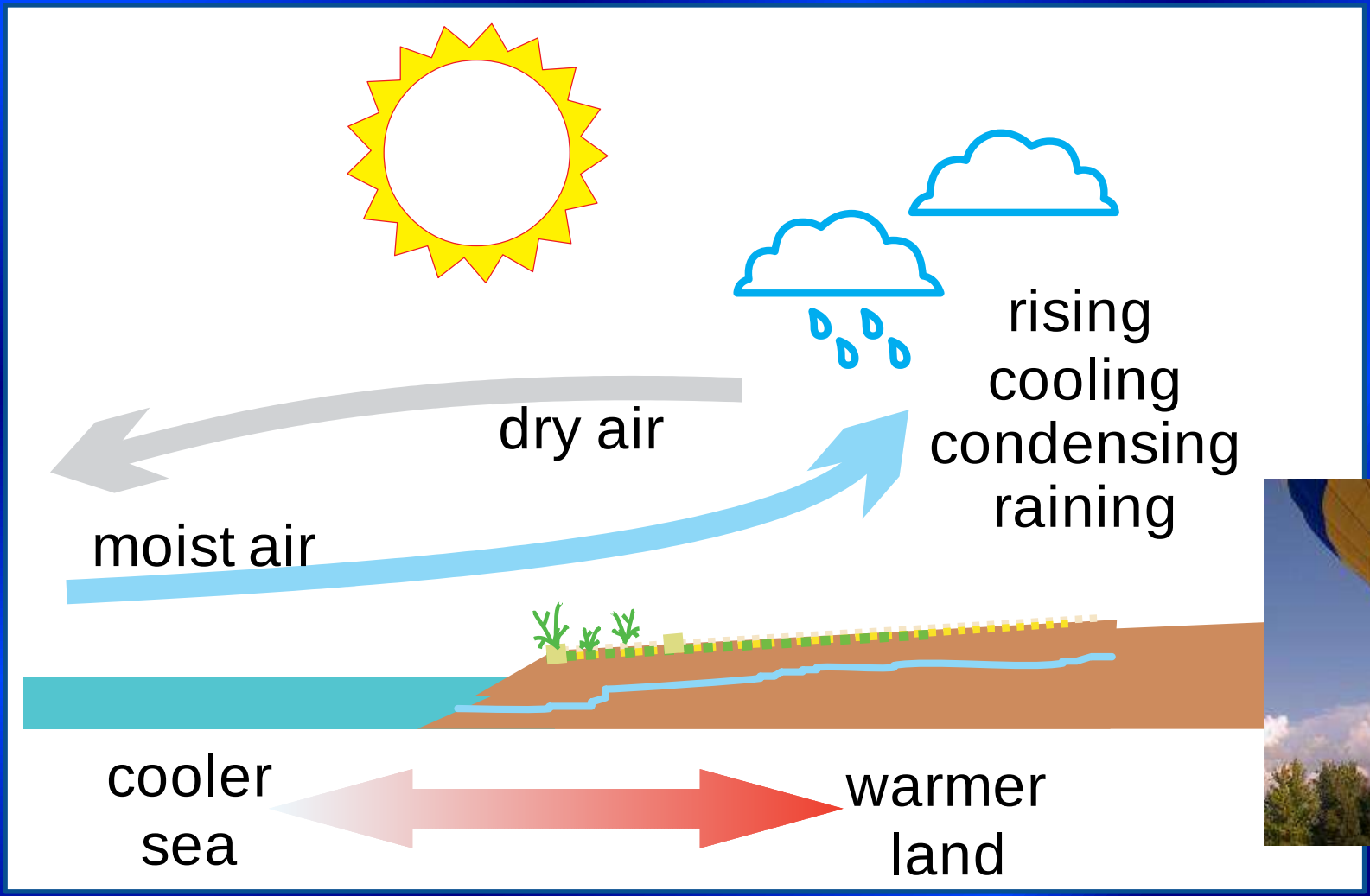
Distance versus rainfall



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

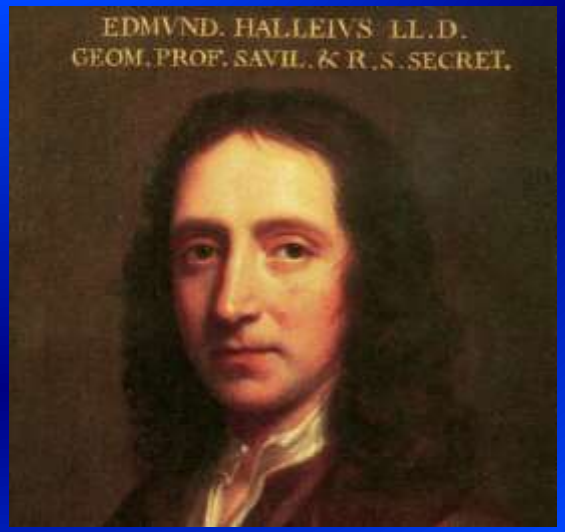
From Sheil & Murdiyarso (2009) *Bioscience,* 59: 341-347.
Data from Makarieva & Gorshkov (2007).

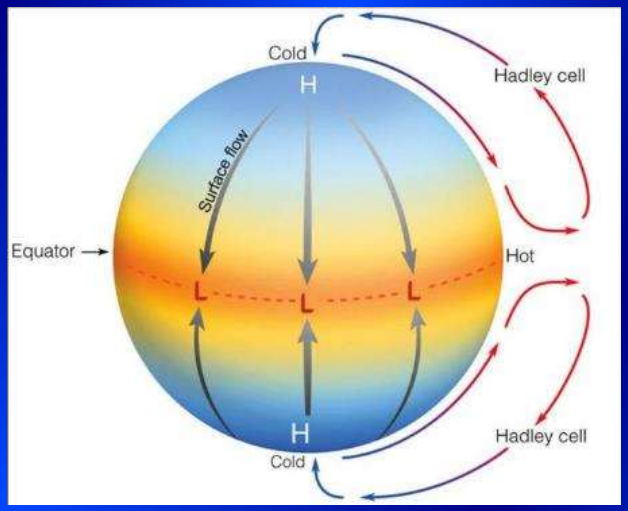
Temperature explanation

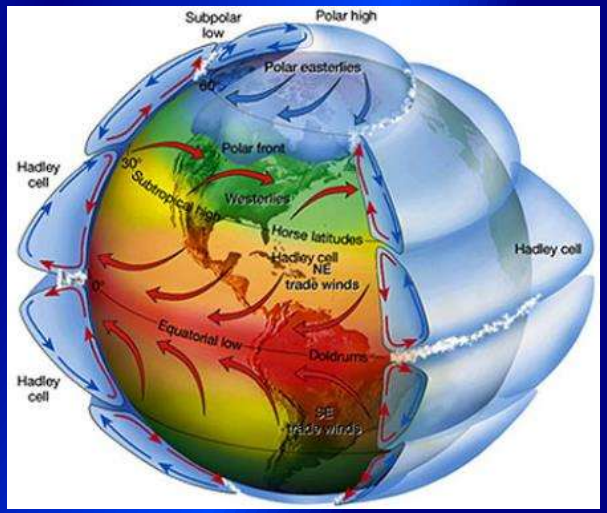


Warm air rises

Temperature explanation







An Hiſtorical Account of the Trade Winds, and Monſoons, obſervable in the Seas between and near the Tropicks, with an attempt to aſſign the Phiſical cauſe of the ſaid Winds, by E. Halley.

Edmund Halley (1686). *Philosophical Transactions*, 16:153-168.

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

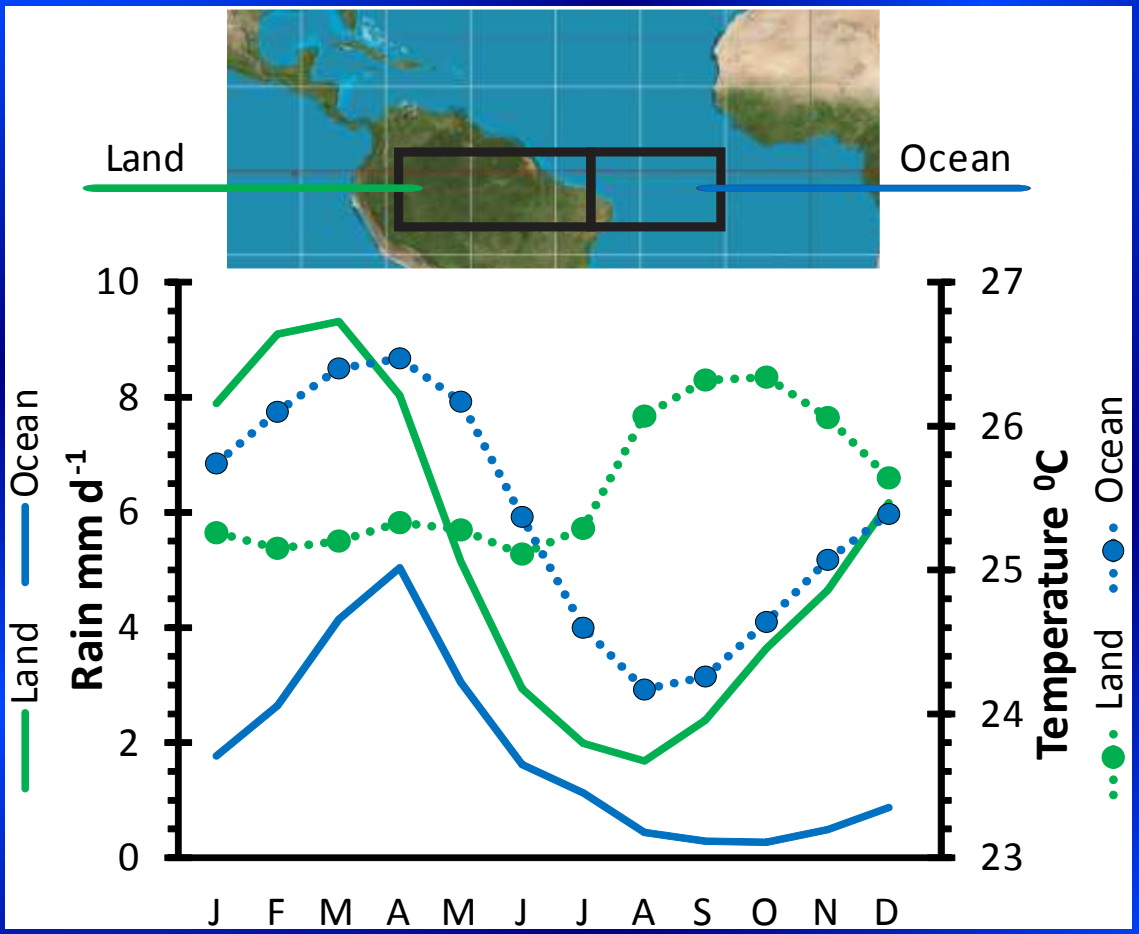
‘Cold Amazon paradox’

Model runoff is ½ 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 ^{o}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

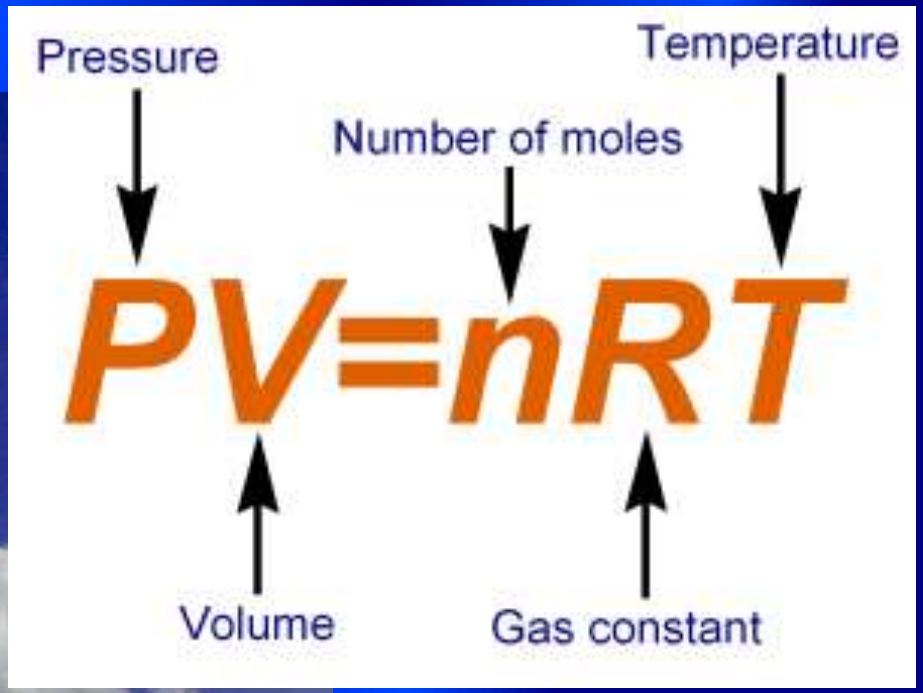
Victor Gorshkov

Good physics, e.g.,

- Makarieva & Gorshkov 2009. *Phys. Lett. A,* 373: 2801–2804
- Makarieva & Gorshkov 2009. *Phys. Lett. A*, 373, 4201-4205
- Makarieva et al. 2010. *Proc. R. Soc. A*, 466, 1893-1902.
- Makarieva & Gorshkov 2011. *Phys. Lett. A*, 375, 1053-1058.
- Gorshkov et al. 2012. *J. Exp. & Theor. Phys*., 115, 723-728.
- Makarieva et al. 2014. *Phys. Lett. A*, 378, 294-298.
- Gorshkov et al. 2011. *Phys. Lett. A*, 375, 2259-2261.

Vapour to liquid/solid

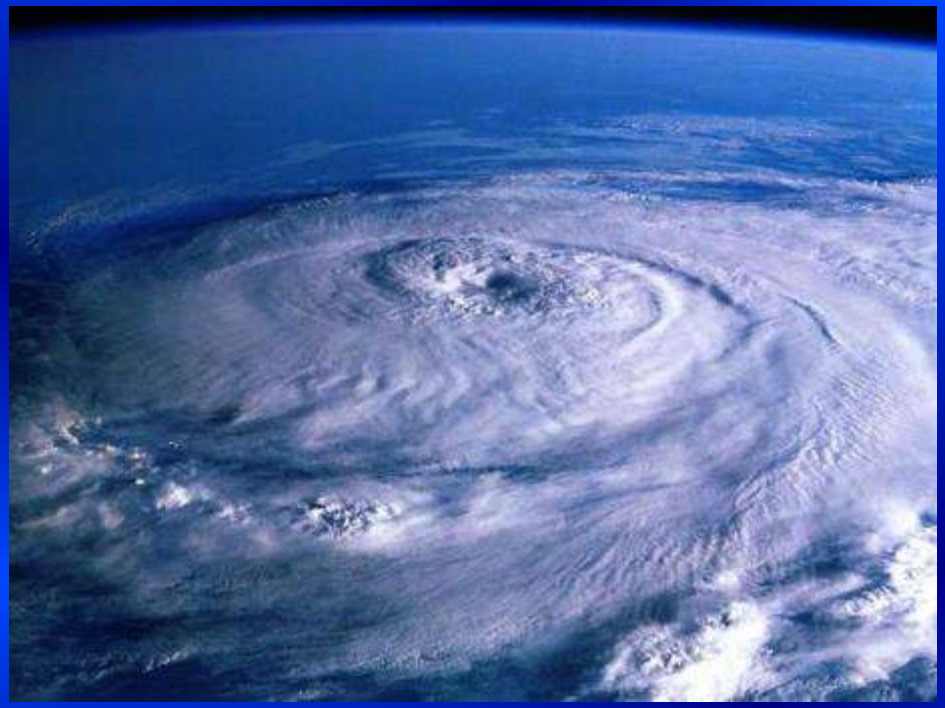
- Condensation
- Fewer gas molecules



Ideal gas law

Prediction

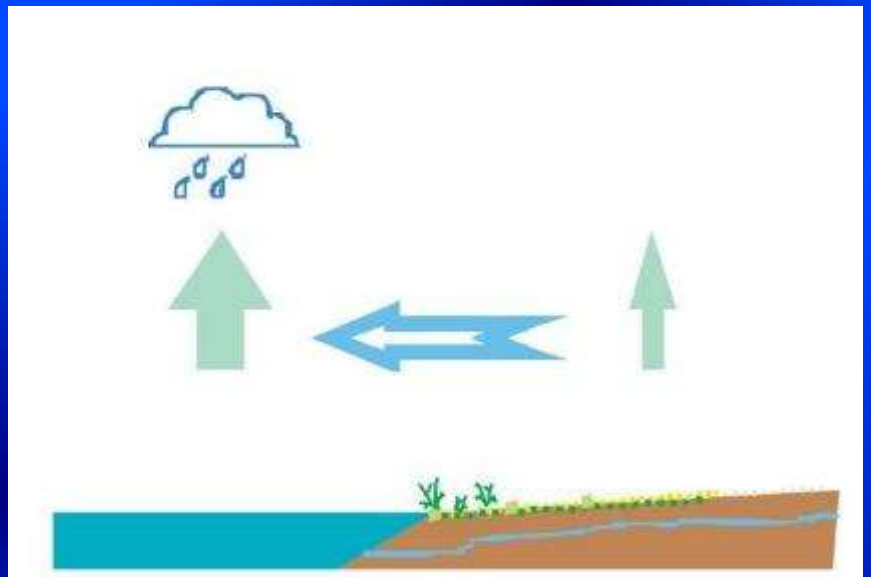
Areas with highest evaporation develop lowest pressure
draw in air and moisture … positive feedback

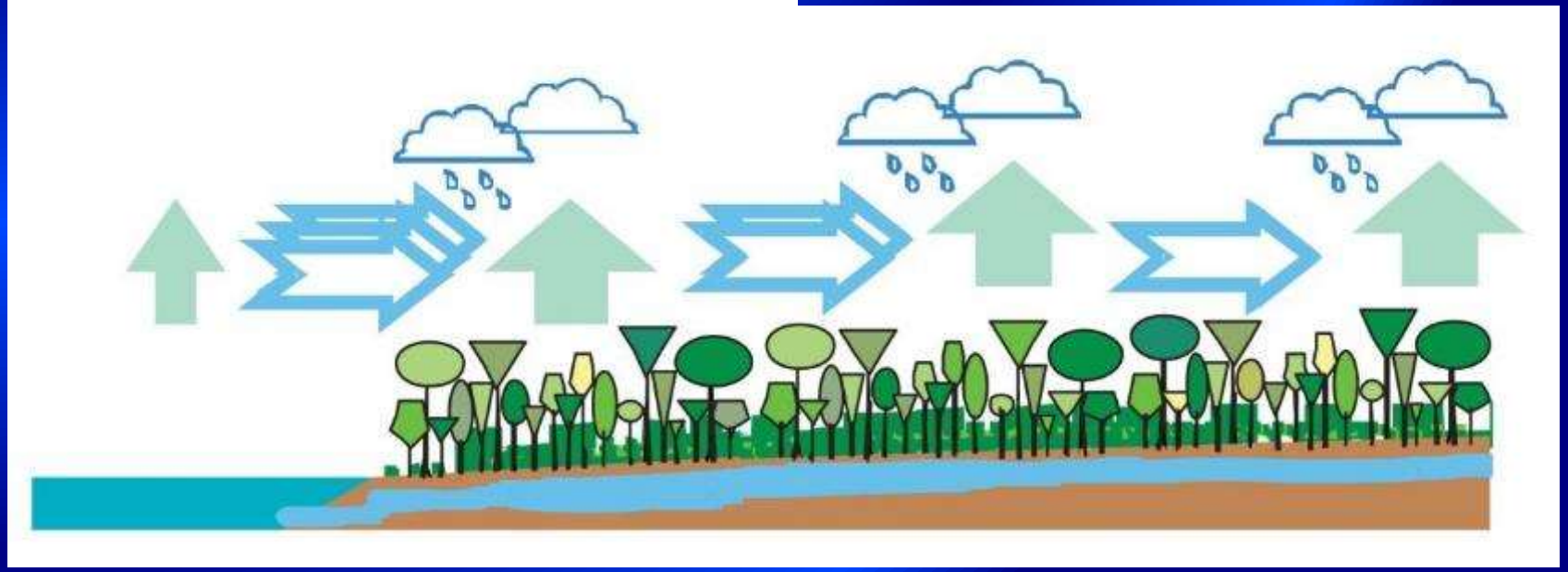


Warm oceans

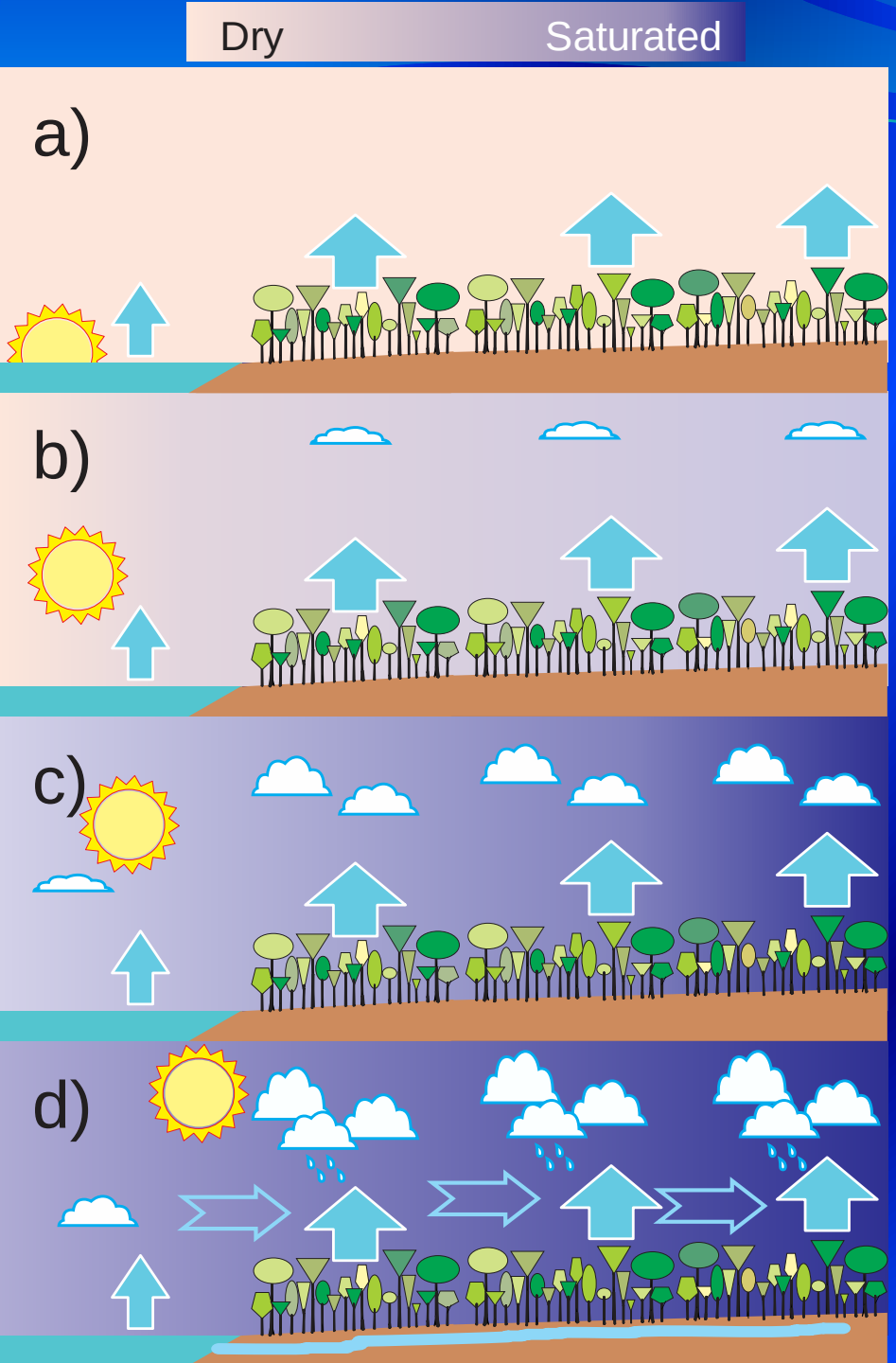
Forests

Condensation winds





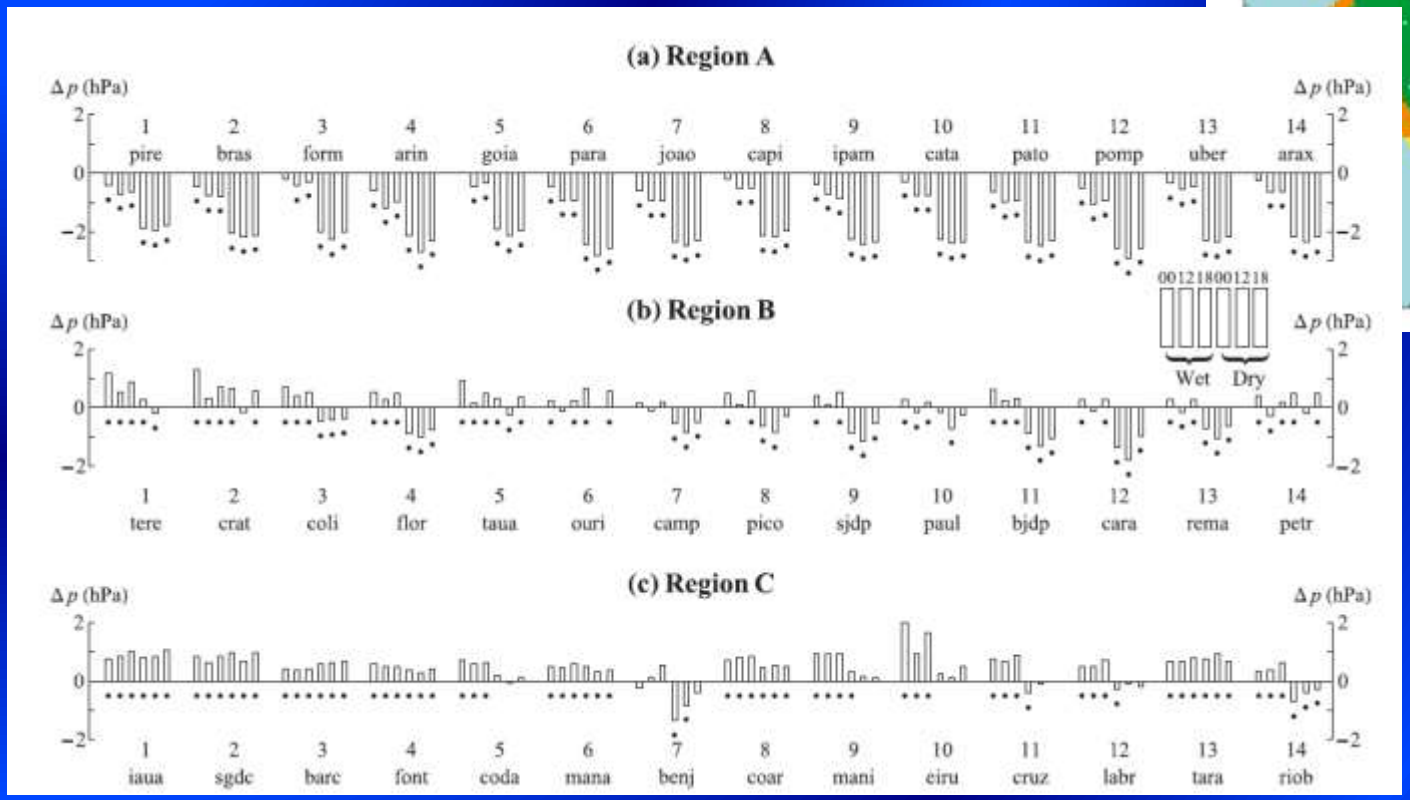
From Sheil & Murdiyarso (2009)
Bioscience, 59: 341-347

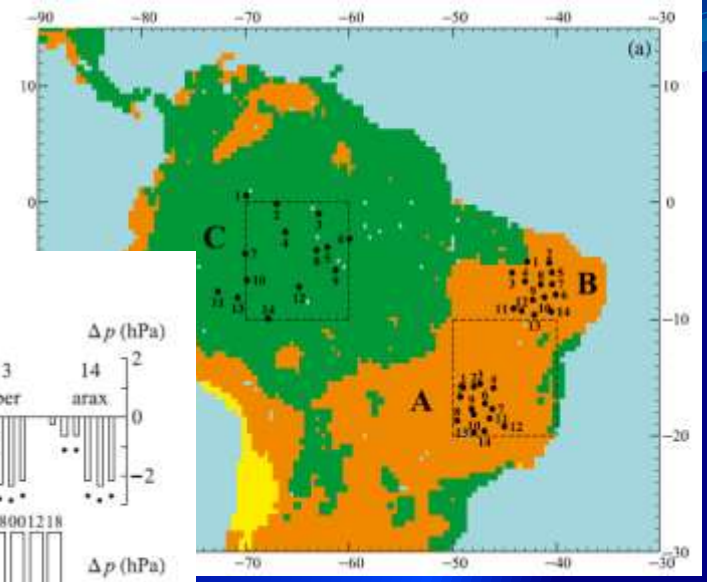


a) Dry air (pinkish)
b) Water vapour accumulates more rapidly over forest (bluish)
c) Condensation begins in the saturated air
d) Condensation lowers local pressure drawing in air from ocean

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

Evidence





Data
Brazilian Meteorological Institute (http://www.inmet.gov.br/portal/index.php?r5bdmep/bdmep).

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).

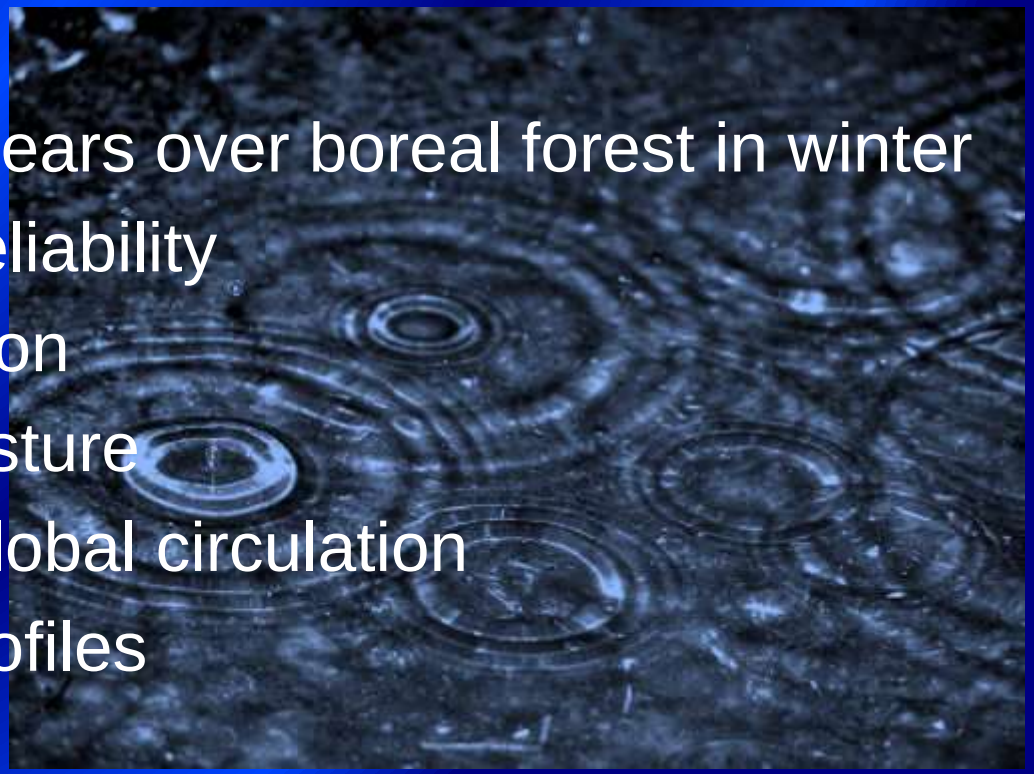
See Makarieva *et al*. 2014. *J. Hydrometerology*, 15, 411-426

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

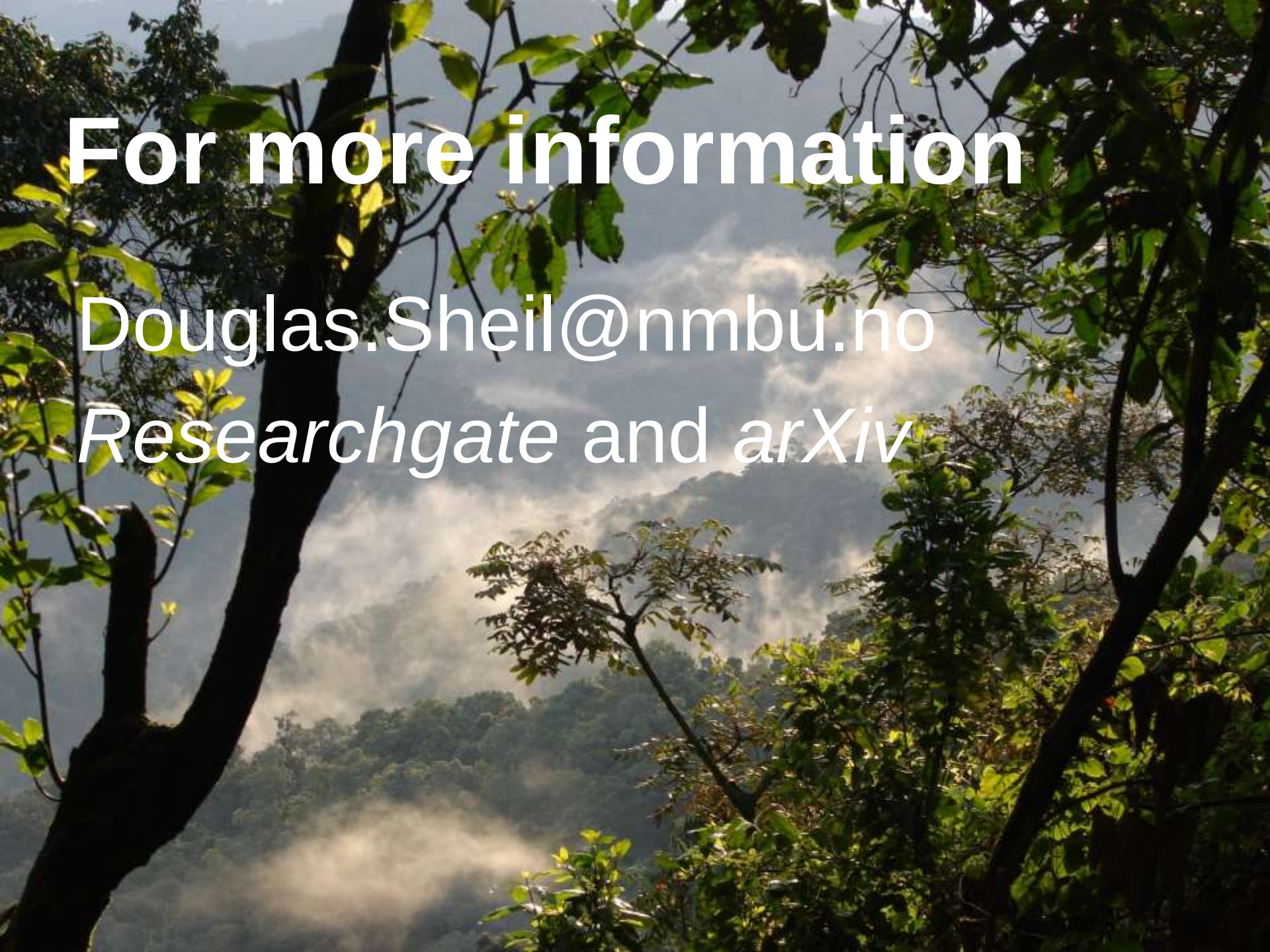
Implications 2: opportunities

Supply-focused interventions

Greening deserts

New regional value

Research



For more information

Douglas.Sheil@nmbu.no

Researchgate and *arXiv*