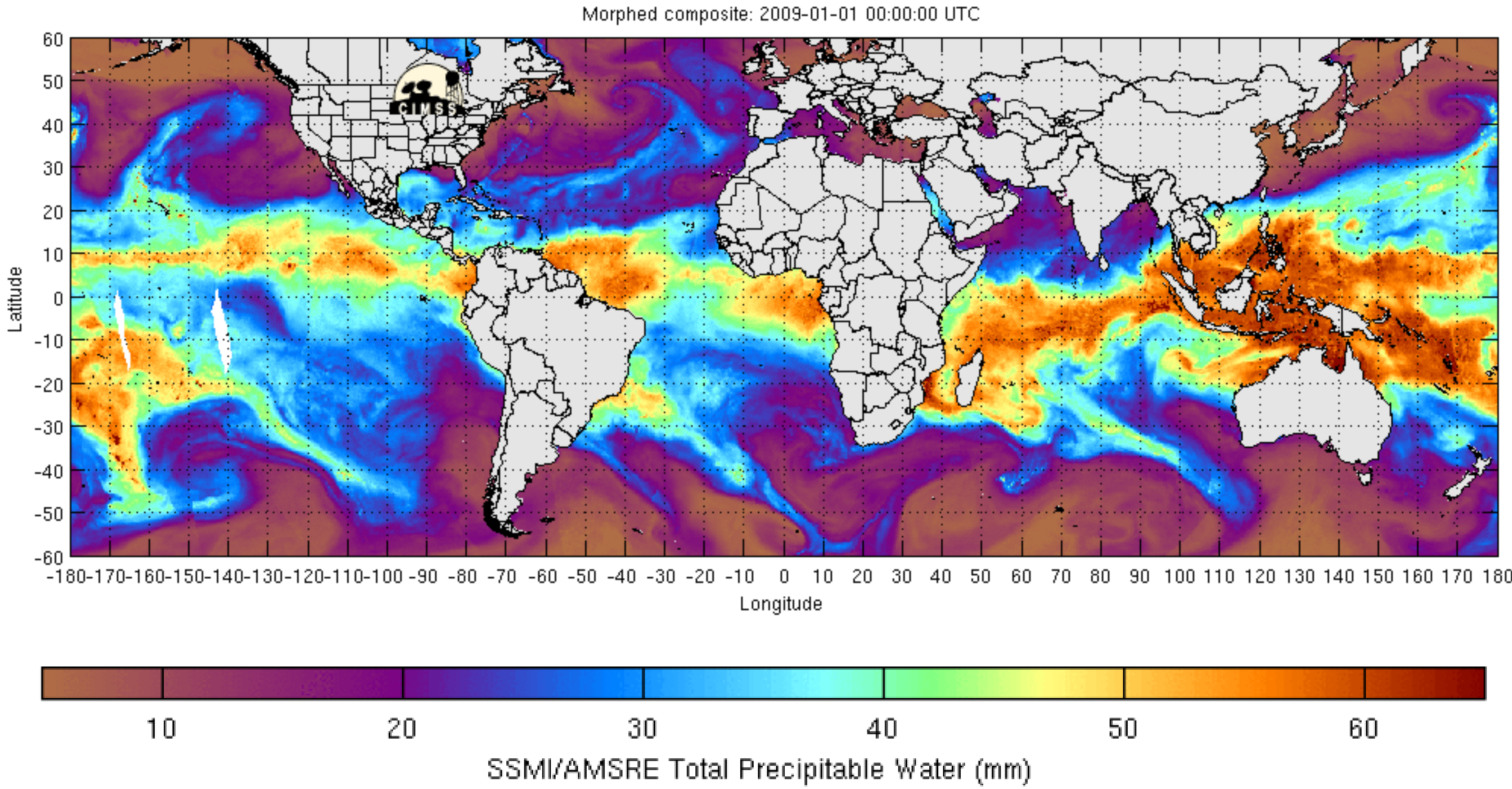
What happens to the moisture we evaporate?

Hubert H.G. Savenije

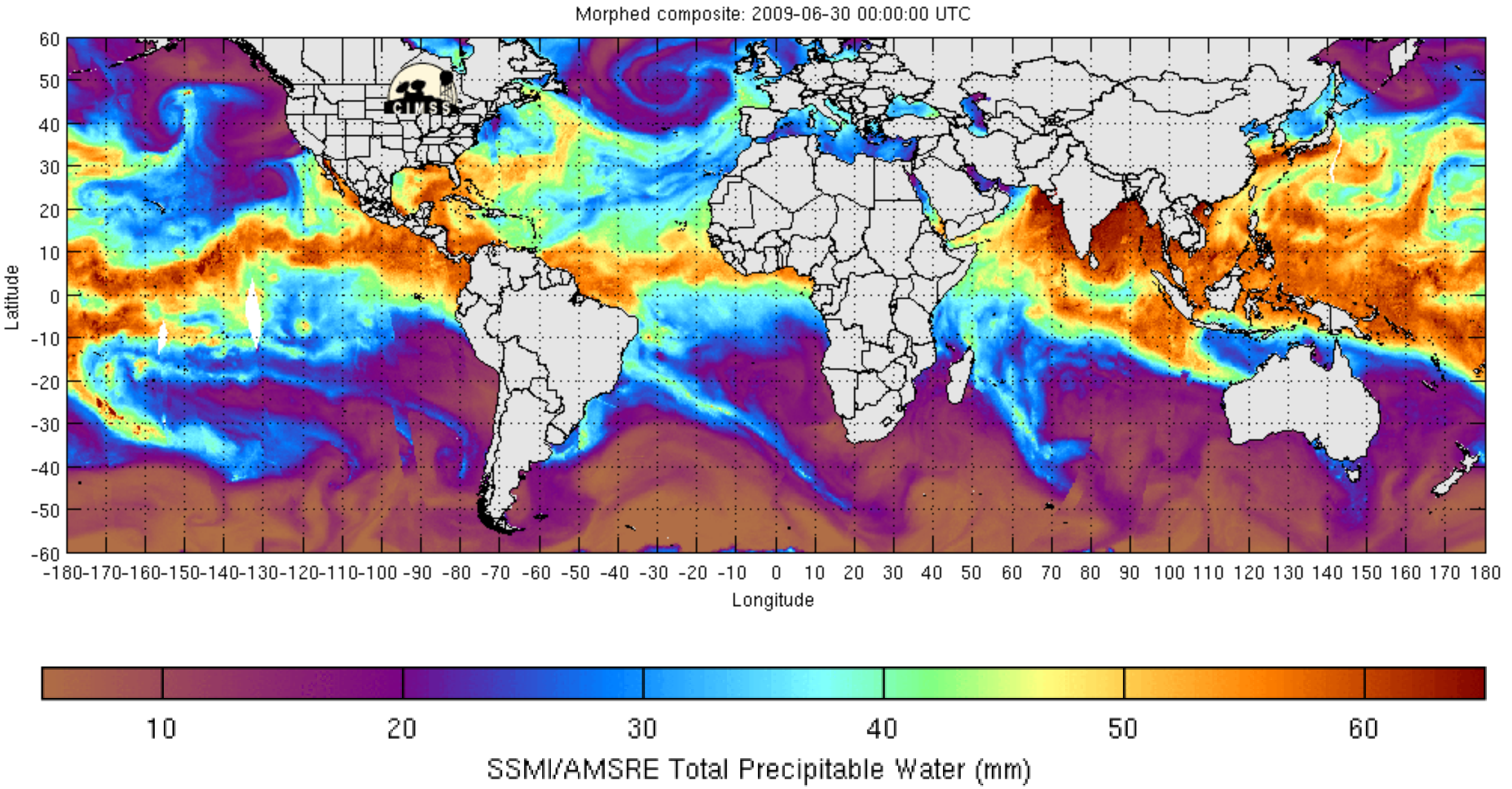
With important contributions from
Ruud van der Ent
and Revekka Nikoli

TU Delft

Atmospheric Moisture January 2009



Atmospheric Moisture
July 2009



New theory on moisture recycling

ELSEVIER
Journal of Hydrology 167 (1995) 57–78
Journal of Hydrology

[4]

New defini

ELSEVIER
Journal of Hydrology 176 (1996) 219–225
Journal of Hydrology

International Institu

The runoff

International Institute for

Pergamon

Phys. Chem. Earth, Vol. 20, No. 5–6, pp. 507–513, 1995.

0079-1946/95 $9.50 + 0.00

PII: S0079-1946(96)00014-6

Does Moisture Feedback Affect Rainfall Significantly?

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Received 10 May 1996; accepted 05 August 1996

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Traditional Approaches

Budyko (1974); Brubaker (1993); Trenberth (1999)

scale dependent bulk method

$$\beta = \frac{P_l}{P} = \frac{EL}{EL + 2Q_{in}} = \frac{EL}{PL + 2Q}$$

Eltahir and Bras (1994)

$$\beta = \frac{P_l}{P} = \frac{Q_l + EL}{Q_l + Q_a + EL}$$

Schär (1999)

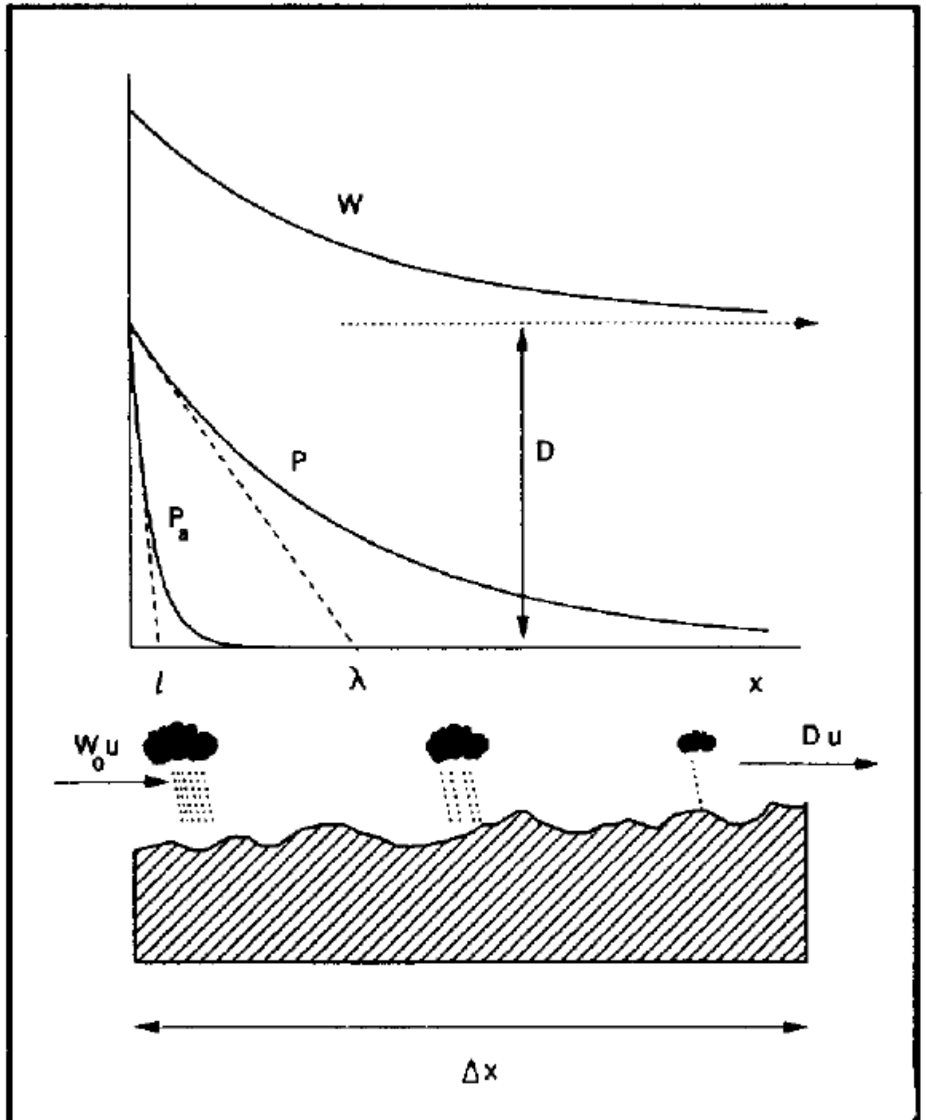
$$\beta = \frac{EL}{EL + Q_{in}}$$

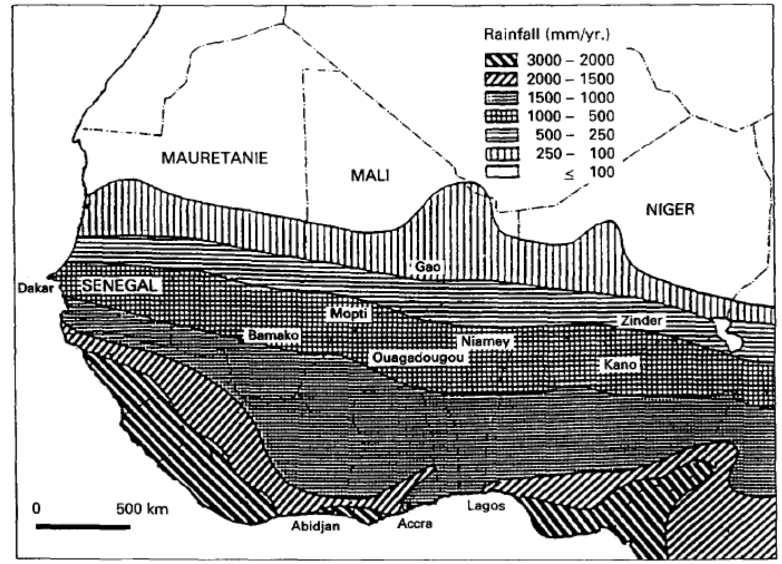
Savenije (1995)

scale independent local method

$$\gamma = \frac{P_e}{P} = \frac{P - P_a}{P} = 1 - \left(\frac{P}{P_0}\right)^{(1-\alpha)/\alpha}$$

Point Recycling across Sahel

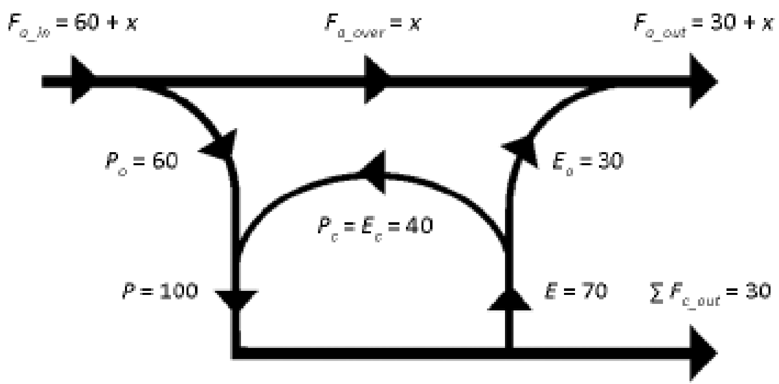


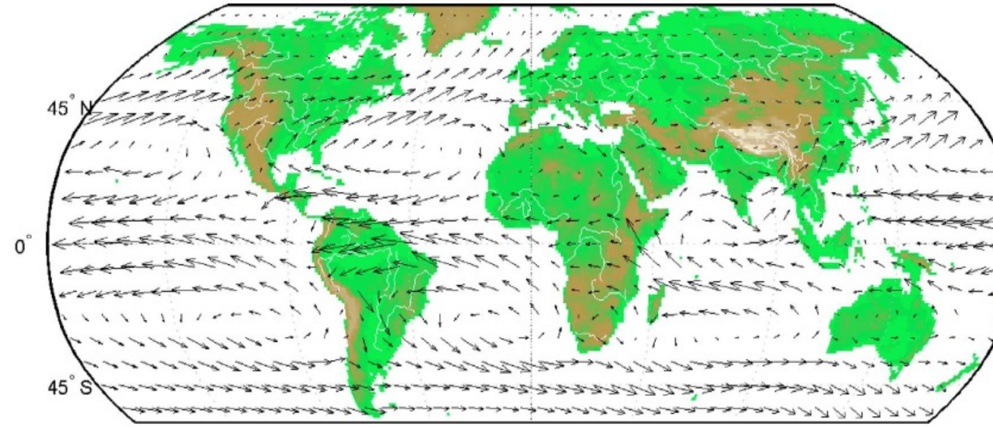


Savenije (1995), P&CoE

But was this right ?

Global analysis of Reanalysis data





40% of P recycles globally
57% of E recycles globally !

Origin and fate of atmospheric moisture over continents

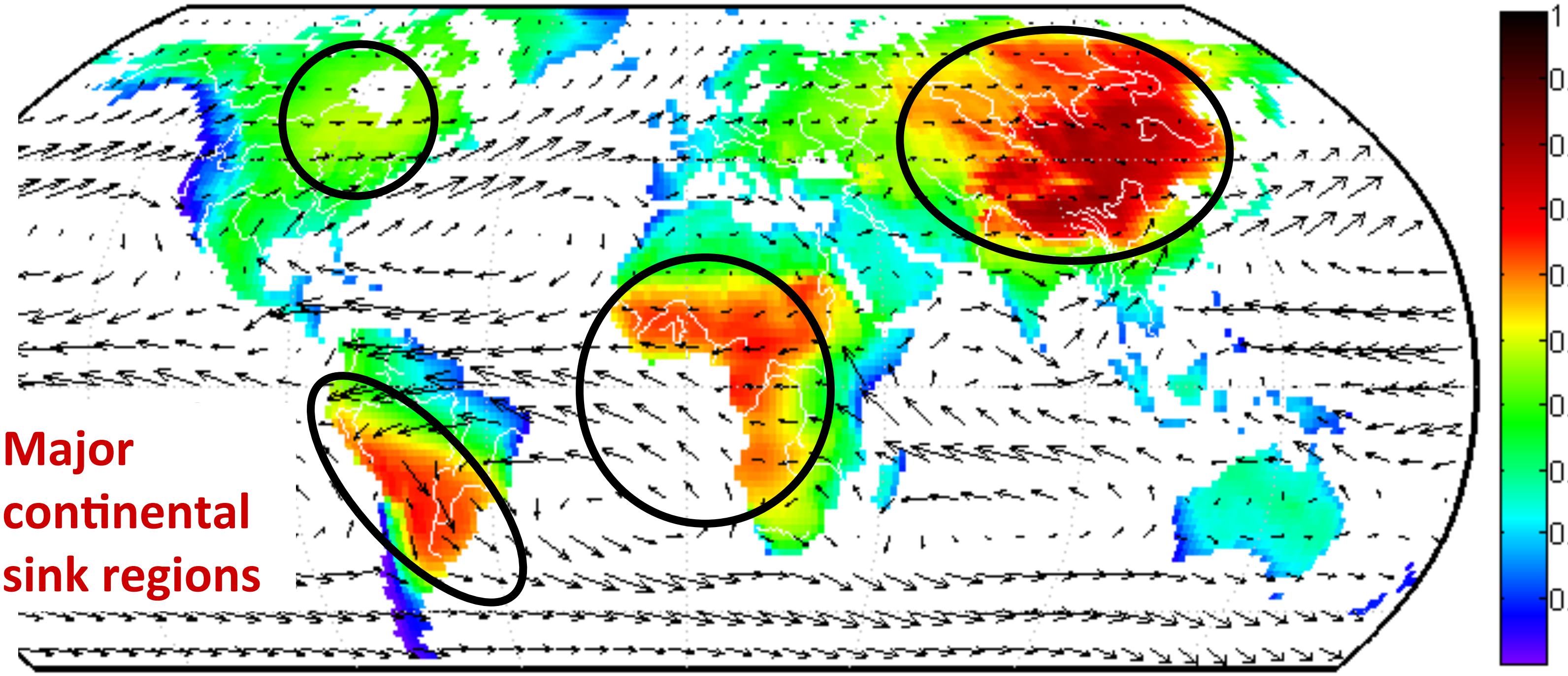
Rudi J. van der Ent,[1] Hubert H. G. Savenije,[1] Bettina Schaefli,[1] and Susan C. Steele-Dunne[1]

Received 19 January 2010; revised 6 April 2010; accepted 24 May 2010; published 22 September 2010.

WATER RESOURCES RESEARCH, VOL. 46, W09525,

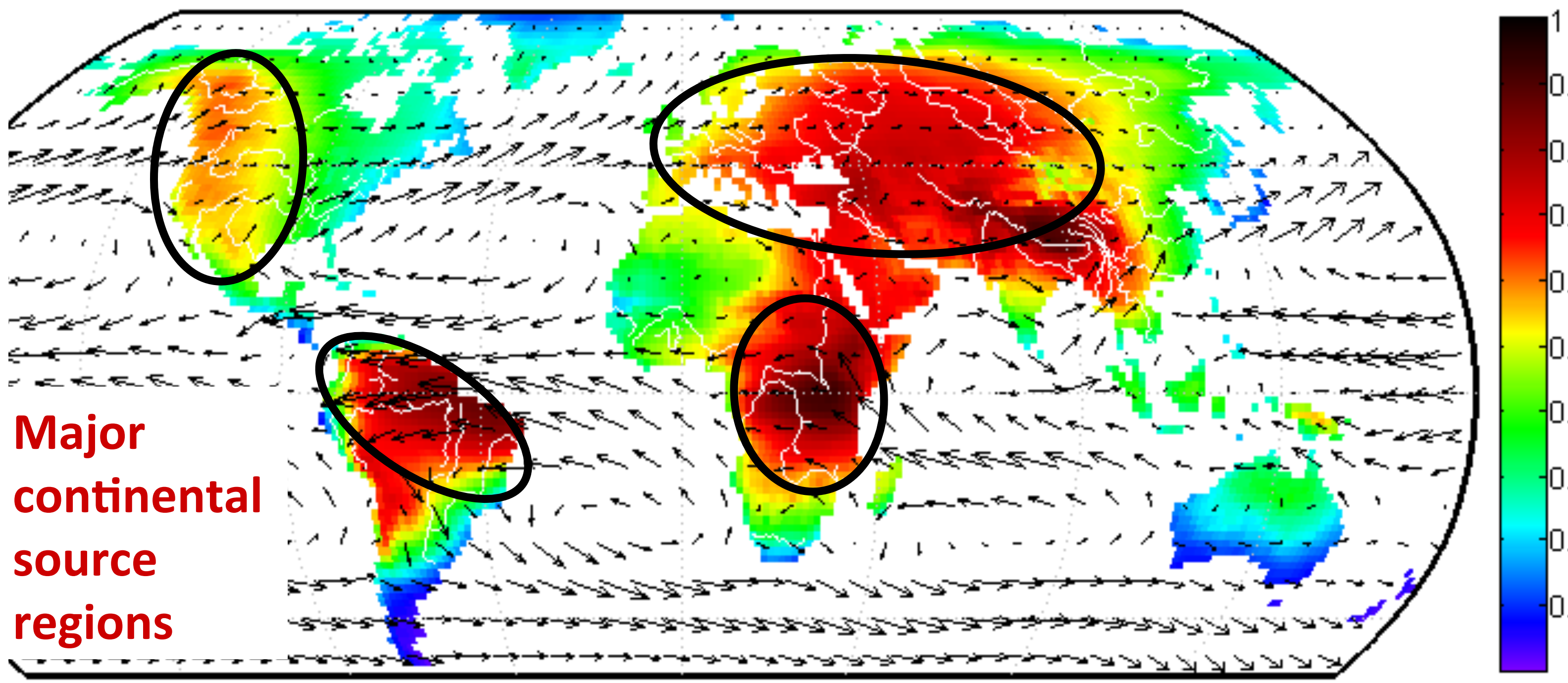
ρ_c:

Fraction of the precipitation that originates from continental evaporation



ε_c:

Fraction of the evaporation that returns as precipitation to any continental area



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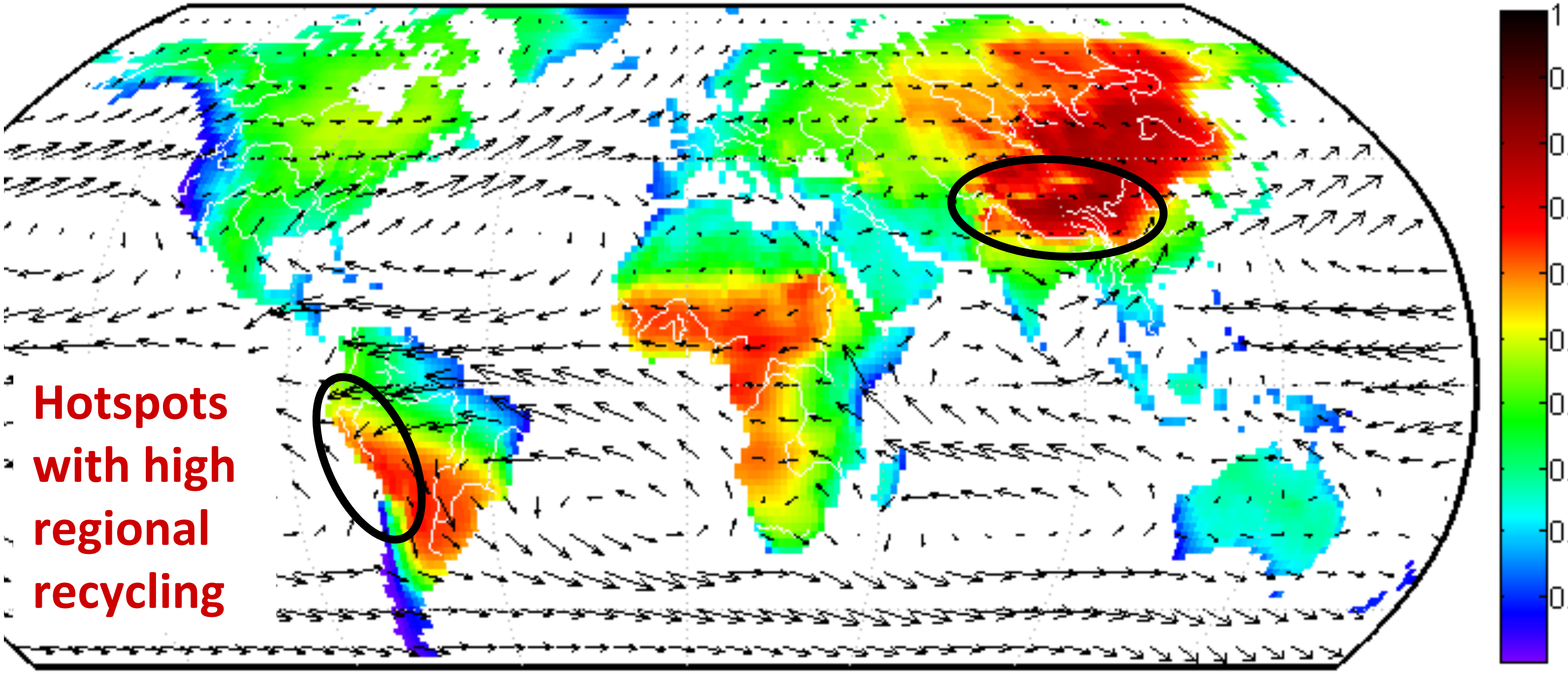

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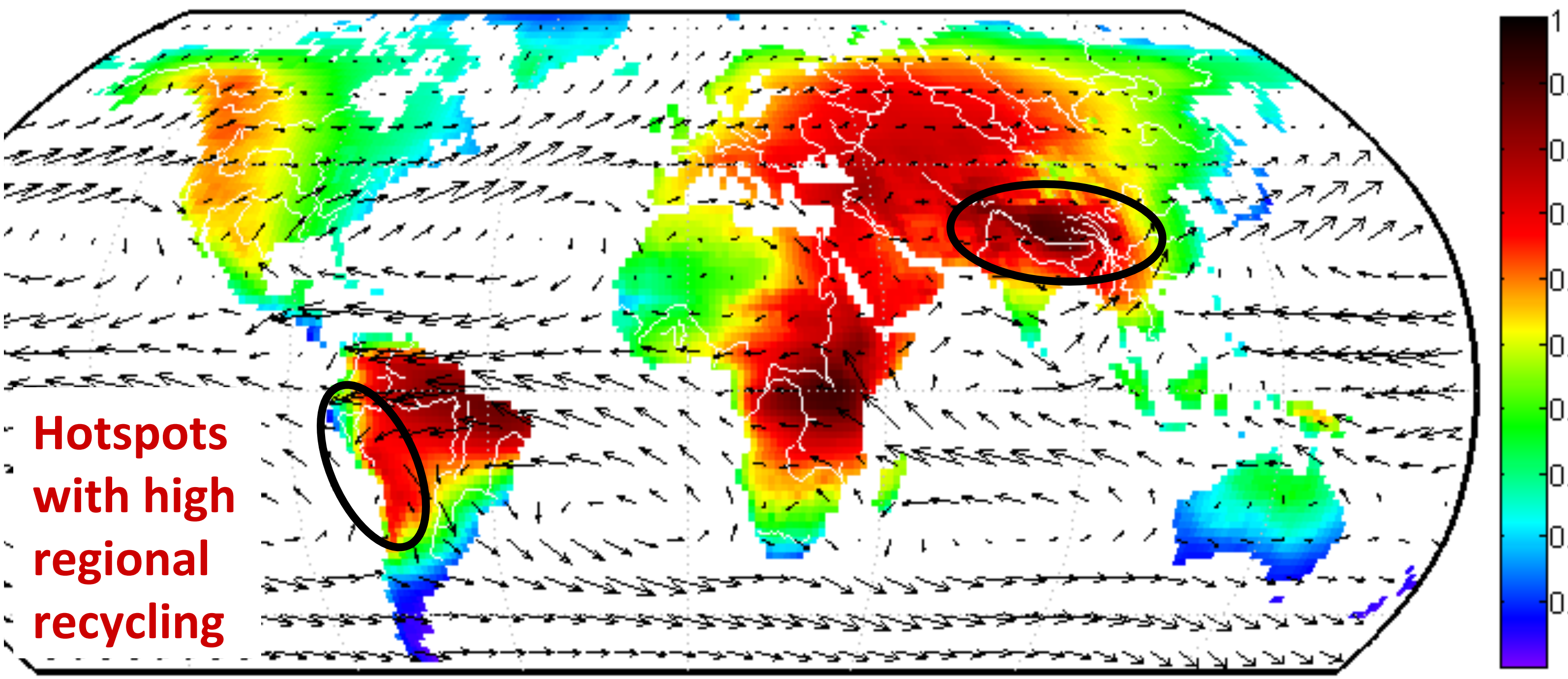
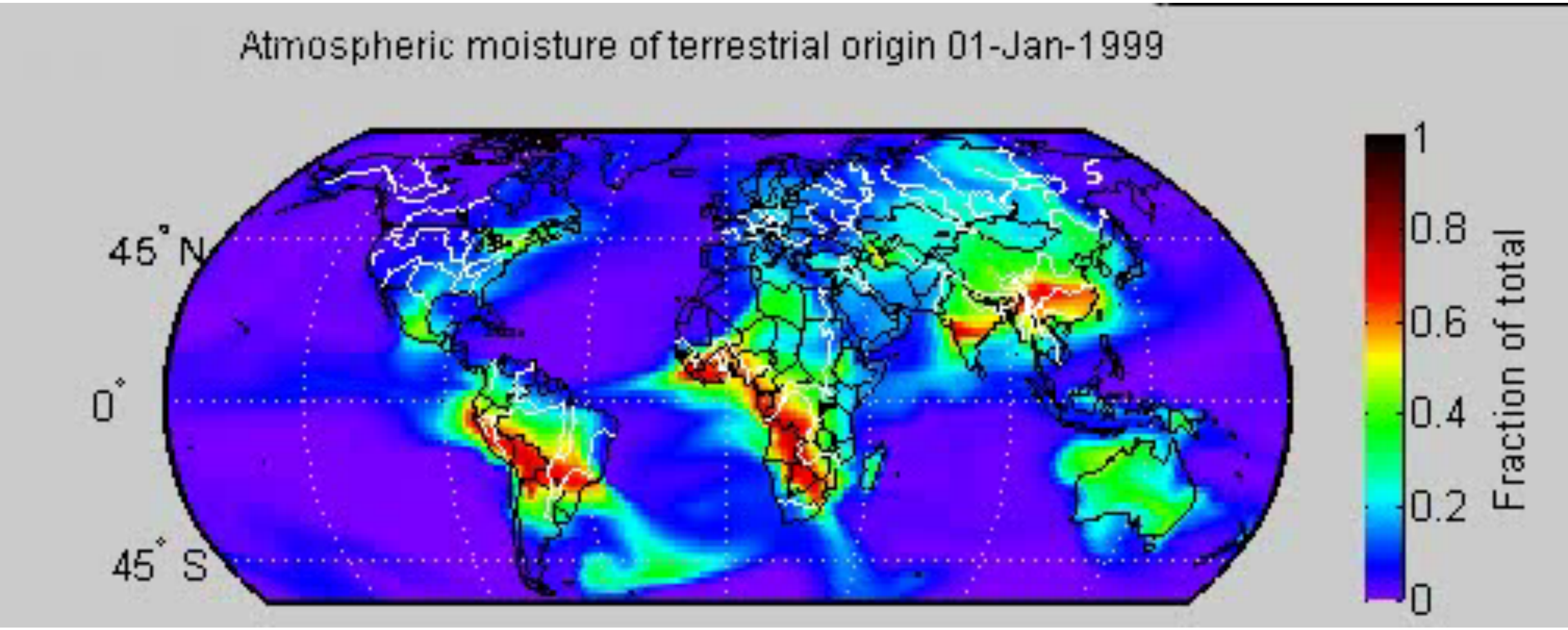


Atmospheric Moisture Content

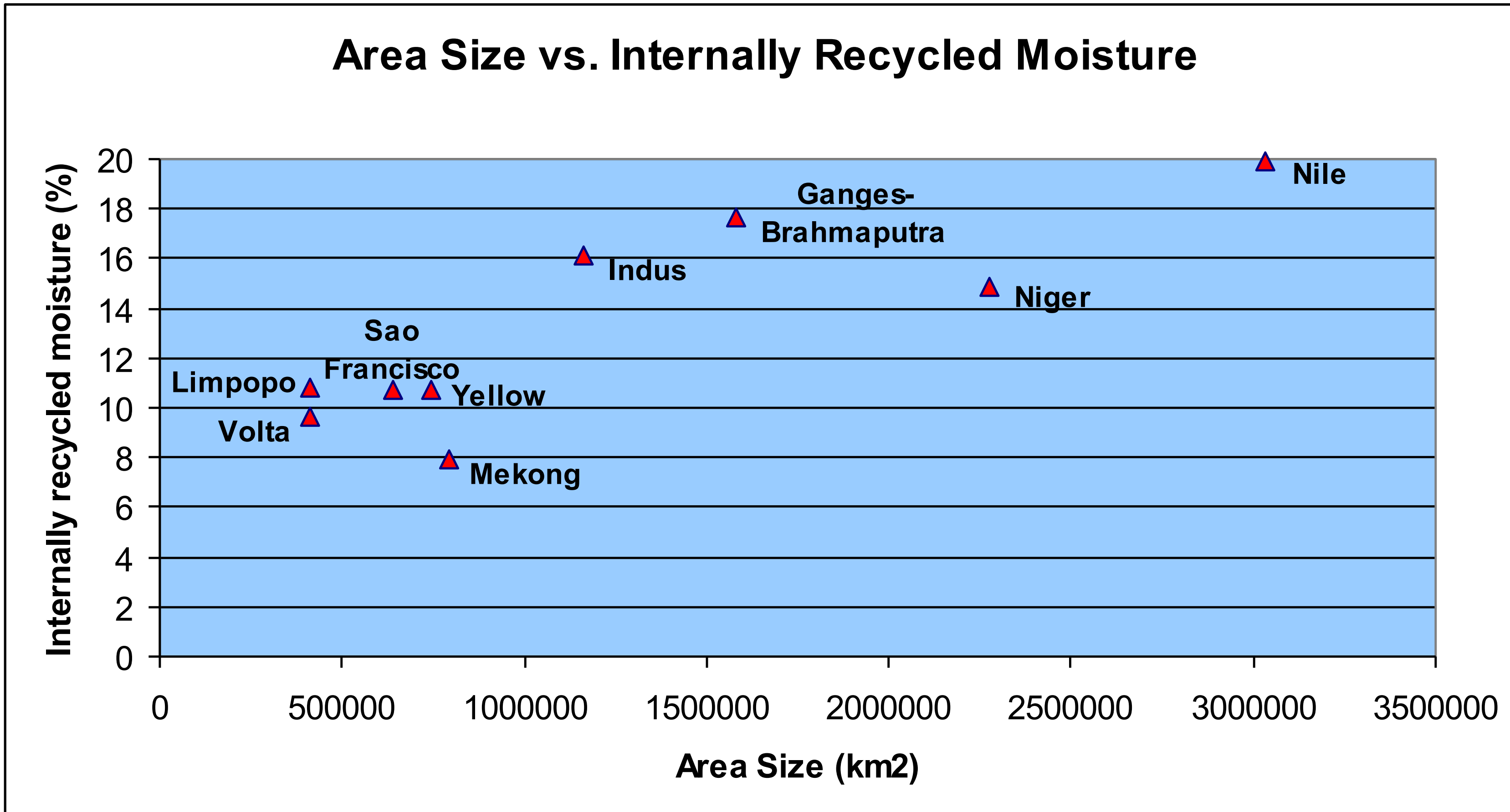


Moisture recycling per basin

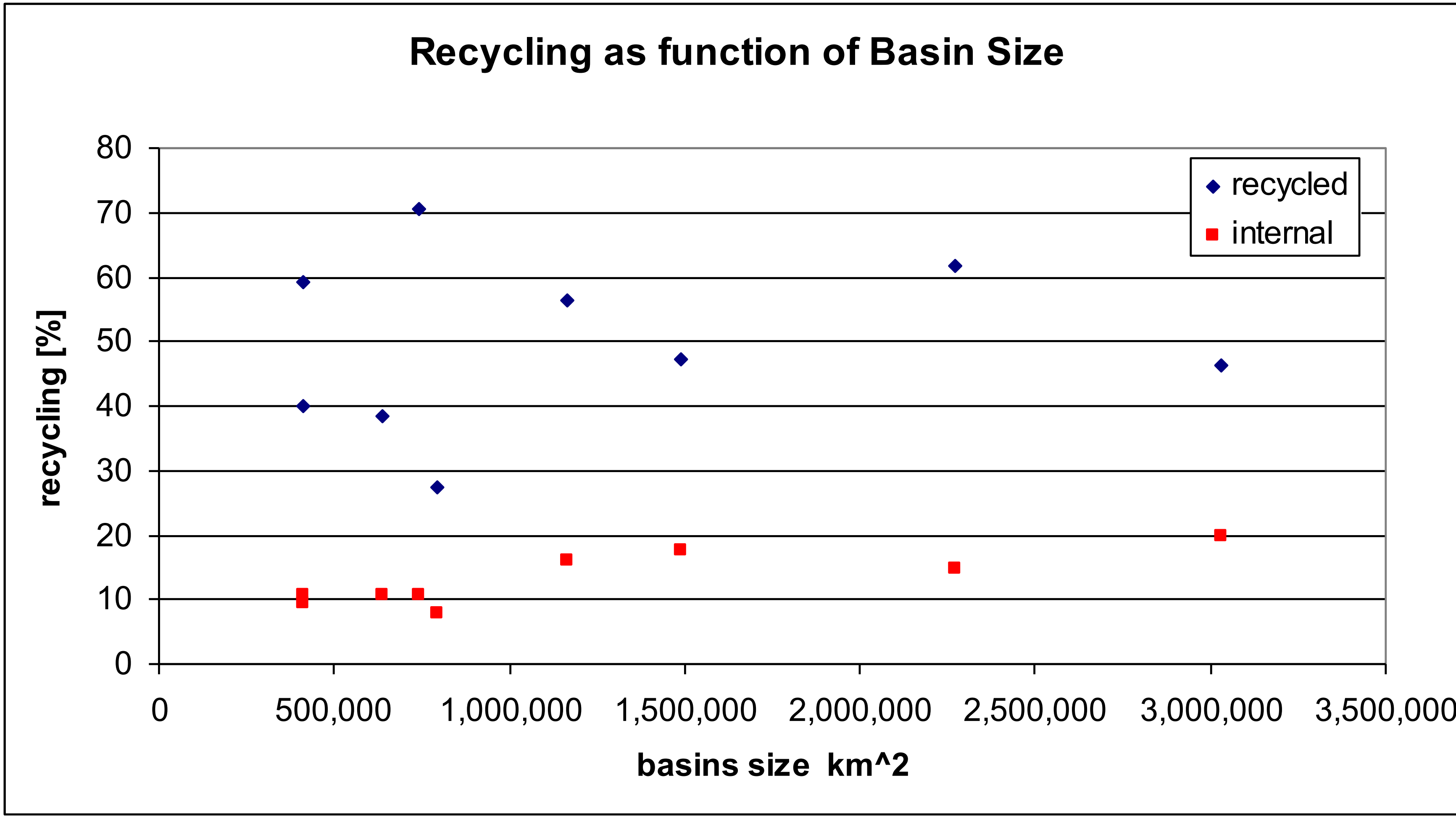
Basin	**Precipitation of Terrestrial Origin (%)**	**Internally recycled moisture (%)**	**Basin size (km^2)**
São Francisco	38.5	10.7	636,920
Volta	59.1	9.6	414,000
Niger	61.6	14.9	2,273,946
Nile	46.3	19.9	3,030,300
Limpopo	39.9	10.8	412,938
Indus	56.5	16.1	1,165,000
Ganges-Brahmaputra	47.1	17.7	1,487,000
Mekong	27.3	7.9	795,000
Yellow	70.5	10.7	742,443

Note: Global average: 40% of terrestrial origin

Relation between Internal moisture recycling and size



Terrestrial Origin not related to size !



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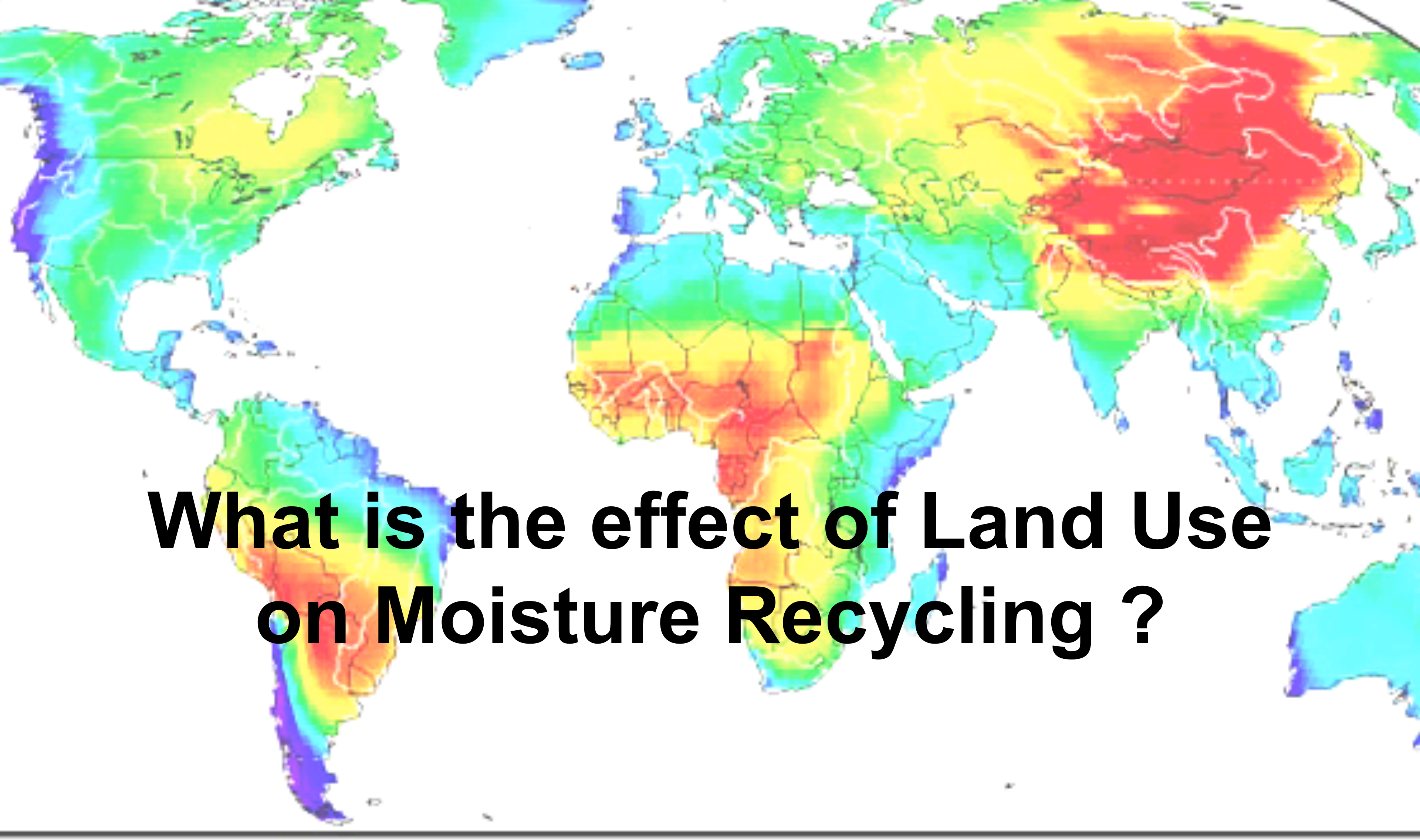
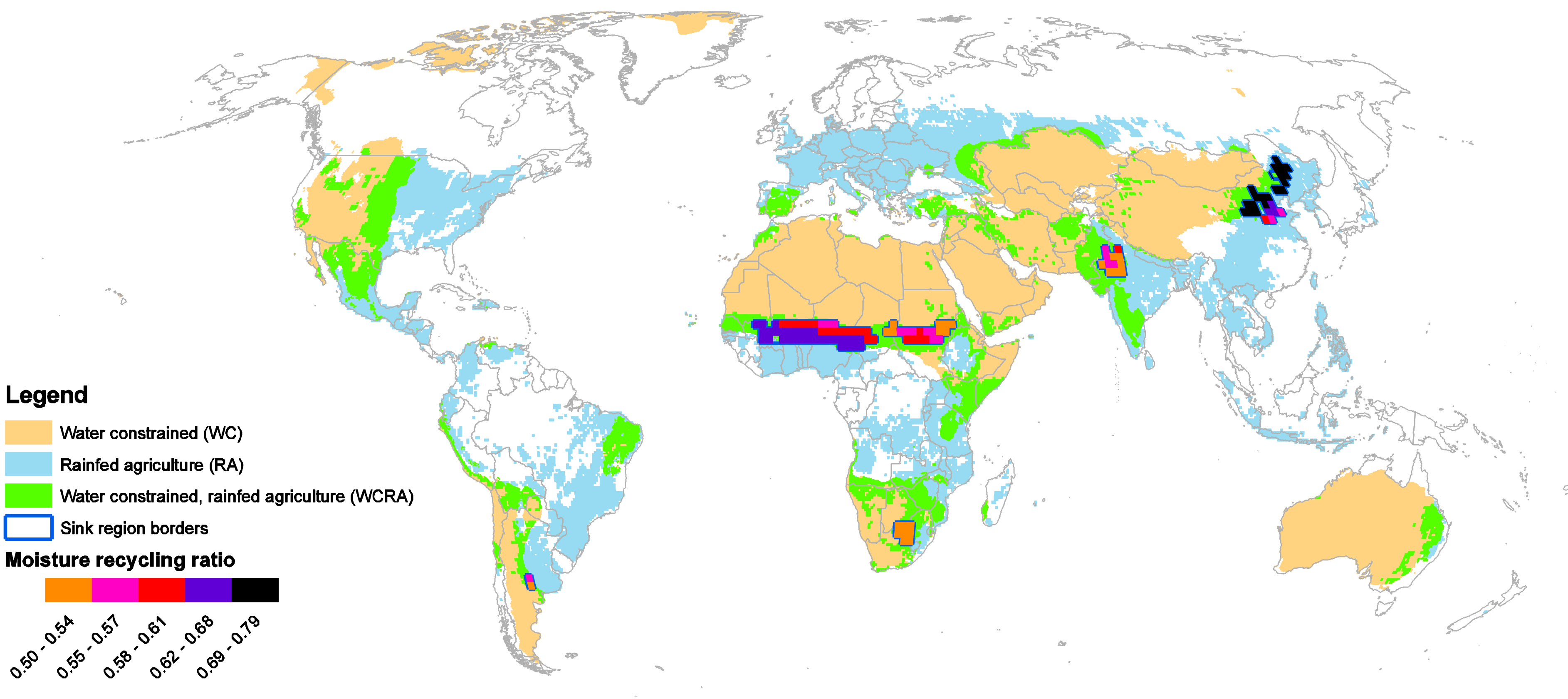


What is the effect of Land Use on Moisture Recycling ?

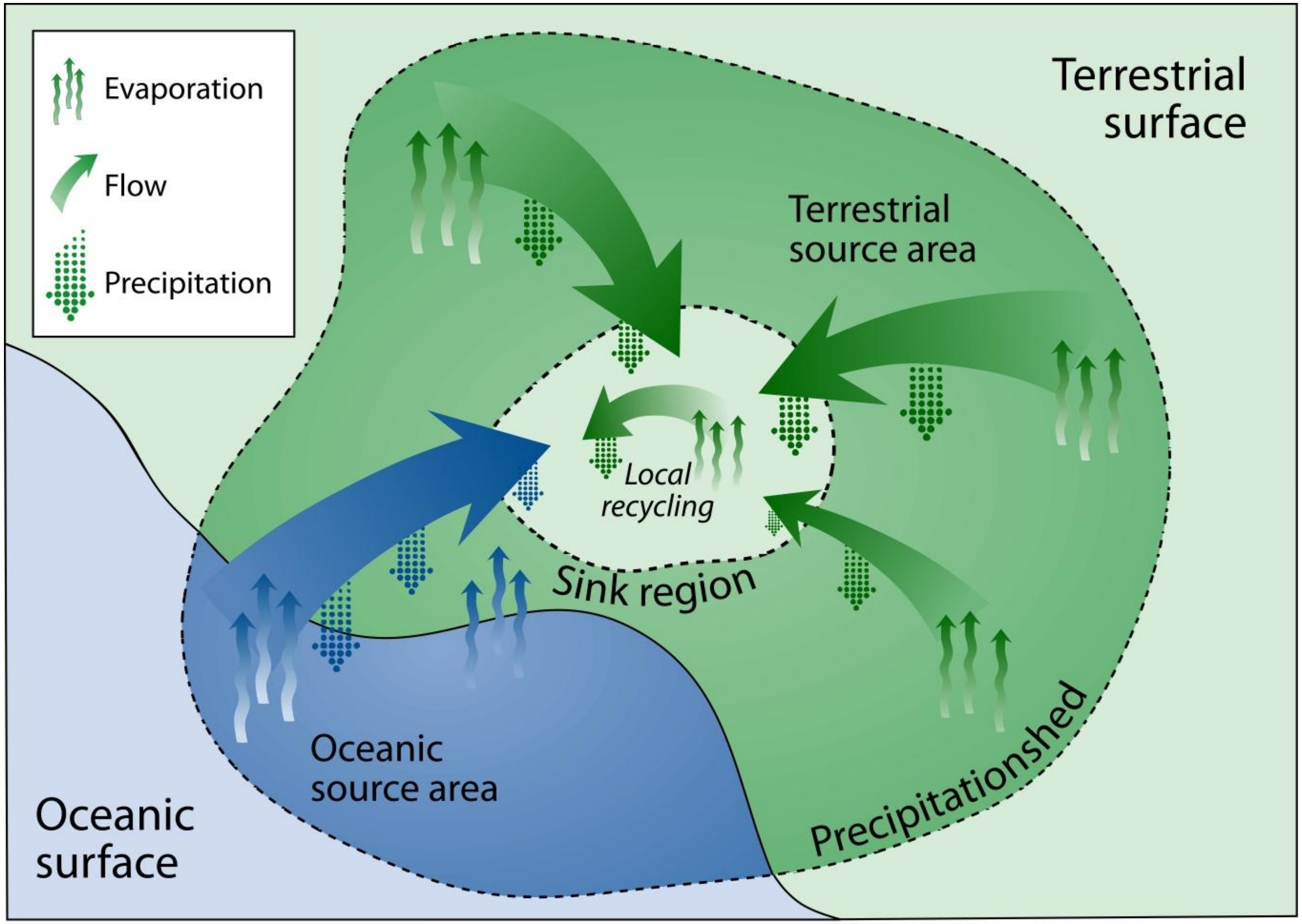
Most vulnerable regions

- Collaboration with Patrick Keys (Stockholm Environmental Institute)



Region	Area size (10^6 km^2)	Growing season	Nations within sink region	Sum of the rainfall during the growing season (mm)	Rainfall during the growing season as a fraction of the yearly precipitation	Rainfall originating from terrestrial sources during the growing season
East China	35	May-Sep	China	419	79%	64%
North China	20	May-Sep	China	334	81%	72%
Western Sahel	137	June-Oct	Benin, Burkina Faso, Cameroon, Chad, Mali, Mauritania, Niger, Nigeria	301	93%	64%
Eastern Sahel	54	June-Oct	Chad, Eritrea, Sudan	452	93%	59%
Argentina	4.5	Nov-Mar	Argentina	583	59%	57%
Pakistan-India	30	Jul-Nov	India, Pakistan	339	78%	55%
Southern Africa	20	Dec-Apr	Botswana, South Africa	343	64%	54%

The Precipitationshed



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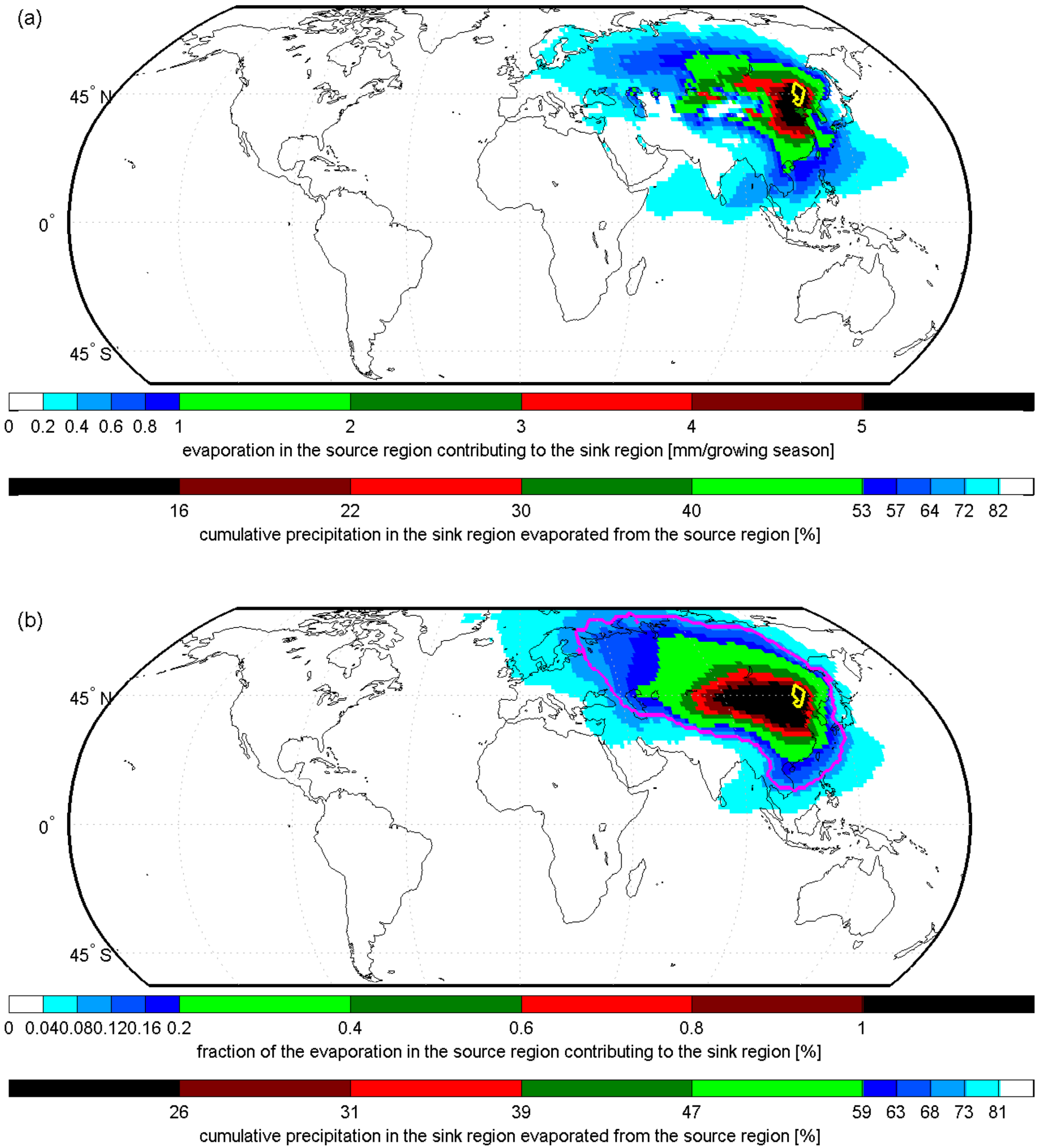
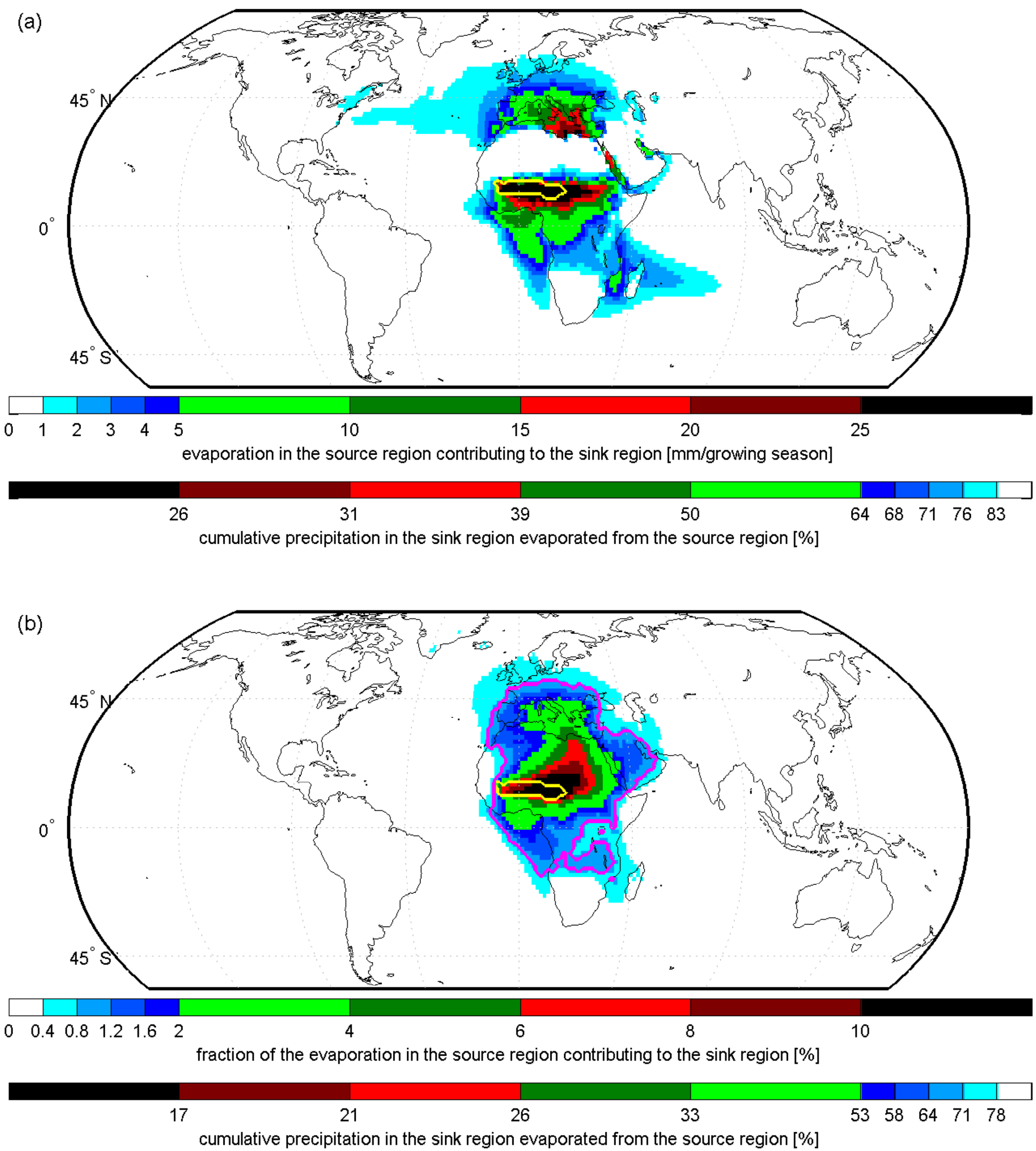
Most vulnerable regions

Northern China

Western Sahel


(a)
45° N
0°
45° S
0 0.2 0.4 0.6 0.8 1 2 3 4 5
evaporation in the source region contributing to the sink region [mm/growing season]
16 22 30 40 53 57 64 72 82
cumulative precipitation in the sink region evaporated from the source region [%]
(b)
45° N
0°
45° S
0 0.040.080.120.16 0.2 0.4 0.6 0.8 1
fraction of the evaporation in the source region contributing to the sink region [%]
26 31 39 47 59 63 68 73 81
cumulative precipitation in the sink region evaporated from the source region [%]

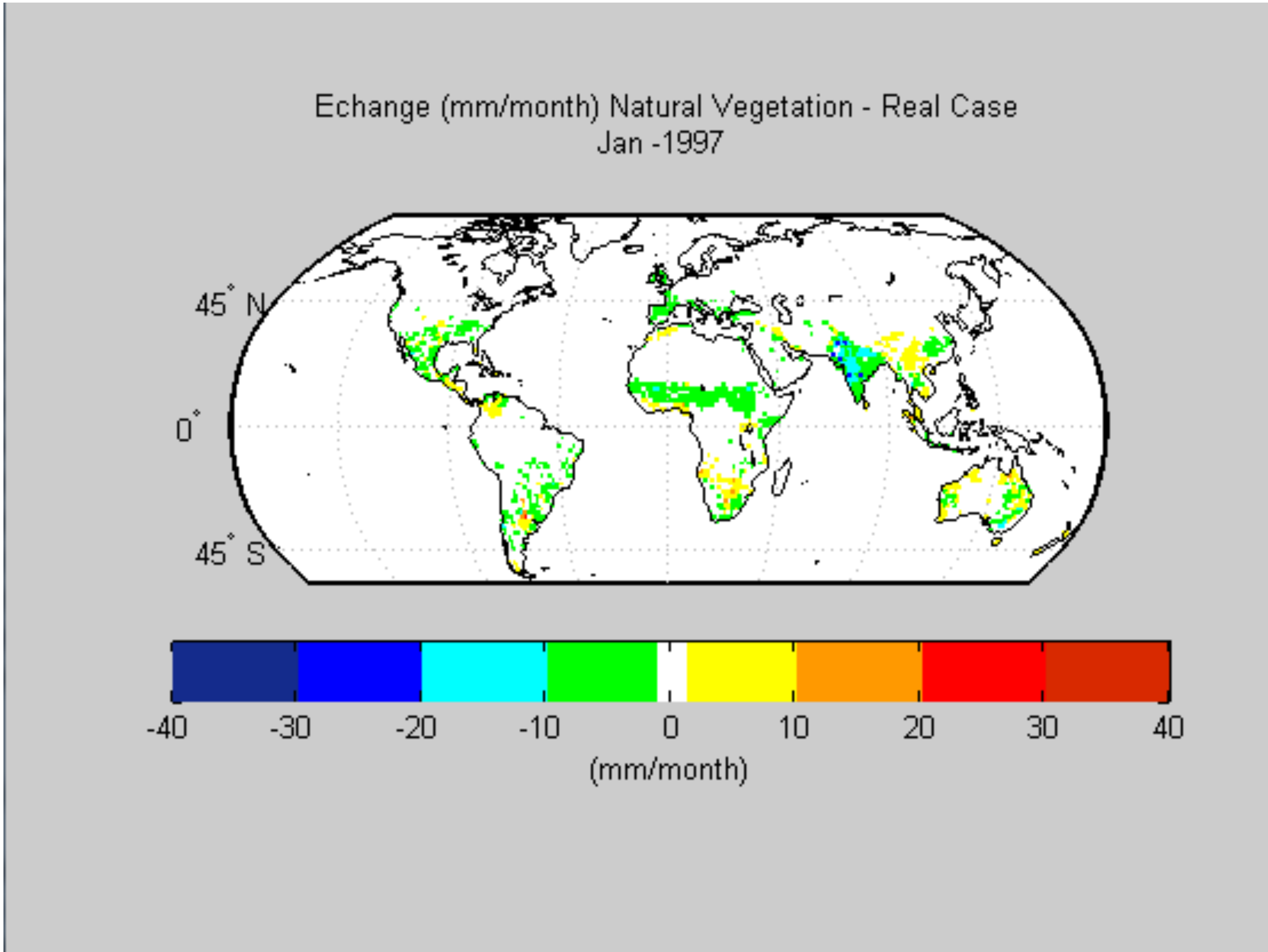

(a)
45° N
0°
45° S
0 1 2 3 4 5 10 15 20 25
evaporation in the source region contributing to the sink region [mm/growing season]
26 31 39 50 64 68 71 76 83
cumulative precipitation in the sink region evaporated from the source region [%]
(b)
45° N
0°
45° S
0 0.4 0.8 1.2 1.6 2 4 6 8 10
fraction of the evaporation in the source region contributing to the sink region [%]
17 21 26 33 53 58 64 71 78
cumulative precipitation in the sink region evaporated from the source region [%]

Is there already an effect?

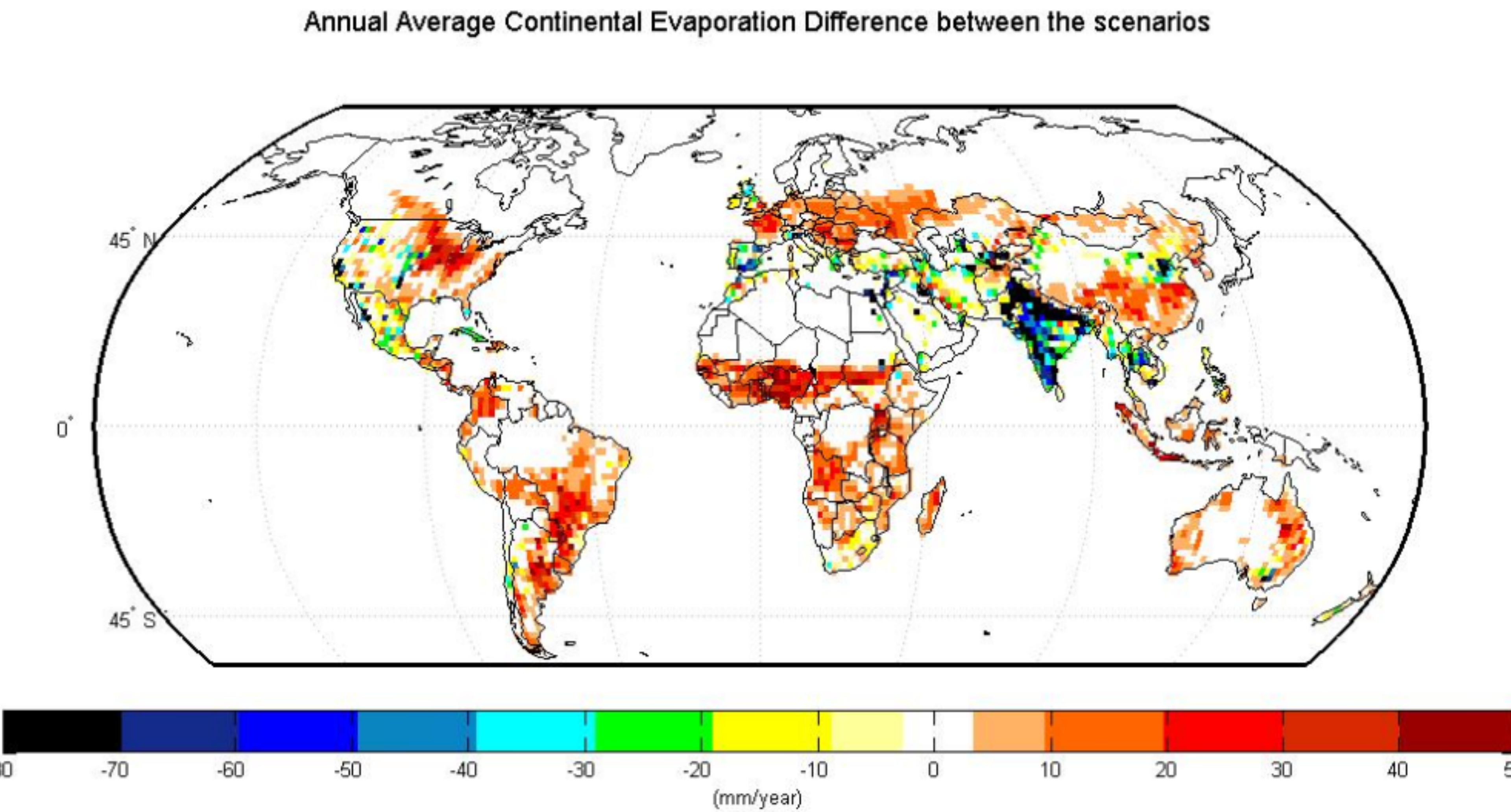
We compared Natural and Current vegetation

- Work by Revekka Nikoli (master student)

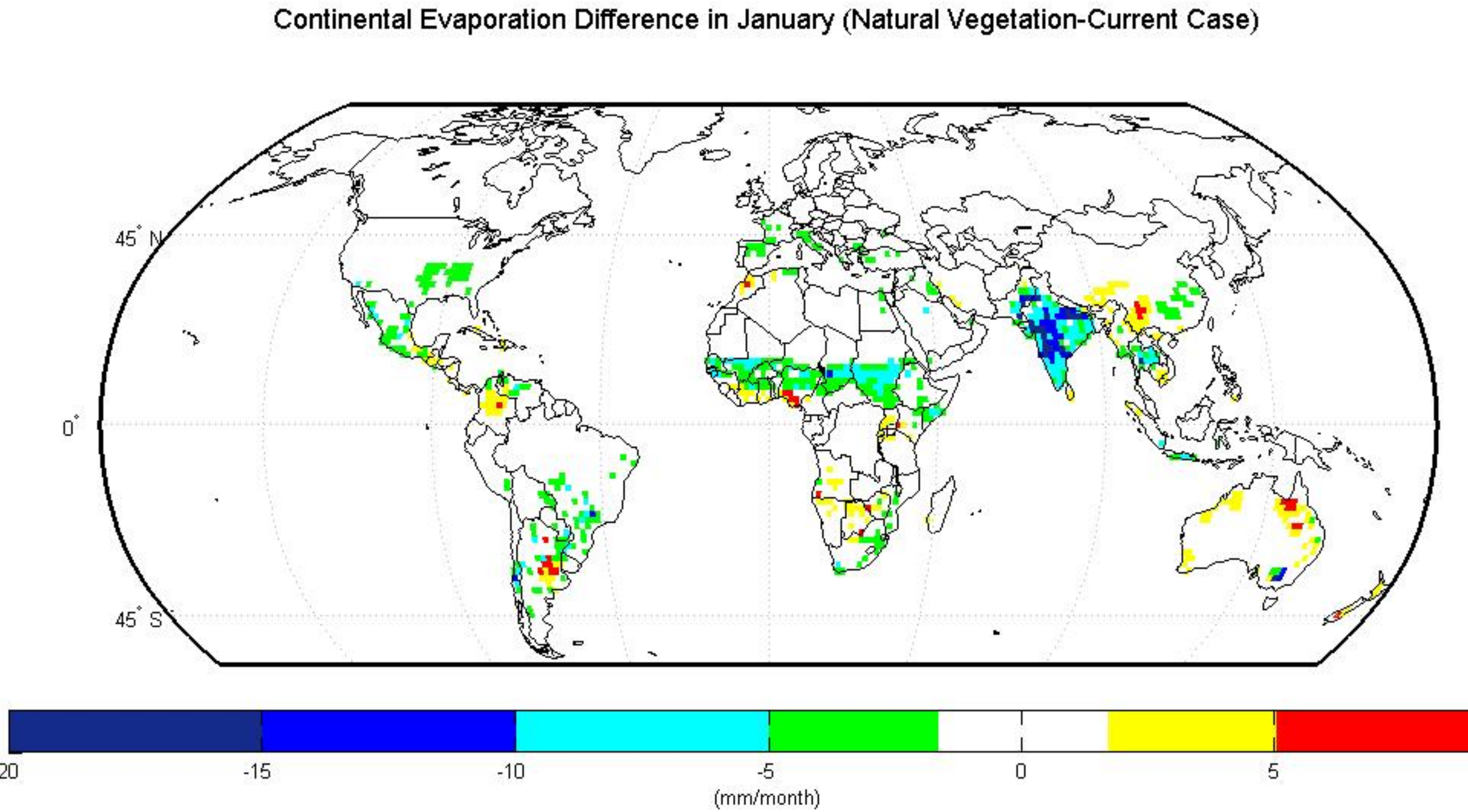
Difference between Natural and Present



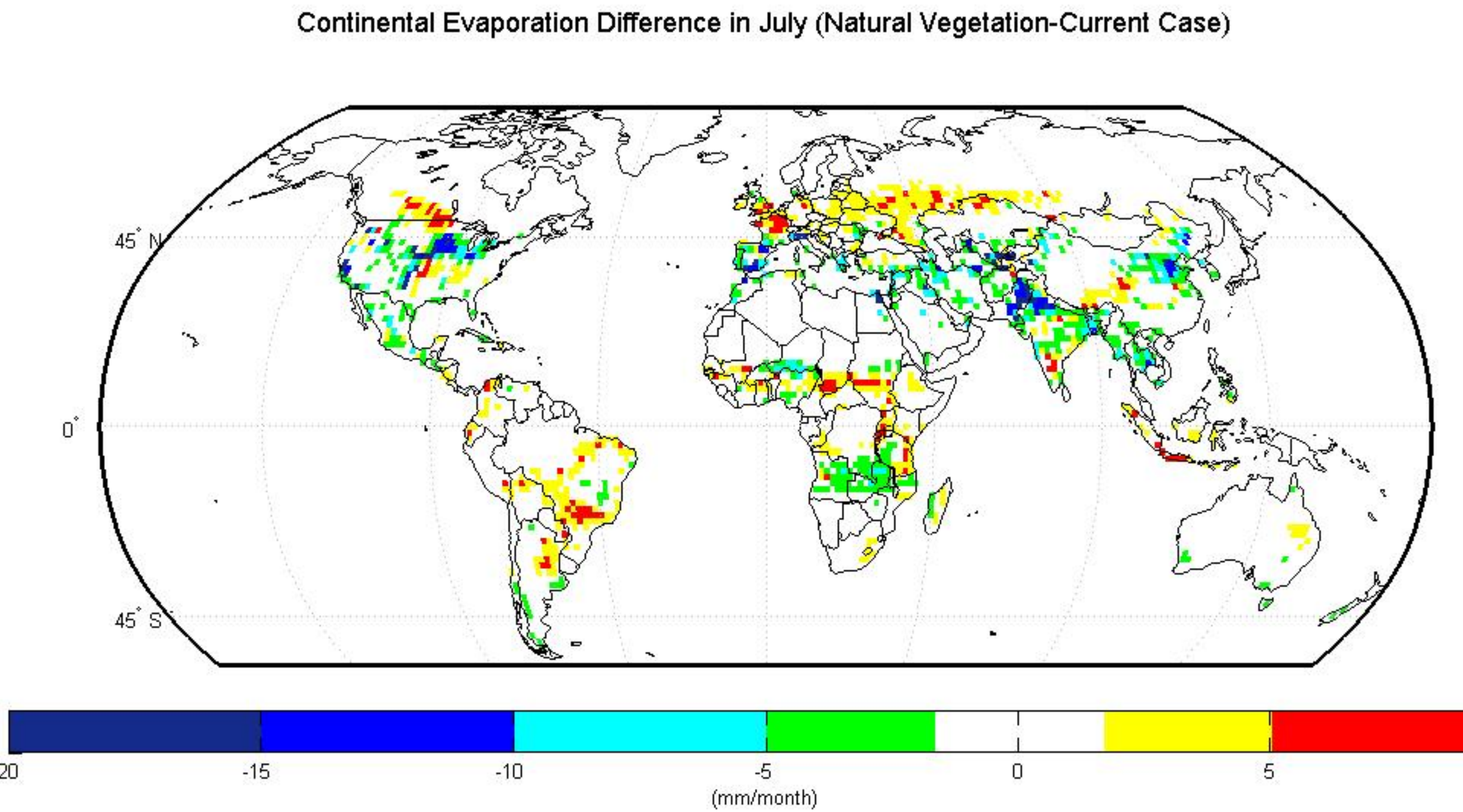
10-year average annual E difference (1997-2006)



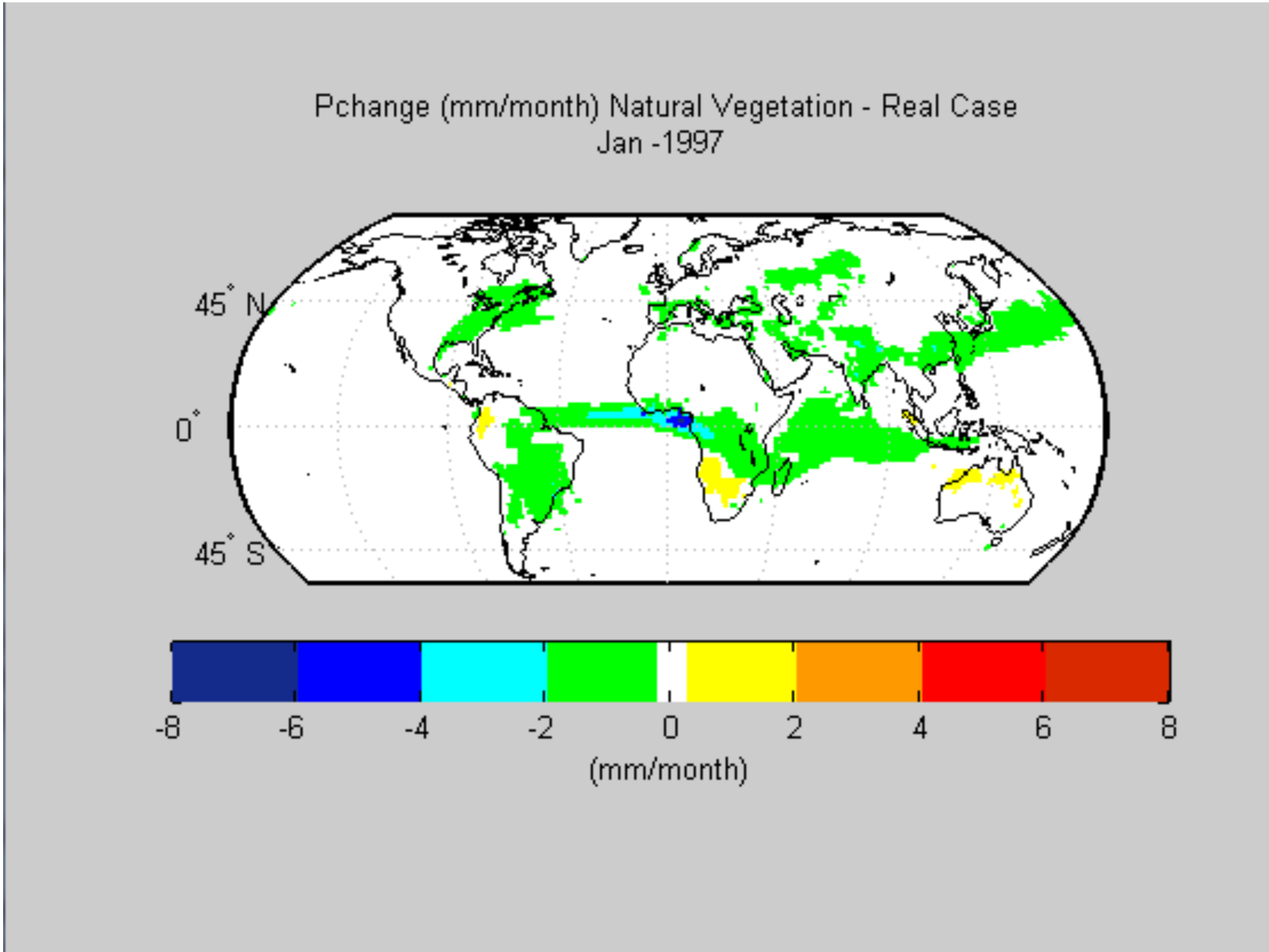
January Evaporation difference



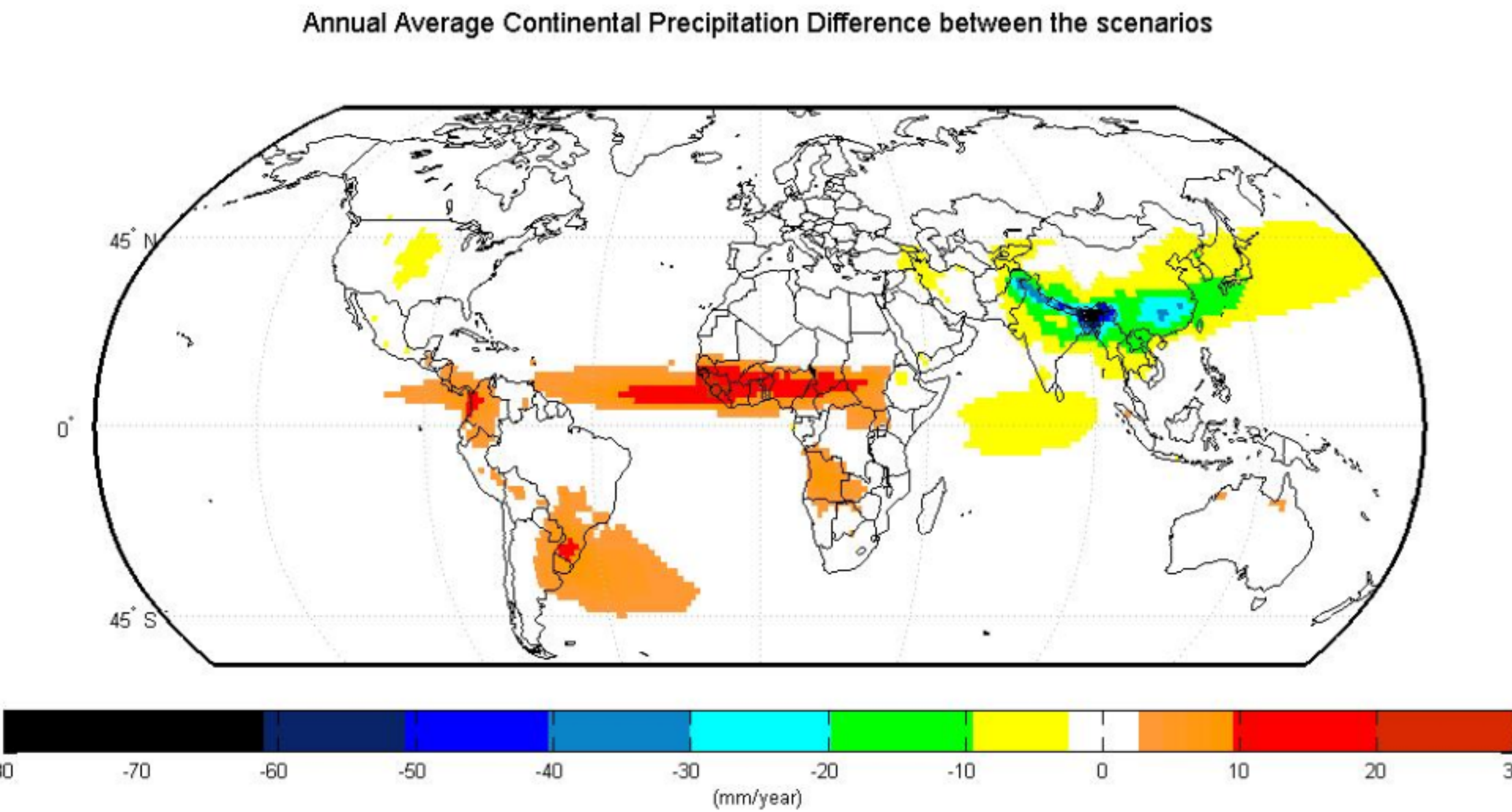
July Evaporation difference



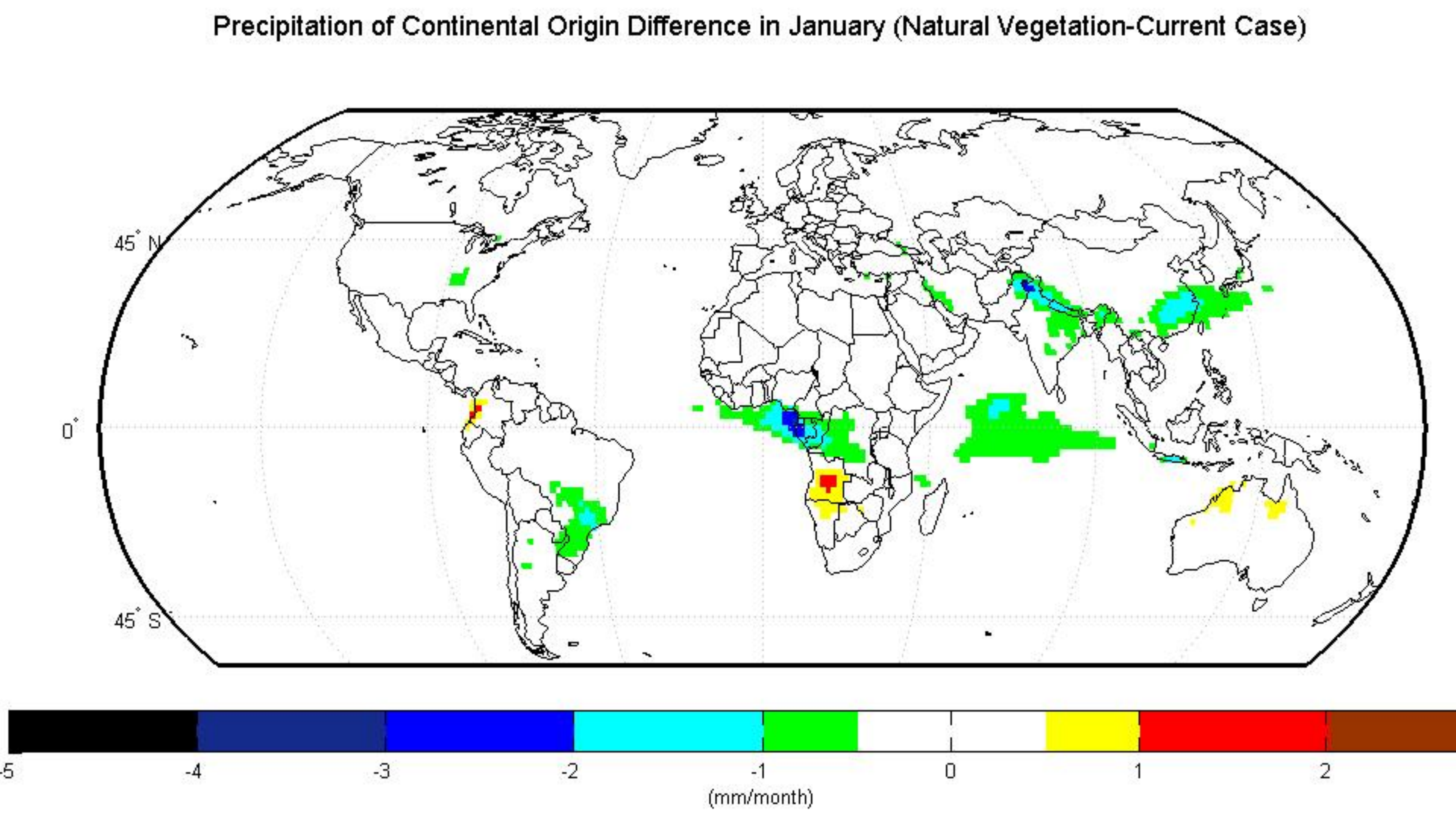
Difference in Precipitation



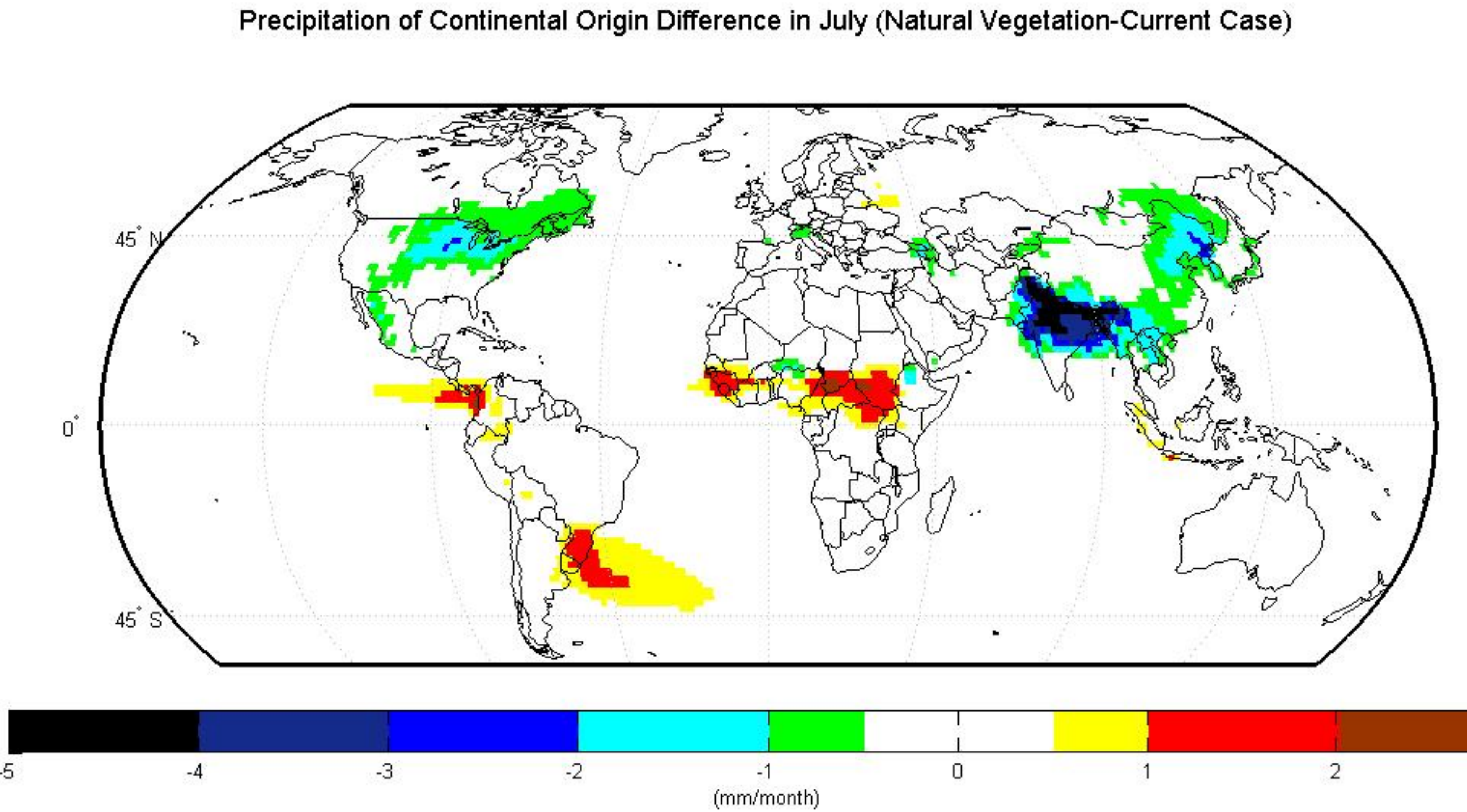
10-year average Continental P difference



January Continental P difference



July Continental P difference



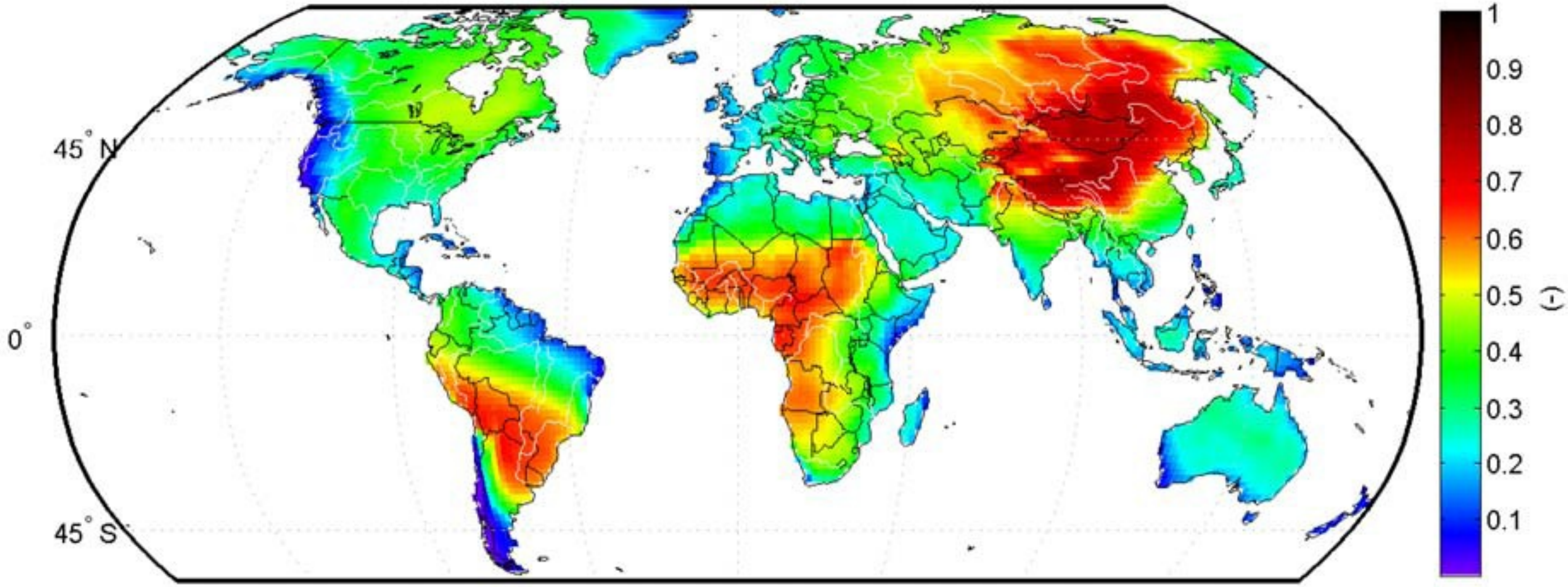
Further reading

- van der Ent, R. J., H. H. G. Savenije, B. Schaefli, and S. C. Steele-Dunne (2010), Origin and fate of atmospheric moisture over continents, *Water Resources Research*, *46*(9), W09525, doi:10.1029/2010WR009127. http://www.agu.org/journals/wr/wr1009/2010WR009127/

- van der Ent, R. J., and H. H. G. Savenije (2011), Length and time scales of atmospheric moisture recycling, *Atmospheric Chemistry and Physics*, 11(5), 1853-1863, doi:10.5194/acp-11-1853-2011. http://www.hydrol-earth-syst-sci-discuss.net/8/8315/2011/hessd-8-8315-2011.html

- Keys, P., R. J. van der Ent, L. Gordon, H. Hoff, R. Nikoli and H. H. G. Savenije, Land cover in precipitationsheds reveals vulnerability of dryland rainfed agricultural regions, *Biogeosciences Discussion.*

Continental precipitation recycling ratio ρ_c



Thank you

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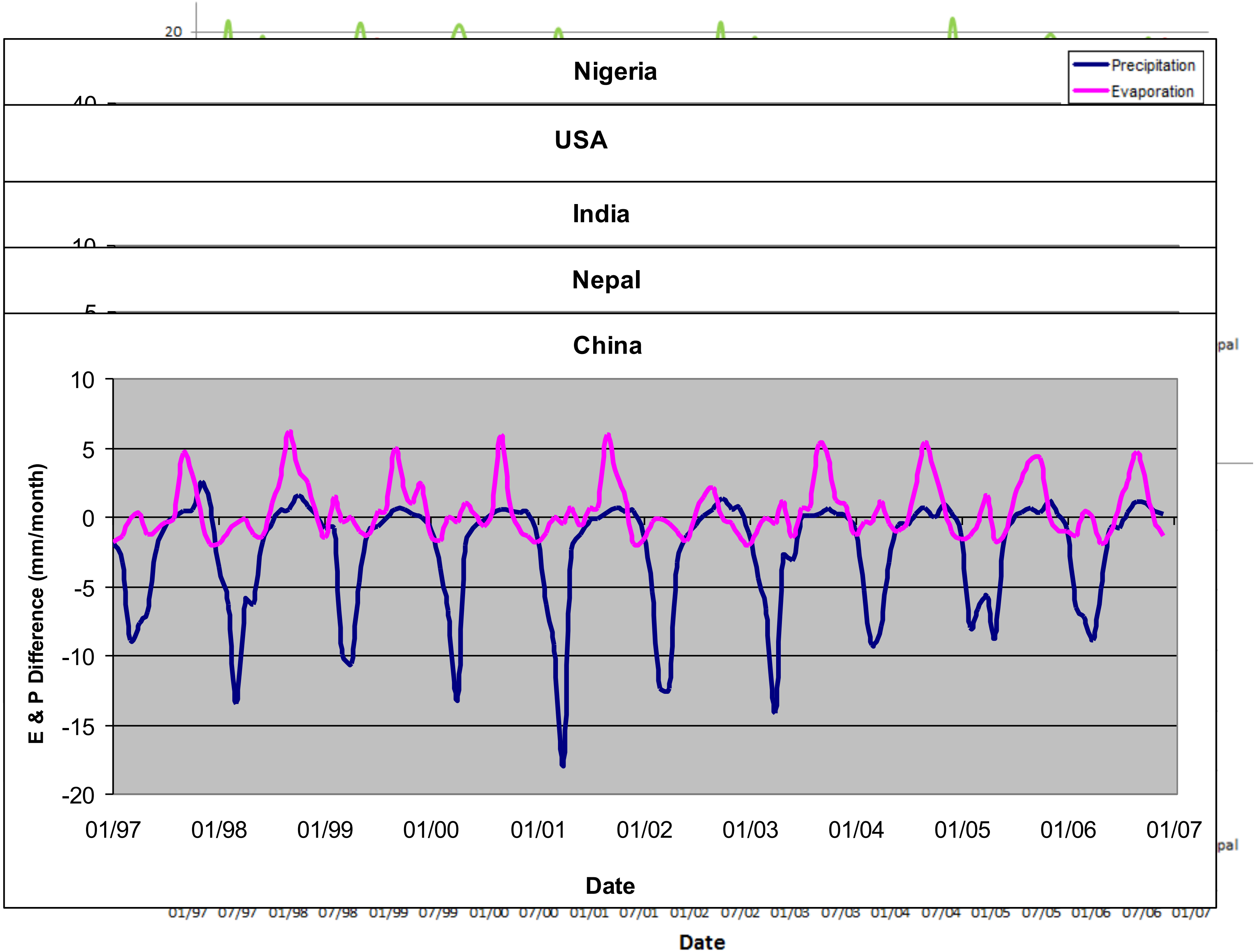
Five characteristic pixels

Evaporation Difference over time



Remaining questions

- Difference between fast and slow (=green) evaporation
- Second order effects
- Ways to combat land degradation

Bringing the scales together

Atmos. Chem. Phys., 11, 1853–1863, 2011
www.atmos-chem-phys.net/11/1853/2011/
doi:10.5194/acp-11-1853-2011

Atmospheric Chemistry and Physics

Length and time scales of atmospheric moisture recycling

R. J. van der Ent and H. H. G. Savenije

Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands

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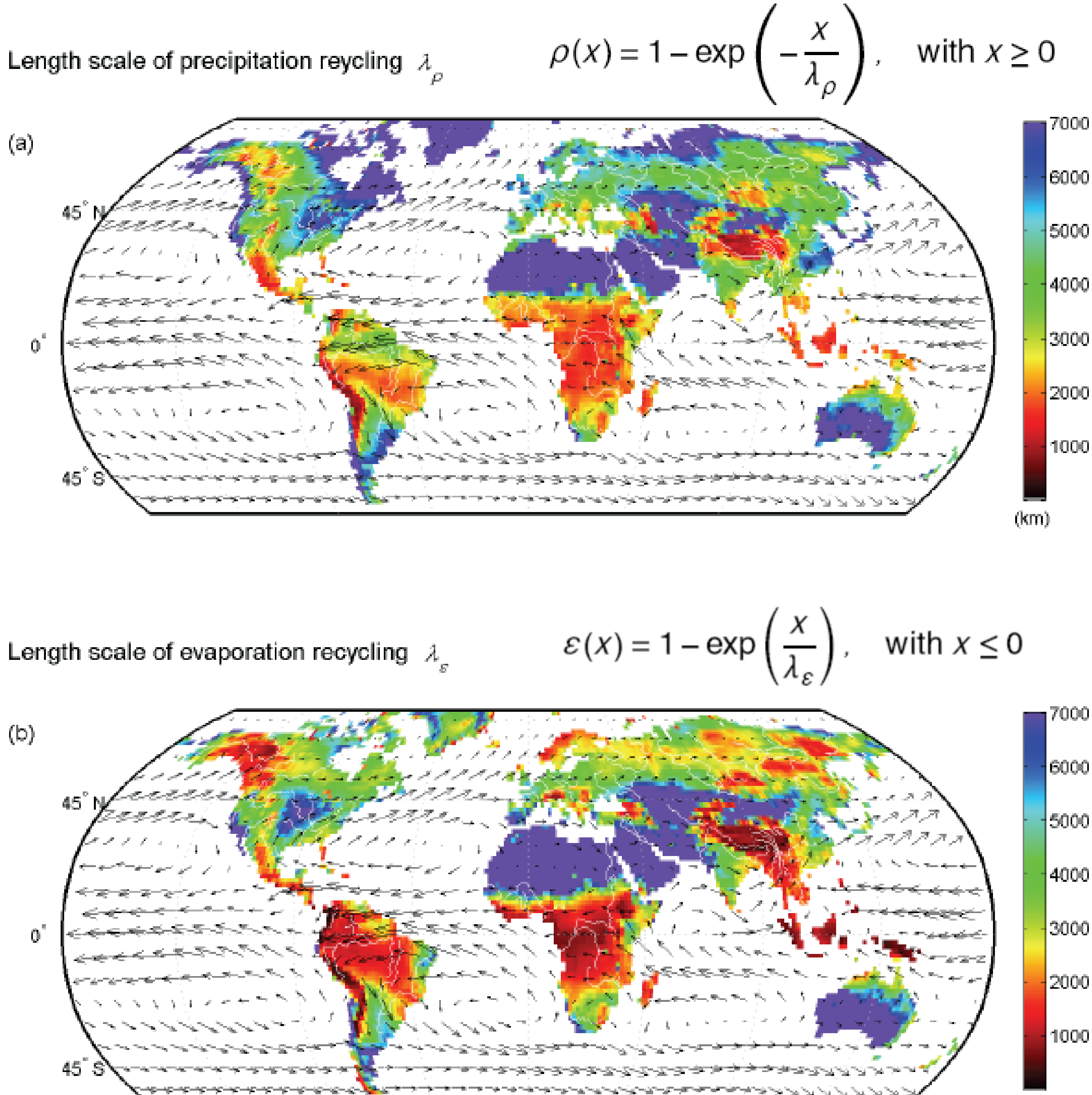
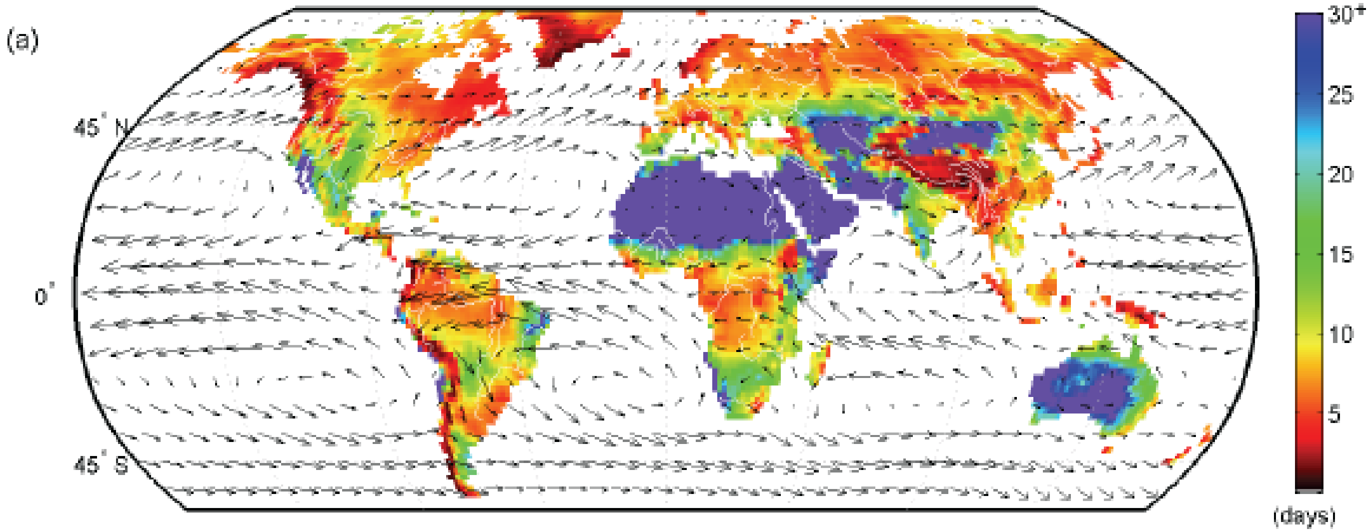
Revised: 1 February 2011 – Accepted: 22 February 2011 – Published: 1 March 2011



Length scale of precipitation reycling λ_ρ
$\rho(x) = 1 - \exp\left(-\frac{x}{\lambda_\rho}\right), \quad \text{with } x \geq 0$
(a)
45° N
0°
45° S
7000+
6000
5000
4000
3000
2000
1000
(km)
Length scale of evaporation recycling λ_ε
$\varepsilon(x) = 1 - \exp\left(\frac{x}{\lambda_\varepsilon}\right), \quad \text{with } x \leq 0$
(b)
45° N
0°
45° S
7000+
6000
5000
4000
3000
2000
1000
(km)

Depletion time T_P



Replenishment time T_E