Contributions of BALTEX towards the understanding of the Earth's water and energy cycle

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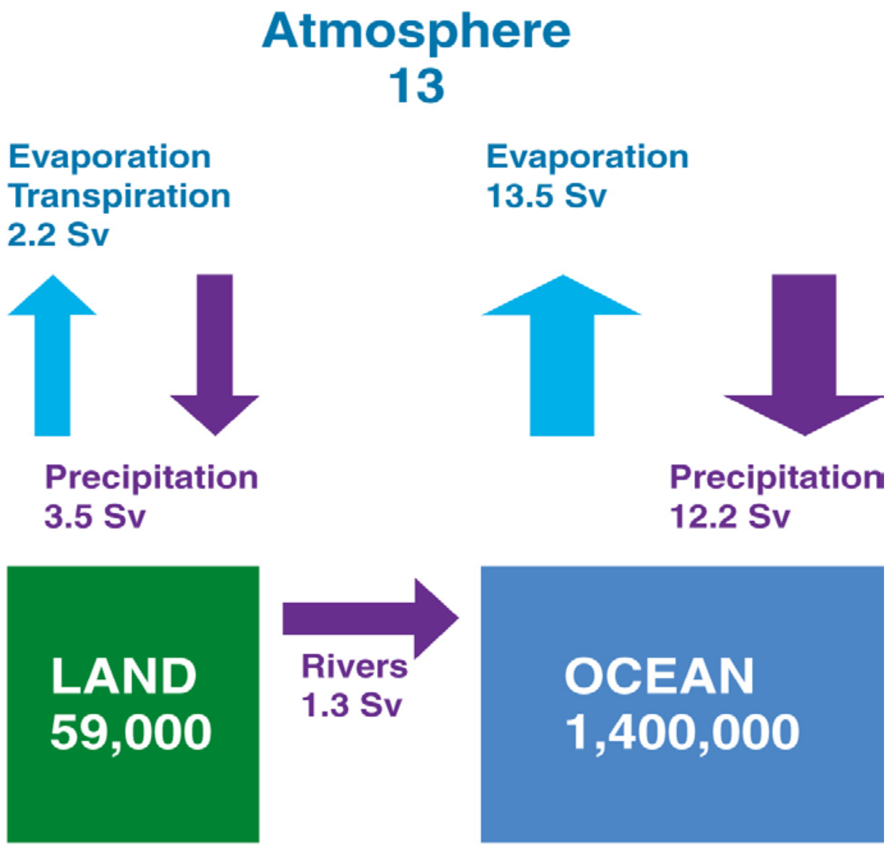
BALTEX and the global water and energy cycle

- The global water cycle and its fundamental importance
- What have we learned from BALTEX?
- Response of the global water cycle to temperature
- What might happen to higher latitudes in a warmer climate?
- Concluding remarks

Global water reservoir and fluxes

(Baumgartner & Reichel; 1975)



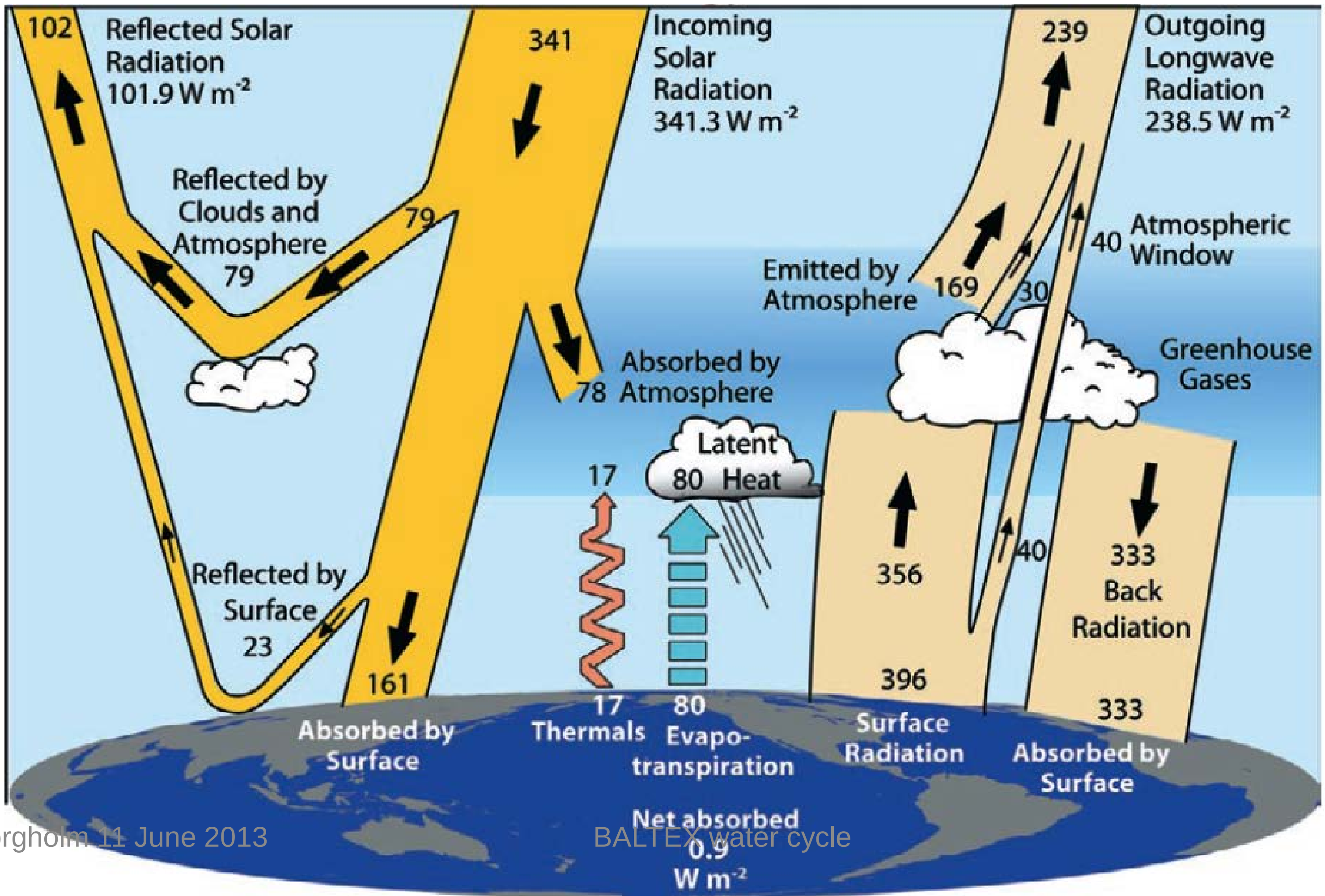
Reservoir in 10^3 km^3, Fluxes in 10^6 m^3/s (=Sv)*

(*/ Sv = 10^6 m^3/s = 31.5 • 10^3 km^3/year)

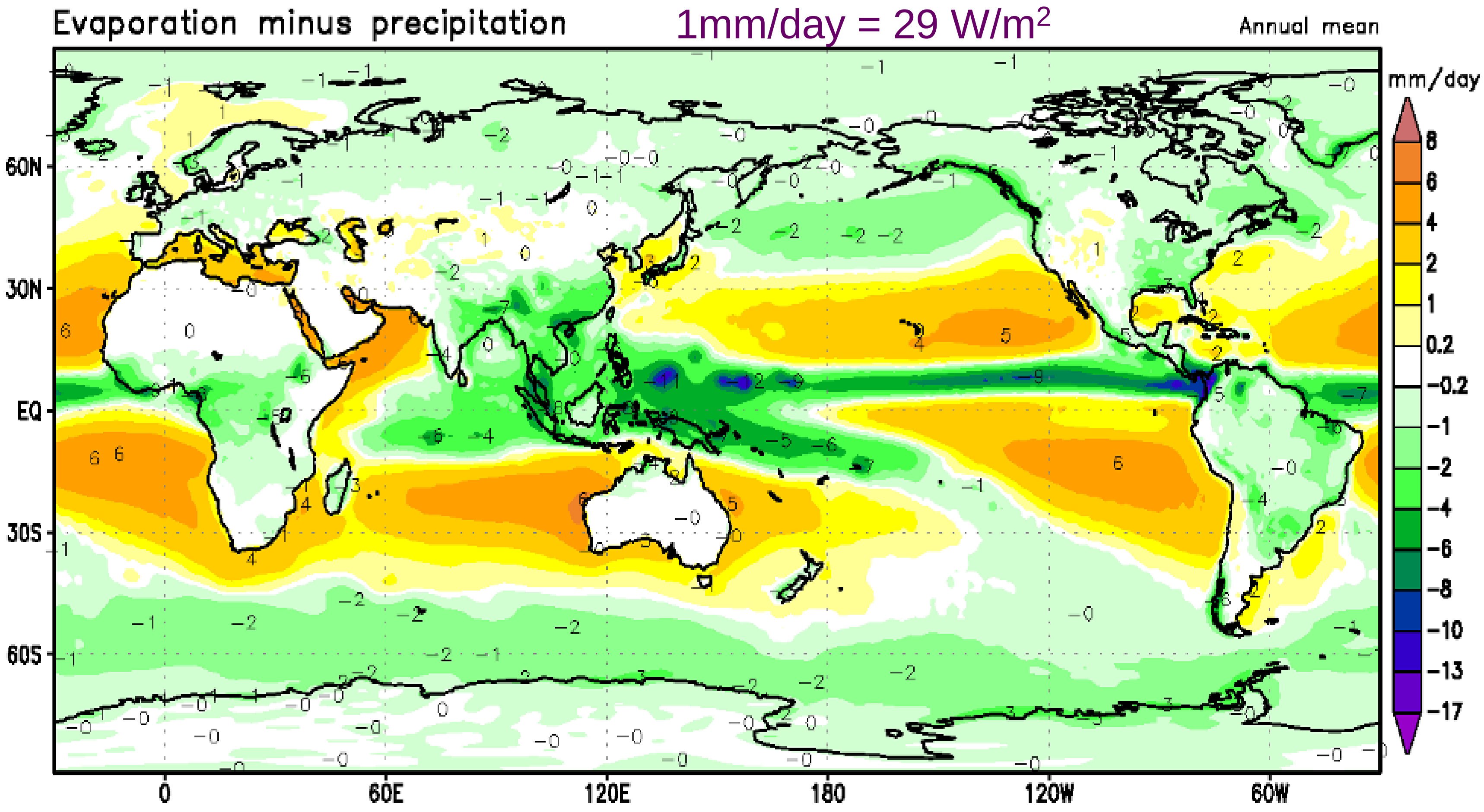
The radiation budget of the Earth

$$E_{in} = E_{out} \Leftrightarrow \frac{1}{4} S_0 (1 - \alpha) = \varepsilon \sigma T_s^4$$

Annual global energy flows W m^{-2} **Latent heat is ca 25% of the solar constant**



Surface water balance, mm/day



The global water cycle

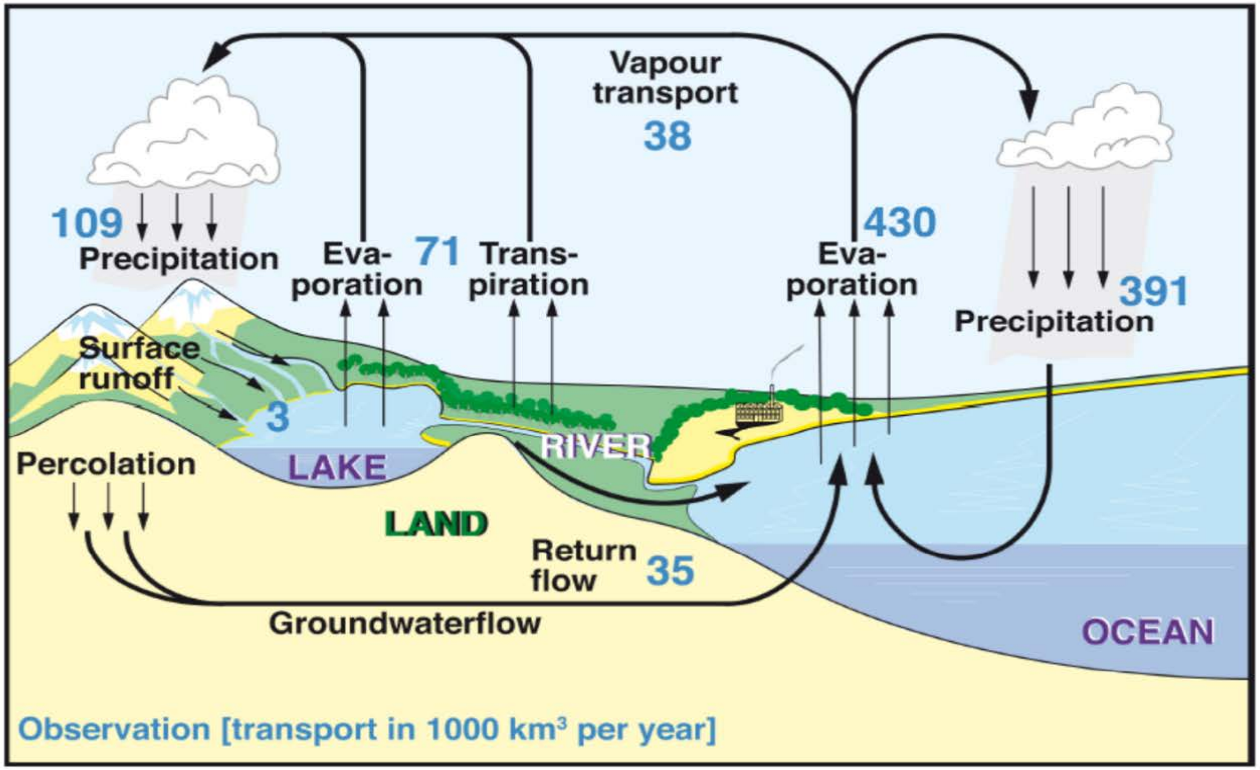
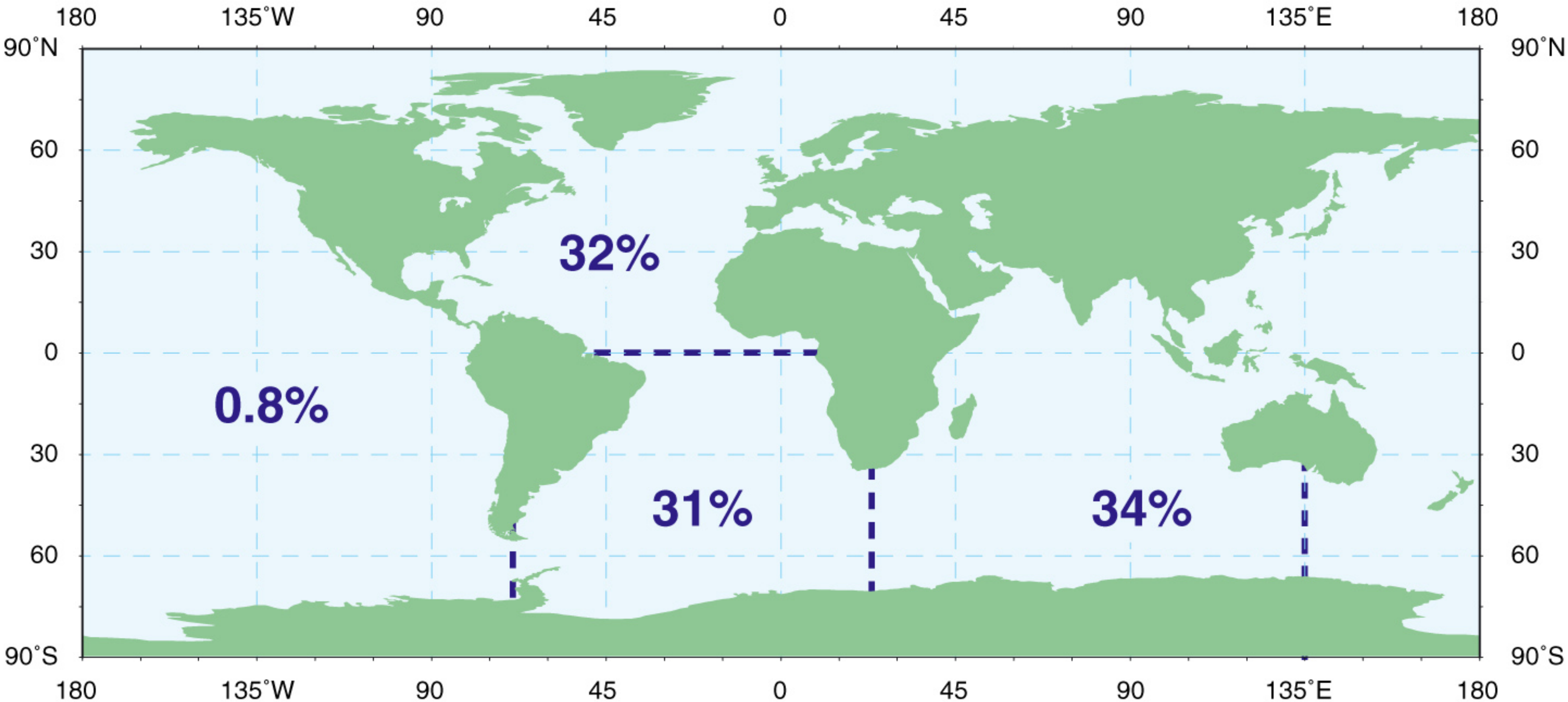
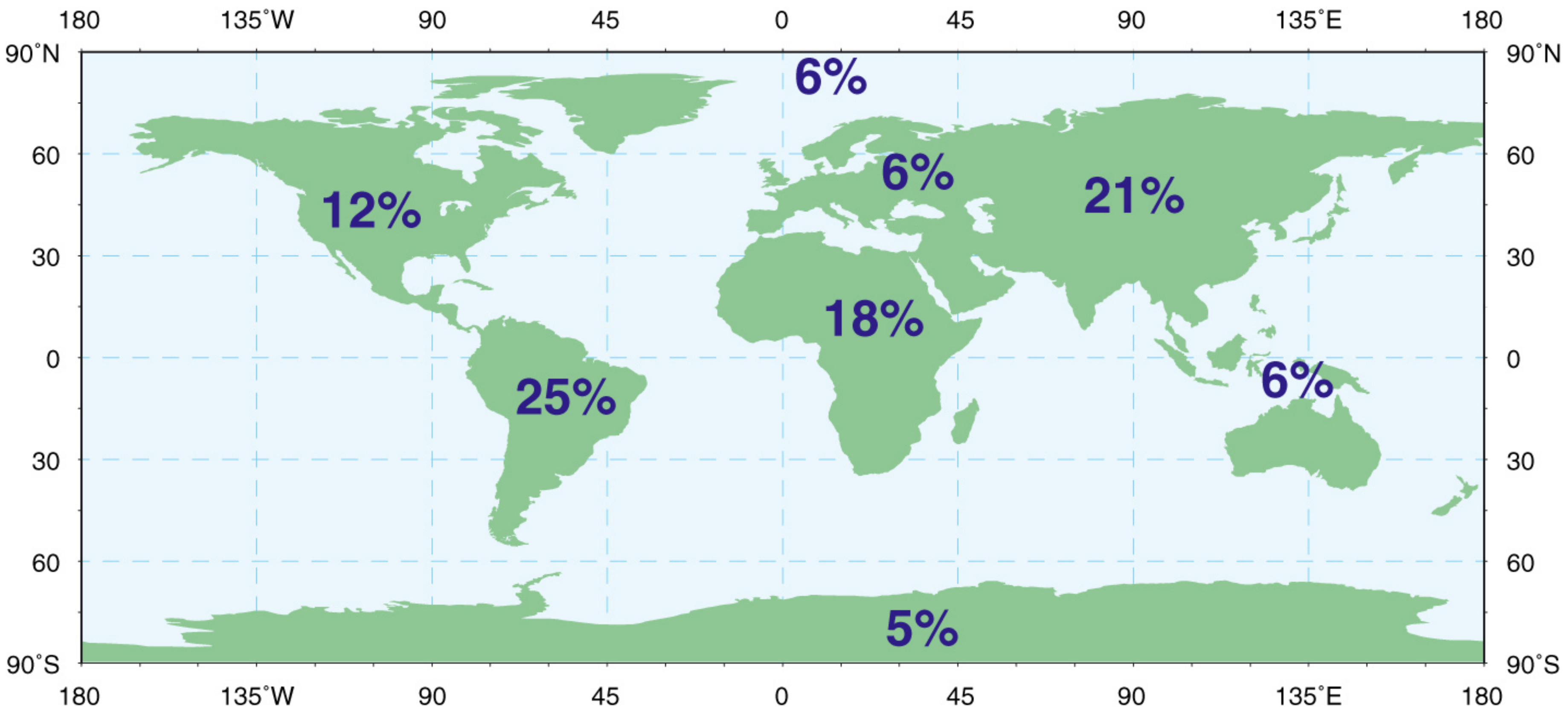


Figure 1. The global water cycle following Baumgartner and Reichel (1975). Annual values are in units of 10^3 km^3 year^{-1}.

Supply of water from the oceans [$36 \bullet 10^3\ km^3$ / year]



Return of water to the oceans $[34 \cdot 10^3 \ km^3 / year]$



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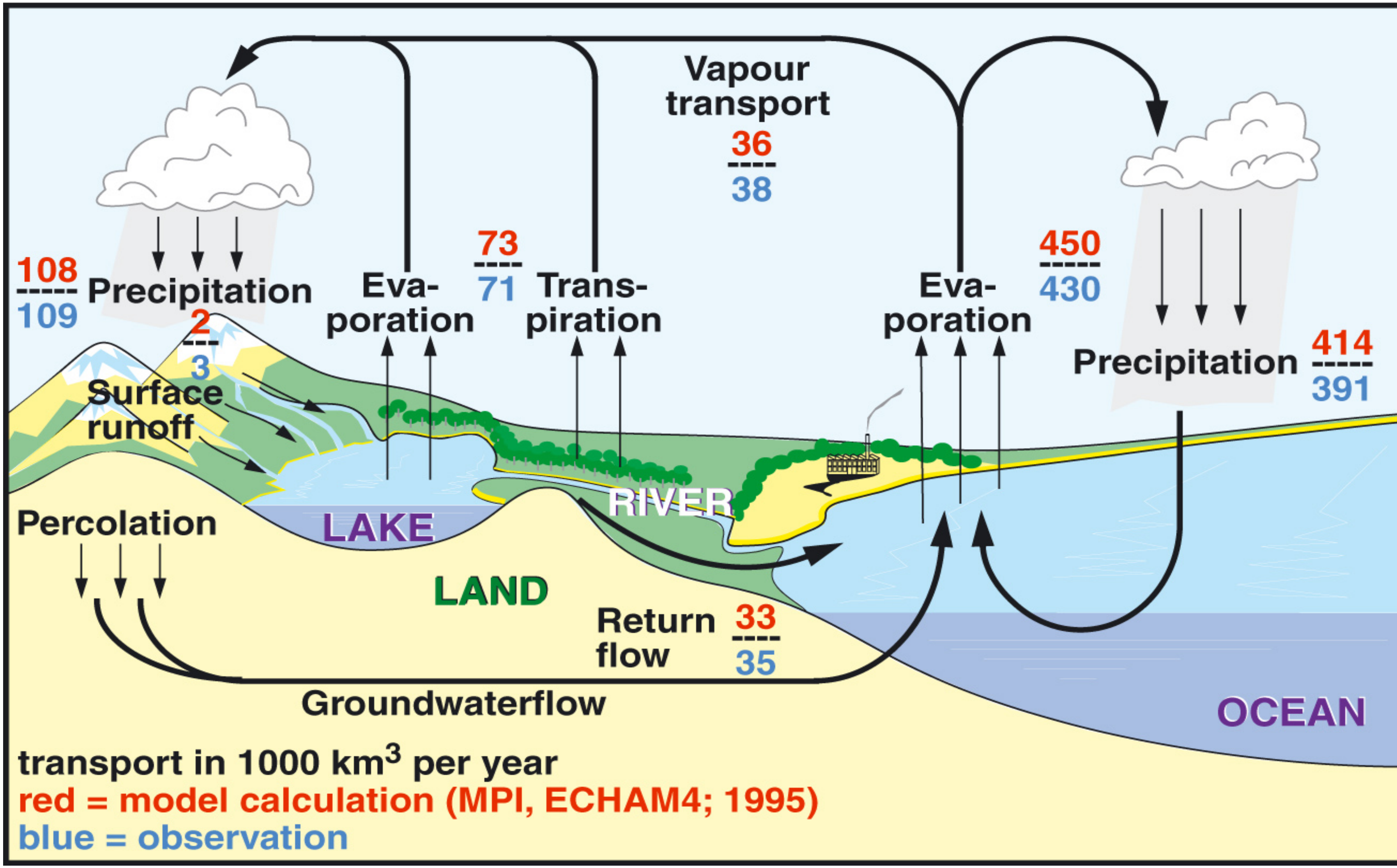
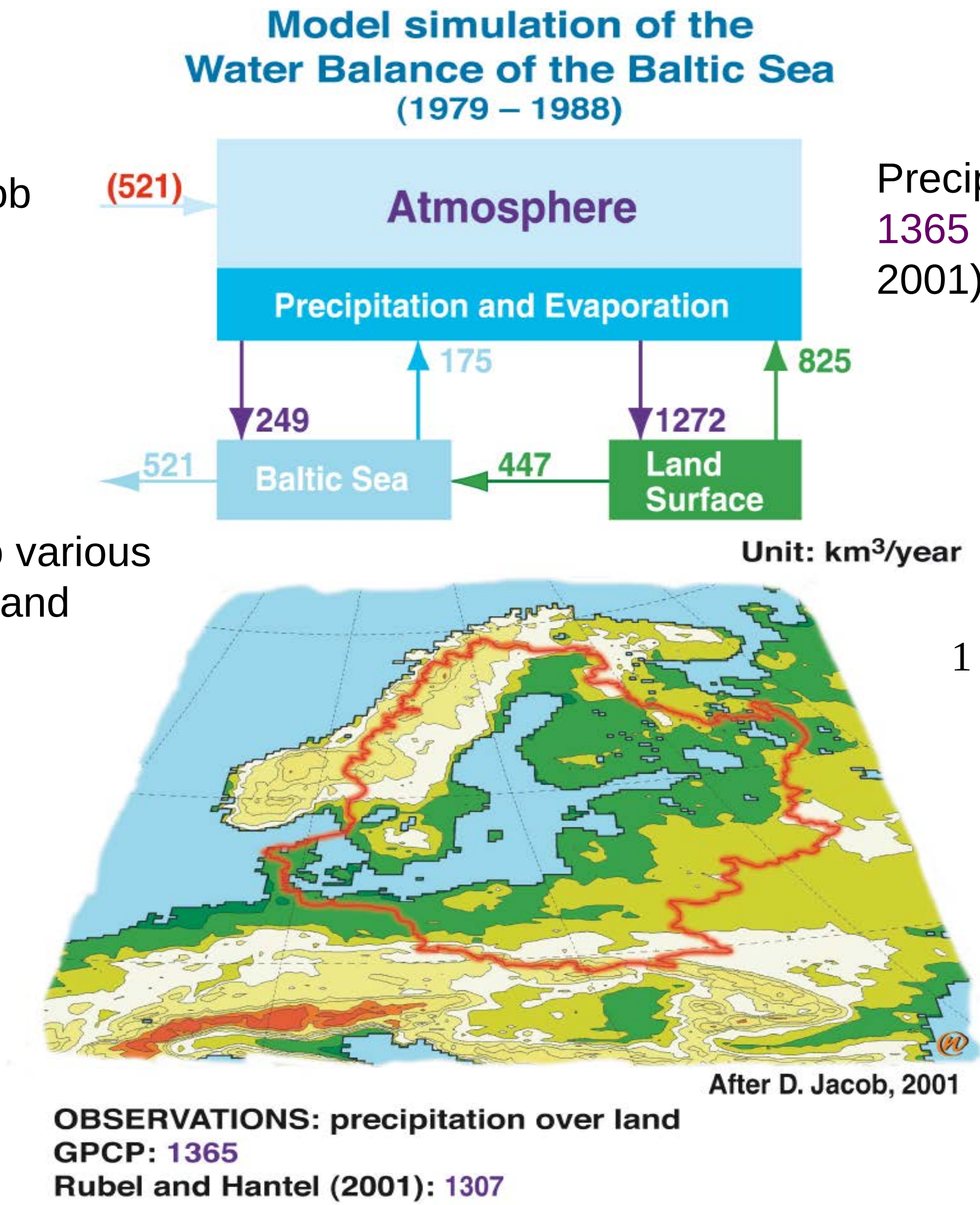
Global water cycle



Credit: Daniela Jacob



Precipitation over land: GPCP: 1365 mm. Rubel and Hantel 2001):1307 mm

Net outflow close to various estimates Omstedt and Rutgersson (2000)

1 km^3/year = 31.7 m^3/sec

Extreme precipitation in Uppsala 1722-2007

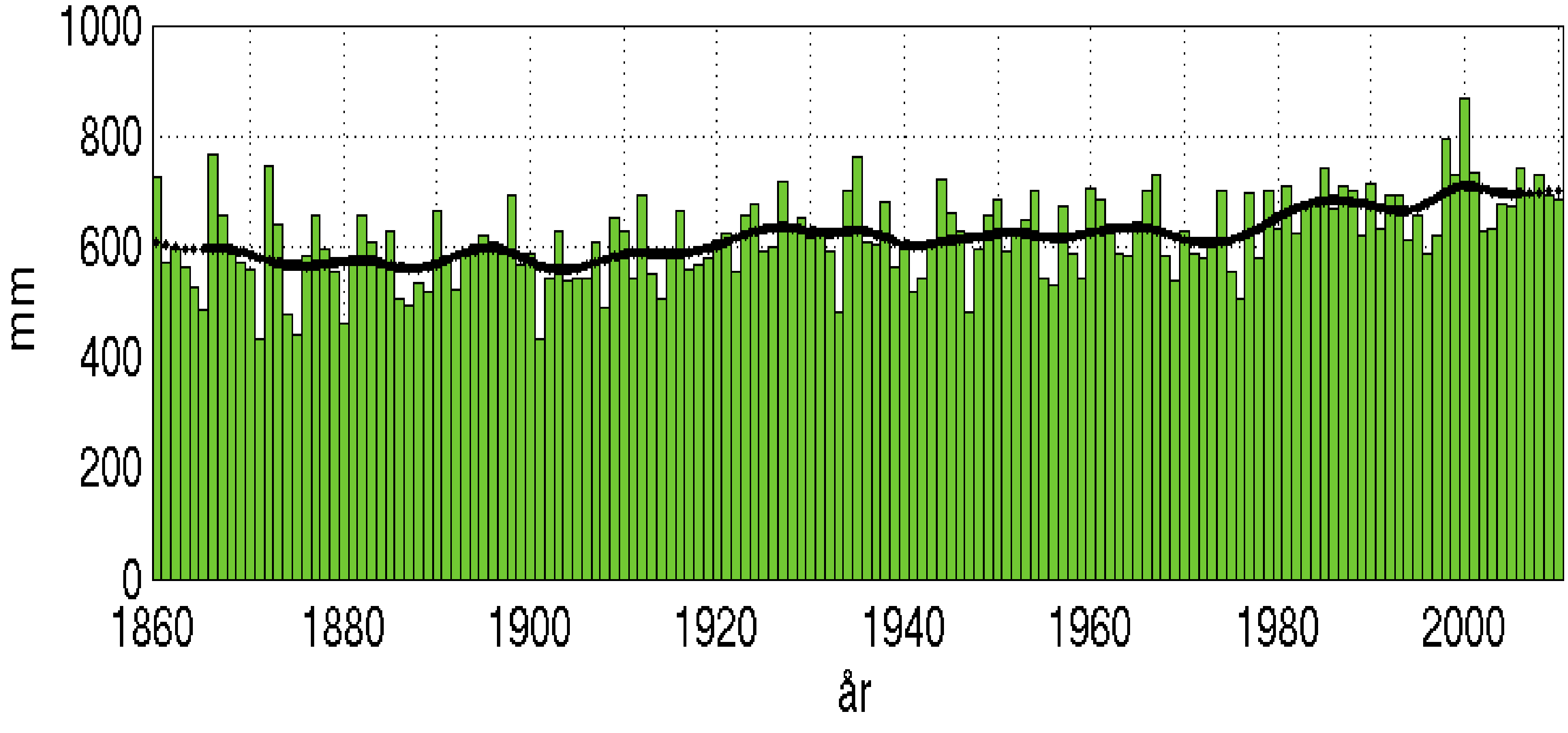
Wettest year: 1866	**812 mm**
Wettest month: **July 1898**	**200 mm**
Wettest day: **17 Aug 1997**	**104 mm**
Driest year: **1875**	**311 mm**
Driest month: **March 1964**	**0.2 mm**

Credit: Hans Bergström, Uppsala University

Annual precipitation for Sweden 1860-2011

Credit: SMHI

A minor increase is indicated, some 50-75 mm



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Clausius-Clapeyron relation

Relation between temperature,T and saturated water vapor, e_s

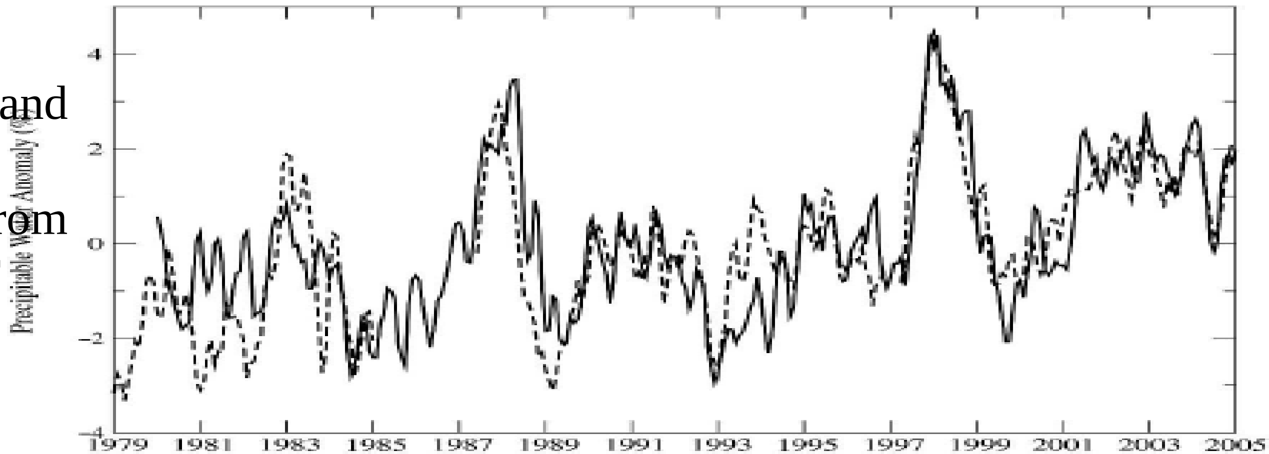
$$\frac{d\ln e_s}{dT} = \frac{L}{RT^2} \equiv \alpha(T),$$

Atmospheric temperature determines water vapour following the C-C relation

Water vapour and temperature

For a temperature change, **dT** , the humidity change, **dq**, follows the C-C relation seen as a conservation of relative humidity

Observations and model calculations from observed SST **1979-2005**



dT + **0.4° C**

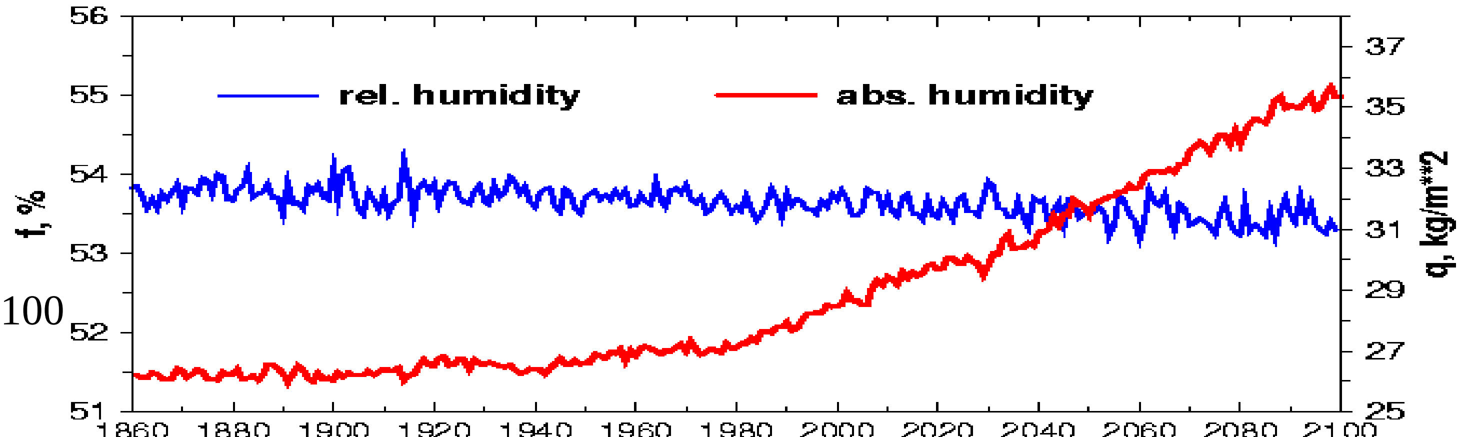
dq + **3%**

Held and Soden, 2006

dT+ **4° C**

dq + **35%**

Model 1860-2100



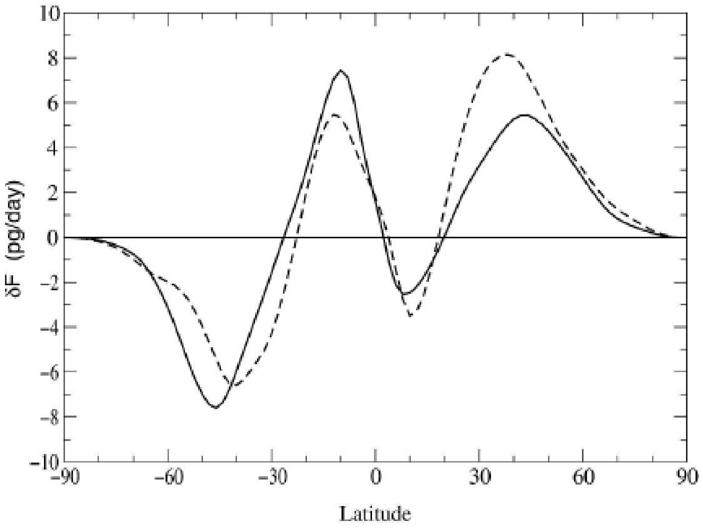
Semenov and Bengtsson, 2002

Horizontal transport of moisture, F

- After Held and Soden (2006)

$$\frac{\delta F}{F} \approx \frac{\delta e_s}{e_s} \approx \alpha \delta T. \qquad (2)$$

- Horizontal transport of moisture from the IPCC scenario A1B (solid)
- Transport by the simple formula (2)
  scaled by CC (dashed)



Effect on P-E

The result for precipitation minus evaporation is

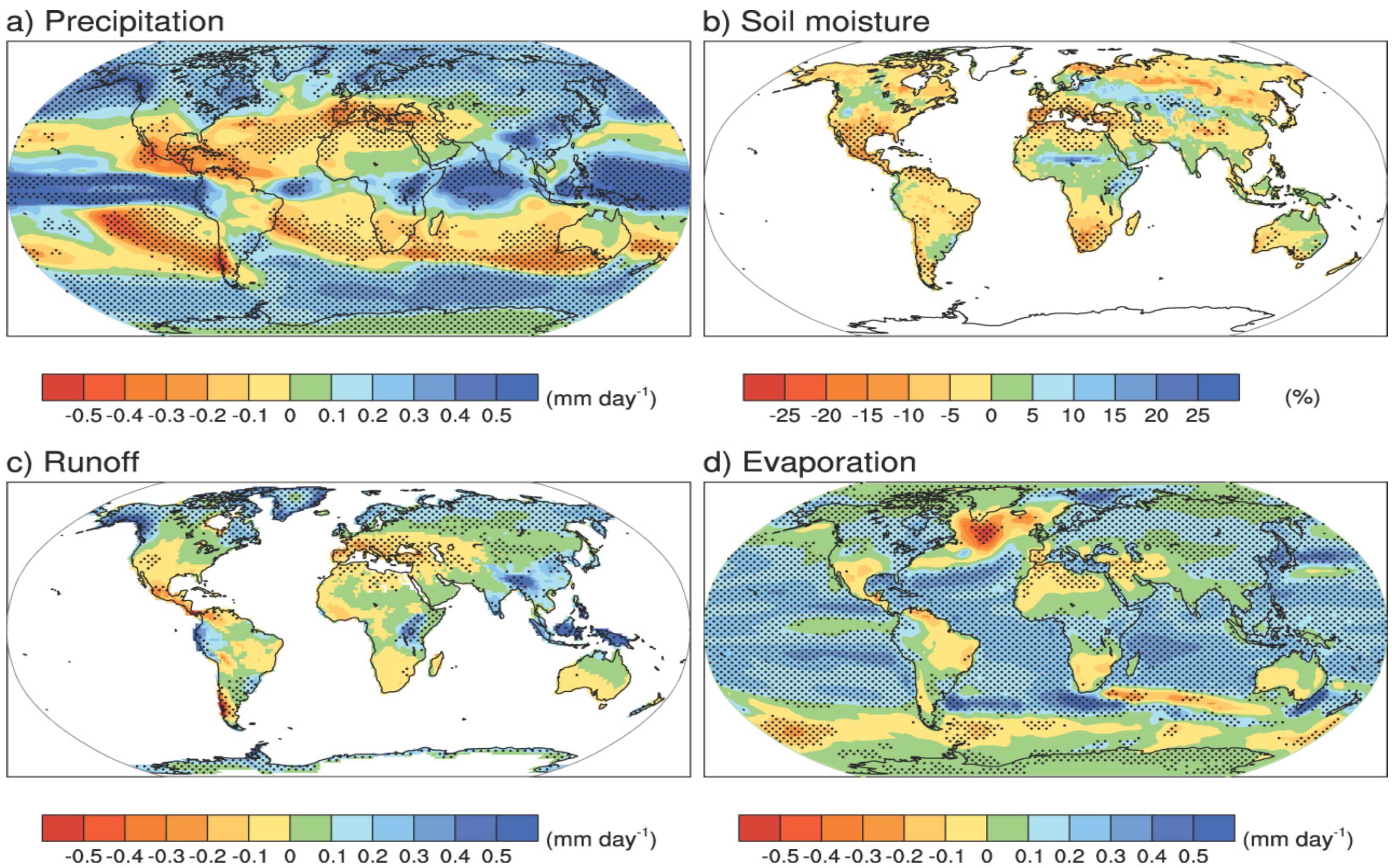
$$\delta(P - E) = -\nabla \cdot (\alpha \delta T F). \tag{5}$$

If one can remove δT from the derivative, assuming that $P - E$ has more meridional structure than δT, then $P - E$ itself satisfies CC scaling:

$$\delta(P - E) = \alpha \delta T (P - E). \tag{6}$$

IPCC 4th assessment , 2007

Change of the hydrological cycle



The atmospheric water cycle

- The atmospheric water cycle follows closely Clausius-Clapeyrons (C-C) relation. (6-7%/ K)
- It also follows that transport of water vapour scales with the C-C relation.
- That means more precipitation in areas of convergence
- The global precipitation increases much slower than global water vapor. (1-2%/ K)

From Lacis et al 2013 (acc. in Tellus)

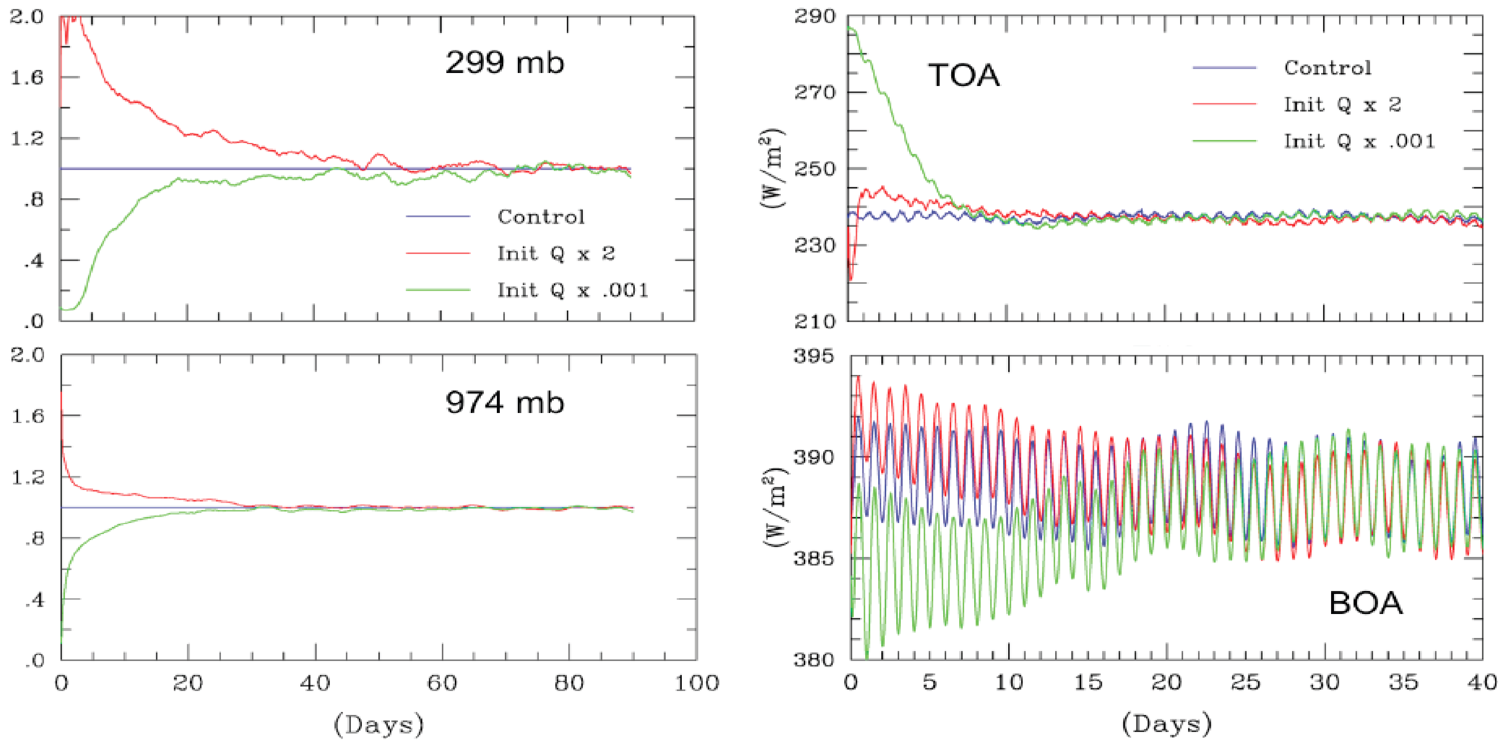


Fig. 3. Hourly model diagnostic results for the 'virtual' forcing of climate by instantaneous water vapor changes. There is rapid convergence to equilibrium following instantaneous doubling and zeroing of atmospheric water vapor. The left-hand panels show global-mean water vapor at 299 and 974 mb level converging to control run equilibrium values. The right-hand panels show the up-welling LW flux at the top (TOA) and the bottom (BOA) of the atmosphere. Diurnal oscillations in the global-mean LW flux arise from the diurnal surface temperature change over land areas. Red curves depict the model response to doubled water vapor amounts. The green curves refer to the model response to zeroed water vapor. The blue curves are for the control run water vapor reference results. Water vapor changes in the left-hand panels have been normalized relative to the control run results.

CO_2 is a genuine forcing, while H_2O is a part of the climate response system

CO_2 H_2O

- The residence time of CO_2 in the atmosphere is from years to multi-millennia
- The residence time of H_2O in the atmosphere is 7-8 days
- H_2O, albeit a more powerful greenhouse gas, is driven by temperature that in turn is forced by the slower components of the climate system.

Why is water vapour increasing faster than precipitation in global mean and what is the reason?

- Water vapour is controlled by the 3-dimensional atmospheric circulation.
- Precipitation = Evaporation is determined by the surface energy balance.
- While water vapour always will increase in a warmer climate, global precipitation can under certain conditions, such as enhanced aerosol load, even decrease!

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Climate change experiment using ECHAM5

Bengtsson et al., 2011(Tellus)

- We have investigated two periods:

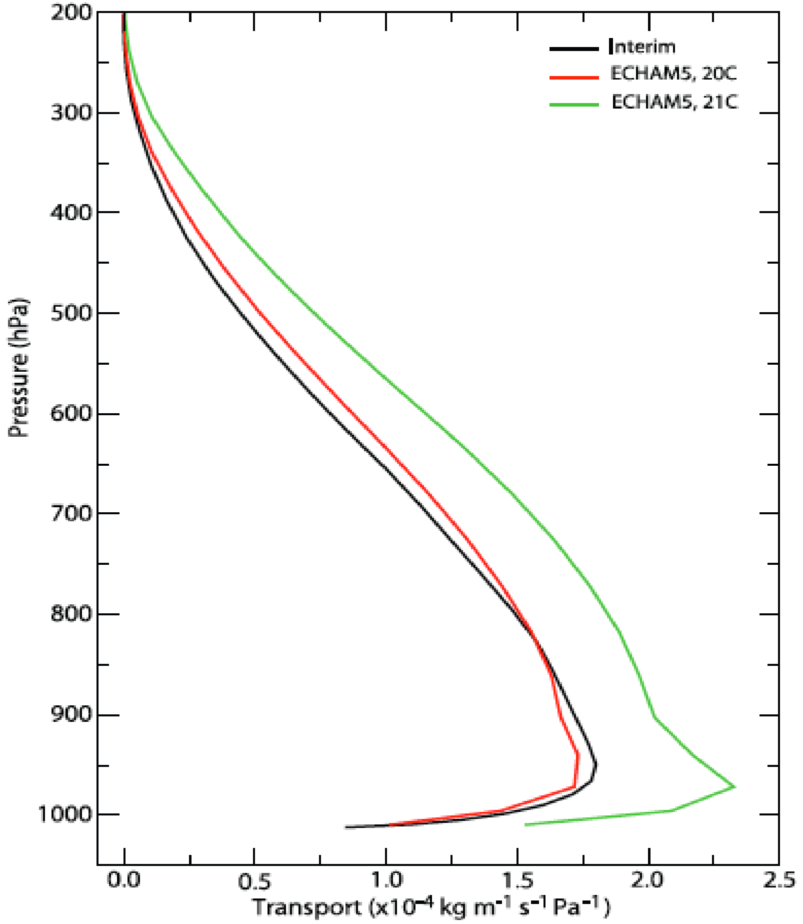
- **20 C: 1959-1990** using observed/estimated greenhouse gases and aerosols
- **21 C: 2069-2100** using scenario A1B

- A1B is a middle-of-the-line scenario

- Carbon emission peaking in the 2050s (16 Gt/year)
- CO_2 reaching 450 ppm. in 2030
- CO_2 reaching 700 ppm. in 2100

- SO_2 peaking in 2020 then coming done to 20% thereof in 2100

Transport of water vapour across 60° N



Annual mean calculated for every 6 hrs. T213 resolution (ca 50 km)

ERA-Interim re-analysis
1989-2009 (*Observation*)

ECHAM5 (T213) for the period
1959-1990 (*Modellberäkning av nuvärdet*)

ECHAM5 (IPCC scenario A1B)
2069-2100 (*Modellberäkning av den framtida värdet*)

Bengtsson et al., 2011

High latitude energy balance end 20C and at the end of 21C

Bengtsson et al. 2013 J. of Climate

Units Watt/m^2 T63(T213)

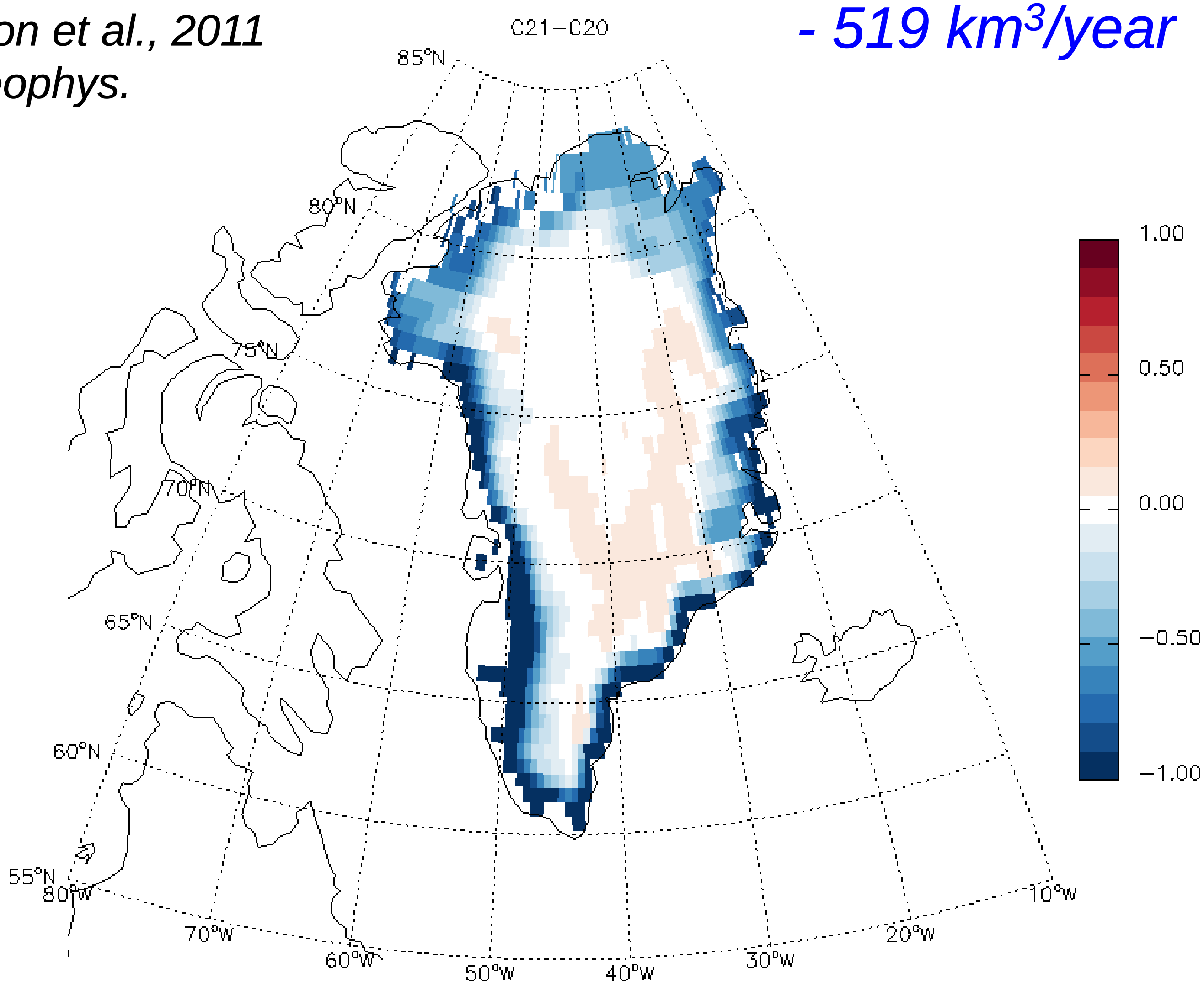
Across 60° N and 60° S

	Lq	C_pT+gZ	F_{Wall}	F_{SFC}	F_{RAD}	dE/dt
NH						
20C	21.7(20.9)	68.5(64.6)	90.2(85.5)	13.4(11.5)	-102.9(-98.7)	0.7(-1.7)
21C	27.3(27.0)	65.0(58.9)	92.3(85.9)	11.5(9.1)	-103.0(-99.3)	0.8(-4.3)
21C-20C	5.6 (6.1)	-3.5(-5.7)	2.1(0.4)	-1.9(-2.4)	-0.1(-0.6)	0.1(-2.6)
SH						
20C	26.0(28.0)	61.8(56.3)	87.8(84.3)	9.7(8.0)	-95.6(-92.2)	1.9(-1.1)
21C	32.1(34.0)	53.2(47.7)	85.3(81.8)	6.1(4.2)	-92.3(-89.7)	-0.9(-3.7)
21C-20C	6.1(6.0)	-8.6(-8.6)	-2.5(-2.5)	-3.6(-3.8)	3.3(2.5)	-2.8(-2.6)

Lq: **wet energy**, CpT+gZ: **dry energy**, Fwall: **net polar transport**, Fsfc: **surface transport**, Frad: **outgoing radiation**

Massbalance changes over 100 years GREENLAND

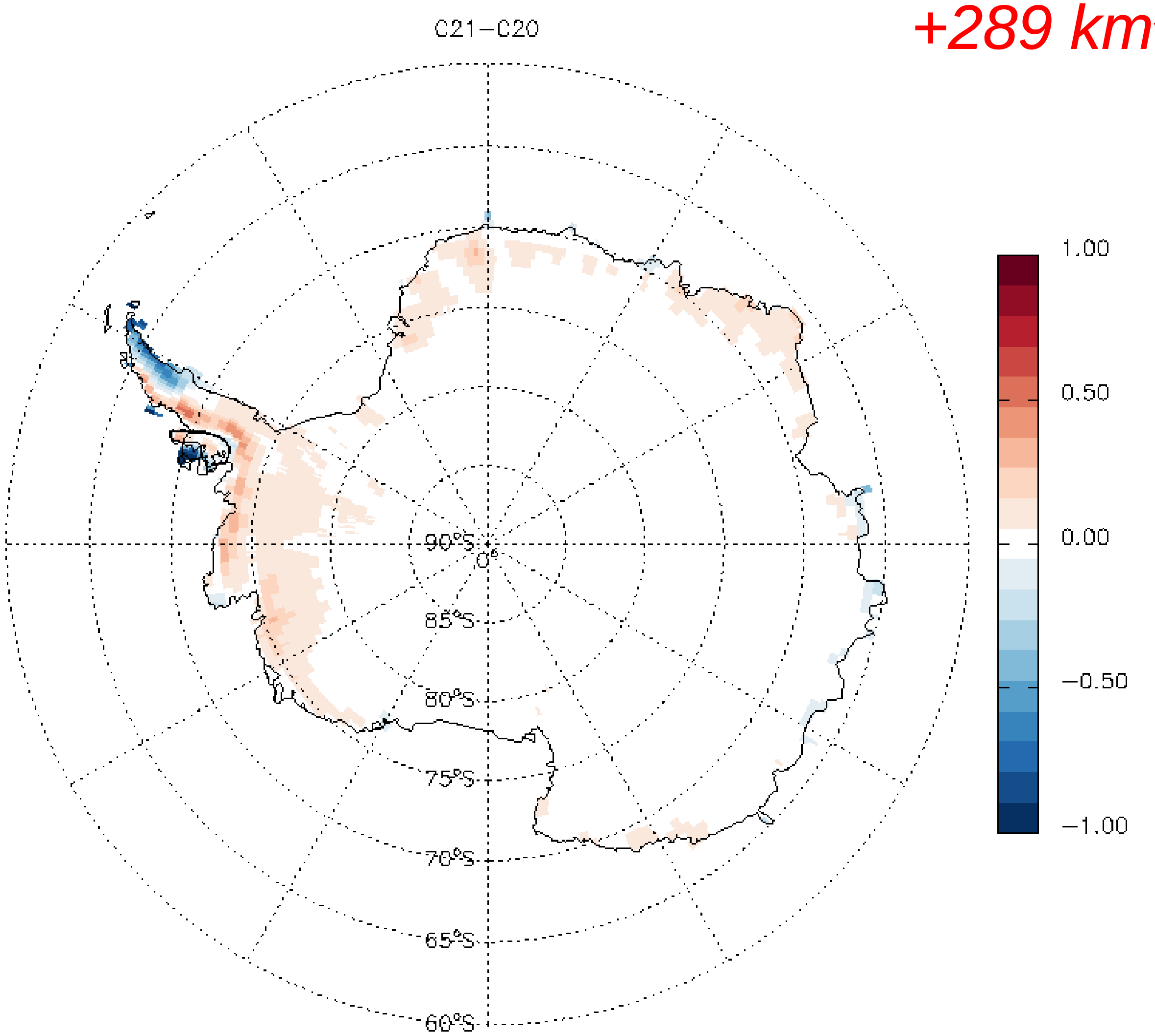
Bengtsson et al., 2011
Surv. Geophys.



- 519 km³/year

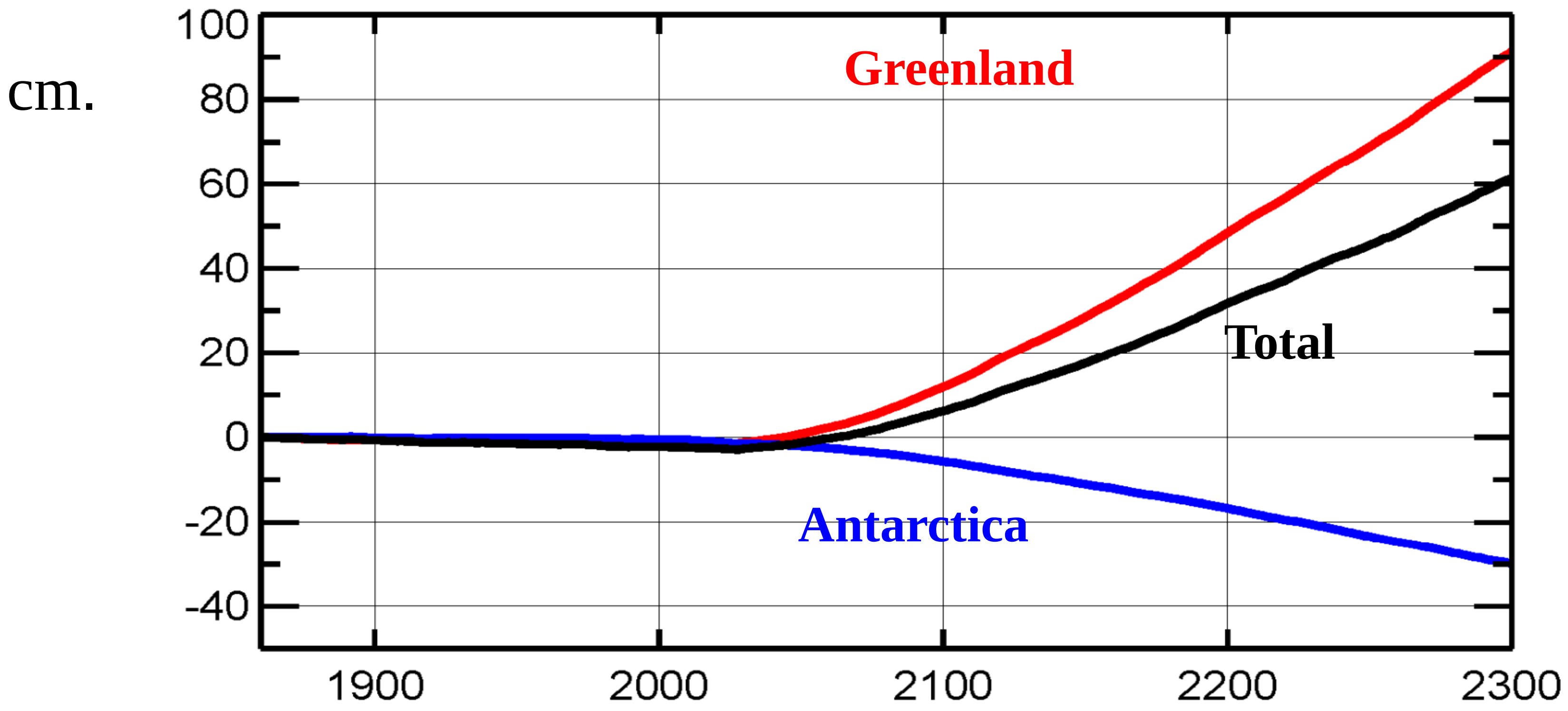
Mass balance changes over 100 years
ANTARCTICA

+289 km³/year



Sea level changes due to mass balance changes on the land ices. Contribution from Greenland(**red**), from Antarctica (**blue**).Total contribution **(black)**.

ECHAM5 model, IPCC Scenario A1B, Credit: MPI, Hamburg



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Conclusions

- BALTEX has been very useful for model development

- There are certainly indications of fine scale deficiencies

- Larger scale features seem to be quite realistic

- While we have good reasons to be critical to models we should not have any over belief in observations

- We have reasons to expect significant changes in the water cycle at a warmer climate but it is probably not possible to identify this at present. The natural variability is generally strongly underestimated

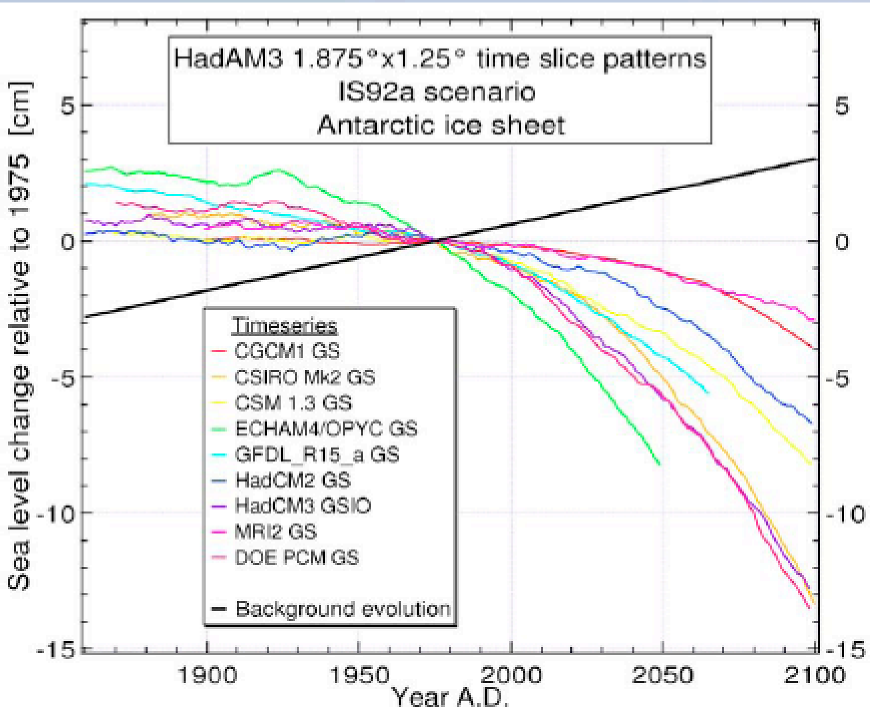
- The poor greenhouse gases are blamed for everything in the weather. In some connections any proofs are not needed any longer.

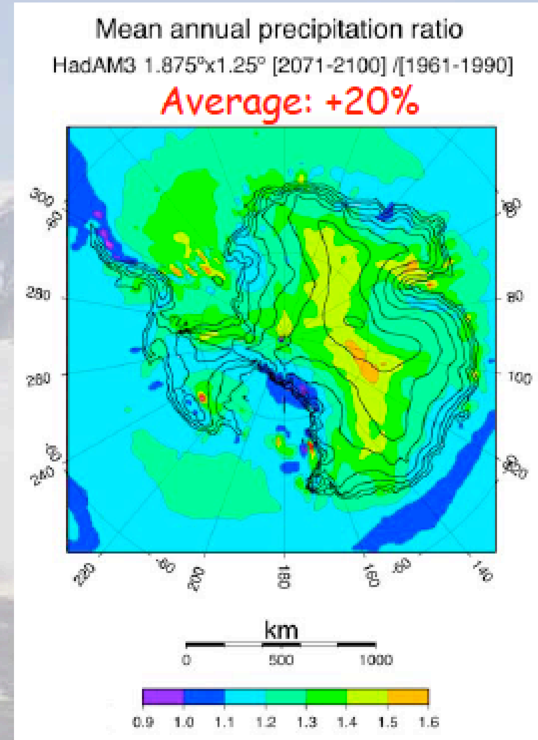
END

Thanks for your attention!

20th and 21st century ice-volume changes from 'IPCC-style' pattern scaling

Surface mass balance changes only
Temperature and precipitation forcing from available AOGCMS





IPCC AR4 sea level change 21st century:

-2 to -14 cm from SMB

To counter this by ice dynamics requires sustained speedup of *all* outlet glaciers by 5-30% ! (or: 25-150% of WAIS only glaciers)

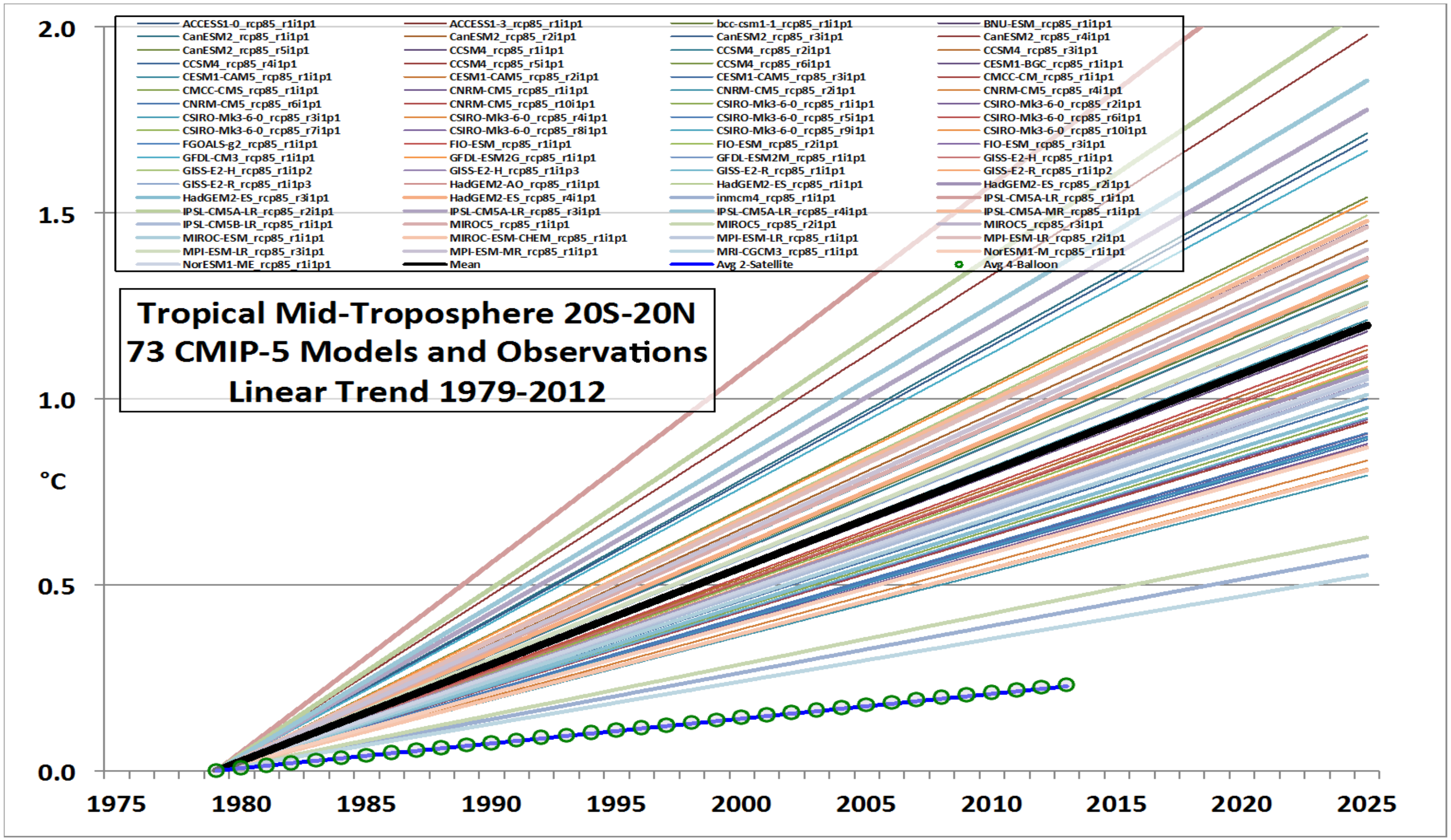
20th century rate: -0.153 ± 0.123 mm/yr
21st century rate: -0.865 ± 0.400mm/yr
or -8.7 cm/ century s.l

Antarctic ice sheet SMB slightly increases

Huybrechts et al. (2004) *Glob. Planet. Change*
Gregory and Huybrechts (2006) *Roy. Soc. Trans. A*

Model results and observations so far.

Credit: J Christy



What is happening to the hydrological cycle?

The global precipitation during100 years