Atmospheric water vapour transports in the tropics and their simulated changes with climate warming

Matthias Zahn

(based on my work as post doc at the University of Reading
with Richard Allan and Lennart Bengtsson)

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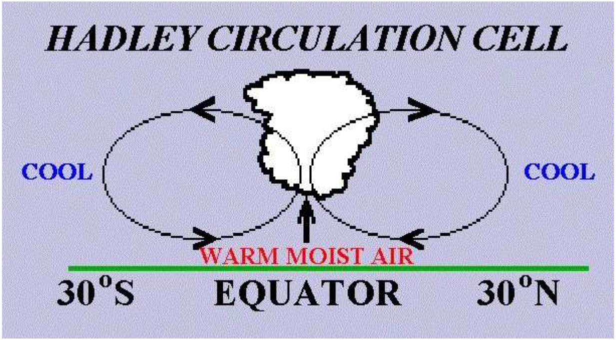
Introduction



from http://climate.ncsu.edu/edu/k12/.atmosphere_circulation

- intensification or weakening of tropical circulations?
- sometimes opposing results based on different, mostly low resolution space and time averaged measures or on point observations

Data

high resolution data

- in space and time
  ($\approx 0.5^\circ$, ≈ 30 vertical levels, $6h$)
- reanalysis (ERAint) 1989 -2008
- time slice model (ECHAM5) experiment
  C20: 1960-1989, A1B: 2070-2100
- ω, **U** and **V**, q, pressure information

Method, two steps

1. define ASC and DESC regions

2. calculate moisture transports across boundary

ASC: ascending air motion
DESC: descending air motion

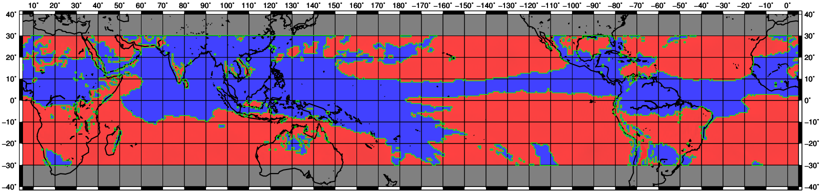
Method, first step

1. define ASC and DESC regions

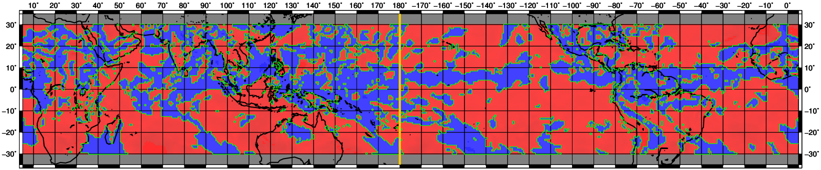
- ω : vertical wind
- monthly mean and quasi-instantaneous (calculation time step) ω used
- for quasi-instantaneous ω :
  $4 * 365 * 20 = 29200$
  ASC/DESC-masks in ERAint

ASC: ascending air motion
DESC: descending air motion

Examples of monthly mean and instantaneous ω fields



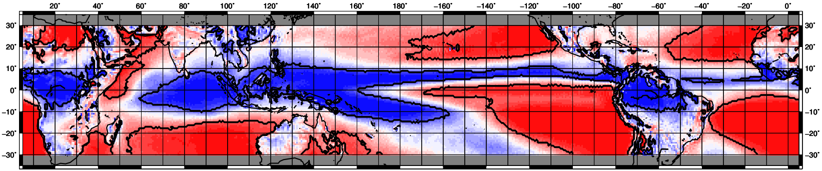
ASC_m , Jun 2008



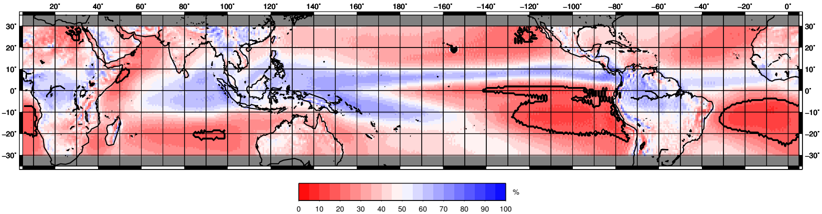
ASC_i 22 Jun 2008, 0:00

blue: ω ascending air motion (ASC)
red: ω descending air motion (DESC)

Spatial frequency distribution of ASC and DESC (1989-2008)



from monthly mean ω fields



from quasi-instantaneous ω fields

black lines: 20%/80%

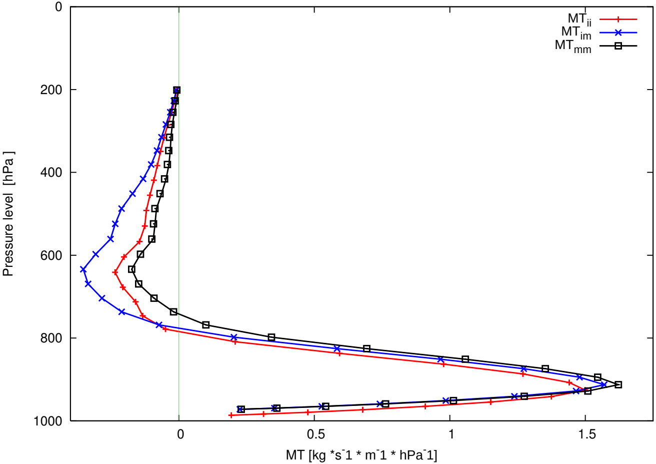
Method, second step

2. calculate moisture transports (MT) across boundary separating ASC and DESC

- linking wind vectors with water content
- along each boundary segment (horizontally and vertically)
- monthly mean and quasi-instantaneous MT and ASC are used

	mean vars	inst vars
mean ASC	MT_{mm}	MT_{im}
inst ASC	(MT_{mi})	MT_{ii}

Vertical profile of MT (1989-2008)

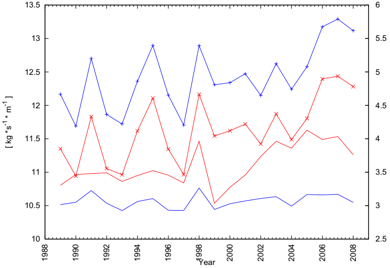


- mid-level MT different
- lower level MT similar
- **implication for the budget**

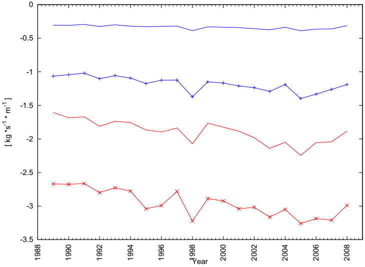
reversal level: height at which MT changes sign

MT below and above reversal level

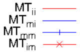
experiment	mean $[\frac{kg}{m \cdot s}]$		trend $[\frac{kg}{m \cdot s} / year]$	
	below	above	below	above
MT_{ii}	11.10	-1.89	0.0336	-0.0226
MT_{im}	11.65	-2.95	0.0509	-0.0272
MT_{mm}	12.42	-1.18	0.0507	-0.0140



(a) time series of lower level MT



(b) time series of mid level MT



MT budget and trend in different experiments

$$budget \approx MT_{in} - MT_{out} \approx P - E$$

experiment	mean $[\frac{km^3}{day}]$	trend $[\frac{km^3}{day}$ per $year]$
MT_{ii}	651.1	0.612
MT_{im}	320.3	0.236
P-E in ASC_m	320.0	0.274
MT_{mm}	404.6	**0.514**

highest statistical significance for MT_{mm} trend

Summary - so far, Zahn and Allan (2011)

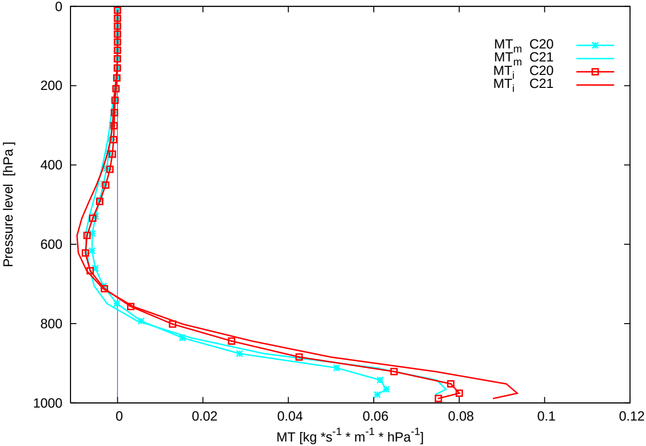
shape of Hadley Circulation depends on data

- only significant in average values
- less distinct when instantaneous measures are applied

tropical hydrological cycle intensified

- more moisture convergence at lower levels
- more moisture divergence at mid levels
- increase in the budget weak
- **BUT:** different significance levels whether or not data are averaged

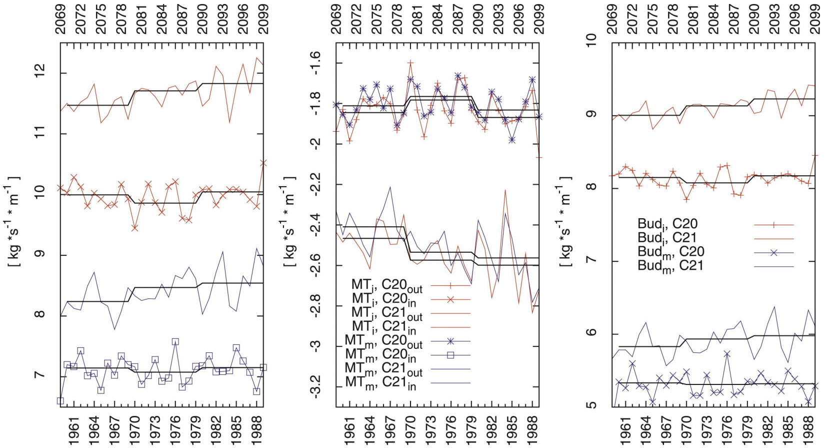
Vertical profile of MT C20/C21



- lower level MT strengthened
- mid-level MT strengthened

MT into ASC_i and ASC_m
only instantaneous variables from ECHAM5 are used

Time series of MT above and below RL

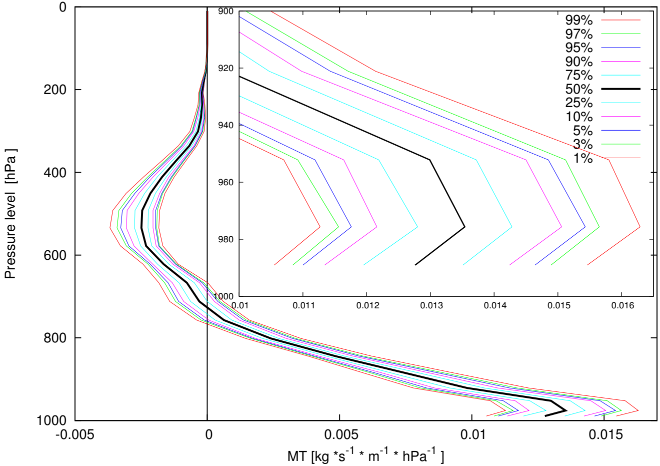


(a) MT_{in} (b) MT_{out} (c) Budget

significant increase in the budget despite

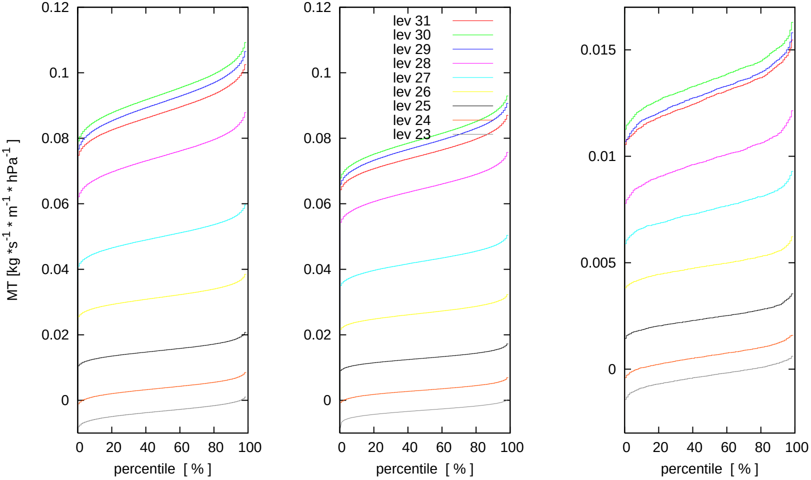
$MT_{in} \approx +17\%$, $MT_{out} \approx +38\%$

MT_{ii} percentile differences (C21 - C20)



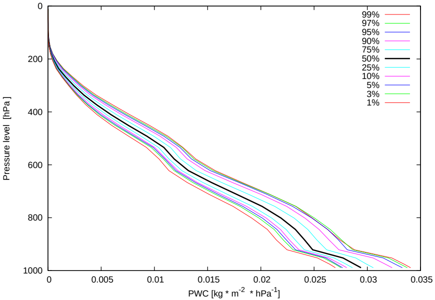
used as a proxy for the intensity change of extreme precipitation events

MT_{ii} percentile differences at lower levels (C21 - C20)

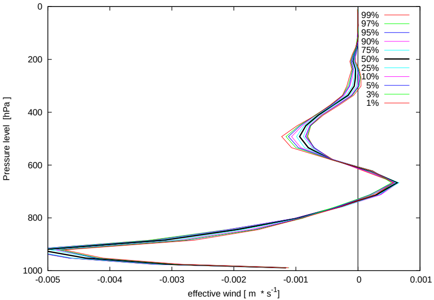


(a) C21 (b) C20 (c) C21 - C20

Changes of wind and humidity (C21 - C20)



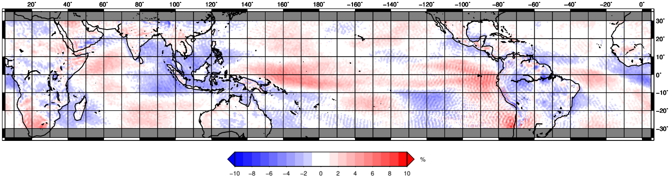
PWC $\frac{kg}{m^2 \cdot hPa}$



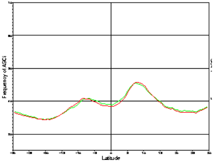
effective wind$[\frac{m}{s}]$

effective wind: wind weighted by $\frac{PWC_{lev}}{PWC_{tot}}$ (Sohn and Park (2010))

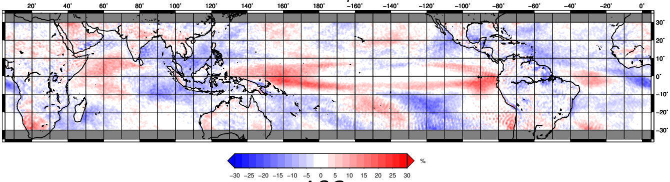
Tropical Circulation. Changing frequency pattern of ASC (C21 - C20)



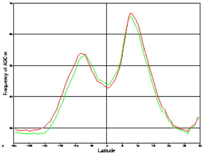
ASC_i



(c) zonal mean ASC_i



ASC_m



(d) zonal mean ASC_m

more distinct pattern and a narrowing when means are applied

green lines: C21
red lines: C20

Summary - with warming, Zahn and Allan (2013)

hydrological cycle projected to intensify with warming

- significantly more water converges in the moist tropics
- especially at higher percentiles (indicating more intense extreme precipitation events)
- due to higher humidity

no signs of a widening Hadley Cell found