Module 2.2:
Understanding model spread in an energy transport perspective

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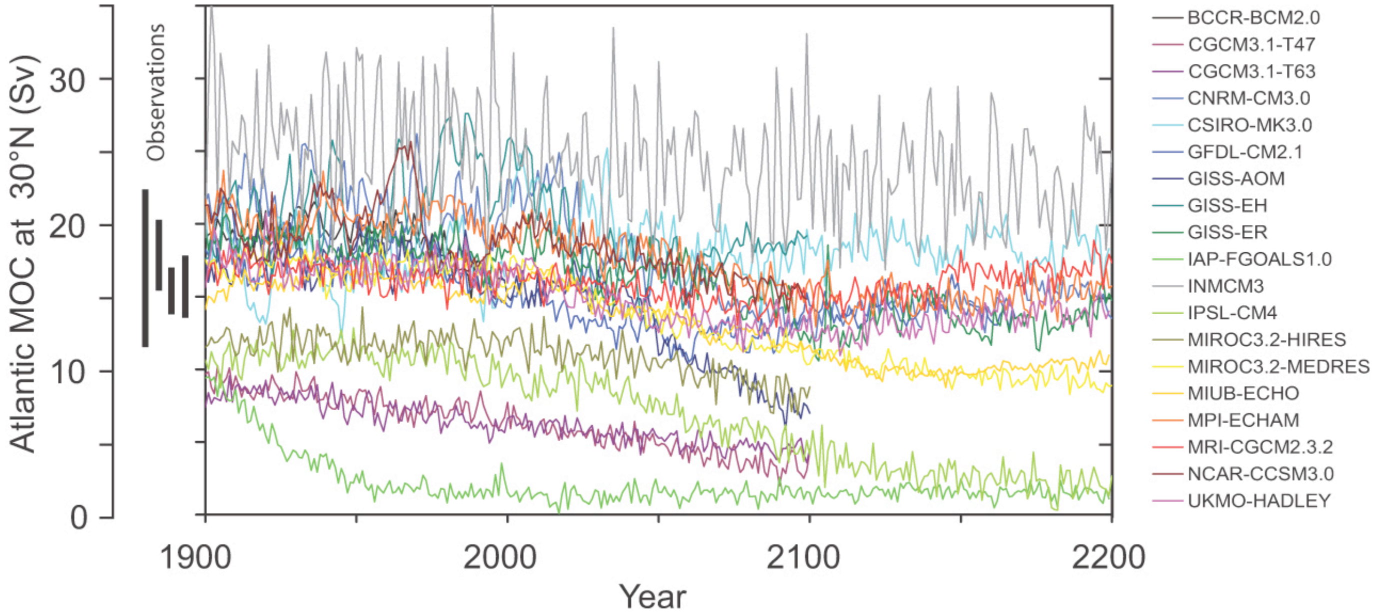
IPCC AR4 Figure 10.15



- Large spread in response (& climatology)
- Response controls timescale at which anthropogenic warming will be realalised
- Relations to atmospheric response?
- Possible to understand in terms of physical principles a'la Bjerknes compensation hypothesis?

Atmospheric energy transport

$$E_D = c_p T + \Phi$$

$$E_M = c_p T + \Phi + l_v q$$

$$F_D = \int_0^\infty v E_D \, dz$$

$$F_{LH} = \int_0^\infty v l_v q \, dz$$

C-C scaling

$$\frac{1}{e_s}\frac{de_s}{dT} = \frac{l_v}{R_v T^2} \qquad \varepsilon\frac{e_s}{p} = q_s$$

$$\frac{\Delta q_s}{q_s} = \frac{l_v}{R_v T^2}\Delta T$$

Constant RH gives:

$$\frac{\Delta q_s}{q_s} \approx \frac{\Delta q}{q} \approx \frac{\Delta F_{LH}}{F_{LH}} \approx 7\% K^{-1}$$

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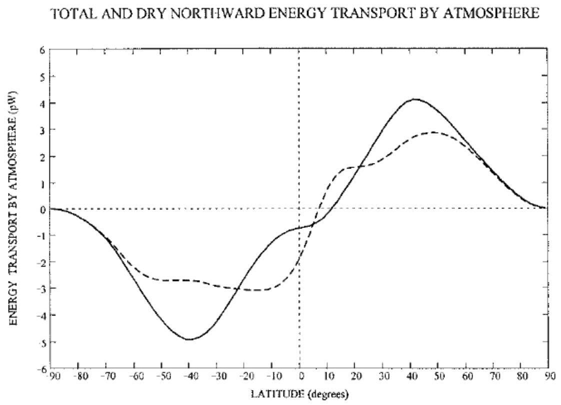


FIG. 9. Zonal annual mean northward dry static energy (dashed line) and total energy (solid line) transport (PW = 10^{15} W) by the atmosphere. The former is obtained from Eq. (5) when precipitation is used to represent latent heating of the atmosphere and excludes the transport of water vapor. The latter includes water vapor transport

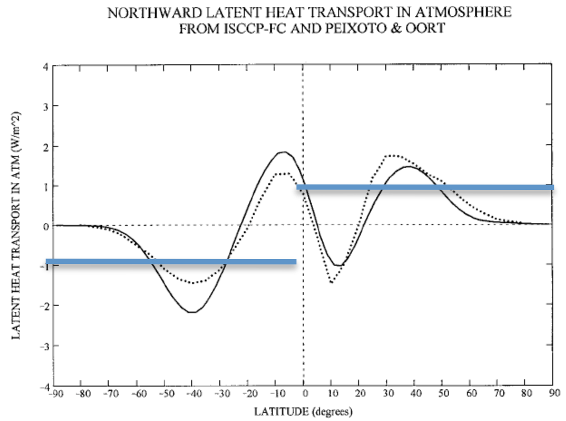
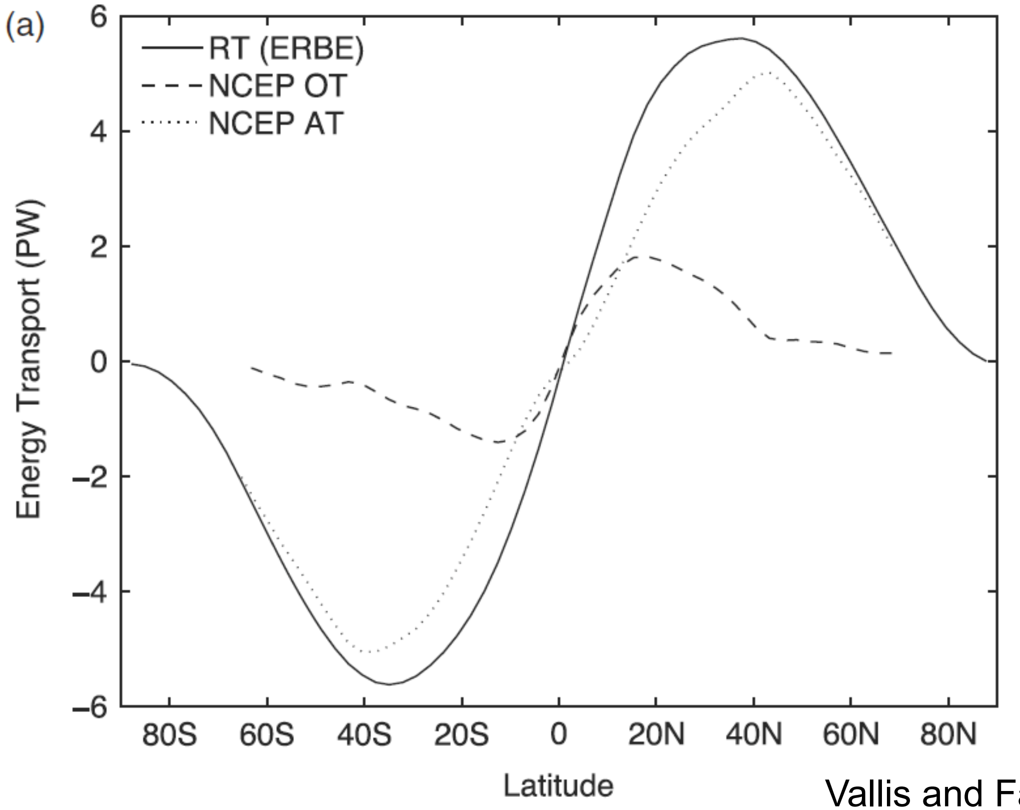


FIG. 10. Zonal annual mean water vapor transport (solid line) in W m^{-2} calculated from the difference of the total and dry static energy transports (shown in Fig. 9) compared with the corresponding result from Peixoto and Oort (1992) (dots).

$$\overline{F}_{LH} \geq 1PW \Rightarrow \frac{\Delta F_{LH}}{F_{LH}} \approx 7\%/K \approx 0.1PW/K$$

Extratropics: O(i.a.fluct) Trenberth & Stephaniak (2003)

Compensation?



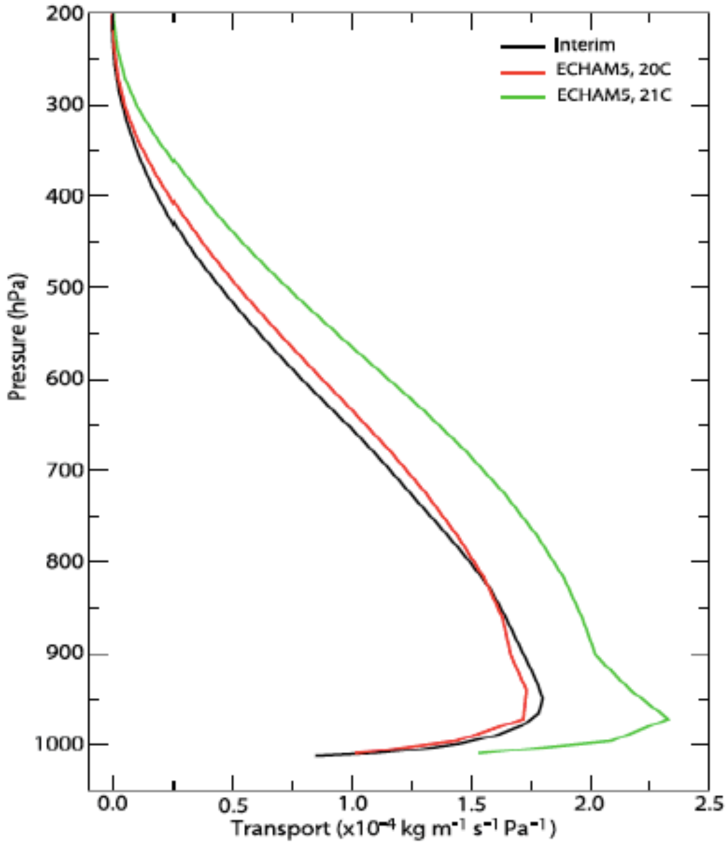
Vallis and Farneti (2009)

[OHT] ≈ 0.5PW (Ext.T)

COMPENSATION

- Ocean heat transport only
- Ocean and F_D combined
- F_D only

Transport of water vapour across 60°N



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

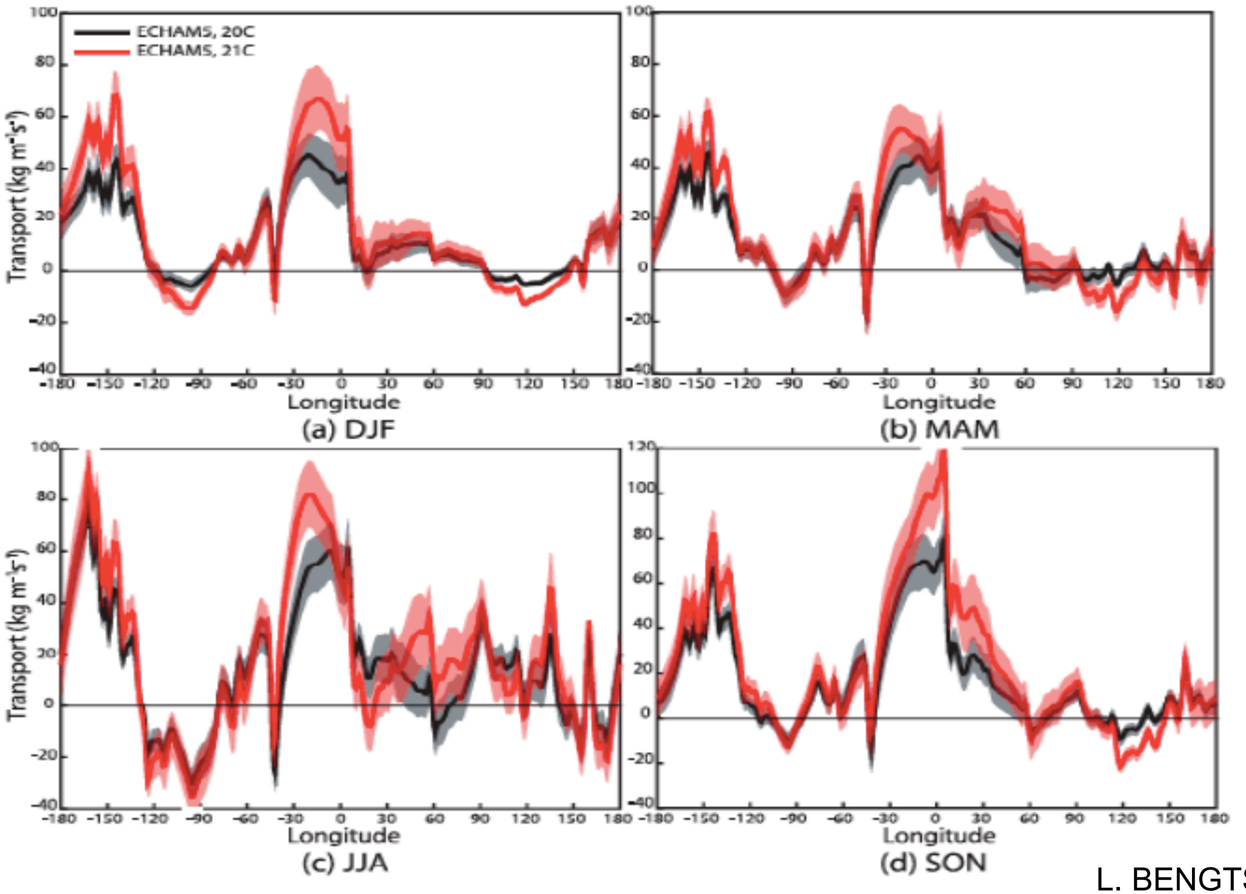
ERA-Interim re-analysis 1989-2009

ECHAM5 (T213) for the period 1959-1990

ECHAM5 (IPCC scenario A1B) 2069-2100

L. Bengtsson (2011), pers.comm

Transport of water vapour as a function of longitude. Note the large transport at the end of the stormtracks



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Storm-tracks control response ΔF_{LH}

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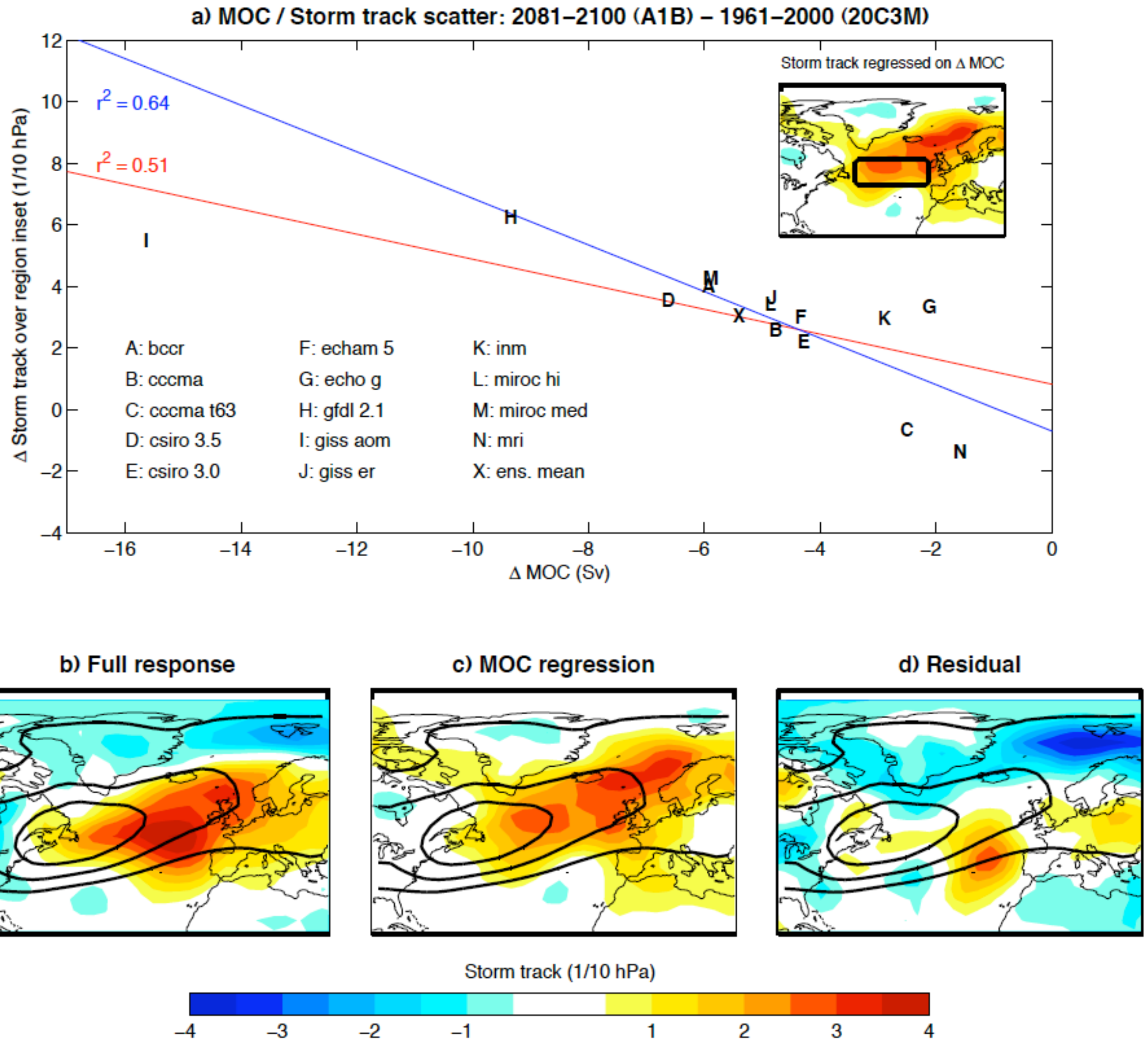
Energy transport across 60° N in a warmer climate

- Moist energy transport is increasing but dry static energy transport is decreasing with increasing temperature.
- Comparing 20C and 21 C we have for 60-90°N:

	20C	21C		
Lq	21.3	27.0	+5.8	W/m^2
CpT + gz	64.9	59.2	-5.7	W/m^2
Total	86.1	86.2	+0.1	W/m^2

L. Bengtsson (2011) pers.comm


a) MOC / Storm track scatter: 2081–2100 (A1B) – 1961–2000 (20C3M)
Storm track regressed on Δ MOC
$r^2 = 0.64$
$r^2 = 0.51$
Δ Storm track over region inset (1/10 hPa)
Δ MOC (Sv)
A: bccr
B: cccma
C: cccma t63
D: csiro 3.5
E: csiro 3.0
F: echam 5
G: echo g
H: gfdl 2.1
I: giss aom
J: giss er
K: inm
L: miroc hi
M: miroc med
N: mri
X: ens. mean
b) Full response
c) MOC regression
d) Residual
Storm track (1/10 hPa)

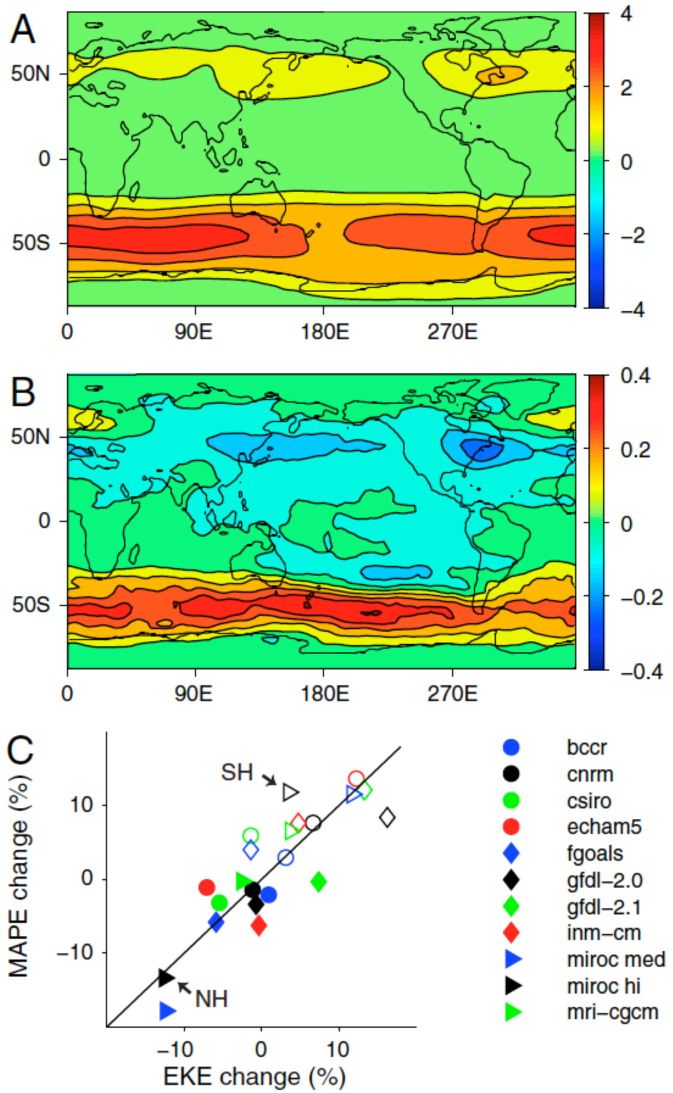


Fig. 1. Storm-track intensity in JJA in climate model simulations: (*A*) Transient EKE (10^5 J m^{-2}) averaged from 1981 to 2000 and in the multimodel mean (with slightly different time periods for some models; *Methods*). (*B*) Changes in multimodel mean EKE under global warming, calculated as the difference between time averages over 1981–2000 and 2081–2100. (*C*) Fractional changes in EKE and nonconvective MAPE under global warming for each model. Values are given for the northern hemisphere (solid symbols) and southern hemisphere (open symbols), but excluding the deep tropics (below 20° latitude in each hemisphere). The solid line indicates the one-to-one relationship corresponding to linear scaling of EKE and MAPE.

Central questions

•Why different sensitivity of F_D in models?

•Link to MAPE?

•What is the role of OHT/AMOC(?) response w.r.t MAPE?

•In-depth investigations of NorESM (AR5) – extend analysis to AR5 ensemble

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Global and regional feedback
21C/20C Scen. A1B

IPCC AR4	Temp.	Albedo	W.vapor	Cloud	Total	dT (2xCO2)
Global 13 mod.	- 4.12	0.28	1.86	0.54	-1.36	**+2.72**
60-90°N 13 mod.	- 4.00	1.76	0.94	- 0.36	- 1.65	**+2.24**
MPI ECH 5	- 4.01	2.02	0.95	**- 0.09**	- 1.13	**+3.27**
GFDL cm2.1	- 4.28	1.77	1.14	**- 1.98**	- 3.35	**+1.10**