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Entropy production in HadCM3 model and MEP conjecture for objective tuning

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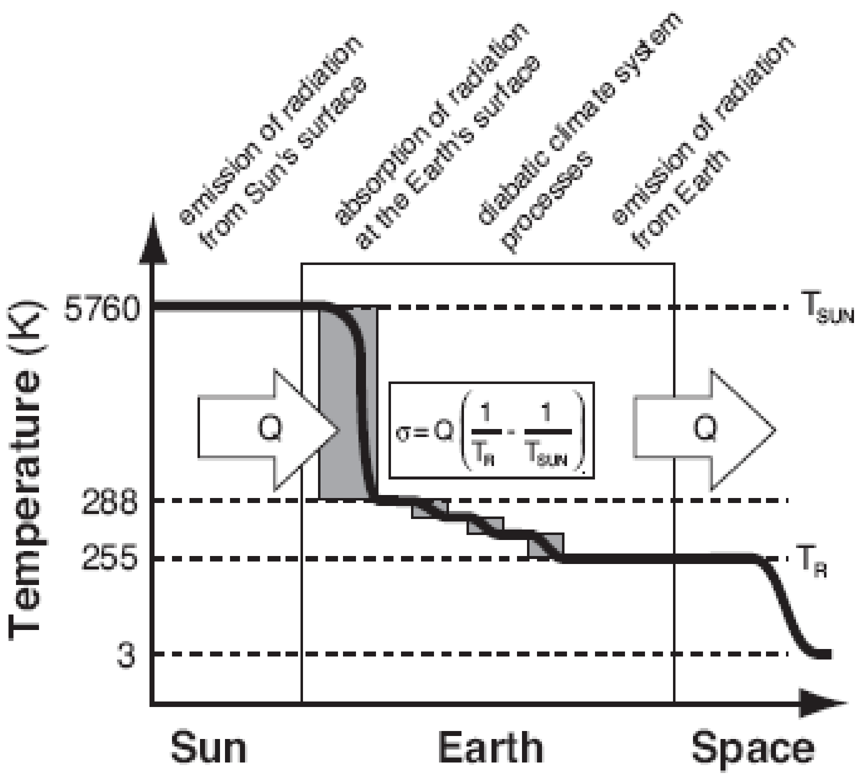
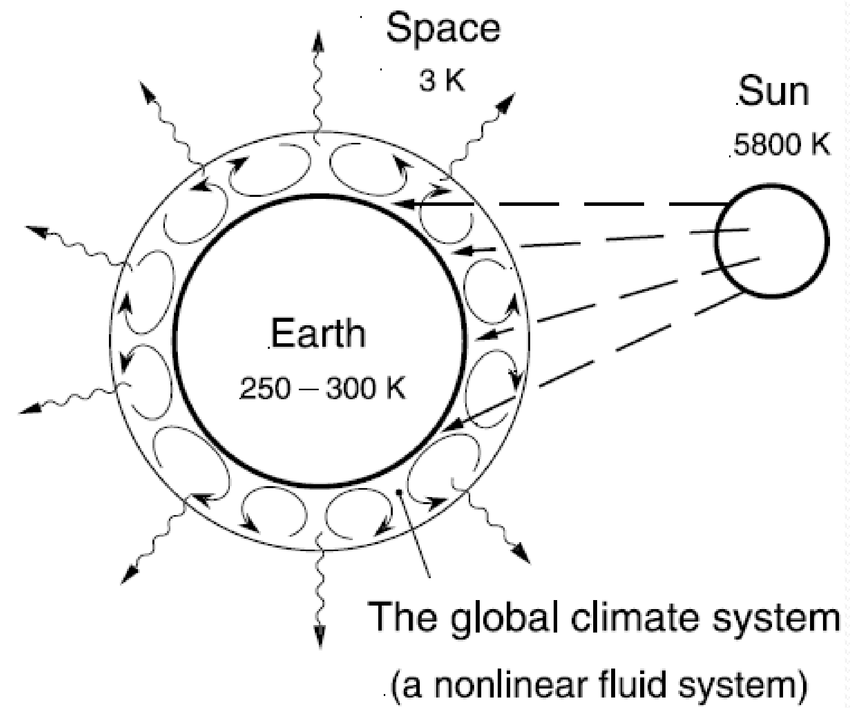
Outline

- **GCMs entropy budgets:** HadCM3 and its low resolution version, FAMOUS
- **MEP and MKD conjectures:** can they provide objective functions for parameter tuning?
- **A case study in FAMOUS:** parameter variation and entropy production

Earth system and entropy production

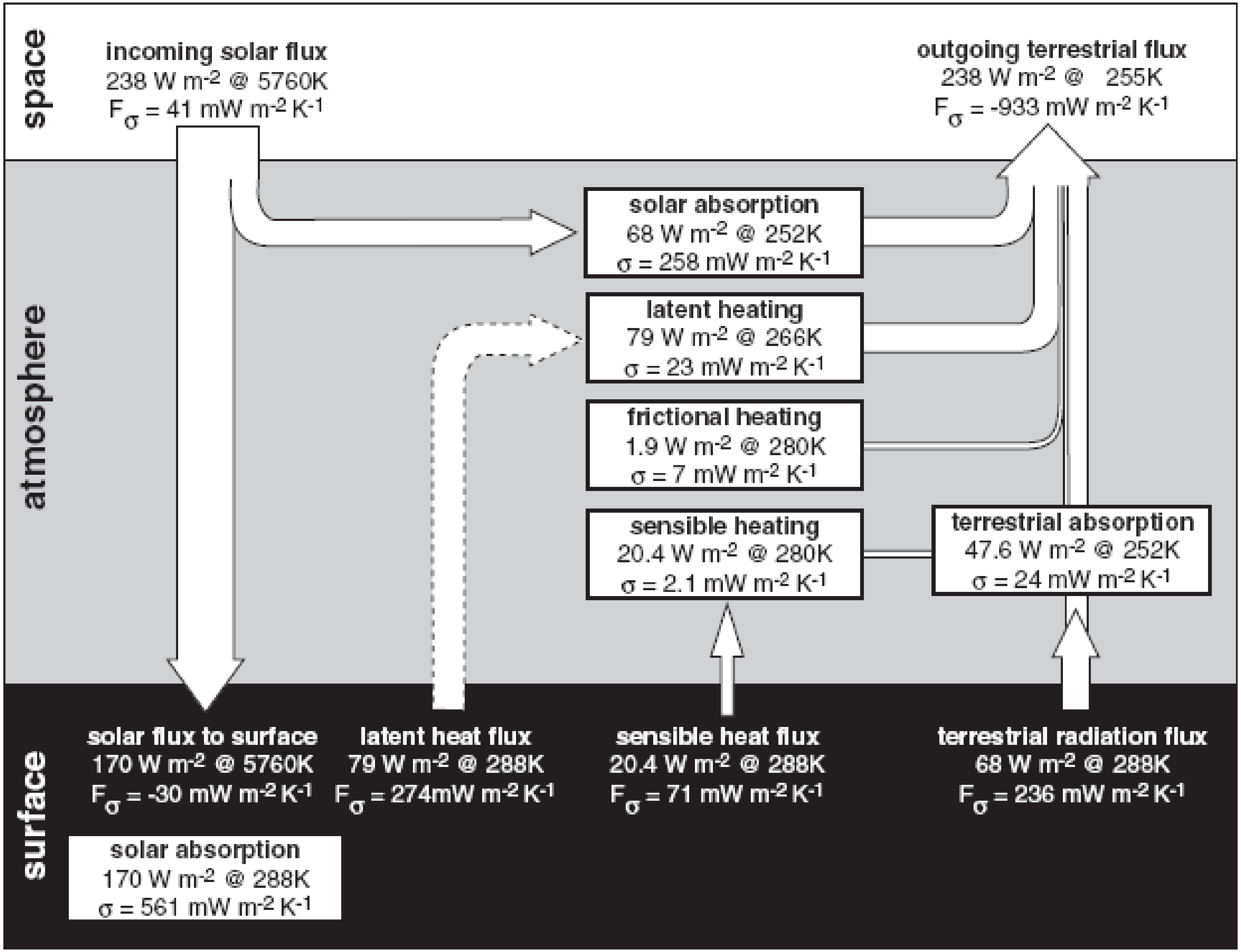


(from Kleidon&Lorenz (2005))



(from Ozawa et al. (2003))

Climate entropy budget



(from Kleidon&Lorenz (2005))

HadCM3 and FAMOUS entropy budget

- **Entropy sources from temperature tendencies:**

$$\frac{\Delta s}{\Delta t} = c_p \frac{\Delta T / \Delta t}{T} \left(-dp / g \right)$$

- **Quantites diagnosed in a 30-year control run (pre-industrial CO_2 concentrations)**

- **Atmosphere: Advection, hyperdiffusion, cloud scheme, BL, radiation, LS precipitation, convection, KE dissipation (energy correction);**

- **Ocean: mixed layer physics, diffusion, convection**

Process	HadCM3	FAMOUS	Fraedrich and Lunkeit (2008)	Goody (GISS)	Goody	Peixoto
Radiative entropy terms						
$\dot{S}_{pl}$	911.3	897.8	882	–	–	892
$\dot{S}_{sw}^{irr}$	811.8	790.9	812	802	–	819
$\dot{S}_{lw}^{sur,at}$	10.6	10.2	6	–	–	24
$\dot{S}_{lw}^{at,at}$	38.6	42.7	28	–	–	–
$\dot{S}_{rad}^{irr}$	861.0	843.7	846	–	–	843
$\dot{S}_{rad}^{rev}$	-51.0	-54.1	–	-72.8	–	–
Material entropy terms						
$\dot{S}_{sh+lh}$	37.8	37.9	29	58.7	21.2	25
$\dot{S}_{sh}^{bl}$	2.2	2.3	1	3.4	2.4	2.1
$\dot{S}_{diss}$	12.5(*)	13.6 (*)	6(**)	11.5	11.3	7
$\dot{S}_{diff}$	0.8	1.1	–	–	–	–
$\dot{S}_{adv}$	-0.1	-0.4	–	–	–	–
$\dot{S}_{tur}^{oc}$	0.8	1.0	–	–	–	–
$\dot{S}_{mat}$	51.8	53.3	35	70.2	32.5	34.1
Rate of change of entropy						
$\dot{S}$	0.8	-0.8	-7	-2.6	–	-17

(*Pascale et al. , 2010*)

Maximum Entropy Production: what proof? What use?

- **Proofs:** many "claimed" proves, none are really satisfactory. Lack of a general understanding.

- **Theoretically:** *Dewar (2003)* claimed to have demonstrated MEP ; Grinstein & Linsker found an error in Dewar's derivation;

- **Toy model:** *Lorenz et al.(2001), Paltridge(1975,1978,2001);* one dimensional vertical models *(Ozawa et al., 1997), (Pujol&Fort , 2002), (Wang et al.,2008), (Noda&Tokioka,1983), (Schulmann, 1977)* . All these demonstrations assume specific ad hoc relations about the physics of the models (which contains no dynamics)

- **Simple GCMs *(Kleidon et al. 2003,2006)***

- **So far as MEP seems to have little predictive power except order-of-magnitude estimations, and so not very useful in Climate Science.**

MEP and GCMs: how to prove, how to use?

- **If MEP holds, it could provide a thermodynamic principle inherent to the system;**
- **How test MEP in a GCM? Some internal processes are parametrised and therefore cannot adjust to select a MEP state;**
- **Instead the MEP state could be found within the corresponding model parameter space: the only degrees of freedom in the model**
- **If MEP holds, parameters should be tuned in a way to maximise Entropy Production**

Optimisation of GCMs trough objective functions (Kunz et al., Clim Dyn 2008))

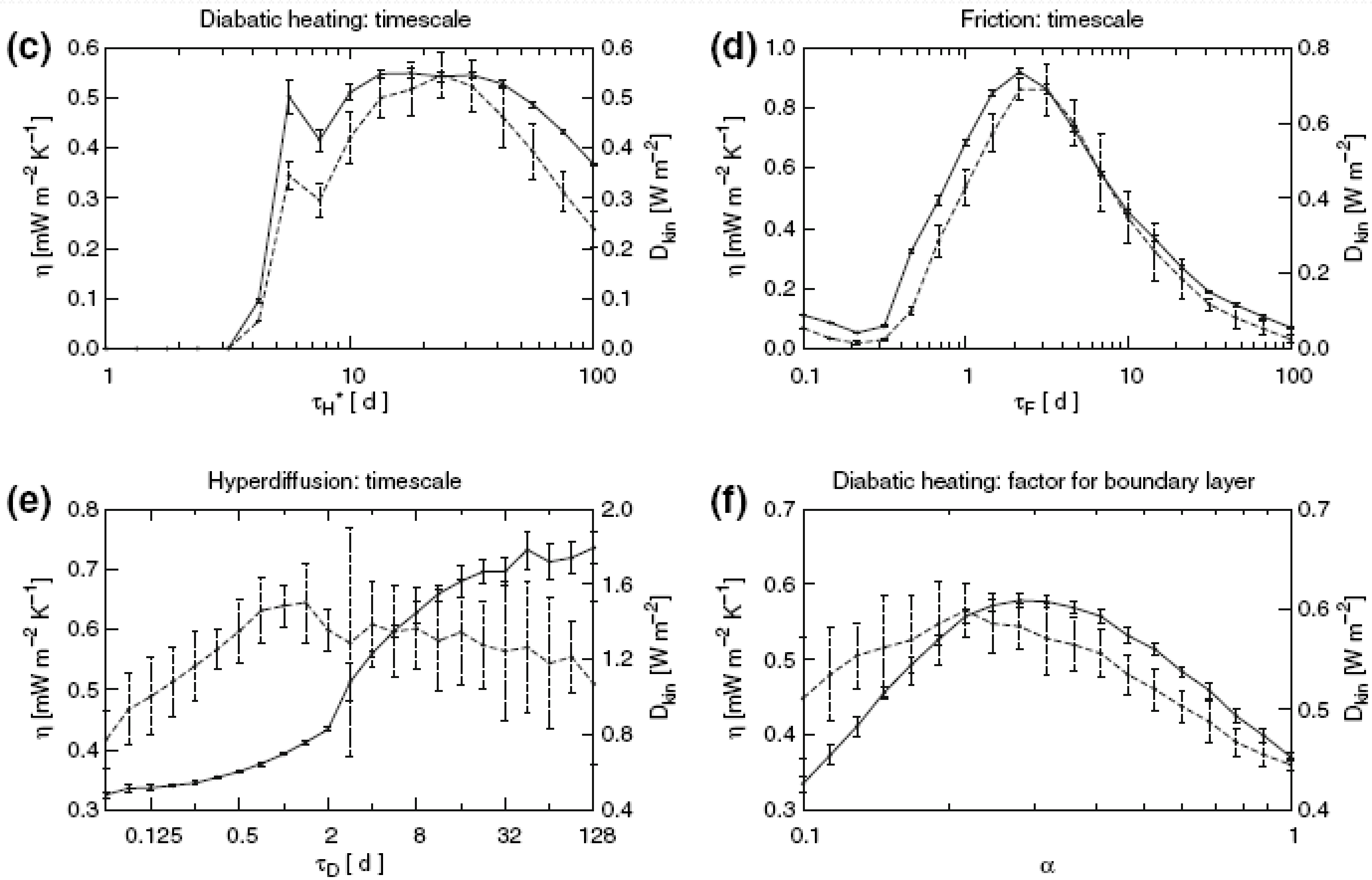
$$\left(\frac{\partial(\zeta, D)}{\partial t}\right)_{\text{Friction}} = -\frac{(\zeta, D)}{\tau_F}$$

$$\left(\frac{\partial(T, \zeta, D)}{\partial t}\right)_{\text{Diffusion}} = -k\frac{\nabla^8(T, \zeta, D)}{\tau_D},$$

$$\left(\frac{\partial T}{\partial t}\right)_{\text{Heating}} = \frac{T_R - T}{\tau_H}$$

$$\begin{aligned} \text{levels 1 to 3:} \quad & \tau_H = \tau_H{}^*, \\ \text{level 4:} \quad & \tau_H = (0.8\alpha + 0.2)\tau_H{}^*, \\ \text{level 5:} \quad & \tau_H = \alpha\tau_H{}^*. \end{aligned}$$

Parameter	$P_{standard}$	P_{max} [η]	P_{max} [D_{kin}]
$(\Delta T_R)_{EP}$	70 K	–	–
L	6.5 K km^{-1}	–	–
τ_H^*	30 days	24 days	18 days
τ_F	1 days	2.2 days	2.2 days
τ_D	6 h	1.4 days	–
α	0.17	0.22	0.28

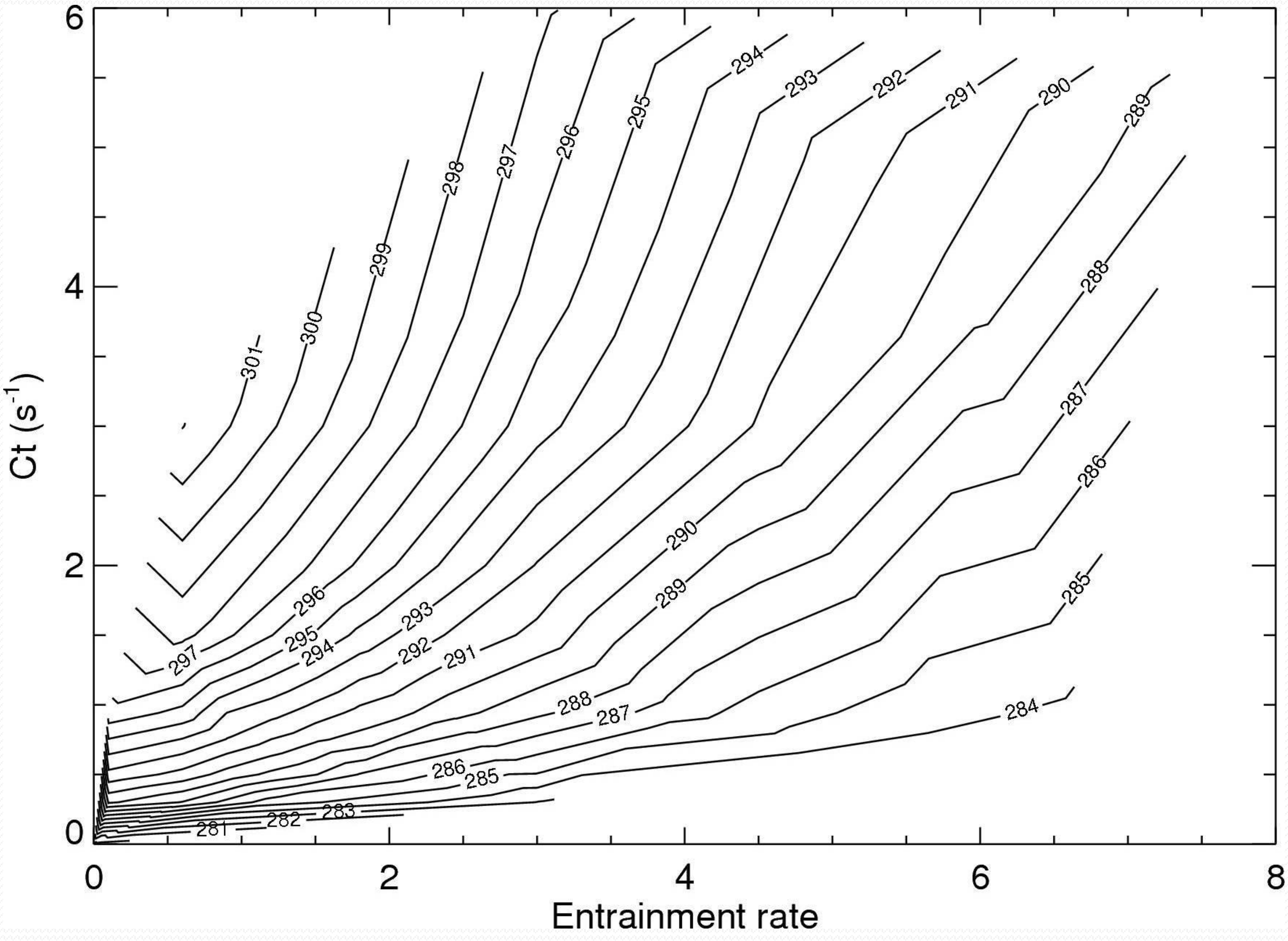


A case study in FAMOUS: entrainment rate and cloud-to-droplet conversion rate

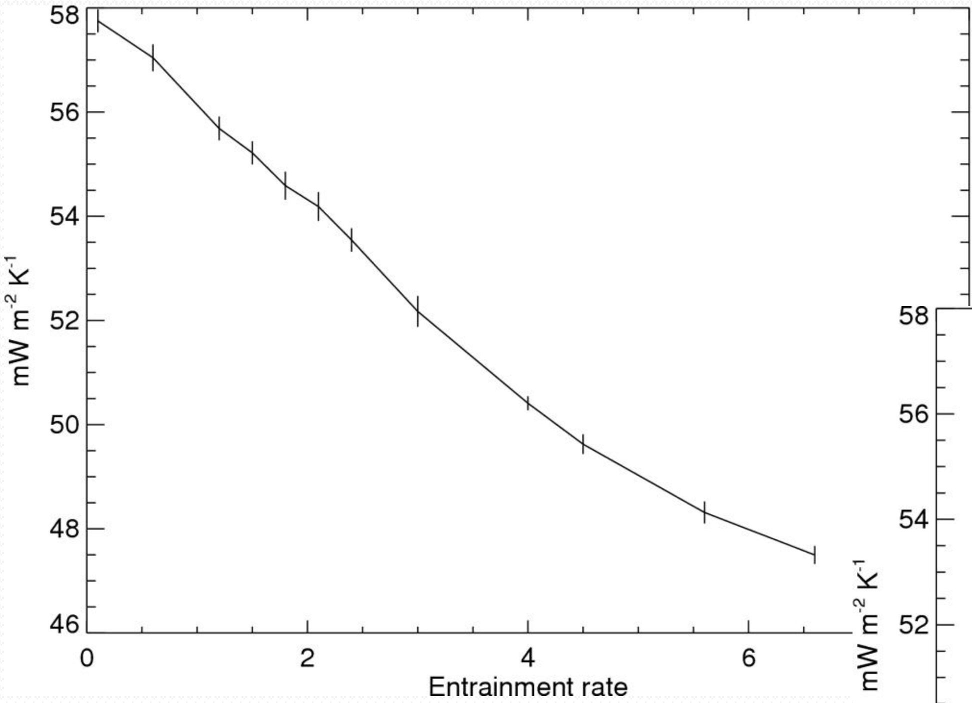
- Try to extend the previous idea to a complex GCM, FAMOUS;
- Consider parameters to which the climate is very sensitive: (see QUMP, Murphy et al. 2004).....
- parameter tuning is one of the main uncertainties of GCM; here MEP could be really useful..

GCM Physics	Process Affected	Range
Entrainment rate	Convection	0.6 - 9
Cloud droplet-rain conversion rate , s^-1	Large scale cloud	(0.5-4)*10^-4
Ice fall speed , m/s	Large scale cloud	0.5-2
Threshold of relative humidity	Large scale cloud	0.6-0.9
Asymptotic neutral mixing length	Boundary layer	0.05- 0.5
Ice particle size (effective radius), m	Radiation	(25-30)*10^-4
Order of diffusion operator	Dynamics	4-6

Set of climates in parameter space: Surface Temperature

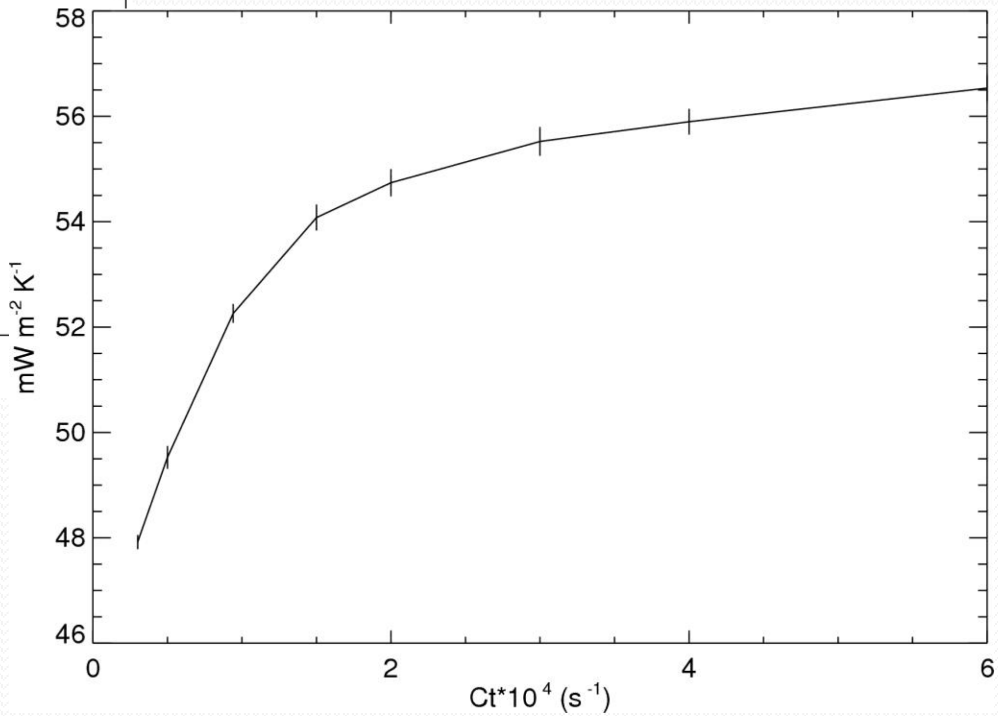


Material Entropy Production (mW/m^2/K)

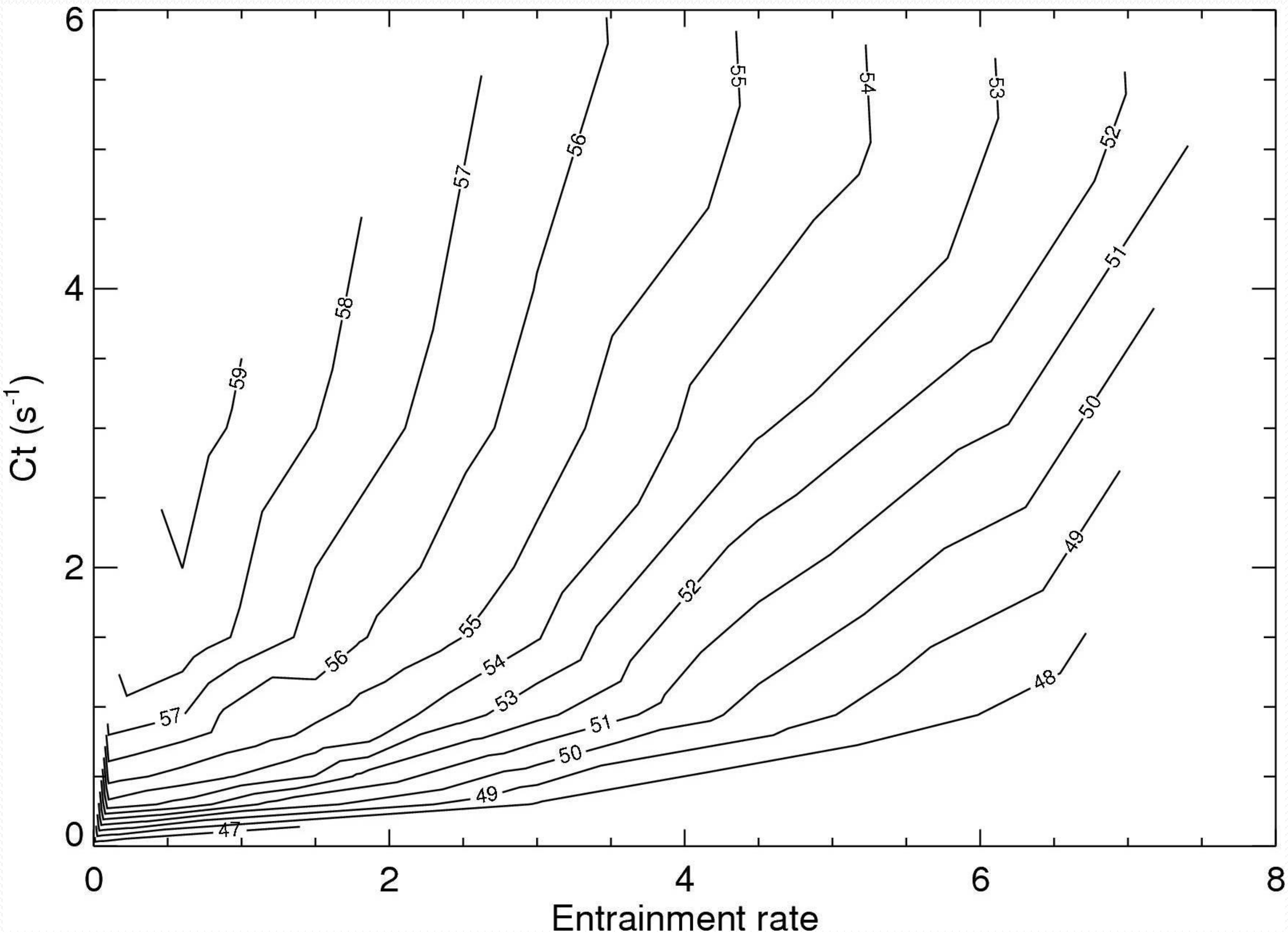


Variation along Entrainment rate, Ct=standard one

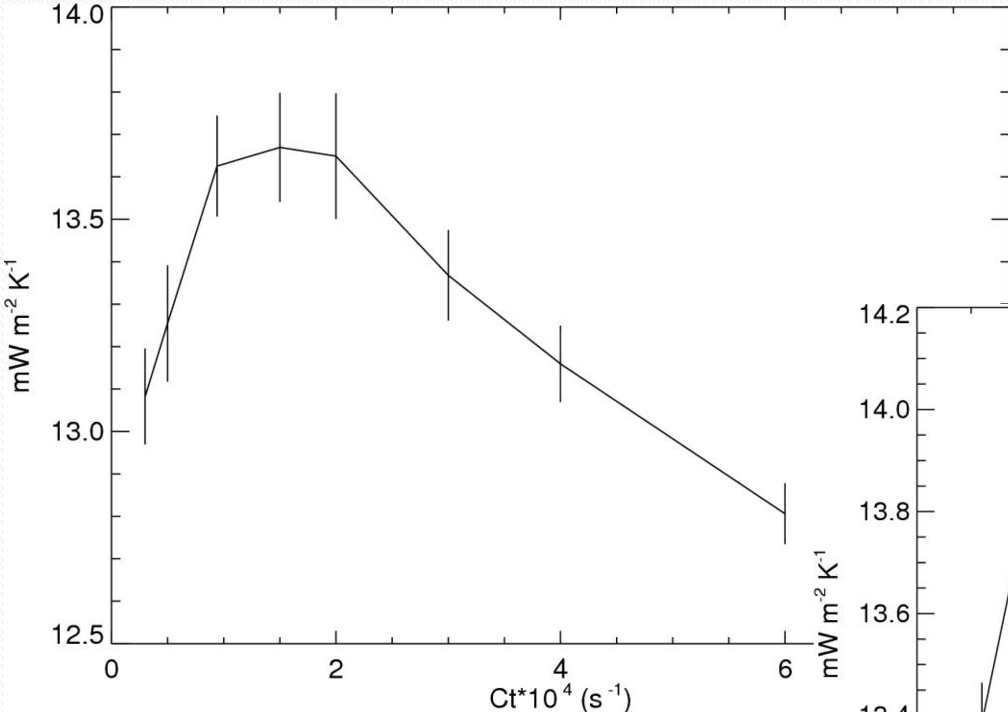
Variation along Ct, entr=standard



Climate Material Entropy Production (mW/m^2/K)

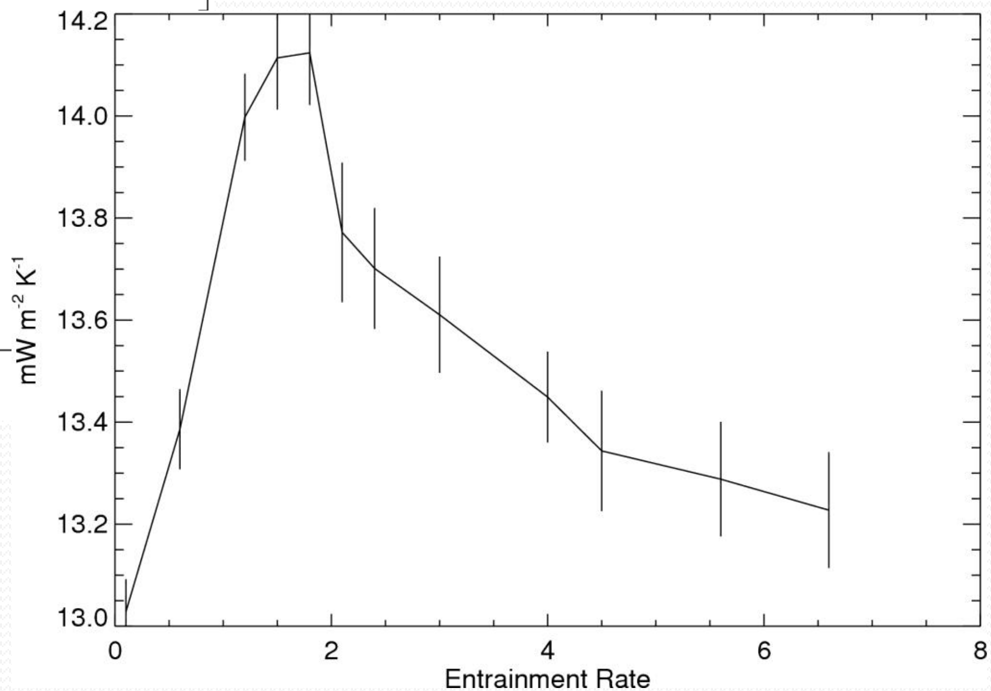


Dissipation Entropy Production (mW/m^2/K)

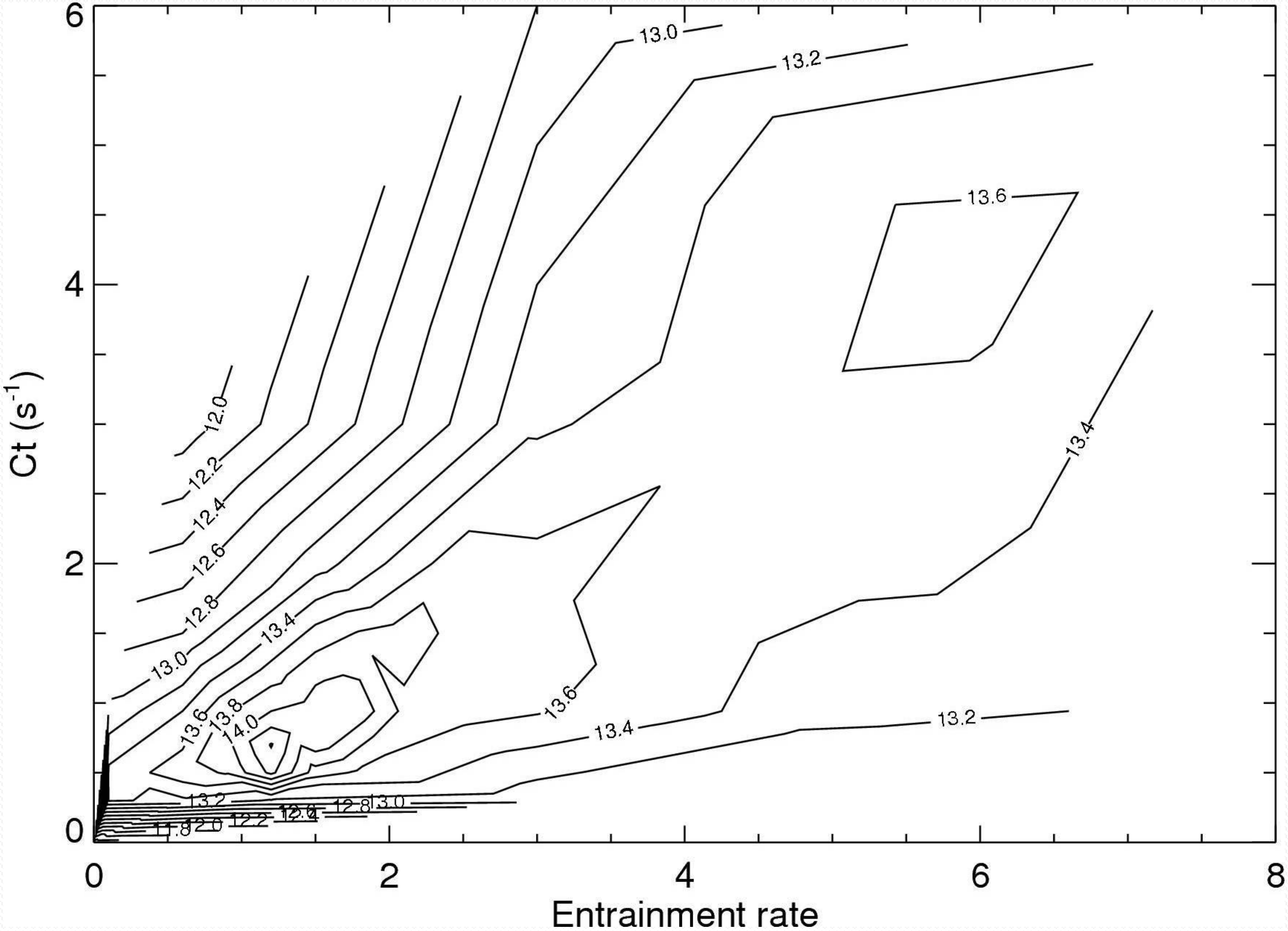


Variation along Ct, entr=standard

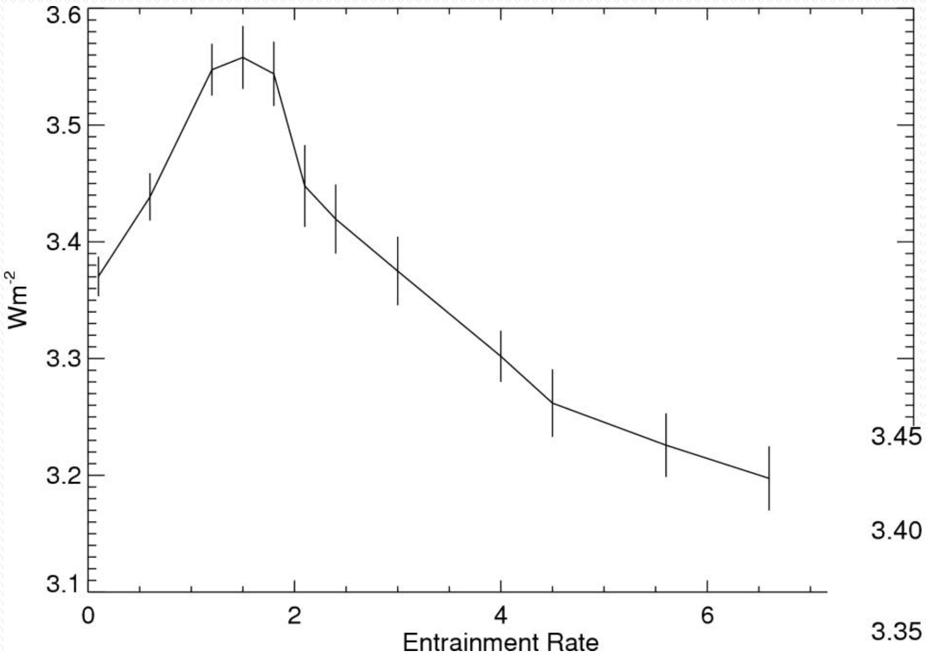
Variation along Entrainment rate, Ct=standard one



Dissipation Entropy Production (mW/m^2/K)

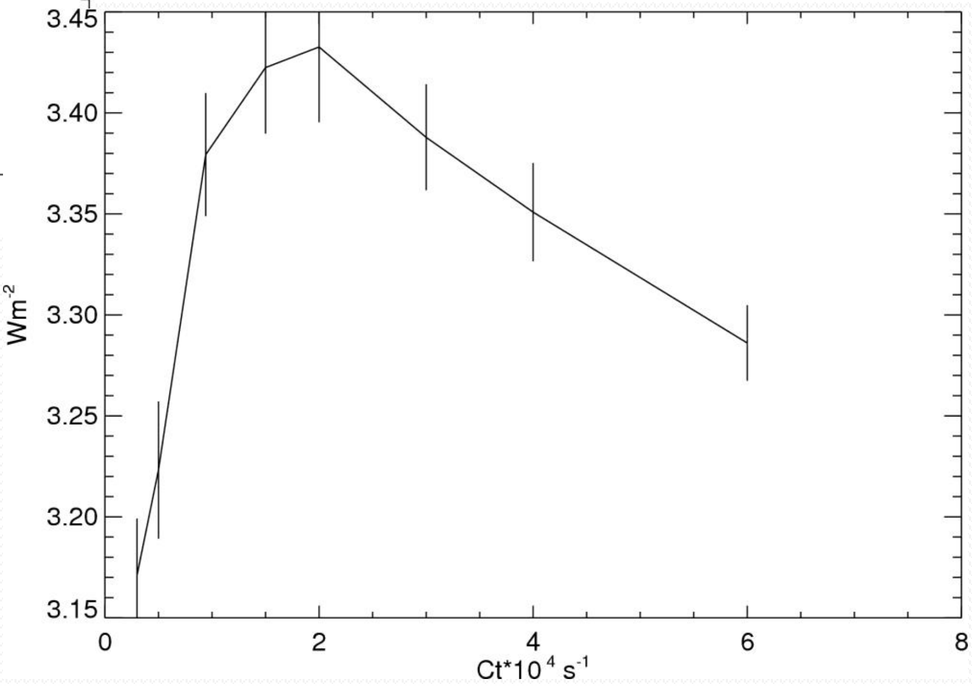


Energy correction (dissipation)



Variation along Entrainment rate, Ct=standard one

Variation along Ct, entr=standard



Caution….

- No maximum in the "material" entropy production of the CS is found; EP dominated by the release of latent heat

- A maximum in the energy correction (dissipation) is found but different from standard values;

- Maybe Dissipation better well-behaved than EP;

- Other parameters : Von Karman constant, Ice fall speed, RHc. A maximum in atmospheric dissipation is shown only by Karman's constant (for k~1): at this stage MEP does not seem to be usefully applicable;

- Perhaps the model is too "constrained" and parameter variation does not produce a states space enough large in order to show MEP;

- A complex GCM is dominated by clouds and ice-sheet feedbacks when physics is perturbed; we are repeating the experiment in a simplified setup with fixed absorbed solar radiation and fixed surface albedo to highlight the differences.

Conclusions

- **Entropy diagnostic tool for a coupled GCM and HadCM3 entropy budget**

- **HadCM3 is quite well entropy balance, but comparison with other model shows still uncertainty in material EP and dissipation;**

- **Maximum in dissipation but not in material entropy production for some parameters, but we must be prudent about conclusions;**

- **At this stage MEP does not seem to be of great utility, even though the experiments shows a qualitative confirmation of Lorenz hypothesis of maximum dissipation**