Met Office SCM results from CGILS:

a positive feedback driven by evaporatively-driven cloud-top entrainment?

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Overview

- Direct comparison of SCM with LES
- Steady vs transient forcing
- An evaporatively-driven feedback?
- Conclusions and further work

Met Office SCM simulations

- Using AR5 GCM (HadGEM2) physics, except:
  - Fixed RH_{crit} profile (cf GCM: Cusack et al (1999) parametrization)
  - Fixed cloud droplet number ($100cm^{-3}$, as for the LES)
- CGILS forcings used:
  - "v2" = standard steady forcing for SCMs (July 2010)
  - "v3" = initial mixed layer and revised steady forcing (as used by LES, Dec 2010)
- Compare v3 with LES

Changes between v2 and v3

- Only for s11 and s12, motivated by LES
- Start with well-mixed stratocumulus layer
  - has no impact on SCM equilibrium
- Small adjustments to horizontal advection forcing above the PBL
- s12 only: reduce subsidence by 5%, impose min q_v above PBL
- LES now generally in agreement making SCM comparison worthwhile…

SW cloud forcings
LES vs SCM

	LES			SCM v2			SCM v3		
	Ctl	+2K	Δ	Ctl	+2K	Δ	Ctl	+2K	Δ
s6	-20 to -30	-20 to -30	0	-20	-20	0	-20	-20	0

- s6: shallow cumulus
  - SCM very similar to LES
  - very little cloud response

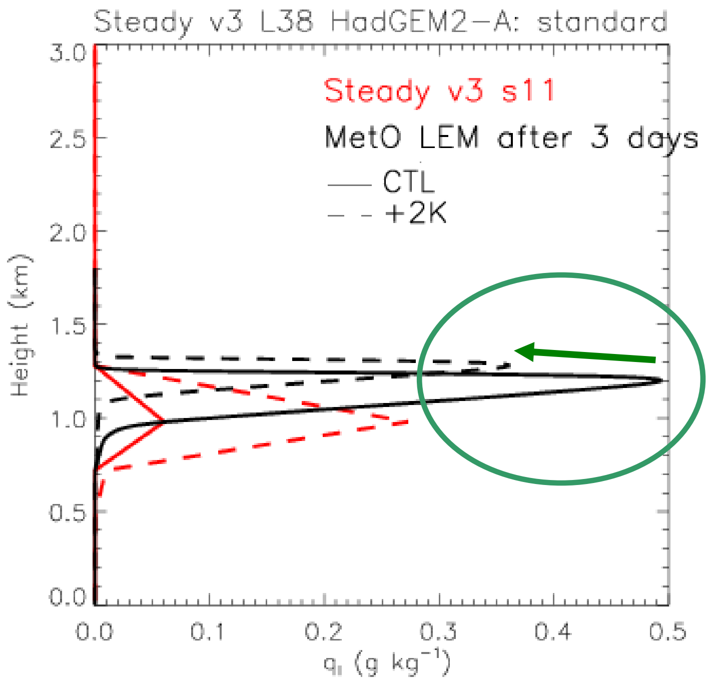
SW cloud forcings
LES vs SCM

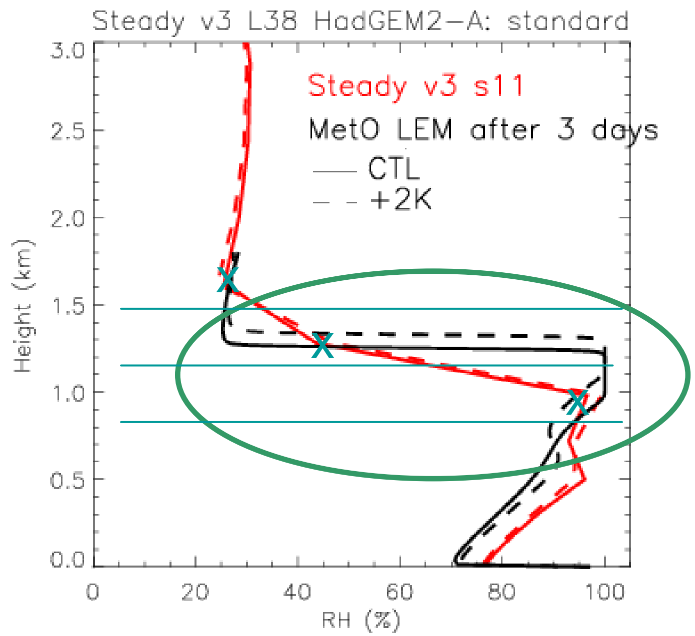
	LES v3			SCM v2			SCM v3		
	Ctl	+2K	Δ	Ctl	+2K	Δ	Ctl	+2K	Δ
s11	-150 to -160	-150	0 to +10	-30	-20	+10	-75	-160	-85
s12	-130 to -150	-130 to -150	-5 to +20	-95	-80	+15	-110	-50	+60

- SCM gets same cloud regimes as LES
  - s11: stratocumulus over cumulus
  - s12: well-mixed stratocumulus
- SCM SW cloud forcing generally underdone
  - SCM very sensitive to LS forcing, even in the sign of response at s11!

s11 profiles
SCM vs LES

- LES suggest feedback is caused by small (100-200m) rise in inversion and resulting change in cloud-top water content
- Very hard for a SCM to capture this small change robustly
  - eg might depend on position of inversion relative to grid in the control
  - Higher vertical resolution would help
- How relevant is this to the GCM?
  - Run an ensemble of SCM or transient forcing…





Transient forcing (1)

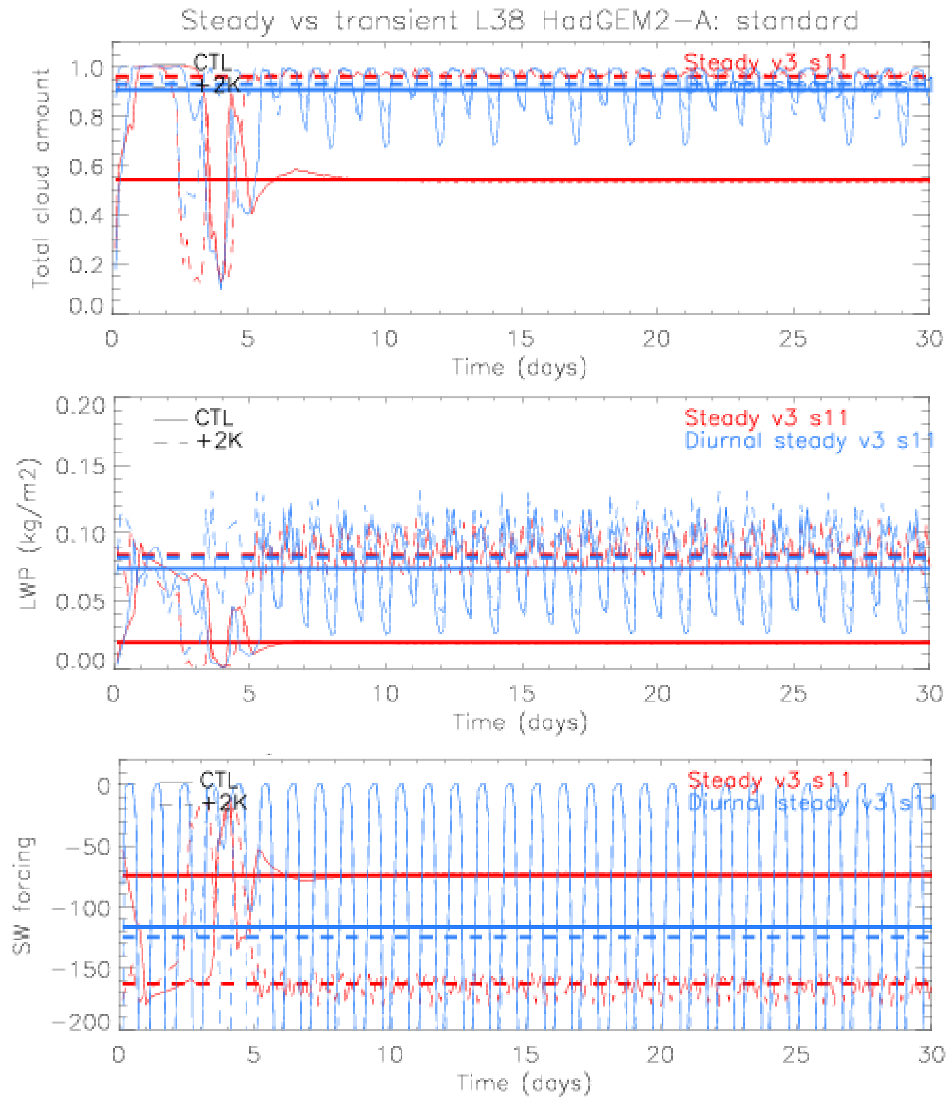
- Steady state forcing, especially mean diurnal SW, is unrealistic
  - expect large diurnal cycle of LWP and hence SW cloud forcing
- So introduce the diurnal cycle to v3
  - permanent 15th July so time mean forcing unchanged, hence no drift in free tropospheric profiles
- Focus on s11 stratocumulus over cumulus point
  - s12 stratocumulus point similar

Diurnal forcing

—— CTL
– – +2K

Thick lines are time-mean

s11

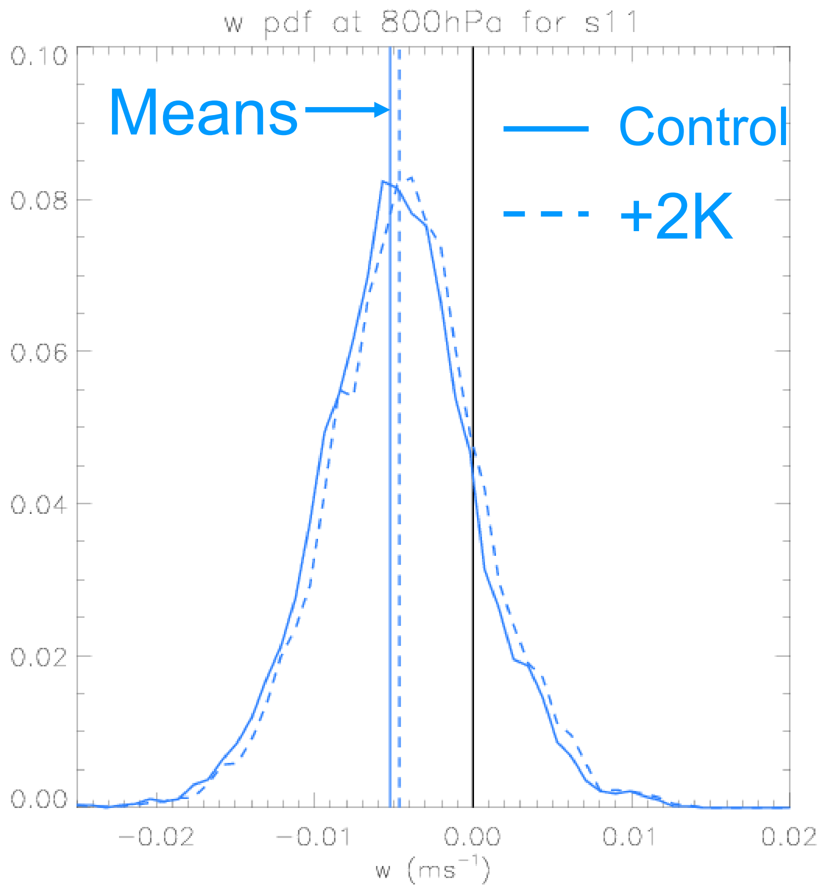


- SCM shows realistic diurnal cycle of cloud with diurnally varying SW compared to steady diurnal mean SW
- Magnitude of SW response reduced very significantly by including diurnal cycle:
  - -85 Wm^{-2} with diurnal mean
  - -10 Wm^{-2} with diurnal cycle

Transient forcing (2)

- Including the diurnal cycle doesn't induce significant perturbations in the gross features of the PBL
  - eg its depth relative to the SCM grid
- Use Minghua's transient forcing
  - time variation of w taken from GCM (ERA?) and imposed in CGILS, keeping time-mean w profile fixed
  - assume variability is the same in +2K and control
  - keep diurnal cycle
  - focus on s11 stratocumulus over cumulus point

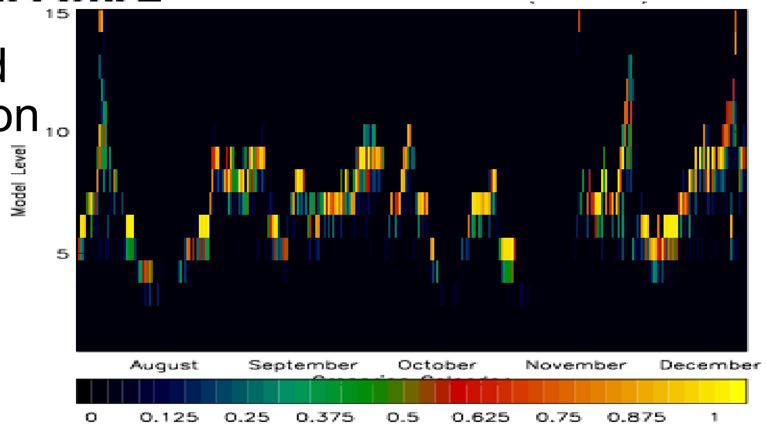
PDFs of standard transient w



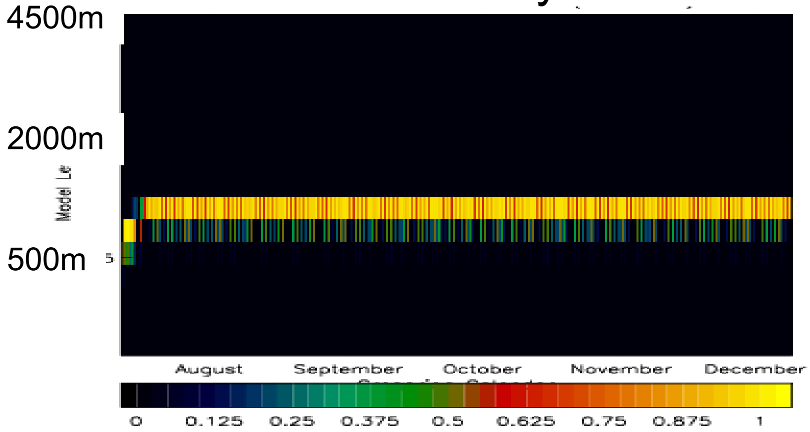
Transient s11 simulation

SCM with transient w

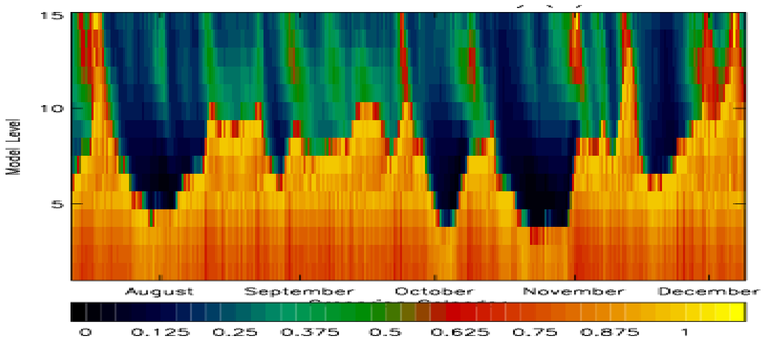
Cloud fraction



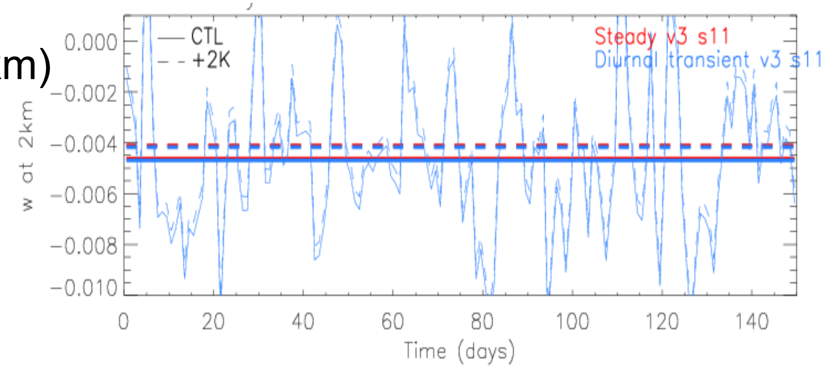
Diurnal but steady SCM



RH



w(2km)

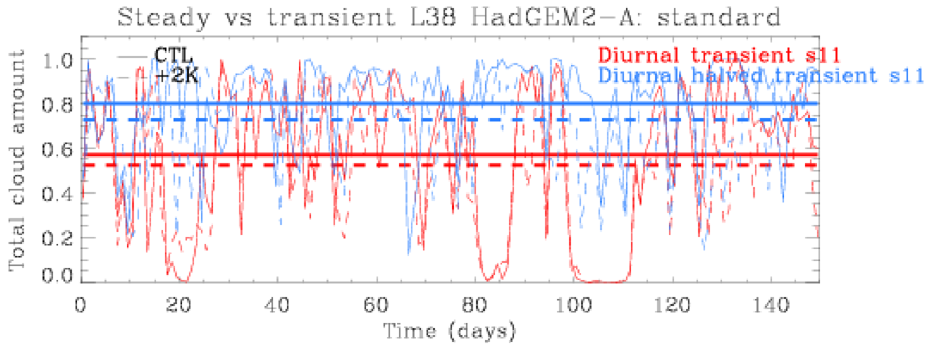


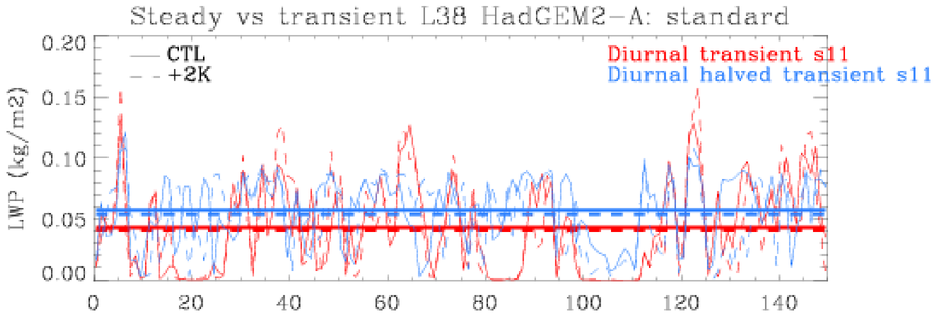
- Very significant w variation
- Height of cloud layer now varies significantly
- Periods of sustained high subsidence squash the PBL and cloud disappears
  - running with w standard deviation halved gives higher mean cloud fraction…

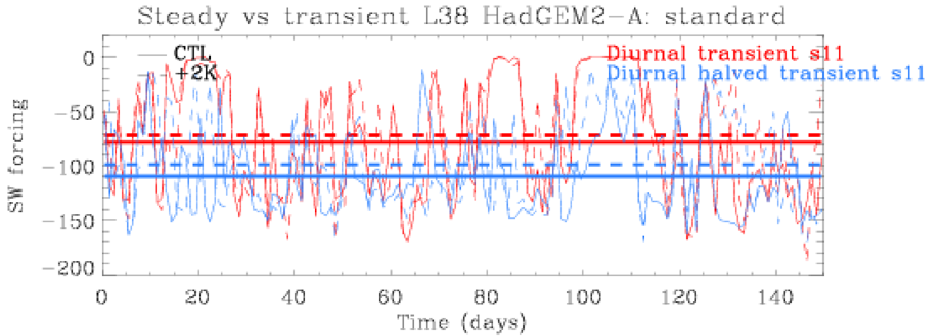
Transient forcing at s11

—— CTL Full transient forcing
– – +2K Halved w transience

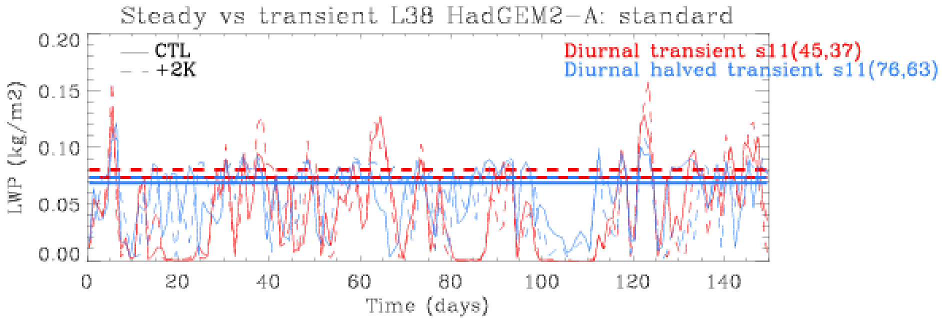
s11 (thick lines are time-mean)

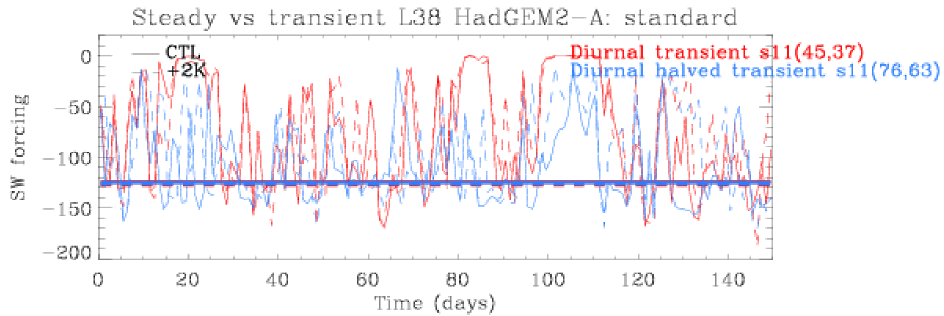






- Halving w std deviation gives more persistent cloud but very similar SW cloud response
- Subsample time averages on cloud cover > 0.7 (ie. "stratocu")
  - "stratocu" LWP increases in +2K giving (small) negative feedback





SW cloud forcing

Steady and transient simulations

	SCM v3			SCM diurnal v3			SCM diurnal transient			SCM diurnal transient/2		
	Ctl	+2K	Δ	Ctl	+2K	Δ	Ctl	+2K	Δ	Ctl	+2K	Δ
s11	-75	-160	-85	-115	-125	-10	-75	-70	+5	-110	-100	+10

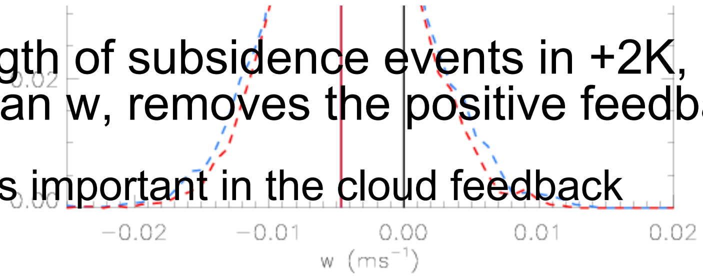
- Transient w simulations appear to give a robust small positive SW feedback but…
- "stratocu" SW feedback is negative in transient simulations (due to increase in LWP in warmer climate)
- So overall positive feedback must be dominated by reduction in frequency of occurrence of stratocu
- But absence of stratocu correlates with strong subsidence events
- Implies assumptions about (lack of) change in transience in perturbed climate are important…

Alternative transience in +2K

- Scale the std dev of w with the mean w, ie fix $\frac{\sigma_w}{\overline{w}}$
  - very slightly reduces the magnitude of the w variations in the +2K simulation

	SCM diurnal transient			SCM diurnal transient/2		
	Ctl	+2K	Δ	Ctl	+2K	Δ
s11	-75	-70	+5	-110	-100	+10
s11 with $\sigma_w/\overline{w}$ fixed	-75	-80	-5	-110	-110	0

- Reducing the strength of subsidence events in +2K, in line with the reduction in the mean w, removes the positive feedback
  - ie, the dynamics is important in the cloud feedback



A positive feedback driven by evaporatively-driven cloud-top entrainment?

A positive feedback driven by evaporatively-driven cloud-top entrainment

Met Office

- The UM boundary layer scheme includes an evaporatively-driven entrainment and mixing term which depends on the inversion temperature and humidity jumps
- If, as the climate warms, RH remains constant then the q jump across the inversion will increase (because RH is much larger in the BL):

$$q \equiv RH\ q_{sat} \quad \text{so} \quad \frac{dq}{dT} = RH\ \frac{dq_{sat}}{dT}\bigg|_{(T,p)}$$

  - Note that because T is warmer above the inversion, dq_{sat}/dT will be larger there, partially off-setting the RH effect

- Larger (more negative) Δq implies larger κ

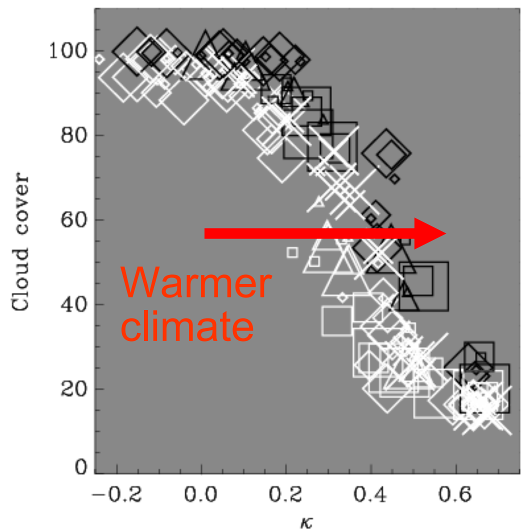
$$\kappa \equiv \frac{\Delta\theta_e}{(L/c_p)\Delta q_t} = \frac{\Delta\theta + (L/c_p)\Delta q_t}{(L/c_p)\Delta q_t}$$

$\Rightarrow$ more evaporatively-driven entrainment of warm/dry air

$\Rightarrow$ drier cloud layer with less cloud water

$\Rightarrow$ positive low cloud climate feedback

- Test in the SCM by disabling this effect…



LES of Sc/Cu from Lock (2009)

What of the feedback driven by evaporatively-driven entrainment?

	SCM diurnal transient			SCM diurnal transient/2		
	Ctl	+2K	Δ	Ctl	+2K	Δ
s11	-75	-70	+5	-110	-100	+10
s11 with no evaporatively-driven BL mixing	-90	-80	+10	-110	-112	-2

- Disabling the evaporatively-driven mixing in the PBL scheme can reduce the positive feedback, *if the dynamics variability is weakened*
- Not clear whether the dynamics response or local PBL effects would dominate in the GCM
- The same sensitivity test in the GCM gives a null result suggesting the effect of this term is small (in HadGEM2)

Conclusions

- Met Office HadGEM2 SCM reproduces the basic features of the LES in the 3 cloud regimes tested
- SW cloud feedback in SCM *with steady forcing* can be erratic
  - LES suggest cloud changes are subtle
  - Higher SCM vertical resolution should improve this (see HadGEM3…)
- Transient forcing looks realistic
  - Mean SW feedback generally small and positive in SCM (as in steady LES)
    - but in transient SCM this is dominated by reduction in frequency of occurrence of stratocu…
    - …in turn dependent on details of the w transience
    - How to constrain the change in w variability?
- Evaporative cooling still a potential positive feedback mechanism but apparently small compared to influence of dynamics

Future work

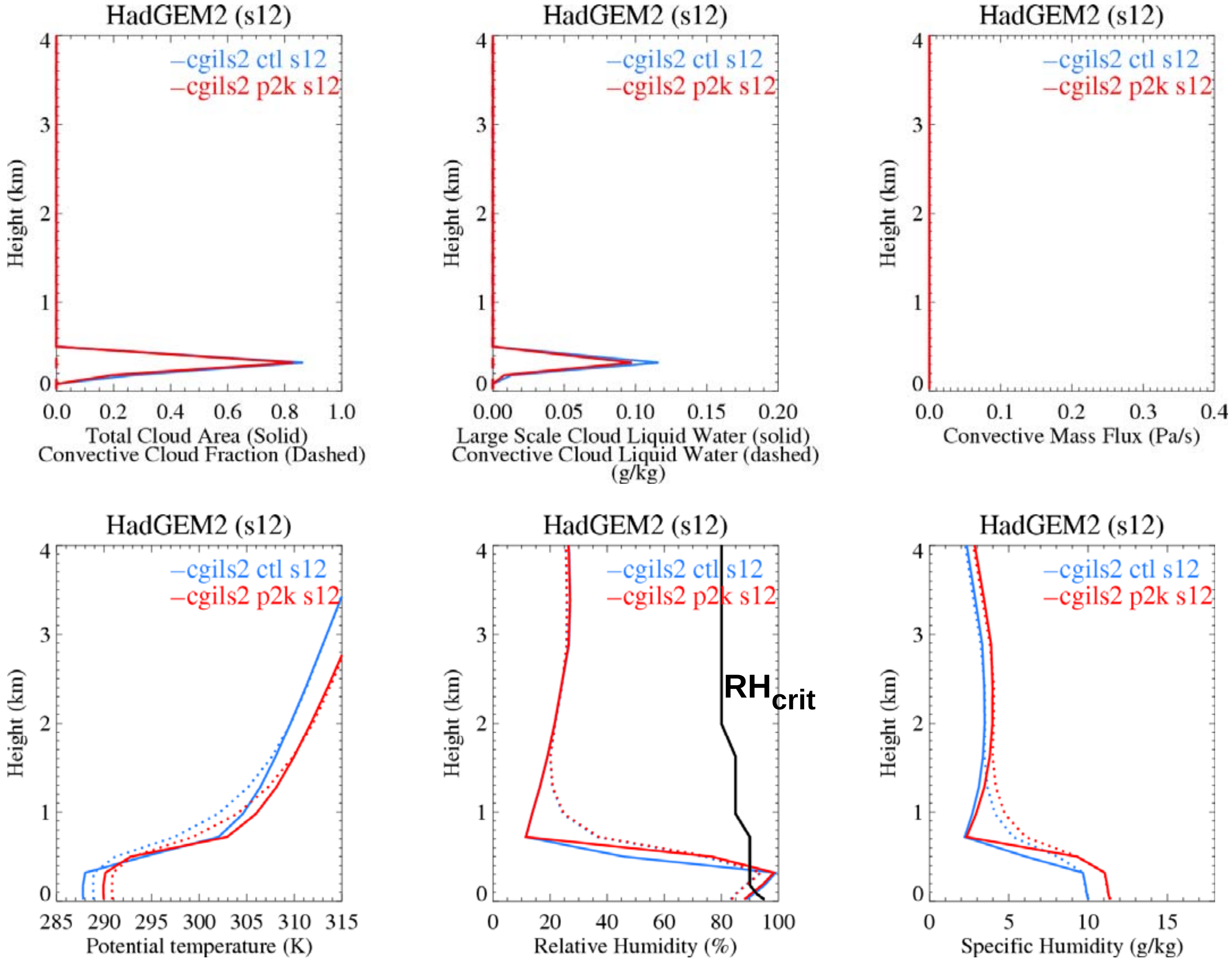
Met Office

- Direct comparisons between CGILS and GCM
  - what is MetO GCM w variability at these points?
  - how does *κ* vary in transient CGILS and in GCM?
  - explore other potential feedback mechanisms (eg changes in downwelling LW)
- Test SCM of CGILS using HadGEM3 physics
  - latest Met Office operational NWP global model (for short range to seasonal prediction and development climate version)
  - at higher vertical resolution
  - better present day climatology in stratocumulus regions

Questions?

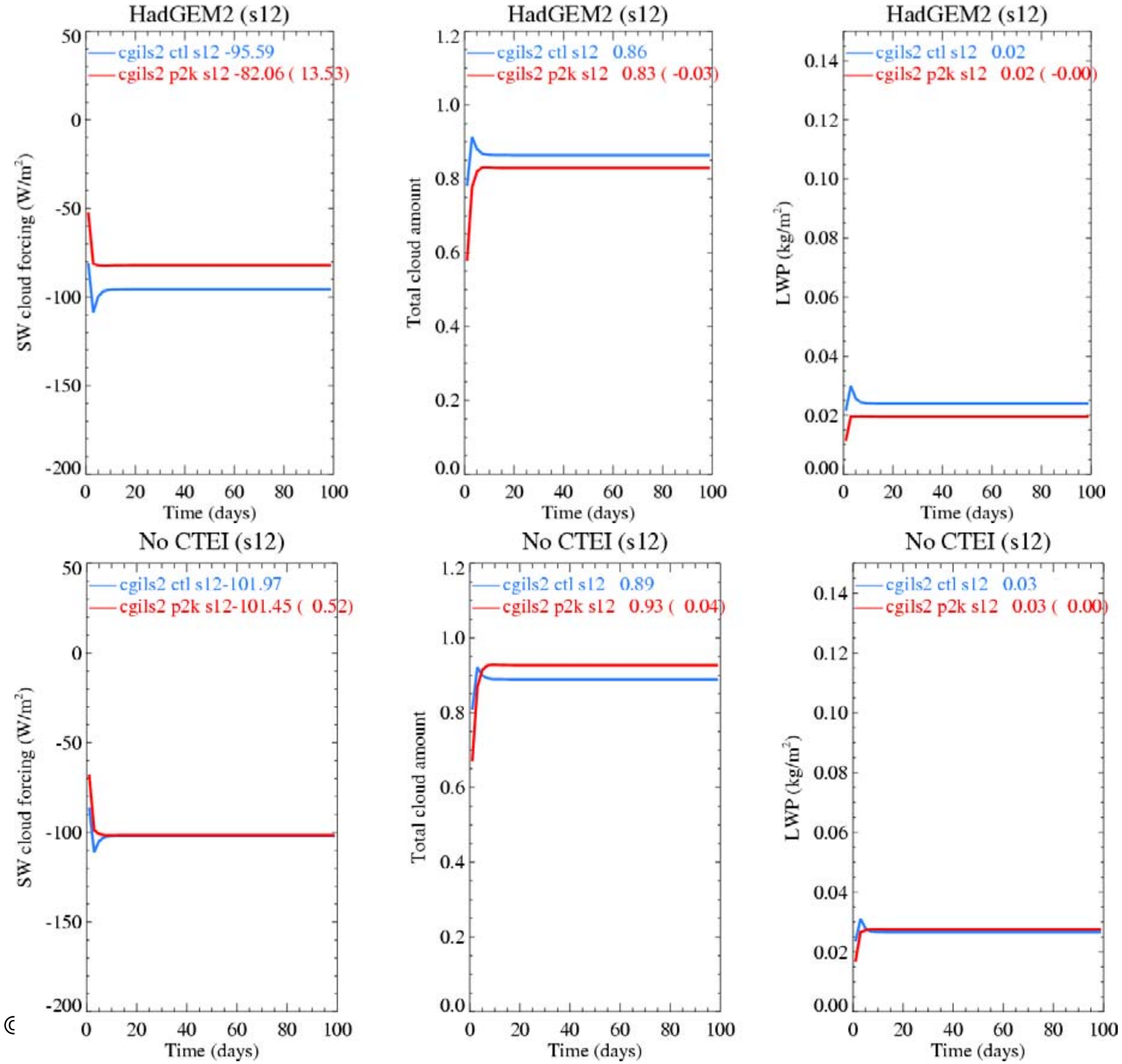
•Where were we in September?

s12 stratocu (s11 Sc/Cu) showed positive SW cloud forcing response of +15 Wm^{-2} (+10Wm^{-2}), similar to GCM!



•Where were we in September?

disabling evaporatively-driven mixing in the SCM removes the positive feedback



Standard HadGEM2

Coastal Stratocumulus (s12)

No evaporatively driven BL entrainment/mixing

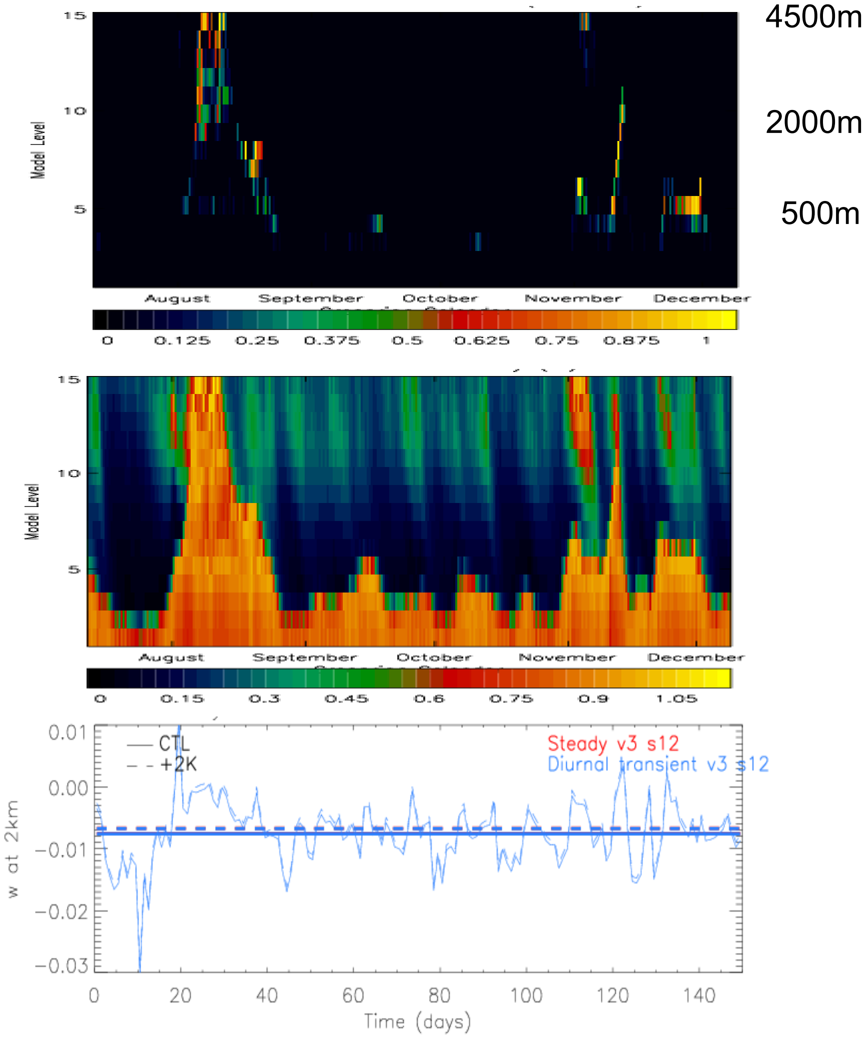
Transient s12 simulation

- BL cloud can't cope with magnitude of variability (even with w std dev halved)

Cloud fraction

RH

w(2km)



w transience: very significant

Control

+2K

Mean (= standard CGILS profile)

+/- 1 std dev

Extremes