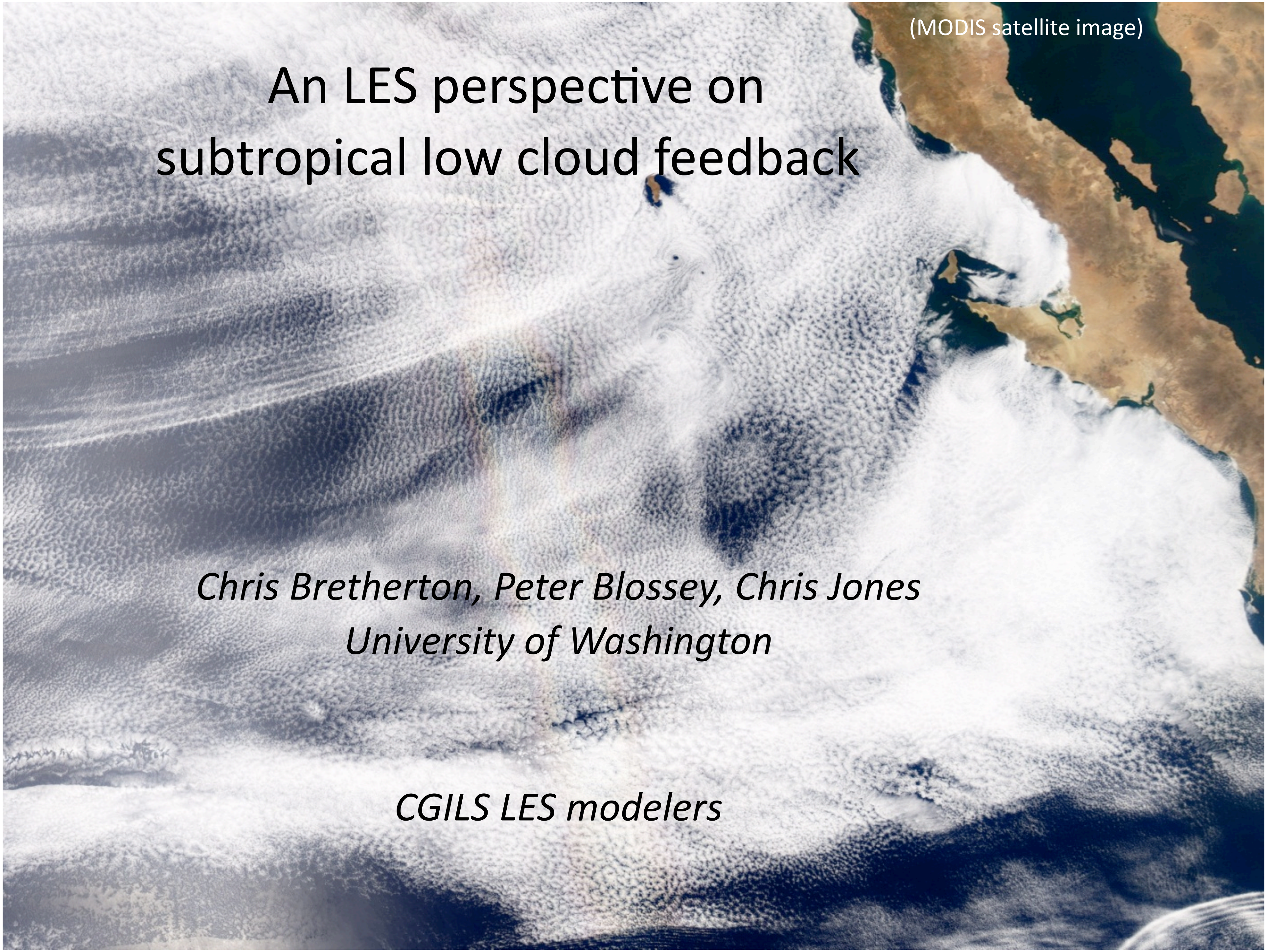

(MODIS satellite image)

An LES perspective on subtropical low cloud feedback

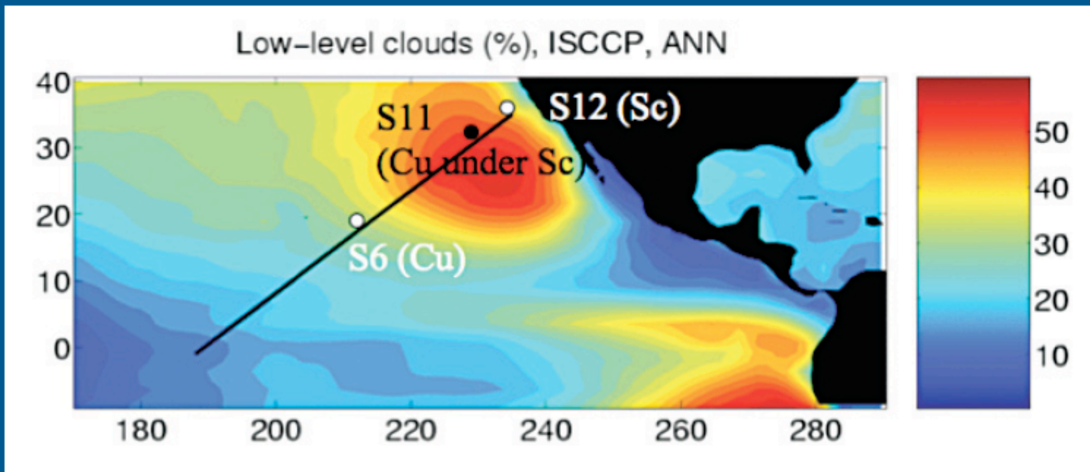
Chris Bretherton, Peter Blossey, Chris Jones
University of Washington

CGILS LES modelers

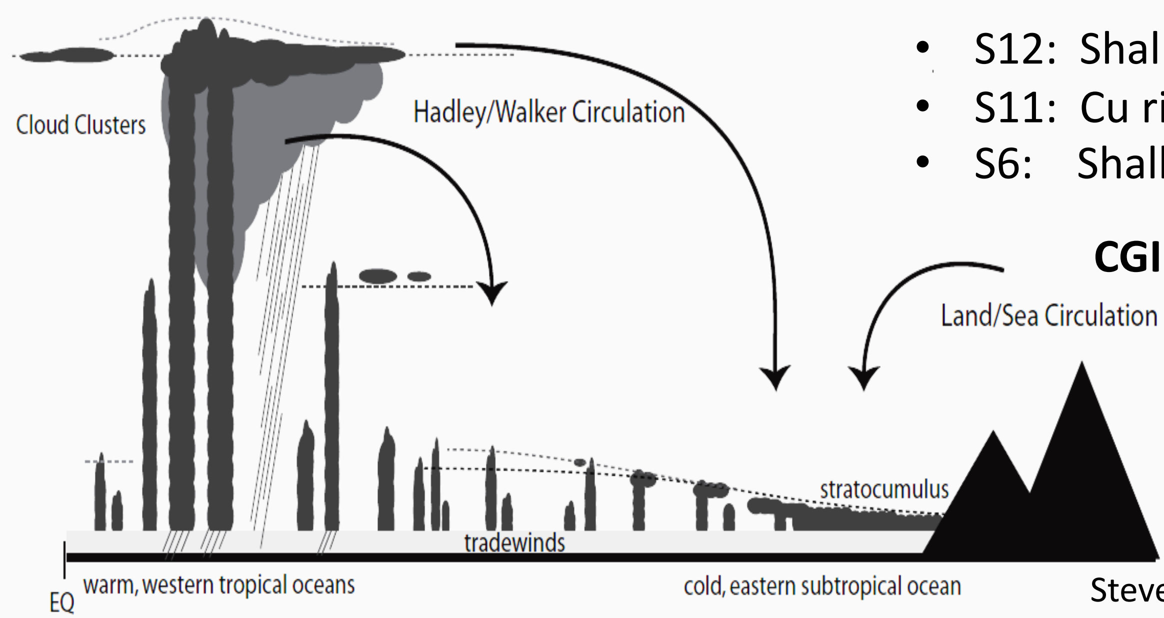
The CGILS Intercomparison

CFMIP/GASS column cloud feedback study: M. Zhang, P. Blossey, C. Bretherton

Zhang et al (2010)



The CGILS intercomparison transect overlaid on the Northeast Pacific annual-mean low cloud amount. Initially, CGILS focused on location S11 (32°N, 129°W) near the northern end of the GCSS Pacific Cross-Section Intercomparison study region. The other two locations are S6 and S12. S11 is near the climatological summertime maximum of low-level cloud cover. S6 is characterized by shallow cumuli, and S12 by shallow coastal stratocumulus.



- S12: Shallow, well-mixed stratocumulus (Sc)
- S11: Cu rising into Sc
- S6: Shallow Cu

CGILS Goal: Compare LES and SCM CTBL simulations of these locations under large-scale forcings representative of present and perturbed climates

Stevens 2006

CGILS LES modeling groups

DALES:	Stephan DeRoode, TU-Delft
LaRC:	Anning Cheng/Kuan-Man Xu, NASA-LaRC
MOLEM:	Adrian Lock, UKMO
SAM:	Peter Blossey, U. Washington
UCLA:	Thijs Heus, MPI-Hamburg
WRF:	Satoshi Endo/Yangang Liu, Brookhaven Natl. Lab

CGILS setup and extra S12 sensitivity studies

Basic setup at each location

- Diurnally averaged summertime insolation
- Control: Large-scale forcings: ECMWF JJA mean:
  - SST
  - T, RH well above CTBL
  - CTBL horizontal T,q advection
  - Subsidence
  - Wind profile
- N_d = 100 cm^{-3}
- Models run 10 d to steady-state
- LES models harmonized surface flux, radiation schemes
- Show LES results
- S12: Add UW mixed-layer model

CGILS sensitivity studies

- **+2K SST increase (p2K)**
  - Reduced subsidence
  - Moist-adiabatic increase in warming aloft (ΔEIS ≈ 0)
  - Free-trop RH unchanged

S12 only:

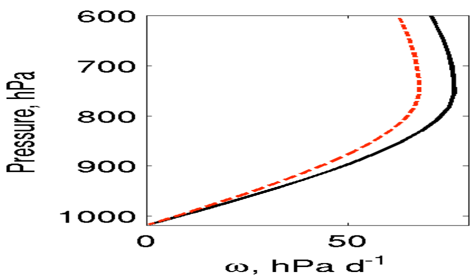
- **4xCO_2 fixed SST**
- **P2K OM0** (unchanged subsidence)
- **P2K FT** (p2K free-trop, fixed SST)
- **dRH** (5% free-trop RH reduction)

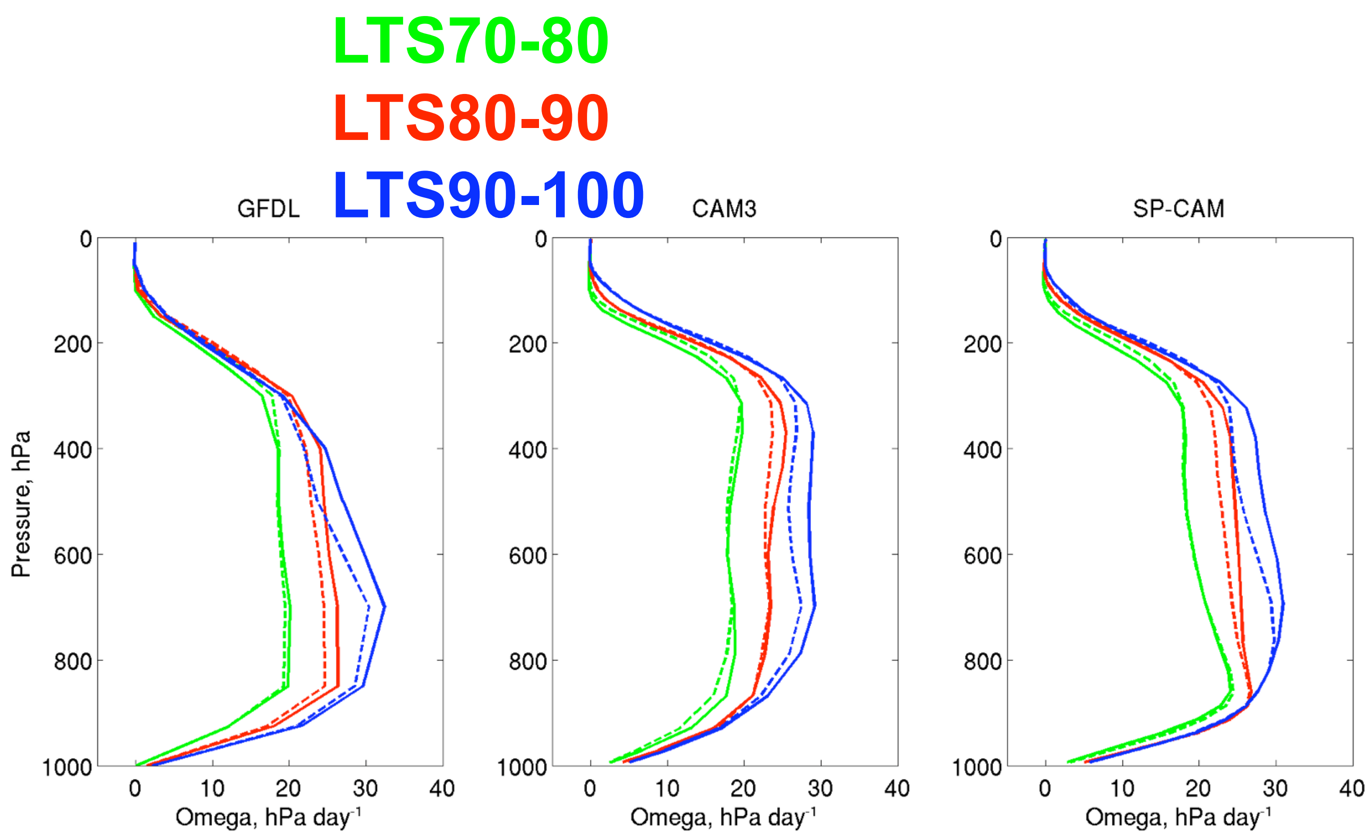
…separate cloud-changing factors

Uncertainty in Omega Changes

- Decrease in subsidence in mid-troposphere is prominent in GCMs (Vecchi & Soden, 2007).
- Not all models show same vertical structure of changes (e.g. Zhu et al, 2007).

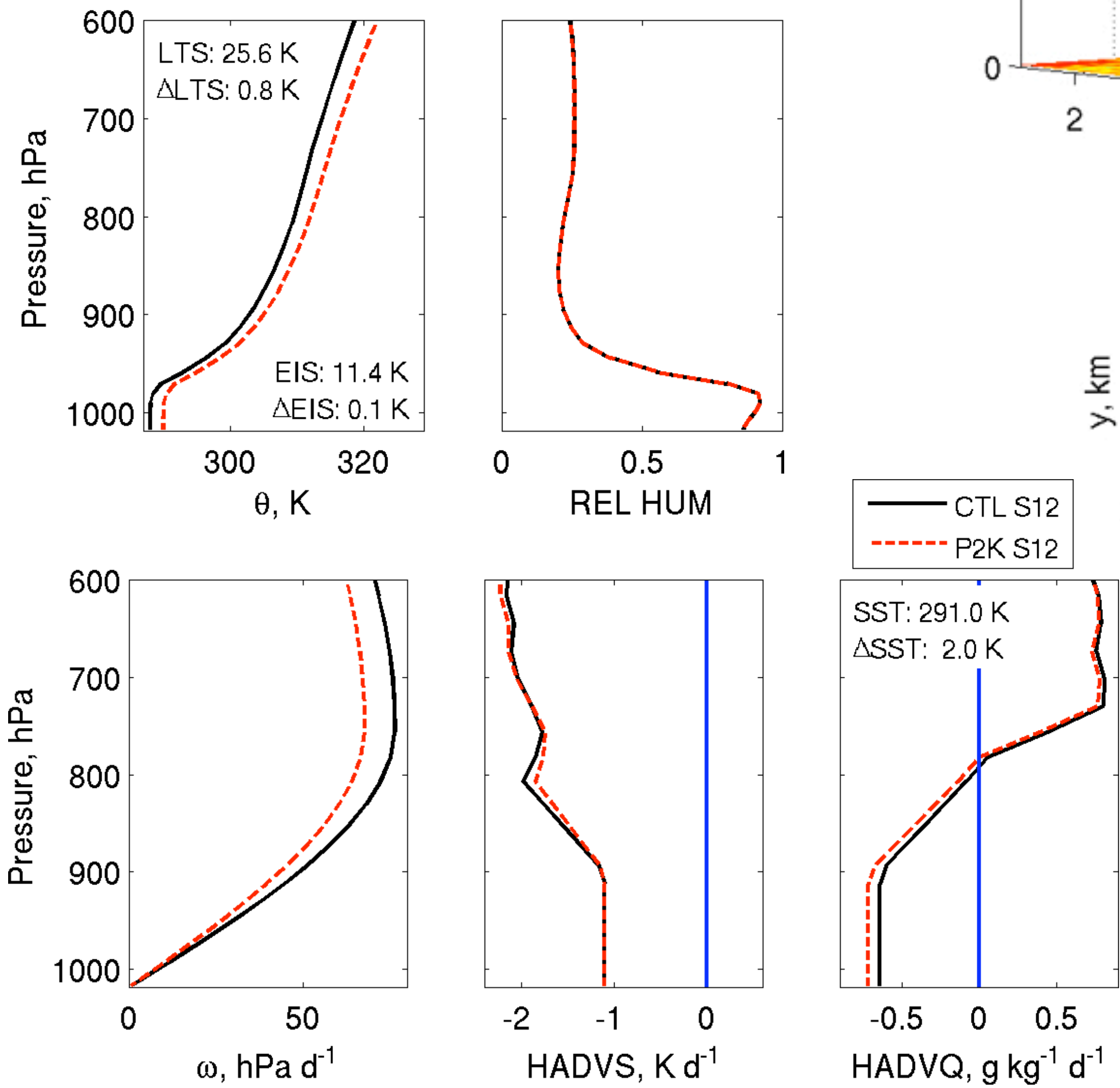
CGILS: S12

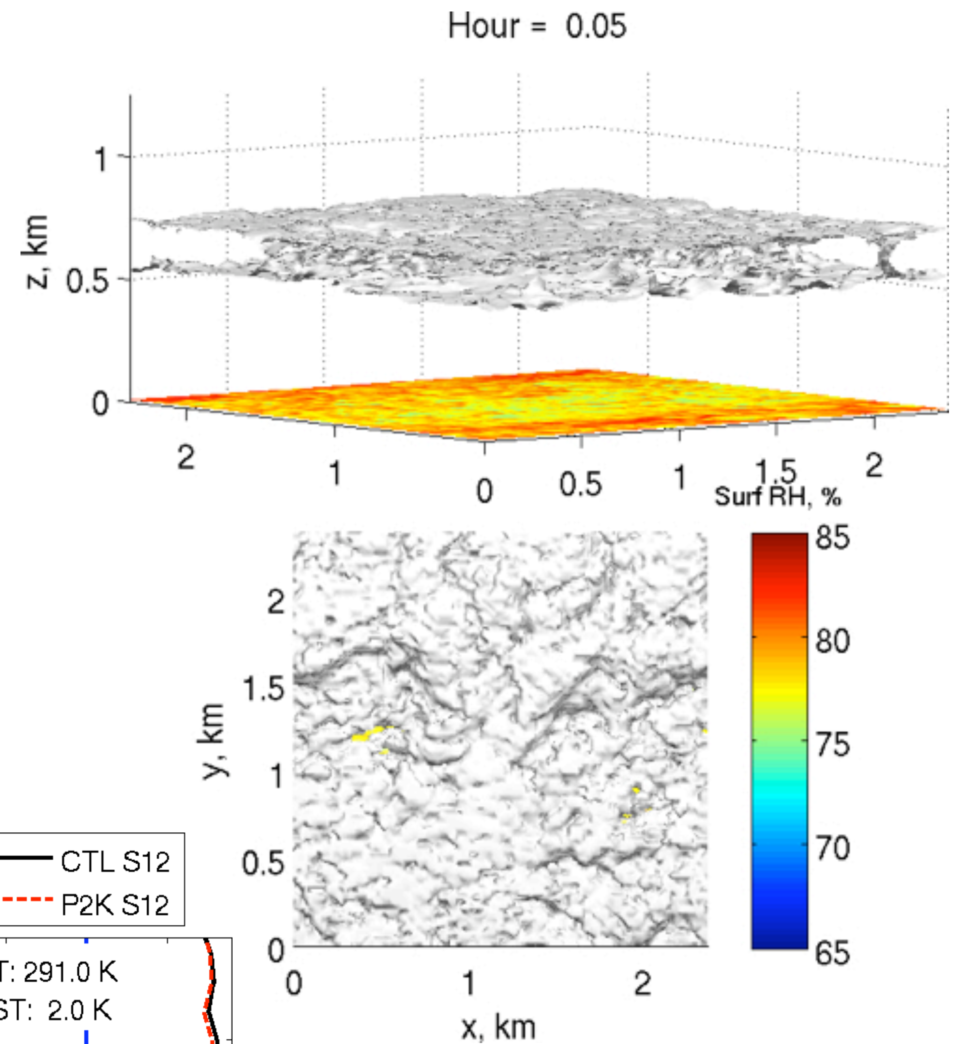




GCM Results Courtesy of Matt Wyant

CGILS S12: Coastal Sc





Δx = Δy = 25m

Δz = 5-15m

96 x 96 x 320

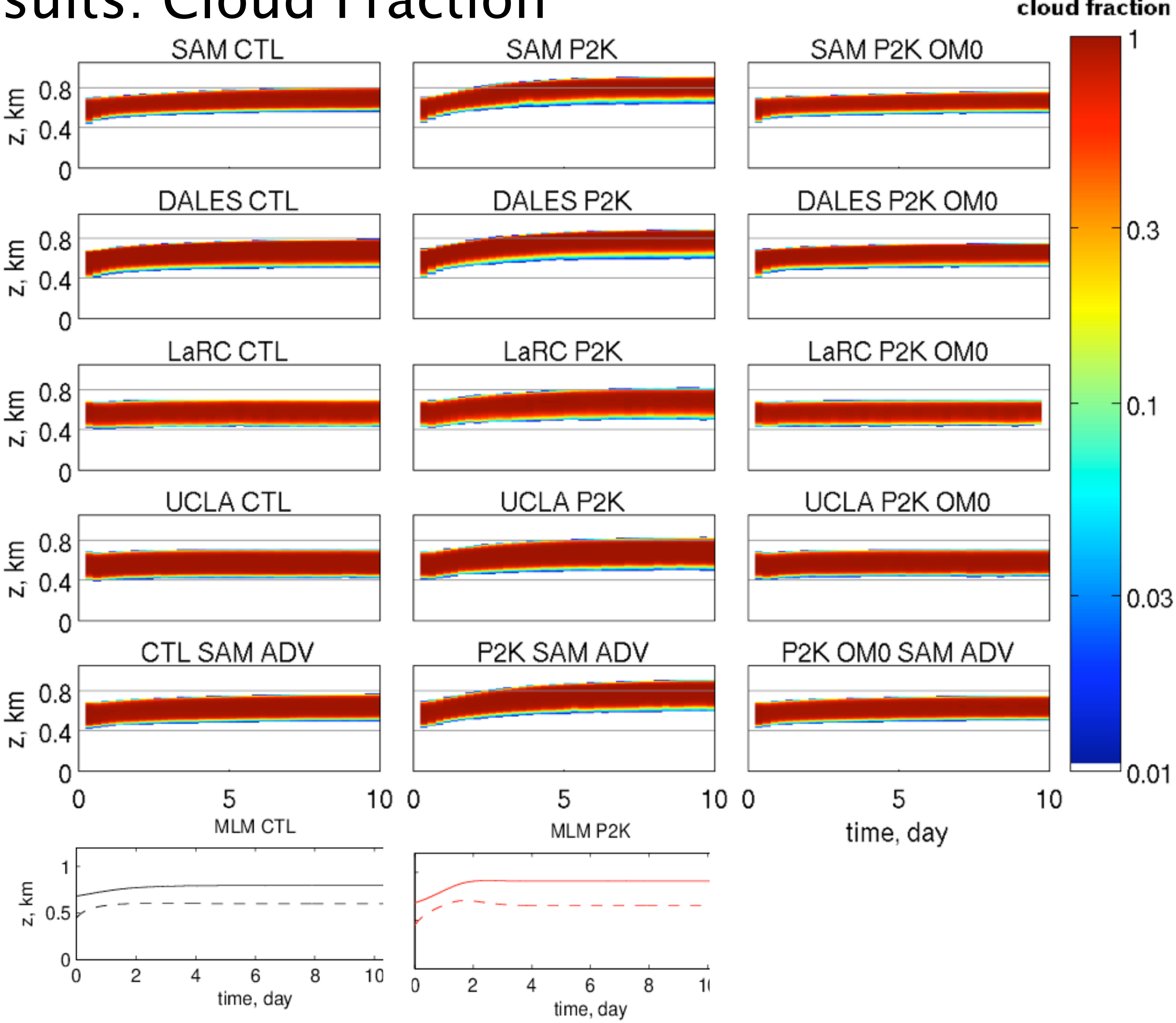
Nudged above 1200 m

S12 Results: Cloud Fraction

LES Results

from CGILS intercomparison

MLM Results

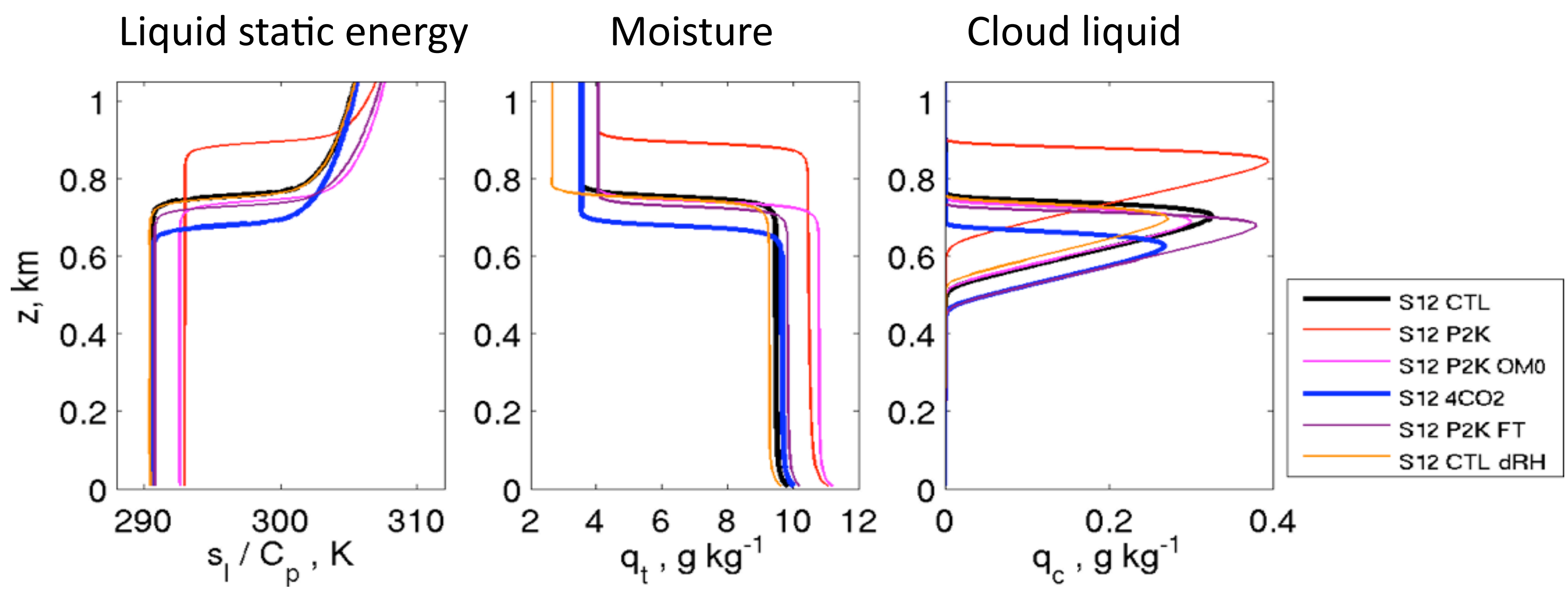


Summary of S12 cloud response

	CTL		P2K OM0		P2K	
LES	LWP g m^{-2}	SWCRE W m^{-2}	ΔLWP g m^{-2}	ΔSWCRE W m^{-2}	ΔLWP g m^{-2}	ΔSWCRE W m^{-2}
DALES	51	−155	−17	+28	−6	+10
LaRC	48	−144	−7	+13	+13	−12
UCLA	57	−175	−7	+11	+16	−10
SAM	35	−133	−9	+20	+2	−2
SAMADV	49	−152	−7	+12	+14	−13

- LES all thin the cloud layer (positive feedback) in OM0
- p2K response mixed (marginal decoupling in SAM, DALES)

S12 SAM ADV sensitivity tests: Profiles



- Simulations appear well-mixed
- Cloud response mechanisms:

  Radiative (more emissive free trop ➔less LWP)

  (4CO2 and p2K OM0 vs. CTL)

  Dynamic (less mean subsidence ➔ more LWP)

  (p2K vs. p2K OM0)

  Thermodynamic

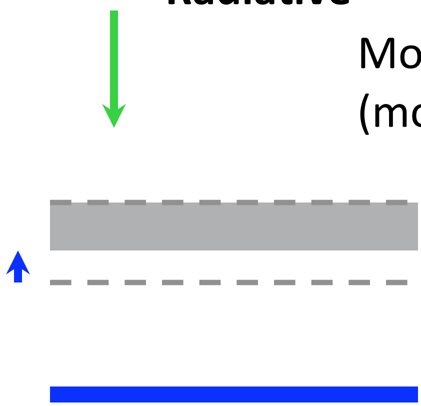
  (stronger inversion ➔ more LWP: p2K FT vs. p2K)

  (drier FT ➔ less LWP: dRH vs. CTL)

‘Initial tendency’ interpretation of cloud responses (i.e. before turbulence adjusts)

Radiative

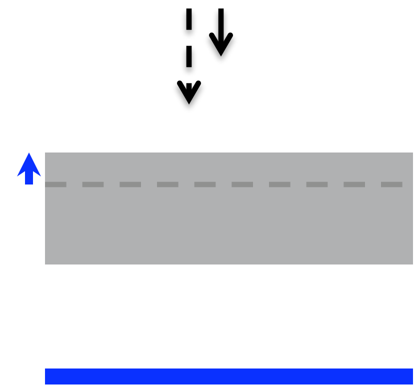
More emissive FT (more CO_2 or H_20)



less rad cooling
BL warms up
cloud thins

Dynamic

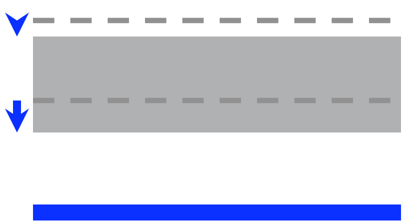
Less subsidence



Sc thickens because top rises.

Inversion stability

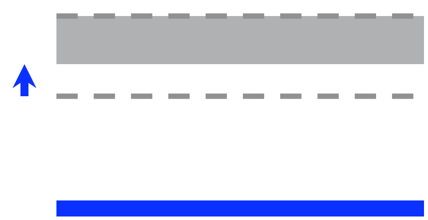
FT warms more than SST



Stronger inversion reduces entrainment
Less drying
➔thicker Sc

Free trop RH

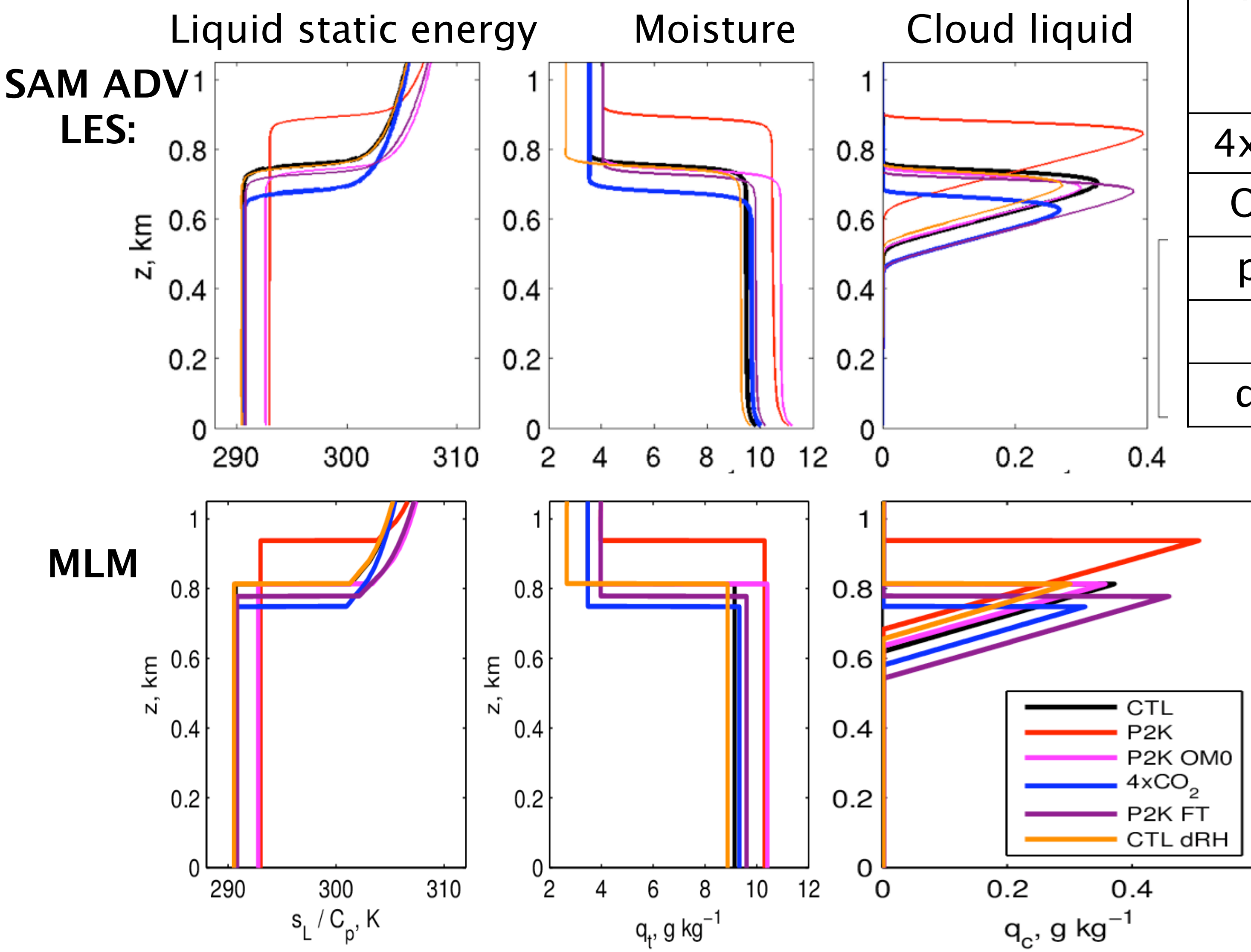
Drier RH



More entrainment drying thins Sc

These mechanisms also apply to decoupled S11 Cu under Sc case

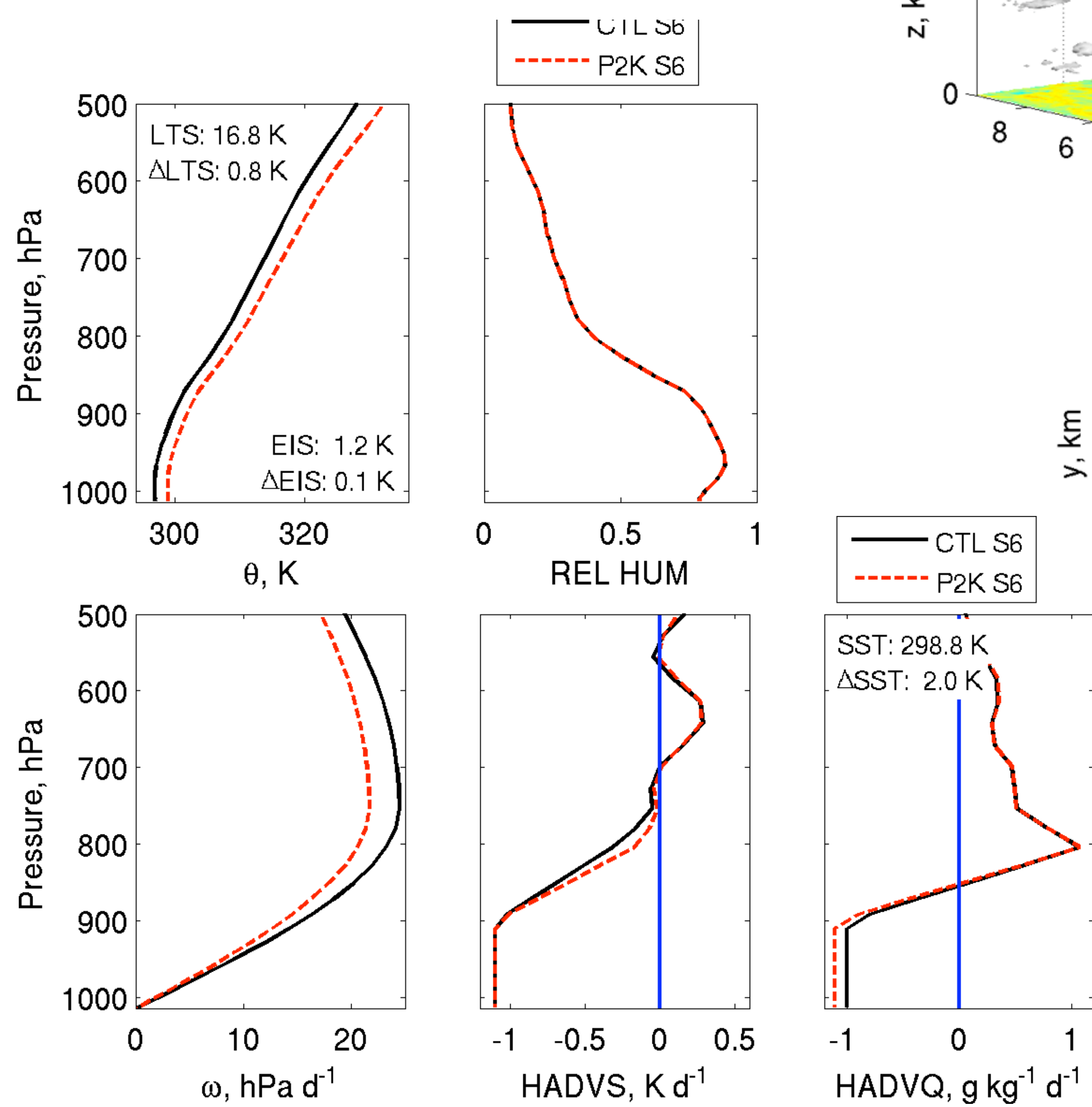
Comparison with MLM

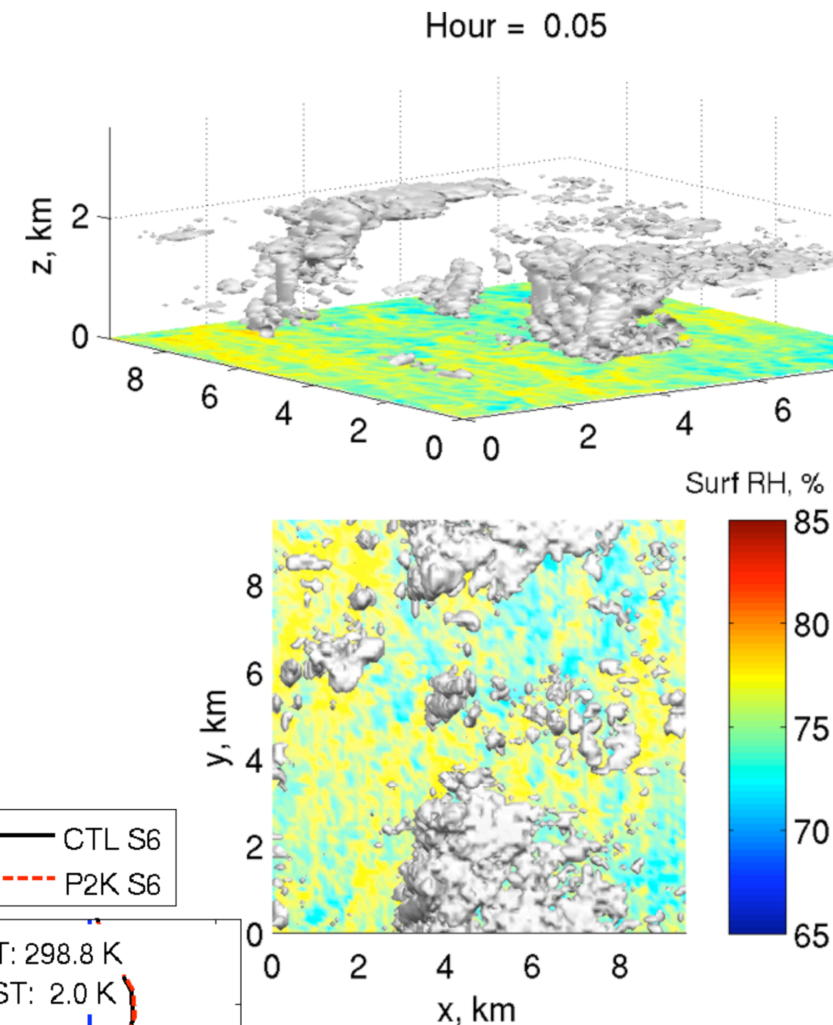


7.5-10 day avg	ΔSWCRE W m^{-2}	
	MLM	SAM ADV
4xCO_2	+16	+19
OM0	+10	+12
p2K	-30	-13
FT	-21	-12
dRH	+21	+15

MLM has similar sensitivities as SAM ➔ Entrainment is key.

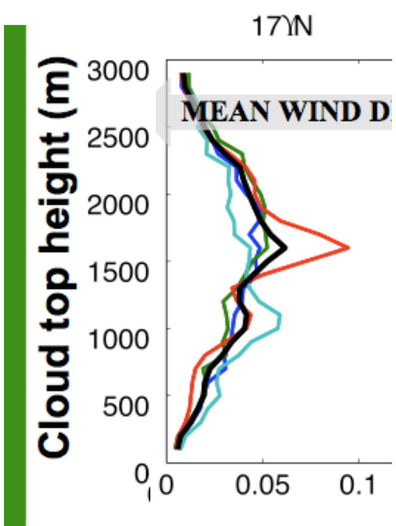
S6: Trade cumulus regime



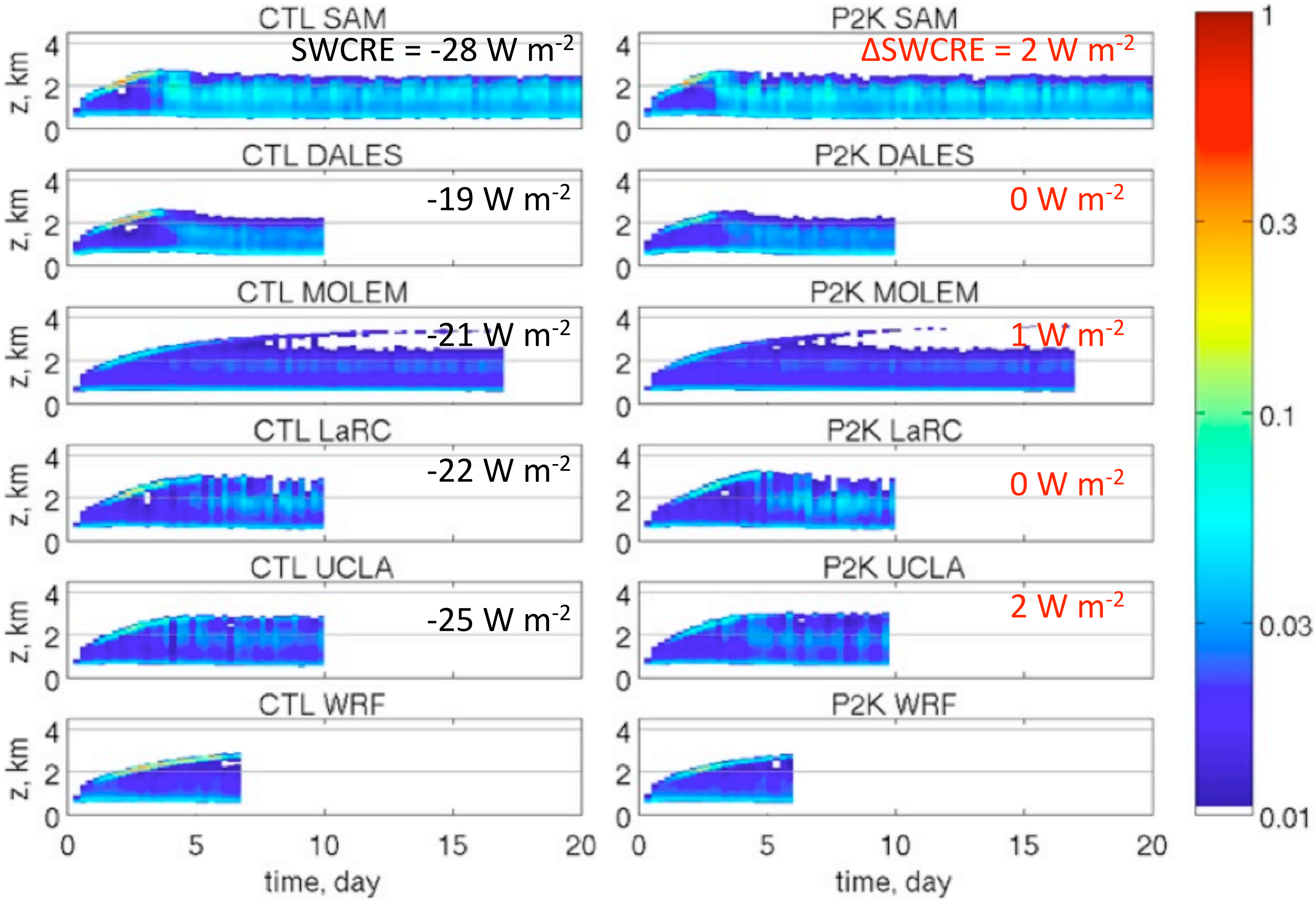


Δx=100m
Δz=40m

S6: Cloud Fraction

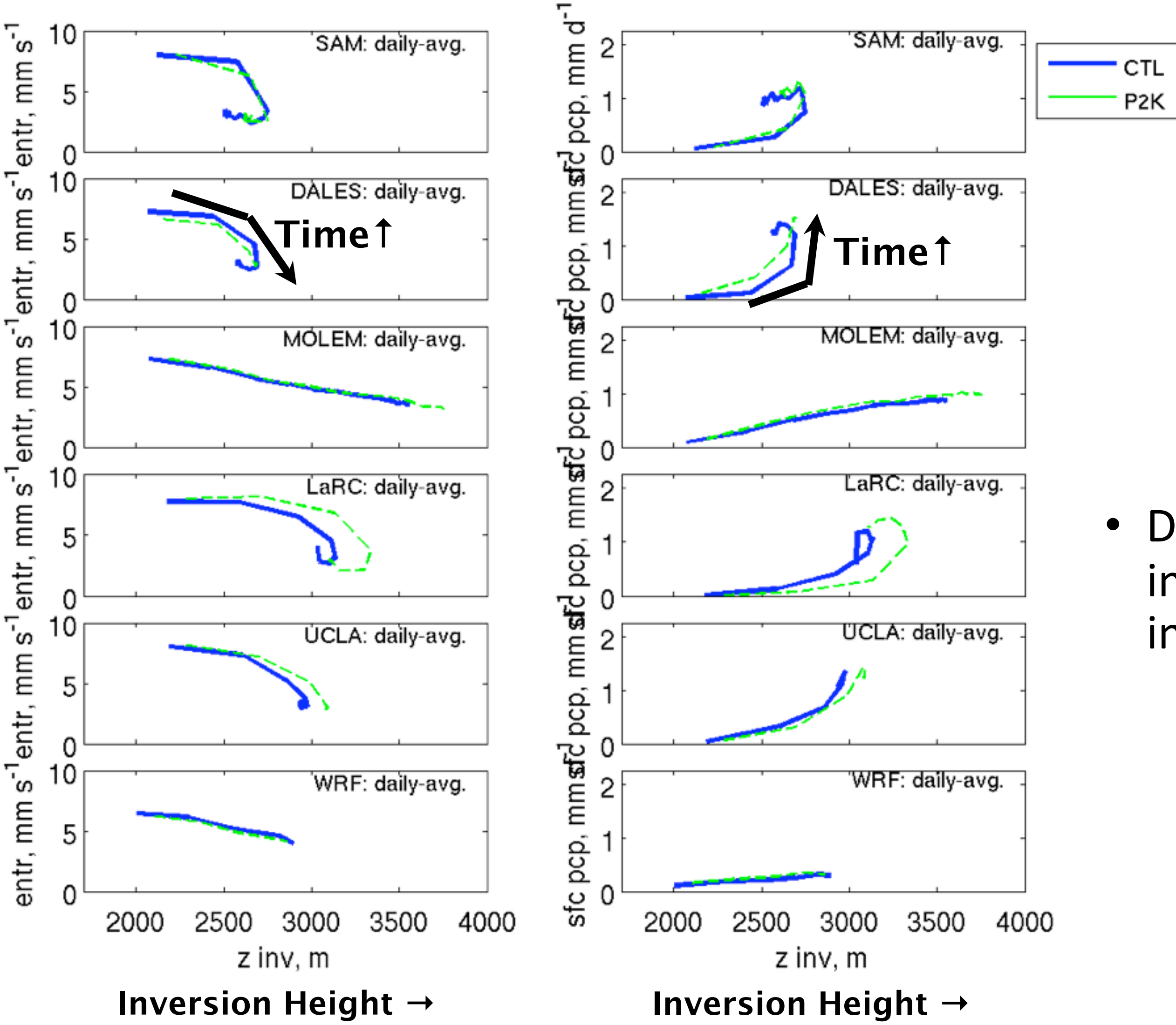


MISR Cloud Top Height PDF Courtesy of J. Karlsson.



- Fair agreement between LES models in BL structure, depth.
- Initial Sc-over-Cu layer deepens and transitions to a Cu-only layer.
- +2K changes are weak; cloud layer depth is regulated by precipitation

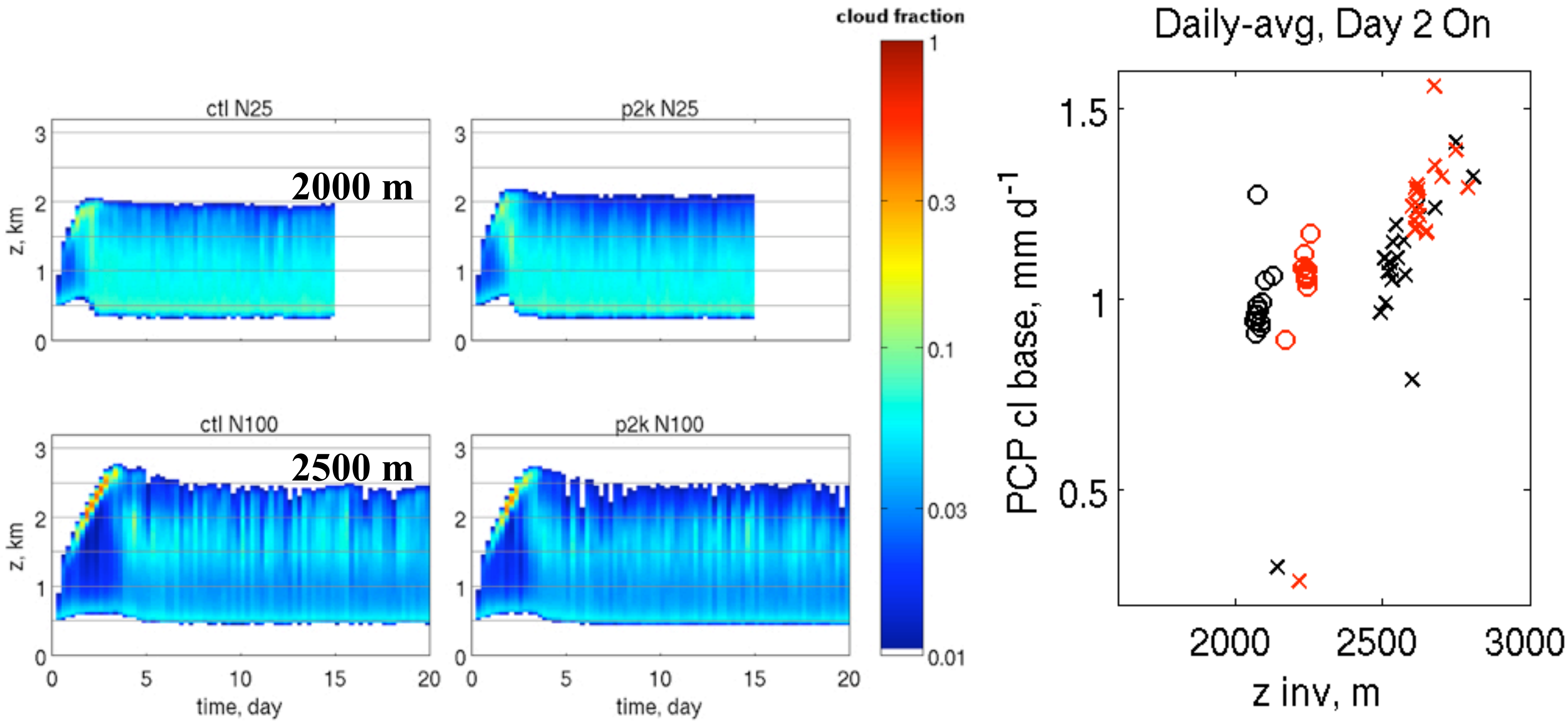
S6: Precipitation-Entrainment Feedback



- Deepening of trade inversion arrested by increase in precipitation.

- Precipitation stabilizes boundary layer and removes liquid water from entrainment zone -- prevents incorporation of warm, dry free tropospheric air by evaporation of cloud.

S6: SAM Droplet Conc. Sensitivity Study



- New pair of runs w/N_d=25/cm3. Default is N_d=100/cm^3.
- Smaller N_d → Onset of precip at smaller zinv, restrains deepening.
- ΔSWCF = 2 W/m^2 (N_d=100) vs. 0 W/m2 (N_d=25)
- Take-Home Message: N_d can affect shallow Cu BL structure and feedbacks.

Conclusions

- Four competing effects of climate perturbations on Sc clouds:

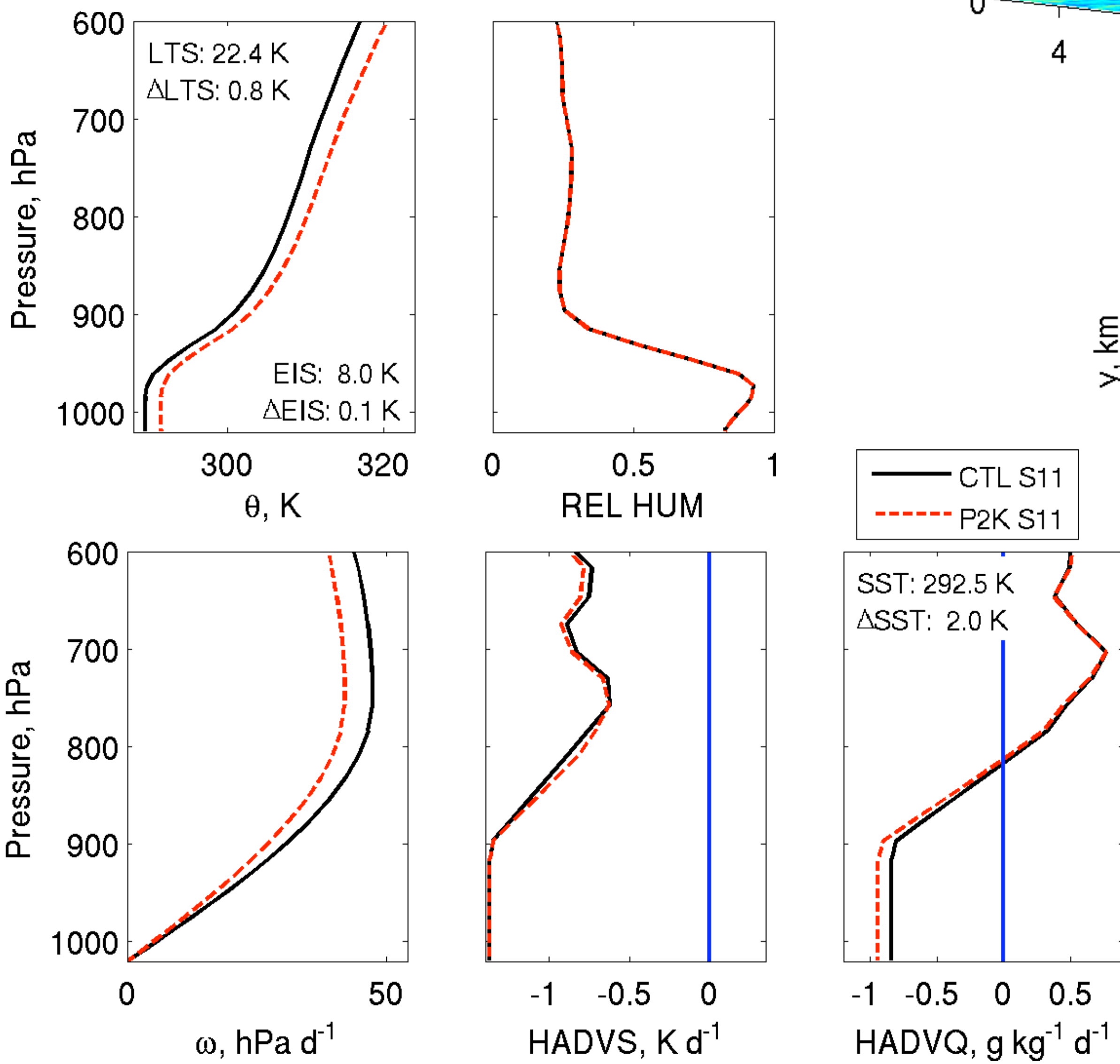
  More emissive free troposphere (CO_2, H_20) thins Sc

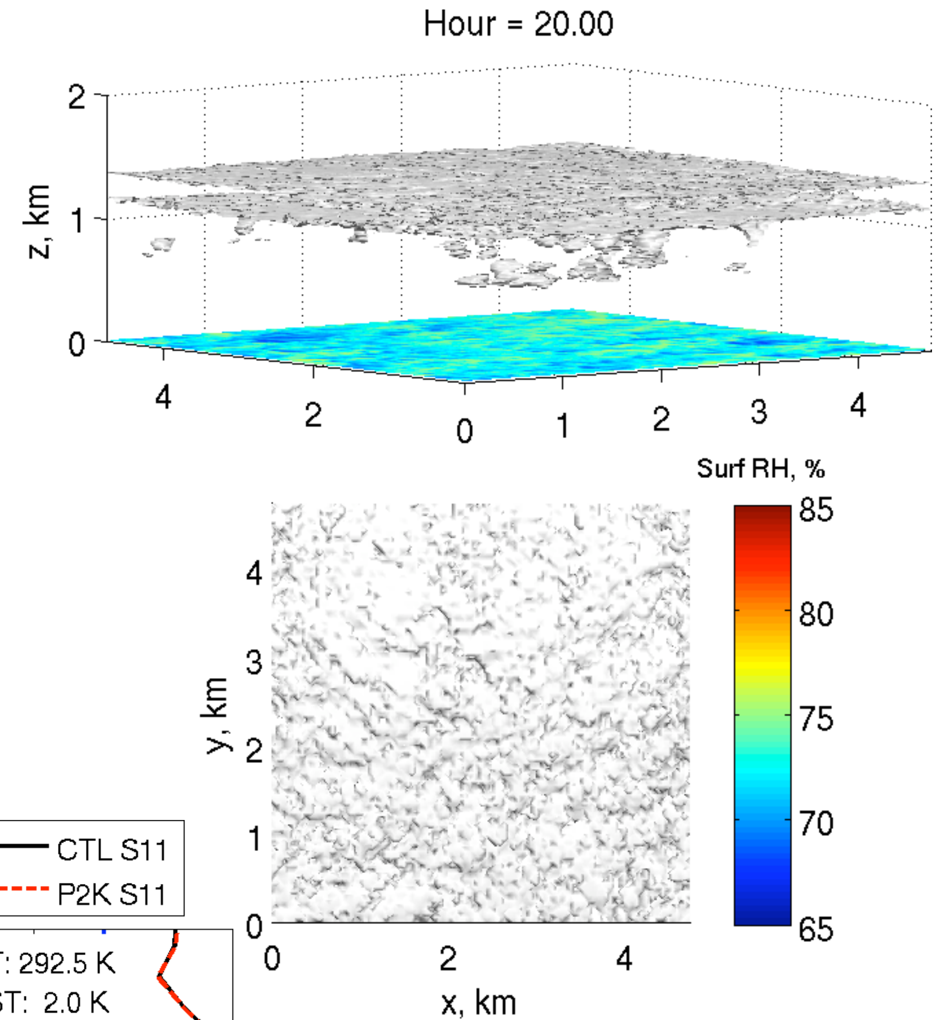
  Less subsidence thickens Sc

  Stronger inversion thickens Sc

  Drier-RH free troposphere thins Sc
- For shallow Cu, precipitation also affects cloud depth/response.
- For p2K cases, LES don't agree on sign of ΔSWCRE.
- However, in Sc cases, other effects (increased CO_2, decreased RH, less subsidence change) suggest ΔSWCRE > 0 (+ cld feedback)

CGILS S11: Cu under SCu

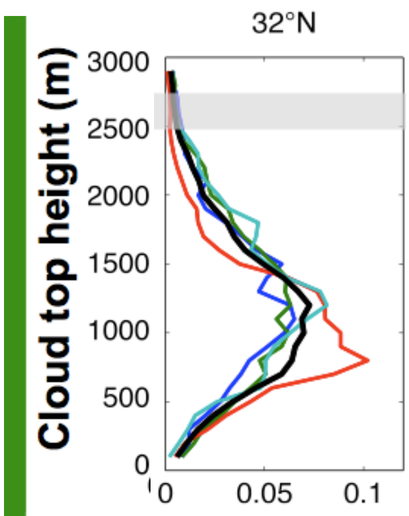




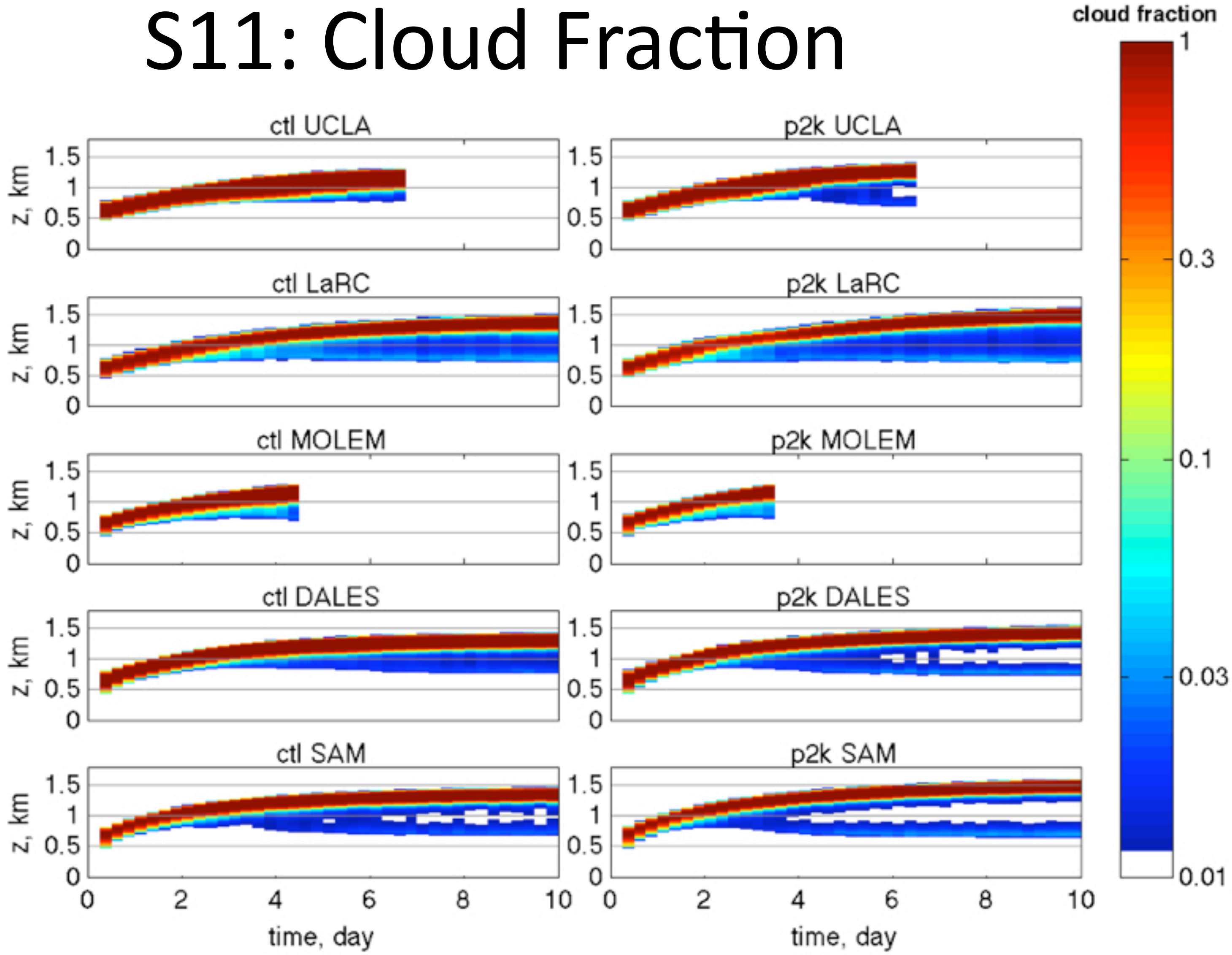
Δx=50m

Δz=5-25m

S11: Cloud Fraction

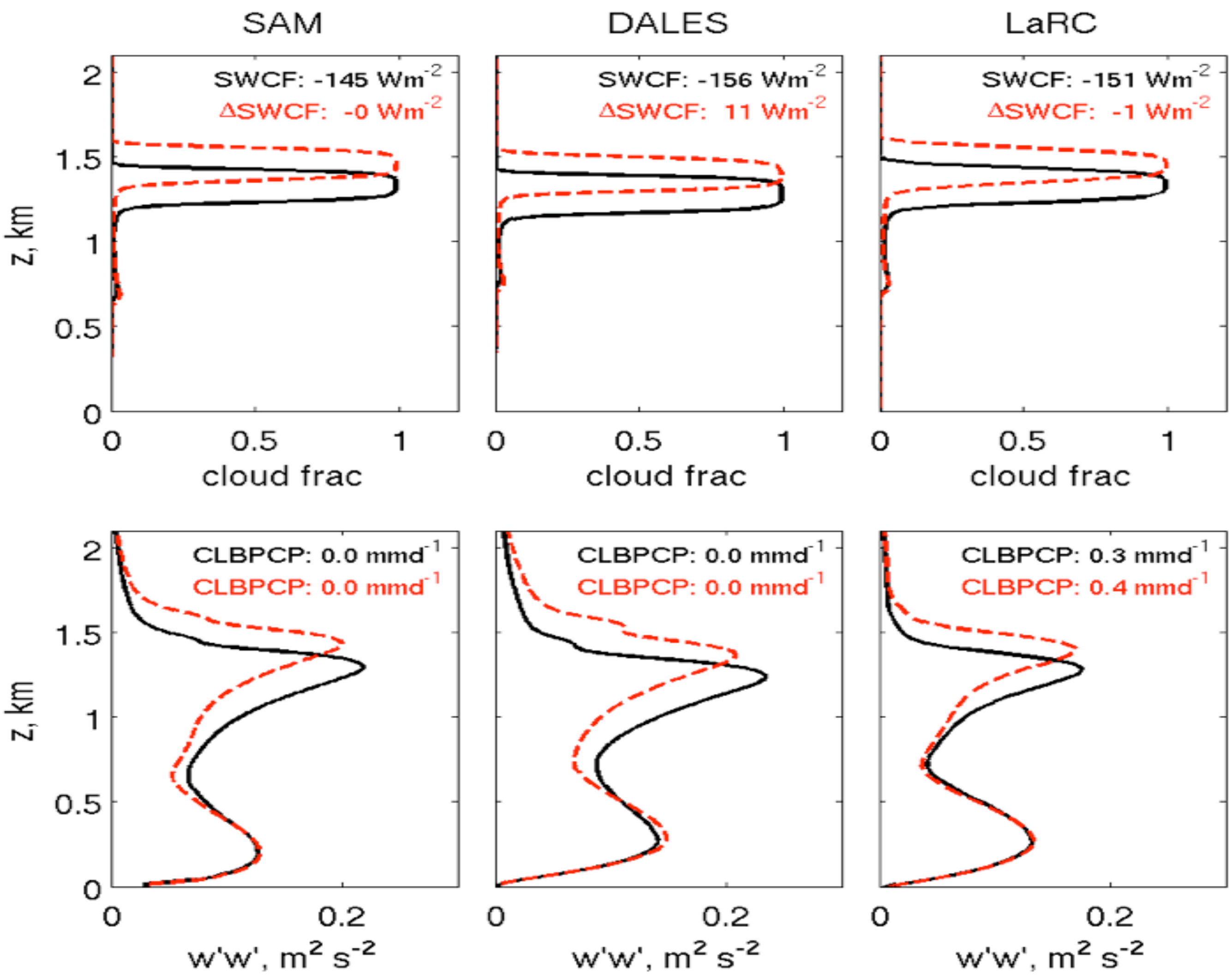


MISR Cloud Top Height PDF Courtesy of J. Karlsson.



- Models broadly consistent when Δz=5m. (LaRC uses Δz=25m.)
- Initial stratocumulus layer decouples after deepening.
- +2K runs more decoupled with higher inversion; some LES slightly thin cloud.
- Radiative balance and reduced subsidence important to cloud changes as in S12

S11: CTL→+2K Cloud/Turbulence Changes (Days 7.5-10)

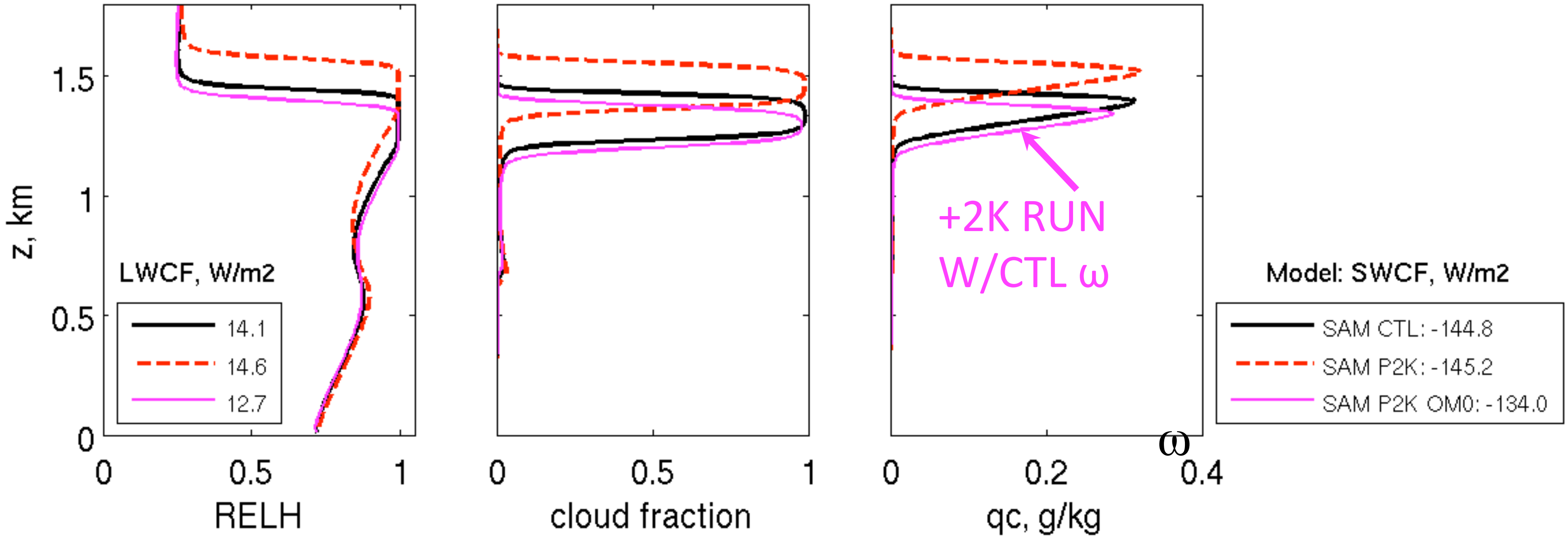


CLOUD FRACTION

w' w'

- Note consistent changes in inversion depth and turbulence profile.
- Strong positive ΔSWCF in DALES, near zero in SAM, LaRC

S11: Omega Sensitivity Study in SAM



- P2K OM0 run uses same omega as CTL.
  - has thinner cloud, lower inversion than CTL.
  - Clearsky BL radiative cooling↑ (suggested as feedback mechanism by Wyant et al, 2009), but full sky BL radiative cooling↓ in this case.
- Cloud thickens as zinv increases in P2K run, leads to small ΔSWCF as in S12
- SAM +2K response: SWCF↓ at same zinv, SWCF↑ as BL deepens.