The CGILS LES Intercomparison (The CFMIP/GCSS Intercomparison of Large Eddy and Single Column Models)

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and CGILS LES Models and Modelers:

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- UCLA: Thijs Heus (MPIM), Irina Sandu (ECMWF),
- LaRC: Anning Cheng, Kuan-Man Xu (NASA LaRC, USA),
- SAM: Peter Blossey (UW), Marat Khairoutdinov (Stony Brook).

Outline

- Why look at low cloud feedback?
- Introduction to CGILS
- CGILS S12 Case Study: Coastal Stratocumulus
- CGILS S11 Case Study: Decoupled Stratocumulus
- CGILS S6 Case Study: Trade Cumulus
- Sensitivity Studies in SAM
- Discussion/Conclusions

Photo courtesy Rob Wood

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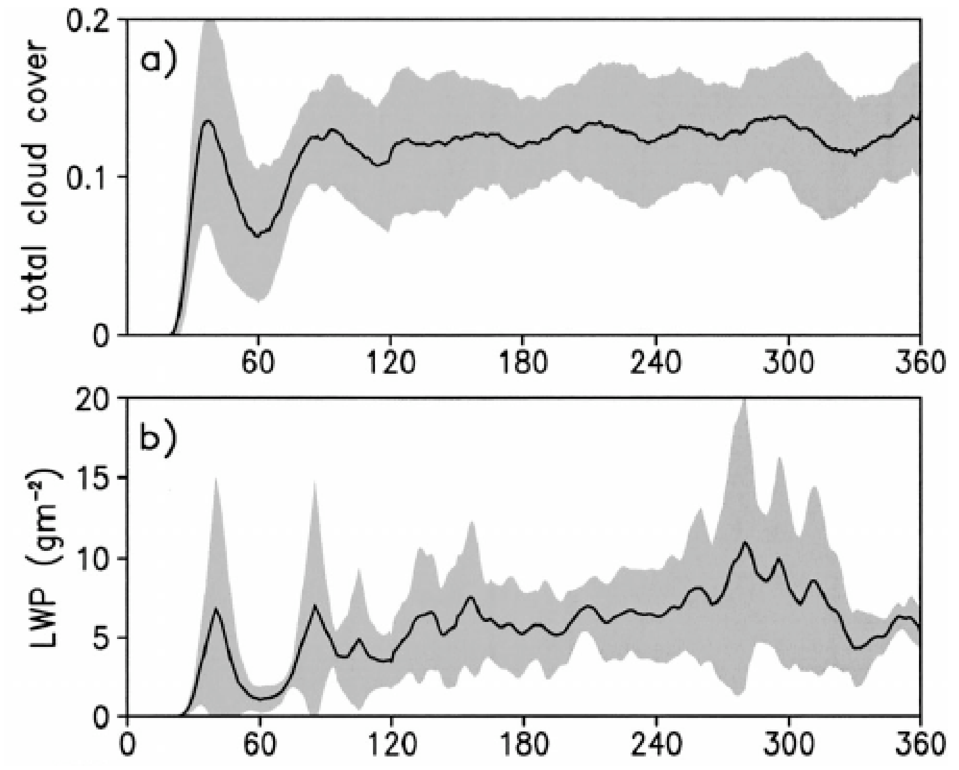
Photo courtesy Rob Wood

Motivation

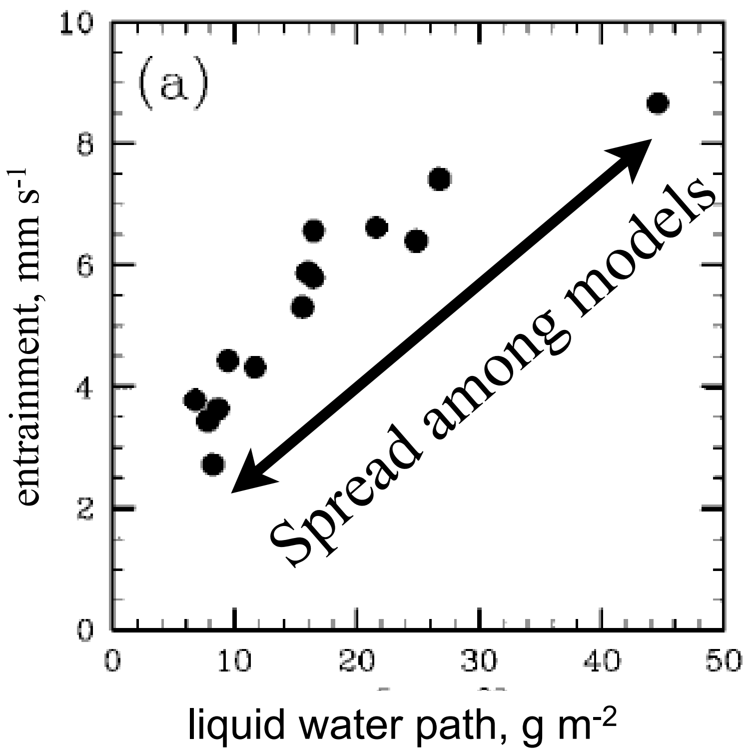
- Cloud feedbacks are among the most poorly constrained components of climate sensitivity.
- Much of scatter in net cloud feedback comes from marine boundary layer clouds (e.g., Bony & Dufresne, 2006).
- LES provides the most realistic simulation tool for boundary layer clouds.
- However, uncertainties are present in LES, especially in Sc entrainment and microphysical processes.

Past Multi-Model Studies of Low Clouds With LES

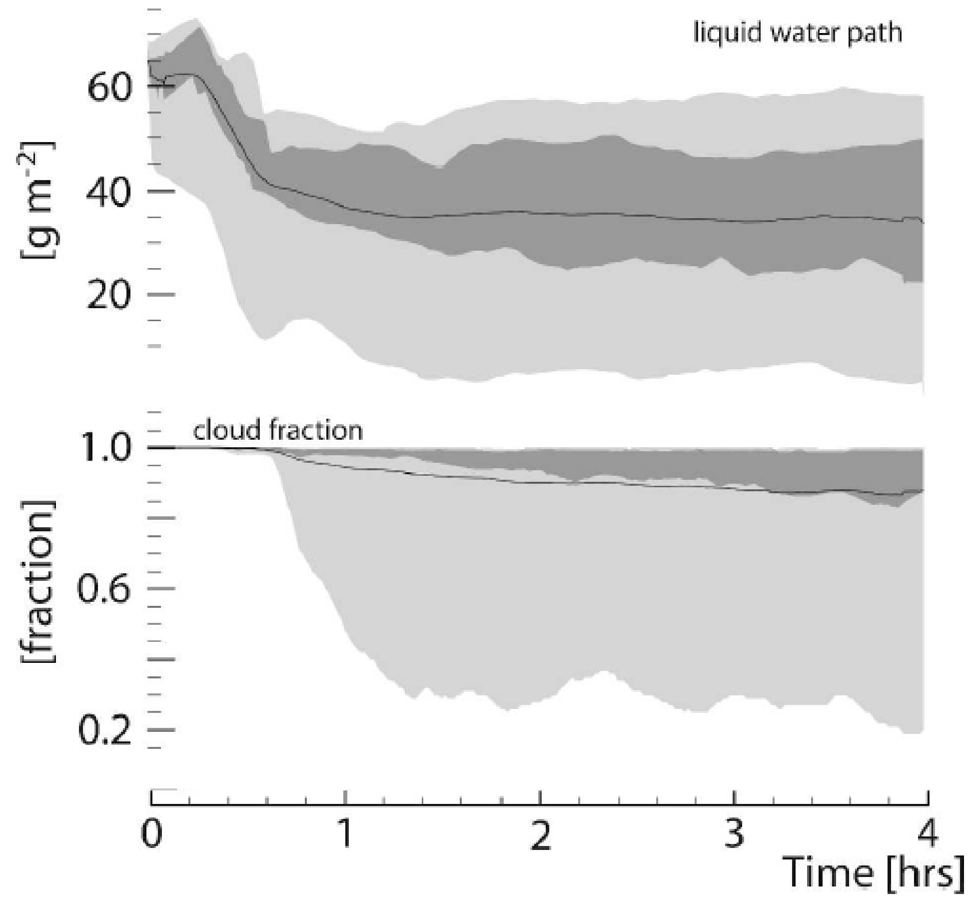
BOMEX: Trade Cu
Siebesma et al (2003)



ATEX: Cu under SCu
Stevens et al (2001)

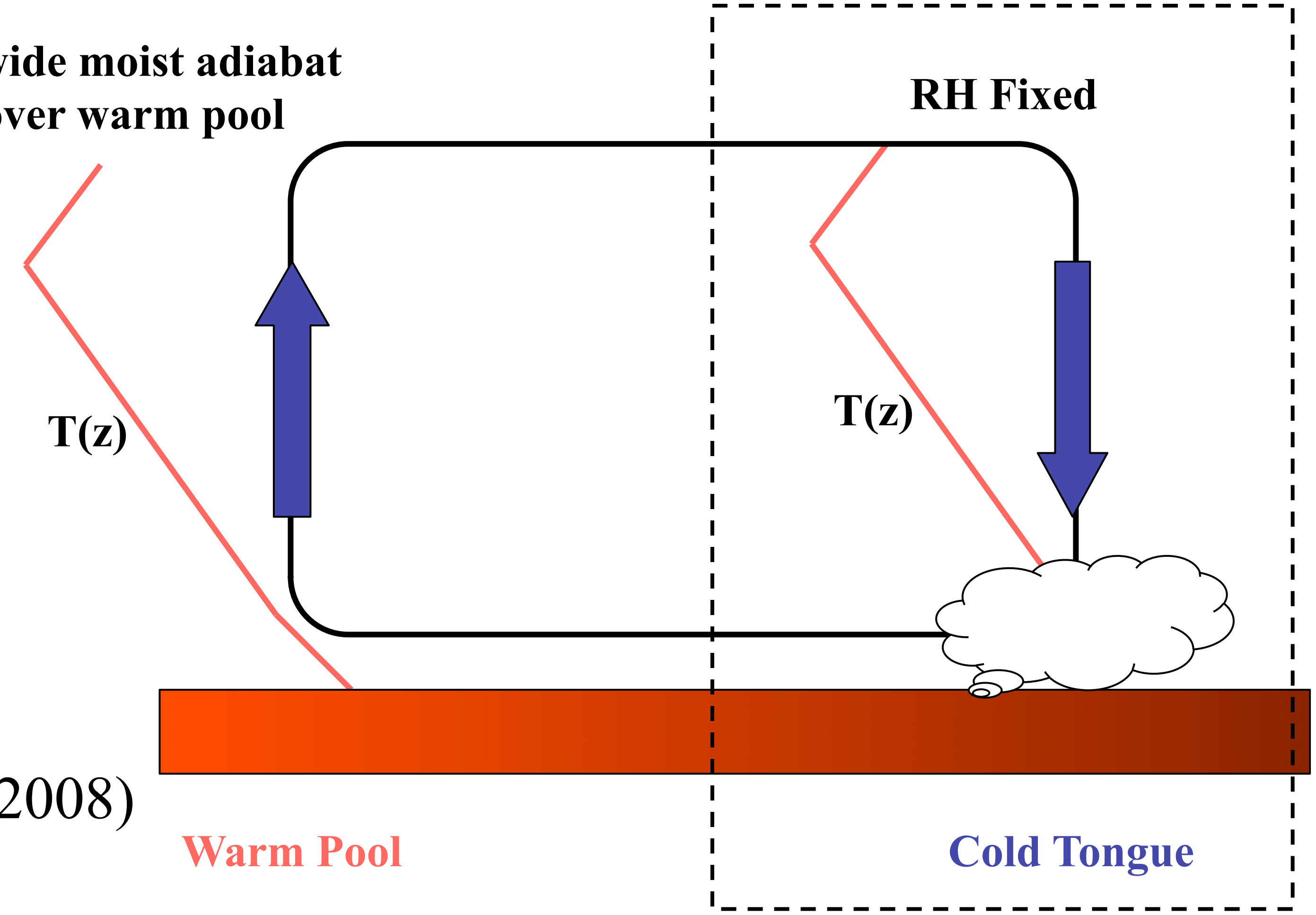


DYCOMS RF01: SCu
Stevens et al (2005)



- LES models show consistent results for shallow cumulus with weak inversion, as in BOMEX. Resolution requirements: $\Delta x = \Delta y \sim 100$m and $\Delta z \sim 40$m.
- Larger spread in cases with cloud capped by a strong inversion (ATEX, DYCOMS, ...). Significant variability among the models persists with $\Delta z = 5$m.

Column Modeling of Climate Sensitivity



(Zhang & Bretherton, 2008)

- Response to idealized SST perturbation in CAM's SCM, connect to response in parent GCM (Zhang & Breth, 2008).
- Response to warm pool/stratus region SST changes in a mixed-layer model (Caldwell & Breth, 2009).
- Response to SST, 4xCO2 changes in LES/CRM (Blossey et al 2009, Xu et al 2010, Wyant et al 2011).
- **Idea:**
  - Look at low cloud feedbacks in models that resolve low cloud processes,
  - Build confidence in results w/many models, compare w/SCMs → CGILS.

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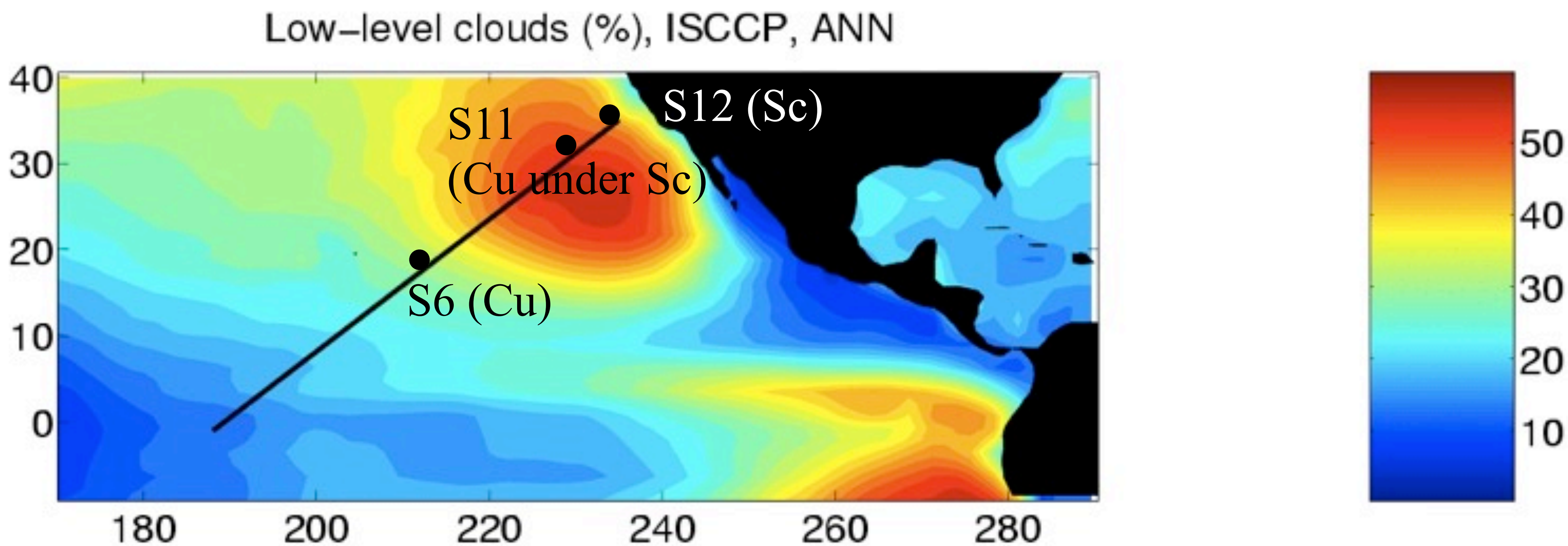
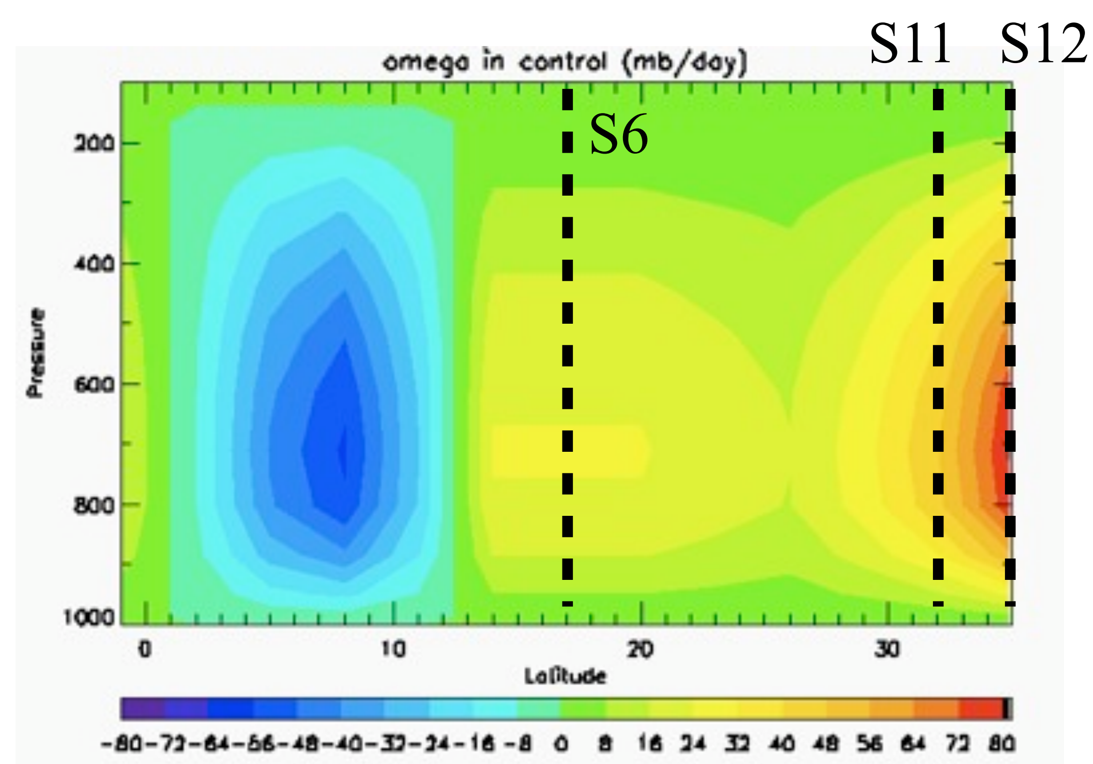
CGILS: CFMIP/GCSS Intercomparison of Large-eddy and Single-column models

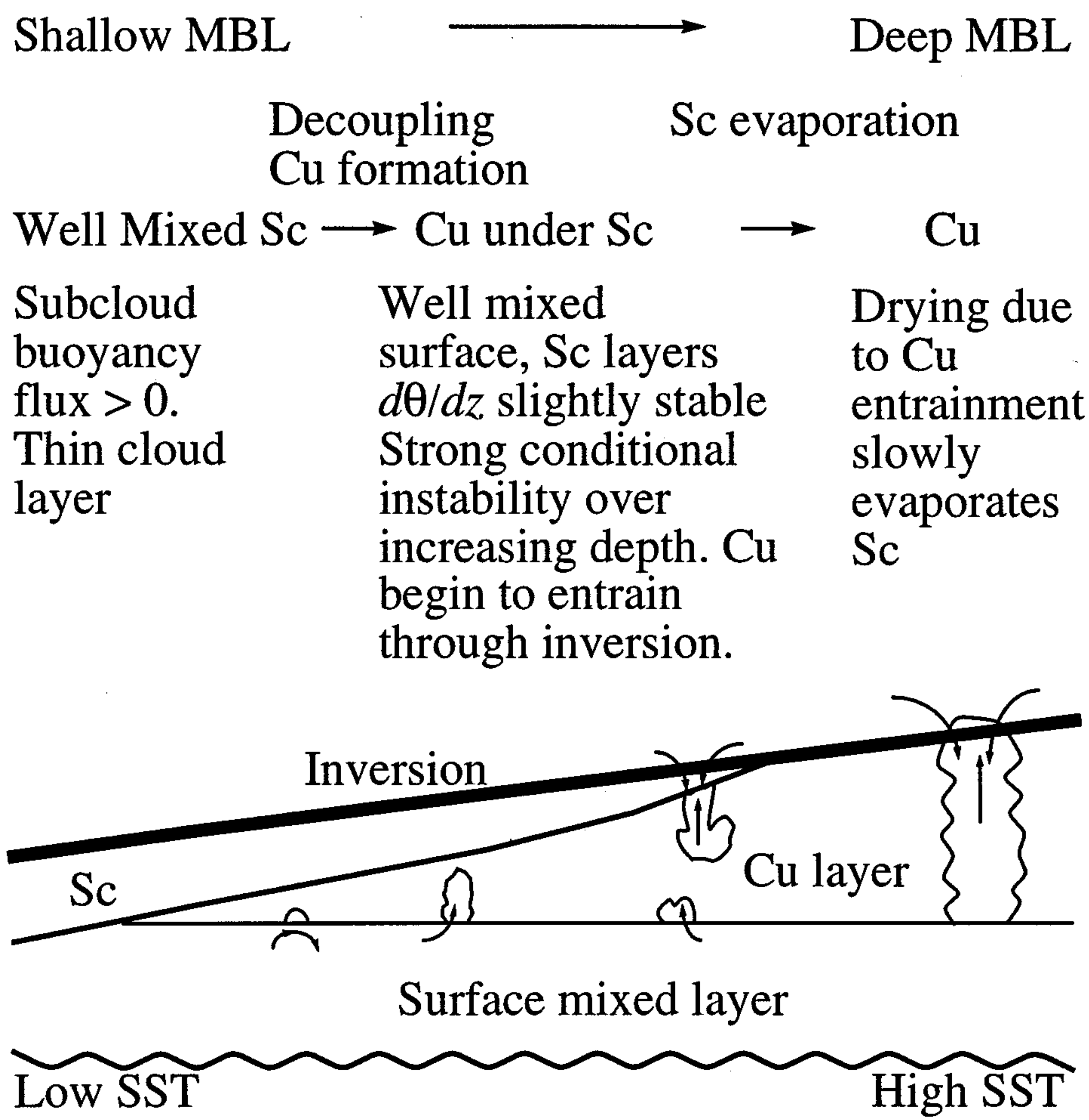


- Focuses on three points along the GCSS Pacific Cross-section.
- Points range from shallow, well-mixed boundary layer near coast to deeper trade cumulus boundary layer well offshore.



$$\omega(p,lat) = \Omega(lat)\,\omega_0(p)$$

CGILS: Eulerian View of Sc→Cu Transition



S12 S11 S6

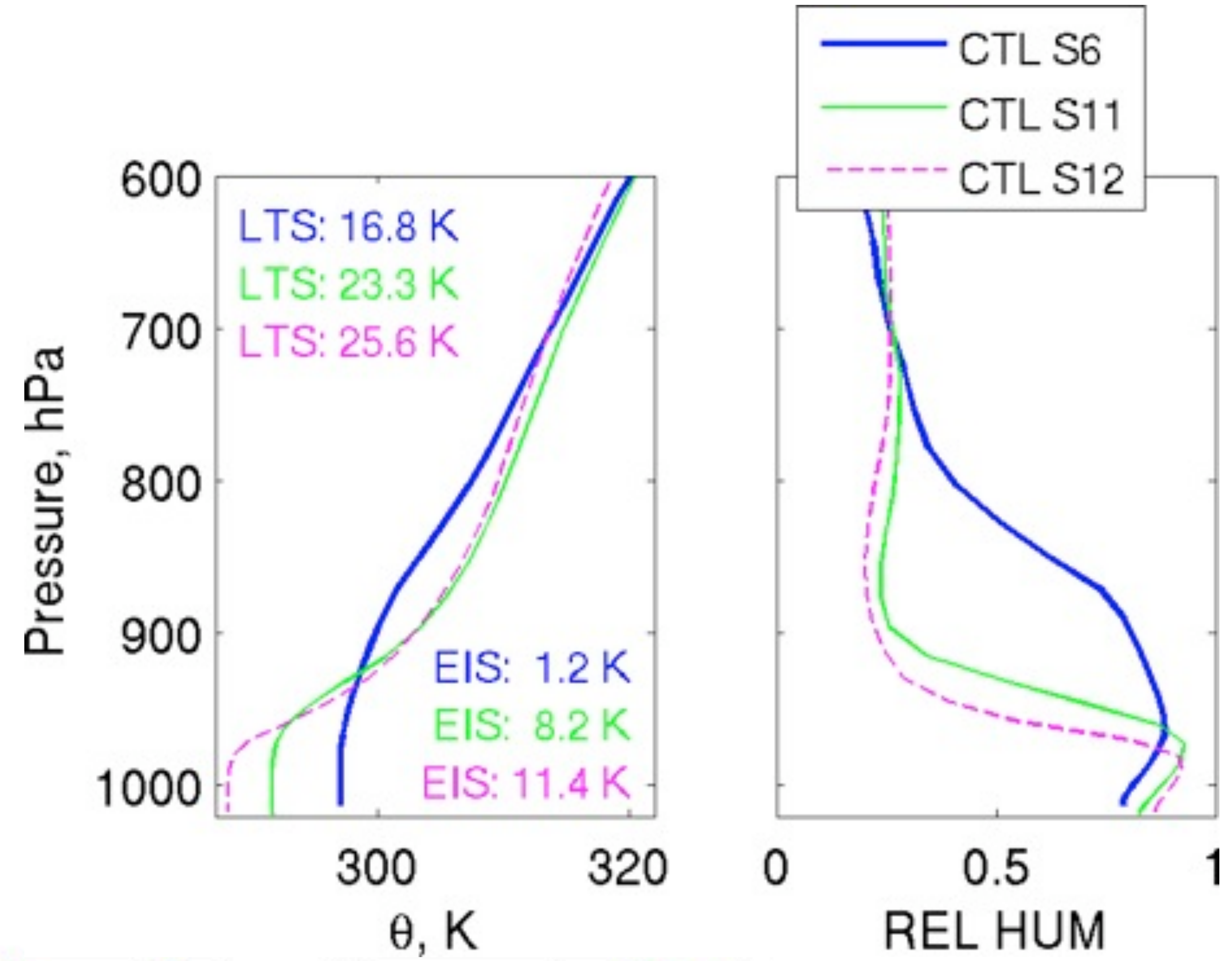
Wyant et al. (1997)

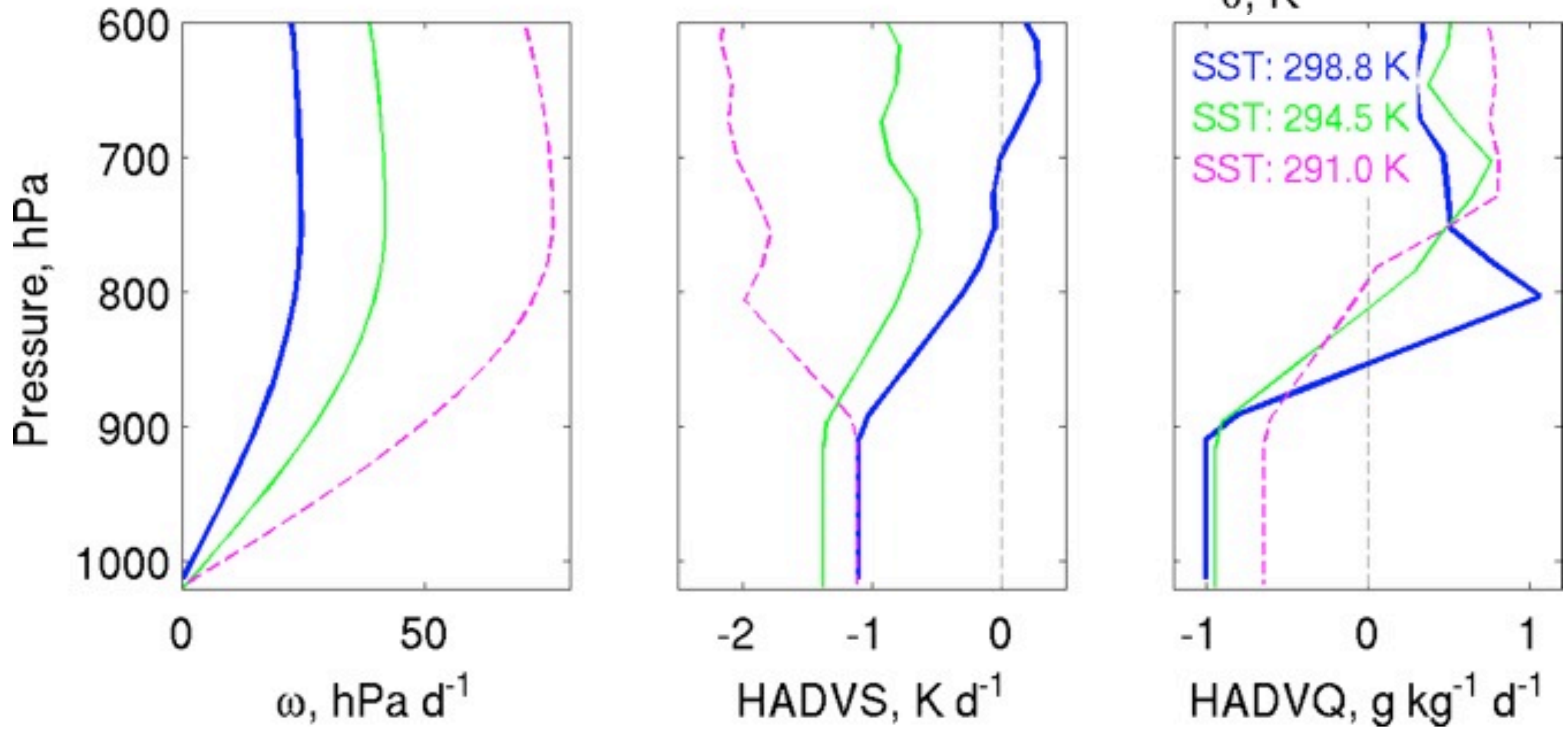
CGILS column cloud feedback intercomparison

- Aims to understand how low clouds respond to an idealized climate perturbation and why they respond as they do.
- Will compare SCM responses with the parent GCMs of the single column models.
- LES models provide benchmark for SCM response.
- First boundary layer cloud intercomparison with full radiation schemes and long runs to equilibrium.
- Current setup:
  - Constant insolation: Neglect diurnal cycle at first.
  - Steady large-scale forcings: Transient later.
  - Summertime conditions: Winter conditions next?

Column Cloud Feedbacks

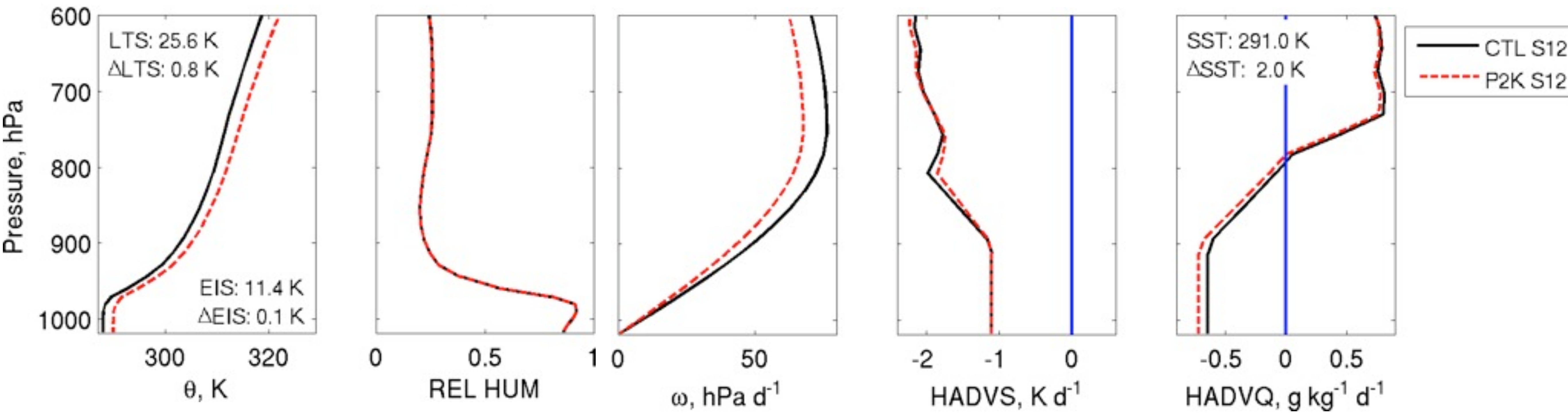
- Control climate forcings:
  - ECMWF July climatology,
  - large-scale advection at low levels ~ SST gradient,
  - advective tendencies aloft balance energy/moisture budgets.





Column Cloud Feedbacks

- Idealized +2K climate perturbation:
  - moist adiabatic warming of T sounding,
  - RH unchanged in warmer climate,
  - omega (LS subsidence) decreased by about 11%,
  - LS advective cooling of BL unchanged,
  - LS advective drying of BL scales with Clausius-Clapeyron.



LES-Specific Setups

- Surface Fluxes: All LES use same bulk surface flux scheme with transfer coefficient that includes dependence on Δz, wind speed.
- Nudging Aloft: Maintain free tropospheric q, θ profiles by nudging away from inversion.
- Moisture floor (S12 only): Nudge moisture above inversion to prevent excessive drying by horizontal advection above BL top.
- Radiation: Uniform specification of droplet concentration (N_c=100/cm^3), effective radius dependence on N_c, LWC.

Next Step: Iterate for Two Years

- Much inter-model variability in early results arose from differences in model setup.
- Differences in
  - Near-surface winds affected surface fluxes,
  - Radiation schemes led to T drifts in free trop.,
  - Effective radius assumptions led to large differences in cloud albedo, surface energy balance,
- Extensive efforts have been made to eliminate inter-model differences due to case setup.

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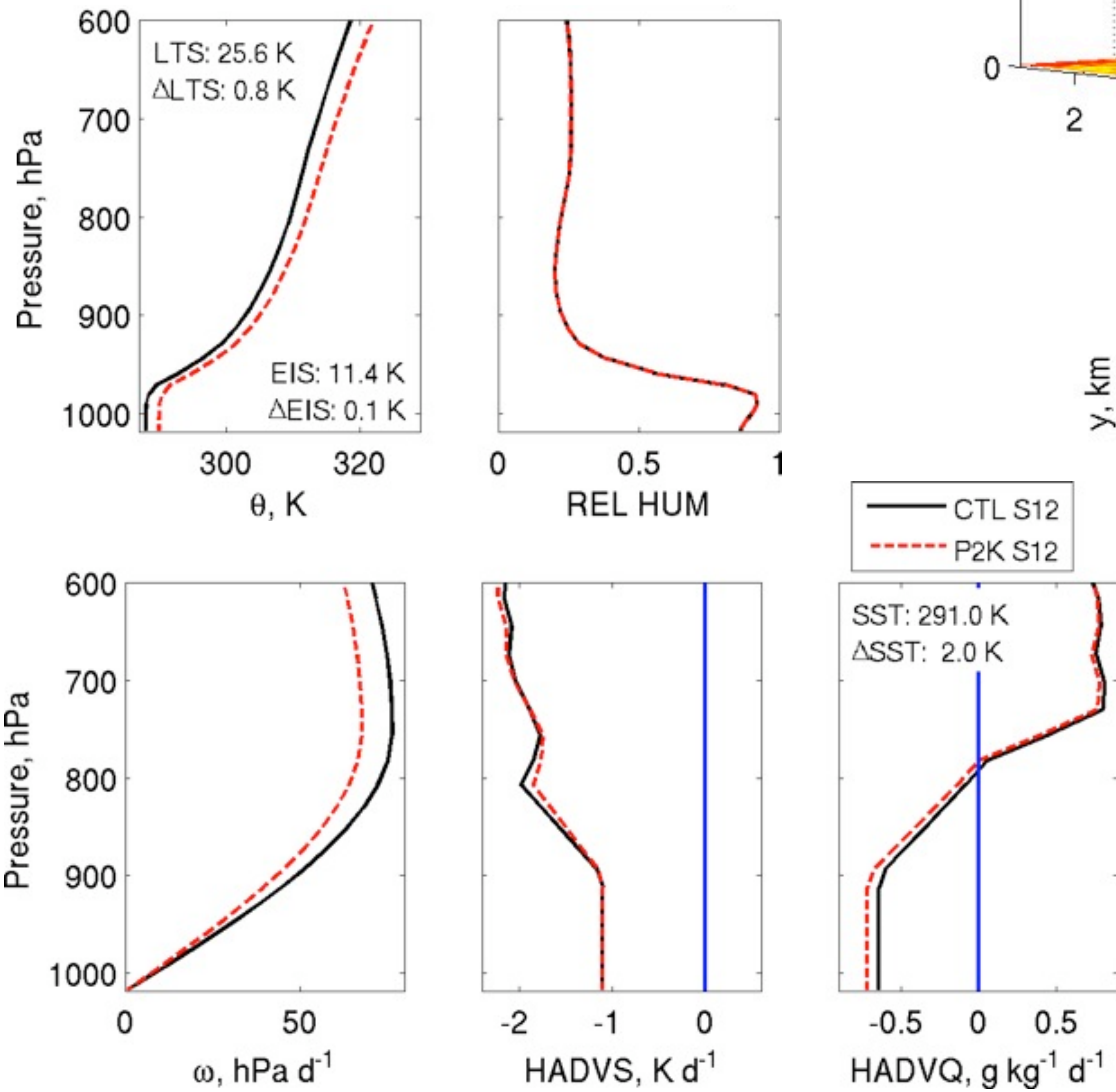
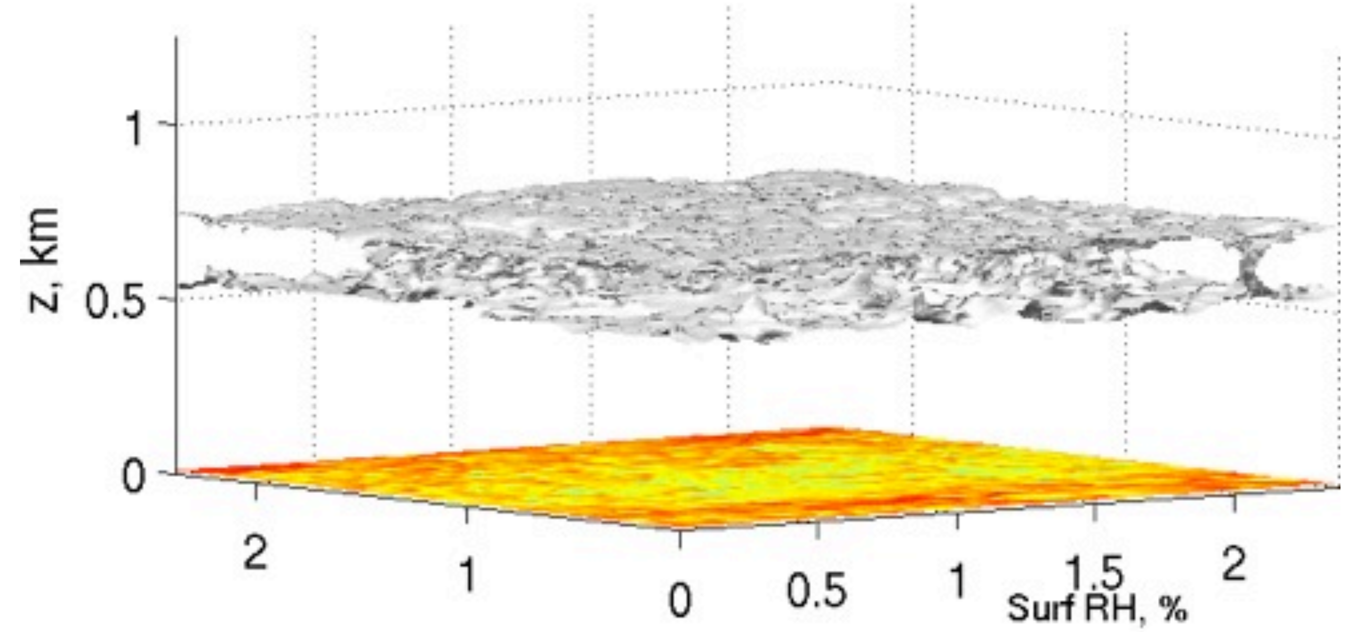
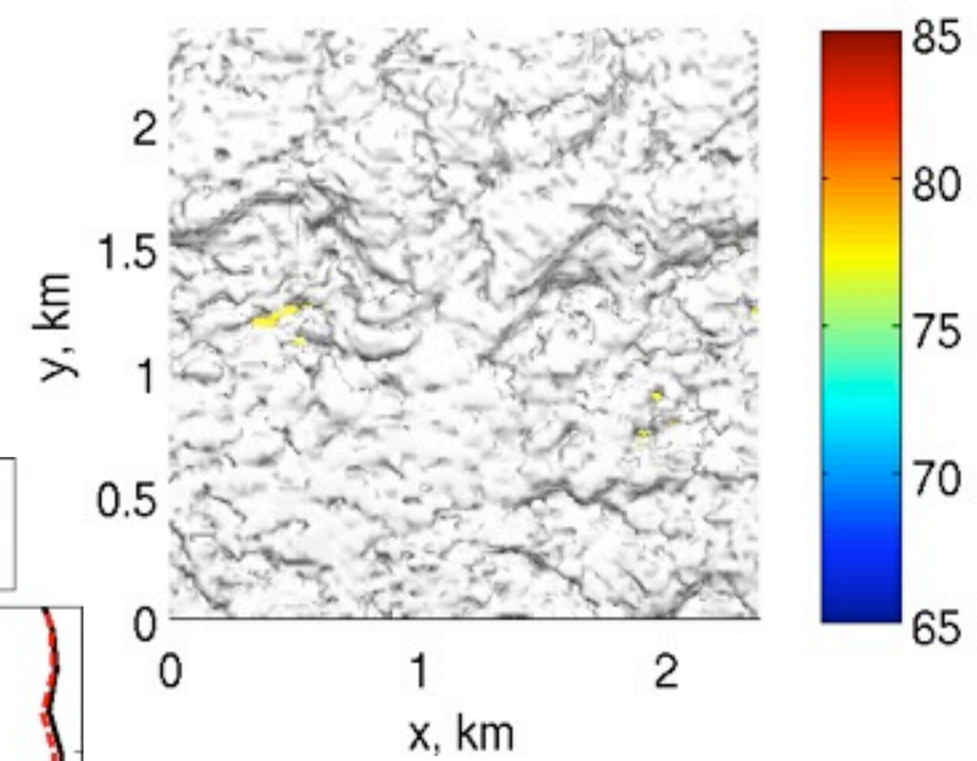
CGILS S12: Coastal SCu

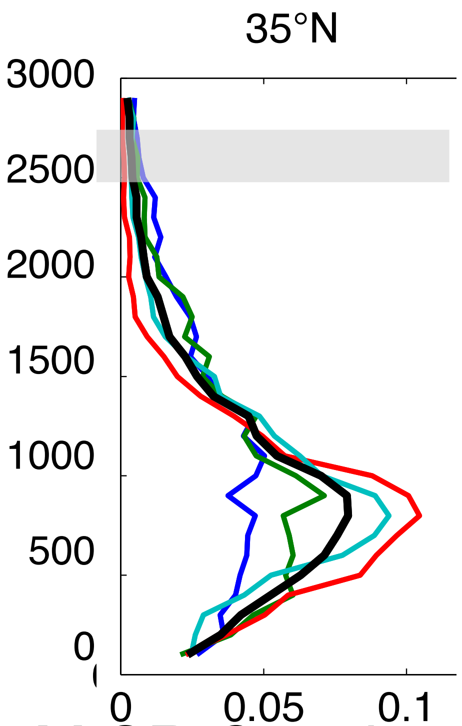




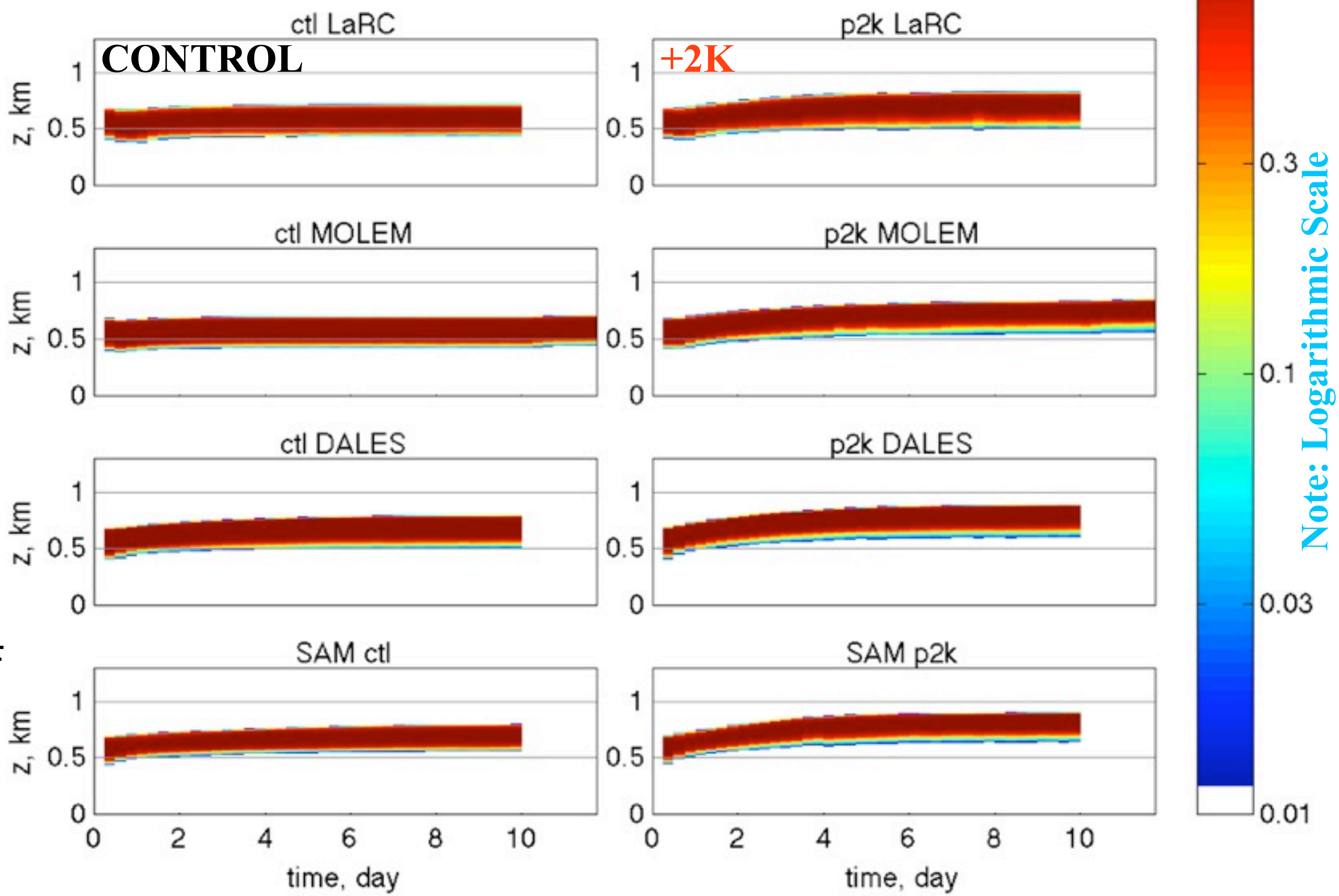


Δx=25m
Δz=5-15m

S12: Cloud Fraction

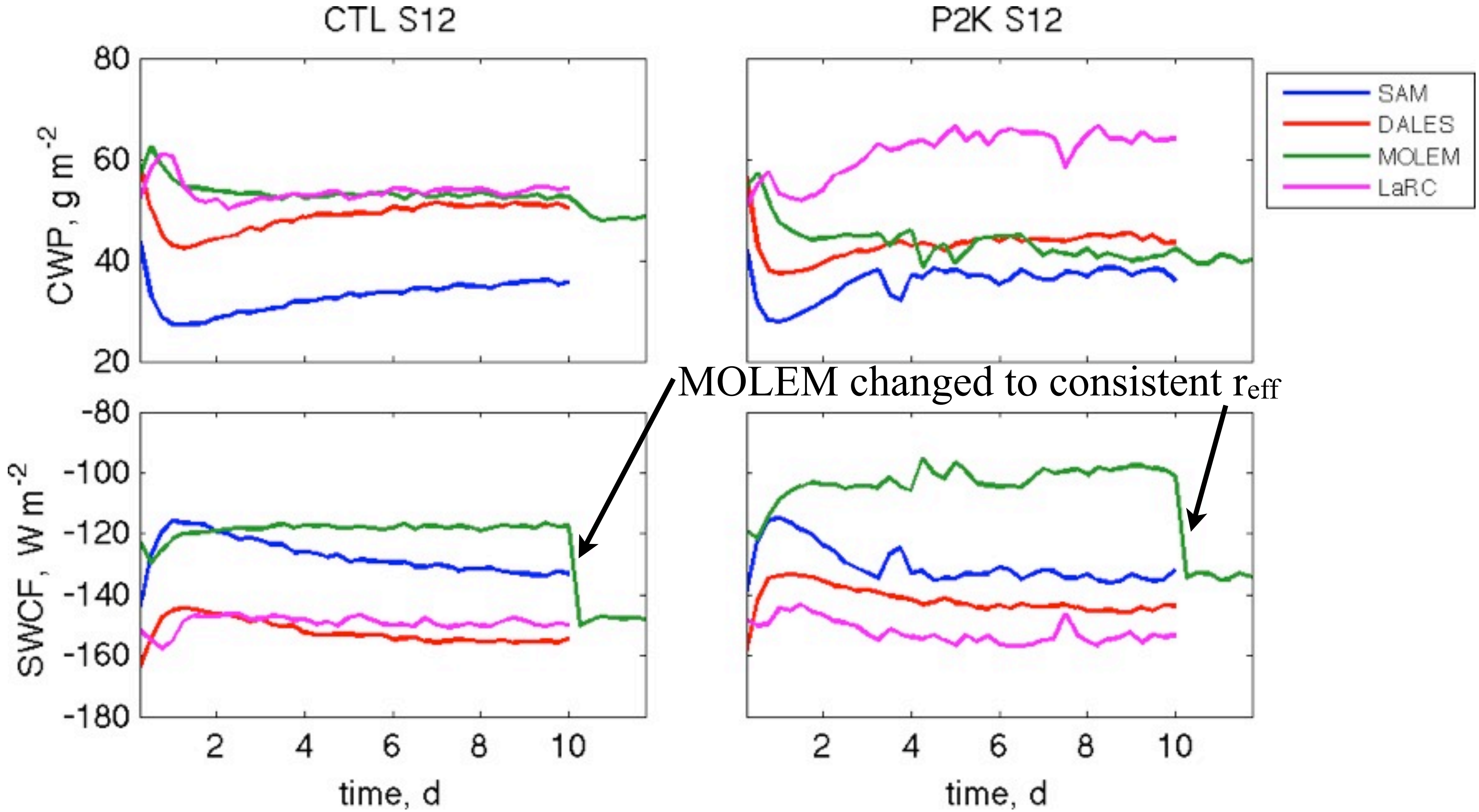


MISR Cloud Top Height PDF Courtesy of J. Karlsson.



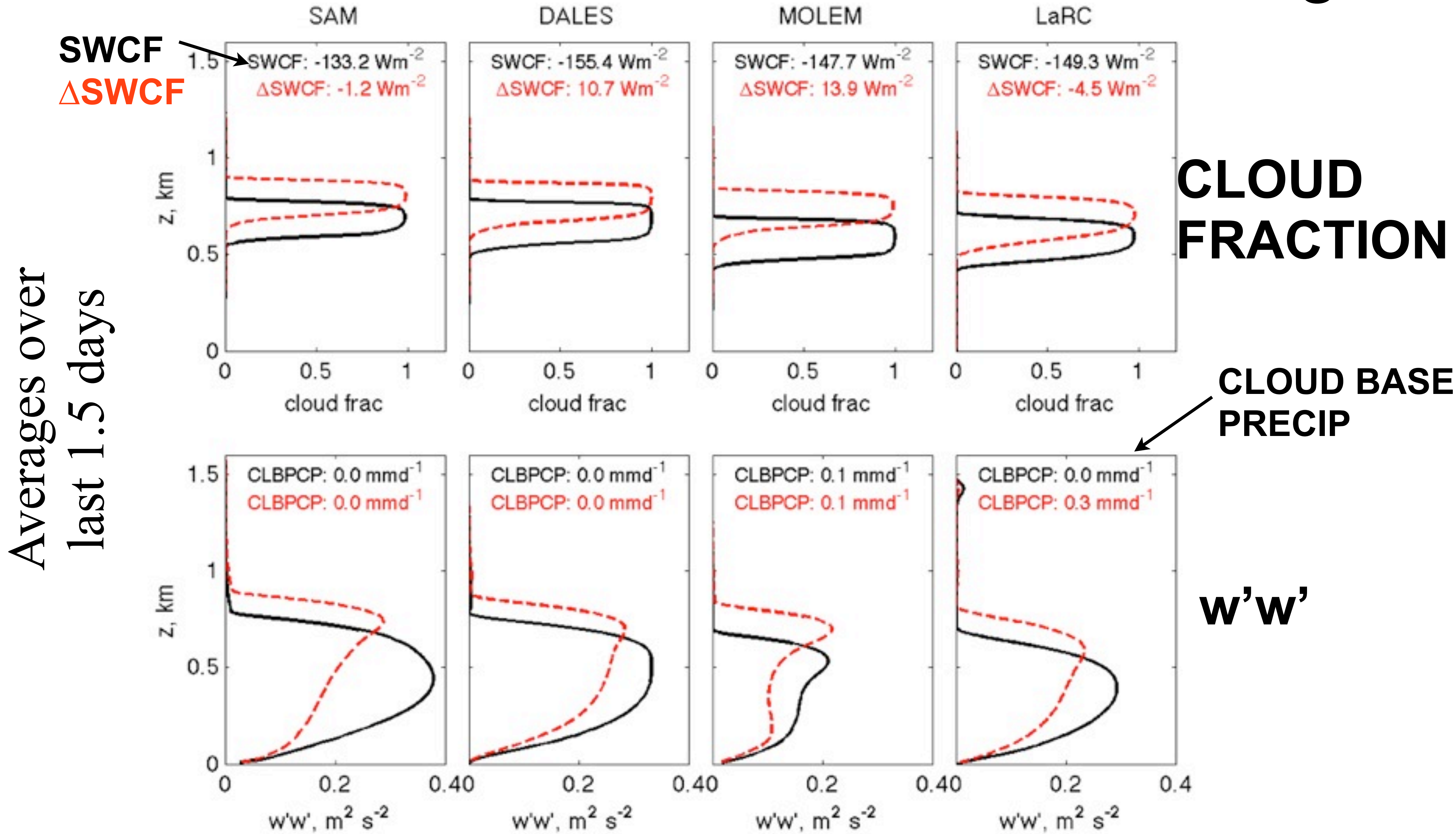
- Models agree well for a case with a strong inversion.
- Control case well-mixed. +2K runs decouple and deepen.

S12: Evolution of Cloud/SWCF



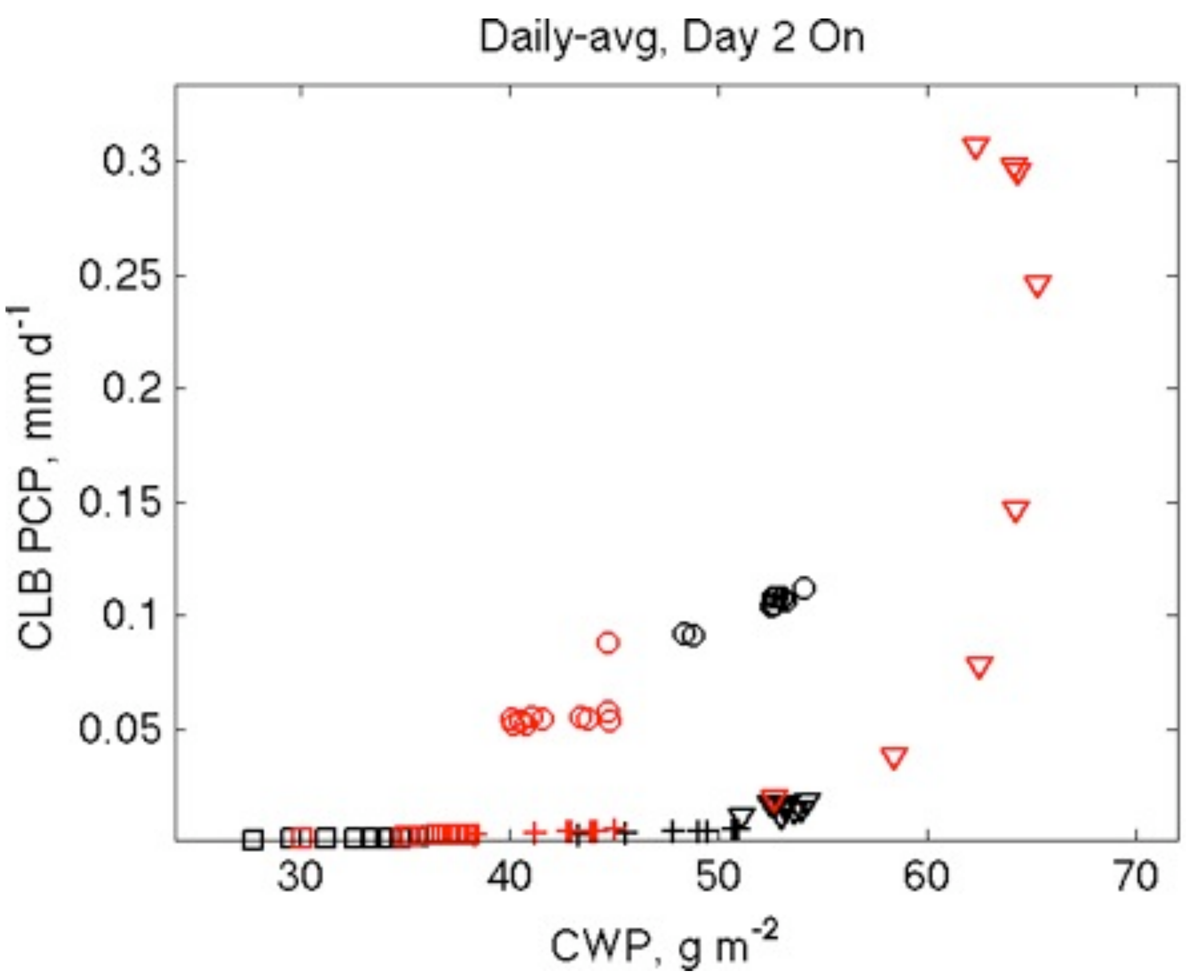
- Quantitative differences remain among models despite extensive efforts to homogenize model setup, radiation, surface flux treatment.
- Note fast/slow timescales in evolution of CWP, SWCF.

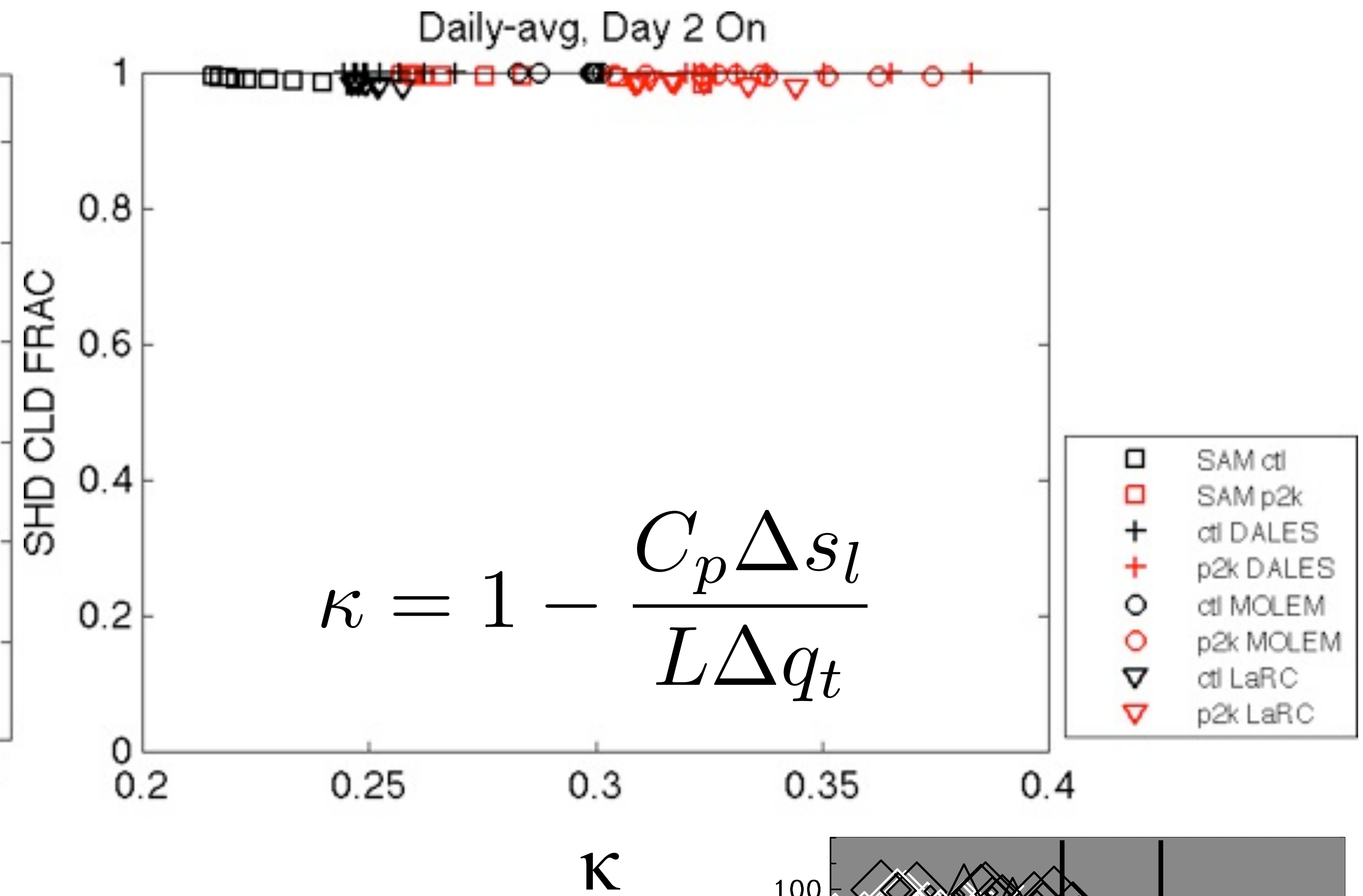
S12: CTL→+2K Cloud/Turbulence Changes



- Models deepen uniformly, show more decoupling in w'w' profiles.
- Strong positive ΔSWCF (>10W/m2) in DALES & MOLEM.
- Weaker negative feedback in SAM & LaRC.

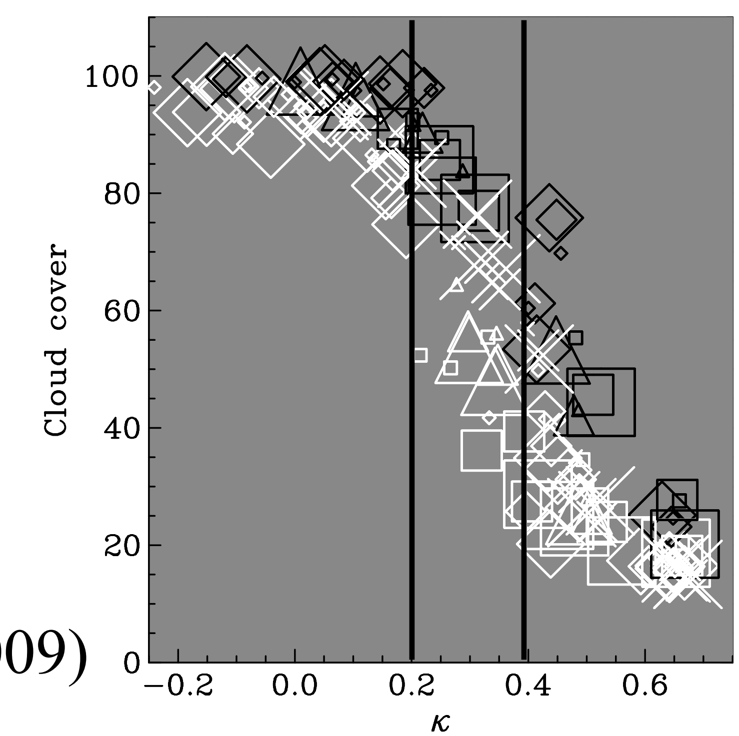
S12: Precip-CWP, κ-CLD relationships





$$\kappa = 1 - \frac{C_p \Delta s_l}{L \Delta q_t}$$

- LaRC precipitates more than other models, apparently due to larger CWP.
- Models maintain full cloud cover in +2K runs despite modest increase in κ.



Lock (2009)

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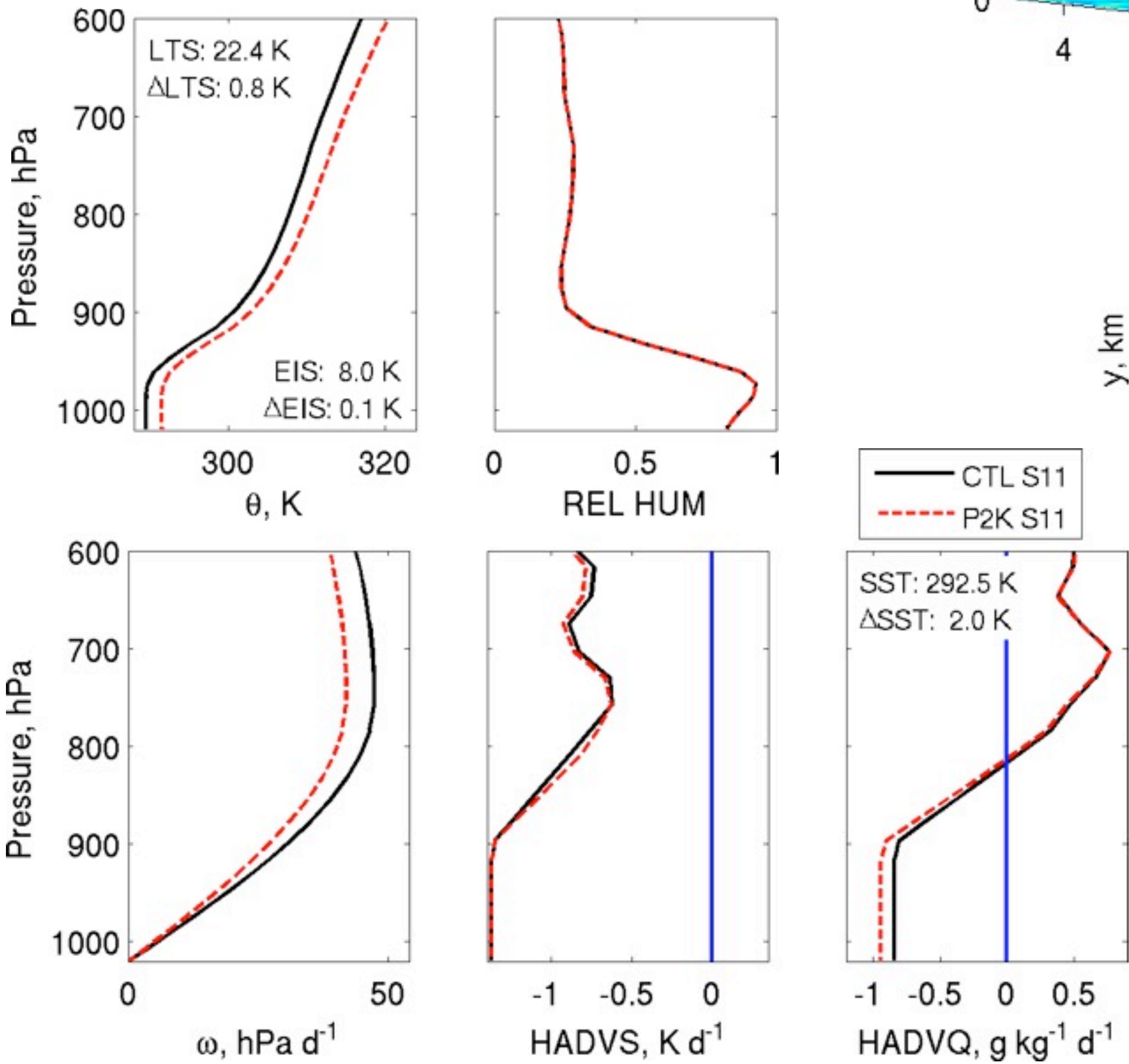
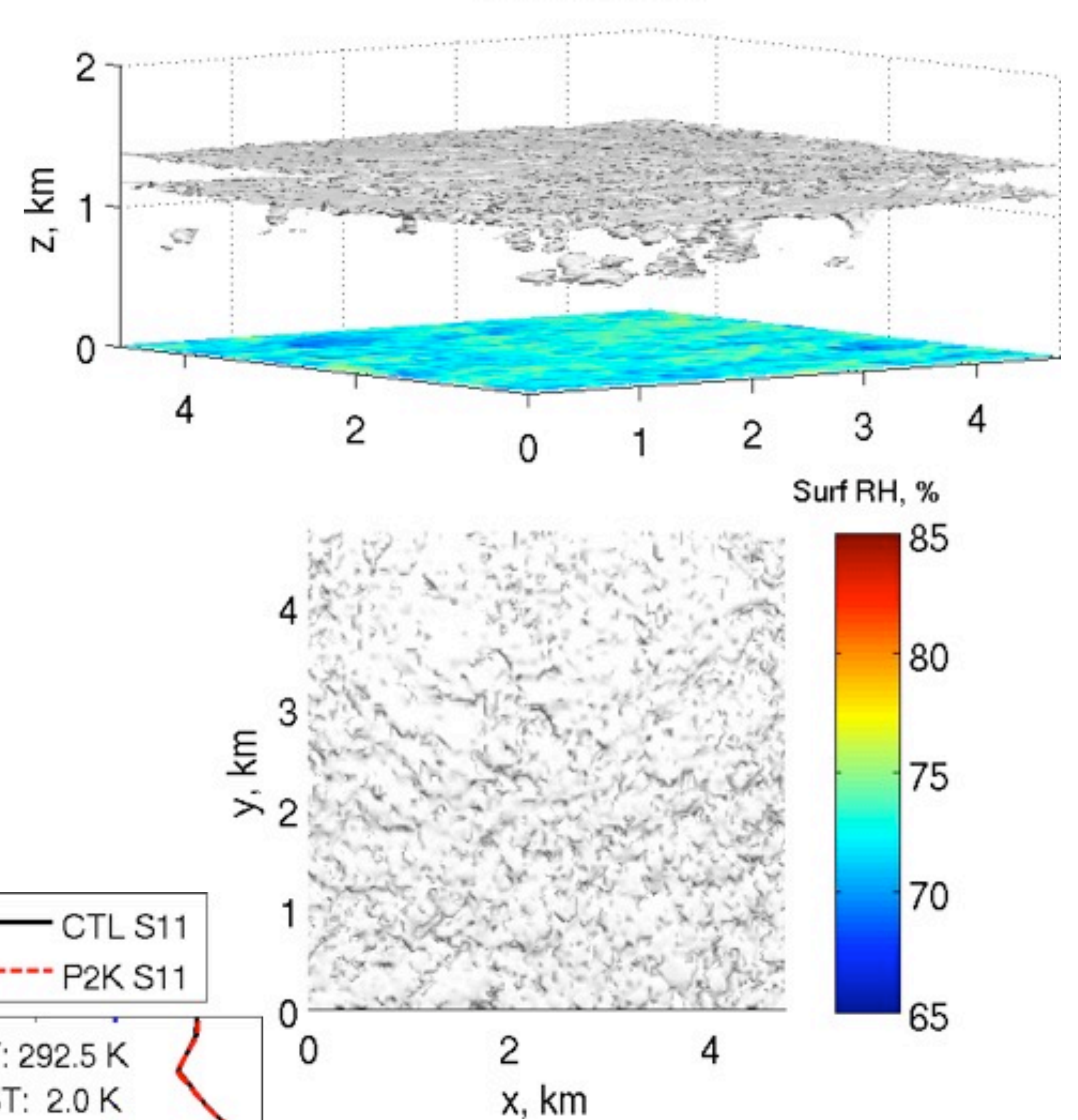
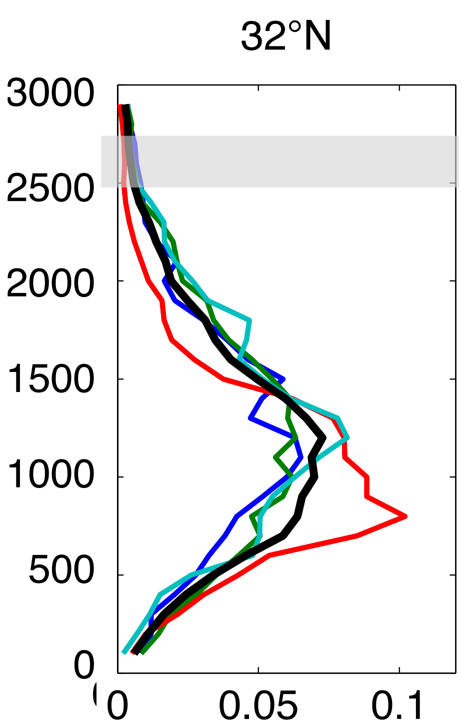
CGILS S11: Cu under SCu



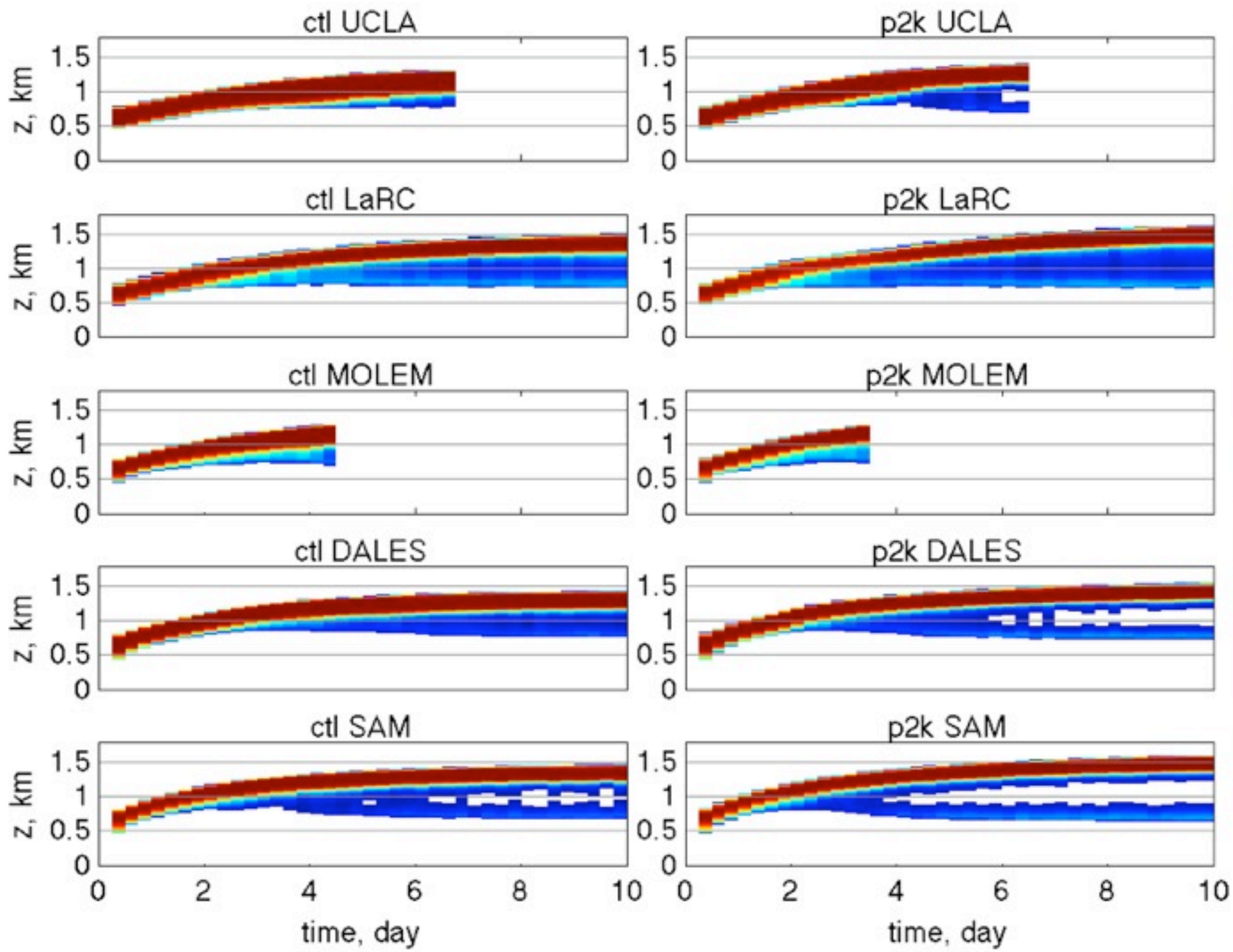


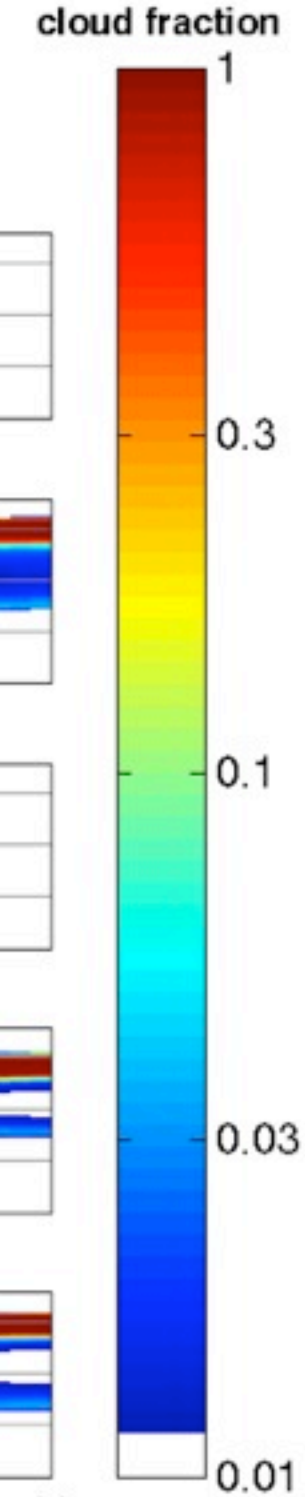
Δx=50m
Δz=5-25m

S11: Cloud Fraction



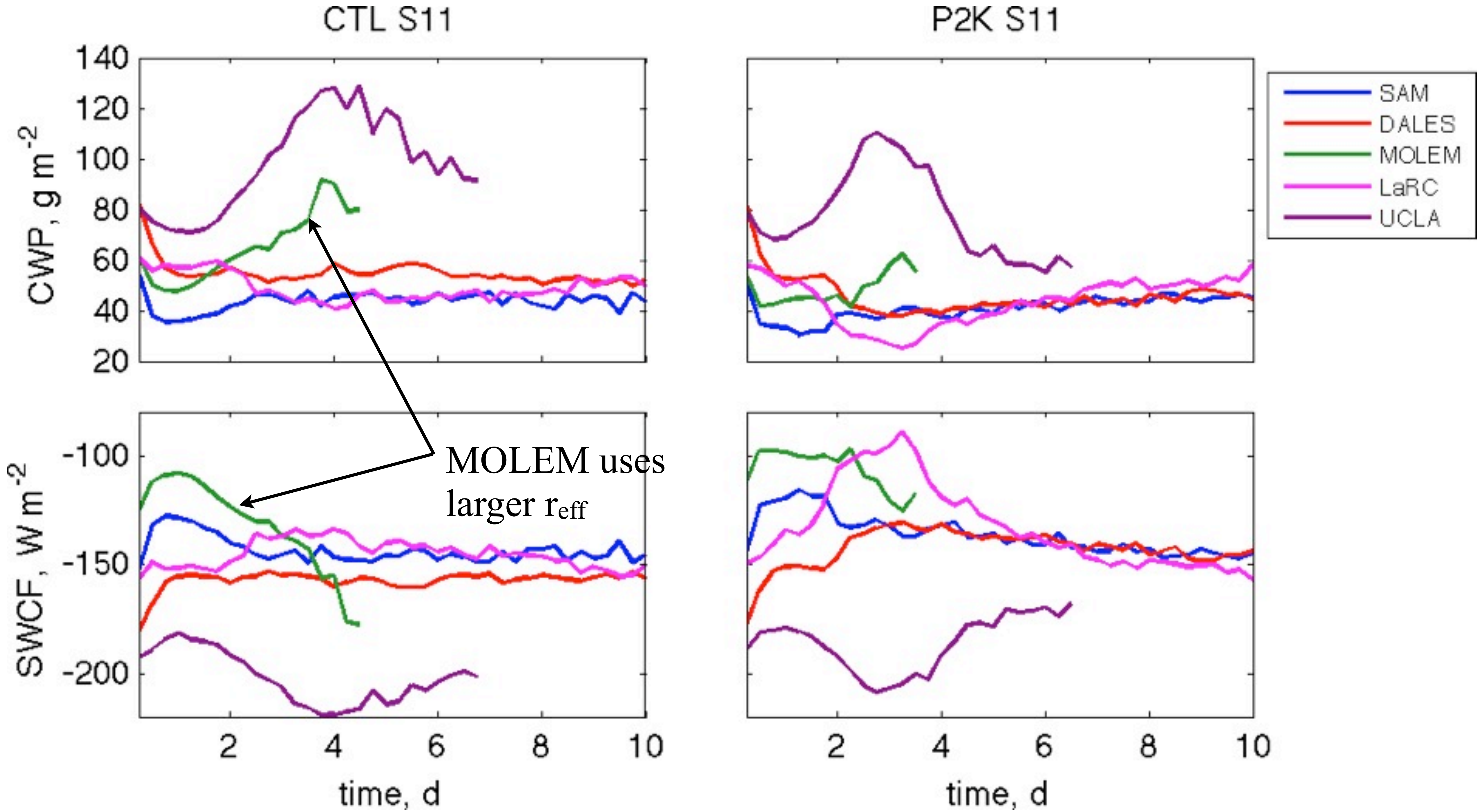
MISR Cloud Top Height PDF Courtesy of J. Karlsson.





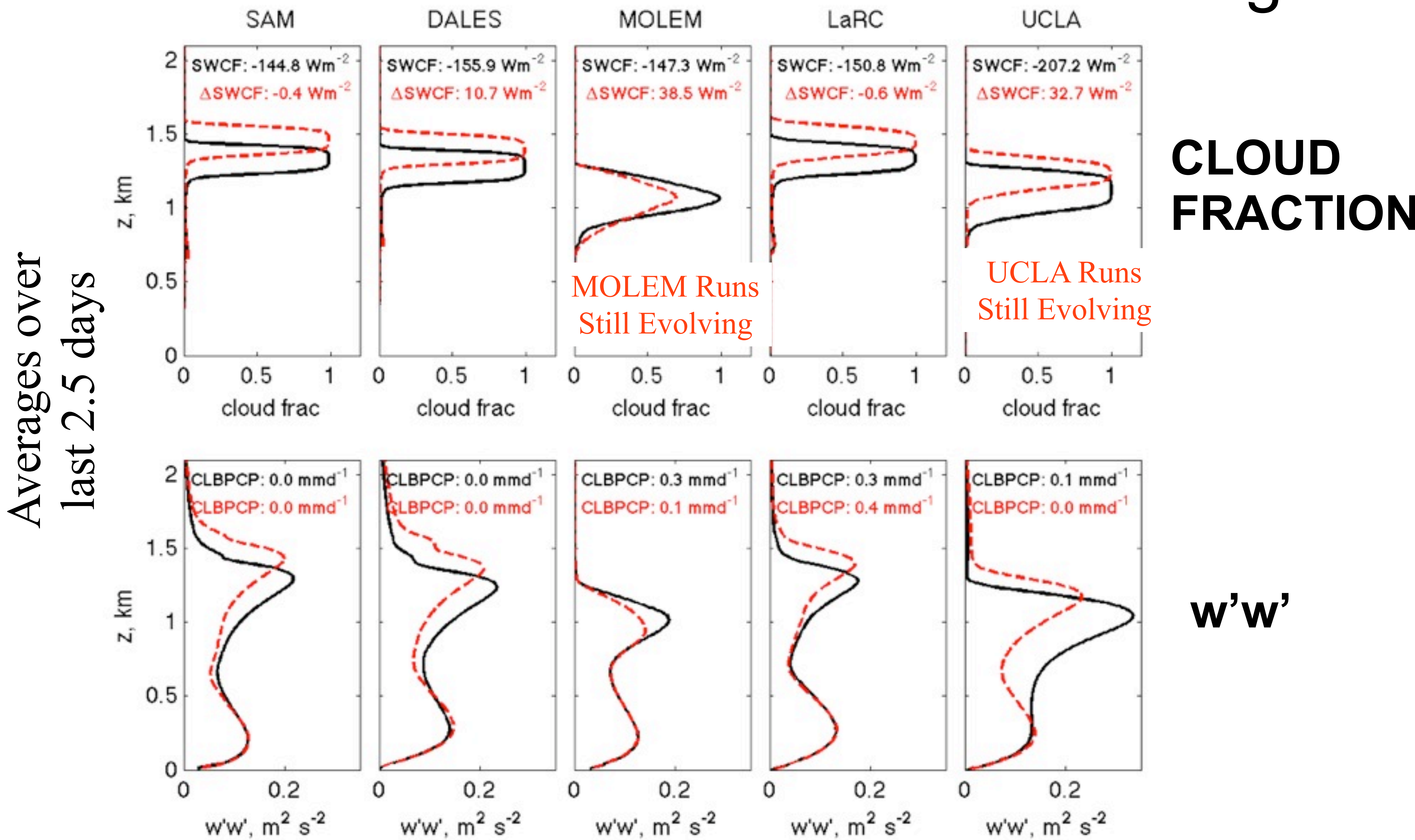
- Models broadly consistent when Δz=5m. (LaRC uses Δz=25m.)
- Initial stratocumulus layer decouples after deepening.
- +2K runs more decoupled with higher inversion than CTL.

S11: Evolution of Cloud/SWCF



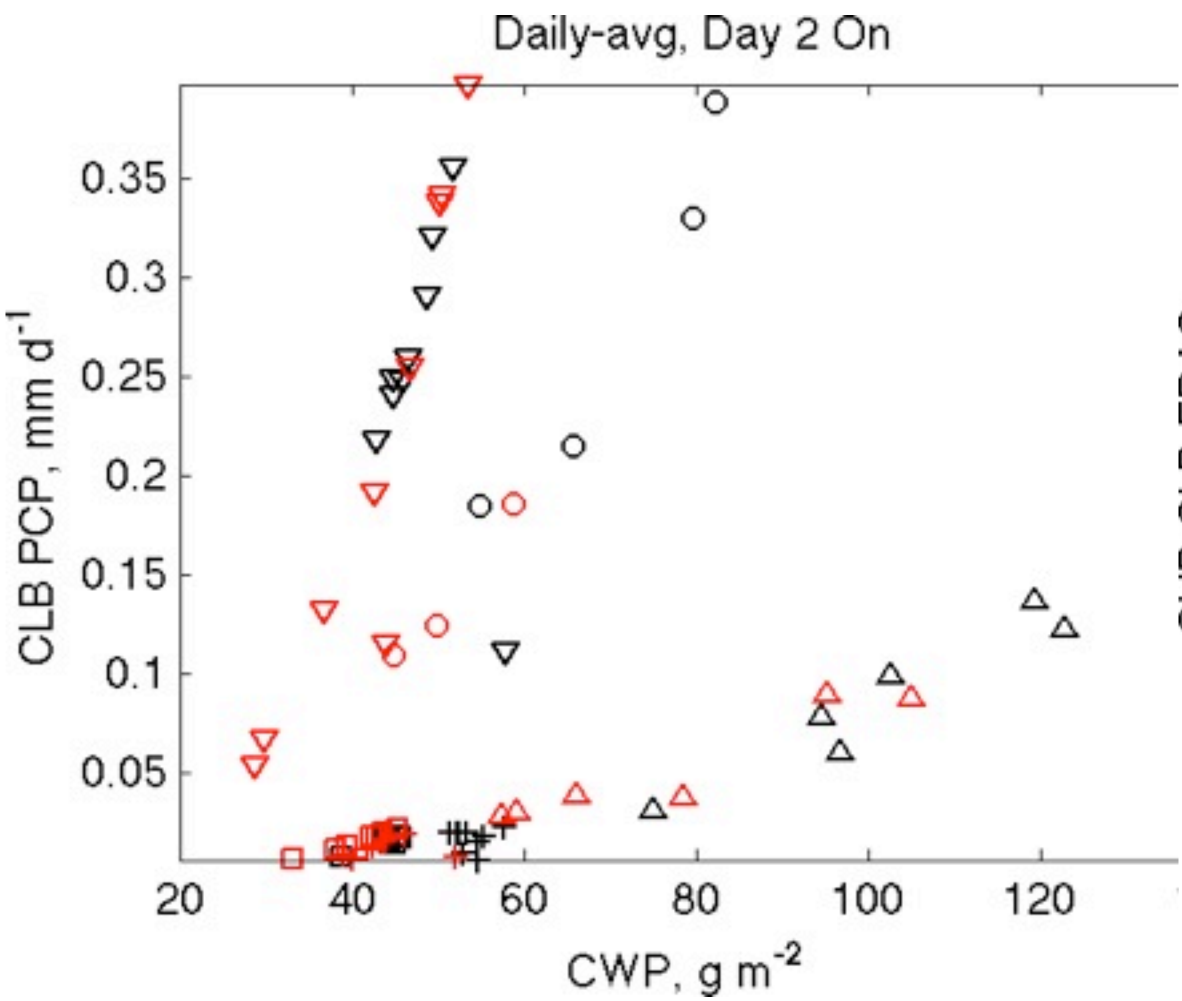
- Inter-model differences in CWP despite similar BL structure.
- LaRC/MOLEM add drizzle in +2K run, respond differently in CWP.
- As in S12, DALES and SAM similar in +2K run, but DALES maintains higher CWP than SAM in CTL run.

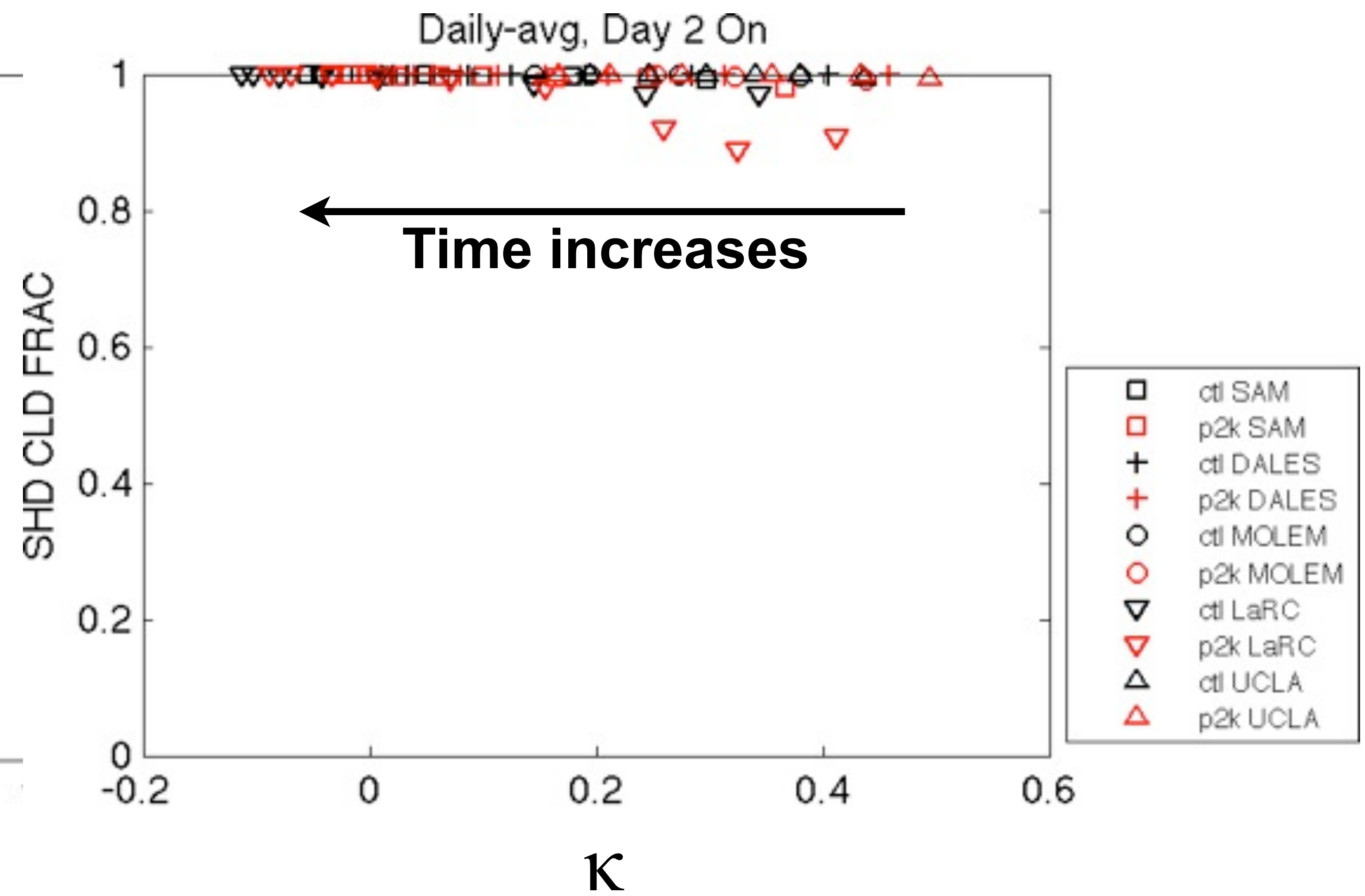
S11: CTL→+2K Cloud/Turbulence Changes



- SAM, DALES, LaRC near equilibrium. UCLA cloud thicker.
- Strong +ve ΔSWCF (>10W/m2) in DALES, near zero in SAM, LaRC.

S11: Precip-CWP, κ-CLD relationships





- LaRC precipitates more than other models, even at small CWP. MOLEM: droplet sed. included.
- Models maintain full cloud cover in +2K runs despite modest increase in κ.

Lock (2009)

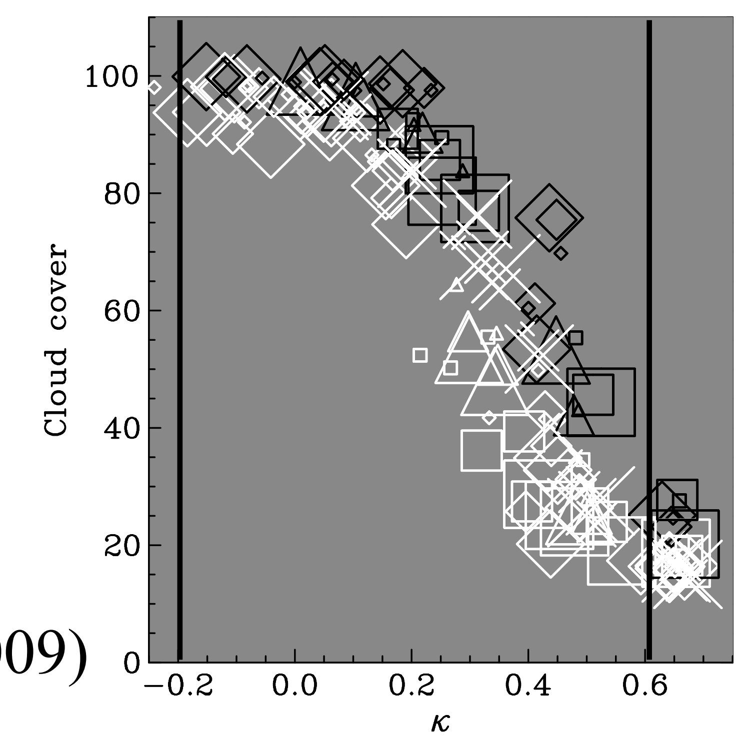


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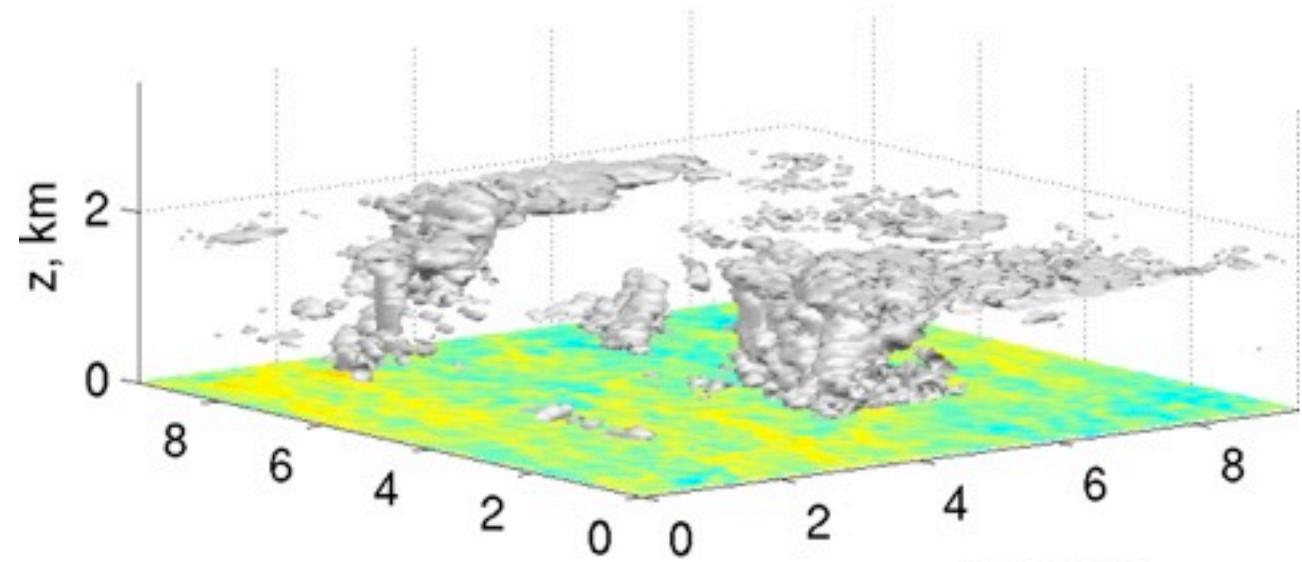
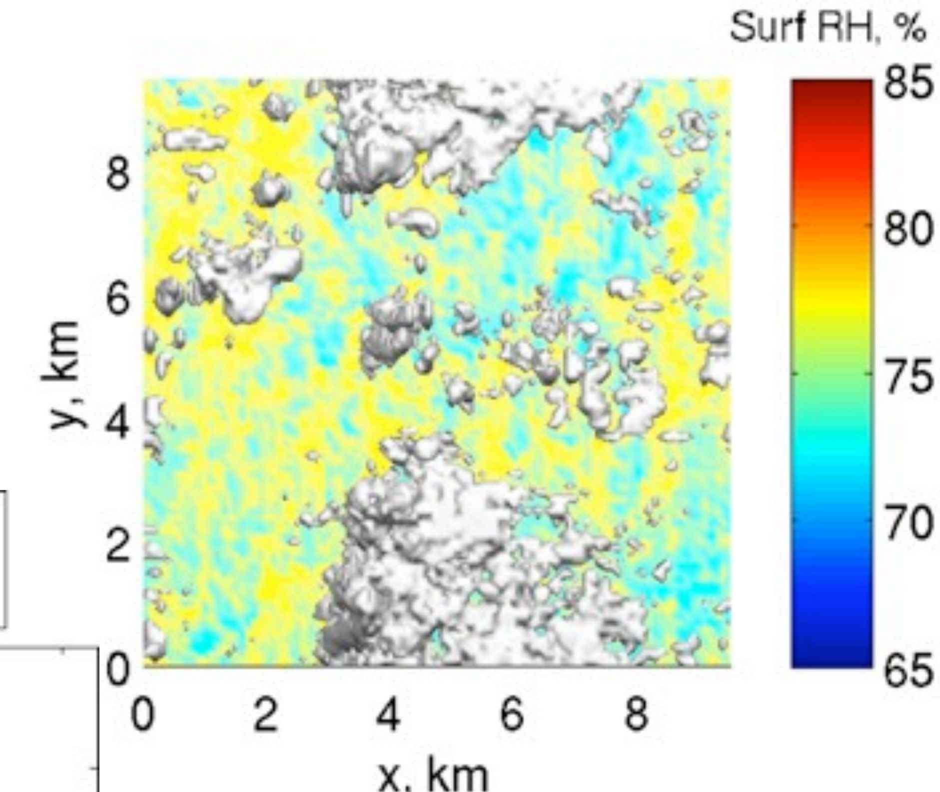
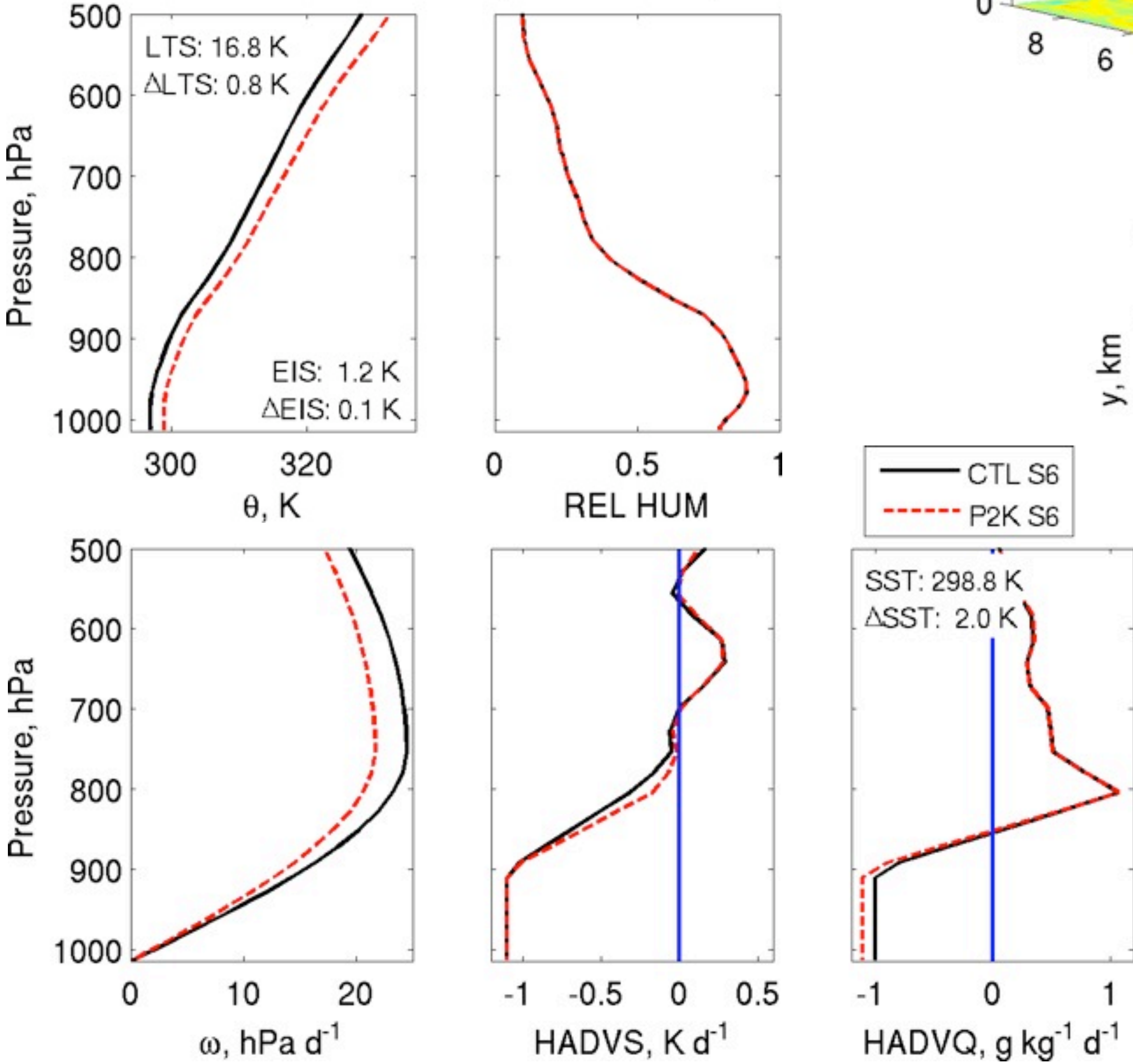
Photo courtesy Rob Wood

S6: Trade cumulus regime: Forcings and Snapshot of Cloud Field

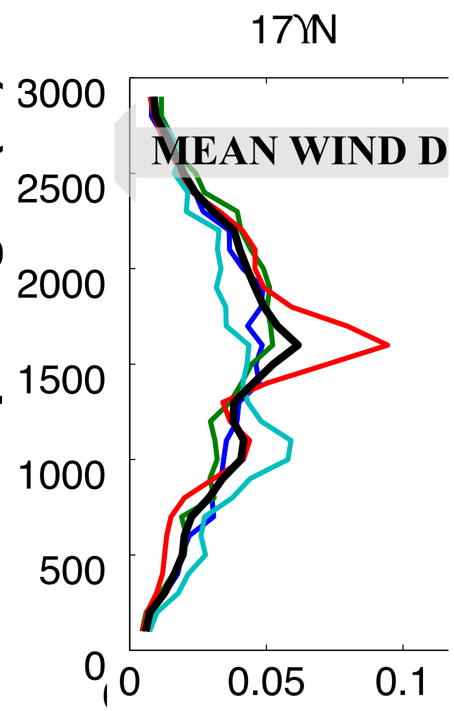




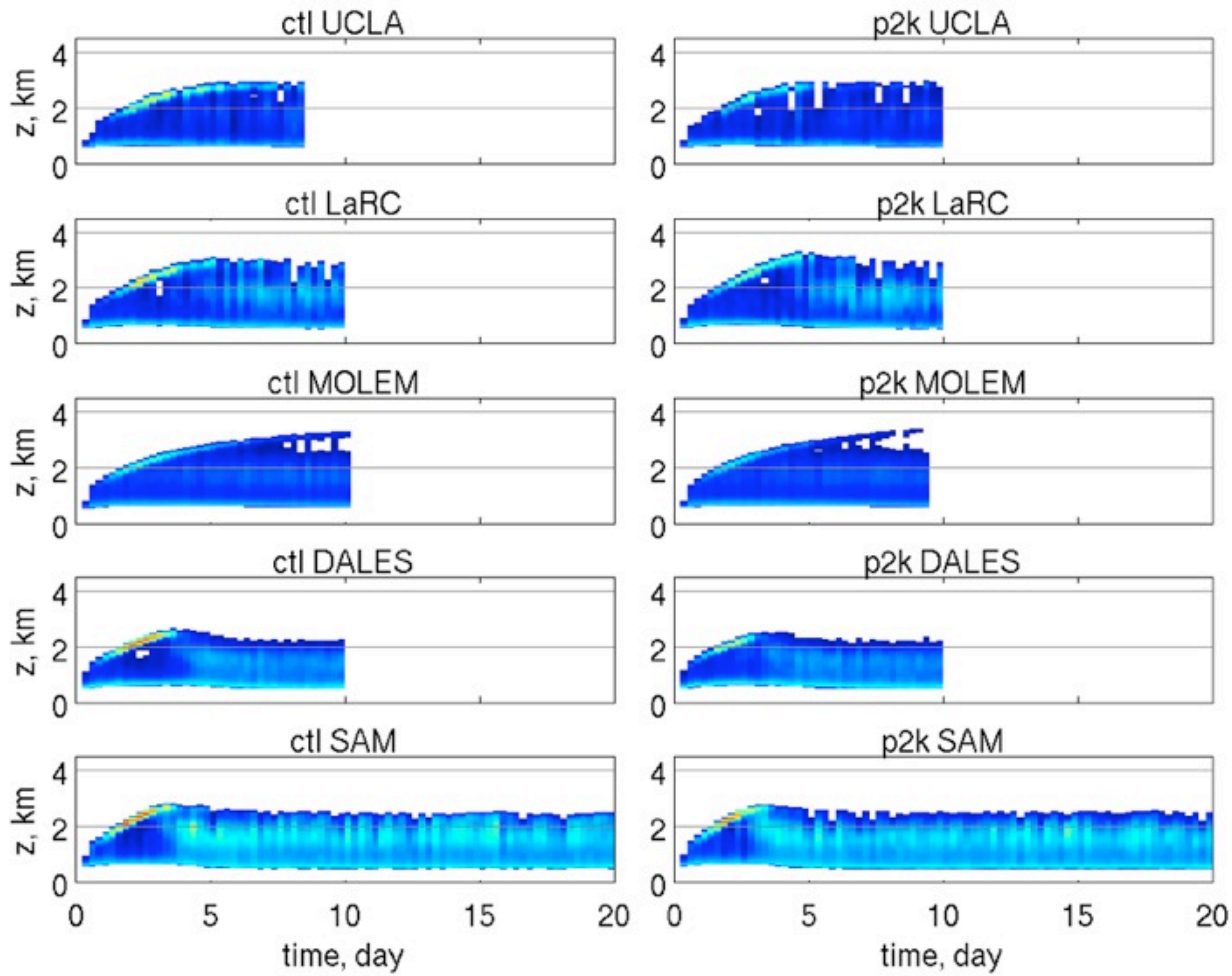


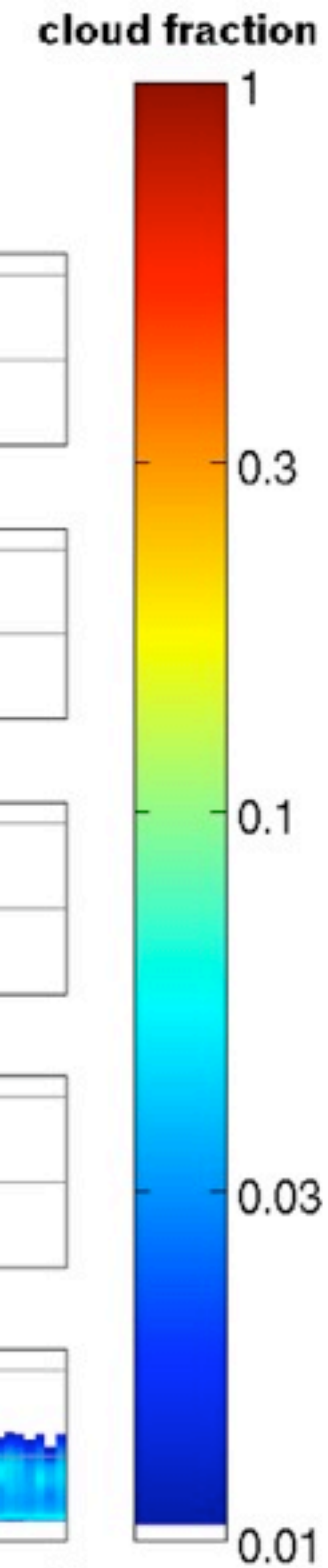
Δx=100m
Δz=40m

S6: Cloud Fraction



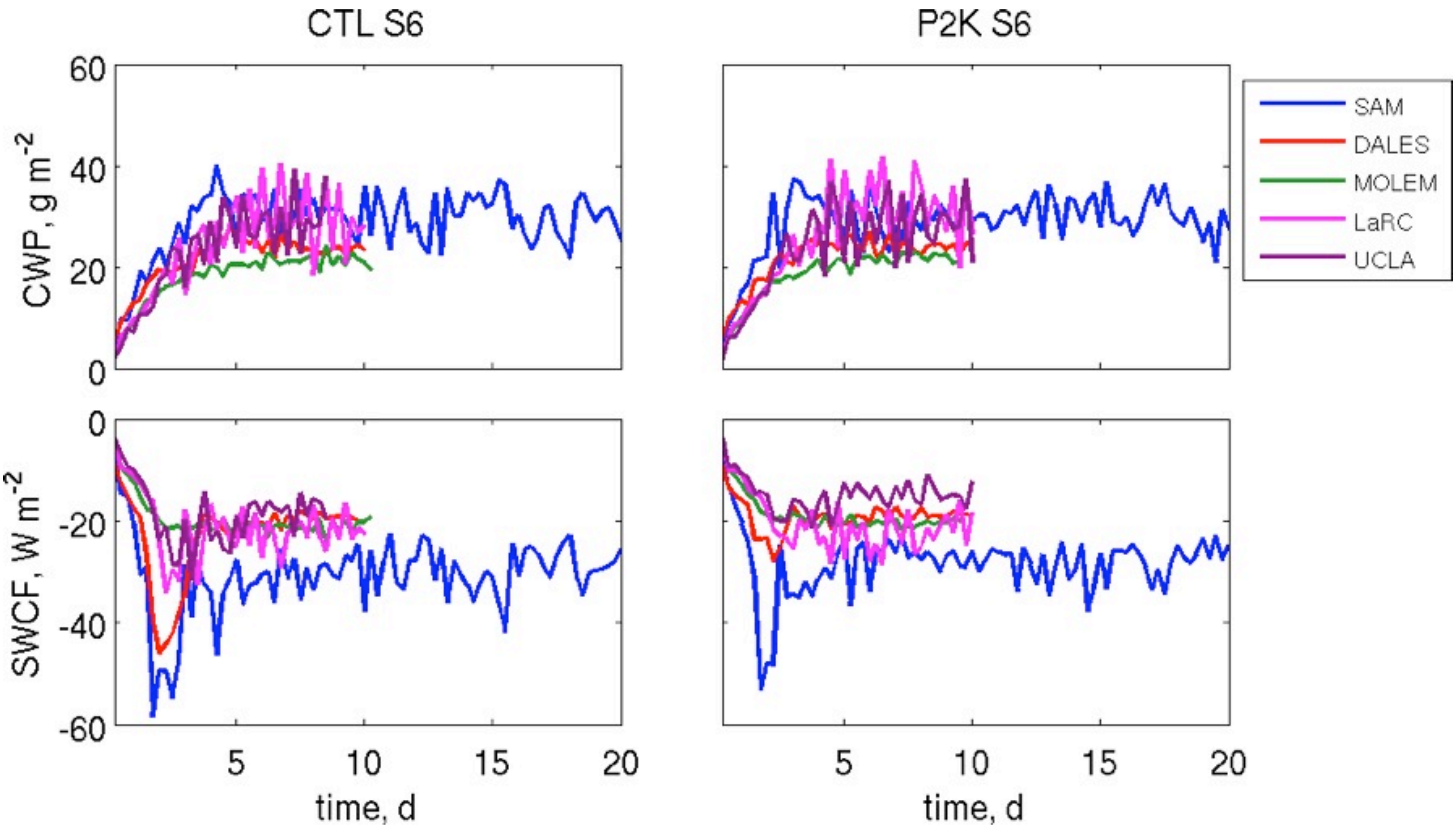
MISR Cloud Top Height PDF Courtesy of J. Karlsson.





- Fair agreement between LES models in BL structure, depth.
- SCu-capped layer deepens; transitions to a Cu-only layer.
- +2K changes are weak.

S6: Evolution of Cloud/SWCF

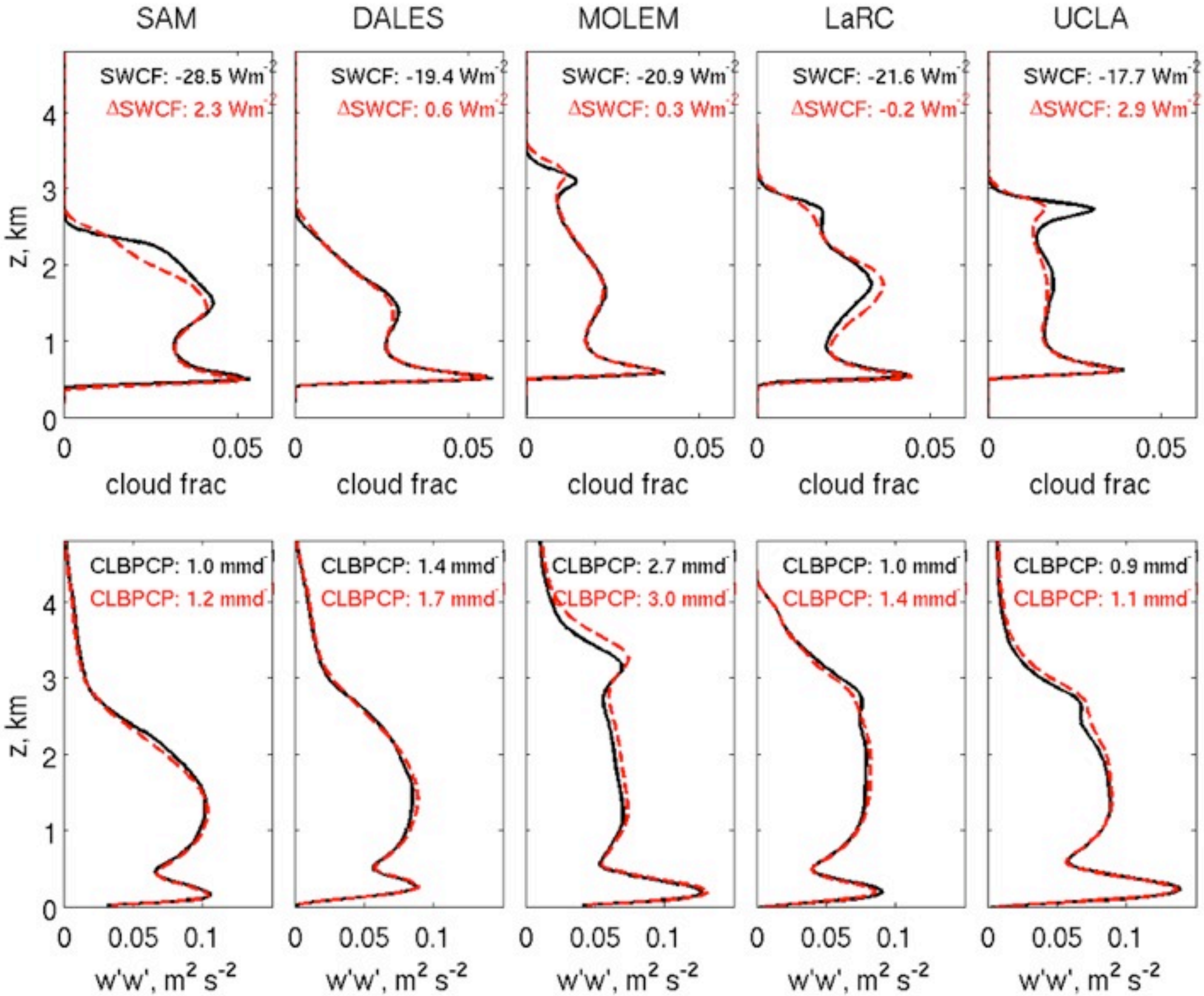


- Broad agreement among models, though timing of Sc-layer breakdown varies.
- SAM has larger cloud fraction in Cu layer than others.
- Variability in CWP related to domain size (Lx=Ly~10 km).

S6: CTL→+2K Cloud/Turbulence Changes

CLOUD FRACTION

w'w'

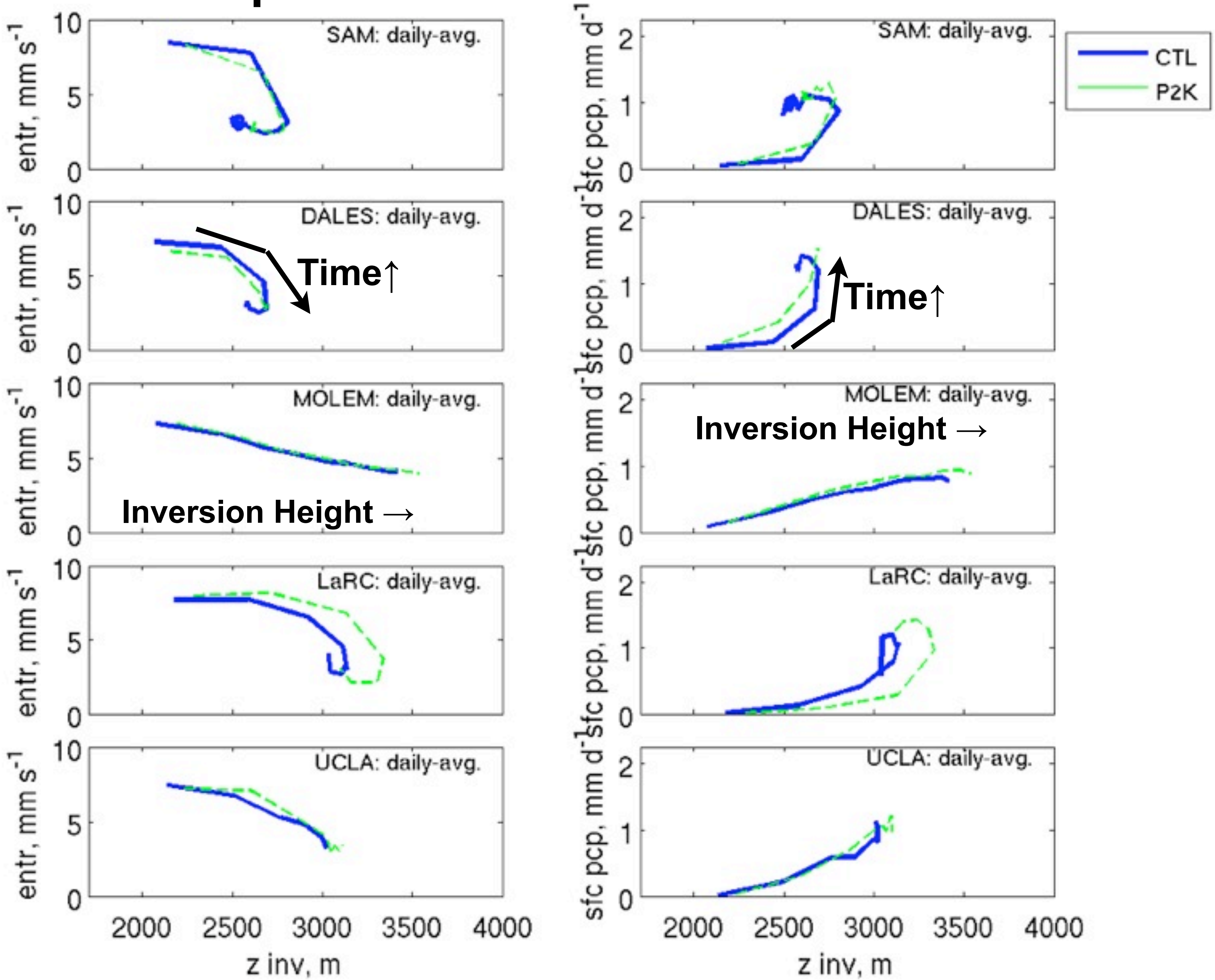


UCLA CTL still evolving.

Averages over last 2.5 days

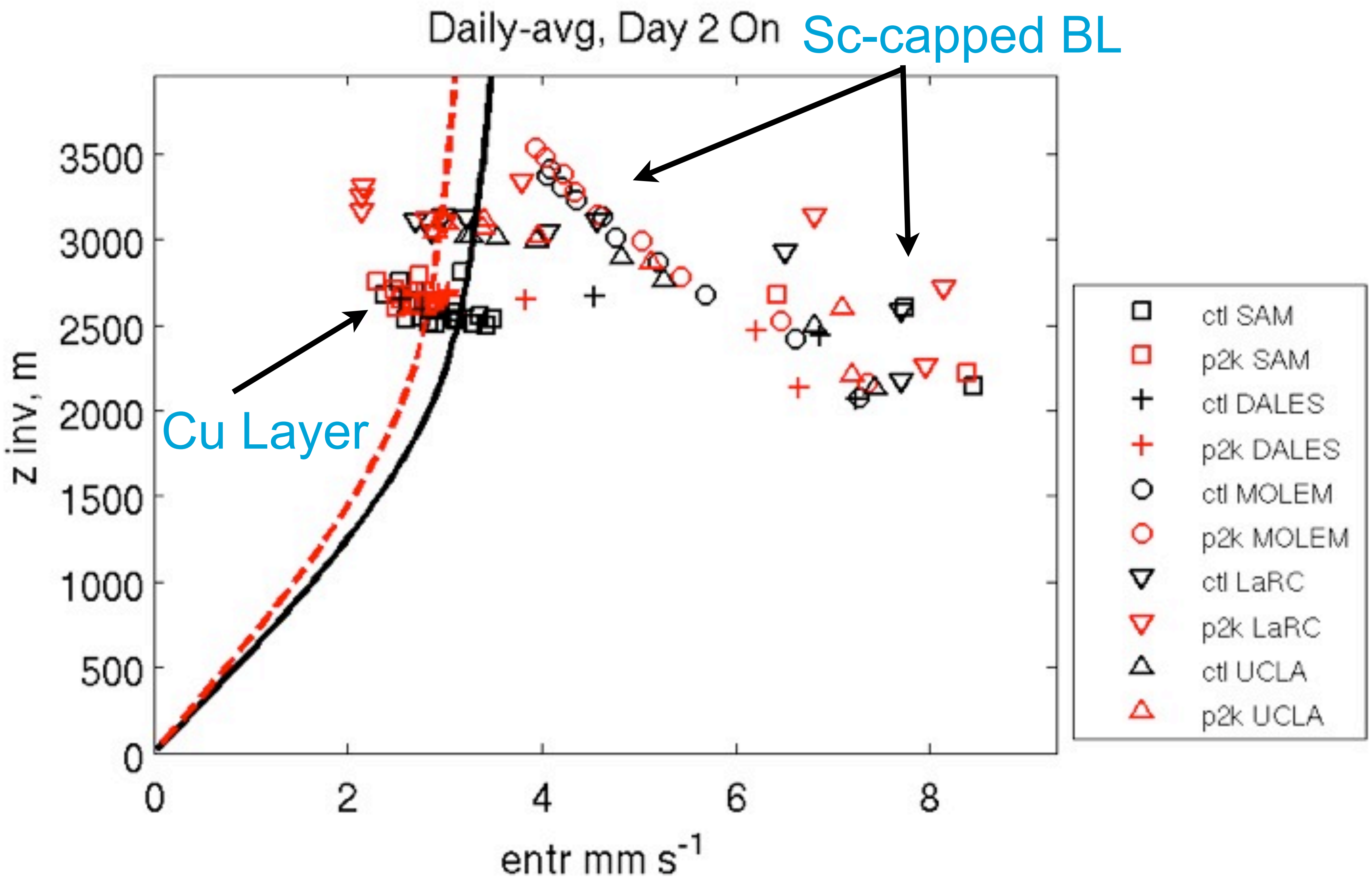
- Precip feedback in +2K runs of SAM/DALES, restrains deepening.
- Weak ΔSWCF changes, slight positive feedback in SAM.
- Precip increases in all models in +2K runs.

S6: Precipitation-Entrainment Feedback



- Deepening of trade inversion arrested by increase in precipitation.
- Precipitation stabilizes BL, removes liquid water from entrainment zone.

S6: Entrainment vs. Subsidence



- Strong entrainment by Sc-capped BL early in run.
- Weaker entrainment by Cu layer after Sc layer breaks down.
- Despite weaker subsidence, precipitation feedbacks restrain deepening of trade inversion in +2K runs.

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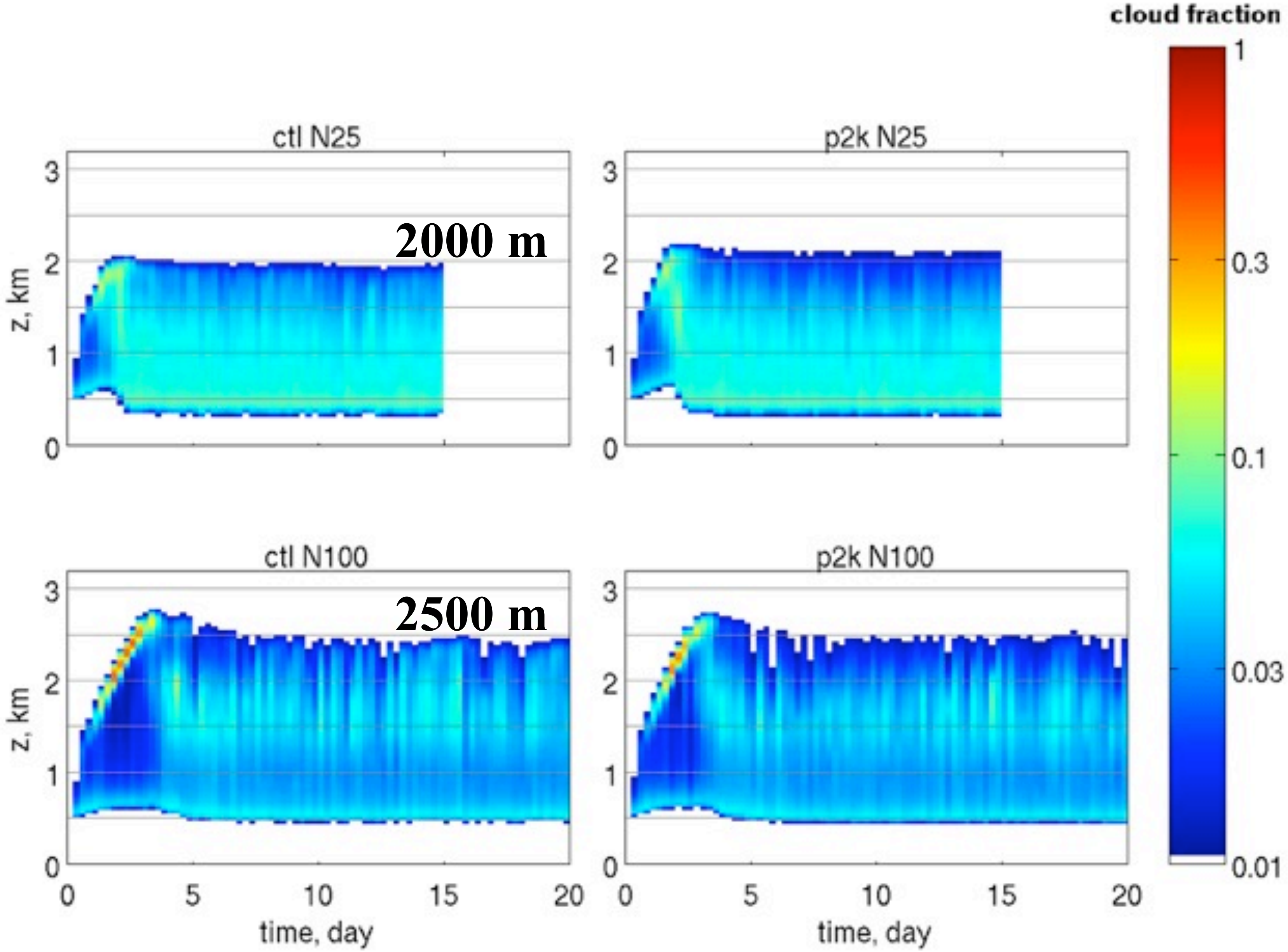
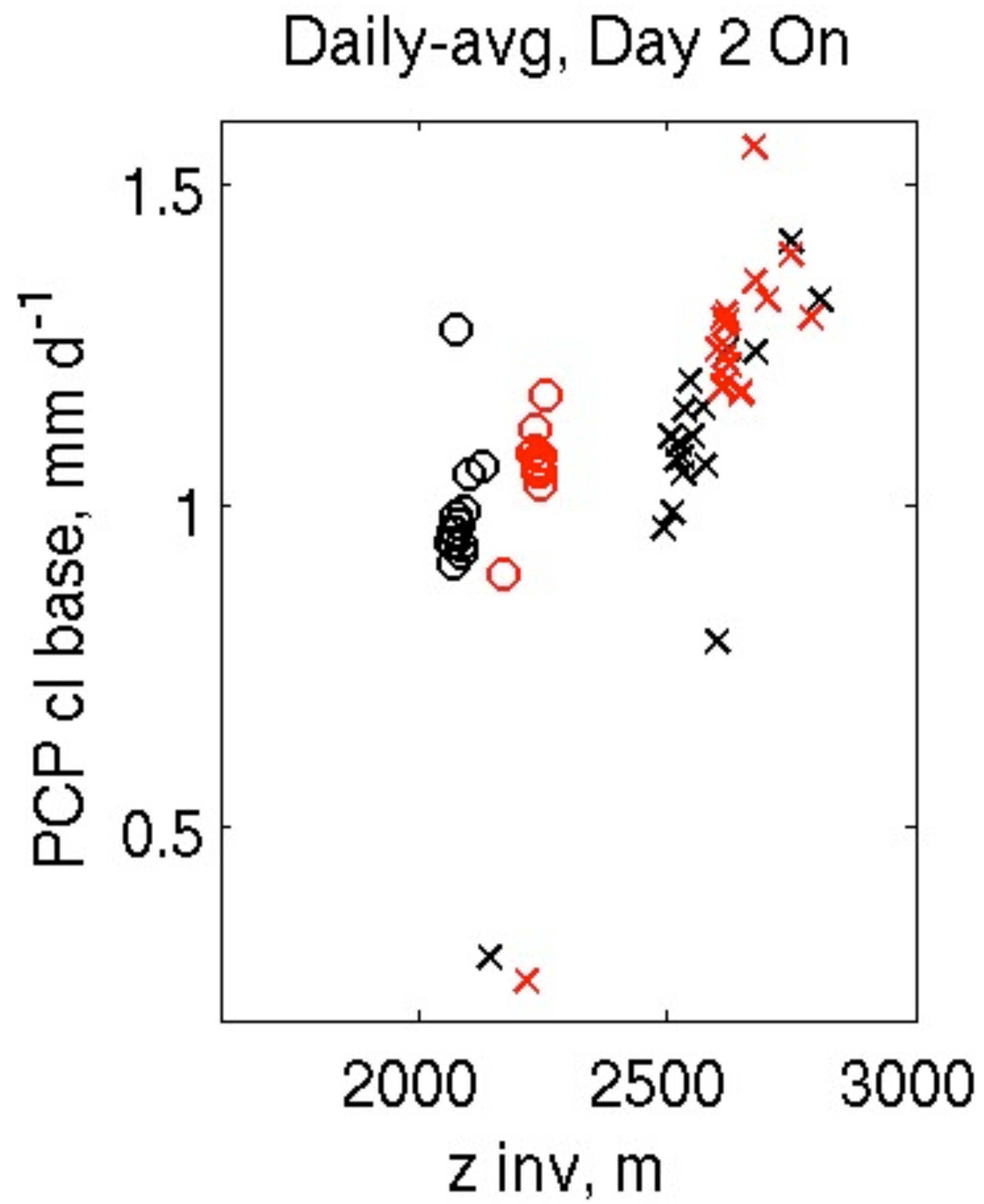
Photo courtesy Rob Wood

S6: Droplet Conc. Sensitivity Study in SAM



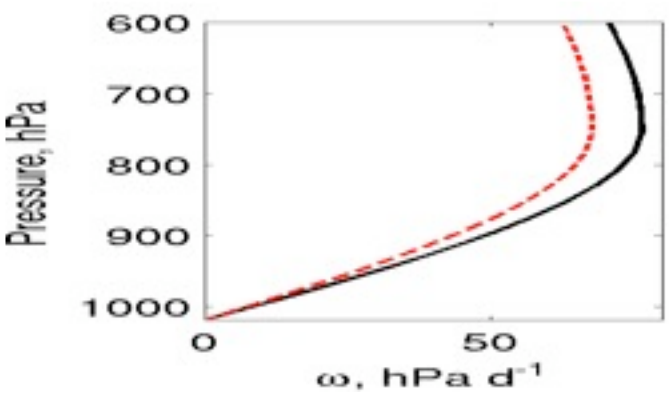


- New pair of runs w/Nc=25/cm3. Default is Nc=100/cm^3.
- Smaller Nc → Onset of precip at smaller zinv, restrains deepening.
- Also modifies ΔSWCF = 1.7 W/m^2 (Nc=100), 0.2 W/m2 (Nc=25)
- Take-Home Message: Nc uncertainty impacts inversion height.

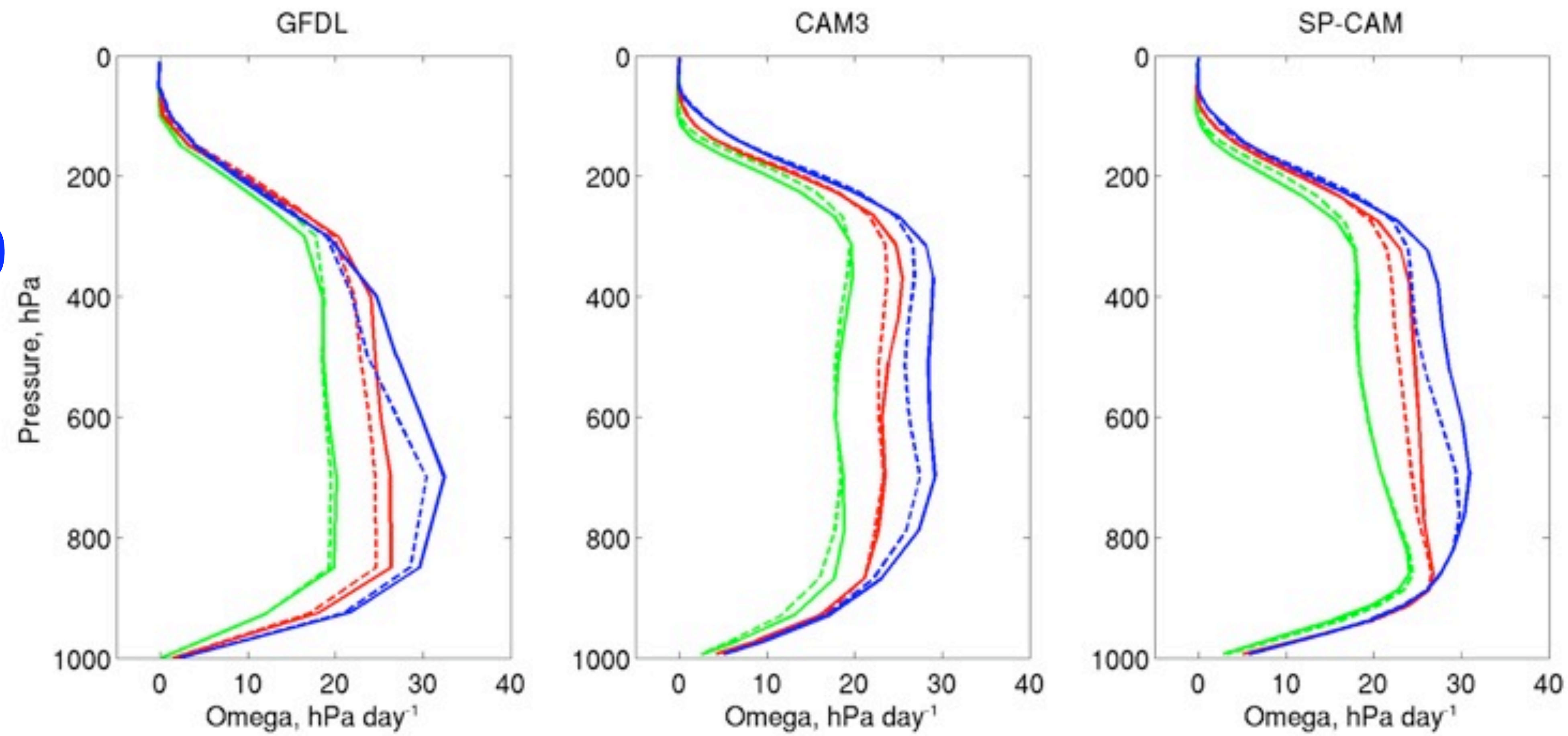
Uncertainty in Omega Changes

- CGILS uses single vertical structure: $\omega(p,lat) = \Omega(lat)\, \omega_0(p)$.
  Is this realistic?
- 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).

LTS70-80
LTS80-90
LTS90-100

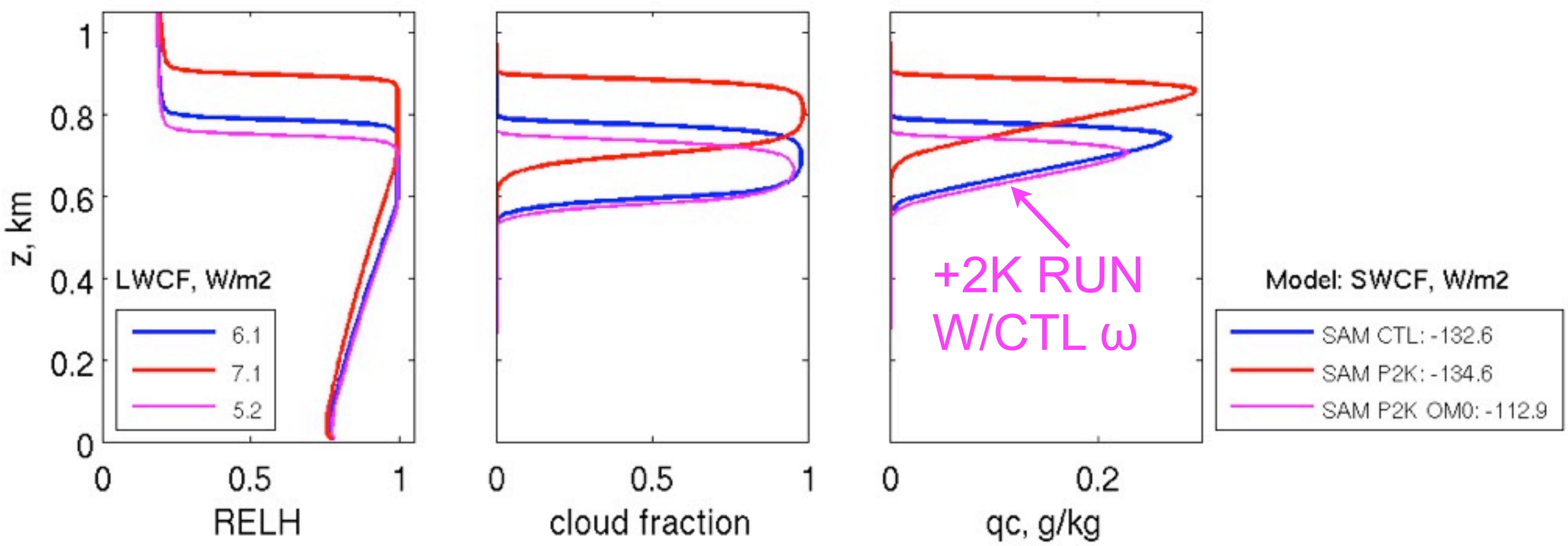


CGILS: S12



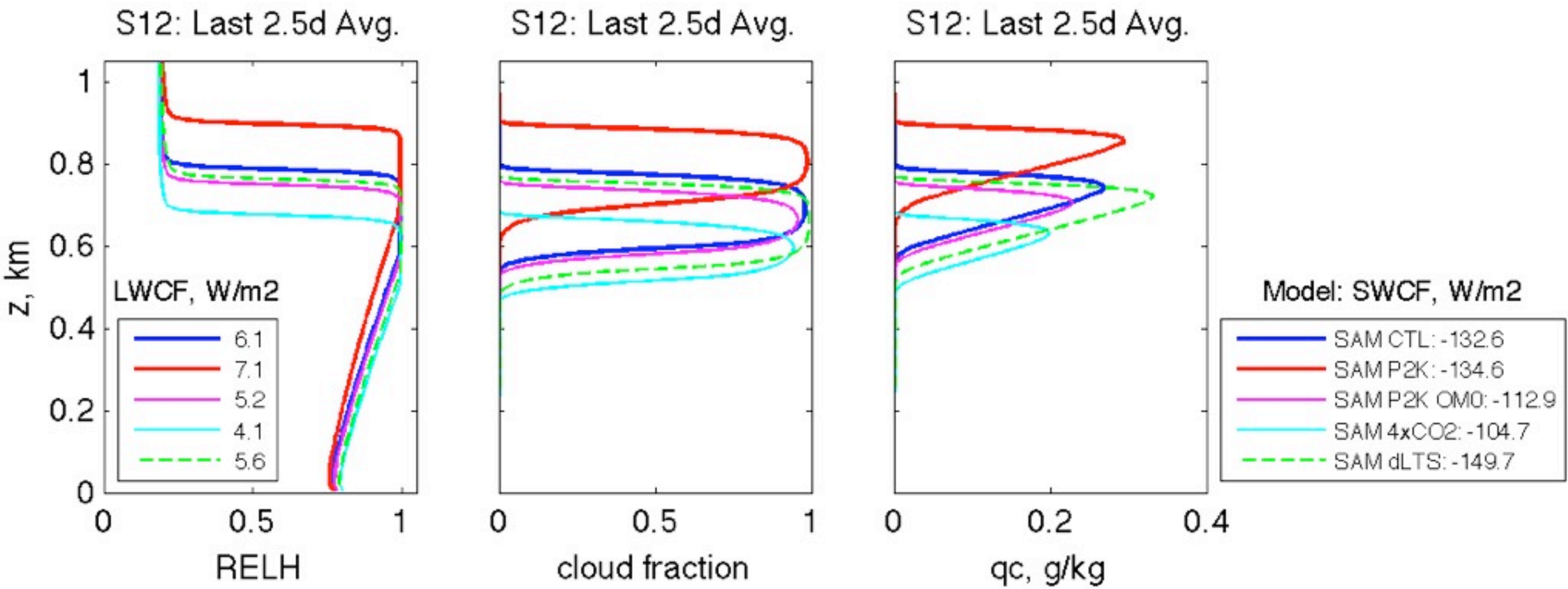
GCM Results Courtesy of Matt Wyant

S12: +2K Forcings with CTL omega



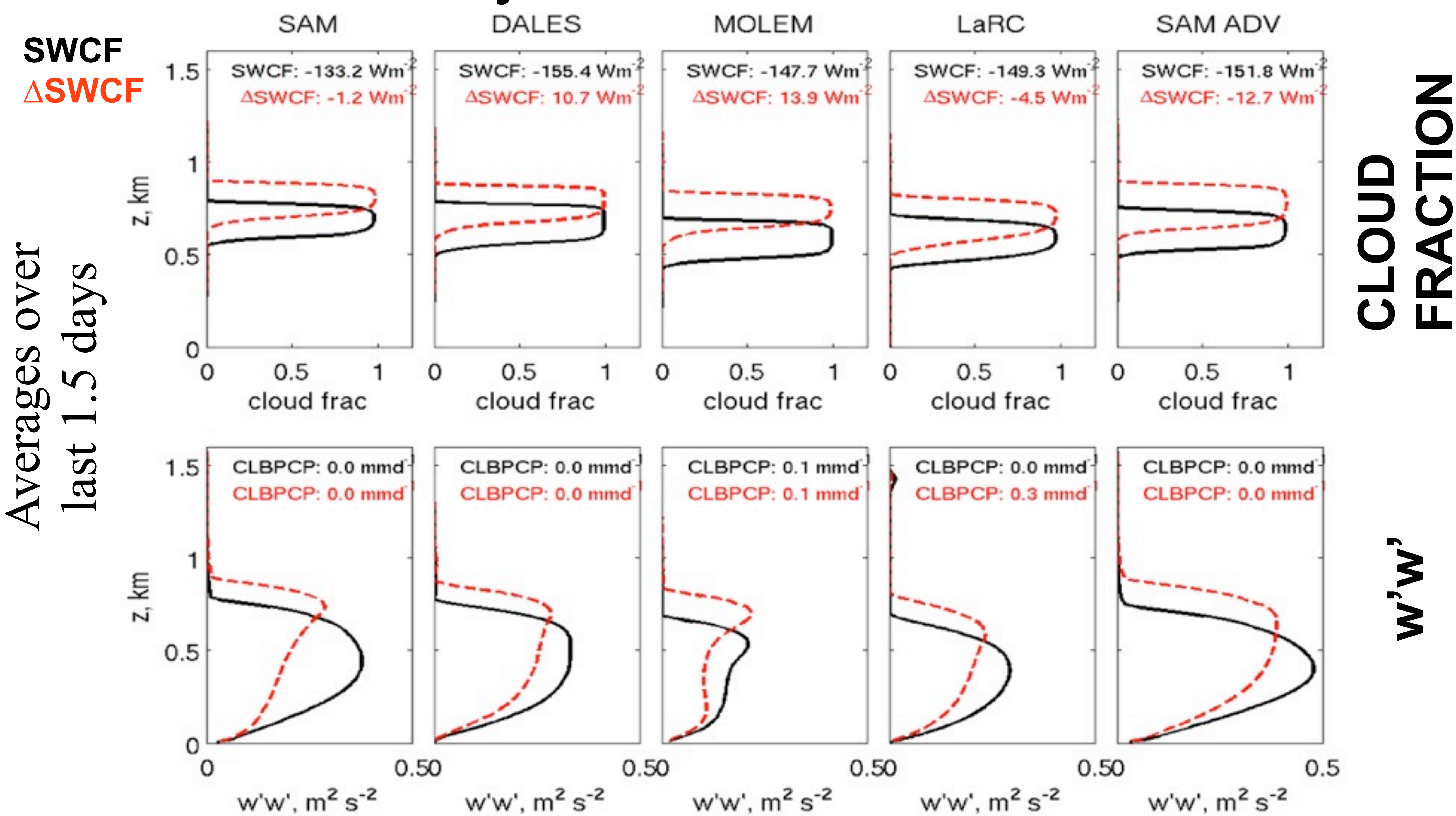
- +2K run w/CTL omega is slightly more decoupled, entrains less than CTL at same inversion height.
- SAM +2K response (similar in S11):
  - SWCF weakens at same inversion height,
  - SWCF strengthens as BL deepens.

S12: $4xCO_2$ and ΔLTS Sensitivity Studies



- $4xCO_2$ (CTL forcings w/hor. adv. adjusted in free troposphere):
  - Inversion lower and cloud thinner (ΔSWCF = +28 W/m^2).
- ΔLTS (SST+2K in deep tropics, SST+0K locally, uses +2K omega):
  - Inversion slightly lower but cloud thickens (ΔSWCF = -17 W/m^2).
- Downwelling LW at inversion similar in $4xCO_2$, ΔLTS cases.

S12: Sensitivity to SAM's Advection Scheme



- SAM run w/Blossey & Durran (2008) PPM-based advection.
  - selective limiting: only monotonic near perceived discontinuities.
- CTL cloud much thicker, BL better coupled, P2K cloud thickens more.

Outline

- Why look at low cloud feedback?
- Introduction to CGILS
- CGILS S12 Case Study: Coastal Stratocumulus
- CGILS S11 Case Study: Decoupled Stratocumulus
- CGILS S6 Case Study: Trade Cumulus
- Sensitivity Studies in SAM
- Discussion/Conclusions

Photo courtesy Rob Wood

Discussion/Conclusions

- Qualitative agreement among models on cloud structure.
- CGILS S12 (Coastal SCu):
  - CTL runs well-mixed, +2K runs deepen with reduced omega.
  - Disagreement among models about sign of feedback.
- CGILS S11 (Cu under SCu):
  - CTL runs decoupled, +2K runs deeper and more strongly decoupled.
  - Sign of feedback uncertain.
- CGILS S6 (Trade Cu):
  - Precipitation feedbacks restrain deepening in most models.
  - Weak cloud feedbacks.
- SAM sensitivity studies:
  - Cloud thins in S11 & S12 +2K runs if +2K climate omega is unchanged.
  - Inversion sinks and cloud thins in $4xCO_2$. Cloud thickens w/ΔLTS>0.
- Continuing work:
  - Other climate perturbations for the group(?): $4xCO_2$, ΔLTS, free trop q.
  - Tease out feedback mechanisms: Deepening-warming decoupling, changes in BL radiative driving, ΔCTEI, precipitation feedbacks.

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Thank You.
Questions?