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:

- MOLEM: Adrian Lock (UKMO),
- DALES: Stephan de Roode (Delft, the Netherlands),
- 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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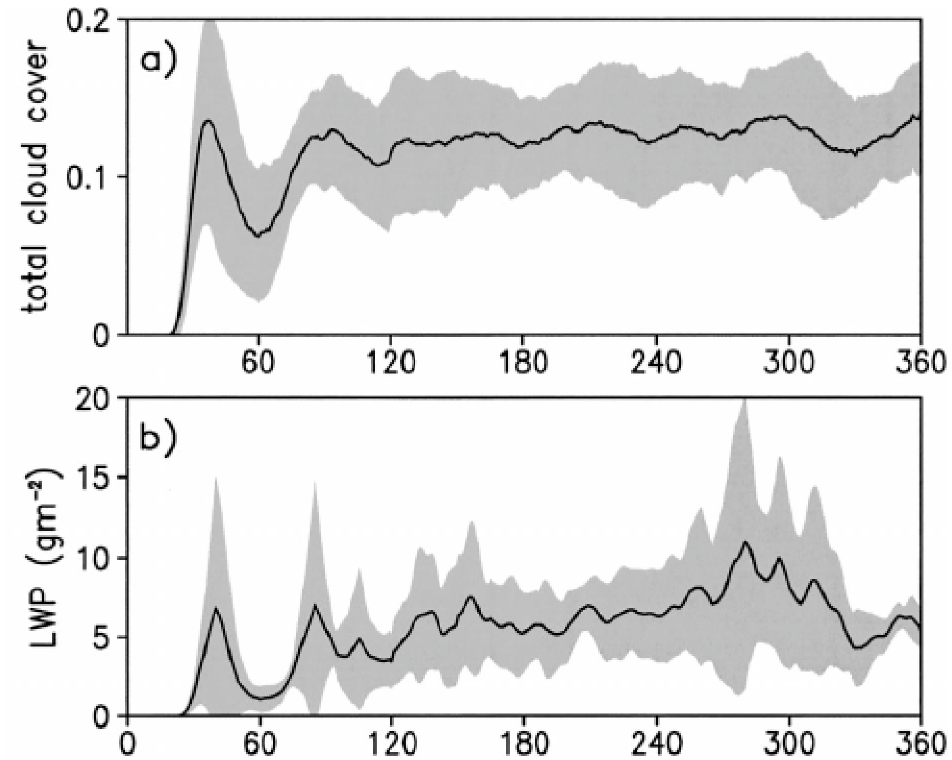
Photo courtesy Rob Wood

Motivation

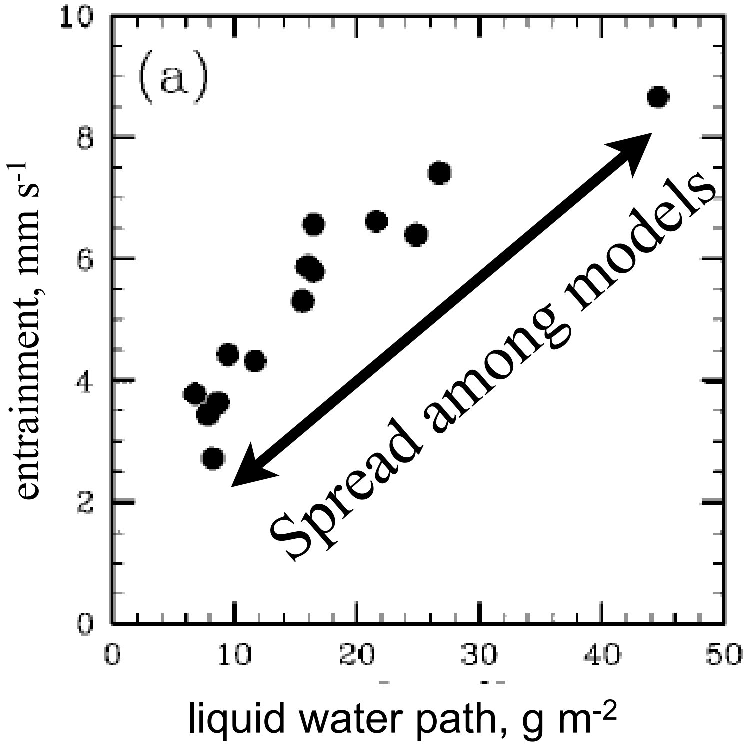
- Cloud feedbacks are among the most poorly constrained components of climate sensitivity.
- Much of scatter in net cloud feedback comes from marine boundary layer clouds (e.g., Bony & Dufresne, 2006).
- LES provides the most realistic simulation tool for boundary layer clouds.
- However, uncertainties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

Past Multi-Model Studies of Low Clouds With LES

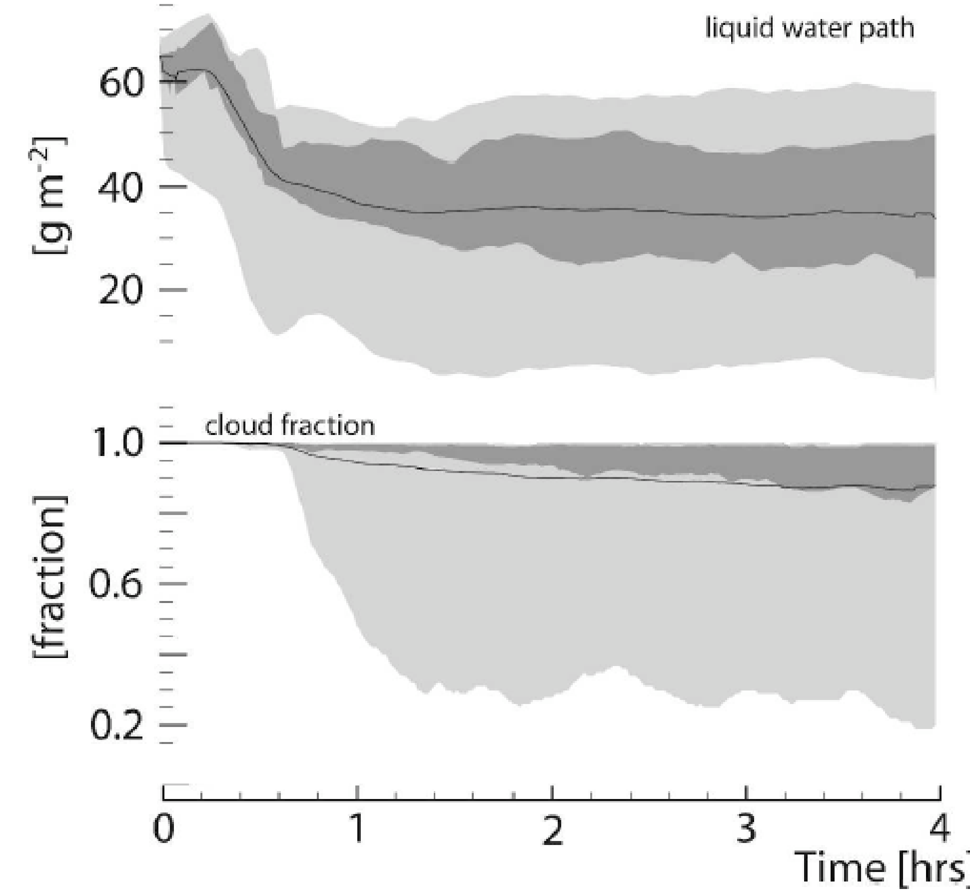
BOMEX: Trade Cu
Siebesma et al (2003)



ATEX: Cu under SCu
Stevens et al (2001)

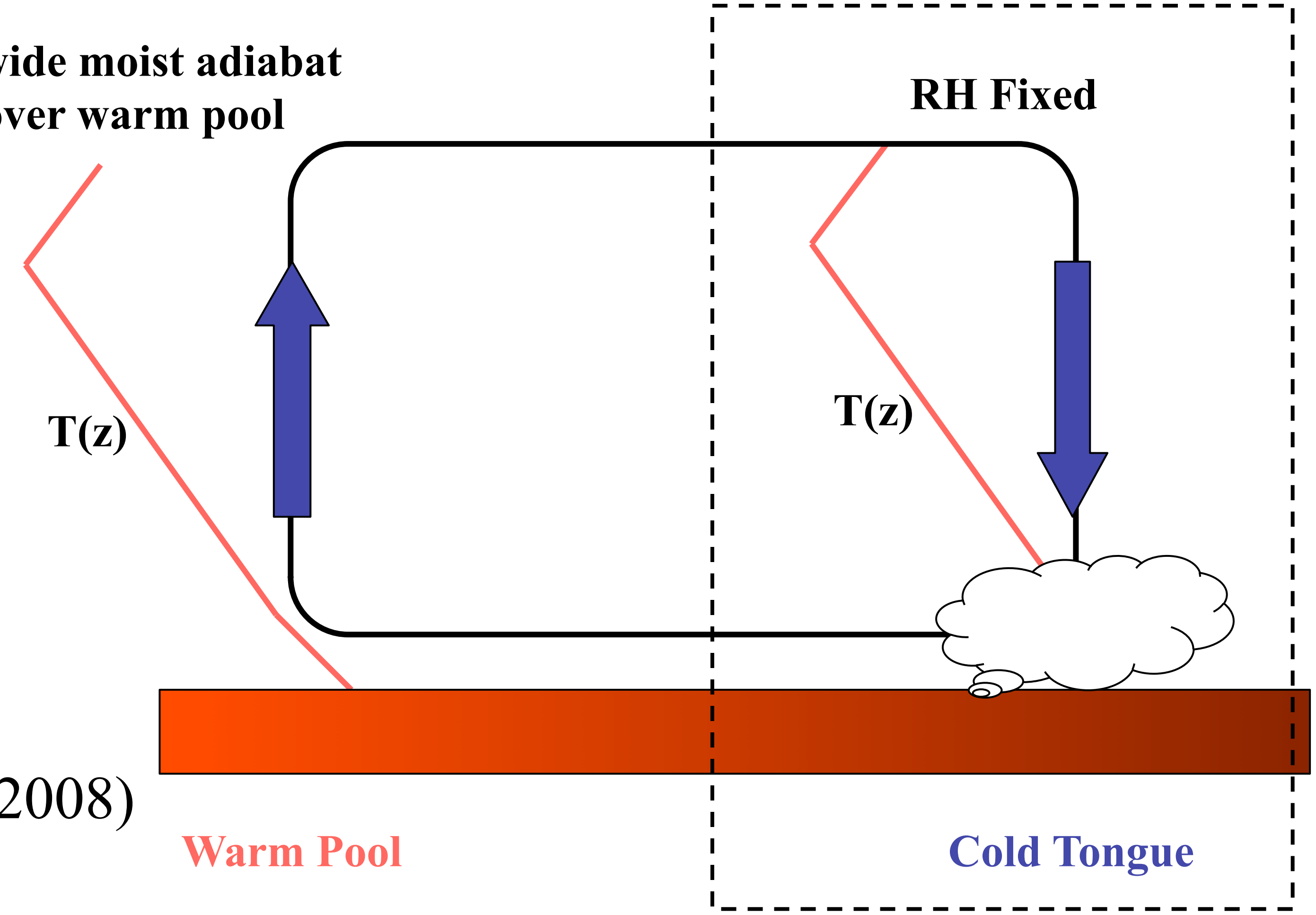


DYCOMS RF01: SCu
Stevens et al (2005)



- 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, $4xCO_2$ 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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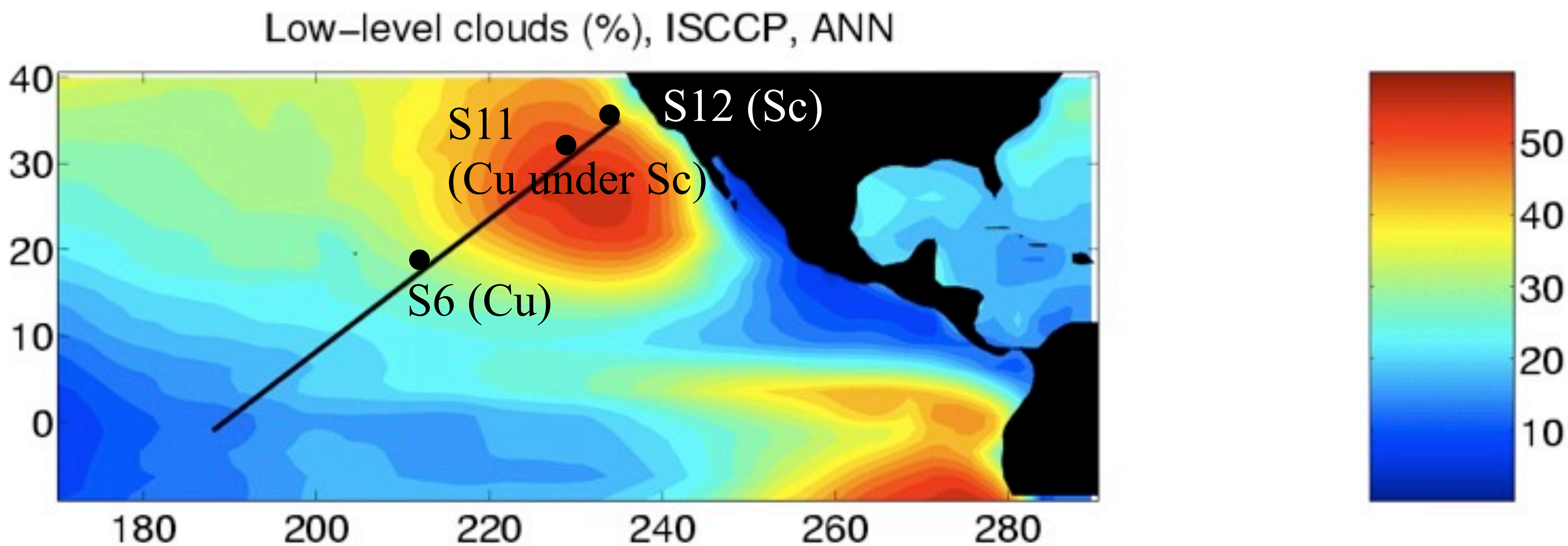
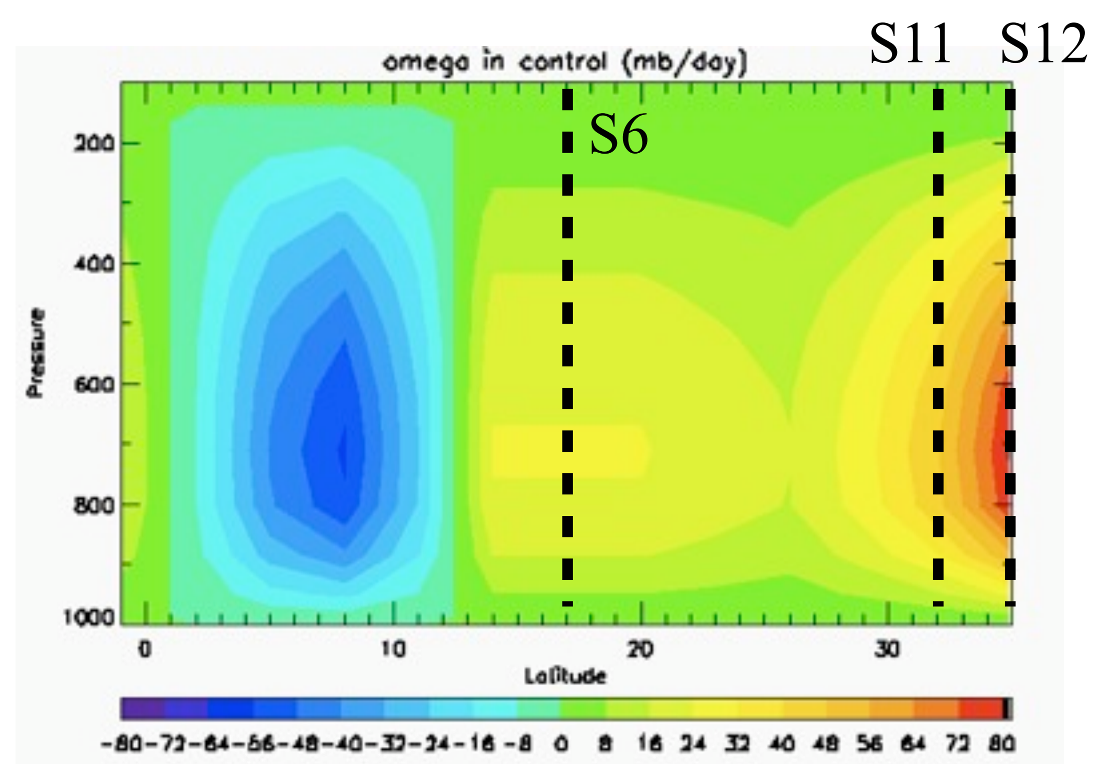
CGILS: CFMIP/GCSS Intercomparison of Large-eddy and Single-column models



- 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.



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

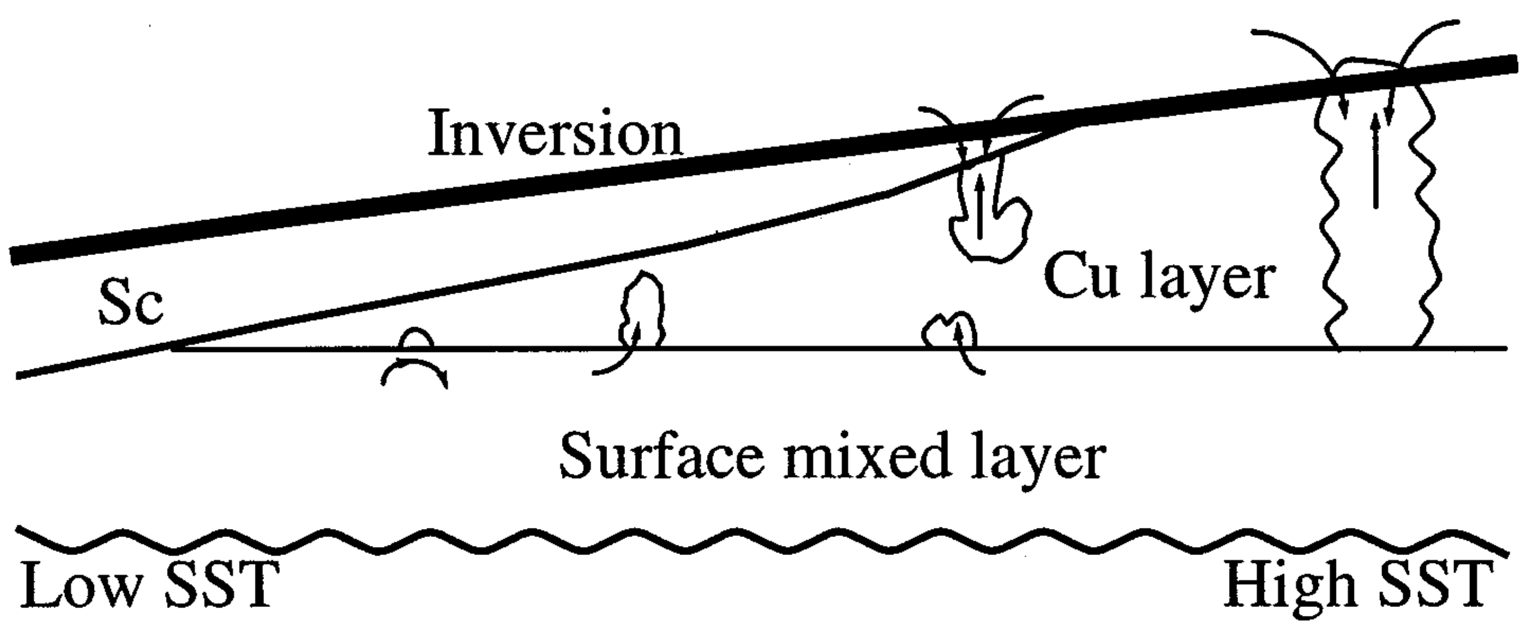
CGILS: Eulerian View of Sc→Cu Transition

Shallow MBL → Deep MBL

Decoupling Cu formation	Sc evaporation

Well Mixed Sc → Cu under Sc → Cu

Subcloud buoyancy flux > 0. Thin cloud layer	Well mixed surface, Sc layers $d\theta/dz$ slightly stable Strong conditional instability over increasing depth. Cu begin to entrain through inversion.	Drying due to Cu entrainment slowly evaporates Sc



S12 S11 S6

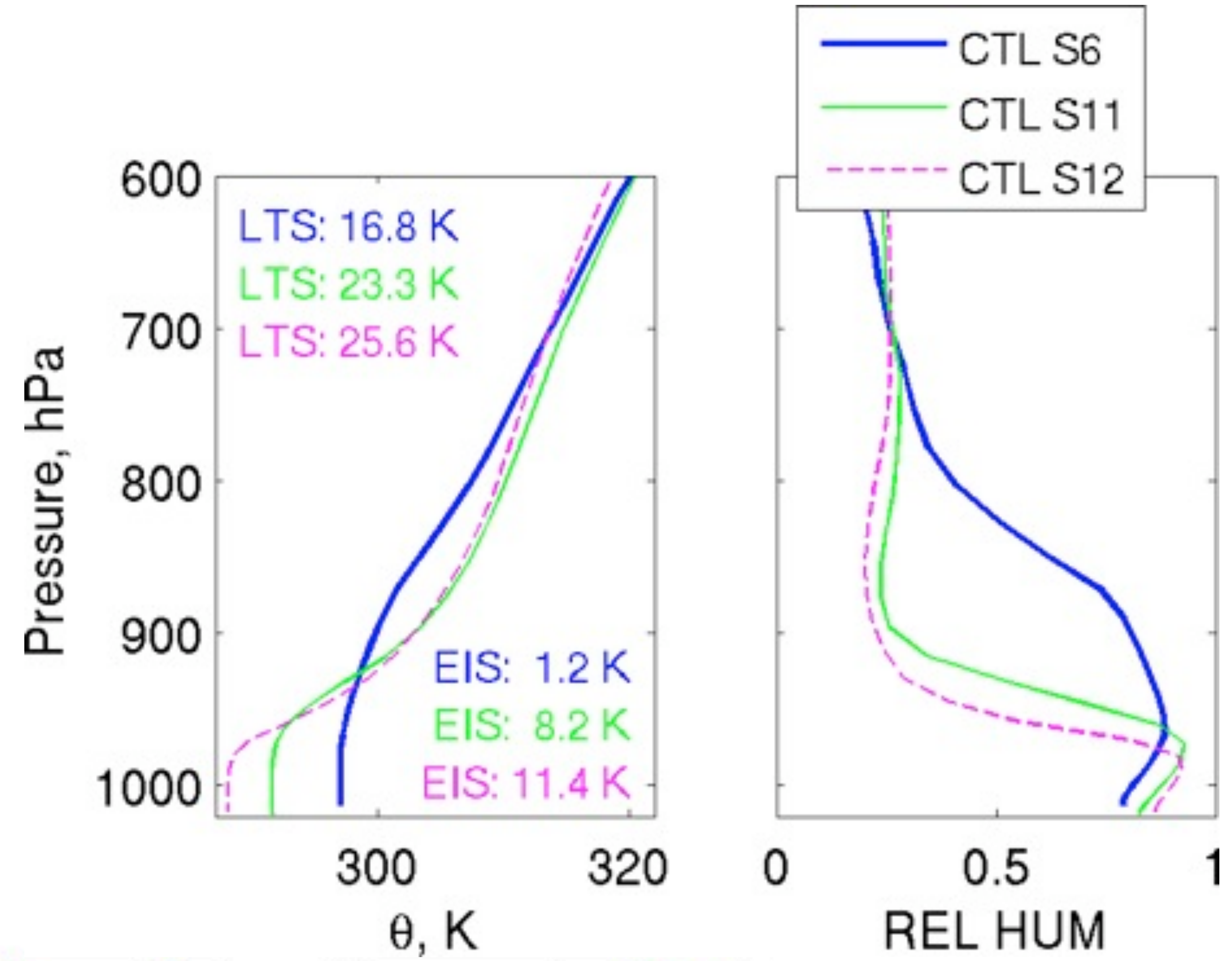
Wyant et al. (1997)

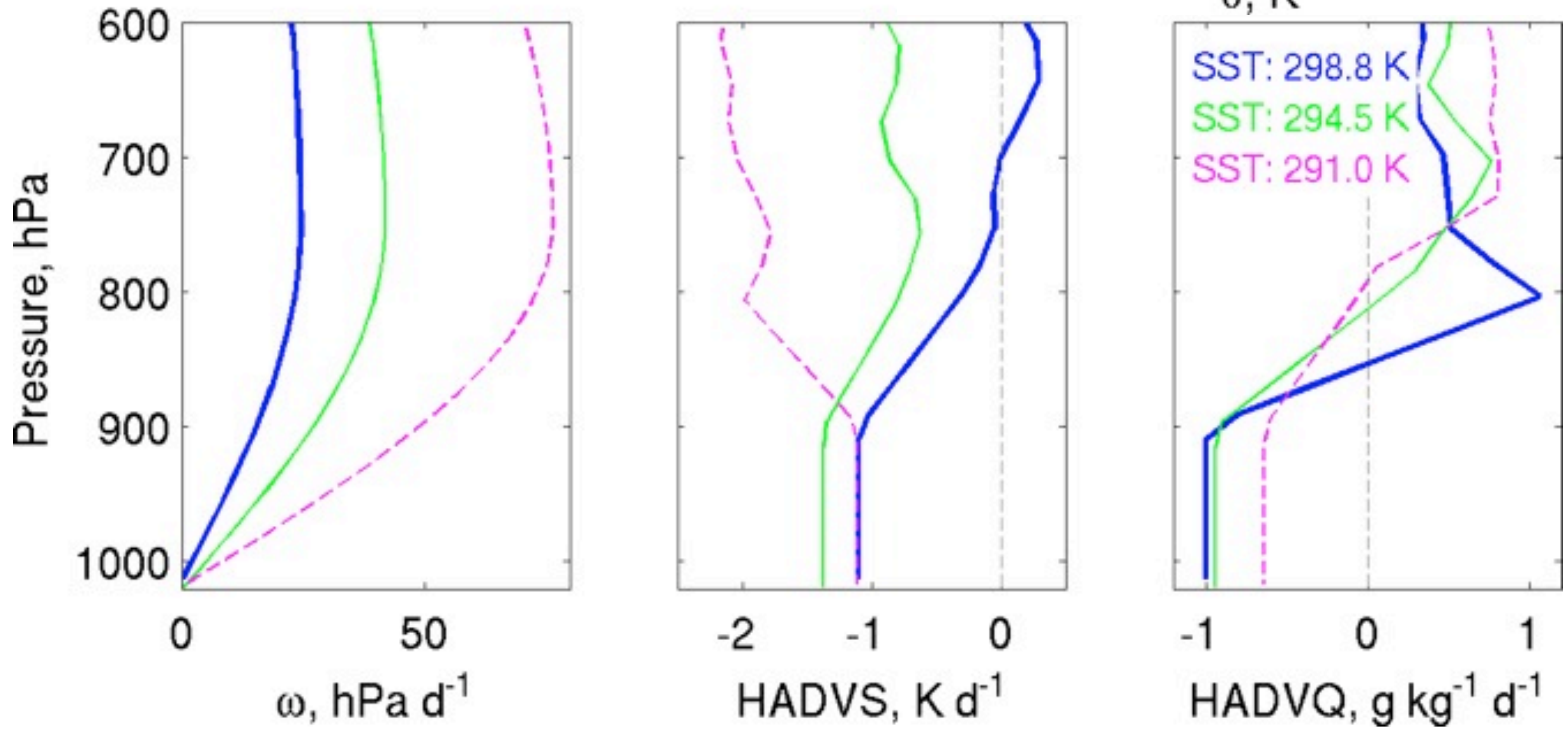
CGILS column cloud feedback intercomparison

- 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

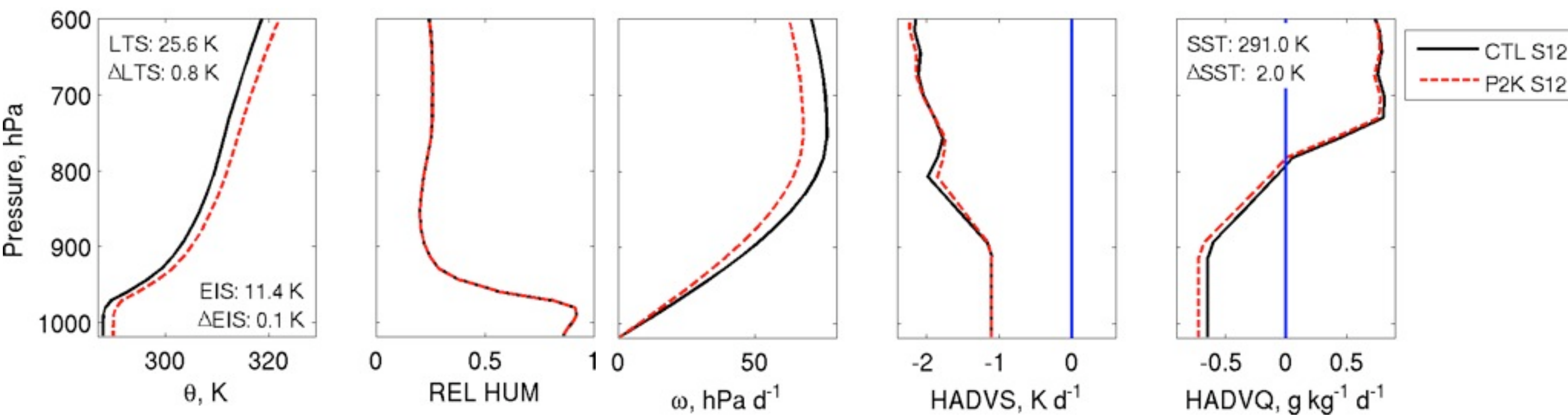
- Control climate forcings:
  - ECMWF July climatology,
  - large-scale advection at low levels ~ SST gradient,
  - advective tendencies aloft balance energy/moisture budgets.





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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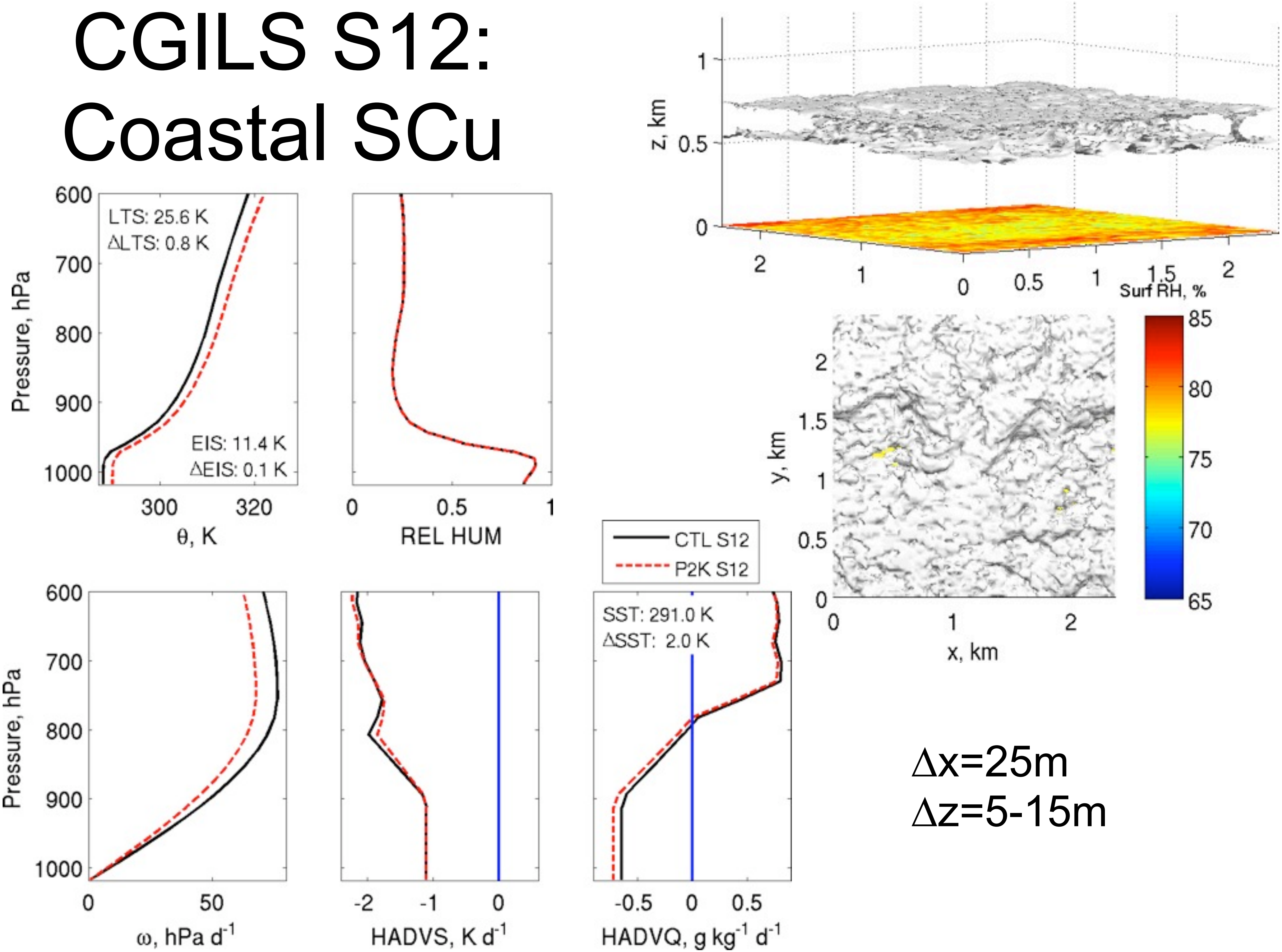
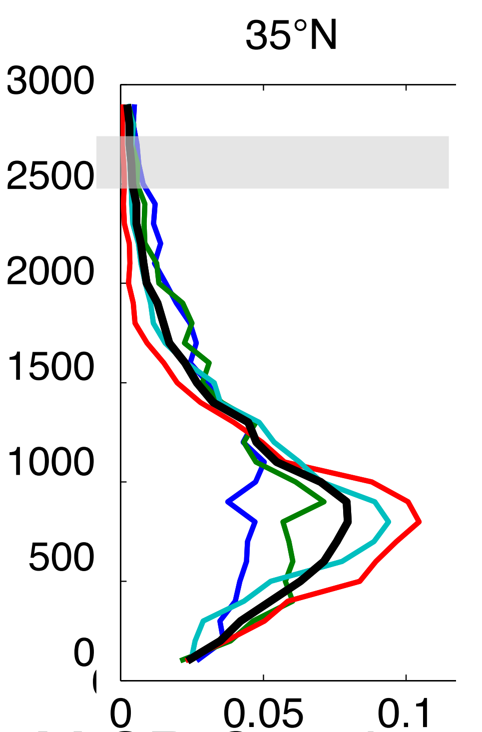
Photo courtesy Rob Wood

CGILS S12: Coastal SCu

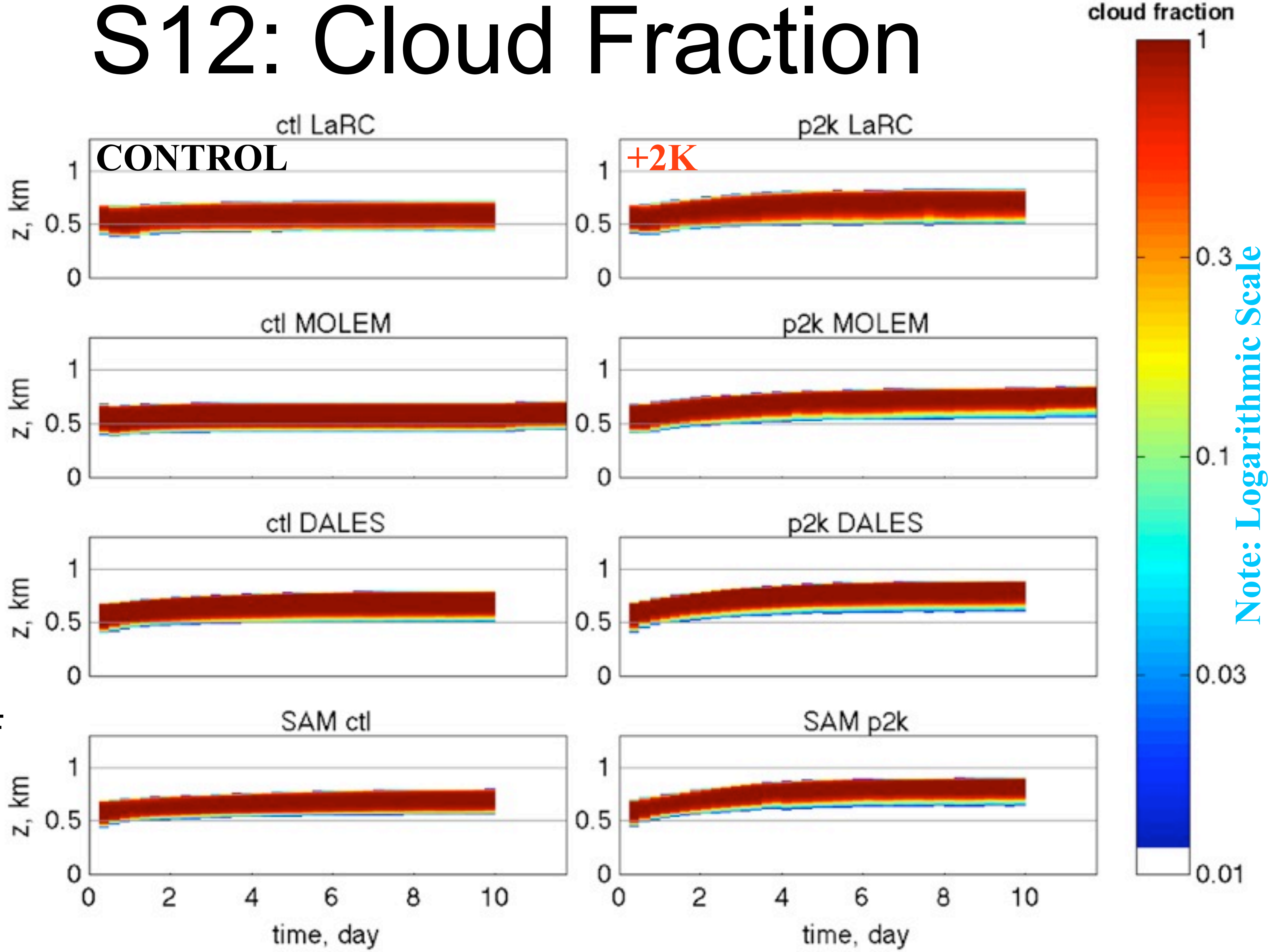


Δx=25m
Δz=5-15m

S12: Cloud Fraction

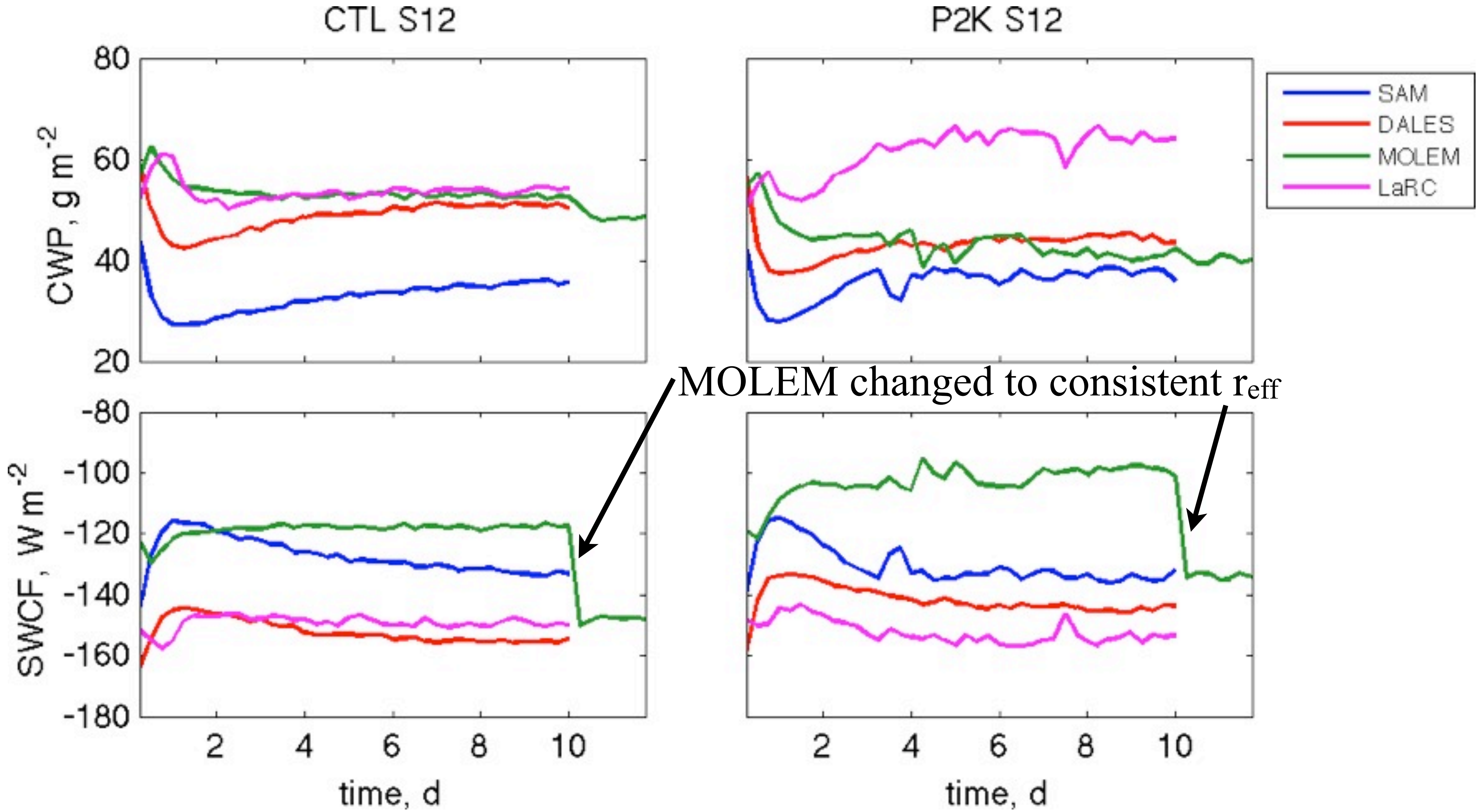


MISR Cloud Top Height PDF Courtesy of J. Karlsson.



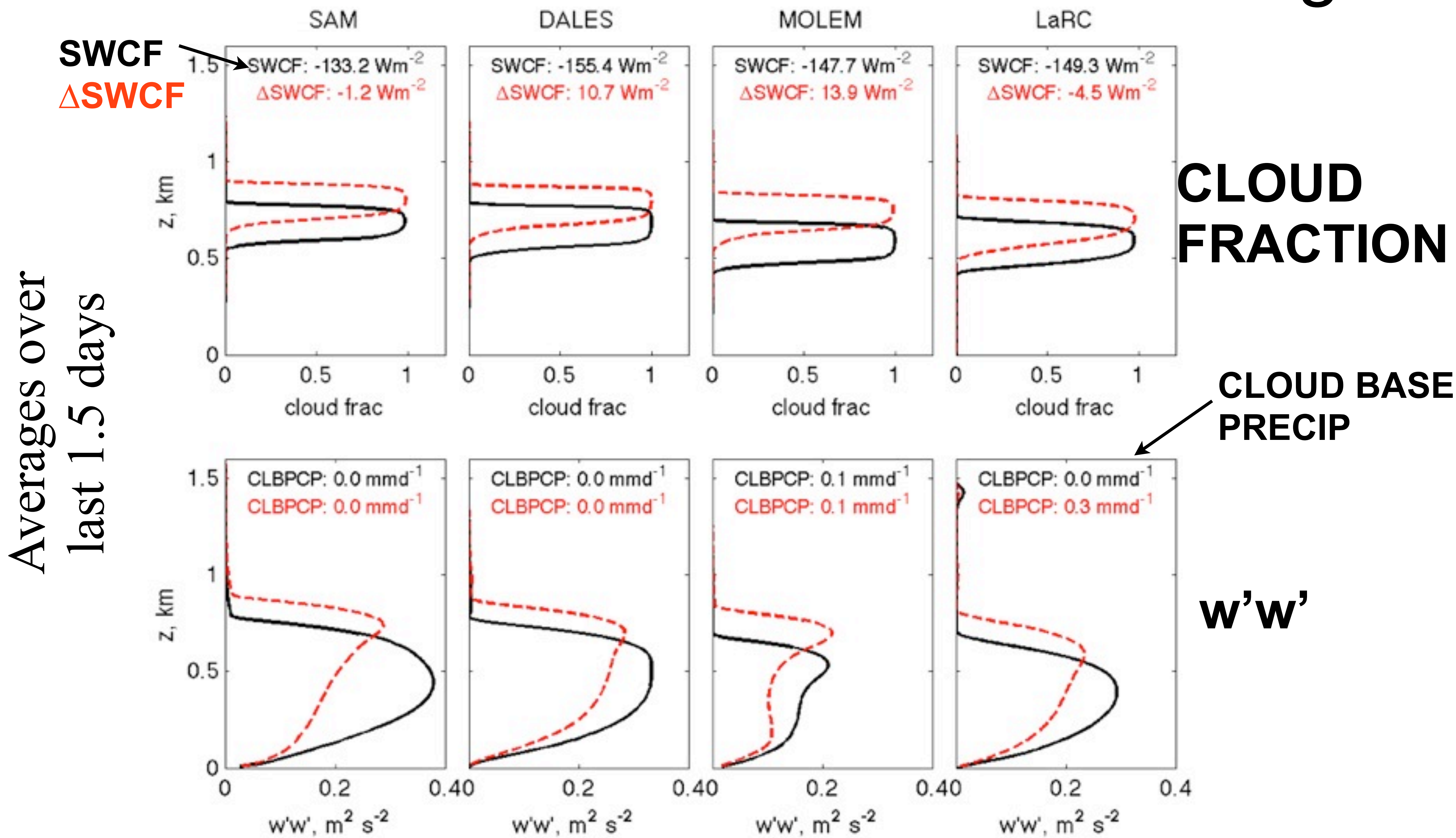
- Models agree well for a case with a strong inversion.
- Control case well-mixed. +2K runs decouple and deepen.

S12: Evolution of Cloud/SWCF



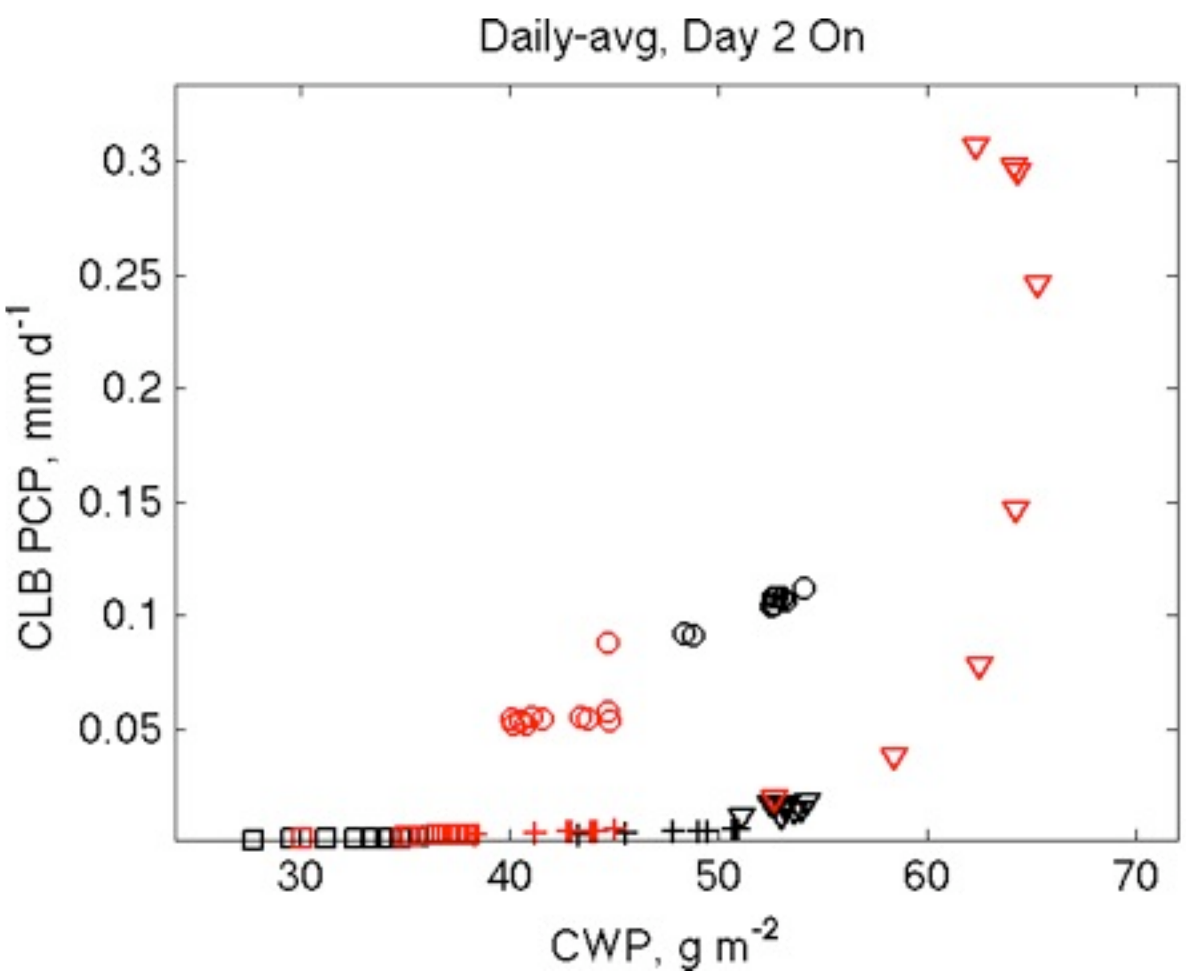
- Quantitative differences remain among models despite extensive efforts to homogenize model setup, radiation, surface flux treatment.
- Note fast/slow timescales in evolution of CWP, SWCF.

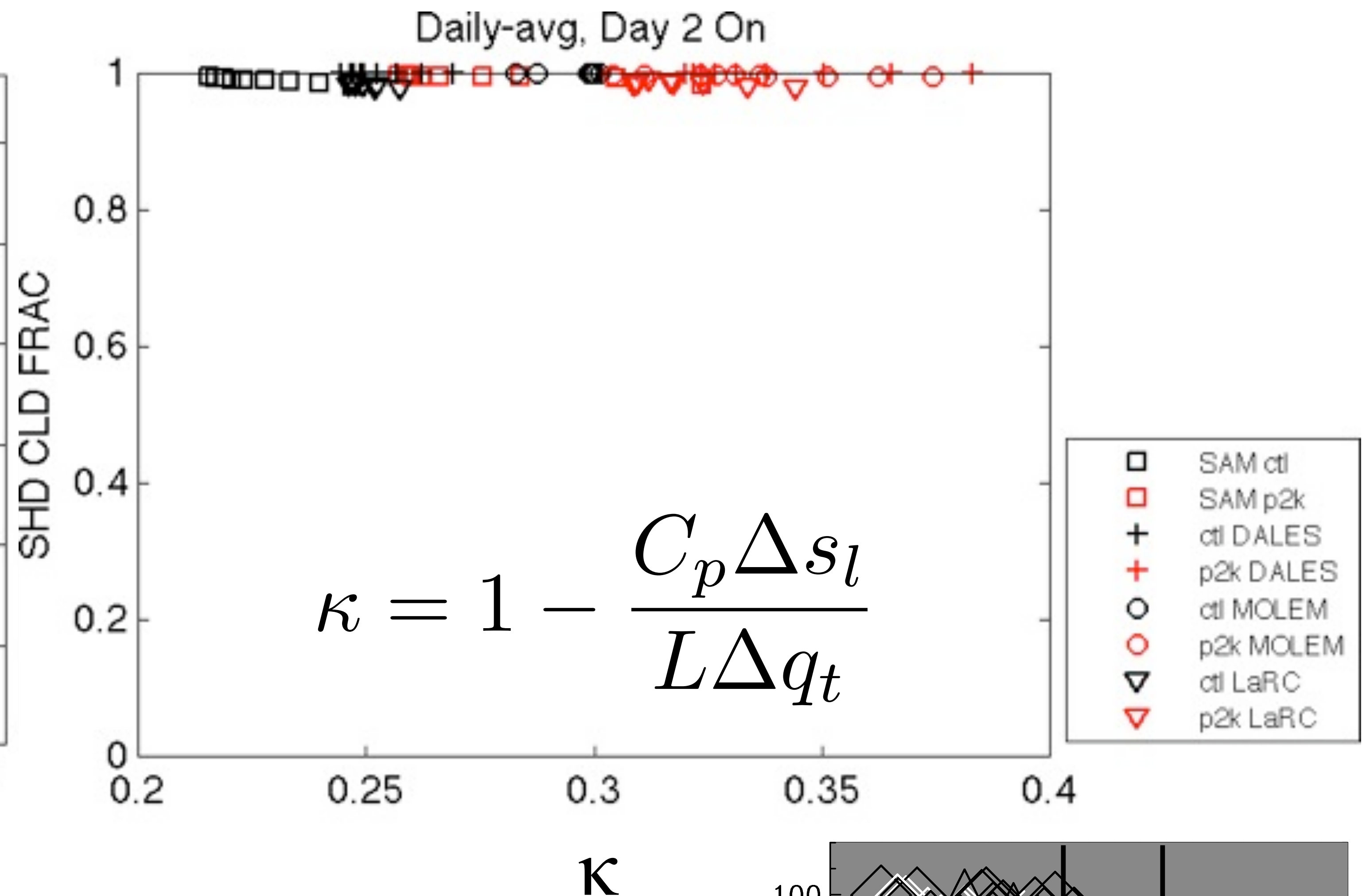
S12: CTL→+2K Cloud/Turbulence Changes



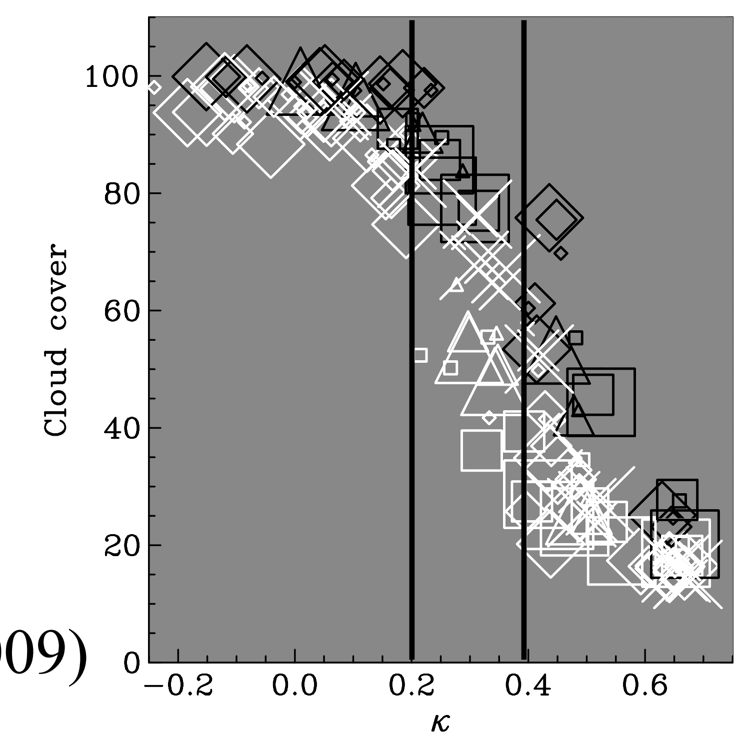
- Models deepen uniformly, show more decoupling in w'w' profiles.
- Strong positive ΔSWCF (>10W/m2) in DALES & MOLEM.
- Weaker negative feedback in SAM & LaRC.

S12: Precip-CWP relationships, Lock diagram





- 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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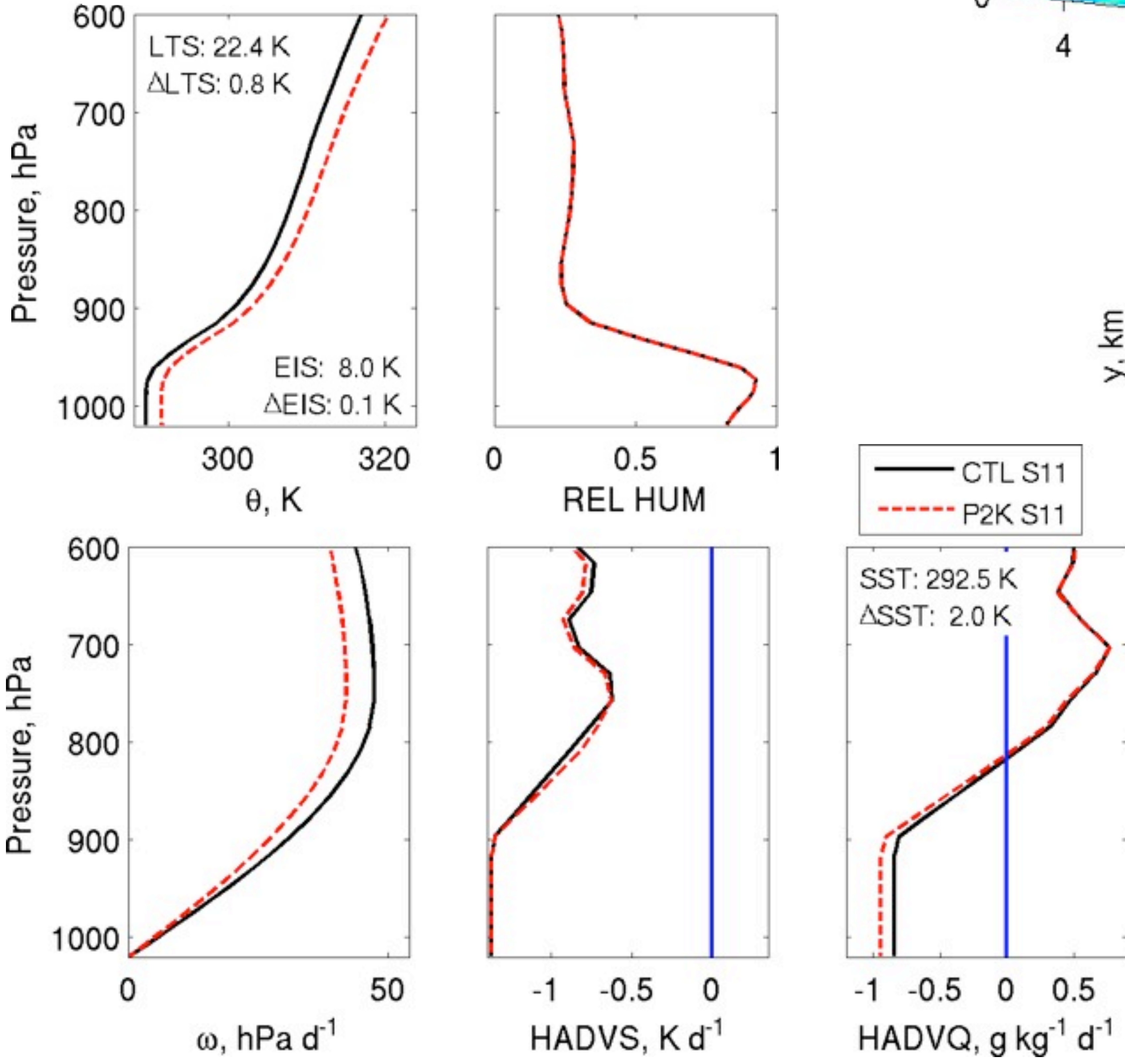
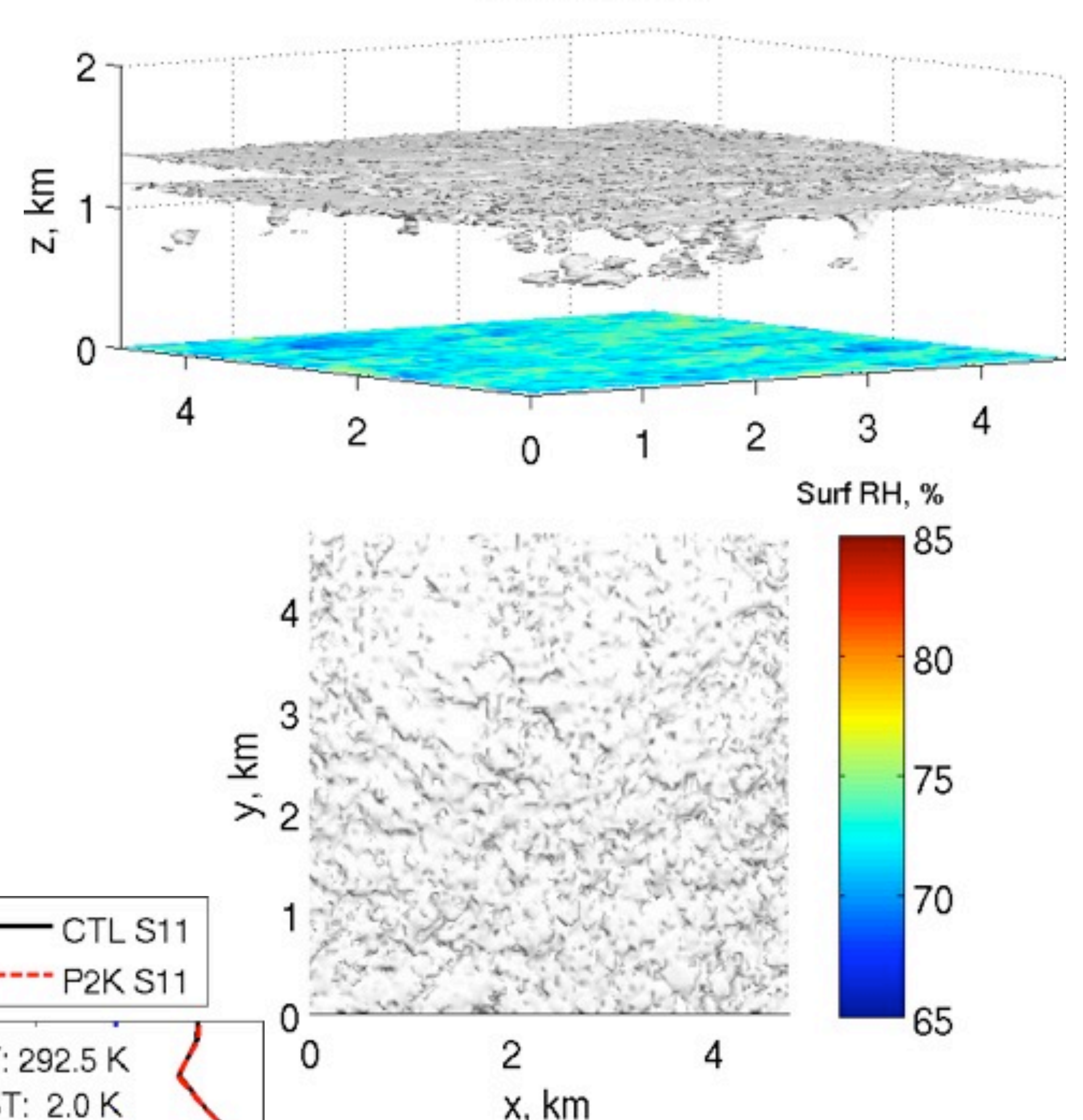
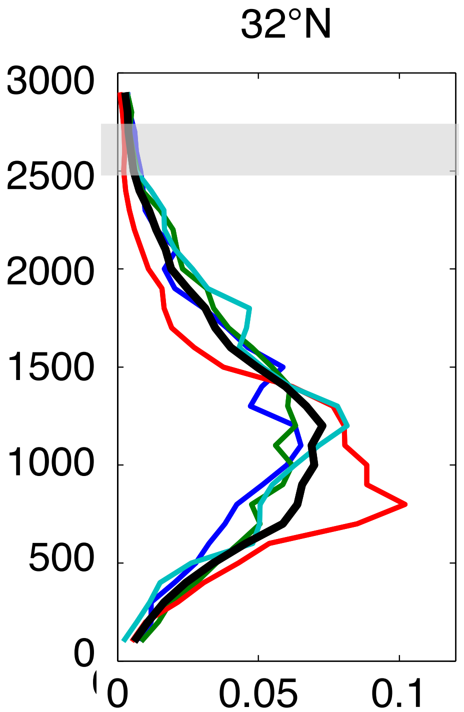
CGILS S11: Cu under SCu



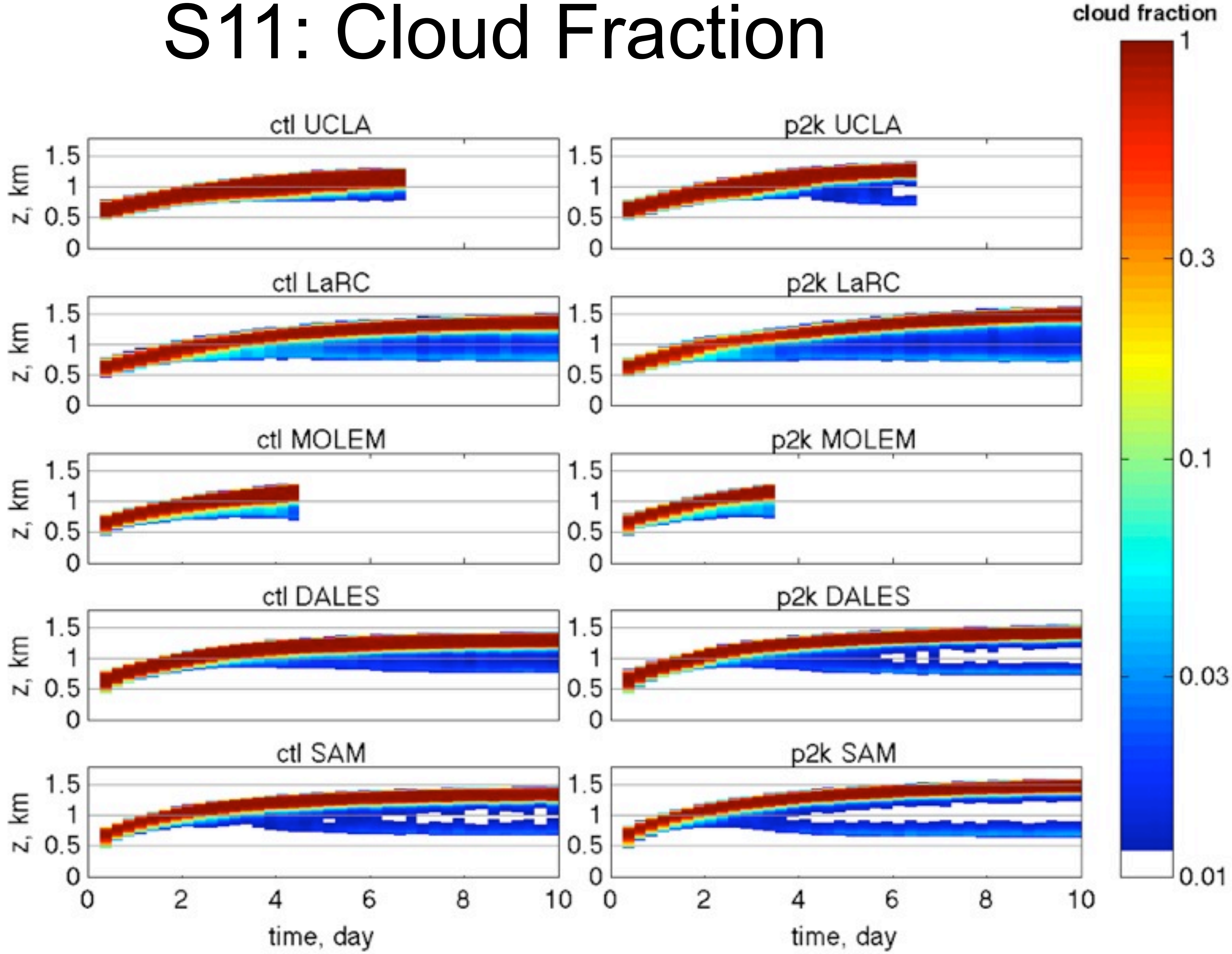


Δx=50m
Δz=5-25m

S11: Cloud Fraction

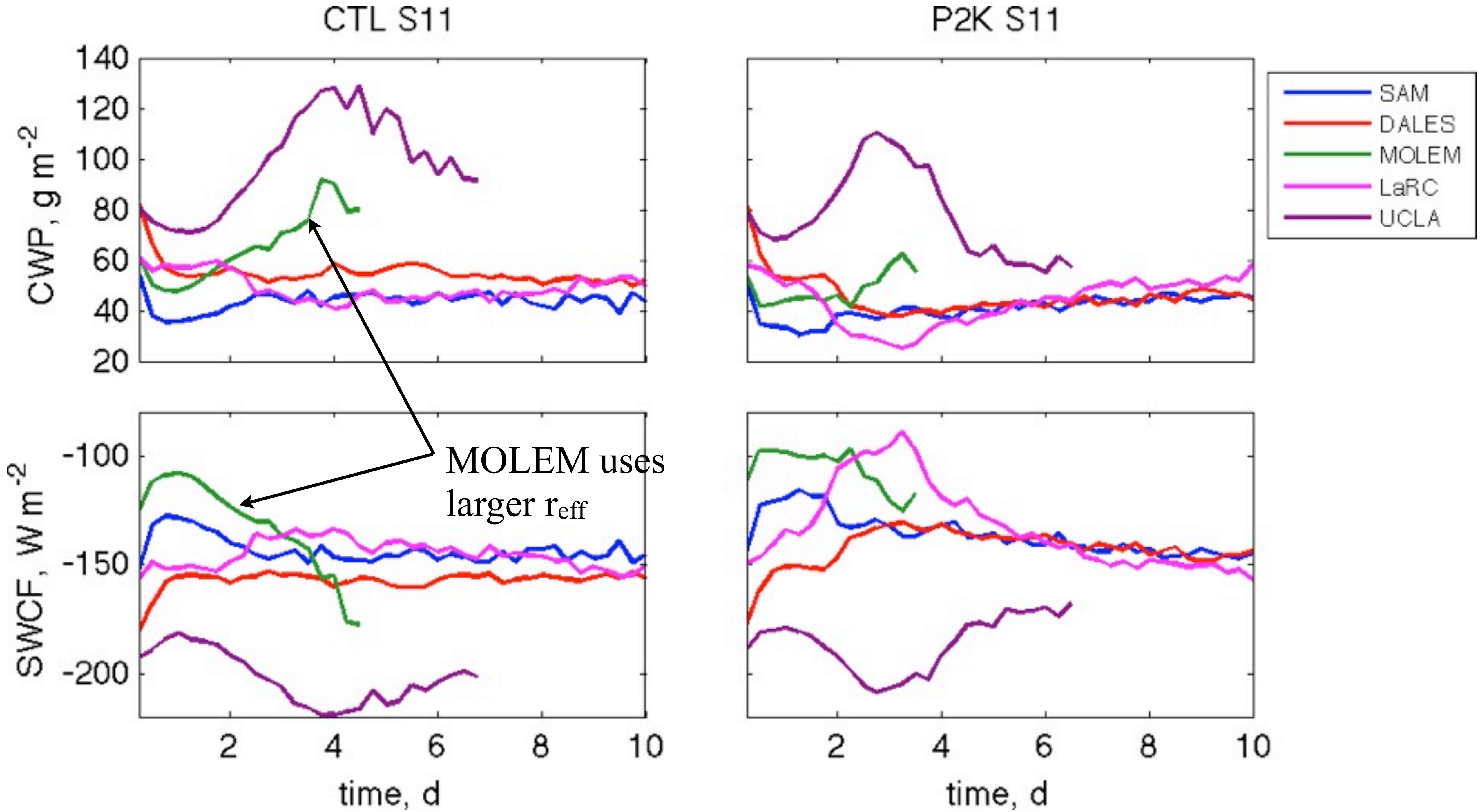


MISR Cloud Top Height PDF Courtesy of J. Karlsson.



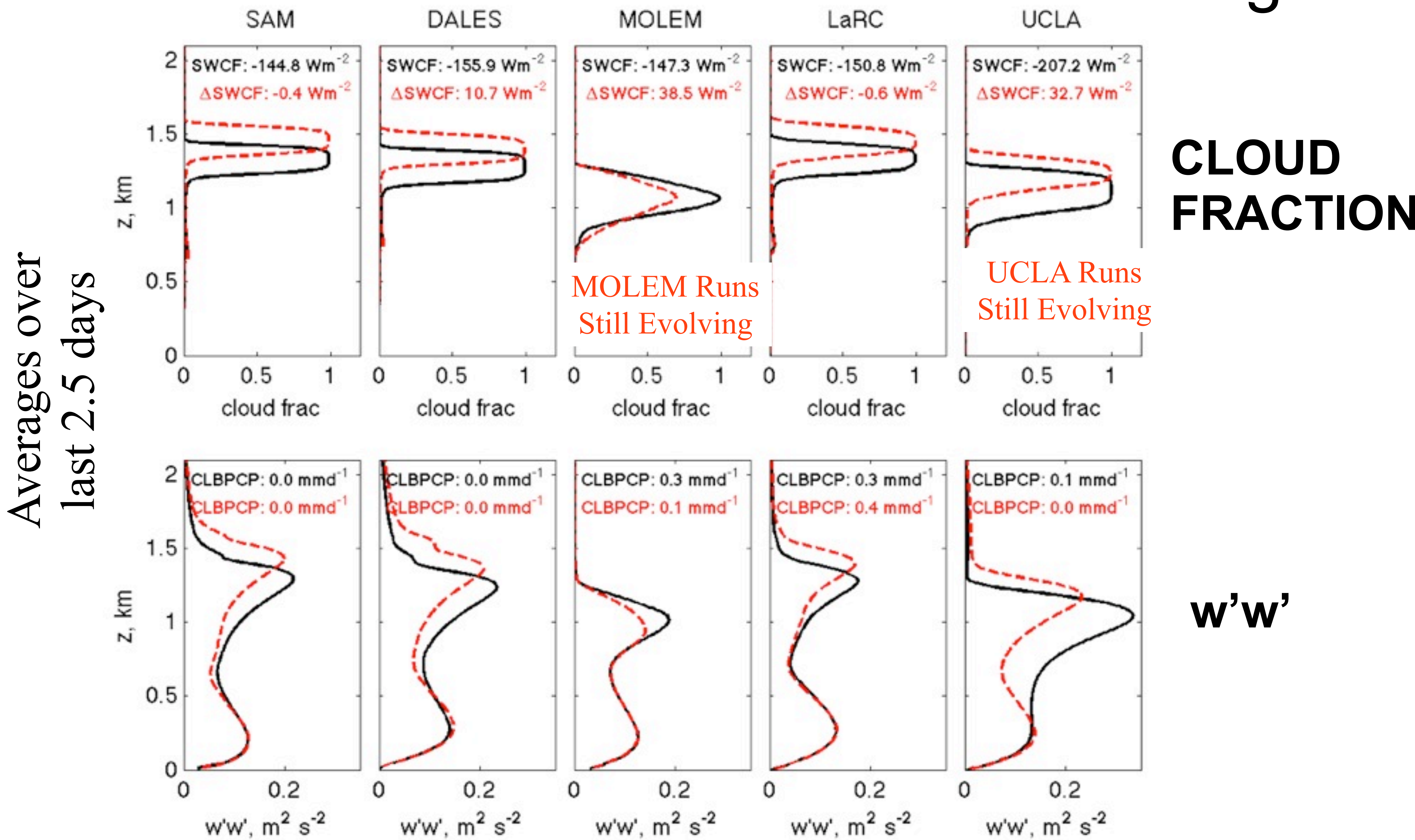
- Models broadly consistent when Δz=5m. (LaRC uses Δz=25m.)
- Initial stratocumulus layer decouples after deepening.
- +2K runs more decoupled with higher inversion than CTL.

S11: Evolution of Cloud/SWCF



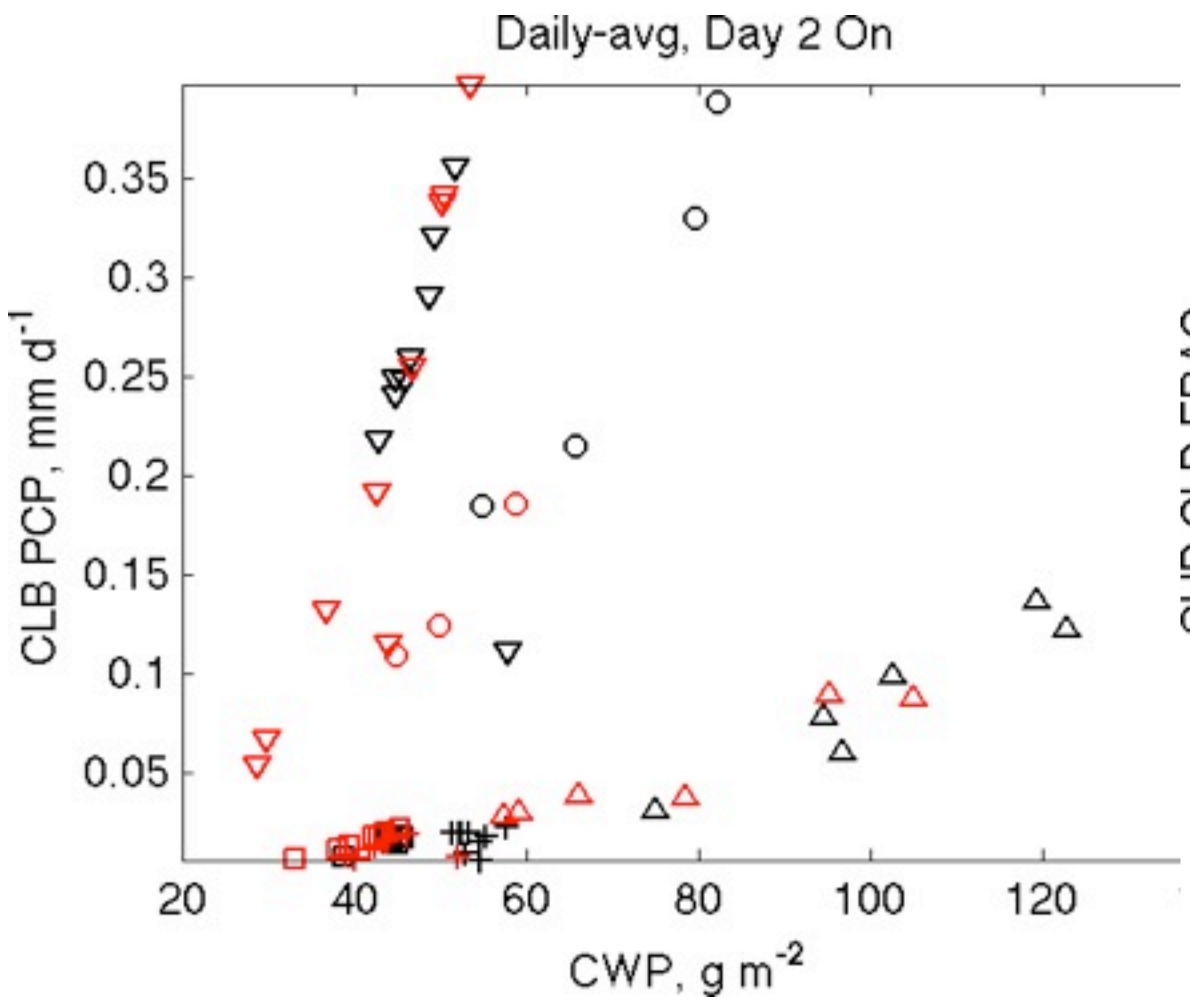
- Inter-model differences in CWP despite similar BL structure.
- LaRC/MOLEM add drizzle in +2K run, respond differently in CWP.
- As in S12, DALES and SAM similar in +2K run, but DALES maintains higher CWP than SAM in CTL run.

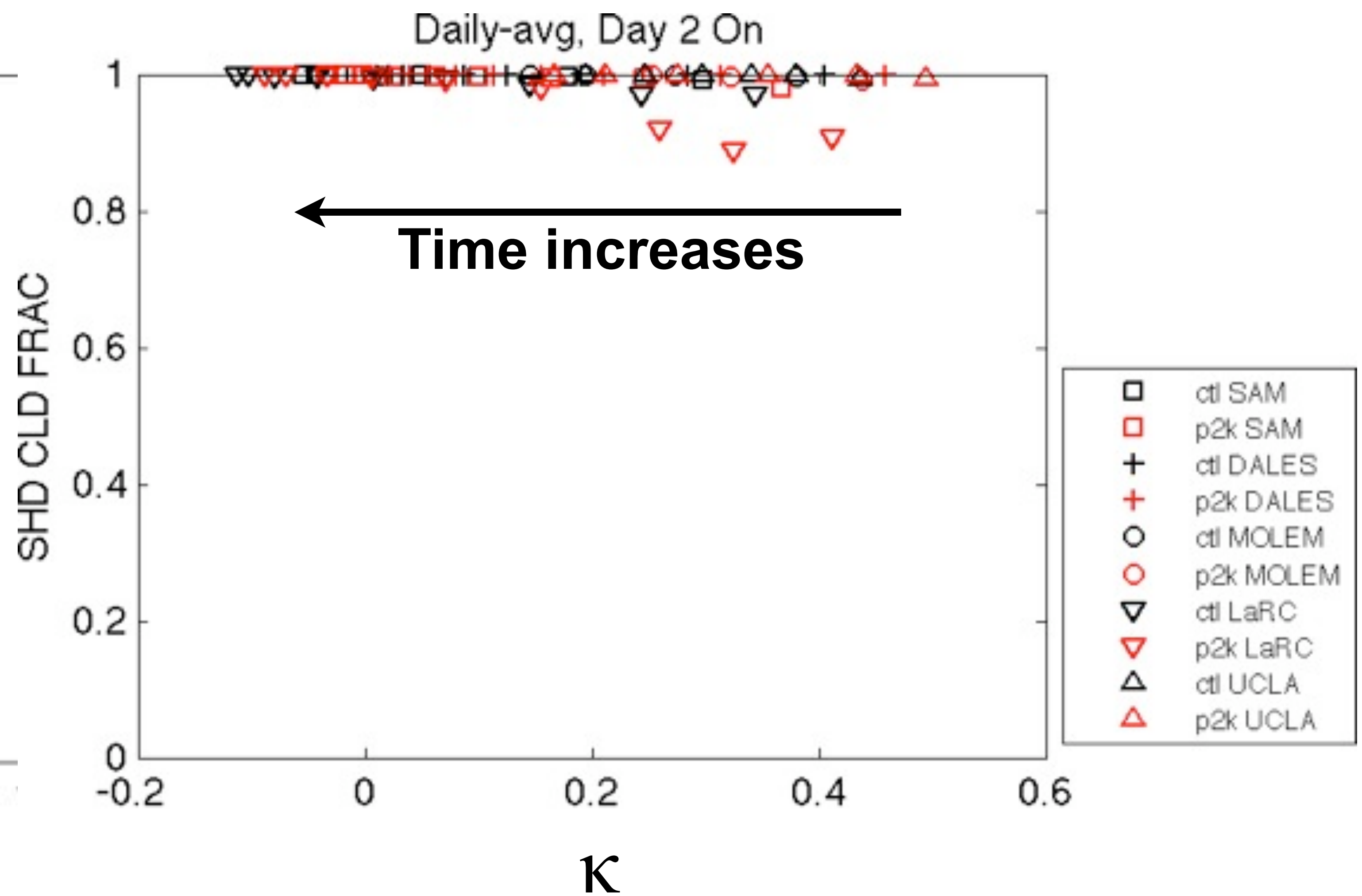
S11: CTL→+2K Cloud/Turbulence Changes



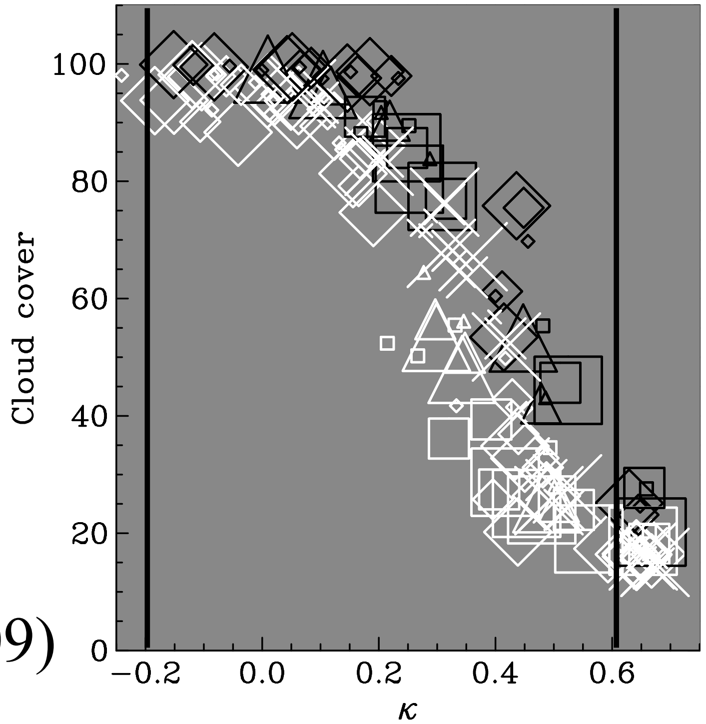
- SAM, DALES, LaRC near equilibrium. UCLA cloud thicker.
- Strong +ve ΔSWCF (>10W/m2) in DALES, near zero in SAM, LaRC.

S11: Precip-CWP relationships, Lock diagram





- 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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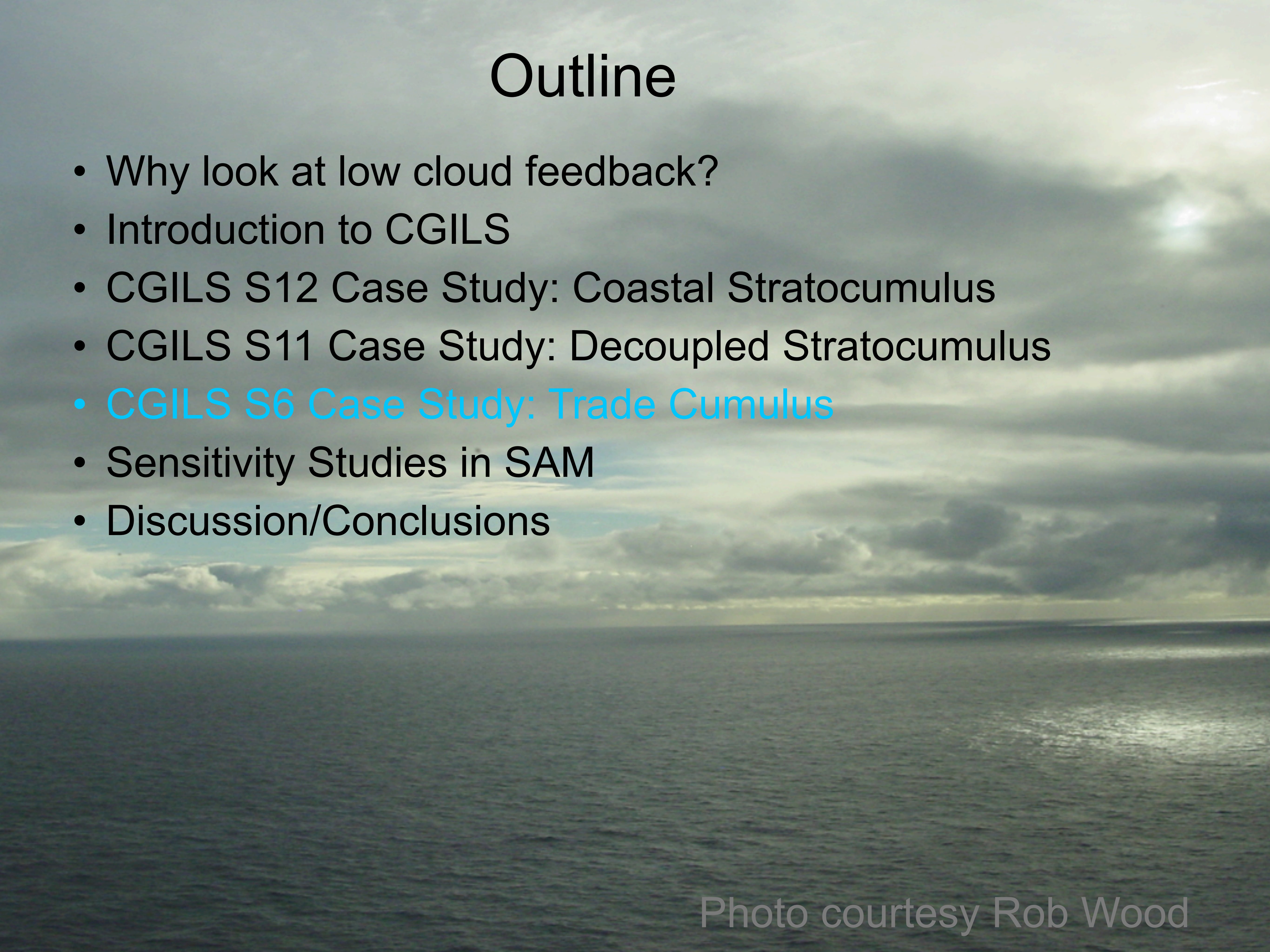
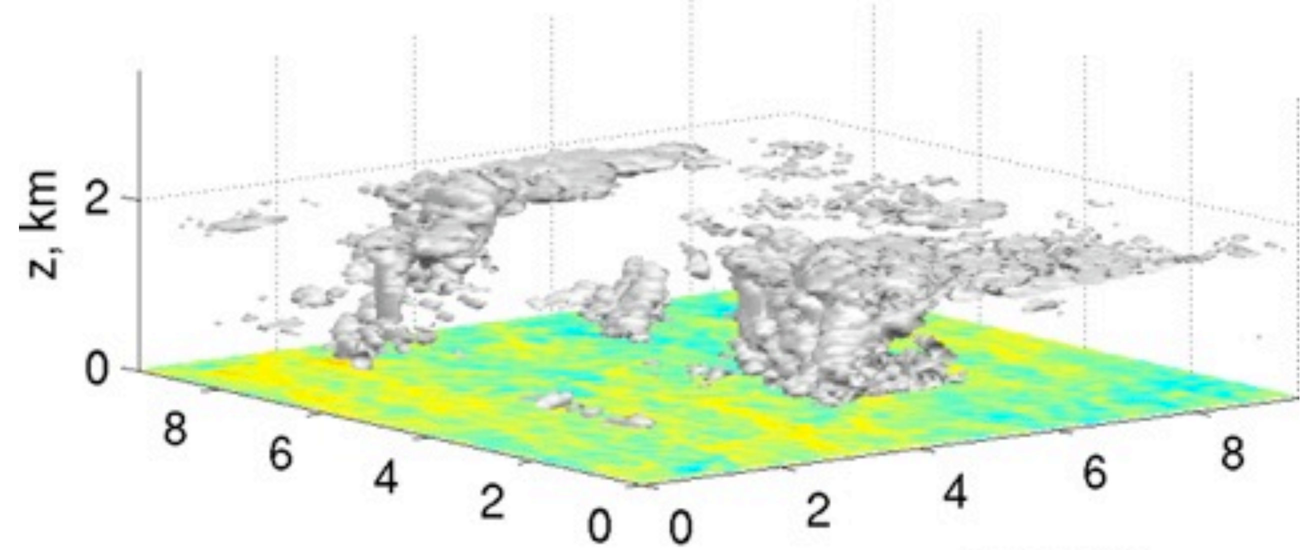
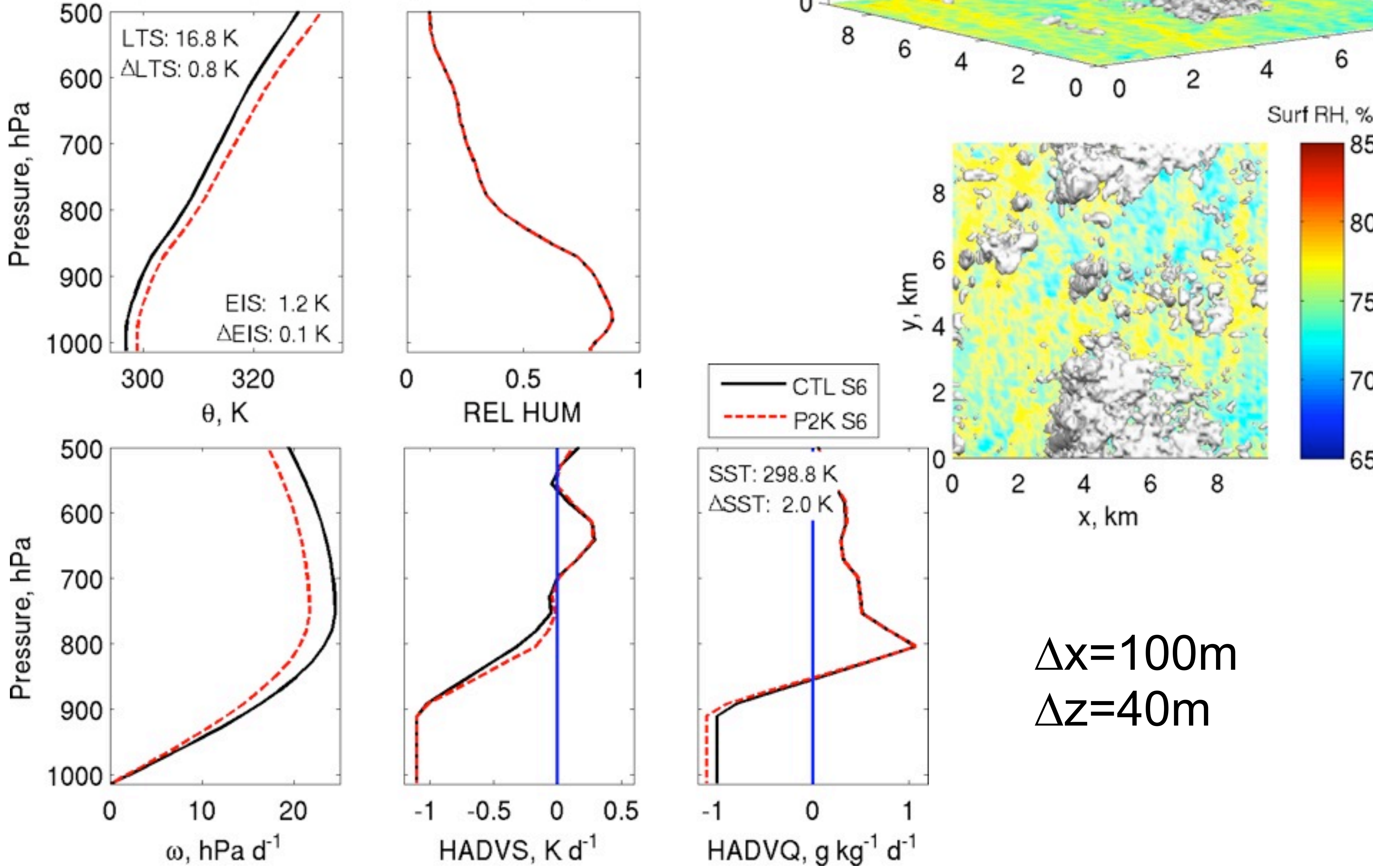


Photo courtesy Rob Wood

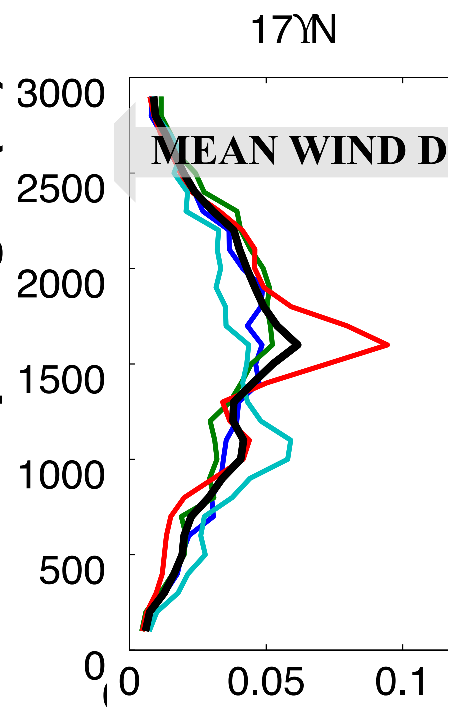
S6: Trade cumulus regime: Forcings and Snapshot of Cloud Field



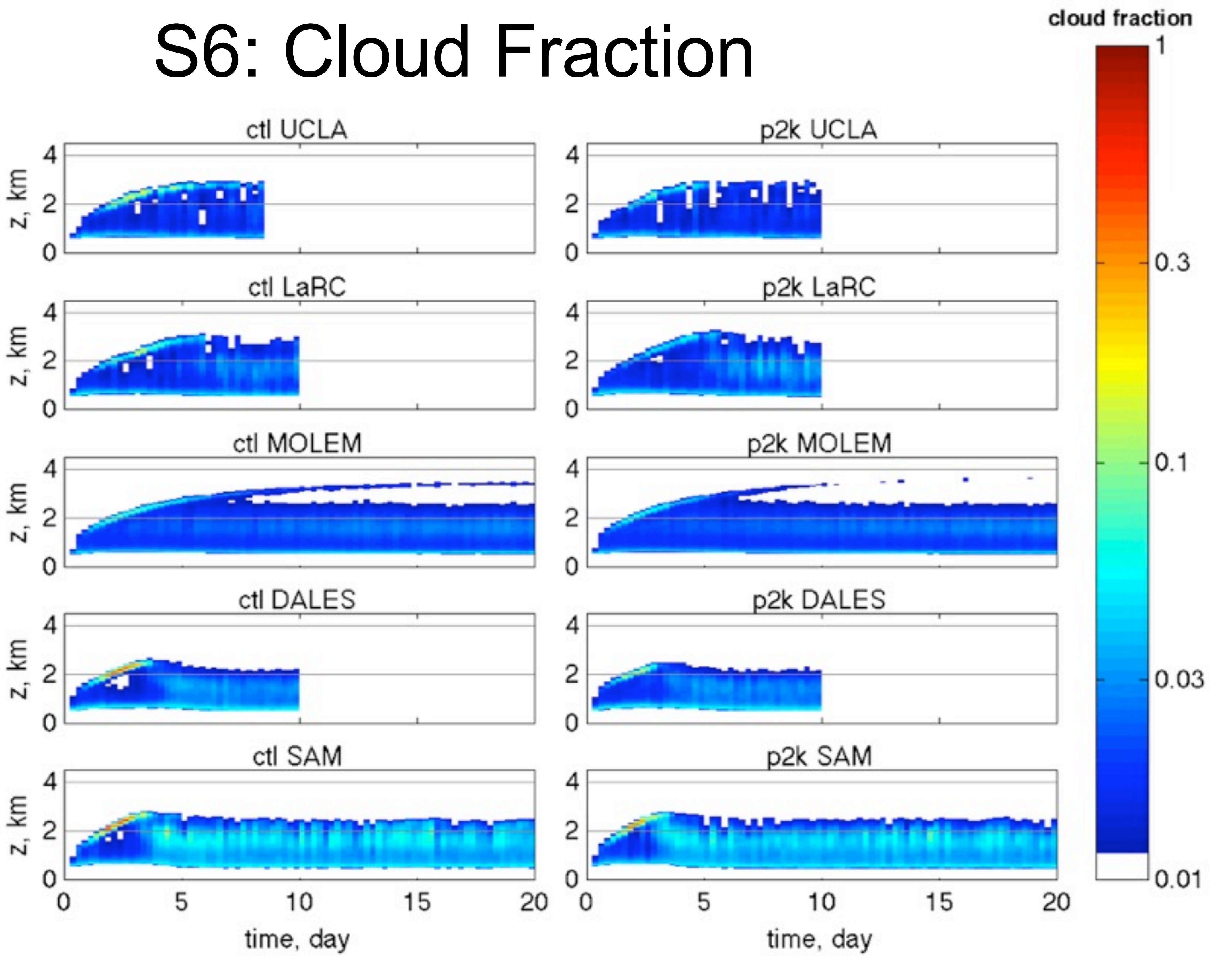


Δx=100m
Δz=40m

S6: Cloud Fraction

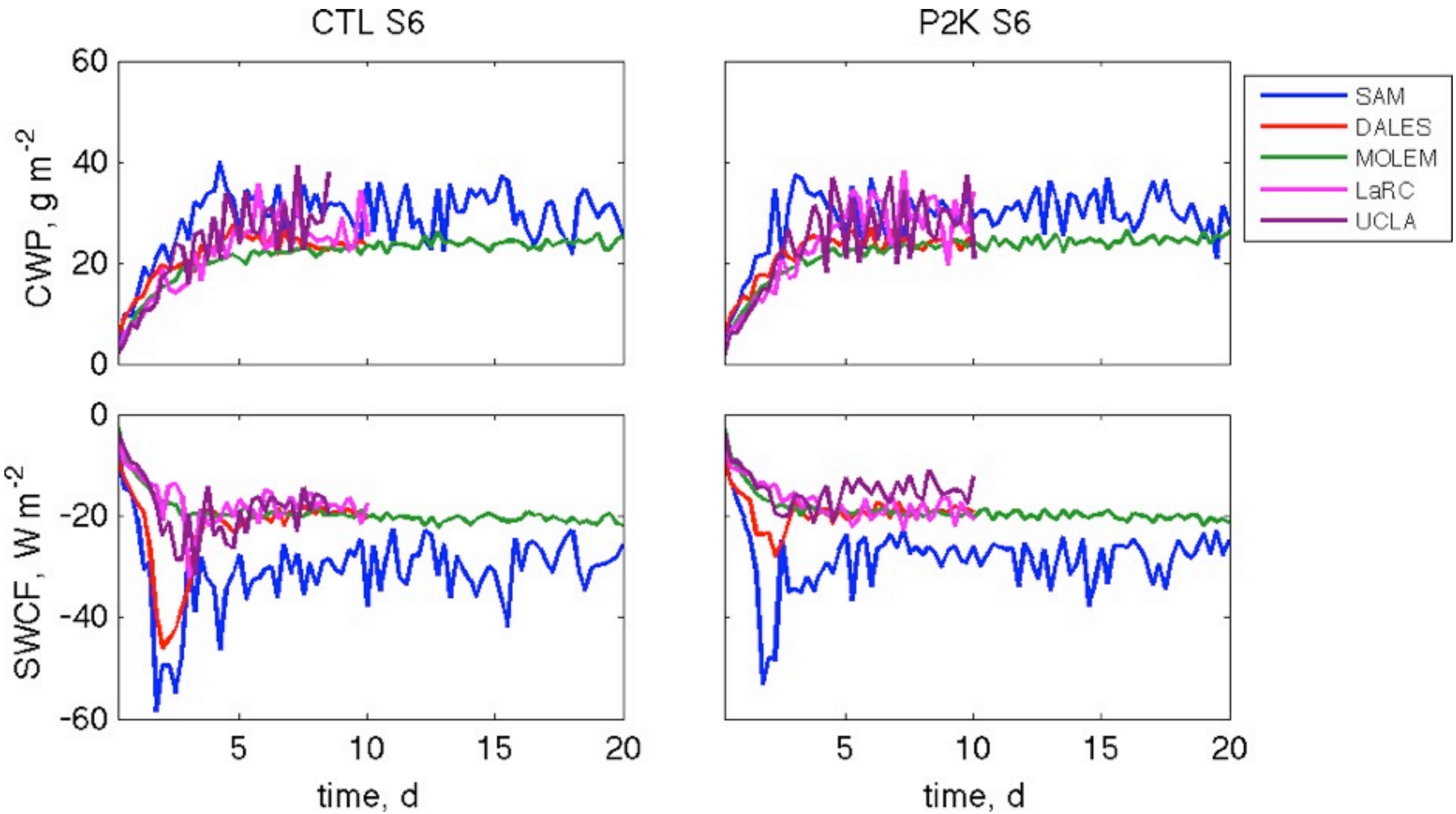


MISR Cloud
Top Height PDF
Courtesy of
J. Karlsson.



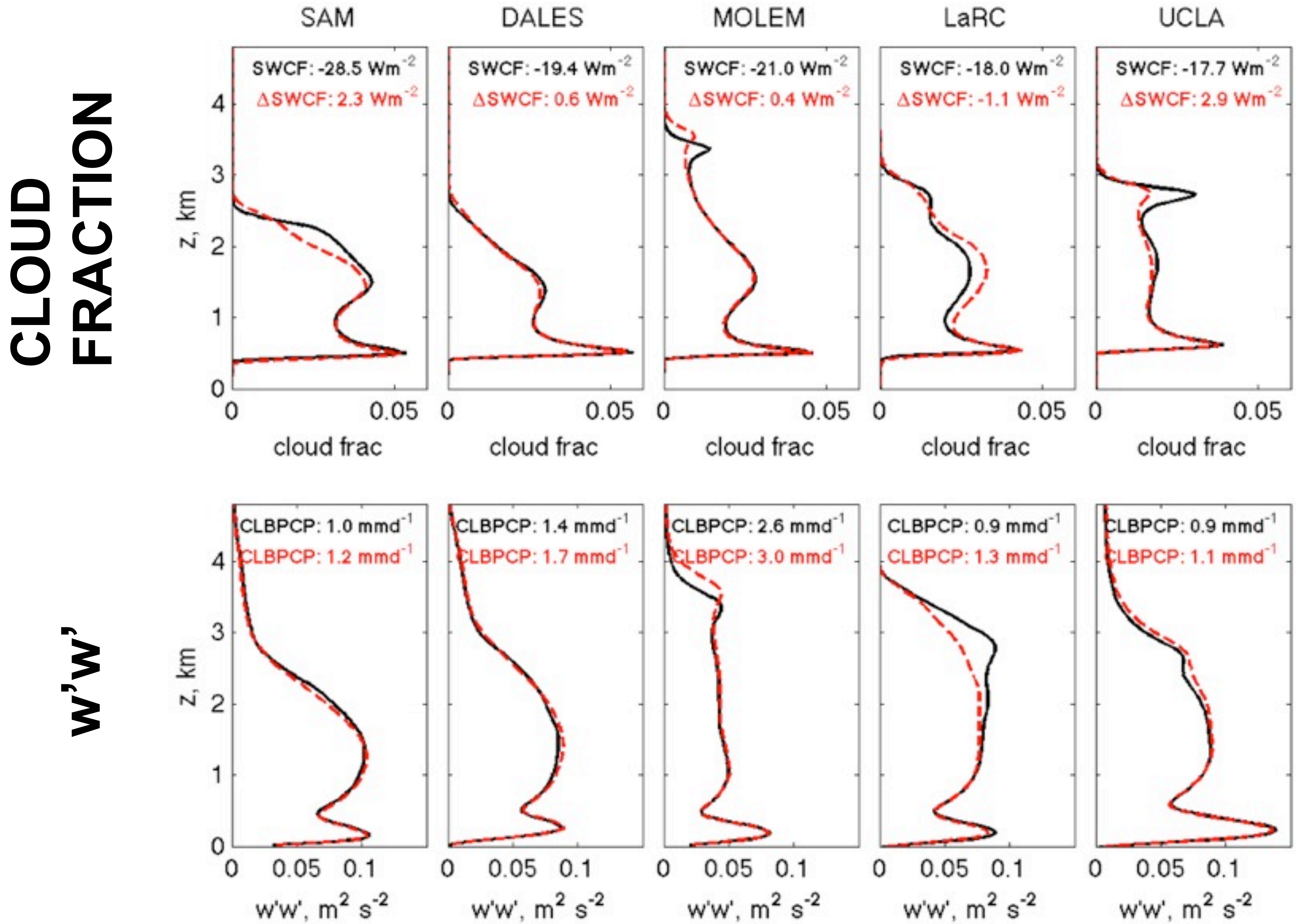
- Fair agreement between LES models in BL structure, depth.
- SCu-capped layer deepens; transitions to a Cu-only layer.
- +2K changes are weak.

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

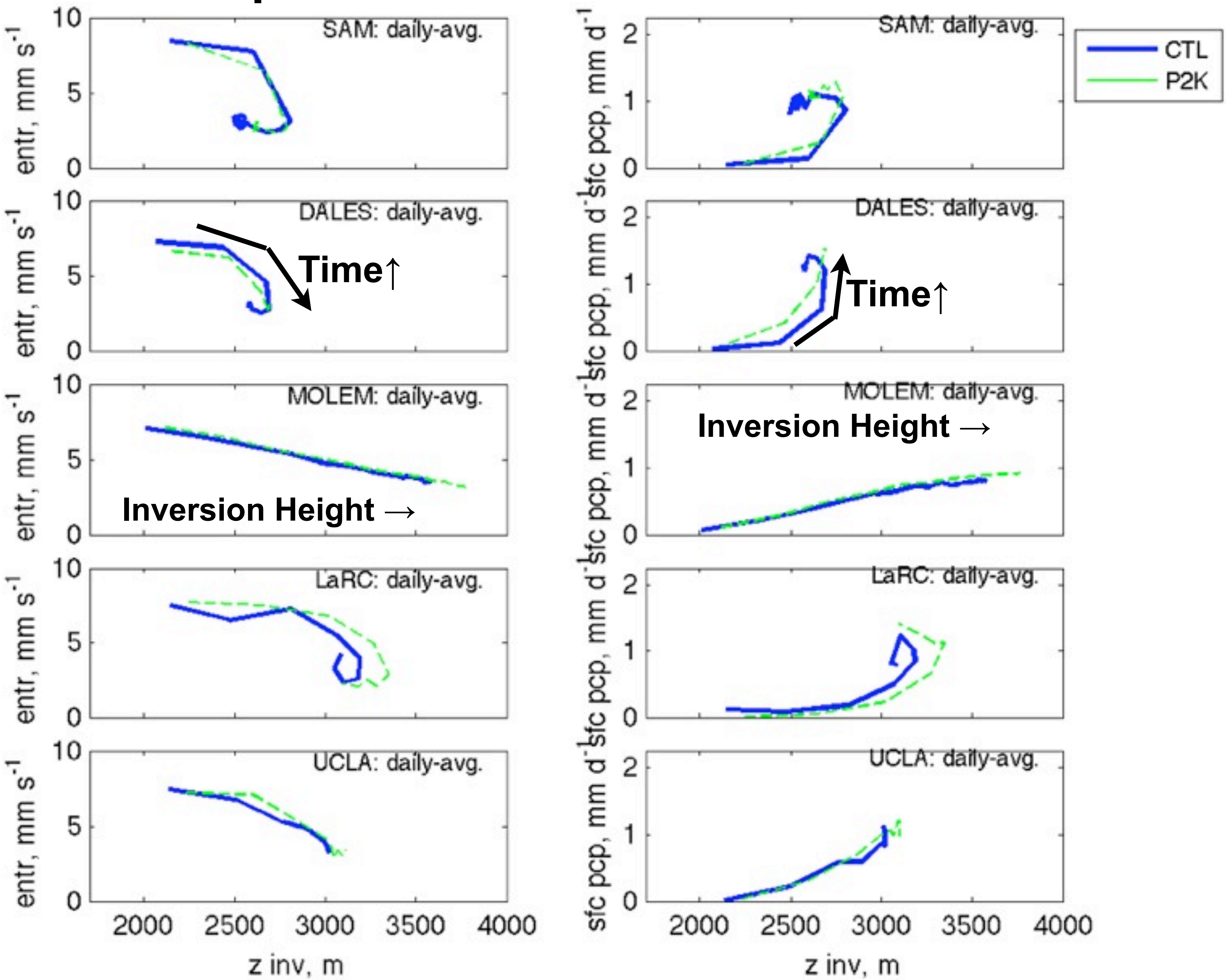


MOLEM/LaRC have setup issues. UCLA CTL still evolving.

Averages over last 2.5 days

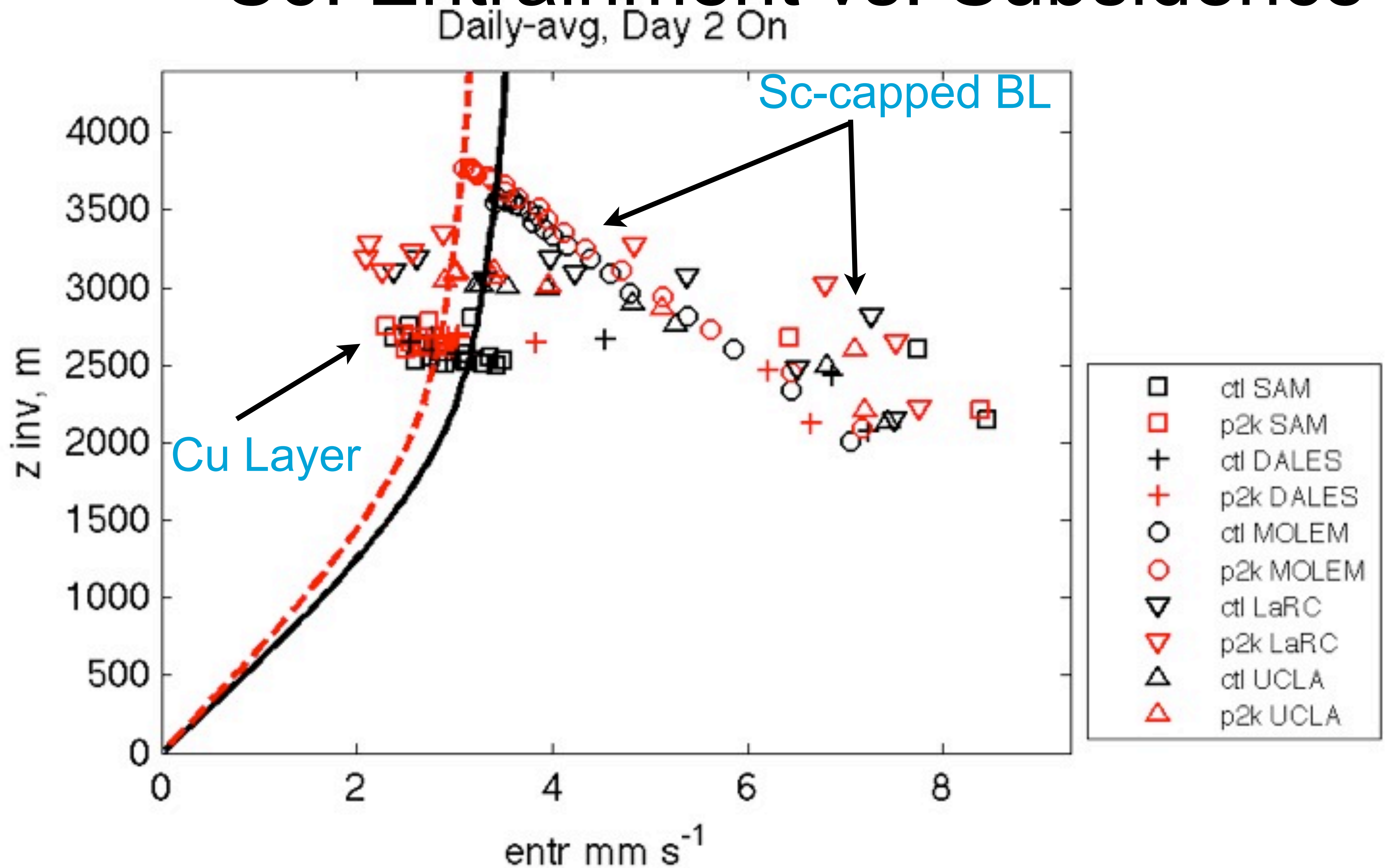
- Precip feedback in +2K runs of SAM/DALES, restrains deepening.
- Weak ΔSWCF changes, slight positive feedback in SAM.
- Precip increases in all models in +2K runs.

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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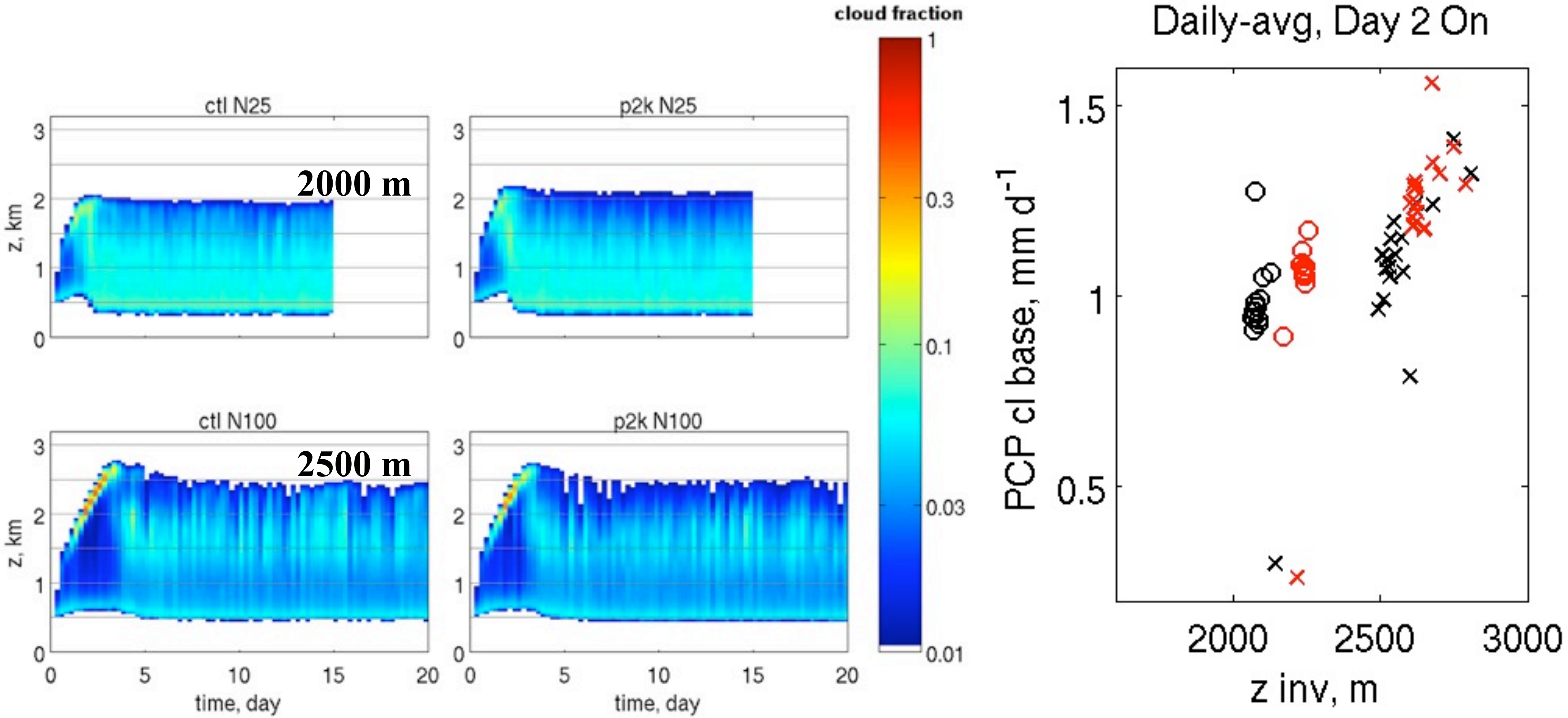
Photo courtesy Rob Wood

S6: Droplet Conc. Sensitivity Study in SAM

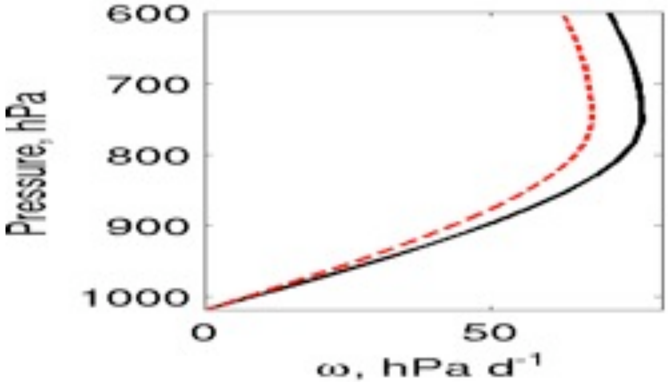


- New pair of runs w/Nc=25/cm3. Default is Nc=100/cm^3.
- Smaller Nc → Onset of precip at smaller zinv, restrains deepening.
- Also modifies ΔSWCF = 1.7 W/m^2 (Nc=100), 0.2 W/m2 (Nc=25)
- Take-Home Message: Nc uncertainty impacts inversion height.

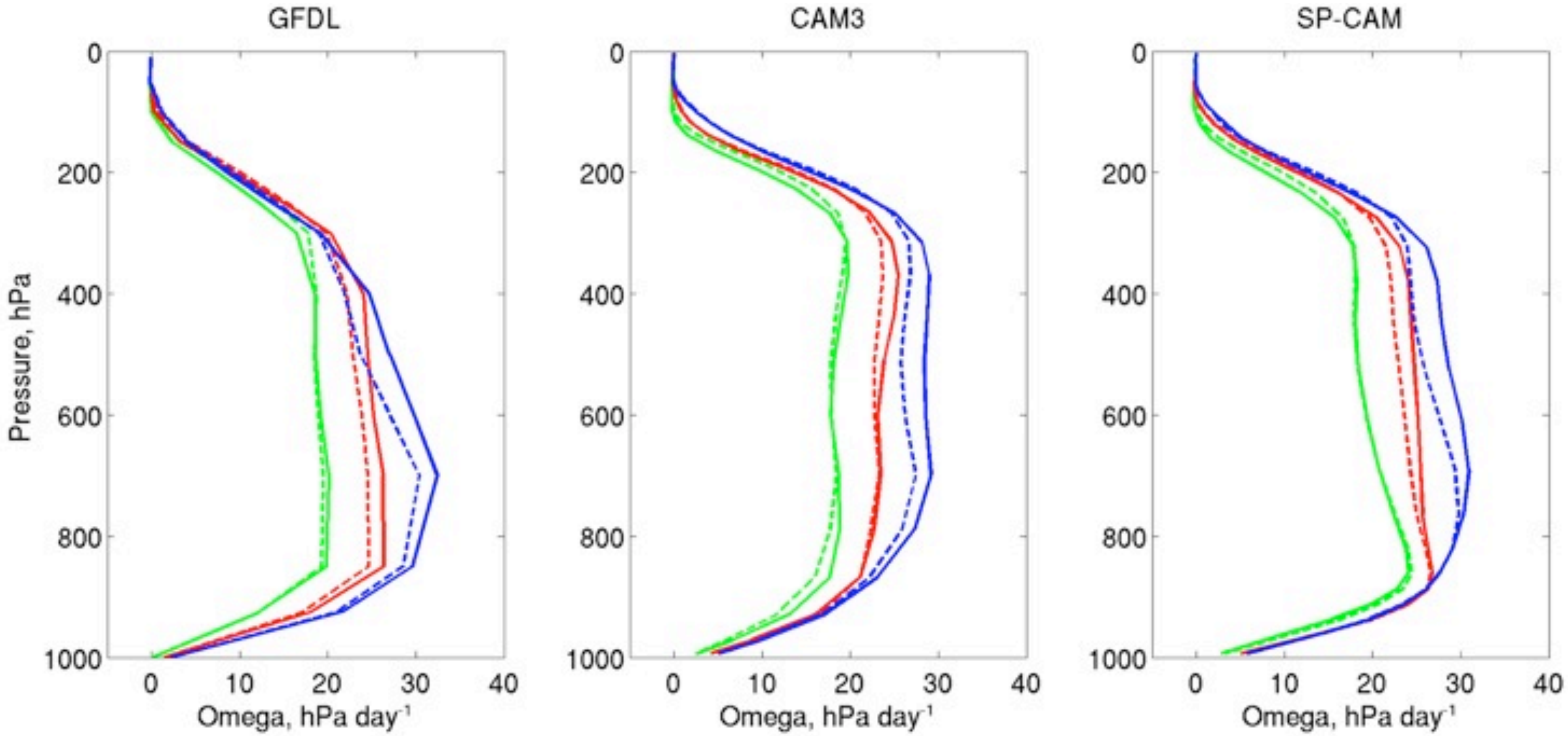
Uncertainty in Omega Changes

- 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

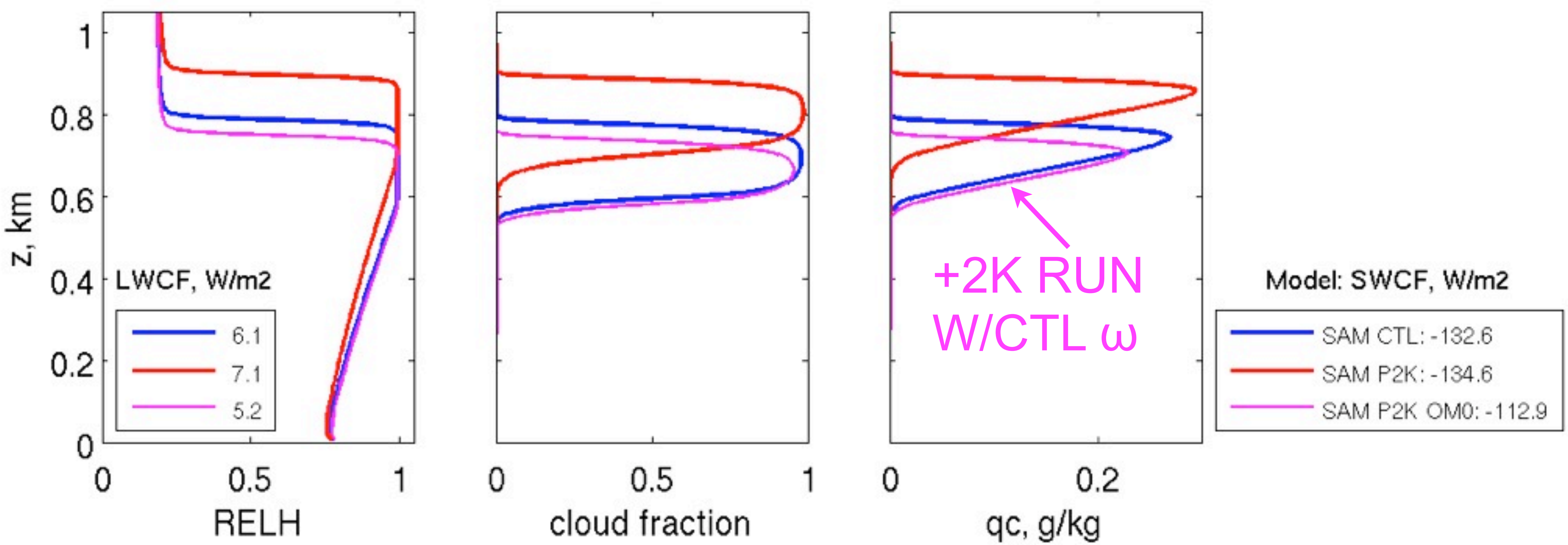


CGILS: S12



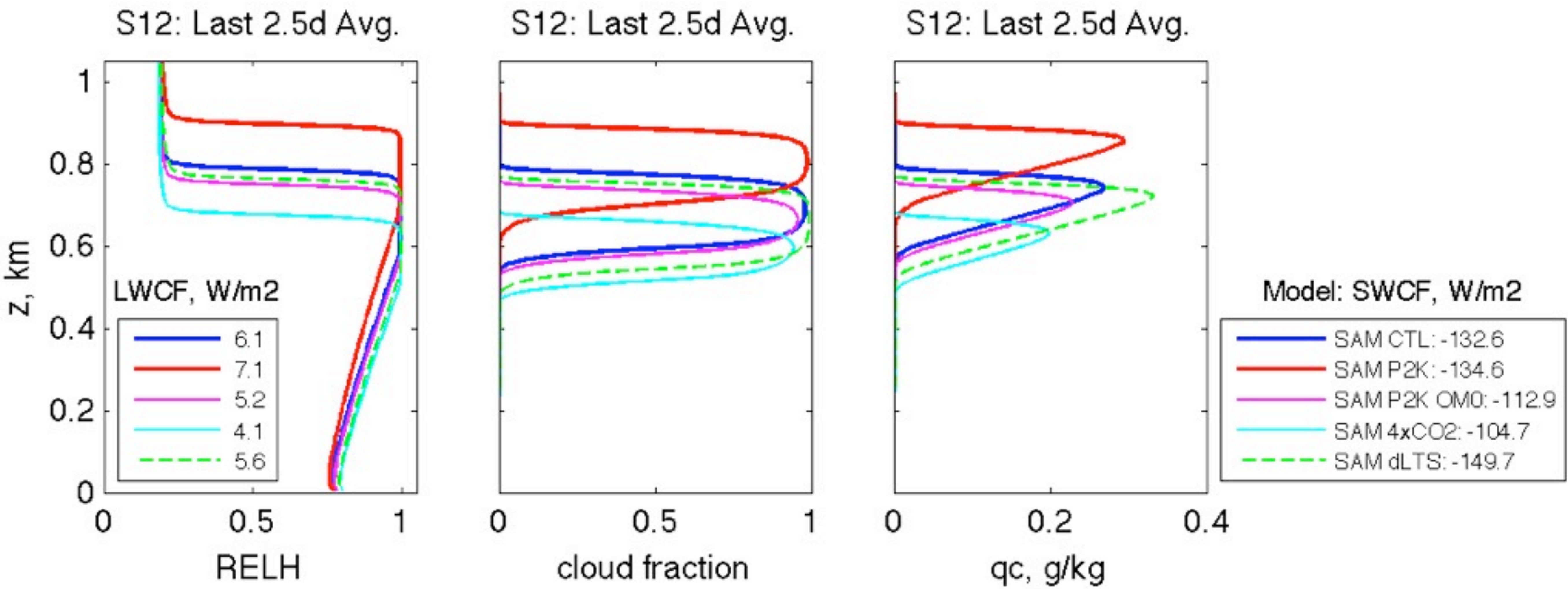
GCM Results Courtesy of Matt Wyant

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.

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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?