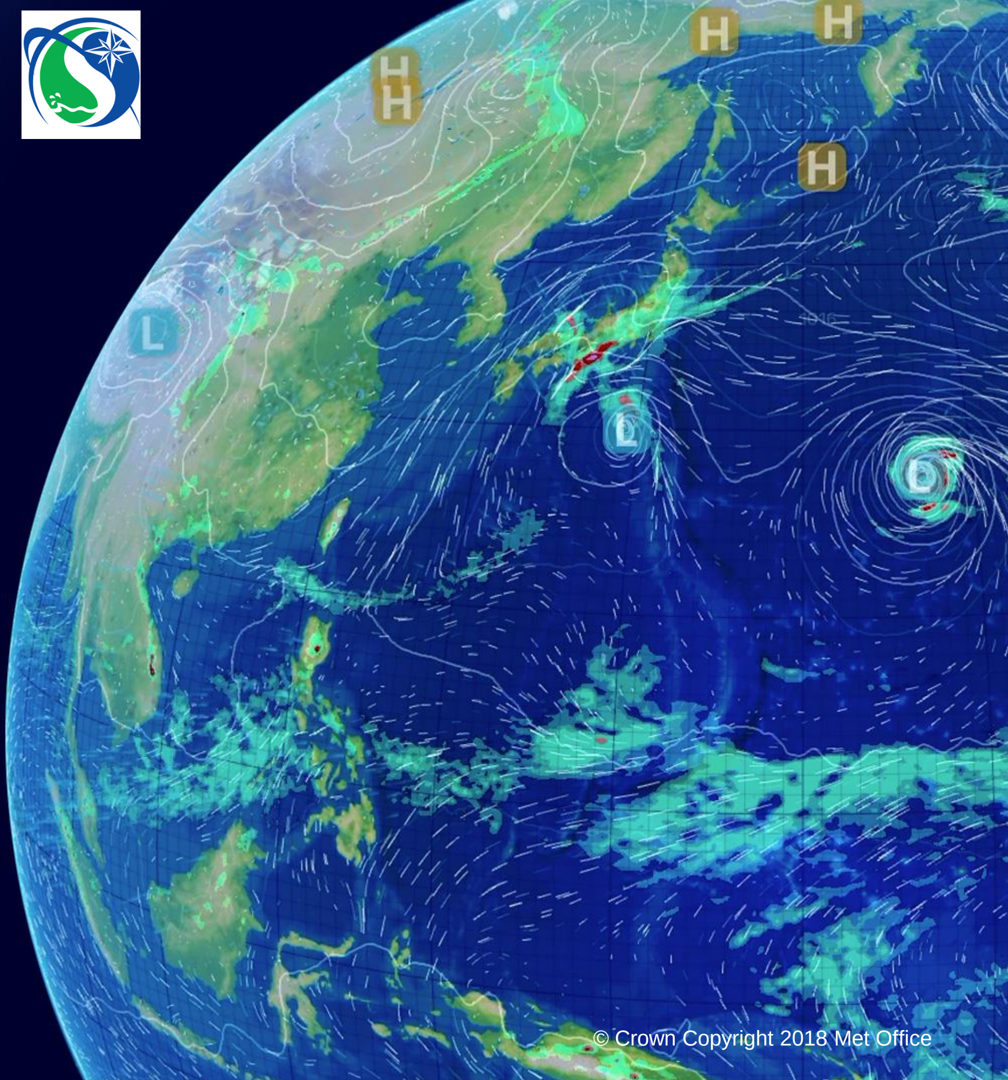
A Physically-Based Diagnostic Bimodal Cloud Scheme

Kwinten Van Weverberg, Ian Boutle, Cyril Morcrette, Kalli Furtado, Paul Field



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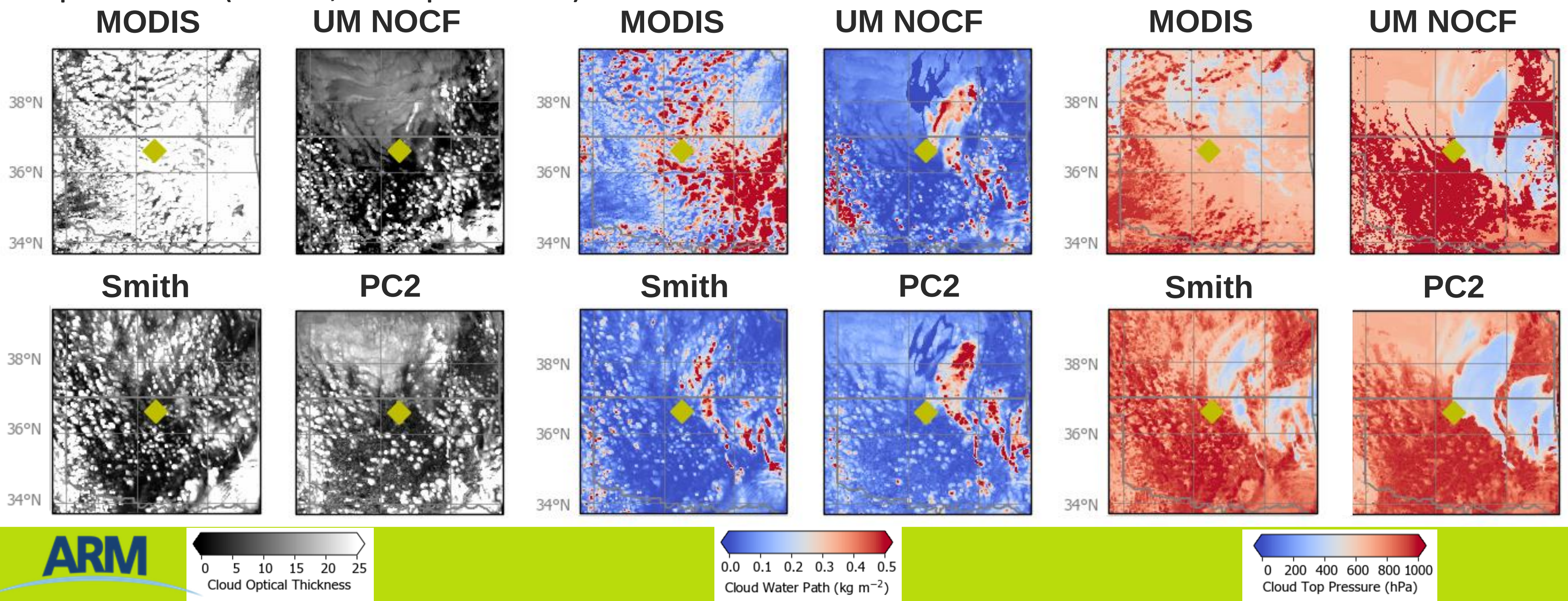
Operational Unified Model Regional Atmosphere Configuration

- Horizontal grid spacing of 1.5 km, 70 vertical levels
- Does not include a shallow-convection scheme, although turbulent fluxes are parametrized using a scale-aware 'blending' of a local Smagorinsky and non-local boundary-layer scheme (Lock et al. 2000; assigning each grid point to one of 7 prescribed boundary-layer types, including 'cumulus' regimes).
- Uses a diagnostic cloud fraction parametrization based on Smith 1990, using a symmetric and unimodal subgrid saturation-departure distribution (midlatitude configuration **RAM**) or a prognostic cloud fraction parameterization based on Wilson et al. (PC2; 2008) adding cloud fraction tendencies whenever the temperature or humidity changes (tropical configuration **RAT**).

How well do current approaches capture low cloud?

Example Stratocumulus case during Midlatitude Continental Convective Clouds Experiment (MC3E, 27 April 2011) over the US Southern Great Plains:



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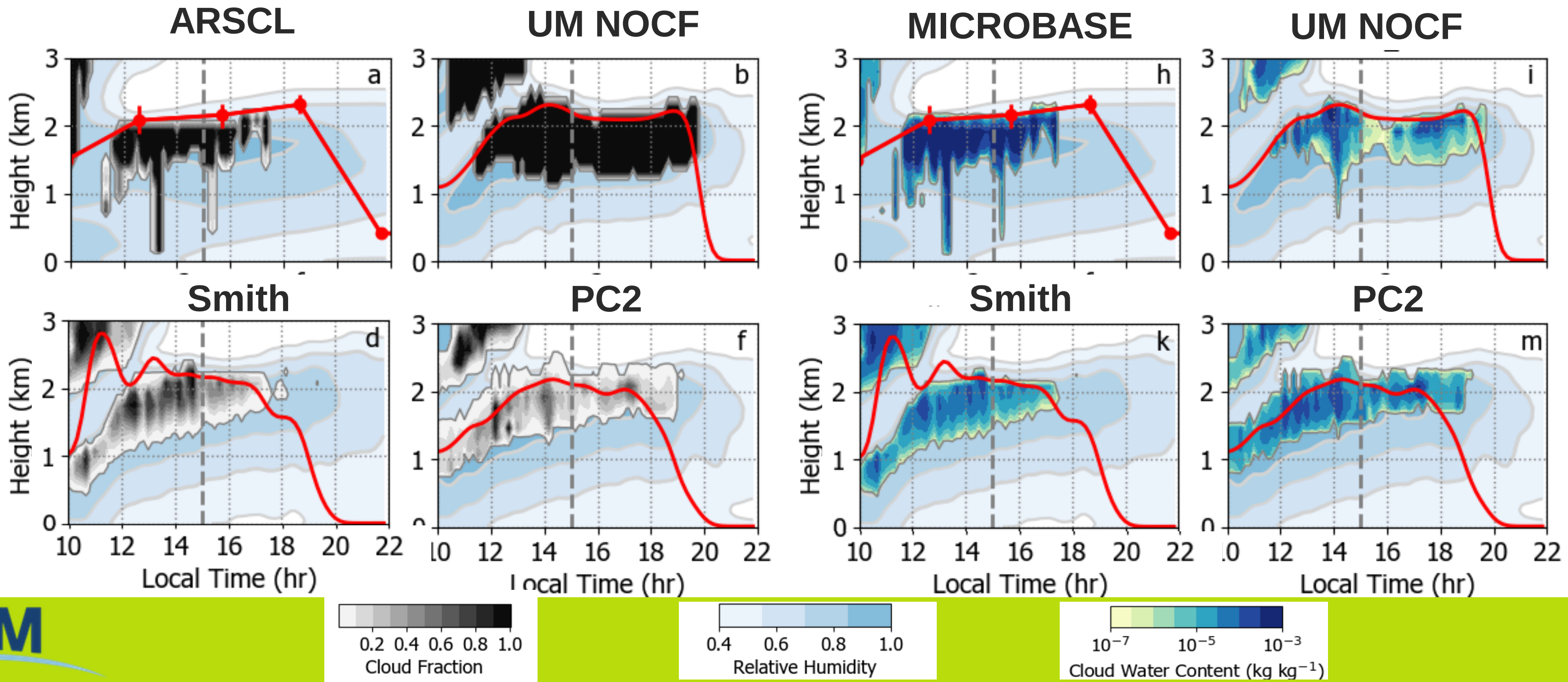
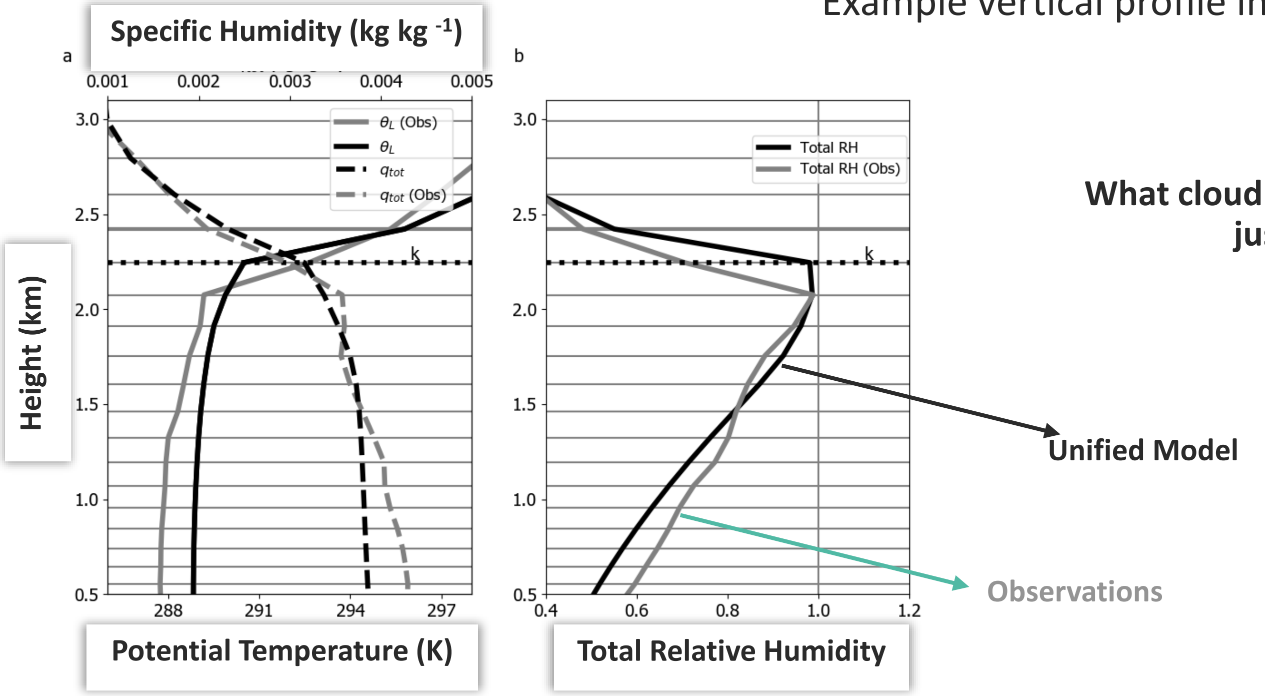


Why do current configurations struggle with Stratocumulus?

Example vertical profile in stratocumulus

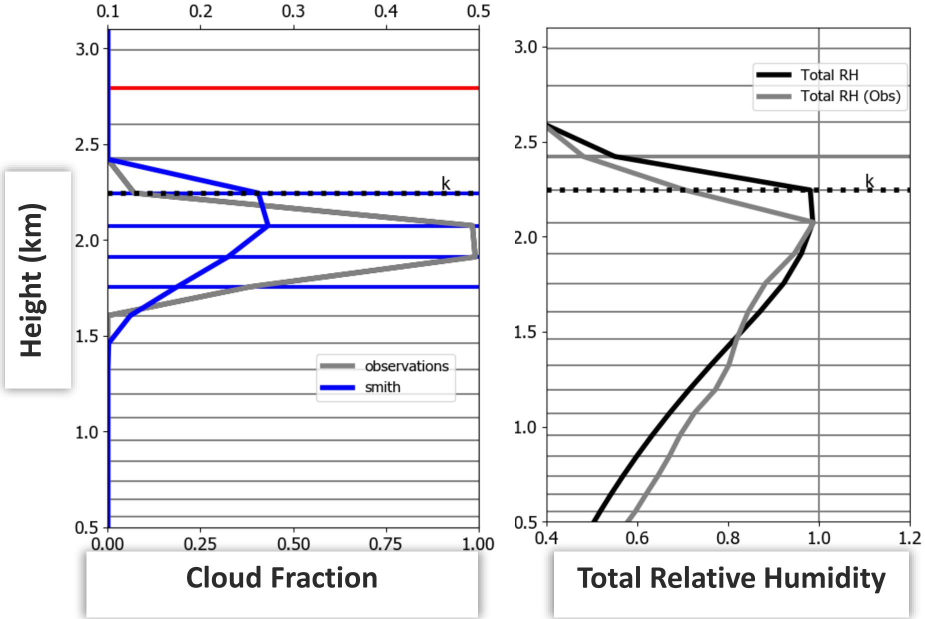


What cloud amount would be diagnosed just below inversion?

Observational data from the 2011 Midlatitude Continental Convective Clouds Experiment (MC3E, Jensen et al. 2016 BAMS)

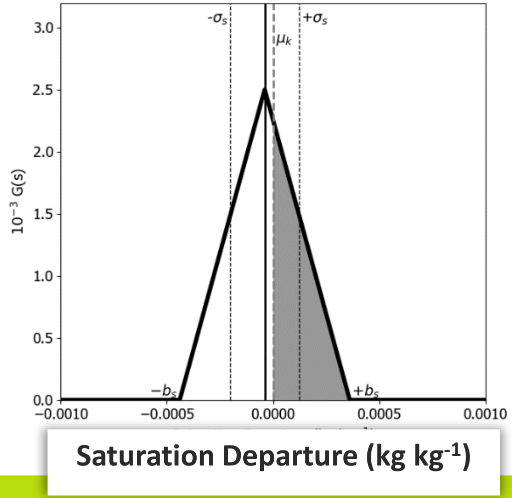
Why do current configurations struggle with Stratocumulus?

Example vertical profile in stratocumulus – cloud cover just below inversion (level *k)*



Original Smith scheme, variance from critical relative humidity – symmetric triangular distribution

41% Cloud Fraction



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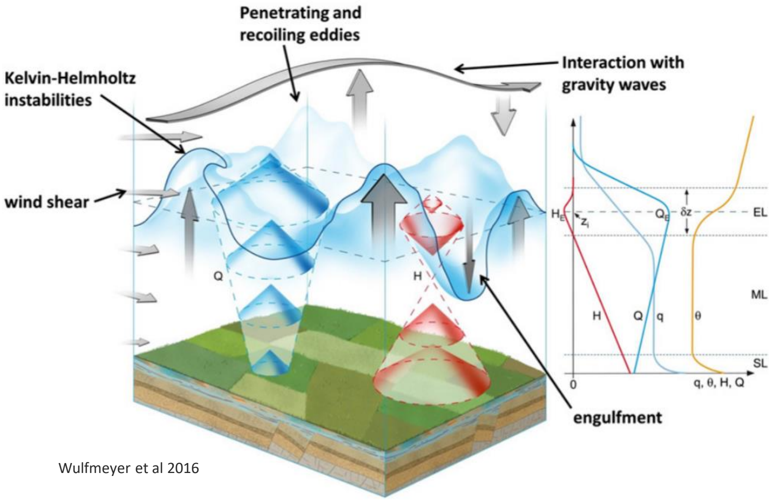
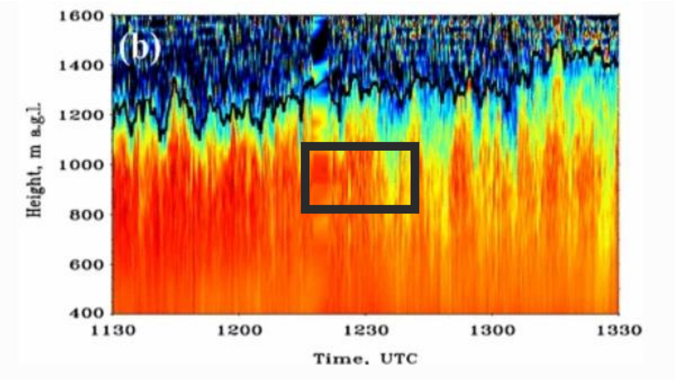
Why do current configurations struggle with Stratocumulus?

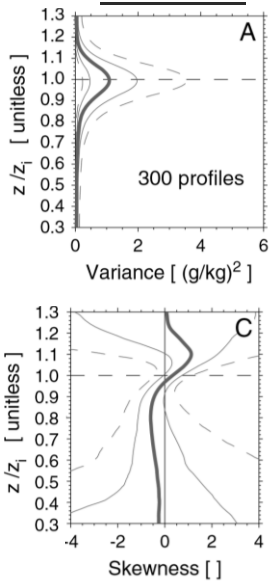
Entrainment zone near top of boundary layer: zone of very large temperature and moisture <u>variance and skewness</u> associated with undulations in the boundary-layer top



Wulfmeyer et al 2016



Muppa et al 2016

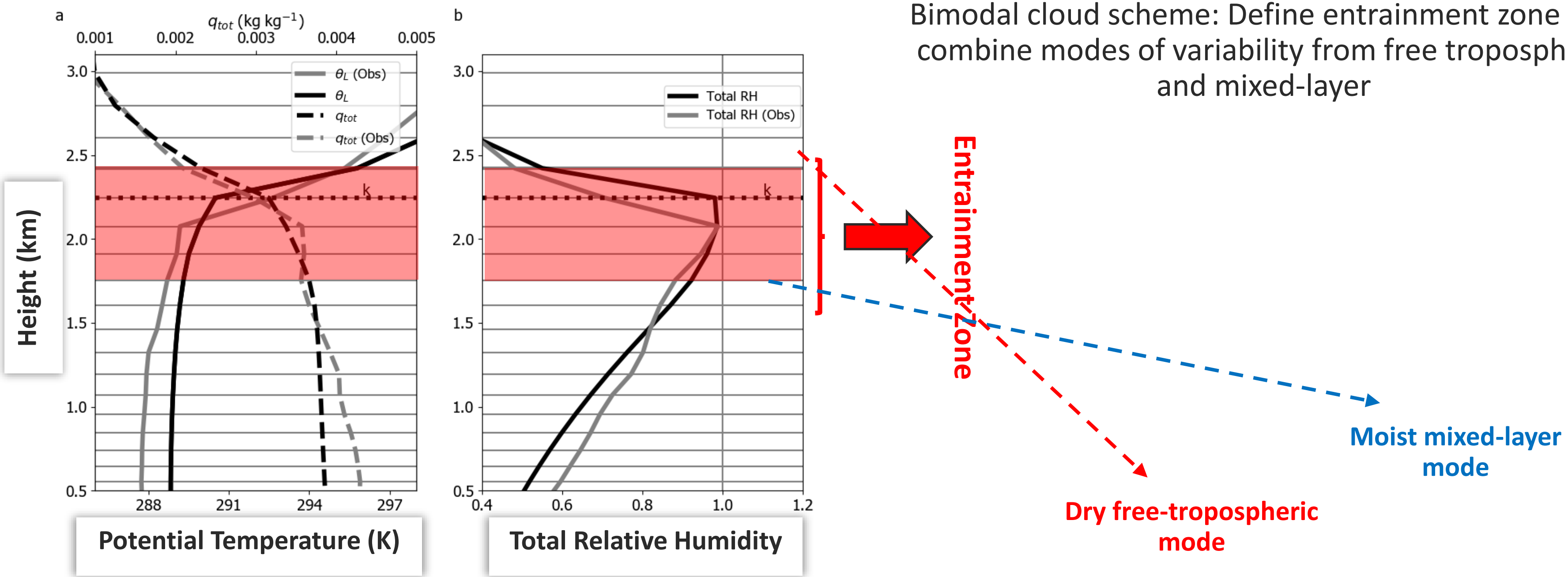


Turner et al. 2014

Bi-modal cloud scheme

Example vertical profile in stratocumulus – cloud cover just below inversion (level *k)*

Bimodal cloud scheme: Define entrainment zone and combine modes of variability from free troposphere and mixed-layer



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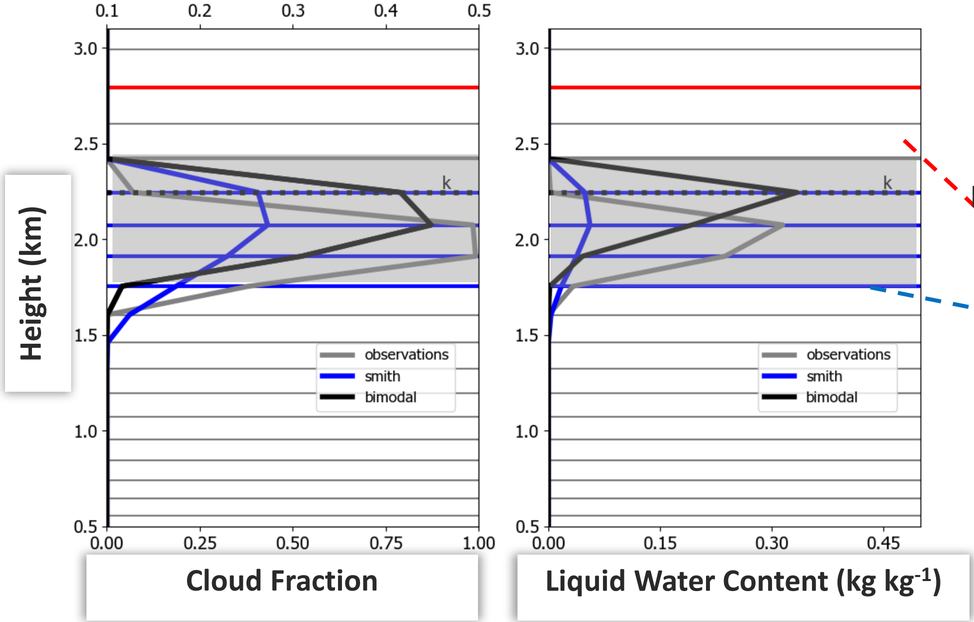
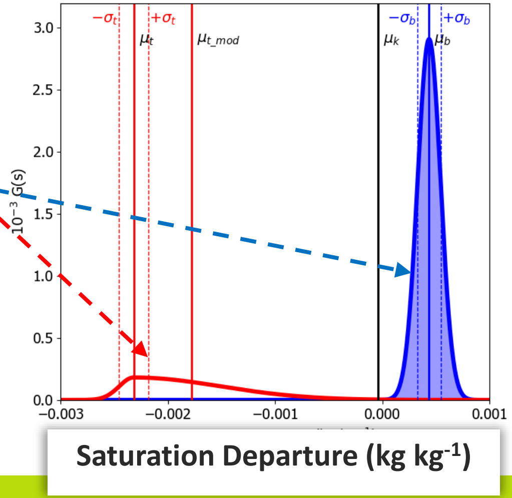


Bimodal cloud scheme: Define entrainment zone and combine modes of variability from free troposphere and mixed-layer

79% Cloud Fraction



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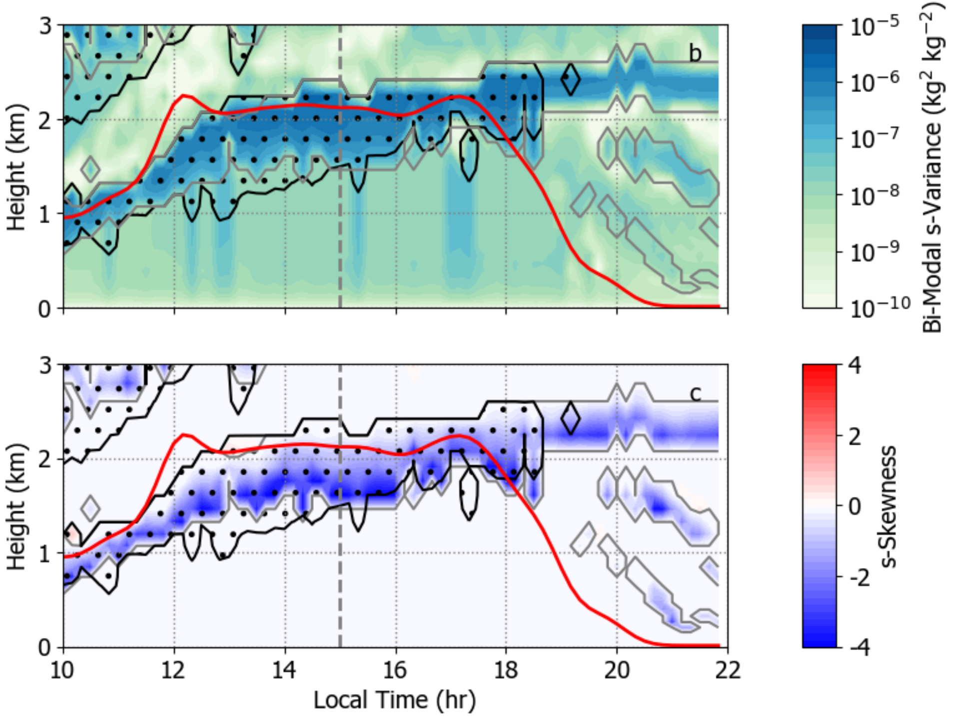
Bi-modal cloud scheme



First and second moment of each individual PDF:

$$\mu_{\text{turb}} = a_L \left[\overline{q_T} - q_{si}\left(\overline{T_{\text{liq}}}\right) \right] \frac{1/\tau_E}{1/\tau_E + 1/\tau_P}$$

$$\sigma^2_{\text{turb}} = \frac{(1/2)\left(a_L \alpha_{\text{ice}} \frac{g}{c_p}\right)^2 \sigma_w^2 \tau_L}{1/\tau_E + 1/\tau_P},$$

Second and third moment of mixture of PDFs:

$$\sigma^2 = w_t\left[\sigma_t^2 + (\mu_t - \mu_k)^2\right) + w_b\left[\sigma_b^2 + (\mu_b - \mu_k)^2\right]$$

$$\varphi = w_t\left[3(\mu_t - \mu_k)\sigma_t^2 + (\mu_t - \mu_k)^3\right] + w_b\left[3(\mu_b - \mu_k)\sigma_b^2 + (\mu_b - \mu_k)^3\right]$$

$$\text{Sk} = \frac{\varphi}{\sigma^{3/2}}.$$

Observational data from the 2011 Midlatitude Continental Convective Clouds Experiment (MC3E, Jensen et al. 2016 BAMS)

Bi-modal cloud scheme

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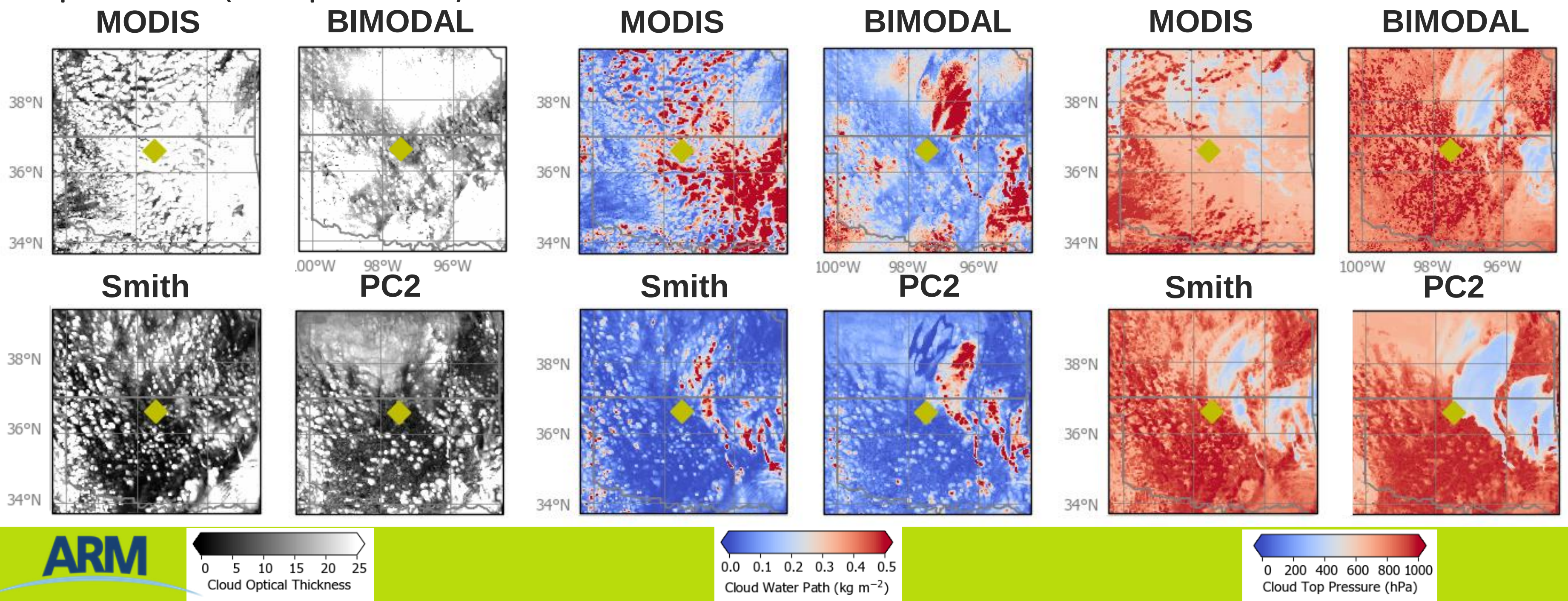

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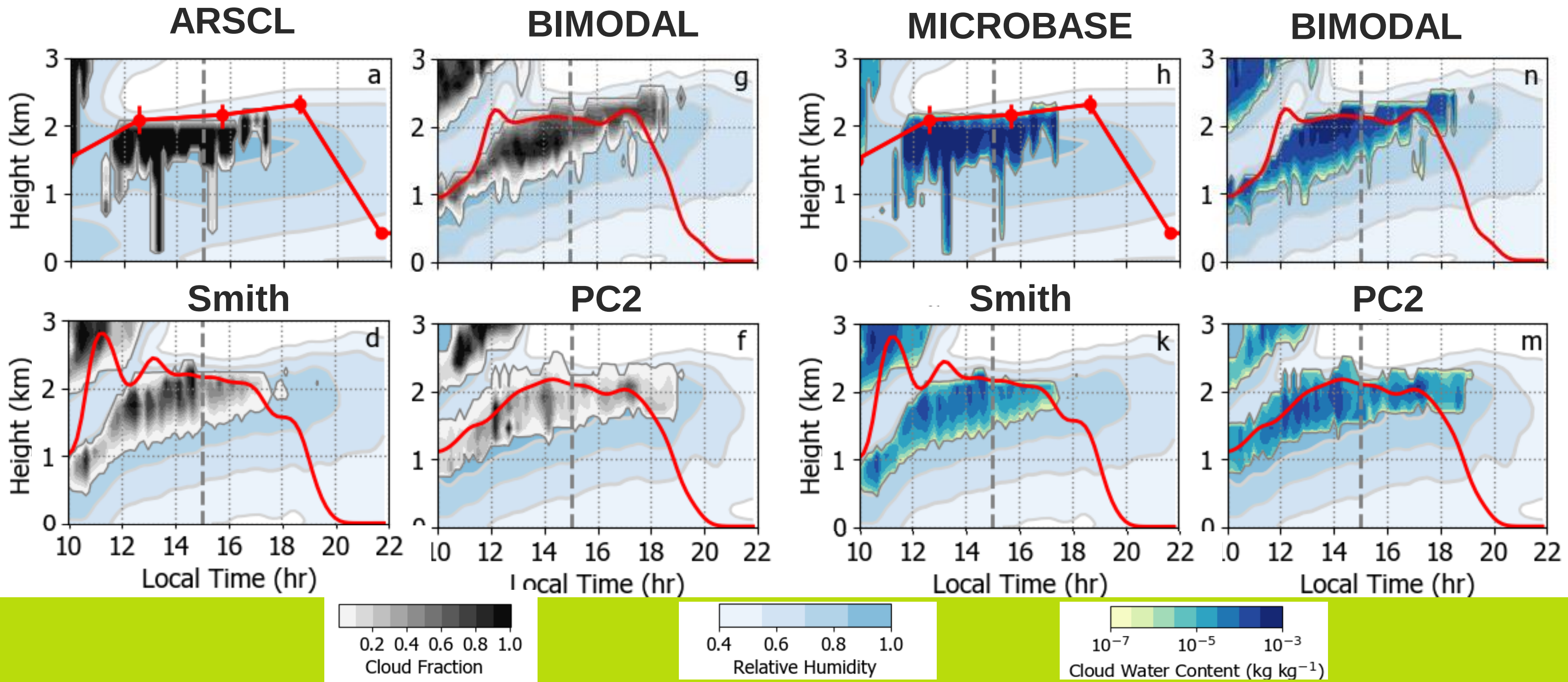
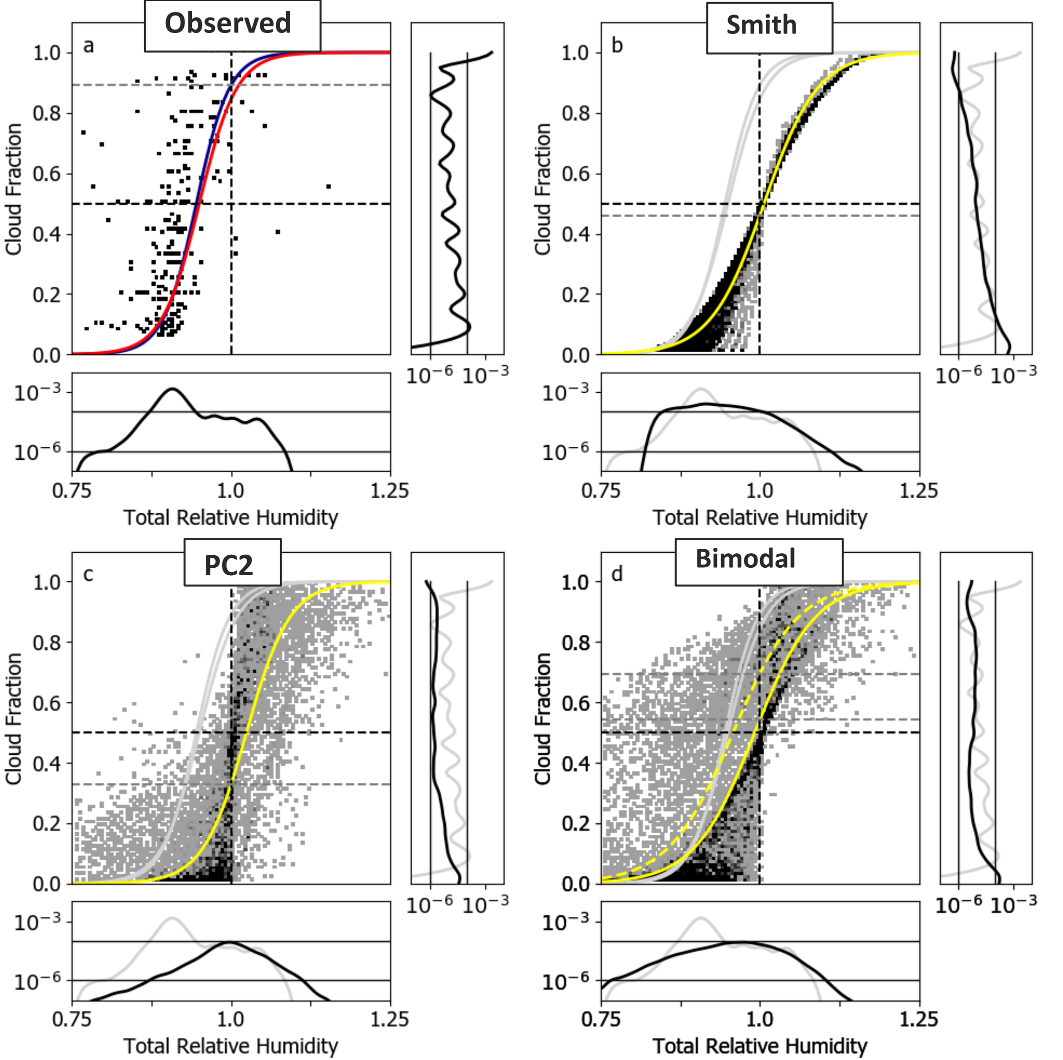


Bi-modal scheme

Observed and simulated joint PDF of relative humidity and cloud cover

(MC3E: April – June 2011, US Great Plains)



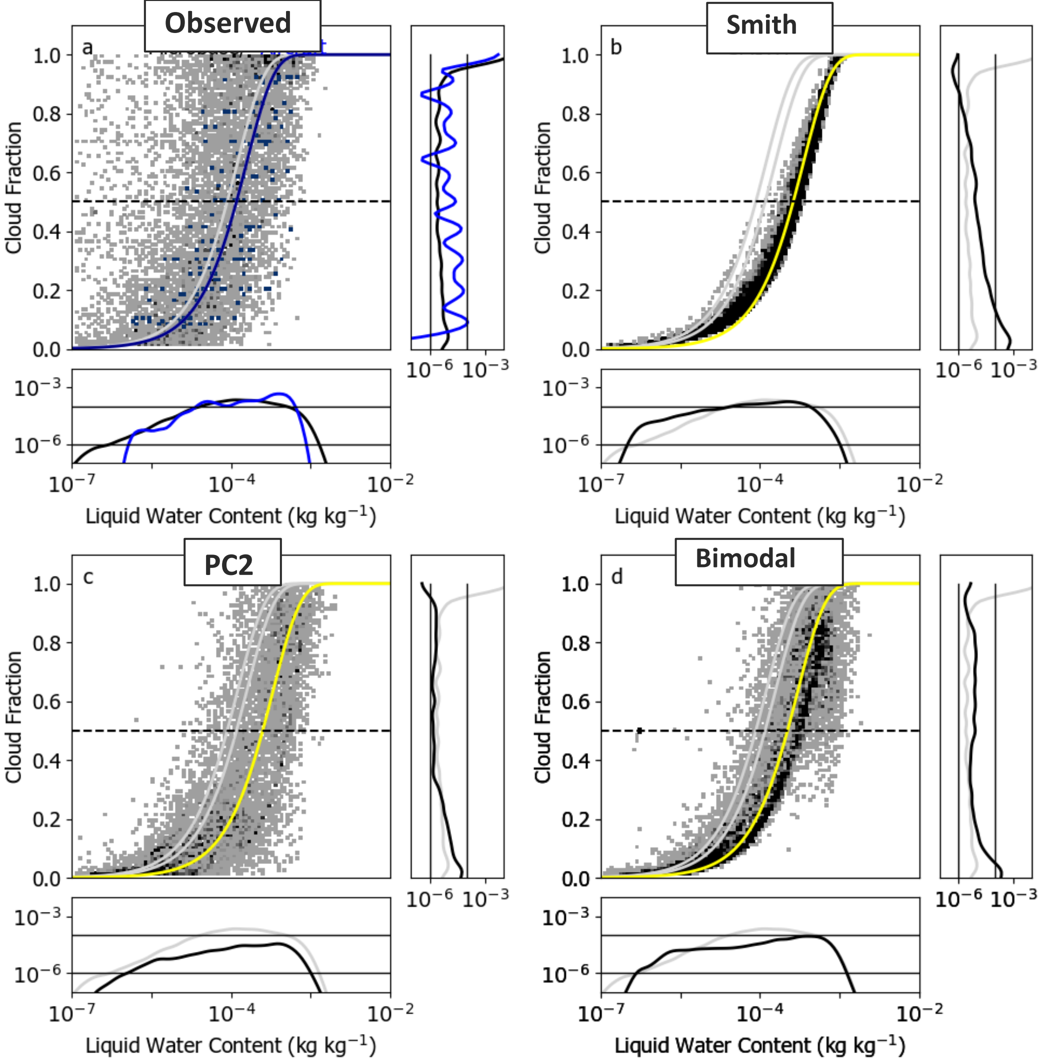
Observational data from the 2011 Midlatitu

Met Office BMKG NAD MA

Bi-modal scheme

Observed and simulated joint PDF of liquid water content and cloud cover

(MC3E: April – June 2011, US Great Plains)



ARM Observational data from the 2011 Midlatitu

Conclusions

- Met Office UM uses cloud fraction parametrization in its regional configurations, but requires operational bias corrections to obtain reasonable cloud cover in stratocumulus
- New diagnostic bimodal cloud scheme is proposed:
  - Diagnose entrainment zones based on the occurrence of sharp inversions and the potential temperature profile
  - Combine PDFs from top and bottom of entrainment zone for any level encompassed by the entrainment zone
  - Weigh each PDF so that the local saturation departure remains conserved (no vertical transport of moisture or heat)
  - Assign variances to each individual PDF based on turbulent properties, and accounting for mixed-phase conditions
- New scheme outperforms current diagnostic and prognostic schemes in terms of parameter space between RH – cloud fraction and RH – water content.
- Scheme also improves surface radiation, optical cloud properties and cloud cover for 6-week long MC3E campaign
- Scheme is more scale-aware than current operational approaches due to better link with turbulence parametrization.

Outlook

- Bimodal cloud scheme will be used in the operational Regional Atmosphere 3 configuration and will be tested by UM partners over tropics and mid-latitudes. First results suggest much improved cloud cover, although organisation of tropical convection remains better in PC2
- Two papers published recently in Monthly Weather Review, Volume 149, Issue 143 (2021):

A Bimodal Diagnostic Cloud Fraction Parameterization. Part I: Motivating Analysis and Scheme Description

KWINTEN VAN WEVERBERG,[a] CYRIL J. MORCRETTE,[a] IAN BOUTLE,[a] KALLI FURTADO,[a] AND PAUL R. FIELD[a]

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A Bimodal Diagnostic Cloud Fraction Parameterization. Part II: Evaluation and Resolution Sensitivity

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