Vertical Dependence of (sub-grid scale) Horizontal Variation of MBL Cloud Microphysics:

Observations from the ACE-ENA field campaign and Implications for Warm Rain simulation GCMs

ARM-ASR Joint PI meeting

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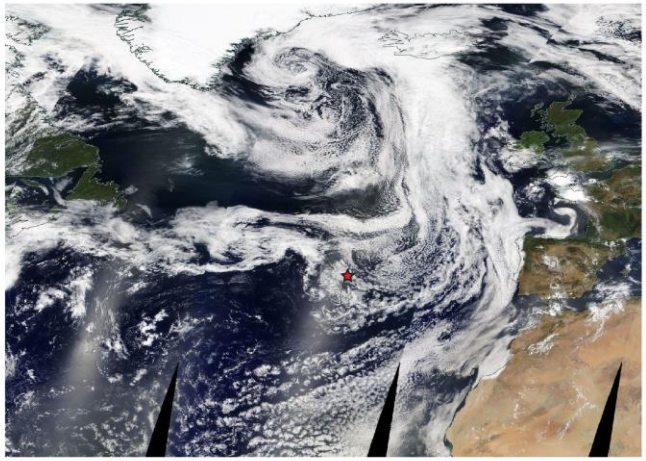
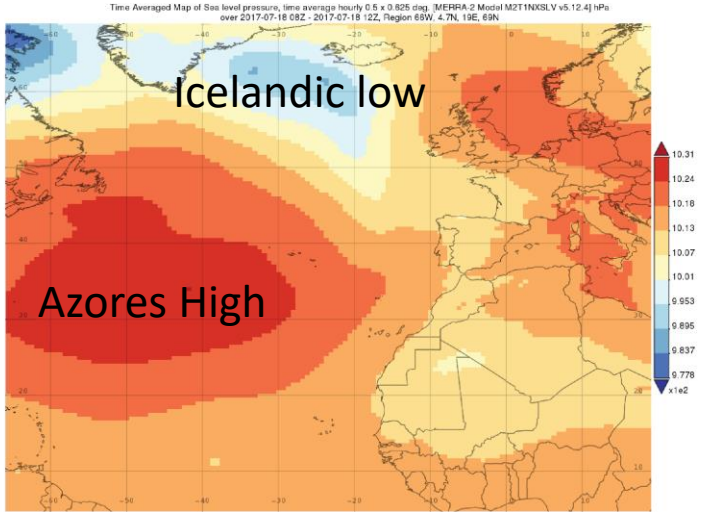
What and Why?

- Objective: Better understand the horizontal variations of LWC and CDNC, as well as their co-variations in MBL clouds at sub-GCM-grid scales.
- Why are we interested in this?
  - Warm rain parameterizations in GCMs are highly non-linear: e.g., $\left(\frac{\partial q_r}{\partial t}\right)_{auto} = \boldsymbol{E} \cdot \gamma < q_c >^{2.47} < N_c >^{-1.79}$ (KK2000)
  - The so-called enhancement factor (*E*) is needed to account for the nonlinearity effect (i.e., Jensen's inequity), which is dependent on the sub-grid cloud variations (Morrison and Gettelman 2008; Larson and Griffin 2013; Lesbsock et al. 2013;Boutle et al. 2014; Zhang et al. 2019)
  - In the current GCM, the EF often assumed const. e.g. *E*=3.2 in CAM5 MG scheme.

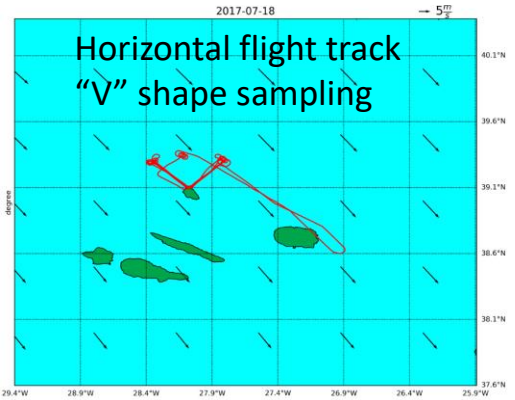
A case study based on July 18, 2017 case

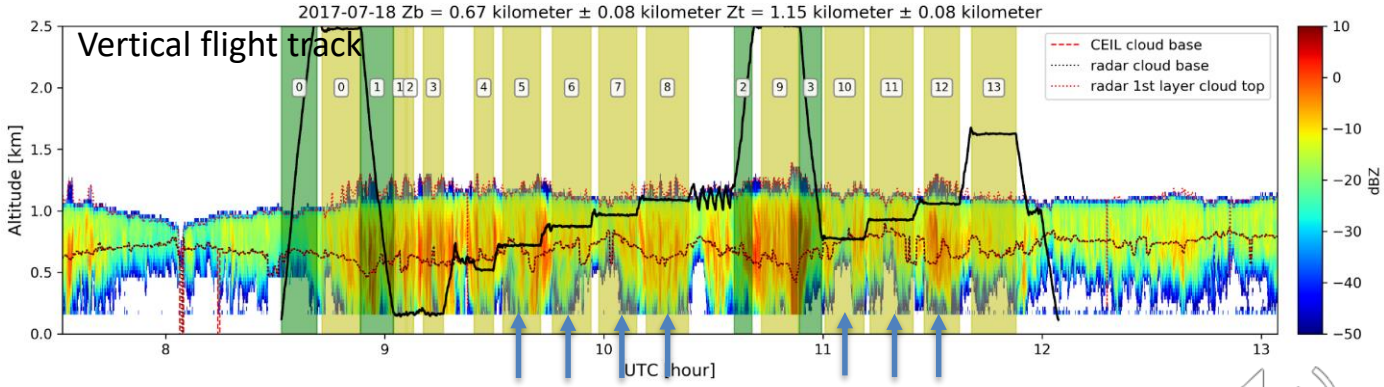




Observations:

- AIMMS
- FCDP
- 2-DS
- KZAR
- CEIL

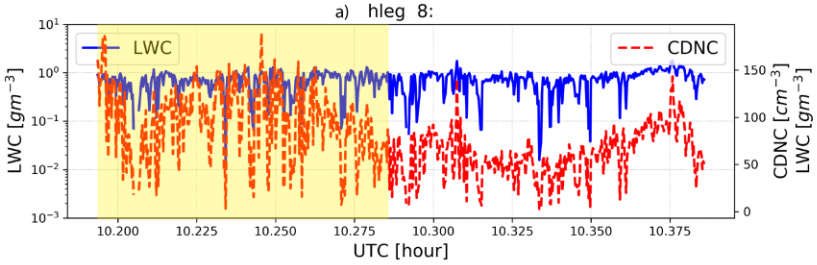


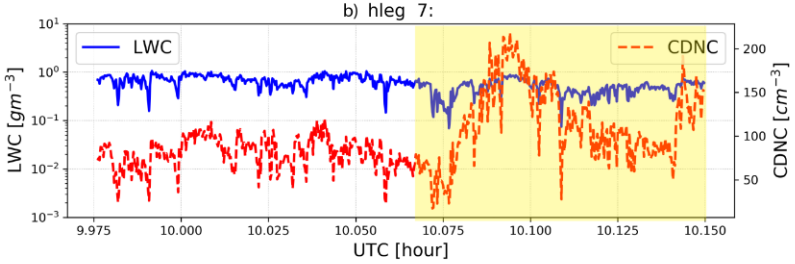


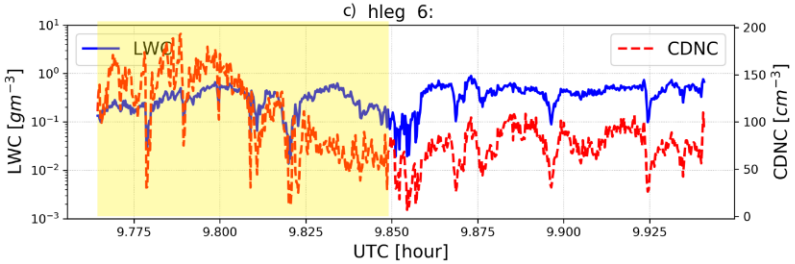
7 hlegs selected: 5,6,7,8 and 10, 11, 12, each corresponding to a "V" shape track

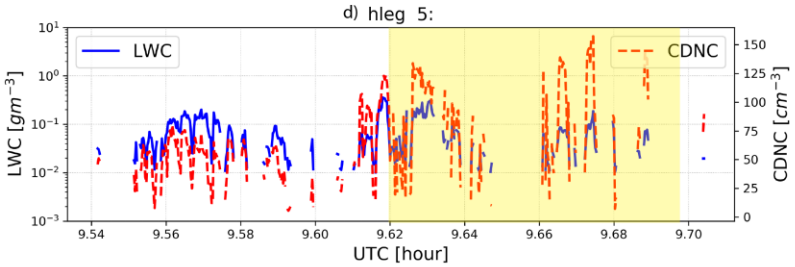
The left side of the "V" shape is along-wind and right side is cross-wind, each side ~40 km

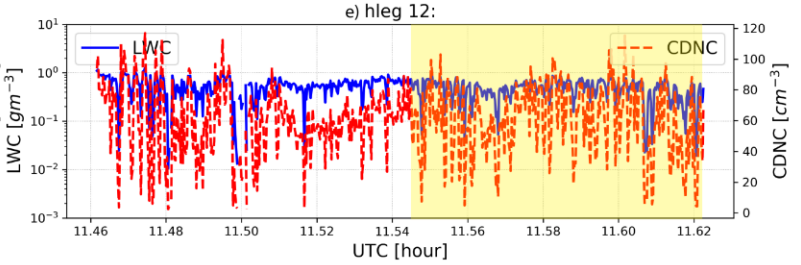
LWC and CDNC horizontal variations





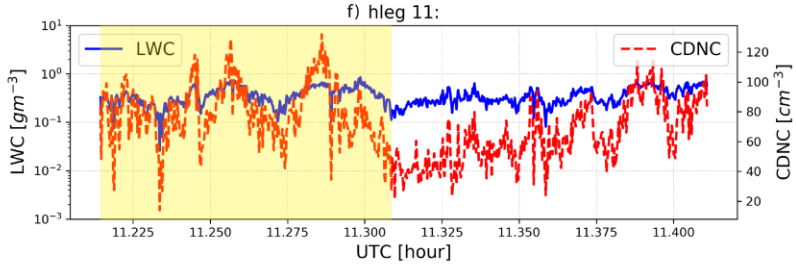


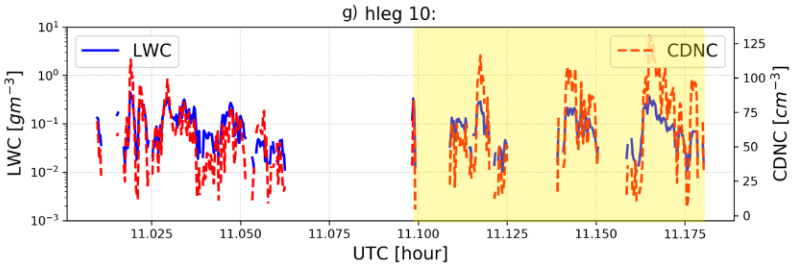




Cross-wind

Along-wind



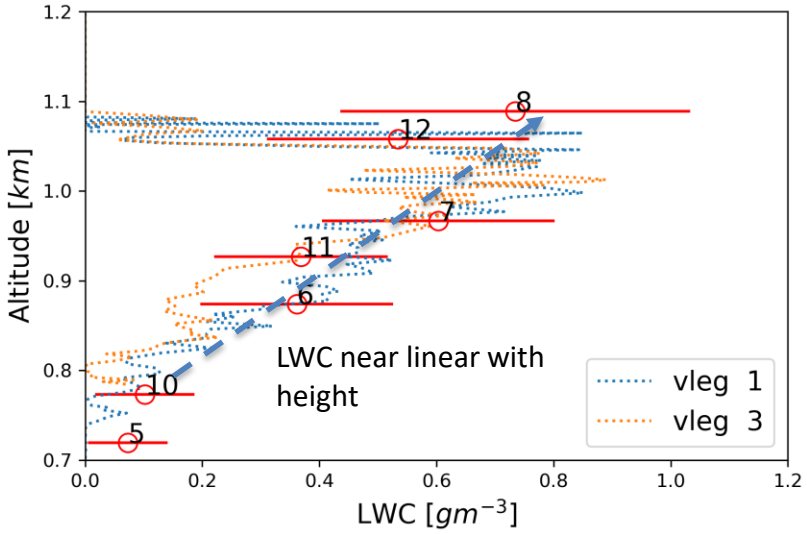


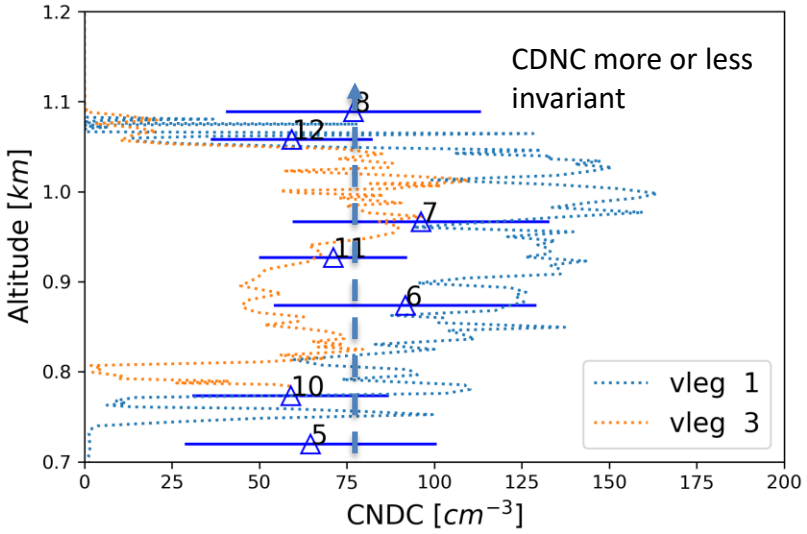
Cloud top

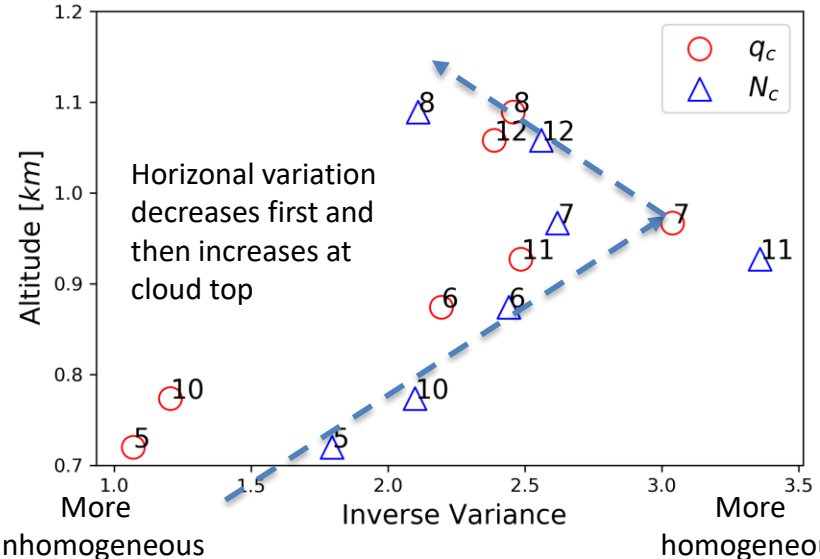
Cloud middle

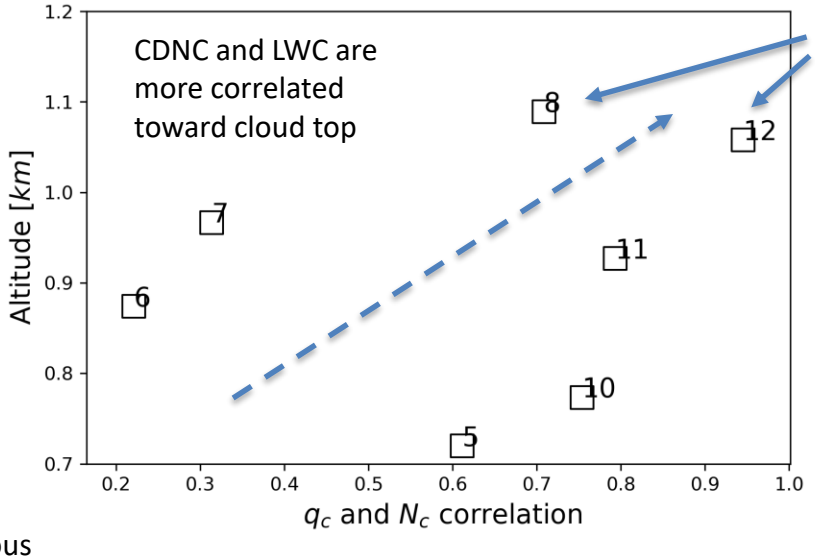
Cloud base

Vertical dependence





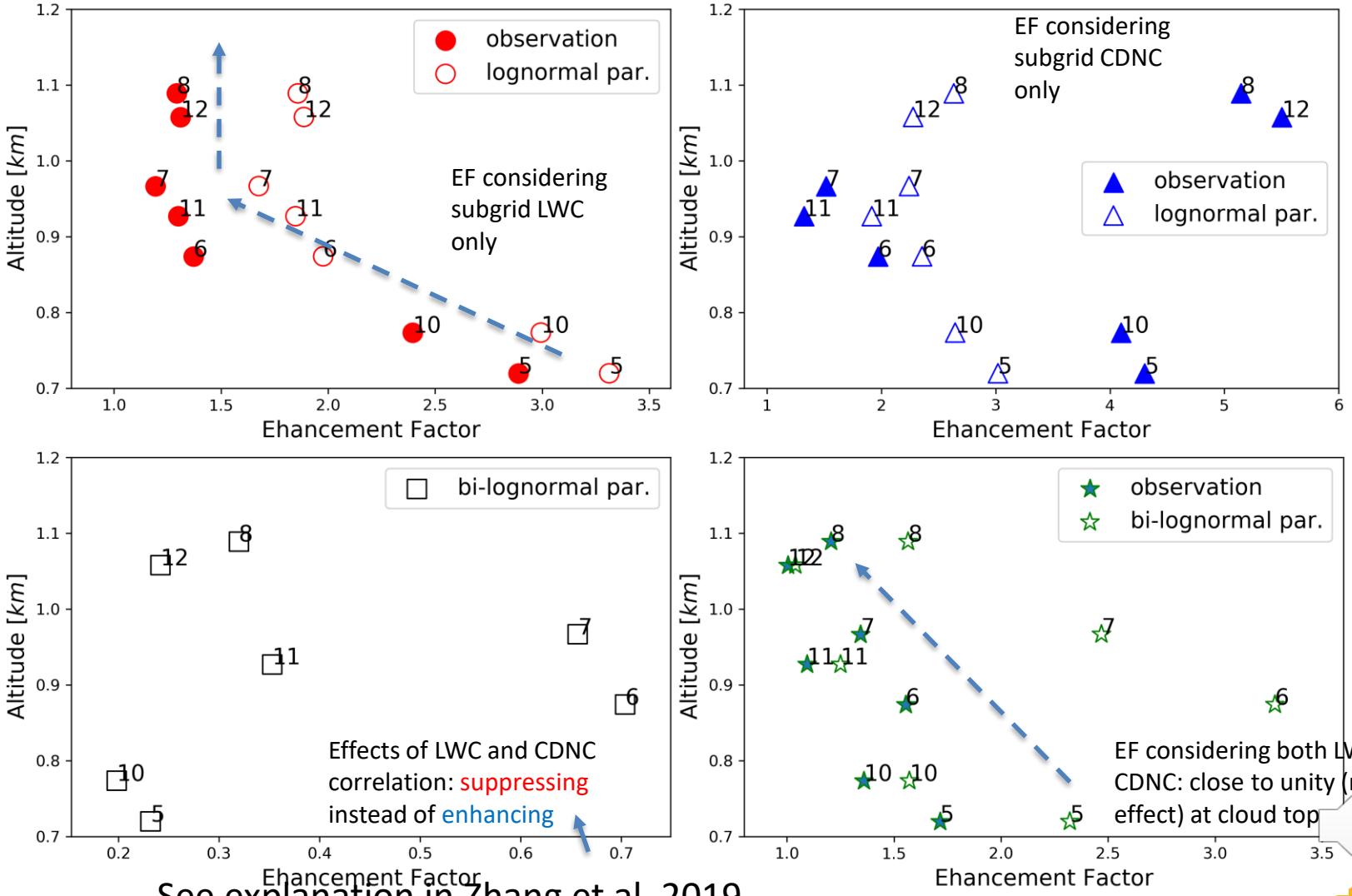




High correlation of LWC and CDNC at cloud top

Implications for warm rain simulations

$$\left(\frac{\partial q_r}{\partial t}\right)_{auto} = E \cdot \gamma < q_c >^{2.47} < N_c >^{-1.79}$$



See explanation in Zhang et al. 2019

Main findings and implications

- The relative inhomogeneity of both LWC and CDNC tends to first decrease from cloud base upward toward cloud based, and then increases in the uppermost (e.g., entrainment zone) of MBL clouds.
- The correlation between LWC and CDNC generally increases from cloud base toward cloud top.
- **The strong positive correlation of LWC and CDNC results in a suppression term in the formulation of enhancement factor**
- As a result, the enhancement factor for autoconversion parameterization in GCMs generally decreases from cloud base toward cloud top.
- **The value of enhancement factor, when consider both the subgrid variations of LWC and CDNC, as well as their correlation is significantly smaller than what is used in CAM5 E=3.2**

Interesting Bimodality of CDNC