Representation of Arctic Mixed-Phase Clouds in Climate Models – Perspectives from a Cloud-Resolving Study

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Objectives

- **To better understand the Arctic mixed-phase cloud (AMC) properties such as variability of cloud properties and Wegener-Bergeron-Findeisen (WBF) process based on CRM simulations with the explicit bin microphysics.**

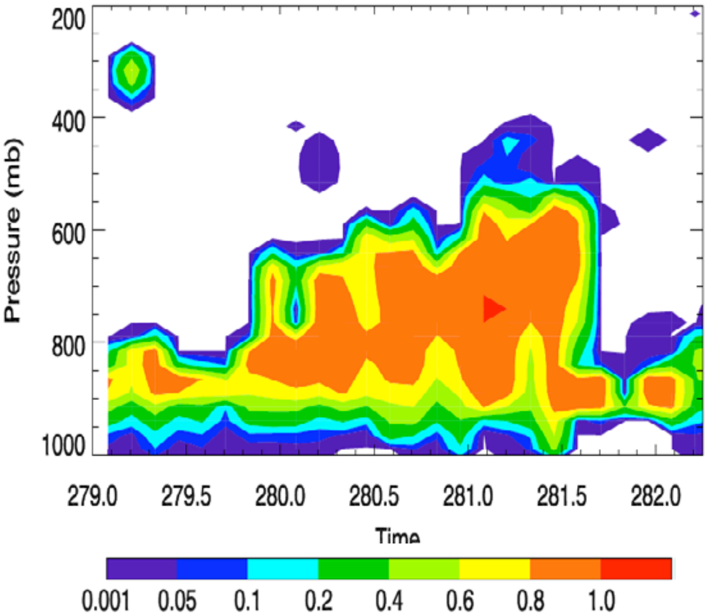
- **To improve the representation of the mixed-phase clouds in the climate models, especially over the Arctic region.**

Case studies

(1) Single-layer mixed-phase cloud (SLMC)

ISDAC: Apr 26 , 2008

(2) Multi-layer mixed-phase cloud (MLMC)



MPACE_A: Oct. 5-8, 2004

- SAM with spectral-bin microphysics (SBM) (Fan et al., 2009)

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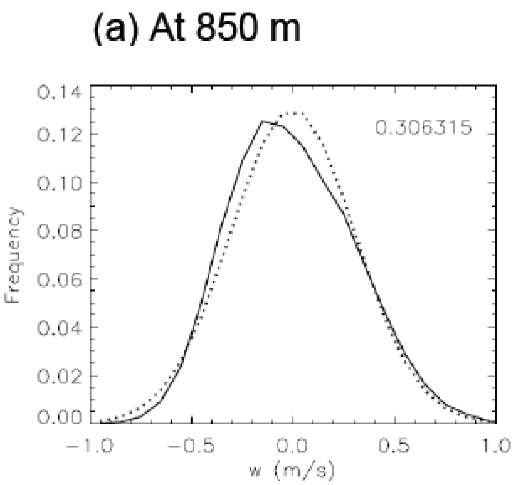
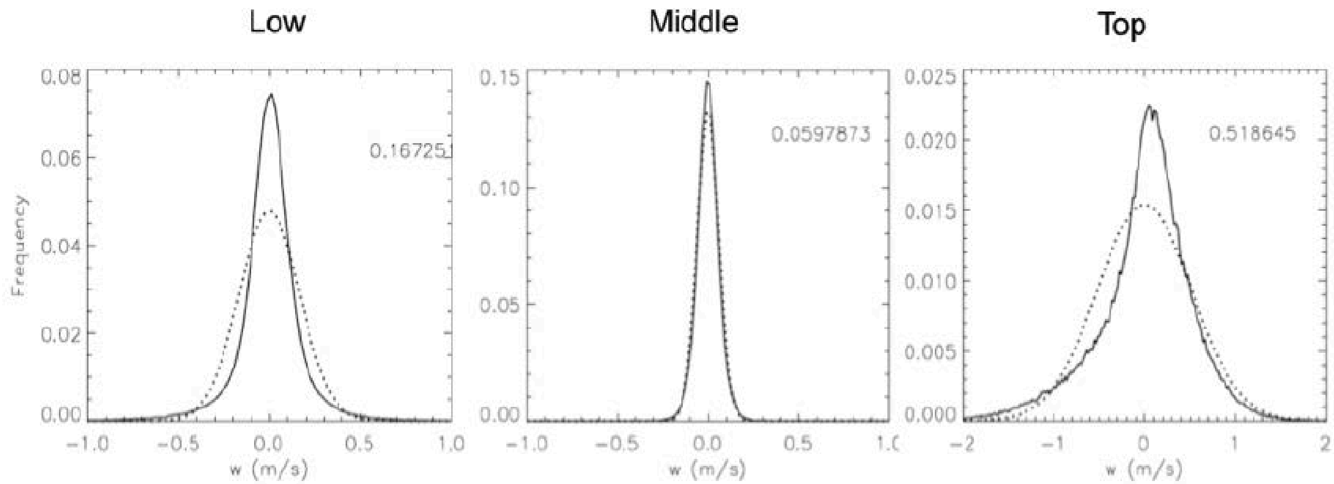
1. Variability of cloud properties

- **Vertical velocity (*w*)**

SLMC



MLMC



- **PDFs of *w* are normal distributions, but σ varies significantly at the different layers in MLMC.**
- **How to accurately account for the change of σ?**

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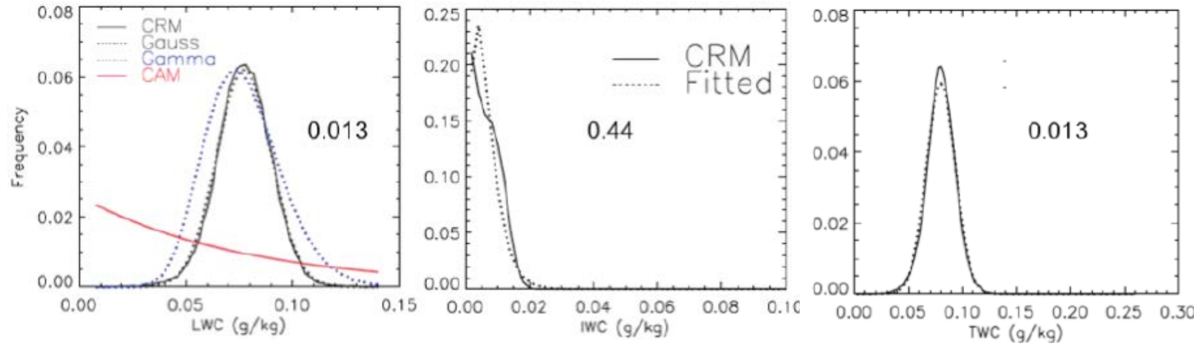
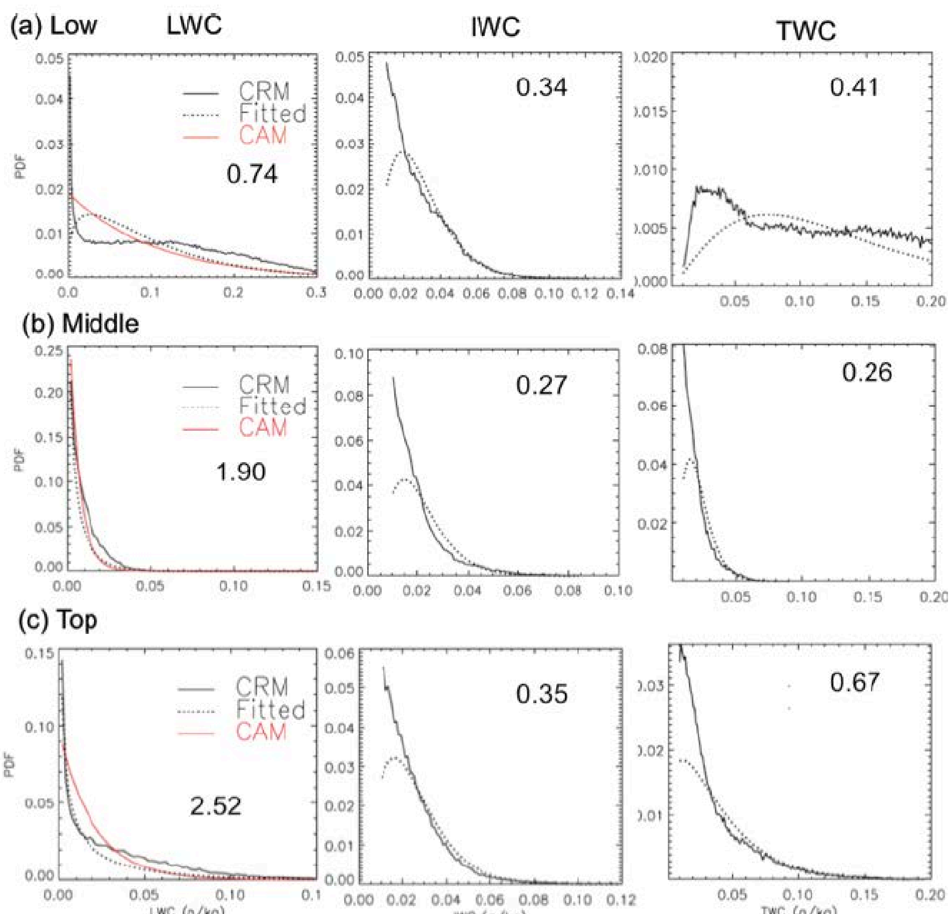
- # CWC, IWC and TWC

SLMC



MLMC



- The PDFs of LWC, IWC and TWC can be represented by a Gamma distribution.
- PDF from the fixed variance (1 or 2) in CAM fits badly with CRM for the boundary mixed-layer.
- **To account for changes of variances in w, qt, LWC and IWC, joint PDF from Larson could be a good approach?**

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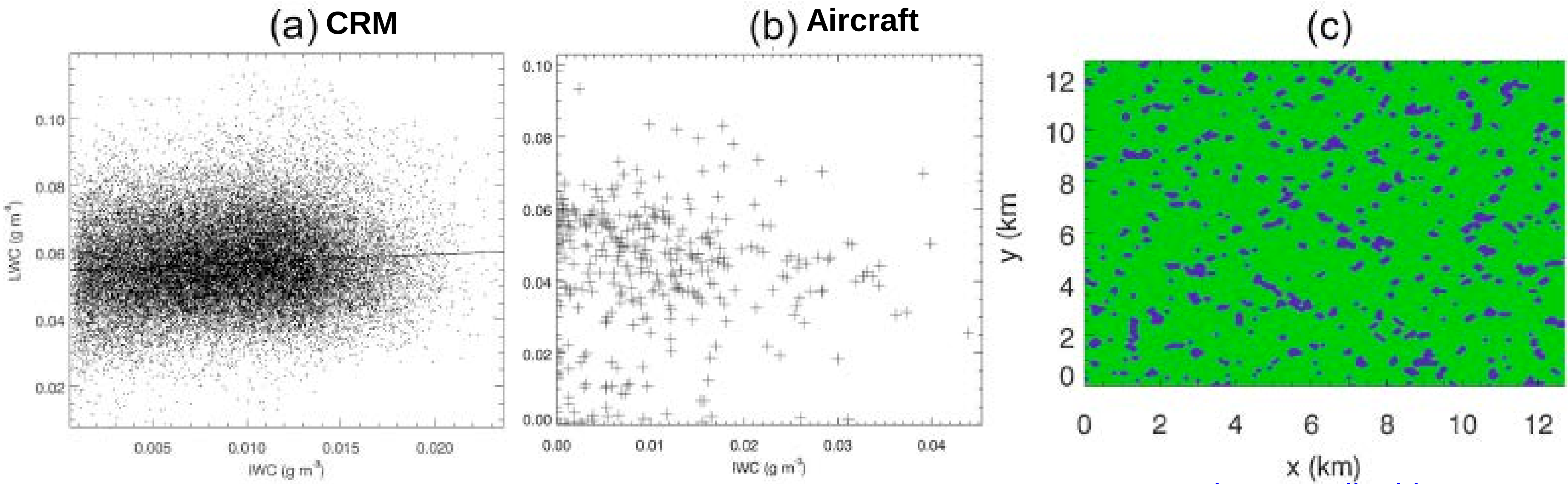
2. Co-location of LWC and IWC



Blue: pure liquid
Green: mixed-phase

- **LWC does not correlate with IWC well in the mixed-phase layer.**
- **The pure liquid portion exists but at the scale of < 1 km. For the scales in GCMs, the maximum overlap assumption looks appropriate.**

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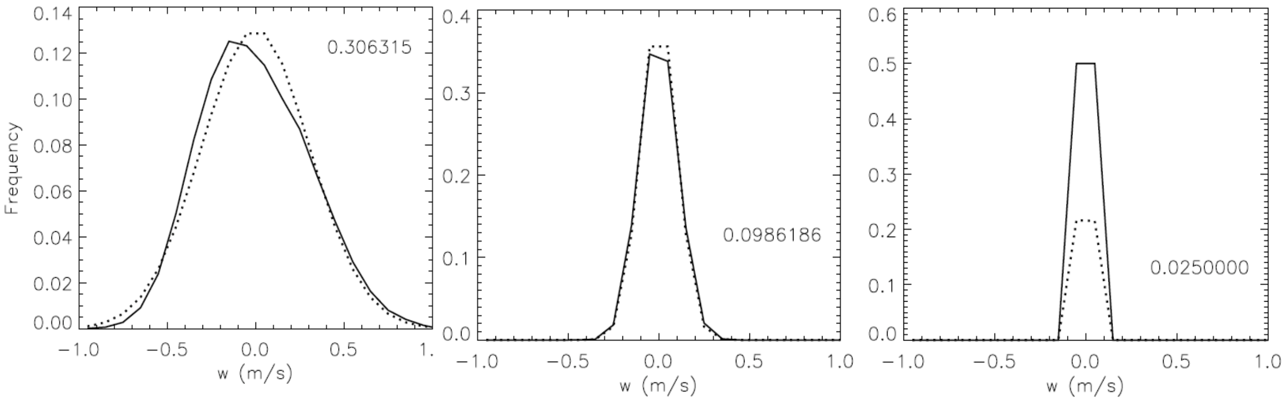
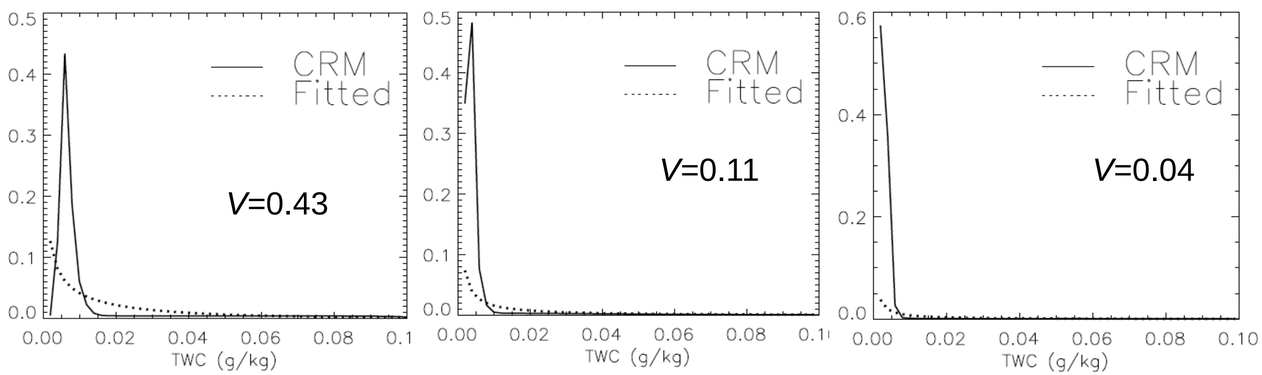
3. Scale-dependence

Vertical velocity (*w*)



TWC



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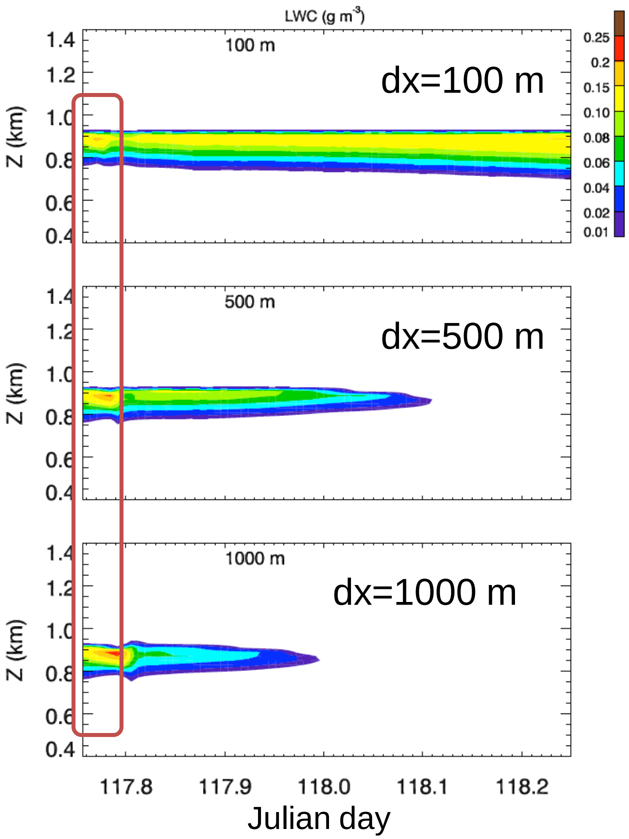
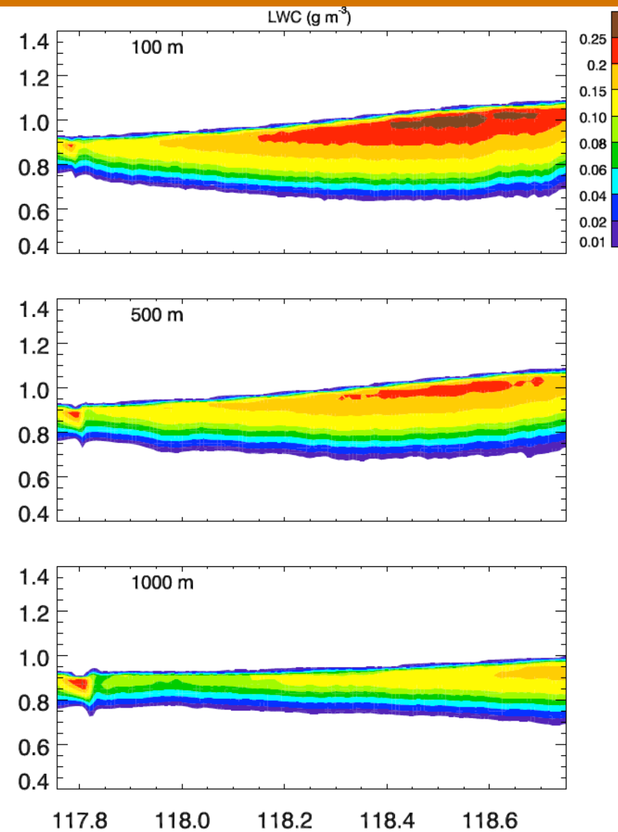
Ni=0.5 L^{-1}



Ni=0.1 L^{-1}



- When the same observed Ni is produced, the mixed-phase cloud (MPC) dies quickly at the 1 km scale (ice falls much faster at weaker updrafts.
- To get the similar amount of MPC, you can decrease the produced Ni. Then your IN would be much lower than obs.
- **How to solve this dilemma at large scales? If can't, which factor matters more, cloud amount or Ni (effective radius)?**

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Background: WBF

- Based on *Korolev 2006, 2008*, WBF process occurs only in the limited range of conditions in the mixed-phase clouds.

(1) $e > e_s > e_i \quad \rightarrow w_{th} = \dfrac{e_s - e_i}{e_i} \eta N_i r_i$ Both droplets and ice particles grow

(2) $e_s > e > e_i$ WBF

(3) $e < e_i < e_s \quad \rightarrow w^*_{\min} = \dfrac{e_i - e_s}{e_s} \chi N_w r_w$ Both droplets and ice particles evaporate

- ***What's the w_{th} and w_{min}^* for WBF in the CRM?***
- ***What are the fractions of these 3 regimes in the AMC?***

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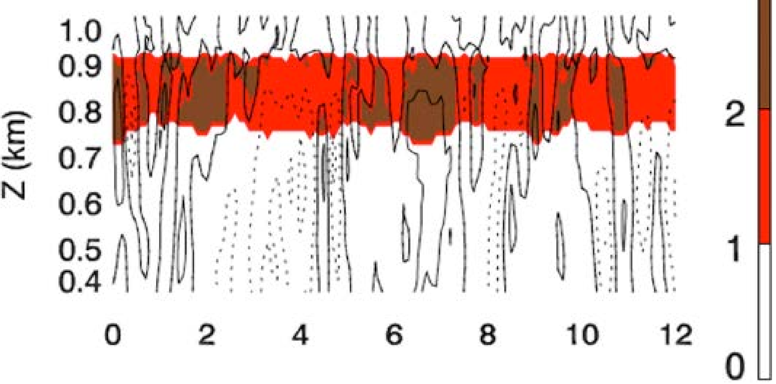
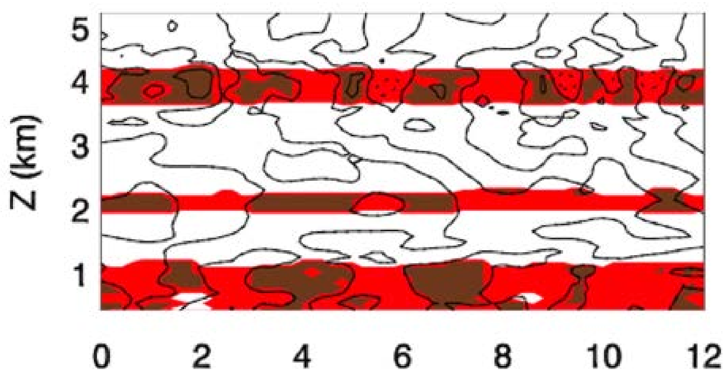
4. WBF Process

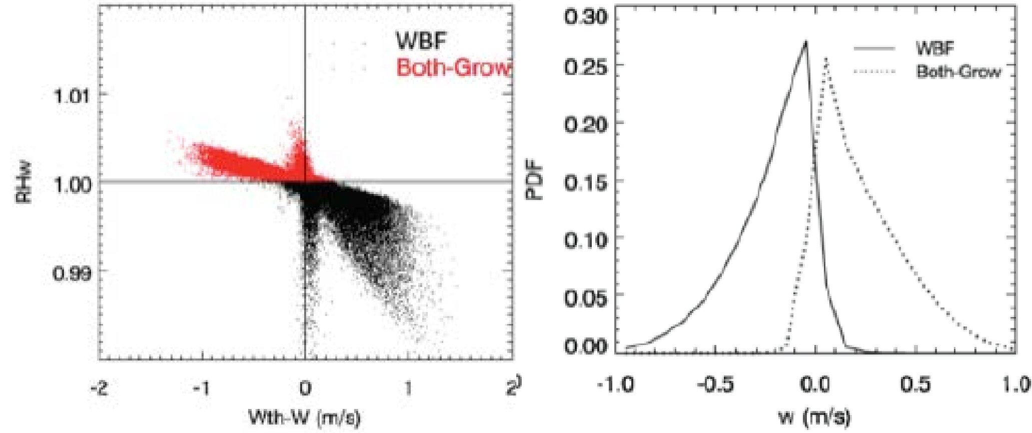
SLMC **Regimes**



MLMC

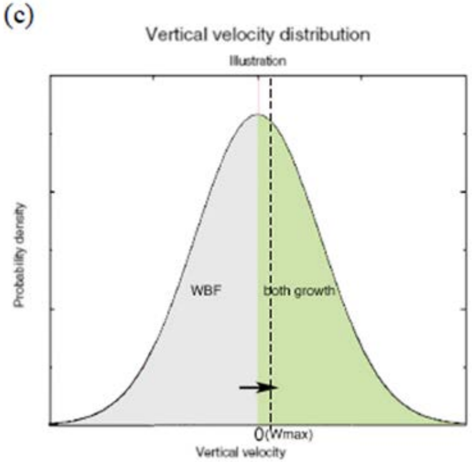


- **WBF:~ 50%**
- **Both-growth: ~50%**



- WBF process occurs only in a limited region (93% in downdraft).
- Wth < 0.1 m/s, meaning a small updraft can easily disable the WBF process

(c)



- So: as W > Wth (close to 0), both liquid and ice would grow
- Since liquid condensation is not calculated explicitly, it is not necessary to account for sub-grid properties.