Analysis of upper tropospheric cloud properties and water vapor variability in relation to the large-scale atmospheric state

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Introduction

Parameterization of the distribution and variability of water vapor, cloud microphysical properties, and cloud fraction within a global climate model (GCM) grid box remains one of the key uncertainties in improving our prediction of future climate. We analyze the distribution and fractional variance of observed cloud scale vertical motion, cirrus microphysical properties, and upper tropospheric water vapor in 12 unique atmospheric states. Within this framework, we also discuss the potential for relating atmospheric states to cirrus formation mechanisms.

(1) Classification of the Large-Scale Atmospheric State

Clustering Algorithm

- Clustering algorithm performed on ~ 3 ½ years of Rapid Update Cycle (RUC) output centered over the ARM SGP site
- Extract at each 3 hour time step:
  - Surface Pressure Temperature, Humidity, winds (U, V, and W)
  - over a 9 x 9 grid where each grid box is roughly equal to a GCM grid box
  - at 8 different pressure levels
- Cluster using a Competitive Neural Network to assign each time step to an atmospheric state

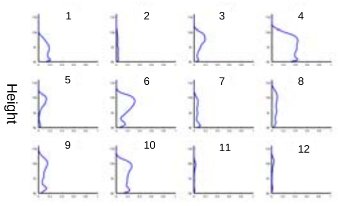
Validation

- Time series of the vertical profile of cloud fraction provides an independent validation data set
- Developed a statistical test to determine if two states are distinct or not:
  - Bootstrap resampling technique to account for the presence of highly correlated data (Wilks 1997; Efron and Tibshirani 1993)
- Test for two things:
  - State Distinctness
  - State Stability
- An iterative process is used to arrive at a final, validated set of states

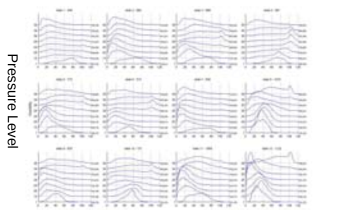
Reference: Marchand et al. (2006), *J. Atmos. Sci*, **63**

(2) Unique Atmospheric States

Cloud fraction as a function of height derived from MMCR reflectivity profiles



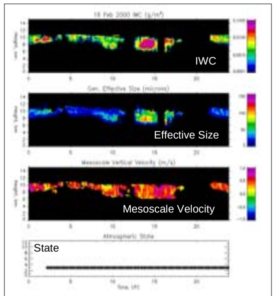
Frequency distribution of RH as a function of pressure level for each state



(3) Cloud Scale Properties

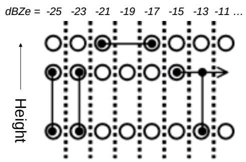
Cloud Properties

- IWC and particle effective size (D_{ge}) for individual cloud systems are retrieved using a lidar-radar algorithm (Wang and Sassen 2002, *JAM*, **41**)
- Lidar/radar algorithm applied to Raman lidar and MMCR data at SGP 1999-2000
- Atmospheric state assigned to cloud observations based on RUC analysis (see (1))
- Mean and fractional variance (f_x) computed for each cirrus event on a given day



Example of retrieved cloud properties and atmospheric state on 16 Feb 2000 at SGP

Mesoscale Velocity (V_{meso})



See Marchand et al. ARM (2004) and Orr and Kropfli (1999)

- Bin MMCR Doppler Velocity (V_D) according to layer height and reflectivity
- Average V_D in each height-Z bin
- Average V_D=Fall Velocity (V_{fall})
- $V_{meso}=V_D-V_{LS}-V_{fall}$ where V_{LS} is the large-scale vertical velocity.
- Require 100 samples in a bin
- Interpolation performed between bins

Summary

- 12 unique atmospheric states are identified using RUC model output and a clustering algorithm.
- Mean and fractional variance of atmospheric and cloud properties are computed for each atmospheric state at the SGP site to understand the variability within states.
- Variability of cirrus properties is less than the variability of atmospheric quantities (T, RH, Winds), implying that fewer states are required to parameterize their variability. However, mean cloud properties vary between states.
- Results imply that cirrus formation mechanisms may be parameterized for specific states rather than globally applied.

Future Work

- Further analysis is needed to understand the sensitivity of the atmospheric state classification to the input assumptions and clustering algorithm. Tailoring the atmospheric states to cirrus related inputs and validation datasets will be explored.

(5) Application: Cirrus Formation

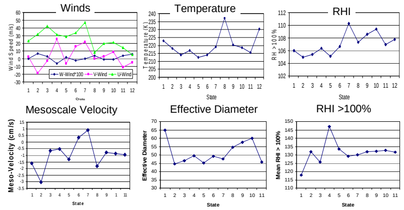
Heterogeneous Nucleation

- 2 cm/s updraft
- Lower critical supersaturation threshold
- Small numbers of ice crystals grow quickly to large sizes

Homogeneous Nucleation

- 50 cm/s updraft
- High critical supersaturation threshold
- Large numbers of ice crystals; growth limited; fewer large crystals

Mean atmospheric and cloud properties in State 1 are consistent with our knowledge of heterogeneous nucleation



(4) Mean and Variability of Cloud and Atmospheric Properties

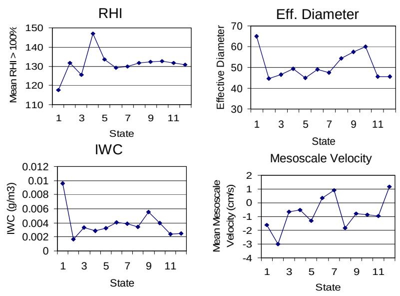
- Mean and fractional variance (f_x) computed for each atmospheric state
- RHI and V_{meso} are for "in cloud" points

$$f_x = \left(\frac{\sigma_x}{\bar{x}}\right)^2$$

Fractional Variance

Hogan and Illingworth (2003), *J. Atmos. Sci.*, **60**

Mean Quantities



Fractional Variance