Research Objective 4:
Develop improved parameterizations of boundary-layer clouds and turbulence for use in MMFs and GCRMs

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CMMAP Site Review
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Scales of Atmospheric Motion

10,000 km 1000 km 100 km 10 km 1 km 100 m 10 m

Planetary waves  Extratropical Cyclones  Mesoscale Convective Systems  Cumulonimbus clouds  Cumulus clouds  Turbulence

Global Climate Model (GCM)  Cloud System Resolving Model (CSRM)  Large Eddy Simulation (LES) Model

Multiscale Modeling Framework
Boundary layer cloud systems

- Marine stratocumulus
- Trade cumulus
- Shallow convection over land (with diurnal cycle)
- Transition from shallow to deep convection
- Deep precipitating convective
- Cold-air outbreaks over mid-latitude oceans
- Convective plumes from leads during winter
- Boundary layers over inhomogeneous surfaces or terrain
Boundary layer clouds in cloud system resolving models (CSRM)s

• CSRM:s used in MMF:s have horizontal grid sizes of 4 km or more.
• Such CSRM:s are expected to represent all types of cloud systems.
• However, many boundary layer clouds are not resolved by such CSRM:s.
• Our objective is to improve the representation of boundary layer clouds and turbulence in CSRM:s used in MMF:s.
Shallow cumulus clouds and mesoscale organization

- Typical CSRMs grid sizes are too large to resolve shallow cumulus.

- A CSRM with a suitable SGS parameterization should be able to represent SGS shallow cumulus and resolve their mesoscale organization.

- Evaluate parameterization with LES and observations.
Meeting the Objectives

**Develop and test** improved representations of SGS convection and turbulence in CSRMs.

- **Parameterizations under consideration**
  - *PDF/HOC (probability density function/high-order closure)*: Predicts statistics of turbulence to infer SGS cloud properties
  - *Two-scale MMF*: 2D LES model predicts a sample of cloud properties.

- **Additional physics to be included**
  - Effects of *surface inhomogeniety* (elevation, land surface properties)

- **Evaluation methods**
  - Use 3D LES *benchmark simulations*
  - Compare to *observational datasets*
Cloud fraction evolution for BOMEX shallow cumulus

CSU System for Atmospheric Modeling (SAM) CRM with LOC and IP–HOC, and LES version
Low-cloud fraction results obtained in tests of a “mini-LES” parameterization of turbulence, coupled with the MMF. The top panel shows results from a control run with the standard MMF, the middle panel shows results from the mini-LES version of the MMF, and the bottom panel shows observations from ISCCP.
Evaluation Methods

• **Benchmark simulations**
  • Large-domain LES (e.g., 100 km x 100 km domain, 100-m grid size)
  • Compare to CSRM results using various SGS parameterizations.
  • Analyze results to gain insight into scale interactions, etc.
Large domain LES of trade wind cumulus

40 km x 40 km domain, 100-m grid size
Evaluation Methods

• Observational datasets
  • High-resolution cloud properties from satellite measurements
  • Vertical structure of clouds from ground and satellite-based cloud radars
  • Aircraft-based measurements during field experiments
Shallow cumulus clouds and mesoscale organization

- Typical CSRM grid sizes are too large to resolve shallow cumulus.
- A CSRM with a suitable SGS parameterization should be able to represent SGS shallow cumulus and resolve its mesoscale organization.
- LES is used to provide benchmark simulations.
High-Resolution Simulation of Shallow-to-Deep Convection Transition over Land

(Khairoutdinov and Randall 2006)

Figure 8. PDF of cloud size as a function of height shown for three different simulation times. Mean and standard deviations are shown by the white and yellow lines, respectively.

150 km x 150 km, 100 m grid size, 6 h
Time-height cross section of cloud fraction simulated by SAM CRM with the Cheng-Xu PDF/HOC for BOMEX. The horizontal grid sizes range from 4 km (a) to 250 m (e). Results from the SAM LES are also shown in (f).