Analysis and Modeling of Satellite Cloud Objects

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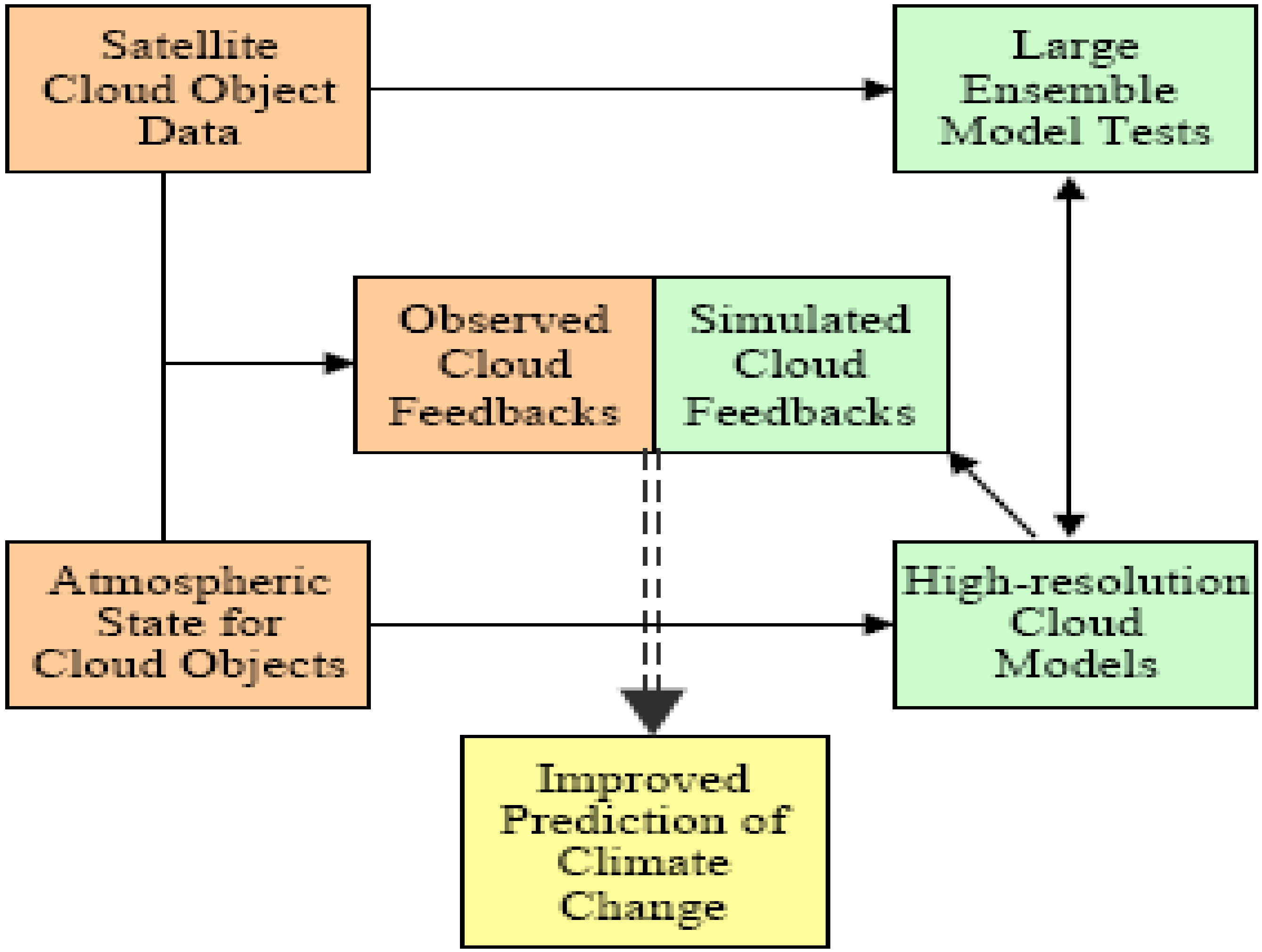
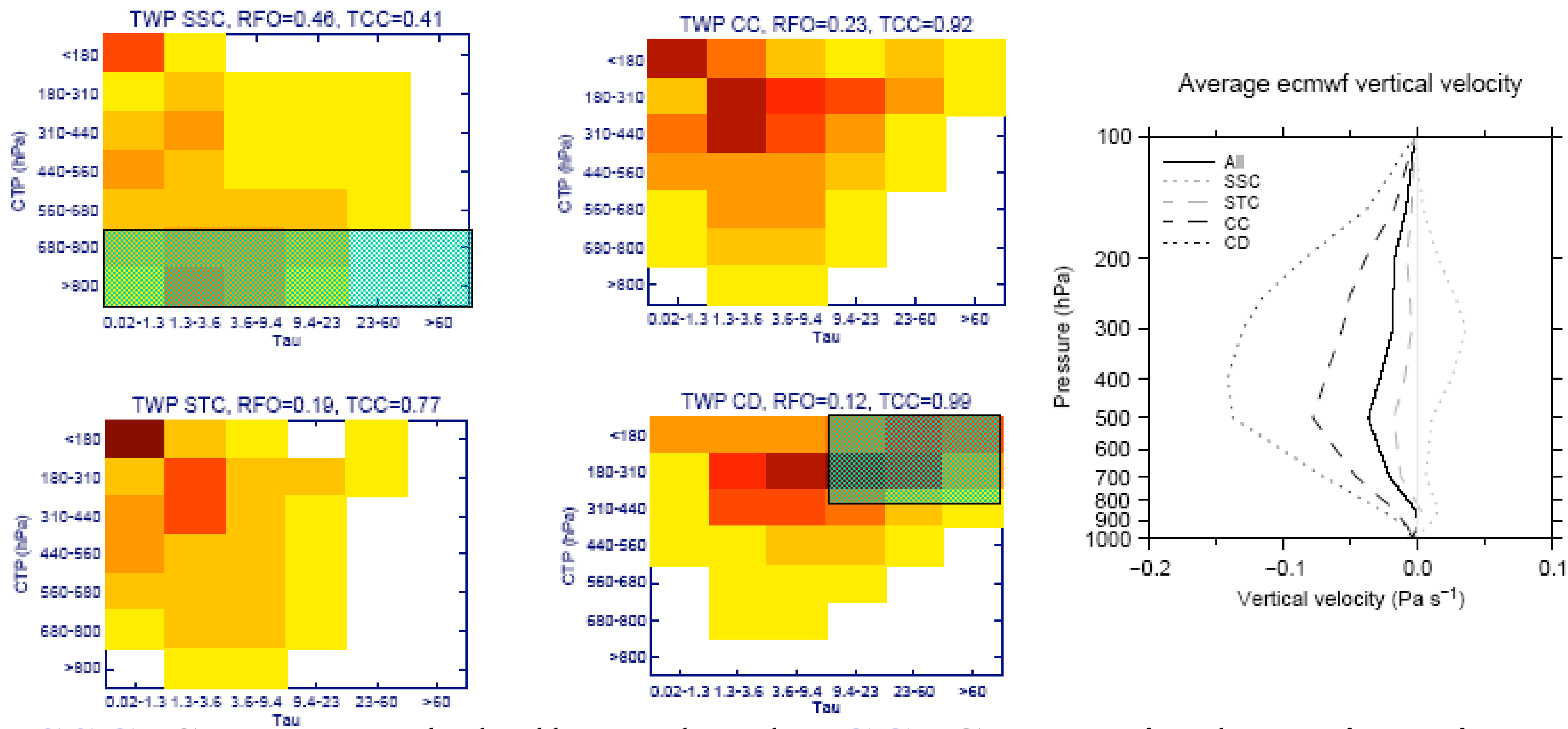
An Integrated Cloud-object Analysis and Modeling Approach



Outline of the Presentation

- Introduction
- Current status
- Analysis of tropical deep convective cloud objects for the TRMM period
- Modeling of tropical deep convective cloud objects for March 1998 and March 2000 periods: Comparison of CRM with ECMWF
- Analysis of boundary-layer cloud object types for the TRMM period
- Summary and future plans

Introduction – *Cluster analysis of satellite data (Jakob et al. 2005)*



SSC: Suppressed shallow clouds; CC: Convectively active cirrus

STC: Suppressed thin cirrus; DC: Deep convection

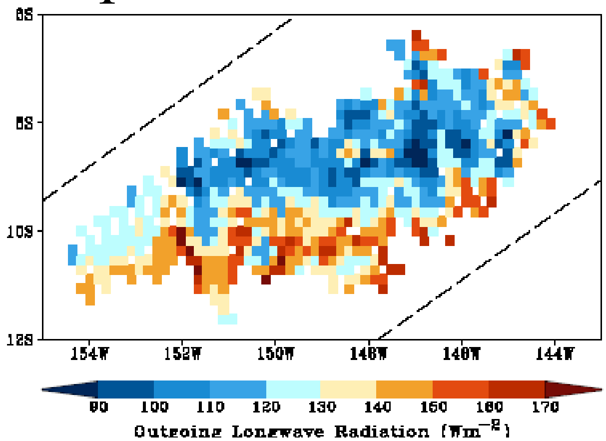
Introduction: *Cloud Objects, predetermined clusters? (Xu et al. 2005)*

- The shape and size of a cloud object is determined by the **satellite footprint data** and by the footprint **selection criteria** for a given cloud-system type
- A cloud object is a contiguous region of the Earth with a **single dominant** cloud-system type, shifting from Eulerian to Lagrangian views of cloud systems

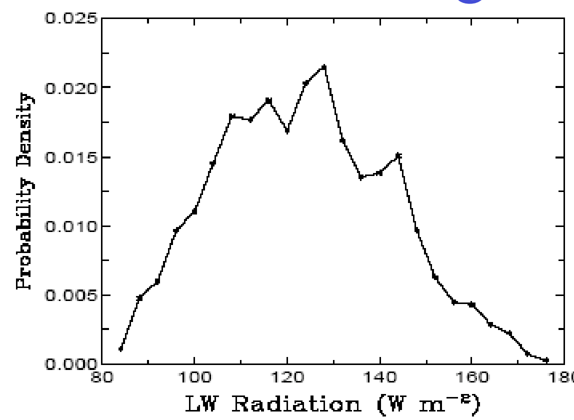
Type of cloud objects	Cloud top height	Cloud optical depth	Cloud cover	Latitude band
Tropical convection	> 10 km	> 10	100%	25S – 25N
Solid stratus	< 3 km	-	99 - 100%	40S – 40N
Stratocumulus	< 3 km	-	40 - 99%	40S – 40N
Shallow cumulus	< 3 km	-	10 - 40%	40S – 40N

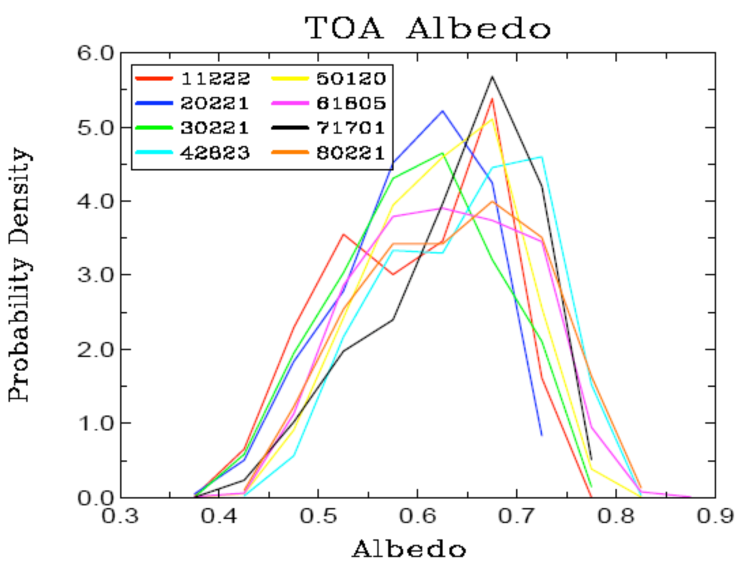
Introduction: *Examples of the Cloud Object Analysis*

Spatial distribution

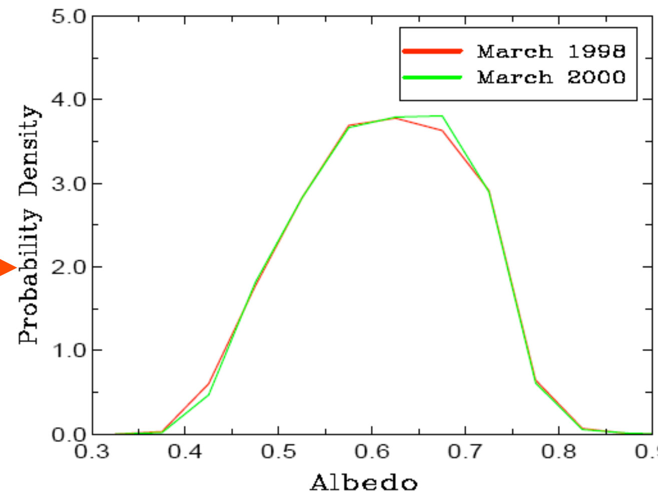


Individual histogram





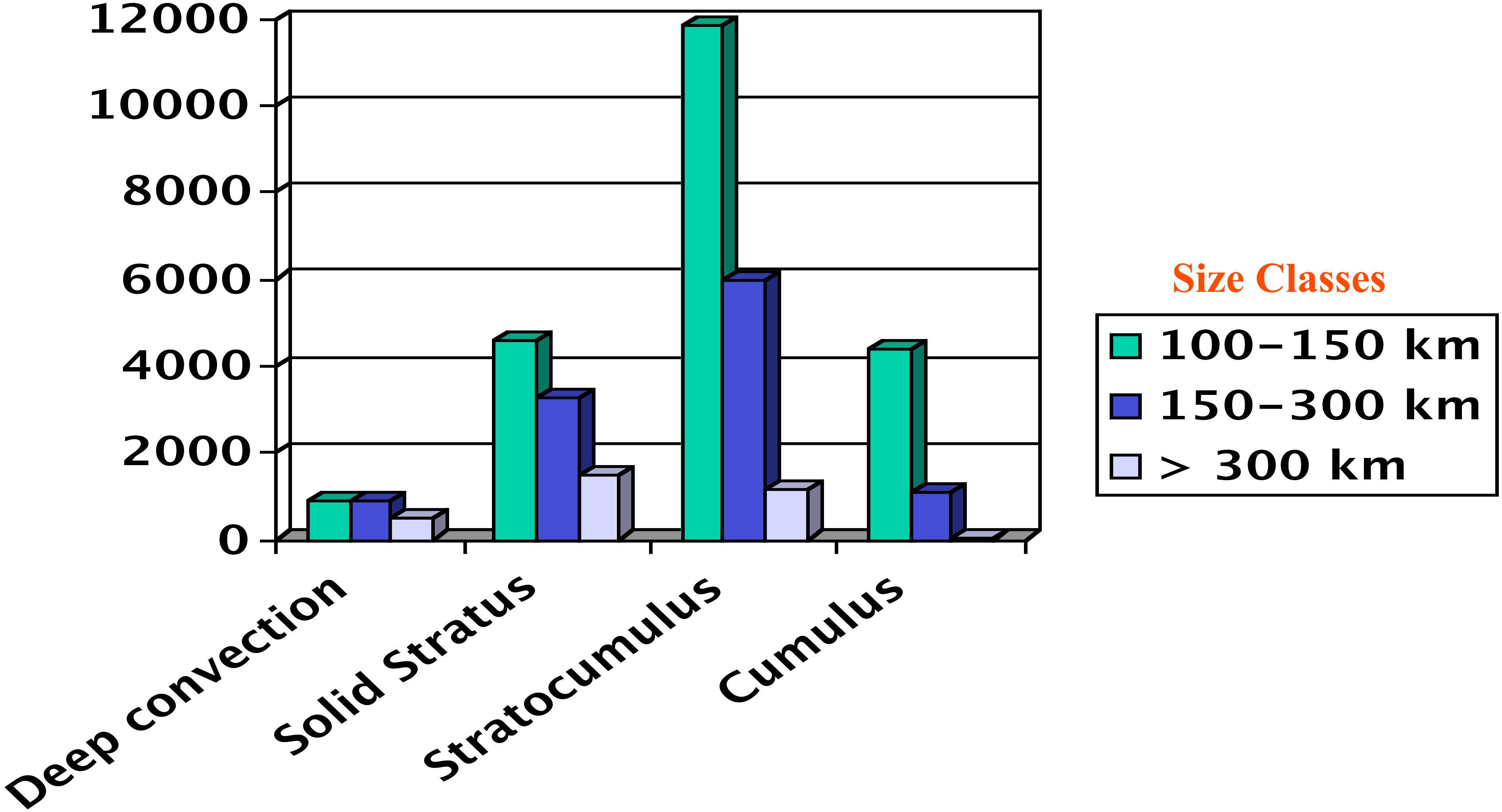
Summary histogram



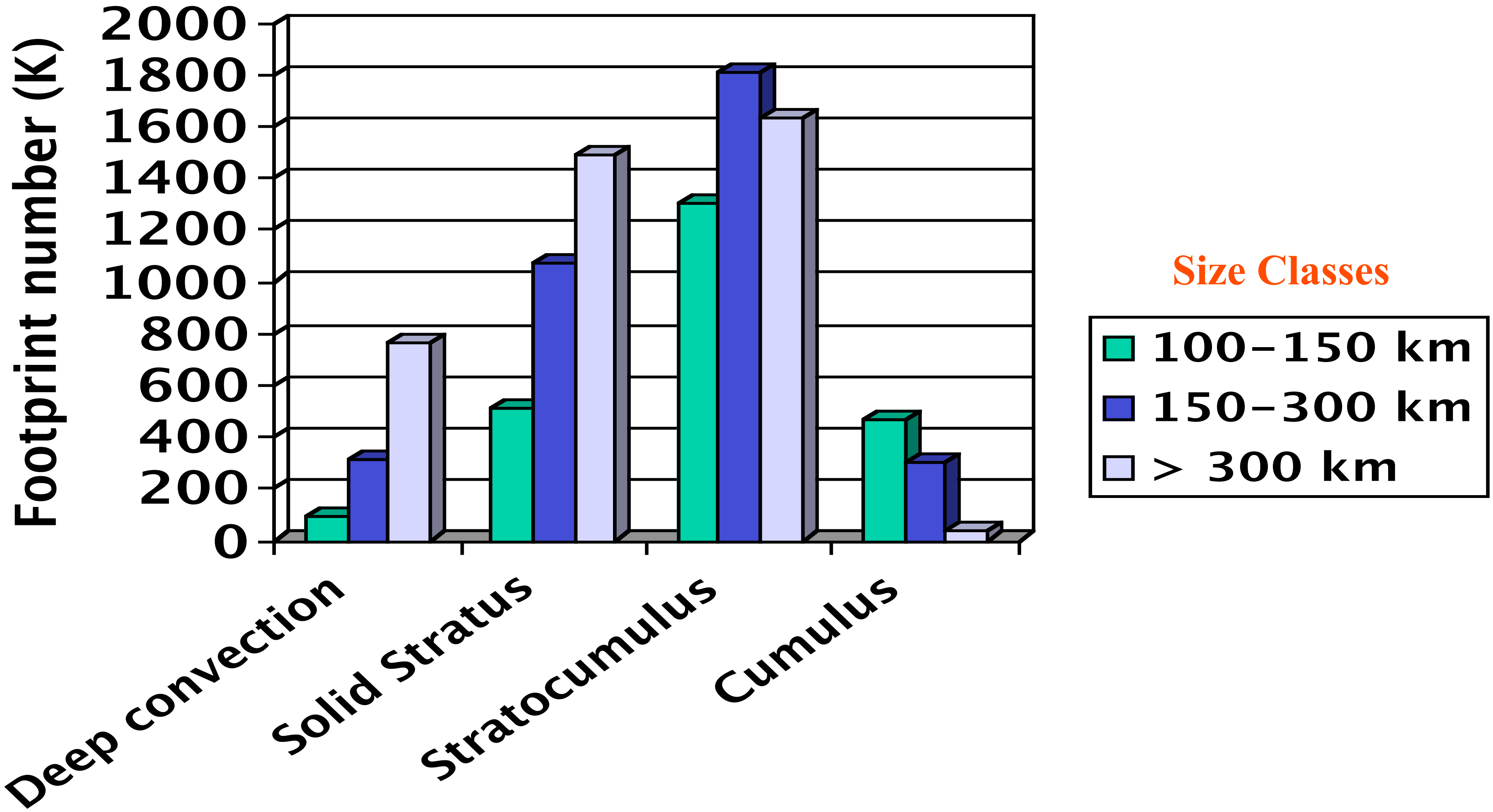
Current Status

- Finished the analysis of all four cloud-object types for the TRMM period
- Created a webpage (http://cloud-object.larc.nasa.gov) for hosting the cloud-object data product, including
  - Cloud object footprint data
  - Cloud object histogram data
  - Cloud object statistical data
  - Matched ECMWF meteorological and forcing data over 13x13 grids
- Published the cloud-object methodology paper (Xu et al. 2005) and initial modeling paper (Eitzen and Xu 2005)
- Simulate the tropical deep convective cloud objects for three different size classes of the March 1998 and March 2000 periods, with the UCLA/LaRC CRM
- Couple the UCLA/LaRC CRM with the GMAO fv-GCM for multi-scale modeling (a.k.a., super parameterization)

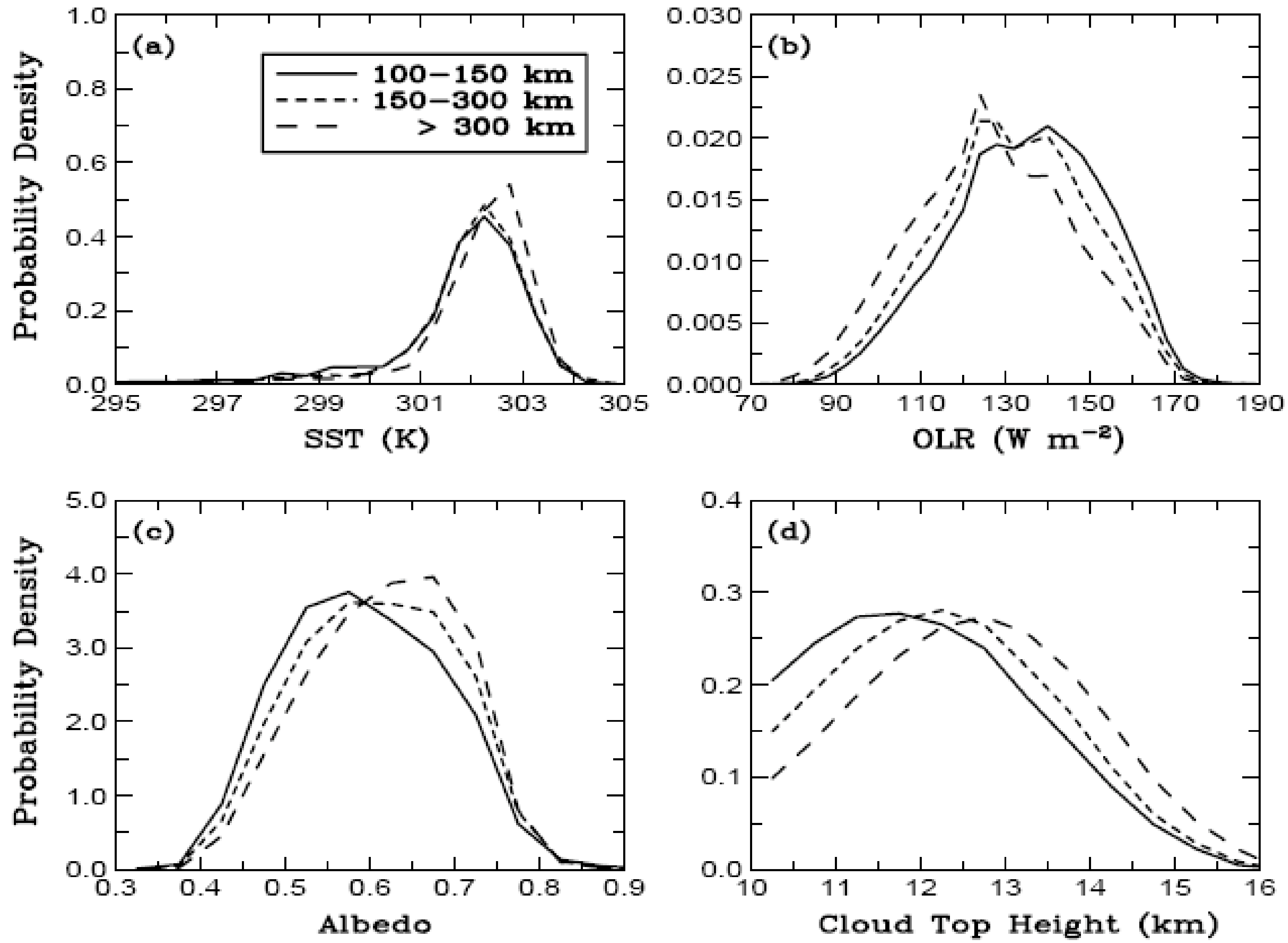
Number of Cloud Objects in the Pacific
during the January-August 1998 Period



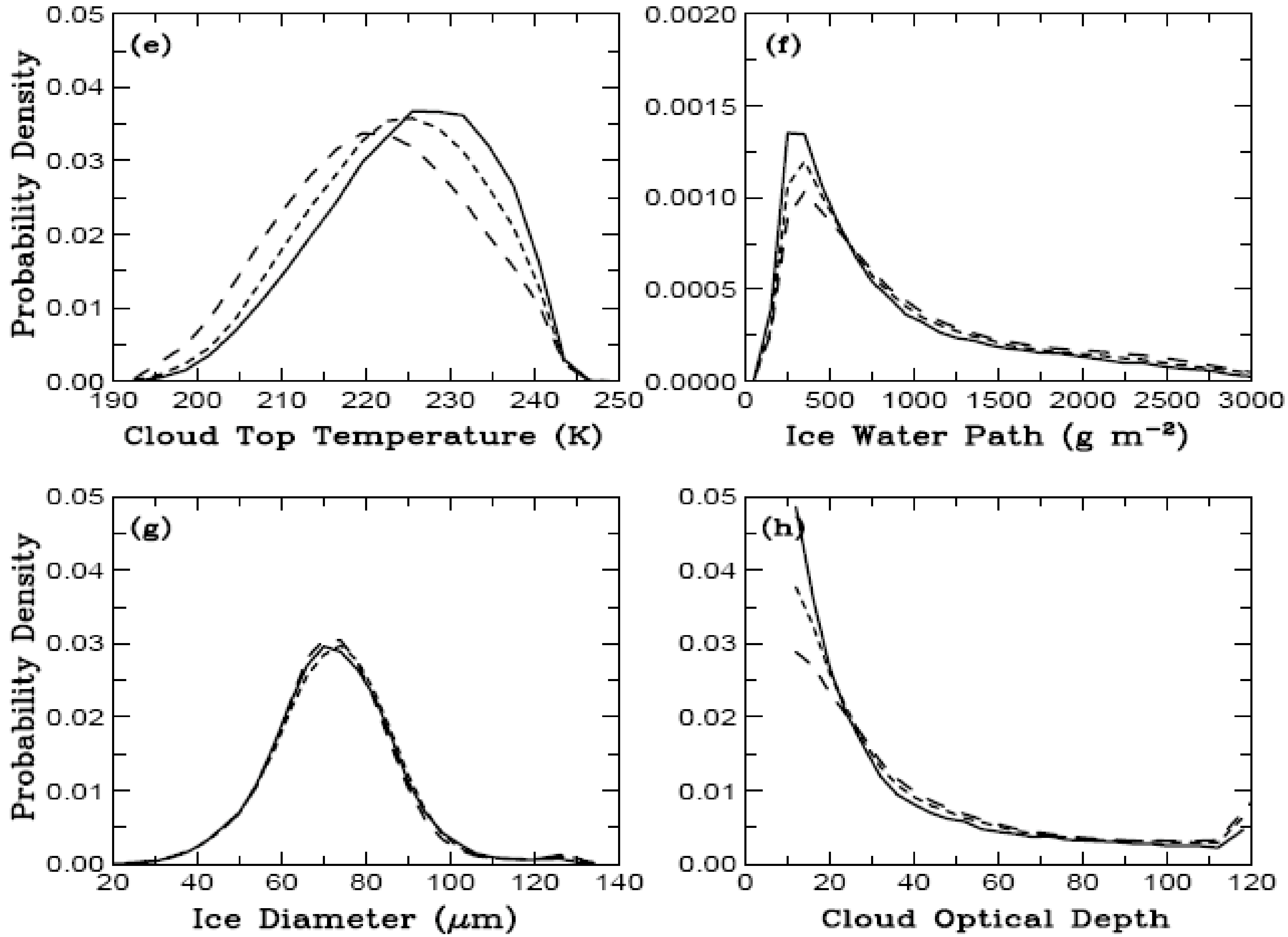
Total Footprint Number of These Cloud Object Types during January-August 1998



Comparison of Different Sizes of Tropical Convective Cloud Objects, 1



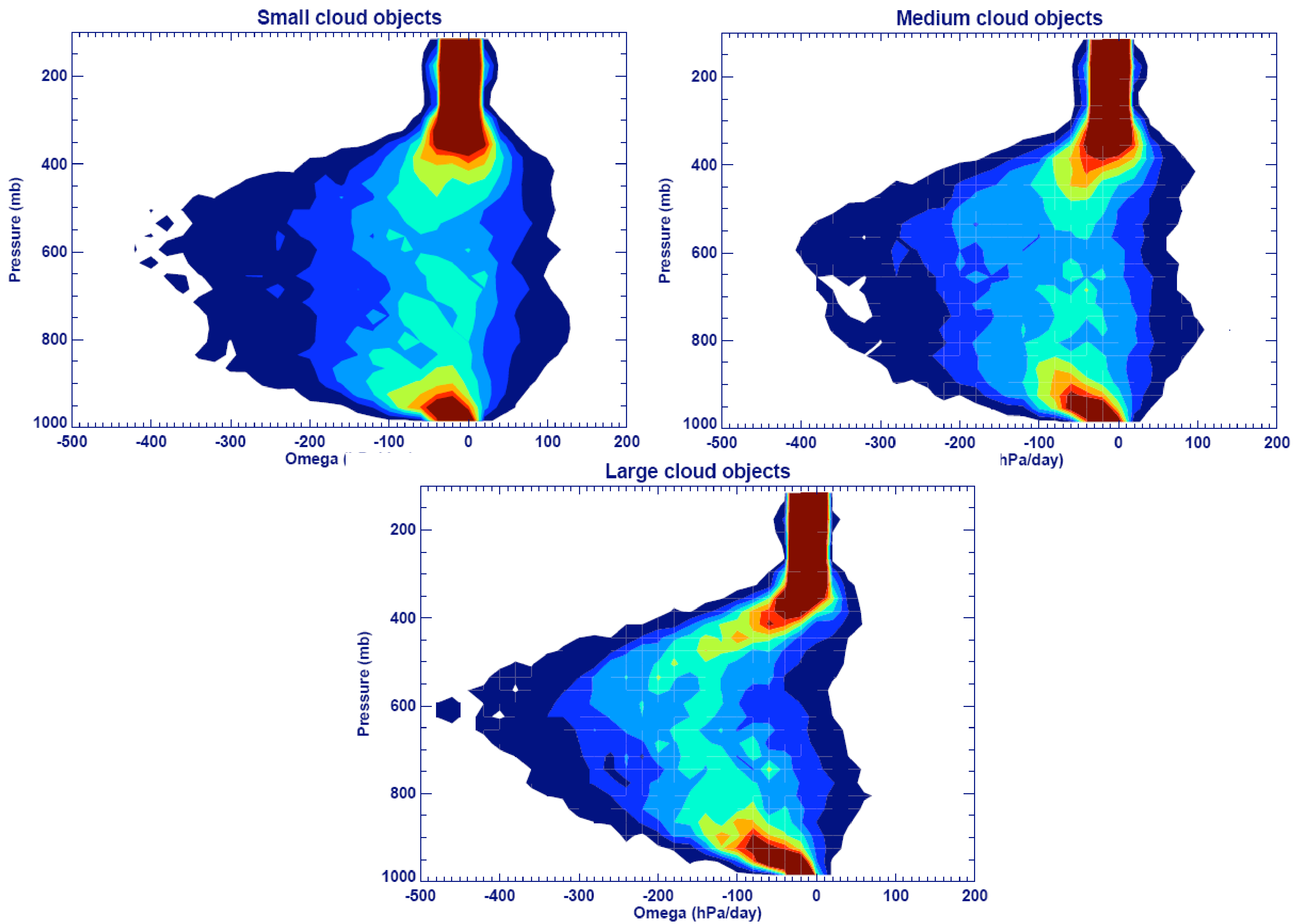
Comparison of Different Sizes of Tropical Convective Cloud Objects, 2



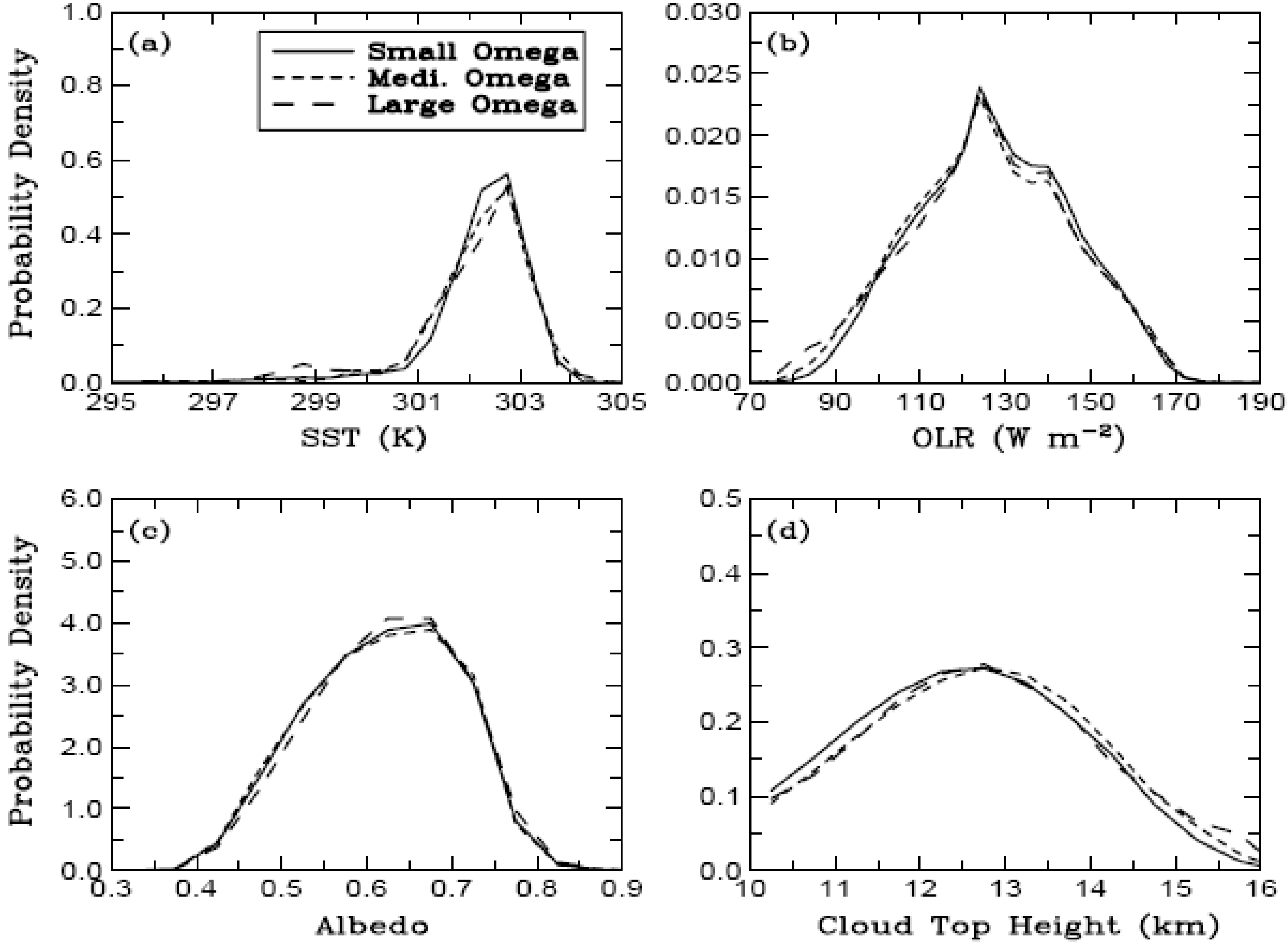
What Determine the Differences among the Three Size Classes?

- Dynamics
  - Strong vertical motion ($\omega < -150$ hPa day^{-1})
  - Moderate vertical motion (-150 hPa day$^{-1} < \omega < -75$ hPa day^{-1})
  - Weak vertical motion ($\omega > -75$ hPa day^{-1})
- Thermodynamics
  - Small CAPE (< 750 J kg^{-1})
  - Moderate CAPE (750 – 1500 J kg^{-1})
  - Large CAPE (> 1500 J kg^{-1})
  - SST (not a dominant factor; compare two small sizes)
- Combined dynamics and thermodynamics
  - Type of mesoscale convective systems
  - Function of multiple variables

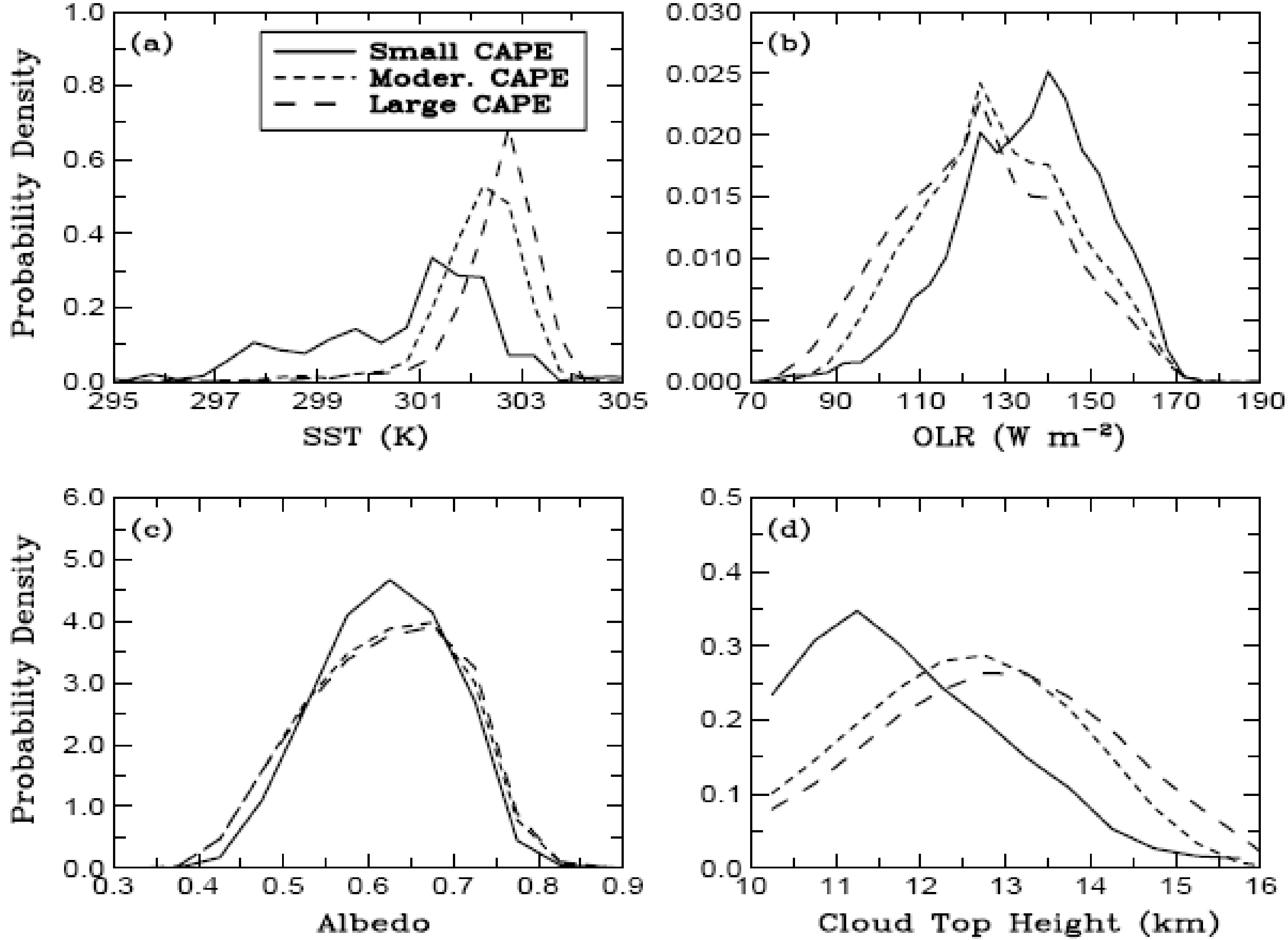
Comparison of Vertical Velocities (ω)



Comparison of ω's of Large-size Tropical Convective Cloud Objects



Comparison of CAPEs of Large-size Tropical Convective Cloud Objects



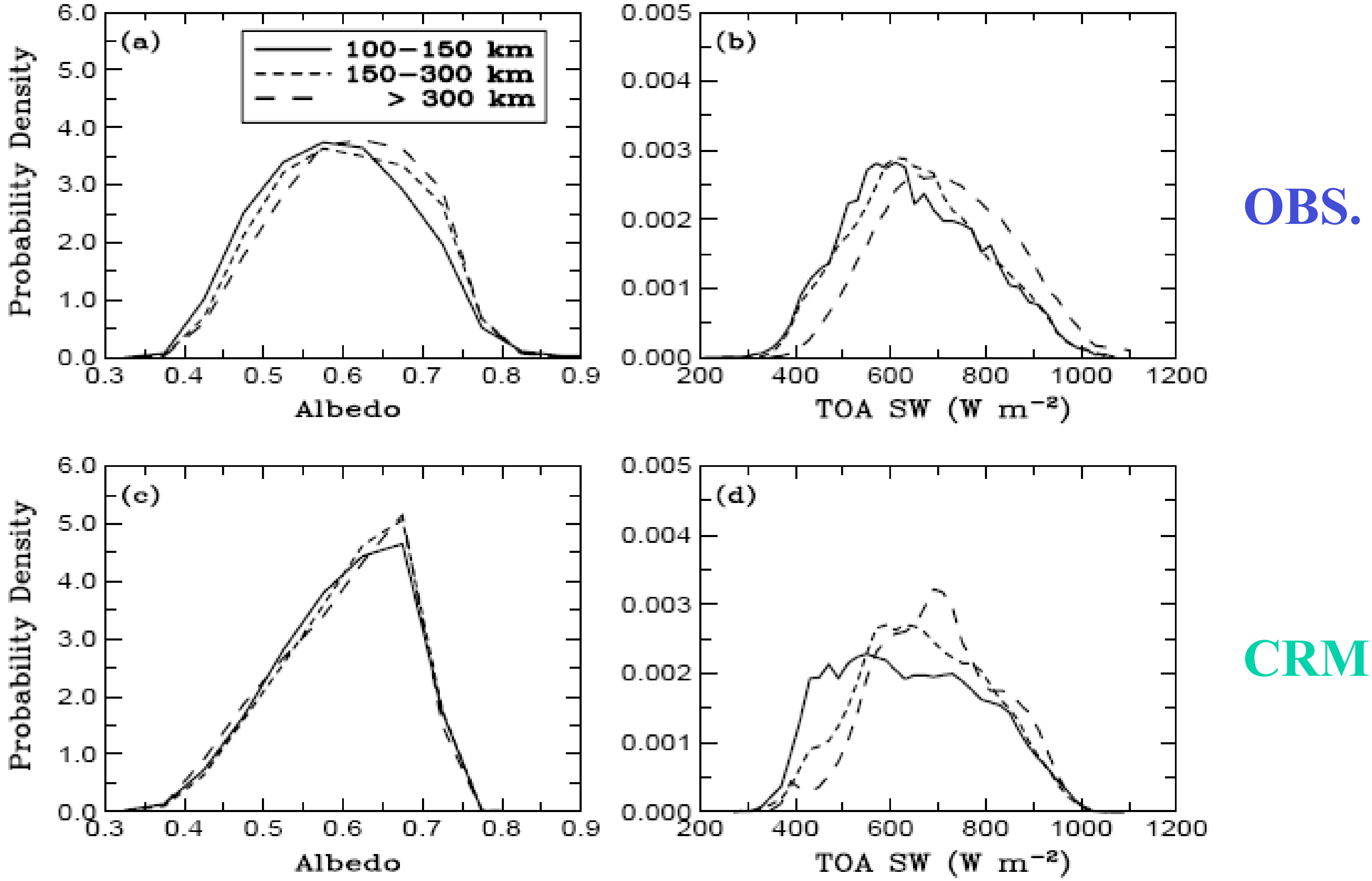
Simulation of March 1998 and March 2000 Deep Convective Cloud Objects

- Use the UCLA/LaRC 2-D cloud-resolving model
- Driven by ECMWF/CSU large-scale advective tendencies
- Integrate only 24 h; analyze the last 12 h (exclude the initial spin-up period)
- Grid size of 2 km; five-point running average (10 km) and selecting "cloud object" grid columns
- Use variable domain sizes for different size classes of cloud objects
  - 256 km for 100-150 km cloud objects
  - 512 km for 150-300 km cloud objects
  - 1024 km for > 300 km cloud objects

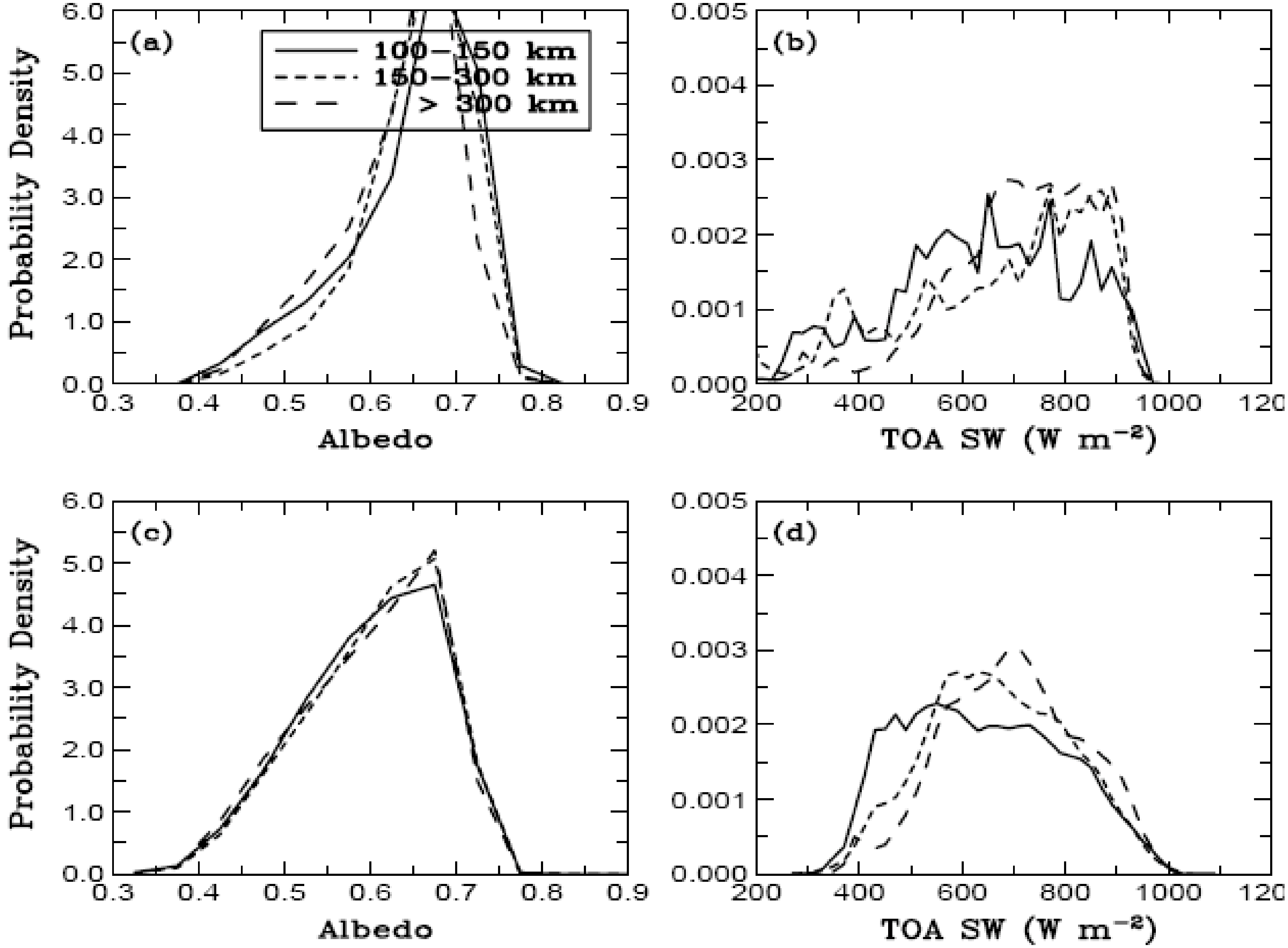
ECMWF Predicted Cloud Fields

- ECMWF uses a prognostic parameterization to predict cloud fraction, liquid+ice contents
- _° x _° grid size, much bigger than CERES footprints; thus each grid is divided into 30 subgrid cells
- Use the maximum-random overlap to horizontally and vertically distribute the clouds in a grid column with 30 subgrid cells (Klein and Jacob 1999; “ISCCP simulator”)
- Compute the optical/radiative properties of each subgrid cell with the Fu-Liou radiation code
- Use the same “cloud object” selection criteria to select subgrid cells for the statistical comparison

Simulation of March 1998 Tropical Convective Cloud Objects, 1a



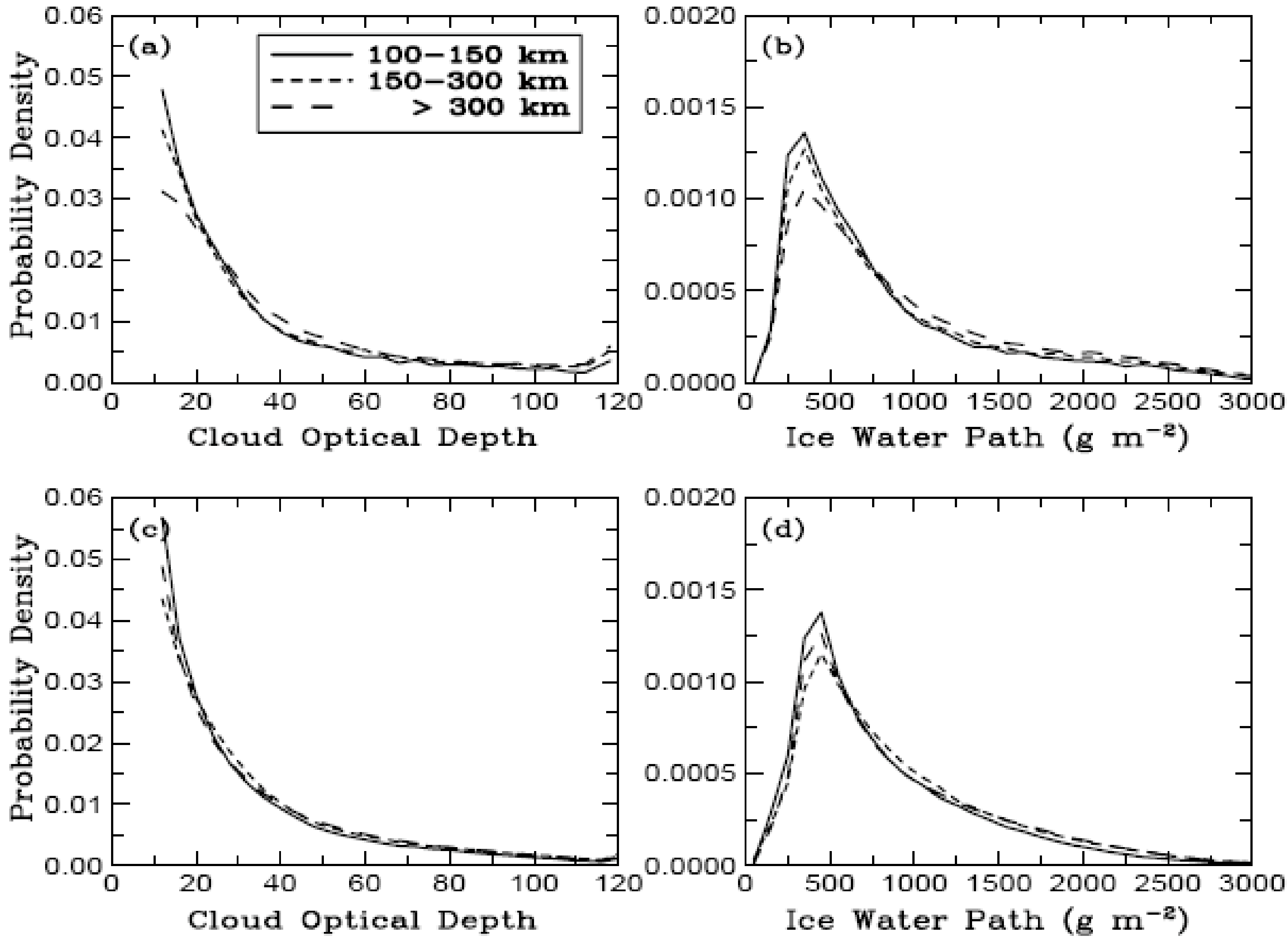
Simulation of March 1998 Tropical Convective Cloud Objects, 1b



ECMWF

CRM

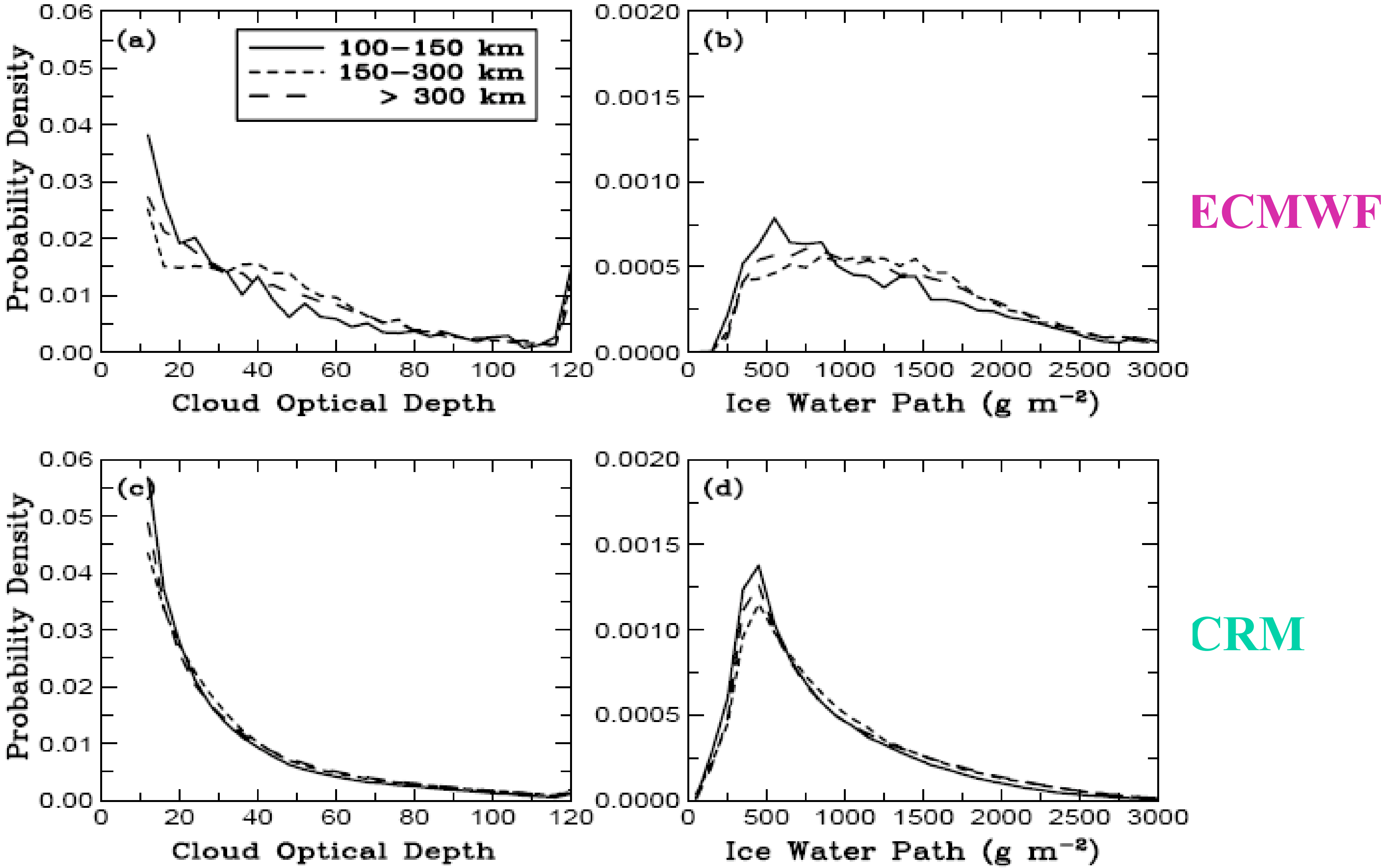
Simulation of March 1998 Tropical Convective Cloud Objects, 2a



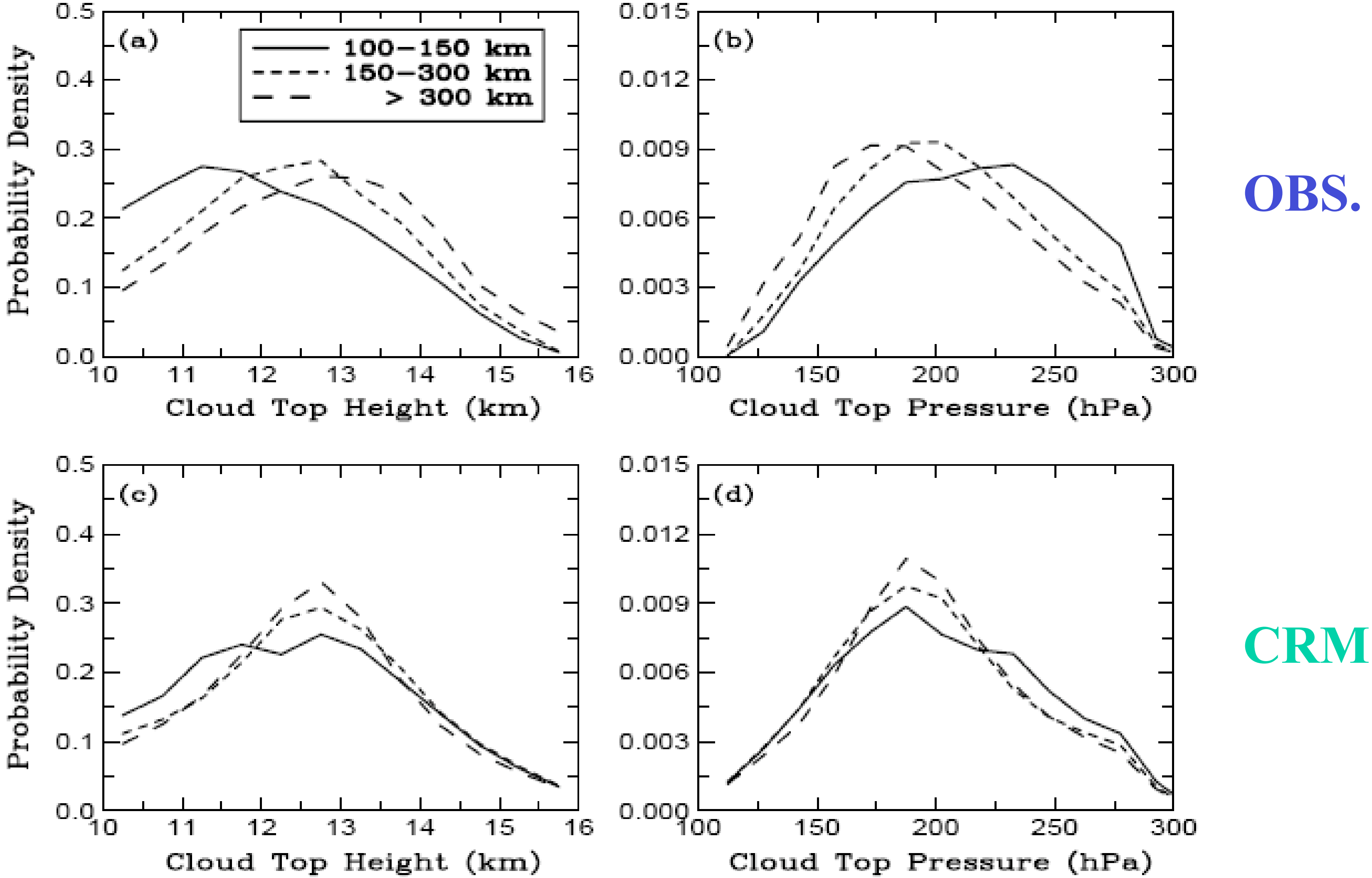
OBS.

CRM

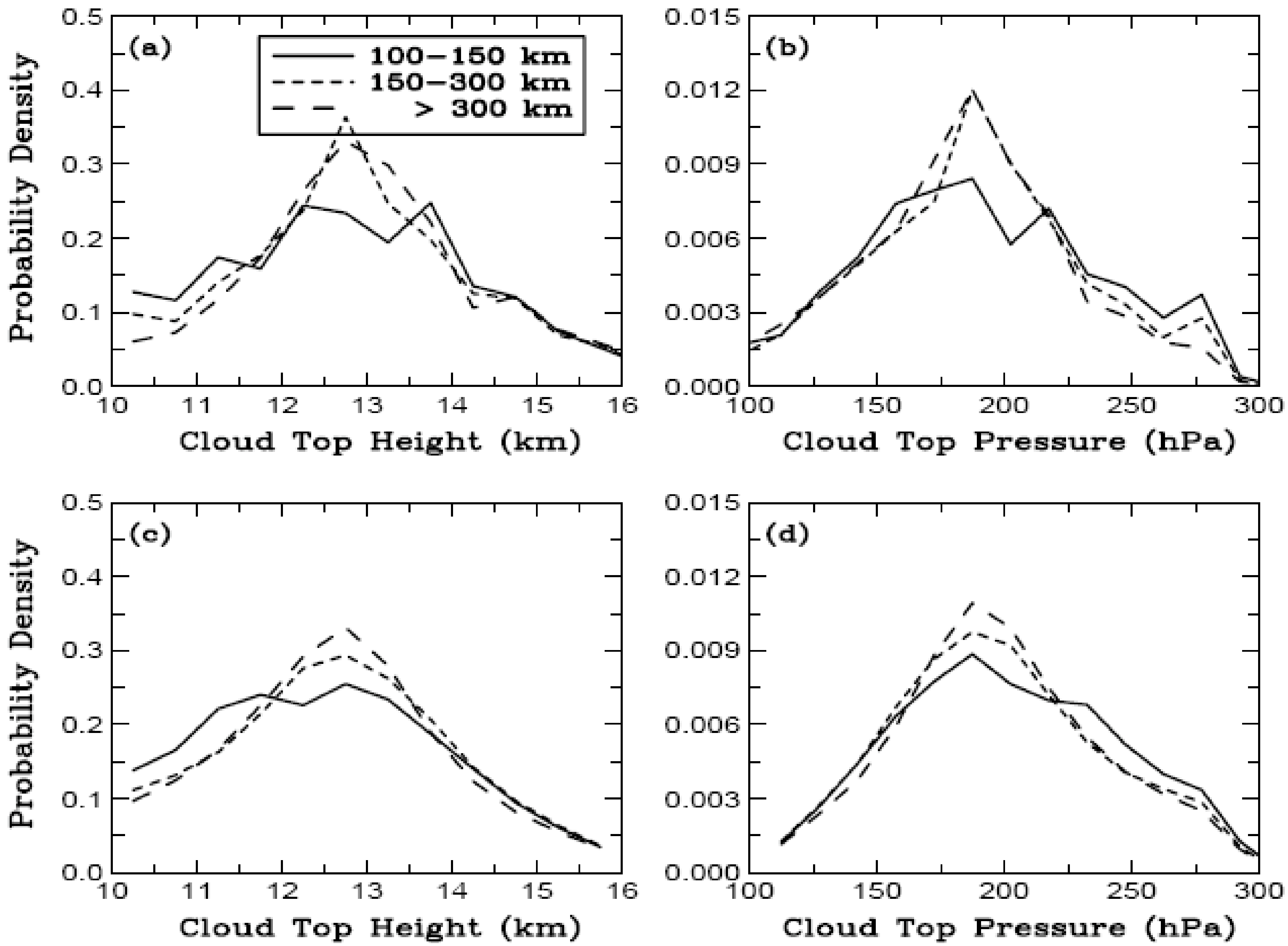
Simulation of March 1998 Tropical Convective Cloud Objects, 2b



Simulation of March 1998 Tropical Convective Cloud Objects, 3a



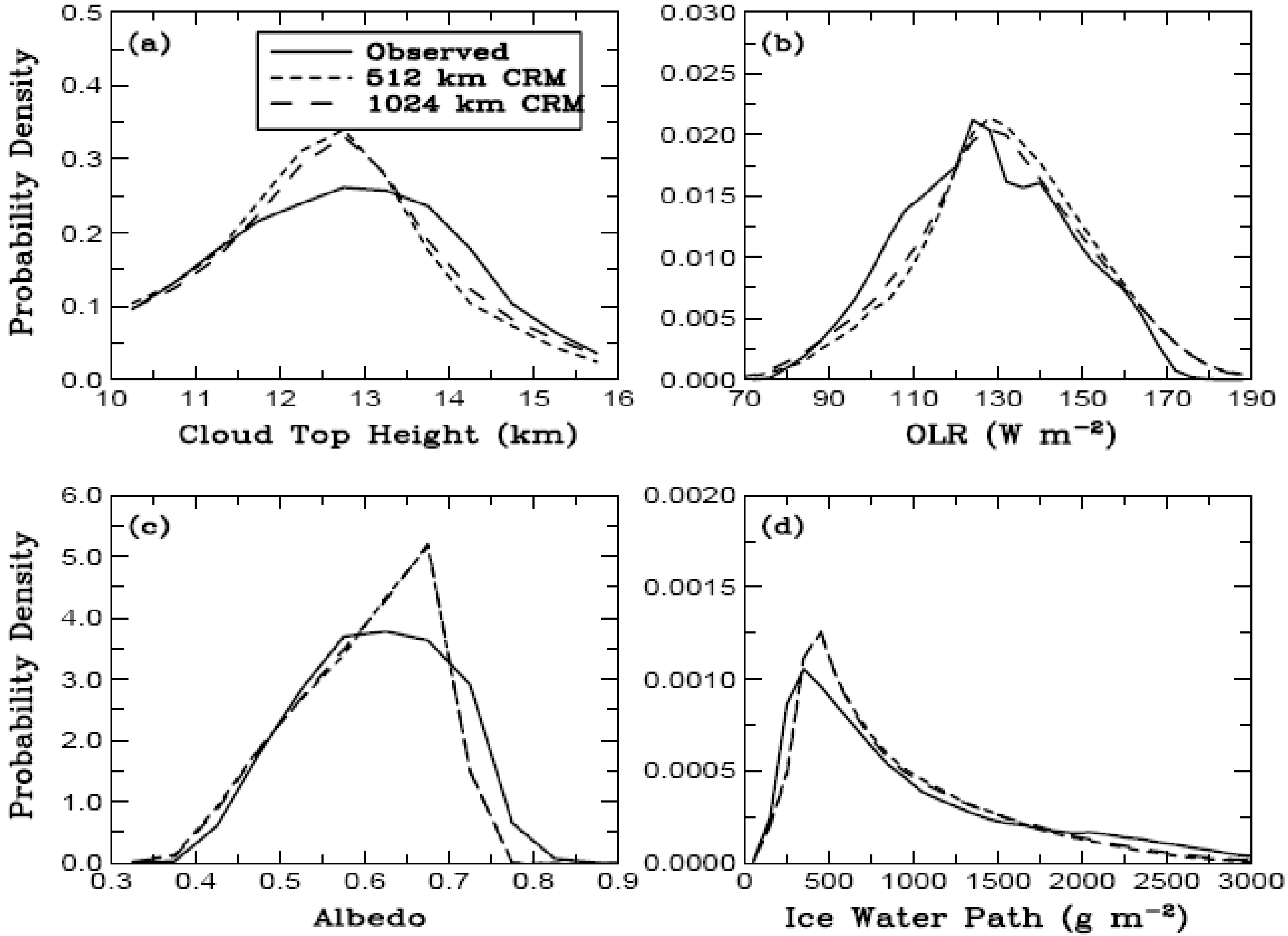
Simulation of March 1998 Tropical Convective Cloud Objects, 3b



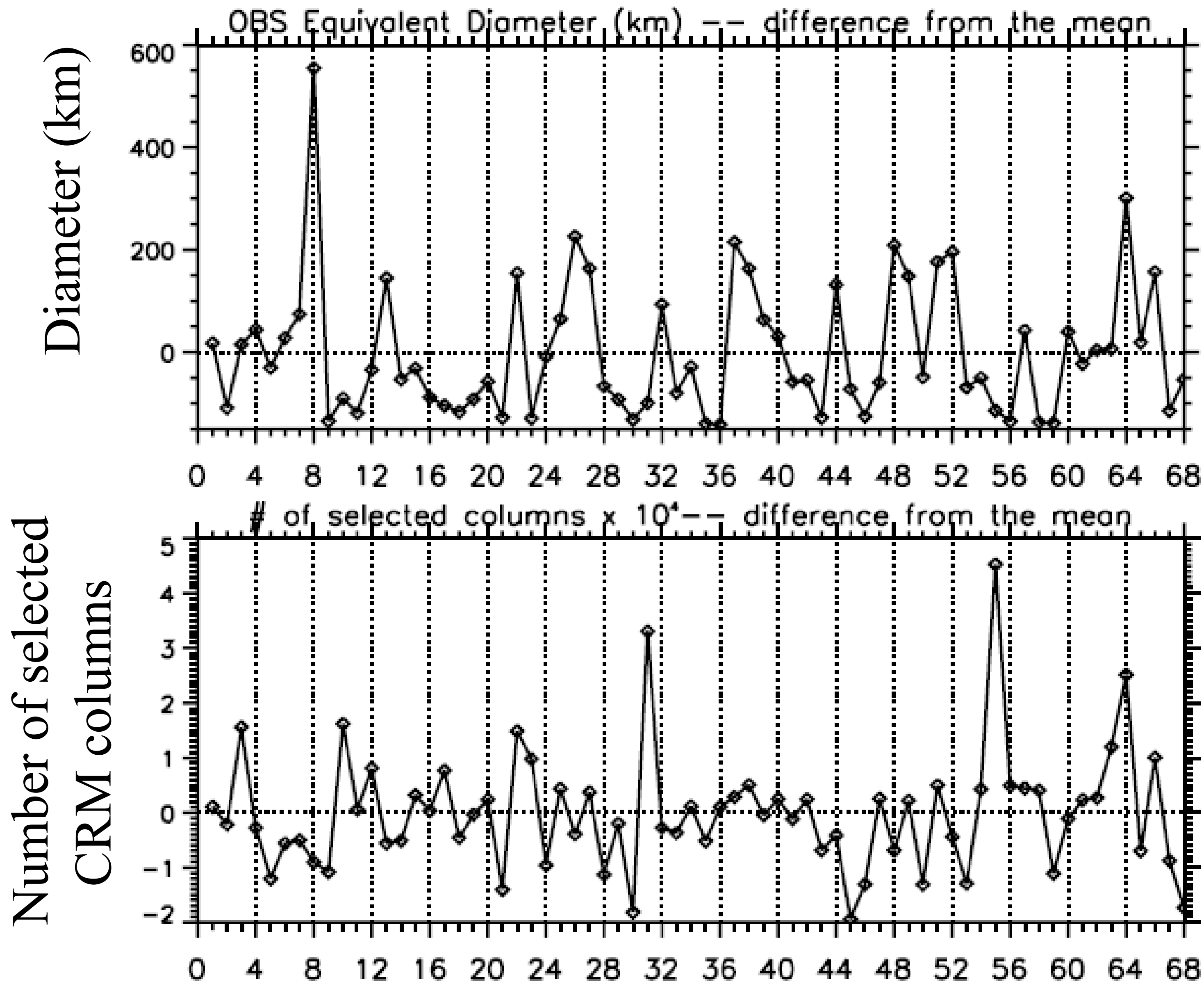
ECMWF

CRM

Simulation of Convective Cloud Objects, Dependence on Domain Sizes, 4



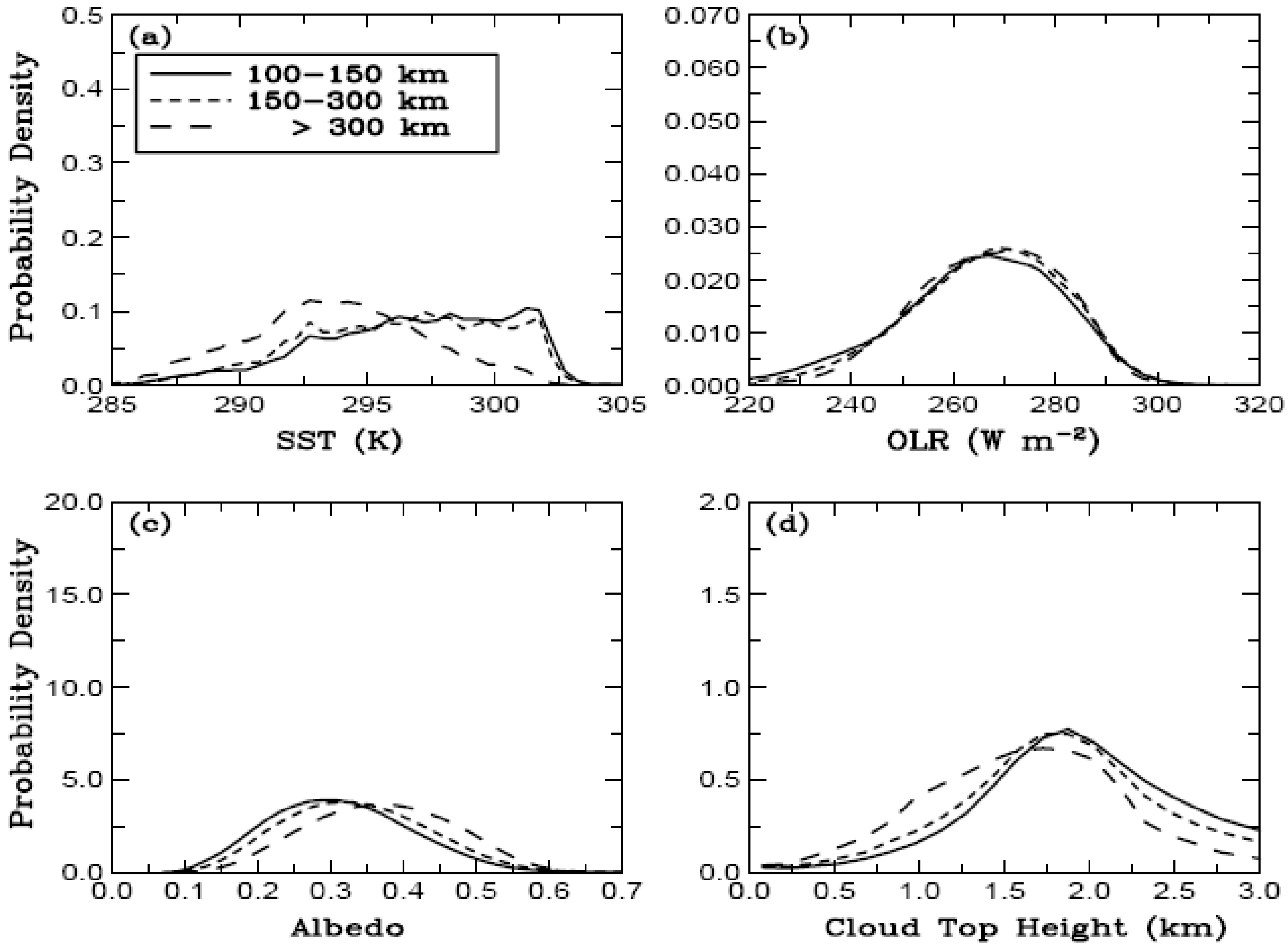
Comparison of Observed Diameters and CRM Selected Columns, 5



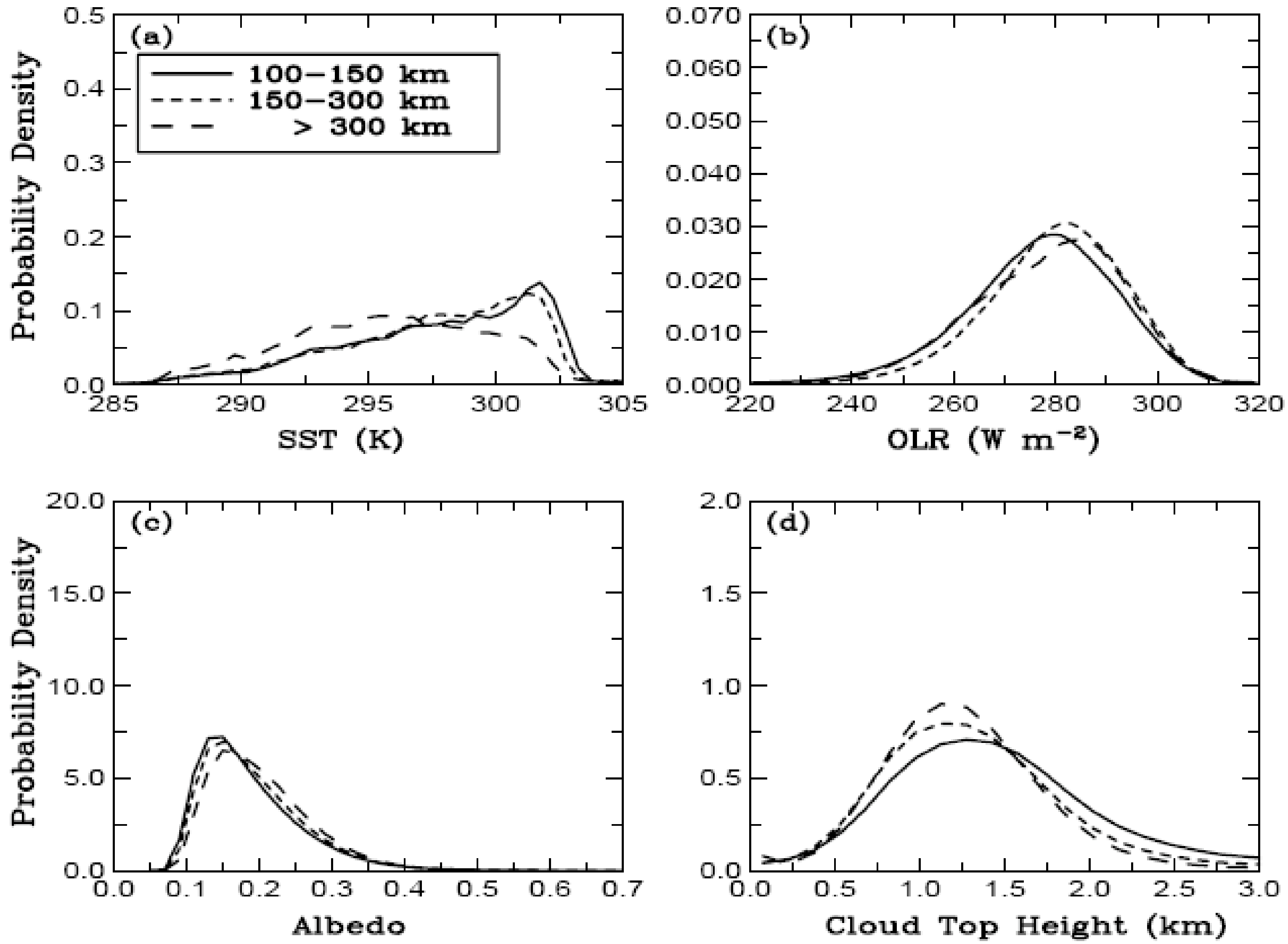
Analysis of Boundary-layer Cloud Object Types

- Solid Stratus (cloud fraction > 0.99)
- Stratocumulus (cloud fraction 0.4 – 0.99)
- Cumulus (cloud fraction 0.1 – 0.4)

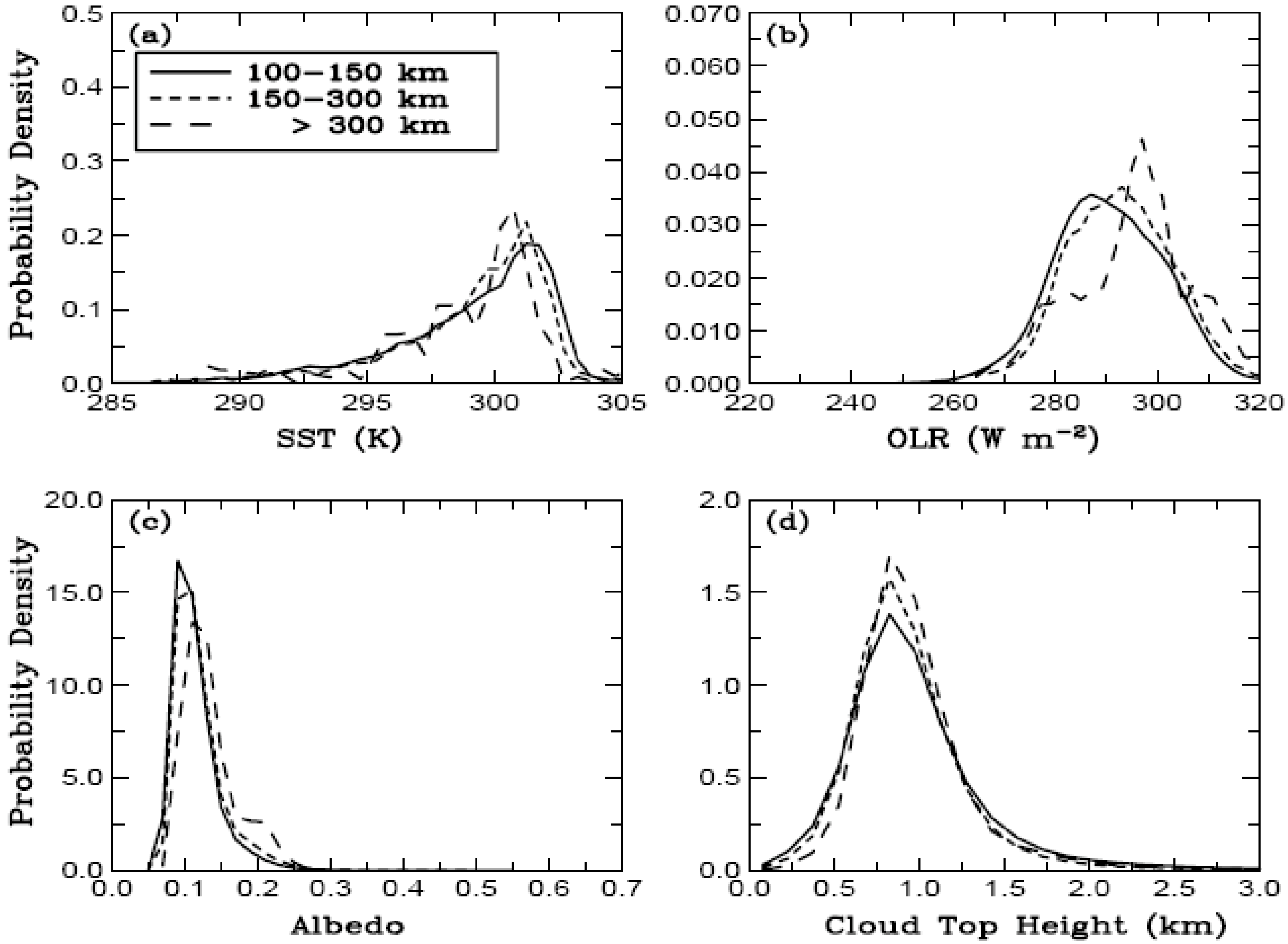
Comparison of Different Sizes of BL Solid-Stratus Cloud Objects, 1a



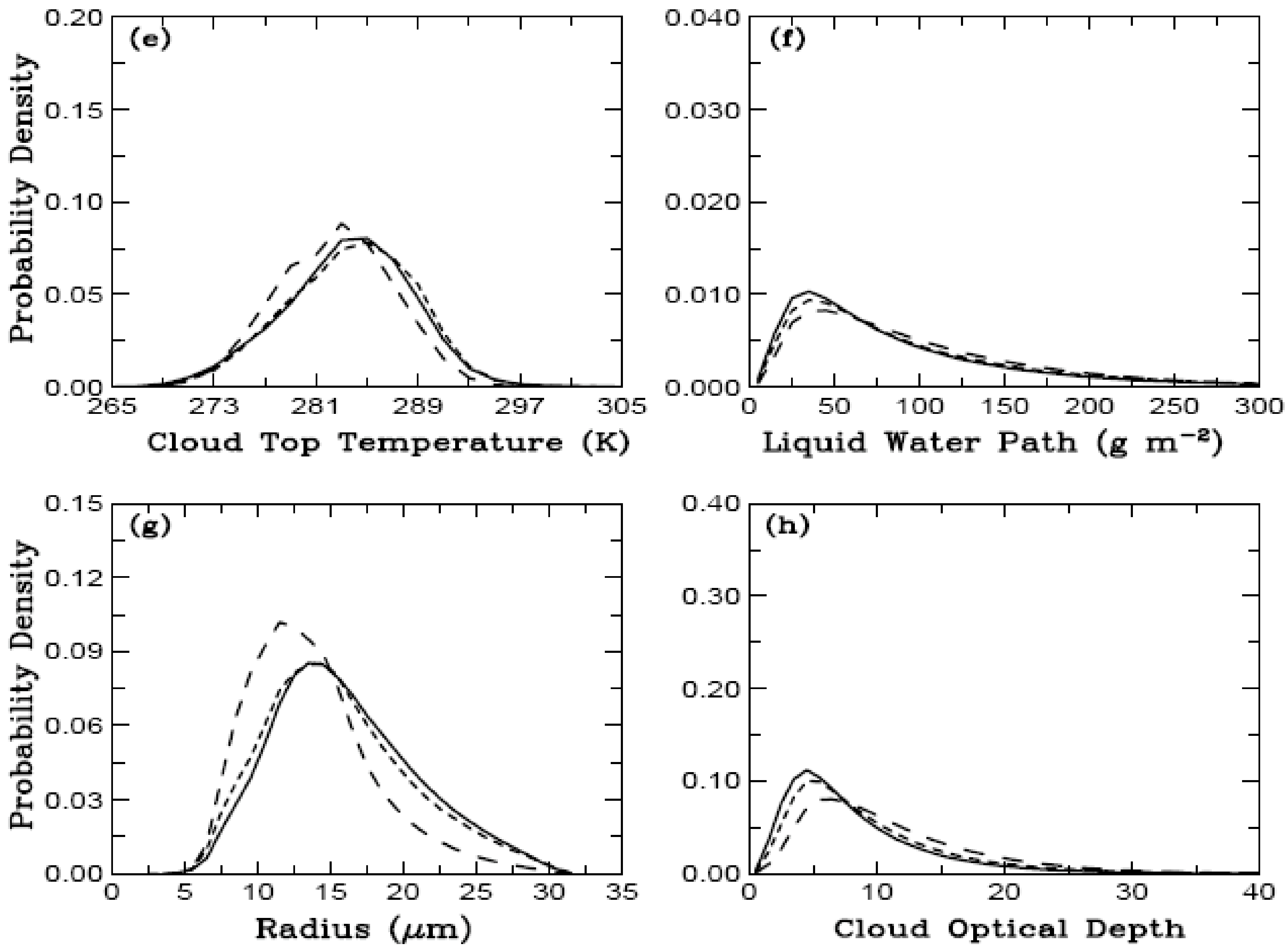
Comparison of Different Sizes of BL Stratocumulus Cloud Objects, 1b



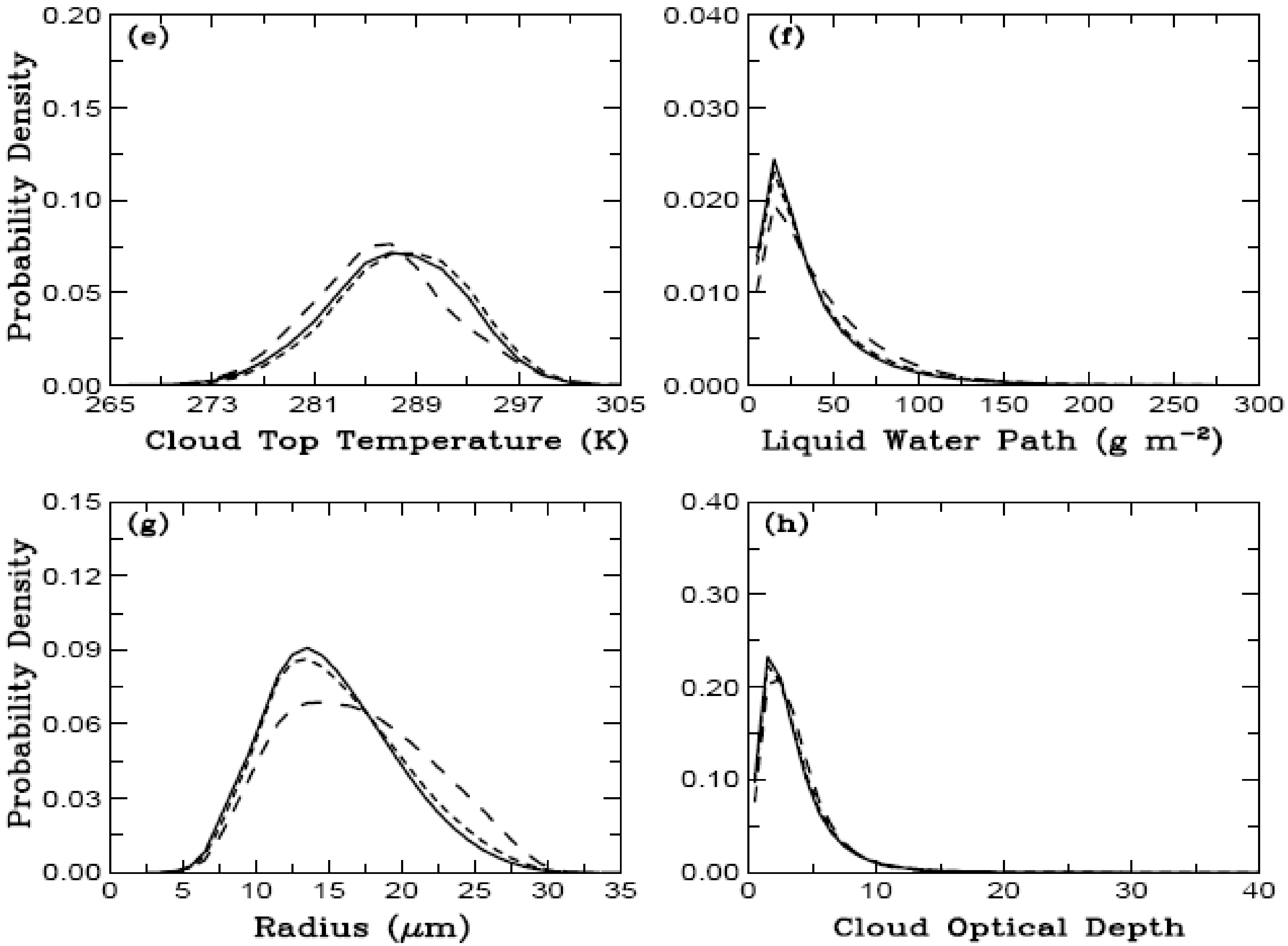
Comparison of Different Sizes of BL Cumulus Cloud Objects, 1c



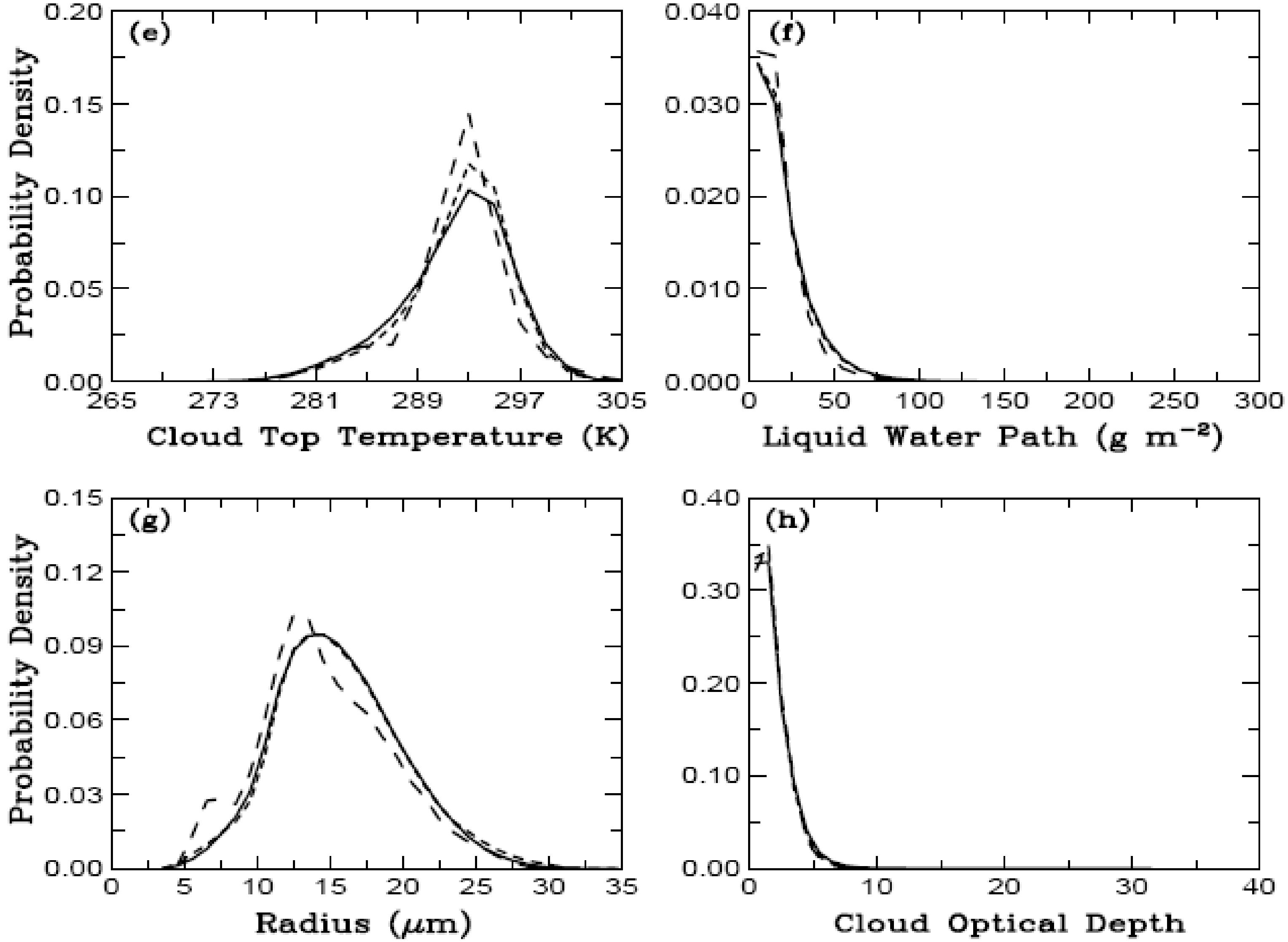
Comparison of Different Sizes of BL Solid-Stratus Cloud Objects, 2a



Comparison of Different Sizes of BL Stratocumulus Cloud Objects, 2b



Comparison of Different Sizes of BL Cumulus Cloud Objects, 2c



Summary and Future Plans, 1

Analysis

¬ For January-August 1998, summary histograms of physical properties are rather different for different cloud object types

¬ Summary histograms of the small-size classes of tropical convective cloud objects differ significantly from those of the large-size class of cloud objects except for ice diameter

¬ Summary histograms of the large-size class of boundary-layer cloud object types differ significantly from those of the small sizes.

¬ These differences among tropical convective cloud-object classes are difficult to be isolated by a single characteristic of cloud objects such as SST, omega and CAPE.

¬ The aforementioned differences are also present on the monthly timescale (e.g., March 1998)

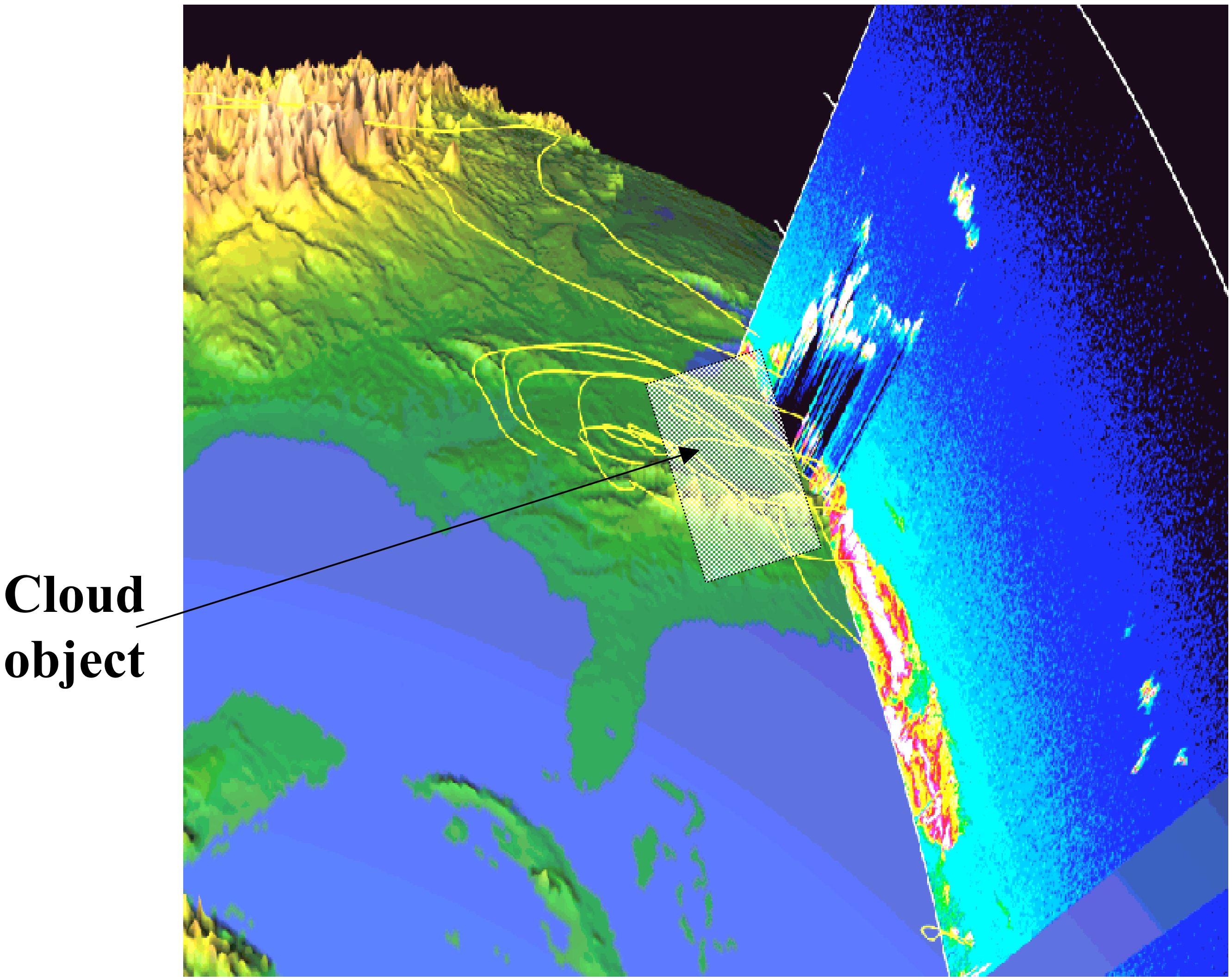
¬ The data product is available at **http://cloud-object.larc.nasa.gov/**

Summary and Future Plans, 2
Modeling

- Both the March 1998 and March 2000 tropical convective cloud objects have been simulated with the UCLA/LaRC CRM [ARPS/LaRC CRM simulations of March 1998 cloud objects were presented in Eitzen and Xu (2005)]
- The CRM-simulated histograms of cloud optical depth, ice water path, TOA SW and TOA albedo are much closer to the observations, compared to ECMWF, related to the lack of horizontal variabilities of ECMWF cloud condensate
- Summary histograms of the large-size class are more difficult to be simulated than those of the small and intermediate size classes although the differences between the small and intermediate size classes are better captured by the CRM than by ECMWF
- The (CRM or ECMWF) differences among the three size classes are less pronounced than the observations for all macrophysical properties and OLR

Summary and Future Plans, 3

Cloud Object and CALIPSO/CloudSat



Analyze Terra/Aqua cloud objects (*x-y* cross sections)

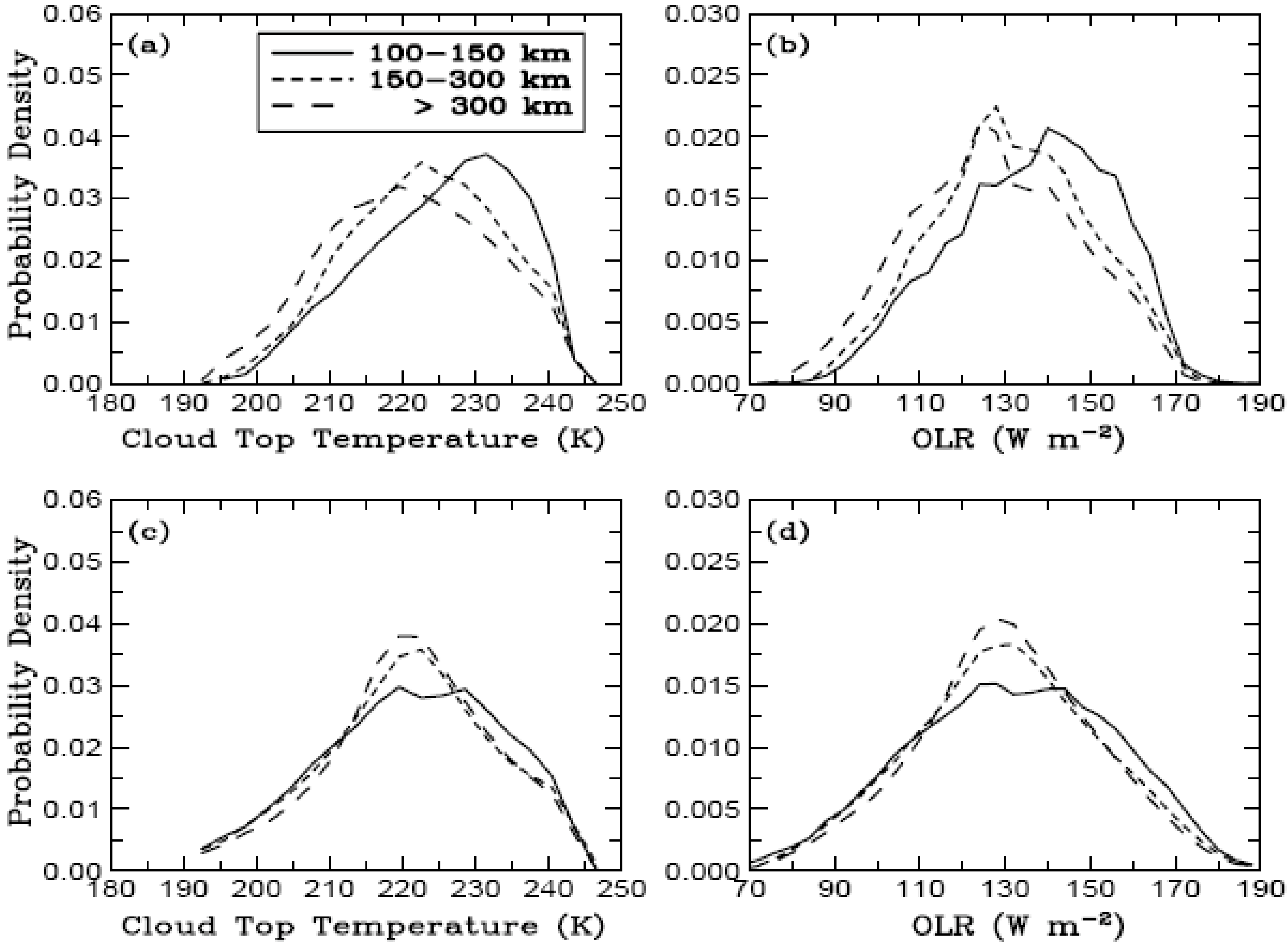
Match the CALIPSO/CloudSat data (*y-z* cross sections) with Aqua cloud objects

Produce 2-D histogram statistics (height as the second dimension) for a few parameters in the CALIPSO/CloudSat data product

Categorize cloud objects according to aerosol information including aerosol types, different cloud/aerosol overlapping layers, single-layer/multi-layer structures

Estimate the aerosol indirect radiative forcings using large ensemble of a specific category of cloud objects with similar aerosol characteristics

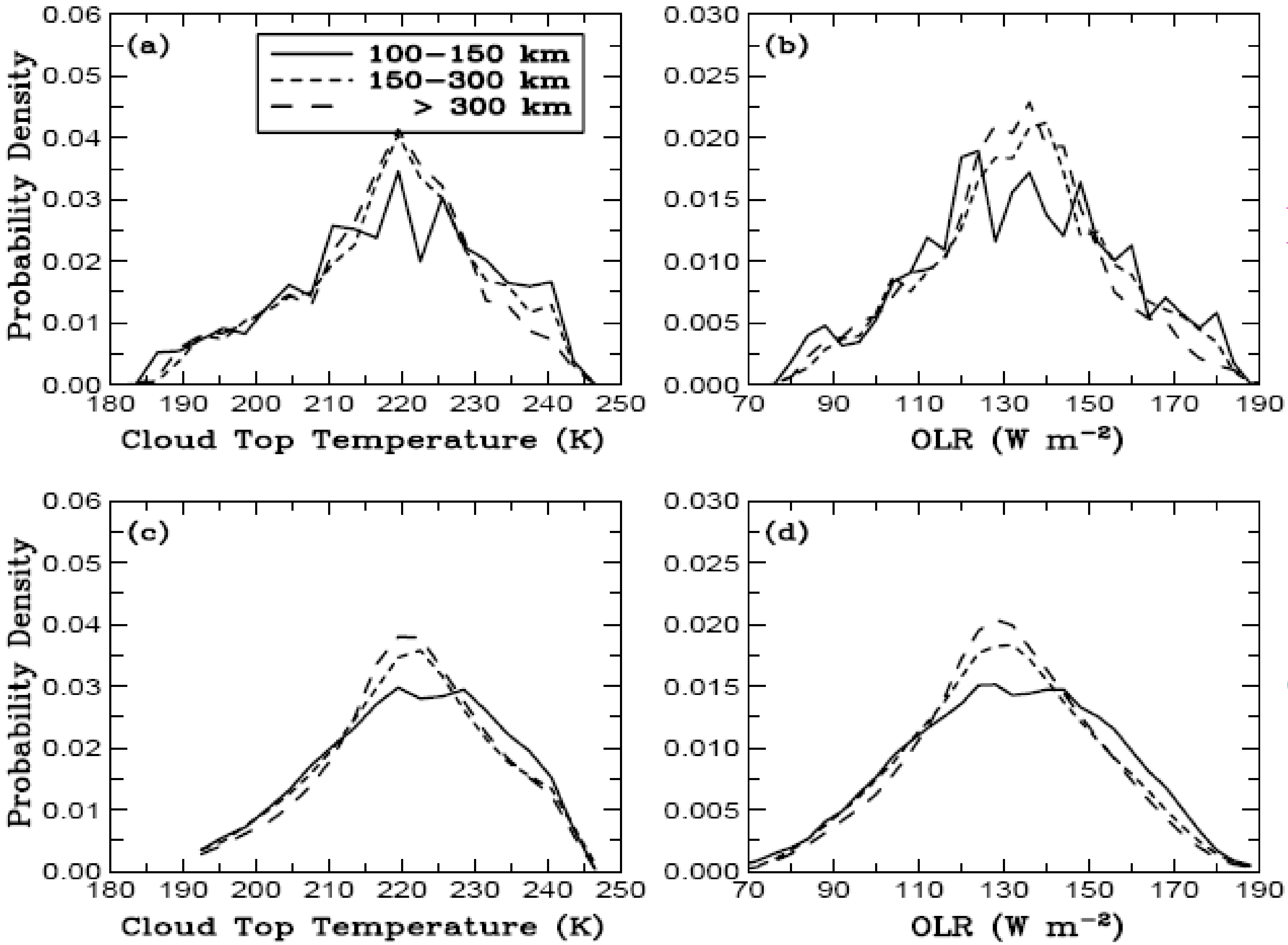
Simulation of March 1998 Tropical Convective Cloud Objects, 3a



OBS.

CRM

Simulation of March 1998 Tropical Convective Cloud Objects, 3b



ECMWF

CRM