Sensitivity Simulations of Boundary-Layer Cloud Objects to Modifications of ECMWF Meteorological Data Using a Cloud-Resolving Model

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Objectives

1. Can a cloud-resolving model (CRM) simulate the observed differences in cloud physical properties between the stratocumulus and overcast cloud-object types?
2. What modifications in meteorological data are needed to represent the atmospheric states of cloud objects in order to simulate the observed differences using a CRM?

A CRM can resolve the cloud-scale circulations, but parameterizes cloud microphysics and radiation

The LaRC CRM implements a two-moment cloud microphysics and the δ-four-stream Fu-Liou radiation

What is a cloud object?

A contiguous patch of cloudy regions with a single dominant cloud-system type; no mixture of different types

The shape and size of a cloud object is determined by

- the satellite footprint data
- the footprint selection criteria

Selection criteria for boundary-layer cloud objects, $z_{top} < 3$ km and a footprint cloud fraction of

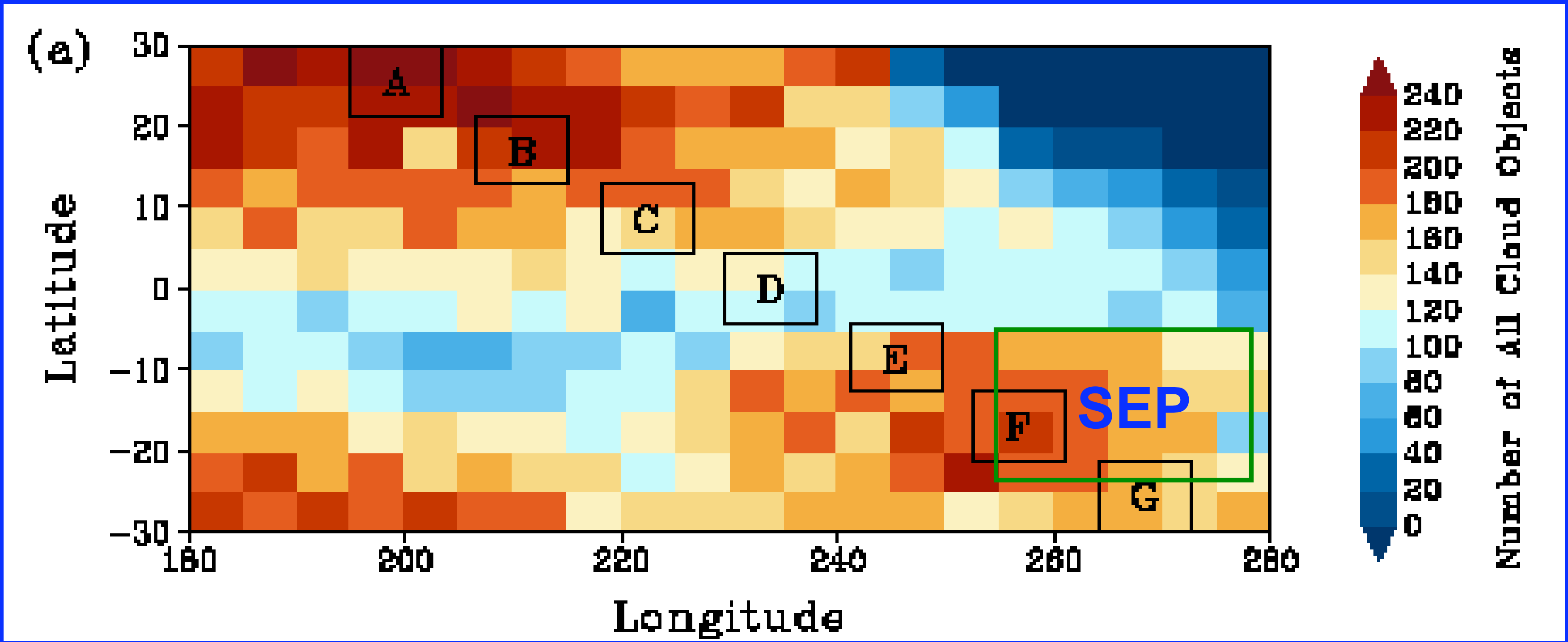
- 0.10 - 0.40 for cumulus type
- 0.40 - 0.99 for stratocumulus type
- 0.99 -1.00 for overcast type

Data available from the NASA/LaRC cloud object database (http://cloud-object.larc.nasa.gov)

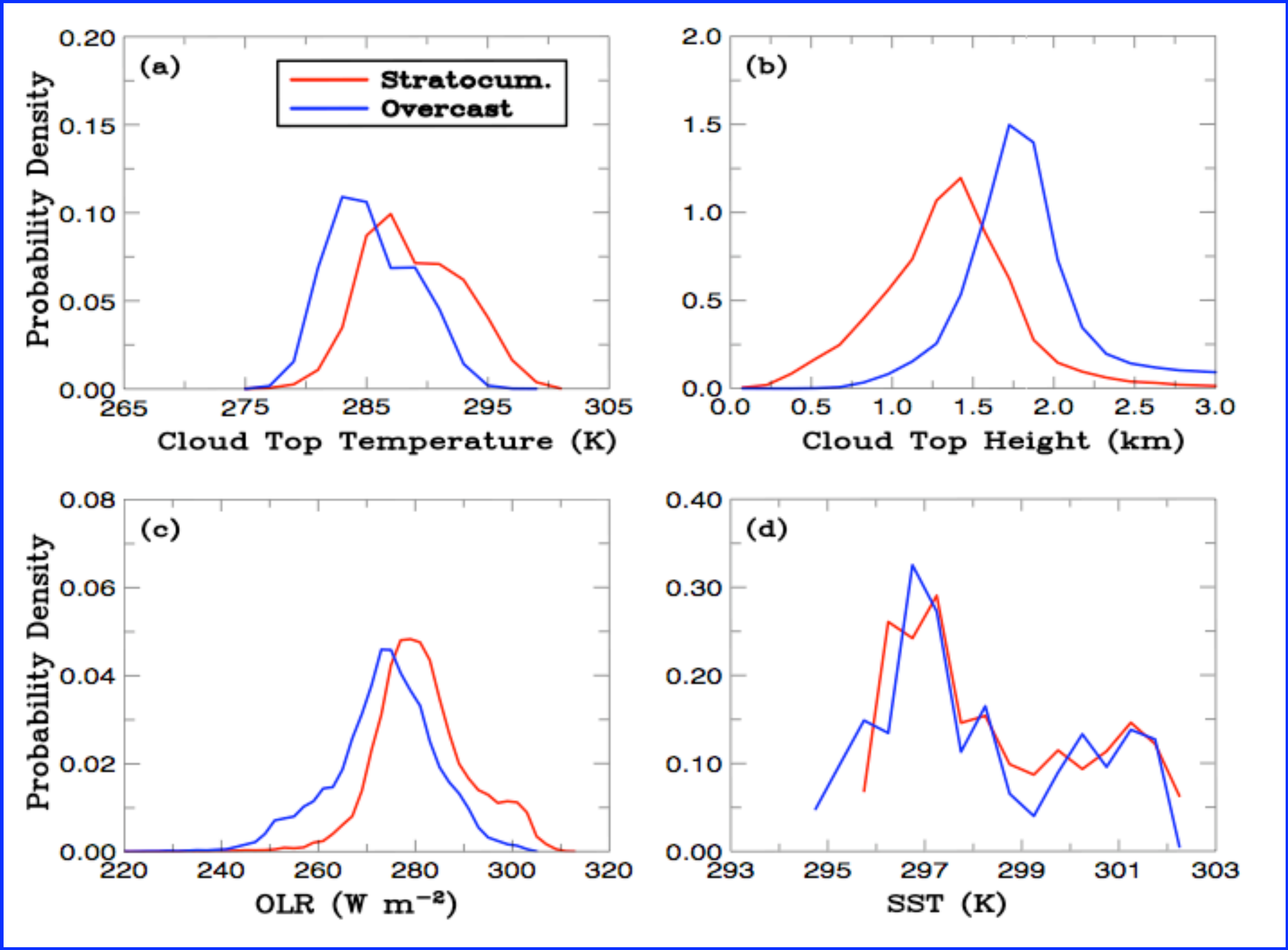
- footprint data from CERES SSF (Level 2)
- statistical information on cloud physical properties
- matched meteorological data (incl. advective forcing from ECMWF)

Selected cloud objects for simulation

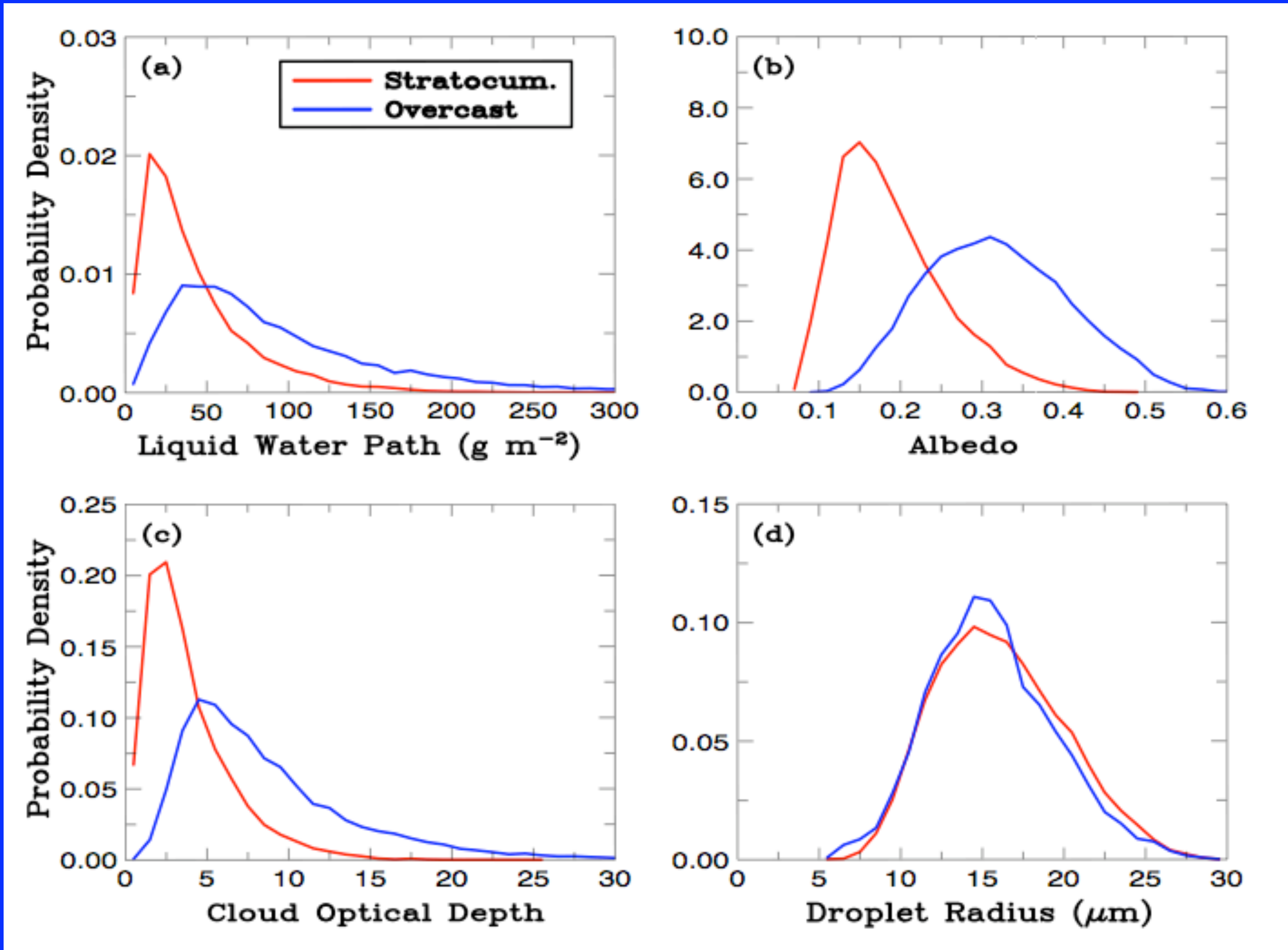
- All 98 cloud objects are located in the southeast Pacific regions (255-278, 5-23 S) for the March 1998 period
- 52 stratocumulus cloud objects (Diameter > 150 km)
- 46 overcast cloud objects (Diameter > 150 km)



Observed cloud physical properties, 1



Observed cloud physical properties, 2

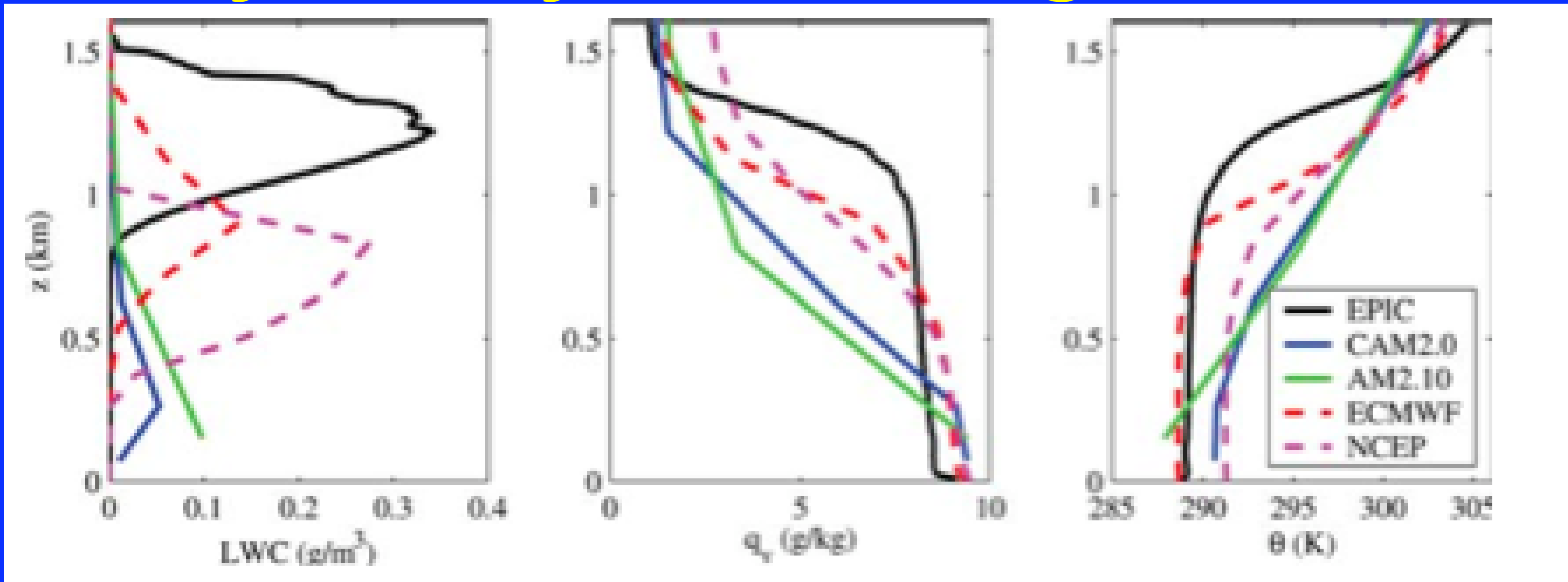


Cloud object-matched meteorological data for CRM simulation

- Initial conditions: potential temperature (θ) and water vapor mixing ratio (q_v)
- Sea surface temperature
- Large-scale advective forcings $\{(\partial\theta/\partial t)_{adv}, (\partial q_v/\partial t)_{adv}\}$
- *x*- and *y*-component winds
- Latitude, longitude, time of observations

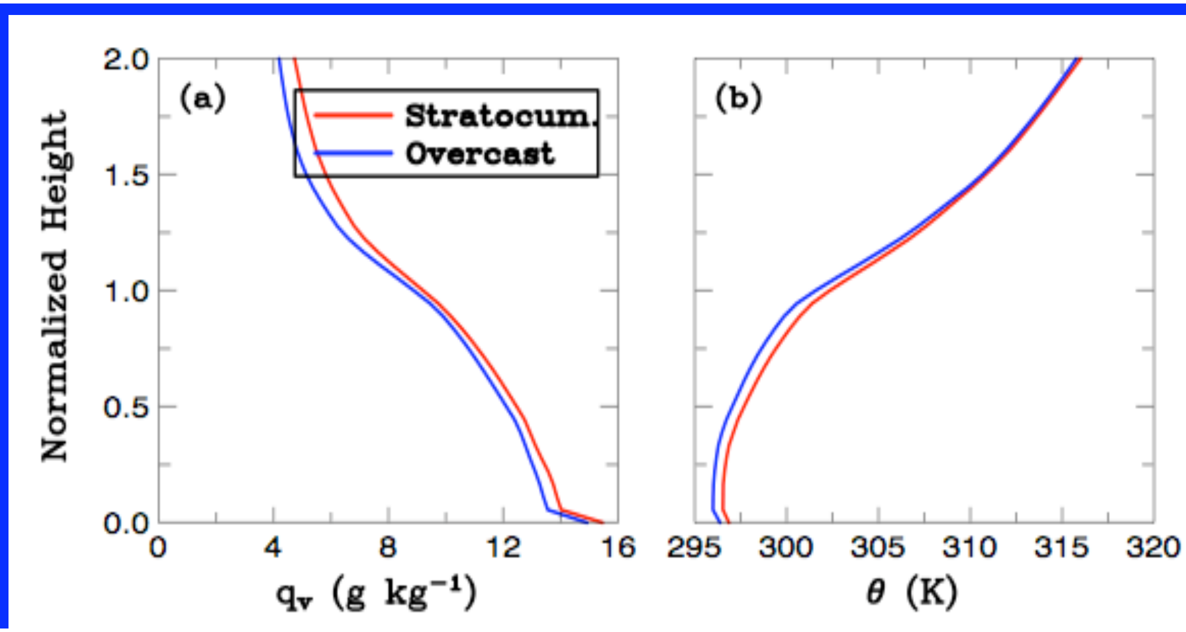
- CRM: dx=2 km, dz=100 m, domain size of 256 km, 12 h integration

Why modify meteorological data?



EPIC observations & models

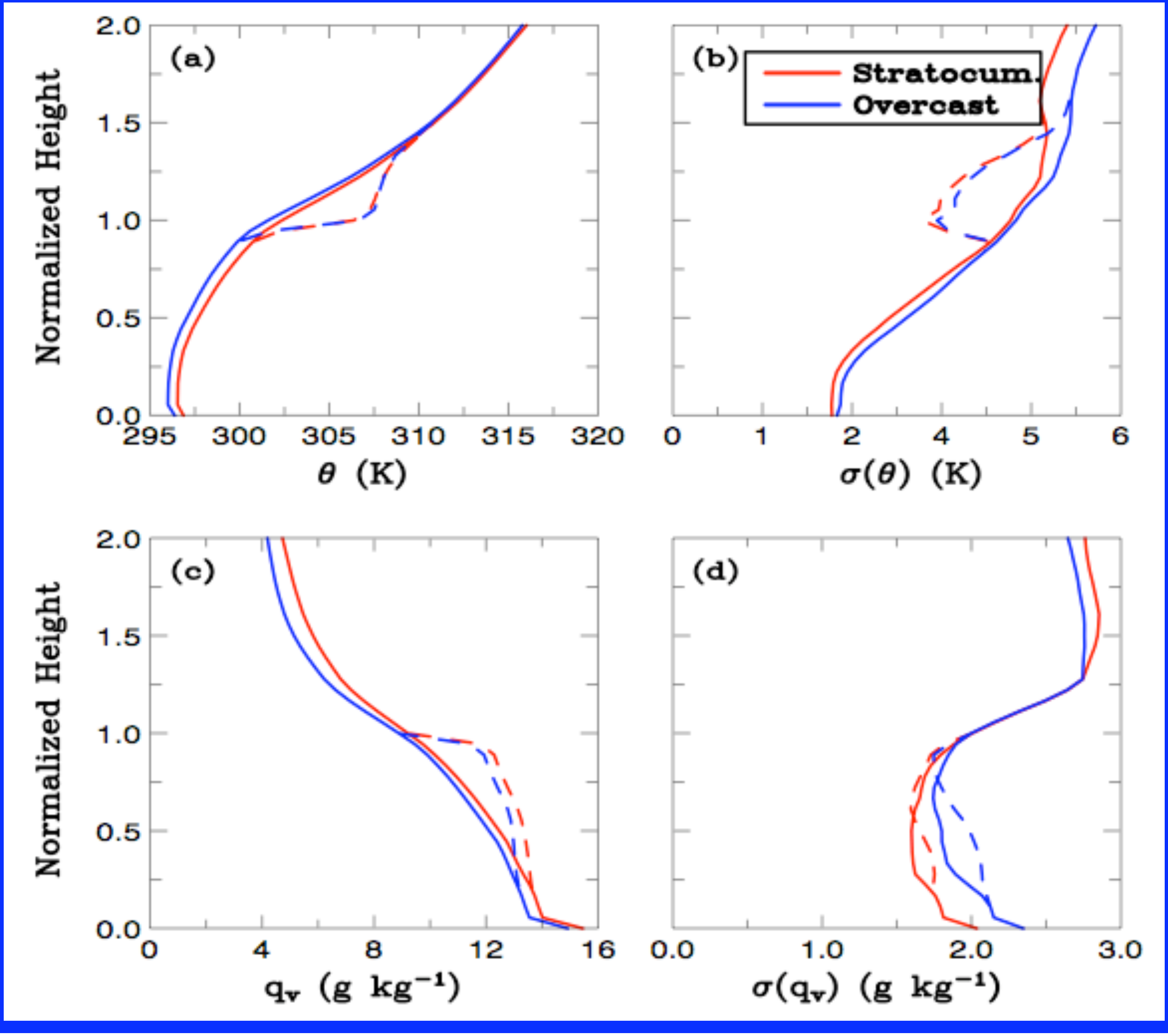
Cloud object mean T & q_v



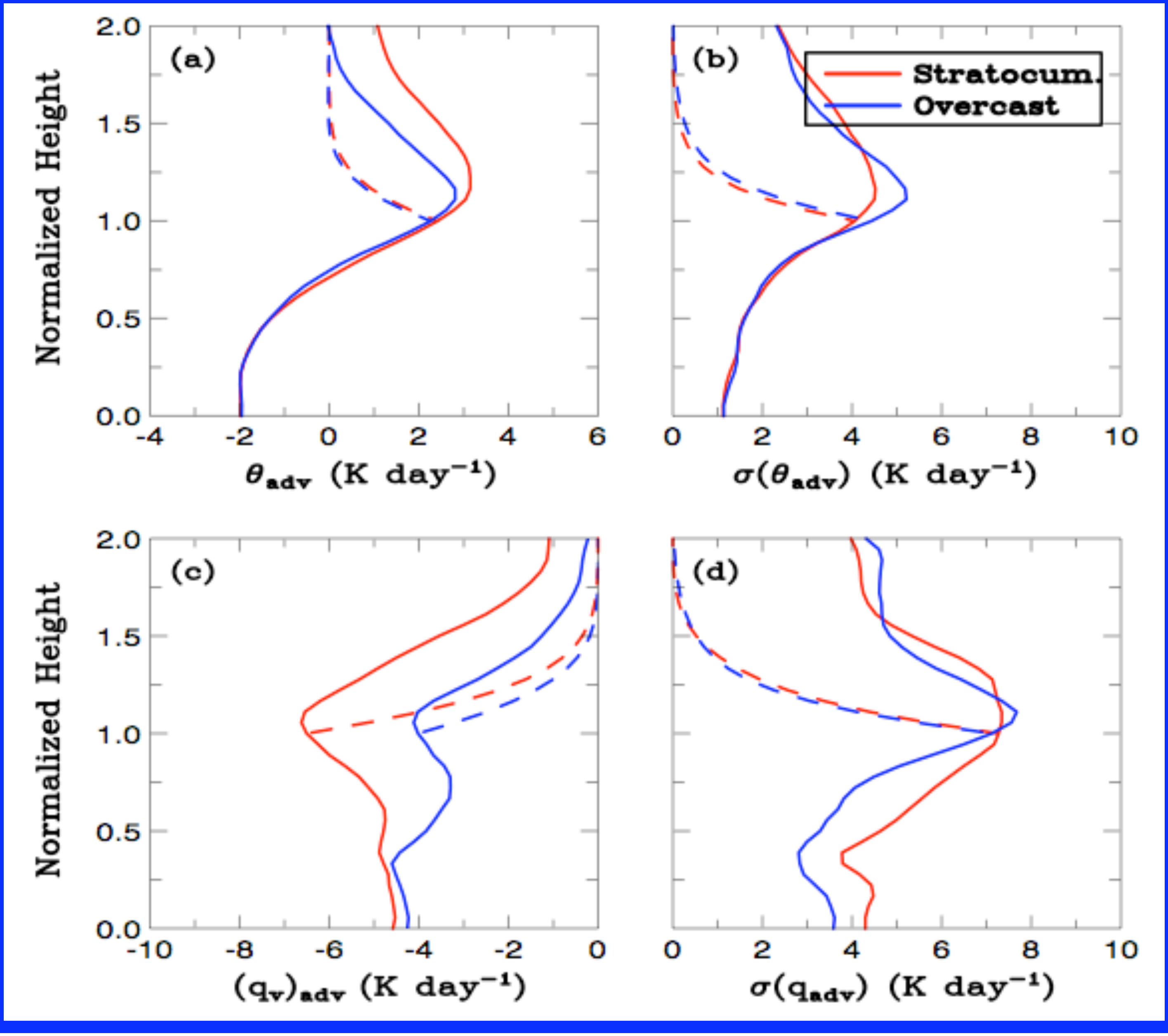
How modify meteorological data?

- Identify the inversion height
  - interpolate the ECMWF sounding to model levels (dz = 100 m)
  - calculate the lifting condensation level (LCL)
  - identify the temperature inversion height, or
  - identify the height with the largest change of relative humidity
- Increase the moisture content between the LCL and the inversion height
  - the smaller of that at LCL and the saturation mixing ratio at a specific level
- Increase θ for the five layers (500 m) above the inversion height using the "estimated inversion strength" (Woods and Bretherton 2006)
- Dynamic forcings can also be modified, e.g., based upon surface divergence; but it is a more complicated task
- This procedure applies to both cloud object types

Potential temperature and water vapor



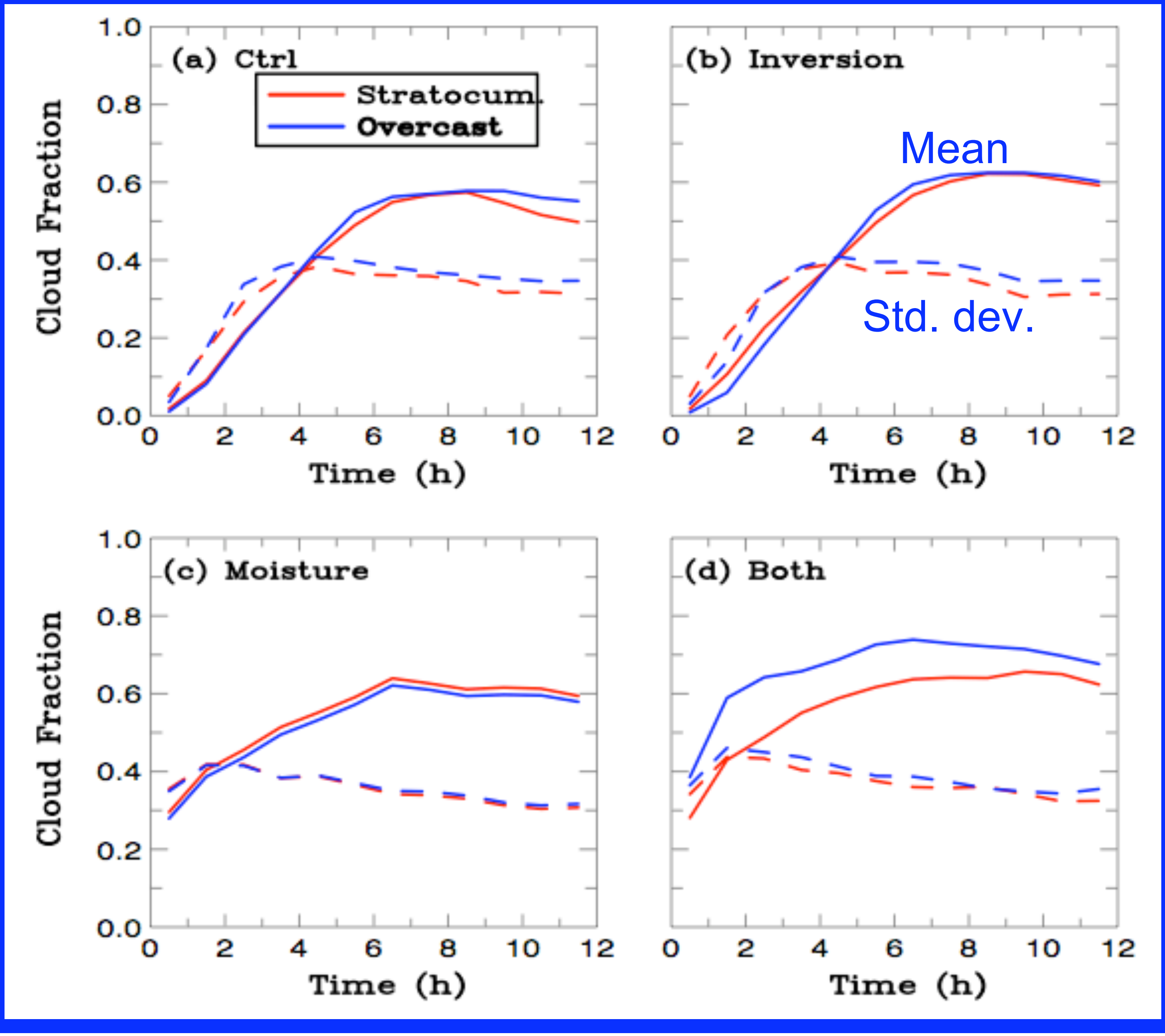
Imposed large-scale advective forcings



Results of the simulations

1. Control (no modifications)
2. Increase of the inversion strength
3. Increase of the moisture content
4. Both

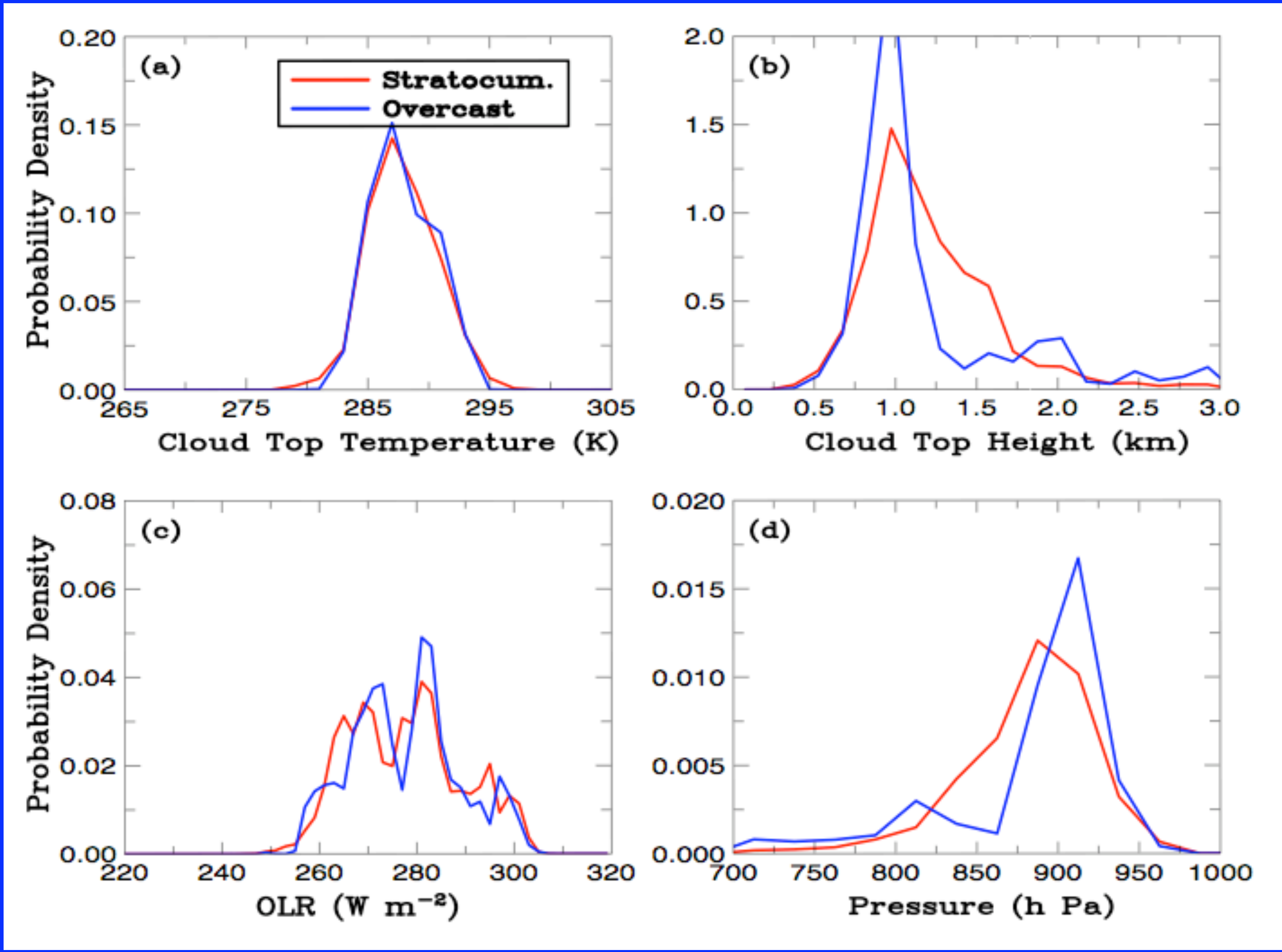
Time series of column cloud fraction



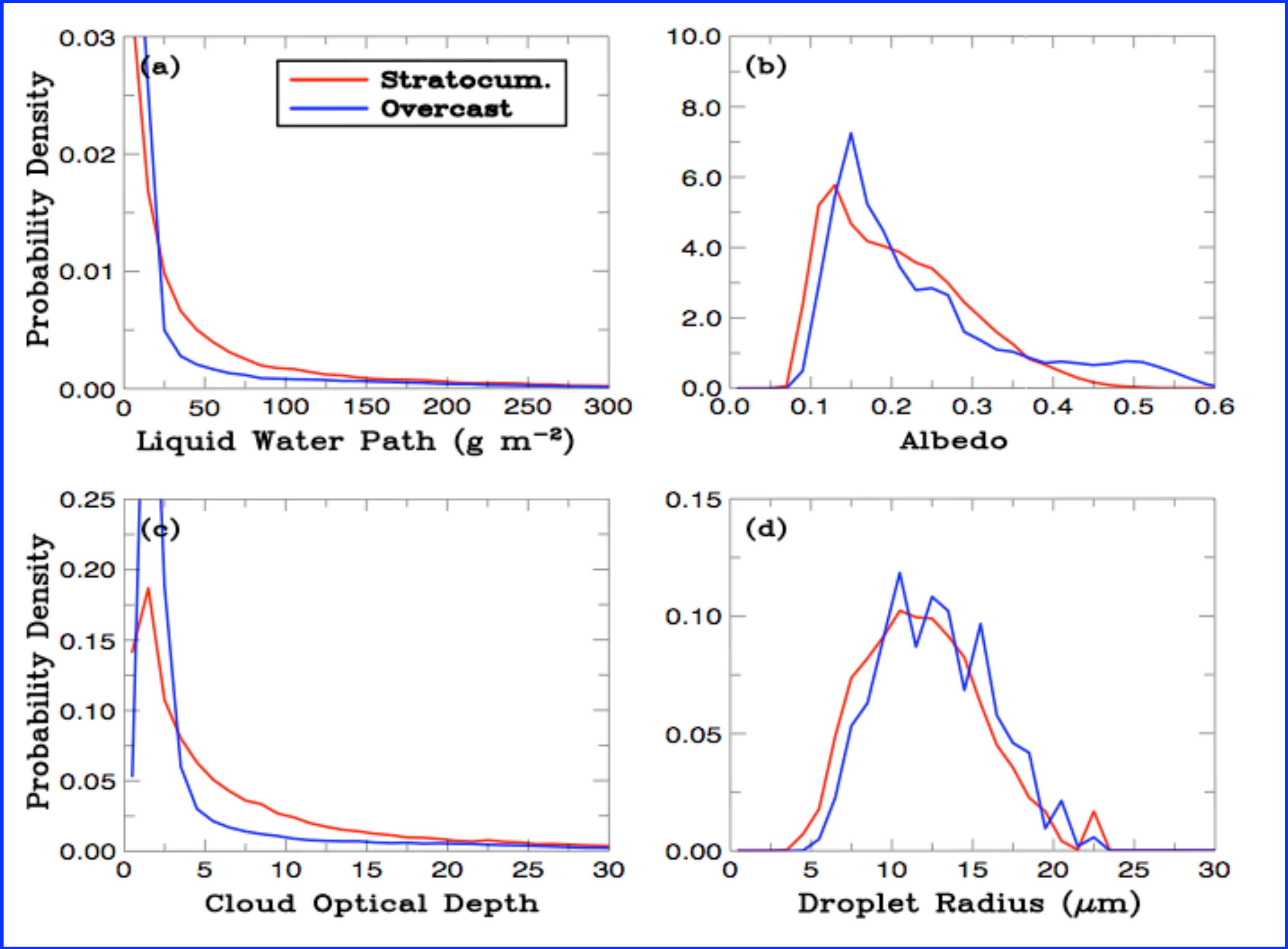
How to diagnose cloud physical properties from CRM simulations?

- A CRM column is cloudy if the cloud optical depth, $\tau > 0.25$
- Cloud top height is defined at the height when integrated τ from model top reaches 0.25
- Radiative properties and cloud fraction are obtained from running average over six CRM columns (12 km)
- All other cloud physical properties are averaged only over the cloudy columns in the running average
- In the "overcast" subset (46 cloud objects), only the (running averaged) overcast columns are used to construct pdfs of cloud physical properties
- In the "stratocumulus" setset (52 cloud objects), only the columns with (runnning averaged) cloud fraction between 0.40 and 0.99 are used to construct pdfs of cloud physical properties

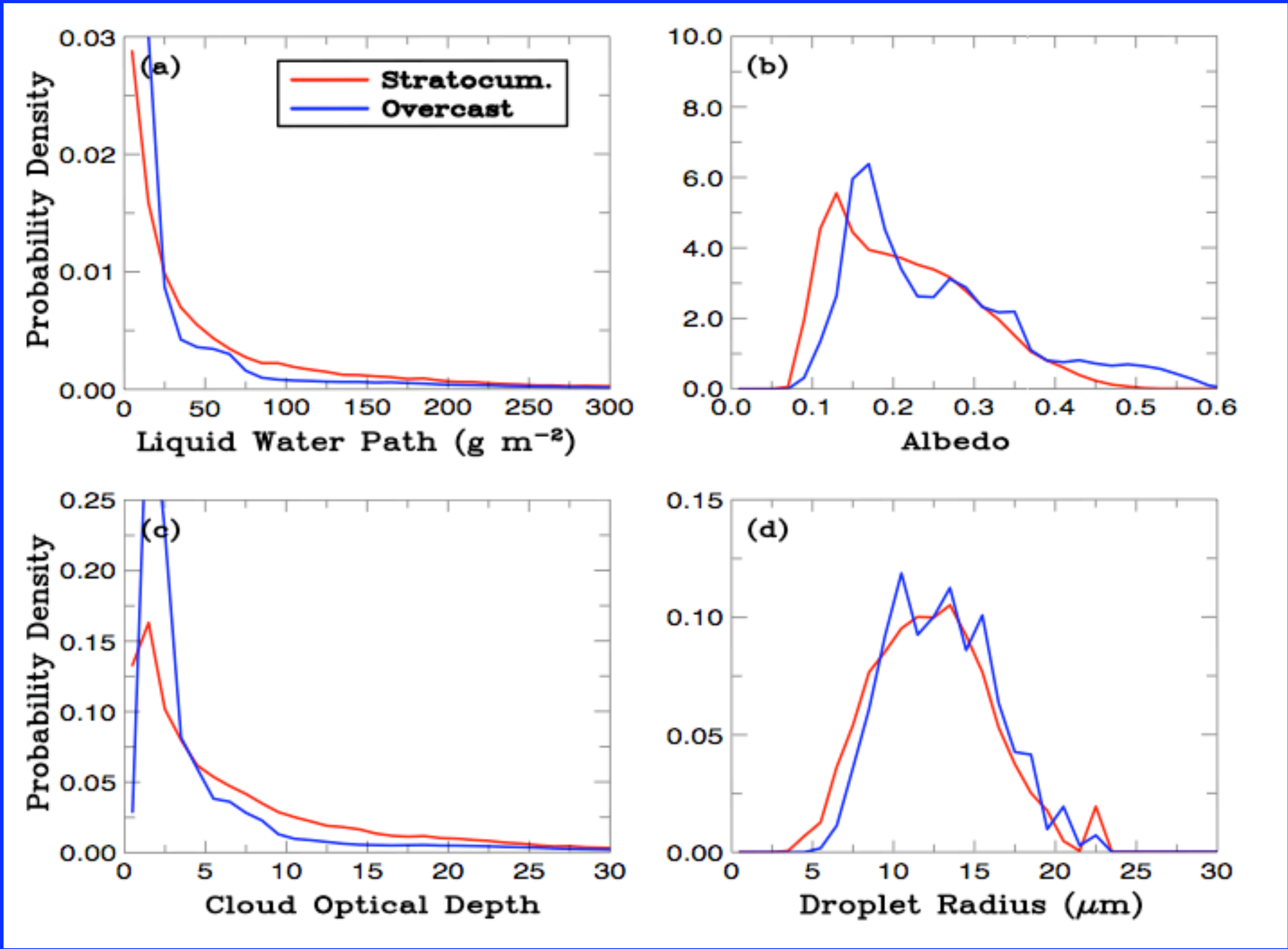
Control simulation (no modification), 1



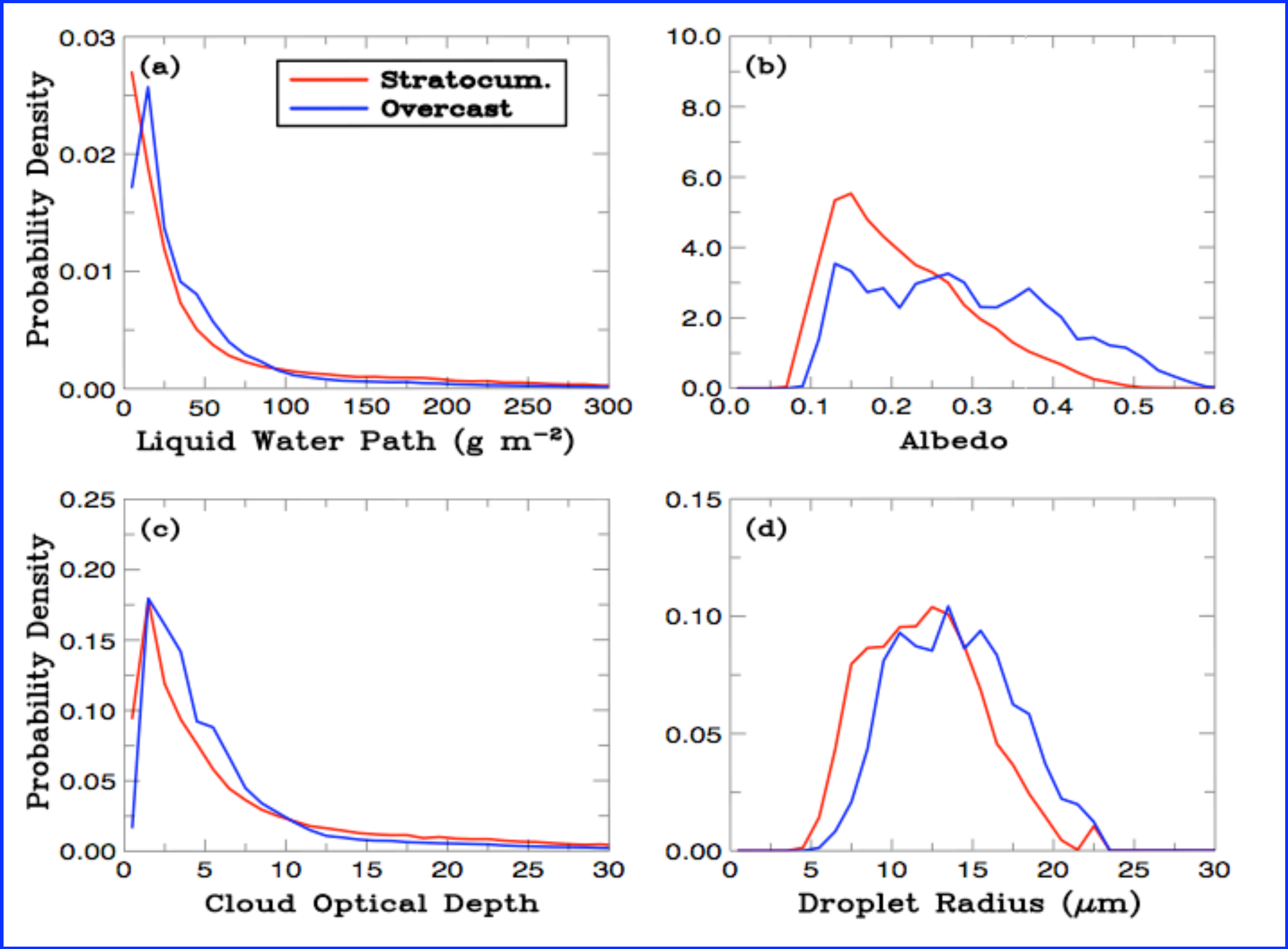
Control simulation (no modification), 2



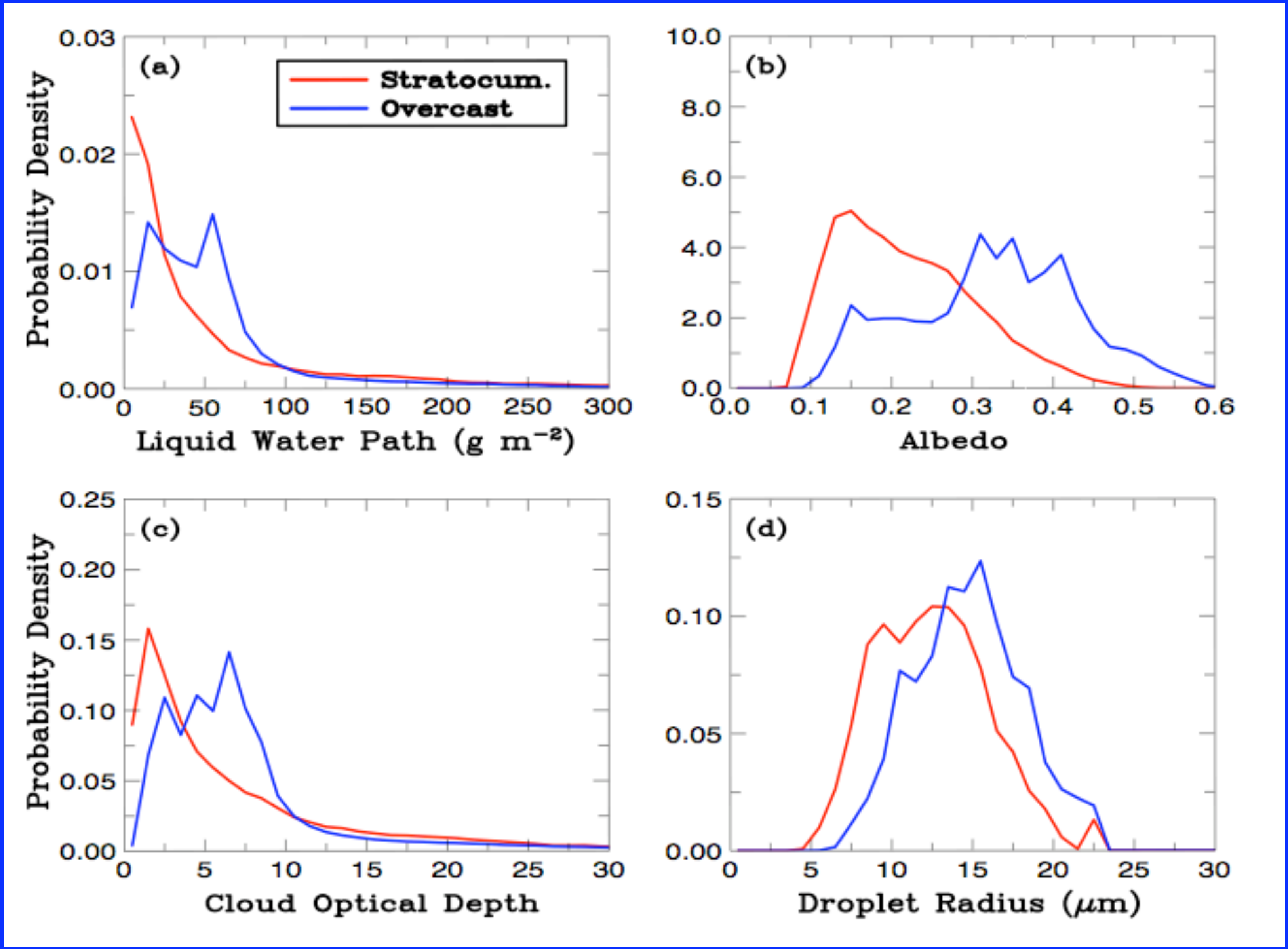
Increase of the inversion strength



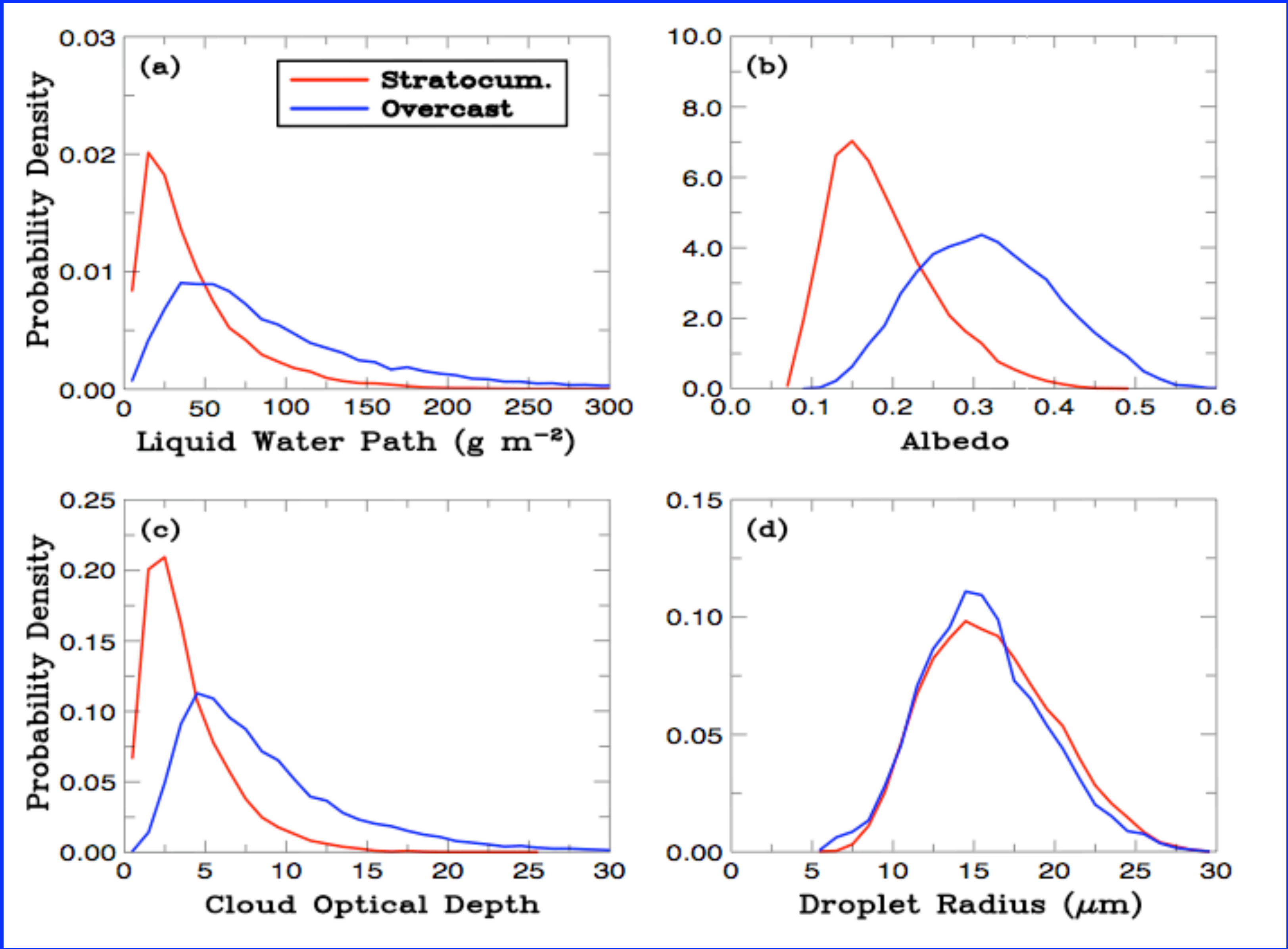
Increase of the moisture content



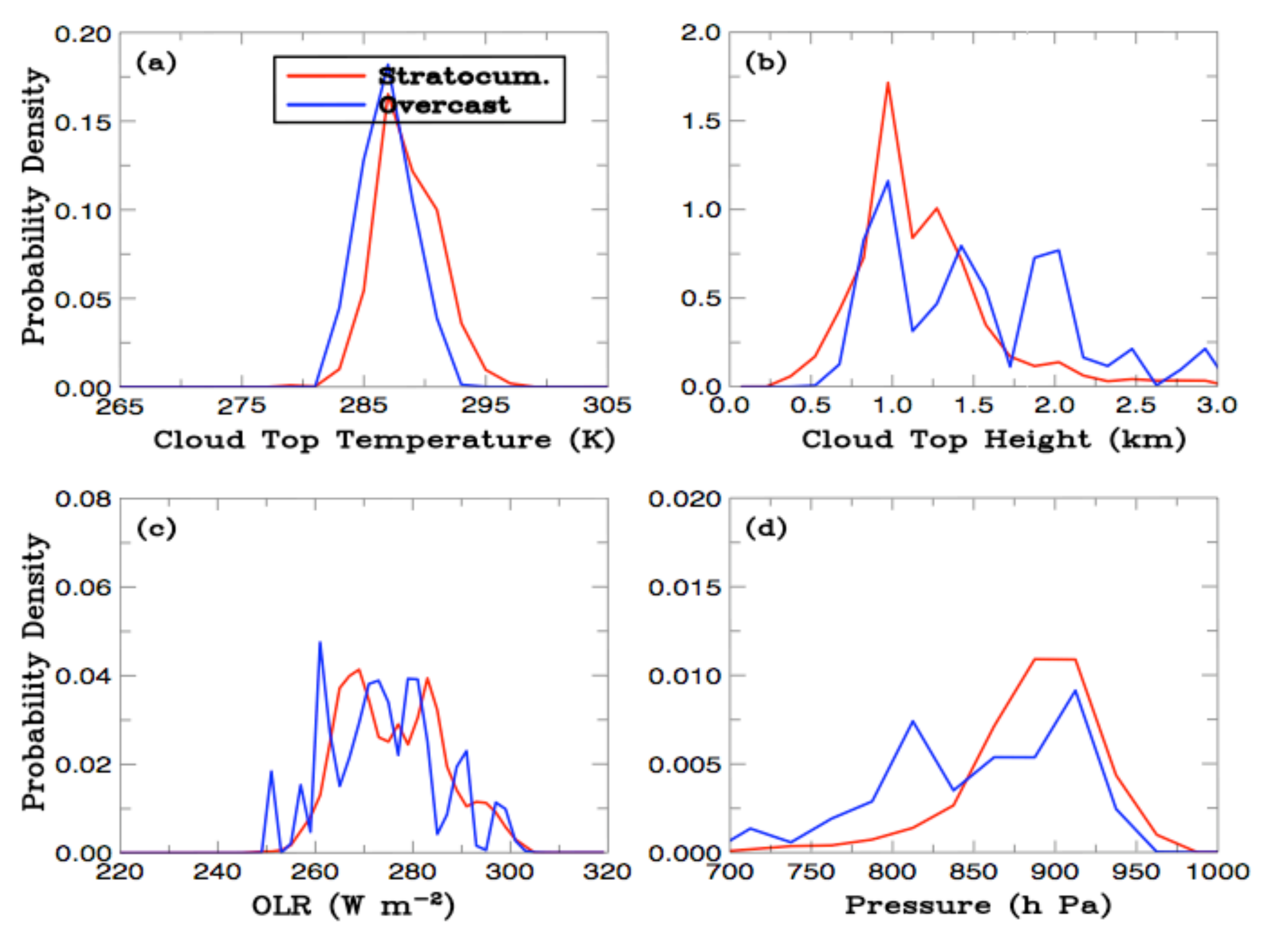
Modify both inversion and moisture, 1



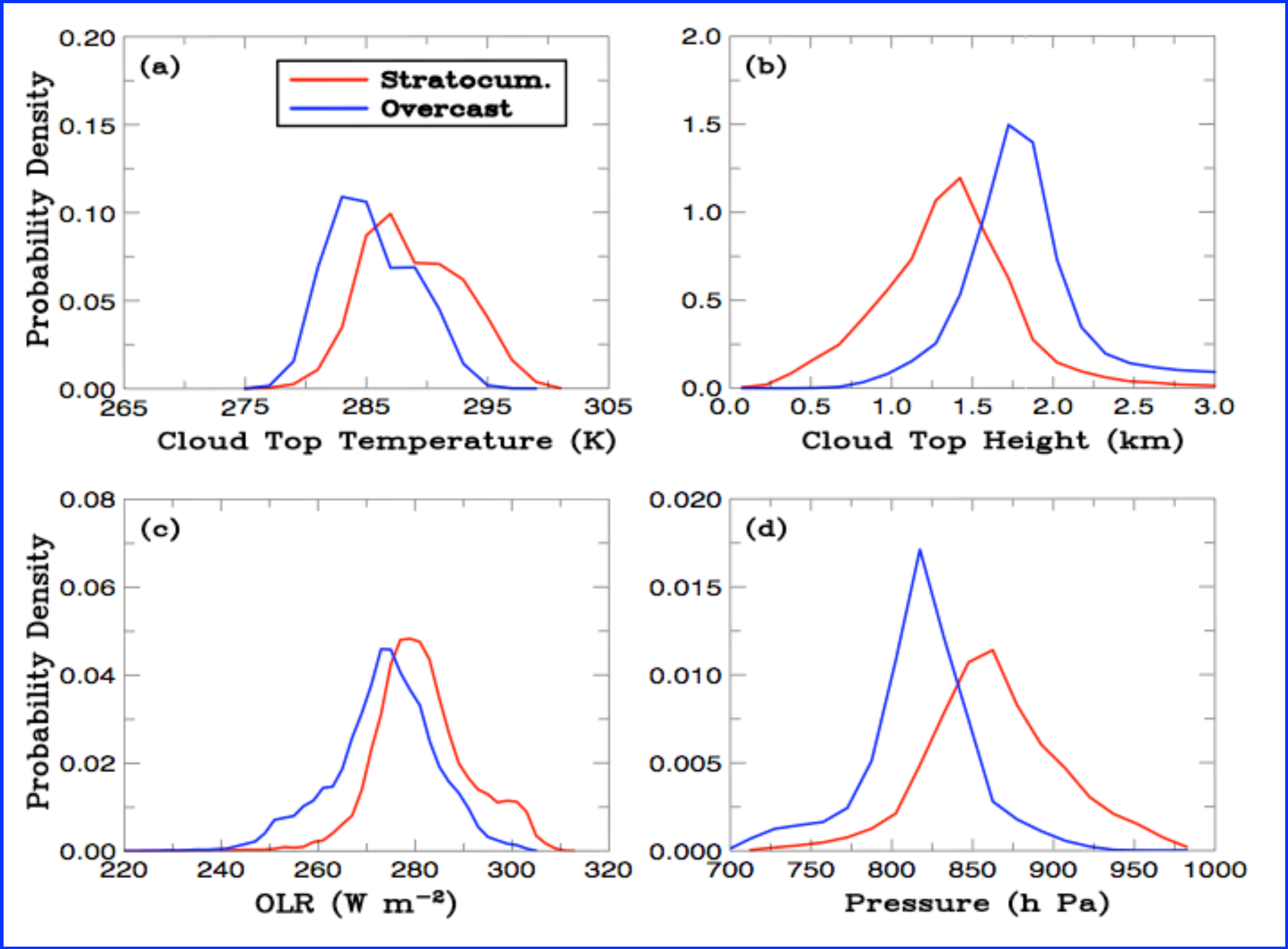
Observed cloud physical properties



Modify both inversion and moisture, 2



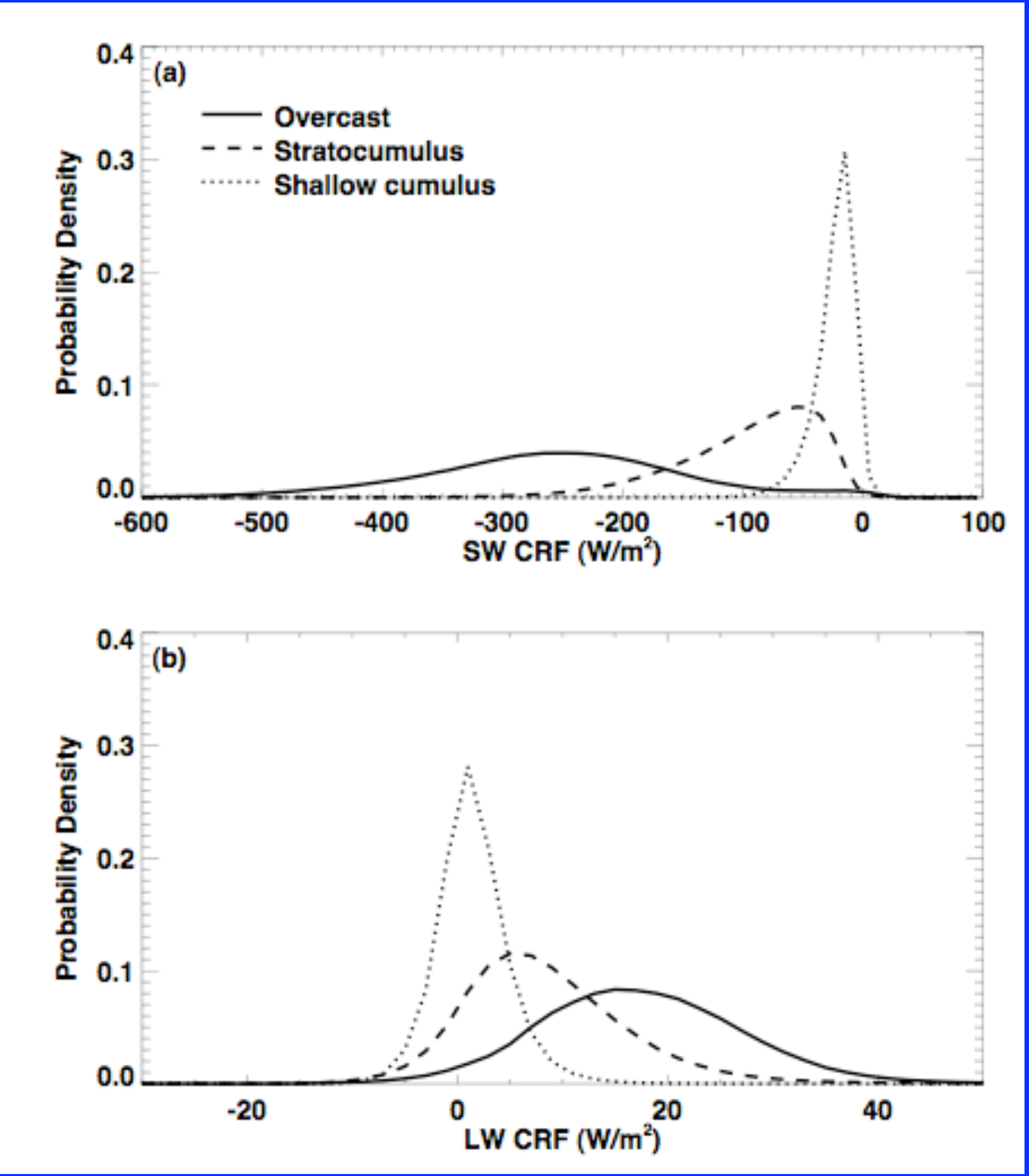
Observed cloud physical properties



Summary and future work

- The mean atmospheric states of cloud objects are rather similar between the stratocumulus and overcast types
- The simulations with unmodified initial soundings produce similar cloud physical properties between the two types of cloud objects
- Modifications of the inversion strength and moisture content individually do not significantly improve the simulations
- However, simultaneous modifications are more helpful to produce the observed differences between the two types
- For the overcast cloud type, potential temperature below the inversion height may need to be modified in order to better simulate cloud physical properties
- Larger numbers of cloud objects will be simulated to increase the robustness of the results
- Studying the aerosol indirect effects will be the next logical step

Shortwave & longwave cloud radiative forcing



$CRF = Flux_{cloudy} - Flux_{clear}$

Probability density is the frequency divided by the bin interval

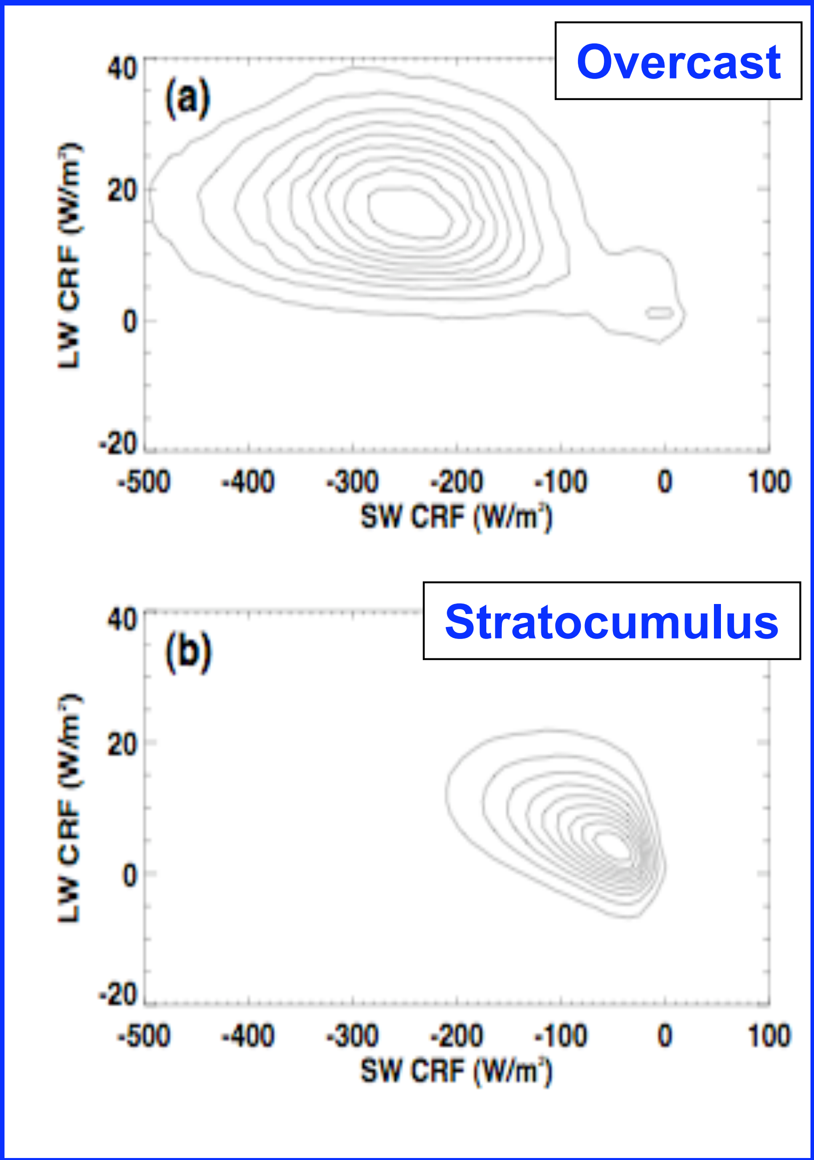
TRMM CERES cloud-object footprint data for Jan. - Aug. 1998

48780 cloud objects

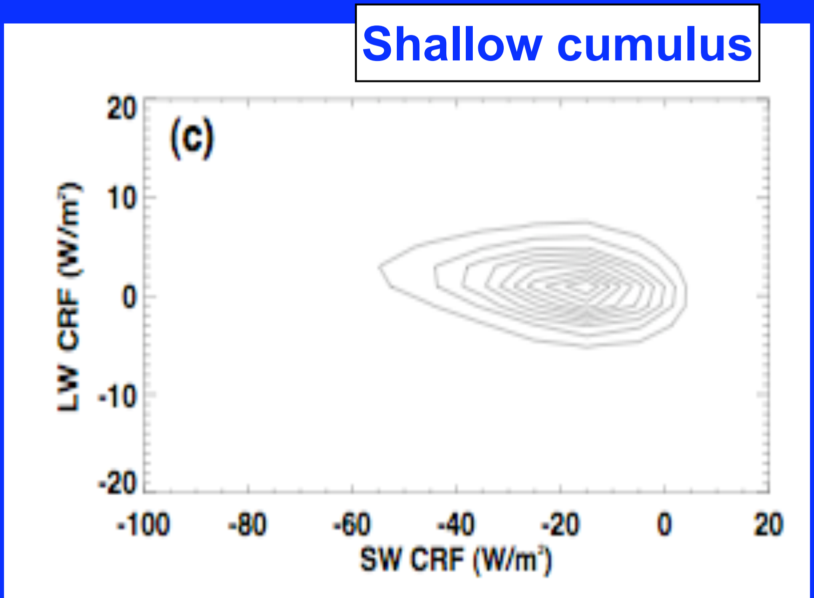
8.362 million footprints

As expected,
1) SW CRF >> LW CRF;
2) Overcast SW CRF >> stratocumulus SW CRF >> cumulus SW CRF

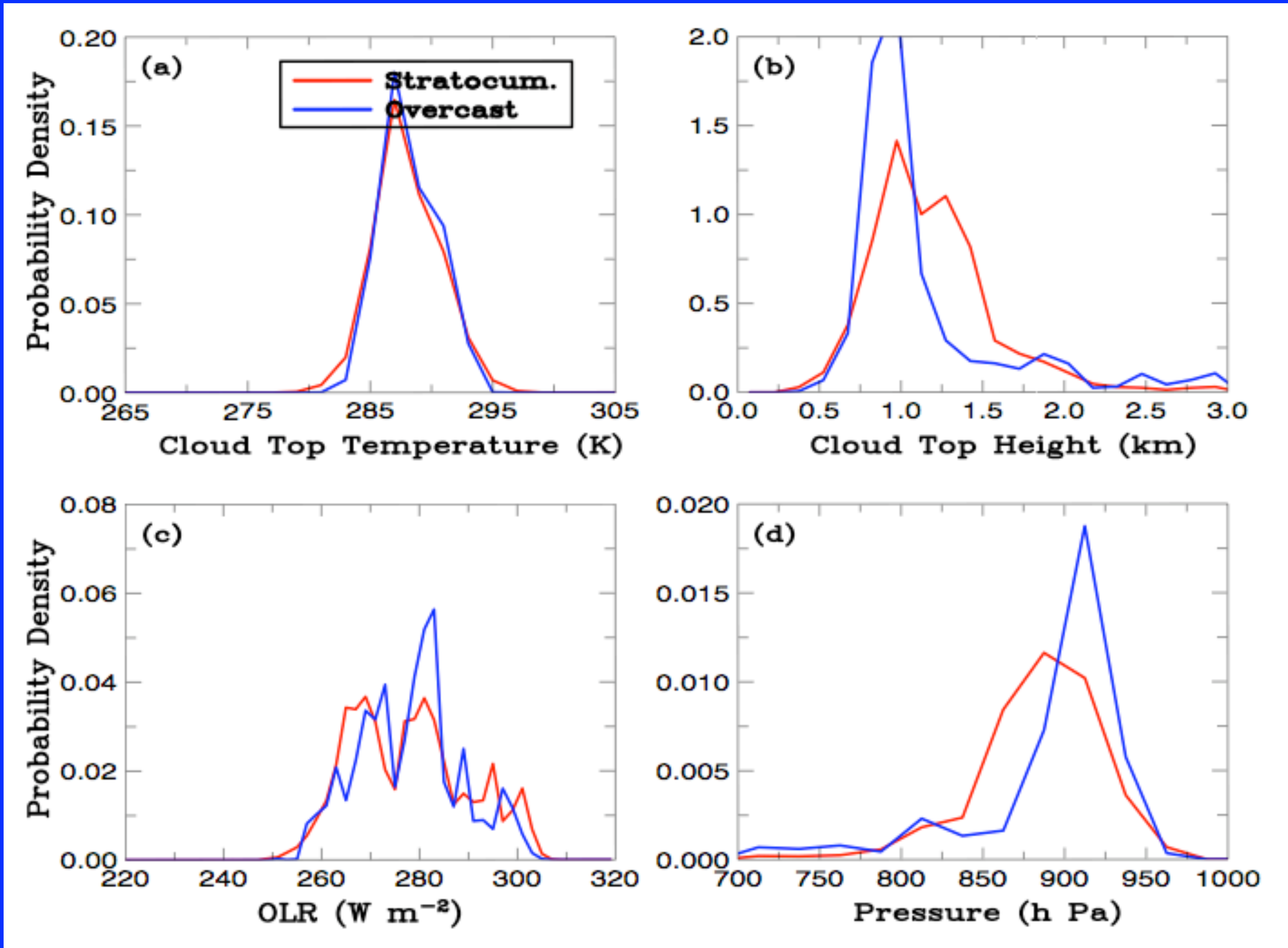
Shortwave & longwave cloud radiative forcing



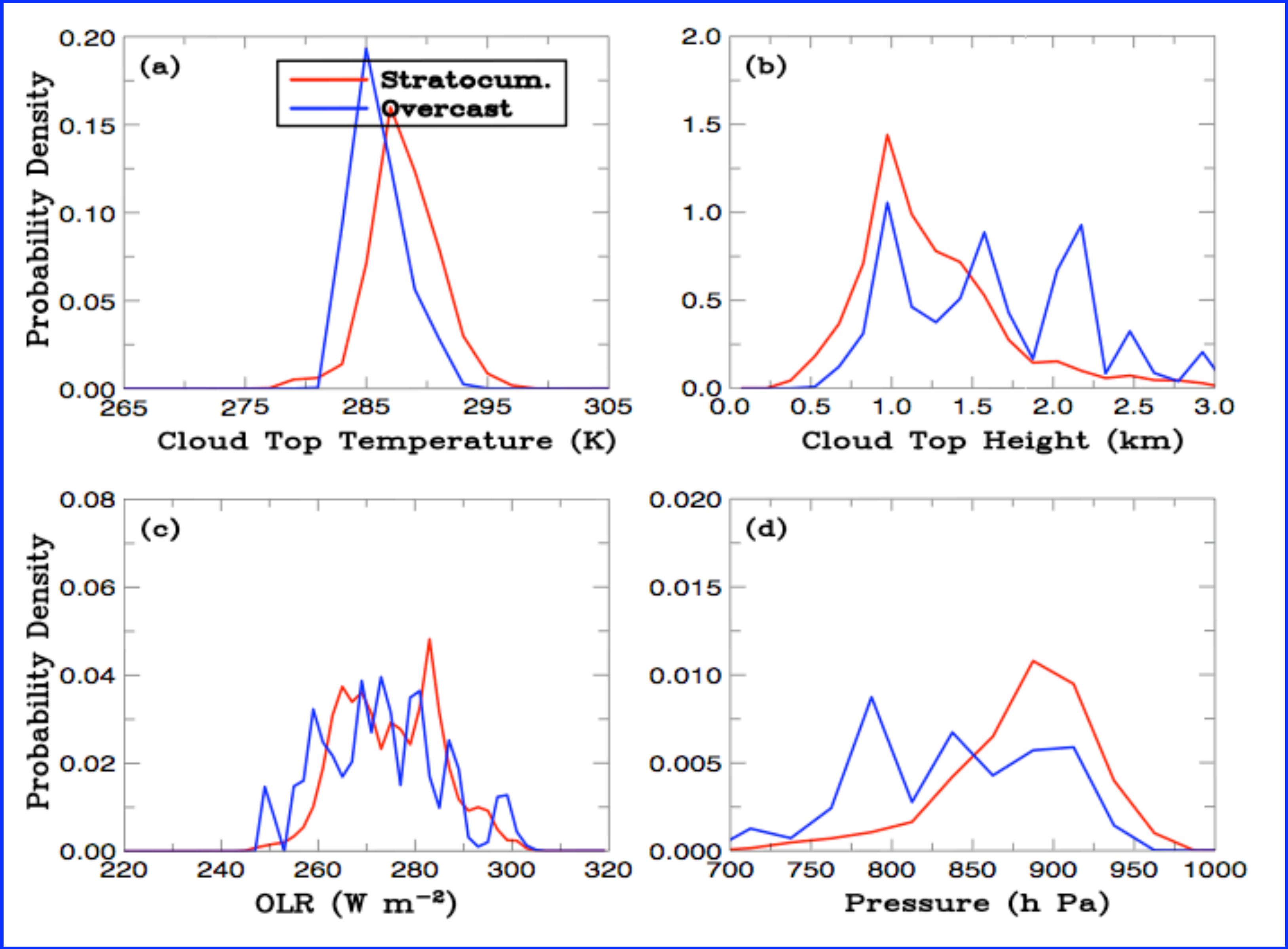
Joint pdf (probability density function) analyses for physical property pairs and cluster analyses of selected pairs (Eitzen, Xu & Wong, 2007; *J. Climate*)



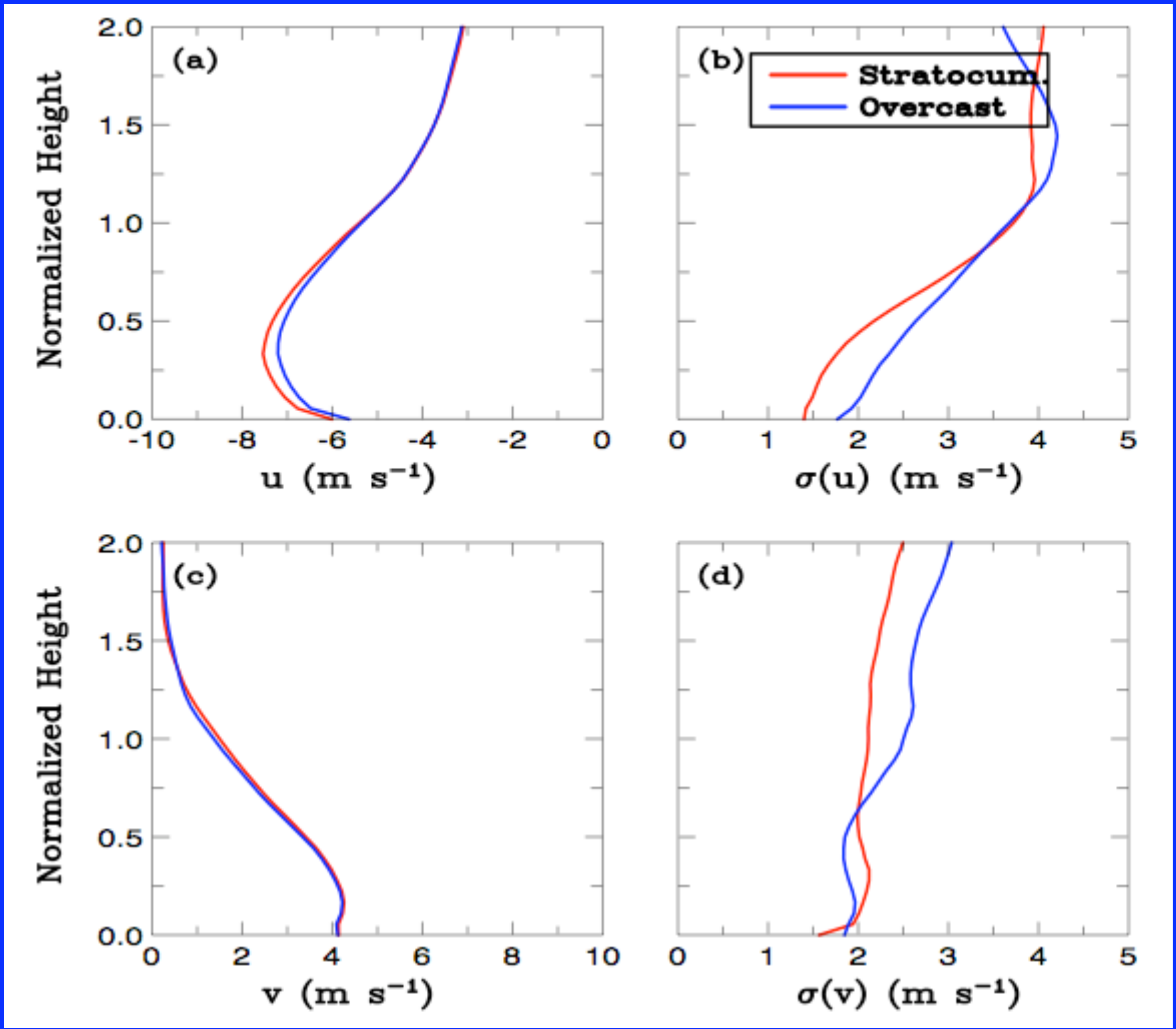
Increase of the inversion strength



Increase of the moisture content



Wind components



Relative humidity