The Gridded Cloud Object Data and Evaluation of ECMWF Operational Analysis and Re-analysis Data

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Objectives

1. How physical and radiative properties of tropical deep convective cloud systems are changed with matched atmospheric dynamics and sea surface temperature (SST)?
2. How well does the ECMWF model reproduce the observed cloud physical and radiative properties with its operational analysis and re-analysis products?

The January-August 1998 TRMM CERES data are used in this study (Xu et al. 2005, 2007 for details)

What is a cloud object?

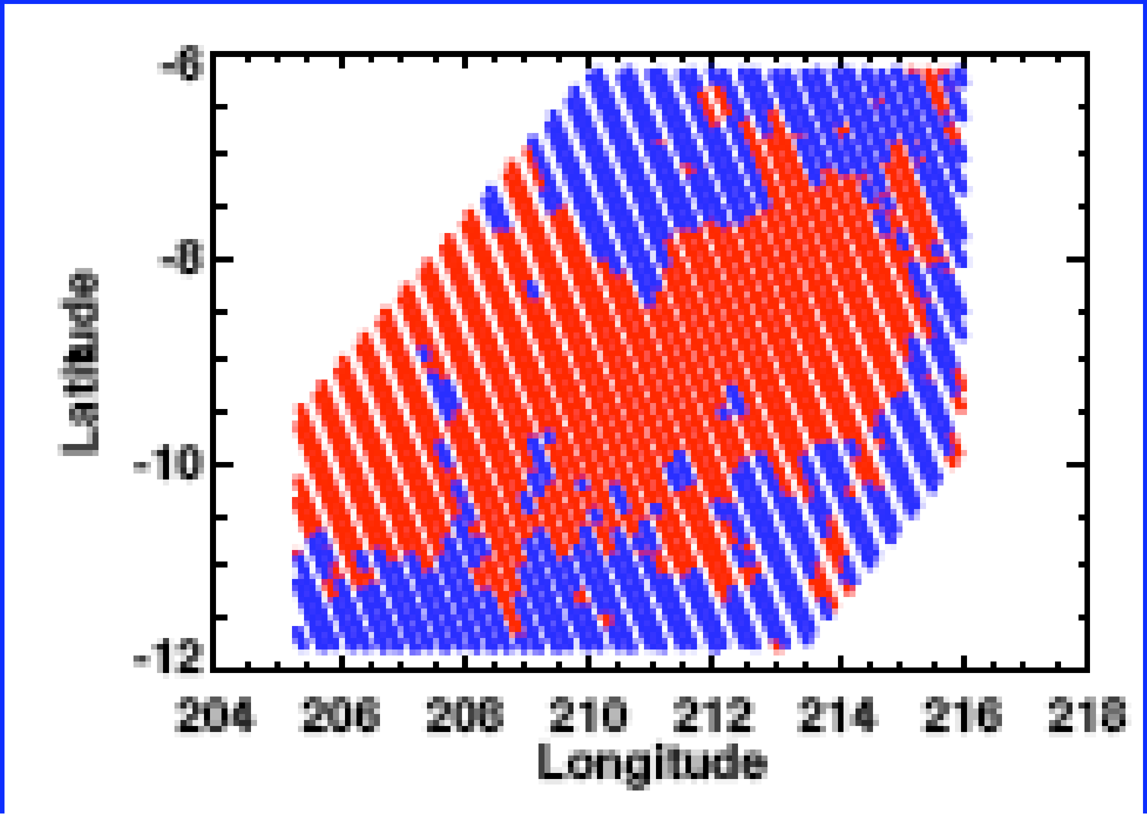
- A contiguous patch of cloudy regions with a single dominant cloud-system type; no mixture of different types
- The shape and size of a cloud object is determined by
  - the satellite footprint data
  - the footprint selection criteria
- Selection criteria for deep convective (DC) cloud objects:
  - Cloud optical depth (τ) > 10
  - Cloud top height (H_t) > 10 km
  - Footprint cloud fraction = 100%
  - Located between 25 S and 25 N
- Data available from the NASA/LaRC cloud object webpage (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)

Why “gridded” cloud objects?

- There are optically thin (τ < 10) and shallow-cloud (H_t < 10 km) footprints adjacent to a deep convective (DC) cloud object within a tropical convective cloud system
- Physical properties of tropical convective cloud systems are contributed by both the DC cloud-object footprints and the adjacent footprints (non-DC); the proportion of their areas is a critical factor
- Since model grid meshes are regularly shaped and sized, the irregular shape and size of a cloud object are difficult to handle when evaluating model performance with the cloud object data
- By allowing mixture of different cloud types associated with a predominant cloud-system type, one can gain a better understanding of physical processes of an “nearly entire” cloud system

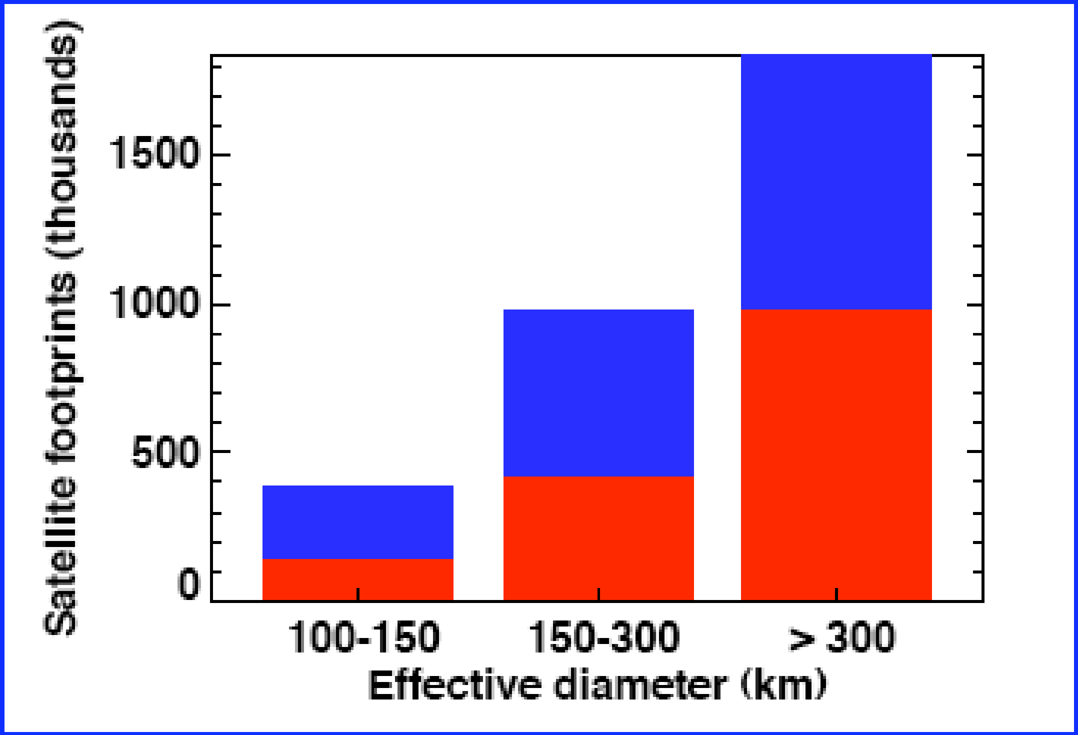
The “gridded” cloud object

- Cloud object: a contiguous region with similar cloud physical properties (τ > 10, H_t > 10 km for DC cloud object)
- “Gridded” cloud object: also includes neighboring areas (blue areas) surrounding a cloud object and small areas of footprints that satisfy the cloud object criteria (isolated red areas)
- Statistics of red and blue areas are examined separately or combined



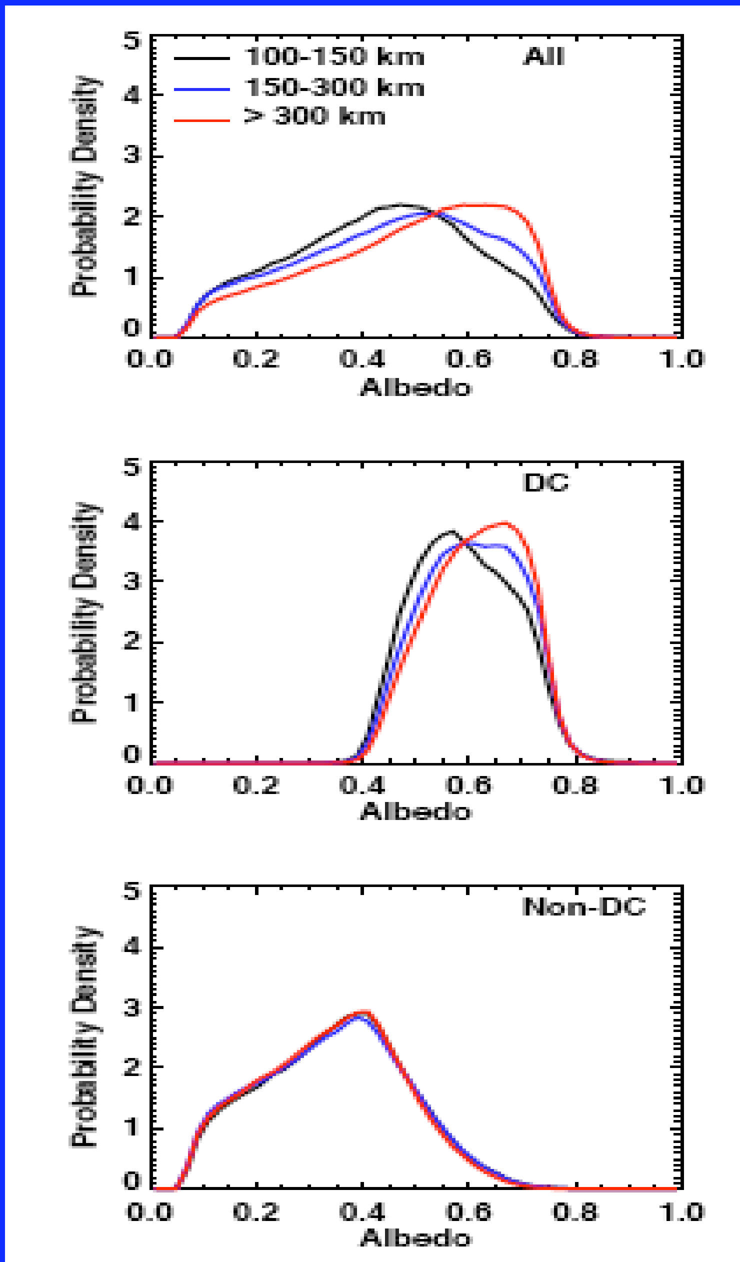
Total numbers of DC and non-DC footprints for size categories

858 899 500 # cloud object

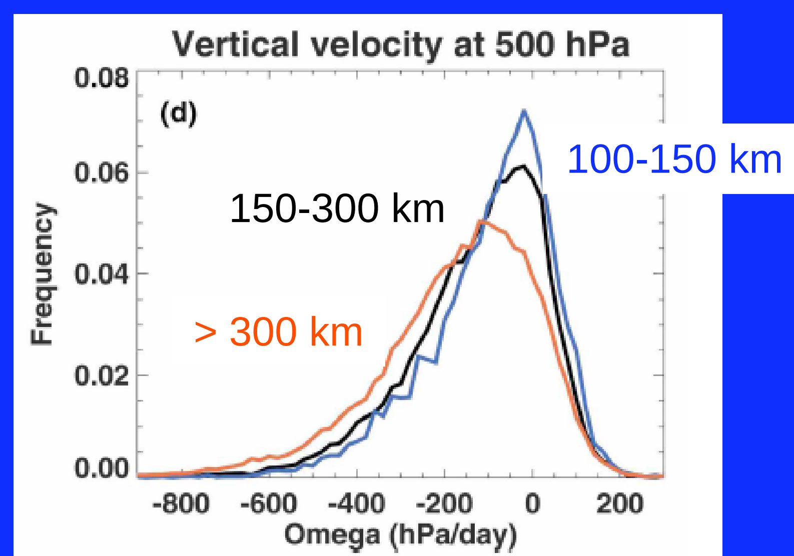


The ratio of DC (red) over non-DC (blue) footprints increases (0.54 to 1.13) as the cloud object size increases

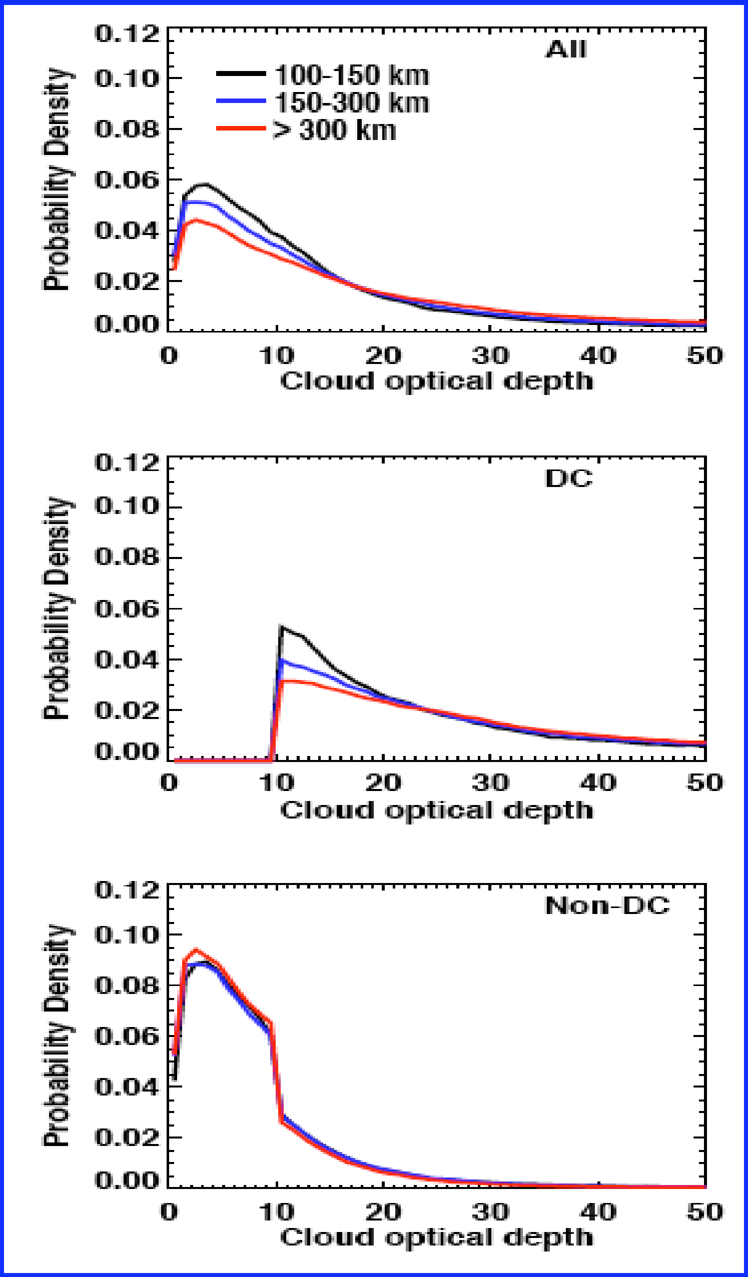
PDFs of TOA albedo for size categories



1. Albedo for non-DC footprints are independent of cloud-object size (due to sampling over the entire tropics)
2. Albedo for DC footprints are strongly dependent upon size (i.e., stronger large-scale ascent for larger objects)
3. The overall pdfs reflect primarily the change of the ratio of DC and non-DC footprints with size, and secondarily the change of the DC pdfs with size



PDFs of cloud optical depth for size categories



Frequency at any bin interval:

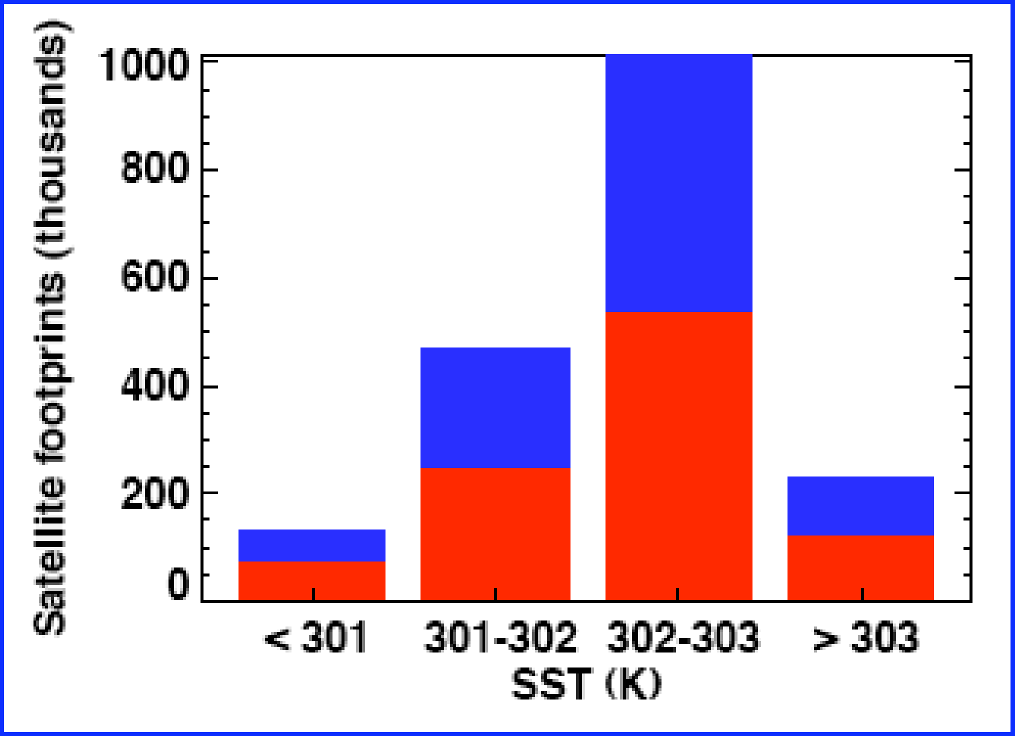
$A_{all}\ pdf_{all} = A_{dc}\ pdf_{dc} + A_{ndc}\ pdf_{ndc}$

A: the total number of footprints

1. NB: pdf values extend to 128….
2. As in albedo, the DC pdfs change with size (i.e., large-scale dynamics)
3. The proportions of DC and non-DC footprints primarily determine the pdfs of all footprints
4. The pdfs of TOA albedo are consistent with those of τ

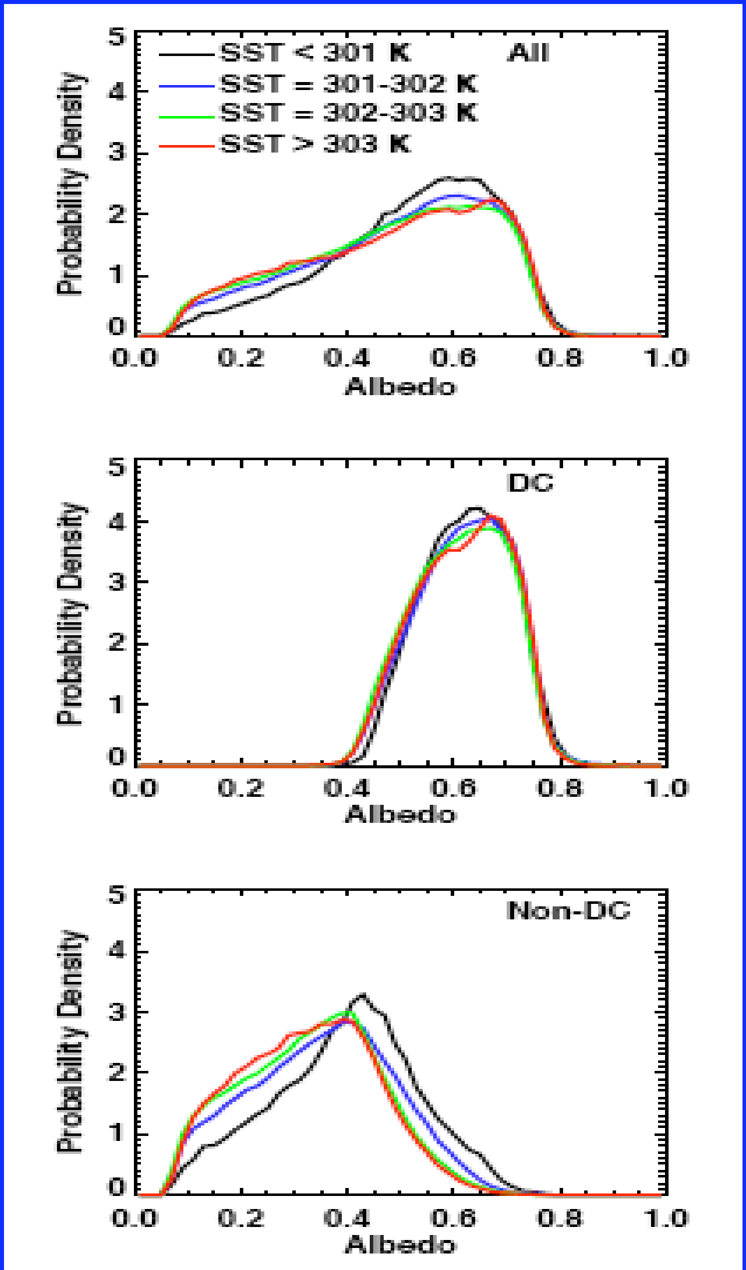
Total number of DC and non-DC footprints for SST ranges of the large size category

46 127 263 64 # cloud object

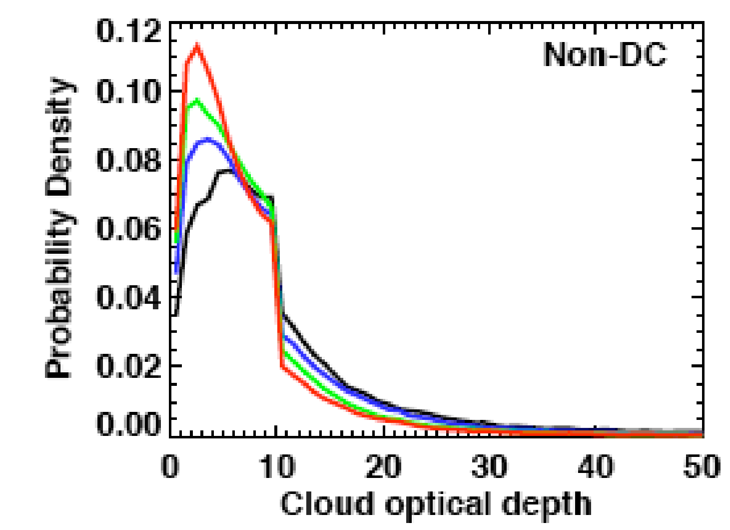


The ratio of DC over non-DC footprints does not increase as cloud-object-mean SST increases

PDFs of TOA albedo for SST ranges



1. Albedo for DC footprints are *not* strongly dependent upon SST
2. Albedo for non-DC footprints are (i.e., weaker large-scale ascent in higher SST regions with more optically thin clouds)
3. The overall pdfs reflect the change of non-DC albedo with SST, due to the constant proportion of DC and non-DC footprints



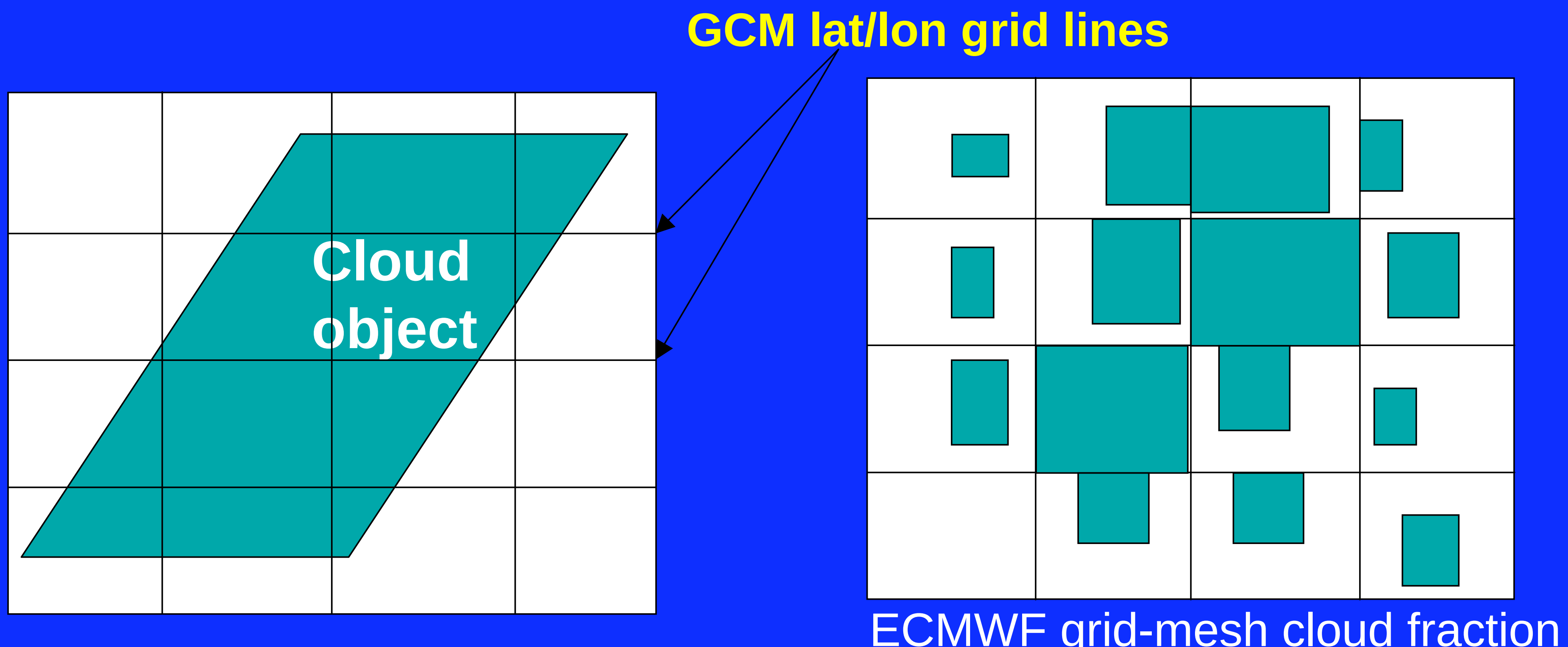
Evaluation of ECMWF operational analysis (EOA) and re-analysis (ERA-40) data

How to convert the vertical profiles of grid-averaged cloud properties from large-scale models to pdfs of subgrid-cell cloud physical properties measured at satellite footprints?

(Xu 2008, *Mon. Wea. Rev.*, submitted)

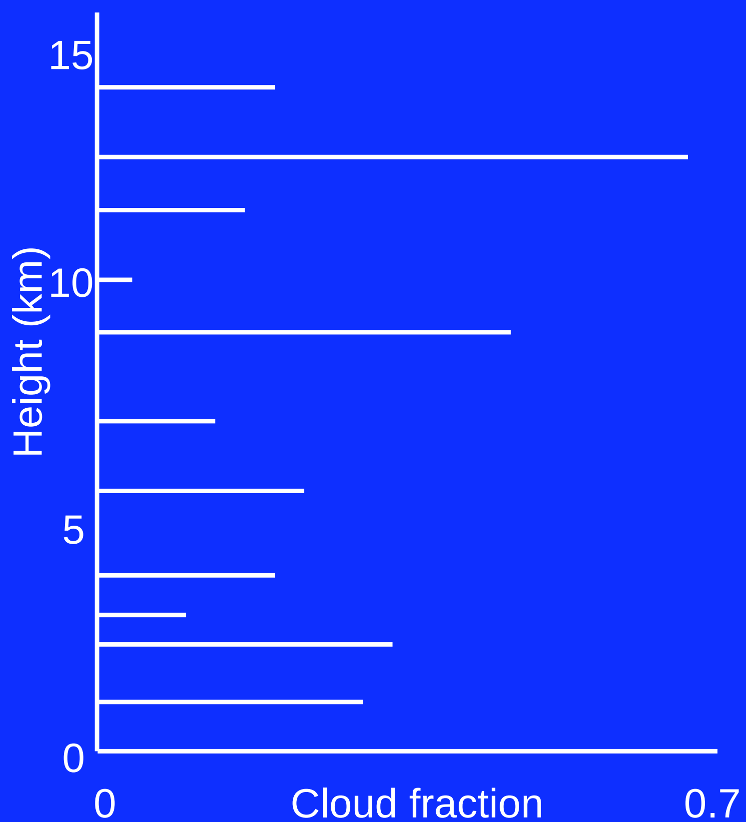
Matching a cloud object with ECMWF grids

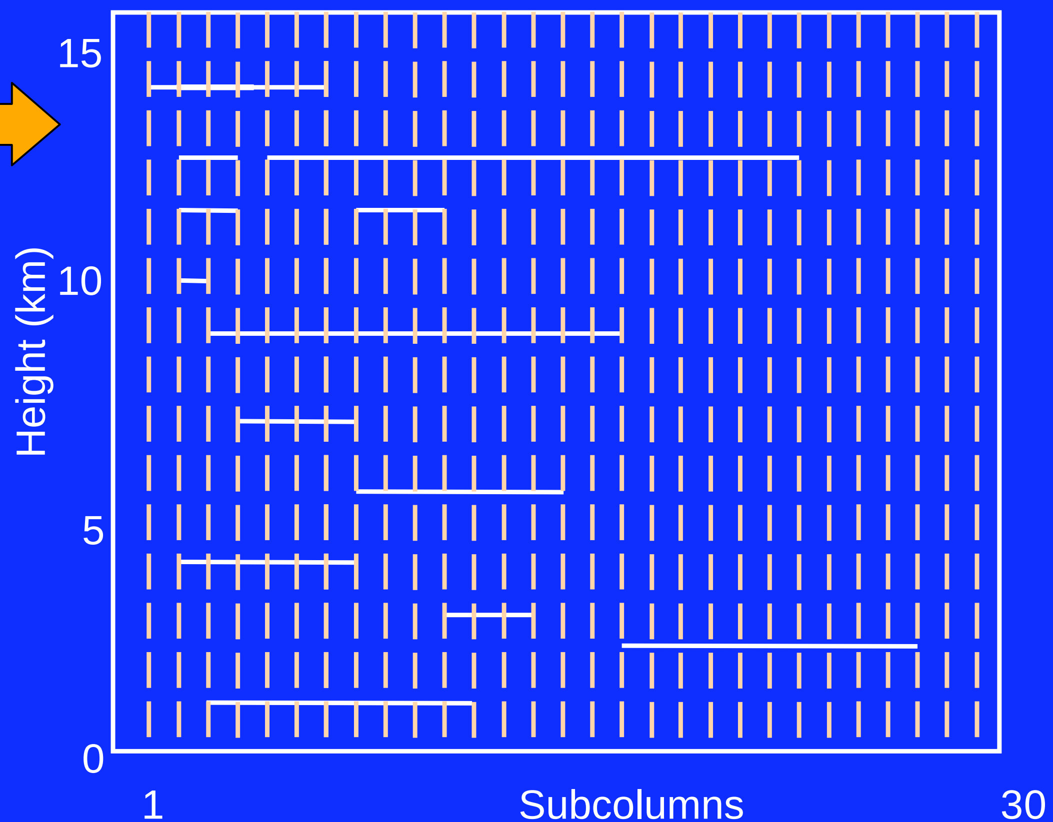
- Spatially, draw a rectangular area covering the most easterly, westerly, southerly and northerly footprints of each cloud object
- Temporally, match within 3 h because ECMWF data are available every 6 h
- Grid sizes: 0.5625° x 0.5625° for EOA, 1.125° x 1.125° for ERA-40



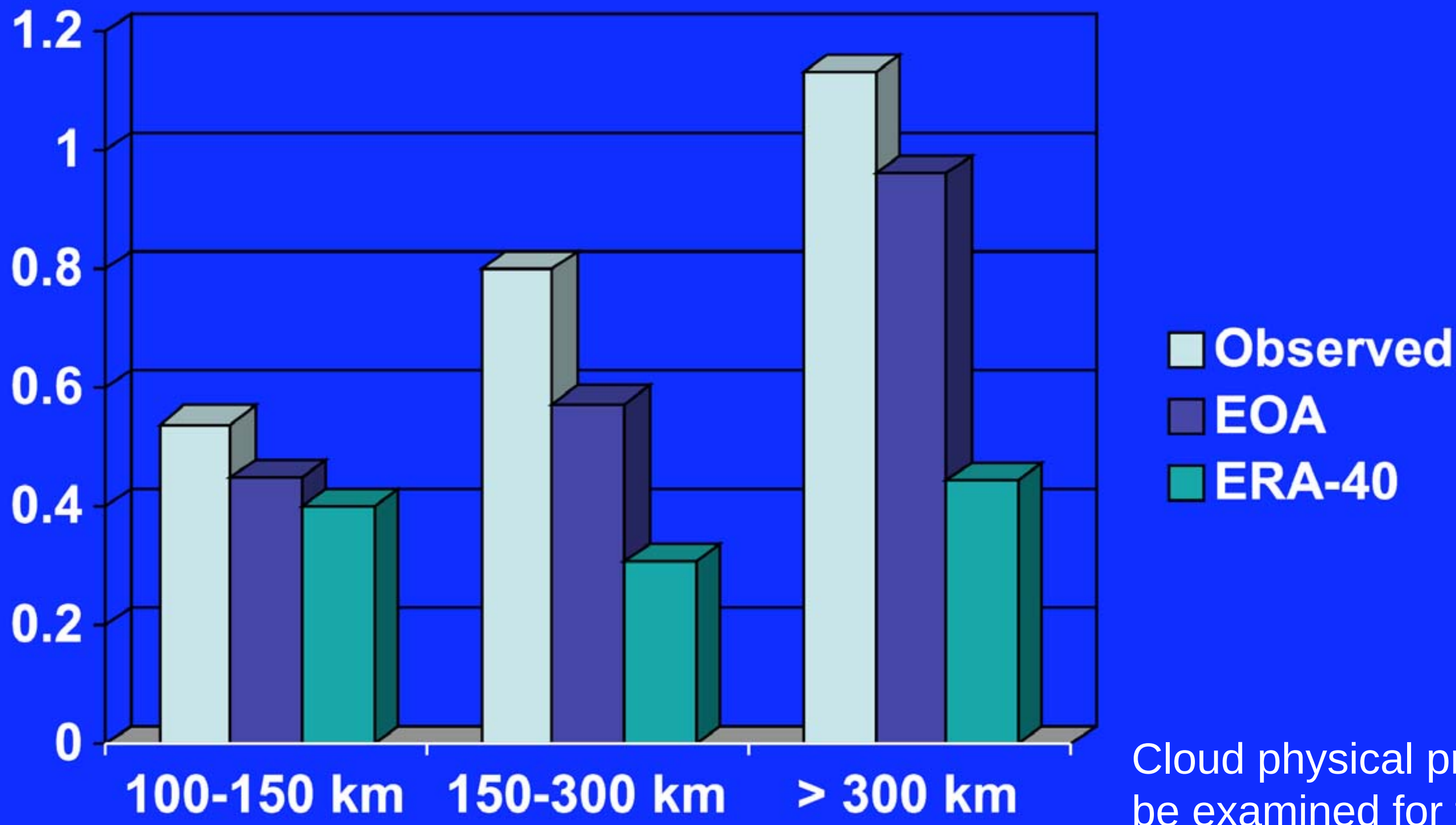
Converting ECMWF-forecasted cloud fields to pdfs of subgrid-cell cloud physical properties

1. Divide each EOA/ERA-40 grid into 30/120 subcolumns (~100 km^2, footprint size)
2. Use cloud overlap assumption to construct cloud distribution in subcolumns from an ECMWF/ERA-40 predicted cloud fraction profile
3. Use the Fu-Liou radiation code to obtain cloud optical properties and radiative fluxes for each subcolumn; determine cloud height and temperature
4. Select "cloud object" subcolumns (τ >10 & H_t >10 km) and construct pdfs





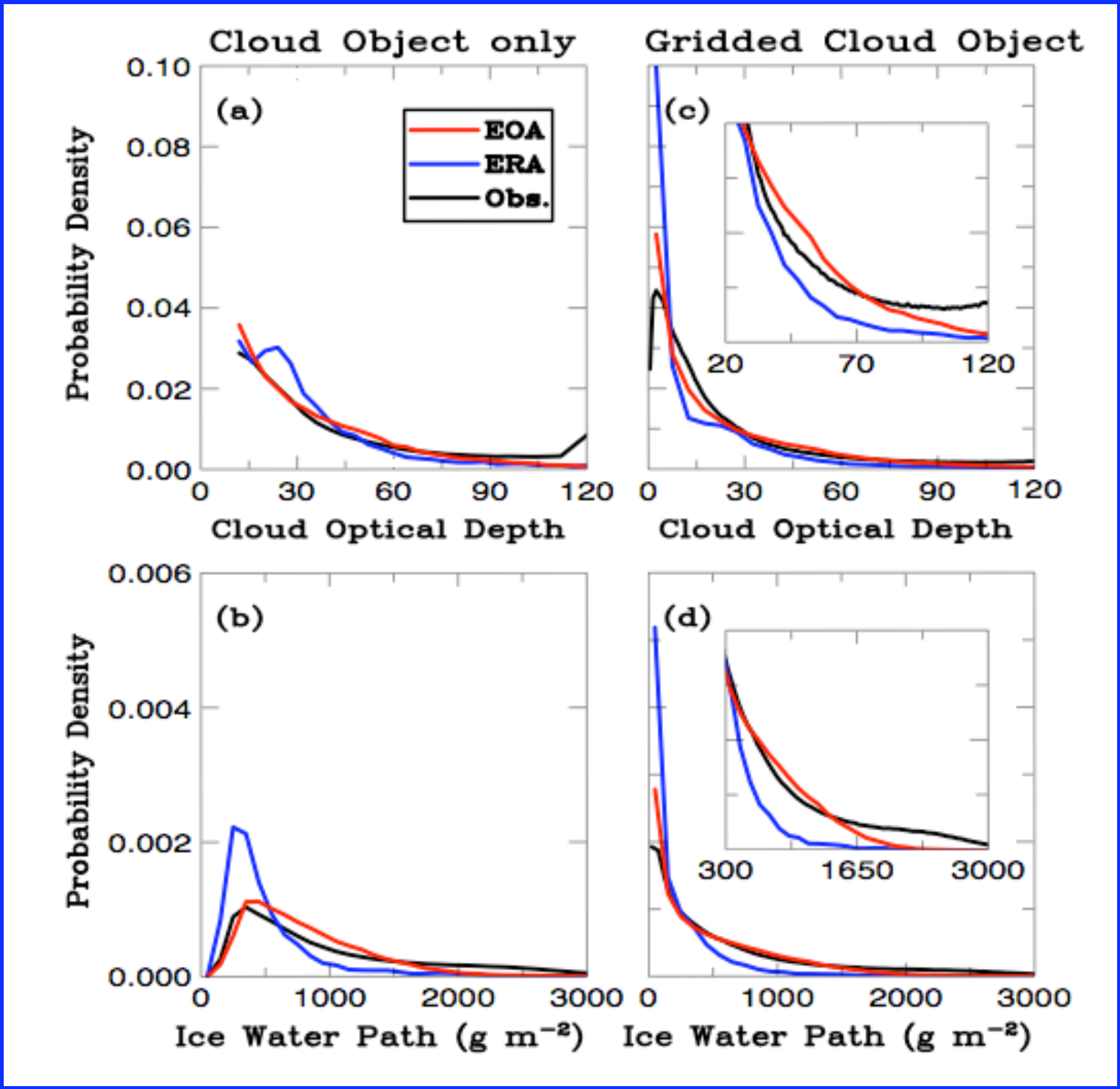
The ratios of DC and no-DC subcolumns



Cloud physical properties will be examined for the large size category

Note the large underestimate of the DC population for this category

PDFs of τ and IWP for size categories



EOA agrees with observations much better for both DC (cloud objects only) and overall (gridded cloud objects) populations

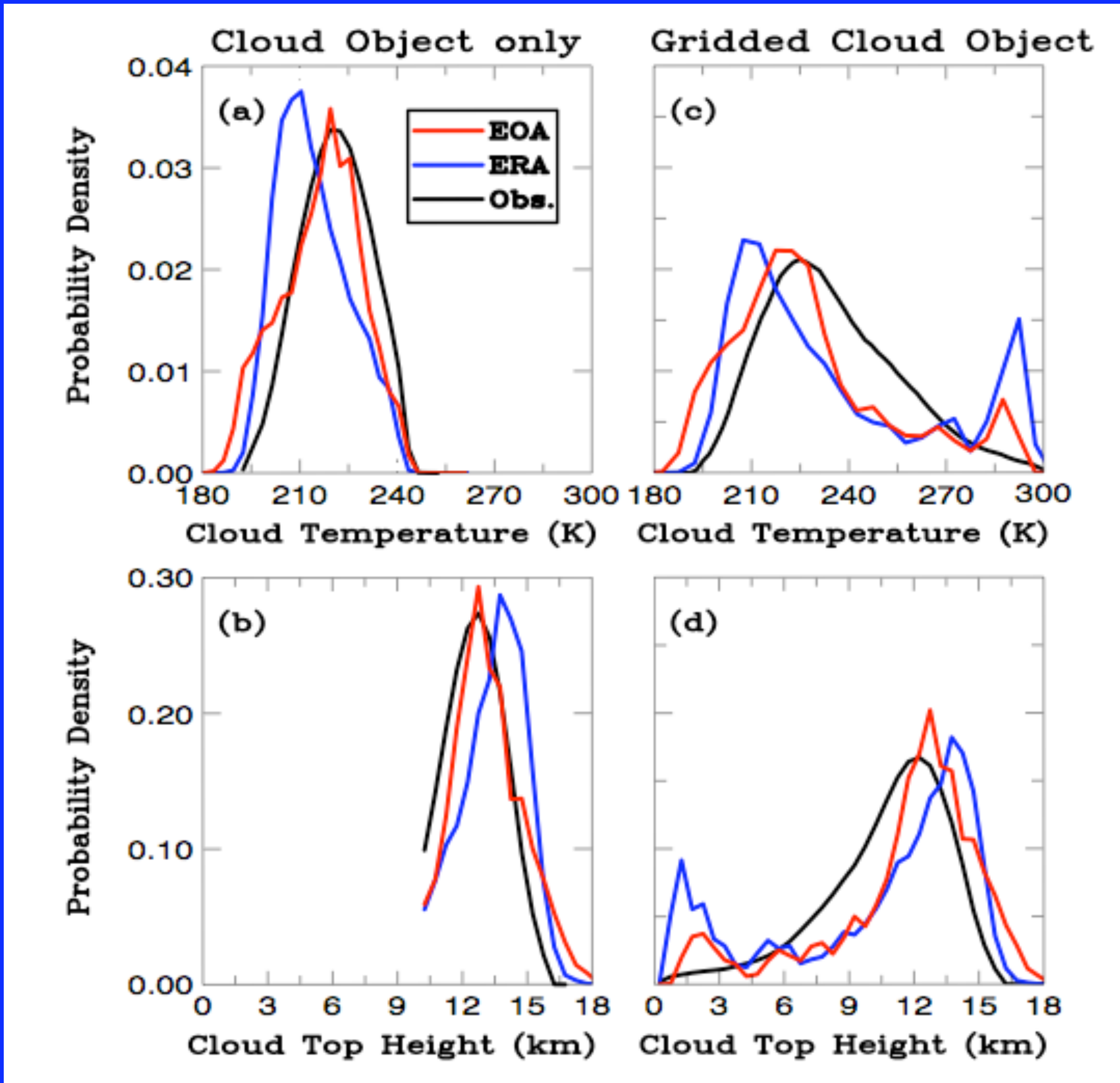
Changed cloud parameterization in Sept. 1999; ERA-40 used the modified parameterization

Narrower ranges of τ and IWP of DC pdfs in ERA-40

Underestimate of the DC portion by ERA-40 also contributes to the large power at the lowest bin of the overall pdfs

Downgrade of data assimilation technique (4D var -> 3D var), changes in parameterization are the likely causes, not the change in the model resolution

PDFs of cloud-top temperature and height



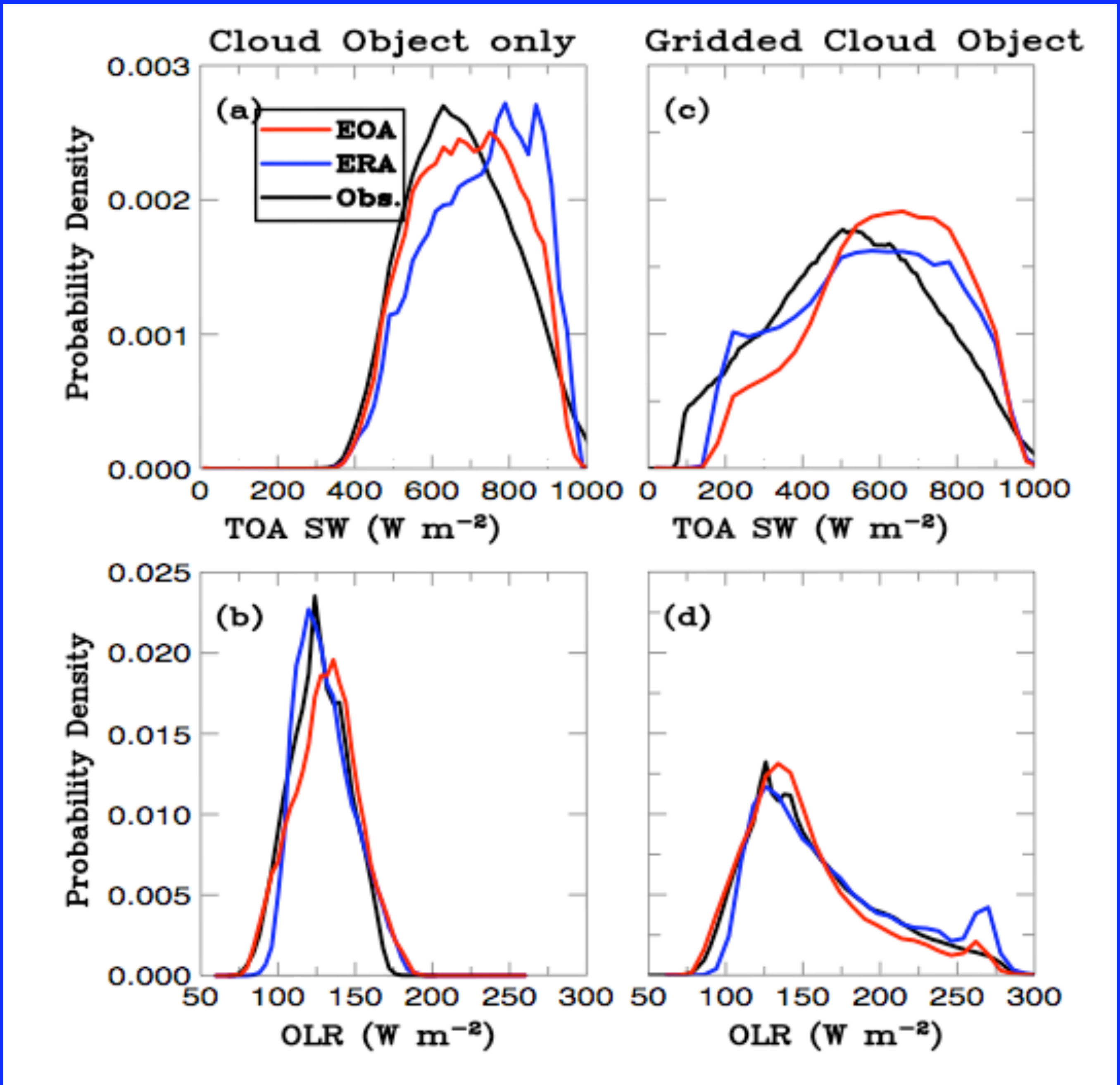
For DC pdfs, EOA has clouds too close to the tropopause; ERA-40 eliminates those clouds, but shifts the power of pdf to slightly lower heights

Modified cloud parameterization produces more shallow clouds at 0.2-3 km range (shallow clouds) at the expense of high clouds

Mid-level clouds (5-11 km) are underestimated by both models

The overestimate of upper-level clouds are also contributed by non-DC population

PDFs of TOA radiative fluxes



Radiative fluxes agree with observations reasonably well despite of large disagreement in cloud physical properties, esp. for ERA-40

Optically thin ($\tau < 1$) also contribute to radiative budget and water vapor distribution is probably more accurate in ERA-40

Summary and future work, 1

- The ratio of DC over non-DC footprints changes greatly (0.54 to 1.13) as the large-scale dynamics (cloud object size) change, but not much as SST changes
- The changes of the overall pdfs of cloud properties reflect primarily those of the ratio of DC and non-DC footprints with large-scale dynamics (size), and secondarily the changes of the DC pdfs with dynamics (size)
- On the other hand, the changes of the overall pdfs of cloud properties with SSTs are solely related to those of non-DC pdfs

Summary and future work, 2

- The pdfs of cloud physical properties from ECMWF operational analysis and ERA-40 are generally similar to those observed
- The discrepancies are larger for ERA-40 than EOA for DC and overall pdfs of most parameters except for radiative fluxes, due to changes in cloud parameterization and downgrade of data assimilation technique
- The cloud parameterization at ECMWF has recently been improved (Bechtold et al. 2004, 2008); it is worthwhile to confirm these conclusions using the ERA Interim data
- Aqua CERES data will be analyzed to confirm the findings