Evaluation of Cloud Physical Properties of ERA-40 and ECMWF Operational Analyses Against CERES Tropical Convective Cloud Object Observations

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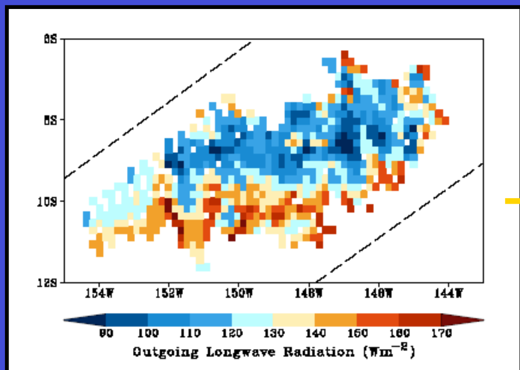
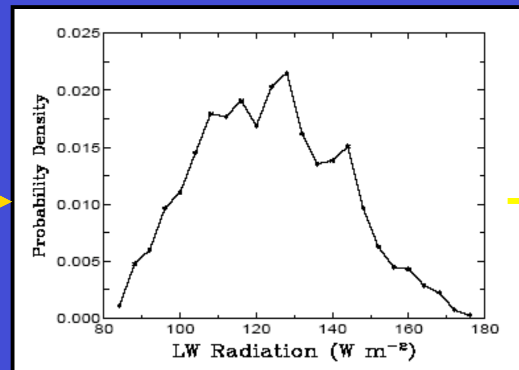
Why the cloud object approach?

1. Fully utilize the available satellite data at their highest possible resolution (i.e., not spatially and temporally averaged)
2. Identify individual cloud systems in many geographic regions for specific types (e.g., deep convection, BL clouds) by taking advantage of the global coverage of satellite data
3. Pinpoint deficiencies in cloud parameterizations for specific cloud types by examining cloud physical properties for an ensemble of cloud systems
4. Improve cloud-resolving models used in the multi-scale modeling framework (MMF) approach and cloud parameterizations with the “single column” approach by matching satellite data with atmospheric state and forcing

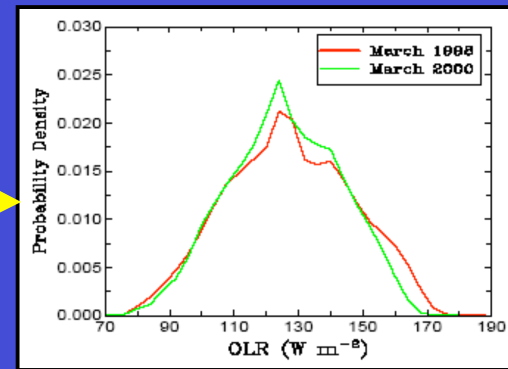
Steps of cloud object analysis



Cloud Object



Single PDF



Combined PDF

Statistical analyses of satellite cloud object data from CERES.

- Part I: Methodology and preliminary results of the 1998 El Niño/2000 La Niña (Xu *et al.* 2005; *J. Climate*)
- Part II: Tropical convective cloud objects during 1998 El Niño and evidence for supporting the fixed anvil temperature hypothesis (Xu *et al.* 2007; *J. Climate*)
- Part III: Comparison with cloud-resolving model simulations of tropical convective clouds (Luo *et al.* 2007; *J. Atmos. Sci.*)
- Part IV: Boundary-layer cloud objects during 1998 El Niño (Xu *et al.* 2008; *J. Climate*, in press)
- Part V: Relationships between physical properties of boundary-layer clouds (Eitzen *et al.* 2008; *J. Climate*, submitted)

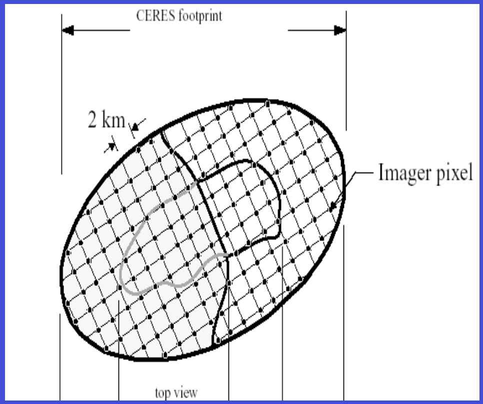
Data sources

- NASA Earth Observing System (EOS) satellites: TRMM, Terra and Aqua

- CERES (Clouds and the Earth's Radiant Energy System) project's Single Scanner Footprint (SSF; Level-2) data product (180 GB/month)
- January - August 1998 & March 2000 TRMM/CERES (40 ºS - 40 ºN)
- ECMWF analyses (EOA, 0.5625ºx0.5625º grids)
- ECMWF Re-Analysis (ERA-40, 1.125ºx1.125º)
- Website for cloud object database:
    - http://cloud-object.larc.nasa.gov/

European Center for Medium-range Weather Forecasts

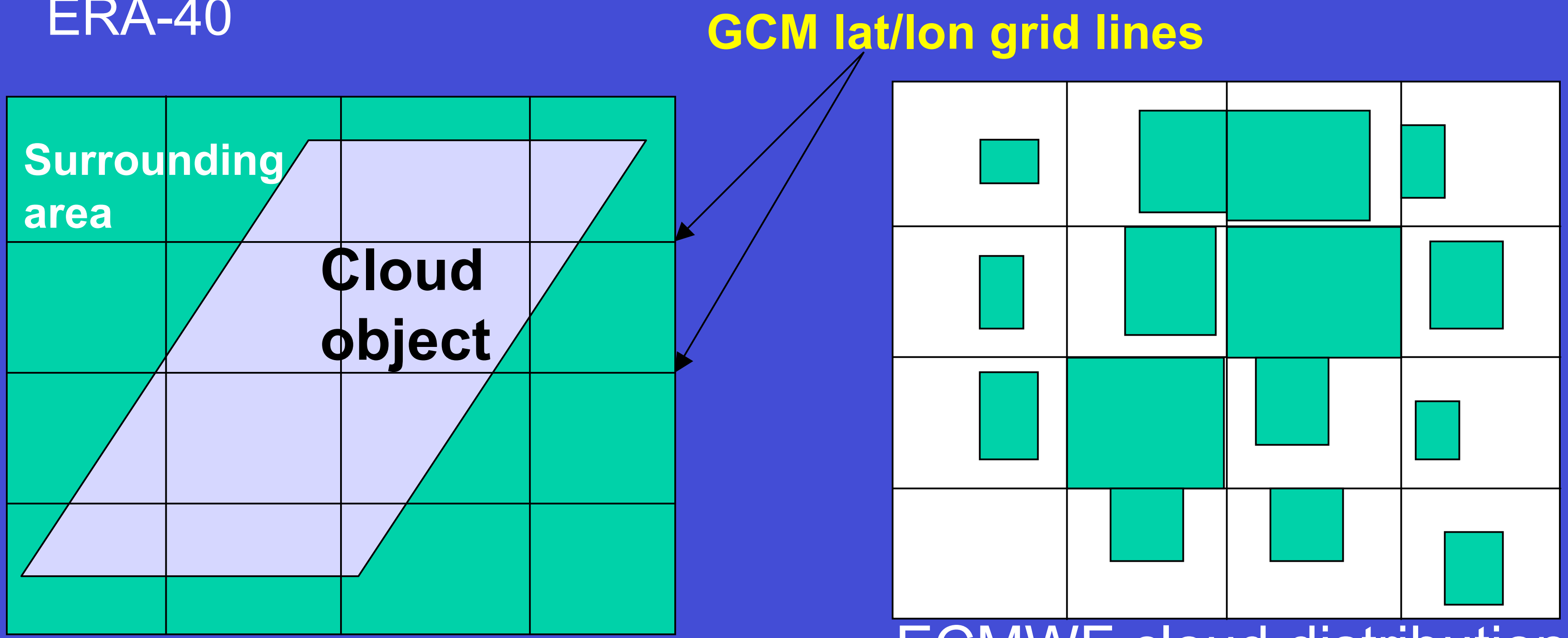
What are available in the cloud-object database?



- Footprint data for individual cloud objects
- Normal statistics such as min, max, median & skewness
- Histogram data for individual cloud objects
- Cloud and radiative properties:
  - cloud fraction, effective cloud height, pressure, radiative temperature;
  - cloud LWP, ice water path, droplet radius, ice particle diameter;
  - cloud visible optical depth, infrared emissivity;
  - TOA albedo, reflected SW flux, outgoing LW radiative flux
- ECMWF (3 x 6-hourly data matched with each cloud object)
  - 3-D P, T, Q_v, Q_c, Q_i, u, v, w; LS advective tendencies, cloud fraction
  - 2-D parameters such as surface albedo, soil wetness and SST
- http://cloud-object.larc.nasa.gov/

Methodology: Matching with ECMWF grids

- Spatially, draw a rectangular area covering the four outermost footprints (corners) of a cloud object
- Temporally, match within 3 h because ECMWF data are available every 6 h
- Grid sizes: 0.5625° x 0.5625° for ECMWF OA, 1.125° x 1.125° for ERA-40

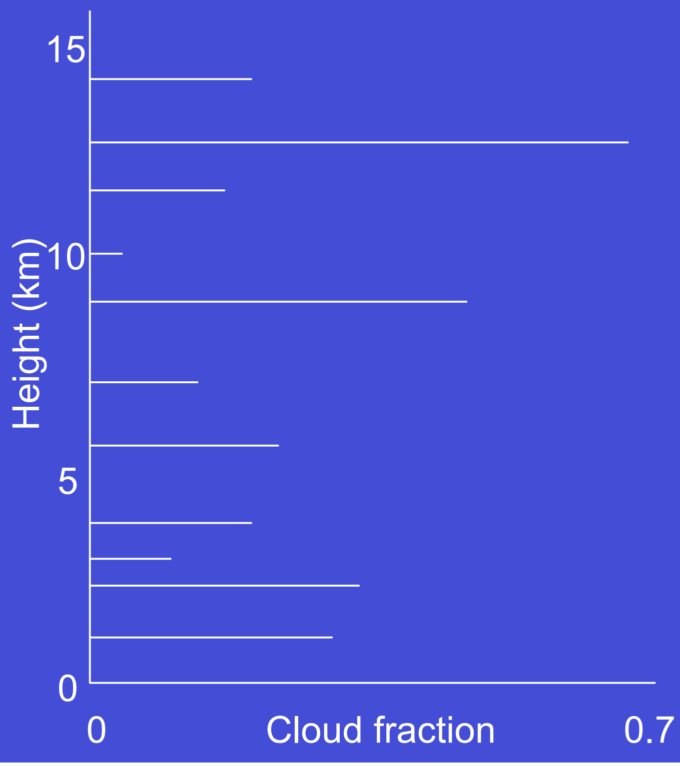


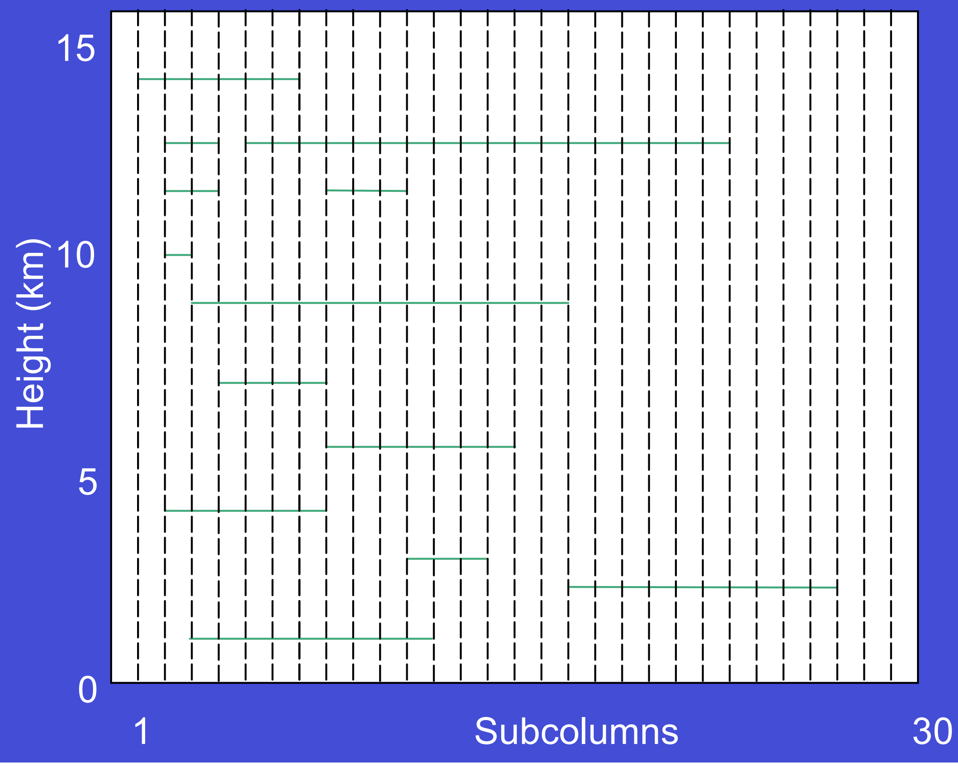
ECMWF cloud distribution

Methodology:

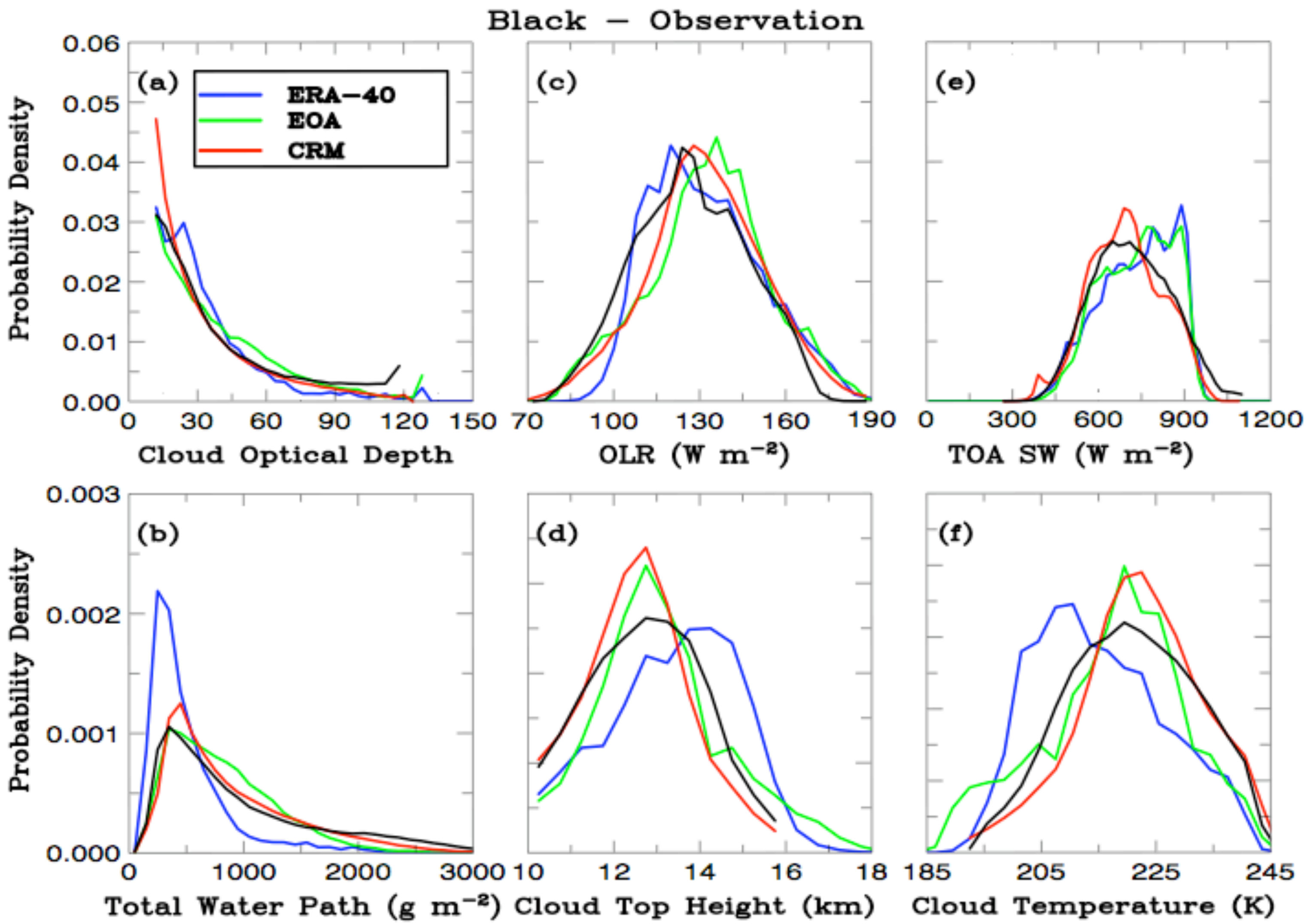
Converting ECMWF predicted cloud fields to satellite observations

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 & z >10 km) and construct pdfs

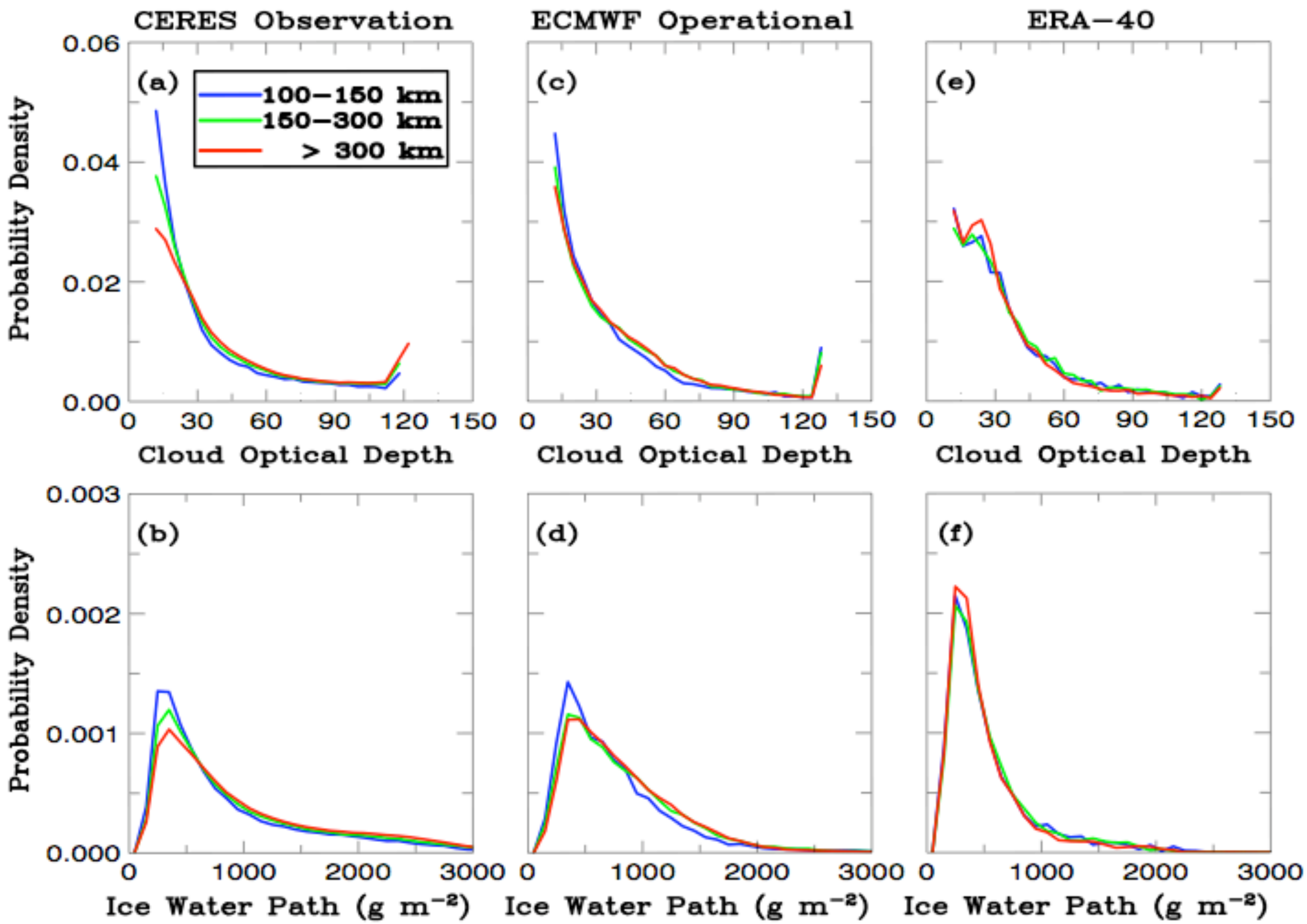




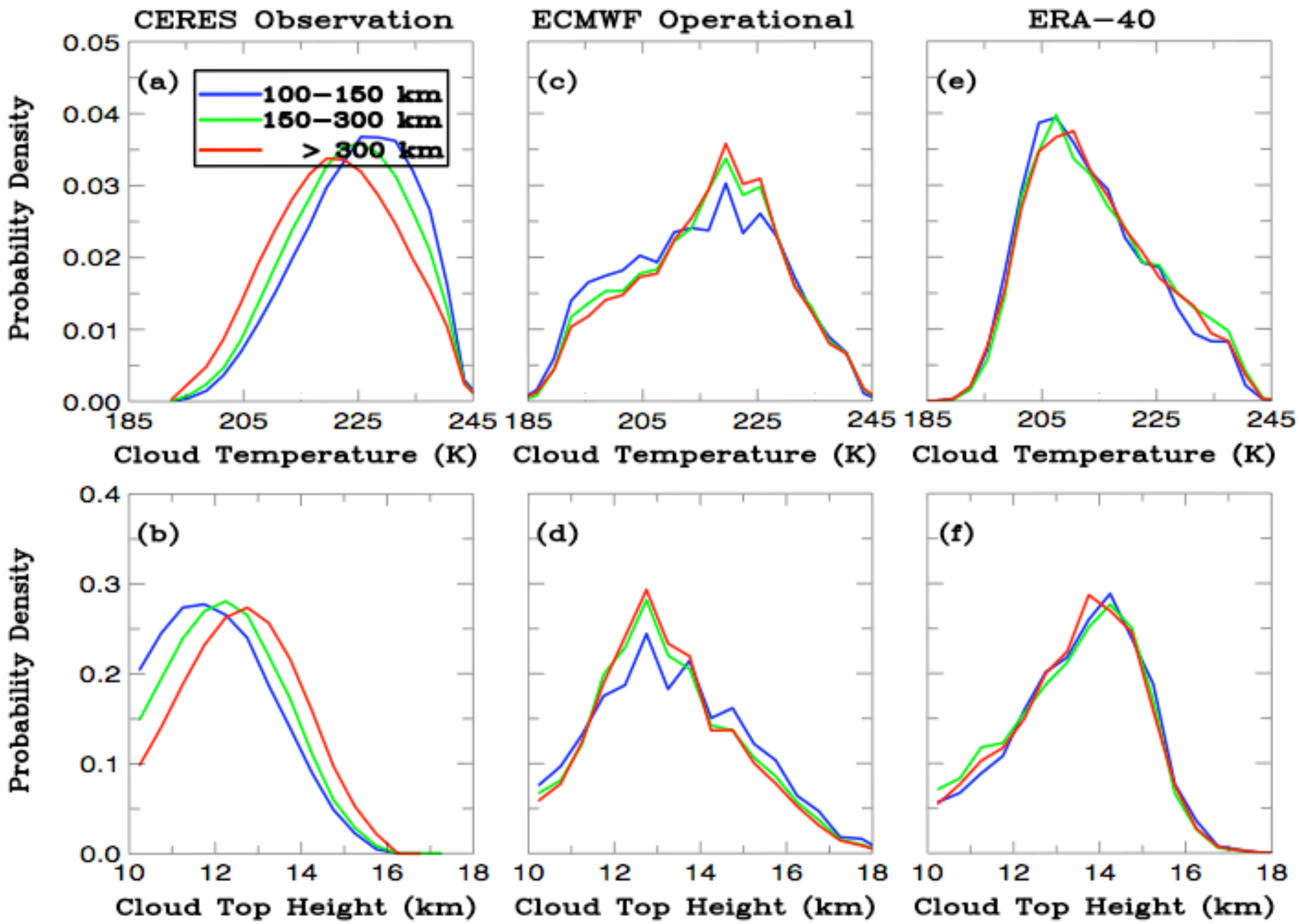
Cloud and radiative properties for March 1998



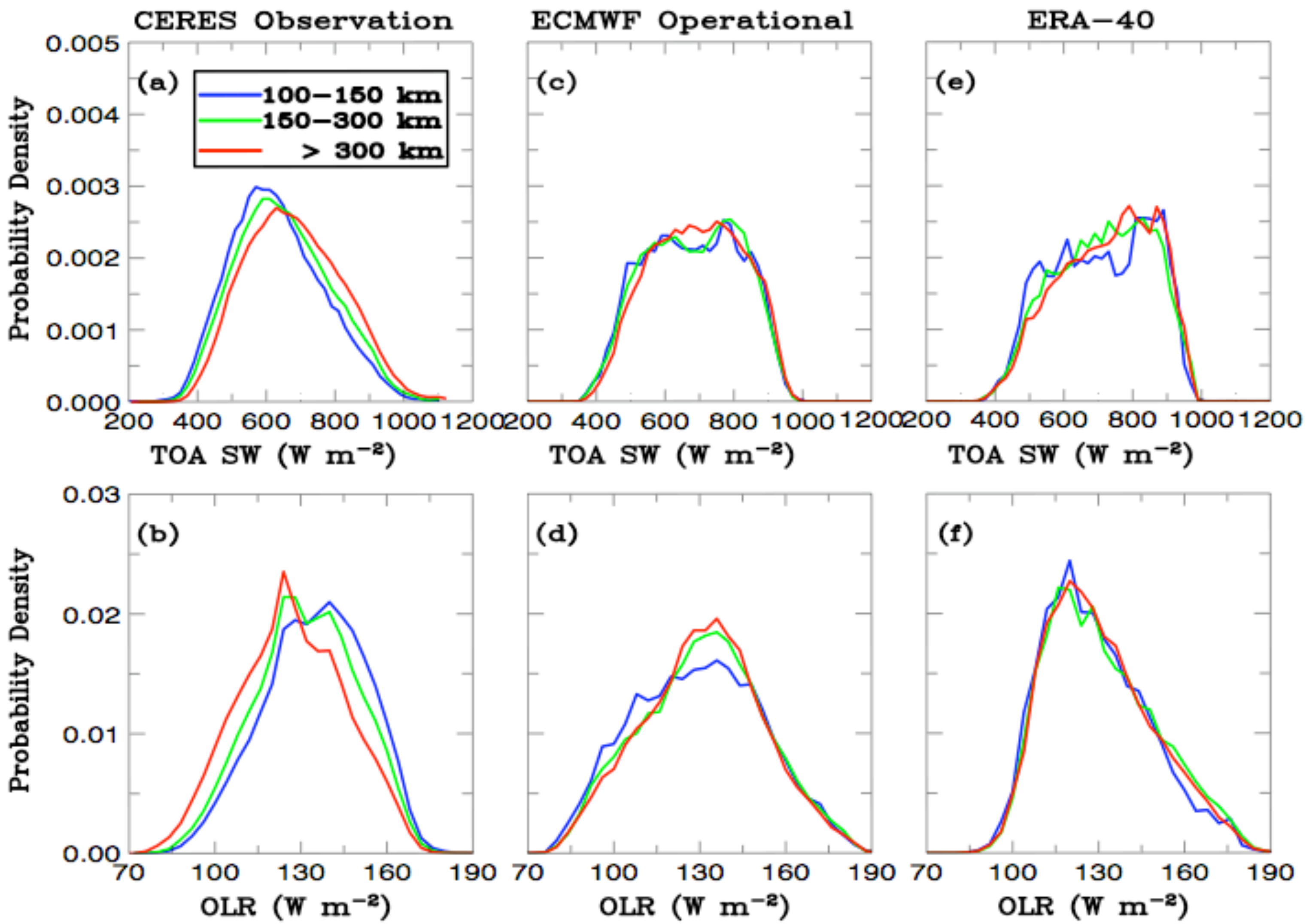
Cloud/radiative properties, Jan-Aug 1998; 1



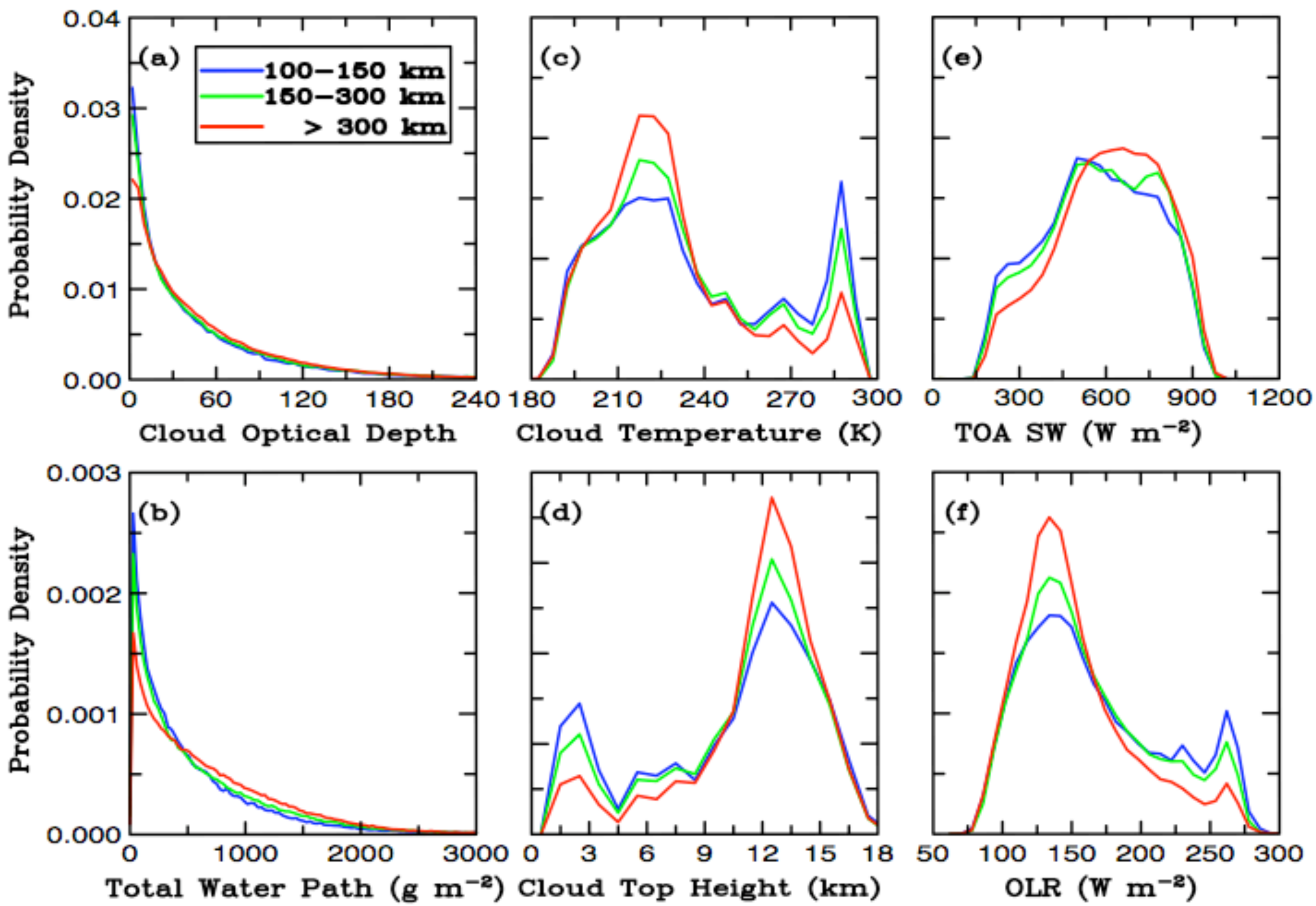
Cloud/radiative properties, Jan-Aug 1998; 2



Cloud/radiative properties, Jan-Aug 1998; 3



All cloud types from EOA, Jan-Aug 1998



Conclusions

- The new evaluation approach allows direct comparisons of NWP model-forecasted cloud physical properties with satellite cloud object observations
- The ECMWF operational analysis (before Sept. 1999) produced more realistic distributions of cloud physical properties than the ERA-40 (except for OLR), due to reduction in ice water content resulted from changes in cloud parameterization
- The dependency of “deep convective” cloud physical properties on cloud object size is weak in both EOA and ERA-40, but this dependency is pronounced in “all cloud” type, which is also pronounced in the large-scale vertical velocity
- Further improvement to ECMWF cloud parameterization includes allowing large variations in the altitude of convective detrainment level with cloud object size, further reducing cloud top heights and increasing the ice water content