Evaluation of Cloud Physical Properties of ECMWF Re-analyses against CERES Tropical Deep Convective Cloud Object Observations (ERA-40 vs. ERA Interim)

Kuan-Man Xu, Takmeng Wong, Shengtao Dong*, Zachary Eitzen* and Fei Chen*

Science Directorate

NASA Langley Research Center

Hampton, VA, USA

*SSAI, Hampton, VA, USA

Objective

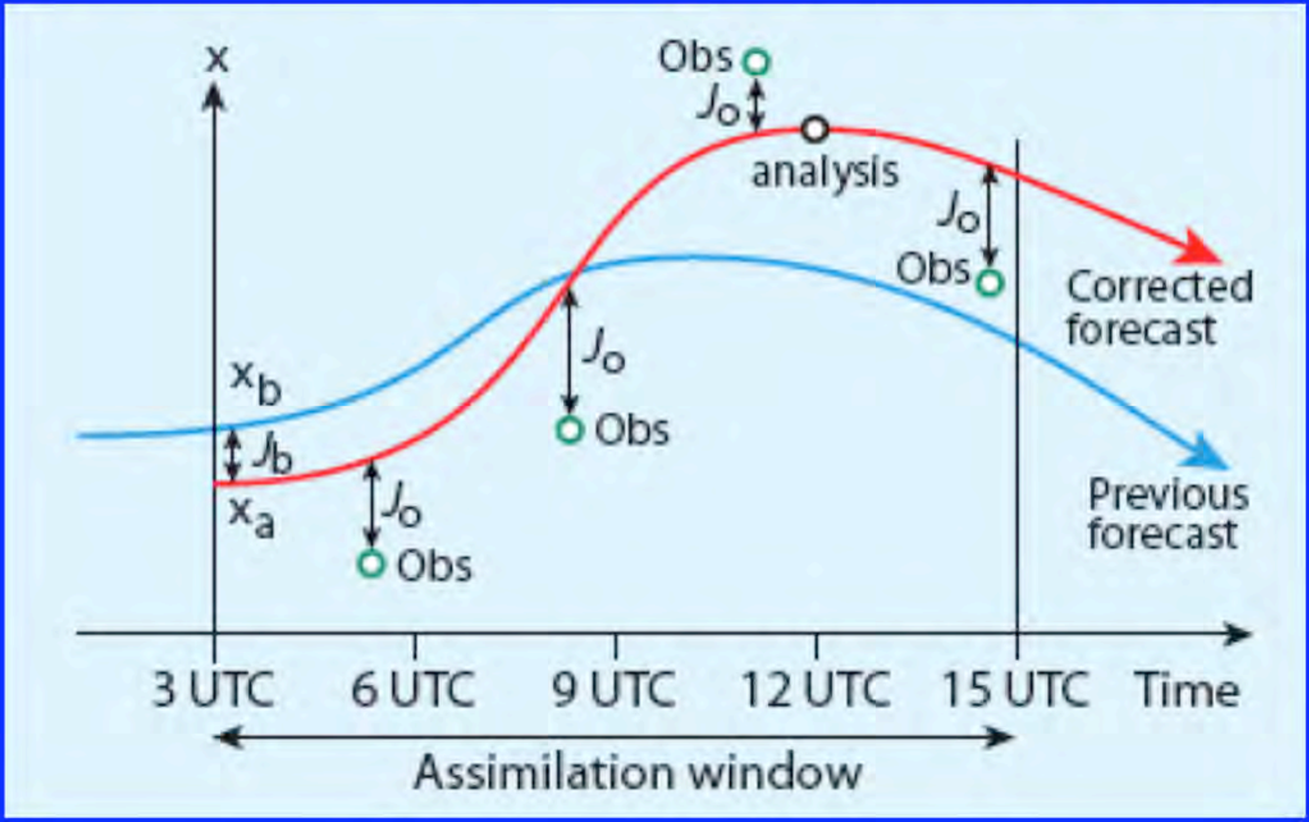
How well does the ECMWF model reproduce the observed cloud physical and radiative properties of tropical deep convective systems with its re-analysis products?

ERA 40 vs. ERA Interim

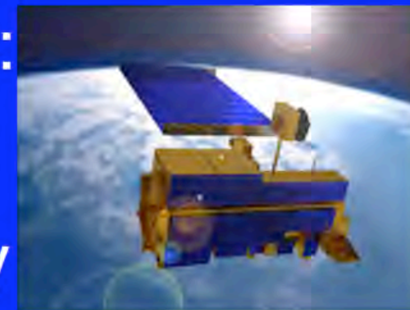
	ERA-40		ERA Interim	
Horizontal grid	1.125º x 1.125º		1.5º x 1.5º	
Vertical layer	35 layers for p >100 hPa	model native	27 layers for p >100 hPa	standard pressure
Full-resolution data	T159L60 (120x120km^2)		T255L60 (80x80km^2)	
Data assimilation technique	3-D variational analysis (6 h window)		4-D variational analysis (12 h window)	
Time period	1957 - 2002		1989 - present	
Known problems in global average data	Excessive precipitation and precipitable water		TBD (locally???)	
Model version	June 2001 (Cy21r4)		Sept. 2006 (Cy29r1)	

An explanation for 4-D Var

- 4-D Var performs a statistical interpolation in space and time between a distribution of meteorological observations and *a priori* estimate of the model state (the background)
- 3-D Var: same as in 4-D Var except not marching in time



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 TRMM CERES (40 ºS - 40 ºN)
- ECMWF re-analysis (ERA-40, 1.125ºx1.125º)
- ECMWF re-analysis (ERA Interim, 1.5ºx1.5º)
- Website for cloud object database:
    - http://cloud-object.larc.nasa.gov/

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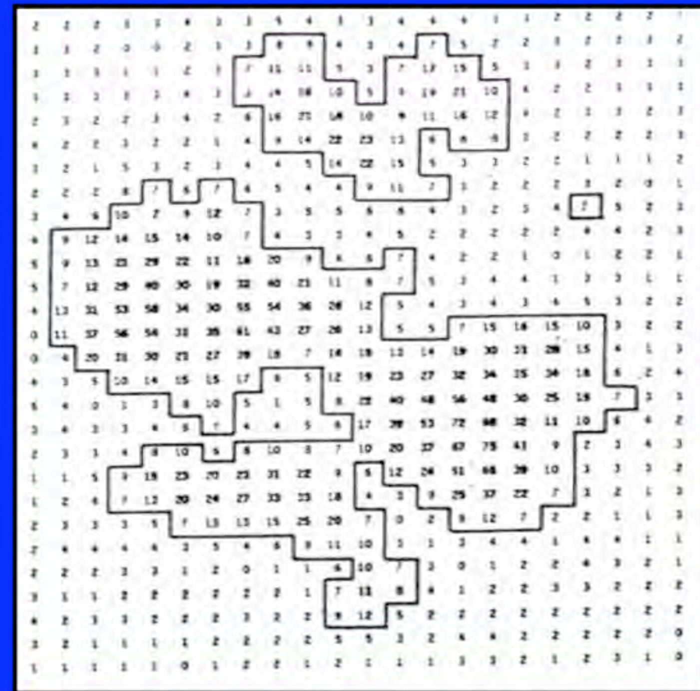
What is a cloud object?

(Xu et al. 2005, 2007, 2008)



- A contiguous patch of cloudy regions with a single dominant cloud-system type; no mixture of different cloud-system types
- The shape and size of a cloud object is determined by
  - the satellite footprint data
  - the footprint selection criteria
- For example, selection criteria for deep convective cloud objects:
  - Cloud optical thickness $\tau > 10$, and
  - Cloud top height $z_{top} > 10$ km, and
  - Overcast

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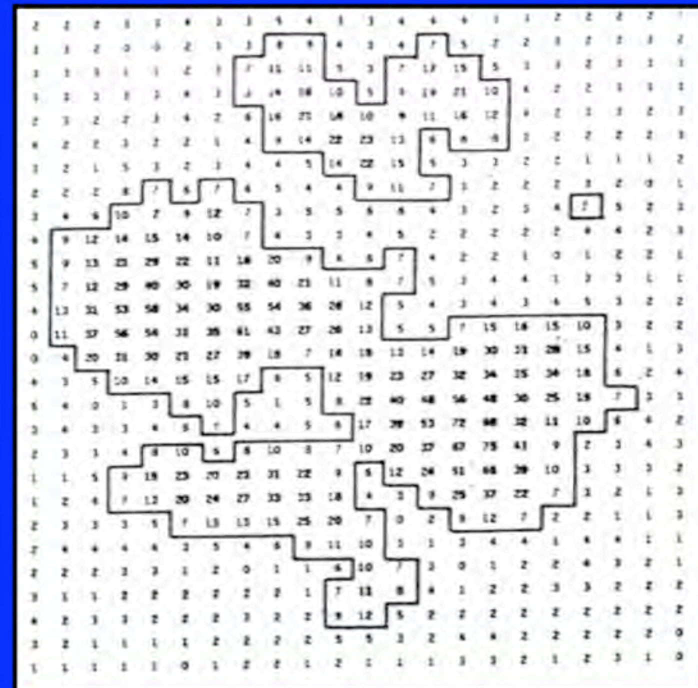
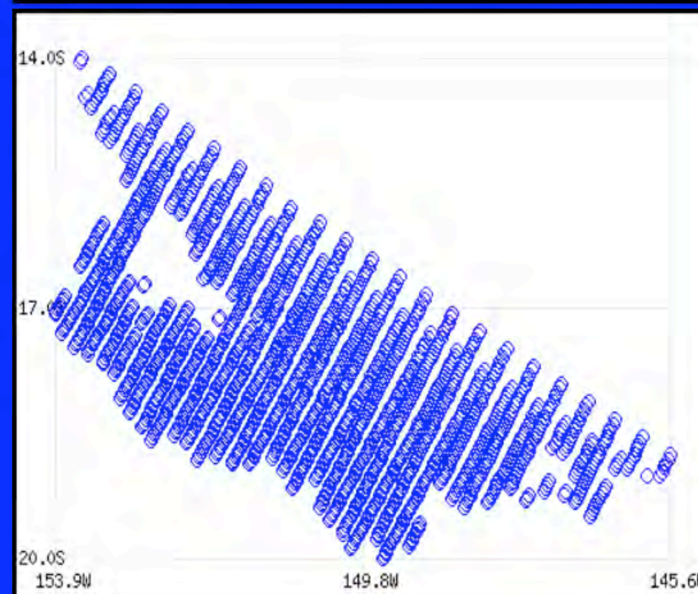
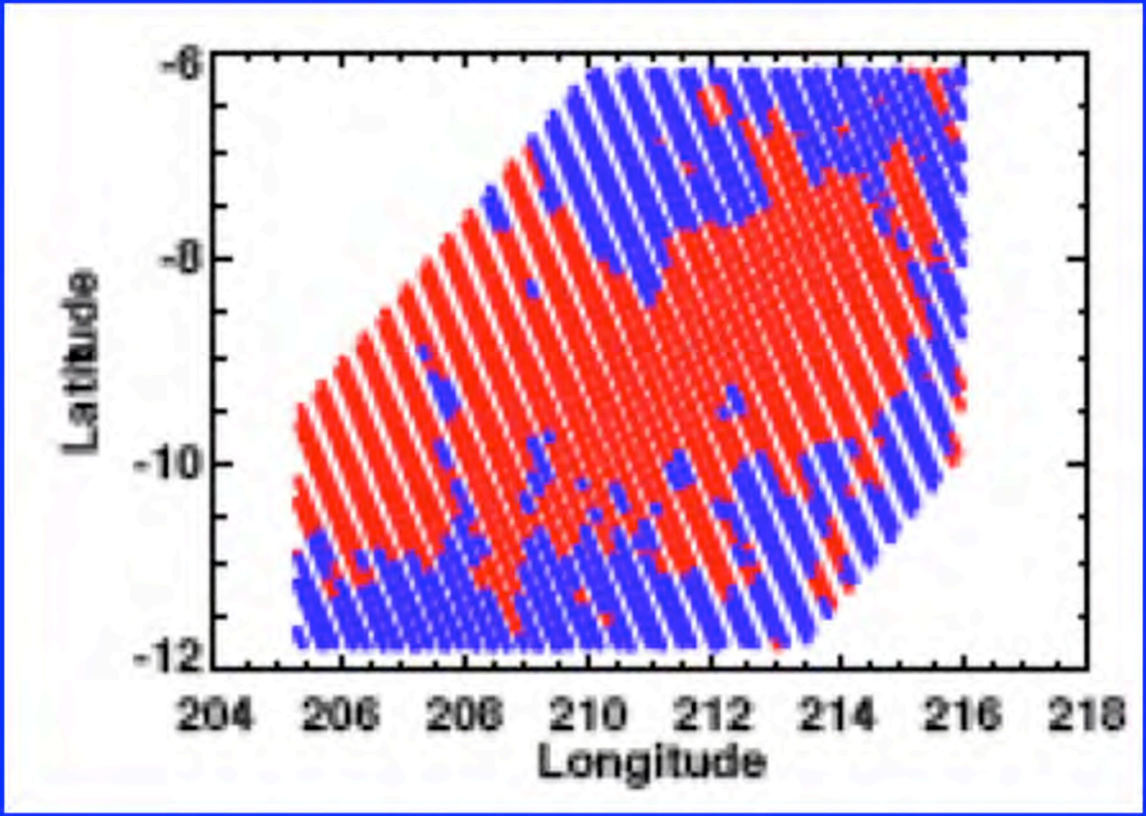




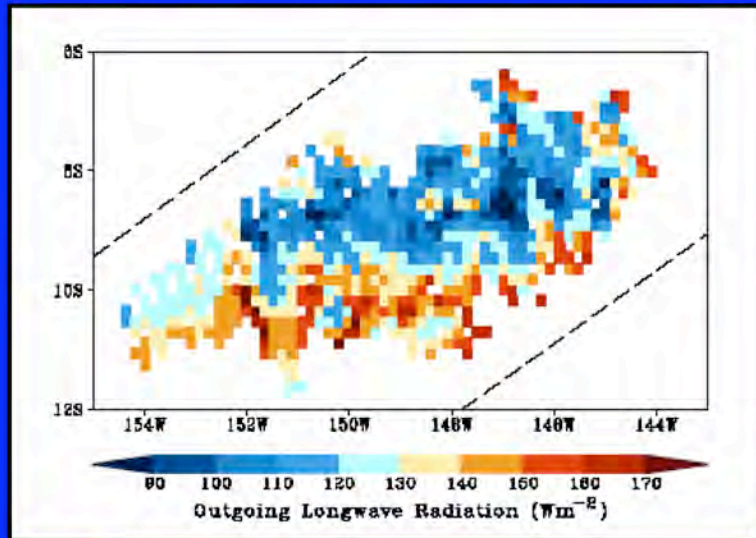
An "entire" cloud system

- Expanded or "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 together



Steps for cloud object analysis

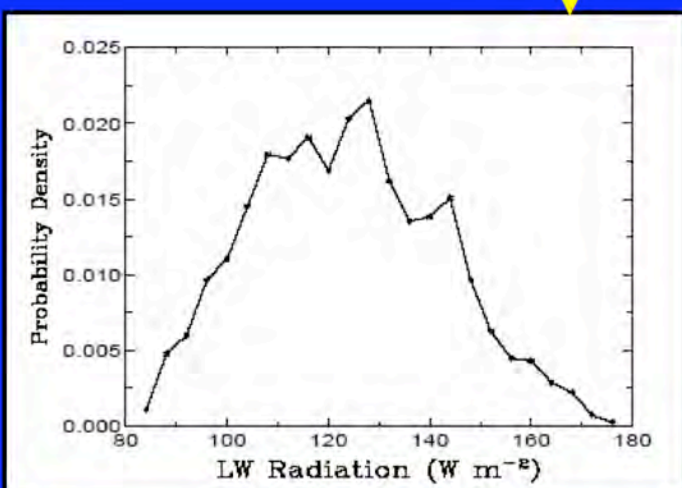
Satellite footprint data



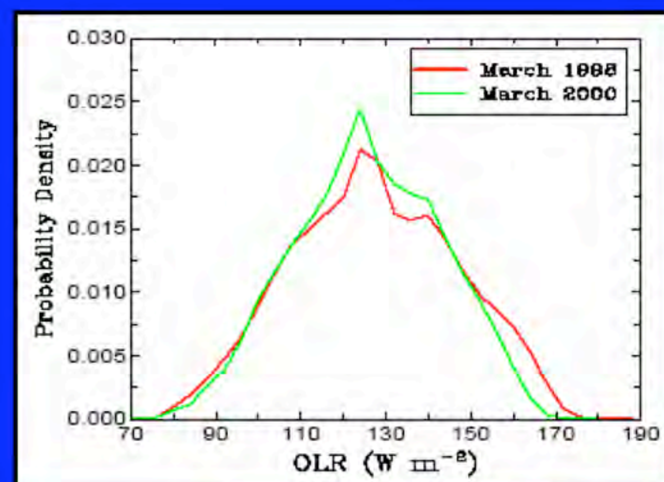
Cloud object

Atmospheric State data

Matching, Stratifying

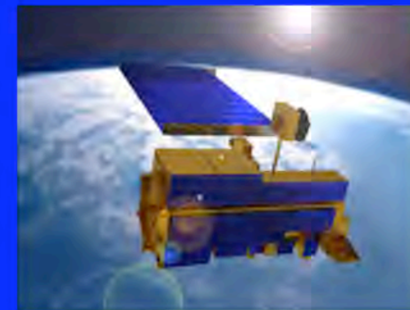


Single PDF



Combined PDF

Current status



- Re-processing all cloud objects by fixing an error on nadir viewing zenith angle, and expanding viewing zenith angles from 49º to 35º
- Finishing the January - August 1998 and March 2000 TRMM CERES tropical deep convective cloud objects
- Re-matching with ECMWF meteorological state data (operational, ERA-40 and ERA Interim)
- Statistical distributions of cloud and radiative properties are unchanged, but numbers of cloud objects for three size categories increase by 25%

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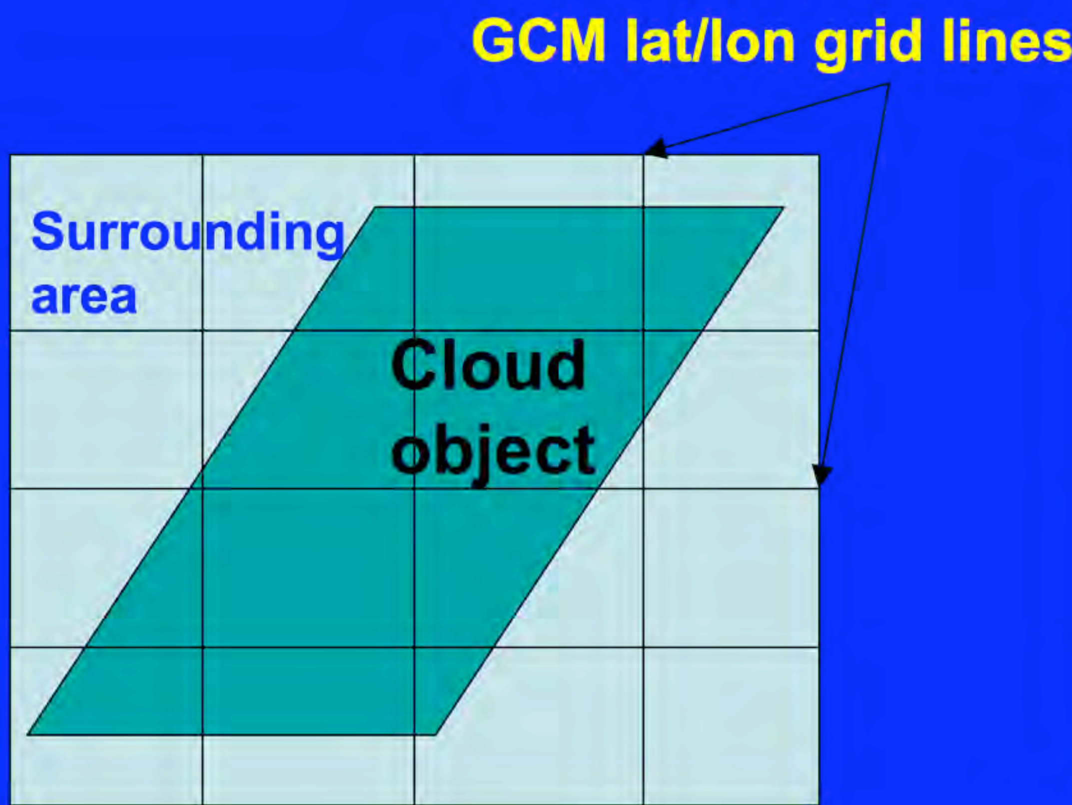
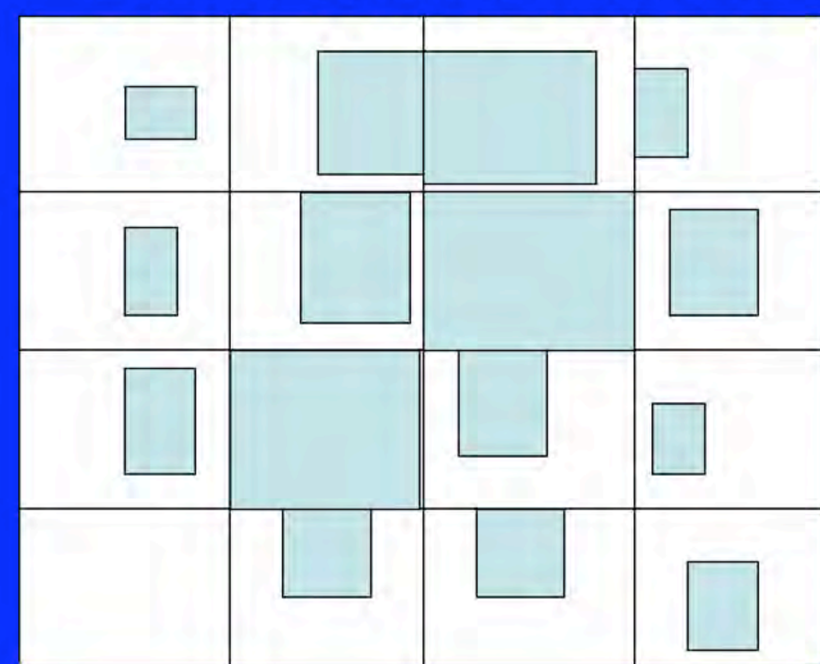
Compare ECMWF re-analyses with observations

1. How?
2. Preliminary results

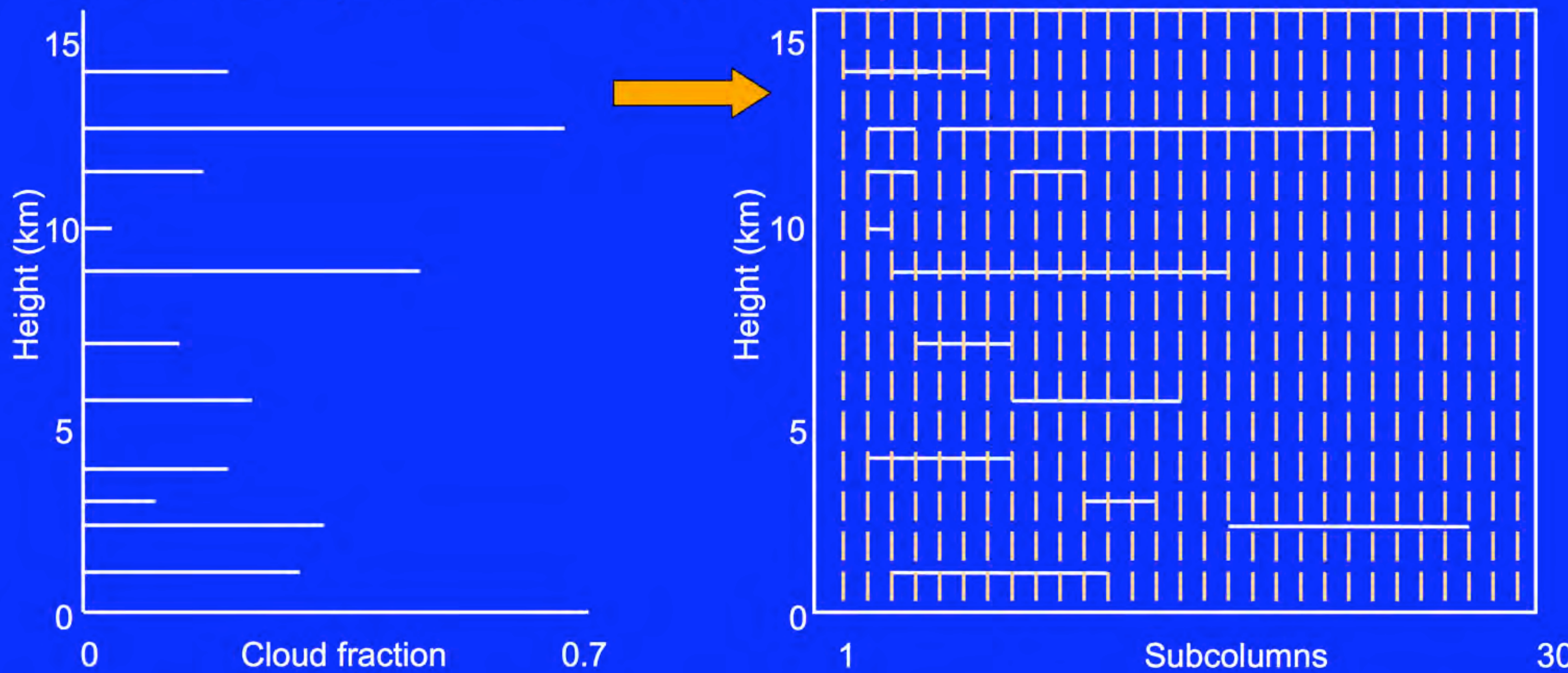


ECMWF cloud dstribution

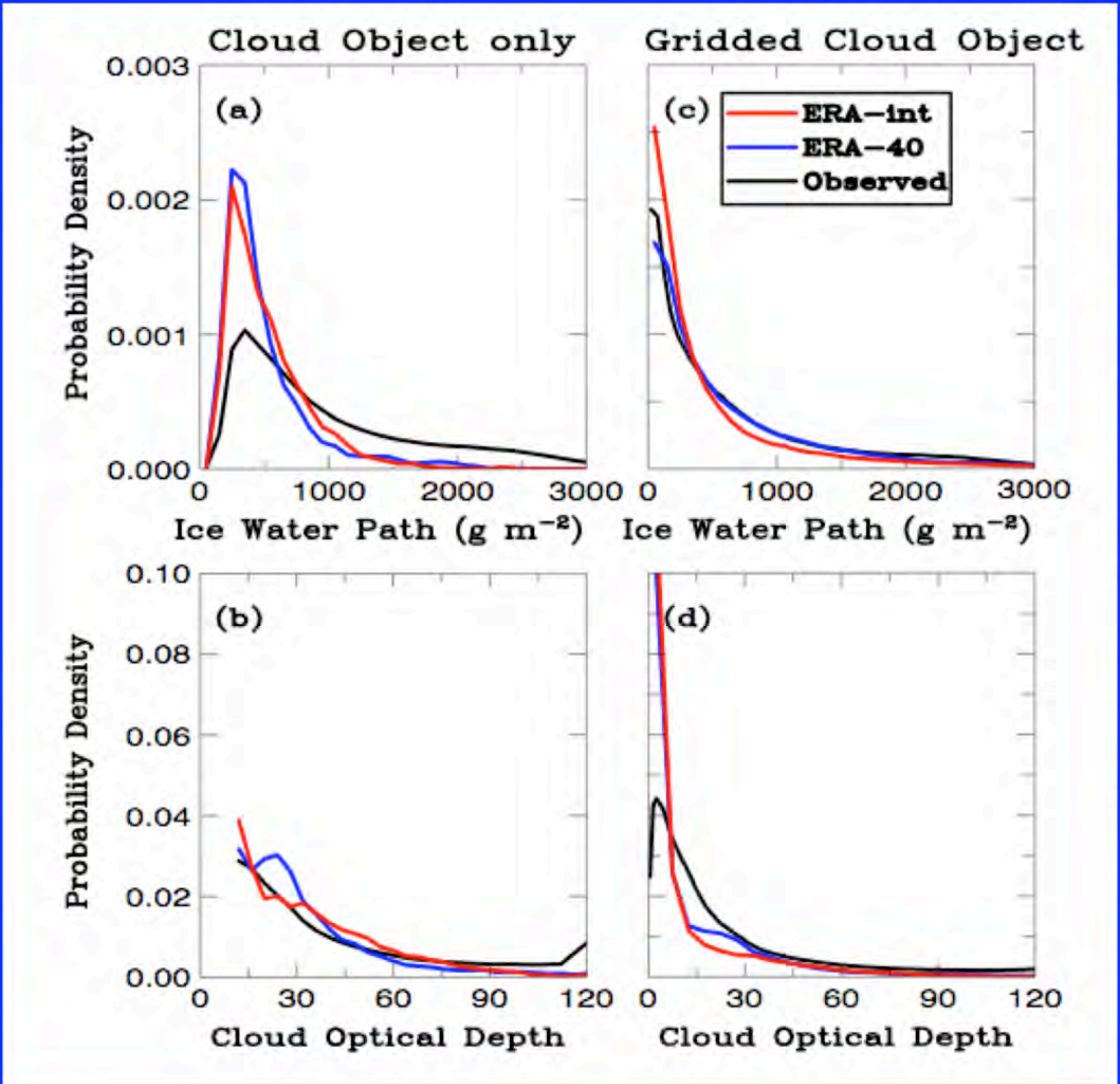


Converting ECMWF cloud fields to pdfs of subgrid-cell cloud physical properties (Xu 2008, *MWR*)

1. Match spatially and temporally with the observed, individual cloud objects
2. Divide each ERA-40/Interim grid into 120/213 subcolumns (~100 km^2, ftprt size)
3. Use cloud overlap assumption to construct cloud distribution in subcolumns from a predicted cloud fraction profile
4. Use the Fu-Liou radiation code to obtain cloud optical properties and radiative fluxes for each subcolumn; determine cloud height and temperature
5. Select "cloud object" subcolumns ($\tau > 10$ & $H_t > 10$ km) and construct pdfs



PDFs of IWP and τ



PDFs of ERA-40 and ERA Interim are rather similar to each other

But both have discrepancies from observations, especially in cloud-object IWP pdf and all-cloud τ pdf

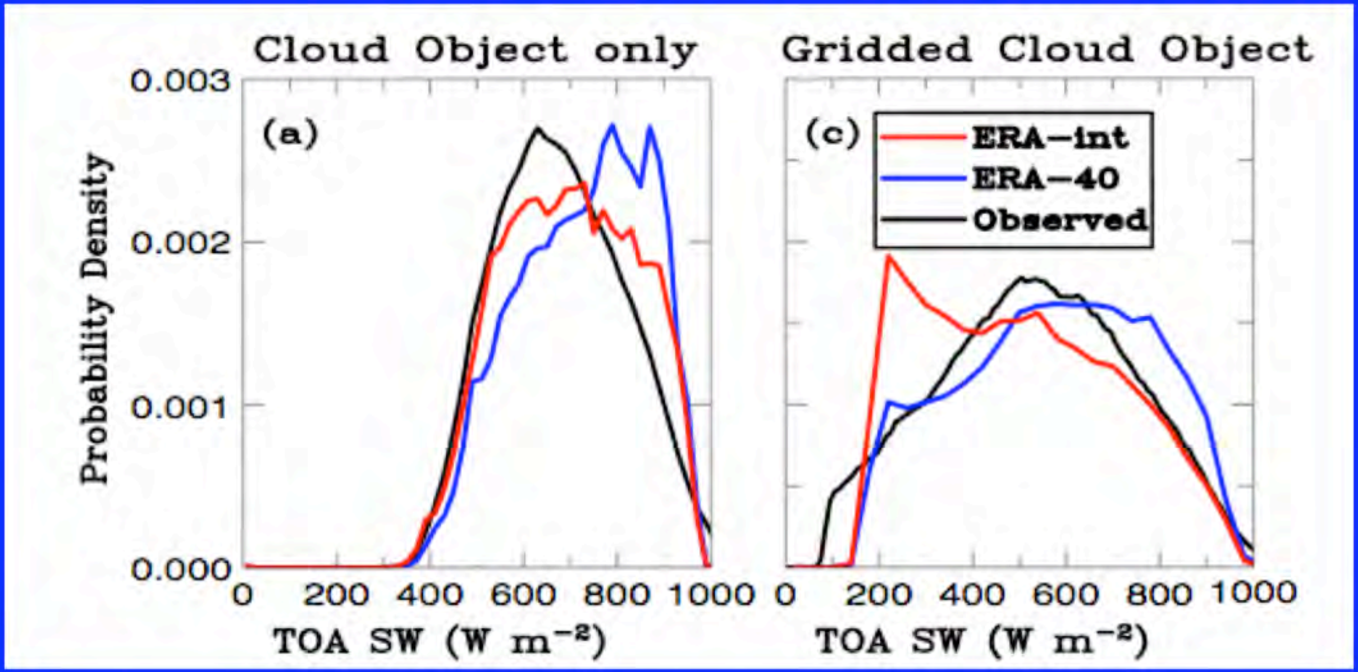
Small differences in pdfs lead to some significant differences in TOA SW pdfs (shown next)

Reasons for large discrepancies:

1) Lack of snow mixing ratio data in ERAs to calculate IWP (τ)

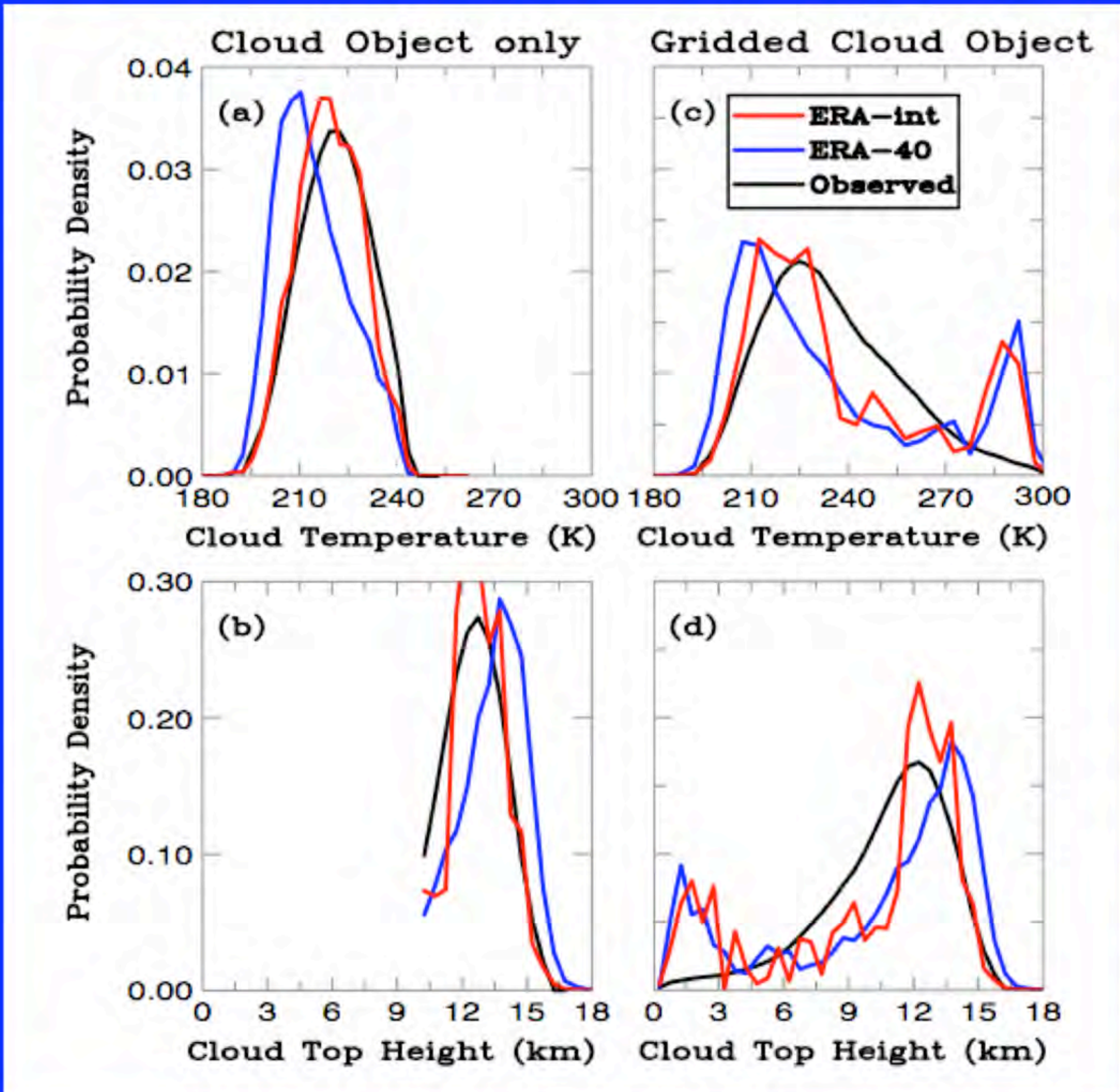
2) Lack of spatial variability in IWC within each model grid (1.125º ~ 1.5º grids in ERAs); e.g., the contribution from small-scale variabilities

PDFs of TOA SW radiative fluxes



- The ERA Interim agrees with cloud-object observations better than the ERA-40, but the opposite is true for "gridded" cloud objects (all-cloud)
- The differences in TOA SW between the two analyses are much greater than those in cloud optical depth; implying there may be differences in the vertical structure of cloud extinctions ($\tau/\Delta z$)
- The excessive non-DC (neighboring clouds with small τ) population in ERA Interim is responsible for the large peak around 200 W m^{-2}

PDFs of cloud-top temperature and height



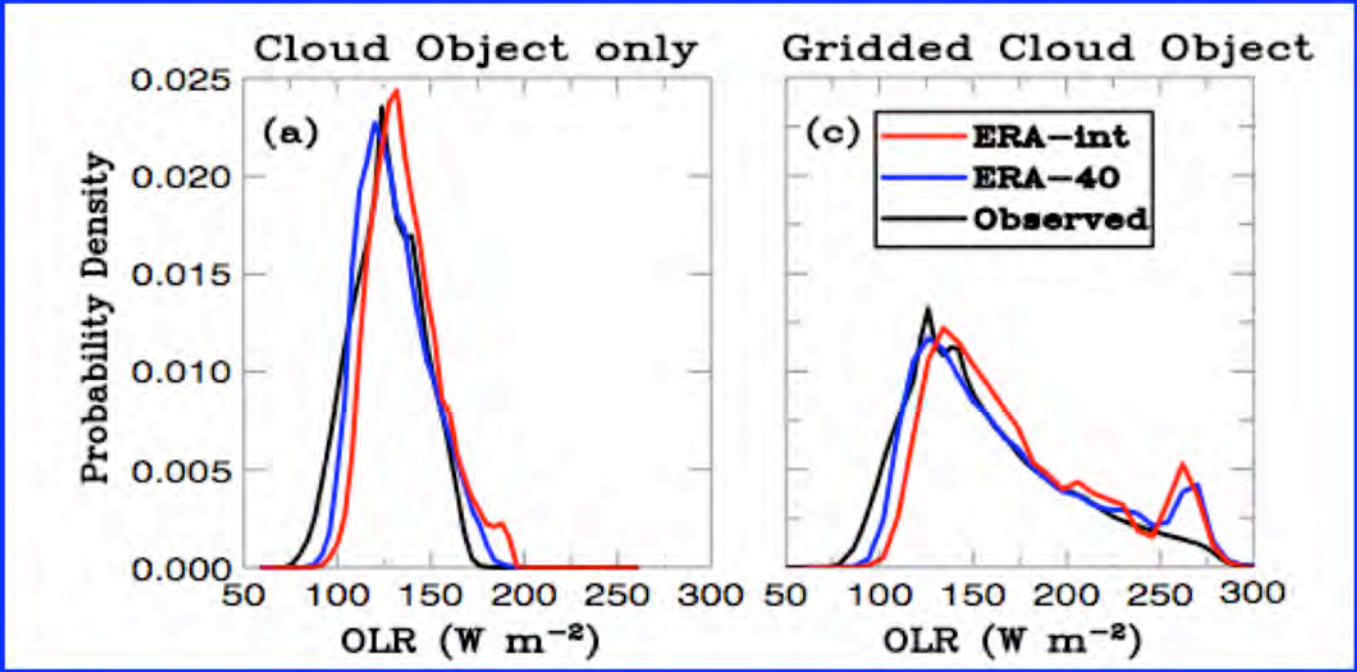
These two cloud macro-physical variables are directly linked to TOA LW radiation

ERA Interim captures the highest clouds (highest tops) rather well, compared to ERA-40, which overestimates these clouds, i.e., they are too close to the tropopause

Shallow clouds (0.2-3 km range) are estimated at the expense of mid-level clouds (5-11 km);

The binary feature (shallow or deep updrafts) of the Tiedtke cumulus parameterization is responsible for this

PDFs of TOA LW radiative fluxes



- The TOA LW radiative fluxes from ERA-40 seem to agree with observations better, despite of larger disagreement in cloud macrophysical properties noted earlier, compared to ERA Interim
- There are consistent overestimates of OLR by ERA Interim; suggesting underestimates of cloud emissivity above the diagnosed cloud top ($\tau = 1$)
- Overestimate of OLR around 270 W m^{-2} is due to overestimate of low-level clouds; but underestimate of mid-level clouds does not impact OLR pdfs

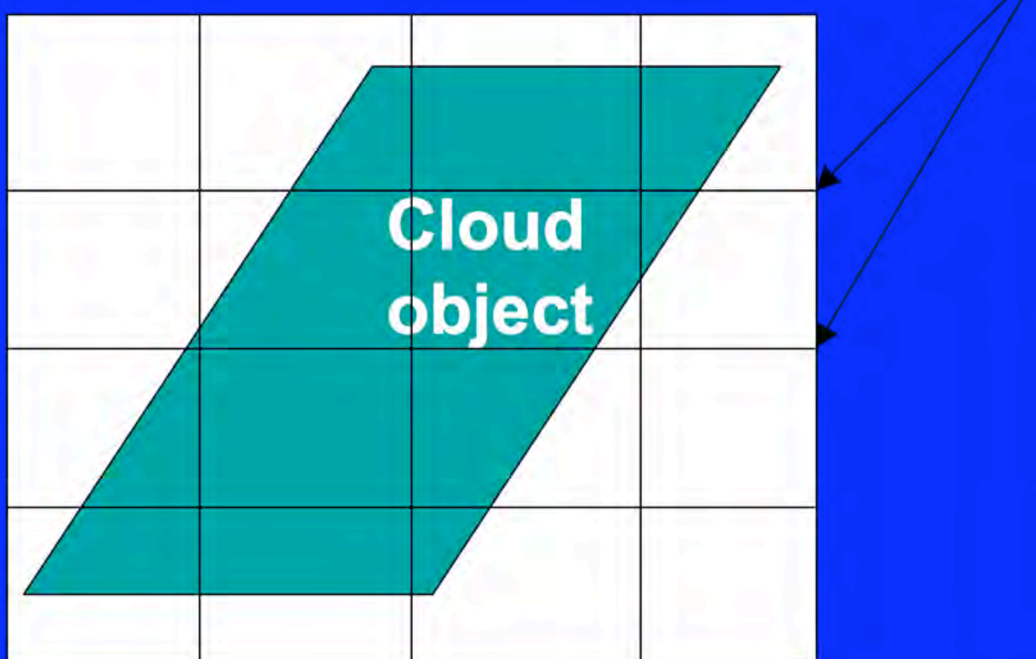
Summary and conclusions

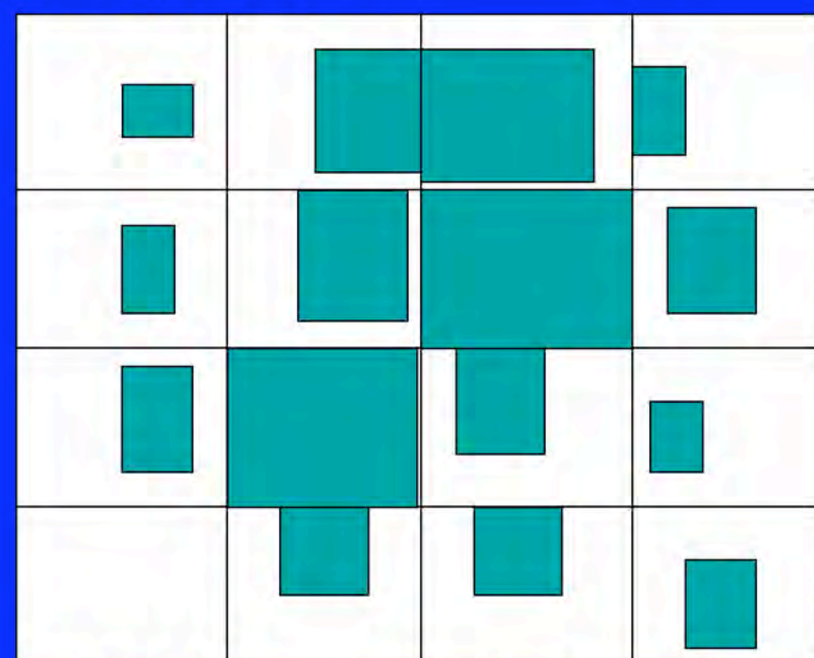
- The pdfs of cloud physical and radiative properties from ECMWF re-analyses are generally similar to those observed, with different strengths and weaknesses
- Strengths:
  - ERA Interim: cloud-object & all-cloud height and temperature & cloud-object SW
  - ERA-40: all-cloud SW, cloud-object and all-cloud OLR
- Weaknesses:
  - ERA Interim: underestimate of emissivity above identified cloud tops
  - ERA-40: cloud-object SW (too large cloud extinctions near tops)
  - Both: overestimate of low-level clouds and underestimate of midlevel clouds; underestimate of cloud-object IWP and all-cloud τ
- Full-resolution ERA Interim data to confirm the preliminary results

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: 1.5° x 1.5° for ERA Interim, 1.125° x 1.125° for ERA-40

GCM lat/lon grid lines





ECMWF grid-mesh cloud fraction

Evaluate cloud physical properties of ECMWF re-analysis 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.;* in press)