Evaluating parameterisations of subgrid-scale variability with satellite data

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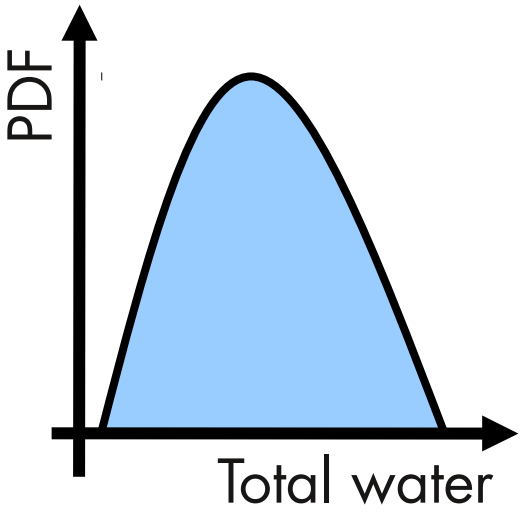
Acknowledgements
Vera **Schemann** and Verena **Grützun** (Max Planck Institute for Meteorology, Hamburg)
Torsten **Weber** (Climate Service Centre Hamburg)

Contents

- The Tompkins cloud scheme in the ECHAM5 GCM
- Evaluation of the moments of the total water path distribution
- Critical relative humidity as a simple metric for variability
- Evaluation with supersite observational data?
- Scale dependency of total-water variance

Prognostic subgrid-scale PDF of total water mixing ratio



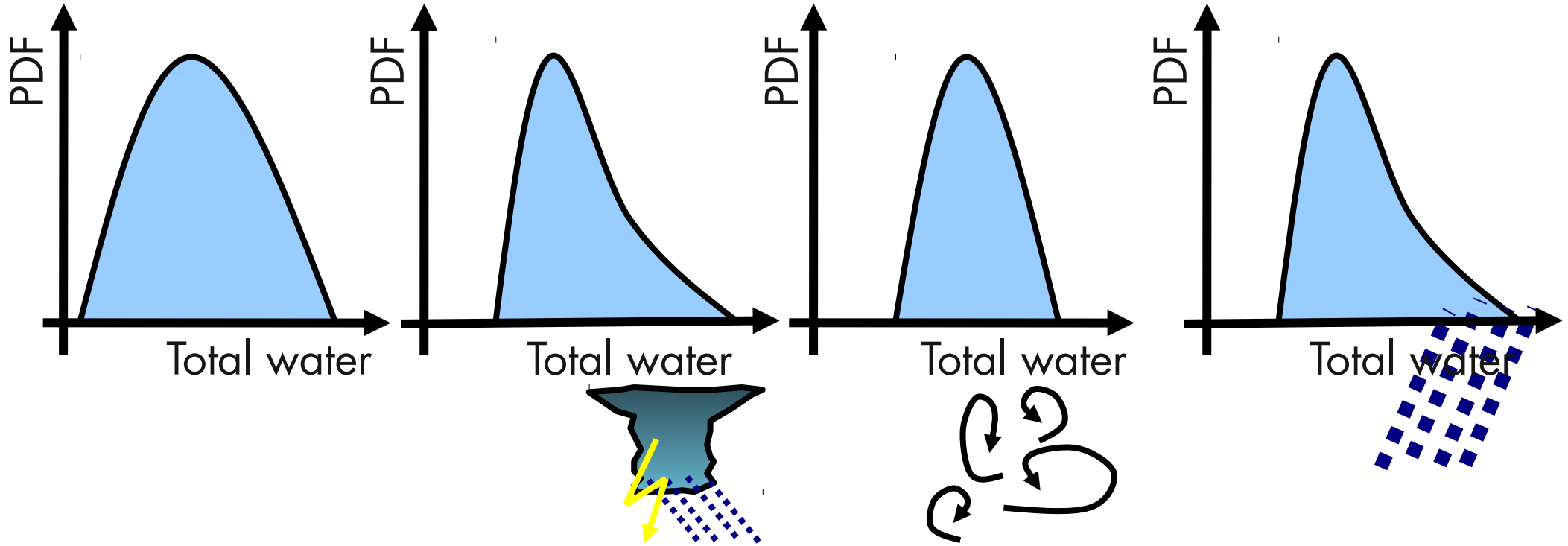
→ PDF of total water mixing ratio follows a β-function

→ prognostic equations for variance and skewness

→ model already includes equations for water vapour, cloud liquid- and ice water mixing ratio

→ symmetric or positively skewed distributions

Prognostic subgrid-scale PDF of total water mixing ratio



Deep convection generates skewness via detrainment

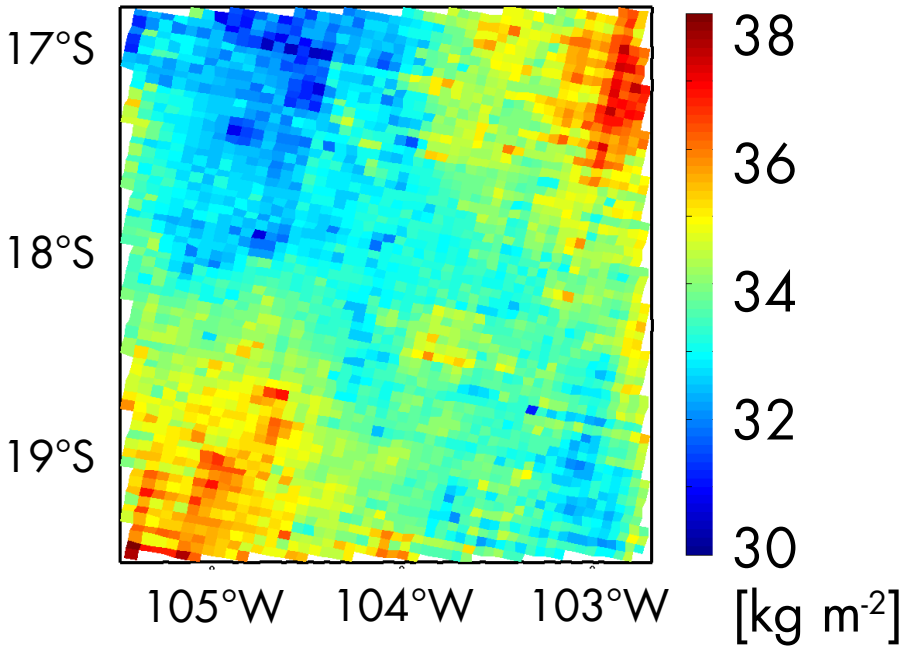
Turbulence dissipates variance

Precipitation reduces skewness

Evaluation of total water path variability

- Spatial PDF of *vertically integrated* total water path (TWP)
  (sum of precipitable water (spatially interpolated), liquid water path and ice water path)
- MODIS resolution: 5x5 km² ⇒ PDF at GCM resolution ~200x200 km²

MODIS TWP in Grid-Box



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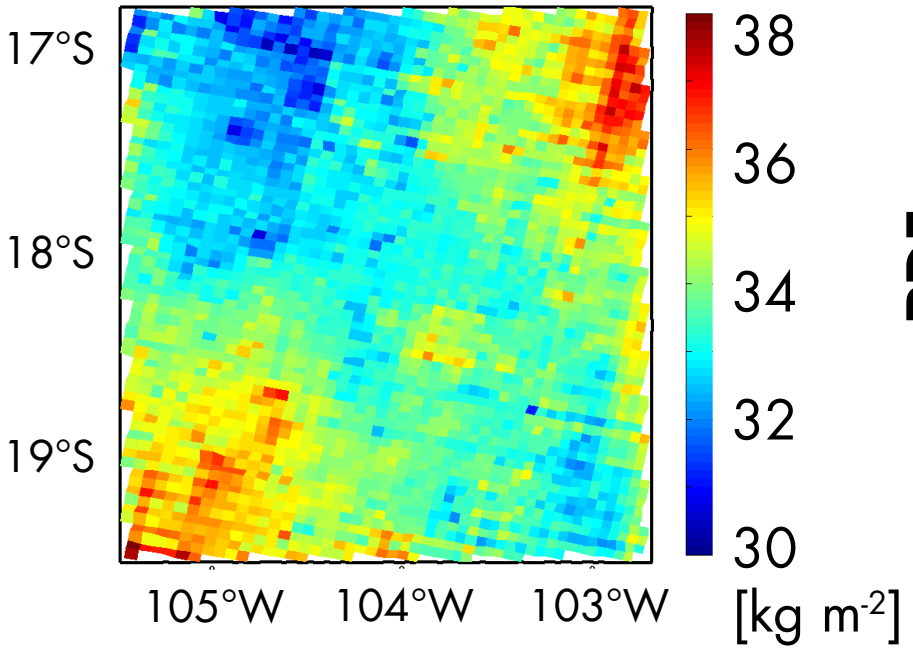
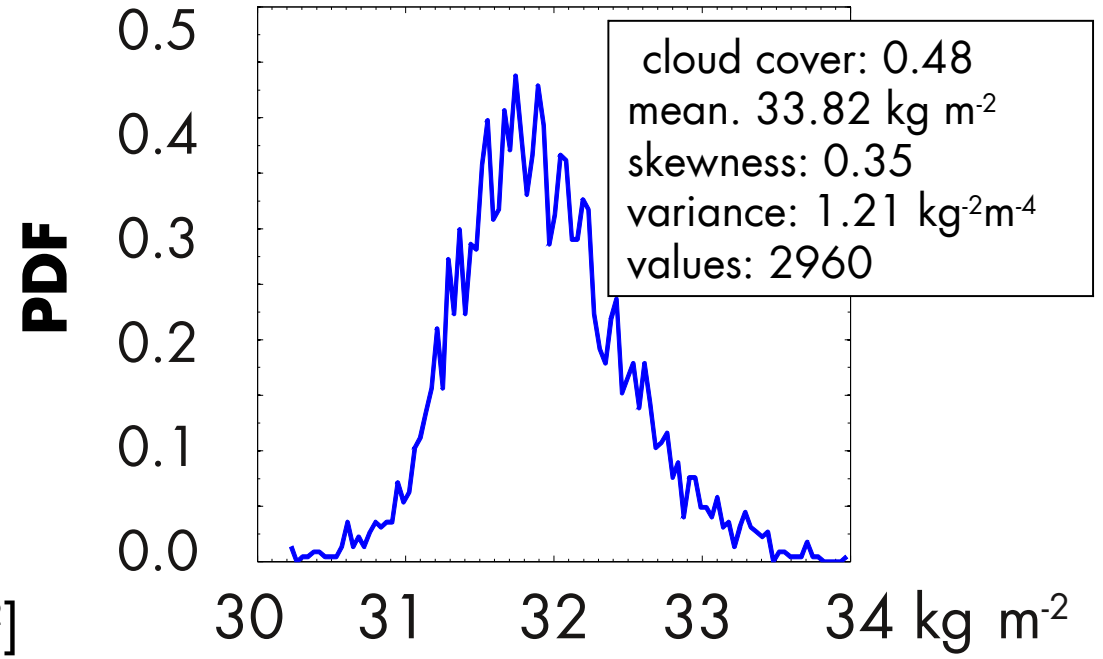
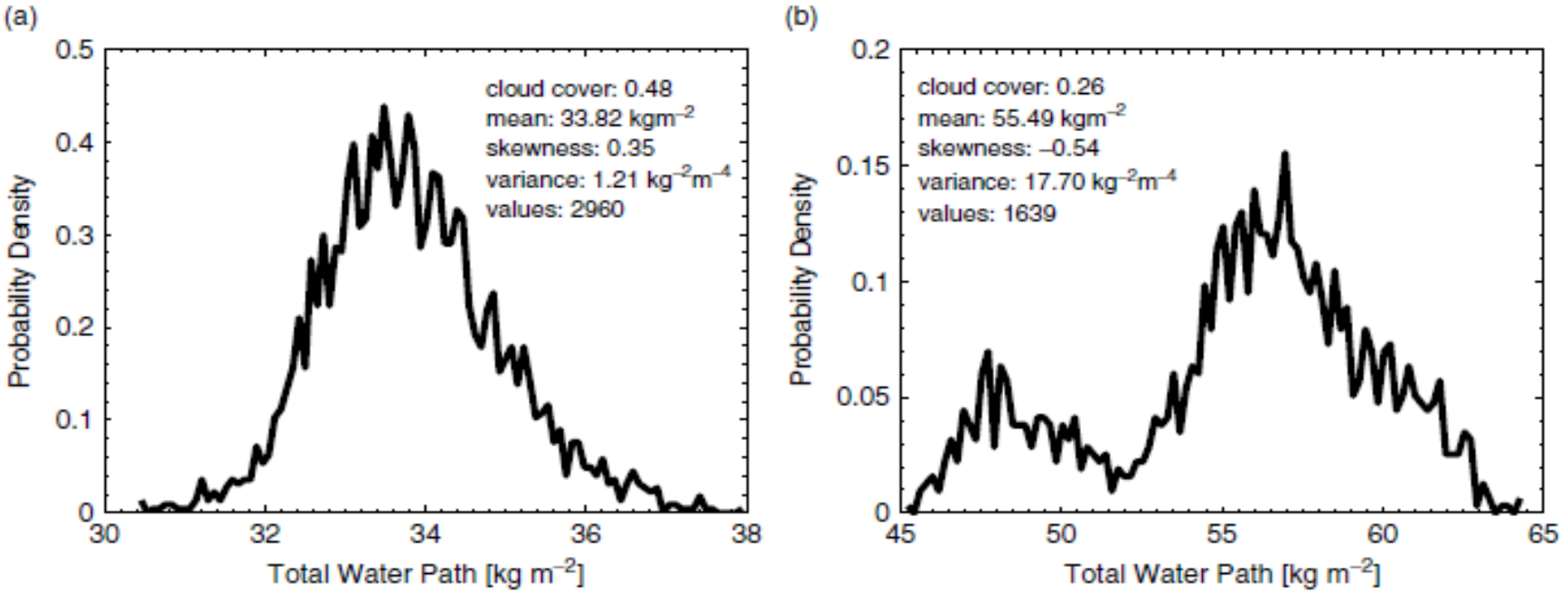
MODIS TWP in Grid-Box

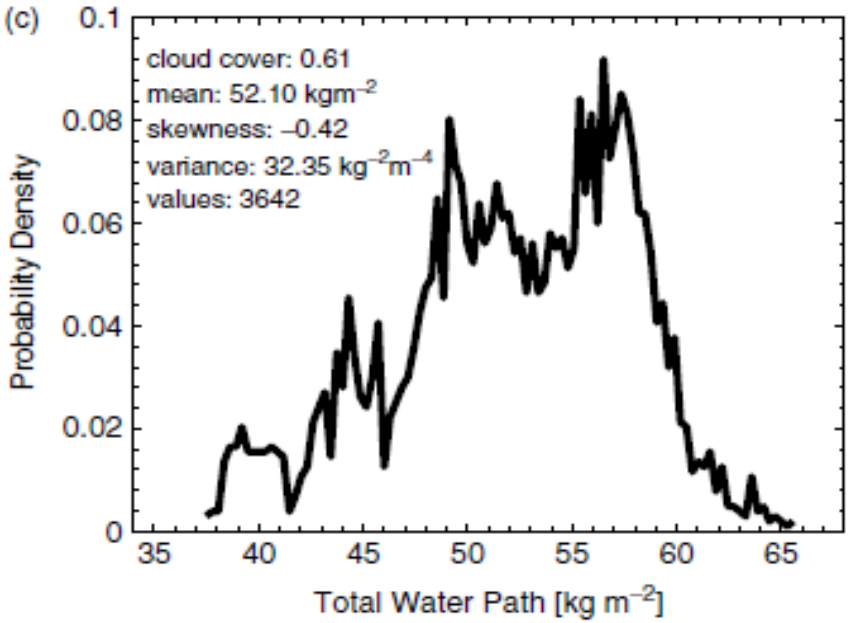


MODIS TWP statistics



Evaluation of total water path variability



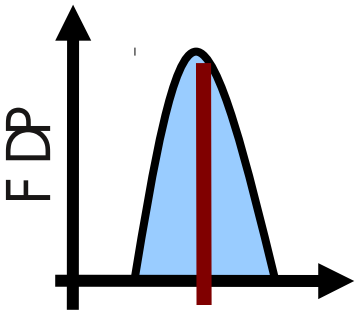


→ Randomly picked examples from individual grid-points

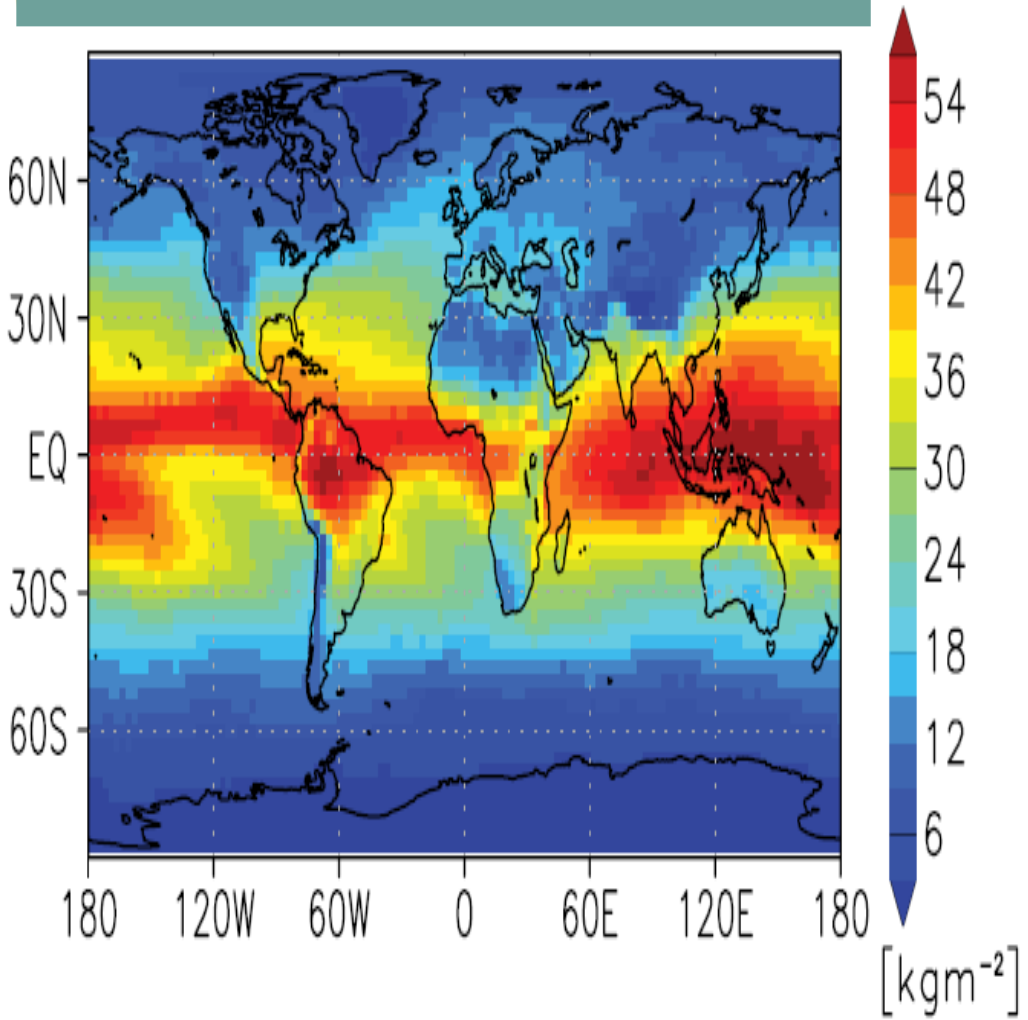
→ Diagnose skewness and variance from any shape

Evaluation of total water path variability

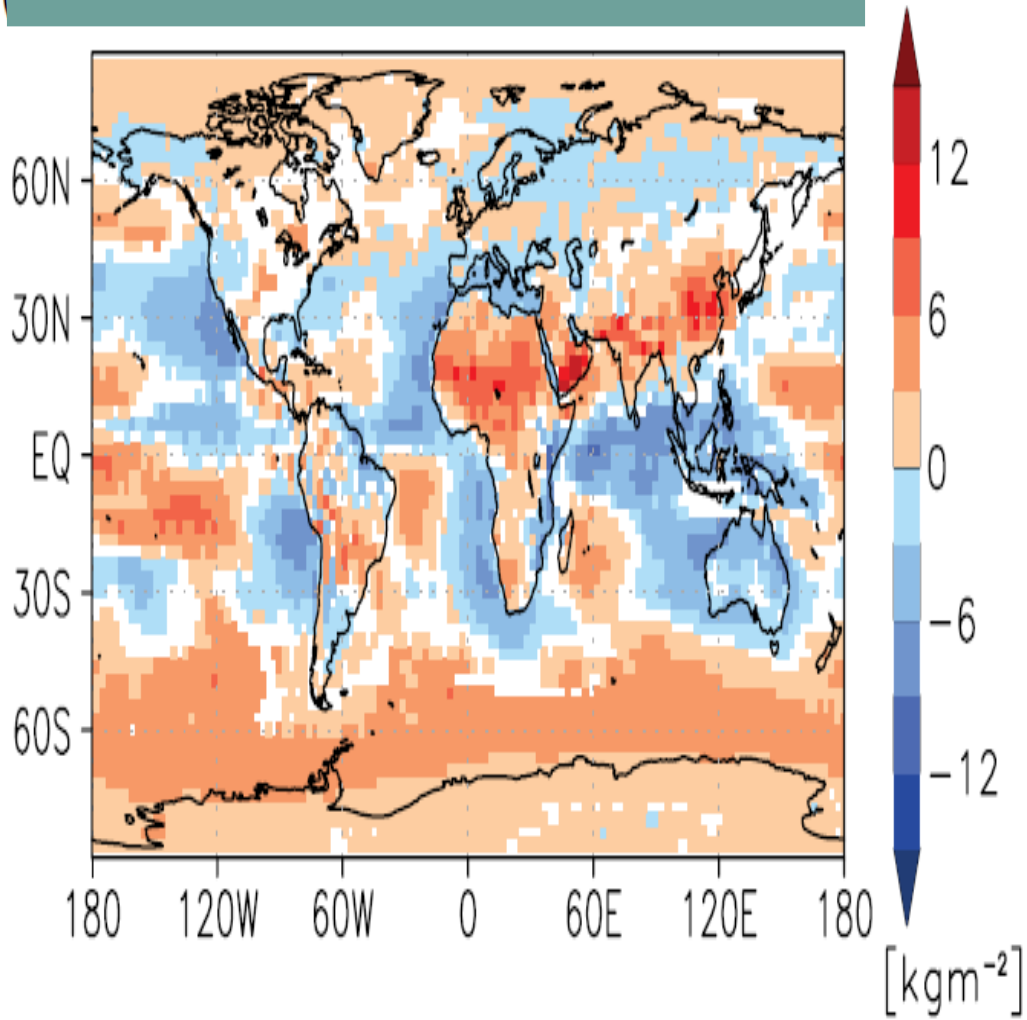
→ **Mean value** of total water path [kg m^{-2}]



MODIS satellite data

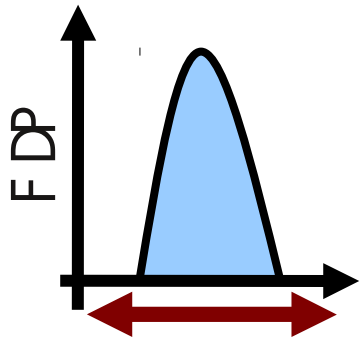


Model – Satellite data

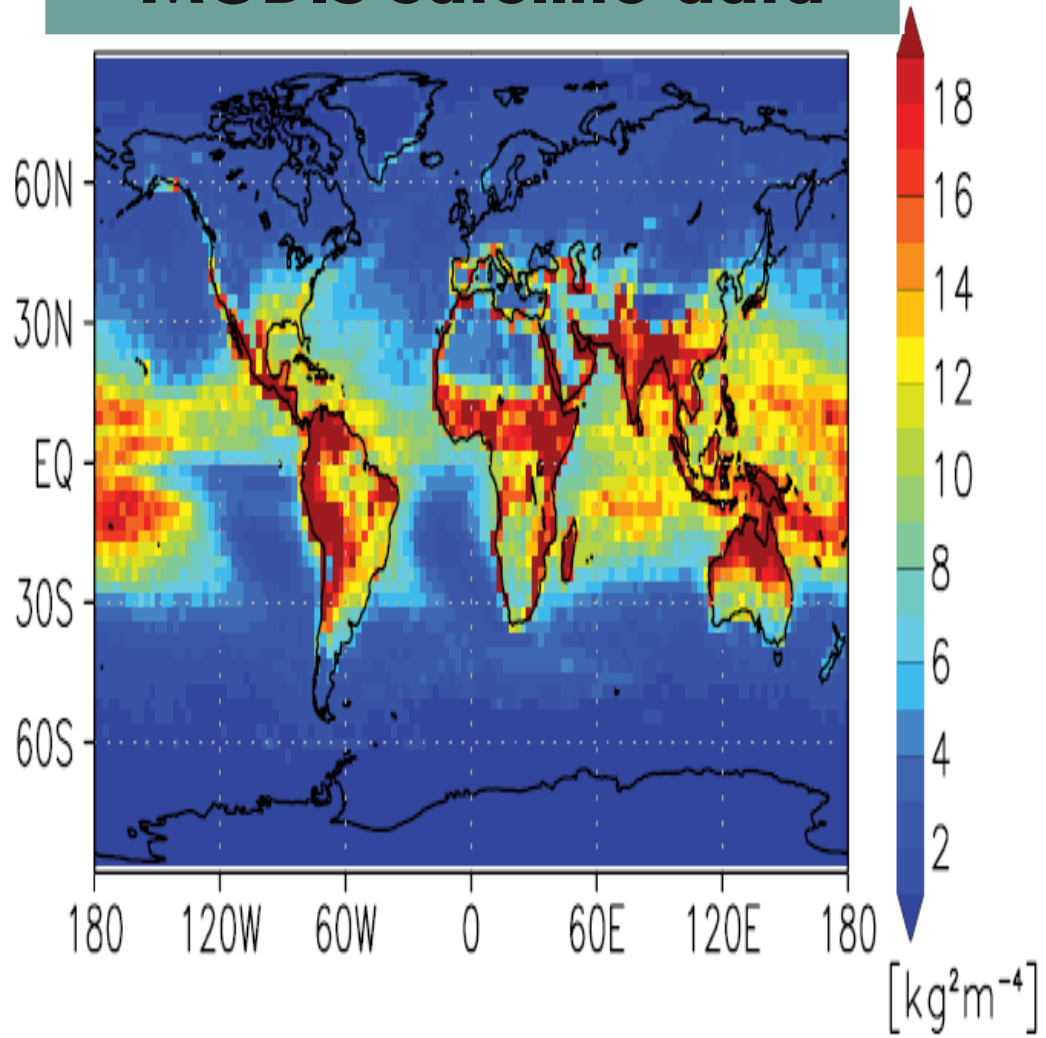


Evaluation of total water path variability

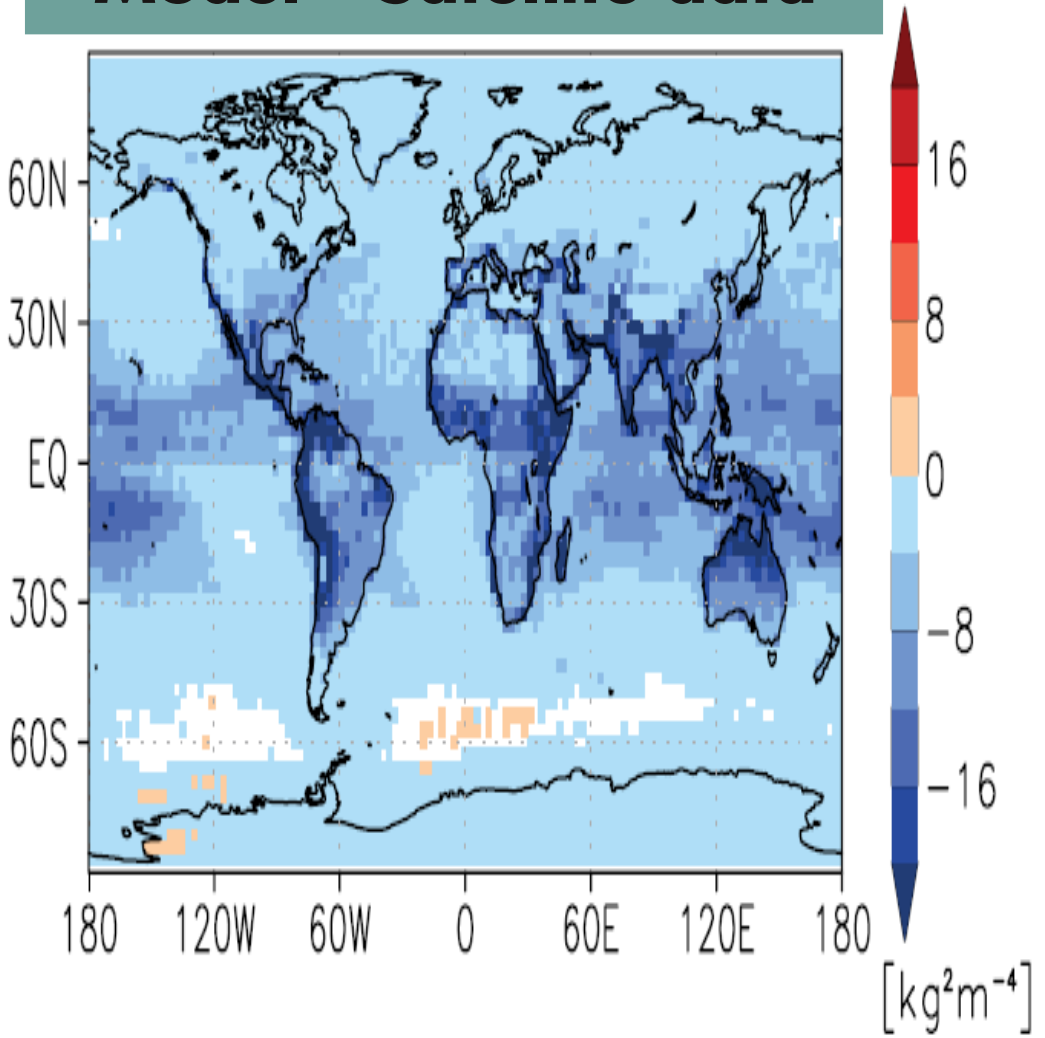
→ **Variance** of total water path [$kg^2\ m^{-4}$]



MODIS satellite data

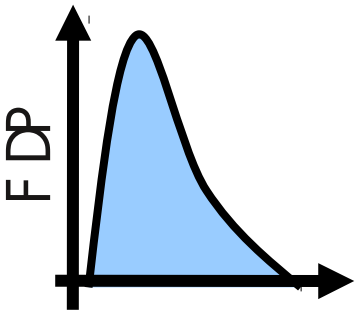


Model – Satellite data

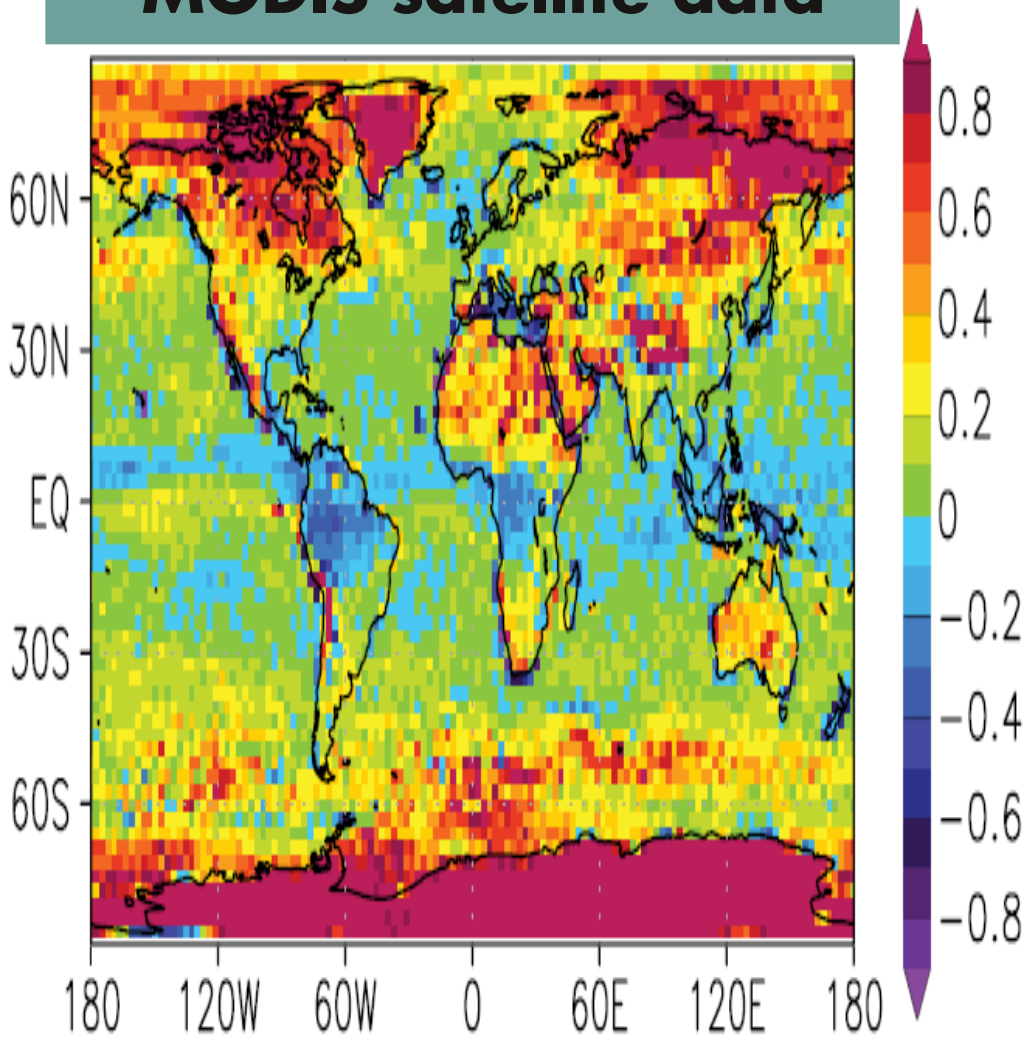


Evaluation of total water path variability

→ **Skewness** of total water path



MODIS satellite data



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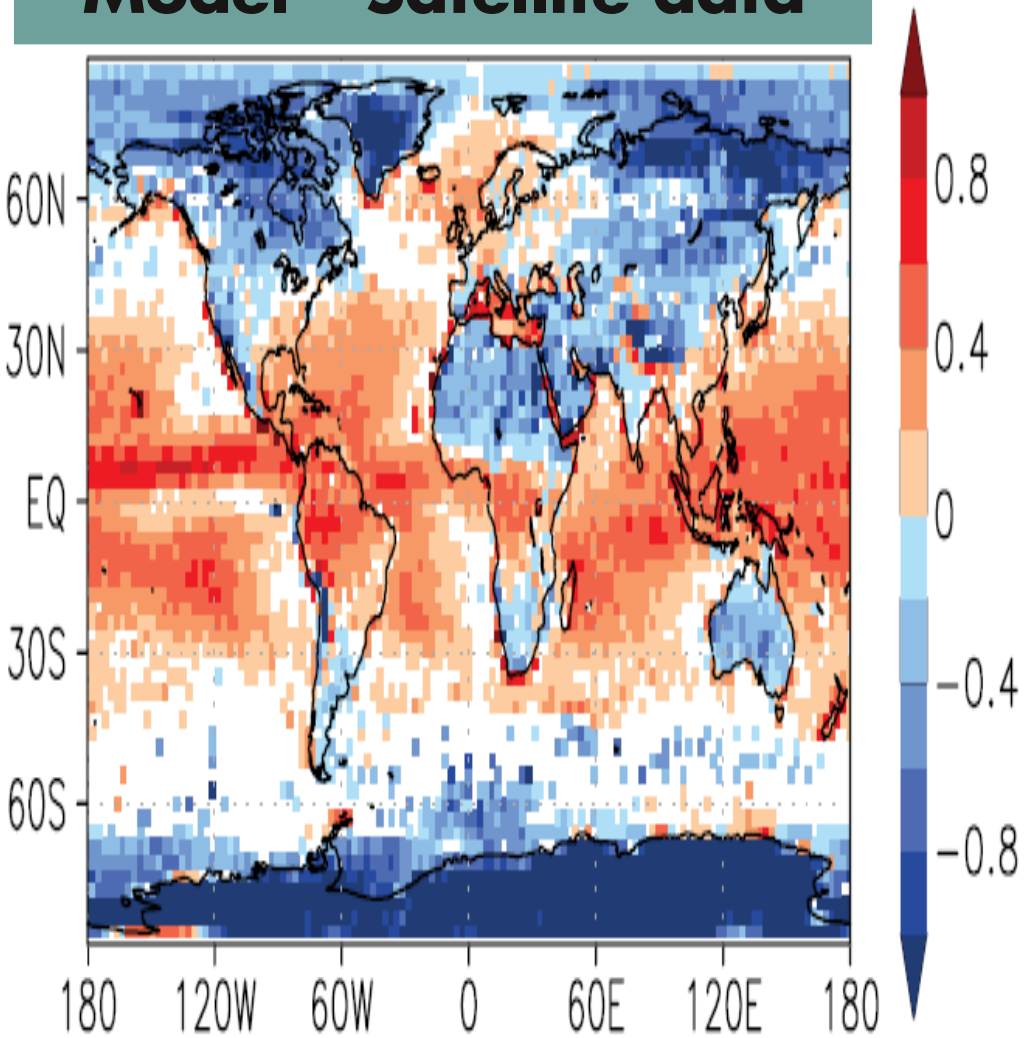
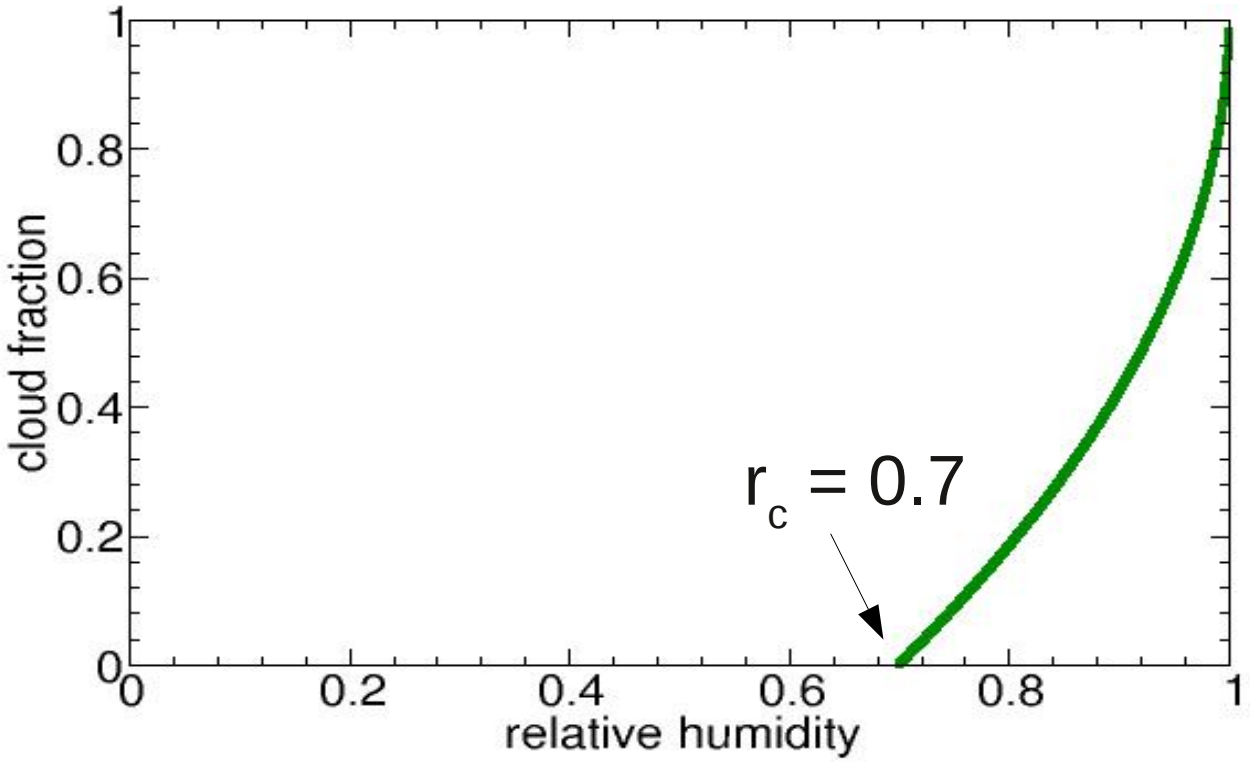


Weber, Quaas, Räisänen, QJRMS 2011

Critical relative humidity as a simple metric

Cloud cover parameterisation

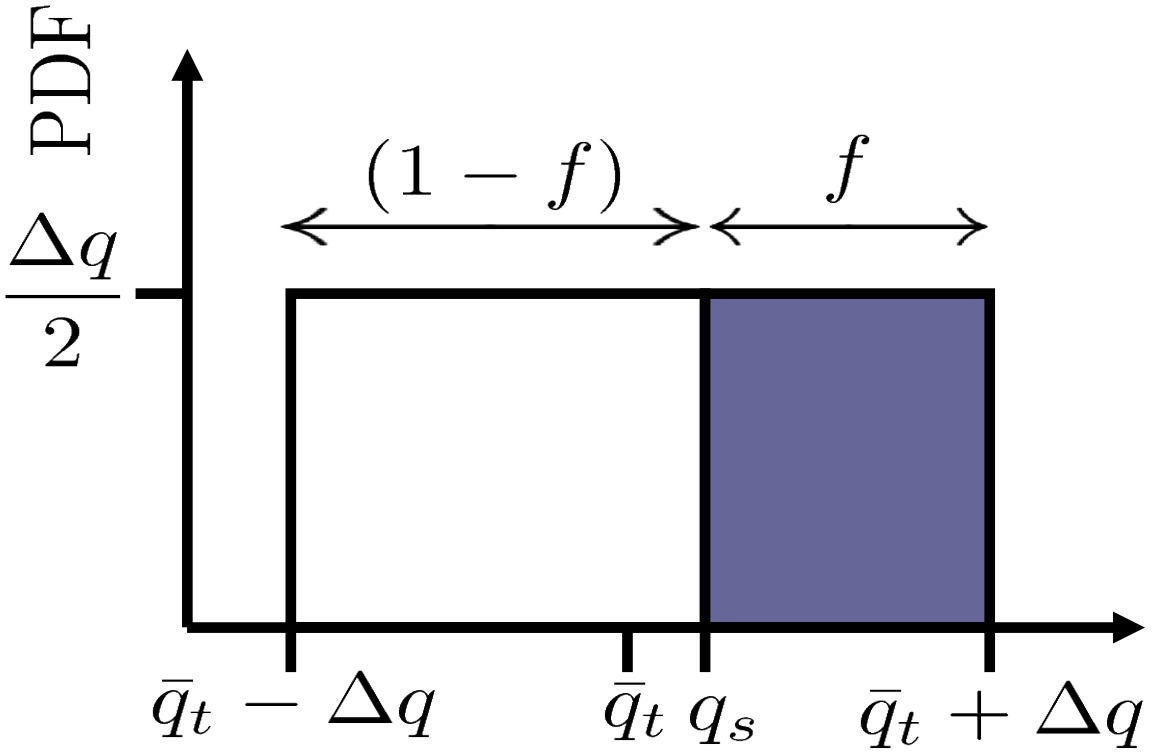


f – cloud fraction
r – relative humidity
r_c – critical humidity

$$f = 1 - \sqrt{\frac{1 - \bar{r}}{1 - r_c}}$$

Sundqvist et al., Mon. Wea. Rev. 1989

Critical relative humidity as a simple metric

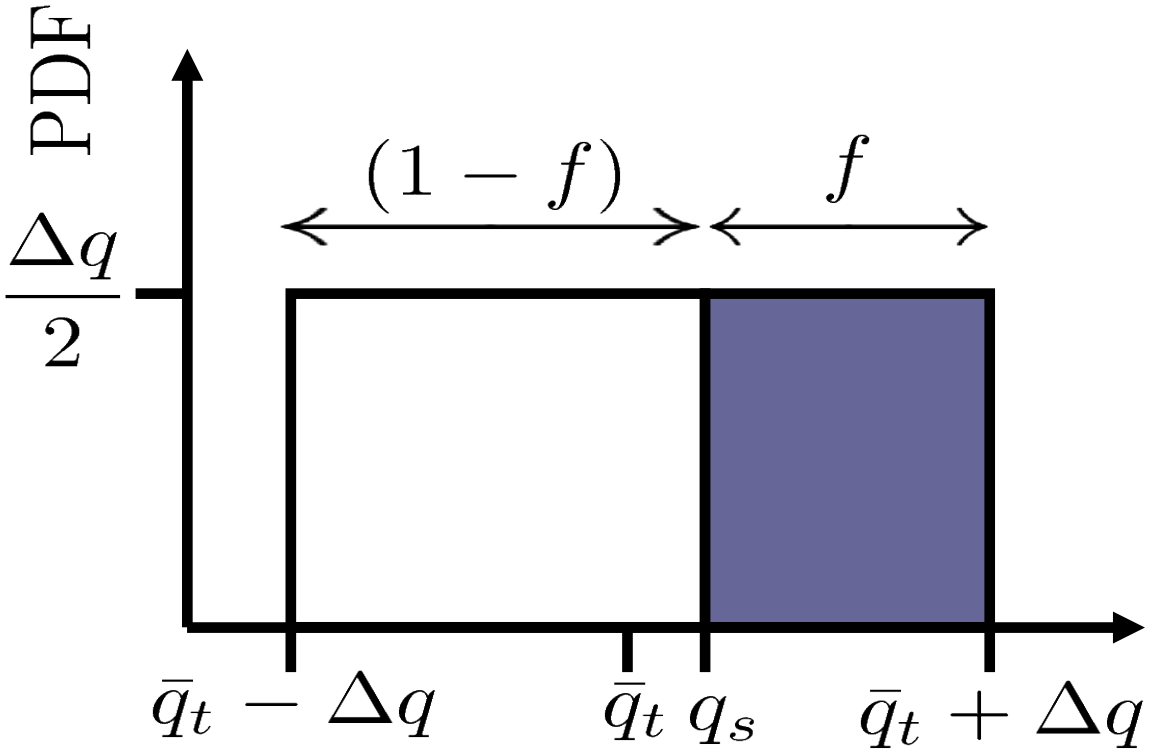


f – cloud fraction
q – specific humidity
q_t – total humidity
q_s – saturation

$$f = \frac{\bar{q}_t + \Delta q - q_s}{2\Delta q}$$

Le Treut and Li, Clim. Dyn. 1996

Critical relative humidity as a simple metric

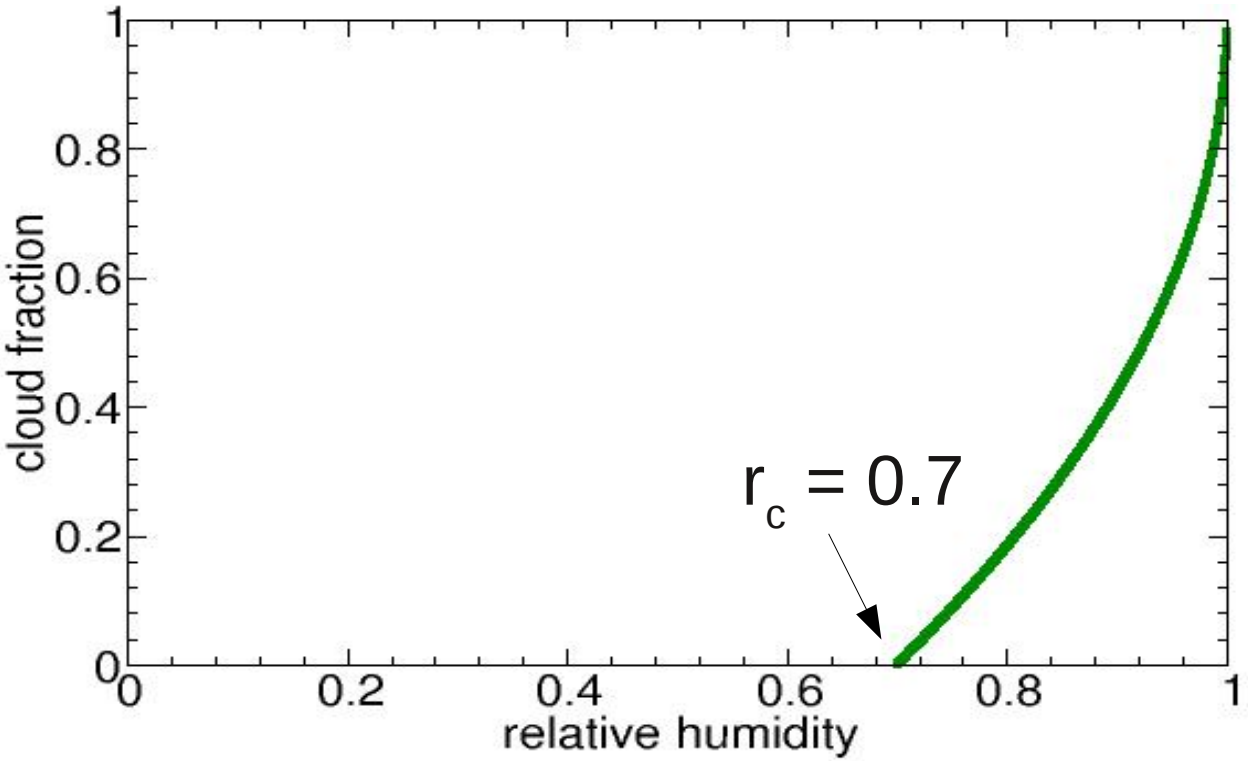


f – cloud fraction
q – specific humidity
q_t – total humidity
q_s – saturation

For
→ the choice $\Delta q = \gamma \cdot q_s$ and
→ assuming saturation within the cloud,
this is equivalent to the critical relative humidity scheme with $r_c = 1 - \gamma$

Le Treut and Li, Clim. Dyn. 1996

Critical relative humidity as a simple metric



f – cloud fraction
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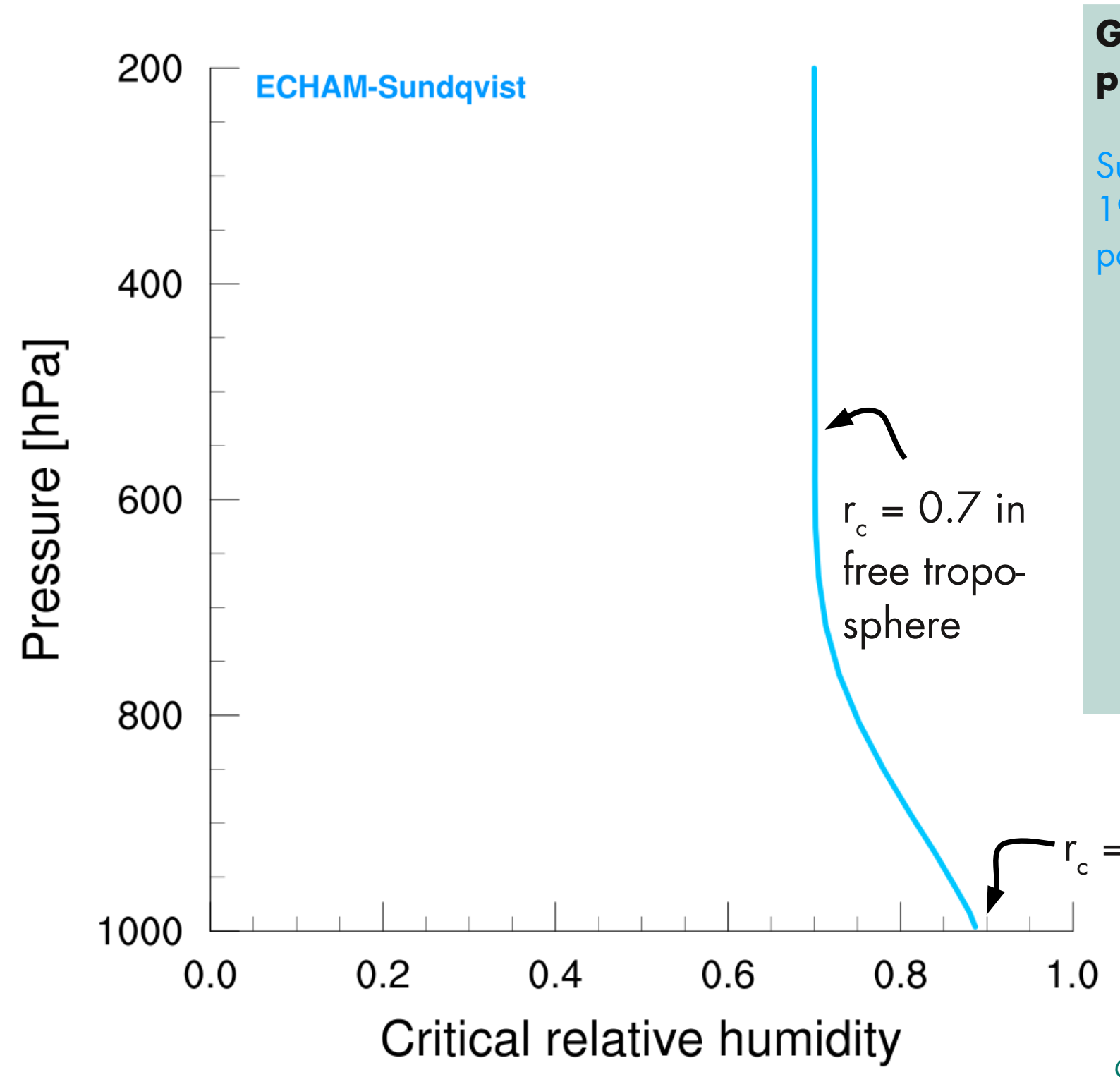
r_c – critical humidity

$$f = 1 - \sqrt{\frac{1 - \bar{r}}{1 - r_c}}$$

***r_c* small ⇔ subgrid-scale variability γ large**

Sundqvist et al., Mon. Wea. Rev. 1989



Global annual mean profile

Sundqvist et al. (MWR, 1978) cloud parameterisation

Quaas, J. Geophys. Res., 2012

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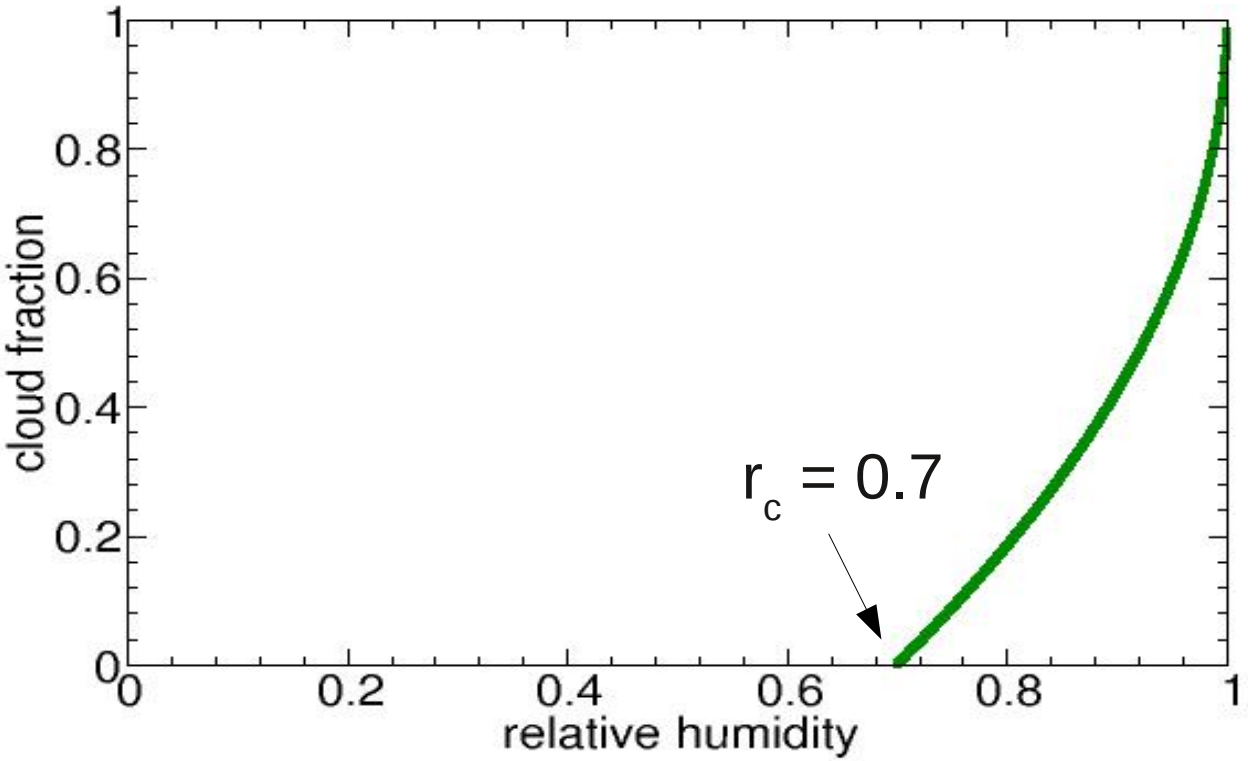


f – cloud fraction
r – relative humidity
r_c – critical humidity

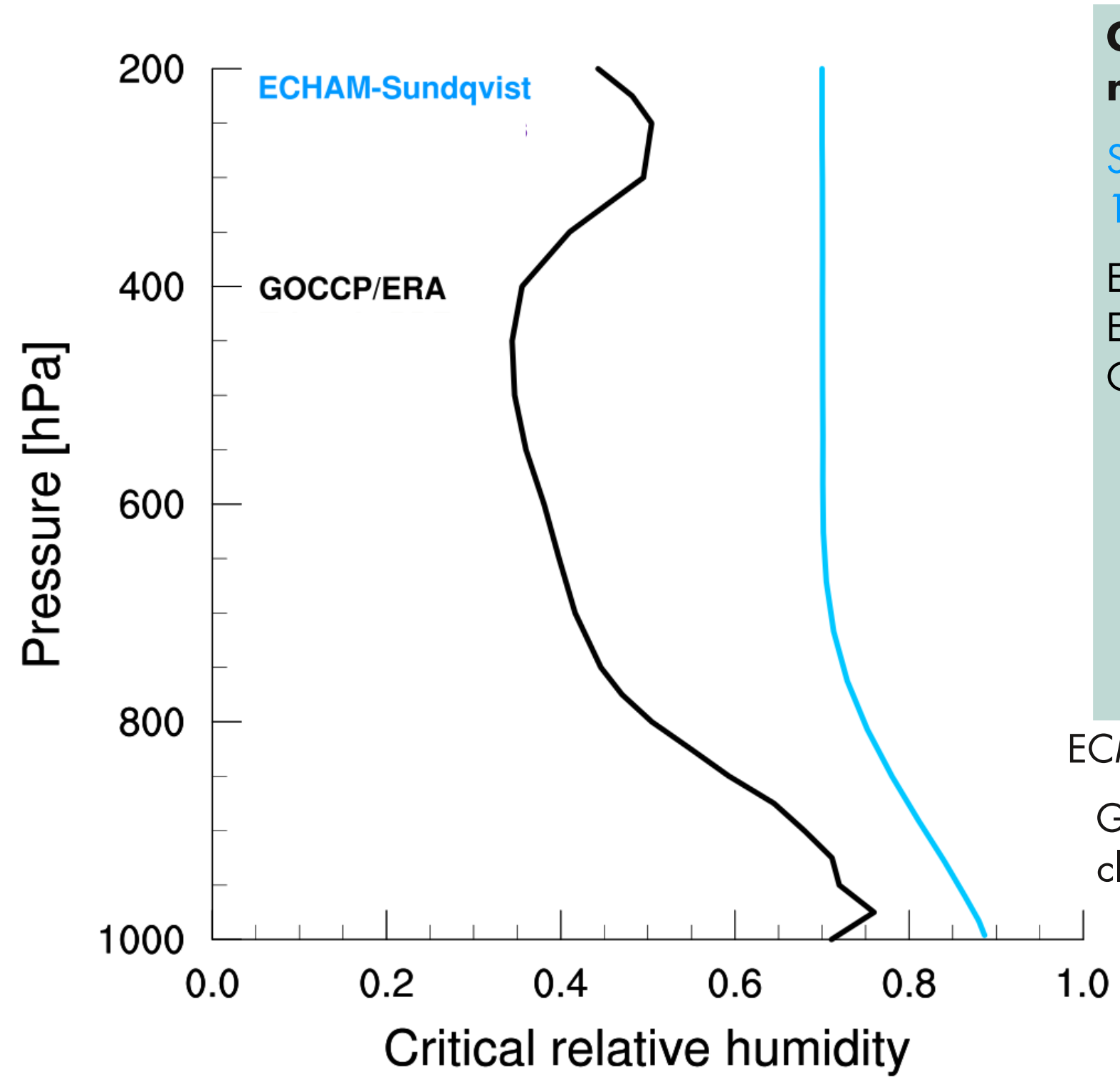
$$f = 1 - \sqrt{\frac{1-\bar{r}}{1-r_c}}$$

$$r_c = 1 - \frac{1-\bar{r}}{(1-f)^2}$$

grid-box mean

observable!
(for 0 < f < 1)

Quaas, J. Geophys. Res., 2012



Global annual mean profile

Sundqvist et al. (MWR, 1978) parameterisation

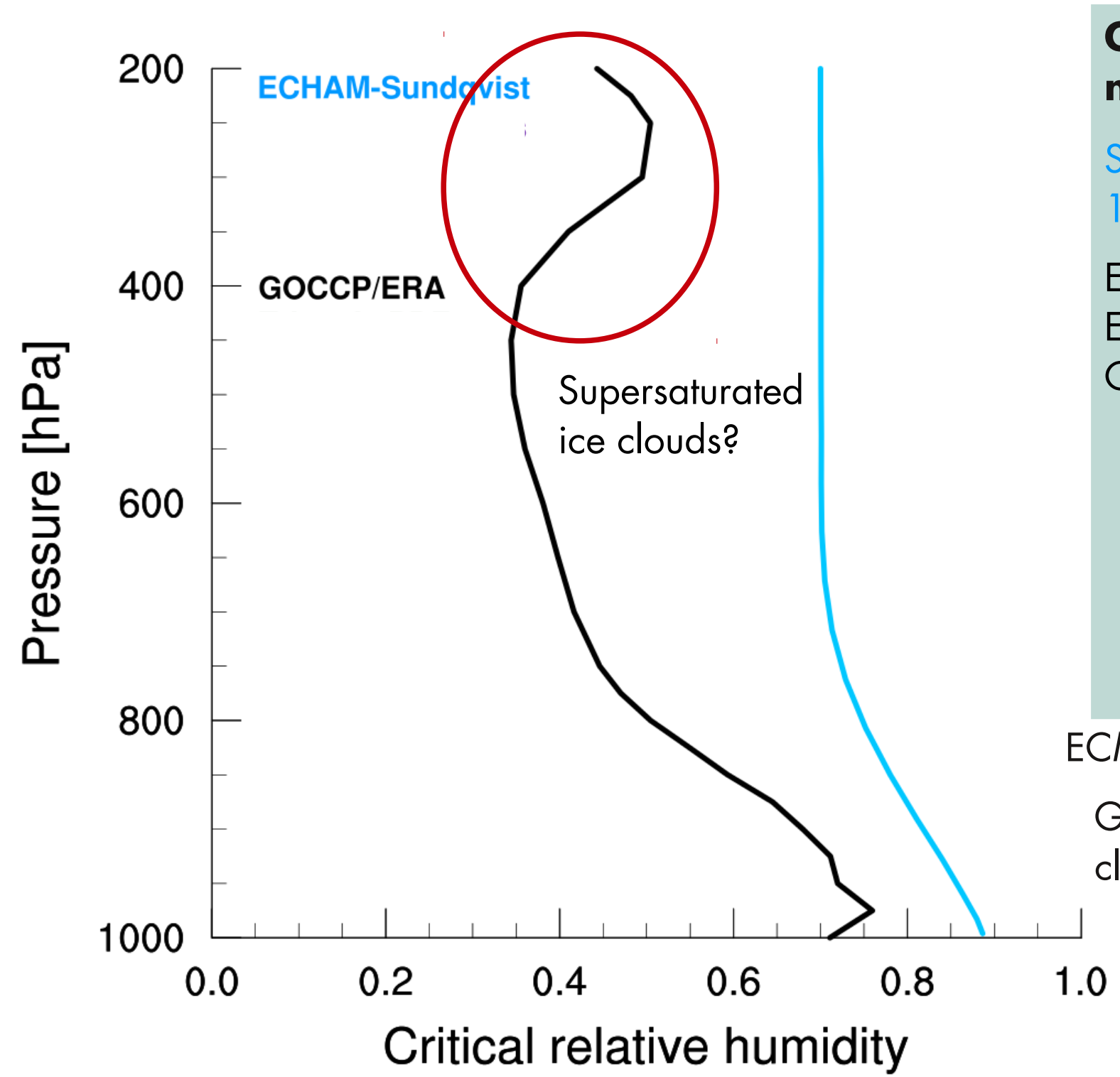
ERA-Interim/CALIPSO
ERA: relative humidity
CALIPSO: cloud cover

ECMWF re-analysis (ERA)

GCM-oriented CALIPSO cloud product (GOCCP)

T63 grid (1.8°x1.8°) daily data 2007

Quaas, J. Geophys. Res., 2012



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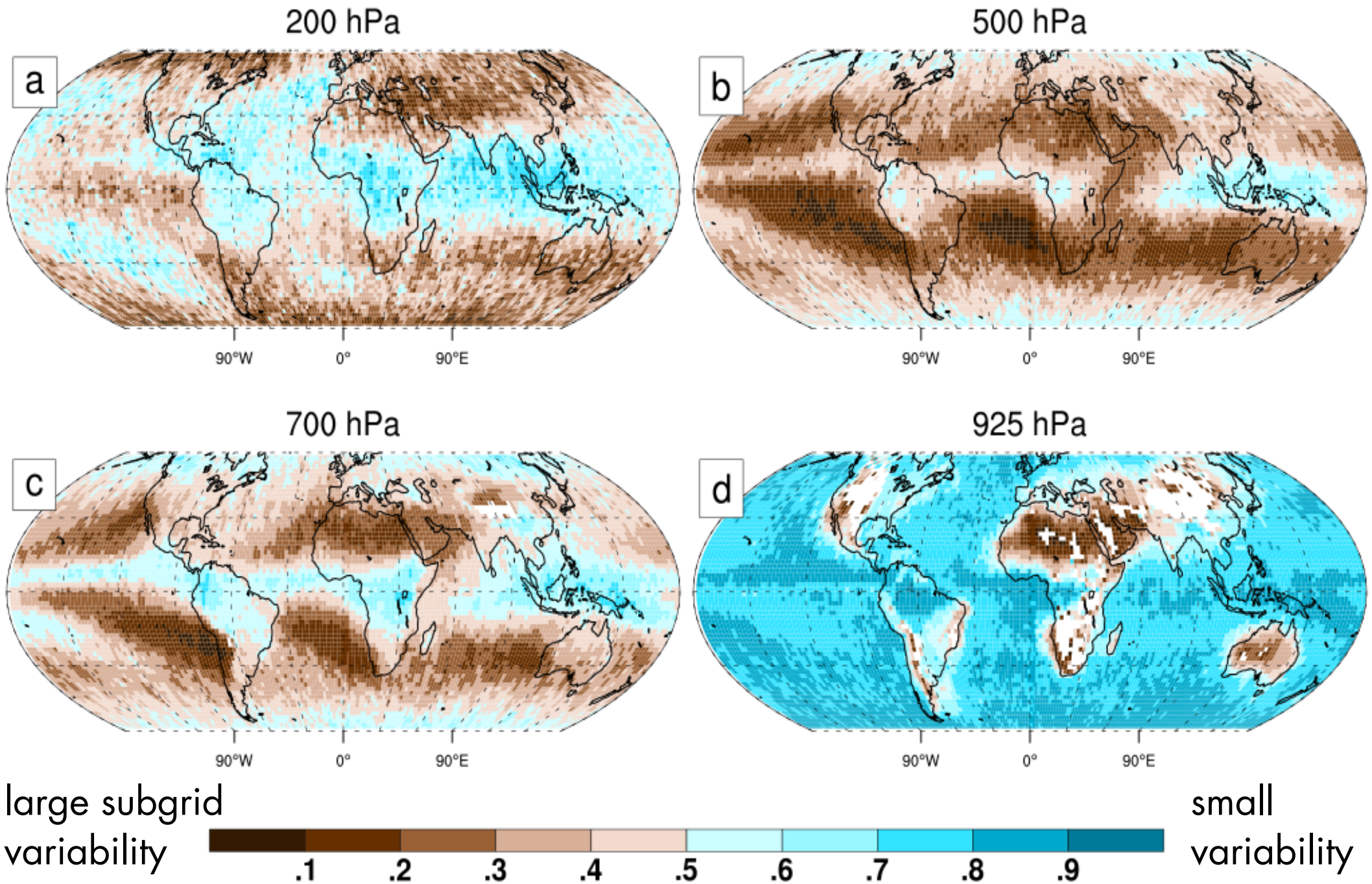
T63 grid
daily data 2007

Quaas, J. Geophys. Res., 2012

ERA-Interim/GOCCP critical relative humidity: annual-mean distribution



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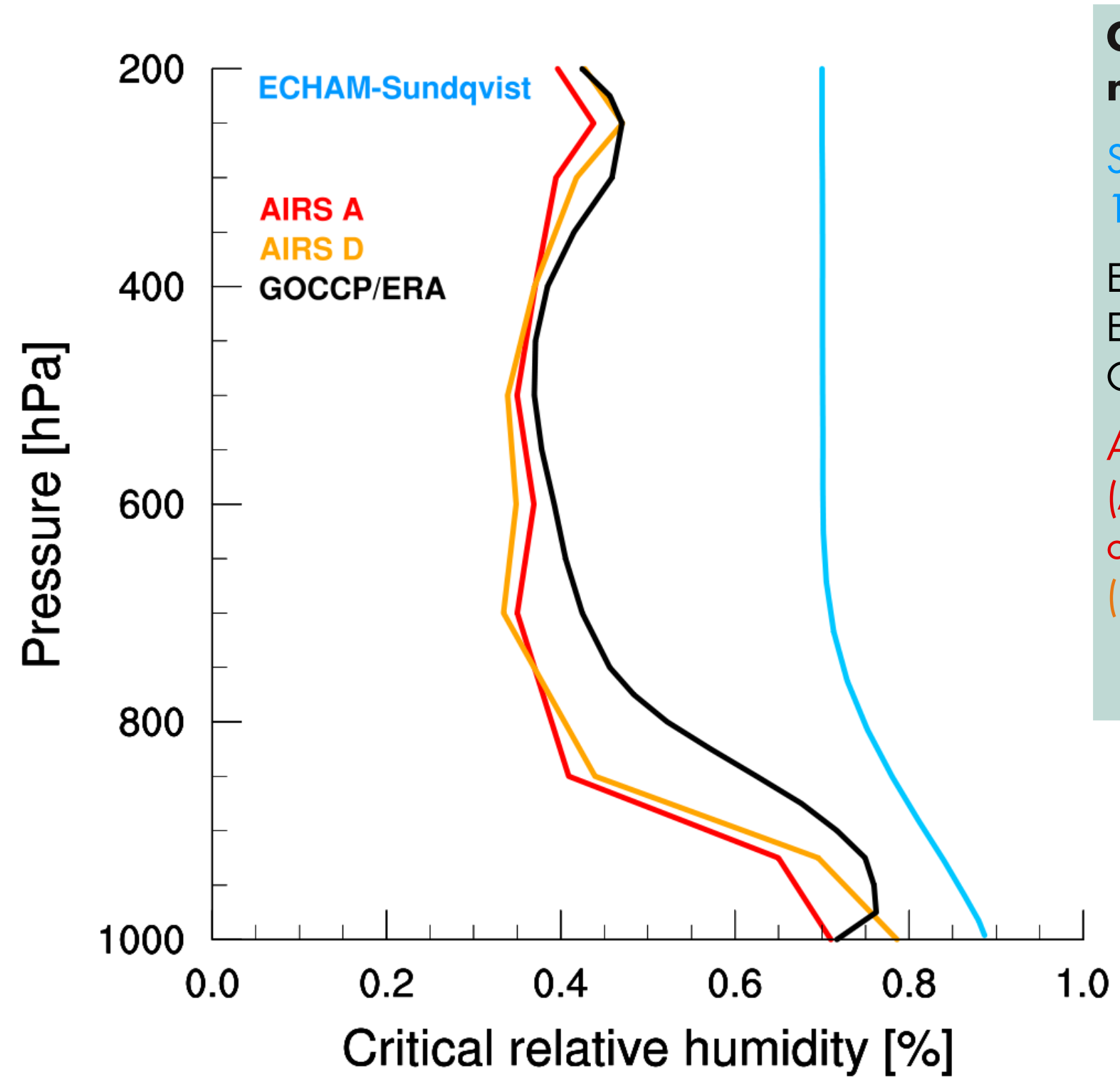

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Sundqvist et al. (MWR, 1978) parameterisation

ERA-Interim/CALIPSO
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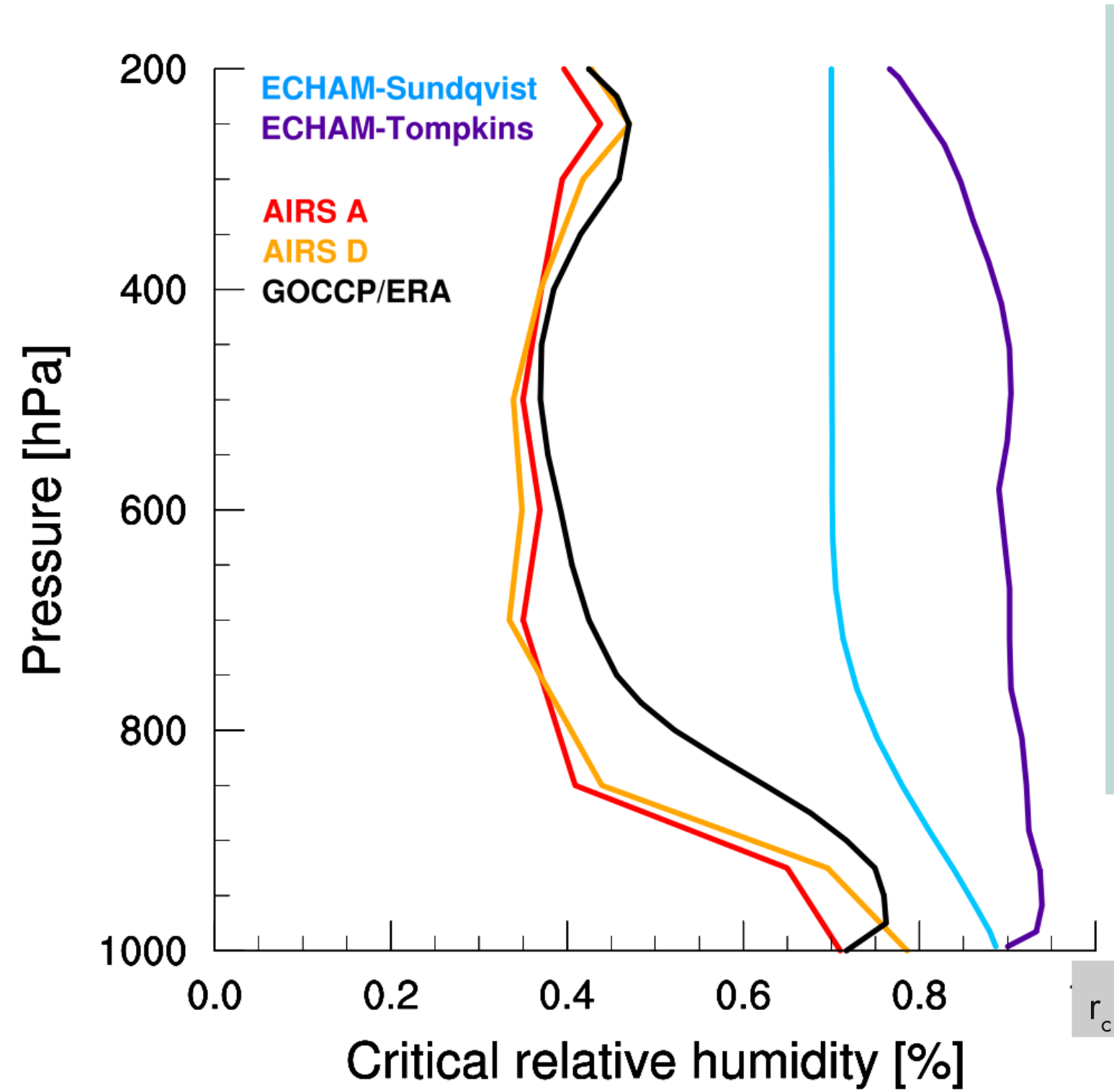
AIRS satellite data
(A – acending orbit/daytime)
(D – descending/night)

Atmospheric InfraRed Sounder (Aqua)
AIRX3STD
T63 grid (1.8°x1.8°)
daily data for 2003

Quaas, J. Geophys. Res., 2012



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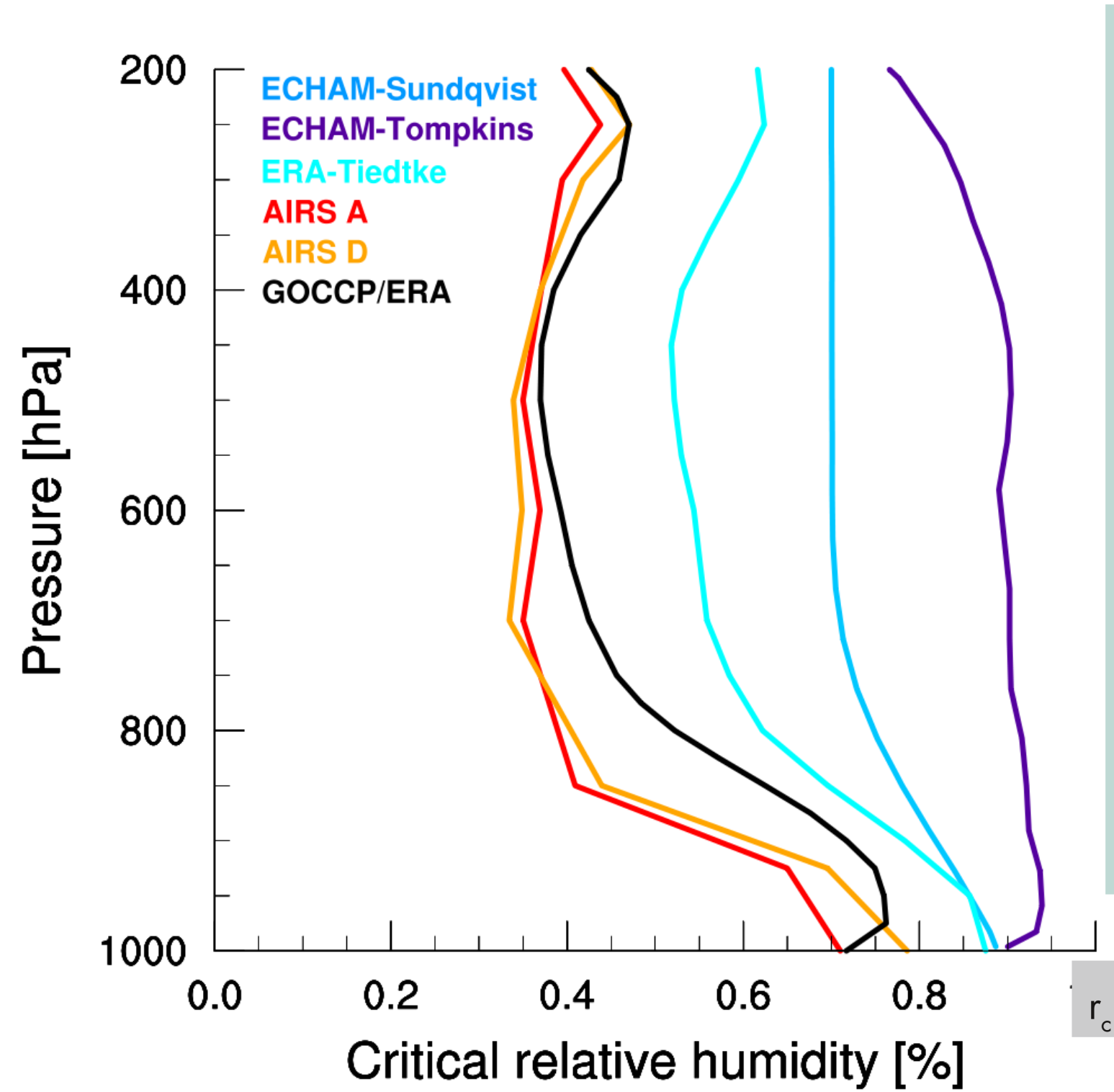
Tompkins (JAS, 2002) cloud parameterisation

r_c diagnostic from f and $\bar{r}$

Quaas, J. Geophys. Res., 2012



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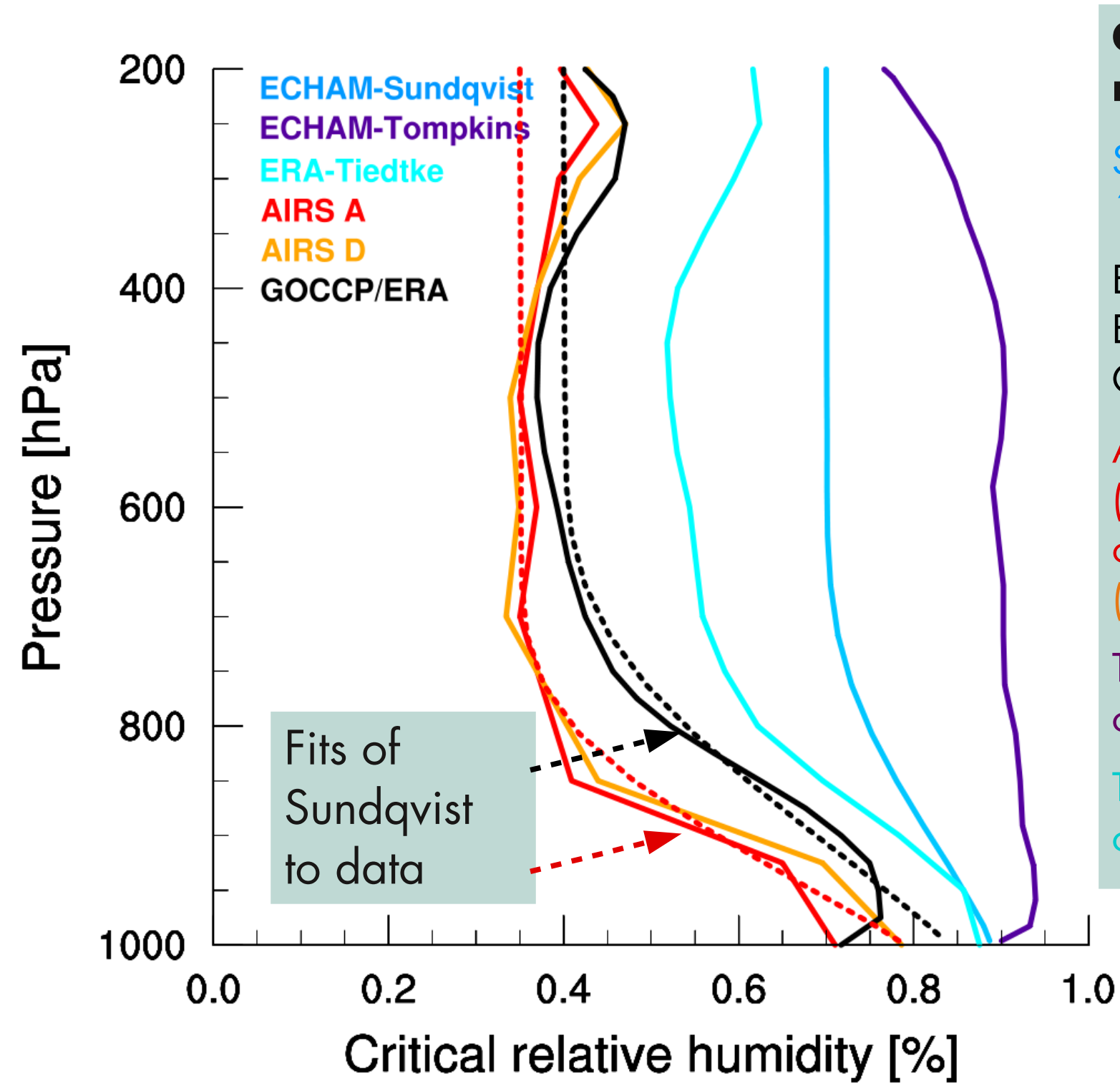

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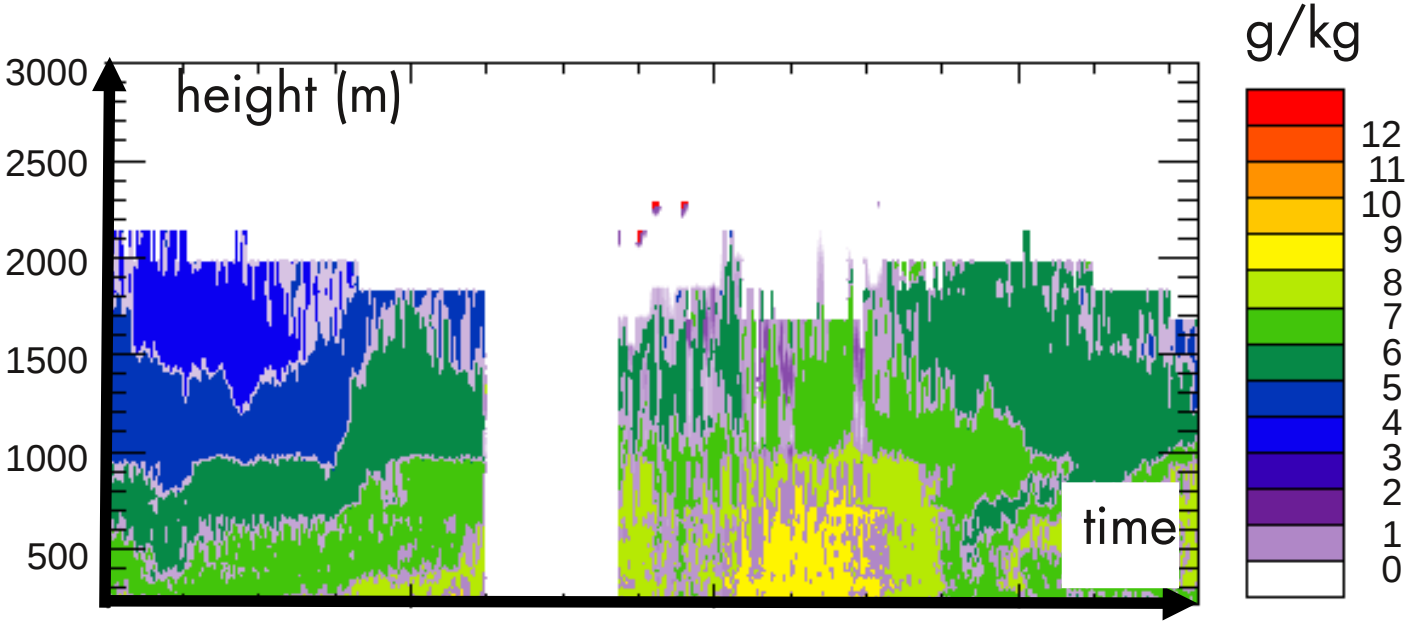
Subgrid scale variability from lidar measurements?

→ Strategy

Differential absorption lidar (DIAL) Hamburg (H. Linné)



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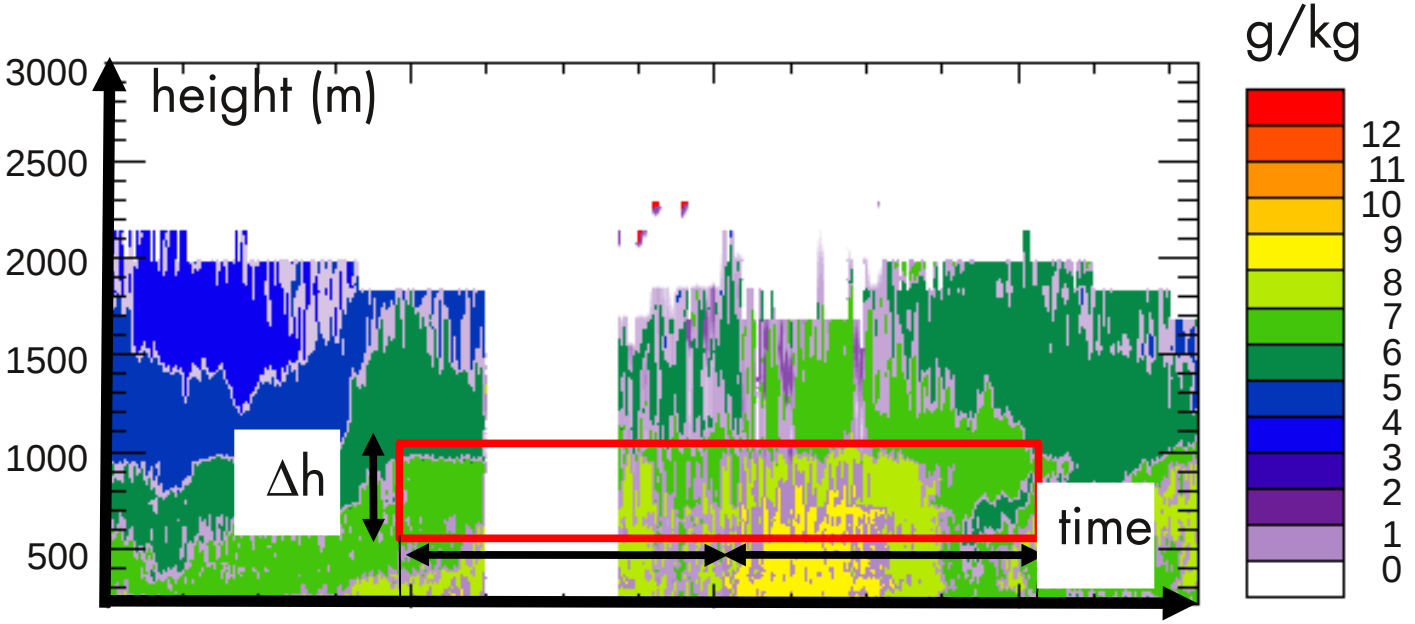
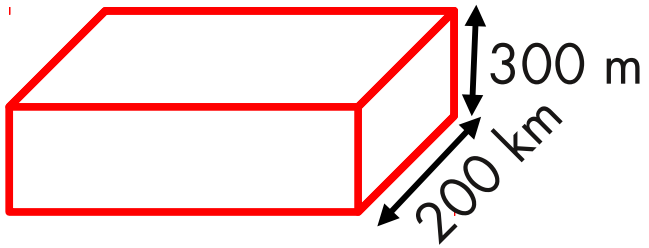


Model



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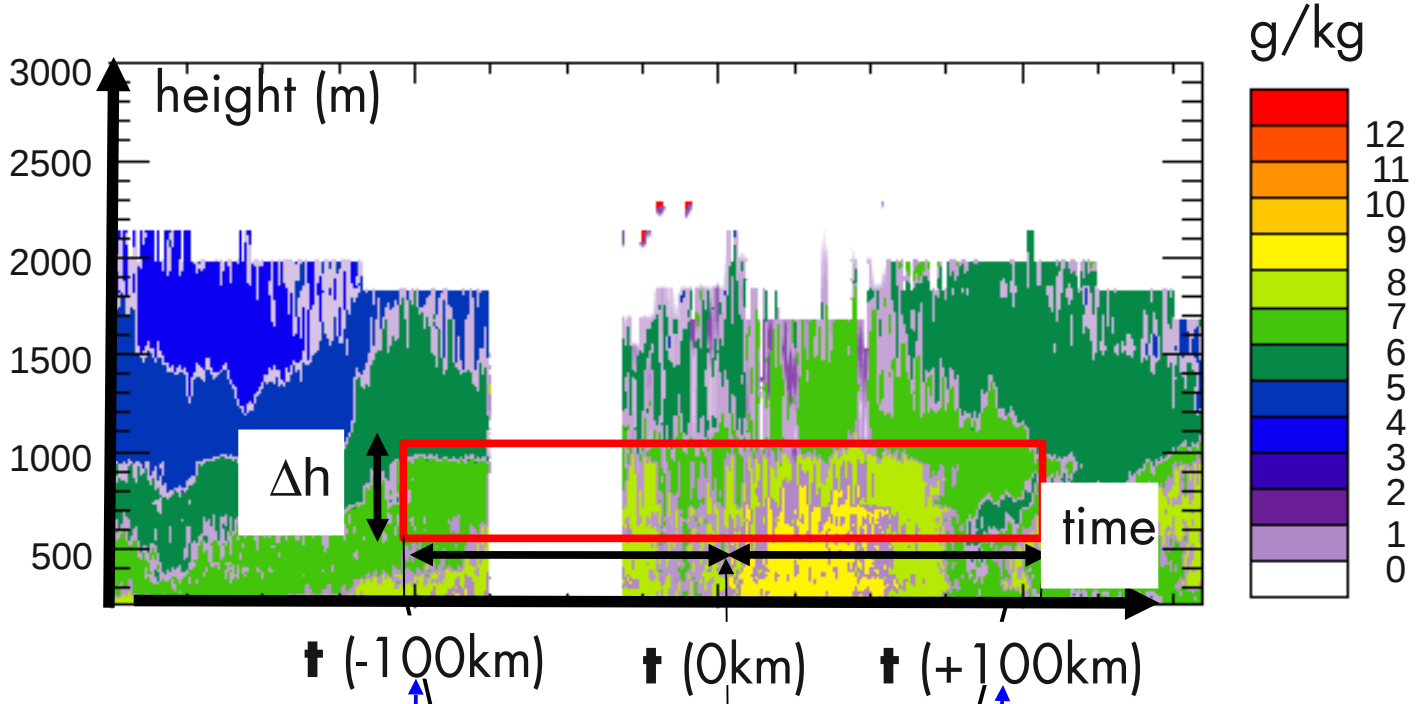
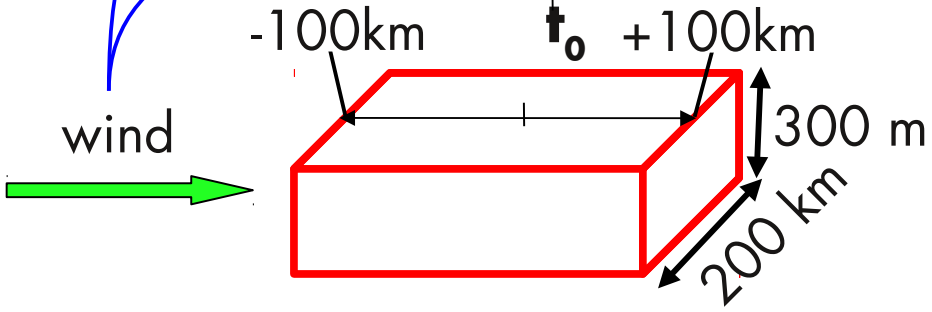
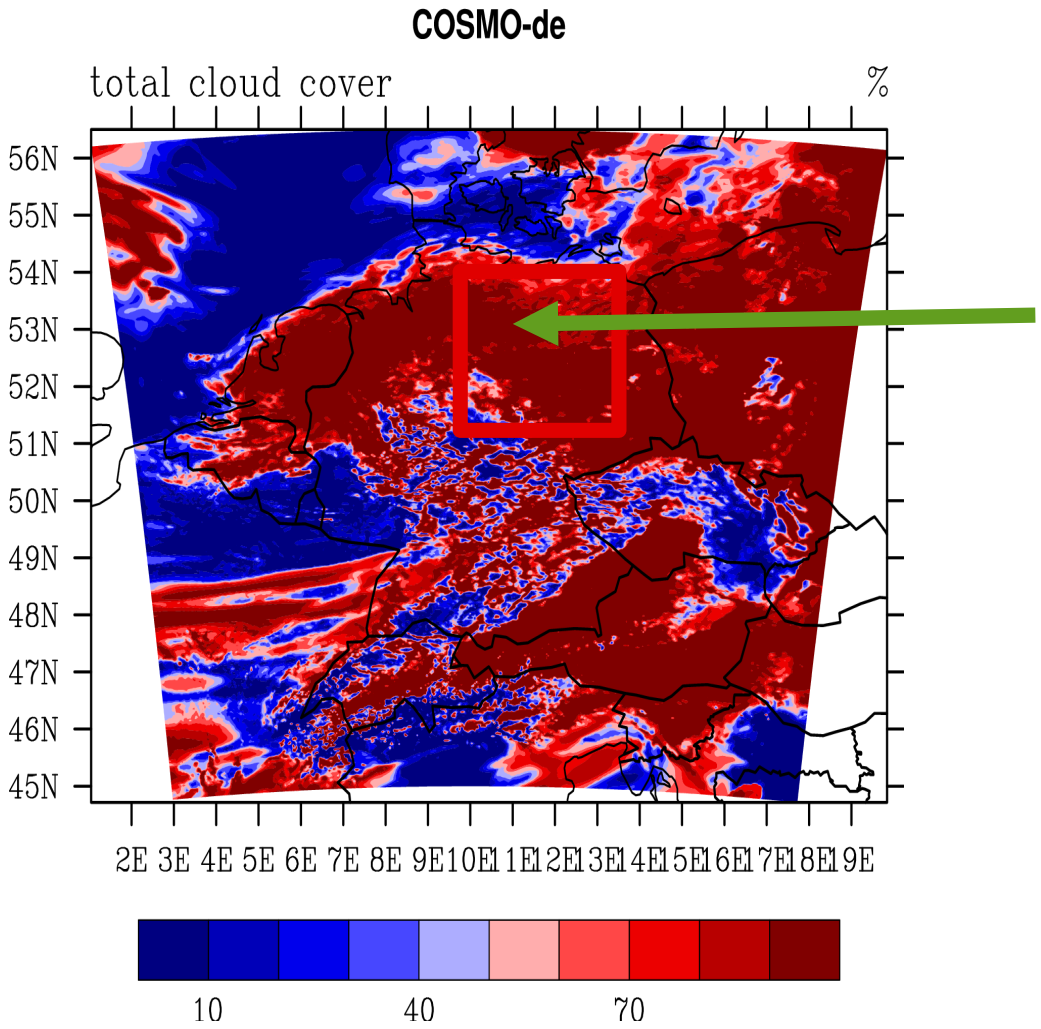


Model



Subgrid scale variability from lidar measurements?

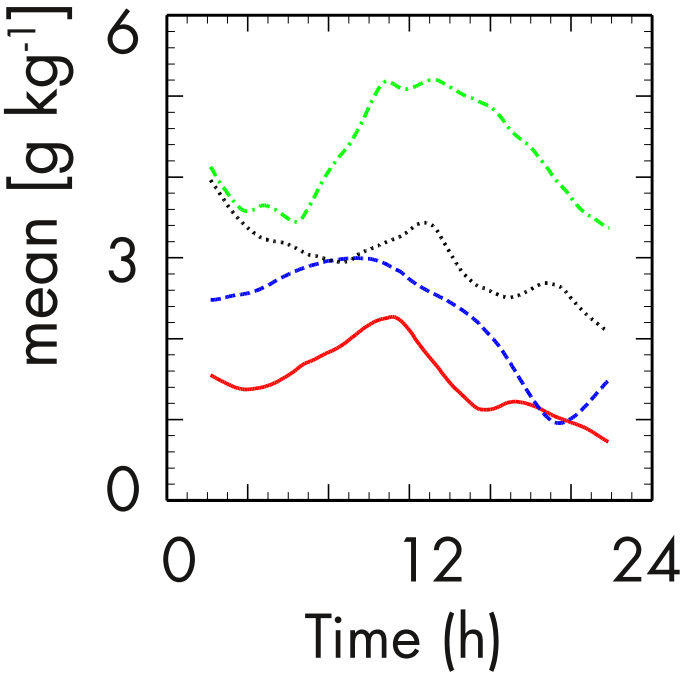
→ COSMO model as "virtual reality"



- High-resolution model (2.8 km)
- "temporal" sampling at one point → "virtual lidar"
- "spatial" sampling at one timestep → "virtual GCM grid-box"

Subgrid scale variability from lidar measurements?

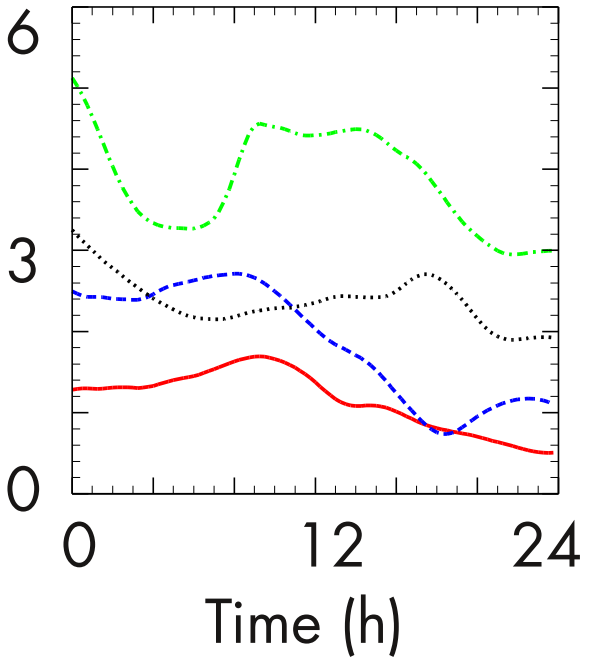
Temporal = "virtual lidar"



Total water
mean

3500 m
2500 m
1200 m
500 m

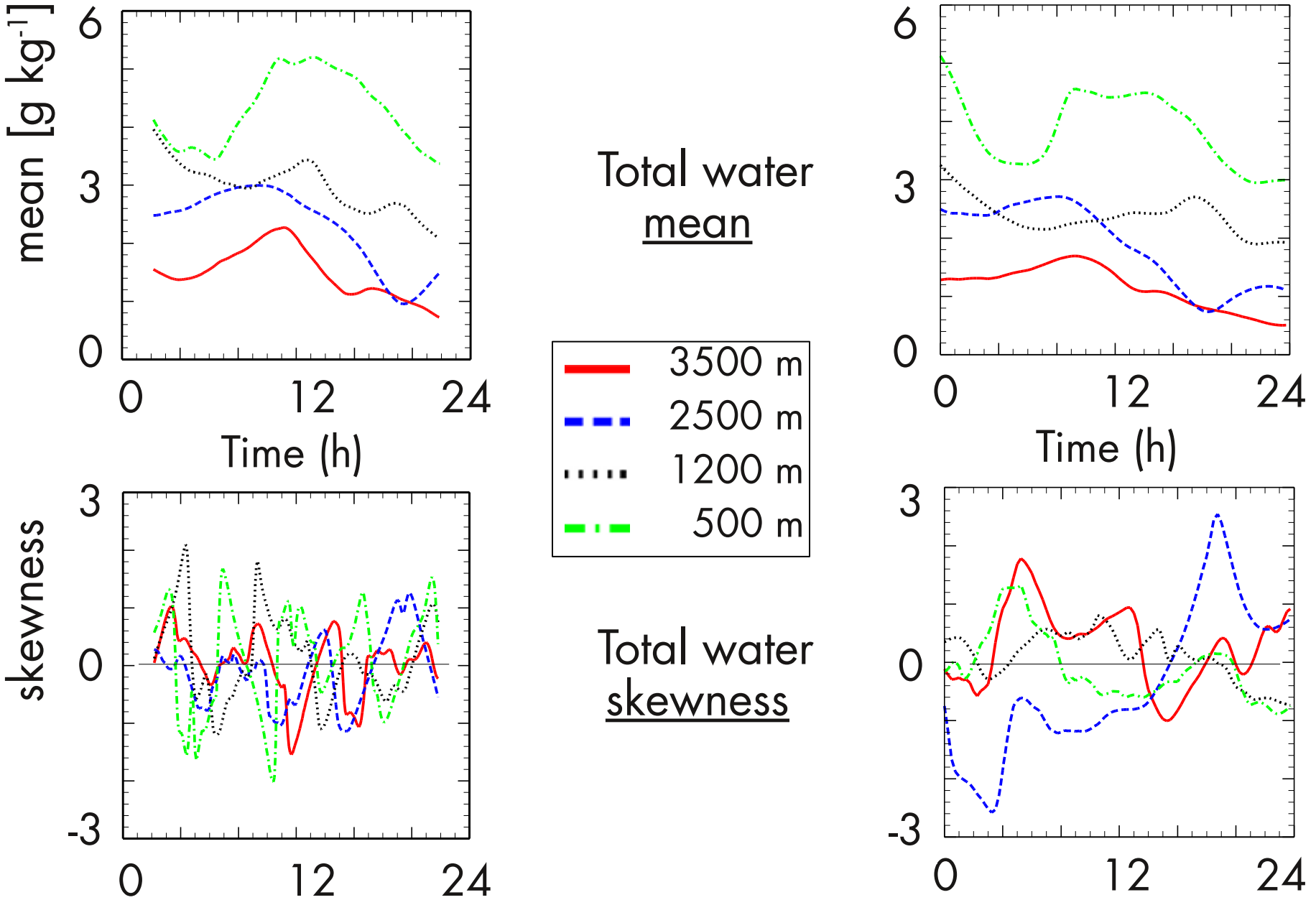
Spatial = "virtual GCM grid-box"



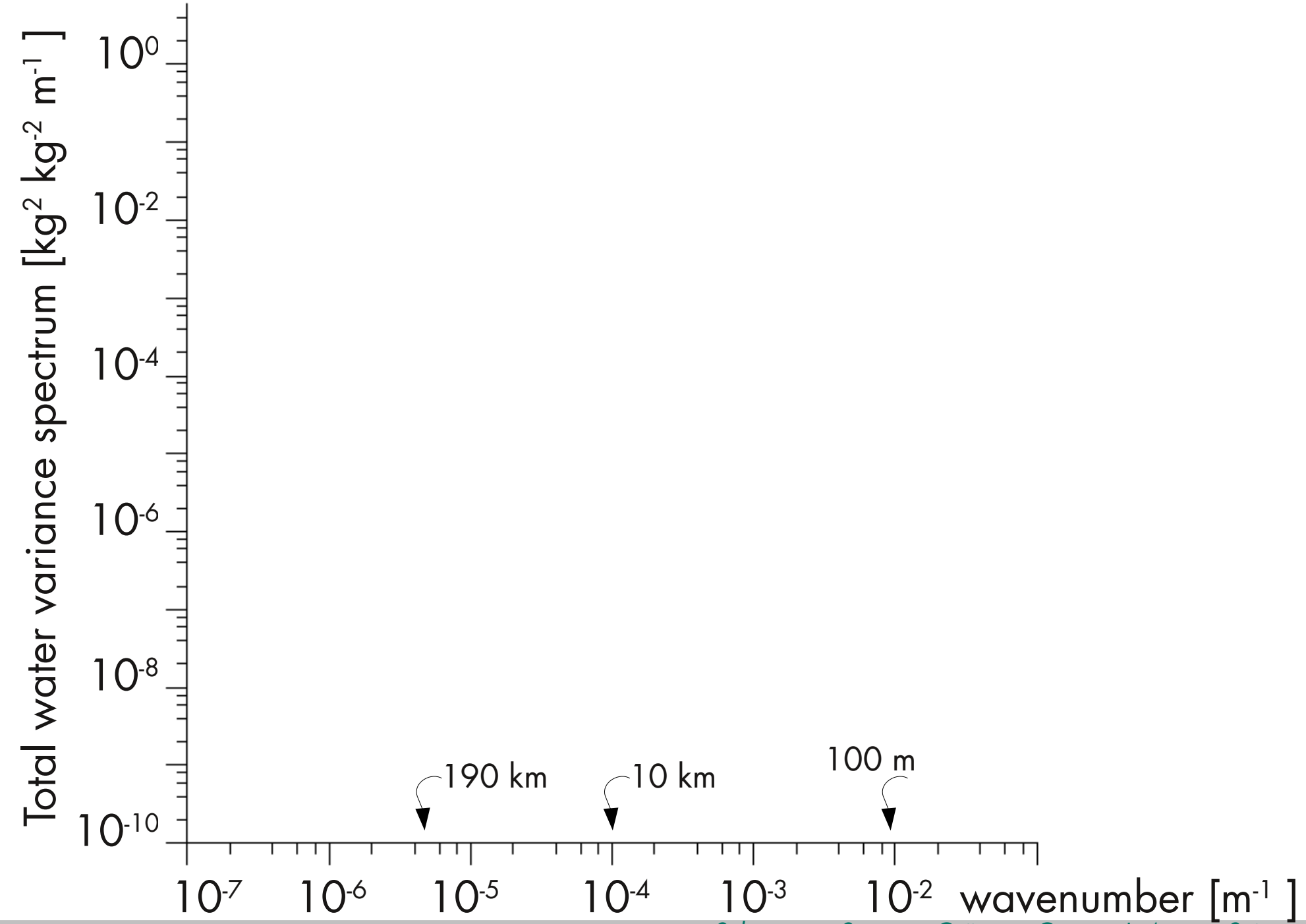
Subgrid scale variability from lidar measurements?

Temporal = "virtual lidar"

Spatial = "virtual GCM grid-box"

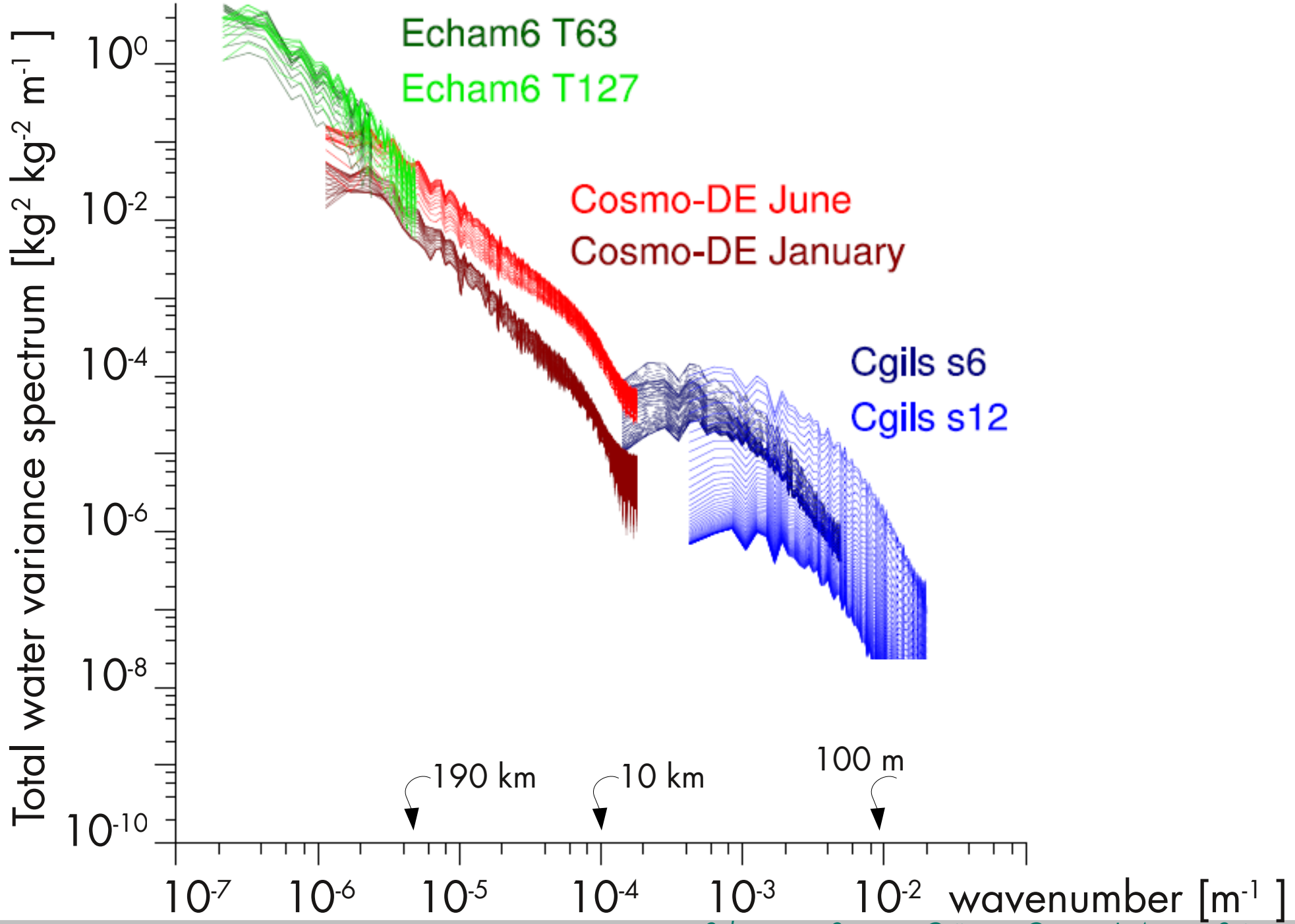


Scale dependency of total water variance



Schemann, Stevens, Grützun, Quaas, J. Atmos. Sci., submitted

Scale dependency of total water variance



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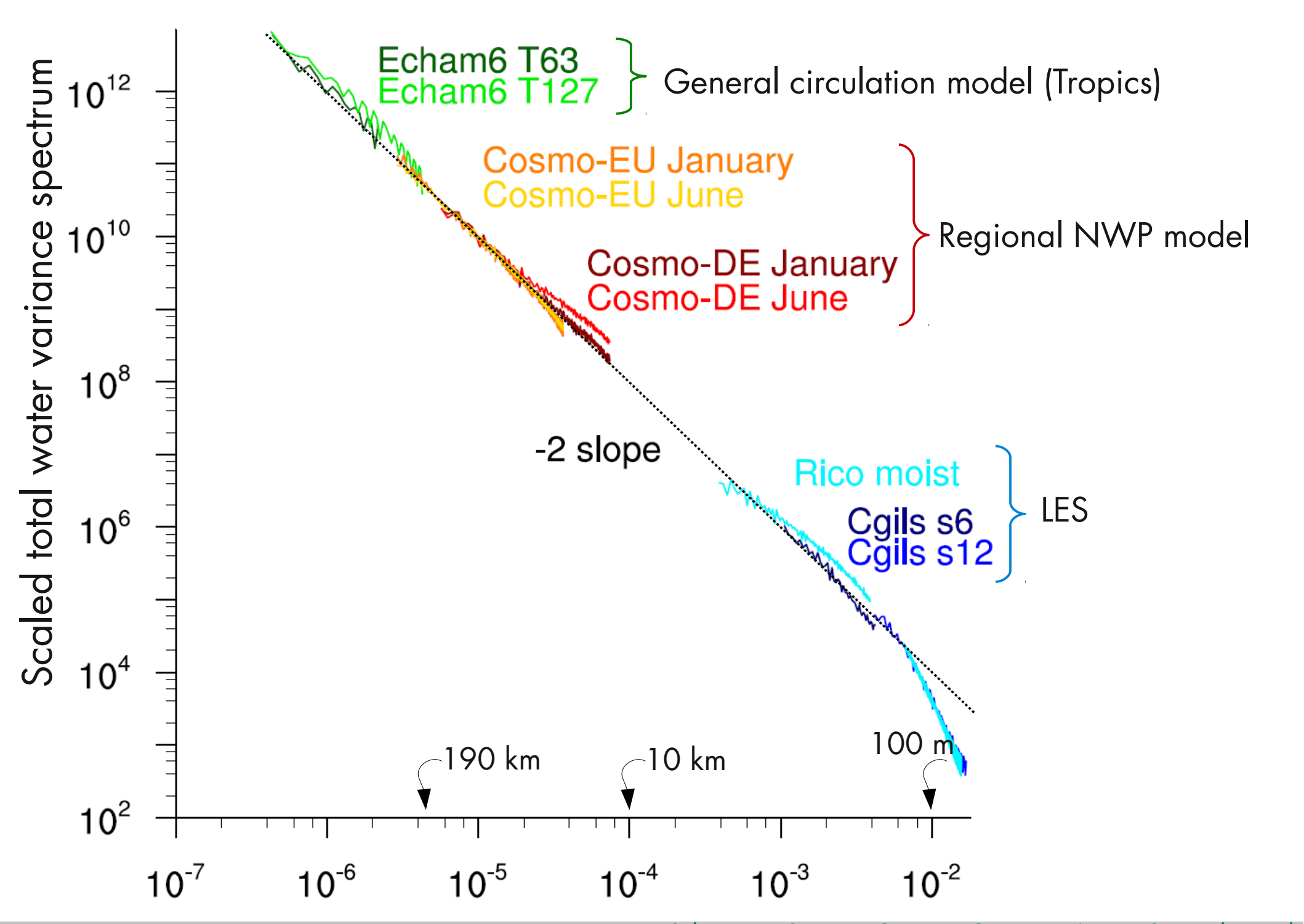
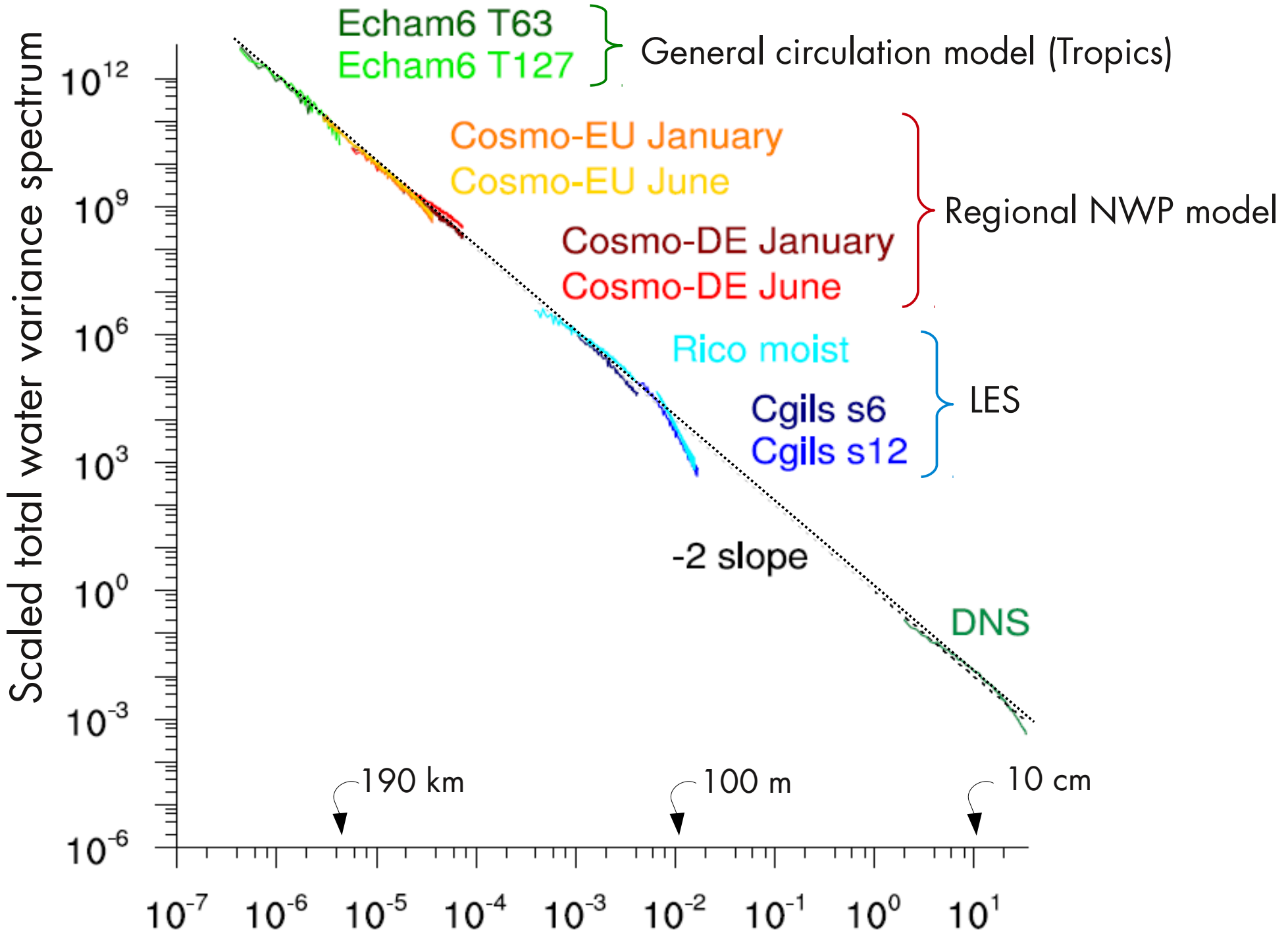

Scaled total water variance spectrum
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
Echam6 T63
Echam6 T127
General circulation model (Tropics)
Cosmo-EU January
Cosmo-EU June
Cosmo-DE January
Cosmo-DE June
Regional NWP model
-2 slope
Rico moist
Cgils s6
Cgils s12
LES
190 km
10 km
100 m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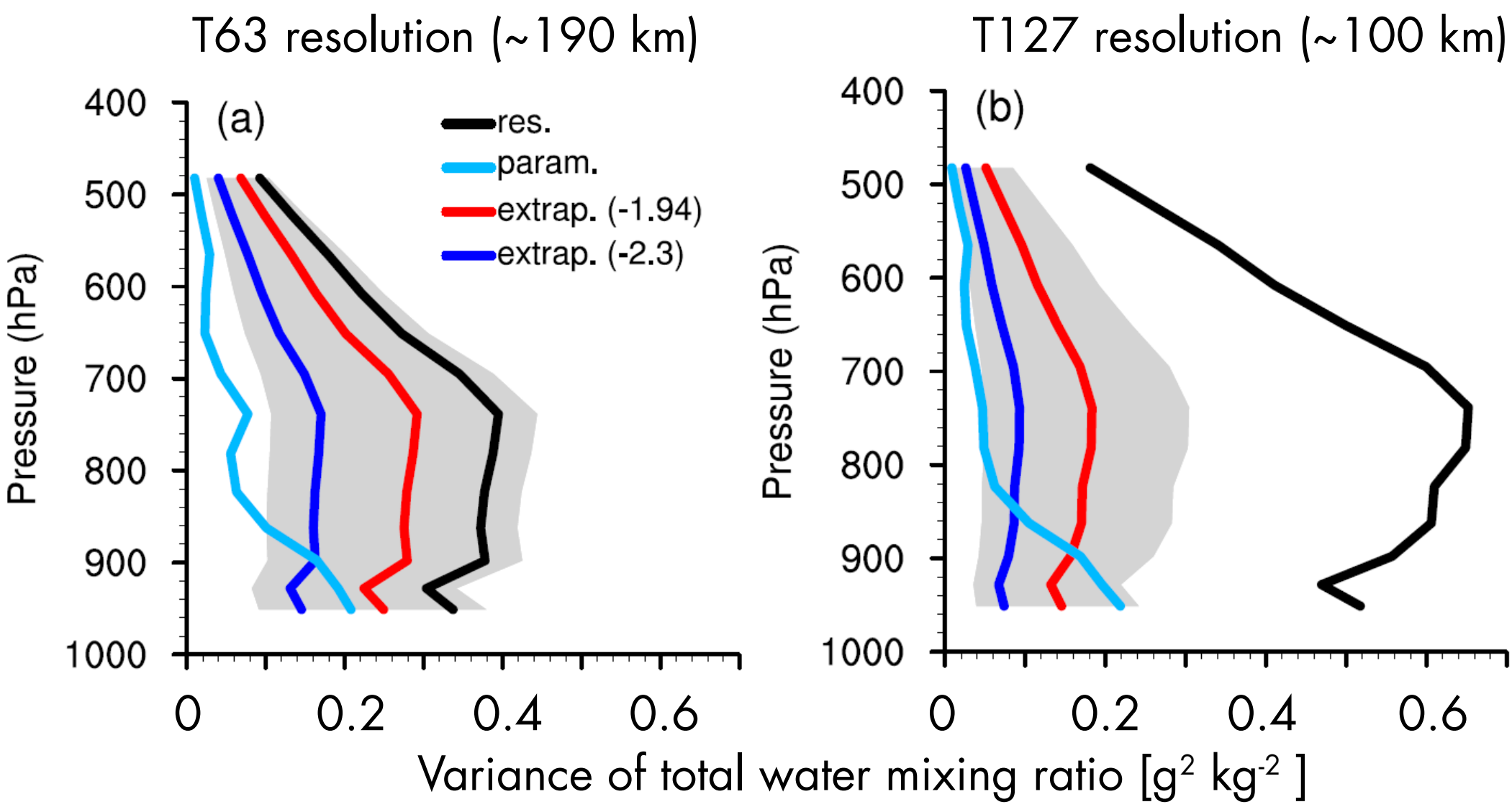
LES
-2 slope
DNS
190 km
100 m
10 cm
Scaled total water variance spectrum
10^{12}
10^{9}
10^{6}
10^{3}
10^{0}
10^{-3}
10^{-6}
10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1}

Scale dependency of total water variance



Resolved

Subgrid Tompkins parameterisation

Subgrid extrapolated using -1.94 slope

Subgrid extrapolated using -2.3 slope

Conclusions

- **Spatially high-resolved satellite data** allow to evaluate total water path variance – allows for useful conclusions
  → too little variance in Tompkins scheme, need for negative skewness

- **Critical relative humidity** is a metric available from satellite data including vertical resolution
  → problematic for ice clouds, dependent on assumptions

- It is difficult to use **supersite measurements** as a reference for higher moments

- Total water mixing ratio **variance scaling** follows a power-law with an exponent of about -2.
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