Sensitivity of simulated cloud objects to changes in the thermodynamic and dynamic states

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Motivation

- There are still large degrees of uncertainty as to how cloud properties will change in a warmer climate.
- Bony et al. (2004) have used GCMs to separate dynamic and thermodynamic components of changes in cloud radiative forcing.
- We use a cloud-resolving model to simulate many different deep convective cloud objects for a relatively short period of time (24 hours).

Model

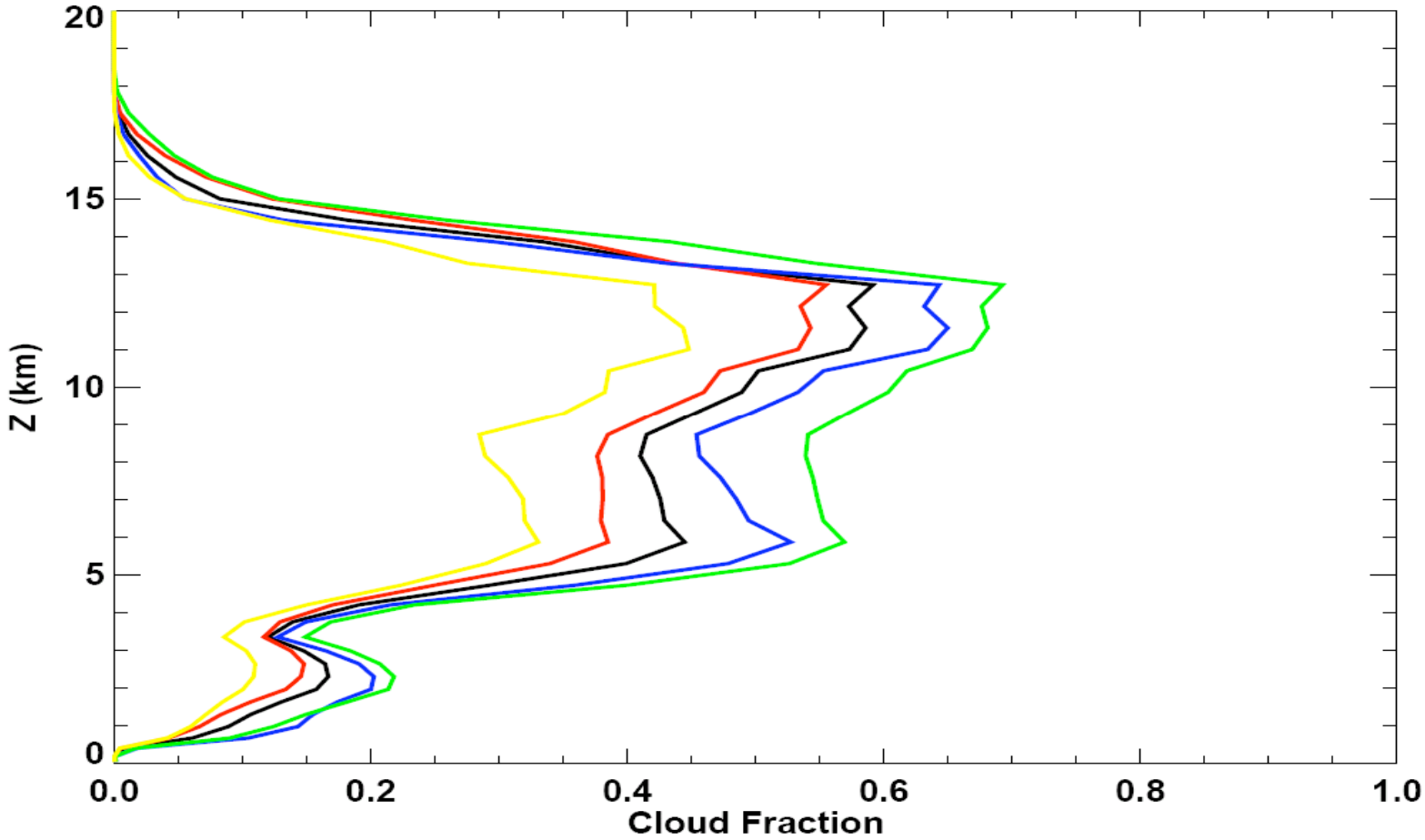
- The Advanced Regional Prediction System/Langley Research Center (ARPS/LaRC) model; based on ARPS (Xue et al. 2000).
- Includes Fu-Liou (1993) radiative transfer parameterization.
- Uses Lin et al. (1983) microphysics, with modifications following Krueger et al. (1995).
- Simulations run for 24 h, only last 12 h is analyzed.
- Periodic domain 512 km wide (Δx = 2km), 25 km high (stretched; average Δz = 500 m).

Methodology

- 68 large (D_{eff} > 300 km) cloud objects (contiguous regions with τ>10 and cloud top z>10 km) were identified by CERES over the Pacific in March 1998.
- The time and location of each cloud object are then matched to an ECMWF analysis to obtain the atmospheric state and large-scale forcing in the area of the cloud object.
- Ran five sets of simulations, a control with observed SSTs and standard large-scale forcing; two sets where the SST is raised or lowered by 2K; two sets where the large-scale forcing is increased or decreased by 50%.

Cloud fraction

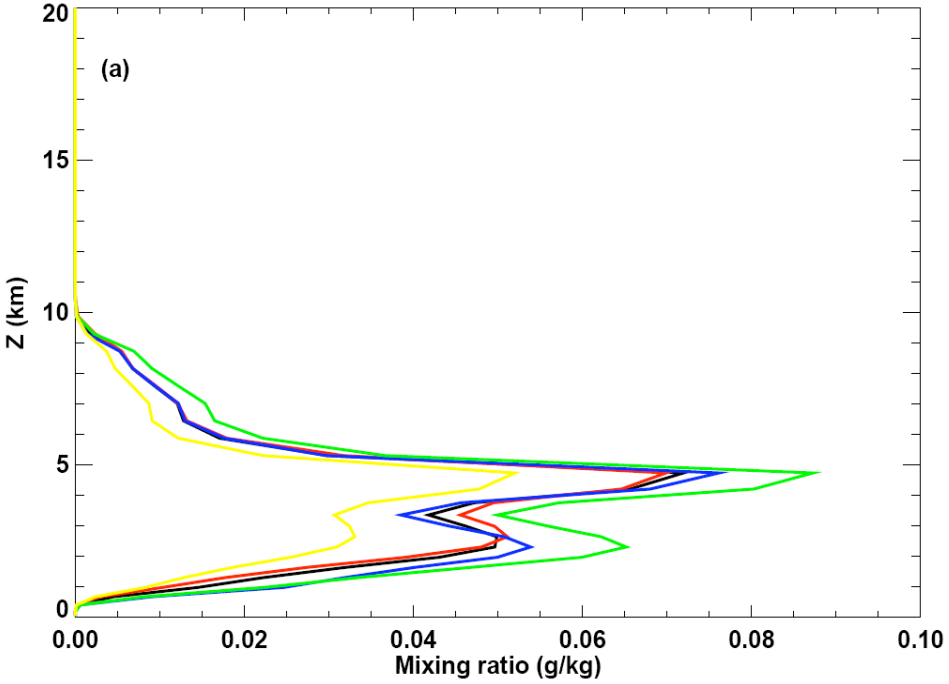
CTL, SST-2K, SST+2K, FRC-50%, FRC+50%



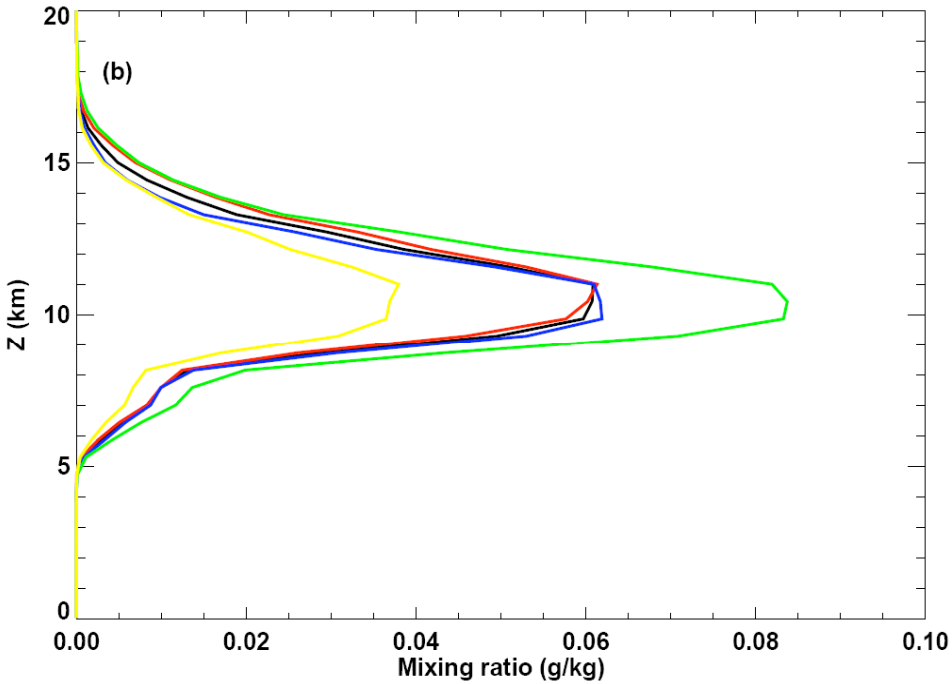
Average hydrometeor profiles

CTL, SST-2K, SST+2K, FRC-50%, FRC+50%

Cloud liquid water



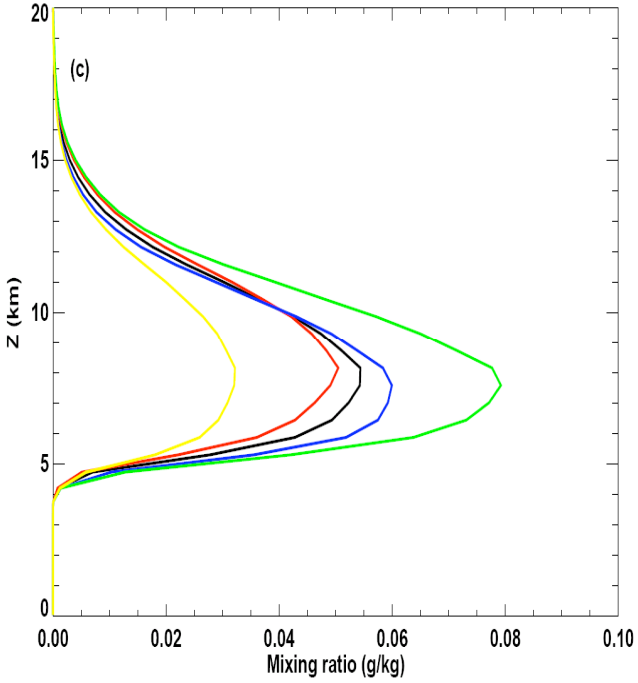
Cloud ice



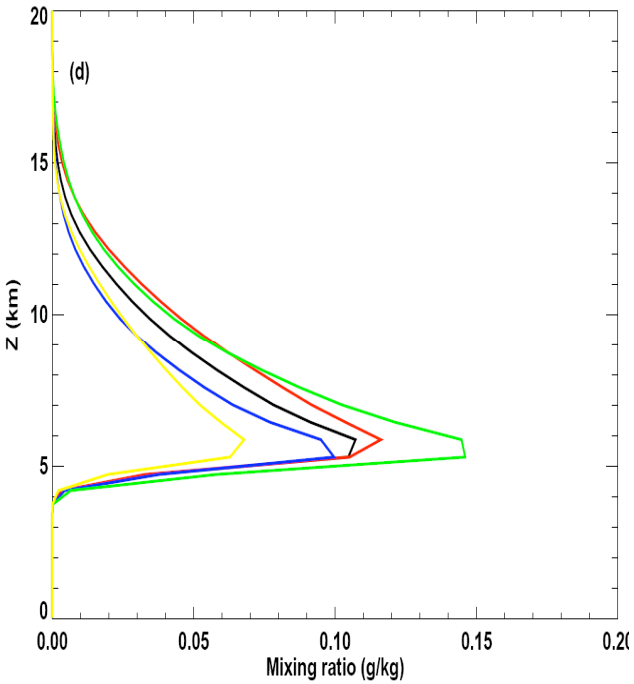
Average hydrometeor profiles

CTL, SST-2K, SST+2K, FRC-50%, FRC+50%

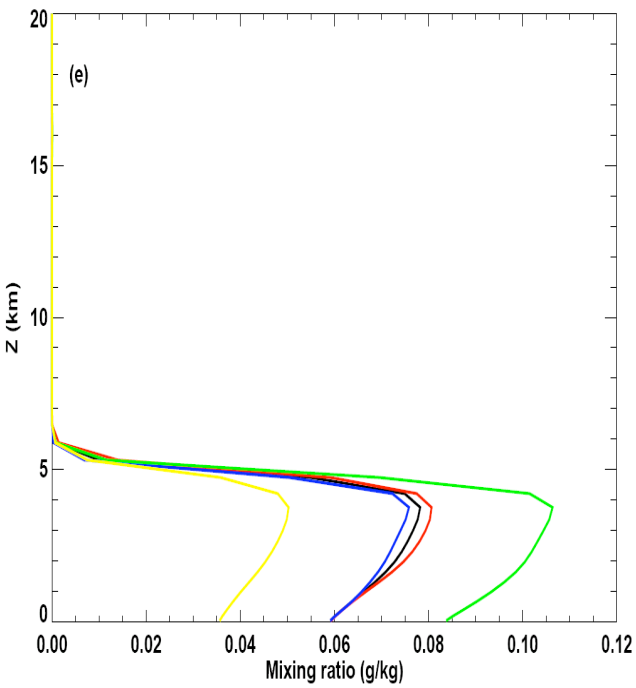
Snow



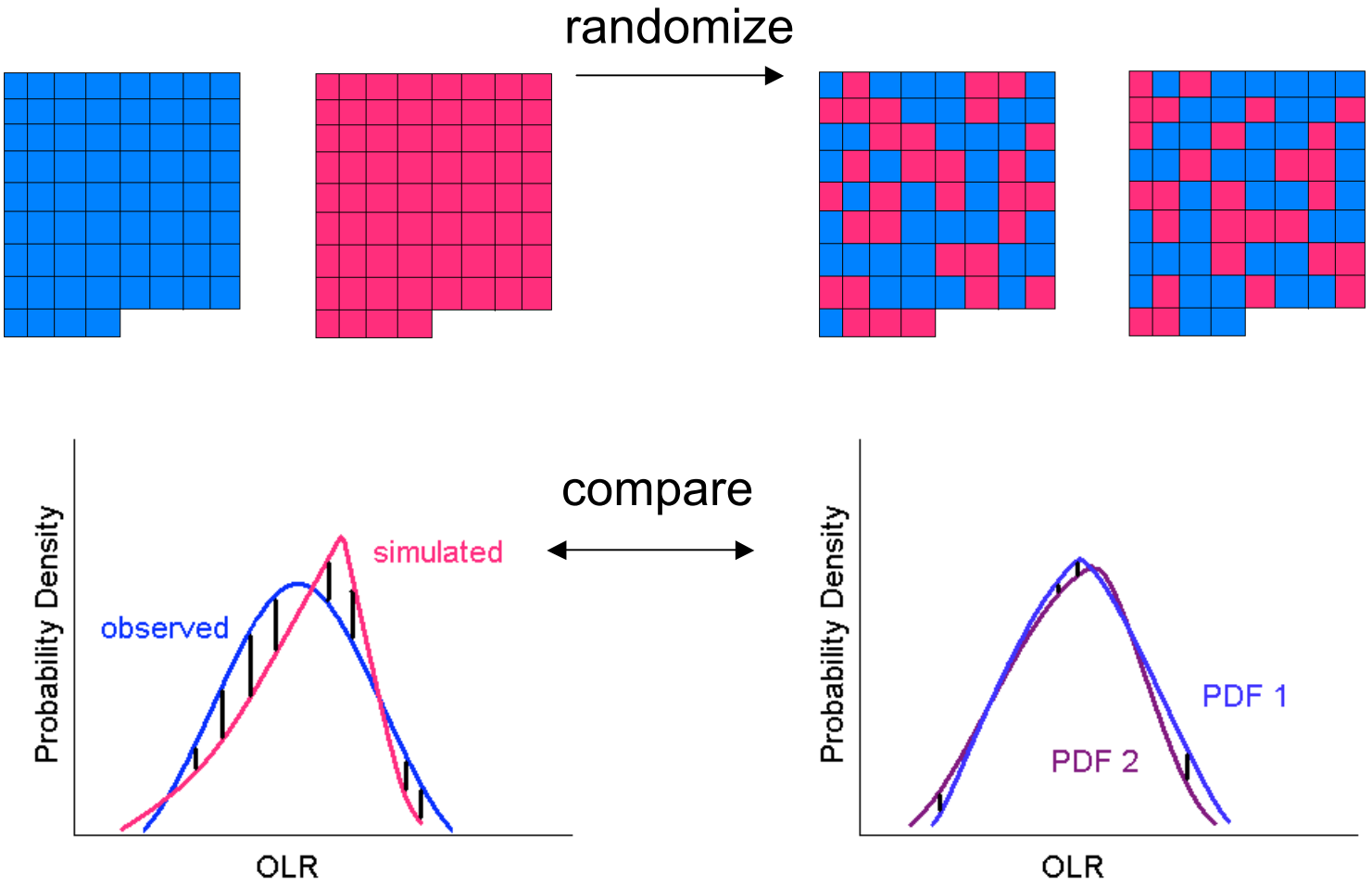
Graupel



Rain



Bootstrap significance test



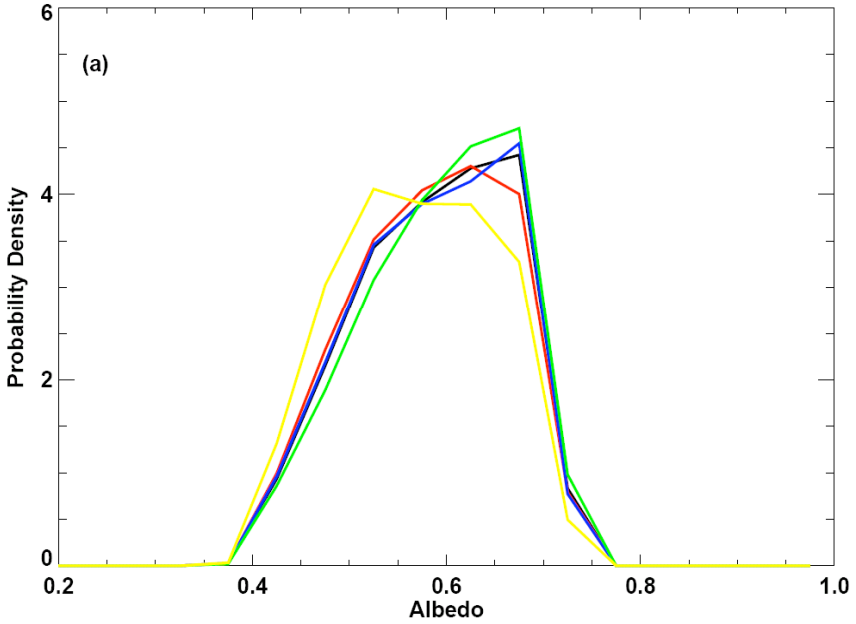
Results: Albedo

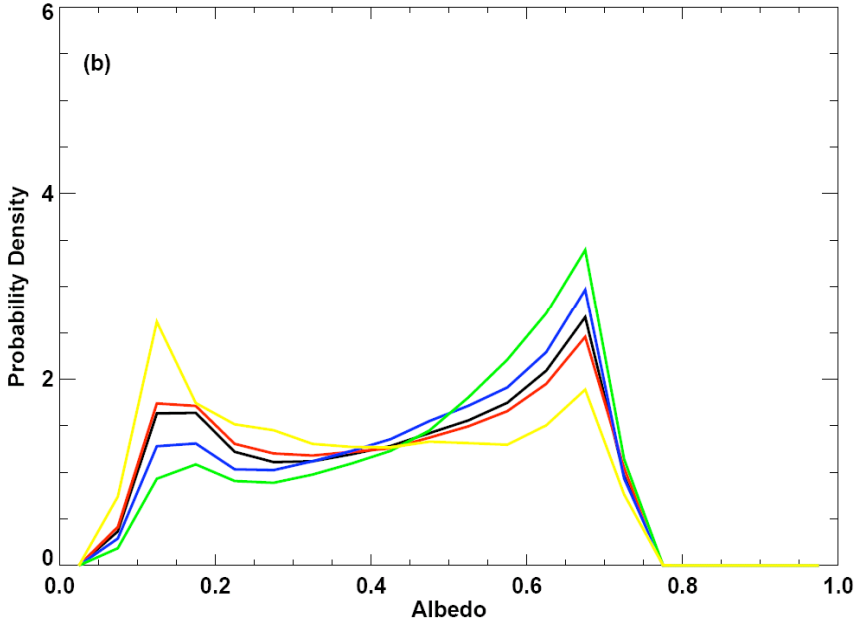
Deep convective clouds

Comparison	L2	p
SST+2K vs. SST-2K	0.030	75%
FRC+50% vs. FRC-50%	0.113	2%

All clouds

Comparison	L2	p
SST+2K vs. SST-2K	0.051	5%
FRC+50% vs. FRC-50%	0.153	<1%





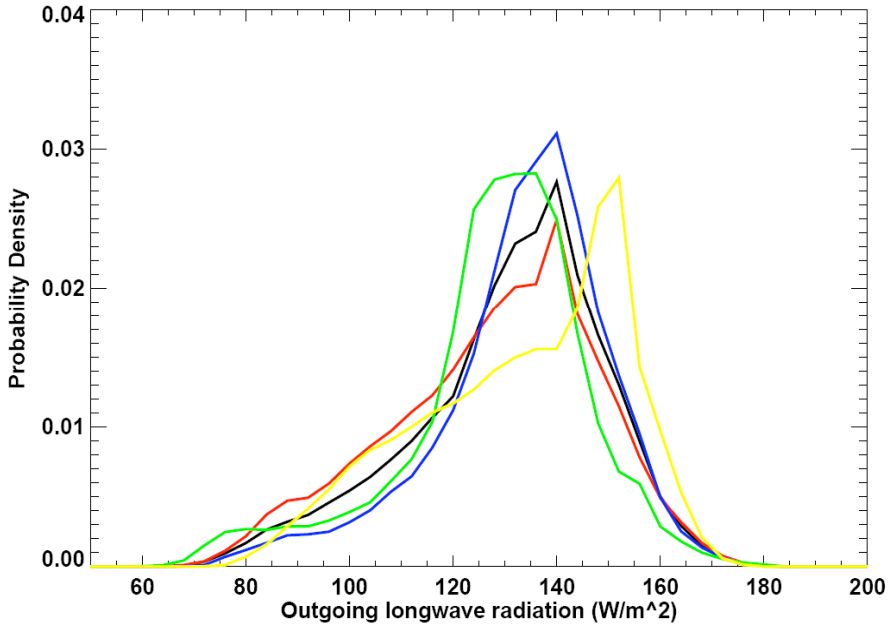
Results: OLR

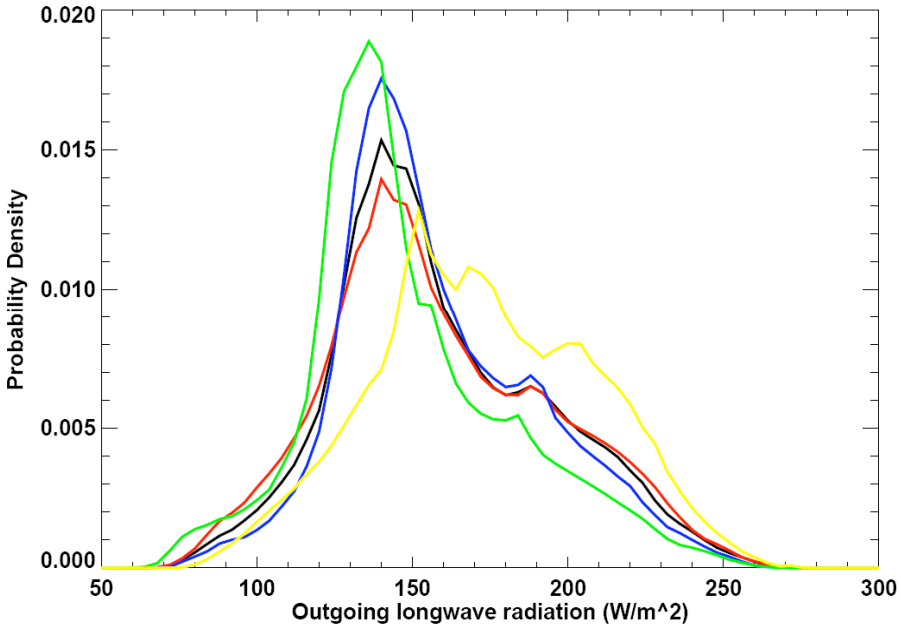
Deep convective clouds

Comparison	L2	p
SST+2K vs. SST-2K	0.078	10%
FRC+50% vs. FRC-50%	0.165	<1%

All clouds

Comparison	L2	p
SST+2K vs. SST-2K	0.039	10%
FRC+50% vs. FRC-50%	0.131	<1%





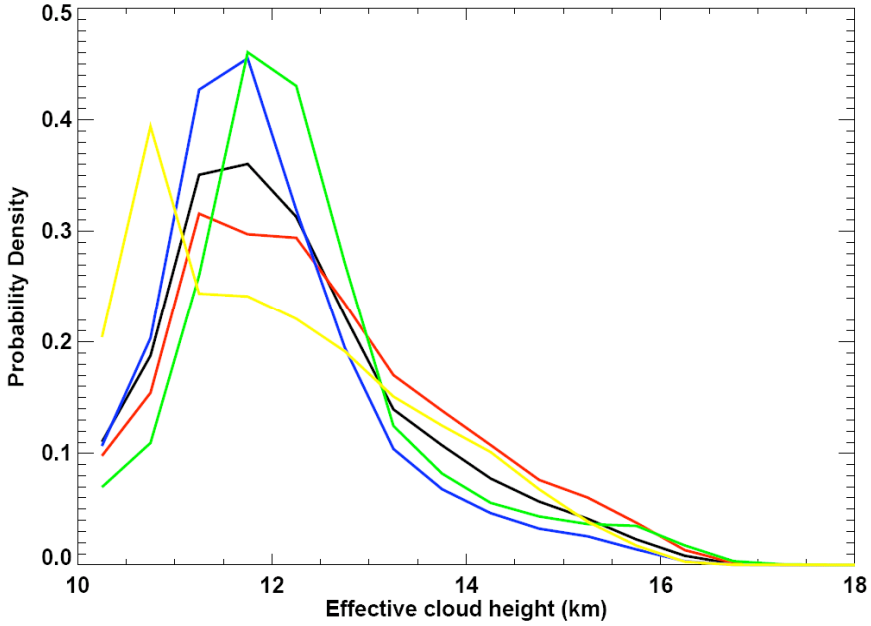
Results: Cloud top height

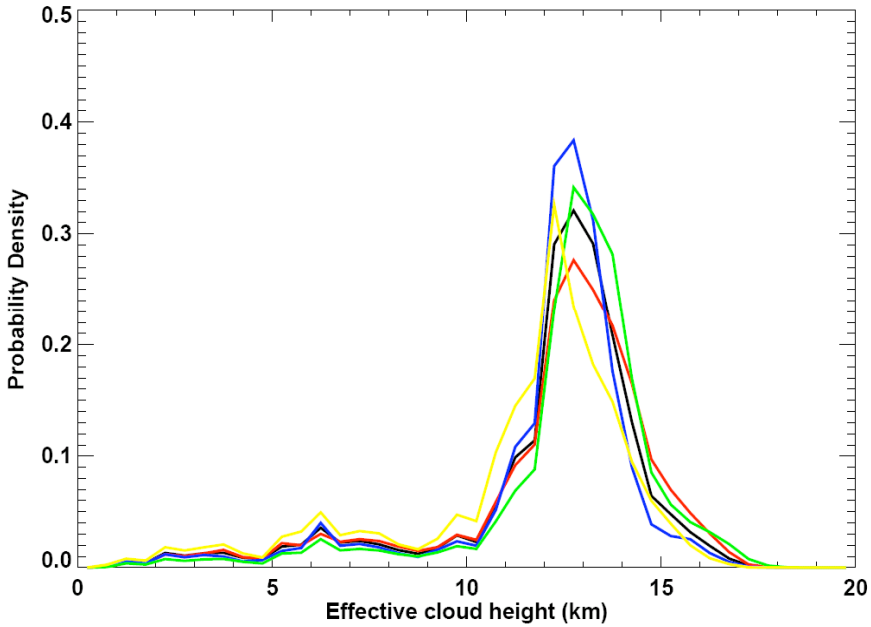
Deep convective clouds

Comparison	L2	p
SST+2K vs. SST-2K	0.088	3%
FRC+50% vs. FRC-50%	0.195	<1%

All clouds

Comparison	L2	p
SST+2K vs. SST-2K	0.105	<1%
FRC+50% vs. FRC-50%	0.145	<1%





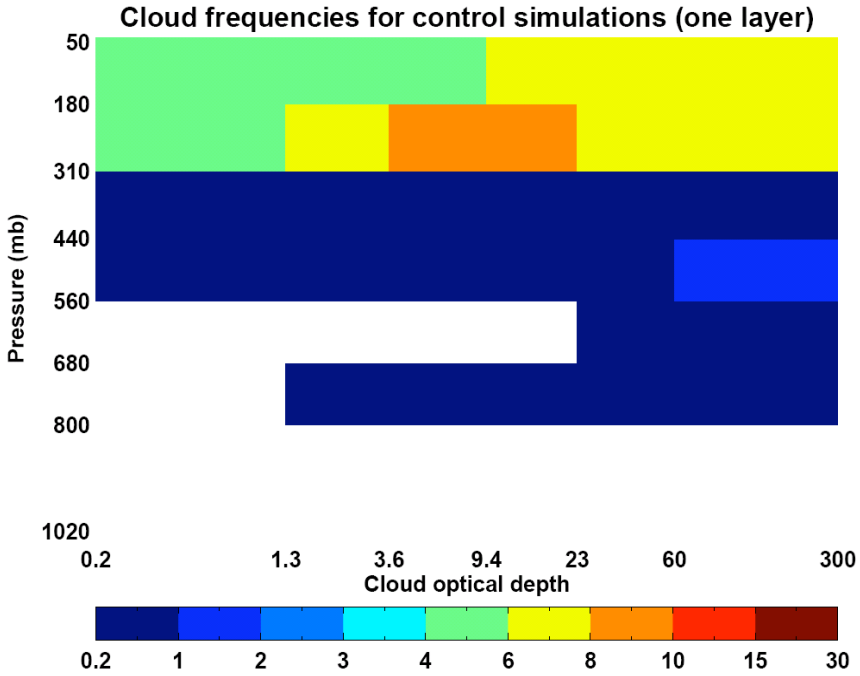
Multilayer Clouds

- The cloud top pressure and total optical depth of each column can be tabulated, or cloud tops and optical depths of discrete cloudy layers within the columns can also be tabulated.

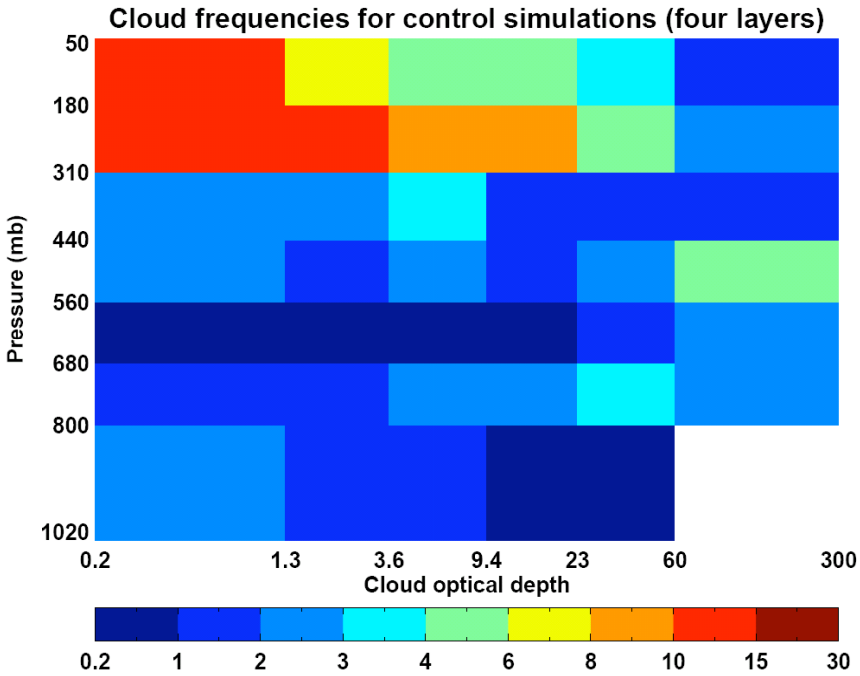
	CTL	SST-2K	SST+2K	FRC-50%	FRC+50%
clear	10.6	6.6	13.2	20.0	5.4
1 cloudy layer	50.5	46.7	52.3	50.2	50.0
2 cloudy layers	30.8	35.1	28.3	24.1	34.4
3 cloudy layers	7.2	10.2	5.7	5.1	9.1
4+ cloudy layers	0.8	1.4	0.6	0.6	1.1

Optical depth – Cloud top height frequency distributions

Single layer (CTL)

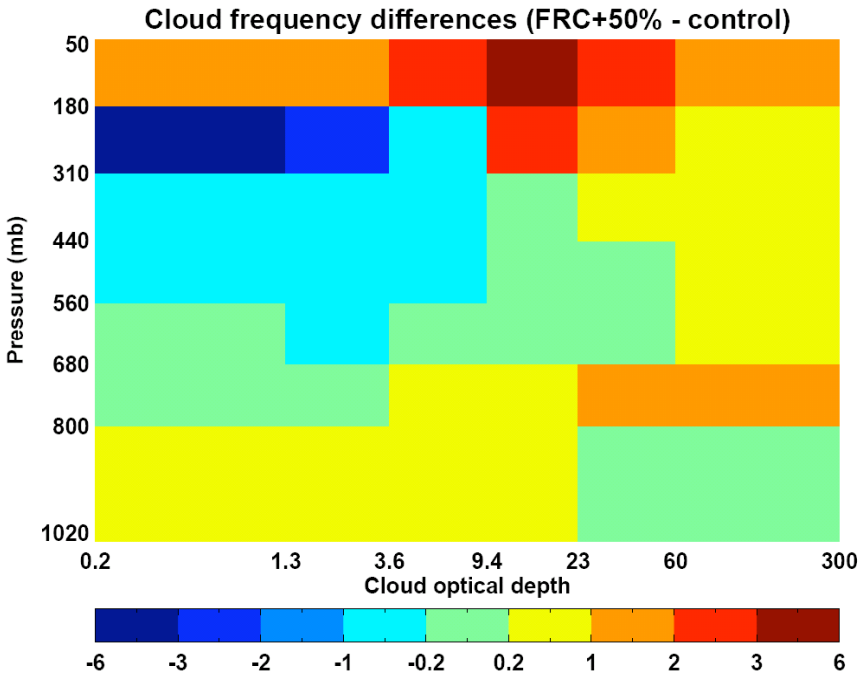


Multi-layer (CTL)

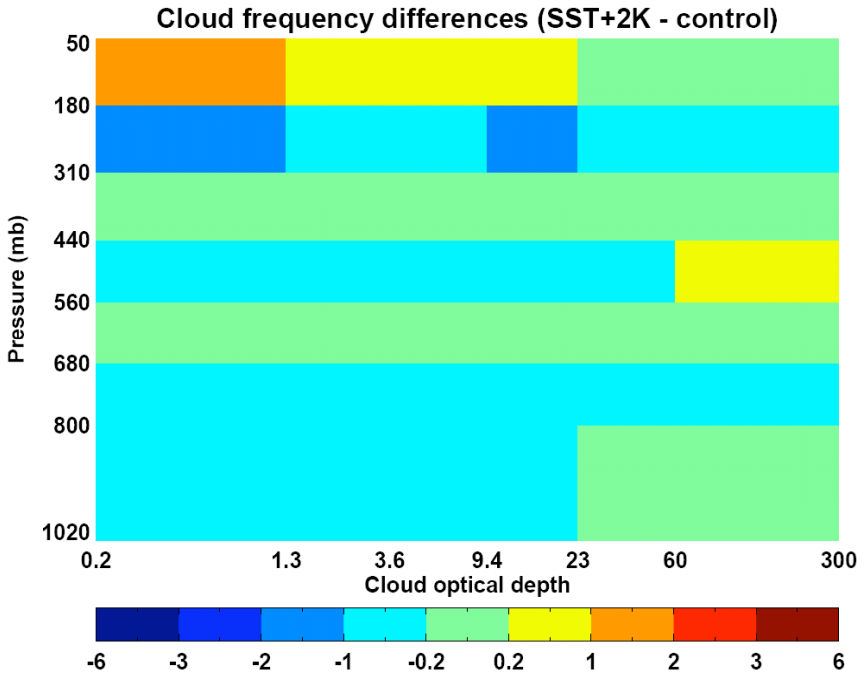


Optical depth – Cloud top height frequency distributions

FRC+50% - CTL



SST+2K - CTL



Conclusions

- The simulated clouds are generally more sensitive to changes in the large-scale forcing than the SST.
- Cloud properties associated with SW (albedo, optical depth, cloud ice) generally less affected than properties associated with LW (cloud top height, cloud top temperature) for deep convective clouds.
- Most cloud properties affected in “all cloud” comparisons.
- Multilayer clouds quite prevalent in simulations, it will be interesting to verify this with CloudSat/CALIPSO.