The CERES Flux-by-Cloud Type Simulator

Zachary Eitzen[1]
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Thanks to: Wenying Su[2], Kuan-Man Xu[2], Norman Loeb[2],
Moguo Sun[1], David Doelling[2], Alejandro Bodas-Salcedo[3], and Fred Rose[1]

1 - Science Systems and Applications, Inc
2 - NASA Langley Research Center
3 - Met Office Hadley Centre for Climate Change

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Evaluation of a general circulation model by the CERES Flux-by-cloud type simulator

Zachary A. Eitzen ✉, Wenying Su, Kuan-Man Xu, Norman Loeb,
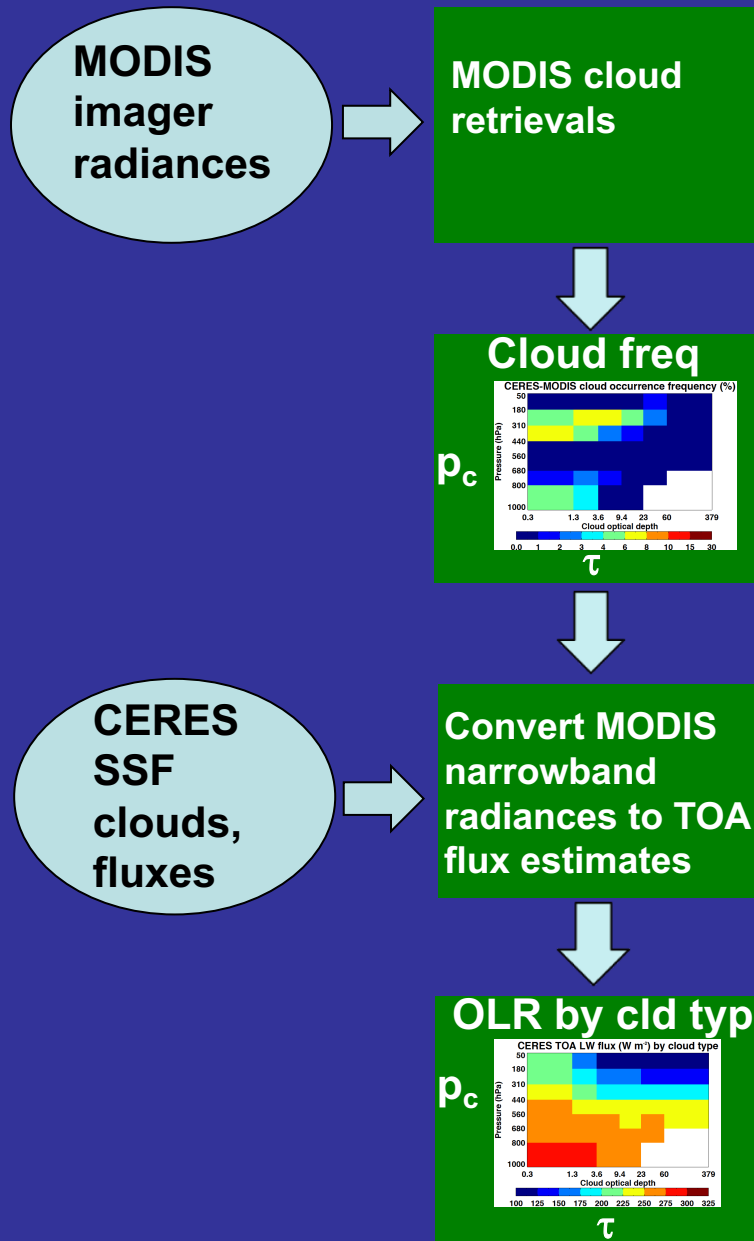Moguo Sun, David Doelling, Fred Rose, Alejandro Bodas-Salcedo

What is the Flux-by-cloud type product?

- Assigns LW and SW TOA fluxes to each observed ISCCP-like cloud type within a region.

- For each 1º×1º region between 60º S and 60º N, each daytime footprint is placed into one or more p_c-τ ISCCP-like categories based on CERES-MODIS cloud property retrievals.

- For the footprints with a single cloud type, the standard Single Scanner Footprint flux is added to that p_c-τ category.

- For footprints with multiple cloud types, narrowband-to-broadband radiance conversions are performed for each cloud type.

- Broadband radiances are converted to fluxes using Angular Distribution Models.
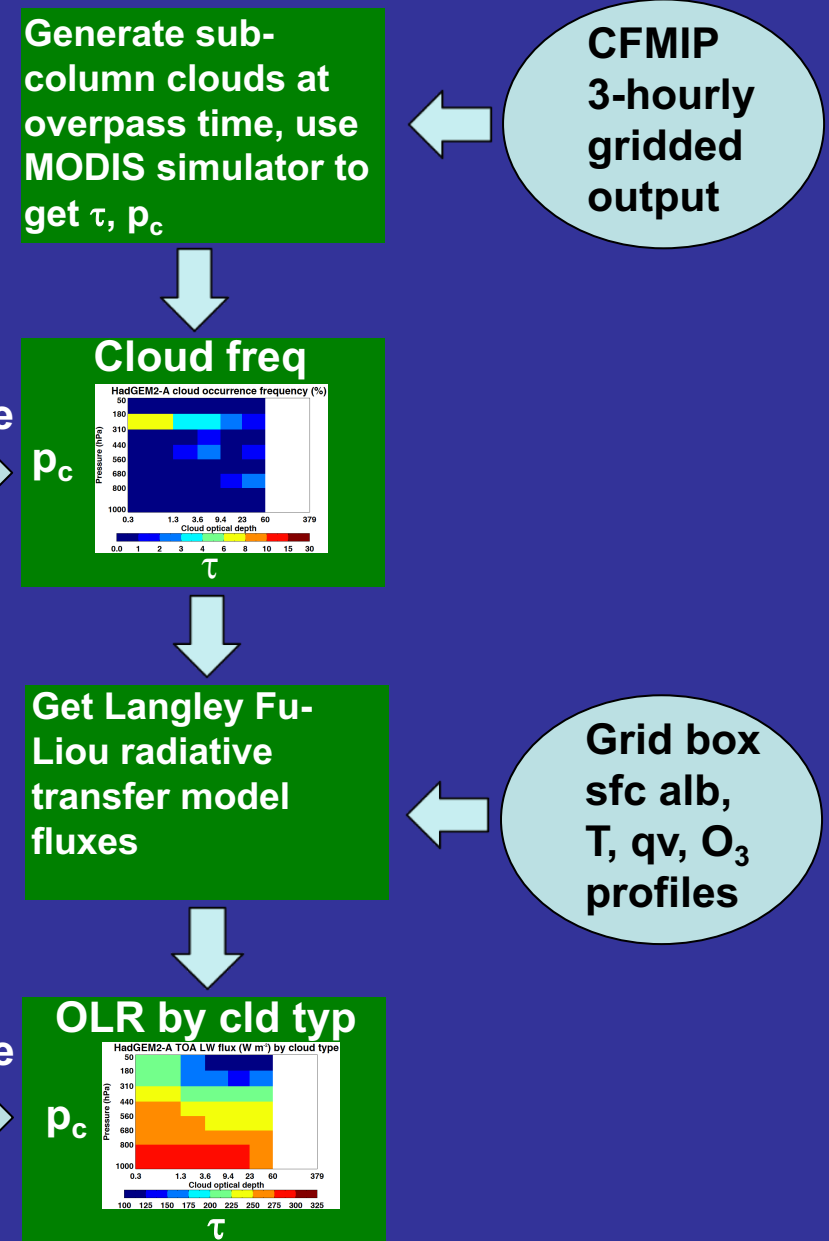
Motivation for flux-by-cloud type simulator

- Cloud properties and fluxes/albedos will be matched within 1.5 hours to the closest CERES overpass, which is important because of the large diurnal cycles in cloud fraction, τ, and p_c in many areas.

- Breaking out the flux by cloud type can help isolate physical parameterizations that are problematic (e.g., convective clouds, boundary-layer parameterizations, or processes involving surface albedo), and provide a test for new parameterizations.

- Having the radiative properties for each τ and p_c provides more information than the cloud frequencies alone, since there can be significant variations in albedo and OLR within a given p_c-τ cloud type, and ice clouds are treated differently among GCMs.

- Diagnoses using flux-by-cloud type combined with frequency of occurrence can also help determine whether an unrealistically small or large occurrence of a given cloud type has an important radiative impact for a given region.

CERES FluxByCloudTyp Product

CERES Flux-by-cloud Type Simulator

MODIS imager radiances → MODIS cloud retrievals

Generate sub-column clouds at overpass time, use MODIS simulator to get τ, p_c ← CFMIP 3-hourly gridded output

Cloud freq

p_c

CERES-MODIS cloud occurrence frequency (%)

τ

Evaluate

Cloud freq

p_c

HadGEM2-A cloud occurrence frequency (%)

τ

CERES SSF clouds, fluxes → Convert MODIS narrowband radiances to TOA flux estimates

Get Langley Fu-Liou radiative transfer model fluxes ← Grid box sfc alb, T, qv, O_3 profiles

OLR by cld typ

p_c

CERES TOA LW flux (W m^{-2}) by cloud type

τ

Evaluate

OLR by cld typ

p_c

HadGEM2-A TOA LW flux (W m^{-2}) by cloud type

τ

Flux consistency check

- In order to verify that the simulator produces fluxes similar to those of HadGEM2-A, TOA LW and SW fluxes were calculated by the simulator for ~500K cases per month at locations between 60º N and 60º S for 2008 and the fluxes averaged over all of the subcolumns were compared to the grid cell mean fluxes.

	TOA Reflected Shortwave (W m^{-2})			TOA OLR (W m^{-2})		
	Mean	Bias	RMS	Mean	Bias	RMS
JFD 2008	242.6	-1.5	14.4	246.2	-1.6	3.4
MAM 2008	238.4	-0.9	15.0	249.6	-1.4	3.8
JJA 2008	223.9	-0.9	14.4	254.2	-1.4	3.9
SON 2008	233.9	-1.6	14.3	252.4	-1.6	3.5

Number of calculations required substantially decreases by identifying identical subcolumns

- Although 1000 subcolumns of cloud are calculated per grid cell using the SCOPS cloud generator and the grid-mean vertical cloud fraction profile, many duplicate subcolumns are identified, making only ~24 calculations necessary per grid cell.

	Number of calculations	Number of grid cells	Calculations per cell
JFD 2008	38956272	1573931	24.8
MAM 2008	38139748	1578995	24.2
JJA 2008	37642400	1591427	23.7
SON 2008	36438316	1590258	22.9
All 2008	151176736	6334611	23.9

Southern Great Plains results
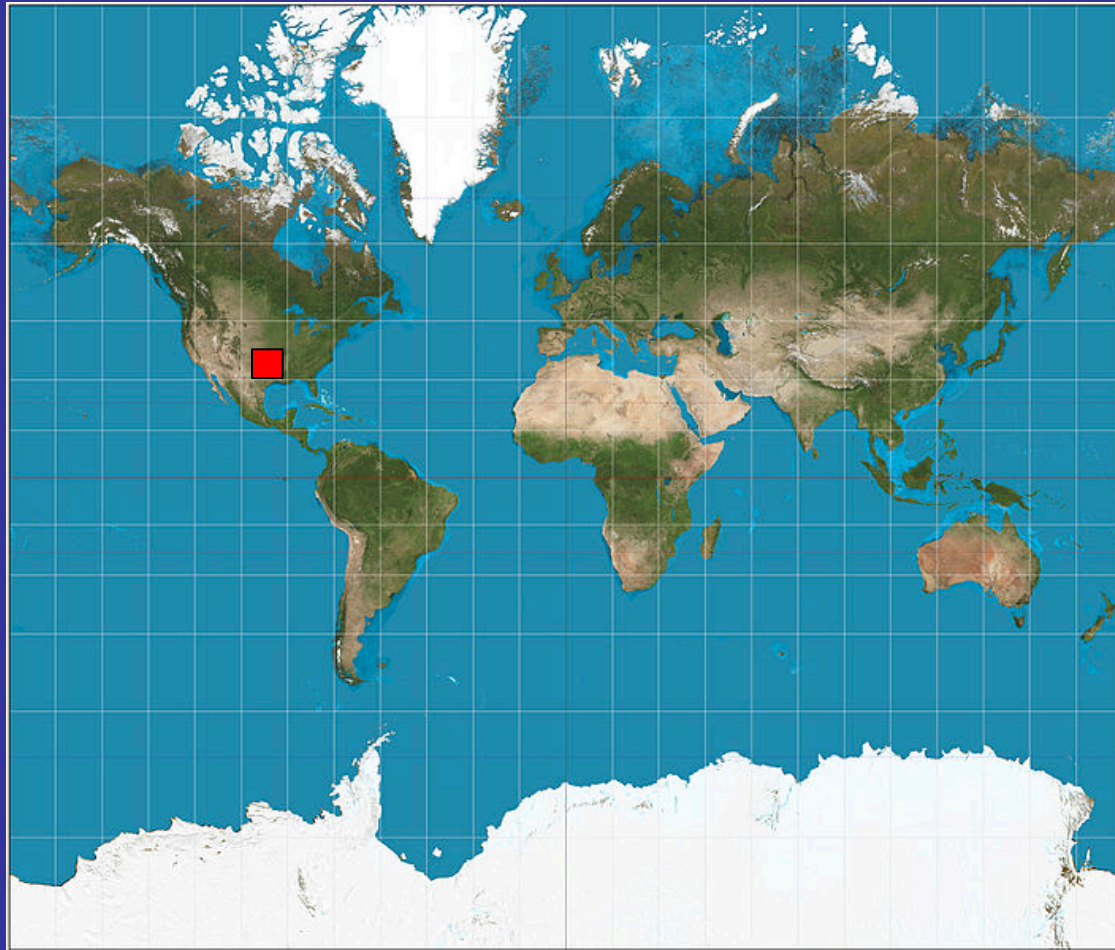
Image from Strebe, https://commons.wikimedia.org/wiki/File:Mercator_projection_SW.jpg

Cloud fraction (%) for CERES, HadGEM2-A over SGP (JFD 2008)
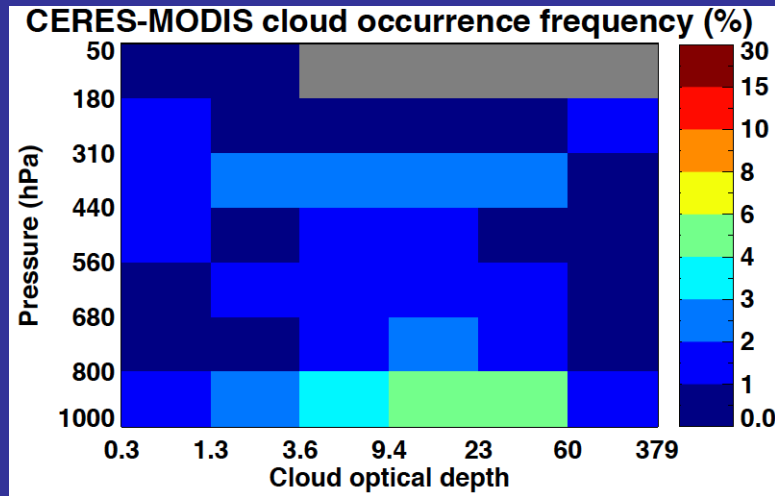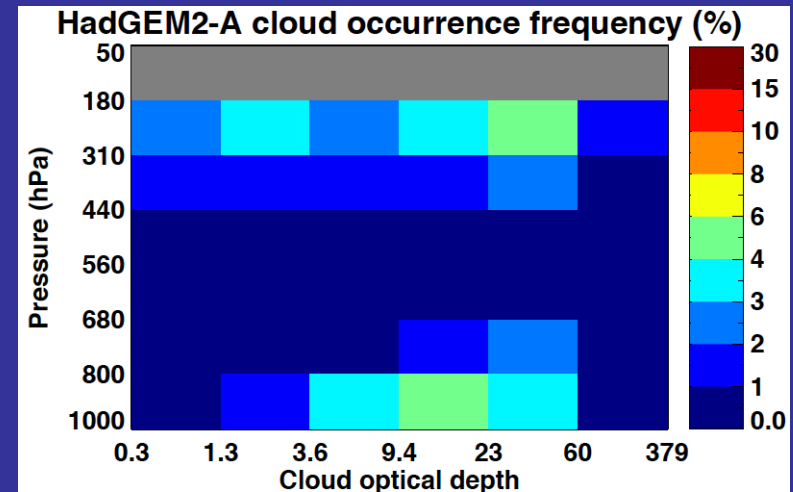
CERES

HadGEM2-A
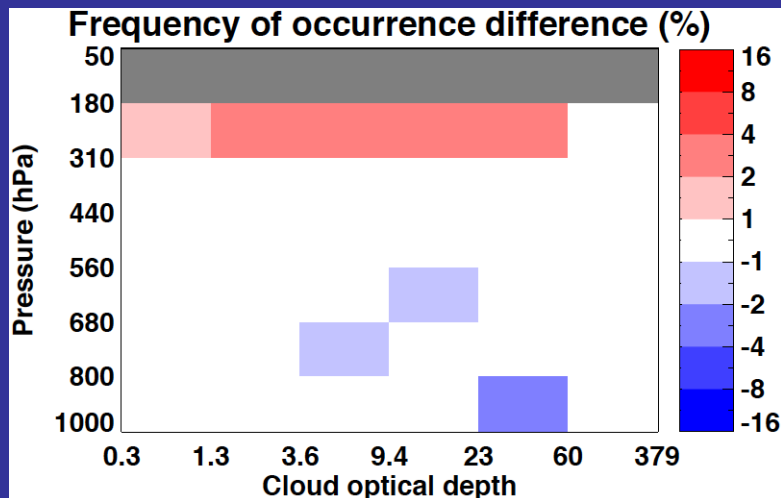
HadGEM2-A – CERES

Grid-mean total cloud fraction:
CERES: 0.558
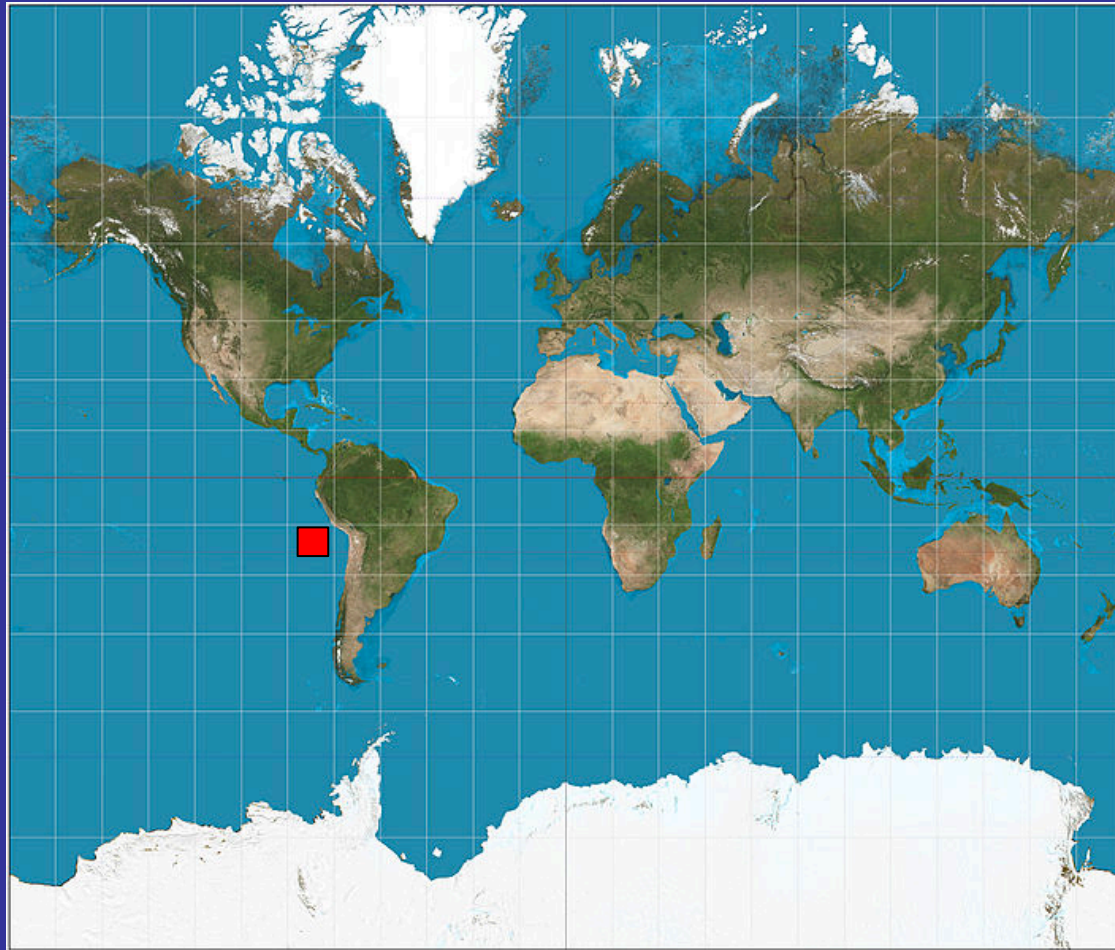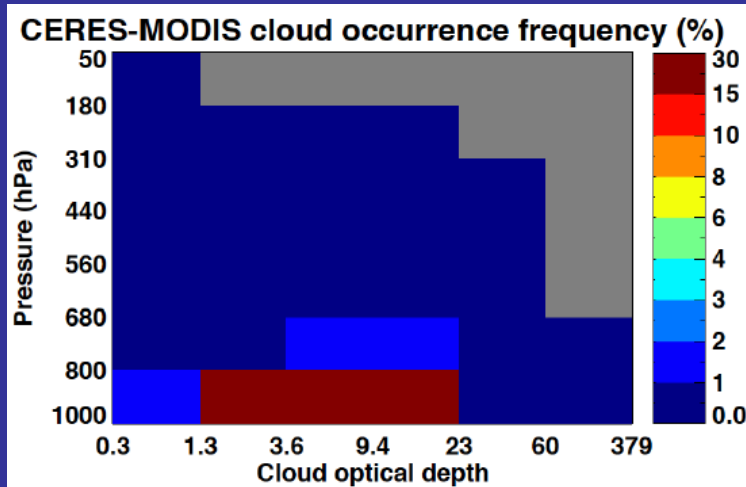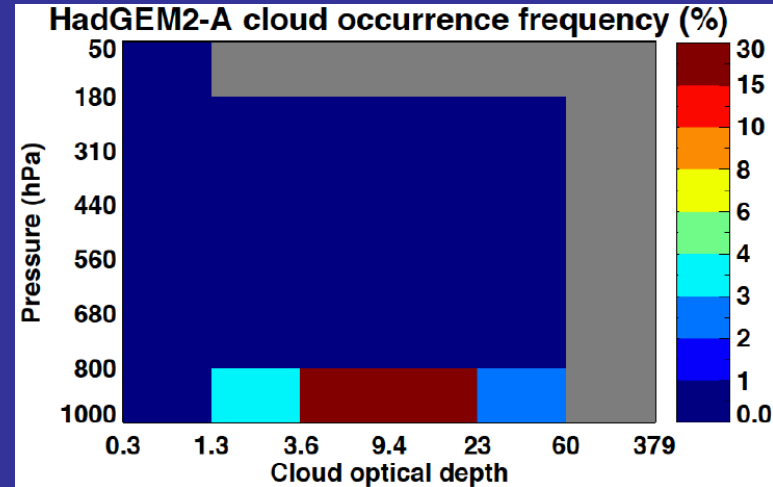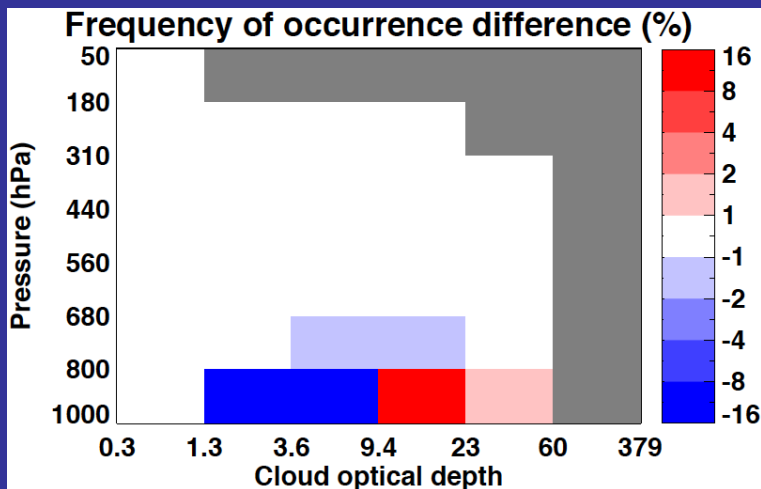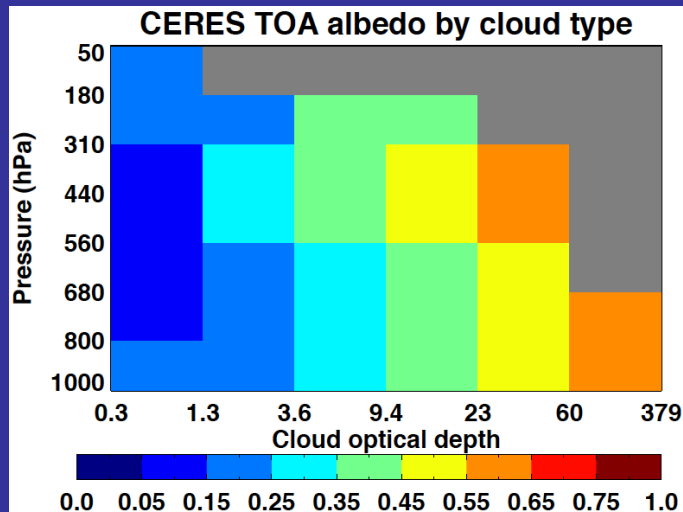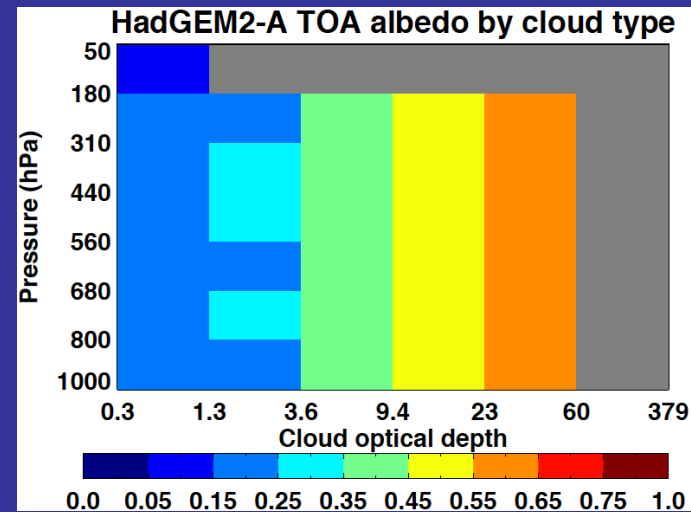HadGEM2-A: 0.520

Cloud fraction weighting

- Many possible ways to do this, but we opted to choose a method that preserves the sign of the LW flux/albedo difference and is large if the CERES (C) and/or HadGEM (H) cloud fraction is large.
- $\Delta OLR_{cf} = 0.5(f_H + f_C)(OLR_H - OLR_C)$
- Quantities are multiplied by 100 in figures to account for small magnitude of most cloud fractions.

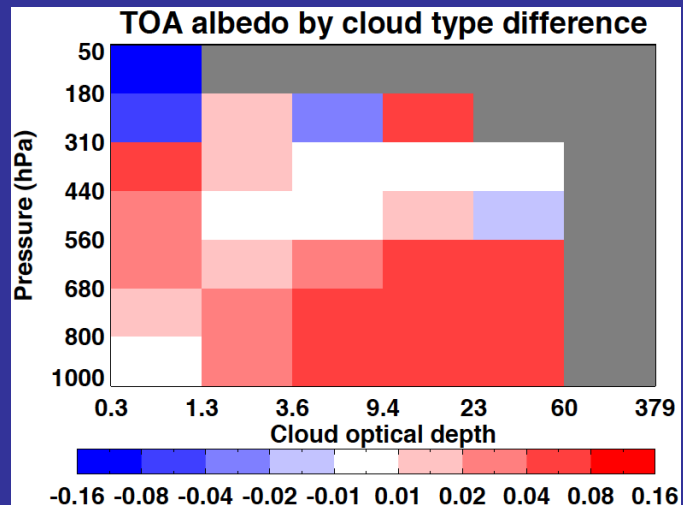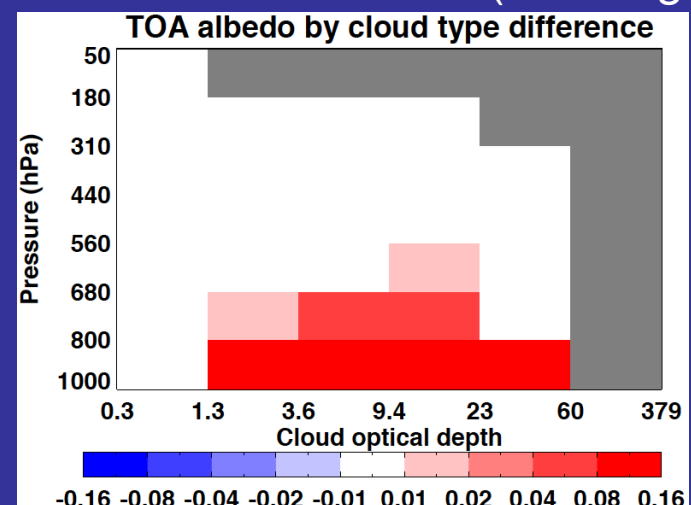# TOA SW albedo by cloud type for CERES, HadGEM2-A for SGP (JFD 2008)

CERES
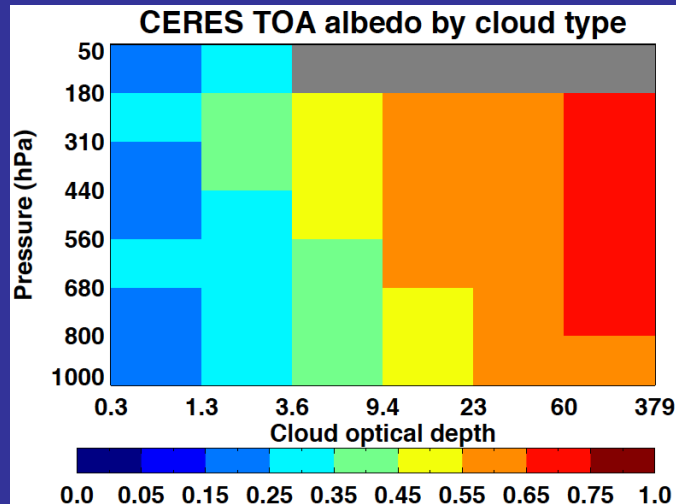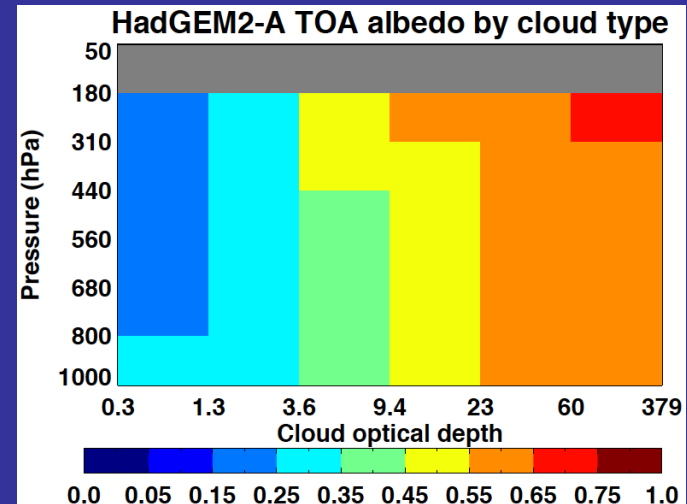
HadGEM2-A

HadGEM2-A – CERES

HadGEM2-A – CERES (CF-weighted)

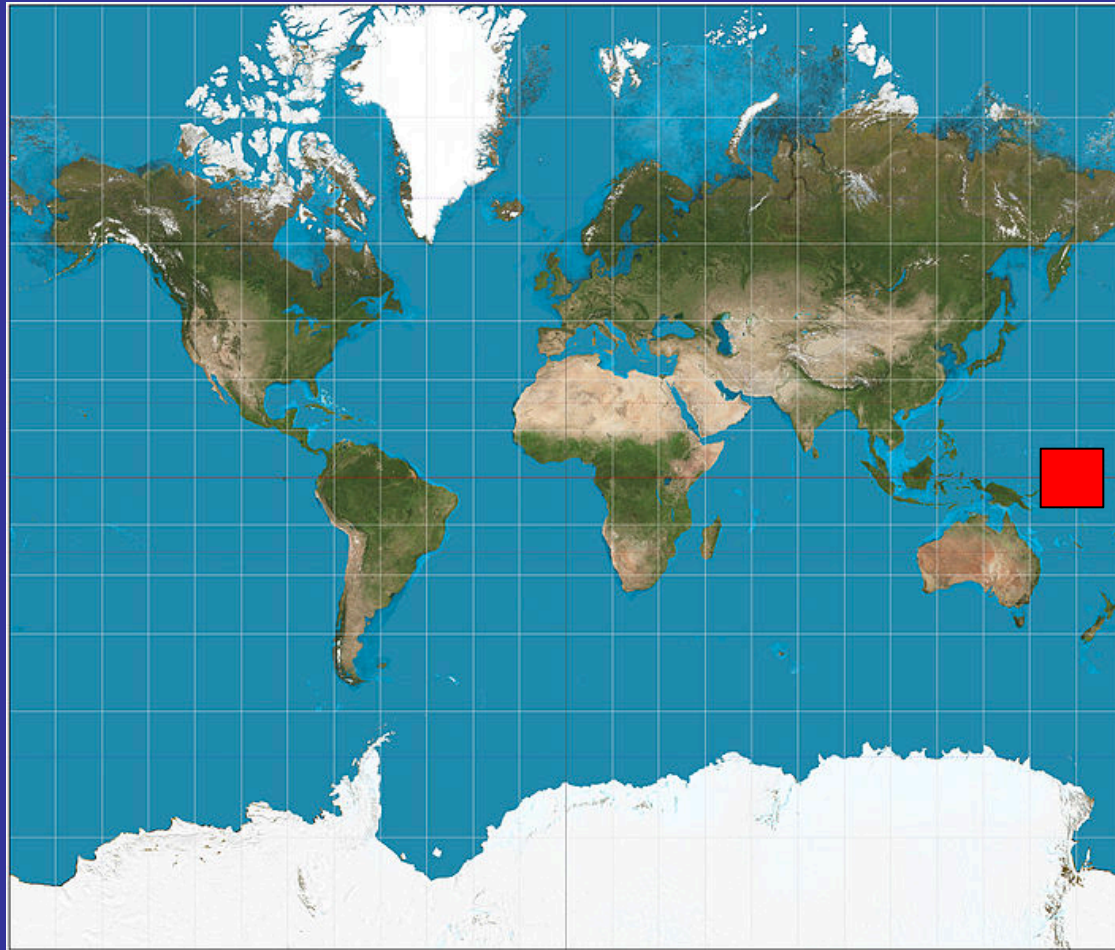Grid-mean all-sky SW albedo: CERES: 0.350 HadGEM2-A: 0.337

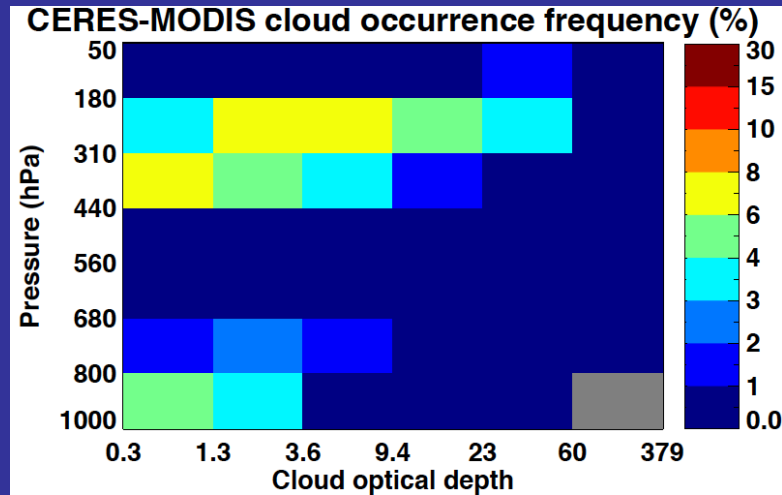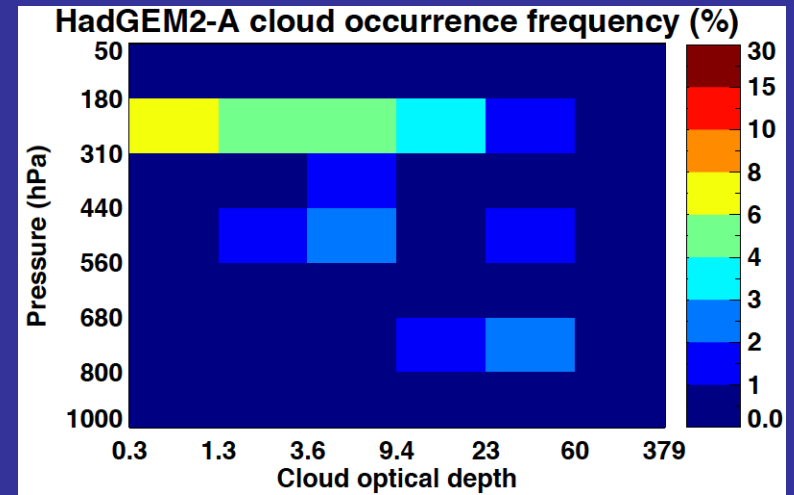# TOA LW flux by cloud type (W m^{-2}) for CERES, HadGEM2-A over SGP (JFD 2008)

CERES

HadGEM2-A

CERES TOA LW flux (W m^{-2}) by cloud type

HadGEM2-A TOA LW flux (W m^{-2}) by cloud type

HadGEM2-A − CERES

HadGEM2-A − CERES (CF-weighted)

TOA LW flux (W m^{-2}) by cloud type difference

TOA LW flux (W m^{-2}) by cloud type difference
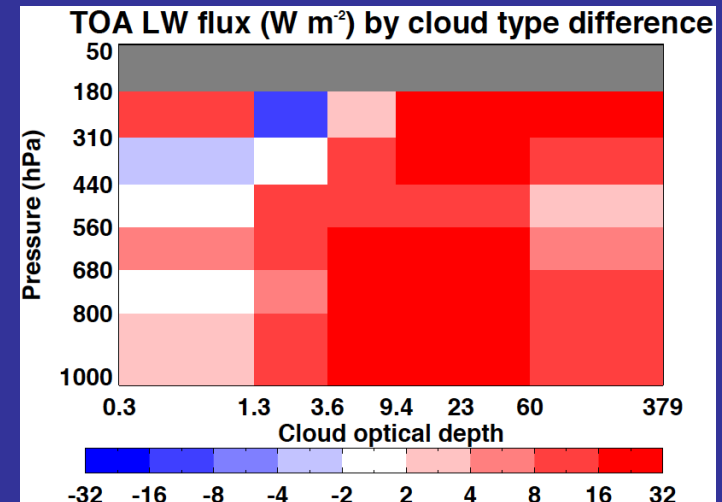
Grid-mean all-sky OLR: CERES: 233.4 W m^{-2} HadGEM2-A: 236.7 W m^{-2}

Temperatures warmer than observed in model atmosphere
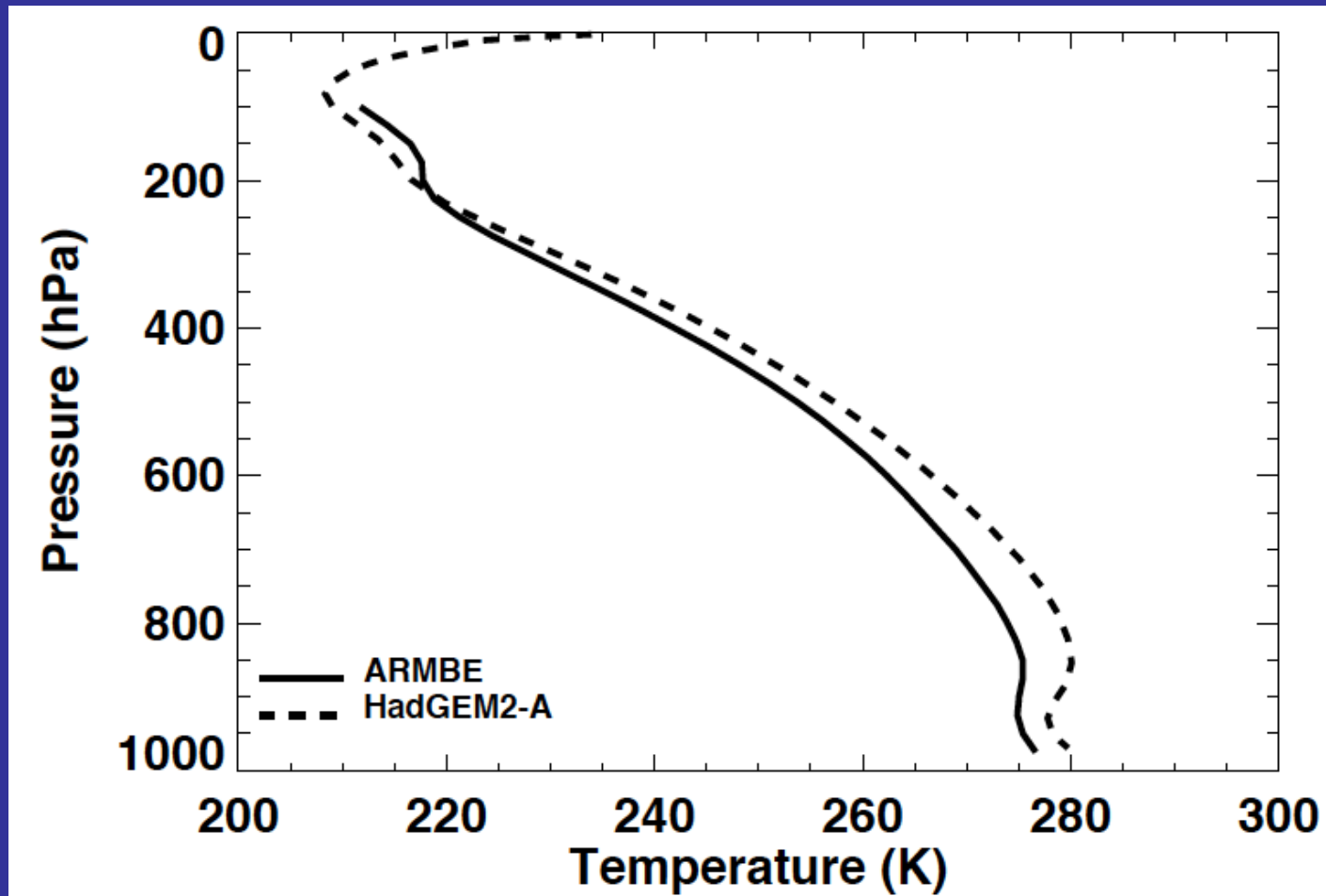
Southeast Pacific results

Cloud fraction (%) for CERES, HadGEM2-A over SE Pacific (JJA 2008)

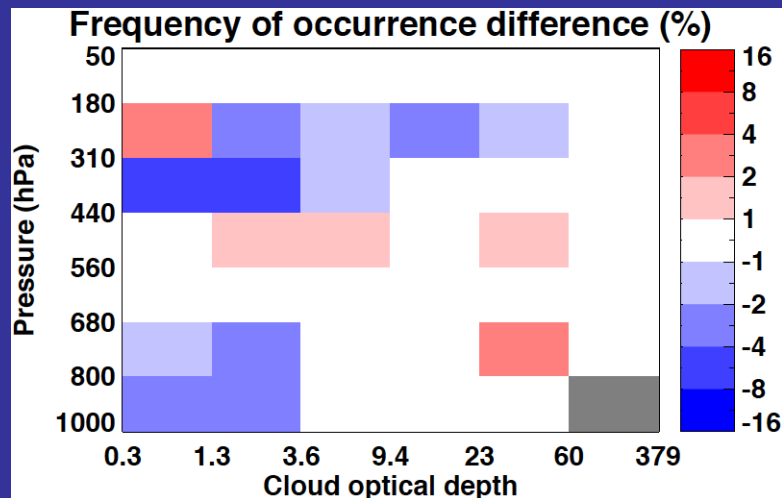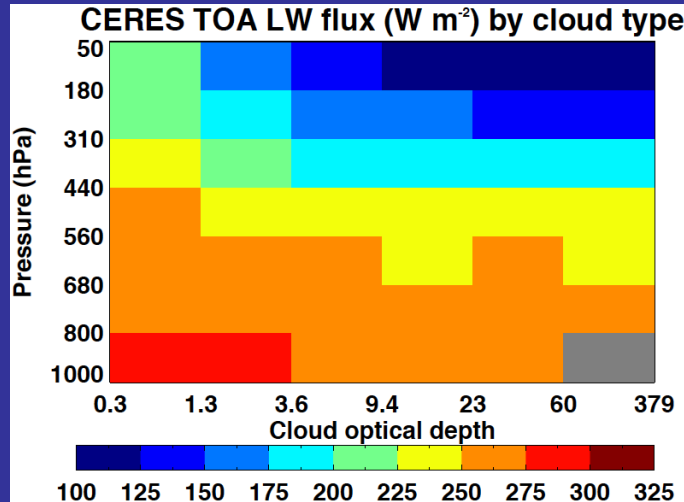CERES

HadGEM2-A

HadGEM2-A – CERES

Grid-mean total cloud fraction:
CERES: 0.801
HadGEM2-A: 0.658

TOA SW albedo by cloud type for CERES, HadGEM2-A over SE Pacific (JJA 2008)

Grid-mean all-sky SW albedo: CERES: 0.274 HadGEM2-A: 0.324

Equatorial Pacific results

Image from Strebe, https://commons.wikimedia.org/wiki/File:Mercator_projection_SW.jpg

Cloud fraction (%) for CERES, HadGEM2-A over Equatorial Pacific (JJA 2008)
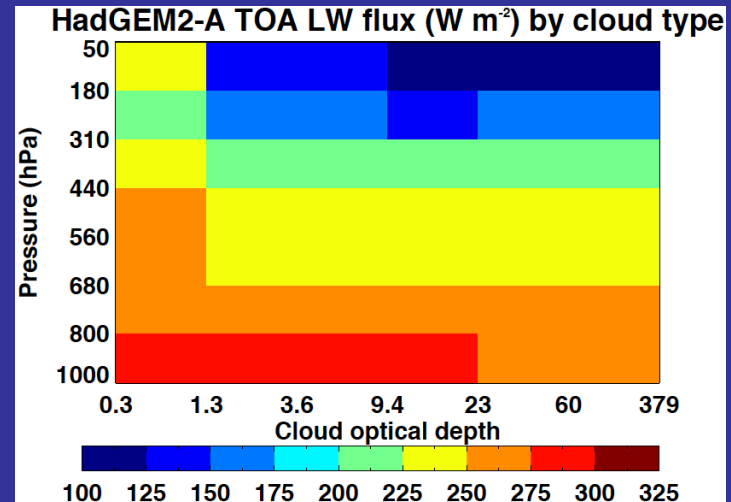
CERES

HadGEM2-A

HadGEM2-A – CERES

Grid-mean total cloud fraction:
CERES: 0.609
HadGEM2-A: 0.366

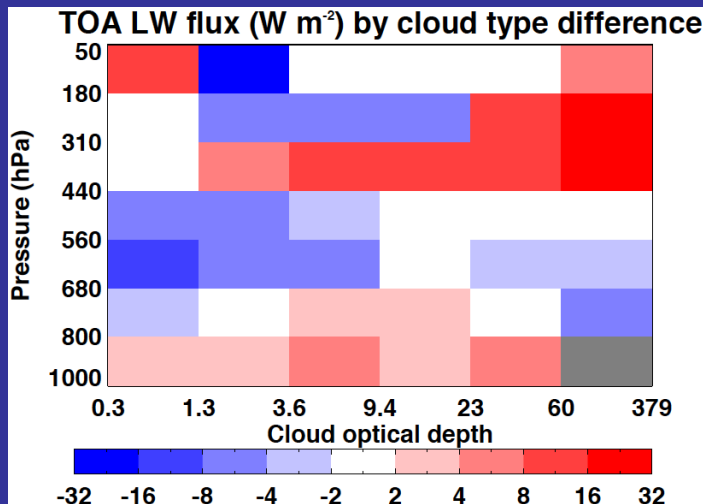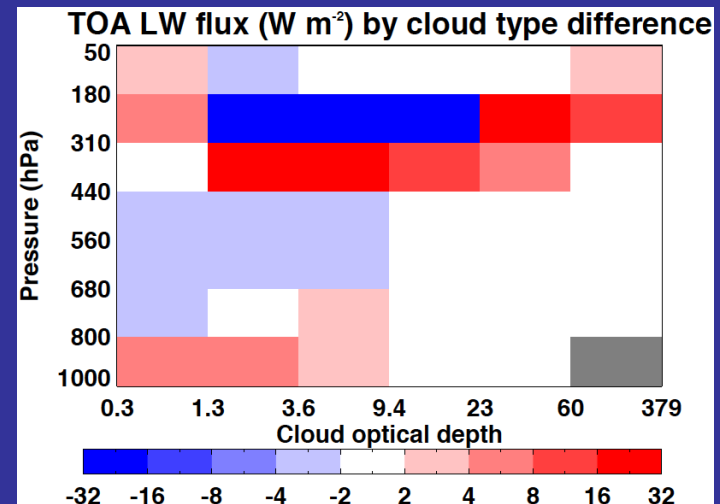# TOA LW flux by cloud type (W m⁻²) for CERES, HadGEM2-A over Equatorial Pacific (JJA 2008)

Grid-mean all-sky OLR: CERES: 236.6 W m⁻² HadGEM2-A: 258.7 W m⁻²
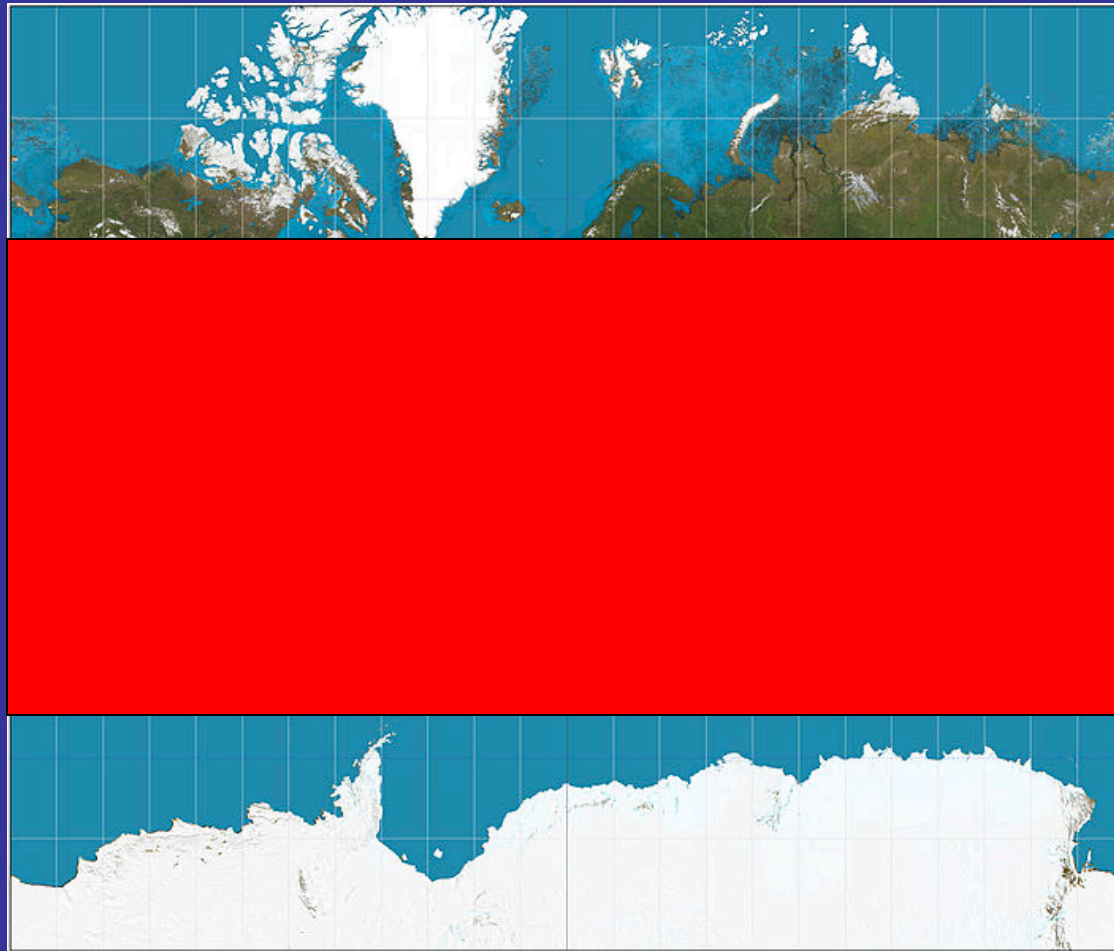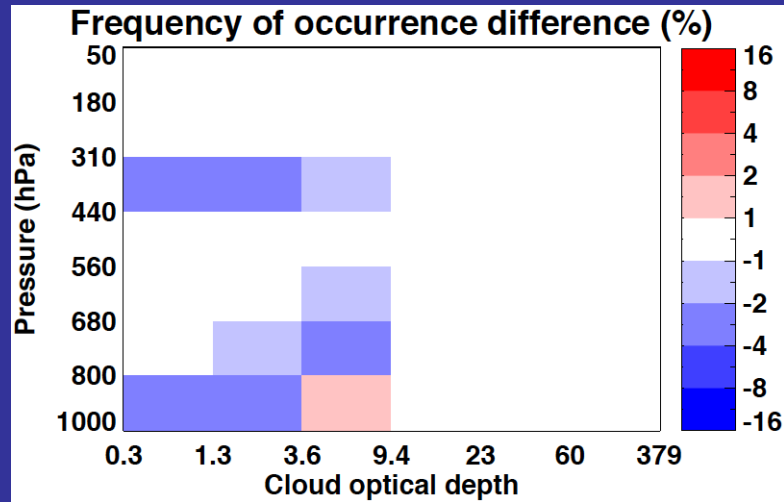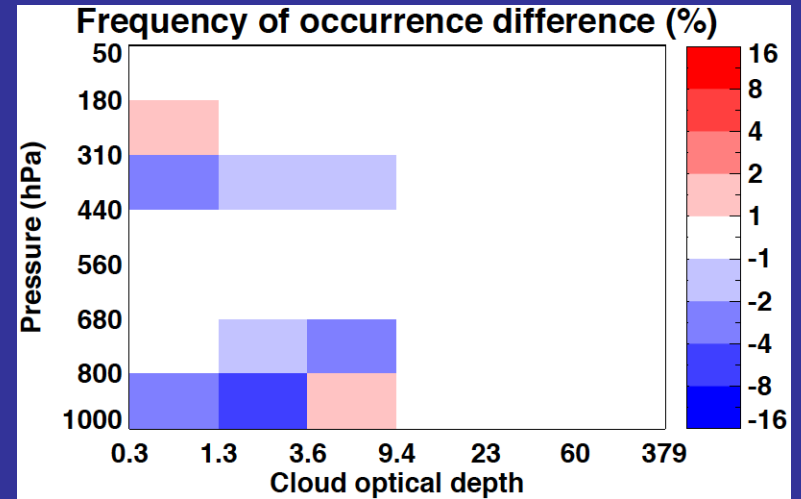
60º N – 60ºS results

Image from Strebe, https://commons.wikimedia.org/wiki/File:Mercator_projection_SW.jpg

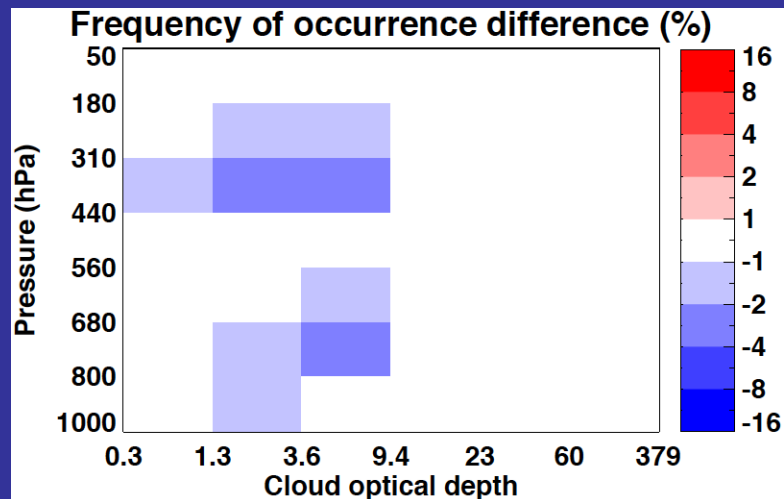# HadGEM2-A – CERES cloud fraction differences (%) over 60ºN – 60ºS (MAM 2008)
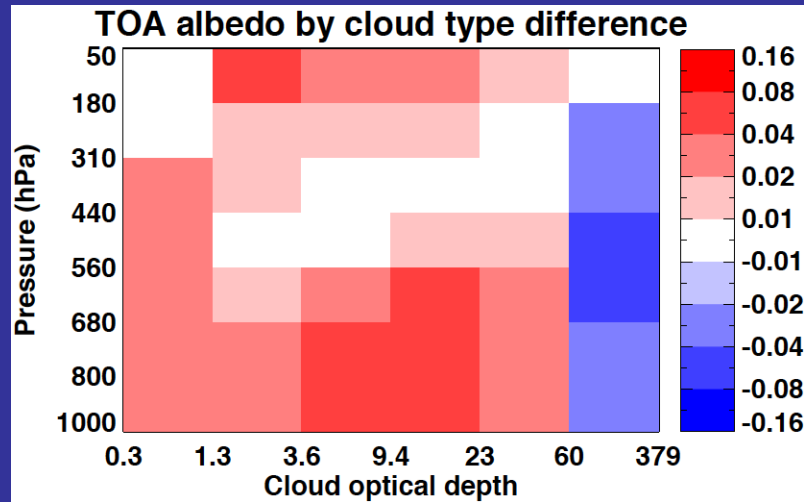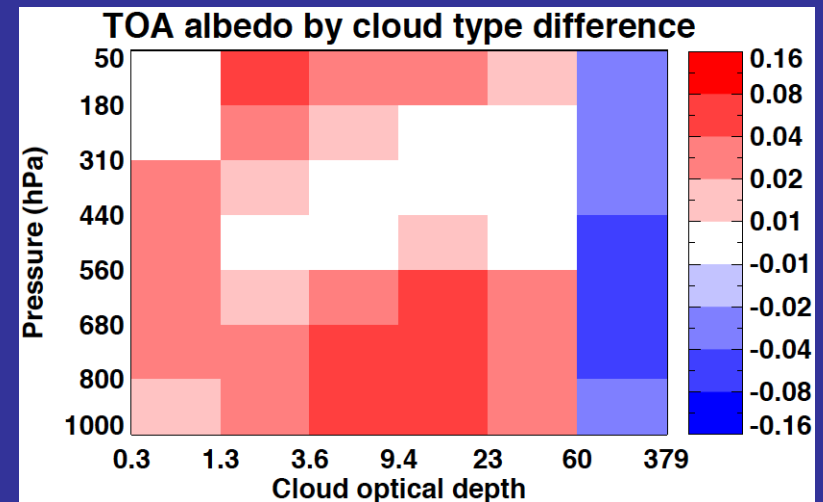
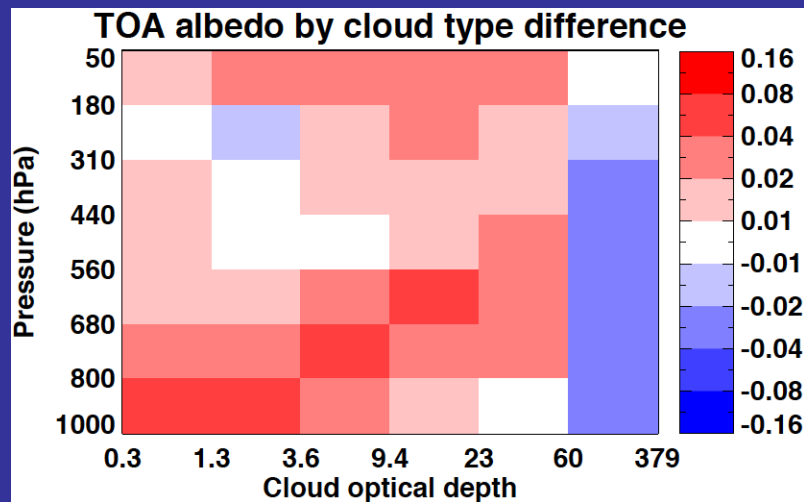# HadGEM2-A – CERES albedo differences over 60°N – 60°S (MAM 2008)

All surfaces

Ocean surfaces

Land surfaces

Summary

- Both LW and SW biases (RT model - HadGEM2-A) are relatively small and negative, while RMS errors seem reasonable.

- Over the Southern Great Plains, the cloud fraction is realistic, with too many high clouds, but OLR is too high for most cloud types, these offsetting errors produce an OLR that is close to observed. The high OLRs appear to be due to an atmosphere that is too warm.

- Over the Equatorial Pacific, HadGEM2-A produces too few clouds, resulting in an unrealistically high all-sky OLR, even though the OLR by cloud type has both positive and negative differences from observations.

- Over the SE Pacific, HadGEM2-A produces low clouds, but they tend to be too few and too thick, and are too bright by cloud type, when comparing to CERES FluxByCloudTyp product.

- This "too few clouds, too bright" bias is also present in the full-domain (60º N – 60º S) results.