Application of the CERES Flux-by-Cloud Type Simulator to GCM Output

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Thanks to Fred Rose[1] for help with the RT model

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

Updates since last STM

- Changed cloud inputs from cloud top/bottom pressure to direct input. This reduced magnitude of OLR biases from -6 W m^{-2} to -3 W m^{-2}. SW fluxes were largely unchanged.
- Ran simulator from 60N-60S for all 12 months of 2008 (the only year that has 3-hourly output), and analyzed Jan, Apr, Jul, Oct.

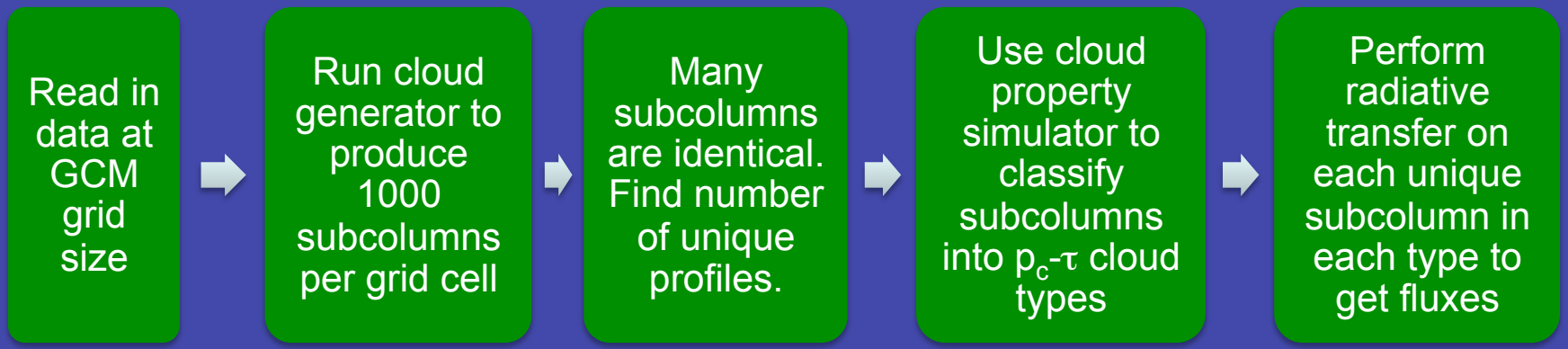
What is the Flux-by-cloud type product?

- Assigns LW and SW TOA fluxes to each observed ISCCP cloud type within a region.
- For each 1°x1° region between 60° S and 60° 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.

Outline of Simulator Approach



Number of RT calculations needed depends upon how many types of clouds there are in a given grid box, but for the four months of 60N-60S data here, the number of calculations is reduced by ~97%.

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 at locations between 60° N and 60° S for Jan, Apr, Jul, Oct 2008 and the fluxes averaged over all of the subcolumns were compared to the grid cell mean fluxes.

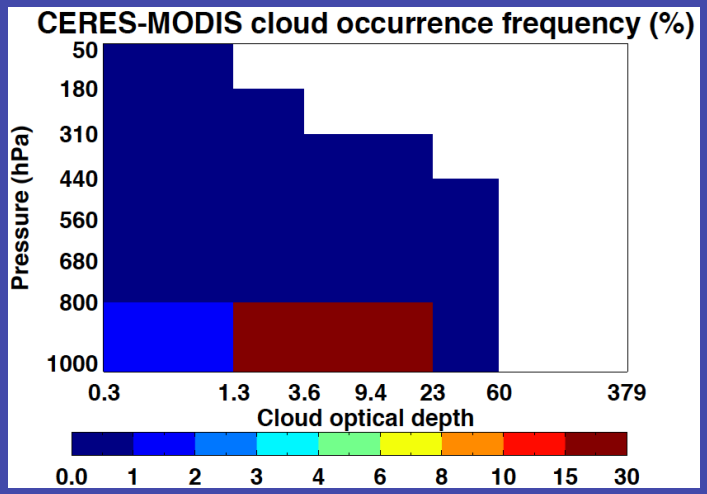
	SW Bias ($W\ m^{-2}$)	**SW RMS ($W\ m^{-2}$)**	**LW Bias ($W\ m^{-2}$)**	**LW RMS ($W\ m^{-2}$)**
Jan 2008	0.3	15.3	-2.9	5.2
Apr 2008	0.6	15.6	-2.7	5.5
Jul 2008	0.5	15.3	-2.6	5.6
Oct 2008	0.4	14.8	-2.8	5.2

Southeast Pacific results

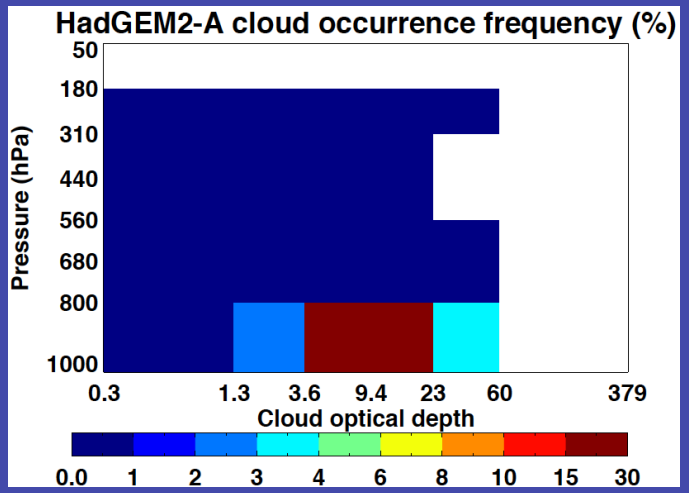
Image from Strebe, https://commons.wikimedia.org/wiki/File:Mercator_projection_SW.jpg

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

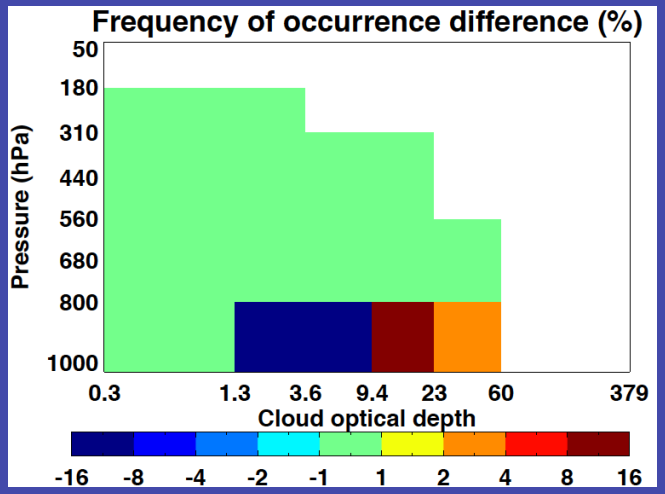
CERES



HadGEM2-A



HadGEM2-A – CERES



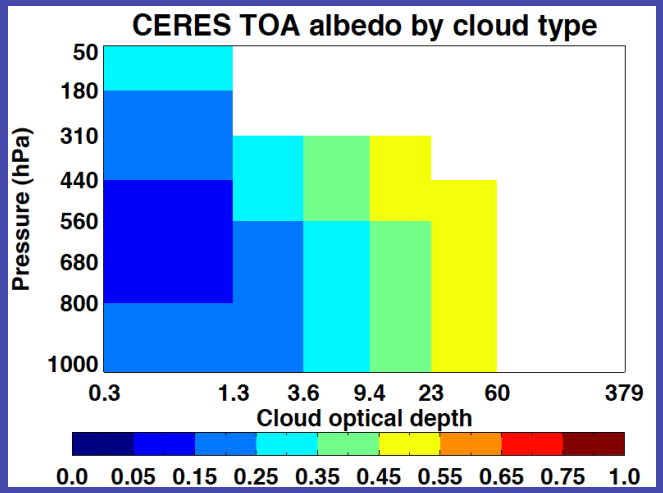
Grid-mean total cloud fraction:
CERES: 0.775
HadGEM2-A: 0.661

Cloud fraction weighting

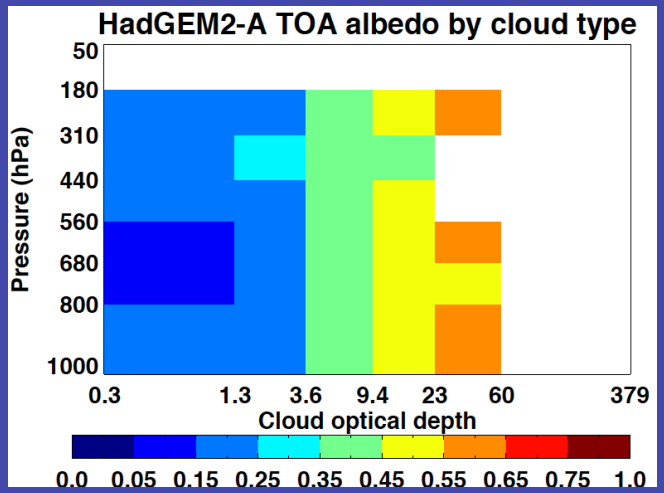
- Many possible ways to do this, but we opted to choose a method that preserves the sign of the LW flux/albedo difference and is large if the CERES and/or HadGEM cloud fraction is large.
- $\Delta OLR_{cf} = 0.5(f_H+f_C)(OLR_H-OLR_C)$
- Quantities are multiplied by 100 in figures to account for small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

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

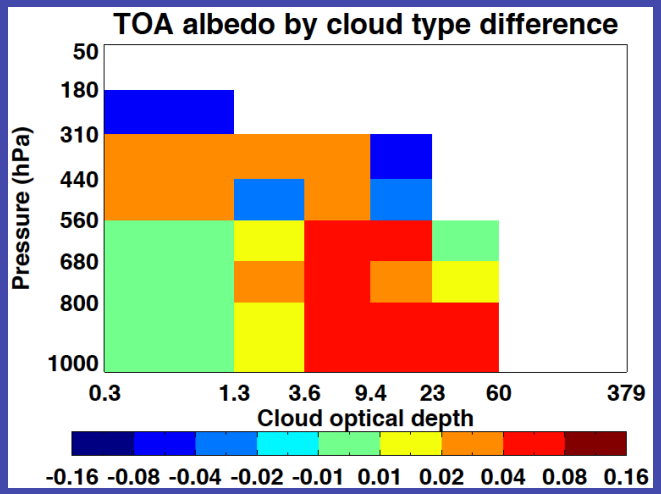
CERES



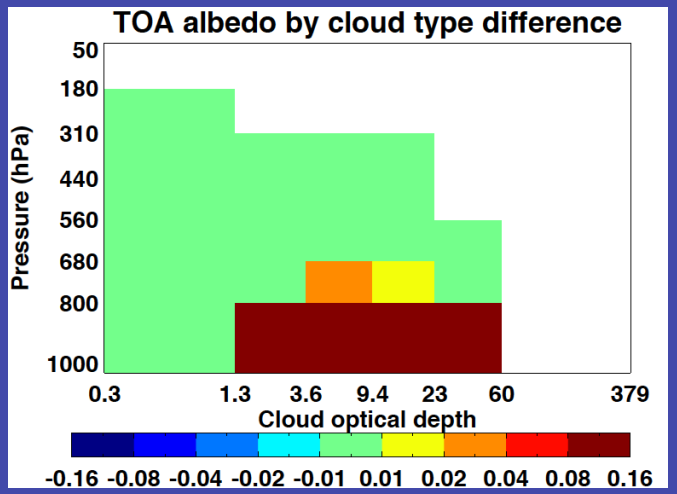
HadGEM2-A



HadGEM2-A – CERES



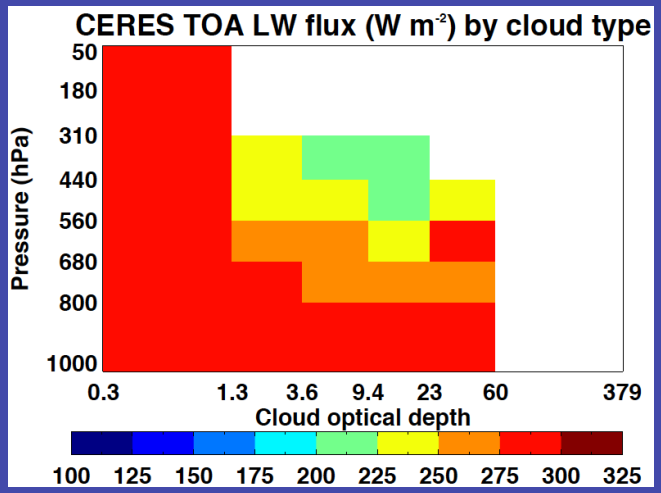
HadGEM2-A – CERES (CF-weighted)



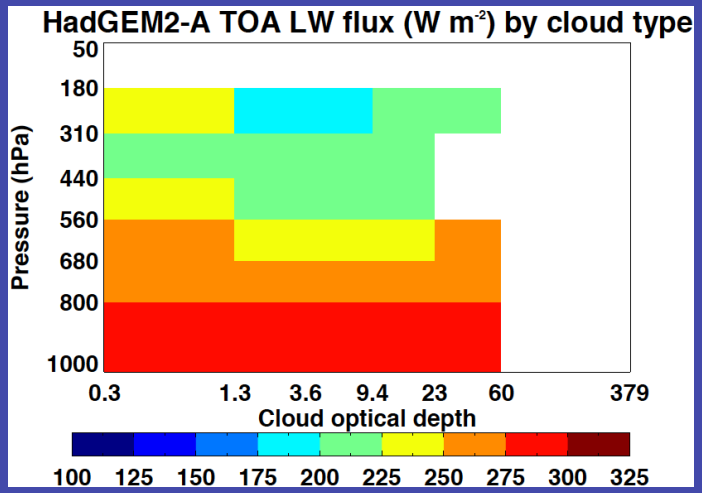
Grid-mean all-sky SW albedo: CERES: 0.269 HadGEM2-A: 0.331

TOA LW flux by cloud type (W m^{-2}) for CERES, HadGEM2-A over SE Pacific (Jul 2008)

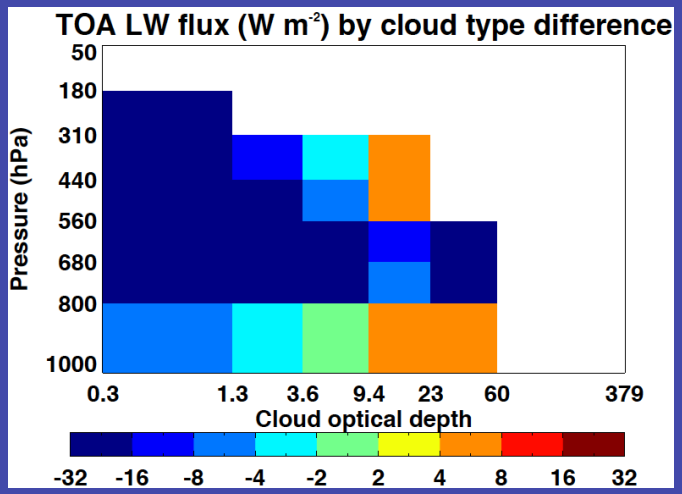
CERES



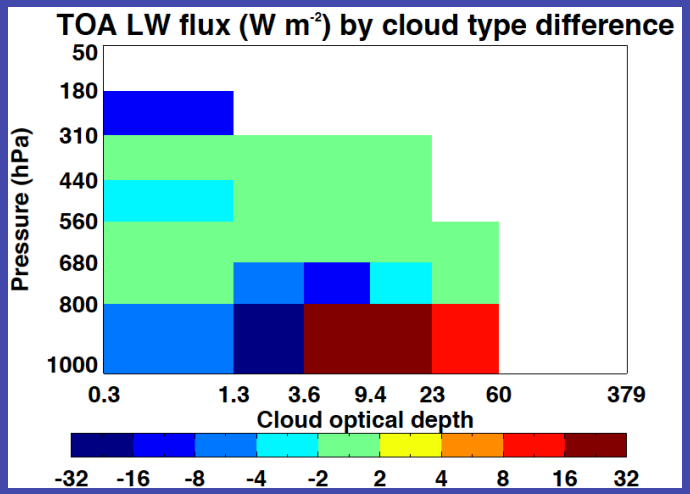
HadGEM2-A



HadGEM2-A – CERES



HadGEM2-A – CERES (CF-weighted)



Grid-mean all-sky OLR: CERES: 282.6 W m^{-2} HadGEM2-A: 286.4 W m^{-2}

Equatorial Pacific results

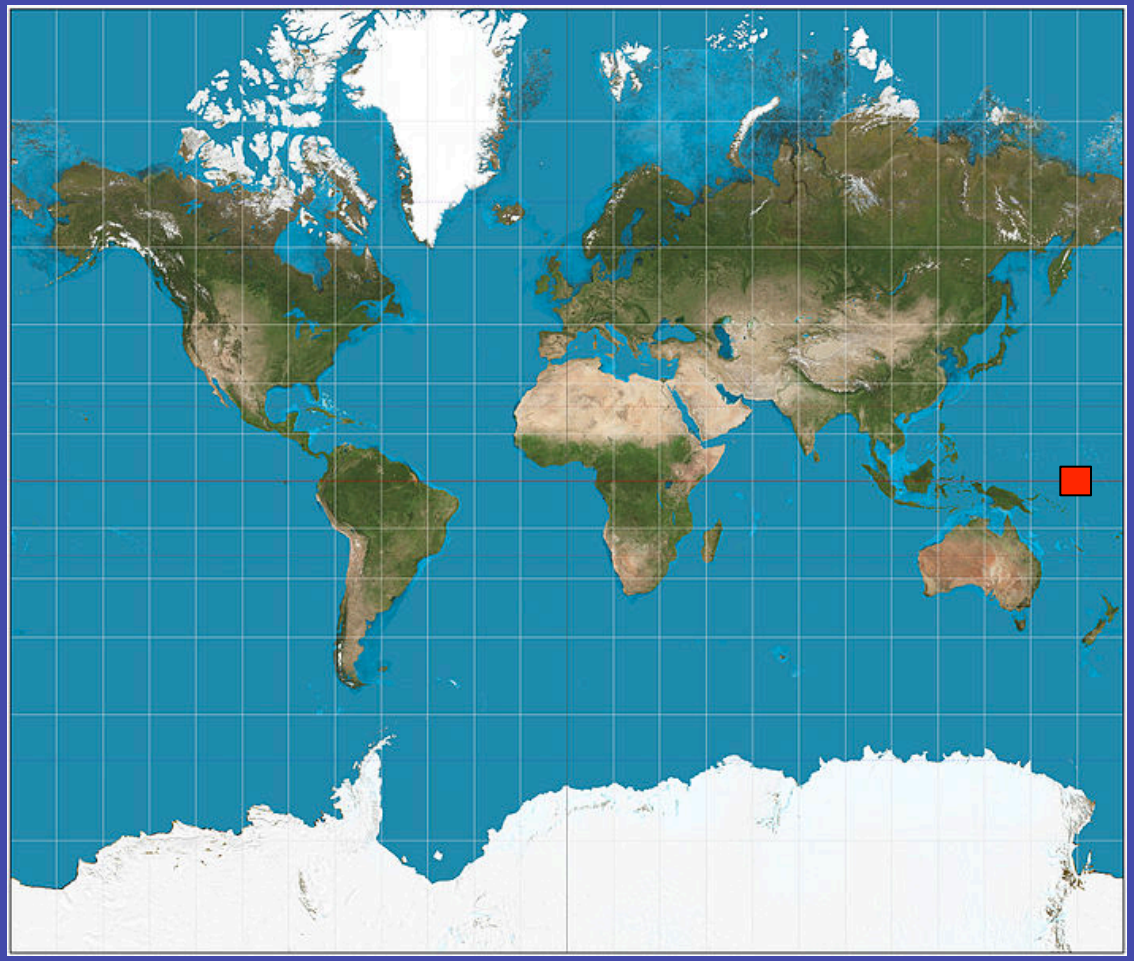
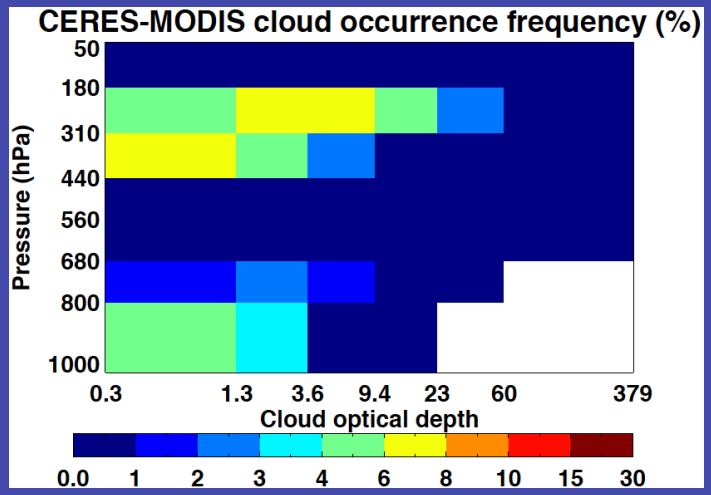


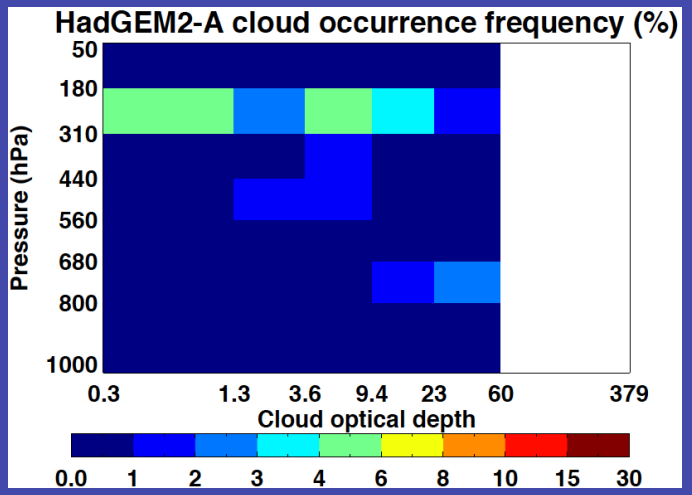
Image from Strebe, https://commons.wikimedia.org/wiki/File:Mercator_projection_SW.jpg

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

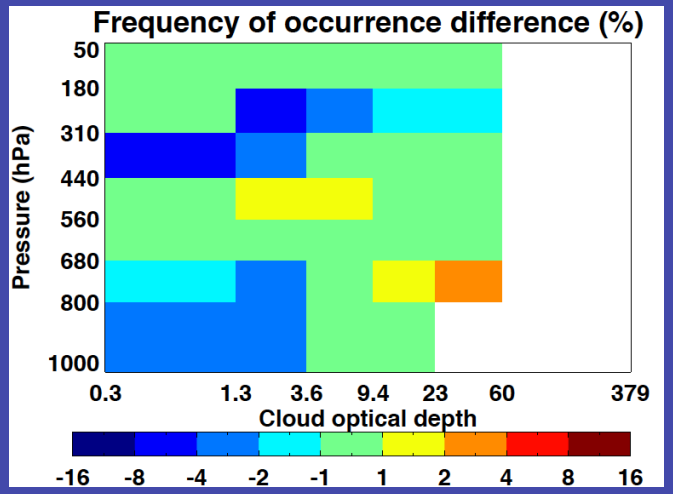
CERES



HadGEM2-A



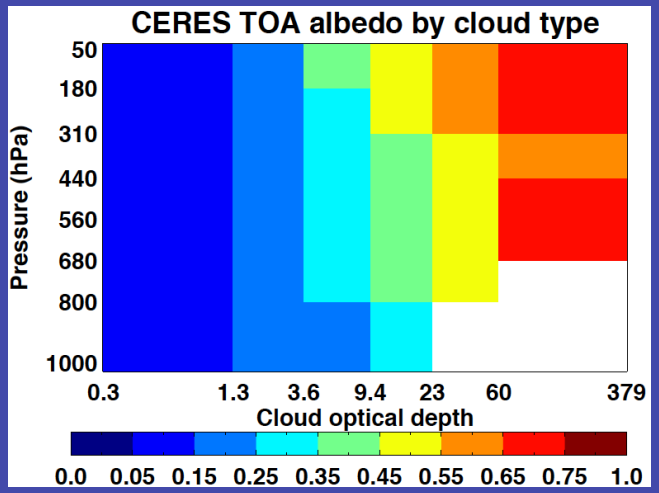
HadGEM2-A – CERES



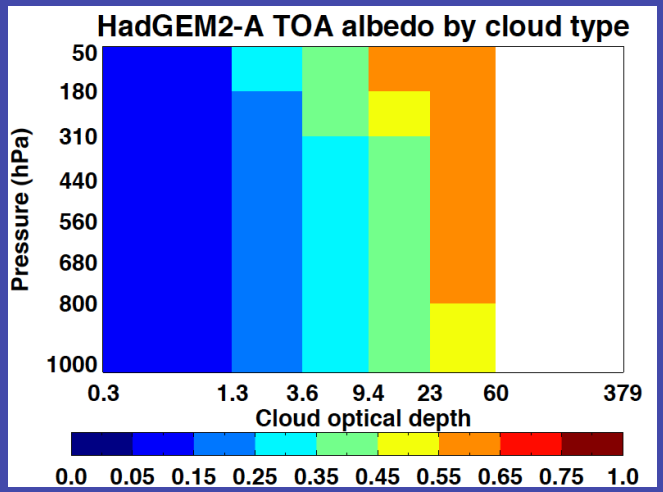
Grid-mean total cloud fraction:
CERES: 0.597
HadGEM2-A: 0.347

TOA SW albedo by cloud type for CERES, HadGEM2-A for Equatorial Pacific (Jul 2008)

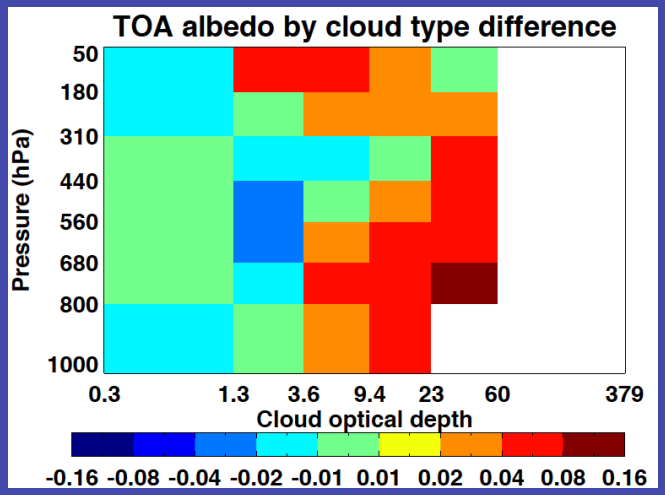
CERES



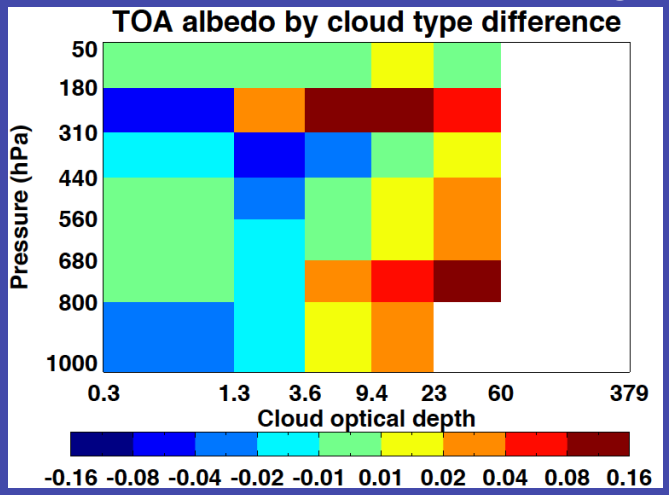
HadGEM2-A



HadGEM2-A – CERES



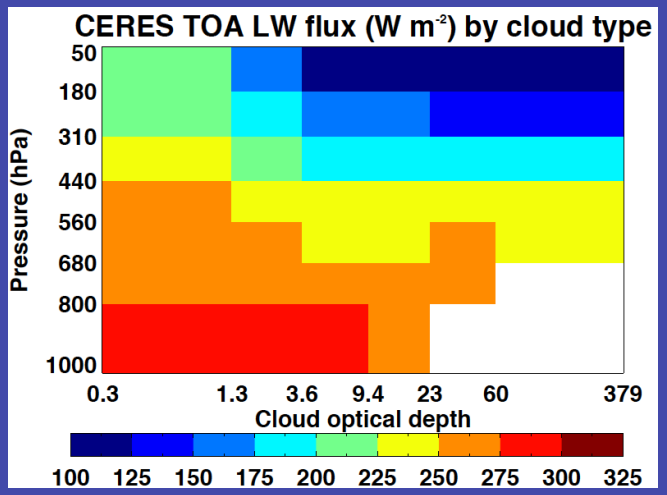
HadGEM2-A – CERES (CF-weighted)



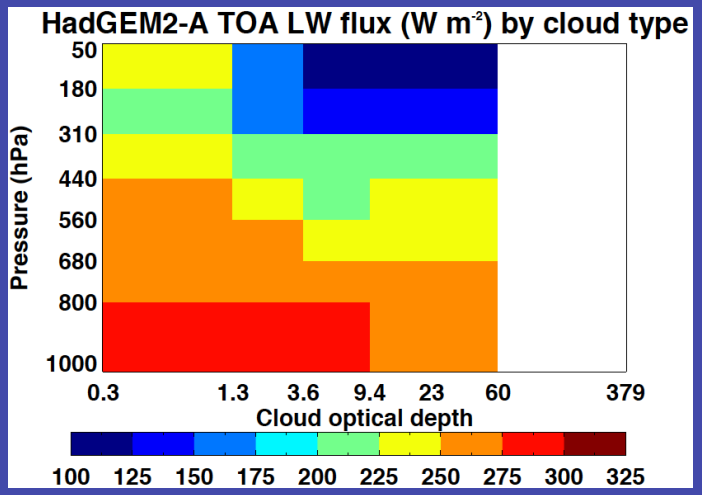
Grid-mean all-sky SW albedo: CERES: 0.192 HadGEM2-A: 0.175

TOA LW flux by cloud type (W m^{-2}) for CERES, HadGEM2-A over Equatorial Pacific (Jul 2008)

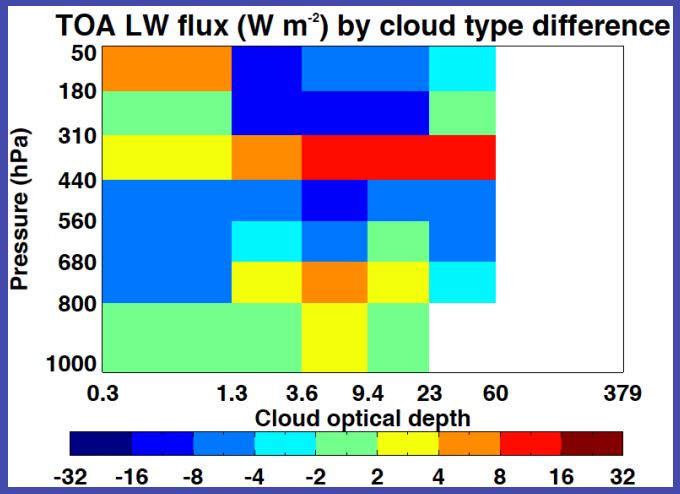
CERES



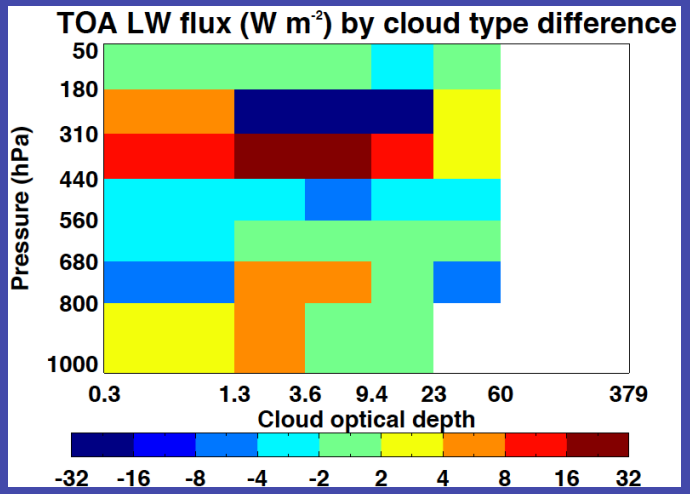
HadGEM2-A



HadGEM2-A – CERES



HadGEM2-A – CERES (CF-weighted)



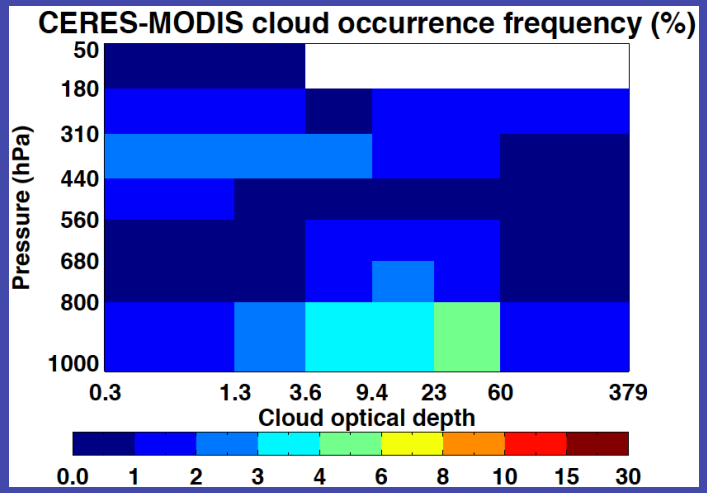
Grid-mean all-sky OLR: CERES: 237.3 W m^{-2} HadGEM2-A: 258.0 W m^{-2}

Southern Great Plains results

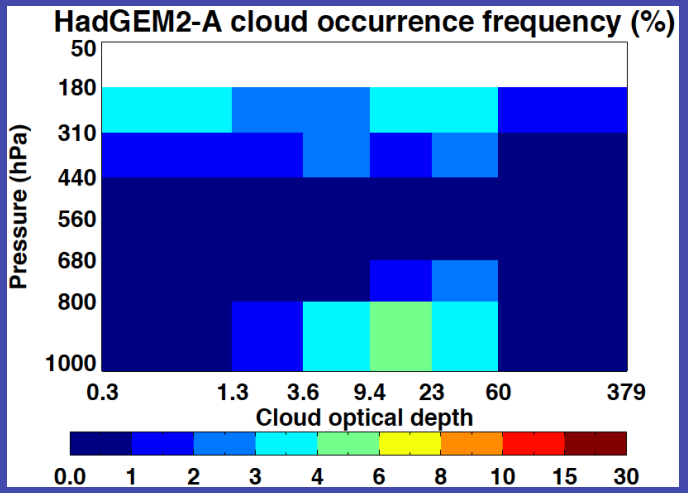
Image from Strebe, https://commons.wikimedia.org/wiki/File:Mercator_projection_SW.jpg

Cloud fraction (%) for CERES, HadGEM2-A over Southern Great Plains (Jan 2008)

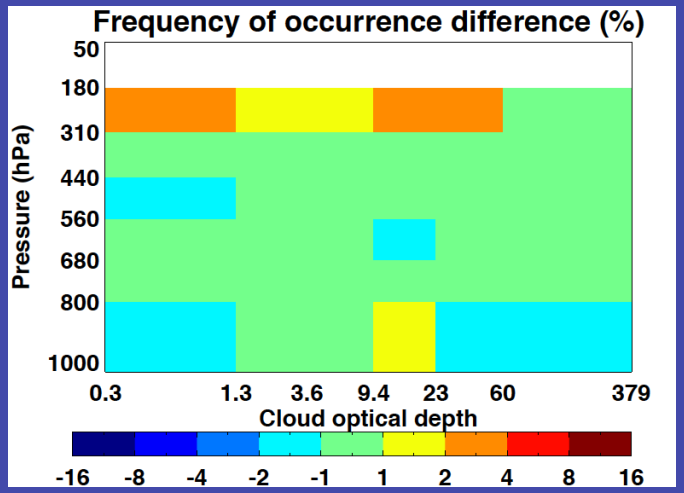
CERES



HadGEM2-A



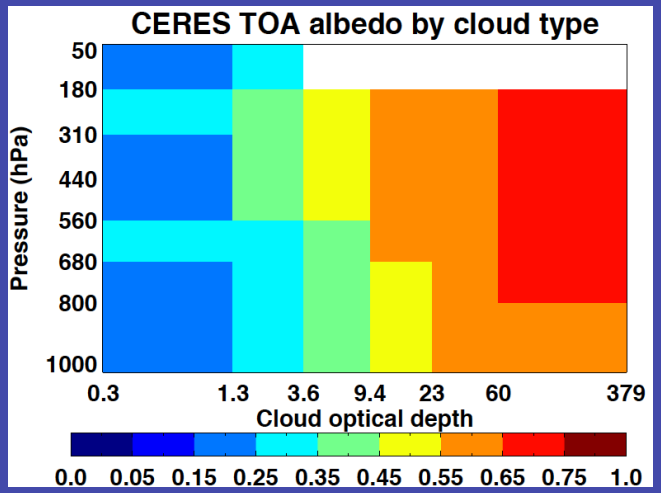
HadGEM2-A – CERES



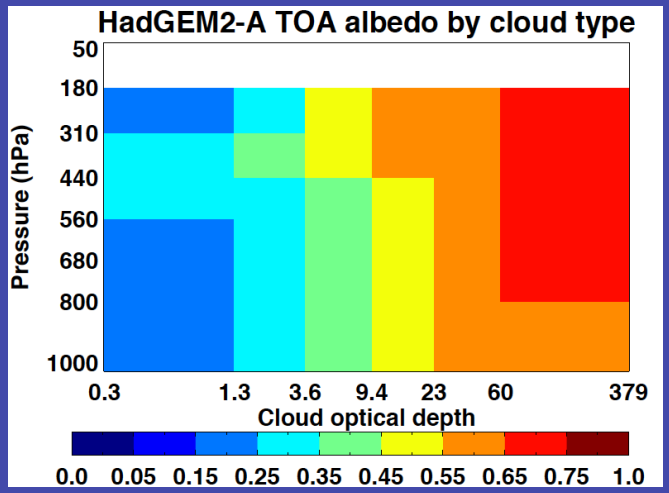
Grid-mean total cloud fraction:
CERES: 0.545
HadGEM2-A: 0.518

TOA SW albedo by cloud type for CERES, HadGEM2-A for Southern Great Plains (Jan 2008)

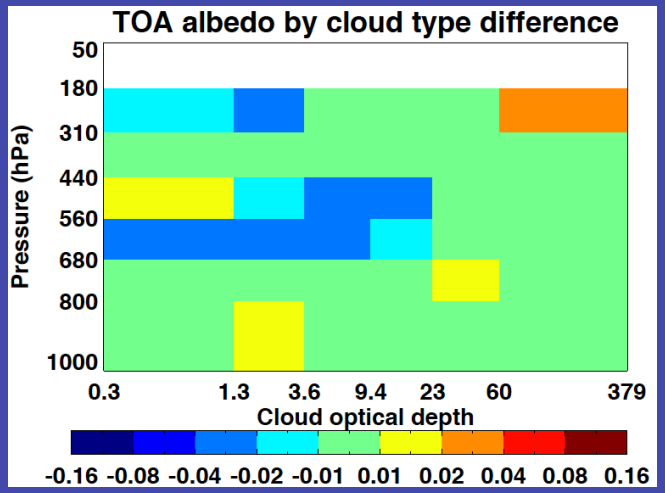
CERES



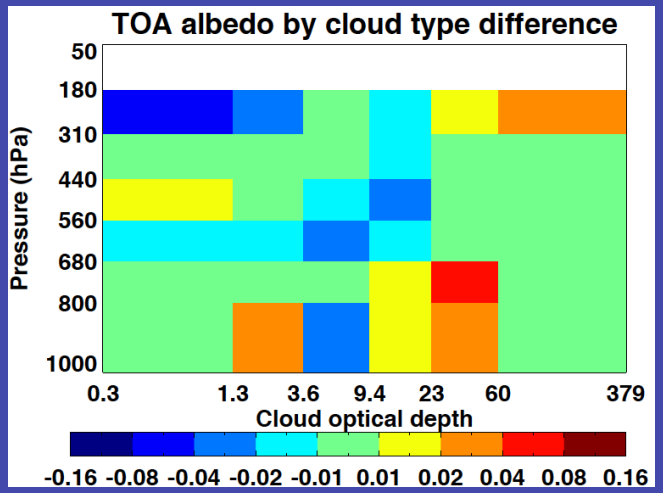
HadGEM2-A



HadGEM2-A – CERES



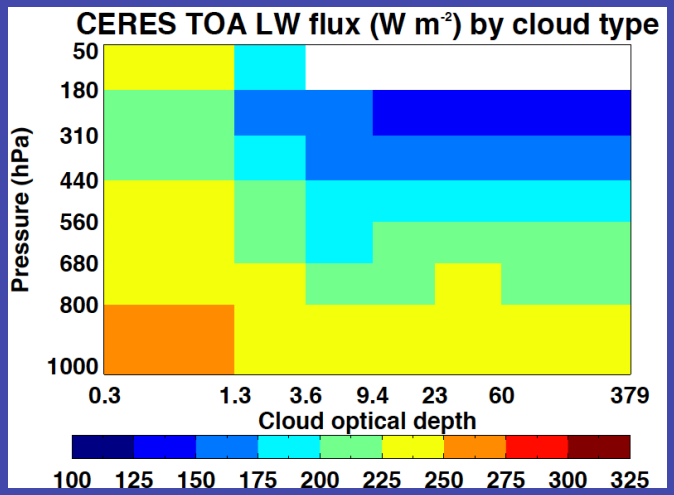
HadGEM2-A – CERES (CF-weighted)



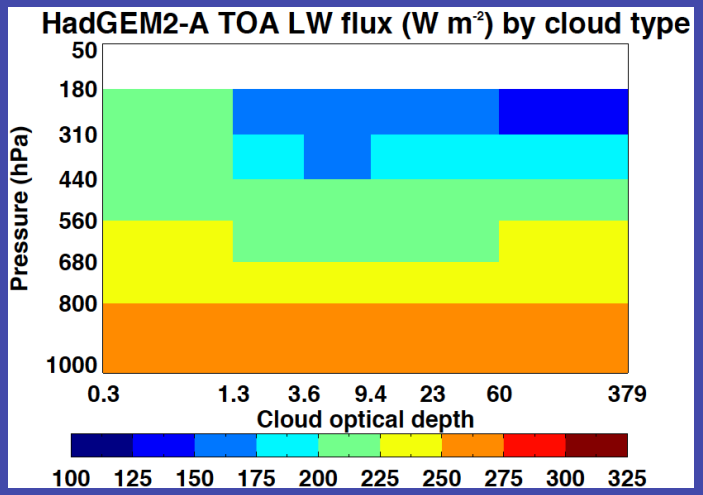
Grid-mean all-sky SW albedo: CERES: 0.348 HadGEM2-A: 0.330

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

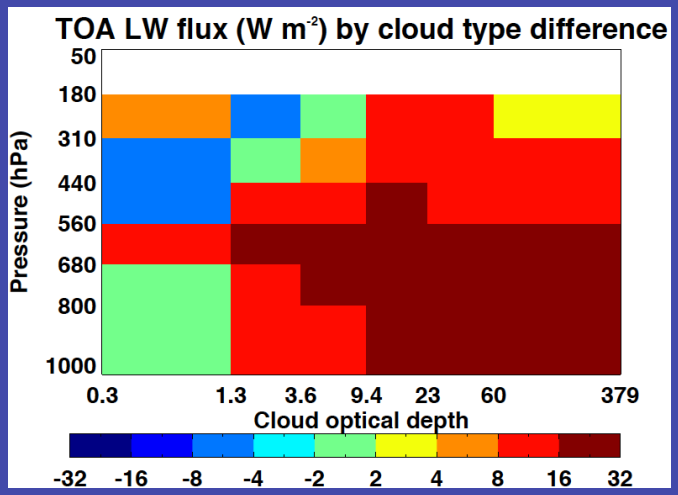
CERES



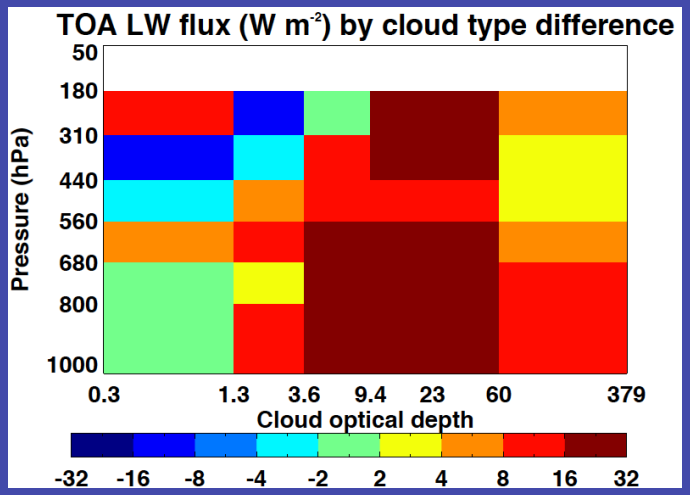
HadGEM2-A



HadGEM2-A – CERES



HadGEM2-A – CERES (CF-weighted)



Grid-mean all-sky OLR: CERES: 231.7 W m^{-2} HadGEM2-A: 239.0 W m^{-2}

Summary

- Identifying unique subcolumns reduces the number of RT calculations required by >95%.
- SW biases and RMS errors between the RT model and HadGEM2-A are relatively small, but there is a negative bias of ~3 W m^{-2} in OLR.
- 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.
- 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 Southern Great Plains, the cloud fraction is realistic, with clouds generally in the right place, but OLR is too high for most cloud types, possibly indicating a problem with an atmosphere that is too warm.

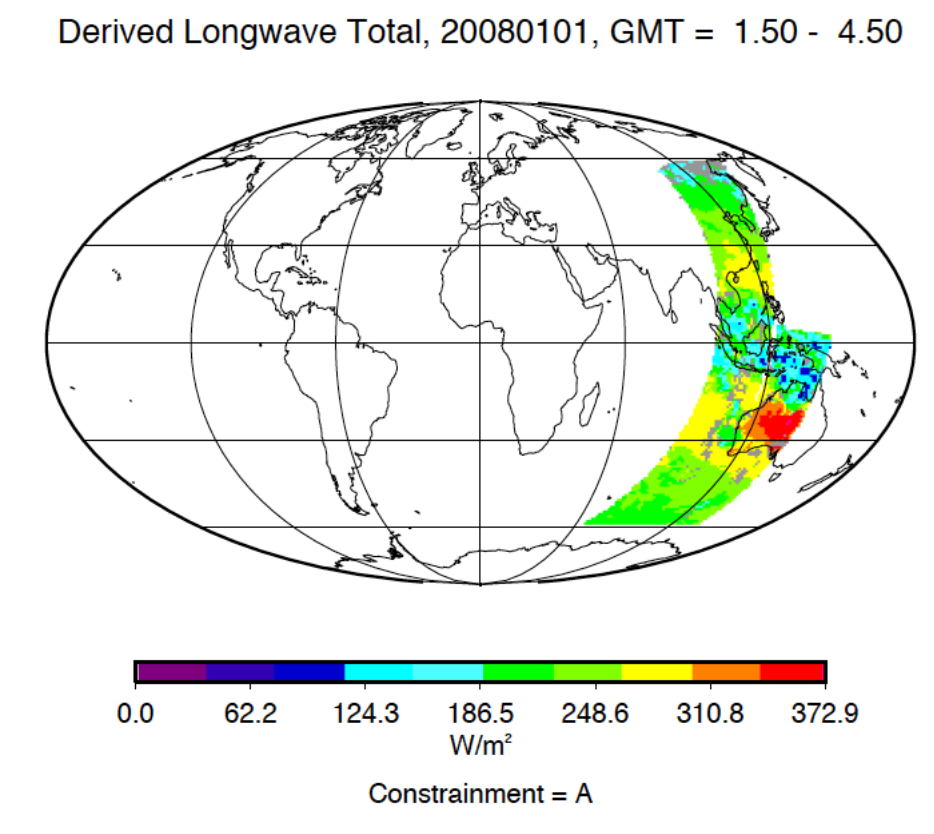
Future Plans

- Analyze simulator output in at least one other marine stratocumulus region (e.g., Southeast Atlantic) to see if similar biases exist.
- Analyze 60N-60S results for remaining months from 2008 and collect into 3-month seasons.
- Write up results in a manuscript for publication.

Extra slides

What is a simulator?

- Put simply, a simulator is meant to replicate what a space-based instrument would measure if it flew above a GCM or other model on the temporal and spatial scales of the measurements.



DPI Results: SE Pacific Jan 2008

- Observed cloud fraction: 0.578 (0.579 with interp)
- Simulated cloud fraction: 0.475
- Observed all-sky OLR: 272.4 (275.5 with interp)
- Simulated all-sky OLR: 272.4 (normalized: 275.5)
- Observed clear-sky OLR: 282.8 (285.4 with interp)
- Simulated clear-sky OLR: 285.4 (normalized: 289.4)
- Observed all-sky TOA albedo: 0.164 (with interp)
- Simulated all-sky TOA albedo: 0.183 (normalized: 0.189)
- Observed clear-sky TOA albedo: 0.070 (with interp)
- Simulated clear-sky TOA albedo: 0.073 (normalized: 0.074)

DPI Results: SE Pacific Apr 2008

- Observed cloud fraction: 0.585 (with interp)
- Simulated cloud fraction: 0.429
- Observed all-sky OLR: 277.5 (with interp)
- Simulated all-sky OLR: 290.9 (294.5 norm)
- Observed clear-sky OLR: 285.9 (with interp)
- Simulated clear-sky OLR: 300.1 (304.1 norm)
- Observed all-sky TOA albedo: 0.176 (with interp)
- Simulated all-sky TOA albedo: 0.207 (0.214 norm)
- Observed clear-sky TOA albedo: 0.078 (with interp)
- Simulated clear-sky TOA albedo: 0.081 (0.083 norm)

DPI Results: SE Pacific Jul 2008

- Observed cloud fraction: 0.775 (with interp)
- Simulated cloud fraction: 0.661
- Observed all-sky OLR: 282.6 (with interp)
- Simulated all-sky OLR: 286.4 (288.9 norm)
- Observed clear-sky OLR: 289.6 (with interp)
- Simulated clear-sky OLR: 296.2 (298.7 norm)
- Observed all-sky TOA albedo: 0.269 (with interp)
- Simulated all-sky TOA albedo: 0.331 (0.337 norm)
- Observed clear-sky TOA albedo: 0.092 (with interp)
- Simulated clear-sky TOA albedo: 0.096

DPI Results: SE Pacific Oct 2008

- Observed cloud fraction: 0.856 (with interp)
- Simulated cloud fraction: 0.627
- Observed all-sky OLR: 274.5 (with interp)
- Simulated all-sky OLR: 276.9 (278.8 norm)
- Observed clear-sky OLR: 282.5 (with interp)
- Simulated clear-sky OLR: 287.9 (290.5 norm)
- Observed all-sky TOA albedo: 0.263 (with interp)
- Simulated all-sky TOA albedo: 0.243 (0.250 norm)
- Observed clear-sky TOA albedo: 0.075 (with interp)
- Simulated clear-sky TOA albedo: 0.078 (0.081 norm)

DPI Results: EQ Pacific Jan 2008

- Observed cloud fraction: 0.798 (0.809 with interp)
- Simulated cloud fraction: 0.397
- Observed OLR: 227.7 (221.9 with interp)
- Simulated OLR: 252.8 (normalized 258.0)
- Observed clear-sky OLR: 276.0 (276.5 with interp)
- Simulated clear-sky OLR: 283.2 (normalized 289.7)
- Observed TOA albedo: 0.206 (with interp)
- Simulated TOA albedo: 0.184 (normalized 0.186)
- Observed clear-sky TOA albedo: 0.074 (with interp)
- Simulated clear-sky TOA albedo: 0.079 (normalized 0.078)

DPI Results: EQ Pacific Apr 2008

- Observed cloud fraction: 0.557 (with interp)
- Simulated cloud fraction: 0.378
- Observed all-sky OLR: 248.9 (with interp)
- Simulated all-sky OLR: 264.1 (269.5 norm)
- Observed clear-sky OLR: 280.5 (with interp)
- Simulated clear-sky OLR: 290.9 (297.2 norm)
- Observed all-sky TOA albedo: 0.167 (with interp)
- Simulated all-sky TOA albedo: 0.149 (0.149 norm)
- Observed clear-sky TOA albedo: 0.072 (with interp)
- Simulated clear-sky TOA albedo: 0.075 (0.074 norm)

DPI Results: EQ Pacific Jul 2008

- Observed cloud fraction: 0.597 (with interp)
- Simulated cloud fraction: 0.347
- Observed all-sky OLR: 237.3 (with interp)
- Simulated all-sky OLR: 258.0 (262.1 norm)
- Observed clear-sky OLR: 281.0 (with interp)
- Simulated clear-sky OLR: 285.7 (290.5 norm)
- Observed all-sky TOA albedo: 0.192 (with interp)
- Simulated all-sky TOA albedo: 0.175 (0.174 norm)
- Observed clear-sky TOA albedo: 0.073 (with interp)
- Simulated clear-sky TOA albedo: 0.077 (0.076 norm)

DPI Results: EQ Pacific Oct 2008

- Observed cloud fraction: 0.489 (with interp)
- Simulated cloud fraction: 0.342
- Observed all-sky OLR: 253.5 (with interp)
- Simulated all-sky OLR: 277.4 (282.0 norm)
- Observed clear-sky OLR: 285.9 (with interp)
- Simulated clear-sky OLR: 297.0 (302.6 norm)
- Observed all-sky TOA albedo: 0.158 (with interp)
- Simulated all-sky TOA albedo: 0.141 (0.142 norm)
- Observed clear-sky TOA albedo: 0.073 (with interp)
- Simulated clear-sky TOA albedo: 0.078 (0.077 norm)

DPI Results: SGP Jan 2008

- Observed cloud fraction: 0.539 (0.545 with interp)
- Simulated cloud fraction: 0.518
- Observed all-sky OLR: 231.1 (231.7 with interp)
- Simulated all-sky OLR: 239.0 (normalized: 240.3)
- Observed clear-sky OLR: 259.3 (258.9 with interp)
- Simulated clear-sky OLR: 271.2 (normalized: 272.1)
- Observed all-sky TOA albedo: 0.348 (with interp)
- Simulated all-sky TOA albedo: 0.337 (normalized: 0.330)
- Observed clear-sky TOA albedo: 0.202 (with interp)
- Simulated clear-sky TOA albedo: 0.165 (normalized: 0.159)

DPI Results: SGP Apr 2008

- Observed cloud fraction: 0.532 (with interp)
- Simulated cloud fraction: 0.354
- Observed all-sky OLR: 260.4 (with interp)
- Simulated all-sky OLR: 268.4 (267.7 norm)
- Observed clear-sky OLR: 291.0 (with interp)
- Simulated clear-sky OLR: 300.0 (298.9 norm)
- Observed all-sky TOA albedo: 0.286 (with interp)
- Simulated all-sky TOA albedo: 0.269 (0.260 norm)
- Observed clear-sky TOA albedo: 0.157 (with interp)
- Simulated clear-sky TOA albedo: 0.149 (0.145 norm)

DPI Results: SGP Jul 2008

- Observed cloud fraction: 0.497 (with interp)
- Simulated cloud fraction: 0.272
- Observed all-sky OLR: 267.0 (with interp)
- Simulated all-sky OLR: 284.5 (286.4 norm)
- Observed clear-sky OLR: 304.3 (with interp)
- Simulated clear-sky OLR: 316.9 (319.1 norm)
- Observed all-sky TOA albedo: 0.247 (with interp)
- Simulated all-sky TOA albedo: 0.211 (0.211 norm)
- Observed clear-sky TOA albedo: 0.150 (with interp)
- Simulated clear-sky TOA albedo: 0.150 (0.151 norm)

DPI Results: SGP Oct 2008

- Observed cloud fraction: 0.369 (with interp)
- Simulated cloud fraction: 0.174
- Observed all-sky OLR: 272.6 (with interp)
- Simulated all-sky OLR: 287.6 (288.9 norm)
- Observed clear-sky OLR: 291.5 (with interp)
- Simulated clear-sky OLR: 306.2 (307.5 norm)
- Observed all-sky TOA albedo: 0.255 (with interp)
- Simulated all-sky TOA albedo: 0.216 (0.216 norm)
- Observed clear-sky TOA albedo: 0.162 (with interp)
- Simulated clear-sky TOA albedo: 0.164 (0.165 norm)

DPI Results: 60N-60S Jan 2008

- Observed cloud fraction: 0.630
- Simulated cloud fraction: 0.494
- Observed all-sky OLR: 240.4
- Simulated all-sky OLR: 244.5 (normalized: 247.4)
- Observed clear-sky OLR: 267.3
- Simulated clear-sky OLR: 277.9 (normalized: 281.5)
- Observed all-sky TOA albedo: 0.311
- Simulated all-sky TOA albedo: 0.287 (normalized: 0.286)
- Observed clear-sky TOA albedo: 0.159
- Simulated clear-sky TOA albedo: 0.153 (normalized: 0.151)

DPI Results: 60N-60S Apr 2008

- Observed cloud fraction: 0.640
- Simulated cloud fraction:
- Observed all-sky OLR:
- Simulated all-sky OLR:
- Observed clear-sky OLR:
- Simulated clear-sky OLR:
- Observed all-sky TOA albedo:
- Simulated all-sky TOA albedo:
- Observed clear-sky TOA albedo:
- Simulated clear-sky TOA albedo:

DPI Results: 60N-60S Jul 2008

- Observed cloud fraction: 0.638
- Simulated cloud fraction:
- Observed all-sky OLR:
- Simulated all-sky OLR:
- Observed clear-sky OLR:
- Simulated clear-sky OLR:
- Observed all-sky TOA albedo:
- Simulated all-sky TOA albedo:
- Observed clear-sky TOA albedo:
- Simulated clear-sky TOA albedo:

DPI Results: 60N-60S Oct 2008

- Observed cloud fraction: 0.644
- Simulated cloud fraction:
- Observed all-sky OLR:
- Simulated all-sky OLR:
- Observed clear-sky OLR:
- Simulated clear-sky OLR:
- Observed all-sky TOA albedo:
- Simulated all-sky TOA albedo:
- Observed clear-sky TOA albedo:
- Simulated clear-sky TOA albedo: