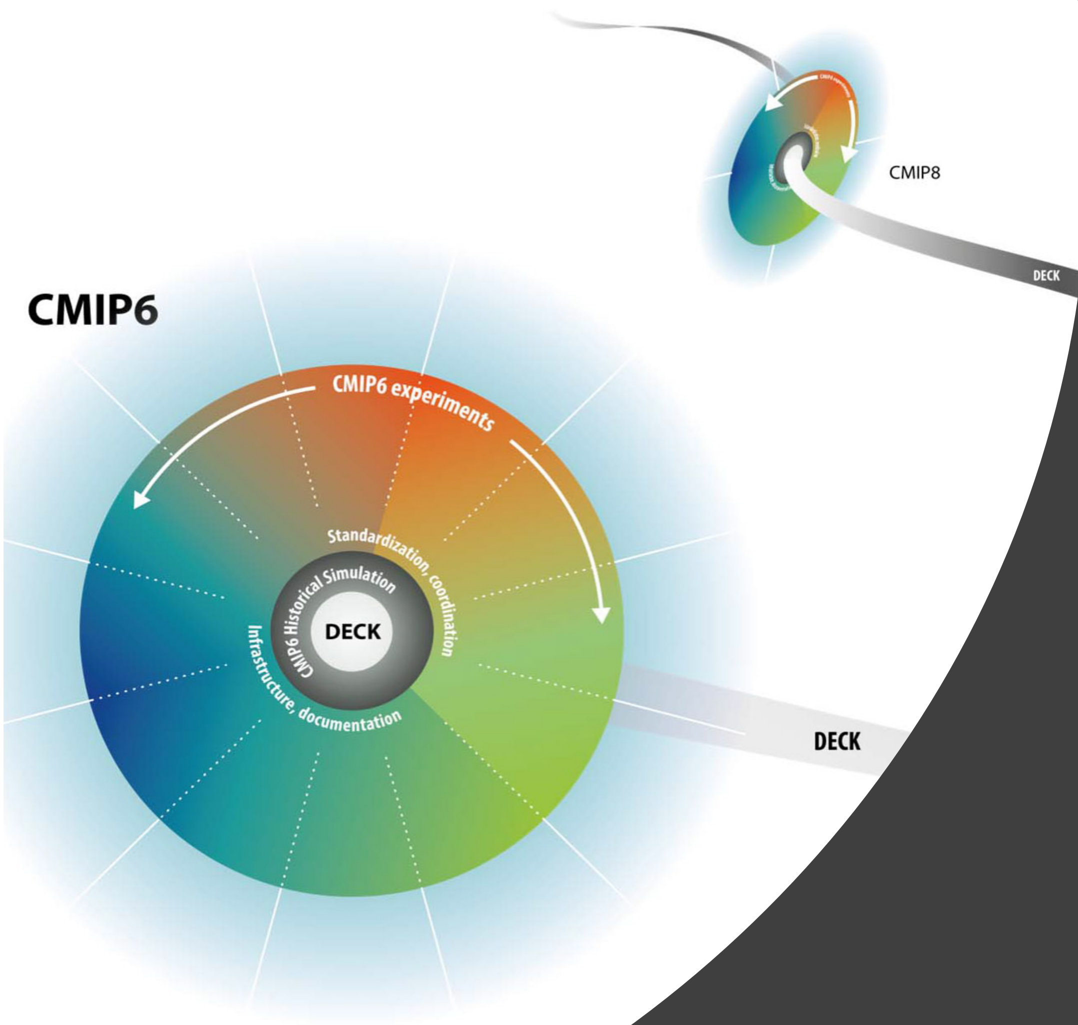

Evaluation of Tropical Cloud Simulations between CMIP6 Models and Satellite Observations

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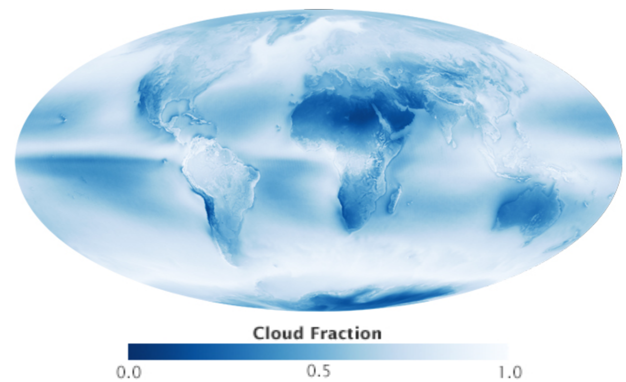
Overview

- Background
  - Importance of Clouds
  - Global Climate Models (GCMs)
  - CMIP Project
- Problem definition
  - Objectives and Hypotheses
- Dataset
  - CMIP6
  - Observational data
- Results and Analysis
- Conclusion and Future Work

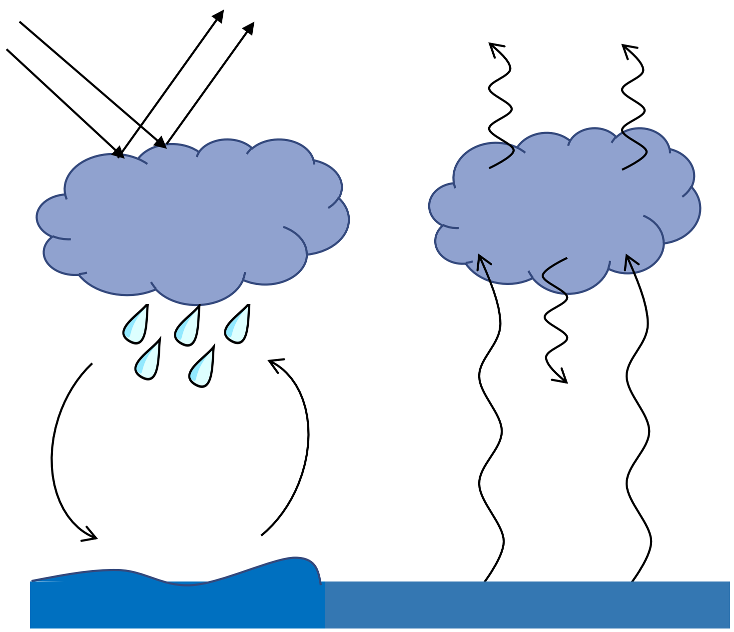
Background

Importance of Clouds

Clouds cover about 70% of the Earth's surface



Src: [NASA's Earth Observatory]



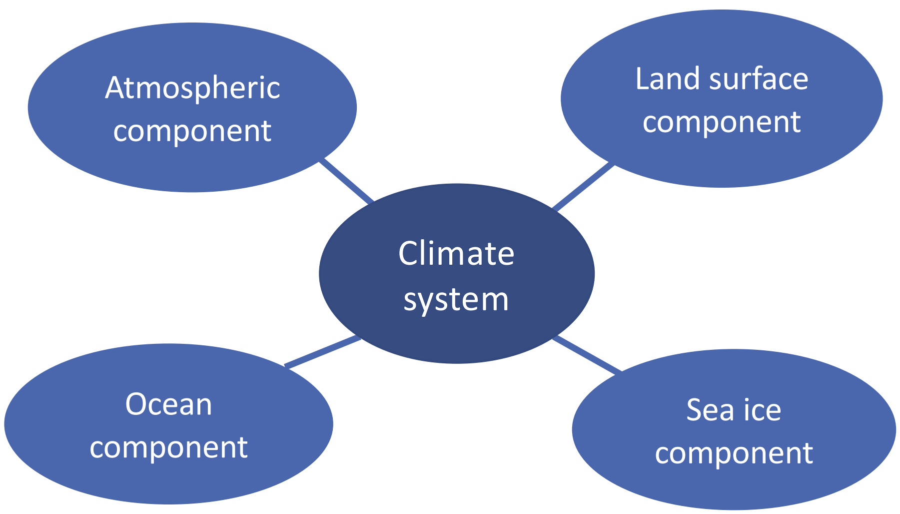
Cloud feedbacks

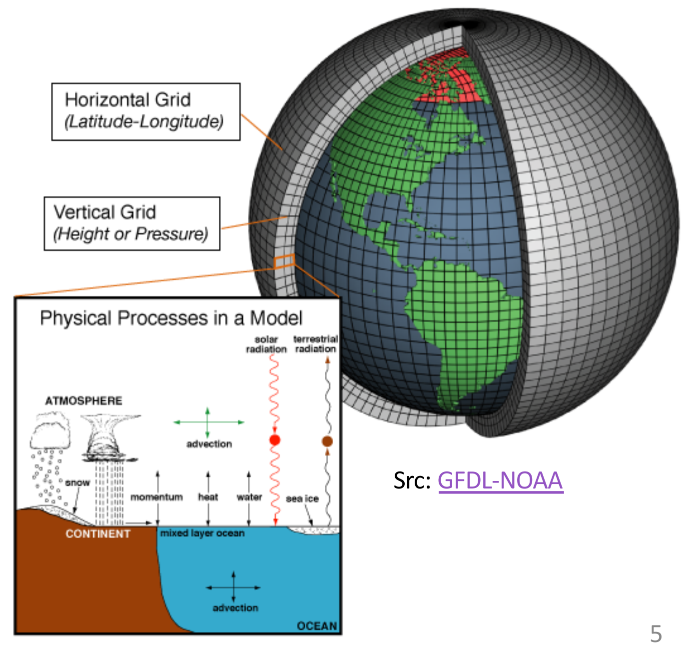
- Clouds modulate Earth's basic radiation balance and produce precipitation.
- Any changes in clouds will modify the radiative energy balance and water exchanges that determine the climate.
- Just as clouds affect climate, changes in the climate affect clouds. (cloud-climate feedback)
- The simulation of clouds and their feedbacks in climate models remains challenging, increasing the model uncertainties.

Global Climate Models (GCM)

- A complex mathematical representation of the physical processes of major climate system components and their interactions.

- Globe divided into a three-dimensional grid of cells.





Src: GFDL-NOAA

Coupled Model Intercomparison Project (CMIP)

- A project of World Climate Research Program (WCRP)'s Working Group of Coupled Modelling (WGCM)
- Multiple modeling teams worldwide have contributed to CMIP since 1995.
- Main goal of CMIP is to advance scientific understanding of the Earth system.
- CMIP simulations get regularly assessed by IPCC Climate Assessments Reports and other national assessments.
- CMIP has been developed in phases.
  - CMIP5 – complete.
  - CMIP6 – in development stage.

https://www.wcrp-climate.org/wgcm-cmip/

- A handful of common experiments, the DECK (Diagnostic, Evaluation and Characterization of Klima) and CMIP historical simulations (1850 – near-present) maintain continuity across different phases of CMIP.

CMIP6

- The DECK comprises four baseline experiments:
  (a) A historical Atmospheric Model Intercomparison Project (amip) simulation
  (b) A pre-industrial control simulation (piControl or esm-piControl)
  (c) A simulation forced by an abrupt quadrupling of CO_2 (abrupt-4×CO2)
  (d) A simulation forced by a 1 % yr^{-1} CO_2 increase (1pctCO2)
- In AMIP simulations, the sea surface temperature (SST) and sea ice concentration (SIC) are prescribed based on observations.
- Data availability – January 1979 to December 2014
- Models we consider for this project:
  - NCAR CESM2.1
  - NASA GISS
  - NOAA-GFDL

Problem

Problem Definition

- A common issue in GCM cloud simulations (Based on CMIP5 and other GCMs):

"Too few - Too bright" problem

A problem related to tropical low-level clouds caused by insufficient low-cloud fraction in the tropical or subtropical ocean, especially over the eastern of major ocean basins (e.g., SE Pacific, NE pacific, SE Atlantic, SE Indian ocean) and simulation of thicker clouds in these regions in the attempt of balancing the radiation in GCM.

Too few - Too bright Problem

Climate models predict too positive LW CRE and too negative SW CRE

Possible reasons for these are combination of (Nam et al., 2012),

- Models overestimate high cloud cover
- Models underestimate low cloud cover
- Models simulate overly thick clouds

Hypotheses

- Radiation bias between CMIP6 models and observations (Models not reflecting enough compared to observations) in the tropical region is mainly due to the deficiency in low level clouds of models in that region.

Objectives

- The objective of this project is to evaluate the cloud simulations in the CMIP6-era GCMs. In particular, we will investigate:

  1. Does the “too few too bright” problem still exist in the CMIP6-era models?
  2. What are the improvements in CMIP6 models as compared to CMIP5-era models?

Dataset

Observational Data

CERES-EBAF

- Clouds and the Earth's Radiant Energy System-Energy Balanced And Filled
- Monthly TOA fluxes
  - Preliminary data : SW flux, LW flux, Net flux, solar incoming,…

CALIPSO-GOCCP

- GCM Oriented Cloud Calipso Product
- CALIPSO (Cloud Aerosol Lidar Infrared Pathfinder Satellite Observation)
- Vertical lidar measurements
- CALIPSO-GOCCP :CALIPSO data fully consistent with the ones simulated by the ensemble “GCM+lidar” simulator (re-gridded data)
- Preliminary data : Cloud fraction and TOA radiation flux

CMIP6 Data

NASA-GISS

- NASA Goddard Institute of Space Studies (GISS)
- Grid: 90x144
- Time Period: 1979-2014
- Preliminary data : Incoming/ougoing SW flux, Net flux clear sky, CALIPSO Low/High/Medium/Total Level Cloud Cover Percentage

NCAR-CESM2

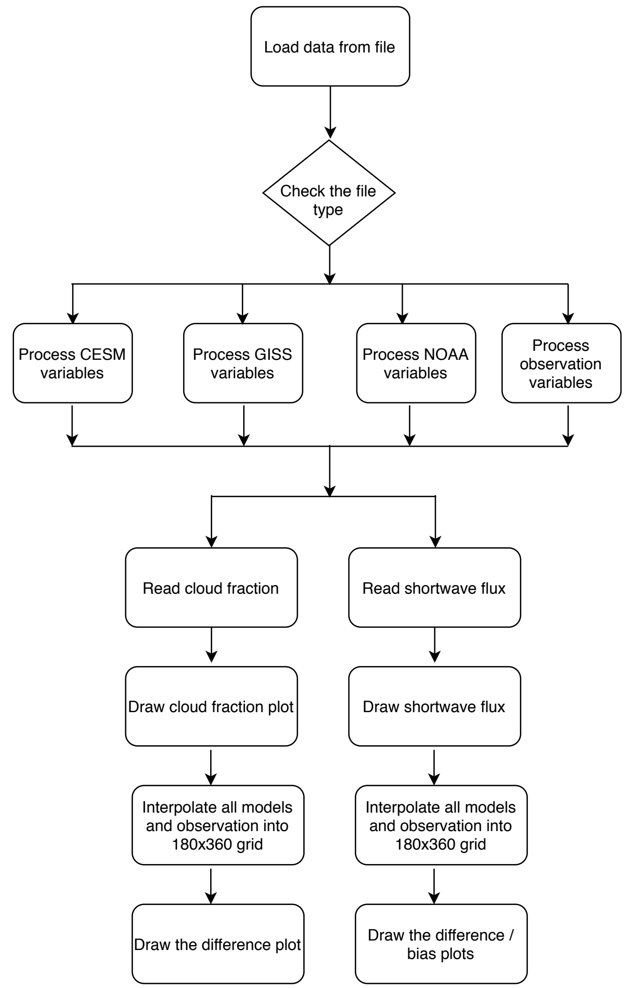
- NCAR's Community Earth System Model (CESM)
- Grid: 192x288
- Time Period: 1950-2014
- Preliminary data : Incoming/ougoing SW flux, Net flux clear sky, CALIPSO Low/High/Medium/Total Level Cloud Cover Percentage

NOAA GFDL-CM4

- NOAA's Geophysical Fluid Dynamics Laboratory Coupled Physical Model (GFDL-CM4)
- Grid: 180x288
- Time Period: 1979-2014
- Preliminary data : Incoming/ougoing SW flux, Net flux clear sky, CALIPSO Low/High/Medium/Total Level Cloud Cover Percentage

Methodology

Workflow



Load data from file
Check the file type
Process CESM variables
Process GISS variables
Process NOAA variables
Process observation variables
Read cloud fraction
Read shortwave flux
Draw cloud fraction plot
Draw shortwave flux
Interpolate all models and observation into 180x360 grid
Interpolate all models and observation into 180x360 grid
Draw the difference plot
Draw the difference / bias plots

Results and Analysis

Shortwave Radiation Flux – Clear Sky

$$F^{net}_{sw\_clr} = F^{\downarrow}_{sw\_clr} - F^{\uparrow}_{sw\_clr}$$

net : Net flux
$\downarrow$: Downward flux
$\uparrow$: Upward flux
sw : Shortwave
clr : Clear sky

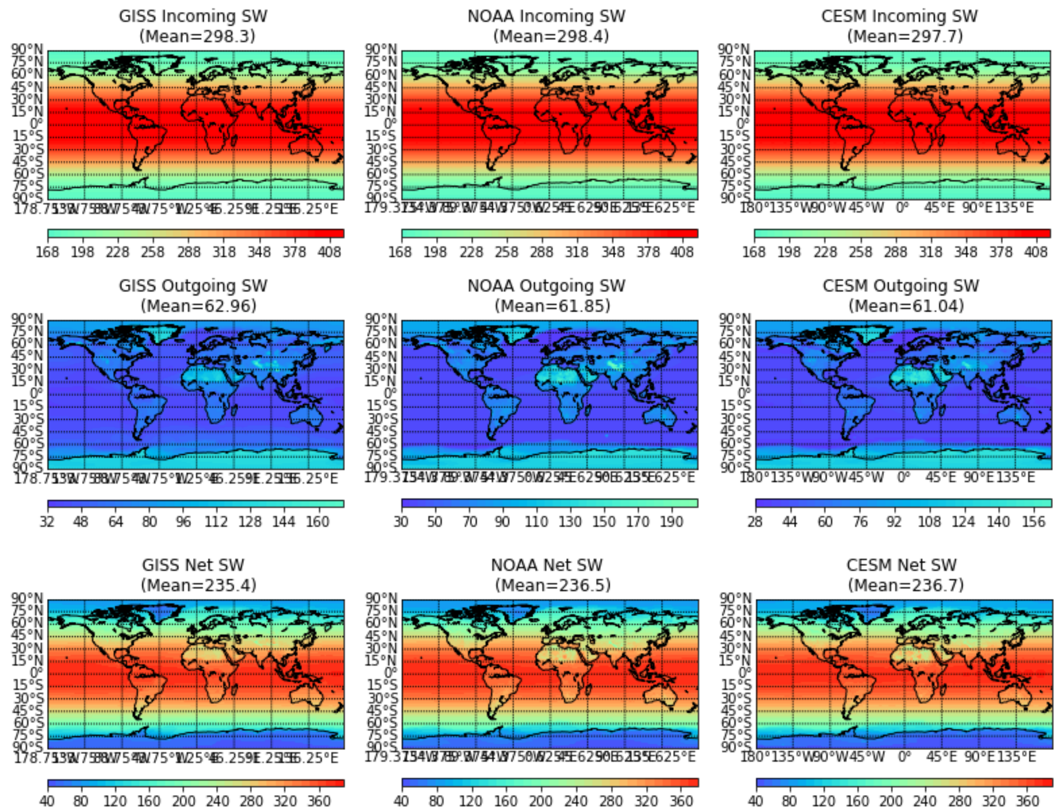


Fig: Shortwave radiation flux for Clear Sky

Shortwave Radiation Flux – All Sky

$$F^{net}_{sw\_all} = F^{\downarrow}_{sw\_all} - F^{\uparrow}_{sw\_all}$$

net : Net flux
$\downarrow$: Downward flux
$\uparrow$: Upward flux
sw : Shortwave
all : All sky

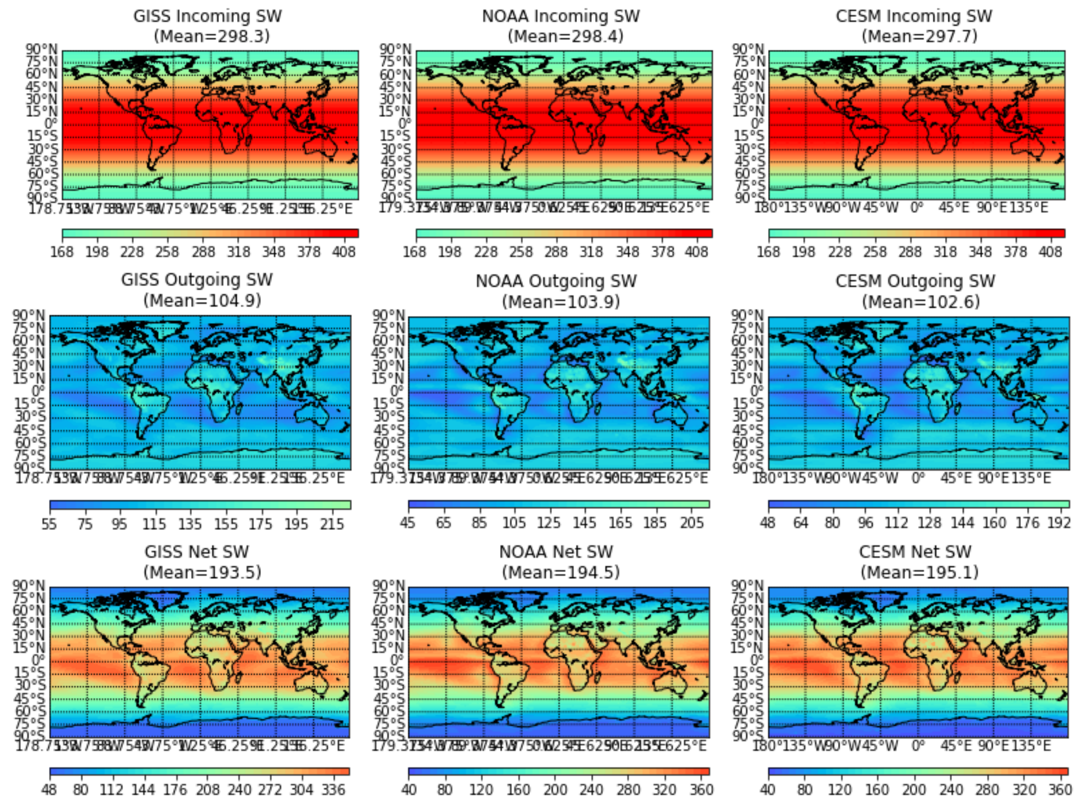


Fig: Shortwave radiation flux for All Sky

Shortwave Radiation Bias

- The regions with a negative total cloud bias (i.e. models not generating enough clouds), are directly correlated with positive net SW bias regions.
- The bias in this region is mainly coming from low cloud fraction and the bias is negative.
- This supports our hypothesis.

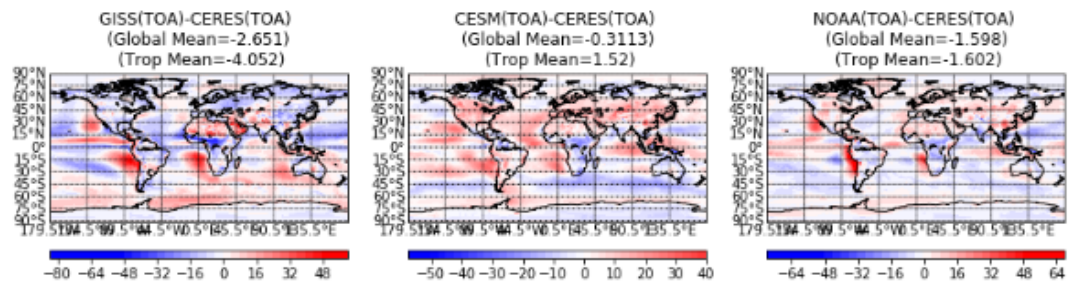


Fig: Shortwave Radiation Bias for All Sky

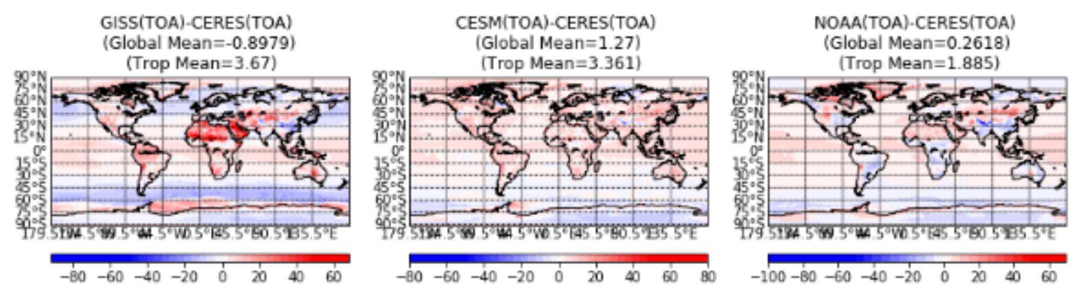


Fig: Shortwave Radiation Bias for Clear Sky

Low, Mid and High Cloud Fraction Bias

- Our area of interest is the tropical region (30N-30S).
- The bias in this region is mainly coming from low cloud fraction and the bias is negative.
- *Too few low clouds problem*

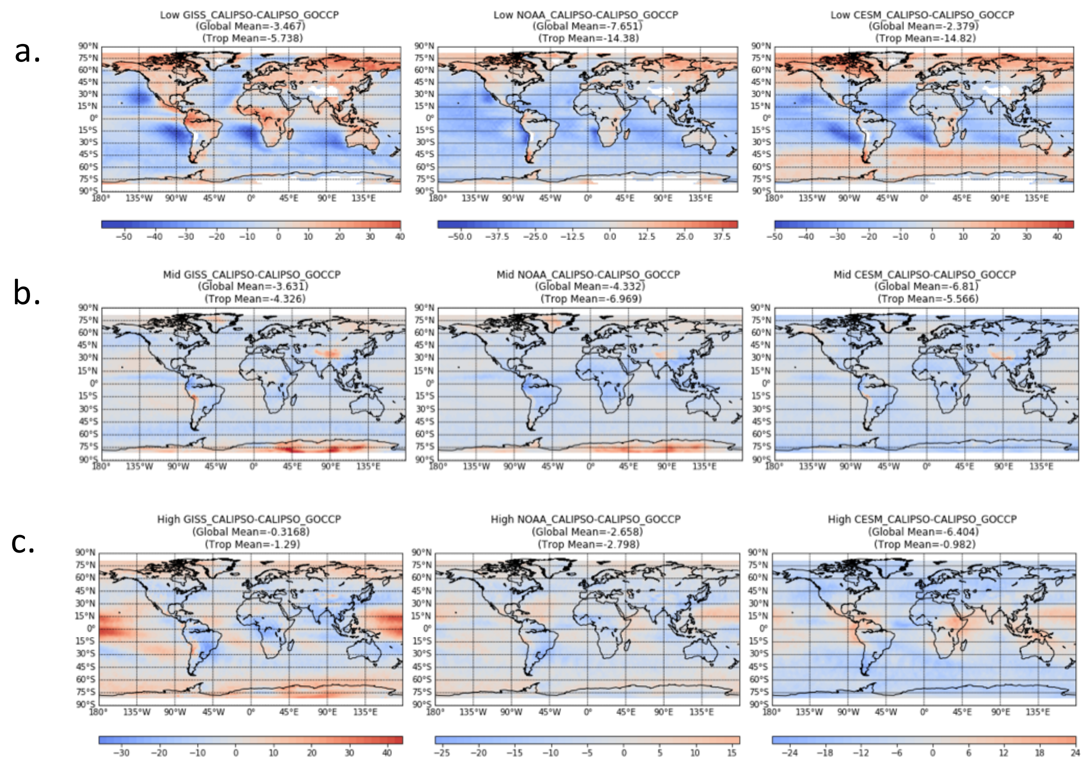


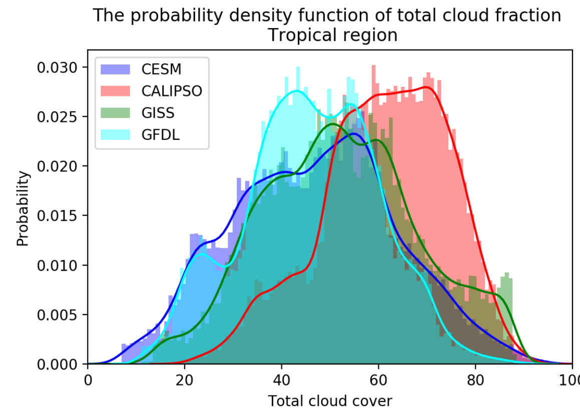
Fig: a. Low, b. Mid, and c. High Cloud Fraction Bias

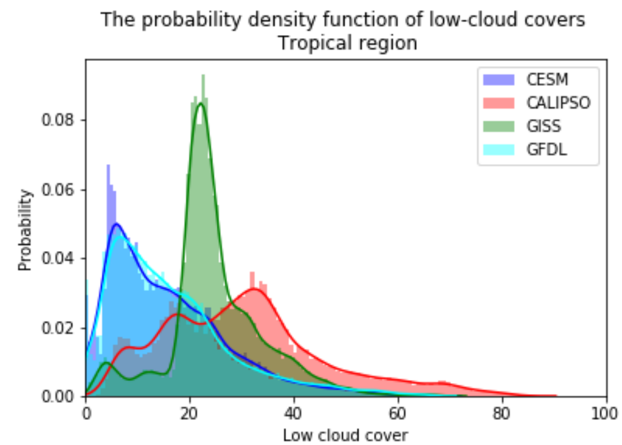
Regional Analysis – Tropical Region

- The distribution of low-level clouds show the models generally over-estimate clouds with small cloud fractions.

- The area under the pdfs account for the low-level cloud cover in the tropical region which are 31%, 25%, 16% and 16% for CALIPSO observations, NOAA-GISS model, NCAR-CESM model and NASA-GFDL model.

- Models have more broken low-level clouds whereas observational low-level clouds are more over-cast.

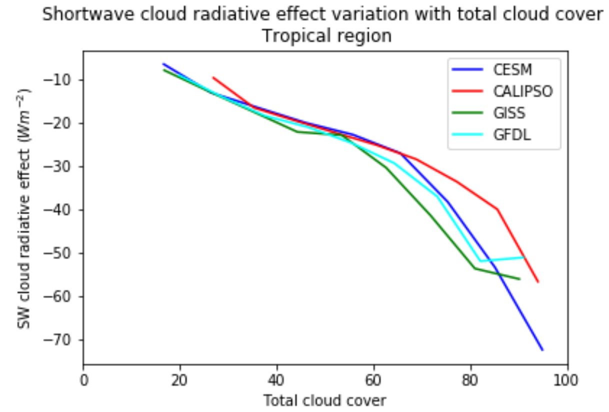


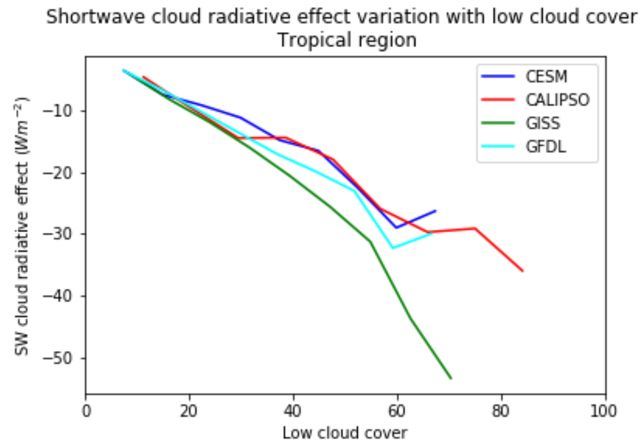


Regional Analysis – Tropical Region

- The Cloud Radiative Effect CRE for total Cloud Fraction CF, all the models agree with the CALIPSO observations up to around 60% of the CF.

- The variation of CRE for low-level CF, shows, all three models agree with the CALIPSO observations up to around 30% of CF and for CF larger than that, GISS seems to generate more brighter clouds while CESM and GFDL continues to match the brightness of CALIPSO low-level clouds.





Conclusion
"Too-Few Too-Bright Problem"

Conclusion

- The three GCMs evaluated, i.e., NASA-GISS-E2.1-G, NCAR-CESM2 and NOAA-GFDL-CM4 from CMIP6 have achieved a shortwave radiation balance in the global scale.

- Total cloud deficiencies in the considered CMIP6 models are mainly contributed by the under-estimation of low-level clouds.

- This supports the presence of ‘too few’ problem of low-level clouds in the CMIP6 generation models.

- When CREs of the models are compared against the observations, not enough evidence was present to show the presence of “too bright” problem in the tropical low-level clouds which previous generations of GCMs have identified.

- Our analysis suggests that the CMIP6-era models no longer have the 'too bright' problem, however, the 'too few' problem still prevails.

References

- M. K. Yau and R. R. Rogers, A short course in cloud physics. Elsevier, 1996.
- J. E. Kay, B. R. Hillman, S. A. Klein, Y. Zhang, B. Medeiros, R. Pincus, A. Gettelman, B. Eaton, J. Boyle, R. Marchand, and T. P. Ackerman, "Exposing Global Cloud Biases in the Community Atmosphere Model (CAM) Using Satellite Observations and Their Corresponding Instrument Simulators," Journal of Climate, vol. 25, pp. 5190–5207, 08 2012.
- O. Boucher and U. Lohmann, "The sulfate-ccn-cloud albedo effect," Tellus B: Chemical and Physical Meteorology, vol. 47, no. 3, pp. 281–300, 1995.
- S. Bony, K. Lau, and Y. Sud, "Sea surface temperature and large-scale circulation influences on tropical greenhouse effect and cloud radiative forcing," Journal of Climate, vol. 10, no. 8,pp. 2055–2077, 1997.
- O. Boucher, D. Randall, P. Artaxo, C. Bretherton, G. Feingold, P. Forster, V.-M. Kerminen, Y. Kondo, H. Liao, U. Lohmann, et al., "Clouds and aerosols," in Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 571–657, Cambridge University Press, 2013.
- G. Myhre, D. Shindell, and J. Pongratz, "Anthropogenic and natural radiative forcing," 2014.
- R. P. Allan, "Combining satellite data and models to estimate cloud radiative effect at the surface and in the atmosphere," Meteorological Applications, vol. 18, no. 3, pp. 324–333, 2011.
- G. Flato, "Earth system models: an overview," Wiley Interdisciplinary Reviews, Climate Change, vol. 2, no. 6, pp. 783–800, 2011.

References

- M. Claussen, L. A. Mysak, A. J. Weaver, M. Crucifix, T. Fichefet, M. F. Loutre, S. L. We-ber, J. Alcamo, V. A. Alexeev, A. Berger, R. Calov, A. Ganopolski, H. Goosse, G. Lohmann, F. Lunkeit, I. Mokhov, V. Petoukhov, P. Stone, and Z. Wang, "Earth system models of intermediate complexity: closing the gap in the spectrum of climate system models," Climate Dynamics, vol. 18, no. 7, pp. 579–586, 2002.

- R. Laprise, R. de Elia, D. Caya, S. Biner, P. Lucas-Picher, E. Diaconescu, M. Leduc, A. Alexan-dru, L. Separovic, and C. Canadian Network Regional, "Challenging some tenets of regionalclimate modelling," Meteorology and Atmospheric Physics, vol. 100, no. 1-4, pp. 3–22, 2008.

- V. Eyring, S. Bony, G. A. Meehl, C. A. Senior, B. Stevens, R. J. Stouffer, and K. E. Taylor, "Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimentaldesign and organization," Geoscientific Model Development, vol. 9, no. 5, pp. 1937–1958, 2016.

- A. Bodas-Salcedo, M. J. Webb, S. Bony, H. Chepfer, J.-L. Dufresne, S. A. Klein, Y. Zhang, R. Marchand, J. M. Haynes, R. Pincus, and V. O. John, "COSP: Satellite simulation softwarefor model assessment," Bulletin of the American Meteorological Society, vol. 92, pp. 1023–1043,08 2011.

- "CESM Configurations-CESM Documentation."https://escomp.github.io/CESM/release-cesm2/cesm_configurations.html, 2020. Accessed: 2020-07-21.

- "Coupled Physical Model CM4, Geophysical Fluid Dynamics Laboratory."https://www.gfdl.noaa.gov/coupled-physical-model-cm4/, 2020. Accessed: 2020-07-23.

- "CERES Data Products." https://ceres.larc.nasa.gov/data/, 2019. Accessed: 2020-07-28.

- "NASA Langley ASDC - CALIPSO Data Sets."https://eosweb.larc.nasa.gov/project/calipso/calipso_table, 2020. Accessed: 2020-07-01.

Future Plan

- Compare 5-10 models for the too-few too-bright problem.
  - Analyze if the problem is widespread across all models under analysis
  - Present analysis included 3 models

- Select 1 model and analyze deeper to see where the error is coming from.

Thank You!