Analysis of CCCma radiative transfer calculations for low-level overcast liquid clouds at SGP and ENA

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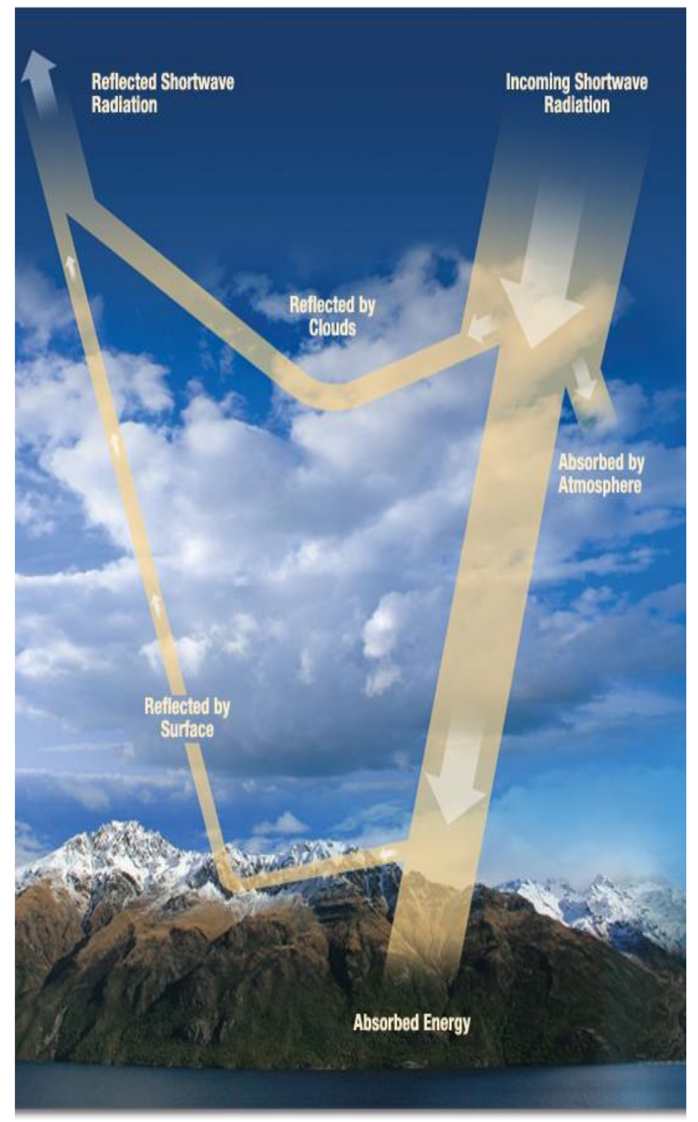
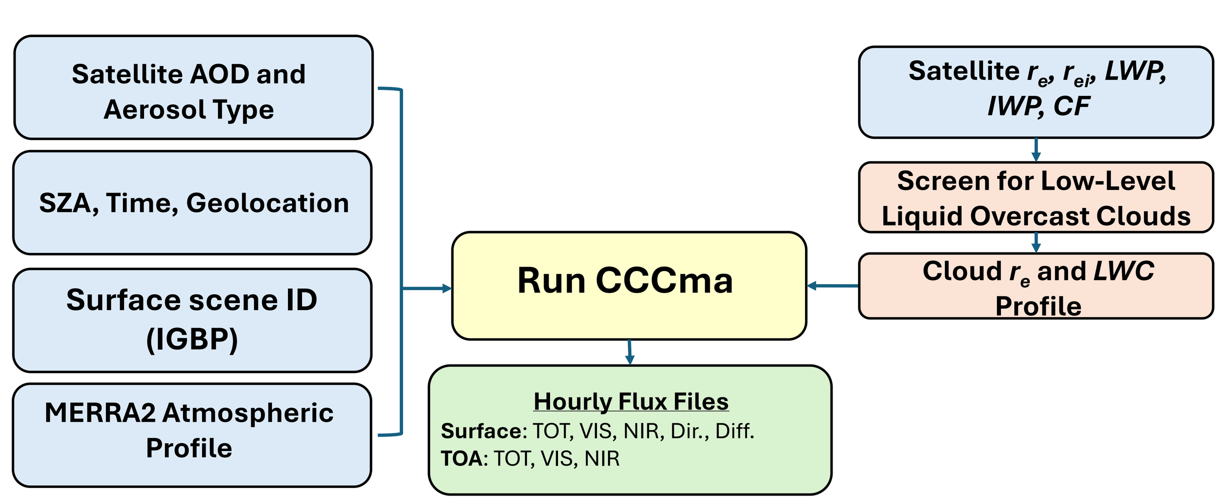
Introduction

Clouds are vital in regulating the Earth Energy Budget. In the shortwave (SW) spectrum, clouds strongly reflect SW, limiting the amount of SW downwelling flux at the surface ($SWDN_{sfc}$) and increase upward SW at the top of atmosphere ($SWUP_{TOA}$). For global estimates of $SWDN_{sfc}$, a radiative transfer model (RTM) is needed to calculate the amount of SW attenuation within the atmosphere. RTMs vary in their complexity and how they handle clouds. Here, the Canadian Center for Climate Modeling and Analysis (CCCma) RTM output of $SWDN_{sfc}$ and $SWUP_{TOA}$ is analyzed on different cloud profiles before global calculations can be performed.



Methodology

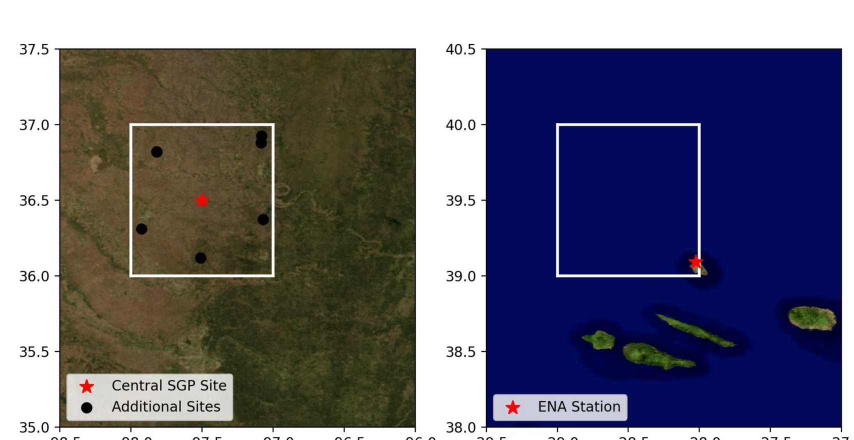
- Cloud and Earth Radiative Energy System (CERES) SYN1 for cloud input
  - MODIS based cloud measurements
  - 1 ° x 1 ° grid resolution
  - Fu-Liou RTM output included in CERES SYN1
- Identify low-level overcast liquid clouds for CCCma calculations
  - No complicated ice particle scattering
  - Less 3-D cloud effects
- 10 years (2014 – 2023) of cases selected
- Compare CCCma output against observation to determine error
  - Surface sites
  - CERES measured $SWUP_{TOA}$



Surface Observations

Two Locations:

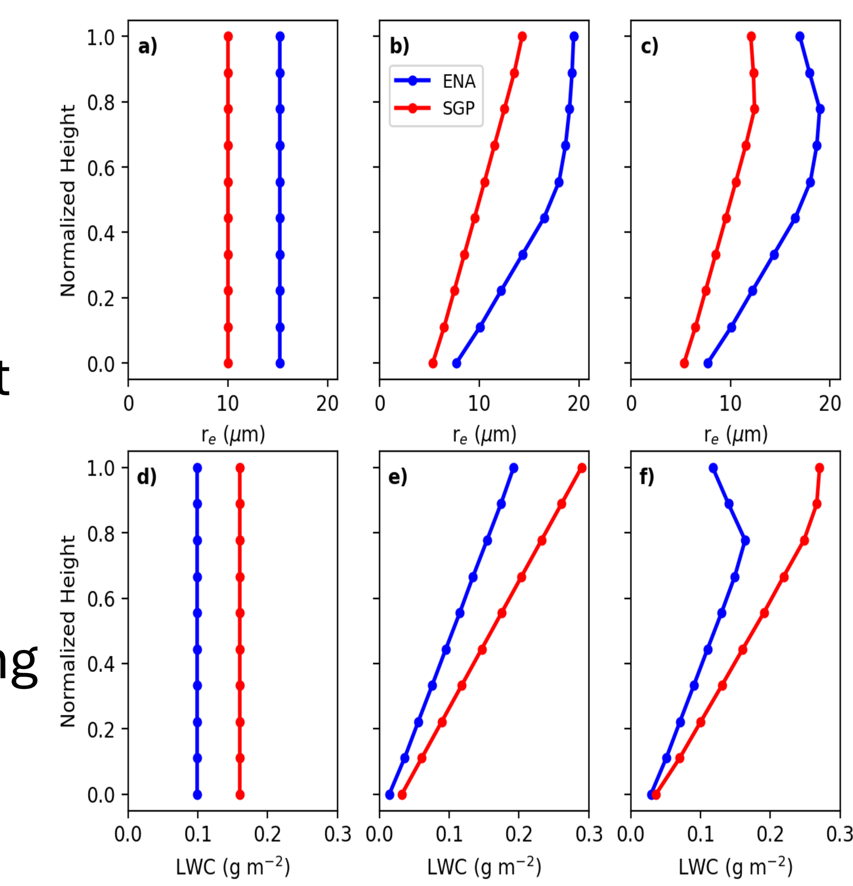
- Southern Great Plains (SGP)
  - 7 sites within 1° grid box
  - 334 cases
- Eastern North Atlantic (ENA)
  - Great for low-level clouds
  - 710 cases



CCCma Cloud Profile

Three Cloud Profiles for r_e and *LWC*:

- **Method 1:**
  - Constant
  - Simplest method
- **Method 2:**
  - Linear increasing with height
  - Similar to climate models
- **Method 3:**
  - Linear increasing until 3/4 height, then linear decreasing
  - Similar to real-world
- **ENA:**
  - Larger droplets, smaller LWP
- **SGP:**
  - Smaller droplets
  - Less entrainment near cloud top



Results

- Lower RMSEs at **TOA** than **surface**
- At the **surface**, increasing variability with higher $SWDN_{sfc}$

Over SGP:

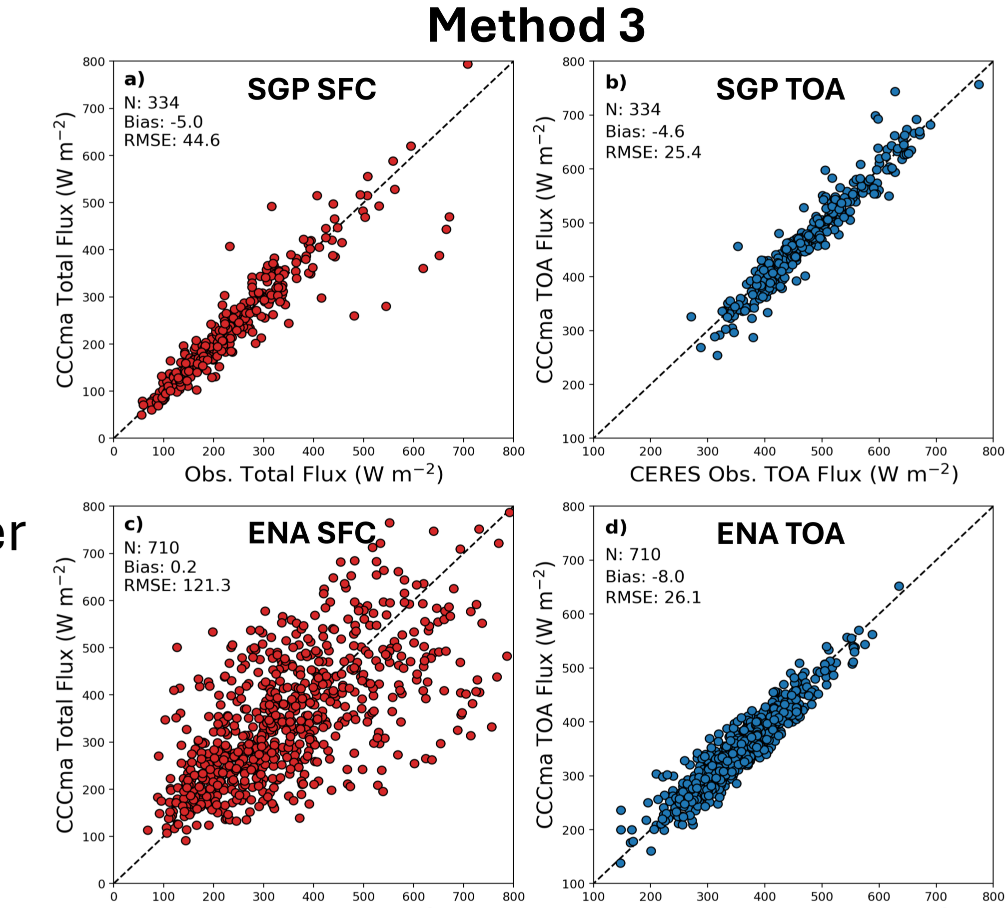
- Increasing absolute bias from M1 to M3 at **surface**
- Better **surface** RMSE for M2 and M3
- RMSE at **TOA** ~20 W m^{-2} lower than surface
- M3 shows the least bias and RMSE at **TOA**

Over ENA:

- RMSE at **surface** ~3x higher than **SGP**
  - Result of only 1 site
- M2 shows the worst performance at **surface** and **TOA**
- M3 outperforms M1, overall

	Observations (Wm^{-2})	Method 1	Method 2	Method 3
SGP SFC	Mean: 195.7	Bias: 0.2 RMSE: 47.1	Bias: -1.5 RMSE: 44.3	Bias: -5.0 RMSE: 44.6
SGP TOA	Mean: 489.6	Bias: -6.0 RMSE: 28.3	Bias: -9.0 RMSE: 26.0	Bias: -4.6 RMSE: 25.4
ENA SFC	Mean: 310.1	Bias: 5.6 RMSE: 122.7	Bias: 12.2 RMSE: 122.3	Bias: 0.2 RMSE: 121.3
ENA TOA	Mean: 376.6	Bias: -9.5 RMSE: 25.6	Bias: -19.1 RMSE: 32.6	Bias: -8.0 RMSE: 26.1

Method 3

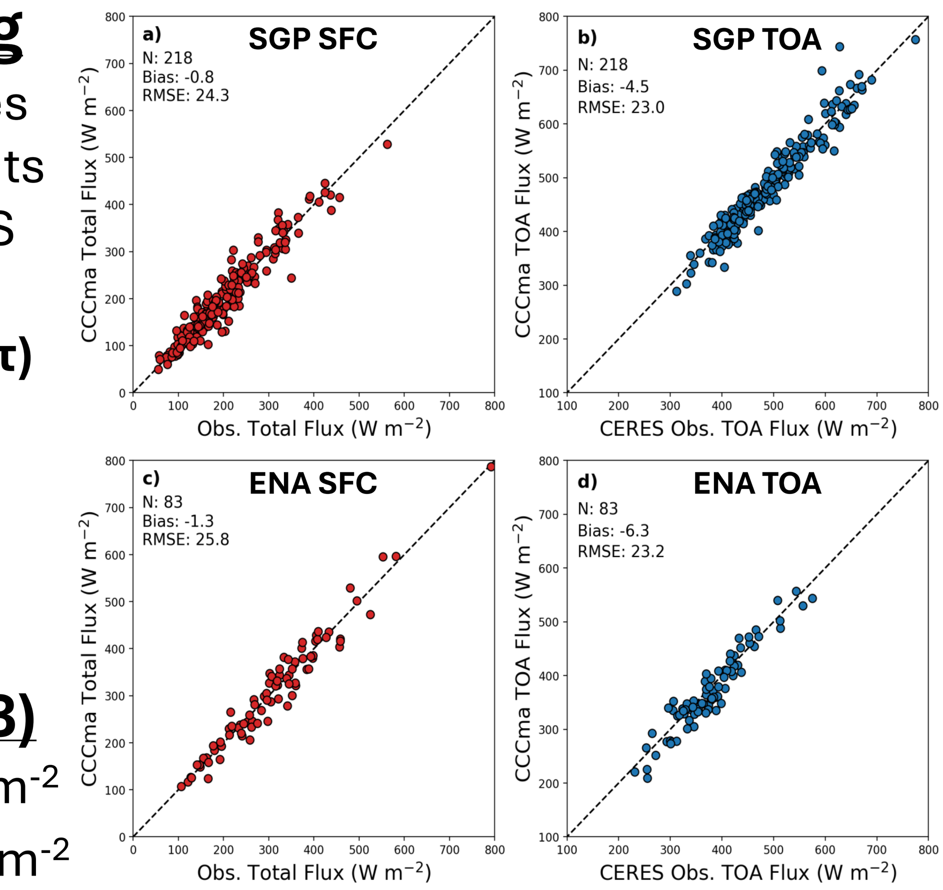


Surface Cloud Screening

- Surface-derived cloud properties from pyranometer measurements are matched with CERES MODIS cloud properties
- **Surface Cloud Optical Depth (τ)**
  - $\tau = \frac{\frac{1.16}{r} - 1}{(1-A)(1-g)}$ where $r = \frac{T}{c\mu_0^{0.25}}$
  - Error < 10%
- **Cloud Fraction**
  - Empirical Fit

Updated Results (Method 3)

- **ENA**: RMSE reduced by 96.0 W m^{-2}
- **SGP**: RMSE reduced by 20.3 W m^{-2}
- Similar errors as before for surface bias and TOA



CERES Fu-Liou RTM Comparison

- Compared with Method 1
  - Same method Fu-Liou uses
- Larger differences at **TOA**
- Similar errors for **surface** and **TOA** at **SGP**
- CCCma has better performance at **ENA**

	Observ. (W m^{-2})	Fu-Liou Bias	CCCma Bias	Fu-Liou RMSE	CCCma RMSE
SGP SFC	195.7	9.1	5.7	27.5	29.9
SGP TOA	489.6	10.3	-6.3	25.7	27.0
ENA SFC	310.1	-12.3	2.1	22.6	19.9
ENA TOA	376.6	24.2	-5.9	30.6	23.1

Conclusion

- Method 3 overall shows the best $SWDN_{sfc}$ and $SWUP_{TOA}$ results at both **SGP** and **ENA**
- Matching CERES MODIS and surface-derived cloud properties can help identify more homogenous clouds for better RTM calculations
- Overall, CCCma outperforms Fu-Liou RTM, especially over ENA

Future Work

- Test CCCma calculations on other cloud types
- Perform global calculations for All-sky conditions

References

Brendecke, J., Dong, X., Xi, B., Zhong, X., Li, J., Barker, H. W., & Pilewskie, P. (2024). Evaluation of clear-sky surface downwelling shortwave fluxes computed by three atmospheric radiative transfer models. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *328*, 109164. https://doi.org/10.1016/j.jqsrt.2024.109164

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