Determining the daytime Earth's shortwave fluxes from DSCOVR

Wenying Su[1], L. Liang[2], D. P. Duda[2], P. Minnis[2], K. Khlopenkov[2], M. K. Thiemann[2], Gregory Elasesser[3], Daniel Feldman[4], Dave Doelling[1], Conor Haney[2],

1. NASA Langley Research Center, Hampton, VA, 2. SSAI, Hampton, VA
3. GISS/Columbia University, 4. LBNL, Berkeley, CA

Objectives of the project

- Produce global daytime mean fluxes from radiances observed by NISTAR and EPIC (Su et al., 2018, 2020, 2021)
  - Determine the global daytime mean SW and LW anisotropic factors (Su et al., 2018)
  - Use EPIC cloud composite data for scene identification (Khlopenkov et al., 2017), and for evaluating EPIC cloud product (Yang et al., 2019)
- Evaluate the global climate models using the high-temporal-resolution fluxes (Carlson et al., 2019, 2021, Feldman et al., 2021, Lacis et al., 2021)
- Calibrate EPIC visible channels using MODIS, VIIRS, and invariant targets (Doelling et al., 2019, Haney et al., 2016, 2021)

Global daytime mean radiances from NISTAR and EPIC

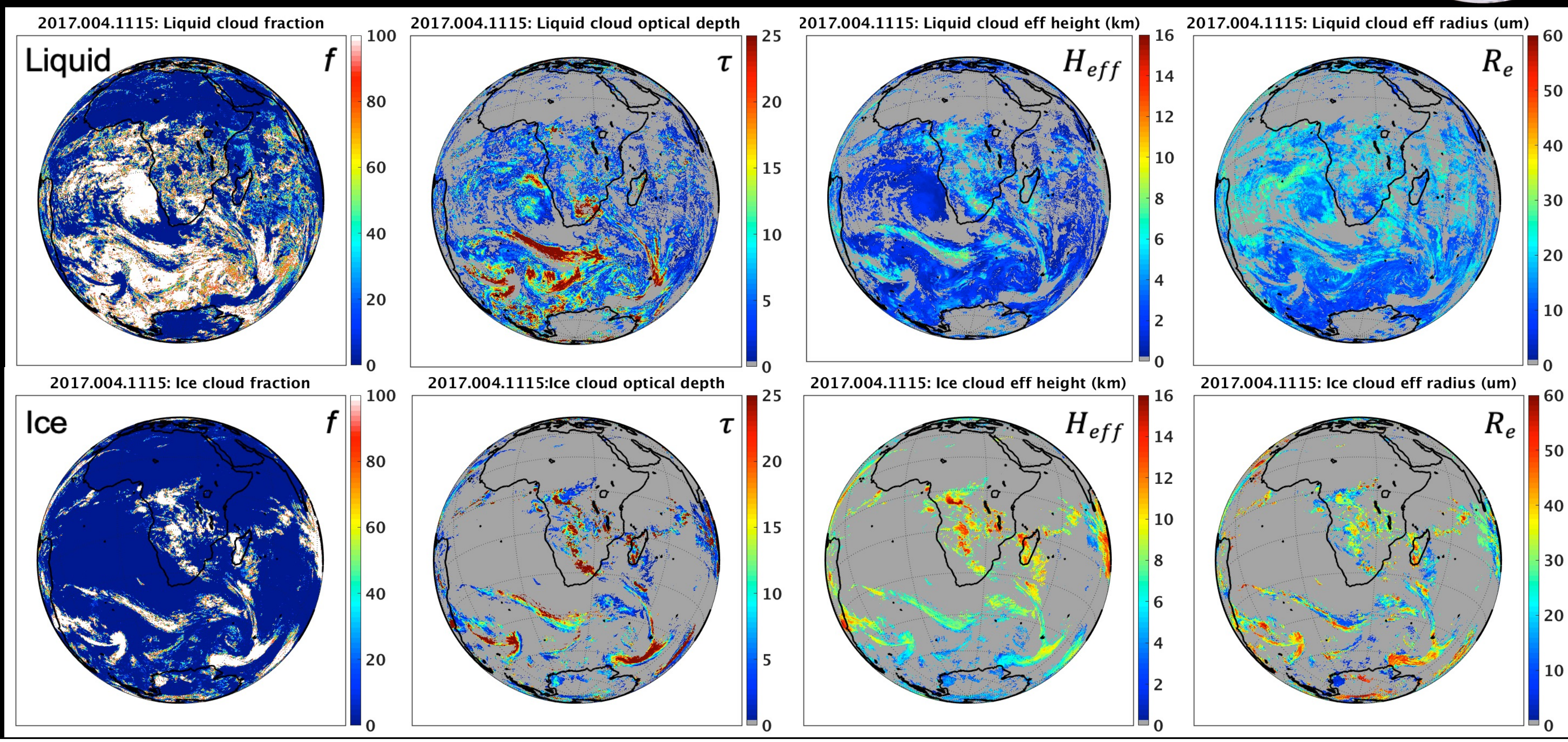
- NISTAR provides continuous broadband radiance measurements for the shortwave and total channels from the sunlit side of the Earth as a single pixel.
- EPIC provides 10 narrow band spectral images of the entire sunlit side of the Earth using a 2048x2048 pixel CCD (Charge Coupled Device) detector.
  - Use the EPIC narrowband channels of blue, green, and red to derive the shortwave (SW) broadband reflectance (Su et al., 2018).
  - Narrowband to broadband (NB2BB) regression coefficients are developed based upon collocated MODIS and CERES data for all-sky conditions separately for ocean and non-ocean surfaces using corresponding MODIS channels.
  - Apply these relationships to EPIC 443, 551, and 680nm channels to derive EPIC broadband radiance (I^{bb}_{e}) for each pixel.
  - EPIC pixel-level broadband SW radiances are averaged to calculate the global daytime mean shortwave radiance.

Anisotropy of the TOA radiance field must be considered when converting radiances to fluxes

$$F(\theta_0) = \frac{\pi I_o(\theta_0, \theta, \phi)}{R(\theta_0, \theta, \phi)}$$

- Using the scene-type dependent CERES empirical angular distribution models (ADMs, Su et al. 2015);
- Scene type is defined based upon many variables: surface type, cloud fraction, cloud optical depth, cloud phase, wind speed, etc.;
- Low spatial resolution of EPIC imagery (20x20 km^2) and its lack of infrared channels diminish its capability to identify clouds and to accurately retrieve cloud properties;
- To determine the scene type for each EPIC pixel, we take advantage of the cloud property retrievals (Minnis et al. 2008, 2021) from multiple imagers on low Earth orbit (LEO) satellites and on geostationary (GEO) satellites;
- Cloud property retrievals from these LEO/GEO imagers are optimally merged together to provide a seamless global composite product at 5-km resolution.

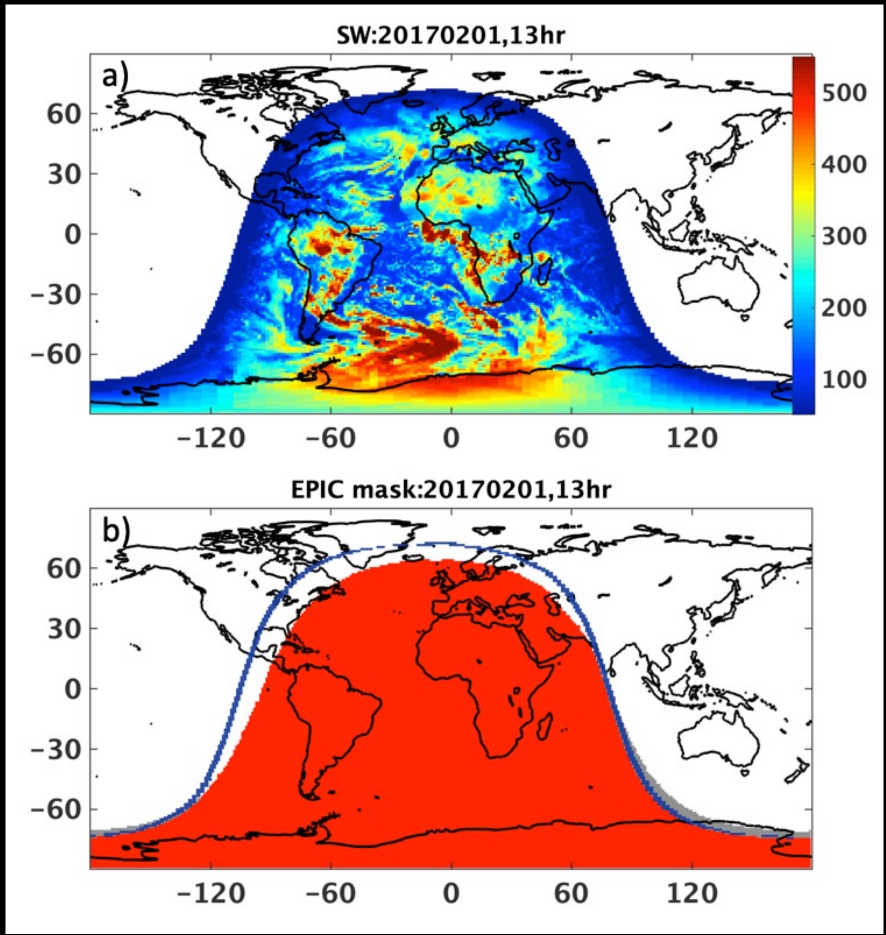
Global composite data are then remapped into the EPIC field of view by convolving the high-resolution cloud properties with the EPIC point spread function to produce the EPIC composite: an example of 11:15 UTC, 4 Jan. 2017



Comparison between EPIC and CERES SYN fluxes

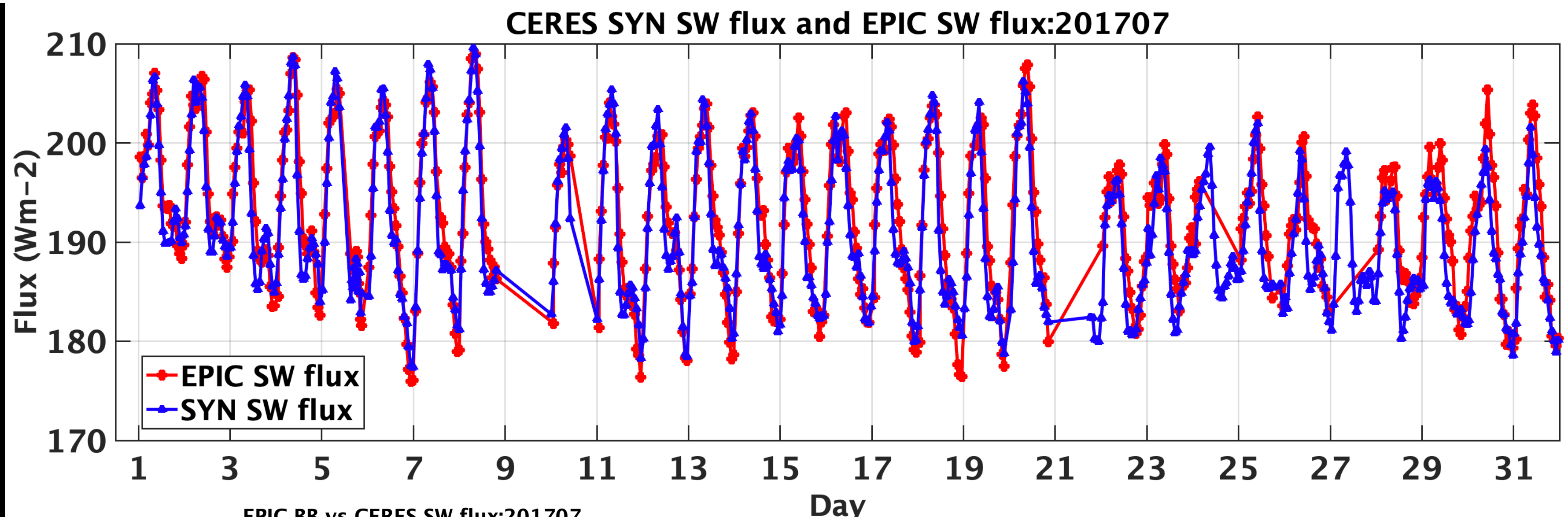
Daytime SW flux from CERES SYN

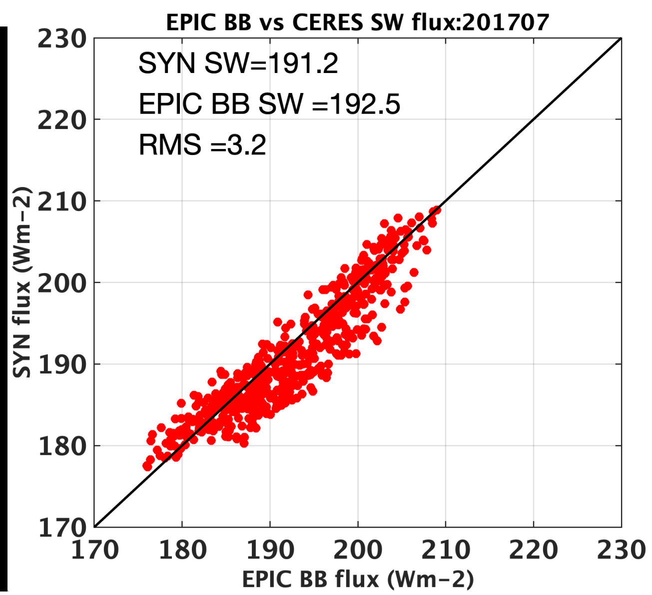
EPIC view mask:
Red: Daytime areas within EPIC view
Grey: Nighttime areas within EPIC view
Blue line: terminator boundary



- CERES synoptic product (SYN) also provides hourly TOA SW and LW fluxes;
- To compare the hourly SYN data with EPIC flux, only consider the daytime SYN grid boxes that are visible to EPIC, and these data are weighted by cos(latitude):

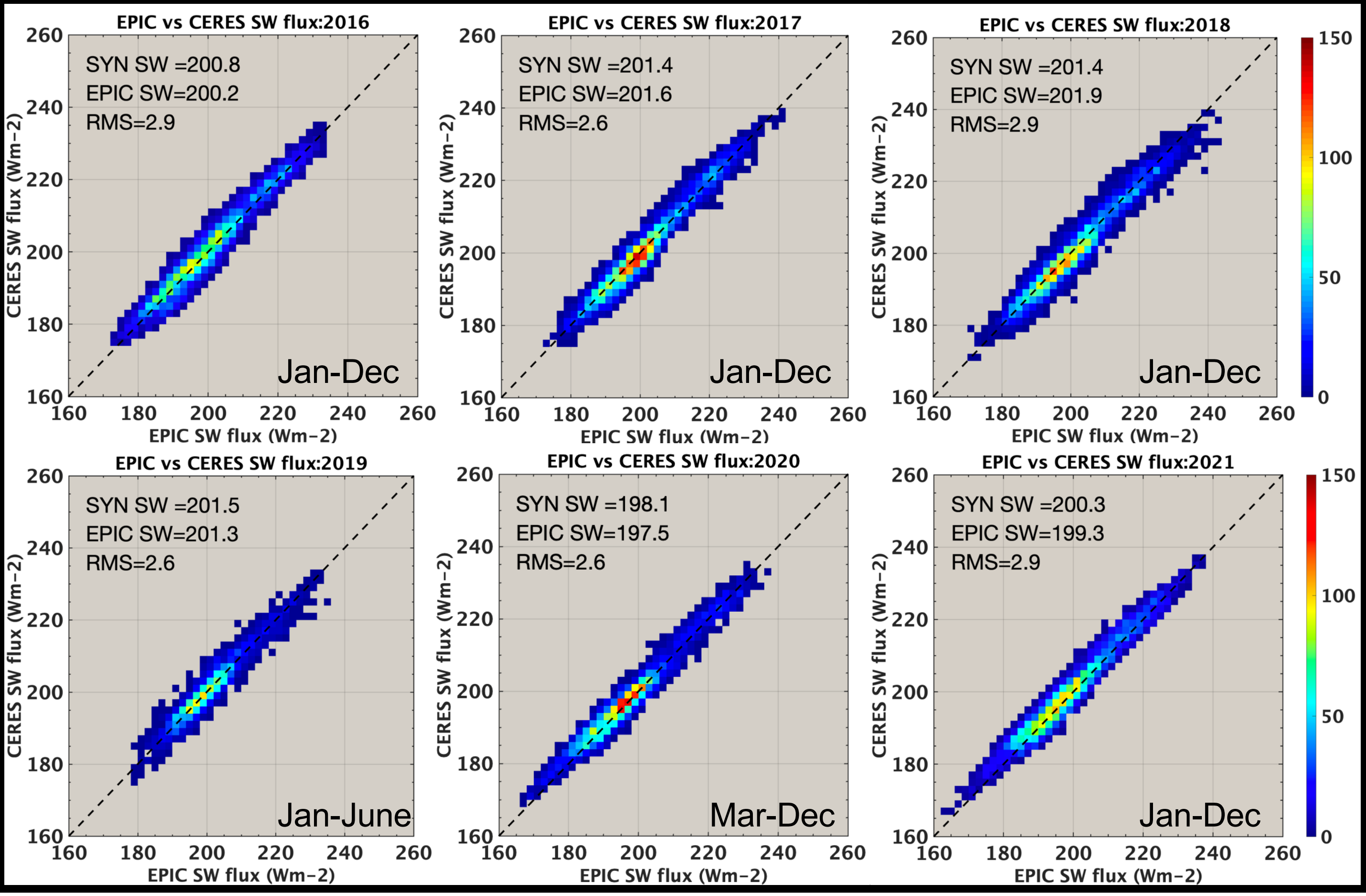
$$\overline{F_{syn}} = \frac{\sum F_j cos(lat_j)\omega_j}{\sum cos(lat_j)\omega_j}$$


CERES SYN SW flux and EPIC SW flux:201707
Flux (Wm−2)
Day
EPIC SW flux
SYN SW flux


EPIC BB vs CERES SW flux:201707
SYN SW=191.2
EPIC BB SW =192.5
RMS =3.2
SYN flux (Wm−2)
EPIC BB flux (Wm−2)

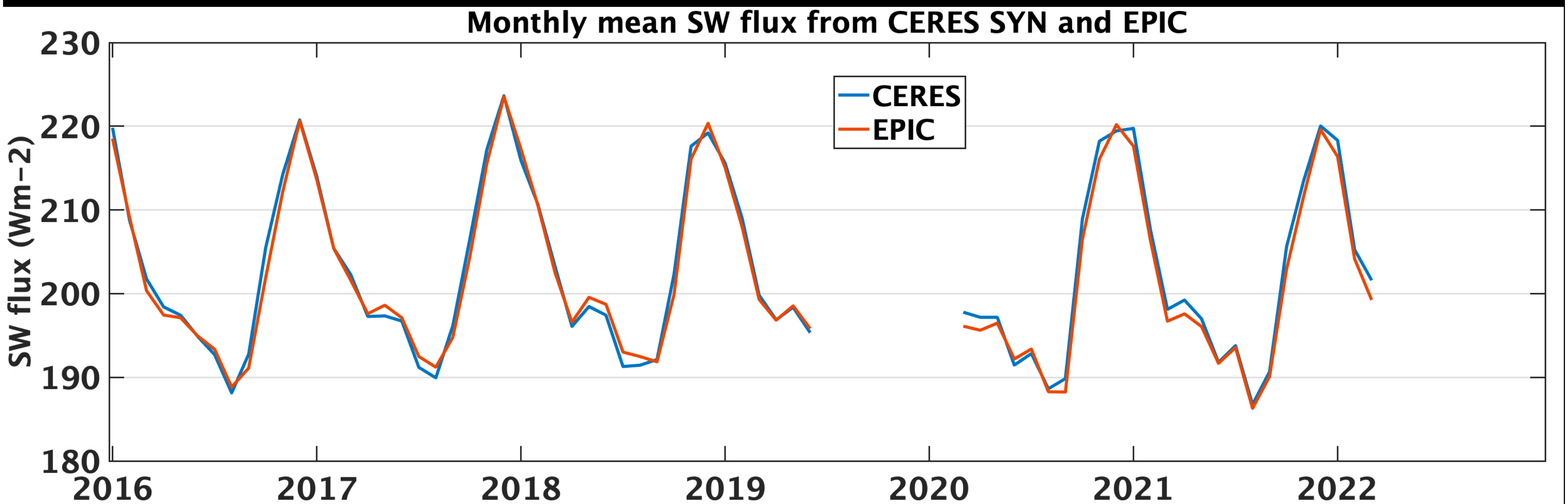
Global daytime SW flux comparison between CERES and EPIC

Hourly gridded CERES synoptic (SYN) SW fluxes are integrated over the areas that are visible to EPIC/NISTAR.



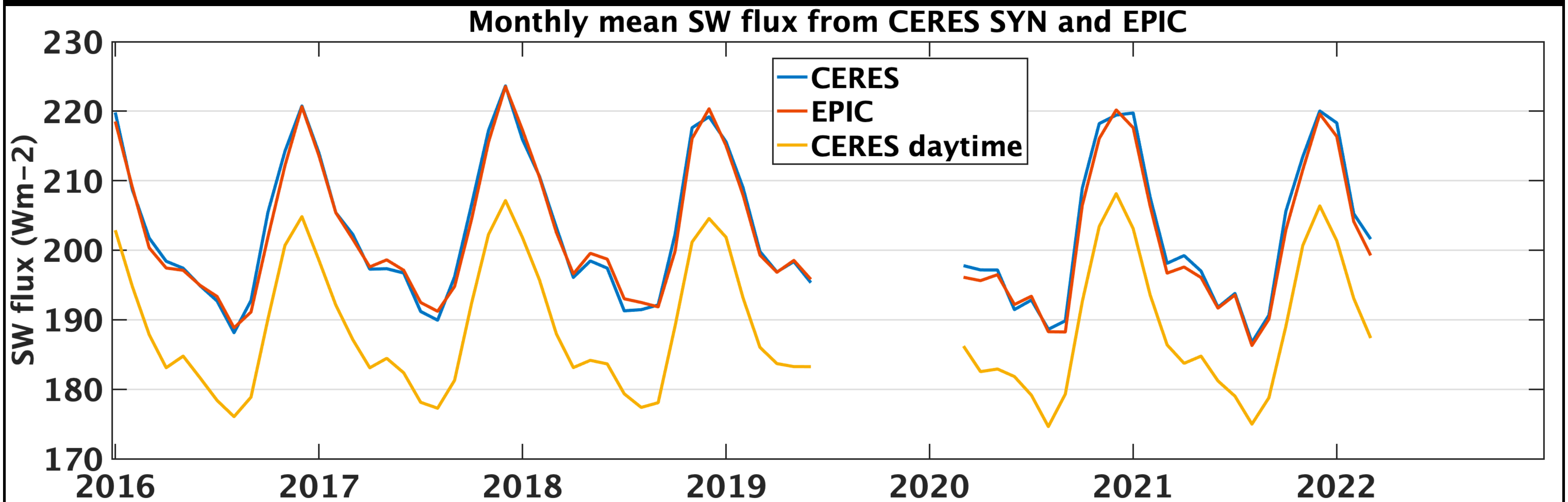
Monthly daytime mean SW fluxes from EPIC and CERES

- Multi-year mean EPIC SW flux is 202.1 Wm-2
- Multi-year mean CERES SYN SW flux is 202.6 Wm-2
- RMS error is 1.3 Wm-2

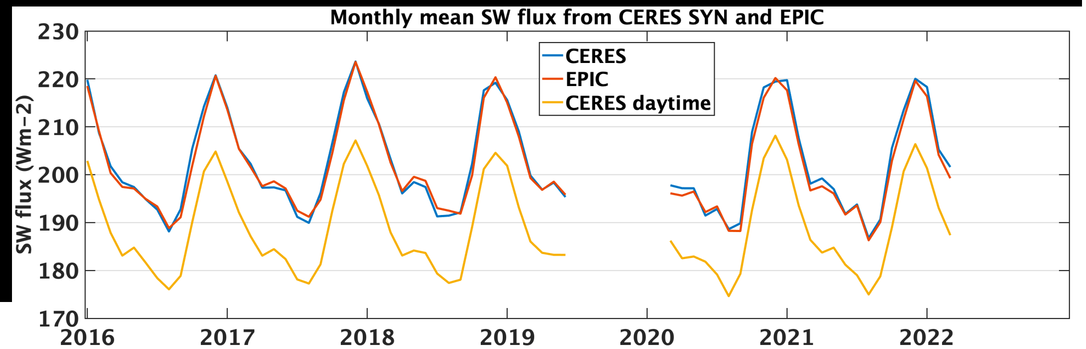


DSCOVR's elliptical Lissajous orbit does not observe the entire daytime portion of the Earth

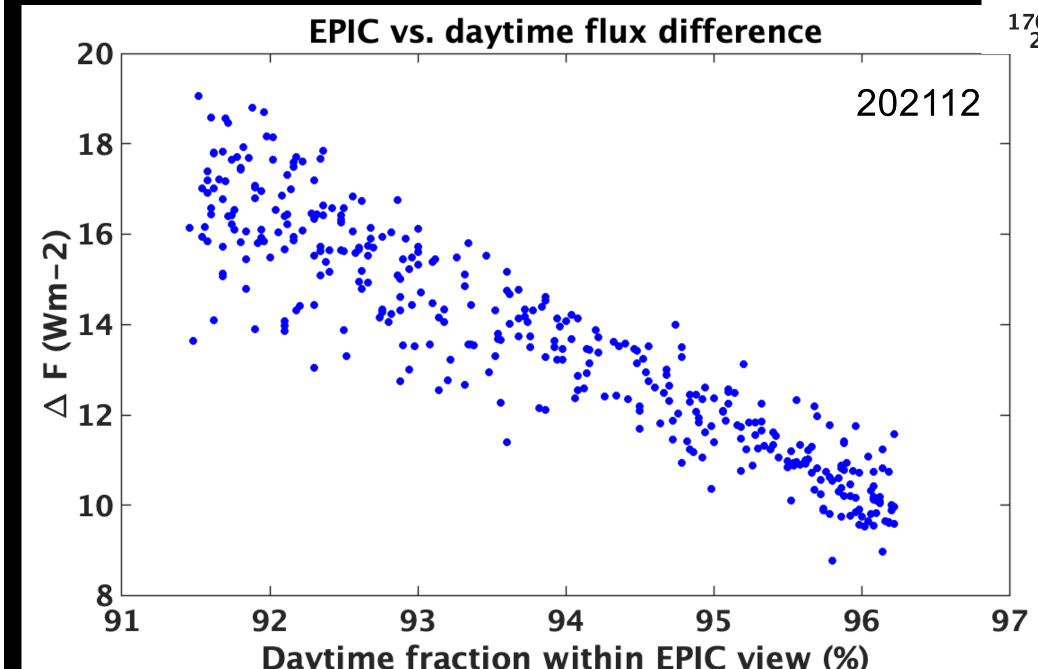
- Fluxes averaged over the daytime portion of the Earth that are visible from DSCOVR orbit are greater than fluxes averaged over the entire daytime portion of the Earth

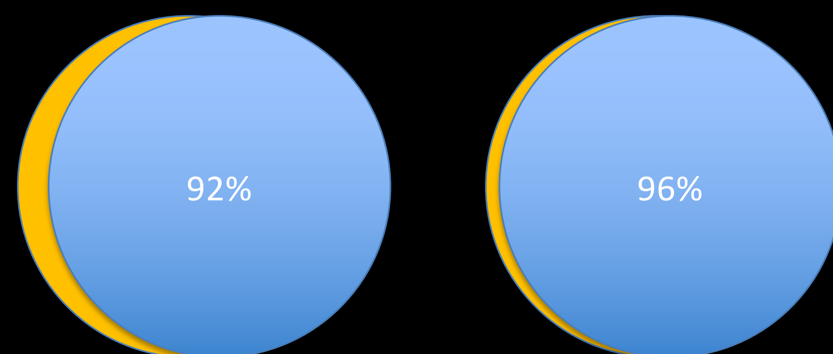


Flux differences between EPIC view and entire daytime view depend on the portion of daytime fraction within the EPIC view

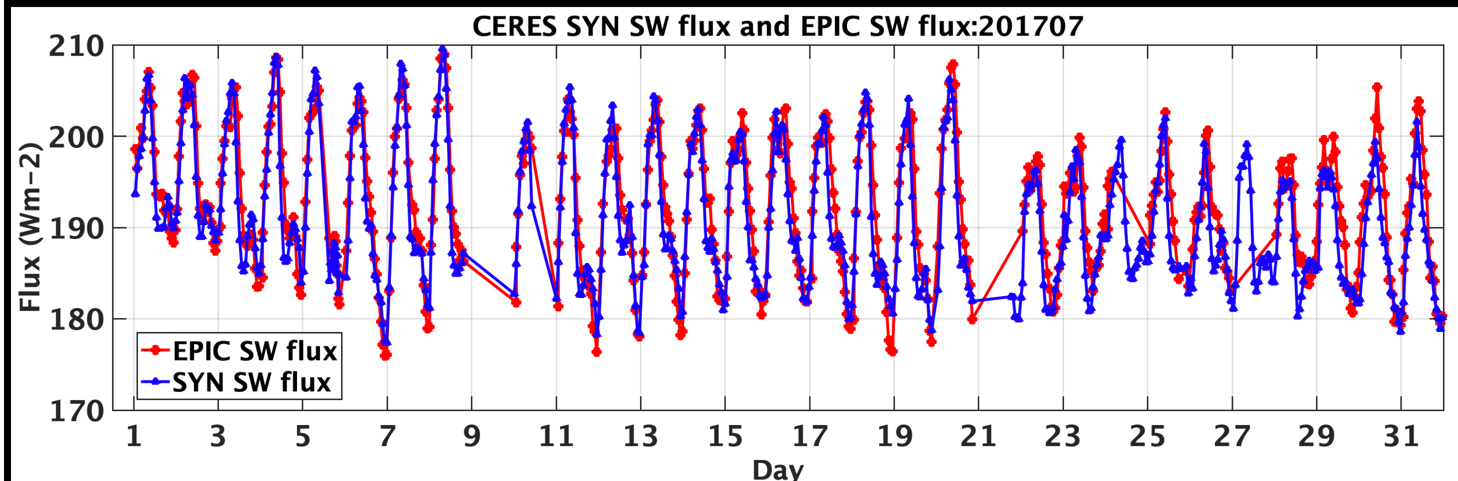


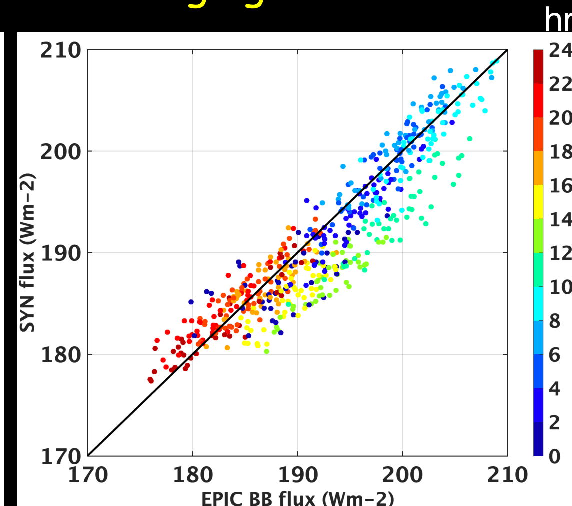
ΔF=CERES over EPIC view- CERES daytime

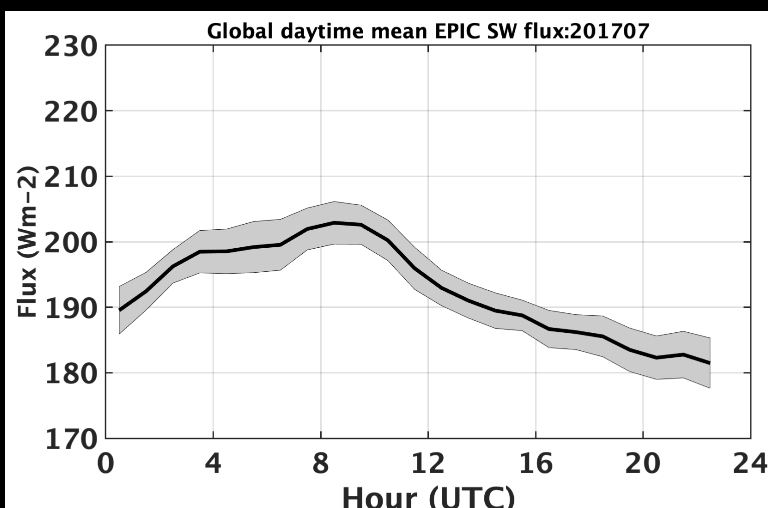


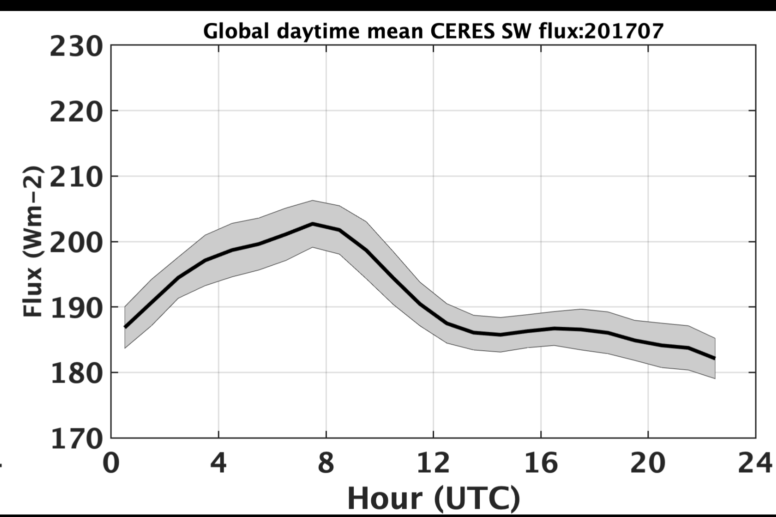


Comparison of SW flux between CERES SYN and EPIC at different imaging time

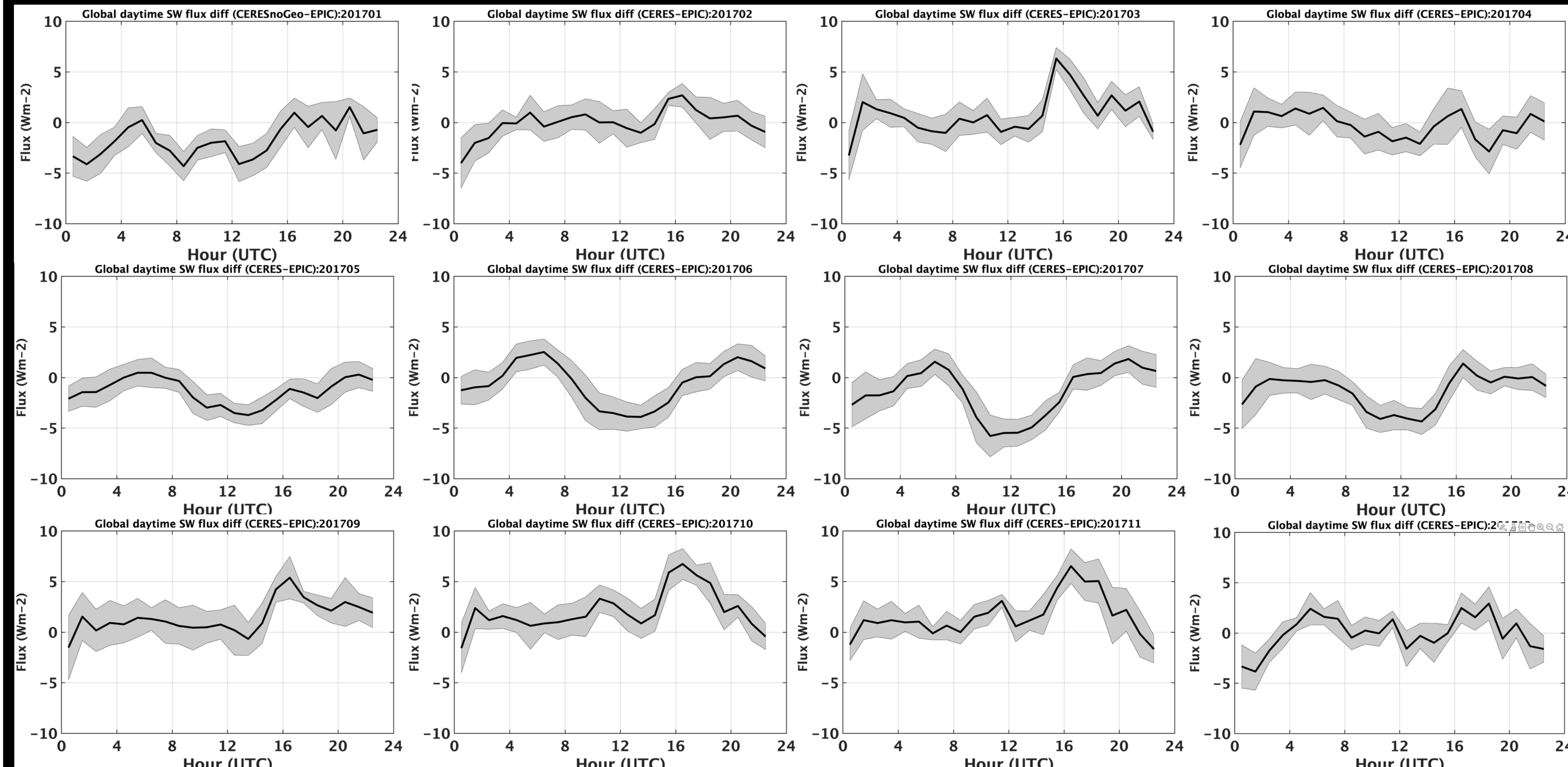






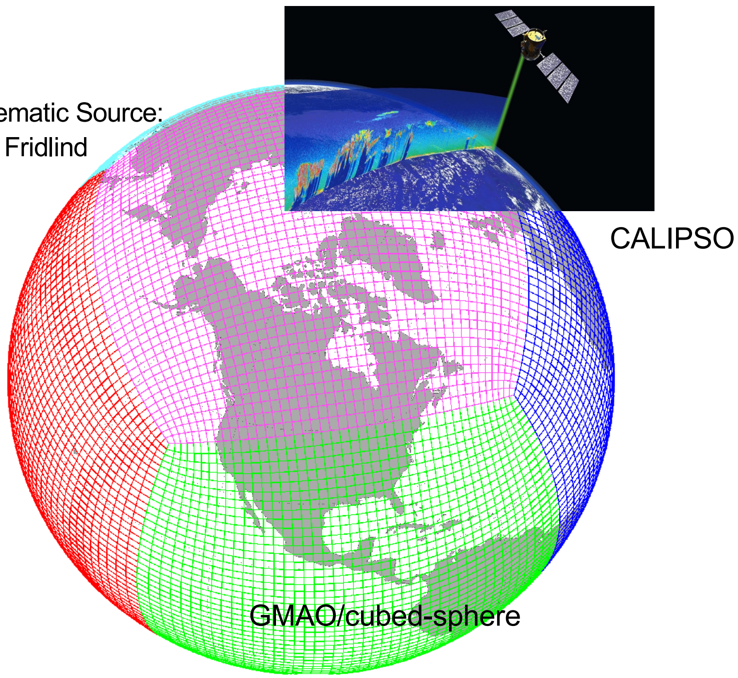


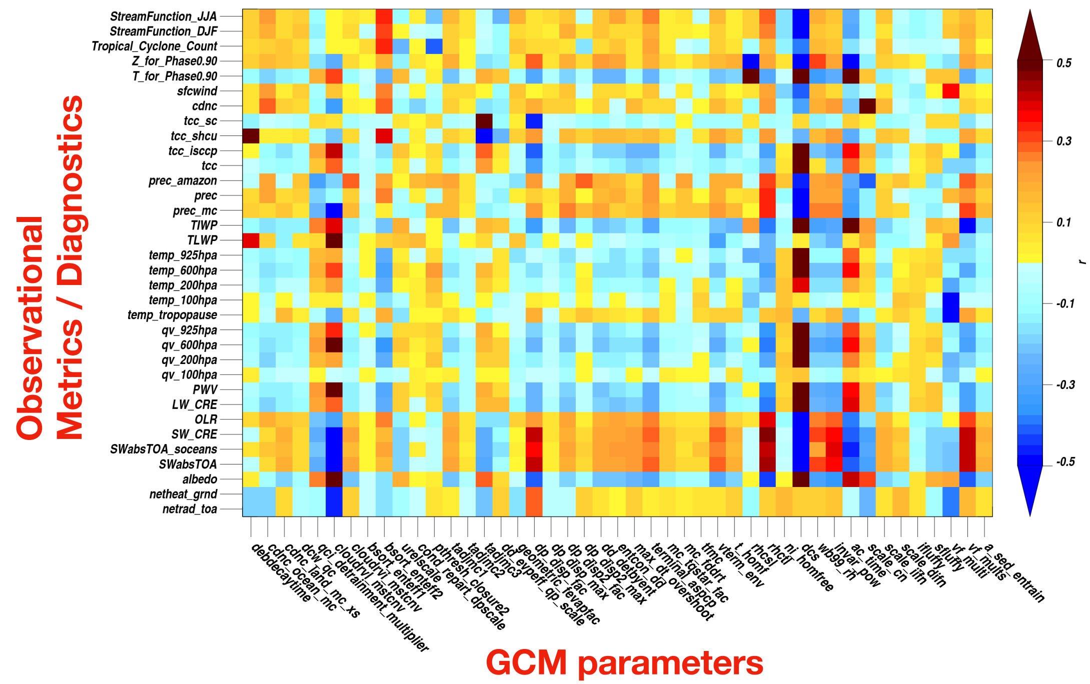
Using EPIC quasi-hourly fluxes to evaluate the diurnal cycle



Evaluating Machine Learning (ML)-Calibrated Climate Model

Global satellite data → input into ML multi-parameter optimization framework → output: globally tuned GISS GCM variants + "power map" showing connections between all 45 model parameters and ~35 diagnostics



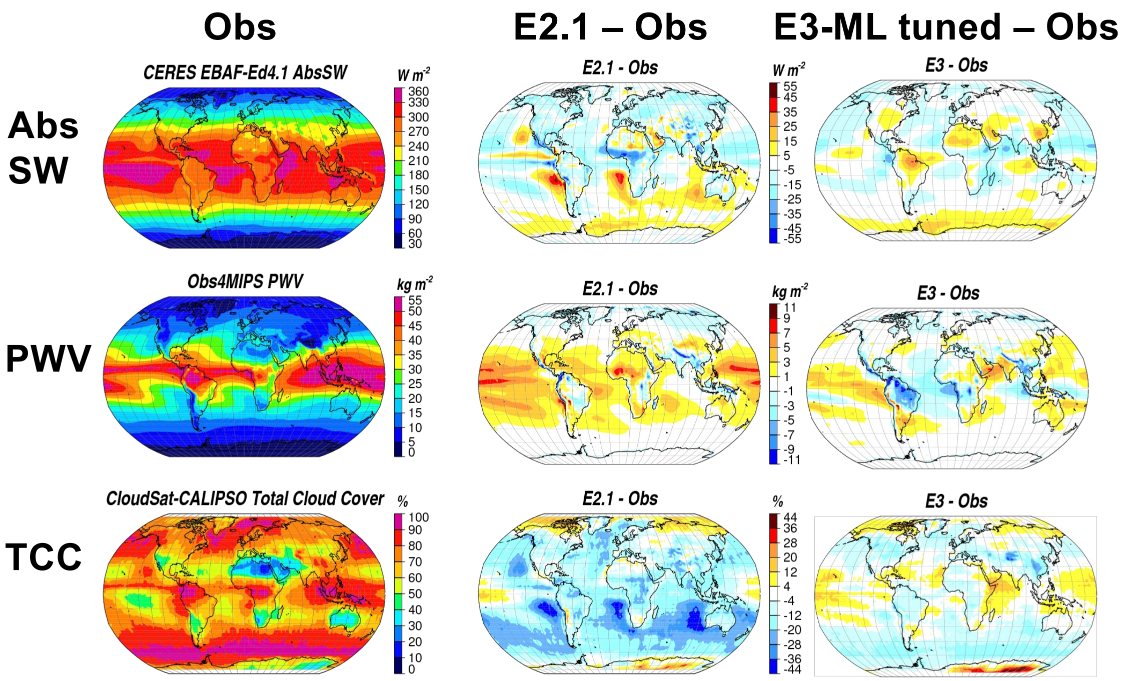


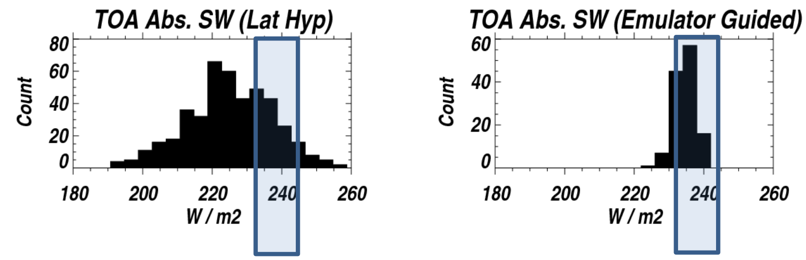
ML Work Led by: Greg Elsaesser, Marcus van Lier-Walqui (NASA-GISS Clouds-Convection Group)

NASA U.S. DEPARTMENT OF ENERGY NSF LEAP

Evaluating Machine Learning (ML)-Calibrated Climate Model

Global satellite data → input into ML multi-parameter optimization framework → output: globally tuned GISS GCM variants





ML Emulator (**top right**) generates GCM parameter variants closer to observations & in radiative balance, an improvement over variants derived using Latin Hypercube Sampling (**top left**). (**left**) Global bias map for one ML-GCM member compared to non-ML GCM (E2.1) for select obs.

One project task : To what extent do improved global GISS-GCM climatologies imply improved radiation and cloud variability on short timescales?

U.S. DEPARTMENT OF ENERGY

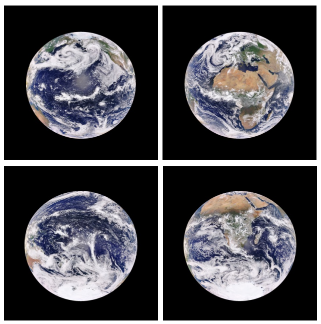
NSF

LEAP

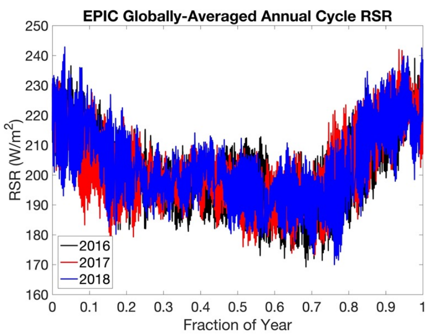
ML Work Led by: Greg Elsaesser, Marcus van Lier-Walqui (NASA-GISS Clouds-Convection Group)

Testing Climate Model TOA Reflected SW radiation across Time-Scales

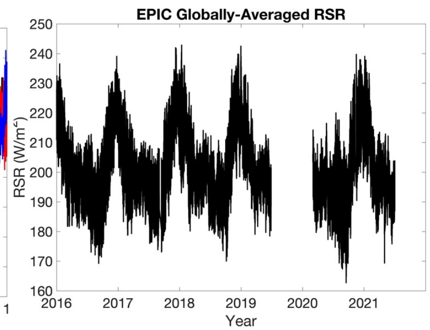
High-frequency RSR measurements from the EPIC/NISTAR record reveal the path the Earth system takes to from diurnal fluctuations in RSR to long-term RSR stability.



Sub-Diurnal

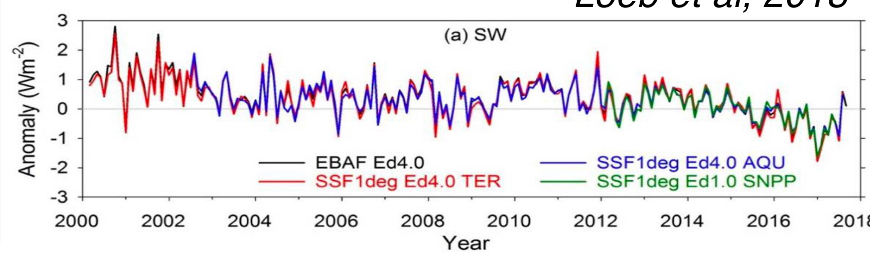


Seasonal



Interannual

Loeb et al, 2018

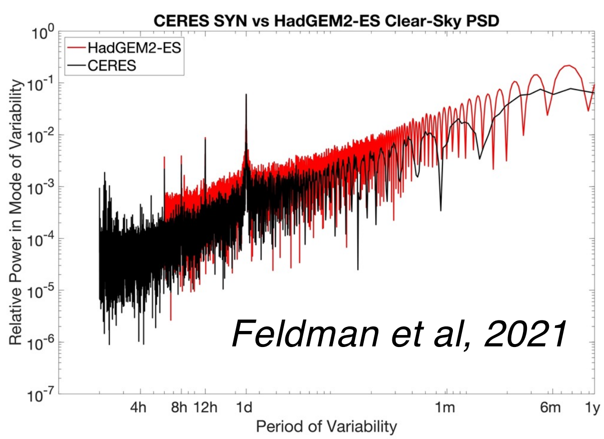


Decadal

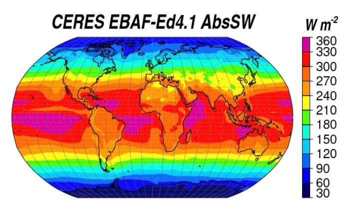
This path can be described by a red-noise process:

$$P(f) = Af^{\alpha}$$

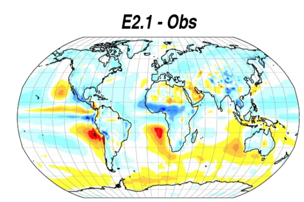
CMIP5 and CMIP6 models overestimate alpha



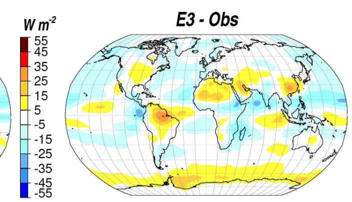
Obs



E2.1 – Obs



E3-ML tuned – Obs



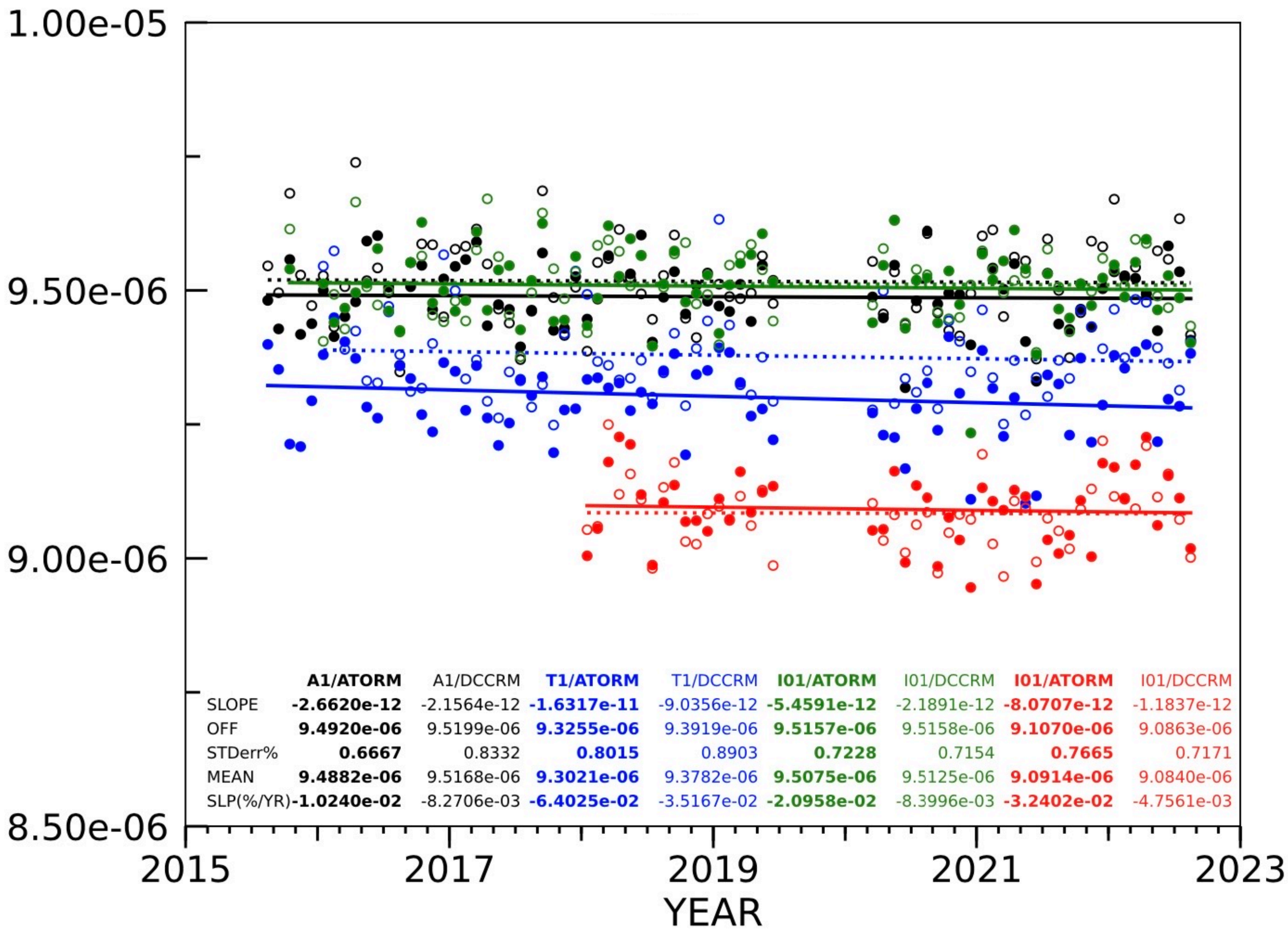
GISS PPE produces better RSR, does it still overestimate alpha?

If it does, RSR stability pathway not constrained by tuned models.

If realistic alpha, tuned models should use EPIC/NISTAR stability pathway.

Climate Model Testing Led by: Dan Feldman, LBNL

DSCOVR EPIC Band 7 (0.68 µm) version 3



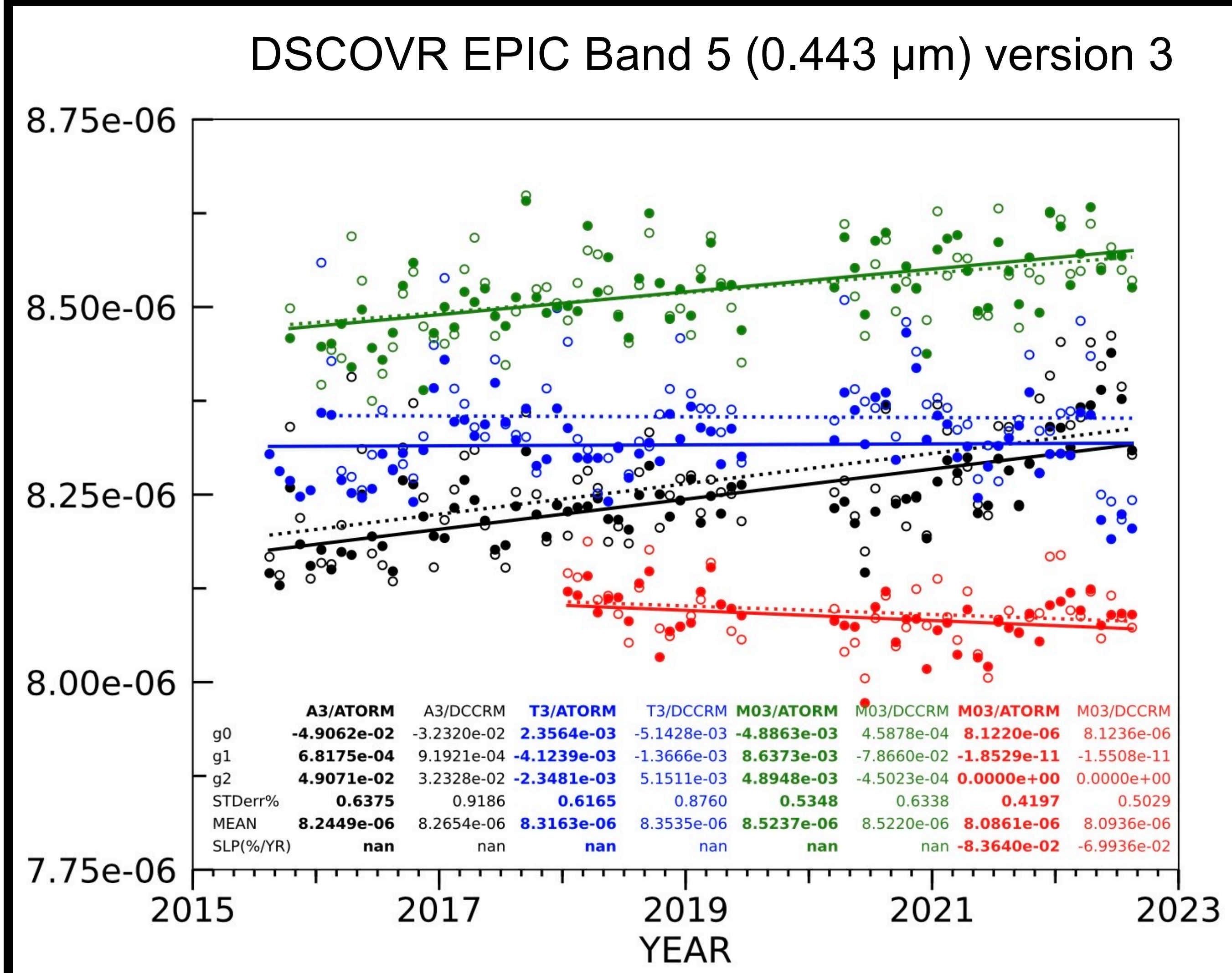
Sensor Legend
Terra-MODIS C6.1
Aqua-MODIS C6.1
NPP-VIIRS C2
N20-VIIRS C2.1

Ray-Match Legend
All-sky Tropical Ocean ___
Deep Convective Cloud ……

Updates since DSCOVR STM 2021

- Extend the timeline from February 2021 to August 2022
- Use the latest NPP C2 and N20 C2.1 VIIRS collections which have all known trends removed
- Add Terra-MODIS reference
- Note that MODIS is in forward processing mode since 2016 (could have residual trends)

all trends <0.2% over 7-years except based on Terra-MODIS



Sensor Legend
Terra-MODIS C6.1
Aqua-MODIS C6.1
NPP-VIIRS C2
N20-VIIRS C2.1

Ray-Match Legend
All-sky Tropical Ocean ___
Deep Convective Cloud ……

Updates since DSCOVR STM 2021

- Notice that the EPIC trend comparison with MODIS and VIIRS is inconsistent (also shown in the Frontiers paper). Still investigating.
- The extension of Feb 2021 till Aug 2022 did not change the inconsistent trends
- Having the longer timelines invalidated the asymptotic fits of the Frontiers paper
- Band 6 trends are more consistent with MODIS and VIIRS

Summary

- Produced EPIC cloud composite and EPIC SW flux from January 2016 to March 2022.
- EPIC SW fluxes agree very well with CERES SYN SW fluxes, despite the viewing geometries of EPIC differ significantly from CERES.
- Caution not to use EPIC flux to study interannual variability, as the magnitude of EPIC flux is also sensitive to the percentage of daytime area visible to EPIC.
- EPIC SW flux dataset provides unique diurnal information to evaluate diurnal fluxes of CERES SYN and climate model.

Publications

1. Wenying Su, L. Liang, D. P. Duda, K. V. Khlopenkov, M. Thieman, Global daytime mean shortwave flux consistency under varying EPIC viewing geometries, *Frontiers Remote Sens.,* 10.3389/frsen.2021.747859, 2021.
2. Conor Haney, David Doelling, Wenying Su, Rajendra Bhatt, Arun Gopalan and Benjamin Scarino, Radiometric Stability Assessment of the DSCOVR EPIC Visible Bands using MODIS, VIIRS, and Invariant Targets as Independent References, Frontiers Remote Sens. , 10.3389/frsen.2021.765913 , 2021.
3. Andrew A Lacis, Barbara E Carlson, Gary L Russell, Alexander Marshak and Wenying Su, NISTAR and EPIC Inspired Climate GCM Diagnostics of the Earth's Planetary Albedo and Cloud Distribution via Longitudinal Data Slicing, Frontiers Remote Sens. , 10.3389/frsen.2021.766917, 2021.
4. Barbara E Carlson, Andrew A Lacis, Gary L Russell, Alexander Marshak and Wenying Su, Unique observational constraints on the seasonal and longitudinal variability of the Earth's planetary albedo and cloud distribution inferred from EPIC measurements, 10.3389/frsen.2021.788525, Frontiers Remote Sens., 2021.
5. Valero, F. P. J., A. Marshak, and P. Minnis, LaGrange point missions: The key to next generation integrated Earth observations. DSCOVR innovation. *Frontiers Remote Sens.*, doi:10.3389/frsen.2021.745938, 2021.
6. Daniel R. Feldman, Wenying Su, Pat Minnis, Subdiurnal to interannual frequency analysis of observed and modeled reflected shortwave radiation from Earth, 48, e2020GL089221, 10.1029/2020GL089221, Geophysical Research Letter, 2021.
7. Wenying Su, P. Minnis, L. Liang, D. P. Duda, K. V. Khlopenkov, M. Thieman, Y. Yu, A. Smith, S. Lorentz, D. Feldman, F. P. J. Valero, Determining the daytime Earth radiative flux from National Institute of Standards and Technology Advanced Radiometer (NISTAR) Measurements, 13, 429-443, Atmos. Meas. Tech., 10.5194/amt-13-429-2020, 2020.
8. Barbara Carlson, Andrew Lacis, Christopher Colose, Alexander Marshak, Wenying Su, Steven Lorentz, Spectral signature of the biosphere: NISTAR finds it in our solar system, Geophys. Res. Lett., 10.1029/2019GL083736, 2019.
9. Doelling, D., Haney, C., Bhatt, R., Scarino, B., and Gopalan, A. (2019). The Inter-Calibration of the DSCOVR EPIC Imager with Aqua-MODIS and NPP-VIIRS. Remote Sens. 11, 1609. doi:10.3390/rs11131609
10. Yang, Y., Meyer, K., Wind, G., Zhou, Y., Marshak, A., Platnick, S., Min, Q., Davis, A. B., Joiner, J., Vasilkov, A., Duda, D., and Su, W.: Cloud Products from the Earth Polychromatic Imaging Camera (EPIC): Algorithms and Initial Evaluation, Atmos. Meas. Tech., 12, 2019-2031, https://doi.org/10.5194/amt-12-2019-2019, 2019.
11. Wenying Su, L. Liang, D. R. Doelling, P. Minnis, D. Duda, K. Khlopenkov, M. Thieman, N. G. Loeb, S. Kato, F. P. J. Valero, H. Wang, and F. Rose. Determining the shortwave radiative flux from earth polychromatic imaging camera. J. Geophys. Res., 123, doi:10.1029/2018JD029390, 2018.
12. K. khlopenkov, D. Duda, M. Thieman, P. Minnis, W. Su, and K. Bedka. Development of multi-sensor global cloud and radiance composites for Earth radiation budget monitoring from DSCOVR, Remote sensing of clouds and the atmosphere XXII, Editors: E. I. Kassianov, K. Schafer, R. H. Picard, and K. Weber, Volume 10424K. Proc. of SPIE, 2017.
13. C. O. Haney, D. R. Doelling, P. Minnis, R. Bhatt, B. Scarino, and A. Gopalan. The calibration of the DSCOVR EPIC multiple visible channel instrument using MODIS and VIIRS as a reference. In Proc. of SPIE, volume 9972, 2016.