TISA Working Group Update

CERES TISA Sublead: D. Doelling

TISA: B. Branch, A. Gopalan, E. Kizer, P. Mlynczak, C. Nguyen, M. Nordeen, M. Sun, J. Wilkins, F. Wrenn

GEO and Imager calibration: R. Bhatt, C. Haney, B. Scarino

Kathleen Dejwakh & subsetter team

36th CERES Joint Science Team Meeting

Virtual Covid-19 Meeting, October 12-14, 2021

TISA (Time/Space Averaging) tasks

- Spatially average the instantaneous CERES footprint fluxes and clouds, as well as the GEO (geostationary imager) cloud properties and channel radiances
- Regionally (1deg) temporally interpolate and average the CERES Terra (10:30AM) and Aqua (1:30PM) flux and clouds into daily/monthly averages
  - SSF1deg use constant meteorology using only CERES observations to compute the daily fluxes and clouds
  - SYN1deg use geostationary derived hourly fluxes to infer the fluxes between CERES measurements
    - Need to build SW and LW GEO narrowband to broadband relationships, which have been normalized to the CERES fluxes
    - Need to calibrate the GEO channel radiances to the MODIS reference
  - FluxByCloudType (FBCT) stratify CERES flux and clouds with cloud-type with the addition of MODIS cloud-type derived fluxes of partly cloud footprints
- Assist other groups in their monthly validation through TISA processing and subsetter
- Code rearchitecture and modularization effort

TISA activities

- GEO Ed5 shortwave narrowband to broadband progress
  - Land application
- MODIS/VIIRS imager radiometric scaling and drift correction
  - Validation with DSCOVR-EPIC
- FBCT product validation
- SYN1deg – hourly dataset improvements for Ed5
  - GOES-17 automated bad scan line detection
  - Static GEO boundaries
  - Mitigation of spurious cloud retrievals during twilight
  - 3-channel 1st generation GEO gridding improvements

CERES TISA and GEO/imager Calibration Publications

- **TISA**
- Benjamin Scarino, David R. Doelling, Konstantin Khlopenkov, William L. Smith, Michele Nordeen, "Improving the CERES SYN cloud and flux products by identifying GOES-17 scan anomalies using a convolutional neural network," Proc. SPIE 11829, Earth Observing Systems XXVI, 1182904 (1 August 2021); doi: 10.1117/12.2594637
- D. Doelling, F. Wrenn and L. Liang, "Radiative Transfer Models for Deriving Geostationary Broadband Shortwave Radiances Directly from Visible Channels for the CERES SYN1deg Product," *IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium*, Waikoloa, HI, USA, 2020, pp. 6690-6693, doi: 10.1109/IGARSS39084.2020.9324370
- **Moguo S., D.R. Doelling, N.G. Loeb, R.C. Scott, J. Wilkins, L.T. Nguyen, P. Mlynczak, Clouds and the Earth's Radiant Energy System (CERES) FluxByCldTyp Edition 4 Data Product, in review *Journal of Atmospheric and Oceanic Technology***

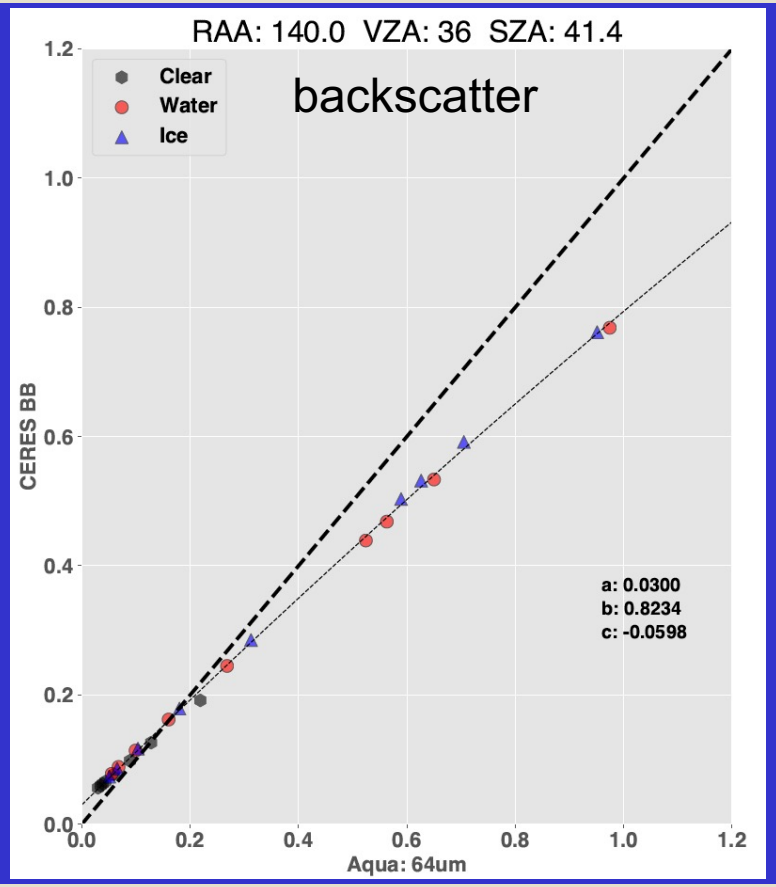
- **CALIBRATION**
- David R. Doelling, Rajendra Bhatt, Benjamin R. Scarino, Arun Gopalan, David Rutan, Ryan Scott, Conor O. Haney, "Additional characterization of Dome-C to improve its use as an invariant visible calibration target," Proc. SPIE 11829, Earth Observing Systems XXVI, 118290D (1 August 2021); doi:10.1117/12.2594294
- Doelling, David R., Conor Haney, Rajendra Bhatt, Benjamin Scarino, Arun Gopalan, Daily Monitoring Algorithms to Detect Geostationary Imager Visible Radiance Anomalies, in review Canadian Journal of Remote Sensing
- Bhatt, R.; Doelling, D.R.; Coddington, O.; Scarino, B.; Gopalan, A.; Haney, C. Quantifying the Impact of Solar Spectra on the Inter-Calibration of Satellite Instruments. *Remote Sens.* **2021**, *13*, 1438. https://doi.org/10.3390/rs13081438

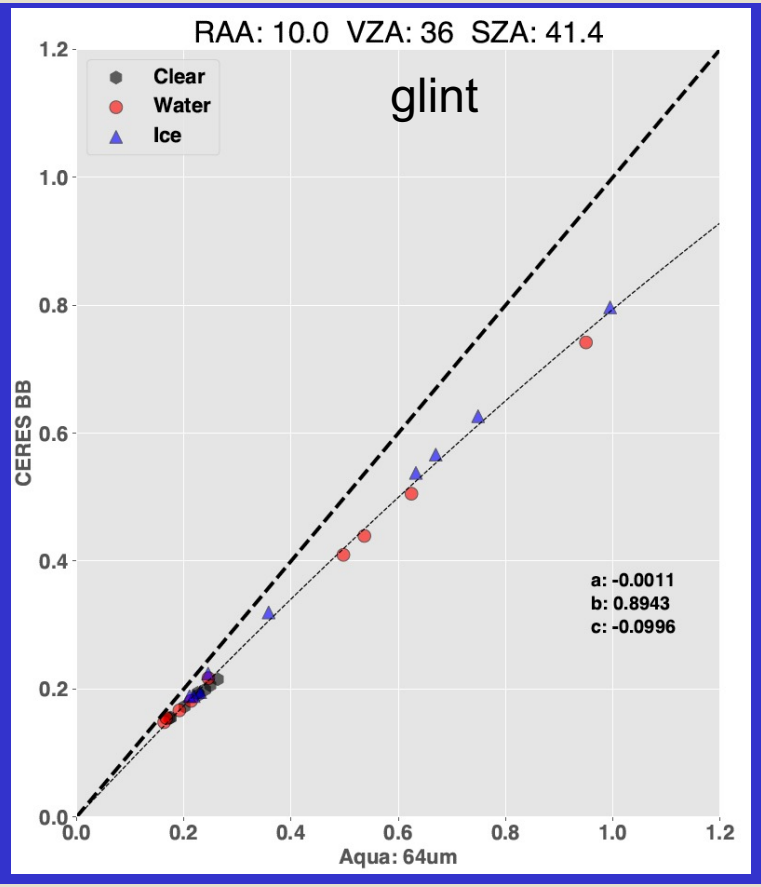
GEO SW NB to BB Ed5

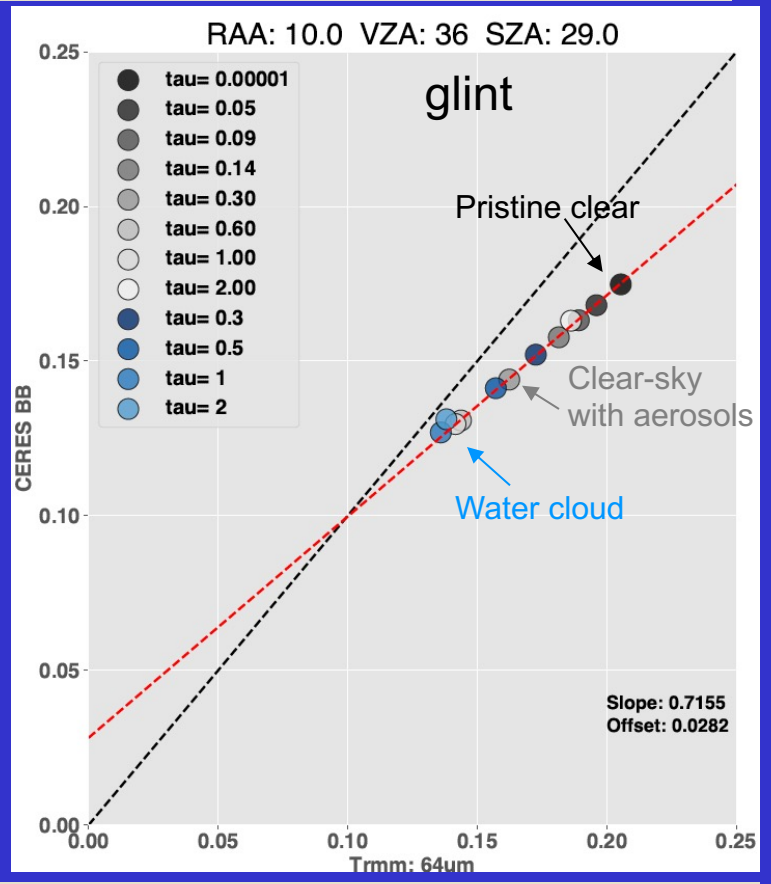
- Convert GEO visible narrowband (NB) channel directly to broadband (BB) radiance using hyper-spectral RTM, ~ 2500 wavelengths (0.2μm to 5μm)
  - Eliminate the Ed4 two step process of converting GEO to MODIS-like and then using empirical MODIS-like to BB radiance (Ed2 SW NB to BB LUT codes no longer exist)
  - Each GEO will have its own customized RTM LUT by convolving the RTM hyper-spectral radiances with the GEO spectral response function
- Continue to use the CERES TRMM ADMs to convert BB radiance to flux
  - TRMM orbit precesses and provides complete solar zenith angle sampling
- GEO Ed4 LW NB to BB uses window (11μm) and water vapor (6.7μm) channel radiances to CERES flux relationships based on Aqua and applied to GEO radiances
  - not planning on updating for Ed5

Ocean SW NB to BB strategy

- Rather than rely on the optical depth bin to predict the NB to BB reflectance, regress the optical depth stratified NB and BB reflectance pairs within an angular bin



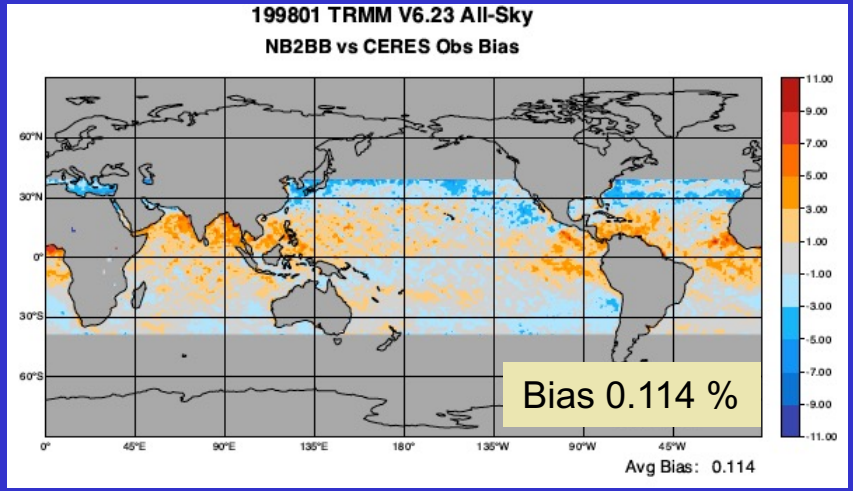


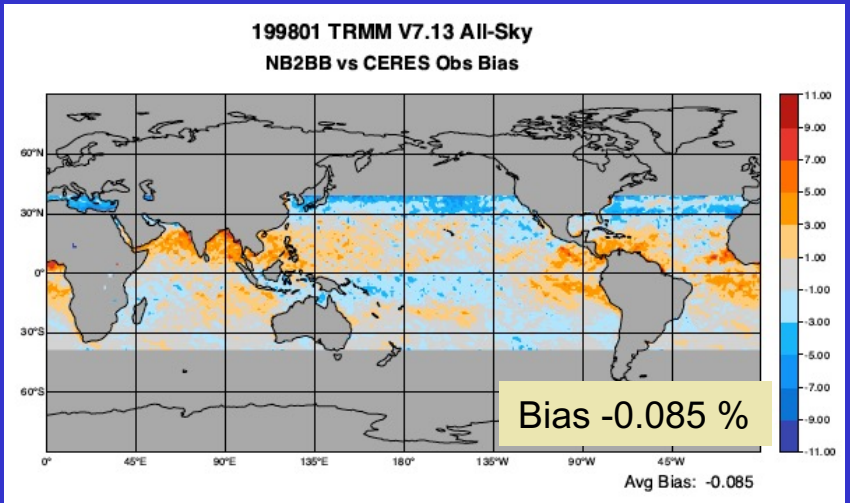


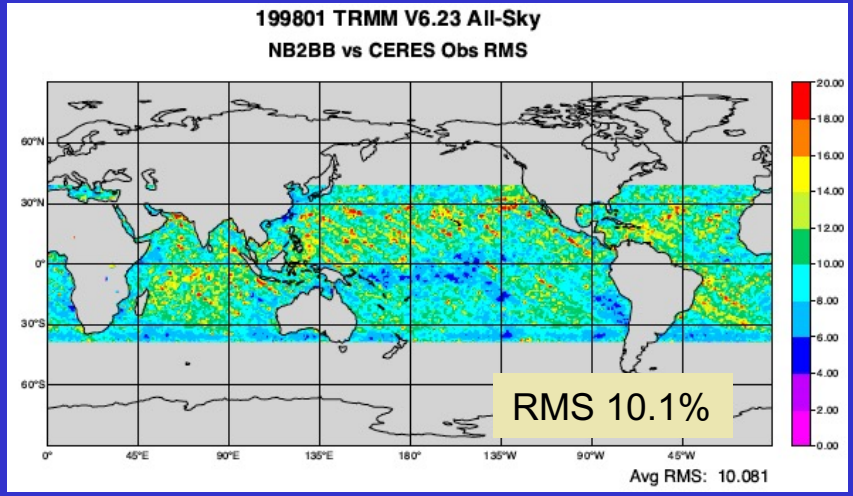
- Over oceans, the clear-sky, water and ice cloud NB and BB reflectance pairs line up along a 2nd order fit.
- The angular regressions now do not need to rely on cloud properties

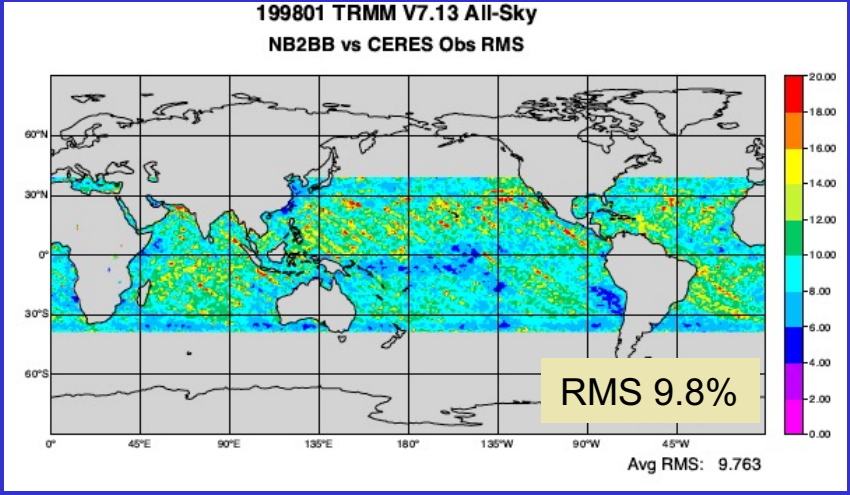
Jan 1998 TRMM VIRS NB to BB vs CERES radiances

Binned with cloud phase









No cloud property binning

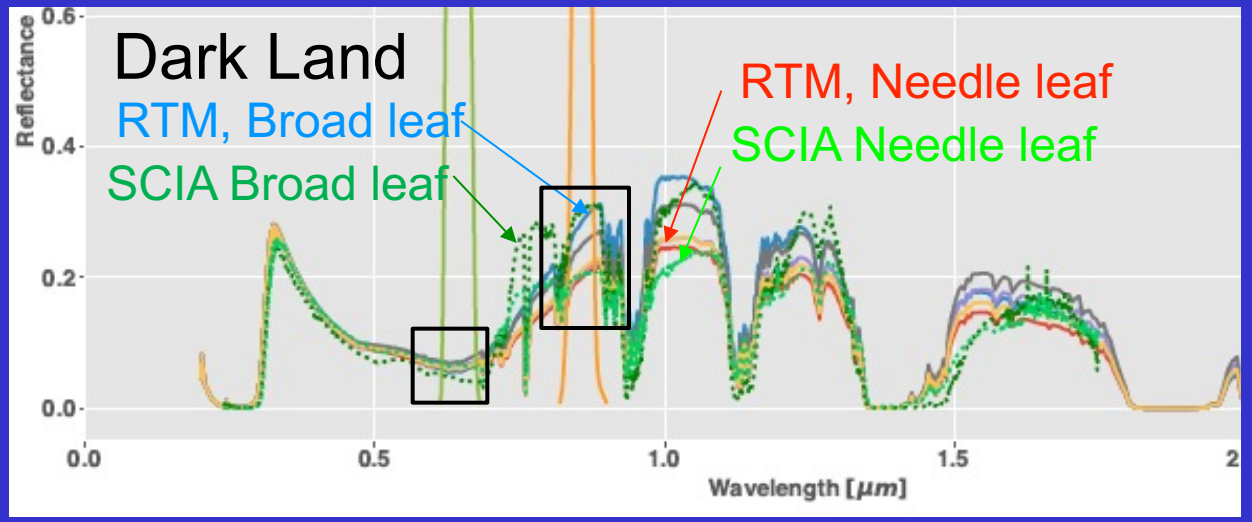
SW NB to BB regional bias and RMS over Oceans

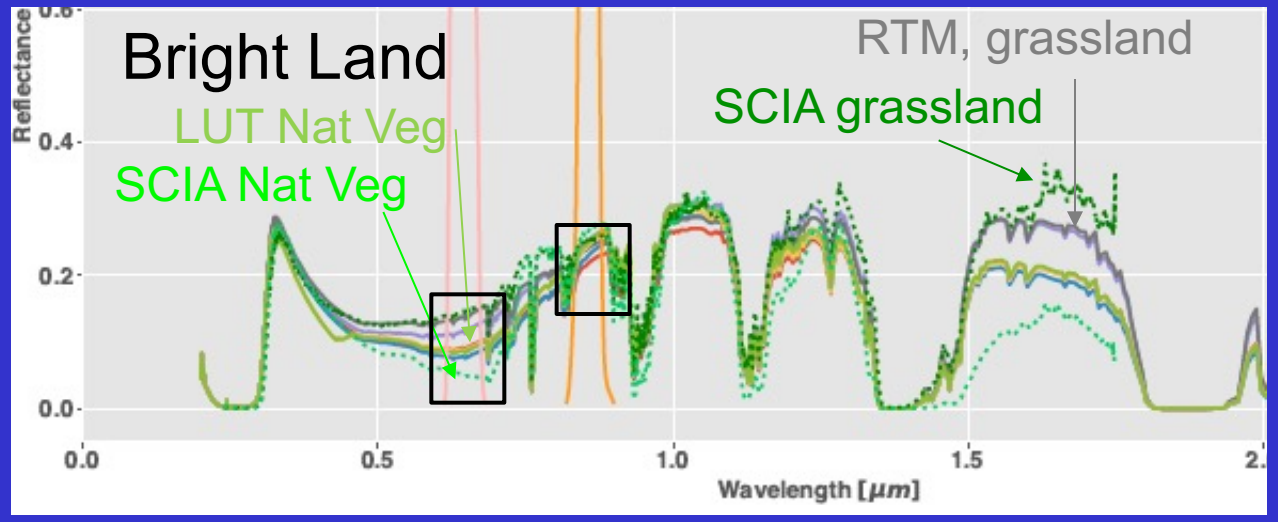
Using cloud fraction and phase/ no cloud information

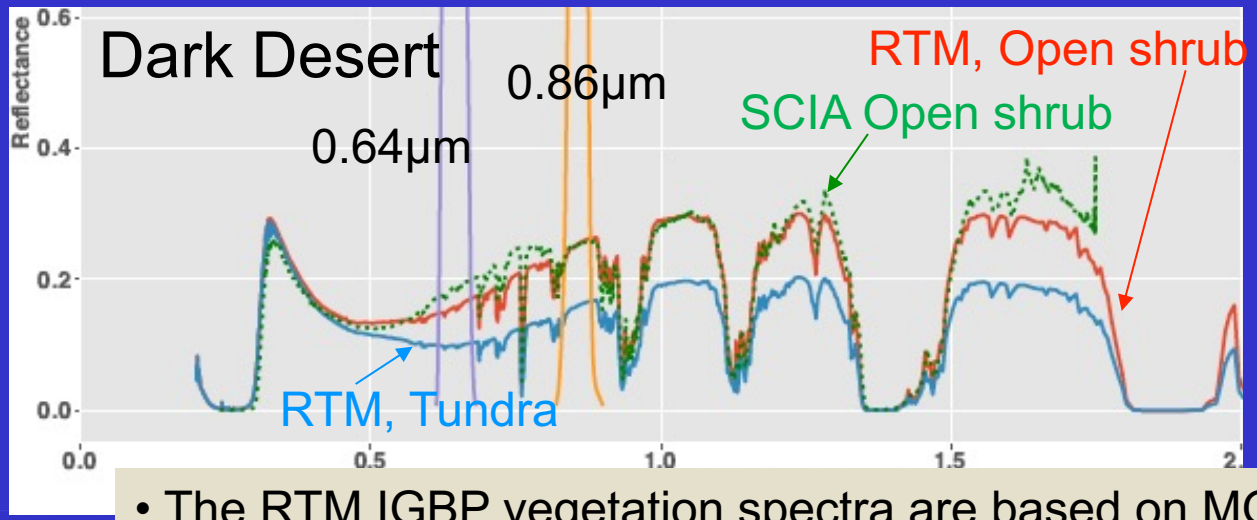
SW radiance %	Bias TRMM	RMS TRMM	Bias Aqua	RMS Aqua
All-sky	+0.11/-0.09	10.1/9.8	+2.55/+2.55	6.9/7.0
Clear-sky	+2.46/+2.01	8.8/8.7	+4.01/+3.58	5.5/5.1
Water clouds	-0.43/+0.24	9.0/8.6	+2.50/+3.50	6.3/6.7
Ice clouds	-0.30/-2.19	7.3/7.1	+2.92/+1.29	5.5/5.0

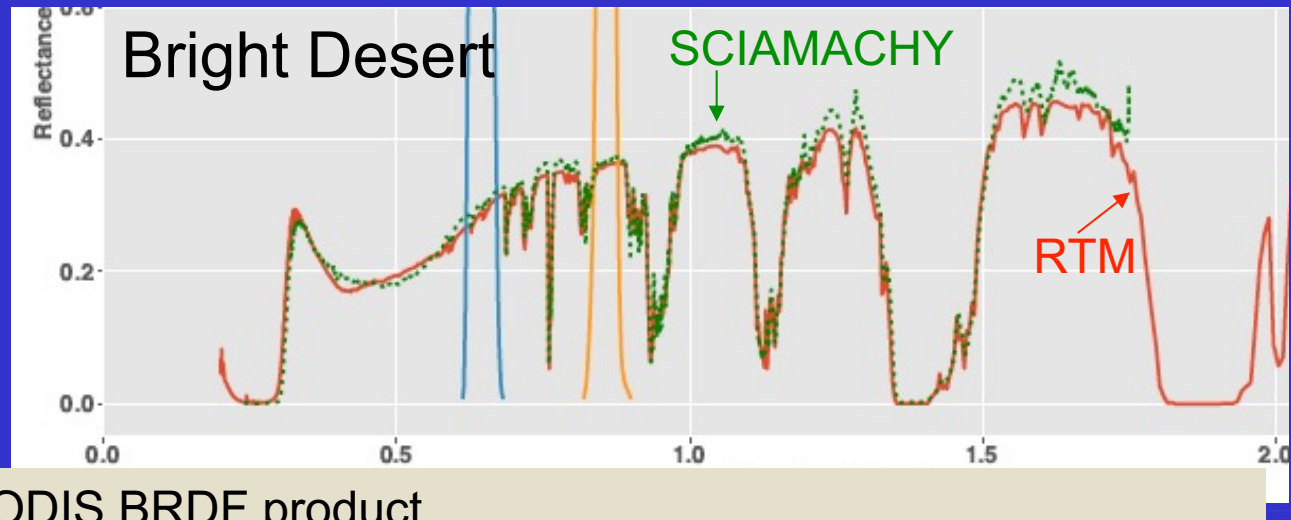
No significant dependency differences with angles, cloud fraction, optical depth, glint probability, or effective pressure

Land LUT and SCIAMACHY spectra by IGBP type





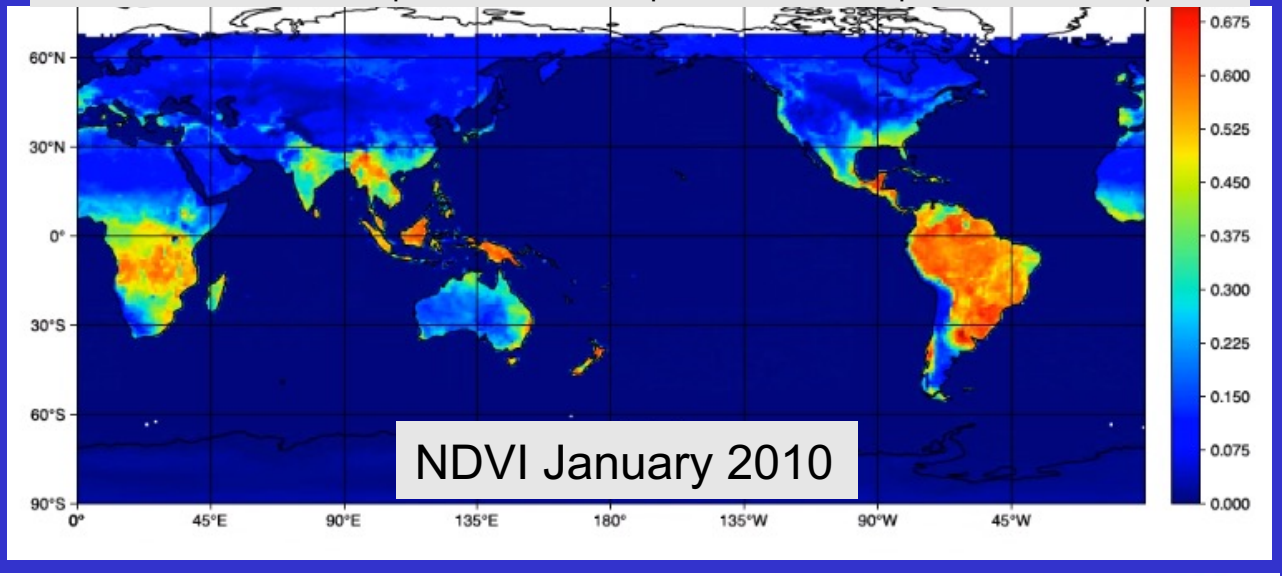




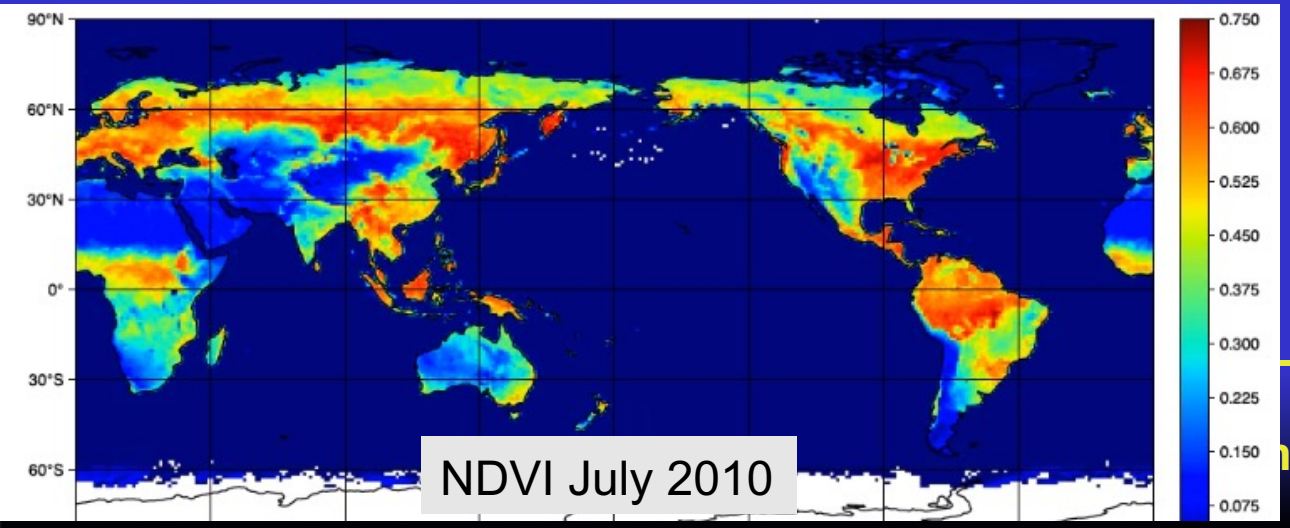
- The RTM IGBP vegetation spectra are based on MODIS BRDF product
- The RTM desert model follows closely the SCIAMACHY clear-sky spectra
- Both RTM and SCIAMACHY have large spectral variations between IGBP types

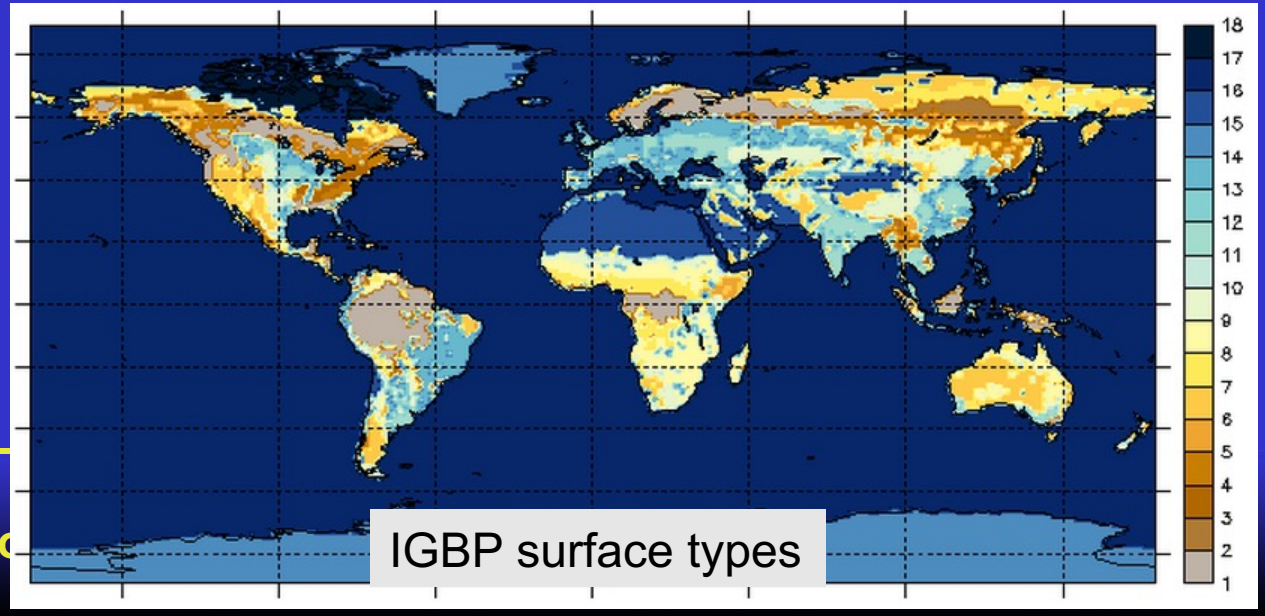
NDVI vs Land IGBP types

$$NDVI = (REF_{0.86\mu m} + REF_{0.64\mu m})/(REF_{0.86\mu m} - REF_{0.64\mu m})$$

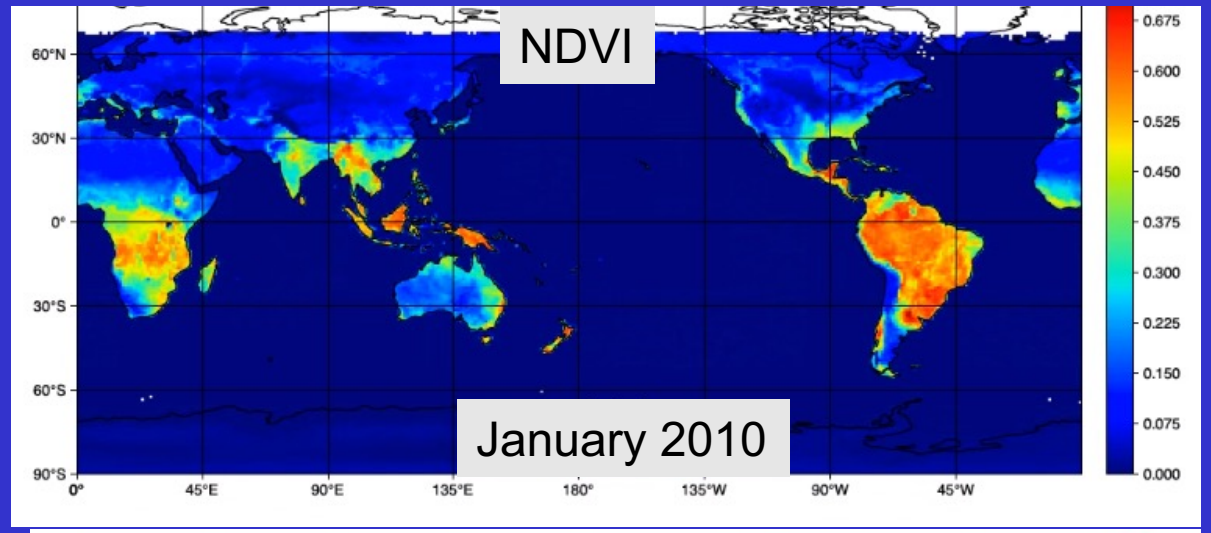


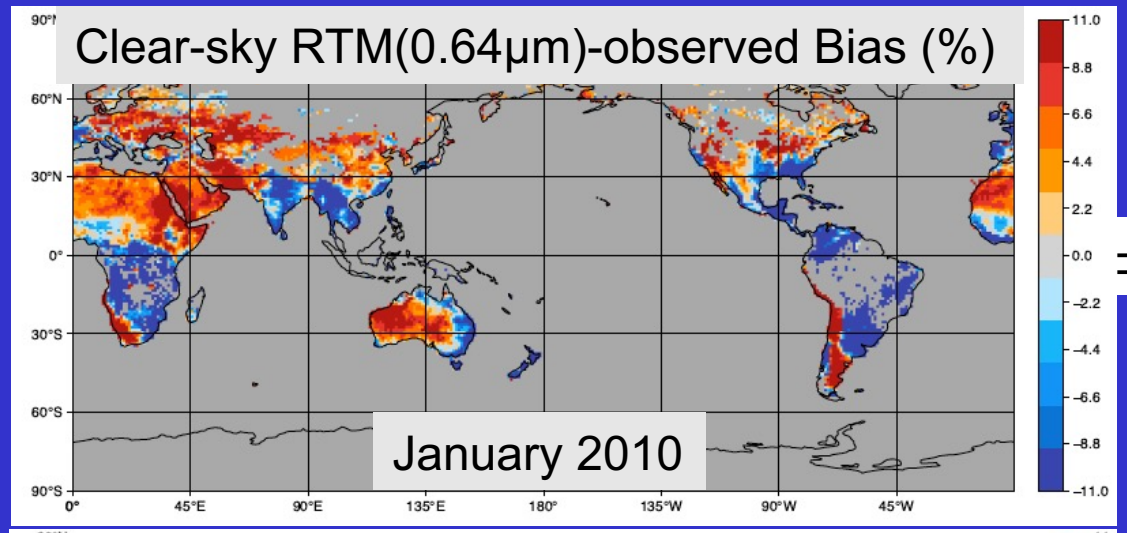
- IGBP maps are static and do not change by season
- NDVI describes the seasonal variation NIR reflection of vegetation
- Most GEO imagers do not have a 0.86μm channel
- Convert the 0.64μm reflectance to the broadband SW reflectance using a single IGBP type (grassland) RTM
- Correlate the climatology or real-time month NDVI based on MODIS with the difference of the observed and RTM reflectance



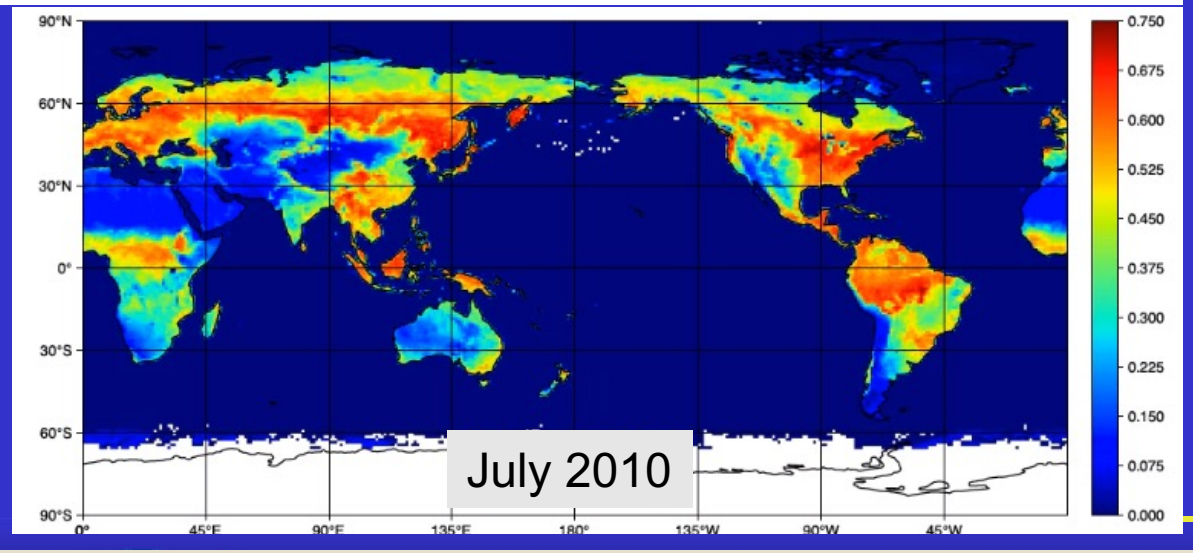


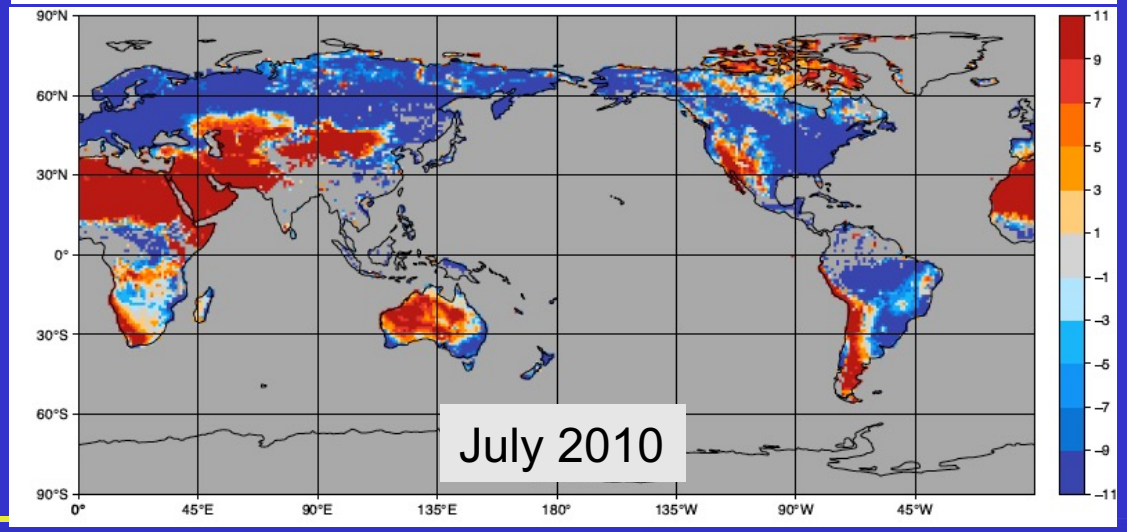
Comparison of NDVI and the SW NB to BB bias





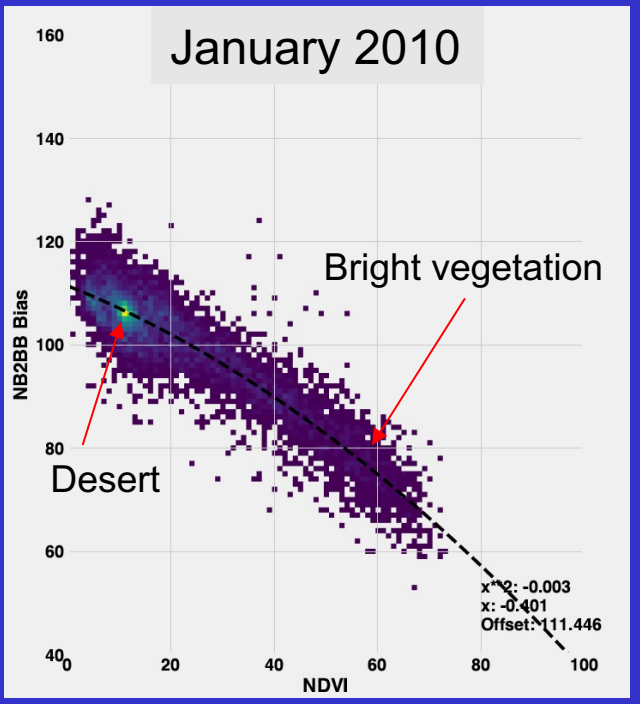
±11%

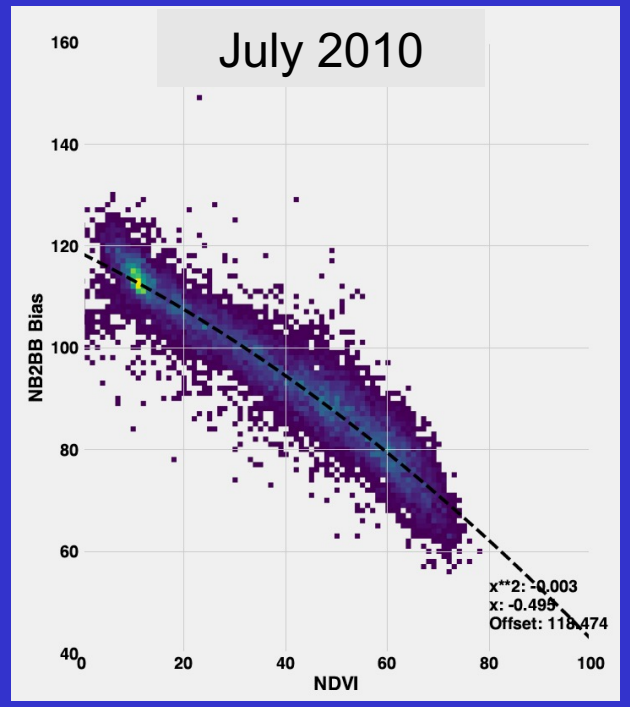


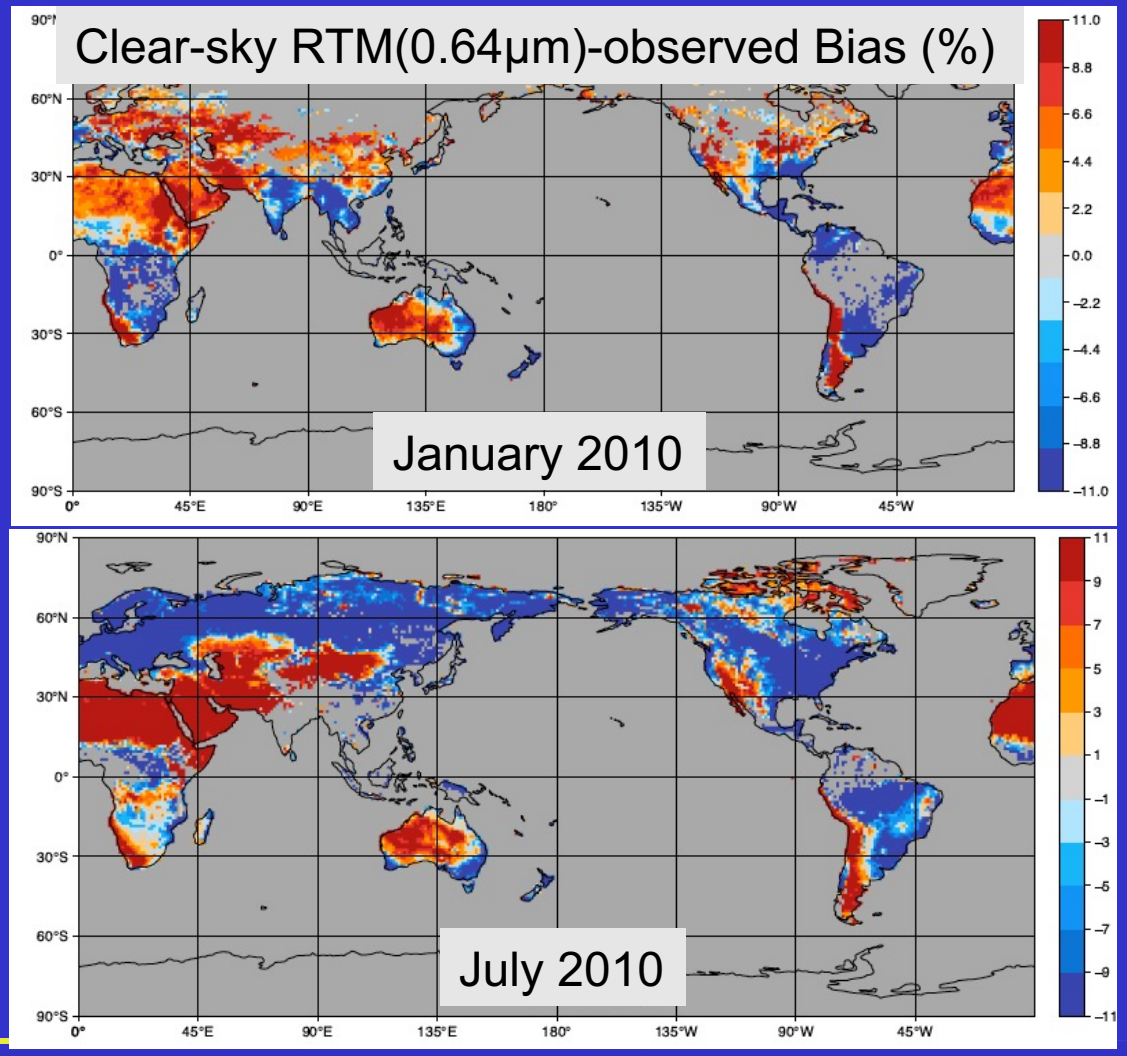


- Note how the SW NB to BB biases based on the 0.64μm channel grassland LUT follow the NDVI

Comparison of NDVI and the SW NB to BB bias



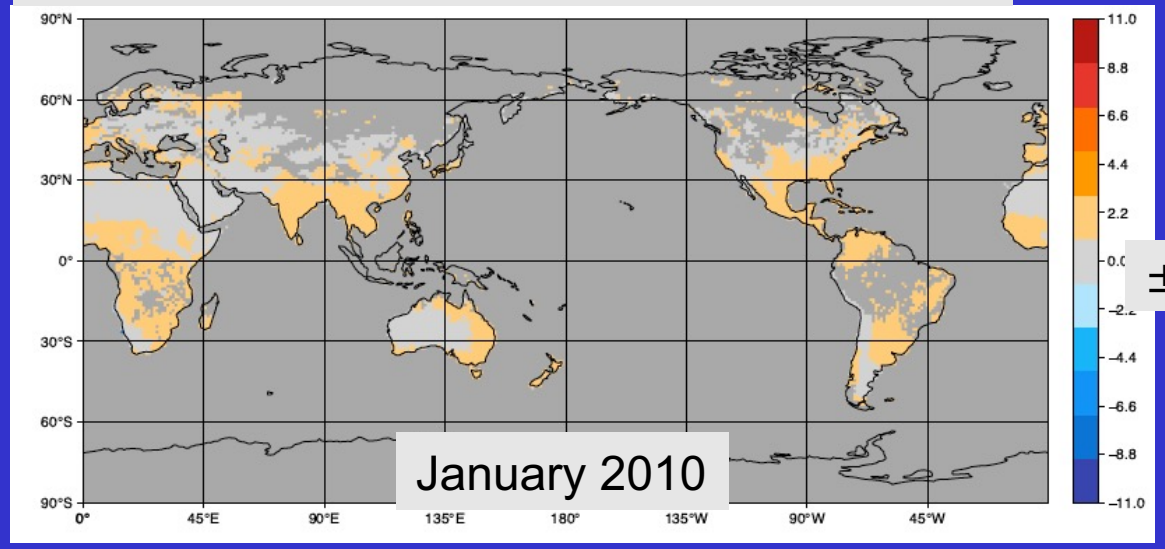




- Note how both desert and vegetative land have the same NDVI relationship, but is a function of month
- Do not have to differentiate barren and vegetative land

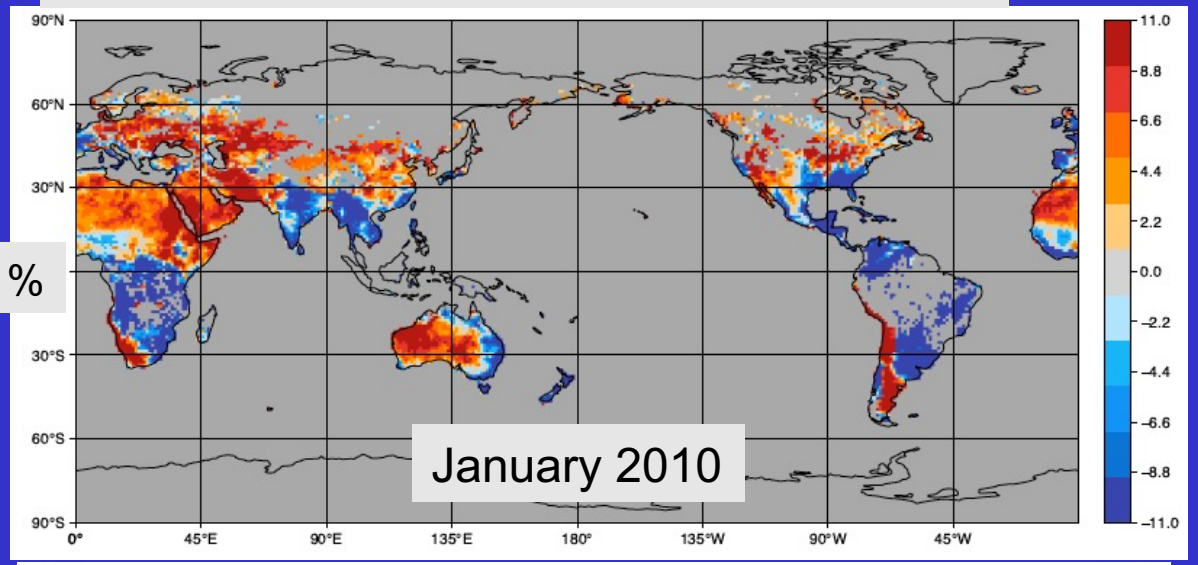
Comparison of SW NB to BB bias with and without NDVI adj

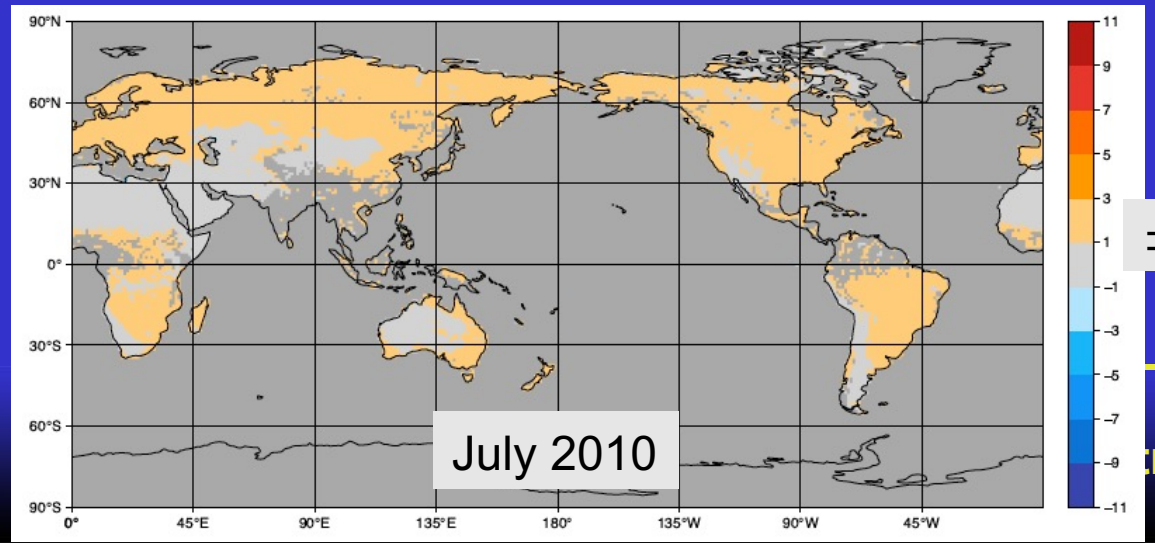
Clear-sky RTM(**NDVI adj**)-observed Bias (%)



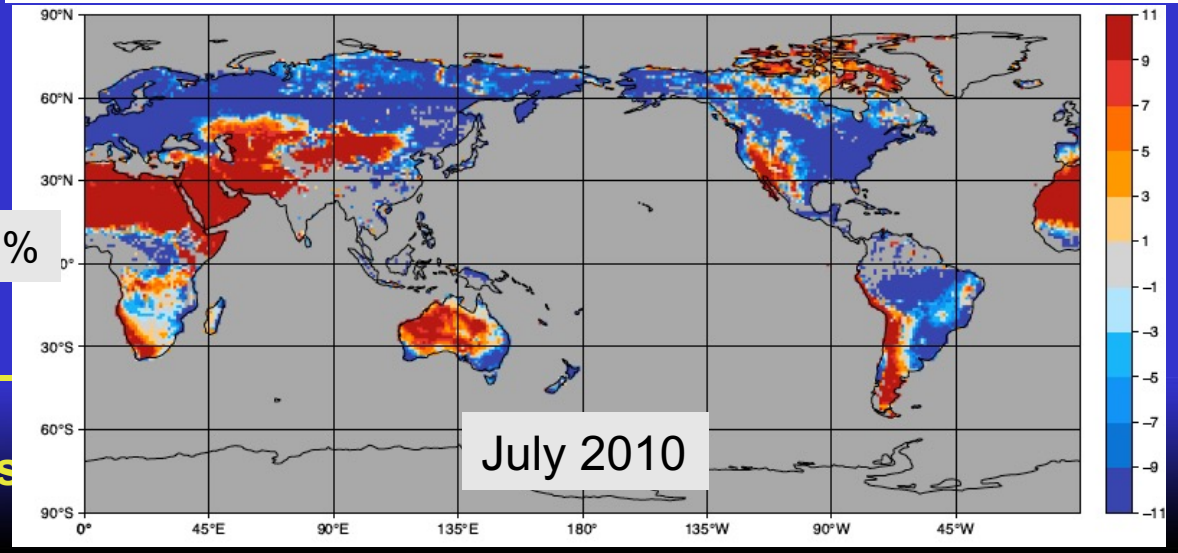
±11%

Clear-sky RTM(0.64μm)-observed Bias (%)





±11%



Comparison of SW NB to BB bias with and without NDVI adj

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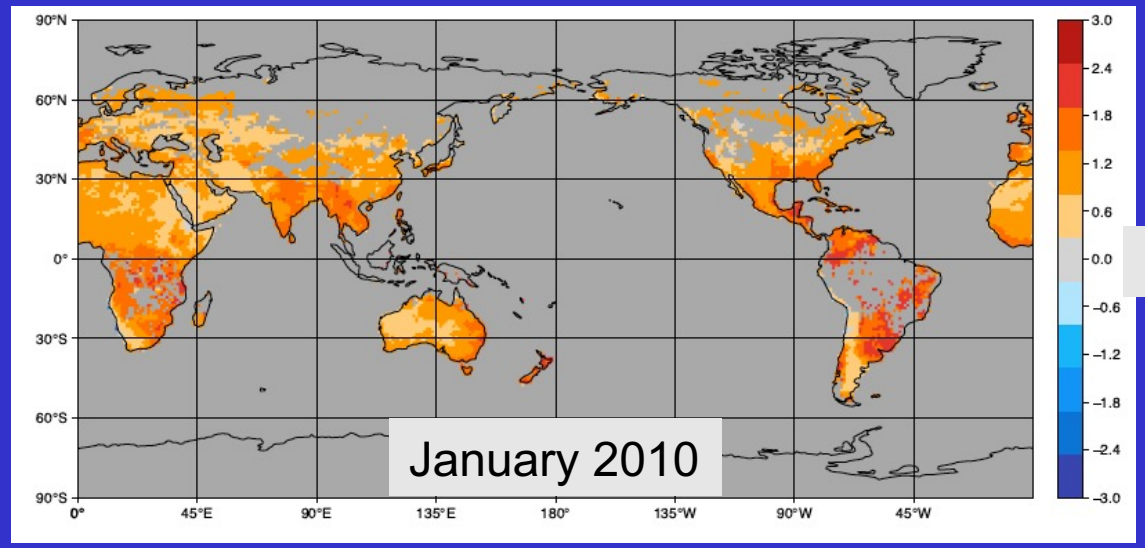
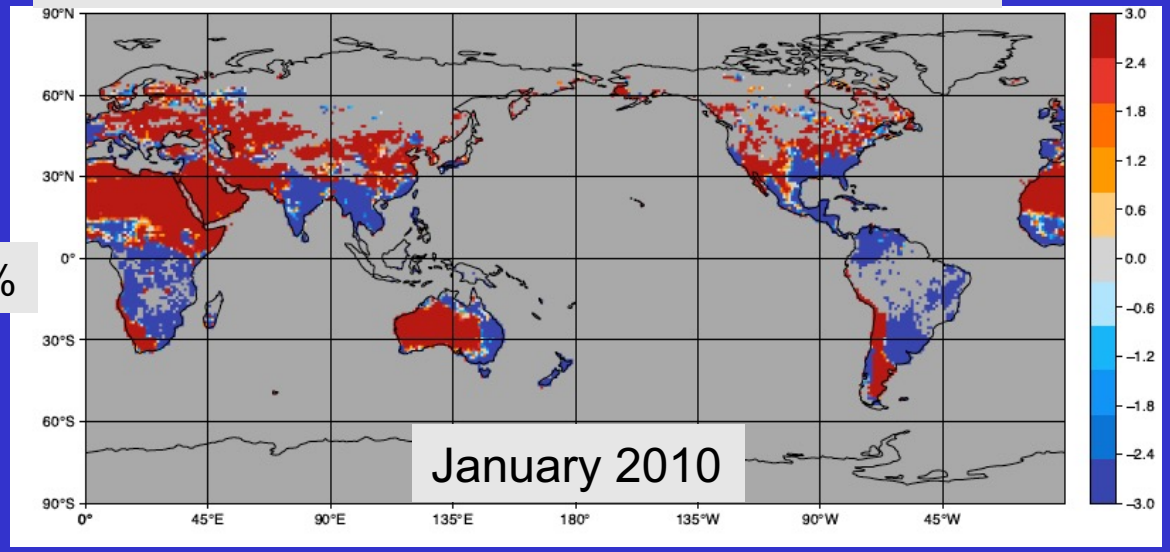
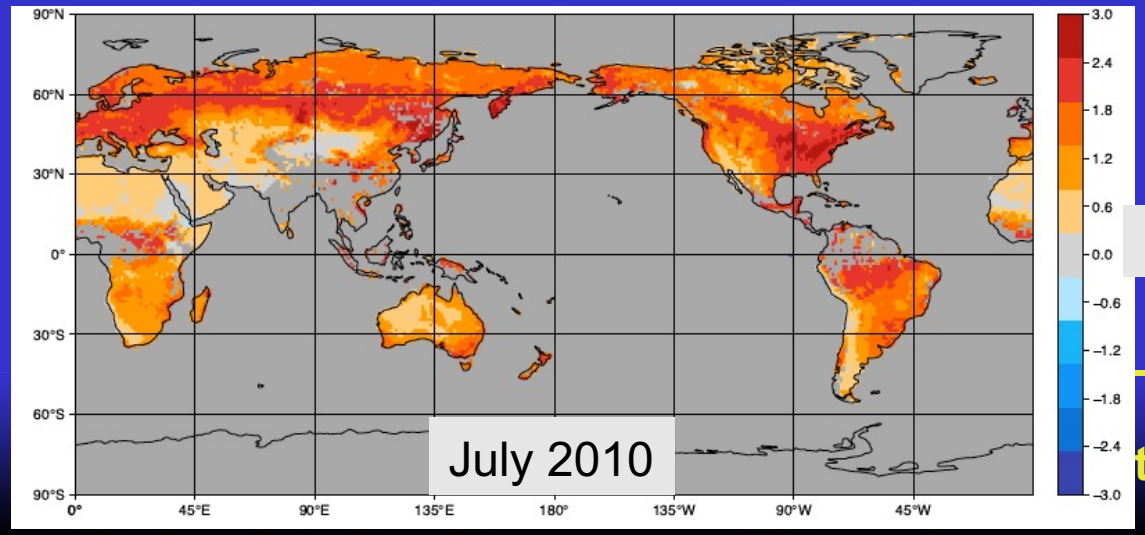


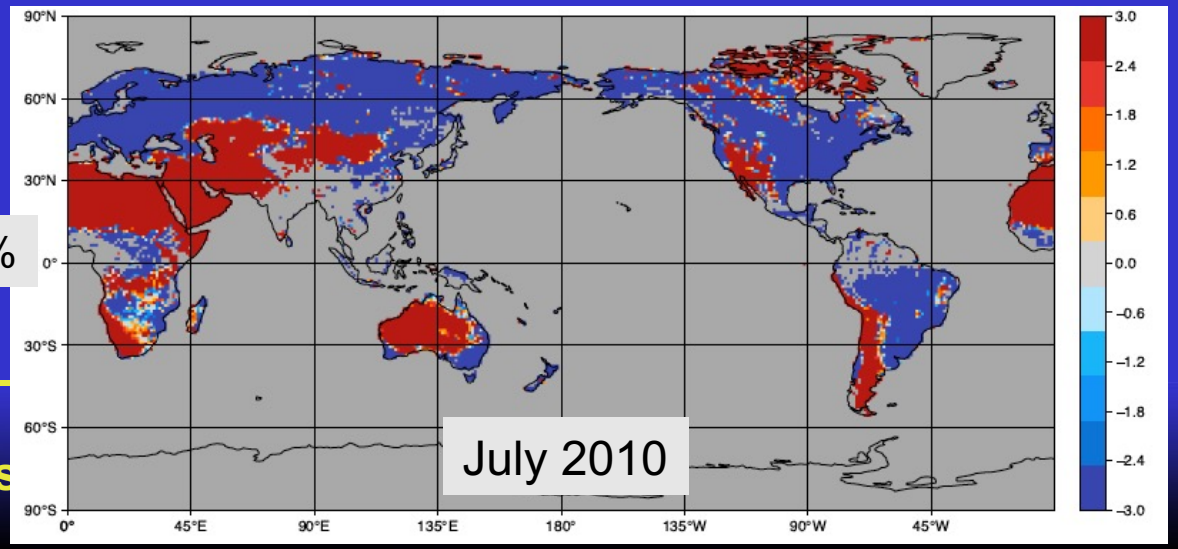
Clear-sky RTM(0.64μm)-observed Bias (%)



±3%



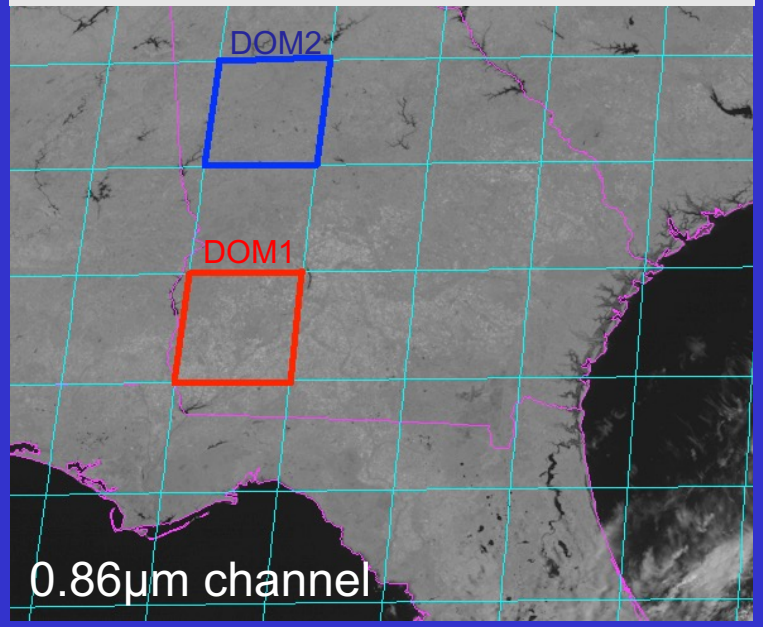
±3%

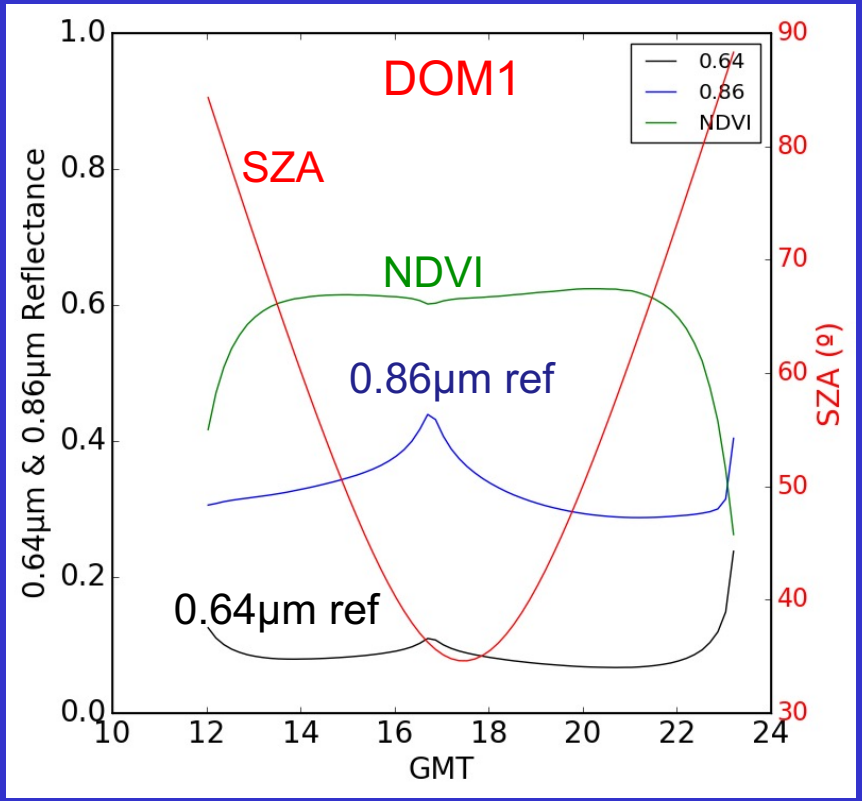


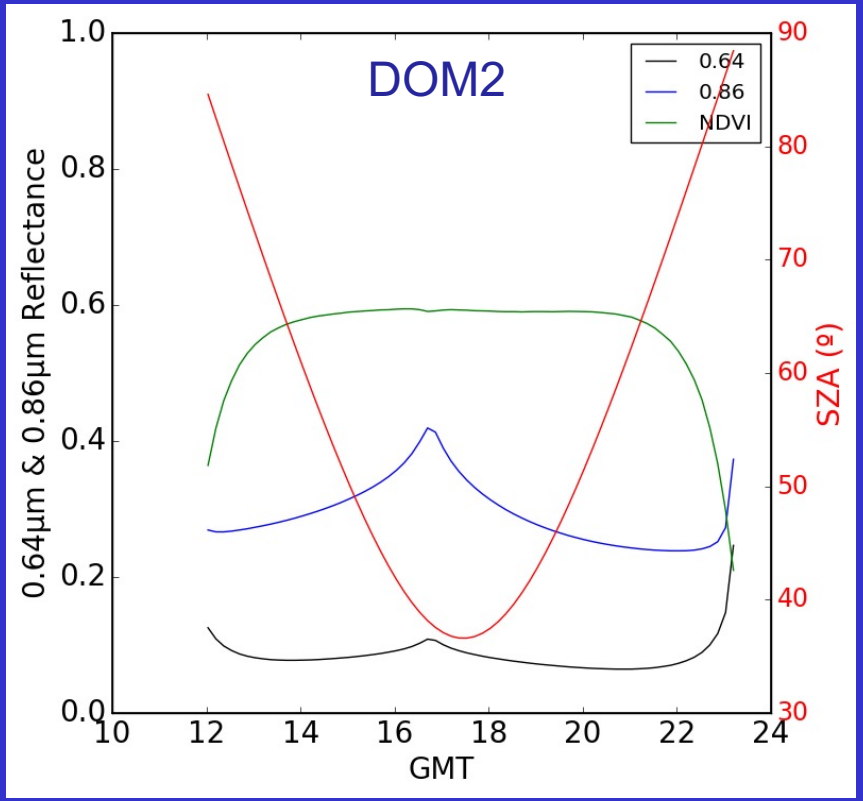
tmos

NDVI as a function of SZA

GOES-16 Sept 30, 2021, 18:30 GMT
Clear day over Georgia, USA







- NDVI is uniform within SZA of 65 deg. Regional NDVI can be obtained from Aqua-MODIS and applied to GEO
- This allows GEOs with no 0.86μm channel to take advantage of the NDVI adjustment

GEO SW NB to BB Summary

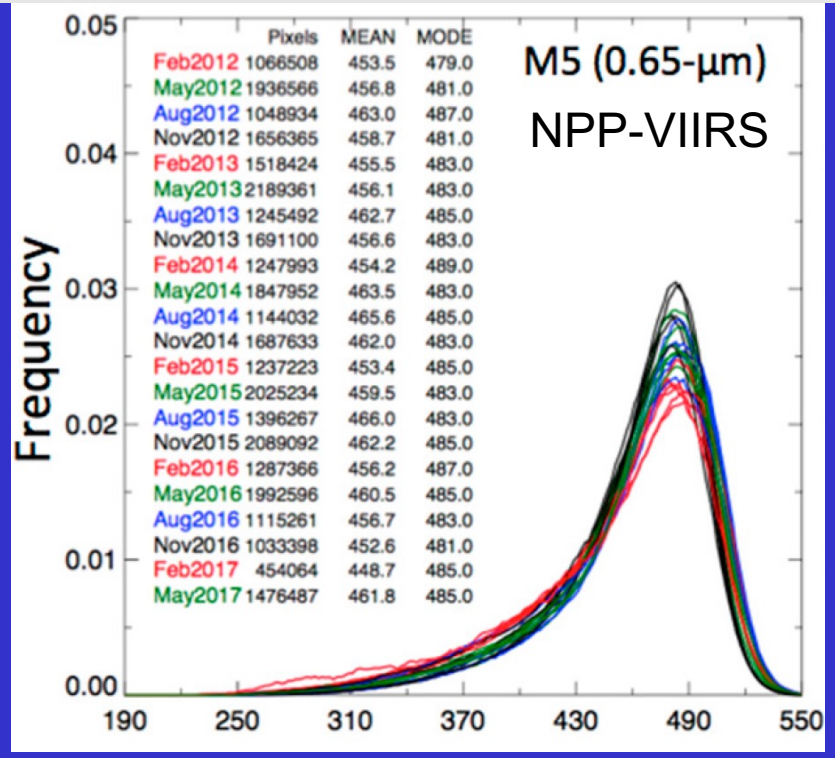
- Find the best RTM model criteria that matches the TRMM VIRS/CERES and Terra or Aqua MODIS/CERES empirical relationships
- For Ocean
  - Large water and ice particle sizes have the least dependencies with SZA, phase, and cloud effective height
  - For each bin, a 2nd order regression of 0.64µm and broadband model water and ice cloud reflectance pairs stratified by optical depths
  - Similar NB to BB biases and RMS errors are achieved, whether combining clear-sky, water and ice cloud reflectance pairs or separating by phase
- For Clear-sky Land
  - Use a single IGPB type (grassland) RTM (0.64µm) to BB conversion and tau based based reflectance pair regressions similar to ocean methodology
  - Account for the vegetation NIR reflection contribution using MODIS based NDVI

MODIS/VIIRS imager radiometric scaling and drift correction

- The MODIS C6.1 and N20 VIIRS C2 analogous channel reflectances are not radiometrically scaled
  - Ed4 imager and GEO calibration reference is MODIS C5
  - Absolute calibration based on the onboard individual sensor solar diffuser
  - CERES will rely on the NOAA-20 flux record once the Aqua and Terra orbits will drift outside of their 15-minute local time control box
  - Consistent Aqua-MODIS and NOAA20-VIIRS calibration is needed have a seamless transition of CERES/GEO observed fluxes and clouds between Aqua and NOAA-20
- Since MODIS and VIIRS are in forward processing mode, calibration drifts/discontinuities are embedded in the record

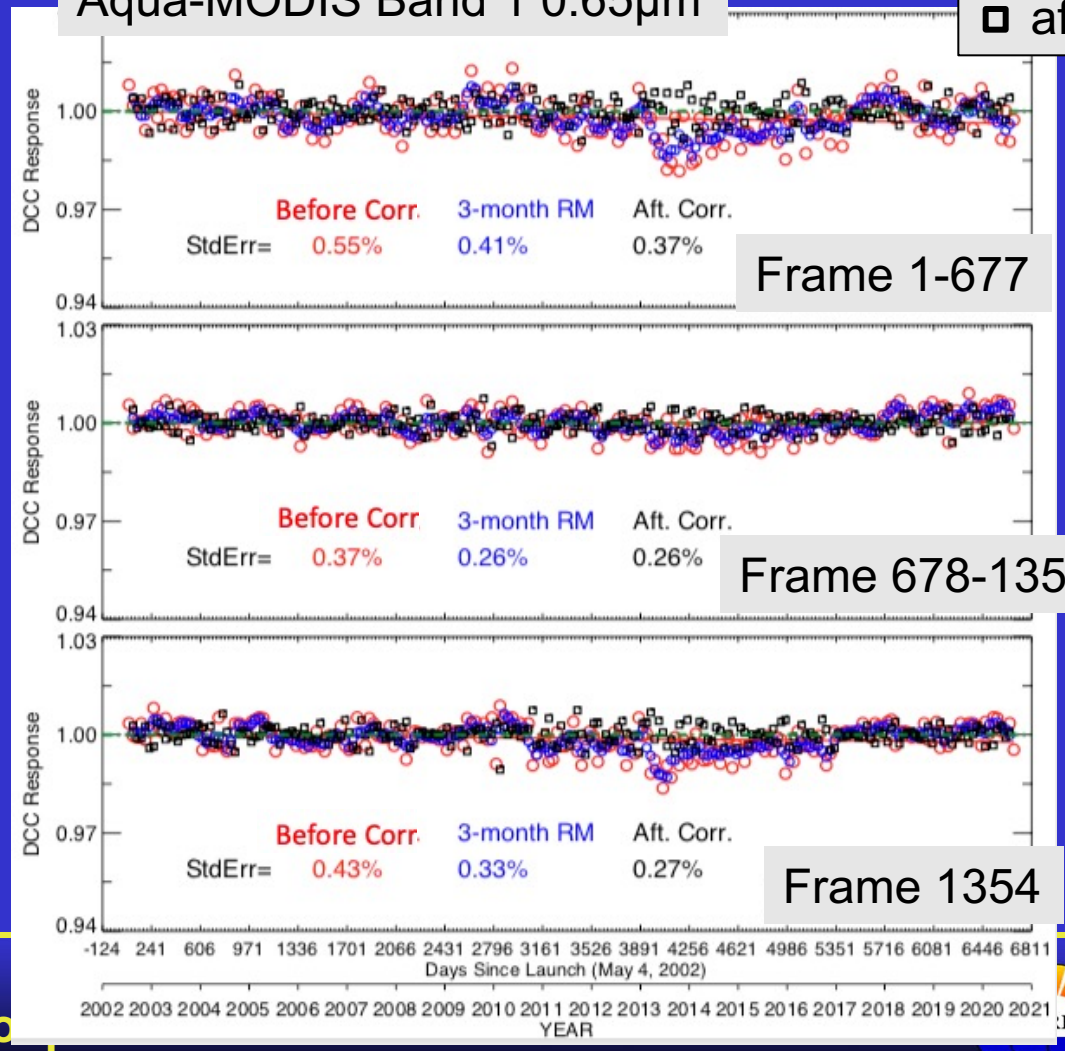
MODIS DCC-IT before and after calibration drift correction

DCC-invariant target method used to assess stability



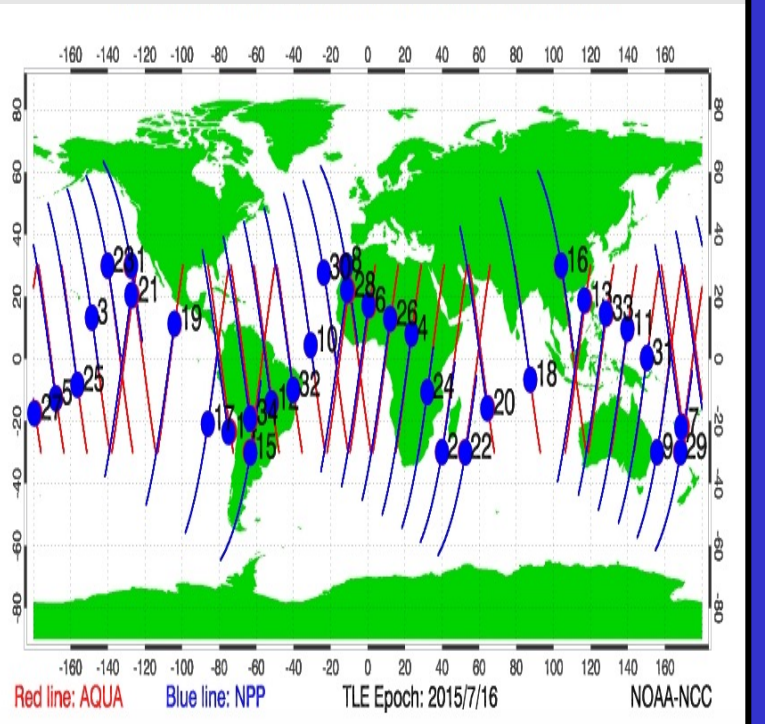
- All of the DCC pixel radiances over the month are histogrammed
- Use the monthly DCC mode to track stability

Aqua-MODIS Band 1 0.65µm



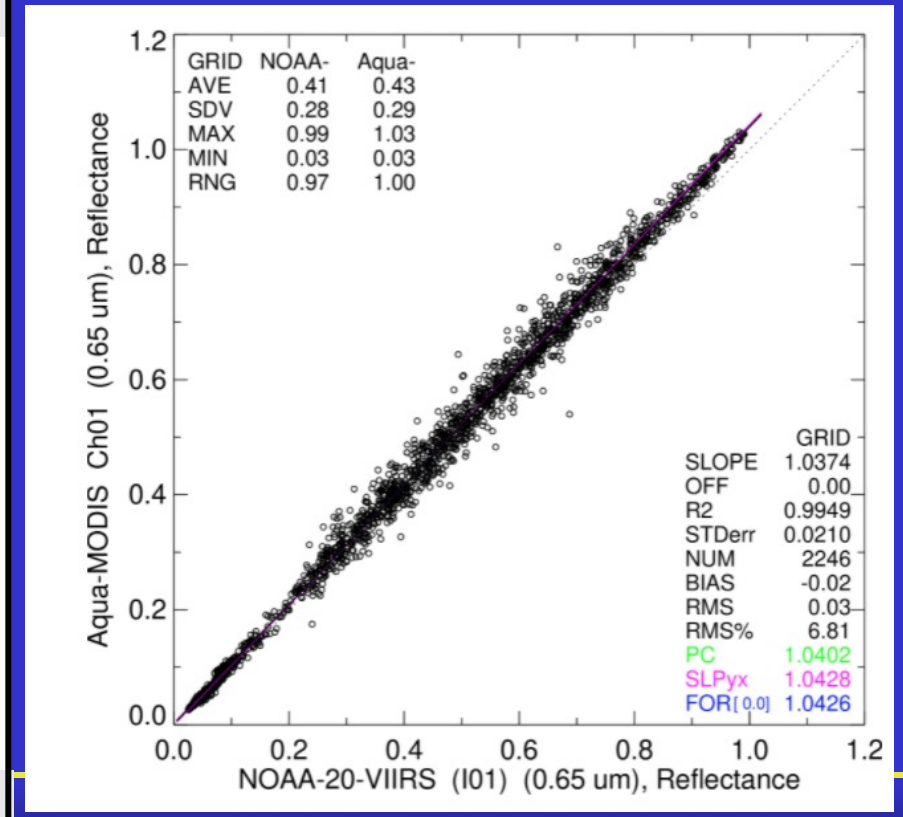
MODIS and VIIRS All-sky Tropical Ocean ray-matching (ATO-RM)

NOAA web site tropical Aqua/NPP SNOs
For July 16, 2015

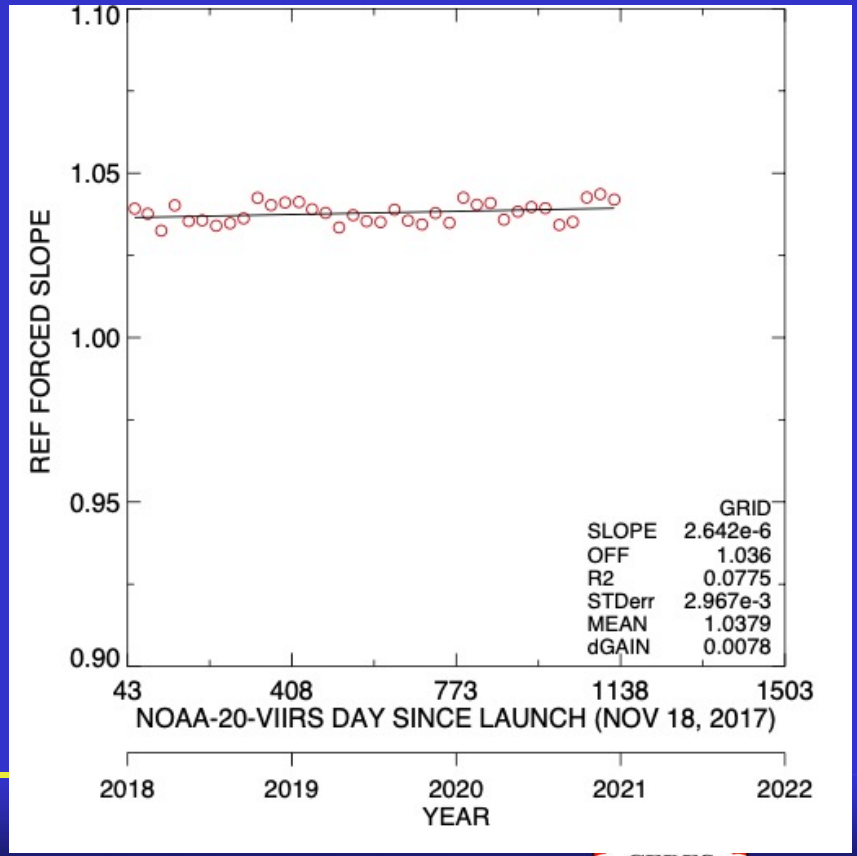


The NPP and Aqua orbit intersects are coincident in time every 64 hours

ATO-RM, MODIS B1 and N20 I1
January 2020

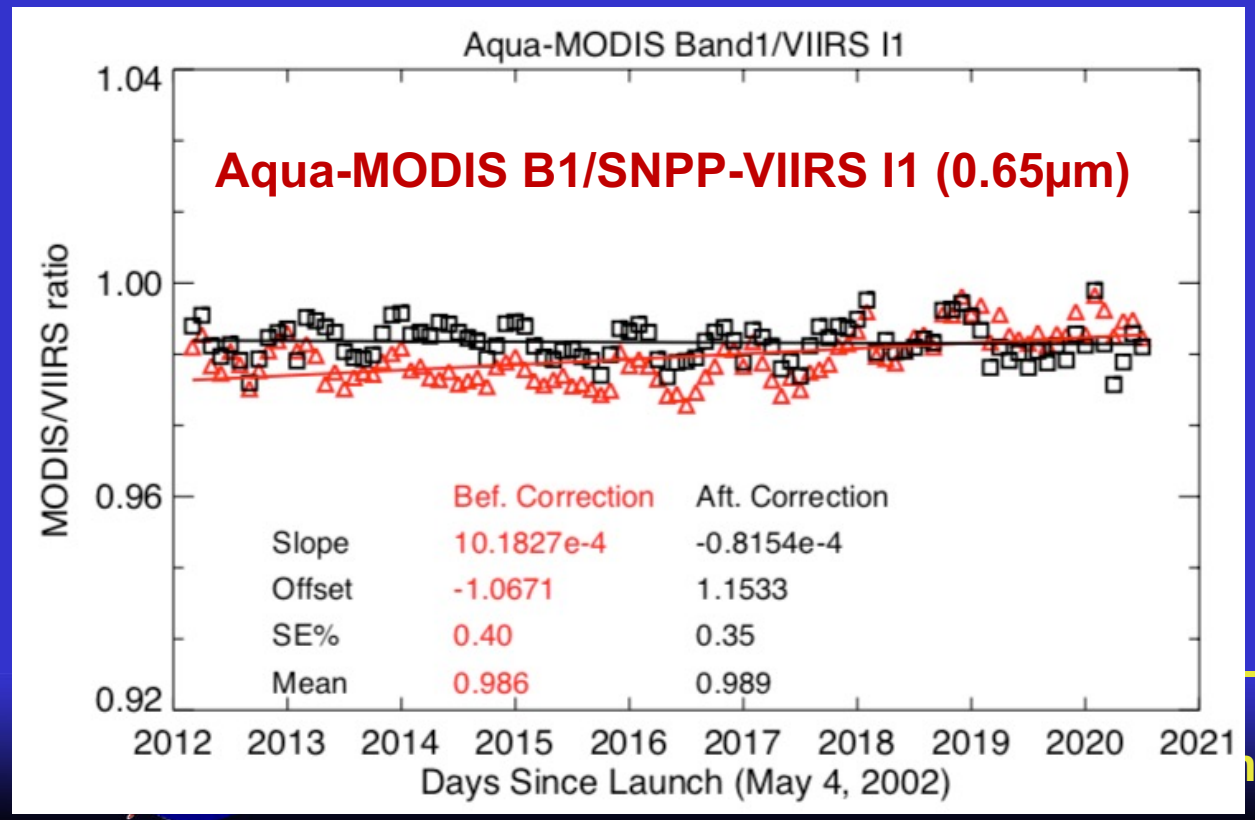


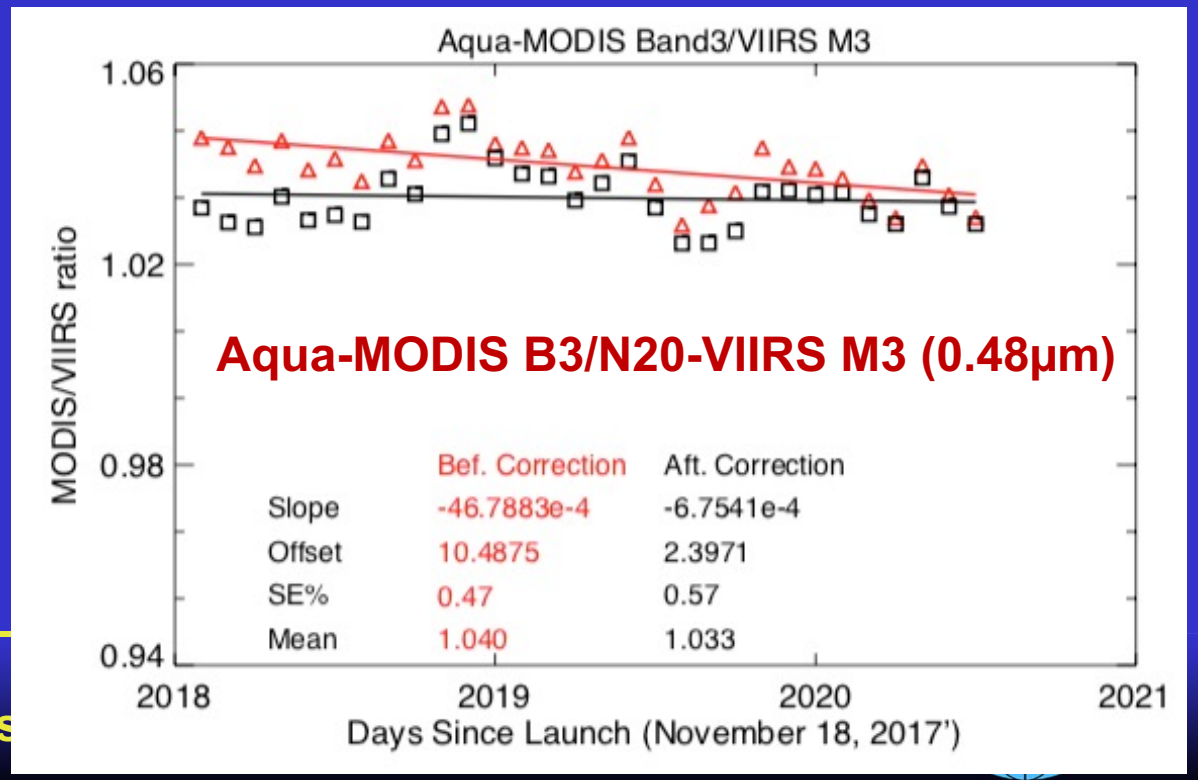
Aqua-MODIS-B1 and N20-VIIRS-I1
ATO-RM



Sensor pair relative trends

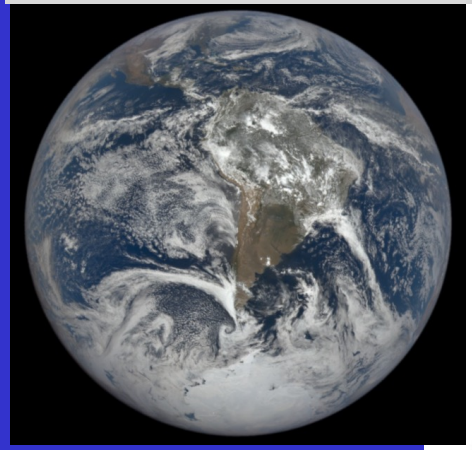
- Before drift corrections the MODIS and VIIRS ratio may have trends, after drift correction the sensor pair relative trend ratio should be stable
- If the MODIS and VIIRS trend is stable then only a one-time scaling factor between the MODIS and VIIRS is needed



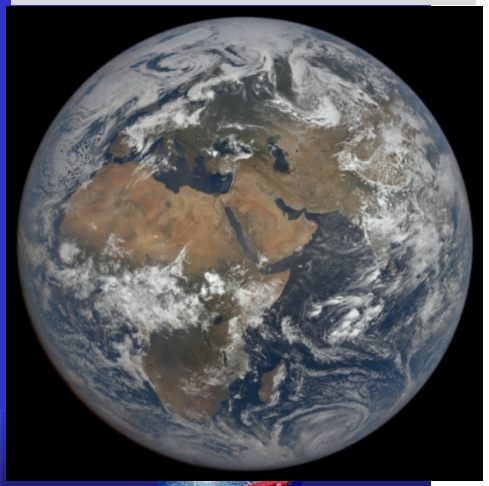


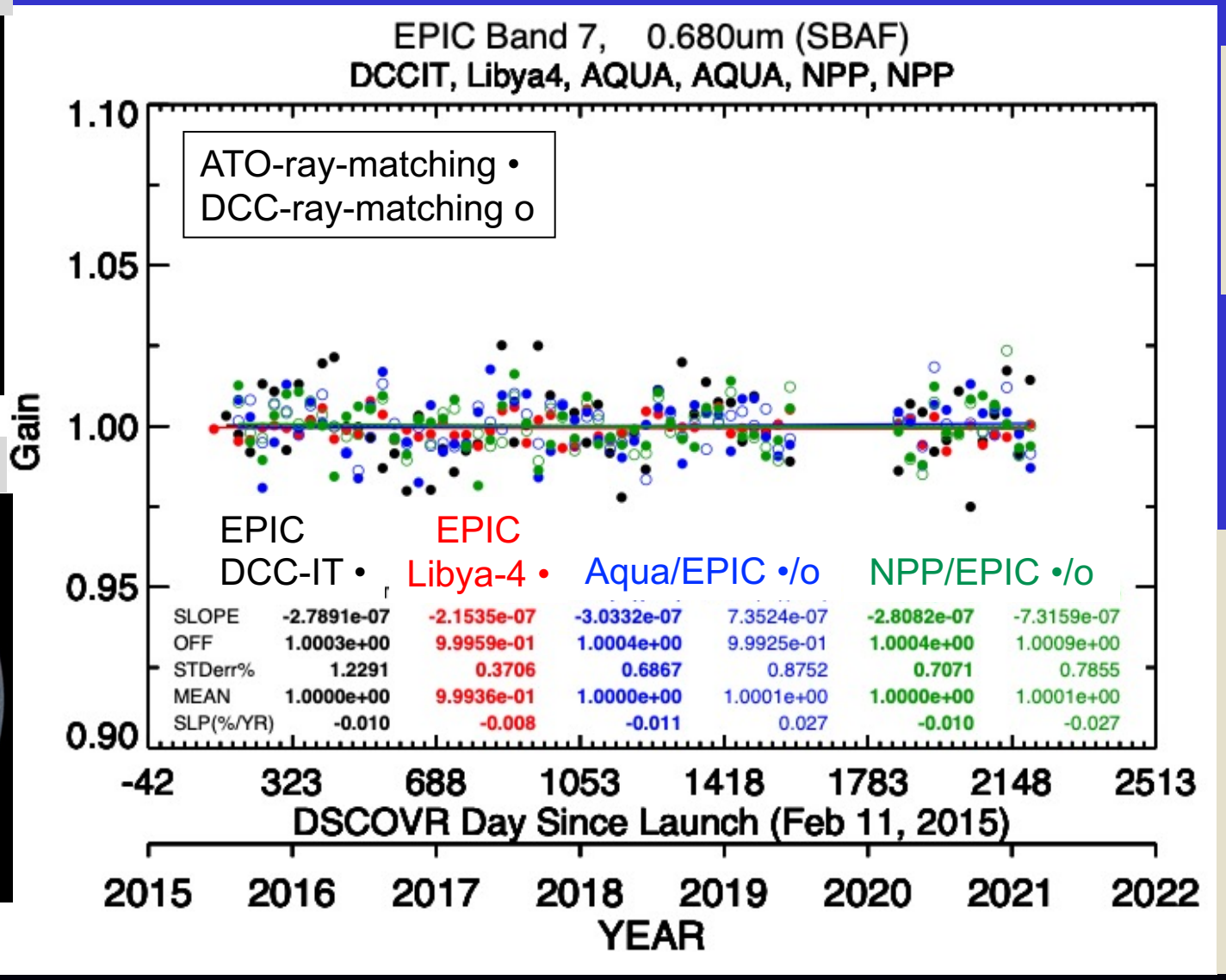
EPIC stability assessment based on imagers and Earth invariant targets

EPIC
Dec 23, 2020, 16:30 GMT



June 23, 2021, 9:01 GMT



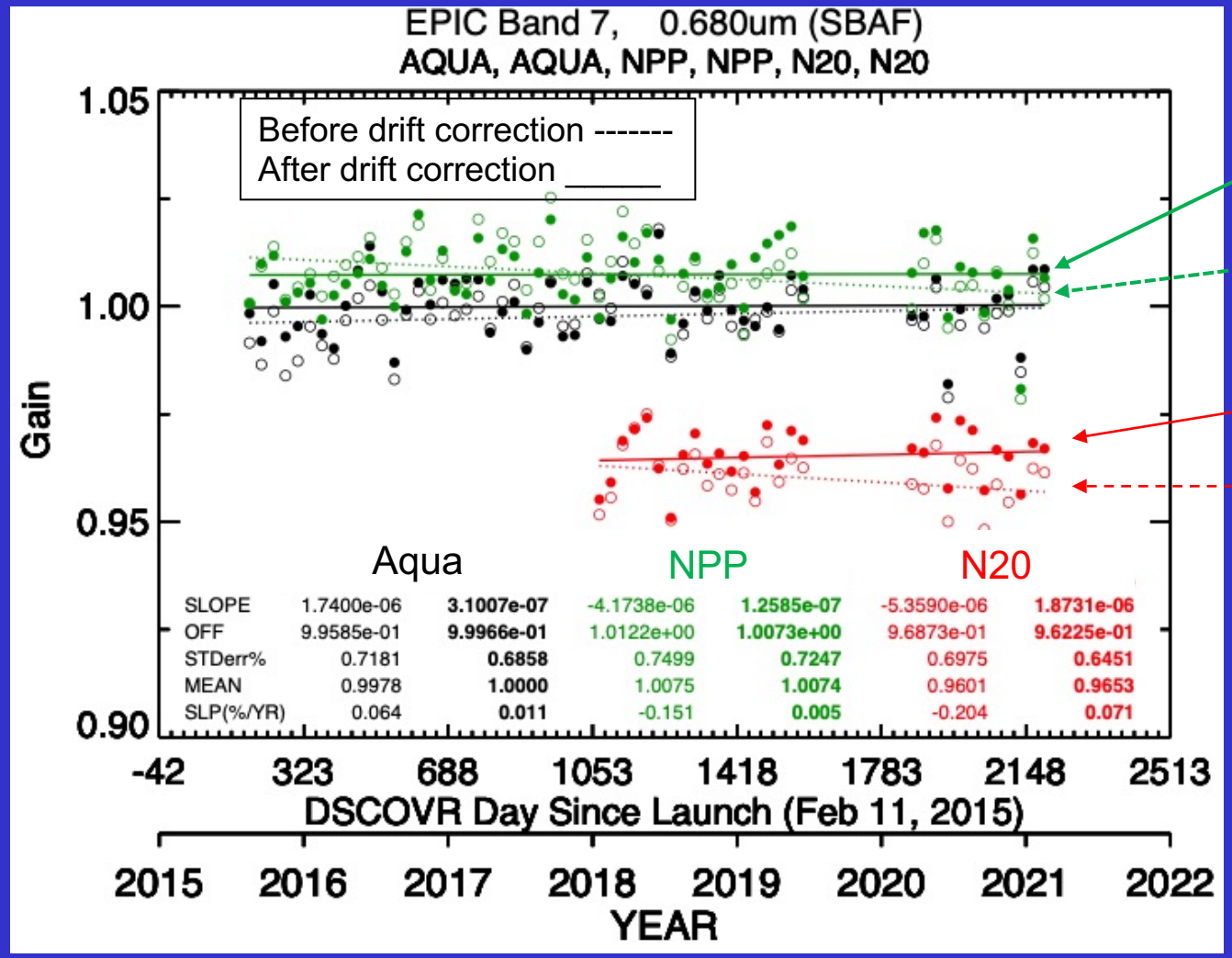


- DCC-IT and Libya-4 invariant targets do not rely on MODIS or VIIRS stability
- Libya-4 and DCC-IT indicate the EPIC band 7 (0.64μm) is stable

- All linear trends within 0.03%/year

- DCC-IT, Libya-4, Aqua MODIS ATO-RM and DCC-RM
- NPP VIIRS ATO-RM and DCC-RM were normalized over the record to take out the absolute calibration difference

DSCOVR EPIC validation of imager drift corrections



NPP VIIRS after drift

NPP VIIRS before drift

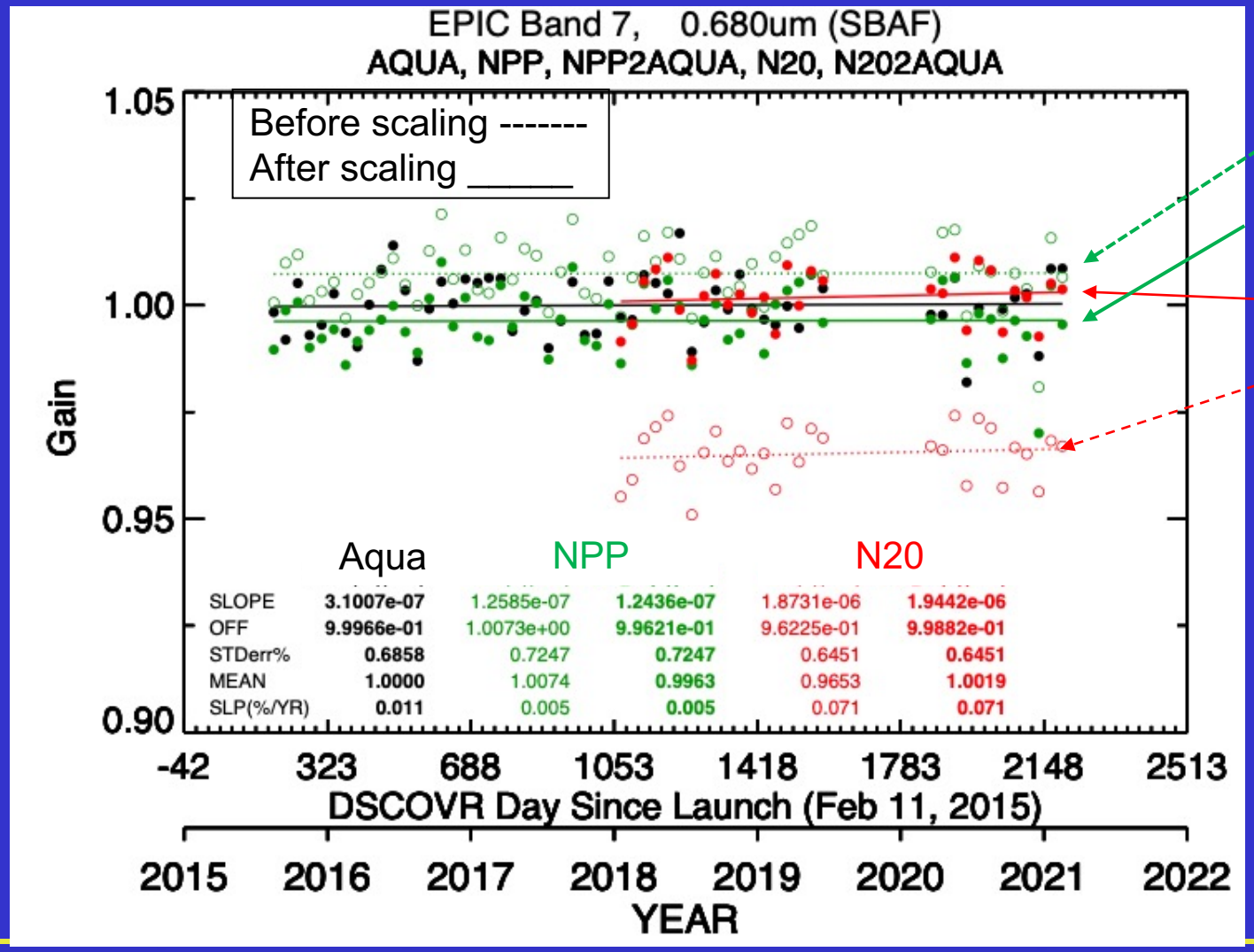
N20 VIIRS after drift

N20 VIIRS before drift

- EPIC and imager radiance pairs monthly linear regression gains

(%/yr)	Aqua	NPP	N20
Before drift	+0.06	-0.15%	-0.20%
After drift	+0.01	+0.01%	+0.07%

EPIC validation of VIIRS radiometric scaling to Aqua



NPP VIIRS before scaling

NPP VIIRS after scaling

N20 VIIRS after scaling

N20 VIIRS before scaling

- The EPIC imager observes all local hours and is suited to calibrate drifting local time sensors
- Including while Terra and Aqua are in drifting orbits

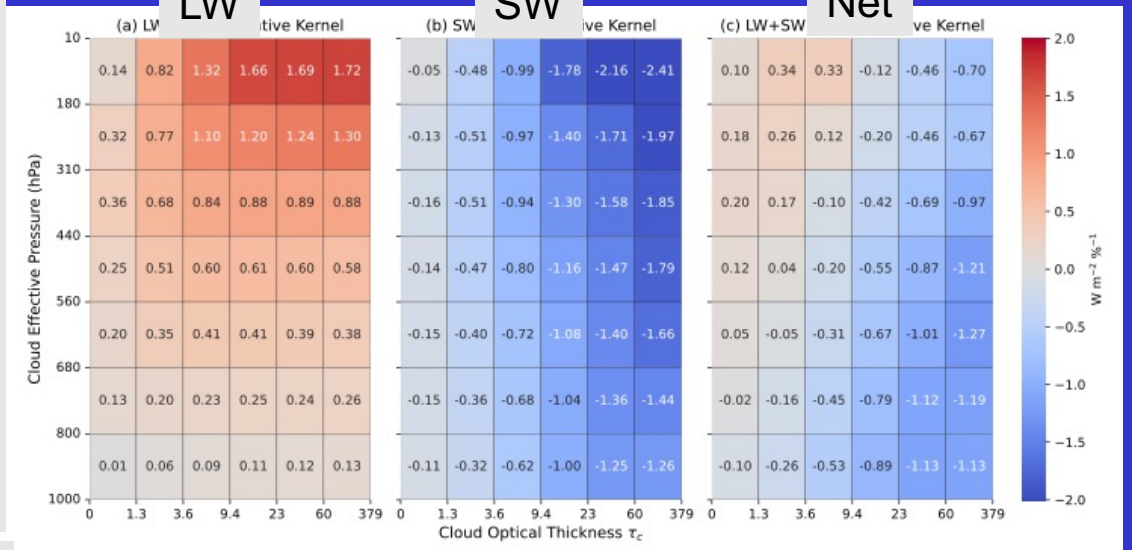
Aqua reference	NPP	N20
Before scaling	0.82%	-3.85%
After scaling	-0.29%	-0.19%

Flux By Cloud Type

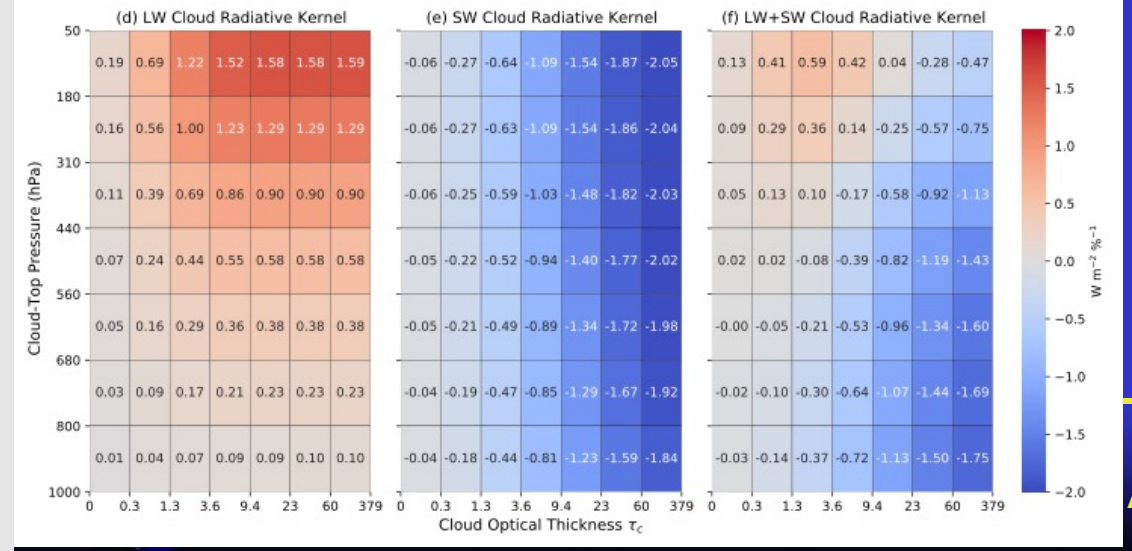
Flux by cloud type 2002-2020

FluxByCldTyp annual and global radiative kernals ($Wm^{-2}\%^{-1}$)

LW SW Net



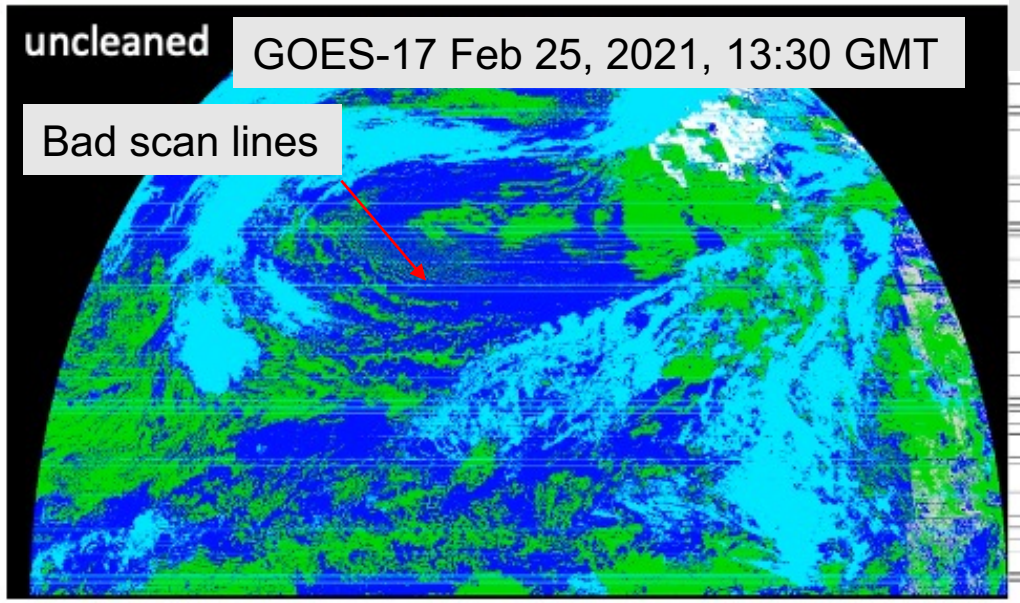
Theoretical Zhou et al. 2013

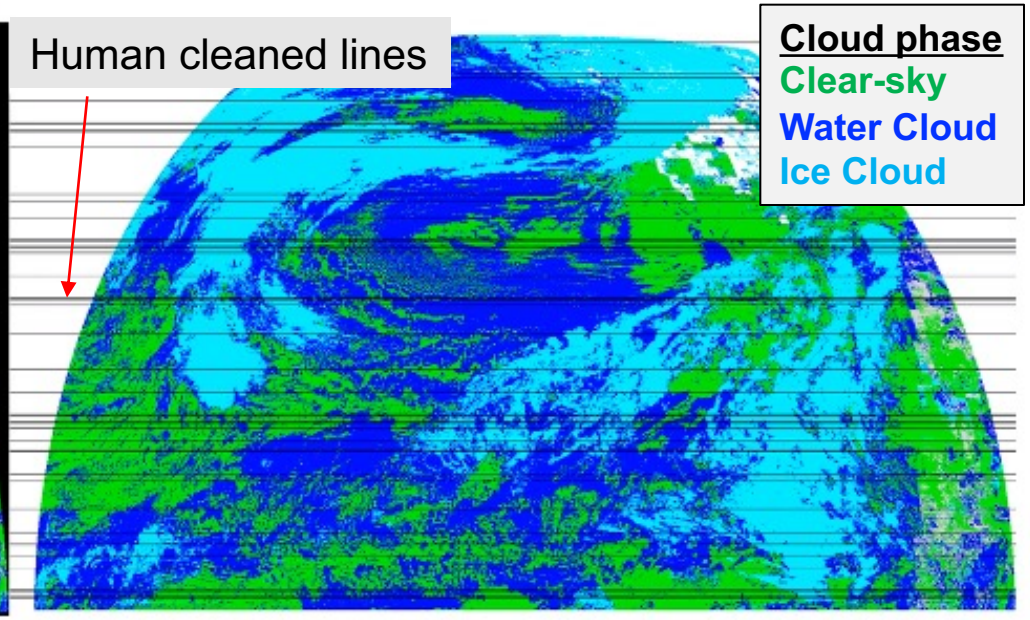


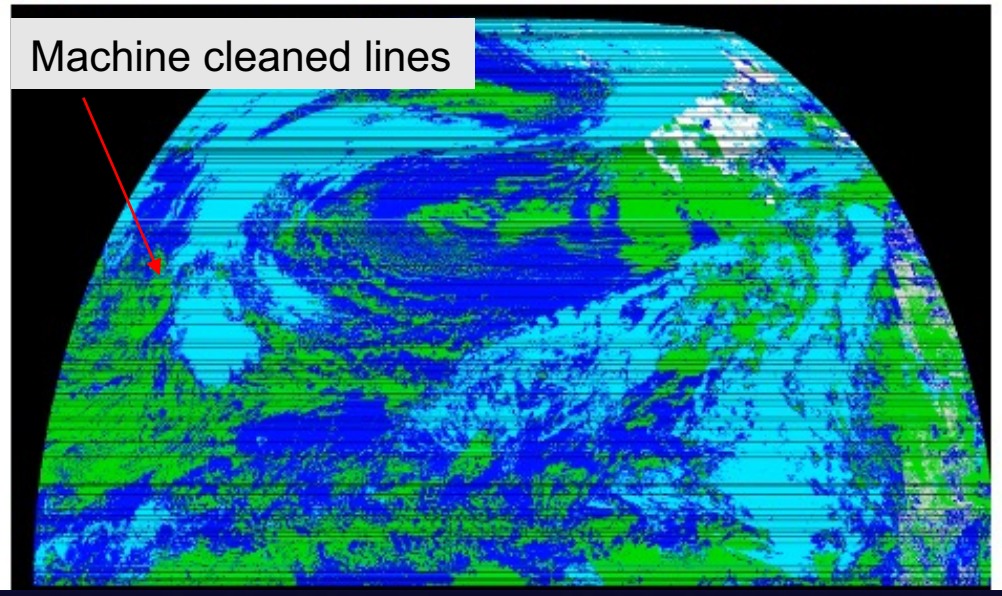
- For transition from Terra+Aqua to a N20 product use climatological adjustment to avoid discontinuities (similar to EBAF)
- Testing machine learning and using additional channels for NB to BB based cloud-type fluxes for application in Ed5
- FBCT paper in the review process

- Plots on the left show the cloud radiative kernals, (clear-sky – overcast cloud type)/(cloud fraction)
- Zhou et al. 2013 Fu-Liou radiative transfer model fluxes using idealized clouds and 20-year zonal mean atmospheric profiles from CMIP3 control runs.
- positive value indicates warming
- Note the similarity between FBCT and climate model, denoting FBCT usefulness to verify climate models

GOES-17 Bad Scan Line Detection





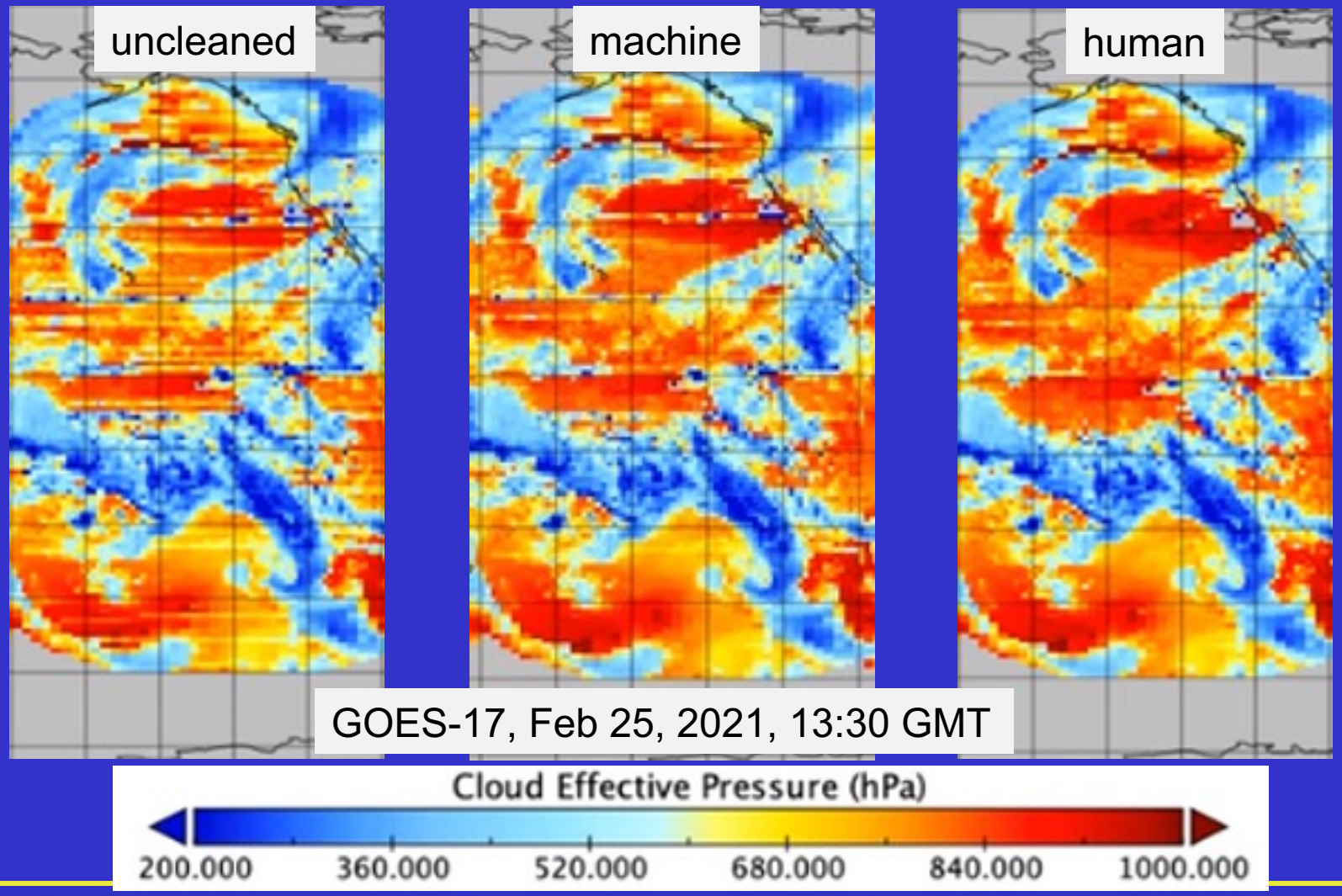


- During GOES-17 nighttime heat loop conditions during equinox, only the 10.4 and 3.9μm are useful and contain scan line pixel noise that manifests itself in the phase imagery
- A KD Tree algorithm constructs the remaining nighttime IR channels required for cloud retrievals based on daytime training
- The Ed4 automated algorithm that identifies potential bad scan line images are examined by humans utilizing a GUI interface, so that not all images need to be examined

- Human cleaning takes hours and is very tedious prone to error
- It is considered as the truth to validate machine cleaned
- if the Ed4 automated algorithm did not identify the image, then the humans did not clean the image

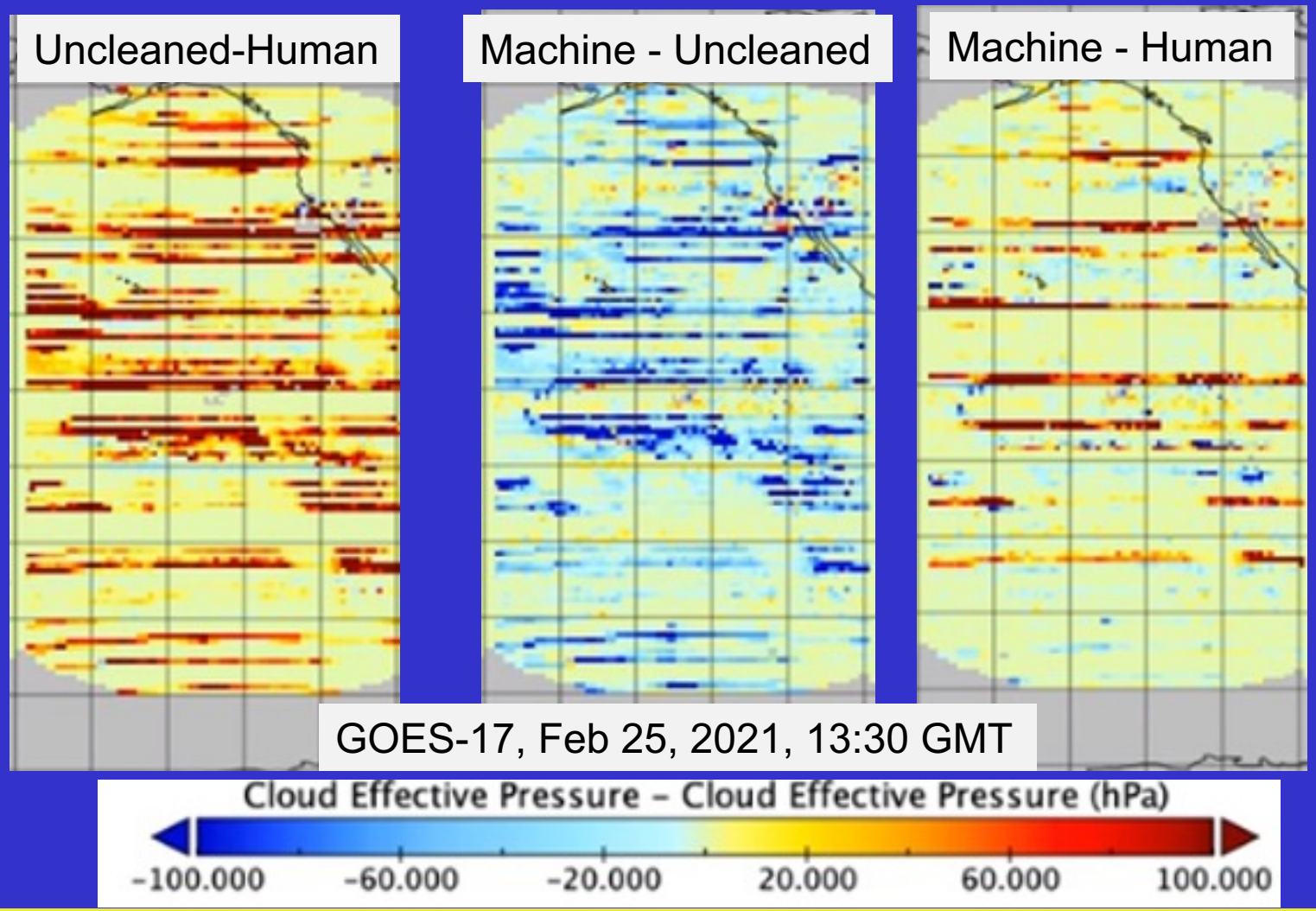
- If machine cleaning removes all of the blatant bad scan lines, while not eliminating too many false positives to get a regional representation of cloud properties it is considered a success

1deg, instantaneous total cloud pressure



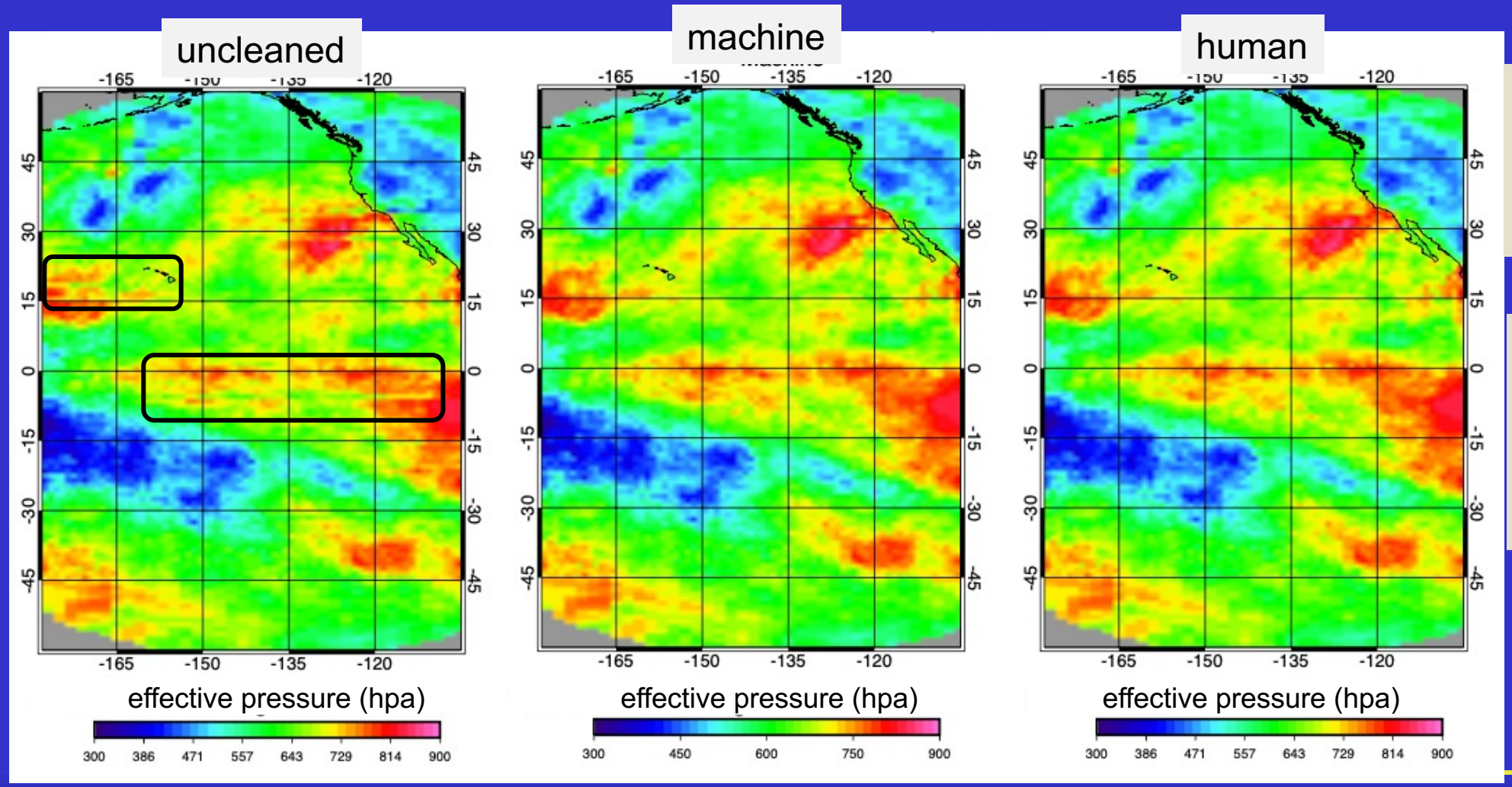
- Misidentified cloud phase in the retrieval translates to a cloud pressure
  - 1deg gridded pixel-level effective cloud pressure averages
- Both machine and humans did not capture all the suspect scan lines.
- Machine cleaning is a significant improvement from uncleaned

1deg, instantaneous total cloud pressure differences



- Machine cleaning is closer to Human cleaning than uncleaned

Monthly Hourly (Feb 2021, 13:30 GMT) effective pressure

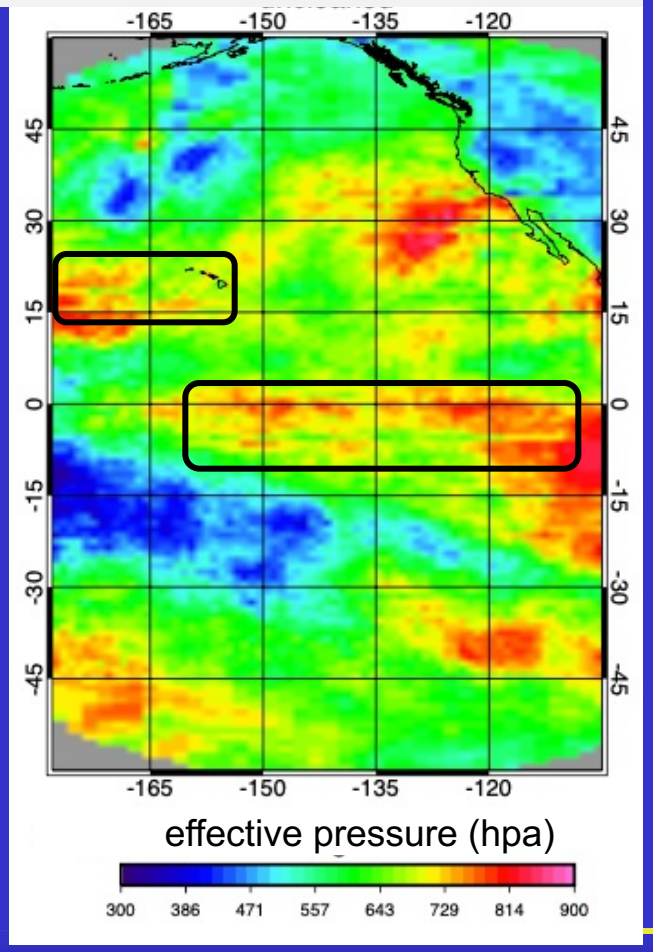


- Uncleaned data shows bad scan lines at the monthly hourly resolution

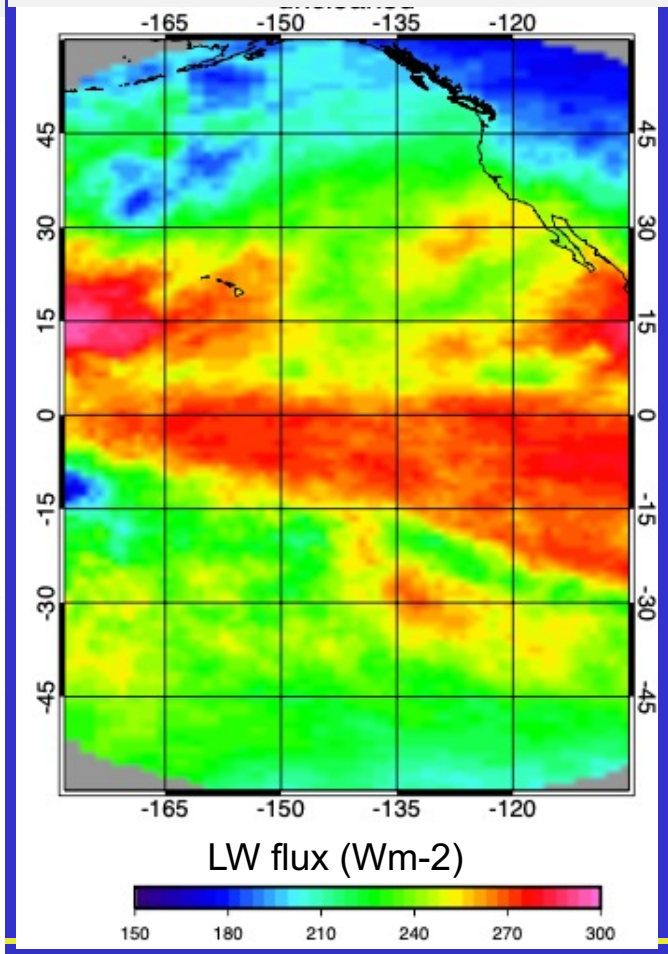
- Human or Machine cleaned data do not show bad scan lines at the monthly hourly resolution

Monthly Hourly (Feb 2021, 13:30 GMT) fluxes

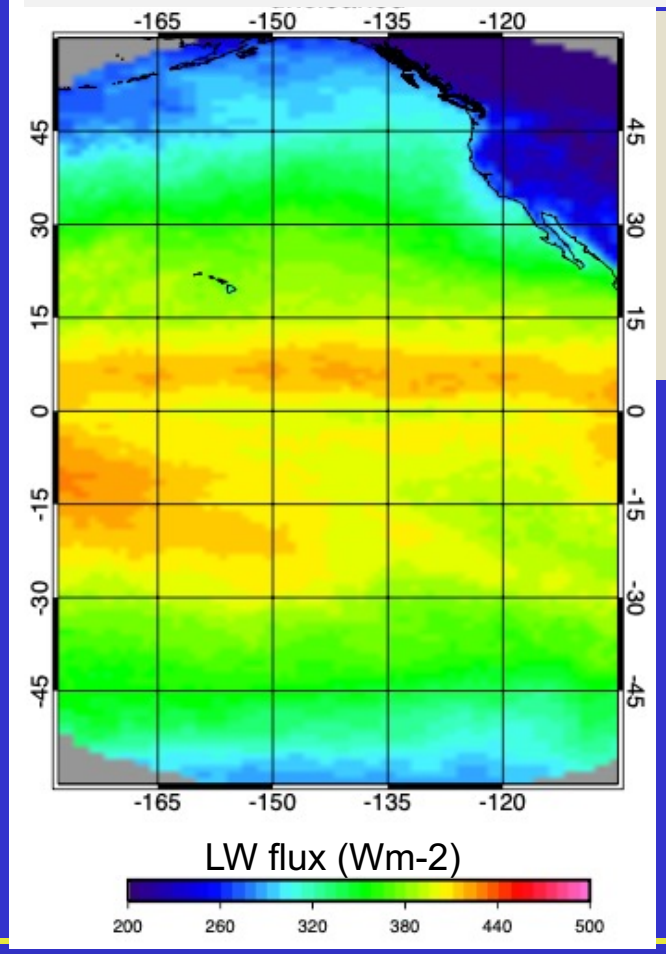
uncleaned effective pressure



uncleaned GEO TOA LW flux

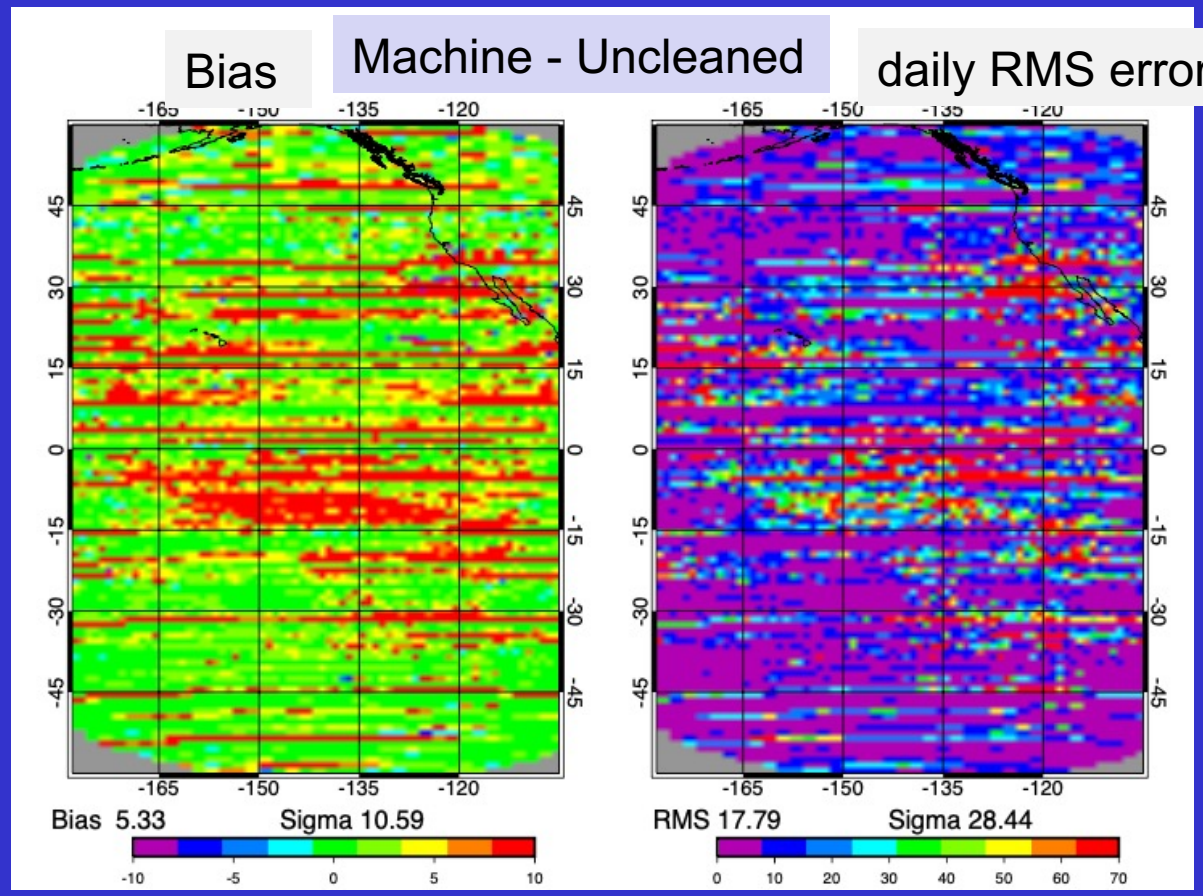


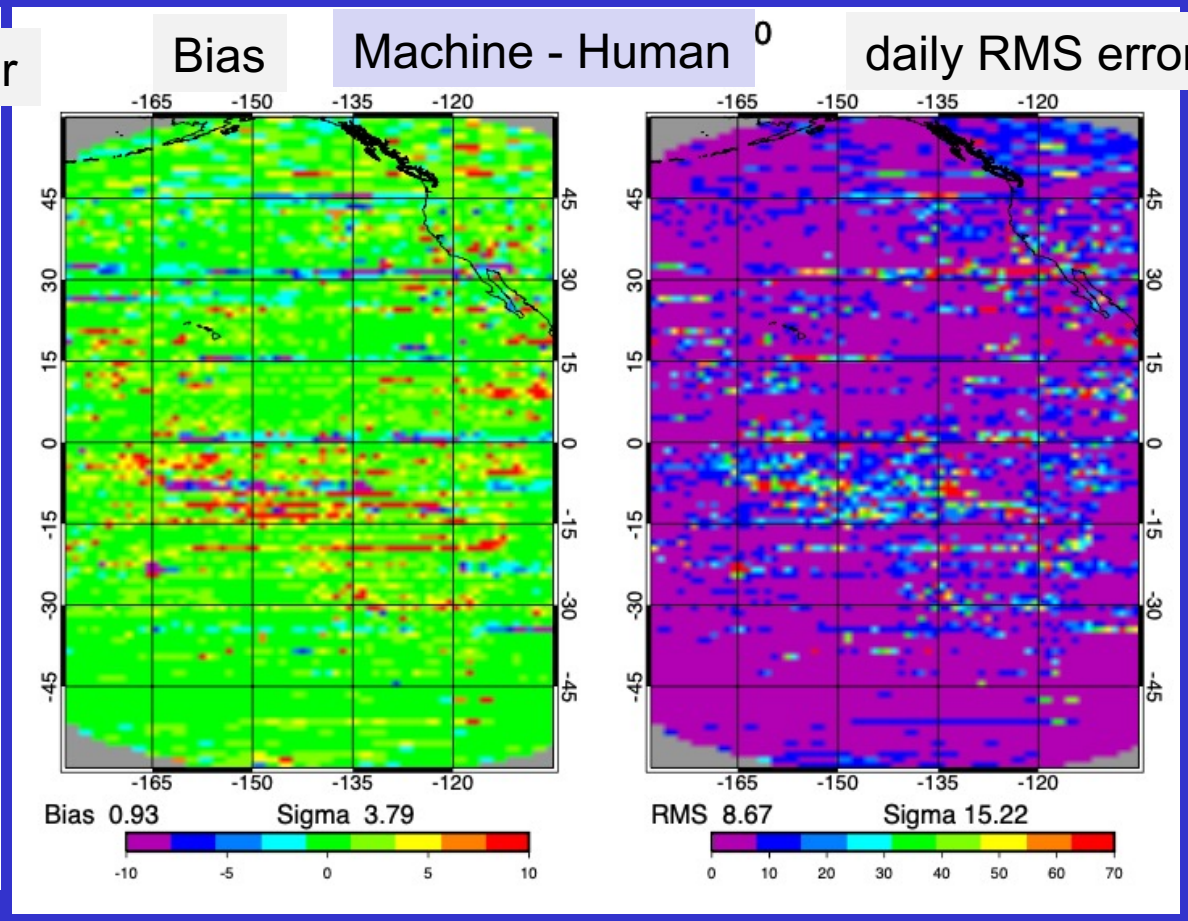
uncleaned surface LW down



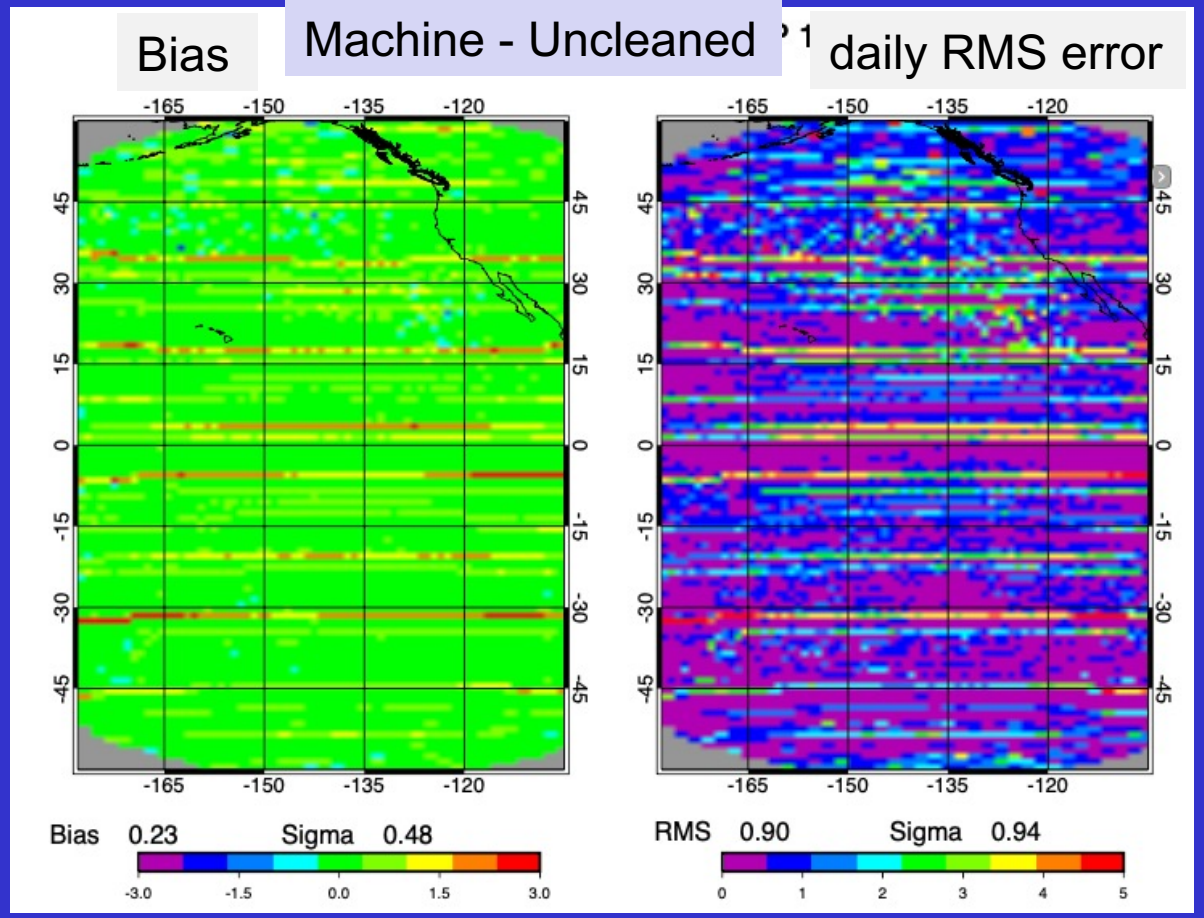
- The GEO derived TOA and computed surface LW fluxes do not seem to be as dependent on the cloud properties

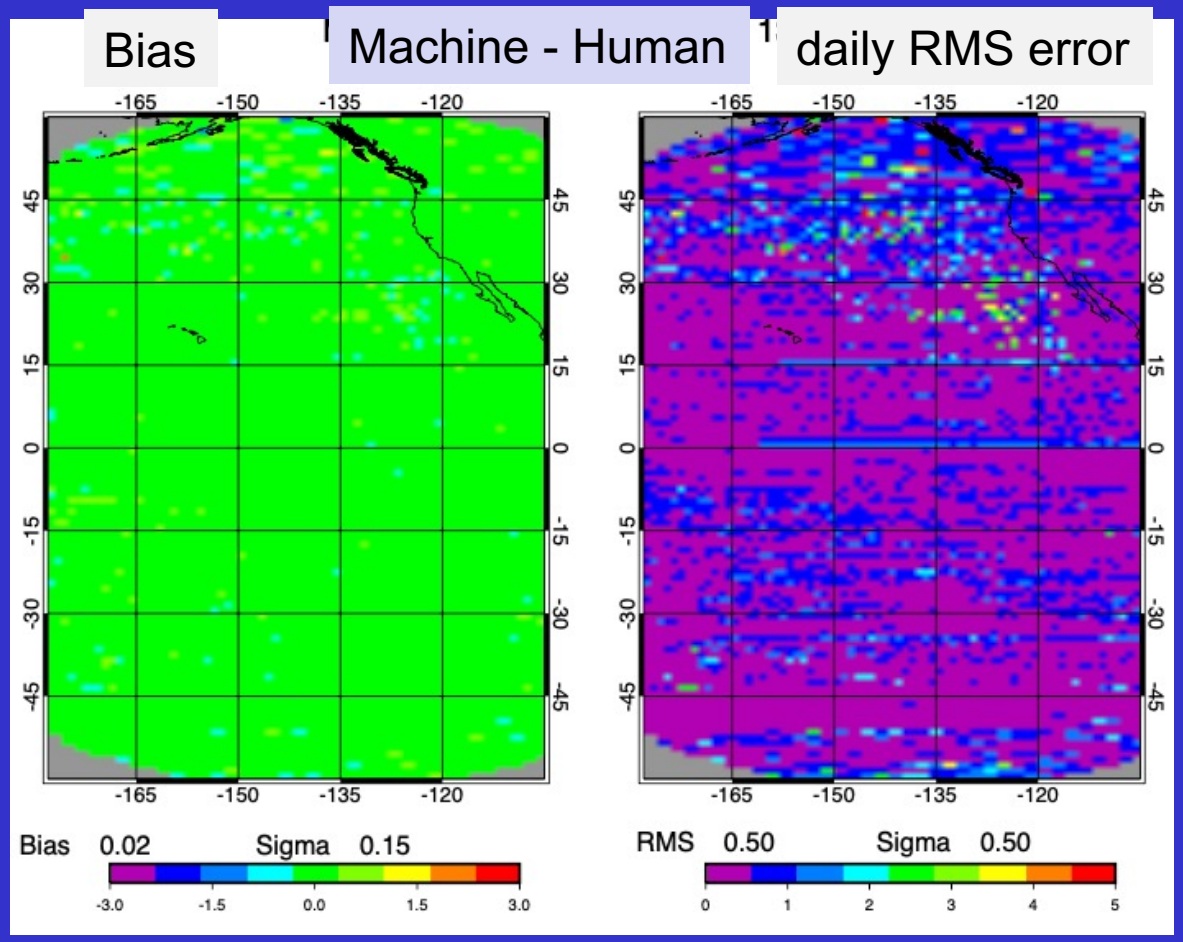
Monthly hourly (Feb 2021, 13:30 GMT) Cloud effective pressure





Monthly hourly (Feb 2021, 13:30 GMT) GEO TOA LW Flux





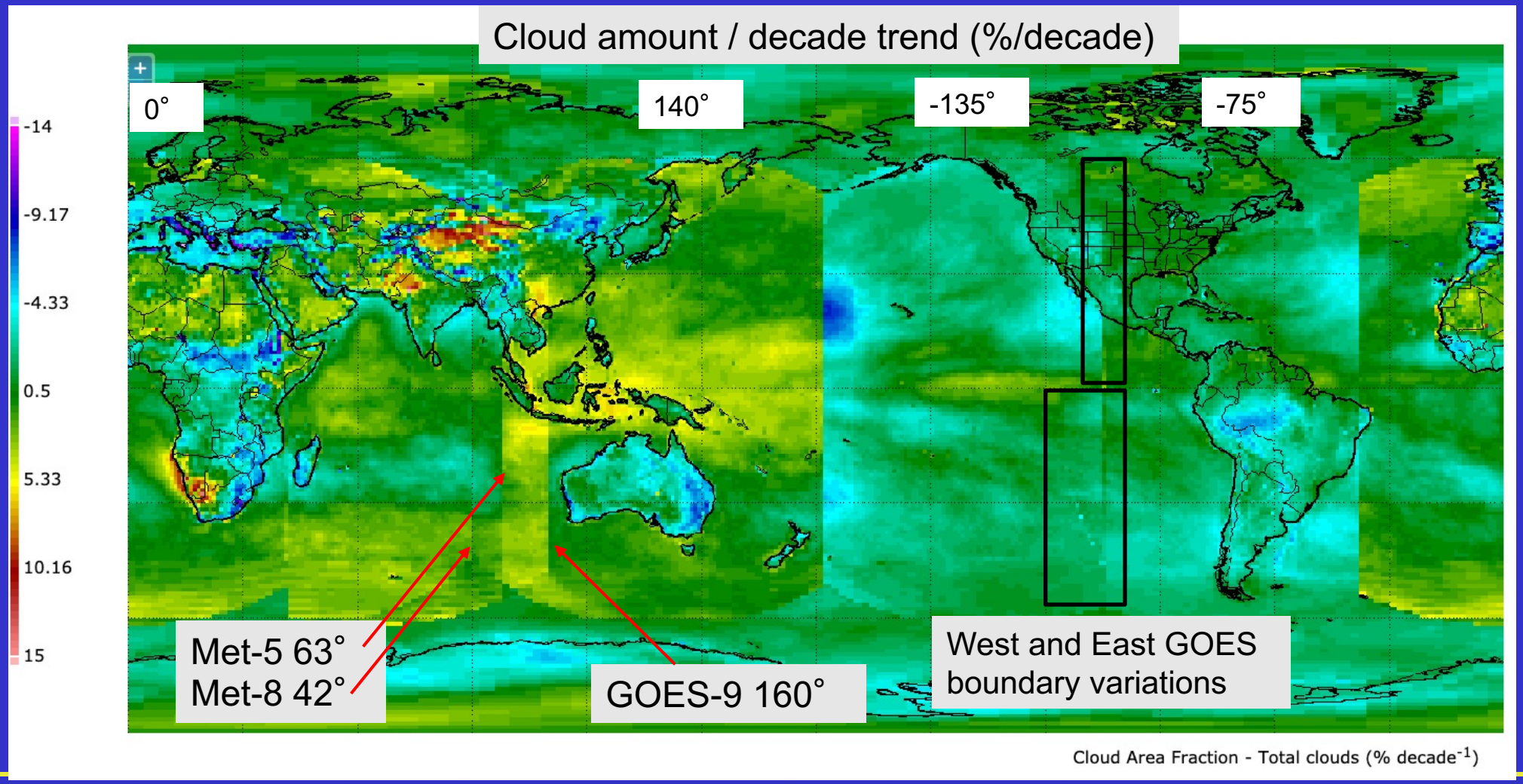
Monthly hourly (Feb 2021) Cloud effective pressure

	BIAS		daily RMS error	
GMT (hpa)	**Machine-uncleaned**	**Machine-human**	**Machine-uncleaned**	**Machine-human**
10:30	0.37, 3.05	0.17, 2.33	3.7, 10.7	3.3, 8.2
11:30	1.06, 4.59	0.48, 2.62	6.7, 16.8	4.9, 10.7
12:30	3.77, 9.04	0.90, 3.18	14.3, 26.1	6.3, 12.5
13:30	5.33, 10.59	0.93, 3.79	17.8, 28.4	8.7, 15.2
14:30	2.27, 6.33	0.65, 2.45	9.2, 19.5	4.8, 10.0
15:30	0.52, 2.76	0.30, 1.64	3.1, 10.7	2.5, 7.1
16:30	0.27, 2.37	0.15, 1.39	1.9, 8.9	1.6, 6.1

domain average, regional standard deviation

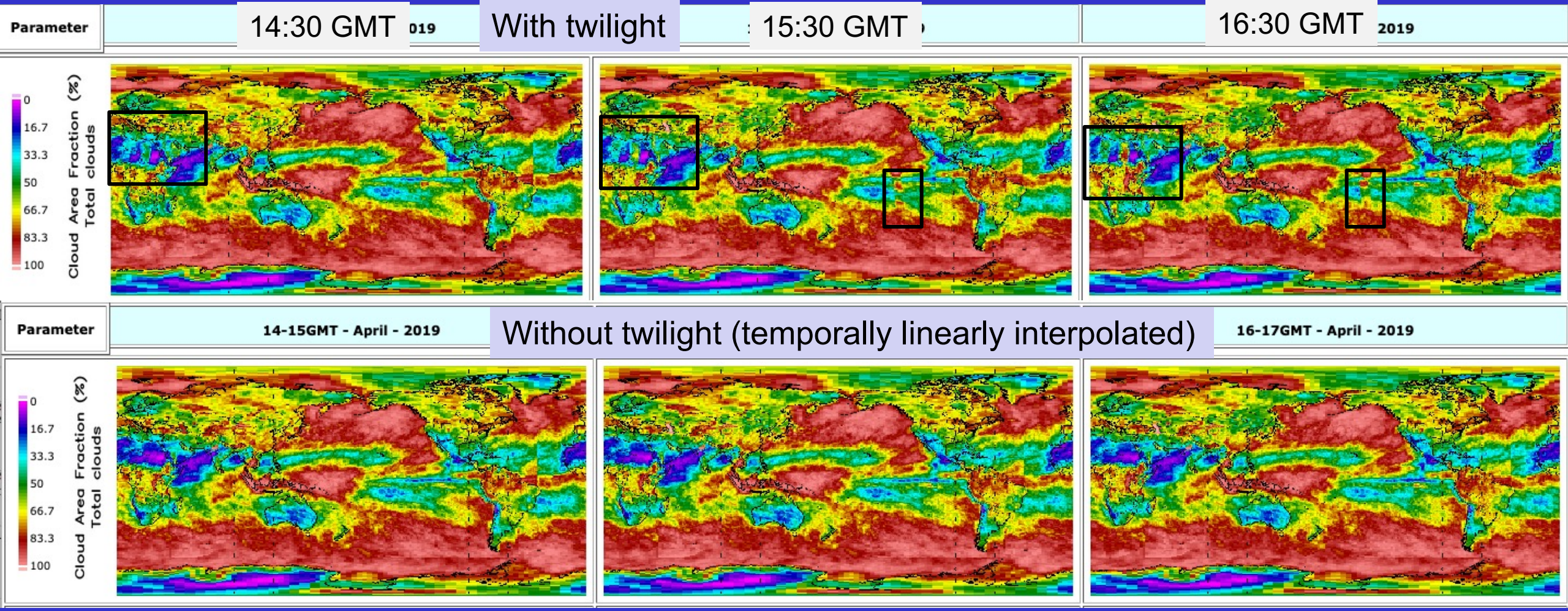
- For the KD tree monthly hourly retrieved cloud effective pressure machine cleaning shows a reduction in both the bias and RMS error over uncleaned
- For GEO TOA and surface fluxes only 12:30 to 14:30 GMT shows a reduction in both the bias and RMS error
- Will be implemented for SYN1deg future GOES-17 heat loop pipe impacted months

GEO spatial boundaries



- For Ed4 the GEO boundaries are dynamically set to the midpoint between GEO sub-satellite locations
- For Ed5, set static GEO boundaries to reduce spatial trend discontinuities

SYN1deg, April 2019 Monthly hourly cloud fraction



- GEO twilight cloud retrievals cause spurious cloud properties (cloud fraction striping), which impact LW surface fluxes
- Similar to the GEO SW TOA flux, which are temporally interpolated for hourboxes with SZA >60 deg, linearly interpolate cloud properties across the twilight hourboxes

SYN1deg 1st generation GEOs gridding improvements

- The 3-channel 1st generation GEO gridding code is Ed2 code, whereas all other GEOs is Ed4 code, Use Ed4 code only moving forward
  - Want to have single path for the GEO gridding code, when gridding improvements need to be applied in the code
  - Less code to maintain by removing the old Ed2 gridding code
  - Produce pixel level cloud properties similar to Ed4
- The Ed2 GEO gridding code has bugs
  - The dominant phase cloud property pixel values were used to average spatially into 1 deg regions rather than using both water and ice clouds
  - A single solar zenith angle was used to determine whether the day or nighttime GEO to MODIS IR scaling coefficients were applied

BACKUP SLIDES

TISA activities with other working groups

- TISA also involved with migrating EBAF Terra&Aqua to N20
  - Next presentation: EBAF Update
- TISA making progress on new coding framework
  - CERES Data Management Team (DMT) Working Group Report
- Comparison of Merra-2 and GEOS.5.4.1 clouds and surface fluxes
  - TOA fluxes not impacted
- Combine EBAF and FLASHFlux monthly fluxes as part of EBAF processing to produce an internal real-time flux product
- GEO 2-channel cloud code reprocessing