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Clear-Sky Flux Simulation Using GMAO FP and MERRA-2 Products and Its Comparison to Ground and Satellite Observations

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Backgrounds

- CERES algorithm have used Global Modeling Assimilation Office (GMAO) Forward Processing (FP) v4 – v5.4 for describing humidity/temperature profiles, and skin temperature (special versions for CERES team).
- Recently, GMAO has released newer versions of FP datasets (e.g., v5.11, v5.13, v5.16).
- Moreover, there is Modern-Era Retrospective Analysis for Research and Applications version 2 (MERRA-2) dataset, which is also produced by GMAO.
- Therefore, it is meaningful to examine sensitivity of clear-sky flux to different GMAO datasets.

GMAO Products Considered in This Study

- ❑ Period

  April/Jul/Oct 2015 and Jan 2016 (four seasonal months)

- ❑ Products

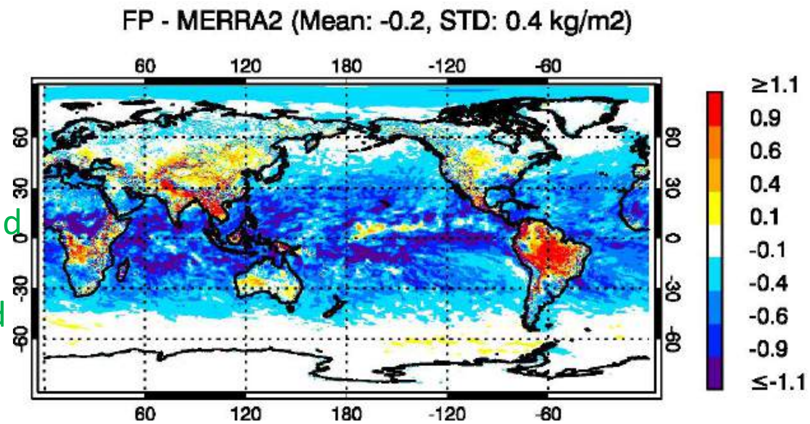
1) MERRA-2 is a continuous reanalysis dataset for 1980 – current. → "MERRA-2"
2) FP v5.13 is a publically available new version of FP dataset for year 2015-2016 → "FP"
3) FP v5.2 is used for SYN Ed3A processing → "SYN"

Four-Seasonal Months (Apr/Jul/Oct 2015 + Jan2016)

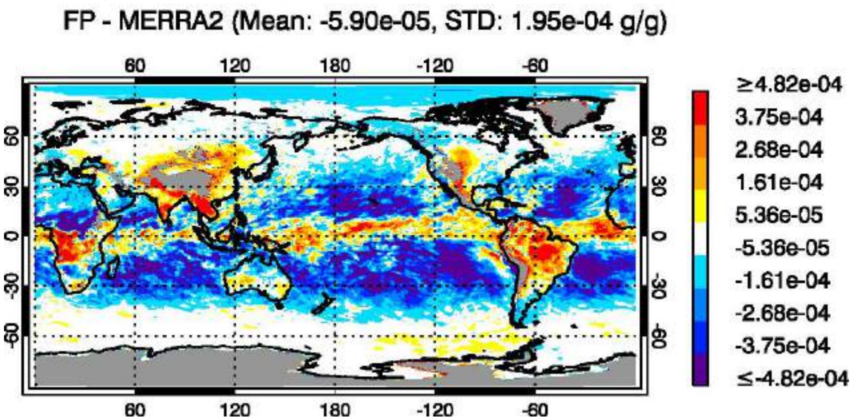
FP v5.13 minus MERRA-2 WV for Year 2015/2016

Total Column WV (kg/m²)

FP drier over ocean and wetter over land

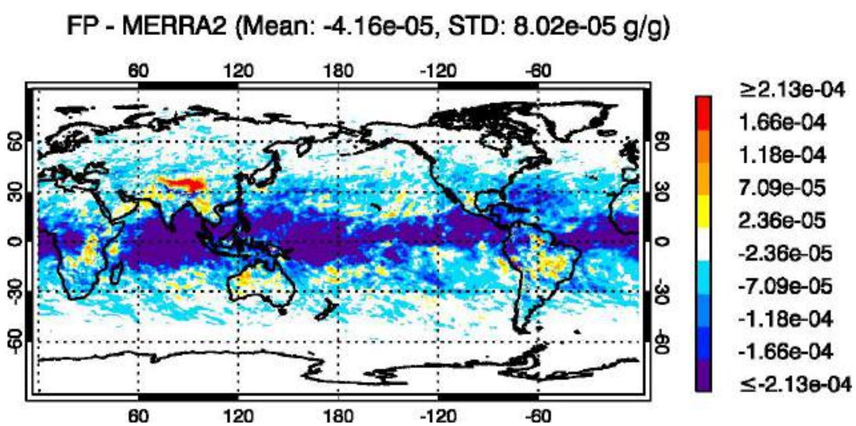


850-hPa WV (g/g)

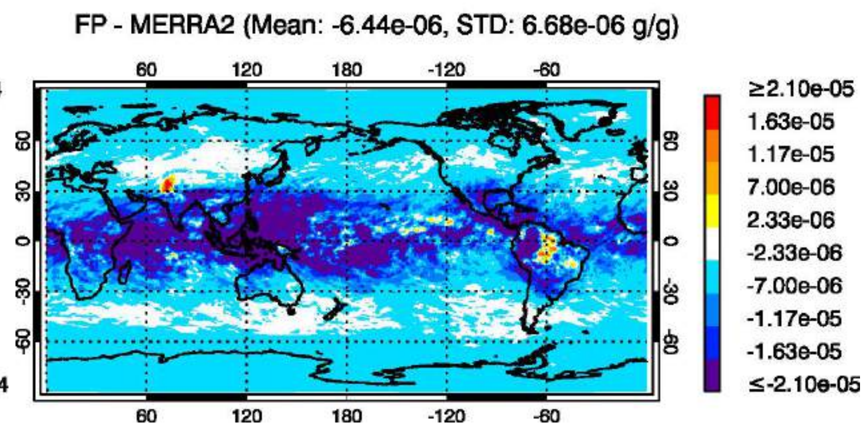


500-hPa WV

FP drier over tropical ocean



250-hPa WV (g/g)



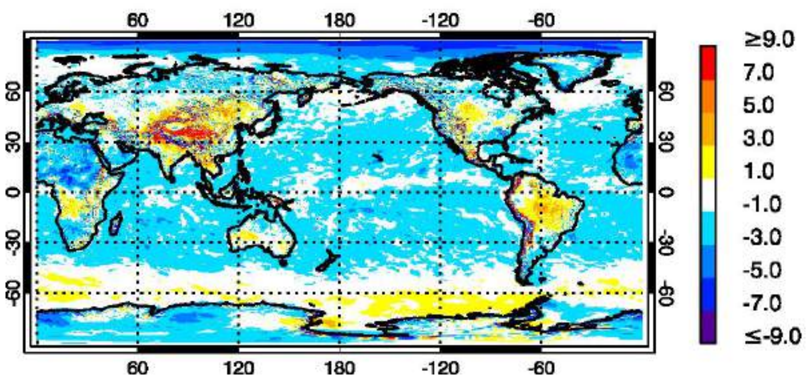
Four-Seasonal Months (Apr/Jul/Oct 2015 + Jan2016)

(FP minus MERRA-2)/ MERRA-2 x 100%

Total Column WV

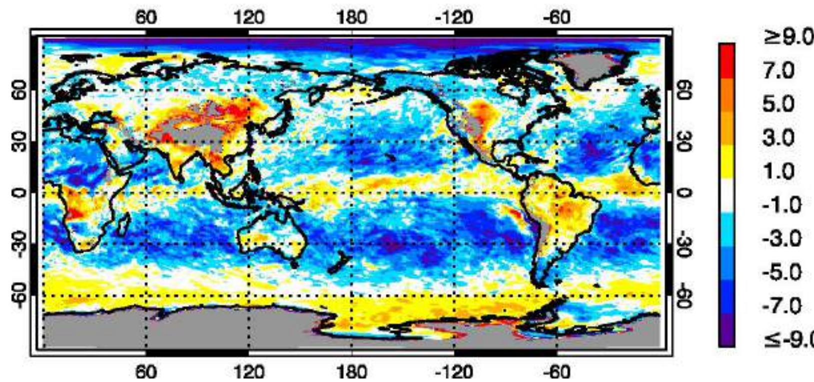
(FP - MERRA2)/MERRA2 x 100% (Mean: -1.1, STD: 2.3%)

1-3% drier FP over ocean



850-hPa WV

(FP - MERRA2)/MERRA2 x 100% (Mean: -1.1, STD: 6.1%)

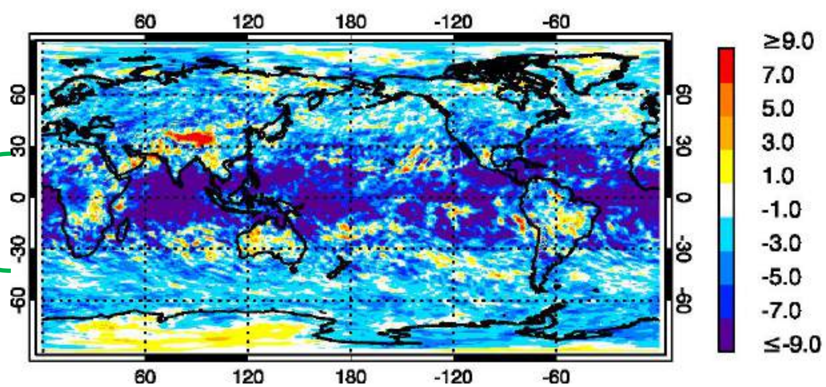


~5 % drier FP

500-hPa WV

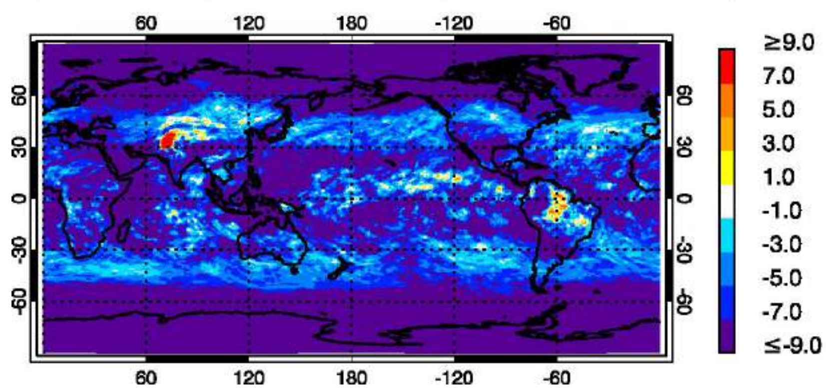
(FP - MERRA2)/MERRA2 x 100% (Mean: -2.9, STD: 3.4%)

5-7% drier FP



250-hPa WV

(FP - MERRA2)/MERRA2 x 100% (Mean: -11.3, STD: 8.4%)



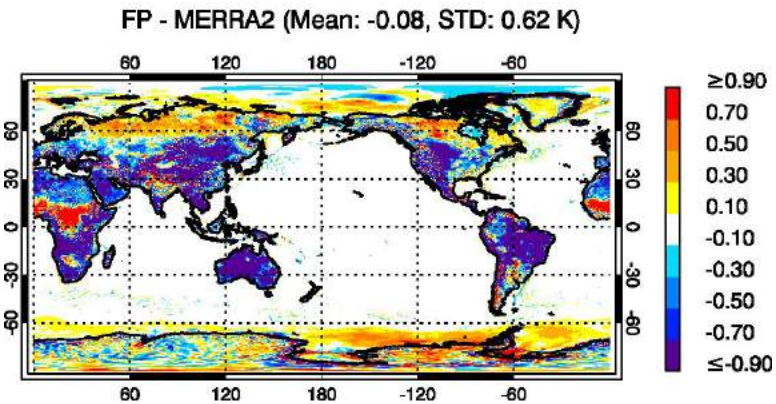
>7% drier FP

Four-Seasonal Months (Apr/Jul/Oct 2015 + Jan2016)

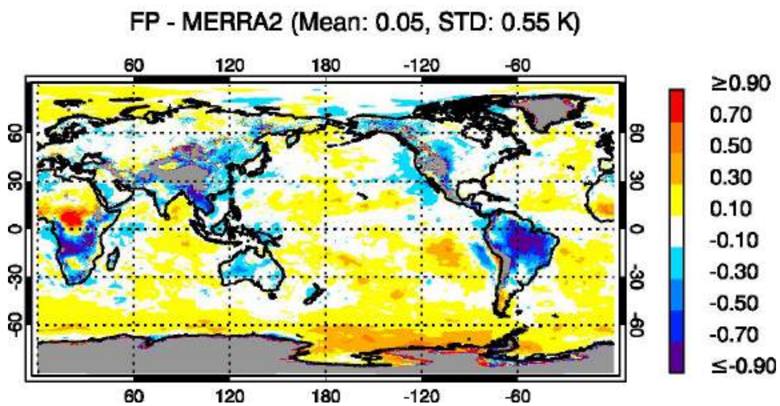
FP minus MERRA-2 Temp (K)

Colder skin temp in FP over land (Also 2-m Temp)

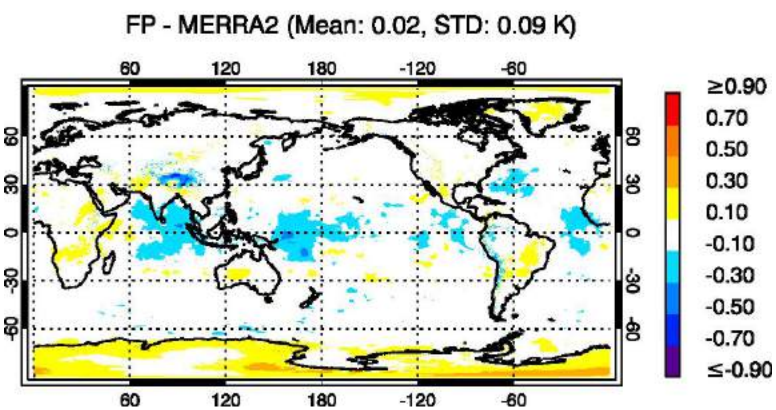
Skin Temp



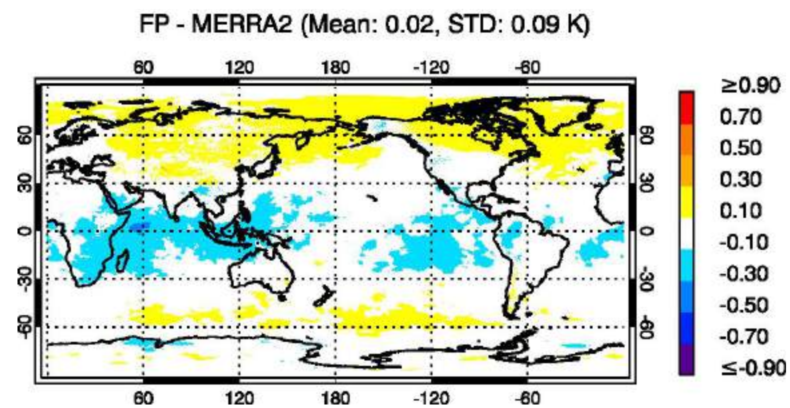
850-hPa Temp



500-hPa Temp



250-hPa Temp



Objectives

- We apply different GMAO datasets to assume atmospheric profiles, and perform clear-sky flux simulation at TOA and surface using Fu-Liou radiative transfer model (RTM).
- We compare the simulated results with ground and CERES satellite observations for cloud-free pixels.

Which Flux Can We Compare?

- ❑ LW SFC Downward Flux

  Lower Temp/Humidity Profiles, Aerosol

- ❑ LW TOA Upward Flux

  Upper Temp/Humidity Profiles, Skin Temperature, Aerosol, Surface Emissivity

- ❑ SW SFC Downward Flux

  Total Column WV, Aerosol

- ❑ ~~SW TOA Upward Flux~~

  ~~Total Column WV, Aerosol, Surface Bidirectional Reflectance~~

RTM & Model Inputs

Langley Fu-Liou Radiative Transfer Model (RTM)

FLux model of CERES with k-distribution and correlated-k for Radiation (FLCKKR) [Fu and Liou, 1993; Fu et al., 1997; Kratz and Rose, 1999; Kato et al., 1999, 2005; Rose et al., 2006]

Two-stream approximation for SW (0–4 μm) and LW (>4 μm) broadband simulations

Atmospheric Profiles & Skin Temperature

FP v5.13 or MERRA-2

Aerosol

MATCH (David Fillmore/Tech-X Coroperation)

[https://ceres.larc.nasa.gov/science_information.php?page=ModisMatchAero]

Surface

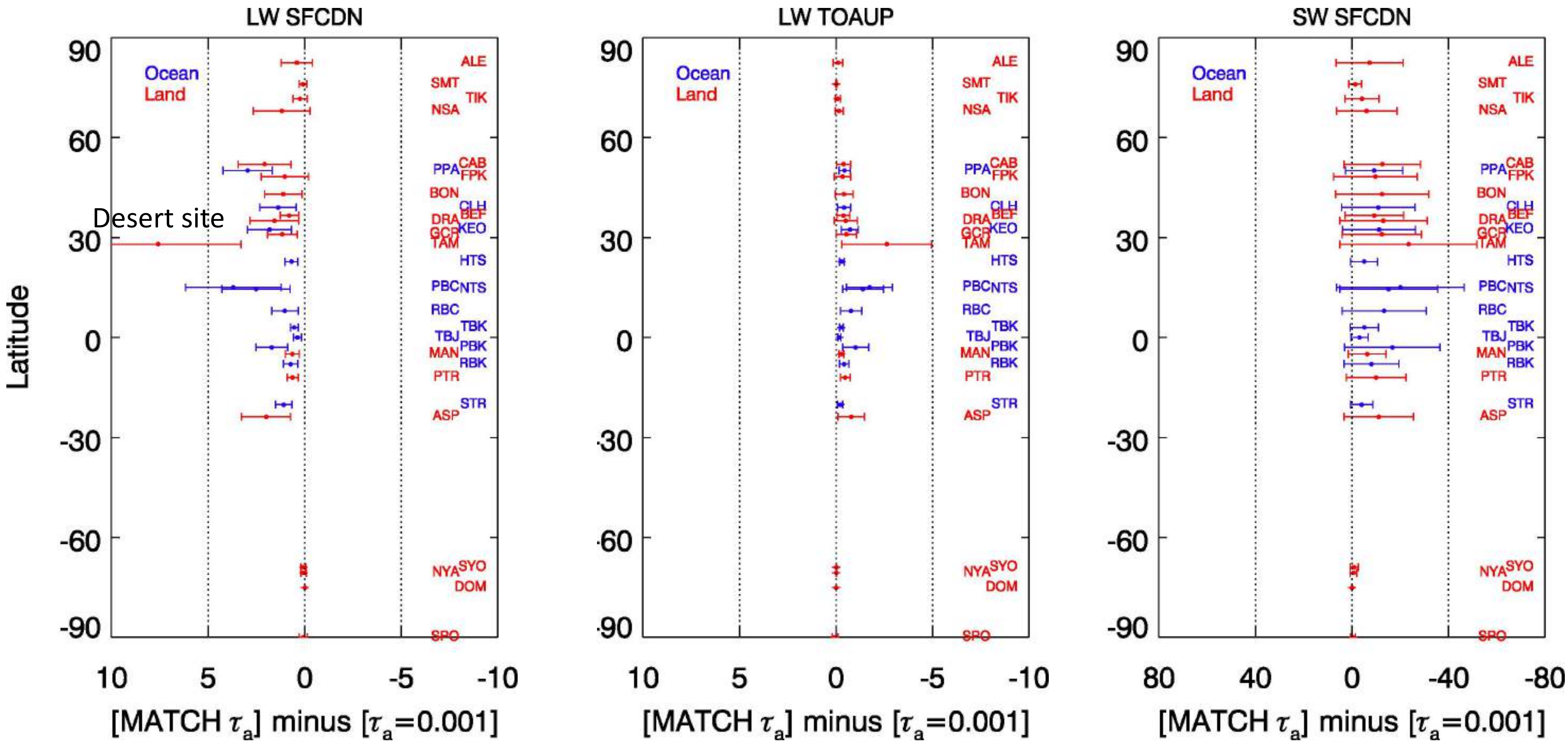
Xianglei Huang (Michigan Univ.)'s Surface emissivity (Monthly, 1-degree gridded)

Impacts of Aerosol Assumption:
Flux (with MATCH τ_a) minus Flux (with τ_a=0.001)

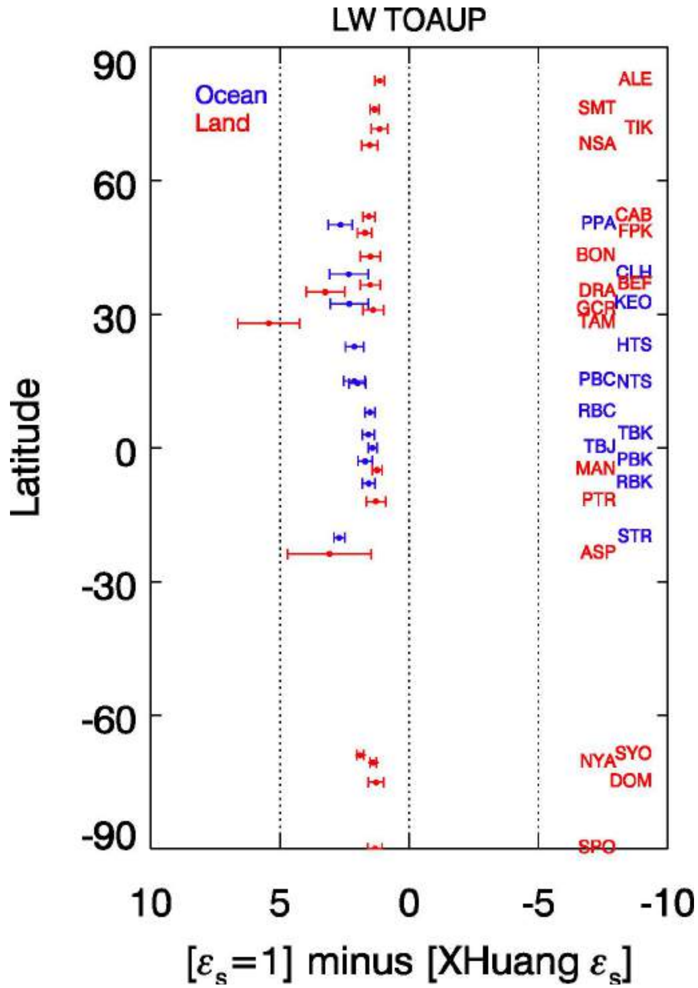
< 2 Wm^{-2} diff except TAM (desert) site

< 1 Wm^{-2} diff except TAM site

0-20 Wm^{-2} diff



Impacts of Surface Emissivity:
Flux (with ε_s=1) minus Flux (with XHuang ε_s)

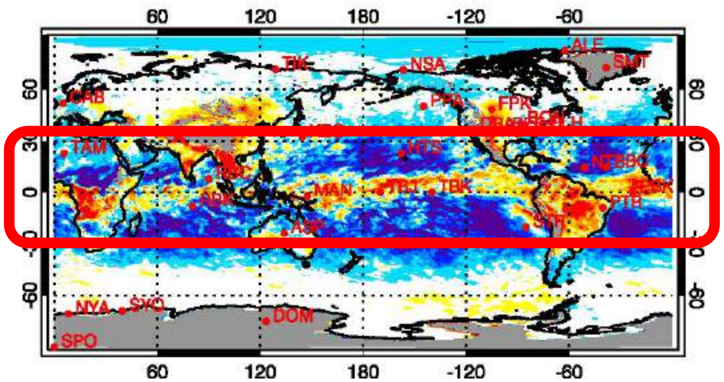


Impact of surface emissivity is larger than aerosol but still mostly less than 2.5 W m^{-2}.

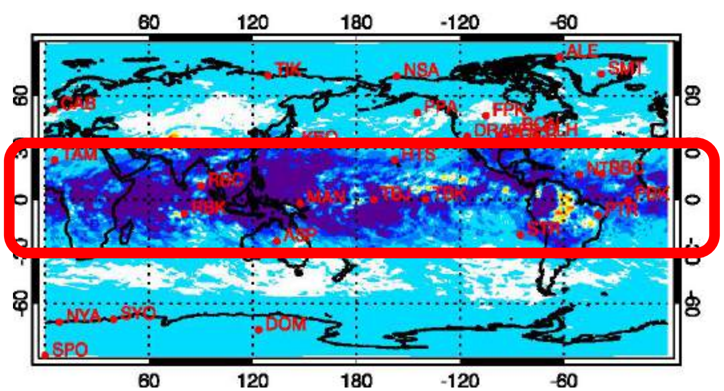
Four-Seasonal Months (Apr/Jul/Oct 2015 + Jan2016)

Ground sites where FP and MERRA-2 are significantly different

850-hPa Specific Humidity Absolute Diff



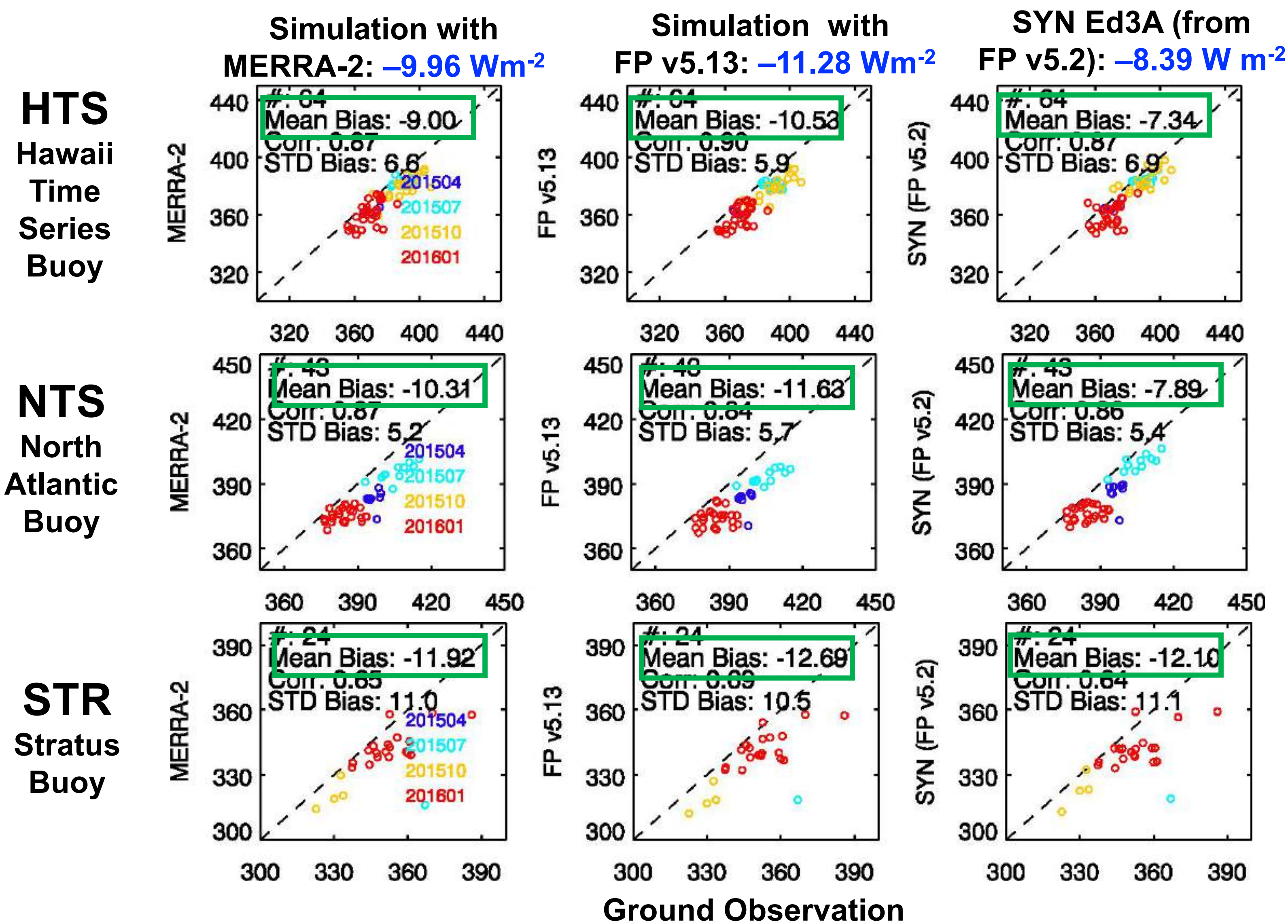
250-hPa Specific Humidity Absolute Diff



Unfortunately, data availability for tropical ocean sites is low...

Site Name	SW SFC DN				SW SFC UP	LW SFC DN				LW SFC UP
	Apr 2015	Jul 2015	Oct 2015	Jan 2016	Apr/Jul/ Oct/Jan	Apr 2015	Jul 2015	Oct 2015	Jan 2016	Apr/Jul/ Oct/Jan
RBC	X	X	X	X	X	X	X	X	X	X
RBK	X	X	X	X	X	X	X	X	X	X
MAN	X	X	X	X	X	X	X	X	X	X
TBJ	X	X	X	X	X	X	X	X	X	X
HTS	O	O	X	O	X	O	O	X	O	X
TBK	X	X	X	X	X	X	X	X	X	X
NTS	O	O	X	O	X	O	O	X	O	X
PBC	X	X	X	X	X	X	X	X	X	X
PTR	X	X	X	X	X	X	X	X	X	X
STR	O	O	O	O	X	O	O	O	O	X
PBK	X	X	X	X	X	X	X	X	X	X

LW SFC DN ($W\ m^{-2}$) over Tropical Oceans



- Smaller LWDN means drier/colder conditions in lower troposphere.
- FP v5.13 produces the largest negative biases, while SYN produces the smallest negative biases.
- Uncertainty related to aerosol < 2 $W\ m^{-2}$

LW TOA UP ($W\ m^{-2}$) over Tropical Oceans

Simulation with MERRA-2: –1.43 Wm^{-2}

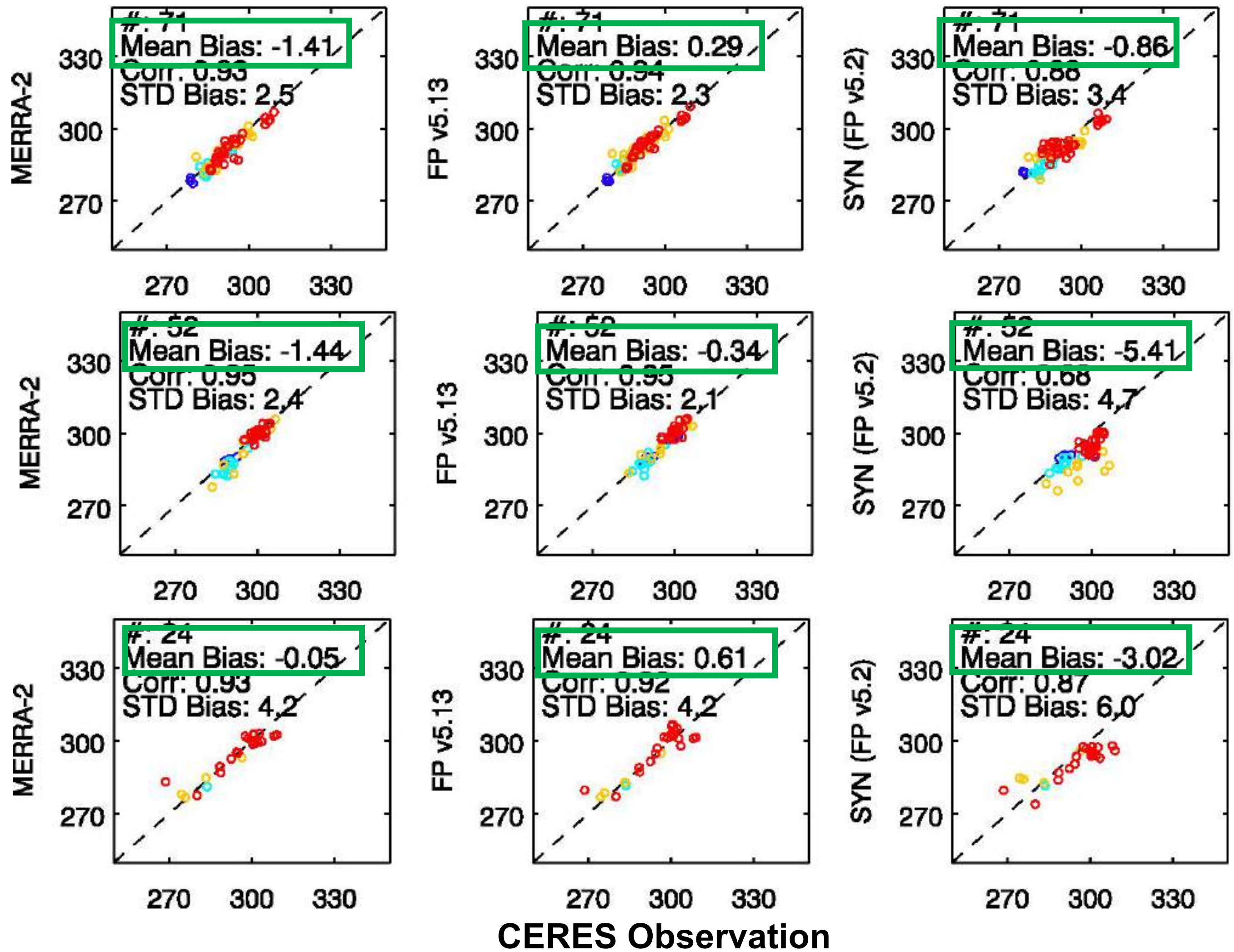
Simulation with FP v5.13: –0.52 Wm^{-2}

SYN Ed3A (from FP v5.2): –3.61 $W\ m^{-2}$

HTS Hawaii Time Series Buoy

NTS North Atlantic Buoy

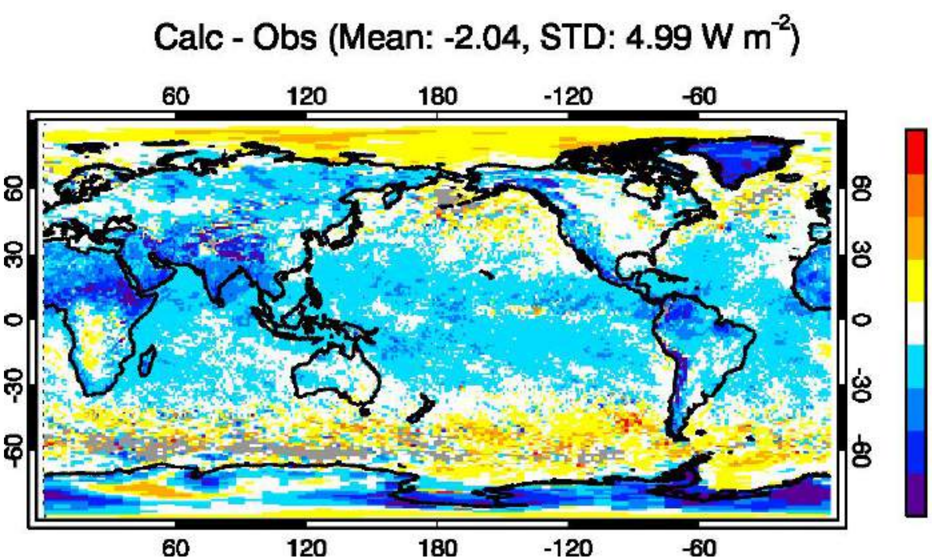
STR Stratus Buoy



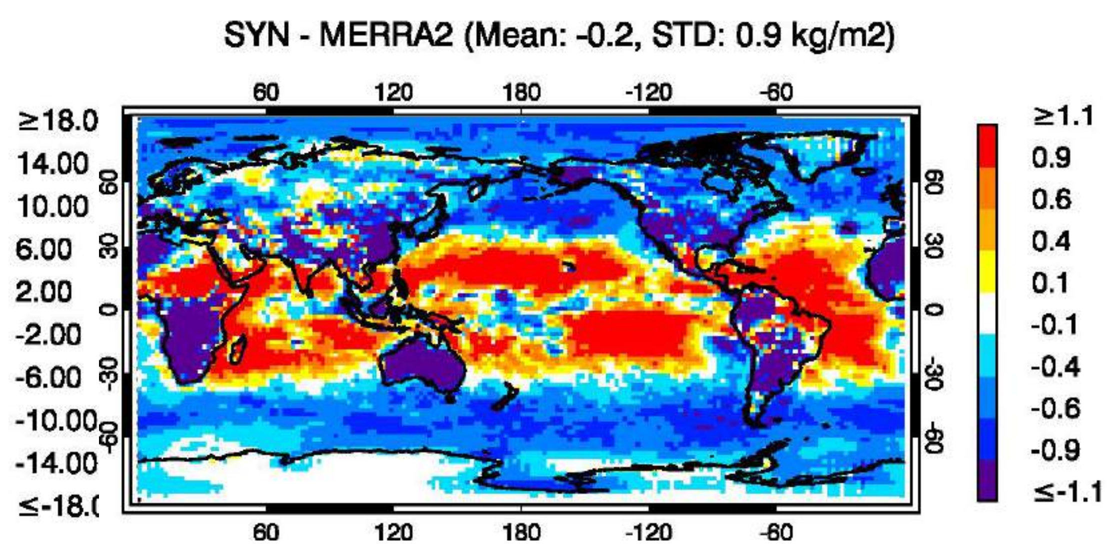
- SYN Ed3A (from FP v5.2) shows larger negative TOA LW biases, compared to those simulated from MERRA-2 or FP v5.13.
- This indicates FP v5.2 (SYN Ed3A) has larger wet biases in upper troposphere.

Global Comparison of TOA LW Clear-Sky Fluxes from SYN Ed3A (FP v5.2) and CERES Observations

SYN Ed3A (from FP v5.2) minus CERES Observed TOA LW

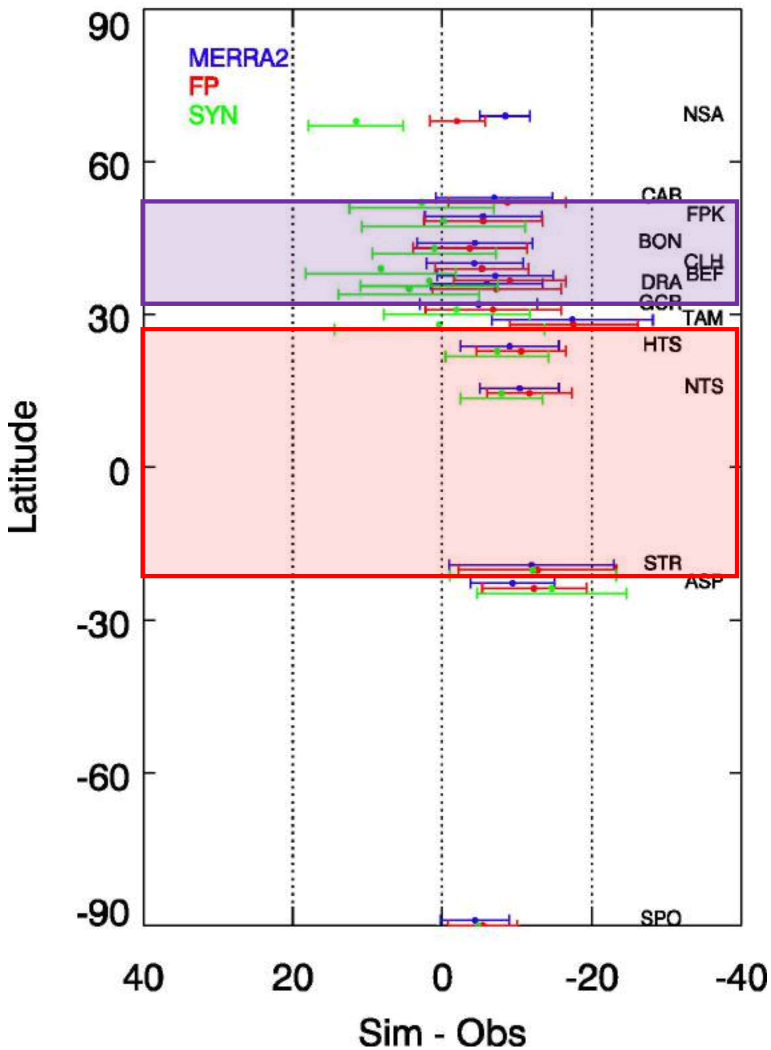


SYN Ed3A (from FP v5.2) minus MERRA-2 Total Column WV



Four-Seasonal Months (Apr/Jul/Oct 2015 + Jan2016)

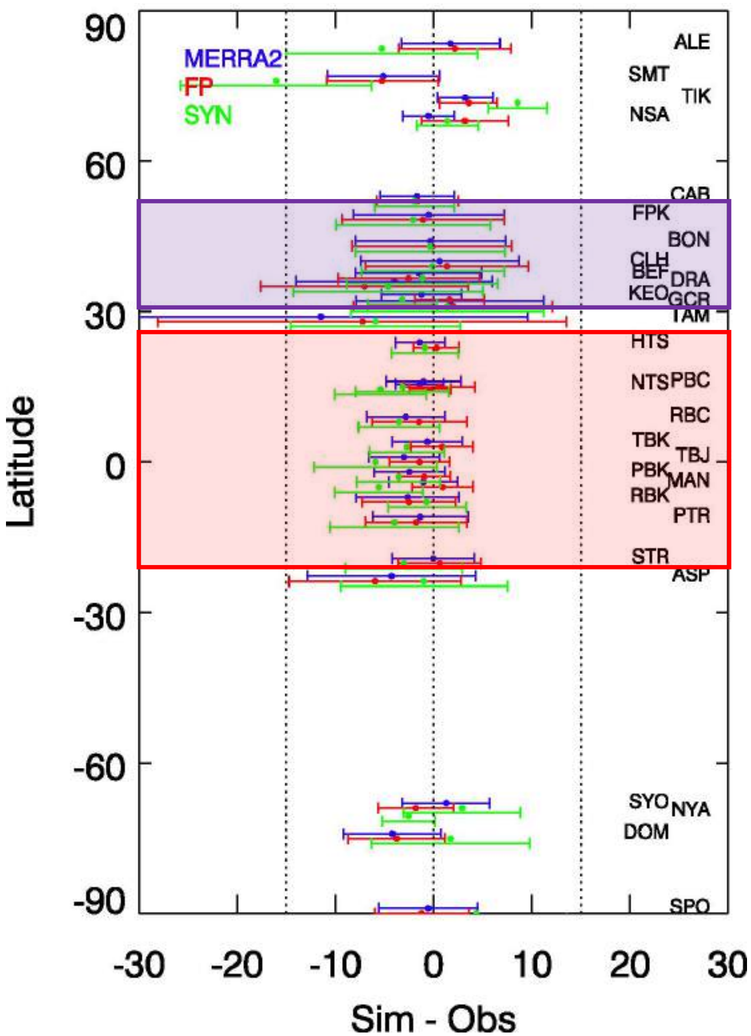
Calc vs Obs of LW SFC DN (W m^{-2}) at All Ground Sites



Site	Bias from Obs (Sim minus Obs) MERRA-2	FP v5.13	SYN Ed3A(FP v5.2)	
NSA	−8.39	−1.98	11.53	
CAB	−6.94	−8.68	2.75	
FPK	−5.43	−5.45	−0.15	US land sites
BON	−4.38	−3.67	1.08	
CLH	−4.26	−5.28	8.22	
DRA	−5.88	−7.25	4.46	
BEF	−7.08	−9.01	1.77	
GCR	−4.87	−6.77	−1.91	
TAM	−17.38	−17.54	0.40	Algeria desert site
HTS	−9.00	−10.53	−7.34	Tropical oceans
NTS	−10.31	−11.63	−7.89	
STR	−11.92	−12.69	−12.10	
ASP	−9.39	−12.27	−14.62	
SPO	−4.36	−5.37	−4.81	

- Over tropical oceans, MERRA-2, FP v5.13, FP v5.2 (SYN Ed3A) produce strong negative biases that cannot be explained by aerosol. This indicates dry/cold biases in lower troposphere. FP v5.2 (SYN) has the wettest lower troposphere humidity.
- Over US sites, FP v5.2 (SYN) produces totally different biases from those found in MERRA-2 and FP v5.13.

Calc vs Obs of LW TOA UP (W m^{-2}) at All Ground Sites



Site	Bias from Obs MERRA-2	FP v5.13	SYN(FP v5.2)
ALE	1.71	2.16	−5.27
SMT	−5.12	−5.25	−16.01
TIK	3.22	3.54	8.56
NSA	−0.52	3.19	1.41
CAB	−1.68	−1.64	−1.93
FPK	−0.49	−1.06	−2.07
BON	−0.30	−0.16	−0.35
CLH	0.61	1.37	−0.12
DRA	−4.01	−7.06	−4.62
BEF	−1.51	−2.55	−1.15
GCR	1.69	2.00	1.38
KEO	−1.21	1.63	−3.23
TAM	−11.47	−7.27	−5.92
HTS	−1.41	0.29	−0.86
PBC	−0.99	0.55	−3.17
NTS	−1.44	−0.34	−5.41
RBC	−2.85	−1.46	−3.54
TBK	−0.62	0.84	−2.74
TBJ	−3.04	−1.42	−5.92
PBK	−2.47	−0.93	−3.56
MAN	−1.01	0.91	−5.59
RBK	−2.66	−2.52	−0.69
PTR	−1.36	−1.78	−3.98
STR	−0.05	0.61	−3.02

US land sites

Generally good agreements with observation except DRA (Desert Rock).

Tropical oceans

SYN Ed3A (FP v.5.2) shows the largest negative biases (Upper troposphere has a wet bias)

Summary & Conclusions

- FP v5.13 has a drier condition than MERRA-2 over tropical oceans. In addition, FP v5.2, used for SYN Ed3A, has a wetter condition than MERRA-2.
- In comparison of LW surface downward flux, all of MERRA-2, FP v5.13, FP v.5.2 (SYN Ed3A) produce strong negative biases (up to –10 W m^{-2}), which cannot be explained by aerosol. This may indicate dry/cold biases in lower troposphere over tropical oceans.
- In comparison of LW TOA upward flux, MERRA-2 and FP v5.13 show slight negative biases (up to –2 W m^{-2}), while FP v5.2 (SYN Ed3A) produce larger negative biases (up to –5 W m^{-2}). This can occur when FP v5.2 has cold biases in skin temperature or wet biases in upper troposphere. Since FP v5.2 has even warmer skin temperatures over tropical oceans, the larger negative biases in TOA LW flux is caused by wet biases in upper troposphere.
- This study indicates that if the CERES algorithm switches into newer version of FP (v5.13) or MERRA-2, TOA LW biases for clear sky would have smaller negative biases over tropical oceans. However, surface downward LW fluxes would decrease by 1–3 W m^{-2}, causing larger negative biases.

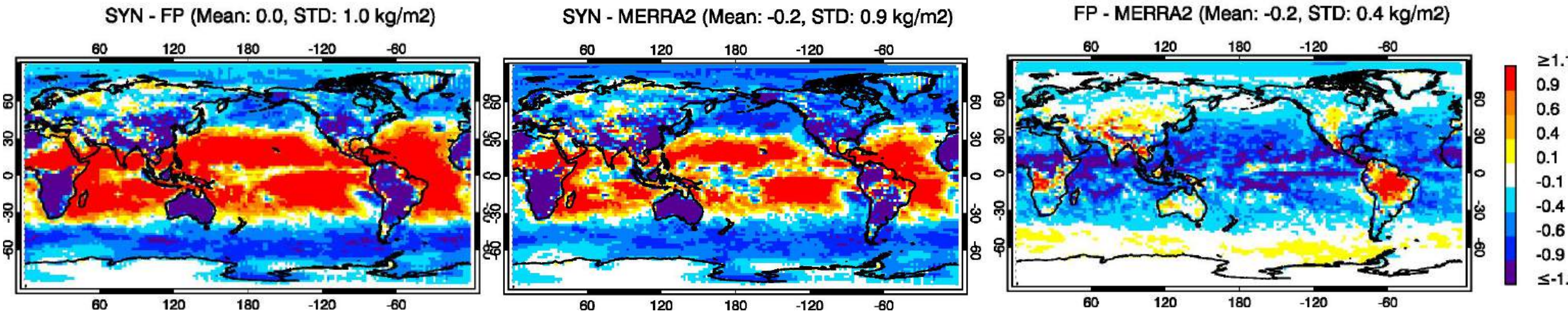
Future Works

- ❑ Need to extend period and domain to increase cloud-free sample numbers and generalize the results
- ❑ Examine clear-sky flux biases for other high-latitude regions
- ❑ Perform global simulation using MERRA-2 and FP v5.13 to compare these with CERES observations

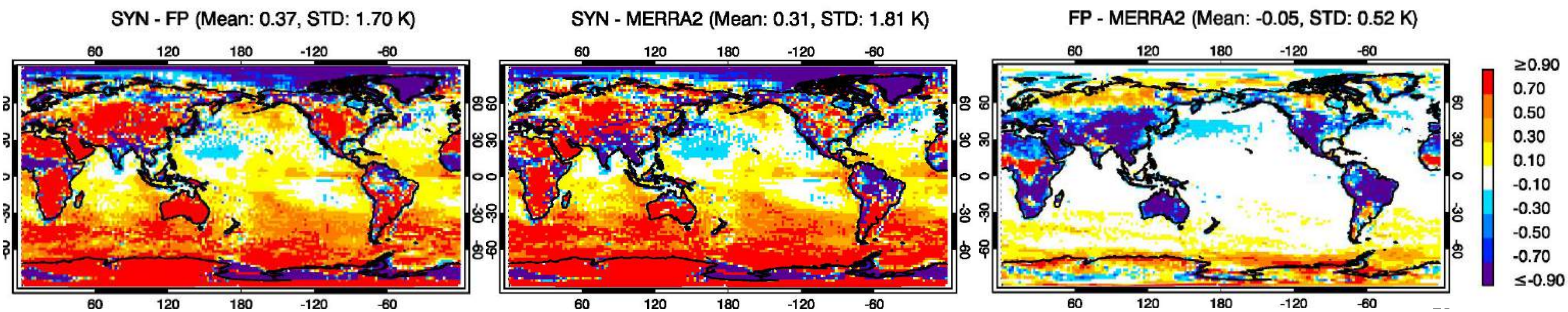
Thank You

SYN – FP SYN – MERRA2 FP – MERRA2

Total Column Water Vapor (kg m^{-2})



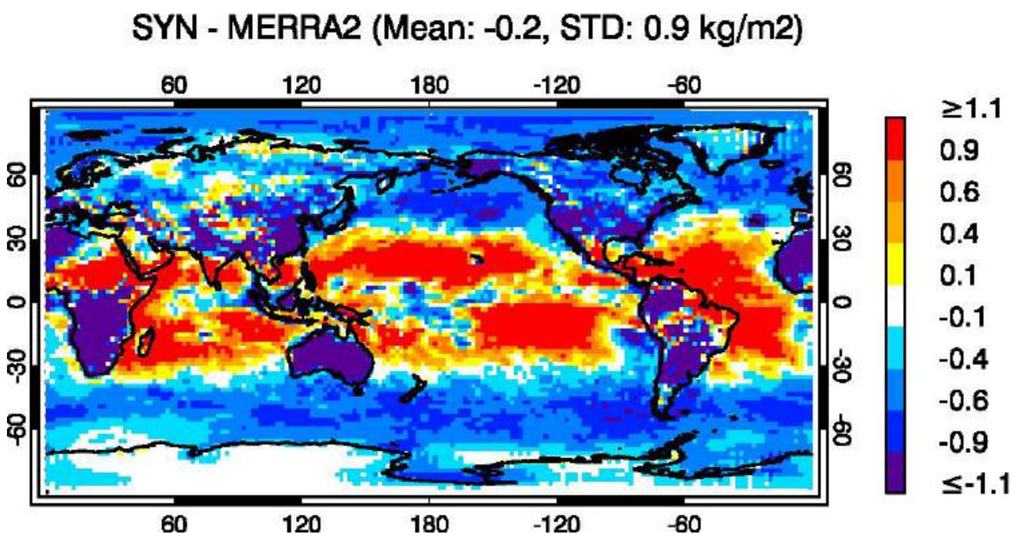
Surface Skin Temperature (K)



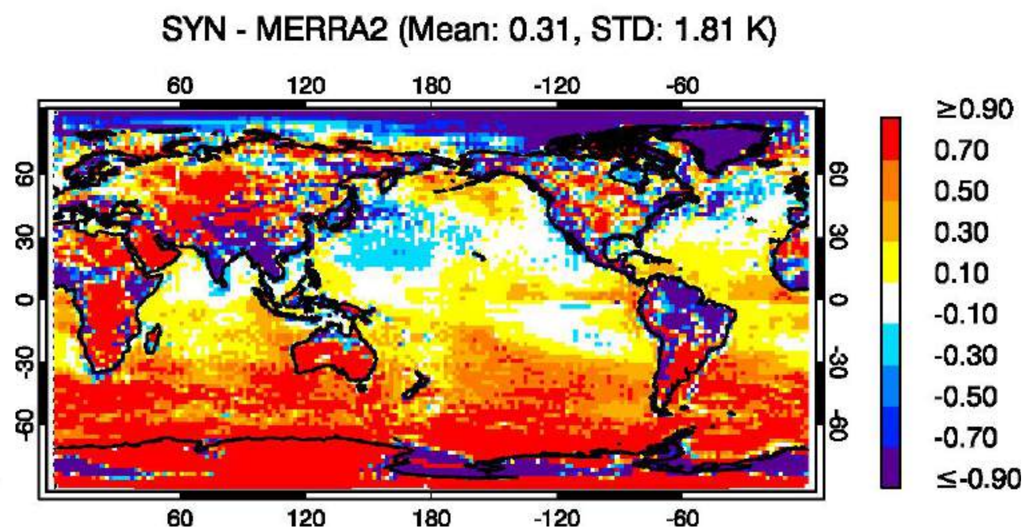
Four-Seasonal Months (Apr/Jul/Oct 2015 + Jan2016)

SYN Ed3A minus MERRA-2

Total Column Water Vapor



Skin Temperature (K)

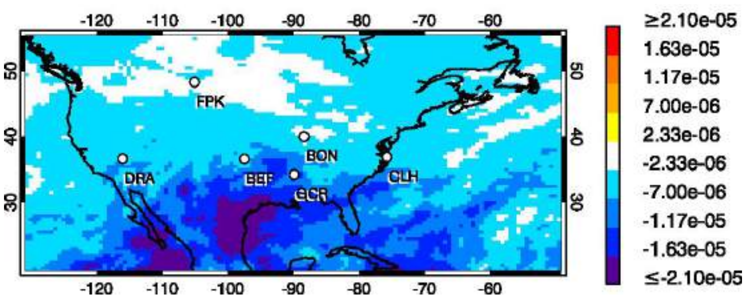


- Total Water Vapor Amount
  SYN Ed3A (FP v5.2) >> MERRA 2 > FP v5.13
  over tropical oceans

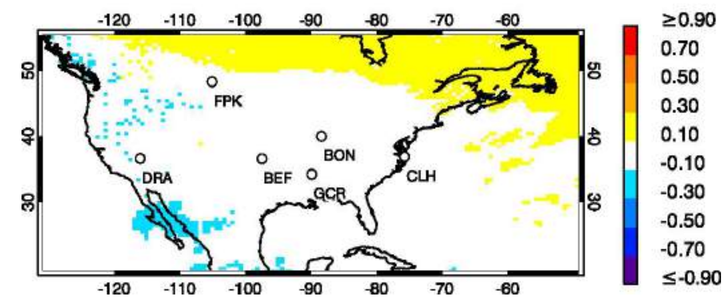
- SYN Ed3A has warmer skin temperatures over tropical oceans.

US Continent (FP v5.13 minus MERRA-2)

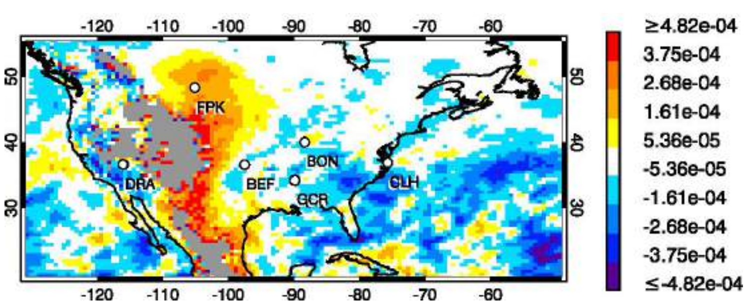
250-hPa Specific Humidity Absolute Diff



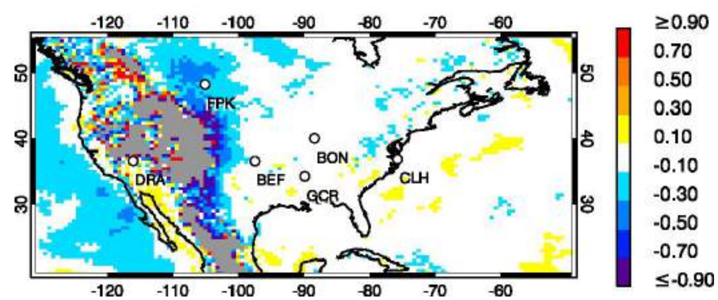
250-hPa Temperature Absolute Diff



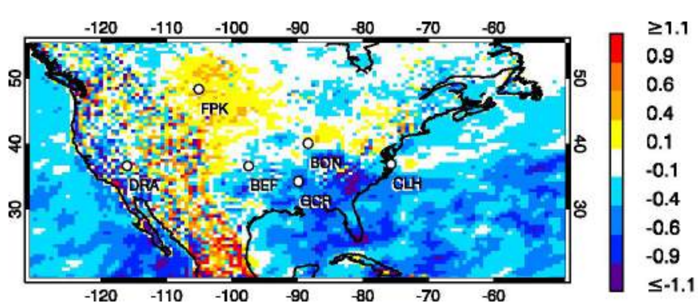
850-hPa Specific Humidity Absolute Diff



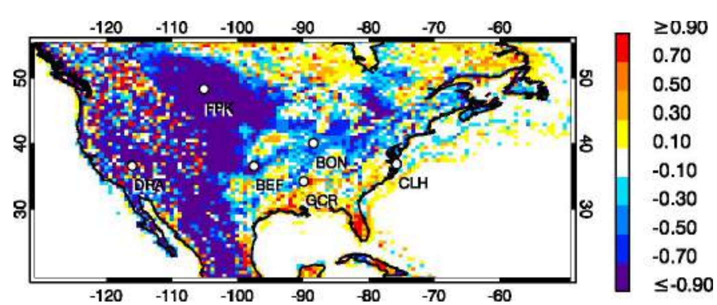
850-hPa Temperature Absolute Diff



Total Column Water Vapor Absolute Diff

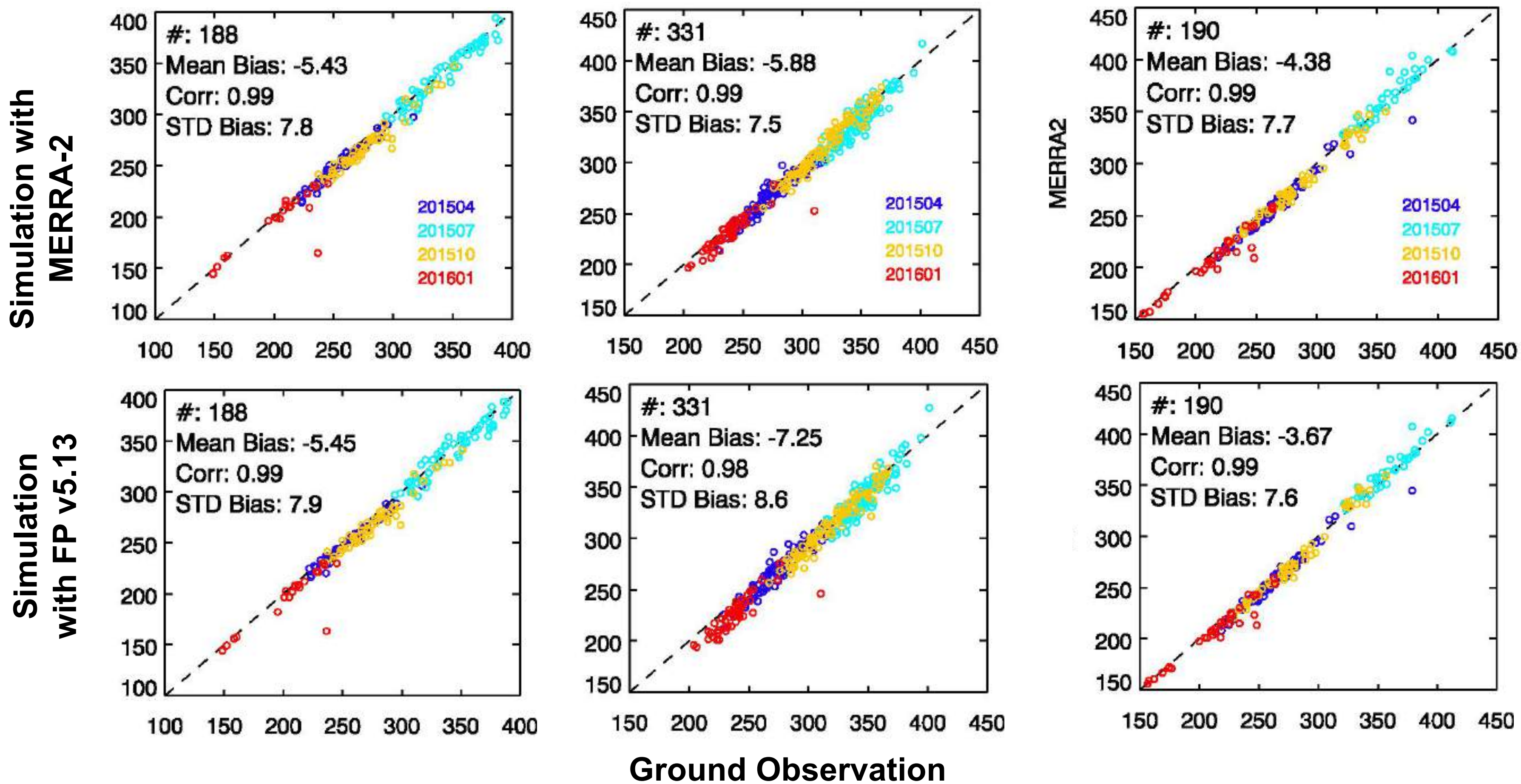


Skin Temperature Absolute Diff



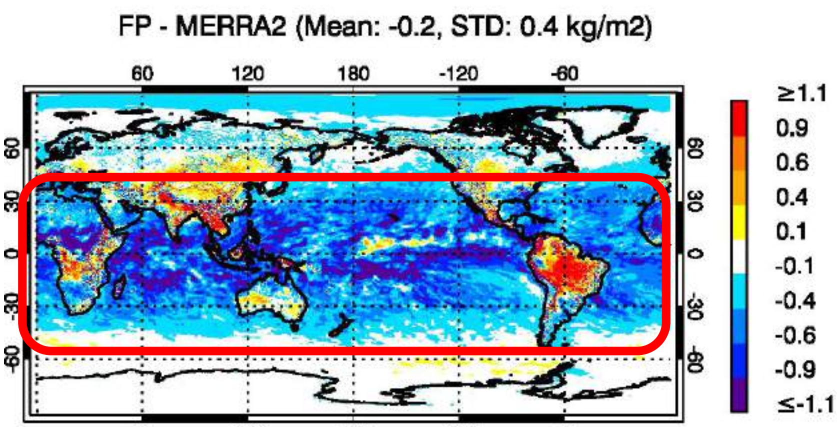
Calc versus Obs LW SFC DN (W m^{-2}) over US Land Sites

FPK Fort Feck, MT (48.3ºN) | **DRA** Desert Rock, NV (36.6ºN) | **BON** Bondville, IL (40.1ºN)

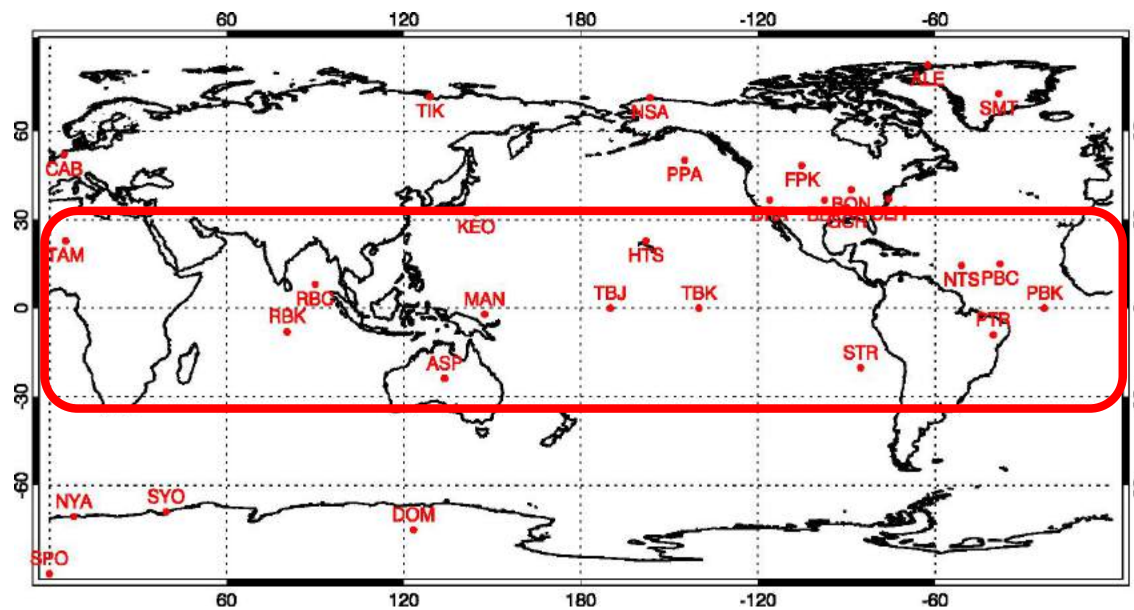


Ground sites where FP and MERRA-2 are significantly different

Absolute difference in Column WV



Location of Ground Sites



Over tropical oceans, FP v5.13 is drier than MERRA2.
Over land, FP v5.13 is generally wetter than MERRA2.

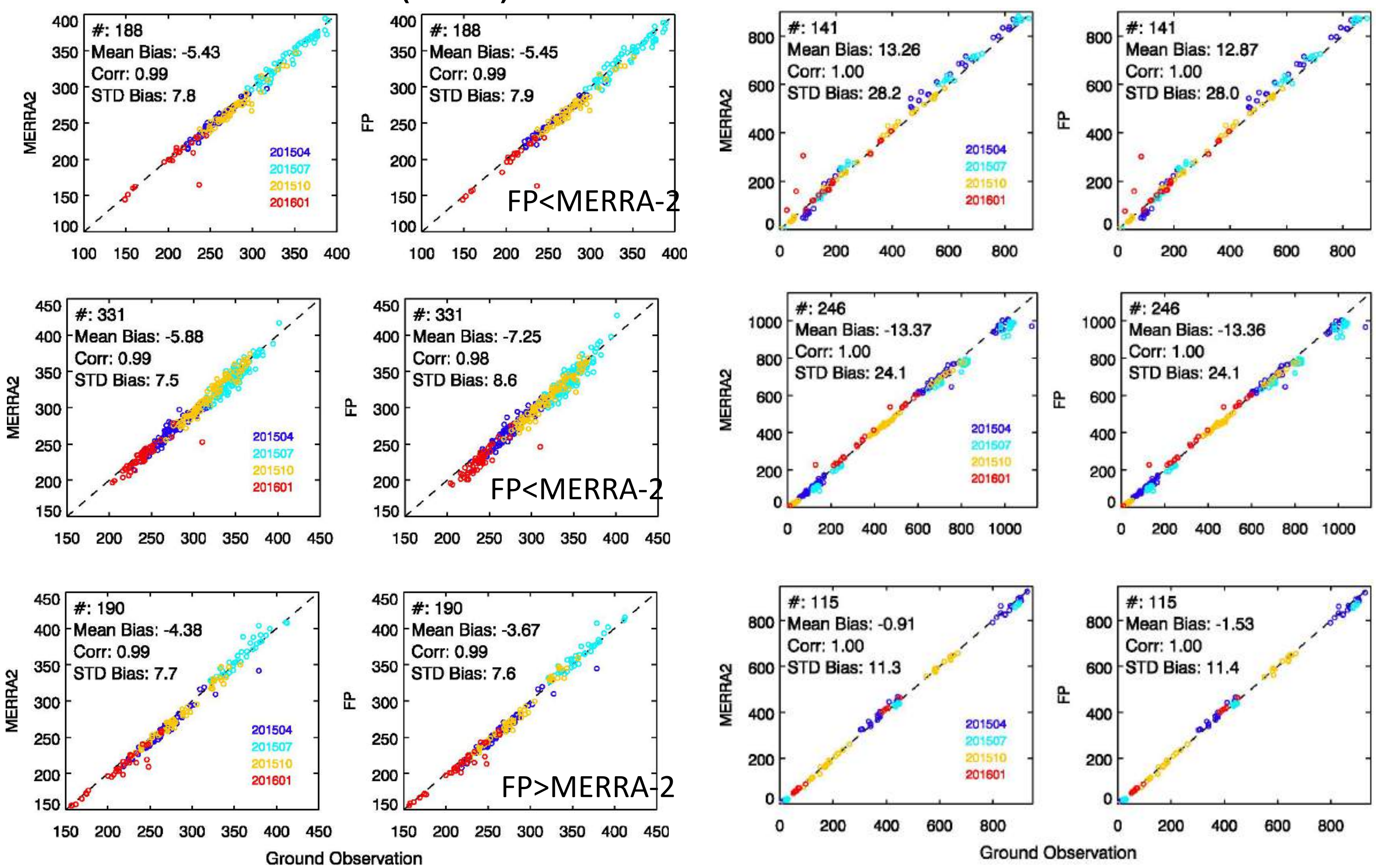
Simulation versus Observation at US Land Sites

LW SFC DN (W m^{-2}) | **SW SFC DN (W m^{-2})**

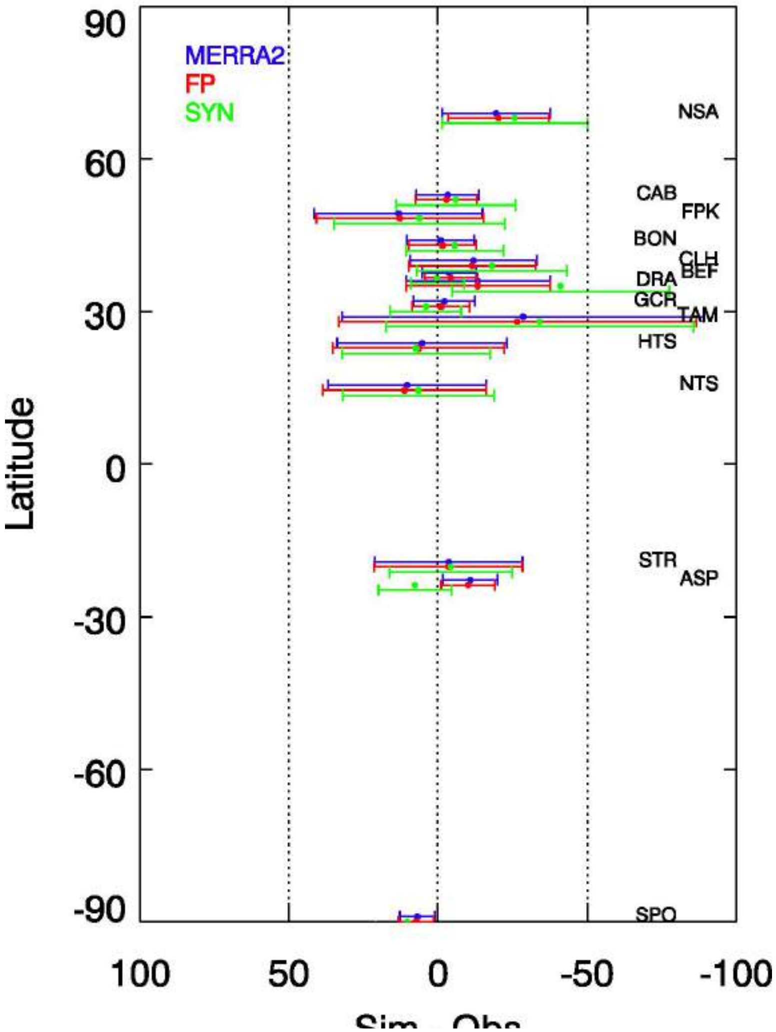
FPK

DRA

BON



Calc vs Obs of SW SFC DN (W m^{-2}) at All Ground Sites

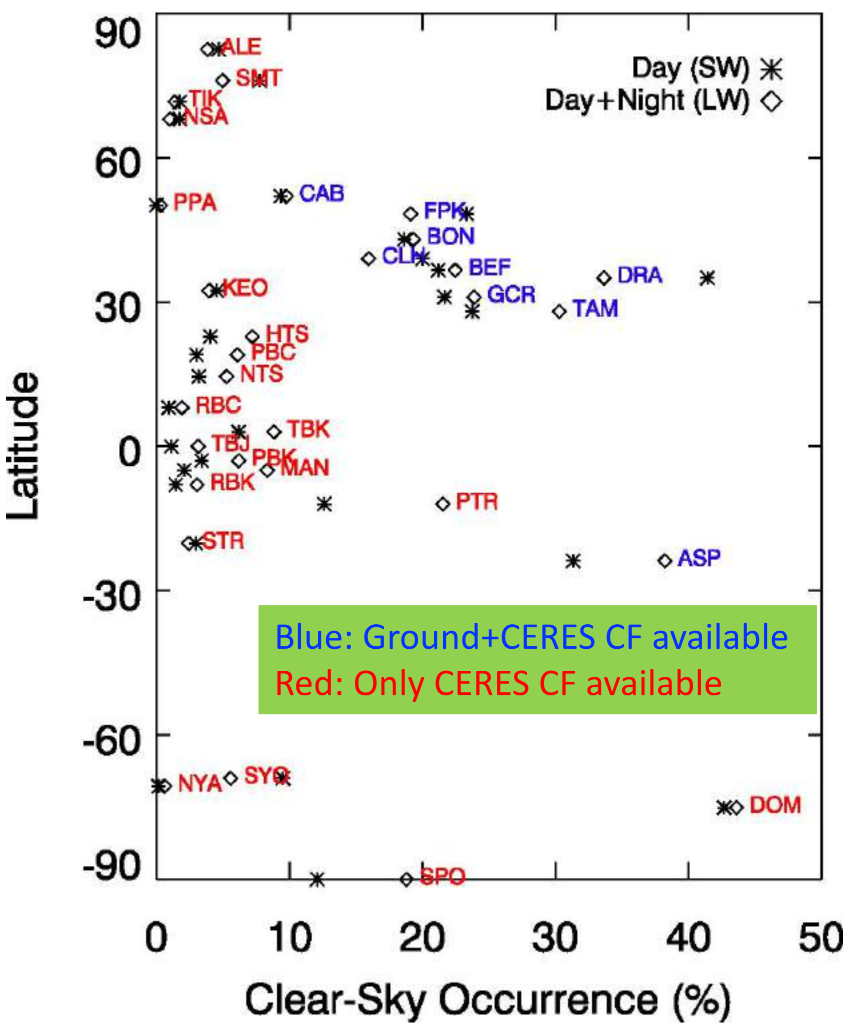


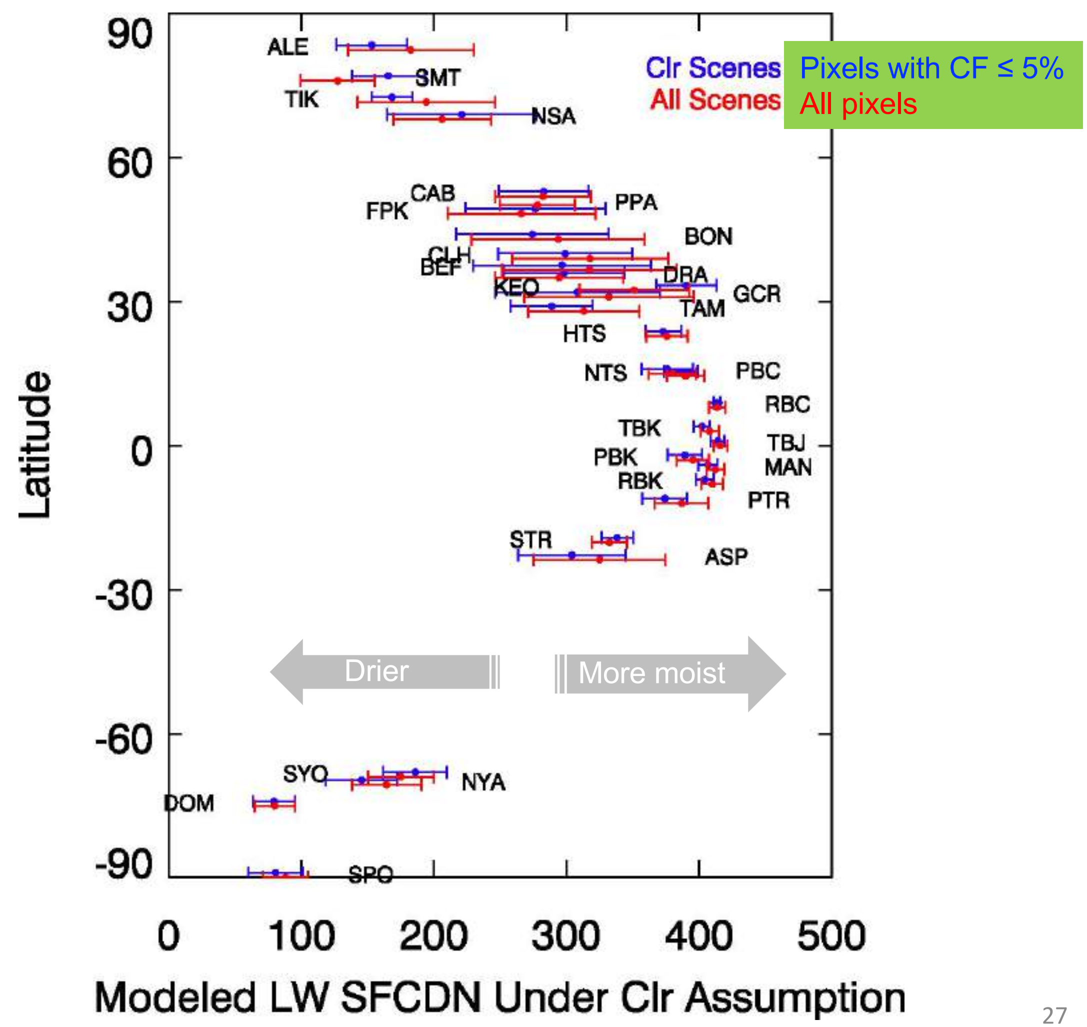
Site	Bias from Obs MERRA-2	FP v5.13	SYN(FP v5.2)
NSA	-19.43	-20.29	-25.66
CAB	-3.21	-2.75	-6.02
FPK	13.26	12.87	6.26
BON	-0.91	-1.53	-5.64
CLH	-11.86	-11.40	-18.08
DRA	-13.37	-13.36	-41.07
BEF	-3.70	-4.35	0.32
GCR	-2.09	-0.92	4.13
TAM	-28.48	-26.53	-34.08
HTS	5.39	6.56	7.39
NTS	10.38	11.31	6.59
STR	-3.53	-3.44	-4.32
ASP	-10.81	-10.02	7.74
SPO	6.92	7.42	10.43

US land sites

Tropical oceans

Clear Sky Sampling Reduces Variability of LW Fluxes?

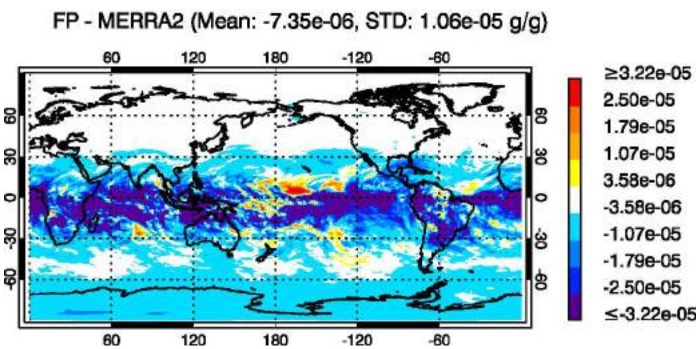


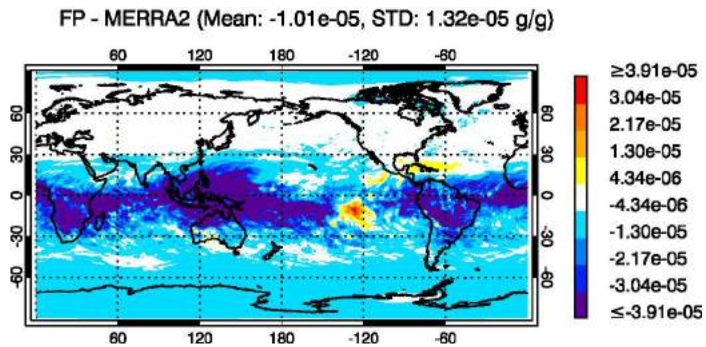


FP v5.13 minus MERRA-2 WV (2016/02)

FP v5.16 minus MERRA-2 WV (2017/02)

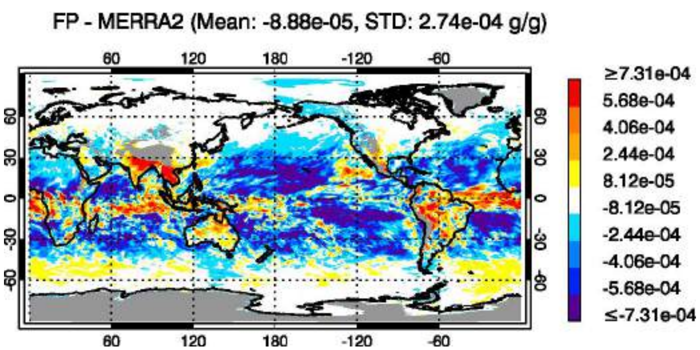
Absolute Diff 250-hPa WV

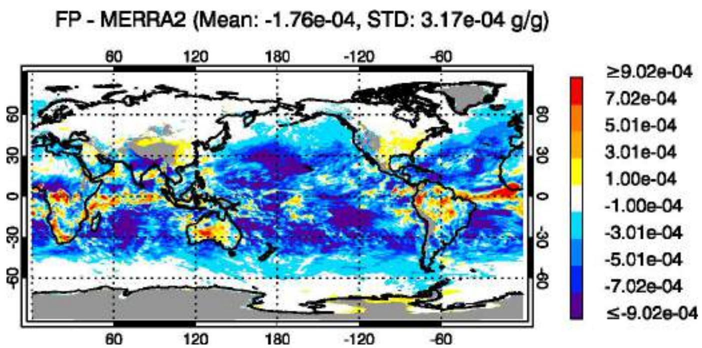




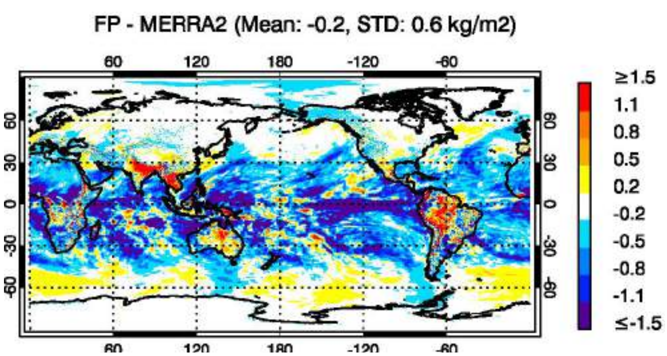
New FP gets slightly drier than old FP

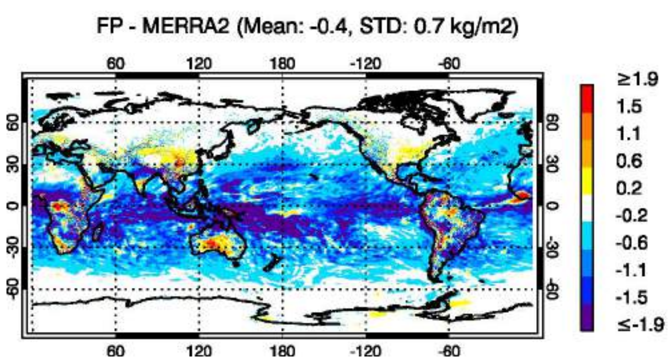
Absolute Diff 850-hPa WV



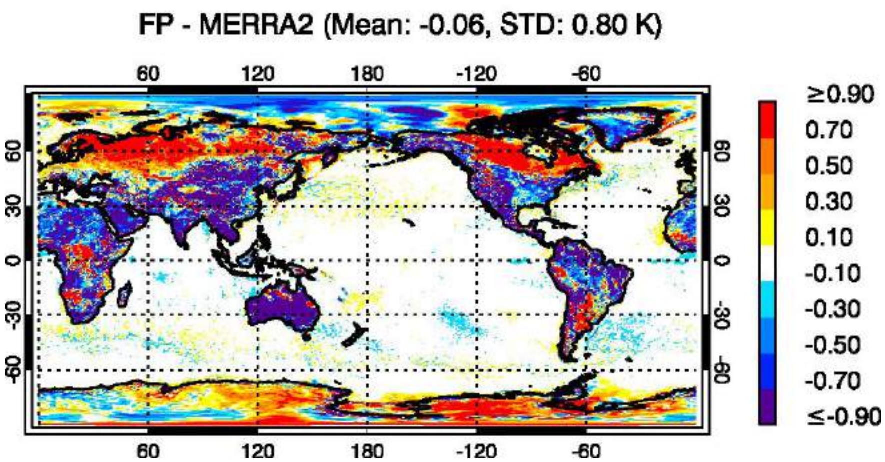


Absolute Diff Column WV

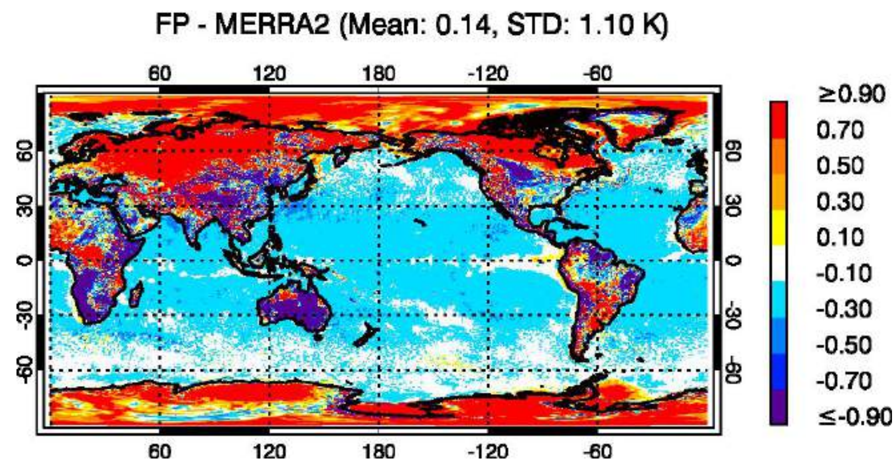




FP v5.13 minus MERRA-2 Skin Temp (2016/02)



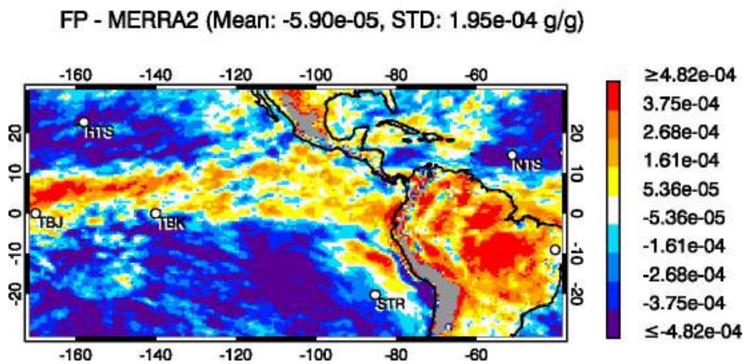
FP v5.16 minus MERRA-2 Skin Temp (2017/02)



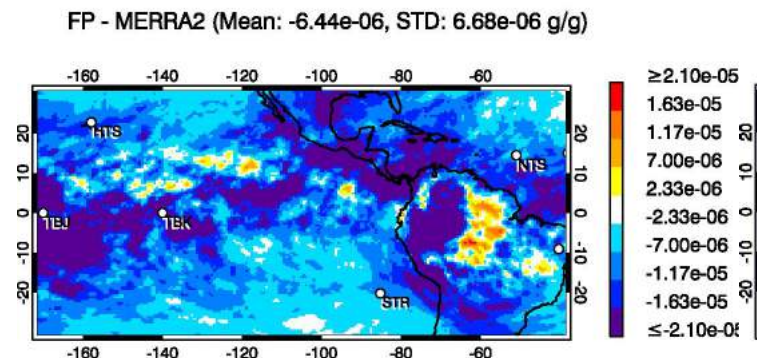
New FP skin temp gets much warmer in polar regions.

Tropical Oceans

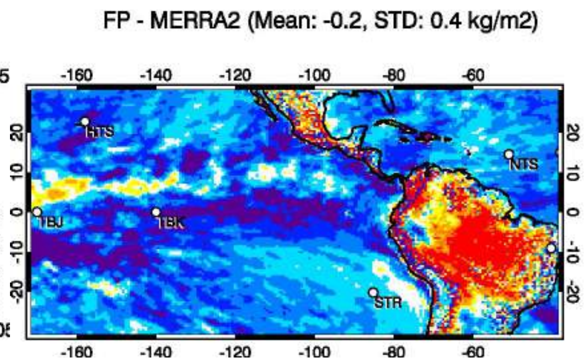
850-hPa Specific Humidity Absolute Diff



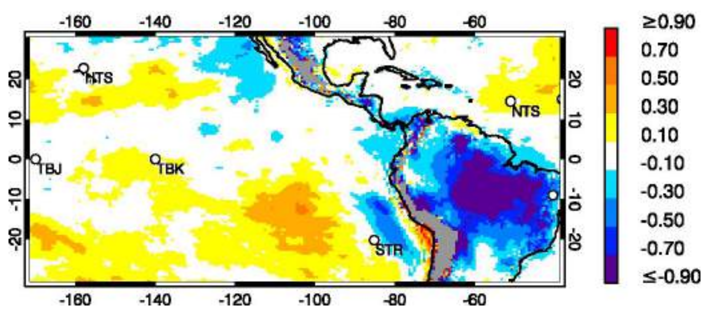
250-hPa Specific Humidity Absolute Diff



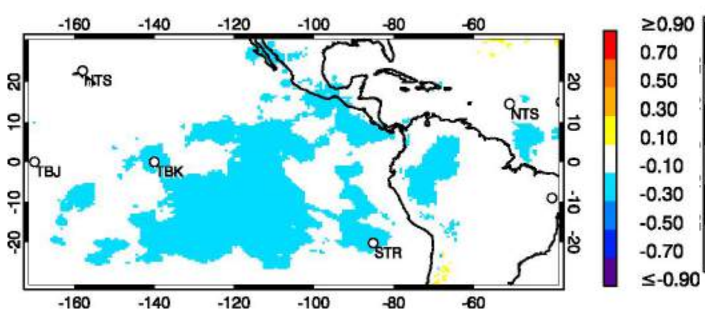
Total Column Water Vapor Absolut



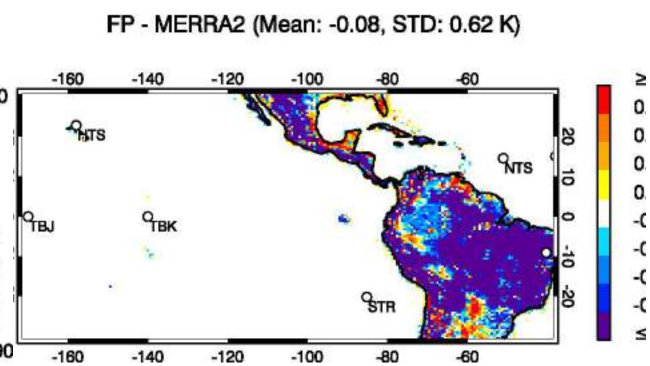
850-hPa Temperature Absolute Diff



250-hPa Temperature Absolute Diff

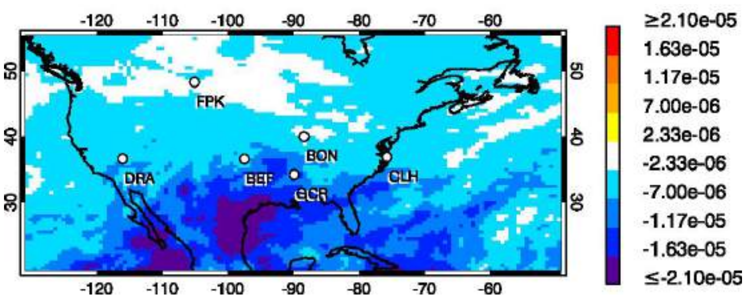


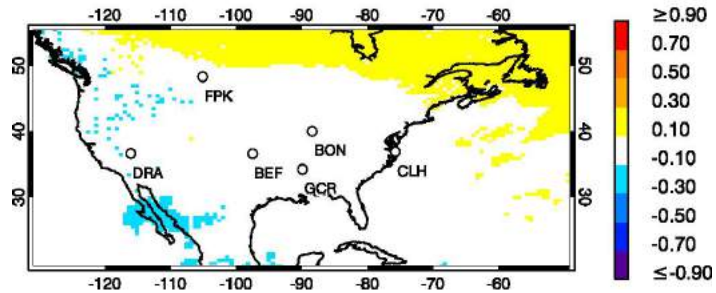
Skin Temperature Absolute Diff



US Continent (FP minus MERRA-2)

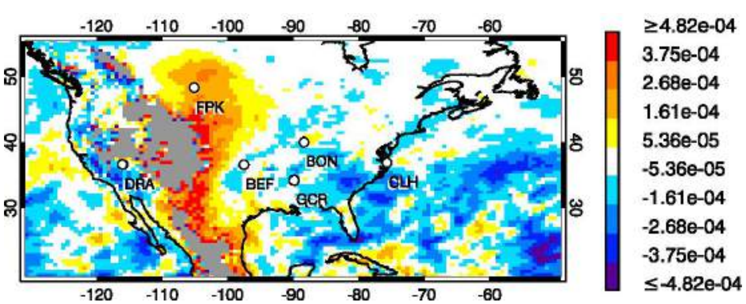
250-hPa Specific Humidity Absolute Diff

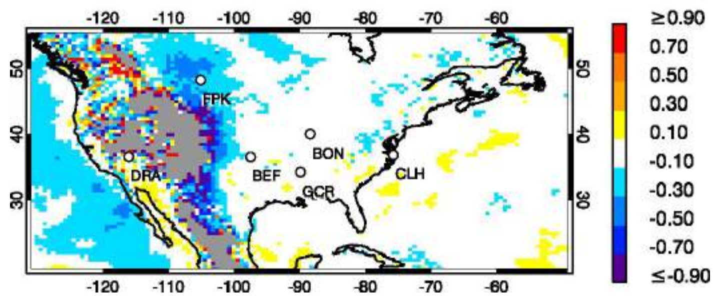




250-hPa Temperature Absolute Diff

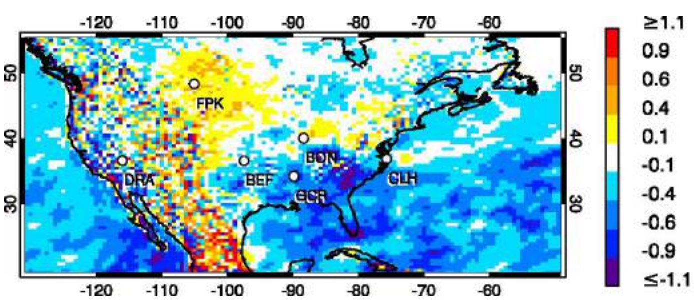
850-hPa Specific Humidity Absolute Diff

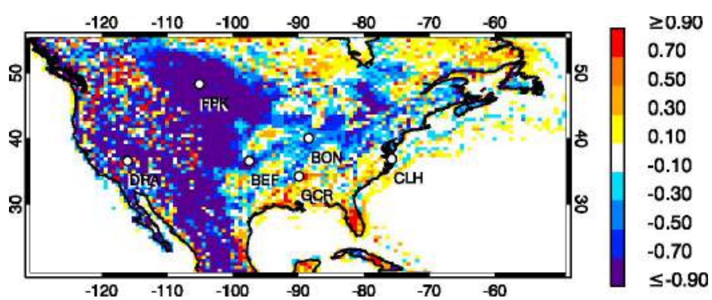




850-hPa Temperature Absolute Diff

Total Column Water Vapor Absolute Diff

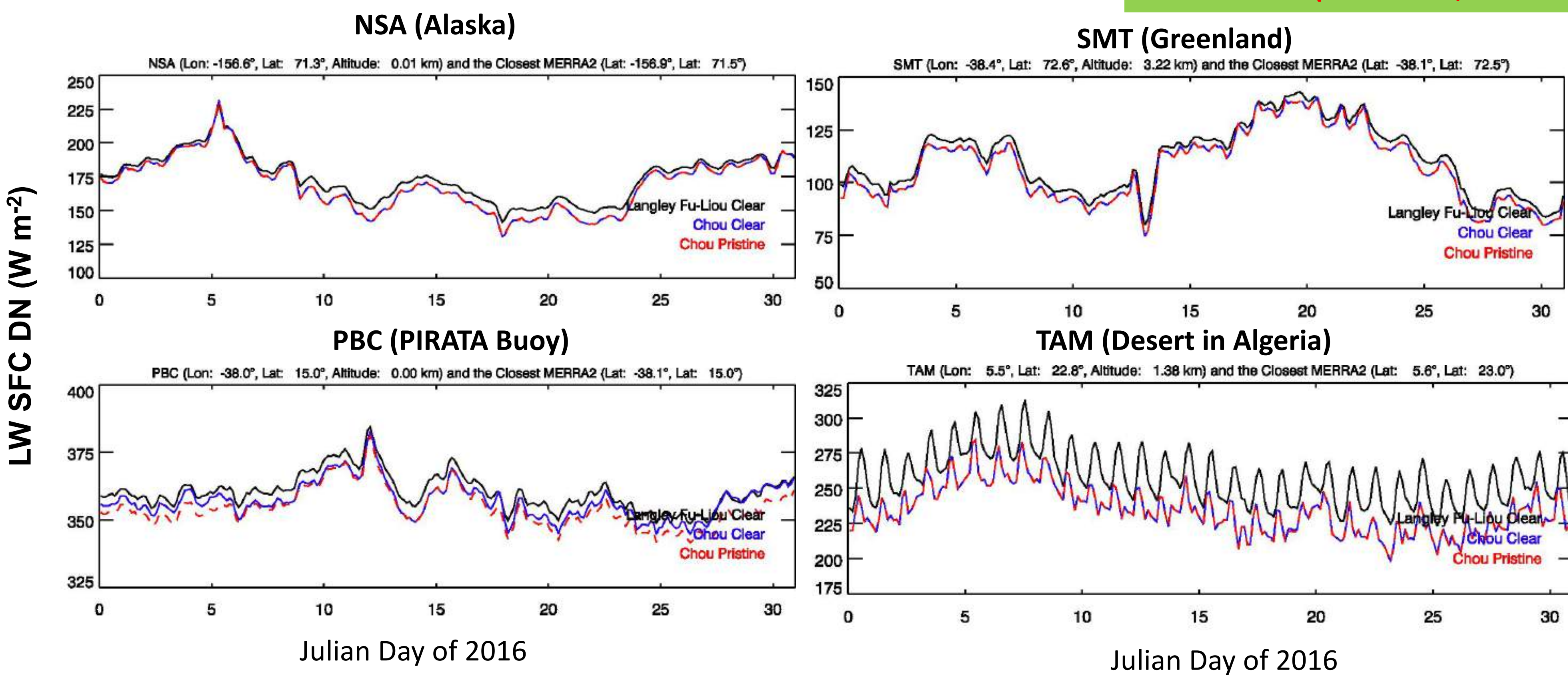




Skin Temperature Absolute Diff

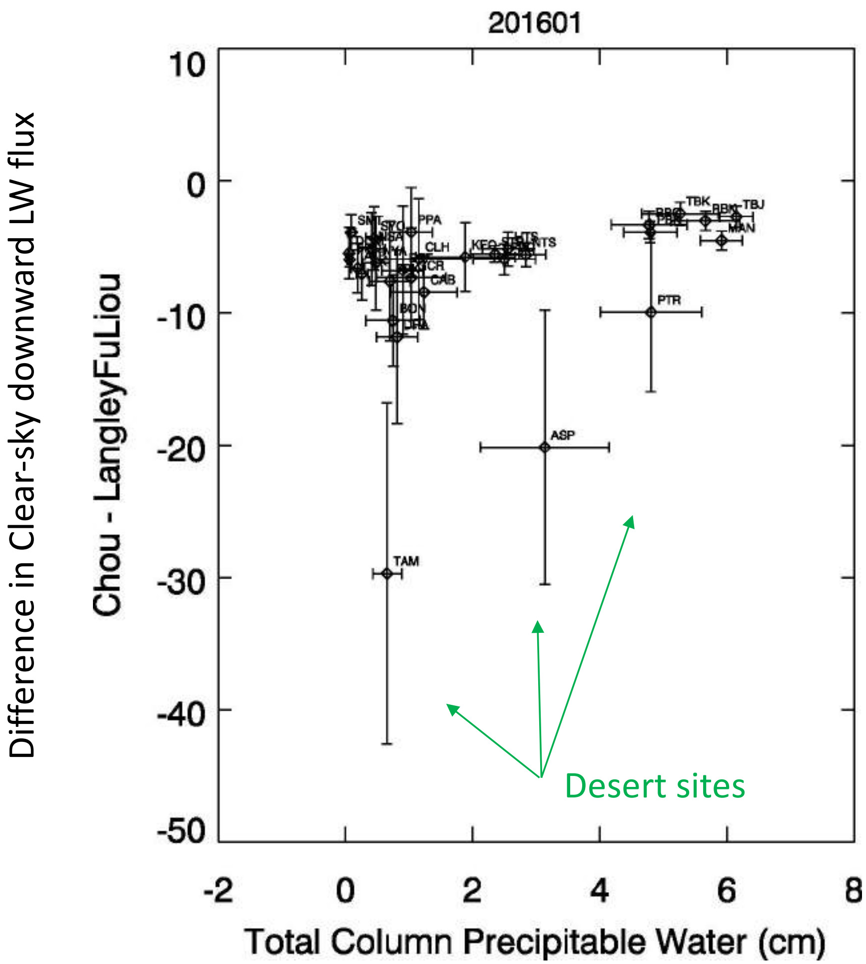
Langley Fu-Liou versus Chou Models?

Langley Fu-Liou Clear (no cloud)
Chou Clear (no cloud)
Chou Pristine (no aerosol, no cloud)



When the same MERRA2 profiles are used, Langley Fu-Liou produces larger LW surface down fluxes than GMAO Chou Model ("Chou model is more transmissive than Langley Fu-Liou model", Fred G Rose in spring CERES Meeting 2015)

Langley Fu-Liou versus Chou Models



- For all sites, Chou model produces smaller LW surface downward flux than Langley Fu-Liou model.
- Desert sites shows larger differences with larger standard deviations but it seems likely to relate to a strong diurnal variation.
- For all sites, mean difference in LW surface downward flux is –7 W m^{-2}.