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

Seung-Hee Ham¹, Norman Loeb², Seiji Kato², Fred G. Rose¹, Michael G. Bosilovich³, and David Rutan¹

¹Science Systems and Applications Inc., Hampton, VA, United States
²NASA Langley Research Center, Hampton, VA, United States
³Goddard Space Flight Center, Greenbelt, MD, United States
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.
  2) **FP v5.13** is a publically available new version of FP dataset for year 2015-2016
  3) **FP v5.2** is used for SYN Ed3A processing
FP v5.13 minus MERRA-2 WV for Year 2015/2016

Total Column WV (kg/m²)
FP - MERRA2 (Mean: -0.2, STD: 0.4 kg/m²)

500-hPa WV
FP - MERRA2 (Mean: -4.16e-05, STD: 8.02e-05 g/g)

250-hPa WV (g/g)
FP - MERRA2 (Mean: -6.44e-06, STD: 6.68e-06 g/g)

850-hPa WV (g/g)
FP - MERRA2 (Mean: -5.90e-05, STD: 1.95e-04 g/g)

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

FP drier over ocean and wetter over land
FP drier over tropical ocean
Four-Seasonal Months (Apr/Jul/Oct 2015 + Jan2016):

\[
\text{(FP minus MERRA-2)/ MERRA-2 x 100%}
\]

Total Column WV

850-hPa WV

500-hPa WV

250-hPa WV

1-3% drier FP over ocean

5-7% drier FP

\sim 5 \% drier FP

>7% drier FP
Colder skin temp in FP over land (Also 2-m Temp)

FP minus MERRA-2 Temp (K)

Four-Seasonal Months (Apr/Jul/Oct 2015 + Jan2016)
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 Corporation)
[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 $\tau_a$) minus Flux (with $\tau_a=0.001$)

- < 2 Wm$^{-2}$ diff except TAM (desert) site
- < 1 Wm$^{-2}$ diff except TAM site
- 0-20 Wm$^{-2}$ diff

Latitude

[Match $\tau_a$] minus [$\tau_a=0.001$]

Ocean Land

Desert site

LW SFCDN

LW TOAUP

SW SFCDN
Impacts of Surface Emissivity:
Flux (with $\varepsilon_s=1$) minus Flux (with XHuang $\varepsilon_s$)

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

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

<table>
<thead>
<tr>
<th>Site Name</th>
<th>SW SFC DN</th>
<th>SW SFC UP</th>
<th>LW SFC DN</th>
<th>LW SFC UP</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBC</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>RBK</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>MAN</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>TBJ</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>HTS</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td>TBK</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NTS</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td>PBC</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PTR</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>STR</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>PBK</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
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\(^{-2}\)
Simulation with MERRA-2: $-1.43 \text{ Wm}^{-2}$

Simulation with FP v5.13: $-0.52 \text{ Wm}^{-2}$

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

**HTS**
Hawaii Time Series Buoy

**NTS**
North Atlantic Buoy

**STR**
Stratus Buoy

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

- 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

Calc - Obs (Mean: -2.04, STD: 4.99 W m\(^{-2}\))

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

SYN - MERRA2 (Mean: -0.2, STD: 0.9 kg/m\(^2\))

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 |
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 |
HTS | -9.00 | -10.53 | -7.34 |
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

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

**Notes:**
- Generally good agreements with observation except DRA (Desert Rock).
- US land sites, Tropical oceans
- SYN Ed3A (FP v5.2) 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
### Total Column Water Vapor (kg m$^{-2}$)

- **SYN – FP** (Mean: 0.0, STD: 1.0 kg/m$^2$)
- **SYN – MERRA2** (Mean: -0.2, STD: 0.9 kg/m$^2$)
- **FP – MERRA2** (Mean: -0.2, STD: 0.4 kg/m$^2$)

### Surface Skin Temperature (K)

- **SYN – FP** (Mean: 0.37, STD: 1.70 K)
- **SYN – MERRA2** (Mean: 0.31, STD: 1.81 K)
- **FP – MERRA2** (Mean: -0.05, STD: 0.52 K)
SYN Ed3A minus MERRA-2

- 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.

Four-Seasonal Months (Apr/Jul/Oct 2015 + Jan2016)
US Continent (FP v5.13 minus MERRA-2)

- **250-hPa Specific Humidity Absolute Diff**
- **850-hPa Specific Humidity Absolute Diff**
- **Total Column Water Vapor Absolute Diff**
- **250-hPa Temperature Absolute Diff**
- **850-hPa Temperature Absolute Diff**
- **Skin Temperature Absolute Diff**
Calc versus Obs LW SFC DN (W m\(^{-2}\)) over US Land Sites

FPK Fort Feck, MT (48.3°N)
- Simulation with MERRA-2
  - #: 188
  - Mean Bias: -5.43
  - Corr: 0.99
  - STD Bias: 7.8

- Simulation with FP v5.13
  - #: 188
  - Mean Bias: -5.45
  - Corr: 0.99
  - STD Bias: 7.9

DRA Desert Rock, NV (36.6°N)
- #: 331
  - Mean Bias: -5.88
  - Corr: 0.99
  - STD Bias: 7.5

- #: 331
  - Mean Bias: -7.25
  - Corr: 0.98
  - STD Bias: 8.6

BON Bondville, IL (40.1°N)
- #: 190
  - Mean Bias: -4.38
  - Corr: 0.99
  - STD Bias: 7.7

- #: 190
  - Mean Bias: -3.67
  - Corr: 0.99
  - STD Bias: 7.6
Ground sites where FP and MERRA-2 are significantly different

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

FPK

DRA

BON

FP>MERRA-2

FP<MERRA-2

FP>MERRA-2

FP>MERRA-2

FP>MERRA-2
Calc vs Obs of SW SFC DN (W m⁻²) at All Ground Sites

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

US land sites

Tropical oceans
Clear Sky Sampling Reduces Variability of LW Fluxes?

Blue: Ground+CERES CF available
Red: Only CERES CF available

Pixels with CF ≤ 5%
All pixels

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

Absolute Diff
250-hPa WV

Resolution change motivated by improved water vapor data.

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

Absolute Diff
850-hPa WV

New FP gets slightly drier than old FP

Absolute Diff
Column WV
New FP skin temp gets much warmer in polar regions.
Tropical Oceans

850-hPa Specific Humidity Absolute Diff

FP - MERRA2 (Mean: -5.90e-05, STD: 1.95e-04 g/g)

250-hPa Specific Humidity Absolute Diff

FP - MERRA2 (Mean: -6.44e-06, STD: 6.68e-06 g/g)

Total Column Water Vapor Absolute Diff

FP - MERRA2 (Mean: -0.2, STD: 0.4 kg/m2)

850-hPa Temperature Absolute Diff

250-hPa Temperature Absolute Diff

Skin Temperature Absolute Diff

FP - MERRA2 (Mean: -0.08, STD: 0.62 K)
US Continent (FP minus MERRA-2)

- 250-hPa Specific Humidity Absolute Diff
- 850-hPa Specific Humidity Absolute Diff
- Total Column Water Vapor Absolute Diff
- Skin Temperature Absolute Diff
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)
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 $-7 \text{ W m}^{-2}$. 