CERES Cloud Radiative Swath (CRS) Validation & Improvements to FLASHFlux via Machine Learning

Ryan Scott, Fred Rose, David Rutan

Science Systems & Applications, Inc.

Paul Stackhouse, Seiji Kato, David Doelling, Norman Loeb

NASA Langley Research Center
CERES CRS

• CERES observes TOA radiation – but to understand climate we also need surface & atmospheric fluxes
  • The current L2 Single Scanner Footprint (SSF) product estimates surface fluxes w/ simple parameterizations (Model B)

• The Cloud Radiative Swath (CRS) product – reintroduced at last STM – builds upon the SSF by calculating instantaneous instrument footprint-level irradiances using the NASA LaRC Fu-Liou radiative transfer model
  • SW↓↑ & LW↓↑ broadband flux profiles + Surface narrowband SW & LW, direct + diffuse SW↓, PAR, UV fluxes
  • How does CRS compare to Surface-Only Flux Algorithms (SOFA) Model B & other CERES flux products?
CERES CRS

• CERES observes TOA radiation – but to understand climate we also need surface & atmospheric fluxes
  • The current L2 Single Scanner Footprint (SSF) product estimates surface fluxes w/ simple parameterizations (Model B)

• The Cloud Radiative Swath (CRS) product – reintroduced at last STM – builds upon the SSF by calculating instantaneous instrument footprint-level irradiances using the NASA LaRC Fu-Liou radiative transfer model
  • SW\(\downarrow\uparrow\) & LW\(\downarrow\uparrow\) broadband flux profiles + Surface narrowband SW & LW, direct + diffuse SW\(\downarrow\), PAR, UV fluxes
  • How does CRS compare to Surface-Only Flux Algorithms (SOFA) Model B & other CERES flux products?

• Here we update & extend our analysis from the last STM to cover an entire year (2019):
  CERES CRS vs (1) CERES TOA observations, (2) SSF Model B surface fluxes, (3) SYN1deg surface fluxes

<table>
<thead>
<tr>
<th></th>
<th>CERES CRS</th>
<th>CERES SSF Ed4A</th>
<th>FLASHFlux SSF v4A</th>
<th>CERES SYN1deg-Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2 / L3</td>
<td>Instantaneous footprint</td>
<td>Instantaneous footprint</td>
<td>Instantaneous footprint</td>
<td>TISA gridded, hourly (L3)</td>
</tr>
<tr>
<td>Surface</td>
<td>Fu-Liou RT model</td>
<td>Model B parameterization</td>
<td>Model B parameterization</td>
<td>Fu-Liou RT model</td>
</tr>
<tr>
<td>TOA</td>
<td>Fu-Liou RT model</td>
<td>Observations</td>
<td>Observations</td>
<td>Fu-Liou &amp; Observations</td>
</tr>
</tbody>
</table>
CERES CRS

- CERES observes TOA radiation – but to understand climate we also need surface & atmospheric fluxes
  - The current L2 Single Scanner Footprint (SSF) product estimates surface fluxes w/ simple parameterizations (Model B)

- The Cloud Radiative Swath (CRS) product – reintroduced at last STM – builds upon the SSF by calculating instantaneous instrument footprint-level irradiances using the NASA LaRC Fu-Liou radiative transfer model
  - SW↓↑ & LW↓↑ broadband flux profiles + Surface narrowband SW & LW, direct + diffuse SW↓, PAR, UV fluxes
  - How does CRS compare to Surface-Only Flux Algorithms (SOFA) Model B & other CERES flux products?

- Here we update & extend our analysis from the last STM to cover an entire year (2019):
  - CRS vs (1) CERES TOA observations, (2) SSF Model B surface fluxes, (3) SYN1deg surface fluxes

<table>
<thead>
<tr>
<th></th>
<th>CERES CRS</th>
<th>CERES SSF Ed4A</th>
<th>FLASHFlux SSF v4A</th>
<th>CERES SYN1deg-Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2 / L3</td>
<td>Instantaneous footprint</td>
<td>Instantaneous footprint</td>
<td>Instantaneous footprint</td>
<td>TISA gridded, hourly (L3)</td>
</tr>
<tr>
<td>Surface</td>
<td>Fu-Liou RT model</td>
<td>Model B parameterization</td>
<td>Model B parameterization</td>
<td>Fu-Liou RT model</td>
</tr>
<tr>
<td>TOA</td>
<td>Fu-Liou RT model</td>
<td>Observations</td>
<td>Observations</td>
<td>Fu-Liou &amp; Observations</td>
</tr>
</tbody>
</table>

Spring 2021 CERES / Libera Science Team Meeting
ryan.c.scott@nasa.gov
CERES CRS

• CERES observes TOA radiation – but to understand climate we also need surface & atmospheric fluxes
  • The current L2 Single Scanner Footprint (SSF) product estimates surface fluxes w/ simple parameterizations (Model B)

• The Cloud Radiative Swath (CRS) product – reintroduced at last STM – builds upon the SSF by calculating instantaneous instrument footprint-level irradiances using the NASA LaRC Fu-Liou radiative transfer model
  • SW↓↑ & LW↓↑ broadband flux profiles + Surface narrowband SW & LW, direct + diffuse SW↓, PAR, UV fluxes
  • How does CRS compare to Surface-Only Flux Algorithms (SOFA) Model B & other CERES flux products?

• Here we update & extend our analysis from the last STM to cover an entire year (2019):

  CRS vs (1) CERES TOA observations, (2) SSF Model B surface fluxes, (3) SYN1deg surface fluxes

<table>
<thead>
<tr>
<th></th>
<th>CERES CRS</th>
<th>CERES SSF Ed4A</th>
<th>FLASHFlux SSF v4A</th>
<th>CERES SYN1deg-Hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2 / L3</td>
<td>Instantaneous footprint</td>
<td>Instantaneous footprint</td>
<td>Instantaneous footprint</td>
<td>TISA gridded, hourly (L3)</td>
</tr>
<tr>
<td>Surface</td>
<td>Fu-Liou RT model</td>
<td>Model B parameterization</td>
<td>Model B parameterization</td>
<td>Fu-Liou RT model</td>
</tr>
<tr>
<td>TOA</td>
<td>Fu-Liou RT model</td>
<td>Observations</td>
<td>Observations</td>
<td>Fu-Liou &amp; Observations</td>
</tr>
</tbody>
</table>
**CERES CRS**

- CERES observes TOA radiation – but to understand climate we also need surface & atmospheric fluxes
  - The current L2 Single Scanner Footprint (SSF) product estimates surface fluxes w/ simple parameterizations (Model B)

- The Cloud Radiative Swath (CRS) product – reintroduced at last STM – builds upon the SSF by calculating instantaneous instrument footprint-level irradiances using the NASA LaRC Fu-Liou radiative transfer model
  - SW↓↑ & LW↓↑ broadband flux profiles + Surface narrowband SW & LW, direct + diffuse SW↓, PAR, UV fluxes
  - How does CRS compare to Surface-Only Flux Algorithms (SOFA) Model B & other CERES flux products?

- Here we update & extend our analysis from the last STM to cover an entire year (2019):
  - CRS vs (1) CERES TOA observations, (2) SSF Model B surface fluxes, (3) SYN1deg surface fluxes

<table>
<thead>
<tr>
<th></th>
<th><strong>CERES CRS</strong></th>
<th><strong>CERES SSF Ed4A</strong></th>
<th><strong>FLASHFlux SSF v4A</strong></th>
<th><strong>CERES SYN1deg-Hr</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L2 / L3</strong></td>
<td>Instantaneous footprint</td>
<td>Instantaneous footprint</td>
<td>Instantaneous footprint</td>
<td>TISA gridded, hourly (L3)</td>
</tr>
<tr>
<td><strong>Surface</strong></td>
<td>Fu-Liou RT model</td>
<td>Model B parameterization</td>
<td>Model B parameterization</td>
<td>Fu-Liou RT model</td>
</tr>
<tr>
<td><strong>TOA</strong></td>
<td>Fu-Liou RT model</td>
<td>Observations</td>
<td>Observations</td>
<td>Fu-Liou &amp; Observations</td>
</tr>
</tbody>
</table>

- Can we use CRS to improve FLASHFlux low-latency surface fluxes for the applied science community?
  - (4) Preliminary development & evaluation of Machine Learning models to provide rapid & accurate surface radiative fluxes
CERES CRS

Inputs

CERES SSF Ed4A
geolocated FOVs, etc.

GEOS 5.4.1
\( T(z), p(z), q(z), O_3(z) \)
surface wind speed

MODIS
cloud properties (Ed4)
AOD (sometimes)
spectral albedo
land temp (clear)

MATCH hourly
aerosol profiles & AOD

IGBP surface type
albedo history
map (cloudy)

Outputs

instantaneous vertical profiles (6 levels) of
broadband flux &
spectrally-resolved fluxes
at the surface and TOA

LW : 12 bands
SW : 14 bands

(sw, all-sky)
SW\( \downarrow \) direct + diffuse
PAR, UV fluxes

All-sky
Clear-sky
Pristine-sky
All-sky no aerosol

2-stream LW
4-stream SW
1. CRS TOA Flux Validation

- (↑) Daily, geographic ΔOLR variability
  - CRS minus CERES SSF observations
- (→) Time series of OLR validation stats
- Global statistics remain relatively stable throughout 2019
- All-sky bias within -1% (~ -1 to -2 W m\(^{-2}\))
- Negative clear-sky bias compensated by excessive OLR from high clouds
- ~ 7 W m\(^{-2}\) global RMSE w/ strong correlation of modeled & observed fluxes
1. CRS TOA Flux Validation

- (↑) Daily, geographic $\Delta$RSW variability
  - CRS minus CERES SSF observations
- (→) Time series of RSW validation stats
- Excessive reflection to space by clouds & occasionally the surface
  - ~ 3 - 4% global mean all-sky bias
- Better clear-sky performance
  - ~ 0 - 1% clear-sky relative bias
- Biases relatively stable through time
- RMS peak in boreal spring from surface albedo retrievals over NH continents

Spring 2021 CERES / Libera Science Team Meeting
ryan.c.scott@nasa.gov
Surface Validation Sites

AWARE @ West Antarctic Ice Sheet Divide

Spring 2021 CERES / Libera Science Team Meeting
ryan.c.scott@nasa.gov
Surface Flux Validation Methodology

- Using 1-min resolution surface data
- Extracting footprints within 10 km
- \( \text{LW}_\downarrow \): instantaneous match to pyrgeometer obs. at footprint time
- \( \text{SW}_\downarrow \): averaging surface obs. for 30 mins centered at footprint time
  - Total = Direct + Diffuse, resort to Global from unshaded PSP if total is unavailable
  - \( \text{SW}_{\text{CRS}} \) scaled by \( \text{avg}(\mu_{\text{OBS}}) / \mu_{\text{CRS}} \) to account for changing \( \mu = \cos(SZA) \)
- FOV size varies with instrument view zenith angle (source of noise)
Surface Shortwave (SW ↓) Flux Validation
Aqua FM3 - 2019 - Daytime Only - All Validation Sites

**CERES CRS**
- N = 7527
- Bias (Δ) = -5.66
- RMSD = 95.0
- Corr = 0.95
- 34-39% (50-60 W m⁻²) RMS reduction relative to Model B

**CERES SSF Ed4A**
- N = 7527
- Bias (Δ) = -0.43
- RMSD = 143.35
- Corr = 0.88

**FLASHFlux SSF v4A**
- N = 7527
- Bias (Δ) = 17.96
- RMSD = 155.62
- Corr = 0.85

---

**Fu-Liou RT Model Fluxes**

**Model B Parameterized Fluxes**
### Aqua FM3 Daytime SW↓
Fu-Liou vs Model B by surface type

#### CERES CRS

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Bias</th>
<th>RMSE</th>
<th>Corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>7527</td>
<td>-5.66</td>
<td>95.0</td>
<td>0.95</td>
</tr>
<tr>
<td>Coastal</td>
<td>1366</td>
<td>-4.4</td>
<td>100.21</td>
<td>0.93</td>
</tr>
<tr>
<td>Desert</td>
<td>378</td>
<td>-11.4</td>
<td>78.87</td>
<td>0.92</td>
</tr>
<tr>
<td>Island</td>
<td>240</td>
<td>45.62</td>
<td>147.13</td>
<td>0.86</td>
</tr>
<tr>
<td>Continent</td>
<td>3049</td>
<td>-1.69</td>
<td>108.32</td>
<td>0.92</td>
</tr>
<tr>
<td>Polar</td>
<td>2494</td>
<td>-15.27</td>
<td>66.11</td>
<td>0.94</td>
</tr>
</tbody>
</table>

#### CERES SSF Ed4A

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Bias</th>
<th>RMSE</th>
<th>Corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>7527</td>
<td>-0.43</td>
<td>143.35</td>
<td>0.88</td>
</tr>
<tr>
<td>Coastal</td>
<td>1366</td>
<td>14.14</td>
<td>130.82</td>
<td>0.88</td>
</tr>
<tr>
<td>Desert</td>
<td>378</td>
<td>-0.54</td>
<td>89.09</td>
<td>0.89</td>
</tr>
<tr>
<td>Island</td>
<td>240</td>
<td>68.57</td>
<td>154.37</td>
<td>0.86</td>
</tr>
<tr>
<td>Continent</td>
<td>3049</td>
<td>6.12</td>
<td>120.36</td>
<td>0.91</td>
</tr>
<tr>
<td>Polar</td>
<td>2494</td>
<td>-23.03</td>
<td>177.32</td>
<td>0.58</td>
</tr>
</tbody>
</table>

#### FLASHFlux SSF v4A

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Bias</th>
<th>RMSE</th>
<th>Corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>7527</td>
<td>17.96</td>
<td>155.62</td>
<td>0.85</td>
</tr>
<tr>
<td>Coastal</td>
<td>1366</td>
<td>10.53</td>
<td>136.55</td>
<td>0.87</td>
</tr>
<tr>
<td>Desert</td>
<td>378</td>
<td>-13.7</td>
<td>92.74</td>
<td>0.88</td>
</tr>
<tr>
<td>Island</td>
<td>240</td>
<td>70.22</td>
<td>156.01</td>
<td>0.86</td>
</tr>
<tr>
<td>Continent</td>
<td>3049</td>
<td>13.39</td>
<td>132.54</td>
<td>0.88</td>
</tr>
<tr>
<td>Polar</td>
<td>2494</td>
<td>27.39</td>
<td>194.32</td>
<td>0.56</td>
</tr>
</tbody>
</table>

**Fu-Liou RT Model Fluxes**

**Model B Parameterized Fluxes**

Results for Terra FM1 are similar
* Bias, RMSE units: W m\(^{-2}\)
Surface Longwave (LW ↓) Flux Validation
Aqua FM3 - 2019 - Daytime Only - All Validation Sites

CERES CRS
- N = 8880
- Bias (Δ) = -0.12
- RMSD = 22.94
- Corr = 0.96

Smallest bias & 17% (~ 4.7 W m⁻²)
RMS reduction relative to Model B

CERES SSF Ed4A
- N = 8880
- Bias (Δ) = -0.66
- RMSD = 27.66
- Corr = 0.95

FLASHFlux SSF v4A
- N = 8880
- Bias (Δ) = -1.01
- RMSD = 27.69
- Corr = 0.95
## Aqua FM3 Daytime LW↓ Fu-Liou vs Model B by surface type

### CERES CRS

<table>
<thead>
<tr>
<th>LW↓</th>
<th>N</th>
<th>Bias</th>
<th>RMSE</th>
<th>Corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>8880</td>
<td>-0.12</td>
<td>22.94</td>
<td>0.96</td>
</tr>
<tr>
<td>Coastal</td>
<td>1608</td>
<td>3.48</td>
<td>15.56</td>
<td>0.97</td>
</tr>
<tr>
<td>Desert</td>
<td>448</td>
<td>-13.04</td>
<td>23.24</td>
<td>0.93</td>
</tr>
<tr>
<td>Island</td>
<td>313</td>
<td>4.98</td>
<td>13.72</td>
<td>0.87</td>
</tr>
<tr>
<td>Continent</td>
<td>3293</td>
<td>3.56</td>
<td>25.75</td>
<td>0.91</td>
</tr>
<tr>
<td>Polar</td>
<td>3218</td>
<td>-4.37</td>
<td>23.65</td>
<td>0.95</td>
</tr>
</tbody>
</table>

### CERES SSF Ed4A

<table>
<thead>
<tr>
<th>LW↓</th>
<th>N</th>
<th>Bias</th>
<th>RMSE</th>
<th>Corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>8880</td>
<td>-0.66</td>
<td>27.66</td>
<td>0.95</td>
</tr>
<tr>
<td>Coastal</td>
<td>1608</td>
<td>-0.38</td>
<td>26.25</td>
<td>0.91</td>
</tr>
<tr>
<td>Desert</td>
<td>448</td>
<td>-7.51</td>
<td>29.71</td>
<td>0.85</td>
</tr>
<tr>
<td>Island</td>
<td>313</td>
<td>6.38</td>
<td>17.82</td>
<td>0.83</td>
</tr>
<tr>
<td>Continent</td>
<td>3293</td>
<td>0.9</td>
<td>28.73</td>
<td>0.89</td>
</tr>
<tr>
<td>Polar</td>
<td>3128</td>
<td>-2.13</td>
<td>27.73</td>
<td>0.93</td>
</tr>
</tbody>
</table>

### FLASHFlux SSF v4A

<table>
<thead>
<tr>
<th>LW↓</th>
<th>N</th>
<th>Bias</th>
<th>RMSE</th>
<th>Corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>8880</td>
<td>-1.01</td>
<td>27.69</td>
<td>0.95</td>
</tr>
<tr>
<td>Coastal</td>
<td>1608</td>
<td>-1.01</td>
<td>26.55</td>
<td>0.91</td>
</tr>
<tr>
<td>Desert</td>
<td>448</td>
<td>-7.83</td>
<td>26.78</td>
<td>0.87</td>
</tr>
<tr>
<td>Island</td>
<td>313</td>
<td>5.35</td>
<td>18.34</td>
<td>0.82</td>
</tr>
<tr>
<td>Continent</td>
<td>3293</td>
<td>0.7</td>
<td>29.16</td>
<td>0.89</td>
</tr>
<tr>
<td>Polar</td>
<td>3128</td>
<td>-1.0</td>
<td>27.6</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Results for Terra FM1 are similar

* Bias, RMSE units: W m⁻²
Systematic underestimation of clear-sky LW↓ @ (left) Dome C & (right) WAIS Divide, Antarctica

Surface-based thermal inversion not well resolved in GEOS 5.4.1

Starting to develop inversion correction following Gupta et al. 2010
3. CRS vs SYN1deg Surface Flux Validation

- SYN1deg provides gridded hourly surface fluxes also calculated using the Fu-Liou RT model
- We also compared CRS to SYN1deg
  - SYN1deg fluxes compared to 1-hr average of the obs. centered on the half hour
- Both products are reasonably consistent & show similar statistics
- CRS has a smaller SW↓ bias & std. dev. (σ) everywhere but Antarctica
  - Footprints more representative of surface observations than 1° grid cells
  - CRS cloud optical depths are unrealistically high over permanent snow and ice surfaces
- CRS and SYN1deg also show similar results in the LW↓
CRS vs SYN1deg Surface (\(\downarrow\)) Flux Validation

- SYN1deg provides gridded hourly surface fluxes also calculated using the Fu-Liou RT model.
- We also compared CRS to SYN1deg.
  - SYN1deg fluxes compared to 1-hr average of the obs. centered on the half hour.
- Both products are reasonably consistent & show similar statistics.
- CRS has a smaller SW\(\downarrow\) bias & std. dev. (\(\sigma\)) everywhere but Antarctica.
  - Footprints more representative of surface observations than \(1^\circ\) grid cells.
  - CRS cloud optical depths are unrealistically high over permanent snow and ice surfaces.
- CRS and SYN1deg also show similar results in the LW\(\downarrow\).

![Daytime Aqua Only CRS1deg\(\beta\)-Hr minus SYN1deg-Hr Cloud Optical Depth [no units] 01-01-2019:00-23h](image_url)

![CRS & SYN1deg SW Calc vs Obs](image_url)
Can We Use CRS & Machine Learning to Improve FLASHFlux SSF Surface Fluxes?

Problem:

• FLASHFlux (P. Stackhouse’s talk next) provides near real-time estimates of Earth’s surface radiation budget components for agricultural, renewable energy, and other applications

• Currently, footprint-level surface fluxes are estimated using decades-old parameterizations (Model B) that, as we just showed, are generally inferior to CRS fluxes from the Fu-Liou radiative transfer model.

• However, running the Fu-Liou code at the CERES instrument footprint level is computationally expensive (~2.3M computations, ~12-16+ hours/day) and increases the difficulty of meeting latency requirements
Can We Use CRS & Machine Learning to Improve FLASHFlux SSF Surface Fluxes?

Problem:

- FLASHFlux (P. Stackhouse’s talk next) provides near real-time estimates of Earth’s surface radiation budget components for agricultural, renewable energy, and other applications.
- Currently, footprint-level surface fluxes are estimated using decades-old parameterizations (Model B) that, as we just showed, are generally inferior to CRS fluxes from the Fu-Liou radiative transfer model.
- However, running the Fu-Liou code at the CERES instrument footprint level is computationally expensive (~2.3M computations, ~12-16+ hours/day) and increases the difficulty of meeting latency requirements.

Approach / Solution:

- Train supervised machine learning algorithms on CRS data, tune hyperparameters, & evaluate model performance to “learn” functional mappings that can accurately & rapidly predict CRS surface fluxes – no need to run the Fu-Liou RT code!
  - Linear, Decision Tree, Random Forest, & XGBoost Regressors
Supervised ML Algorithms:
- Linear
- Decision Tree
- Random Forest
- XGBoost

• Provides functional mappings between meteorological parameters
  \[ X = T, CF, COD, CT, PWV, LTS, ALT \]
  that are physically relevant and readily available in the FLASHFlux data processing stream & the CRS flux

\[ LW \downarrow = f_i(X) \]

• Standardize X prior to training
• Train on day & night footprints
• Assess performance & tune hyperparameters using different evaluation metrics:
  • 80/20 Train-Test Split
  • K-Fold Cross Validation
  • Randomized Search CV (in progress)
Supervised ML Algorithms:
- Linear
- Decision Tree
- Random Forest
- XGBoost

TOA Insolation (INS)
Surface Altitude (ALT)
Cloud Fraction (CF)
Cloud Optical Depth (COD)
Solar Zenith Angle (SZA)
Precipitable Water Vapor (PWV)
Aerosol Optical Depth (AOD)

\[ \text{Surface Shortwave Flux (SW}_\downarrow) = g_i(X) \]

- Provides functional mappings between meteorological parameters
- \[ X = \text{INS, SZA, CF, COD, AOD, PWV, ALT} \]
- that are physically relevant and readily available in the FLASHFlux data processing stream & the CRS flux

- Standardize \( X \) prior to training
- Train on daytime footprints
- Assess performance & tune hyperparameters using different evaluation metrics:
  - 80/20 Train-Test Split
  - K-Fold Cross Validation
  - Randomized Search CV (in progress)
CER_CRS4_Terra-FM1-MODIS_GH4_1111TH.20190101:00-23h
Training features: Cloud properties (fraction, optical depth, temperature), $\bar{T}$, PWV, LTS, ALT

Linear Regression
- $N = 1122767$
- MSE: 155.33±0.31
- MAE: 9.71±0.01
- RMSE: 12.46±0.01

Decision Tree
- $N = 1122767$
- MSE: 17.91±0.1
- MAE: 2.67±0.01
- RMSE: 4.23±0.01

Random Forest
- $N = 1122767$
- MSE: 7.39±0.04
- MAE: 1.73±0.00
- RMSE: 2.72±0.01

XGBoost
- $N = 1122767$
- MSE: 9.1±0.06
- MAE: 2.13±0.01
- RMSE: 3.02±0.01
CER_CRS4_Terra-FM1-MODIS_GH4_1111TH.20190101:00-23h
Training features: Insolation, SZA, CF, COD, AOD, PWV, Altitude

**Linear Regression**
- N = 1122727
- MSE: 10226.39±16.77
- MAE: 75.72±0.06
- RMSE: 101.13±0.08

**Decision Tree**
- N = 1122727
- MSE: 584.18±4.84
- MAE: 12.42±0.03
- RMSE: 24.17±0.1

**Random Forest**
- N = 1122727
- MSE: 278.57±5.54
- MAE: 8.79±0.03
- RMSE: 16.69±0.17

**XGBoost**
- N = 1122727
- MSE: 258.45±5.17
- MAE: 9.4±0.05
- RMSE: 16.08±0.16
Random Forest (RF) surface flux predictions much closer to CRS than FLASHFlux Model B
(top) FLASHFlux SSF v4A – CRS (bottom) RF – CRS flux difference ($\Delta$) [ W m$^{-2}$]
Summary & Future Work

• CRS computes instantaneous footprint-level irradiances using the NASA Langley Fu-Liou RT code
  • Here we summarized our progress resurrecting & validating CRS since we first reintroduced it 6 months ago
• Comparisons to CERES global TOA measurements show reasonable & stable performance
  • Global mean all-sky LW↑ within 1% of CERES, SW↑ within 3 - 4% of CERES throughout 2019
• CRS surface fluxes are superior to SOFA Model B parameterized fluxes (SSF Ed4A, FF SSF v4A)
  • Based on 2019 validation by surface site type using measurements from the CAVE database
  • SW↓ – RMS reduction of 34 - 39% (50 - 60 W m⁻²), higher correlation, lower bias for most site types
  • LW↓ – RMS reduction of 17% (~ 4.7 W m⁻²), marginally increased correlation, lowest overall bias
  • Corrections needed for excessive Antarctic cloud optical depth & unresolved temperature inversions
• Machine learning with CRS offers a viable solution to improve FLASHFlux SSF surface fluxes
  • We have developed, trained, & evaluated Linear, Decision Tree, Random Forest, & XGBoost regressors
  • Random Forest & XGBoost successfully reproduce CRS fluxes w/ model RMS values less than the validation RMS Δ between CRS & Model B; individual footprint errors are typically << Δ(FF – CRS)
  • Next Steps: continue tuning models (RF & XGBoost) & devise scalable training methodology
deploy models in production & use as the operational source of FLASHFlux SSF surface fluxes
• We plan to release CRS publicly with CERES Edition 5 data products
• Thank You!

Spring 2021 CERES / Libera Science Team Meeting
ryan.c.scott@nasa.gov
Extra Slides
Surface LW↓ Model Performance
Predicted - Actual Flux [ W m⁻² ]

**Linear Regression**
- Predicted Minus Actual CRS Flux ΔLW↓ - 01/01/2019-00:23h

**Decision Tree**
- Decision Tree Predicted Minus Actual CRS Flux ΔLW↓ - 01/01/2019-00:23h

**Random Forest**
- Random Forest Predicted Minus Actual CRS Flux ΔLW↓ - 01/01/2019-00:23h

**XGBoost**
- XGBoost Predicted Minus Actual CRS Flux ΔLW↓ - 01/01/2019-00:23h

Downwelling Longwave Flux Difference - Surface
Watts per square meter

---

Spring 2021 CERES / Libera Science Team Meeting
ryan.c.scott@nasa.gov
Surface SW↓ Model Performance
Predicted - Actual Flux [ W m⁻² ]

**LINEAR**
Linear Regression Predicted Minus Actual CRS Flux ΔSW↓ - 01/01/2019-00-23h

**RANDOM FOREST**
Random Forest Predicted Minus Actual CRS Flux ΔSW↓ - 01/01/2019-00-23h

**DECISION TREE**
Decision Tree Predicted Minus Actual CRS Flux ΔSW↓ - 01/01/2019-00-23h

**XGBOOST**
XGBoost Predicted Minus Actual CRS Flux ΔSW↓ - 01/01/2019-00-23h

Downwelling Shortwave Flux Difference - Surface
Watts per square meter

Spring 2021 CERES / Libera Science Team Meeting
ryan.c.scott@nasa.gov
ARM West Antarctic Radiation Experiment (AWARE)
WAIS Divide, Antarctica

Spring 2021 CERES / Libera Science Team Meeting
ryan.c.scott@nasa.gov