Libera's split-shortwave irradiance inversion: concept and initial analysis

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Thanks to: Sebastian Schmidt, Maria Hakuba, Bruce Kindel, Dan Feldman, Xianglei Huang + extended Libera science team
Outline

• Background
  ➢ Shortwave Angular Distribution Model (ADM) basics
  ➢ The challenge of split-shortwave ADMs for Libera

• Concept
  ➢ Proposed approach
  ➢ Utilizing the Libera camera

• Initial analysis
  ➢ Wavelength-to-split-shortwave relationships
  ➢ Scene property dependence

• Machine learning for imager-independent split-shortwave fluxes
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Work-in-progress
Shortwave radiance-to-flux conversion: the basics

**Solar-viewing geometry**

- Solar zenith angle ($\theta_s$)
- Viewing zenith angle ($\theta_v$)
- Relative azimuth angle ($\phi$)

Radiance, $I(\theta_s, \theta_v, \phi)$

Angular Distribution Model (ADM)

Flux, $F(\theta_s)$

Scene type
Shortwave radiance-to-flux conversion: the basics

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![Diagram of solar viewing geometry]

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Angular Distribution Model (ADM)

Flux, $F(\theta_s)$

Scene type

$$F(\theta_s) = \int_0^{2\pi} \int_0^{\pi/2} I(\theta_s, \theta_v, \phi) \cos \theta_v \sin \theta_v \, d\theta_v \, d\phi$$
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- **Isotropic:** $\pi I(\theta_s, \theta_v, \phi)$
- **Anisotropic:** $\frac{\pi I(\theta_s, \theta_v, \phi)}{R(\theta_s, \theta_v, \phi)}$

$R(\theta_s, \theta_v, \phi)$ is the anisotropic factor

ADMs are the set of anisotropic factors $R(\theta_s, \theta_v, \phi)$ for each scene type.
Generating anisotropic factors

Example: $\theta_s = 30$-$40^\circ$, ocean, clear-sky, wind speed $<$3.5 m s$^{-1}$

From CERES TRMM ADMs: *Loeb et al., JAM, 2003a,b*
Generating anisotropic factors

Example: $\theta_s, 30-40^\circ$, ocean, clear-sky, wind speed <3.5 m s$^{-1}$

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\[ R(\chi, \theta_V, \phi) = \frac{\pi I(\chi, \theta_V, \phi)}{F(\chi)} \]

For $\theta_V$ bin $i$ and $\phi$ bin $j$:

\[ R_{i,j} = \frac{\pi I_{i,j}}{F} \]

\[ F = \int_0^{2\pi} \int_0^{\pi/2} I(\theta_V, \phi) \cos \theta_V \sin \theta_V \, d\theta_V \, d\phi \]

\[ \approx \sum_{i=1}^{N_i} w_i \sum_{j=1}^{N_j} w_j \overline{l_{i,j}} \] (or similar functional form)

From CERES TRMM ADMs: Loeb et al., JAM, 2003a,b
Challenge for Libera split-shortwave ADMs

- Directly observed split-shortwave ADMs do not currently exist.
- How will Libera split-shortwave radiance be converted to flux?
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  - Repeat RAPS mode with new split-shortwave radiometer?
    - Takes a long time. e.g. ADMs from Terra/Aqua use 6 years and 8 months of RAPS data *Su et al, AMT, 2015a,b* 
    - Continuity best served by cross-track sampling.

**OG1:** Provide seamless continuity of the Clouds and the Earth’s Radiant Energy System (CERES) ERB Climate data record (CDR).

**OG2:** Advance the development of a self-contained, innovative & affordable observing system.
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    - \[ \text{✗ Need detailed scene information to apply latest ADMs.} \]
  - Wide field-of-view camera for new split-shortwave ADM development with simpler scene ID.
    - \[ \text{✔ addresses above issues. To be demonstrated in practice..} \]

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Libera’s split-shortwave ADM approach

1. OSSE “prior” split-shortwave ADMs [Daniel Feldman]
2. Wide-field-of-view camera will provide dense angular sampling for observational basis
3. Ultimately, constrain with azimuthal scans whenever available e.g. calibration maneuvers [Bruce Kindel]

Credit: Stephane Beland
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Credit: Stephane Beland
Convolve with Libera Point Spread Function

Instantaneous angular sampling
MODIS/VIIRS (cross track scan)
MISR (9 fixed angles)
Libera WFOV camera (entire Earth disk)
Compromise: focus on ERBE-like ADMs (initially)

- A key motivation for camera is to “develop self-contained system”
  - 12 scene types: appropriate for scene ID from a single wavelength
  - Based on imaging at CERES/Libera scales; not ERBE approach
  - Could be extended in future “ERBE+” e.g., cloud optical depth retrieval

<table>
<thead>
<tr>
<th>Cloud fraction</th>
<th>Surface type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear-sky (0-5%)</td>
<td>Ocean</td>
</tr>
<tr>
<td>2</td>
<td>Land</td>
</tr>
<tr>
<td>3</td>
<td>Snow</td>
</tr>
<tr>
<td>4</td>
<td>Desert</td>
</tr>
<tr>
<td>5</td>
<td>Land-ocean mix</td>
</tr>
<tr>
<td>6</td>
<td>Partly cloudy (5-50%)</td>
</tr>
<tr>
<td>7</td>
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*Suttles et al., NASA Tech Rep, 1988*
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    *Nataraja et al., in prep. 2021*

- Solar-viewing geometry
  - 10 $\theta_S$ bins
  - 7 $\theta_V$ bins
  - 8 $\phi$ bins
  - Anticipate finer resolution bins in future

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Optimizing the Libera camera for ADMs: OSSE data

Cloud fraction (CSIRO)

- Climate model output
  - Monthly mean
  - Jan 2040
  - 96 lat × 192 lon = 18,432 columns

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Camera wavelength: high correlation with sub-band

Note: nadir only

- Single wavelength camera acts as a proxy for one of the split channels
  - Need high correlation between single wavelength and NIR or VIS
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- MISR 865 nm correlates well with CERES total SW
  
  Corbett and Su, AMT, 2015
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- MISR 865 nm correlates well with CERES total SW
  - *Corbett and Su, AMT, 2015*

- Initial OSSE data here suggests 865 nm may not be optimal for NIR
  - Highest correlation is ~555 nm with VIS
Correlations by scene type: 865 nm vs. NIR

**Note: nadir only**

- Sub-band correlations do not hold equally well across all scene types
- Conversion between camera wavelength -> sub-band should be a function of scene type and solar geometry
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  - Above cloud water vapor
  - Cloud height (phase)
Correlations by scene type: 555 nm vs. VIS

Note: nadir only!

- Much tighter relationship between 555 nm and VIS
- No “break down” for any scene types
Correlations by scene type: 555 nm vs. VIS

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- **Issue 1:** lack extremes of cloud fraction
  - Monthly-mean, ~1 deg
Correlations by scene type: 555 nm vs. VIS

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- No “break down” for any scene types

- Issue 1: lack extremes of cloud fraction
  - Monthly-mean, ~1 deg

- Issue 2: angular variability

Credit: Sebastian Schmidt, Hong Chen
Independent Libera split-shortwave fluxes

• For a single wavelength camera, a visible wavelength is most appropriate to generate VIS sub-band ADMs with ERBE scene types
  ➢ Additional scene segregation e.g. CERES is expected to be more important for NIR sub-band

• How to derive a self-contained Libera NIR flux?
Independent Libera split-shortwave fluxes

• For a single wavelength camera, a visible wavelength is most appropriate to generate VIS sub-band ADMs with ERBE scene types
  ➢ Additional scene segregation e.g. CERES is expected to be more important for NIR sub-band

• How to derive a self-contained Libera NIR flux?

  \[
  \text{NIR flux} = \text{SW flux} - \text{VIS flux}
  \]

  Directly derived with new ADMs

  Wait for RBSP SW flux? \(\times\) relies on imager

  Calculate new ERBE-like SW or NIR ADMs from camera? \(\times\) camera not a good proxy

  Use existing ERBE SW ADMs? \(\checkmark\) yes, but expect larger uncertainty

  Determine CERES-like scene type using machine learning? \(\checkmark\) maybe..

Loeb et al., JAOT, 2007
Machine learning CERES-like scene type

- Scene type predicted with ~95% accuracy for almost all scenes, many scenes >99% (excludes very thin cloud)
Machine learning CERES-like scene type

- Scene type predicted with ~95% accuracy for almost all scenes, many scenes >99% (excludes very thin cloud)
- Footprint radiances are most important; adding camera radiances (ie. imaging of the footprint) should yield further improvements
Summary and conclusions

- New split-shortwave ADMs are required for Libera, which will be generated from the wide-field-of-view camera.

- A camera wavelength of 555 nm is optimal for VIS ADMs, which are well suited to simpler ERBE-like scene types.

- One promising approach to determine NIR flux is machine learning of CERES-like scene type.
Camera angular sampling

- Preliminary Libera camera sampling pattern at center of CERES-TRMM angular bins

- An example of randomization to sample angular variability within angular bins
Appropriateness of a camera for generating ADMs

- Is a single wavelength sufficient to capture angular distribution?
  - Cloud ($\tau=10$) over ocean
  - $\theta_s=20^\circ$
  - $\theta_v=45^\circ$

**Credit: Sebastian Schmidt, Hong Chen**

- Can a camera obtain data with sufficient quality?
  - Radiometric accuracy requirement: 5 %
  - Uniformity requirement: 1.5 %

**Credit: Bruce Kindel**
ERBE scene type from OSSEs

- All surfaces considered “land” except ocean, snow, desert, land-ocean mix

- Only select surface type with >90% in model grid
  - For land-ocean mix only select 30-70% ocean

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**Table 1. Scene Types for Angular Models**

<table>
<thead>
<tr>
<th>Scene</th>
<th>Cloud coverage, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear over ocean</td>
<td>0 to 5</td>
</tr>
<tr>
<td>Clear over land</td>
<td></td>
</tr>
<tr>
<td>Clear over snow</td>
<td></td>
</tr>
<tr>
<td>Clear over desert</td>
<td></td>
</tr>
<tr>
<td>Clear over land-ocean mix</td>
<td></td>
</tr>
<tr>
<td>Partly cloudy over ocean</td>
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</tr>
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Cloud height separates “arms” very well

Two reasons:
1. Above cloud water vapor
2. Cloud phase

Note: nadir only

Gristey et al., J. Clim., 2019

Pilewskie and Twomey, JAS, 1987
ERBE SW ADM examples
CERES-TRMM SW ADM examples