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

Understanding Earth's Energy Budget

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

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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

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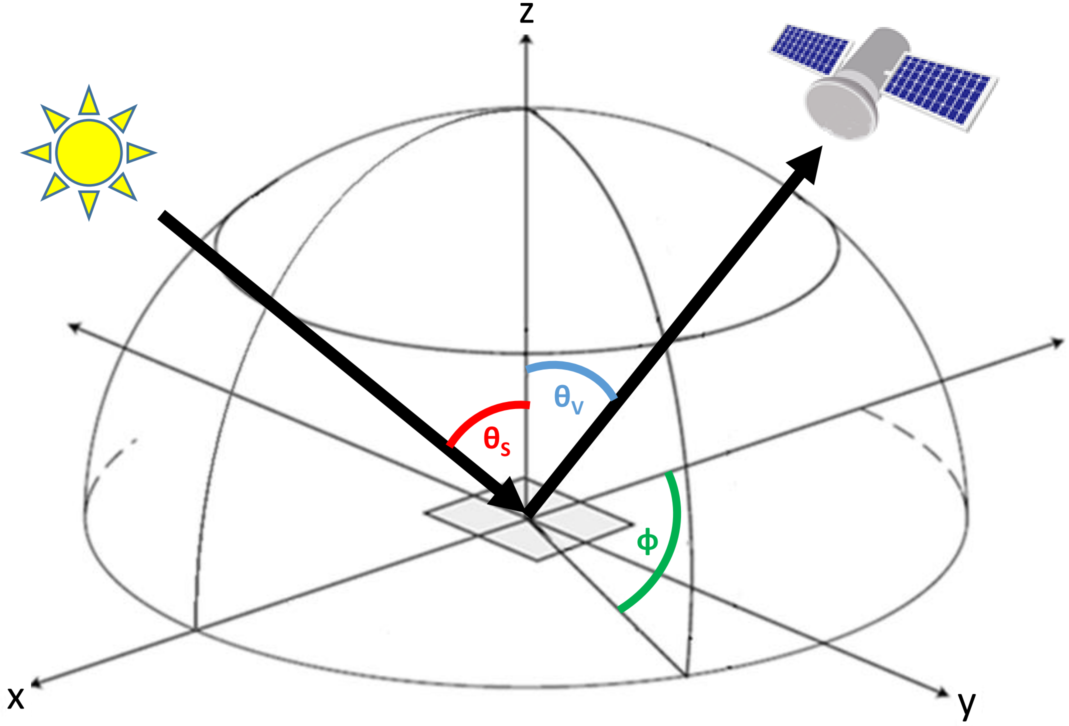
Shortwave radiance-to-flux conversion: the basics

Solar-viewing geometry

- Solar zenith angle (θ_s)
- Viewing zenith angle (θ_v)
- Relative azimuth angle (ϕ)



Radiance, $I(\theta_s, \theta_v, \phi)$ → **Angular Distribution Model (ADM)** → Flux, $F(\theta_s)$

Scene type → **Angular Distribution Model (ADM)**

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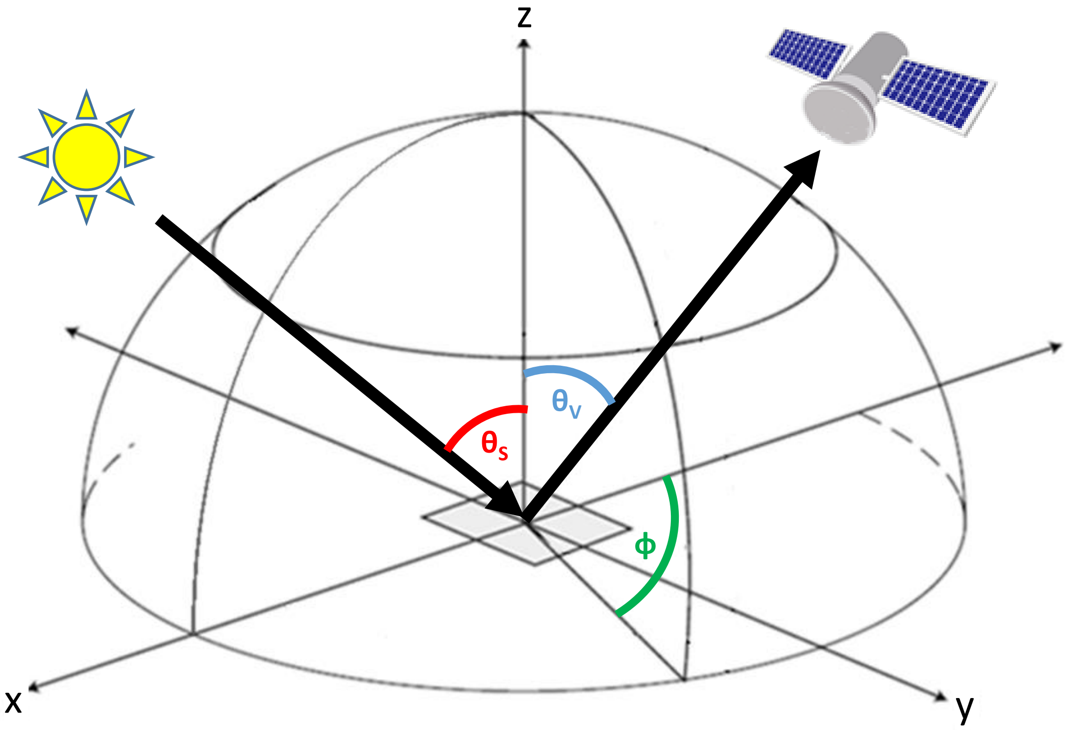

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$$F(\theta_s) = \int_0^{2\pi} \int_0^{\pi/2} I(\theta_s, \theta_v, \phi) \cos\theta_v \sin\theta_v \, d\theta_v d\phi$$

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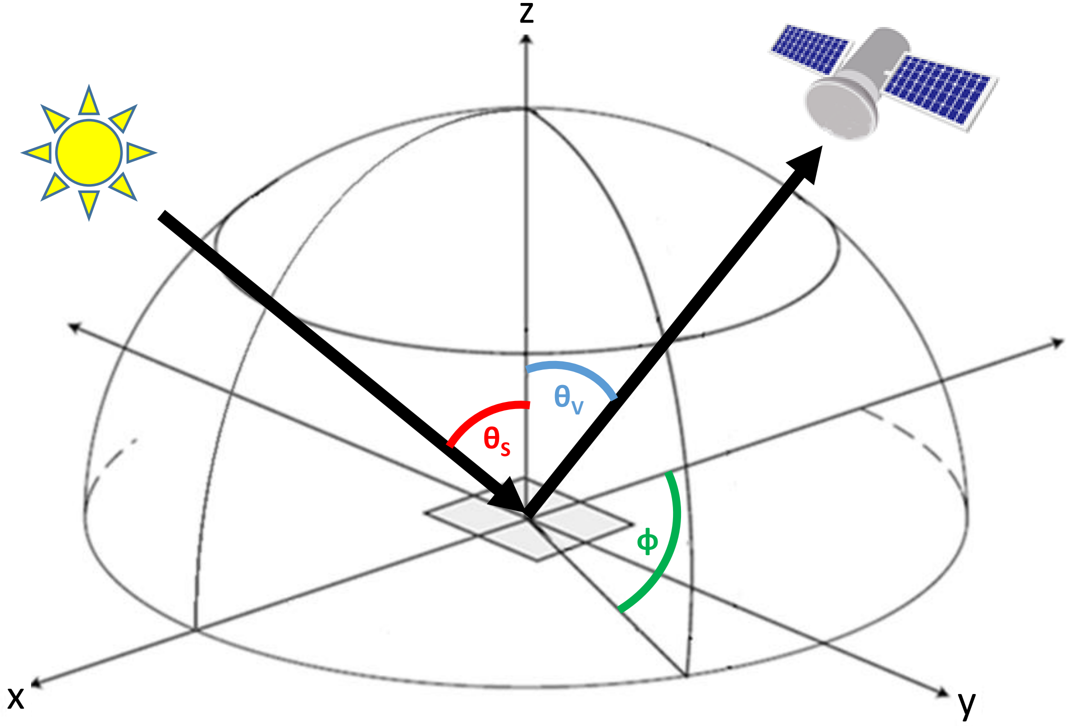

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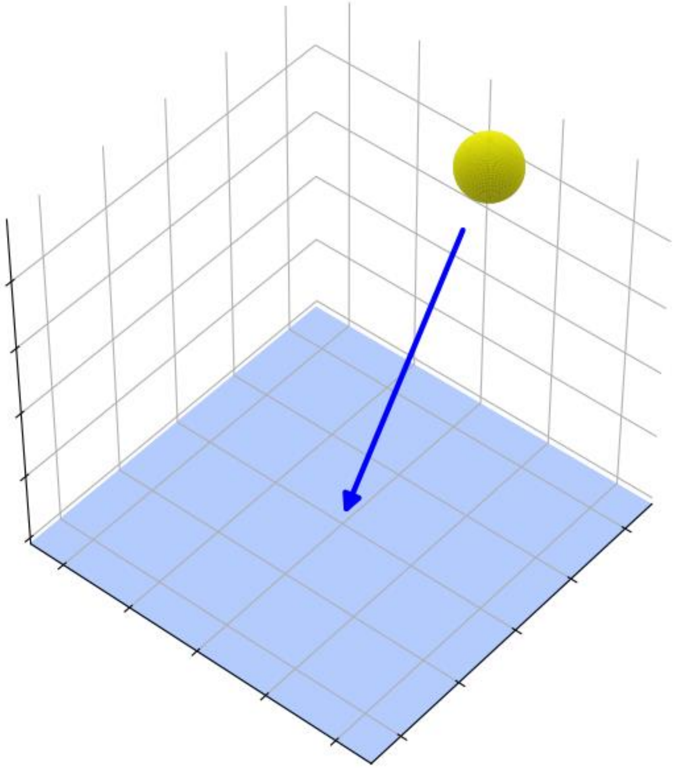
isotropic: $= \pi I(\theta_s, \theta_v, \phi)$

anisotropic: $= \dfrac{\pi I(\theta_s, \theta_v, \phi)}{R(\theta_s, \theta_v, \phi)}$ ← anisotropic factor

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

Generating anisotropic factors

Example: θ_S 30-40°, ocean, clear-sky, wind speed <3.5 m s^{-1}



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

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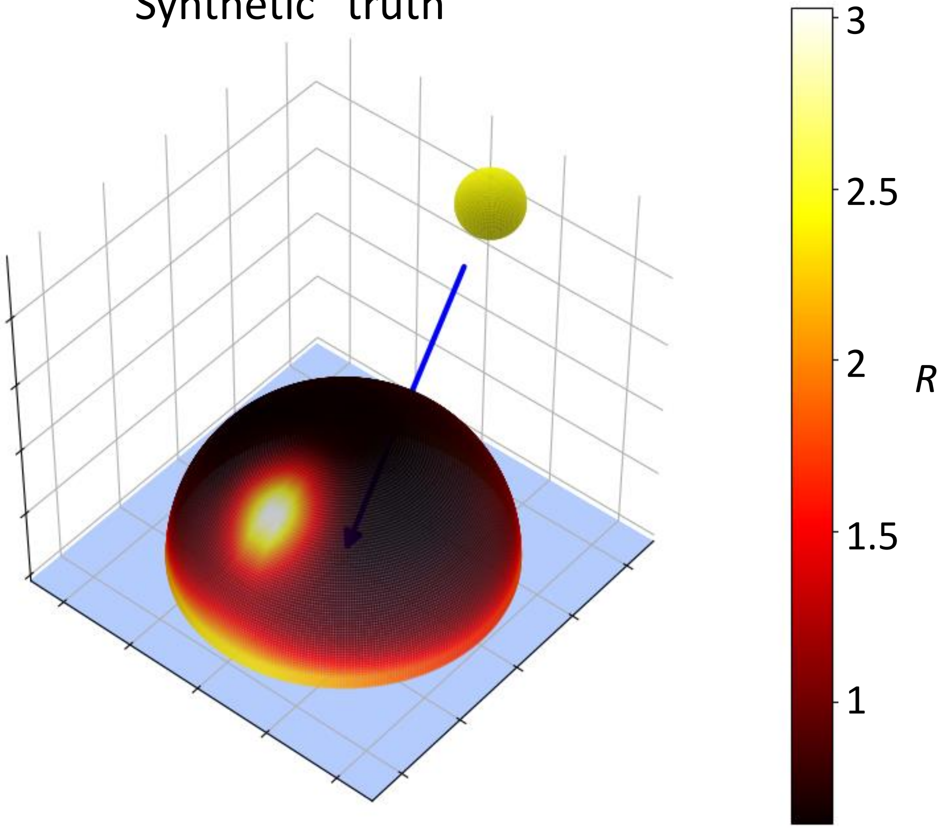

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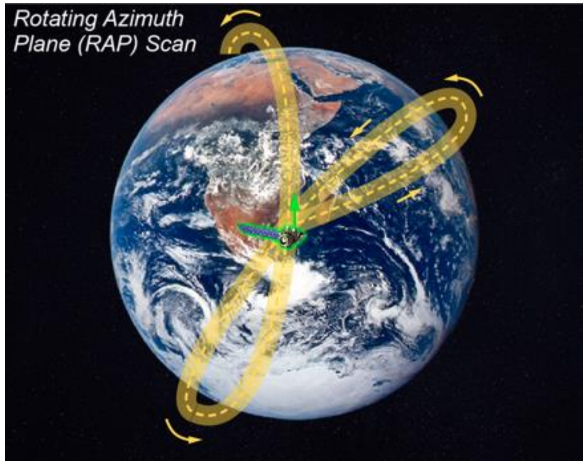

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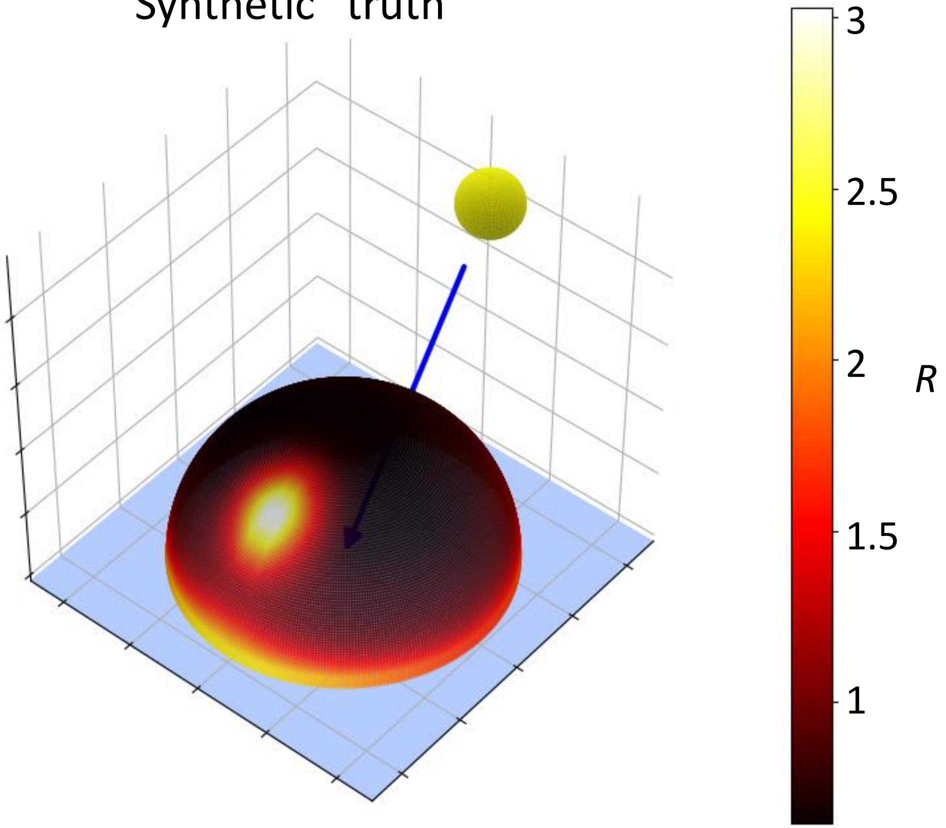

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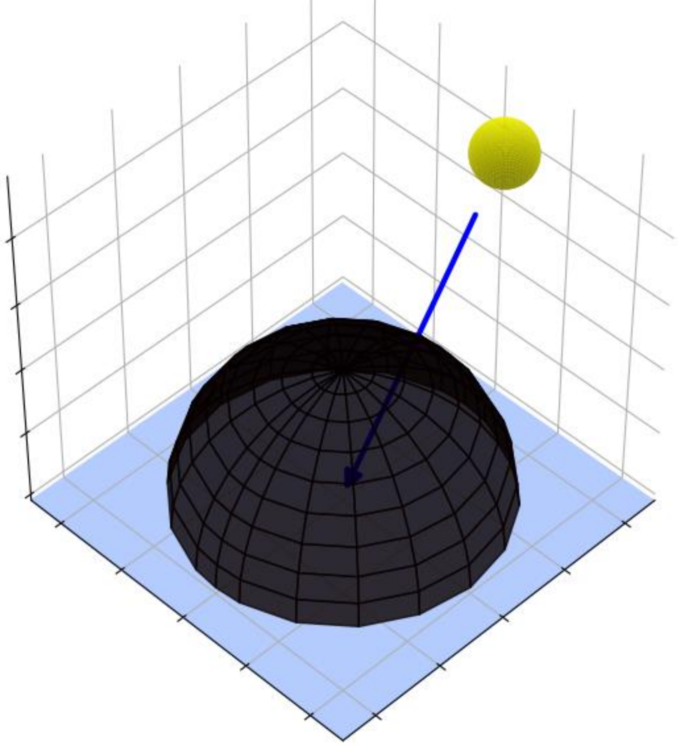

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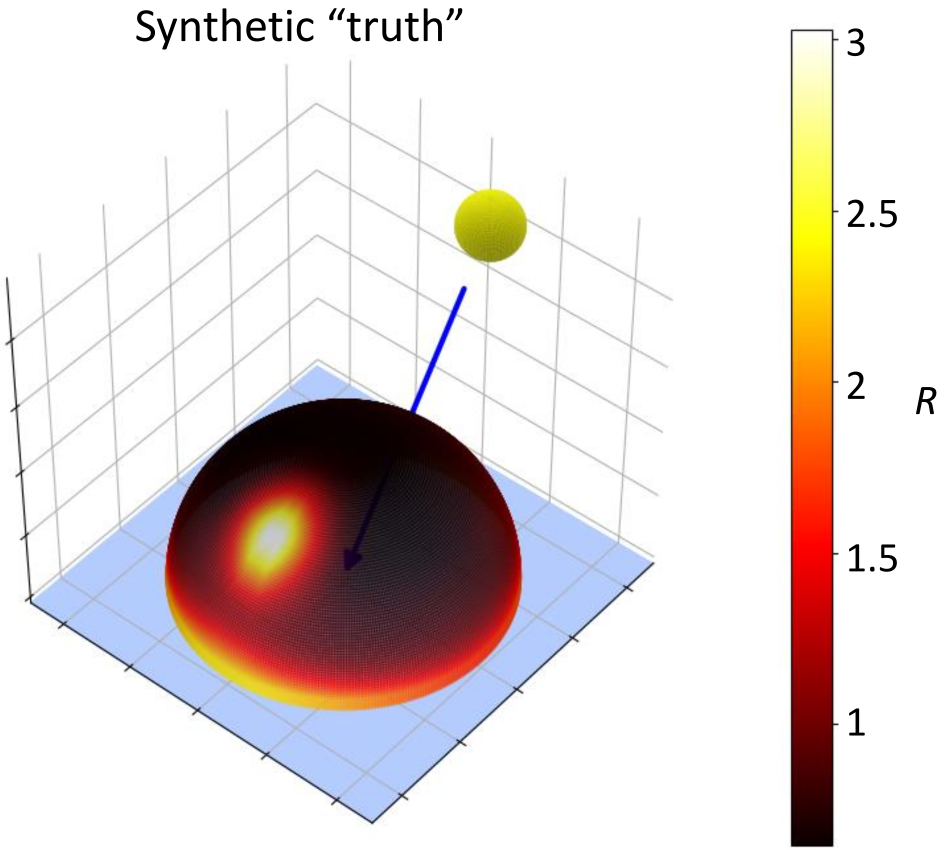

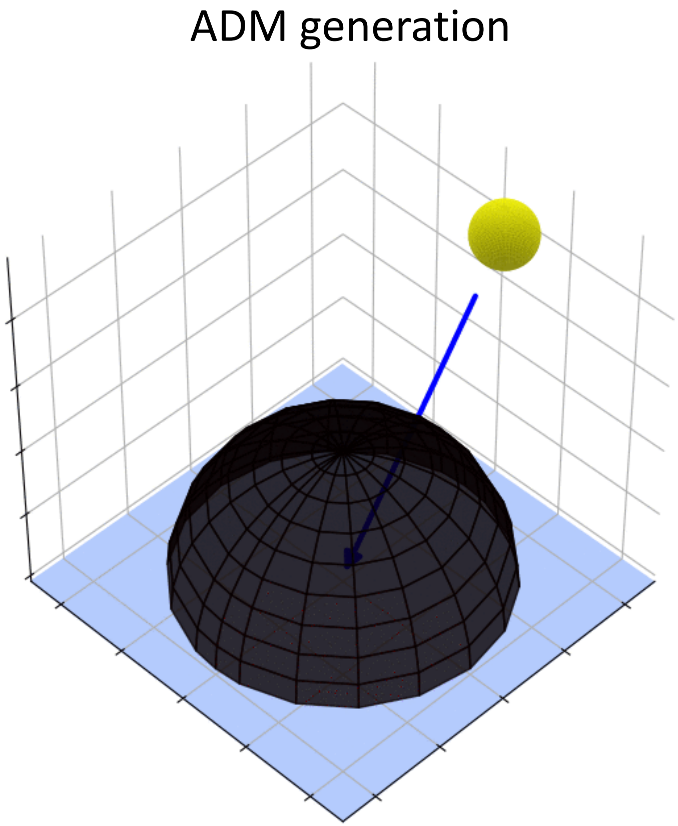

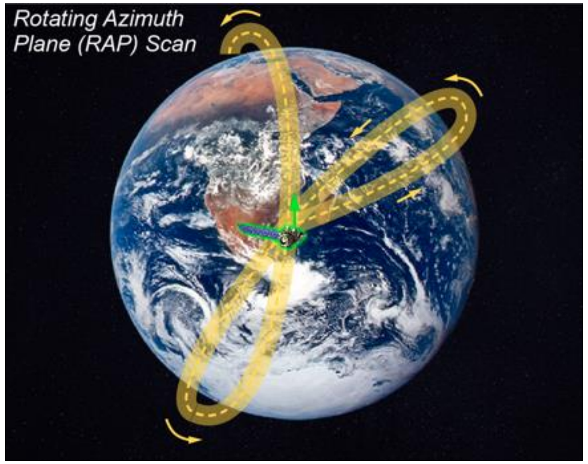

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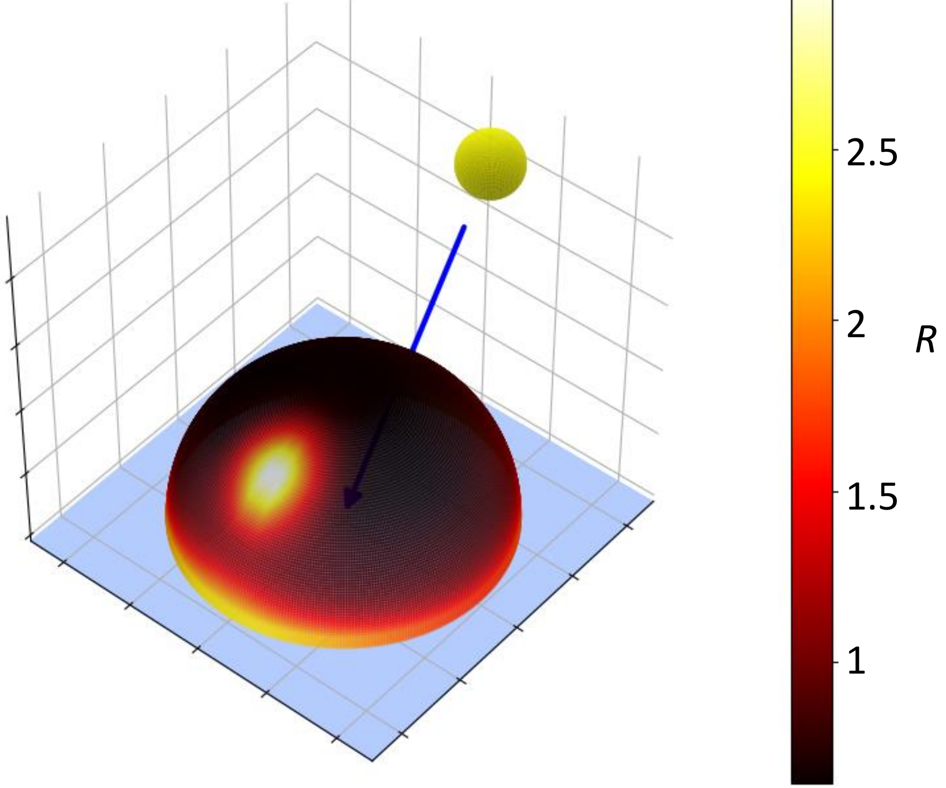

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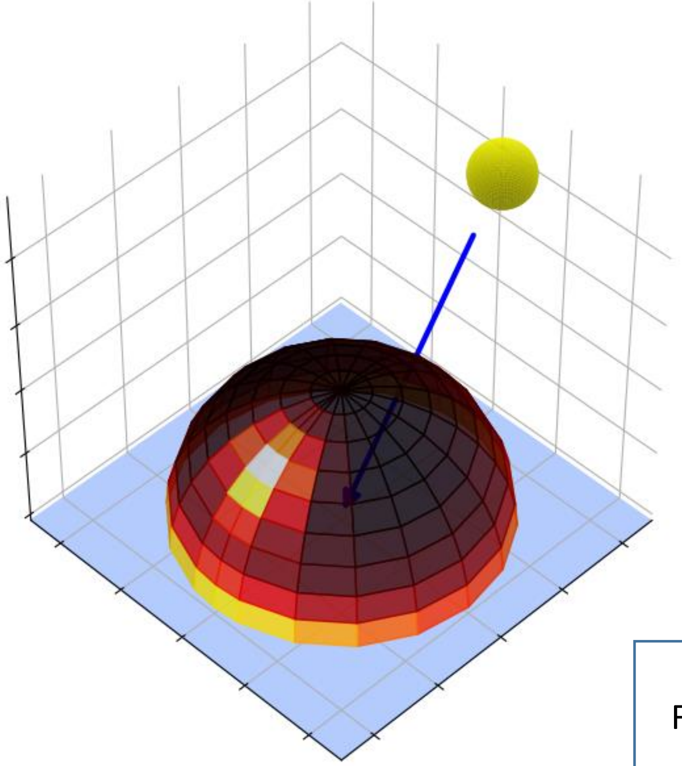

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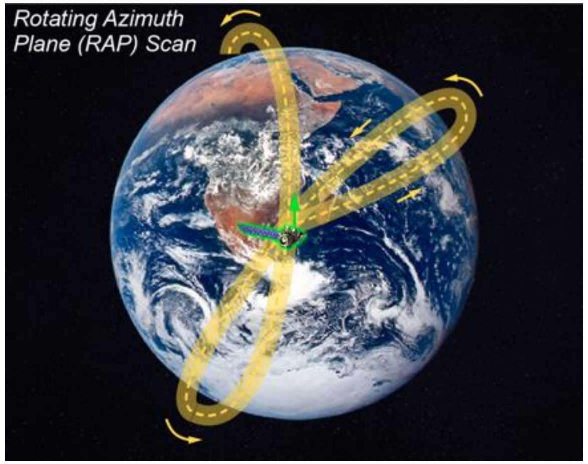

$$R(\cancel{\theta_s}, \theta_V, \phi) = \frac{\pi I(\cancel{\theta_s}, \theta_V, \phi)}{F(\cancel{\theta_s})}$$

For θ_V bin *i* and ϕ bin *j*:

$$R_{i,j} = \frac{\pi \overline{I_{i,j}}}{F}$$

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

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

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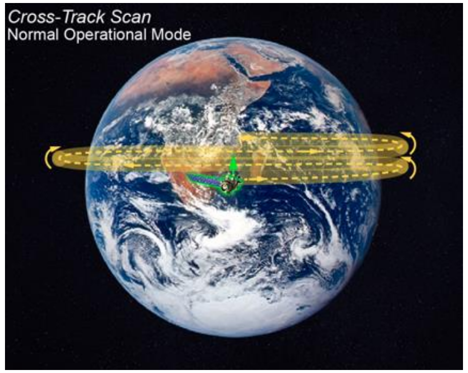

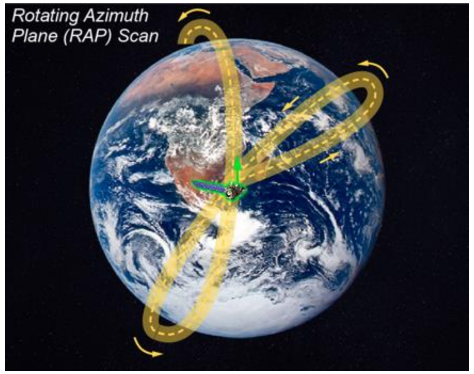

OG1: Provide seamless continuity of the Clouds and the Earth's Radiant Energy System (CERES) ERB Climate data record (CDR).

OG2: Advance the development of a self-contained, innovative & affordable observing system.

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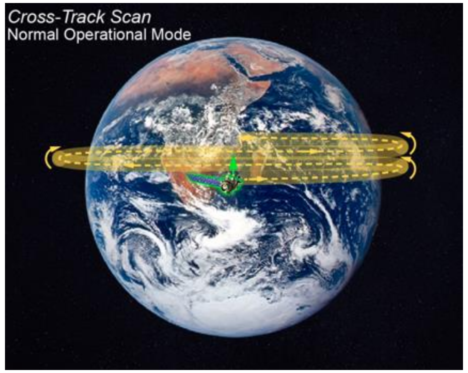

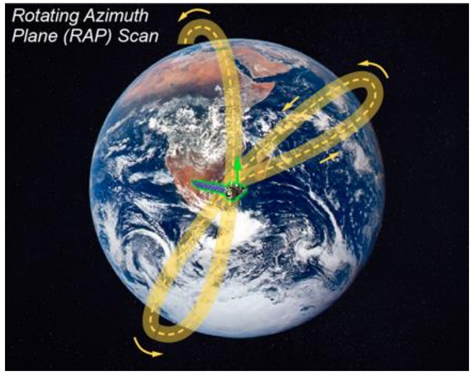

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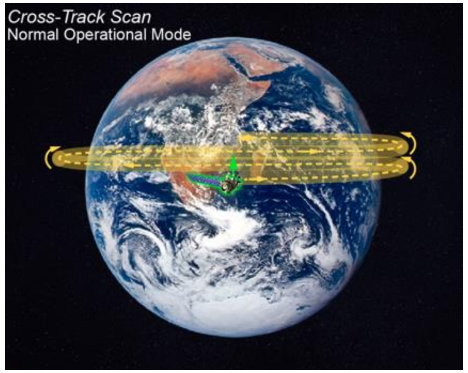
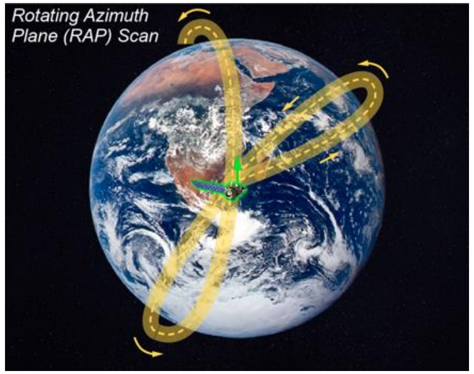
  - ➢ Wide field-of-view camera for new split-shortwave ADM development with simpler scene ID.
    - ✓ addresses above issues. To be demonstrated in practice..





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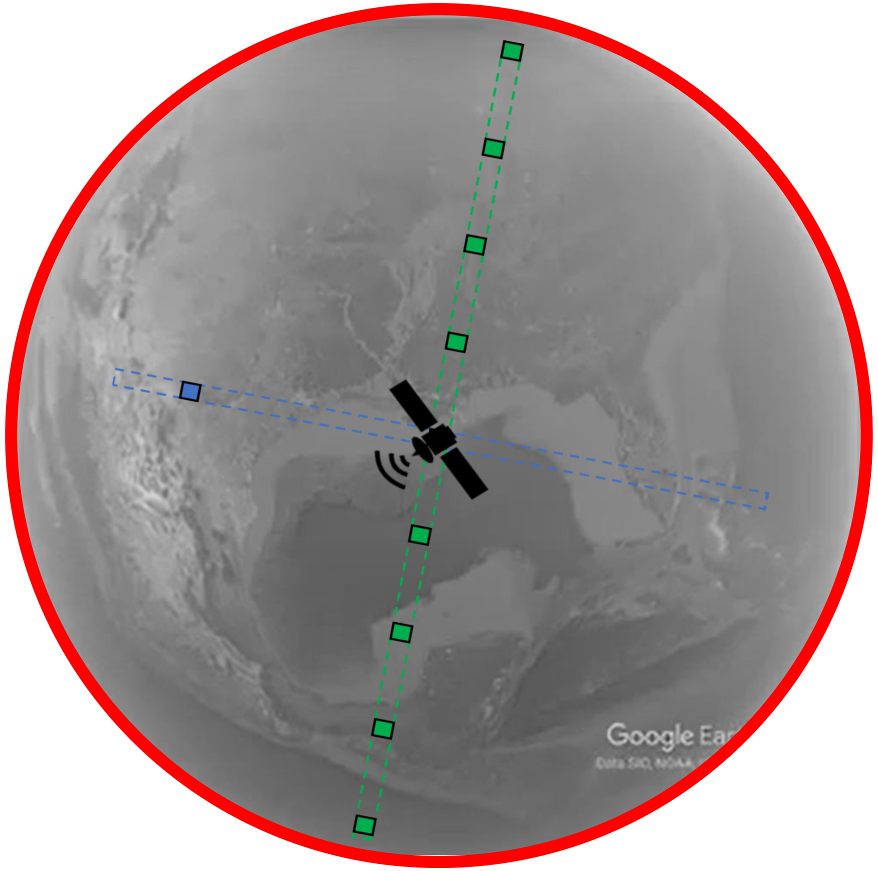
Libera’s split-shortwave ADM approach

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]

Instantaneous angular sampling



Credit: Stephane Beland

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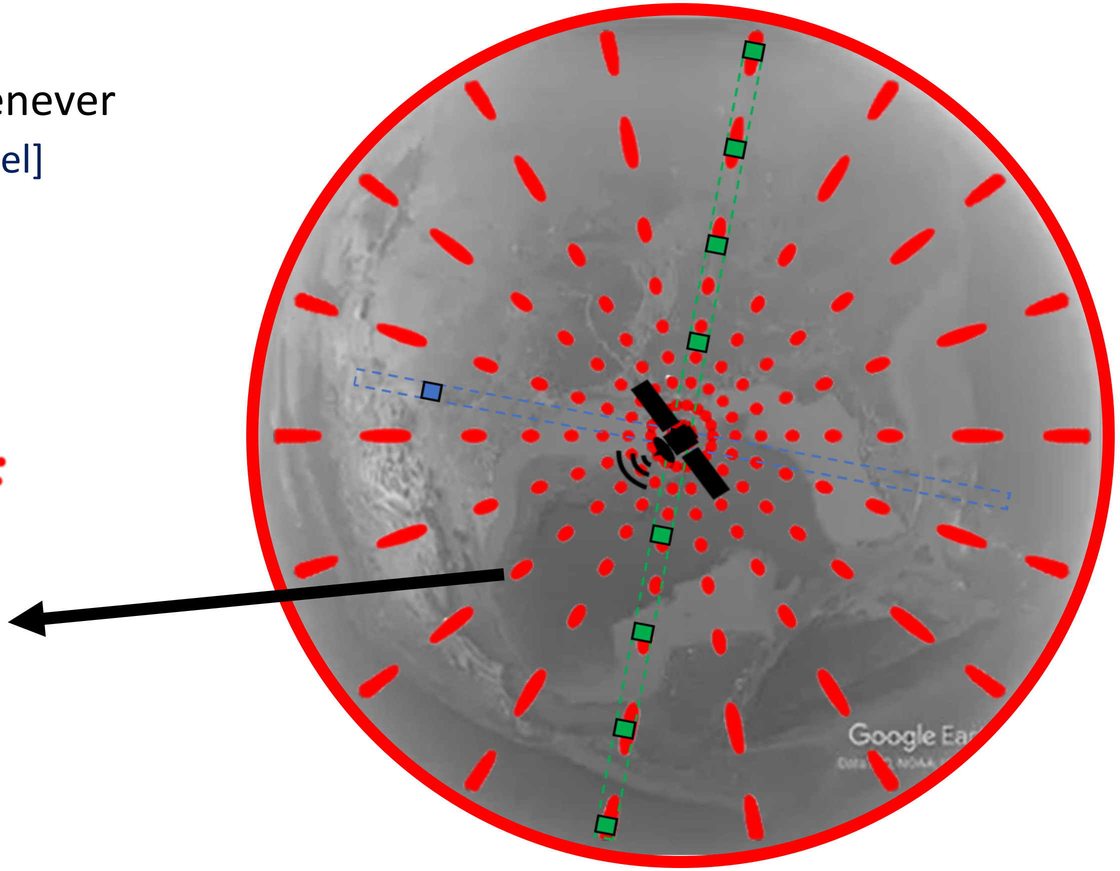
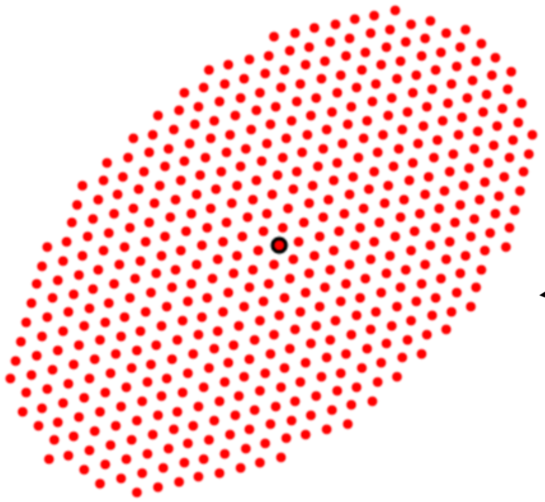
Instantaneous angular sampling

MODIS/VIIRS (cross track scan)
MISR (9 fixed angles)

Libera WFOV camera
(entire Earth disk)



Convolve with Libera Point Spread Function



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Compromise: focus on ERBE-like ADMs (initially)

	Cloud fraction	Surface type
1	Clear-sky (0-5%)	Ocean
2	↓	Land
3		Snow
4		Desert
5		Land-ocean mix
6	Partly cloudy (5-50%)	Ocean
7	↓	Land or desert
8		Land-ocean mix
9	Mostly cloudy (50-95%)	Ocean
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11		Land-ocean mix
12	Overcast	All

Suttles et al. , NASA Tech Rep, 1988

- 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

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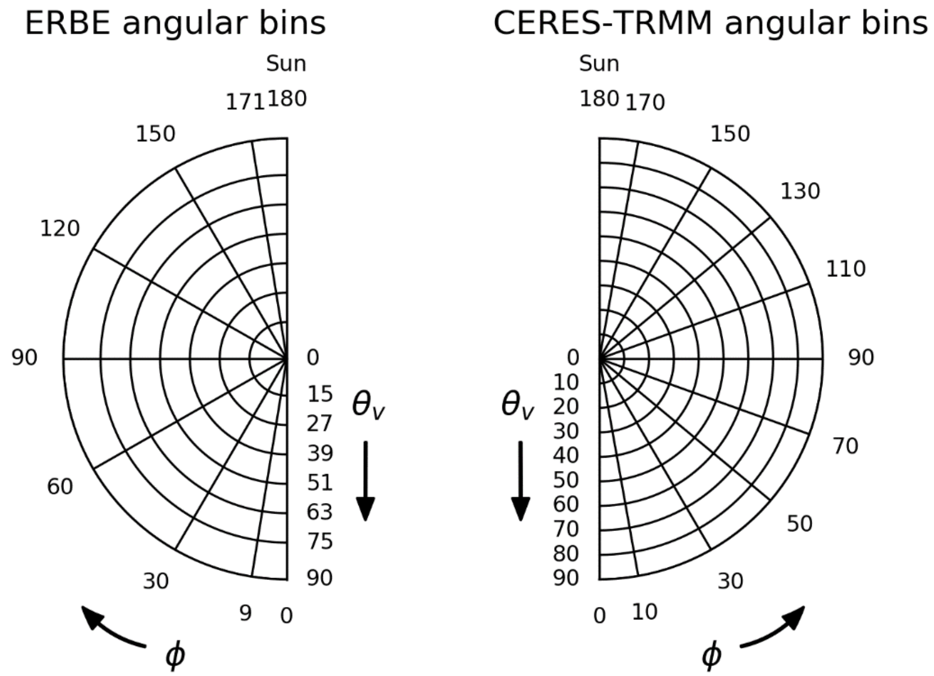
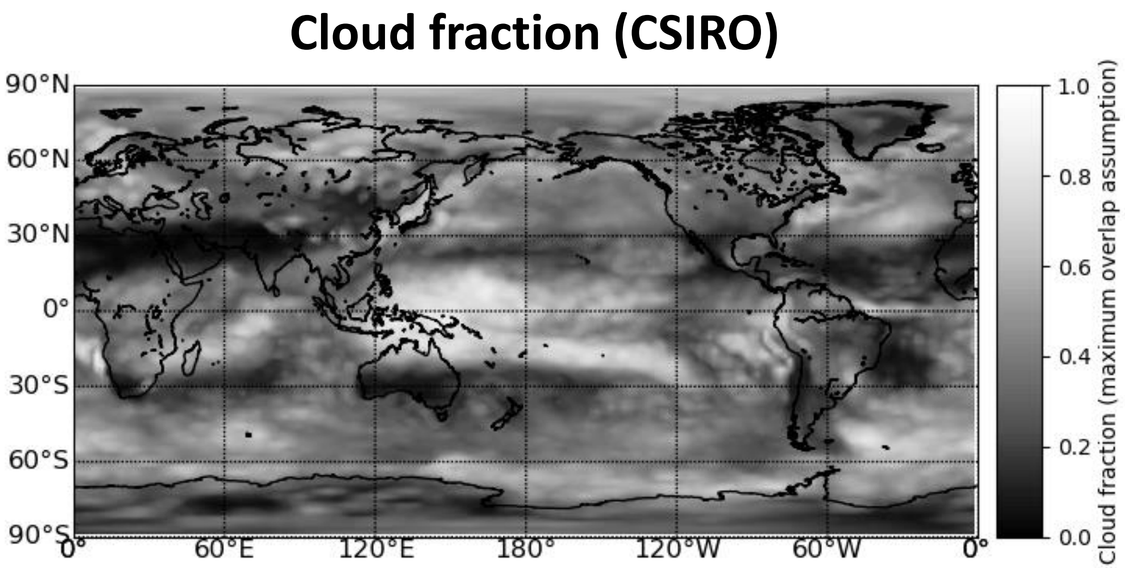
- Solar-viewing geometry
  - ➢ 10 θ_s bins
  - ➢ 7 θ_v bins
  - ➢ 8 ϕ bins
  - ➢ Anticipate finer resolution bins in future



Optimizing the Libera camera for ADMs: OSSE data



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

Credit: Dan Feldman

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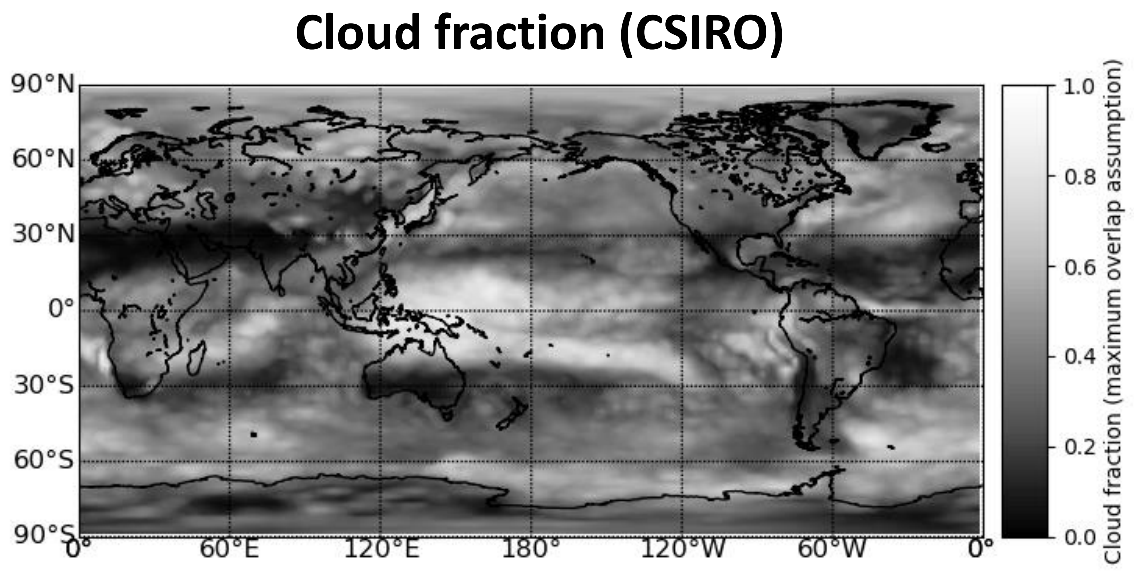

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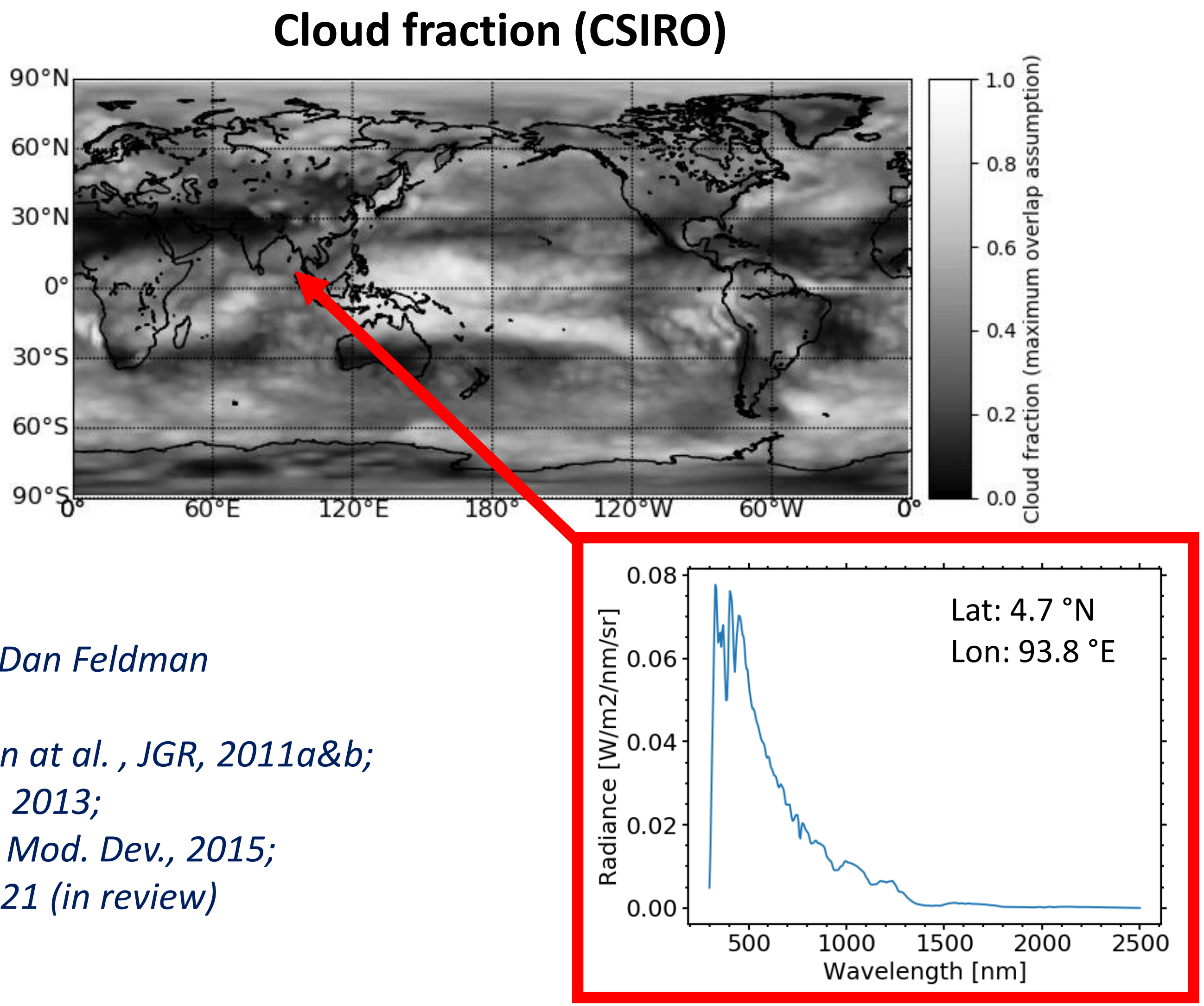

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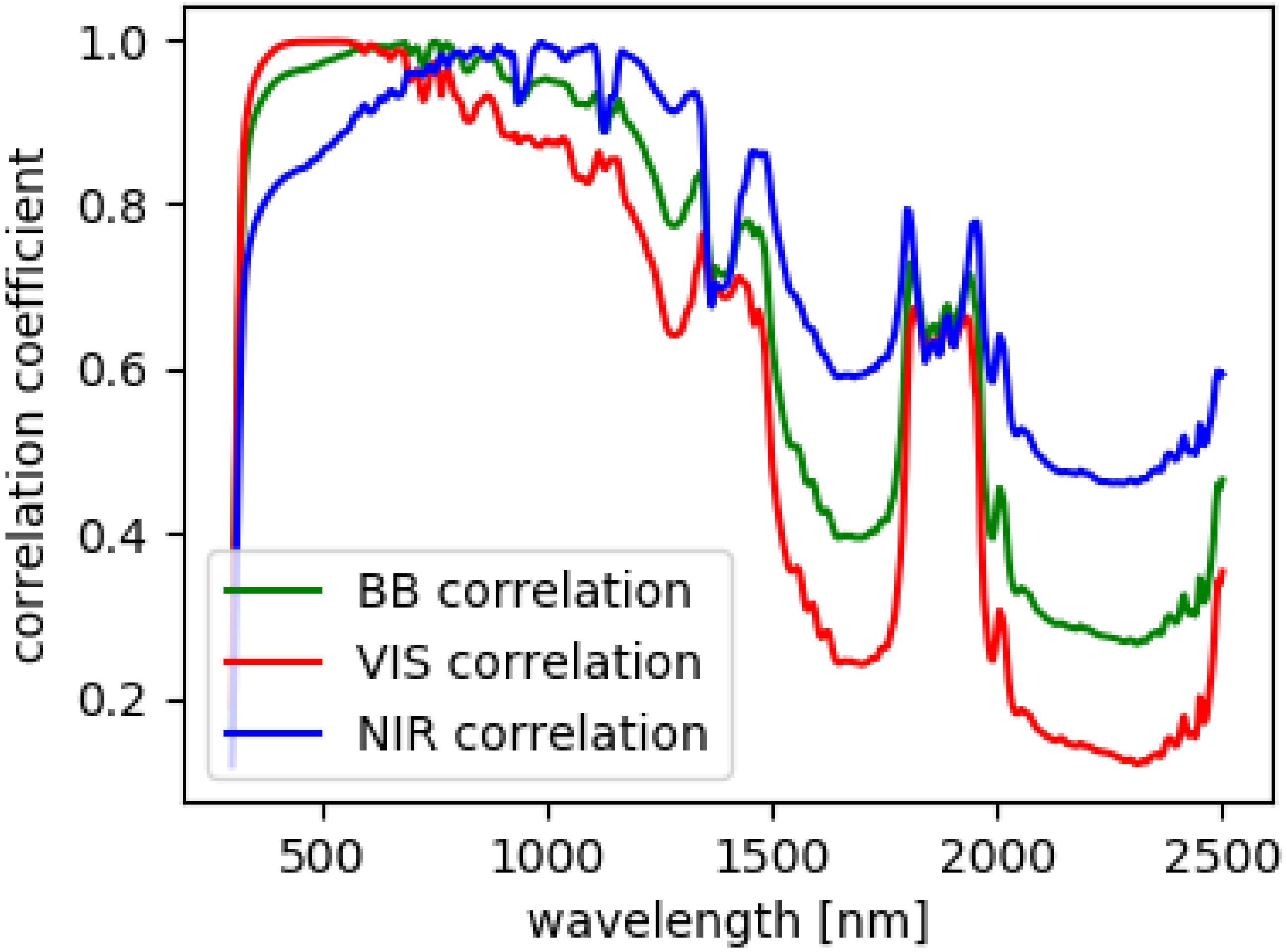
Camera wavelength: high correlation with sub-band

Note: nadir only



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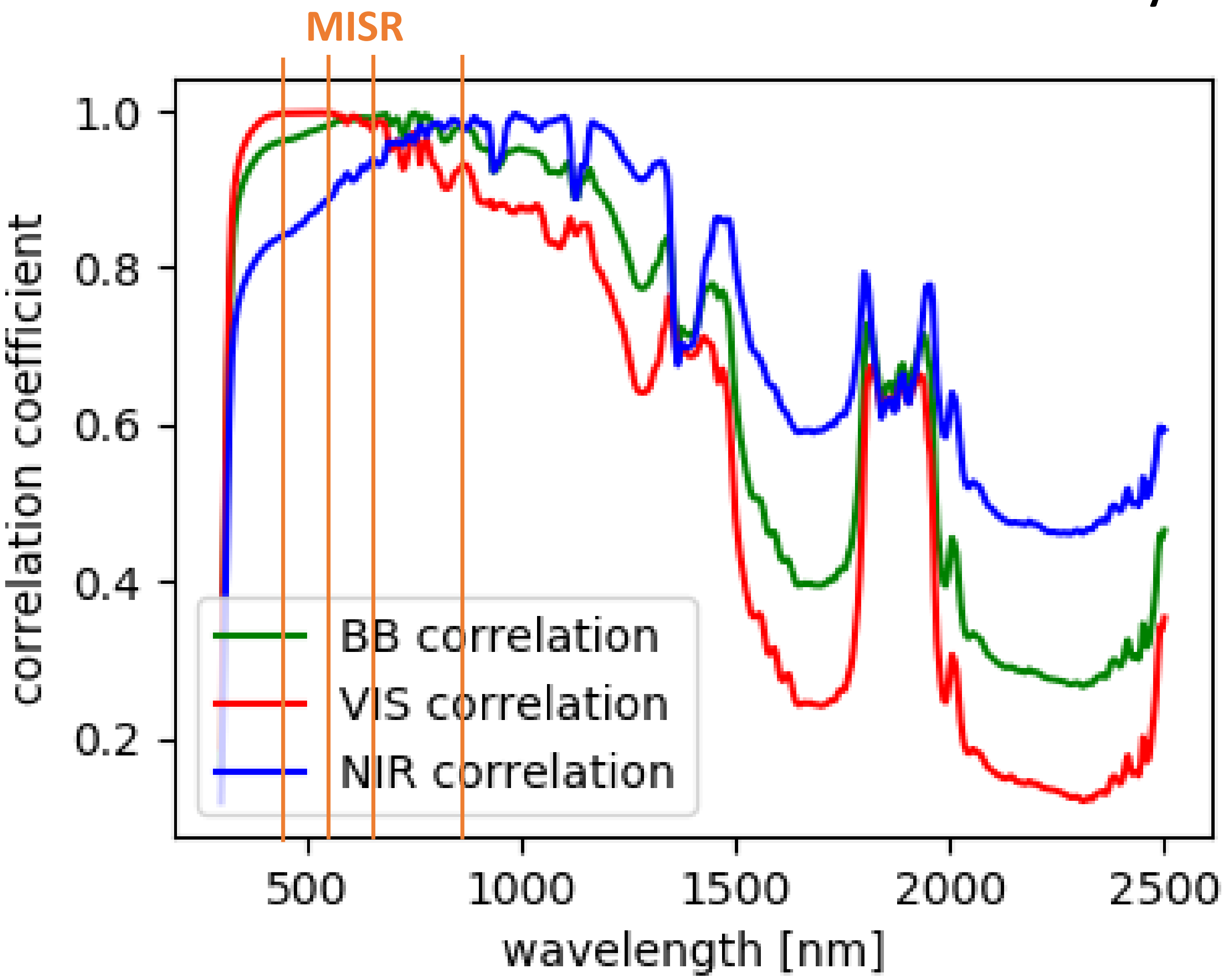

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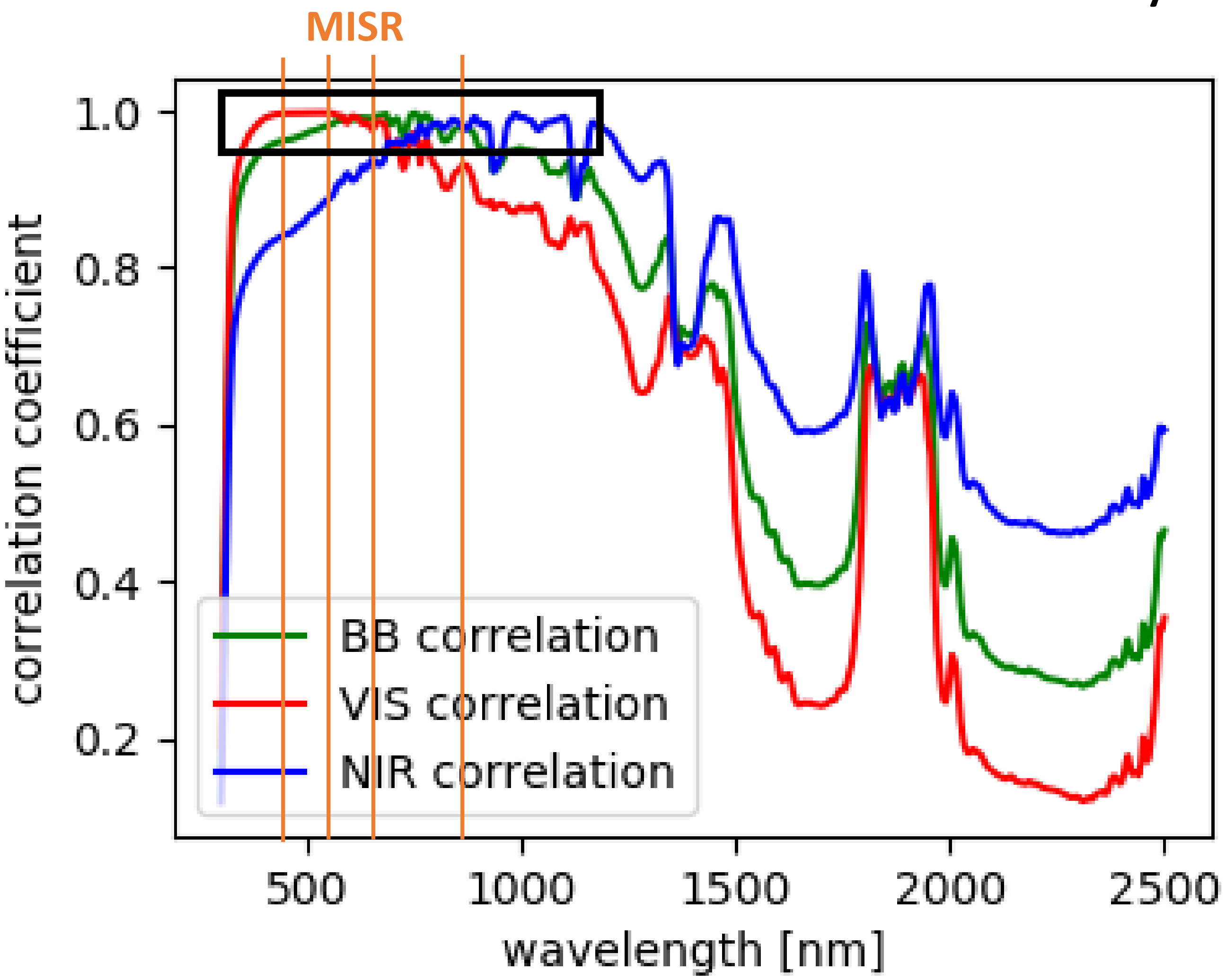

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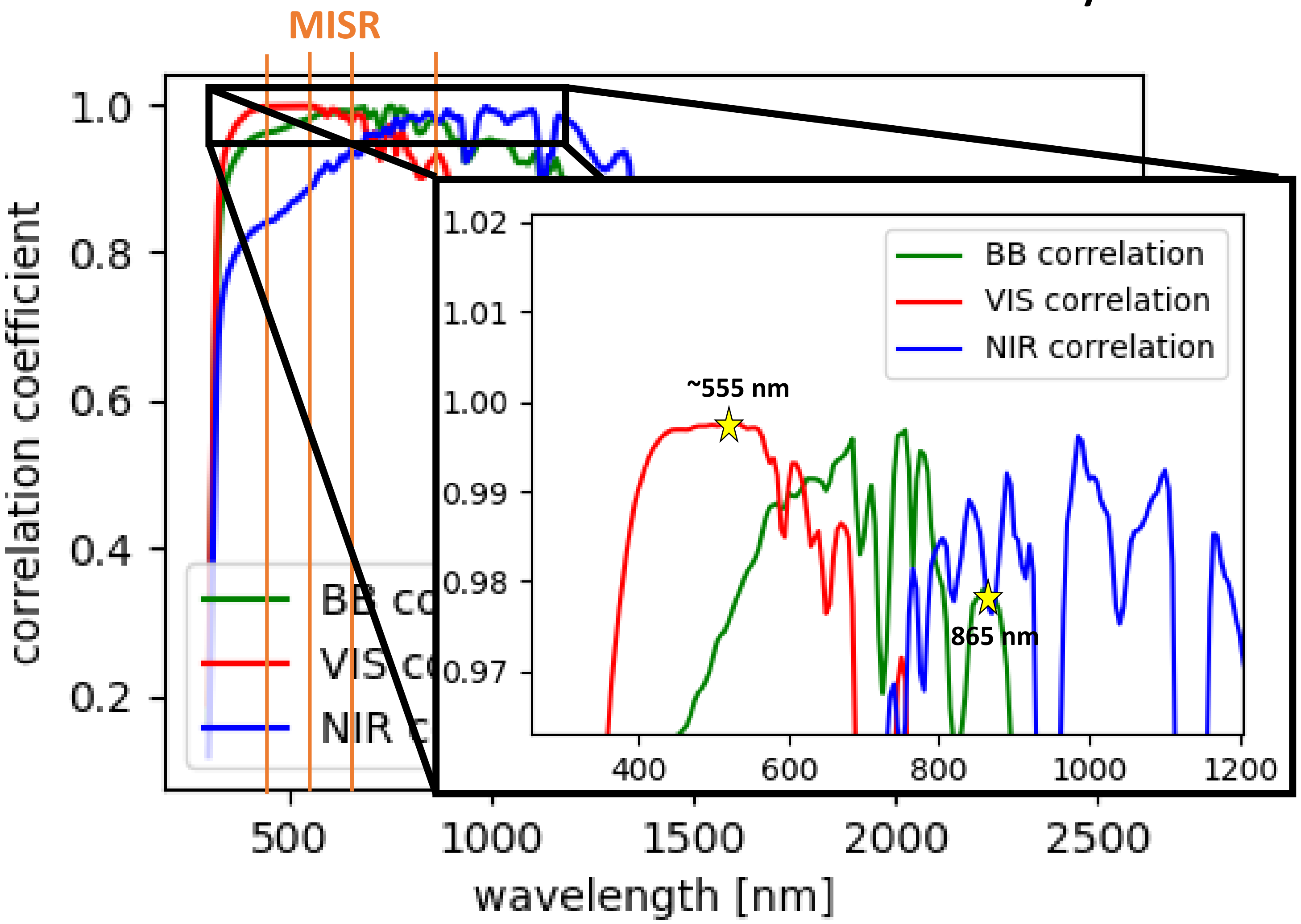

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- MISR 865 nm correlates well with CERES total SW
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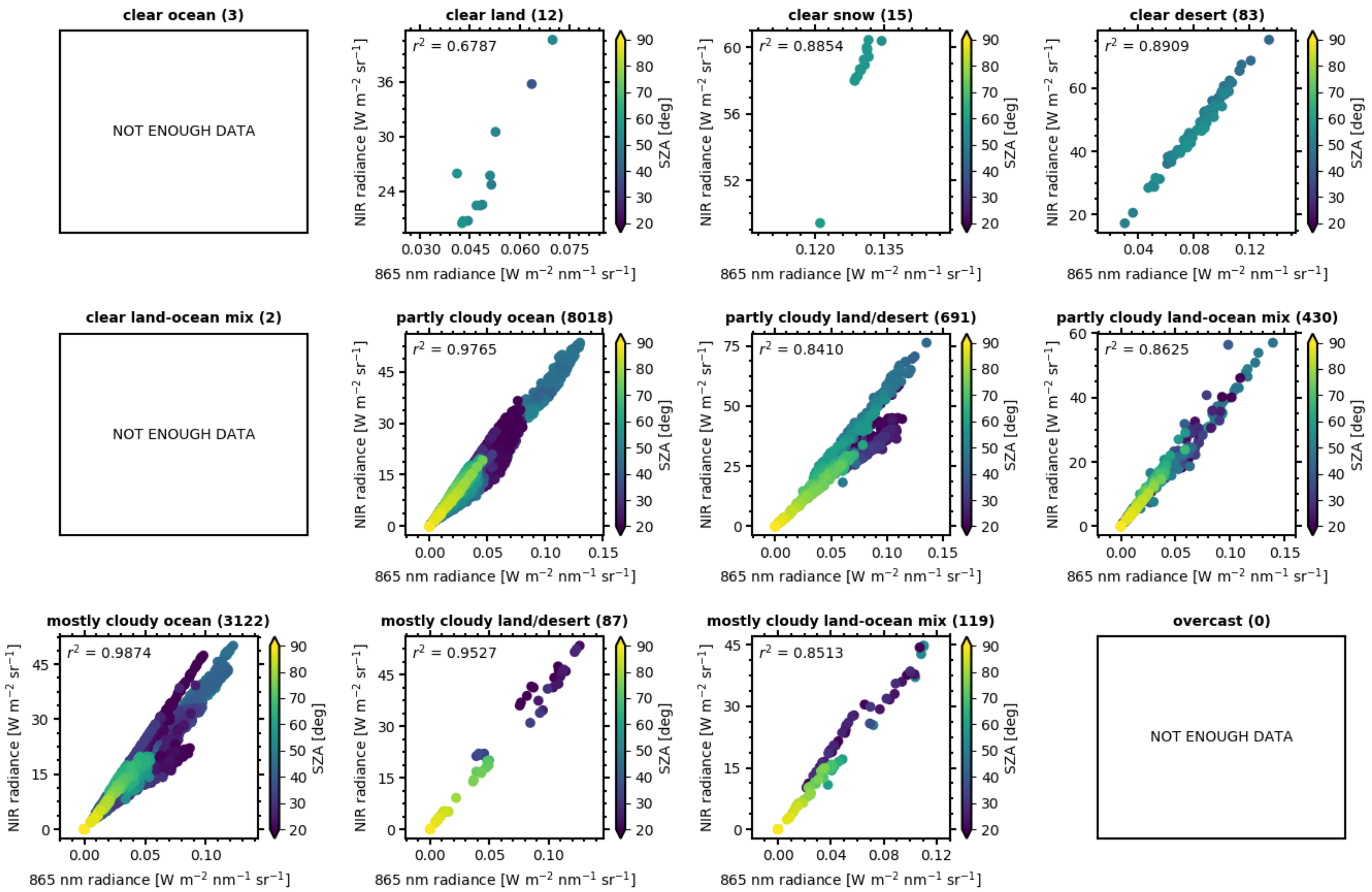
- Initial OSSE data here suggests 865 nm may not be optimal for NIR
  - ➢ Highest correlation is ~555 nm with VIS

Correlations by scene type: 865 nm vs. NIR

Note: nadir only



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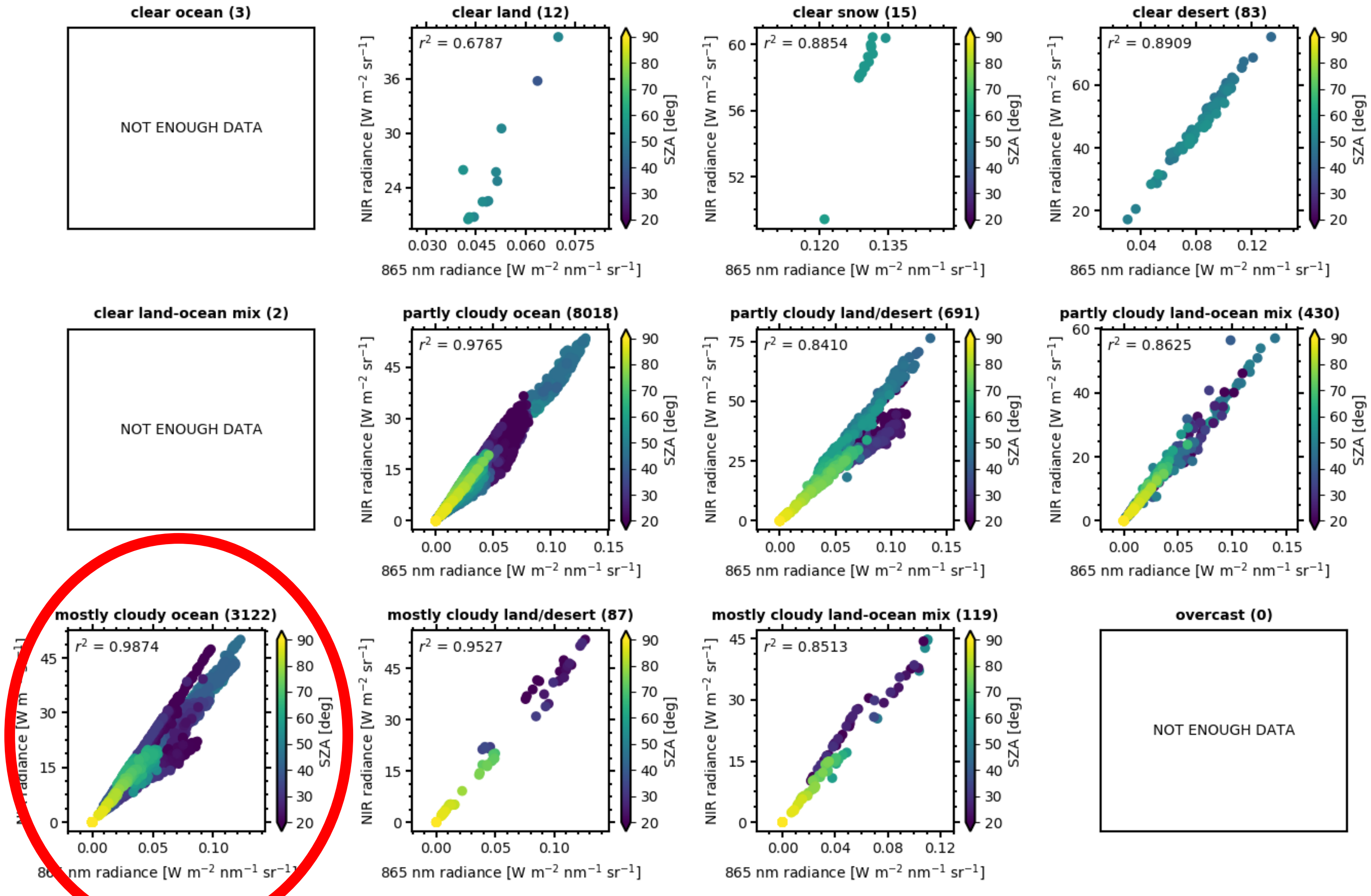

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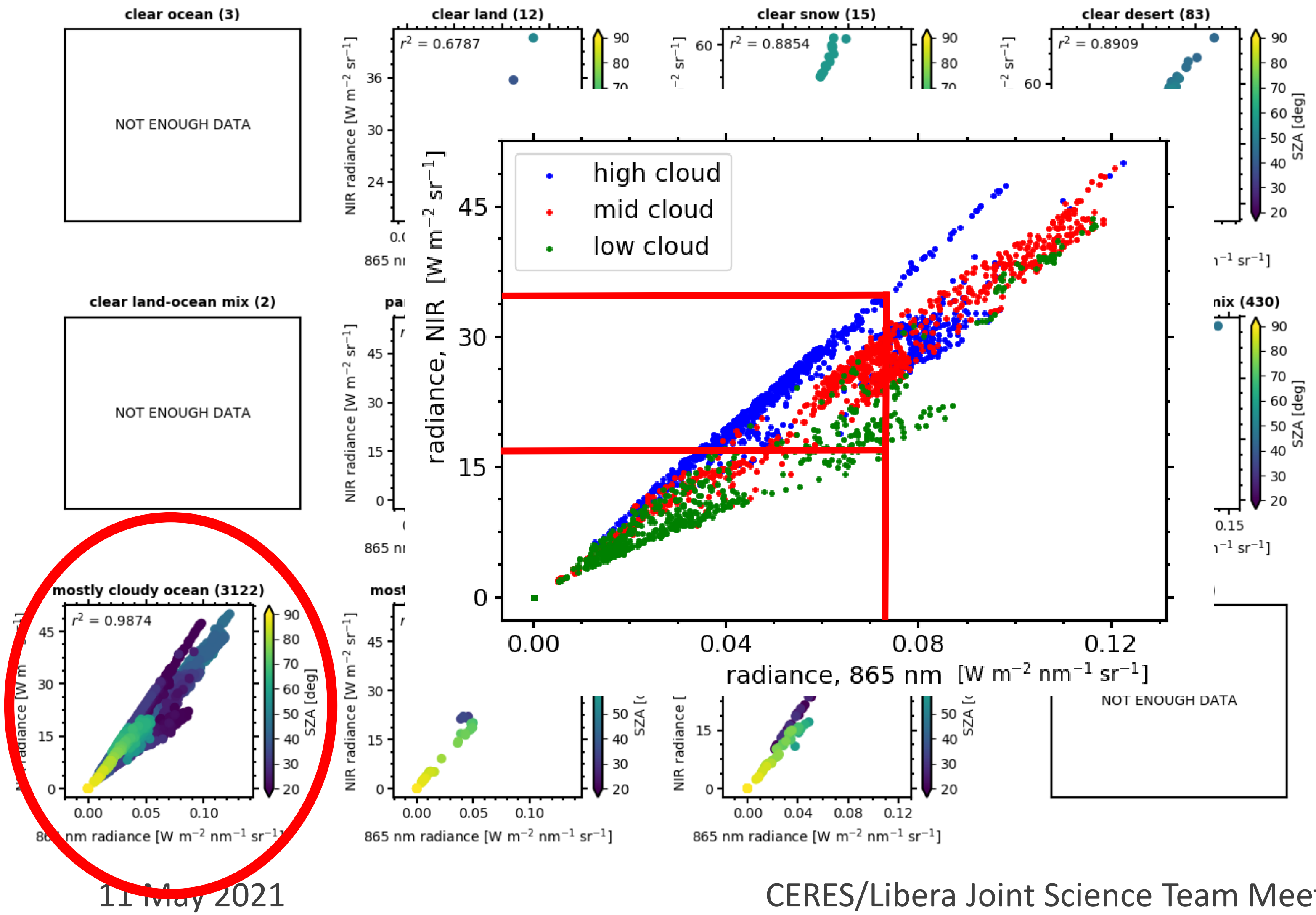

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- Conversion between camera wavelength -> sub-band should be a function of scene type and solar geometry
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  - Above cloud water vapor
  - Cloud height (phase)

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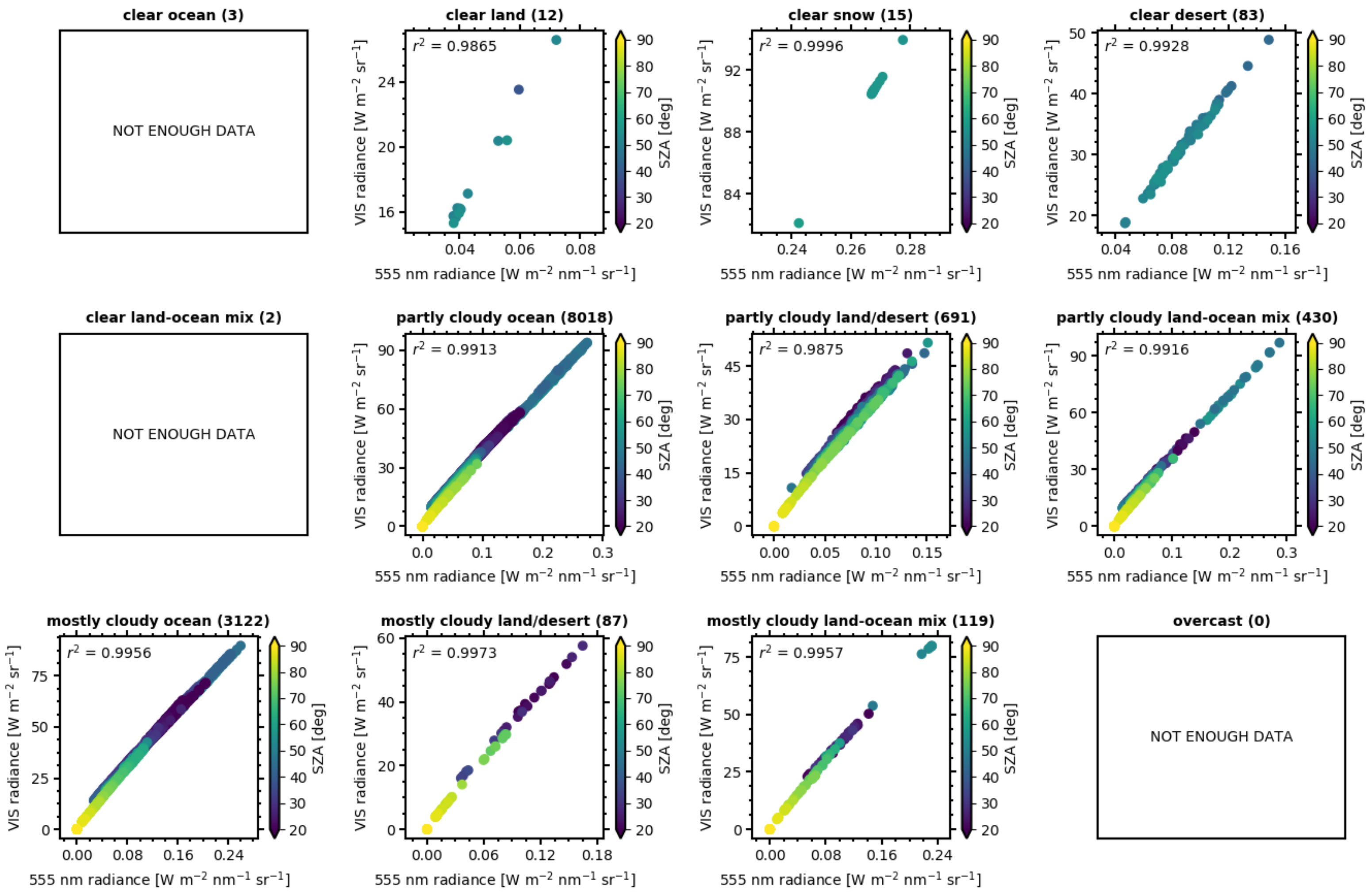
Correlations by scene type: 555 nm vs. VIS

Note: nadir only!



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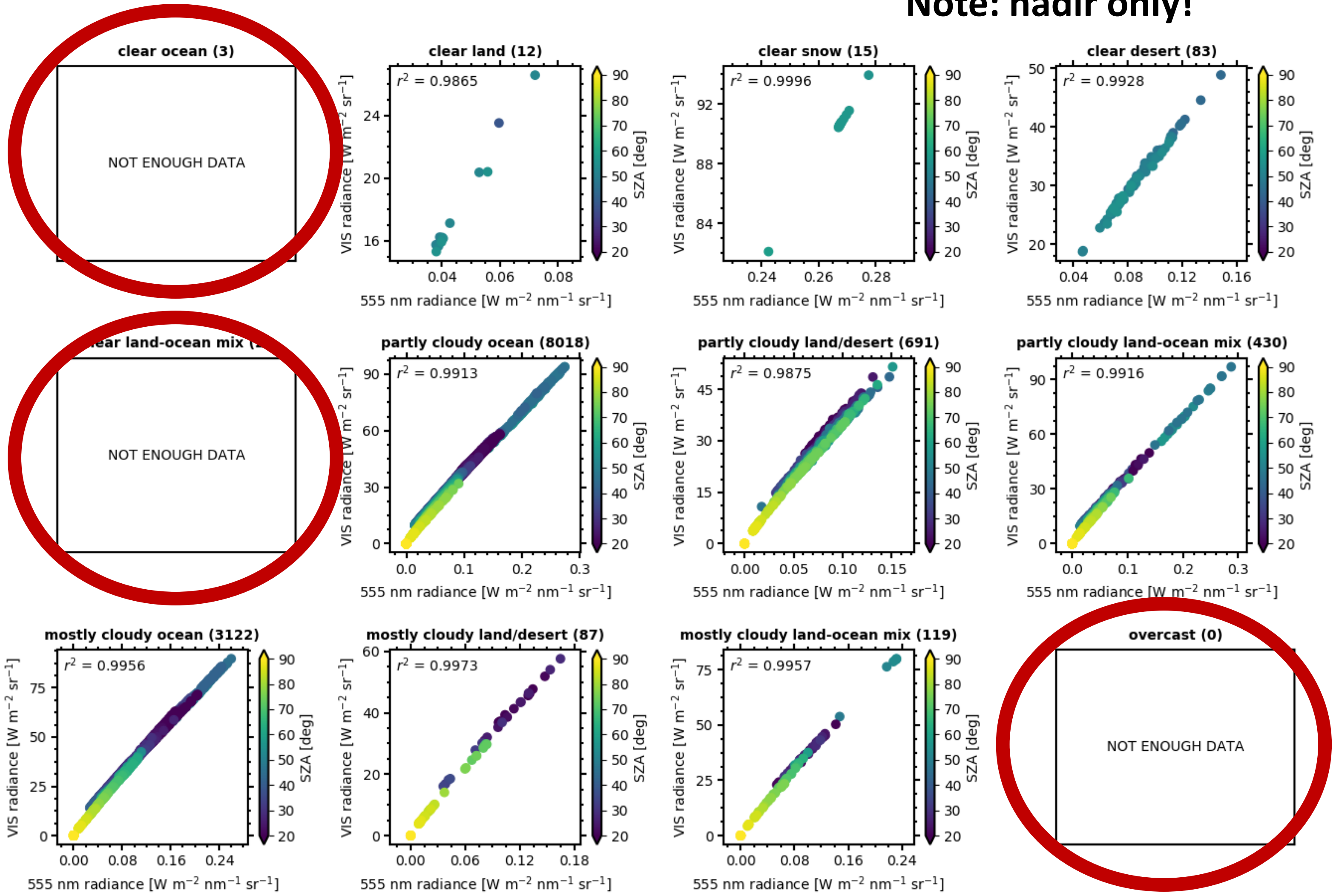

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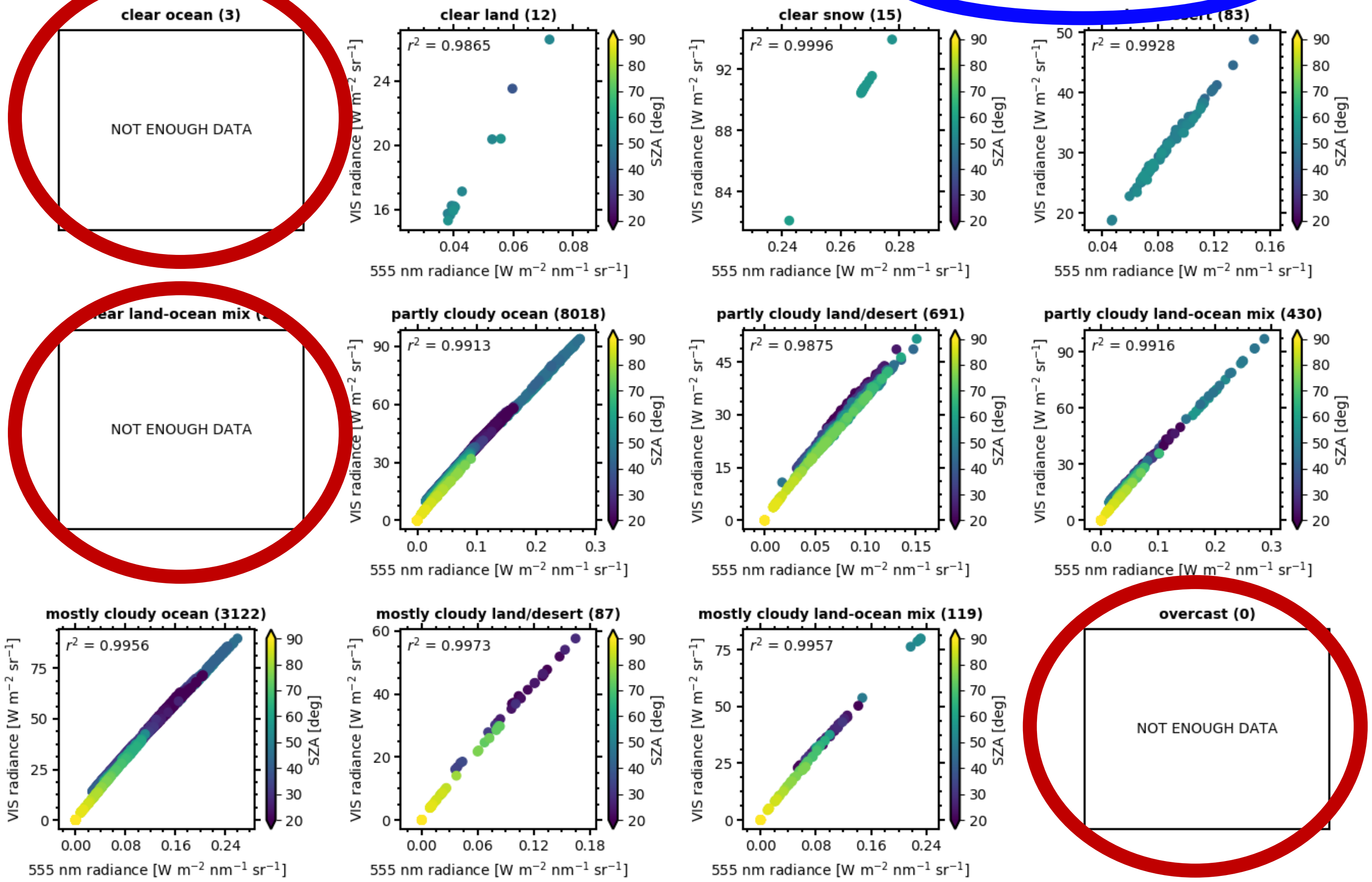

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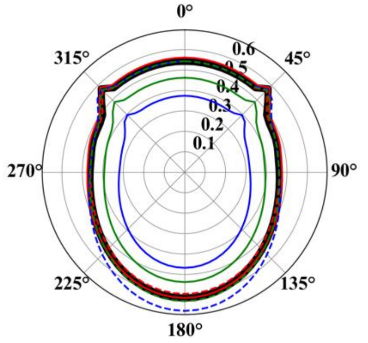
  - Monthly-mean, ~1 deg
- Issue 2: angular variability



530 nm
VIS
NIR
TOTAL SW

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?

Jake.J.Gristey@noaa.gov

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?

NIR flux = SW flux - VIS flux ← Directly derived with new ADMs

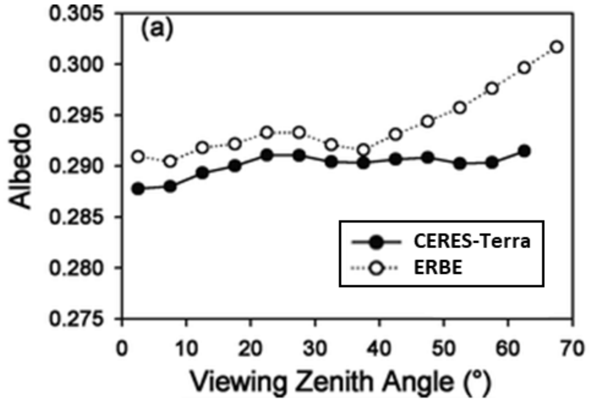
Wait for RBSP SW flux? ✗ relies on imager

Calculate new ERBE-like SW or NIR ADMs from camera? ✗ camera not a good proxy

Use existing ERBE SW ADMs? ✓ yes, but expect larger uncertainty →

Determine CERES-like scene type using machine learning? ✓ maybe..

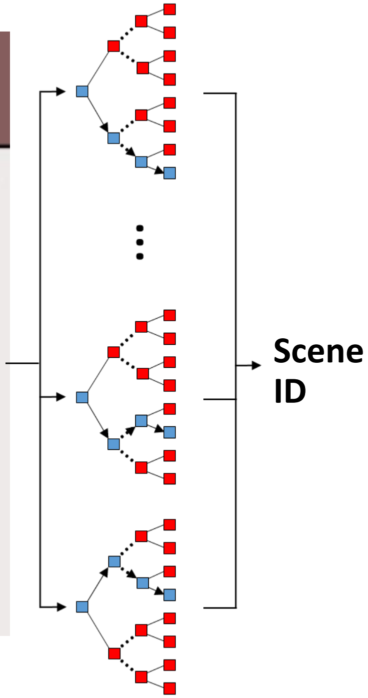
Loeb et al., JAOT, 2007



Machine learning CERES-like scene type

Input Variables

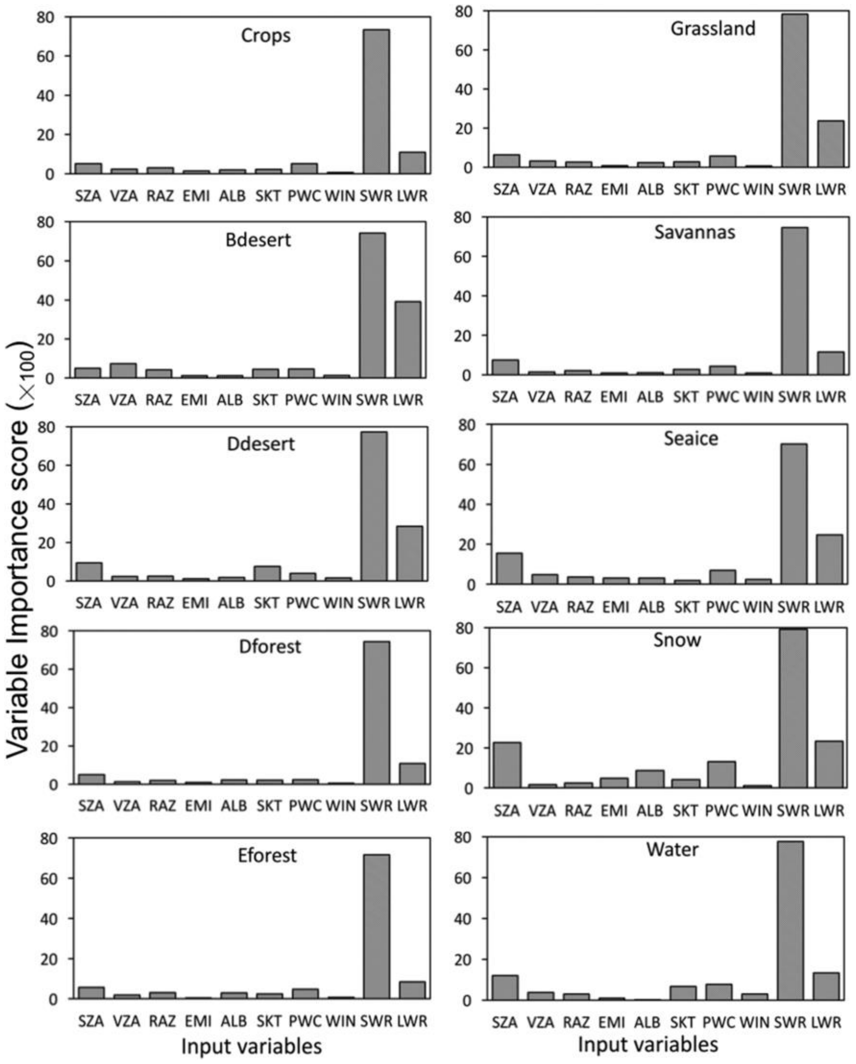
- Solar & viewing zenith- angles
- Relative azimuth angle
- CERES Shortwave (SW) and Longwave (LW) broadband radiances
- LW surface emissivity
- Broadband surface- albedo
- Surface skin temperature
- Precipitable water



Thampi et al., JAOT, 2017

TABLE 4a. RF (daytime) modified misclassification rate (%) estimated for the calendar months of January and July (2013–14).

Surface type	January		July	
	Clear	Cloud	Clear	Cloud
bdesert	5.0	5.1	4.2	5.1
crops	0.2	0.5	0.2	0.2
ddesert	1.4	2.4	1.1	2.4
dforest	0.3	0.1	1.8	0.2
eforest	0.1	0.0	0.7	0.0
grass	1.4	2.9	0.4	1.6
savannas	0.6	0.4	0.1	0.2
seaice	0.4	2.5	3.1	1.1
snow	0.4	7.0	0.2	2.5
water	0.0	0.0	0.0	0.0



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

Machine learning CERES-like scene type

Input Variables

Solar & viewing zenith- angles

Relative azimuth angle

CERES Shortwave (SW) and Longwave (LW) broadband radiances

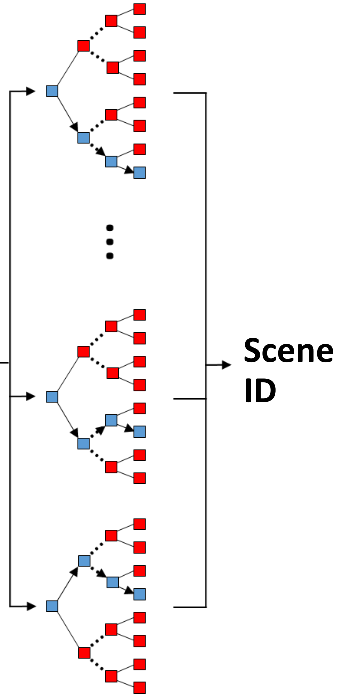
~~LW surface emissivity~~

~~B~~

~~S~~

~~Precipitable water~~

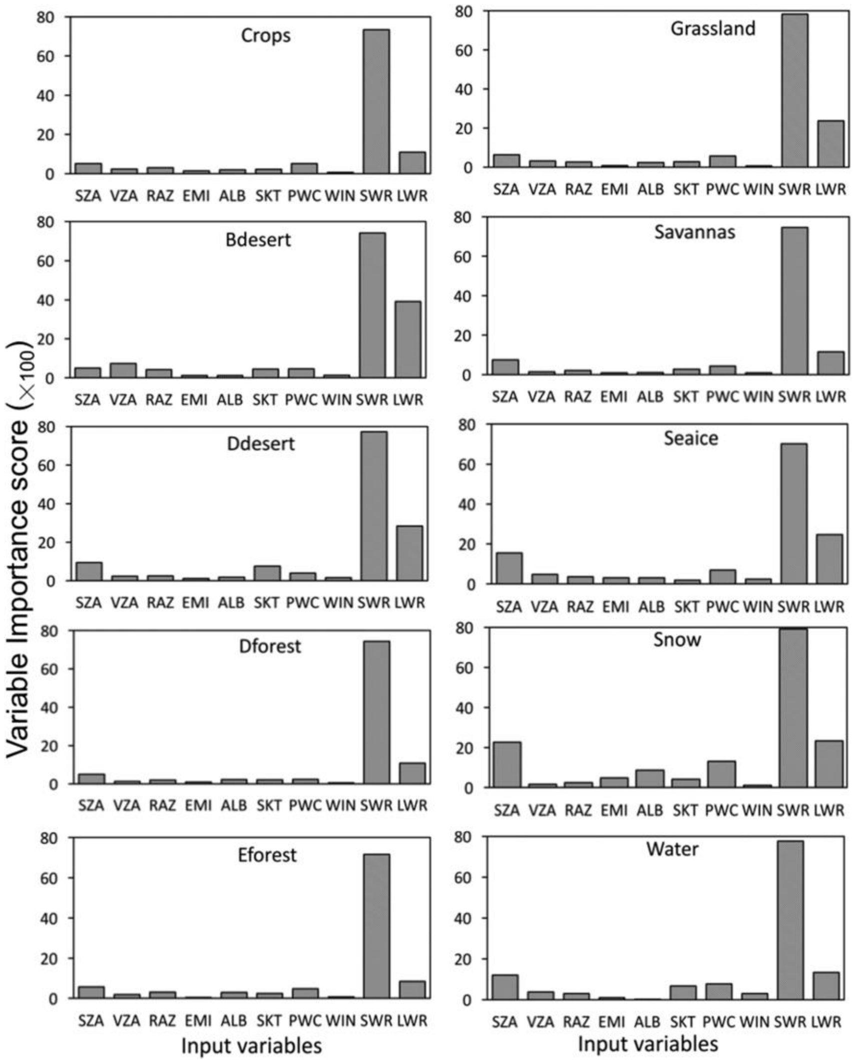
Split SW radiance & Camera pixel radiances (~400)



Thampi et al., JAOT, 2017

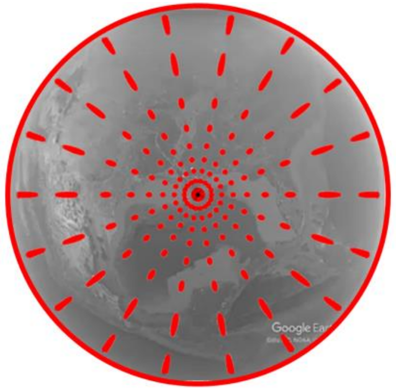
TABLE 4a. RF (daytime) modified misclassification rate (%) estimated for the calendar months of January and July (2013–14).

	January		July	
Surface type	Clear	Cloud	Clear	Cloud
?				

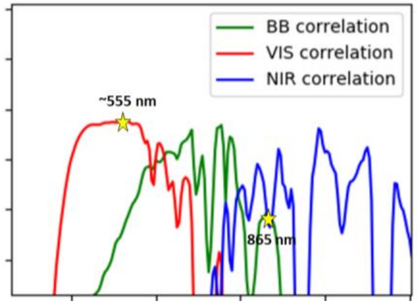


- Scene type predicted with ~95% accuracy for almost all scenes, many scenes >99% (excludes very thin cloud)
- Footprint radiances are most important; adding camera radiances (ie. imaging of the footprint) should yield further improvements

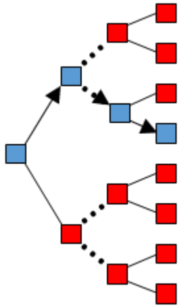
Summary and conclusions



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



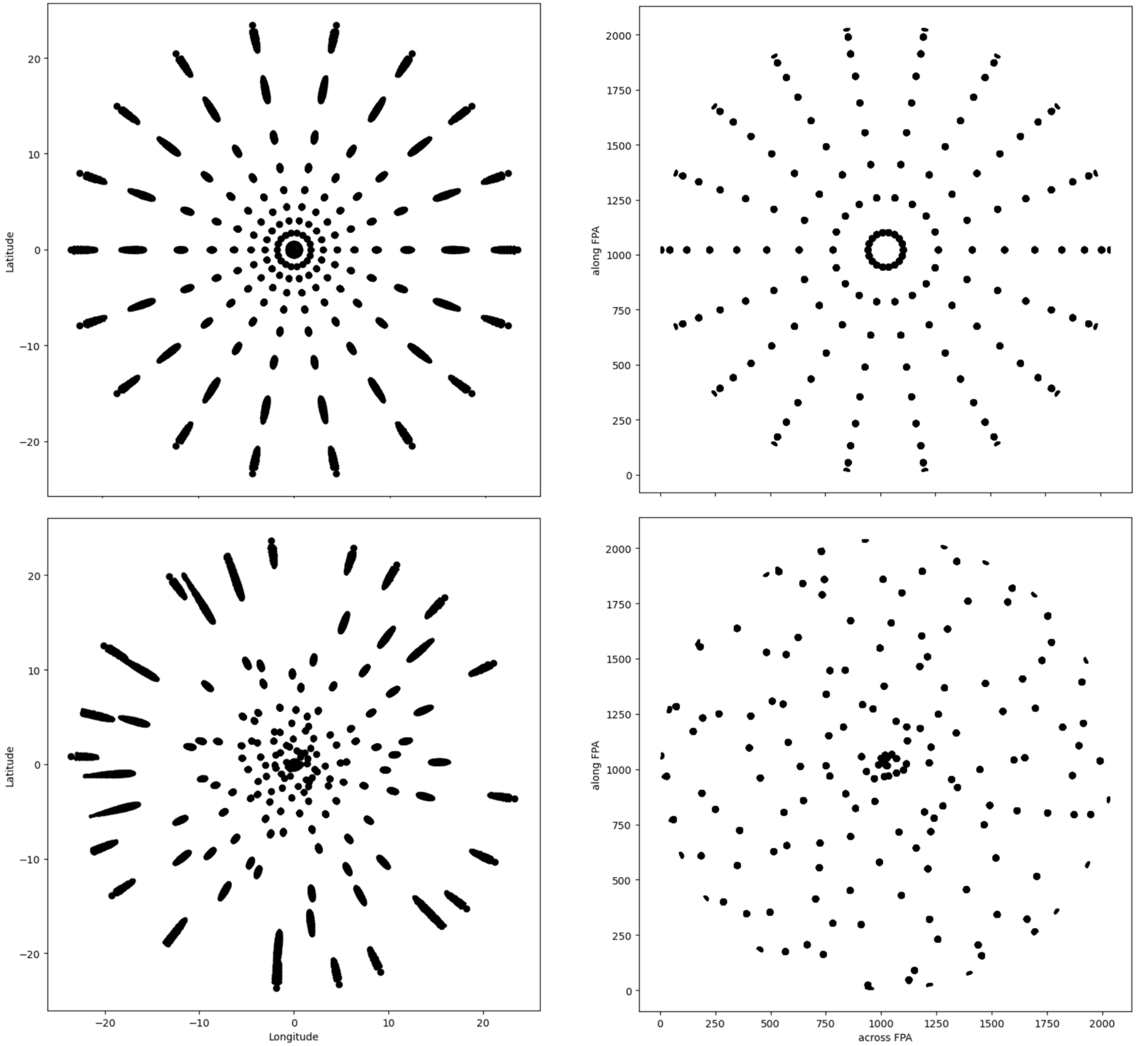
- A camera wavelength of 555 nm is optimal for VIS ADMs, which are well suited to simpler ERBE-like scene types



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

Camera angular sampling

extra



- 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

extra

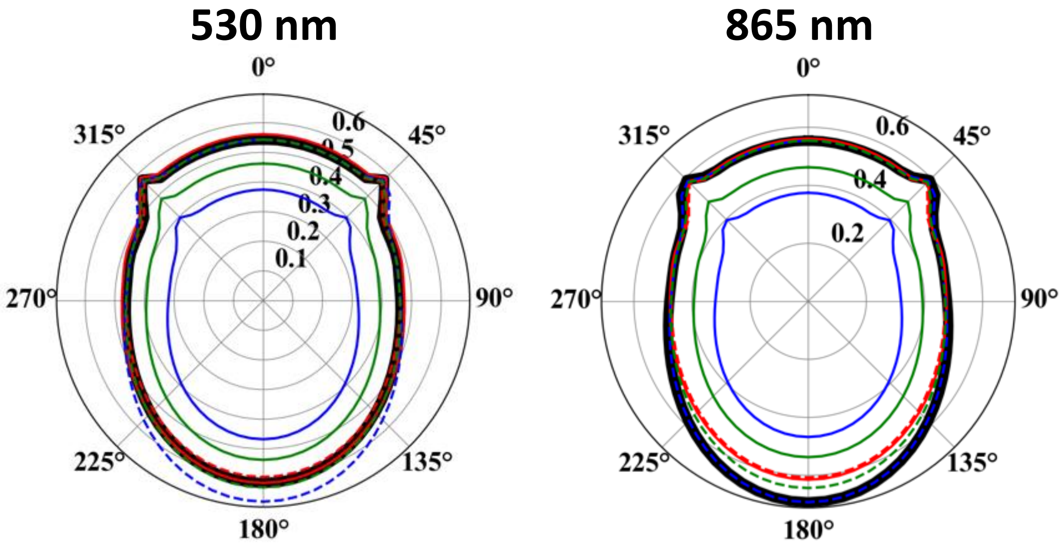
- Is a single wavelength sufficient to capture angular distribution?
  - Cloud (τ=10) over ocean
  - θ_s=20°
  - θ_V=45°

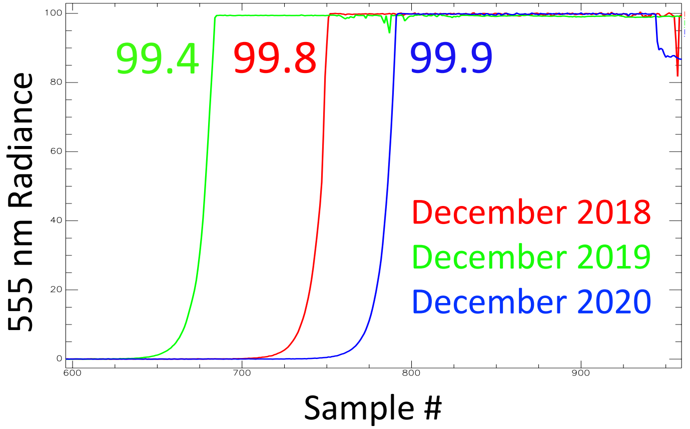
Credit: Sebastian Schmidt, Hong Chen

VIS

NIR

TOTAL SW





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

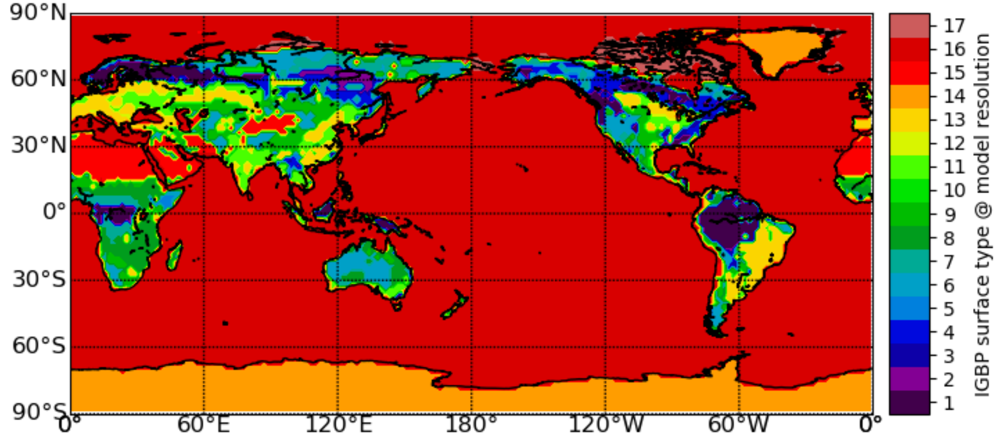
$$R_{i,j} = \frac{\pi \overline{I_{i,j}}}{F}$$

Credit: Bruce Kindel

ERBE scene type from OSSEs

extra

Surface type (IGBP)



Cloud fraction (CSIRO)

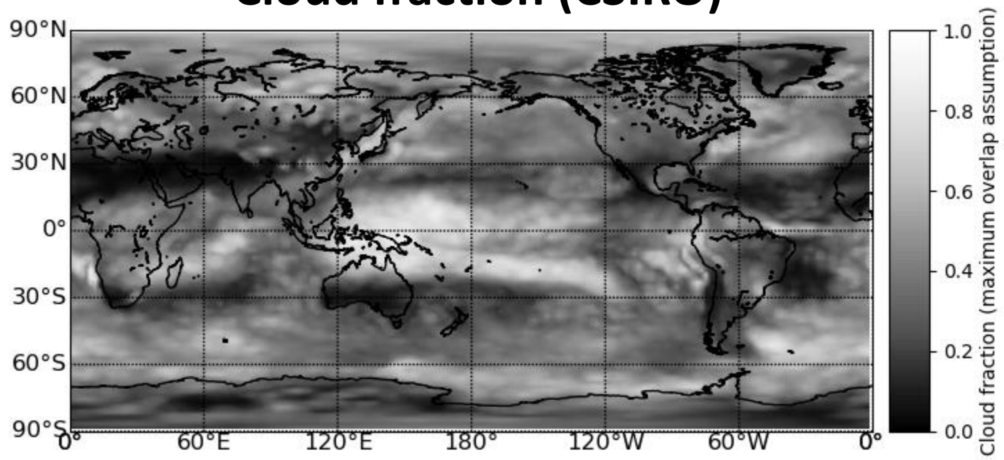


Table 1. Scene Types for Angular Models

Scene	Cloud coverage, percent
Clear over ocean	0 to 5
Clear over land	↓
Clear over snow	
Clear over desert	
Clear over land-ocean mix	
Partly cloudy over ocean	5 to 50
Partly cloudy over land or desert	5 to 50
Partly cloudy over land-ocean mix	5 to 50
Mostly cloudy over ocean	50 to 95
Mostly cloudy over land or desert	50 to 95
Mostly cloudy over land-ocean mix	50 to 95
Overcast	95 to 100

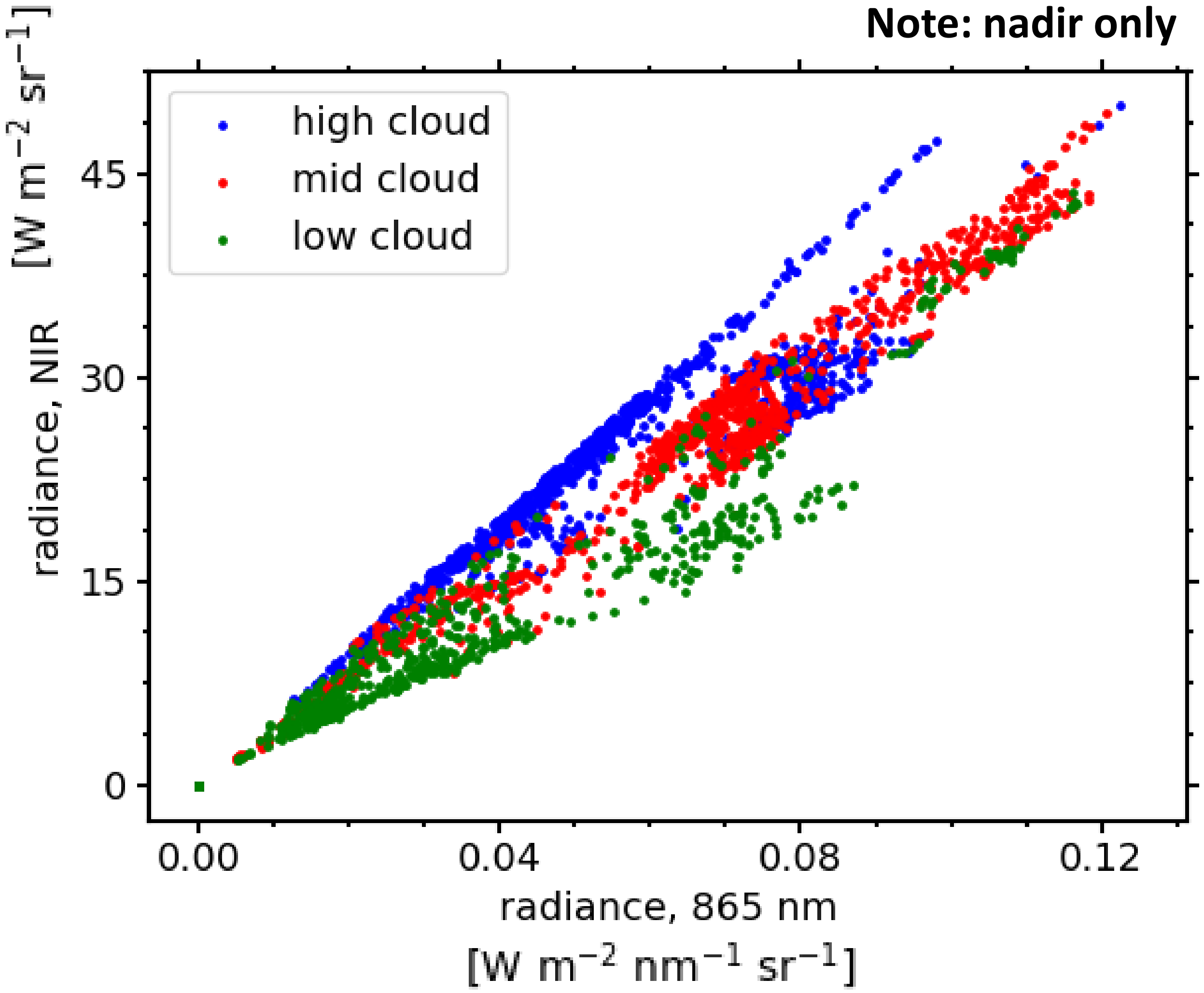
- All surfaces considered “land” except ocean, snow, desert, land-ocean mix
- Only select surface type with >90% in model grid
  - ➢ For land-ocean mix only select 30-70% ocean

 Jake.J.Gristey@noaa.gov

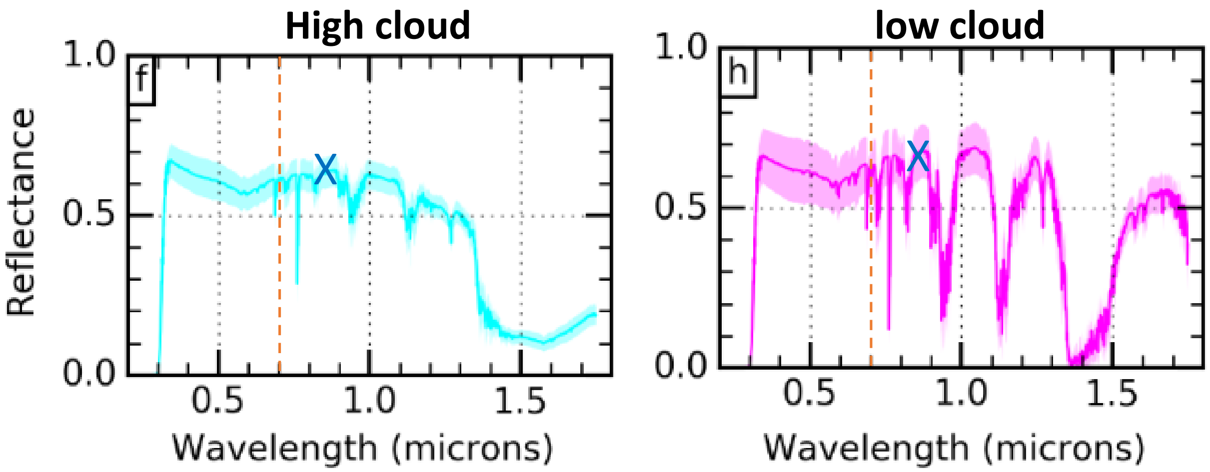
Cloud height separates "arms" very well

extra

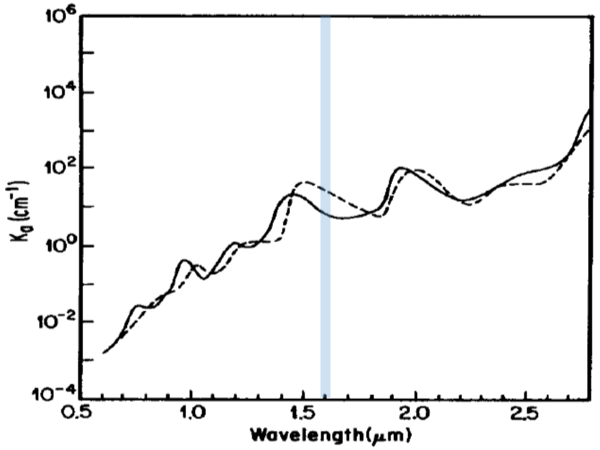
Note: nadir only



Gristey et al., J. Clim., 2019



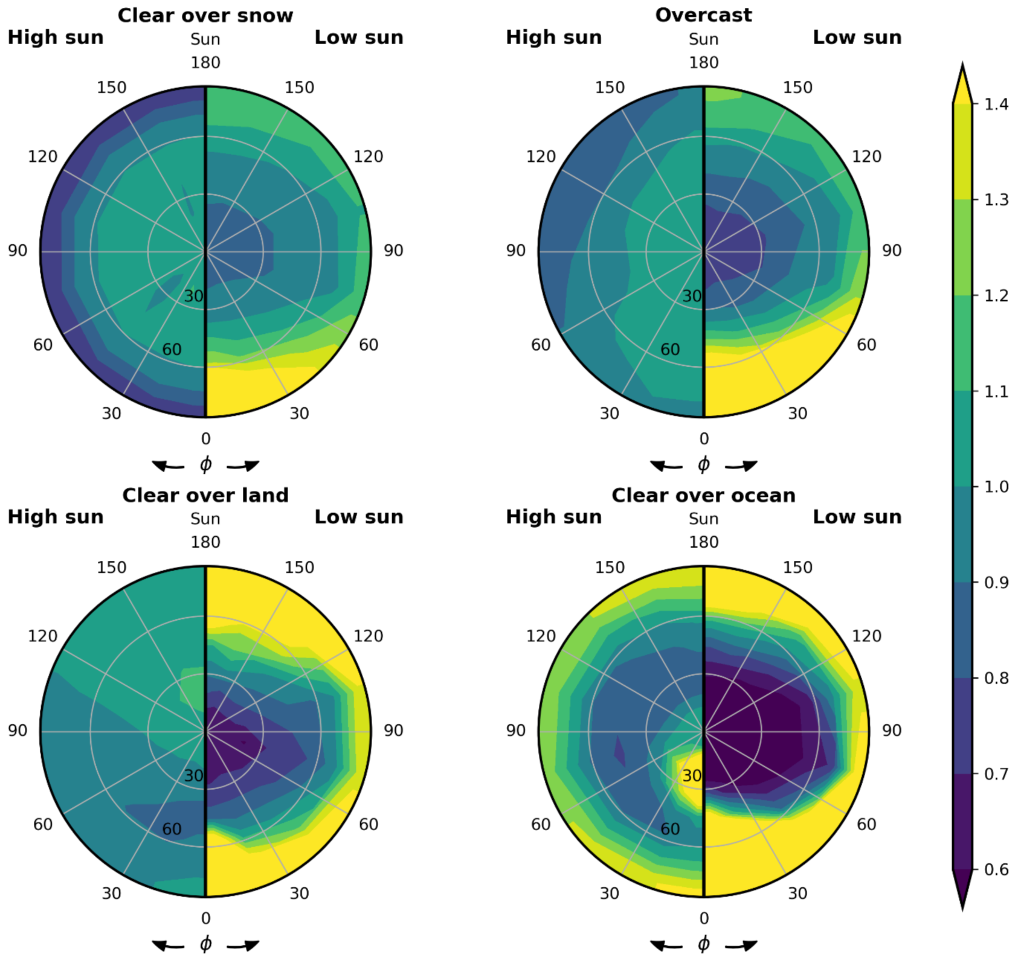
Pilewskie and Twomey, JAS, 1987



Two reasons:

1. *Above cloud water vapor*
2. *Cloud phase*

ERBE SW ADM examples



CERES-TRMM SW ADM examples