Observing Earth's energy balance in the era of the Atmospheric Observing System

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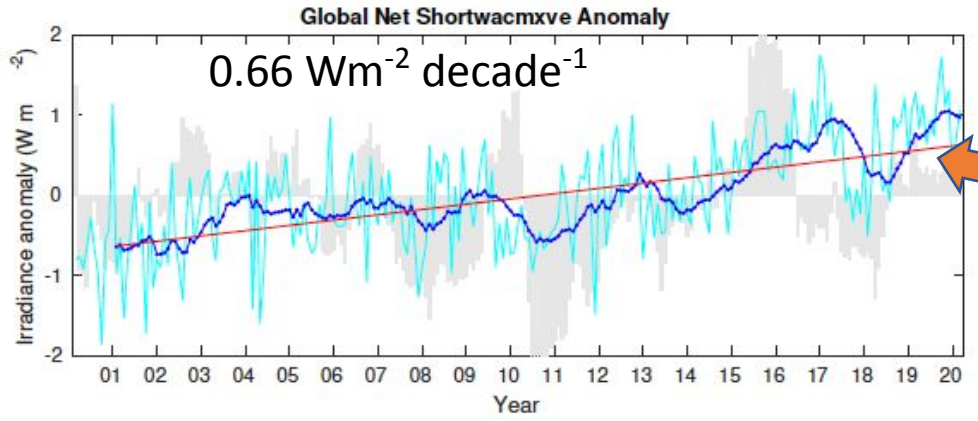
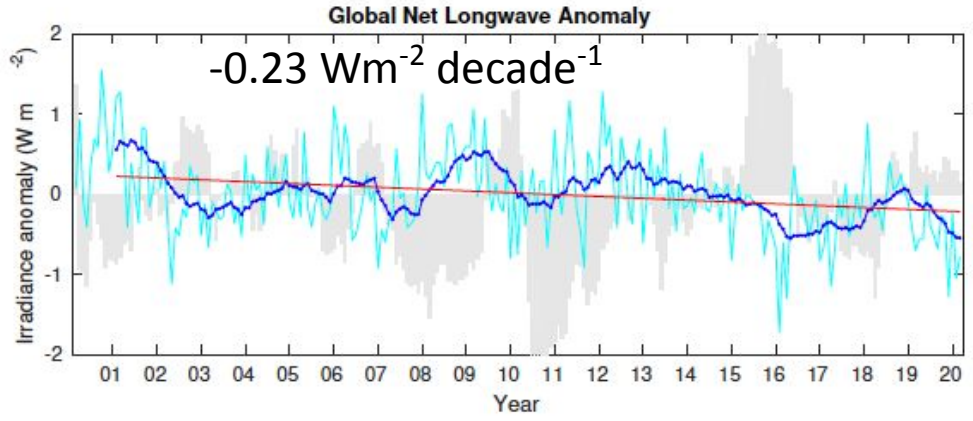
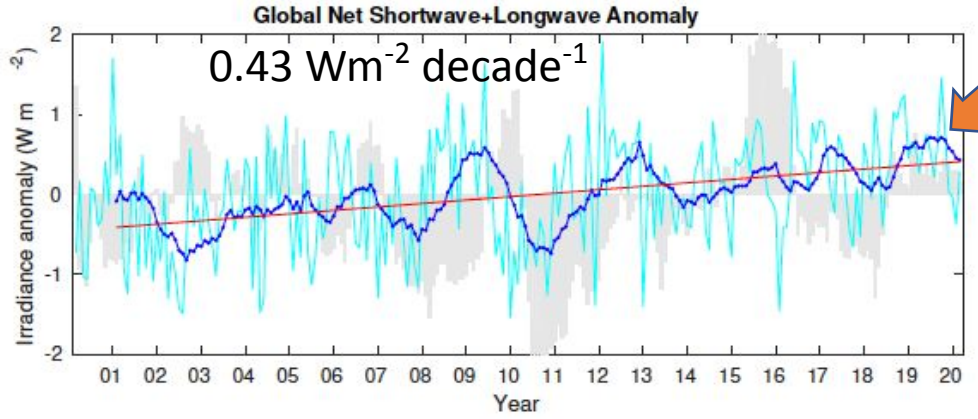
My message:

Measurement of spectrally resolved reflected sunlight is a vitally important and integrative 'Earth system' measurement. It provides insights on the many different ways Earth's energy balance might be and is changing.

Some context







Earth's energy balance appears to be increasing over time

A principal factor in this increase is the reduced reflected sunlight that too has decreased over time

Outline

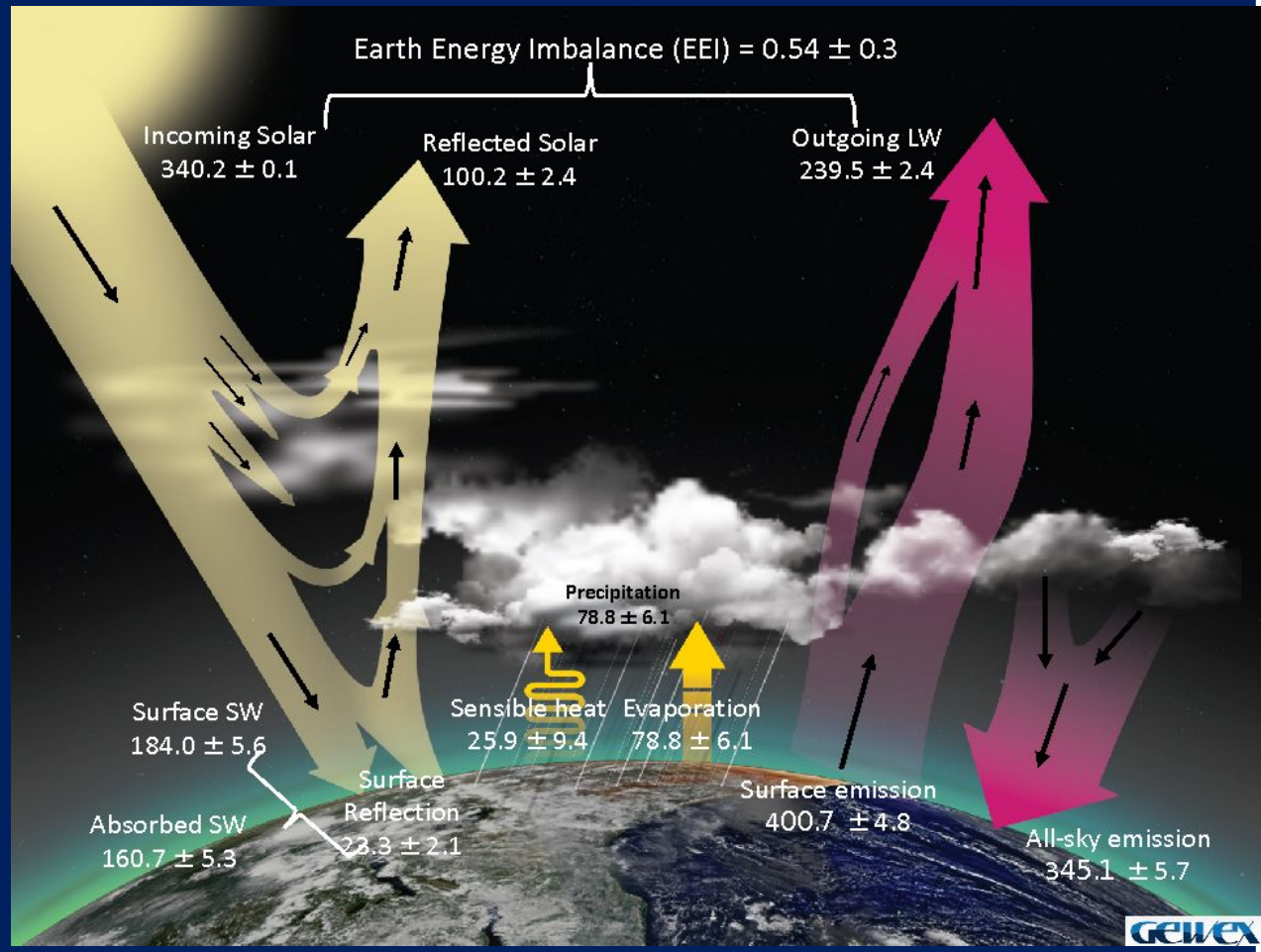
- The elements of an Energy balance observing system
- Why spectral?
  - The Libera split channel vis/nir
  - Other
- The ERB in AOS
  - Objective
  - ‘approach’
- Summary

What might be the elements of a comprehensive Earth energy balance observing system?

1) Broadband fluxes measurements of component fluxes to understand the 'what' of the budget - ERBE: 1984-1990; CERES, 1998 to present; SCARAB mid-nineties, GERB, Libera ~2028

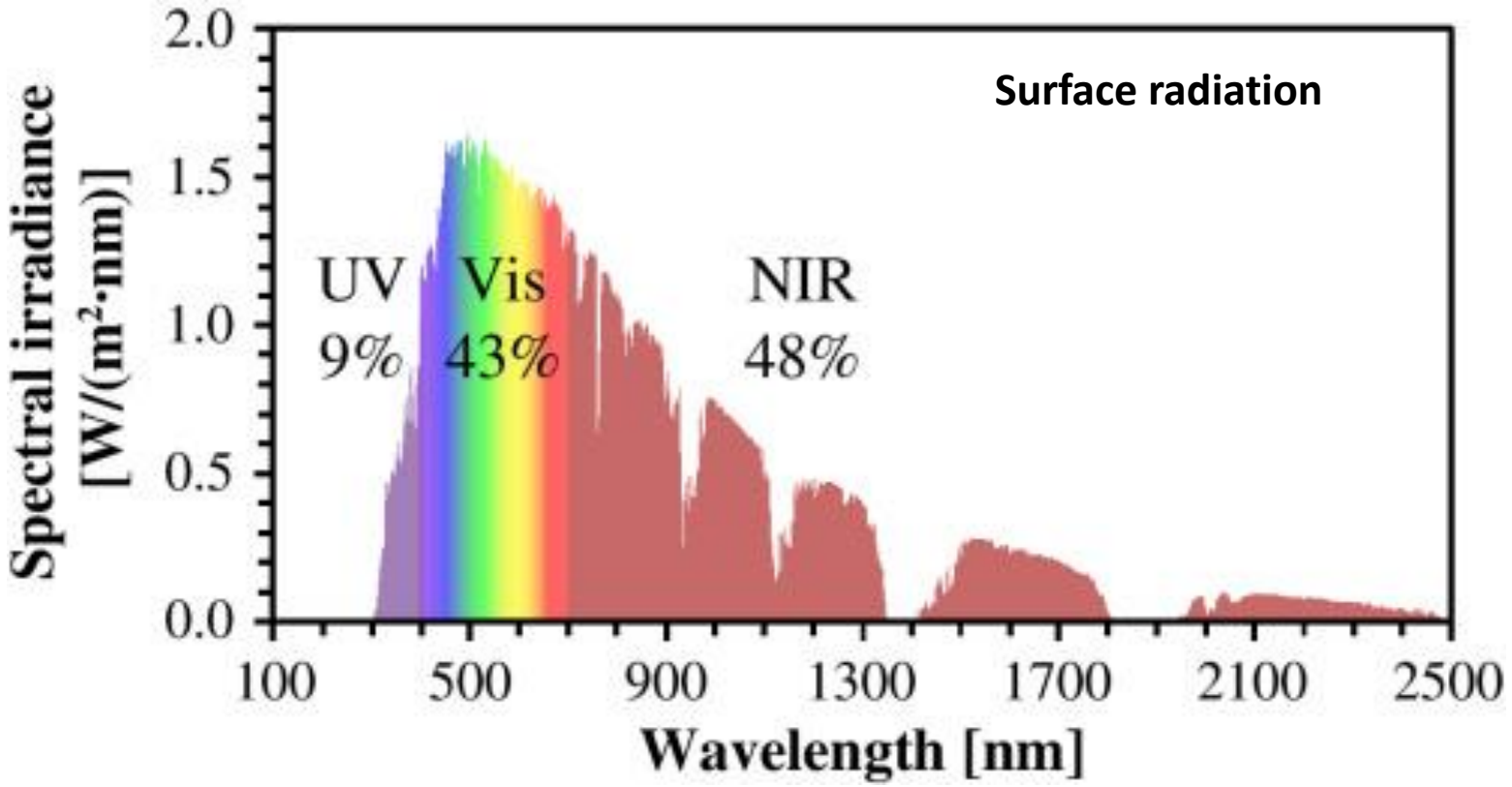
2) Spectral radiances/fluxes to quantify process influences to understand the 'how & why' of the budget - CLARREO PF -2022; PREFIRE -2023; Libera & AOS -2030

3) 'Resolved' measurements of the net energy imbalance to connect to broader Earth system impacts - ???



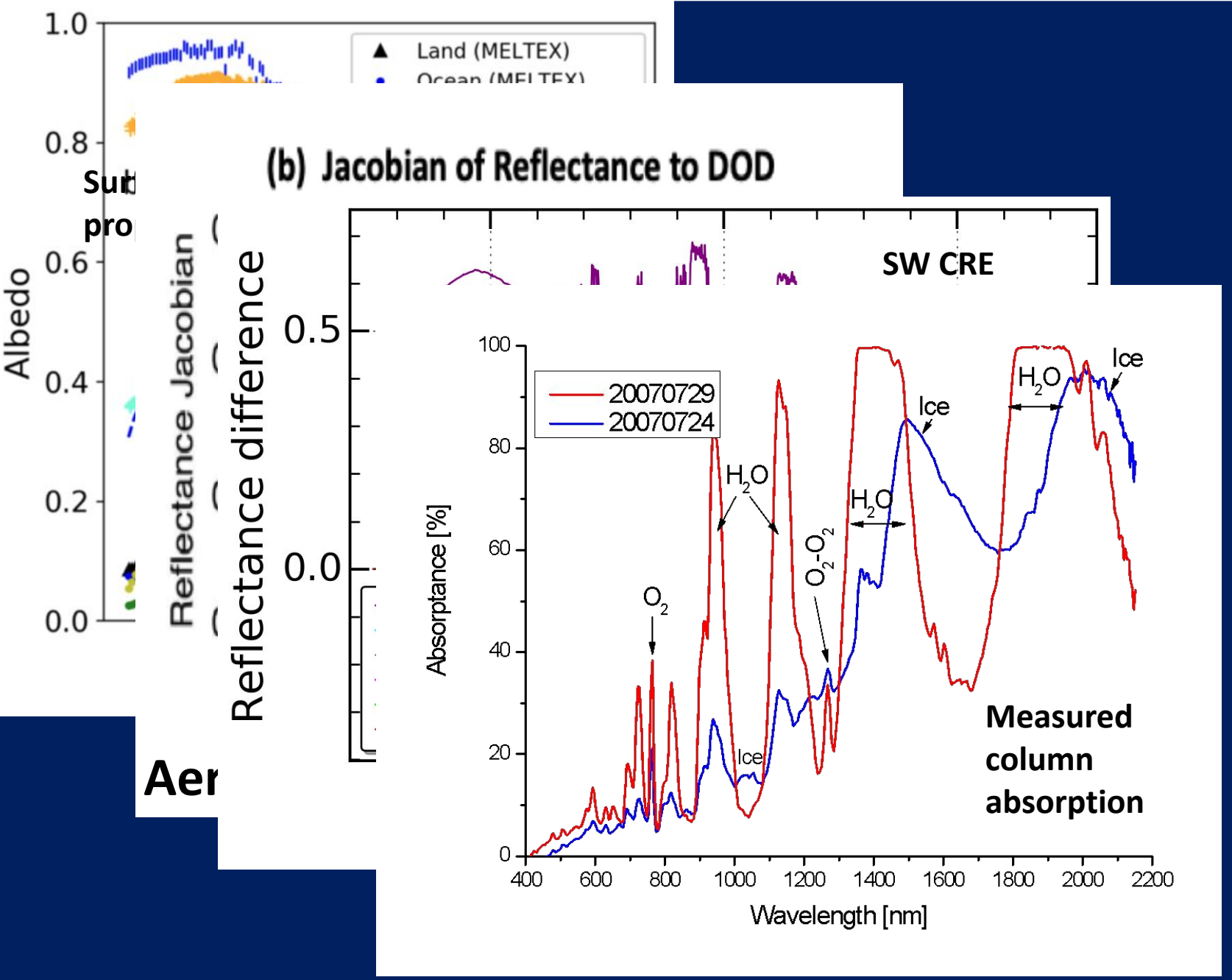
Stephens et al., 2022; *The thirty years of GEWEX,* submitted to BAMS

Why spectral?

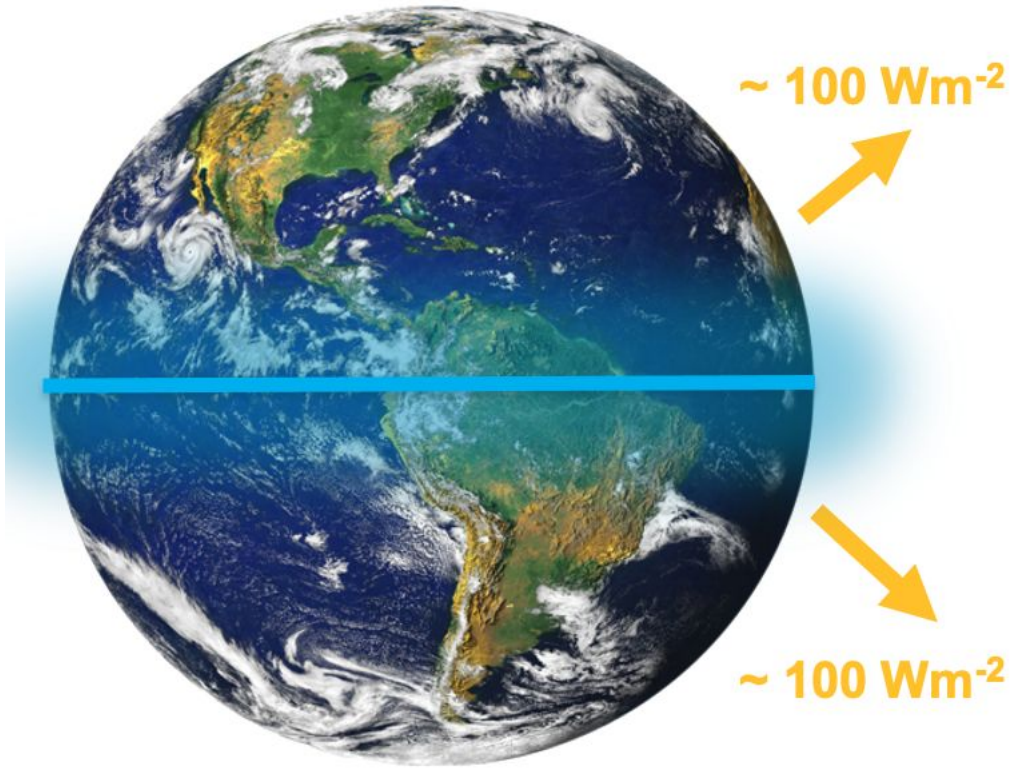


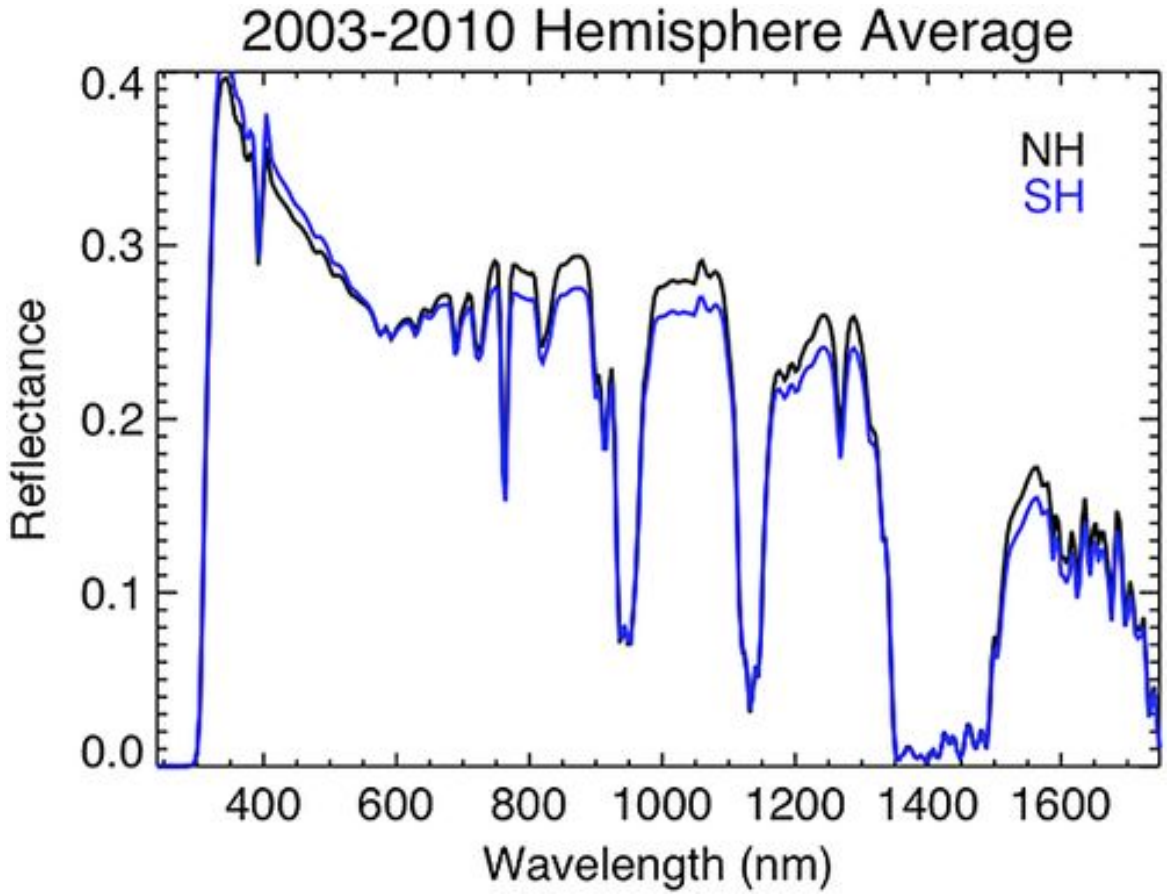
Why spectral?

The spectra contain so much information and insight on that which scatters, absorbs and reflects sunlight

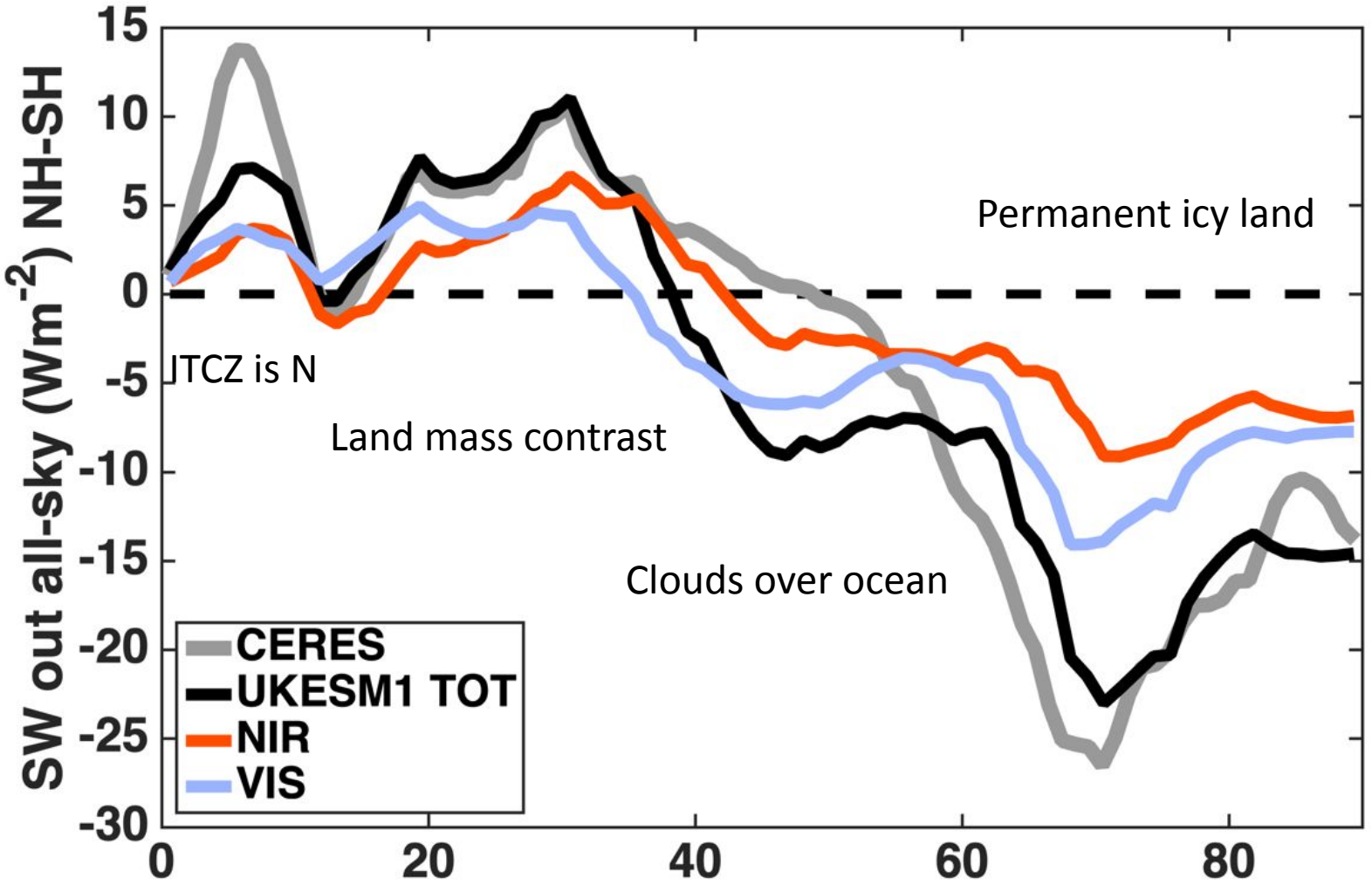


Why spectral: The hemispheric symmetry of Earth's Albedo





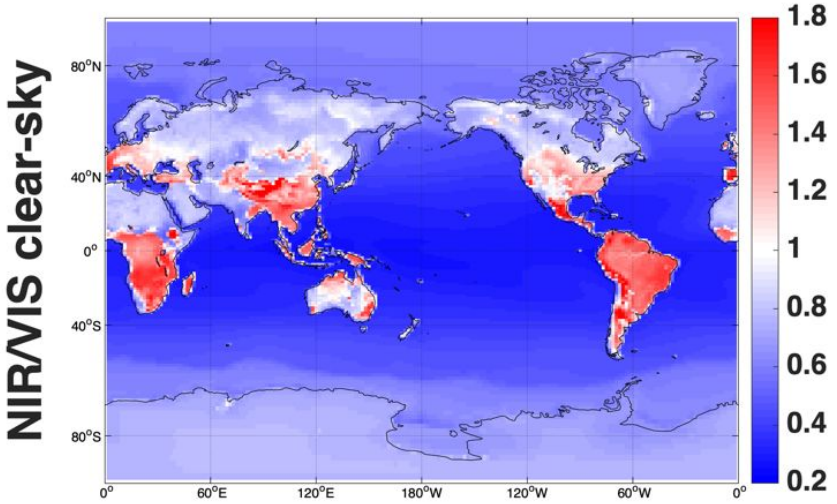
NH-SH differences per latitude



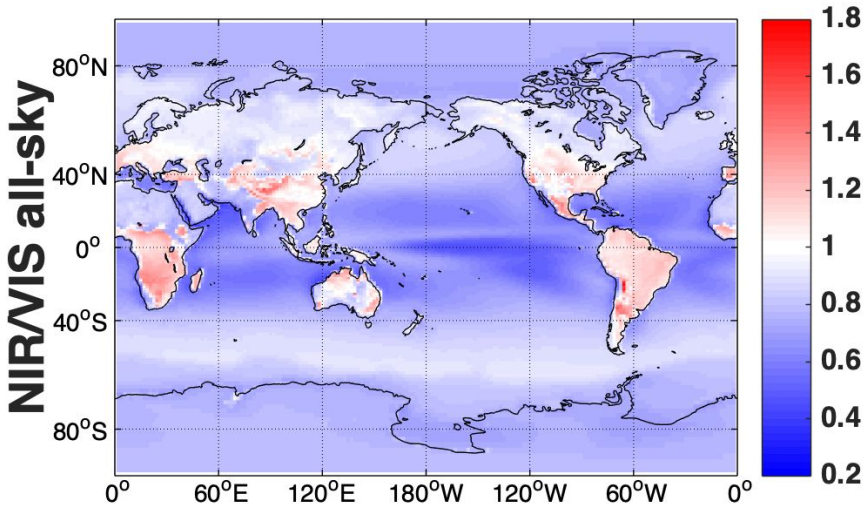
- NH is mostly brighter over 0-40 degree, but darker poleward
- Model agrees OK with CERES
- NIR & VIS zonal variability looks similar to total SW…

Hakuba et al., 2022

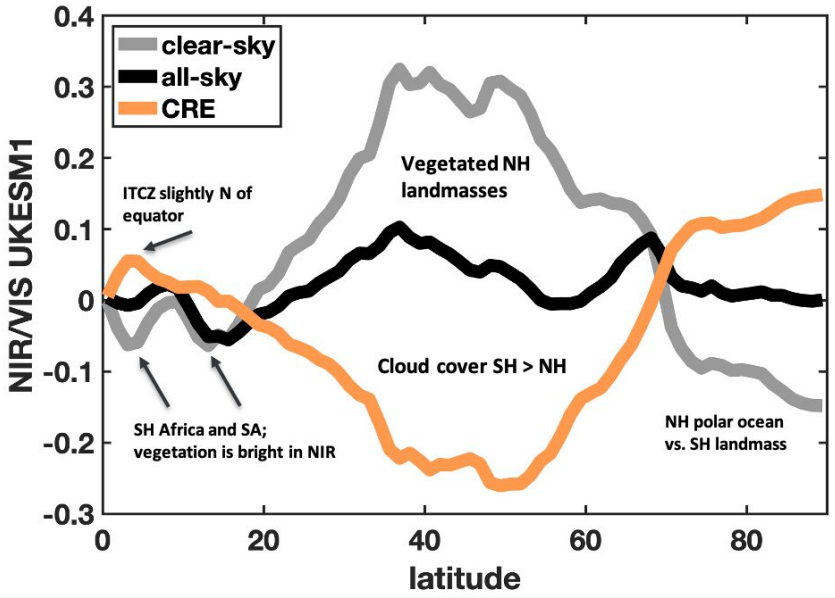
UKESM1 NIR/VIS per latitude



- Clear-sky asymmetry is a hemispheric “land-sea contrast”, where NIR/VIS higher over land
- Highest NIR/VIS in Southern Africa and South America! (but outweighed by vast ocean low NIR/VIS)
- CRE increase NIR/VIS especially over SH ocean
- CRE diffuse spatial gradients in NIR/VIS

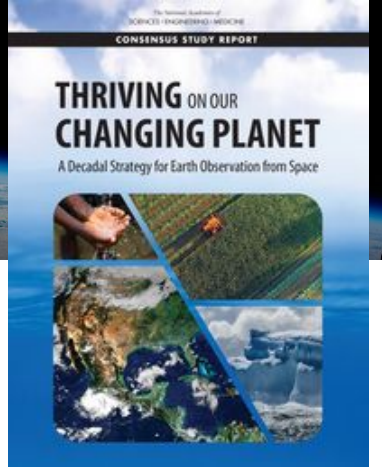


NH-SH differences NIR/VIS ratio per latitude

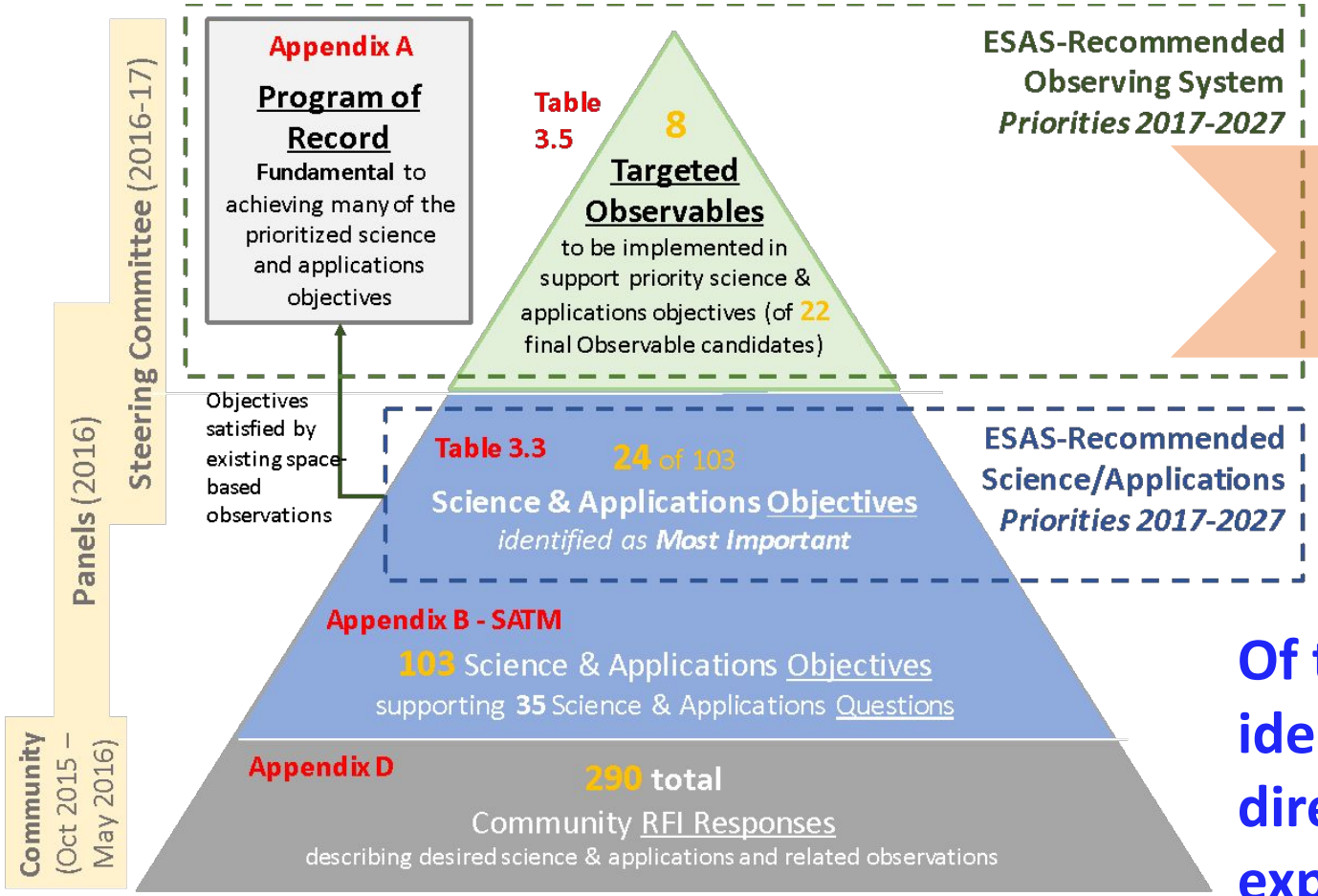


Hakuba et al, 2022

Path to ~~ACCP~~ AOS



Blue: Science & Applications; Green: Observables



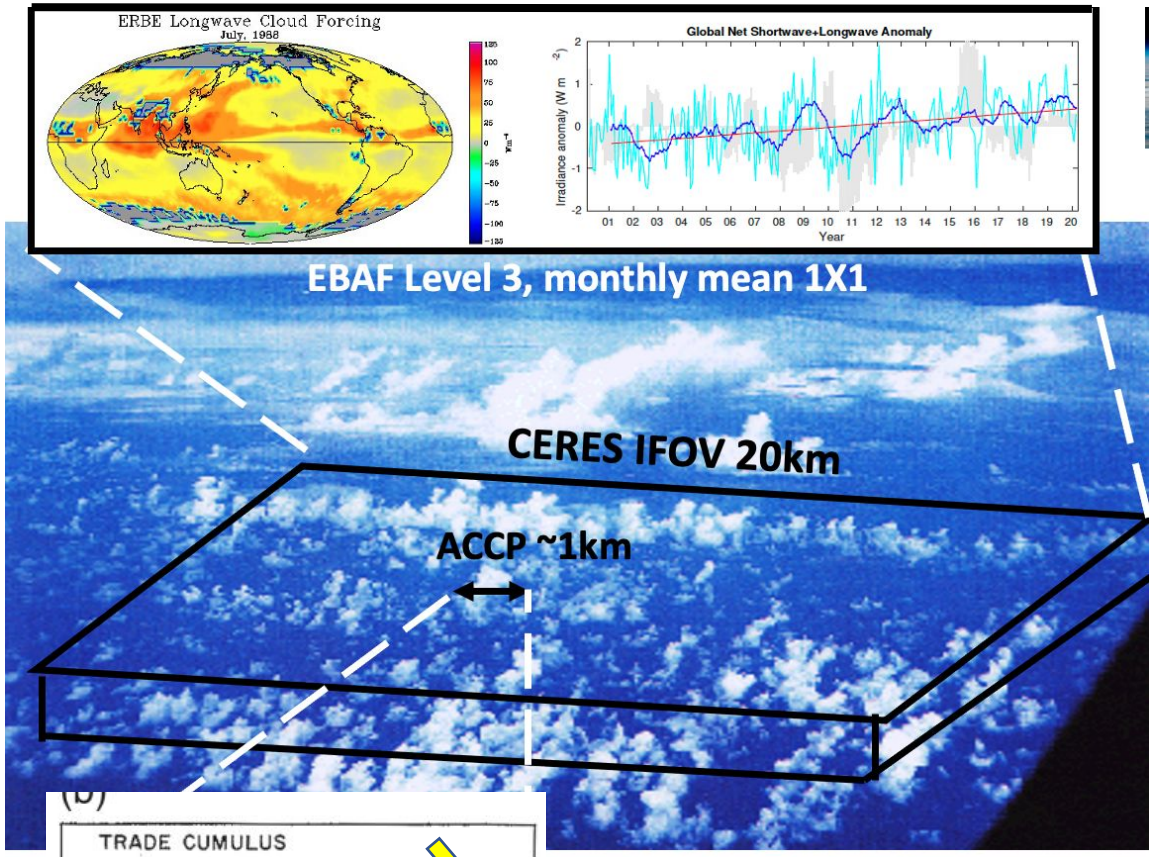
Designated Observables
Aerosol
Clouds, Convection & Precipitation
(process)

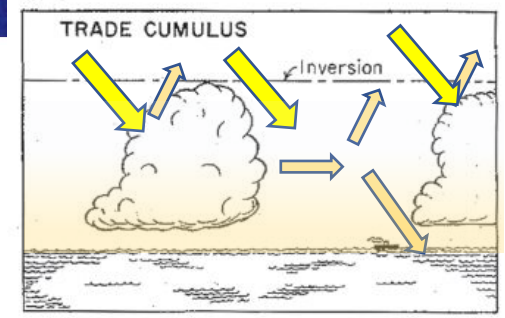
Lidar & Radar

ACCP→ AOS

Of the 24 most important DS objectives identified by the community, AOS directly relate to 12 of them and explicitly addresses 8 of these

The AOS approach to measure cloud & aerosol radiative effects





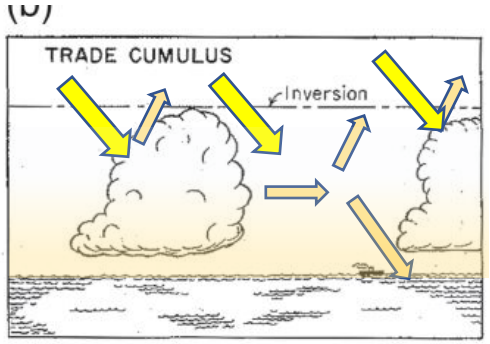
For AOS, we want to

1) Distinguish radiative effects of clouds and aerosol separately **(~1km) and match these in *space and time*** to cloud aerosol properties (L2)
2) Test the 'binned' AOS fluxes against the PoR (L3)
3) **Quantify 'kernels' (L2) on the km scale**

$$\frac{\text{Changes in radiation}}{\text{Changes in cloud or aerosol}}$$

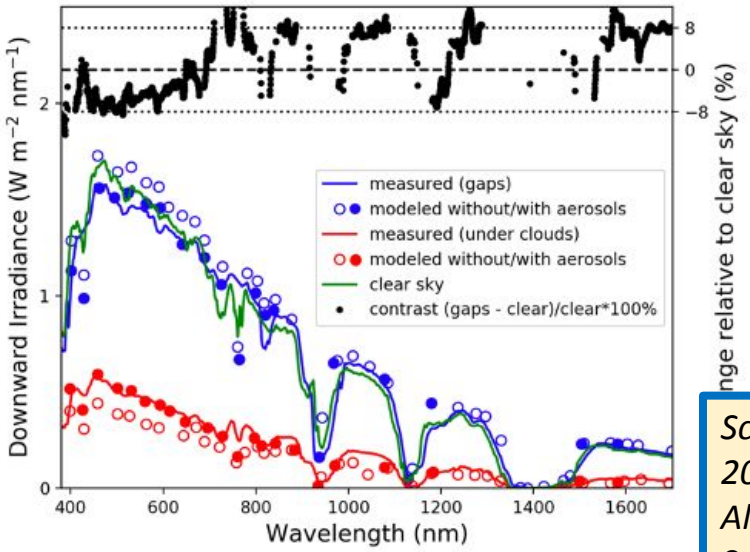
Spectral measurements offer a transformative and tightly constrained way of quantifying these 'ratios' based on observations

The importance of spectrally resolved measurements

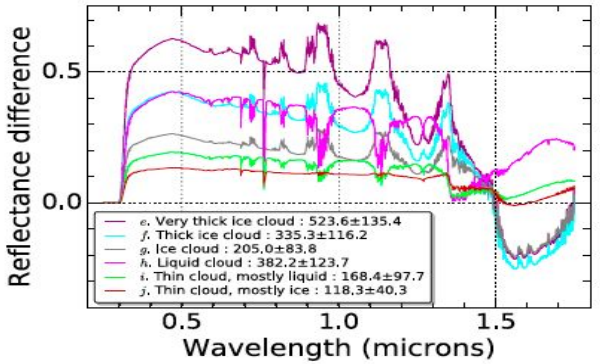


Spectral measurements differentiate aerosol from cloud effects

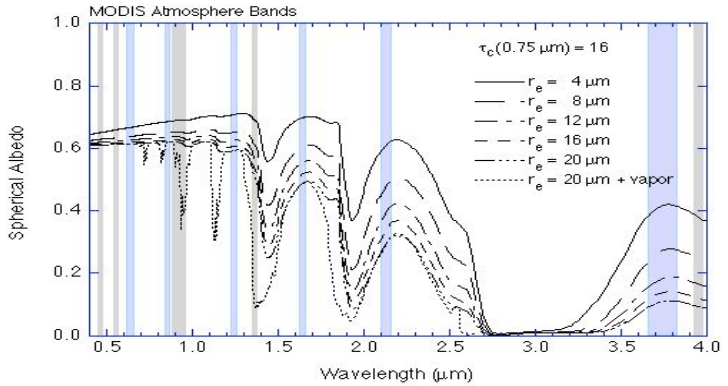
Example of Measurements



Schmidt et al., 2009, GRL
Also
Song et al., 2016 Atmos.Chem Phys



Cloud minus clear spectra (simulated, Gristey et al., 2019)



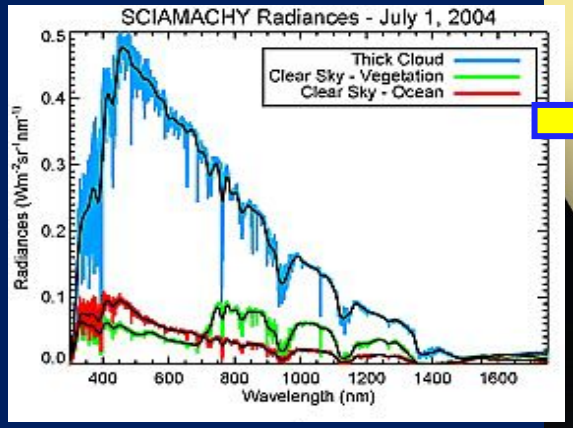
Spectra reveal dependencies on properties typically hidden in broadband

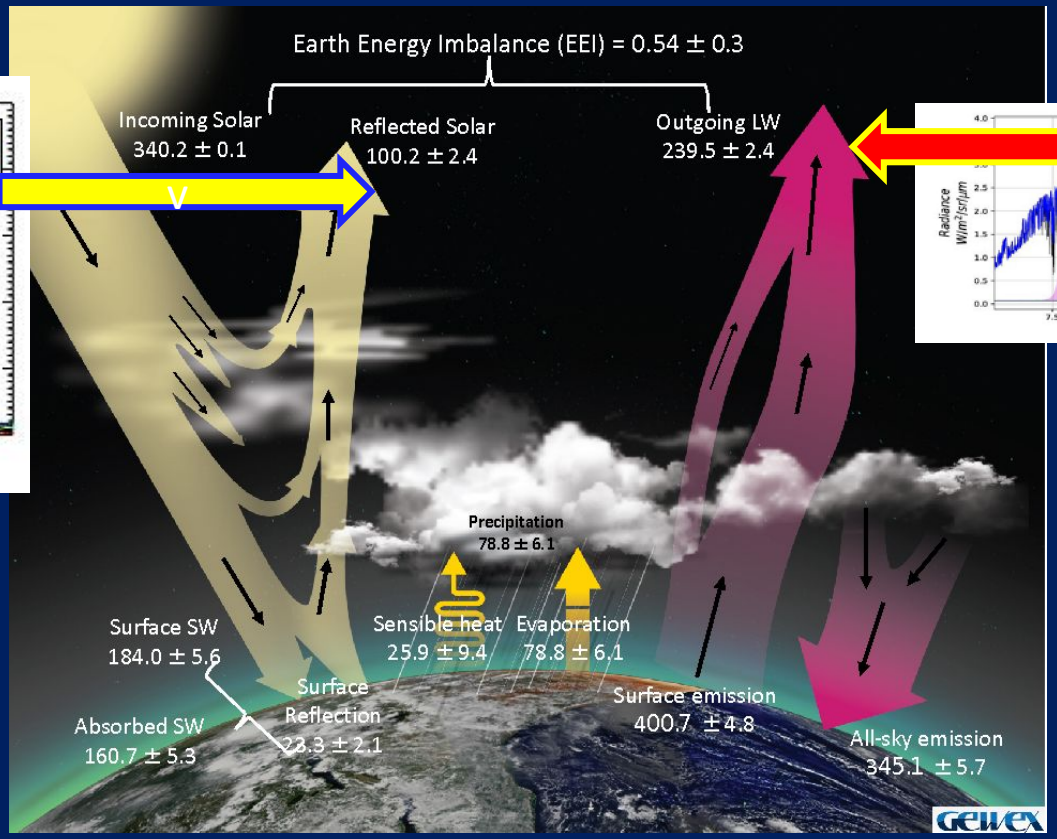
- *x*=optical depth & cloud amount
- *x*=liquid or ice water path
- *x*=particle size & profile
- *x*=cloud top height
- *x*=phase

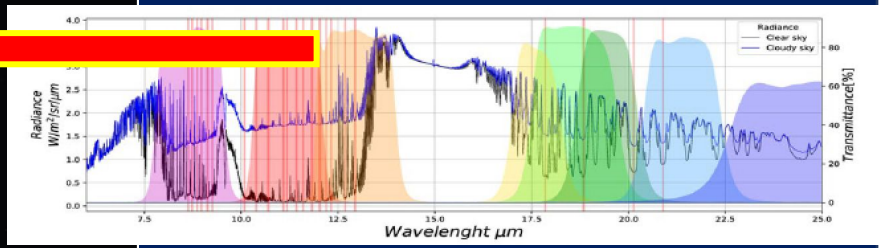
Stephens et al., 2021; ACCP special issues Frontiers Remote Sens

Radiation – an integrated measure of the 'AOS' processes

An AOS example: The connections between changes to the properties of clouds and aerosol observed by AOS & the changes to the flows of radiant energy out of Earth are more extensively & better quantified when linking these properties to energy flux spectra of the type provided by the proposed AOS spectrometers.



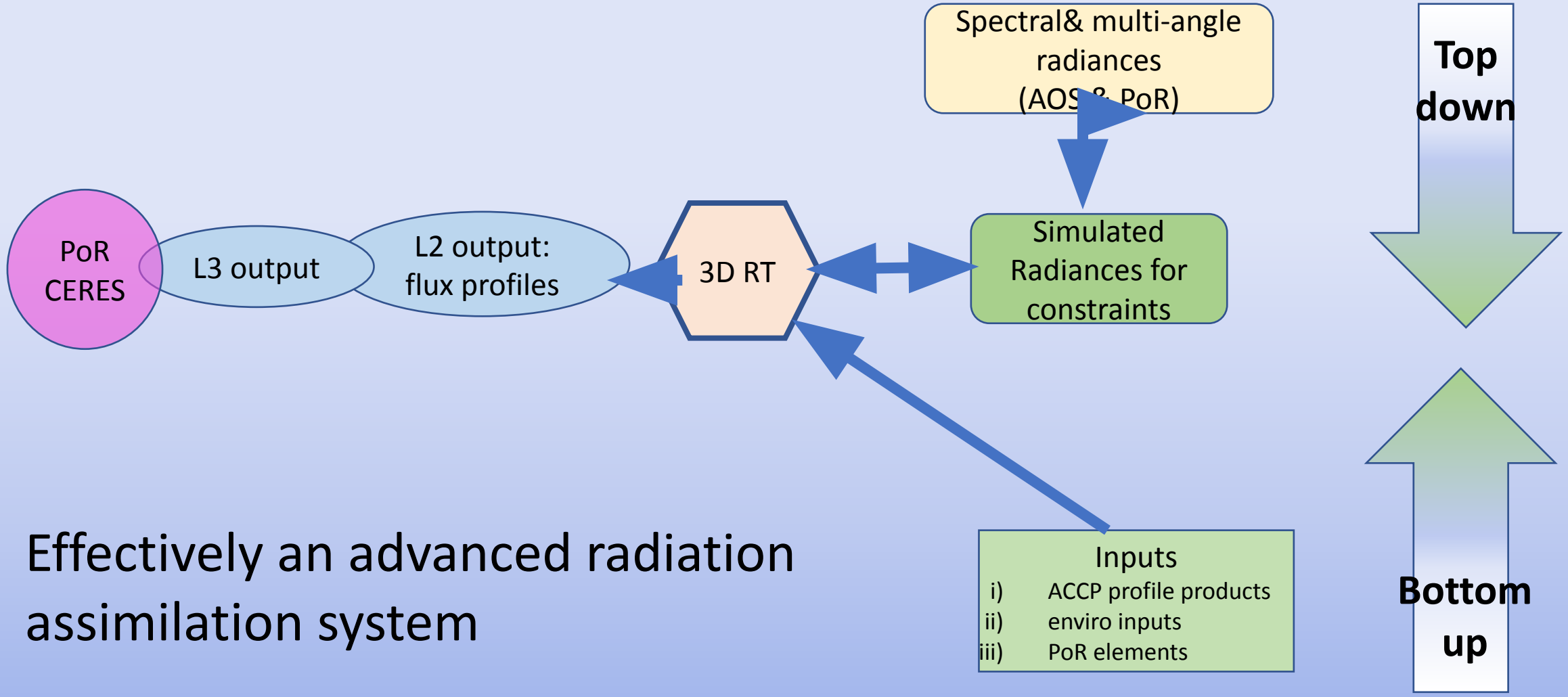




CSA 'TICFIRE' IR spec

CSA- TICFIRE

The AoS approach - a top down-bottom up approach



Effectively an advanced radiation assimilation system

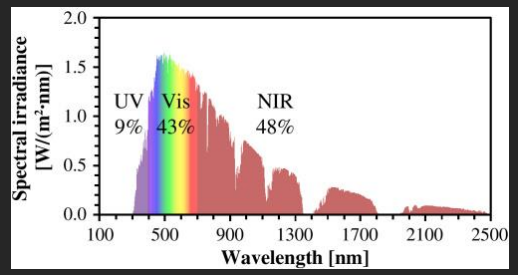
Summary #1 AOS

Spectral Long & shortwave

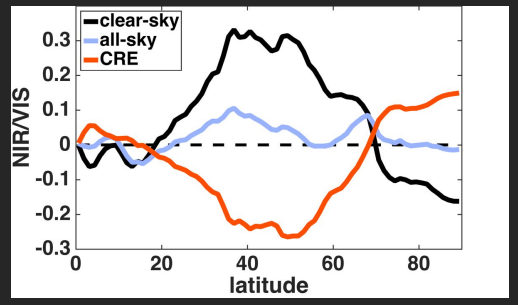
	Longwave (thermal IR)	Shortwave (Solar)
Heritage of method, measurement	PREFIRE	EarthCARE
	TIRS	CLARREO PF

Required Features	AOS	PoR
Broadband fluxes	✔	✔
‘cloud’ scale rad fluxes	✔	❌
Property dependences (‘kernels’)	✔	(❌)

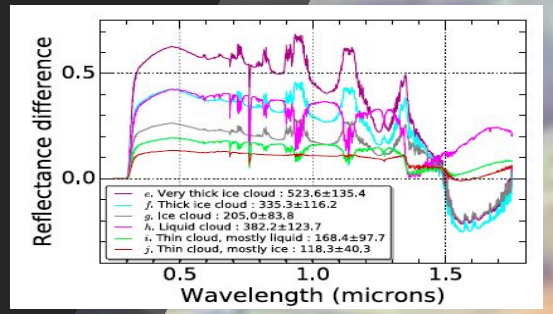
Summary #2: A vision

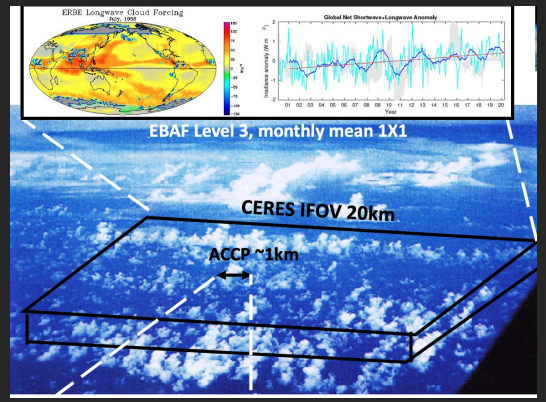


- The elements of an Energy balance observing system - spectral is the next step

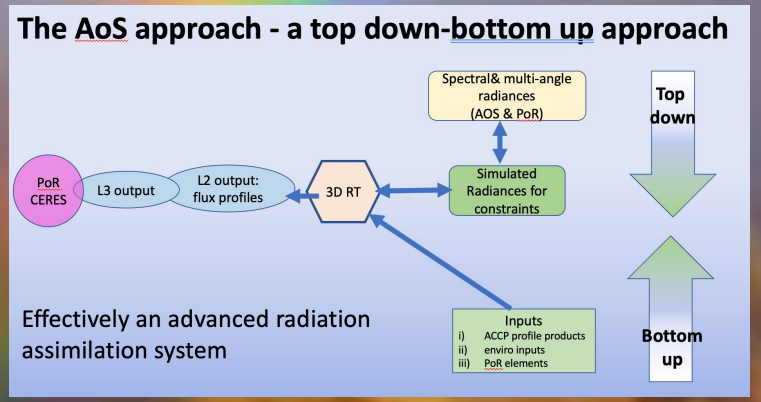


- Why?



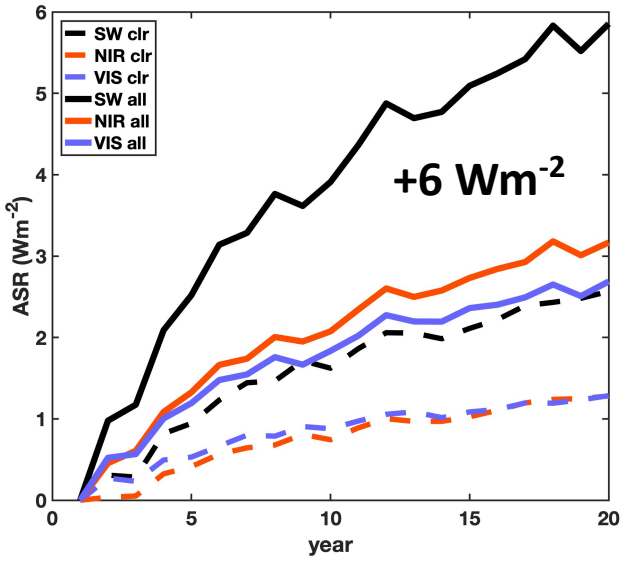


- The ERB in AOS ’



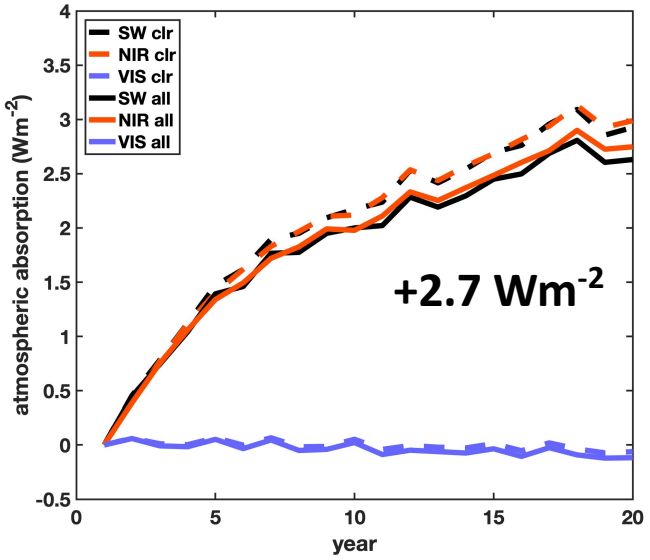
20-year ASR at surface vs. in atmosphere

ASR at TOA



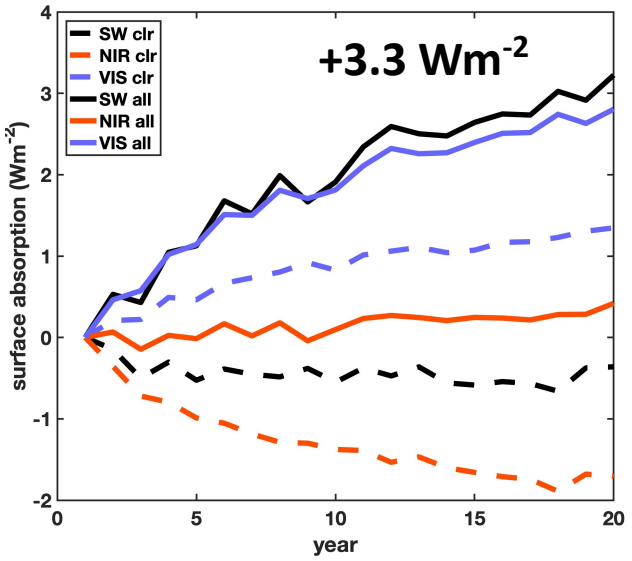
- Clouds double ASR: VIS surface effect (~40% SA + ~60% cloud+ feedback)
- Clear-sky: atmospheric ASR in NIR (water vapor feedback)

Atmospheric absorption

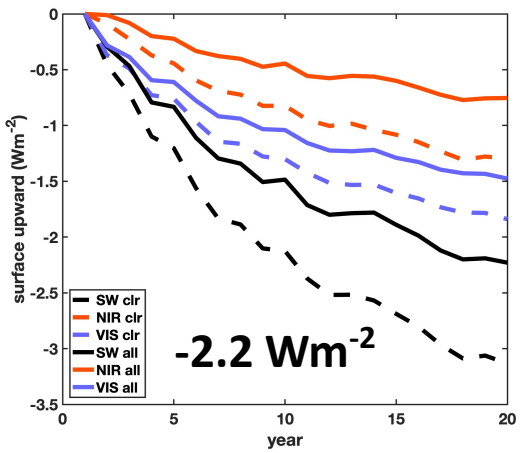


- SW atm. ASR = NIR atm. ASR
- Clear-sky: total ASR = atm. ASR in NIR
- All-sky: atm ASR is 45% of total ASR increase

Surface absorption



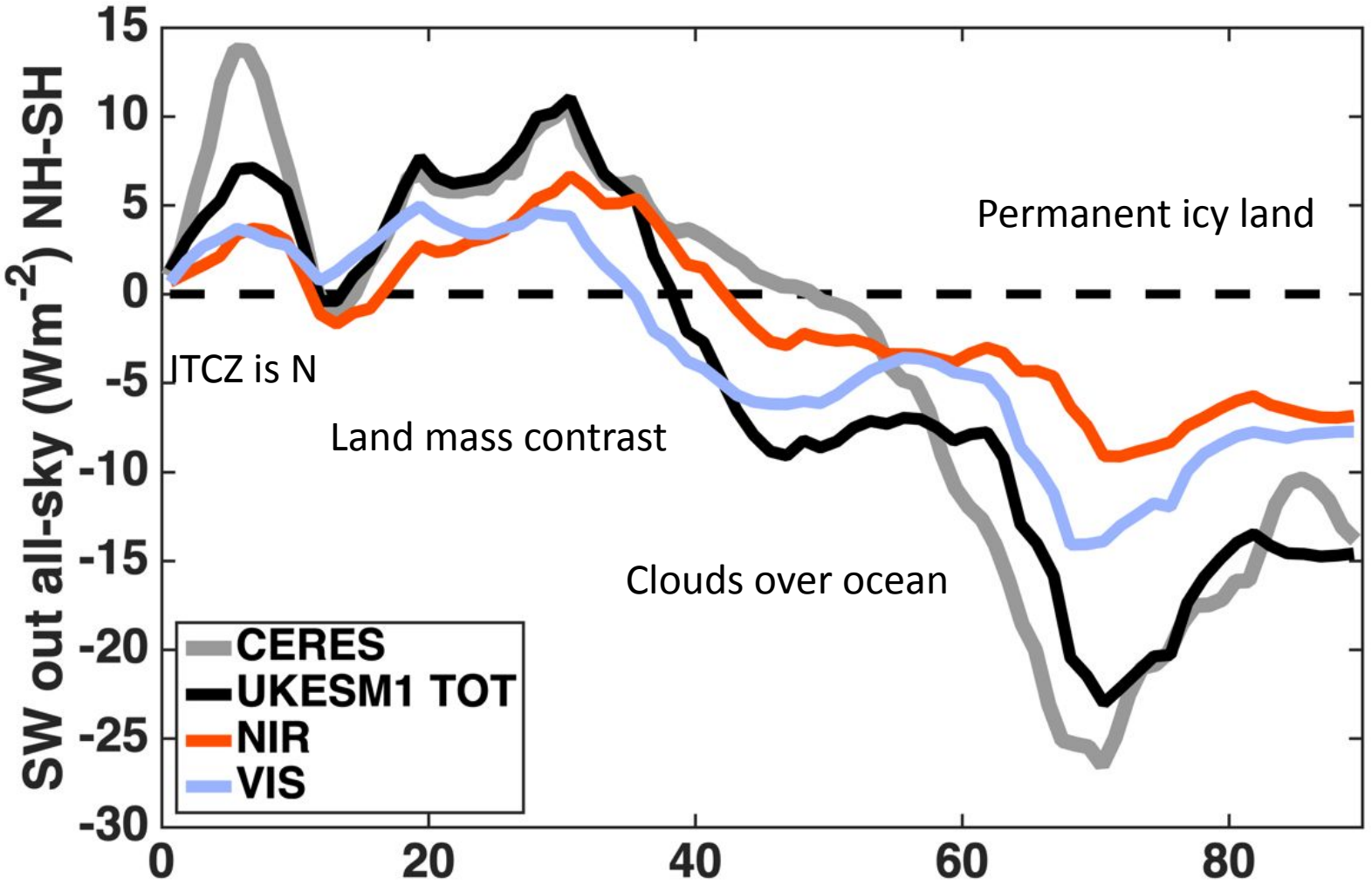
Surface upward



- Surface upward flux decline in NIR and **VIS:** albedo is darkening
- Surface ASR mostly in VIS (albedo ~70% + increase in downward ~30% radiation); NIR surface clr decrease ~ NIR atm clr increase
- NIR all-sky: positive CRE cancel negative water vapor

ASR increase = 45% atmosphere (NIR minus tiny bit VIS) + 55% surface feedbacks (VIS plus tiny bit NIR)

NH-SH differences per latitude



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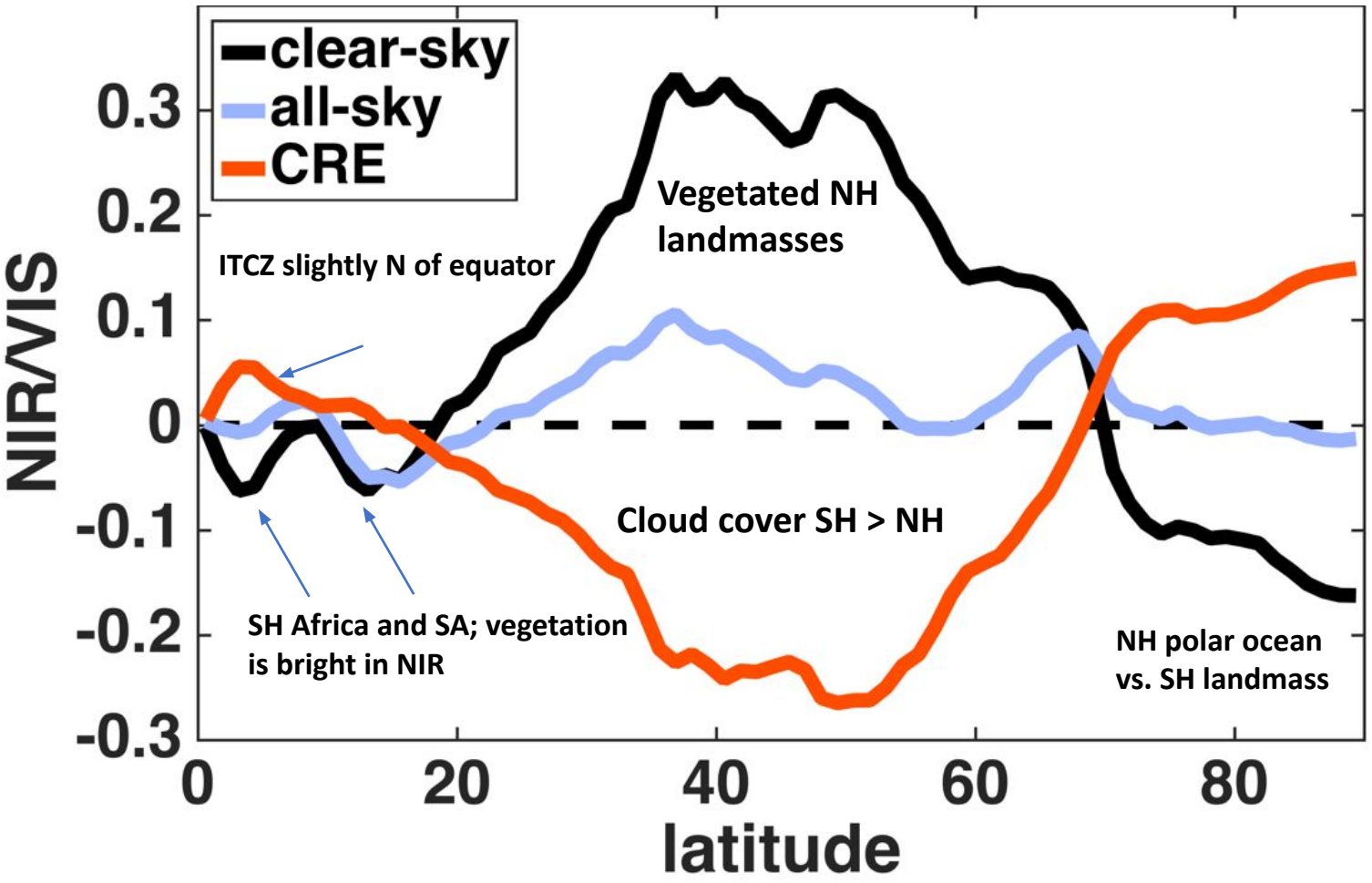
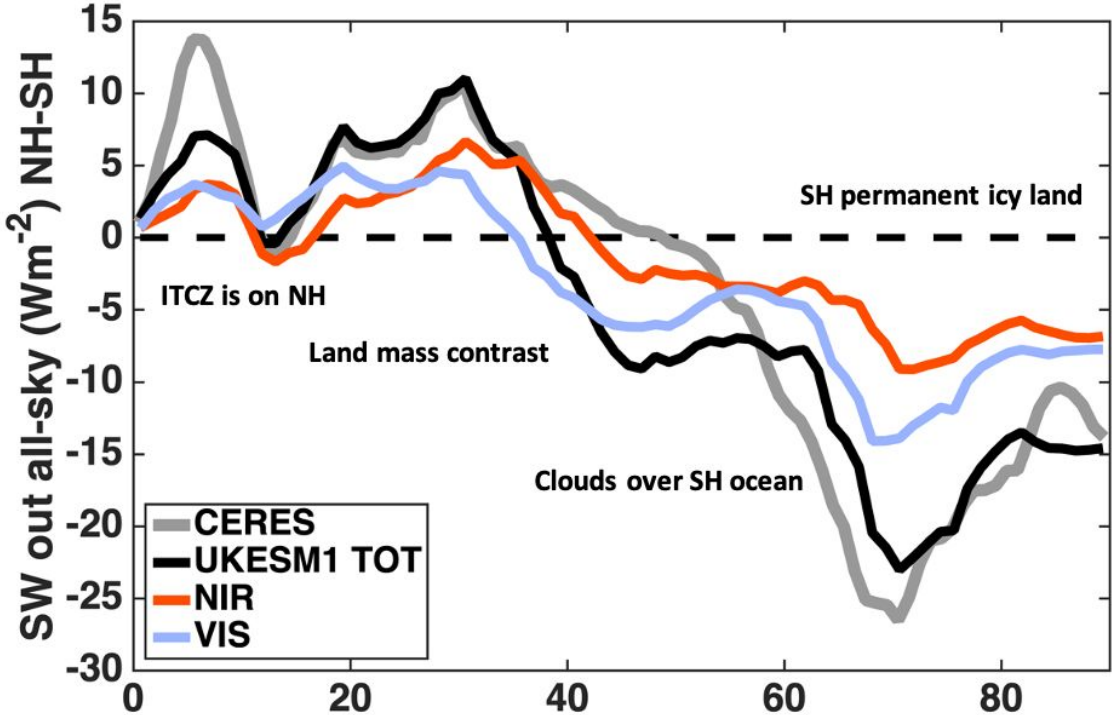
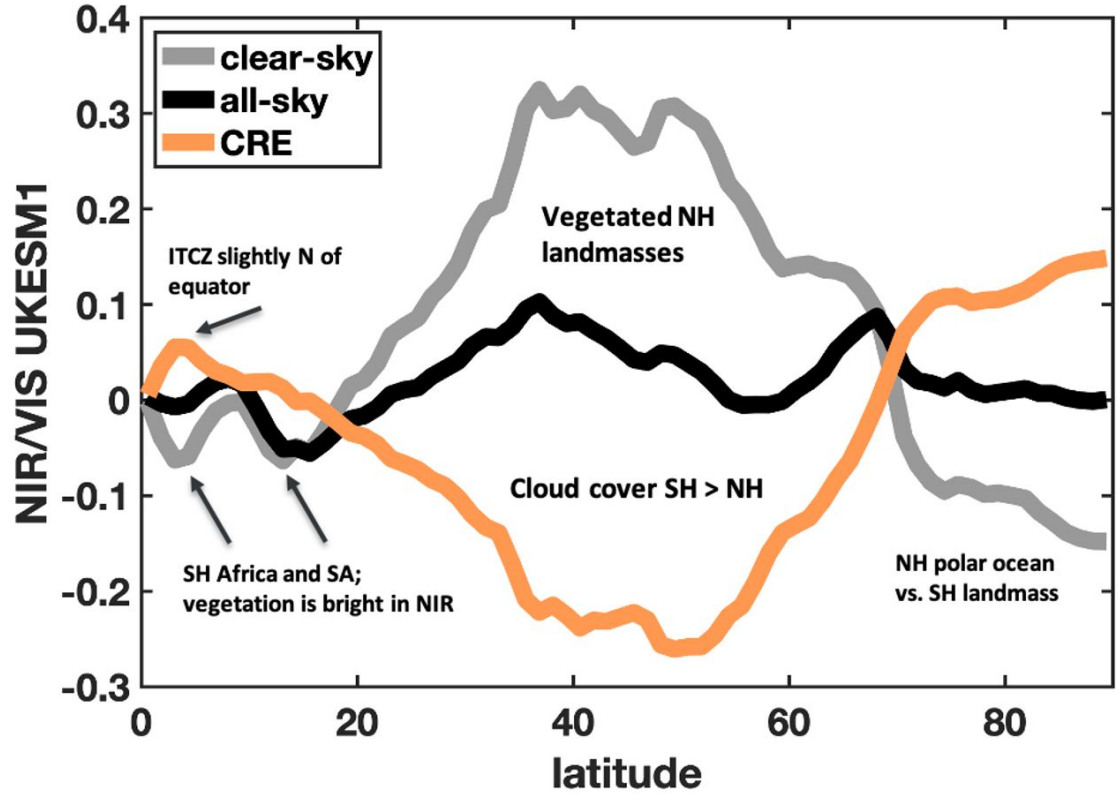
NH-SH differences NIR/VIS ratio per latitude



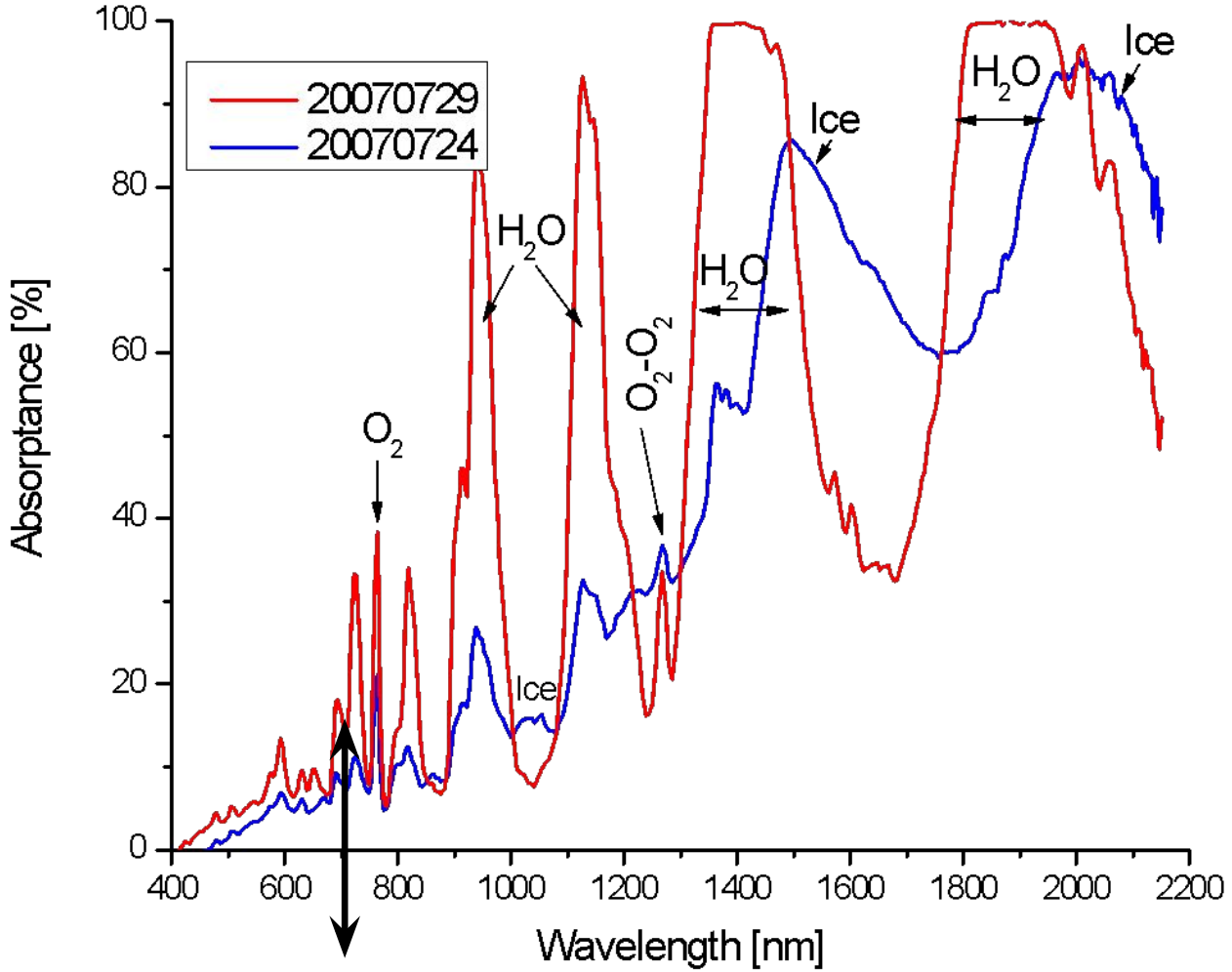
- Positive values: NIR/VIS ratio is larger on NH than on SH; especially true under clear-sky between 20-70 deg. (note: locally, SH Africa and SA have largest NIR/VIS)
- CRE balance the hemispheric NIR/VIS ratio zonally & mirror the Clear-sky effects.
- But NIR/VIS ratio remains slightly larger on NH under all-sky conditions.

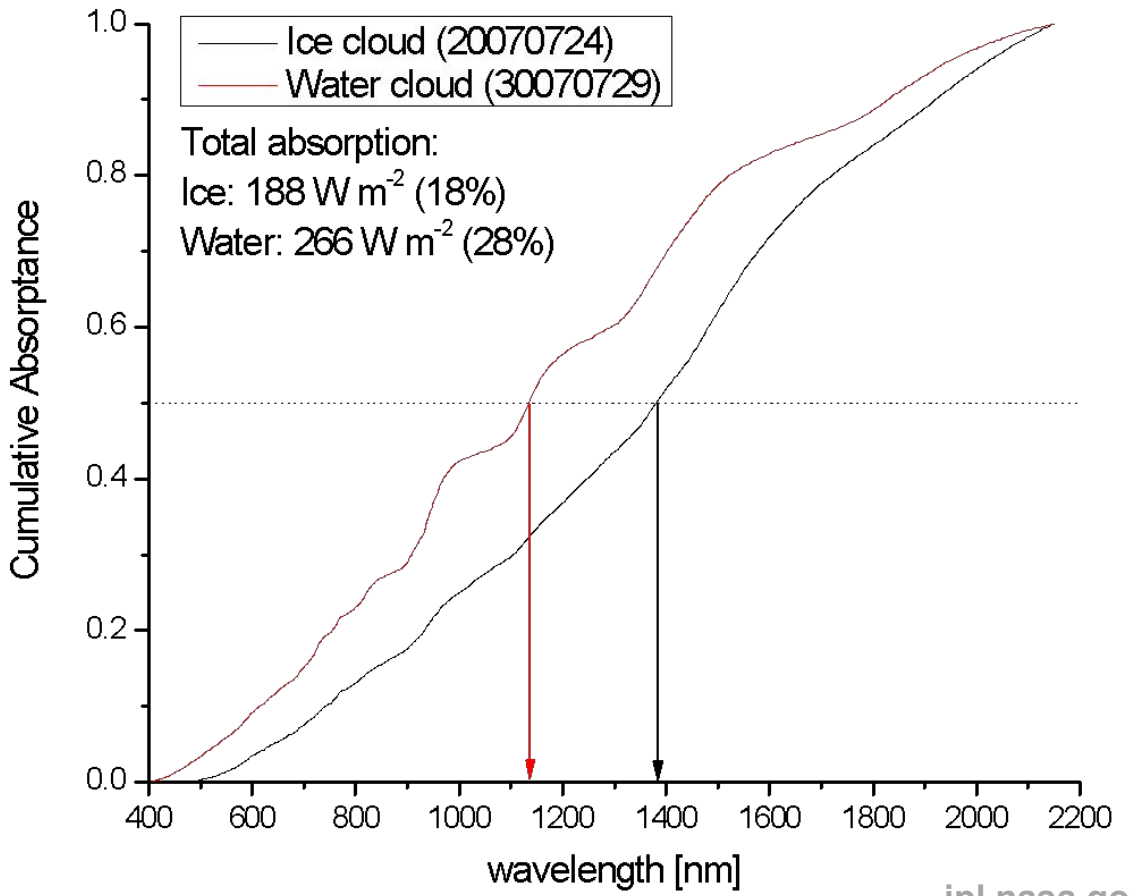

SW out all-sky (Wm^{-2}) NH-SH
15
10
5
0
-5
-10
-15
-20
-25
-30
0
20
40
60
80
SH permanent icy land
ITCZ is on NH
Land mass contrast
Clouds over SH ocean
CERES
UKESM1 TOT
NIR
VIS


NIR/VIS UKESM1
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
20
40
60
80
latitude
clear-sky
all-sky
CRE
Vegetated NH landmasses
ITCZ slightly N of equator
Cloud cover SH > NH
SH Africa and SA; vegetation is bright in NIR
NH polar ocean vs. SH landmass

Shortwave spectral information - clouds

Water Cloud vs. Ice Cloud Column Absorption Derived from Measurements: tropical above-below cloud solar irradiance spectra **(Schmidt and Pilewskie, 2012)**





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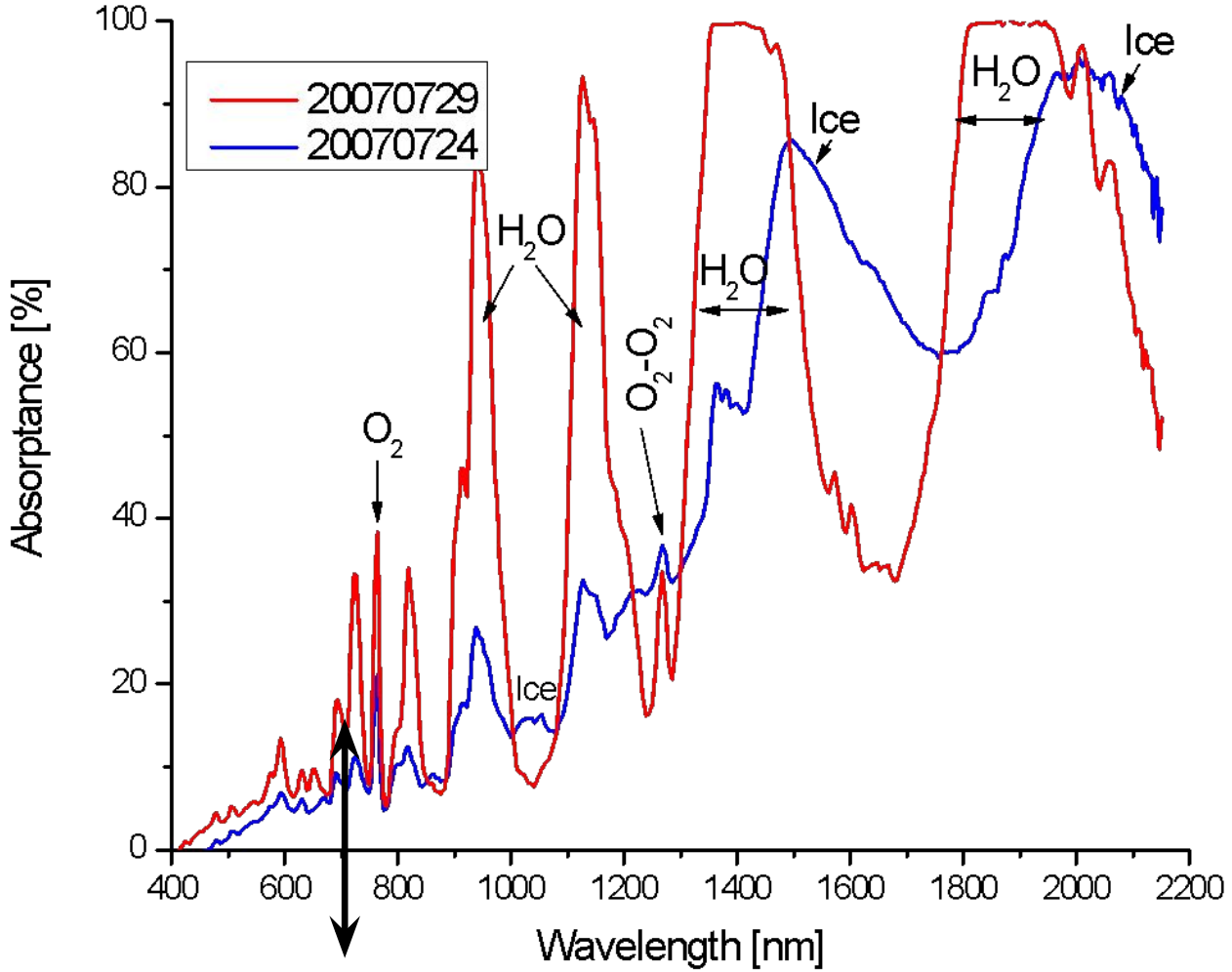

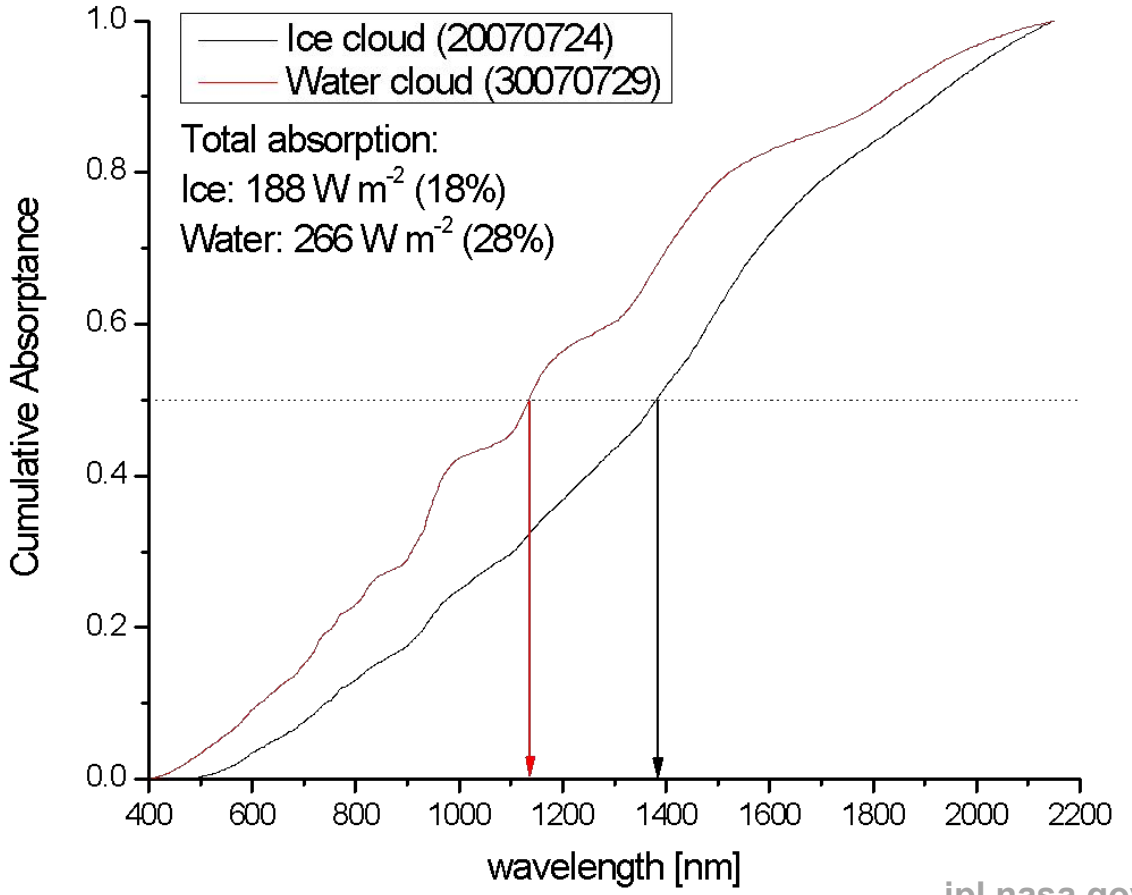

Addressing the radiation requirements for AOS

Required Features	ACCP	PoR
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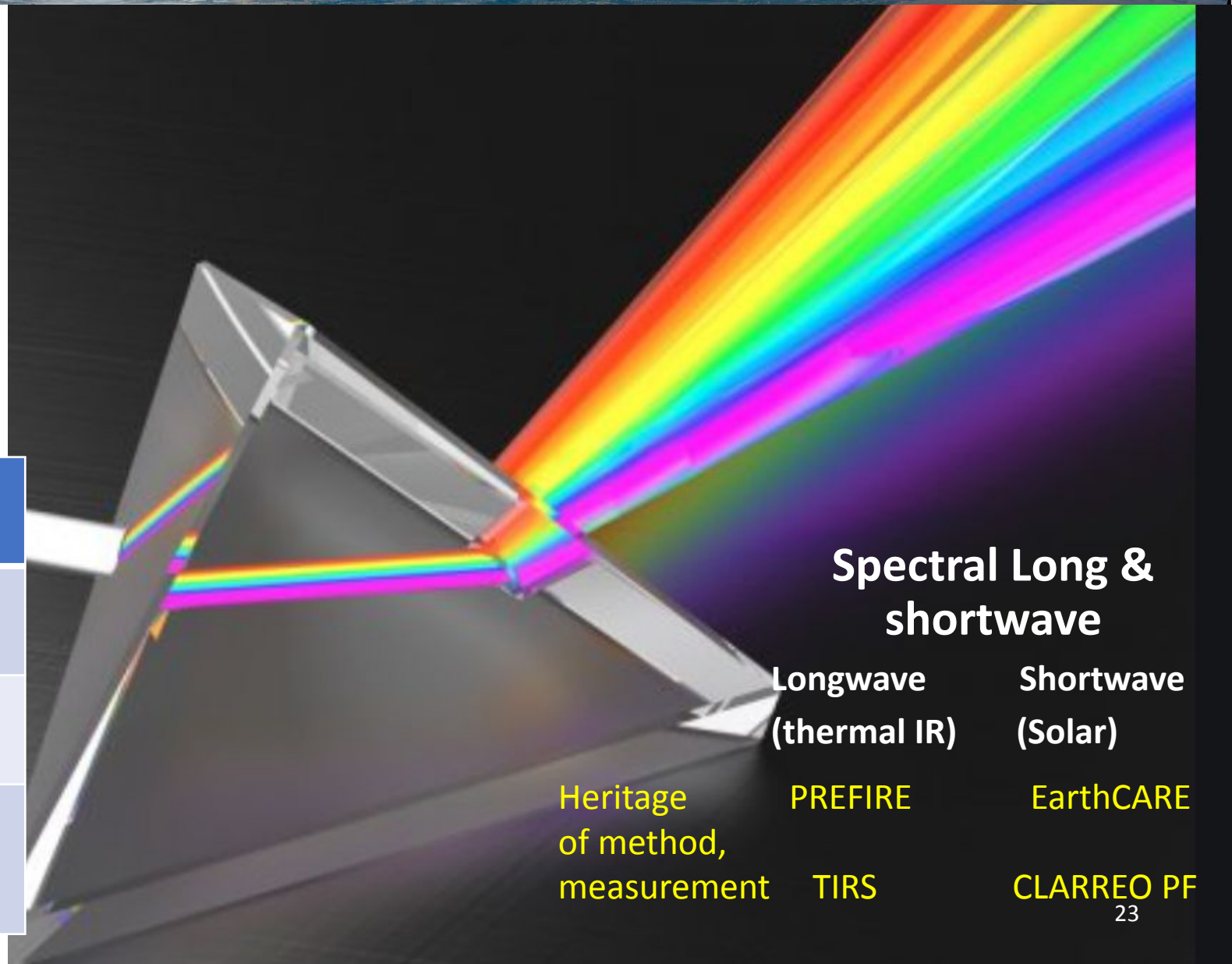
‘cloud’ scale rad fluxes	✔	❌
Property dependences (‘kernels’)	✔	(❌)



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