# COSP-RTTOV: Flexible radiation diagnostics to enable new science applications in model evaluation, climate change detection, and satellite mission design

Jonah Shaw

CESM Working Group Meetings

02/03/2025

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WISCONSIN
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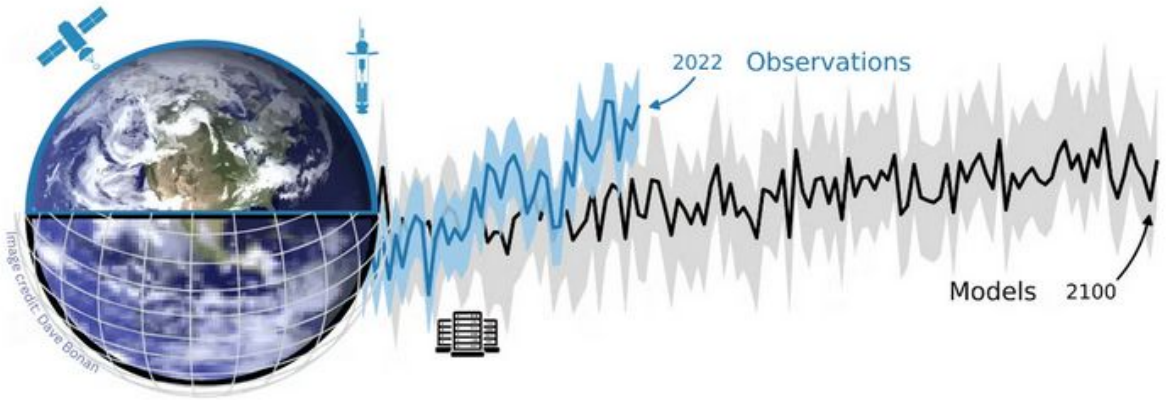
BLUE CANYON
TECHNOLOGIES

- March 2024 in Boulder

## Workshop on Confronting Earth System Model Trends with Observations: The Good, the Bad, and the Ugly



| Wednesday, March 13, 2024 | | | |
|---|---|---|---|
| **Time** | **Agenda** | **Presenter** | **Presentation file** |
| 7:00 AM | Workshop registration and breakfast | | |
| 8:15 AM | Introduction and welcome | | |
| 8:30 AM | Session 1: Overview | | |
| 8:30 AM | (Invited) Subtle lessons from the art of model-observation confrontations* | Gavin Schmidt, NASA GISS | |
| 8:50 AM | (Invited) Challenges in comparing observed and model-simulated climate trends on regional scales | Clara Deser, NCAR | |
| 9:10 AM | Open discussion | | |

## Philosophical Footnote #2

**All observations and comparisons are based on models too**

**(It's models all the way down!)**

# Models all the way down: CERES broadband fluxes

1. CERES observes radiation over a narrow solid angle (radiance) but reports hemispherically-integrated fluxes.

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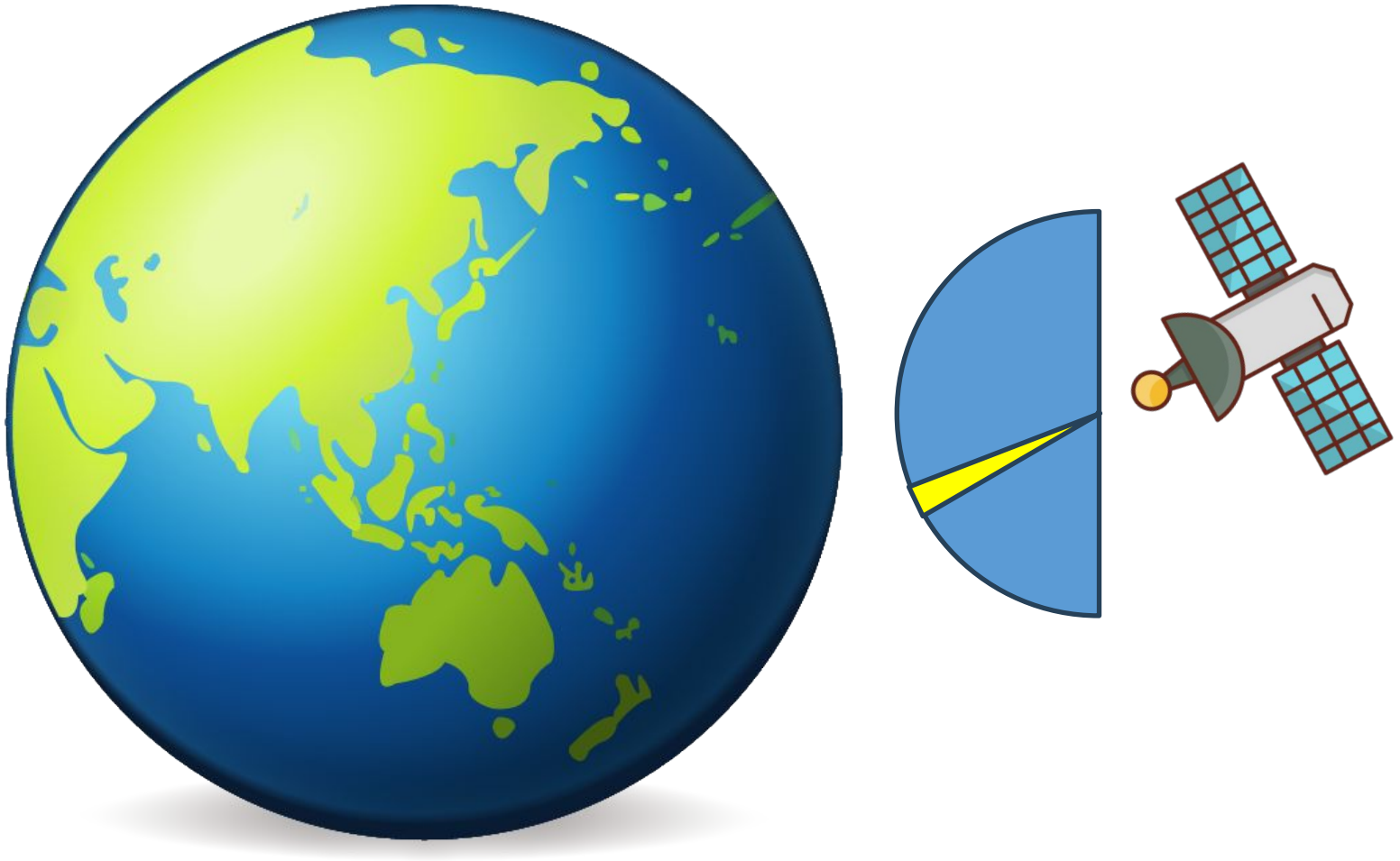
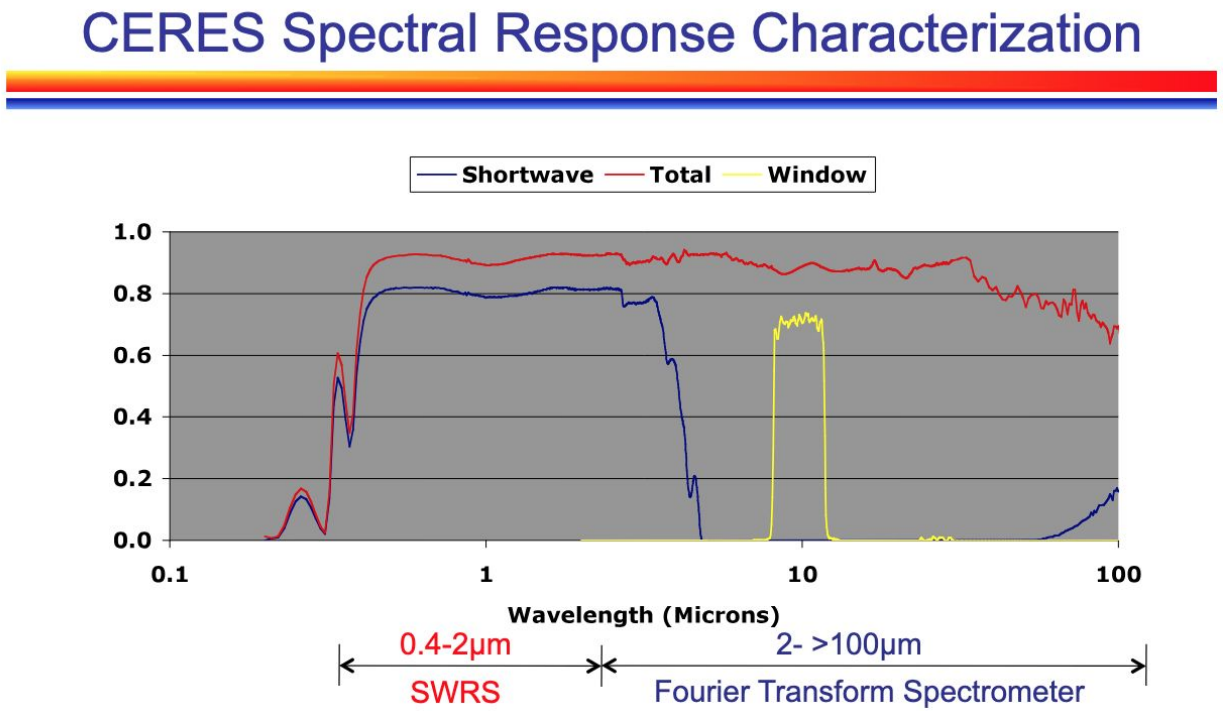
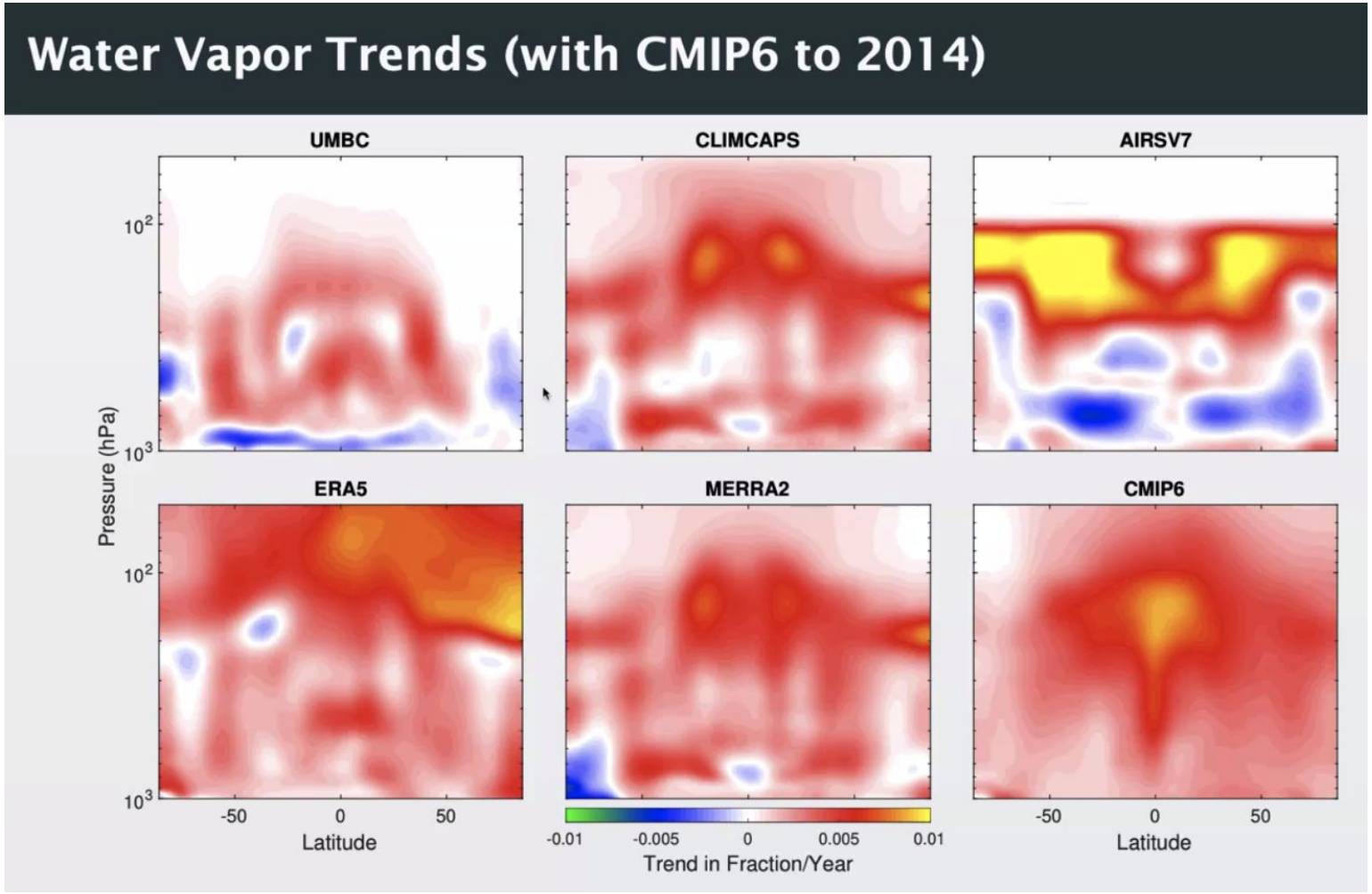


# Models all the way down: CERES broadband fluxes

1. CERES observes radiation over a narrow solid angle (radiance) but reports hemispherically-integrated fluxes.
2. CERES instruments respond differently to different wavelengths of radiation but report broadband shortwave and longwave fluxes.



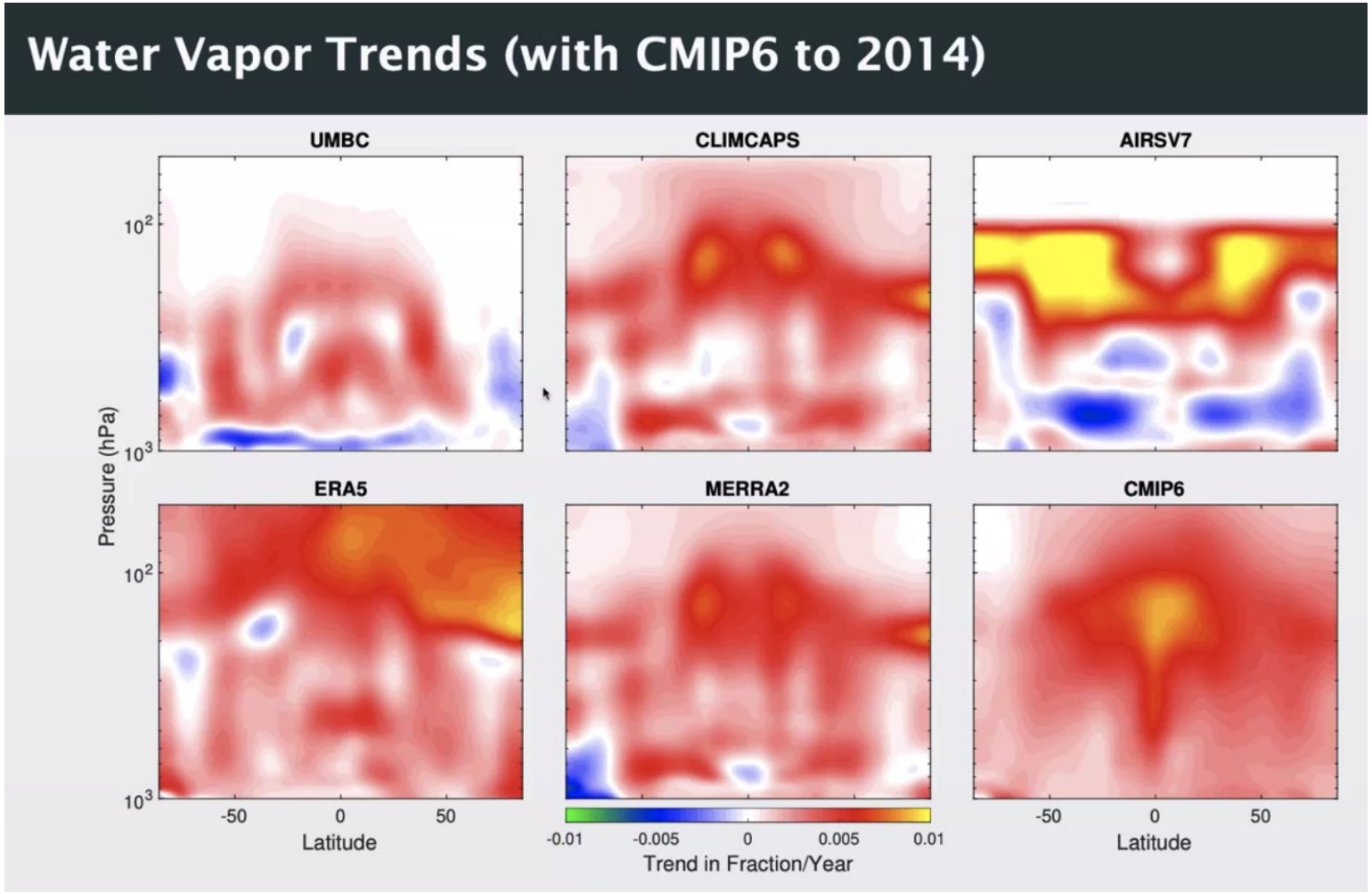
# Models all the way down: Reanalysis and Satellite Retrievals




Credit: Sergio DeSouza-Machado, UMBC

# Models all the way down: Reanalysis and Satellite Retrievals

- Reanalysis and satellite retrieval products disagree **even when ingesting the same direct observations**.

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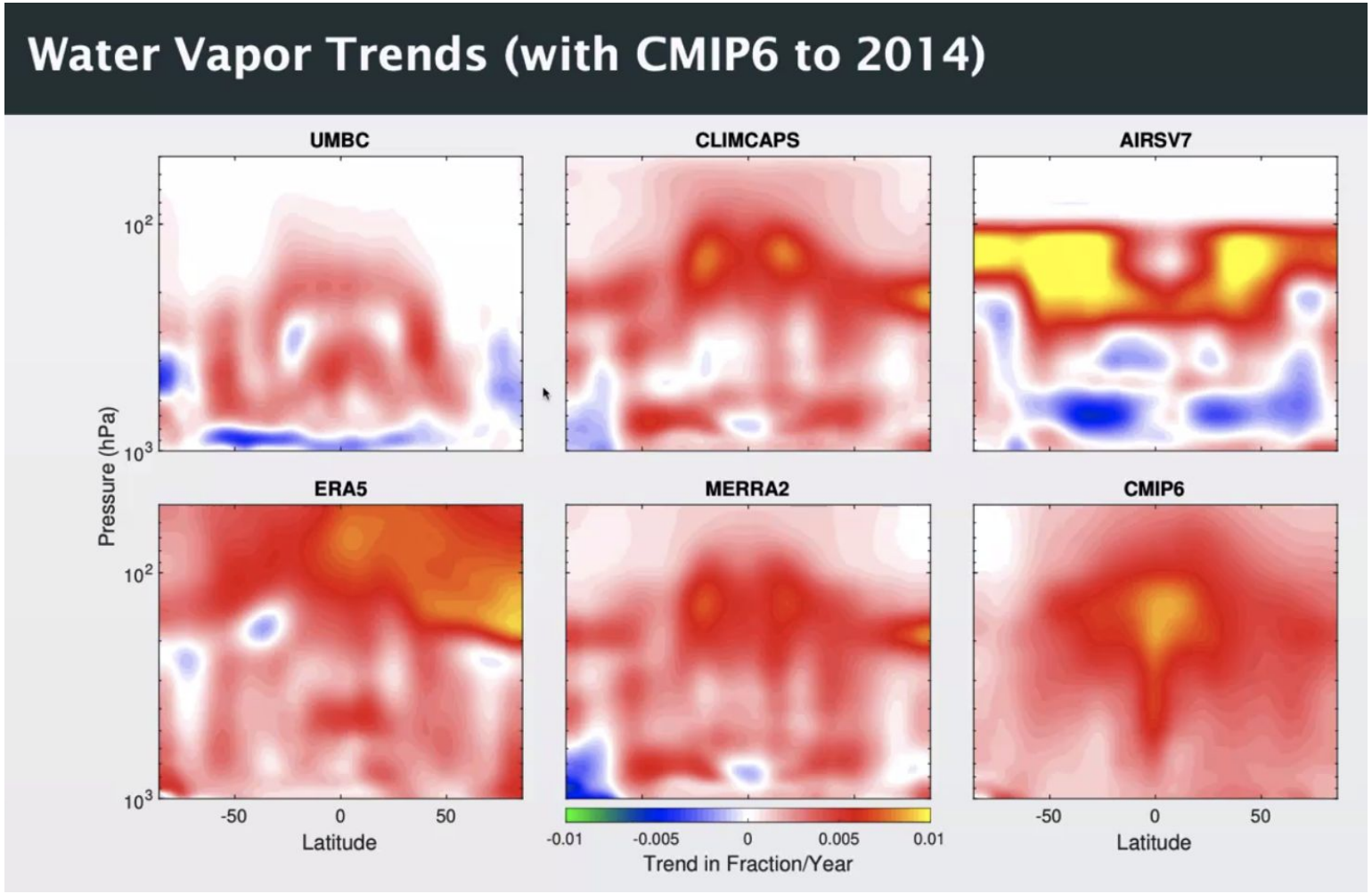
# Models all the way down: Reanalysis and Satellite Retrievals

- Reanalysis and satellite retrieval products disagree **even when ingesting the same direct observations**.
- The differences between data products imply **large, unquantified structural uncertainties**.

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# Models all the way down: Reanalysis and Satellite Retrievals

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- Th
  da
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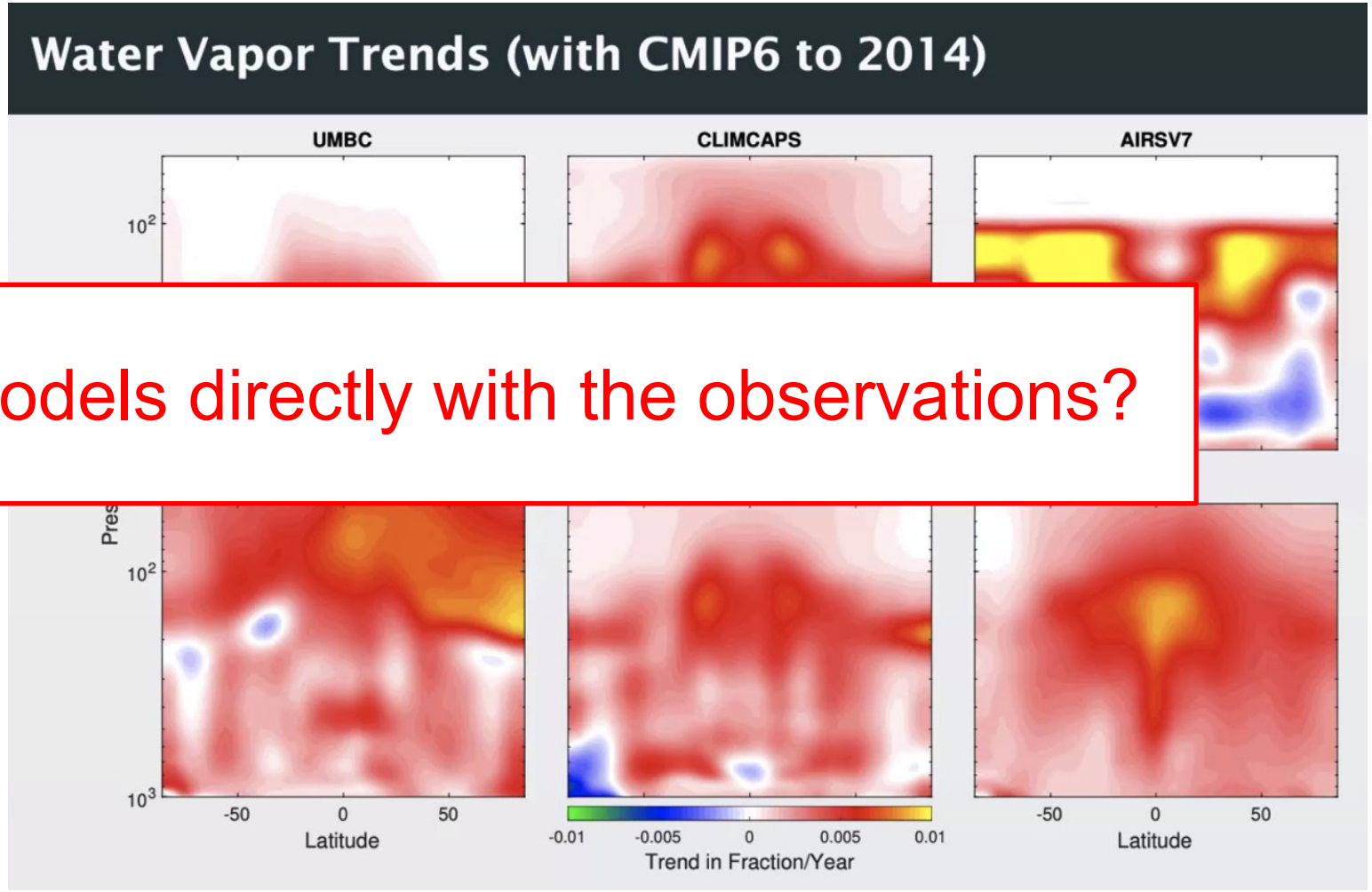
  **uncertainties**.

Why not compare models directly with the observations?

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# Challenges to satellite-model comparisons

Definitional differences hinder fair comparisons:

- Observed radiances are not comparable with model radiative fluxes
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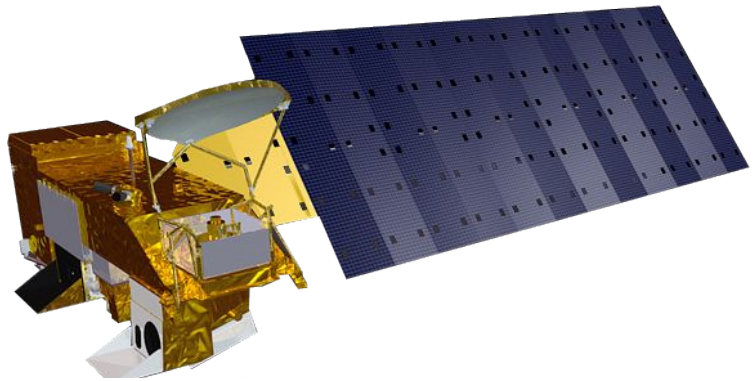
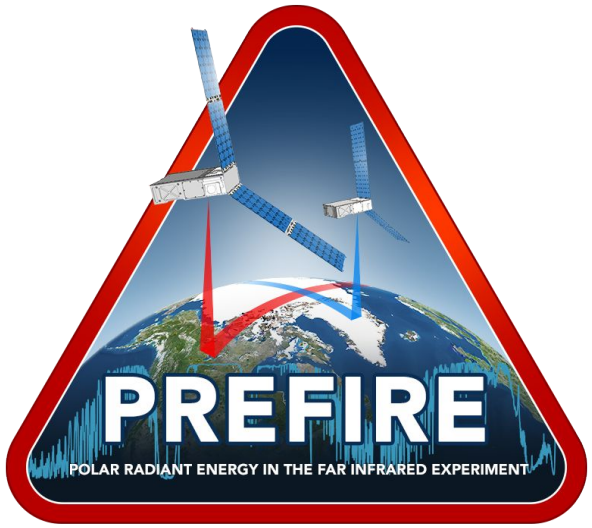
Can we make spectral radiation comparisons easier for climate models?





# Simulating Spectral Radiances in Climate Models with COSP

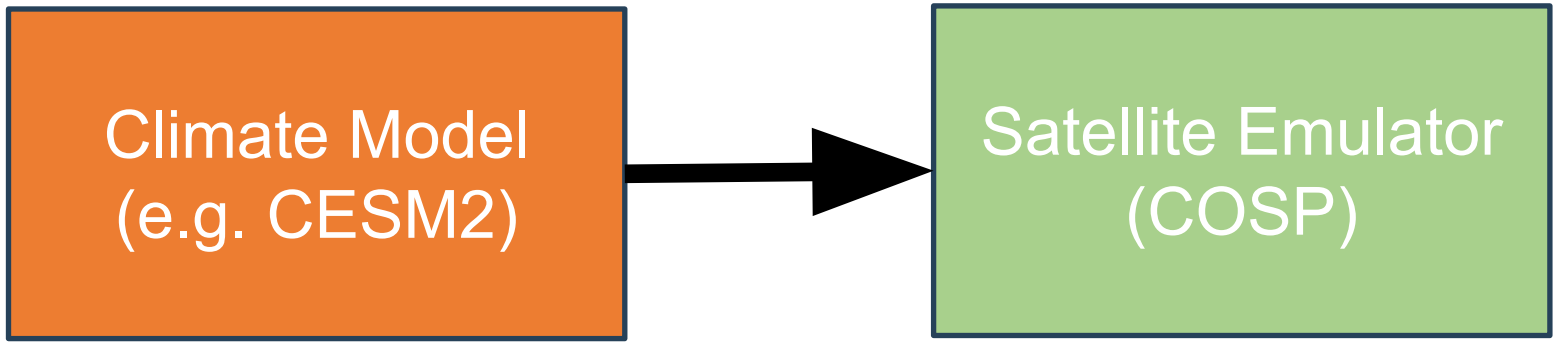
Climate Model
(e.g. CESM2)

1. Climate model simulates the coupled climate system.

Climate model :

- Coupled atmosphere, ocean, land, and sea ice components

# Simulating Spectral Radiances in Climate Models with COSP




1. Climate model simulates the coupled climate system.

2. COSP reads the model state (e.g. q, T profiles) and computes simulated satellite output.

Climate model :
- Coupled atmosphere, ocean, land, and sea ice components

COSP:
- Used by multiple modelling centers
- Sub-grid sampling
- Diurnal sampling for satellite orbits

# Simulating Spectral Radiances in Climate Models with COSP


1. Climate model simulates the coupled climate system.

2. COSP reads the model state (e.g. q, T profiles) and computes simulated satellite output.

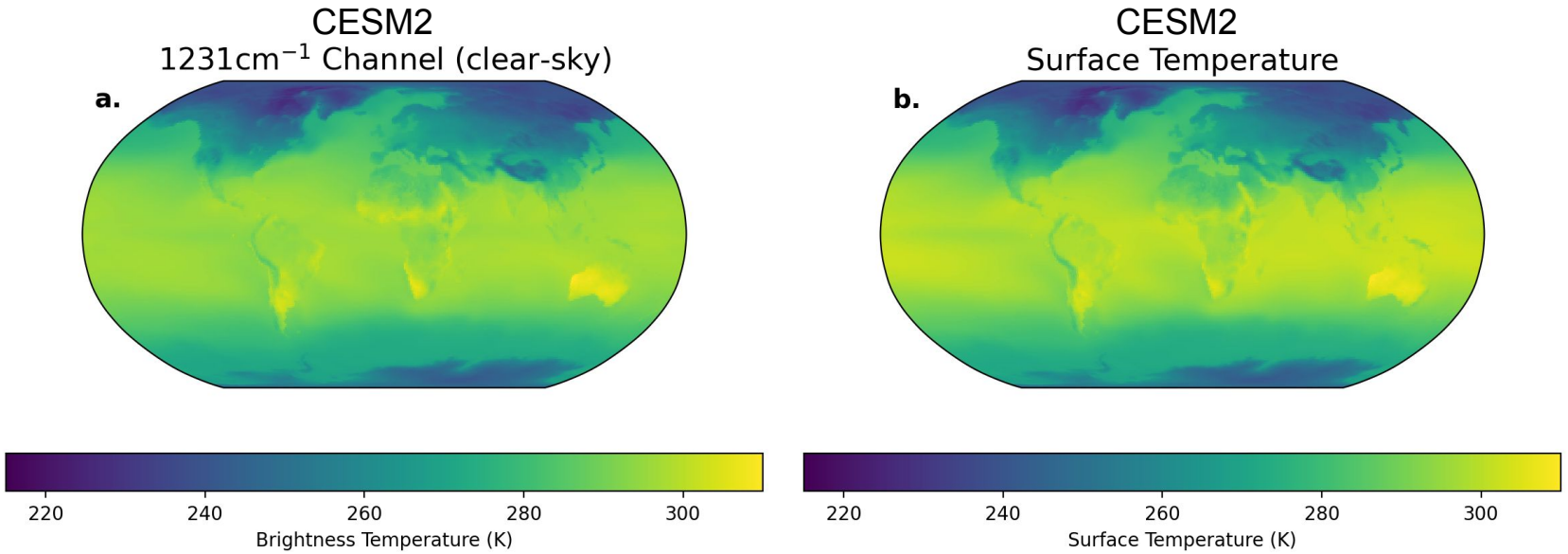
3. RTTOV simulates all-sky and clear-sky radiances for requested instruments + channels.

Climate model :
- Coupled atmosphere, ocean, land, and sea ice components

COSP:
- Used by multiple modelling centers
- Sub-grid sampling
- Diurnal sampling for satellite orbits

RTTOV:
- Fast, accurate radiative transfer model
- Instrument-specif ic

# Output: “Satellite-like” spectra with intuitive meaning



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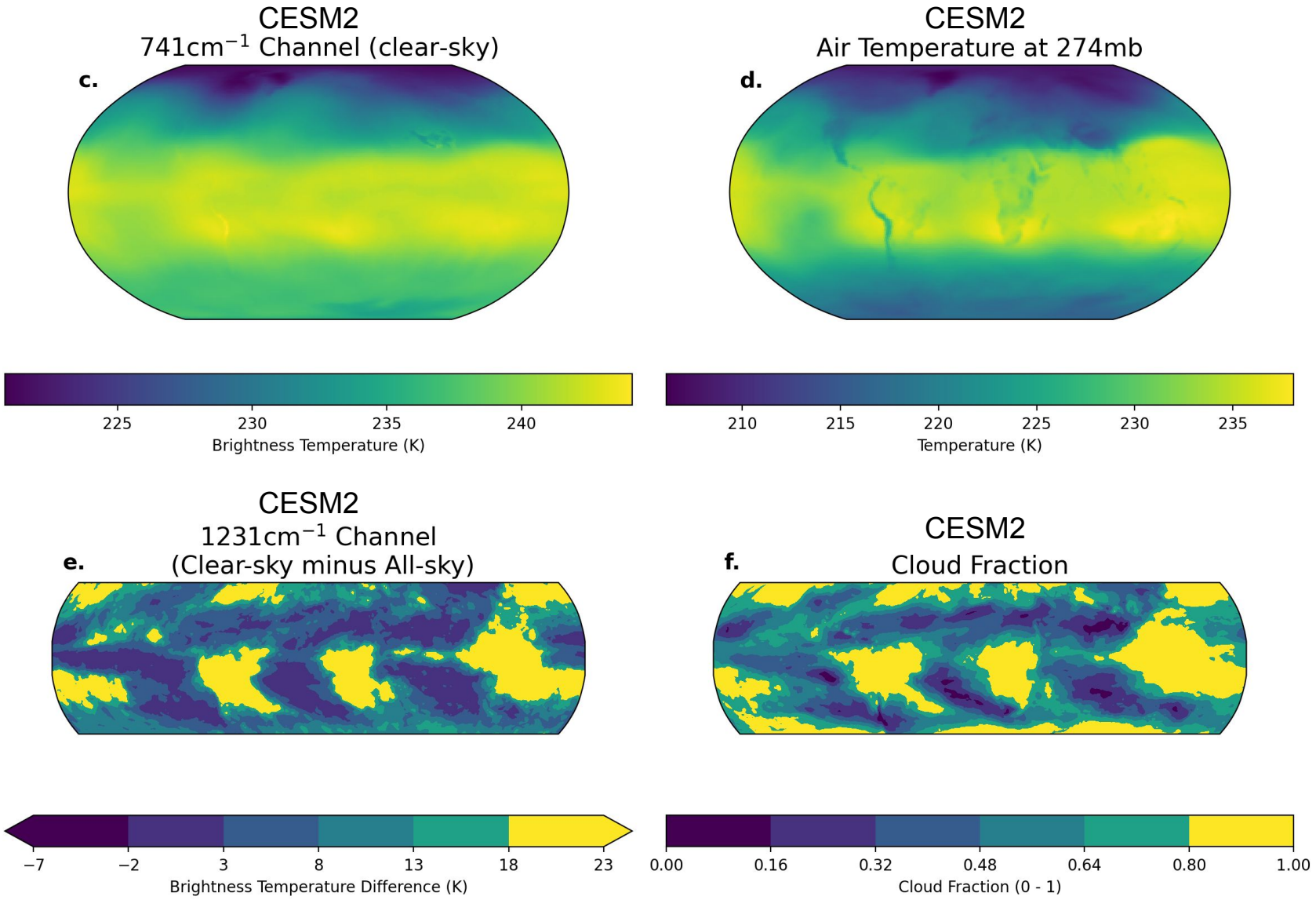
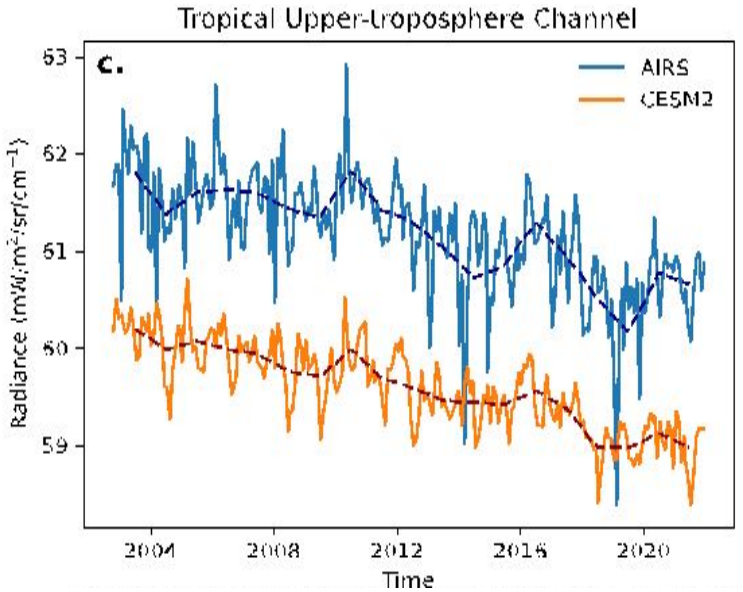


# Output: Model evaluation against direct satellite observations



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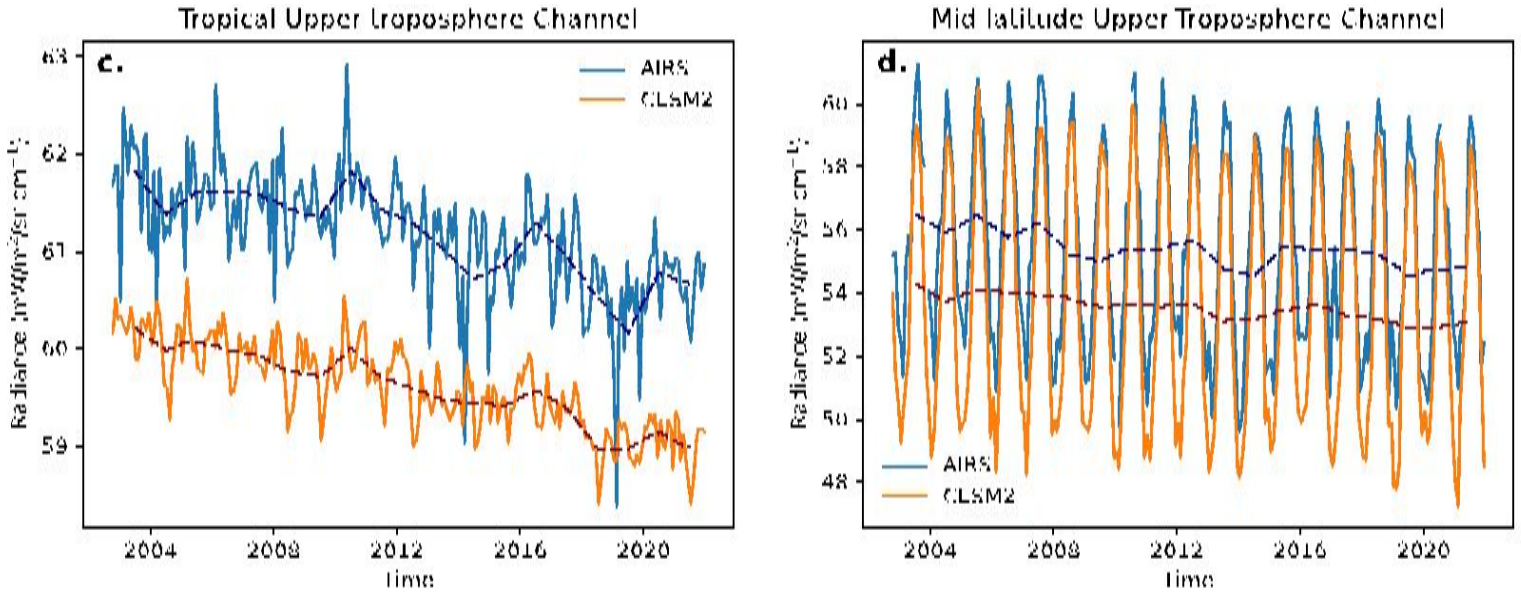

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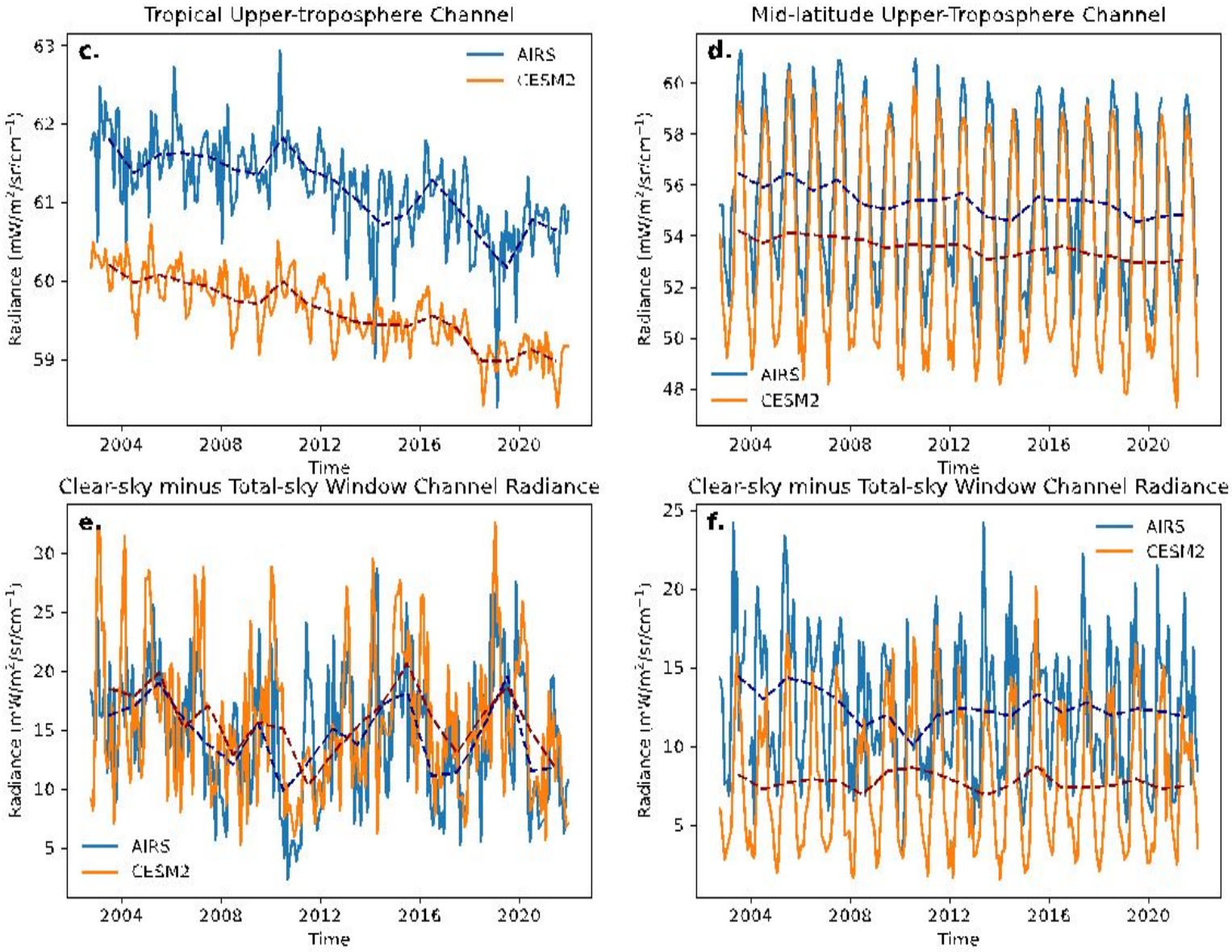
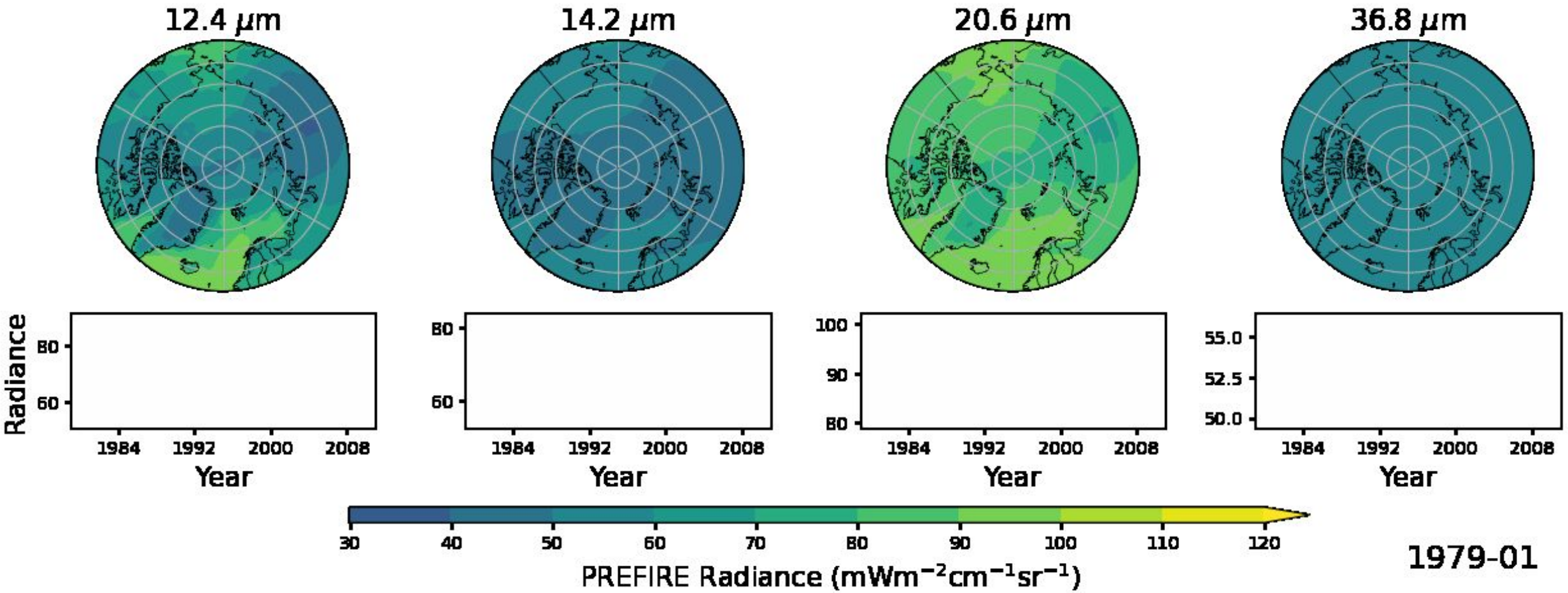
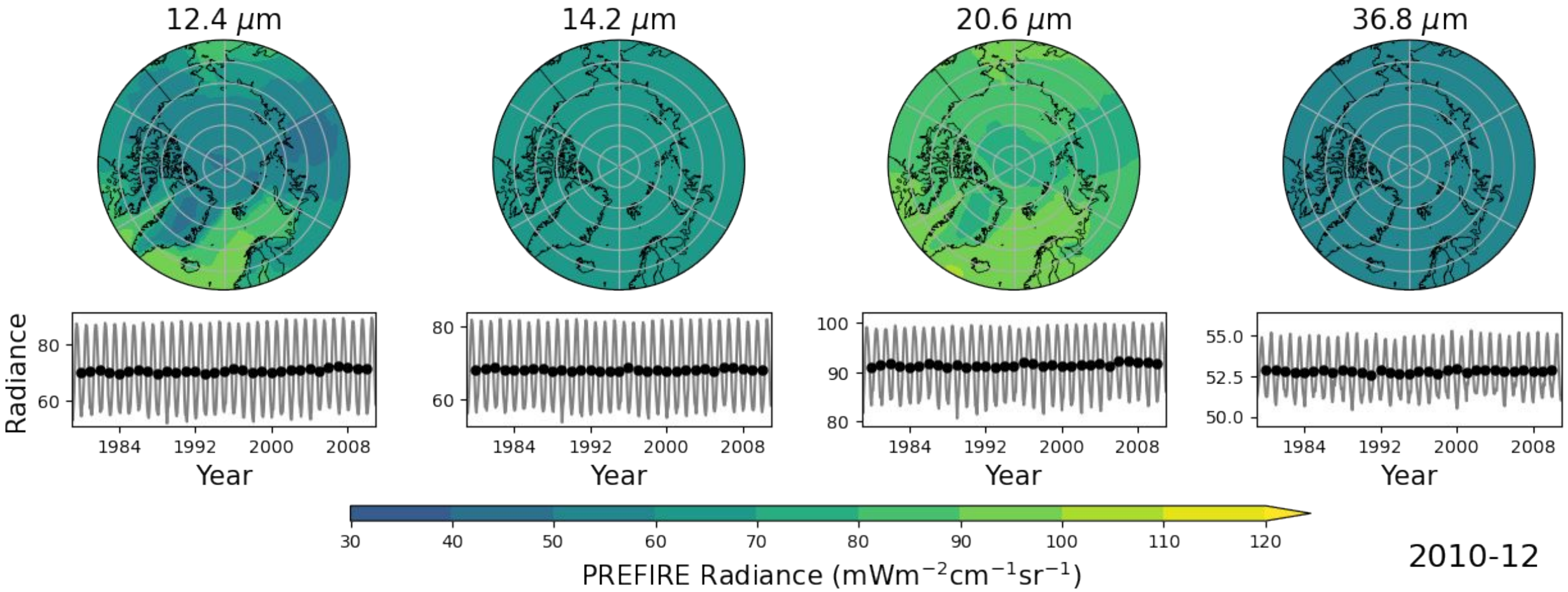


# Output: “PREFIRE-like” spectra 1979 to present

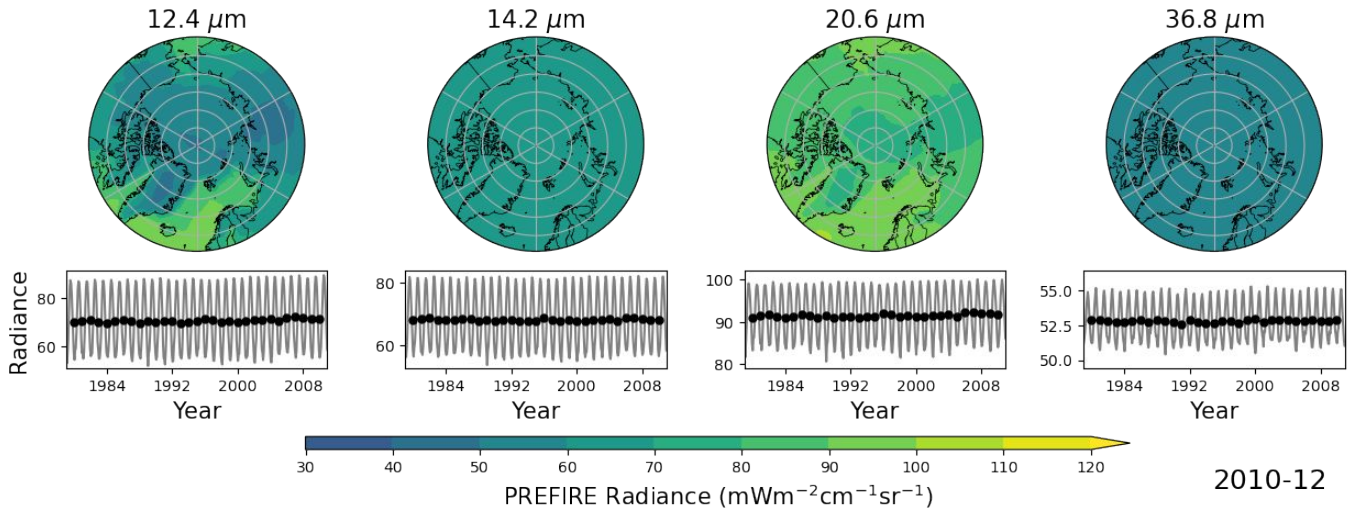


# Output: “PREFIRE-like” spectra 1979-present



# COSP-RTTOV makes spectral radiation comparisons easy

- Simulate “satellite-like” spectral radiation directly in CESM2
- Evaluate model performance against direct observations
- Support future satellite missions by simulating them ahead of time.




Preprint here:

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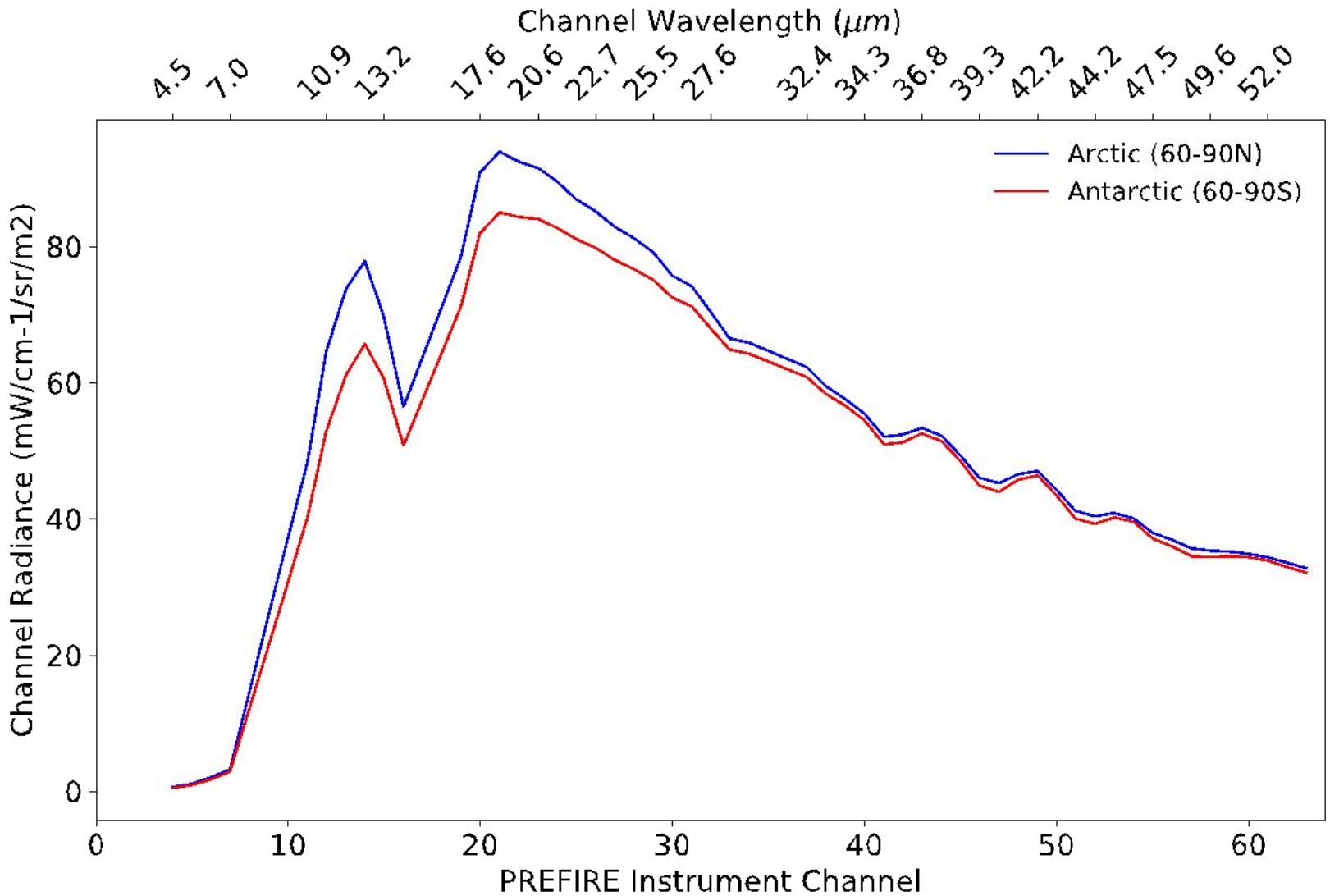
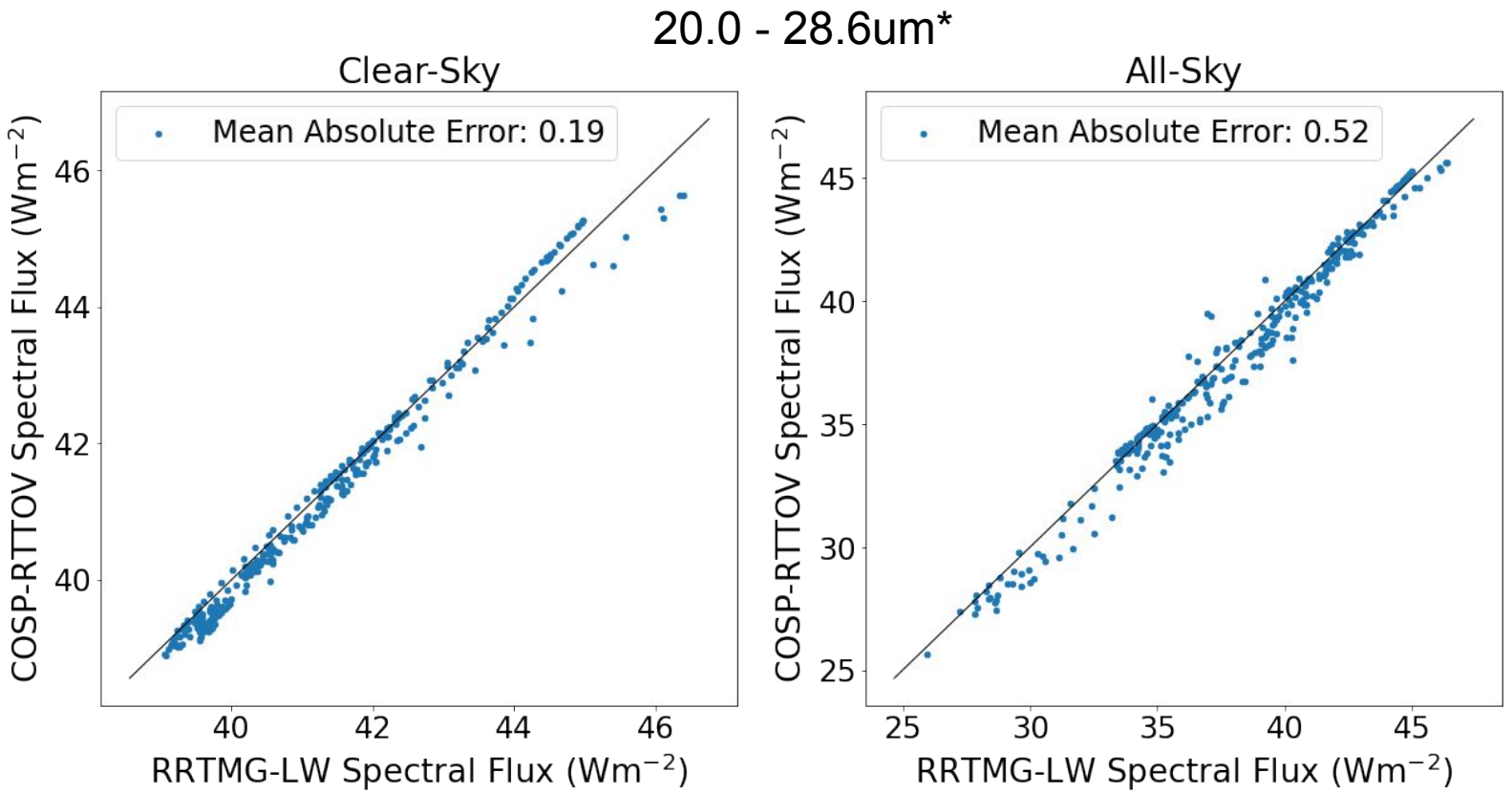
# Output: “Satellite-like” spectra



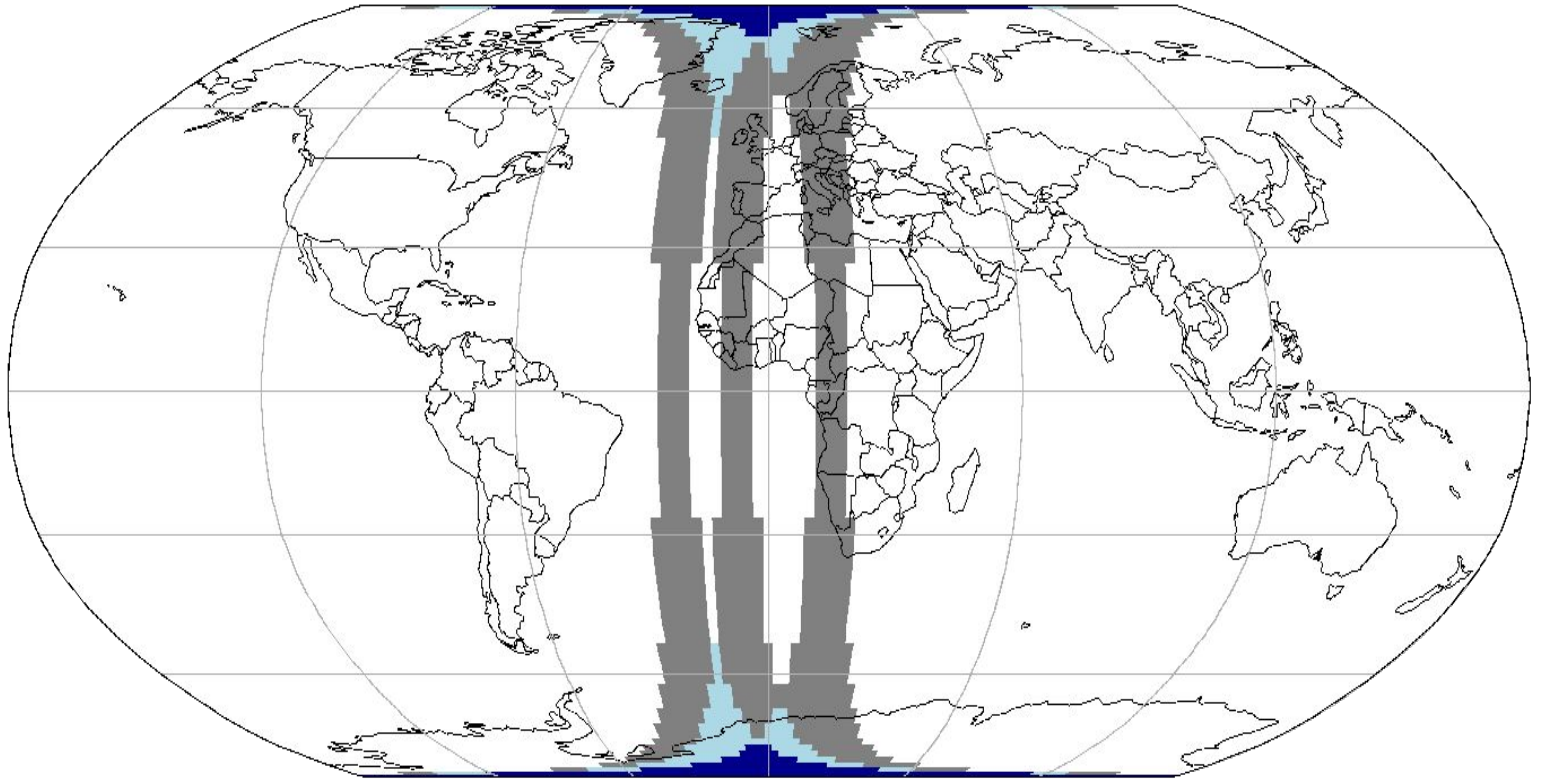
# Output: "Satellite-like" spectra consistent with GCM radiation fields



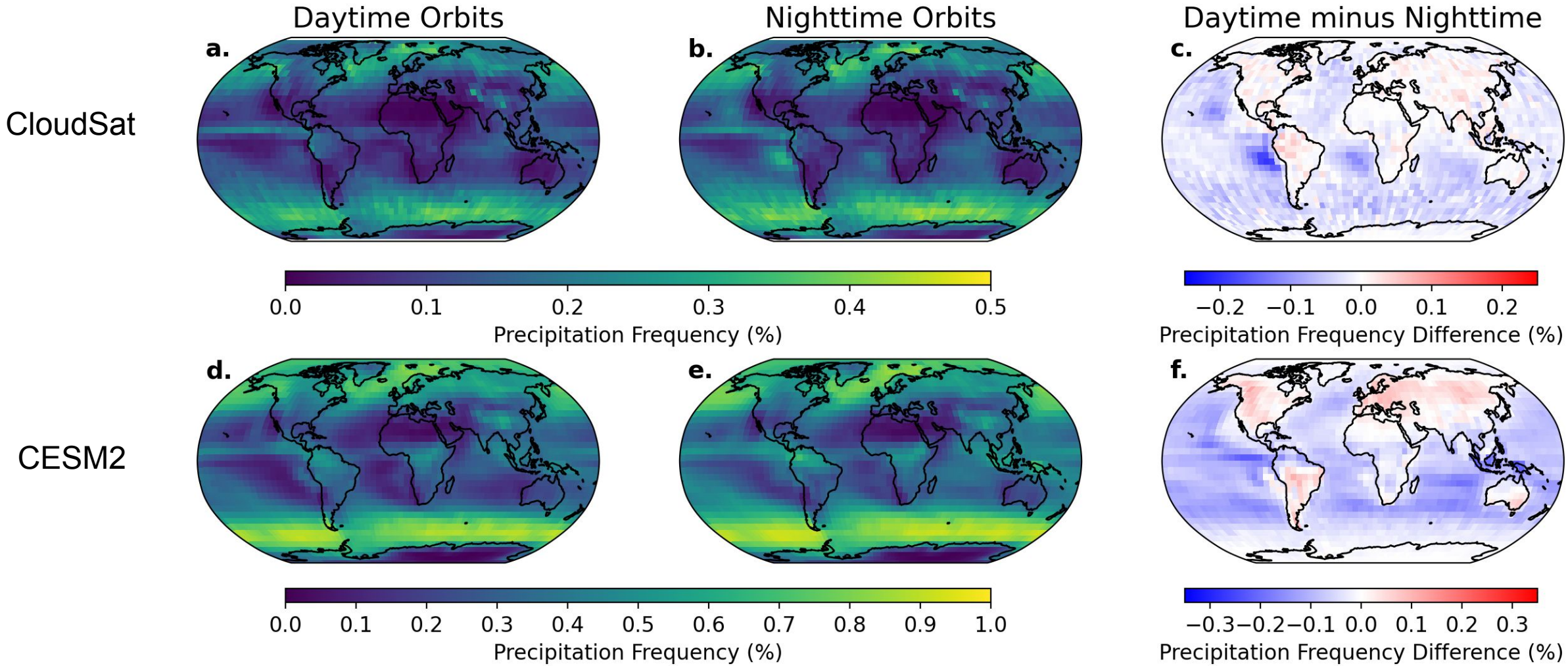

*Comparison with RRTMG radiative fluxes uses SRFs with 0.3cm-1 spacing and a 6-point gaussian quadrature.

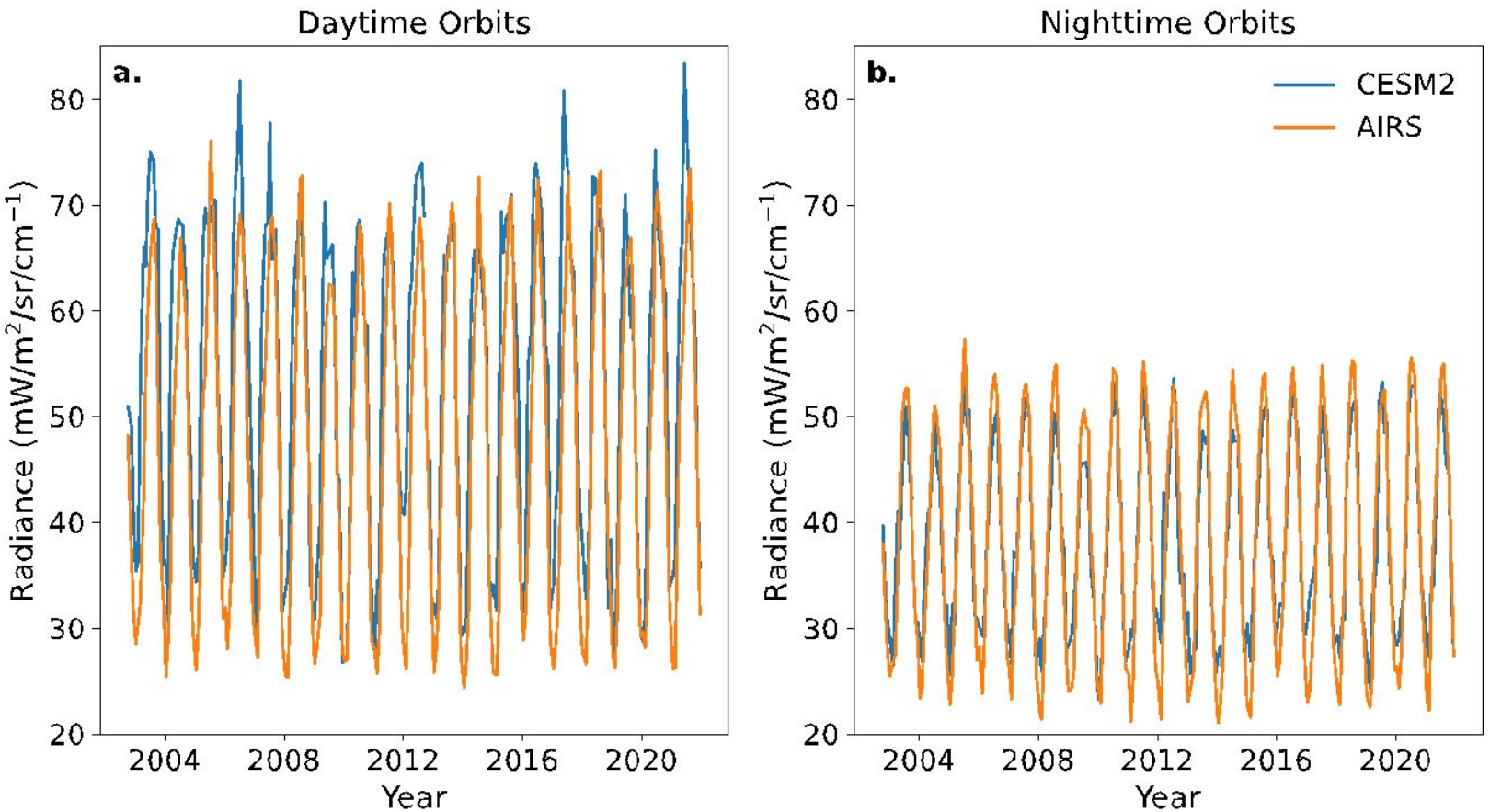
# “Satellite-like” diurnal sampling: Implementation

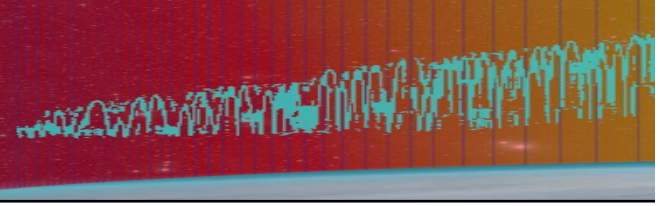
- User specifies local times and swath widths.
- Simulators only run on appropriate model gridcells.
- Reduced simulator calls reduce computational cost.

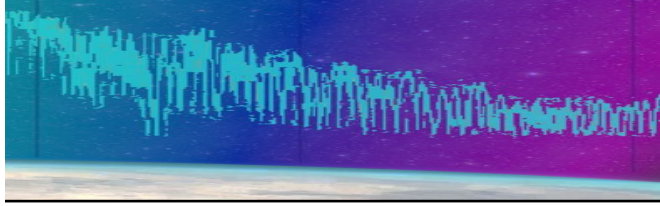


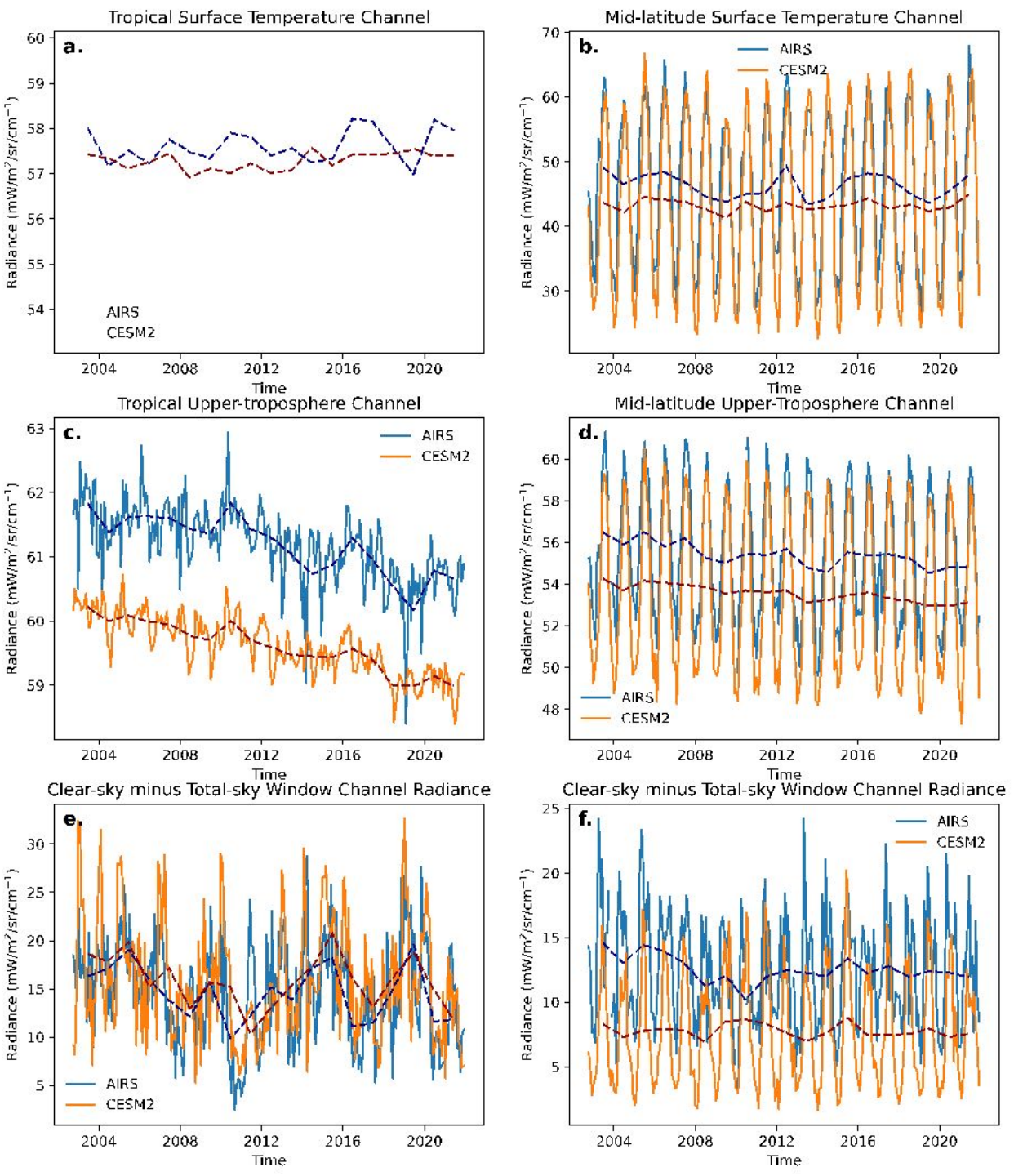
# “Satellite-like” diurnal sampling: Results

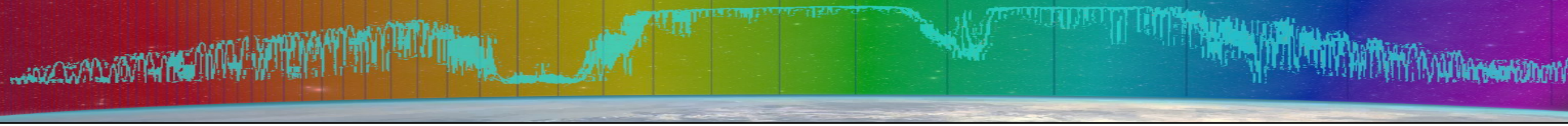


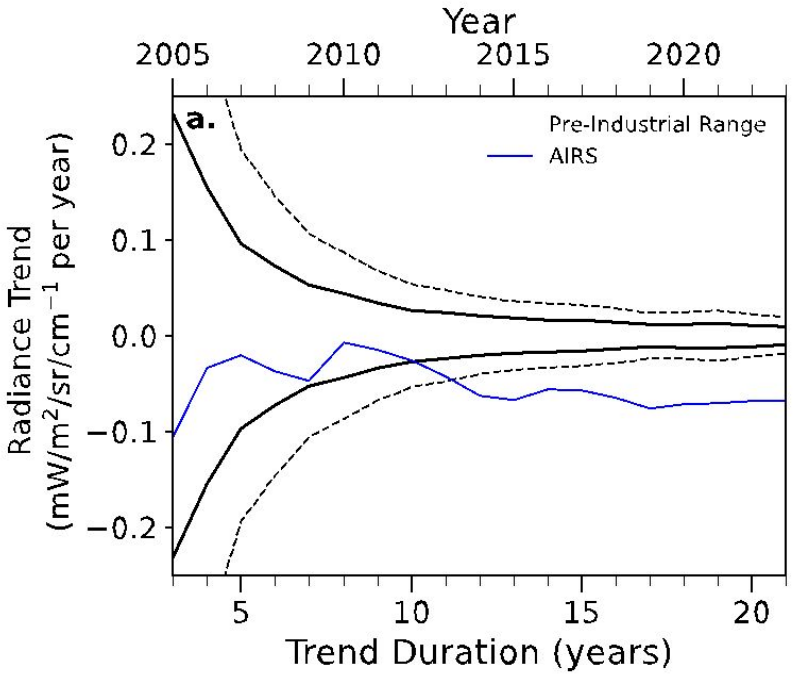

Daytime Orbits
a.
Nighttime Orbits
b.
CESM2
AIRS
Radiance (mW/m$^2$/sr/cm$^{-1}$)
Year
20
30
40
50
60
70
80
2004
2008
2012
2016
2020

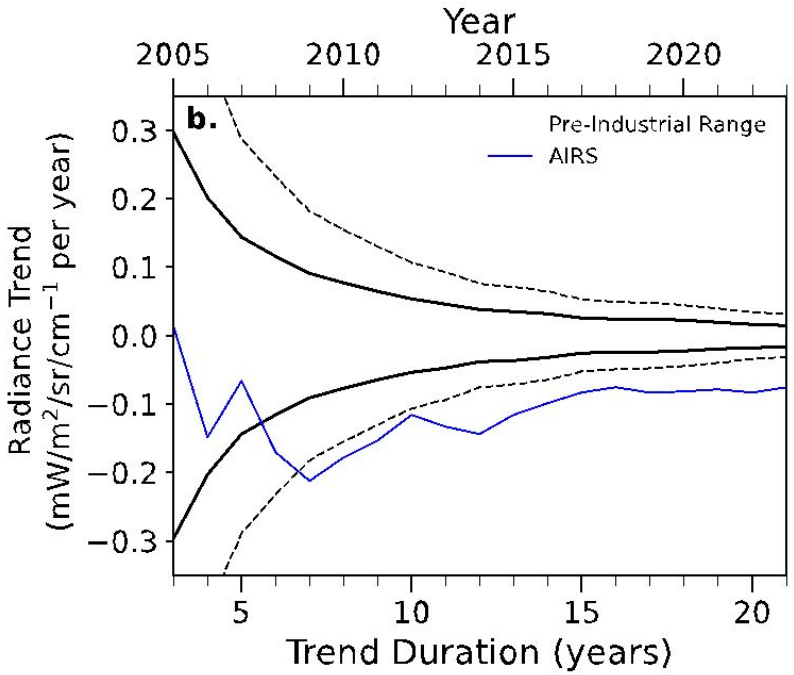





Tropical Surface Temperature Channel
a.
AIRS
CESM2
Radiance (mW/m²/sr/cm⁻¹)
Time
Mid-latitude Surface Temperature Channel
b.
AIRS
CESM2
Tropical Upper-troposphere Channel
c.
Mid-latitude Upper-Troposphere Channel
d.
Clear-sky minus Total-sky Window Channel Radiance
e.
Clear-sky minus Total-sky Window Channel Radiance
f.
2004
2008
2012
2016
2020




Year
2005
2010
2015
2020
a.
Pre-Industrial Range
AIRS
Radiance Trend
(mW/m²/sr/cm⁻¹ per year)
0.2
0.1
0.0
−0.1
−0.2
5
10
15
20
Trend Duration (years)


Year
2005
2010
2015
2020
b.
Pre-Industrial Range
AIRS
Radiance Trend
(mW/m²/sr/cm⁻¹ per year)
0.3
0.2
0.1
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−0.1
−0.2
−0.3
5
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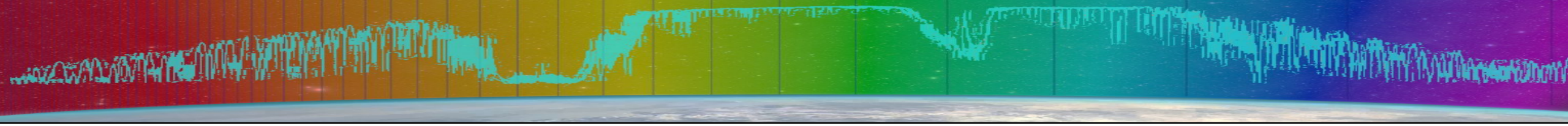
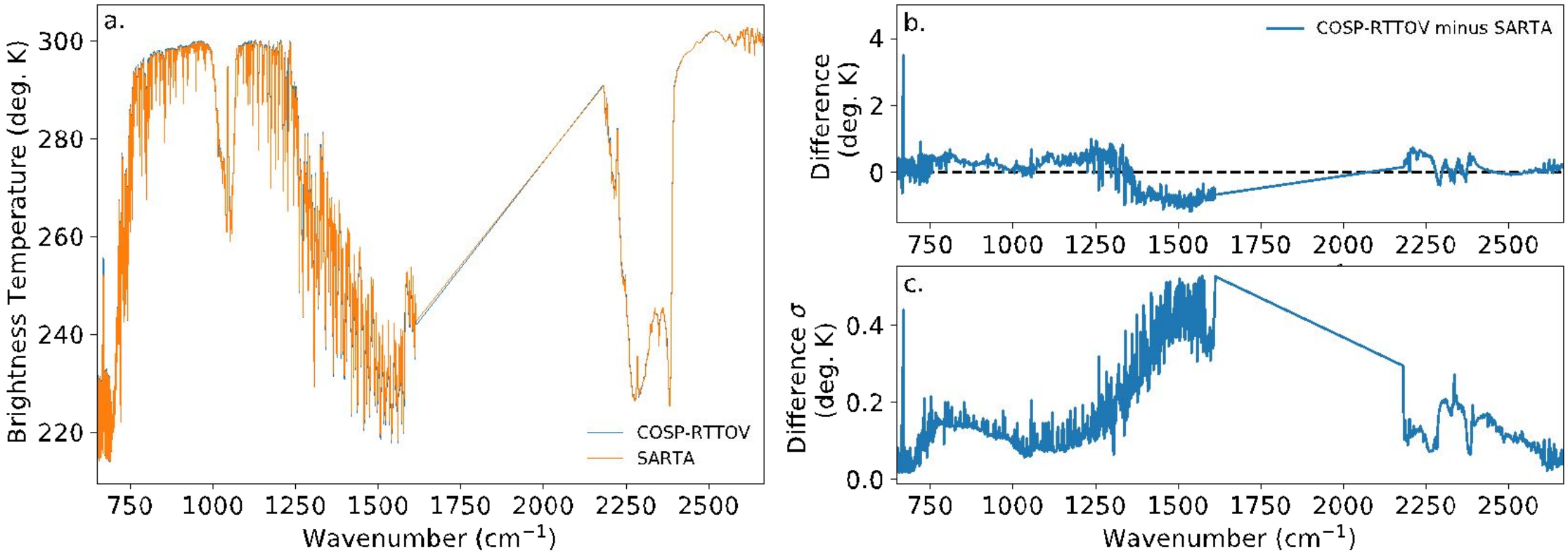
15
20
Trend Duration (years)




a.
Brightness Temperature (deg. K)
300
280
260
240
220
750
1000
1250
1500
1750
2000
2250
2500
Wavenumber (cm$^{-1}$)
COSP-RTTOV
SARTA
b.
COSP-RTTOV minus SARTA
Difference (deg. K)
4
2
0
c.
Difference σ (deg. K)
0.4
0.2
0.0

# COSP-RTTOV makes spectral radiation comparisons easy

- Simulate “satellite-like” spectral radiation directly GCMs
- All-sky and clear-sky fields
- Experiment design (wind-nudging) allows evaluation of short records

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# Challenges to satellite-model comparisons

1. Definitional differences hinder fair comparisons:

- Obs[COSP-RTTOV satellite simulator]tive fluxes
- Differences in diurnal sampling, spatial resolution, etc.

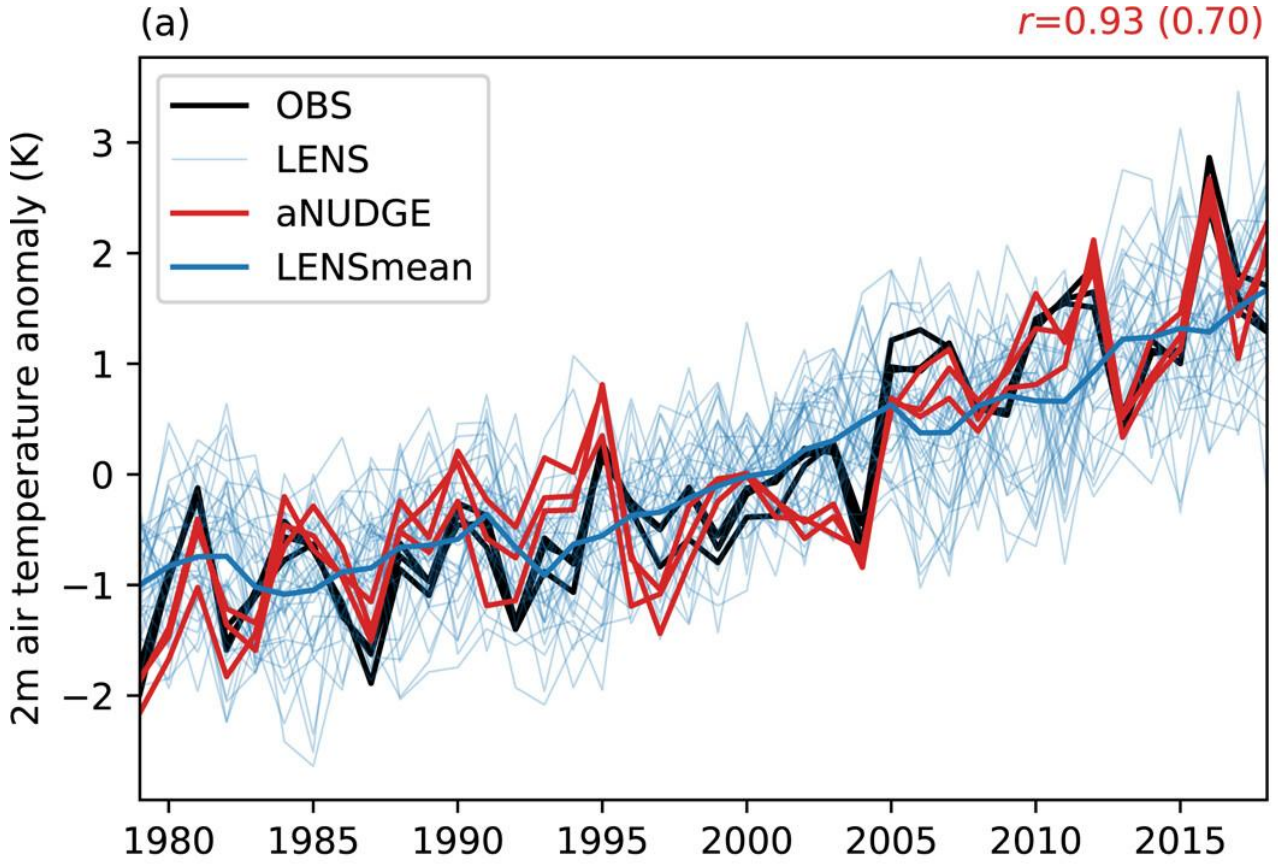
2. Internal climate variability:

- Large year-to-year differences in climate fields
- Most trusted observational records are 5+ years (10+ years even better)

# Flexibly simulating spectral in global climate models

1. In-line global model radiative transfer tool (COSP-RTTOV)
2. GCM experiment design

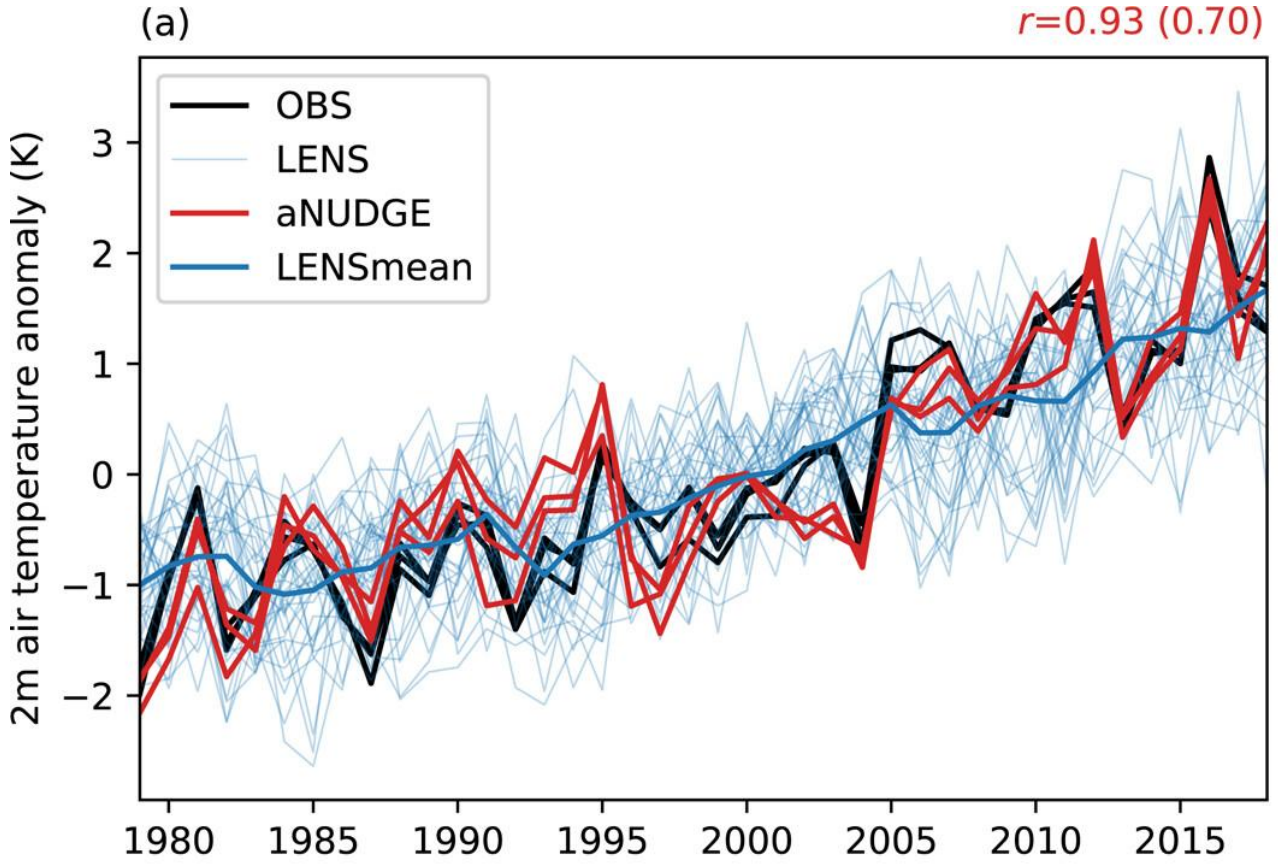
# Wind nudging: Constrain atmospheric circulation to observations




Roach and Blanchard-Wrigglesworth (2022)

# Wind nudging: Constrain atmospheric circulation to observations

- Models capture internal variability well when wind nudging is used.
- Nudged simulations enable meaningful comparisons with short observational records.

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# Simulating PREFIRE and AIRS in atmosphere-only simulations

Atmosphere-only simulation beginning in 1979:

- SSTs and sea ice boundary conditions come from observations (ERSST)

Model winds “nudged” towards ERA5 reanalysis (methods of Gilbert et al.):

- Nudging domain: 60-90N, 850hPa and above
- Boundary layer still evolves freely

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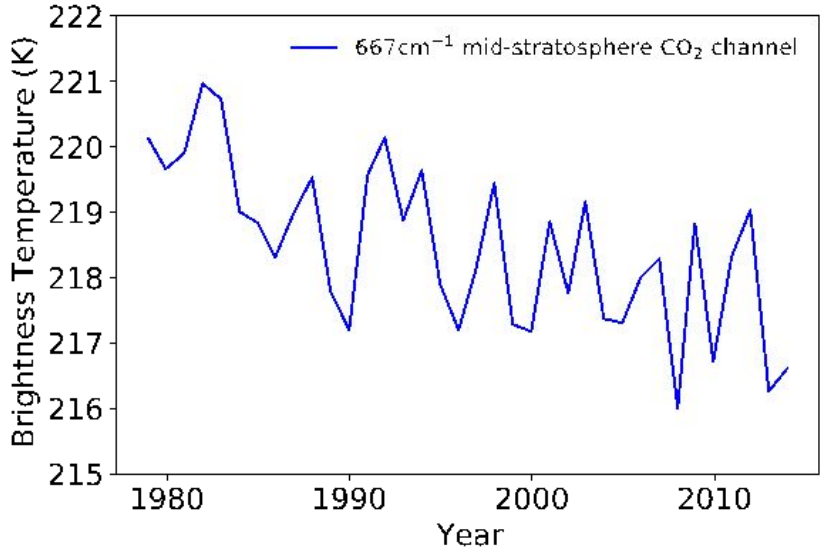
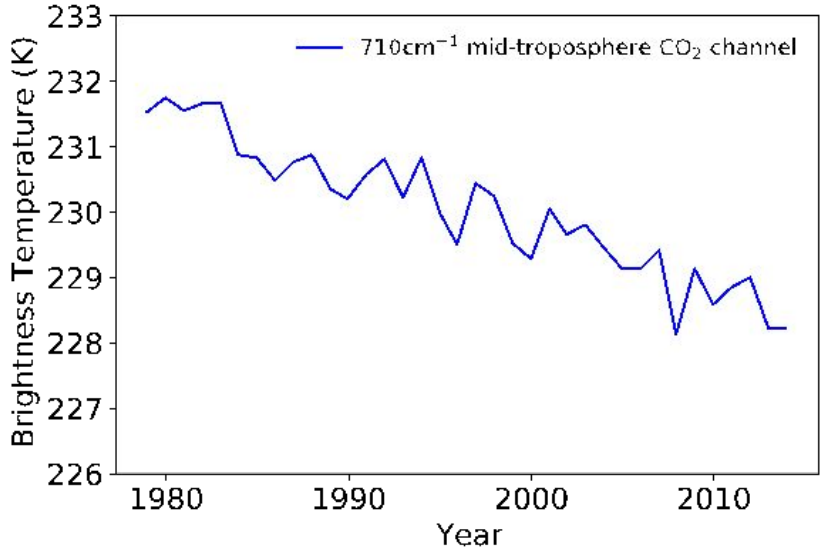
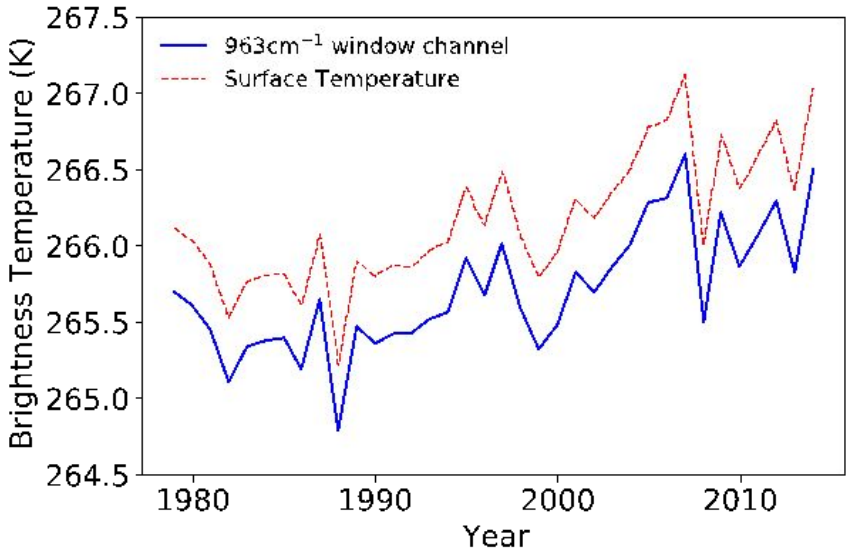
Simulate all-sky and clear-sky radiances + BTs for a subset of AIRS and PREFIRE channels

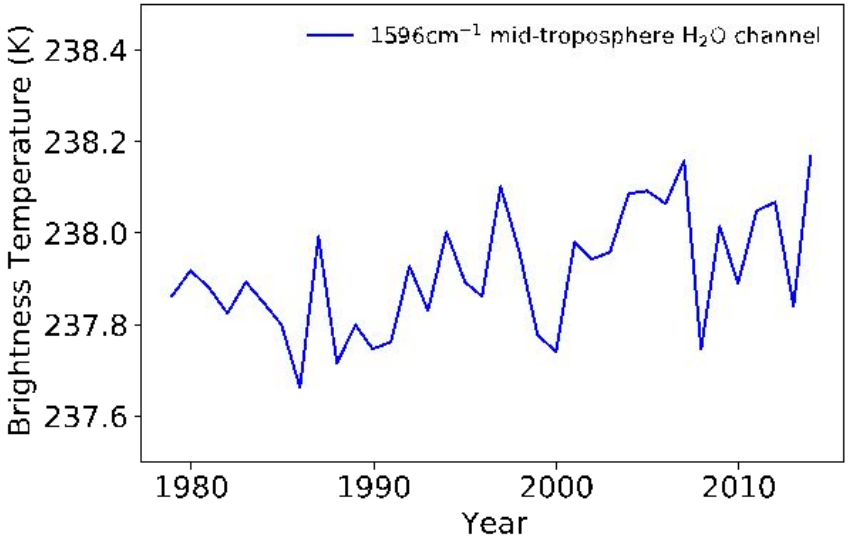
**Can extend simulations into the future as SST and reanalysis is released.**

# AIRS radiances capture different changes in the Arctic climate



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# Comparing spectral radiation with models is valuable…

**A strict test in climate modeling with spectrally resolved radiances: GCM simulation versus AIRS observations**

Yi Huang,[1] V. Ramaswamy,[2] Xianglei Huang,[3] Qiang Fu,[4] and Charles Bardeen[5]

Received 26 July 2007; revised 12 November 2007; accepted 20 November 2007; published 28 December 2007.

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Models do not produce spectral radiation fields for comparison with observations.

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# Challenges to satellite-model comparisons

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Can we make spectral radiation comparisons easier for climate models?

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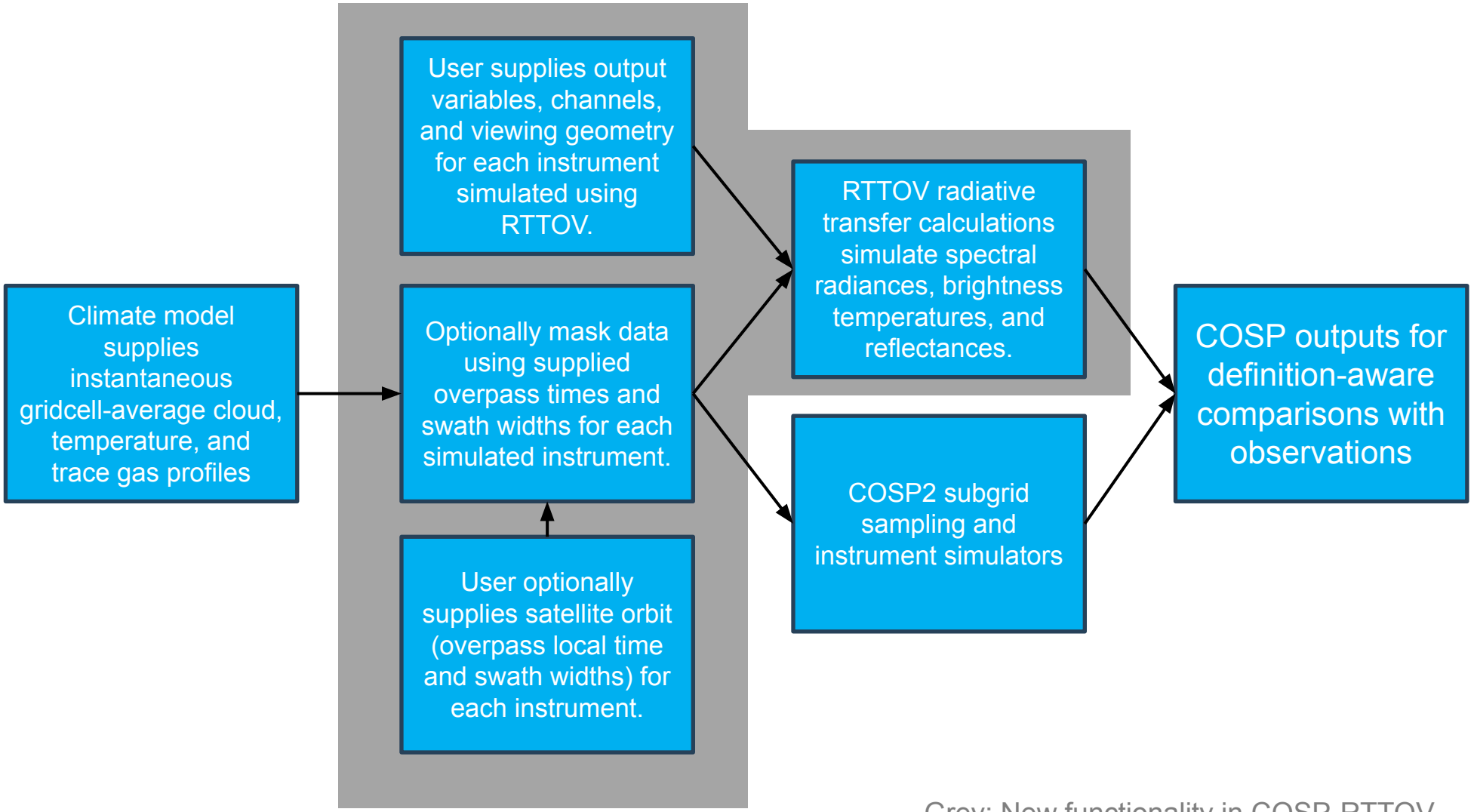


Grey: New functionality in COSP-RTTOV