Evaluating CESM Against Satellite Spectral Radiation Observations

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2025 CESM Workshop

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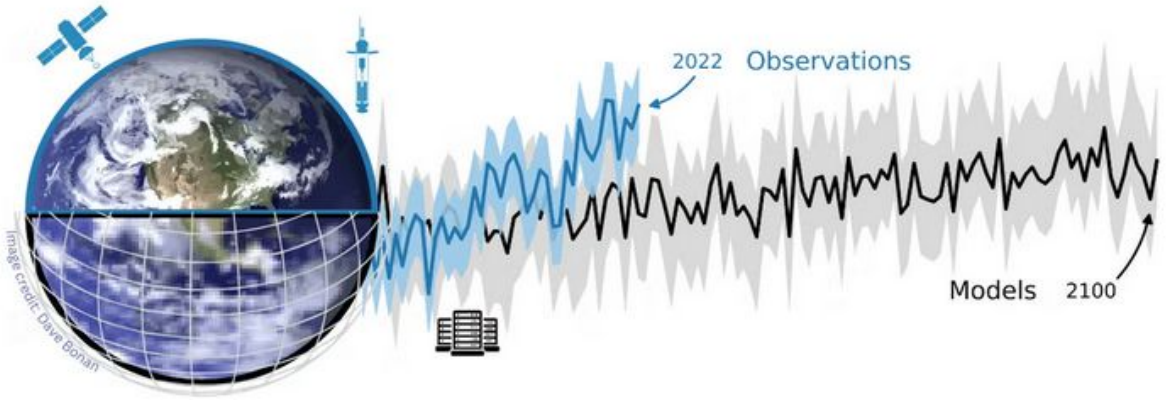
BLUE CANYON TECHNOLOGIES
NSF

- March 2024 in Boulder

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



8:30 AM	(Invited) Subtle lessons from the art of model-observation confrontations*	Gavin Schmidt, NASA GISS

Philosophical Footnote #2

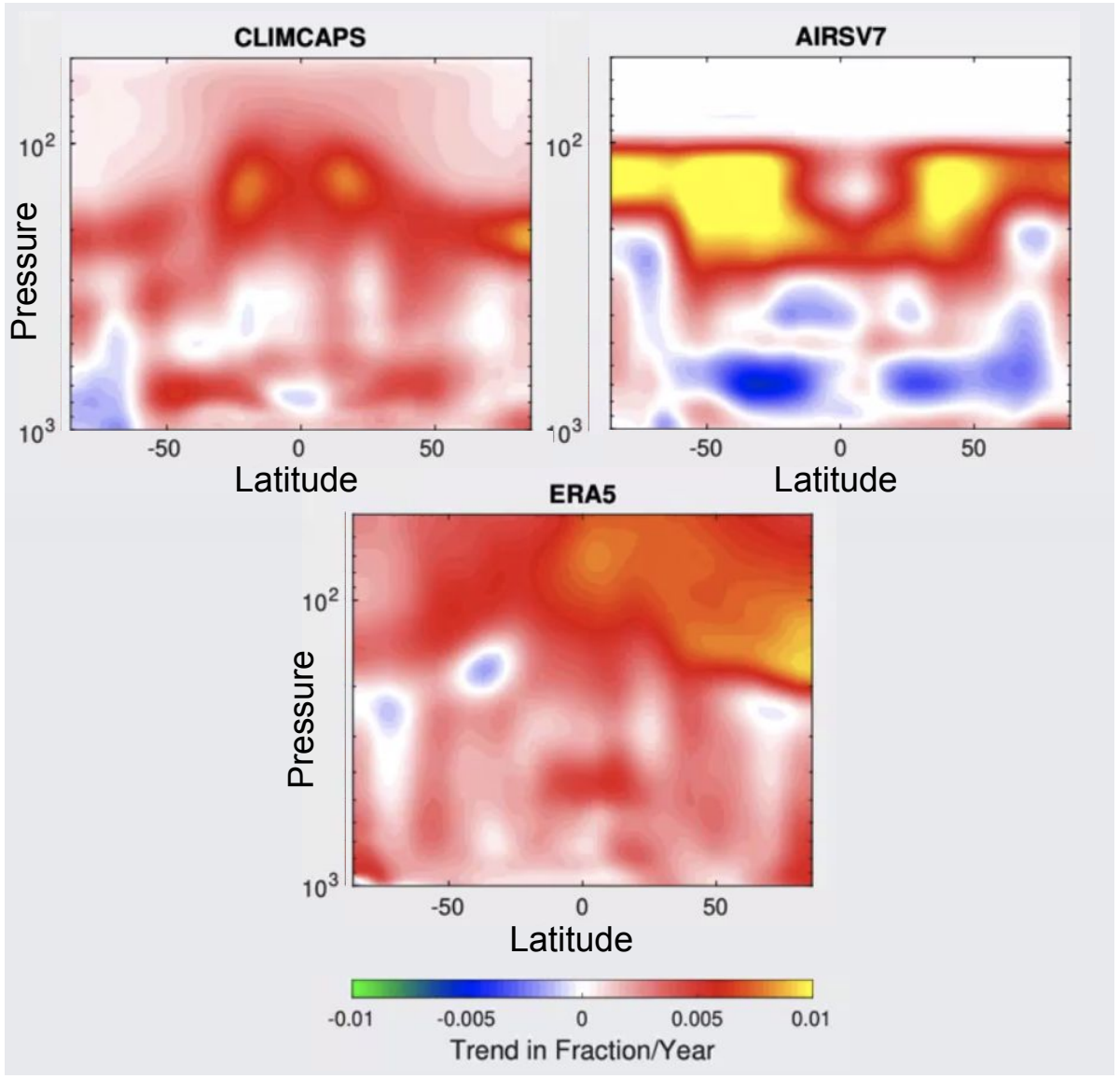
All observations and comparisons are based on models too

(It's models all the way down!)

Models all the way down: Reanalyses 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**.
- Differences between data products are a **conservative estimate** of uncertainty (e.g. Chemke and Polvani, 2019).

Fractional Water Vapor Trends 2003-2014



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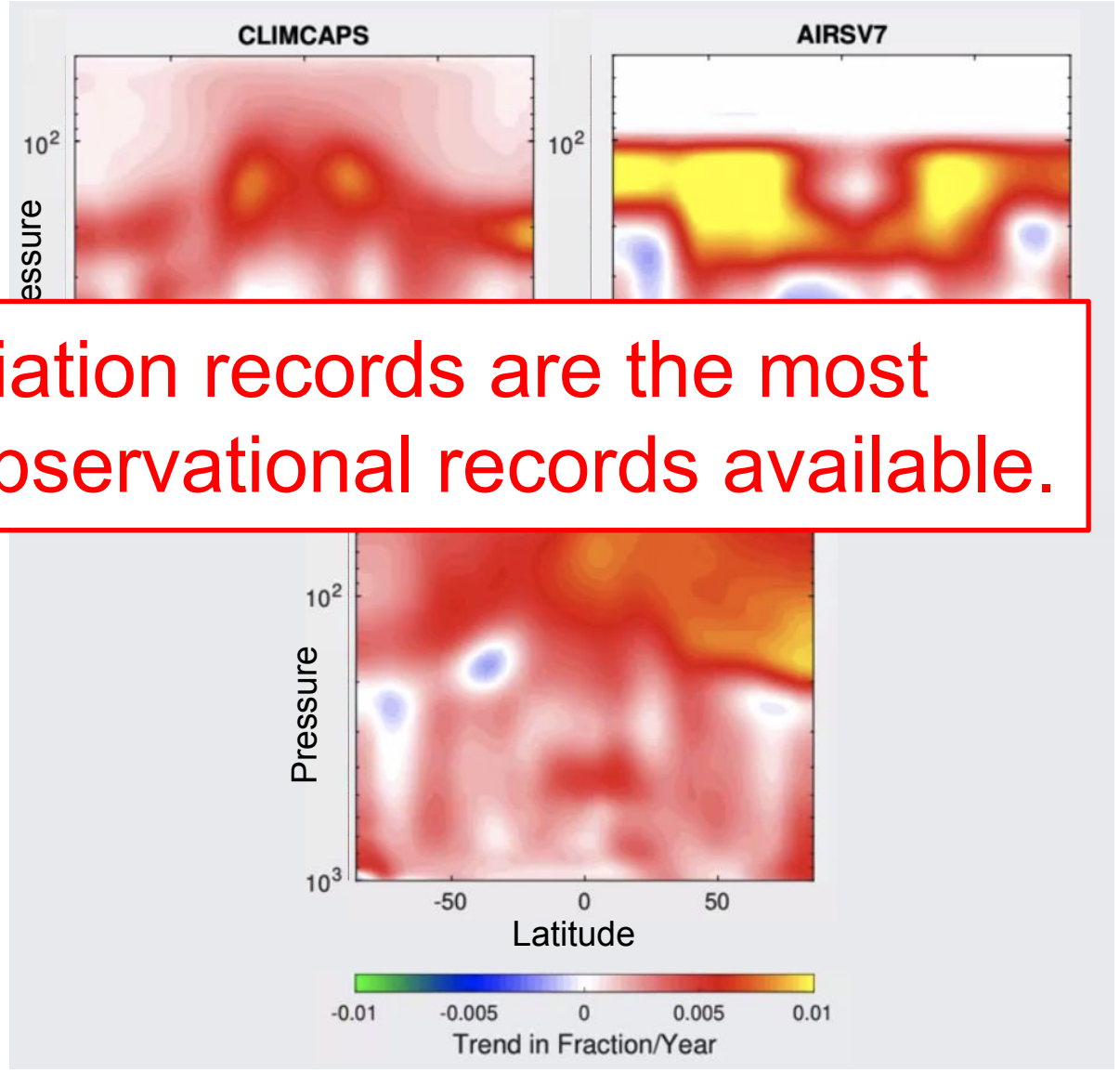


Satellite spectral radiation records are the most complete and detailed observational records available.

Challenges to satellite-model comparisons

Definitional differences hinder fair comparisons:

- Observed radiances and brightness temperatures are not comparable with model radiative fluxes
- Differences in diurnal sampling, spatial resolution, etc.

Simulating Spectral Radiances in Climate Models with COSP-RTTOV

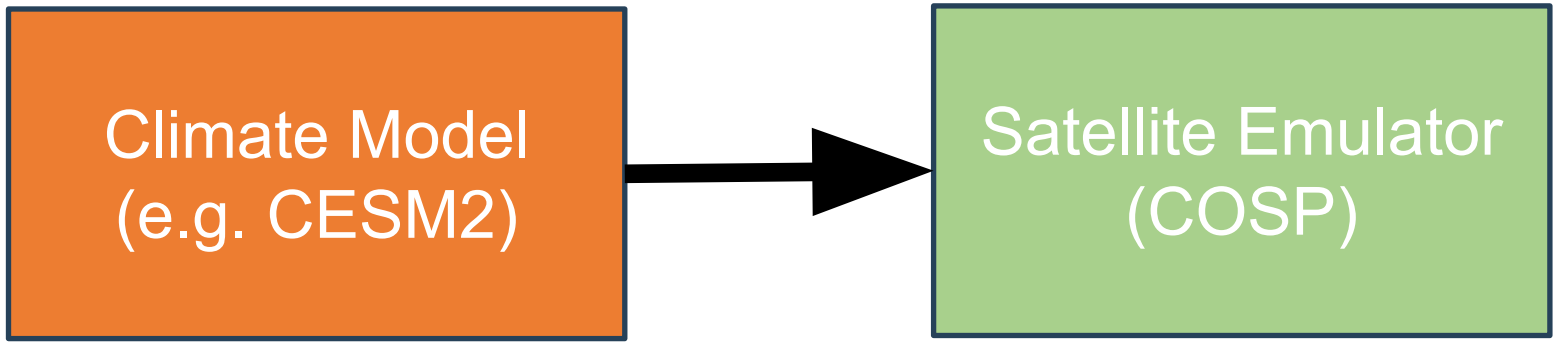
Climate Model
(e.g. CESM2)

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-RTTOV



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-RTTOV

1. Climate model simulates the coupled climate system.

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

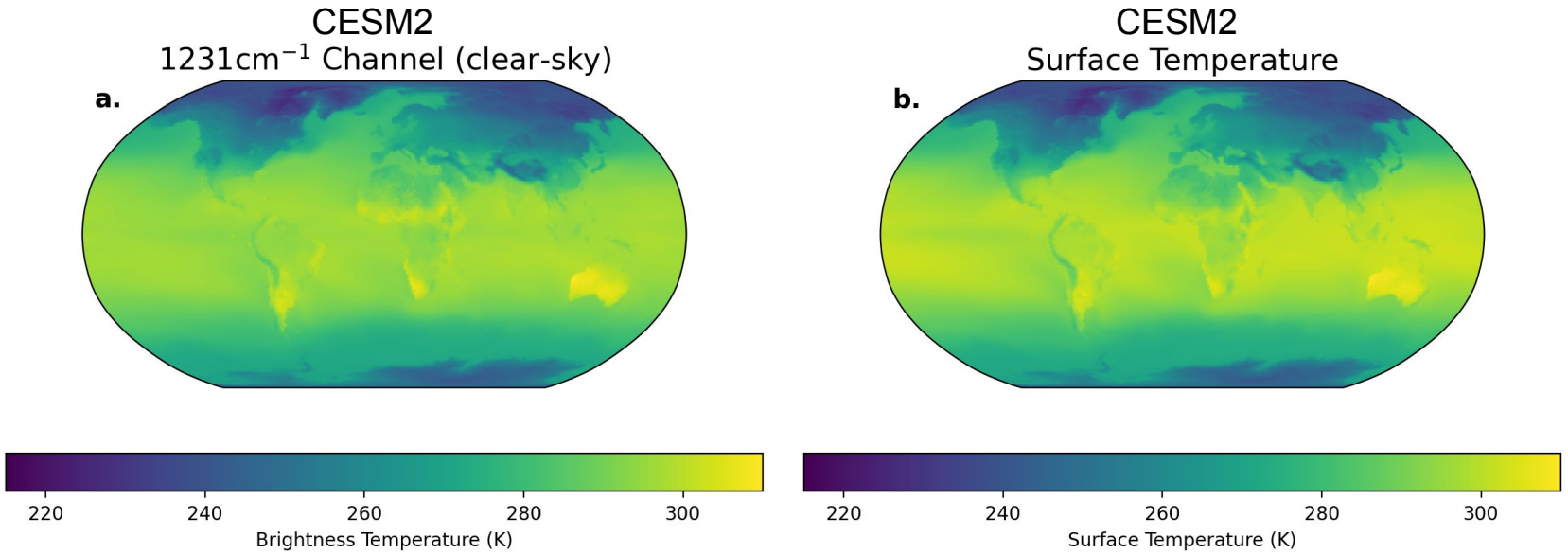
3. RTTOV simulates all-sky and clear-sky radiances for requested instruments + channels.

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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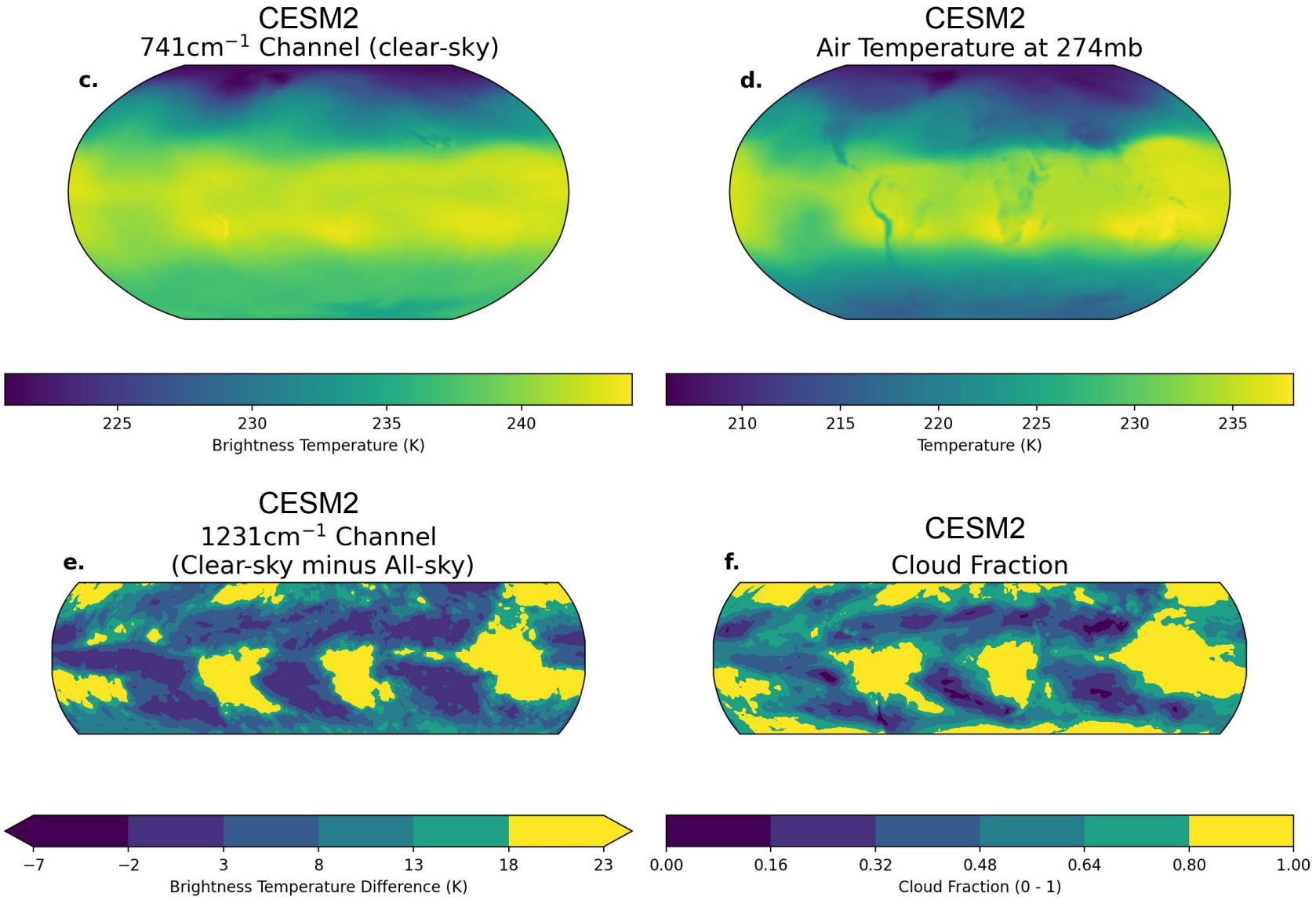
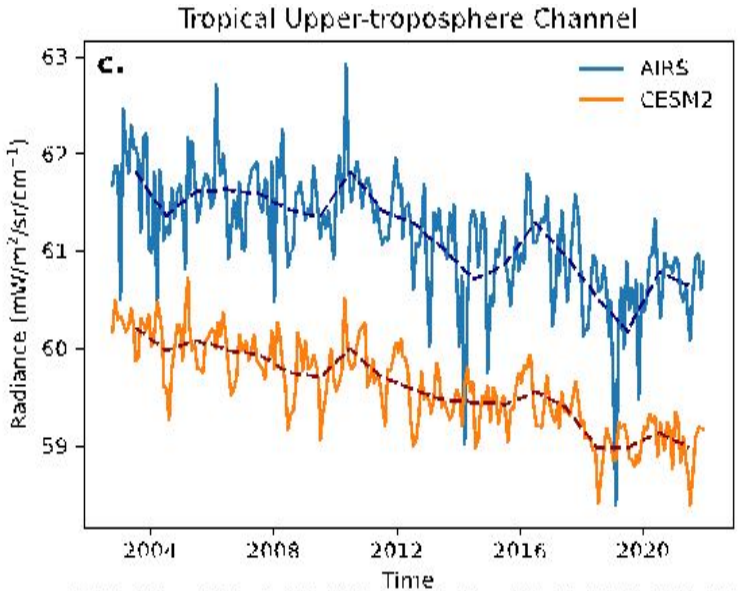


Output: Model evaluation against direct satellite observations



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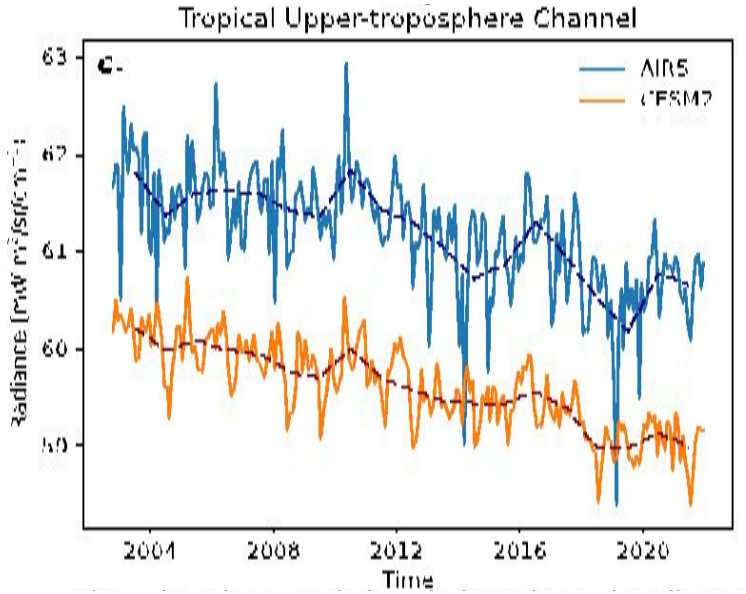
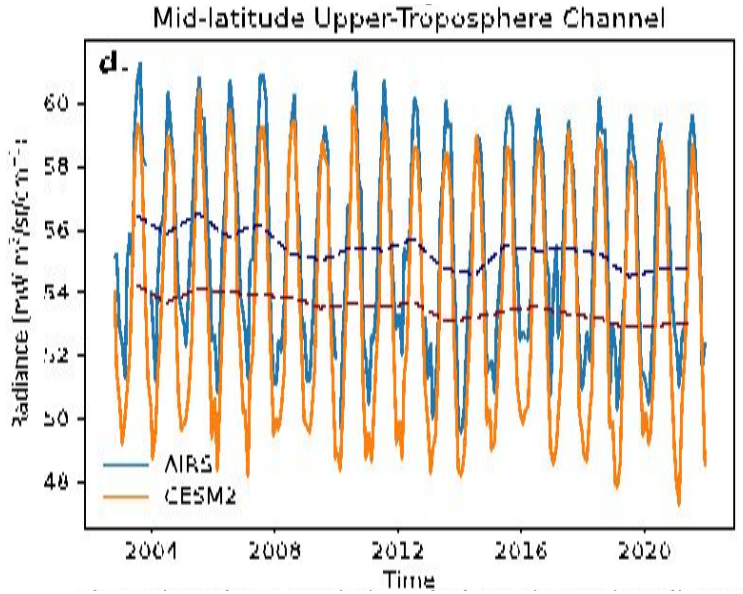
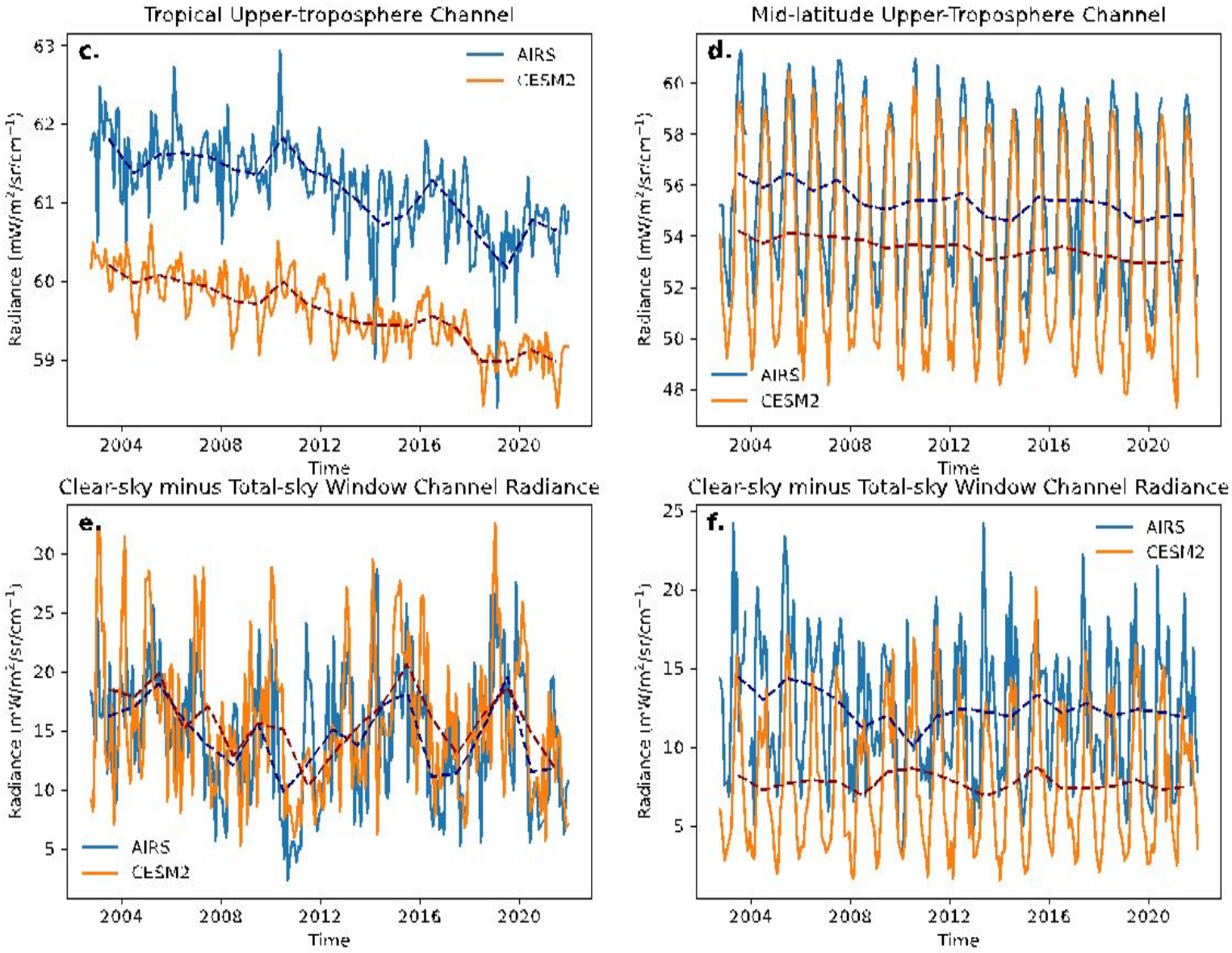


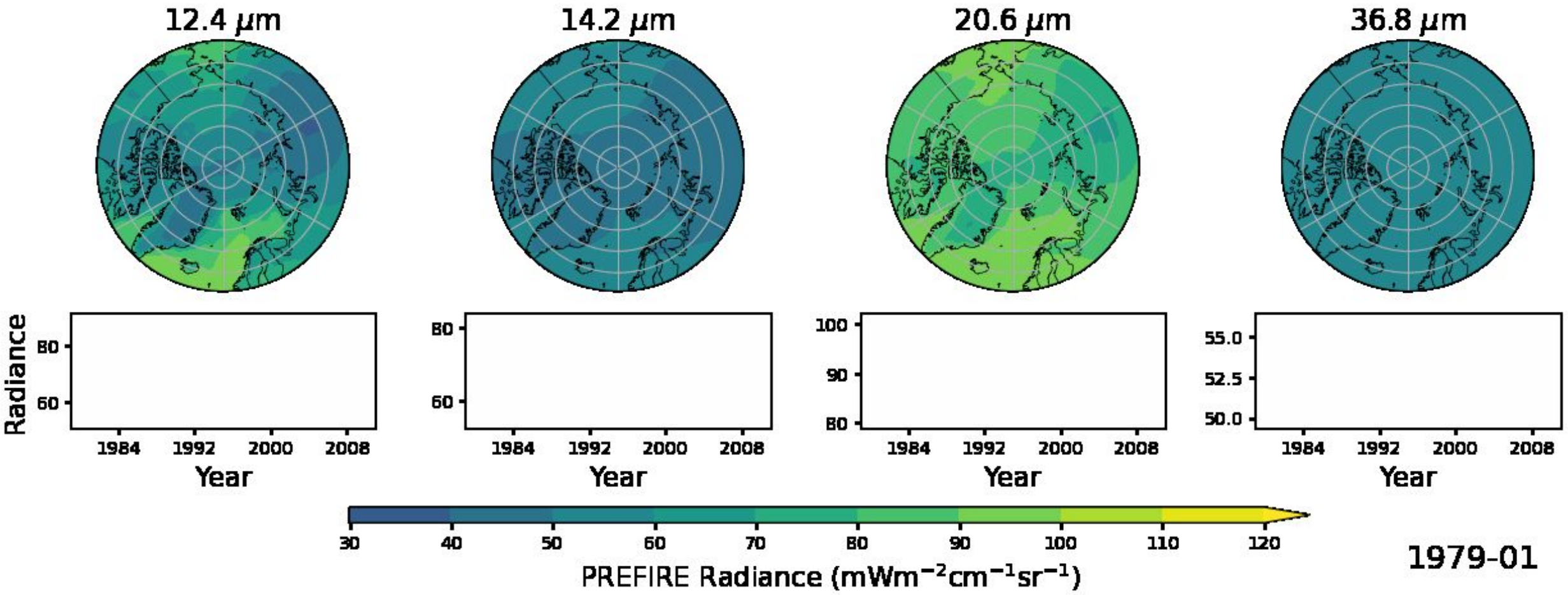


Output: Model evaluation against direct satellite observations

Standard methods for model evaluation can be applied to these fields just like normal CESM output

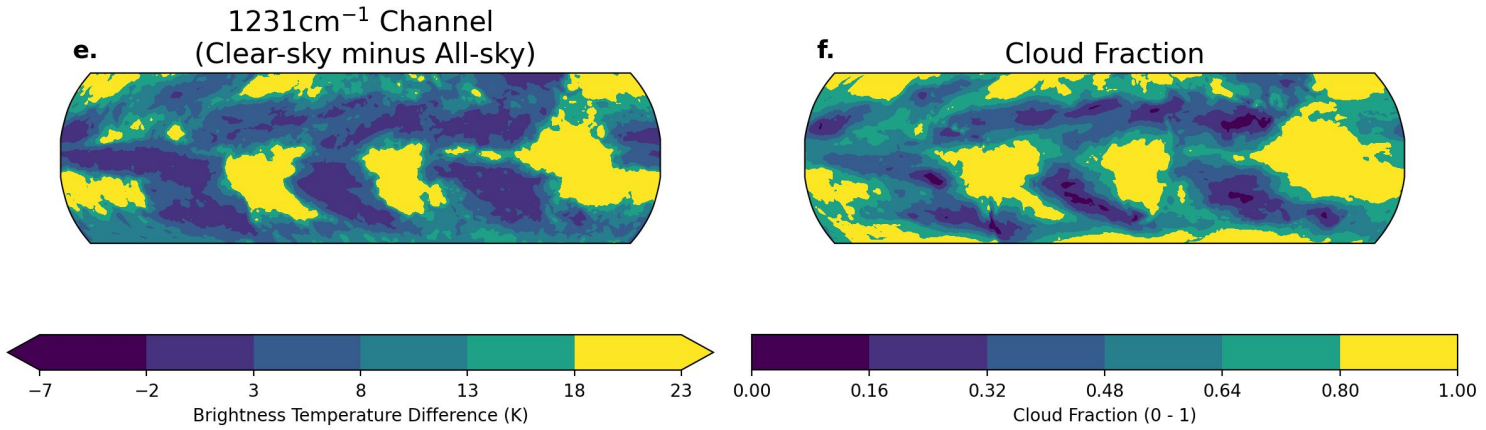


Output: “Satellite-like” fields for new and nascent missions



Key Points

- Commonly-used “observational” data products have large, unquantified structural uncertainties.
- Satellite spectral radiation fields are long-term, globe-spanning, and information-rich.
- Evaluating CESM against these direct spectral radiation observations is easy and complements current methods.



GMD article here:

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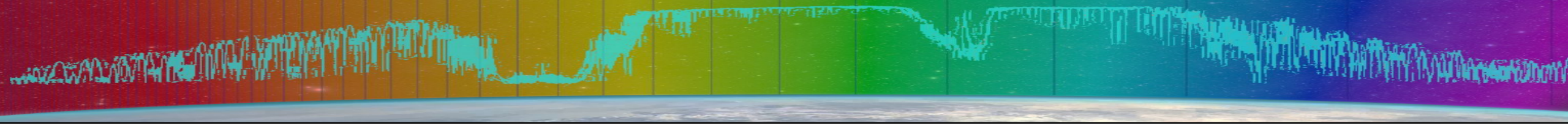
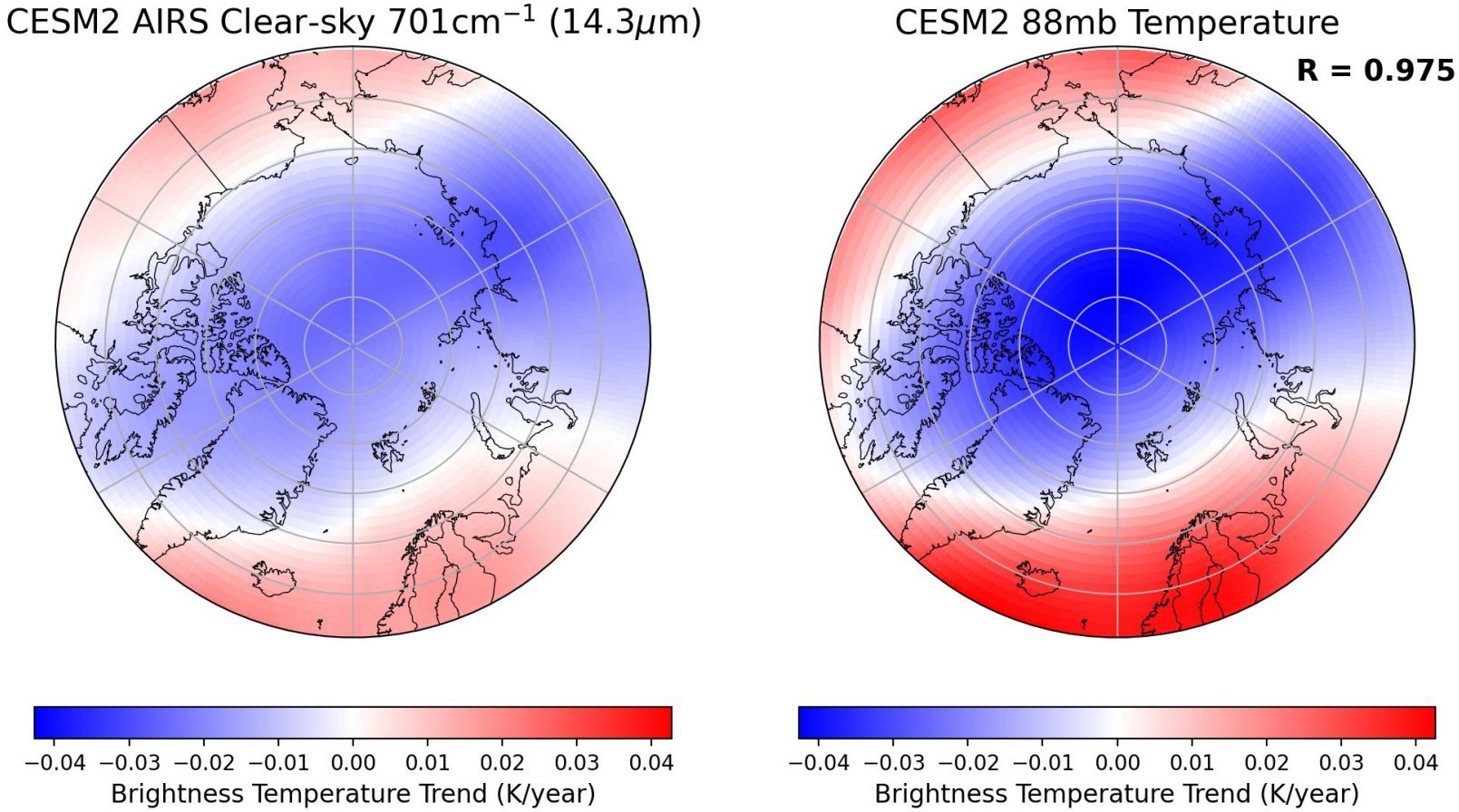
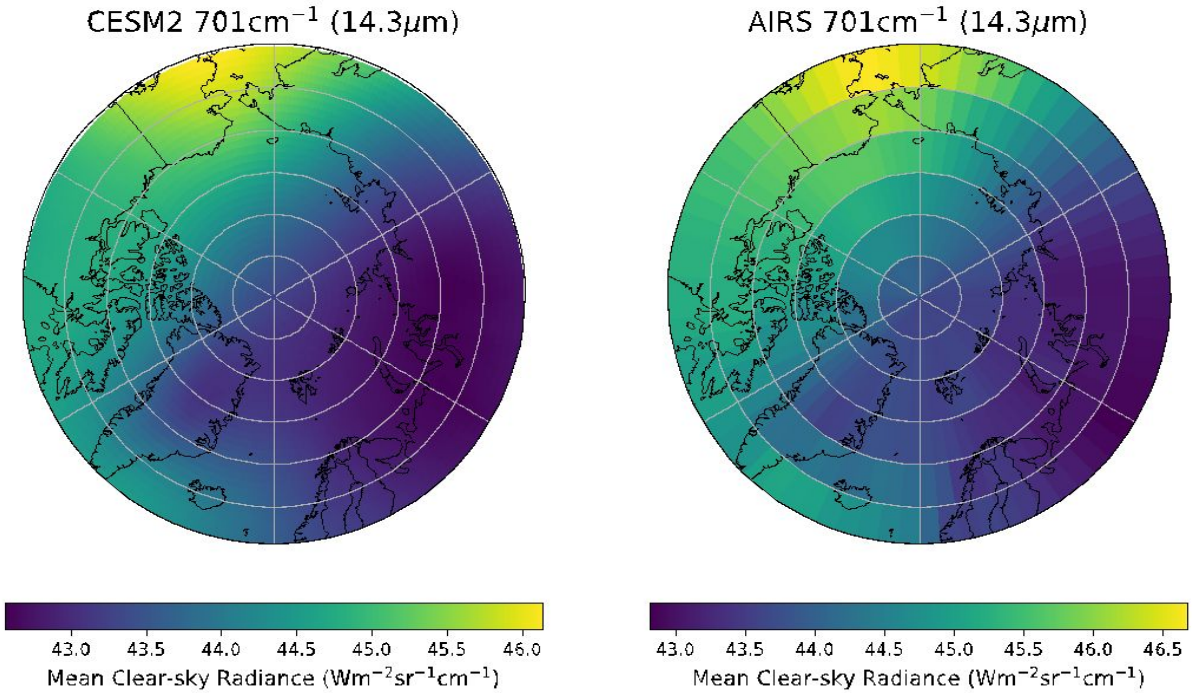


Example: Arctic Stratospheric Temperatures

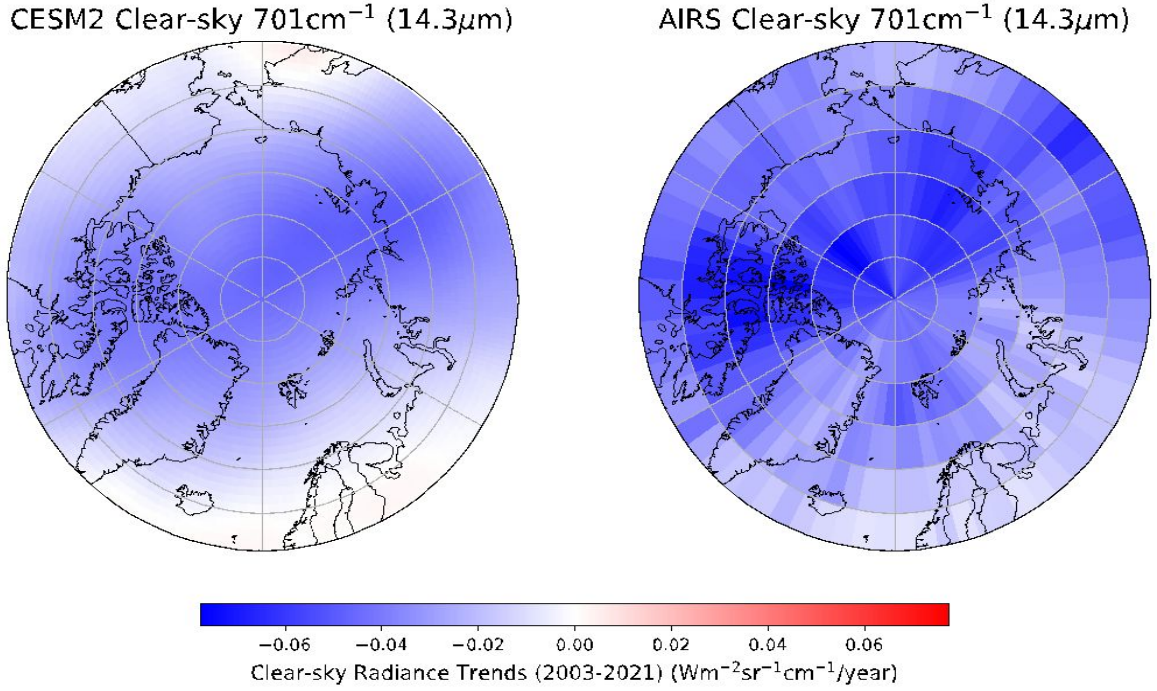


CESM2 captures the observed mean state and trends (2003-2021)

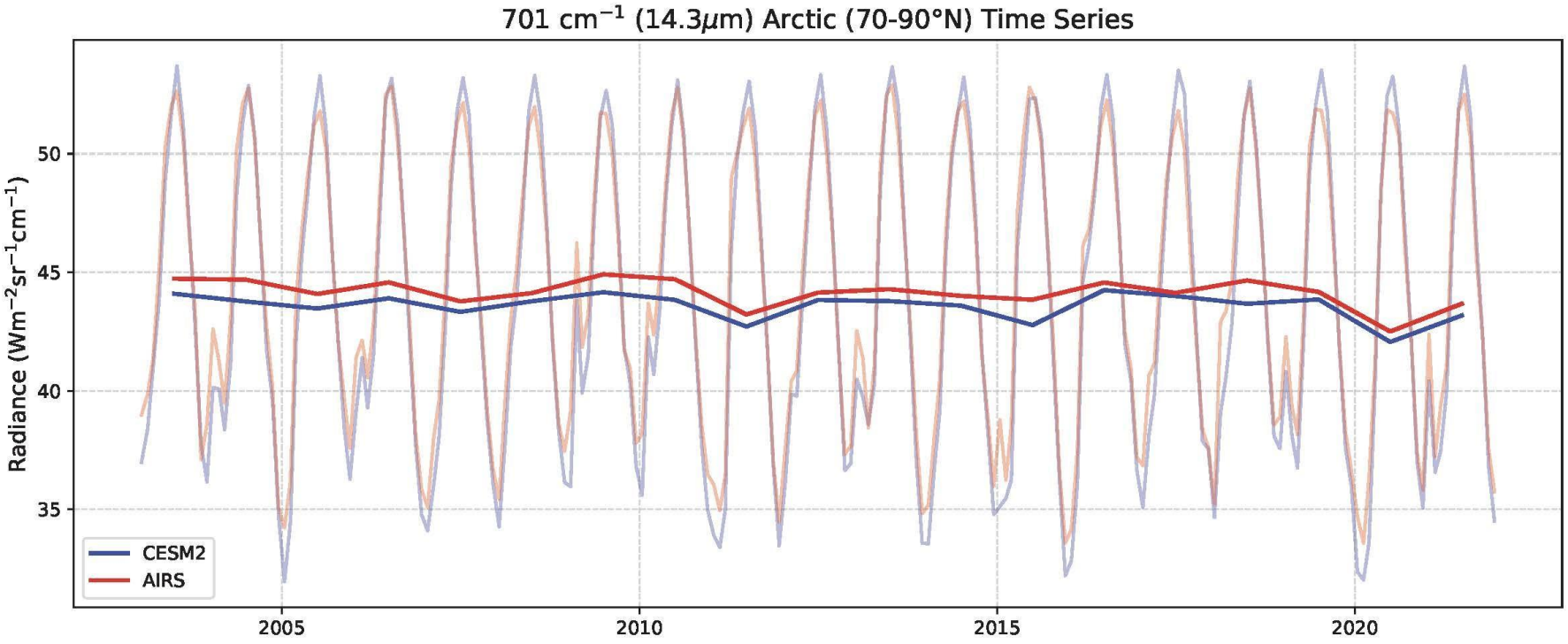
Mean State



Trends



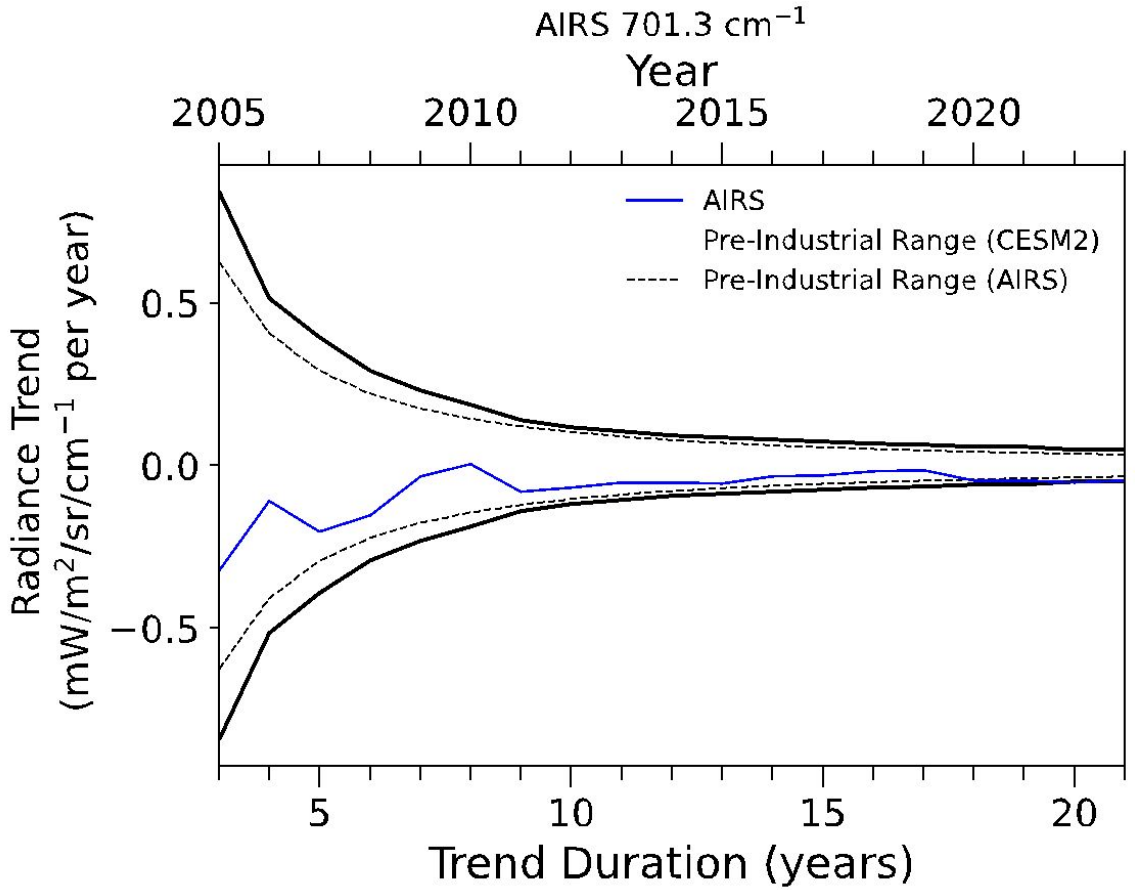
CESM2 captures the observed inter- and intra-annual variability

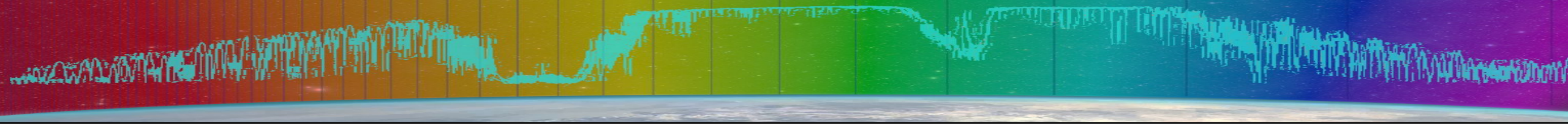


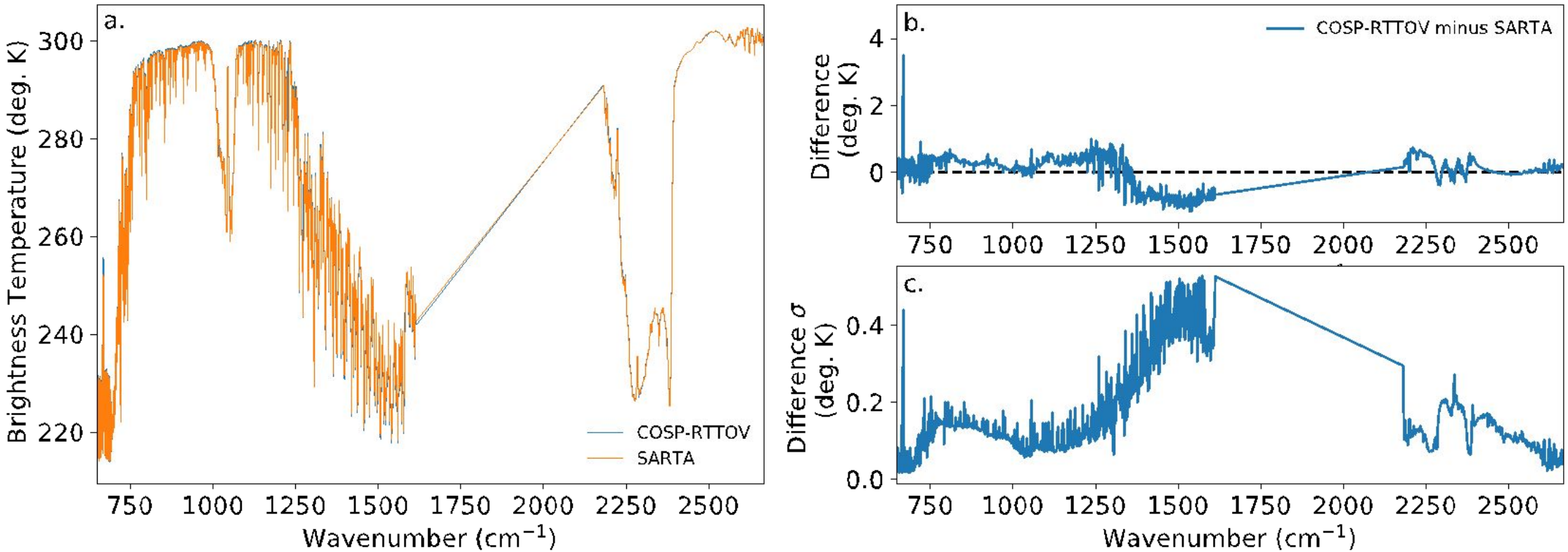
Standard modeling methods can be applied:

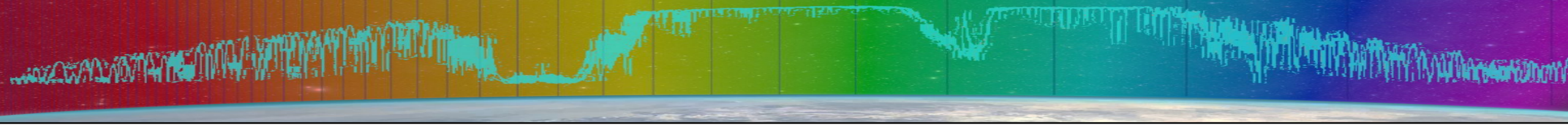
- Nudging
- Model hierarchies

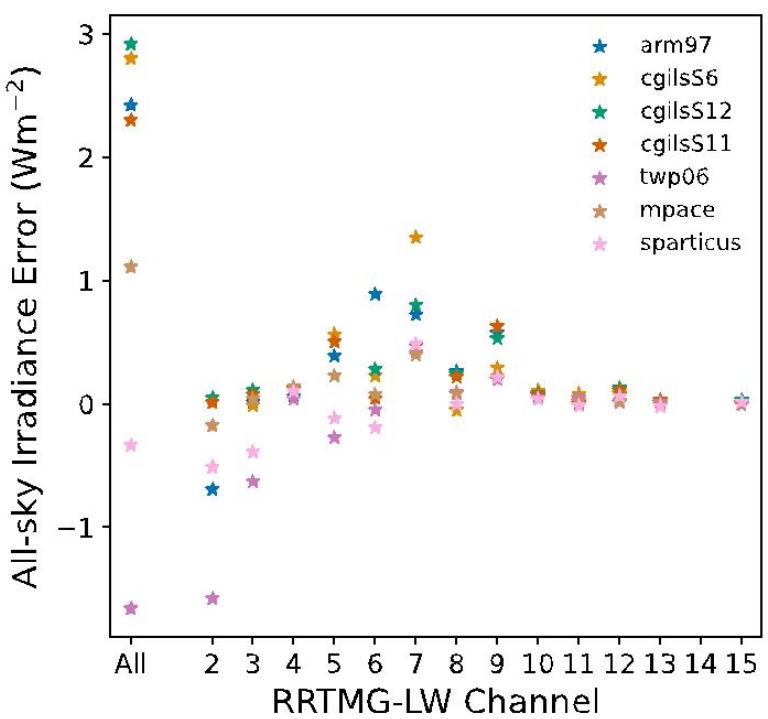
Stratospheric cooling trends in the Arctic are nearly detectable

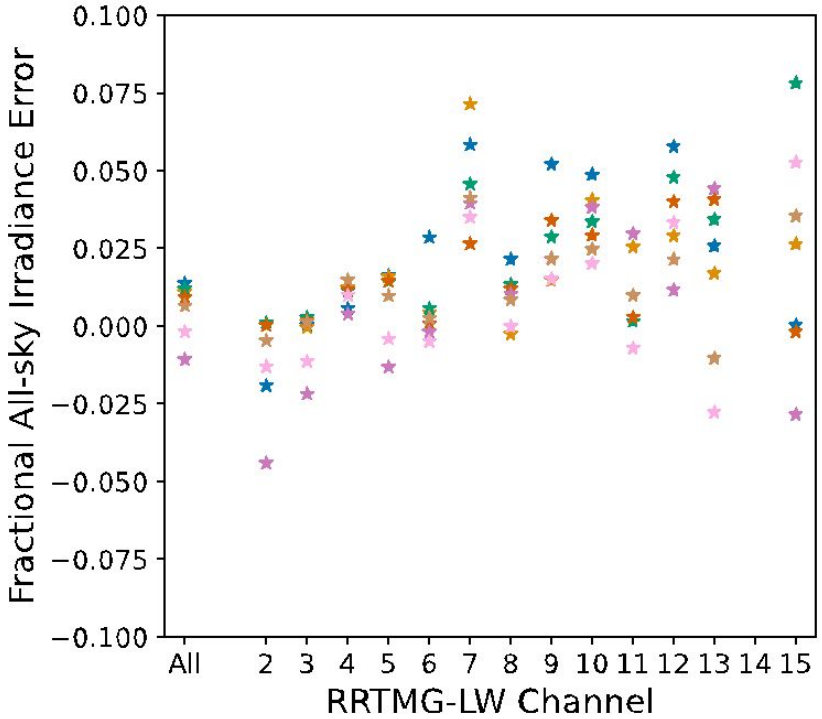


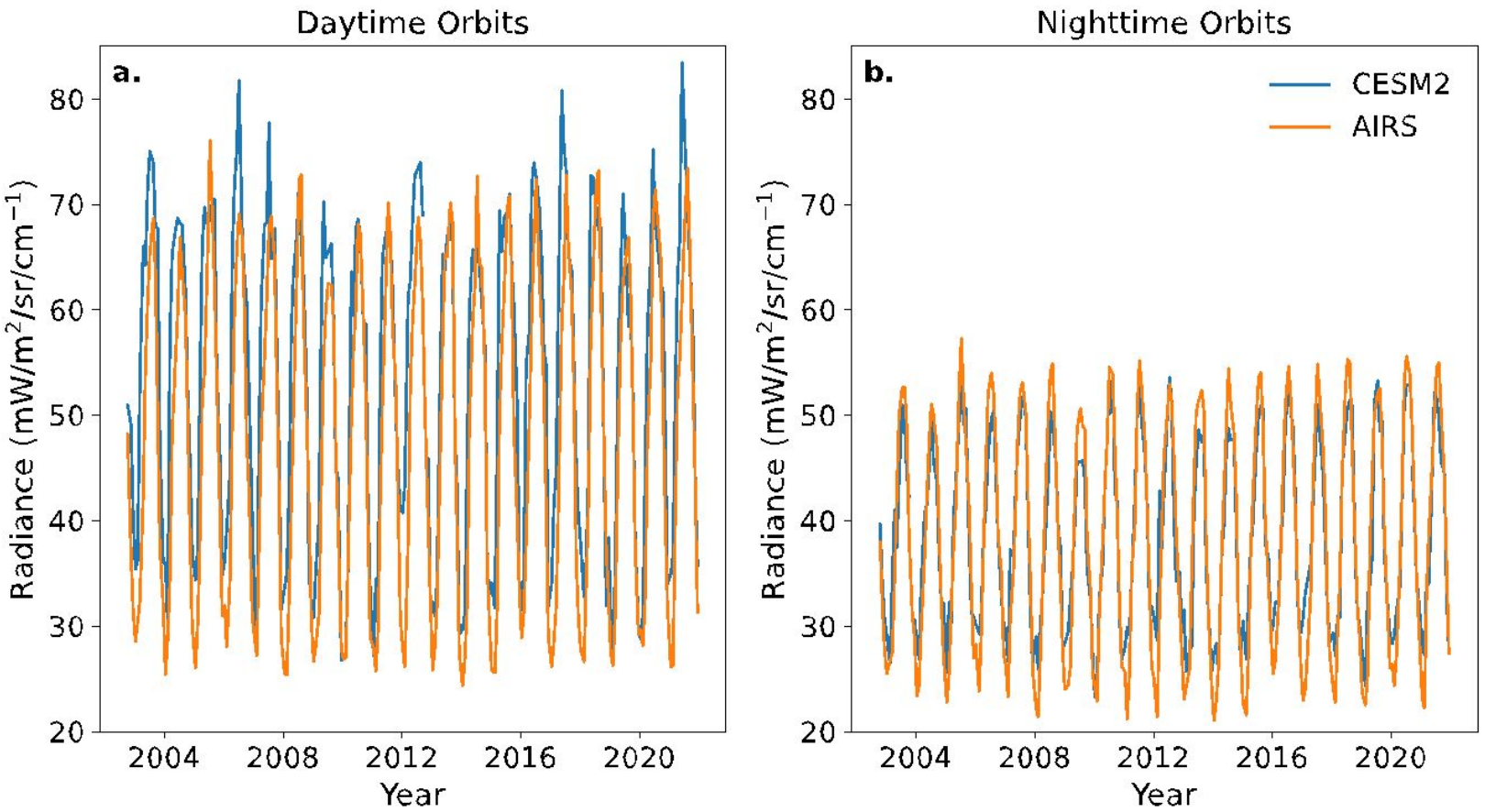



a.
Brightness Temperature (deg. K)
300
280
260
240
220
750
1000
1250
1500
1750
2000
2250
2500
Wavenumber (cm^{-1})
COSP-RTTOV
SARTA
b.
COSP-RTTOV minus SARTA
Difference (deg. K)
4
2
0
c.
Difference σ (deg. K)
0.4
0.2
0.0



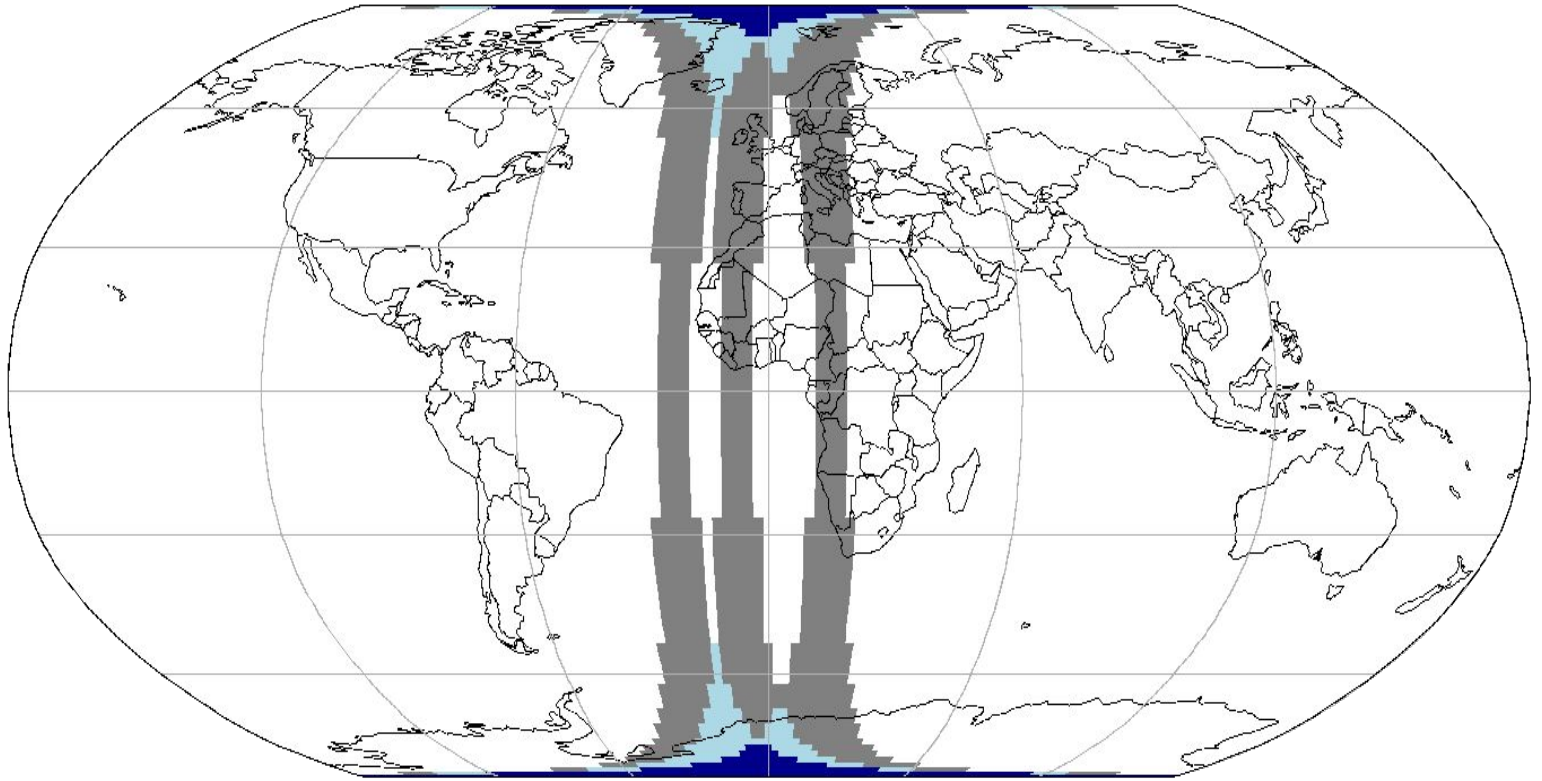

All-sky Irradiance Error (Wm^{-2})
RRTMG-LW Channel
All 2 3 4 5 6 7 8 9 10 11 12 13 14 15
3 2 1 0 −1
arm97
cgilsS6
cgilsS12
cgilsS11
twp06
mpace
sparticus


Fractional All-sky Irradiance Error
RRTMG-LW Channel
All 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0.100 0.075 0.050 0.025 0.000 −0.025 −0.050 −0.075 −0.100

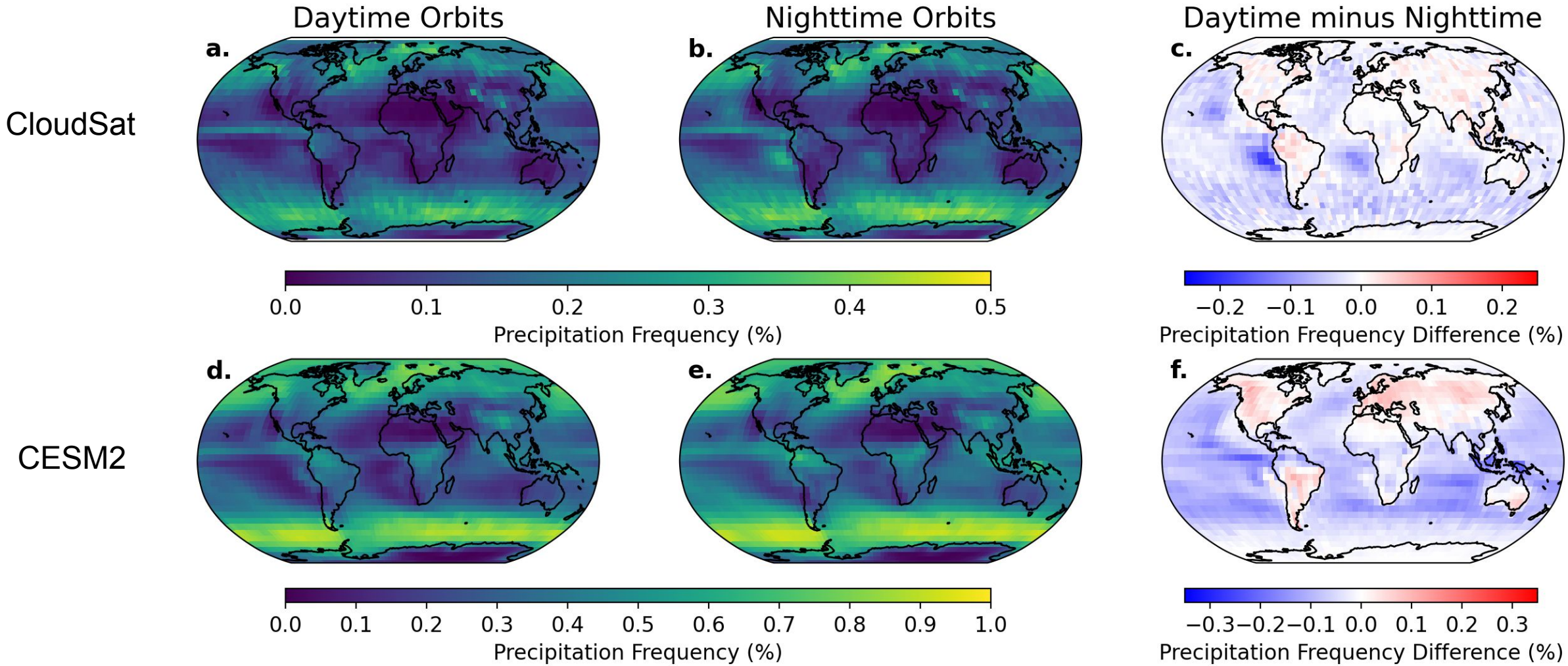

Daytime Orbits
a.
Nighttime Orbits
b.
CESM2
AIRS
Radiance (mW/m^2/sr/cm^{-1})
Year
20
30
40
50
60
70
80
2004
2008
2012
2016
2020

“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

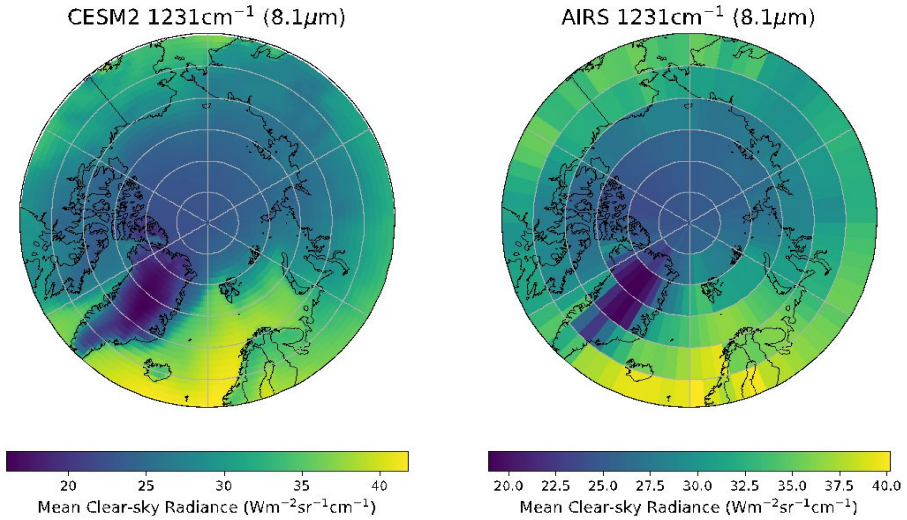


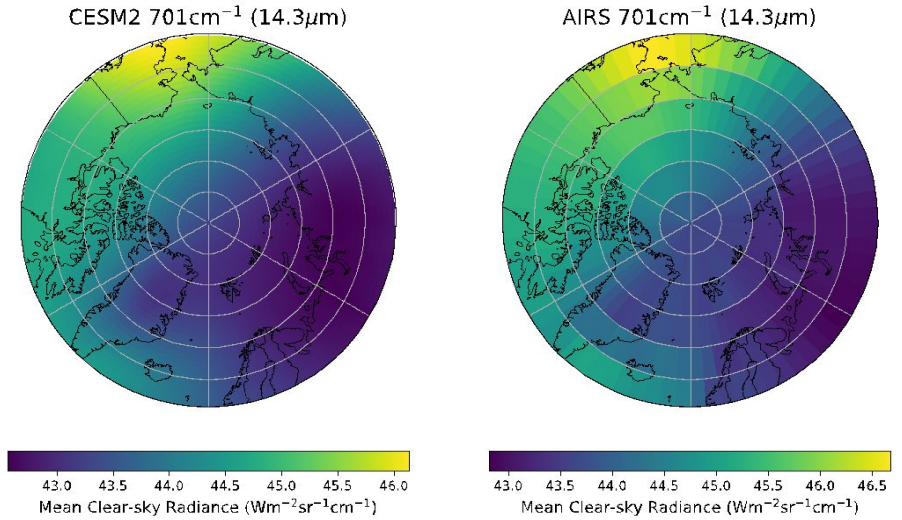
CESM2 captures the observed mean state and trends (2003-2021)

Surface Temperature Spectral Channel

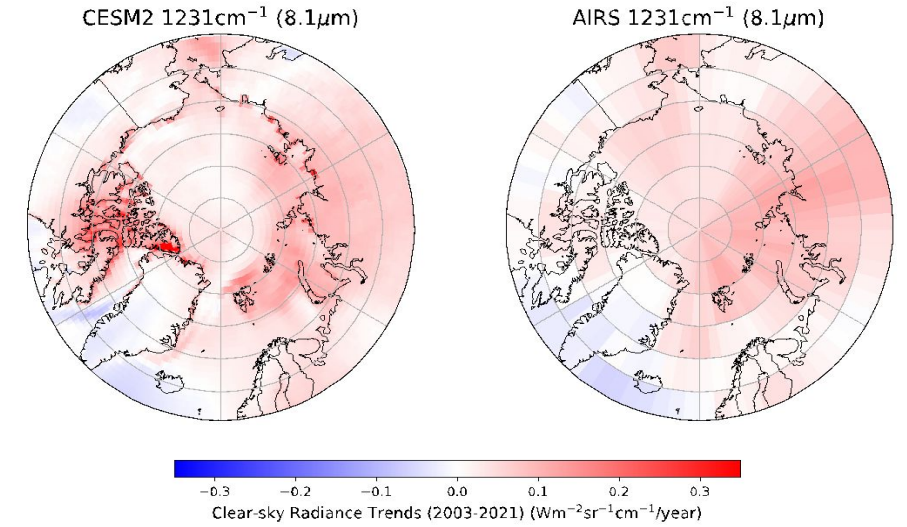
88mb Temperature Spectral Channel

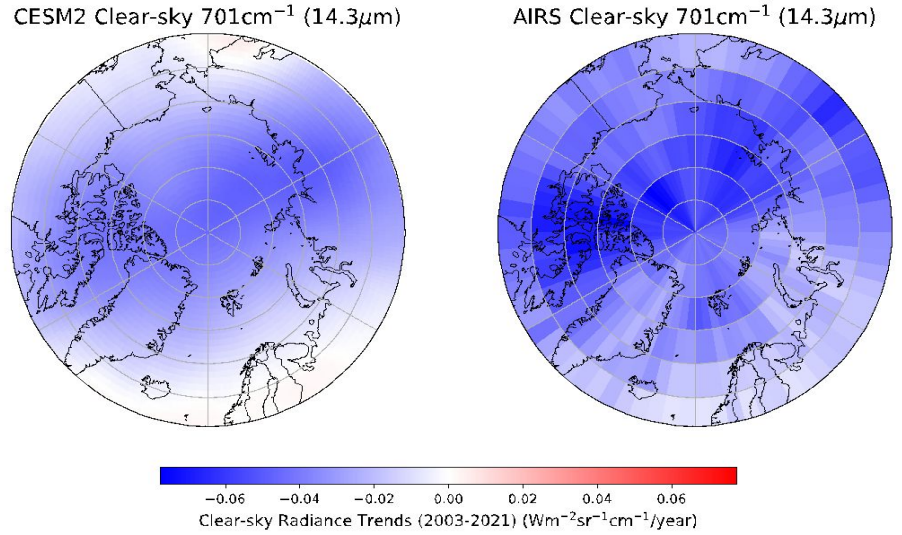
Mean State



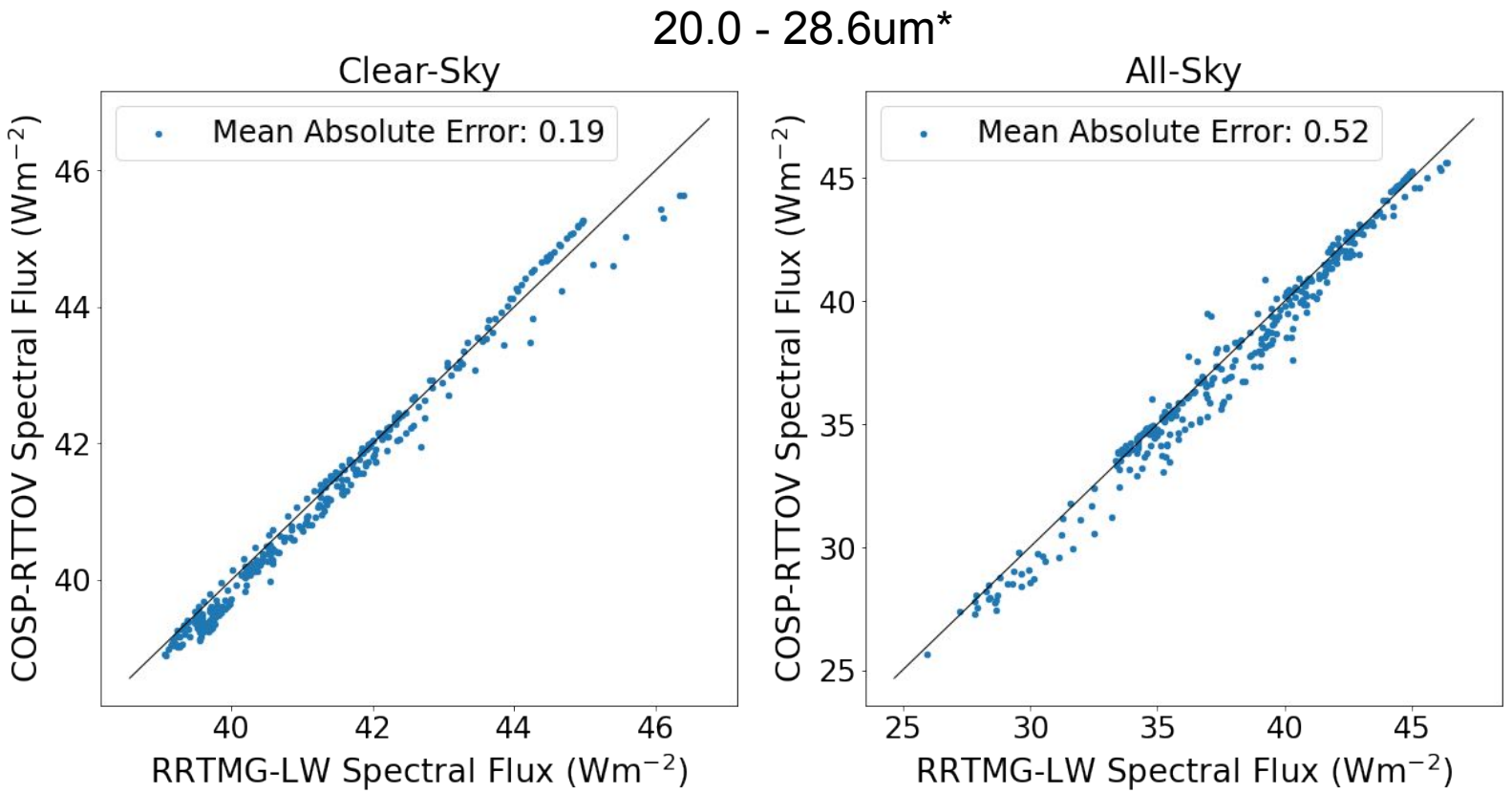


Trends

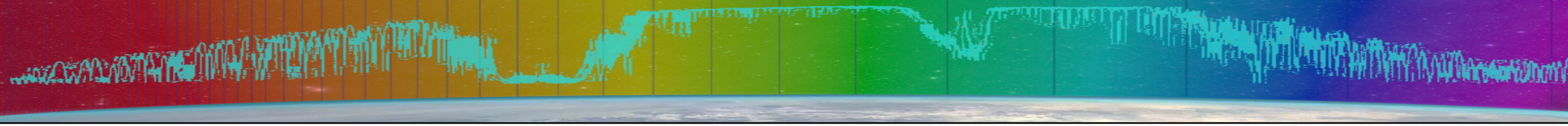


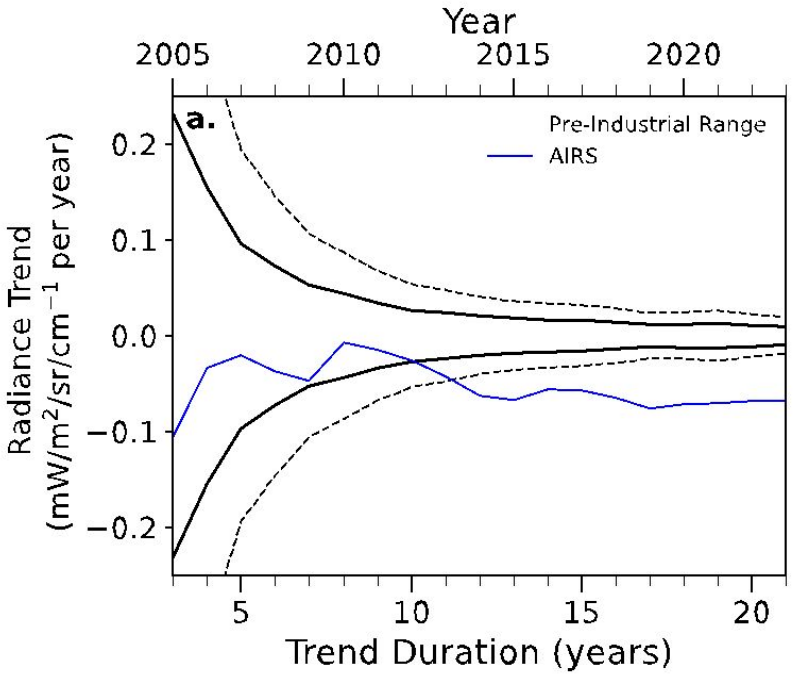


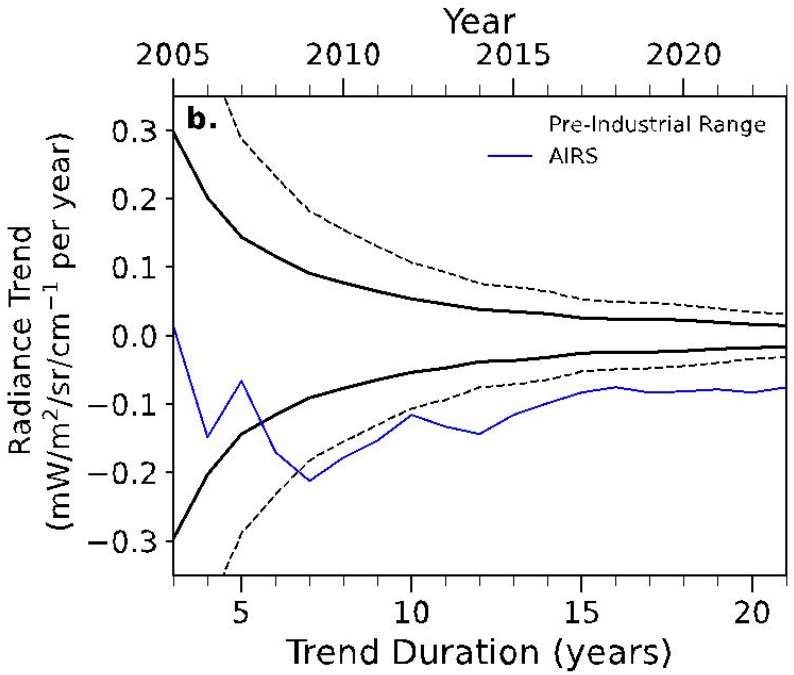
Output: "Satellite-like" spectra consistent with GCM radiation fields

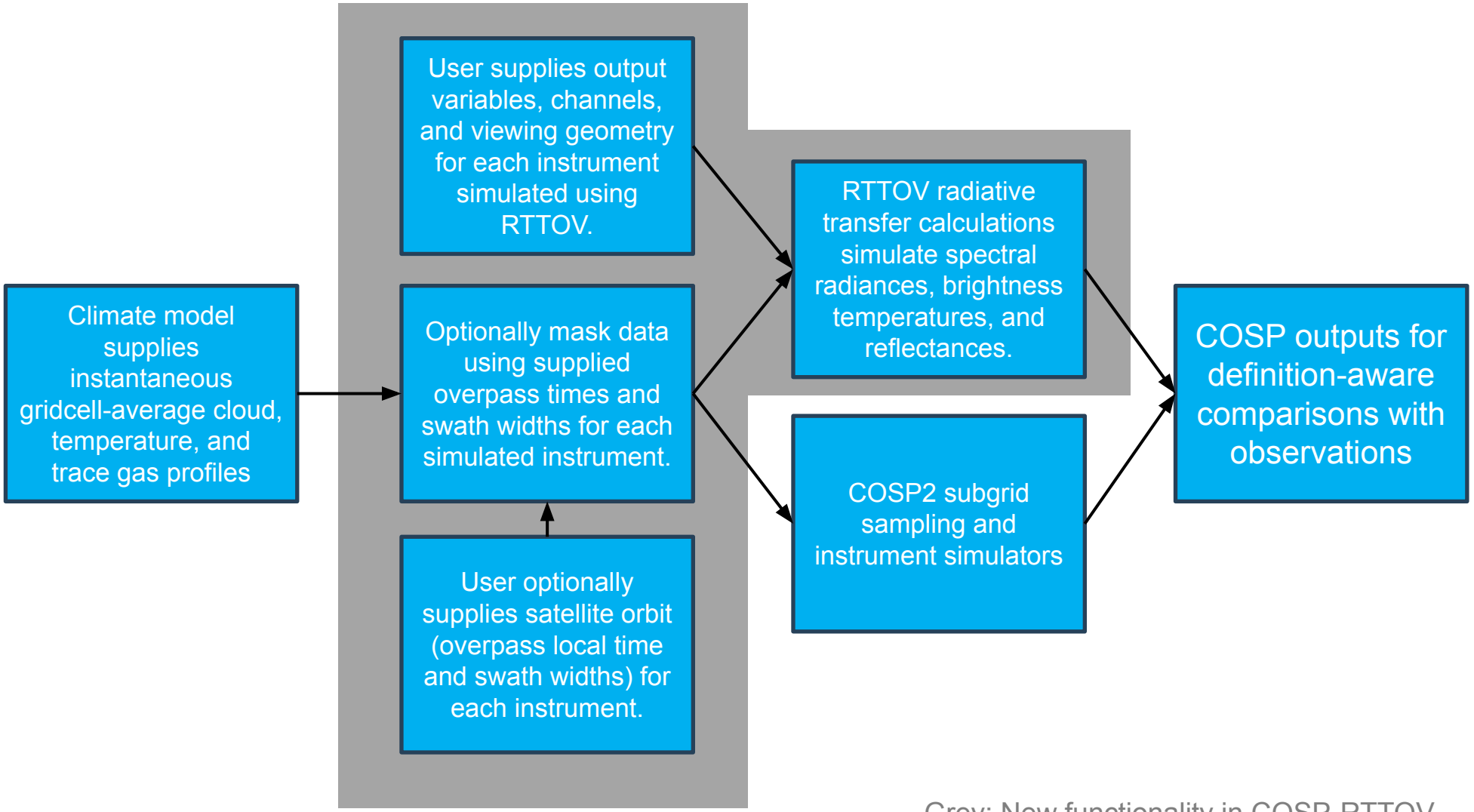


*Comparison with RRTMG radiative fluxes uses SRFs with 0.3cm-1 spacing and a 6-point gaussian quadrature.




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
0.0
−0.1
−0.2
−0.3
5
10
15
20
Trend Duration (years)



Grey: New functionality in COSP-RTTOV