Enhancing Climate Change Detection and Model Evaluation with Spectral Radiation

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Motivation

- Spectral measurements contain more information than broadband radiation or surface observations, making them an excellent tool for climate change detection and model evaluation.
- Ongoing (e.g. AIRS) and upcoming (e.g. PREFIRE) satellite missions create a climate change record in the spectral domain.
- A flexible tool for generating spectral radiation in climate models will open new avenues for confronting models with observations.

COSP-RTTOV: A New Tool for Simulating Spectral Radiation in Climate Models

Climate Model (e.g. CESM2) → Satellite Emulator (COSP) → Radiative Transfer (RTTOV)

Climate Model (e.g. CESM2)	Satellite Emulator (COSP)	Radiative Transfer (RTTOV)
1. Climate model simulates the coupled climate system.	2. COSP reads model output and computes simulated satellite output.	3. RTTOV simulates radiances for requested instruments + channels.
Climate model : - Coupled atmosphere, ocean, land, and sea ice components	COSP: - Standardized interface for model-observation comparisons. - Realistic satellite sampling patterns.	RTTOV: - Fast, accurate radiative transfer model. - Instrument-specific radiance fields.

Key Points

- Climate models are needed to place observed radiation trends into the broader context of forced change and internal variability.
- Detection and attribution of spectral radiation changes can identify specific climate processes modifying the earth's radiation budget.
- Simulating radiation fields in GCMs using COSP-RTTOV enables direct comparisons between models and satellite observations, and thus a strict constraint on model behavior.

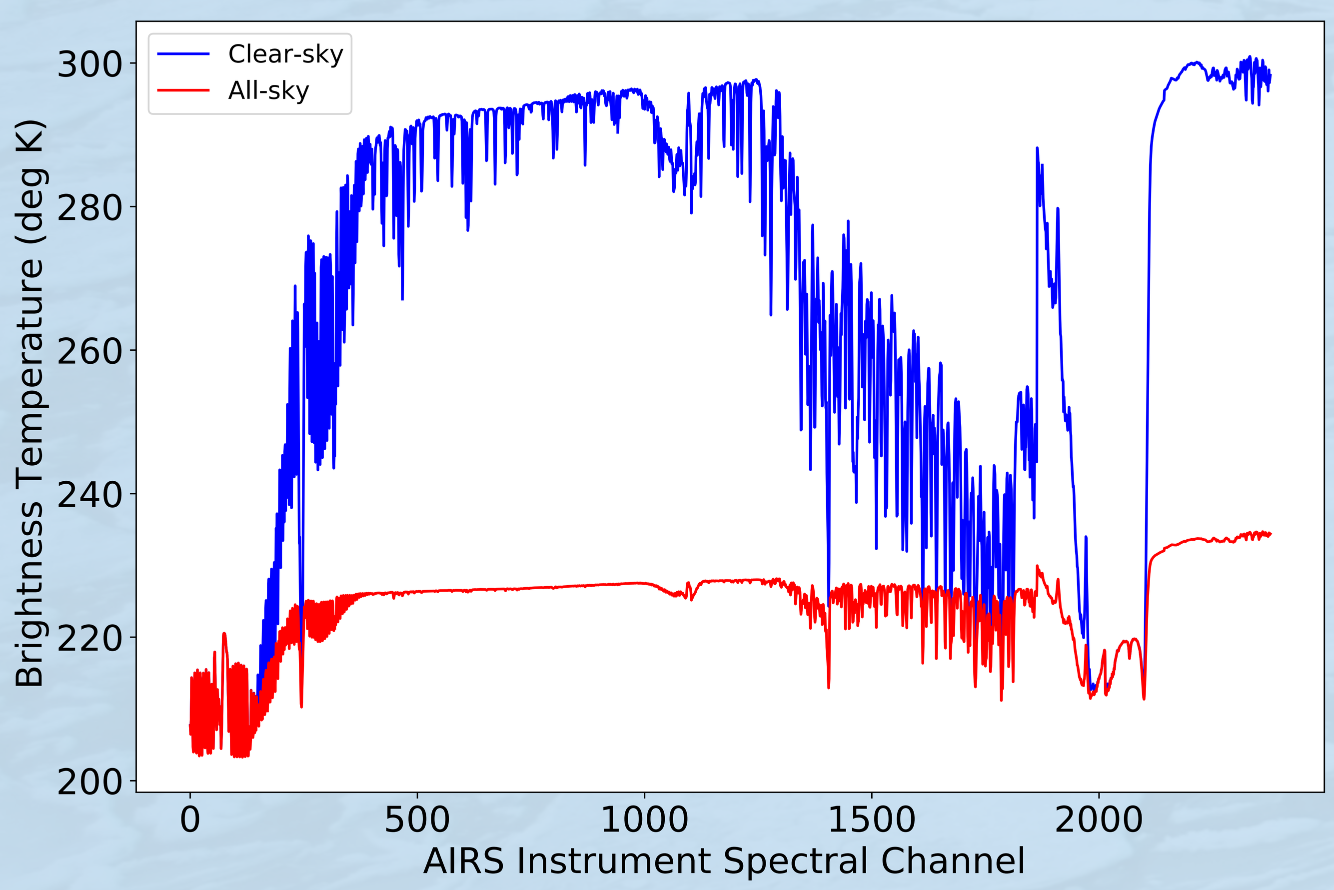

Figure 1: Simulated clear-sky and all-sky brightness temperatures for spectral channels of the NASA AIRS instrument. The atmospheric profile used in the radiative transfer model is taken from a climate model simulation as it runs.

COSP-RTTOV realistically samples the diurnal cycle at lower computing cost.

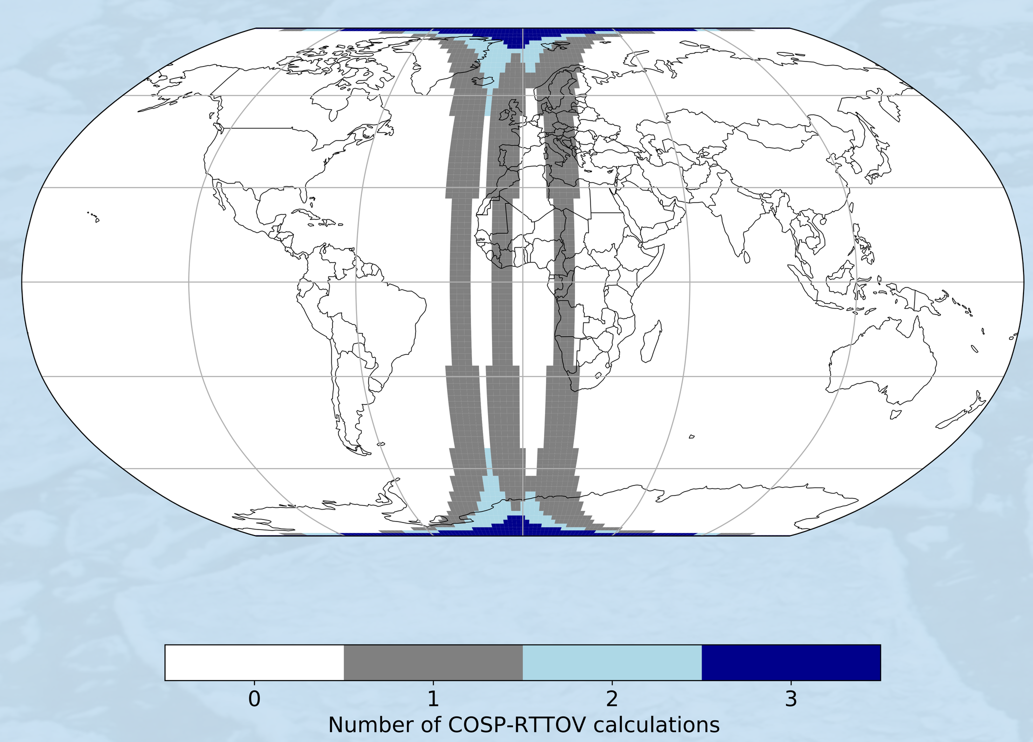

Figure 2: Number of RTTOV radiation fields calculated each at model gridcell during a 3-hour CESM2 simulation. The sampling density of radiation fields produced in COSP-RTTOV realistically captures the sampling patterns of polar orbiting satellites.

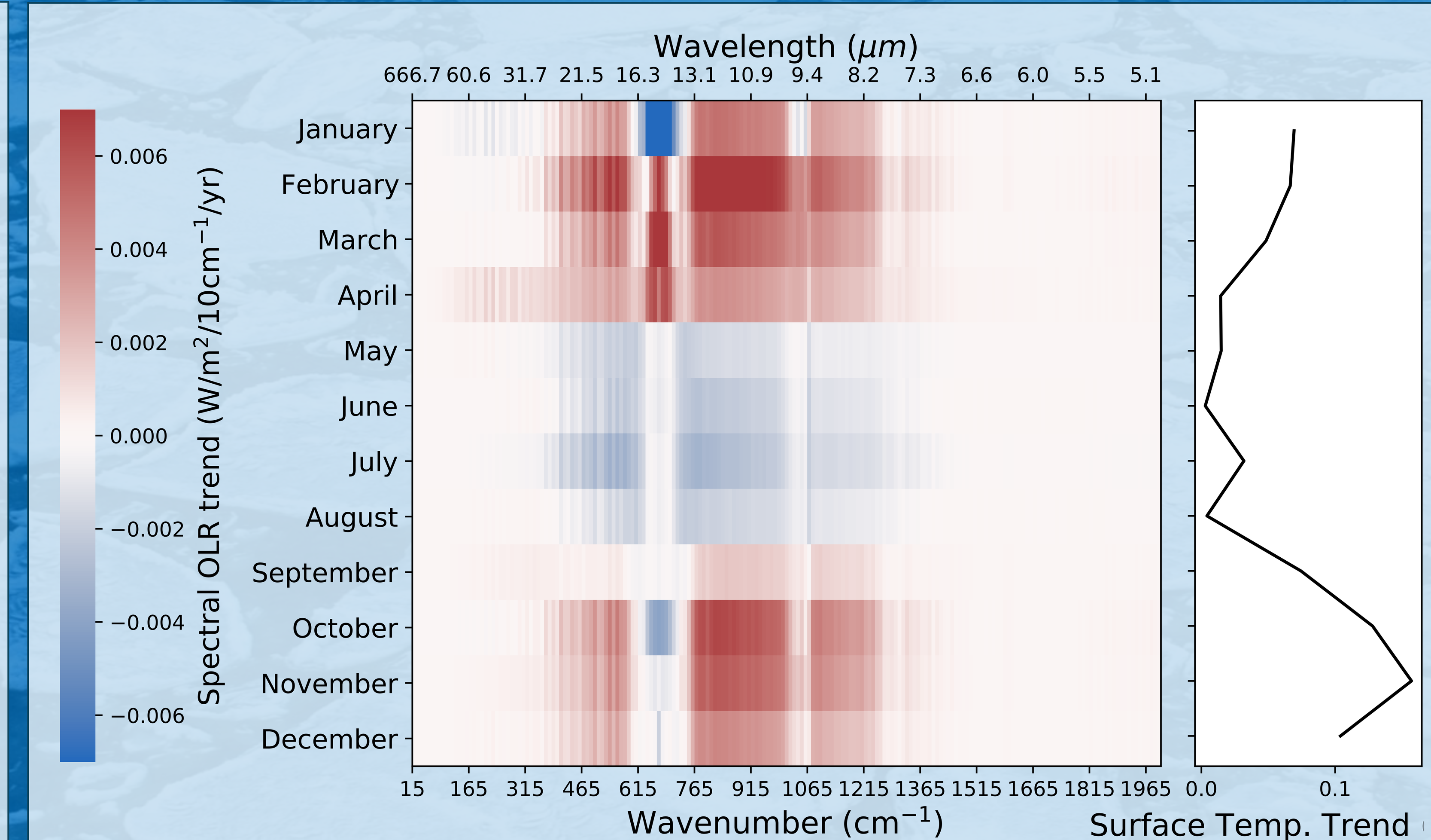

Figure 3. Left: Arctic (60-90N) trends in the outgoing infrared spectrum from the AIRS Spectral OLR product. Right: Arctic surface temperature trends from GISTEMPv4. All trends are calculated for 2003-2018. Increasing outgoing radiation mirrors surface warming across most wavelengths.

The detection of Arctic climate change is mediated by seasonal cycles of forced changed and variability.

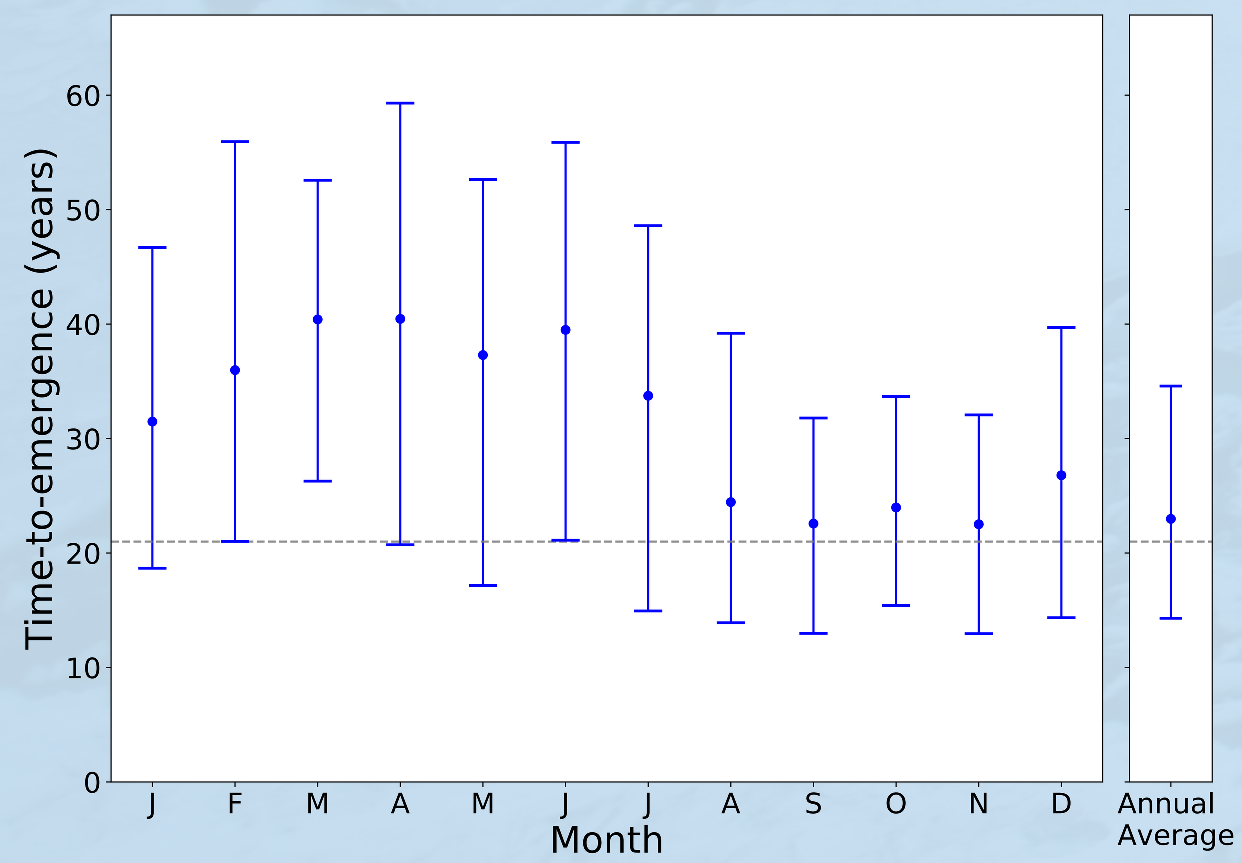

Figure 4: Monthly and annual time-to-emergence of Arctic broadband longwave radiation. It is difficult to separate the contributions from different climate processes using broadband radiation fields. From Shaw and Kay (2023).

Far-infrared radiation (λ>15μm) makes up >40% of global OLR, but is not spectrally resolved by any current satellite platforms. The upcoming NASA PREFIRE mission (launching in 2024!) will measure the far-infrared spectrally for the first time.

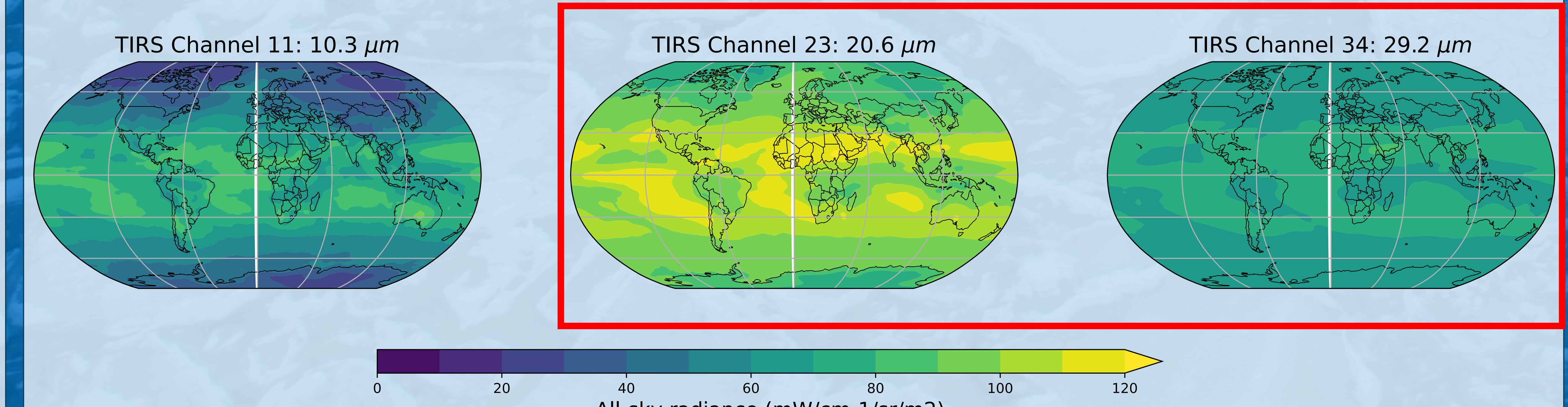

Figure 5: Global maps of "PREFIRE-like" radiance fields for Thermal IR Spectrometer (TIRS) channels centered near 10μm, 20μm, and 30μm. Radiances are produced in COSP-RTTOV using an hourly instantaneous model state from CESM2. Average radiance fields for January 2000 are plotted.

Future Work

- Simulate AIRS and PREFIRE radiances in atmosphere-only CESM2 simulations. Evaluate CESM2's ability to reproduce trends and variability in the 20-year AIRS spectral record. Compare CESM2 with PREFIRE radiances.
- Determine the spectral regions where AIRS observations detect Arctic climate change. Identify the responsible climate processes.

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References:

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AIRS Spectral OLR (doi: 10.5067/5P7KQ31XI7XJ)
GISTEMPv4 (doi: 10.1029/2018JD029522)