An Update on the Direct Influence of Solar Spectral Irradiance on the Surface Climate

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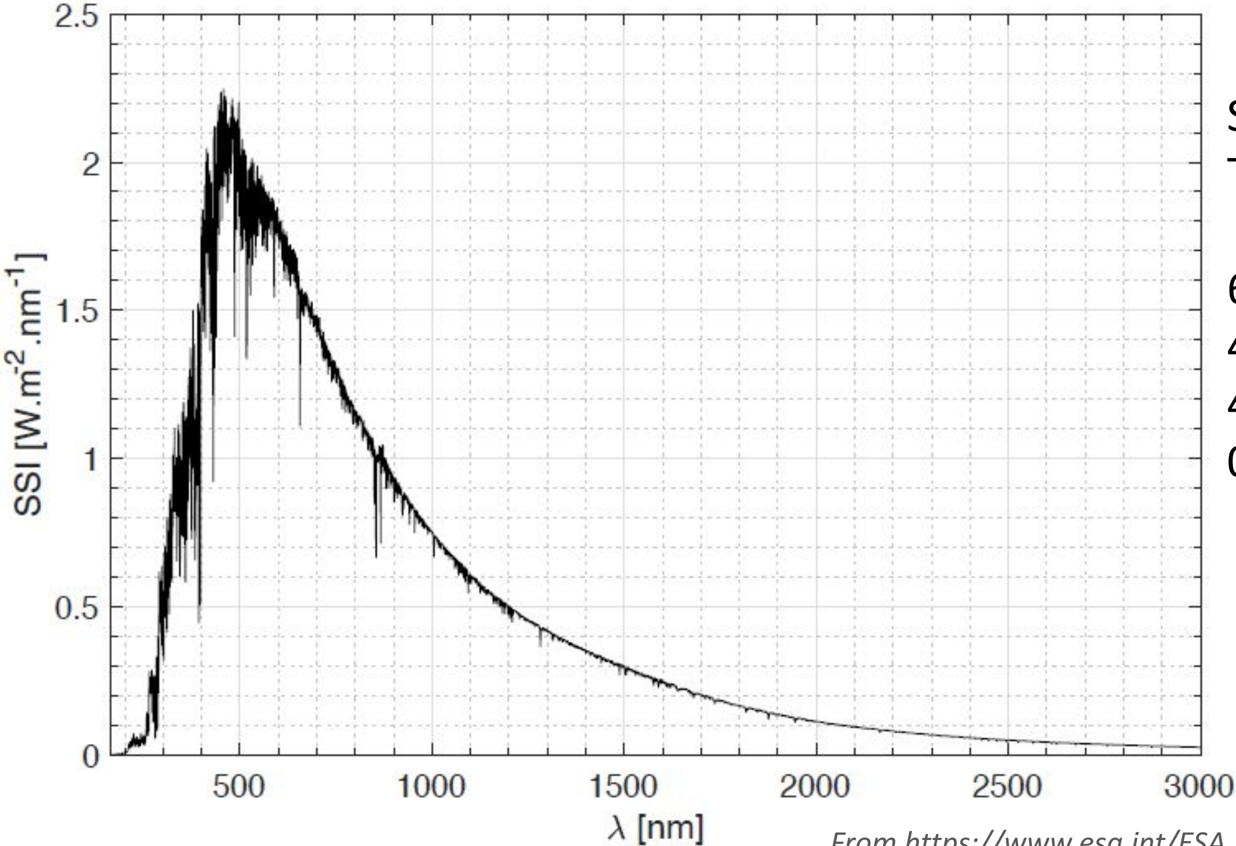
*Some results are in Jing, X. et al., **Direct influence of solar spectral irradiance on the high-latitude surface climate**, Journal of Climate, 34(10), 4145–4158, 2021*.



SSI: solar spectral irradiance
TSI: total solar irradiance

6.4% from UV (0.1-0.38 μm)
48.1% from Visible (0.38-0.78 μm)
45.0% from Near-IR (0.78-5μm)
0.6% from IR >5μm

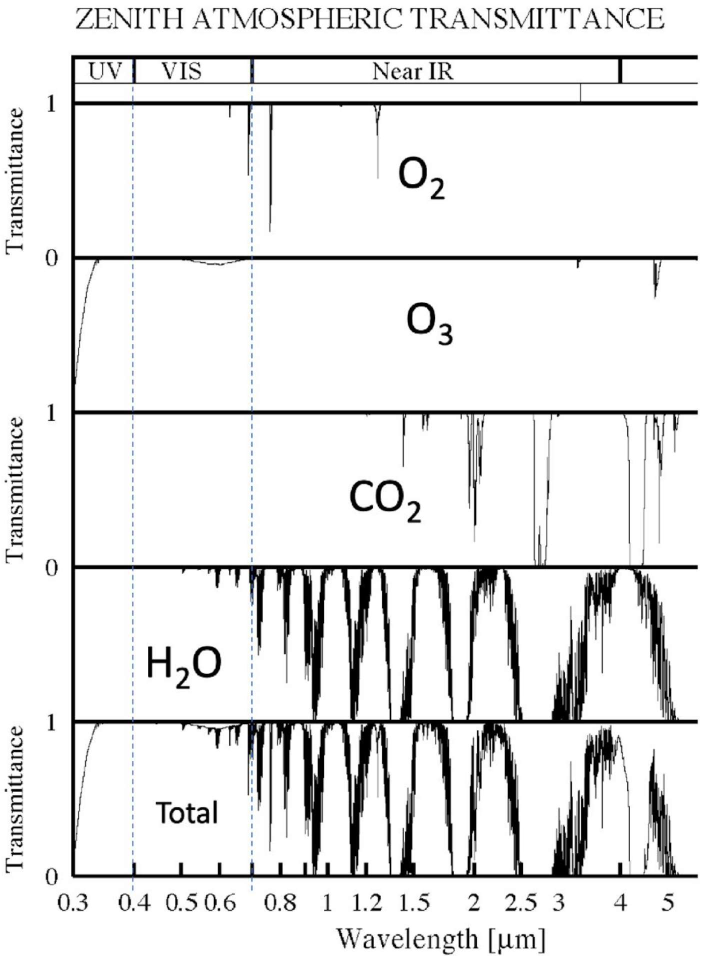
From https://www.esa.int/ESA_Multimedia/Images/2017/12/Solar_spectrum

Initial question to be addressed:

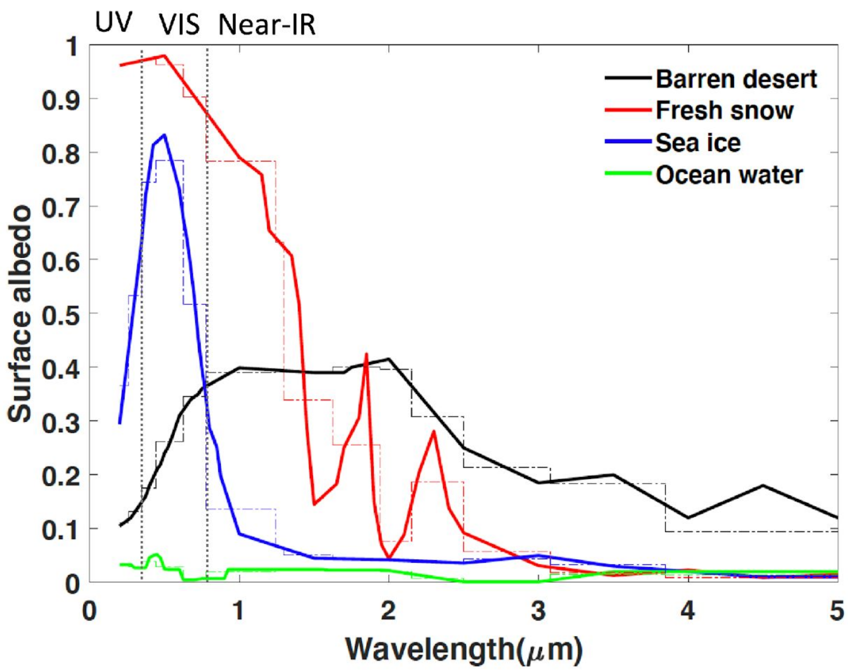
Assuming that two sets of SSIs have identical TSI but different partitions between visible and near-IR SSI, ***up to current observational uncertainty***, then, when they are used in the climate model simulations separately, will the simulated climate be the same or statistically different?

Different partitions: CMIP6 default vs. TSIS-1 observations

Why does VIS-NIR partition matter?



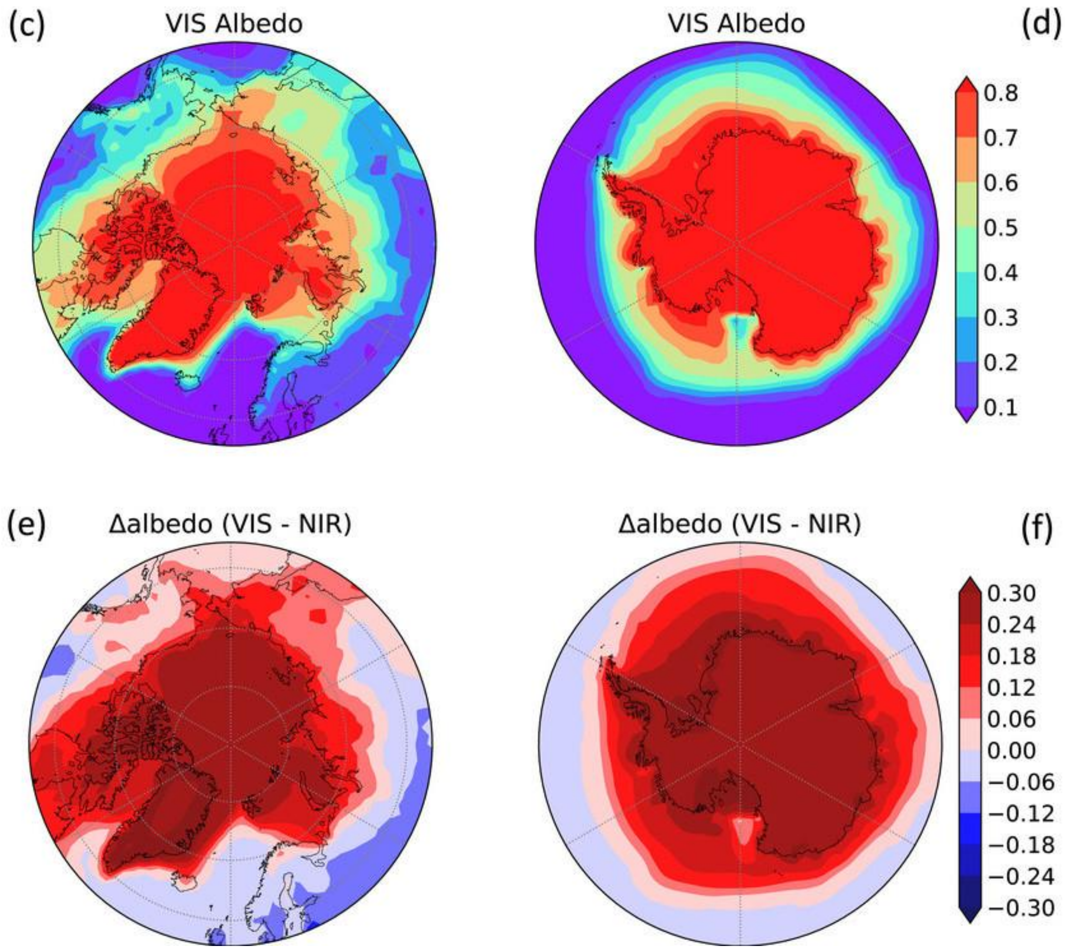
(Petty, Fig 7.6)



Sea ice vs. open water: VERY different reflections for VIS vs. NIR

H_2O: much more absorption in the near-IR than in the visible

CESM2 annual-mean surface albedo



Hypothesis

Spectral ice-albedo feedback

For the same TSI
More Visible/Less NIR

↓

More reflection from polar surfaces

↓

Surface temperature decreases

↓

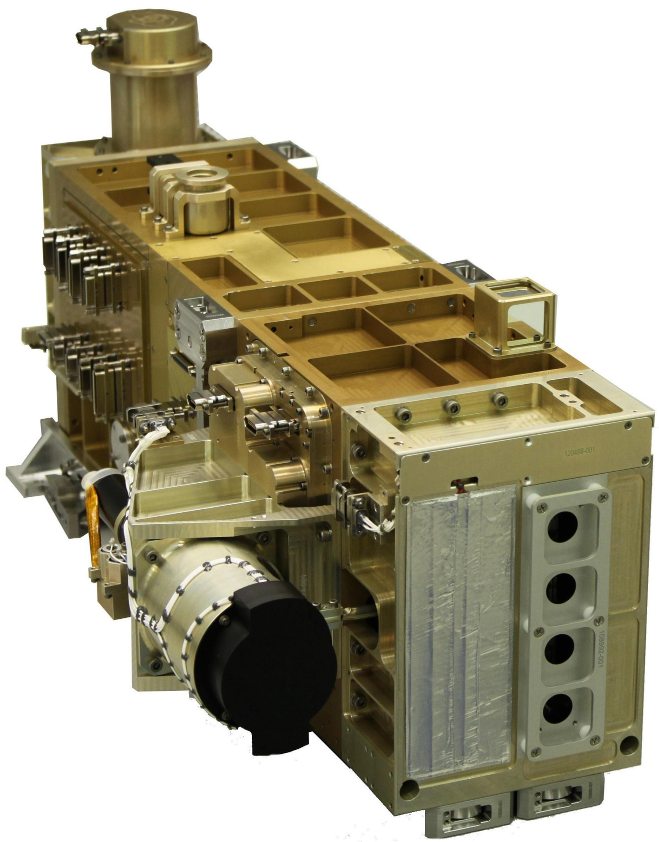
More snow/ice coverage

Starting Points

- Sun-climate connection matters
- Both TSI and SSI matters: the
  - TSI: “bottom-up” mechanism
  - SSI: “top-down” mechanism for UV SSI
    - UV→ozone →strato. radiative heating →temperature gradient → strato. circulation →STE →tropo circulation →surface climate
    - Little discussion about VIS and near-IR
      - Partly limited by the past observations
- CMIP6 solar forcing data set (1850-2300; Matthes et al, GMD, 2017)
  - Used by all modeling centers for IPCC AR6 model simulations (CMIP6)

TSIS-1 SSI measurements

- Successor of SORCE SIM
  - TSIS-1 SSI covers 0.2 to 2.4 μm
- Improved performance for visible and near-IR SSI
  - 0.25% radiometric uncertainty (10x better than before)



TSIS-1 SIM
(from lasp.colorado.edu)

Solar irradiance vs. TOA radiative forcing

- TOA radiative forcing is a common metric used in climate change studies
- Like what we have learn in Atmospheric Physics 101

$\Delta RF = \Delta SSI/4$

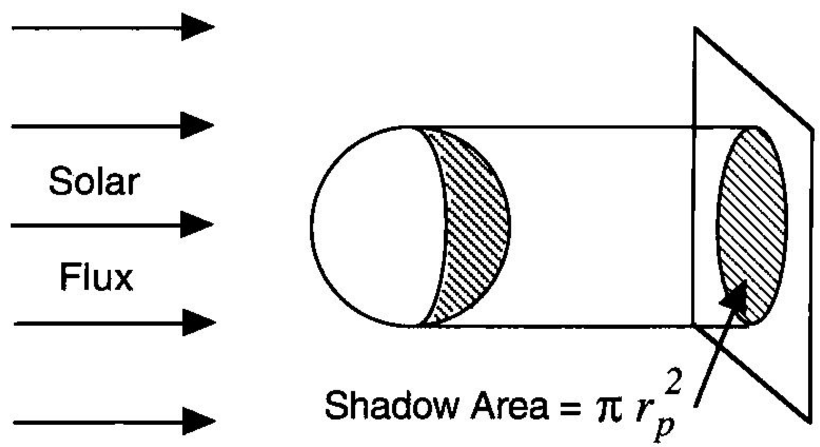


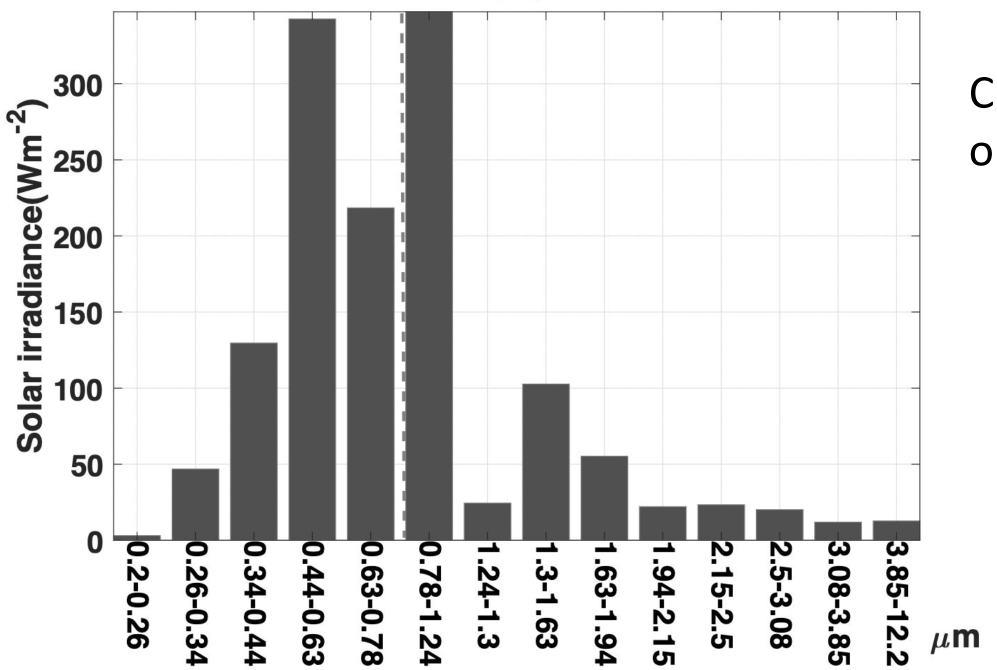
Fig. 2.2 Diagram showing the shadow area of a spherical planet.

(Hartmann, 1994)

CMIP6 Solar irradiance dataset

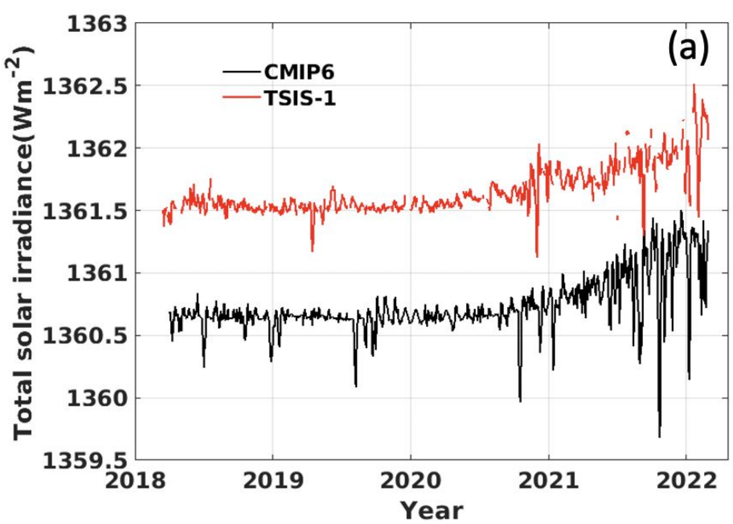
	Mean (Wm^{-2})	Daily standard deviation (Wm^{-2})
TSI	1360.9	0.42 (0.031%)
UV	85.8	0.13 (0.15%)
Visible	655.2	0.22 (0.034%)
Near-IR	613.6	0.10 (0.017%)

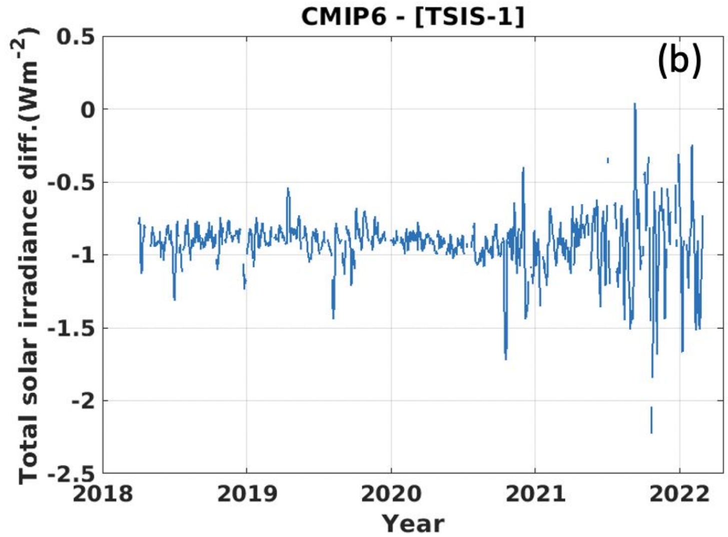
(a)

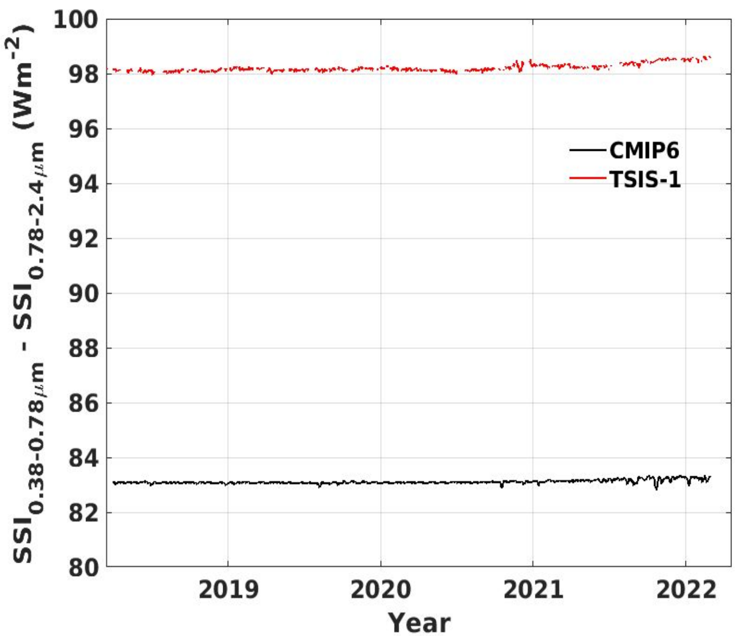


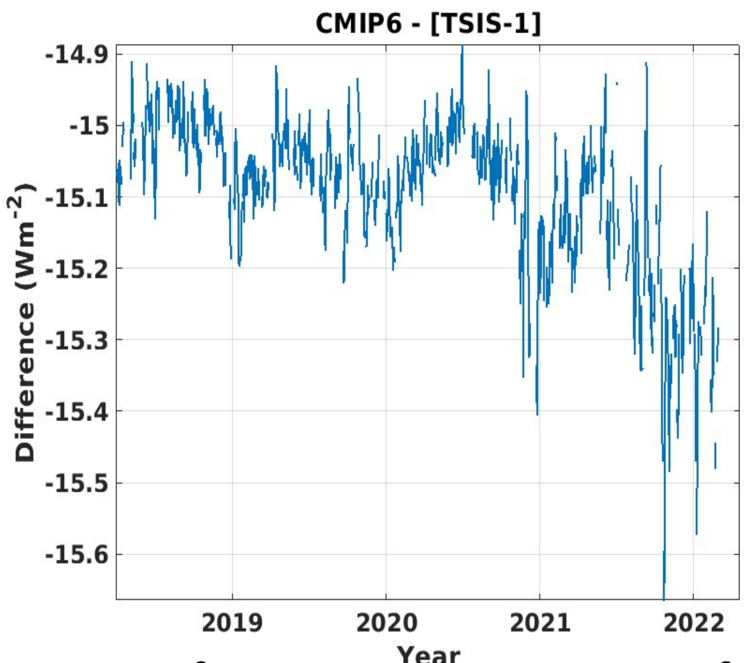
CMIP6 SSI: 1978-2014 on RRTMG_SW bands

CMIP6 TSI/SSI vs. TSIS-1 obs. (2018-2022)



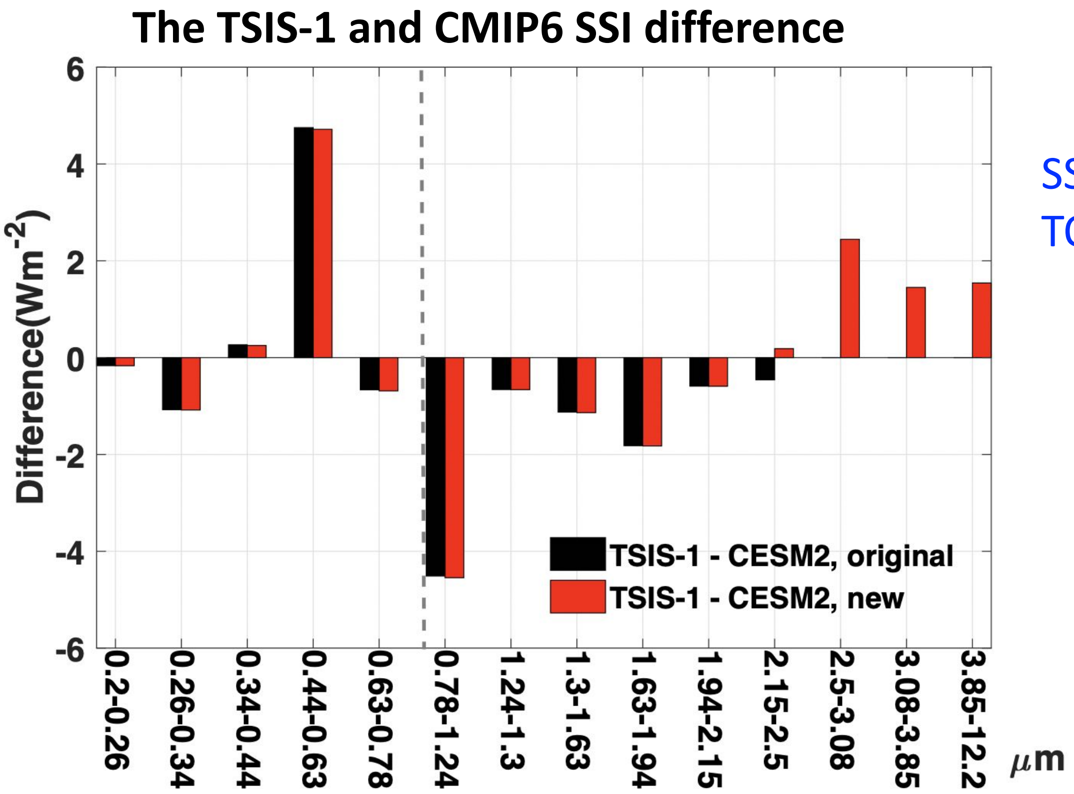






CO_2 Radiative forcing: 1.66 Wm^{-2}

~15 Wm^{-2} difference, i.e., -3.75 Wm^{-2} difference in TOA forcing (Vis – NIR)



SSI is not TOA forcing

TOA forcing = SSI/4

- The difference is orders of magnitude lager than the temporal variations of SSI in CMIP6
- First-order question: how such differences between visible and near-IR can affect the simulated climate?
- Making two SSI datasets:
    - CESM2 SSI: 1978-2014 CMIP6 SSI scaled to TSIS-1 TSI by a factor of 1.00003
    - TSIS-1 SSI:
        - Within 0.2-2.4um, time-averaged TSIS-1 observed SSI
        - Outside, CMIP6 SSI but scaled to make the identical TSI as TSIS-1 observation

CESM-2 numerical experiments

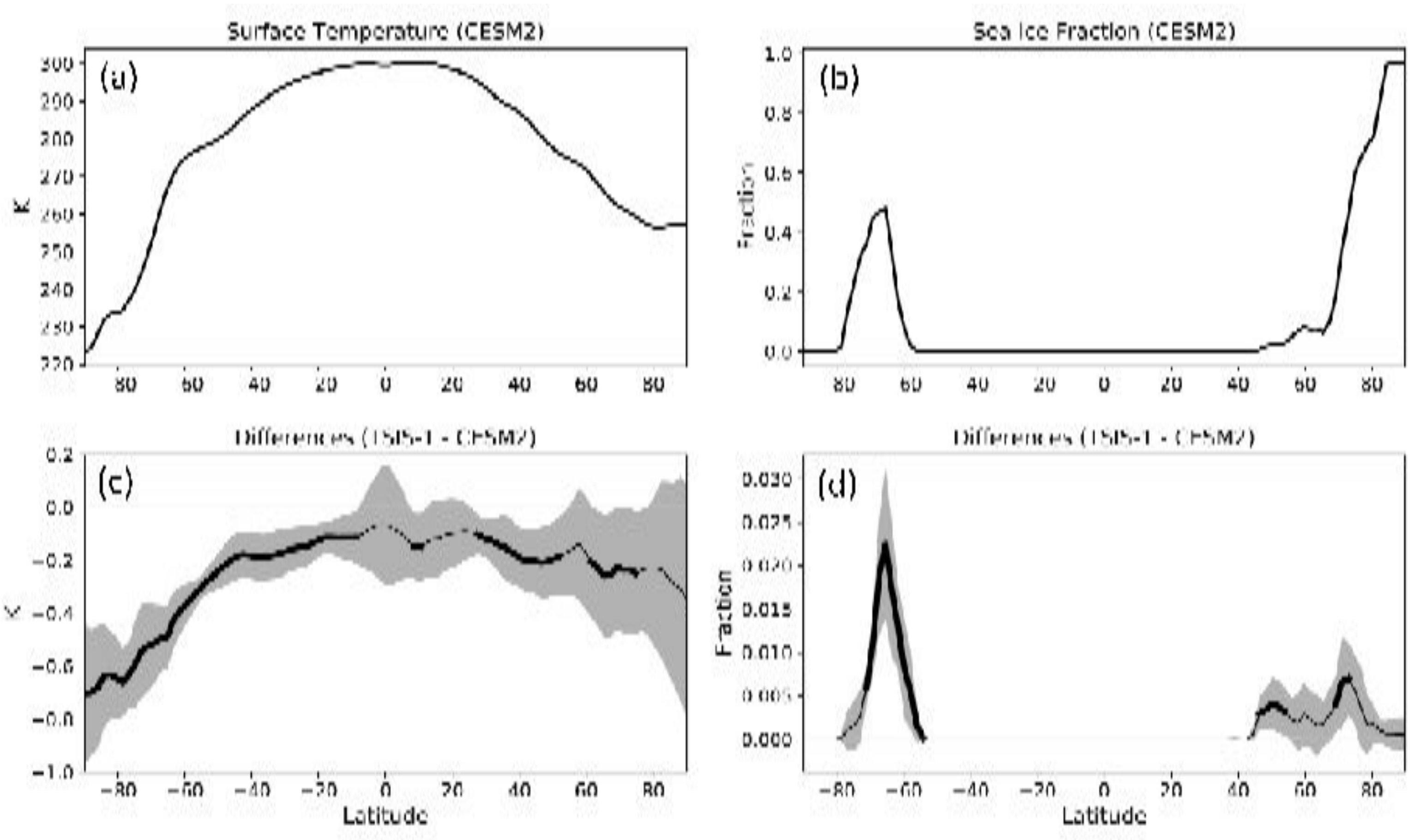
- Slab-ocean and fully-coupled runs at present-day conditions
- Four-member ensemble runs
  - One ensemble with CESM2 SSI (control)
  - The other with TSIS-1 SSI (perturbation)

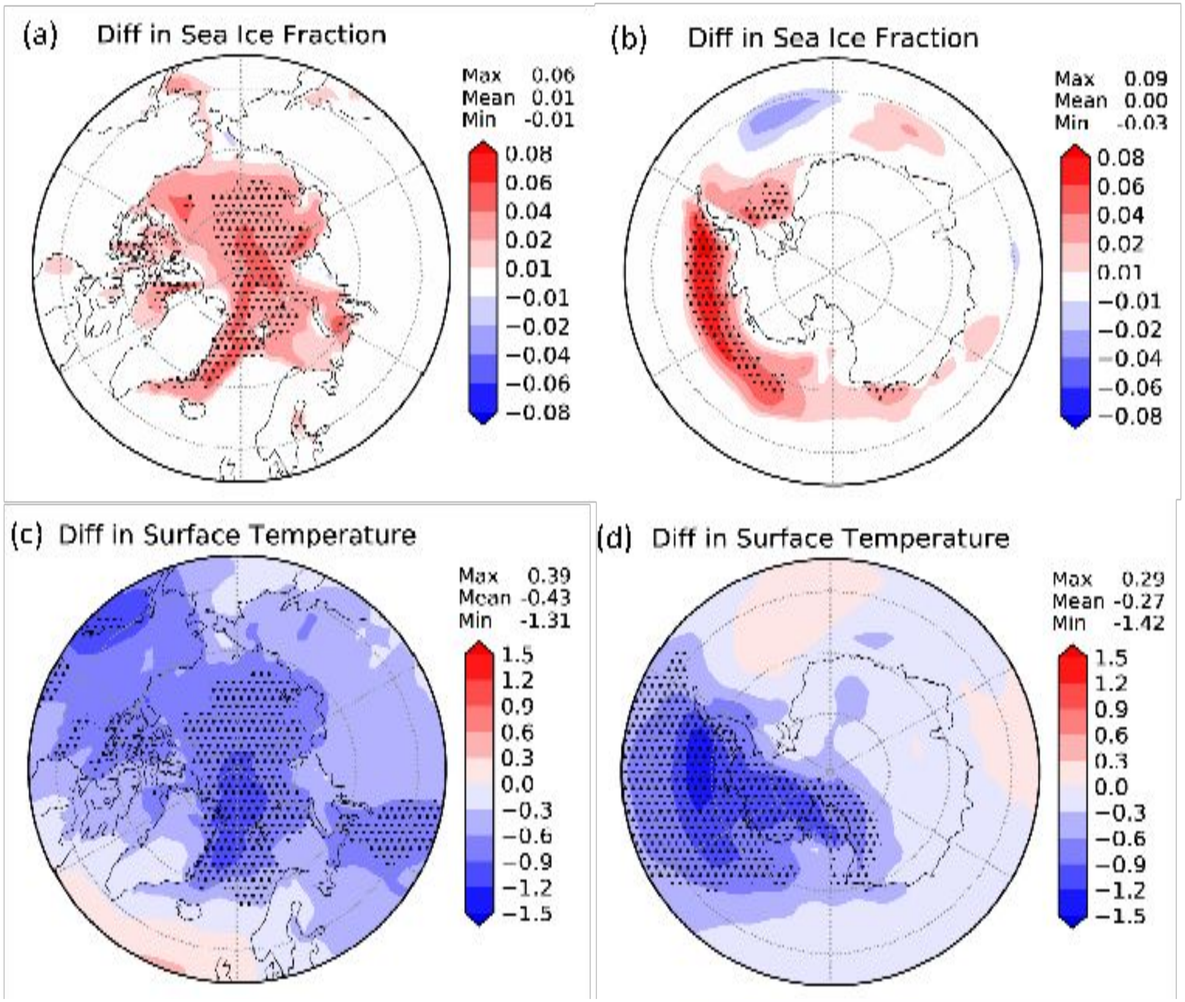
    Identical TSI/Different VIS-NIR SSI

    TSIS-1 SSI has more in VIS and less in NIR than the CESM2 SSI
- Slab-ocean run: 20-year simulations and last 10 years used for analysis
- Fully-coupled run: 50-year simulations and last 30 years used for analysis

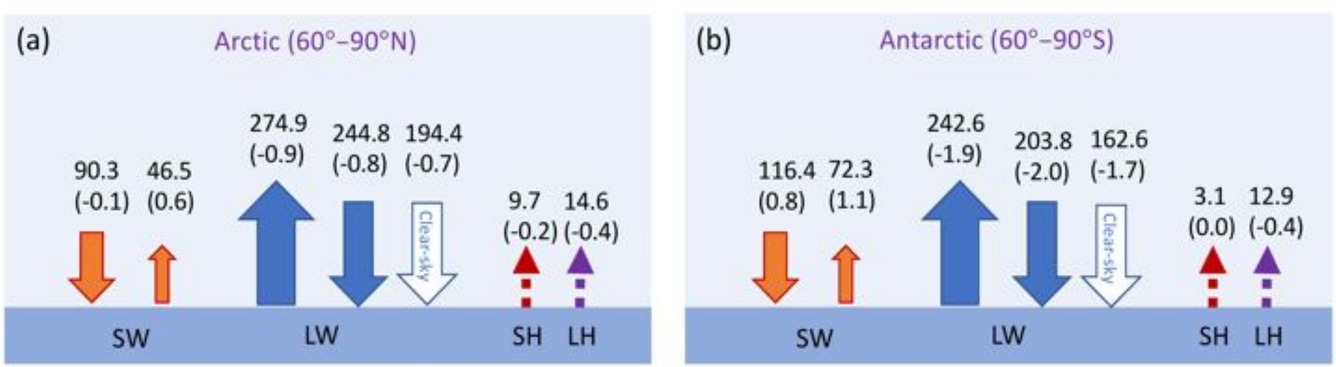
Slab-ocean run results in Jing, X. et al., ***Direct influence of solar spectral irradiance on the high-latitude surface climate****, Journal of Climate, 34(10), 4145–4158, 2021.*

Zonal-mean climatology difference (Slab-ocean run; 10-year mean difference)





(a) Diff in Sea Ice Fraction
Max 0.06
Mean 0.01
Min -0.01
0.08
0.06
0.04
0.02
0.01
−0.01
−0.02
−0.04
−0.06
−0.08
(b) Diff in Sea Ice Fraction
Max 0.09
Mean 0.00
Min -0.03
(c) Diff in Surface Temperature
Max 0.39
Mean -0.43
Min -1.31
1.5
1.2
0.9
0.6
0.3
0.0
−0.3
−0.6
−0.9
−1.2
−1.5
(d) Diff in Surface Temperature
Max 0.29
Mean -0.27
Min -1.42

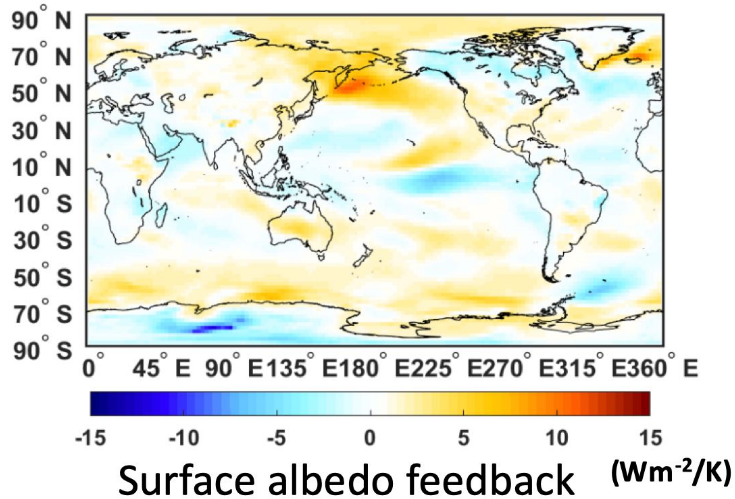


(a)
Arctic (60°–90°N)
90.3 (-0.1)
46.5 (0.6)
274.9 (-0.9)
244.8 (-0.8)
194.4 (-0.7)
Clear-sky
9.7 (-0.2)
14.6 (-0.4)
SW
LW
SH
LH
(b)
Antarctic (60°–90°S)
116.4 (0.8)
72.3 (1.1)
242.6 (-1.9)
203.8 (-2.0)
162.6 (-1.7)
Clear-sky
3.1 (0.0)
12.9 (-0.4)
SW
LW
SH
LH

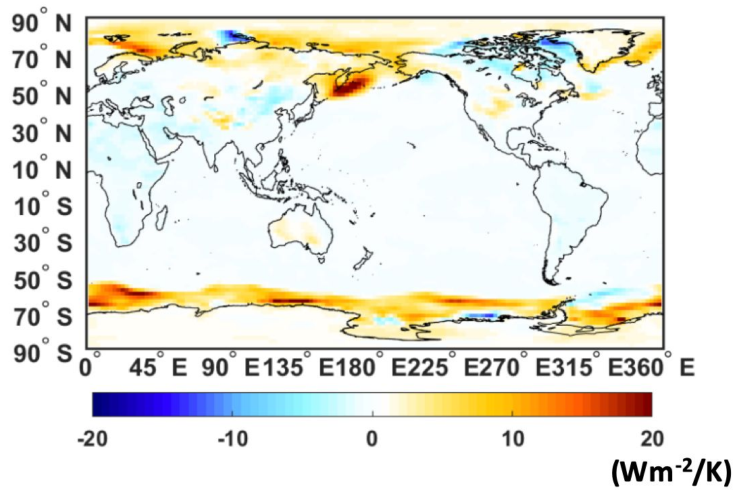
Feedback analysis (TSIS-1 – CESM2)

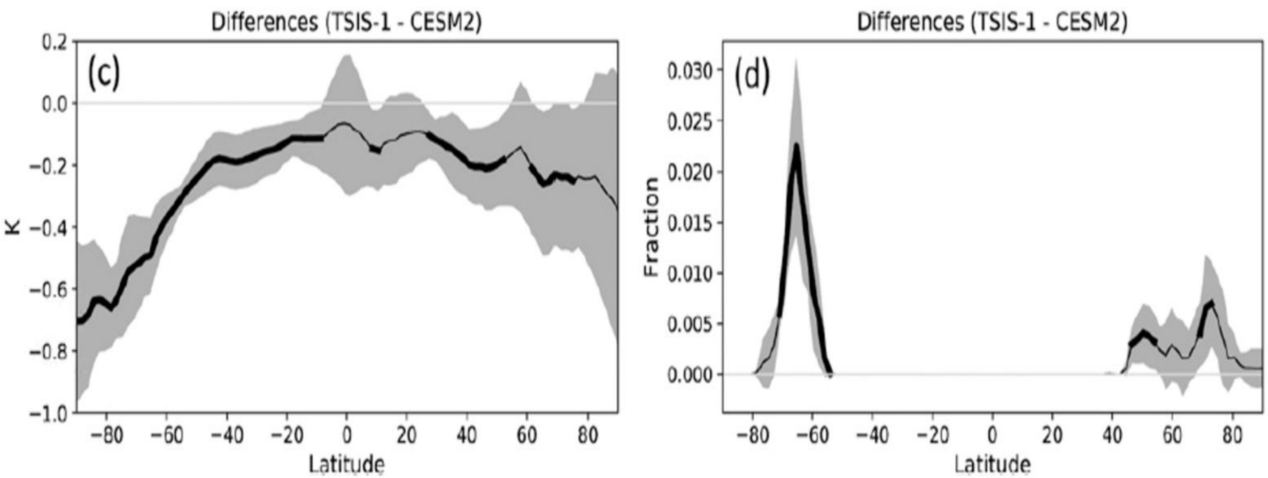
All-sky Feedback (Wm^{-2}/K)	
Planck	-3.01
Lapse-rate	0.49
water vapor LW	0.87
water vapor SW	0.28
Surface albedo	0.42
Cloud LW	-0.61
Cloud SW	0.70

Lapse-rate feedback

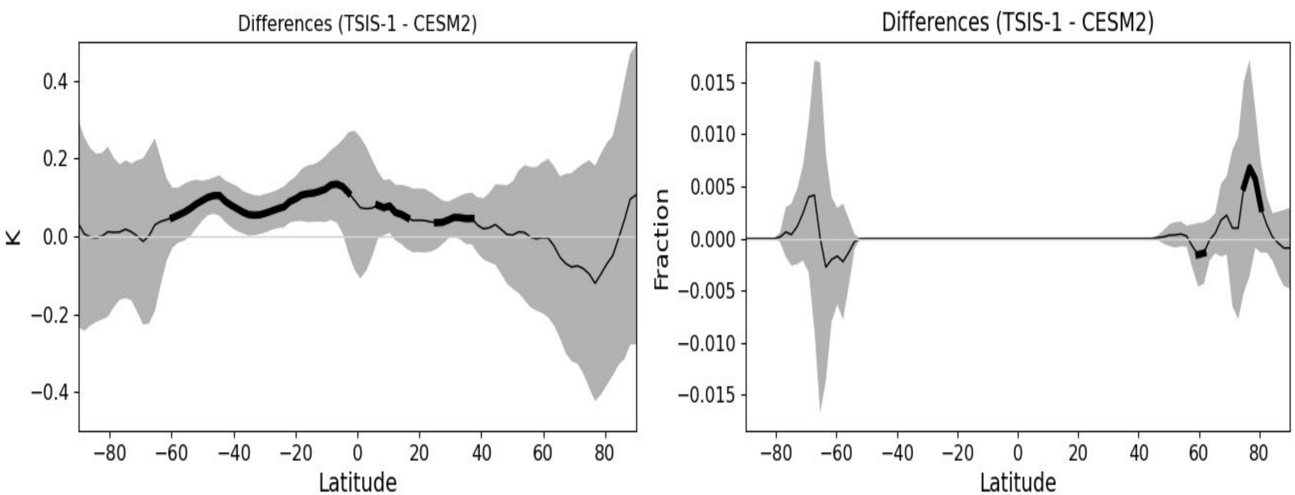


Surface albedo feedback





Jing et al., 2021
Slab ocean run
(10-year mean difference)



Fully coupled run
(30-year mean difference)

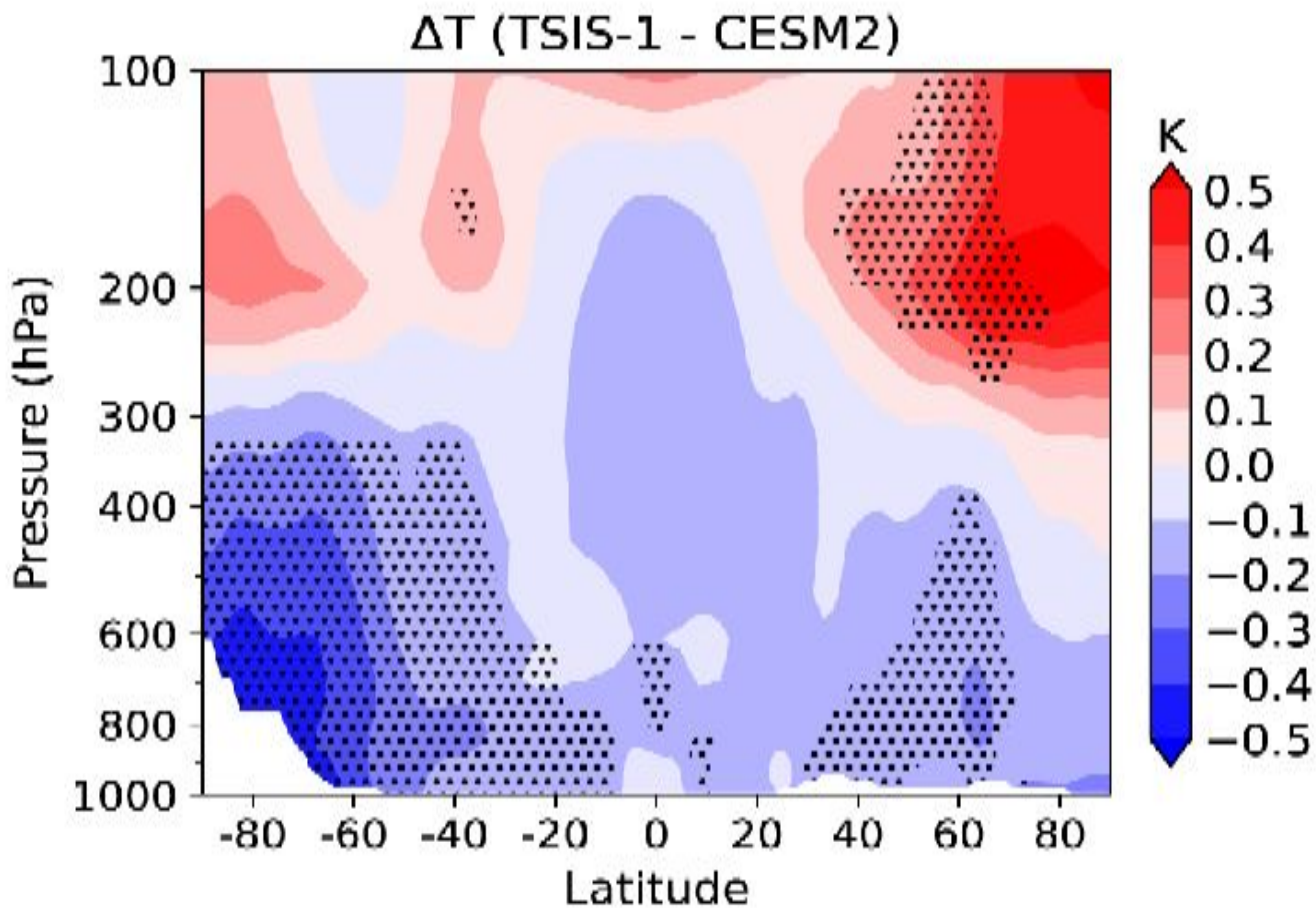
1. Ocean dynamics, especially for the Southern Ocean
2. Time of average/high-latitude variability
3. Difference in CESM 2.1.1 vs. 2.1.3

Conclusions

- A discrepancies between CMIP6 and TSIS-1 SSI in the visible and near-IR: as large as ~ 4 Wm^{-2} in the TOA forcing
- Even with the identical TSI, SSI partition between the visible and near-IR matters for the climate simulation
  - Disparity between visible and near-IR absorption by high-latitude surface
  - Also the atmospheric near-IR absorption(?)
- Spectral TOA forcing matters, not just the broadband TOA forcing
  - Ice spectral albedo feedback
- Next step: how does the time-varying SSI affect the simulated climate via this bottom-up mechanism?

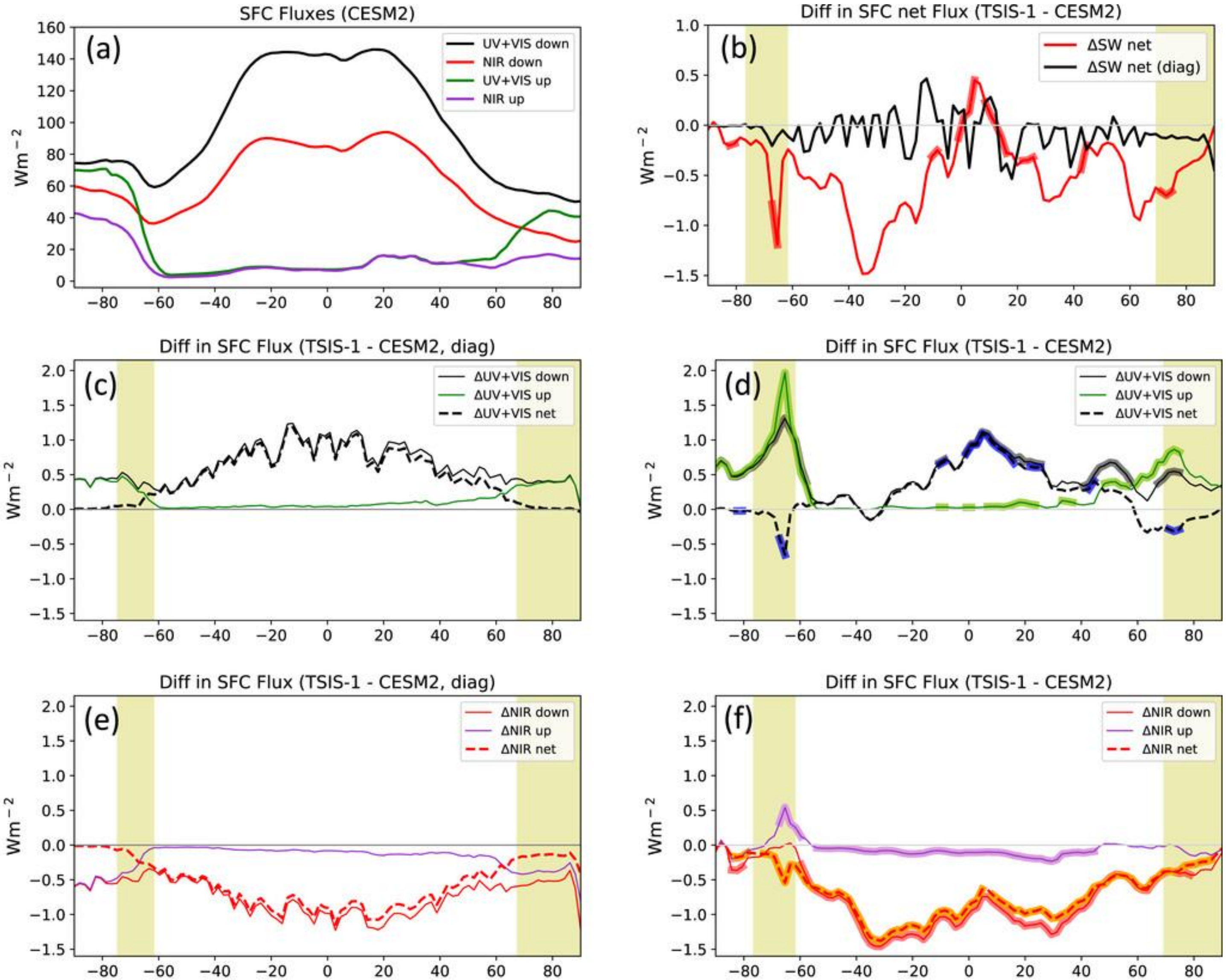
THANK YOU!

Atmosphere temperature differences



Surface SW Flux (net positive downward)

TSIS-1 has more SSI in visible than CESM2



- Ensemble run: sea ice must play a role

Vertical shades: sea ice changes are statistically significant

Feedback analysis (TSIS-1 – CESM2)

All-sky Feedback (Wm^{-2}/K)	
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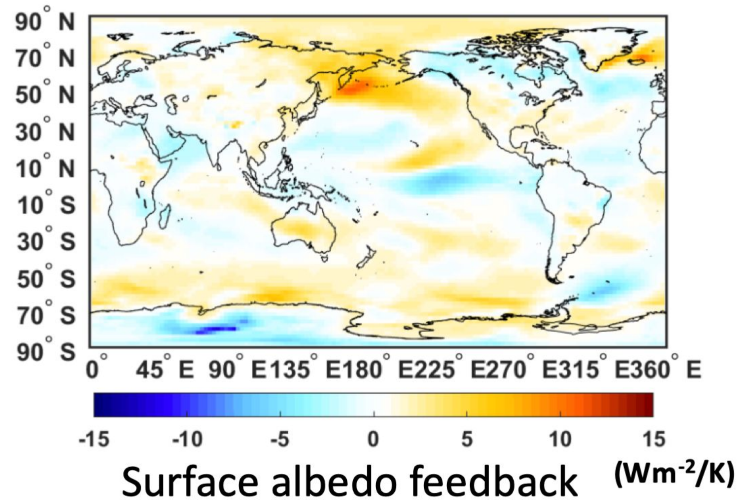
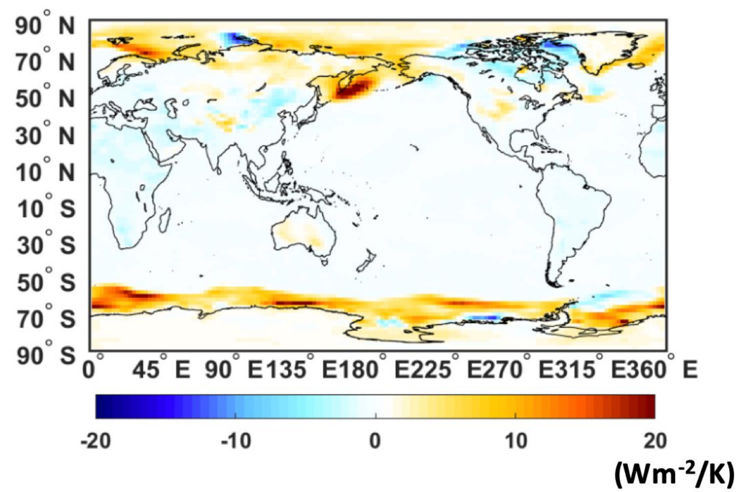
Lapse-rate feedback

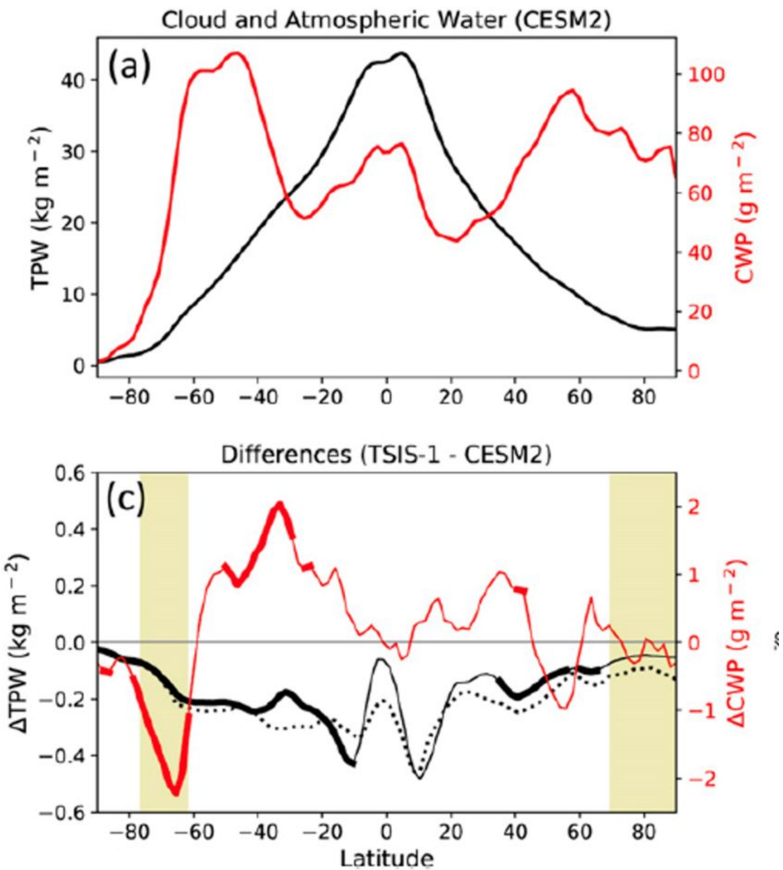


Surface albedo feedback

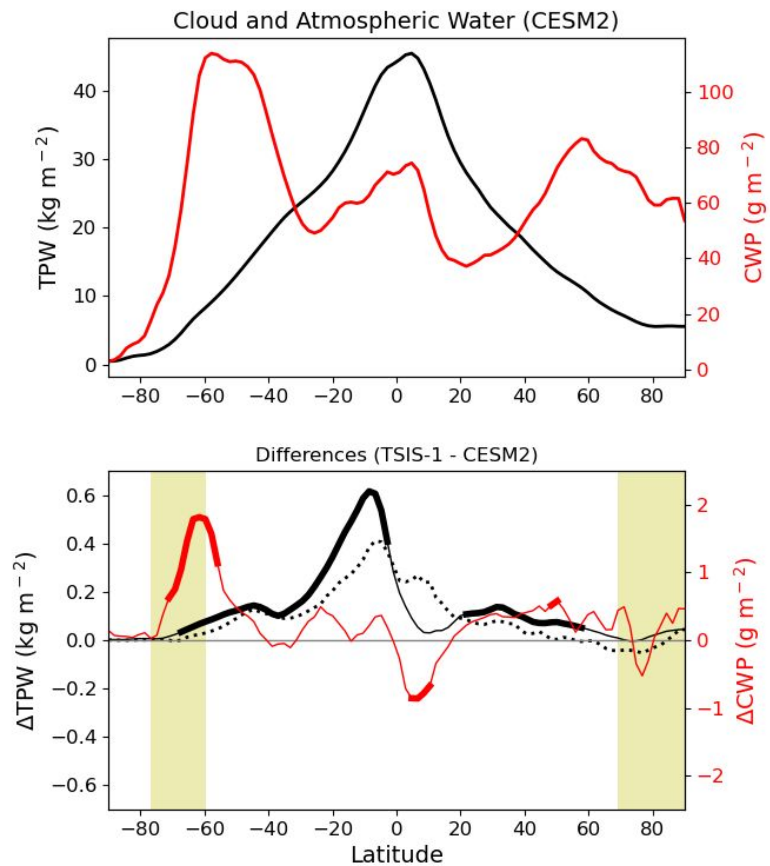


Besides ocean dynamics, what could be reasons for slab-ocean vs. fully-coupled differences? (Preliminary results)

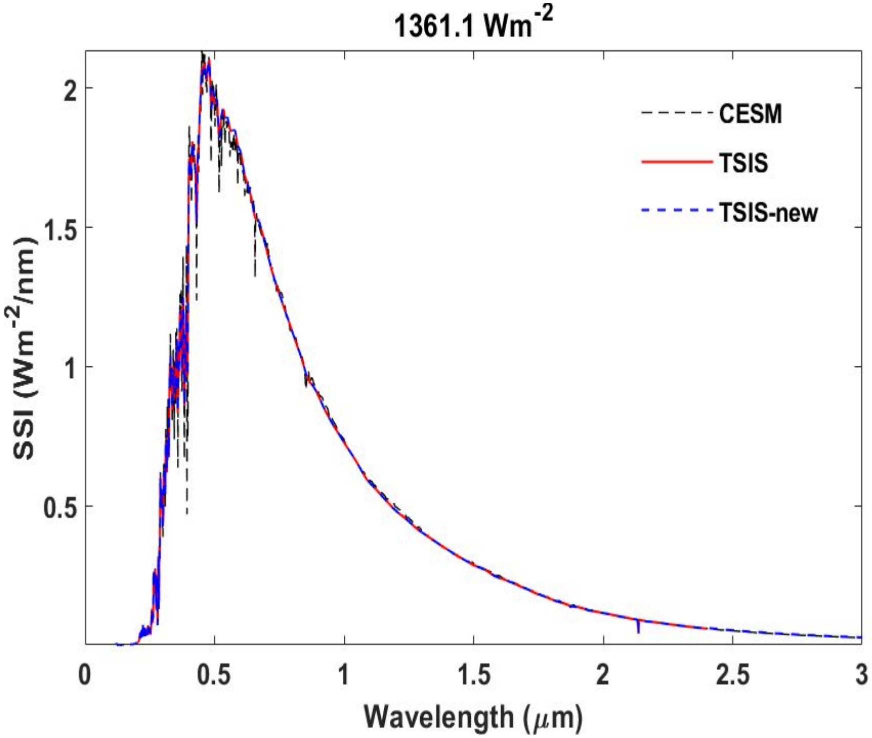
Jing et al., 2021
Slab ocean run

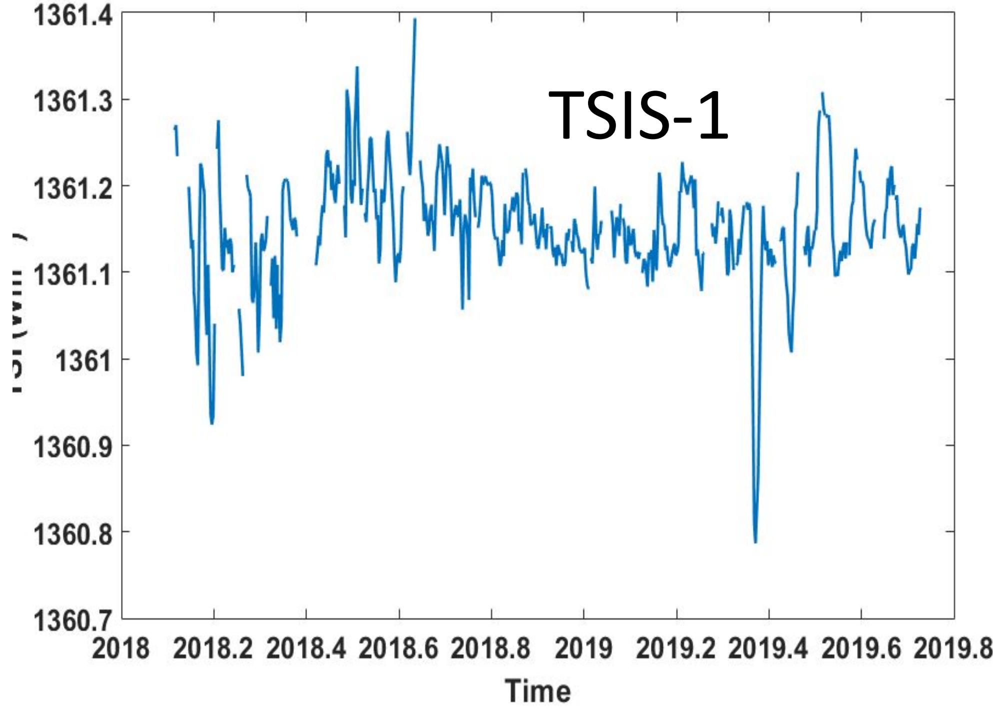


Fully coupled run



The yellow shades indicate latitudes where zonal mean sea ice fraction . 0.1





CESM spectral interval: 1, 3, 5, 7, 10, 30, 50 nm
TSIS spectral interval: 0.04~9 nm