Isolating the Influence of Temperature-dependent Cloud Optics on Infrared Radiation within a Model Hierarchy

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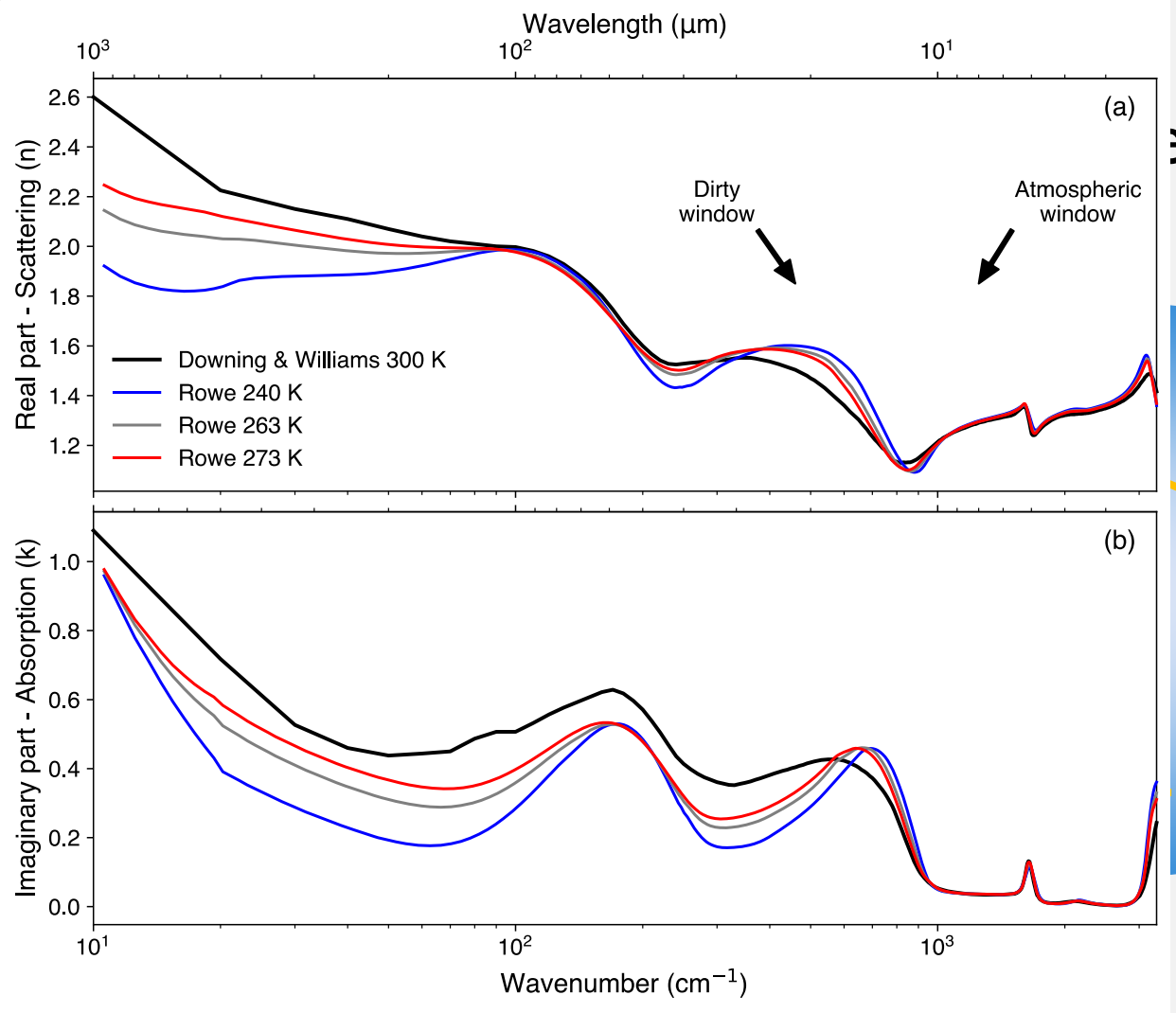
Optical properties of liquid water have a temperature dependence for supercooled liquid water



Gilbert et al., *in prep.*

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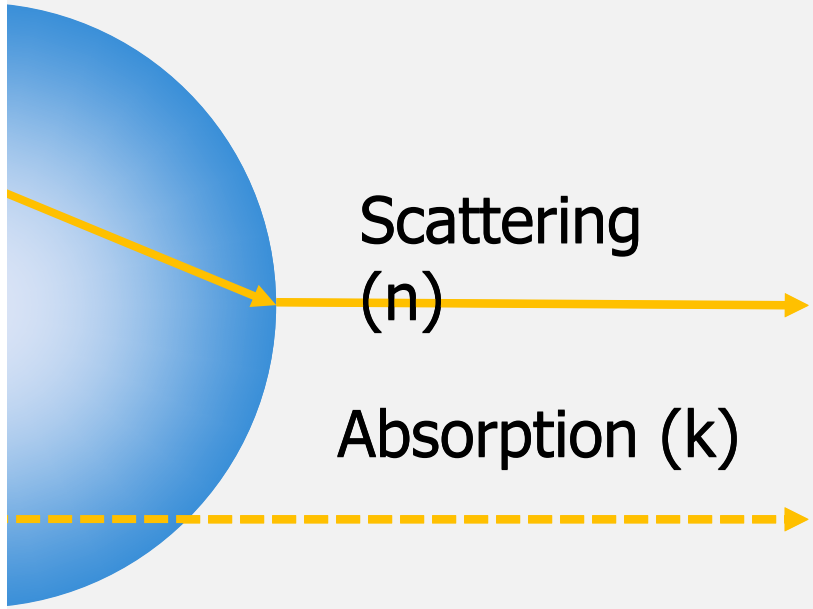
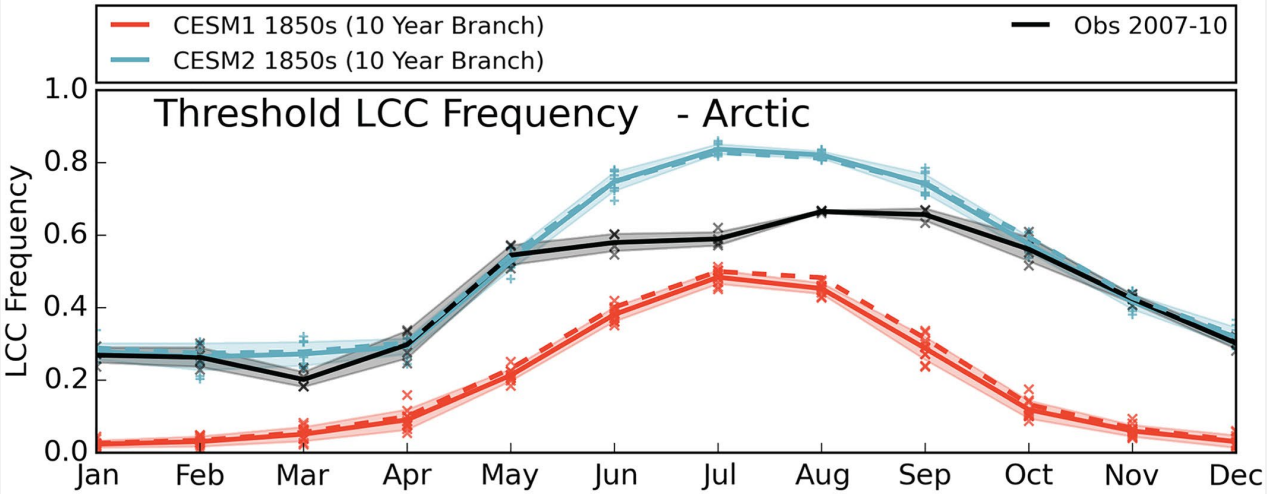


Research Questions

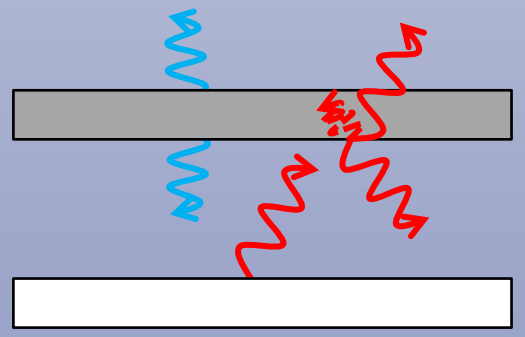
1) How can we assess the importance of a cloud optics change like adding temperature-dependent optics?

2) Are the effects of temperature-dependent liquid water optics on longwave radiation substantial enough to be incorporated into model radiation schemes?

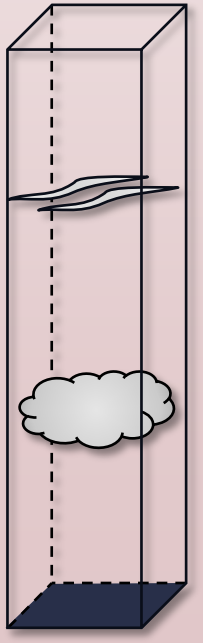


McIlhattan et al. 2020.

1) Two-stream radiative transfer model – *do we see an effect with a conceptual model on a spectral scale?*

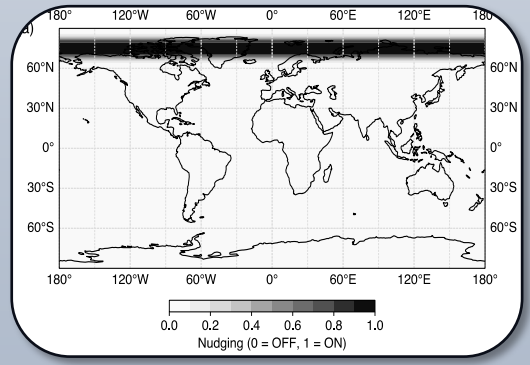


2) Single-column atmospheric model – *do we see an effect with an atmospheric model at a single location on a daily time scale?*



3) Freely-evolving global climate model – *do we see an effect with a global climate model over the entire Arctic on a decadal time scale?*

4) Wind-nudged global climate model – *do we see an effect with a dynamically constrained global climate model over the entire Arctic at various time scales?*



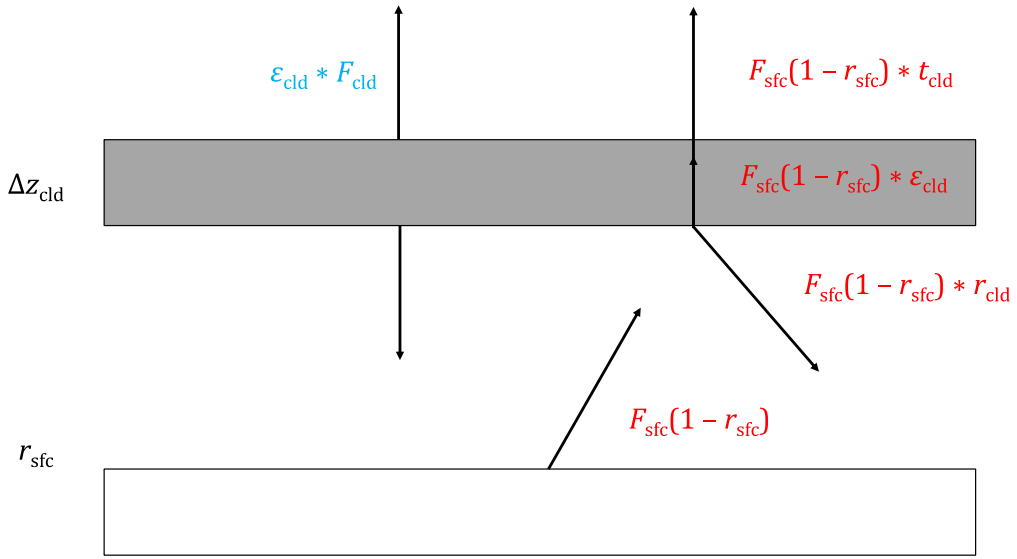
Increasing Model Complexity

Two-stream Radiative Transfer Model

Do we see an effect with a conceptual model on a spectral scale?

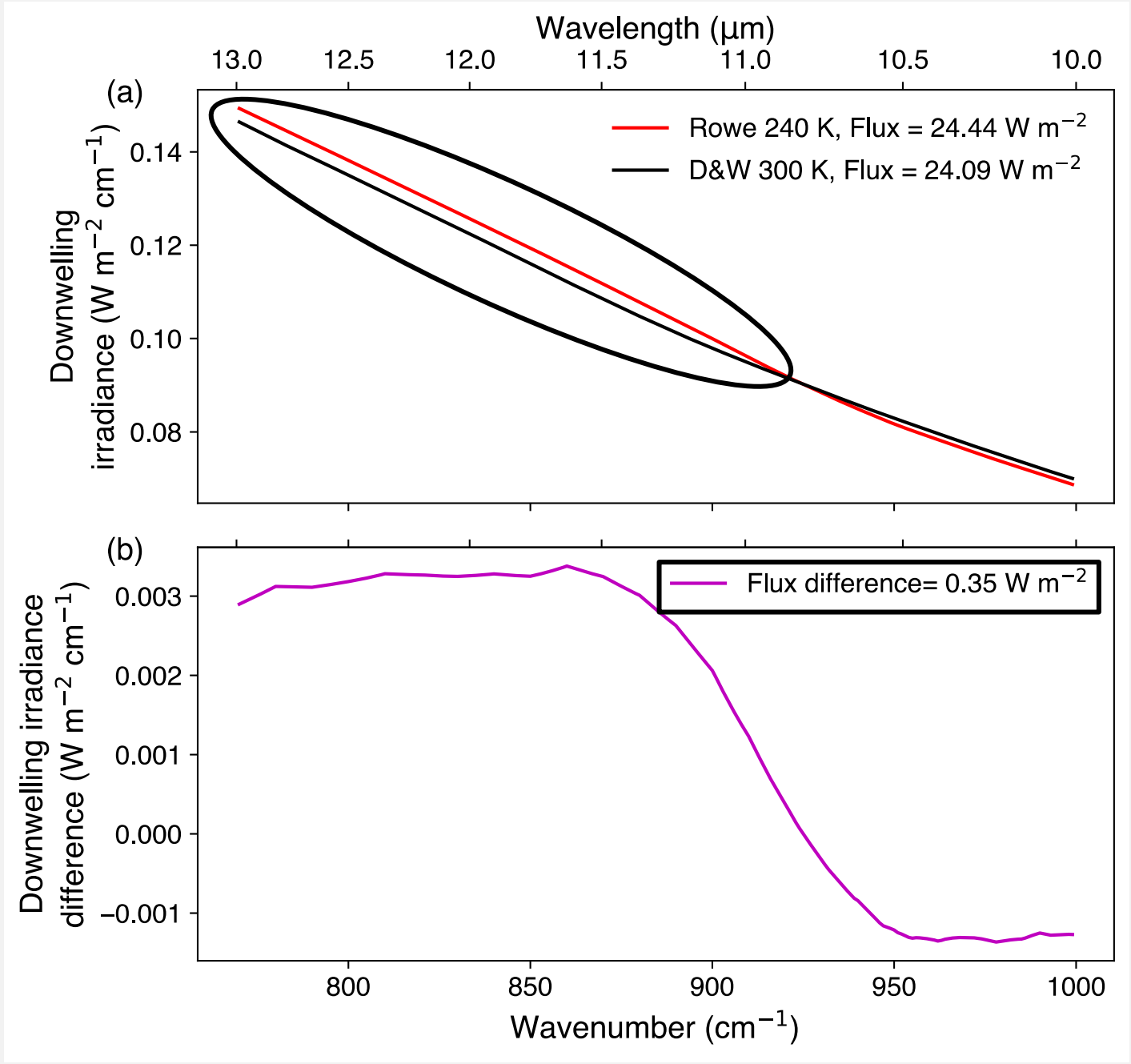
Simplistic radiative transfer model

- Modeled downwelling spectral longwave from a single supercooled liquid cloud with temperature-dependent and temperature-independent optics



Two-stream downwelling longwave flux:
reflected ground emission + cloud emission
$F_{sfc}(1 - r_{sfc}) * r_{cld} + \varepsilon_{cld} * F_{cld}$

Gilbert et al., *in*

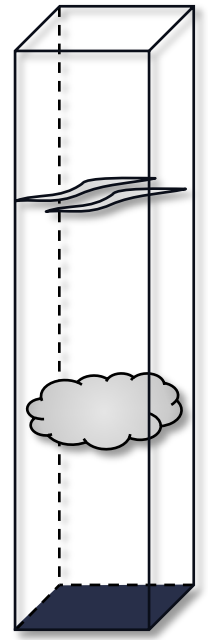


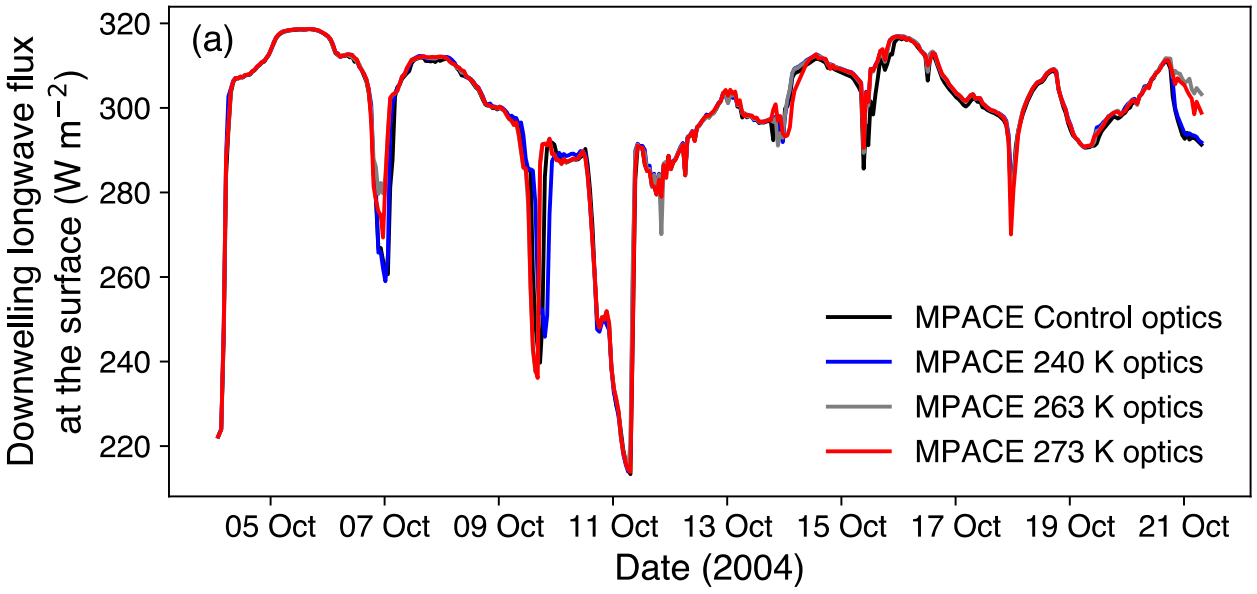
Gilbert et al., *in prep.*

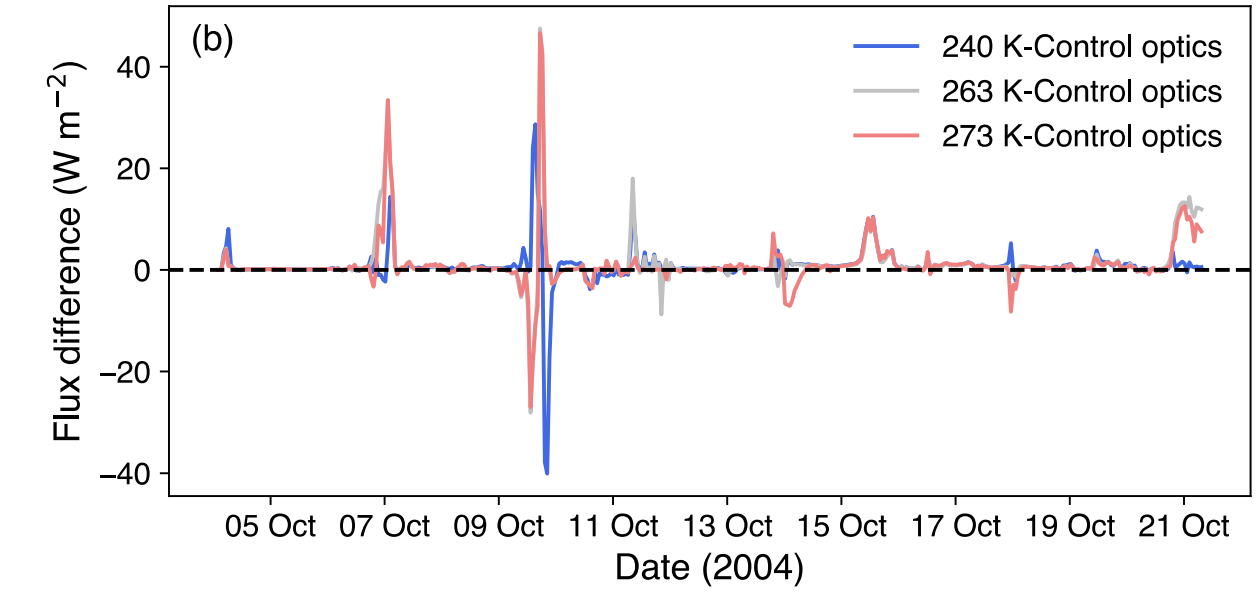
Single-column Atmospheric Model

Do we see an effect with an atmospheric model at a single location on a daily time scale?

- Single-Column Atmospheric Model Version 6 (SCAM)
  - Single-column version of the atmospheric component from CESM2
  - Forced by 17 days of observations from an Arctic field campaign (MPACE)







Gilbert et al., *in prep.*

Downwelling longwave data only when low-level supercooled liquid clouds were present

Optics Set	Median (W m^{-2})	Median$_{optics\ set}$ - Median$_{control\ optics}$ (W m^{-2})	Statistically significant difference?
Control	306.99		
240 K	307.32	0.33	**No**
263 K	307.40	0.41	**No**
273 K	307.10	0.11	**No**

Freely-evolving Global Climate Model

Do we see an effect with a global climate model over the entire Arctic on a decadal time scale?

CESM2

1) Prescribed sea ice and SSTs with pre-industrial climate (F1850 compset) – ***decadal time scale with freely evolving atmosphere***
   - 40 year run

No stippling! → Optics effect is not statistically significant!

Gilbert et al., *in prep.*

Wind-nudged Global Climate Model – Part I

Do we see an effect with a dynamically constrained global climate model over the entire Arctic?

CESM2

1) Prescribed sea ice and SSTs with pre-industrial climate (F1850 compset) and nudged winds from 1980 – ***yearly time scale with constrained atmosphere***
   - 1 year run with 10 ensemble members
2) Coupled ocean & sea ice models with pre-industrial climate (B1850 compset) and nudged winds from 1980 – ***ocean/sea ice feedbacks with constrained atmosphere***
   - 1 year run with 10 ensemble members

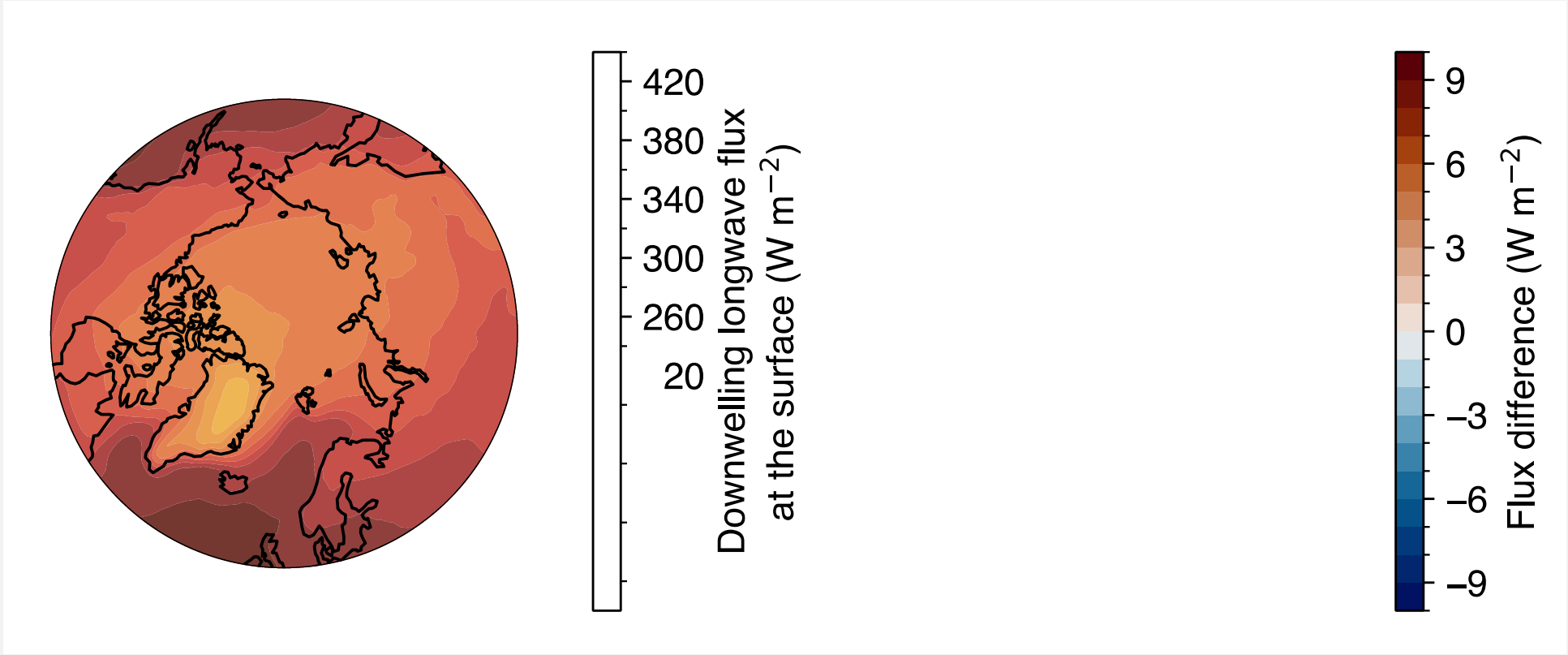
Stippling!

Optics effect is statistically significant for 1 year nudged ensemble!

Gilbert et al., *in prep.*

No stippling!

Optics effect is not statistically significant for coupled 1 year nudged ensemble!



Gilbert et al., *in prep.*

Wind-nudged Global Climate Model – Part II

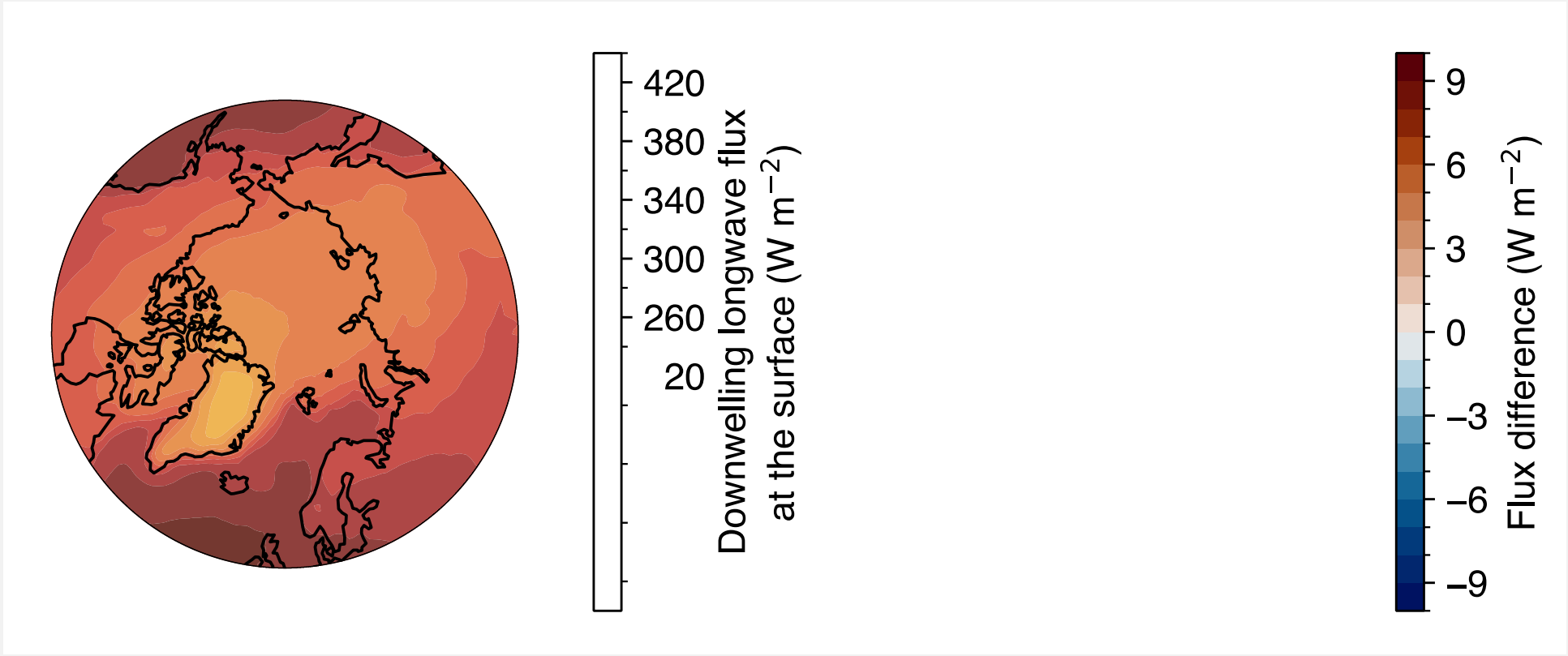
Do we see an effect with a dynamically constrained global climate model over the entire Arctic at decadal time scales?

CESM2

1) Prescribed sea ice and SSTs with pre-industrial climate (F1850 compset) and nudged winds from 1980-2018 – ***decadal time scale with constrained atmosphere***
   - 39 year run with 3 ensemble members

Stippling!

Optics effect is statistically significant for 39 year nudged ensemble!



Gilbert et al., *in prep.*

Conclusions

Was the effect of the temperature-dependent optics on longwave flux substantial?

1) **Two-stream radiative transfer model:** *small effect on the order of a few tenths of W m^{-2}*
2) **Single-column atmospheric model:** *no effect for all clouds, small effect on the order of a few tenths of W m^{-2} for supercooled liquid clouds only*
3) **Freely-evolving global climate model:** *small and statistically insignificant effect on the order of a few W m^{-2}*
4) **Wind-nudged global climate model:** *statistically significant effect for the year-long and decades-long ensembles, but statistically insignificant effect for the coupled ensemble*

Conclusions

Takeaway #1: The effects of temperature-dependent optics are not substantial enough to be a first priority for model parameterization development

Takeaway #2: A model hierarchy that includes wind nudging is a powerful model development tool to assess the importance of a model physics change

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