Diagnosing the Cryosphere Radiative Effect in CESM

Mark Flanner & Justin Perket

CESM Land Model Working Group Session
June 19, 2013

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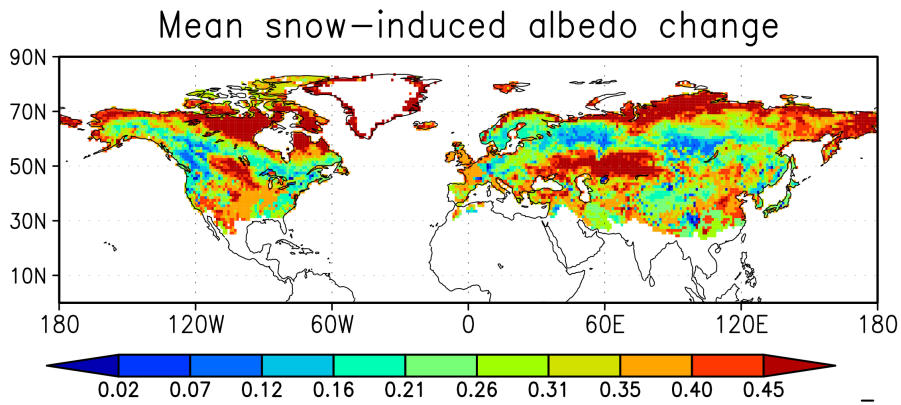
- Metrics of snow and sea-ice cover are important and often used to evaluate climate models, but do not capture the cryospheric radiative influence. Factors:
  - Vegetation structure and phenology
  - Insolation
  - Cloud cover
  - Snow-free albedo



Motivation and Definition

- The *cryosphere radiative effect* (CrRE) integrates these factors, and enables precise diagnosis of the influence of snow/ice evolution on changes in both surface albedo and TOA energy flux

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- Definition of CrRE: the instantaneous perturbation to Earth's TOA energy balance induced by the presence of surface cryospheric components
- Directly analogous to the *cloud radiative effect*
- We now have a 30+ year observational record of CrRE derived from remote sensing measurements (*Flanner et al*, 2011)

1979–2008 mean CrRE from observations

As derived from observations, area-averaged CrRE is:

$$\mathrm{CrRE}(t,R) = \frac{1}{A(R)} \int_R \underbrace{S_x(t,r)}_{1} \underbrace{\frac{\partial \alpha}{\partial S_x}(t,r)}_{2} \underbrace{\frac{\partial F}{\partial \alpha}(t,r)}_{3} \, dA(r) \qquad [\mathrm{W\,m^{-2}}] \qquad (1)$$

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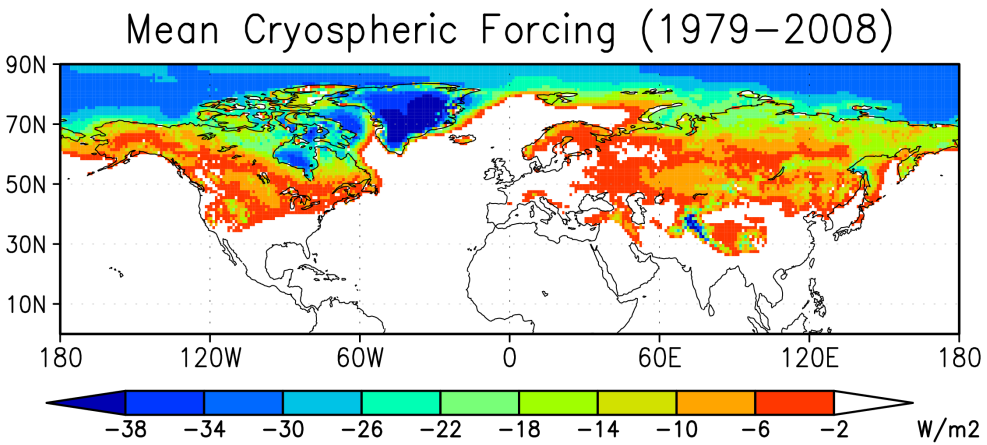
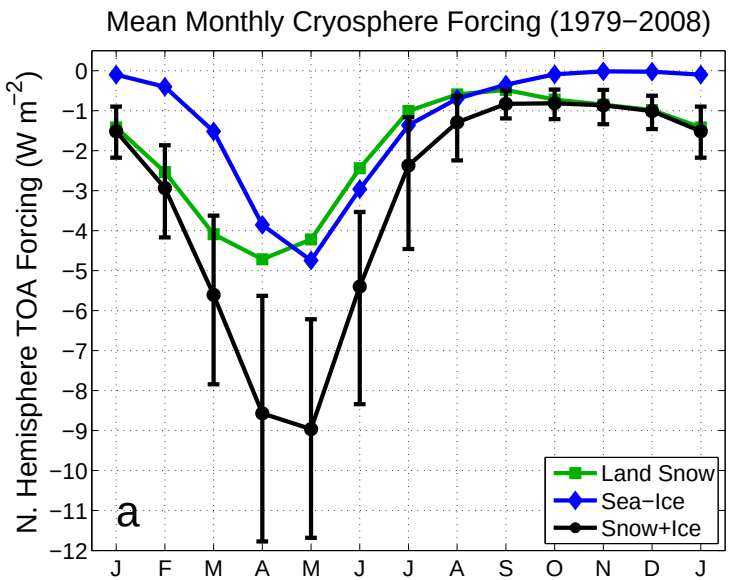
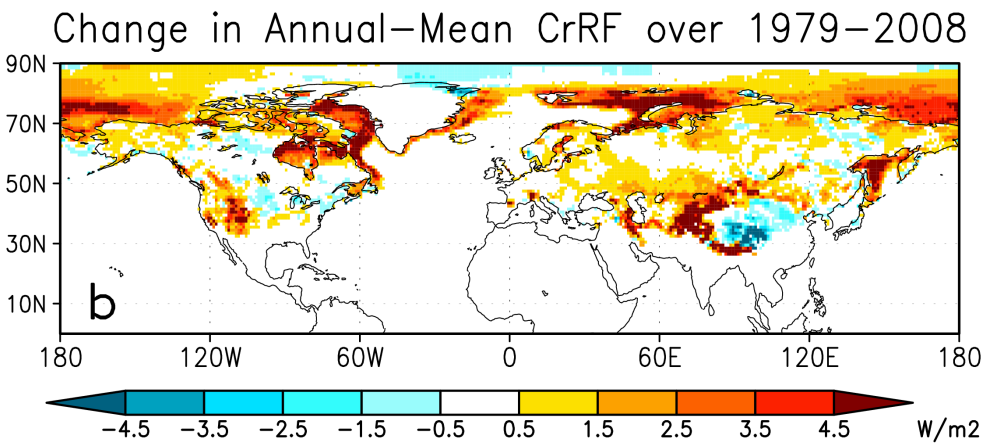
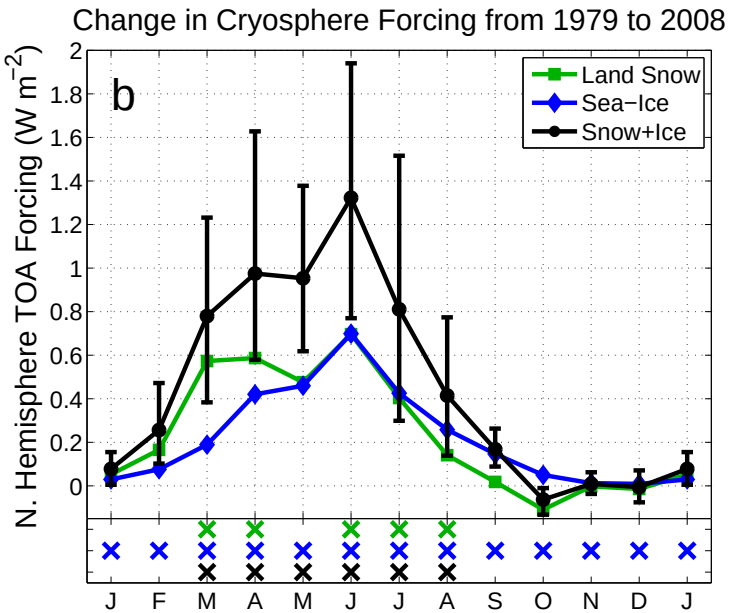




- Annual-mean Northern Hemisphere CrRE of land snow: $-2.0 \pm 0.6\,\mathrm{W\,m^{-2}}$
- Peak land-snow CrRE season: March–May

1979–2008 change in CrRE





- 30-year change in land snow CrRE: $+0.22 \pm 0.08\,\mathrm{W\,m^{-2}}$

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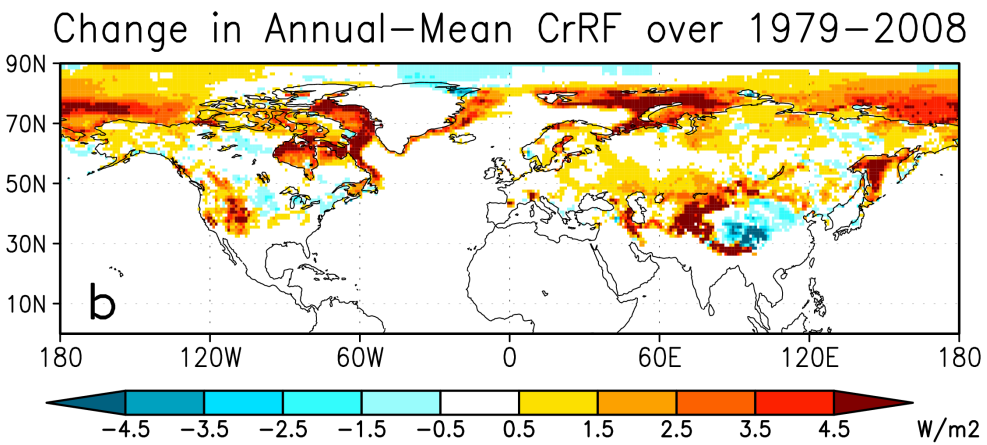

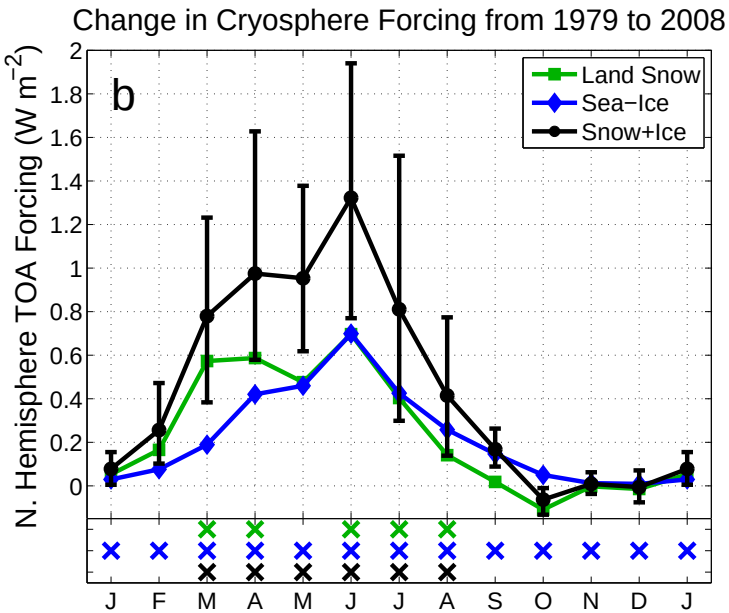

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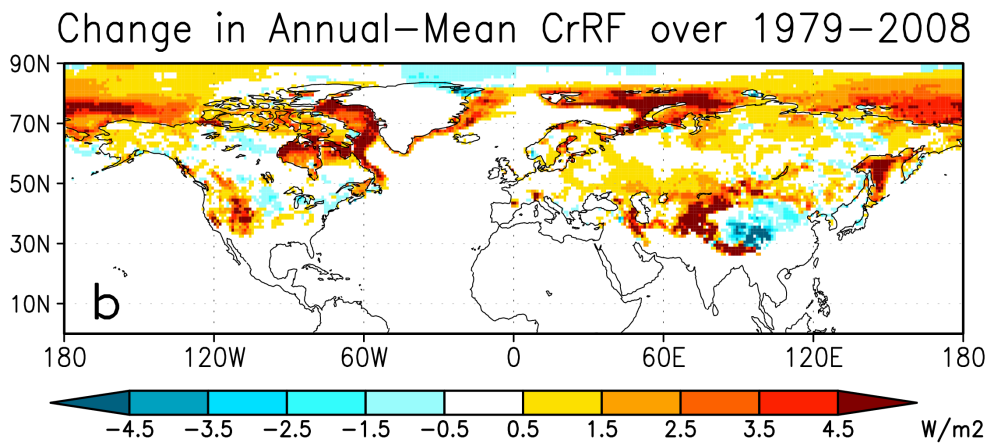

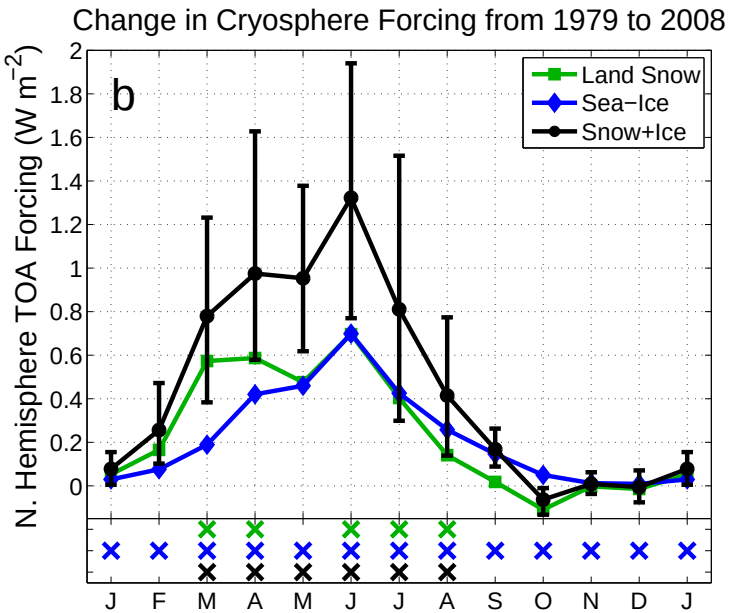

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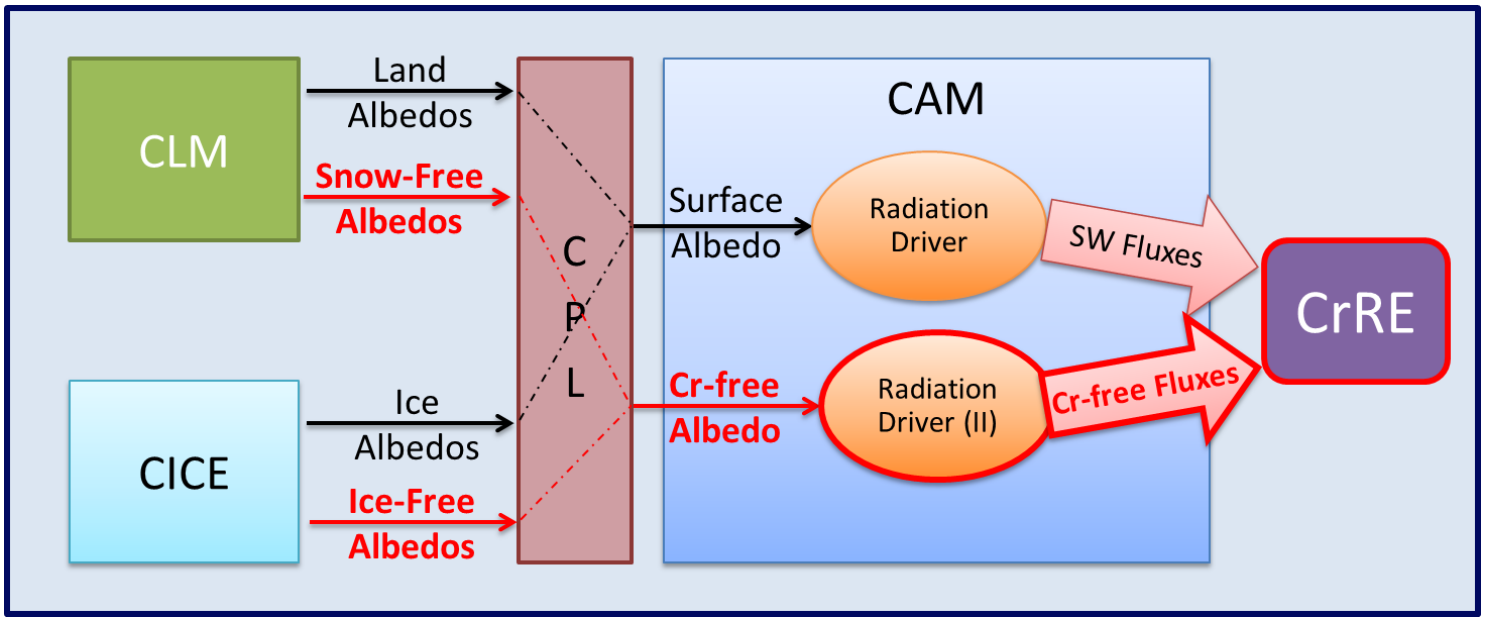
- Large spring increase, small autumn effect from *increased* snow
- Land-snow CrRE changes are significant during March–August

Diagnostic CrRE in CESM

Implemented by Justin Perket:



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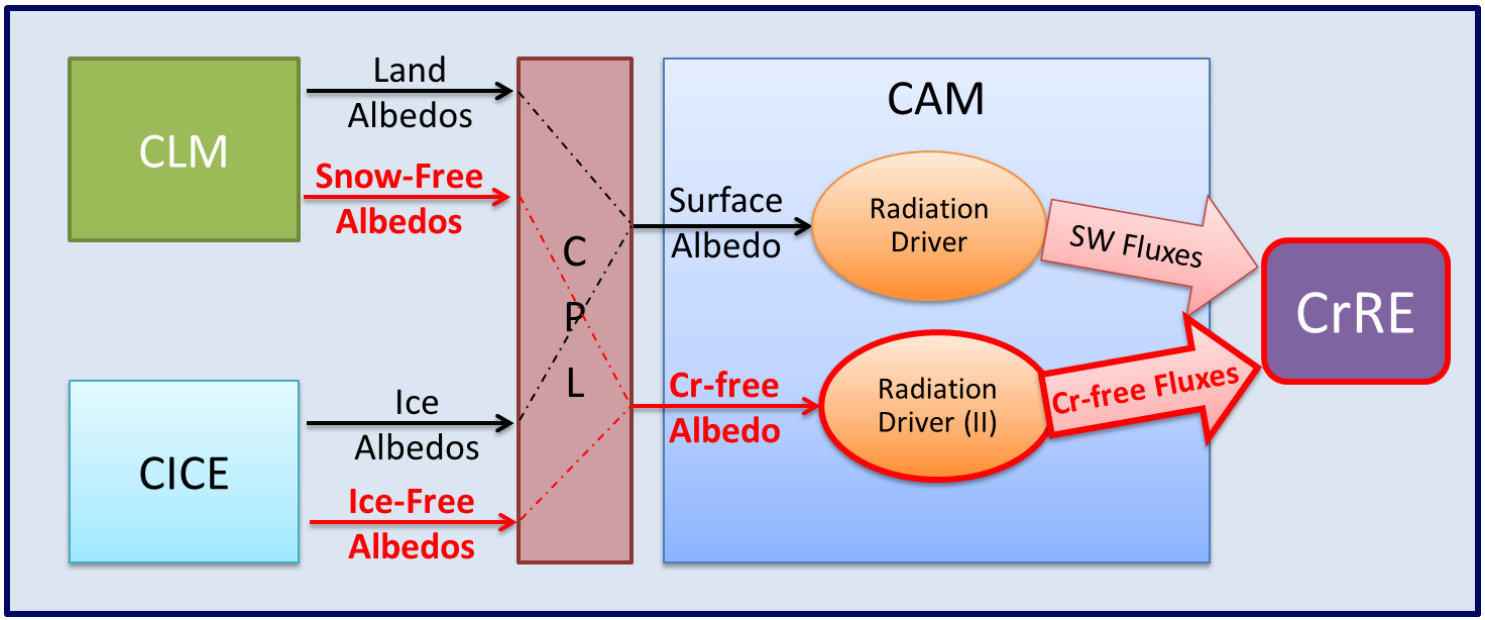

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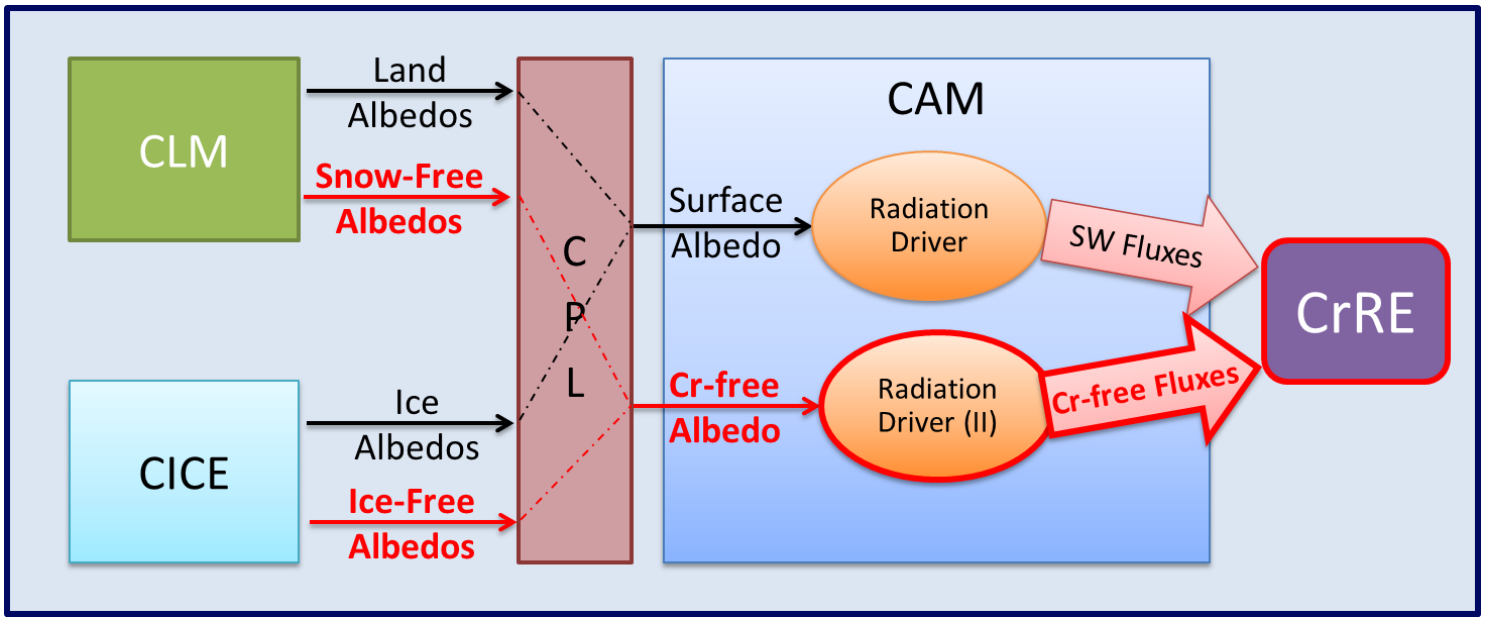

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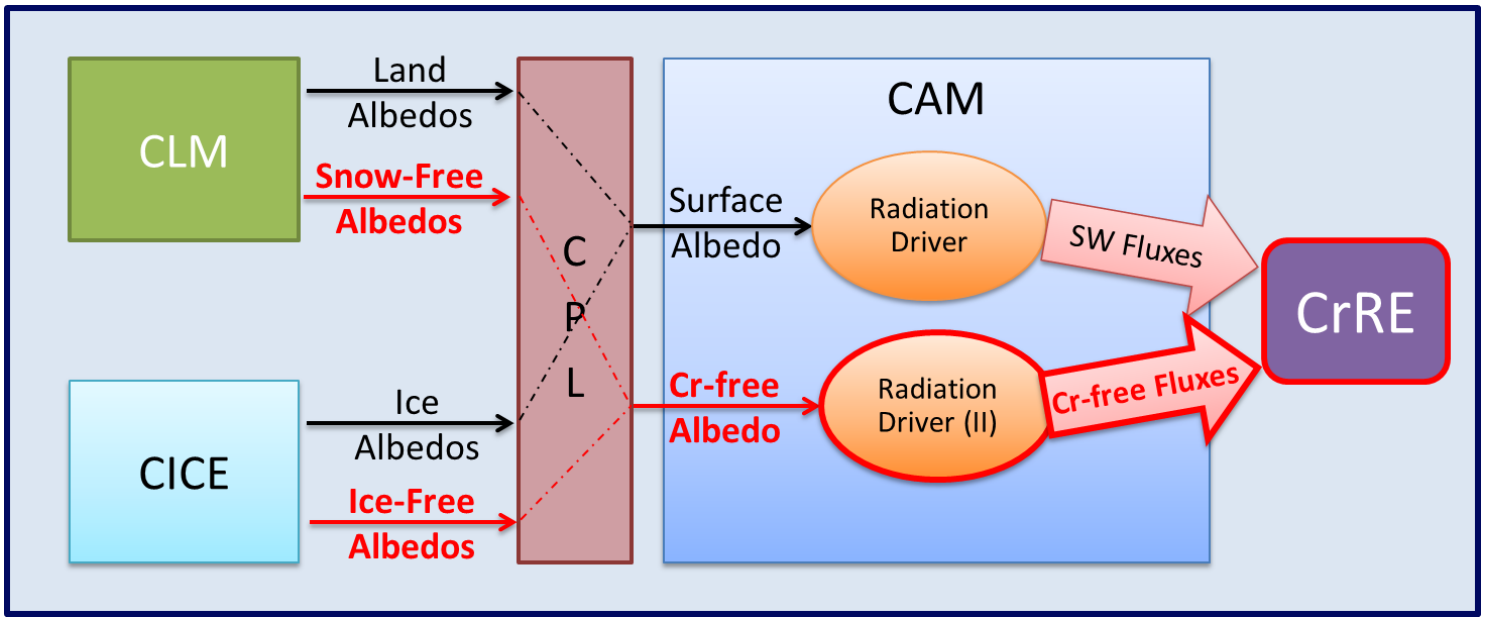

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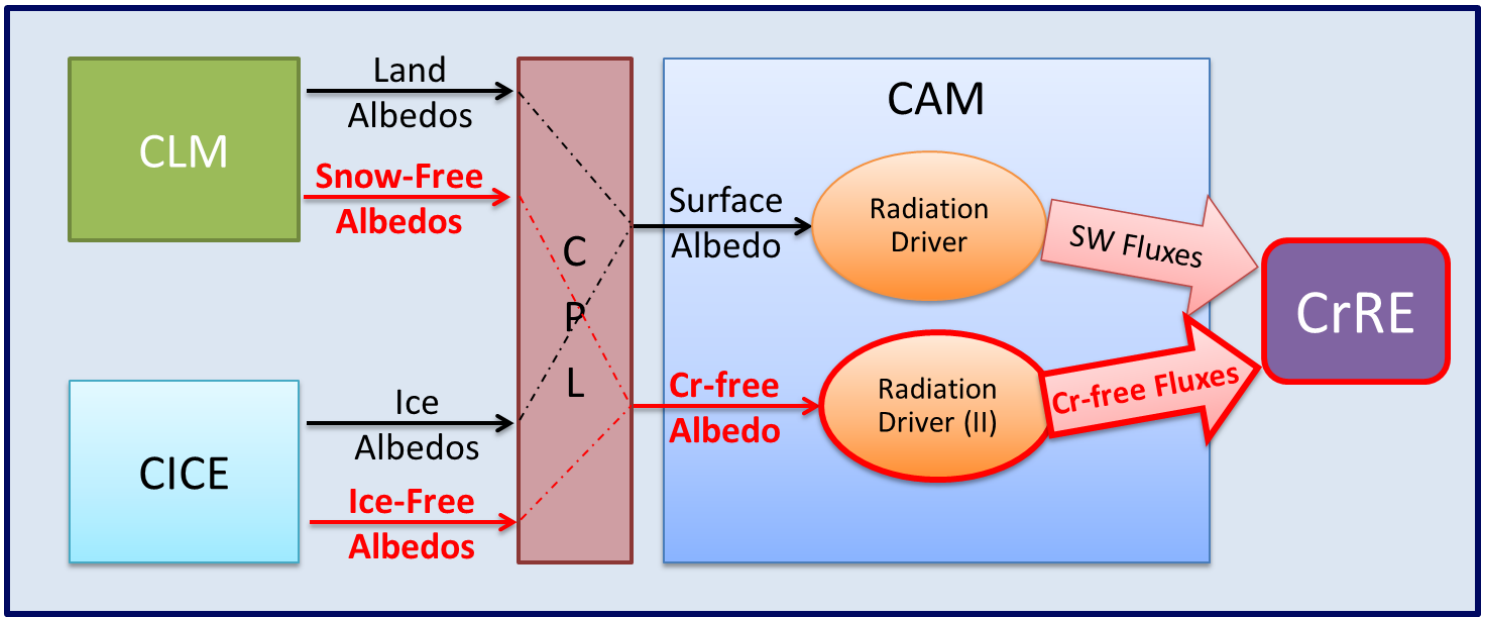

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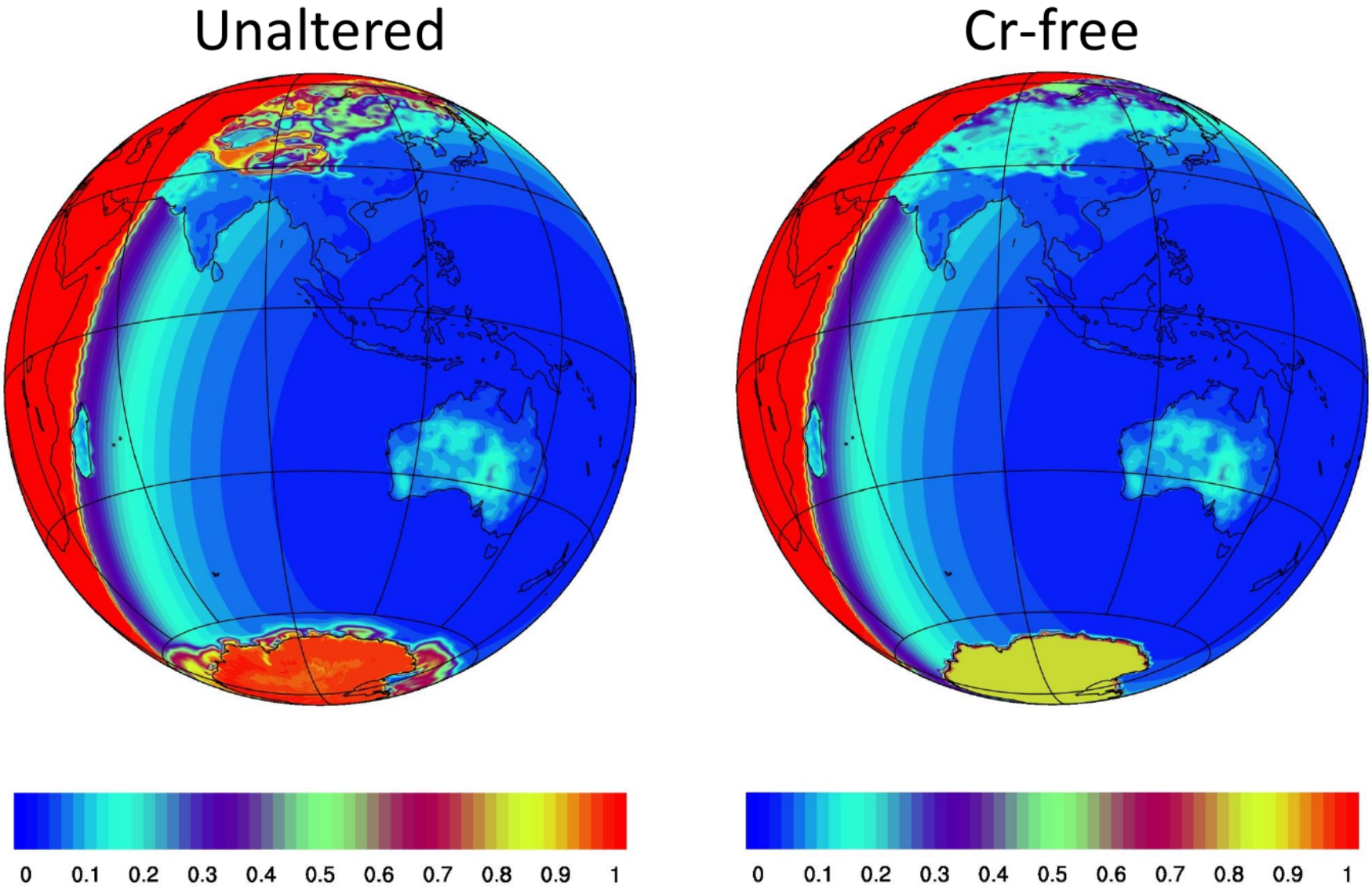
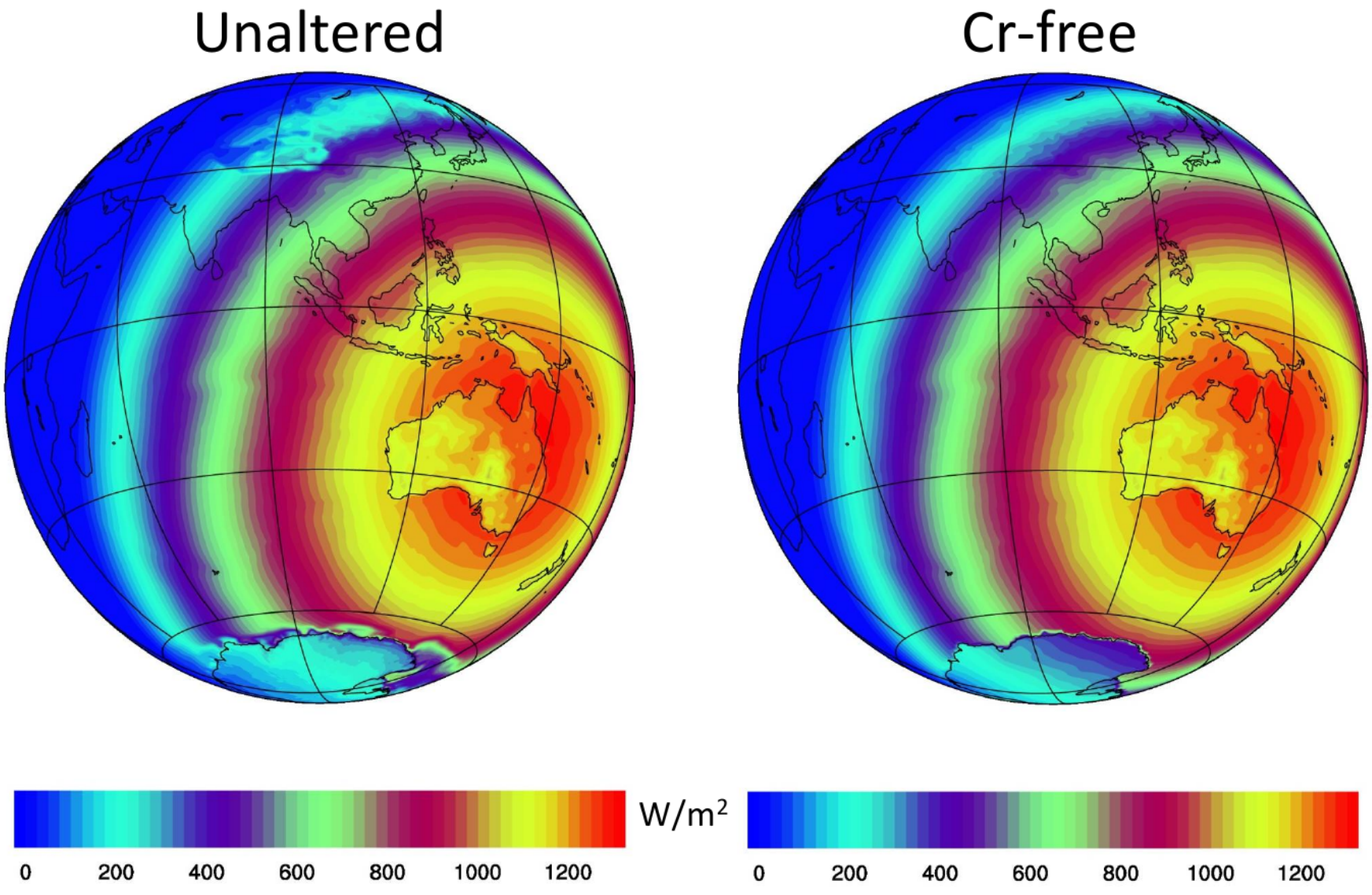
- Implemented in CESM1.1.1 and CESM1.0.3

Visible direct albedo (single timestep)

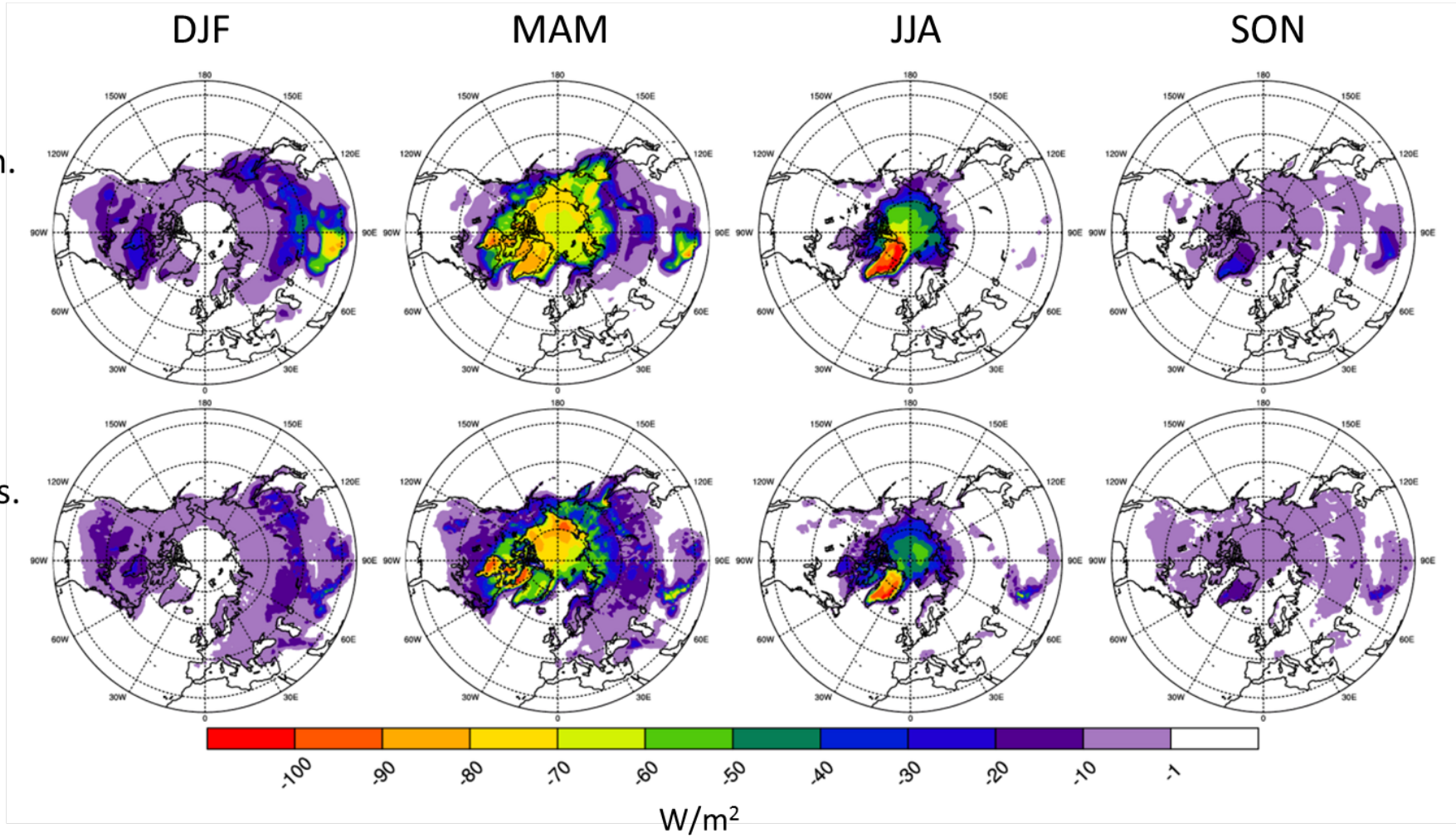


Clear-sky TOA flux (single timestep)

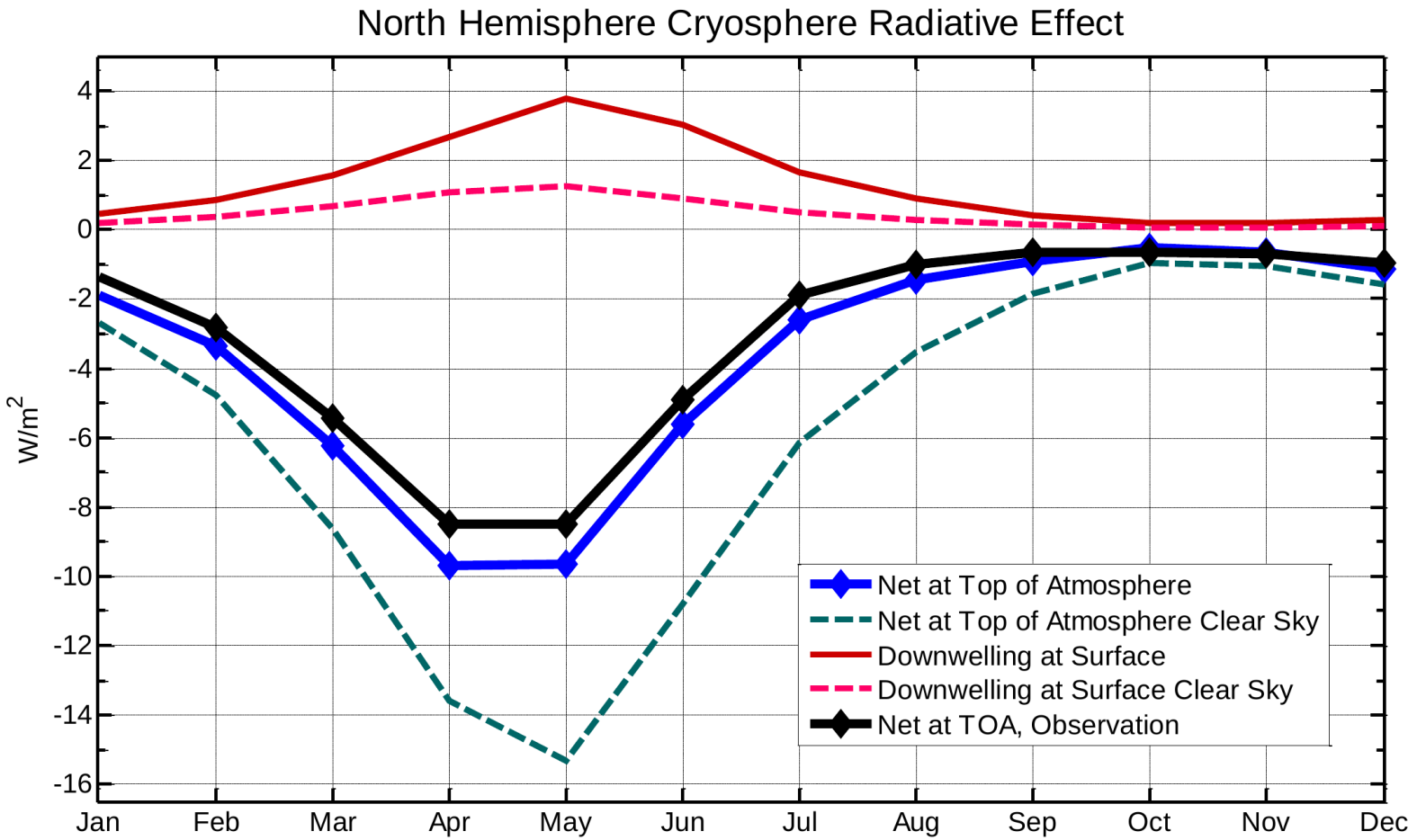


Initial model–observation evaluation

CESM 1.0.3, CAM4, E_2000 run



Initial model–observation evaluation: Seasonal cycle



- Favorable evaluation of NH-mean TOA CrRE (blue vs. black)

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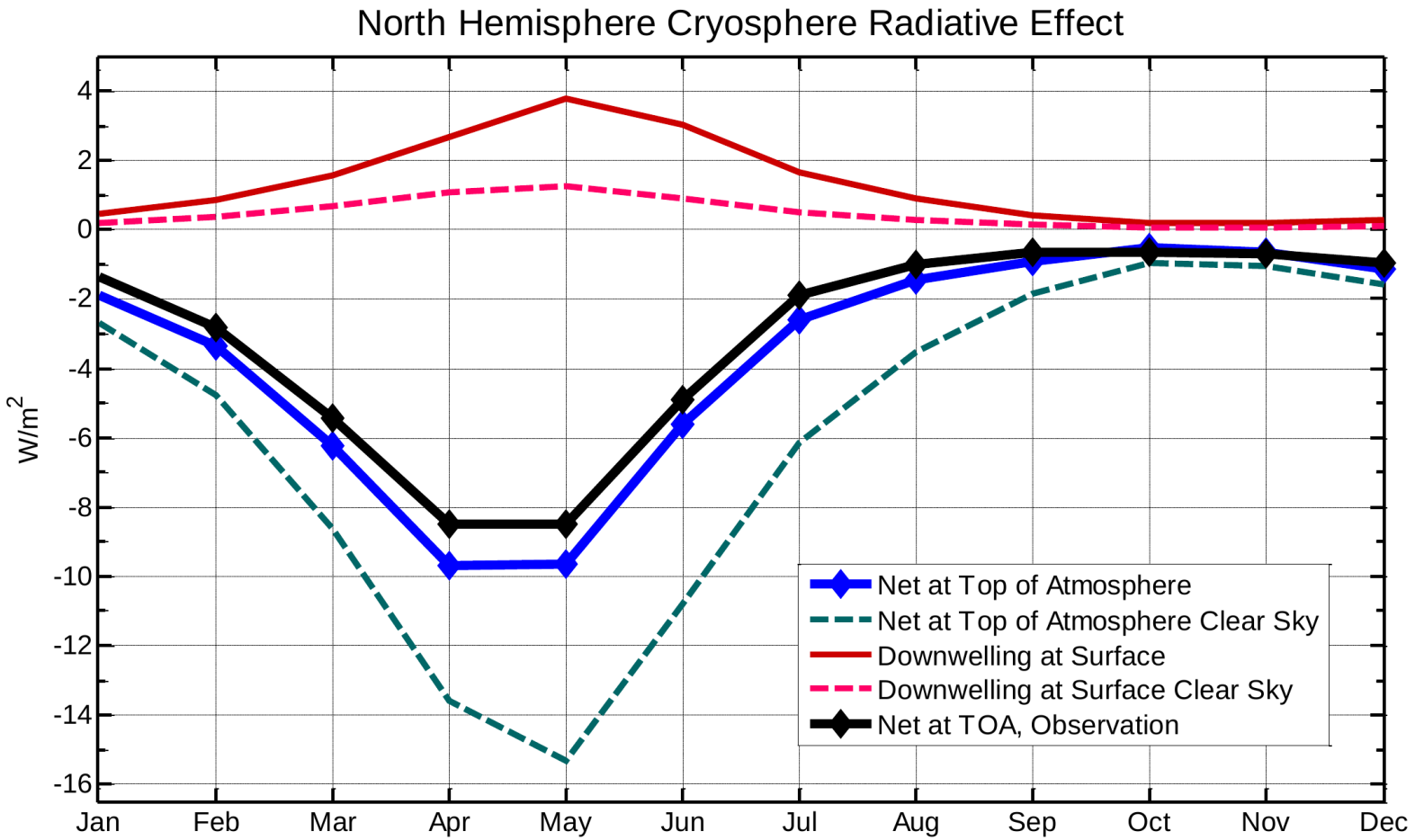
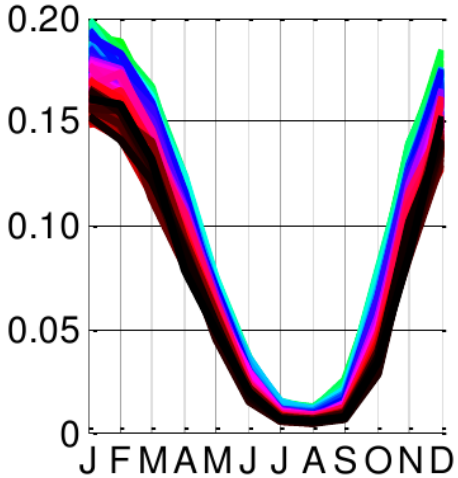
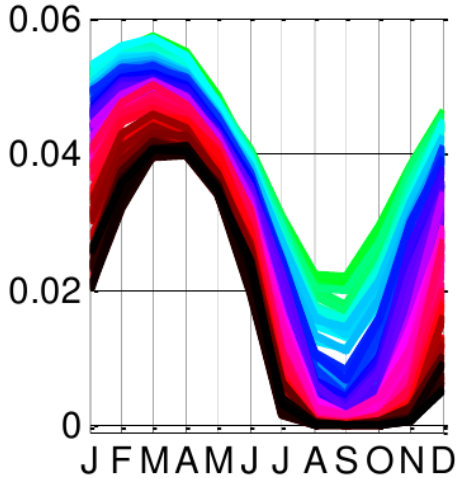


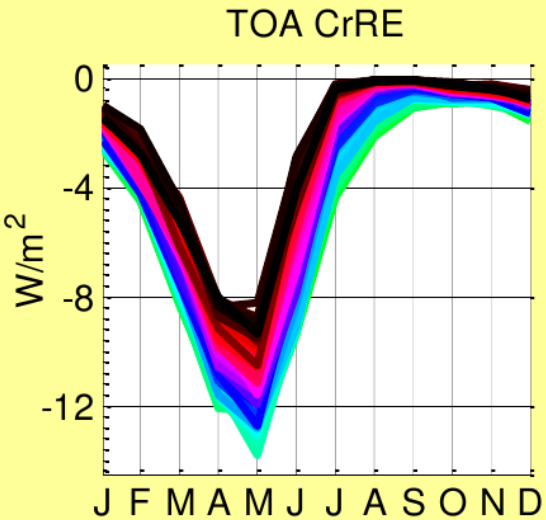
- Favorable evaluation of NH-mean TOA CrRE (blue vs. black)
- Multiple scattering between snow and clouds *increases* surface downwelling flux

21st century B_RCP8.5_CAM5_CN 1° run (via PCWG)

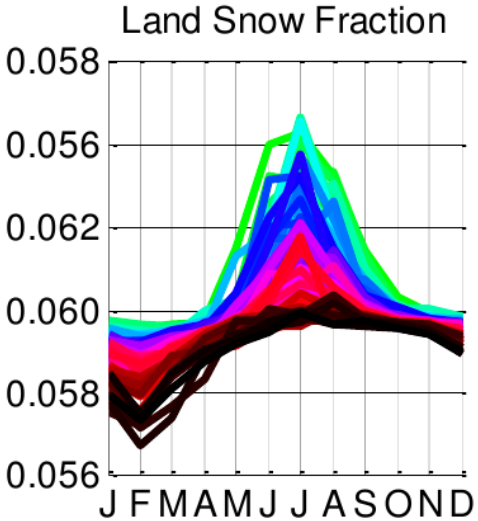
NH

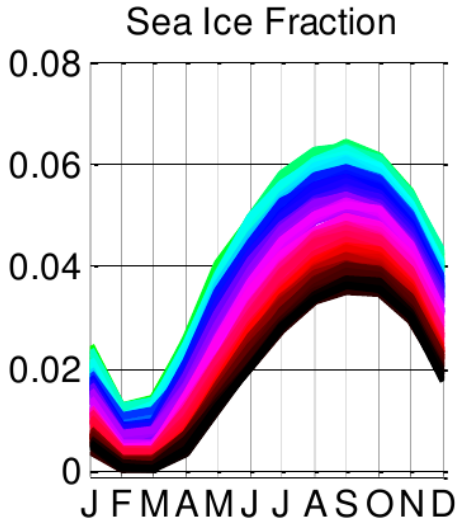


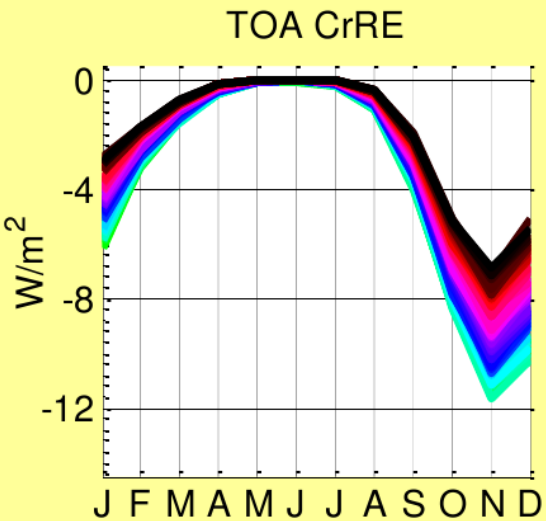




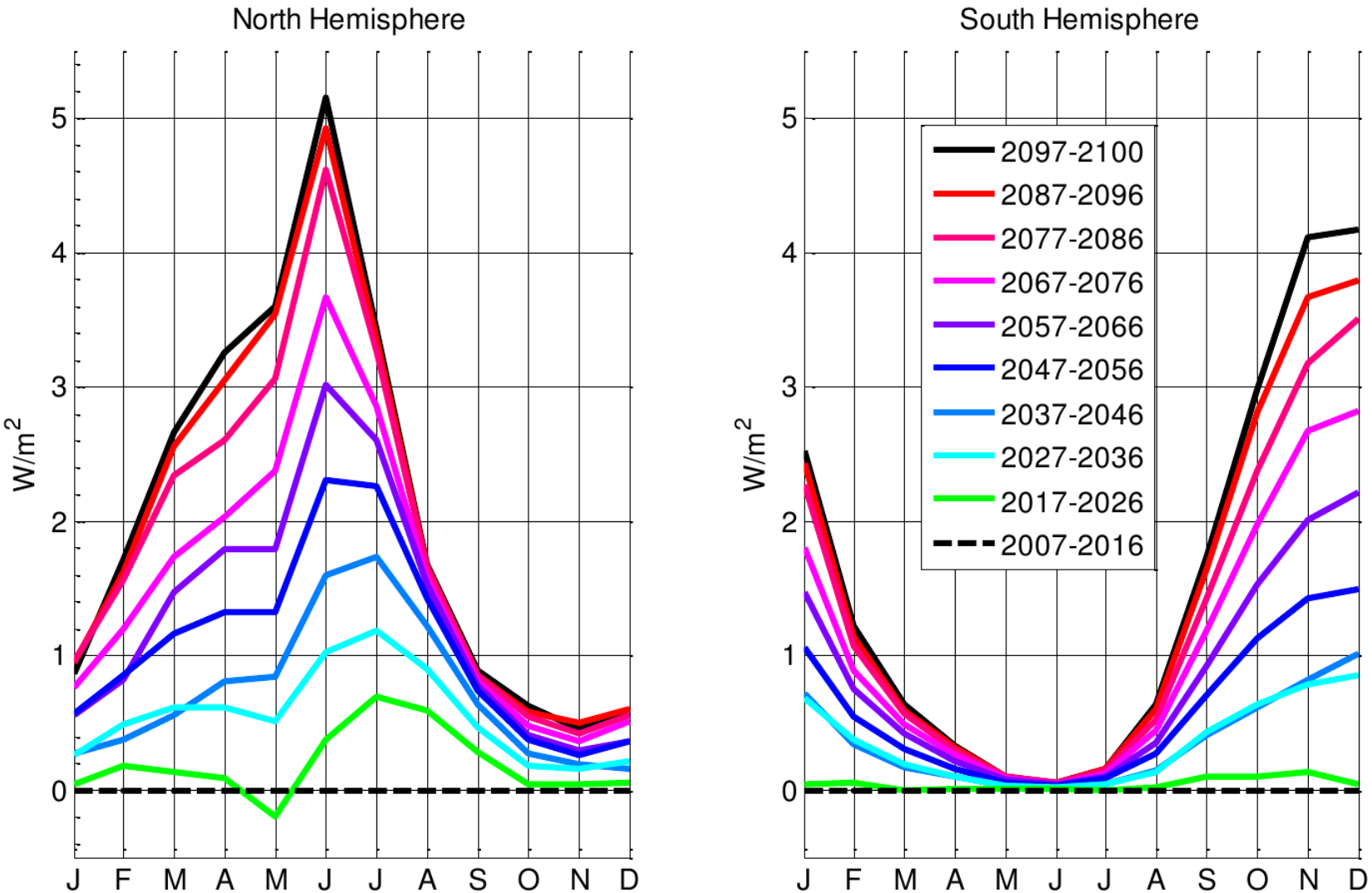
SH







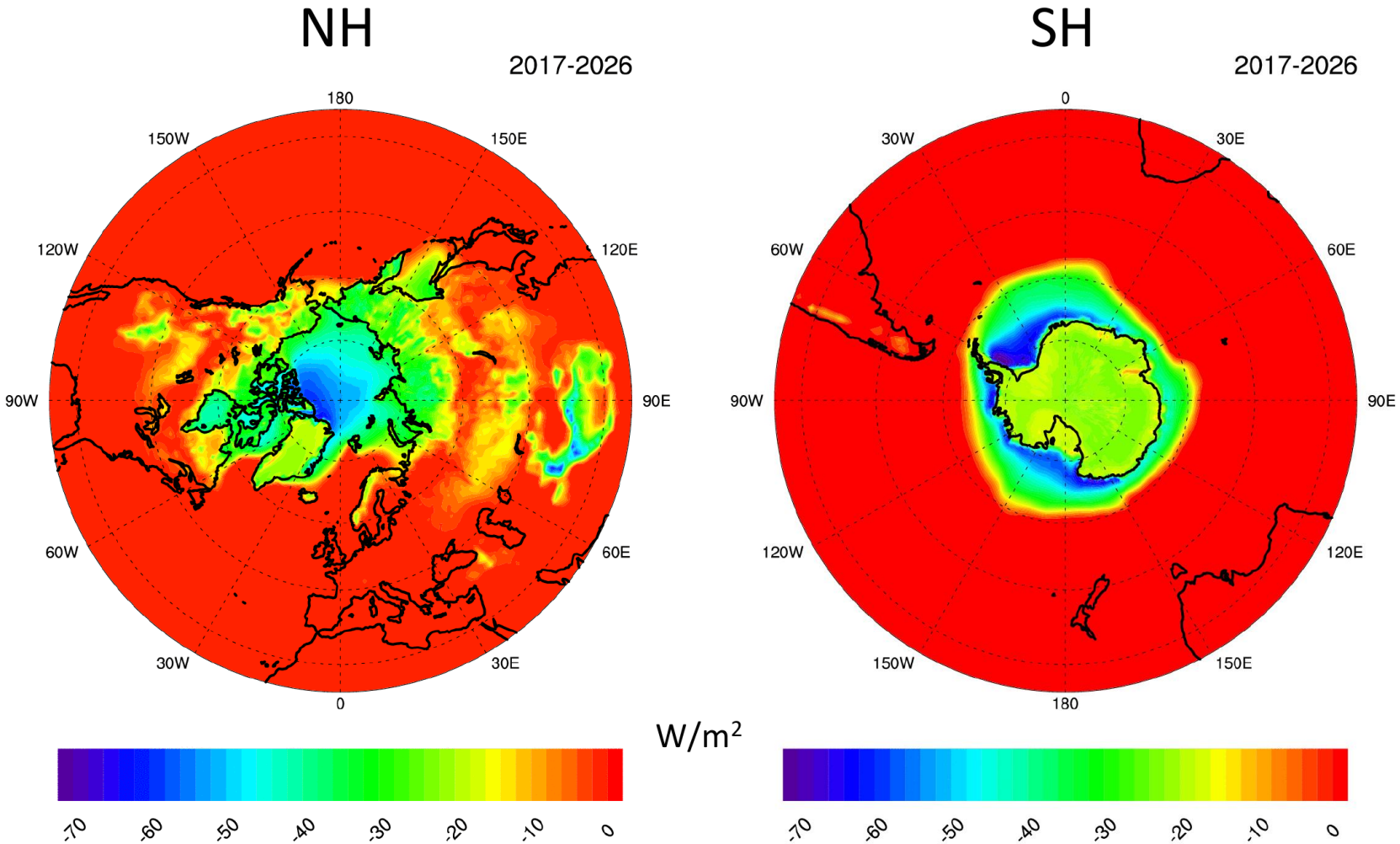
Decadal changes in CrRE relative to 2007–2016



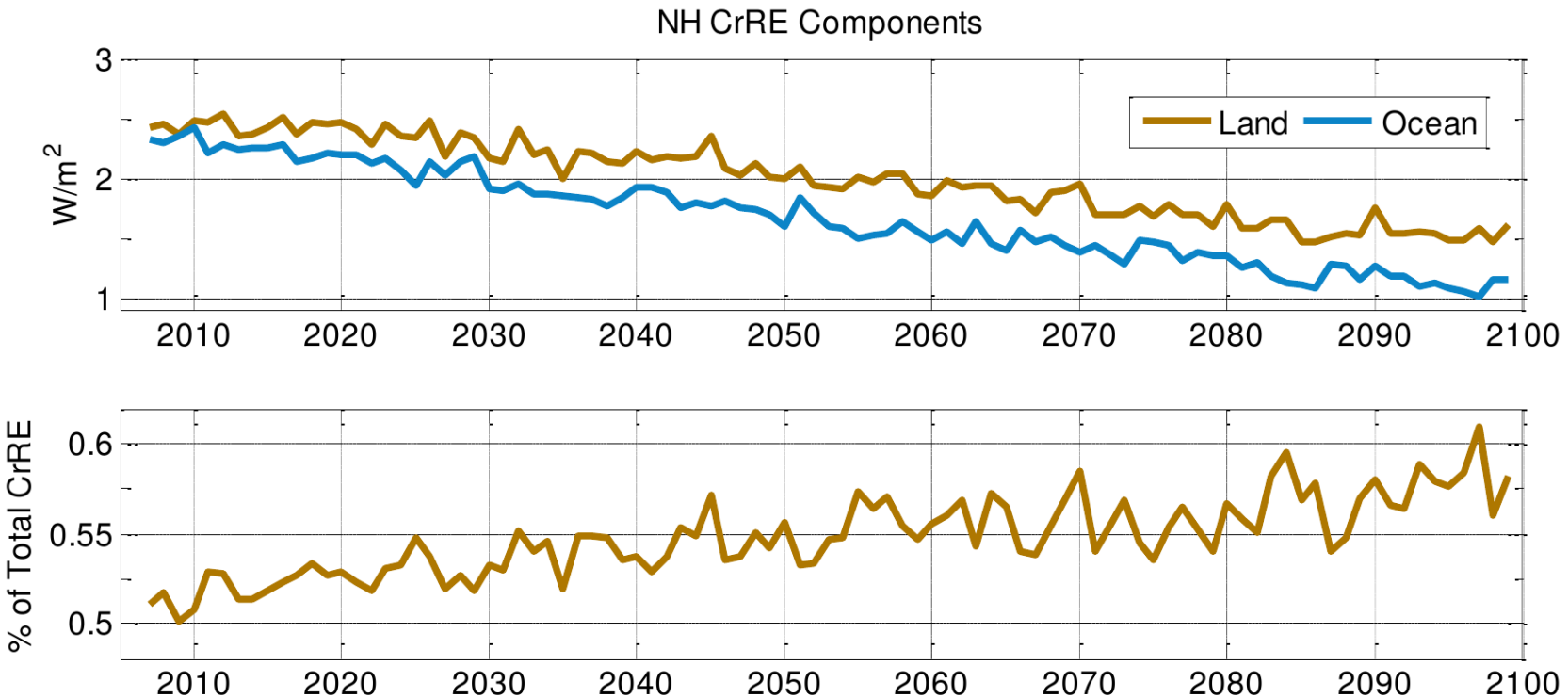
- Peak changes occur during summer solstice seasons

21st century evolution of CrRE

Animation:



Time evolution of N. Hemisphere CrRE



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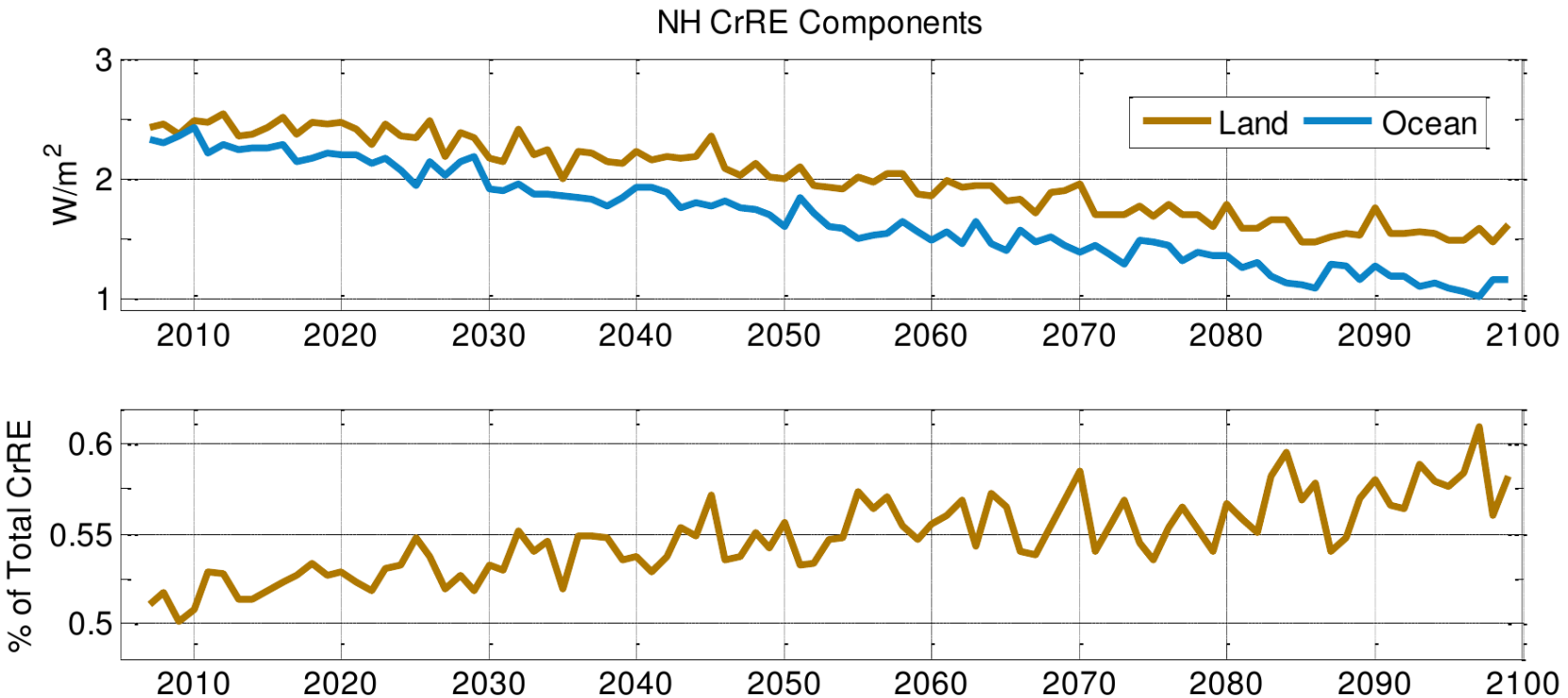

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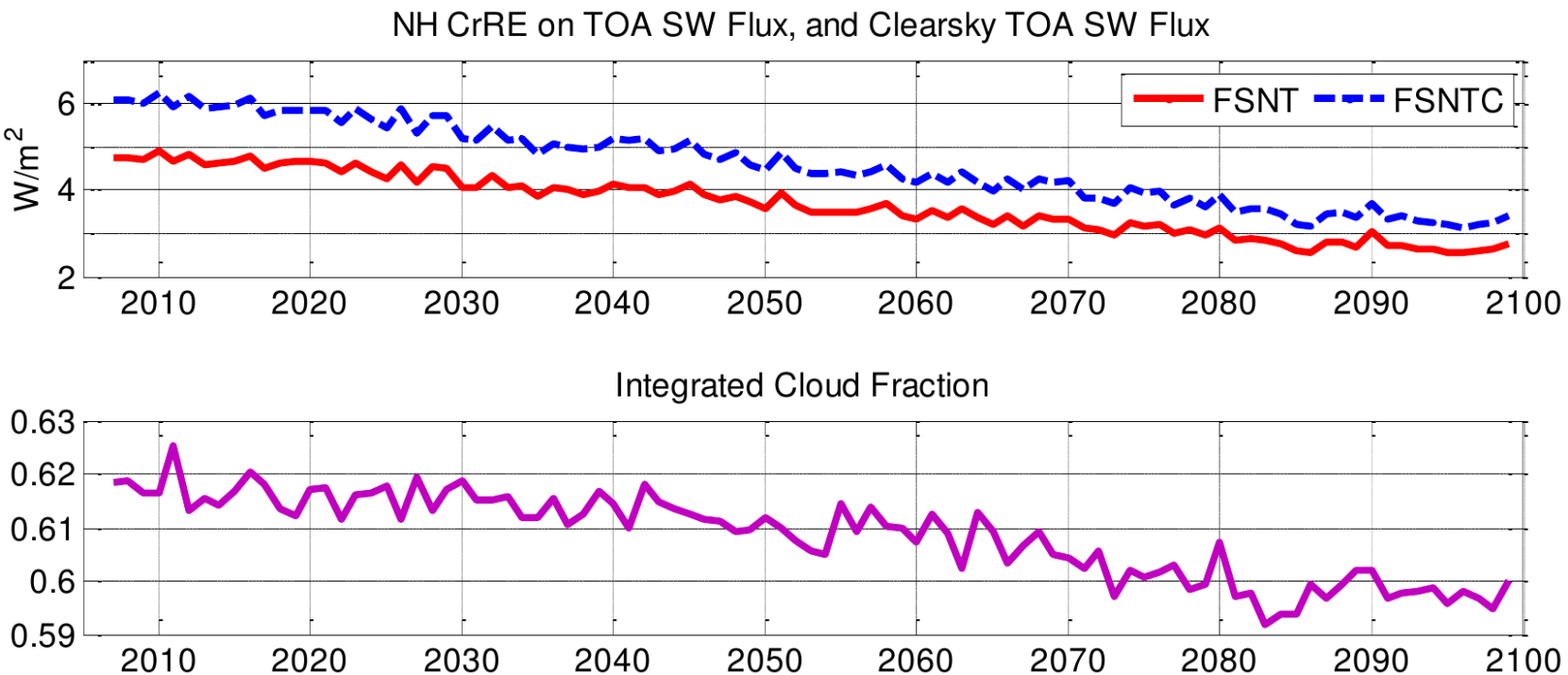
- Greater change in sea-ice than land CrRE

Changes in CrRE

Table: 2007–2099 Changes in CrRE [$\mathrm{W\,m^{-2}}$]

	Total	Land Snow	Sea-Ice
Global	1.8	0.5	1.3
Northern Hemisphere	2.0	0.8	1.2
Southern Hemisphere	1.6	0.1	1.5

Clouds also affect CrRE



Conclusions and future directions

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- Initial evaluation of seasonal cycle in present-day N. Hemisphere CrRE is favorable, though regional biases appear
- N. Hemisphere cryospheric influence at TOA declines by $\sim 2.0\,\mathrm{W\,m^{-2}}$ by 2100 in an RCP8.5 CESM1.1 simulation
- Next steps: Exploration of how CrRE is influenced in CLM by:
  - Snow cover fraction
  - Snow burial fraction
  - Snow metamorphism
  - Impurity-induced snow darkening
  - Surface downwelling insolation (cloudiness)
  - Precipitation