Cryosphere Radiative Forcing: An Indicator of Climate Feedback and Environmental Change

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Motivation and goal

- Presence of snow and sea-ice increases Earth’s reflectance
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- **Goal**: Provide a continuously updated, near real-time product of the global *cryosphere radiative effect*
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  1. Seasonal snow cover
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- **CrRE influences:**
  1. Albedo of the snow or ice
  2. Albedo of the underlying substrate (contrast induced by cryospheric presence)
  3. Insolation
  4. Cloud masking
Reduced snow albedo impact over mature forests
Snow-covered / snow-free albedo contrast

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- Mean contrast varies with definition of “snow-covered”
1979–2008 change in boreal CrRE

- Long-term record derived from AVHRR snow cover data, microwave sea-ice data

**Figure:** Flanner et al, 2011
1979–2008 change in boreal CrRE

- Long-term record derived from AVHRR snow cover data, microwave sea-ice data
- 30-year change in NH land CrRE:
  $+0.22 \ (0.11 - 0.41) \ \text{W m}^{-2}$
- 30-year change in sea-ice CrRE:
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- Combined global effect was \(\sim 30\%\) as large as the change in \(\text{CO}_2\) forcing over the same time period

**Figure:** Flanner et al, 2011
1979–2008 change in CrRE: Seasonal cycle

Peak sea-ice change occurs in June

Figure: 'X' indicates month of statistically-significant change ($p = 0.01$). Flanner et al. (2011)
1979–2008 change in CrRE: Seasonal cycle

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- Land-snow CrRE changes are significant during March–August

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- Land-snow CrRE changes are significant during March–August
- June peak in land snow change is sensitive to mountain snow cover estimates (Himalaya, Tien Shan)

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Recently, *Pistone et al.*, (2014, PNAS) derived a larger estimate (0.43 W m\(^{-2}\)) of the NH-averaged 1979–2011 change in CrRE due to Arctic sea-ice loss.

**Figure:** Pistone et al. (2014)
Work in progress

- Phase 1a: Develop 2001–2013 spatially-continuous land-based CrRE from MODIS, NISE, and model-generated radiative kernels
- Phase 1b: Adapt algorithm to accommodate VIIRS data
- Phase 2: Develop algorithm for sea-ice CrRE that accommodates frequent updates
Snow-free albedo

- 16-day snow-free albedo climatologies from *Moody et al.* (2007) serve as baseline (MODIS product MOD43B3).
Phase 1a: Algorithm

MODIS Q2 available?

- yes → Snow present?
  - yes → Snow present in NISE?
    - yes → 16-day snow-covered albedo climatology?
      - yes → \[ \Delta \alpha = \alpha(t) - \alpha_{\text{snow free}}(t) \]
      - no → \[ \Delta \alpha = 0 \]
    - no → \[ \Delta \alpha = \alpha_{\text{snow covered}}(t) - \alpha_{\text{snow free}}(t) \]
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CrRE(all-sky) = \[ \Delta \alpha \cdot \partial F_{\text{AS}} / \partial \alpha \]

CrRE(clear) = \[ \Delta \alpha \cdot \partial F_{\text{CS}} / \partial \alpha \]
Example: Cryosphere-induced Change in Albedo

Cryospheric change in albedo, January 1, 2001 (+16)
Example: Method used to determine $\Delta \alpha$

Data Flag, January 1 - January 16, 2013
Example: All-sky and clear-sky CrRE

Global-mean: $-4.3 \text{ W m}^{-2}$

$-4.7 \text{ W m}^{-2}$
Example: Animated Timeseries of All-sky CrRE
Example: Global annual-mean timeseries
Example: Continental seasonal timeseries

N. Hemisphere June (p=0.0055)

Eurasia April–June (p=0.0083)
Global annual-mean land-based cryosphere radiative effect (CrRE) is \( \sim -2.6\, \text{W m}^{-2} \)
Conclusions and next steps

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- Trends in Eurasian spring CrRE are evident, while North American timeseries are more noisy (preliminary)
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- Next steps: Extend algorithm to VIIRS data, enabling continual updating of CrRE product into near future.
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Produce spatially-averaged timeseries for key regions of interest.
Application of observational CrRE

Evaluation of CrRE in the CESM [Perket et al, 2014]