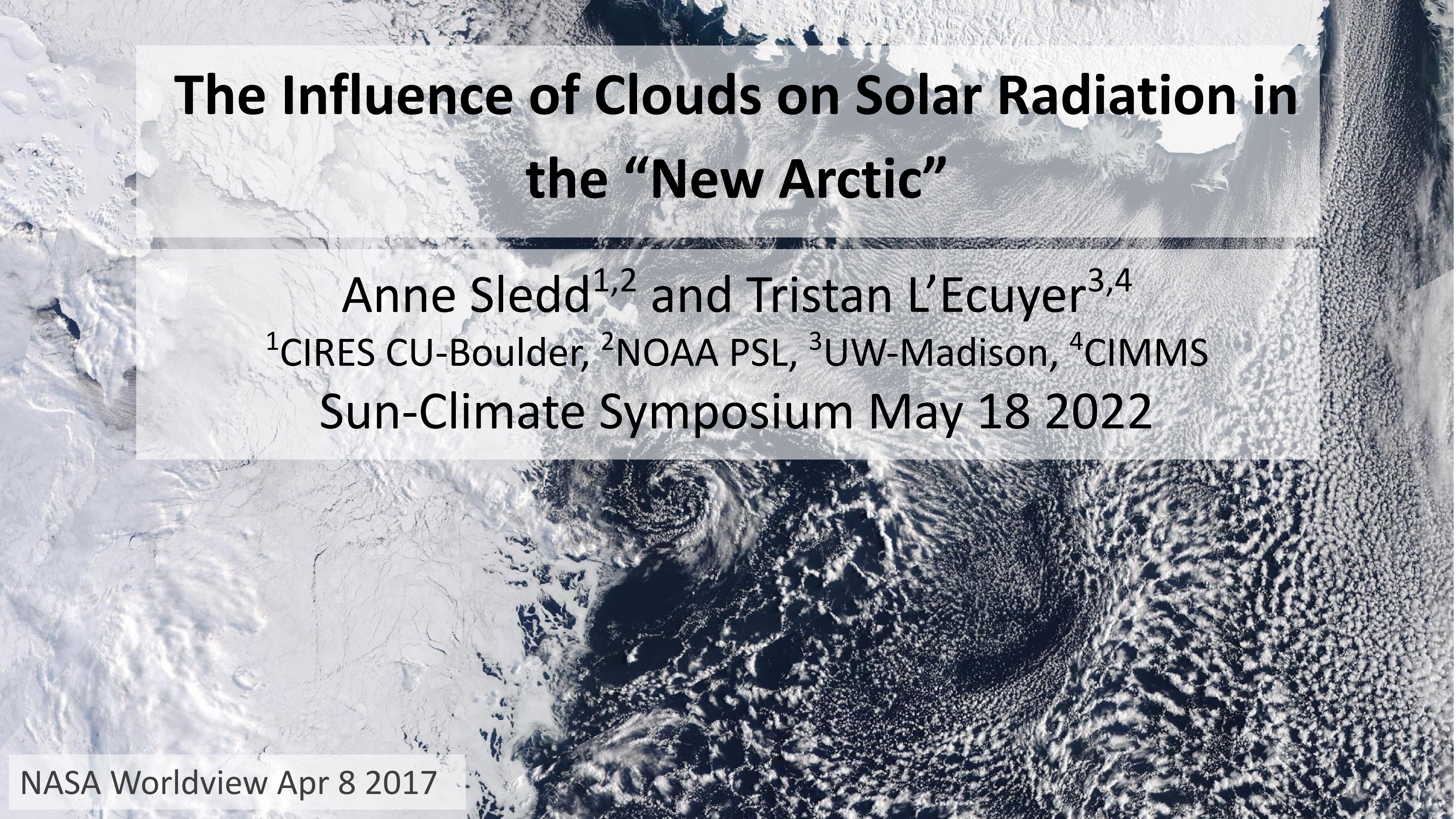
The Influence of Clouds on Solar Radiation in the "New Arctic"

Anne Sledd[1,2] and Tristan L'Ecuyer[3,4]

[1]CIRES CU-Boulder, [2]NOAA PSL, [3]UW-Madison, [4]CIMMS

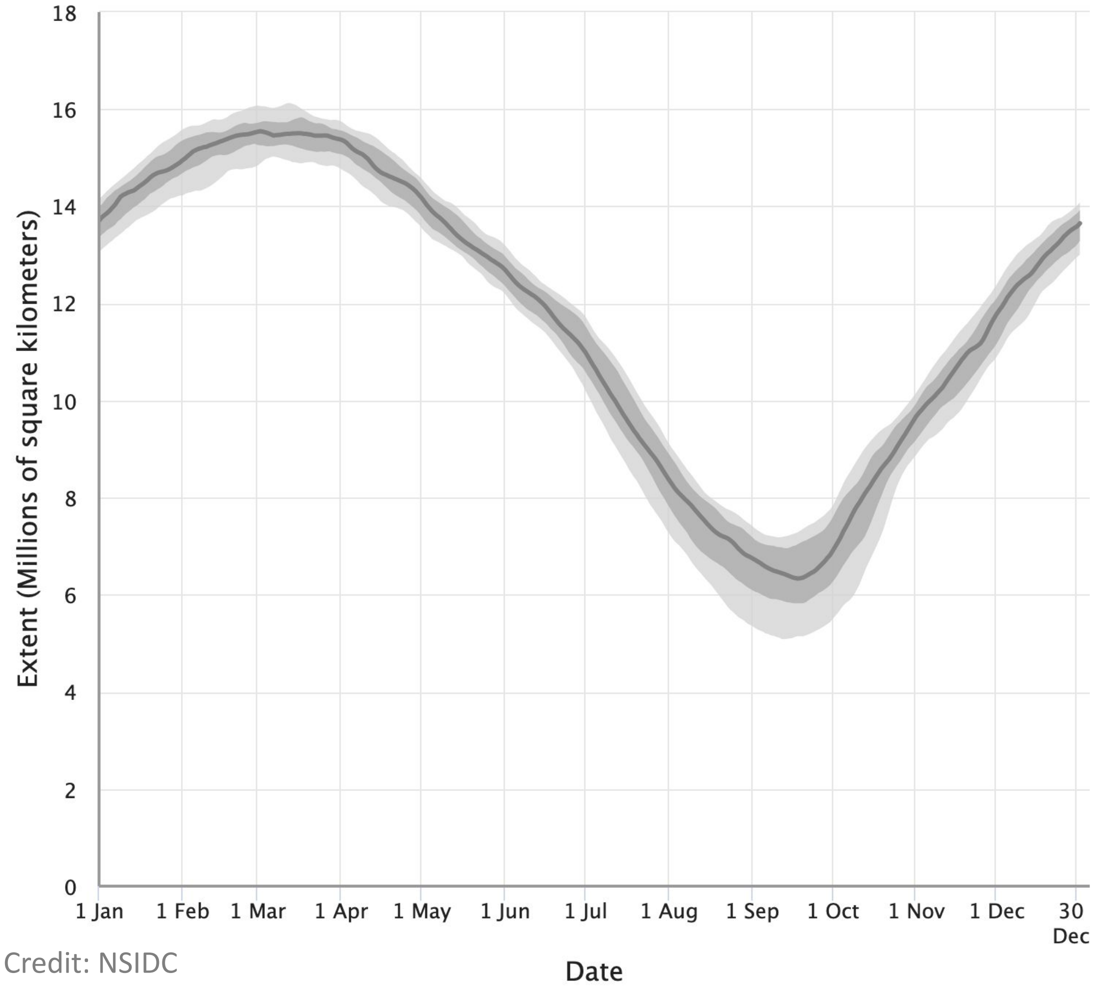
Sun-Climate Symposium May 18 2022



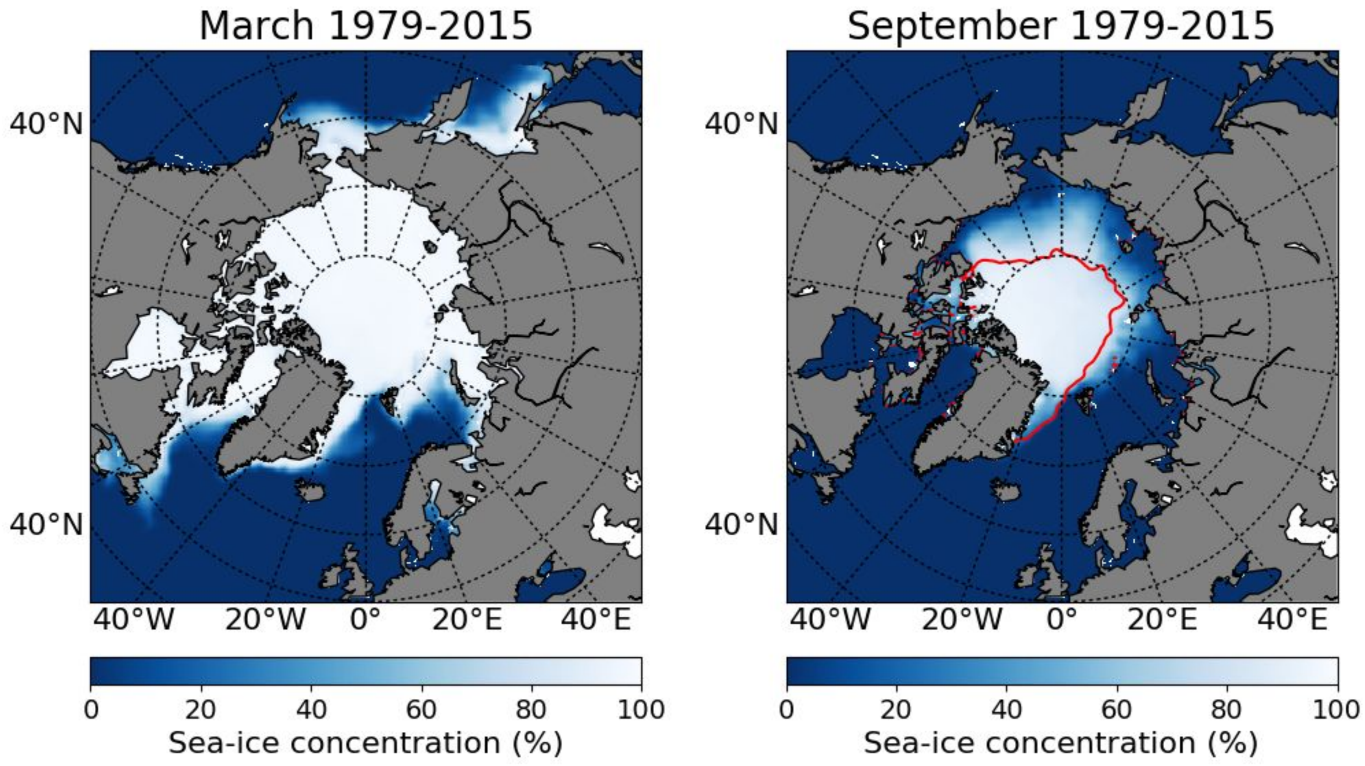
NASA Worldview Apr 8 2017

The Arctic has strong seasonal cycles

Median Arctic Sea Ice Extent 1981-2010
(Area of ocean with at least 15% sea ice)



Credit: NSIDC



Credit: OSI SAF

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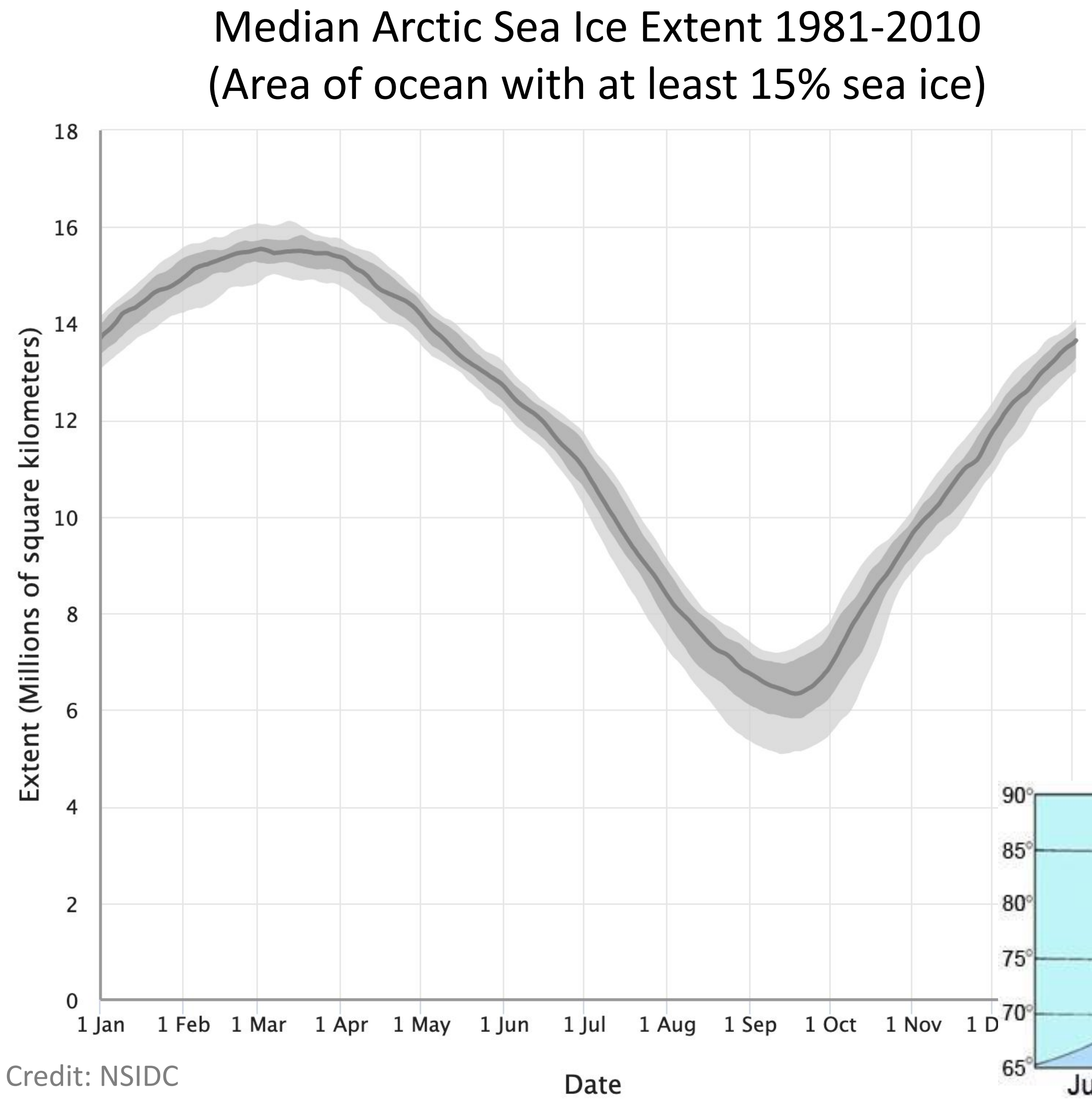
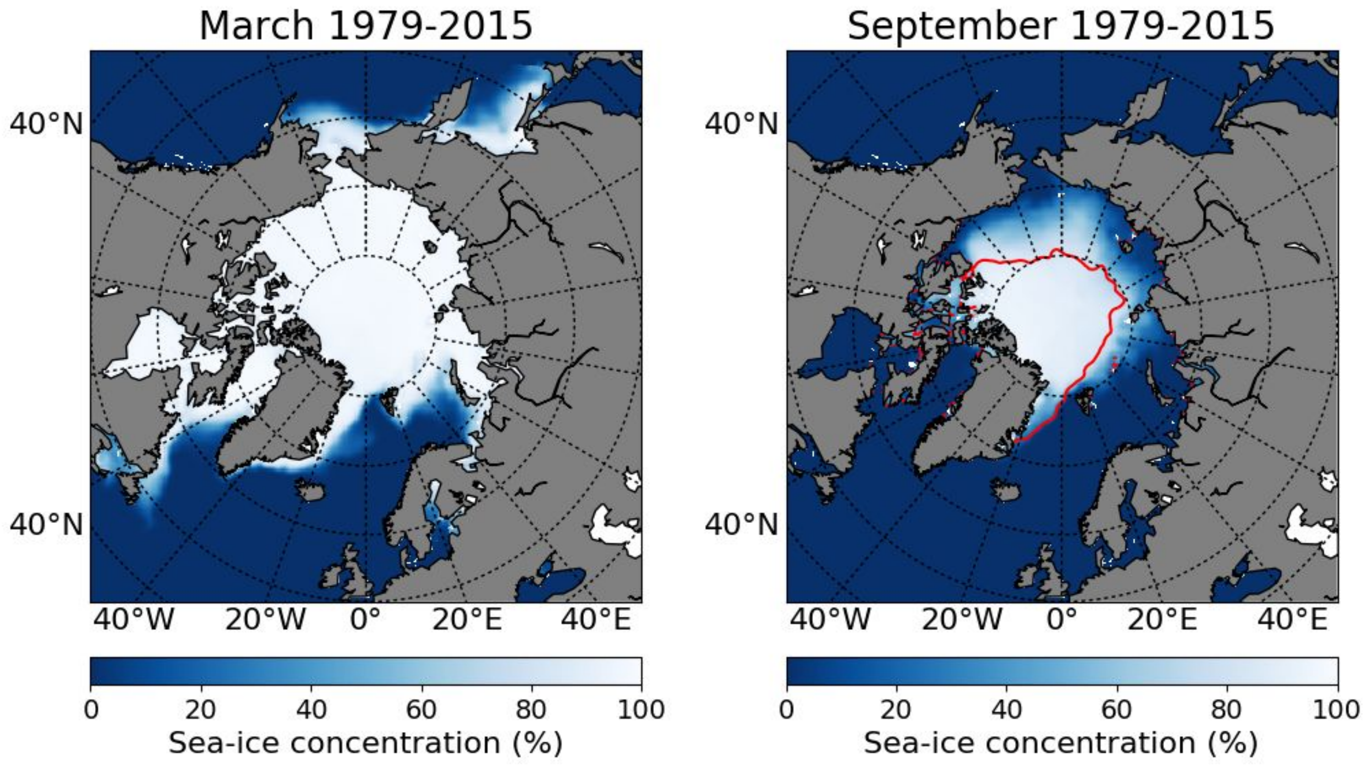
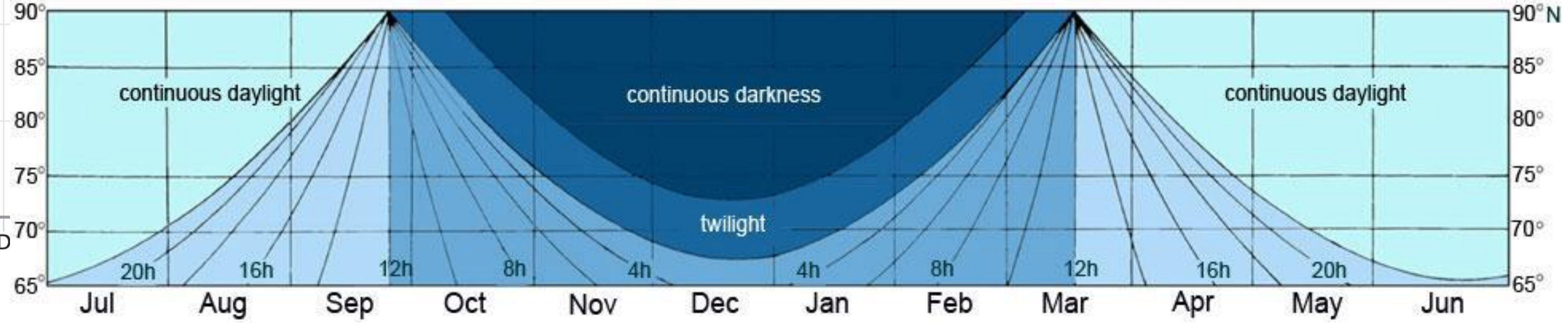
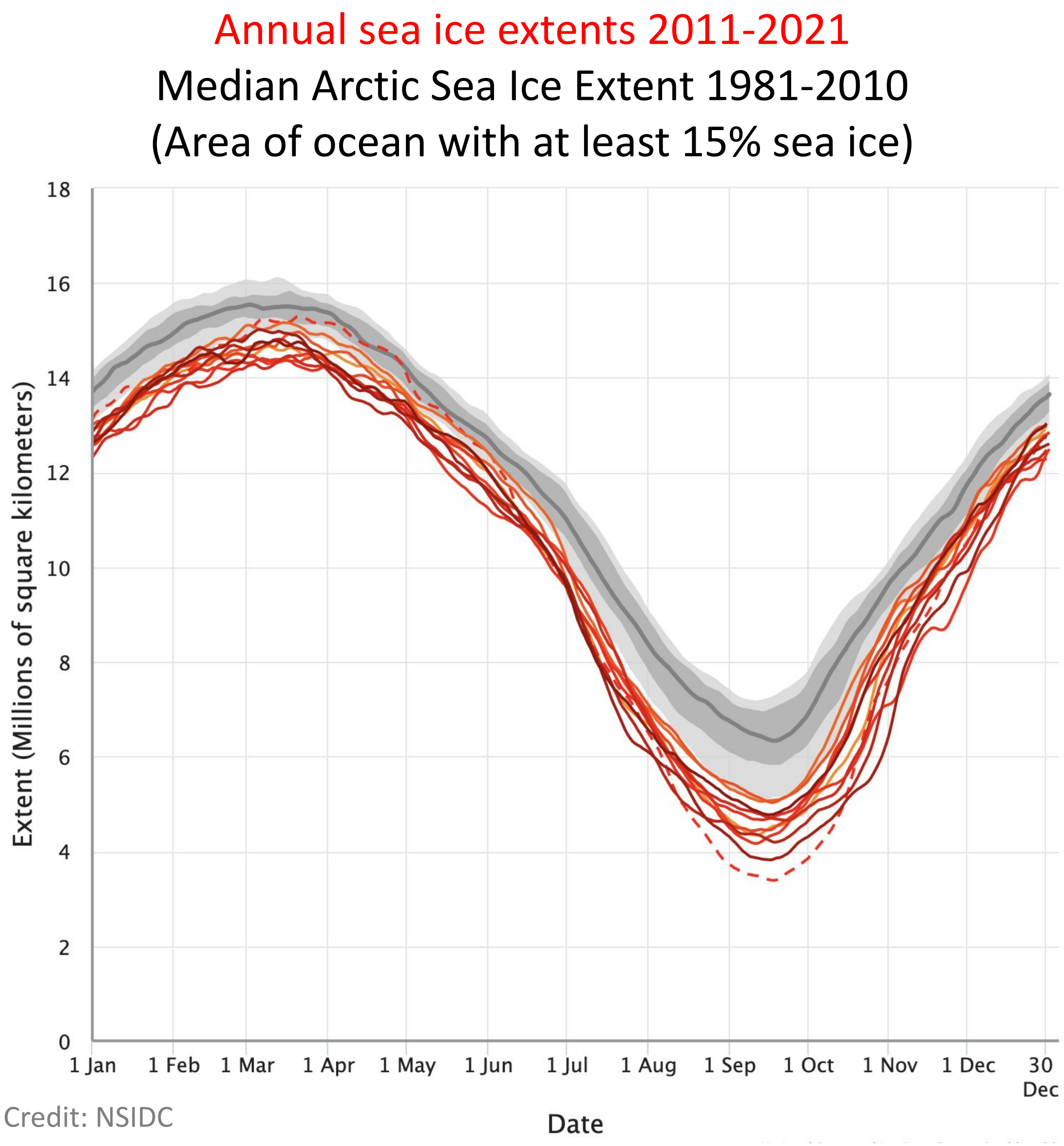






Credit: NSIDC

The Arctic is undergoing dramatic changes



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Annual sea ice extents 2011-2021

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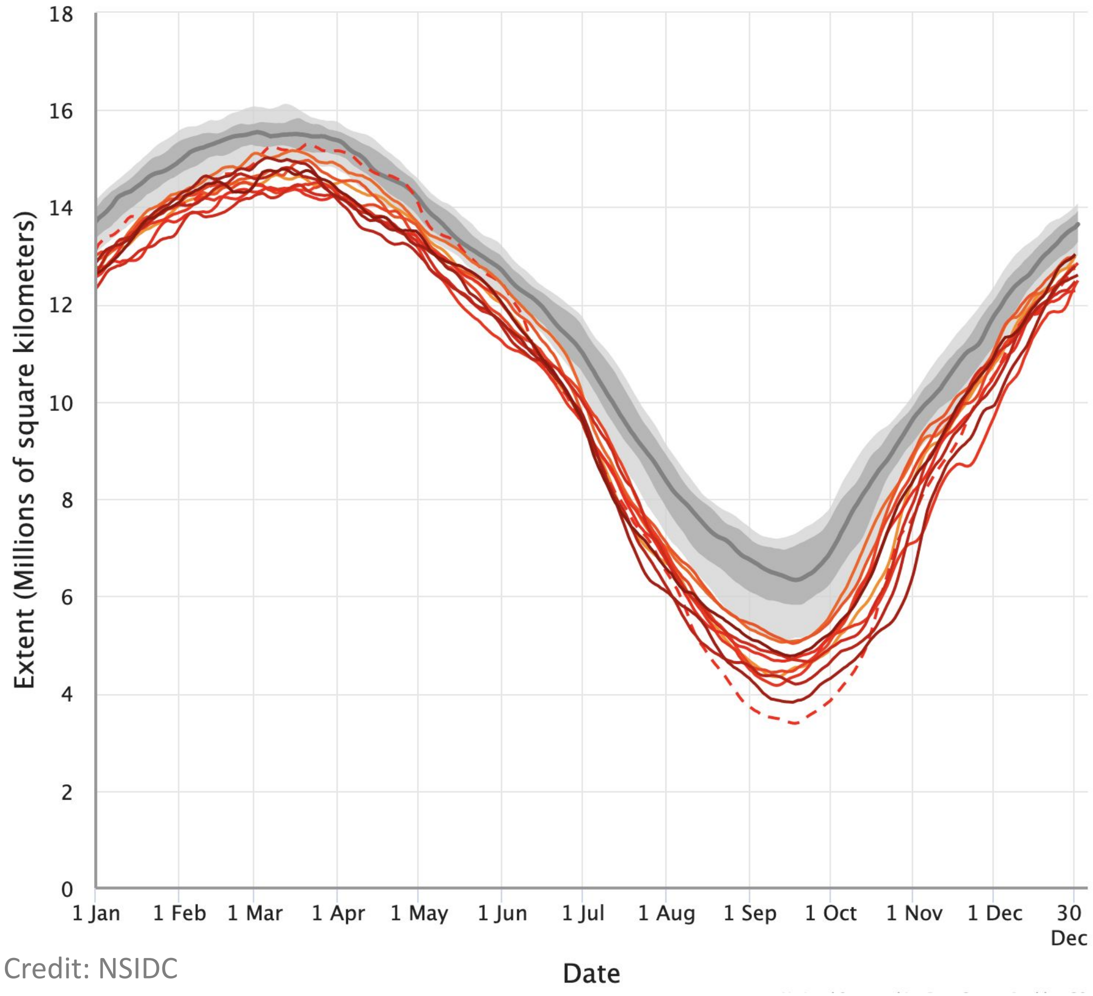

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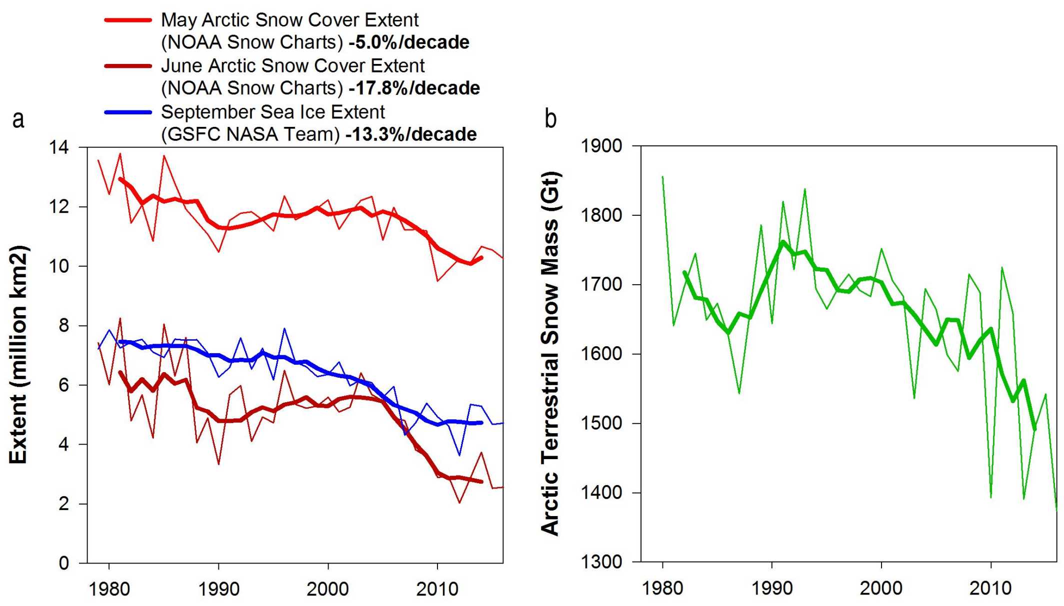

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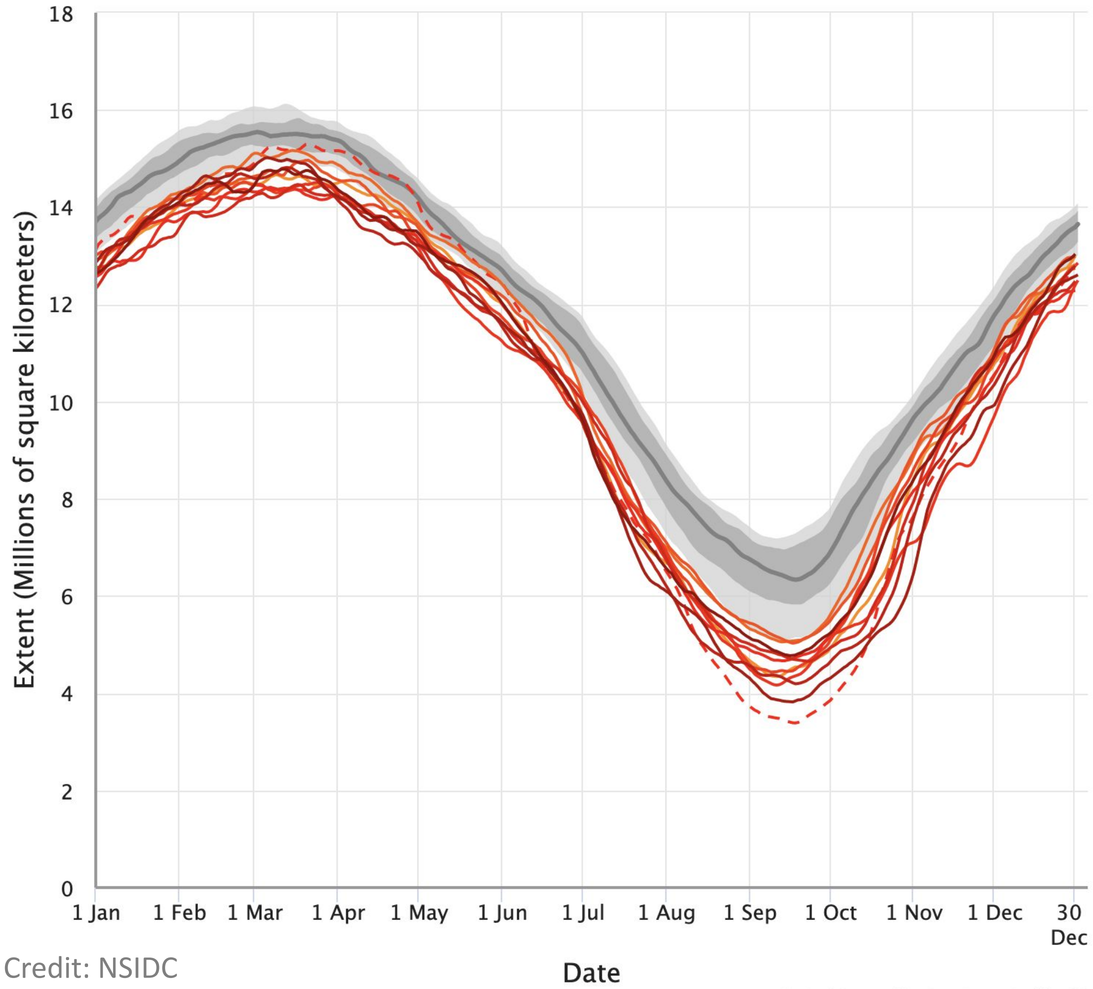

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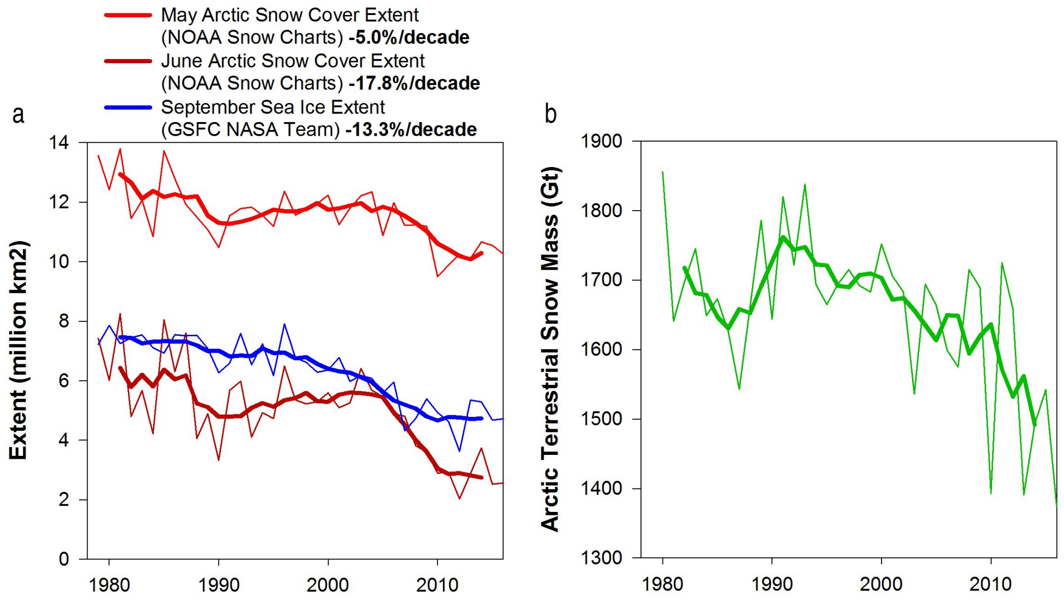
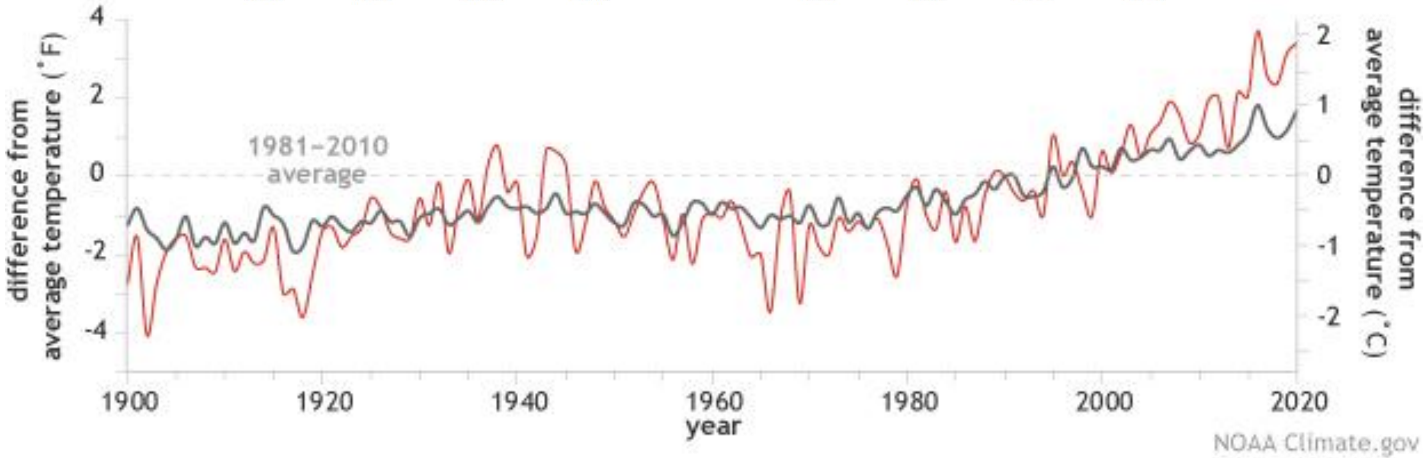
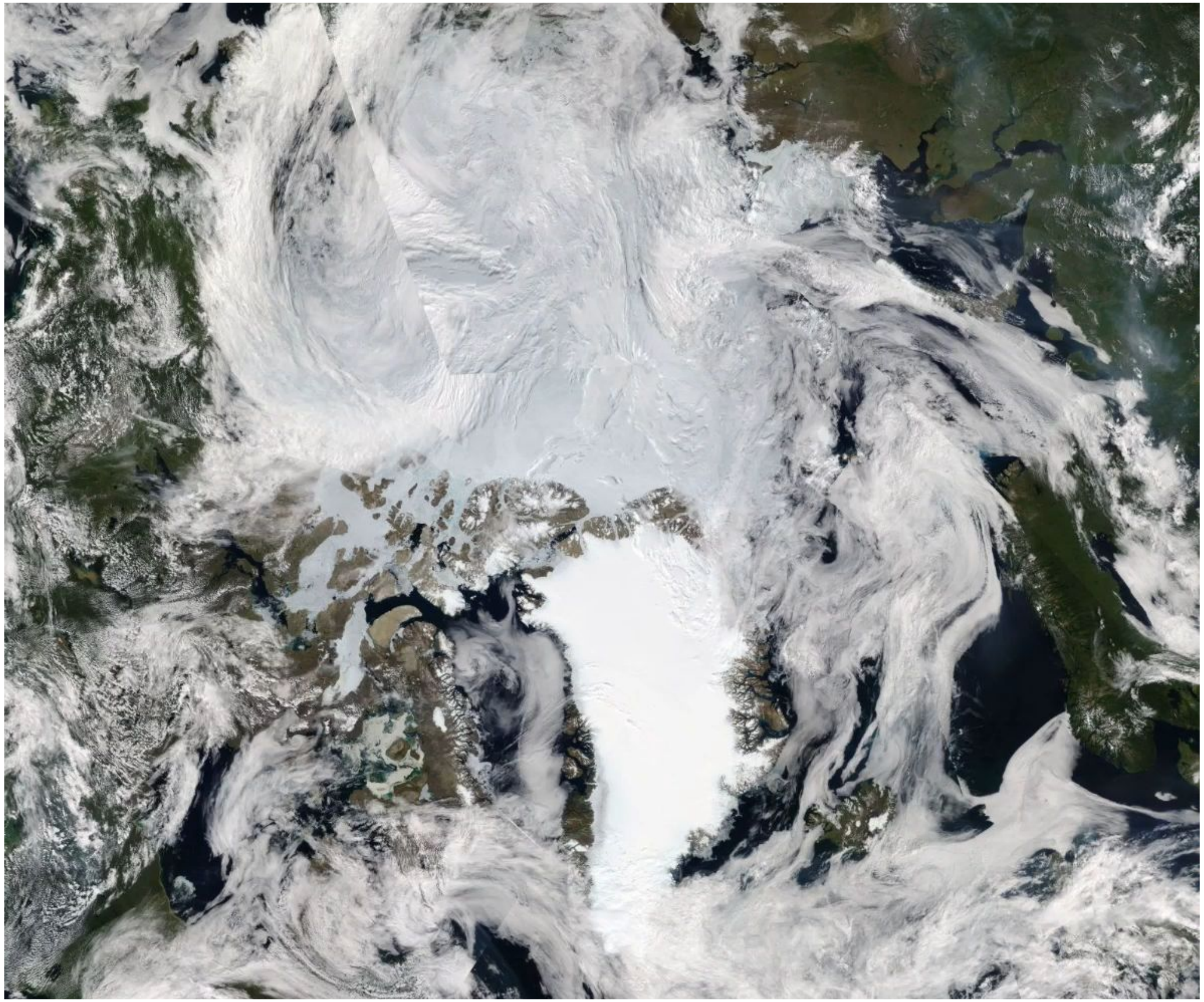




NOAA Climate.gov
Data: ARC 2020

The sea ice albedo feedback is an important driver of Arctic change

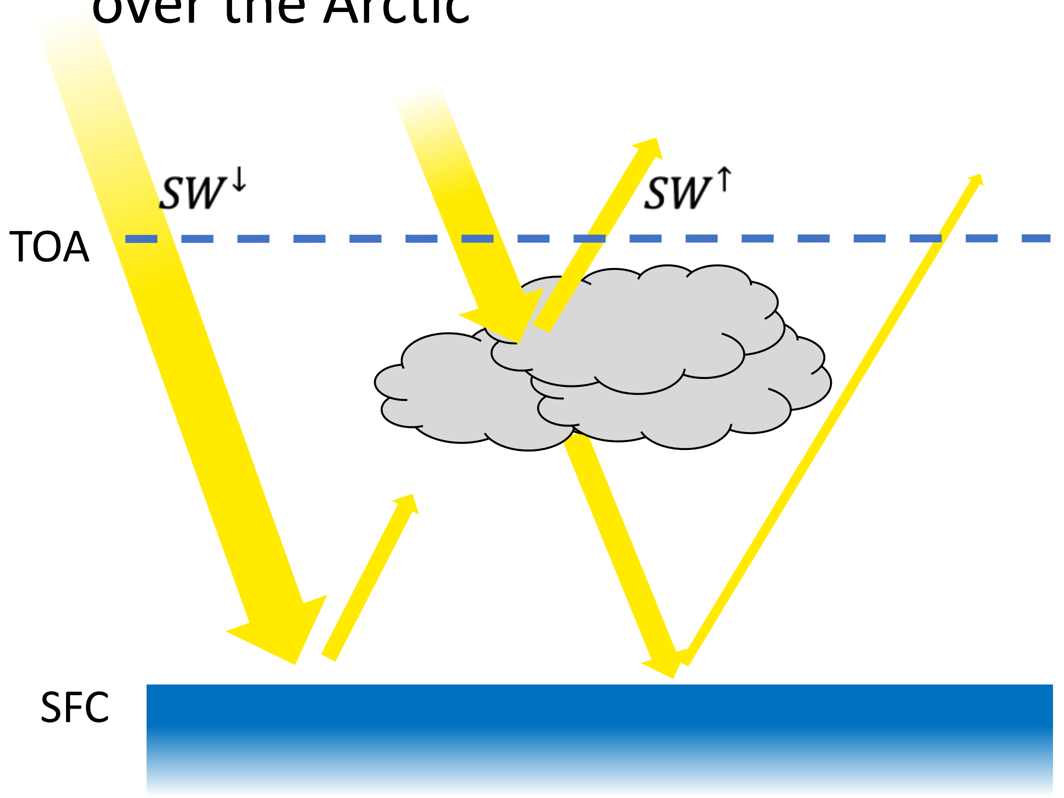
What do we see from space?



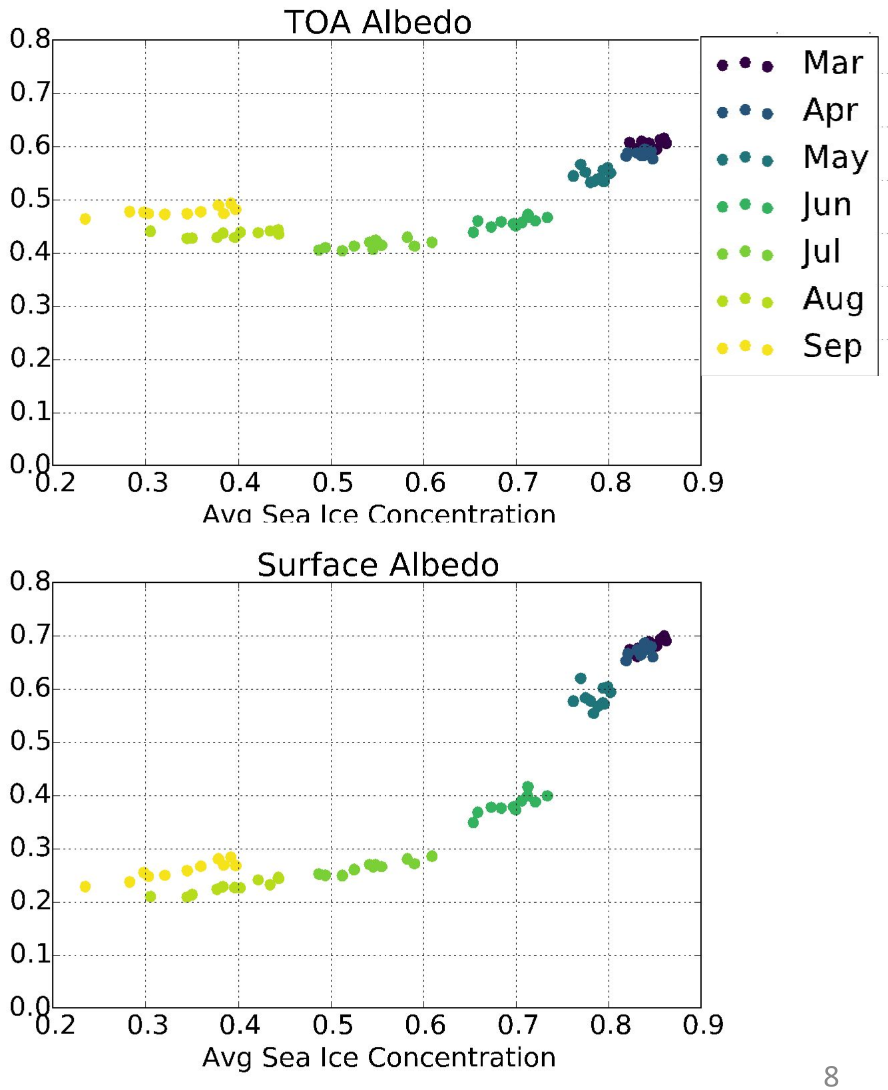
NASA Worldview (corrected reflectance): July-Sept 2013

Clouds reduce top-of-atmosphere (TOA) albedo variability compared to the surface albedo

- CERES-EBAF v2.8 2000-2012 monthly averages over the Arctic



$$albedo = \frac{reflected\ SW}{incident\ SW}$$



Sledd and L'Ecuyer 2019

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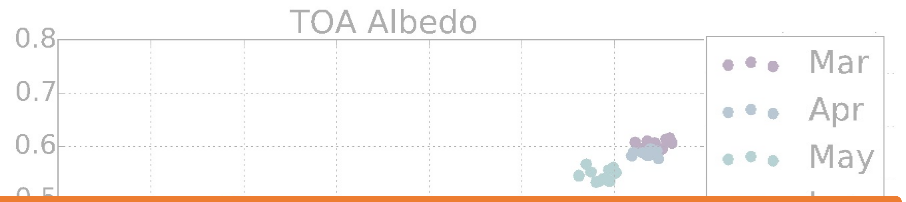
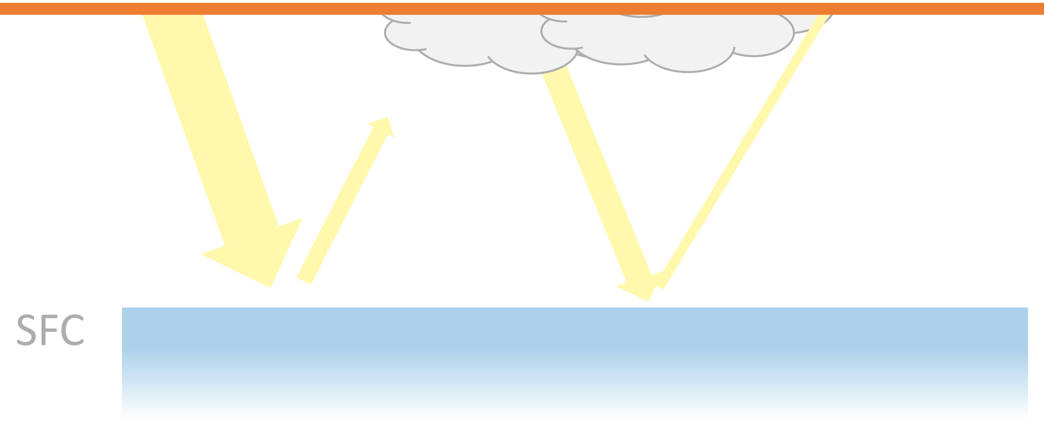
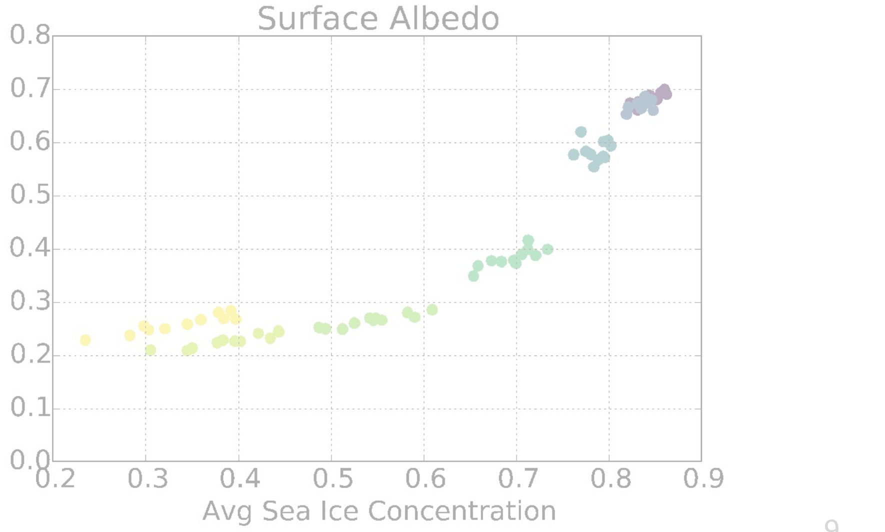


How do clouds impact SW absorption and how it's changing? Can we detect trends in how much solar radiation the Arctic absorbs at the TOA since 2000?





$$albedo = \frac{reflected\ SW}{incident\ SW}$$

Sledd and L'Ecuyer 2019

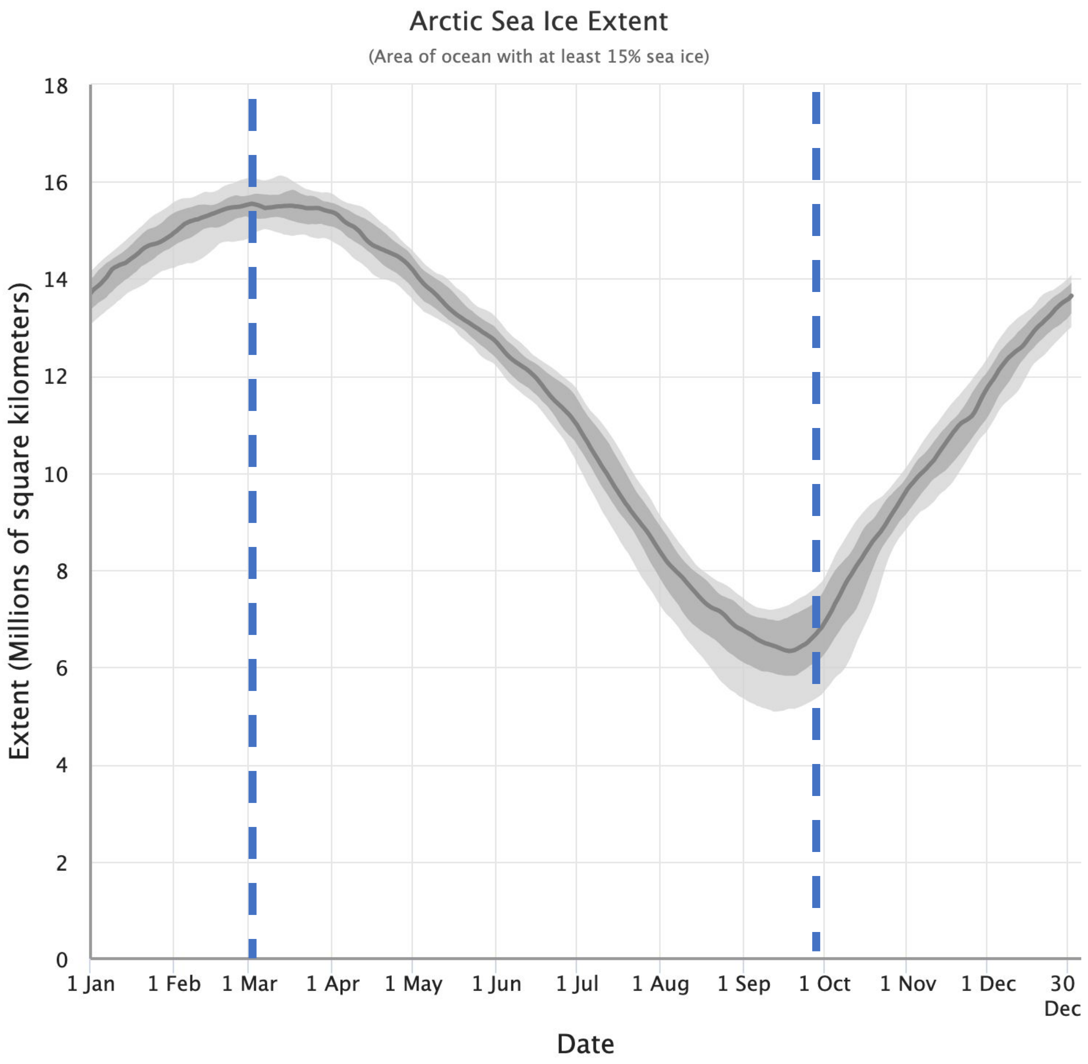
Accumulated SW is the **total solar energy absorbed over the March-Sep**

Energy per unit area [Jm^{-2}]

Seconds in each month [s]

$$SW_{acc_{i,j}} = \sum_{m=3}^{9} (SW^{\downarrow} - SW^{\uparrow})_{i,j} t_m$$

Monthly mean fluxes [Wm^{-2}]



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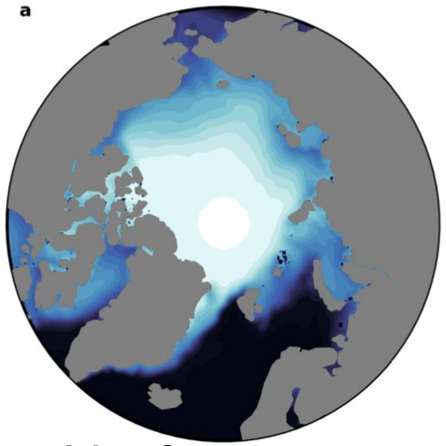
Monthly mean fluxes [Wm^{-2}]

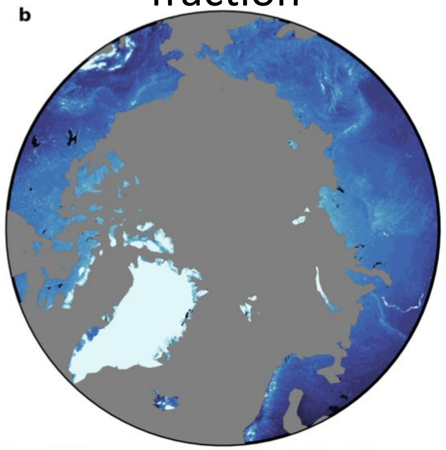
- CERES-EBAF Ed. 4.1 at TOA, 2000-2020 monthly mean broadband SW fluxes (Loeb et al 2018)
  - All-sky: all data
  - Total-region clear-sky: radiative transfer code re-run without clouds – what fluxes would have been measured if clouds were not present (Loeb et al 2020)

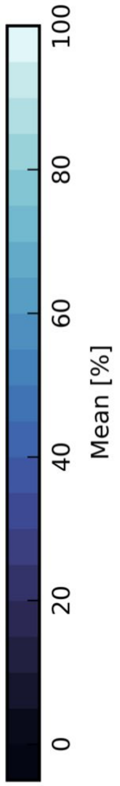
Accumulated SW is the **total solar energy absorbed over the March-Sep**

Avg Mar-Sep **sea ice** concentration

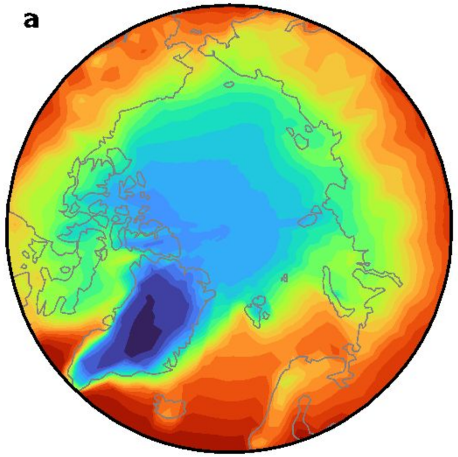


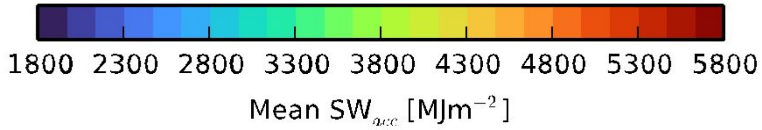
Avg Mar-Sep **snow** cover fraction





TOA Clear-Sky





TOA All-Sky

NASA Worldview: June 1, 2009

Sledd and L'Ecuyer 2021b

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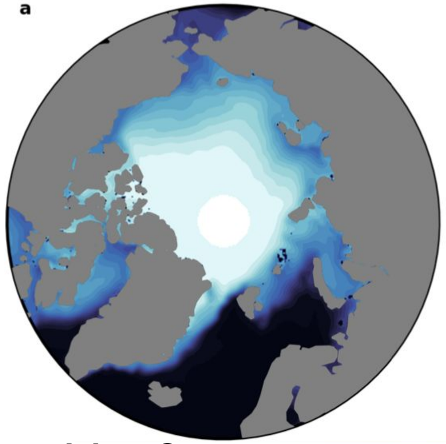

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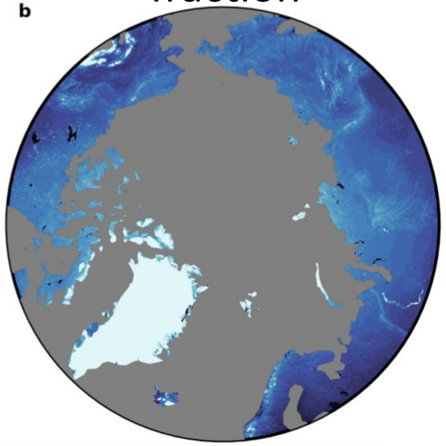

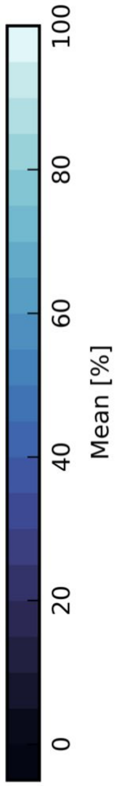

TOA Clear-Sky

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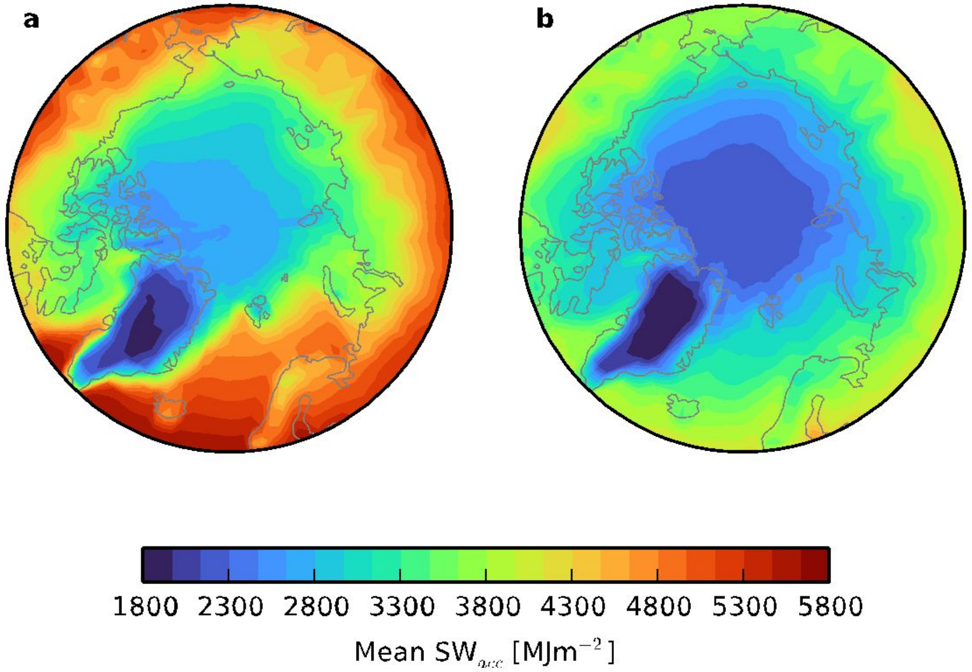
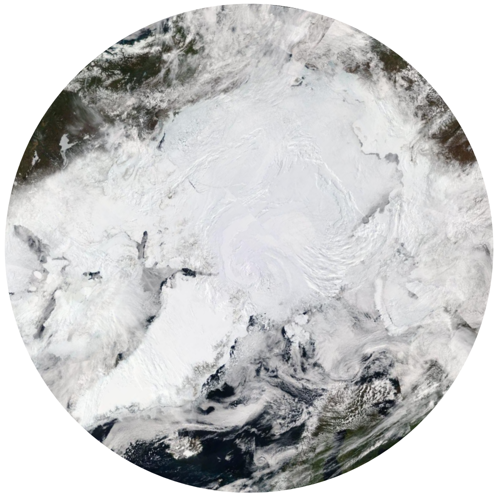


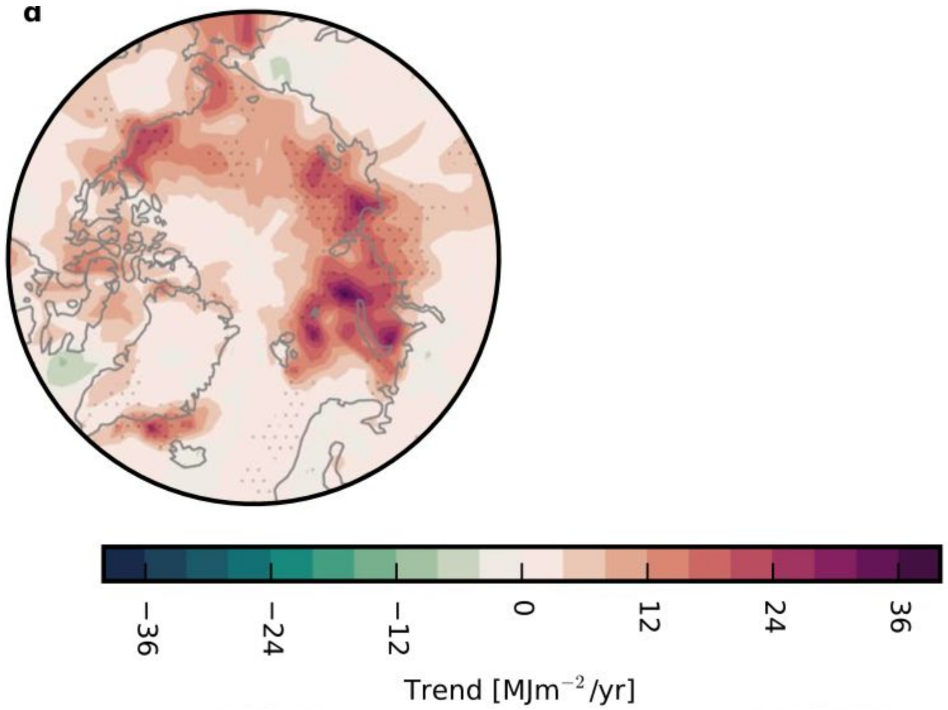


NASA Worldview: June 1, 2009

Sledd and L'Ecuyer 2021b

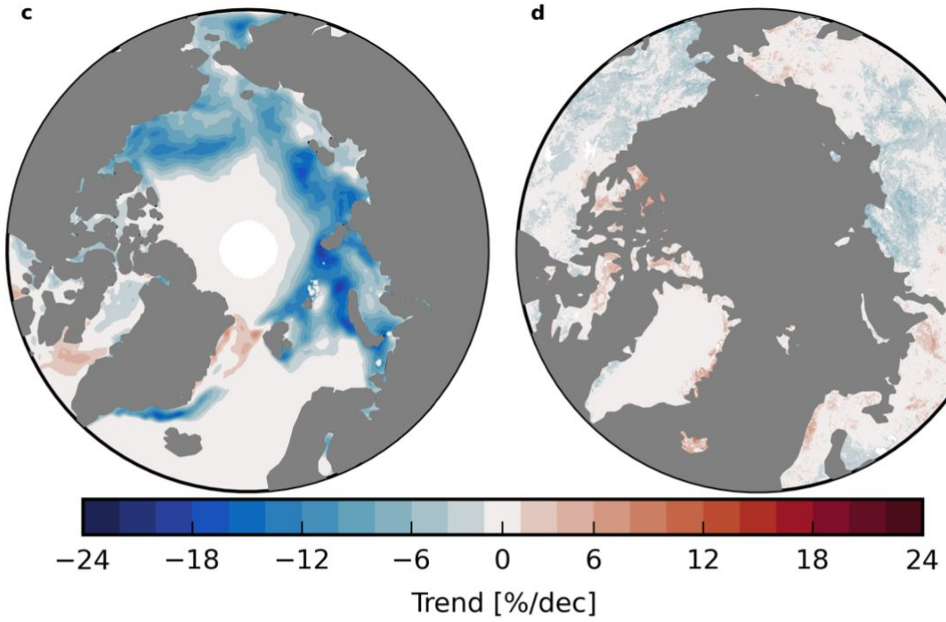
Clouds decrease the magnitude of SW_{acc} trends

TOA Clear-Sky



Trends in avg Mar-Sep **sea ice** concentration

Trends in avg Mar-Sep **snow** cover fraction



Sledd and L'Ecuyer 2021b

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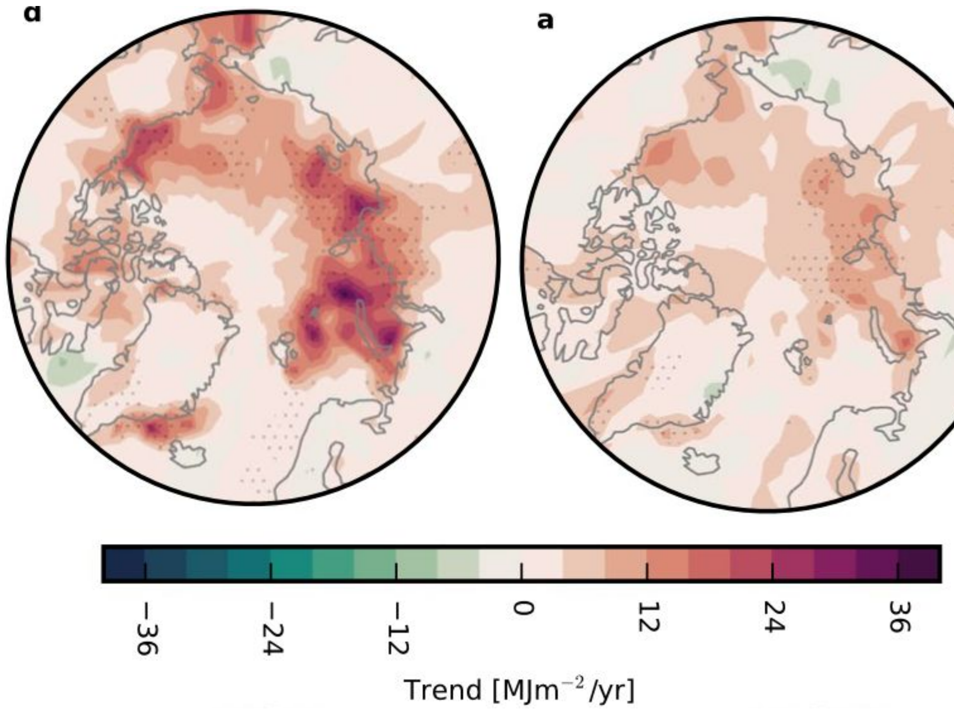
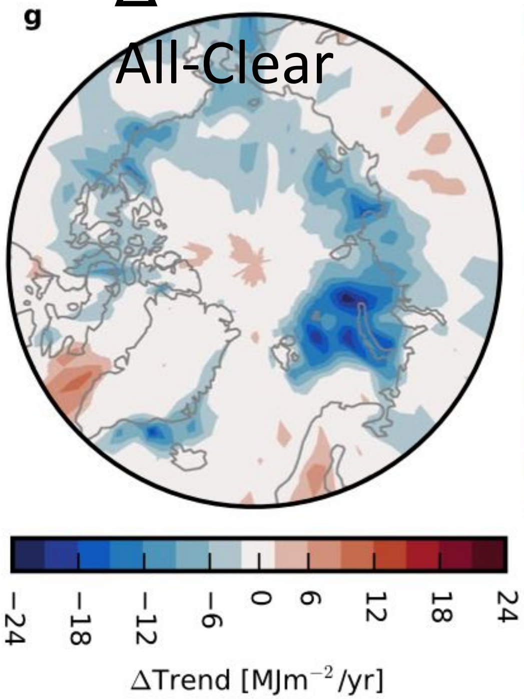


Δ All-Clear



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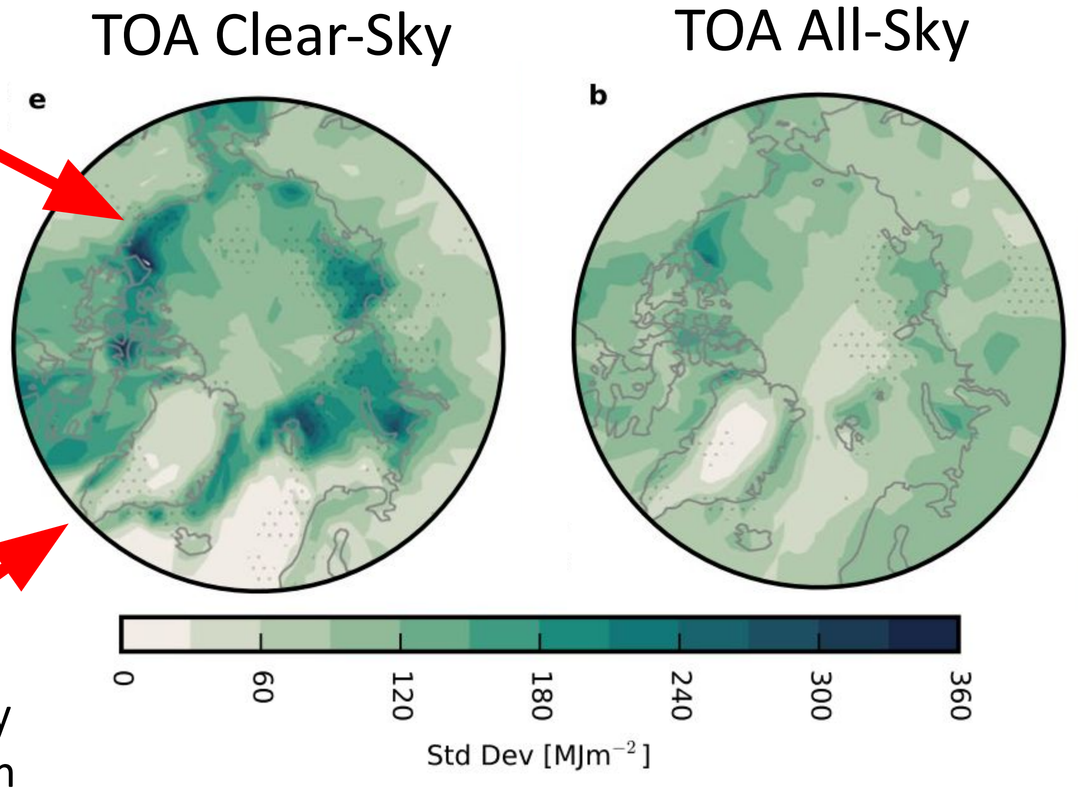
Clouds' impact on SW_{acc} variability depends on underlying surface

Higher variability in areas with seasonal sea ice or snow



Lower variability over open ocean and Greenland ice sheet

Sledd and L'Ecuyer 2021b

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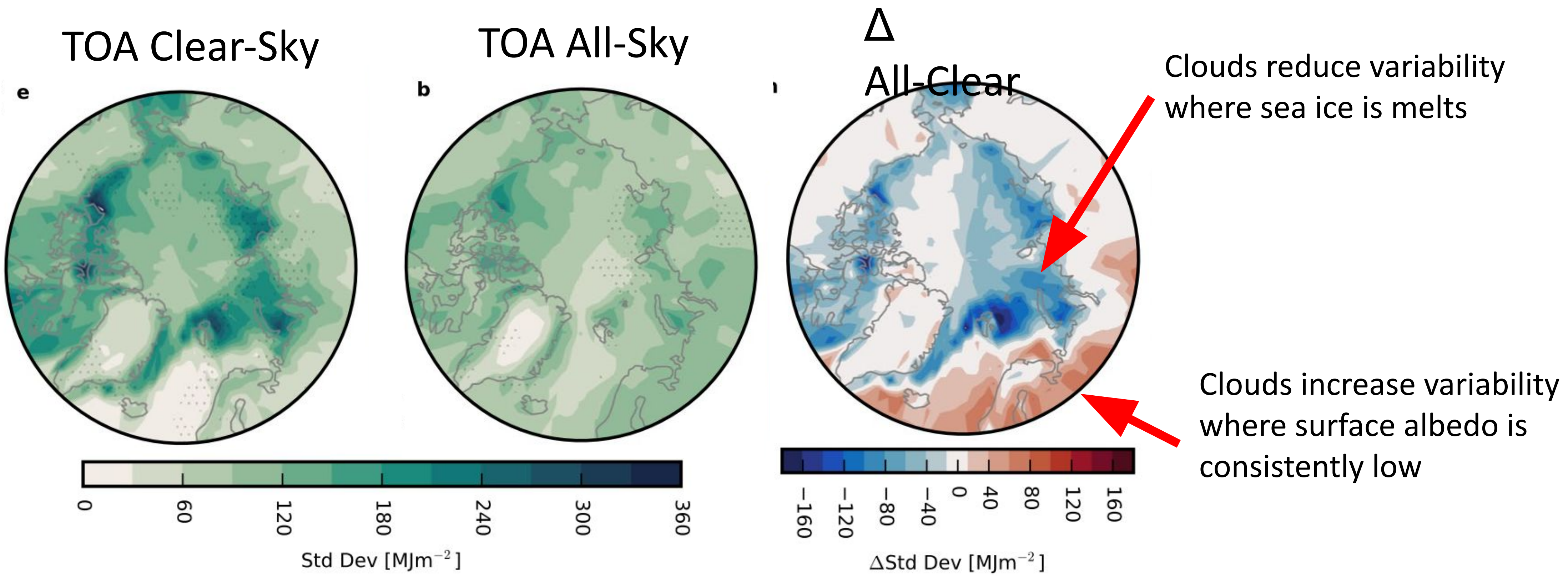


Sledd and L'Ecuyer 2021b

How do clouds impact the time needed for trends to be statistically significant?

- Sum SW_{acc} from each grid cell to get total SW energy absorbed into the Arctic:

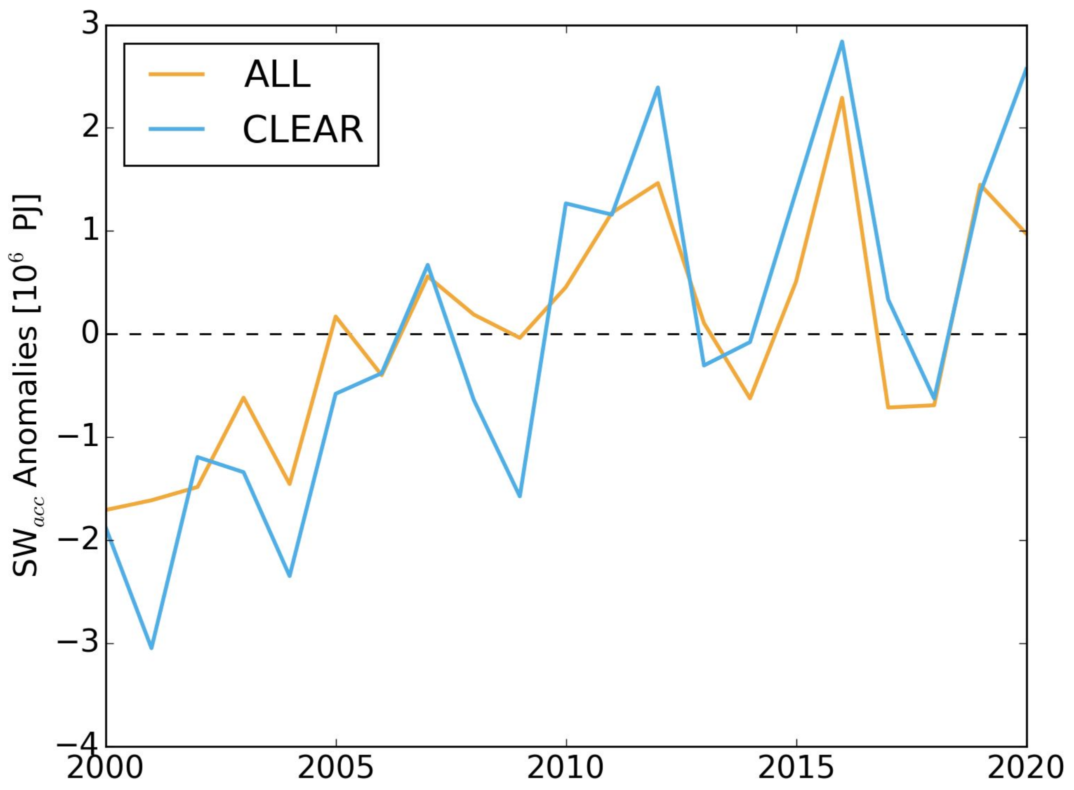
Energy [J]

Area in each grid cell [m^2]

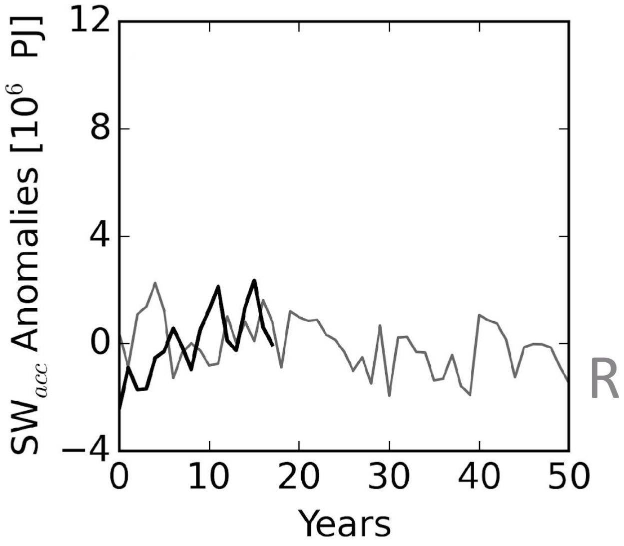
$$SW_{acc} = \sum_{m=3}^{9} \sum_{i,j} (SW^{\downarrow} - SW^{\uparrow})_{i,j} A_{i,j}\, t_m$$

Monthly mean fluxes [Wm^{-2}]

Seconds in each month [s]



Synthetic time series and trend detection



- Trend ($\widehat{\omega}$) is considered statistically significant with 95% confidence when it is 2x greater than standard deviation:

$$\left|\frac{\widehat{\omega}}{\sigma_{\widehat{\omega}}}\right| > 2$$

- Standard deviation of the trend ($\sigma_{\widehat{\omega}}$) can be approximated by:

$$\sigma_{\widehat{\omega}} \approx \sigma_N \left[\frac{12dt\,(1+\phi)}{T^3\,(1-\phi)}\right]^{1/2}$$

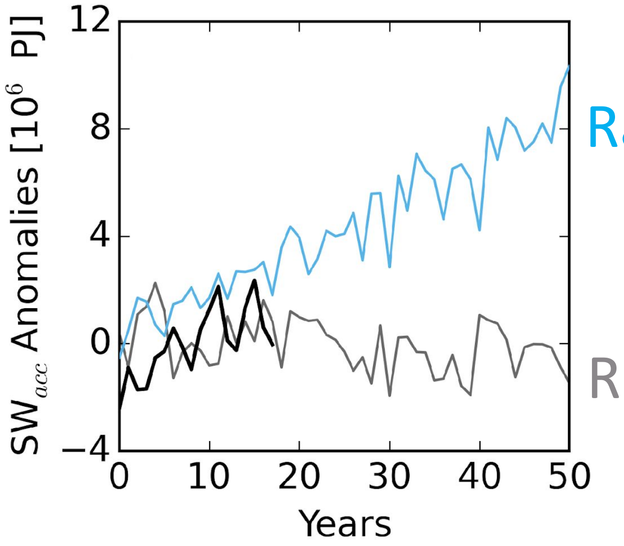
- **Calculate variance ($\sigma_N{}^2$) and 1-lag autocorrelation (ϕ) from de-trended anomalies**
  - Assume anomalies (N_t) can be represented by AR(1) process, i.e. red noise

$$Variance(N_t) = \sigma_N^2(1-\phi^2)$$

Sledd and L'Ecuyer 2021a

Weatherhead et al. 1998, Chepfer et al. 2018

Synthetic time series and trend detection



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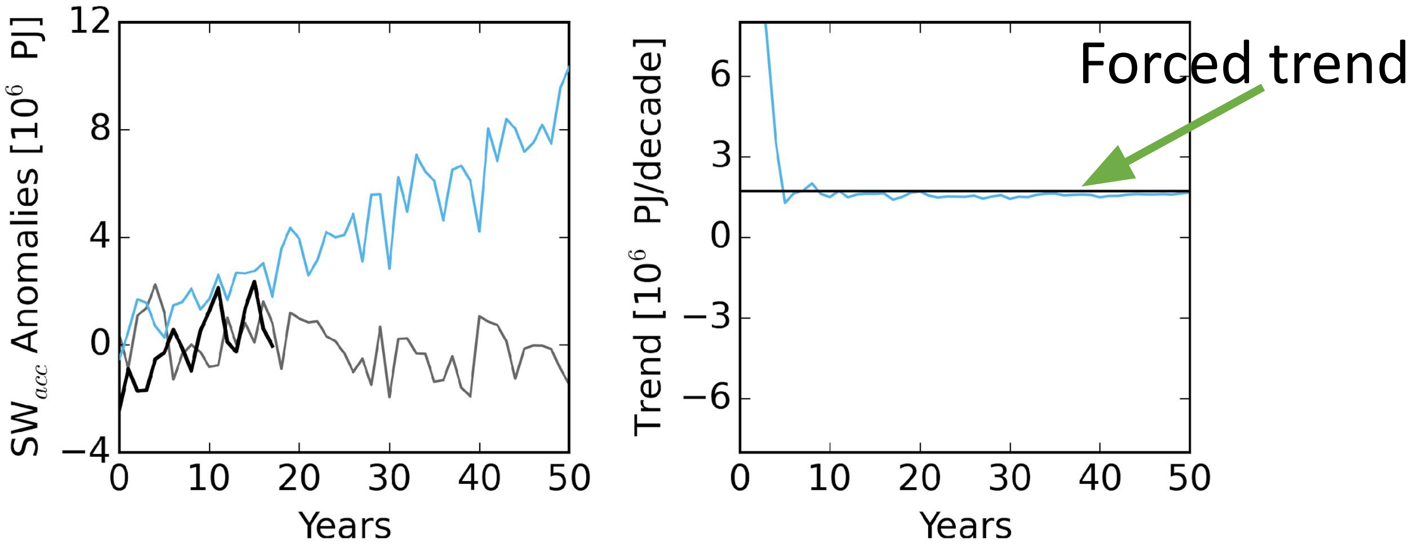

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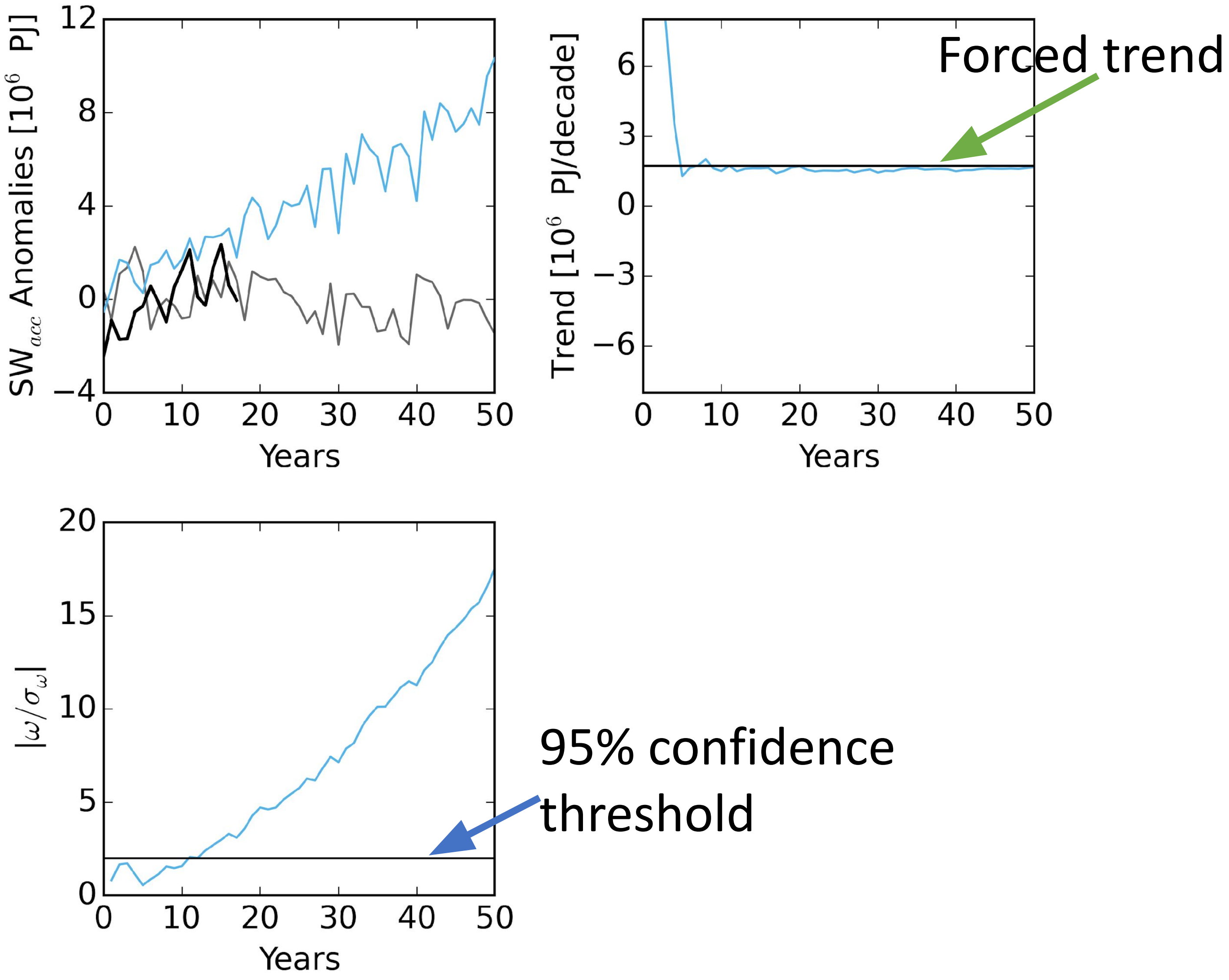

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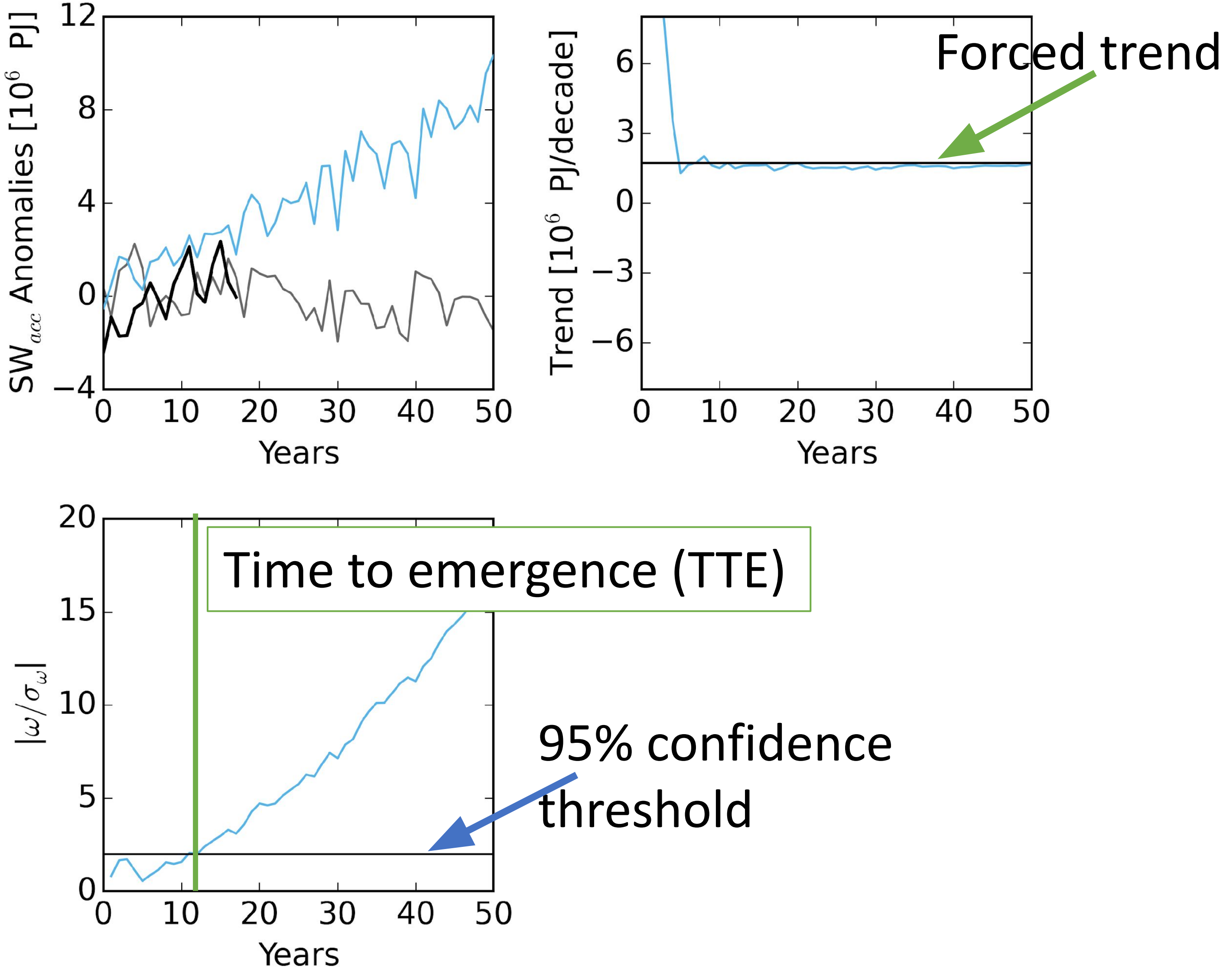

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Sledd and L'Ecuyer 2021a

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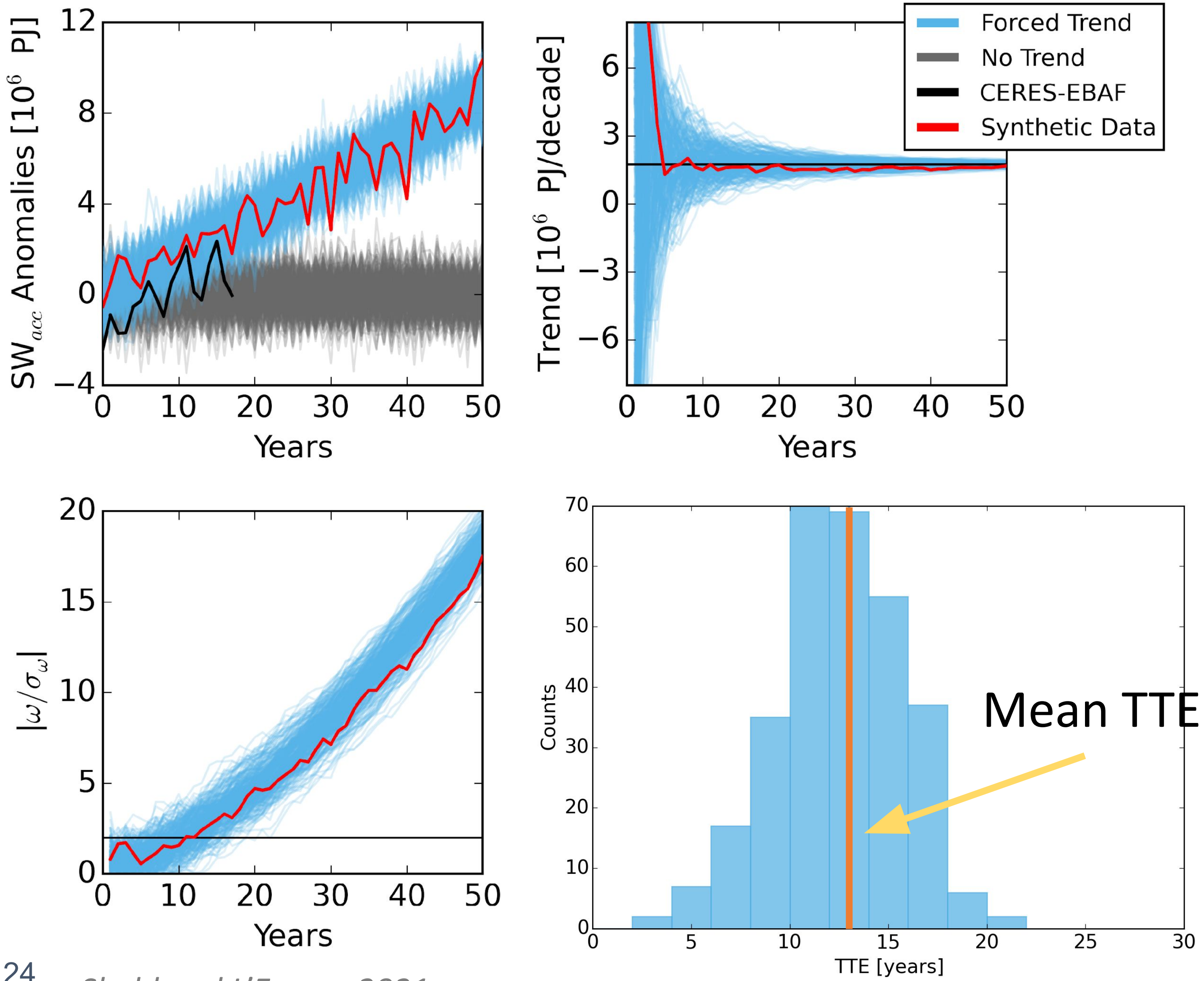

Sledd and L'Ecuyer 2021a

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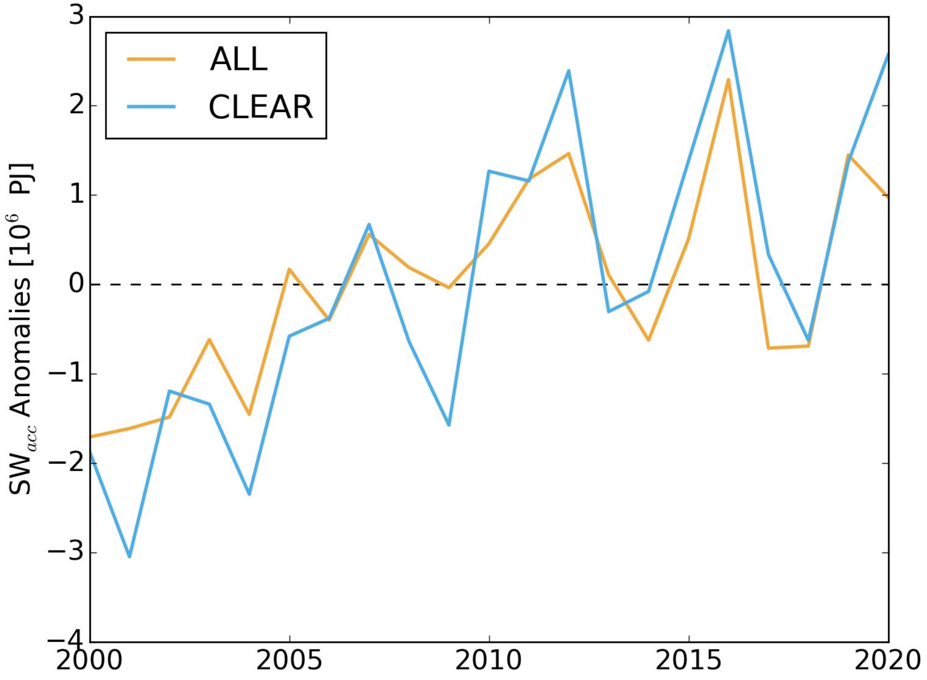
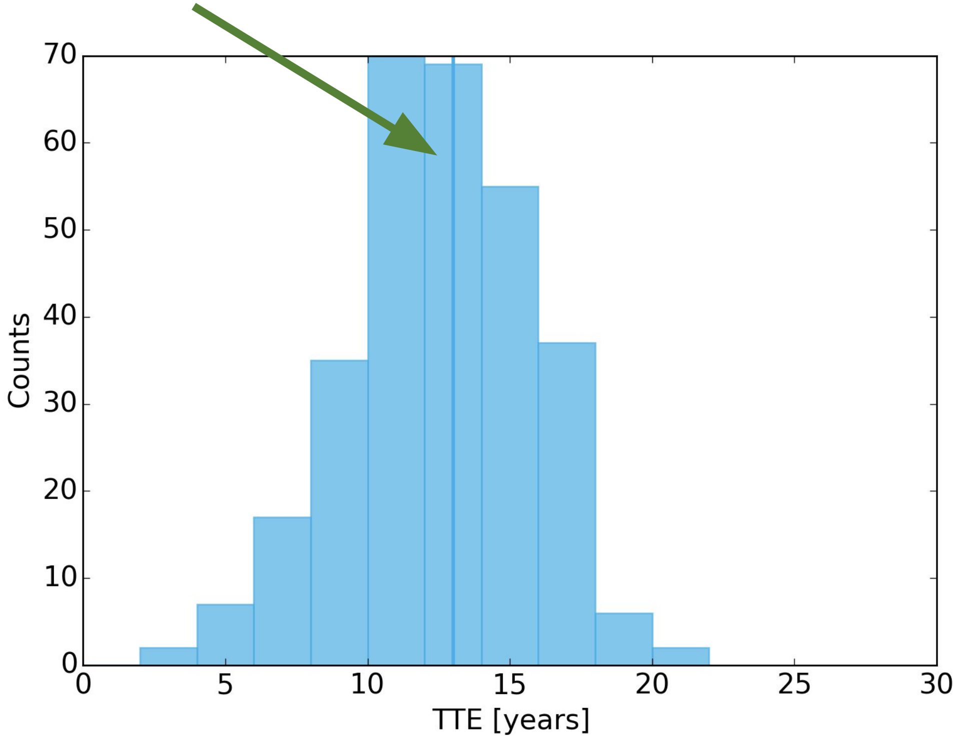
Weatherhead et al. 1998, Chepfer et al. 2018

Without clouds, SW_{acc} trend would emergence quickly

Clear-sky: mean TTE=12±3 years

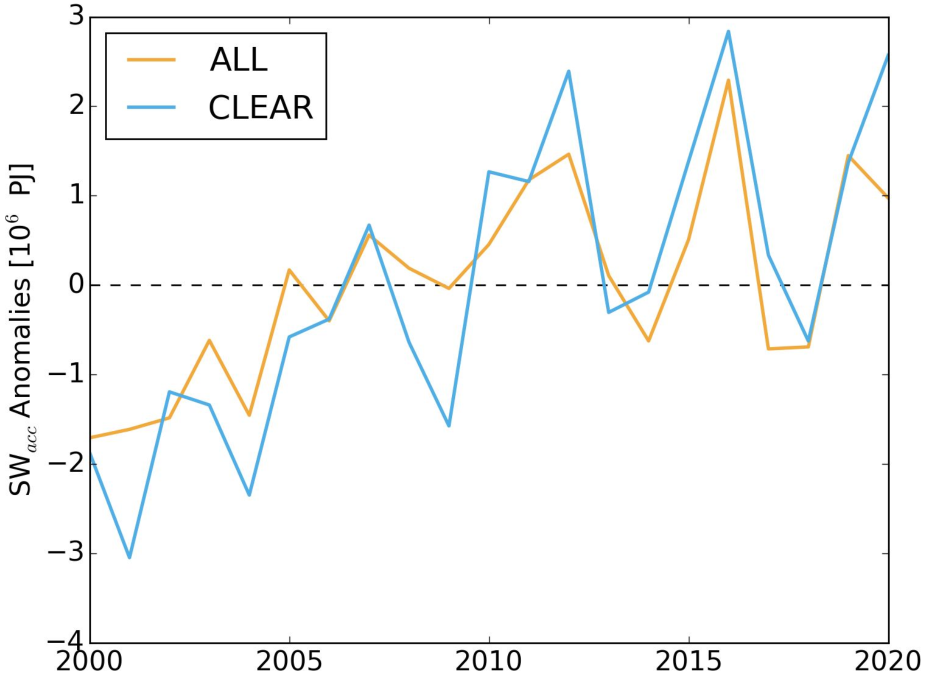




Clear-sky	1.08	0.06	1.93

Sledd and L'Ecuyer 2021b

Clouds have delayed SW_{acc} trend emergence but it's still statistically significant



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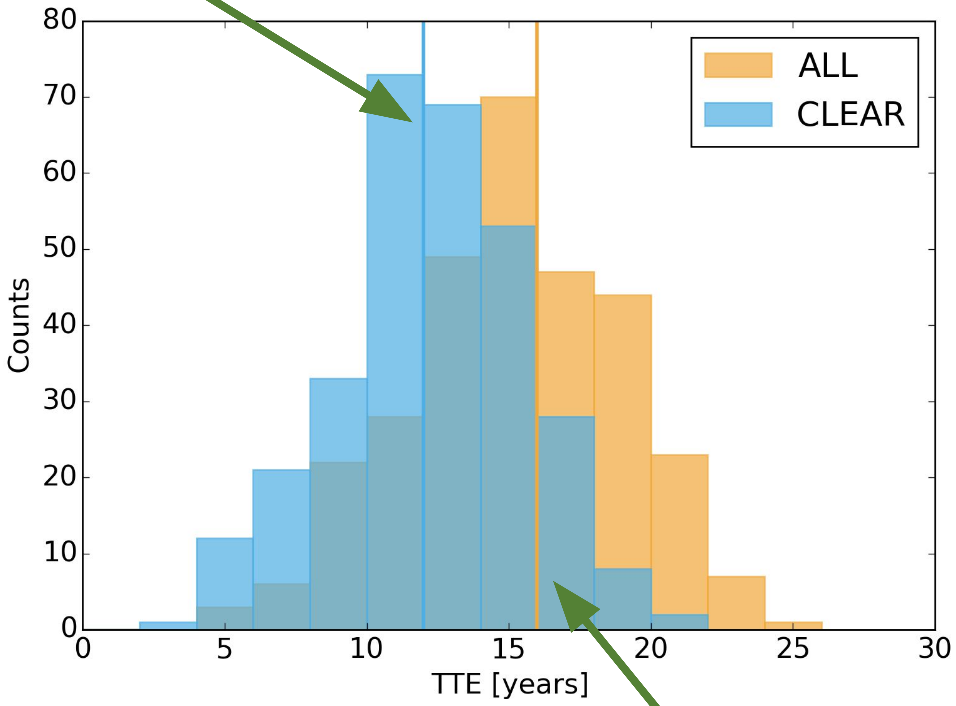


All-Sky: mean TTE=16±4 years

Clear-sky	1.08	0.06	1.93
All-sky	0.84	0.09	1.11

Sledd and L'Ecuyer 2021b

Conclusions

- Significantly more solar radiation is being absorbed into the Arctic now than at the turn of the century
- Clouds increase the time needed to detect trends in solar absorption across the Arctic
- Clouds exert the largest masking effect over oceans and areas with the greatest sea ice loss

Questions?

Contact: anne.sledd@colorado.edu

NASA Worldview Sep 5 2012

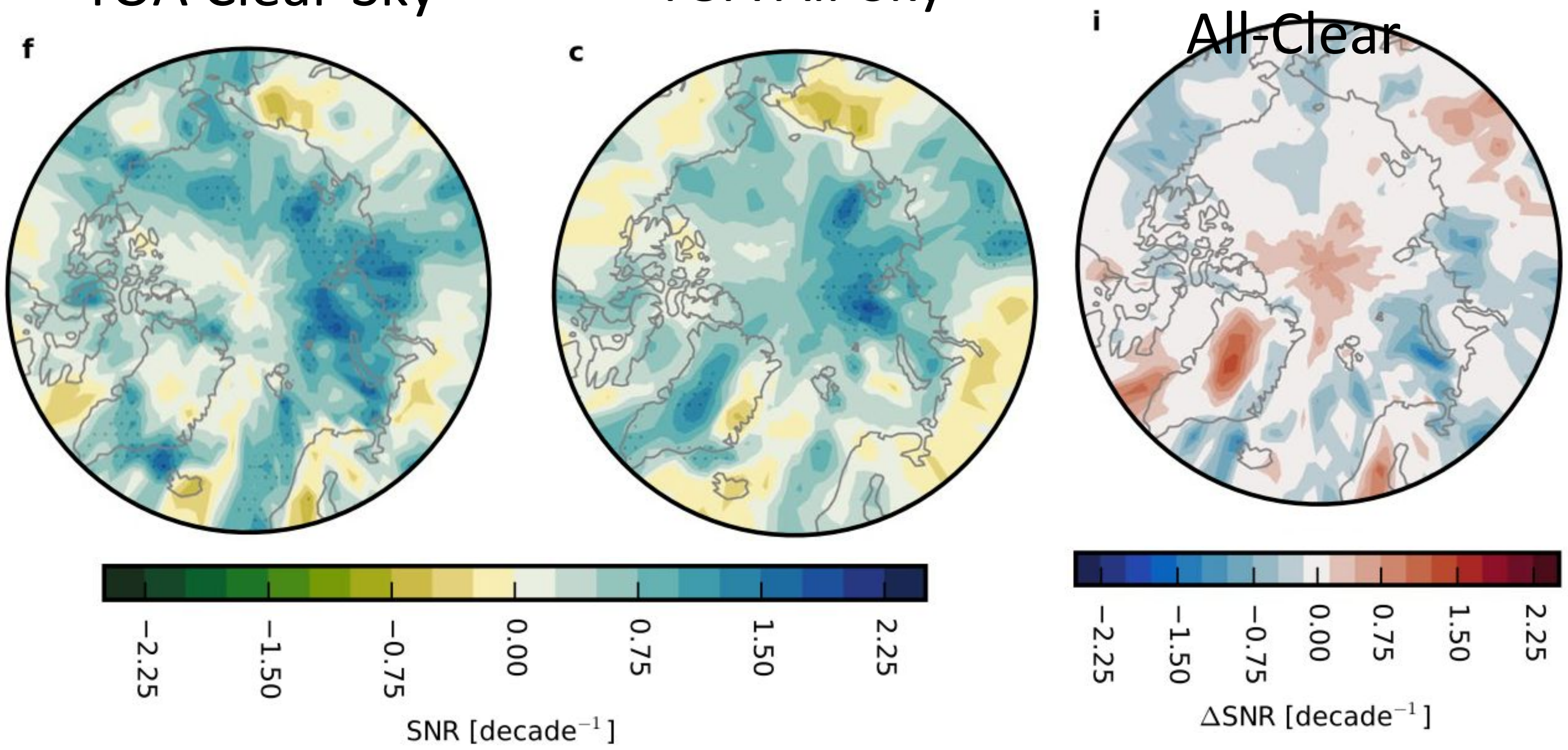
Signal-to-noise ratio (SNR) as a measure of detectability

$$SNR = \frac{trend}{standard\ deviation}$$

TOA Clear-Sky

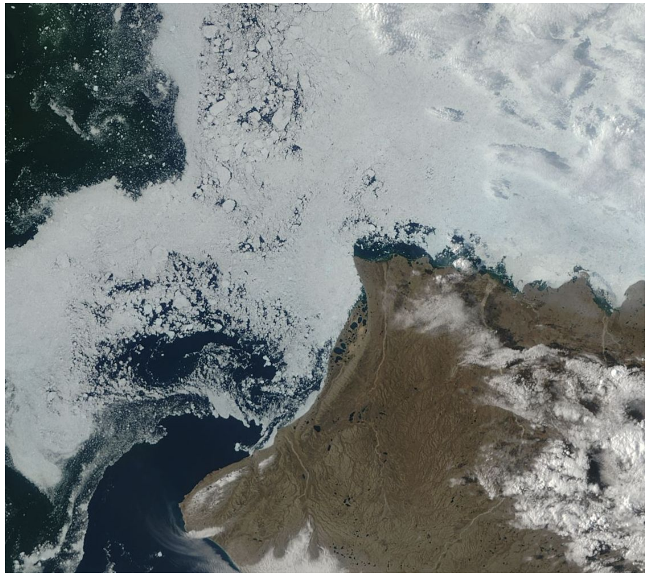
TOA All-Sky

Δ All-Clear

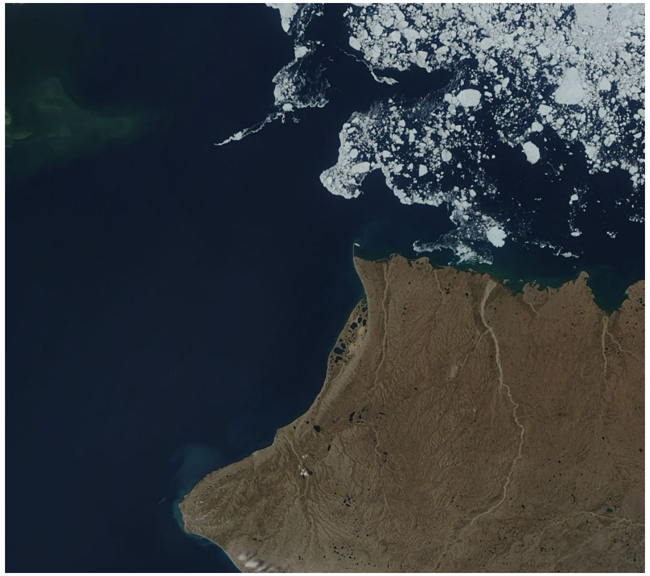


Sledd and L'Ecuyer 2021b

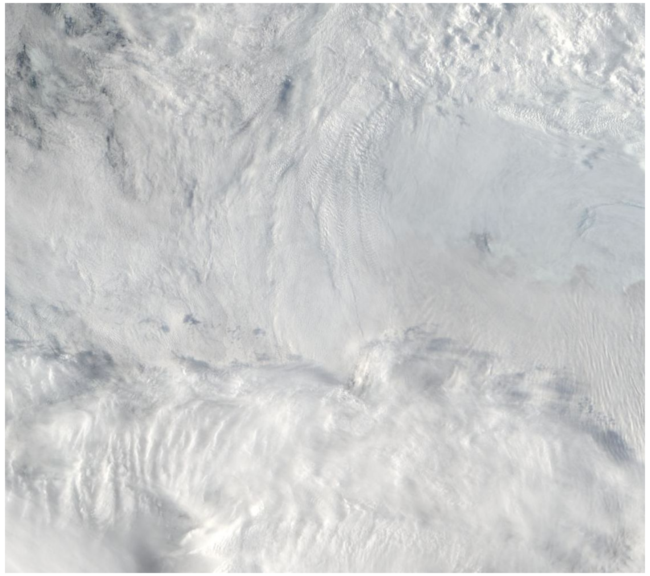
August 28, 2002



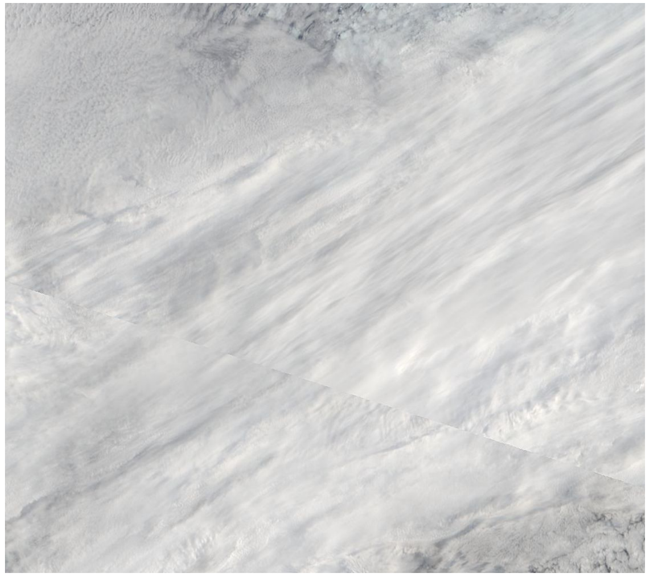
August 26, 2009



August 30, 2002



August 27, 2009

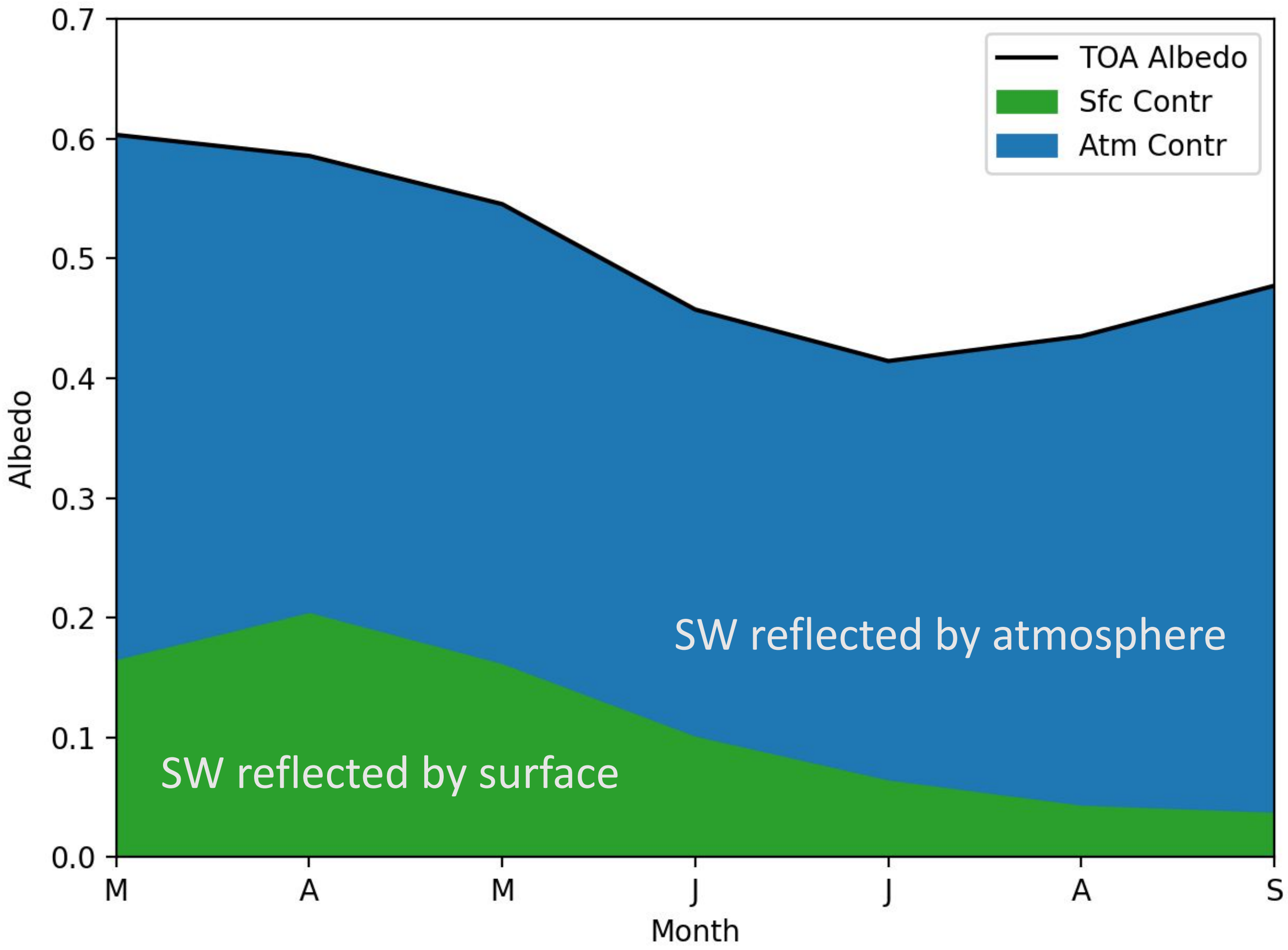


Images from NASA Worldview

Clouds reduce top-of-atmosphere (TOA) albedo variability compared to the surface albedo

- CERES-EBAF v2.8 2000-2012

- Atmosphere contributes at least 2x more to the TOA albedo than the surface, on average

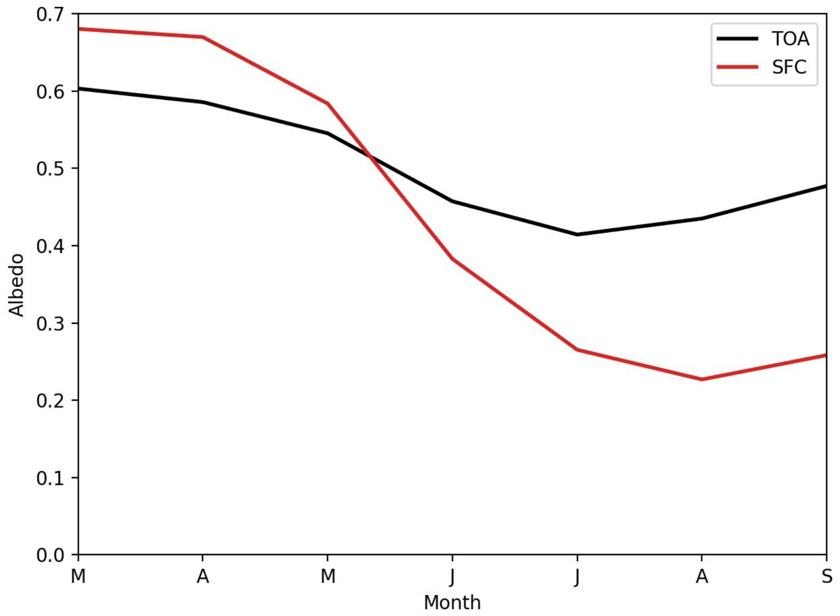


Sledd and L'Ecuyer 2019

Clouds reduce top-of-atmosphere (TOA) albedo variability compared to the surface albedo

- CERES-EBAF v2.8 2000-2012 monthly averages

$$albedo = \frac{reflected\ SW}{incident\ SW}$$

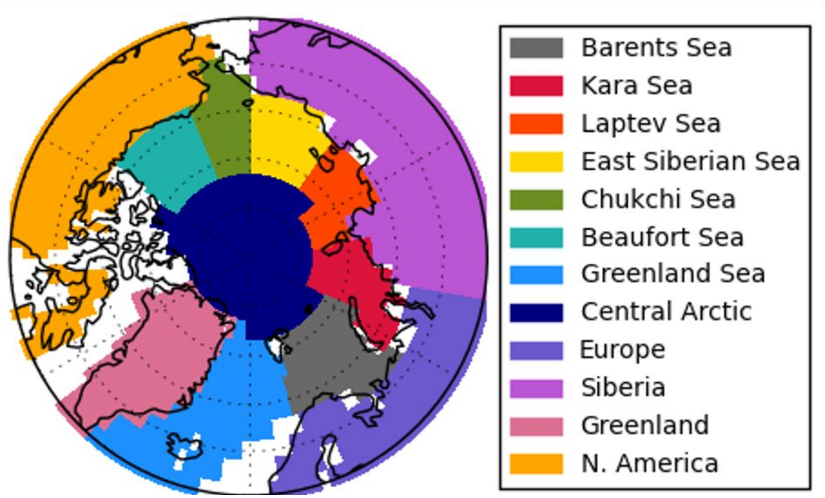


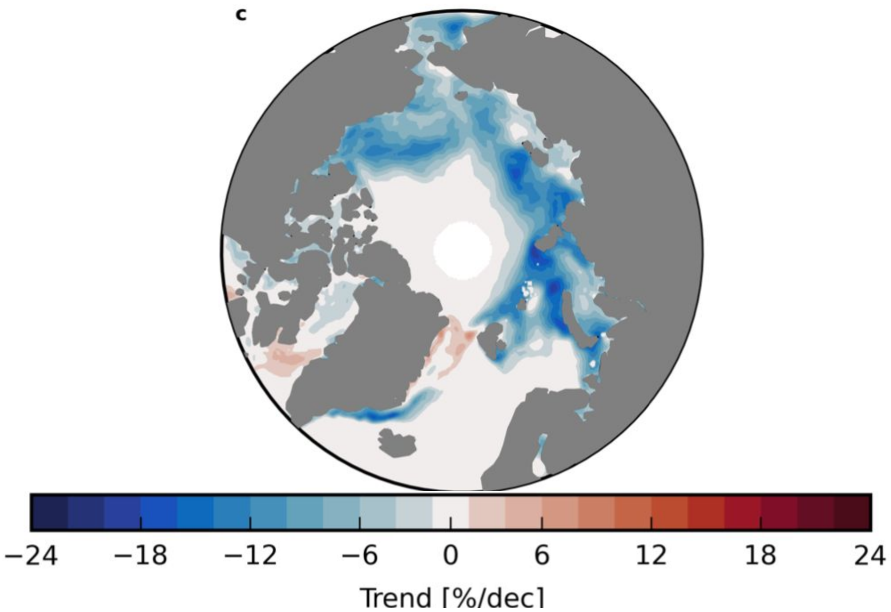
Sledd and L'Ecuyer 2019

Past studies on shortwave absorption trends

Study	Data	Years	Sfc or TOA?	Findings
Katlein et al 2017	APP-X	1982-2014	SFC	Absorbed SW trend >50N: 8.77 $\cdot$ 10^{25}J/yr
Letterly et al 2018	APP-X	1982-2015	SFC	Absorbed SW increased 10 % over ocean and 2.7 % over land
Kato et al 2006	CERES	200-2004	TOA	reflected SW irradiance trend: −2.0 ± 2.0 Wm^{-2} /dec (80% confidence)
Hartmann and Ceppi 2014	CERES	2000-2012	TOA	Reflected SW trends >60N: -2--5 Wm^{-2} /dec

Clouds delay TTE over marginal seas





	Clear-Sky TTE [years]	All-Sky TTE [years]
Barents Sea	16 (4)*	24 (7)
Kara Sea	16 (3)*	17 (4)*
Laptev Sea	14 (4)*	17 (5)*
East Siberian Sea	17 (5)	20 (5)*
Chukchi Sea	13 (4)	22 (6)*
Beaufort Sea	19 (6)	26 (6)
Greenland Sea	17 (5)*	31 (9)
Central Arctic Ocean	22 (5)*	22 (5)

Mean TTE from 300 member synthetic ensembles with standard deviations in parentheses. * denotes trends that have emerged in the observations record.