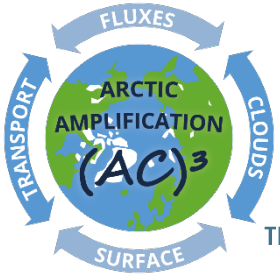
ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms (AC)³

Clouds and Arctic Amplification

Manfred Wendisch, Johannes Stapf, and Jan Kretzschmar
Leipzig Institute for Meteorology (LIM), University of Leipzig
Seminar at University of Warsaw, 16 April 2021



http://ac3-tr.de/ Funded by DFG (Deutsche Forschungsgemeinschaft)

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UNIVERSITÄT LEIPZIG

Universität Bremen

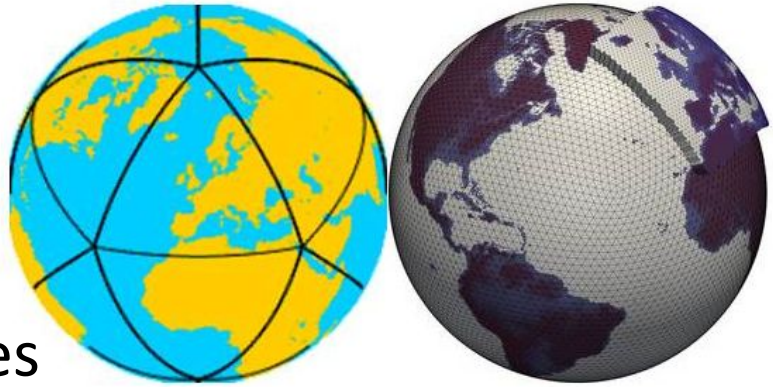
University of Cologne

TROPOS Leibniz Institute for Tropospheric Research

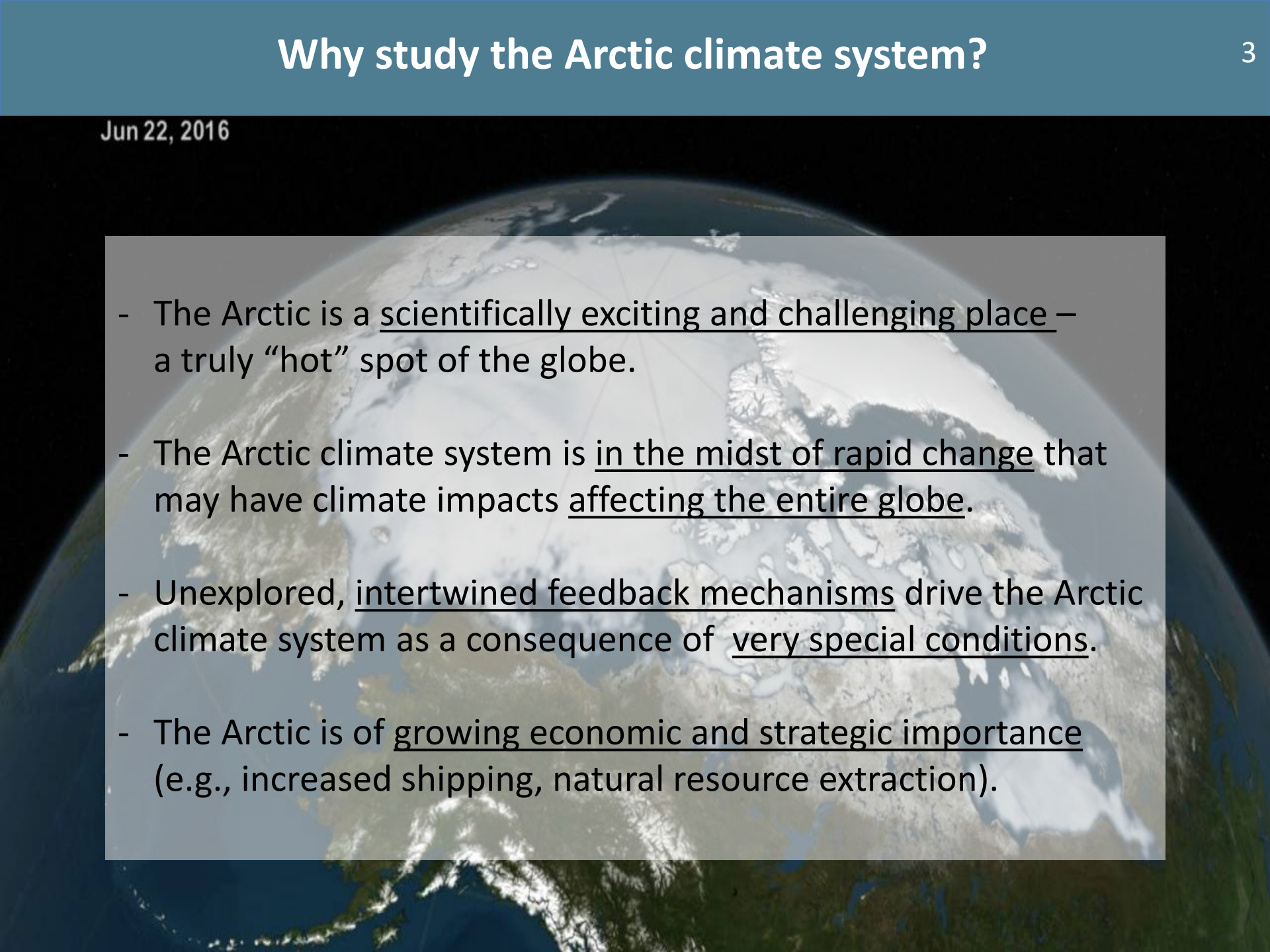
AWI

Contents

ICON (ICOsahedral Non-hydrostatic)

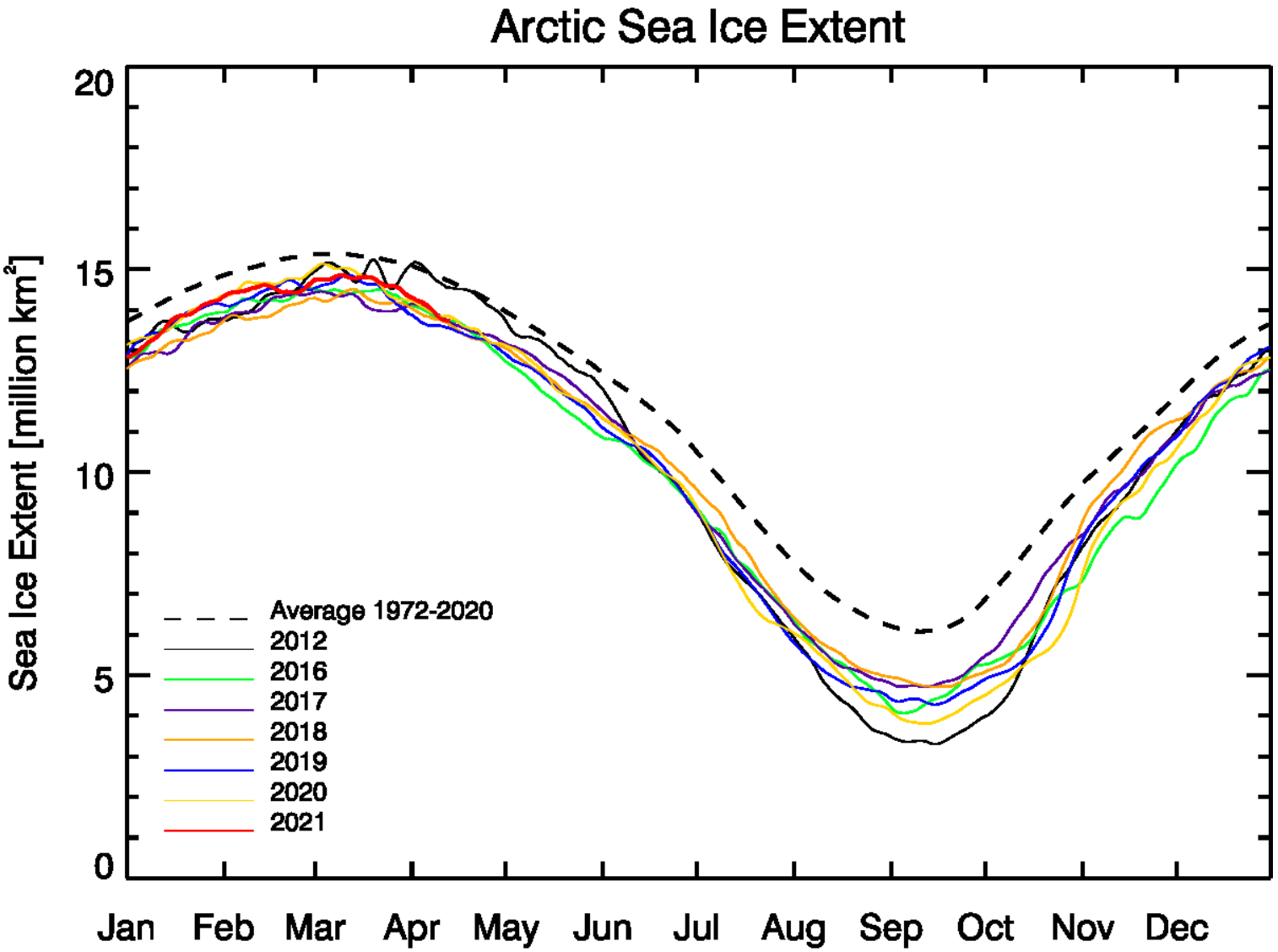


Why study the Arctic climate system?



- The Arctic is a scientifically exciting and challenging place – a truly "hot" spot of the globe.
- The Arctic climate system is in the midst of rapid change that may have climate impacts affecting the entire globe.
- Unexplored, intertwined feedback mechanisms drive the Arctic climate system as a consequence of very special conditions.
- The Arctic is of growing economic and strategic importance (e.g., increased shipping, natural resource extraction).

The Arctic Sea Ice Melts



https://seaice.uni-bremen.de/sea-ice-concentration/time-series/

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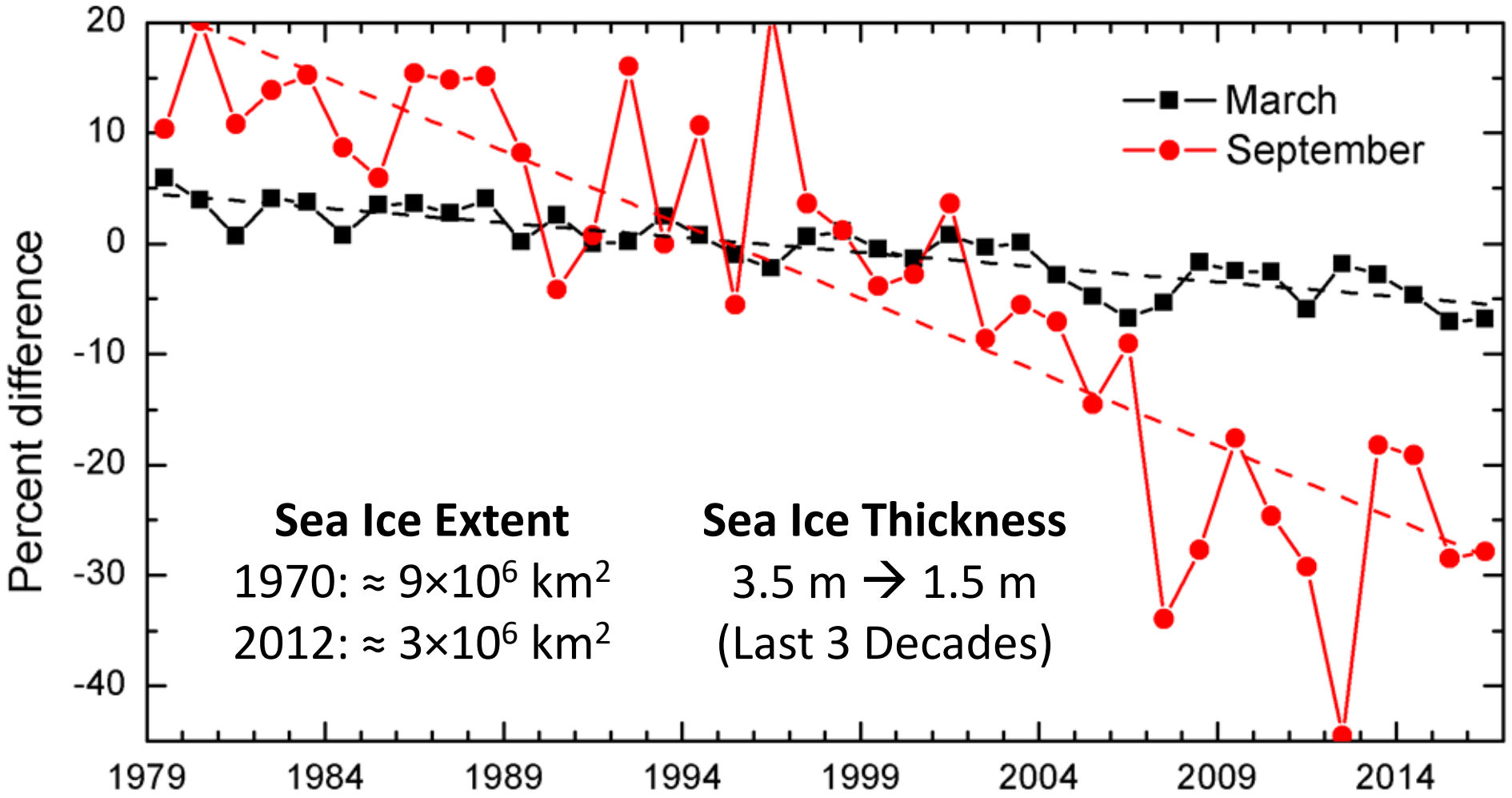
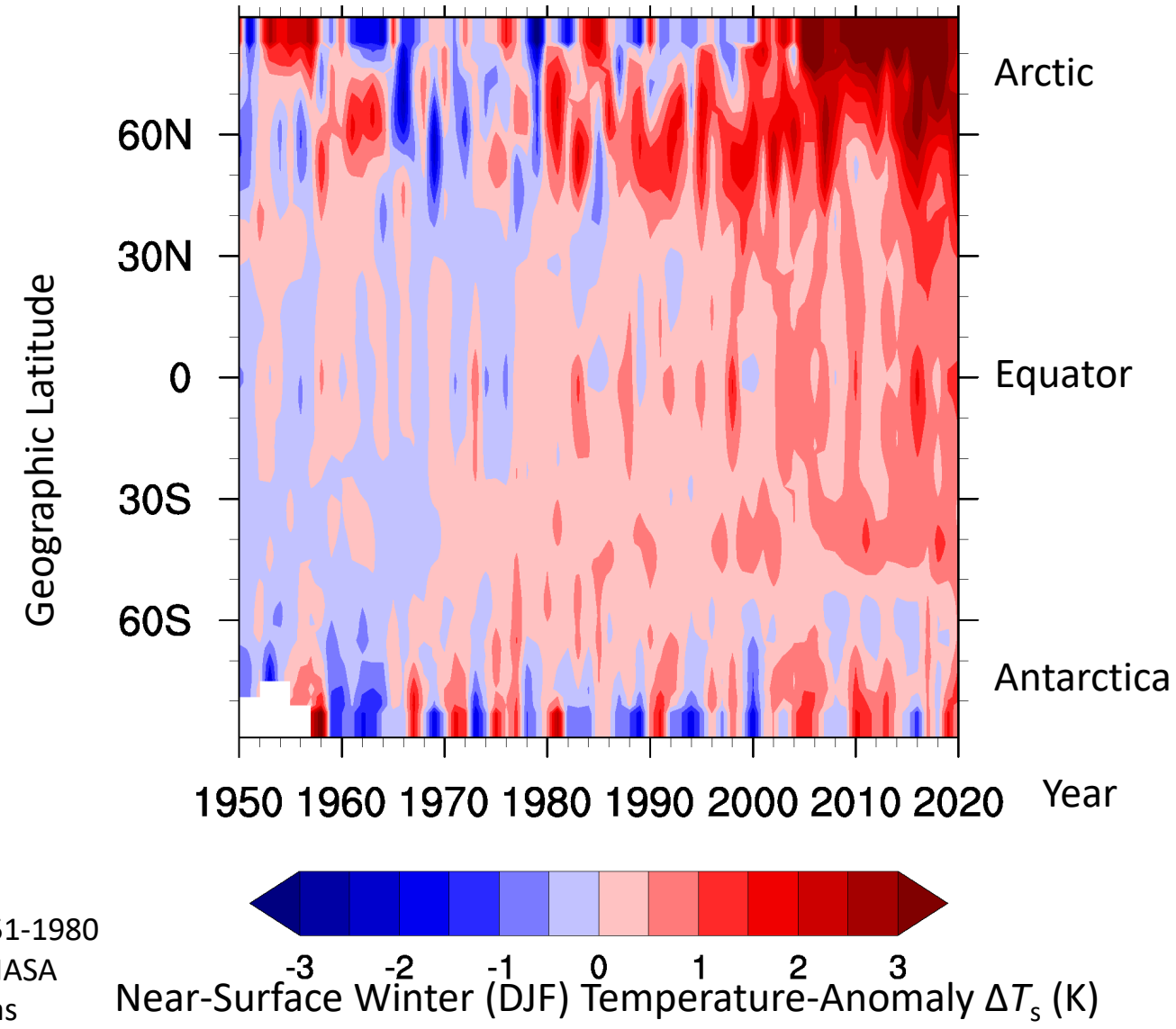


Arctic Report Card 2016

The Near-Surface Air Temperature Rises



Reference period: 1951-1980
data provided by NASA
K. Block, J. Quaas

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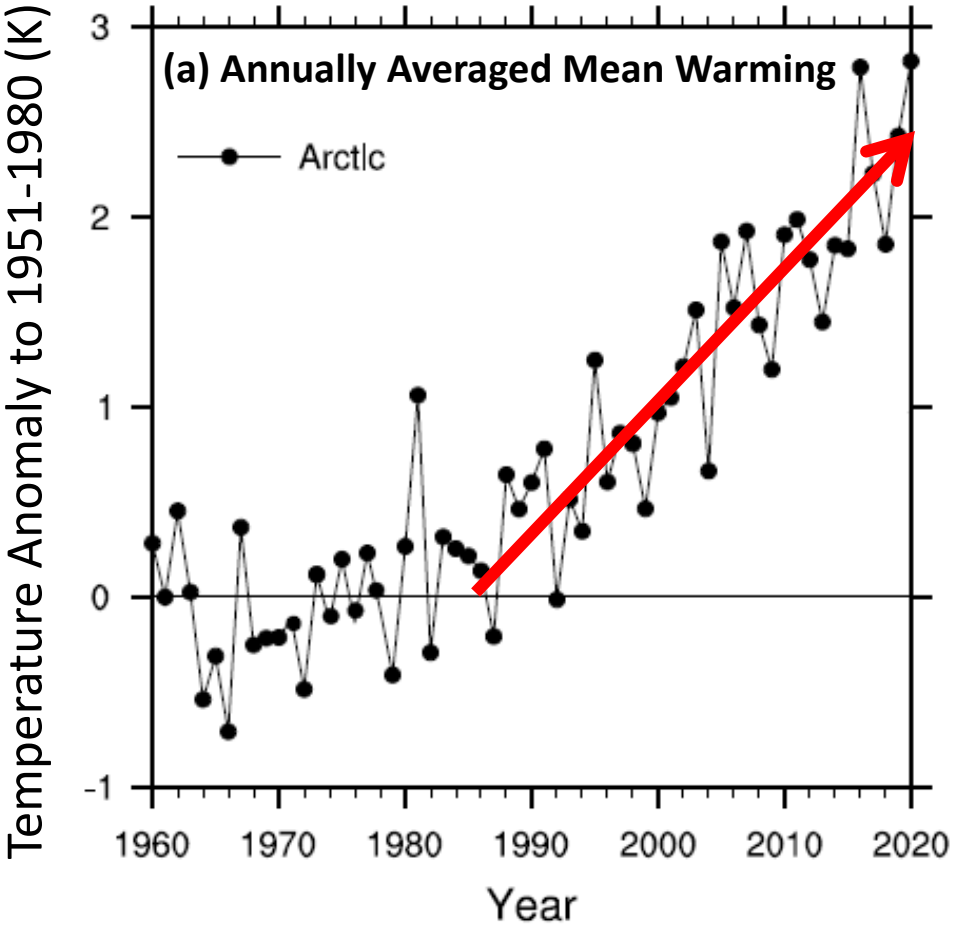

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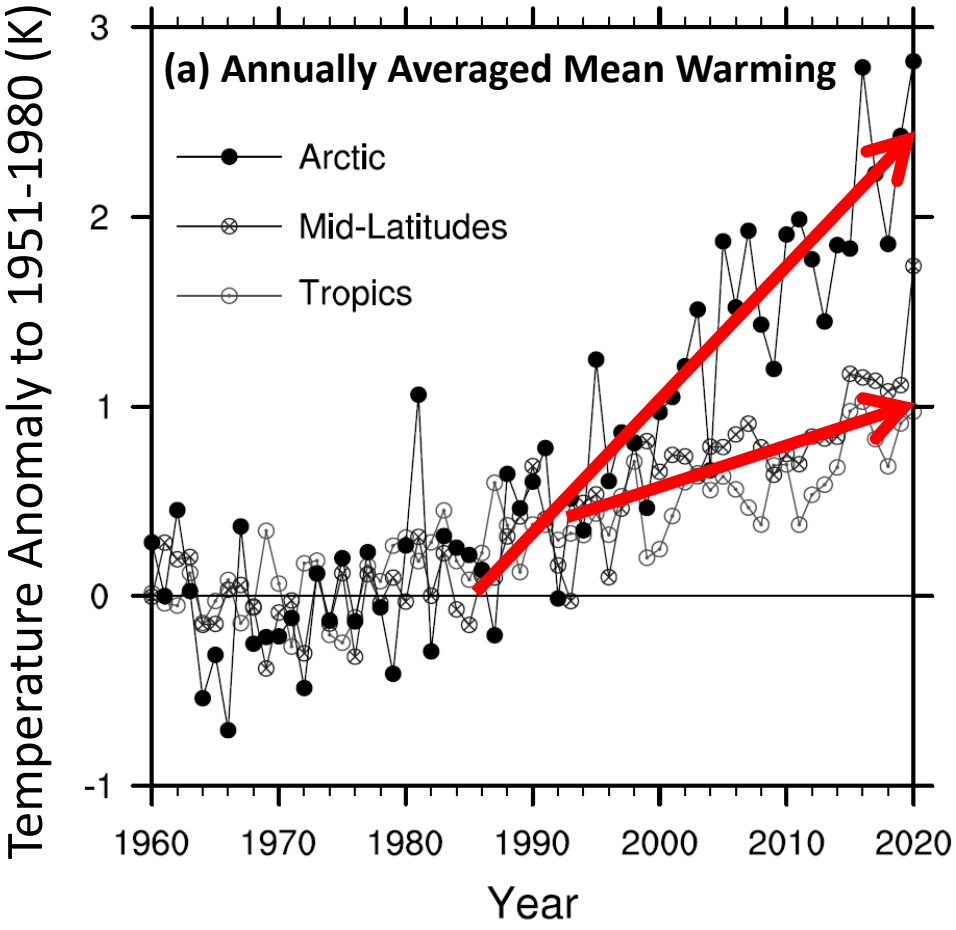

TABLE 2. Amplification factors (annual averages).

Region	1990–2020	2010–2020
Arctic/Mid-Latitudes	1.82	2.02
Arctic/Tropics	2.45	2.77
Arctic/Global	2.32	2.48

Reference period: 1951-1980
data provided by NASA
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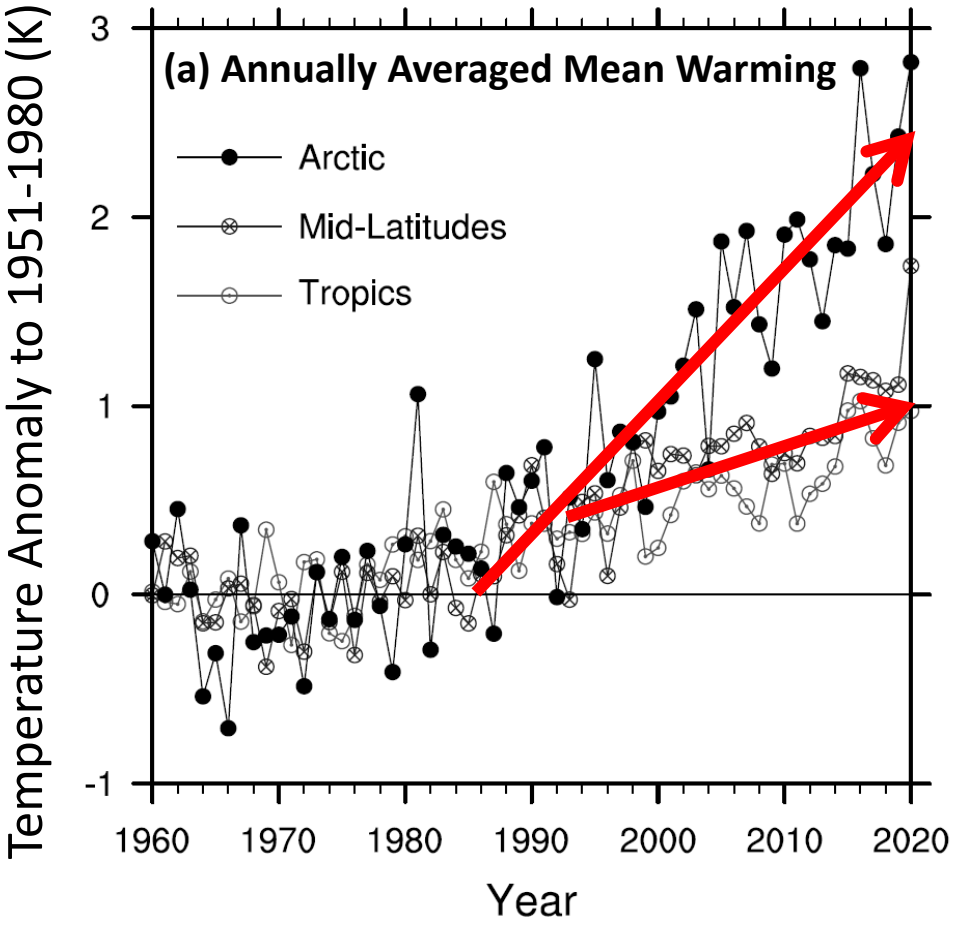
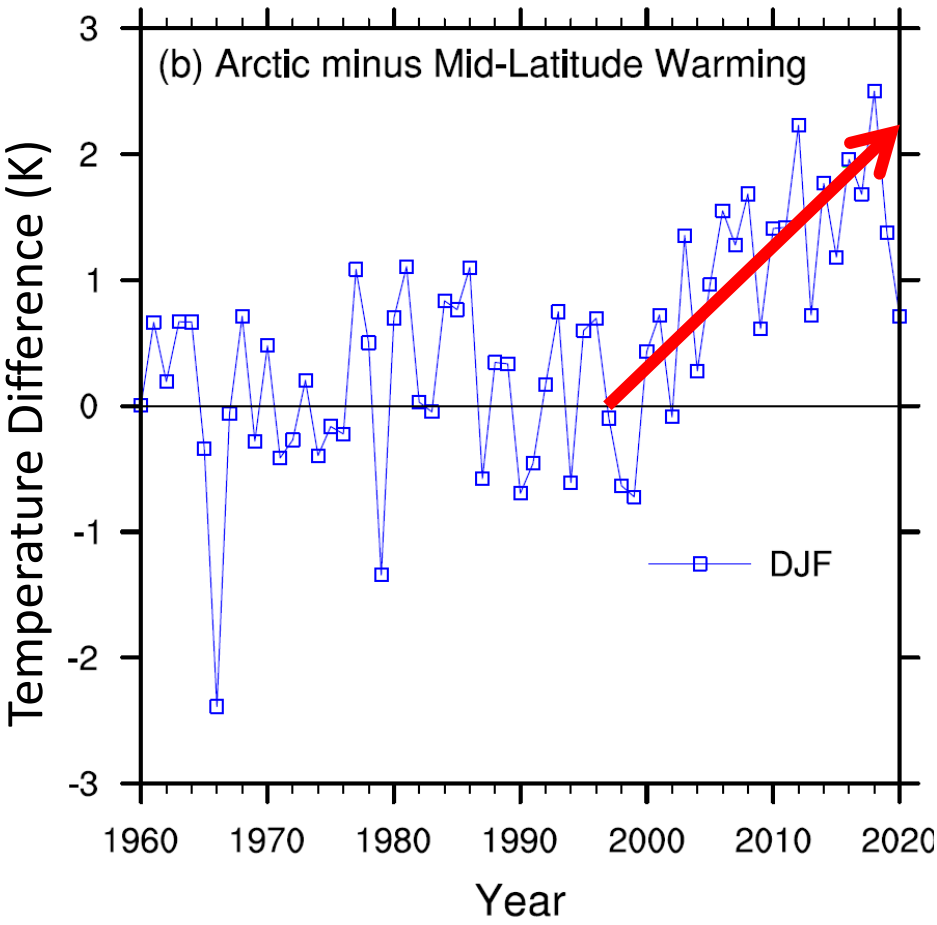
The Near-Surface Air Temperature Rises





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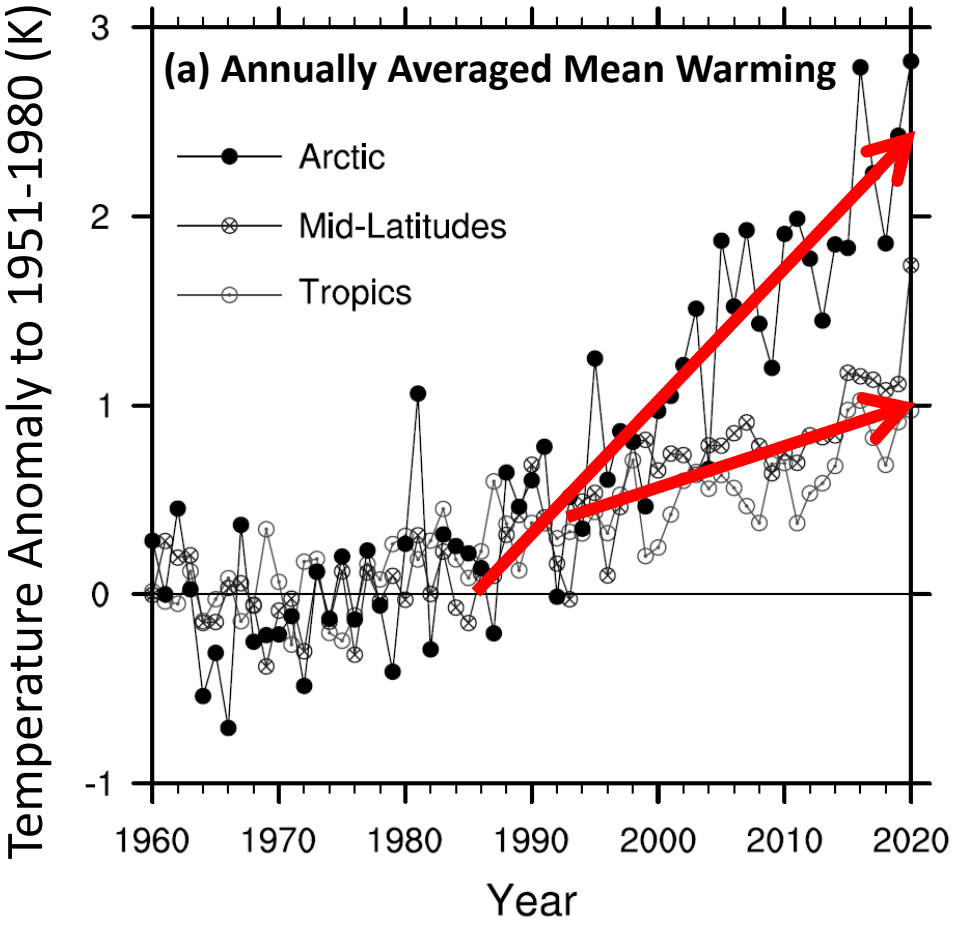

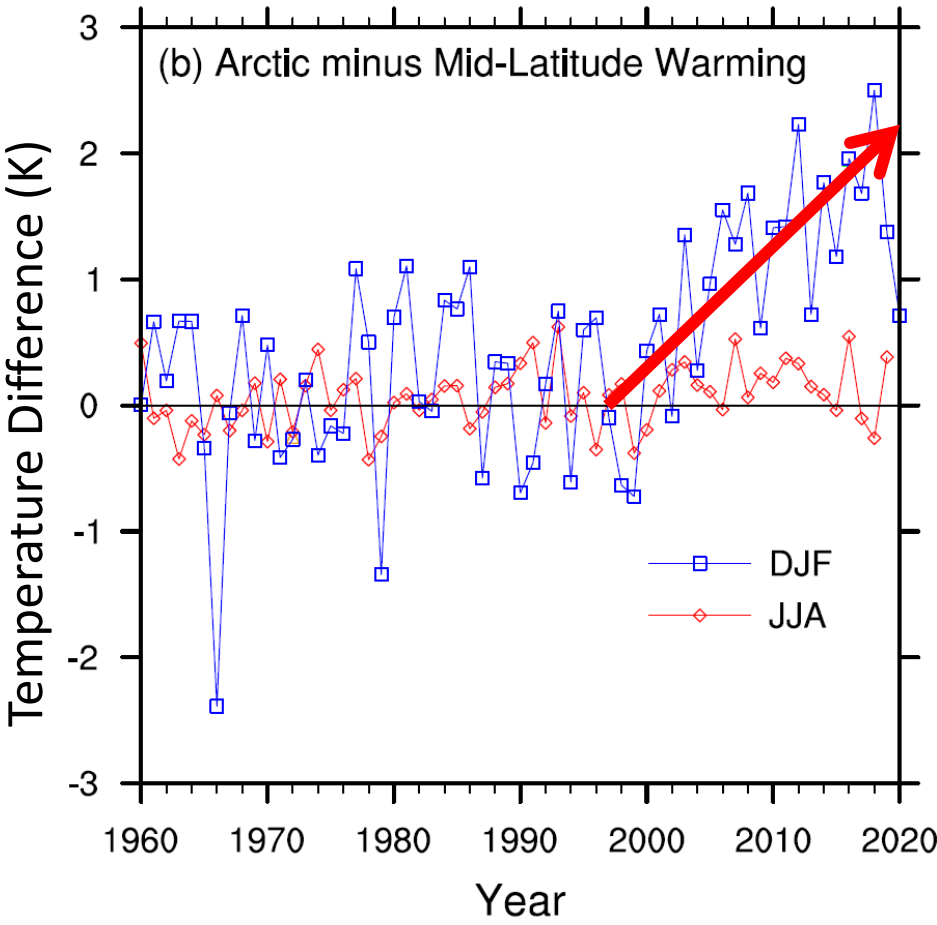

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data provided by NASA
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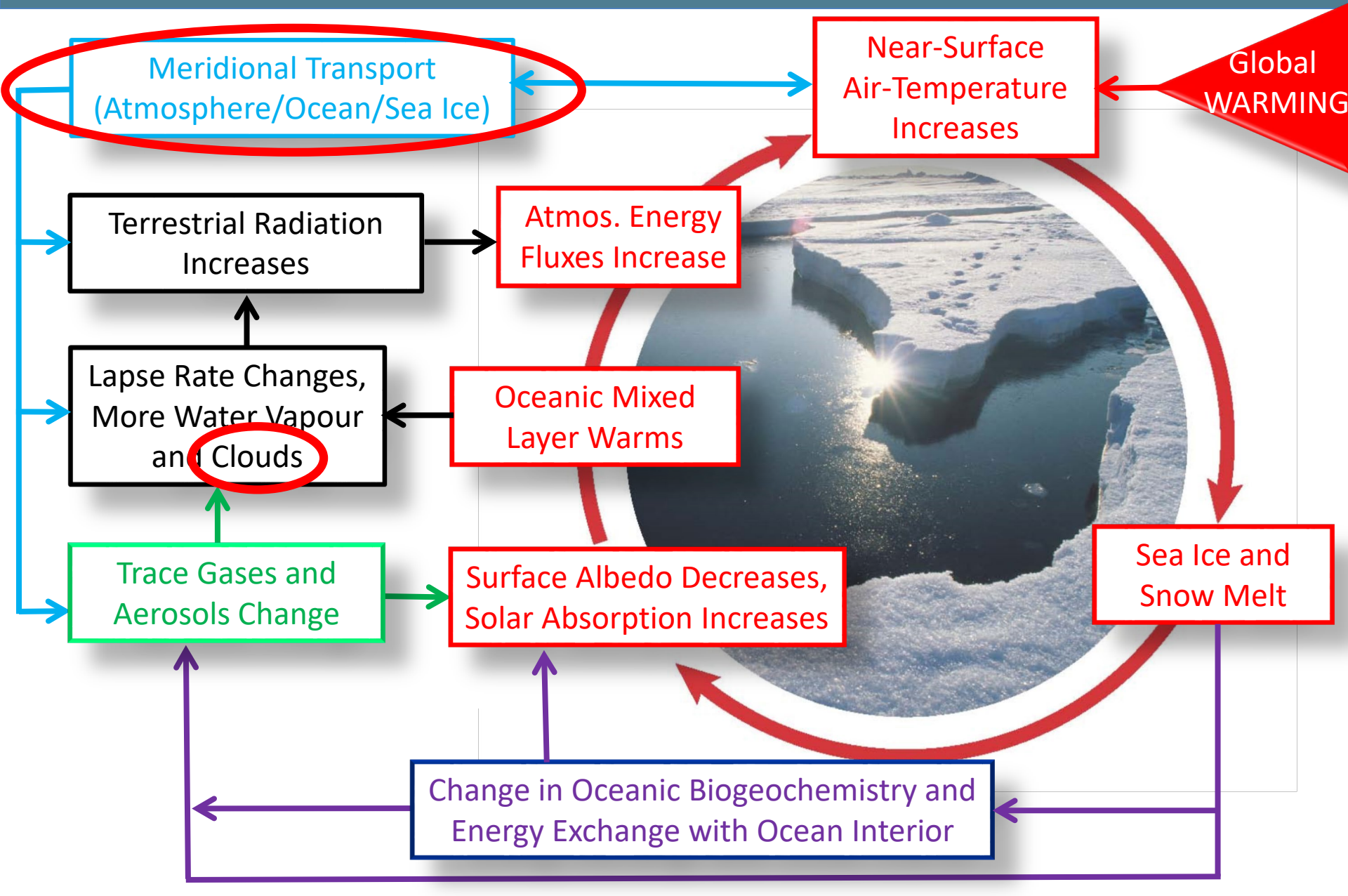
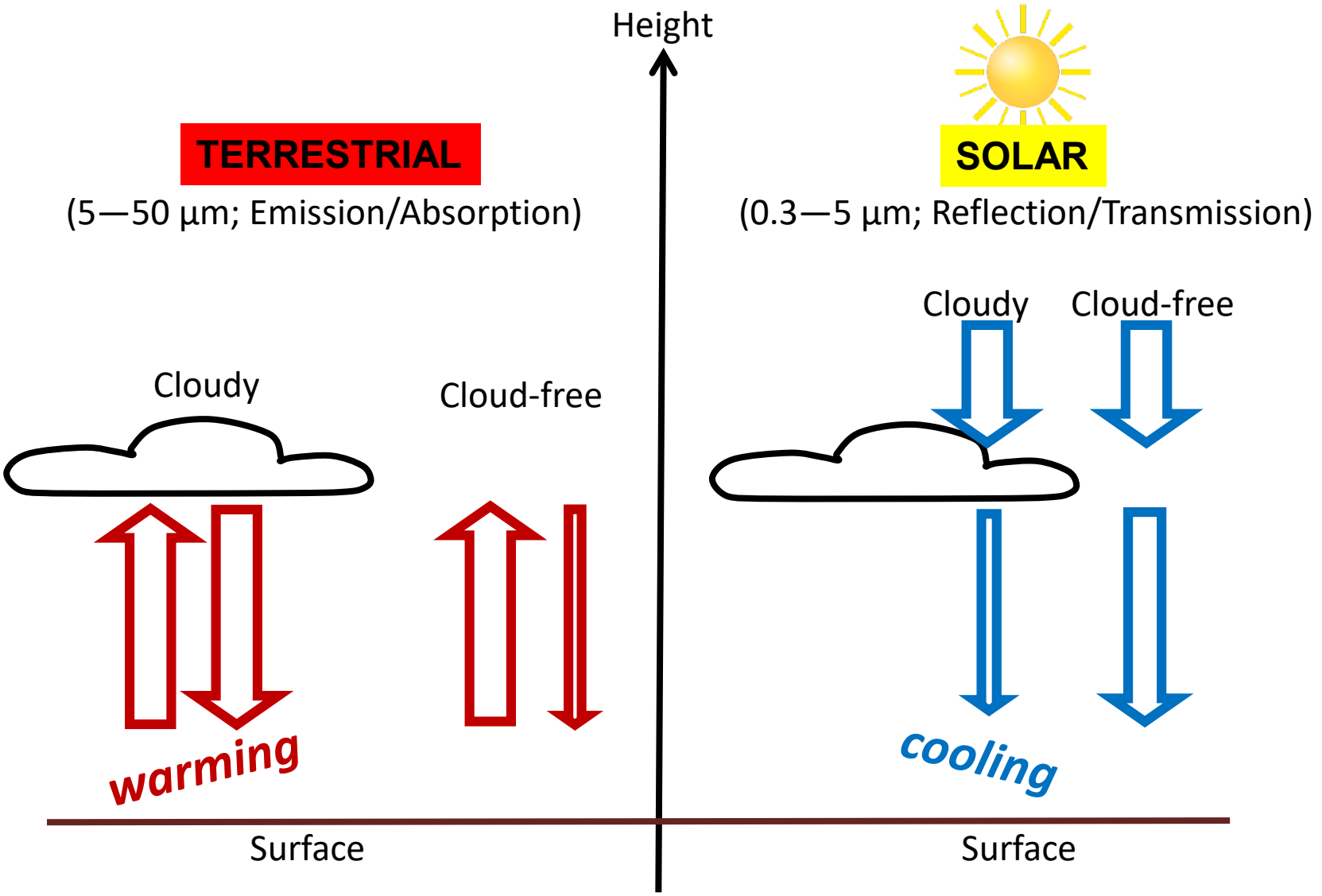
Examples of Feedbacks



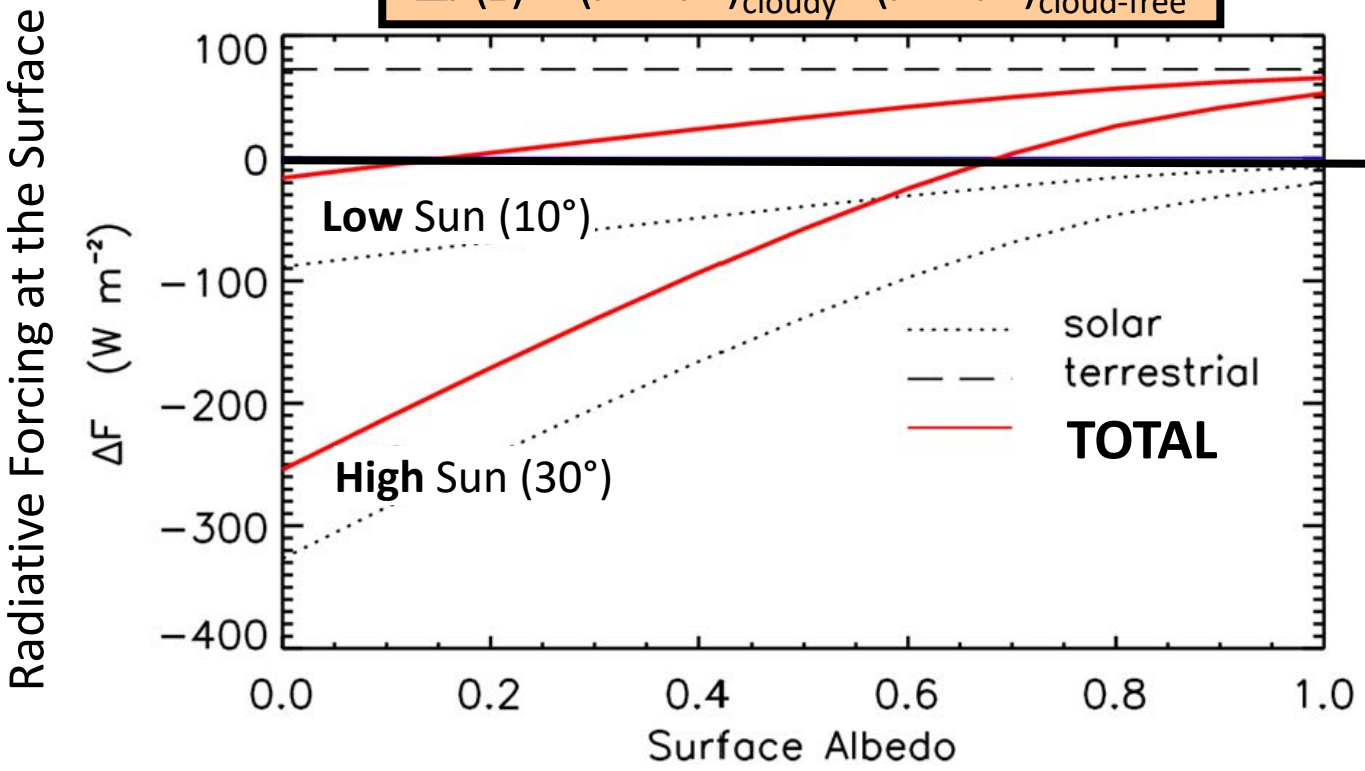
Arctic Mixed-Phase Clouds

Warming or Cooling — General Effects



Warming or Cooling — Simulations

$$\Delta F(z) = (F^{\downarrow} - F^{\uparrow})_{\text{cloudy}} - (F^{\downarrow} - F^{\uparrow})_{\text{cloud-free}}$$

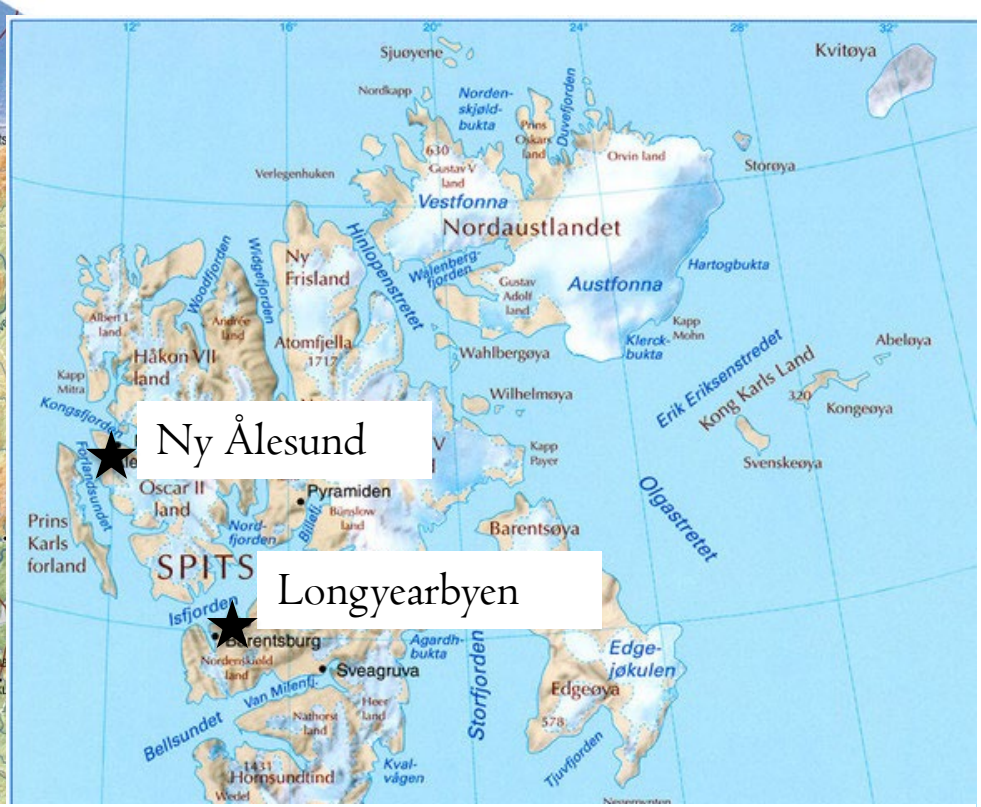


Influencing Factors:

- Cloud Height, Geometric Thickness and Cloud Cover
- Thermodynamic Phase and Ice Crystal Shape
- Optical and Microphysical Properties (τ, r_{eff})

Wendisch et al. (2013)

Warming or Cooling — Observations



ACLOUD: May—June 2017

Arctic **Cl**oud **O**bservations **U**sing Airborne Measurements During Polar **D**ay

Wendisch et al. (2019)

AFLUX: March—April 2019

Joint **A**ircraft Campaign Observing **FLUX**es of Energy and Momentum in the Cloudy Boundary Layer Over Polar Sea Ice and Oceans

Warming or Cooling — Observations

Research Aircraft P5 & P6 (AWI)

R/V Polarstern & Ice Camp

Tethered Balloon

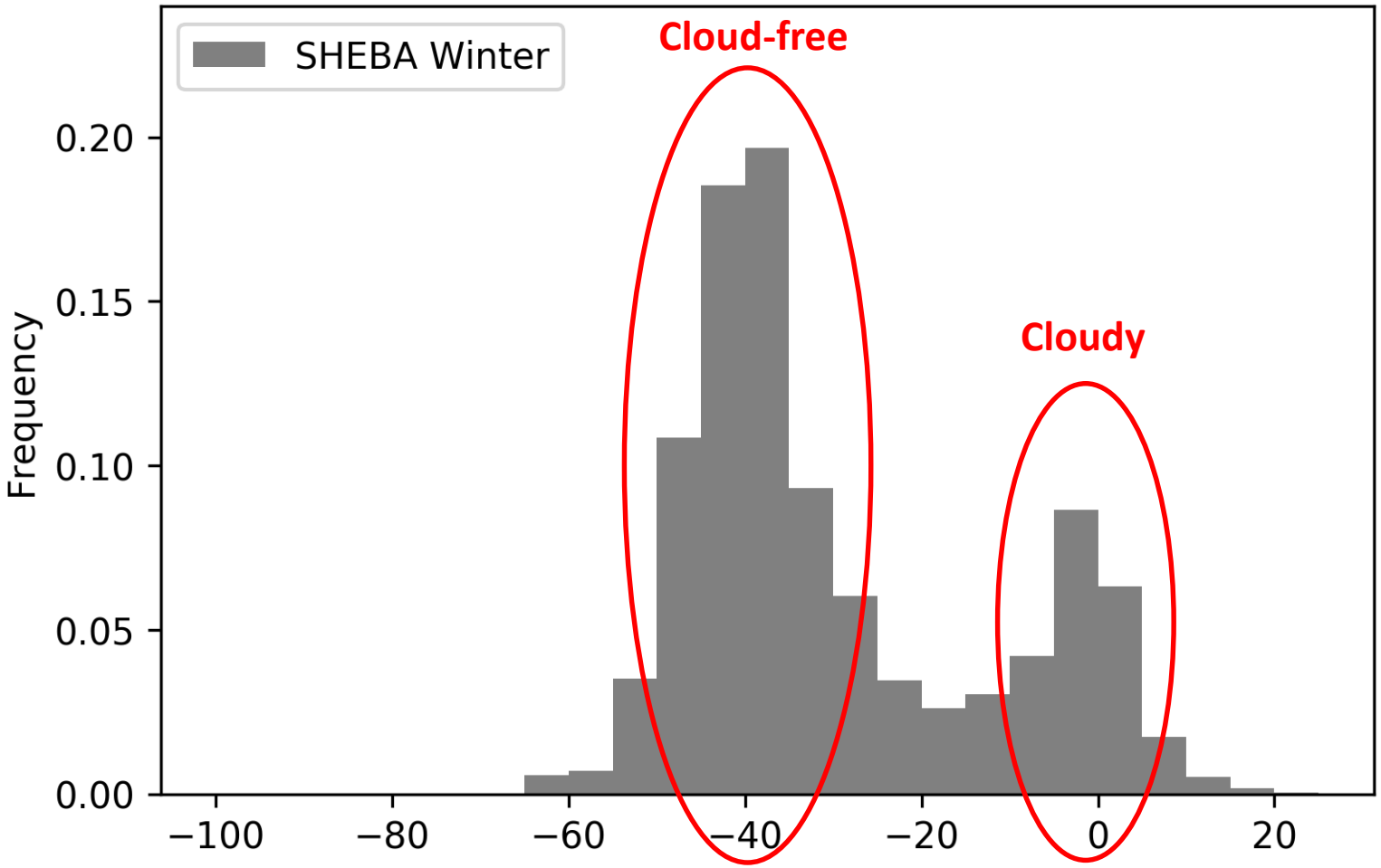
Foto: Stephan Schön, Sächsische Zeitung

Ny-Ålesund

Warming or Cooling — Observations

TERRESTRIAL

Over Sea Ice, Near the Surface



Stamler et al. (2011), Stapf et al. (2020)

Warming or Cooling — Observations

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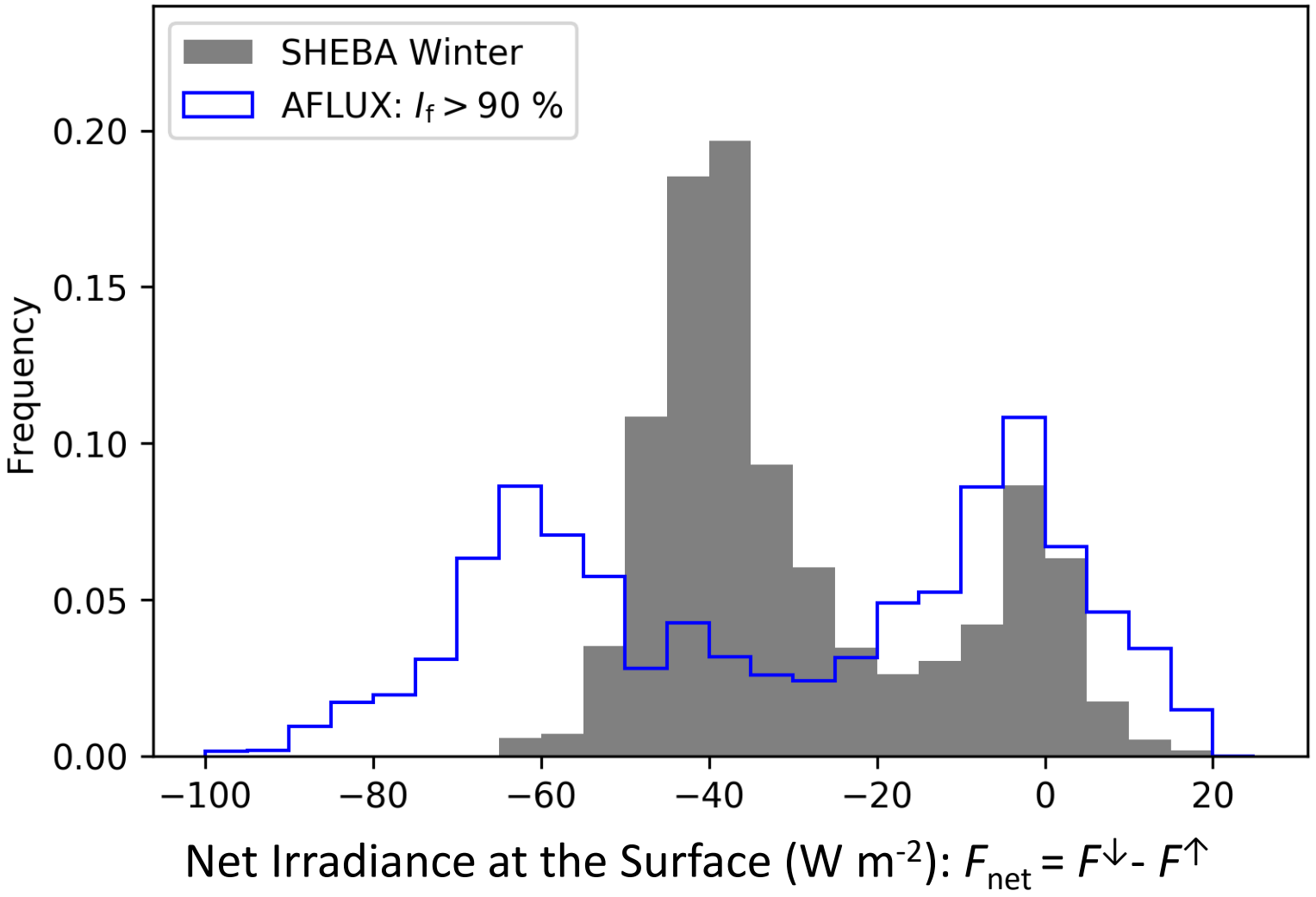

Stapf et al. (2020)

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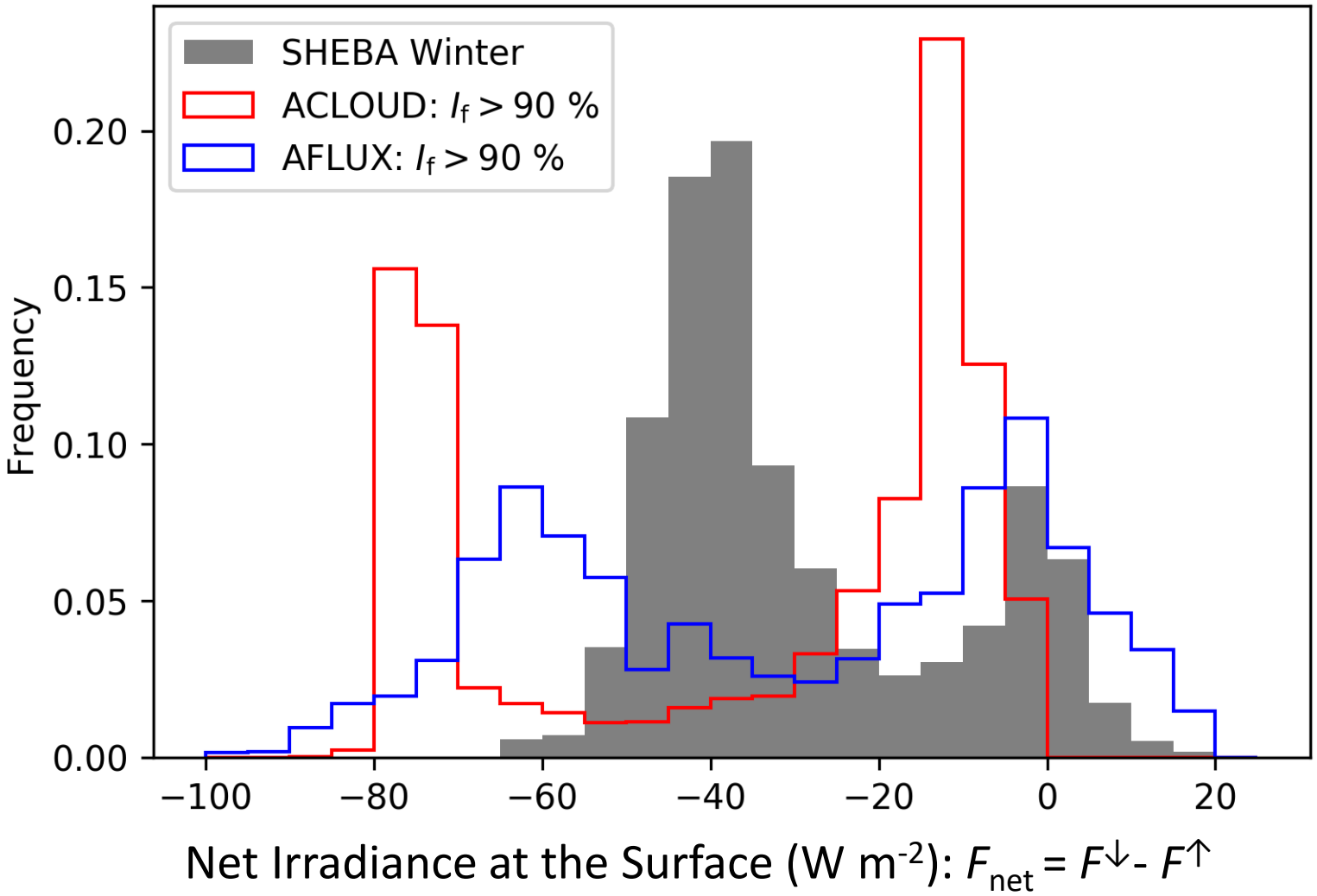
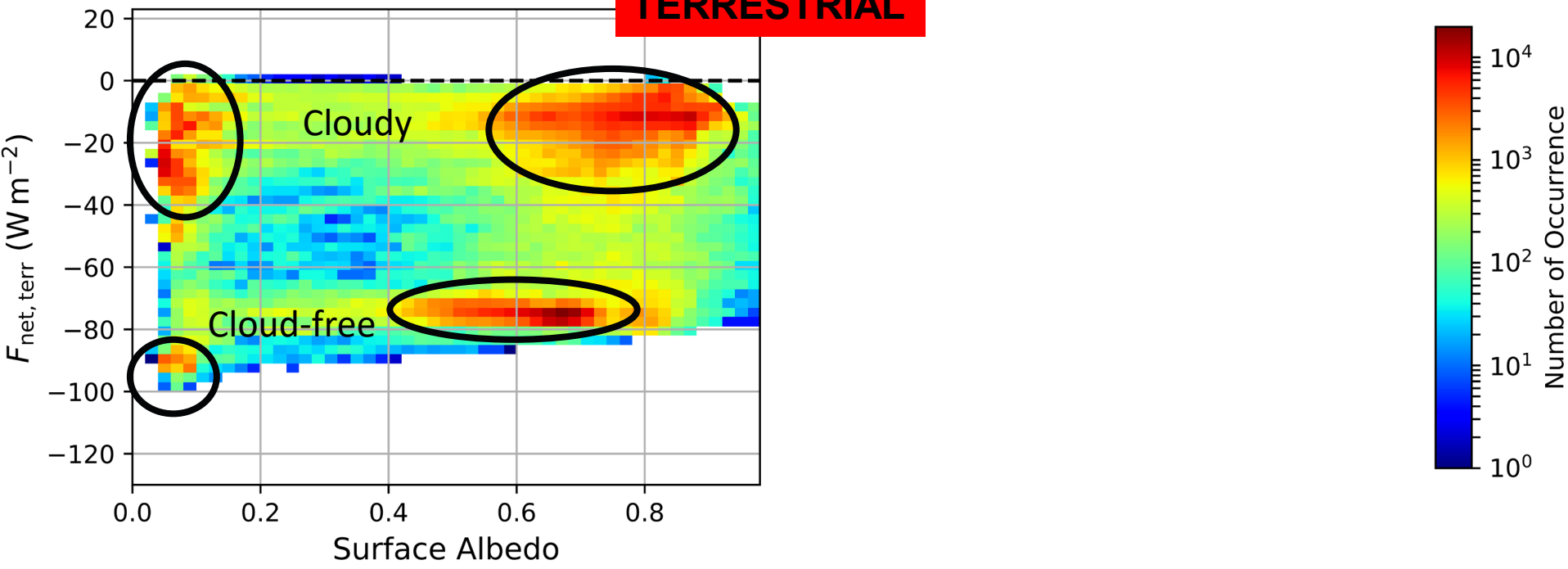


Stapf et al. (2020)

Aircraft Observations (Below Cloud): $F_{net} = F^{\downarrow} - F^{\uparrow}$

TERRESTRIAL



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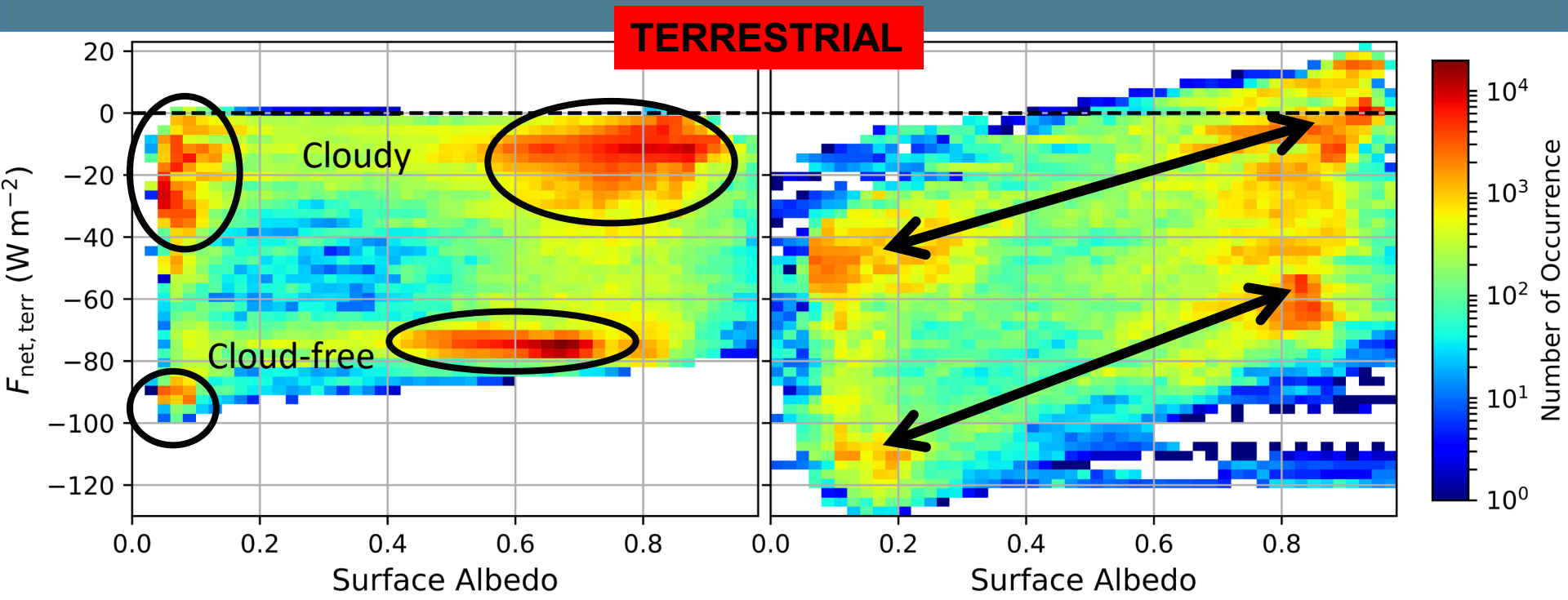

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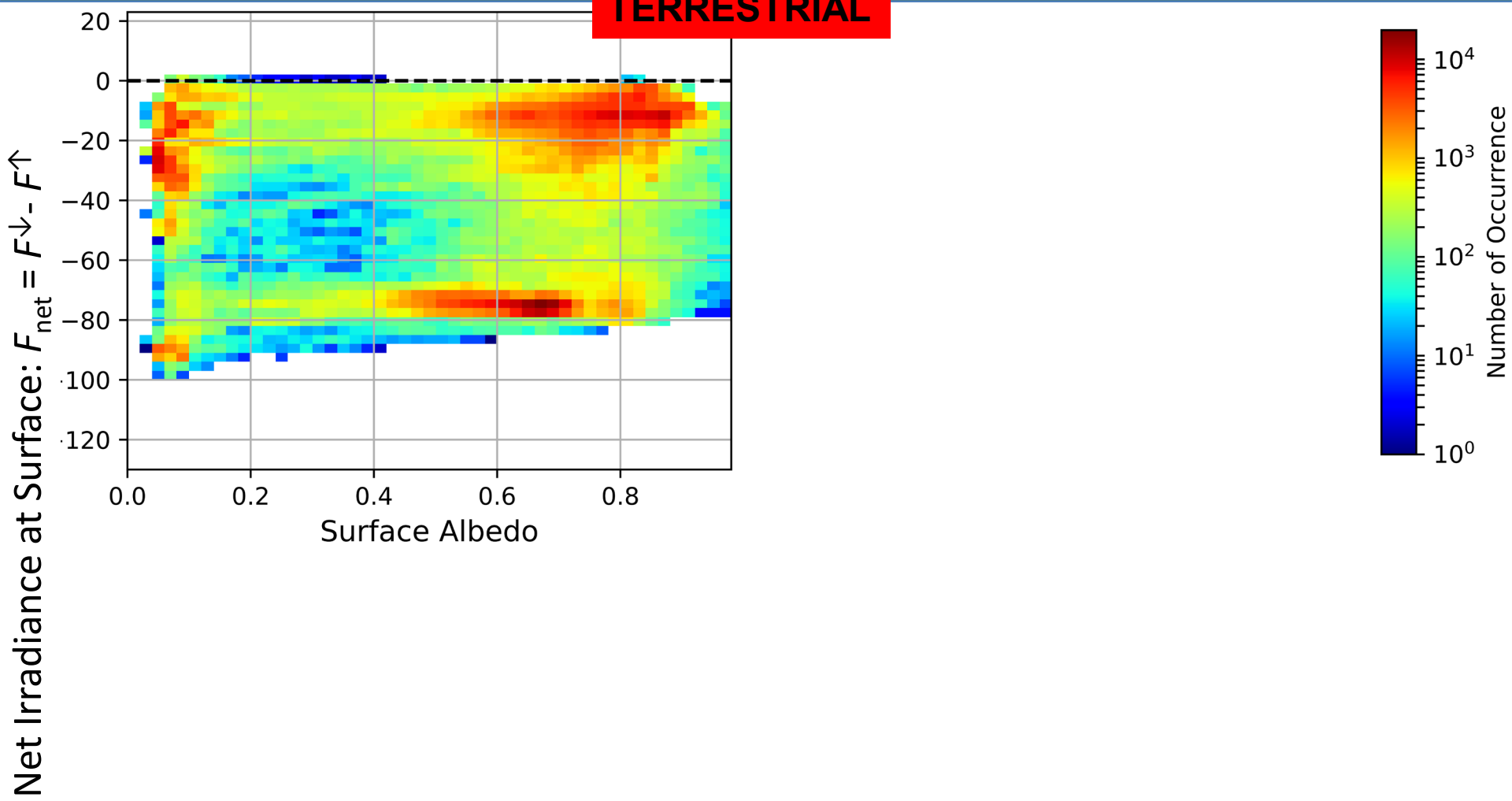

Wendisch et al. (2019)

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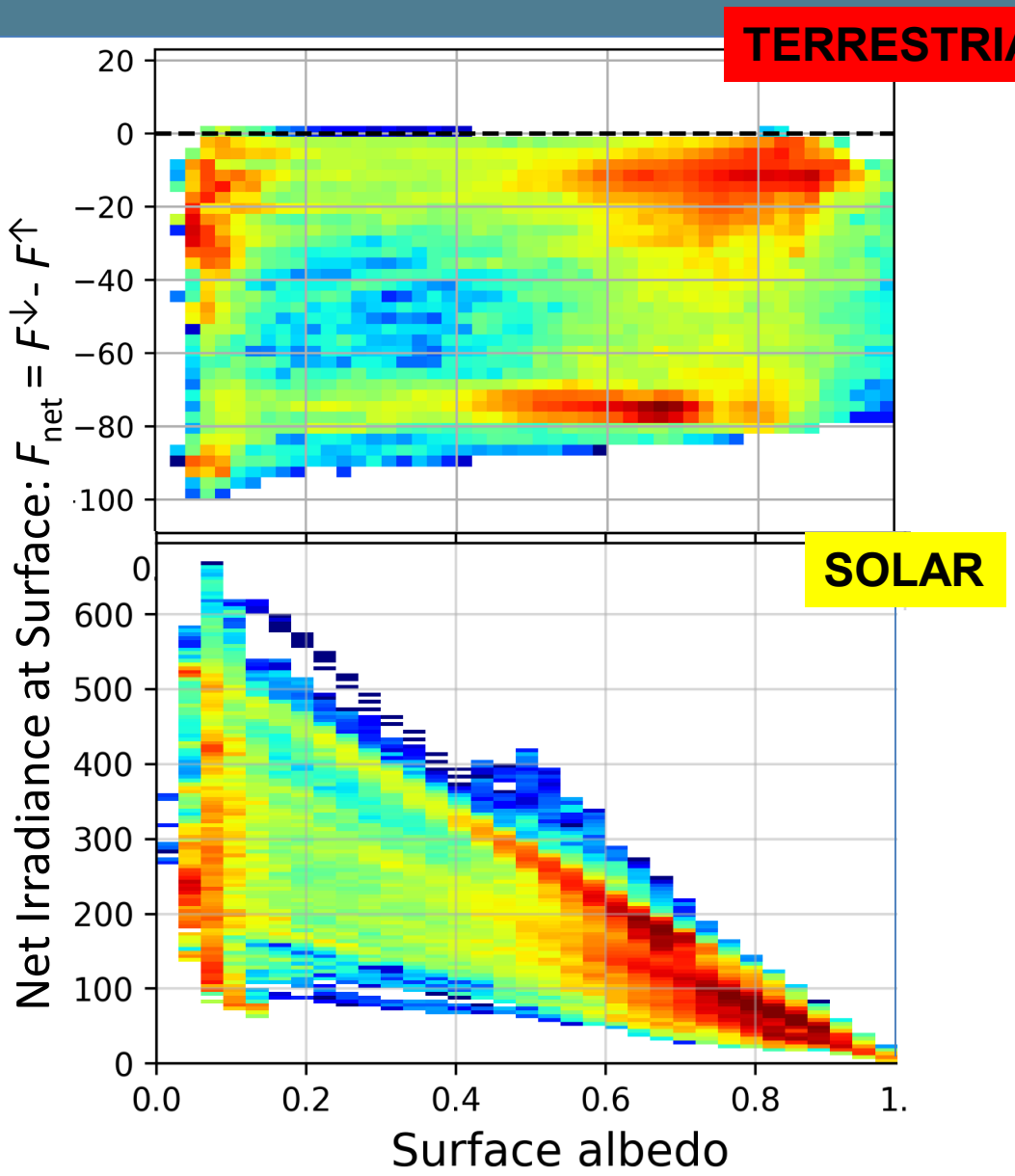
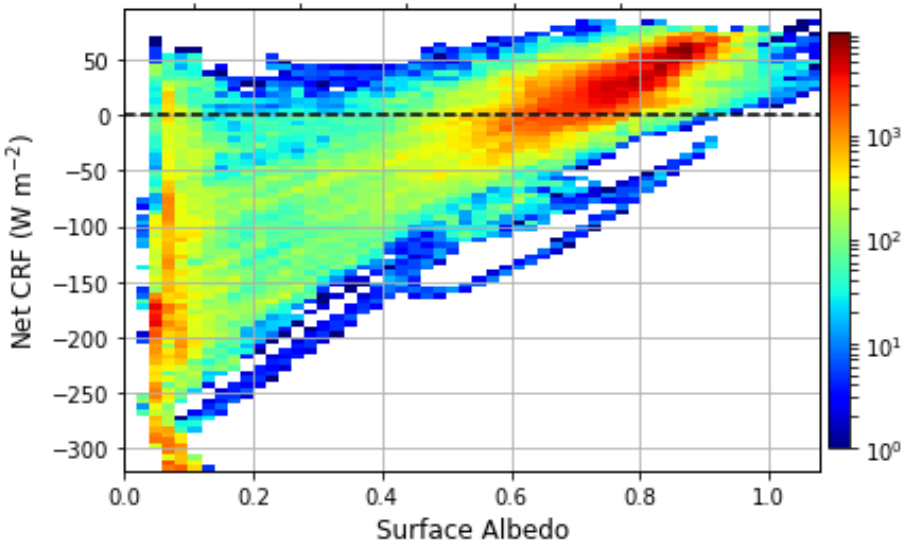


Wendisch et al. (2019)

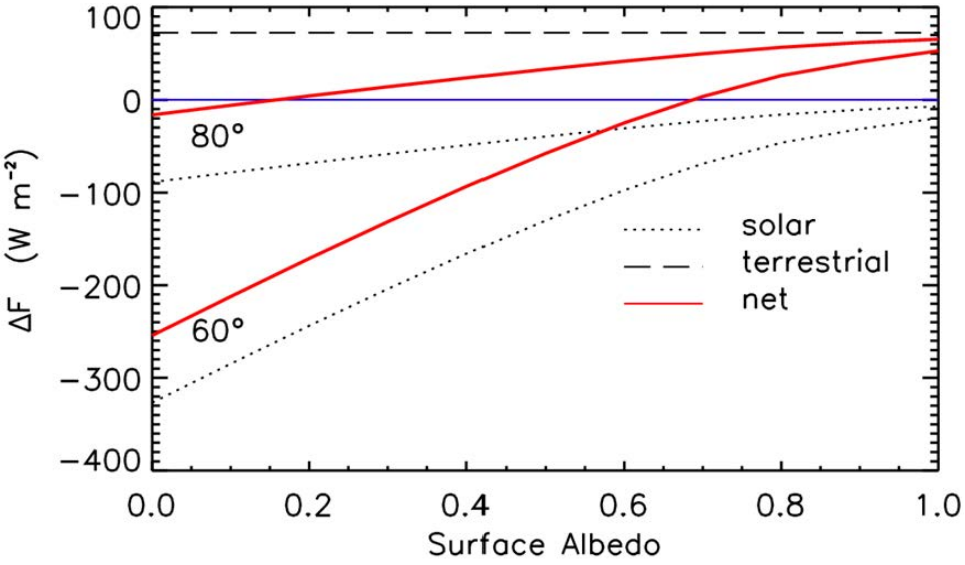
Cloud Radiative Forcing: $\Delta F = F_{\text{net,cloud}} - F_{\text{net,cloud-free}}$

SOLAR + TERRESTRIAL

Aircraft—Measured (ACLOUD) & Cloud-free Simulation



Radiative Transfer Model



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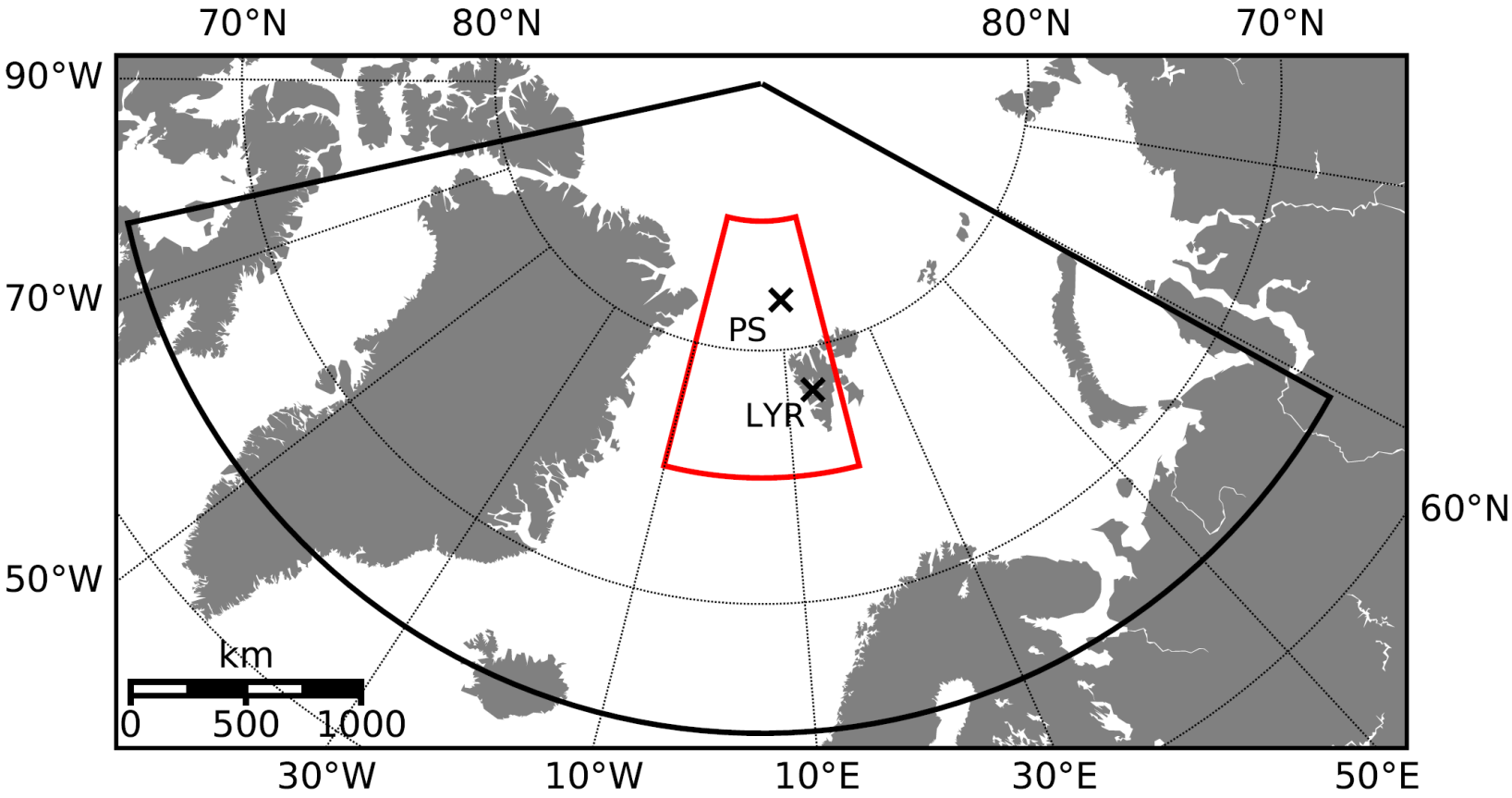
Wendisch et al. (2019)

Wendisch et al. (2013,2019)

Warming or Cooling — Simulations with ICON



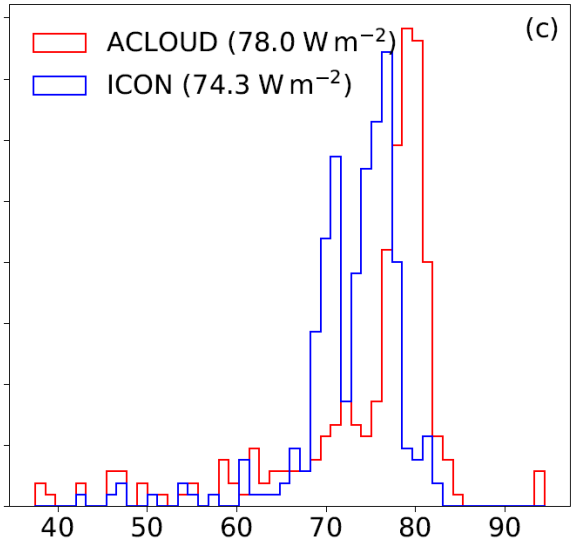
- ICON runs (2.4 km, nest with 1.2 km, 75 vertical layers each)
- Intital and boundary condition from IFS (reinitialized every day)
- Sampled model output (temporal and spatial) along flight track

Kretzschmar et. al. (2020)

Cloud Radiative Forcing: $\Delta F = F_{\text{net,cloud}} - F_{\text{net,cloud-free}}$

Cloud Mode over Sea Ice

TERRESTRIAL



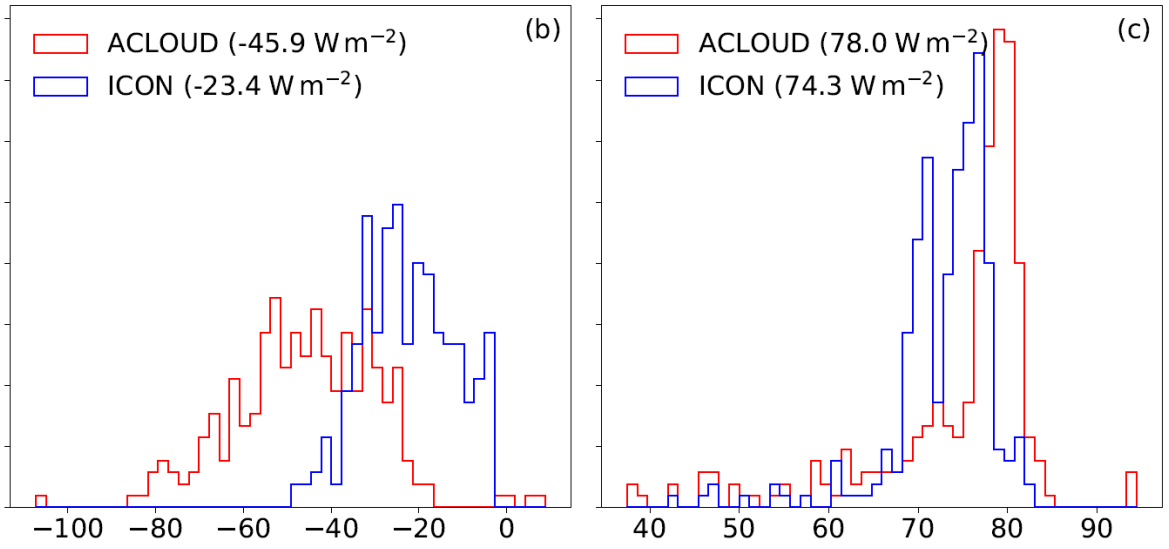
Cloud Radiative Forcing at Surface (W m^{-2}): $\Delta F = F_{\text{net,cloud}} - F_{\text{net,cloud-free}}$

Kretzschmar et. al. (2020)

Cloud Radiative Forcing: $\Delta F = F_{\text{net,cloud}} - F_{\text{net,cloud-free}}$

Cloud Mode over Sea Ice

SOLAR **TERRESTRIAL**



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Kretzschmar et. al. (2020)

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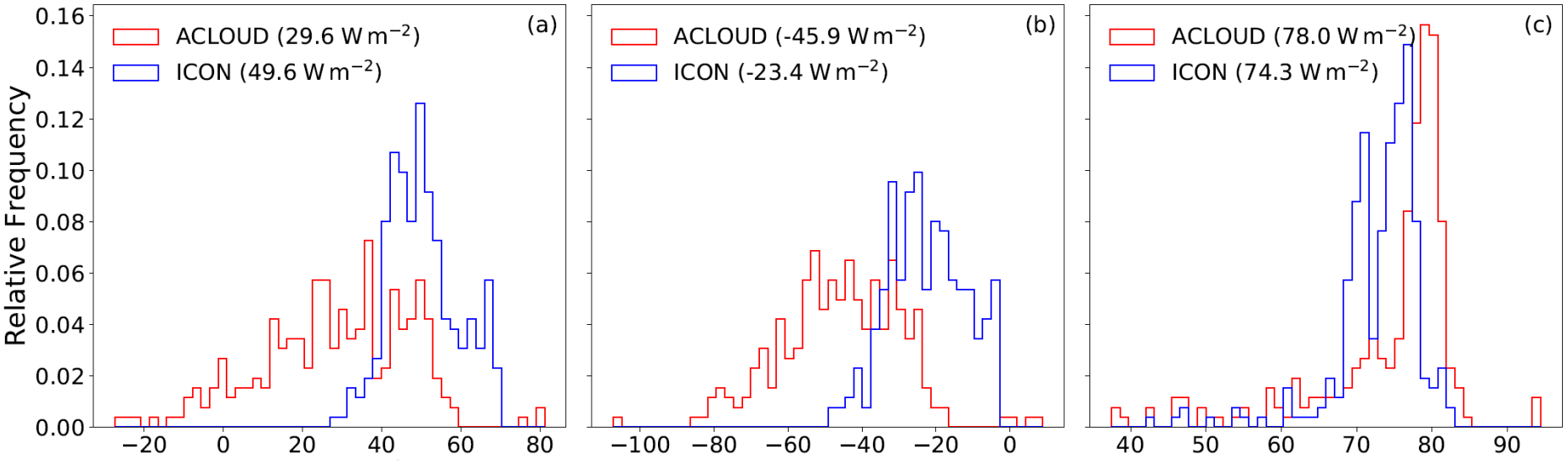
Cloud Mode over Sea Ice

SOLAR + TERRESTRIAL **SOLAR** **TERRESTRIAL**



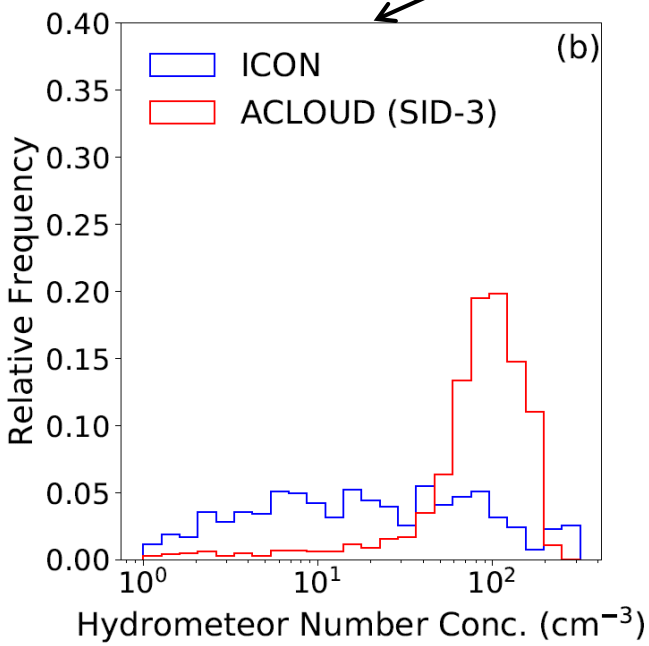
Cloud Radiative Forcing at Surface (W m^{-2}): $\Delta F = F_{\text{net,cloud}} - F_{\text{net,cloud-free}}$

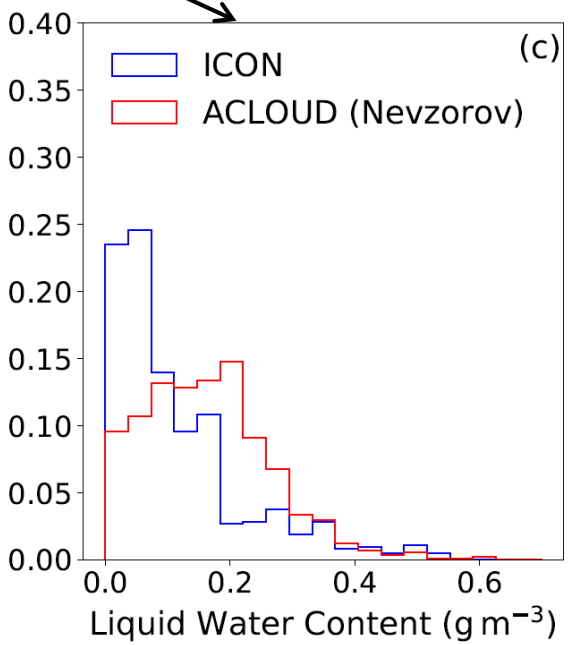
Kretzschmar et. al. (2020)

Potential Issues within ICON: MICROphysical Properties

$$\tau_c = \int_{z_{base}}^{z_{top}} \beta_{ext}(z)\,dz$$

$$\beta_{ext} \sim N_d^{\frac{1}{3}} \cdot q_c^{\frac{2}{3}}$$





Kretzschmar et. al. (2020)

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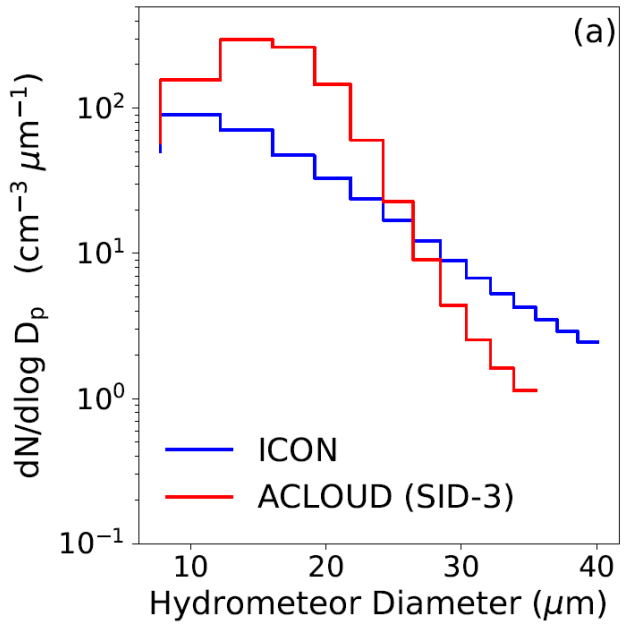

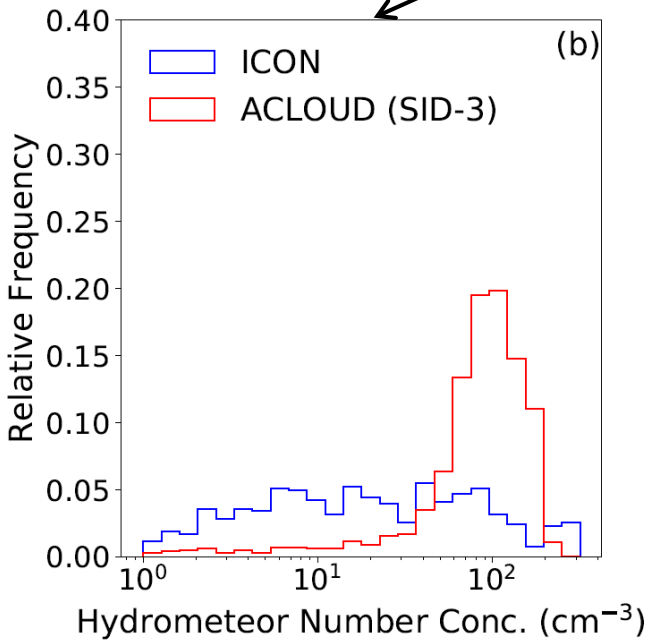

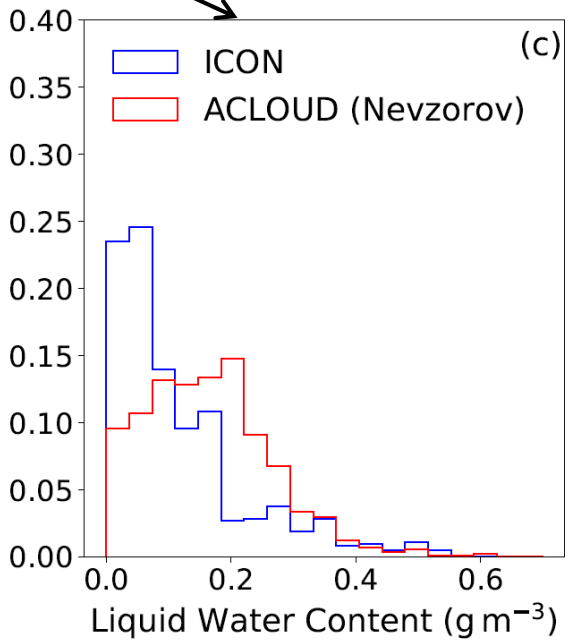

Kretzschmar et. al. (2020)

Issues/Actions/Results

Issues

- Clouds **optically too thin**, because **too few small droplets** are being generated by ICON
- Problem: Droplet activation is parameterized as a function of **grid-scale averaged vertical velocity**
- 1.2 km grid resolution does not resolve **in-cloud vertical motion and turbulence**, producing major sub-grid scale velocity fluctuations resulting in supersaturation spikes, causing droplet activation

Action

Results

Kretzschmar et. al. (2020)

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Action

- Modification of **droplet activation scheme**
- Parameterization of **sub-grid scale vertical motion** as a function of specific turbulent kinetic energy
- Instead of on average value of vertical velocity per grid cell → **Gaussian distribution**

Results

Kretzschmar et. al. (2020)

Issues/Actions/Results

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- Clouds **optically too thin**, because **too few small droplets** are being generated by ICON
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Action

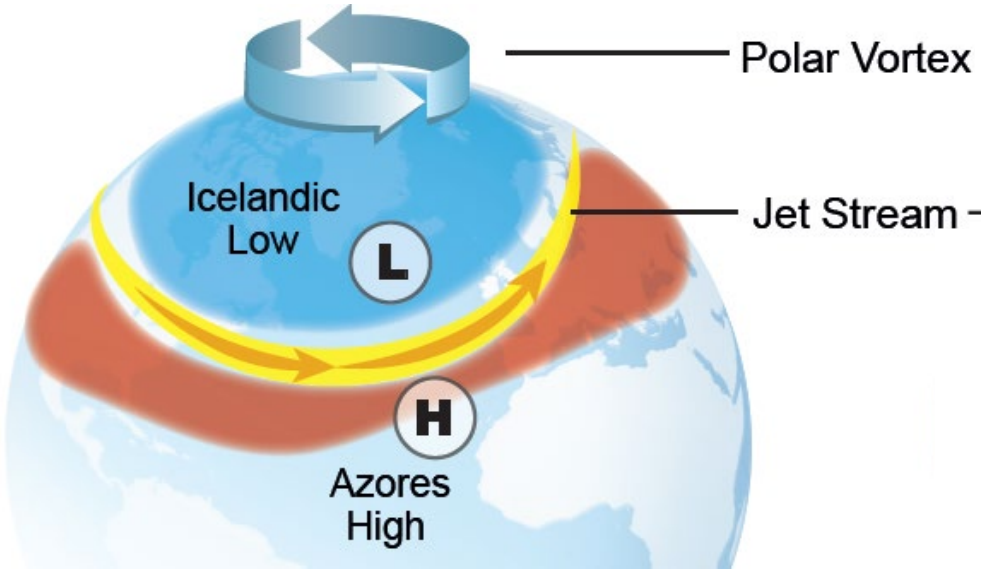
- Modification of **droplet activation scheme**
- Parameterization of **sub-grid scale vertical motion** as a function of specific turbulent kinetic energy
- Instead of on average value of vertical velocity per grid cell → **Gaussian distribution**

Results

- Missing small droplets are generated
- Systematic underestimation of LWC is partly resolved
- Improved representation of cloud radiative forcing by ICON, as compared to the aircraft measurements

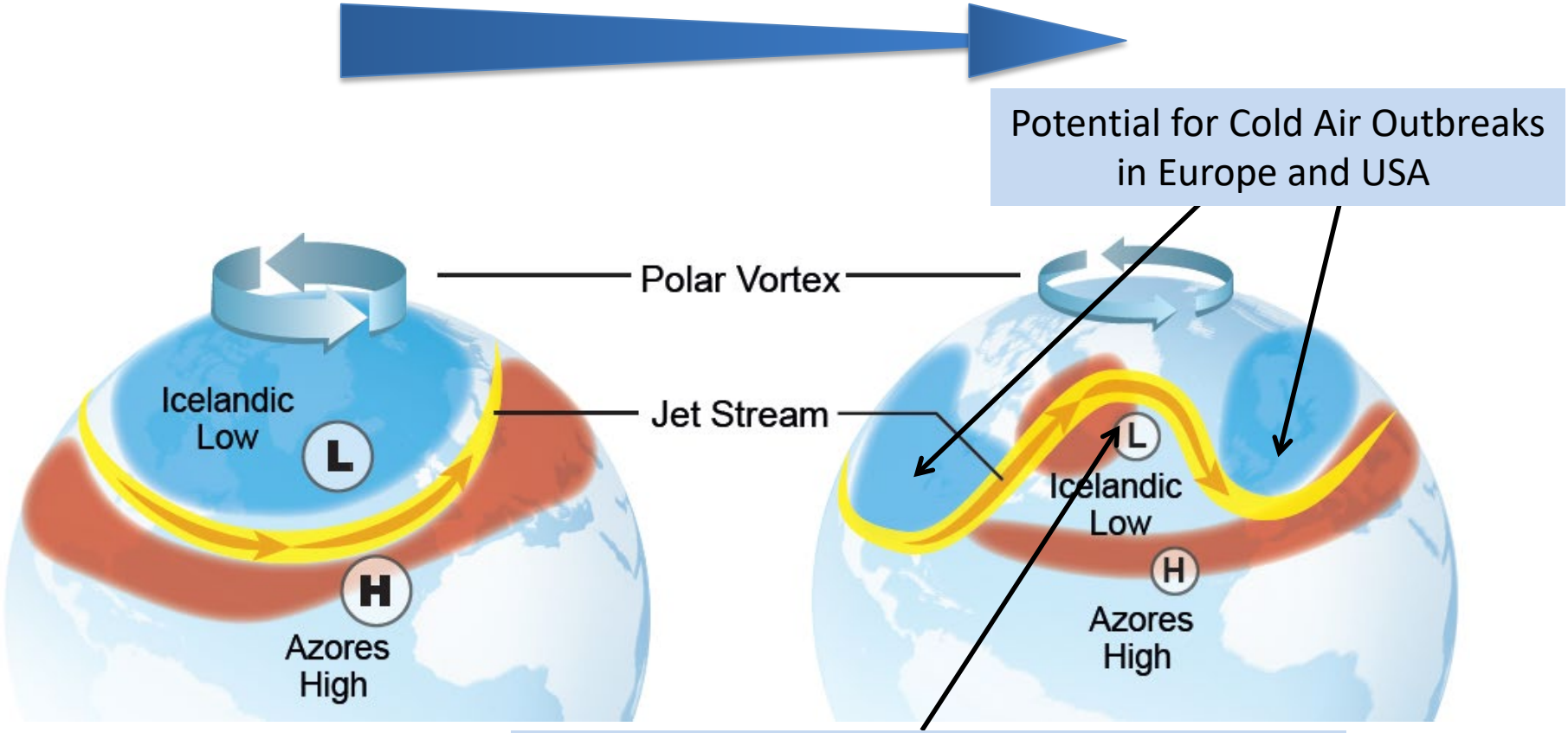
Kretzschmar et. al. (2020)

Arctic-Midlatitude Interactions

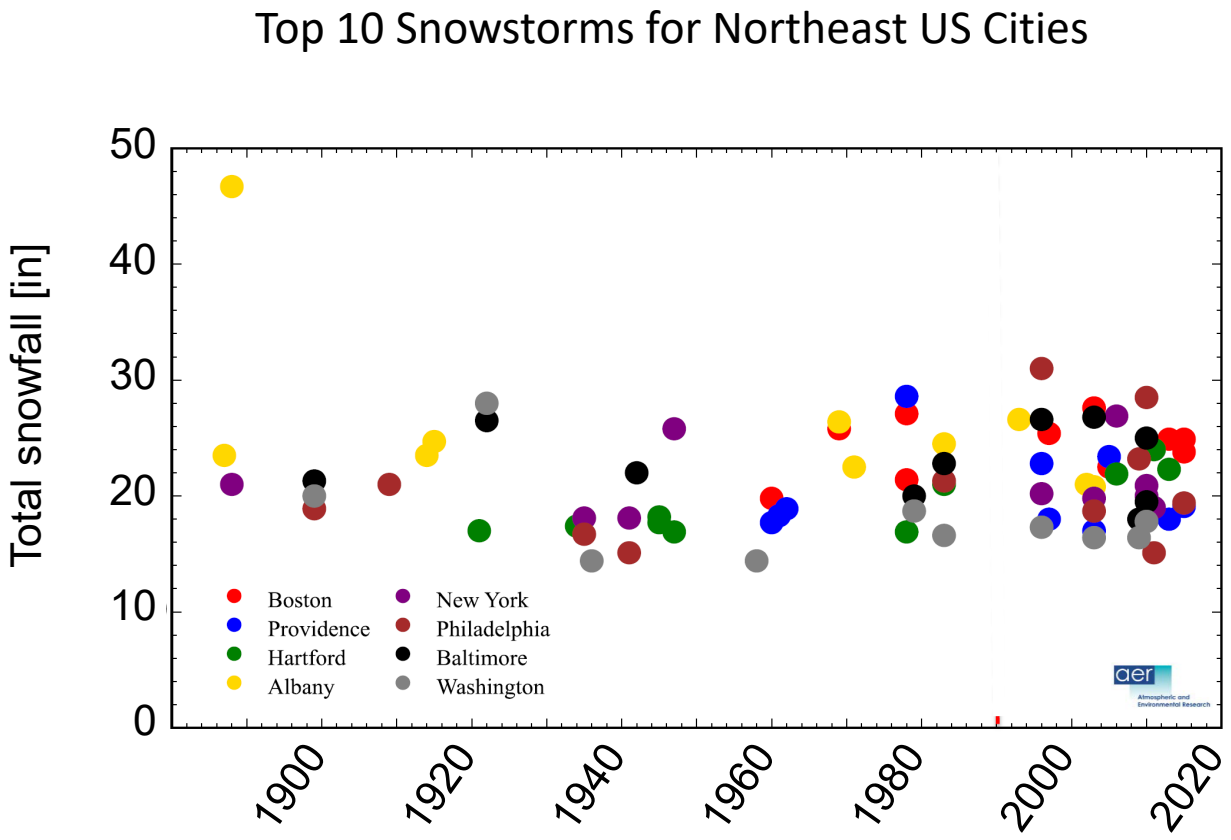


Arctic-Midlatitude Interactions

Enhanced Rossby Wave Amplitudes, More Blocking Situations



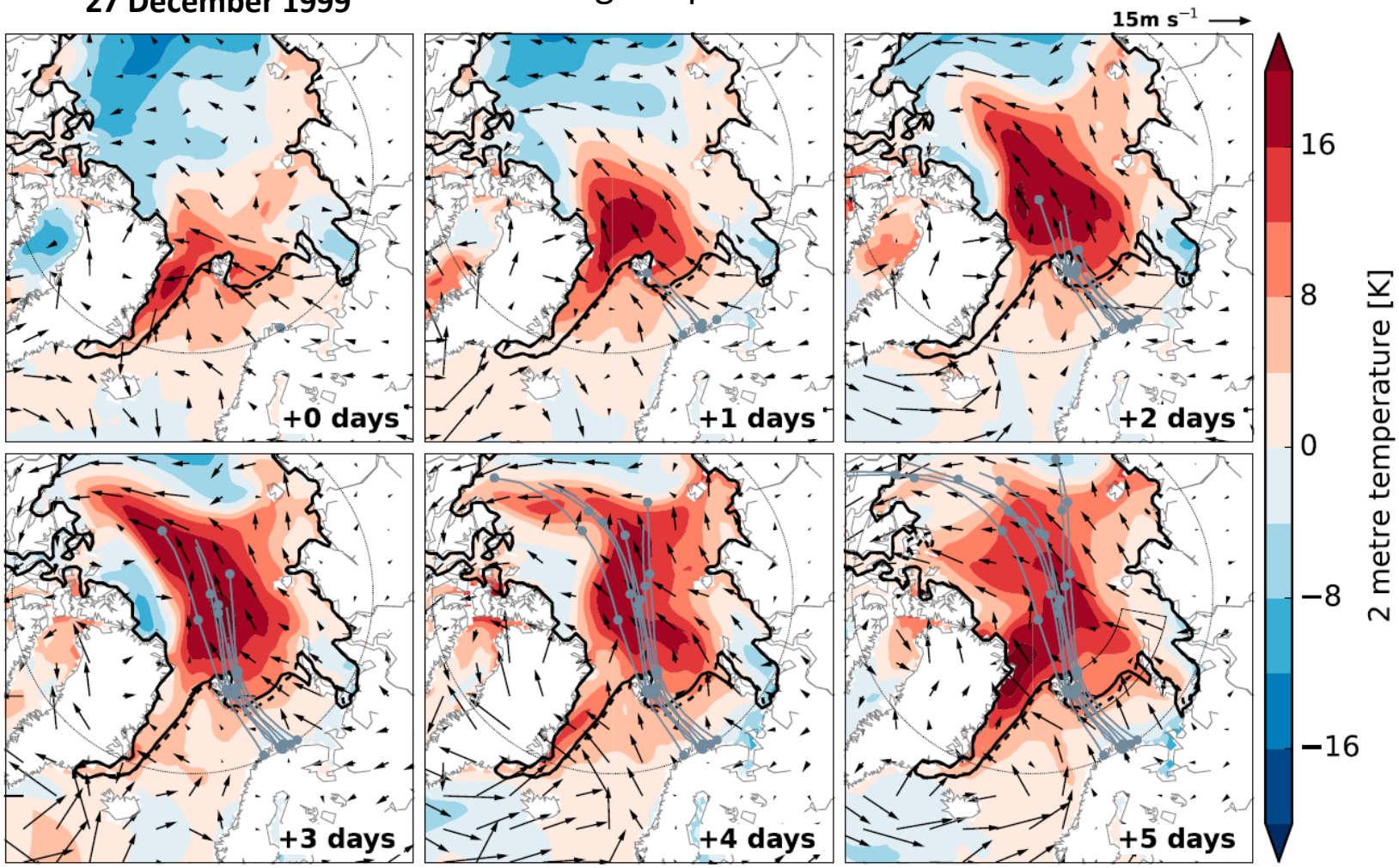
Cold Air Outbreaks



Cohen et al., 2016

Warm Air Intrusions

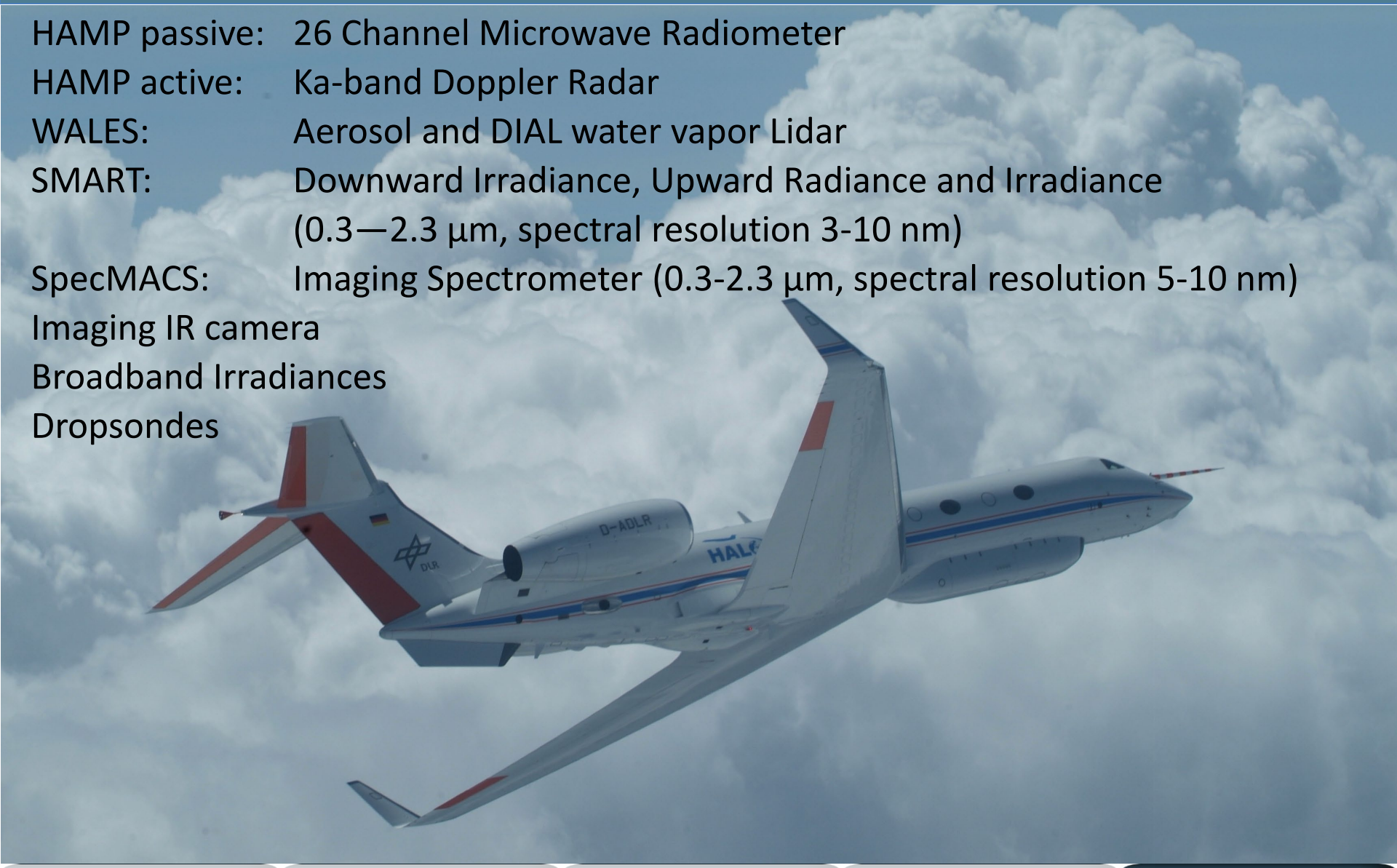
Filametary, intense, spatially localized warm air/moisture injections (mostly in pulses), reaching deep into inner Arctic



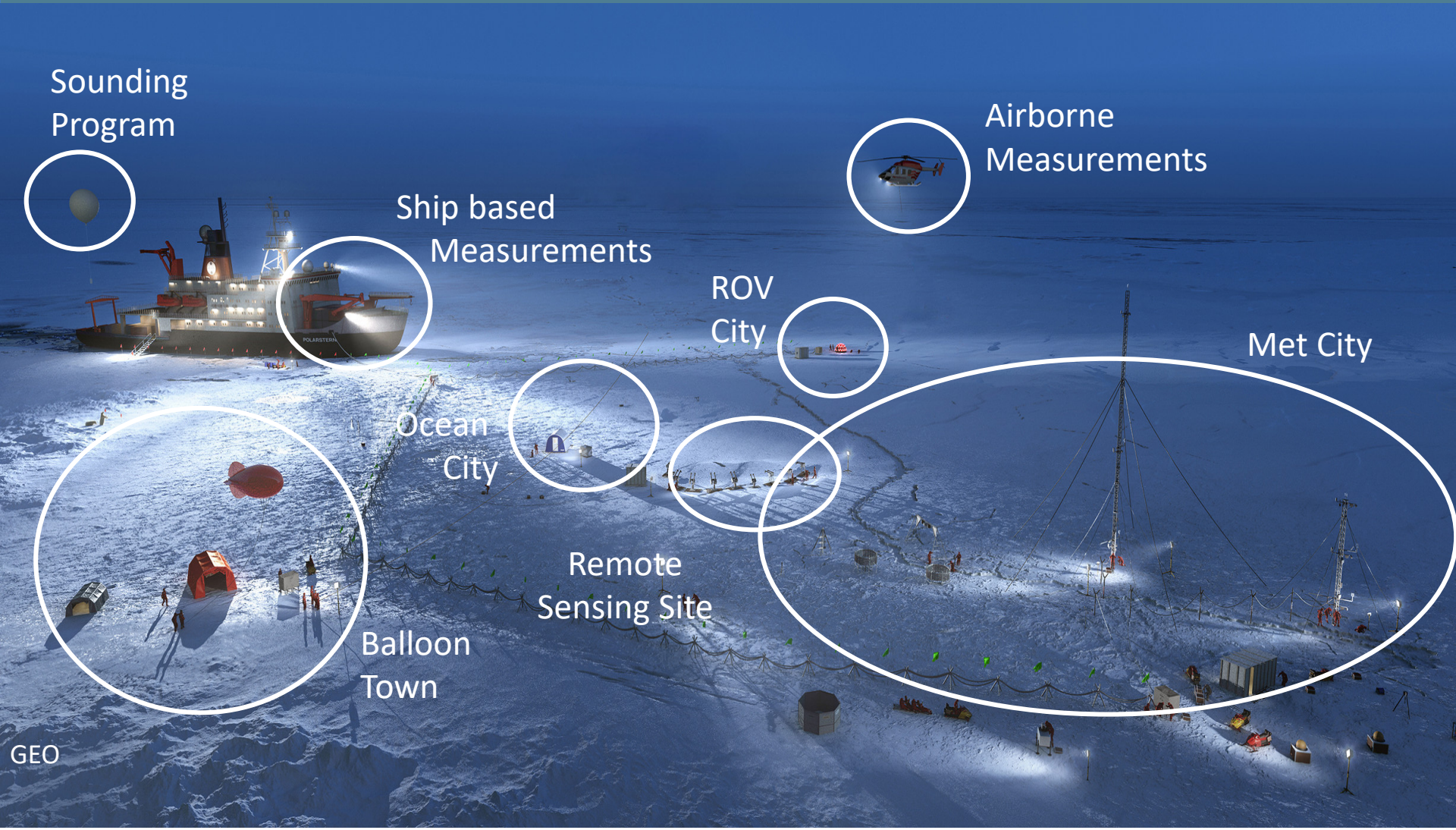
Woods and Caballero (2016)

HALO—High Altitude and Long Range Research Aircraft

HAMP passive: 26 Channel Microwave Radiometer
HAMP active: Ka-band Doppler Radar
WALES: Aerosol and DIAL water vapor Lidar
SMART: Downward Irradiance, Upward Radiance and Irradiance (0.3—2.3 µm, spectral resolution 3-10 nm)
SpecMACS: Imaging Spectrometer (0.3-2.3 µm, spectral resolution 5-10 nm)
Imaging IR camera
Broadband Irradiances
Dropsondes

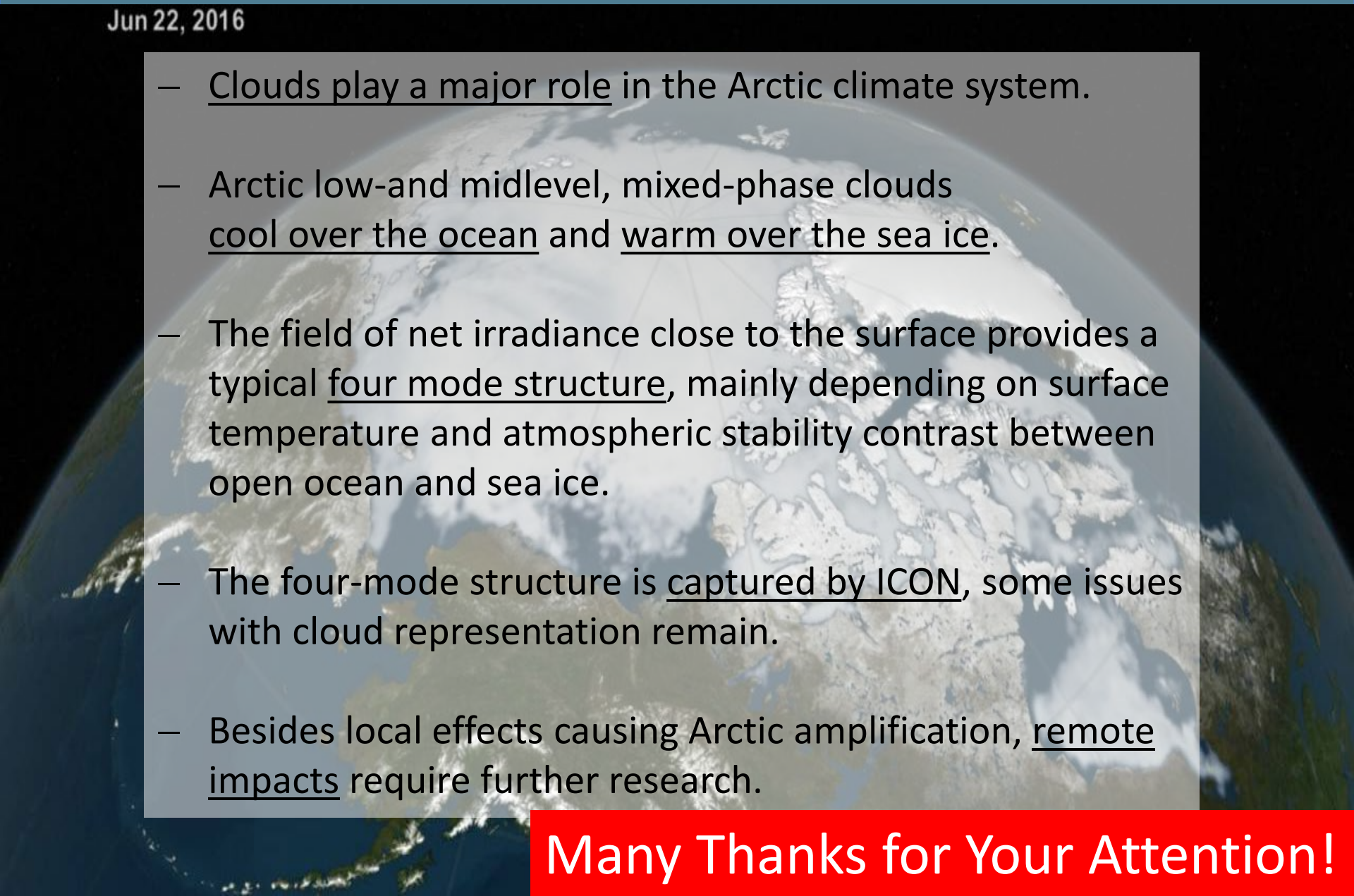


MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate)



https://mosaic-expedition.org/

Take-Home-Messages



- Clouds play a major role in the Arctic climate system.
- Arctic low-and midlevel, mixed-phase clouds cool over the ocean and warm over the sea ice.
- The field of net irradiance close to the surface provides a typical four mode structure, mainly depending on surface temperature and atmospheric stability contrast between open ocean and sea ice.
- The four-mode structure is captured by ICON, some issues with cloud representation remain.
- Besides local effects causing Arctic amplification, remote impacts require further research.

Many Thanks for Your Attention!