Extratropical and Polar Cloud Systems

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What is special about polar regions

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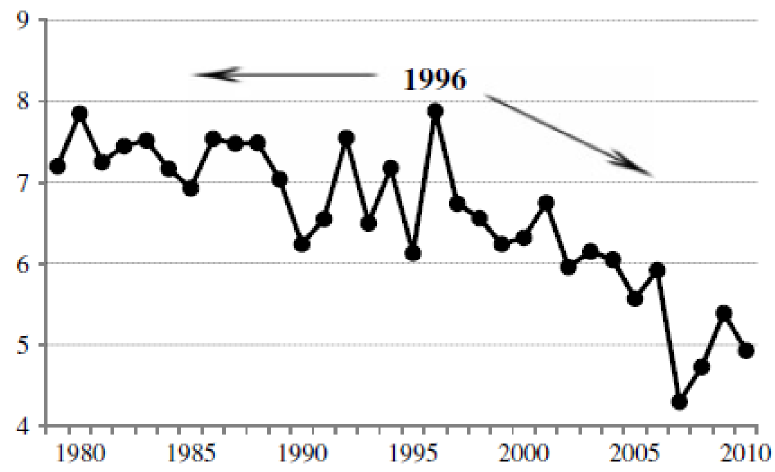
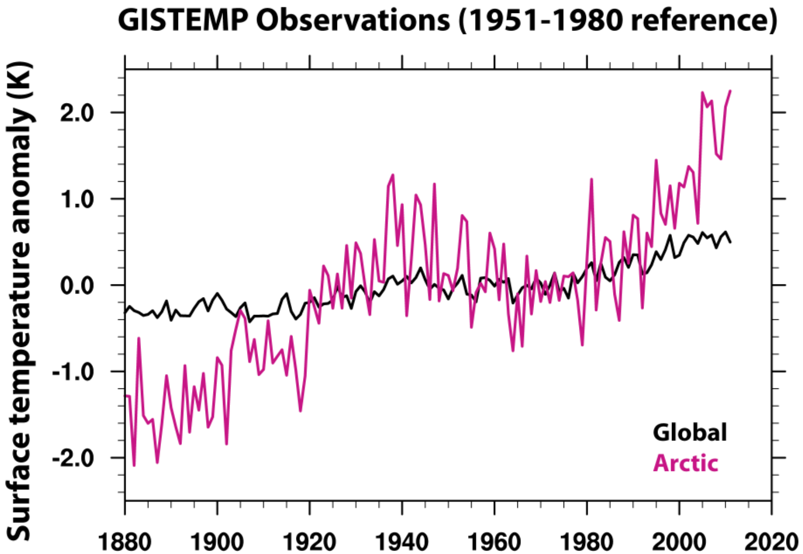
- The diurnal cycle is weak, the annual cycle is very strong
- Strong interaction with the surface
- Underlying surface has either very high albedo (sea-ice) or low (ocean)
- Arctic climate is changing faster than elsewhere

September sea-ice extent (millions of square km)





Arctic climate system

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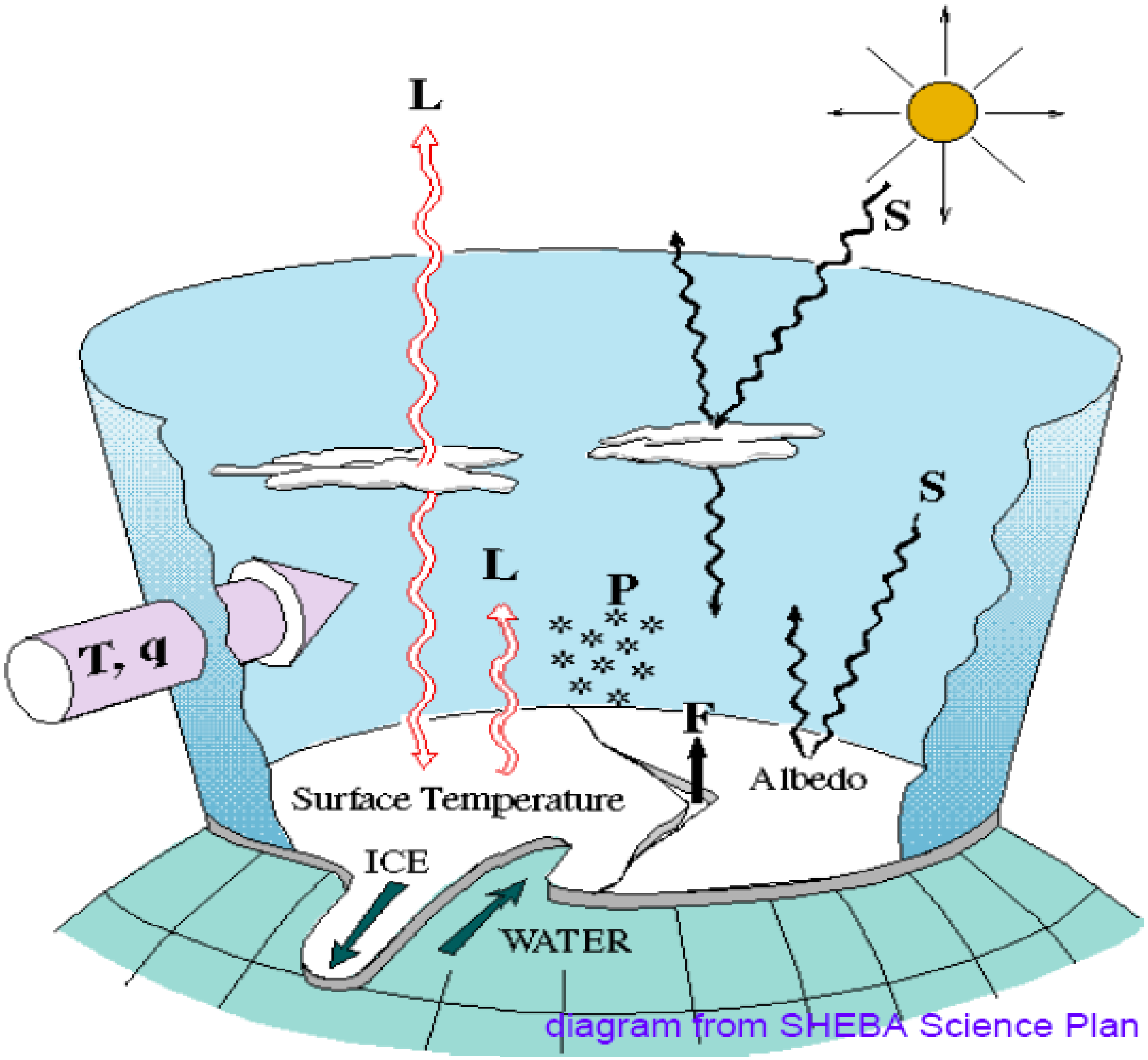


diagram from SHEBA Science Plan

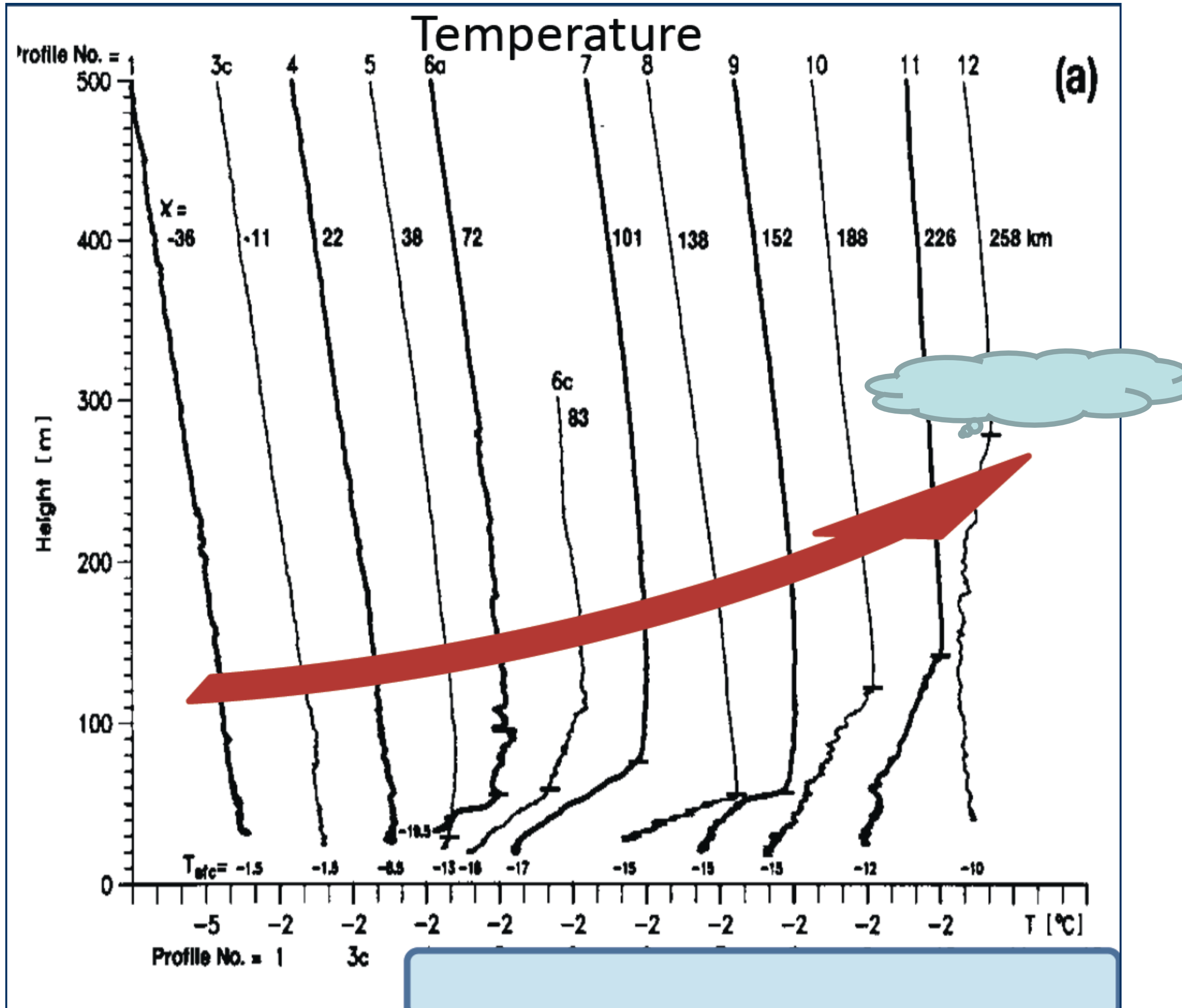
Air mass transformation

A stably stratified internal boundary layer is formed when the air is transported in over the sea-ice

Low-level clouds are formed due to the cooling

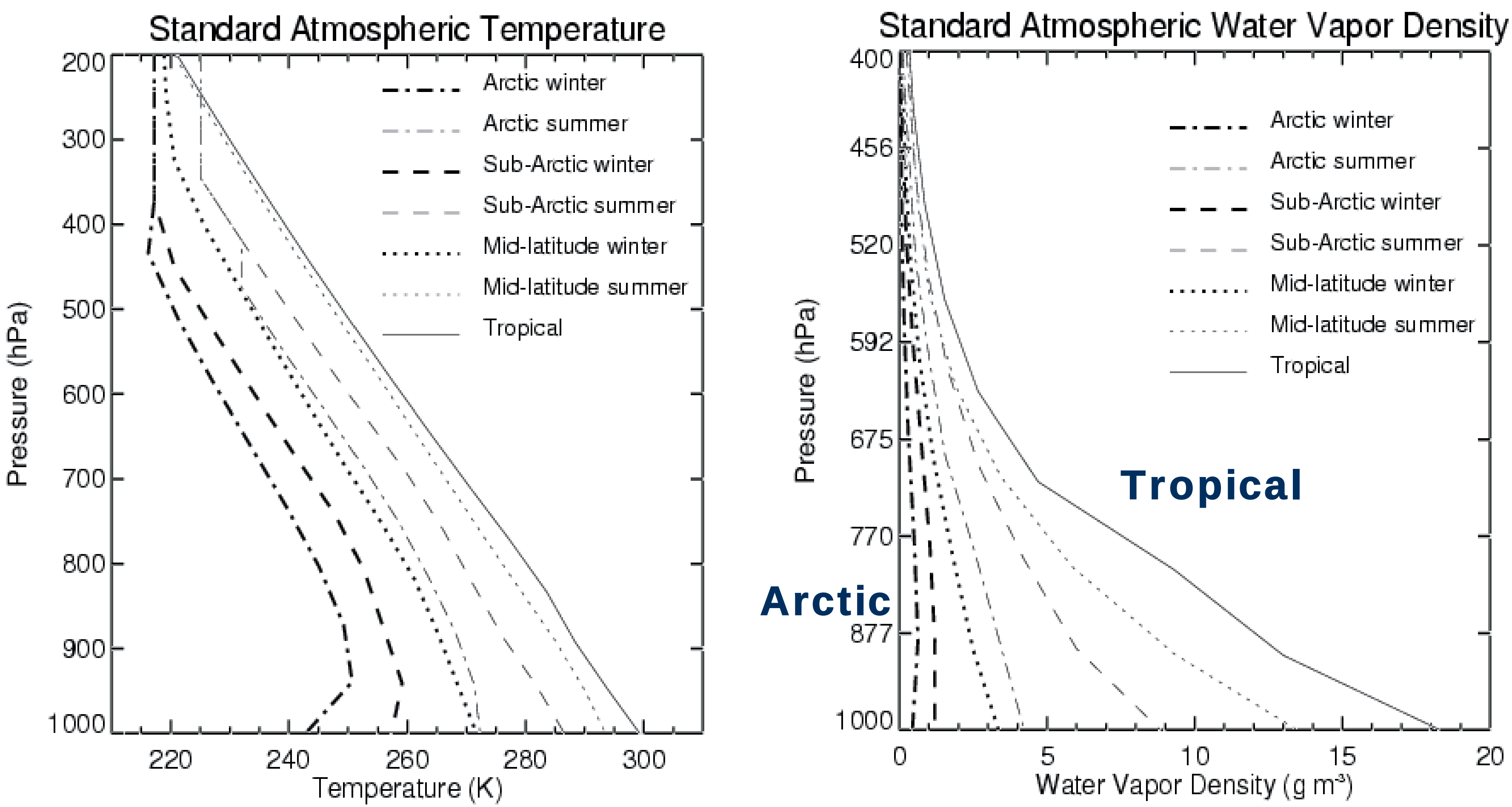
Precipitation will reduce the number of CCN in the boundary layer

This explains the warmer and moister air aloft in all seasons

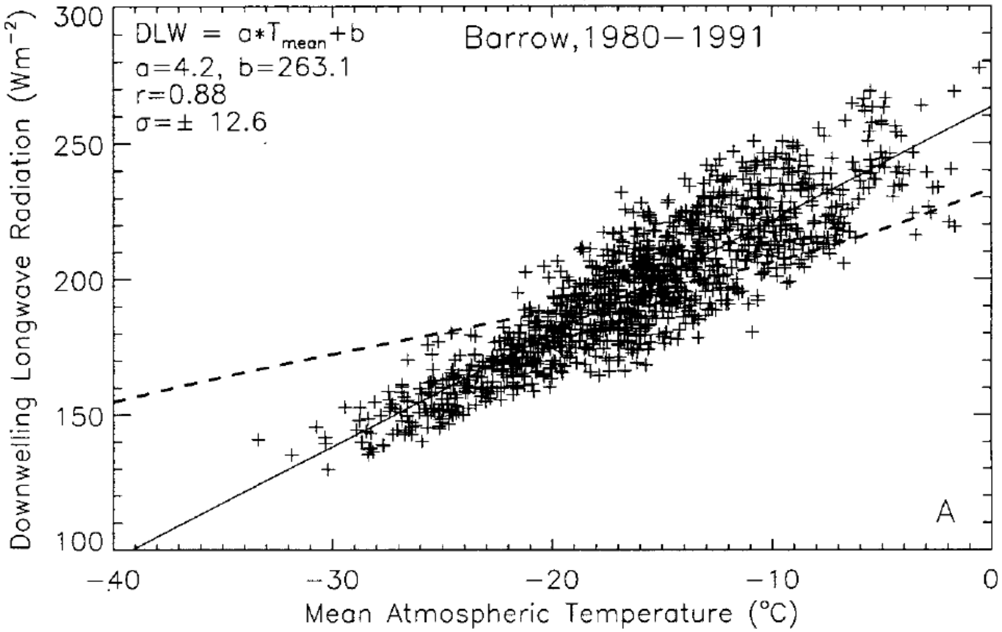


Brümmer and Thiemann, 2002

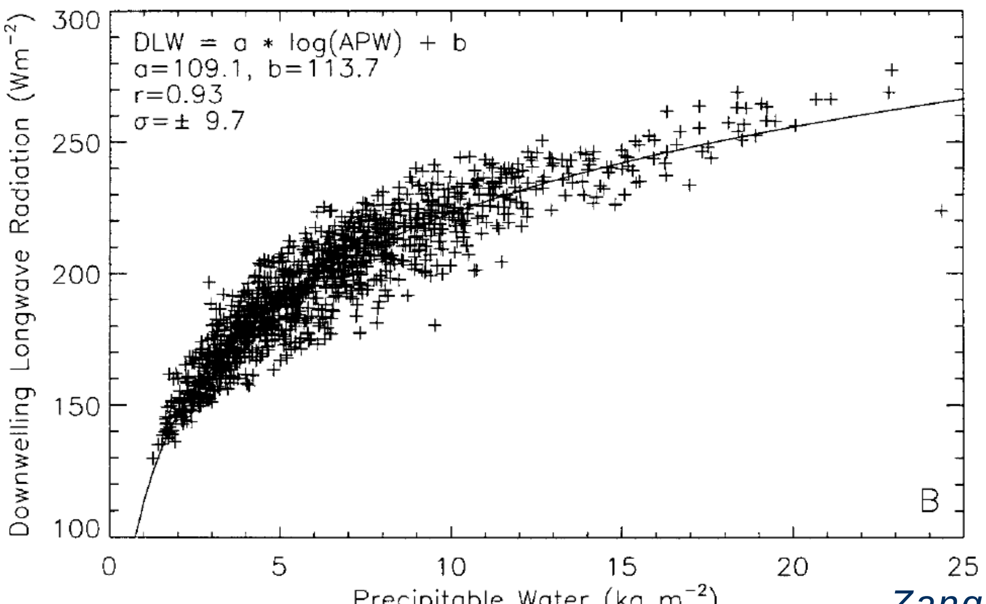
Temperature and humidity



LWD in cold and dry environment



Clear sky conditions
Based on soundings

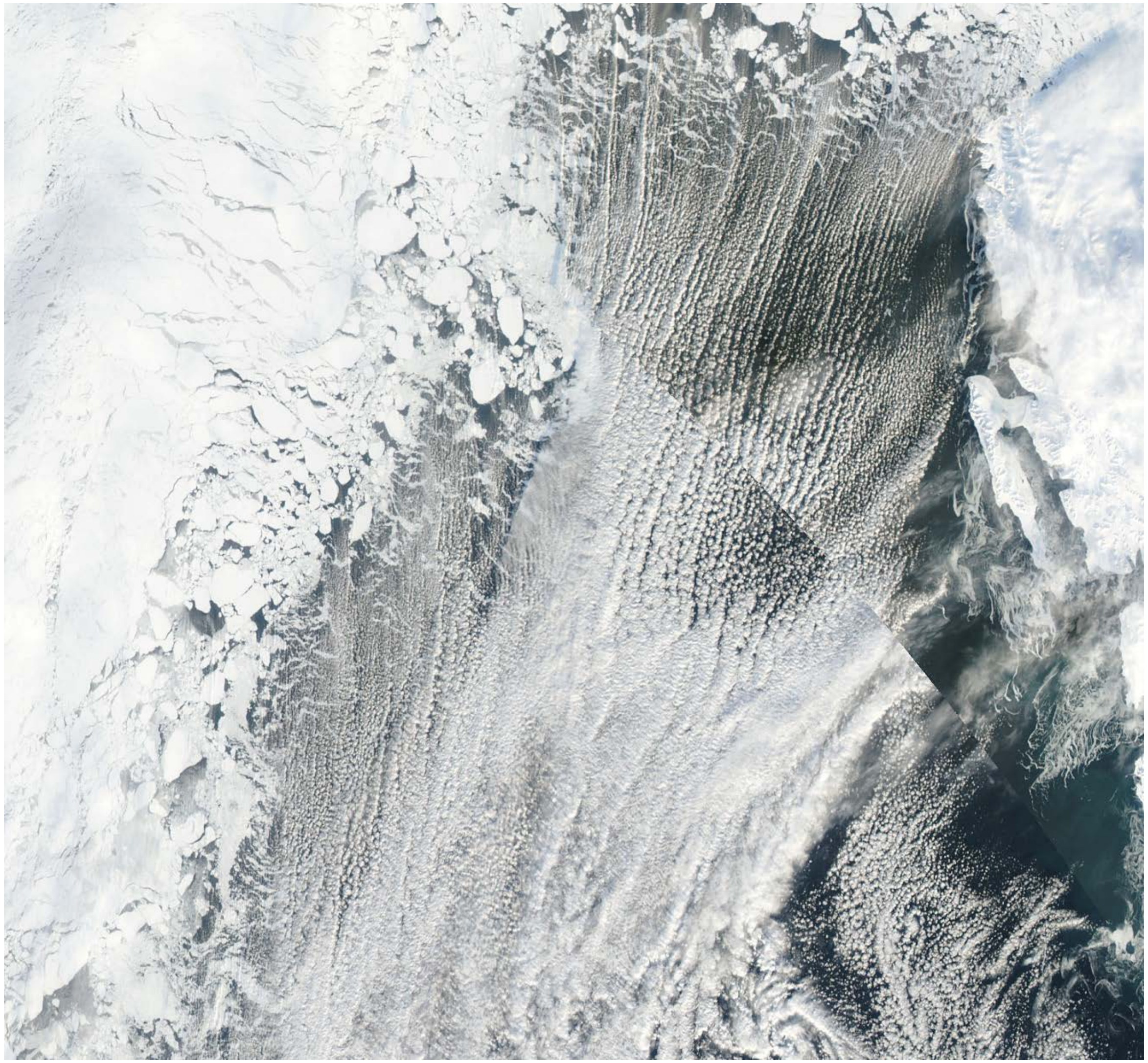


Zang et al., 2001

Air mass transformation

The boundary layer is becoming unstably stratified when the air is transported from the sea-ice over the warmer ocean

Convective clouds are formed and occasionally polar lows



Brümmer and Thiemann, 2002

Annual surface turbulent heat fluxes north of 70°N

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CMIP3 models

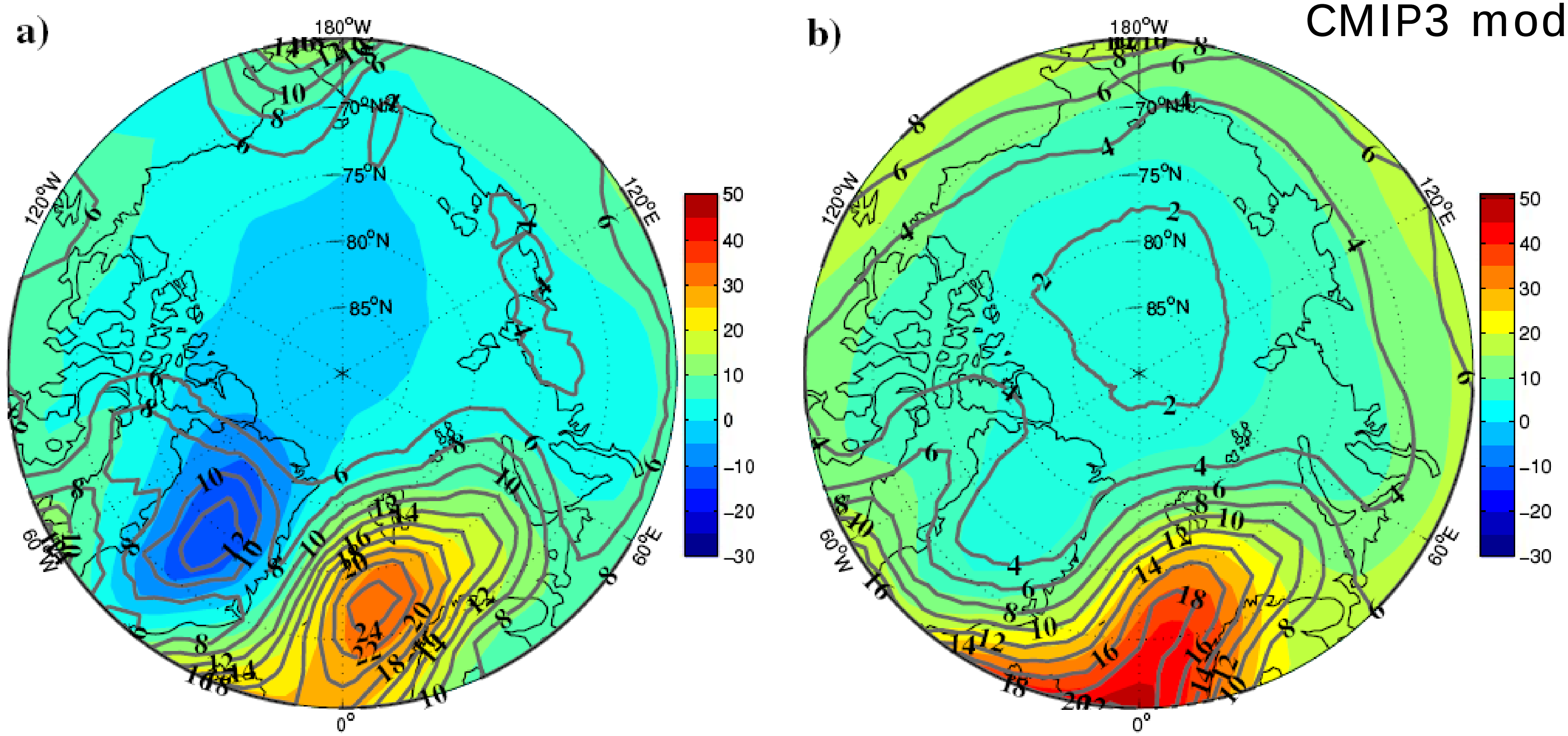

Fig. 5 The IPCC multimodel ensemble annual mean sensible (**a**) and latent (**b**) heat flux (*color*) and intermodel spread (*lines*). The spread is calculated as the standard deviation among the different models. The fluxes are positive up. Units: W/m^2

Sorteberg et al, 2008

Regular observations in Arctic

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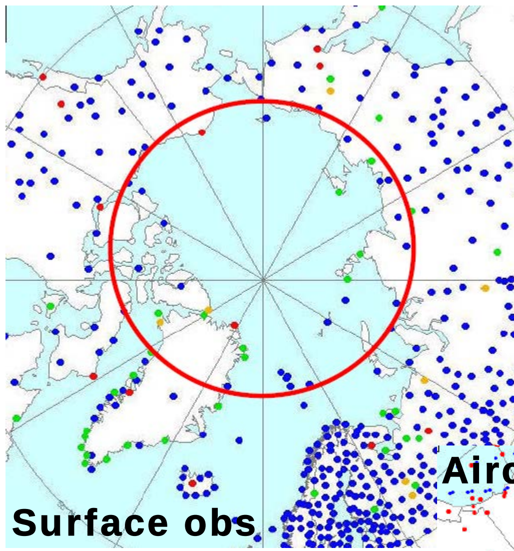
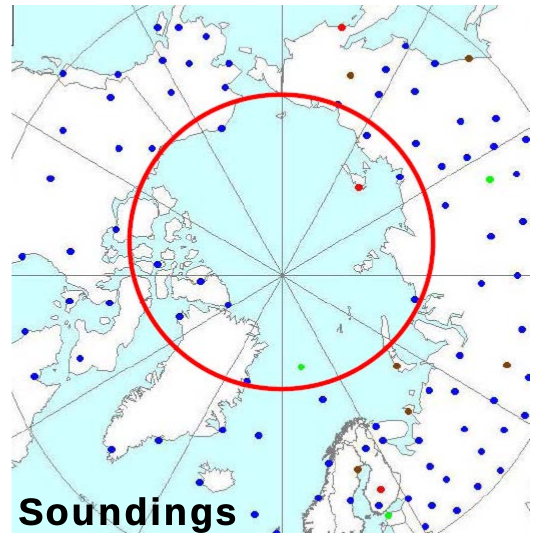
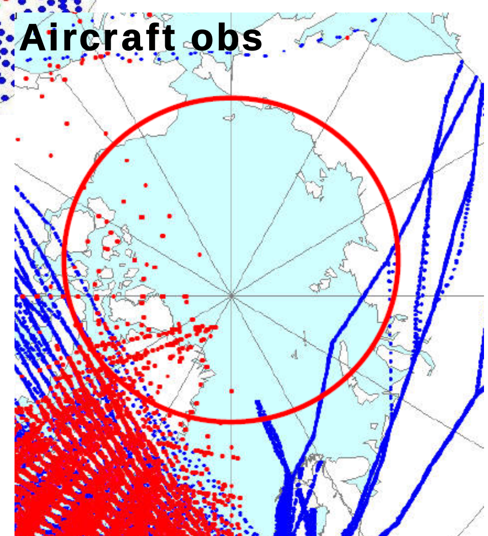
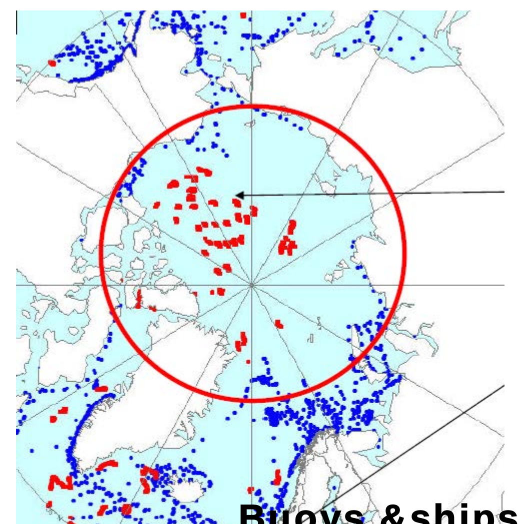
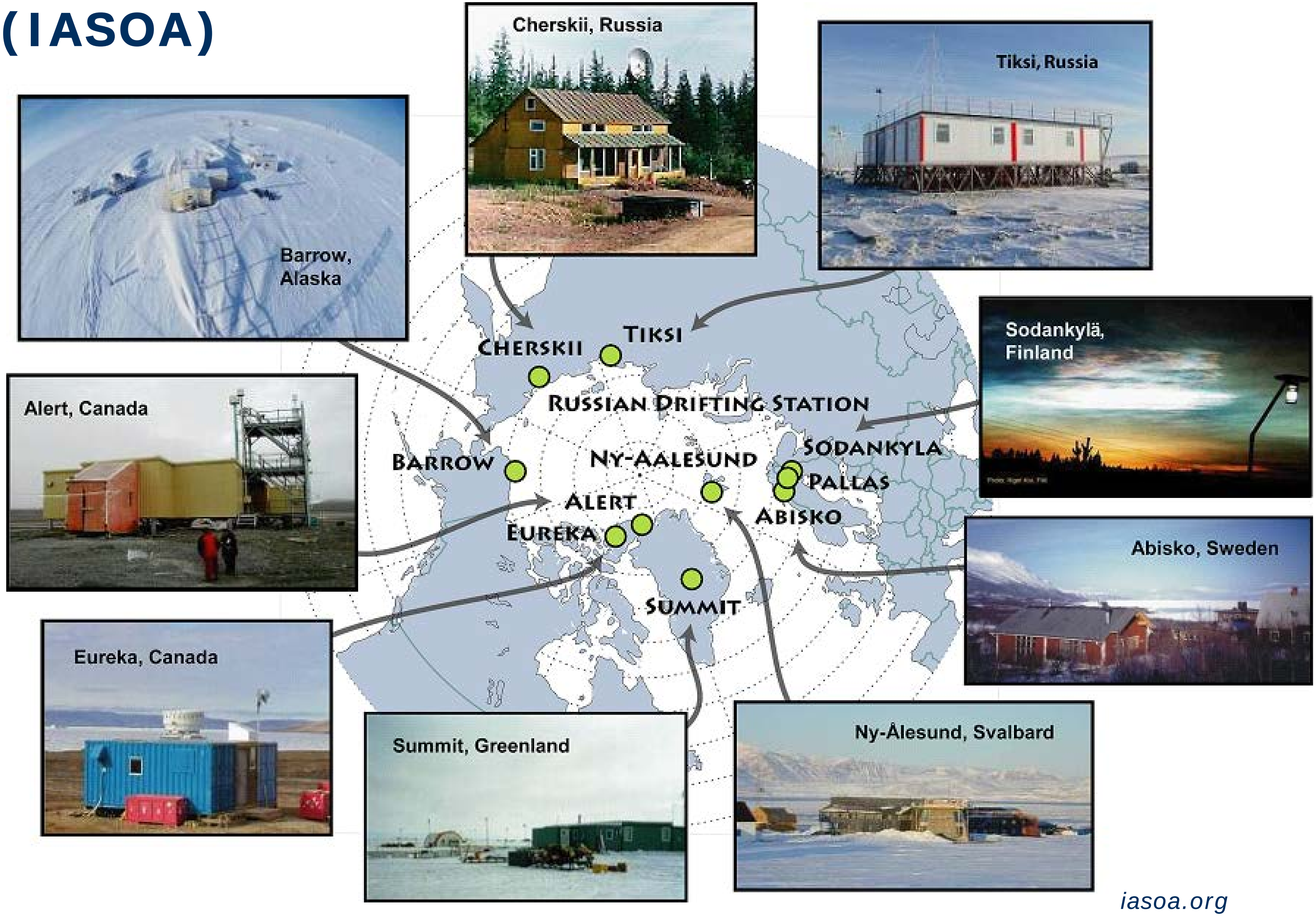








International Arctic Systems for Observing the Atmosphere (IASOA)



iasoa.org

Observations of Arctic clouds

FIG. 1. Map showing Arctic observatories.

The Surface Heat Budget of the Arctic Ocean (SHEBA) project was created to study the ice-albedo and cloud-radiation feedback mechanisms in the Arctic. North of Alaska during October 1997 to October 1998.

Observations of Arctic summer clouds

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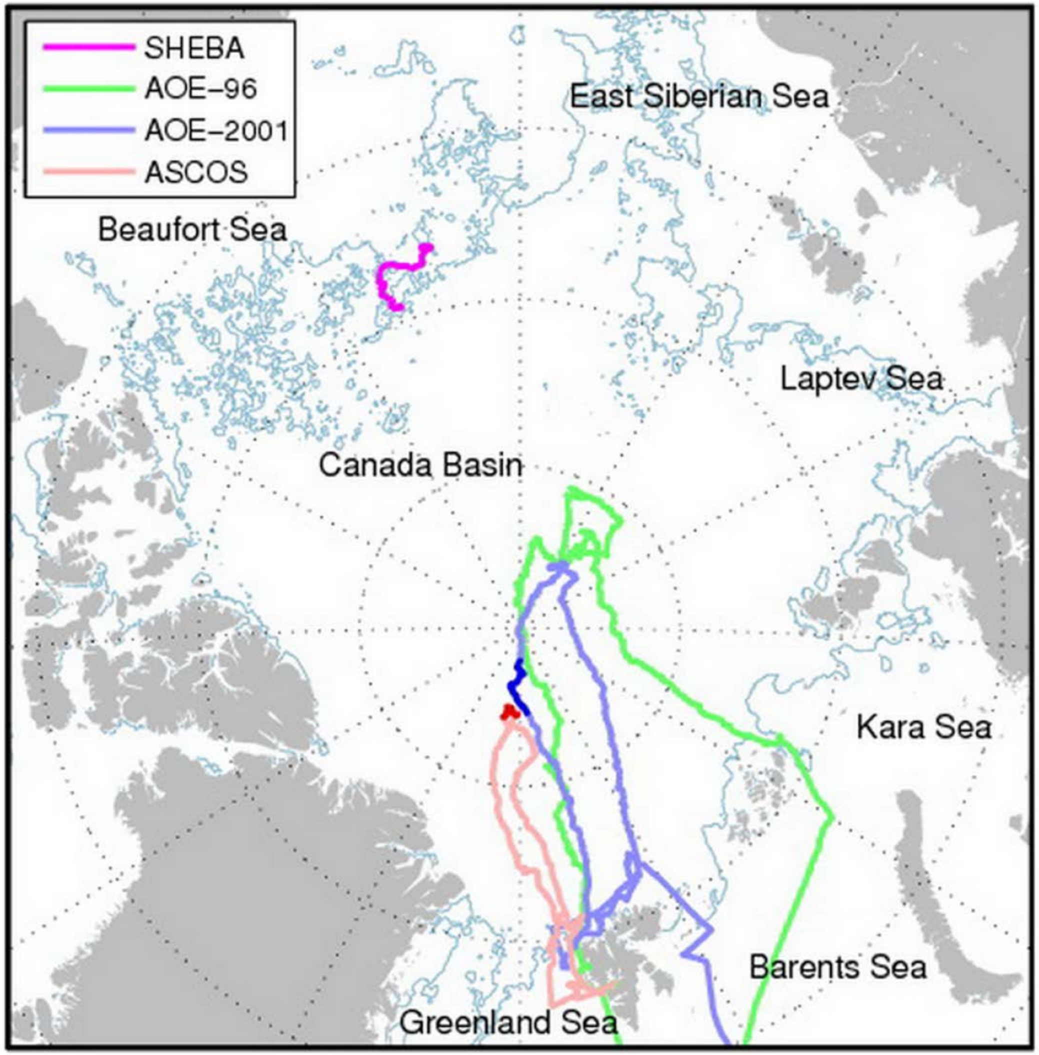
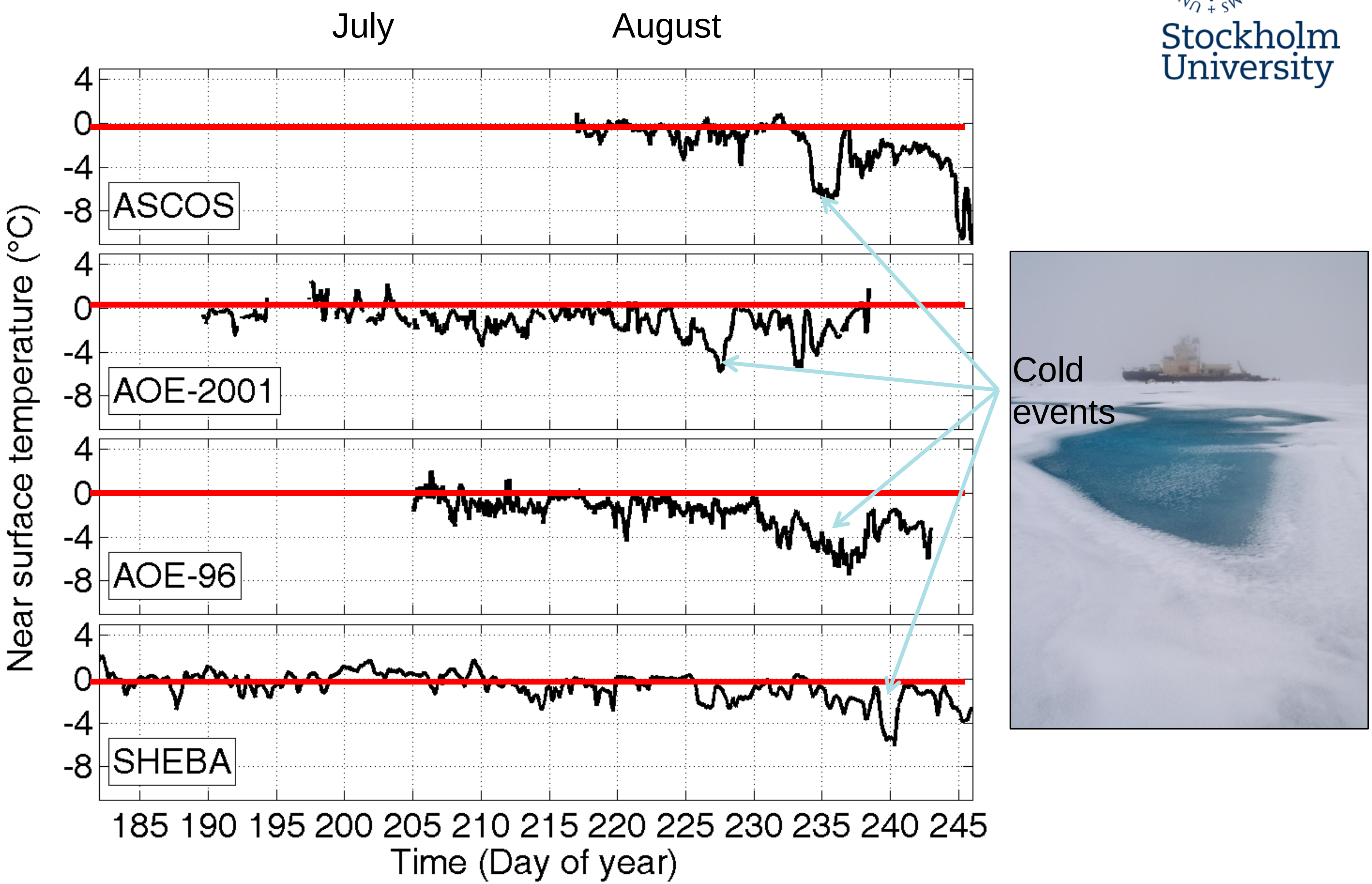


Summer Arctic temperatures

Stockholm University

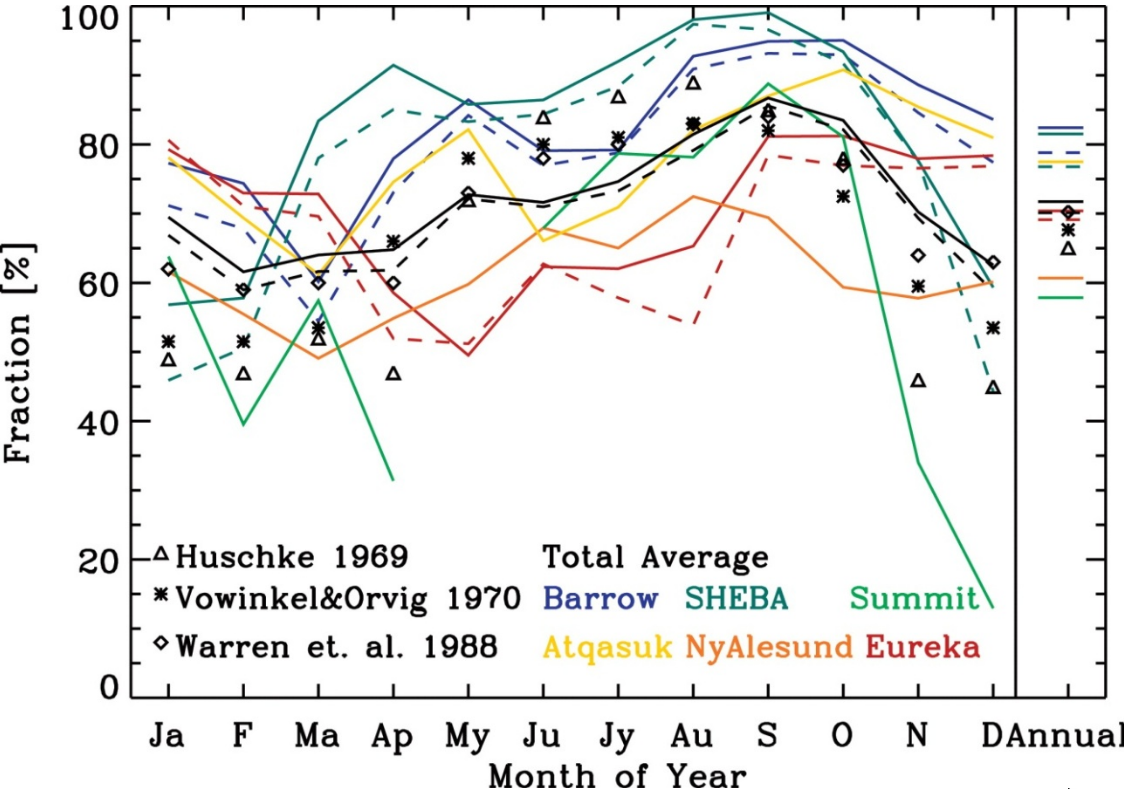


Tjernström et al., 2012

Stockholm University

Courtesy M. Tjernström

Observations of Arctic clouds



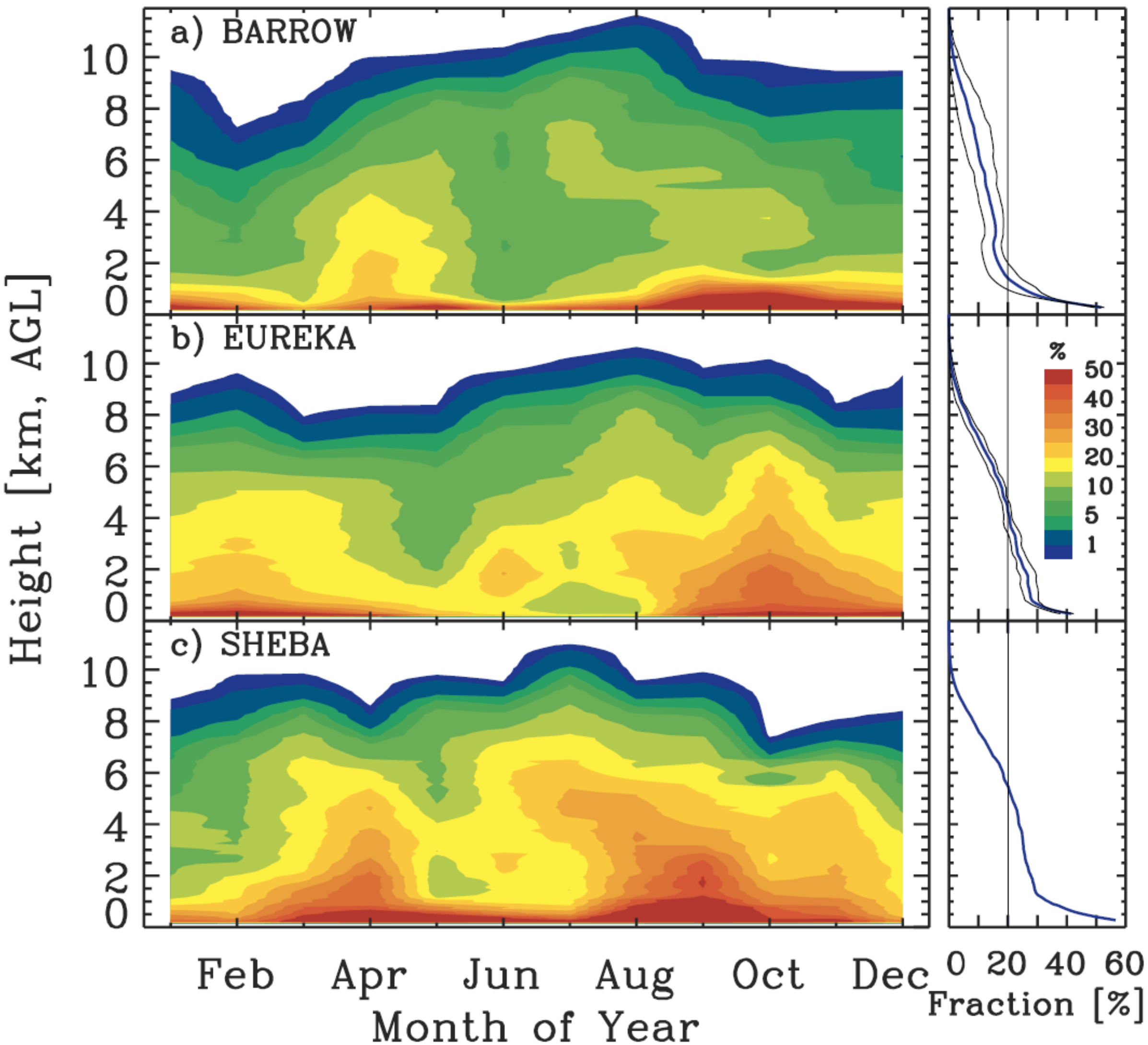
Cloud Fraction
- sites with multiple-year remote sensing observations (Barrow, Atqasuk, Eureka, Ny Ålesund; 5-12 yrs) or one full year (SHEBA and Summit).

Annual cloud fraction 58%-83% (site avg. 72%):
- least at Summit (58%) and Ny Ålesund (61%)
- greatest at Barrow (83%) and SHEBA (82%)
- historical climatologies 65%-70%

Annual variability
- min. in winter (DJF) 61-70%;
- max. in late summer/autumn (ASO) 81-86% (92-99% at BRW & SHEBA)
- Eureka exception: min in spring/early summer; max – autumn/winter

Shupe et al., 2011

Monthly mean cloud fraction



1) High frequency of low clouds (<1.2 km) at all 3 sites (40-55% of time)

2) Low clouds most frequent Aug-Nov at Barrow and SHEBA and Sep-Mar at Eureka

3) Mid-level clouds (2-6 km) least frequent at Barrow (2-20% of time) and most frequent at SHEBA (15-35% of time)

4) Mid-level clouds most frequent in late summer/autumn and Mar-Apr (BRW, SHEBA) or Sep-Mar (EUR)

Shupe et al., 2011

Cloud-layer persistence with height

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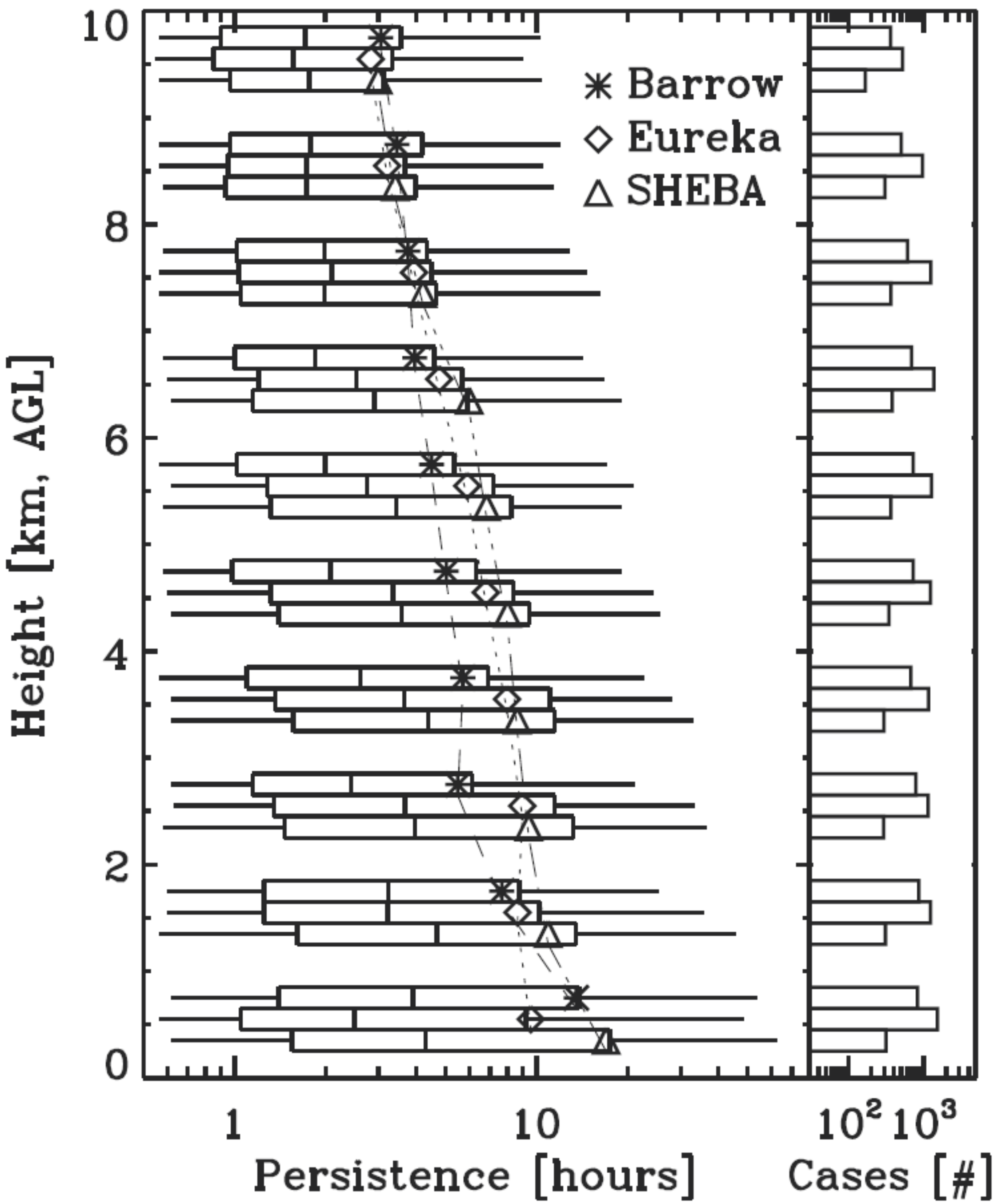
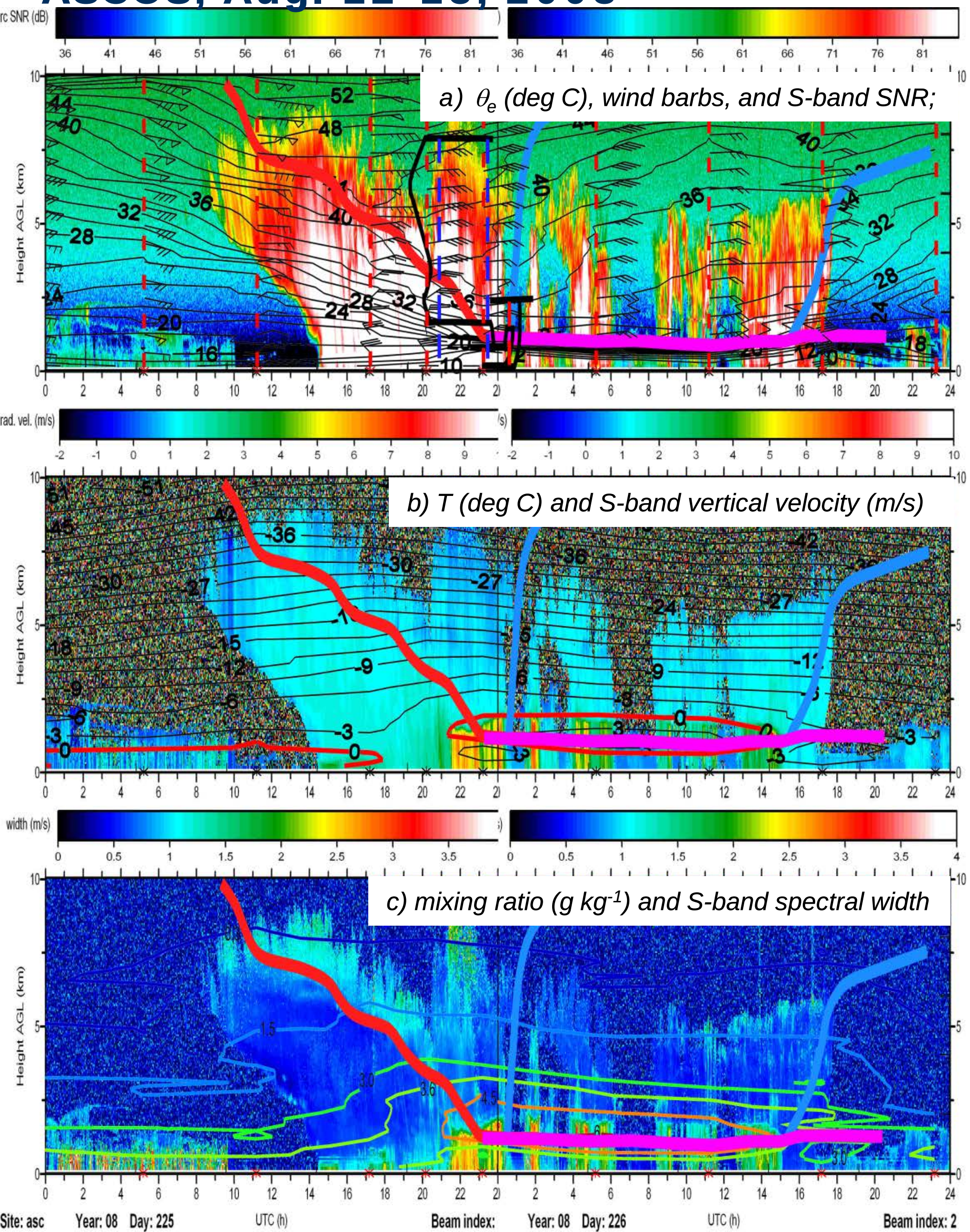


1) Low clouds most persistent (2.5-4.5 h; 10-18 h; 50-65 h)
2) Mid-level clouds more transitory (2.5-4.0 h; 7-10 h; 20-30 h)
3) High frequency of low clouds due to greater persistence

Shupe et al., 2011

Arctic storm clouds

ASCOS, Aug. 12-13, 2008



Time-height cross section of a) q_e (deg C), wind barbs, and S-band SNR; b) temperature (deg C) and S-band vertical velocity; and c) mixing ratio (g kg^{-1}) and S-band spectral width.

Each panel is overlaid with a frontal analysis based primarily on q_e (heavy red, blue, and purple lines), theDC-8 flight track data (heavy black line), radiosondes (red stars on abscissa & vertical dashed lines), and dropsondes (vertical dashed blue lines). The heavy red isopleth in b) is the 0° C isotherm, and the heavy magenta line shows the location of a strong inversion.

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1) Classical occluded frontal system, with warm/moist advection in narrow warm sector above surface inversion
2) Post-frontal warm air separated from surface by inversion
3) Deep clouds and precipitation primarily associated with warm-front
4) Elevated warm-air advection producing period of surface freezing rain and sleet
5) Turbulence near top of warm-frontal clouds likely producing convective generating cells for warm-frontal precipitation and possibly supercooled liquid water
6) Classical occluded frontal structure (except low-level inversion); clouds dynamically forced

Courtesy Ola Persson

Low-level clouds

Persisted for more than five days
Supercooled liquid with ice precipitation

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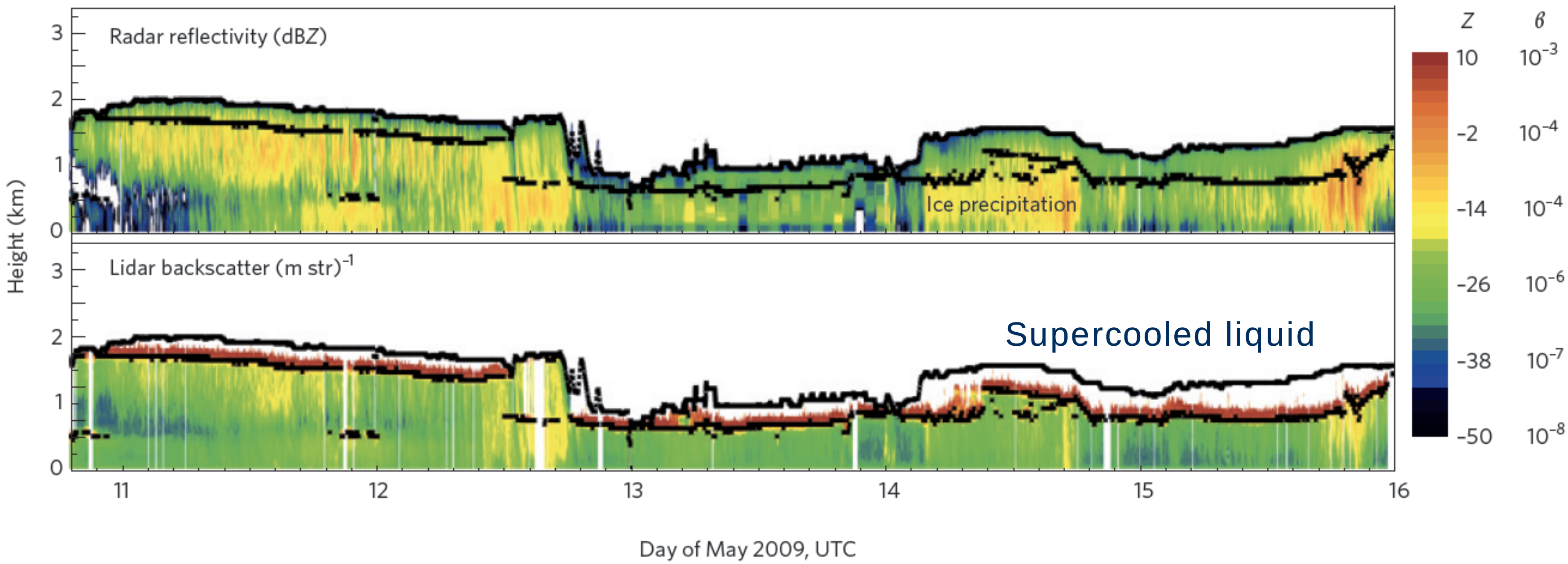

Figure 1 | Cloud radar and lidar indicating the characteristic structure of long-lived Arctic mixed-phase stratiform clouds. In this example, supercooled liquid water perseveres for more than 5 days despite a near-continual loss of mass owing to ice precipitation. Cloud radar reflectivity (top), *Z*, is dominated by the relatively large ice crystals that form in, and fall from, supercooled liquid cloud layers. Lidar backscatter (bottom), *β*, is dominated by the much smaller, yet more numerous, droplets found in liquid layers. The lidar signal is attenuated within the supercooled liquid layer, whose boundaries are defined by the black contour. UTC, coordinated universal time.

Morrison et al., 2012

Persistent Arctic mixed-phase

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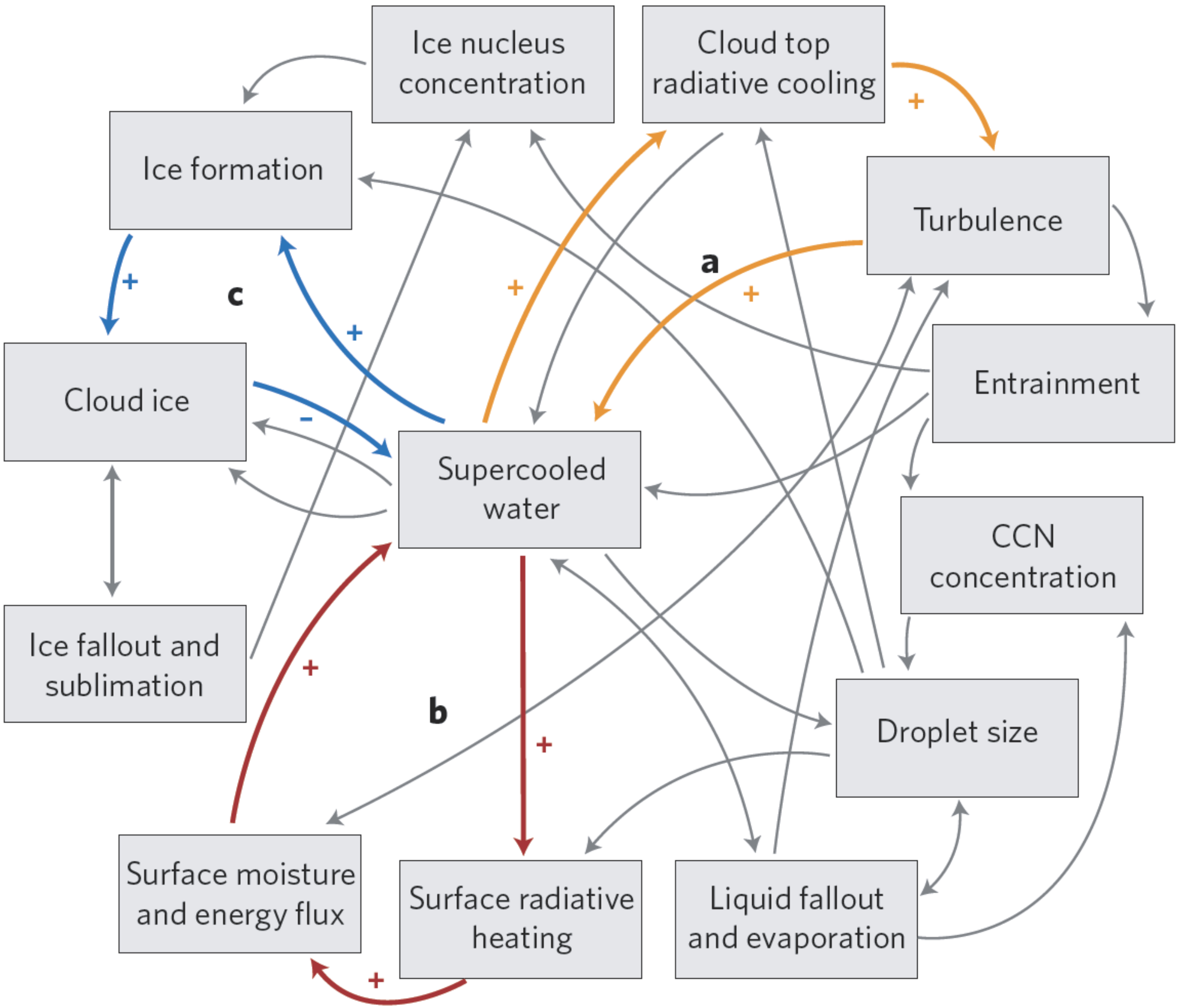
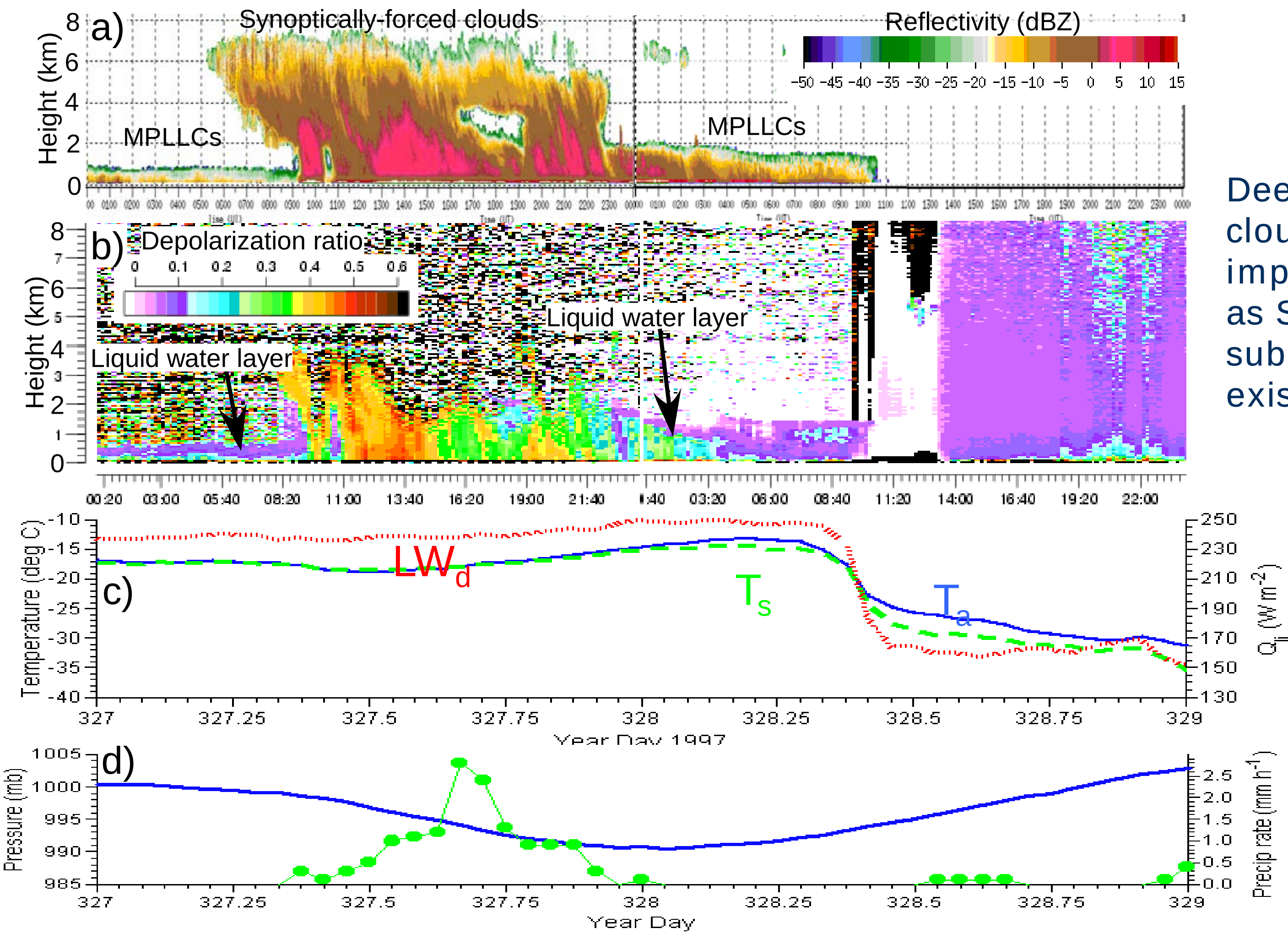


Morrison et al., 2012

Frontal clouds and Sc clouds

SHEBA Nov 23-24 1997



Deep synoptically-forced clouds (Ns) have similar impact on surface radiation as Sc clouds, though some subtle differences may exist

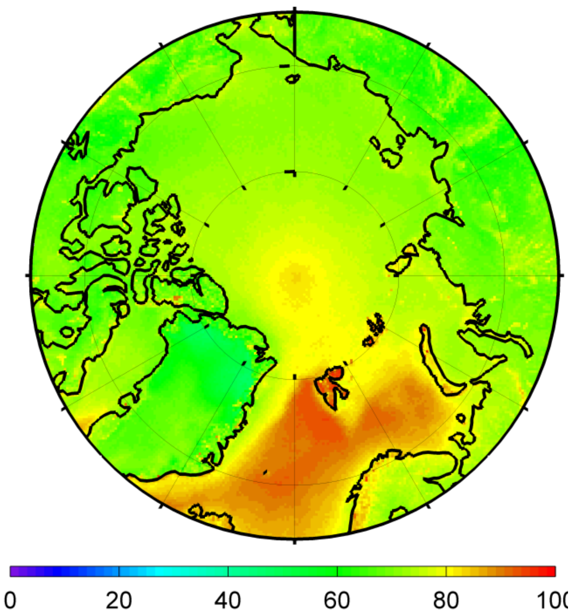
Time-height series and time series from the SHEBA site on Nov. 23-24, 1997, of a) cloud radar reflectivity, b) lidar depolarization ratio (< 0.11 indicates liquid water), c) 10-m (solid) and surface (dashed) temperatures, and incoming longwave radiation at the surface (red dotted), and d) surface pressure (solid) and precipitation rate from the optical raingauge (dots). The MPLLCs, synoptically forced clouds, and liquid water layers are marked.

Courtesy Ola Persson

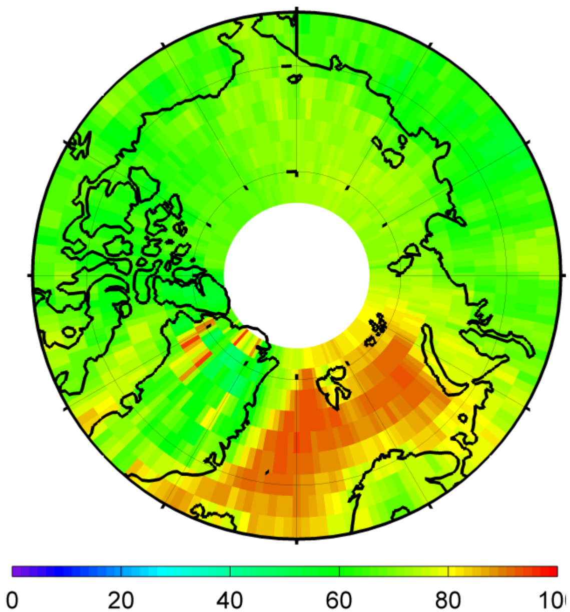
Cloud fraction

As seen from space

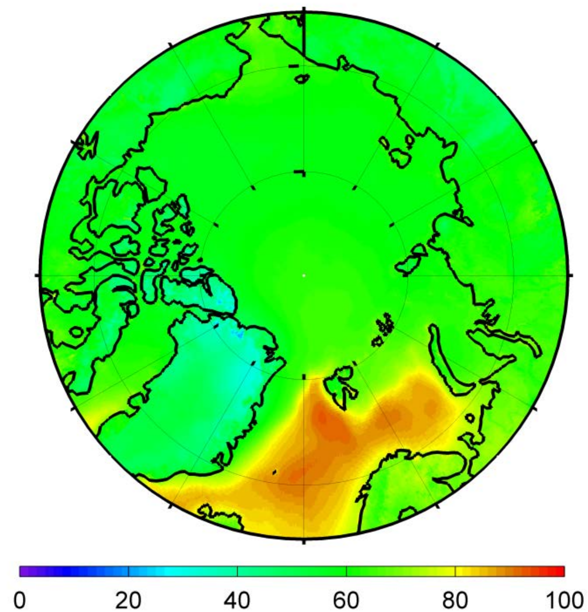
Annual mean



APP-x
1982-2009



CALIPSO
2006-2009



CMSAF
2006-2009

Extended AVHRR Polar Pathfinder Product (APP-x) *Wang and Key (2003, 2005)*

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) www-calipso.larc.nasa.gov

Climate Monitoring Satellite Application Facility (CMSAF) AVHRR based *Karlsson and Dybbroe (2012)*

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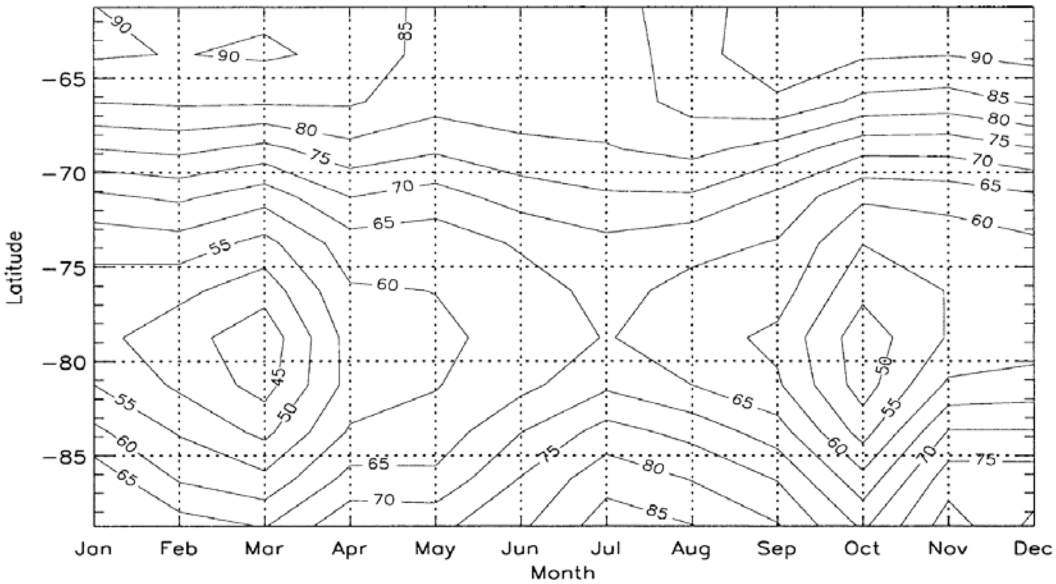
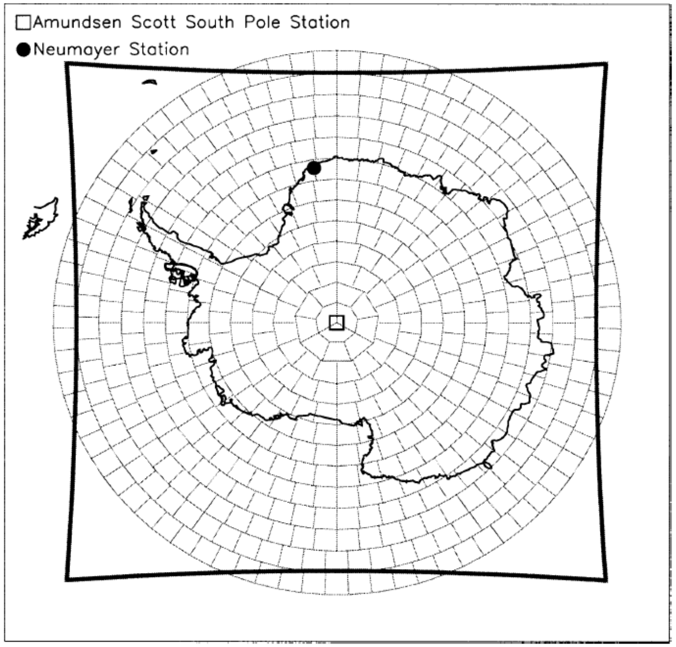
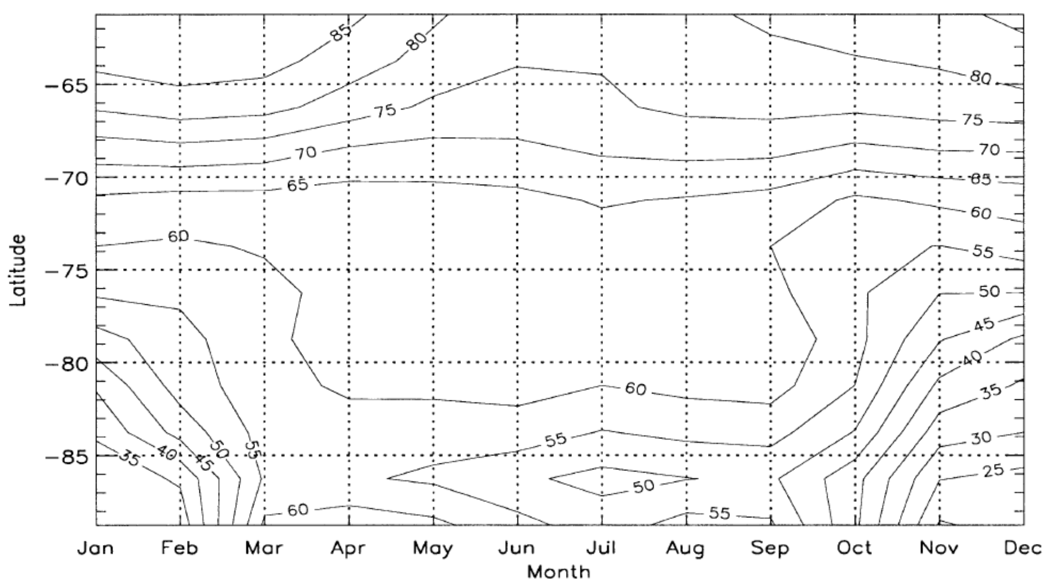
Antarctic cloud cover

APP-x (1985-1993)





ISCCP (1985-1993)



Maxium in wintern over continent
Minimum at 80˚S
Cloudy all year round

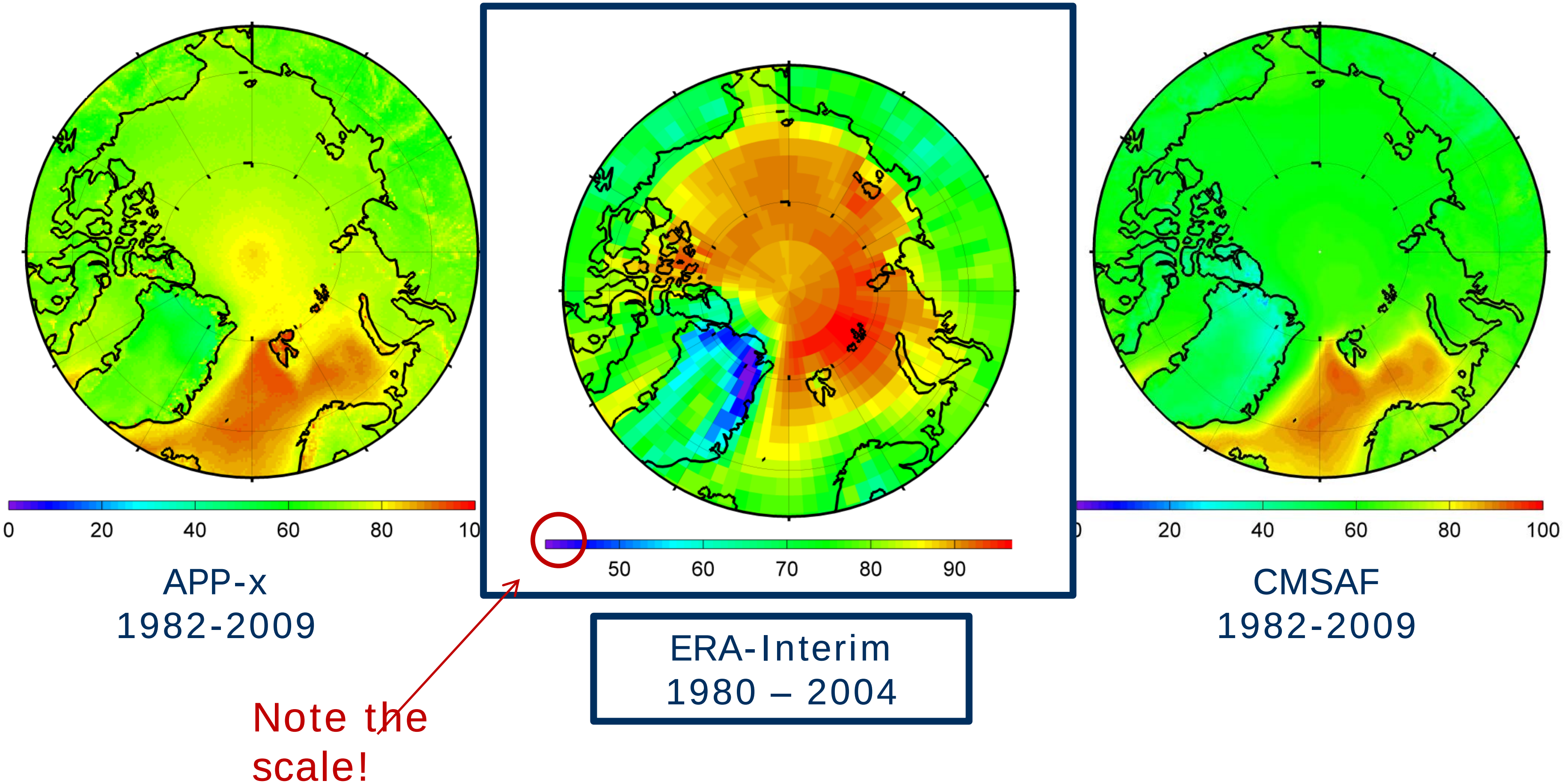
Pavolonis and Key, 2003

Cloud fraction

As seen from space

Stockholm University

Annual mean



Reanalysis in the Arctic

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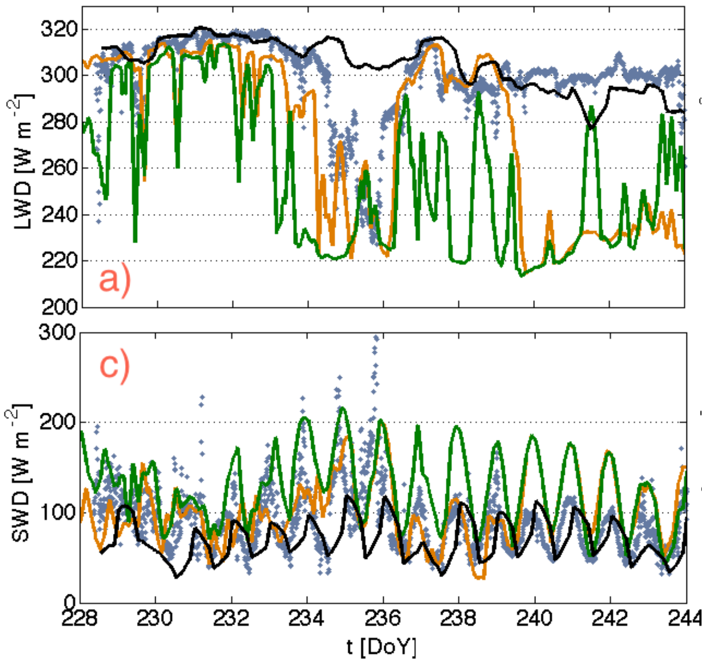
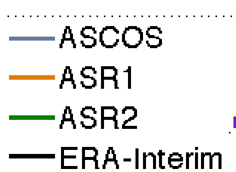
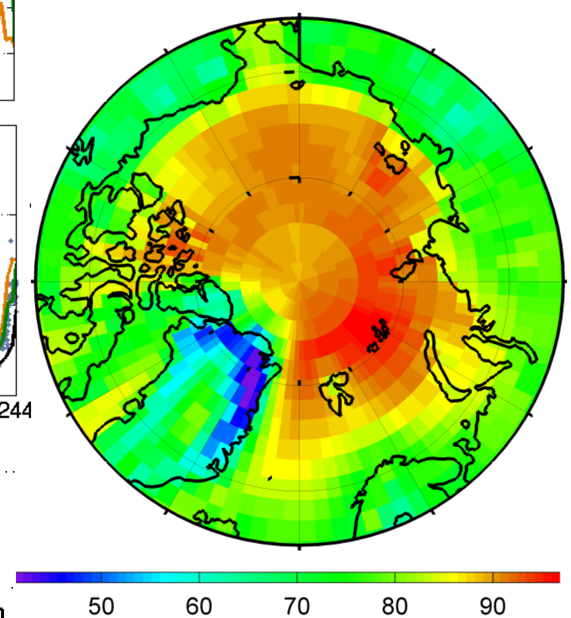
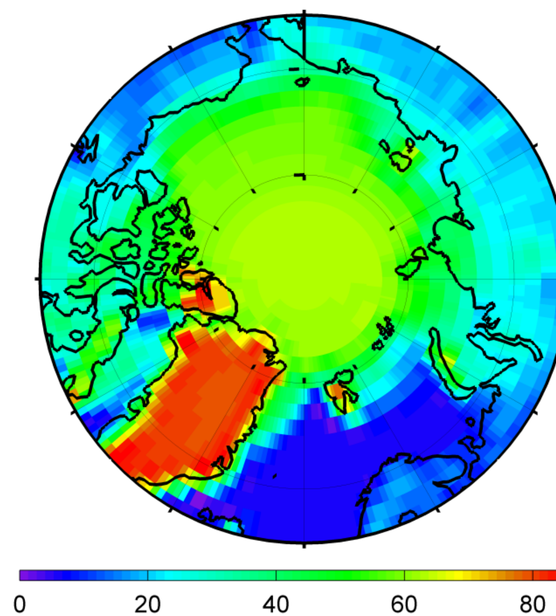


Wesslèn et al. 2013



Cloud fraction
Annual mean





Data assmilation issues:
Vertical gradients are smeared out
Near surface information not used
Not enough variability in observations to inform on obs errors

ERA-Interim
1980 – 2004

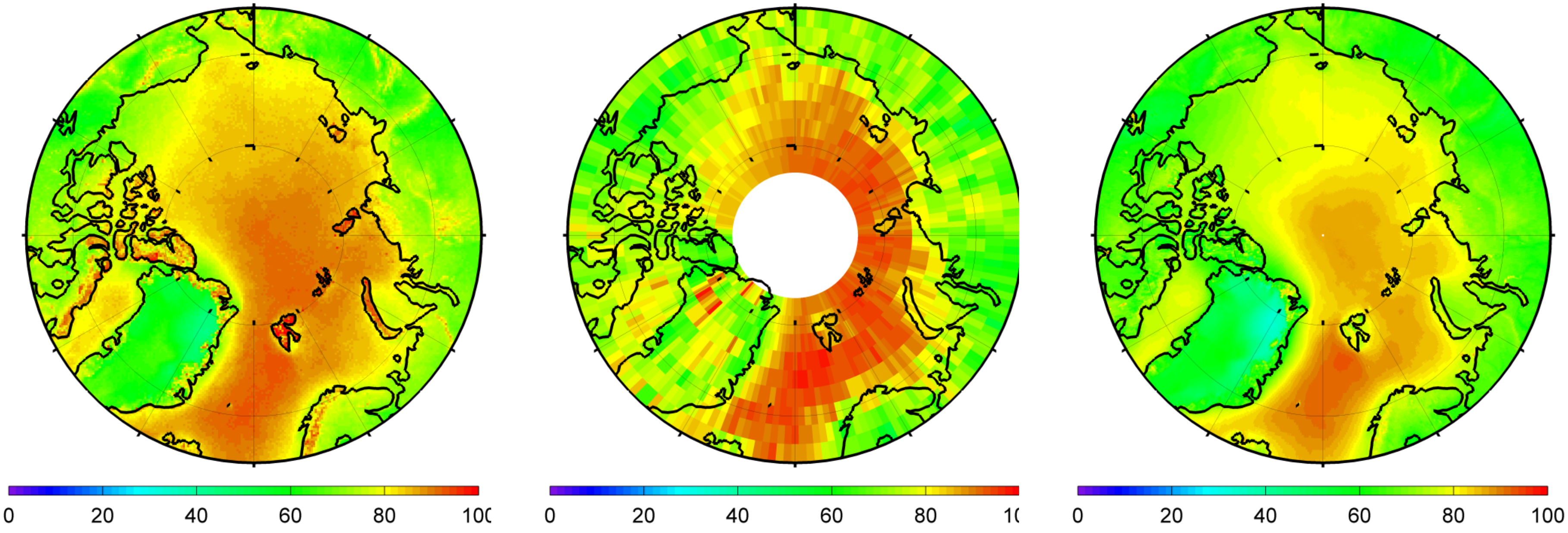
Prescribed Climatological Sea-Ice albedo with annual cycle

Be careful when using reanalyses in the Polar regions!

Cloud fraction

As seen from space

Summer JJA



APP-x
1982-2009

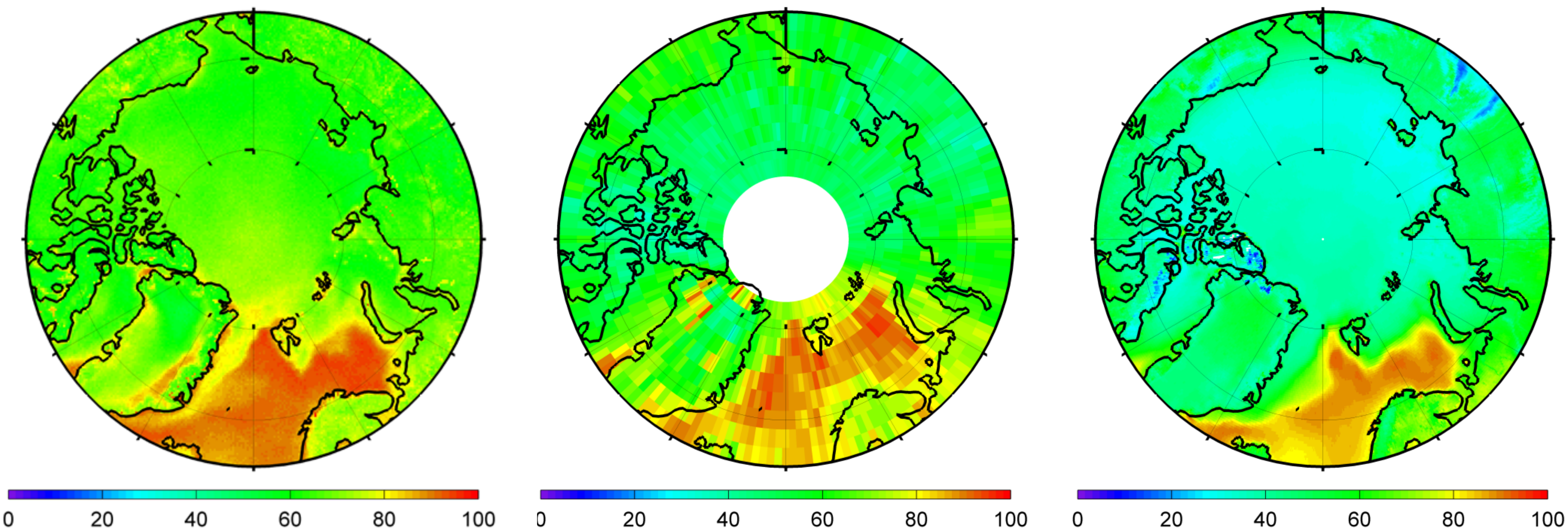
CALIPSO
2006-2009

CMSAF
1982-2009

Cloud fraction

As seen from space

Winter DJF



APP-x
1982-2009

CALIPSO
2006-2009

CMSAF
1982-2009

Cloud fraction
As seen from space

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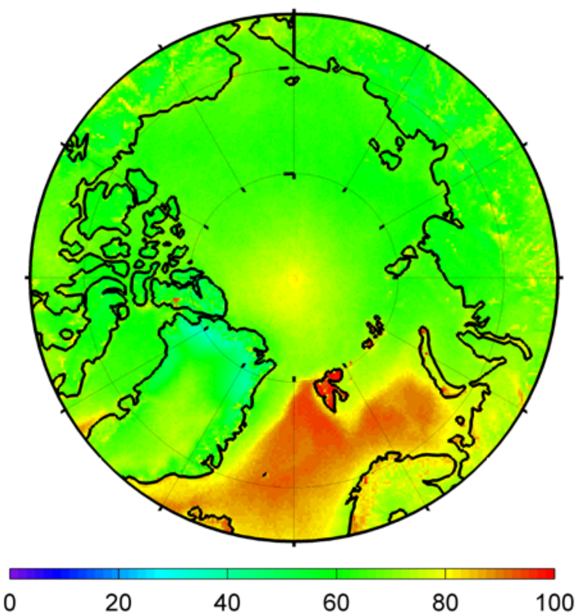
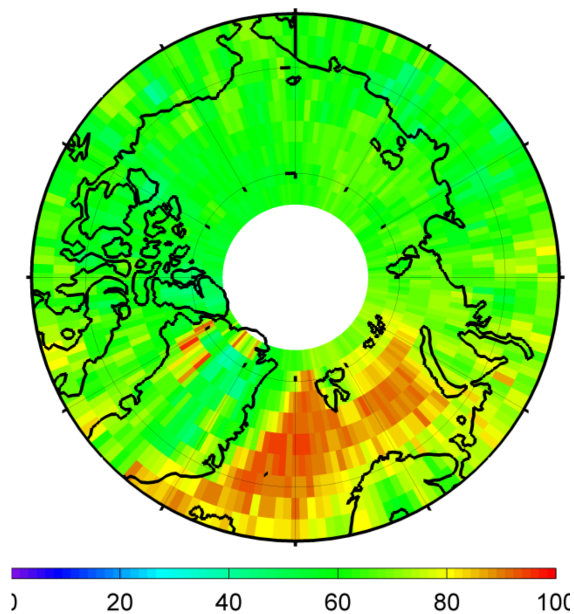
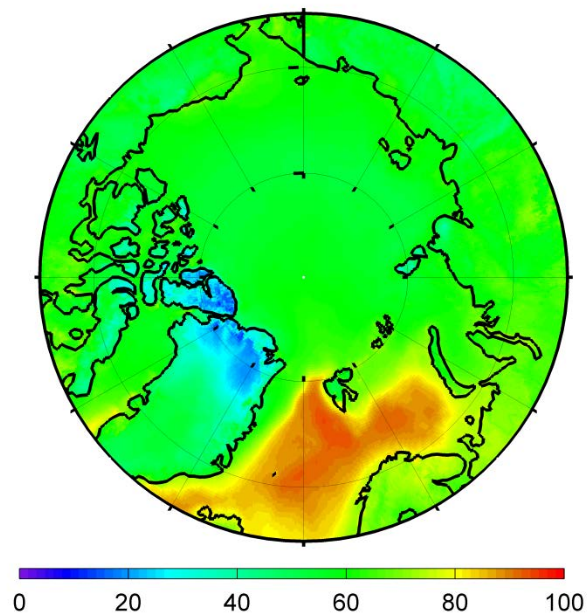
Spring MAM



APP-x
1982-2009



CALIPSO
2006-2009

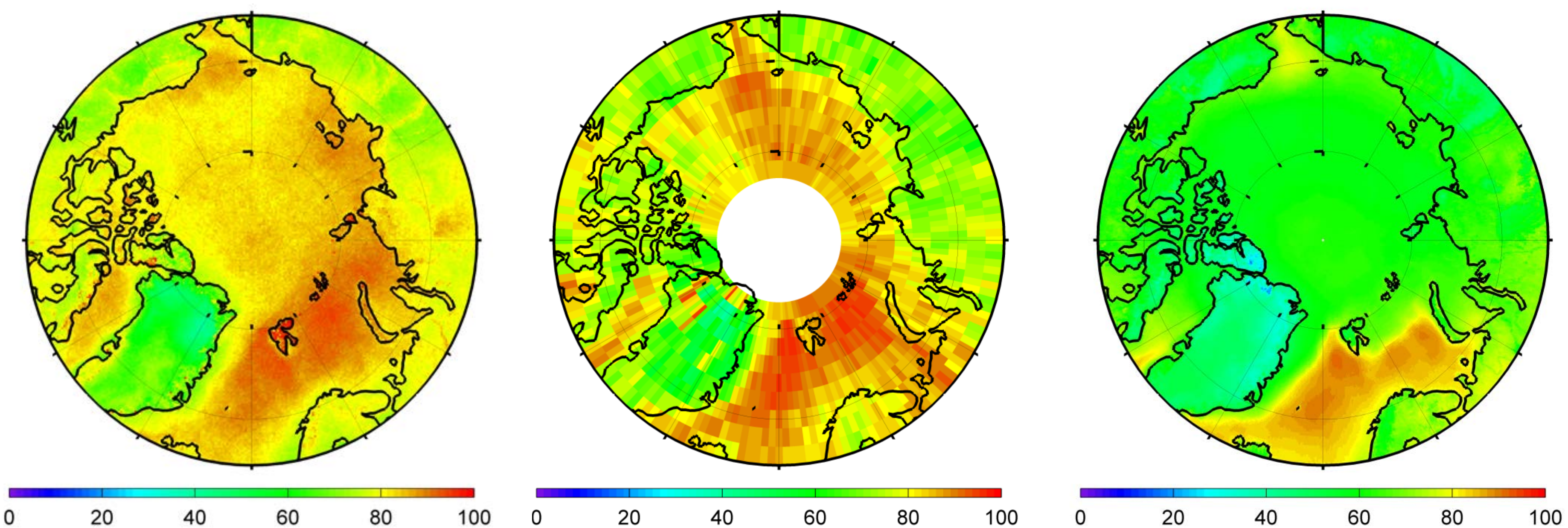


CMSAF
1982-2009

Cloud fraction

As seen from space

Autumn SON



APP-x
1982-2009

CALIPSO
2006-2009

CMSAF
1982-2009

Observational uncertainties

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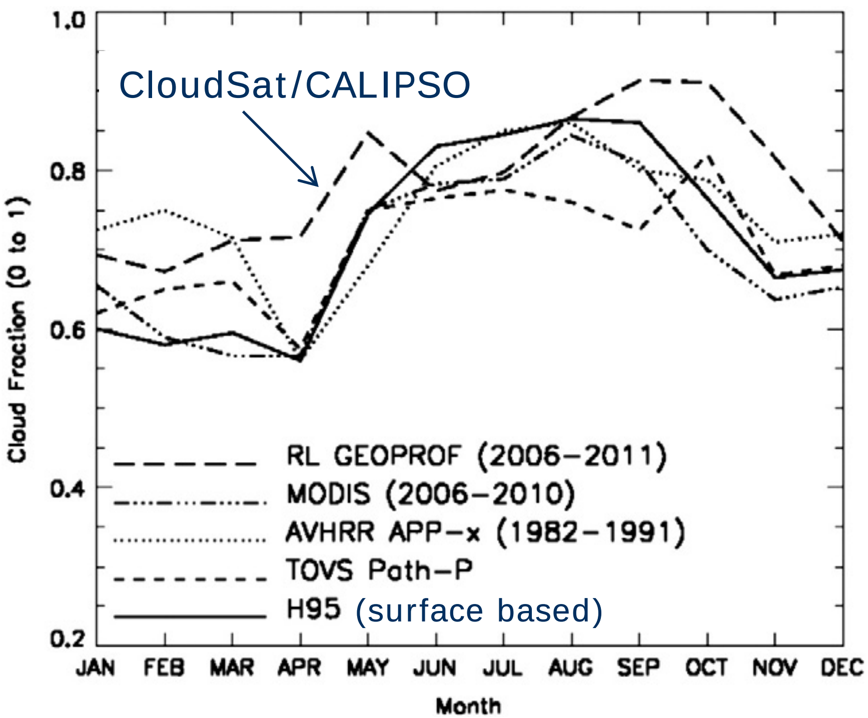
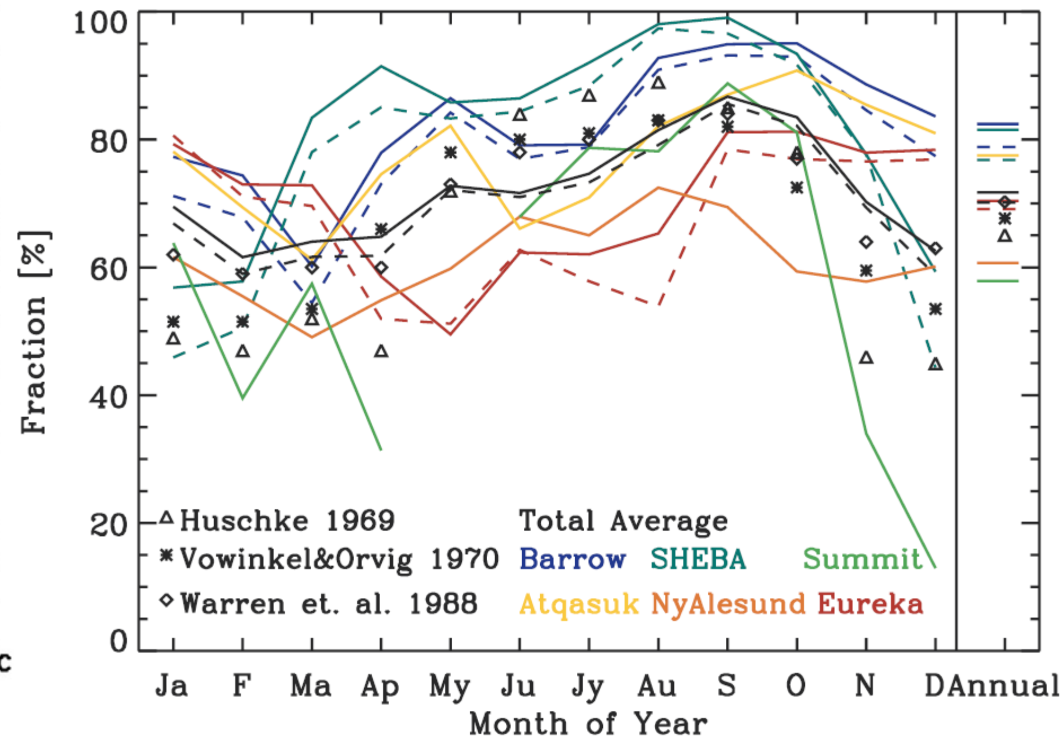


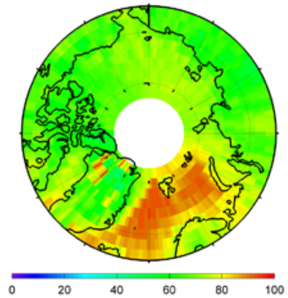


Liu et al., 2012

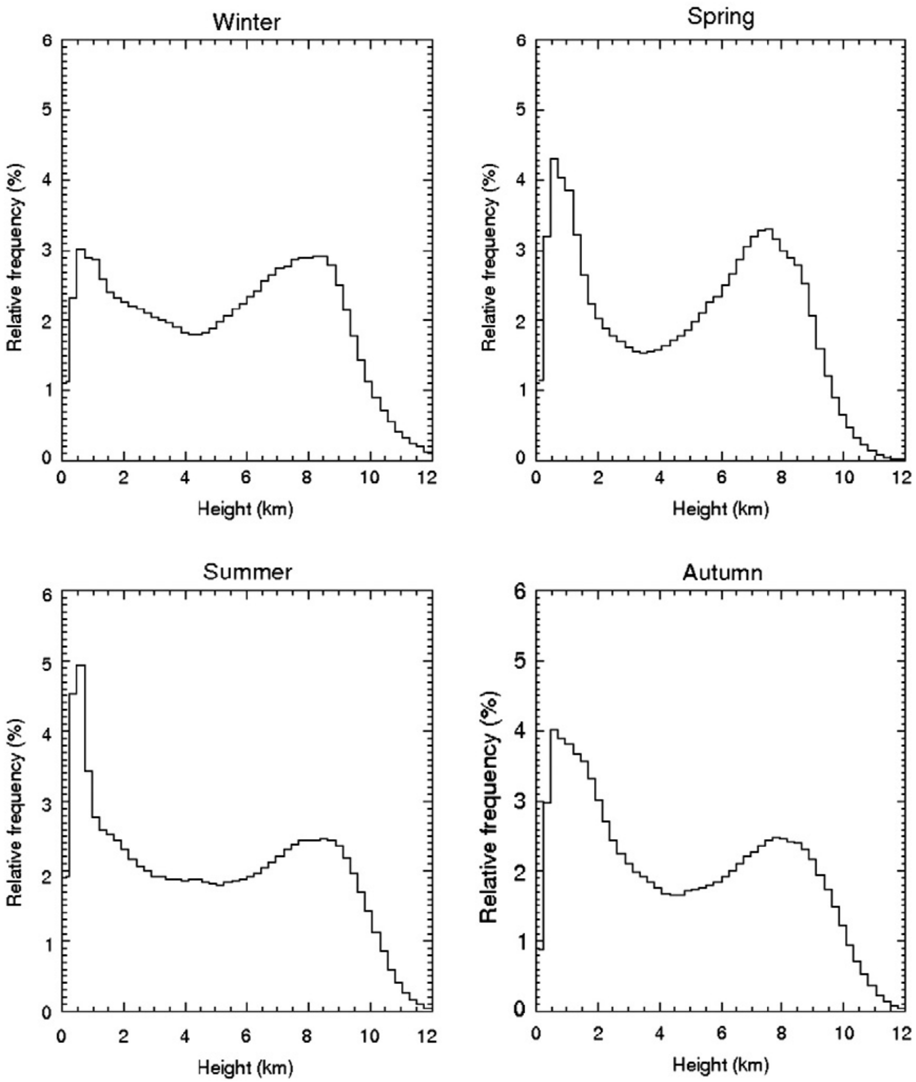
Shupe et al., 2011

CloudSat & Calipso

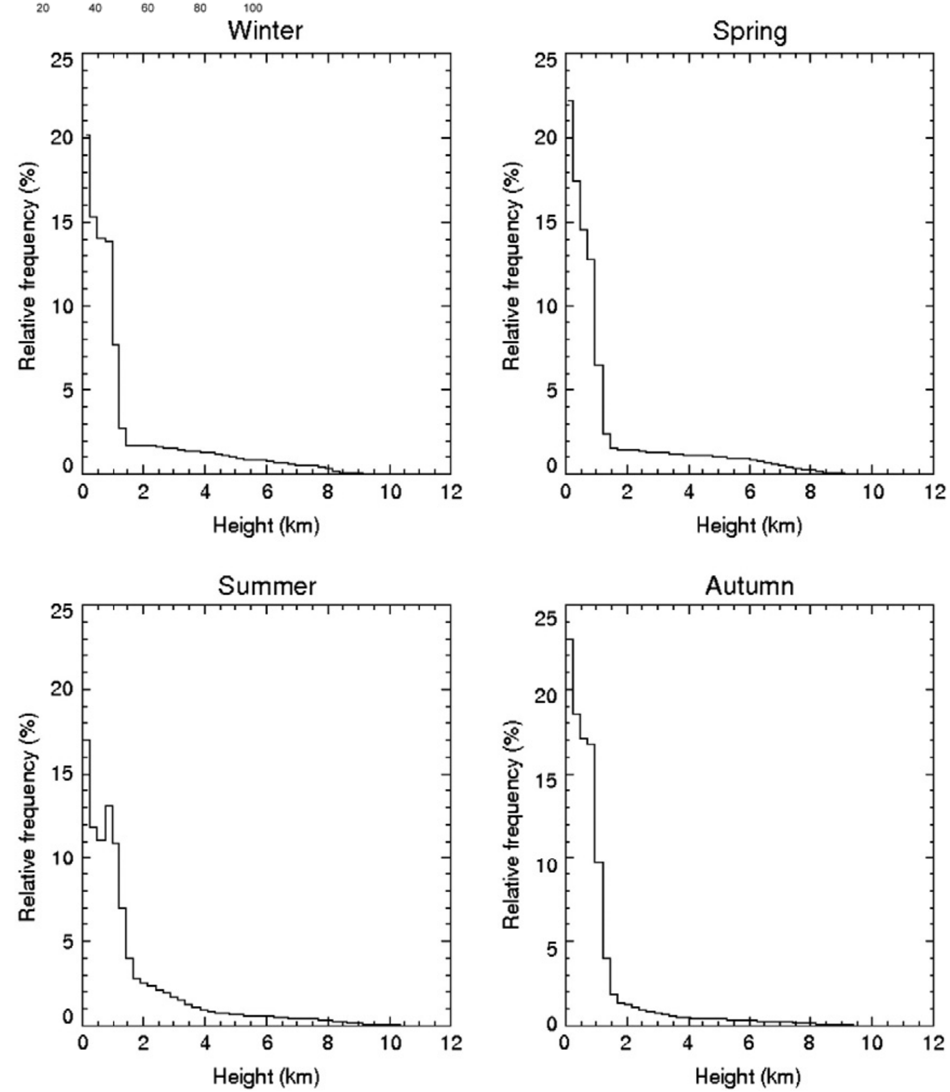
60°N > lat < 82°N



Cloud top



Cloud base



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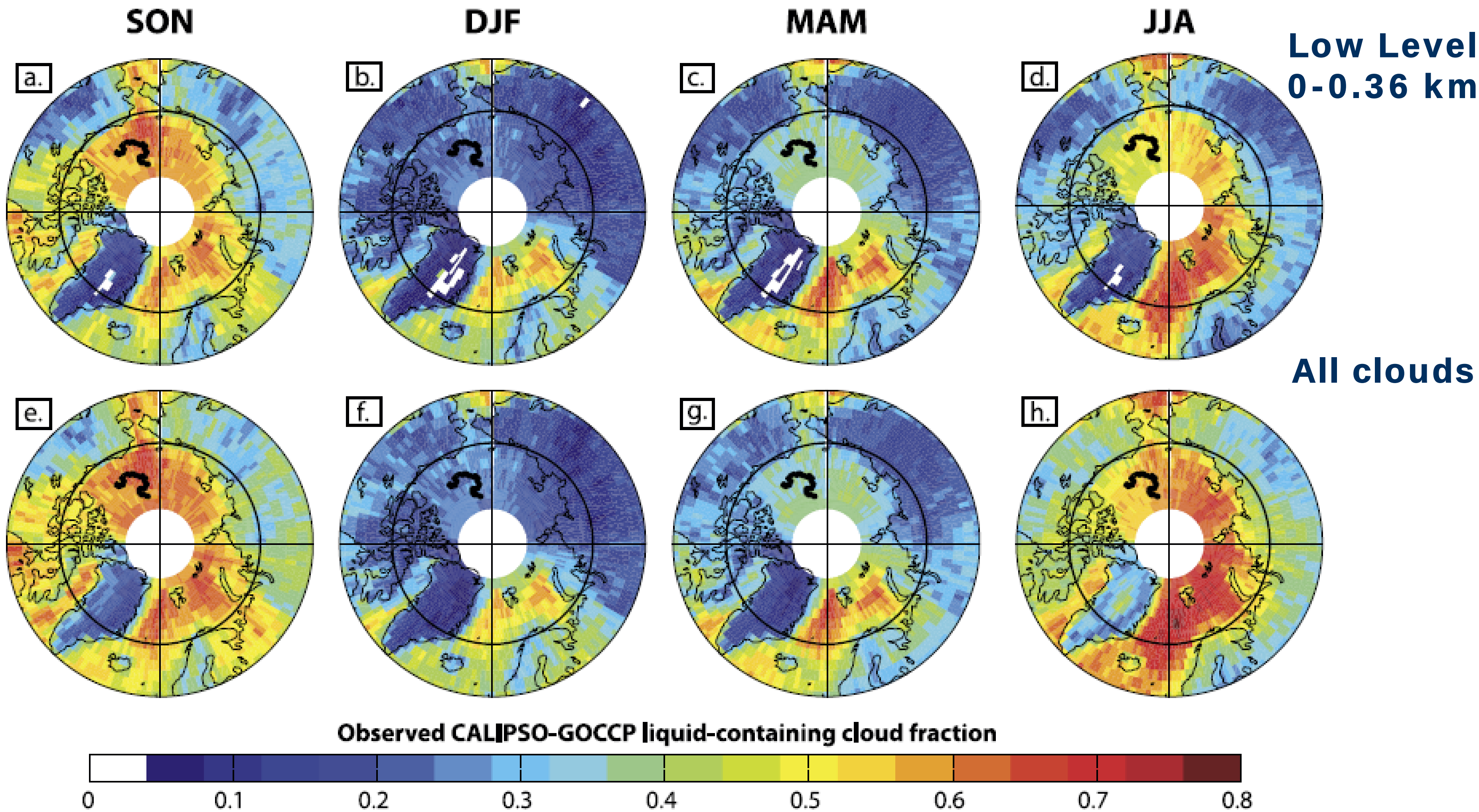
Liu et al., 2012

Fraction of liquid clouds, Calipso-GOCCP (2006-2011)



Cesana et al., 2012

Phase of clouds in Antarctic

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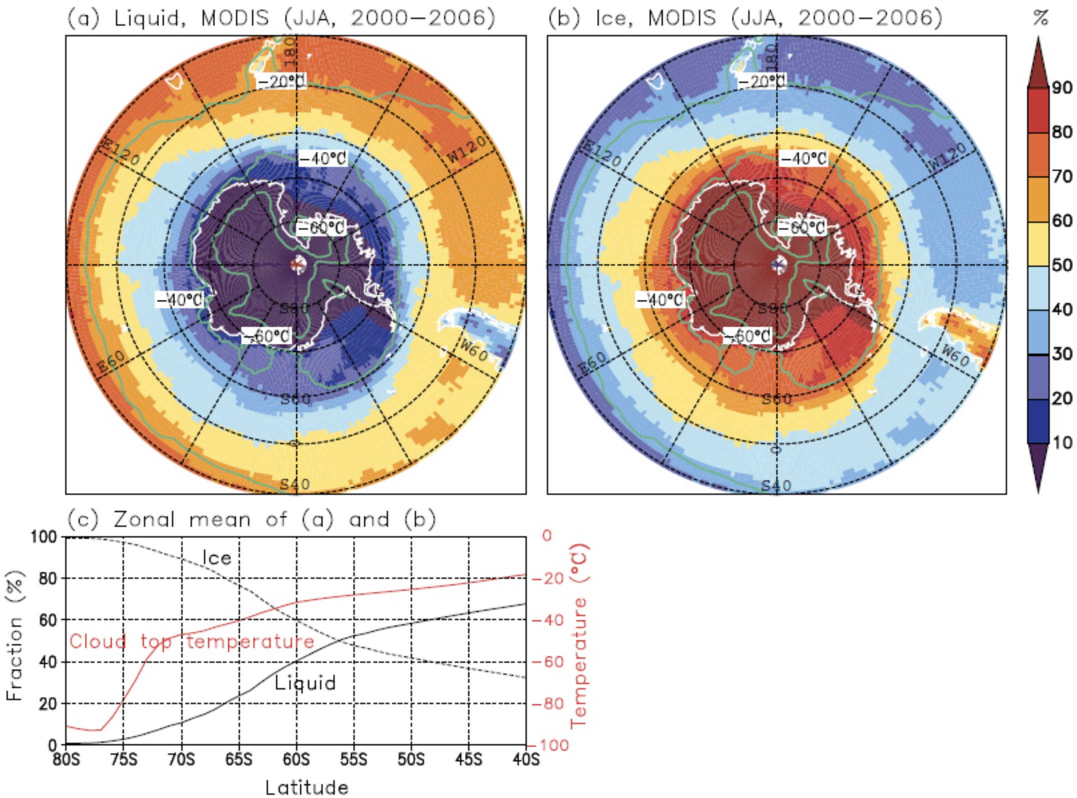


Fig. 1. (a) Liquid water and (b) ice fractions at cloud tops for each 1°-grid box from the MODIS data over the extratropics and the Antarctic (40°–90°S), averaged for the winter (June–July–August) months of 2000–2006. Green curves show the winter-mean cloud-top temperature observed by MODIS. Zonal means of fraction (black) and temperature (red) in (a) and (b) are given in (c).

Winter Antarctic atmosphere has abundant liquid clouds in the range of temperatures between −40°C to 0°C

Choi et al., 2010

Phase of clouds in Antarctic

Stockholm University

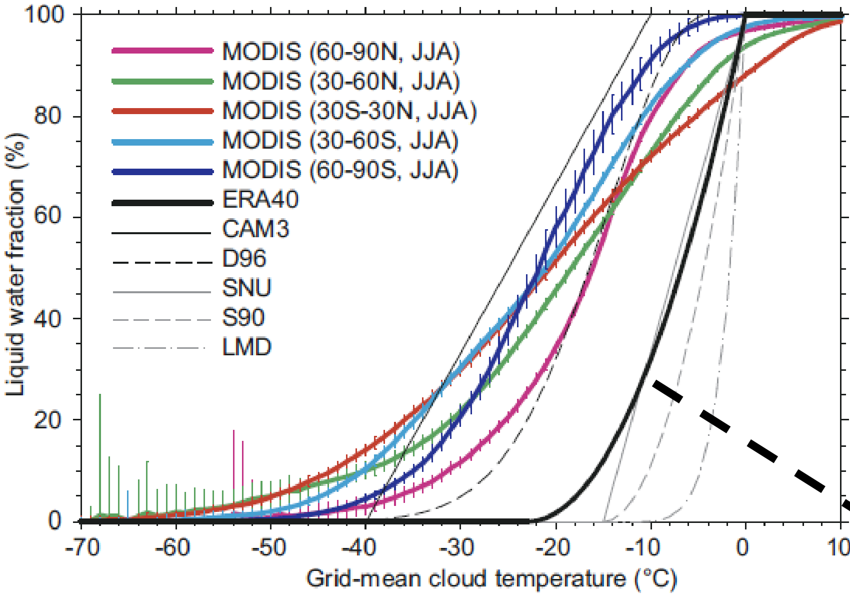
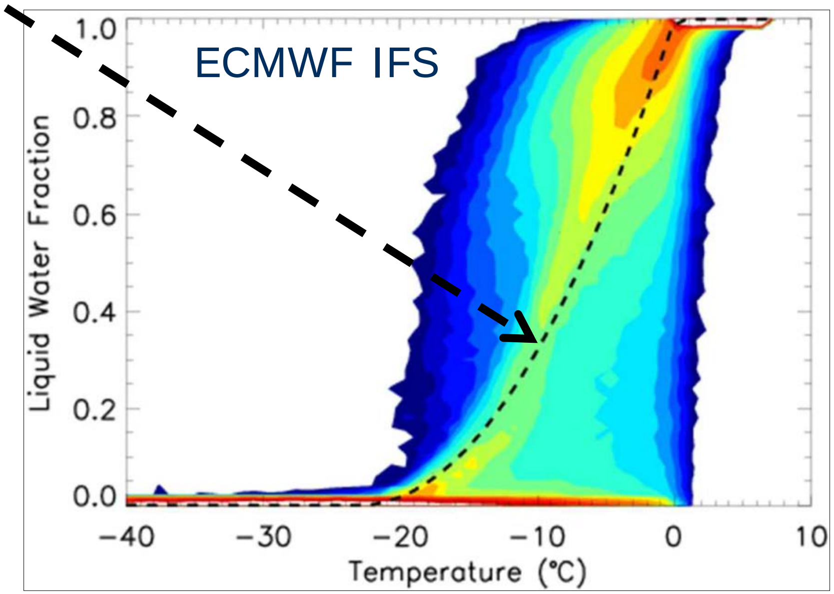


Fig. 5. Liquid water fraction at cloud tops versus grid-mean cloud-top temperature observed by MODIS for different latitudes for JJA. The error bar corresponds to 20 times the standard error of the mean. The functions (black and gray) assumed for the cloud phase parameterizations in the GCMs include CAM3, the NCAR Community Atmosphere Model version 3.0, Del Genio et al. (1996; D96), the ECMWF 40-year reanalyses (ERA40), Smith (1990; S90), the Laboratorie de Météorologie Dynamique GCM (LMD), and the Seoul National University GCM (SNU). Thicker lines indicate the observations and reanalysis estimate.

Choi et al., 2010

MODIS and CALIOP data

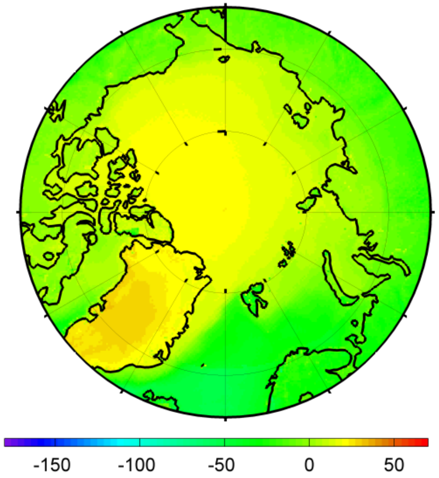
Winter Antarctic atmosphere has abundant liquid clouds in the range of temperatures between −40 °C to 0 °C



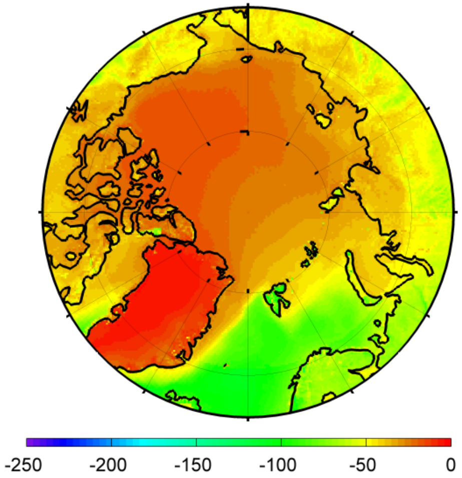
Cloud Radiative Effect at surface

APP-x Interim:1982-2009

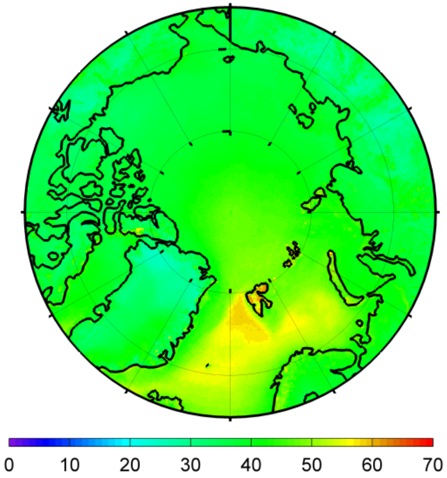
Total CRE



Shortwave CRE



Longwave CRE



This involves other data than observed from space, atmospheric profiles and albedo assumptions

How well do climate models simulate the effects of clouds in the Arctic?

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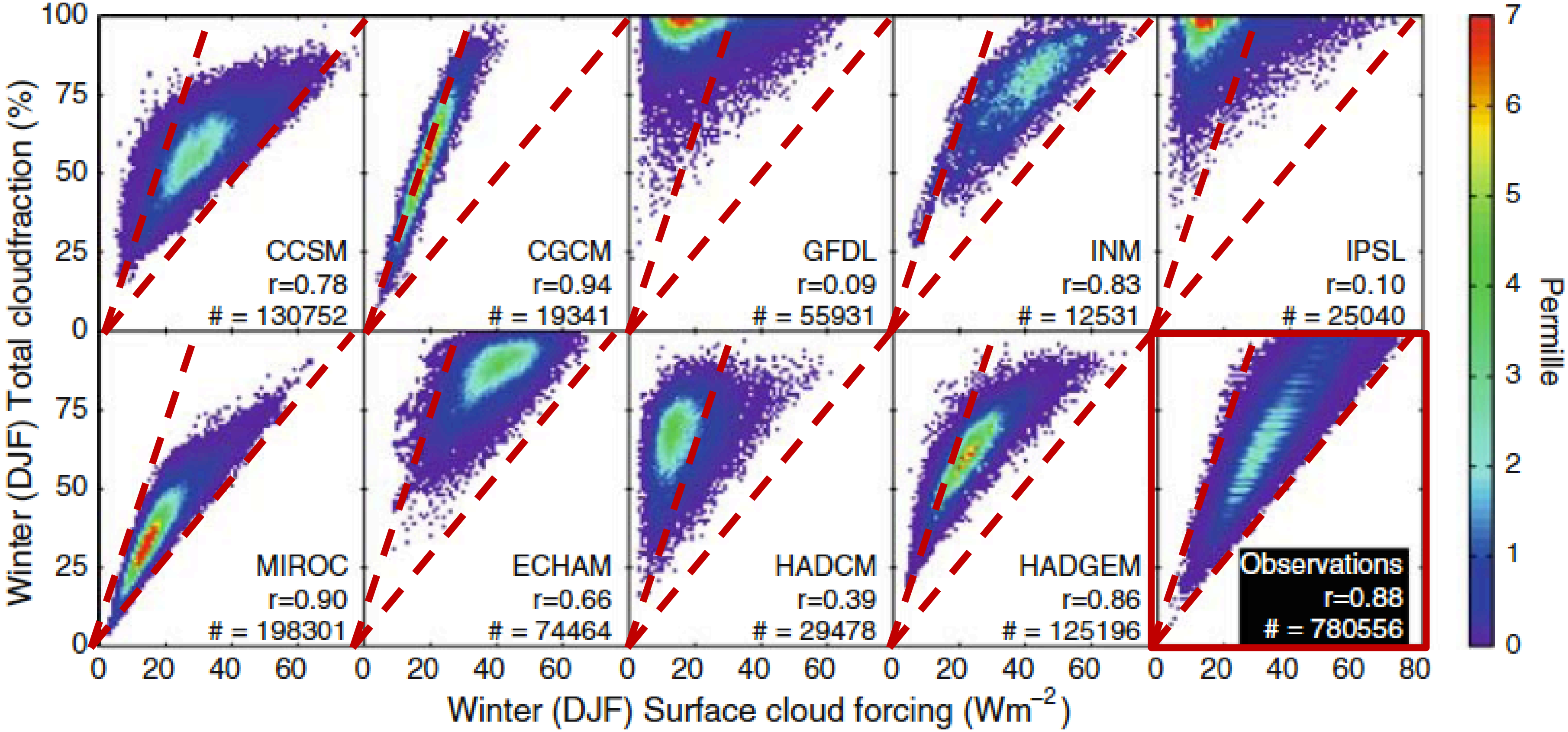
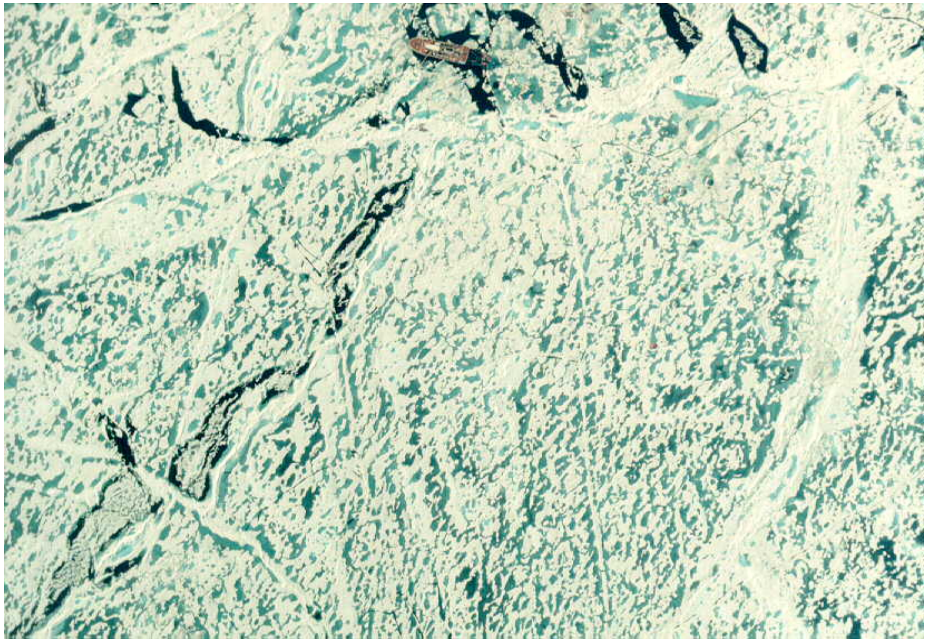
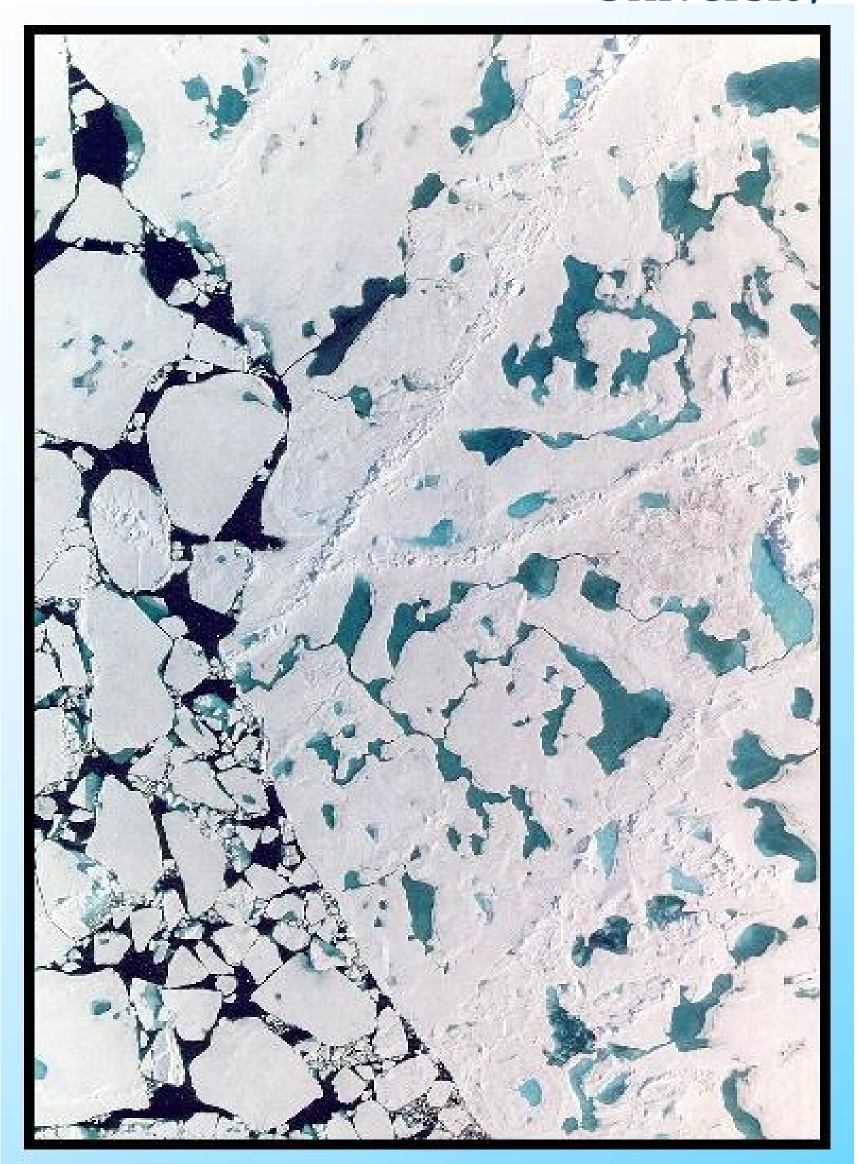


All models tend to underestimate the impact of clouds on the surface energy balance

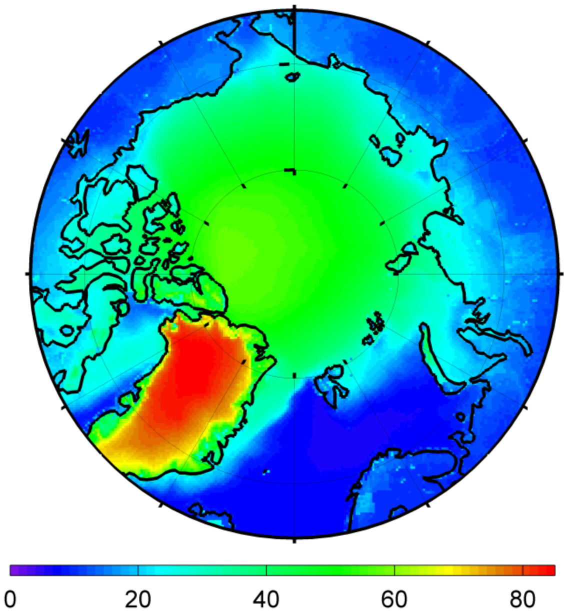
Karlsson and Svensson, 2010, Climate Dynamics
Svensson and Karlsson, 2011, J. Climate

Sea-ice albedo

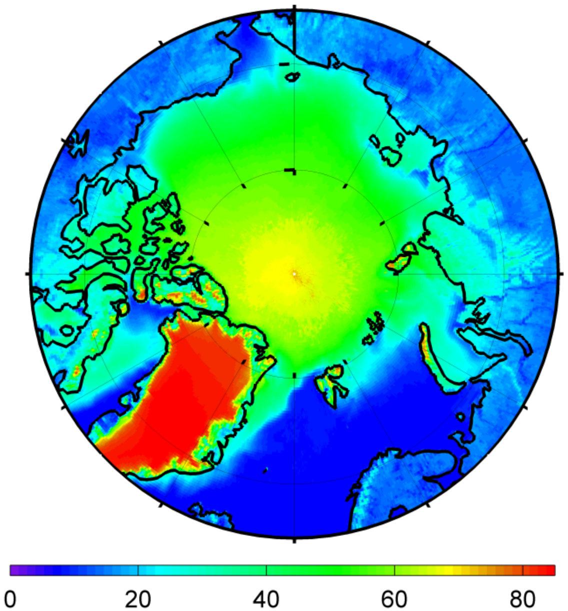




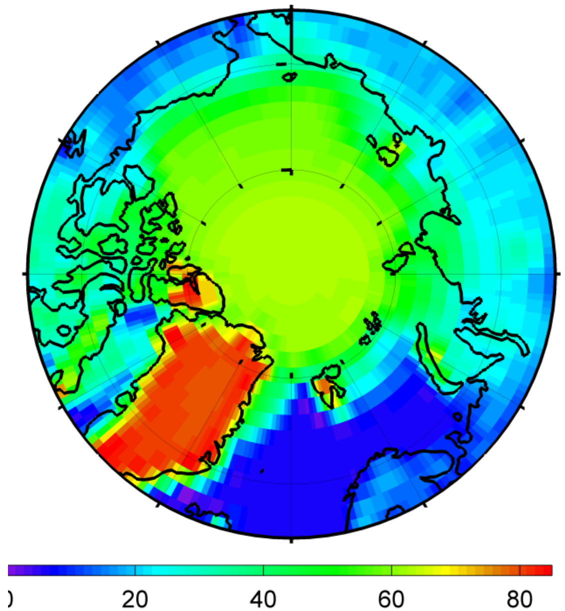
Summer (JJA) surface albedo



APP-x
1982-2009

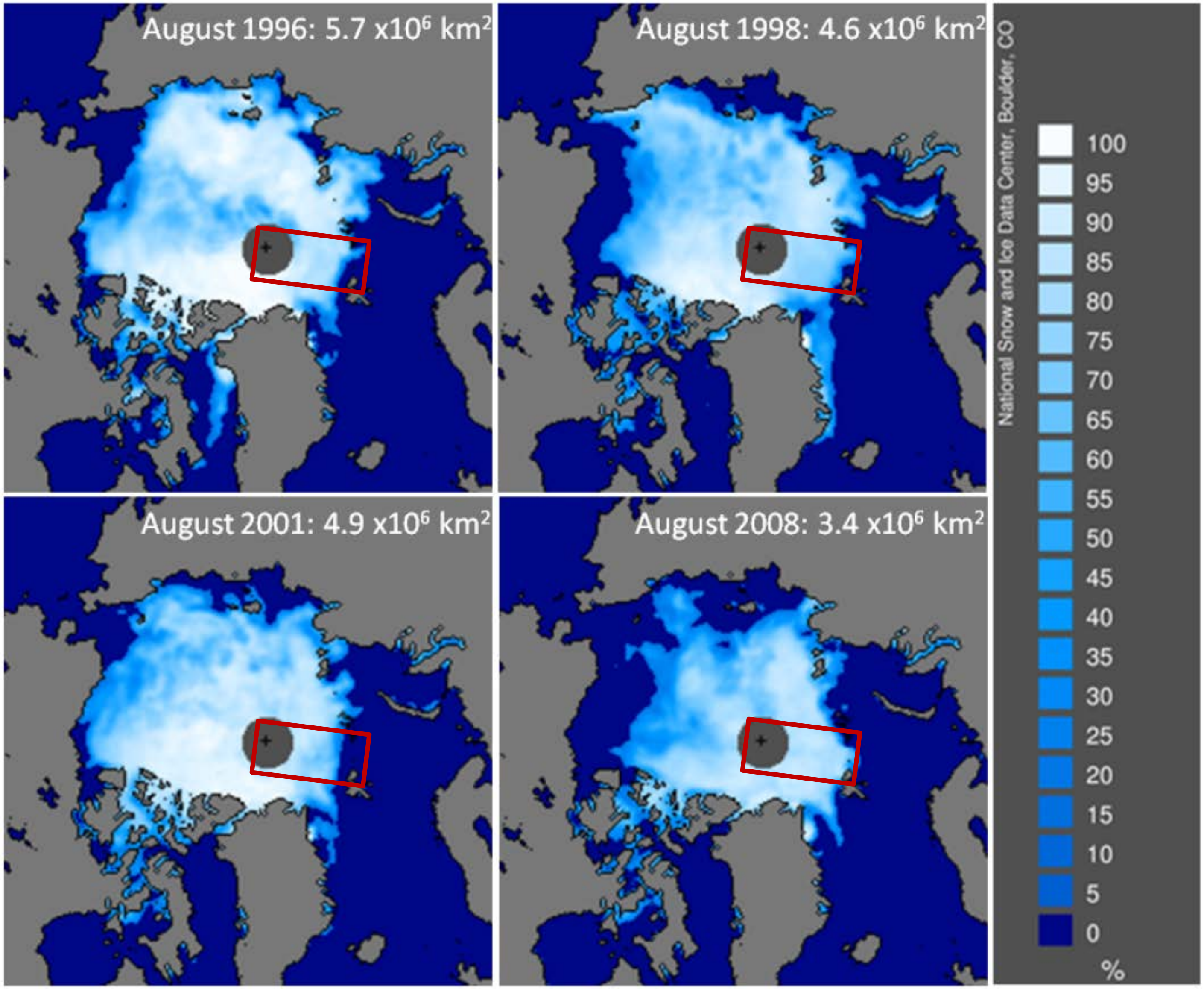


CMSAF
1982-2009



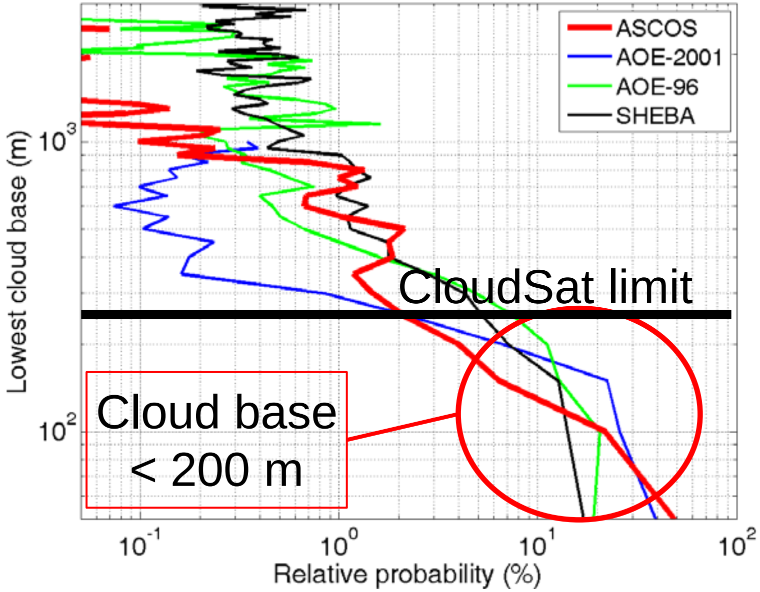
ERA-Interim
1980 – 2004

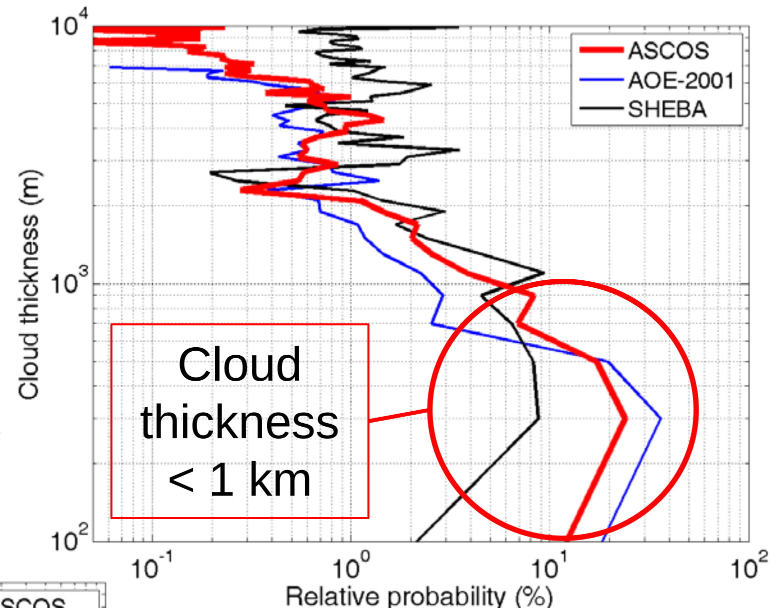
Observations of summer sea-ice extent

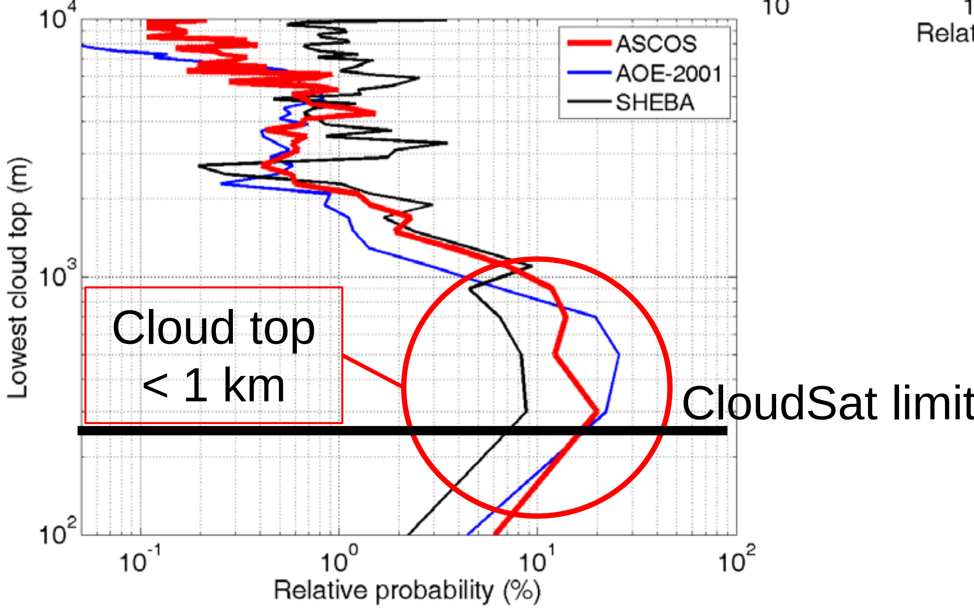


Tjernström et al., 2012

Summer cloud dimensions







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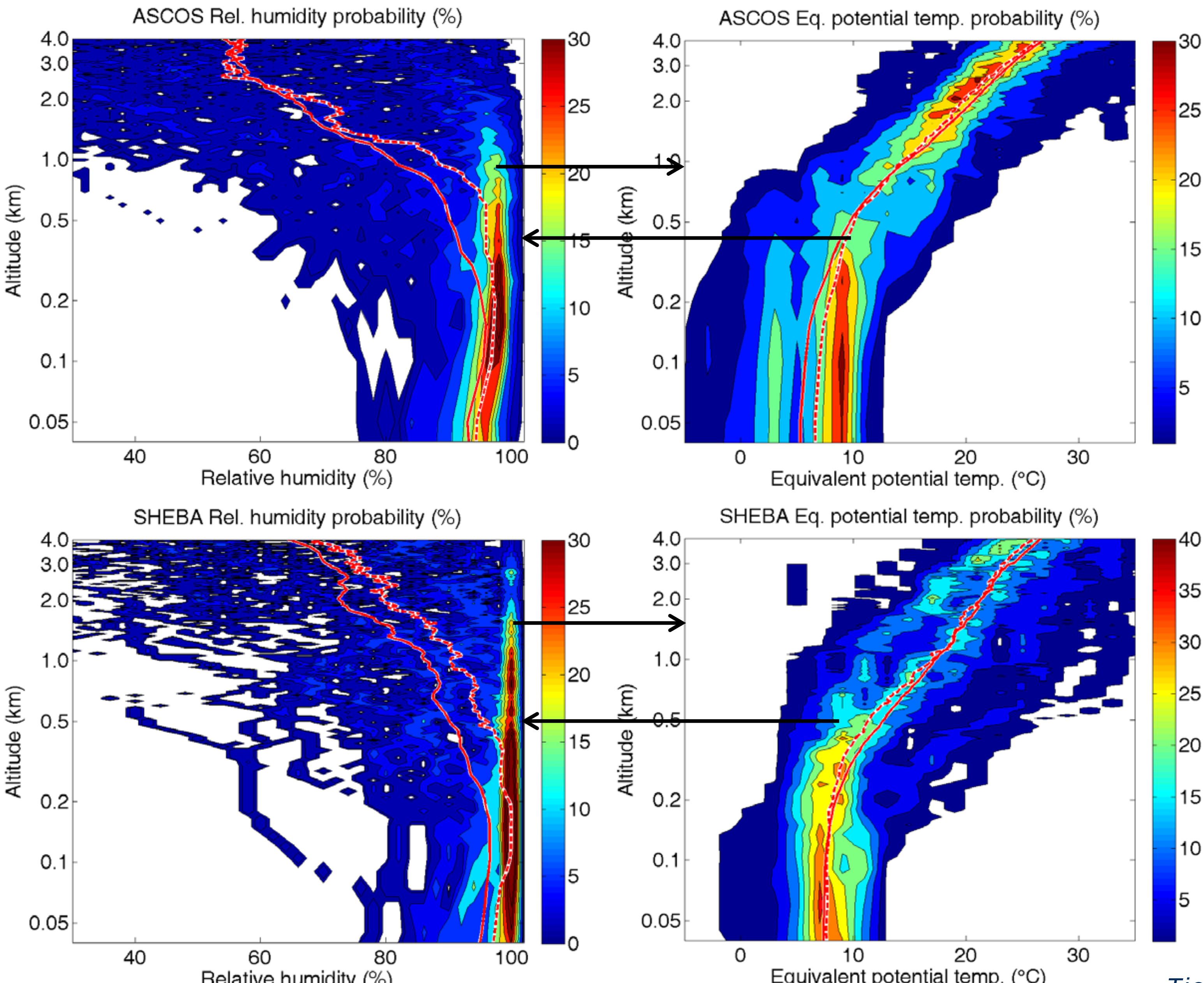
Summer near-surface vertical structure



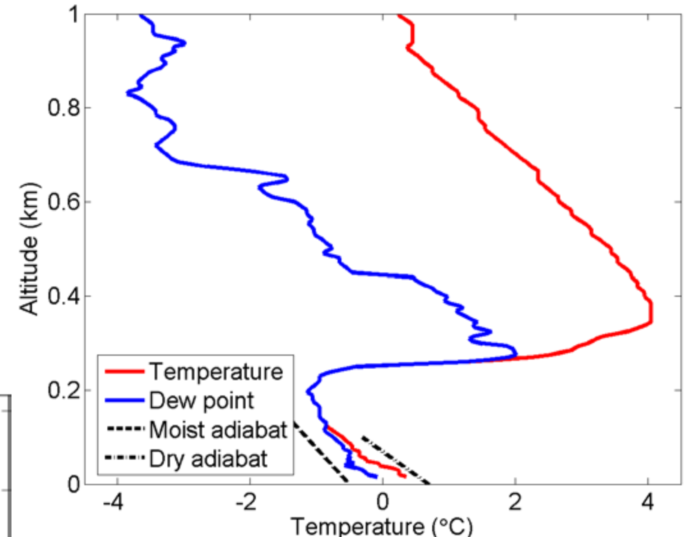
Normally a well-mixed very moist shallow boundary layer

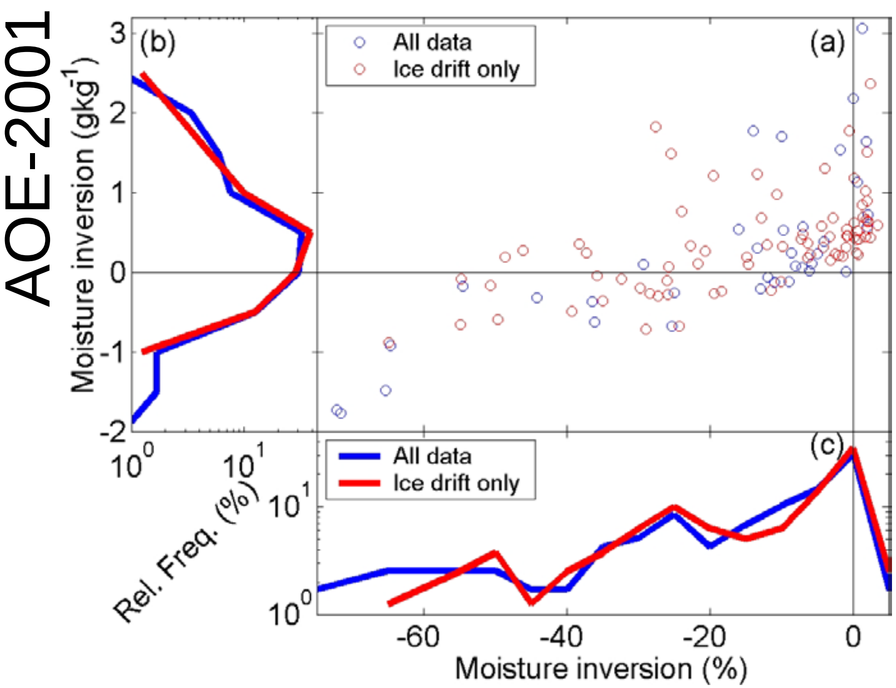
The moist layer is deeper than the well-mixed boundary layer

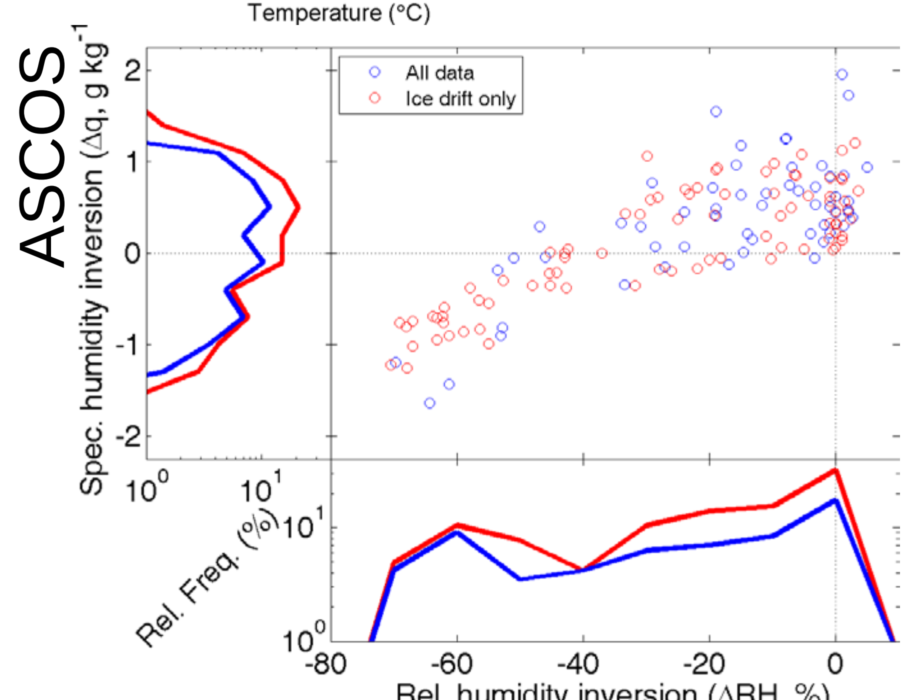
Tjernström et al., 2012

Moisture increasing in the inversion

Consequences for entrainment







Persistent Arctic mixed-phase

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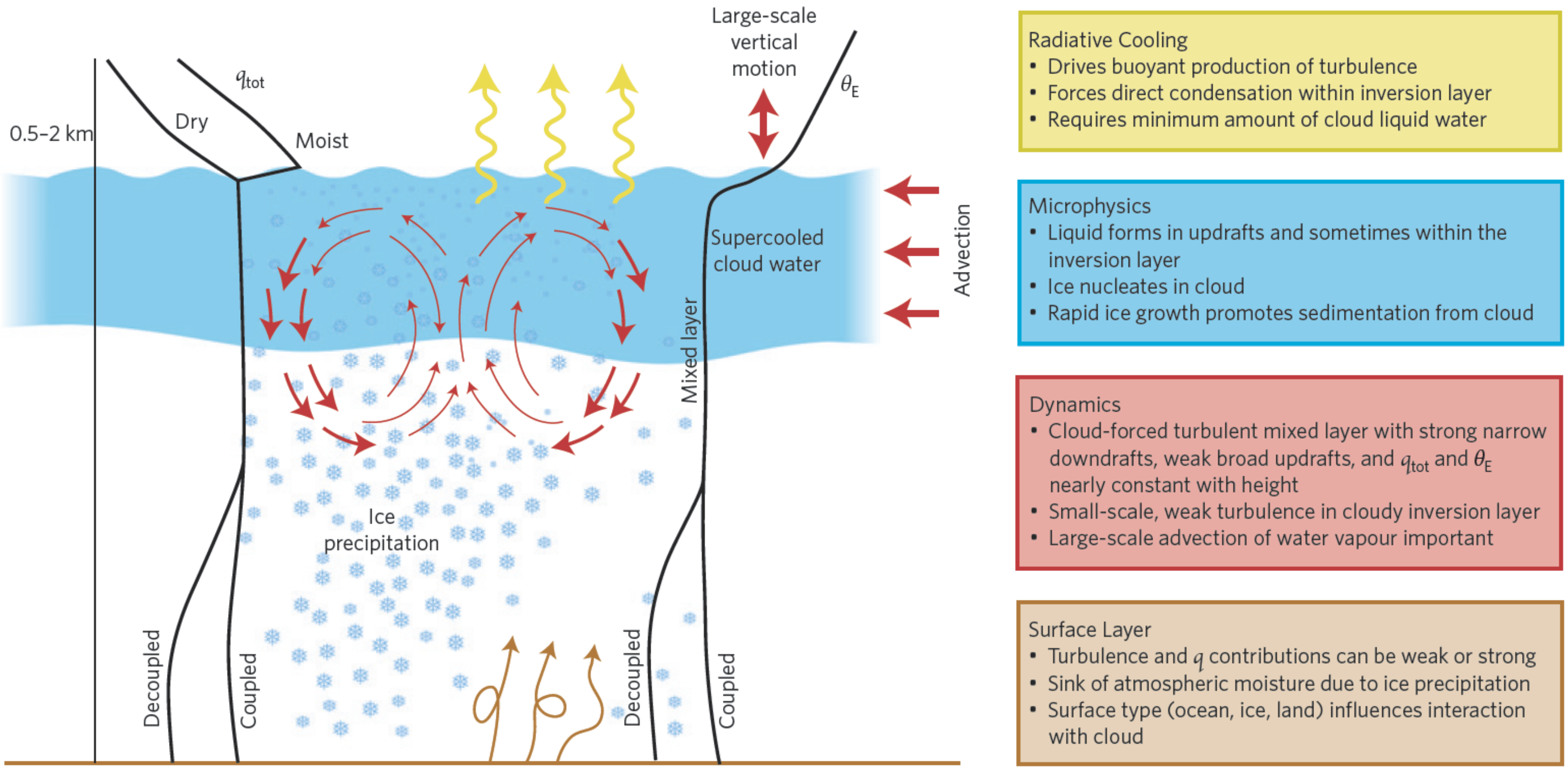
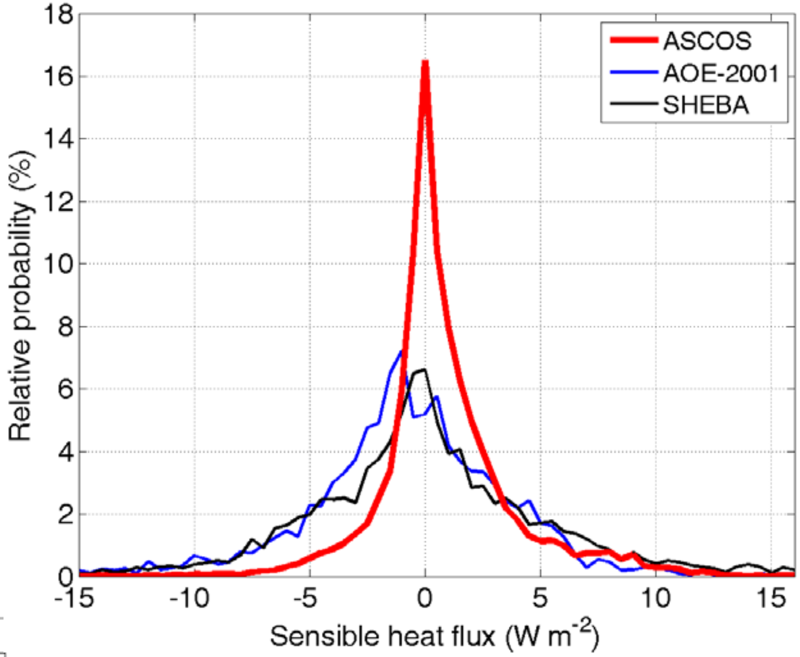
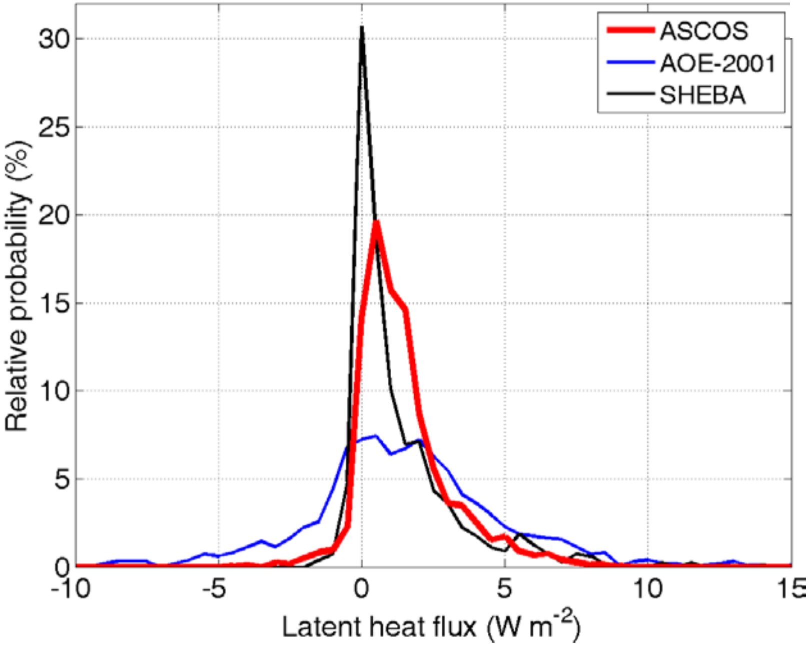


Figure 3 | A conceptual model that illustrates the primary processes and basic physical structure of persistent Arctic mixed-phase clouds. The main features are described in text boxes, which are colour-coded for consistency with elements shown in the diagram. Characteristic profiles are provided of total water (vapour, liquid and ice) mixing ratio (q_{tot}) and equivalent potential temperature (θ_E). These profiles may differ depending on local conditions, with dry versus moist layers/moisture inversions above the cloud top, or coupling versus decoupling of the cloud mixed layer with the surface. Cloud-top height is 0.5–2 km. Although this diagram illustrates many features, it does not fully represent all manifestations of these clouds.

Morrison et al., 2012

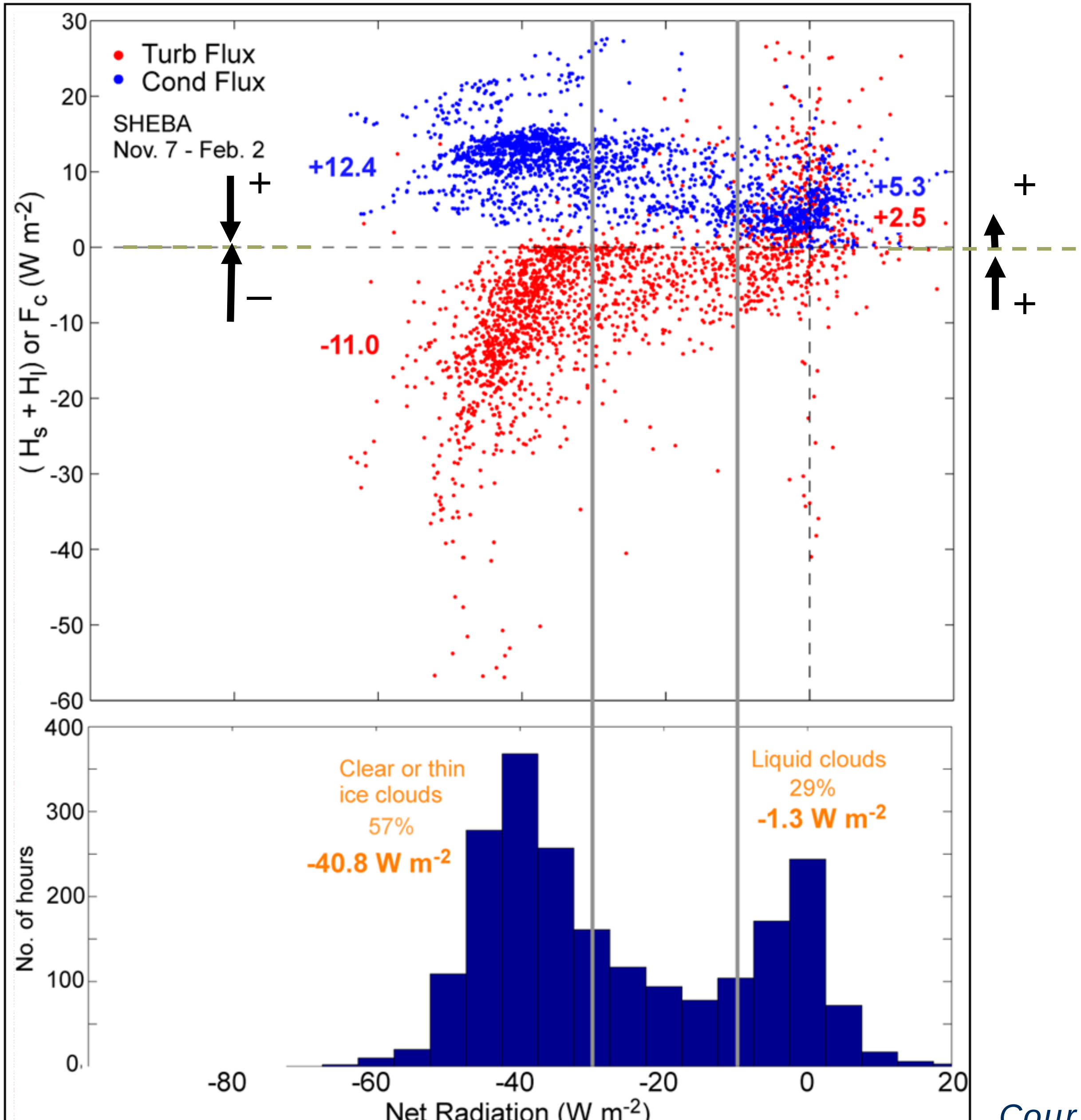
Surface turbulent heat fluxes





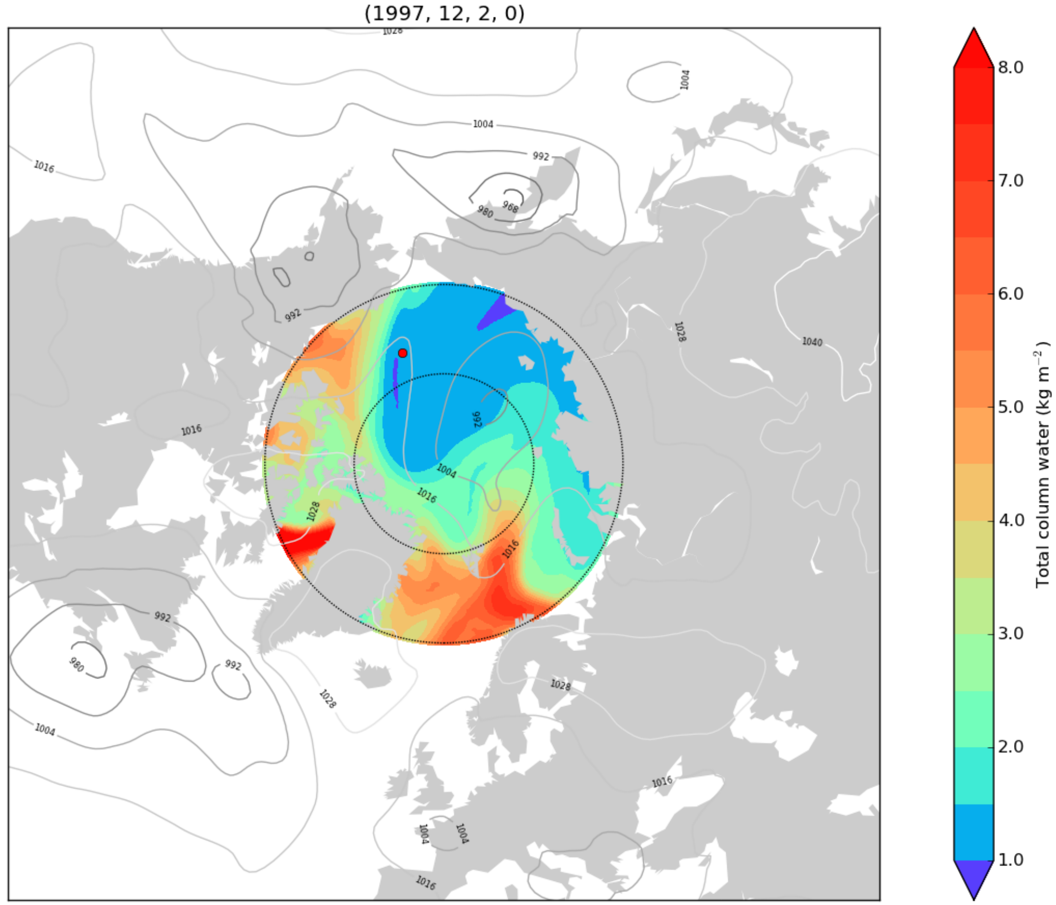
Surface budget terms

SHEBA winter



Courtesy Ola Persson

Arctic winter

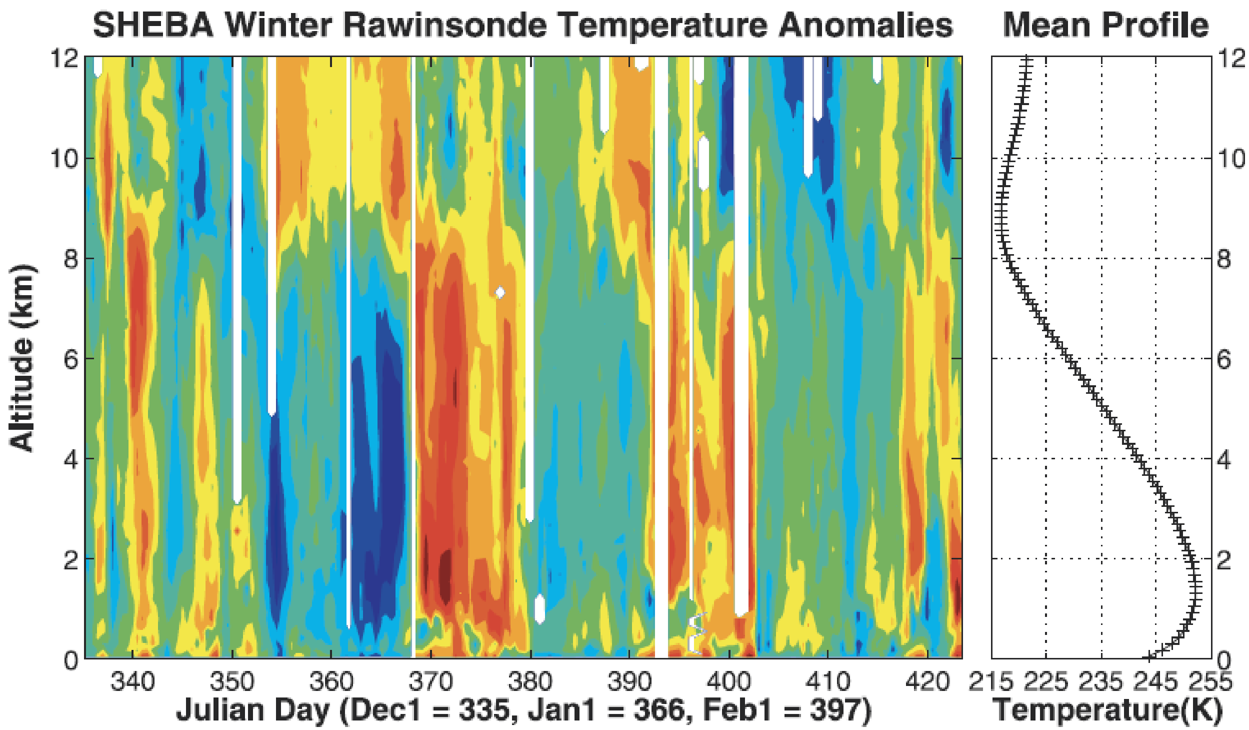


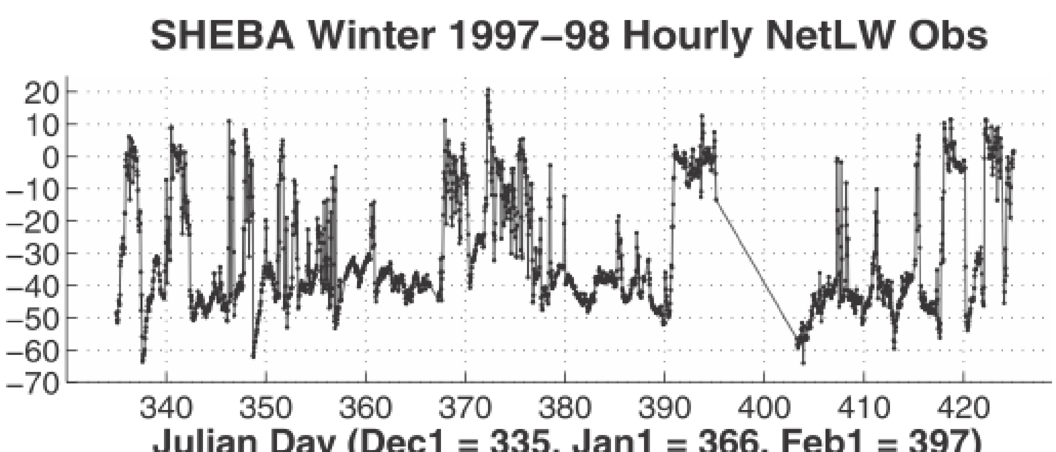
Surface pressure and total column water vapor (kg m^{-2})

Red dot SHEBA location

Courtesy of Cian Woods

SHEBA observations 1997-98





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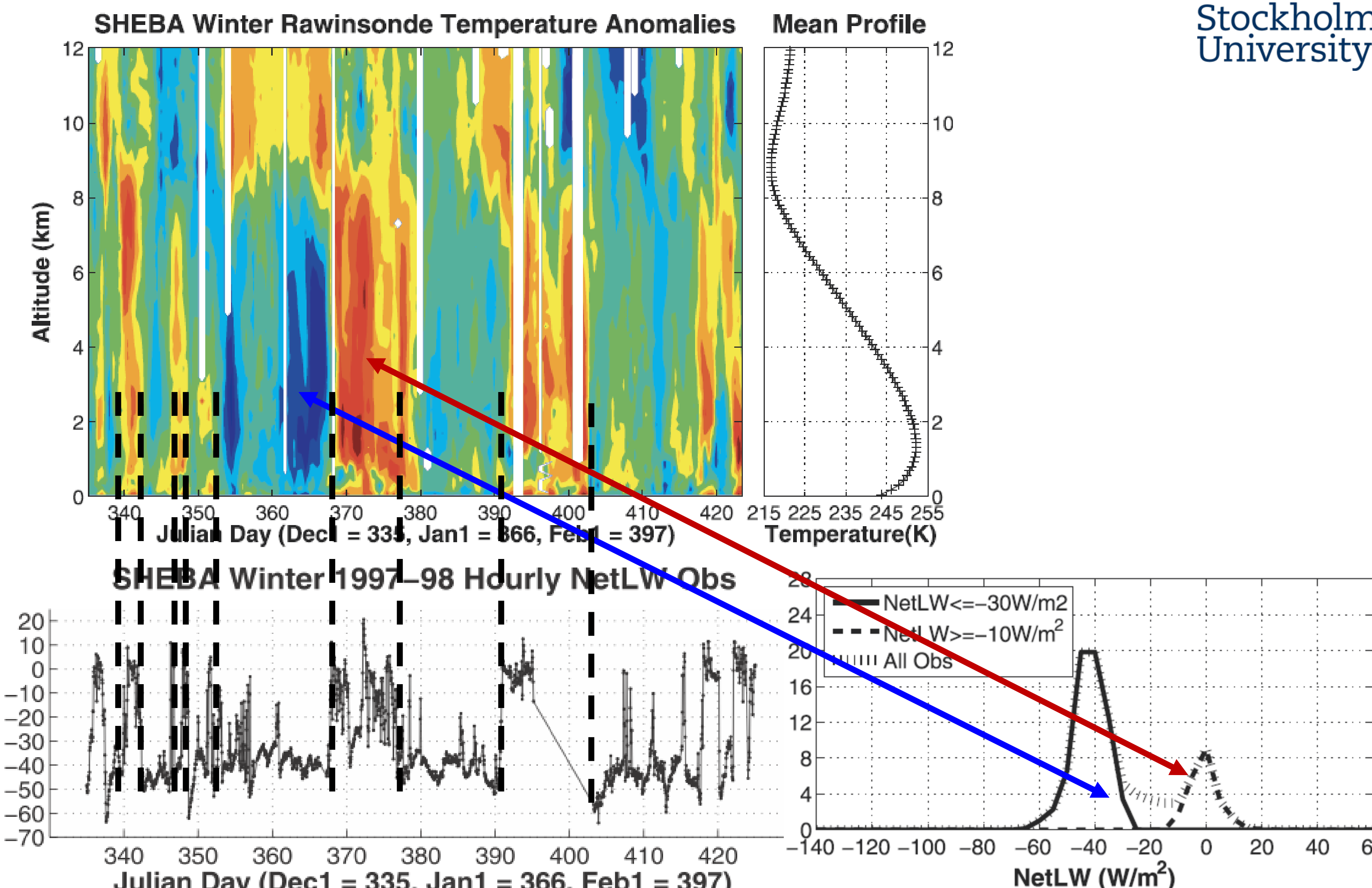
Stramler et al., 2011

SHEBA observations 1997-98



Stramler et al., 2011

What is special about polar regions

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- Annual mean CRE at TOA is small, clouds tend to be optically thin and have similar cloud top temperatures as surface
- Annual mean CRE at surface is usually positive, due to the high albedo of the surface
- Large cloud fraction (especially mixed-phase)
- Aerosol climate is different (extremely low numbers of CCN not uncommon, sources of IN unknown)
- Relatively few observations = less understanding relative to lower latitudes
- Problems with interpreting satellite-based observations and coverage (some only ≤ 82°N)
- Few observations makes reanalysis products more uncertain also for the flow and thermodynamic state