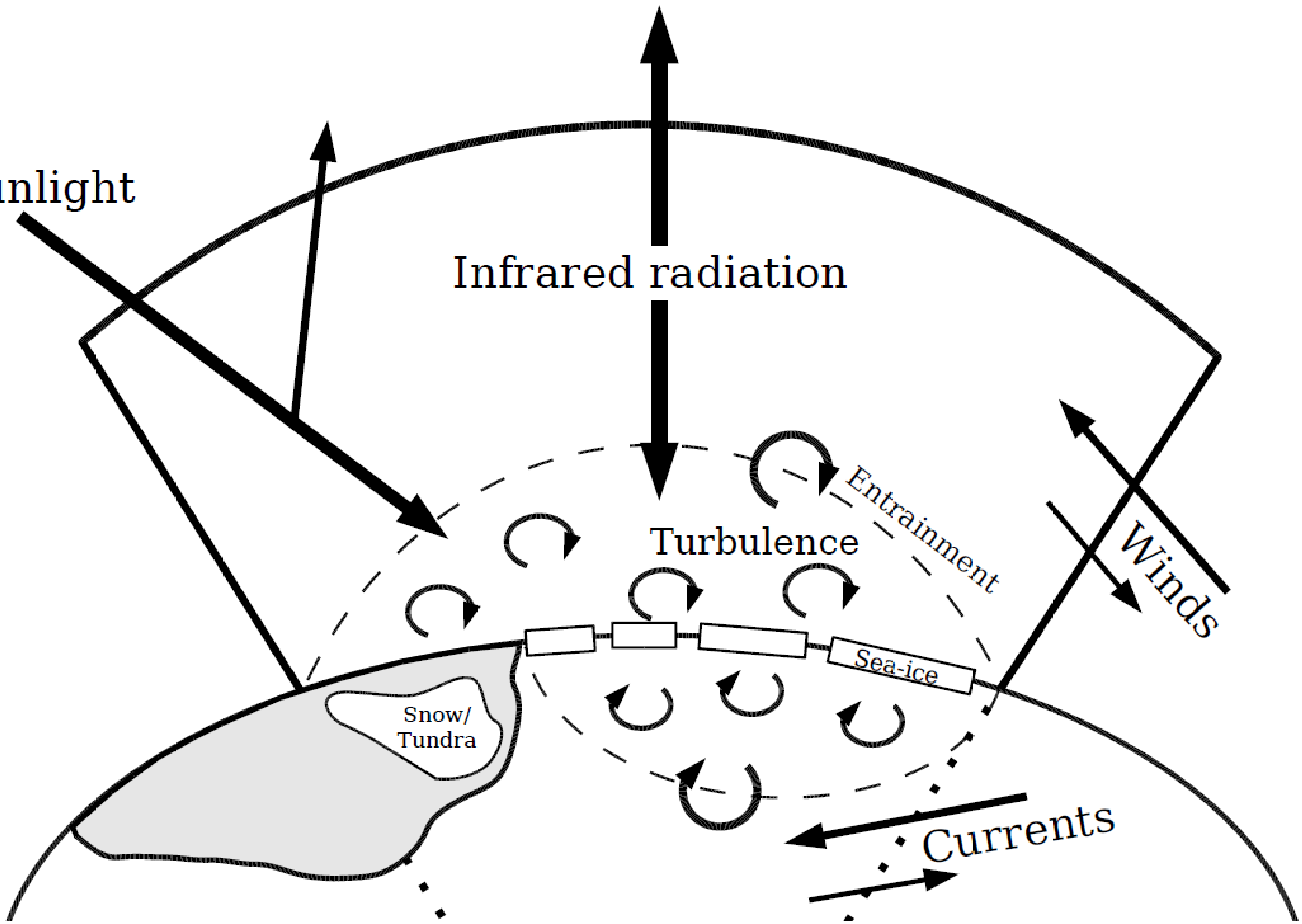
Extratropical and Polar Cloud Systems

Gunilla Svensson

Department of Meteorology &
Bolin Centre for Climate Research

George Tselioudis

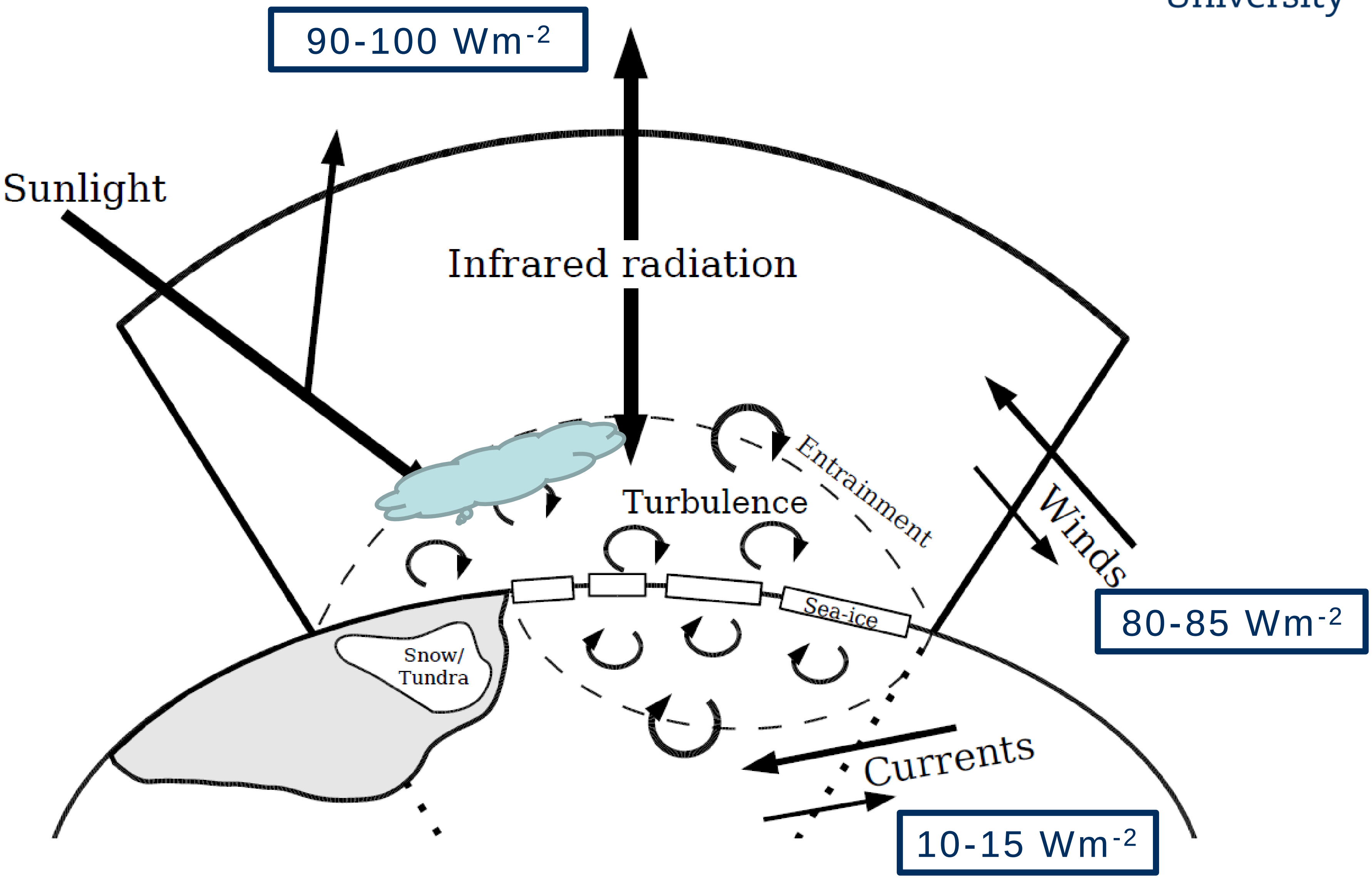
Arctic climate system



Courtesy of Thorsten Mauritsen

Arctic climate system

Bengtsson et al., 2013



Trends in surface temperature (°C year^{-1})

NASA GISS (1960-2010)

Stockholm University

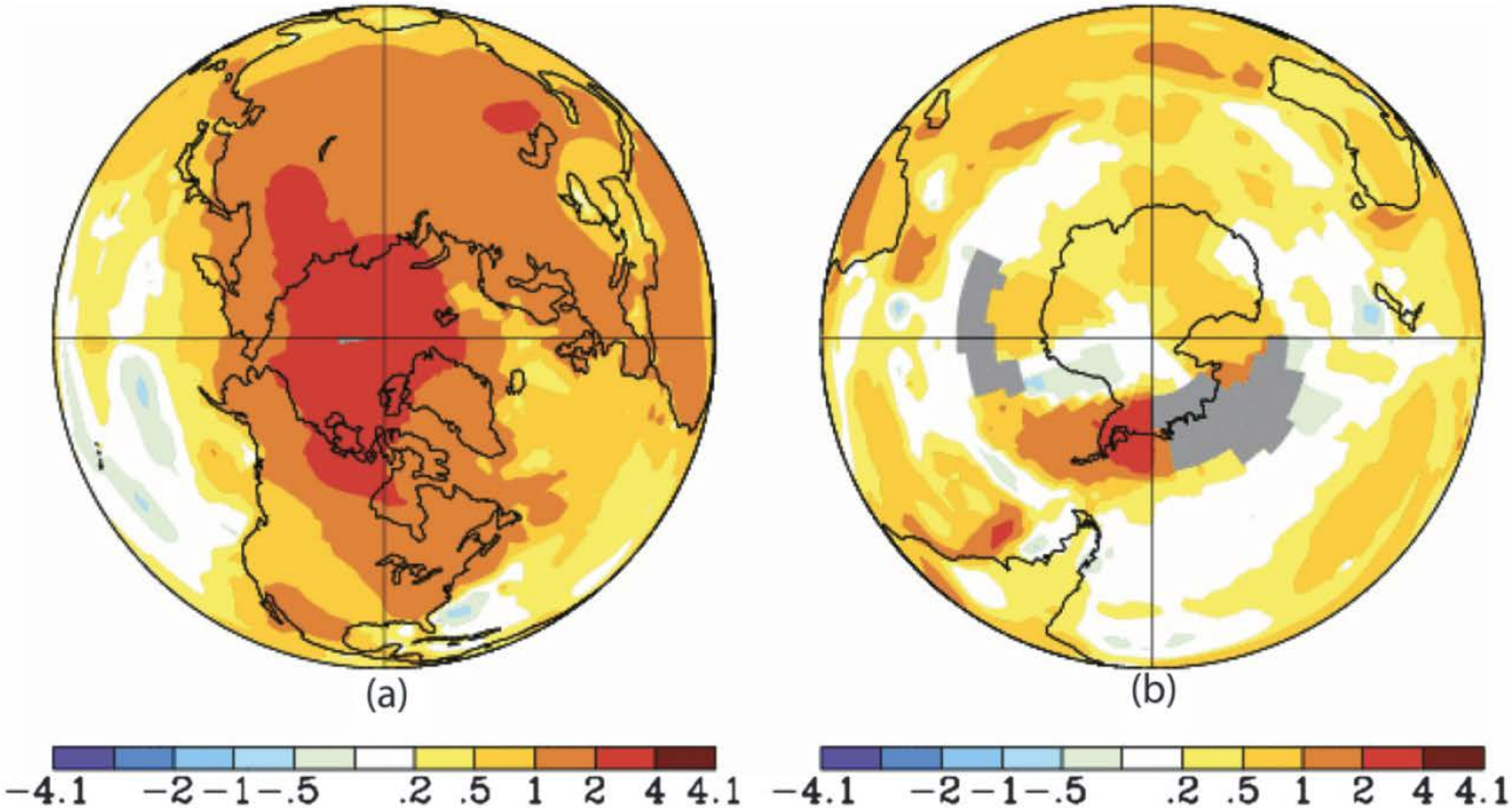
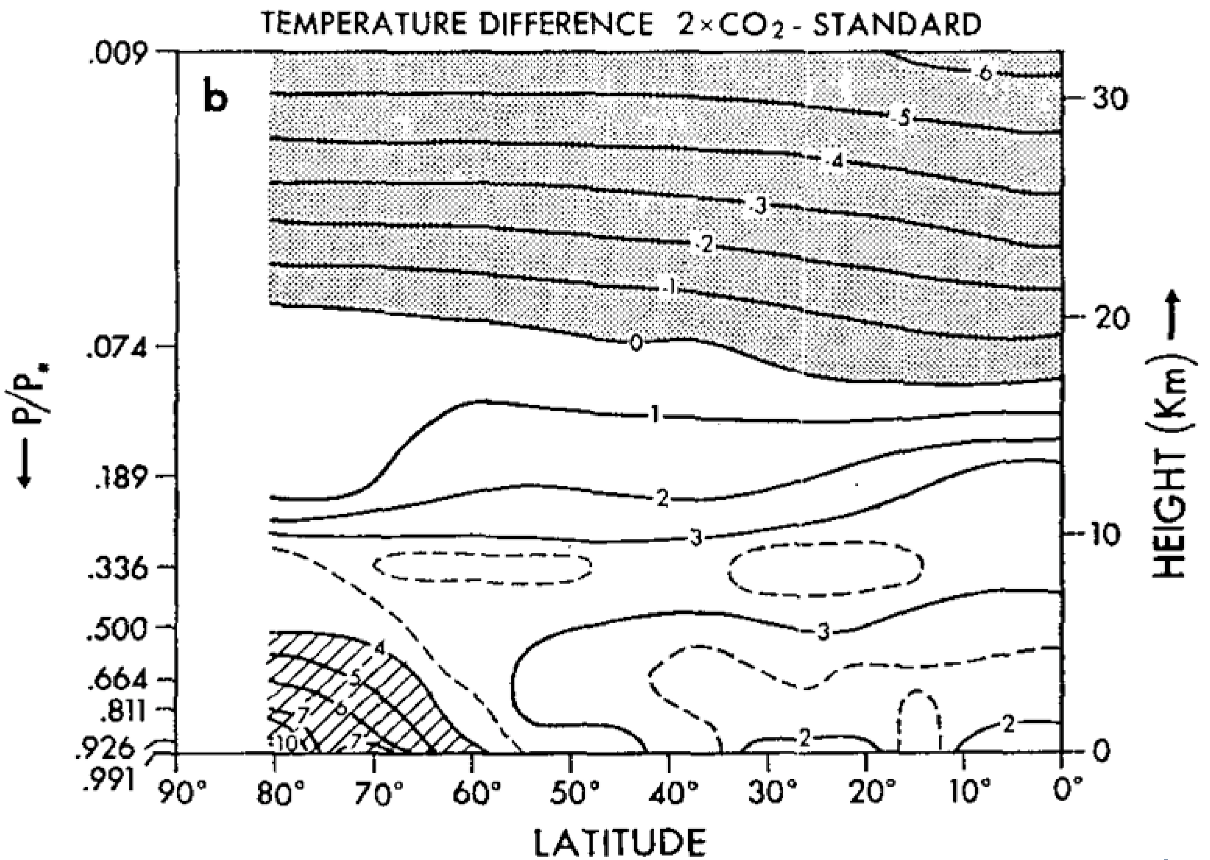


FIG. 1. Trends in surface temperature from the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS) surface temperature analysis for the period 1960–2010: (a) NH and (b) SH. Units are °C (50 yr)$^{-1}$.

Bengtsson et al., 2013

Arctic climate response to increased forcing

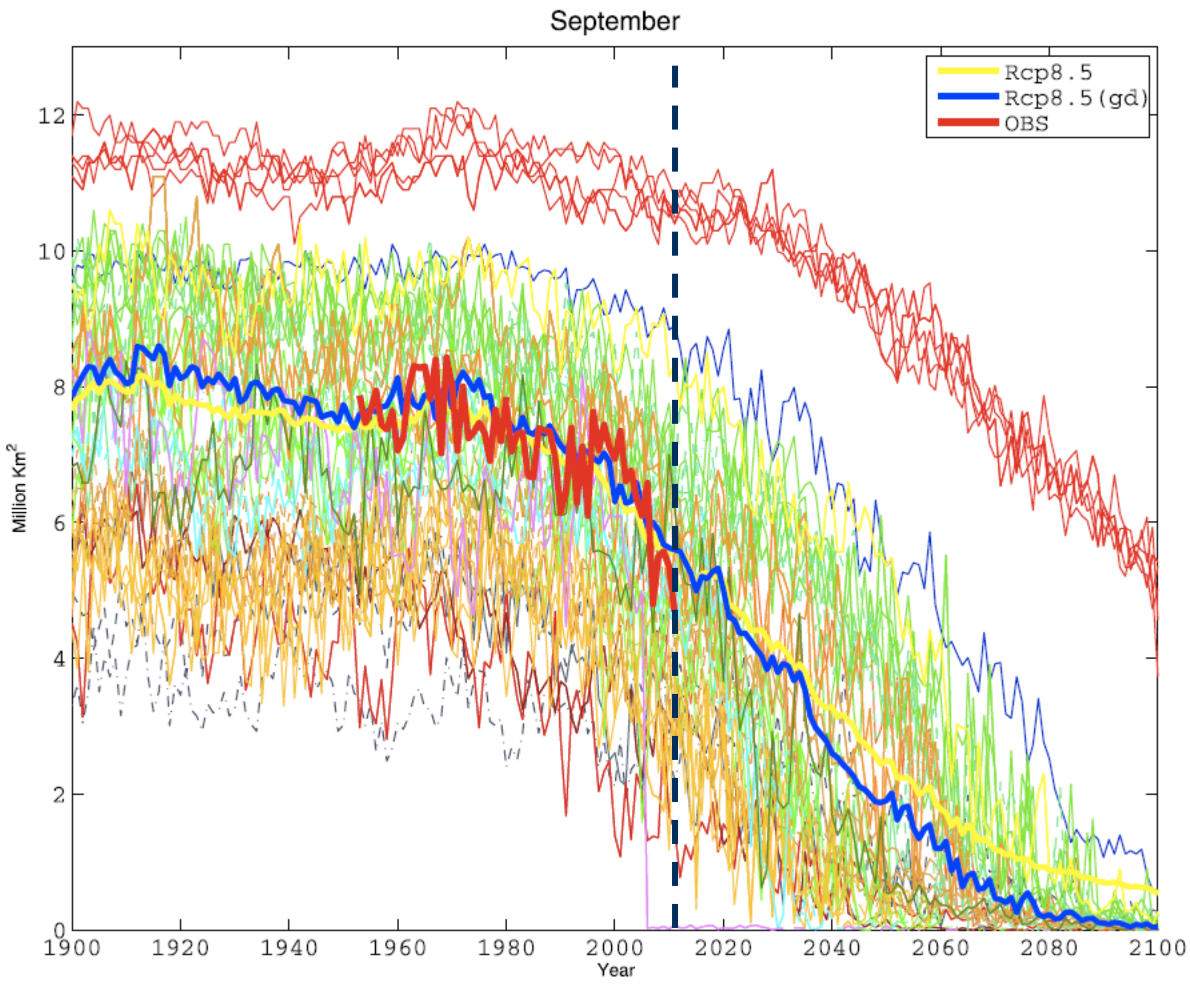
Prescribed clouds



Results from comparing normal ($1x\ CO_2$) and twice normal ($2xCO_2$) concentrations

Manabe and Wetherald, 1975

Arctic sea-ice extent in CMIP5 models and observed



Ensemble mean

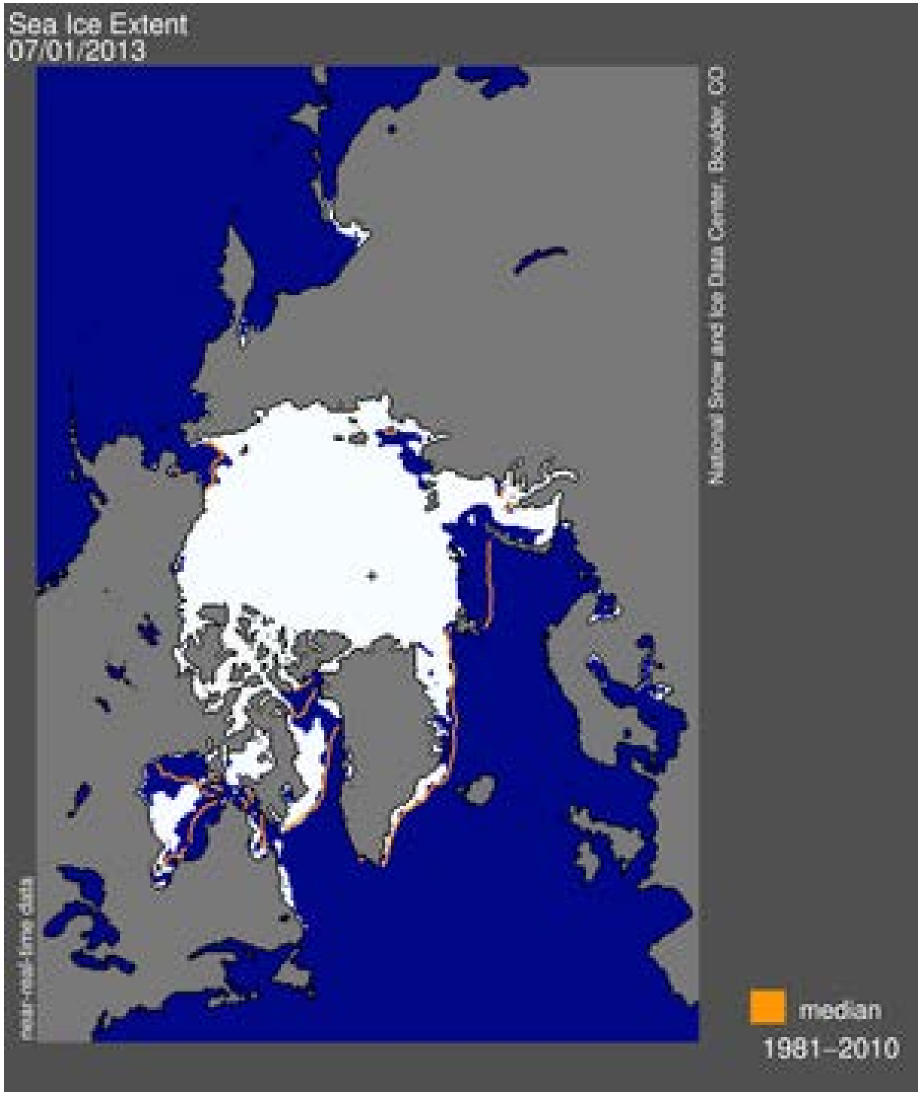
Ensemble mean, selected models

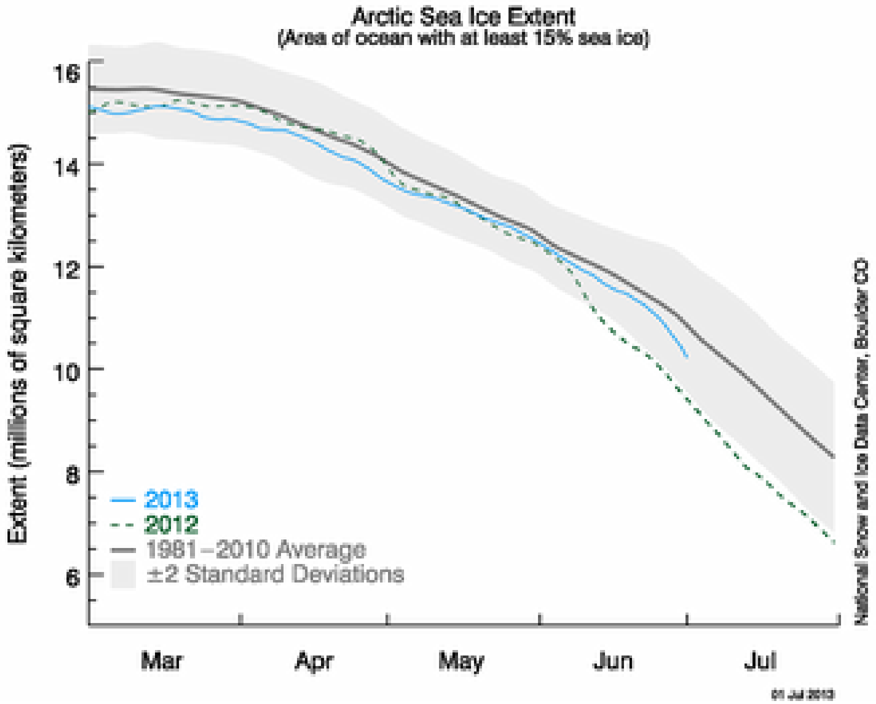
Observed

Wang and Overland, 2012

Arctic sea ice July 1, 2013

Stockholm University





http://nsidc.org/

Cloud influence on and response to seasonal Arctic sea-ice loss

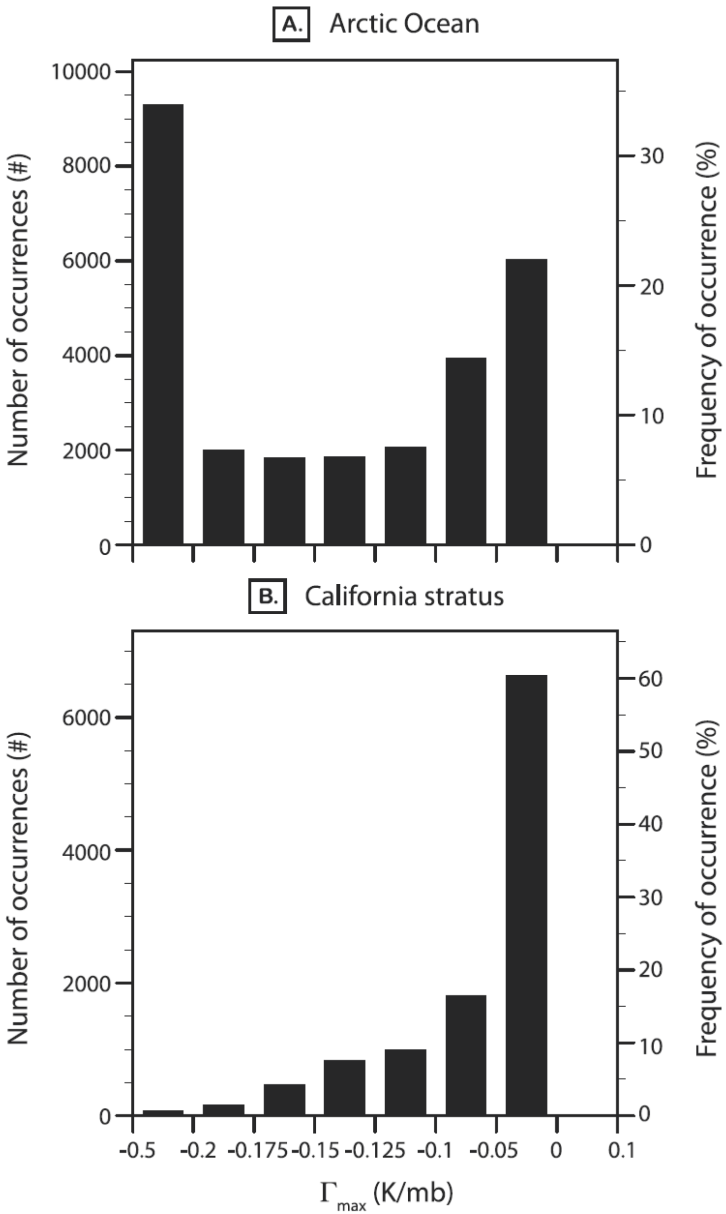
Observations show that large-scale atmospheric circulation patterns, near-surface static stability and surface conditions control Arctic cloud cover during melt season

No cloud response to summer sea ice loss, but cloud increases over newly open water during early fall

Kay and Gettelman, 2009

Arctic low clouds and parameterizations

CAM4 experiments



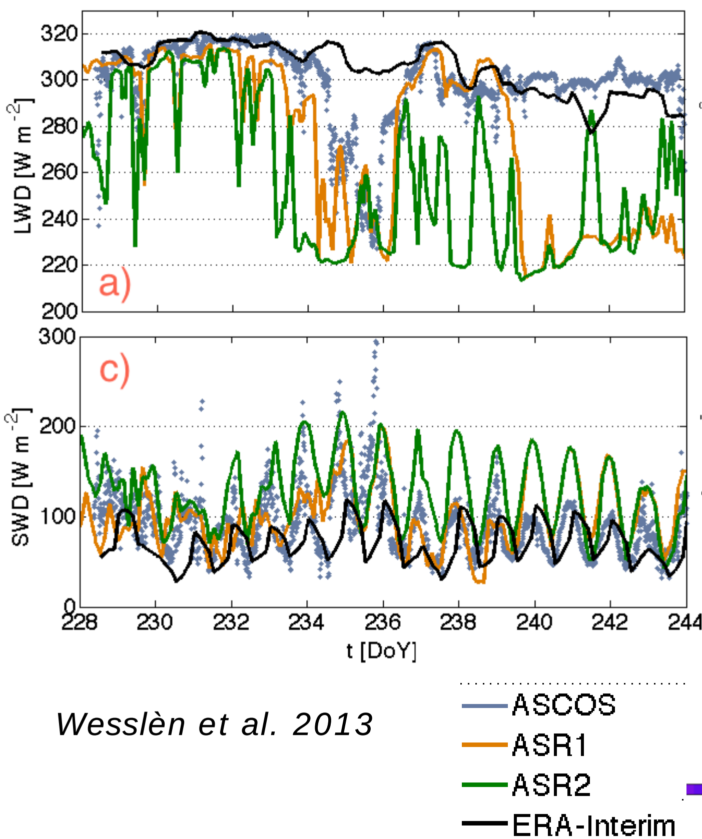
Klein and Hartman (1993) based parameterizations applied over the Arctic Ocean gives far too much low-level clouds in the Arctic summer over the sea ice

Parameterization modification, before diagnosing low-level cloud amount, a check for surface or near surface based inversions change the response of clouds to sea-ice melt

Study performed using short forecasts with the climate model

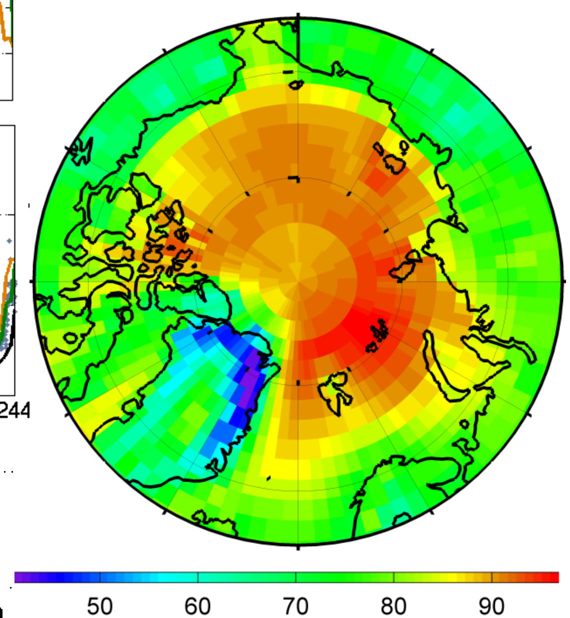
Kay et al., 2011

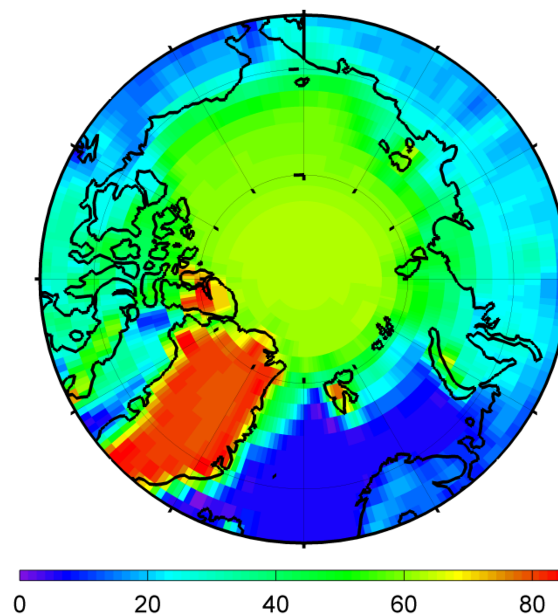
Reanalysis in the Arctic



Wesslèn et al. 2013

Cloud fraction
Annual mean





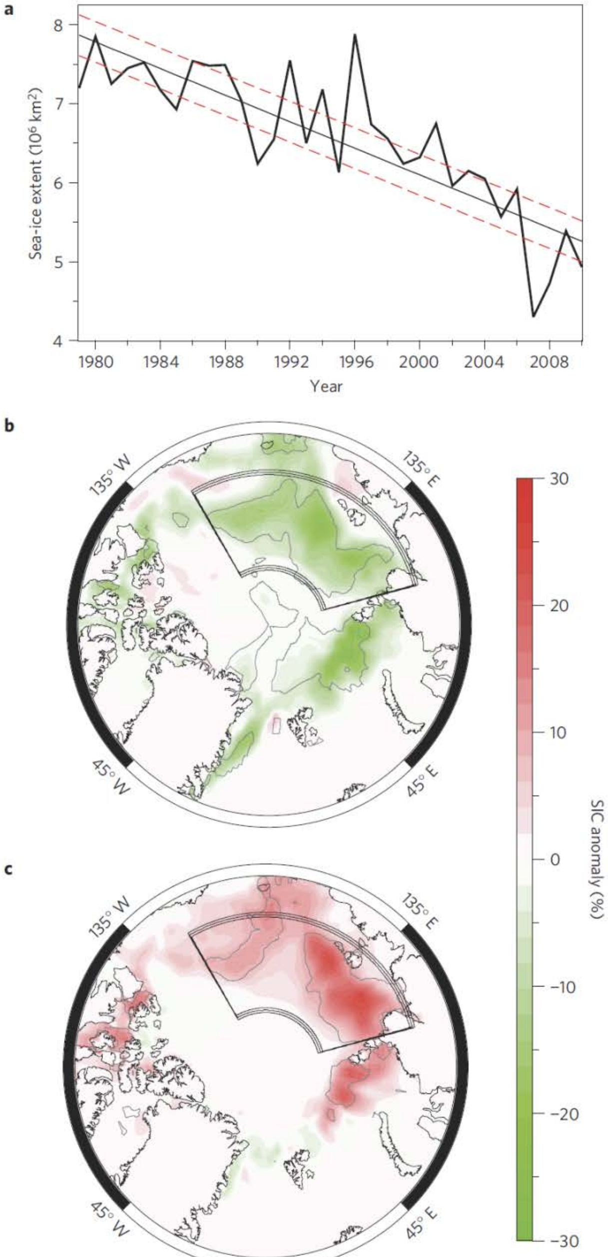
Data assmilation issues:
Vertical gradients are smeared out
Near surface information not used
Not enough variability in observations to inform on obs errors

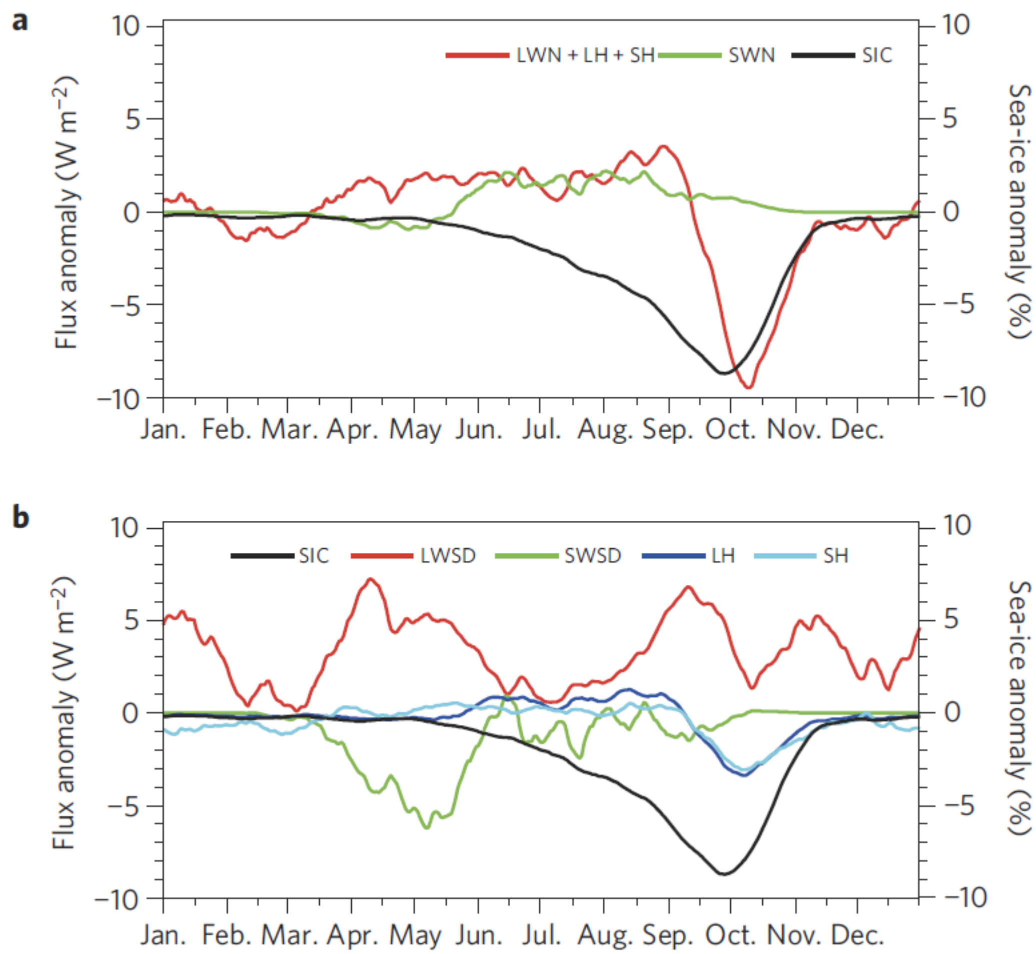
ERA-Interim
1980 – 2004

Prescribed Climatological Sea-Ice **albedo** with annual cycle

Be careful when using reanalyses in the Polar regions!

Spring conditioning for summer sea-ice melt
ERA-Interim (1989-2010)





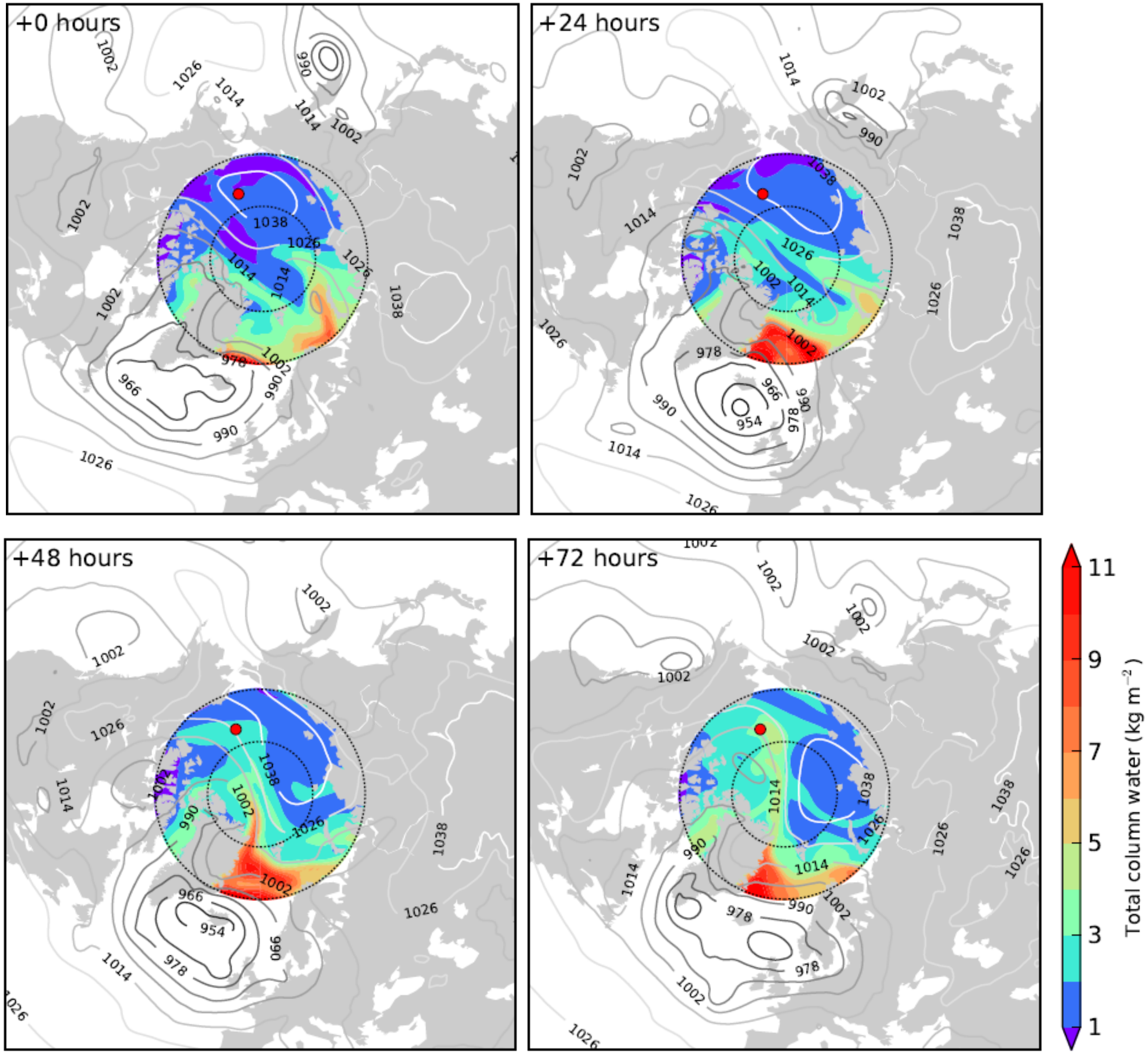
Stockholm University

Kapsch et al., 2013

Moisture transport to the Arctic

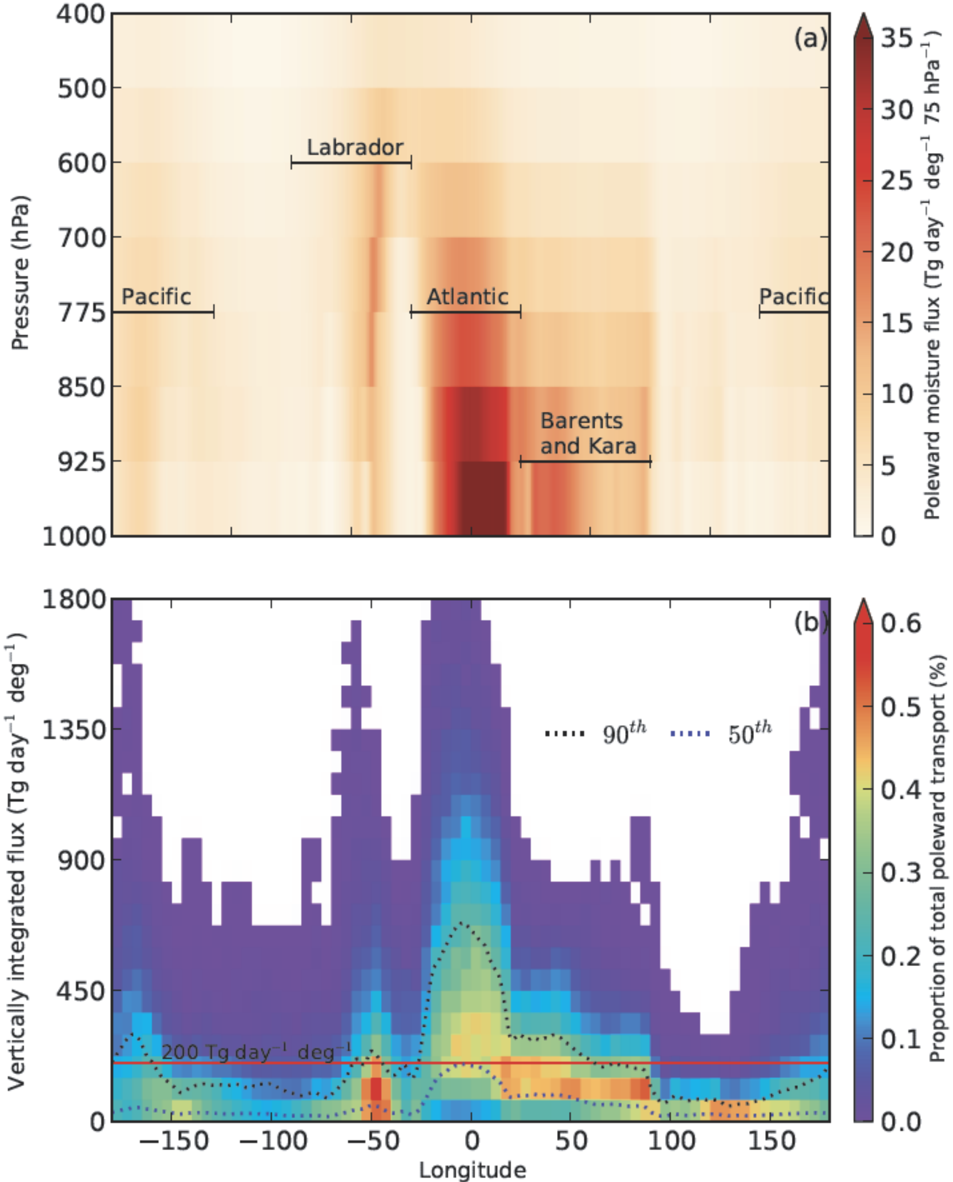
ERA-Interim (1989-2010) SHEBA year

Stockholm University



Woods et al., 2013

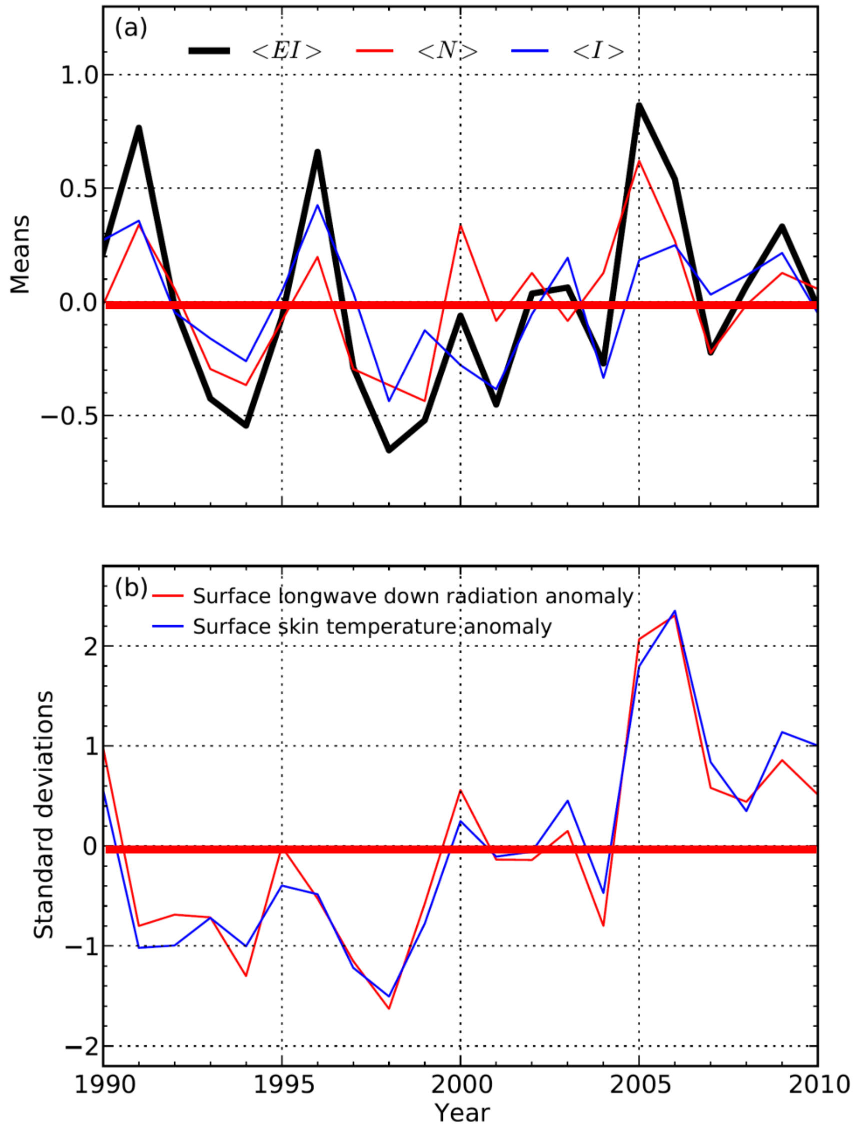
Moisture transport across 70°N
ERA-Interim (1989-2010)



Woods et al., 2013

Winter anomalies in LWD related to moisture transport across 70°N

ERA-Interim (1989-2010)



Note that the LWD is likely underestimated in ERA-Interim due to lack of supercooled liquid clouds but the anomaly signal is less affected

Woods et al., 2013

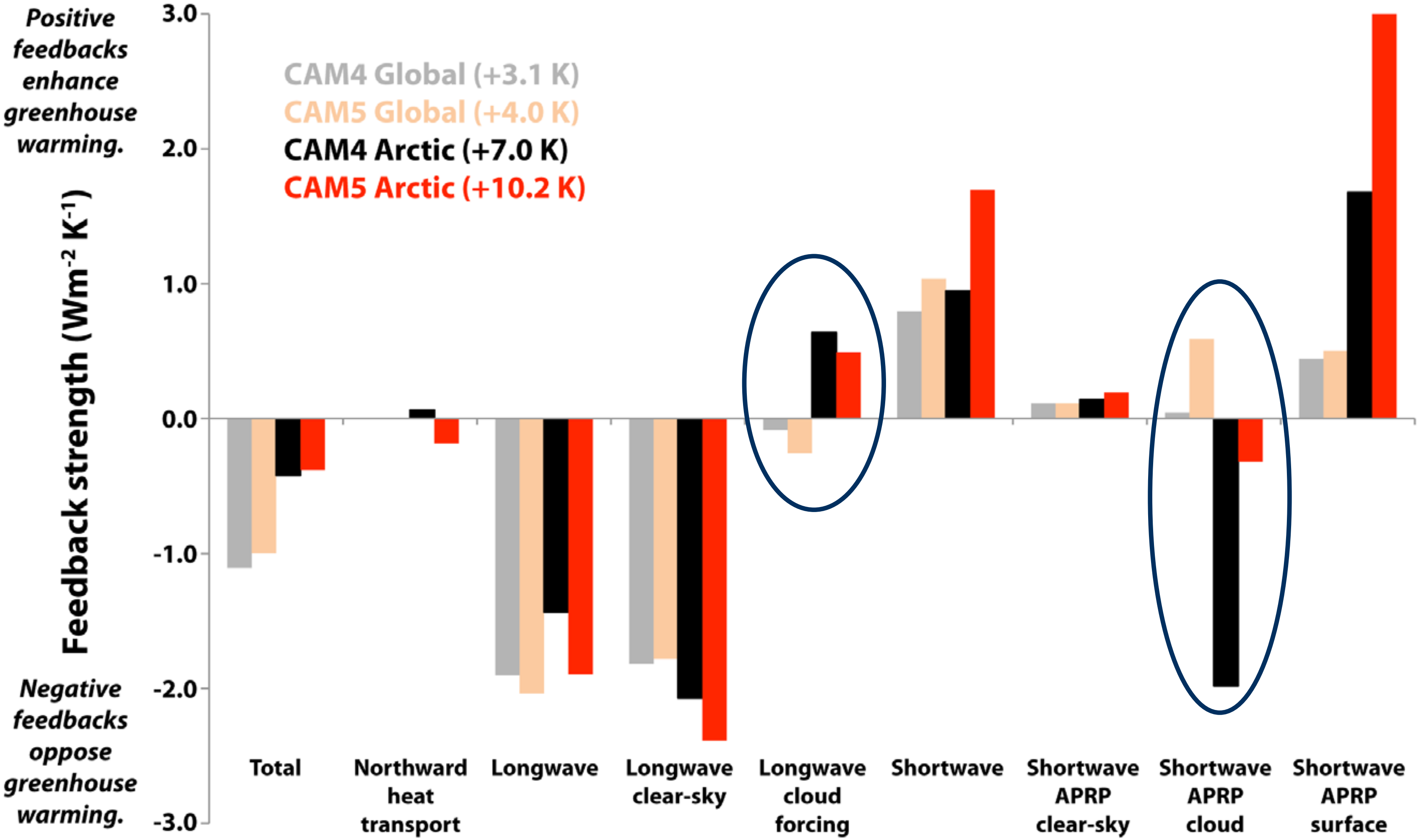
Which processes enhance GHG-induced Arctic amplification?

Stockholm University

Mechanism	Effect (compared with global effect)
Surface albedo feedback	More positive
Planck feedback	Less negative
Lapse rate feedback	Positive (negative globally)
Ocean heat transport	Increases with increasing GHG
GHG forcing	Less positive
Water vapor feedback	Less positive
Atmospheric transport	Positive (small) ?
Clouds shortwave Clouds longwave	Negative ?(positive globally) Positive ?(negative globally)

Kay et al. 2012

Feedback analysis of Global and Arctic climate
CAM4 and CAM5



Kay et al. 2012

Annual cycle of energy budget
ECHAM 20th century, >60°N

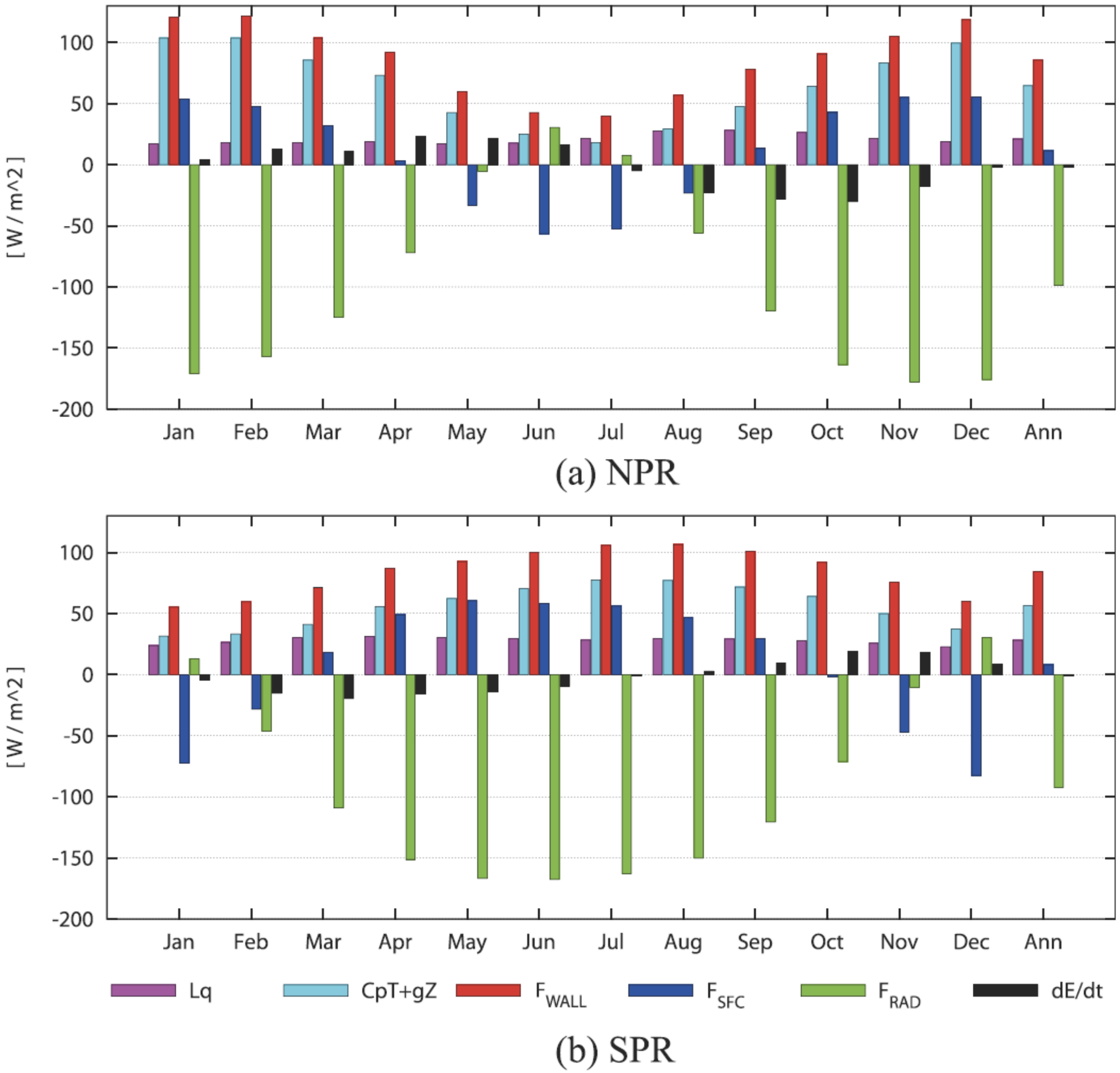


FIG. 2. Annual cycle of components of the energy budget in the (a) NPR and (b) SPR for the model 20C period. Units are W m^{-2}.

$$F_{\mathrm{WALL}} = \nabla \cdot \frac{1}{g}\int_{p_s}^{0} (c_p T + gZ + Lq + k)\mathbf{V}\,dp$$

Bengtsson et al., 2013

Dry and moist static energy are not independent

ECHAM 20th and 21st century, >60°N & < 60°S

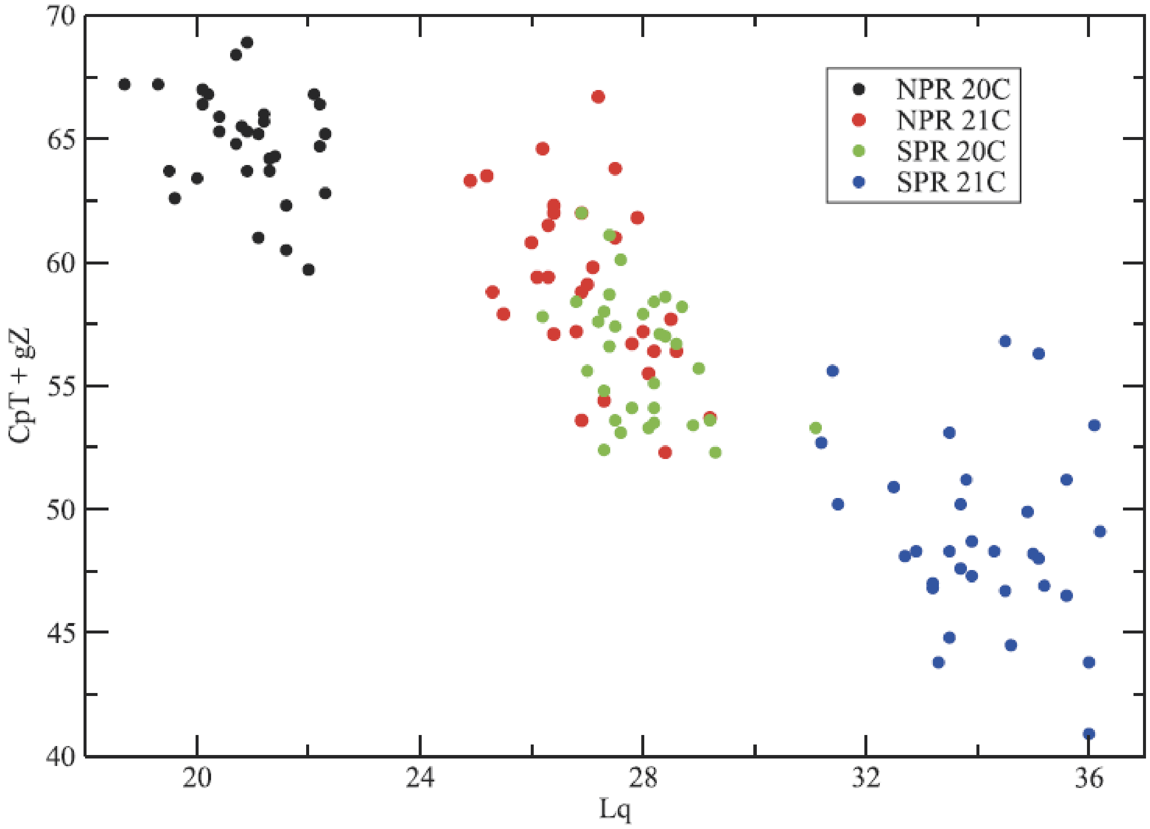


FIG. 6. Scatterplot of the annual transport of energy associated with moisture (Lq) vs the transport of dry static energy ($c_pT + gZ$). Units are W m^{-2}.

Bengtsson et al., 2013

Total energy transport across 60°N

ECHAM 20th and 21st century

Stockholm University

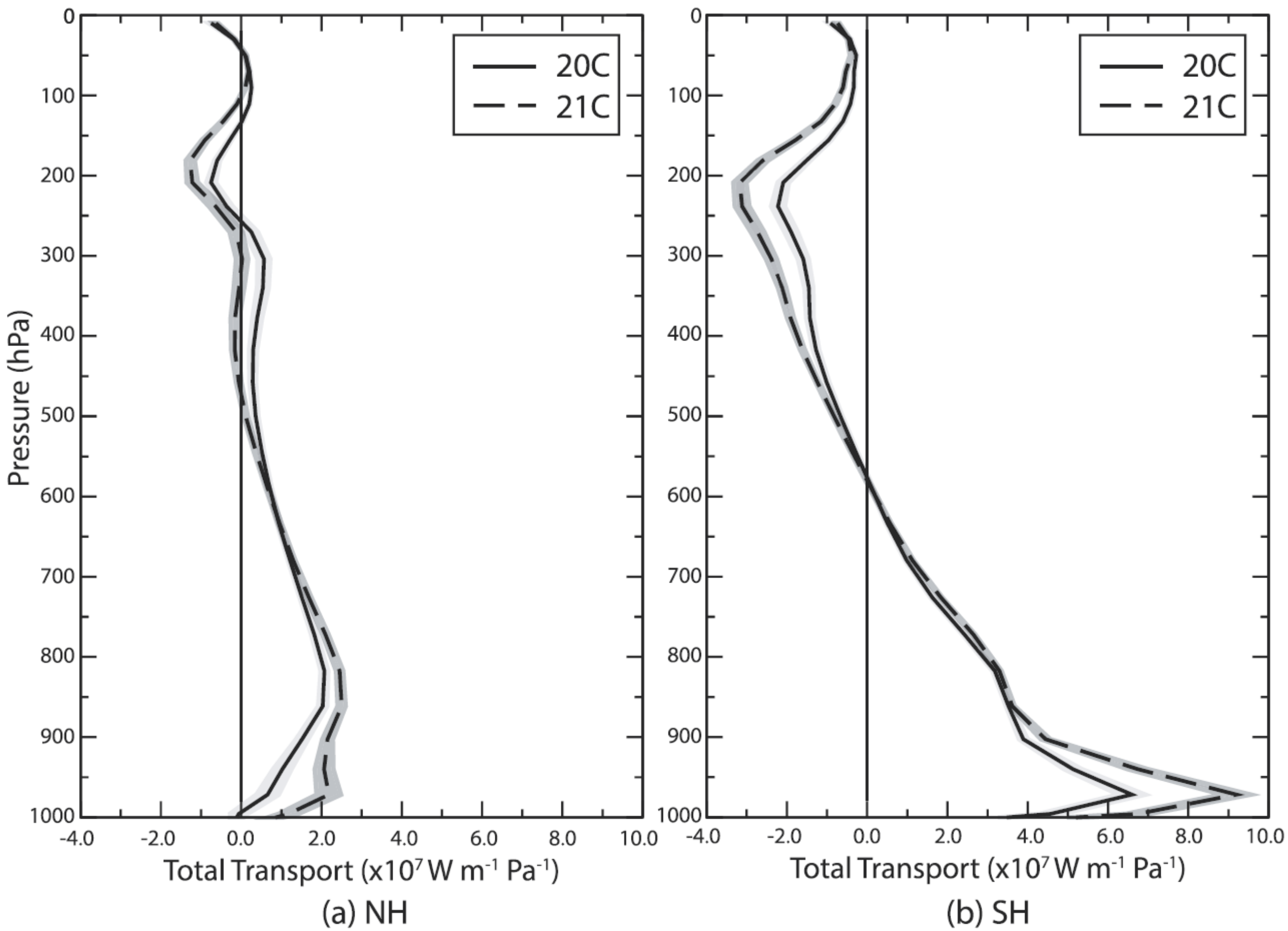


FIG. 7. Mean annual vertical profiles of total energy transport ($c_pT + gZ + Lq$) across 60°N and 60°S for 20C and 21C in the (a) NH and (b) SH. Pressure levels are nominal values. Energy transport units are W m^{-1} Pa^{-1}.

Total energy transport for NH is increasing with about 6 Wm^{-2} Moist part is increasing more

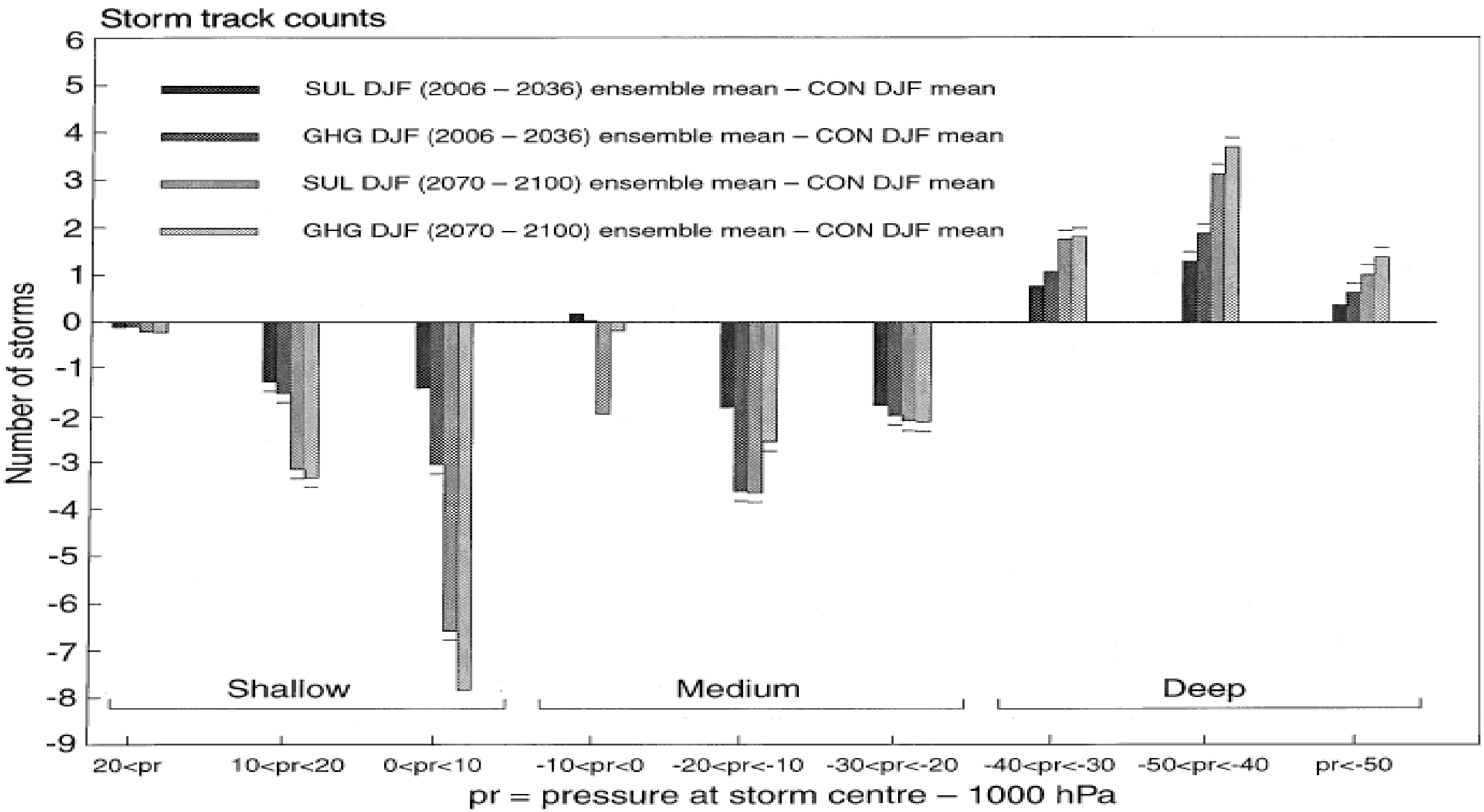
Increase is about the same for SH although the moist contribution is larger

Bengtsson et al., 2013

Midlatitude storms and climate change

UKMO for 2XCO2 storm changes

Stockholm University



Carnell and Senior 1998

Midlatitude storm density

North Atlantic, CMIP5 models

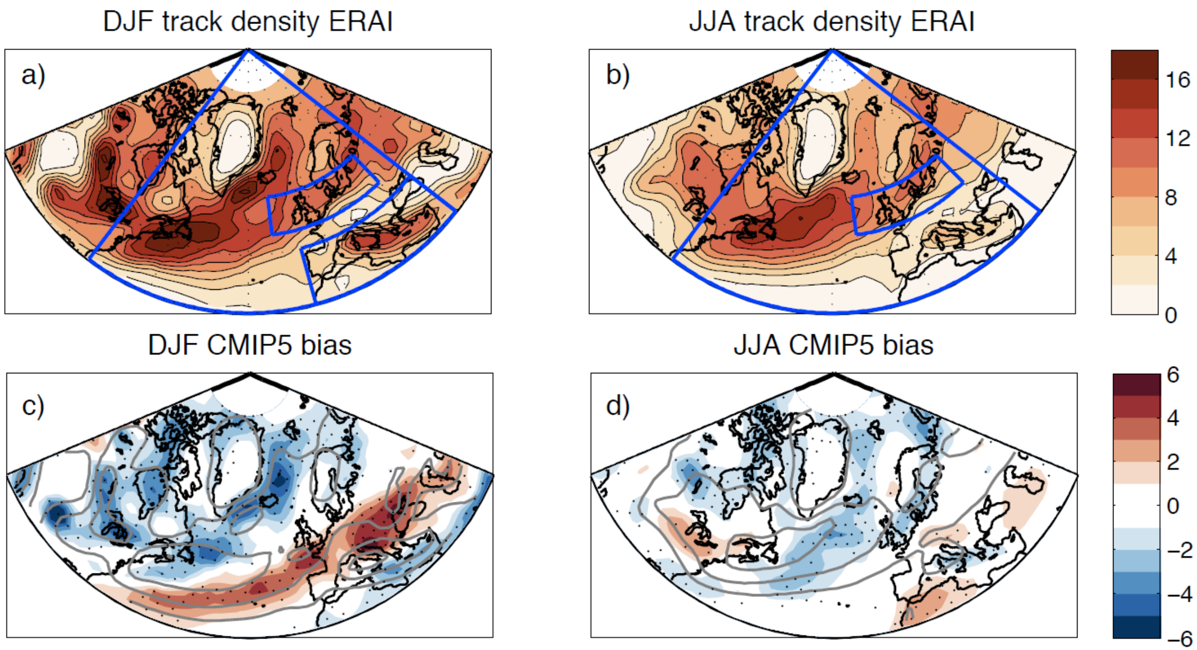


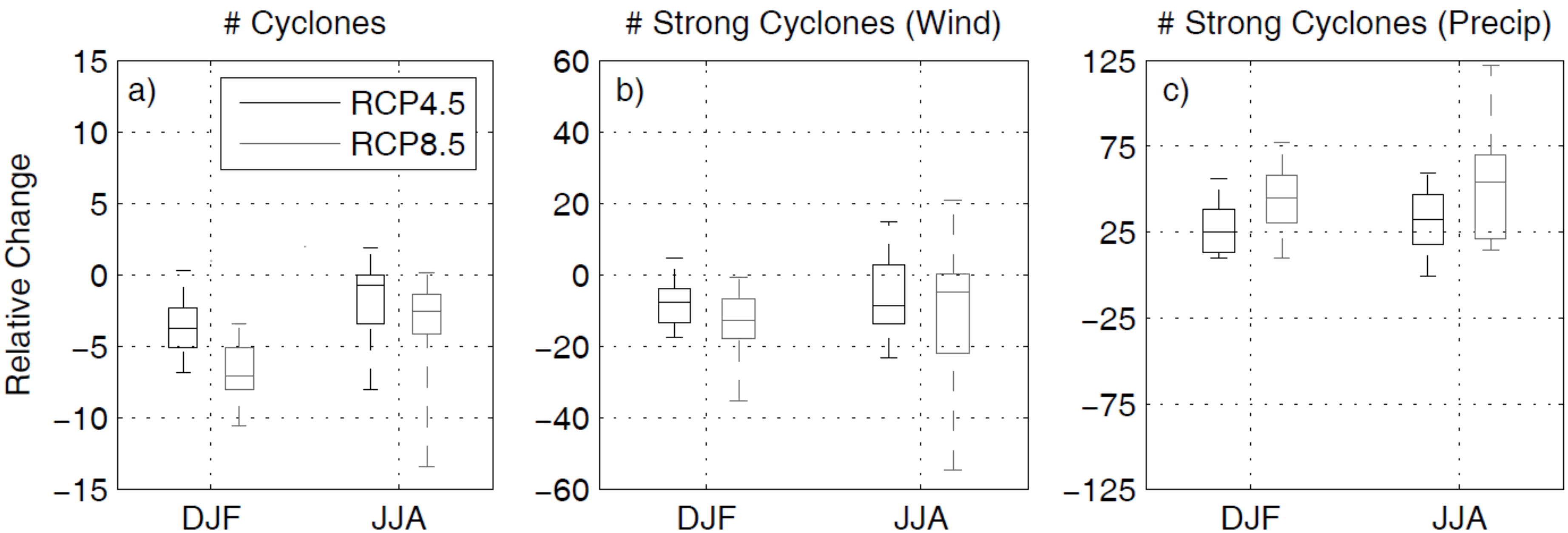
FIG. 1. Track density in ERA–Interim reanalysis (1980–2009) (a,b) and mean track density bias of CMIP5 models in the HIST simulations relative to ERA–Interim (c,d). The results are shown for DJF (a,c) and JJA (b,d). Unites are in number of cyclones per month per unit area, where unit area is equivalent to a 5 degree spherical cap. In a,b the circular sector defines the region of the North Atlantic and European cyclones. The small *boxes* define the Mediterranean (DJF only) and Central European area of interests. In c,d stippling shows where more than 80% of the models have a bias of the same sign, and the contours show the CMIP5 averaged track density with isolines every 4 cyclones per month per unit area.

Storm track biases over the North Atlantic have decreased in CMIP5 models compared to CMIP3, although models still produce too zonal storm track in this region and most models underestimate cyclone intensity

Zappa et al., 2013

Midlatitude storm projected change

North Atlantic, CMIP5 models

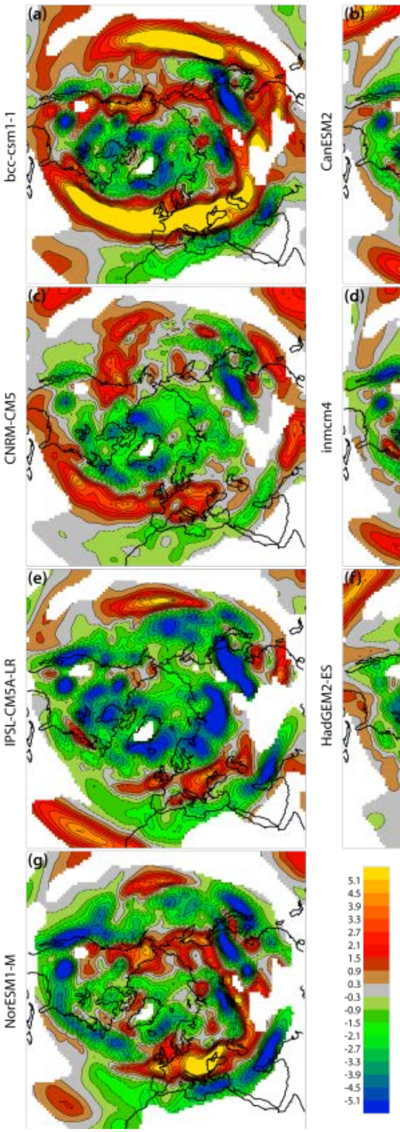


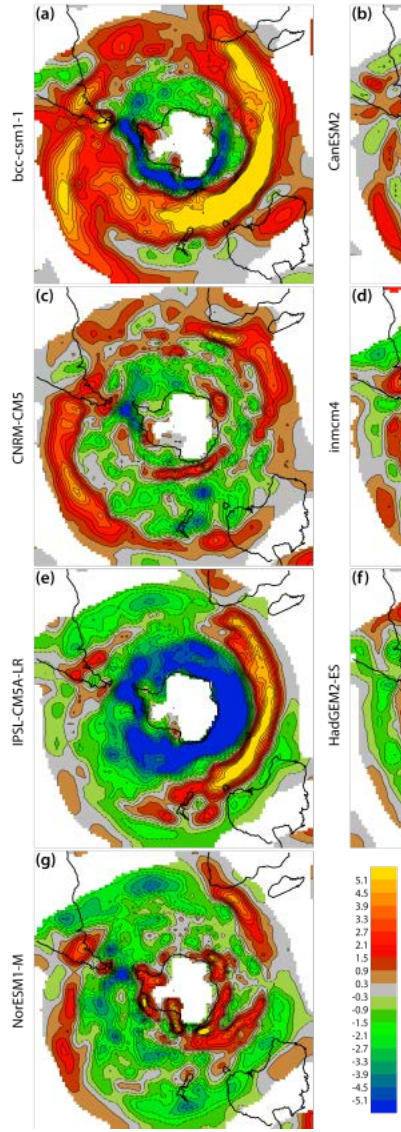
The total number of cyclones decreases in both summer and winter

Zappa et al., 2013

Extratropical storm tracks

CMIP5 models, present climate (1986-2005)



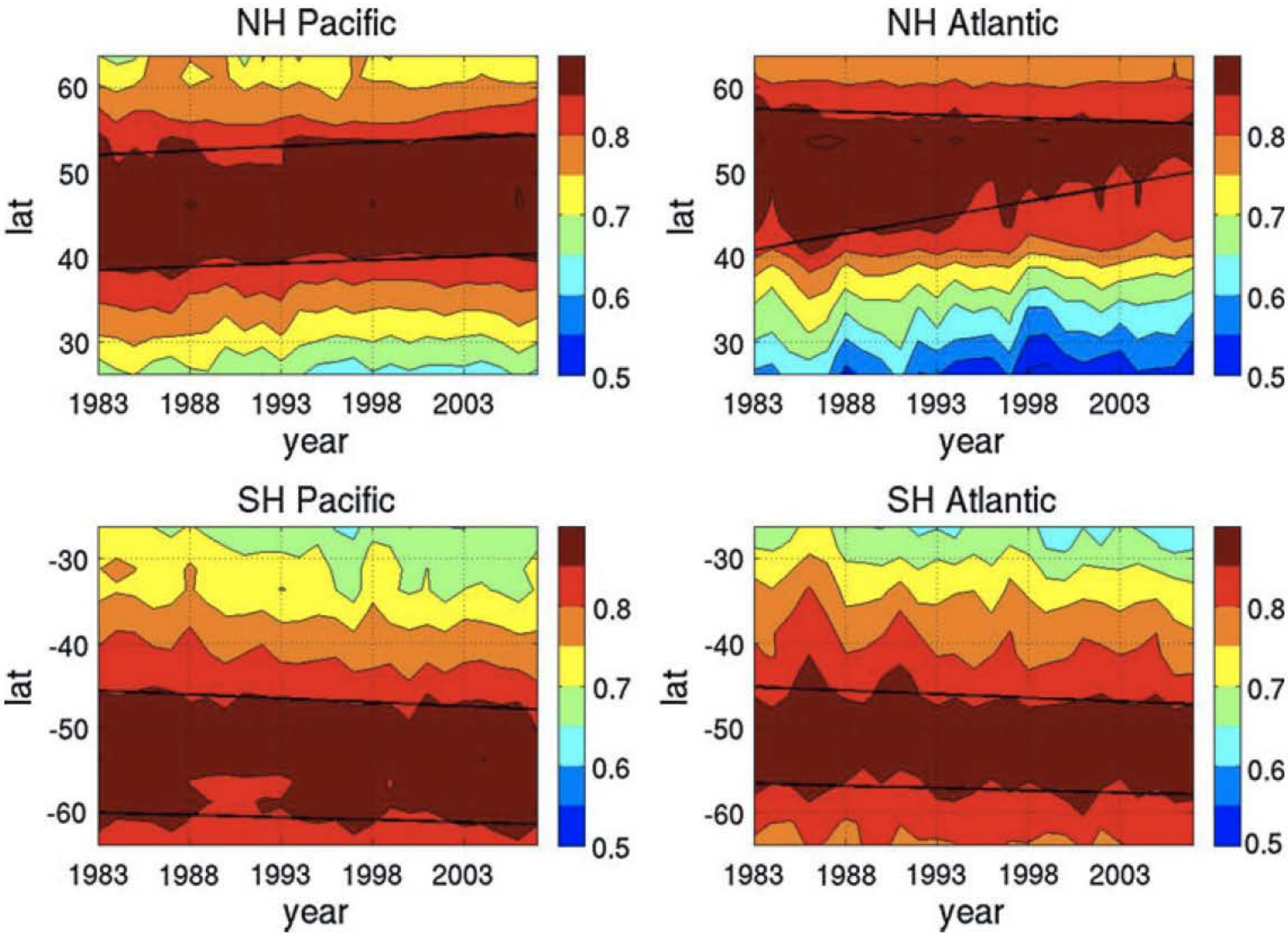


Differences in 850hPa relative vorticity extratropical cyclone track densities in the Northern (left) and Southern (right) Hemisphere winter seasons, Historical Control – ERA-Interim

Courtesy R. Lee

Midlatitude storms clouds

Observational evidence, ISCCP ocean (1983 – 2008)

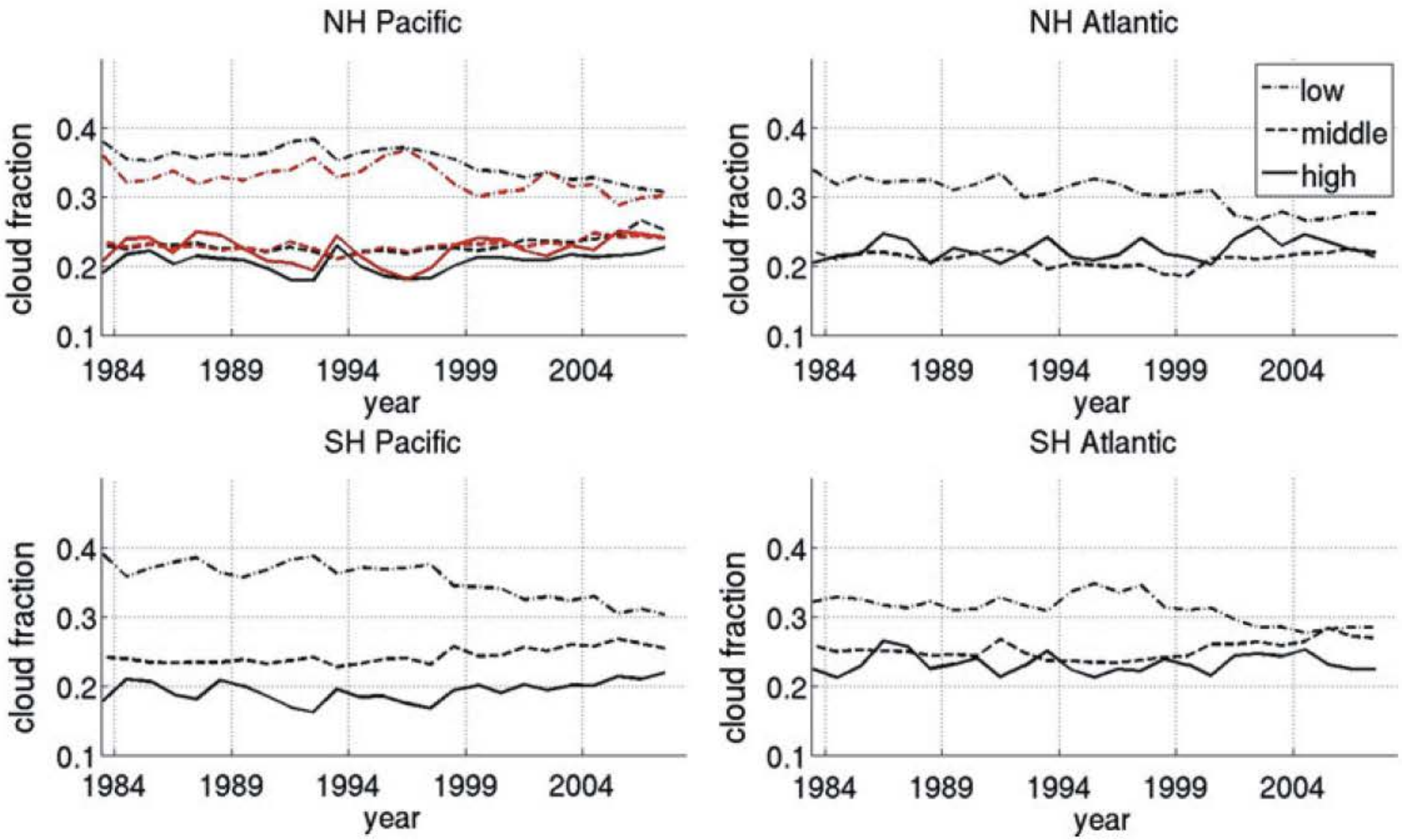


The observed magnitudes of these effects are larger than in CMIP3 models

Bender et al., 2012

Midlatitude storms clouds

Observational evidence, ocean (1983 – 2008)

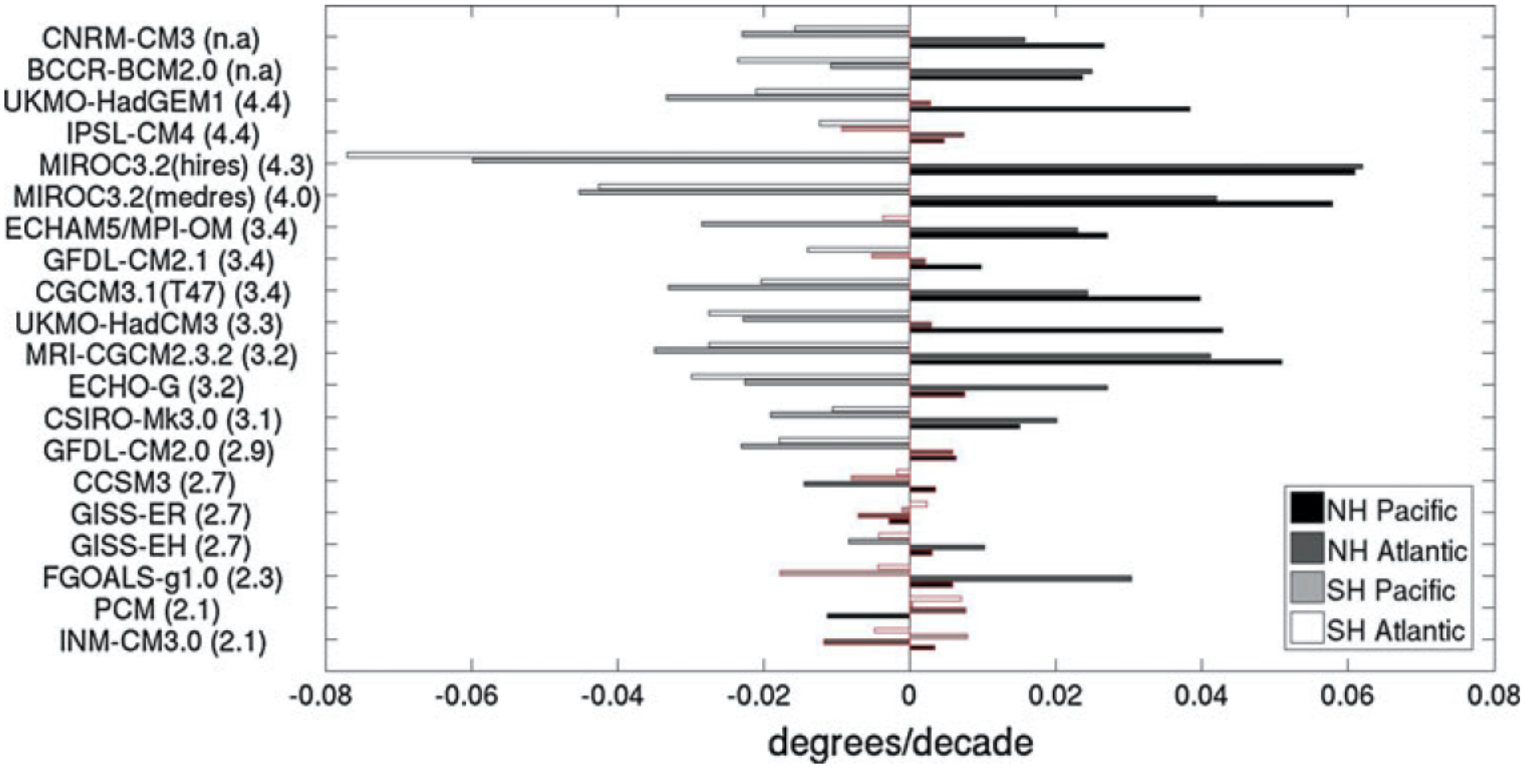


The observed changes in storm track cloudiness can be related to local cloud-induced changes in radiative effect. The shortwave and the longwave components are found to act together, leading to a positive (warming) net radiative effect in response to the cloud changes in the storm track regions, indicative of positive cloud feedback.

Bender et al., 2012

Midlatitude storms and climate

CMIP3 models, 1% CO_2 increase per year



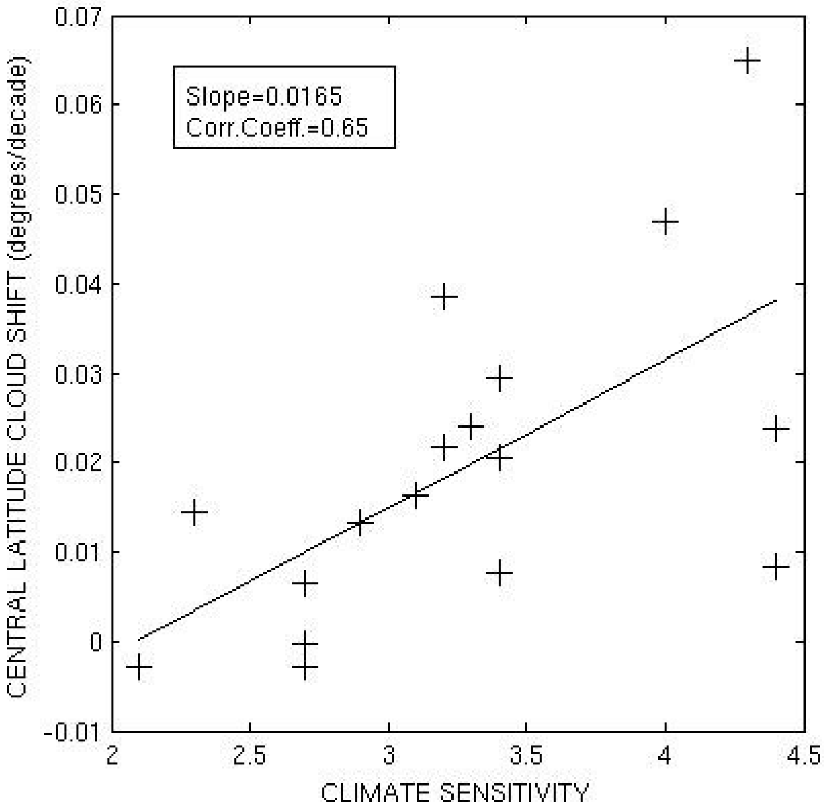
Variable among the models, red bars are not statistically confident results

Bender et al., 2012

Midlatitude storms and climate

CMIP3 models, 1% CO_2 increase per year

Stockholm University



Models with higher climate sensitivity show larger cloud shifts

Bender et al., 2012

Arctic clouds

Historical, over sea ice (>80% and > 66.7°N)

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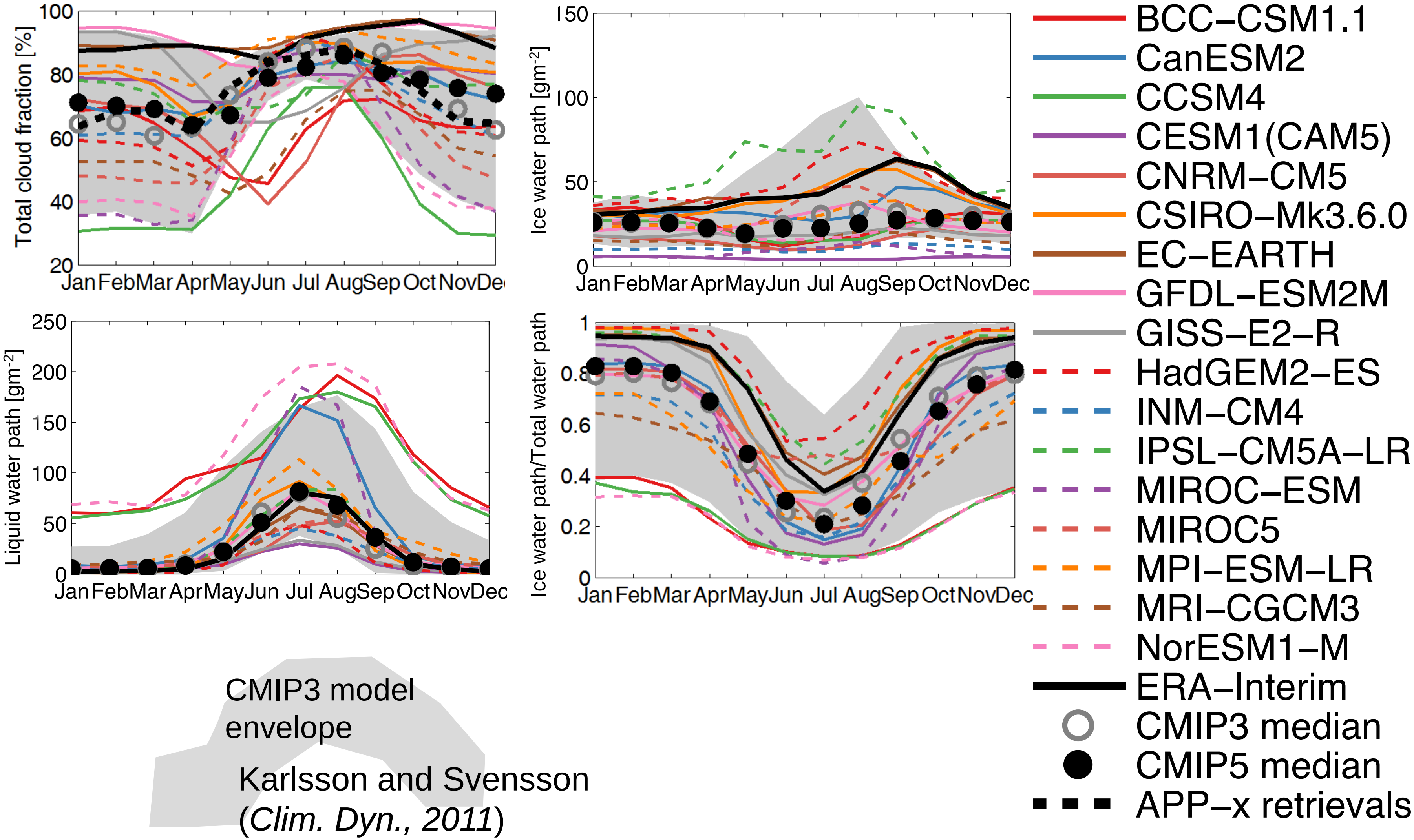
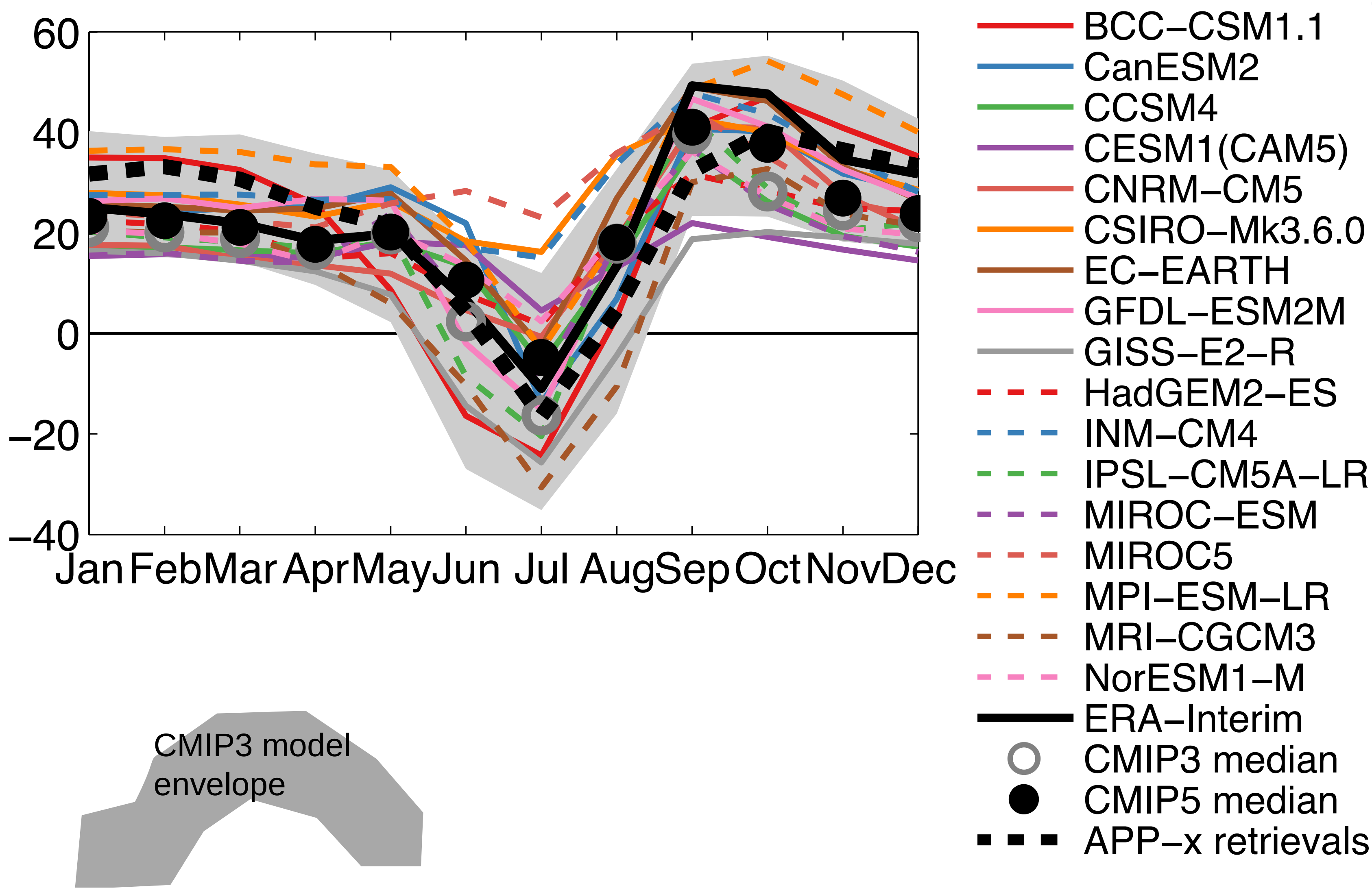


Karlsson and Svensson, 2013

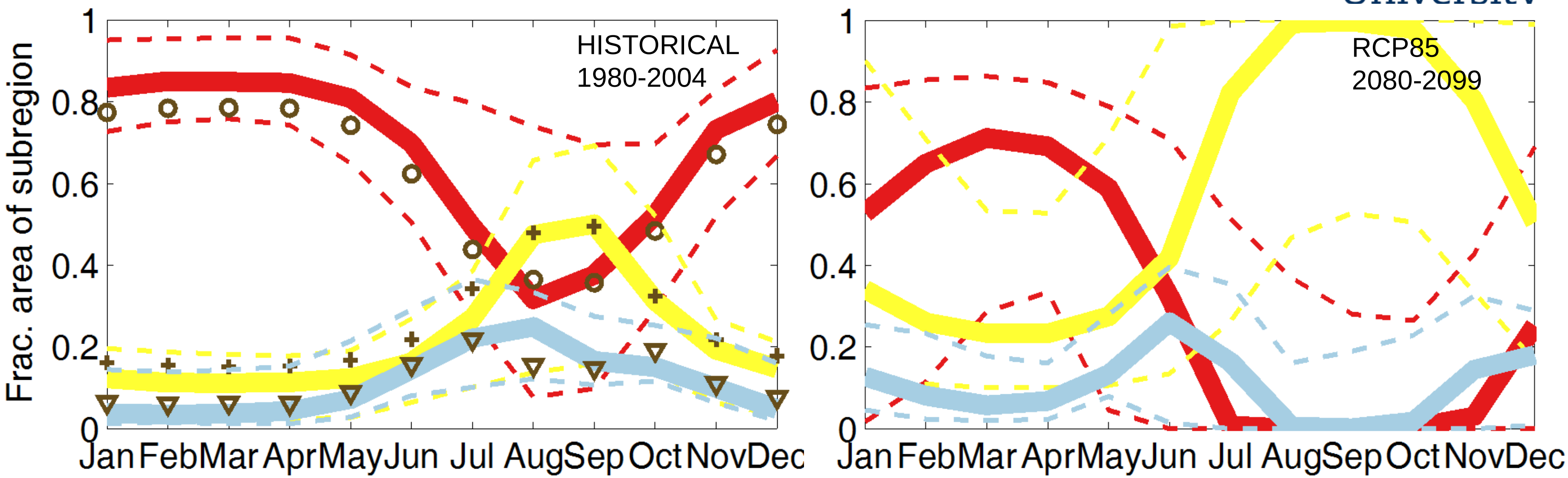
Arctic clouds CRE

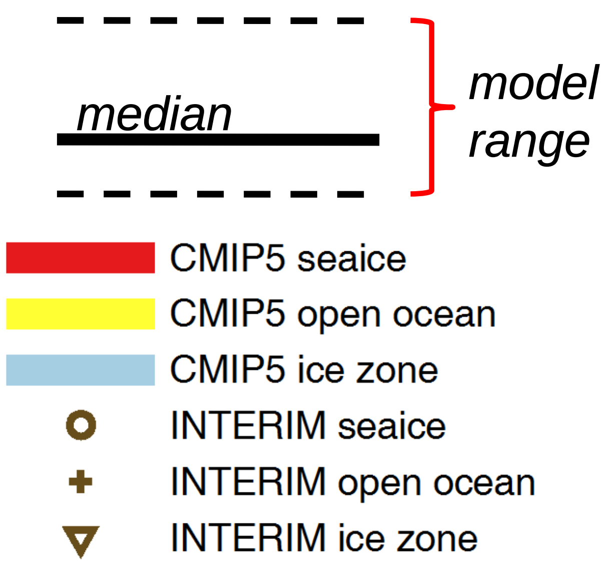
Historical, over sea ice (>80% and > 66.7°N)



Changing Arctic surface

(> 66.7°N)

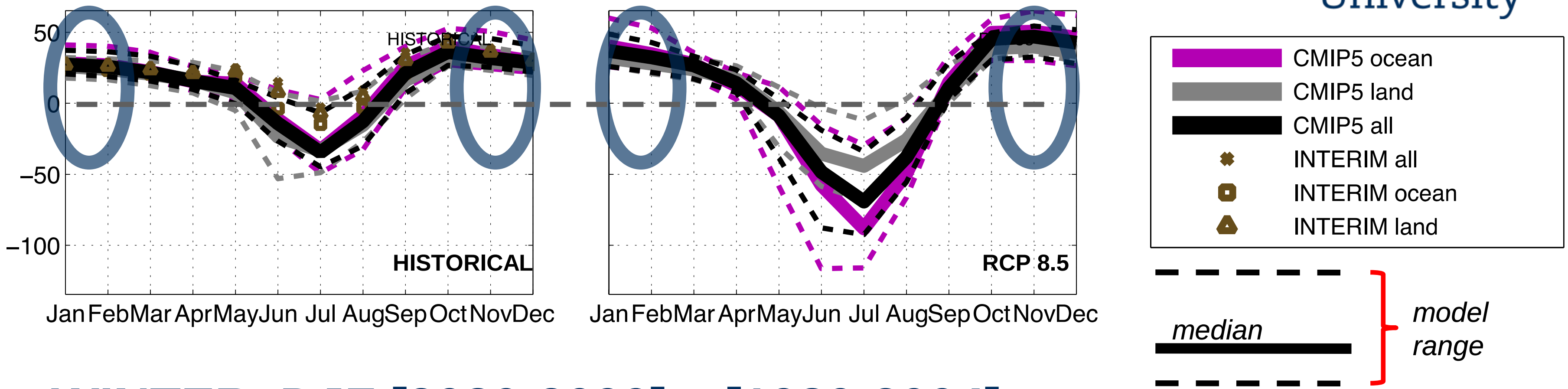




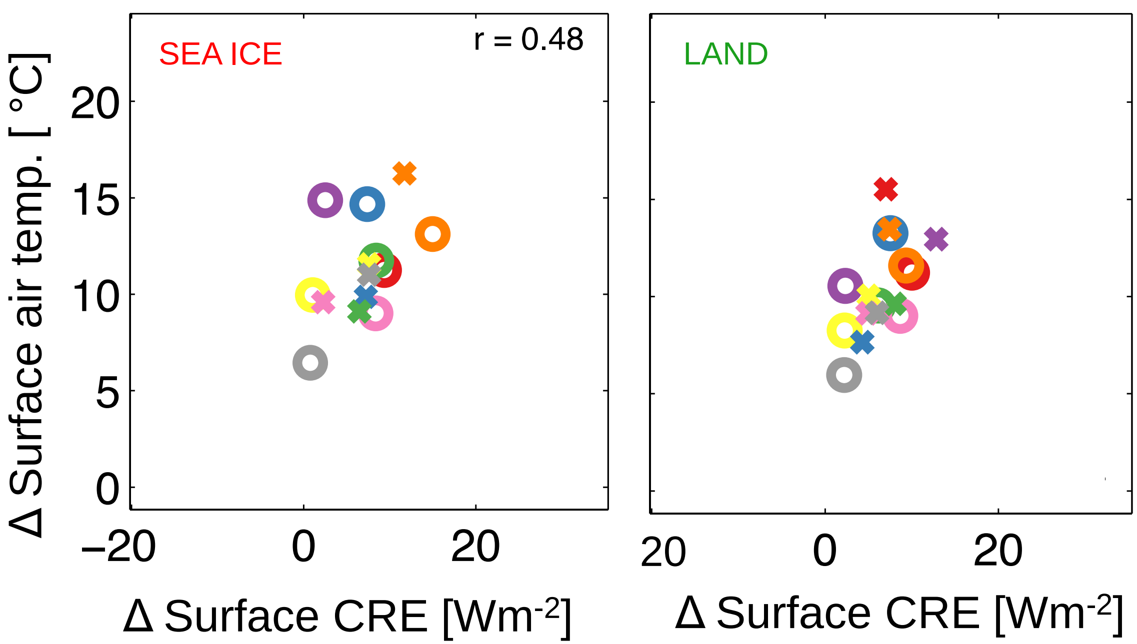
For the RCP8.5, most models show an sea-ice free Arctic from July to November in the 21st century

Changing Arctic surface CRE

(> 66.7°N)



WINTER, DJF [2080-2099] – [1980-2004]

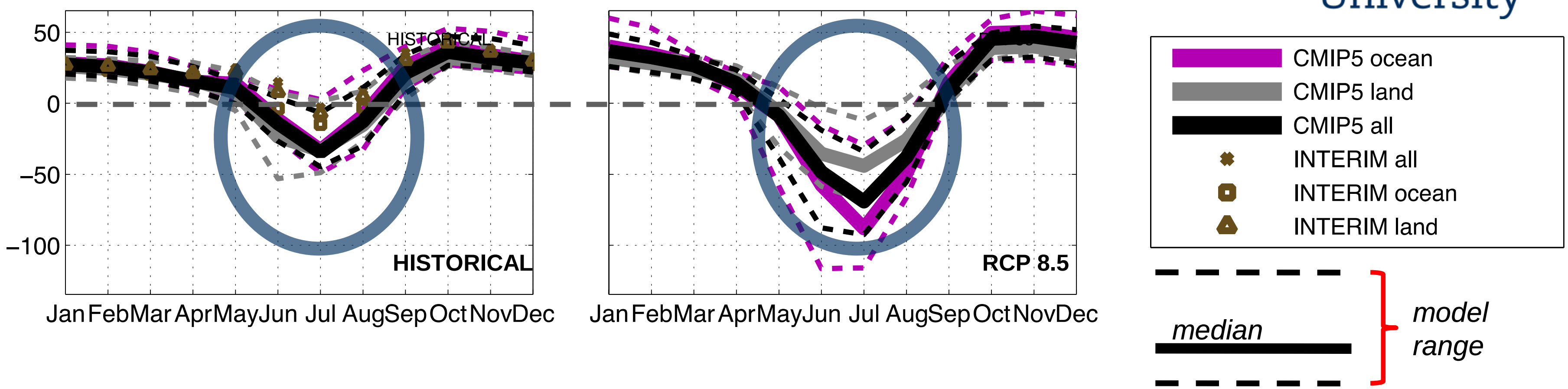


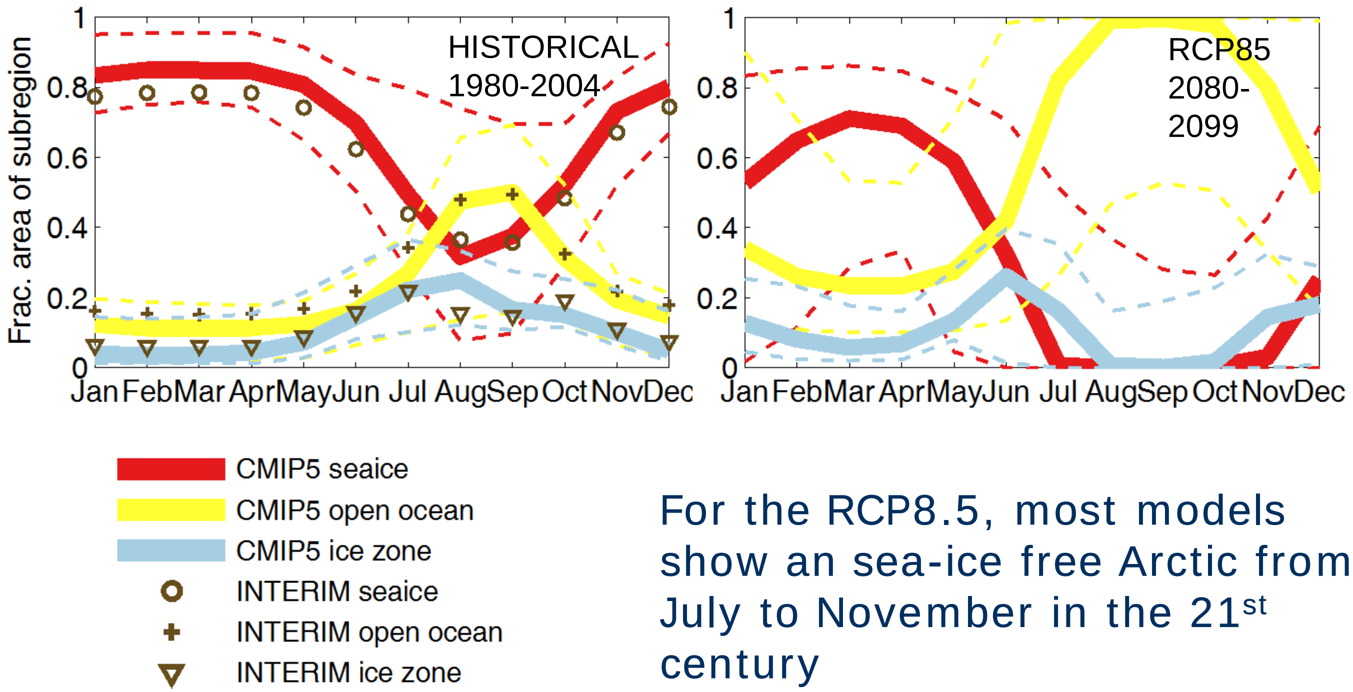
In winter, over sea ice and land areas, there seems to be an across-model correlation, such that models with a larger increase in CRE also show larger changes in temperature

Changing Arctic surface CRE

(> 66.7°N)

Stockholm University



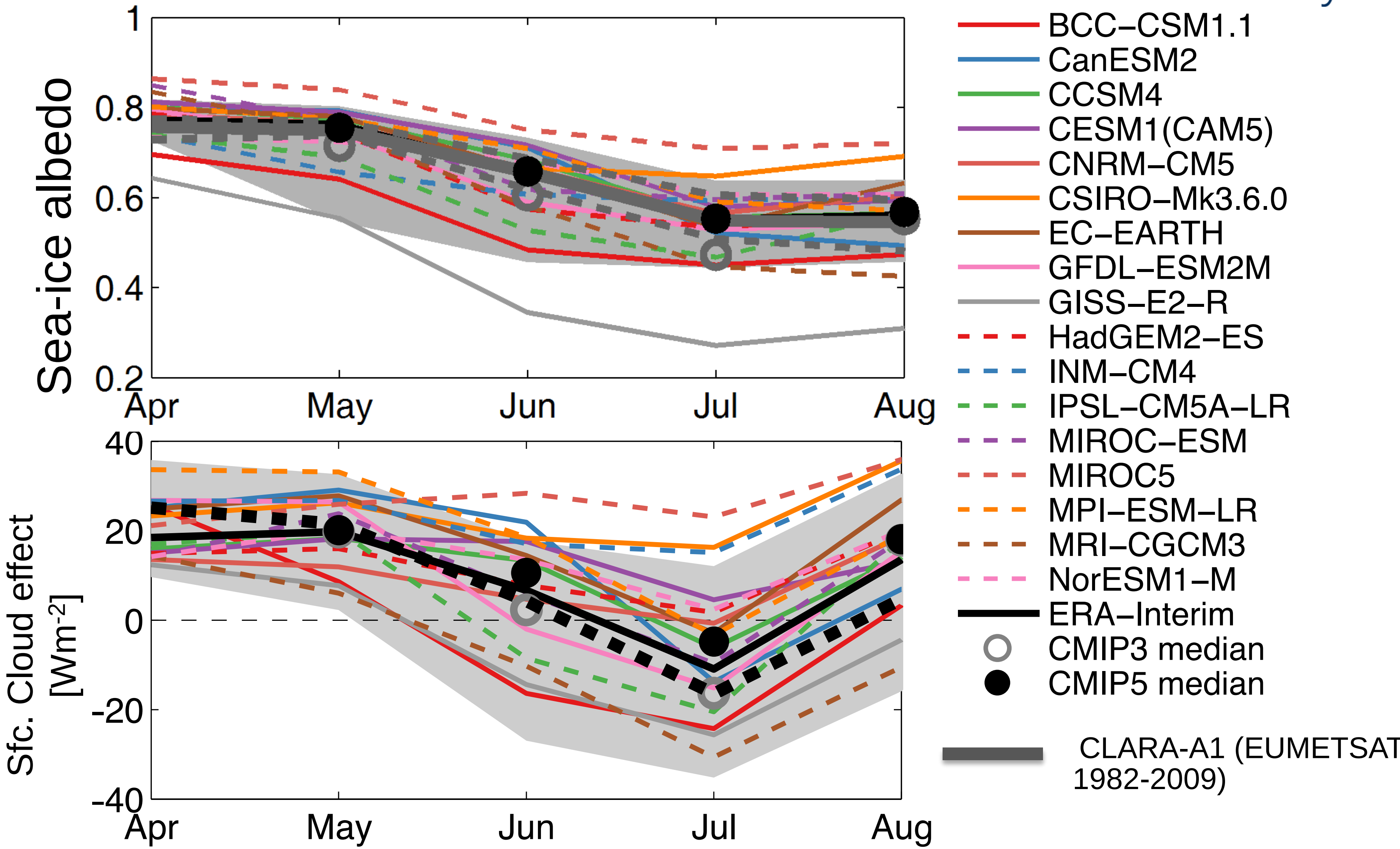


For the RCP8.5, most models show an sea-ice free Arctic from July to November in the 21st century

Arctic sea-ice albedo

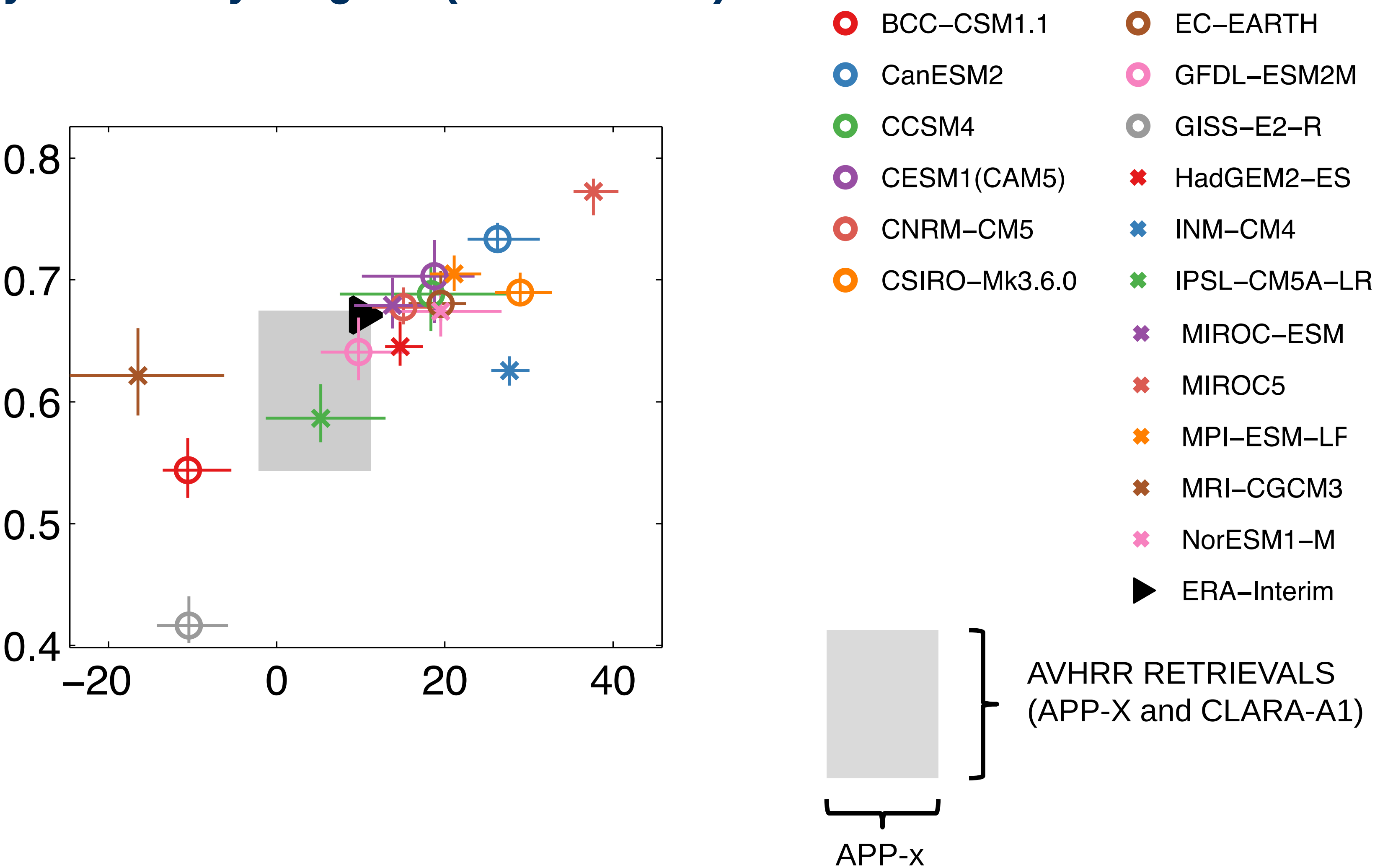
"Sunlit season", Historical (> 66.7°N)

Stockholm University



Seasonal averaged sea-ice albedo and summer CRE

May June July August (1980-2004)



Karlsson and Svensson, 2013

Seasonal averaged sea-ice albedo and summer CRE

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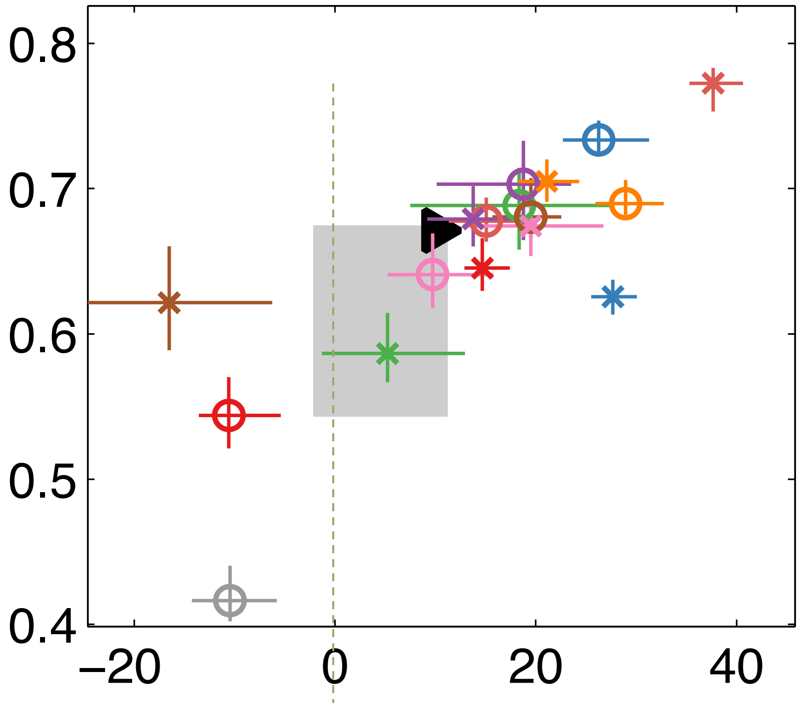


The sea ice albedo dependency of the surface cloud radiative effect determines its magnitude and **sign**

A change in cloudiness will feed back very differently on the models' surface energy budget

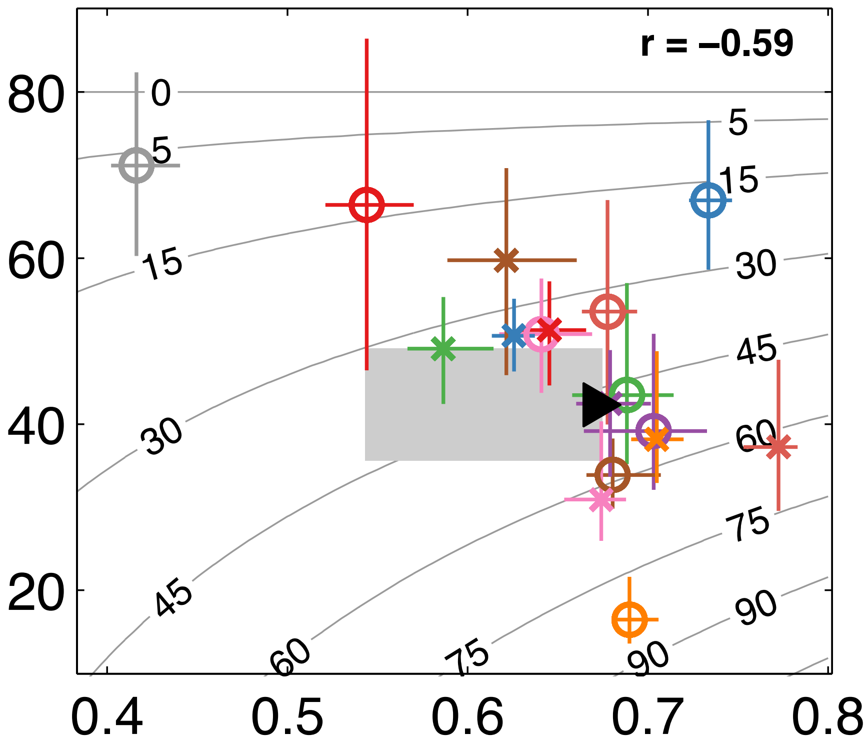
Can differences in sea-ice albedo explain the model-spread in the annual amplitude of sea-ice cover?

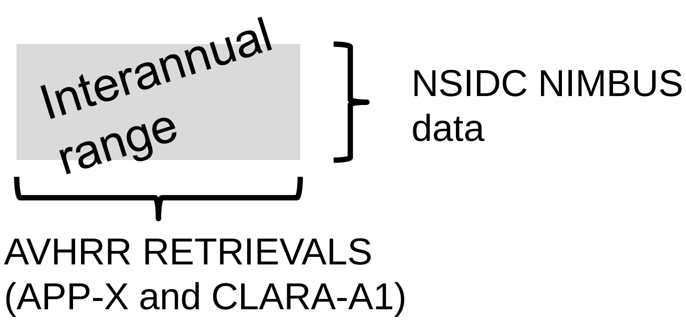
Karlsson and Svensson, 2013

Sea-ice extent and summer sea-ice albedo

May June July August (1980-2004)

Stockholm University





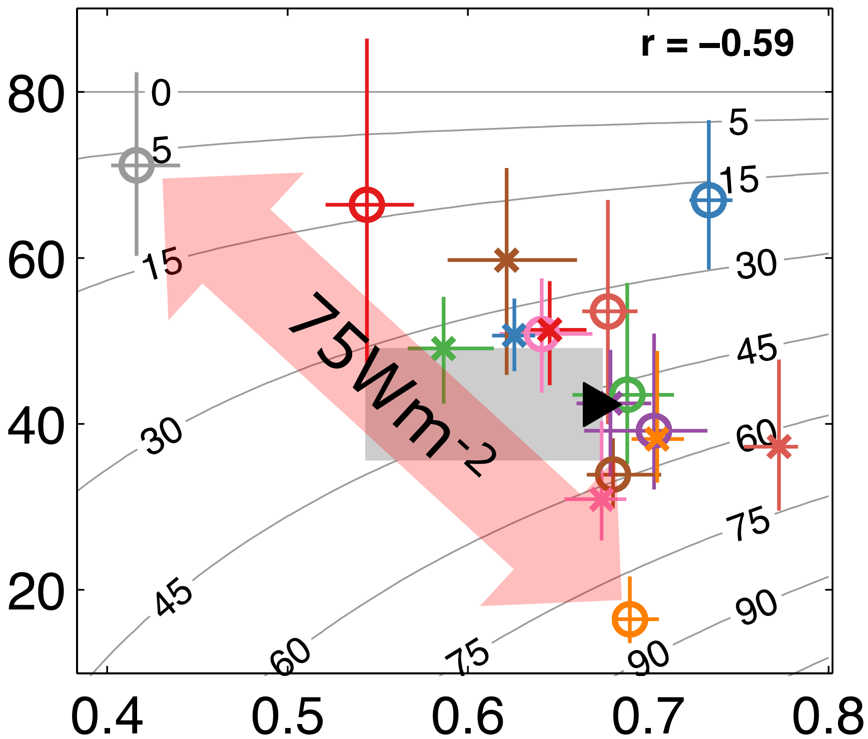
Present day sea-ice concentration and sea-ice albedo conditions the potential future change of absorbed surface solar radiation in the Arctic.

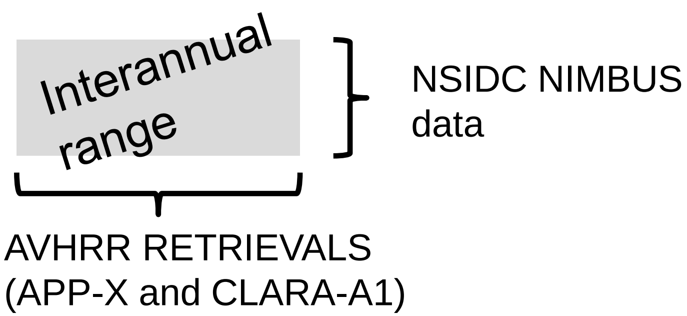
Isolines indicate the increase in absorbed solar radiation (Wm^{-2}) at the surface in the transition to an ice-free Arctic ocean, assuming 80% winter sea-ice extent, 0.1 ocean albedo and unchanged summer surface insolation of 220 Wm^{-2}.

Karlsson and Svensson, 2013

Sea-ice extent and summer sea-ice albedo

May June July August (1980-2004)

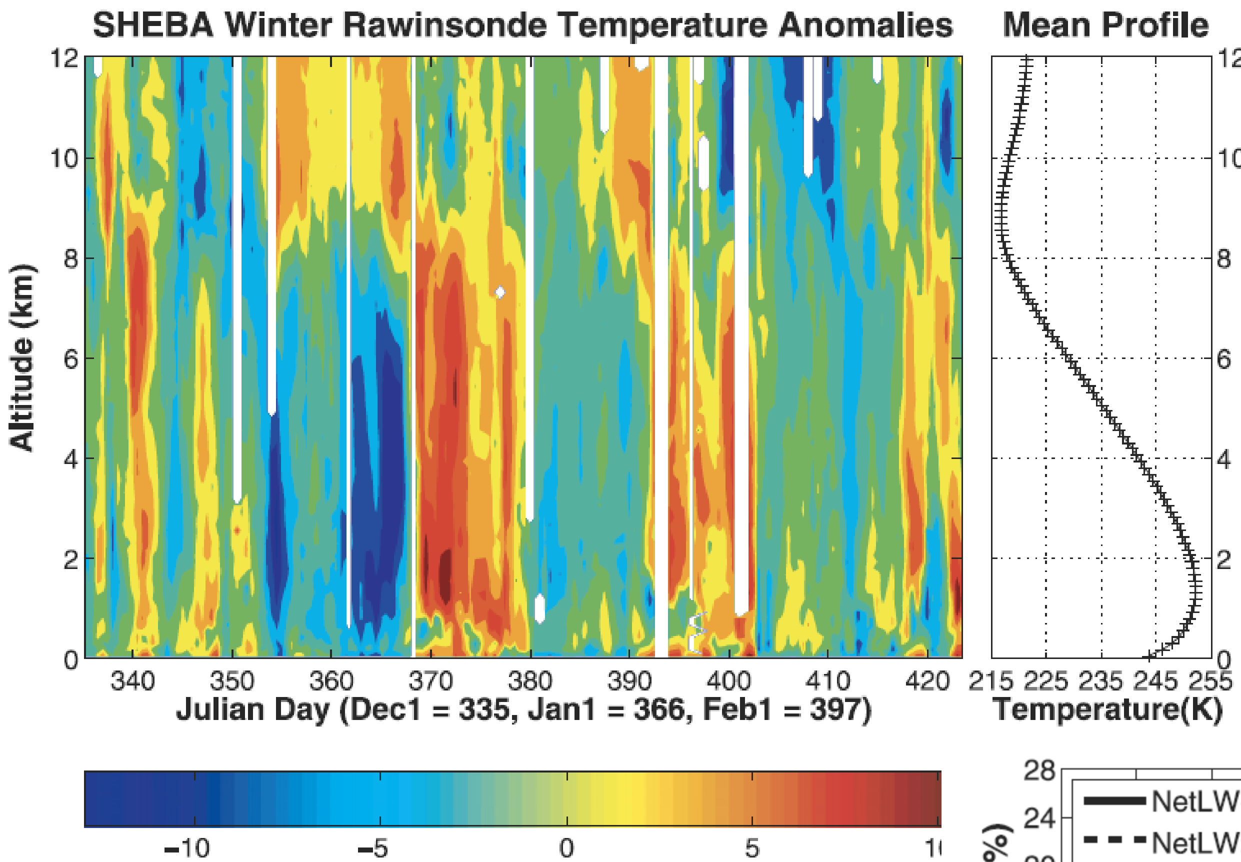


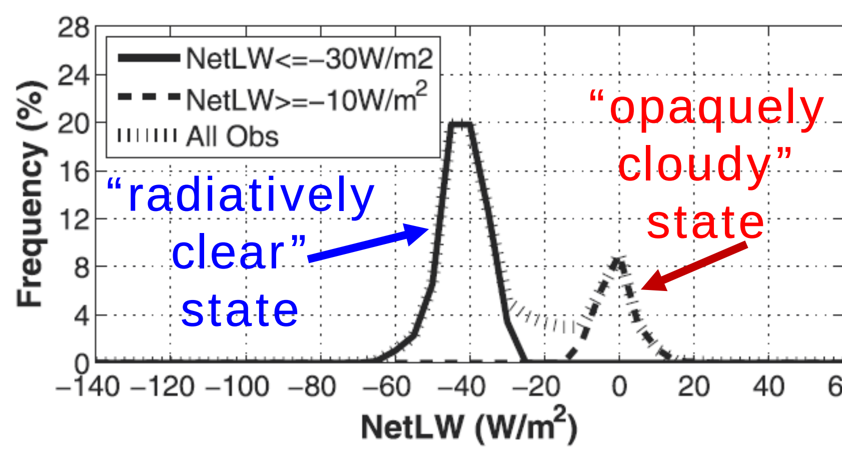


The models differ by up to 75 Wm^{-2}, as seasonal average, in how much energy the ice-free ocean could potentially absorb

Karlsson and Svensson, 2013

SHEBA observations 1997-98

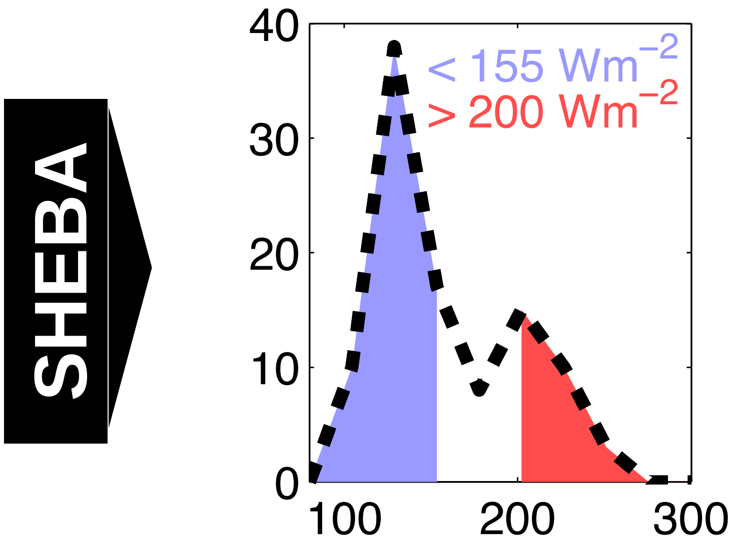


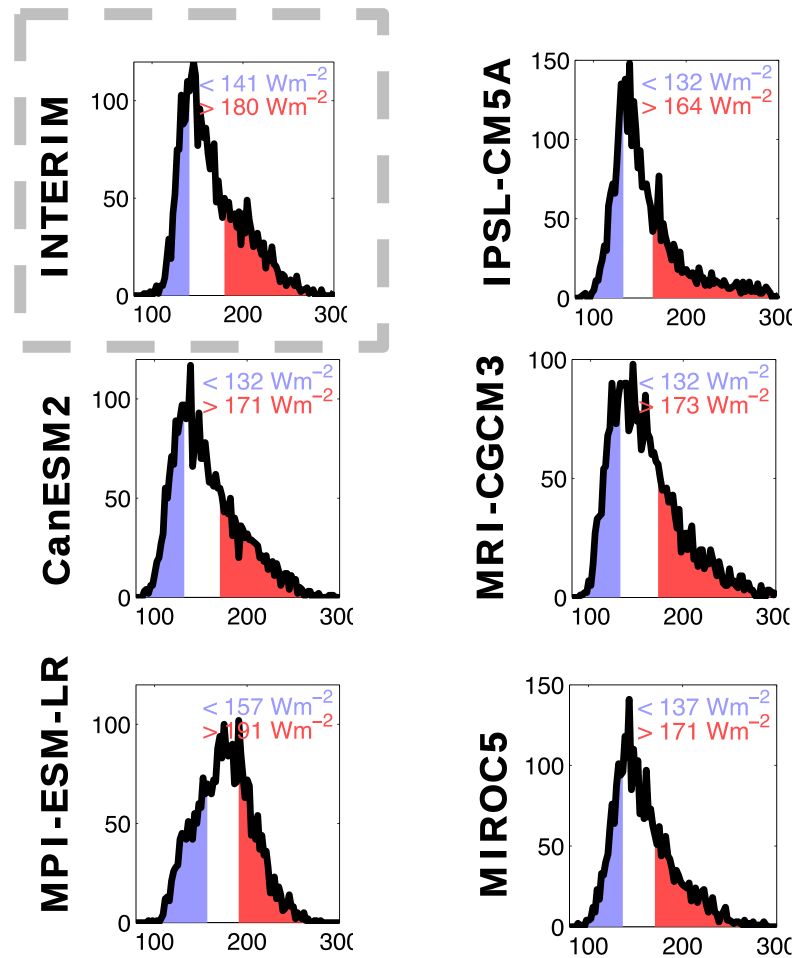


Stramler et al., 2011

SHEBA observations 1997-98 and CMIP5 models

Stockholm University

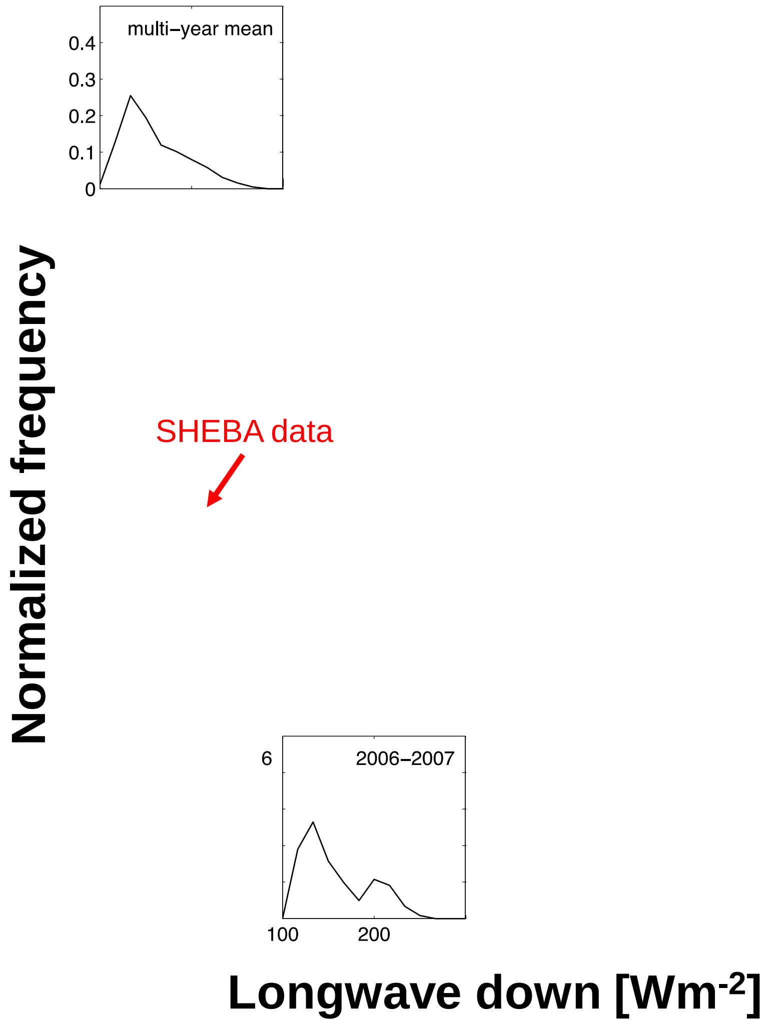


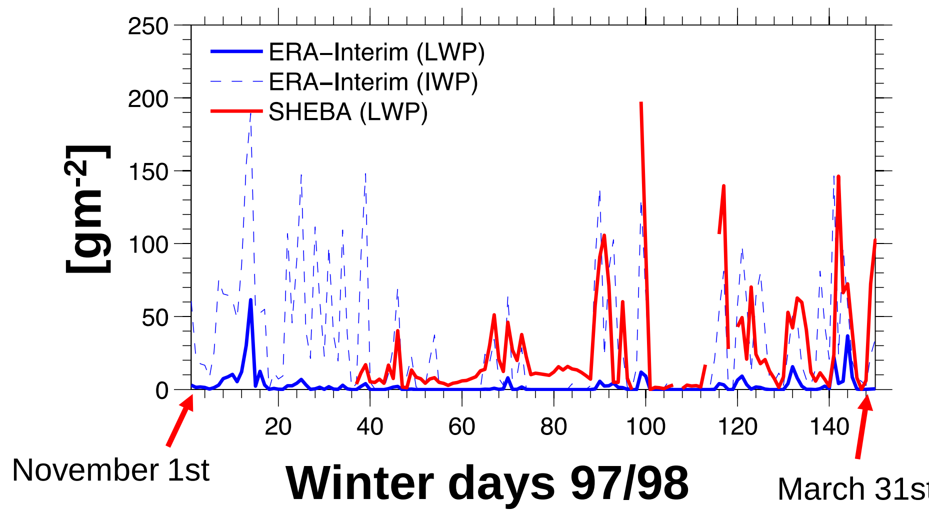


CMIP5 models DJFM (1980-2004) for the gridpoint closest to SHEBA

Interannual variability

ERA-Interim (1990-2009)





ERA-Interim mean LWP: 3 gm^{-2} (IWP: 50 gm^{-2})

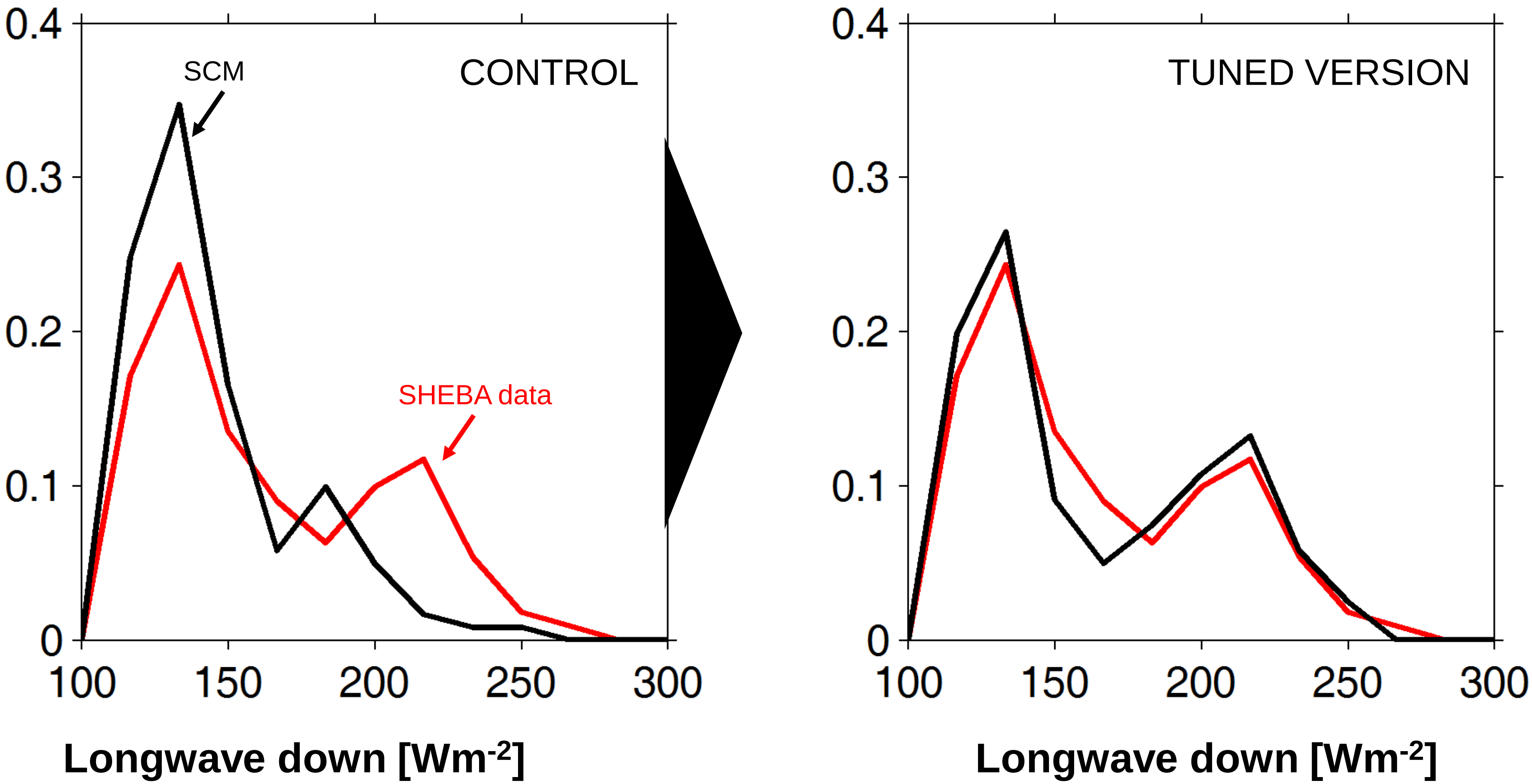
SHEBA mean LWP: 32 gm^{-2}

Importance of microphysics

Tuning glaciation efficiency

Stockholm University

Single column version of EC-EARTH 3, forced with INTERIM data

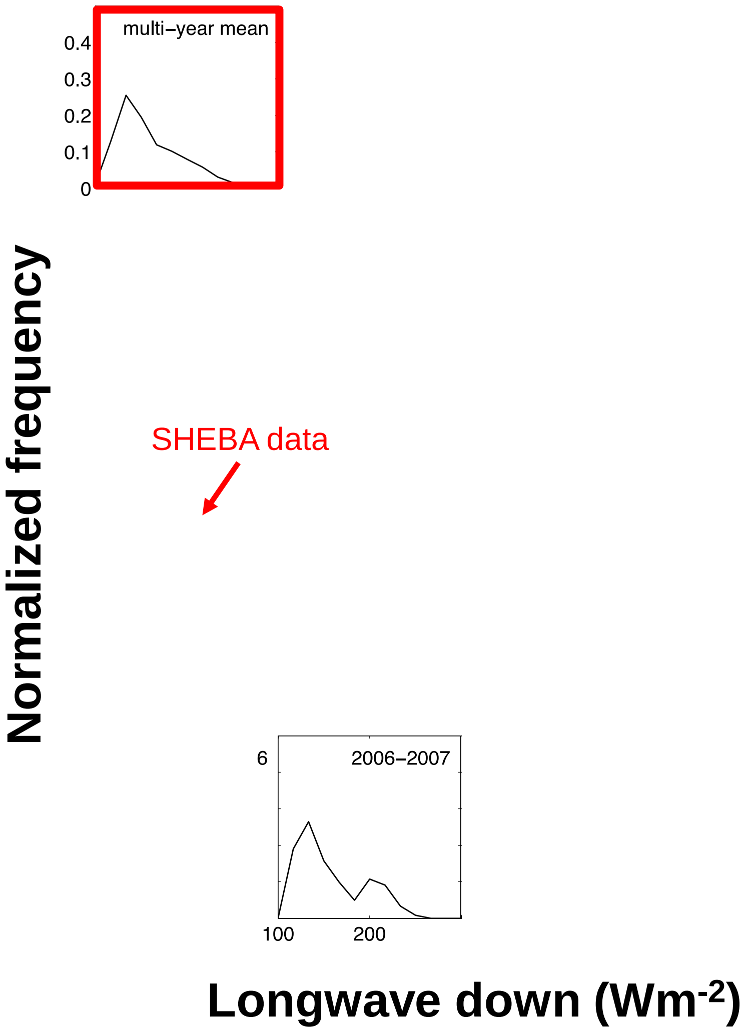


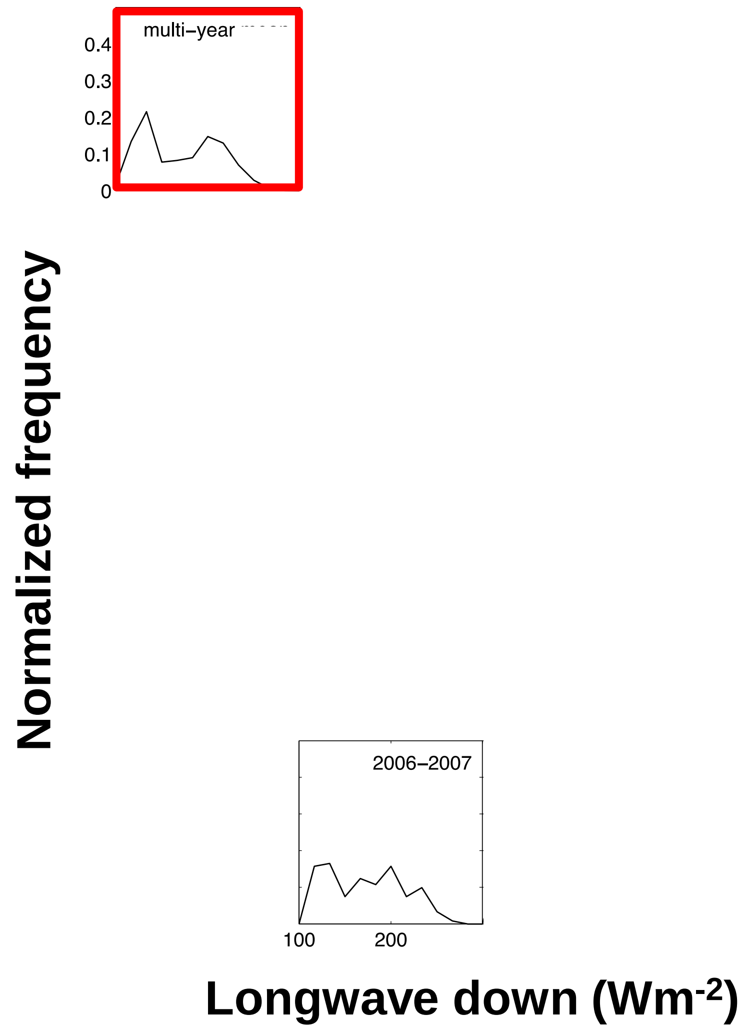
Interannual variability

ERA-Interim (1990-2009)

Stockholm University

“TUNED” SCM

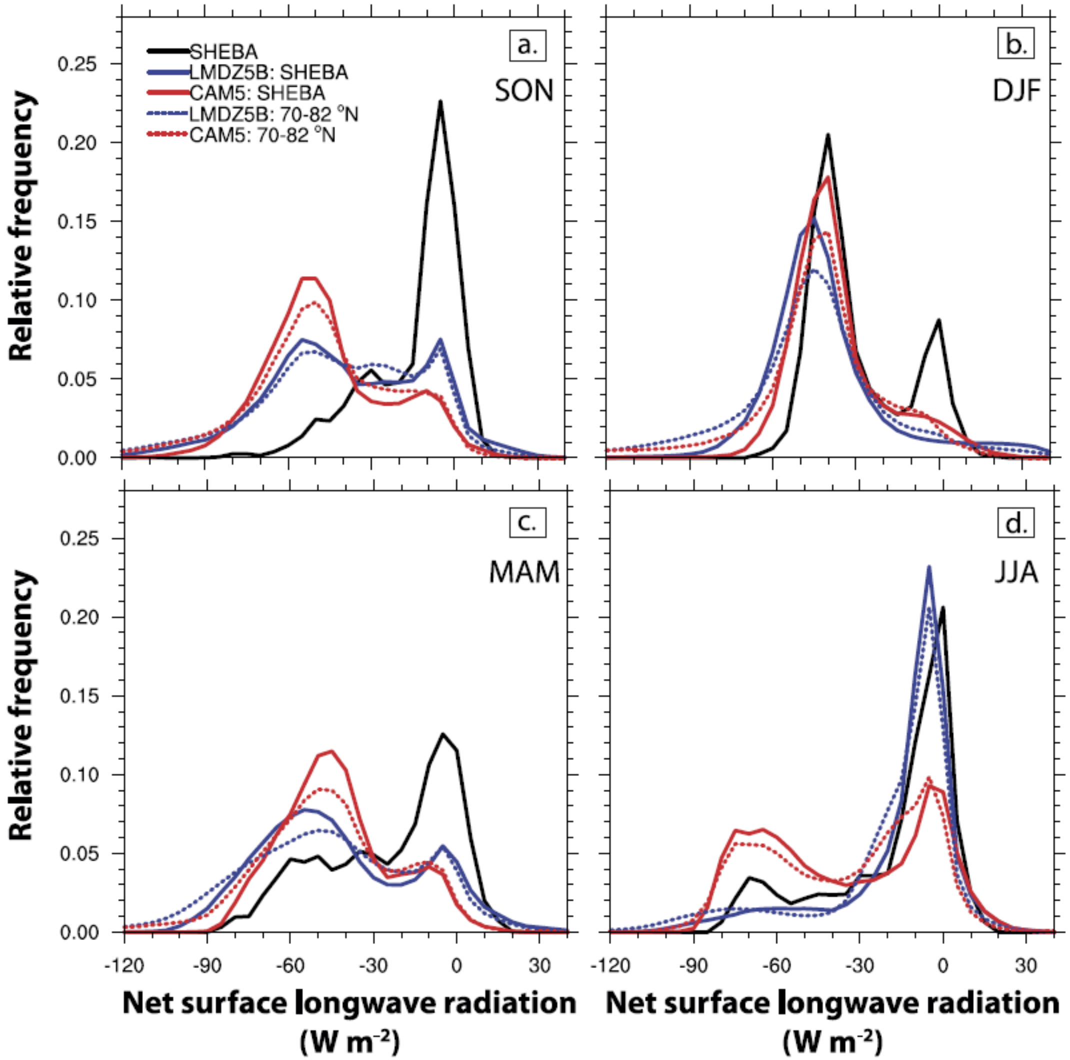




Engström et al., 2013

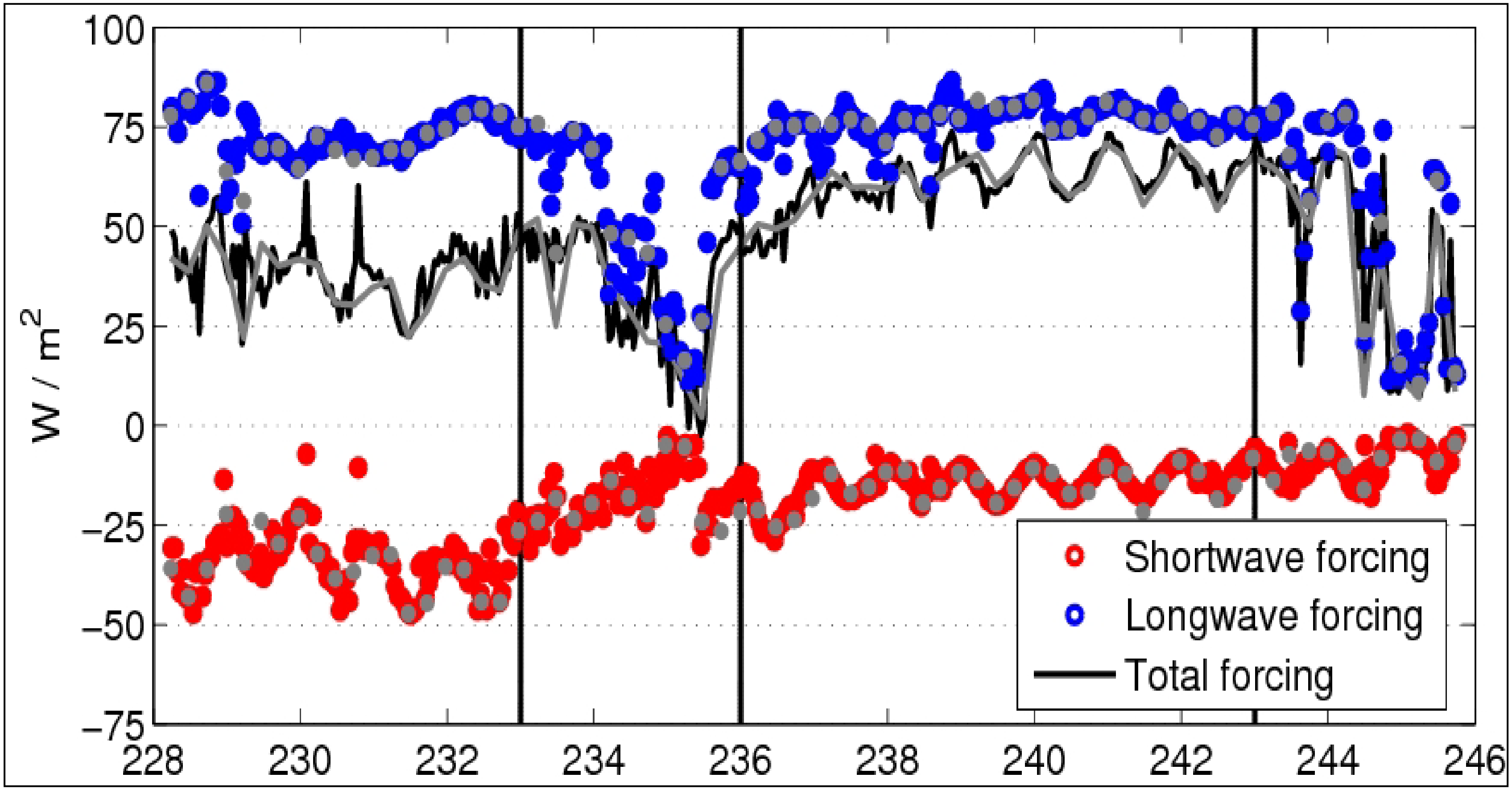
Seasonal surface longwave radiation

CMIP5 models



de Boer et al. 2012

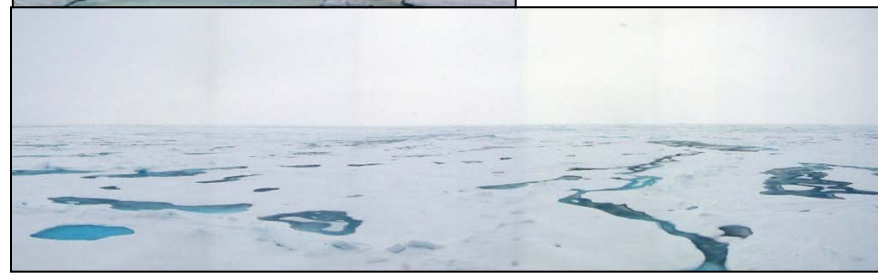
Summer CRE at surface
ASCOS

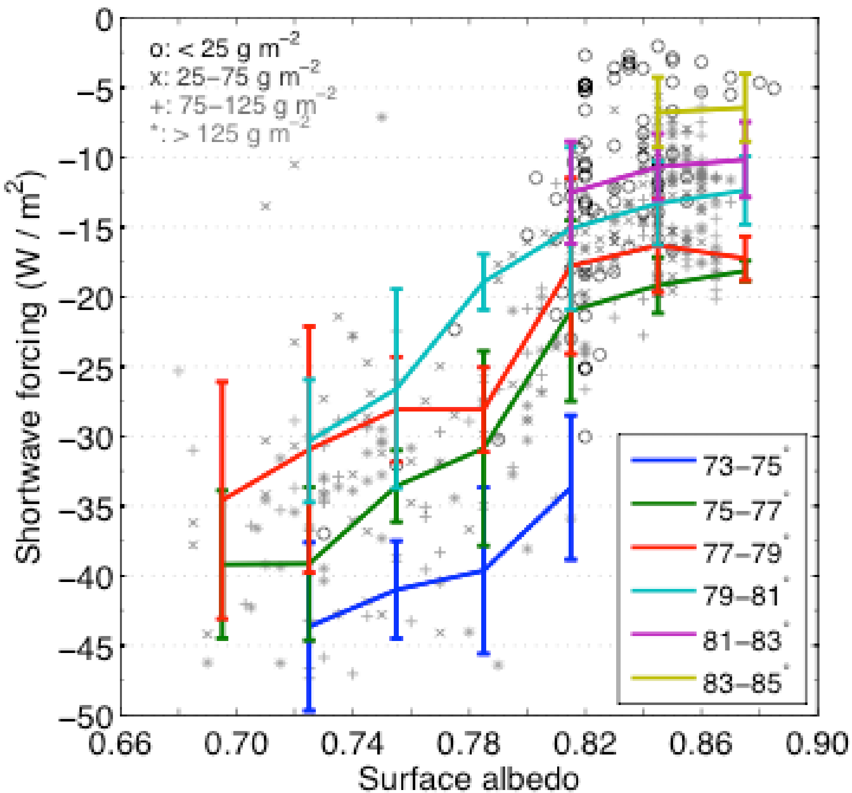


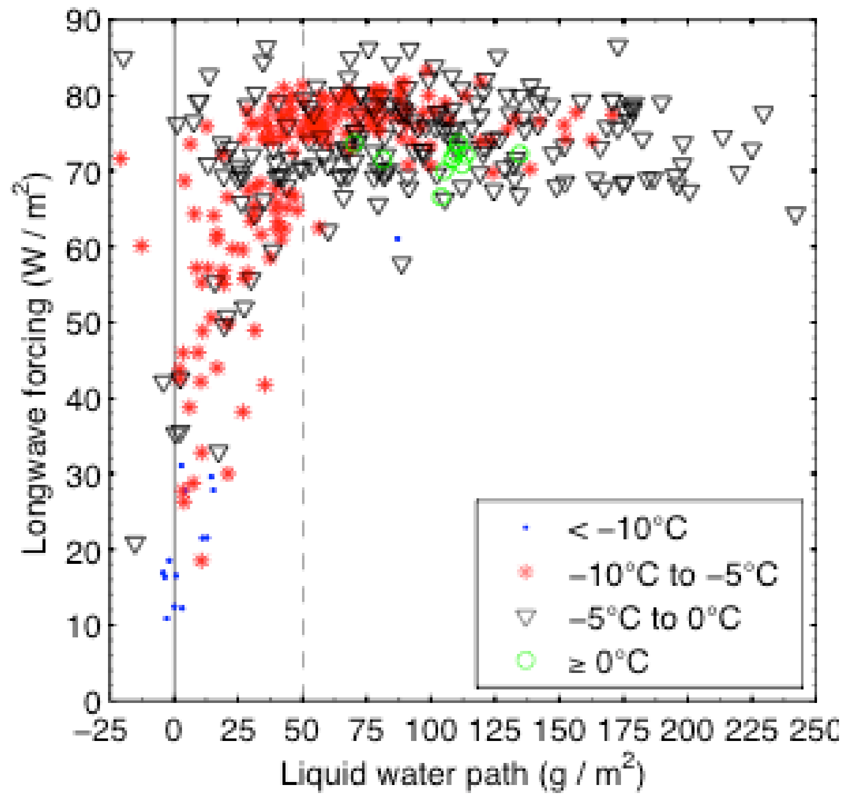
Sedlar et al. 2010

Summer CRE at surface
ASCOS

Stockholm University



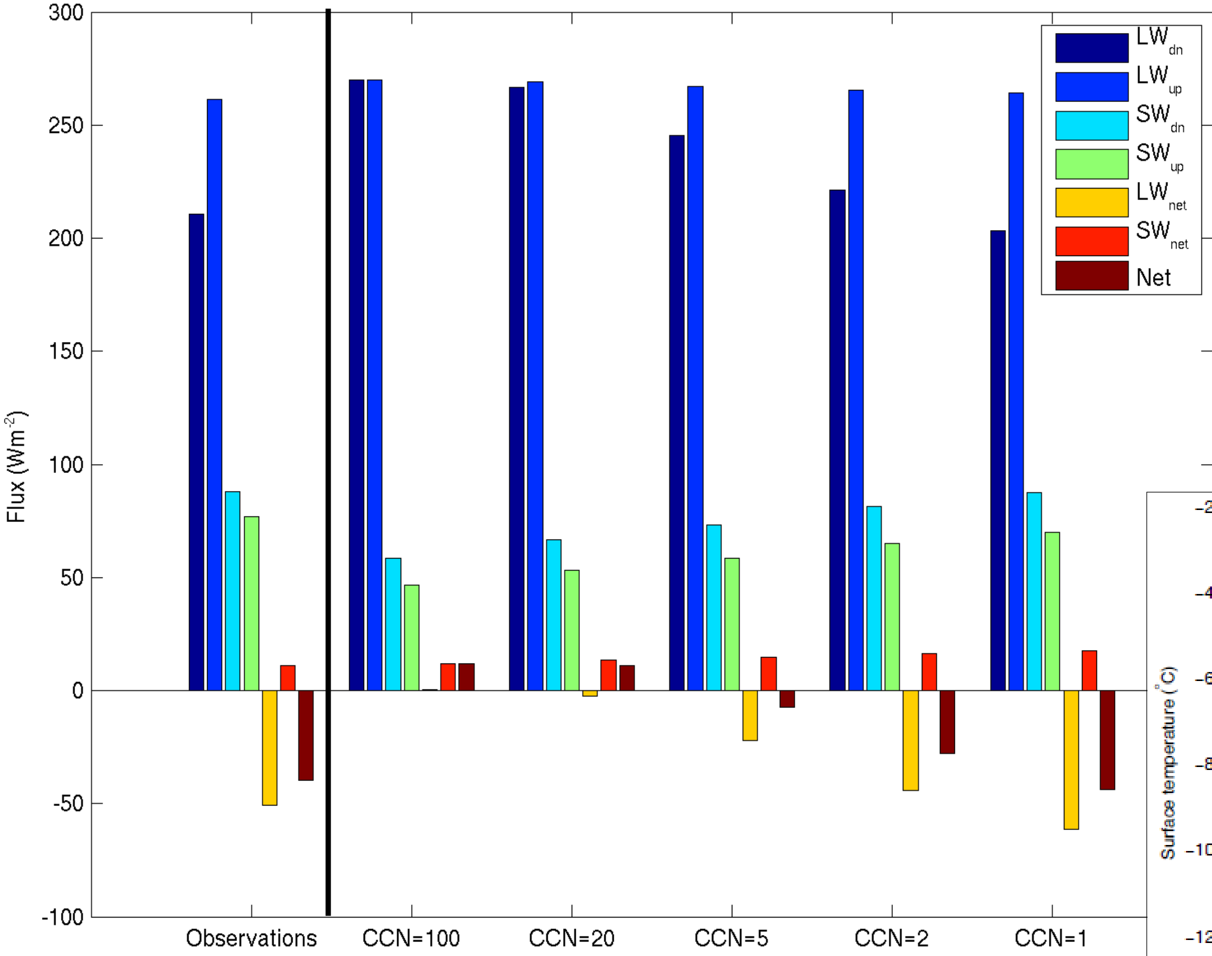


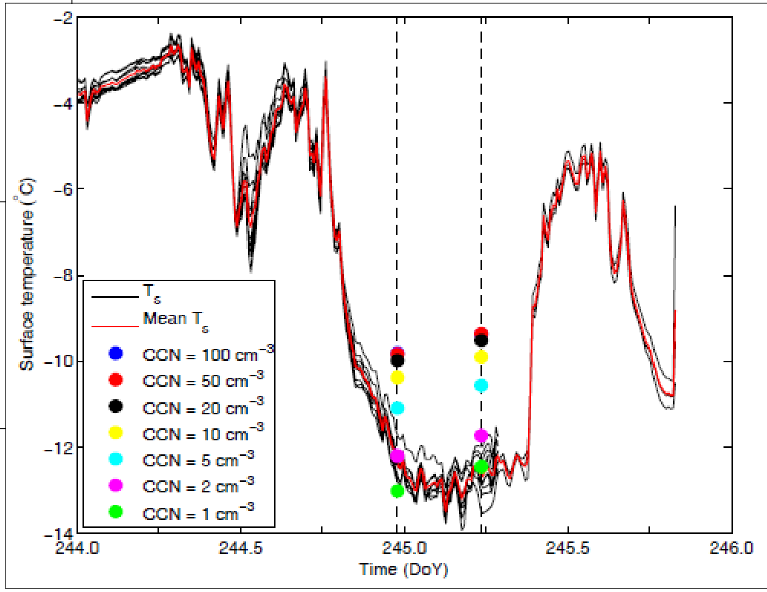


Sedlar et al. 2010

Optically thin clouds and suface energy budget

Regional model results





Birch et al. 2012

Summary extratropical clouds

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- Observations show a poleward/equatorward increases/decreases in frequency of extratropical storms
- The net radiative effect of these changes are positive in observations, indicative of a positive cloud feedback
- Warmer climates indicate that there will be a poleward storm track shift, increase in storm strength and decrease in storm frequency
- Some improvement in CMIP5 models compared with CMIP3 but storm tracks are still too zonal – part of the improvement is likely because of increased horizontal resolution
- Most studies of midlatitude storms are in terms of dynamic effects and precipitation
- Cloud changes and radiative effects have not been extensively studied

Summary polar clouds

- From observations, we know the initial cloud response to removing sea-ice
- From feedback analysis we know the sign but not the magnitude of most possible mechanisms, the most uncertain are the atmospheric transport and changing clouds
- Arctic clouds in CMIP5 models have very different properties and spread in CRE and no obvious decrease in across-model spread in cloud related variables in CMIP5 compared to CMIP3
- In general, clouds become more plentiful and optically thicker (LWP and IWP both increasing) in the warmer climate in the CMIP5 models :
  - for winter this results in increased surface CRE
  - in summer, the decrease in surface albedo is more important than the changes in cloud properties for the surface CRE
- Sea ice albedo is badly constrained in models, which results in large present-day summertime model spread of surface cloud radiative effect

Key outstanding questions

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- The interaction between the dynamics and clouds (the Hadley circulation and the extratropical cyclones, warm conveyor belt, polar lows, cyclones in polar regions)
- Cloud parameterizations are designed for lower latitudes, does not describe the right physics in the polar regions
- Clouds interact strongly with the surface in the polar regions, have to be studied as a coupled problem involving the parameterized turbulence, sea-ice, radiation, aerosol and clouds
- Vertical resolution is not designed for the shallow dynamic and thermodynamic processes in the polar regions and lack of observations in polar regions makes it hard to constrain the problem
- WMO initiatives for polar prediction on all time scales WWRP Polar Prediction Project (hours to seasonal) and WCRP Polar Climate Predictability Initiative (seasonal to multi decadal)

Photo: M. Tjernström