Trends and variability of the clouds over the Southern Ocean and the link to sea ice

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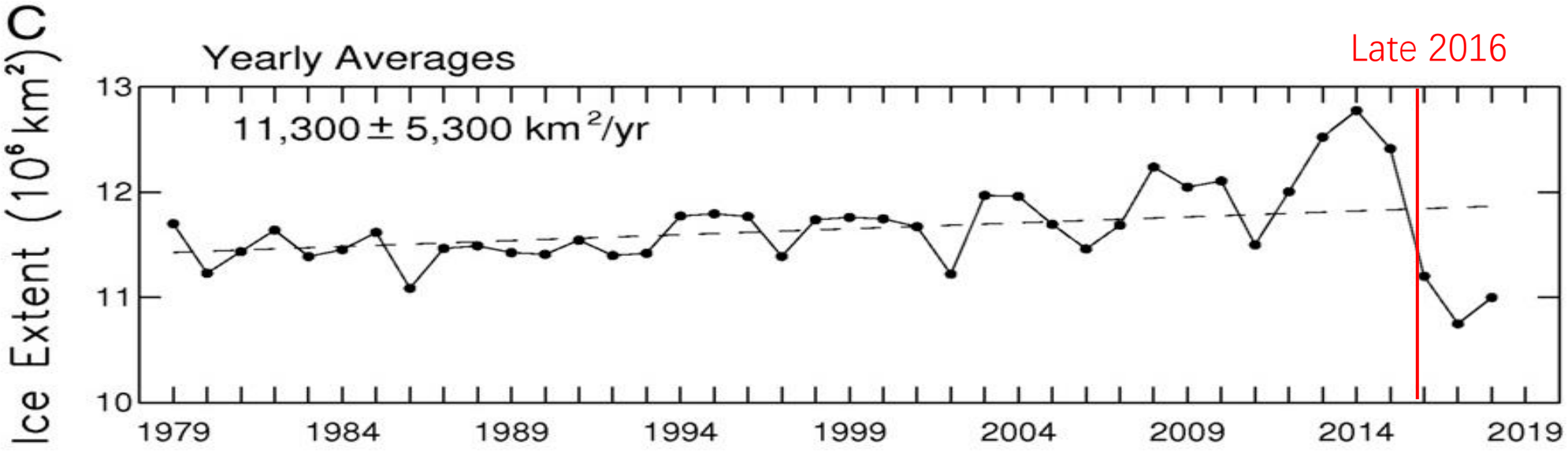
Motivation

- Precipitation is found to be decreasing at lower latitudes and increasing at higher latitudes (Manton et al. 2020). Do such trends exist for clouds and radiation?

- There is much less research on link between cloud and sea ice in the Southern Ocean.



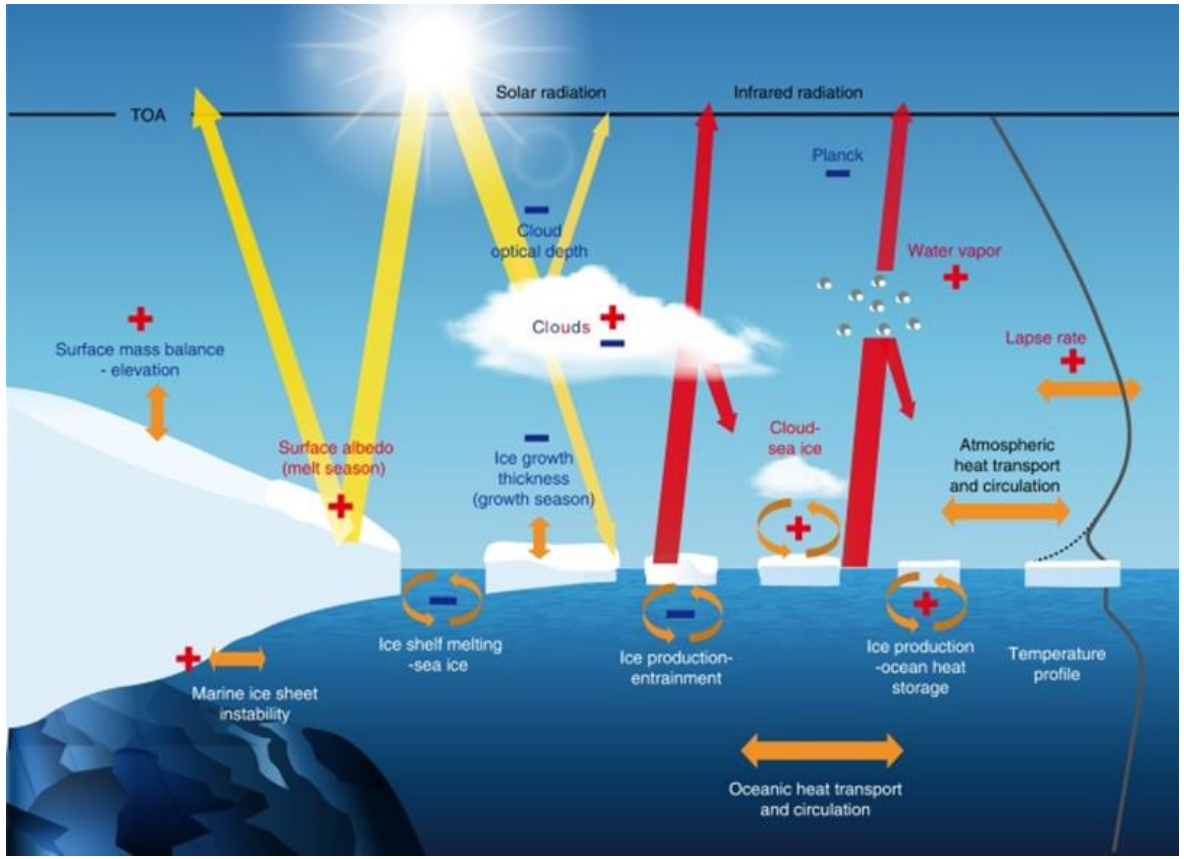
Yearly average sea ice extents and their line of linear least squares fit. The ice extents are derived from passive-microwave data from the NASA Nimbus 7 and Department of Defense DMSP satellites. (Parkinson et al. 2019)

The melting or formation of sea ice is determined by the change of surface energy budget, which can be shown as:

$$F_{net} = Q_{net} + H_s + H_l + \mathrm{C}$$

$$Q_{net} = \mathrm{LW}\downarrow - \mathrm{LW}\uparrow + \mathrm{SW}\downarrow - \mathrm{SW}\uparrow$$

Clouds – Radiation – Sea ice Interactions



Datasets (2003-2018):

Cloud and radiation properties:

- Cloud_cci Advanced Very High Resolution Radiometer post meridiem (AVHRR-PM) monthly dataset (Stengel et al. 2020)
- MODIS Cloud Properties
- The Clouds and the Earth's Radiant Energy System (CERES)

Sea ice concentration:

- Hadley Centre Sea Ice and Sea Surface Temperature data set (HadISST)
- The National Snow and Ice Data Center (**NSIDC**)

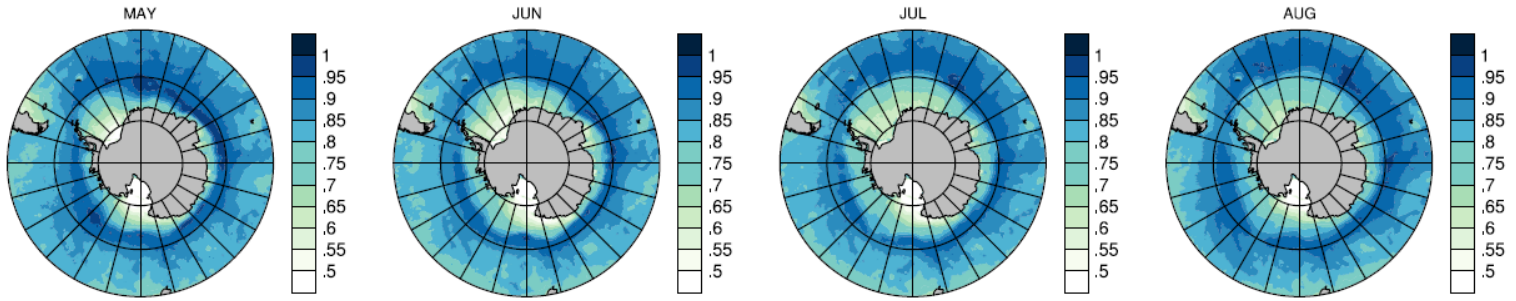
Meteorology:

- ECMWF ERA-5 Reanalysis

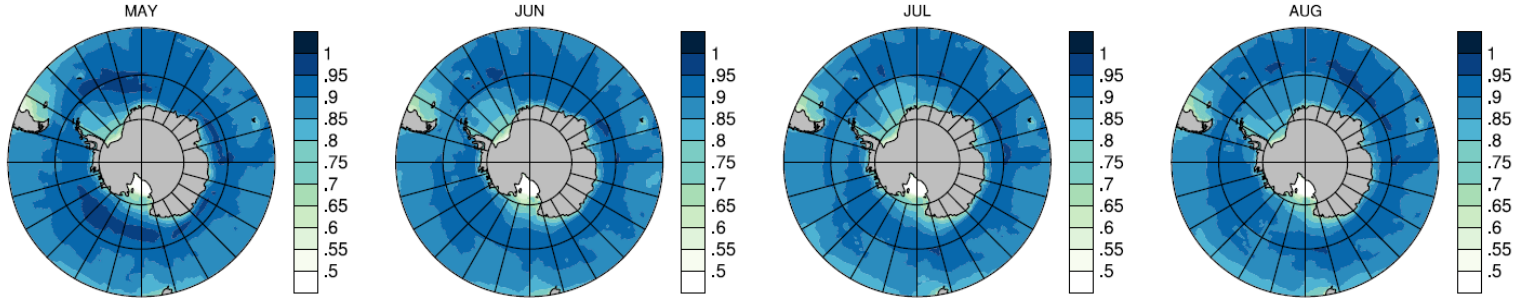
Preliminary results: Mean Cloud Cover

Mean Cloud Cover Fraction by each month, from 2003 to 2018

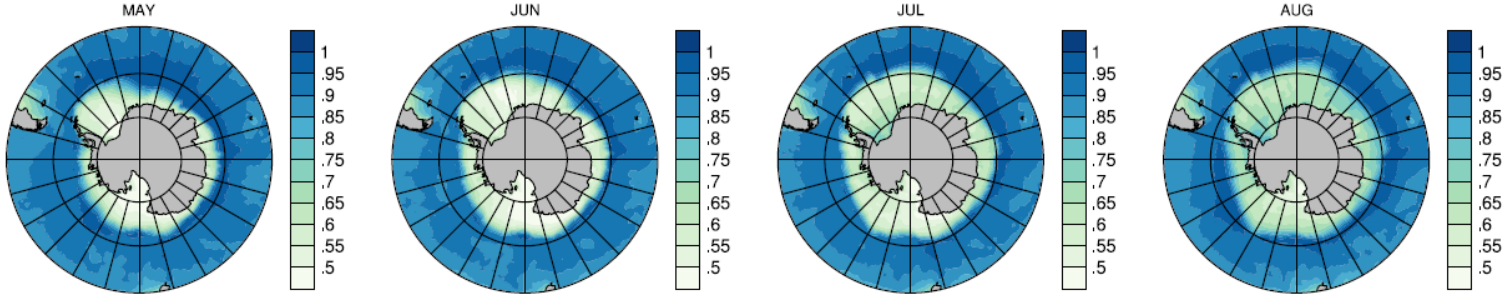
Cloud CCI AVHRR-PMv3 L3C



The Clouds and the Earth's Radiant Energy System (CERES) EBAF 4.1 Monthly data

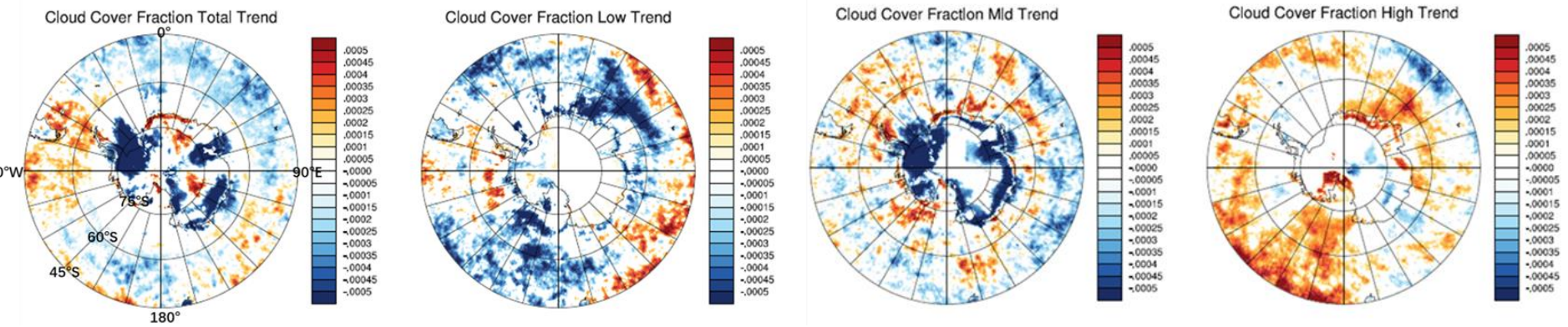


MODIS/Aqua Cloud Properties Level 3 monthly



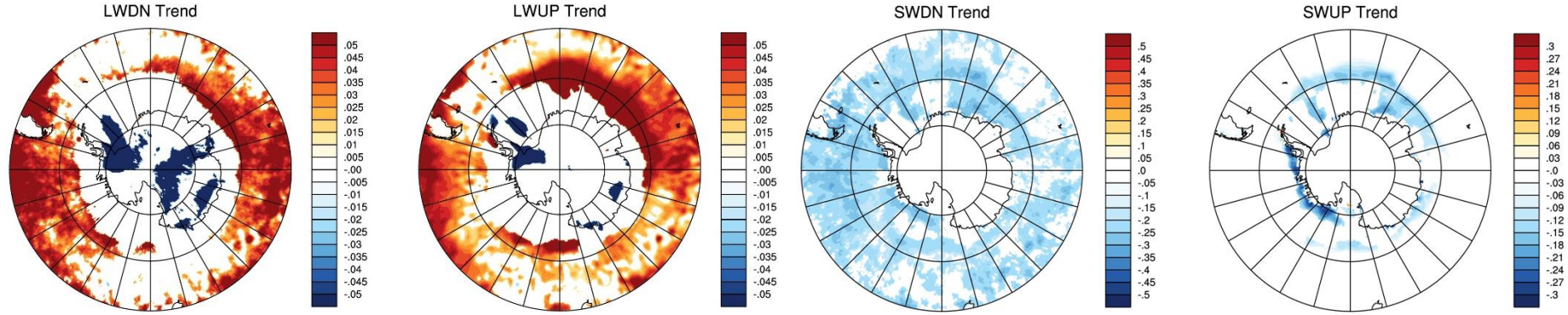
Preliminary results: Trends of clouds and radiation properties

Trends of cloud cover fraction over the Southern Ocean from Cloud CCI



- High-top clouds show positive trends over the high-latitude SO adjoining the Antarctic continent, consistent with observed poleward shift of the SO storm track (e.g. Bender et al. 2012) and increased precipitation poleward (Manton et al. 2020).

Trends of Bottom of Atmosphere (BOA) radiation flux from Cloud CCI over the Southern Ocean



- Increased BOA LW radiation flux reflects the increased temperature and moisture in a warming climate, qualitatively consistent with earlier studies (e.g. Stephens et al. 2012).
- Decreased SW downward radiation flux is broadly consistent with increased reflected TOA SW flux found using CERES dataset (Hartmann and Ceppi 2014).

Introduction of Cloud Radiative Forcing (CRF)

$$CRF_{BOA} = F^{\downarrow} - F^{\downarrow}_{clr}$$

Ramanathan et al. (1989) proposed to quantify the CRF by comparing radiation fluxes in cloudy (all-sky) and noncloudy (clear-sky) conditions. $F^{\downarrow}$ conctitues a broadband radiation flux and can be SW or LW. A down-pointing arrow indicates a downwelling flux. $F^{\downarrow}$ indicates all-sky flux and $F^{\downarrow}_{clr}$ indicates a clear-sky flux.

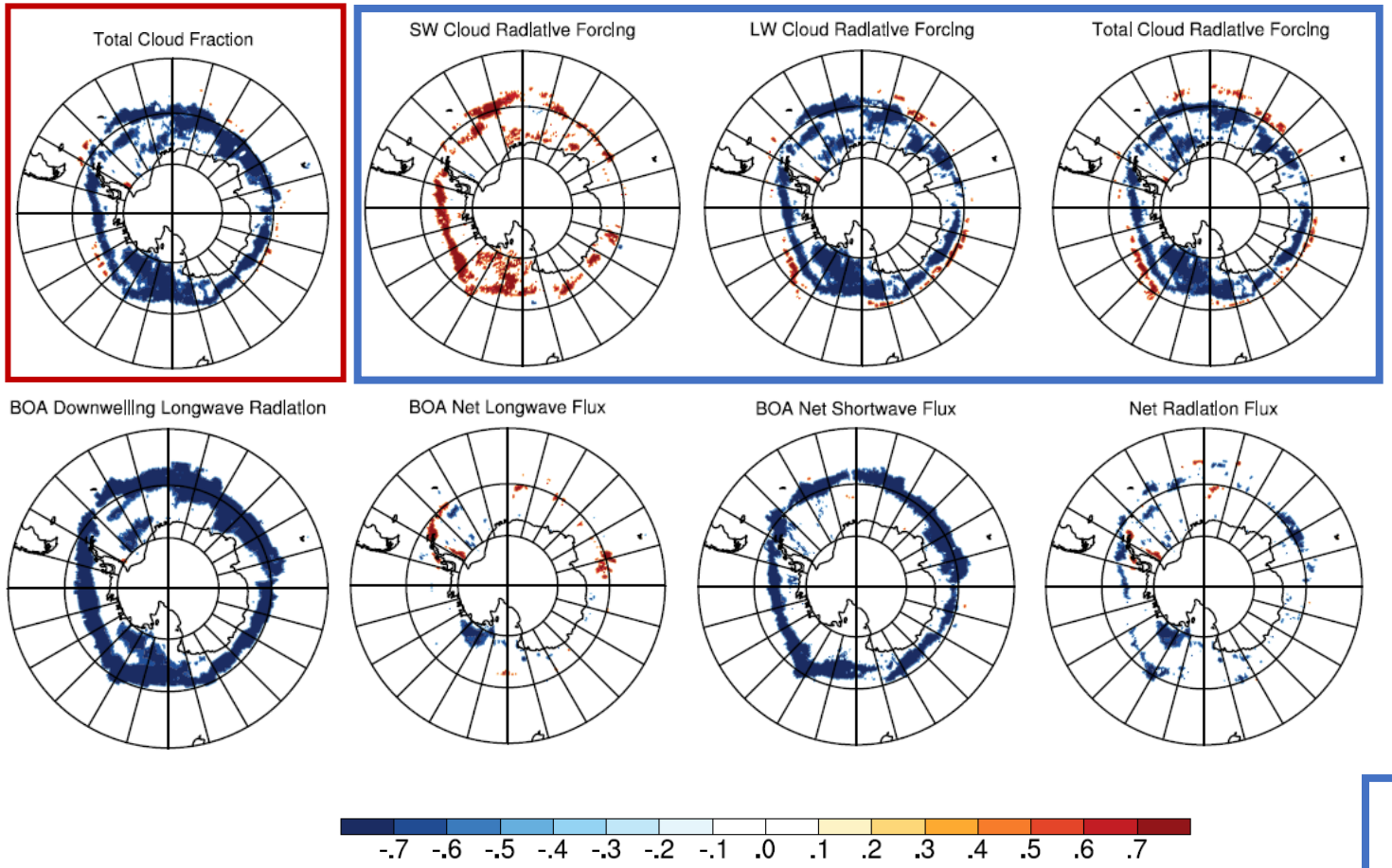
$$TCRF = SWCRF + LWCRF$$

The Total CRF (TCRF) is the sum of shortwave CRF (SWCRF) and longwave CRF (LWCRF).

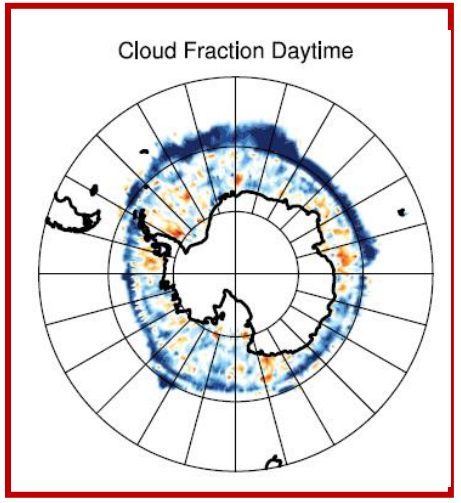
Preliminary results: Correlation between Sea Ice Concentration (SIC) and clouds / radiation properties

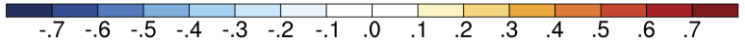
Spring （SON）

Cloud CCI

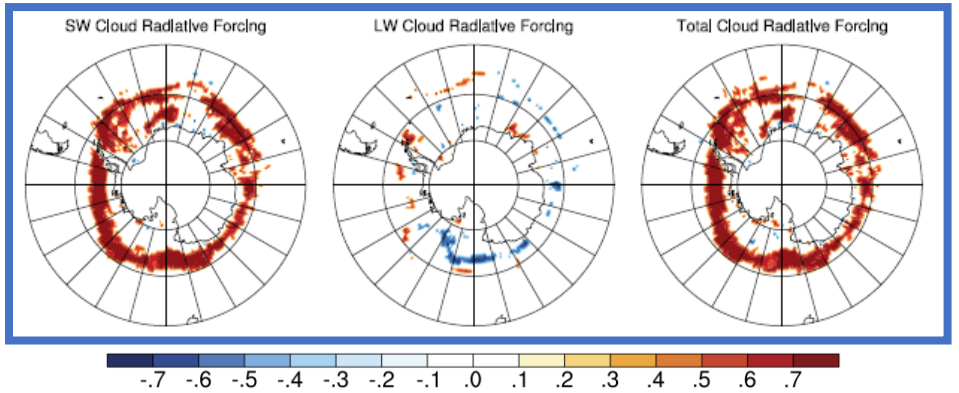


MODIS AQUA





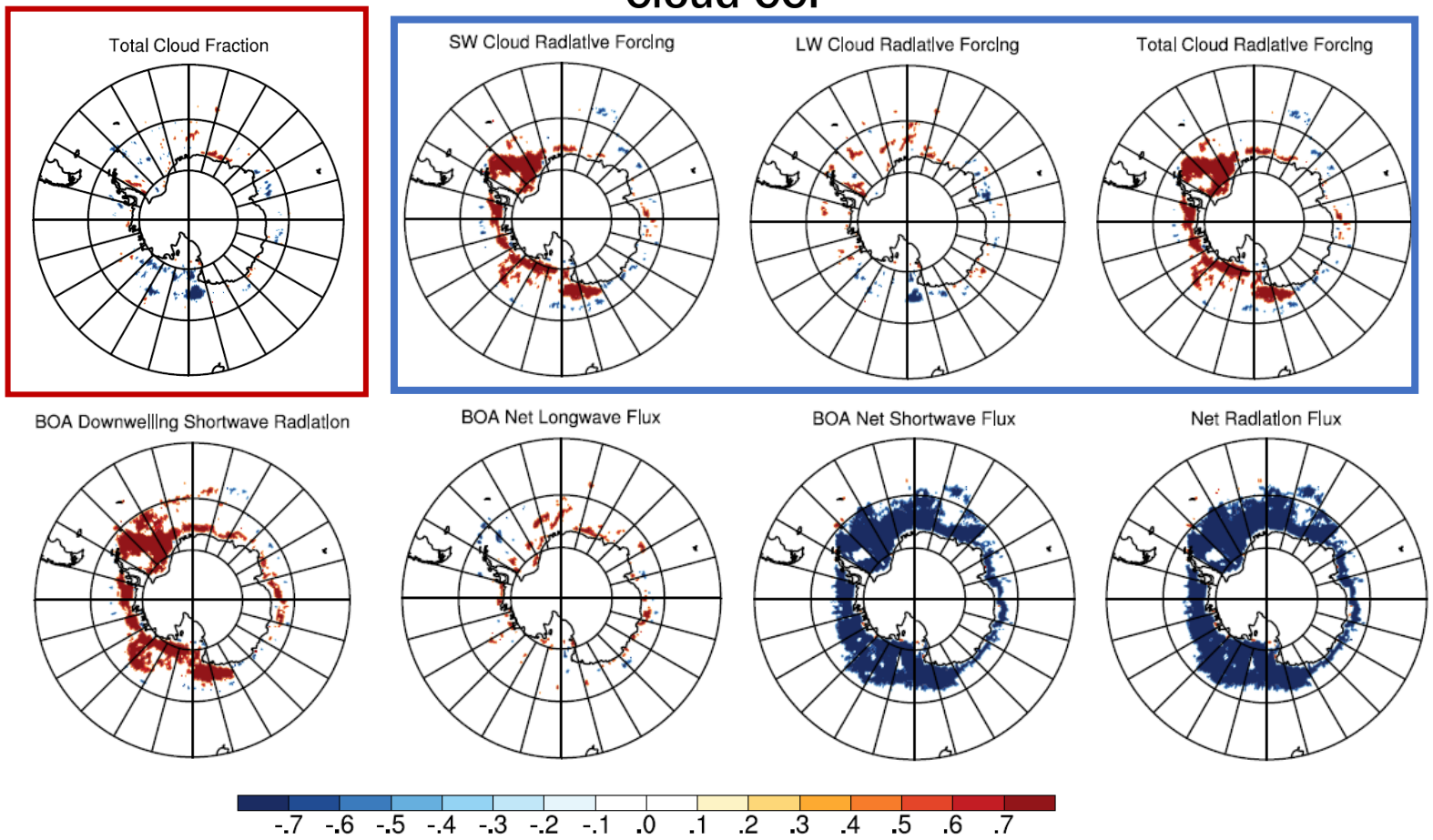
CERES



- *The correlation between cloud properties, radiation fluxes anomalies from Cloud CCI and sea ice concentration anomalies in winter with 95% confidence level from 2003 to 2018..*

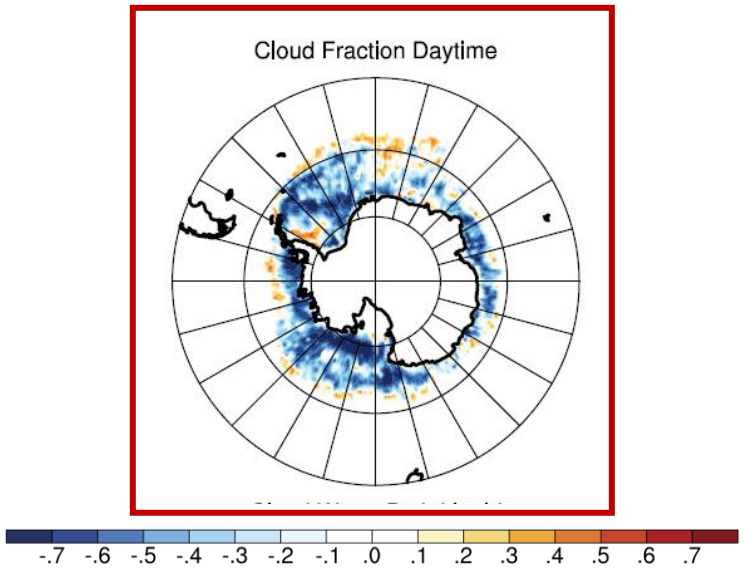
- Strong correlations between SIC and total cloud fraction anomalies (good consistency can be seen for Cloud_cci and MODIS).
- Strong negative correlation between SIC and Cloud Radiative Forcing which is mainly longwave cloud radiative forcing.

Cloud CCI



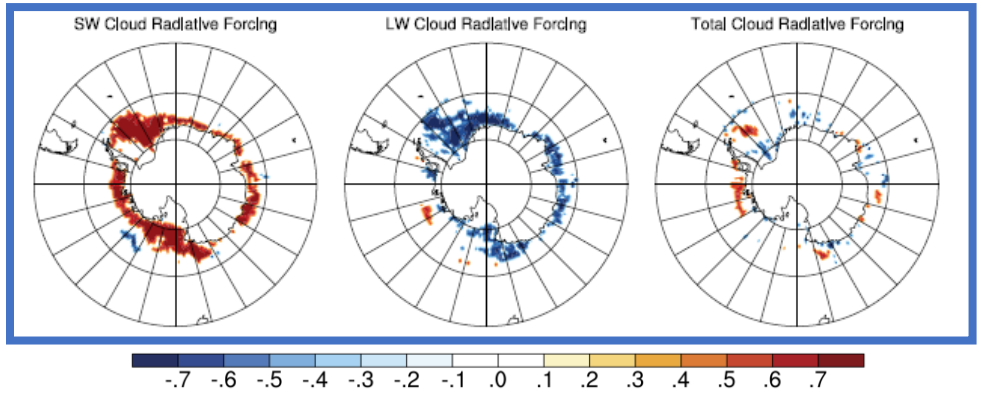
Autumn（MAM）

MODIS AQUA



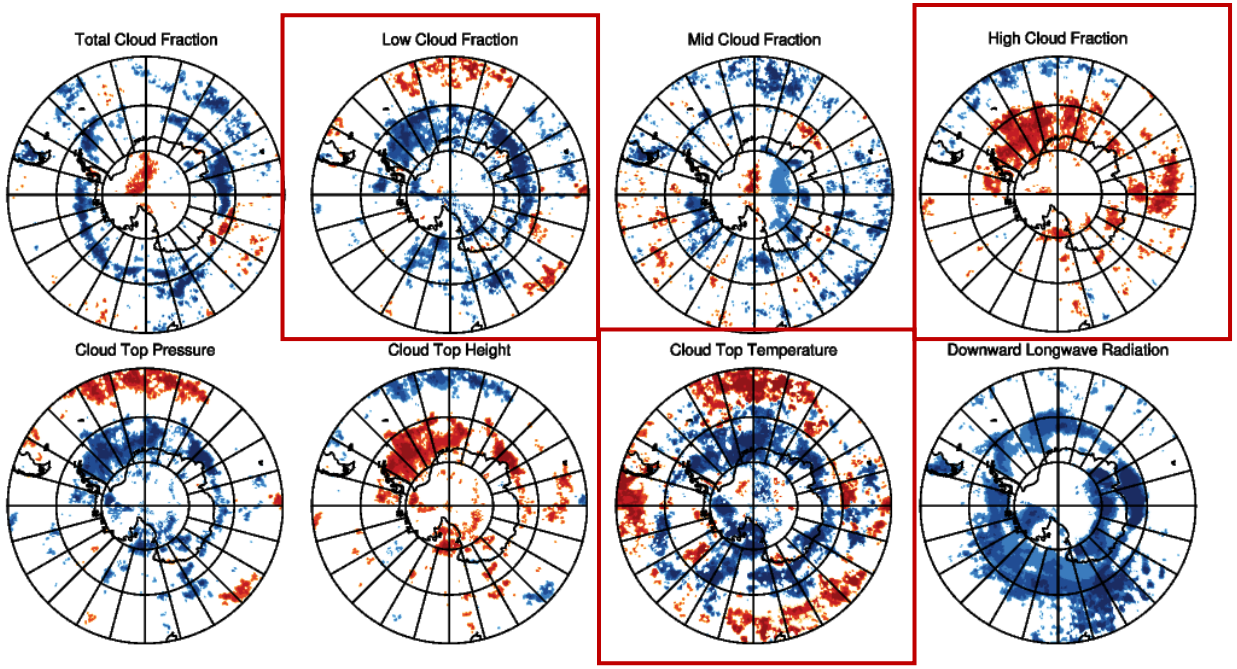
- *The correlation between cloud properties, radiation fluxes anomalies from Cloud CC and sea ice concentration anomalies in spring with 95% confidence level from 2003 to 2018. The data has been detrended first before calculating anomalies.*
  - Weak correlation between SIC and total cloud fraction anomalies
  - Strong negative correlation between SIC and net radiation anomalies, primarily driven by SW radiation flux. (some consistency can be seen for Cloud_cci and CERES).

CERES

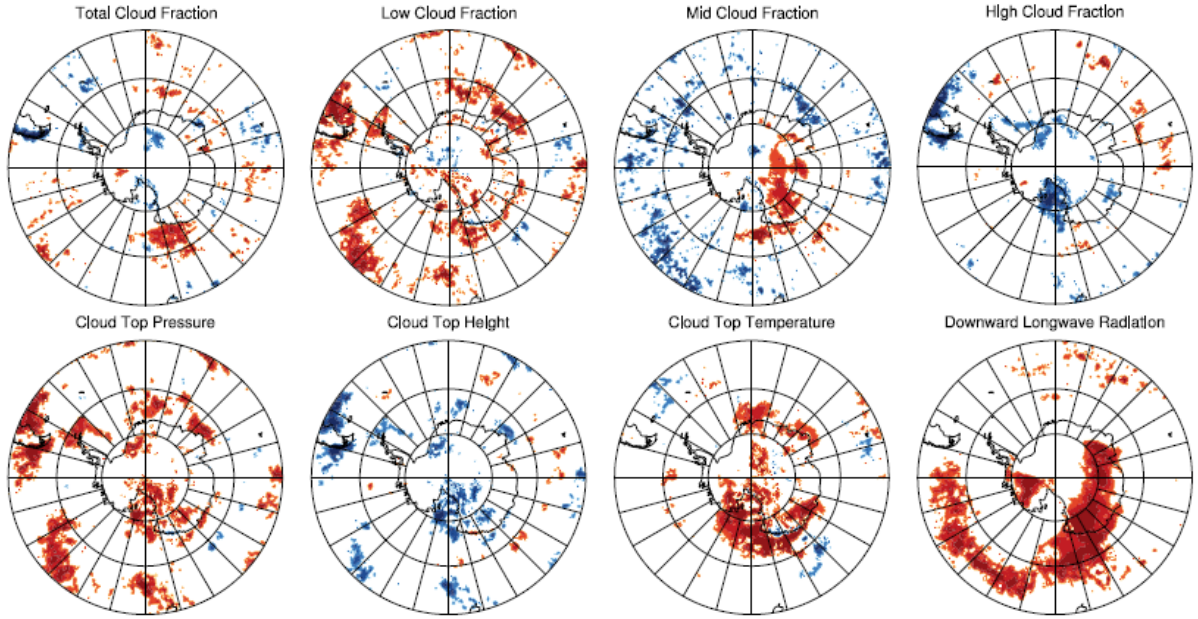


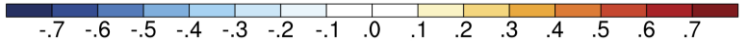
Preliminary results: Correlation between Southern Annular Mode (SAM) / Mean Sea level Pressure (MSLP) and clouds / radiation properties

Relationship between cloud properties and SAM (autumn)



Relationship between cloud properties and MSLP (autumn)





- High SAM (low MSLP) is correlated with lower low cloud fraction, greater high cloud fraction, and colder cloud top at high latitude
- The opposite relationships are found for mid latitudes.
- No statistically significant relationship is found with Southern Oscillation Index (not shown).

Preliminary Conclusion

- Increased fraction of high clouds at higher latitudes coincides with increased precipitation.
- High SAM -> low pressure at high latitudes. Correlation of SAM and Cloud Top Temperature is negative (but highly correlated).
- **During the sea ice growth season**, SIC anomalies are negatively correlated with net radiation flux anomalies, but correlation with cloud cover is much weaker.
- **During the sea ice melting season**, SIC anomalies are negatively correlated with total cloud cover and CRF (mainly longwave), but correlation with net radiation flux is less evident.

Question?