Investigate the feedback mechanisms of Arctic clouds and radiation on sea ice changes

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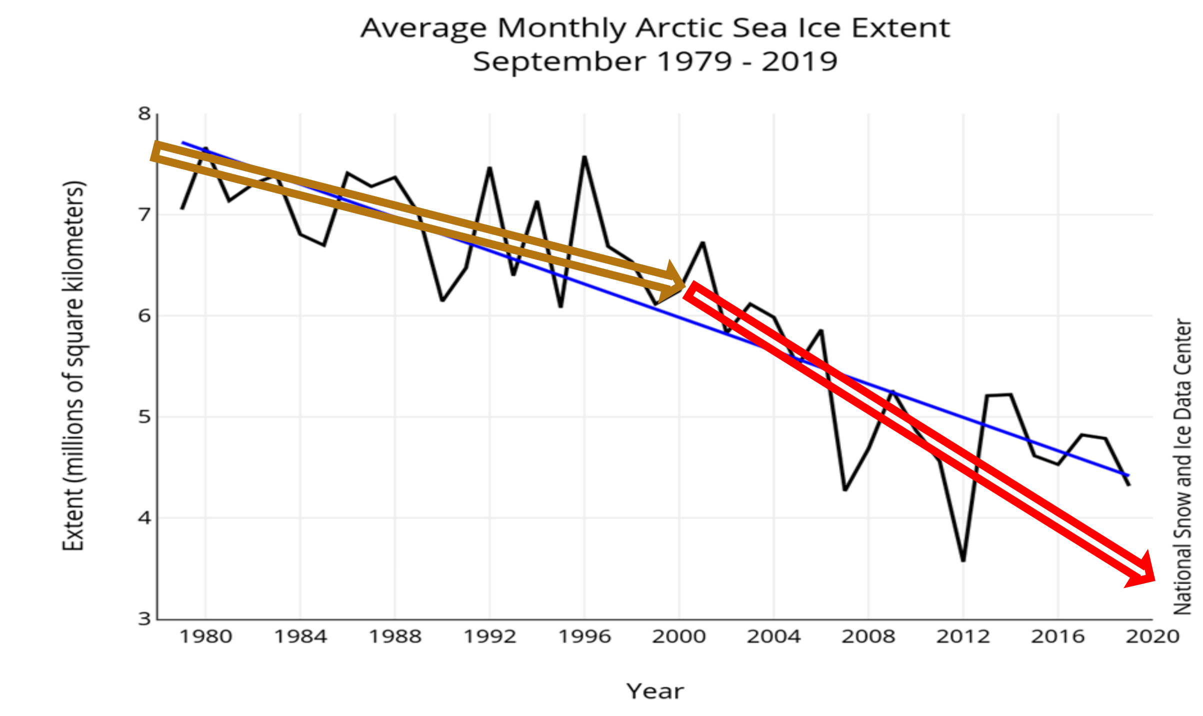
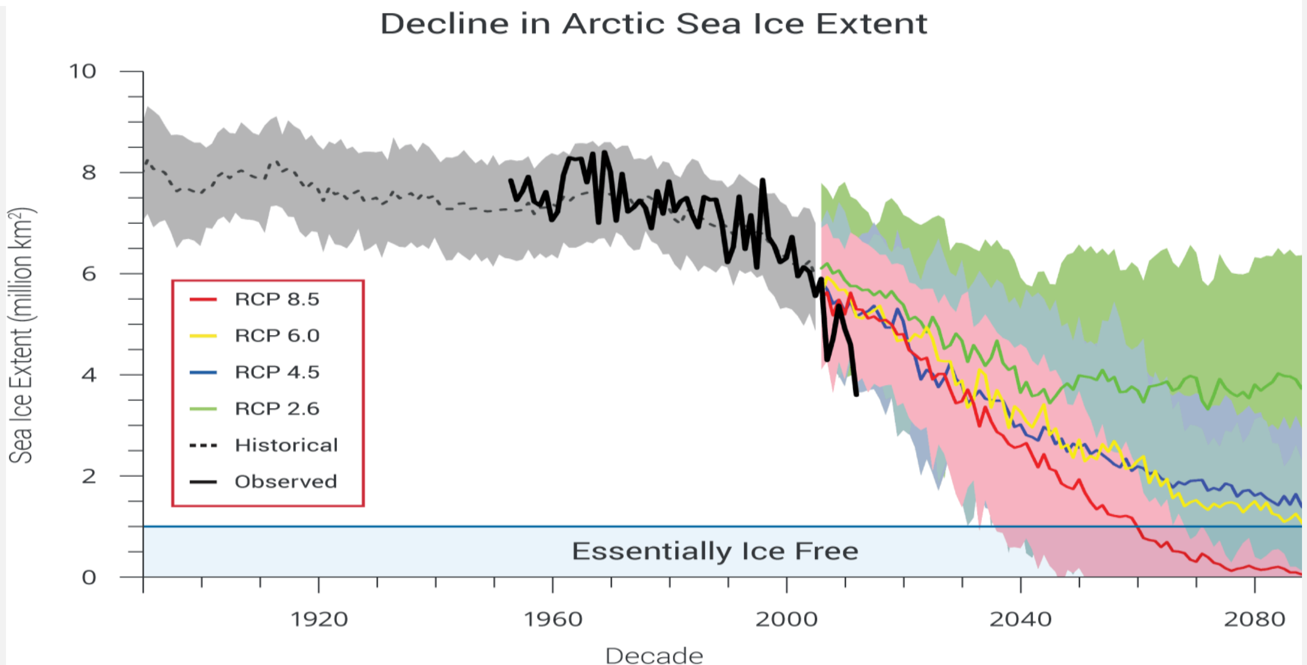
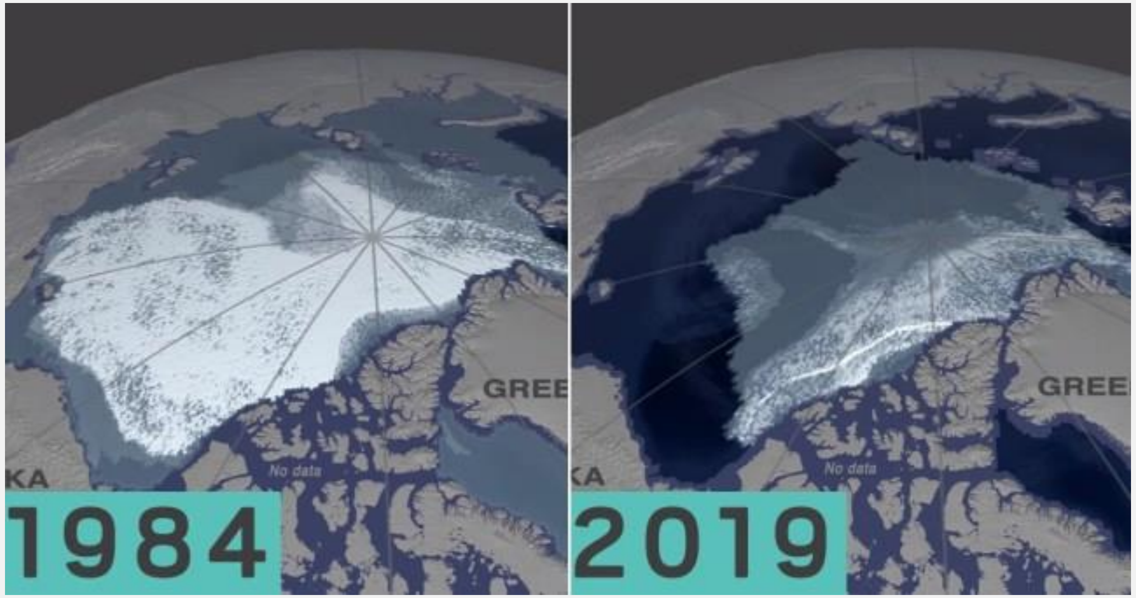
THE RAPID SEA ICE DECLINE IN THE ARCTIC





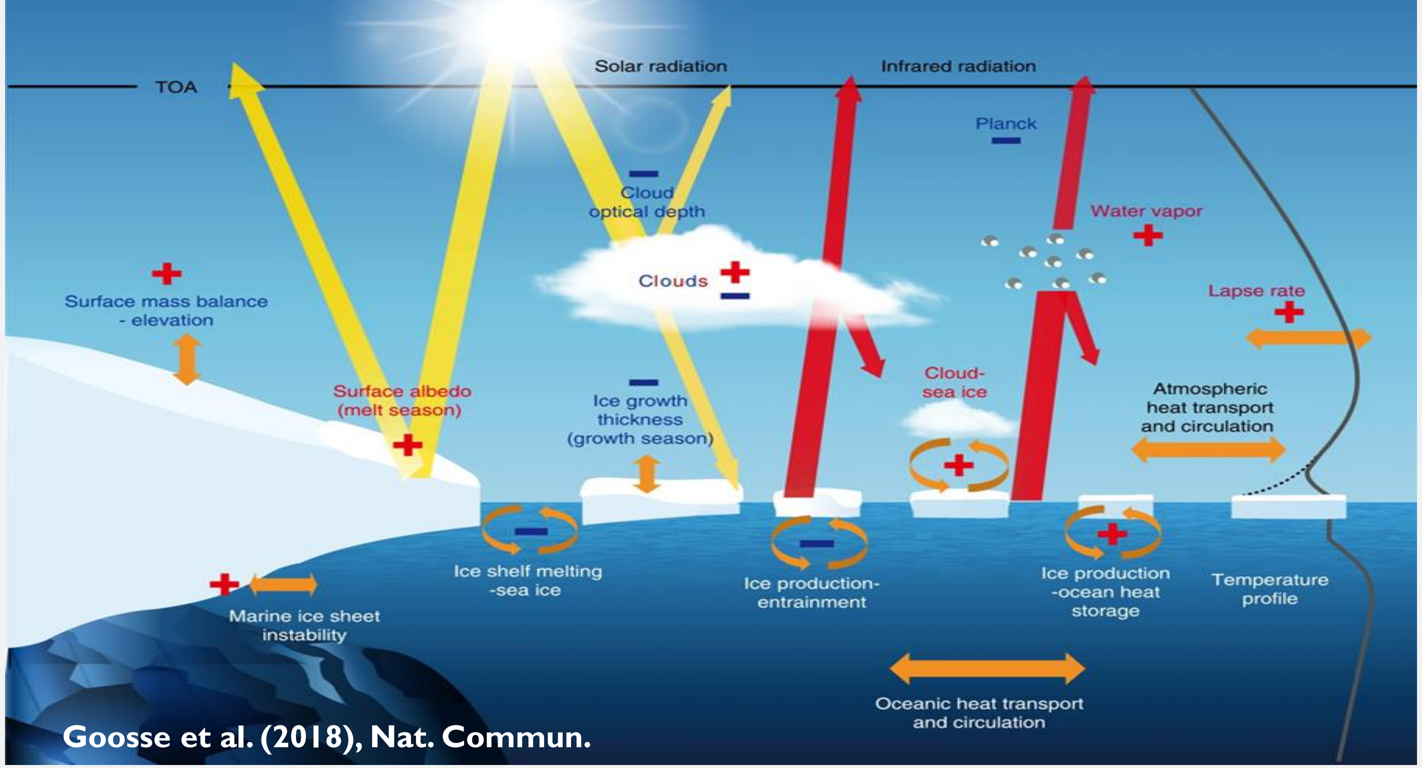


NASA satellite image from NSIDC

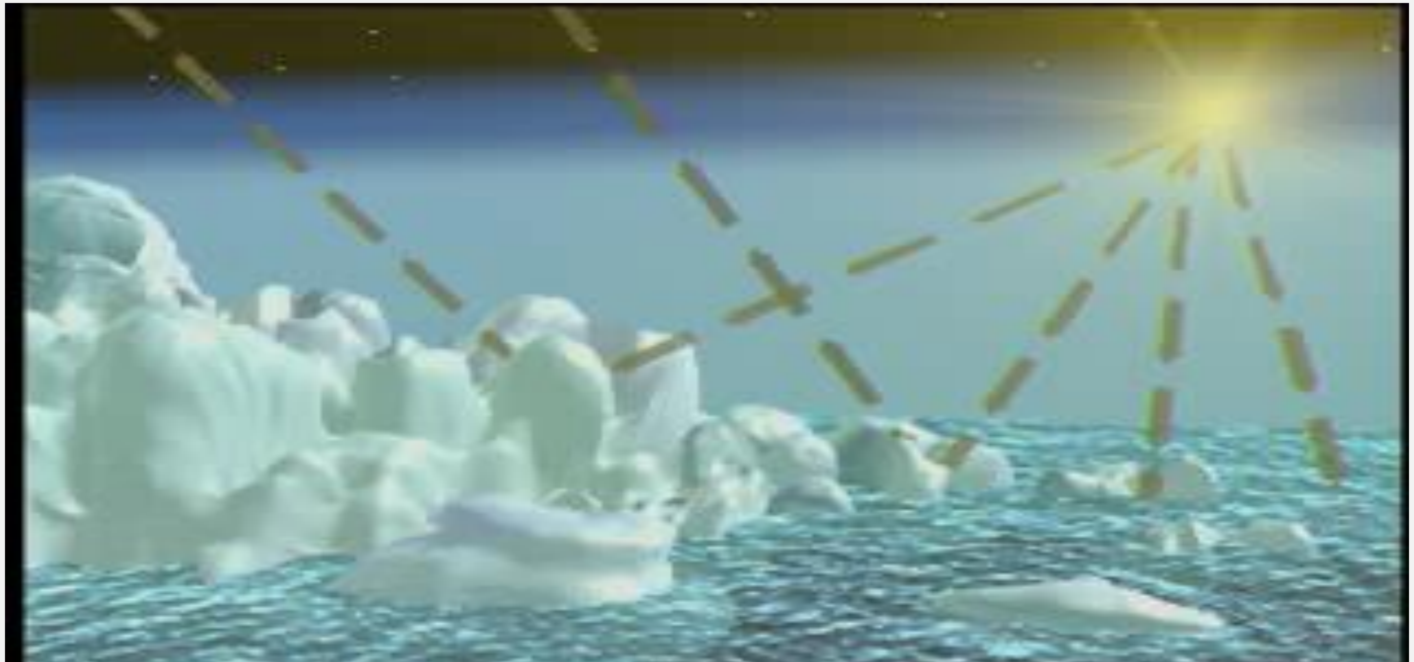
Since the dawn of the satellite era, Arctic summer sea ice coverage has declined by nearly 50% and this decline has accelerated in the early 21st century

THE RAPID SEA ICE DECLINE IN THE ARCTIC

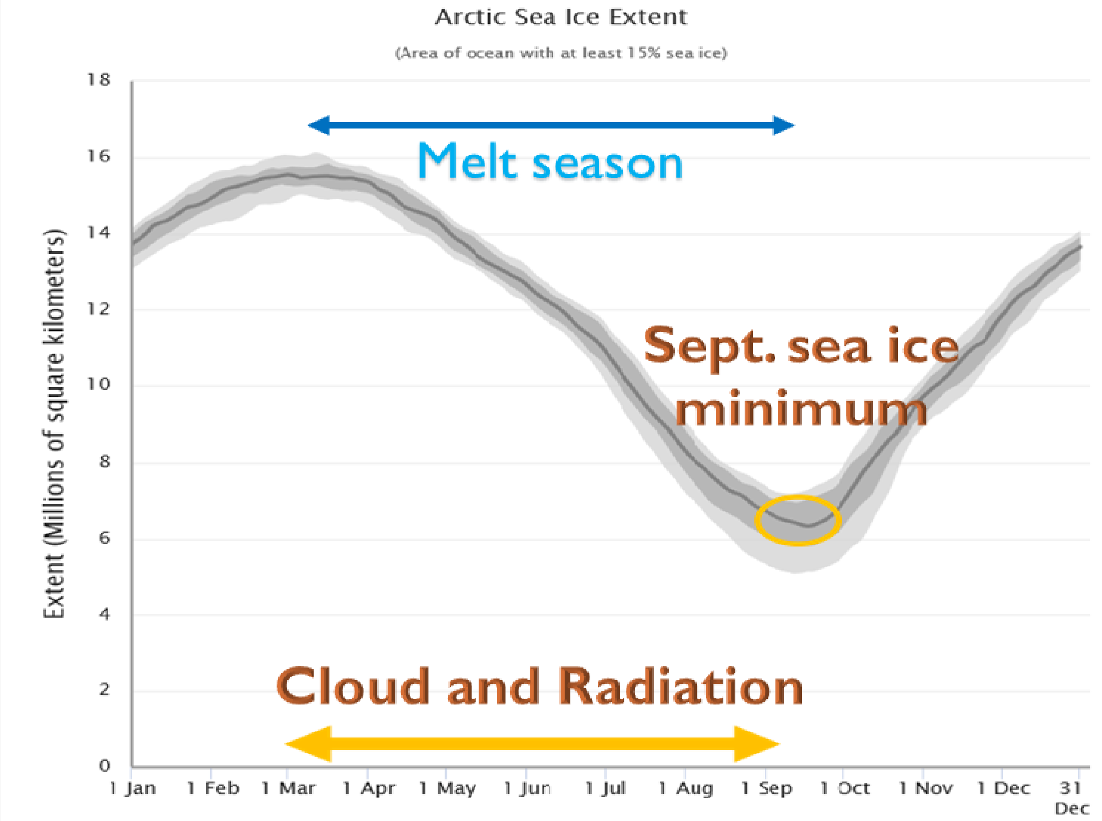
- The Arctic sea ice variations are caused by different dynamic and thermodynamic processes
- The surface energy budget anomaly is one of the most important thermodynamic forces associated with Arctic sea ice changes
- Clouds impact the long-term trend and year-to-year variability of Arctic sea ice due to their strong modulation of radiative energy fluxes at the surface



Goosse et al. (2018), Nat. Commun.



SCIENTIFIC QUESTIONS



Adapted from NSIDC

- **How do the radiative effects of clouds and water vapor modulate the melt onset of Arctic sea ice in spring?**
- **How do the melt season cloud and radiation properties have an impact on the September sea ice concentration decline?**
- **Can the Earth System Models reproduce these relationships between the cloud/radiation and sea ice in the Arctic?**

To investigate the role of cloud-radiation feedback in modulating Arctic sea ice changes from weekly to interannual time scales through an integrative analysis of *satellite observations, global reanalysis products and model simulations*

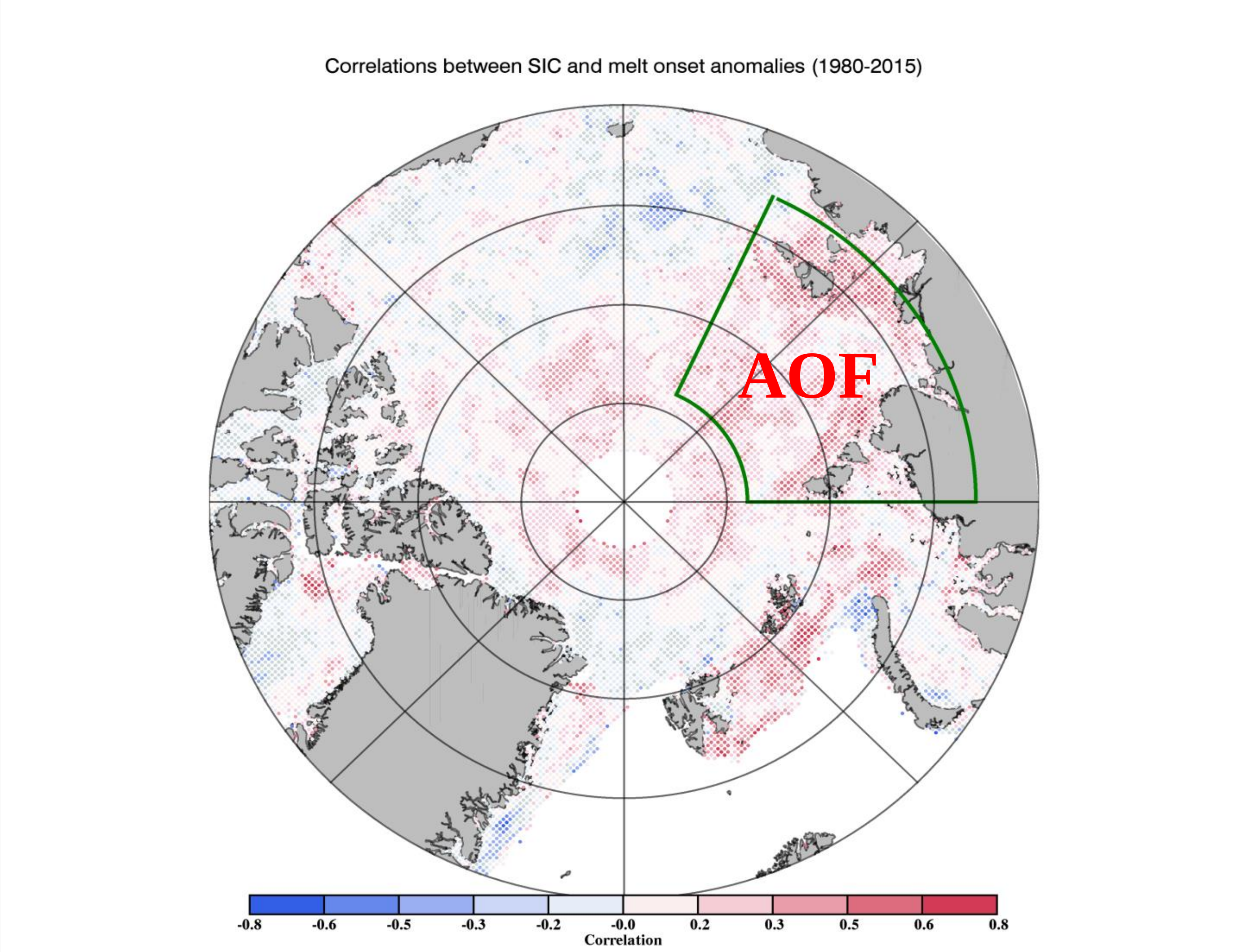
OUTLINE

The impacts of Arctic cloud and radiation properties on September sea ice retreat

- Weekly to monthly time scales
- Seasonal to interannual time scales

The impacts of large-scale circulation on Arctic clouds

PART I: CORRELATIONS BETWEEN SEPT. SEA ICE EXTENT (SIE) AND MELT ONSET DATE ANOMALIES



- **September sea ice extent (SIE) is most sensitive to the early melt onset over the East Siberian Sea and Laptev Sea (73°-84°N, 90°-155°) in the Arctic, which is defined here as the area of focus (AOF)**
- **Initial melting onset: The day with melting onset exceeding 10% area of the AOF is marked as the areal initial melt date for a given year**
- **Four early and four late years of melting onset events are selected**

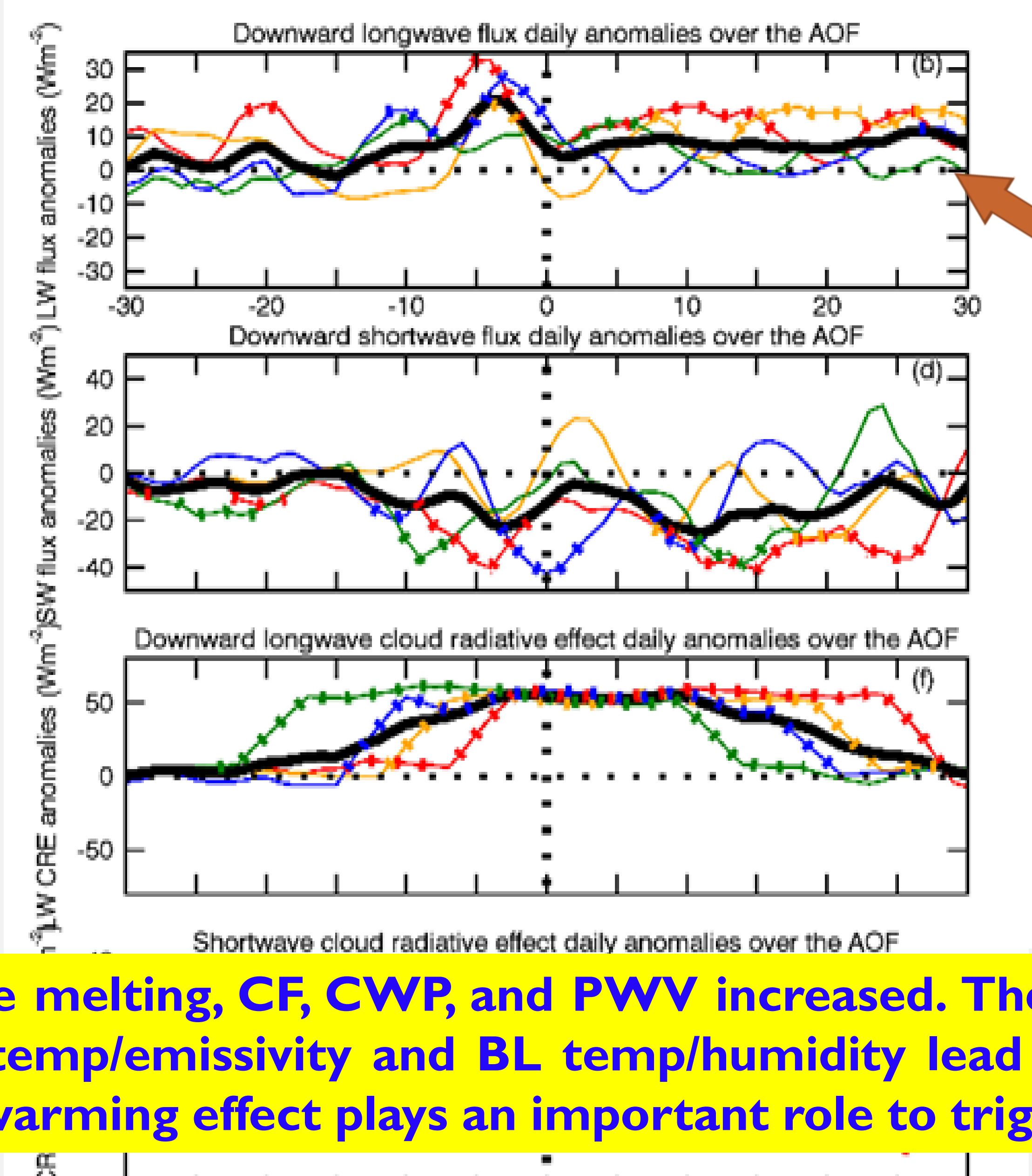
Huang et al., Clim Dyn, 2018

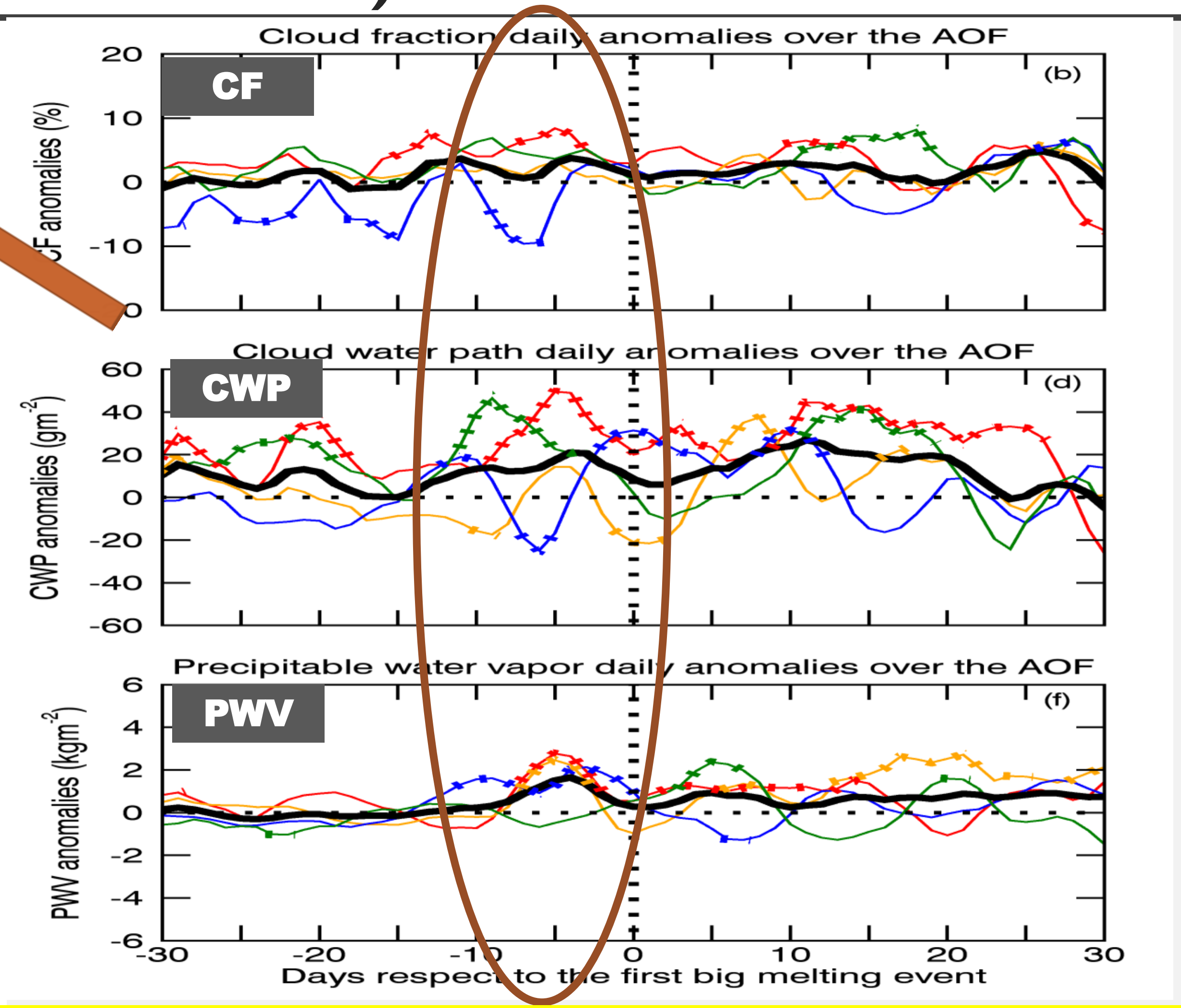
EARLY MELTING YEARS: CLOUD AND RADIATIVE PROPERTIES (MERRA-2 REANALYSIS)

LW_dn

SW_dn

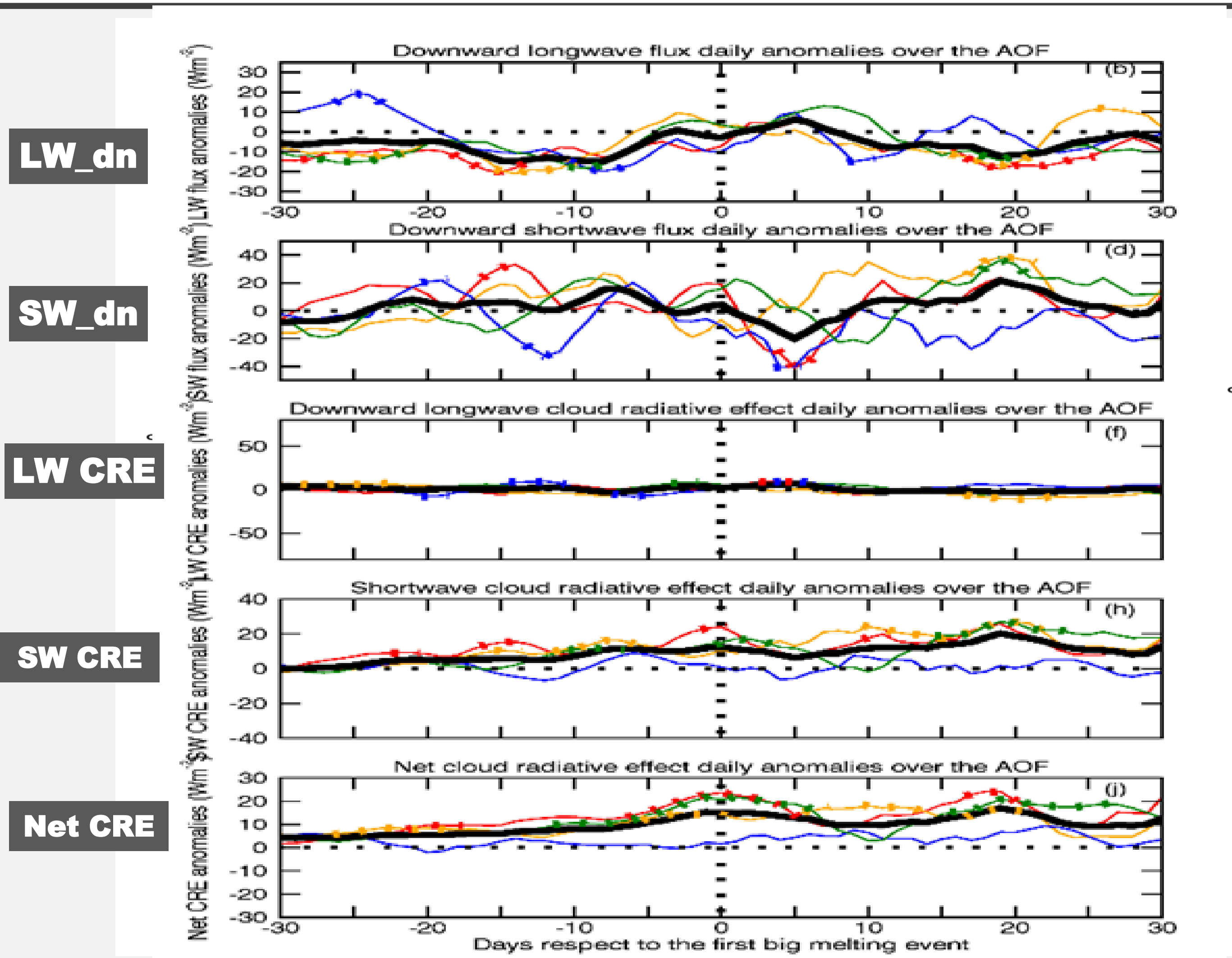
LW CRE

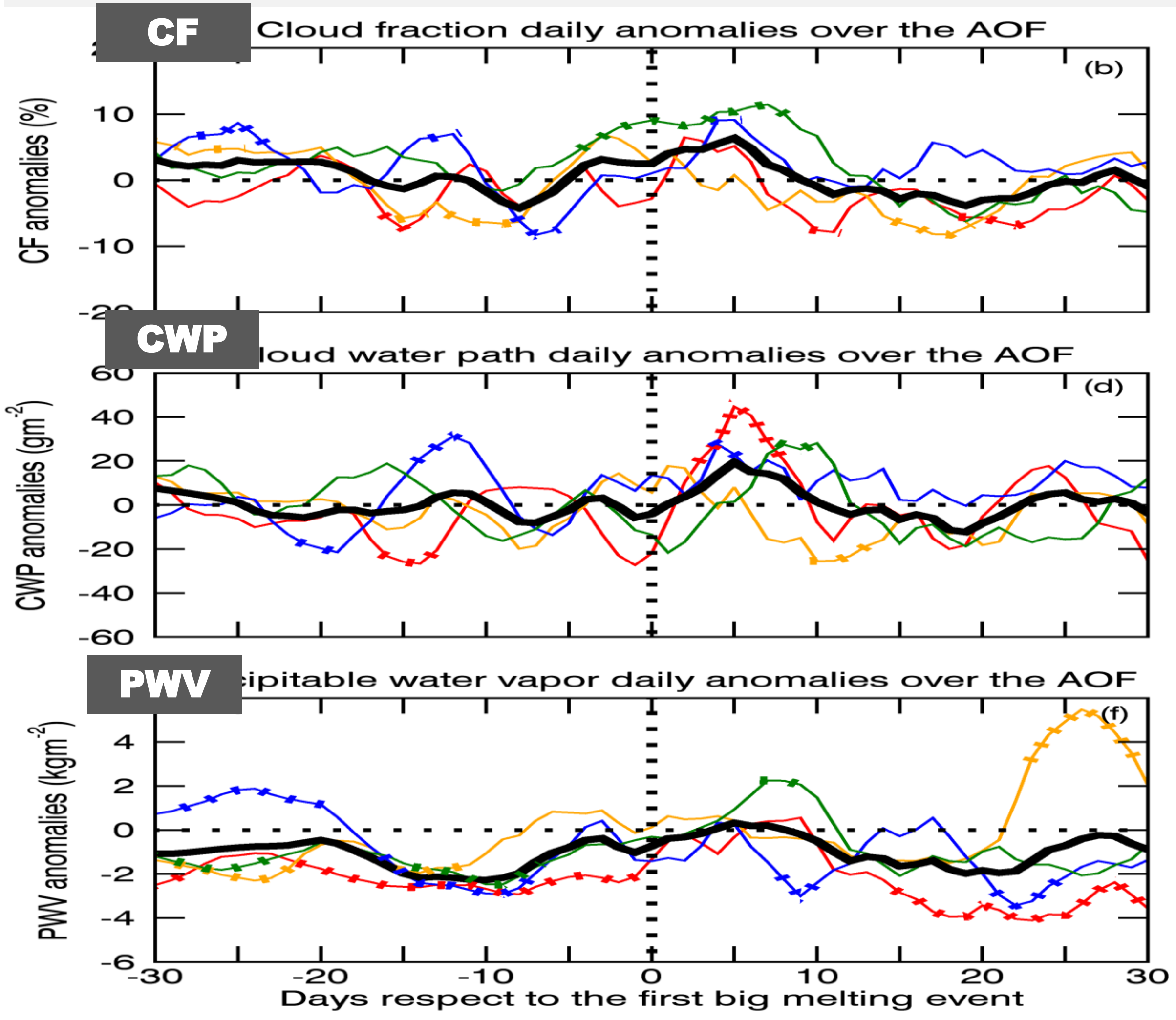




Before melting, CF, CWP, and PWV increased. These increased cloud properties along with cloud-base temp/emissivity and BL temp/humidity lead to increased downward LW flux at the surface. This warming effect plays an important role to trigger the earlier-than-usual initial melt of sea ice

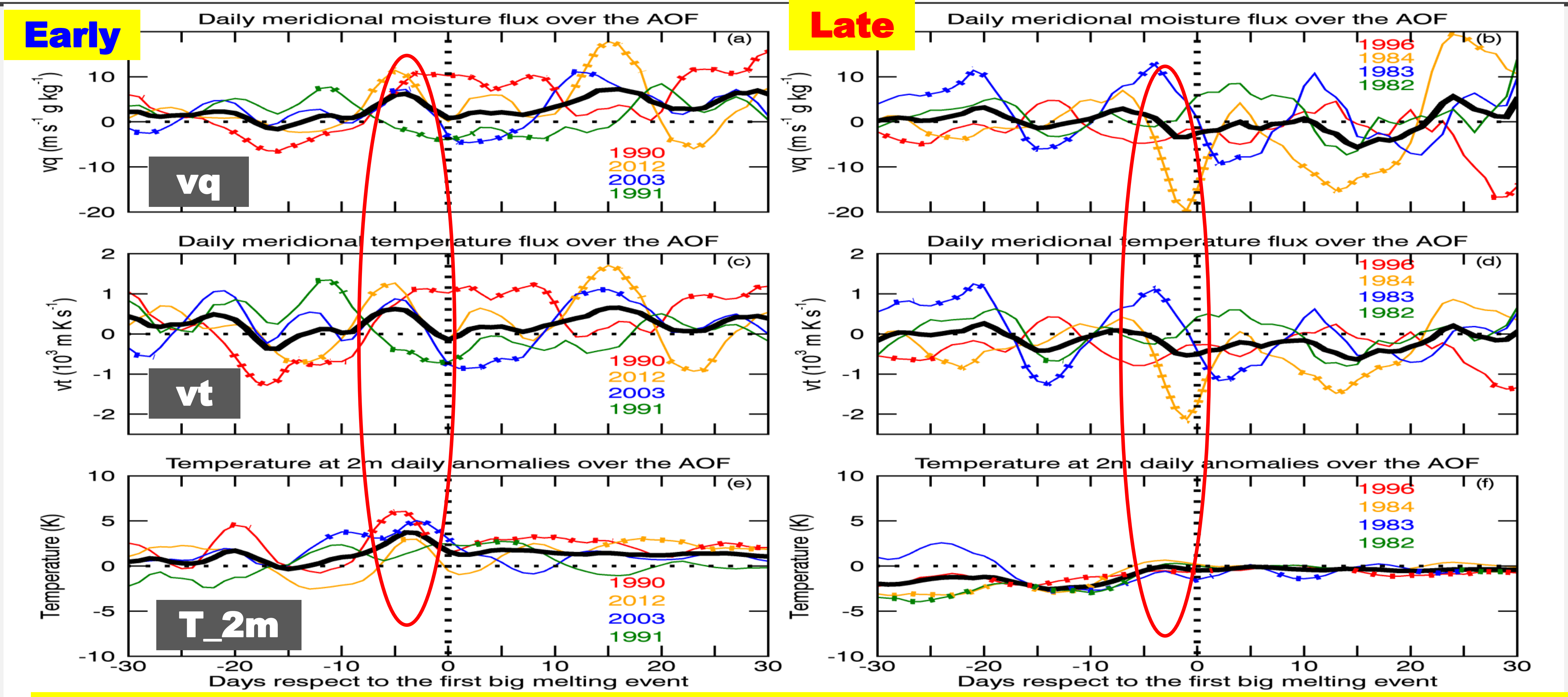
LATE MELTING YEARS: CLOUD AND RADIATIVE PROPERTIES





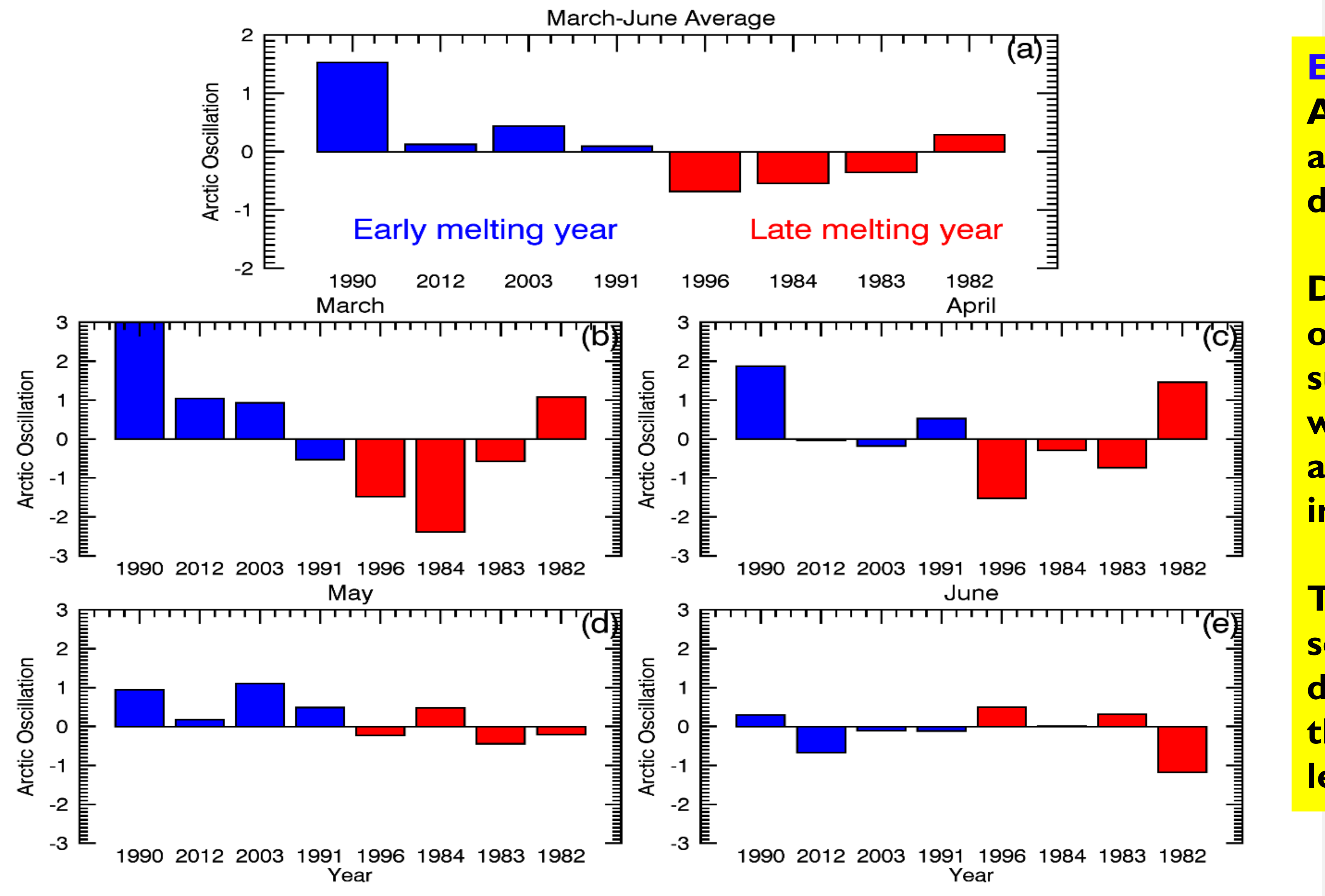
For the late sea ice melt onset, incoming solar radiation is a more important contributor to the sea ice melt

EARLY/LATE MELTING YEARS: MERIDIONAL MOISTURE/TEMPERATURE FLUX



For early melting years, warm and moisture air transported from mid-lat (Northward), resulting in a higher surface temperature. Late years are Southward.

EARLY/LATE MELTING YEARS: ARCTIC OSCILLATION (AO) INDEX

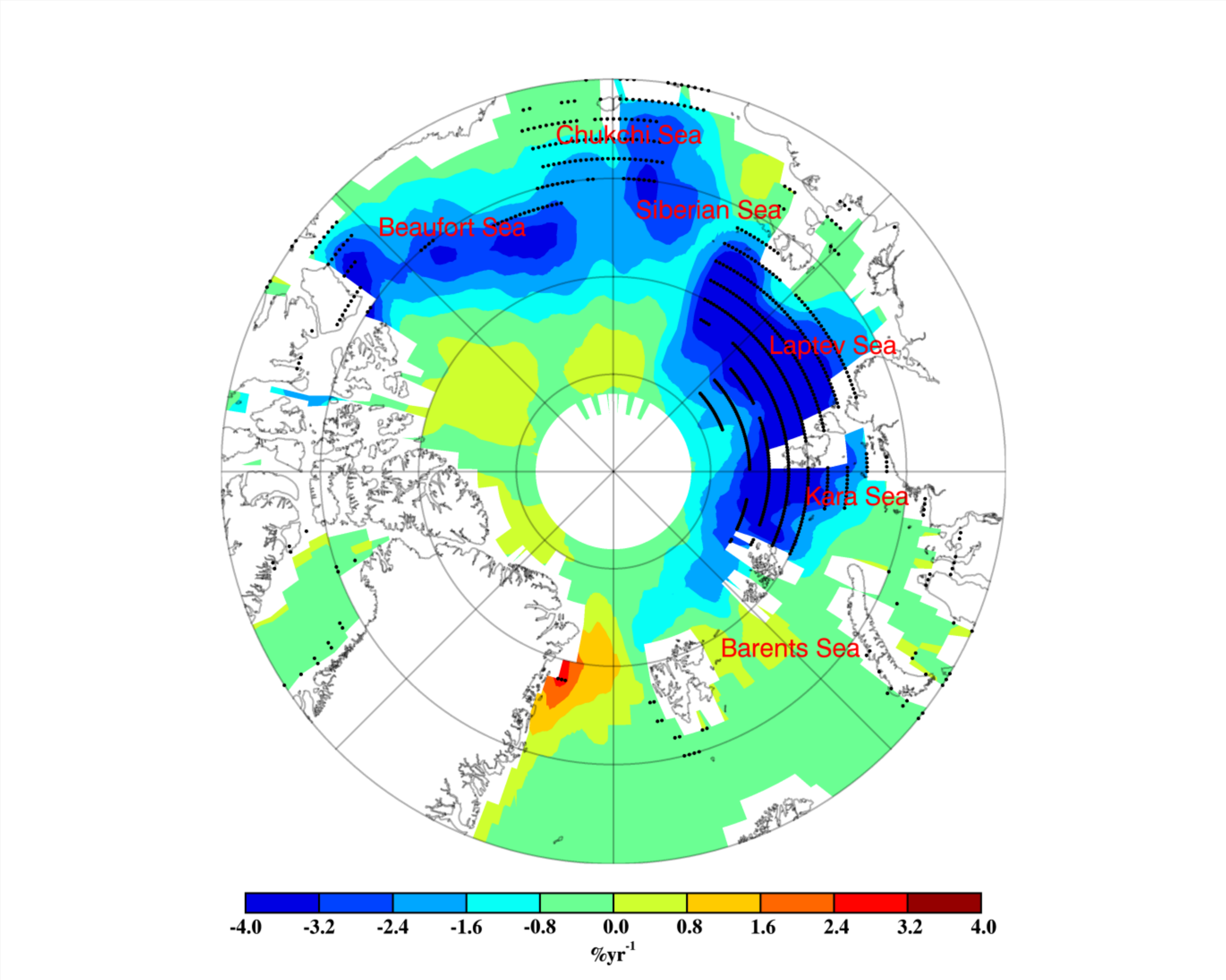


Early melting years exhibit positive AO phases and late melting years are related with negative AO index during March-June except 1982.

During the early melting years, SLP over the central Arctic Ocean is substantially lower, and cyclonic wind fields over the Siberian sector are more prevalent under the high-index AO condition.

This synoptic pattern forces cyclonic sea ice motion anomalies, increases divergence, and further enhances the formation of thin ice and open leads

PART II: LINEAR TRENDS OF SEPT. SEA ICE CONCENTRATION (SIC) OVER THE ARCTIC (70°-90°N) DURING 2000-2015

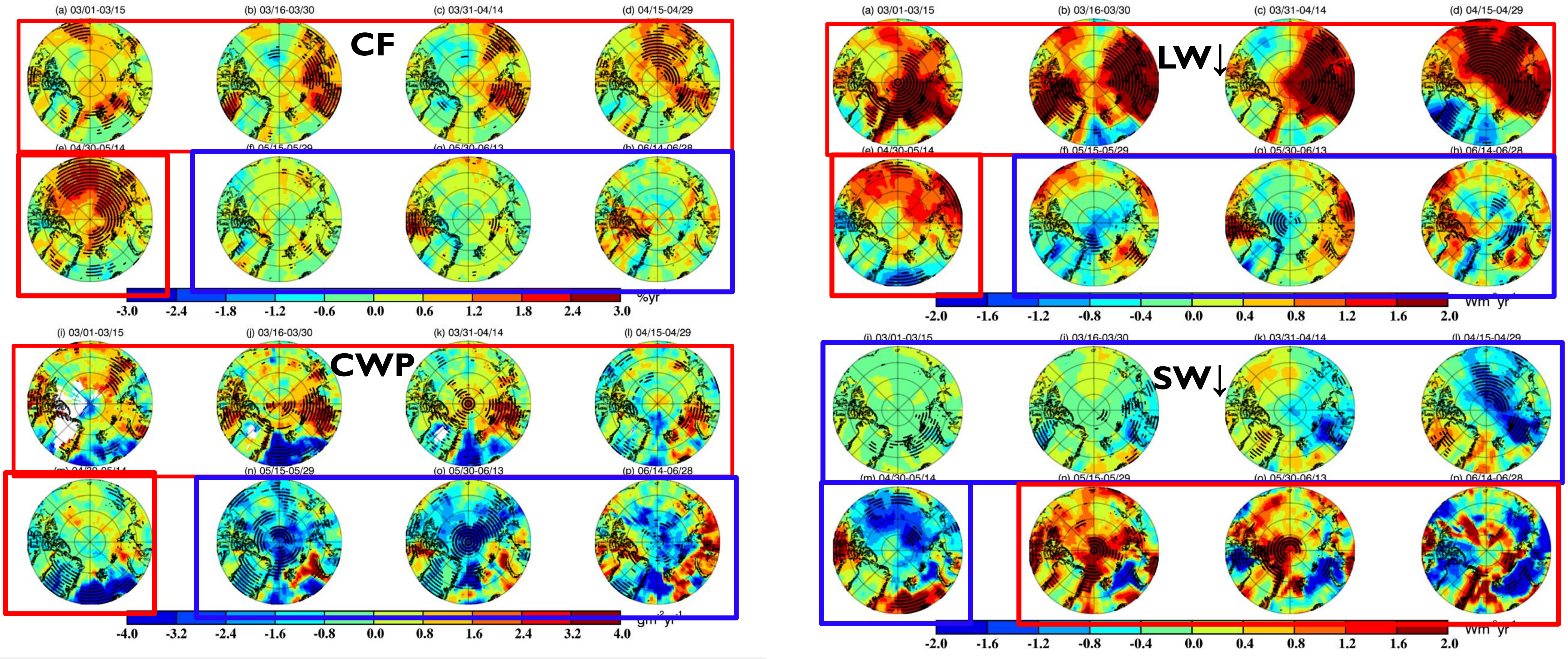


Black dots mark 5% significance level

- **The most prominent September SIC decline over the period of 2000 - 2015 occurs over the East Siberian Sea, Laptev Sea and Kara Sea**

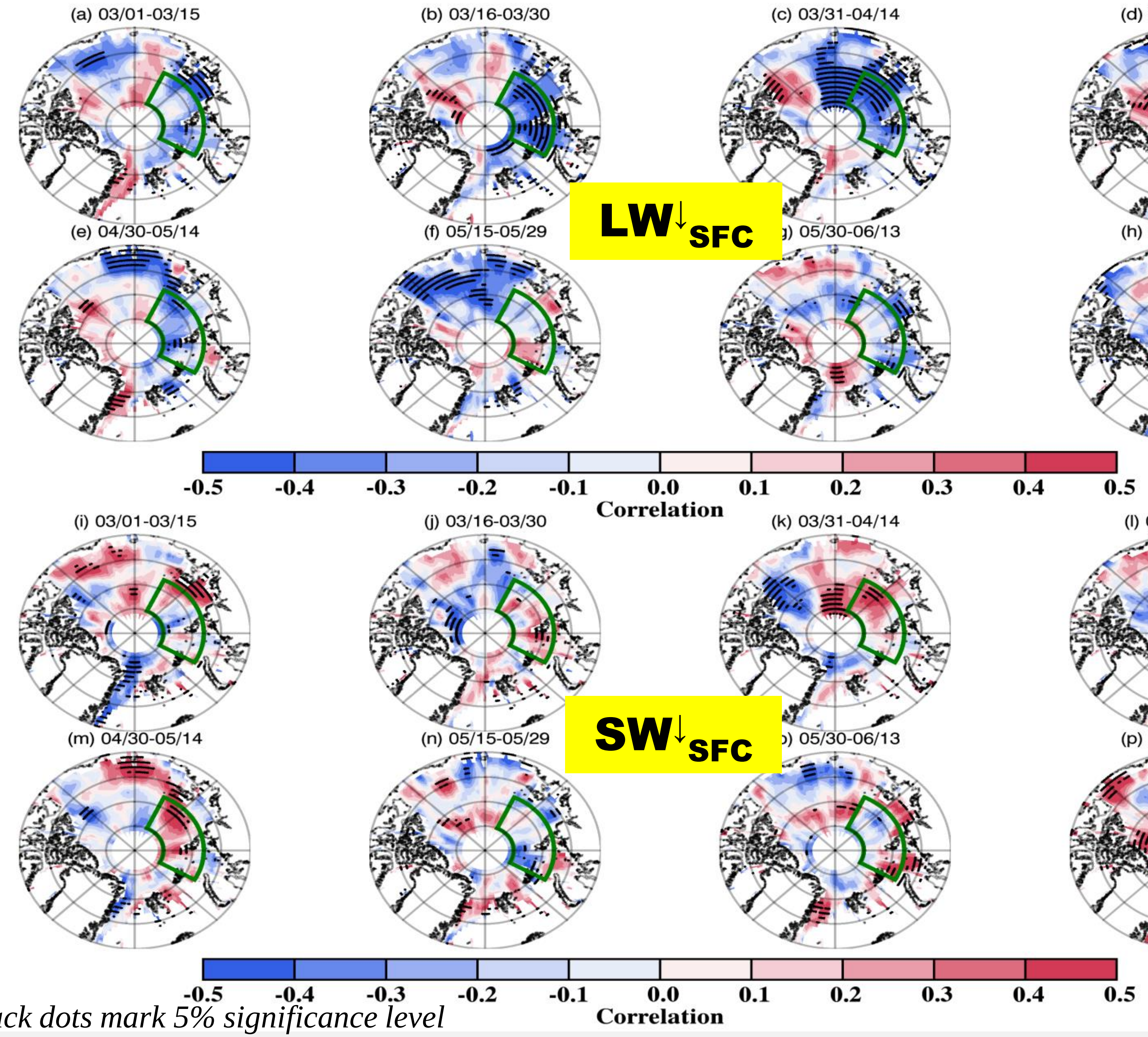
Huang et al. JGR, 2017

16-YR LINEAR TRENDS OF CF, CWP, LW_{DN} AND SW_{DN}



Positive trends of CFs, CWPs and surface downward LW flux over the September sea-ice retreat areas are found over the period of March 1st to May 14th, while negative trends are found over the period of May 15th to June 28th. SWdn trend is opposite to cloud and LWdn trends.

CORRELATION PATTERNS BETWEEN SPRINGTIME RADIATIVE FLUXES AND SEPT. SIC

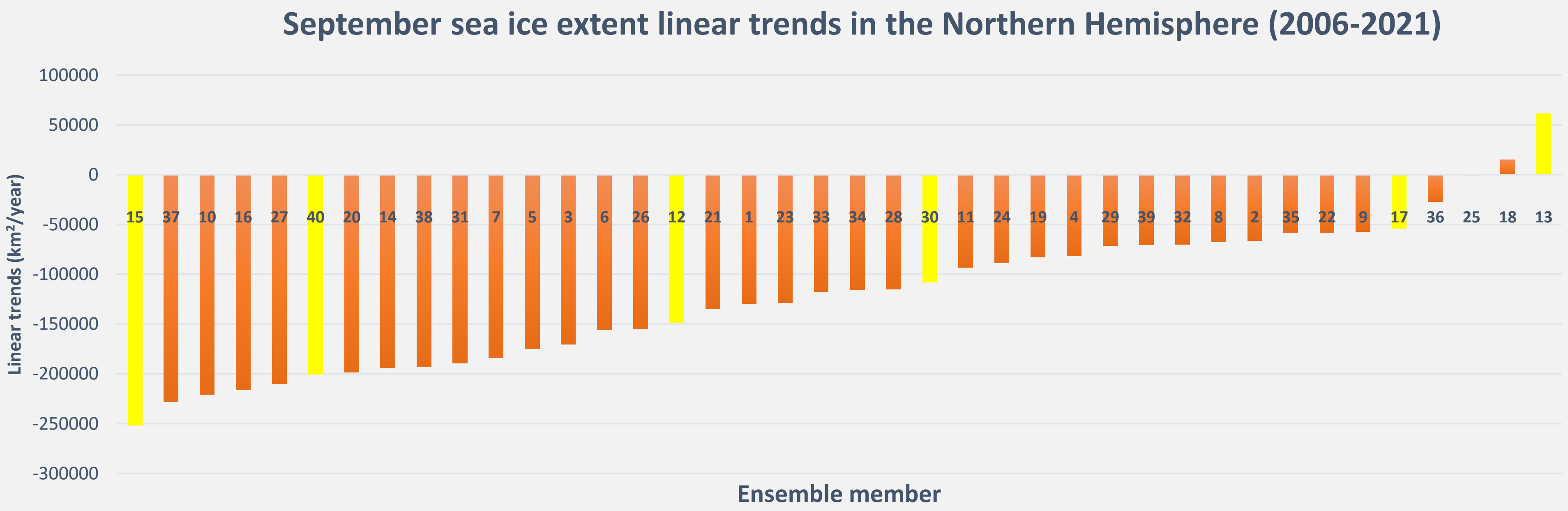


*Black dots mark 5% significance level

- **Increasing cloud fractions and surface downward LW flux in spring tend to enhance sea ice melting due to strong cloud warming effect (cloud-greenhouse > cloud-albedo effect)**
- **Surface downward SW flux plays a more important role in late spring and early summer**

PART III: SEPTEMBER ARCTIC SIE LINEAR TRENDS IN CESM-LARGE ENSEMBLE

- **Due to internal climate variability, all 40 members in CESM-Large Ensemble exhibit different Arctic sea ice linear trends in early 21st century (2006-2021)**
- **Seven ensemble members (member 15, 40, 12, 30, 17, 25, 13) among them are selected to provide a large contrast in September SIE linear trends**
- **Investigate cloud and radiation response to different September SIE trends over the Arctic by running present-day atmosphere-only simulation**



Does the atmosphere primarily drive the sea ice changes or does the sea ice dominate changes in atmosphere in the spring?

Huang et al. GRL, 2019

THE LINEAR TRENDS OF ARCTIC SIC, CLOUD AND RADIATION PROPERTIES FOR MARCH DURING 2006-2021 IN CESM ATMOSPHERE-ONLY EXPERIMENTS

- **With accelerated sea ice decline and surface warming, the presence of more open water in spring generates stronger evaporation, which favors the formation of clouds**

- **The result is a positive feedback where more clouds lead to increased downward LW flux, which further enhances sea ice melt**

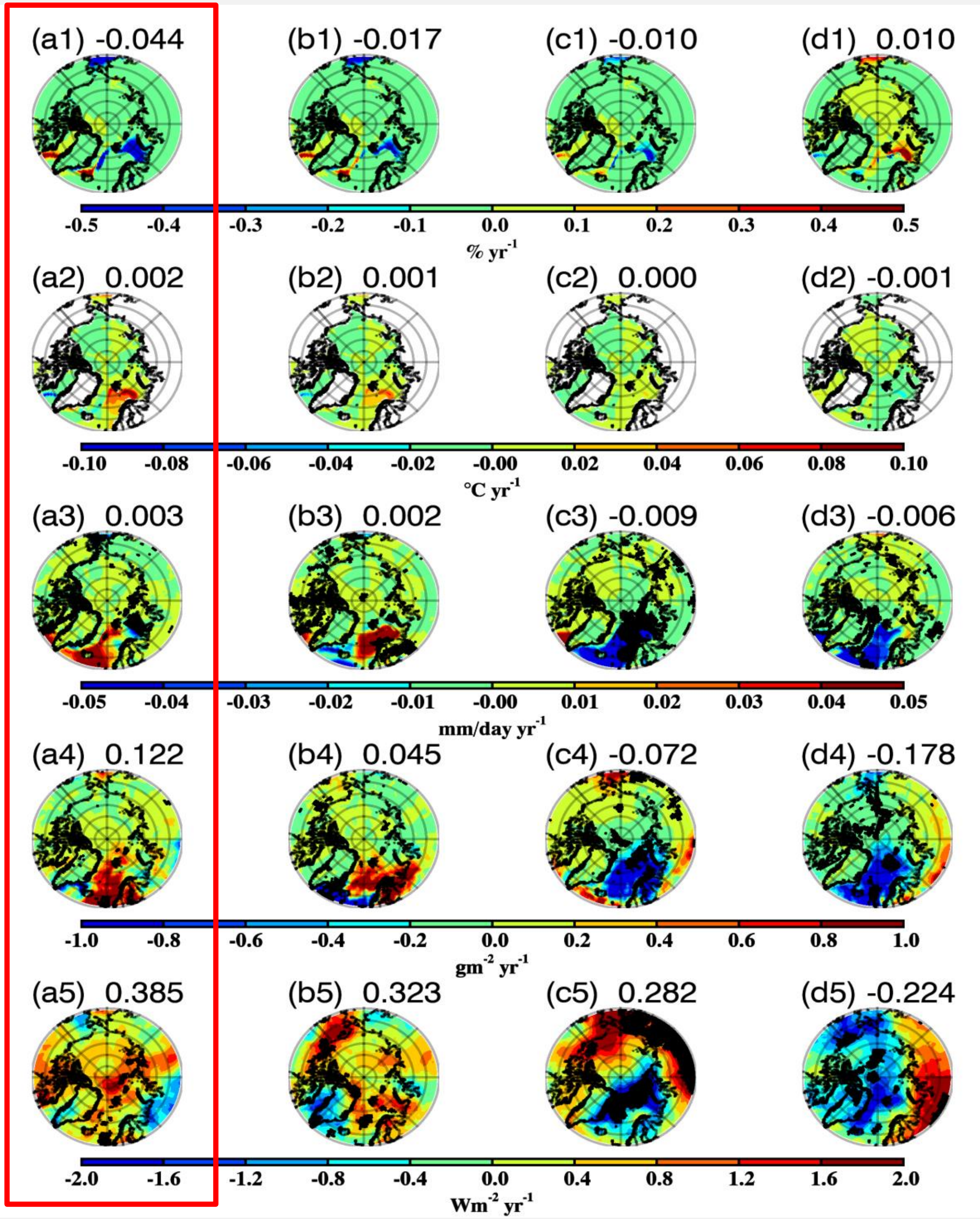
SIC

SST

EVPR

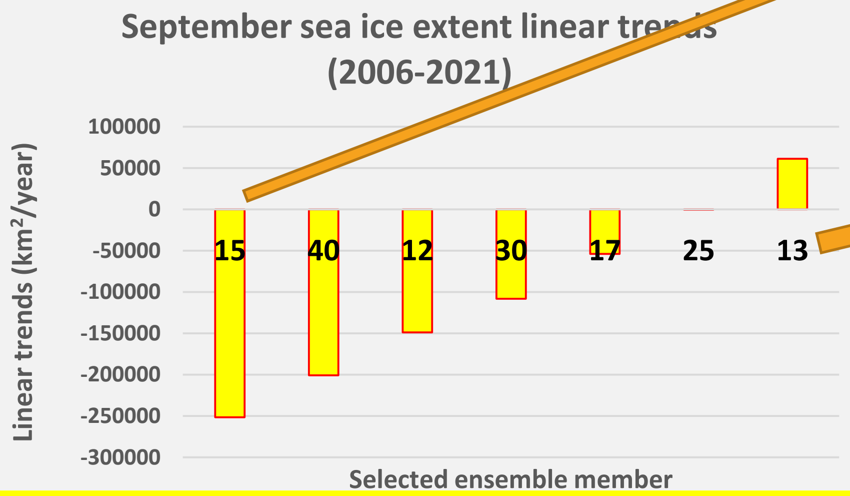
LWP

LW_down

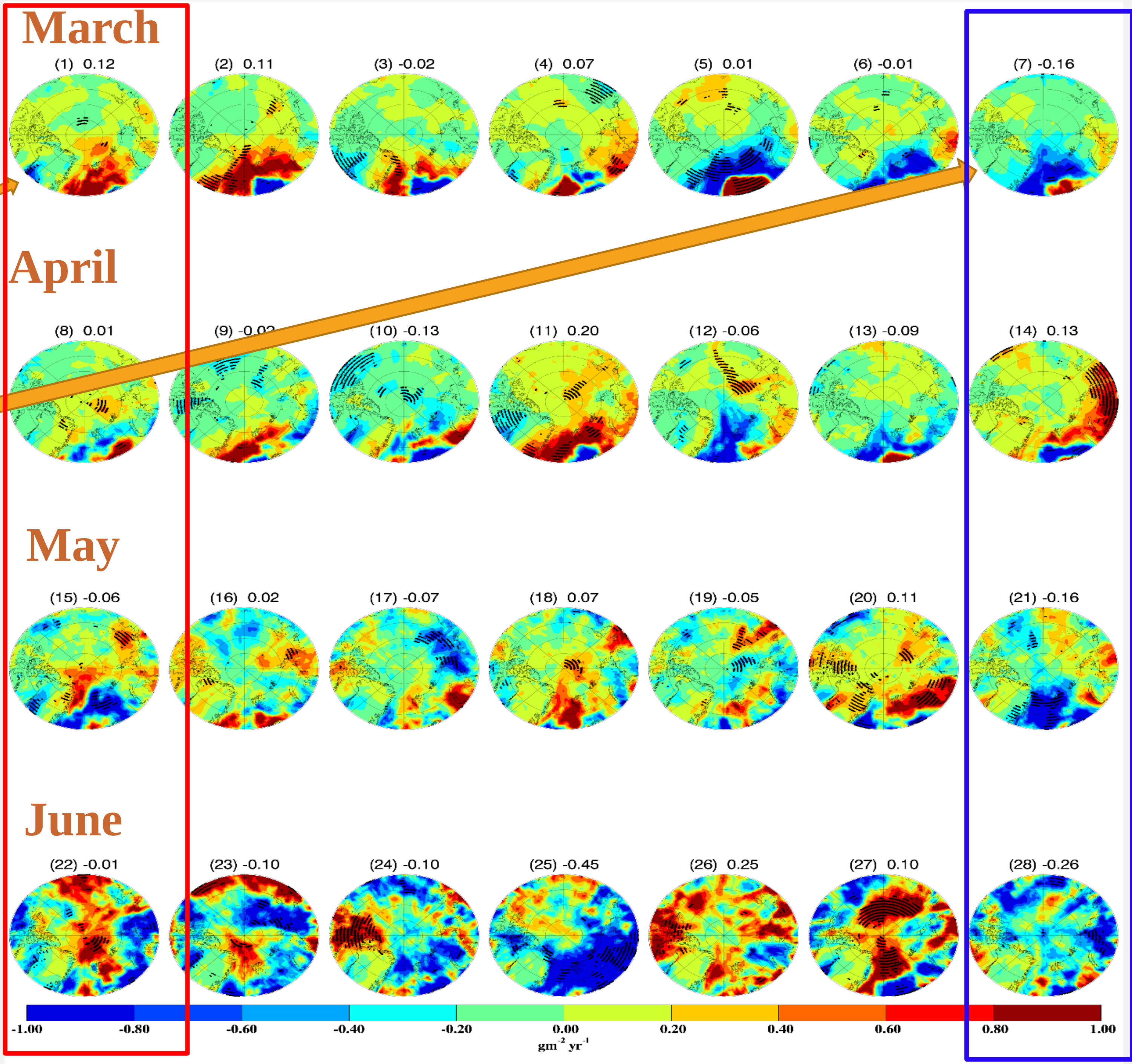


**Black dots mark 5% significance level*

THE LINEAR TRENDS OF SPRINGTIME TOTAL CLOUD WATER PATH (LIQUID + ICE) FROM CESM AMIP EXPERIMENTS DURING THE PERIOD 2006-2021



- **CWP increased more in EM15 (more sea ice decline) than in EM13**
- **The CWP patterns are more random across different members in May and June**
- **The cloud response to sea ice loss largely depends on the strength of atmosphere-ocean coupling which is modulated by air-sea temperature gradients and near-surface static stability in the Arctic**



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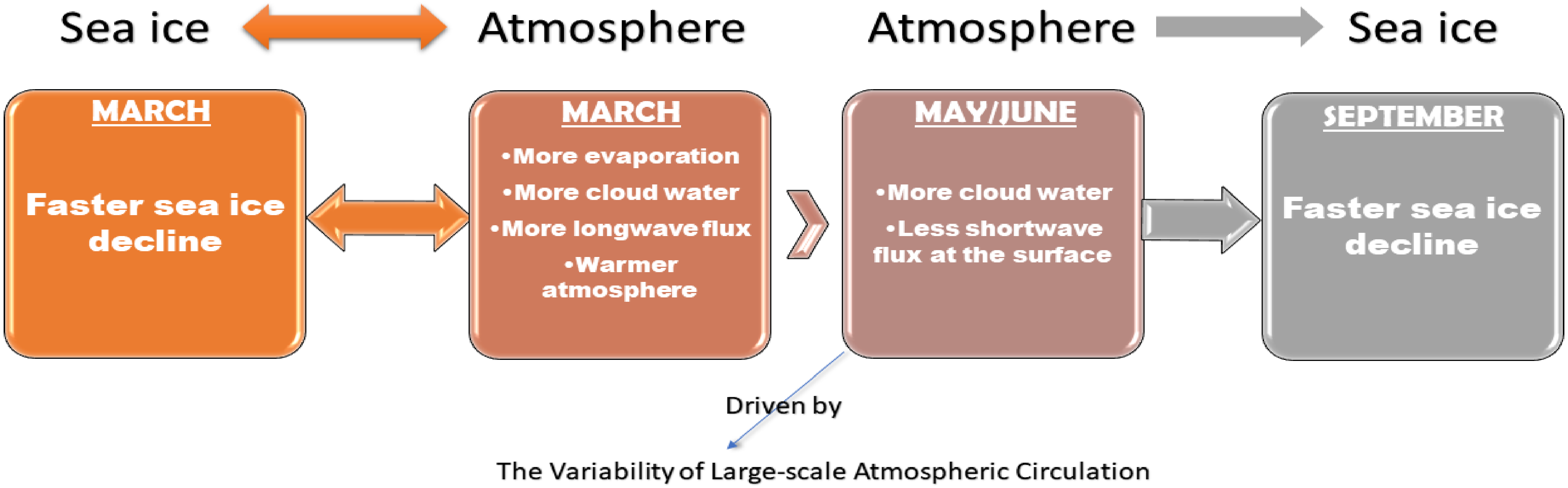
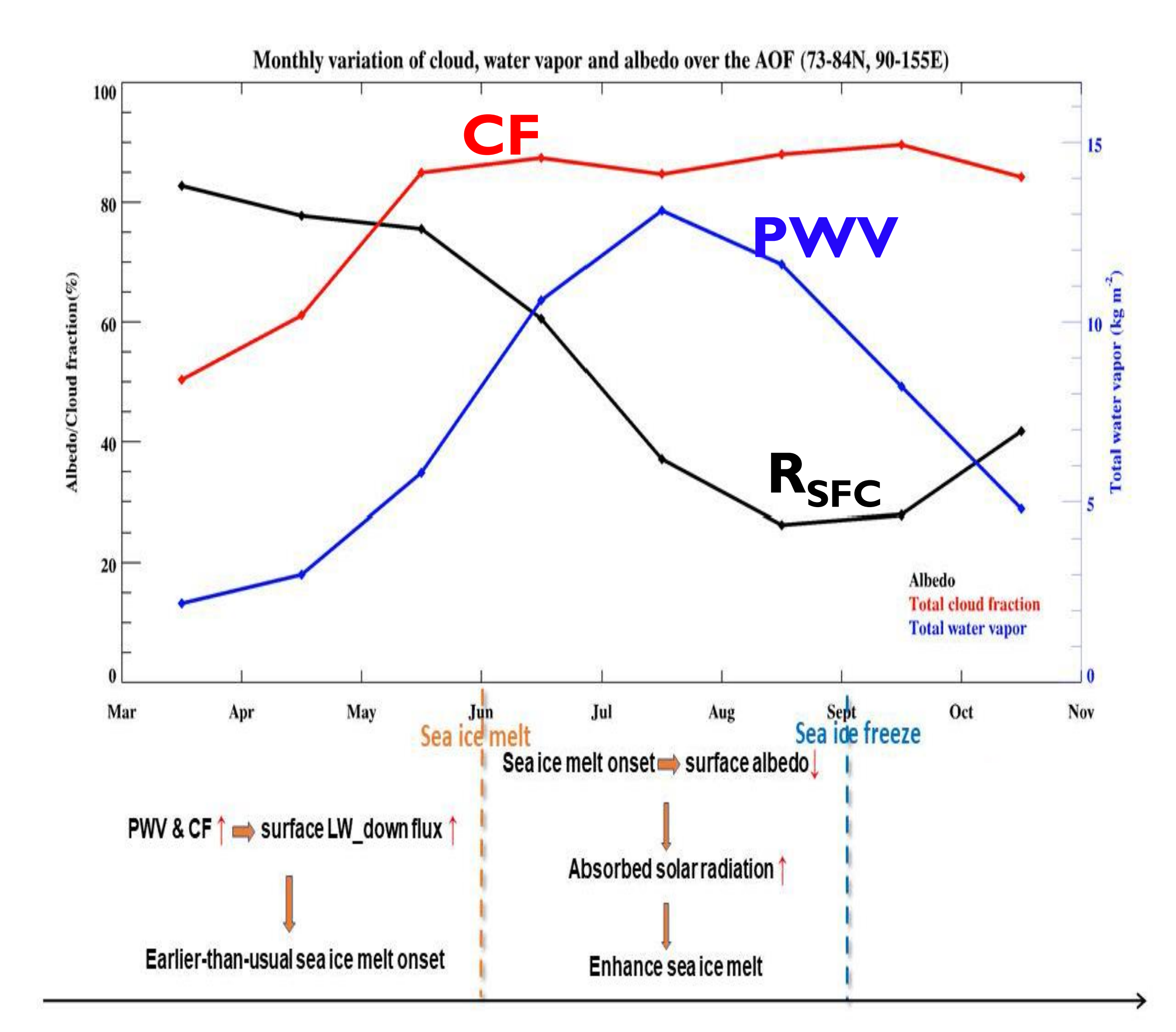
SUMMARY



In March, the atmosphere and sea ice have a two-way interaction (strongly coupled).
With declined sea ice and increased SST➔more water vapor and clouds➔ more LWdn ➔ enhance surface warming and sea ice melting

- **From April to June, the impacts of cloud and radiation on se ice become dominant.**
- **Sea ice has a limited influence on the overlying atmosphere.**
- **The changes in cloud are mainly controlled by large-scale atmospheric circulation variability.**

SUMMARY (CONT')



- The onset of earlier-than-usual sea-ice melting is triggered by a large-scale atmospheric circulation anomaly during early spring
- Strong southerly winds bring warm and moist air from mid-latitudes, which increases PWV and forms more clouds over the Arctic and further initiates sea-ice melting
- Increasing springtime water vapor and clouds tend to increase LWdn
- This will further enhance the melt onset of sea ice and reduce R_{SFC}
- This results in additional absorbed solar radiation which will further accelerate sea-ice melting and SIE retreat.

References

- Huang, Y., X. Dong, D.A. Bailey, M.M. Holland, B. Xi, A.K. DuVivier, J. E. Kay, L. Landrum and Y. Deng (2019): Thicker Clouds and Accelerated Arctic Sea Ice Decline: The Atmosphere-Sea Ice Interactions in Spring. Geophysical Research Letters, 46: 6980– 6989, doi: 10.1029/2019GL082791

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- Huang, Y., X. Dong, B. Xi, E. Dolinar and R. Stanfield (2017): The footprints of 16-year trends of Arctic springtime cloud and radiation properties on September sea-ice retreat. Journal of Geophysical Research-Atmospheres, 122: 2179-2193, doi: 10.1002/2016JD026020.

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DATASETS AND TOOLS

Satellite observations and retrievals

- *Cloud properties*
- CERES-MODIS SYN1 Edition 3A/4.1
- Combined CloudSat/CALIPSO/CERES-MODIS (CCCM) product
- The GCM-Oriented CALIPSO Cloud Product (CALIPSO-GOCCP)
- *Radiative properties*
- CERES EBAF-TOA and -Surface Edition 2.8/4.0
- *Air temperature and humidity*
- Atmospheric Infrared Sounder (AIRS)/Aqua level 3 monthly standard physical retrieval product version 6
- *Sea ice concentration*
- Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1
- *Sea ice melt onset*
- NASA Cryosphere Science Research Arctic Sea Ice Melt Product

Global reanalysis products

- Japan Meteorological Agency (JMA) JRA-55
- National Oceanic and Atmospheric Administration (NOAA)-CIRES 20CRv2c
- National Centers for Environmental Prediction (NCEP)-CFSR
- European Centre for Medium-Range Weather Forecast (ECMWF) ERA-Interim
- NASA MERRA-2

Model simulation

- National Center for Atmospheric Research (NCAR) Community Earth System Model (CESM)
- CESM Large Ensemble (CESM-LE) project