

# Identifying Dynamical Forcing and Cloud-Radiative Feedbacks Critical to the Formation of Extreme Arctic Sea-Ice Extent in the Summers of **2007** and **1996**

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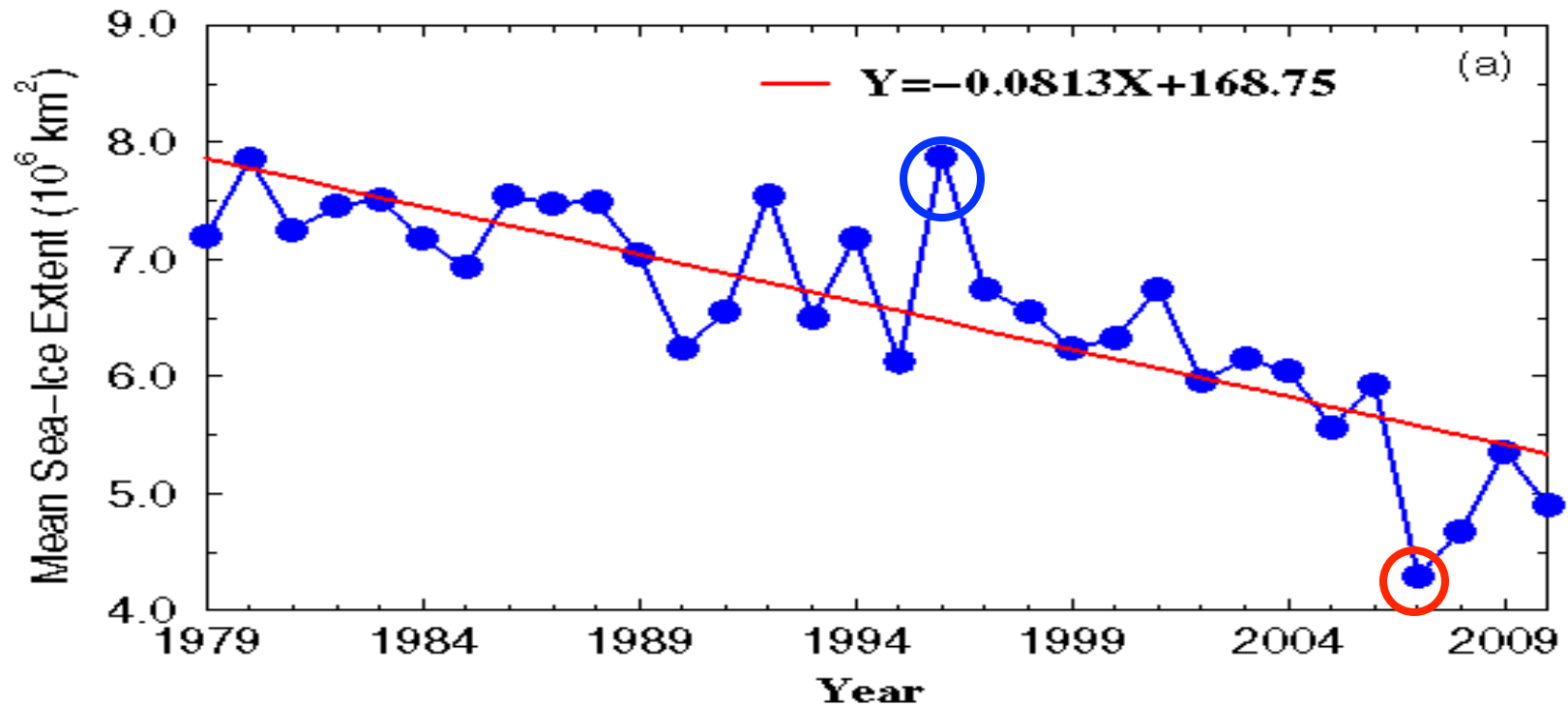
## **Outline:**

- 1) Extremes were triggered by anomalous synoptic patterns**
- 2) Cloud-Radiation-PWV positive feedback on **2007 low SIE****



# Motivation

## September Arctic Sea–Ice Extent (1979–2010)

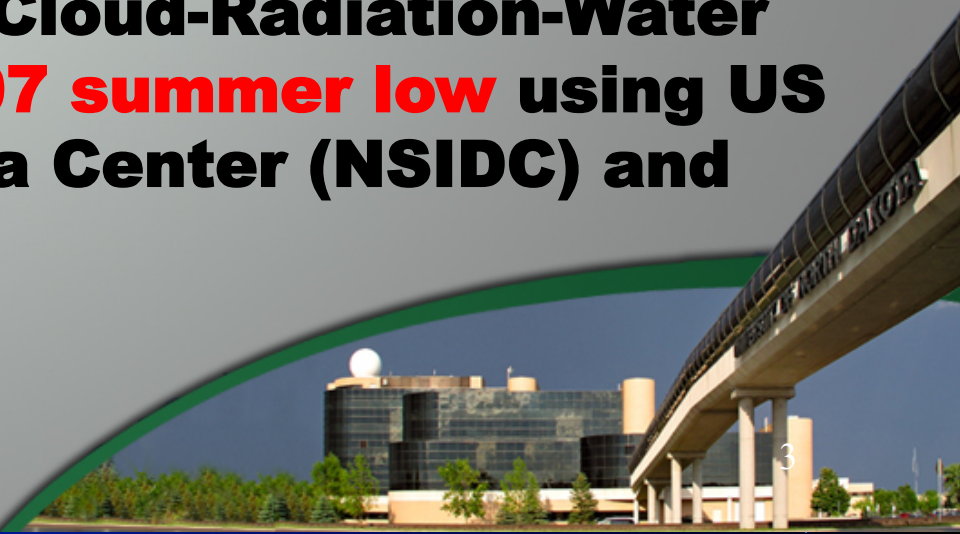


**The summer of 2007 caught the attention of the Arctic research community because September sea-ice extent plummeted to a record minimum, it was 35% below the 1979-2010 average.**

**Although most efforts have been devoted to understanding the 2007 low, a contrasting high September SIE in 1996 might share some related but opposing forcing mechanisms.**

## Objectives

- 1. Explore the detailed insights about the underlying mechanisms driving these two contrasting extreme events (**2007** and **1996**), and compare their similarities and differences with respect to the major contributing factors and different atmospheric conditions.**
- 2. Investigate the positive Cloud-Radiation-Water vapor Feedback on the **2007 summer low** using US National Snow and Ice Data Center (NSIDC) and NASA MERRA**



# September Sea-Ice Extent Comparison

**2007**

Sea Ice Extent  
Sep 2007

**Major  
difference is  
over Laptev,  
East Siberian,  
and Chukchi  
Seas**



**1996**



National S

National Snow and Ice Data Center, Boulder, CO

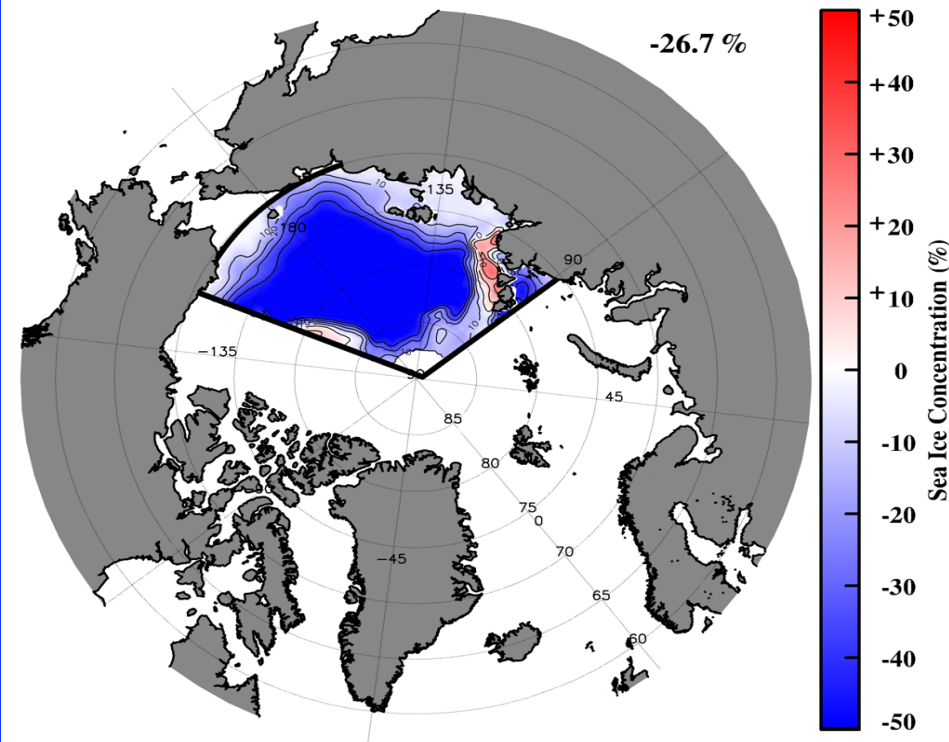
**Therefore, we focus on the area of Laptev, East Siberian and Chukchi seas (70-90 °N, 90-210 °E) and define it as the Area Of Focus (AOF) in this study.**

# September Sea-Ice Concentration Comparison

**2007**

Sep 2007 Sea Ice Concentration Anomaly

-26.7 %

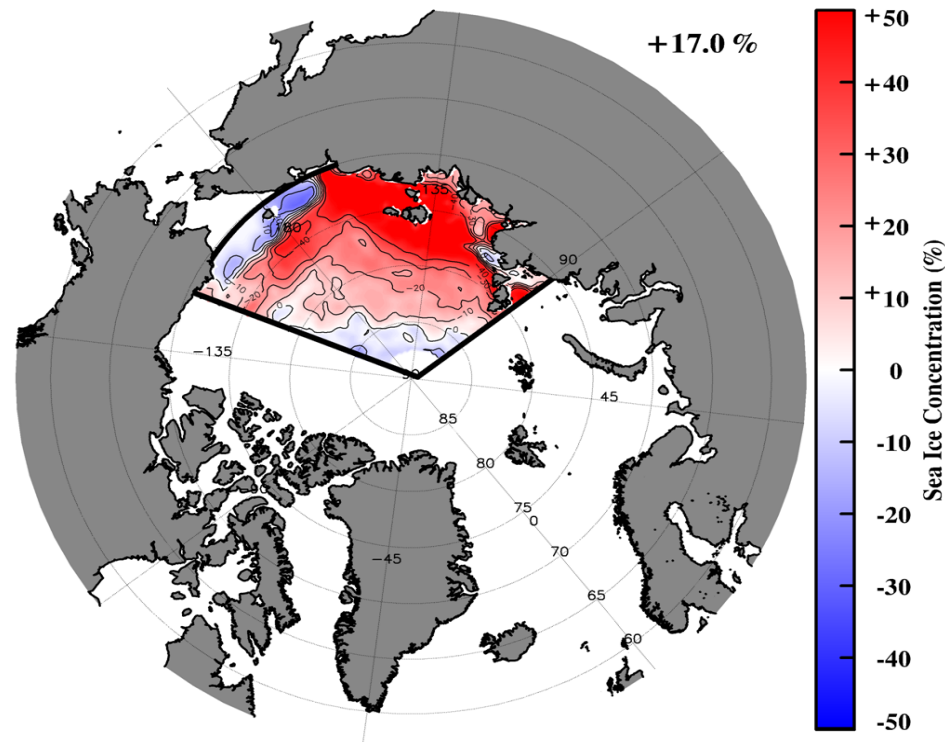


**-26.7% below climate mean**

**1996**

Sep 1996 Sea Ice Concentration Anomaly

+17.0 %



**+17.0% above climate mean**

**The area of Laptev, East Siberian and Chukchi seas (70-90 °N, 90-210 °E) is defined as the Area Of Focus (AOF) in this study.**



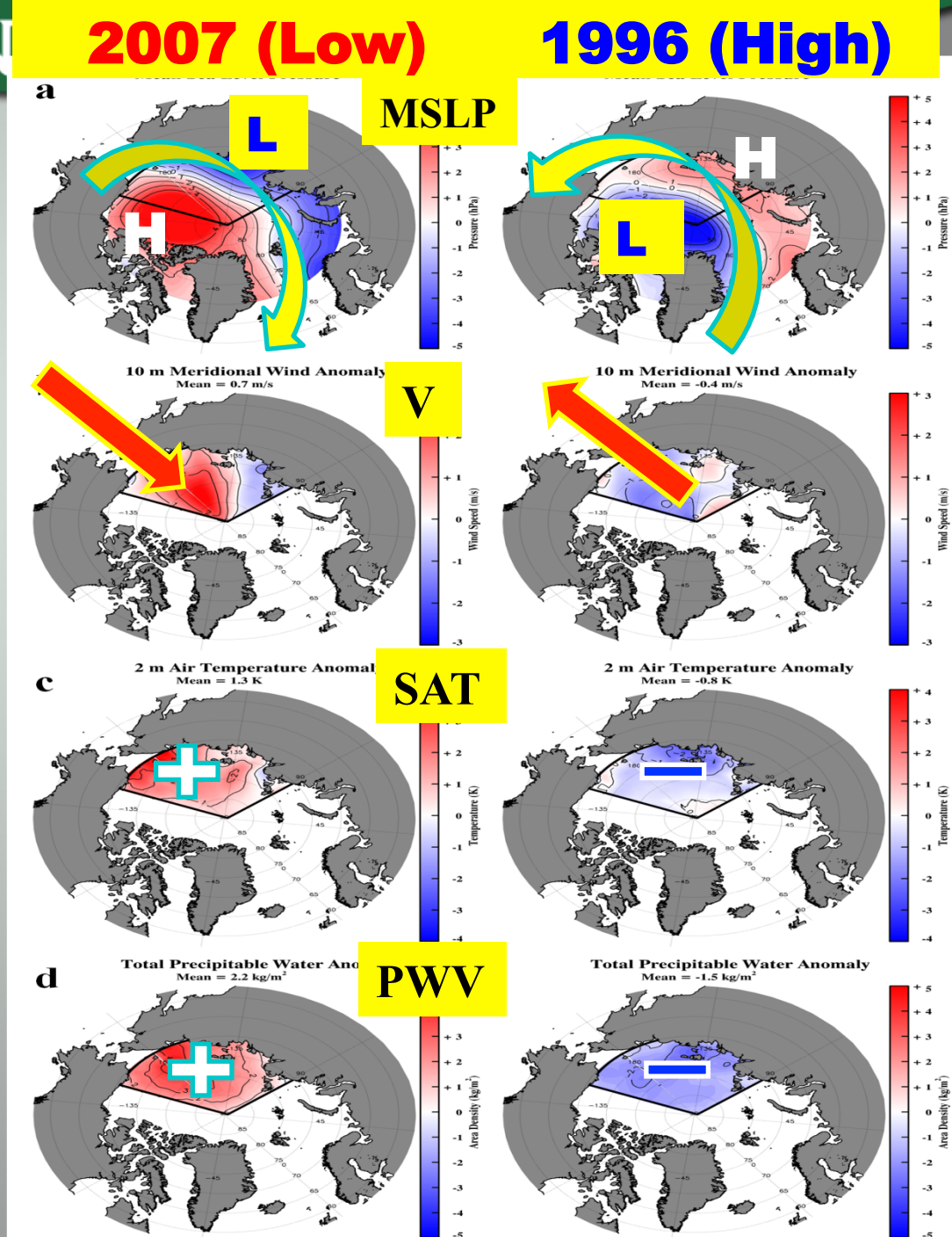
# Atmospheric anomalies over AOF

## During Summer 2007

→ A persistent anticyclone was positioned over the Beaufort Sea, coupled with an area of low pressure over the Eurasia region.

→ Under this synoptic pattern, strong positive anomalies in meridional winds (southerly) are evident over the AOF, which transports warm (positive anomaly of SAT) and moist air (positive anomaly of PWV) from the North Pacific.

On the contrary, the variables during the summer 1996 are opposite to those in 2007.



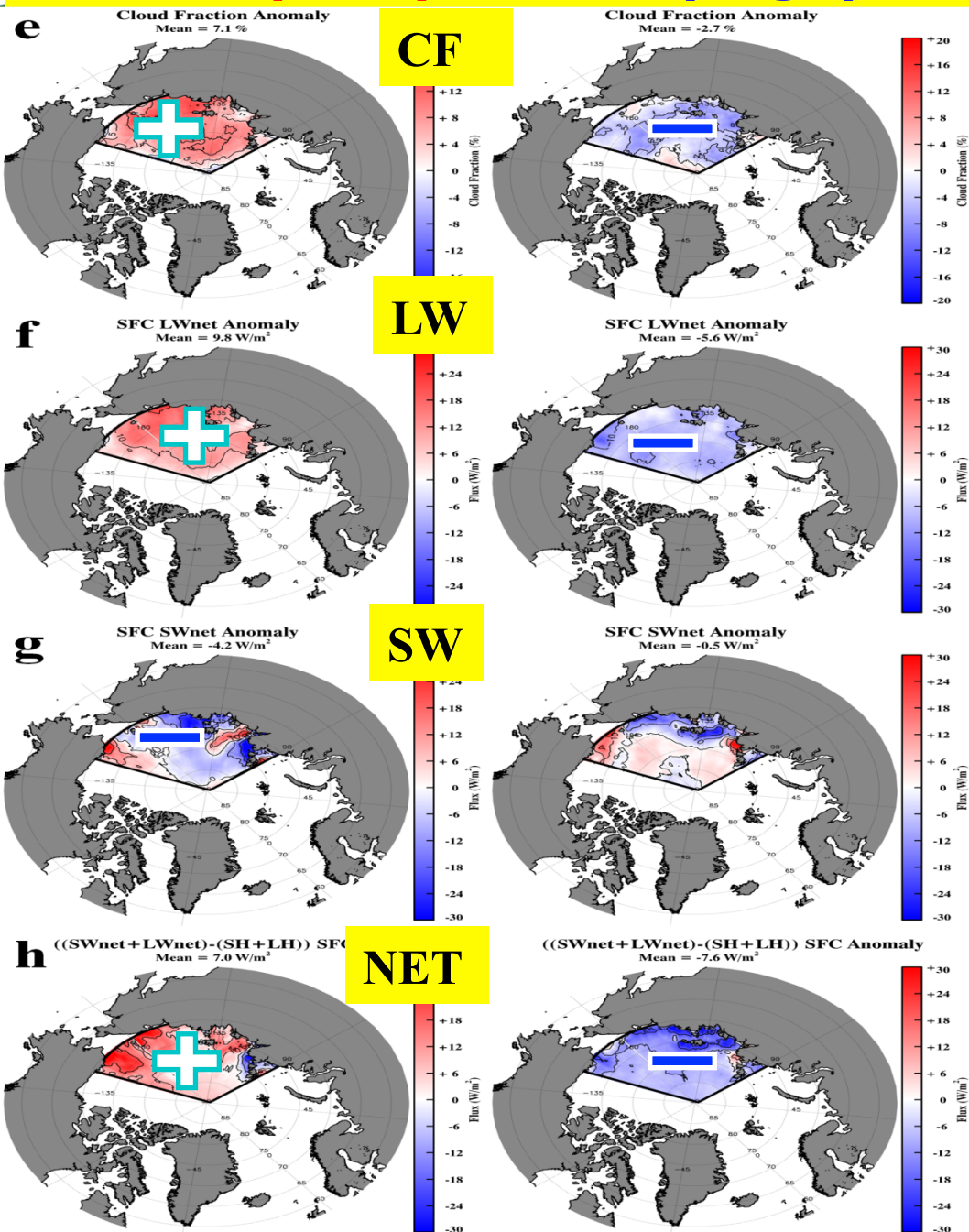
**2007 (Low)****1996 (High)**

### During Summer 2007

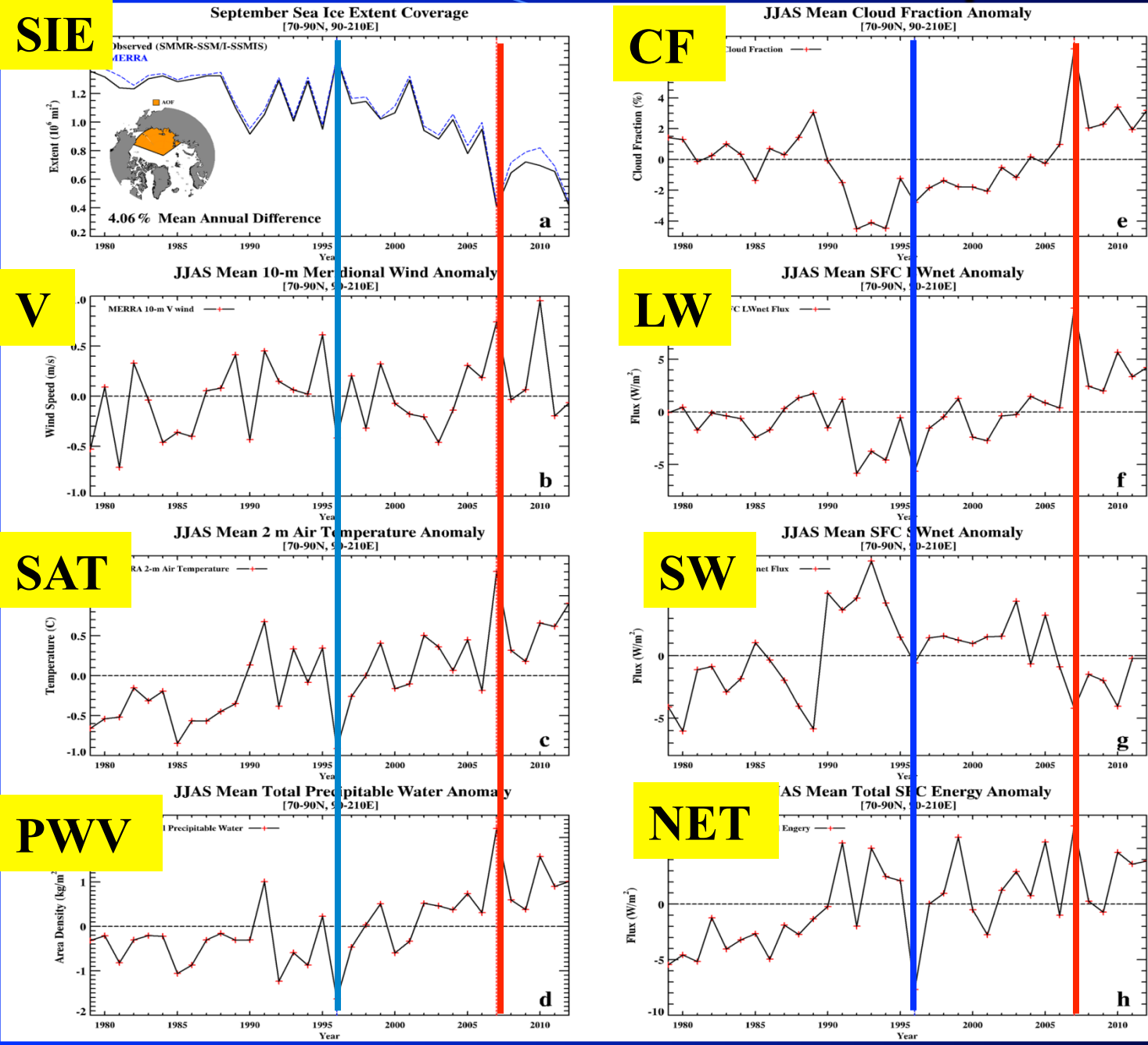
- CF over the AOF is 7.1% higher than climate mean
- NET LW flux is  $+10 \text{ Wm}^{-2}$
- NET SW flux is  $-4.2 \text{ Wm}^{-2}$
- Total NET surface energy budget =  $(\text{NET LW} + \text{NET SW}) - (\text{SH} + \text{LH}) = +7 \text{ Wm}^{-2}$ .

Indicating that  $7 \text{ Wm}^{-2}$  more heat than its climate mean value was absorbed by Arctic oceans over the AOF during the summer 2007. This extra  $7 \text{ Wm}^{-2}$  has partially contributed to the 1.3 K increase in SAT and the low September sea-ice extent in 2007.

In contrast, the Summer 1996 is reversed



# Inter-annual Variations of atmospheric anomalies



**During summer 2007, all variables have max positive anomalies Except for SW.**

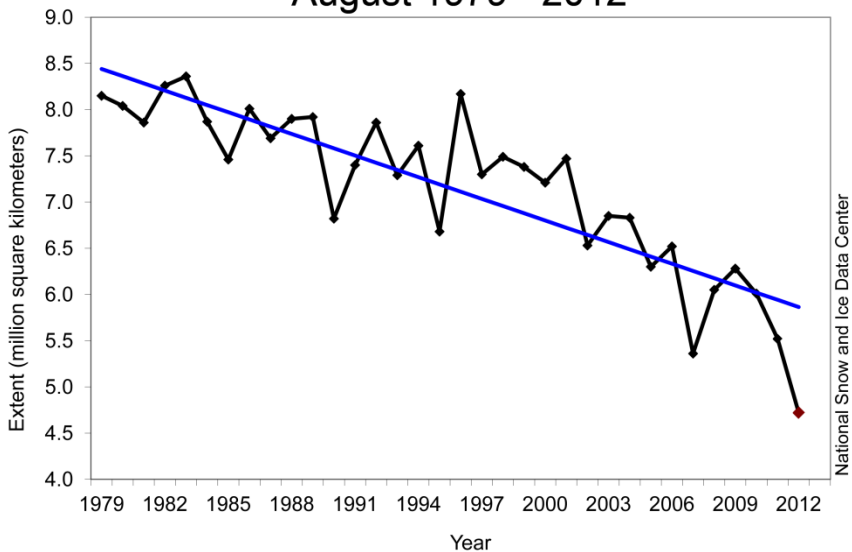
**During summer 1996, most are Max negative anomalies.**

**These results indicate the selected two opposing extreme years 2007 and 1996 are robust.**

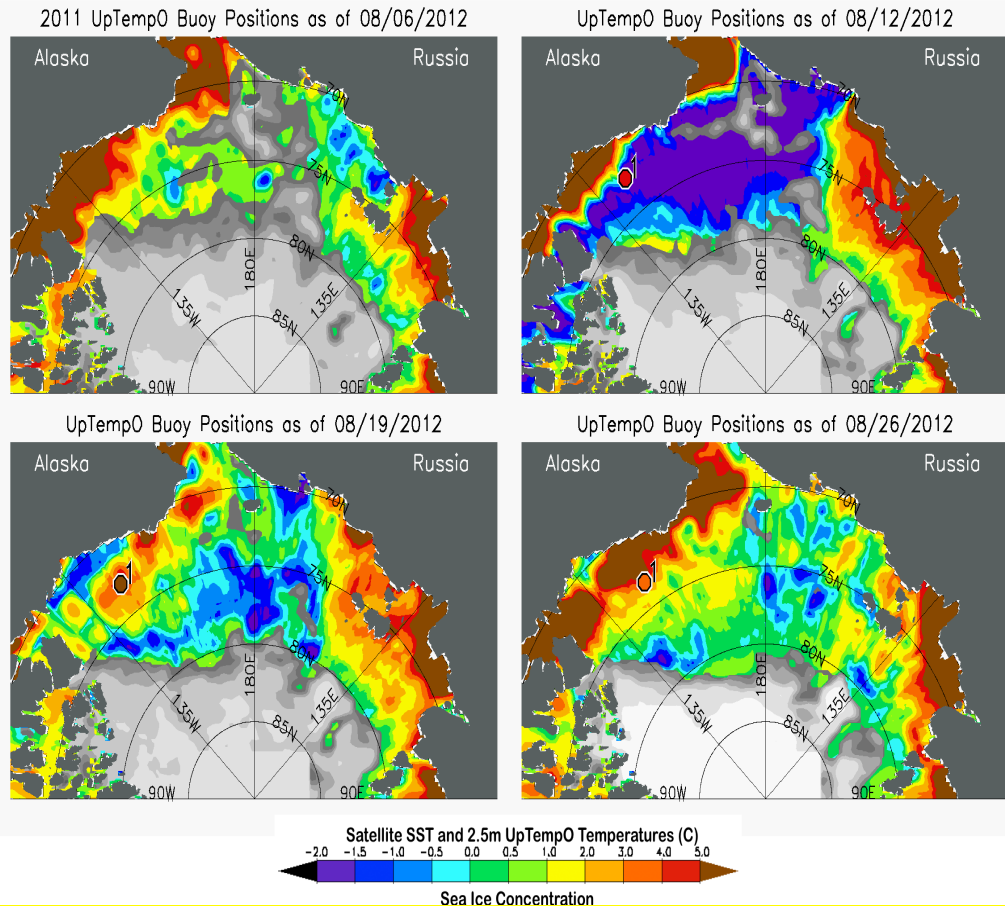


# 2012 new record low in SIE

Average Monthly Arctic Sea Ice Extent  
August 1979 - 2012



Sea Surface Temperatures  
August 2012



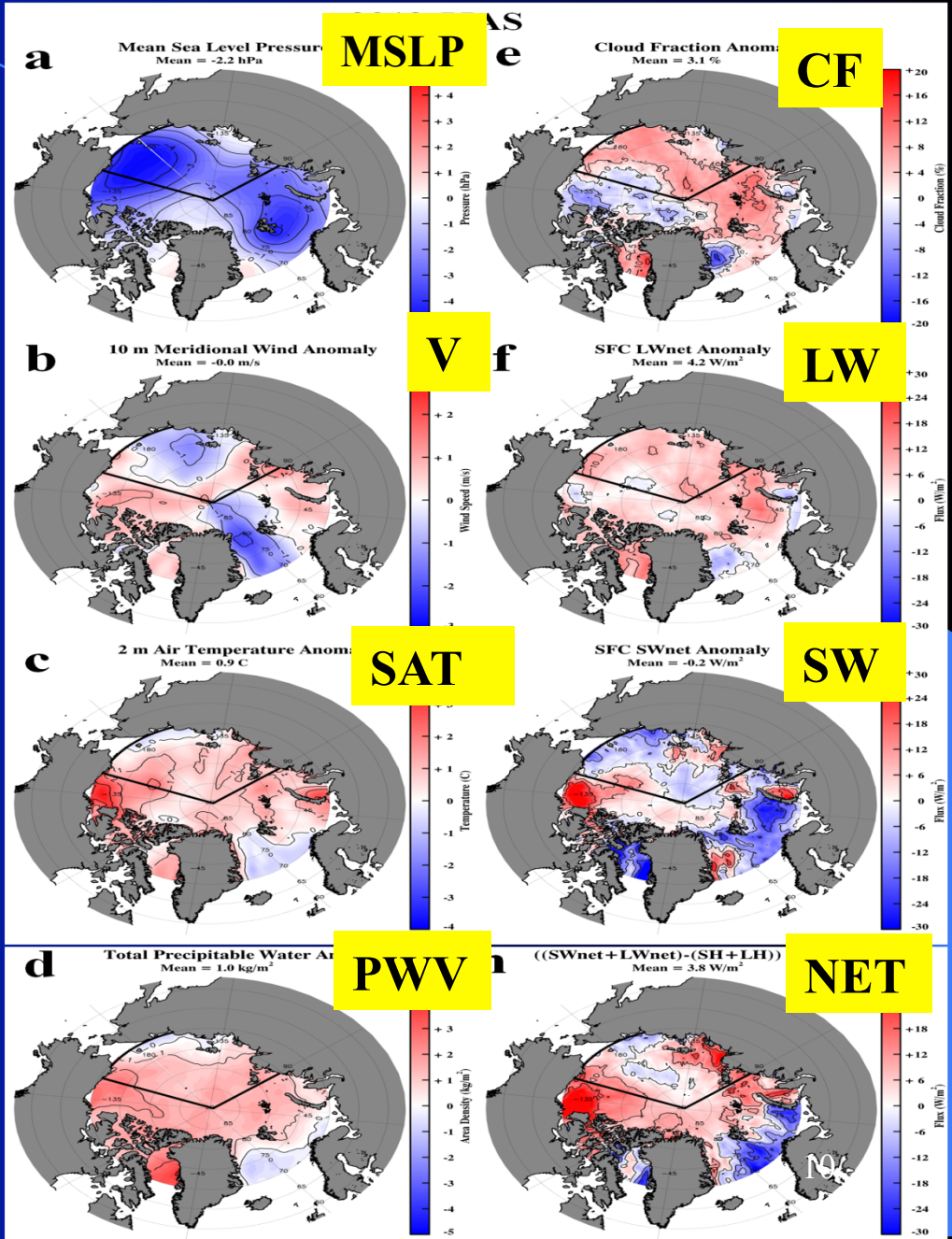
**It was mainly triggered by a super storm over the central Arctic Ocean in early August that caused substantial mechanical ice deformation on top of the long-term thinning of an Arctic ice pack**

# 2012 Summer

→ The synoptic and wind patterns in 2012 were significantly different from those in 2007.

→ Low pressure systems covered the entire Arctic with two centers, resulting in weak anomalous northerly winds over most of the AOF and the Fram Strait.

→ Although the patterns and signs of the anomalies of the atmospheric parameters in 2012 are the same as those in 2007, their magnitudes are much smaller.



# Summary I: two extreme years

**1) The low Sea Ice Extent (SIE) in 2007 was associated with a persistent anticyclone over the Beaufort Sea coupled with low pressure over Eurasia, which induced anomalous southerly winds. Ample warm and moist air from the North Pacific was transported to the AOF and resulted in positive anomalies of cloud fraction (CF), precipitable water vapor (PWV), surface LWnet (down-up), total surface energy and temperature.**

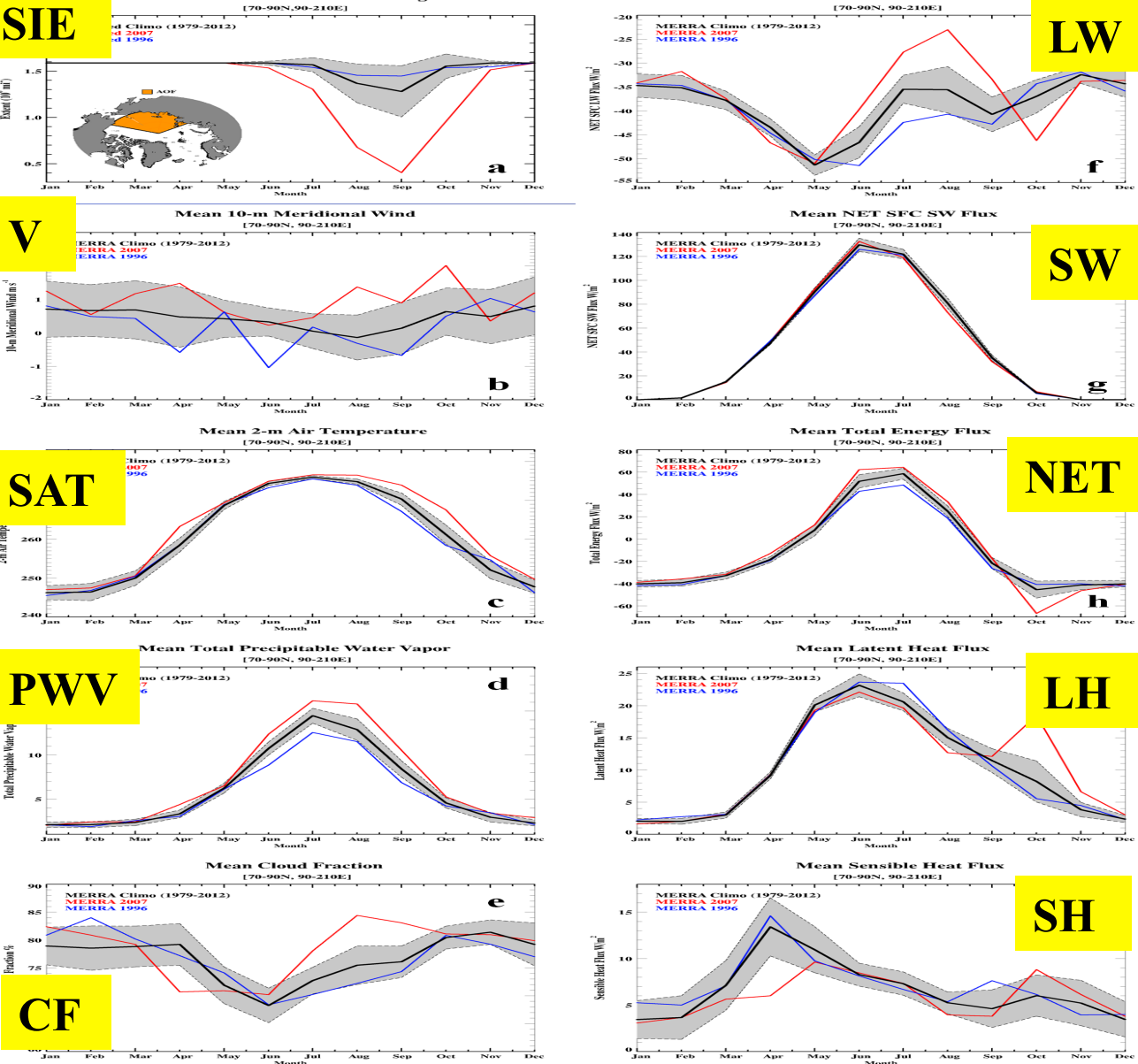
**2) In contrast, the high SIE event in 1996 was associated with a persistent low pressure over the central Arctic coupled with high pressure along the Eastern Arctic coasts, which generated anomalous northerly winds and resulted in negative anomalies of above mentioned atmospheric parameters.**

# Part II: Cloud-Radiation-PWV feedback on 2007 low SIE

- We hypothesize that the onset of the **2007 low** sea-ice extent was triggered by the large-scale atmospheric circulation anomaly during spring, and later on enhanced by a positive cloud-radiation-PWV feedback process over the AOF during the summer and early autumn of **2007**.
- Now we want to prove this hypothesis using seasonal variation and daily anomalies from **June 15 to Sept. 15 of 2007**.



# Seasonal Variations of SIE and atmospheric variables over the AOF



During Spring months of 2007, **→ strong southerly winds occurred, which brought more warm and moist air to the AOF.**

**→ However, the CF, LW and SW were below their climat.**

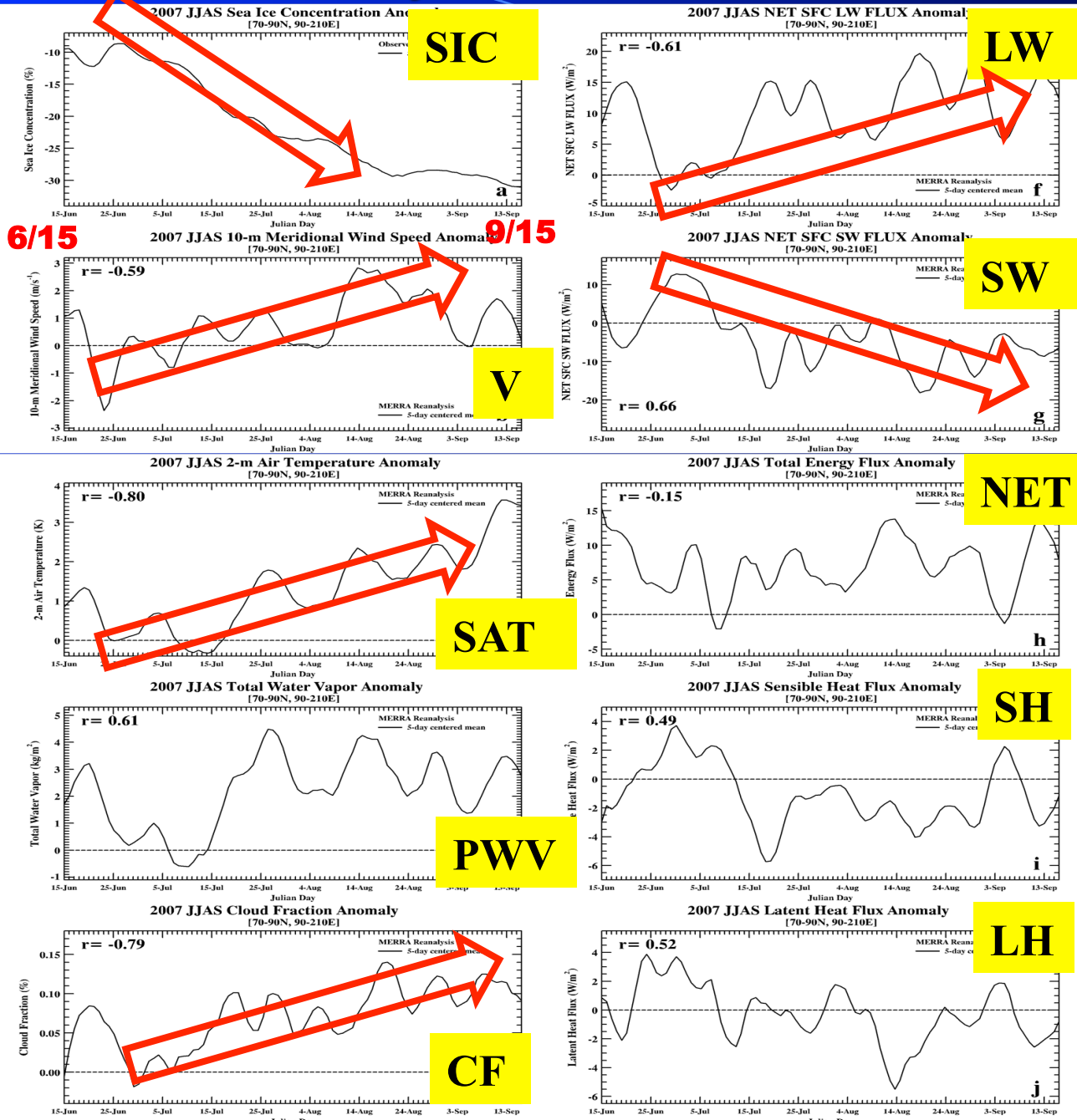
Values because most of Arctic Ocean surfaces were still covered by sea ice during spring, thus there are minimal interactions between ocean and atmosphere

**→ SH flux in April was 8 Wm<sup>-2</sup> lower than the climatology (less upward flux, resulting in 3–5 Wm<sup>-2</sup> more total surface energy (down in) than the climatology.**

**→ This 3–5 Wm<sup>-2</sup> extra energy during spring months, as well as 10 Wm<sup>-2</sup> extra energy in June, used to trigger the onset of 2007 low.**

Monthly means (solid black line) and standard deviations (shaded area) for 1979-2012, 2007 (red) and 1996 (blue) (averaged over the AOF).

# Correlations of daily anomalies between SIC and atmospheric parameters



→ The high correlations (0.58-0.79) of anomalies between SIC and V, SAT, PWV, CF, LWnet and SWnet further proved that meridional winds, water vapor, clouds, and radiation are indeed having significant impacts on the SIC variations.

→ The increased SAT along with a positive cloud-radiation-PWV feedback amplified the signal initiated by the atmospheric circulation anomaly, accelerated the sea-ice retreat during the summer of 2007.

# **Summary II (feedbacks)**

**The proposed hypothesis regarding the triggering and enhancing mechanisms of the Arctic sea-ice retreat during the summer of 2007 has been proved as**

- The onset of the 2007 low sea-ice extent was triggered by the large-scale atmospheric circulation anomaly during the spring months of 2007.**
- Strong southerly winds brought warm and moist air from the North Pacific, which not only initiated sea-ice melting, but also increased PWV and formed more clouds over the AOF, particularly over open seas.**
- When CF was high and Arctic surfaces were covered by snow and ice, particularly during the onset of sea-ice melting (May-June), the cloud-greenhouse (LW) effect overwhelmed the cloud-albedo (SW) effect, producing a positive cloud radiative effect on the surface radiation budget.**
- Downwelling LW flux increased significantly with increased PWV, generating another positive feedback to increase surface temperature and enhance sea-ice retreat.**
- Later on, more sea-ice was melted, additional SW (and LW) radiation was absorbed by open seas to increase surface temperature, and more water vapor evaporated to form more clouds, which further enhanced the positive cloud-radiation-PWV feedback.**