Sea ice outlook in 2010: Atmospheric forcing and sea ice extent

July Report

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1) Extent projection

Estimate for sea ice extent for September, 2010; less than the value for the 2007 minimum in sea ice extent , with a value on the order of $\sim 4.0 \cdot 10^6 km^2$.

2) Methods/Techniques

A heuristic assessment of the surface, stratosphere and ice conditions in 2010 relative to 2007 atmospheric and ice conditions in June provides the basis for a projection of sea ice extent less than the record minimum in ice extent encountered in September, 2007. Comparison of SAT and SLP anomalies, in addition to temperature anomalies at 850 mb for 2007 and 2010 relative to the 1979 – 2010 climatological mean highlight differences in near-surface atmospheric conditions leading up to the minimum in summertime ice extent. Upper atmospheric contributions to sea ice extent are examined in the context of relative vorticity to highlight variations in wintertime preconditioning events when the cold core polar vortex governs surface phenomena (Hare, 1968; Overland, 2009). Examined in particular are the stratospheric (10 mb) relative vorticity fields in 2007 and 2010 for March and April during the breakup of the wintertime polar vortex. Monthly means of ECMWF ERA-Interim relative vorticity used in this study were obtained from the ECMWF data server.

Stratospheric winds for March and April are also examined and compared with composites for years characterized by minima in sea ice extent, as presented in the 2009 June and July SIO submissions, and additional information may be found therein (Lukovich and Barber, 2009). Stratospheric winds were once again obtained from the NCEP reanalysis dataset provided by the NOAA/ESRL Physical Sciences Division. Revised composites (relative to the 2009 SIO outlook submission) based on record minima in sea ice extent in September include the years 2002 - 2009, in accordance with time series for monthly records of sea ice extent (http://earthobservatory.nasa.gov/Features/WorldOfChange/sea_ice.php).

Zonal and meridional surface wind anomalies, composites for vector surface winds and SLP for years associated with record lows in ice extent for June also provide an indication of anticipated dynamical properties at the surface during years characterized by record minima in ice extent. Differences in patterns for surface winds and in record minimum composites for SLP minimum in June provide a reference for regional differences in advection and convergence/divergence properties that will accelerate or inhibit summertime sea ice decline. A comparison of ice extents for June, 2007 and June, 2010 is also presented to illustrate regional differences in ice conditions leading up to the September minimum in ice extent.

Figures

1. SAT, SLP and 850 mb temperature anomalies relative to the 1979 – 2010 climatological mean.
2. Stratospheric relative vorticity in March and April for 2007 and 2010
3. Vector stratospheric winds in March for 2007, 2010, and years characterized by minima in sea ice extent.
4. Zonal surface wind anomalies and composites in June
5. Meridional surface wind anomalies and composites in June
6. Vector surface wind composites for minima in sea ice extent. Minima in sea ice extent and dipole anomaly pattern.
7. SLP composites and differences for 2007 and 2010
8. Sea ice extent in June, 2007 and June, 2010.

3) Results and Rationale

SLP and SAT anomalies for 2007 and 2010

Positive surface air temperature anomalies in 2010 are spatially comparable to those found in 2007, with the exception being the presence of positive temperature anomalies over much of the Canadian Archipelago and Hudson Bay in 2010. Considerable breakup of fast ice in Parry Channel and McClure Strait has been observed in June 2010 (more so than 2007), and sea ice cover is rapidly being removed within Hudson Bay. It is therefore expected that the Northwest Passage will be navigable by icebreakers (using satellite and helicopter reconnaissance) as early as late July, and by any vessel by mid-August.

A dipole structure in mean sea level pressure is present for both June 2007 and 2010, with low (high) pressure anomalies over central Siberia (the North pole). A stronger pressure gradient is indicated in 2010 versus 2007, which suggests stronger surface winds, and temperature advection which may enhance both sea ice motion and sea ice decay. The prevalence of high pressure over much of the Arctic pack ice during June 2010 maintained lower amounts of cloud cover, having a net positive effect on the radiation balance of the sea ice surface.

The state of the El Nino Southern Oscillation and the Arctic Oscillation play an important role on winter atmospheric circulation in the Northern hemisphere. Winter 2009/2010 was characterized by a moderate El Nino, resulting in a deepened westward-shifted Aleutian Low, and a split jet stream. Although the El Nino event has now subsided in the tropics, meridional circulation patterns have persisted in the Northern hemisphere into

June. This has resulted in deepened ridges and troughs persisting over North America and Eurasia into June, and has resulted in numerous warm air intrusions into the High Arctic. The Arctic oscillation was strongly negative, and is attributed to cold air outbreaks in Europe, and a deepened Icelandic Low. Meridional temperature advection is observed at the 850mb level. 850mb air temperature anomalies are somewhat less in magnitude than in 2007, but describe the advection of warm air aloft into the ridge of high pressure that is centred over the North Pole, which helps maintain the surface high pressure zone.

The frequency and intensity of summer cyclones will place a key role in the reduction of sea ice cover this summer, particularly if large areas of open water characteristic in the past 3 years are present. Summer storms can form over Eurasia and track into the Arctic Basin, increasing winds and subsequent divergence in the sea ice cover. Storms that are maintained by deep upper-level lows can persist for weeks, and even cause the Beaufort Gyre to reverse direction (McLaren et al., 1986; LeDrew et al., 1991). These summer reversals have become more frequent in recent years, with an increase in mobility of the ice pack that accompanies decreased summer sea ice coverage (Lukovich and Barber, 2006; Asplin et al., 2009). Reversals of the BG lead to ice divergence, lower sea ice concentrations, and lead to increased export of multi-year ice through Fram Strait.

Stratospheric relative vorticity fields

Stratospheric (10mb) relative vorticity fields in March of 2007 exhibit a pattern comparable to the dipole anomaly presented in studies by Wang et al. (2009), with predominantly anticyclonic (cyclonic) circulation over the western (eastern) Arctic Ocean (Figure 2a), as noted in previous sea ice outlook submissions (Lukovich and Barber, 2009). A similar, albeit less distinctive pattern in relative vorticity is observed in March of 2010 (Figure 2b). The transition from positive to negative vorticity, or between cyclonic and anticyclonic circulation in April is oriented parallel to Fram Strait and over the transpolar drift stream in 2007 (Figure 2c). The transition from cyclonic to anticyclonic circulation is however shifted westward in 2010 and oriented over Baffin Bay, suggesting differences in zonal and meridional stratospheric dynamical contributions and their anomalies to surface preconditioning phenomena in late winter.

It is also interesting to note that relative vorticity fields in April, 2010 resemble those in March, 2007. Moreover, patterns in SLP fields in June, 2007, reflect the reversal in relative vorticity fields in April, 2007; east-west asymmetry in the SLP low (high) in the western (eastern) Arctic in June is also apparent in the stratospheric anticyclonic (cyclonic) circulation in the western (eastern) Arctic in April.

Stratospheric winds in March and April

Stratospheric (10 mb) winds and composites for years associated with minima in sea ice extents in March 2007 exhibit maximum wind speeds in the western Arctic in a manner similar to composites for vortex displacement events noted in previous SIO submissions (Figure 3). As noted by Hare (1968) and Overland (2009) the cold core polar vortex governs surface winter conditions; as described in the June, 2009 submission, a similarity in composites for years associated with vortex displacements and minimum sea ice extent may be attributed to coherent deformation of the vortex during vortex displacement events, in contrast to vortex splitting events where cyclonic remnants erode stratosphere-surface connections in late winter. Differences between 2010 and 2007 and composite stratospheric winds in March and April (Figure 3b) and Figure 3e) compared to Figure 3c) and Figure 3f)) suggest that wintertime preconditioning events due to stratospheric dynamical phenomena in 2010 will not contribute to accelerated ice loss and retreat in summer due to dynamical phenomena in winter, relative to ice loss and retreat in 2007.

Surface zonal and meridional wind anomalies in June

Surface zonal wind anomalies in June, 2007 and 2010 indicate strong easterlies in the Beaufort Sea region relative to the 1979 – 2010 climatological mean, indicating enhanced advection of sea ice out of this region throughout summer (Figure 4a) and Figure 4b). Similarity between the spatial patterns in surface zonal wind anomalies in June, 2007, 2010 and sea ice minimum composite (Figures 4 a), b), and e) suggests a continued decline in sea ice due to dynamic contributions associated with advection.

Similarity in spatial patterns for meridional wind anomalies in June, 2007, 2010 and for the difference between the climatological mean and sea ice minimum composite (Figures 5 a), b) and e) indicate advection and entrainment associated with northerly flow to the west of Banks Island in 2010, in addition to enhanced export through Fram Strait due to stronger northerly flow. Also of interest is the maximum in southerly winds over the Laptev Sea which, if sustained during the summer, could lead to enhanced ice retreat in this region. Increased northerly flow to the west of Banks Island and decreased southerly flow in the southern Beaufort Sea for 2010 (Figure 5b) also indicates dynamical contributions to a decline in sea ice due to advection, rather than advanced retreat from the coastline, depending on ice conditions and the persistence of meridional winds in this region.

Surface wind anomalies for June

Surface vector winds for June, 2007, 2010, sea ice minima composites and the difference between 2010 and sea ice minima composite summarize spatial patterns from zonal and meridional wind anomalies (Figure 6). Noteworthy in particular is the aforementioned eastward shift in maxima and enhanced southerly flow in the Laptev Sea region (Figure 9d), indicating contributions to enhanced ice retreat due to southerly flow in this region.

SLP composite and differences for June

Information on regions of convergence and divergence associated with SLP highs and lows (and associated anticyclonic and cyclonic circulation) is illustrated, and regional differences highlighted, through investigation of the SLP composites and differences for June (Figure 7). East-west asymmetry in high and low SLP in the eastern and western Arctic region evident during vortex displacement events and minimum ice extent components in June (as noted in a previous SIO submission) is also apparent in June of

2007 and 2010 (Figures 7a) and 7b)). Noteworthy is the difference field for 2010 – 2007 in Fram Strait compared to the difference field for 2010 and the sea ice minimum composite, indicating export through Fram Strait comparable to that encountered in 2007. SLP patterns in the Beaufort Sea region are also similar in 2007 and 2010, with an eastward and poleward shift in the SLP high for 2010.

Recent studies have noted the role of persistent SLP over the Beaufort Sea during July, August and September and strong meridional flow in the retreat of, and record reduction in, sea ice in the summer of 2007 (Kwok, 2008; Ogi et al., 2008). Comparison of SLP for 2010 with sea ice minimum composites illustrates a strengthened SLP high in the Beaufort Sea region and raises the question as to whether June conditions will now play a role due to the earlier onset of ice melt, and act as a dynamical predictor for ice retreat in September.

Ogi et al. (2008) also highlighted in their assessment of the record reduction in sea ice in 2007 the role of free drift conditions in ice retreat. In particular, buoys will travel to the right of the surface winds and towards the centre of an anomalous anticyclone if in a state of free drift. Also of interest is convergence/divergence of the ice pack depending on free drift conditions of sea ice and ice thickness. Recent updates of ice conditions in the Arctic have indicated a reduction in ice loss due to a filament of multi-year (two- to three-year) ice that may inhibit Ekman drift towards the centre of the SLP high and further ice retreat

Sea ice extent for June 2007 and 2010

The occurrence of large areas of open water during the summer months (July – August) represent large areas of fetch distance, where persistent winds from cyclones may churn up long period waves that can propagate across the open water, and into the pack ice where they cause large ice floes to fracture (Figure 8). Such an event was observed in situ by the authors in September 2009. A longwave swell of period 16s with wavelength 200m was observed to cause flexural failure in large multi-year floes (5km+ diameter) approximately 250nm from the ice edge (Asplin et al., 2010 *in prep*). Furthermore, heavily decayed (rotten) first-year ice, interspersed with small old ice floes were observed in the Beaufort sea during the same cruise (Barber et al., 2009). The effects of flexural fracture in the old ice, and remnant rotten ice may have resulted in a weaker ice cover in 2010. Although speculative, it could prove to be a critical factor this year as much old ice was observed in the Southern Beaufort and Chukchi seas in April 2010, and will be more resistant to melting. It will be very interesting to observe this sector of the Arctic Basin as the surrounding first-year ice decays, leaving predominantly old ice to persist later into the summer.

4) Executive Summary

Similarity in the surface air temperature (SAT) and sea level pressure (SLP) fields in June 2007 and 2010, with increased temperatures over Hudson Bay and the Canadian Archipelago, and stronger winds associated with a strengthened SLP high over the western Arctic indicate that sea ice decline will exceed the 2007 record minimum in ice extent. Differences in wintertime stratospheric dynamical phenomena in late winter between 2007 and 2010 suggest that dynamic contributions to ice loss will not be as significant in September 2010 as in 2007. June conditions of surface meridional anomalies however highlight the possibility of enhanced ice loss due to advection out of the Beaufort Sea region and through Fram Strait, and ice retreat in the Laptev Sea region. Further investigation of ice thickness and free ice drift conditions, in addition to persistence of SLP maxima will provide further insight as to whether convergence (divergence) of sea ice associated with SLP highs (lows) will give rise to increased ice retreat in the Arctic and the Beaufort Sea region in particular.

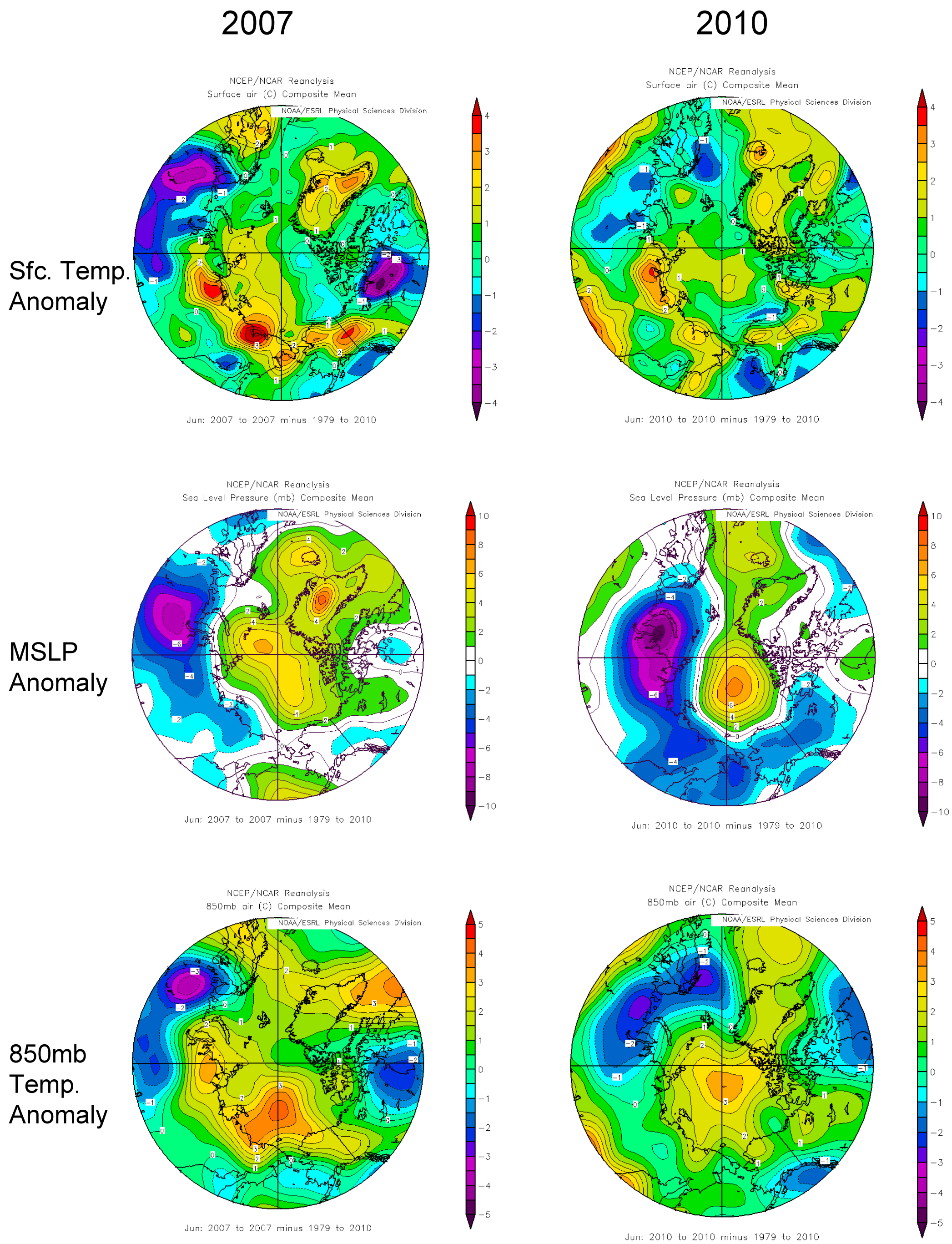

Figure 1. SAT, SLP and 850 mb temperature anomaly for 2007 (left column) and 2010 (right column). Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/

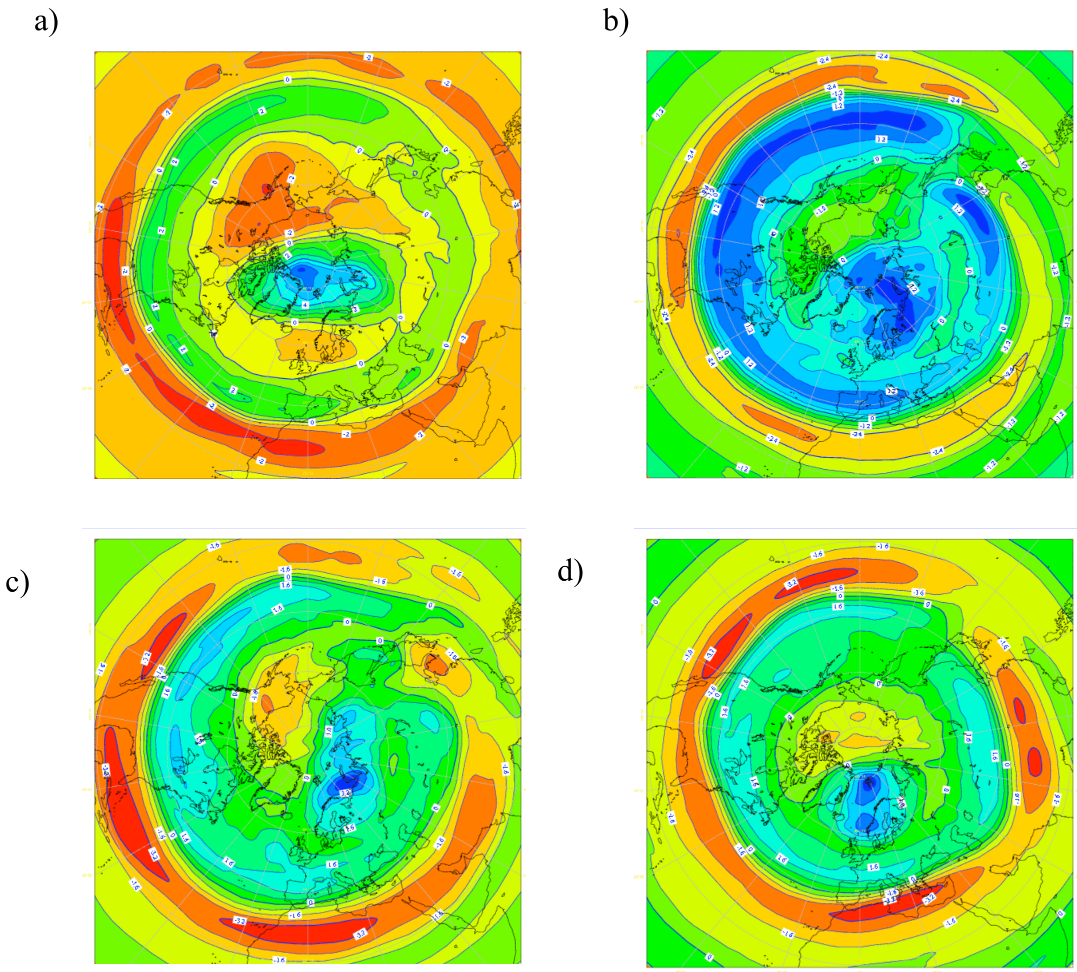

Figure 2. Stratospheric (10 mb) relative vorticity fields for March in a) 2007 and b) 2010, and April in c) 2007 and 2010 d). Anticyclonic activity (negative relative vorticity) is depicted by red shading. Image provided by the ECMWF ERA-Interim data portal at http://data-portal.ecmwf.int/data/d/interim_moda/levtype=pl/.

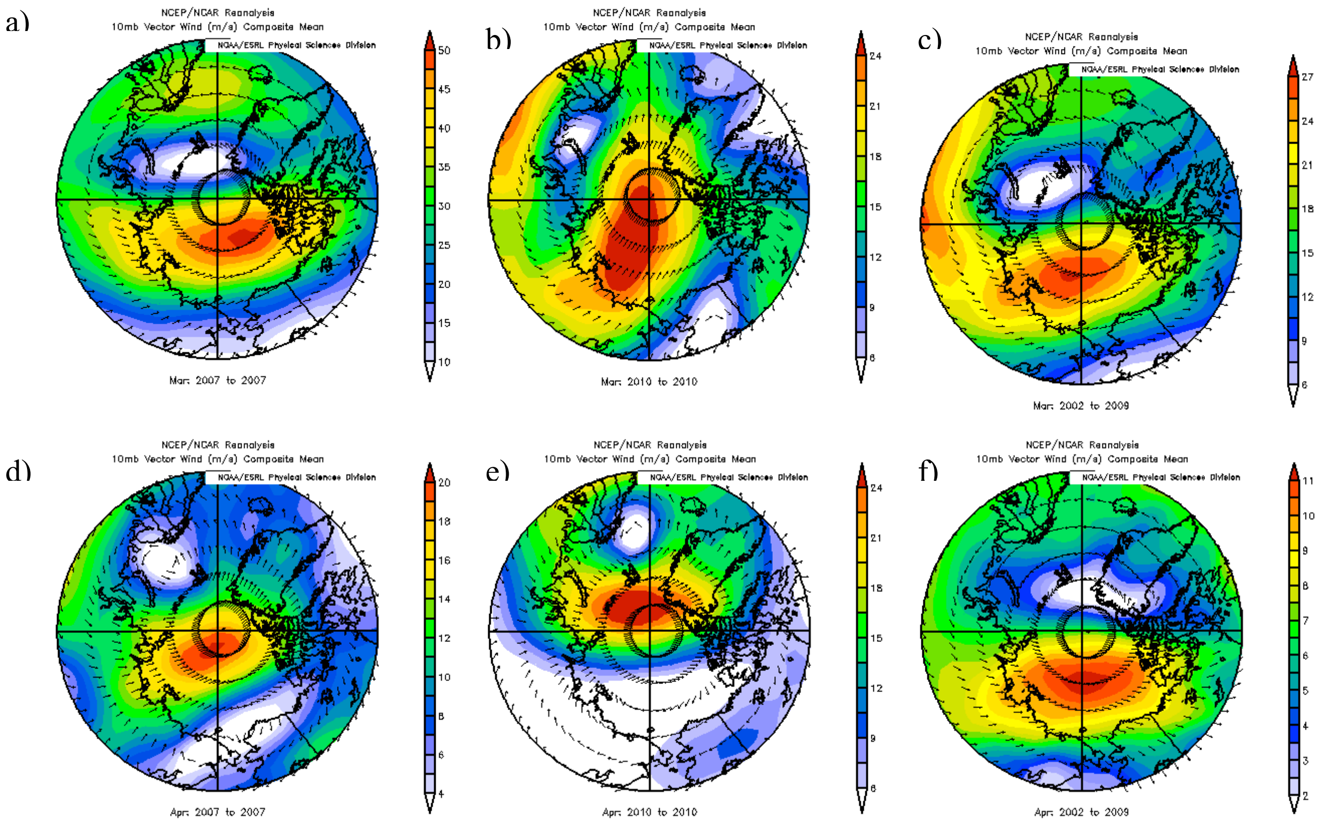

Figure 3. Stratospheric winds in March in a) 2007, b) 2010 and for minima in sea ice extent, and in April in d) 2007, e) 2010, and f) for minima in sea ice extent. Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/

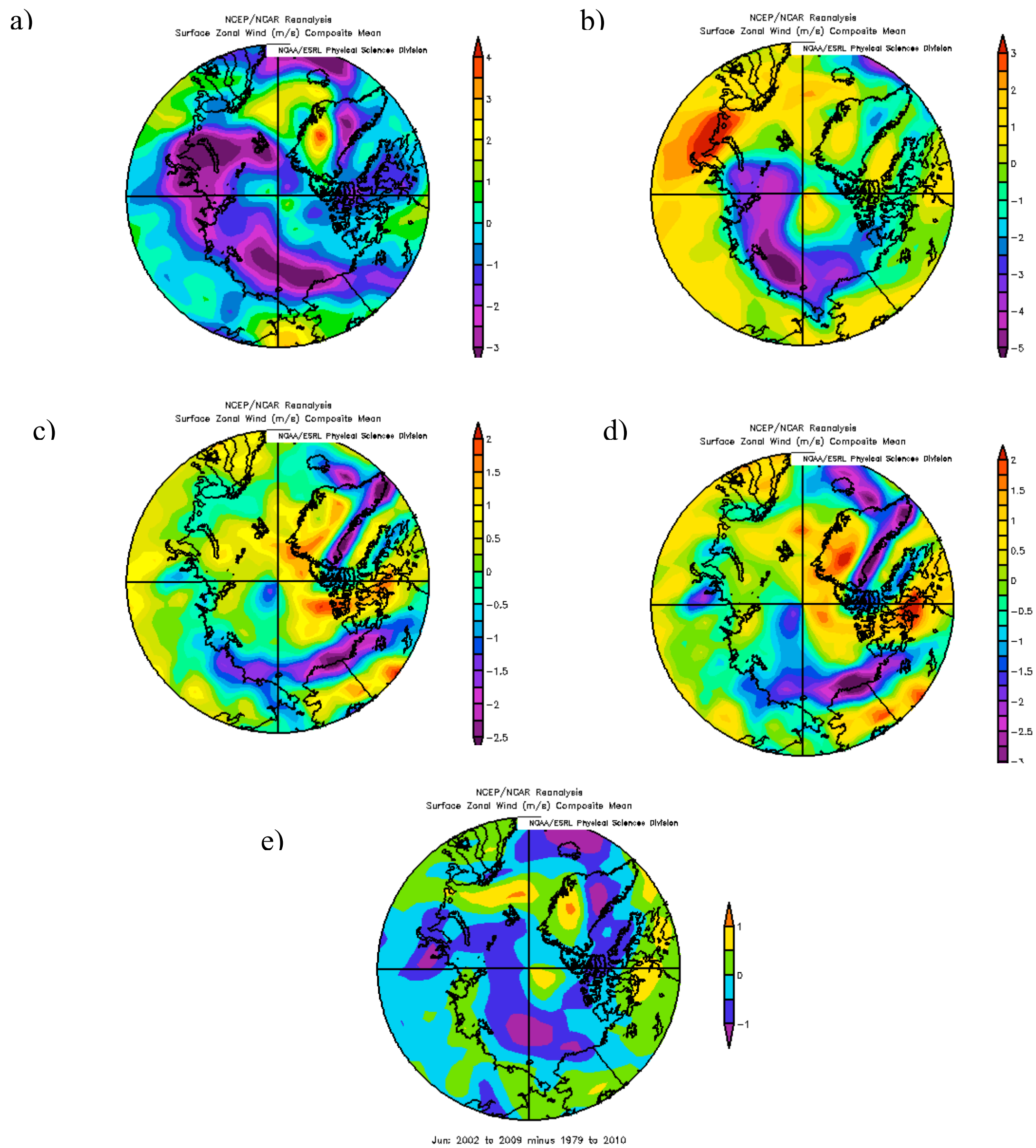

Figure 4. Surface zonal wind anomalies in June in a) 2007 and b) 2010, and c) average zonal winds from 1979 – 2010 c), d) composites for minima in sea ice extent and e) difference between composite and climatology. Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/

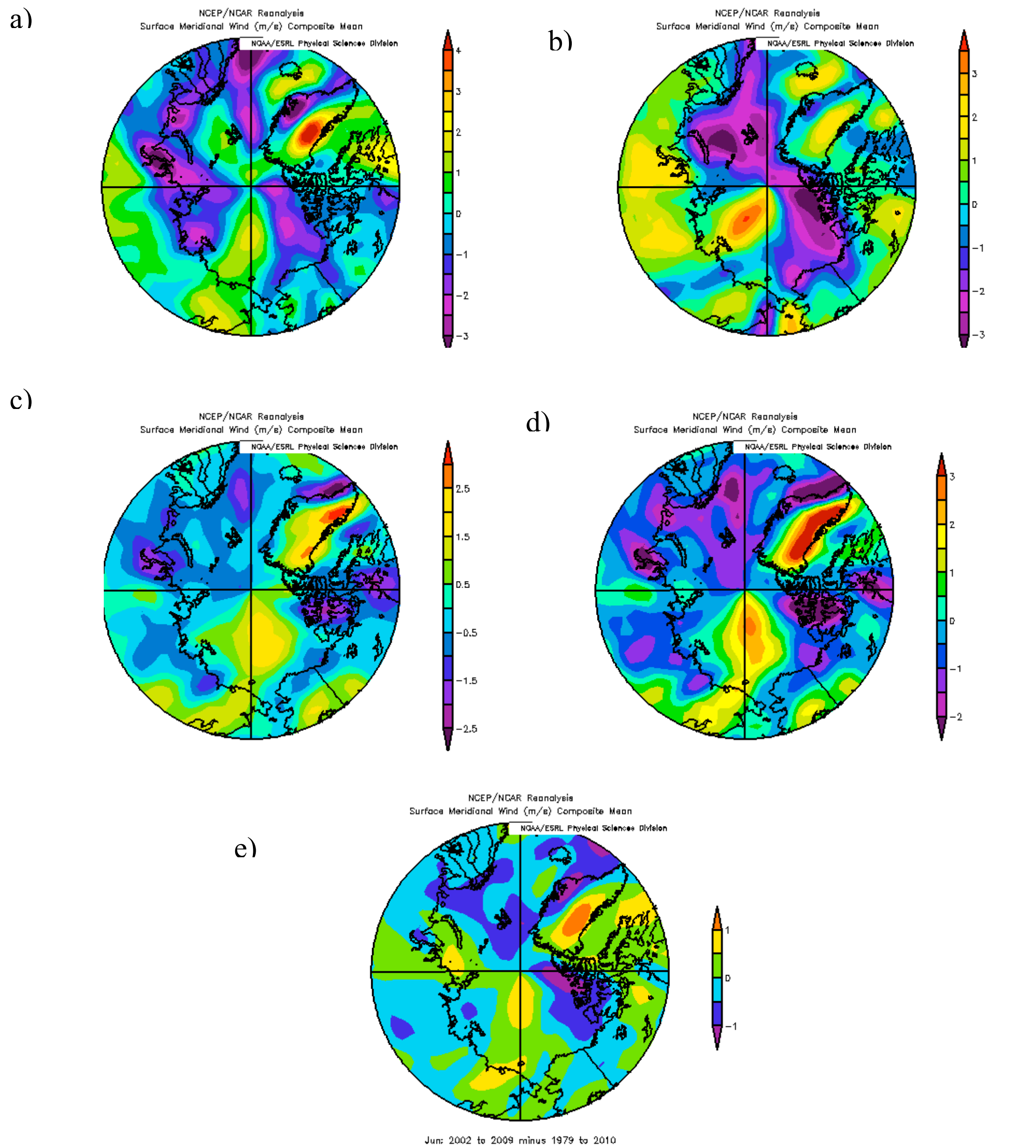

Figure 5. Meridional wind anomalies in June in a) 2007, b)2010 and mean meridional winds from c) 1979 – 2010, and d) composite for years associated with minima in sea ice extent.

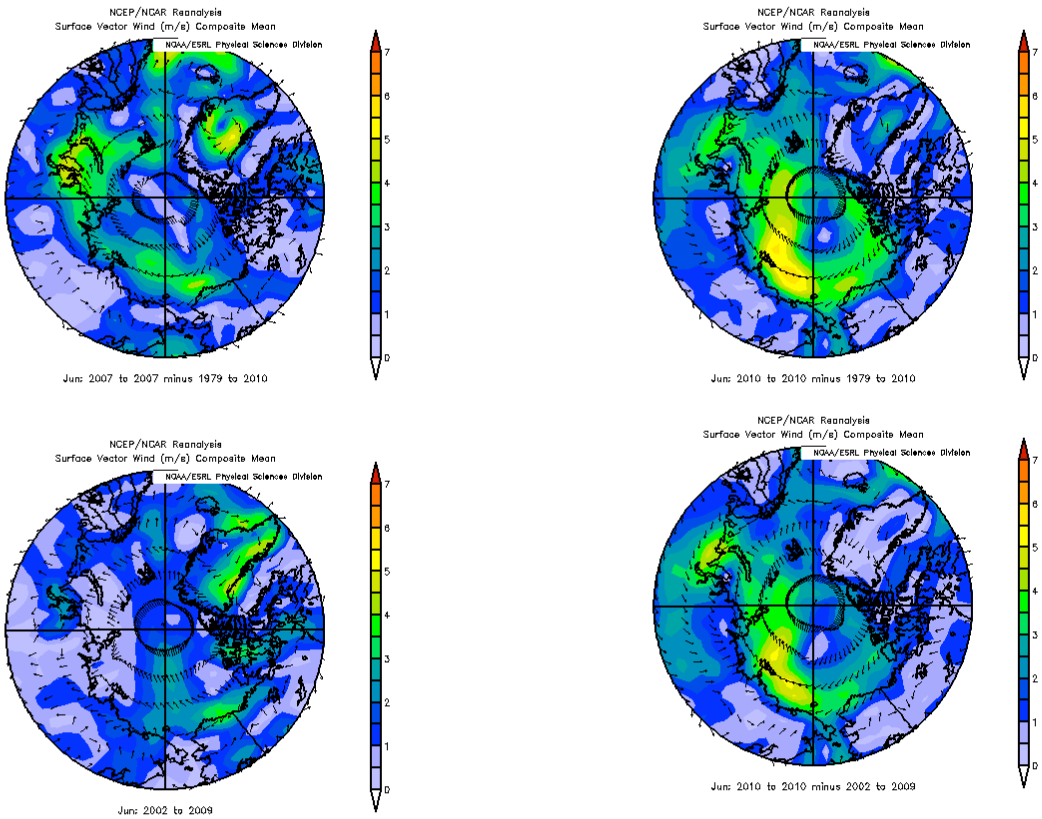

Figure 6. Vector winds for June in a) 2007, b) 2010, c) sea ice extent minimum composite for 2002 to 2009 and d) difference between June, 2010 and sea ice extent composite. Image provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/.

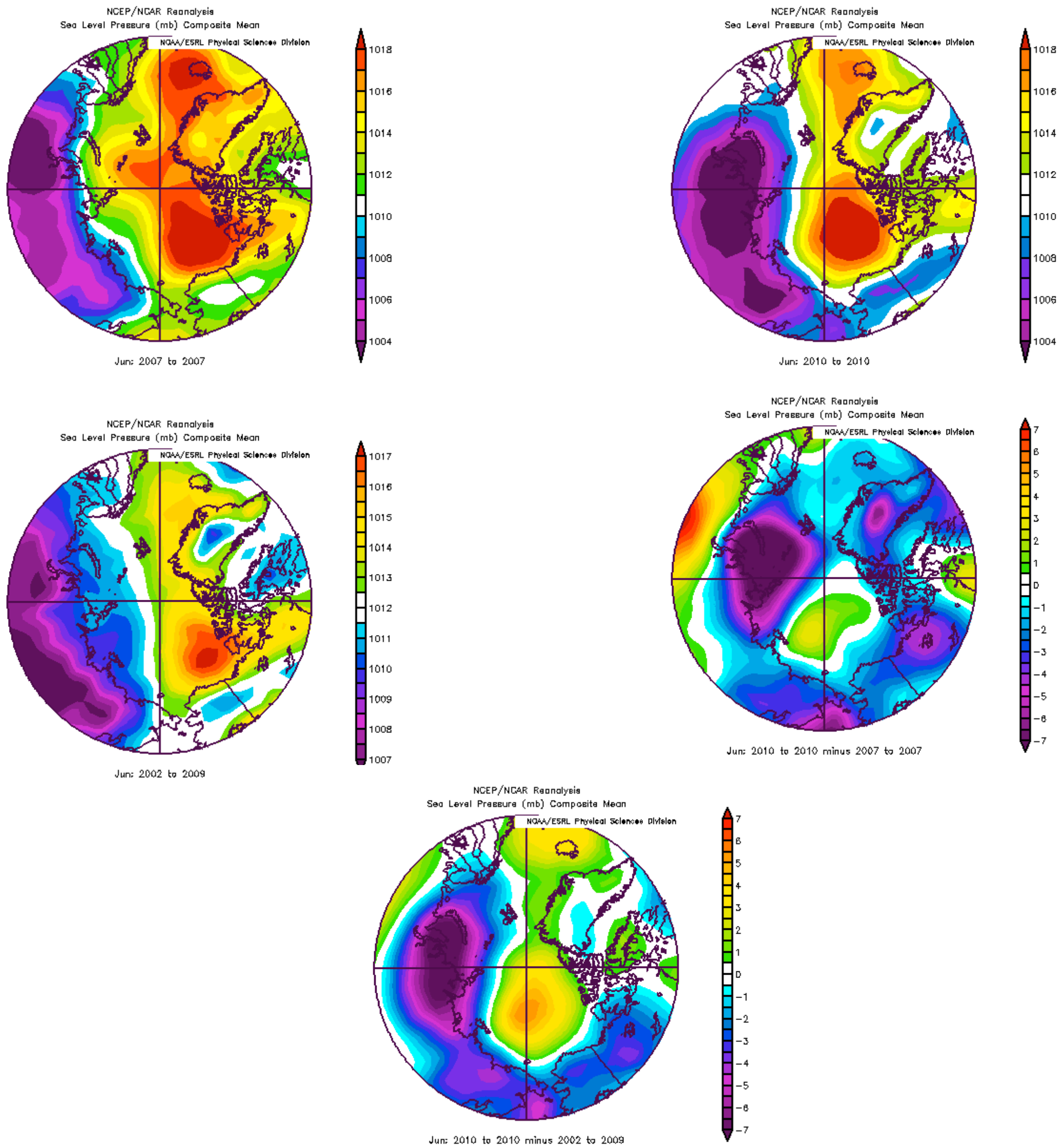

Figure 7. SLP for June in a) 2007, b) 2010, c) sea ice minimum composite from 2002 to 2009, d) difference between 2010 and 2007, and e) difference between 2010 and sea ice minimum composite.

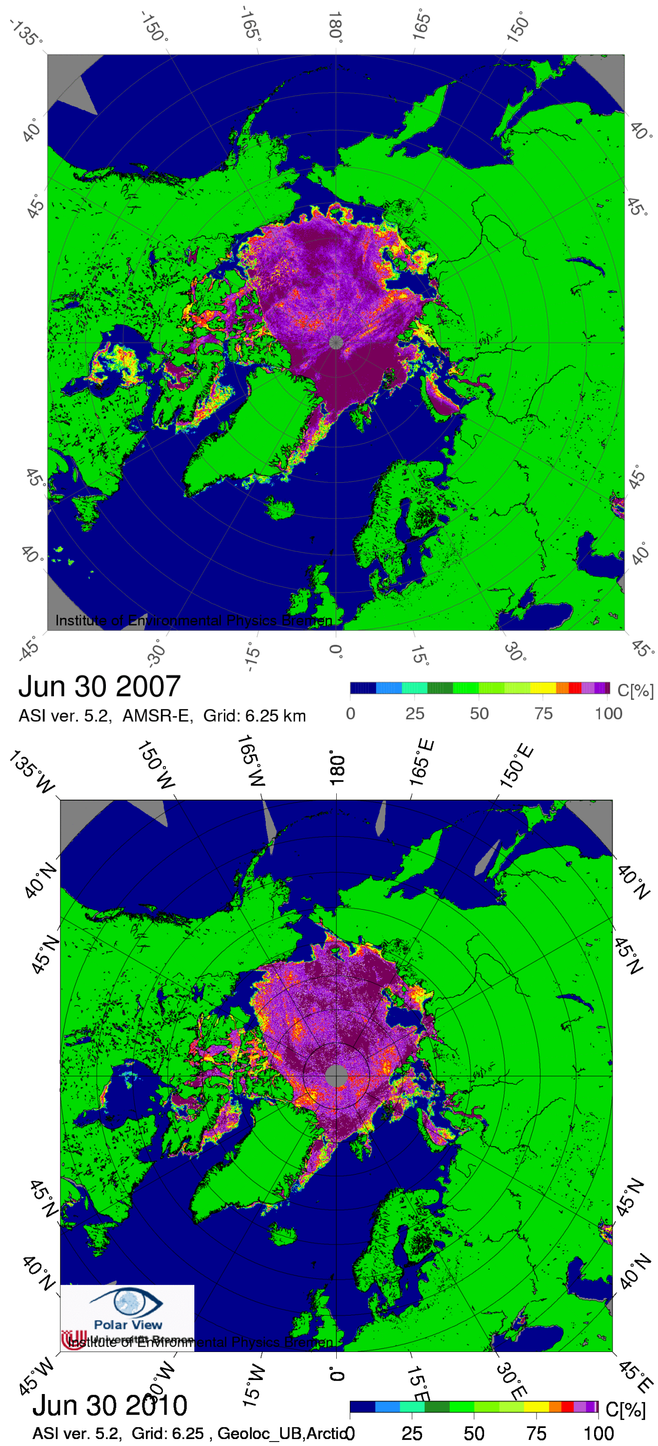

Figure 8. Sea ice extent and ice concentrations for a) June 30, 2007 and b) June 30, 2010. Source: http://www.iup.uni-bremen.de:8084/amsr/