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Does Arctic sea ice decline increase the occurrence of extreme weather conditions in mid-latitudes?

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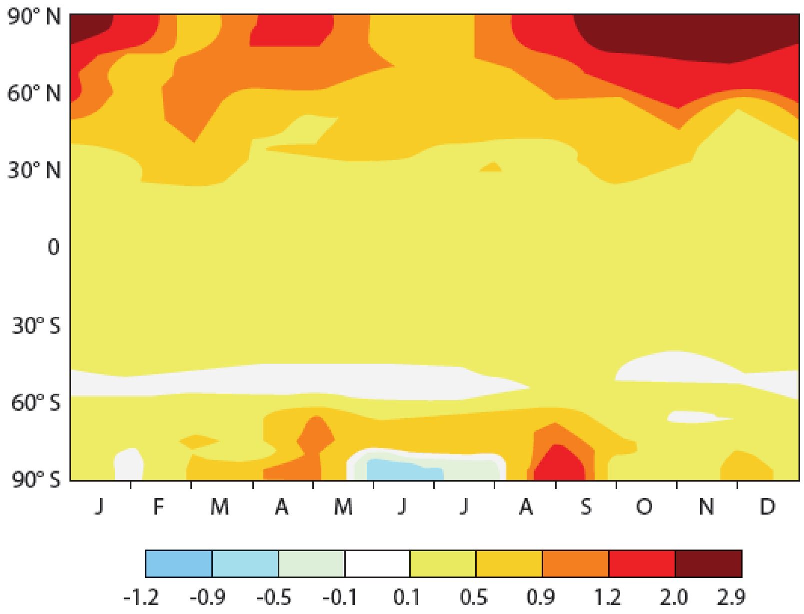
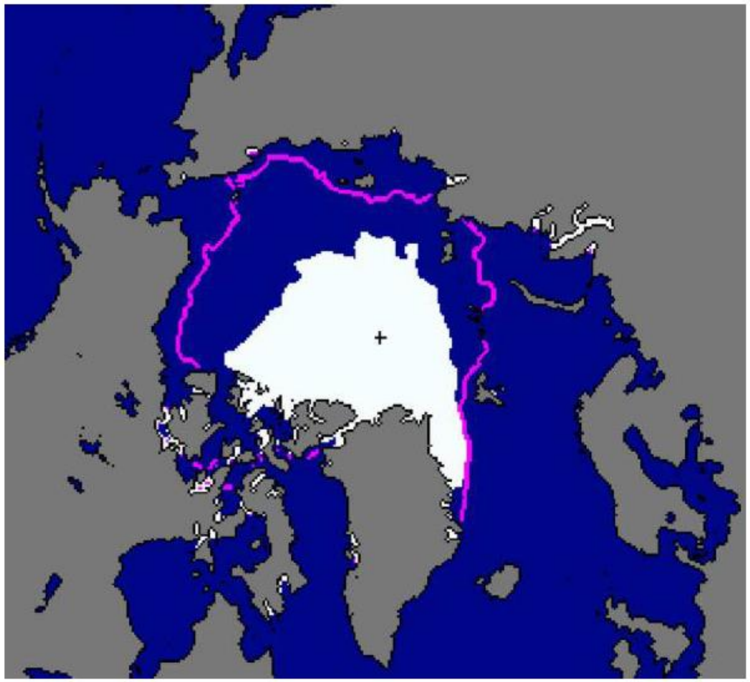
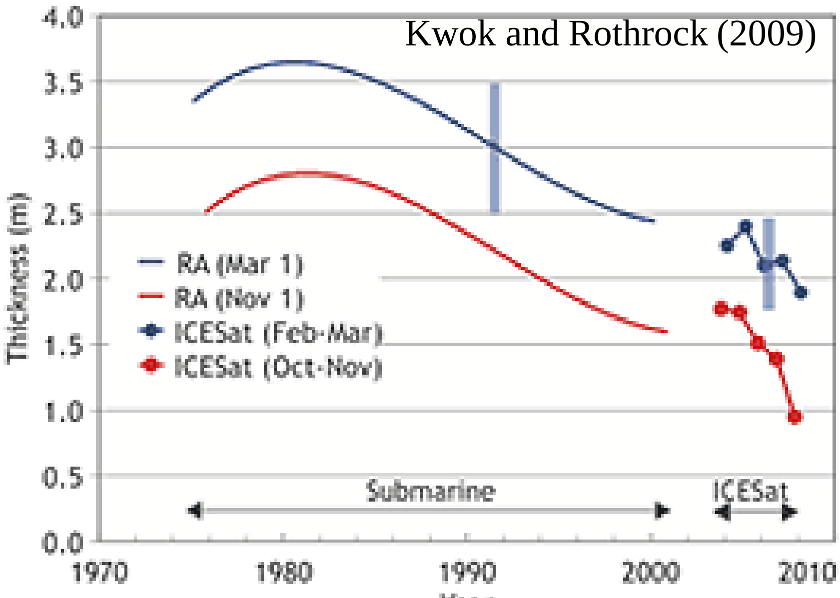
Arctic is warming and sea ice is declining

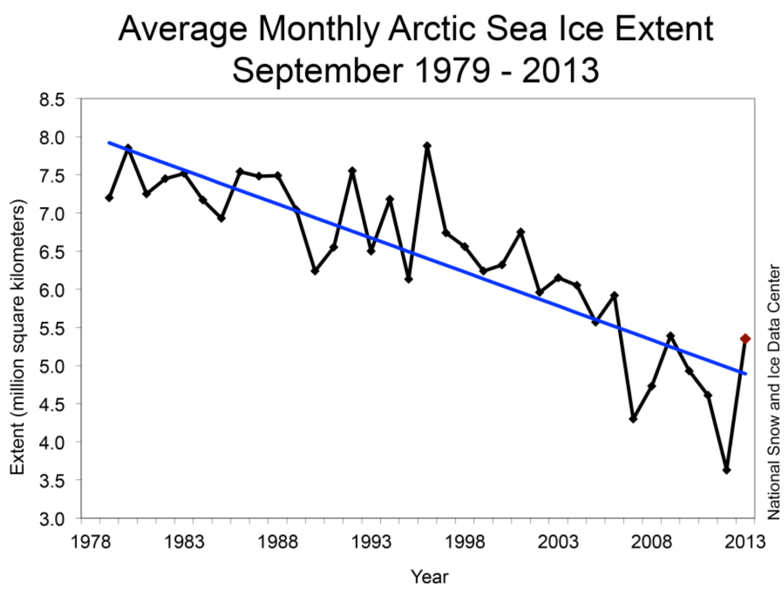


Monthly surface air temperature anomalies averaged over 2001 to 2009 (relative to the mean for 1951 to 2000). Walsh et al. (2011).

September 2012







Observations

Since 2005, several mid-latitude regions have experienced cold, snow-rich winters.

- winter 2005–2006 was very cold in large parts of Europe and northern Asia
- winter 2009-2010 was extremely cold in large parts of the northern mid-latitudes with a record low North Atlantic Oscillation (NAO) index since 1864
- winter 2010-2011 was exceptionally cold in most of Europe
- Many record cold events in winter 2013-2014 in the USA

Is there a link between the Arctic sea ice decline and cold winters in mid-latitudes?

Public poll in New Hampshire, USA (Hamilton and Lemcke-Stampone, 2013, Int. J. Clim.): If the Arctic region becomes warmer in the future, do you think that will have major effects, minor effects or no effects on the weather where you live?

Major effects: 60%
Minor effects 29%
No effects: 5%

Roughly 100 scientific papers published during the last 5 years

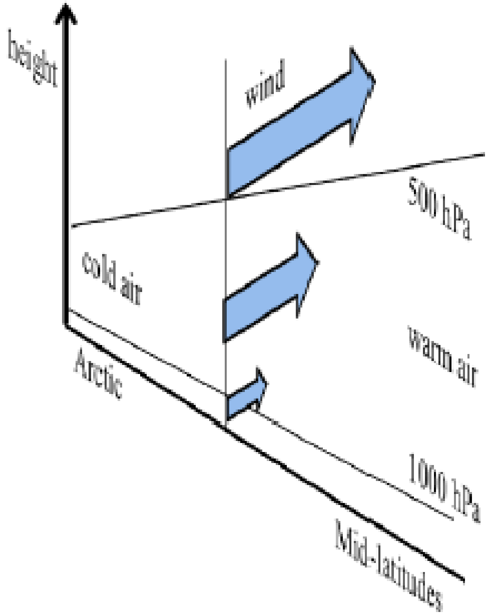
Studies based on observatios and reanalyses

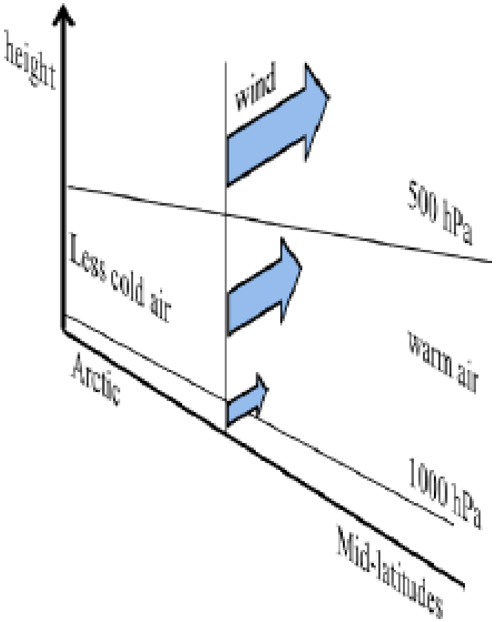
• Local warming in the Arctic → advective effects on nearby regions (Serreze et al., 2009; 2011; Stroeve et al., 2012): does not cause mid-latitude cooling

• Local warming in the Arctic → decrease of poleward gradiet in the 1000 – 500 hPa layer thickness → weaker Polar jet stream (Francis et al., 2009; Overland and Wang, 2010).

• Indirect response seen in surface pressure fields: changes in planetary wave patterns (Jaiser et al., 2012).

• Autumnal sea ice decline → increase of cold-air outbreaks (Lie et al., 2012)





Francis ja Vavrus (2012)

- Compared observations from the warm period 2000-2010 against the previous 30 years
- Warming in the lower troposphere stronger in the Arctic than at mid-latitudes, which has two consequences:

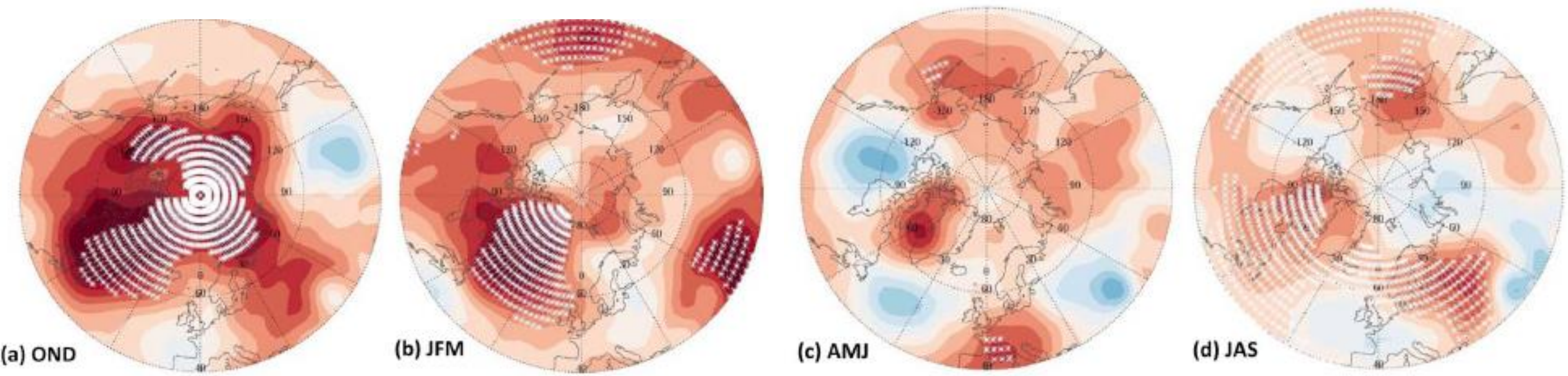
1. Westerly win … wind weakens
2. Ridges at 50 …

→ 1 and 2 toge… s and highs

→ Favours mor…

→ Increases the … heat waves, draughts, floods, …).

Methodology criticised by Barnes (2013)



Anomaly in the 1000-500 hPa thickness in 2000-2010 compared to 1970-1999 in (a) autumn, (b) winter, (c) spring, and (d) summer.

Modelling studies addressing processes and the recent past

Sokolova et al. (2007): the atmospheric pressure pattern with few sea ice resembled the negative AO pattern.

Honda et al. (2009):
The model sea ice cover was modified in the eastern Arctic in September – December
→ Remarkable effects in the Far East throughout the winter; in northern Europe only in late winter, as the reduction of sea ice cover weakens the Icelandic low with a time lag.
→ westerly winds in northern Europe become weaker.
The mechanisms of the lagged effect are not well understood

Strey et al. (2010): the effects of September 2007 sea ice minimum.
Remote responses in the atmospheric circulation generated anomalous cold-air advection, which further affected the air temperature and precipitation over eastern North America and the North Atlantic

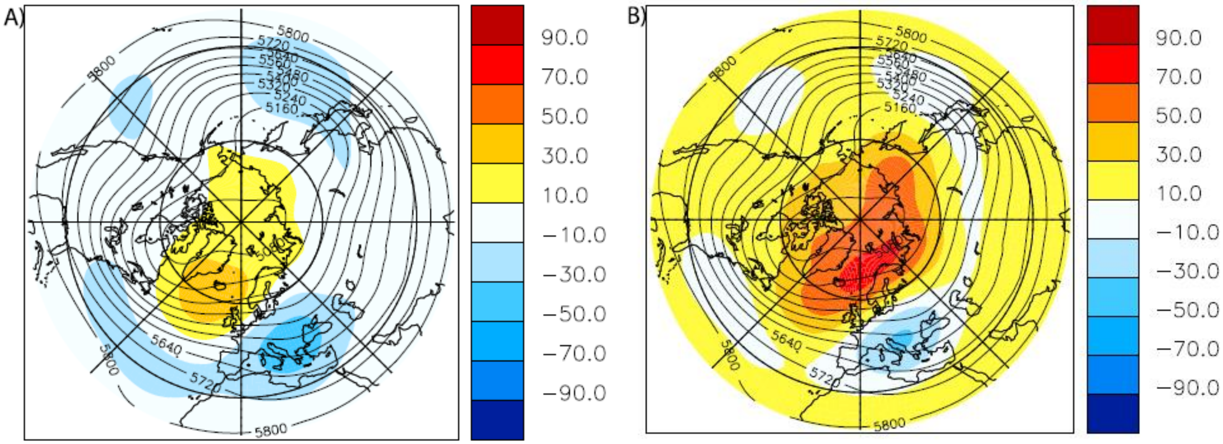
Yang and Christensen (2012): analysis of the results of CMIP5.
In 1956–2005, cold winters in Europe were rarely associated with a reduced sea ice cover in the Barents and Kara Seas.

Modelling studies addressing the future

Yang and Christensen (2012):

• while a warming trend will prevail in Europe, episodes of cold winter months will remain rather common in the first half of the 21st century. Only in the second half, the occurrence is expected to remarkable drop; down to 31% of that in 1971-2000.

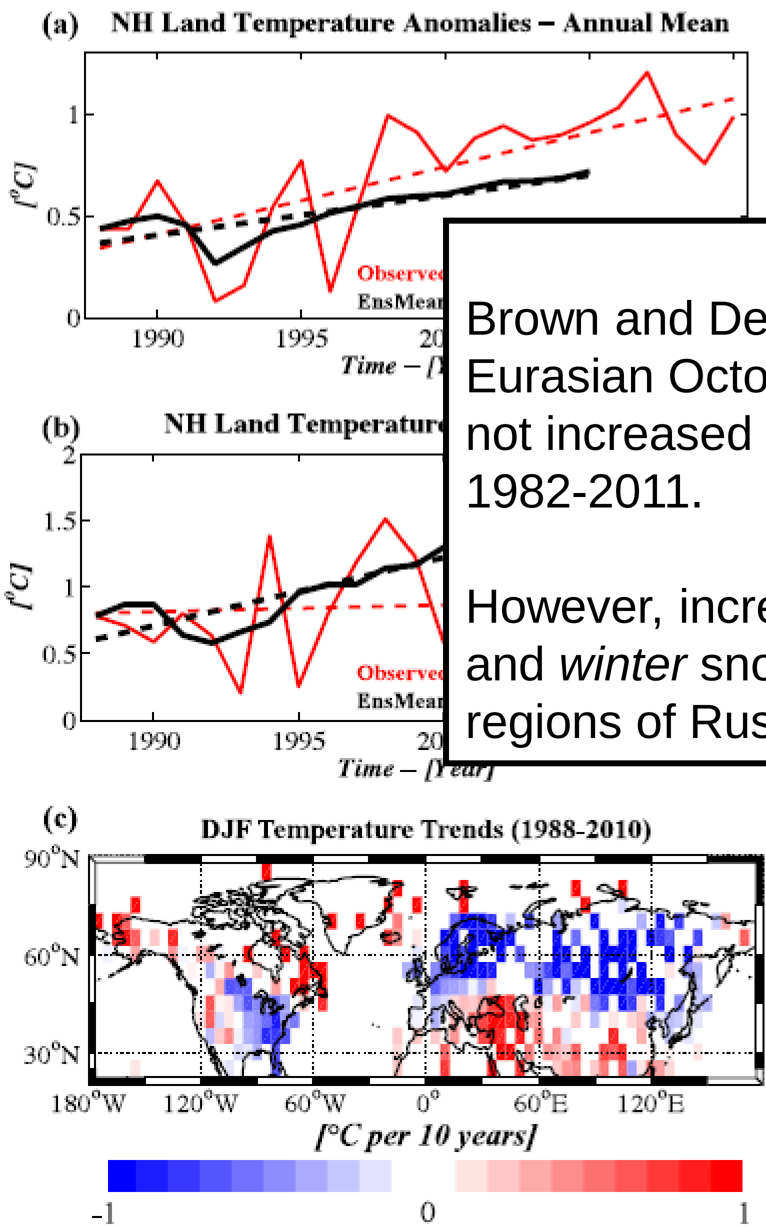
• negative AO with an anomalously cold Europe and warm Arctic is typical for the cold events in the future.



Multi-model ensemble mean of composites of 500 hPa geo-potential height (contour lines) and its anomalies (color shadings) for European cold Januaries for
(a) the historical period of 1956–2005,
(b) the future period of 2006–2050 as projected in scenario RCP4.5.

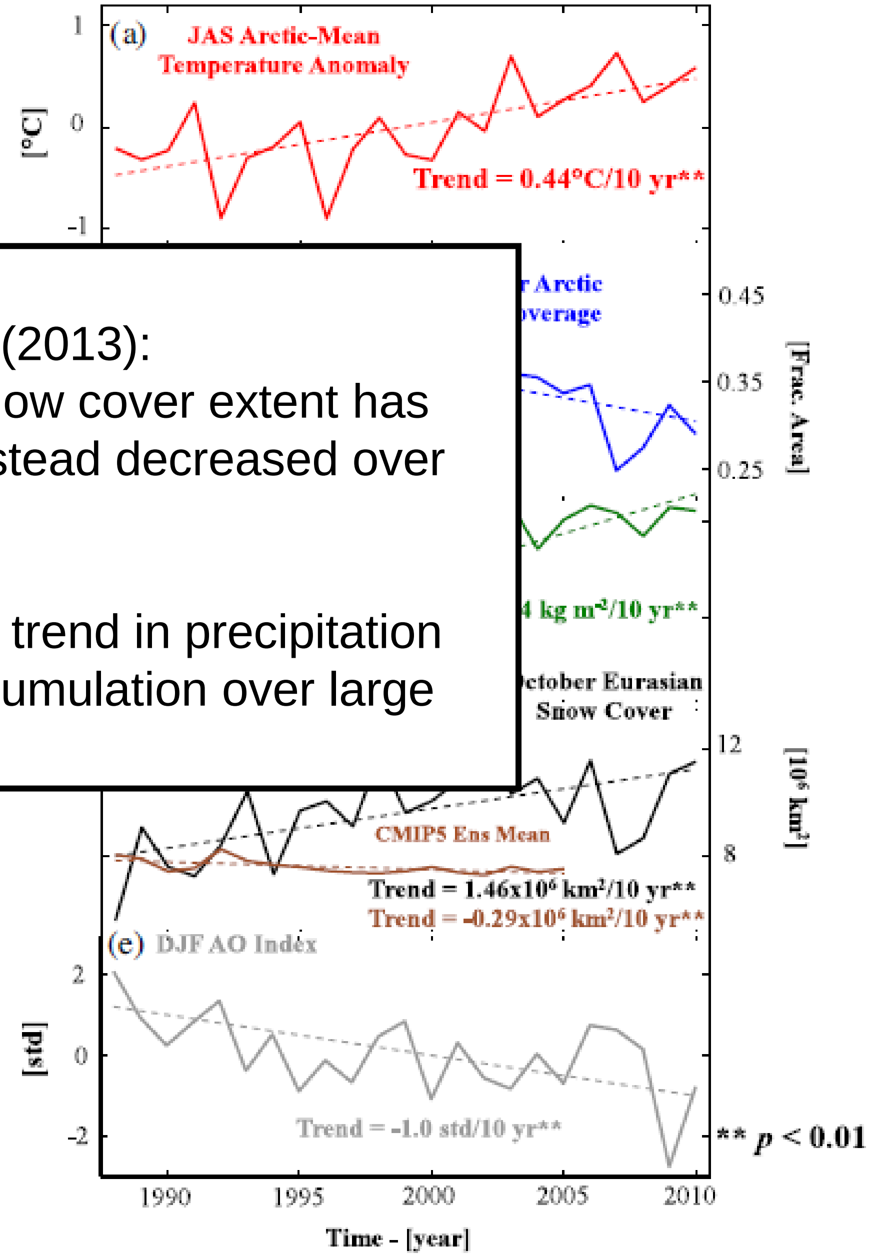
Also terrestrial snow cover is important

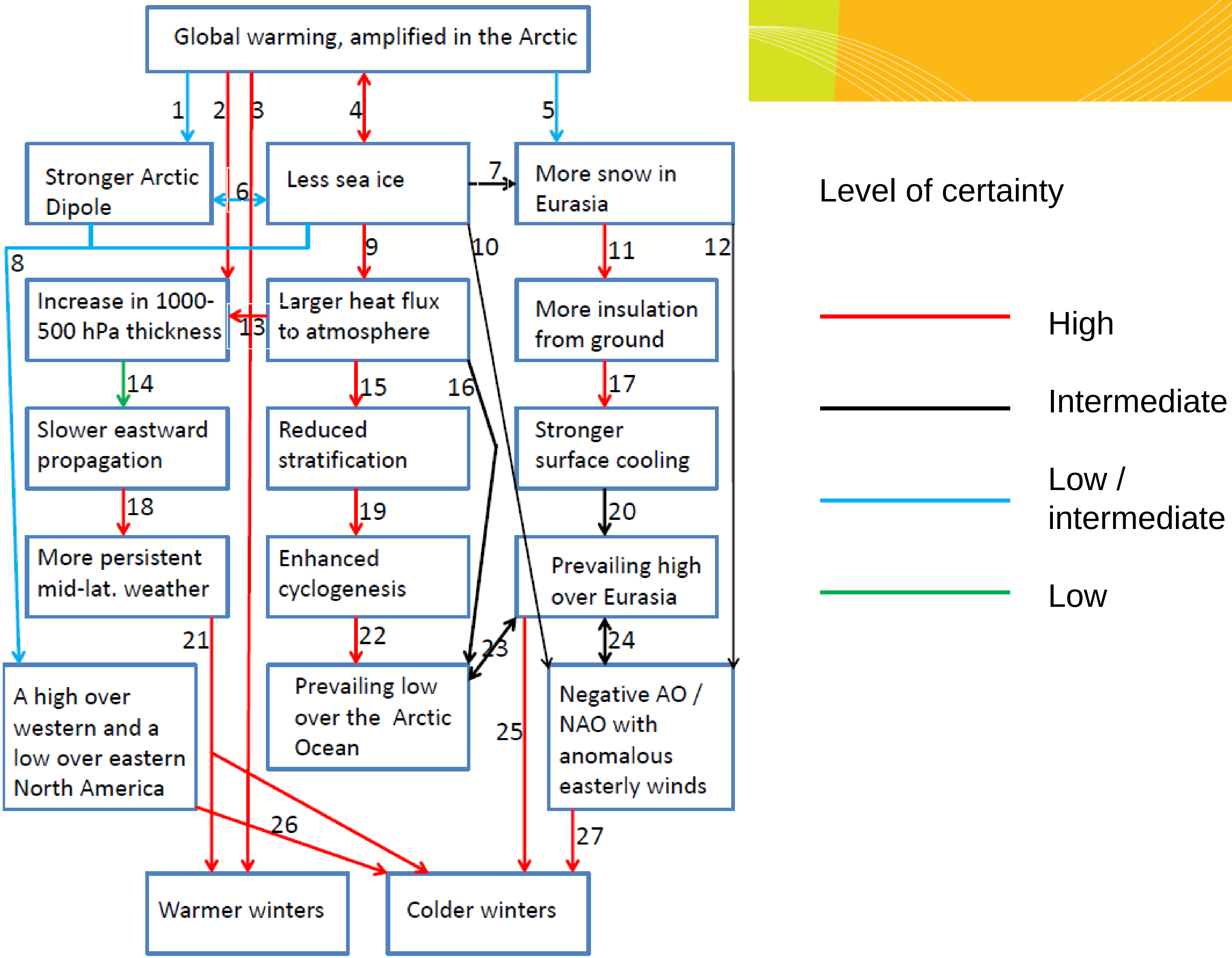
Cohen et al. (2012)



Brown and Derksen (2013):
Eurasian October snow cover extent has not increased but instead decreased over 1982-2011.

However, increasing trend in precipitation and *winter* snow accumulation over large regions of Russia




Global warming, amplified in the Arctic
1
2
3
4
5
Stronger Arctic Dipole
6
Less sea ice
7
More snow in Eurasia
8
9
10
11
12
Increase in 1000-500 hPa thickness
13
Larger heat flux to atmosphere
More insulation from ground
14
15
16
17
Slower eastward propagation
Reduced stratification
Stronger surface cooling
18
19
20
More persistent mid-lat. weather
Enhanced cyclogenesis
Prevailing high over Eurasia
21
22
23
24
A high over western and a low over eastern North America
Prevailing low over the Arctic Ocean
25
Negative AO / NAO with anomalous easterly winds
26
27
Warmer winters
Colder winters
Level of certainty
High
Intermediate
Low / intermediate
Low

No.	References	Level of certainty[1]
1	Overland and Wang (2010), Blüthgen et al. (2012)	Low / intermediate
2	Francis et al. (2009), Overland et al. (2010; 2011b, 2012)	High
3	Christensen et al. (2007), Serreze et al. (2009; 2011), Deser et al. (2010), Petoukhov and Semenov (2010), Overland et al. (2011a); Yang and Christensen (2012), Stroeve et al. (2012), Peings and Magnusdottir (2013)	High
4	Effects of climate warming on sea ice decline: e.g., Meier et al. (2011), Polyakov et al. (2012) and Stroeve et al. (2012). Effects of sea ice decline on climate warming: e.g. Serreze and Barry (2011), Kumar et al. (2010), Screen et al. (2012, 2013a)	High
5	Cohen et al. (2012a) for autumn, but not supported by Brown and Derksen (2013). Bulygina et al. (2009), Borzenkova and Shmakin (2012), Callaghan et al. (2011), and Park et al. (2012) suggested an increase in winter.	Intermediate for winter, probably not valid for autumn
6	Overland and Wang (2010), Blüthgen et al. (2012)	Low / intermediate
7	Cohen et al. (2012a), Ghatak et al. (2012), Park et al. (2012), Callaghan et al. (2011)	Intermediate for winter, probably not valid for autumn
8	Francis et al. (2009); Strey et al. (2010); Balmaseda et al. (2010)	Low / intermediate
9	E.g., Rinke et al. (2006), Lüpkes et al. (2008a,b), Francis et al. (2009), Serrezze et al. (2009), Screen and Simmonds (2010a,b), Overland and Wang (2010), Stroeve et al. (2011), Jaiser et al. (2012), Strey et al. (2012), Outten and Esau (2012)	High
10	Alexander et al. (2004), Magnusdottir et al. (2004), Deser et al. (2004; 2010), Cohen et al. (2012a), Seierstad and Bader (2009), Petoukhov and Semenov (2010), Liu et al. (2012), Outten and Esau (2012), Magnusdottir et al. (2004), Sokolova et al. (2007), Honda et al. (2009), Strey et al. (2010), Yang and Christensen (2012), Rinke et al. (2013), Peings and Magnusdottir (2013), Tang et al. (2013), Grassi et al. (2013), Screen et al. (2013b)	Intermediate[2]

11	Cohen et al. (2012a), Tang et al. (2013)	High
12	Cohen et al. (2007, 2012a), Hardiman et al. (2008), Allen and Zender (2011), Peings et al. (2012)	Intermediate[2]
13	Francis et al. (2009), Overland and Wang (2010), Overland et al. (2010; 2011b, 2012), Rinke et al. (2013), Screen et al. (2013b)	High
14	Farncis and Vavrus (2012), Overland et al. (2012), Peings and Magnusdottir (2013), but questioned by Barnes (2013) and Screen and Simmonds (2013)	Low
15	Francis et al. (2009), Deser et al. (2010), Overland and Wang (2010), Stroeve et al. (2011), Kay et al. (2011), Jaiser et al. (2012), Rinke et al. (2013), Screen et al. (2013b)	High
16	Alexander et al. (2004), Singarayer et al. (2006), Higgins and Cassano (2009), Strey et al. (2010), Blüthgen et al. (2012), Jaiser et al., (2012), Cassano et al. (2013), Screen et al. (2013a)	Intermediate; location of the low and timing of its occurrence vary
17	Cohen et al. (2012a), Park et al. (2012), Tang et al. (2013)	High
18	Francis and Vavrus (2012)	High[3]
19	Jaiser et al. (2012)	High[3]
20	Allen and Zender (2011), Cohen et al. (2012a), Tang et al. (2013), Peings et al. (2012)	Intermediate / high
21	Francis and Vavrus (2012)	High
22	Higgins and Cassano (2009)	High
23	Cohen et al. (2012a), Tang et al. (2013)	Intermediate
24	Cohen et al. (2007, 2012a), Hardiman et al. (2008), Allen and Zender (2011), Peings et al. (2012)	Intermediate[2]
25	Cohen et al. (2007, 2012a), Hardiman et al. (2008), Allen and Zender (2011), Outten and Esau (2012), Peings et al. (2012), Liu et al. (2012), Rinke et al. (2013)	High
26	Francis et al. (2009), Strey et al. (2010)	High
27	Basically all papers listed in 10 and 12 above	High[4]

1 Subjective estimate by the author of this review

2 The effects resemble the negative phase of AO /NAO, with negative index values, but the vertical structure of the response is often baroclinic, i.e., different from the equivalent barotropic structure of AO/NAO.

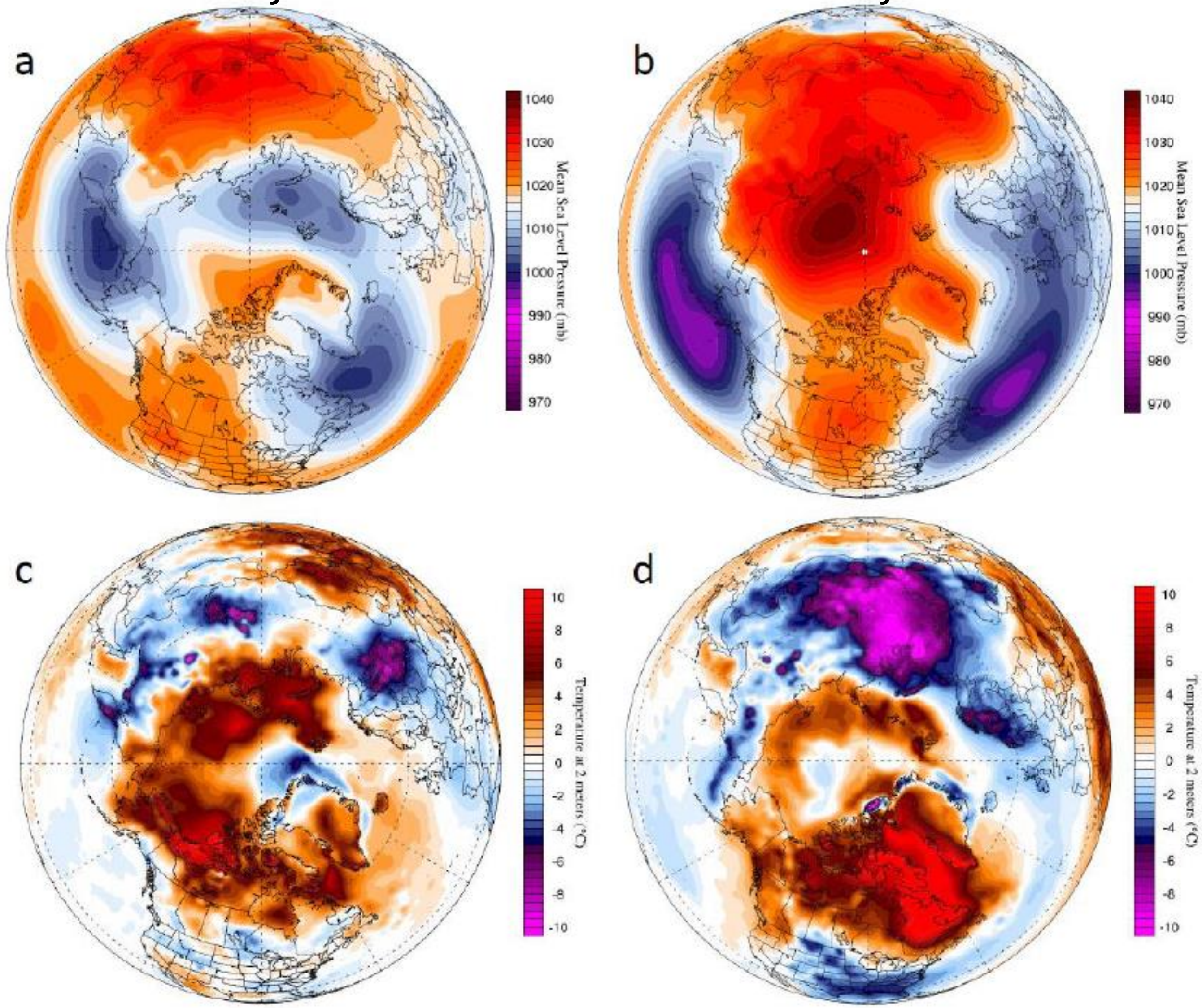
3 The mechanisms are well known, but it is unclear how often they dominate over other factors.

4 The relationship is sensitive to the mid-latitude region.

February 2006 | February 2010

sea level pressure

2-m air temperature anomaly



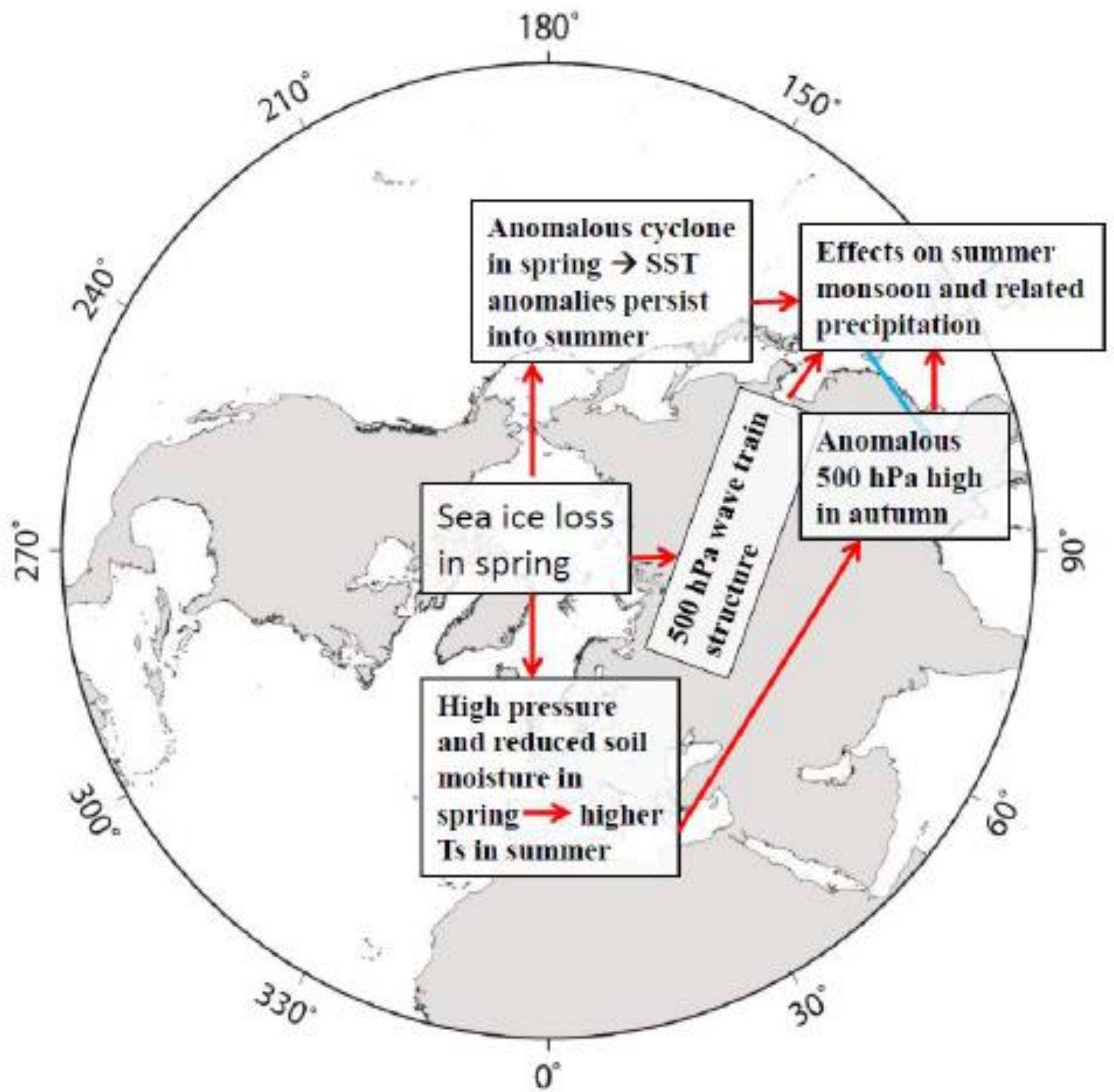
based on ERA-Interim

Effects of sea ice loss in spring

The link via Eurasia: Zhao et al. (2004) and Wu et al. (2009),

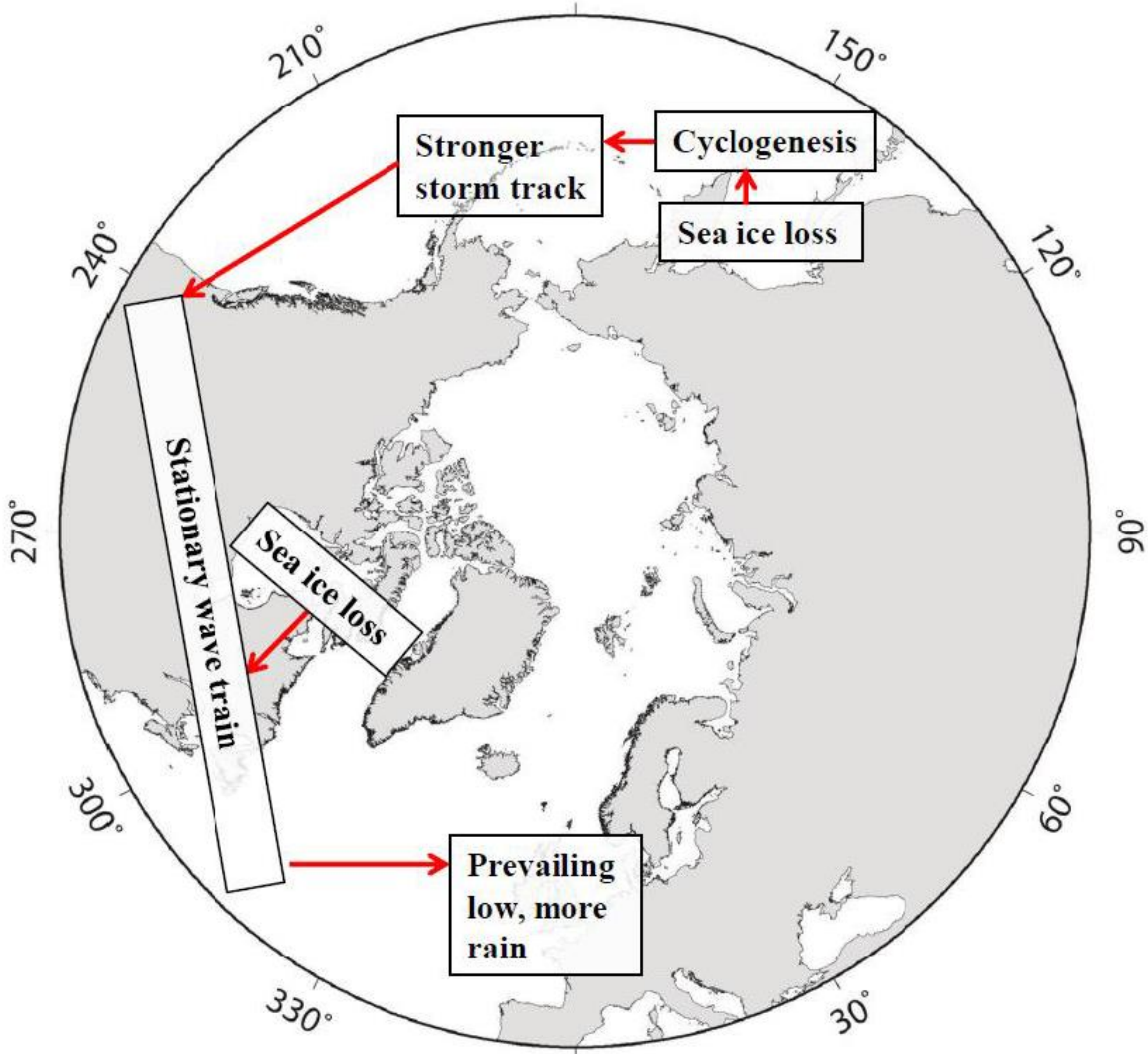
The link via Pacific: Guo et al. (2013).

The blue line indicates the approximate location of the Meiyu front.



Effects of sea ice loss in the Sea of Okhotsk , Hudson Bay, and Labrador Sea

The mechanisms have been suggested by Screen (2013), Mesquita et al. (2011), and Wu et al. (2013).



Conclusions

The decrease of Arctic sea ice area and extent in summer and autumn has affected the local weather and climate over the Arctic Ocean and its marginal seas.

Many recent studies suggest that the Arctic sea ice decline has affected and will further affect mid-latitude weather, but results scatter on the magnitude, timing, and spatial extent of these effects, as well as on the mechanisms behind them.

A message from majority of recent literature is that the Arctic sea ice decline tends to favour circulation patterns that resemble the negative phase of AO and NAO in winter, with a low over the eastern Arctic surrounded by a high over Siberia and western North America. This would result in cold winter weather in large parts of Europe and North America. However, not all studies have yielded such results.

The atmospheric response to sea ice extent strongly depends on the state of the atmosphere, and the winter weather in mid-latitudes and sub-Arctic is also affected by many other factors than the sea ice extent and terrestrial snow cover.

→ in any of the coming winters, it is by no means guaranteed that the effects of cryospheric changes will dominate over the other forcing factors.

It is not clear for how far in the future the scenario of cold winters over Eurasian and North American continents will be relevant.

The model results of Deser et al. (2010), Petoukhov and Semenov (2010), Yang and Christensen (2012), and Peings and Magnusdottir (2013) all suggest that a sea ice decline much larger than we have experienced so far no more favours the occurrence of cold winters in northern mid-latitudes.

Climate model simulations for the end of the 21st century do not predict colder winters for northern high- and mid-latitude continents, but a strong warming instead.

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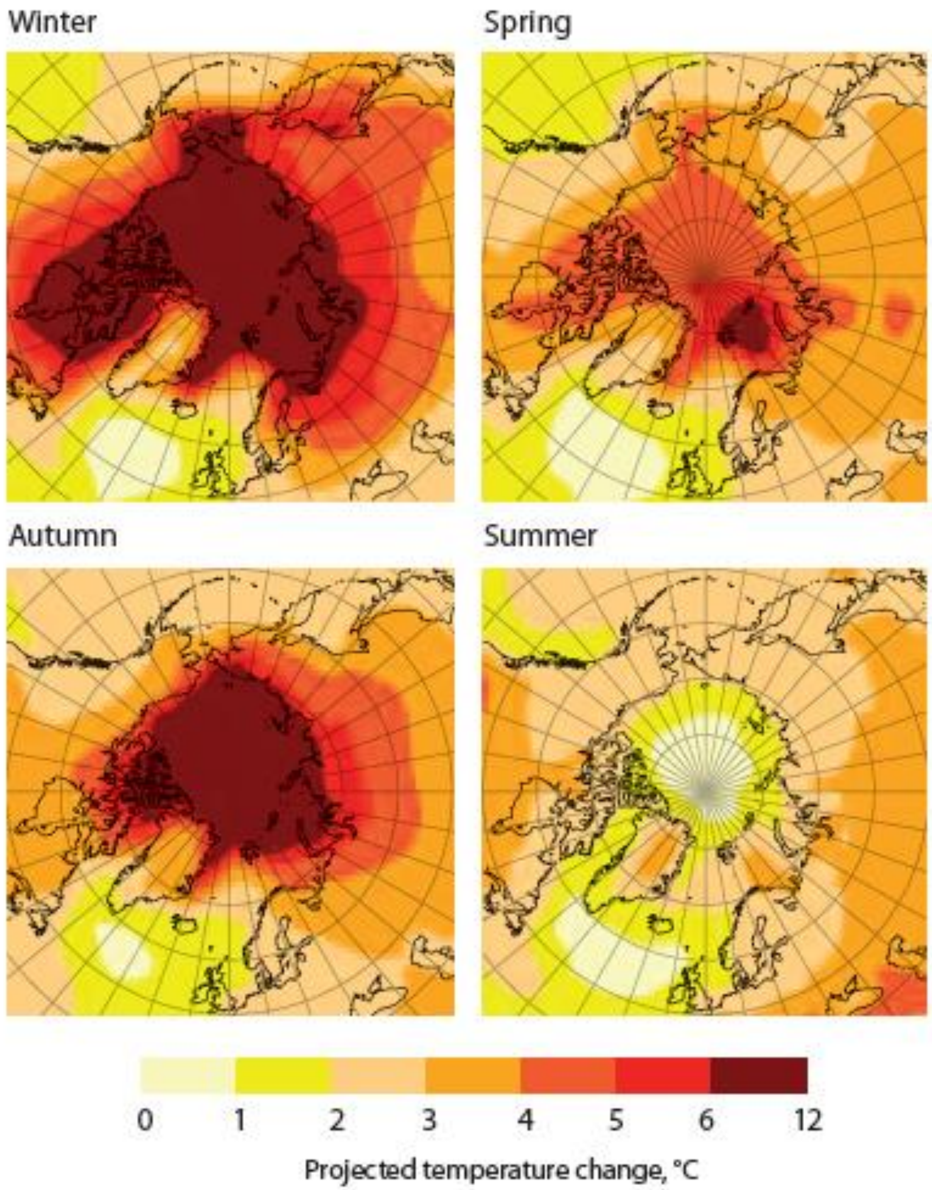

T2m change for 2070-2090, based on a selected subset of CMIP3 models, forced by A1B emission scenario (Walsh et al., 2008; Overland et al., 2011)