# The role of Fram Strait winter cyclones on sea ice flux and on Spitsbergen air temperatures

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[1] The link between high latitude Atlantic winter cyclone activity and both the climate of Spitsbergen and Fram Strait ice export is examined. Cyclones are more frequent over Fram Strait in relatively mild, low ice export, winters and are associated with south-southwesterly flow around anomalous high pressure over Scandinavia. There is an increased tendency for cyclogenesis to occur off the northeast Greenland coast and East Greenland Current in those winters. Fram Strait cyclones then typically continue into the western Arctic basin north of Greenland and Canada. Anomalously cold/high ice export winters have higher cyclone activity in the Barents Sea and Eurasia side of the Arctic basin. Cyclones in mild winters have close proximity to Spitsbergen and may simultaneously advect Arctic sea ice across Fram Strait, possibly accounting for the low (under 30%) shared variance in winter time series of temperatures and sea ice export. **Citation:** Rogers, J. C., L. Yang, and L. Li (2005), The role of Fram Strait winter cyclones on sea ice flux and on Spitsbergen air temperatures, *Geophys. Res. Lett.*, *32*, L06709, doi:10.1029/2004GL022262.

## 1. Introduction

[2] The area around Spitsbergen and Fram Strait is one of the most climatically sensitive in the world. Early in the 20th century, stations on Greenland and islands of the northernmost Atlantic experienced an abrupt warming from 1919–1926 [*Rogers*, 1985] that appears in time series of Arctic mean temperature [*Jones and Moberg*, 2003, Figure 2]. The Arctic warming in the Atlantic sector was highest on Spitsbergen, where winter temperatures rose nearly 7°C [*Rogers*, 1985] and local sea ice diminished. Fram Strait, west of Spitsbergen, is characterized by large meridional exchanges of sea ice and oceanic heat [*Vinje et al.*, 1998]. Southward flux of sea ice and relatively cold fresh water in the East Greenland Current has been linked to the Great Salinity Anomaly of the late 1960s [*Dickson et al.*, 1988]. The comparatively smaller northward volume flux of the West Spitsbergen Current has peak heat transport in winter and exhibits higher interannual variability than the East Greenland Current [*Schauer et al.*, 2004].

[3] The correlation between Fram Strait sea ice export and the North Atlantic Oscillation (NAO) is highly variable with time [*Schmith and Hansen*, 2003] and has been relatively high and positive since the mid-1970s [*Kwok and Rothrock*, 1999; *Vinje*, 2001], associated with north-eastward displacement of the mean low-pressure area toward the Norwegian Sea in many winters [*Hilmer and Jung*, 2000]. This decadal scale spatial displacement in the Icelandic low, in relation to ice and climate around Fram Strait, is likely linked to changes in synoptic cyclone activity in the northernmost Atlantic. *Zhang et al.* [2004, Figure 2a] show that cold season cyclone frequencies are climatologically quite high around Fram Strait and Spitsbergen in addition to the high cyclone counts occurring around Iceland and in the Norwegian and Barents Seas. This paper specifically examines the cyclone activity around Fram Strait, evaluating its role in Spitsbergen's winter temperature variability and Fram Strait ice export, as well as its relation to cyclone activity near Iceland and over the Norwegian and Barents Seas.

## 2. Data

[4] Spitsbergen air temperatures include monthly averages at Isfjord Radio (1912–1976; 78.1°N, 13.6°E) and Lufthavn (1977–2003; 78.3°N, 15.5°E), obtained from the Global Historical Climate Network data set (Version 2.3). Coldest and warmest months (Table 1) are determined using departures from long-term normals obtained separately for each station. Fram Strait monthly sea ice volume fluxes from 1950–2000 [*Vinje*, 2001] are parameterizations based on the cross-Strait pressure differences between points 80°N, 10°W and 73°N, 20°E. The parameterized monthly ice volumes are formulated based on extensive ice draft measurements by upward looking sonars from 1990–1996 [*Vinje et al.*, 1998] and ice velocities obtained from synthetic aperture radar data. Southward sea ice volume flux is highest in JFM [*Vinje*, 2001], which are also the three coldest months in Spitsbergen's annual air temperature cycle. Winters having the highest and lowest sea ice volume fluxes appear in Table 1. The NAOI is updated [http://polarmet.mps.ohio-state.edu/NAO] from *Rogers* [1984] and based on pressure differences between Ponta Delgada, Azores, and Akureyri, Iceland.

[5] Atmospheric circulation data consist of NCEP/NCAR reanalysis monthly sea level pressure (SLP). Analysis of surface cyclone frequencies is performed using *Serreze*'s [1995] cyclone tracking algorithm on NCEP/NCAR 6 hourly $2.5° \times 2.5°$ grid data. The algorithm identifies SLP cyclones and tracks them from cyclogenesis to cyclolysis across the hemisphere. It starts by identifying grid points where SLP is a set interval lower than that occurring at the surrounding 8 grid points [*Serreze*, 1995; *Zhang et al.*, 2004]. The incipient cyclone must be more than 1200 km from its nearest neighbor to be considered a separate storm. It must subsequently (6 hours later) be found within a 600 km radius of its earlier location in order to be considered the

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**Table 1.** List of the Warmest and Coldest Spitsbergen Winters (JFM), 1950–2003, and Winters With Lowest and Highest Fram Strait Ice Export, 1950–2000

| Warm | Cold | Low | High |
|---|---|---|---|
| 1950 | 1959 | 1954 | 1952 |
| 1954 | 1963 | 1956 | 1955 |
| 1956 | 1965 | 1963 | 1957 |
| 1957 | 1966 | 1964 | 1958 |
| 1958 | 1967 | 1972 | 1962 |
| 1972 | 1968 | 1973 | 1966 |
| 1974 | 1969 | 1974 | 1967 |
| 1976 | 1977 | 1976 | 1968 |
| 1984 | 1978 | 1980 | 1978 |
| 1985 | 1979 | 1984 | 1981 |
| 1990 | 1981 | 1985 | 1982 |
| 1991 | 1986 | 1986 | 1983 |
| 1996 | 1988 | 1987 | 1994 |
| 1999 | 1989 | 1990 | 1995 |
| 2000 | 1993 | 1991 | 1998 |
| 2001 | 1998 | 1996 | 2000 |

same cyclone. The incipient low-pressure area is no longer considered a cyclone and discarded from the analysis if it lasts less than 12 hours. The analysis subsequently interpolates pressures and places cyclones onto a 50 km × 50 km grid using a bilinear interpolation routine [*Li*, 2003].

## 3. Results

[6] The impact of the northeastward shift in the mean winter Icelandic low since the 1970s [*Hilmer and Jung*, 2000] has been to decrease the NAO correlation to Spitsbergen JFM air temperatures from a 1950–1977 peak r = +0.53 (n = 28, 99% confidence) to r = +0.10 from 1978–2003 (non-significant). The NAO correlation with Fram Strait ice volume export [*Vinje*, 2001] is negative (r = −0.34; 90%) from 1950–1977 but positive thereafter (r = +0.33; 80%). Thus, unusually low mean pressure near Iceland (+NAO) is linked to warmer, low ice export, conditions from 1950–1977. More recently however, the northeastward displacement of the Icelandic low toward the Norwegian Sea leads to advection of air from polar and Eurasian sources and high ice export, as well as more frequent below normal Spitsbergen temperatures during NAO + events. Furthermore, the JFM temperature/Fram ice export correlation is r = −0.54 (99%) from 1950–1977 and r = −0.28 (not significant) from 1978–2000, indicating that shared variance ($r^2$) is under 30% in both periods. Five winters in Table 1 (1957, 1958, 1963, 1986, 2000) contribute, for example, to the weak negative correlations when warm (cold) Spitsbergen temperatures combine with high (low) Fram Strait ice export.

[7] To illustrate the pressure field changes with time, mean SLP is obtained for the warmest and coldest Spitsbergen winters, as well as those having lowest and highest Fram Strait ice export (Table 1). The mean pressure differences (warm minus cold Spitsbergen) for the 1950–1977 subperiod, identified in the correlations above, exhibit significant negative values around Denmark Strait and Greenland (Figure 1a), where below (above) normal SLP occurs in relatively warm (cold) winters. The pressure differences for winter Spitsbergen temperature cases 1978–2003 (not shown) are small and everywhere non-significant, a much weaker version of Figure 1c. Mean pressure differences between low and high ice export

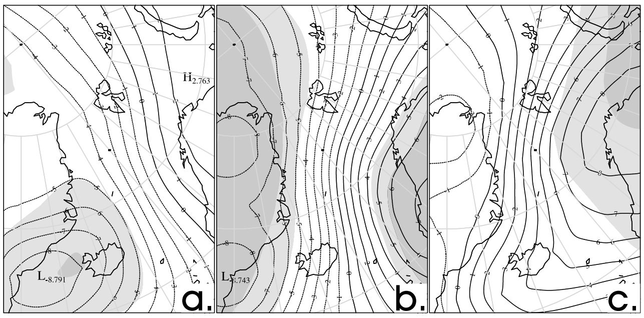


**Figure 1.** Mean differences in SLP (hPa) occurring between (a) warmest and coldest Spitsbergen winters 1950–1977, and between lowest and highest Fram Strait ice export winters from (b) 1950–1977 and (c) 1978–2000. Light and dark shading indicate differences statistically significant with 95% and 99% respectively.

winters (Figure 1b; 1950–1977) are highly significant, exhibiting large negative values across Greenland and northward into the Arctic basin, with positive values over Scandinavia. Greenland was particularly dominated by anomalous high pressure in the 1960s that produced nearby advection of Arctic sea ice and fresh water flux over the East Greenland Current before and during the Great Salinity Anomaly [*Dickson et al.*, 2000, Figure 16]. Greenland area pressure differences weaken dramatically in Figure 1c and the Scandinavian center in Figure 1b is displaced toward the Barents Sea. Low pressure in the Norwegian and Barents Seas is more significant in producing Arctic ice export in the period since 1977 [*Hilmer and Jung*, 2000, Figure 4]. The meridionally oriented isopleths in Figures 1b and 1c shift west in 1978–2000 (note the zero line) and reverse sign over Iceland and Spitsbergen (illustrating the NAO sign reversal between subperiods) but bring anomalous southwesterly (northeasterly) flow over Fram Strait in warm/low ice (cold/high ice) winters in both subperiods.

[8] Cyclone frequencies are obtained for the extreme winters of Table 1, as are the mean differences occurring between them. Figures 2 and 3 illustrate results for 1978–

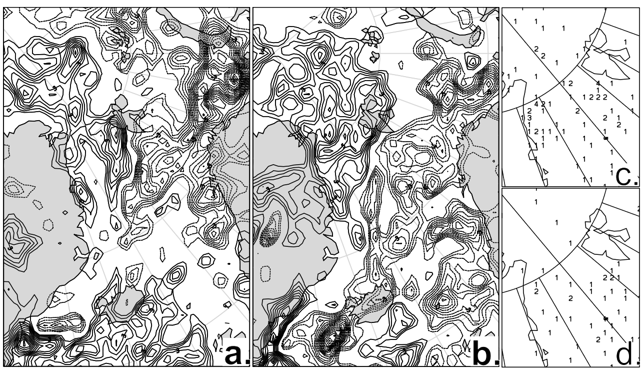


**Figure 2.** Winter cyclone frequency differences since 1977 obtained by subtracting cyclone counts in (a) cold Spitsbergen winters from those in warm winters, and (b) high ice export winters from low export winters. The zero contour is removed. Total number of occurrences of cyclogenesis (zero values excluded) at grid points around northeastern Greenland, 1978–2000, for (c) low Fram Strait ice export and (d) high ice export.

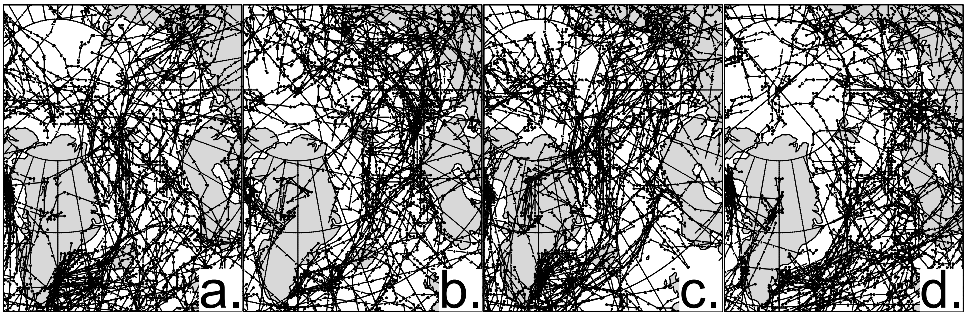


**Figure 3.** Cyclone trajectories during 6 winter months, 1978–2000, when Spitsbergen was (a) warmest and (b) coldest, and when Fram Strait had (c) lowest and (d) highest ice flux.

2003, the period in which Spitsbergen temperature and Fram Strait ice flux variability was much less impacted by time-averaged mean pressure field variability near Greenland or Iceland (e.g., Figure 1c). Positive cyclone frequency differences (warm minus cold) occur across Fram Strait, over Spitsbergen, and into the Arctic basin north of Greenland to the North Pole, representing more cyclones in warm Spitsbergen winters compared to cold (Figure 2a). The positive cyclone frequency differences around Fram Strait are separated from another maximum centered near Iceland. This pair of positive cyclone frequency differences also appears during 1950–1977 (not shown), although less separation occurs between the two centers. Negative frequency differences (Figure 2a) occurring across the Norwegian and Barents Seas and represent lower (higher) cyclone frequencies in relatively warm (cold) winters. The same analysis for Fram Strait JFM ice export extremes (Figure 2b; low export minus high) reveals more extensive Arctic basin positive cyclone differences than occurs in Figure 2a, representing more frequent cyclones in low ice flux winters. Negative differences (Figure 2b) now occur around Iceland and extend northeastward to the Barents Sea.

[9] To better visualize cyclone movement, storm tracks are obtained for sets of the 6 most extreme months since 1978. In warm months (Figure 3a), compared to cold (Figure 3b), more cyclones occur (i) off the northeast coast of Greenland, (ii) over and west of Spitsbergen, and (iii) over the western Arctic basin north and northwest of Greenland. Cases (i) and (ii) are consistent with the notion of warm sectors or occlusions moving across Spitsbergen. Cyclones in unusually cold winters (Figure 3b) tend to avoid Fram Strait but are abundant over the Barents Sea and toward the east, north of Eurasia. The apparent Eastern/Western Hemisphere change in cyclone paths over the Arctic Ocean Basin between Figures 3a and 3b appears as positive differences in Figure 2a and negative differences over the Barents Sea. Some winter cyclones traverse Greenland in Figures 3a and 3b, and other examples of this are described by *Li* [2003].

[10] A clear concentration of cyclones moving toward Fram Strait and Spitsbergen occurs in the 6 months with lowest ice export (Figure 3c). The 6 high ice export months (Figure 3d) have few cyclones near Greenland or Fram Strait but many storms cluster in the Norwegian and Barents Seas. Figure 3d is characterized by relatively low cyclone activity in the Arctic basin north of 80°N, having even fewer storms than appear in the analogous cold Spitsbergen case (Figure 3b). The large differences between Figures 3c and 3d are part of the broad Arctic basin positive differences of Figure 2b.

[11] The presence of cyclones over Fram Strait in low ice winters (Figure 3c) is also linked to enhanced cyclogenesis (Figure 2c) at grid points immediately adjacent to the northeast Greenland coast over the East Greenland Current. Grid point cyclogenesis frequencies are much lower in high ice export winters (Figure 2d) with development tending to occur farther from Greenland's coast. Anomalous southwesterly (northeasterly) flow accompanying these low (high) ice export winters, per Figures 1b and 1c, is relatively barotropic, extending into the upper troposphere (not shown). Warm Spitsbergen winters are also linked to high cyclogenesis near the northeast Greenland coast, as in Figure 2c, and much less activity in cold winters.

## 4. Discussion

[12] This study shows the spatial link between local cyclone activity and both Spitsbergen winter temperatures and Fram Strait ice export. Fram Strait regional cyclone activity is more frequent during relatively mild Spitsbergen winters, as well as when Arctic ice export is relatively low (Figures 2a and 2b). Concurrently, cyclogenesis is more common along the northeast coast of Greenland (Figure 2c). This synoptic activity would appear to be part of a localized cold season cyclone frequency maximum found to occur west and southwest of Spitsbergen [*Zhang et al.*, 2004] that is separated from two other maxima over the Barents Sea and southwest of Iceland. It is apparent from Figures 2 and 3 that interannual Fram Strait cyclone activity is out-of-phase with that of the Barents Sea; the three northernmost Atlantic centers identified by *Zhang et al.* [2004] will not simultaneously be active in any given winter month. Mean high pressure over the Norwegian and Barents Seas (e.g., the case represented by warm winters in Figure 1c), would allow fewer cyclones in that area but frequent cyclone activity and cyclogenesis occurs near Fram Strait accompanying anomalous surface and upper air southwesterly flow. Conversely, low Norwegian and Barents Seas pressure occurs with few Fram Strait cyclones (e.g., Figures 3b and 3d). The combination of anomalous southwesterly flow with the placement of frequent cyclogenesis very close to the Greenland coast (Figure 2c) is suggestive of lee cyclogenesis processes in mild, low ice export winters.

[13] The time series of Spitsbergen temperatures and Fram Strait ice export have considerable unshared variance since

1950. For example, some relatively warm Spitsbergen winters occur with high ice export, and conversely. Cyclones in milder winters traverse areas just west of Spitsbergen (Figures 2a and 3a), bringing a warm sector over the island. Their close proximity to the island suggests cold air and southward ice movement may occur to their west over the East Greenland Current, illustrating the potential impact of synoptic-scale activity on the time series correlations. Southward ice export may be directly influenced both locally, by cyclones near Spitsbergen (in warm winters), and by Barents Sea cyclones (in cold winters). This study has shown that the Fram Strait region cyclone center [*Zhang et al.*, 2004] represents a crossroads of cyclone activity into the high Arctic. During relatively mild winters, cyclones are prevalent around Fram Strait and enter into the western Arctic across northern Greenland. Fewer Fram Strait cyclones occur in cold winters, preferring instead the Barents Sea and seas north of Eurasia. Differences in high Arctic basin cyclone activity appear to be even more dramatic between low and high Fram Strait ice export winters (Figures 3c and 3d) and the SLP difference index used by *Vinje* [2001] to parameterize ice volume export may also serve as a rough gage of overall high Arctic basin cyclone activity.

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## References

Dickson, R. R., J. Meincke, S.-A. Malmberg, and A. J. Lee (1988), The "Great Salinity Anomaly" in the northern North Atlantic 1968–1982, *Prog. Oceanogr.*, *20*, 103–155.

Dickson, R. R., et al. (2000), The Arctic Ocean response to the North Atlantic Oscillation, *J. Clim.*, *13*, 2671–2696.

Hilmer, M., and T. Jung (2000), Evidence for recent change in the link between the North Atlantic Oscillation and Arctic sea ice export, *Geophys. Res. Lett.*, *27*, 989–992.

Jones, P. D., and A. Moberg (2003), Hemispheric and large-scale surface air temperature variations: An extensive revision and update to 2001, *J. Clim.*, *16*, 206–223.

Kwok, R., and D. A. Rothrock (1999), Variability of Fram Strait ice flux and North Atlantic Oscillation, *J. Geophys. Res.*, *104*, 5177–5189.

Li, L. (2003), Greenland's influence on cyclone activity, Ph.D. diss., 147 pp., Ohio State Univ., Columbus.

Rogers, J. C. (1984), The association between the North Atlantic Oscillation and the Southern Oscillation in the Northern Hemisphere, *Mon. Weather Rev.*, *112*, 1999–2015.

Rogers, J. C. (1985), Atmospheric circulation changes associated with the warming over the northern North Atlantic in the 1920s, *J. Clim. Appl. Meteorol.*, *24*, 1303–1310.

Schauer, U., E. Fahrbach, S. Osterhus, and G. Rohardt (2004), Arctic warming through Fram Strait: Oceanic heat transport from 3 years of measurements, *J. Geophys. Res.*, *109*, C06026, doi:10.1029/2003JC001823.

Schmith, T., and C. Hansen (2003), Fram Strait ice export during the nineteenth and twentieth centuries reconstructed from a multiyear sea ice index from southwestern Greenland, *J. Clim.*, *16*, 2782–2791.

Serreze, M. C. (1995), Climatological aspects of cyclone development and decay in the Arctic, *Atmos. Ocean*, *33*, 1–23.

Vinje, T. (2001), Fram Strait ice fluxes and atmospheric circulation: 1950–2000, *J. Clim.*, *14*, 3508–3517.

Vinje, T., N. Nordlund, and Å. Kvambekk (1998), Monitoring ice thickness in Fram Strait, *J. Geophys. Res.*, *103*, 10,437–10,449.

Zhang, X., J. E. Walsh, J. Zhang, U. S. Bhatt, and M. Ikeda (2004), Climatology and interannual variability of Arctic cyclone activity: 1948–2002, *J. Clim.*, *17*, 2300–2317.

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