ARCTIC
VOL. 43, NO. 1 (MARCH 1990) P. 55-59

Winter Offshore/Onshore Wind Differences in Southeastern Hudson Bay, Canada

PIERRE LAROUCHE[1]

(Received 23 March 1989; accepted in revised form 26 July 1989)

ABSTRACT. Acquisition of two 38-day wind data sets collected over a fast-ice shelf and at a nearby coastal weather station (Kuujjuarapik) in Hudson Bay allowed the calculation for the first time of an offshore/onshore wind speed ratio for an ice-covered environment. Mean wind over the ice was 29% higher than at the coast, compared to values of 65% for open ocean locations. This reflects the effect of the higher drag coefficient of the sea ice that more strongly attenuates the wind than does the sea surface. The data set also allowed the evaluation of the change in the wind field by local topography. Thus, a strong orographic effect was found in the SW quadrant, as winds of less than 5 m·s^{-1} were deflected toward the SE and NW.

Key words: Arctic, Subarctic, weather, winds, Hudson Bay, comparison, orographic effects, offshore, ice shelf

RÉSUMÉ. L'acquisition pendant 38 jours de deux enregistrements de vent mesurés sur une banquise de glace fixe et à une station météorologique côtière (Kuujjuarapik) à la Baie d'Hudson a permis le calcul pour la première fois d'un ratio de vitesse de vents pour un environnement couvert de glace. Le vent moyen sur la glace était de 29% plus élevé que sur la côte comparé à des valeurs oscillant autour de 65% pour une situation en eau libre. Ceci réflète l'effet du plus fort coefficient de trainée de la glace de mer qui atténue plus fortement le vent que la surface de l'océan. L'ensemble de données a aussi permis l'évaluation de la modification du champ de vent par la topographie locale. Un fort effet orographique a été noté dans le quadrant sud-ouest alors qu'aucun vent de moins de 5 m·s^{-1} n'a été enregistré sur la côte, les vents étant déviés vers le sud-est et le nord-ouest.

Mots clés: Arctique, subarctique, météorologie, vent, baie d'Hudson, comparaison, effets orographiques, banquise de glace

INTRODUCTION

"How representative of offshore conditions are the wind data recorded at a coastal station?" This question is often asked by scientists working in the coastal environment, where it is difficult to measure winds accurately. Most of the existing comparisons have been made using data taken in the open sea by weather ships, buoys or on remotely situated islands (Dorman, 1982; Sethuraman and Raynor, 1980; Marsden, 1987; Hsu, 1979, 1981; Weisberg and Pietrafesa, 1983; Danard, 1977), leading to predictive models for offshore winds based on onshore data (Hsu, 1986).

Even if weather is particularly important for operational planning, such comparisons are rarely possible in the Arctic (Canada, 1976; Fraser, 1983; Hill *et al.*, 1978; Keliher and Earle, 1979; Maxwell, 1980; Conway, 1976). The most extensive study was made by Olson (1986), who compared results from different numerical models as well as data supplied by passing ships with measurements made at various coastal stations throughout the Canadian Arctic for both summer and winter. Most other studies were made during the summer, when it is easier to install temporary weather stations along the coasts or on islands or moor buoys in the offshore. Moreover, the selected sites were often located far away from permanent coastal stations, thus rendering offshore/onshore comparisons difficult.

Comparisons in the wintertime between onshore and offshore wind velocities are almost non-existent because of the difficulty in making measurements at offshore locations due to the drifting ice and severe weather. As the frozen ocean has quite different attenuation characteristics from that of open seas, there is a definite need for more research in these areas. Such an opportunity was recently given to us, as we were able to install a weather station on a fast-ice shelf during the winter for a 38-day period. The objective of this study was thus to describe and discuss the differences existing between offshore wind speeds and wind velocities at the coast during the winter season.

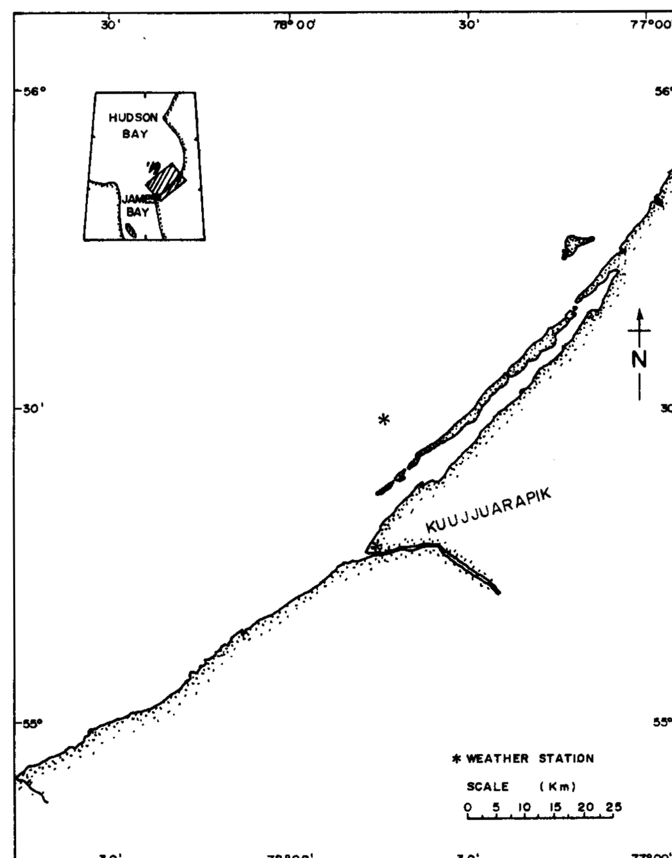

FIG. 1. Study area showing the location of both weather stations.

[1]Institut Maurice-Lamontagne, Ministère des Pêches et des Océans, B.P. 1000, Mont-Joli, Québec, Canada G5H 3Z4

METHODOLOGY

The two data sets used in the experiment were collected in southeastern Hudson Bay (Fig. 1) during the course of an oceanographic research project in the winter of 1986. This location was selected because almost every winter the ice shelf between the Belcher Islands and the Quebec coast is very stable for periods of up to three months (Larouche and Galbraith, 1989), thus allowing the installation of a weather station without the risk of losing it with drifting ice.

The first sampling location was situated 12 km offshore and consisted of an Aanderaa automated weather station (Fig. 2) equipped with sensors for wind direction, wind speed, pressure, temperature and solar radiation. The measurements were made at a height of 5 m over the ice surface. To prevent interference, the station was located 100 m from the tent containing the data logger. The camp was installed on a smooth floe having a diameter of approximately 1 km. Ice ridges around the floe did not exceed 2 m. Wind speed was measured by a cup anemometer having a threshold of 0.5 $m{\cdot}s^{-1}$ and an accuracy of 0.2 $m{\cdot}s^{-1}$ (Aanderaa, 1987). Direction was measured with a small vane having an accuracy of better than 5°.

The second data set was acquired 25 km away from the ice station in the coastal community of Kuujjuarapik at the weather station operated by Atmospheric Environment Service of Canada (St. # 7103536). Wind speed and direction were measured by means of a cup and vane anemometer at a height of 10 m over the land surface, thus 35 m above mean sea level. Winds were measured every hour by the station personnel by observing graphic recorders during a one-minute period and recording estimated mean wind and direction over that period. Wind speed was measured to the closest knot and direction to the closest 10°. The Aanderaa station recorded data at 10-minute intervals between 27 March and 3 May, except for a 5-day period when a dead battery interfered. The data were recorded on magnetic tapes. Wind speed estimation consisted of an average over the 10-minute period, while direction was measured instantaneously at the end of the period. For this comparison, however, only the data points taken at the same time as in Kuujjuarapik were retained. The series length was thus reduced to 748 points.

FIG. 2. Weather station located on the fast-ice shelf.

In order to take into account the different height of the sensors, the winds recorded at the offshore location were adjusted to a 35 m height using a logarithmic wind profile:

$$U_z = U^{*}{\cdot}k^{-1} \ln (z/z_0)$$

where U_z is the wind speed at height z above the mean sea level, U^* is the shear velocity, k is the von Karman constant (0.4) and z_0 is the roughness length.

Using a 10 m drag coefficient (U^*/U_{10}) of 1.55 x 10^{-3} (Overland, 1985), we calculated a roughness length of 0.0387 cm, thus leading to a ratio U_{35m} / U_{5m} of 1.206. All 5 m wind observations were thus adjusted by this ratio prior to other analysis.

RESULTS AND DISCUSSION

Offshore/Onshore Wind Speed Ratio

Figure 3 shows wind speed histograms for the two locations. Some differences exist between the two records. First, there is an unexpected frequency drop in the wind speed in the 2 – 3 $m{\cdot}s^{-1}$ range for the Kuujjuarapik record. This pattern is not seen on the ice shelf data, where the distribution closely

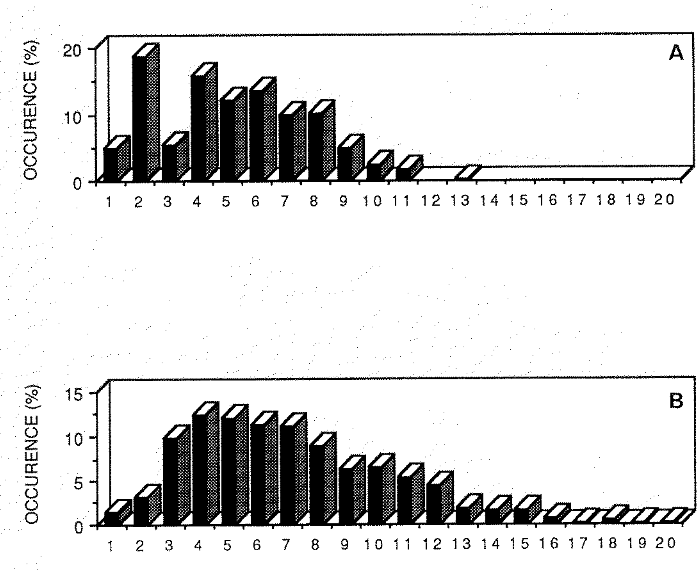

FIG. 3. Wind speed histogram. A: Kuujjuarapik; B: ice shelf.

resembles a gamma law. The high percentage of winds in the 1 – 2 m·s^{-1} range for the onshore station seems to indicate that most winds in the next higher range are probably recorded in Kuujjuarapik as being in the 1 – 2 m·s^{-1} range instead. This anomaly may be the result of human or mechanical factors. Wind speed distributions for similar periods over the past years indicate that this kind of distribution occurred consistently since 1977, practically eliminating the human factor as the source of the anomaly. It thus seems to be a permanent characteristic of data from this station, probably related to the instruments or their location.

The second difference in the distribution patterns was the presence of stronger winds on the ice shelf than onshore. This indicates stronger wind attenuation over the land due to a higher surface roughness. Approximately 16.8% of the winds were above 10 m·s^{-1} at the ice camp, compared to only 2% at Kuujjuarapik. Mean recorded wind speed was 6.04 m·s^{-1} on the ice and 4.68 m·s^{-1} at the coast, leading to an offshore/onshore ratio of 1.29.

Using the results of Olson (1986) for Kuujjuarapik, the offshore/onshore ratio falls between 1.6 and 1.8 for the wintertime. Values of this order are also found for open ocean situations (Sethuraman and Raynor, 1980). Our value is thus much lower than these and does not fit with the predictive algorithm of Hsu (1986) relating offshore winds to observed land winds. His formula was developed for the open seas using data from all over the world, including some values from arctic areas (Alaska). The ratio calculated by Hsu (1986) for 4.5 m·s^{-1} winds was 1.54. This higher value was probably the result of a relatively small drag coefficient for the open sea surface. Using the mean wind speed recorded on the ice shelf, we calculate a drag coefficient of 1.16×10^{-3} for an open water situation using equations given by Garratt (1977). On the other hand, drag measurements made on large ice floes yielded a value of 1.55×10^{-3} (Overland, 1985), not including form drag that contributes significantly to the total drag coefficient (Arya, 1973), which could then easily reach 3×10^{-3} (Overland, 1985). The sea ice drag coefficient is thus about twice the water drag coefficient, which in turn affects in the offshore/onshore wind speed ratio. It thus appears from our results that a ratio closer to 1.3 should be used to predict offshore winds in ice-covered areas from observed coastal winds.

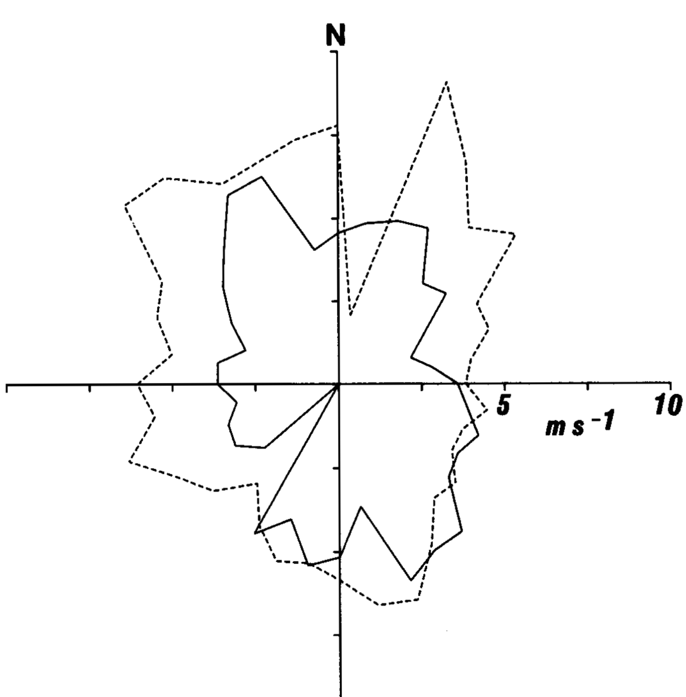

FIG. 4. Directional mean wind speed distribution (solid line is Kuujjuarapik).

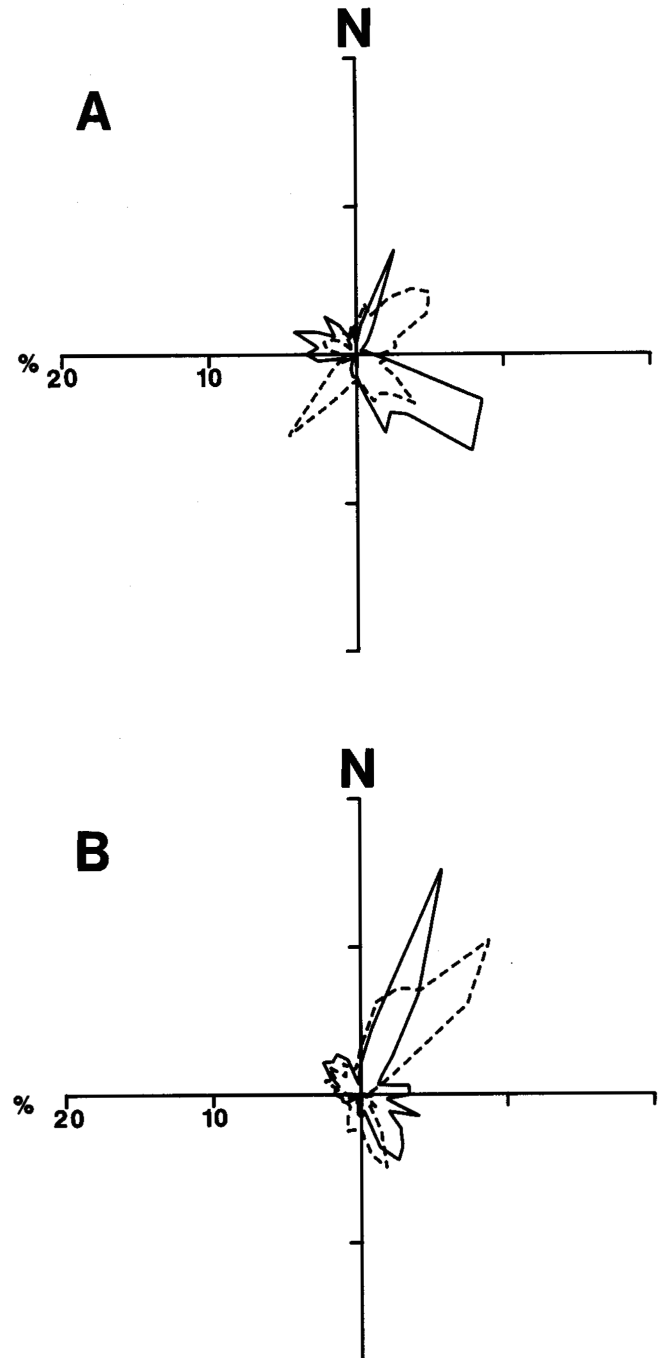

FIG. 5. Directional frequencies for both locations (solid line is Kuujjuarapik) and for two speed ranges. A: 0 – 5 m·s^{-1}; B: 5 – 10 m·s^{-1}.

This ratio, however, represents the mean situation. There are some differences locally, as the ratio is not constant for all wind directions, as shown by the directional mean wind speed distribution (Fig. 4). Winds are stronger on the ice between 20 and 70° and between 230 and 360°. For other directions, the intensity of the wind is unaffected. The ratio between speeds on the ice and at the coast is 1.54 for onshore winds (240–350°) and 1.26 for offshore winds (20–220°). This again indicates stronger wind attenuation over the land than over the ice.

Local Orographic Effects

Besides velocity differences, winds recorded at the coast are often distorted by local orographic effects. Figure 5 shows the directional frequencies for both locations and two velocity ranges. For brevity, winds of less than 5 $m \cdot s^{-1}$ are called weak and those over this value, strong. Some differences exist between the two records. First, for both speed ranges the location of the NE peak in Kuujjuarapik is rotated counterclockwise to the peak on the ice. When winds are weak, the strong SW peak observed on the ice is completely missing at the coastal station, while there are broader peaks in the SE and NW quadrants. Finally, for stronger winds an eastern peak appears in Kuujjuarapik, while it is not recorded at the ice station. Strong winds between 70 and 110° at the coast are in fact recorded as 65° winds on the ice shelf.

All these differences can be explained by the local topography (Fig. 6). The 200 m elevation at 60° seems likely to cause the wind deviations observed in the NE quadrant. Its effects, however, differ slightly for the different wind speeds. For weak winds, all the air flow seems deviated to the right of the obstacle, thus producing the sharp change observed in the peak position. For stronger winds, it looks as if the air sometimes deviated to the left of the range and flowed along the river valley, leading to the observed eastern peak in Kuujjuarapik. This happened approximately 20% of the time, while for the other 80% the wind went around the obstacle to the right.

Another important orographic effect can also be seen in the SW quadrant. This time the most likely cause of the observed deflections was the 150 m elevation lying toward the SE. The situation in the SW quadrant is, however, more complicated, as winds were deflected in two directions. The SW winds recorded offshore were almost equally distributed between the SE (36%) and NW (38%) at the coast, explaining the broader peaks for these two directions. A closer examination of the data shows no correlation between the observed deflection and the original wind direction. There is also no correlation with the wind speed (Table 1). The deflection was almost equally distributed between the SE and the NW for the two speed ranges. The proportion of undeflected winds was, however, higher for stronger winds, indicating that orogra-

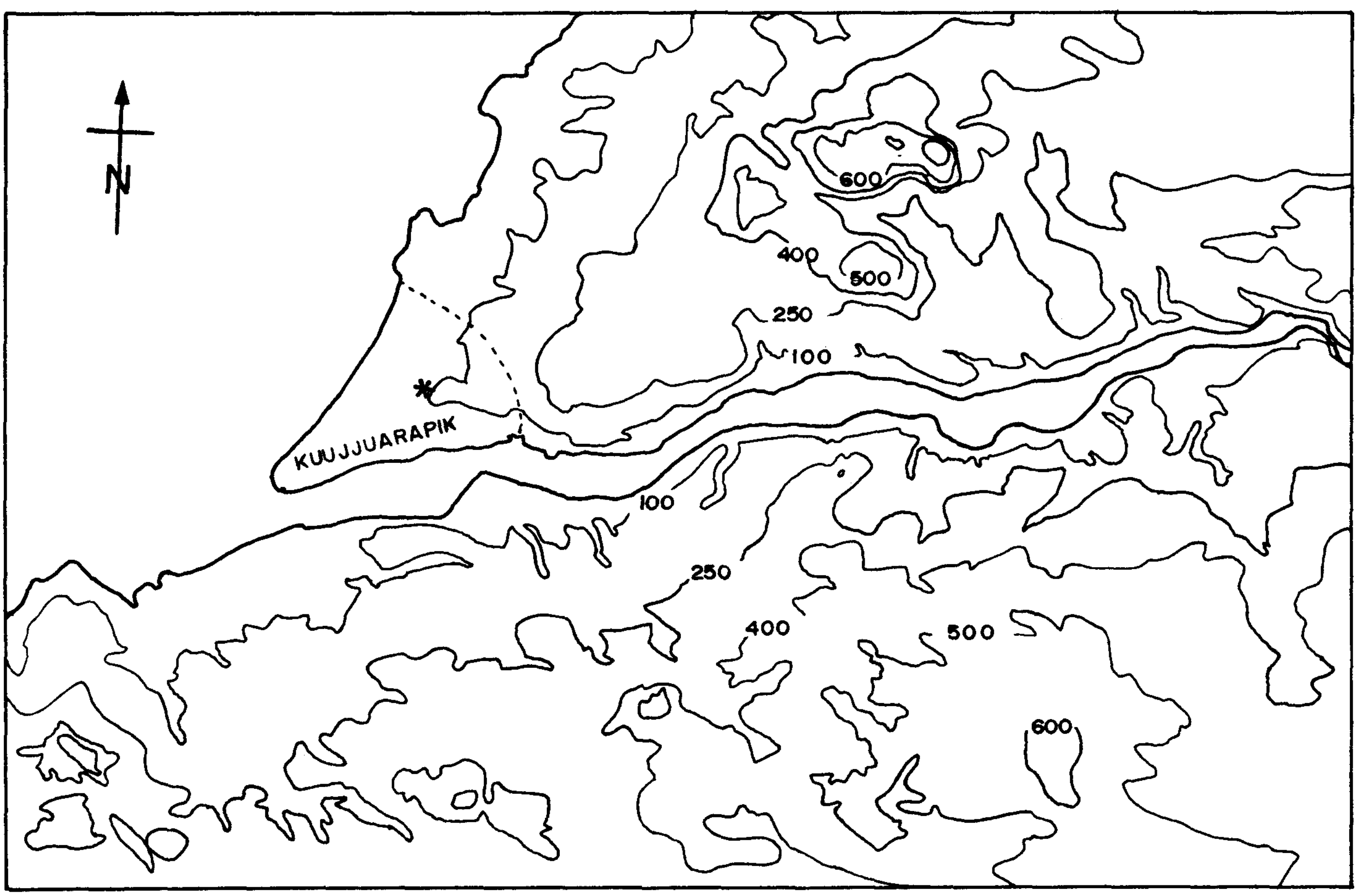

FIG. 6. Topography in the Kuujjuarapik vicinity. Heights are in feet.

phic effects become less important as wind speed increases. No explanation is possible at this time for these observations.

TABLE 1. Percentage of southwesterly winds deflected toward other directions

Wind speed	NW	SE	Undeflected
< 5 $m{\cdot}s^{-1}$	39.6	37.5	8.3
> 5 $m{\cdot}s^{-1}$	34.5	34.5	27.6

CONCLUSION

This study illustrates a strong difference between the open and frozen ocean. The offshore/onshore wind speed ratio for an ice cover is significantly different from that for an open ocean situation. For this location on the Hudson Bay coast, measured wind directions were close to those for offshore winds for most directions. Orographic effects were detected for two directions. For operational purposes, there is almost no error for NE winds observed at the coast, as only 20° separates them from offshore winds. Strong easterly winds should, however, be corrected as really coming from the NE on the ice shelf. Weak coastal winds observed from the SE have a 13% chance of being southwesterly offshore, and NW winds have a 26% chance of being the same. For higher wind speeds, the percentage is reduced to 7 and 10% for both directions respectively. As for the wind speed, differences of 35% occur at 35 m height. At a height of 5 m, the difference is reduced to only 12%.

ACKNOWLEDGEMENTS

The author thanks S. Cantin and D. Lachance for their help in the preparation and installation of the ice weather station and L. Corriveau for the drawings. Also thanks to the reviewers for their helpful comments.

REFERENCES

AANDERAA. 1987. Datasheet D152. Aanderaa Instruments, 560 Alpha St., Victoria, British Columbia, Canada.

ARYA, S.P.S. 1973. Air friction and form drag on arctic sea ice. AIDJEX Bulletin 19:43-57.

CANADA. 1976. A comparison of weather on the ice pack to that of coastal stations in the arctic islands. Ottawa: Environment Canada, Atmospheric Environment Service. 33 p.

CONWAY, F.J. 1976. A summer climate study for Barrow Strait, N.W.T. M.Sc. thesis, Department of Meteorology, McGill University, Montreal. 128 p.

DANARD, M. 1977. Environmental conditions off the east coast of Canada: sites 1 and 2. Imperial Oil Limited, Production Research Division. Arctic Petroleum Operators Association Report 138-22, Calgary, Alberta, Canada. 88 p.

DORMAN, C.E. 1982. Winds between San Diego and San Clemente Island. Journal of Geophysical Research 87:9636-9646.

FRASER, D.B. 1983. Climate of Northwestern Baffin Bay and Lancaster Sound. Environmental Studies No. 29, Northern Affairs Program. Ottawa: Indian and Northern Affairs Canada. 93 p.

GARRATT, J.R. 1977. Review of drag coefficients over oceans and continents. Monthly Weather Review 105:915-928.

HILL, S.H., FISSEL, D.B., and SERSON, H. 1978. A study of wind and atmospheric pressure in Eastern Parry Channel, N.W.T., Summer 1977. Pacific Marine Science Report 78-21, Institute of Ocean Sciences, Patricia Bay, British Columbia, Canada. 59 p.

HSU, S.A. 1979. An operational forecasting model for the variation of mean maximum mixing heights across the coastal zone. Boundary-Layer Meteorology 16:93-98.

______. 1981. Models for estimating offshore winds from onshore meteorological measurements. Boundary-Layer Meteorology 20:341-351.

______. 1986. Correction of land-based wind data for offshore applications: a further evaluation. Journal of Physical Oceanography 16:390-394.

KELIHER, T.E., and EARLE, A.G. 1979. Comparison of meteorological data from Brevoort Island and the "Asiak" buoy. Eastern Arctic Marine Environmental Studies. Unpubl. ms., 6 p. Available at Esso Resources Canada Limited, Calgary, Alberta, Canada.

LAROUCHE, P., and GALBRAITH, P.S. 1989. Factors affecting fast ice consolidation in southeastern Hudson Bay, Canada. Atmosphere-Ocean 27:367-375.

MARSDEN, R.F. 1987. A comparison between geostrophic and directly measured surface winds over the Northeast Pacific Ocean. Atmosphere Ocean 25:387-401.

MAXWELL, J.B. 1980. The climate of the Canadian arctic islands and adjacent waters. Vol. 1. Ottawa: Environment Canada, Atmospheric Environment Service. 559 p.

OLSON, R. 1986. An assessment of Canadian Arctic wind data sets. Canadian Climate Centre Report 86-9. Unpubl. ms. 58 p. Available at Environment Canada, Atmospheric Environment Service, Downsview, Ontario, Canada.

OVERLAND, J.E. 1985. Atmospheric boundary layer structure and drag coefficients over sea ice. Journal of Geophysical Research 90:9029-9049.

SETHURAMAN, S., and RAYNOR, G.S. 1980. Comparison of mean wind speeds and turbulence at a coastal site and an offshore location. Journal of Applied Meteorology 19:15-21.

WEISBERG, R.H., and PIETRAFESA, L.J. 1983. Kinematics and correlation of the surface wind field in the South Atlantic Bight. Journal of Geophysical Research 88:4593-4610.