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Sea Level at Port Leopold, N.W.T., in 1848

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ABSTRACT. Forty-seven days of hourly sea level and atmospheric pressure data collected in 1848 at Port Leopold, N.W.T., are analyzed using modern time series computation techniques. Tidal analysis reveals a mixed tide but mainly semi-diurnal. A detailed analysis of the tidal data reveals that the time-keeping of the record was as good as today's standard. A high correlation between hourly sea level and atmospheric pressure data demonstrates the inverse barometric effect.

Key words: Arctic, sea level, tide, ice cover, free oscillation, lowpass, scatter diagram, time series, Resolute, Port Leopold

RÉSUMÉ. Les données horaires, pour 47 jours, du niveau de la mer et de la pression atmosphérique, recueillies en 1848 à Port Léopold, (T.N.-O), sont analysées à l'aide des méthodes modernes de calcul sur les séries chronologiques. L'analyse de la marée révèle la présence d'une marée mixte, mais principalement semi-diurne. L'analyse détaillée de la marée indique que la précision du temps utilisée alors est aussi bonne que celle d'aujourd'hui. L'effet barométrique inverse est démontré par une corrélation élevée entre les données du niveau de la mer et celles de la pression atmosphérique.

Mots clés: Arctique, niveau de la mer, marée, couvert de glace, oscillation libre, goulet, diagramme de dispersion, series chronologiques, Resolute, Port Léopold

> In September 1848 Her Majesty's ships Enterprize and Investigator entered the harbour of Port Leopold, in latitude 74°N. and longitude 91°W., for the purpose of establishing there a depôt of provisions, and of extending, in boats, the examination of the north, south, and west coasts of North Somerset, in search of the missing expedition under the command of Sir John Franklin. No sooner, however, were the ships anchored, than a heavy pack of ice was driven down upon, and completely closed the harbour's mouth, and this effectually preventing their egress, they were compelled there to pass the winter of 1848-49. [Ross, 1854]

Traditionally naval forces of world nation states have allocated ship time to duties close to or directly related to science. Perhaps the foremost example is that of HMS *Beagle* and the studies of Darwin (Stoddart, 1983), but there are others. It may be argued that much of this work is a form of self-preservation, as it is in hydrography and oceanography, for it behooves the mariner to know as much as possible about the water on which he travels. Likely it was such concern that led Captain Sir James Clark Ross to understand more about the changes of depth that occurred in Port Leopold (Fig. 1) during the enforced stay of his two ships. That is, his concern for the safety of his ships led him to ascertain by observation "the amount of irregularities" in the tide there, and he soon perceived a connection between the irregularities and variations of atmospheric pressure. In particular he mentioned the records of 9 and 20 November as evidence for such irregularity, but "occasioned by a heavy gale of wind," each of two days' duration. For the nine months they were locked in ice each ship carried out a similar program. According to Ross (1854:287):

> At the exact hour of mean time the heights of the tide and of the mercury in the barometer were taken; the former by the quartermaster, and the latter by the officer of the watch, who immediately entered both observations in the meteorological journal, . . .

Ross had made extensive tide observations in the course of his explorations — i.e., in New Zealand, Cape Horn and the Falkland Islands (p. 296), so he likely had a practised eye for irregularities in a record. Of course he lacked modern timekeeping (radio was not yet available), making it seem possible that the precision in his data with regard to time might have been rather less than now. As shown below, we were able to determine that the extent of systematic error in time was not greater than anticipated in modern tidal data.

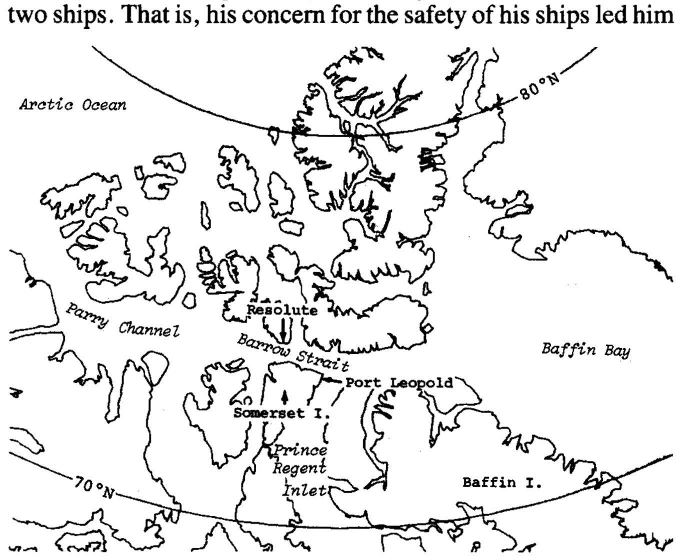

FIG. 1. Port Leopold is a relatively small indentation (5.5 × 2.5 km) on northeast Somerset Island facing Prince Regent Inlet and is about 170 km from Resolute.

Port Leopold, "once a favourite harbour for exploring expeditions and whalers" (Dunbar and Greenaway, 1956), is relatively shallow, 20 m at the mouth, and without apparent particular bathymetric feature, although it has not yet been adequately surveyed. Each winter it is covered with fast ice that probably attains a maximum thickness of about 2 m. It is known that an ice cover can influence long waves such as tides, particularly in areas where depth is limited, but not in areas as freely connected to the ocean as Port Leopold appears to be; for example, at nearby Resolute it was not possible to discern an influence of the ice cover on the main tidal constituents (Godin and Barber, 1980). The tide at the port is "mixed: mainly semidiurnal" (Dohler, 1964), with higher high water following lower low water; large tides range up to 2.5 m. The amplitude of M2 appears to be about 60 cm and that of K1 about 27 cm; the ratio (01 + K1)/(M2 + S2) is 0.51. In Ross's time series, i.e., the 47 days of hourly tide pole and barometer observations (Fig. 2), there are a number of values that appear to be the result of error, perhaps of transcription, and while the corrections to some values appear obvious, for the work here we adhere to the

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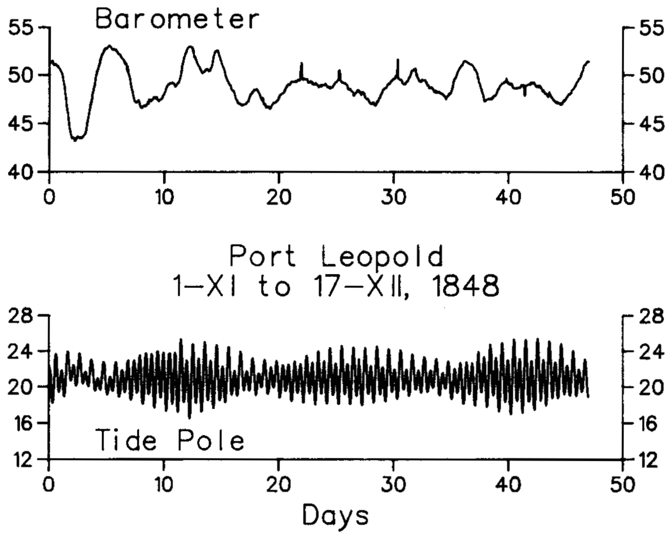

FIG. 2. Time series of the 47 days (1 November-17 December 1848) of hourly tide pole and barometer readings at Port Leopold tabulated by Ross (1854).

Royal Society account. From correspondence with Dr. D.E. Cartwright of the Bidston Observatory it seems that while some of Ross's data, e.g., sea temperature, are still available, the hourly values of sea level from either ship are not.

We had "in hand" an examination of recent Resolute tidal data and eventually reduced a length of data there similar to that for Port Leopold but for 1975. In this, in addition to the semidiurnal and diurnal constituents, we were able to identify others including the lunar monthly (Mm), lunar fortnightly (Mf), ter-monthly (9-day and 7-day), several shallow-water constituents and a short-period free oscillation of the harbour. A similar free oscillation of Port Leopold probably also occurs but cannot be discerned in hourly data; nevertheless, variance in the Port Leopold spectrum (Fig. 3) at 0.0305 cph (period of about 33 h) has been tentatively identified as the gravest mode of co-oscillation of parts of the system and the exterior ocean, as in Helmholtz resonance. That it is not seen in the Resolute spectrum suggests that Barrow Strait acts as a connecting channel to the exterior ocean (the current is variable in the channel, but sea level is not) and supports the Helmholtz resonance conjecture. Through simple application of well-known formulae to a variety of average configurations of depth, surface area, area of channel cross section, etc., it is possible to derive a number of periods of free oscillation close to that observed. For example, with Barrow Strait as a channel, a co-oscillation of parts of the Parry Channel system can be contrived to give a gravest period of oscillation close to 33 h.

Although the level of noise in Ross's data appears low, it is not as low as at Resolute. This could be due to the method of observation, which could contribute to non-systematic error in both time and level, or, more likely, due to the errors of transcription noted above. As well, that shallow-water constituents are not clearly seen in the Port Leopold material may be related to the level of noise, but it is possible that the thickness of the ice cover has an influence. At Resolute, for example, in late winter data some of these constituents are better defined than in early winter data, while at another location (Tuktoyaktuk) some shallow water constituents are stronger when an ice cover is in place (Barber *et al.*, 1984).

Interestingly, there is less power at longer periods in the Port Leopold spectrum — e.g., very little, if any, lunar monthly (Mm), rather less lunar fortnightly (Mf), no ter-monthly (9-day) and little quarter-monthly (7-day) — but it is known that these components may vary in strength over time. More significantly perhaps, their relative smallness indicates that the tide pole remained securely fixed to the sea floor and that an alteration of reference level did not occur over the interval of the spectrum; on 18 December the pole was dislodged (Ross, 1854:287).

While further consideration of Ross's time-keeping seemed trivial, it did appear necessary that we assure ourselves that serious error in time did not exist, recognizing that he could have achieved a precision of about a second a day (Landes, 1983). We applied several methods of spectral analysis, of which that of Vanicek (1971) eventually proved applicable. This showed that Ross's time-keeping was as good, perhaps better, than that at Resolute and of the order of 4 sec·day or less; Ross's clock and the Resolute clock appear to have been fast.

In a postscript (p. 296) Ross acknowledged that his was not the first observation of the inverse barometer effect (in 1966 Roden noted that the first observation of the inverse barometer effect is that of N. Gissler in 1747), but we can understand Ross's attention, for "at low spring-tides" the keels of his vessels "sometimes rested on the ground." And although it is not clear from his account, there can be little doubt that during the period of observation of the data he had in process a diagram similar to that of Figure 4, which would of course have provided

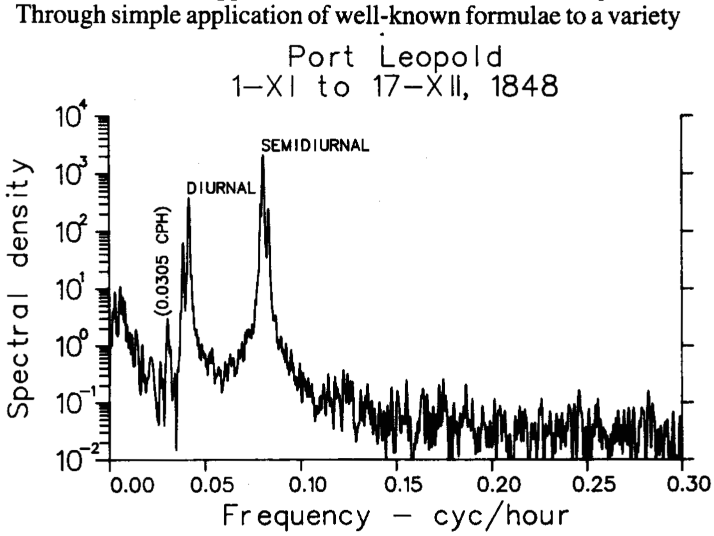

FIG. 3. Spectral analysis of the 47 days (1 November-17 December 1848) of tide pole readings at Port Leopold. (This is an unsmoothed power spectrum produced using the fast Fourier transform technique.)

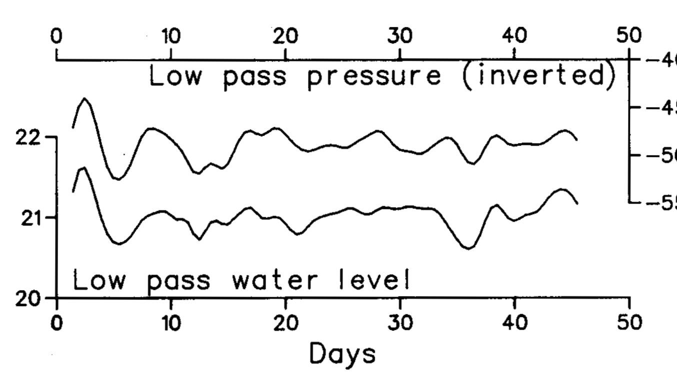

FIG. 4. The lowpass of the pressure and the lowpass of the sea level data so presented that each has the same vertical range and with the pressure (upper) curve inverted. (In the lowpass all waves of a period shorter than one day have been filtered out.)

him with a strong indication of an inverse relationship between pressure and daily mean sea level (the lowpass), i.e., between pressure and sea level after the daily tides have been removed. Apparently it was the "first few days' observations" that engaged him (p. 285), but again it is not clear to which record he was referring, for the program of observation was begun in September. In any event, the first few days of the November portion of the record indicate such a relationship rather clearly. Further visual comparison reveals several other occasions of marked inverse correlation, e.g., around days 10, 35 and 40.

It seems likely, too, that he produced a scatter plot of the lowpass values, i.e., pressure versus sea level. We found in simple regression of the lowpass of pressure on the lowpass of sea level a strong inverse correlation ($r = -0.76$). In further confirmation we carried out a cross-spectrum analysis between the two lowpass time series that shows (Fig. 5) that the coherence between the lowpassed water level and pressure is significantly large over almost the entire frequency range from zero to 1 cycle·day. As well the phase difference between the two series is close to 180° over the entire range. Thus the strong negative correlation is well confirmed.

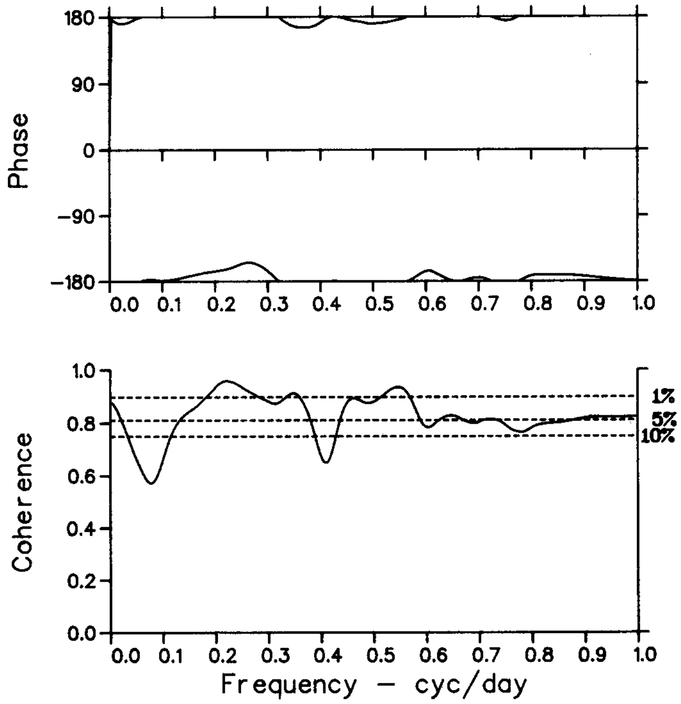

FIG. 5. Cross-spectrum between the lowpass of the tide pole and lowpass of barometer with significance levels.

Ross also commented that mean sea level increased during the period of observations "to the middle of July" (p. 287), which seems somewhat unusual, for in the Arctic sea level is generally lowest in spring and highest in autumn (Lisitzin, 1974). The long-term record at Resolute supports the latter generalization, but in at least one year (1968) sea level there appears to have increased over most of the year, so that in this respect Ross's data may not be unusual. What seems unusual is that Ross appears to have determined from the outset to obtain barometer readings in conjunction with the sea level observations, although he seemed to suggest (p. 296) that he had previously noted in other areas an influence of the atmosphere on sea level — i.e., it seems likely that he was testing an earlier formed notion about sea level and atmospheric pressure. He may even have considered the likelihood that the inverse barometer effect is best seen at high latitude. The installation of the tide pole could have been achieved easily enough, and we suspect that the routine of hourly observations was not that onerous. That this early time series in arctic waters happens to have occurred at a Canadian site is, we think, a happy one. That the numbers were printed by the Royal Society and so became available for "crunching" by modern methods is even happier.

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