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EXAMPLES OF COMPARISON OF WIND AND AIR-SEA INTERACTION CHARACTERISTICS ON THE OPEN SEA AND IN THE COASTAL AREA OF THE GULF OF FINLAND

by

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Abstract

Wind conditions and thermal air-sea interaction characteristics were studied using observations made by two automatic marine meteorological stations, one situated on the open sea of the Gulf of Finland, and the other in its archipelago area. Remarkable differences in wind conditions revealed the effects of changes in surface roughness conditions, modified by atmospheric surface layer stability effects. However, due to differences in seasonal air-sea temperature relationships, there often exist significant differences in local stability conditions between the coast and the open sea.

1. *Introduction*

The importance of marine meteorological observations has continuously increased both from the point of view of the atmospheric and oceanographic science and of problematics concerning environmental questions and modelling. However, most of the regular observations for the above purposes at the Baltic Sea have been made in coastal or in archipelago areas. Therefore, a kind of representativity of observations has often been called in question. For example, differences in the mean wind speed observed in the coastal area and on the open sea, measured by a ship, may often be very big. On the other hand, reliable and representative wind estimation, and further, the prediction of it, is of primary importance for most kinds of mixed-layer oceanographic and air-sea interaction studies and modelling, owing to the fact that the tangential shearing stress at the surface is proportional to the square of the wind speed.

A significant contribution to the situation was achieved a few years ago when the Finnish National Board of Navigation provided four automatic marine meteorological stations which were placed in four open-sea lighthouses.

From the point of view of the problematics discussed, there was in 1980 from June to November a specially interesting situation to get for comparison data of high quality observed on the open sea and also in the coastal area of the Gulf of Finland. This paper gives some results of the comparison of the wind conditions and thermal air-sea interaction characteristics, the latter primarily for the interpretation of the wind conditions.

2. *Data*

The open sea measurements were made by an automatic marine weather station (MIDAS by Vaisala Co; see LUUKKONEN 1976, not in detail discussed in here) installed in the lighthouse Kallbådagrund at the Gulf of Finland (Fig. 1A). Observations were made every three hours, and the mean wind (over a 10 min period) was meas-

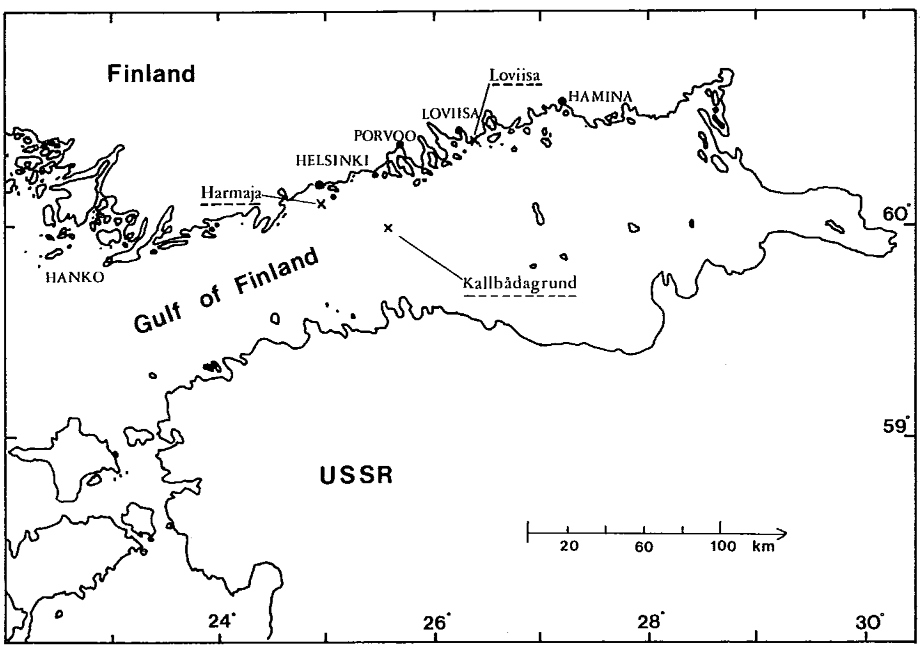

Fig. 1A. Location of Kallbådagrund and Loviisa automatic marine weather stations at the Gulf of Finland.

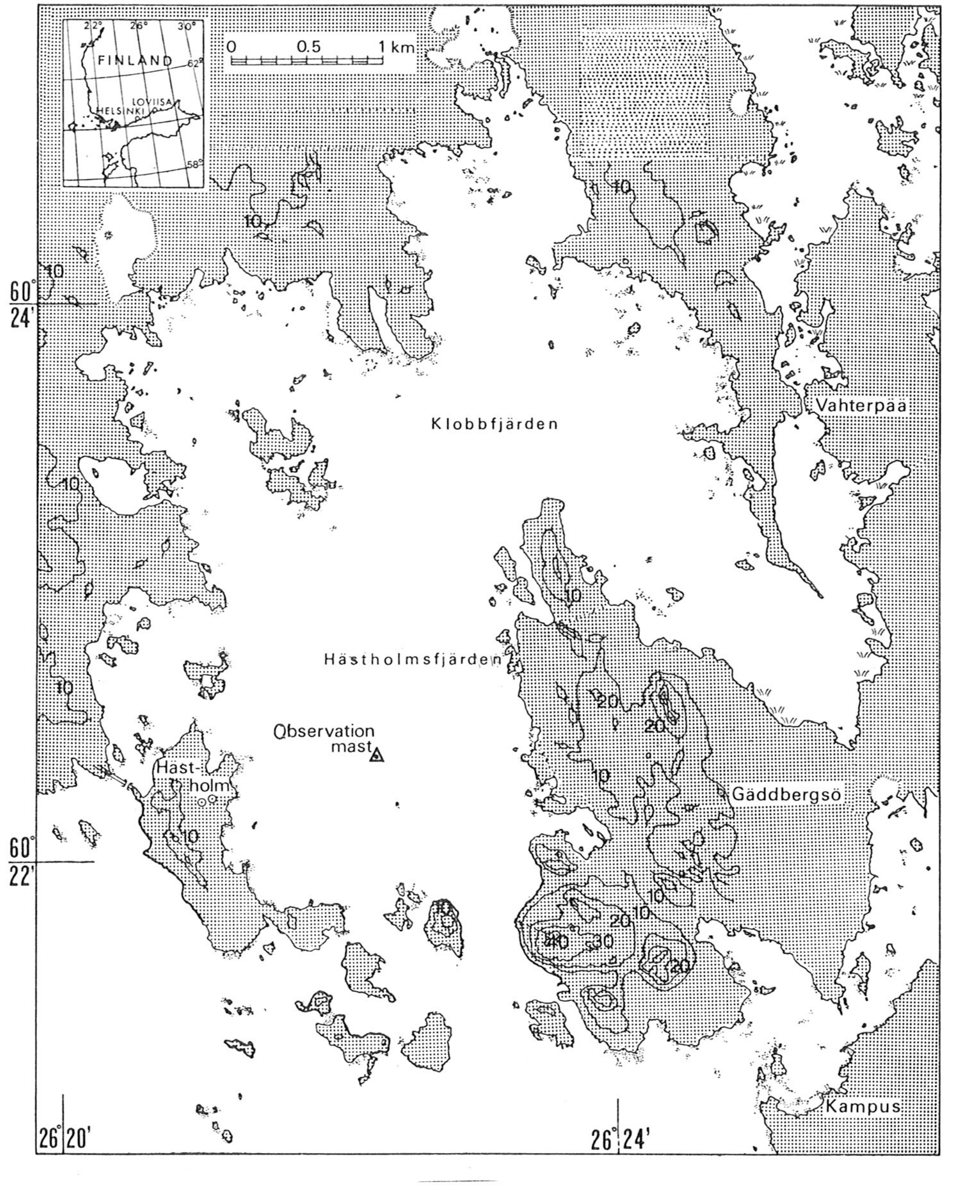

Fig. 1B. Local map and the main topographic features around the Loviisa automatic marine meteorological mast.

ured at a height of 31 m. Air temperature and humidity were measured at 26 m above the mean sea level and water temperature was measured as a »bucket» temperature. In addition, several other marine meteorological quantities were measured.

At the coastal site (Fig. 1) the observations were made by an automatic sea mast near the Loviisa nuclear power plant (for a detailed description of the instrument and area, see LAUNIAINEN 1979), which was not in use during the summer 1980. The over-water fetch in all directions was more than 1 km, but the topographic features in the area are rather complicated (Fig. 1B). Observations were made every fifteen minutes and the mean wind (over a 15 min period), air temperature, dry and wet bulb temperature were measured at a height of 6 m above the mean sea level, and the water temperature was measured as a »bucket» temperature.

The checking and calibration of Loviisa measurements were maintained regularly and, in addition, in the Loviisa mast the measurements were made at several height levels »comparing» thus mutually each other. At Kallbådagrund, which is an automatic station primarily for marine meteorological service, the question of calibration and accuracy is more difficult and partly unknown; for practical reasons of service *e.g.* the atmospheric sensors are changed a couple of times a year. However, except *e.g.* the humidity and some other sensors, the observations of the weather station type in question have been proved in different studies to be stable and reliable, especially in wind (within a few per cent) and temperature measurements (within a few tenths of centigrades). So it is believed that this potential inaccuracy is not critical from the point of view of the results obtained in this study, which, vice versa, gave the above conclusion as a result of the comparison, because a goal of this work was to study big differences of the observed mean wind speed on the open sea station and coastal stations.

3. *Results and discussion*

a. Wind speed relations

A preliminary study of the wind results showed that the winds observed on the open sea, at Kallbådagrund, were generally noticeably higher than those observed on the coast. As an example, a vector presentation of simultaneous observations during a period of high winds is given in Fig. 2. In fact, there was a difference in the heights at which the winds were measured, but the effect of this will be discussed later. Fig. 3 gives the time series of the daily mean wind speeds during the comparison period. Further, Fig. 4 gives the daily average shearing stress ($\tau = \rho C_{Dz} u_z^2$) indicating big differences especially due to the differences in wind velocities for overall comparison. The stress has been cal-

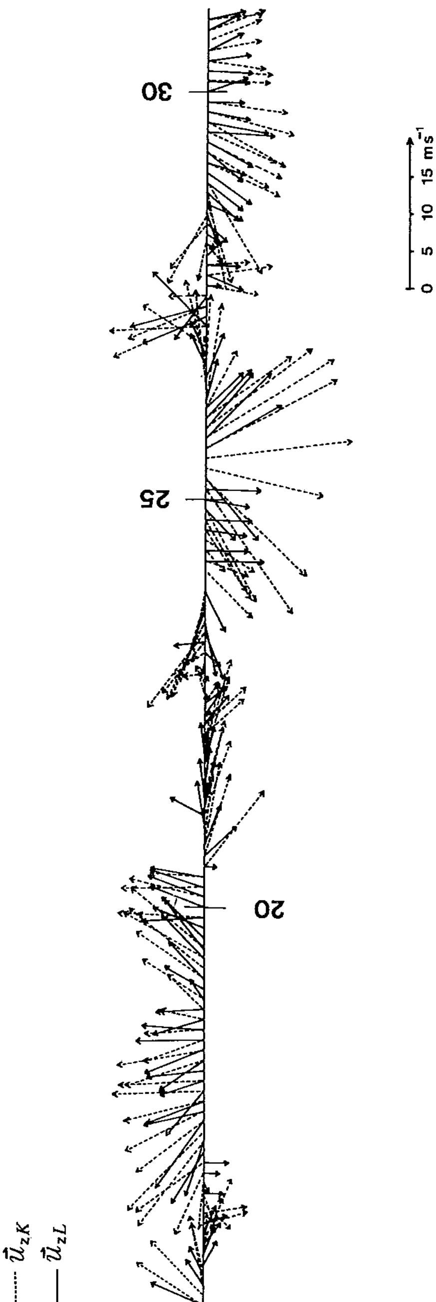

Fig. 2. Vector presentation of the mean wind observed at Kallbådagrund (u_{zK}, broken arrows) and Loviisa (u_{zL}) during a period of high winds 16.10.–31.10.1980. Observation levels: z_K = 31 m, z_L = 6 m.

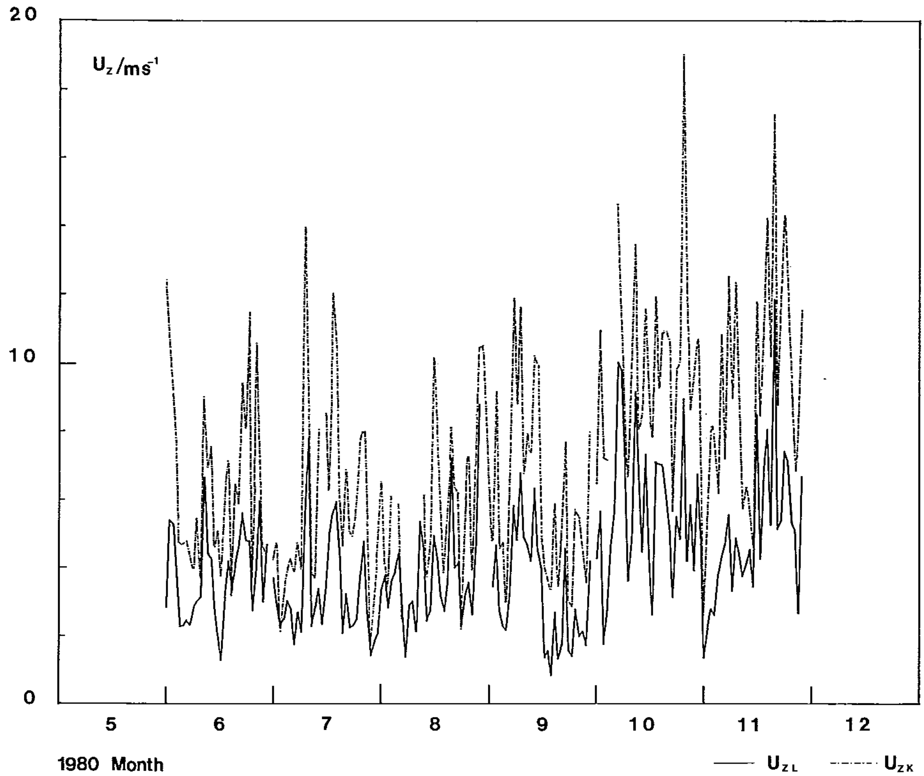

Fig. 3. Daily mean wind speed at Kallbådagrund (u_{zK}) and at Loviisa (u_{zL}) during the comparison period. Observation levels: z_K = 31 m, z_L = 6 m.

culated by an iteration method (*cf.* LAUNIAINEN 1979) taking the atmospheric surface layer stratification into account. The neutral drag coefficient (C_{Dz}) or rather the roughness height (z_0) was calculated for the open sea from a formula by GARRATT (1977) and for the Loviisa area from the results by LAUNIAINEN (1979), which for moderate wind speeds are very close to those by GARRATT (1977).

The results showed, as may be seen from Figs. 2 and 3, that the observed wind speed ratio between these two sites is not constant. Considering the situation on the basis of fluid dynamics, as a case in which the roughness and orographic conditions modificating the surface wind field are above the land different from those above the sea, one may expect a »working hypothesis» for the observed wind speed

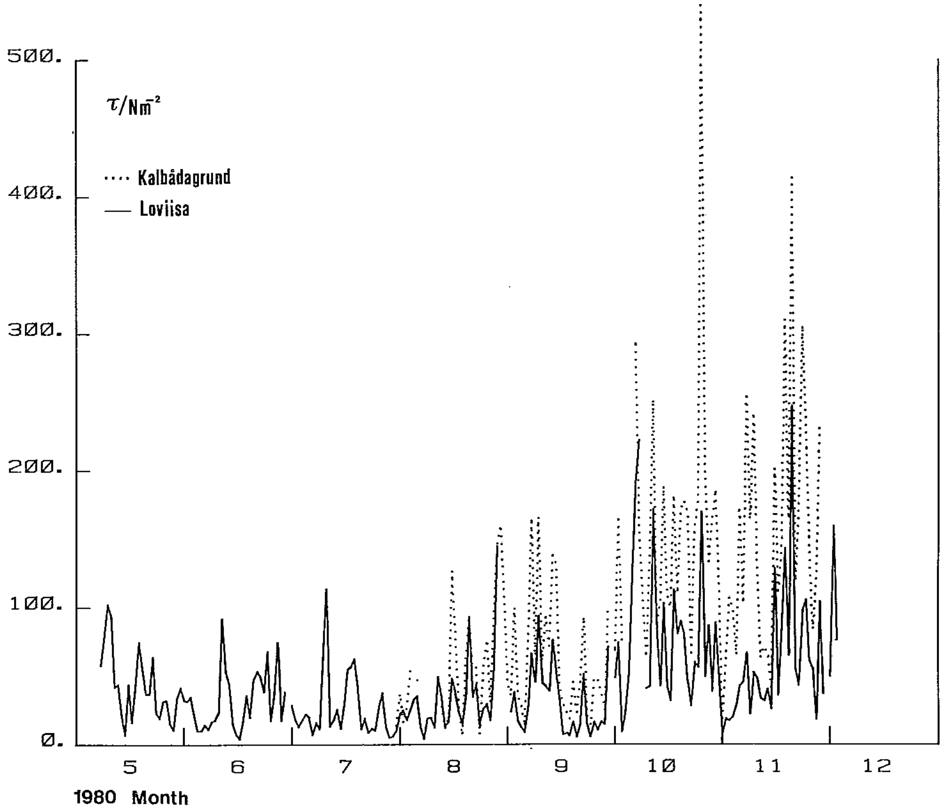

Fig. 4. Daily average tangential shearing stress at Kallbådagrund and at Loviisa (calculated by an iteration method which takes the surface layer stratification effects into account).

relation to be a function of a set of the following quantities

$$\frac{u_{zK}}{u_{zL}} = f\,(z_K/z_L, dir, u, stab) + res \tag{1}$$

in which z_K/z_L characterizes the portion of the height difference in the results, »dir» is the direction of the wind field which characterizes roughness and orographic effects for a certain wind direction, »*u*» is the mean wind speed and »*stab*» is the atmospheric surface layer stability. The term »residual» must be seen to include the observation errors, a difference in the averaging period of the mean wind, as well as *e.g.* the unhomogeneities of the wind field to be compared, *e.g.* because of rather a big distance between these two places there are several possibilities (sea- and land

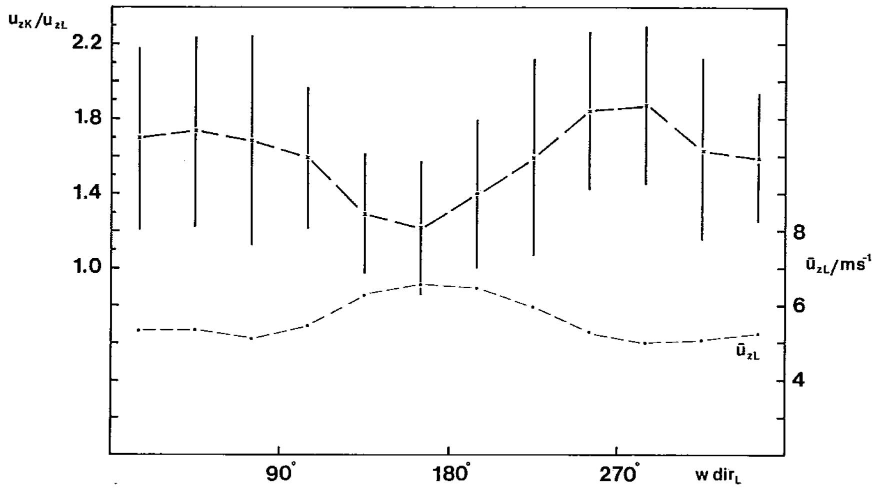

Fig. 5. Wind speed ratio u_{zK}/u_{zL} (mean and standard dev.) as a function of the wind direction observed at Loviisa. Cases in which the mutual difference in the observed wind direction was $> 70°$ and $u_{zL} < 3$ ms^{-1} were discarded. Fine line represents the mean wind speed (of the comparison data) observed at Loviisa.

breeze) that the observations do not always represent the same wind field. This latter, probably much more serious effect than pure observational errors, was tried to be diminished by taking a limit ($< 70°$) for the difference of the observed mutual wind directions and taking a lower limit for the wind speed. No more special attention was paid in this phase to the semi-stationarity of the wind field.

The wind speed ratio u_{zK}/u_{zL} of simultaneous observations is given as a function of the wind direction observed at Loviisa in Fig. 5. As may be seen, the wind speed ratio is distinctly dependent on the wind direction. The ratio is smallest for the winds from open sea directions from southeast to southwest, and largest from land directions from west to north-east. Comparing the results of Fig. 5 to the Loviisa local topography (Fig. 1B) one might see some physically relevant features in the fine structure of the behaviour of the wind speed ratio, but the scattering is very big and therefore, it remains unknown what the role of very local properties is. In Fig. 5 the cases $u_{zL} < 3$ ms^{-1} were discarded, but the overall result is rather similar discarding the cases $u_{zL} < 5$ ms^{-1}.

For considering the effect of wind speed on the observed ratio, in Fig. 6 the speed ratio is given as a function of wind speed for two main directional classes; from open sea directions (6A) on one hand, and from land directions on the other hand. The continuous line in Fig. 6 represents the role of a higher observation

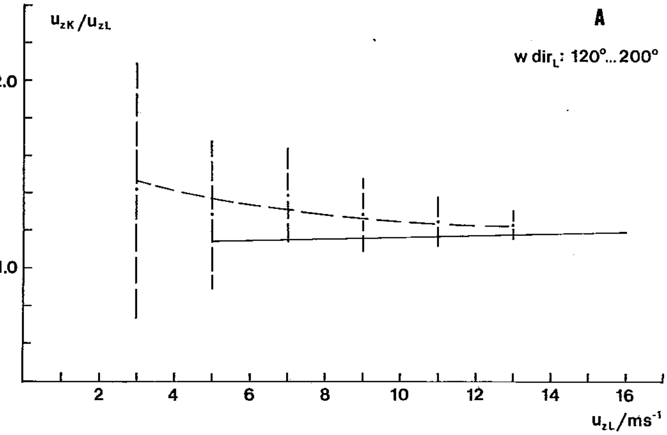

Fig. 6A. Wind speed ratio u_{zK}/u_{zL} (and standard dev.) for winds from the open sea directions as a function of the wind speed observed at Loviisa. The continuous line represents the wind speed ratio due to the difference of the observation heights only (calculated according to the logarithmic wind profile).

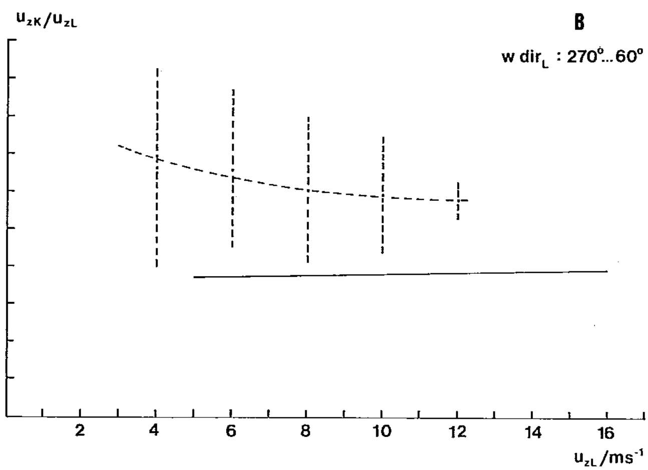

Fig. 6B. Wind speed ratio u_{zK}/u_{zL} (and standard dev.) for winds from land directions as a function of the wind speed observed at Loviisa.

level of Kallbådagrund in the results. This effect of the difference in the observation heights has been calculated according to the well-known logarithmic wind profile, giving for the wind speed ratio

$$\frac{u_{zK}}{u_{zL}} = \ln \frac{z_K}{z_o} / \ln \frac{z_L}{z_o} \qquad (2)$$

where z_0 is the roughness height for the open sea surface; it was calculated from a drag coefficient formula by GARRATT (1977). The form (2) gives the ratio of observed wind speeds in neutrally stratified conditions and without any coastal effects on the roughness conditions. In stable conditions the effect of the difference in observation height is larger, and in unstable conditions smaller than the one calculated according to (2), respectively.

From Fig. 6A it can be seen that for winds from the open sea directions the overall curve approaches rather nicely to the line describing the effect of the difference in the observation height, and thus at moderate and high wind speeds the observations in the two sites agree well, taking into account *e.g.* a zone of small islands in front of the Loviisa observation site. On the contrary, though the speed ratio for the winds from the land also seems to decrease with wind speed, the winds on the open sea are 1.6 to 1.3 times higher than those observed at Loviisa, in addition to the estimated effect of the different observation levels.

b. Stability effects and temperature relationships

For considering the atmospheric stability effects on the results of Figs. 5 and 6 we may express (1) for a certain class of wind direction as

$$\frac{u_{zK}}{u_{zL}} = 1 + \Delta_{z,\,dir,\,u} + \Delta_{stab} + \Delta_r \tag{3}$$

in which $1 + \Delta_{z,\,dir,\,u}$ is assumed to represent the broken curves in Fig. 6. This assumption is relevant because the data represent rather a wide distribution of stability. The term $\Delta_{stab} + \Delta_r$ characterizes the deviation of individual observation sets from the curves as represented by the standard deviation in Fig. 6. As discussed, Δ_r represents scattering due to measurement errors as well as certain weaknesses of data and of the comparison method.

The term $\Delta_{stab} + \Delta_r$ was calculated from (3) by subtracting $1 + \Delta_{z,\,dir,\,u}$ (Fig. 6) from each u_{zK}/u_{zL} data sets and it is plotted in Fig. 7 for winds from open sea directions as a function of a bulk stability parameter, bulk-Richardson number

$$R_{zL} = \frac{gz(t_z - t_s)}{T u_z^2} \tag{4}$$

in which g is the acceleration due to gravity, z is the measurement height (6 m), $t_z - t_s$ is the air-sea temperature difference, T is the mean (absolute) temperature of the surface layer and u_z is the wind speed.

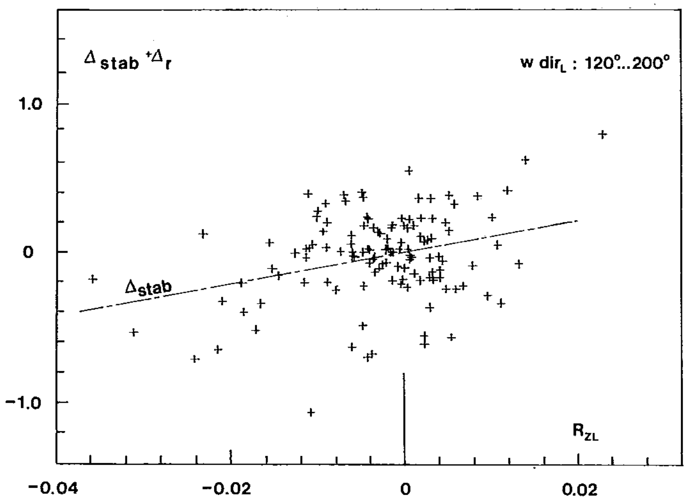

Fig. 7. Term $\Delta_{stab} + \Delta_r$ of eq. (3) as a function of bulk stability R_{zL} at Loviisa. Δ_{stab} represents the portion of stability effect in observed wind speed ratio (3).

From Fig. 7 it may be seen that there is at least a qualitatively relevant behaviour so that under unstable conditions the stability effect diminishes the wind speed ratio ($\Delta_{stab} < 0$) and under stable conditions the stability effect is opposite. The scattering *i.e.* Δ_r is rather big but, however, the regression line gives $\Delta_{stab} + \Delta_r = 0$ at $R_{zL} = 0$ which justifies the assumption that the curves of Fig. 6 represent near-neutral conditions and the regression line represents Δ_{stab}, by which the first approximation of stability effects on wind speed ratio may be done.

For the winds from land directions a consideration like the above yielded similar but more scattered results. However, this effect of stability on the air entering above the coast may be rather a complicated phenomenon for the reasons discussed below.

When considering the wind field variations, stability effects and air-sea interaction between the coast and the open sea, there exists a characterizing feature which is created by different seasonal air and water temperature relationships. Differing from the open sea, at the very coast the water surface warms up rapidly and reaches high temperatures and, on the other hand, also cools down more rapidly than on the open sea. Therefore, the atmospheric surface layer on the coast may be unstable generally already from the early summer (Fig. 8A), whereas open sea surface temperature is generally lower than air temperature until August

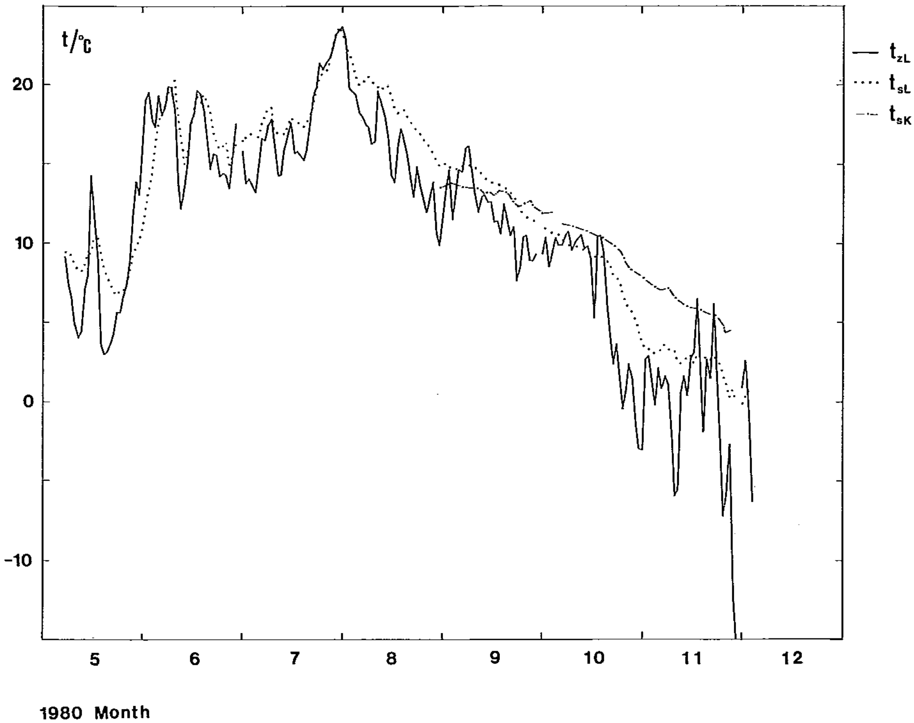

Fig. 8A. Daily average air temperature (t_{zL}) at Loviisa and sea surface temperatures at Loviisa (t_{sL}) and at Kallbådagrund (t_{sK}).

and the atmospheric surface layer stays somewhat stable (*cf.* LAUNIAINEN and MAKKONEN 1982). (In this case correct sea surface temperature data from Kallbådagrund were obtained since the end of August but there are, however, several additional data from the Gulf of Finland, which justify the overall conclusion above for 1980, too). On the contrary, due to a slow cooling of the open sea during the autumn, the mutual relation of the stability is generally opposite to the early summer; especially during a cold break the stratification over the open sea may be very unstable when the sea is still warm (Fig. 8A), whereas the coastal region is noticeably less unstable. As an illustrative indication of all mentioned above, the difference of the daily average air temperatures at Loviisa and Kallbådagrund is given in Fig. 8B. Therefrom it may be seen that the average air temperature was higher on the coast until the beginning of the cooling season and thereafter the slow cooling of the open sea was indicated also in the mutual air temperature difference.

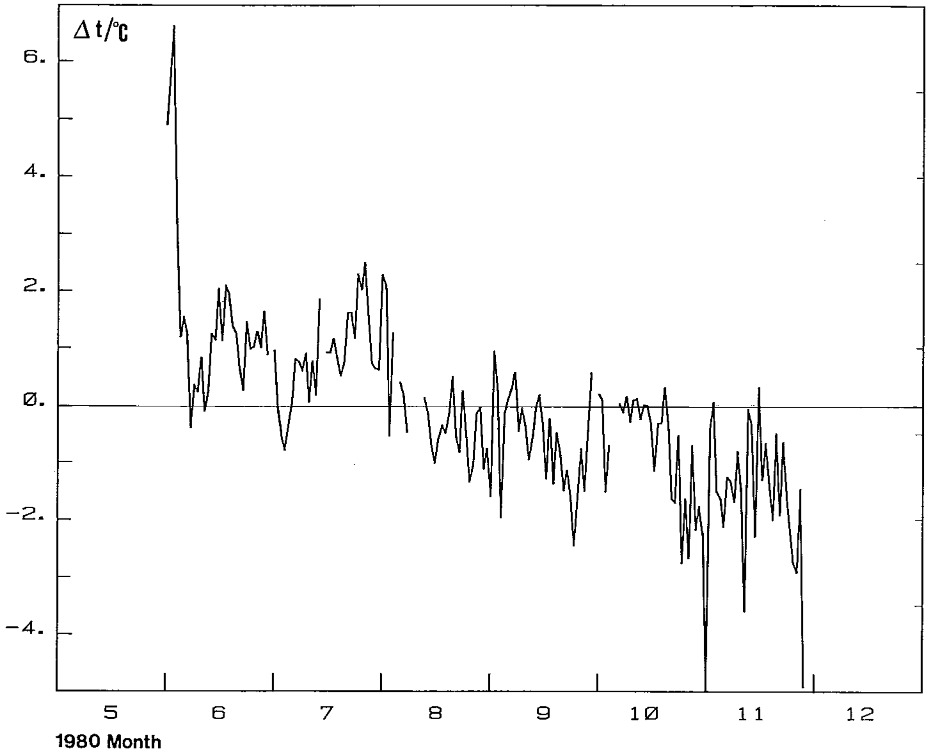

Fig. 8B. Difference of daily average air temperature at Loviisa and at Kallbådagrund ($\Delta t = t_{zL} - t_{zK}$) in 1980.

Summarizing implications of the temperature relationship characteristics above, we may note that the stability conditions on the coast and the open sea are rather seldom equal, modifying the overpassing wind field. More generally speaking, different temperature relationships in the coastal area and on the open sea reflect in many ways and with many differences to air-sea interaction *e.g.* to the turbulent fluxes of latent and sensible heat. The topic in more detail is, however, out of the scope of the present paper.

4. *Conclusions*

This study was a case study of the comparison of the wind conditions and air-sea interaction characteristics on the coast and on the open sea. It was found that these quantities on the coast may be rather different from those in the open sea.

For example, besides great differences of the wind speed there often exist noticeable differences in stability conditions reflecting in turn to wind conditions and all air-sea and open sea-coast interaction. The results emphasize the importance of choosing representative observation sites on one hand, and the correct interpretation and further use of coastal observations, on the other hand. The results showed that after a careful comparison analysis, *e.g.* the wind conditions for the open sea may be roughly approximated by coastal observations. On the other hand, when the relation between the open sea-coast wind conditions and air-sea interaction characteristics is known, the results may be utilized *e.g.* in wind forecasting and verification.

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