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ON THE PREDICTION OF LOCAL EFFECTS OF PROPOSED COOLING PONDS

by

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ON THE PREDICTION OF LOCAL EFFECTS OF PROPOSED COOLING PONDS

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ABSTRACT

A Fog Excess Water (FEW) Index has been shown to provide a good measure of the likelihood for steam fog to occur at specific cooling pond installations. The FEW Index is derived from the assumption that the surface boundary layer over a cooling pond will be strongly convective, and that highly efficient vertical transport mechanisms will result in a thorough mixing of air saturated at surface temperature with ambient air aloft. Available data support this assumption. An extension of this approach can be used to derive a simple indicator for use in predicting the formation of rime ice in the immediate downwind environs of a cooling pond. In this case, it is supposed that rime ice will be deposited whenever steam fog and sub-freezing surface temperatures are predicted. This provides a convenient method for interpreting pre-existing meteorological information in order to assess possible icing effects while in the early design stages of the planning process. However, it remains necessary to derive accurate predictions of the cooling pond water surface temperature. Once a suitable and proven procedure for this purpose has been demonstrated, it is then a simple matter to employ the FEW Index in evaluations of the relative merits of alternative cooling pond designs, with the purpose of minimizing overall environmental impact.

INTRODUCTION

Industrial cooling ponds often give rise to localized environmental effects, particularly in winter when steam fog and rime ice can become problems downwind of the hottest areas. Fog generation above artificially-heated water surfaces has been the subject of a number of studies[1,2,3], but similar studies of rime ice have not been found. A preliminary study of the matter demonstrated the practical difficulties likely to confront experimental investigations of riming[4,5]. This study, performed at the Commonwealth Edison Dresden plant (near Morris, Illinois) during the winter of 1976/7, provides a four-month record of the occurrence and intensity of fog and rime associated with the operation of a fairly typical industrial cooling lake.

Earlier studies at Dresden succeeded in obtaining direct measurements of turbulent fluxes of sensible and latent heat from the heated water[6]. The resulting improved formulations of these convective and evaporative heat losses can be used in much

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the same way as the familiar wind speed functions that are used in most contemporary cooling pond design studies. In this regard the earlier Dresden experiments, which were conducted over the three-year period 1973-1976, addressed the question of how to predict the water temperature characteristics of cooling pond installations. Subsequent studies have refined these techniques by parameterizing the subsurface thermal boundary layer[7], which effectively limits heat exchange between deep water and the air. The premise of the present study is, therefore, that we can predict the temperature characteristics of a proposed cooling pond, but need to assess the potential environmental impact.

STEAM FOG

Hicks[2] introduced a Fog Excess Water Index, e_{xs}, based on the supposition that air saturated at surface temperature rises and mixes with equal quantities of ambient, background air. The excess vapor pressure e_{xs} of the mixture can be written as

$$e_{xs} = (e_s(T_s) + e_a)/2 - e_s((T_s + T_a)/2)$$

where $e_s(T)$ is the saturated vapor pressure at temperature T, T_a is the ambient air temperature and e_a is the air vapor pressure. When tested against the data of Currier et al.[1], the FEW Index was found to provide a good indication of the occurrence of steam fog, as well as some measure of its intensity. The FEW Index was further verified by use of observations of fog generated by cooling-pond simulators at Argonne National Laboratory and by data from Dresden.

Figure 1 is a further test of the FEW Index, again largely based on observations made at Dresden but supplemented by a series of measurements made at the Cal-Sag shipping canal, a major inland waterway which passes conveniently near Argonne. Canal water temperatures in winter are typically more than 20°C higher than in nearby lakes and streams, due to heavy industrial usage. The data illustrated in the diagram give further support for the validity of the FEW Index method.

RIME ICE DEPOSITION

A few obvious (and perhaps trivial) considerations should be set down at the outset. Firstly, it is clear that rime ice deposition is a cold-weather phenomenon which is constrained, by definition, to occasions when the surface temperature is below freezing. This constraint does not apply to the generation of steam fog, and hence rime deposition might well be considered as a sub-set of steam fog cases. Secondly, it follows that riming will be mainly a wintertime phenomenon, most often at night. In the nocturnal case, it seems likely that accurate prediction of riming will prove extremely demanding, since nocturnal surface temperatures are highly variable both in space and in time and thus great care must be taken in selecting an appropriate data base.

Figure 2(a) illustrates the first point; the Dresden 1976/7 winter data do indeed show riming to be a subset of the fog occurrences. Observations were made on a total of 84 mornings. On no occasion was the observation of overnight rime deposition not accompanied by steam fog from the pond. Furthermore, the amount of rime deposited is well correlated with a measure of steam fog intensity. To show this, rime deposits have been quantified according to the visual observations; none = 0, slight rime = 1, moderate rime = 2, heavy rime = 3. The fog intensity is conveniently quantified by the reported depth of the fog layer over the hottest part of the cooling pond, estimated from a comparison with the known heights of surrounding obstacles. Figure 3 demonstrates the correlation. Thus, it appears reasonable to expect the FEW Index to be an appropriate measure of the intensity of rime deposit, since it has already been shown to be an indicator of steam fog intensity. The present limited set of data do not allow direct investigation of the interrelation between rime intensity and e_{xs}, since reliable nocturnal evaluations of e_{xs} at the Dresden site are not available[8].

Figure 2(b) shows the frequency of occurrence of fog and rime that would have been expected on the basis of the arguments presented above. It is assumed that steam fog will occur when $e_{xs} > 0$, based on the observed Dresden water temperatures and overnight air temperatures and humidities measured some 40 km away at Argonne National Laboratory. Rime is then predicted on each of those occasions for which sub-freezing overnight temperatures were reported. Comparison between Figures 2(a) and 2(b) shows fairly good agreement: the rime curves are drawn to be identical.

DISCUSSION AND CONCLUSIONS

Although it is clear that the depth of steam fog and the amount of rime deposited are well correlated, there is no strong dependence of riming upon meteorological quantities such as wind speed, nocturnal net radiation, etc. To a considerable extent, this is as must be expected as a consequence of the lack of correlation between e_{xs} and wind speed (see Figure 1). The 1976/7 results are not suitable for investigating this matter with confidence. Nor is it clear that the physics involved will permit a clear-cut conclusion to be obtained. Nevertheless, it is intended to proceed with investigations of the thermal and moisture plumes arising from heated water surfaces, in part to derive better methods for predicting the frequency of events in the design stage but also to investigate the role of steam fog as an interference with the natural infrared radiation regime of a water surface.

ACKNOWLEDGEMENTS

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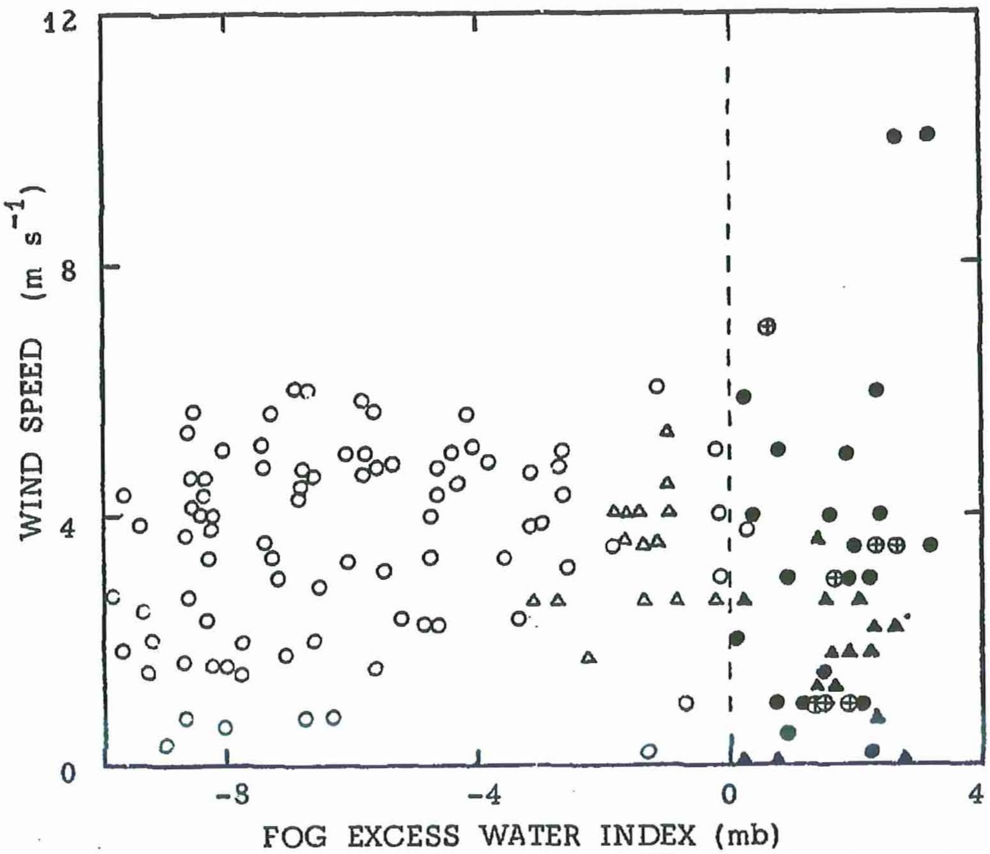

Fig. 1. Observations of the Fog Excess Water Index made at the Dresden cooling lake (circles), over cooling pond simulators at Argonne[8] (triangles), and above a shipping canal near Argonne (circles and crosses). Except in the last case, solid symbols indicate that fog was observed; fog was always observed over the canal.

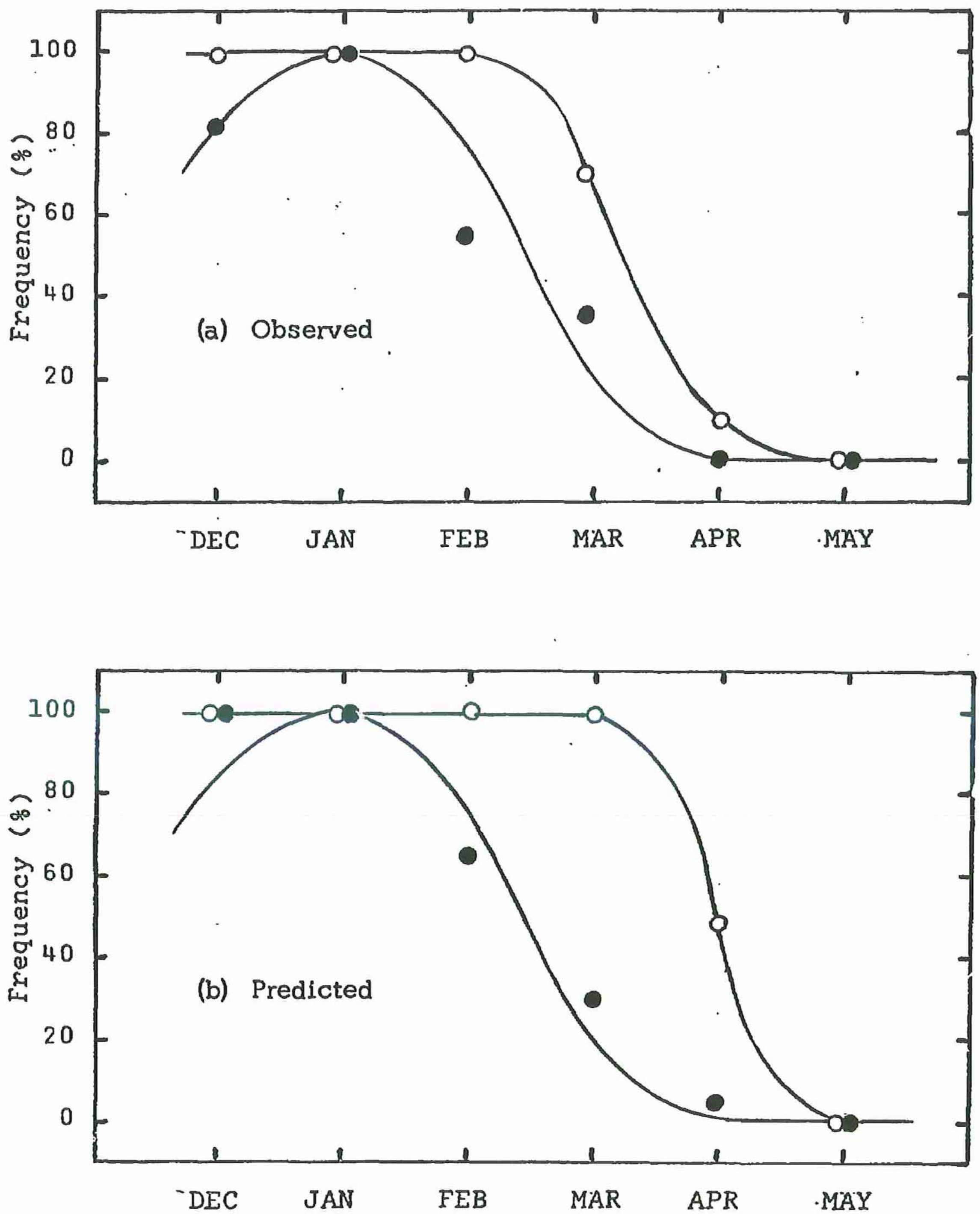

Fig. 2. Observed (a) and predicted (b) frequencies of occurrence of overnight steam fog (open circles) and local rime ice deposition (solid circles) at the Dresden cooling lake.

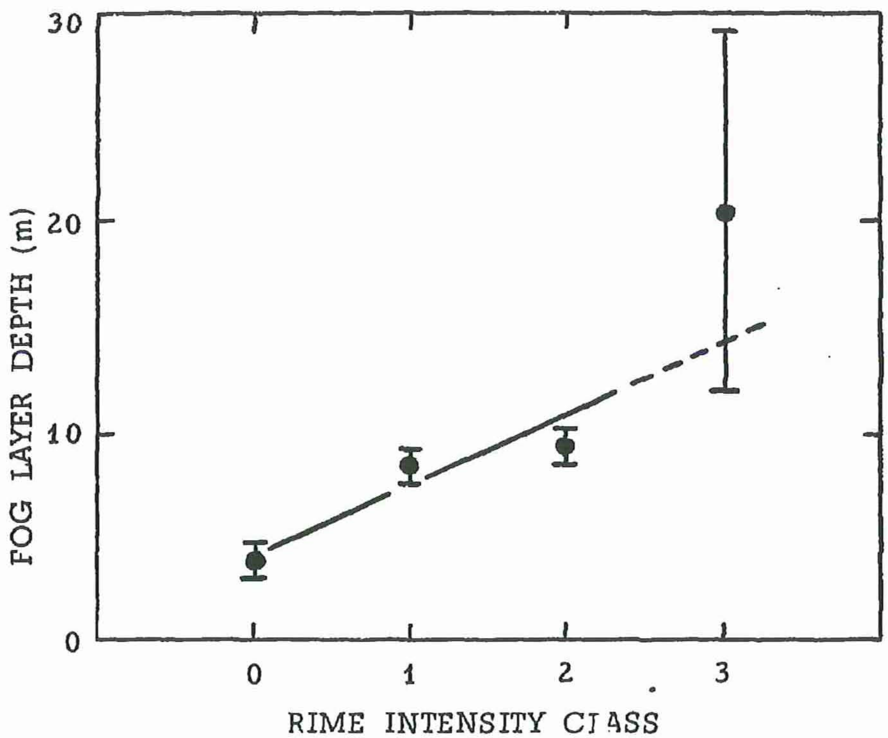

Fig. 3. The relationship between the intensity of overnight rime deposition and the reported depth of the fog layer at Dresden.