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 RM-5234-NASA
 JANUARY 1967

AN APPARENT STATISTICAL RELATIONSHIP BETWEEN POLAR HEAT BUDGET AND ZONAL CIRCULATION

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PURPOSE: To report quantitative evidence that variations in atmospheric circulation are directly relatable to variations in net atmospheric heat loss in the polar regions, and to suggest that the meteorological satellite is an ideal device for providing data needed in the forecasting of atmospheric circulation.

RELATED TO: RAND's work in Arctic meteorology for Air Force Project RAND and in satellite meteorology for NASA. The figures on net loss of heat from the Arctic atmosphere used here were drawn from RAND Report R-444-PR, The Heat Budget of the Arctic Basin and Its Relation to Climate, October 1965, and are also found in RM-5233-NSF, Proceedings of the Symposium on the Arctic Heat Budget and Atmospheric Circulation: January 31-February 4, 1966.

METHODOLOGY: In attempting to determine the difference between the radiation balance of the earth-atmosphere system and the heat supplied to the atmosphere from the underlying surface, the greatest uncertainties lie in the role of atmospheric absorption and emission of shortwave and longwave radiation. Lacking the precise data of satellite measurements, calculated values were used in this first attempt to quantify the relationship of atmospheric circulation to the net atmospheric heat loss in the Arctic region.

Arctic heat loss was estimated by two different methods. One estimate assumes a cloudless Arctic atmosphere, devoid of longwave absorption by liquid water or ice particles. The other, which may be more realistic, assumes a prevalent dense ice-crystal haze. Mean monthly values of the net Arctic heat loss during the years 1941 to 1961 were compared with a mean monthly index of the circulation in the subarctic zone, the zonal circulation index being the difference in the average height of the 500-millibar surface at 60 and at 70 degrees North in the sector from 40 degrees West to 30 degrees East. For each of the two methods, heat loss was lag-correlated with the mean monthly index of subarctic zonal circulation for periods of one month ahead to three months behind.

FINDINGS: The results of the calculations show that the two methods are remarkably similar in their correlations with atmospheric circulation. Both of the derived cycles of Arctic atmospheric heat loss yield correlation coefficients of about 0.95 (0.956 and 0.945) with the zonal index lagged one month.

SUGGESTIONS FOR FURTHER WORK: The relationship between values of Arctic atmospheric heat loss and a zonal index should be tested for specific months. Also, plans for the regular collection of polar data should be developed and implemented. Satellite measurements should include: data on the total outgoing fluxes of shortwave and longwave radiation; data on the surface albedo and its distribution; data on surface temperatures; and any data from which the absorption and emission characteristics of the atmosphere and aerosols can be inferred.

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PREFACE

This Memorandum relates a potential function of meteorological satellites to the possible fulfillment of a gross need in forecasting. Several approaches are suggested for investigating the feasibility of relating the polar heat budgets to atmospheric circulation. The suggestion expressed here grew out of RAND's work in satellite meteorology for the National Aeronautics and Space Administration, and our related interest and activity in the field of Arctic meteorology.

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SUMMARY

On the basis of the best available data and several reasonable assumptions, it is possible to show a 0.95 correlation between the annual cycle of the atmospheric heat loss in the Arctic and the cycle of the general circulation of the atmosphere with a lag of one month. The chief uncertainties in this potentially valuable correlation could be removed entirely or diminished significantly if satellites were used to collect pertinent data on the Arctic heat budget.

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I. INTRODUCTION

In a previous paper, Fletcher (1965) systematically examined the available empirical data and the hypotheses needed to deduce all the terms of the equations describing the heat budget of the Arctic. His purpose was to derive the individual annual cycles of the major components of the heat budget. Therefore, the data were used, and the results couched, in the form of long-period monthly means.

In the course of that work and in a subsequent search for Antarctic heat-budget data, it became clear that, for polar observations, advantage was not being taken of satellites to the degree warranted by the potential value of the data.

A heat-budget component of particular interest is the net loss of heat from the Arctic atmosphere. At present, this net loss can be estimated only by making assumptions (1) as to total radiation escaping to space, and (2) as to the quantities of radiation absorbed and emitted within the atmosphere. The satellite is the ideal device for measuring the total radiant loss to space and can provide data that would greatly enhance the quantification of atmospheric absorption and emission. The thermal gradient established by the net cooling of the polar atmosphere, in conjunction with the net warming of the atmosphere at low latitudes, provides the basic force to drive the atmospheric general circulation. While tropical heating remains relatively constant throughout the year, the amount of atmospheric cooling at the poles shows a large seasonal variation. The resulting variations in atmospheric circulation should, therefore, be quite directly relatable to variations in net atmospheric heat loss in the polar regions.

Lacking satellite data, for a first step in attempting to quantify this relationship, we have taken Fletcher's mean monthly values of Arctic atmospheric heat loss and have lag-correlated them with a mean monthly index of sub-Arctic zonal circulation. Of five 1-month-interval lag-correlations examined, the highest ($r = 0.95$) is found when the circulation indices are lagged one month behind the heat-loss data. Of course, no practical prognostic inferences can or should be drawn from this preliminary result.

II. DISCUSSION

The mean monthly values of Arctic atmospheric heat loss derived by Fletcher are discussed in three papers (Fletcher, 1965; Fletcher, Keller, and Olenicoff, 1966; Fletcher (ed.), 1966). This quantity is determined simply as the difference between the radiation balance of the earth--atmosphere system and the heat supplied to the atmosphere from the underlying surface. Of all the variables involved in this computation, the greatest uncertainties center on the role of atmospheric absorption and emission of shortwave and longwave radiation. In deriving his first estimate of atmospheric heat loss, Fletcher followed the assumptions of Marshunova, principally that an Arctic atmosphere with no reported clouds is a truly "cloudless" atmosphere, that is, devoid of longwave absorption by liquid water or ice particles. Alternatively, Fletcher has re-estimated the annual cycle of atmospheric heat loss assuming a prevalent dense, ice-crystal haze high in the Arctic troposphere. The results of these two calculations are shown as bars in Fig. 1. The reason for employing both sets of results in this Memorandum lies not in the implications of their differences; on the contrary, it lies in the remarkable similarity of their correlations with atmospheric circulation.

An index of the sub-Arctic, zonal, atmospheric circulation that was available for comparison with the Arctic heat-budget data was the zonal index published by Putnins (1963). This index is the average difference between the height of the 500-millibar surface at 60°N and its height at 70°N in the sector from 40°W to 30°E . The mean monthly values of this zonal index (computed for the period 1949 to 1961) are shown as dots, also in Fig. 1.

It is obvious from the figure that the correlation between heat loss and zonal index one month later is a strong one. Indeed, the correlation coefficients corroborate this emphatically. Both of the derived cycles of Arctic atmospheric heat loss yield correlation coefficients of about 0.95 (0.956 and 0.945) with the zonal index lagged one month. A complete set of correlation coefficients with the zonal index lagged from -1 to +3 months is plotted in Fig. 2.

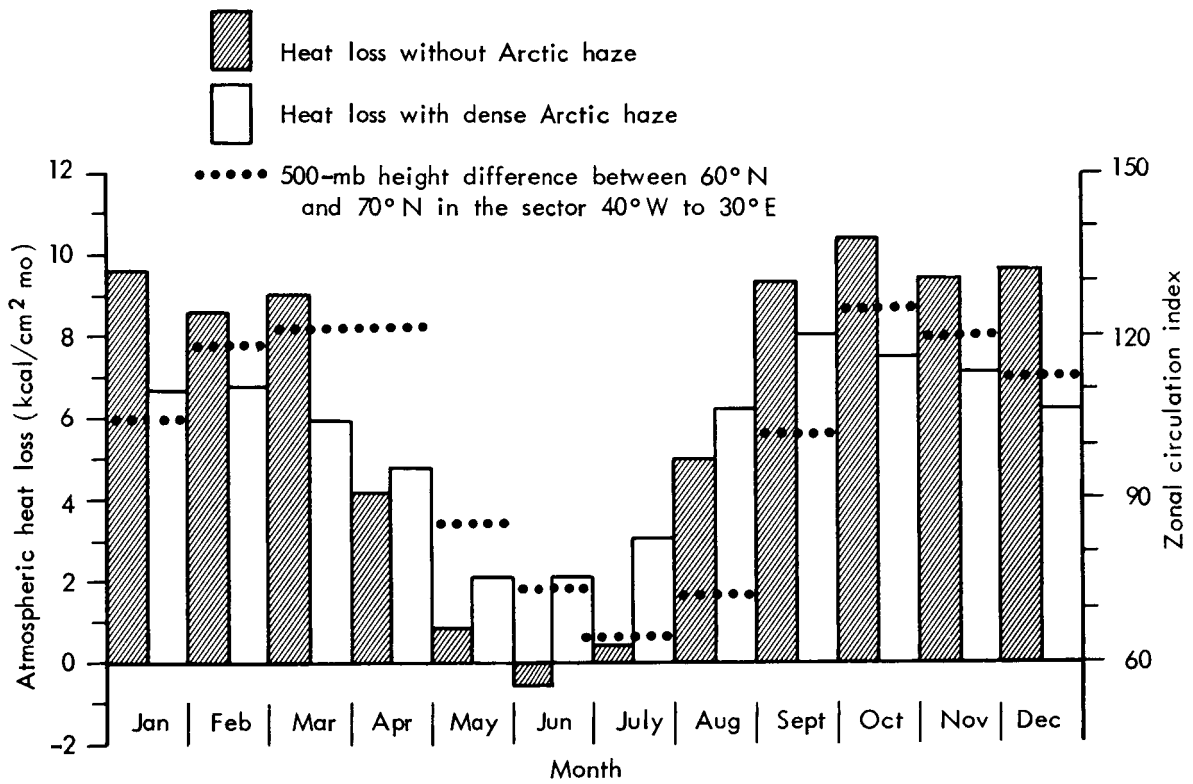


Fig.1—Comparison of the calculated monthly atmospheric heat losses (bars) in the Arctic with a sub-Arctic zonal circulation index (dots)

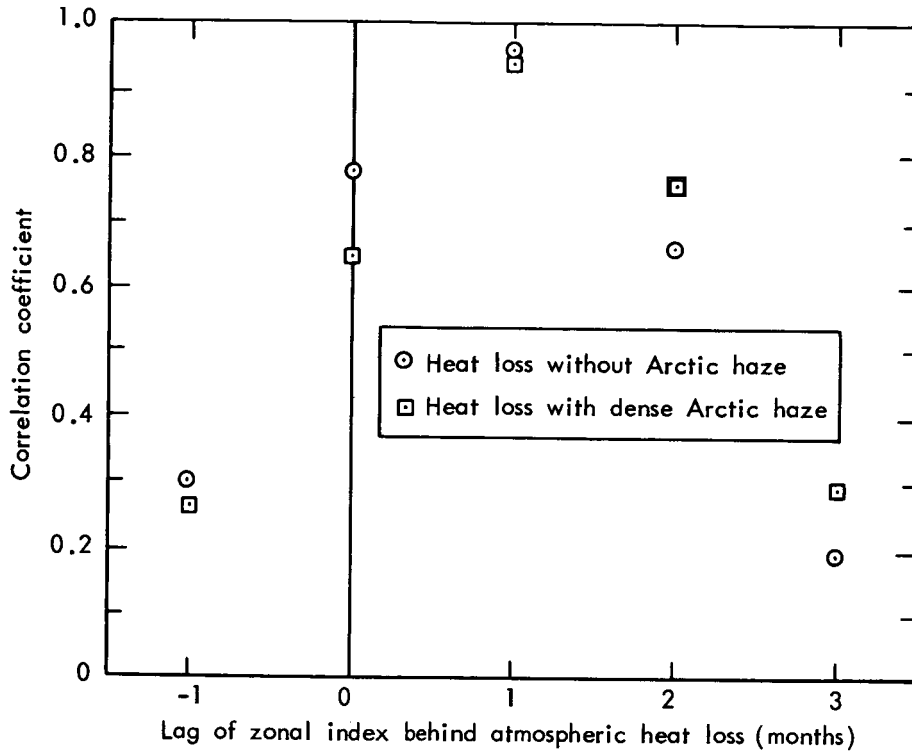


Fig.2—Lag correlation of mean monthly Arctic atmospheric heat loss with mean monthly zonal index

III. IMPLICATIONS

The fact that we have used long-period monthly means as parameters in this correlation makes it impossible for us to conclude even that we have identified a physical relationship, much less a predictable cause and effect. On the other hand, what is now being learned about general atmospheric dynamics leads us to be considerably more optimistic. In the Mintz--Arakawa general circulation model, for example, it takes about 20 to 30 days for the atmosphere to reach dynamic equilibrium following the establishment of a meridional heating gradient (turning-on the sun), which makes an interesting comparison with the highest correlation coefficient shown in Fig. 2.

Of the several courses which this study could next take, probably the most informative would be to test, for individual months, the relationship between values of Arctic atmospheric heat loss and a zonal index. If it should appear from this inquiry that monthly departures from the mean heat-loss data are reflected in corresponding departures in the sub-Arctic circulation, a number of further measures are immediately indicated.

First, plans for the regular acquisition of pertinent polar radiation data should be developed and implemented. A number of satellite measurements are definitely indicated: the total outgoing fluxes of shortwave and longwave radiation; the surface albedo, especially the distribution of the albedo of the snow and ice; surface temperatures; and any data from which the absorption and emission characteristics of the atmosphere and aerosols can be inferred.

Concurrently, the following approaches will deserve attention:

1. Extension of studies to include available historical data in the Southern Hemisphere and Antarctica.
2. Attempts to derive estimates of tropical atmospheric heat gain that are compatible with the polar heat-loss data.
3. Extension and refinement of the statistical definition of atmospheric response, through correlation with other parameterizations of the circulation.

4. Investigation of the physical details of the assumed cause and effect; for example, by ad hoc testing in a numerical general-circulation model.

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