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ATLAS OF HORIZONTAL EDDY HEAT
TRANSPORT IN THE ATMOSPHERE

by

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1. Summary

This atlas contains selected fields of average horizontal eddy heat transport, temperature and temperature gradient in the lower atmosphere of the Northern Hemisphere. These were used as part of the "working data" in a project for parameterizing transient eddy heat transport. It was decided that these fields should be saved in some form of documentation, because they, together with an earlier study by Peixoto (1960), comprise a unique collection of charts on the climatology of heat transport over the Northern Hemisphere. Therefore they will be useful to students of the general circulation.

These fields are presented as they were originally analyzed. No attempt is made here to interpret or discuss them, except when this is necessary to explain how they were constructed and what they contain.

2. Sources of data

In the course of a study of horizontal eddy heat transport in the atmosphere, the author was generously given a considerable amount of unpublished data processed by Abraham H. Oort and Eugene M. Rasmusson of the Geophysical Fluid Dynamics Laboratory and by Jay S. Winston and Arthur F. Krueger of the Meteorological Satellite Laboratory, both of the National Oceanic and Atmospheric Administration.

The final reports of that study (Clapp, 1968; 1970) contain results drawn from the heat transport data, but these are cast into special forms which were needed to meet the immediate objectives of the project. Therefore, it now seems desirable to document at least part of the original data, since it is quite likely that this will prove useful to students of the general circulation. Furthermore, the above-mentioned researchers do not intend to publish the data in the mapped form used here, but have kindly given the author permission to do so. Publications of these authors dealing with other aspects of heat transport and energy transformation are referenced in Section 3.

3. Outline of data processing methods

Before describing the figures, it is desirable to give some idea of the methods used in processing the data. This will also serve to clarify the contents of the charts.

The local northward transport of heat (H_n) across 1 cm of a latitude circle and in a vertical layer of the atmosphere is given by the formula:

$$H_n = (C_p / g) \int_{p_1}^{p_2} VT dp \quad (1)$$

where C_p is the specific heat of the air; g , the acceleration of gravity; V , the northward component of wind speed; T , absolute temperature; and p_1 and p_2 are the pressures at the top and bottom of the layer, respectively.

If we define a vertical average with respect to pressure, for any quantity (\cdot), as:

$$\widetilde{(\cdot)} = \int_{p_1}^{p_2} (\cdot) dp / (p_2 - p_1) \quad (2)$$

then formula (1) may be written:

$$H_n = [C_p(p_2 - p_1) / g] \widetilde{VT} \quad (3)$$

The thermal advection term, \widetilde{VT} , may be subdivided by using the usual definitions:

$$V = \bar{V} + V'; \quad \bar{V} = [\bar{V}] + \bar{V}^* \quad (4)$$

where the "bar" and "prime" superscripts represent a local time average (usually for a time interval of a month or more) and an instantaneous departure from that average; and the "brackets" and "star" represent an average around a latitude circle (zonal mean) and a local departure from that average.

Substituting the definitions (4), and their equivalents for the absolute temperature, into the advective term of (3) and then averaging zonally and over the same time interval, one gets:

$$[\widetilde{VT}] = [\widetilde{V'T'}] + [\widetilde{V^*T^*}] + [\bar{V}] [\bar{T}] \quad (5)$$

In this report are presented only the Northern Hemisphere fields of the local contribution to the first two terms of (5). The first local term, $\overline{V'T'}$, when substituted for \overline{VT} in (3), gives the northward component of what is called the transient eddy heat transport, which is usually considered to be the heat transported northwards by the travelling cyclones and anti-cyclones; while the second local term, $\overline{V^*T^*}$, represents the northward "standing" eddy heat transport, associated with the time-averaged planetary-scale waves.

Corresponding formulas may be obtained for the eastward components of the transient and standing eddy heat transports, merely by replacing the northward component of the wind speed, V , by its eastward component, U .

Formula (2) may also be used to define vertically-averaged values of temperature, \overline{T} . The absolute temperature gradient, $|\nabla \overline{T}|$, may then be obtained from the field of \overline{T} .

The data processed at the Geophysical Fluid Dynamics Laboratory (GFDL) consist of fields of the two transient eddy components as well as temperature and temperature gradient; and are averages for each calendar month for the 5 years, May 1958 through April 1963. These analysed fields were obtained by evaluating finite-difference equivalents of formula (2), using as basic data analysed fields of the 5-year monthly averages of \overline{U} , \overline{V} , \overline{T} , $\overline{U'T'}$ and $\overline{V'T'}$ at the 11 pressure levels 1000, 950, 900, 850, 700, 500, 400, 300, 200, 100 and 50 mb; where the instantaneous wind speeds and temperatures are from 00Z synoptic data. The pressure at the bottom of the layer, p_2 , is the standard surface pressure for a smoothed Northern Hemisphere topography, and the pressure at the top, p_1 , is either 300 mb (Figs. 1 to 4) or 25 mb (Figs. 5 and 6). Further details of the data processing may be obtained from a GFDL report (Oort and Rasmusson, 1971).

The information derived from the data of the Meteorological Satellite Laboratory (MSL) consists of Northern Hemisphere fields of the northward component of the transient and standing eddy heat transport in the layer 850 to 500 mb for each of 7 winter, 3 spring and 2 summer months, based on once-daily temperatures and geostrophic winds at these levels. Essentially, the computations were made using formulas (2) and (3) with p_2 set equal to 850 mb and p_1 , 500 mb; but layer averages of the wind speed and temperature (actually, its equivalent, the "thickness") were used. Thus, the thermal advection term in formula (3) for computing the transient and standing eddy heat advectons, respectively, must be replaced by the following:

$$\text{Transient part} = \overline{\widetilde{V'T}}$$

$$\text{Standing part} = \widetilde{V^*T^*}$$

Since the computations were made for each individual month, the time interval (represented by the "bar" overscore) is one month. Other information on the data processing is contained in two publications of the MSL group (Haines and Winston, 1963; Krueger, Winston and Haines, 1965).

The field of transient eddy heat transport for all 7 winter months was computed, and is shown here as Fig. 7A. The months are Jan. 1961, 62, 63, 64; Dec. 1960, 62; and Feb. 1963. It should be noted that there is a subtle computational difference between this average and that from the GFDL data, shown in Fig. 1A. Thus, Fig. 7A contains the average field of the 7 individual monthly transient eddy transports; whereas in deriving Fig. 1A, only a single eddy transport field was computed from averages of the product of wind times temperature for 5 Januaries. This means that Fig. 1A contains the transient contribution from the large-scale monthly-mean eddies, whereas Fig. 7A does not. However, there is no evidence that this causes any significant differences in the transports. Other more obvious differences are of greater importance.

No other heat transport averages were computed from the MSL data, but to give some idea of the differences between the transient and standing parts, the standing eddy heat transport for January 1962 is shown here in Fig. 7C; and the corresponding transient eddy transport (chosen for its resemblance to the mean), in Fig. 7B. It is worth noting that the strong northward standing eddy heat transports in eastern Siberia, the eastern Pacific Ocean, Central Canada and the west central and north Atlantic Ocean are present on each of the 7 individual months; but of course they are in somewhat different locations and are of different magnitudes.

4. Further clarification of the figures

For ease in quick reference, it was decided to insert abbreviated legends on each figure; but this means that some additional clarification is desirable. Also, in order to save time and expense, the figures were drafted directly from the work charts of the project, so that there are differences in the units of eddy heat transport between the GFDL and MSL data. Therefore multiplication factors are provided for converting to the uniform unit $\text{cal cm}^{-1}\text{sec}^{-1}\text{mb}^{-1}$. For those interested in comparing the present charts with those of Peixoto for the year 1950, the multiplication factor to convert from his units ($10^5 \text{ gr A cm}^{-1}\text{sec}^{-1}$) is 26.7.

In constructing Figures 1 through 6, Parts A and B, only the thermal advection term of formula (3) was evaluated, the units being $10^{-1} \text{ }^{\circ}\text{C} \times \text{meters}$ per second. To convert to $\text{cal cm}^{-1} \text{sec}^{-1} \text{mb}^{-1}$, multiply by 2.45. Isolines are drawn for every 50 units; negative isolines (southward or westward transport) are dashed.

In Figures 1 to 6, Part C, isolines of mean temperature are drawn for every 5 $^{\circ}\text{C}$, with zero line heavier.

In Figures 1 to 4, Part D, isolines of absolute temperature gradient are drawn for every 5 units ($^{\circ}\text{C}/1000 \text{ km}$); whereas in Figures 5 and 6, Part D, although the same units are used, isolines are drawn for every 2 units. In Figures 1 to 6, Part D, as well as in a few of the other figures, some of the relative maxima and minima are labeled with a "dot" superscript and subscript, respectively; but only when deemed necessary for clarity.

Note the strong influence of topography revealed in the temperature and temperature gradient fields of Figures 1 to 6, Parts C and D, which reflects the choice of the earth's surface (rather than sea-level) as the lower boundary for the vertical averages.

In Figure 7, the units are $10^4 \text{ cal cm}^{-1} \text{sec}^{-1}$. To convert to $\text{cal cm}^{-1} \text{sec}^{-1} \text{mb}^{-1}$ multiply by 28.6. In order to properly define the fields of heat transport, which have different scales in the three parts of this figure, isolines have been drawn for every 5 units in Fig. 7A, 10 units in Fig. 7B and 20 units in Fig. 7C.

Anyone desiring more copies of this report, or individual page-size copies of one or more of the 27 parts of the figures, may obtain them by writing to National Meteorological Center, National Oceanic and Atmospheric Administration, Washington, D. C. 20233.

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