The Counter-Gradient Flux of Sensible Heat in the Lower Stratosphere

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(Manuscript received December 4, 1953)

Introduction

Several recent investigations, KUO (1951), VAN MEIGHEM (1953), STARR (1953) and ARAKAWA (1953), have been concerned with examining the physical processes which account for the maintenance of the kinetic energy of zonal motion in the atmosphere. These studies have pointed up the important role played by the large scale horizontal eddies. The fundamental point made by all these investigators centers on the existence within the free atmosphere of a systematic organization of the large scale eddy momentum exchange processes in such a manner that momentum flows from regions of low to regions of high momentum. The reflection of this condition is most prominent equatorward of the jet stream where for example observational studies of STARR and WHITE (1952) show that the flux of momentum by the large scale horizontal eddy processes is poleward into the jet. STARR (1953) and ARAKAWA (1953) have actually evaluated the work done by such large scale eddy stresses and indicate that the rate of generation of kinetic energy of zonal motion by such processes seems to be sufficient to maintain the westerlies of middle and high latitudes. It is of interest, therefore, to inquire whether similar conditions prevail in the atmosphere with regard to the transfer of other atmospheric properties and in particular with respect to the transfer of sensible heat. Sufficient data are now at hand to show that similar counter-gradient sensible heat flows do occur on a systematic basis.

Data

In connection with a more extensive study of the atmospheric energy balance, computations of the large scale horizontal eddy flux of sensible heat were undertaken. Except for a constant factor, the large scale meridional horizontal eddy flux of sensible heat is measured by the term $[\overline{v'\ T'}]$, where the brackets represent a mean with respect to longitude, the bar a mean with respect to time, the primes represent deviations from the longitudinal means, v is the northward component of the wind velocity, and T the absolute temperature. The evaluation of this term at various latitudes and at the standard pressure levels in the atmosphere, was made using observed wind and radiosonde observations available in the data compilations of the Northern Hemisphere Historical Weather Map Series, prepared by the U. S. Weather Bureau, in cooperation with the Army, Navy and Air Force, for the full year 1950. The procedure was similar in many respects to that used in connection with investigations of the angular momentum balance reported by STARR and WHITE (1951),

Table 1. Numerical analysis of sensible heat flux data for the entire year 1950. Temperature in degrees absolute, velocities in *m* sec^{-1} and *N* is the total number of observations. The 95 % confidence intervals defined as twice the standard error of the time means is also given.

Level mb	70° N			55° N			42.5° N			31° N		
	$[\overline{T}]$	$[\overline{V'T'}]$	N	$[\overline{T}]$	$[\overline{V'T'}]$	N	$[\overline{T}]$	$[\overline{V'T'}]$	N	$[\overline{T}]$	$[\overline{V'T'}]$	N
100	225	+0.4 ±2.9	288	220	+5.6 ±2.7	763	215	+4.8 ±3.8	546	206	+3.2 ±2.9	1253
200	223	+1.4 ±4.0	919	220	+5.2 ±4.0	1601	219	+8.3 ±4.5	1684	218	+7.4 ±2.7	2859
300	222	+0.0 ±3.2	1302	225	+2.5 ±2.7	2361	231	+3.0 ±3.3	2463	236	+3.0 ±1.8	4003
500	244	+5.2 ±3.1	2047	249	+8.5 ±2.4	3295	256	+1.9 ±1.9	3625	262	+1.5 ±1.1	5181
700	259	+9.2 ±2.1	2266	264	+12.7 ±2.0	3599	272	+6.6 ±1.3	4319	278	+2.3 ±0.9	5756
850	266	+9.6 ±2.0	2374	271	+17.5 ±2.0	3684	279	+10.8 ±1.5	4425	285	+5.0 ±1.1	5218
1000	267	+7.6 ±2.3	1716	275	+11.8 ±2.0	2207	284	+5.5 ±1.2	2494	292	+2.8 ±0.7	4507

in which strings of stations in the vicinity of certain latitudes were selected from which observations were collected. A complete listing of these stations together with the frequency distribution of the observations will be forthcoming in a paper soon to be published by Starr and White.

For purposes at hand it is sufficient to present the relevant data in Table 1, where the mean temperature, magnitude of the eddy transfer of sensible heat, and total number of observations entering the evaluations, are shown. From this table it will be noticed that throughout the troposphere, at all latitudes up to the 200 mb level the eddy-flux of sensible heat is poleward from regions of high to regions of low temperature as might normally be expected. At and above this level the reverse is true. There is an eddy flux of sensible heat from the cold tropical lower stratosphere poleward to the warm polar regions at these levels. This condition was also recognized by PRIESTLEY (1949) and MINTZ (1951) from data compilations which were restricted in space or time. The 95 % confidence limits of the time means of the eddy-transfer term are also indicated and in almost all cases exclude zero, indicating that at least a necessary statistical condition is satisfied by these data.

Meteorological implications

a. The existence of conditions illustrated by these data, and similar ones indicated by STARR (1953) point up the fact that meteorologists should recognize not only the possible existence of these counter-gradient eddy transfer processes but also the actual prevalence of such conditions in certain regions of the atmosphere.

b. The flux of sensible heat from cold to warm regions on the scale of the general circulation at and above the jet-stream-tropopause level indicates that the eddy processes are acting to build up rather than dissipate the existing temperature gradient.

c. Certain fundamental questions concerning the location of the height of the tropopause, and the height of the jet are inseparable from the questions concerning the reversed meridional temperature gradient in the lower stratosphere. Hence a process such as that indicated by these data which obviously acts to build up this reversed gradient may be of considerable importance.

d. Since the full significance of these observational findings is not clear, the data are presented primarily in the hope that they will encourage other interested investigators to consider the implications of such conditions.

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