

ROYAL METEOROLOGICAL SOCIETY: AUSTRALIAN BRANCH MEETING

9 August 1977

Poleward Heat Fluxes from Selected Southern Ocean Stations

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Dr Bennett, Department of Mathematics, Monash University, opened his talk by pointing out that two recent indirect estimates of annual mean poleward heat flux in the oceans have differed by a factor of two. Based on atmospheric data, Sellers in 1965 came up with a figure of $10^{15}W$ towards the poles in both the southern and northern hemispheres. An indirect estimate for the northern hemisphere only, made by Von der Haar and Oort in 1973, produced a figure of $2 \times 10^{15}W$ towards the pole. From a direct approach, using hydrographic data at $30^{\circ}S$, Dr Bennett indicated that he had made a calculation that agreed with Seller's figure in magnitude, but was in the opposite direction. The difference, he said, may be due to misrepresentation of the mid-ocean eddies or due to seasonal variability. He considered only the first of these possibilities in some detail.

Dr Bennett began the detailed discussion of his direct approach by writing down the general formula for the instantaneous meridional flux of *total* energy per unit mass as

$$\int \rho v \epsilon dA$$

where A is an oceanic cross-section at a fixed latitude, ρ is the density of seawater and v is the meridional velocity (positive northwards). This total energy ϵ was made up of three components: kinetic energy, geopotential energy and enthalpy. The first, Dr Bennett pointed out, had been calculated before by Jung in 1952 and found to be negligible. Changes in enthalpy due to typical oceanic variations in salinity were negligible, and thus contributions from temperature and pressure variations in the ocean appeared to be most important. He finally arrived at the conclusion that the total energy per unit mass was the energy which may be extracted from a water mass isobarically after it has been raised to the sea surface adiabatically.

Dr Bennett then went into some detail showing how the meridional velocity v , without the effect of eddies, was calculated. He divided this velocity into three parts: the surface geostrophic velocity, the geostrophic velocity relative to the surface, and the Ekman velocity. Hellerman's wind data was used to calculate the latter. Then using hydrographic data collected on a number of cruises made between the years 1936 and 1967, Dr Bennett estimated the contributions to the total energy and the meridional velocity in all the southern hemisphere oceans and arrived at a figure for the grand total heat flux as lying between $1.13 \times 10^{15}W$ and $2.23 \times 10^{15}W$ towards the equator. He also pointed out that the poleward salt flux was very small.

The audience was now confronted with this surprising result of northward rather than southward heat flux in the Southern Ocean. Dr Bennett now posed the idea of calculating the heat flux due to mid-ocean eddies, to see if this was large enough and towards the south in order that the intuitive idea of poleward heat flux could be derived.

Statistics of the eddy field were chosen using the results of the MODE-1 data collected in the Sargasso Sea in 1973. These were length scale of 100 km, velocity scale of 10 cm/s and temperature $1^{\circ}C$. Geostrophically balanced eddies were assumed by Dr Bennett and he justified this in some detail. Contributions to the eddy flux from the baroclinic eddy field and the barotropic eddy field were considered separately. Dr Bennett pointed out, however, that unless absolute velocity measurements were available the contribution from the barotropic eddy field cannot be estimated

reliably. His complicated calculations of the baroclinic eddy field heat flux showed that his original estimate could only be altered by $\pm 0.8 \times 10^{15} \text{W}$, and thus concluded that this still was not large enough to give a poleward heat flux.

In conclusion, Dr Bennett remarked that maybe the barotropic eddy field was contributing a large poleward heat flux that counteracts the equatorial flux that he has calculated. However, until the data set in the Southern Ocean is made larger with actual measured velocities, this quantity cannot be estimated.