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COMMENTS ON 'SEASONAL VARIABILITY OF THE FLORIDA CURRENT,' BY NIILER AND RICHARDSON¹

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Niiler and Richardson (1973) have presented the results of direct measurements showing the seasonal variation of the volume flux of the Florida Current, from the average low of 25.4×10^6 m³/s in about November to the average high of 33.6×10^6 m³/s in about June. These excellent measurements give us, for the first time, reliable quantitative information about the seasonal variation of a major ocean current.

Unfortunately, like Wüst (1924) before them, they make the mistake of going on to calculate what they call the 'transport of heat' or 'heat flux' of the Florida Current by integrating $C_p VT$ over the cross-sectional area of the Florida Strait. The quantity ' V is the northward component of velocity and T is the temperature of the water'. Apparently they use the Celsius scale of temperature. 'We recognize that this integral represents only a portion of the gross northward transport of heat and that the zero is arbitrary. However, it is adequate to define the seasonal change of heat flux through the Straits of Florida.' I disagree with this statement.

'Fig. 14 gives the summer and winter distribution of the heat flux . . . The amplitude of the annual cycle of the heat transport is one-half the area between the curves and is equal to 2.0×10^{19} cal/day.' (My measure of half the area between the two curves is only 0.6×10^{19} cal/day, but this discrepancy seems unimportant.) The trouble is that the zero on the temperature scale is arbitrary, so the heat flux computed this way is meaningless. The seasonal change in heat flux would be meaningful if the mass flux were constant, but Niiler and Richardson have shown that it is not constant. They conclude that the heat flux is greater in summer, which is also the season when they find the mass flux to be greater. By choosing a lower zero point on their temperature scale, they would have found a still greater difference between summer and

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winter heat flux. By choosing a higher zero point, the difference would become smaller, and a sufficiently high zero point would result in greater heat flux in winter than in summer.

The crux of the matter can be illustrated by the example that the heat carried by 1 ton of water at 30°C cannot be compared with the heat carried by 30 tons of water at 1°C. The convection of heat into a system becomes meaningful if the mass of the system is constant. And the variation in heat flux through a surface is meaningful if the mass flux is constant. I have discussed this matter more generally elsewhere (Montgomery 1954).

If the system is, for instance, the Gulf of Mexico (or the North Atlantic Ocean north of the latitude of Miami) and if a time interval is chosen during which the net change in mass and composition of the system can be neglected, then the heat convected into the system can properly be computed by integrating $\rho C_p VT$ (where ρ is density and C_p is specific heat capacity) over the time interval and over the cross-sectional areas of *all* the channels opening into the system. A uniform temperature must be chosen as zero, but the zero point does not affect the integral. The integral of $\rho C_p VT$ over only one of several channels, however, usually has no meaning by itself. If the mass flux and composition of the water flowing through this channel are constant, then the time variation of the integral becomes meaningful, because in this special case the zero point does not affect the time variation of the integral.

It would be useful if the authors would present for different seasons the volume flux by temperature classes. This information would show the seasonal variation in fluxes of water of different temperatures. This information, however, cannot be converted to a single variable representing 'heat flux'.

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NIILER AND RICHARDSON REPLY:

In the paper on the "Seasonal Variability of the Florida Current", we calculate the northward advection of the temperature field in the Florida Current and attempt to relate its seasonally variable portion to the net northward heat flux carried by the North Atlantic Ocean currents. Such a calculation was included because we found that the quantity $\iint VTdA \equiv (VT)$ can be computed

in a statistically significant fashion from 12-13 samples for both summer and winter, and the seasonal difference is also significant. Here V is the northward velocity component and T is the temperature in degrees Celsius. Montgomery is correct in emphasizing that such a relationship is specious by itself, without, for example, computing this integral over the rest of the North Atlantic gyre. When comparable observations are available at other parts of the Gulf Stream System, it will be possible to take the difference of the advected flux within a stream tube for a particular season, and this will be equal to the heat loss by the water flowing north in the tube. This loss may be to the atmosphere or to the surrounding water by eddy diffusion.

Montgomery's critical point is that the seasonally varying part of $(C_p \rho VT)$ cannot be unambiguously called the seasonal change in heat flux, and he suggests it might be interesting to note what part of the seasonally varying temperature and transport field contributes most to its seasonal variation. In the Florida Current, the water temperature near the surface reaches a maximum very nearly at the summertime maximum of the northward flow. Let \bar{T} , \bar{V} be the mean values, and the amplitude of the seasonal harmonics be V' , T' . Hence, $(VT)_{\text{summer}} - (VT)_{\text{winter}} \cong 2\{(V'\bar{T}) + (\bar{V}T')\}$. The temperature flux proportional to $(V'\bar{T})$ depends on the arbitrary zero of \bar{T} , while the term $(\bar{V}T')$ has an unambiguous definition.

We have recalculated each of these temperature fluxes separately from the data. The seasonal transport of the mean thermal field gives rise to an apparent heat flux of

$$C_p \rho (V'\bar{T}) \leq C_p \rho (V')(\bar{T})/A \cong 4.0 \times 10^{12} \text{ cal/sec}^\circ\text{C} \times 16^\circ\text{C} = 0.63 \times 10^{19} \text{ cal/day,}$$

since the amplitude of the season transport variation is $4 \times 10^{12} \text{ cm}^3/\text{sec}$, and the area averaged temperature of the Florida Current is 16°C .

The mean transport of the seasonally varying thermal field gives rise to a heat flux principally within the seasonal thermocline. In Table IV we have calculated the variation of transport within the seasonal thermocline (our Region I water where $\sigma_\tau > 24.5$) and $(V_I) \cong 6.3 \times 10^{12} \text{ cm}^3/\text{sec}$, and from Figures 10, 11, and 12, we note that $(T'_I)/A_I \cong 1^\circ\text{C}$. Hence,

$$C_p \rho (\bar{V}T') \leq C_p \rho (\bar{V}_I)(T'_I)/A_I \cong 0.06 \times 10^{19} \text{ cal/day.}$$

Montgomery points out that the half amplitude of the seasonal variation $0.1 C_p \rho (VT)$, based on Figure 14, should be $0.60 \times 10^{19} \text{ cal/day}$, (not $2.0 \times 10^{19} \text{ cal/day}$ as reported in our paper). We see from the above that this variation is produced principally by the season advection of the mean thermal field and is sensitive to the zero of the temperature field. We are grateful for Professor Montgomery's sharp eye, and apologize for our failure to present a self-consistent text with Figure 14.