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UPPER-OCEAN HEAT CONTENT AND ENERGY EXTRACTED BY THE STORM: AN ANALYTICAL LOOK

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The concept of upper-ocean "hurricane heat potential" (a.k.a. "upper ocean heat content") (Q_H) was originally quantified by Leiper and Volgenau (1972) and is defined as the integrated vertical temperature from the sea-surface to the depth of the 26° C isotherm. Q_H is given by:

$$Q_H(x,y,t) = \rho \, C_p \int_{z_{26}}^{0} \Delta T(x,y,t) \, dz, \qquad (1)$$

where C_p is the specific heat at constant pressure (1 $\mathrm{cal\,g^{-1}\,{}^\circ C^{-1}}$), ρ is the average density of the upper-ocean (1.026 $\mathrm{g\,cm^{-3}}$) and ΔT is the difference between the local temperature and 26° C over the depth interval dz.

Since much of the ocean-to-atmosphere exchange of energy in tropical cyclones occurs within the high-wind inner core, analyses and estimates presented here will focus on conditions potentially present with this critical region. Exactly how much of the upper-ocean heat content within the hurricane inner-core ($Q_{H_{core}}$) is actually extracted by the storm ($Q_{H_{core-use}}$) is very difficult to quantify without highly-accurate, direct and continuous measurement. However, by making some reasonable assumptions and using recent findings from Cione et al. (2000), it may be possible to construct a realistic parameter space for 'upper-ocean energy utilization' (i.e. $Q_{H_{core-use}}/Q_{H_{core}}$). For this analysis, $Q_{H_{core}}$ and $Q_{H_{core-use}}$ are defined as:

$$Q_{H_{core}} = Q_H \, A_{core-cum}, \qquad (2)$$

$$Q_{H_{core-use}} = H_{core} \, A_{core} \, TC_{transit-time}, \qquad (3)$$

where A_{core} is the storm's inner-core area, $A_{core-cum}$ is the cumulative inner-core area covered by a translating storm over a finite period, $TC_{transit-time}$ is the time it takes for a storm to traverse $A_{core-cum}$ and H_{core} is the storm-induced total surface enthalpy flux (latent plus sensible) generated within A_{core} at any given time. For these calculations, the storm's inner-core area remained constant (r = 60 km) and a storm speed of 5 $\mathrm{m\,s^{-1}}$ over a 24 hr period was used. Using these values, $A_{core-cum}$ was found to be $6.314 \cdot 10^{14}\ \mathrm{cm^2}$. By assuming a uniform inner core hurricane heat potential value of 75 $\mathrm{kJ\,cm^{-2}}$, $Q_{H_{core}}$ was found to be $4.735 \cdot 10^{16}\ \mathrm{kJ}$. (Note: on average, the tropical North Atlantic typically supports Q_H values between 40-110 $\mathrm{kJ\,cm^{-2}}$ for much of the hurricane season. A visual representation of the spatial and seasonal variability of Q_H within the tropical North Atlantic can be found at: http://www.aoml.noaa.gov/phod/cyclone/data/2001/map.html.)

A primary objective of this study is to establish a reasonable parameter space for upper-ocean energy utilization ($Q_{H_{core-use}}/Q_{H_{core}}$) within the well-mixed hurricane inner-core over a wide range of possible storm speeds and intensities. Upper-ocean energy utilization as a function of storm speed and total surface heat flux (the latter serving as a proxy for TC intensity) is illustrated in Figure 1. From this illustration, we see that upper ocean energy utilization varies between 2-14% when the effects of storm speed and total surface heat flux are combined. This range encompasses a wide array of potential storm speeds (2-12 $\mathrm{m\,s^{-1}}$) and inner-core surface heat flux values (650-3250 $\mathrm{W\,m^{-2}}$).

Even though these preliminary findings do not take into account all physical processes that could potentially come into play (such as advection), the results nevertheless illustrate the vast energy resources typically available to most tropical cyclones under most storm conditions. These analyses suggest that for most propagating systems, the magnitude of upper-ocean heat content should not be a limiting factor affecting storm maintenance and/or intensification.

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Figure 1

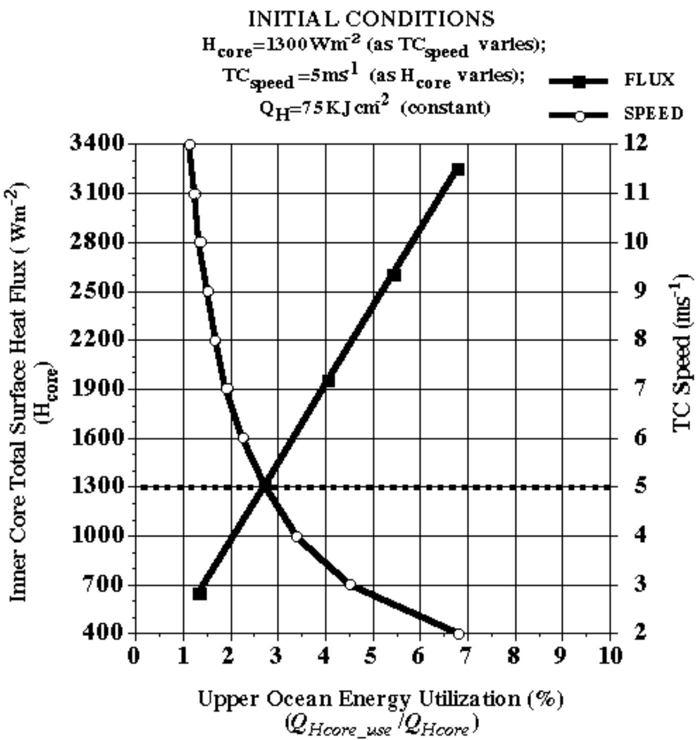

Figure 1: Upper-ocean energy utilization: The percentage of upper-ocean heat content extracted by the storm ($Q_{H_{core-use}}/Q_{H_{core}}$) as a function of inner-core surface heat flux (W m^{-2}) and storm speed (m s^{-1}). In this illustration, inner-core surface heat flux (H_{core}) was held constant (1300 W m^{-2}) as storm speed (TC_{speed}) varied from 2-12 m s^{-1} . Similarly TC_{speed} was then held constant (5 m s^{-1}) as H_{core} varied from 650-3250 W m^{-2}. Dashed line denotes "fixed" H_{core} and TC_{speed} values used (i.e. 1300 W m^{-2} and 5 m s^{-1} , respectively). In all cases, hurricane heat potential (Q_H) was held constant (75 kJ cm^{-1}).