Final Report for the Ocean and Climate Change Institute funded project:

Investigating the influence of surface heat flux on the North Atlantic Circulation and Global Climate

The Project aimed at answering the following question: How do changes in the surface buoyancy forcing of the North Atlantic Ocean influence the strength of the horizontal flow between the equator and the Polar Regions?

In collaboration with a visiting European scientist, Prof. Anna Wåhlin, and an Italian guest student, Flavio Greggi, we conducted laboratory experiments during the spring of 2008 in the Geophysical Fluid Dynamic (GFD) laboratory at WHOI, using the 2m rotating turntable facility. We used a new infrared technology which allowed a free adjustment of the temperature in the tank. Fresh water was heated from above by an infra-red (IR) lamp, and then, as the warm water moved away from the heat source, it naturally cooled at the surface. The surface temperature was monitored by an infra-red (IR) camera and the temperature below the free surface was monitored with vertically sampling temperature probes. These experiments were a natural extension of the non-rotating experiments of Wåhlin et al. (2010), and the novelty of this study was in the presence of background rotation. At the beginning of the project we had some challenges and difficulties due to the fact that the air above the large 2m rotating tank acted as a 'wind' and, for large rotation rates of the table, it set up an unwanted circulation in the tank. By reducing the rotation rate of the table and by positioning a "curtain" around the table (see Figure 1, left) we were able to remove any unwanted circulation in the tank.

The results of the experiments highlighted how the presence of rotation facilitates the horizontal and vertical 'diffusion' of heat through the generation of eddies. In the laboratory the heat source is located at the center of the tank at r = 0cm, where r is the radial coordinate starting at the center of the tank (see Figure 1, right). In the absence of rotation, the heat generated by the IR lamp spreads radially outwards in an axisymmetric manner, as shown in Figure 2 (left). The introduction of rotation changes the dynamics dramatically, eddies are formed as shown in Figure 2 (right) and the surface temperature distribution is no longer axisymmetric. These eddies, which are absent in the non-rotating experiments, can detach from the central heated region and propagate radially outward, hence enhancing the horizontal diffusion of heat. This can be seen in Figure 3 where the averaged radial surface temperature measurements are compared for rotating and non-rotating experiments with a heat forcing equal to 250W (a similar result is obtained with a forcing equal to 150W). This result is also confirmed by the vertical temperature profiles which show how the presence of rotation, though the action of the eddies, allows the heat to be present at greater distance from the heat source also at depth, as shown in Figure 4. For example, in the case of a 250W forcing, having an initial maximum temperature anomaly of 15 ˚C, in the non-rotating experiments the maximum temperature anomaly is reduced to 1 ˚C or less while in the rotating experiment such anomaly is still 10 ˚C at r = 10cm. Another interesting result is that the presence of rotation allows the heat to spread at deeper levels than when rotation absent, as can be seen in Figure 4. For example, if we compare the 250W forcing experiments, in the non-rotating experiment the temperature anomaly is confined within the top 0.5 cm while in the rotating experiment the temperature anomaly is measured down to 1.5 cm.

In summary, the present study showed how the presence of rotation and the consequent generation of baroclinic eddies moving radially outwards from the heating source contribute to the enhancement of heat diffusion both horizontally and vertically. Increasing the buoyancy forcing, i.e. increasing the forcing from 150W to 250W, allowed the generation of larger and warmer eddies which enhanced the diffusion of heat horizontally and vertically.

The results of the present study constituted the Master Thesis of Flavio Greggi at the University of Rome "la Sapienza" entitled "*Moti convettivi in sistemi rotanti e non-rotanti*". A manuscript describing the above results is in preparation and further experiments continuing this international collaboration and including the effect of bottom topography are planned in the nearby future by the PI, Dr. Cenedese, and the visiting European scientist, Prof.Wåhlin. The PI is grateful for the funding received which enabled the successful realization of the project, the productive international collaboration with a European scientist (which is bound to continue), and the supervision of an international guest student who successfully defended his Master Thesis.

References:

Wåhlin, A., Ericsson, M., Aas, E., Brostrøm, G., J. Weber and J. Grue, 2010. Horizontal convection in water heated by infra-red radiation and cooled by evaporation. Tellus A, 62, 154 - 169.

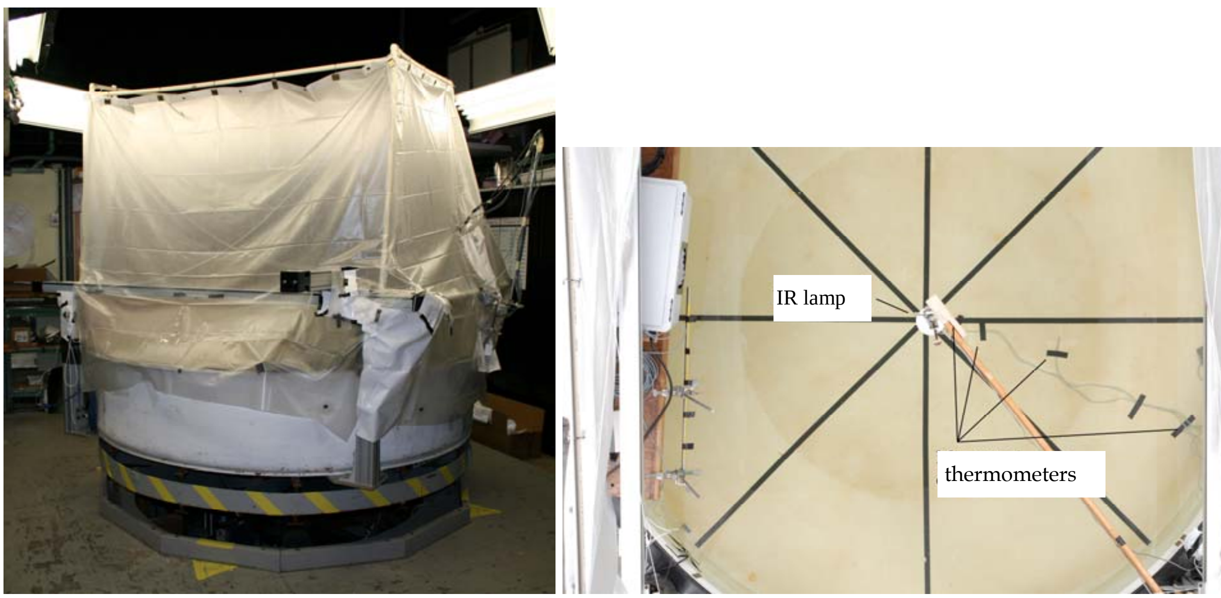

Figure 1: Experimental apparatus in the Geophysical Fluid Dynamics Laboratory at WHOI. Left: rotating table with 'curtains' to avoid 'wind' effects. Right: Top view of the rotating tank with labeled the infra-red (IR) lamp (heat source) at the center of the tank, and the fixed location digital thermometers which monitored the temperature at the bottom of the tank.

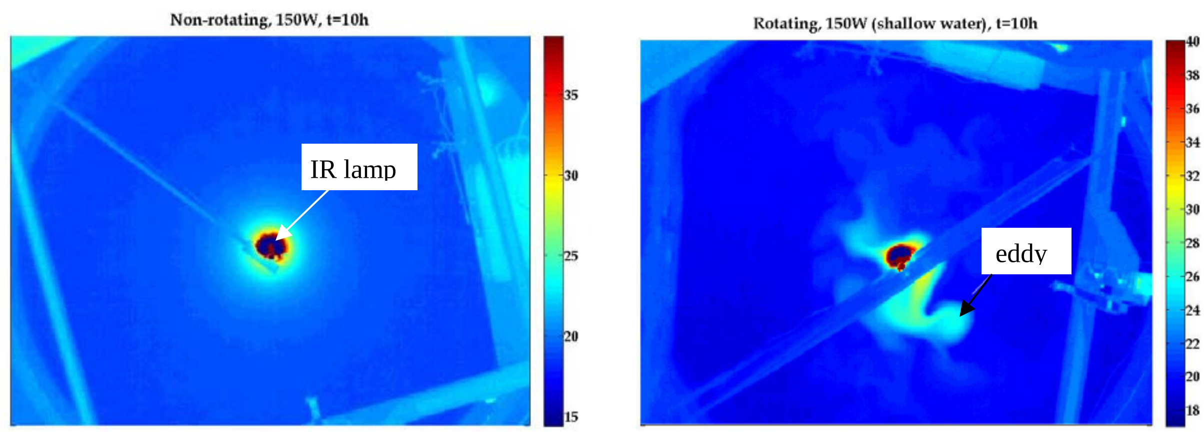

Figure 2. Non-rotating (left panel) and rotating (right panel) surface temperatures measured by the infra-red (IR) camera after 10 hours the IR lamp forcing at 150W was started.

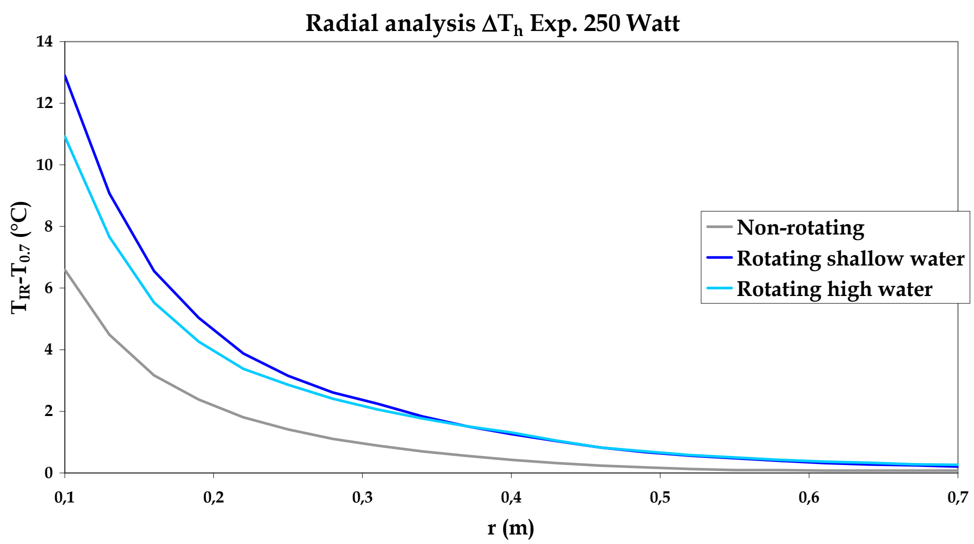

Figure 3: Averaged radial temperature for rotating (blue) and non-rotating (black) experiments with a forcing of 250W.

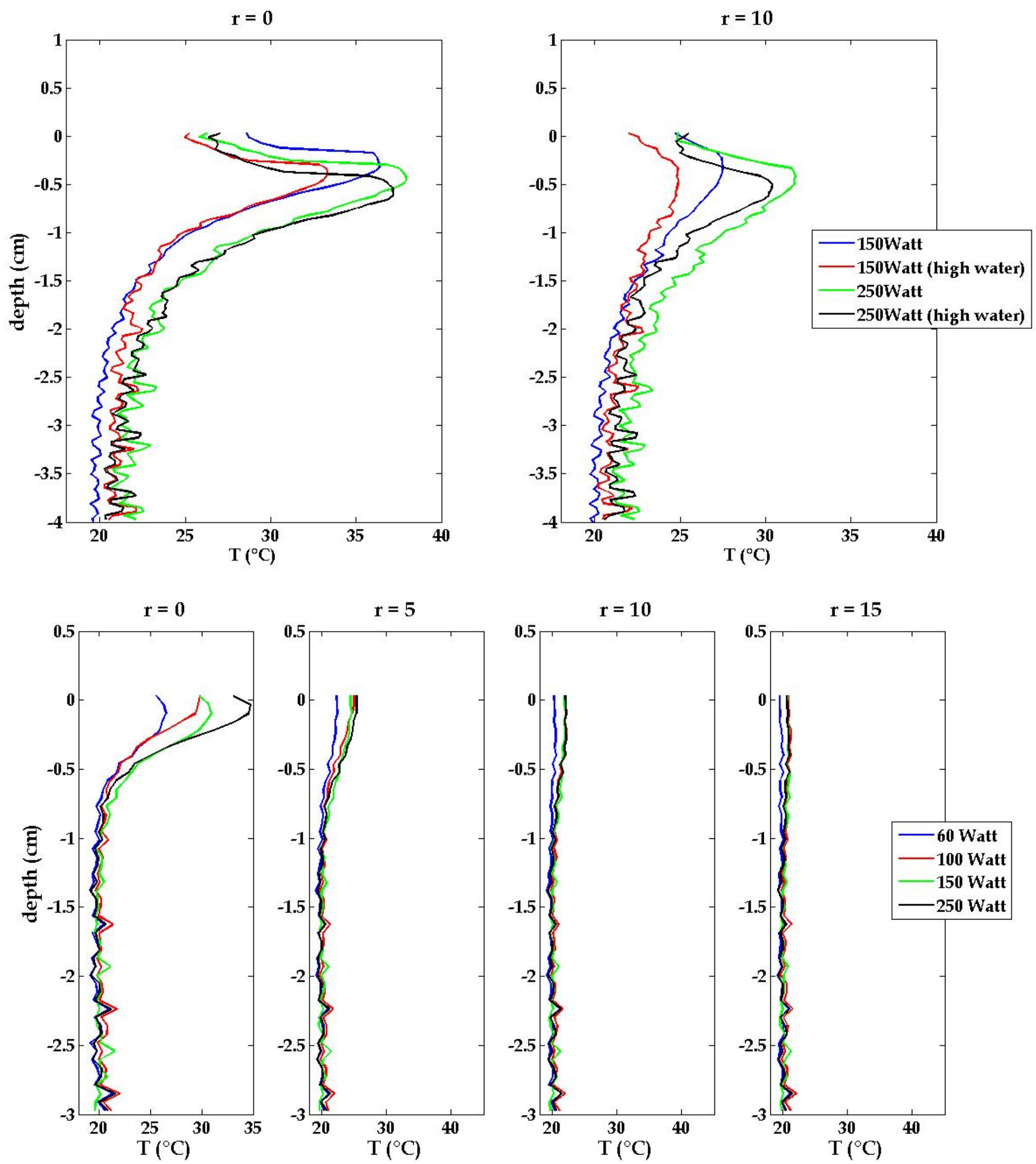

Figure 4. Rotating (top panels) and non-rotating (bottom panels) temperature vertical profiles at different radii.