Does Europa's subsurface water ocean have a stratosphere?

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Jupiter's moon Europa has a mean density suggestive of rock, but a reflectance spectrum that shows that it is covered by water ice. Europa's moment of inertia indicates that its surface may be underlain by 100 to 200 km of mostly pure water. Many authors have discussed the interesting possibility that Europa may possess a surface ice shell overlying a liquid water ocean. That this scenario is possible at all is due to a peculiarity of water ice: Solid ice is less dense than the liquid from which it freezes. In this abstract we investigate the possible consequences of another peculiarity of water: Liquid water is densest at a temperature a few degrees above the freezing point.

The rocky interior of Europa probably produces some amount of radiogenic heat. Assuming the rocky component produces as much heat per kg as a carbonaceous chondrite, a surface heat flow of about 8 mW/m^2 will result. In addition, an unknown amount of tidal heat will be dissipated in the deep interior (as well as some in the flexed ice shell). Even with this small amount of radiogenic heat flux, the deep ocean will convect vigorously, with Rayleigh numbers in the vicinity of 10^{20} and Nusselt numbers near 10^6. Convection theory tells us that under these conditions the super-adiabatic temperature difference between the top and the bottom of the ocean will be only a few millikelvins and the mean convective velocities less than a mm/sec.

The interesting question is, what is the mean temperature of this deep, vigorously convecting ocean? Most of the ocean is at such high pressure that the temperature of the highest density of water coincides with the melting temperature. But if the ocean salinity is low enough, and the ice shell thinner than about 23 km (less as salinity increases), then the top of the convecting system falls in the zone where warm water is denser than cold water. If convection is vigorous enough to pierce this layer where the coefficient of thermal expansion is negative, then the mean temperature of the ocean falls close to the melting point of ice. However, if the upper, cool, buoyant water is stable, then the mean temperature of the convecting ocean will be close to the temperature at maximum density just below the ice/water interface.

The thickness of the buoyant layer at the top of the ocean depends on the heat flux, salinity of the ocean, and thickness of the ice shell and is ~100 m for realistic parameter values. Convective plumes from the hot (~4 °C) oceanic interior that penetrate this layer become negatively buoyant and descend back into the oceanic interior. We have performed a stability analysis that suggests that this layer might be stable against penetration by the vigorously convecting water below.

Geologic studies of Europa have shown a wealth of features that are consistent with the presence of water not far below the surface. In particular, broad areas known as "Chaos" may be regions where the ice shell briefly melted through. Although many theories for how this might happen have been proposed, the most natural explanation may be that they represent areas where deep, warm ocean waters have come into contact with the overlying ice. Long-lived thermal upwellings in the deep ocean may breach the stably stratified layer and permit the voluminous warm water of the deep ocean to directly impinge on the ice shell. This would result in rapid melting so long as the supply of warm water is continued.

More speculatively, Europa's global tectonics may operate in the mode that has been suggested for Venus: After a paroxysmal overturn that resurfaces the satellite, the ice shell may gradually cool and thicken for a time as the ocean warms beneath. When the ocean becomes sufficiently warm to breach the stable layer once again the ice shell is consumed and another cycle begins. The interval between such catastrophes can be calculated as follows: The ocean must warm by of the order of 4-8 °C (if the ocean starts throughout at 0 °C, it must warm to 8 °C to be buoyant enough to breach the stable layer). A 100 km deep ocean corresponds to 10^8 kg/m^2 of water, requiring $4x10^{11}$ J/ °C to warm. If the core supplies a reasonable net heating of 10 mW/m^2 (radiogenic plus core tidal heat) the ocean will take 1-$3x10^{14}$ s to heat up to the overturning point, or around 5 Myr. This is, perhaps not coincidentally, the same order as the age of the surface of Europa, estimated at about 10 Myr from crater counts. This time increases for lower net heating rates or a deeper ocean.