CHAPTER 8 BOX 1

UNDERSTANDING WESTWARD INTENSIFICATION OF SUBTROPICAL GYRE BOUNDARY CURRENTS.

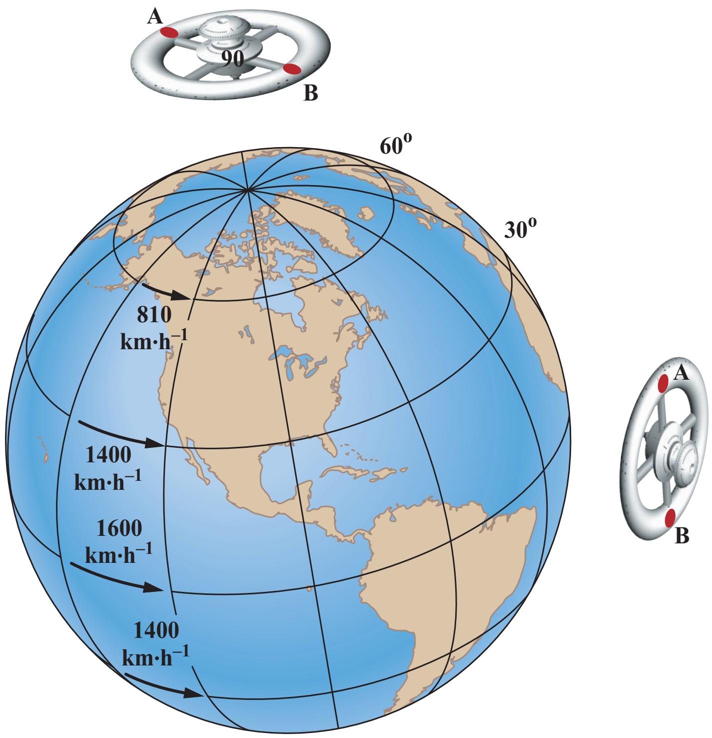

FIGURE 10.11 Vorticity (apparent rotation) increases with increasing latitude. Imagine a rotating Earth with a circular space station orbiting above a specific location on the equator but not rotating around its own axis. An observer looking up from the equator would see that the nonrotating space station stays in the same position in the sky and does not rotate. Now imagine the space station being positioned directly over the North Pole, but still not rotating about its own axis. To an observer looking up from the pole, the nonrotating space station would appear to rotate one revolution each 24 h. It is more difficult to explain what an observer would see if the space station were moved from the equator to mid latitudes. However, the observer would see it rotate, and the rotation rate would increase progressively faster with increasing latitude until, at the poles, it reached one apparent rotation per 24 h.

Imagine a motionless wheel suspended horizontally above the Earth's surface at the equator (**Fig. 8B1-1**). To an observer on the Earth, the wheel does not appear to rotate as the Earth rotates. Now imagine that we transport this still motionless wheel to the North Pole and again suspend it horizontally above the Earth. To an observer on the Earth, the stationary wheel appears to spin, and at the same rate as the Earth spins. This effect also applies to spinning gyres of water in the oceans. The rate of apparent rotation increases with distance from the equator and is called planetary vorticity. Western boundary currents undergo an increase in their apparent rate of rotation as they flow poleward, whereas eastern boundary currents undergo a decrease in their apparent rate of rotation as they flow toward the equator. This is the underlying reason for the westward intensification, but it requires some explanation.

In a spinning fluid, the angular momentum must be conserved. It is not necessary to fully understand this, but you can see an application of this principle when an ice-skater spins. With the arms close to the body, the skater spins quickly. If the arms are extended, the spin becomes much slower, but momentum is not lost. When the arms are once more brought in, the spin becomes faster again. Of course, friction with the ice does eventually steal momentum, slowing down the spin. Angular momentum and vorticity are related, and vorticity is conserved in much the same way as angular momentum. However, the vorticity that must be conserved is a combination of the planetary vorticity and the relative vorticity. The relative vorticity is the vorticity due to the wind-driven motion of the water in the gyre. The math can be a little complicated, so the process is just summarized in **Figure 8B1-2**.

Figure 8B1-2a represents a symmetrical gyre with no westward intensification. On the east side of the gyre, the planetary vorticity is counterclockwise and the relative vorticity is clockwise. Thus, the decrease in planetary vorticity as water moves south can be compensated for by an increase in the relative vorticity (speeding up the wind-driven rotation of the gyre, which is in fact what happens as the current flows farther south into the trade wind belt). However, on the west side both the planetary vorticity and the relative vorticity are counterclockwise. The increase of planetary vorticity could be partly offset if the relative vorticity decreased, but the magnitude of the planetary vorticity at the north end of the western boundary current is much larger than the relative vorticity, so the clockwise motion would be stopped unless there was a strong source of positive (counterclockwise) relative vorticity. This can be supplied by a strong frictional stress that opposes the northward flow of the western boundary current. A strong frictional stress, in turn, can be established if the current is constrained to flow against the land boundary (**Fig. 8B1-2b**), which generates friction at the interface between the current and the seafloor. If the current flows fast and is narrow and deep, the area of contact with the seafloor (along the edge of the continental shelf) is maximized, and, therefore, so is the shear "frictional" stress. As a result, the westward intensification occurs in all ocean current gyres and is caused by the variation in magnitude of the Coriolis effect with latitude.

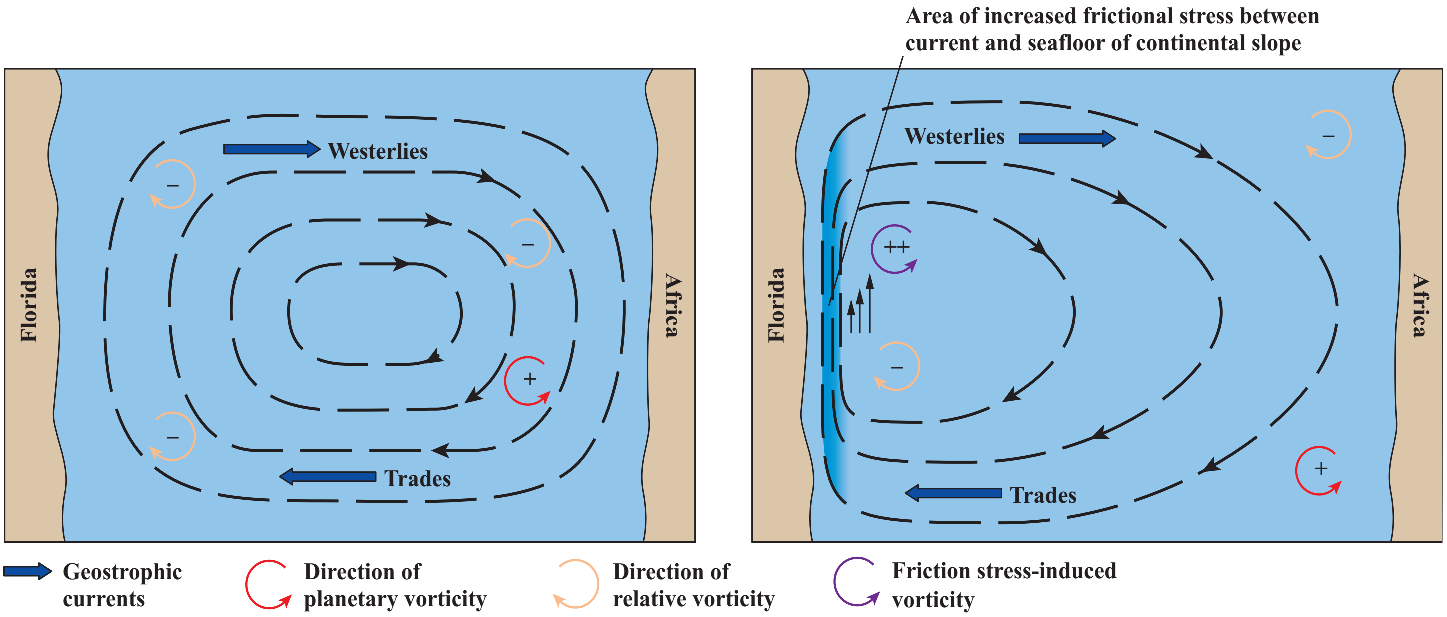

FIGURE 8B1-2. In the Northern Hemisphere, winds generate clockwise rotating gyres. This rotation creates clockwise vorticity (or spin) relative to the Earth, called relative vorticity. Vorticity, called planetary vorticity, is also imparted by the variations in the magnitude of the Coriolis Effect. On the eastward side of the gyre, water flowing southward is subject to a decreasing Coriolis Effect, which induces an anticlockwise planetary vorticity (for simplicity, a reduced tendency to turn to the right or spin). On the westward side of the gyre the northward flowing water is subject to increasing Coriolis Effect, which induces clockwise planetary vorticity. However, the total vorticity, or spin, must be the same for all parts of the gyre. If it were not, then the total mass transport rate of one part of the gyre would speed up while another slowed down, which is not possible. (a) Shows that, if the gyre were symmetrical, the relative vorticity on the eastward side can be balanced by the planetary vorticity as they are opposite. On the westward side, planetary and relative vorticity are in the same direction and cannot be balanced. (b) If the gyre is offset (intensified) to the west, friction is increased between the flowing water and the seafloor of the continental slope against which the gyre current is concentrated. The friction provides a source of counterclockwise vorticity to balance the clockwise relative and planetary vorticities.