Oceanography

Tides, solitons and nutrients

from Melbourne G. Briscoe

TIDAL energy mixes the coastal waters, providing nutrients for biological processes. The mechanism is indirect; the topography of the shelf-break, the stratification of the coastal waters and the tides interact to produce groups of solitons — strong, short, high frequency internal waves — and it is the breaking of these solitons as they propagate inshore to even shallower water that is responsible for the mixing. That is the suggestion offered by H. Sandstrom and J.A. Elliott of the Bedford Institute of Oceanography in Canada[1]. Their idea, based on their work on the Scotian Shelf, seems sound but perhaps does not go far enough.

Solitons are so-called because of their similarity to the mathematically precise idea of a non-linear wave that retains its identity and form as it propagates along as a singular bump on the sea surface. However, in most situations an internal wave actually travels as a singular wave of depression, since there is usually a deeper layer of water underneath the pycnocline (the layer where the water density changes most quickly with increasing depth) than above it. As the internal depression on the pycnocline propagates, it tends to disperse into the free-wave components that compose it. This tendency is balanced by the nonlinearities that arise from the finite amplitude of the depression and allow the wave to retain its soliton form. This fragile balance of forces is easily realized in equations, can sometimes be simulated in the laboratory, but probably never really occurs in the ocean; I therefore use the word soliton with some reservations.

Solitons are thought to be produced by the surface tide running up against the edge of the continental shelf. The pycnocline overlying the shelf is disturbed vertically by the tidal flows and a depression in the pycnocline begins to travel shoreward. There is some uncertainty about the mechanism that forms the depression: Sandstrom and Elliott consider that the surface tide forms an essentially linear, internal tide at the shelf edge, and that the leading edge of the propagating internal tide is the depression that finally resolves into the soliton[1]. The scales of these processes differ greatly. The surface and internal tides (called barotropic and baroclinic tides, respectively, in the oceanographic literature) occur once or twice a day, depending on location, but the wave sequence in the soliton is of just a few minutes period. The horizontal scales of these three processes decrease from thousands of kilometres, to tens of kilometres, to hundreds of metres.

Because of the tidal generation of solitons they can be recorded every 12.4 h in those locations where the semi-diurnal tide is dominant. One might also expect a spring-neap cycle in the intensities of the process, but I am aware of no good data that confirm this; since the dynamics of the generation of the solitons and of their eventual propagation depend on the strength and depth of the pycnocline, the inevitable changes in the hydrography with space and time probably obscure spring-neap effects.

Surprisingly, solitons are often easy to observe in the ocean. The interaction of wave currents in the soliton with short surface wind waves causes a modulation of the roughness of the sea surface that is visible to the eye and to radar. Landsat satellite images described by C. Sawyer[2] show that the entire eastern seaboard of North America is covered with a pattern of surface streaks characteristic of solitons. This is especially so in the 50–150 m depth range of the shelf, and is most marked in summer and early autumn, when the thermocline is well developed. (Georges Bank and its surroundings perhaps have the most solitons in the western North Atlantic; does this account for the nutrient supply and the fishing industry on Georges Bank?)

Sandstrom and Elliott propose that the surface tides at the shelf edge are converted to internal tides and then to solitons that dissipate on the shelf[1]. They calculate a figure of 6×10^7 J per metre of crest length for their solitons. If extrapolated to the coastlines of the world this yields 1×10^{15} J, less than a third of a percent of the total internal tidal energy, a negligible contribution to the problem of how the energy is dissipated. On the other hand 6×10^7 J dissipated on a 10 km wide shelf in half a day provides about 50 mW m^{-2} towards the vertical mixing of the water and the erosion of the base of the mixed layer. This is at least ten times the energy supply estimated from internal wave dissipation in the deep sea and several times larger than estimates of the energy available from typical winds.

A.R. Osborne and T.L. Burch[3] have described solitons in the Andaman Sea near Sumatra that are 15 times more energetic than the examples of Sandstrom and Elliott. Even if all of the coastlines of the world were covered with such solitons, and all these solitons were dissipated in half a day, this would still only account for 0.3×10^{12} W, just 20 percent of what needs to be dissipated from the surface tide in shallow seas according to G. Miller's calculations[4]. (These take into account surface tide dissipation due to conversion to internal tides or solitons on the shelves for some areas of the world, but not for the North American east coast where so many solitons have been observed.)

So even this extreme estimate of the energetics and dissipation of solitons, we are not much closer to understanding where tidal energy goes, but Sandstrom and Elliott's suggestion[1] of the importance of solitons for shelf-mixing and for the supply of nutrients to the euphotoic zone seems plausible on the Scotian Shelf. It may even be applicable to thousands of kilometres of other soliton-covered shelves. ☐

1. Sandstrom, H. & Elliott, J.A. *J. geophy. Res.* **89**, 6415 (1984).
2. Sawyer, C. *NOAA Tech. Memo. Envir. Res. Lab. Pacific mar. envir. Lab.* Publ. **46** (1983).
3. Osborne, A.R. & Burch, T.L. *Science* **208**, 451 (1980).
4. Miller, G. *J. geophys. Res.* **71**, 2485 (1966).

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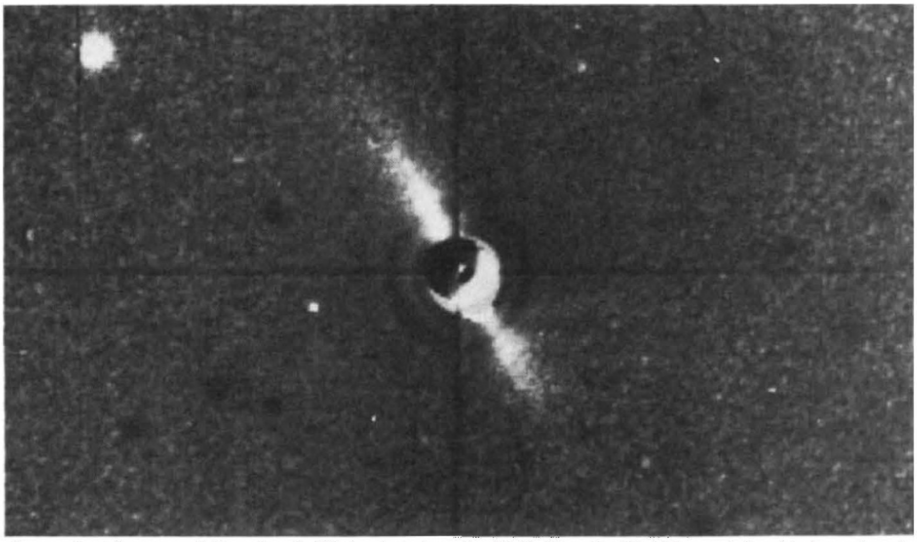

A masked image of the star β Pictoris taken by R.J. Terrile (Jet Propulsion Laboratory) and B.A. Smith (University of Arizona) using a charge coupled device on the 2.5 m telescope at Las Campanas Observatory, Chile. The bright extended emission is thought to come from a circumstellar disk of silicates, ices and carbonaceous organic material. The disk, seen edge-on, is 40 billion miles across; the star is 50 light years away. This disk is the first of its kind to be seen clearly in astronomical photographs. (JPL and U. Arizona).