ALTIMETRY SINCE 1980

Carl Wunsch

Room 54-1524, Massachusetts Institute of Technology, Cambridge MA 02139 USA

1. Introduction

Physical oceanography and marine geodesy have changed almost beyond recognition since the flight of the high accuracy altimetric satellites, particularly TOPEX/-POSEIDON. R. Stewart is discussing the history of this and other missions, and there is a full session on the future of altimetry later in the week. Here therefore, I will focus on the way in which the science has changed in the interim, highlighting the impact that altimetry accurate altimetry has had on the subject as a whole.

Because altimetry caused a slow revolution, many people hardly noticed while it was going on. It is also important to recall that the idea of using satellites seriously to determine the ocean circulation was far from universally accepted for many years. Indeed, the mission planners had enormous difficulty in even finding a critical mass of physical oceanographers to discuss the possibilities.

2. Physical Oceanography and Its Changes

Altimetry has had a huge impact on the entire subject, but the measurements were directly applicable to certain elements of the subject whose change since about 1980 provides a metaphor for the wider implications. Consider, for example, understanding of tides.

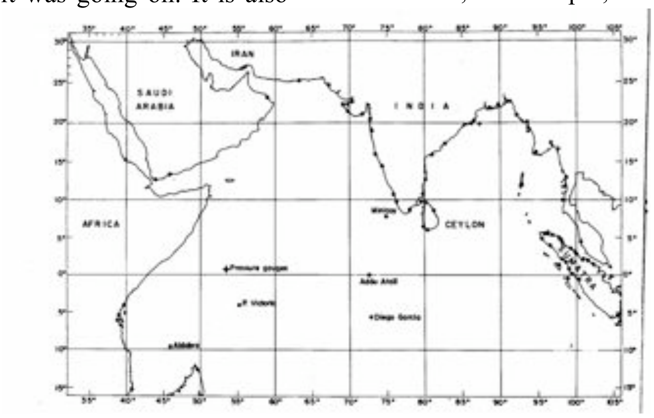

Figure 1 Positions of tide gauges available to construct tidal distribution in the Indian Ocean (from McCammon and Wunsch, 1977).

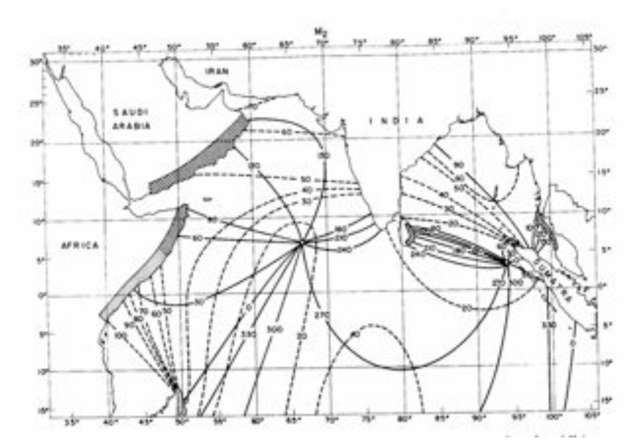

Figure 2 Tidal distribution manually constructed from the instruments shown in Figure 1.

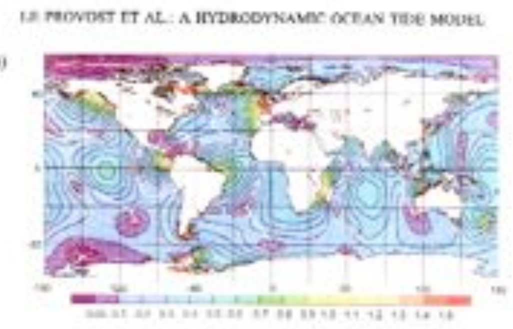

Figure 3 From LeProvost et al. (1998) showing the global tide estimated from TOPEX/POSEIDON data and to be contrasted with Fig. 2.

Figure 1 displays the tide gauge positions available to McCammon and Wunsch (1977) to calculate the open ocean tides prior to the altimeters, and Figure 2 shows their estimate of the tidal amplitude and phase lines. The result is restricted to this part of the Indian Ocean. In contrast, Figure 3 shows the global estimate made from the dense altimetric tracks from LeProvost et al. (1998).

Similarly, Fig. 4 shows where an estimate of the internal tide was available in the mid-1970s (from Wunsch, 1976), while Fig. 5 is typical of the continuous (with position) estimates of Ray and Mitchum (1998) from altimetry, and which can now be made globally.

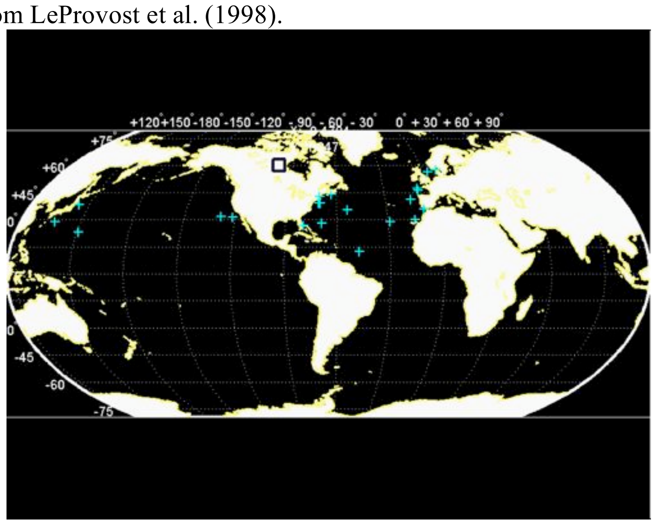

Figure 4 Positions where the internal tide could be estimated by Wunsch (1975).

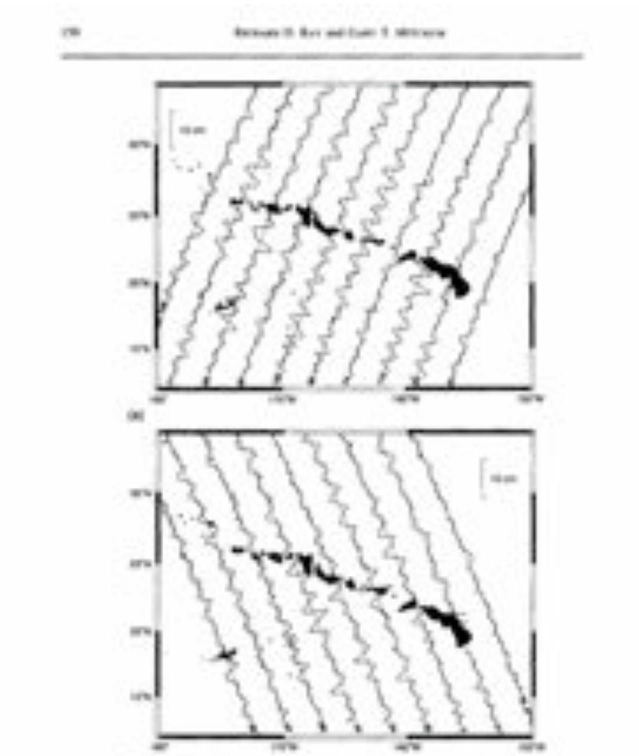

Figure 5 Ray and Mitchum (1998) depiction of the internal tide near Hawaii from TOPEX/POSEIDON.

Numerical general circulation models (GCMs) have developed in parallel with altimetry and are essential to interpreting the data. To a very great extent, altimetry drove modeling, because for the first time, it became possible to test such models globally, and because models are the only known way to fully exploit the data. Fig, 6 shows a model from 1972 in which the computing power only permitted the ocean to be described as steady and viscous. In constrast, Fig. 7 shows a recent model, and its comparison to the altimetric measurement of the sea surface variability. The model clearly has a high degree of realism, but which could only be tested by the availability of the altimetry.

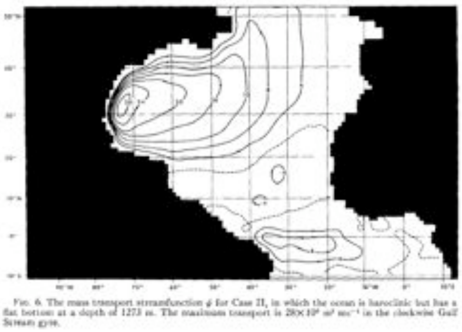

Figure 6 From Holland and Hirschman (1972) showing the North Atlantic as essentially steady and viscous.

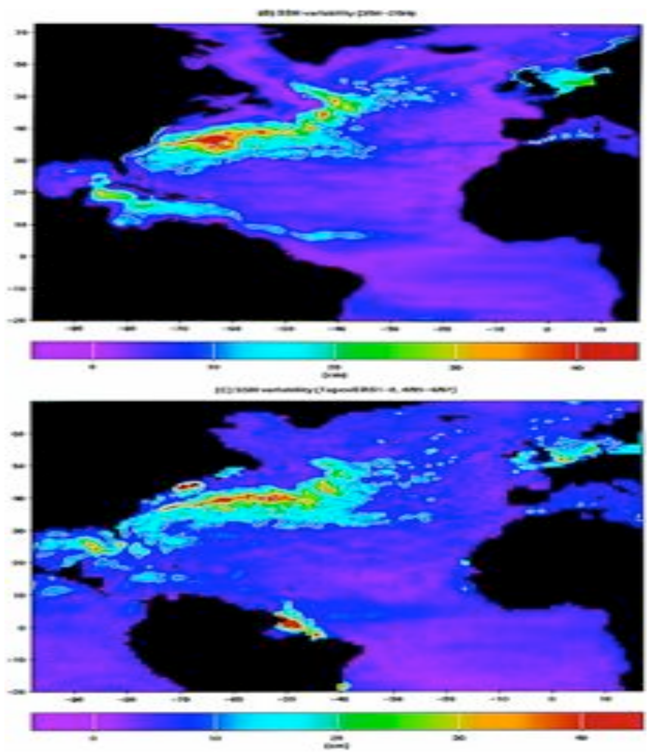

Figure 7 Upper panel shows the North Atlantic seasurface height variability from them model of Smith et al. (2000) and the lower one is the altimeter measured variability as calculated by Le Traon et al. (1998). Without the altimetry, it would be very difficult to make any inferences about the model skill.

3. The Major Surprises

The designers of the altimetric missions anticipated many of the major results, including the very strong El Nino signals, the ability to determine the mesoscale variability everywhere, the estimation of frequency-wavenumber spectra and the considerable, if still limited, capability of determining the absolute circulation. In contrast, the very high accuracies and precisions of the missions produced some results which were never anticipated (at least by me). These include, especially, the very strong high latitude barotropic fluctuations, and the internal tide results. The latter in particular triggered a huge new interest in the role of tides in controlling the ocean circulation and more generally in the question of the energetics of the circulation.

Another major surprise, of widespread interest, was that the measurements proved accurate enough to detect global sealevel rise at an accuracy of about 1mm/y. For the first time, the spatial complexity of the sea level rise patterns could be seen. The observations have stimulated a major, and continuing, effort to partition the rise between heating, cooling and net evaporation and precipitation.

4. The Future

The nature of the science of physical oceanography has changed, largely because of the availability of altimetric data. We have a true global observing system, consisting of continued altimetry, scatterometry, ARGO profiling floats, and other elements, although it remains incomplete. We have models which are demonstrably skillful and useful. The basic descriptive (exploratory) days of physical oceanography are now over. The ocean is seen to be time varying on all space and time scales---something we must live with. To understand the nature of climate variability we must extend our record.

A major issue is that the time scales we are interested in are long compared to the time to do a PhD, promotion, tenure, human lifespan, and government funding cycles. In many ways, and paradoxically, the success of the altimetric satellites has made justification of further measurements much more difficult: some of the scientific community was sufficiently excited by the prospect of a few years of high accuracy altimetry to devote themselves to the launch and maintenance of these satellite missions. Today, we know a great deal more, the value of the data is widely understood, but inevitably, some of the excitement is gone. Apart from the financial commitment, sustaining long-term, operational measurements is extremely challenging – the science community loses interest or turns away for long periods---until the records are of significantly greater duration than previously available; the technologies become obsolescent; and constant vigilance is required to maintain calibration. Moving from a 15-year record to a 30 or 50-year one implies making an investment for a future generation, not our own.

The study of climate, if serious, requires a different organizational structure than anything we have today. Governments everywhere operate on an annual budgetary time scale, or on one set by the time to the next election. Can we construct a new form of endowed organization with a long time-horizon, able to tolerate an intellectual investment payback over decades or generations? Some organizations exist (the Roman Catholic and Orthodox Churches, and the old universities are the obvious ones). But note that these have greatly checkered histories---times of extended disarray and dysfunction. The challenge for those of us interested in future altimetry, the future of our science, and of global change, is perhaps less scientific than it is of constructing mechanisms capable of sustained global measurements of the same high quality we achieved over the last 20 years.

The support of the National Aeronautics and Space Administration and of its program managers over many years is greatly appreciated.

5. References

Holland , W. R. and A. D. Hirschman, A numerical calculation of the circulation in the North Atlantic Ocean, **J. Phys. Oc**., 2, 336-3254, 1972.

LeProvost, C., F. Lyard, J. M. Molines, M. L. Genco, F. Rabilloud, A hydrodynamic ocean tide model improved by assimilating a satellite altimeter-drived data set, **J. Geophys. Res**., C103, 5513-5529, 1998.

McCammon, C. and C. Wunsch, Tidal charts of the Indian Ocean north of 15 S, **J. Geophys. Res**., 82, 5993-5998, 1977.

Ray, R. D. and G. T. Mitchum, Surface manifestation of internal tides generated near Hawaii **Geophys. Res. Letts.**, 23, 2101-2104, 1996.

Smith, R. D., M. E. Maltrud, F. O. Bryan, and M. W. Hecht. Numerical simulation of the North Atlantic Ocean at $1/10^o$, **J. Phys. Oc**., 30, 1532-1561, 2000.

Wunsch, C., Internal tides in the ocean, **Revs. Geophys. and Space Phys.**, 13, 167-182, 1975.