RECENT RESEARCH AT SOC AND POL WITH TOPEX/POSEIDON DATA

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The Southampton Oceanography Centre and the Proudman Oceanographic Laboratory have been active members of the TOPEX/POSEIDON (T/P) Science Working Team since its beginning, and have had extensive programmes of altimeter research since the early 1980s. In this short article, some recent research at the two institutes is described which has made use of the superb T/P data set.

Introduction

The Southampton Oceanography Centre (SOC) and the Proudman Oceanography Laboratory (POL) in the UK have several overlapping research interests concerning the monitoring and understanding of the ocean circulation, and a number of individual research themes which reflect the historical specialisations of each laboratory.

As examples of research of common interest, SOC and POL have both recently been involved in the use of TOPEX/POSEIDON (T/P) altimetry in combination with data from other sensors, in order to demonstrate more clearly certain aspects of ocean variability. The other sensors include the ERS-1/2 altimeters and the ERS-1 Along Track Scanning Radiometer (ATSR). Both laboratories have long standing interests in ocean circulation monitoring and numerical modelling, and the identification of features such as Rossby waves by the combined data sets has provided important new insights into ocean dynamics.

A second example concerns the common interest of each laboratory in the circulation of the Southern Ocean, and particularly the Drake Passage, as part of the World Ocean Circulation Experiment. SOC and POL have undertaken cruises across the Passage for each year of the WOCE period so far, have deployed in situ instrumentation and performed ship current meter measurements, all of which provide a validation data set for altimetry [Challenor et al., 1996; Meredith et al., 1996; Woodworth et al., 1996].

Research topics more specific to each laboratory include the long standing interest in altimeter waves at SOC, and the use of tide gauge data at POL for complementarity to and calibration of altimeter information.

Research at SOC

Ocean Dynamics

In the last decade, satellite altimetric measurements of sea surface height (SSH) and infrared radiometric measurements of sea surface temperature (SST) have provided a wealth of information about ocean circulation and atmosphere/ocean interactions. SSH is a depth-integrated quantity dependent upon the temperature and salinity structure of the water column and on the depth-independent barotropic contribution. SST from infrared radiometers is a surface parameter representing the temperature of the top few microns of the ocean surface. Hence any relationship between SST and SSH provides dynamical information about the coupling between the ocean surface and subsurface. It also offers the promise of new techniques such as interpolating SSH data using SST , and of improved calculations of eddy kinetic energy.

SST data from the ATSR on ERS-1 and SSH data from T/P have been used to examine the relationship between SST and SSH anomalies within the South Atlantic region for 1993 and 1994. We find that positive (~0.2-0.6) spatial cross correlations between SST and SSH anomalies at zero lag are present throughout the region at large scales (wavelengths > 1000 km). Small scale correlations, however, are high (~0.7) only in areas associated with fronts and mesoscale variability. These small scale correlations are seasonal, being strongest in winter and weakest in summer.

T/P SSH data and ATSR SST measurements, spanning December 1992 - June 1995, reveal westward propagating, long-wavelength baroclinic Rossby waves near 34°N in the Northeast Atlantic ocean [Cipollini et al., 1997]. Three spectral components corresponding to westward wave propagation have been identified and estimates made of their wavelengths, periods and propagation speeds. We observe three distinct speeds: ~2.7, ~1.6 and ~0.8 km/day, which could correspond to the first three baroclinic modes of Rossby wave propagation. First-mode speeds are consistent with a revised theory of baroclinic Rossby wave propagation [Killworth et al., 1997] which has recently been introduced to explain the observed discrepancy [Chelton and Schlax, 1996] between altimeter-derived wave speeds and the speeds computed from the standard linear theory. The energy associated with the propagating waves near 34°N is distinctly higher than in the surrounding areas. It is possible that the interaction between the Rossby waves and the Azores current plays a major role in the amplification of the waves, such that even baroclinic modes higher than the first become observable here.

Wave Measurements

Using buoy data from 24 NDBC wave buoys, SOC have generated a co-located altimeter and buoy wind and wave data set which includes data from all recent satellite altimeters, dating back to 1985. With almost 1000 data points for each of the Geosat, ERS-1 and TOPEX altimeters, this represents one of the most extensive co-located altimeter-buoy data sets available, and has been used in an assessment of the relative and absolute accuracies of each of the altimeter data sets. Using principle components regression techniques to compare the altimeter and buoy data, calibration corrections were generated and accuracy estimates derived for wind speed and significant wave heights from each altimeter data set:

$$U_{10}(\text{buoy}) = 0.903 + 0.792\, U_{10}(\text{Geosat}) \quad (1)$$

rrms = 3.05 ms^{-1} N=677

$$U_{10}(b) = 0.409 + 0.875\, U_{10}(\text{TOPEX}^{*}) \quad (2)$$

rrms = 1.69 ms^{-1}(*$sigma^0$ unadjusted) N=1283

$$U_{10}(b)=1.023+ 0.912U_{10}(\text{ERS-1 OPR}) \quad (3)$$

rrms = 1.50 ms^{-1} N=1533

$$U_{10}(b) = 0.980+ 0.980\, U_{10}(\text{ERS-2 OPR}) \quad (4)$$

rrms = 0.98 ms^{-1} N=164

$$H_s\,(b) = 0.089 + 1.069\, H_s\,(\text{Geosat}) \quad (5)$$

rrms = 0.42 m N=706

$$H_s\,(b) = -0.082 + 1.049\, H_s\,(\text{TOPEX}) \quad (6)$$

rrms = 0.28 m N=1189

$$H_s(b) = 0.333 + 1.126\, H_s\,(\text{ERS-1 OPR}) \quad (7)$$

rrms = 0.26 m N=1277

$$H_s\,(b) = 0.189 + 1.053\, H_s\,(\text{ERS-2 OPR}) \quad (8)$$

rrms = 0.18 m N=179

These analyses revealed that, when compared to the buoy data, all the altimeter data sets underestimated at low wind speeds, but overestimated higher winds. Wind speeds from Geosat were seen to exhibit higher variability than those from TOPEX, ERS-1 and ERS-2. All the altimeters were found to underestimate significant wave height (with respect to the buoy data) over most of the normal range. There remain problems in providing calibrations and accuracy estimates at low wave heights (where buoy data may be unreliable) and at high wind speed and wave height values beyond the ranges available in the co-located altimeter-buoy data sets. Model hindcast data may provide a solution to this.

These calibration corrections have been used to generate a consistent altimeter derived wave height climate data set, dating back to 1985. Analysis of this climatological data set has confirmed previous (in-situ) evidence of an increasing trend in wave height in the North Atlantic (now apparently slowing down), and established that this increase is limited to the north-east Atlantic. Further investigation has revealed that changes in the wave climate in the north-east Atlantic are correlated with variability in the North Atlantic Oscillation index, on both medium (monthly) and long (inter-annual) time scales. Consideration of global patterns also indicates a strong anti-phase correlation between the wave climates of the north-east Pacific and Atlantic Oceans.

Research at POL

Ocean Dynamics

Using dual altimeter crossover measurements between T/P and ERS-1, a high precision ERS-1 altimeter data set has been produced by Aston University to effectively increase the spatial resolution of T/P. With this improved resolution, it has proved possible to extend the observation of Rossby waves in the Southern Ocean, previously only resolved in a region of the Pacific sector [Hughes, 1995], to the whole Southern Ocean. Altimetry measurements have been used to define the direction of propagation of Rossby waves throughout the Southern Ocean, confirming predictions from the Fine Resolution Antarctic Model (FRAM), that the waves are advected eastwards by strong eastward currents, travelling westwards elsewhere [Hughes, 1996].

In a joint analysis between POL, SOC and Aston, the direction of propagation defined by sea surface slopes has been compared with that which can be seen from ATSR sea surface temperature gradients [Hughes et al., 1997], with remarkably consistent results. Eastward propagation occurs in the Antarctic Circumpolar Current (ACC) as well as other strong eastward currents in the Southern Ocean (Figure 1), permitting the identification of mean currents from the statistics of the transient disturbances. The observation that the ACC is supercritical with respect to propagation of baroclinic Rossby waves is important for the dynamical balance of the current, allowing it to penetrate deep enough to interact with the bottom topography.

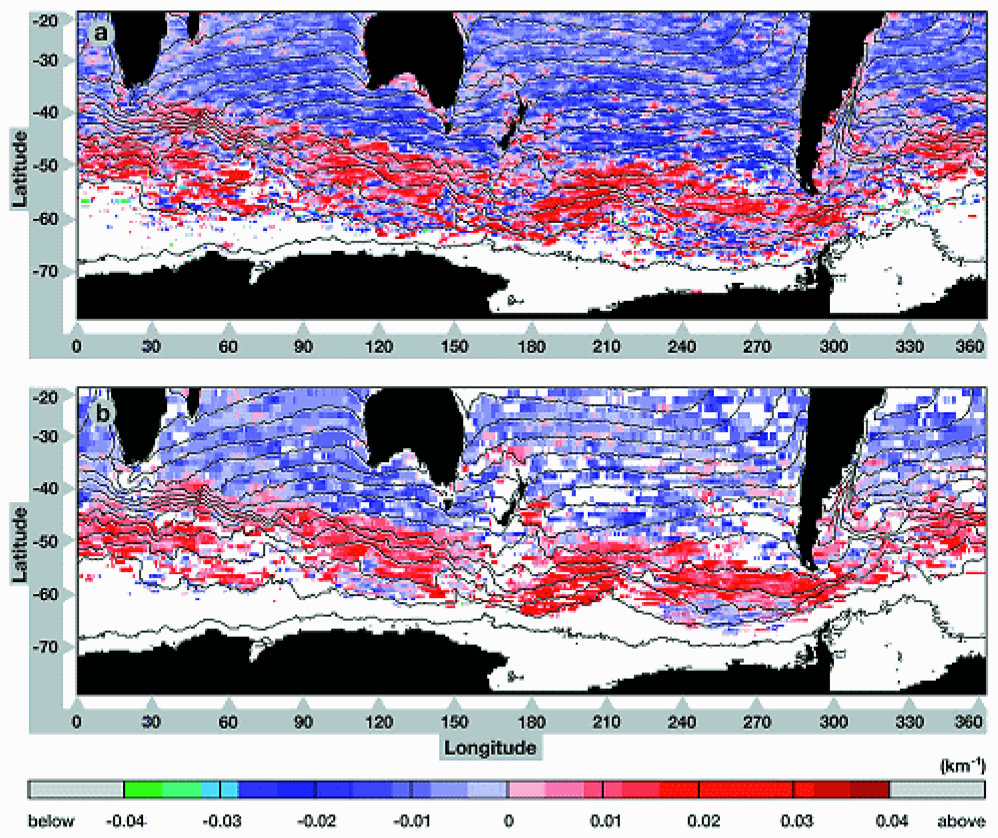

Figure 1

Wavenumbers, calculated from (a) sea surface temperatures (ATSR wavenumbers for dT/dx at 4.8 months), and (b) altimetry (ERS ALT wavenumbers at 4.6 months). Positive (red) values correspond to eastward propagation.

Altimeter Calibration

The ongoing calibration of altimeters has been a research theme at POL and Aston University for several years [e.g. Murphy et al., 1996]. In March 1997, the Permanent Service for Mean Sea Level (PSMSL) at POL and the International GPS Service for Geodynamics (IGS) at the Jet Propulsion Laboratory (JPL) held a two day meeting at JPL which discussed the many technicalities with using GPS-equipped tide gauges for altimeter calibration. The proceedings of this meeting will be produced during 1997 [Neilan and Woodworth, 1997].

Ocean Tides

Ocean tide models have improved significantly in the last few years, thanks to the availability of precise altimetry from T/P. Reviews of different models have established the typically 2 cm accuracy of the M2 component in the deep ocean [Andersen et al., 1996; Shum et al., 1997]. In October 1996, POL and NASA organised a two day meeting called 'Tidal Science 1996' at the Royal Society to celebrate this major achievement. Papers based on presentations at the meeting will appear shortly.

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