UK-GOCE Research Plans

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CALCULATION OF LOCAL GEOIDS

The in situ gravity measurements over the NW shelf of Europe are as good as anywhere else in the world. Recent work [1], has gathered data over the shelf and surrounding land areas in order to calculate a new geoid, EDIN2000, and this geoid has then been tested against satellite altimeter data. Fig.1a shows the result of subtracting EDIN2000 from the most recent mean sea level from altimeter data [2]. The result should represent dynamic sea surface topography. In this case the features on much of the shelf and around the NW shelf edge look very consistent with the output of the best numerical models of the region, eg. Fig.1b. The realistic features that appear have signatures as small as 5cm showing the accuracy of our geoid.

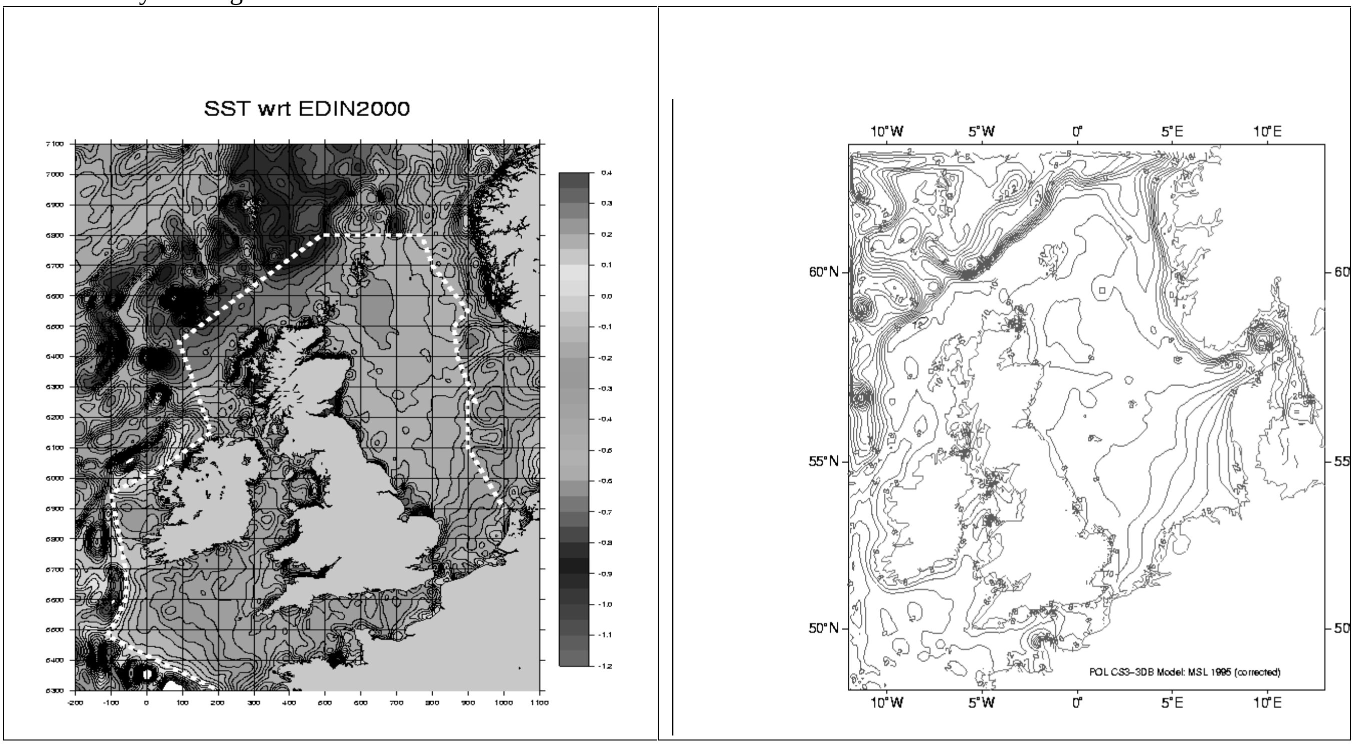

Figure (1a) shows the mean sea level derived from satellite altimeter data minus the EDIN2000 geoid. The result should give dynamic sea surface topography. The area inside the dashes are where the gravity data are good. Contour interval is 5cm. (1b) A model derived mean sea level for 1995 from the Proudman oceanographic laboratory shelf sea model [3]. Contour interval is 2cm.

In preparation for the GOCE mission we would like to extend the techniques used for calculating such local geoids to larger geographical areas and develop ways of combining local and satellite based gravity measurements to produce enhanced local geoids, and to make estimates of their errors. The UK has specific interests in level 1b GOCE data for regional geoid solutions of specific interest to UK geodesy, oceanography and surveying. The UK has obvious interest in a combined GOCE/gravimetric geoid for the UK and surrounding seas but also has long-standing interests in the Southern Ocean, North Atlantic etc. The methods used for local geoid calculation need to be carefully and thoroughly tested and we are in a good position to do this over the ocean by combining the products with altimeter data and testing the results against the UKs extensive ocean observational and modelling expertise. The tide gauge network based at the Permanent Service for Mean Sea Level at the Proudman Laboratory can also be used as a basis for testing geoids and connecting tide gauge records together, see section below.

ROLE OF THE GEOID IN OCEAN MODELLING AND ASSIMILATION

Several groups in the UK have developed programs for assimilating altimeter data into ocean models. The main groups are at the UKMO, ECMWF and the OCCAM assimilation group now at Reading University. A Mean sea surface topography is needed for altimeter assimilation work and the best way of producing this is to assimilate hydrographic data into an ocean model in a preliminary experiment. Fig.2 shows the mean sea level from the ¼ degree 36 level OCCAM model, based on assimilation of 1993-95 ocean hydrography data. This mean sea level has many advantages. It should be more accurate than any model simulation as it has hydrographic data already assimilated. Also unlike any mean sea level based on dynamic height from a climatological hydrography, it will have a good representation of the barotropic component of the sea level due the high resolution of the OCCAM bottom bathymetry. Finally it is based on a model assimilation study which is specific to the period usually used for referencing TOPEX altimeter data.

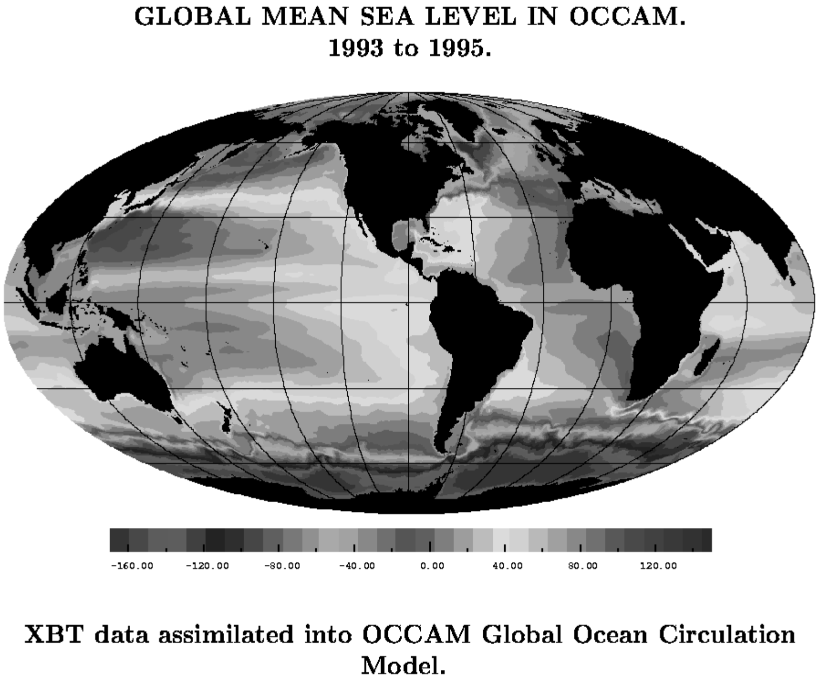

Figure 2 shows mean sea level from the global OCCAM model with assimilated Temperature profiles for the period 1993-1995.

There are several ways of using the result in Fig.2. It can be used to help assimilate altimeter sea level anomaly data. The data can also be combined with altimeter mean sea level data to calculate a geoid. This geoid should be considerably more accurate over the oceans than one based on altimeter sea level data alone. Ideally an independently determined geoid provided by GOCE could be combined with a mean seal level from altimetry and a best dynamic topography from ocean modelling/assimilation, to improve the accuracy of all three data sets.

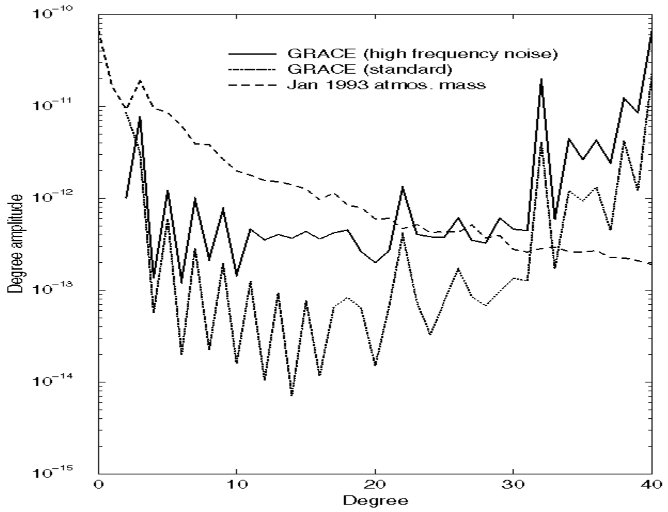

Figure 3. High frequency effect modelled by annual variability in 1993 atmospheric mass redistribution calculated using ECMWF data and mapped onto windows of 30 days for the GRACE recovery simulation.

CURRENT WORK ON THE TIME DEPENDENT GRAVITY FIELD FOR GRACE

A program to interpret and model the time dependent component of the large scale gravity signal has recently begun between the Proudman Laboratory, Newcastle University's Geomatics dept. and Water Resources Systems Research Laboratory and the Environmental Systems Science Centre (ESSC) at Reading University. The main aim is to investigate aliasing of the GRACE temporal gravity field from high frequency fluctuations in global mass distributions and hence validate the 'monthly' mass anomaly fields from GRACE. Towards this aim we will develop a new global barotropic ocean model, which will use the same grid as the UKs high resolution baroclinic model OCCAM. This model will be used to simulate the tides and the fast wind and pressure driven barotropic ocean responses. Forcing data from ECMWF will be used. Other temporal signatures from atmospheric loading, hydrology and glaciology will be combined into a mass conserving whole. The study will attempt to characterise the space and time scales of these temporal signals with upwards extension to the GRACE altitude to study the implied variability in GRACE inter-satellite range. A related study in hydrology will use rainfall, snow cover and river run-off data to study variations in large scale groundwater storage, and its implications for the gravity field, after the residual signal in surface and soil water has been accounted for.

The more slowly varying components of the mass field over the ocean is a direct measure of the ocean bottom pressure, which can be measured directly by bottom pressure recorders and is also related to the deep currents through the geostrophic relation. Therefore, a program of deep pressure recorder deployments will be used to study the variability of bottom pressure at a few key locations. In addition, the bottom pressure variability complements the surface pressure variability, which is presently measured from satellite altimeters. Bottom pressure variations from GRACE can also be used to assist the ongoing programme of assimilating satellite altimeter data into the OCCAM ocean model. These data can be used to help distinguish the barotropic and baroclinic modes and thus allow a better downward extension of the altimeter data.

To investigate the effect of high frequency temporal effects on GRACE an error simulator has been developed. The simulator includes satellite mis-pointing and errors in the GRACE inter-satellite range and accelerometer data. A first look at possible aliasing from high frequency effects was undertaken by mapping monthly mean values of atmospheric pressure into a 30 day period. Gravity field harmonics for each month minus the mean annual signal were thus taken to represent the atmospheric mass distribution over a 2.5 day period. Fig.3 plots the degree amplitudes of the error signal for the 30 day GRACE solution with and without the high frequency atmospheric effect. Note that the GRACE error exceeds the atmospheric signature at about degree 30. The figure shows that the lower degree recovery has been heavily aliased by the high frequency signal. Although this is an extreme example the study illustrates the need to consider high frequency terms to avoid corruption of the solution through aliasing.

The GRACE study can be extended to GOCE with analysis of the time varying components of the gradiometer data. By this means we seek to minimise aliasing of annual signals across the two in-phase six month periods of the GOCE data from tides and other oceanic phenomena, hydrological loading, atmospheric loading etc. Particular emphasis will be placed on regional solutions.

LEVELLING OF TIDE GAUGES

The global tide gauge network GLOSS is a significant part of the Global Ocean Observing System with the important attribute that some of the tide gauge records are decades or even centuries long, a great rarity for an oceanographic time series. Consequently there is great interest in using these data to monitor ocean dynamics, for example, the EU Framework 5 programme MAIA (Monitoring the Atlantic Inflow towards the Arctic) is investigating the possibility of using coastal tide gauges to measure an important branch of the Atlantic thermohaline circulation.

One difficulty with this is that the tide gauges tend to be located in shelf seas, separated from the ocean dynamics by a region of shallow water in which storm surges and viscous processes are important. While great progress has been made in modelling the dynamics of these regions, the most accurate sea level predictions are made by models optimised for their ability to model short period phenomena (tides and storm surges). At the longer periods of most relevance to deep ocean dynamics, the models are relatively untested.

A strong test of the models would be to see if they can reproduce mean sea level variations around the globe, or along global scale stretches of coastline. However, this has not been possible because of the lack of accurate knowledge of the geoid at tide gauge positions. GOCE will help to solve this problem but, since tide gauges are point measurements, some auxiliary local data will be needed to fill in the detail of the geoid at length scales below about 80 km, if centimetric accuracy is to be attained. Hence, the UK interest in calculating accurate levels of tide gauges by combination of GOCE and local gravity and topography data. Initially an assessment will be made of the attainable accuracy, using various type of auxiliary data. Subject to the success of this, the techniques will be applied to selected tide gauge sites around the world.

The small scales on which ocean dynamics vary on approaching the coast mean that a levelled global tide gauge data set will provide significant additional information to that which can be provided by the combination of satellite altimetry and the GOCE geoid. In addition, knowledge of the exact level of tide gauges will enhance their value as a calibration system for satellite altimetry.

SMALL SCALE OCEAN FEATURES

Although the main ocean circulation takes the form of gyres with typical length scales of thousands of kilometres, the ocean is a highly nonlinear, turbulent system, and interacts with sometimes very narrow scale features of the ocean bottom topography. The currents which make up these gyres are therefore on much smaller length scales, typically around 100 km or less, in the mean flow as well as the transients.

It is widely acknowledged that eddies in the ocean play a crucial part in maintaining the global dynamical balances, which control such things as heat and CO2 fluxes. There is, however, still rather poor understanding of how the eddies operate. An important reason for this is the lack of observations of the mean flow on the short length scales relevant to eddy dynamics.

A particular example is given by [4], in which mean sea surface temperature gradients are used as a qualitative proxy for the mean flow in the Southern Ocean. The small scale information made available by the satellite temperature data, together with transient current data from satellite altimetry makes possible a calculation of the momentum and vorticity fluxes into jets in the Antarctic Circumpolar Current. This has shown that model predictions of these interactions are quite wrong, at the resolutions attained so far. However, quantification of the eddy-mean flow interaction, and extension to other ocean regions, will require more than just a qualitative proxy for the mean flow. The combination of satellite altimetry with the GOCE geoid will provide that information, permitting a wide variety of studies in combination with high resolution modelling activities.

A region in which the problem is particularly acute is the continental slope. Over this region, the very steep topography makes the oceanic length scales particularly narrow, and the currents are strongly correlated with topography, which in turn correlated with the small scale geoid, making extra problems for the use of GOCE data. Nonetheless, this is a very important area for global ocean dynamics, marking the interface between the deep ocean and shelf seas, and controlling exchanges between the two regions. As a result, the dynamics of this region play a strong controlling role for the deep ocean, and there is great interest in exploiting GOCE data to the full, possibly in combination with local topography and gravity information.

REFERENCES

1. Beggan C., K. Haines and R. Hipkin: The Geoid EDIN2000: II Estimating dynamic sea surface topography around the British Isles, unpublished.
2. Hernandez, F., http://www.cls.fr/mss
3. Holt, J. T., I.D. James and J.E. Jones: An s-coordinate density evolving model of the northwest European continental shelf. Part 2: Seasonal currents and tides. *J. Geophys. Res.,* in press
4. Hughes, C.W. and E.R. Ash, Eddy forcing of the mean flow in the southern ocean, *J. Geophys Res.,* in press