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Digital Atlas of Earth System Modelling

Cretaceous Palaeotidal Model Results

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Executive Summary

Tidal modelling provides a powerful tool for predicting marine depositional systems through time that can help to minimise exploration risks in new ventures operations. As part of the Globe exploration platform, Getech has developed an extensive series of Stage-level digital atlases for the Cretaceous using the Fluidity Imperial College Ocean Model (ICOM). These 3D non-hydrostatic parallel ocean model results are being used to develop lithofacies prediction models, including ones for source and reservoir facies. The results are also being used in our regional exploration studies around the world. The models are built on Getech's global palaeogeographies (Globe core deliverables) and are carried out by Dr Peter Allison of the Department of Earth Science and Engineering, Imperial College, London. Model results are quantitatively tested against Getech's extensive observational databases of the present and past.

Study Aims

This volume of the Globe Earth System Modelling Digital Atlases is one of a series aimed at providing palaeotide results for tidal range, tidal constituents and bed shear stress values over geological time. This volume covers the Cretaceous in 12 Stage-level timeslices. The variables selected are tidal range; tidal constituents S2, M2, O1 and K1; maximum bed shear stress magnitude; average bed shear stress magnitude; maximum bed shear stress vectors and average bed shear stress vectors.

Report Structure

The report is split into 5 parts: 1) Introduction to Tidal Models (Chapter 1), providing a brief overview of the development of this method; 2) Fluidity ICOM: Imperial College Ocean Model (Chapter 2), which details the particular model used in this study, including the boundary conditions that were set and the variables provided; 3) Getech Conversion Methods (Chapter 3), outlining the processing used to convert the original NetCDF files provided by Imperial College into ArcGIS^{TM} format, and 4) File Geodatabase (Chapter 4), which outlines the final format of the Globe Tools deliverable. References cited in this volume are given in Chapter 5.

1 Introduction to Tidal Models

Global ocean tide models for the Present Day oceans have developed significantly in the last 30 years. Early models such as SCW80 by Schwiderski (1980), a dynamic model with assimilation from long-term globally distributed tide gauge data, were followed by the Geosat altimeter data based C&R91 Model, which was developed in the early 1990s (Cartwright & Ray, 1990). Most recently, several models have been derived from altimeter data of the NASA/CNES satellite TOPEX/Poseidon. This satellite provided accurate bathymetry and ocean surface topography data from 1992 until 2006, when it was decommissioned owing to a malfunction. Data assimilation models such as these are regarded as an accurate method to use for recent ocean models. This method is not appropriate for the mapping of palaeotides, however, because the dynamic model will always conform to the provided altimetry/tidal gauge data, which in the case of palaeotides, is not accurately available. The Fluidity ICOM used in this study is the first to have been accurately applied to palaeotides.

2 Fluidity ICOM: Imperial College Ocean Model

2.1 The Fluidity Imperial College Ocean Model

All tidal model results in this study are from the Fluidity Imperial College Ocean Model (ICOM) developed by Drs Chris Pain and Matthew Piggott, led by Dr Peter Allison of the Department of Earth Science and Engineering.

Fluidity ICOM is a 3D non-hydrostatic finite element ocean model that uses an innovative mesh that adapts to fine-scale features of the tidal flow to simulate complex currents. The model's unstructured code in all three dimensions makes it a thousand times faster than most previous tidal models. Fluidity ICOM is a purely hydrodynamic model with no data assimilation, unlike other recent tidal models that have used assimilation of altimetry data from the TOPEX/Poseidon satellite in order to map palaeotides. Without data assimilation, the Fluidity ICOM still has the capability to calculate accurate tidal range and bed shear stress predictions.

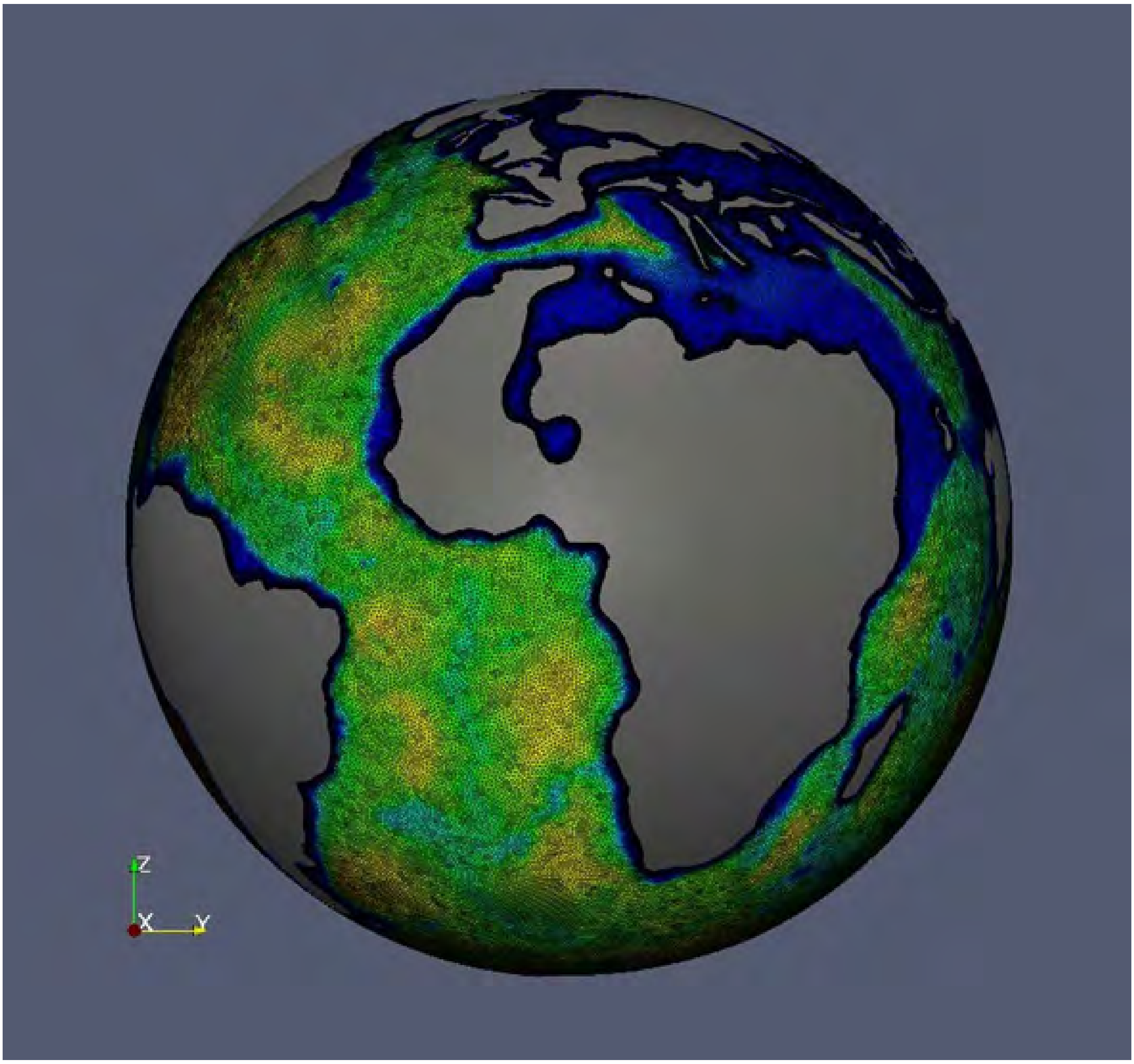

Figure 1: *Example of the mesh used in the Fluidity ICOM (Lutetian; courtesy of Dr Alexandros Avdis, Imperial College).*

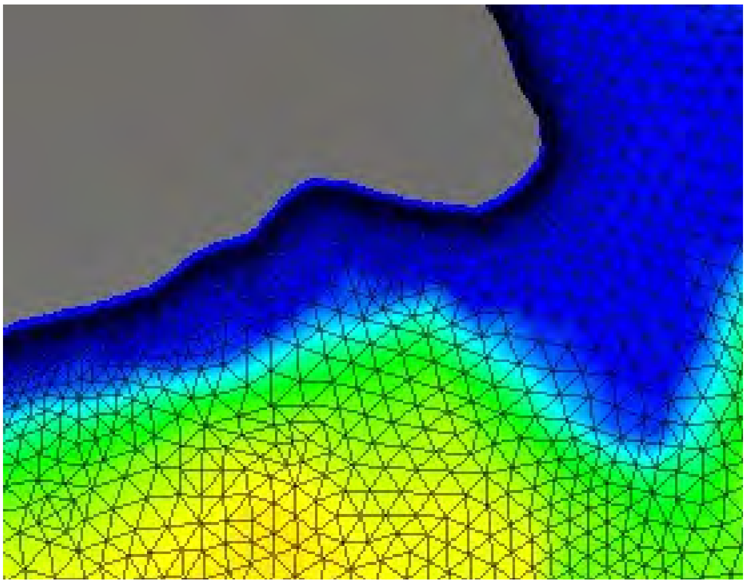

Figure 2: Detailed example of the mesh used in the Fluidity ICOM (Lutetian; courtesy of Dr Alexandros Avdis, Imperial College).

The unstructured mesh of the model means it conforms accurately to coastlines and ocean floor topography, and it also provides higher-resolution, especially in areas of steep bathymetry and high activity. It also uses a Cartesian coordinate system that means the mesh is wrapped around a sphere; therefore, the model does not have the pole issues associated with latitude-longitude grids.

An astronomical forcing parametisation is applied for the tide simulation to replicate the Earth's gravitation interactions.

The model was run for 60 days in total: 30 days spin up to reach a state of statistical equilibrium and 30 days of daily measurements.

The model is validated for tidal range results against several locations across the globe by comparing the results to those produced by other models, satellite altimetry and tide gauges (Wells et al., 2010a, 2010b). Bed shear stress is verified against results of other models on the North European Shelf and sediment grain size distribution maps (Mitchell et al., 2011). Fluidity ICOM is also validated against 10 well-known global tidal models, ranging from 1980 to 2006.

2.2 *Boundary Conditions*

The boundary conditions set for the model are the Globe palaeotopography and palaeobathymetry solutions supplied by Getech using the Global Plate Model v1.0 (2011) and Global Palaeogeography Vol 2, v1.0 (2011).

The other main boundary conditions set are 'no normal flow' on the seabed and coastlines, and 'free surface' on the ocean top surface. The initial conditions were zero velocity, pressure and free surface.

More in-depth information on the model set up and the equations used can be found in Imperial College's Fluidity Manual at https://launchpadlibrarian.net/147749123/fluidity-manual-4.1.10.pdf.

2.3 *Timeslices/Variables (NetCDFs)*

This section contains details of the timeslices and variables used for this study.

Timeslices

This volume comprises the Cretaceous, with one timeslice modelled per Stage, as shown in Table 1.

Stage
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian

Table 1: Stages provided in this study.

The set of variables detailed below (sections 2.3.2, 2.3.3 and 2.3.4) was produced for each of the timeslices listed in Table 1.

Tidal variables

Tidal range

This is the tidal amplitude measured globally over 30 days, encompassing both spring and neap tides.

Data Set Name: (4 letter Stage)_range

Data Layers Created: Tidal Range
Tidal Range Specified

S2 Tidal Constituent

This is the amplitude of the principal solar semi-diurnal tidal constituent, S2.

Data Set Name: (4 letter Stage)_s2

Data Layers Created: S2 Tidal Constituent

O1 Tidal Constituent

This is the amplitude of the lunar diurnal tidal constituent, O1.

Data Set Name: (4 letter Stage)_o1

Data Layers Created: O1 Tidal Constituent

M2 Tidal Constituent

This is the amplitude of the principal lunar semi-diurnal tidal constituent, M2.

Feature Raster Data Set Name: (4 letter Stage)_m2

Data Layers Created: M2 Tidal Constituent

K1 Tidal Constituent

This is the amplitude of the lunar diurnal tidal constituent, K1.

Data Set Name: (4 letter Stage)_k1

Data Layers Created: K1 Tidal Constituent

Bed Shear Stress Variables

Maximum Bed Shear Stress Vectors

We have combined the meridional (v) and zonal (u) components of the bed shear stress vector (supplied by Imperial College) to generate an azimuth (current direction) and velocity, which are then used in conjunction with the maximum bed shear stress magnitude.

Data Set Name: (4 letter Stage)_bss_max_uv

Data Layers Created: BSS Maximum Vectors

Maximum Bed Shear Stress Magnitude

This is the maximum magnitude of bed shear stress during a 30-day period, given in N/m2. It has been displayed both in gradational colour and specified into the strengths required to move varying sizes of sediment, from clay to gravel.

Data Set Name: (4 letter Stage)_bssmaxmag

Data Layers Created: BSS Maximum Magnitude
Sediment Transport Capability (Maximum)

Average Bed Shear Stress Vectors

We have combined the meridional (v) and zonal (u) components of the bed shear stress vector (supplied by Imperial College) to generate an azimuth (current direction) and velocity, which are then used in conjunction with the average bed shear stress magnitude.

Data Set Name: (4 letter Stage)_bss_ave_uv

Data Layers Created: BSS Average Vectors

Average Bed Shear Stress Magnitude

This is the average magnitude of bed shear stress during a 30-day period, given in N/m2. It has been displayed both in gradational colour and specified into the strengths required to move varying sizes of sediment, from clay to coarse-grained sand.

Data Set Name: (4 letter Stage)_bssavemag

Data Layers Created: BSS Average Magnitude
Sediment Transport Capability (Average)

Simpson-Hunter Stratification

Simpson-Hunter

This is a measure of tidal mixing and stratification. The Simpson-Hunter parameter is a dimensionless ratio of water depth and the cube of the tidal velocity: log10 (h/u3). Values below 3 show a tidal current strong enough to mix the water column; values above 3 indicate areas in which seasonal stratification will occur. The layer is clipped to show values on the shelves only, as in the deep ocean, the tidal currents will generally be lower and water depth will be greater (so an increasing value divided by a decreasing value will result in larger Simpson-Hunter values).

Data Set Name:	(4 letter Stage)_HS_5
Data Layers Created:	Simpson-Hunter

3 Getech Conversion Methods

All files were originally supplied by Imperial College in NetCDF format and were brought into ArcMap as feature raster data sets before adding to the file geodatabase. The original files had a cell size of 0.1 degrees and were subsequently resampled to 0.5 degrees in order to be consistent with other Getech Globe deliverables.

4 File Geodatabase

A file geodatabase is supplied for all 12 Cretaceous timeslices. This is supplied in geographic coordinate system WGS84 to allow for integration with other Getech Globe deliverables. For consistency, the data layers have the same filename structure within each timeslice; each variable also has a four letter prefix in order to identify which timeslice it relates to if it is moved to different locations. Each data layer also has metadata attached that give the age and description of that file as well as details of the version of the Plate Model and Palaeogeography used as basemaps.

In addition to the data layers listed in Tables 2a and 2b, all of the timeslices include the following features: 1) modern country outlines rotated to the relevant stage, 2) hillshade created using Getech's global palaeogeographic maps and 3) sea level highstand for the appropriate stage, created as part of the global (Globe core deliverable) palaeogeographic mapping project. The data are displayed in three formats: Mollweide global projection and North and South Polar Orthographic projections.

Variable	*Units*	*Timescale*
Tidal Variables		
Tidal range	m	30 days
S2 tidal constituent	m	30 days
O1 tidal constituent	m	30 days
M2 tidal constituent	m	30 days
K1 tidal constituent	m	30 days
Bed Shear Stress		
Bed shear stress maximum vectors	m/s	30 days
Bed shear stress maximum magnitude	N/m^2	30 days
Bed shear stress average vectors	m/s	30 days
Bed shear stress average magnitude	N/m^2	30 days
Simpson-Hunter Stratification		
Simpson-Hunter	Dimensionless ratio	30 days

Table 2: Variables included within Globe Tools.

5 References

Cartwright, D. E. & Ray, R. D. (1990). Oceanic tides from Geosat altimetry. Journal of Geophysical Research, 95 (C3), pp. 3069-3090.

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Mitchell, A. J., Allison, P. A., Gorman, G. J., Piggott, M. D. & Pain, C. C. (2011). Tidal circulation in an ancient epicontinental sea: The Early Jurassic Laurasian Seaway. Geology, 39 (3), pp. 207-210.

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Wells, M. R., Allison, P. A., Piggott, M. D., Hampson, G. J., Pain, C. C. & Gorman, G. J. (2010a). Tidal modeling of an ancient tide-dominated seaway, part 1: model validation and application to global Early Cretaceous (Aptian) tides. Journal of Sedimentary Research, 80 (5), pp. 393-410.

Wells, M. R., Allison, P. A., Piggott, M. D., Hampson, G. J., Pain, C. C. & Gorman, G. J. (2010b). Tidal modeling of an ancient tide-dominated seaway, part 2: the Aptian lower Greensand Seaway of Northwest Europe. Journal of Sedimentary Research, 80 (5), pp. 411-439.