Validation of a TELEMAC-3D model of a seamount

Alan J. Cooper and Jeremy Spearman
HR Wallingford, Coasts and Oceans,
Howbery Park, Wallingford, OX10 8BA, UK
a.cooper@hrwallingford.com

***Abstract*—A survey was carried out at Tropic Seamount off the Atlantic coast of Africa. This has allowed a TELEMAC-3D model to be constructed and validated using the measured data. The importance of internal tides at the site and possibility of a Taylor column have been assessed.**

I. Introduction

In late 2016 an extensive survey was carried out of the flows at and around Tropic Seamount. The data was to be used both to understand the flow regime and also to calibrate a flow model to be set up using TELEMAC-3D. TELEMAC-3D is the 3D hydrodynamic component of the open source, industry driven, TELEMAC system (www.opentelemac.org).

Fig. 1 below shows the bathymetry as coloured contours and the 2D spatial mesh used with TELEMAC-3D.

The observations have been analysed to understand the flow processes going on at Tropic Seamount with particular reference to internal tides at the seamount and the possibility of a Taylor column (rotating circulation pattern including closed streamlines) being observed here. The numerical model has been set up and calibrated using the observations. This has allowed the semi-diurnal internal tides to be seen and also to look for features of a Taylor column.

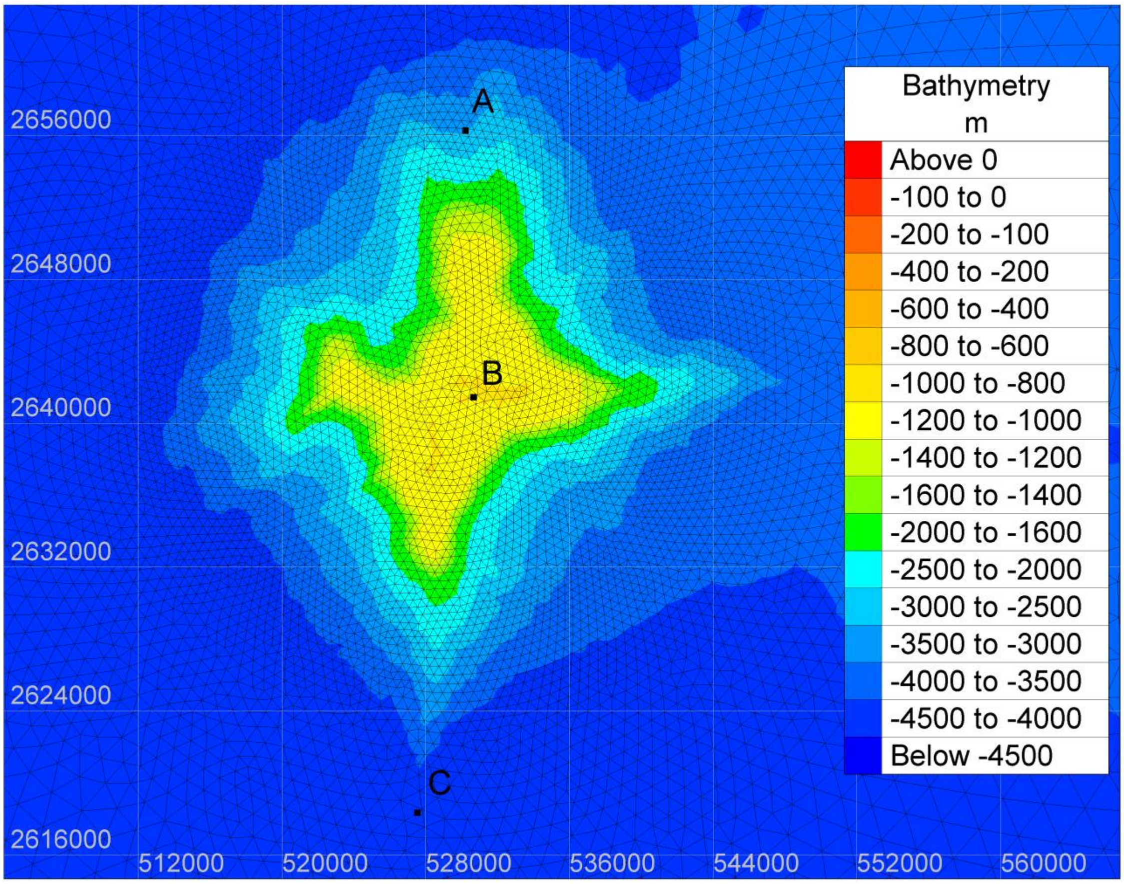

Figure 1. *Model mesh in area of the seamount*

II. Observed Currents at Tropic Seamount

Fig. 1 above shows the location of three instruments relative to the bathymetric contours of the Tropic Seamount.

A. *Yo-yo casts near the seamount summit*

During the survey (17-18 November 2016), a yo-yo set of casts at a location near the seamount peak in about 1,000 m of water was carried out over a 6.25 hour period at approximately hourly intervals while the vessel was stationary. The vessel also had two ADCPs attached to its hull measuring current at different frequencies.

Throughout the survey period at a close location B (see Fig. 1) there was an ADCP mooring attached to the sea bed and there was an ADCP at about 50 m below the surface attached to the bed by a 900 m long cable. The yo-yo currents cover almost the entire water depth over the seamount. The measured currents in the u and v directions are presented in Fig. 2 (top and bottom insets respectively).

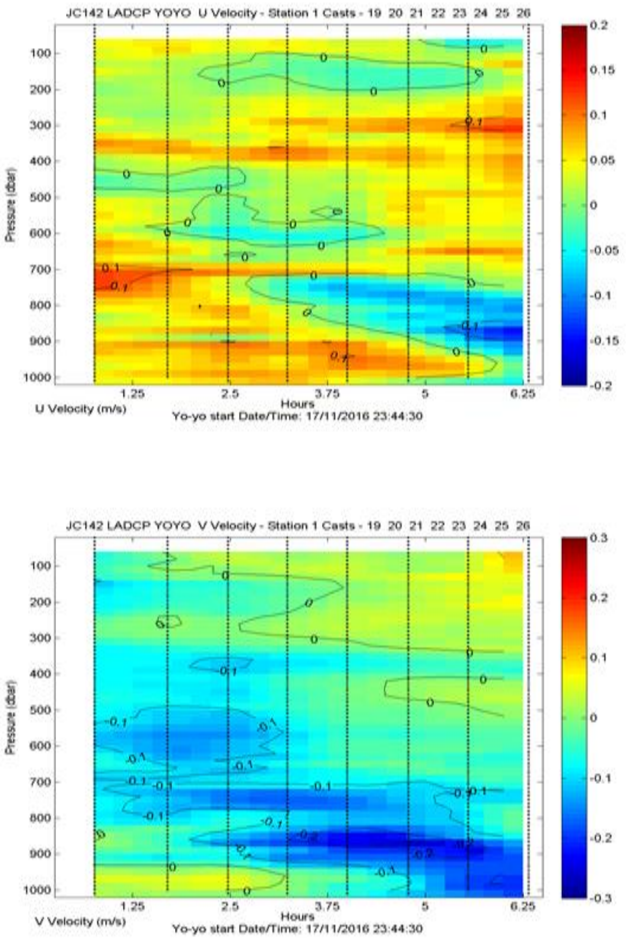

Figure 2. *Observed currents (above u-velocity, below v-velocity)*

As can be seen there is a semi-diurnal wave or "beam" (in blue) shown by both u and v currents travelling down from mid-depth to the bed over this half a semi-diurnal period. This is the expected behaviour of a semi-diurnal internal tide generated above the seamount as the surface tide carries the water up and down above the steep seabed topography.

However, what can also be seen are a quantity of narrow horizontal slices of both u and v slowly varying currents that last continuously for a period of nearly 6 hours.

It is not certain how accurate the currents from these casts are, as they are on a very long cable down from the ship and the ADCPs are falling and rising rapidly to get a cast completed in a fast enough time. However the following suggest that the currents are correct:

- The vessel's ADCPs give quite similar currents in the top 50 m or so of the water column;
- The moored current meter at 50 m depth gives a similar result to the casts near 50 m depth;
- The moored ADCP at the seabed gives a similar result to the casts near the bed; and
- The intrinsic consistency of the result indicates that the ADCP cannot have been rotating significantly as the u and v velocity components would then fade up and down and they do not greatly but they stay consistent for a long time.

All of this suggests that the narrow stripes of different current speed are actually real and not instrumental noise or error.

Similar results have been measured before (see [6] and [7]) and they signify the presence of diurnal currents in the signal with a high spatial wavenumber in the vertical. That is why they vary through a tidal period at only half the rate of change of the semi-diurnal current, but with strong spatial variation in the vertical.

To some extent this result is surprising as there is little apparent diurnal forcing that can cause these longer period currents. The barotropic tide here appears strongly dominated by semi-diurnal constituents (see Fig. 3).

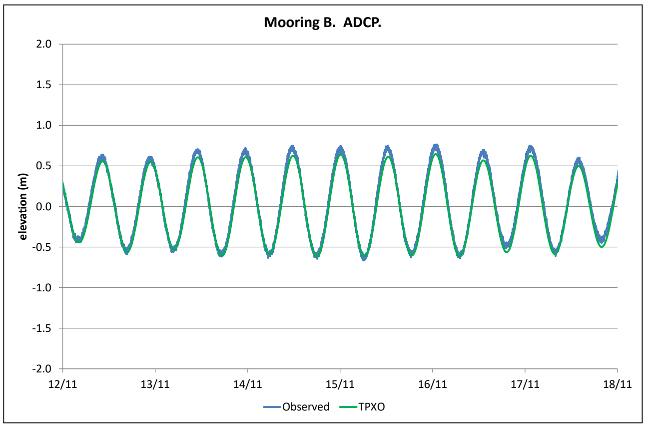

Figure 3. *Observed and modelled water level*

B. *Moored current meters*

Moored current meters were deployed for the survey period at location A (2 depths), B (2 depths) and C (1 depth), where locations are shown on Fig. 1. They operated continuously giving a high quality dataset enabling use of T-Tide, a freeware used for tidal harmonics analysis (see [10]). T-tide is written in the Matlab programming environment. It is based upon original FORTRAN program developed by M.G.G. Foreman (see [11] and [12]).

Tab. 1 below shows aspects of the statistics of the measured currents at the moorings.

TABLE 1 RESIDUAL CURRENTS AT MOORING LOCATIONS

Location + depth	u (m/s)	v (m/s)	Ratio
A1000	0.012	-0.027	0.18
A2000	0.005	-0.004	0.03
B50	0.010	-0.019	0.88
BADCP	0.005	-0.027	0.64
C3300	0.000	-0.009	0.35

The ratio is of minor to major M2 tidal ellipse, which indicates how linear or nearly circular the tidal ellipse is.

Clearly at all of the mooring locations and heights there is a general mean flow towards the east and towards the south. The strongest mean flow is about 0.03 m/s. At all the moorings the flow is dominated by tidal oscillations, mainly semi-diurnal.

Further, it is clear that the ellipse is closest to circular at the two B mooring locations representing a tendency for the current to rotate around the compass during each M2 tidal period. At A2000, by contrast, the ellipse is almost just a straight line with flows all going east or west.

Tab. 2 below shows which locations are more or less semi-diurnal dominated. Based on the tidal analysis of the observed currents at the moorings the degree to which the current is semi-diurnal (Ratio) is derived from the two largest diurnal and semi-diurnal constituents (O1+K1)/ (M2+S2) for the ellipse major axis.

TABLE 2 DEGREE TO WHICH CURRENT IS (SEMI-)DIURNAL

Location + depth	O1+K1	M2+S2	Ratio
A1000	0.028	0.078	0.36
A2000	0.021	0.052	0.40
B50	0.058	0.068	0.85
BADCP	0.061	0.129	0.47
C3300	0.013	0.053	0.25

This shows that greatest tendency towards diurnal variation is found at B50. Although the diurnal at 1,000 m depth at location B is almost the same, the semi-diurnal there is nearly twice as large and dominates.

At A1000 the current flows mainly north and south. As the meter is 1,000 m below the water surface, it is possible for the water to continue towards approximately north or south. This shows that the southward moving flow to the north of the seamount at 1,000 m depth is able to keep travelling south and sometimes flows north. During the measurement period the average u velocity is 0.01 m/s (to the east). The mean v velocity is 0.03 m/s south with periods of current greater than 0.15 m/s south.

III. 3D MODEL ASSUMPTIONS

A. *Model setup*

The model was set up to cover an approximately square area of side 450 km centred on the seamount.

The model was run using the hydrodynamic model TELEMAC-3D in hydrostatic mode. This open source model has the capability of a flexible mesh of triangles in the horizontal and a choice of meshing approaches for the vertical. In this case flat planes were used that drape the top of the seamount where they are lower than the peak.

Fig. 1 above shows the bathymetry as coloured contours and the 2D spatial mesh used over the seamount with TELEMAC-3D.

B. *Boundary conditions*

The model boundary conditions were taken from the Mercator Ocean global ocean circulation model (see [13]) with 52 horizontal layers with spacing closest near the surface and largest at depth. The model layers were taken the same as those in the Mercator Ocean model but with a spacing not greater than 20 m in the top 1,000 m. Initial conditions of salinity and temperature were taken from average conditions over the survey casts. Boundary conditions of water level were taken from the Mercator Ocean model added to the global TPXO levels (see [9]), the Mercator Ocean model not including tides. The currents on the boundaries were taken from the sum of the 3D currents from Mercator Ocean and those from TPXO, which were assumed to be uniform over the whole water depth.

As Mercator Ocean model outputs do not include tide variation they could not represent internal tide currents. The TPXO model does not include baroclinic variations so neither model allows boundary conditions representing internal tides to be applied. Although it was not possible to drive the model including actual internal tide motions at the boundaries, it was possible to absorb the internal tides generated inside the model by using sponge layer boundary conditions on the horizontal boundaries. However to ensure realistic water levels in the model the water level was imposed on the model boundaries without any sponge layer.

Model runs were carried out including different numerical recipes, different density formulations, and different winds (simulations reported here use the local measured wind). The Wu formula was used to specify the surface drag due to the wind.

IV. 3D MODEL VALIDATION

The 3D model result for the yo-yo period is shown in Fig. 4. The semi-diurnal beam from the middle moving downward can be seen but there is much less of the diurnal stripes in the upper part of the figure compared to what is observed.

A longer period presentation (Fig. 5) shows that the lower half of the water column at the yo-yo location is predominantly semi-diurnal and the top becomes diurnal after the first few tides. The reason for not reproducing better the diurnal detail could be due to:

- Diurnal internal tides propagating into the model area have not been reproduced;
- Semi-diurnal internal tides that propagate into the model and then change into diurnal stacked tides have not been reproduced; and / or
- The model has not been run with sufficient resolution to reproduce the detail of the stacked tides.

However the model clearly does reproduce the transition of the semi-diurnal beam into a diurnal one as the current at the surface is diurnal and no significant diurnal influence has caused this to happen.

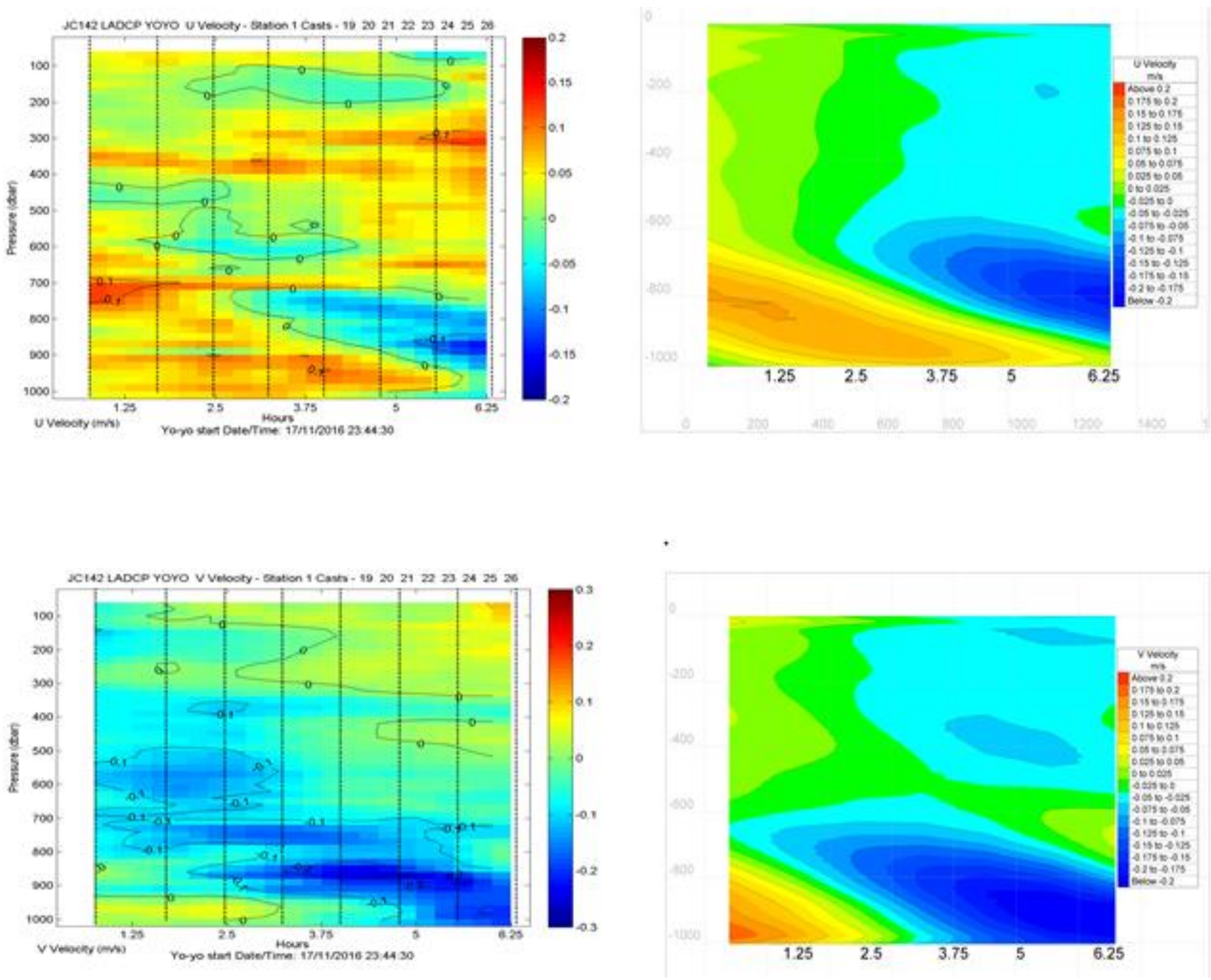

Figure 4. *Model yo-yo comparison (observed currents on left, model on right)*

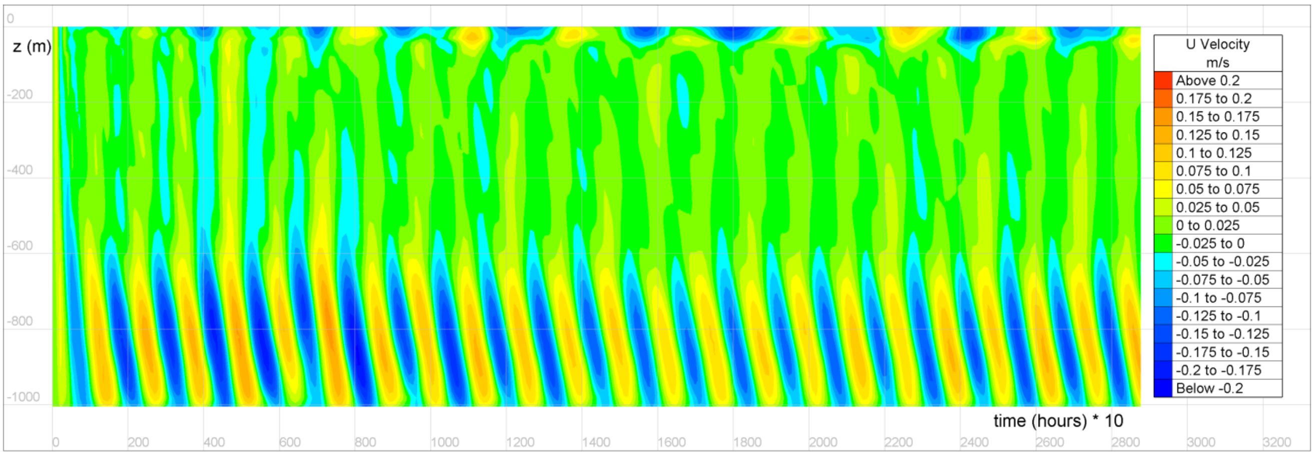

Figure 5. *Model u-velocity at yo-yo location, through tides*

Fig. 6 below shows a model result depicting the v velocity semi-diurnal magnitude (positive towards north) along a south to north section of the seamount. The propagation of the beam away from the top of the seamount towards the surface northward and southward can be seen, followed by its reflection back downward. The angle of the beam depends on the degree of stratification so it bends more near the surface where the density gradient is largest. The strongest semi-diurnal signal at the surface is about 60km from the seamount summit.

The data do not naturally lead to a conclusion that there is a Taylor column present at the seamount (this would be apparent in closed streamlines around the seamount).

The time averaged currents at 20 m above the sea bed are shown in Fig. 7 and they do show a tendency to a weak anti-cyclonic residual circulation around the seamount just above the bed (as has been seen at other sites). So it appears likely that there is a very weak Taylor column in the sea around the seamount close to the sea bed. This may be important in keeping material at the seamount.

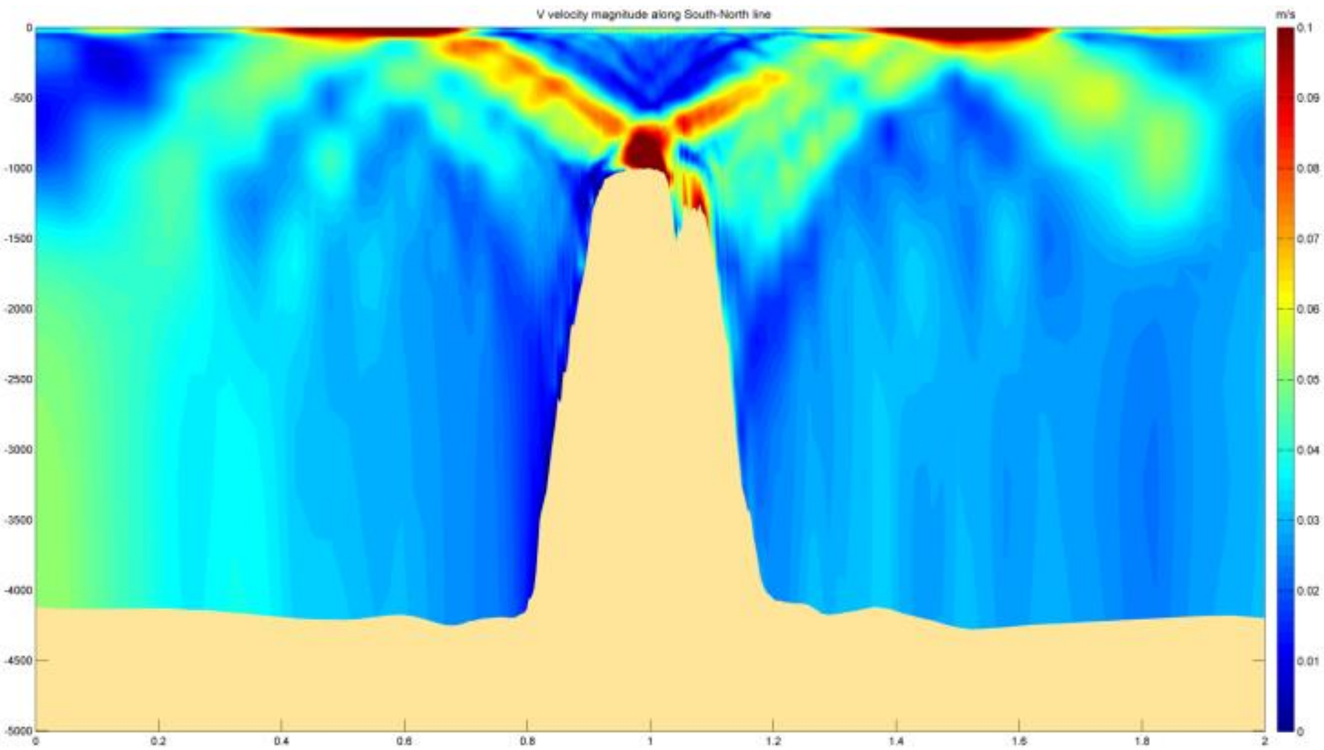

Figure 6. *Model v velocity (semi-diurnal) along a south-north section through the seamount (internal tidal beams)*

V. Conclusion

The observations show not only semi-diurnal internal tides but also a plethora of diurnal tides due to subharmonic instability. Because the area is bathed with internal semi-diurnal and diurnal tides arriving from further away, it is not readily possible to deduce the origin of all the observed flows.

The data do not naturally lead to a conclusion that there is a Taylor column present at the seamount. However, a 3D numerical model has been constructed and validated and it leads to the conclusion that there is a very weak Taylor column close to the sea bed.

References

[1] HR Wallingford, "Submarine Fe-Mn Crusts, Marine E-Tech, JC142 (Tropic Seamount)" – HR Cruise Report, 2017

[2] Gerkema, T., C. Staquet and P. Bouruet-Auberto, "Decay of semi-diurnal internal-tide beams due to subharmonic resonance." Geophys. Res. Lett., 33, L08604, 2006

[3] Hibiya, T., M. Nagasawa and Y. Niwa, "Nonlinear energy transfer within the oceanic internal wave spectrum at mid and high latitudes". J. Geophys. Res., 107, 3207, 2002

[4] MacKinnon, J. A. and K. B. Winter, "Subtropical catastrophe: significant loss of low-mode tidal energy at 28.9°N". Geophys. Res. Lett., 32, L15605, 2005

[5] Hans van Haren, Leo R. M. Maas and Theo Gerkema, "Patchiness in internal tidal beams", Journal of Marine Research, 68, 237–257, 2010

[6] Glenn S. Carter and Michael C. Gregg, "Flow and Mixing around a Small Seamount on Kaena Ridge", Hawaii Applied Physics Laboratory, and School of Oceanography, University of Washington, Seattle, Washington.

[7] Gerkema, T. and H. van Haren. "Internal tides and energy fluxes over Great Meteor Seamount", Ocean Science, 3, 441-449, 2007.

[8] White M and Mohn C, "Seamounts: a review of physical processes and their influence on the seamount ecosystem", Dept of Earth and Ocean Sciences, NUI, Galway, Ireland

[9] Oregon State University, "OSU Tidal Data Inversion Software and Atlas", TPXO-08 ATLAS, 2008, http://volkov.oce.orst.edu/tides/tpxo8_atlas.html

[10] R. Pawlowicz, B. Beardsley, and S. Lentz (2002), "Classical Tidal Harmonic Analysis Including Error Estimates in MATLAB using T_TIDE". Computers & Geosciences, Volume 28, Issue 8, 929-937.

[11] M.G.G. Foreman (1978, 2004 revision), "Manual for Tidal Currents Analysis and Prediction". Pacific Marine Science Report 78-6, Institute of Ocean Sciences, Patricia Bay, Sidney, B.C., 57 pp.

[12] M.G.G. Foreman (1977, 2004 revision), "Manual for Tidal Heights Analysis and Prediction". Pacific Marine Science Report 77-10, Institute of Ocean Sciences, Patricia Bay, Sidney, B.C., 58 pp.

[13] The European Commission's Copernicus Programme, in situ, satellite, and model output, http://marine.copernicus.eu

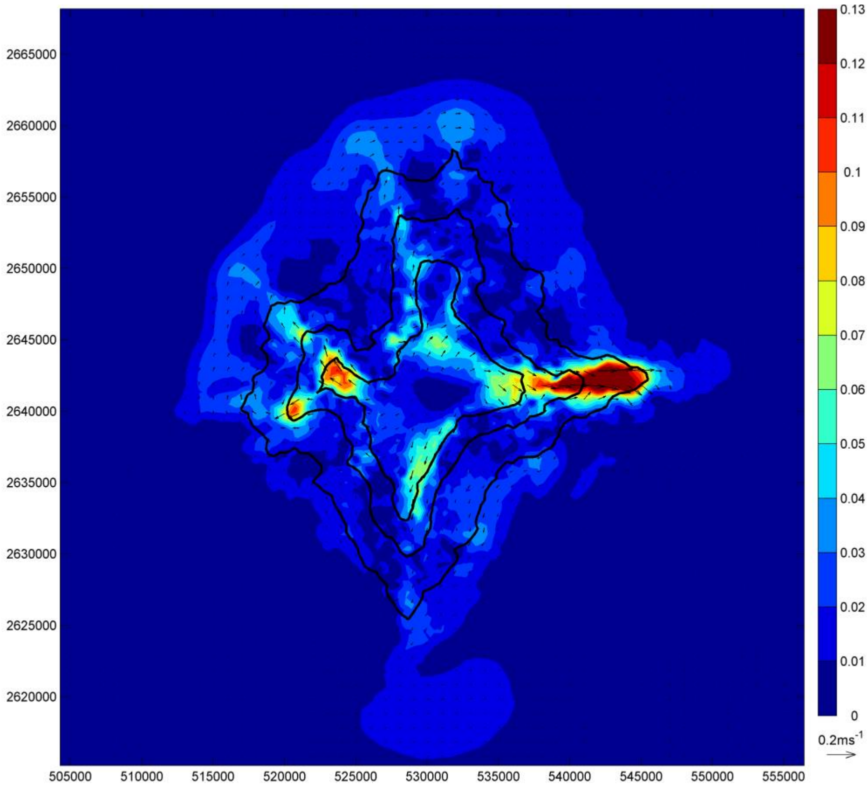

Figure 7. *Residual flow 20 m above sea bed*