Hydrography, current and turbulence moorings and SPM modelling

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Abstract
This account of OMEX II-II work at POL relates to planned POL contributions to the following elements of the Technical Annex:

- Task II.1 (moorings, currents, circulation and flow fields)
- Task II.2.1 (classical hydrography and water masses)
- Task III.1.2 (spatial and temporal variability of the benthic boundary layer dynamics), specifically deployment of a lander measuring near-bed turbulence
- Task III.1.6 (benthic model), specifically use of simple diffusion and prognostic models to investigate observed distributions of suspended matter
- Work Package IV in respect of Tasks IV.1 (water budget and circulation), IV.2 (carbon sources, cycling and fates), IV.6 (integrated margin exchange model) and IV.7 (Work Package IV coordination).

Introduction
For Work Package II, as reported at 12 months, a draft OMEX synthesis paper *Physical structures, advection and mixing at the Goban Spur* (Huthnance *et al.*, 1999) was submitted for the planned volume of OMEX I synthesis papers. This paper is being revised to take account of referees' comments.

For Work Packages II and III, swath bathymetry was carried out over the NW Iberian continental slope in 9° – 10.1°W, 41.4° – 43.1°N in June 1997 and largely determined subsequent plans for coring and mooring deployments. The latter were initiated on the first cruise (*Charles Darwin CD105*, 29 May to 23 June 1997). CTD and water sampling stations (especially for nutrients and primary production) on this cruise also set a pattern for later cruises, as reported at 12 months. The cruise *CD110a* (23 December 1997 to 5 January 1998) and acquisition of sea time also for *CD110b* (6 to 19 January 1998) and *CD114* (29 July to 24 August 1998), as reported at 12 months, actually completed POL's role in data acquisition for Work Package II. The work described below concerns the interpretation of physical data towards flux estimation, and leads into Work Package IV (Task IV.1).

For Work Package III, a model of diffusion and settling (only) in the cross-slope section was used in OMEX II-I to investigate steady-state distributions of SPM (Amin and Huthnance, 1999), as reported at 12 months.

Work Package II

Methods
(Task II.1)
A workshop for all the physics partners was held in November 1998, convened by POL and UCG and held at UWB. Summaries of work were given by the participants: NIOZ-b, POL, NSS, UCG, IH-a, IST, UWB-a,-b, and a representative (University of Brest) of the US-French programme ARCANE in the region.

Results (conclusions of physics workshop)
Water mass analysis (NIOZ) could be done at depth, but at mid-level there were too many water types. On cruises nutrient profiles (silicate, nitrate, phosphate) as well as temperature, salinity, dissolved oxygen should be measured.

NSS analysis of remote sensed features (filaments etc.) included boundary definition, composite locations and dynamic visualisation, using SST and colour (effective depth order 10 m).

UCG had analysed available current meter data for mean currents and variance (generally decreasing downward but maximum at Mediterranean Water levels; ellipses "fat" but aligned along-slope).

IH moorings in March to May 1998 showed some upwelling events. Current spectra showed M_2 and higher tidal harmonics but changes of tidal form on a 30-day period. Salinity maxima in 100-200 m (upper slope) were found associated with poleward flows.

IST aim to compute (with their numerical model) long current series to compare with data (statistics). ECMWF meteorological forcing caused long-term temperature and salinity divergence. Developments were to use monthly mean density, a new flux algorithm relaxing to observations (with much better results including mixed layer depth in 1994) and a generalised vertical coordinate.

UWB-b measurements in August 1998 showed solitons at 15-20 min intervals most of the time. An energy balance for them would be considered. Vertical diffusivity would be calculated from their turbulence measurements. (Internal wave packet development inshore had been tracked in MORENA.)

UWB-a deployed groups of drifters in filaments in August 1998. CTDs included sections across filaments, where current maxima (also from the ship's ADCP) were 20-30 cm s^{-1}. From MORENA, one CTD section at 10.2°W showed (filament?) salinity maxima at 41°N and 41.8°N near 100 m.

ARCANE (observations in 1996-1999) extends from Biscay to 40°N and 25°W and includes: 90 acoustically tracked floats (450, 1000, 1500 m), 40 buoys drogued at 150 m, hydrography, current moorings - two just off Vigo and three at 9.5°W, 44-45°N. Off Vigo, strong tides were seen at 700 m, near-bed mixing in 1700 m, and semi-diurnal wave energy spreading up and down from near 1000 m. Eddying had been tracked, esp. near Galicia Bank and near filaments.

Proposals were made for model validation. The year 1994 might be simulated and compared with archived data sets used in historical analysis. For this task, four mooring positions are available as well as possible MORENA/IEO data sets. Experiments to determine whether boundaries were far enough away would be made. Atmospheric forcing and river inputs would be omitted initially, but information including any nutrient content should be checked. Data for comparison could include: currents (statistics); remote sensing including altimetry; UWB turbulence data with varied air-sea temperature difference, wind ... (data could give the Thorpe scale, a possible basis to convert tke to diffusivity); drogued buoys for lateral dispersion (ARCANE pairs, Haynes and Barton).

Flux estimation was discussed. Owing to the distribution of most measurements, combination of fluxes to a budget probably meant a "box" 42-43°N, and from the coast to about 10°W, divided at the shelf break. Vertically, partitioning might be by the mixed layer and water mass bodies (density surfaces) as determined by NIOZ-b. A process-based approach to fluxes was preferred. Processes identified to occur in summer and winter regimes were discussed.

Summer is dominated by filaments and upwelling. External pressure gradients are believed to favour northward flow, especially along the upper slope but also nearshore at the Algarve, except where countered by the wind. The meridional gradient in sea surface height is weaker off Iberia than to the north or south, but still has to be overcome by the southward wind stress for upwelling to occur. Moroccan influence past Gibraltar is an open question. Cape St. Vincent is a particular location for filaments and distinctive regarding whether flows can pass around it. The vertical upwelling flux is $\tau/(\rho f)$ but lateral exchange in filaments may be more. Different phases of upwelling should be distinguished: initial thermocline displacement, later surfacing, moving offshore, establishment at the shelf break, filament formation. Secondary upwelling fronts can form inshore of the established front.

Stronger seasonal stratification (larger deformation radius) may imply more work to raise the thermocline to the surface - also affected by thermocline depth and friction. A shallower thermocline implies strong current response. Along-shelf flow to the south will tend to intensify until energy and momentum are lost (to filaments, eddies or friction). Persistence of upwelling was thought to be related primarily to the wind forcing; there may be a criterion - the time-integral of (signed) wind stress - for upwelling to be established; this should be investigated. Upwelling breakdown was poorly observed but might be rapid, related to change of wind regime and perhaps seasonal deepening of the thermocline. Remote sensing showed that upwelling at Finisterre was enhanced (starts earlier and more persistent).

Internal tides and solitons: it was suggested that their momentum could generate longshore drift and rip current as do surface waves. IH had data showing 30-day modulation of tidal current forms (including internal tides) along with strong non-linearity (rectification might be the source of the modulation).

In winter, wind events can give sediment resuspension on the shelf. IH has wave data off Porto and showed evidence for resuspension during a winter survey cruise, and associated off shelf flows. There is a question of the upwelling versus non-upwelling total nutrient supply. IH data around a canyon (February 1998) suggested flow onto the shelf at the head but into the canyon around the sides of denser shelf water. There is generally a warm flow along the upper slope, 15 cm s^{-1} or more; Des Barton had observed its establishment with a "nose" going north at this speed. The external pressure field is a possible forcing with maximum gradient in the sea surface slope close to the latitude of Cabo Roca. There may be a branch around Galicia Bank. The surface temperature field often shows a much broader (100s km) northwards extension of warm water, probably affected by winds; the seasonal thermocline from the previous summer persists through January at least. Pulsing of the slope current has been observed at mid-slope depths in the IH data. Coastal waters show cooler river runoff. There was varied evidence of some eddy motion around Capes Finisterre and Ortegal at both surface and deeper levels (MEDDIES).

Work Package III

Methods

(Task III.1.2)

The Sediment Transport and Boundary Layer Equipment (STABLE) measures near-bed turbulent phenomena and associated sediment resuspension. It uses electromagnetic current meters in pairs (for three velocity components) at 0.4, 0.7 and 1 m above bed, a pressure sensor and 3-frequency acoustic backscatter sensors, all recording at 8 Hz for 20-minute “bursts” each hour. Mean transport phenomena and near-bed shear are measured using a rotor stack (0.3, 0.5, 0.7 and 0.9 m above bed) and a vane 1 m above the bed, recording at 1-minute intervals. Four simple settlement tubes collect falling particles; other sensors measure average water depth, heading, pitch, roll and temperature.

STABLE was deployed in 202 m water, position 42°40′41″N, 09°30′30″W on 27th December 1997 (as reported at month 12) and recovered on 14th January 1998. Relevant data in the water are bursts 155 (2000 on 27 December) to 579 (1200 on 14 January) although the electro-magnetic current meters failed towards the end; data after about burst 470 are suspect and are definitely false after burst 555. Grab samples of surficial sediment were taken near to this deployment. A second successful deployment was carried out during *Charles Darwin* cruise *CD114*, in 200 m water, position 42°40′31″N, 09°30′29″W from 1st August 1998 to 20th August 1998. Relevant data in the water are bursts 154 (2000 on 1 August) to 593 (0500 on 20 August) although one of the electro-magnetic current meters at the bottom level failed to log data. Just prior to the deployment on 1st August, a bed-hopping camera was deployed to obtain 21 shots of the sea bed in the immediate vicinity.

From the burst-sampled currents, shear stress was estimated using two approaches:

Reynolds stress $u_*^2 = \tau/\rho = [\langle u'w'\rangle^2 + \langle v'w'\rangle^2]^{1/2}$

Total turbulence $u_*^2 = \tau/\rho = 0.19E$, $E = 0.5\langle u'^2 + v'^2 + w'^2\rangle$

Here τ is shear stress, ρ is water density, u_* is shear velocity, u,v,w are the components of flow. Primes denote departures of the variable from the burst-average denoted $\langle . \rangle$.

(Task III.1.6)

The POL model of SPM diffusion and settling (only) in the cross-slope section (as used in OMEX II-I; Amin and Huthnance, 1999) proceeds by iteration. This numerical procedure is equivalent to discretised time-stepping. The equivalence has been demonstrated in an example calculation with a surface source showing material sinking successively deeper after 5000, 10000, … successive iterative (time) steps.

A general-purpose three dimensional baroclinic model has been developed (Xing and Davies, 1998) incorporating a range of turbulence energy closure schemes. The model has been applied in cross shelf form to the Iberian Shelf edge region where OMEX II-II internal tide measurements were made by UWB-b. Initial calculations have been made for the internal tide, near-bed currents and sediment movement using a range of grain sizes. For the example runs hitherto, the sediment pick-up function was

$$E_s = \alpha[u_*^2/u_{*c}^2 - 1]^{3/2}$$

with $\alpha = 0.1$.

The model in cross shelf form has been made available to NIOO for use in their biological model.

Results

(Task III.1.2)

The winter grab samples showed fine sand in the area of the STABLE deployment. At the time of the summer deployment, the sea-bed photographs show rather turbid water over a muddy bottom with no obvious current-induced bedforms but considerable bioturbation.

For both the winter and summer deployments of STABLE, the mean logger worked correctly throughout and data quality is good. Comparisons between the mean and burst data are also good. The pressure and current channels in the burst data show evidence of waves, particularly in winter, as do the rotors during 31 December to 8 January.

Maximum recorded flow speeds (from the rotors, effectively 1-minute averages), were about 0.45 m s^{-1} (winter) and 0.25 m s^{-1} (summer). Both show a clear tidal signal but in winter some of the tidal peaks are strengthened, probably by wind forcing; the non-tidal part, at lower and higher frequencies, is greater than in summer.

For the purposes of estimating stress, there was little shear in the currents recorded by the rotors on which to base a logarithmic velocity profile. Hence the results shown are based on the turbulence data from the burst sampling with the electro-magnetic current meters. For both summer and winter, the total turbulence method gave the most consistent values between the three levels (of electro-magnetic current meters). Values obtained by the Reynolds stress method are similar but are particularly dependent on the difficult estimate of the vertical component w and hence show more variability between levels. It is noticeable that the large winter values by the total turbulence method in 31 December to 7 January are not consistently matched by the Reynolds stress calculation and coincide with the period when the rotor records are noisy, possibly as a result of wave action. These total turbulence stress estimates are closely matched in winter by the acoustic backscatter signal. (No such clear signal was obtained in summer; *i.e.*, suspended material was too fine to be detected by the acoustic backscatter in August 1998).

The temperature records from STABLE for 27 December 1997 to 14 January 1998 show a near-bed warming during the second half of the period, from a within-tide range 13-13.5°C at the beginning to 14-14.7°C at the end. This indicates that the remaining previous summer's thermocline, above the bottom rig at the time of deployment, was mixed down to the bottom at this time. The amplitude of the semi-diurnal tidal currents is irregular through the record, and may reflect rapidly changing stratification as the deepening thermocline neared the sea bed. The temperature records for 1-20 August show a within-tide range decreasing from 0.5°C at the beginning to 0.1-0.2°C in the second half of the record. The mean value decreases from about 12.0° to 11.7°C (12 August) rising to about 12.0°C again (17 August); smaller variations than in winter and showing end-of-winter cooled values or cooler upwelled water.

(Task III.1.6)
The internal tidal magnitude as calculated by the model was less than that found in the measurements. Improvement might require development of a 3-D non-hydrostatic model; for the present the main thrust of the modelling is to concentrate on sediment movement.

To simulate sediment movement and near-bed currents in the region of the STABLE measurements, preliminary calculations using the model in cross-section form have been performed in the absence of wind-wave effects. However, the near-bed measurements showed that wind-forced currents, wind and possibly wave activity are major processes causing sediment movement at the STABLE location. The model is being modified to take account of wind-wave effects and wave-current interaction in the bottom boundary layer. Preliminary calculations using a range of grain sizes have been performed, and show the importance of sediment type and settling velocity in determining sediment movement. With increased grain size, sediment movement decreases.

Discussion

The analysis of STABLE records for near-bed stress should be of interest in the apparent context of variable stratification sufficient to affect the amplitude of the tidal currents so that a spring-neap cycle is not recognisable. This winter period was also notable for large swell, which may contribute to near-bed stress. Further analysis is needed to assess the possible contributions of swell waves to the large winter stress estimates, and to check whether any correction is needed for the implicit assumption that all measurements were in the bottom logarithmic layer.

In both the Hebrides (1995) and these NW Iberian shelf-edge deployments in 200 m, the time-series of stress estimates have shown encouraging correlation with winter records of acoustic backscatter (an indicator of suspended material). This was not the case in either of the corresponding summer deployments, possibly because (a) finer suspended material in summer was not well recorded by the acoustic backscatter of frequency 4 MHz or less (b) the backscatter was used in profiling mode rather than aggregating the signal from the bottom metre as would be justified by the larger bottom layer depth for fine material.

We are now in a position to summarise the friction velocities (u_*, mm s^{-1}) that have been obtained at three locations around the west European shelf edge.

Location	Depth (m)	Typical tidal peak	Maximum
Hebrides, 56.5°N (winter and summer)	200	15	41
Goban Spur, 51°N, winter	879	5	13
NW Iberian (here), winter	202	10	40
summer	200	10	<28.

Not surprisingly, the Goban Spur values are smaller, being in deeper water with weaker tidal currents and below the direct influence of wind forcing or any surface waves. Hebridean and Iberian values are very similar. Both are amply sufficient to move frequently (within days-weeks) sandy material found on the shelf and shelf edge. Further down the slope, as exemplified by the Goban Spur record, stress values may be expected to decrease, whereas in the Iberian context critical shear stresses tend to increase, as the sediment becomes muddy and more cohesive. Therefore the frequency with which currents may be expected to move the bottom sediment is expected to decrease down the slope, and there is interest in determining at what depth such movement becomes rare (< once per year, say). As part of this, it is intended to compare the stress estimates with contemporary current measurements and assess how these contemporary statistics compare with other measurements over longer periods of time and greater depths, as a means of extrapolating stress estimates from these rather short STABLE records. Models of currents and bottom stress can also help in this process.

For the hitherto steady-state SPM diffusion/settling model, plans are to focus on the bottom boundary layer as well as adding time-dependence. For the prognostic bottom boundary model with SPM, plans are to include a density effect of SPM, compare results with STABLE data from OMEX II-II and so (using STABLE data from elsewhere also) to improve sediment movement predictions in relation to wind-forced effects.

Under-prediction of the internal tide in the cross-sectional form of the prognostic model may be due to using the hydrostatic assumption, in a region of steep slope; here vertical accelerations are important, and a non-hydrostatic model may be required. Moreover, the along-shelf component of the tide may be significant, requiring the use of a 3-D formulation. The latter will be attempted but additional inclusion of non-hydrostatic effects would be a major task.

Work Package IV

With regard to the substantive work in the six scientific tasks of WPIV, for which POL is overall co-ordinator, Task IV.5 only commences in month 31. An overview of progress in the other tasks has been maintained and is summarised in the WPIV overview report. Task IV.2 “Carbon sources, cycling and fates” was advanced *via* parallel sessions at the Plymouth Annual meeting in April 1999 corresponding with the main components of carbon cycling. POL has more specific roles in Tasks IV.1 and IV.6.

Task IV.1 concerns water budget and circulation. Progress with moorings, current data and water mass analysis is reported by UCG, IH and NIOZ-b. As reported under *Work Package II* above, a workshop for all the physics partners (*i.e.*, those concerned with Task IV.1) was held at UWB in November 1998 convened by POL and UCG.

Task IV.6 is entitled “Integrated margin exchange model”. A workshop for the principal modelling partners (those concerned with Task IV.6) was held at UCG in November 1998, convened by POL and UCG. Presentations were given by the partners (IST, NIOO-a, POL, SINTEF) and interactions between models and between partners were discussed extensively. The discussion was continued at the Plymouth Annual meeting in April 1999 in a session “Modelling requirements, integration and output”.

Results

(conclusions of the workshop)

IST outlined the model components to be connected in order to model fluxes and the 'OMEX food web': hydrodynamics with atmospheric forcing, turbulence, grid, bathymetry, initial conditions and boundary conditions as sub-components; this gave velocity, elevation, water fluxes (and geometry) to a Lagrangian or an Eulerian transport module; ecological model. The issues in connecting these (interfaces, module substitution, ...) were almost exactly as in the MAST project COHERENS (although the latter has no sea-bed fluxes). The COHERENS framework is available as a possible scheme. IST have connected hydrodynamics to transport models and tracer 'particles' can evolve. Hydrodynamic developments continue.

NIOO had run a version of the IST physics in 3-D in an area extending 132 km along the shelf. A spurious response to upwelling winds, especially near the southern boundary, had the appearance of a shelf wave with zero group velocity from a boundary condition mismatch. To avoid this, it was suggested that the biology model might be run on the sub-area of interest, with hydrodynamics done off-line (previously) on a larger area.

POL outlined calculations of cross-slope circulation and bottom boundary-layer flow associated with along-slope flow, and of internal tides and consequent structure in SPM concentrations and transport.

SINTEF models have unequal levels for the vertical coordinate and a 10-km grid over a wide area. For slope-current forcing using Levitus density, prognostic runs gave sharper features than diagnostic runs. There was some anticyclonic flow around Galicia Bank, favoured by wind from the north. Varied conditions at the southern boundary made little difference to results in the Galicia area, even when the boundary was brought closer, to about 34°N. Nesting had also been carried out, with the Galicia area having 2-km resolution and 39-45°N having 3.33-km resolution. The density forcing alone favoured an anticyclonic eddy at the shelf edge near 42°N.

There was further discussion of linking modules to a 'framework', as in the MAST projects ERSEM and PROFILE (→ COHERENS). It was agreed that all partners should describe their modules, define needed inputs and outputs produced. Subroutines should exchange variables, defining the interfaces and using Fortran 90 with optional arguments. Each module would want its own initialisation, and optimised data input files with identifying keywords. Partners should put modules on FTP sites for access. Case studies should be defined to check and intercompare modules. POL would send its cross-section model to NIOO.

Hydrodynamic results would be wanted on sub-domains for the ecological models.

Validation was discussed, especially module inter-comparison involving definition of how results would be compared. Inter-comparisons would include
- turbulence and air-sea flux parametrisations; 1-D (vertical) calculations comparing mixed layer depths (IST and NIOO lead)
- grid (x,y; z), bathymetry, boundary conditions and location (SINTEF lead) to give agreed grids
- hydrodynamics; cases (applying equally to the grid comparisons) to include stratified tide under varied conditions, density forcing, density + wind, tide (internal relative to resolution). For contrasted upwelling cases, the MOMOP and MORENA examples should be used. Flow fields and kinetic energy could be compared
- initial conditions: there may be a 'window' after the solution settles down and before it drifts; what is the difference with more detailed initial temperature and salinity than Levitus?
- ecological model; experiment with different combinations of state variables in the 1994 Goban Spur context; for the Galicia area also there may be earlier data for comparison, from IIM, *Belgica BG9309* and other OMEX I, SEFOS; compare the bloom peak and time, total annual production.

The IST physics model would be compared with data series (current meters, buoys) processed by UCG.

For model runs, and comparisons, there are Portuguese wave data from buoys, river runoff, meteorological data (IST contacts) which should include wind vectors, wind stress, heat fluxes, atmospheric temperature, humidity, cloud cover (problematic, from remote sensing?), rainfall. Spanish Meteorological Office data from June 1997 are available via BODC.

Simulations to exploit the models should include
- the period observing the filament in 1998
- contrasting upwelling seasons: 1994, 1997, 1998, 1999(?) for which there are good cruise data. Interests were criteria/conditions for upwelling onset/establishment and ending, and the character of response. 1998 was a good year for looking at the biology (NIOO, SINTEF), possibly 1994 too.
- possibly water masses, which depend on initial and boundary conditions, flow and diffusion. This is only sensible for conservative behaviour, *i.e.*, below the depth of seasonal mixing. It is also only sensible if there are only three possible point end members (*cf.* the problem with middle waters), given that the analysis of Levitus data for the model input sources concerns only temperature and

salinity. Another approach may be simply to simulate and compare the long-term evolution of temperature and salinity.
- attaching numbers to the summer and winter process outlines from the physics meeting (as above). The models may be the best source of flux estimates, and would automatically give closed budgets, but would be good only if representing beliefs about processes occurring and agreeing with observations.

An OMEX 'box' for attempting (closed) budgets was discussed. This ought to be away from a filament at its northern and southern boundaries (about 41.5°N and 43°N), enclosing the 1998 filament. Sub-partitions in depth might be at the base of the mixed layer and about 250 m, below seasonal mixing (to be checked with CTD profiles from Poseidon, Feb-Mar 1998). (The bottom would be the sea-bed surface - sub-bed divisions were not discussed). Other sub-boundaries for fluxes might relate to flow features (*e.g.*, just inshore of the upwelled front) rather than be fixed *a priori*.

(Report from the Plymouth meeting)
Continuing dialogue is needed regarding the desired model results and their form. Models should: represent filaments, vertical exchanges controlling profiles; distinguish DOM, POM, respiration as components of gross and hence "net" primary production for "export" (lateral and vertical). They should capture 1-day time-scales, upwelling (2-3 weeks) and aggregate winter and summer conditions for gross budgets, estimate lateral off-shelf flux and capture all (upwelling-) enhanced production by extending far enough off-shelf. All models are flexible regarding variable boundaries for an OMEX budget "box".

OMEX models include 3-D physics (IST, SINTEF) with coupled biology most relevant to WP1 in describing some rate processes. NIOO are investigating parametrisations for various taxonomic groups, simplifications appropriate to longer-term integrations and (extensions to) benthic processes. An air-sea exchange model (Risø) enables flux estimates from CO_2 concentration measurements. IST are carrying out work to combine the various elements: (waves), hydrodynamics, advection-diffusion (Eulerian or Lagrangian), turbulence, air-sea exchange, sediment transport and water quality or ecosystem. Links are simplified by confining dimensionality to the hydrodynamics, advection and diffusion. POL is modelling near-bed turbulence and stresses suspending sediment.

There are some technical challenges. Computational needs inhibit complex biology in 3-D. Processes should be included as not in equilibrium if their time-scale is as long as evolution times. More complex biology might be run for particular (short) periods within a longer run. Fine resolution is needed for filament flow structures (as distinct from location, which models already reproduce). Internal wave mixing (across the thermocline) should be represented, perhaps *via* shear input to turbulent energy.

Models have two-way relations with measurements. They need data for formulation, initialisation, forcing and validation (not guiding assimilation at this stage). Some comparisons with measurements have been made, with limited success for currents. More work is needed to compare "like with like": treat model output and observations similarly (*e.g.*, Principal Component Analysis); compare meteorology - model and meteorology - observation correlations; improve the "reality" of model forcing (actual meteorology; balanced oceanic pressure field derived from Levitus density field).

References

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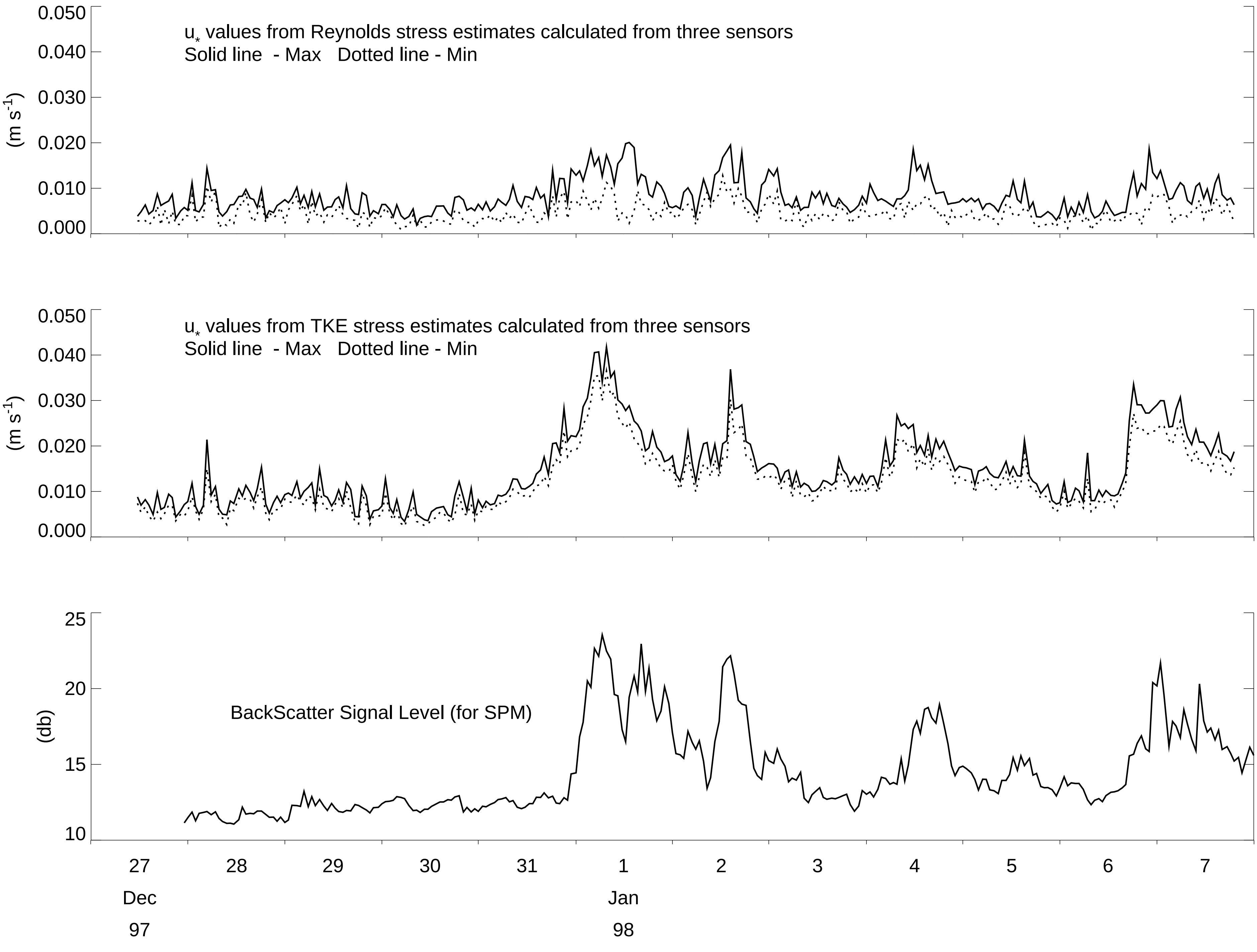
BOTTOM STRESS ESTIMATES FROM STABLE DEPLOYMENT CD110



BOTTOM STRESS ESTIMATES FROM STABLE DEPLOYMENT CD114