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Cyclone Xaver pounded the North Sea on 5-6 December 2013 and reached its maximum in the German Bight the second day. The radar altimeter on-board the SARAL/AltiKa satellite measured the largest storm surge signal captured by satellite altimetry to date, nearly 3 m, at the maximum. A local dense network of in-situ stations (tide gauges and GPS) monitored the event over several days. The combined geodetic measurements detect alongshore and cross-shelf surge variations and land subsidence.

The GPS network detects a maximum land subsidence at the GPS locations of 4-6 cm, in excellent agreement with the loading of the predicted surge by two forecast models in both measure and occurrence. The differences between the surge model predictions at the peak event are mainly caused by different wind forcing and reduce from 1 to 0.3 meters when the same wind forcing is used in both models.

Observations largely agree with model predictions on wind speed (Root-Mean-Square (RMS) of the differences is 4 m/s) and surge height (RMS 30 cm) and mostly differ on wave height (RMS 2 m).

The temporal and spatial characteristics of the surge and vertical displacement derived from the observations along the coast agree with the simulations. The water height indicates both a direct large scale forcing and a shelf wave dynamics with anticlockwise propagation of the surge. Instead, the temporal and spatial evolution of the vertical displacement appears to be mainly affected by this last component. After post-processing, the 1-minute sampling GPS time series monitor very well the propagation direction of the storm; the maximum subsidence is reached in the stations following the anticlockwise path of the surge. The along-track off-shore observations provided by satellite altimetry are valuable information to validate the simulations off-shore.

The results underline the importance of geodetic measurements in improving existing forecast approaches.

Marcello Passaro* Paolo Cipollini, Jerome Benveniste: Annual sea level variability of the coastal ocean: the Baltic Sea-North Sea transition zone

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Up to now, the use of satellite altimetry for sea level studies in the coastal regions has been has been limited due to the lack of confidence in the accuracy of the satellite measurements close to land and in shallow areas. This research focuses on validating the coastal capabilities of satellite altimetry to detect the annual cycle of sea level on a regional and sub-regional scale. The study area is the intersection of North Sea and Baltic Sea.

Coastal-dedicated satellite altimetry data (from ALES) are compared with the state-of-the-art standard altimetry products (from the ESA Climate Change Initiative). Estimations of the annual cycle of sea level are also derived from a network of coastal tide gauges. The analysis spans the Envisat years (2002-2010) and is performed both along each satellite track (or grid point for the mapped dataset) and by dividing the area into sub-basins.

We demonstrate that dedicated processing improves the quality of the altimetry dataset in the area, showing for example that the root mean square difference between the annual cycle sinusoid estimated by the tide gauges and coastal altimetry within only 15 km of the coast is constantly less than 1.5 cm. We provide interpretation of the results by using wind stress data and a local climatology, highlighting small-scale differences, such as a smaller annual variability in the West Arkona due to steric cycle phase opposed to mass component phase and a slope in the amplitude of the annual cycle along the Norwegian coast due to a coastal current.

To our knowledge, this is the first time that the improvements brought by coastal satellite altimetry to the description of the annual variability of the sea level have been evaluated and discussed. The methodology applied in this paper is generally applicable to other coastal areas and the coastal reprocessed ALES dataset will soon be available to the community over the whole coastal ocean.

Guillaume Sérazin [*], Thierry Penduff, Laurent Terray, Bernard Barnier, Jean-Marc Molines (CNRS-CERFACS, Grenoble/France): Imprints of oceanic intrinsic variability on altimetric measurements: an OGCM study

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Recent Ocean Global Circulation Model studies have highlighted the ability of the turbulent ocean to spontaneously generate low frequency variability of sea level over a wide range of spatial scales (Serazin et al., 2015). In terms of variance in the interannual band (i.e. from 1.5 to 20 years), this intrinsic variability is very comparable to the total hindcasted variability at small scales (12°). This low frequency intrinsic variability may be seen in the 22 year record of altimetric data and we propose a method to isolate some intrinsic features in this dataset based on a high pass spatial filtering. Global and Regional Sea Level Variability and Change. This study also focus on timescales longer than 20 years using a 300 year long 1/4° simulation, which shows that the ocean spontaneously generates decadal sea- level fluctuations in eddy active regions. It is shown that this ocean only variability may have an imprint on observed regional sea level trend, especially in the ACC and in the Western Boundary Current areas. The incertitude on sea level trends induced by truncating this decadal intrinsic variability is comparable to the one estimated from Global Coupled Models in which the oceanic intrinsic component is not taken into account yet.

Hilkka Pellikka[*], Milla M. Johansson, Ulpu Leijala, Katri Leinonen, Kimmo K. Kahma: A probability-based method to estimate sea level rise and future flooding risks on the Finnish coast

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Current sea level rise scenarios are subject to large uncertainties, and decision-makers have to consider how to incorporate the uncertainties in long-term coastal management, e.g. in determining the building elevations of new coastal infrastructure. Preparing for the worst case is usually not cost-effective. Rather, the risk level chosen should depend on the potential damage in case of flooding. To be highly valuable for decision-making, flood risk analysis should provide estimates of flood levels with different probabilities in the future. We present the method used to make such estimates on the coast of Finland in the Baltic Sea.

The foundation of our calculations are the long (ca. 100 years) tide gauge records from the Finnish coast. Historically, sea level has been declining relative to land in Finland because of postglacial land uplift. We determine the rate of land uplift as a residual trend once the effects of global mean sea level rise and changes in the wind climate have been removed from the tide gauge time series. The land uplift is expected to continue with a constant rate for the next few centuries.

We construct a probability distribution of sea level rise in 2000-2100 using an ensemble of recently published predictions, which have been scaled to take into account regional deviations from the global mean. In the resulting distribution, the 5-95% range of global mean sea level rise is 33-156 cm. Regional effects reduce the upper limit by an estimated 20-25% on the Finnish coast. By combining this distribution with an exceedance frequency distribution of short-term sea level variations, derived from the last 30 years of measurements, we can estimate the probabilities of different flood levels in the future.

Christopher G. Piecuch[*], Rui M. Ponte: The Annual Global-Mean Thermosteric Height Budget

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Changes in global-mean thermosteric height (GMTH) reflect expansion or contraction of the oceans due to thermally induced ocean density changes. While past works diagnose GMTH changes using in situ data or remote measurements, understanding of physical processes contributing to the GMTH changes is lacking. Unlike heat, density (or buoyancy) is not conserved in the ocean—a consequence of the nonlinear nature of the seawater equation of state. While GMTH can be affected by surface heat fluxes, it can also be influenced by net creation or destruction of buoyancy by ocean heat transports across constant-pressure and -temperature surfaces.

To investigate the annual GMTH budget, we first perform comprehensive diagnostics of the ECCO-Production Release 1 ocean state estimate. Estimated annual GMTH changes are wholly compensated by net surface buoyancy flux (NSBF) due to surface heat exchange. Ocean heat transports do not contribute mainly because annual ocean heat content anomalies are mostly stored in the upper ocean (and are not transported along strong temperature gradients). These results suggest that, for the annual frequency, the GMTH budget can be diagnosed observationally from knowledge of the temperature and NSBF fields. To corroborate these findings, and also to gauge the consistency of available datasets, we compare to GMTH and NSBF annual cycles computed based on different observational products. The amplitude and phase of annual cycle in GMTH derived from Argo gridded data are nearly indistinguishable from those derived from NSBF based on OAFlux surface heat exchanges, supporting findings from the state estimate. Additional analyses consider annual cycles in GMTH estimated from altimetry and GRACE, and in NSBF determined from NOCS v2.0 marine surface fluxes along with satellite sea-surface temperature. Results highlight the usefulness of GMTH as a measure of the quality of surface flux data.