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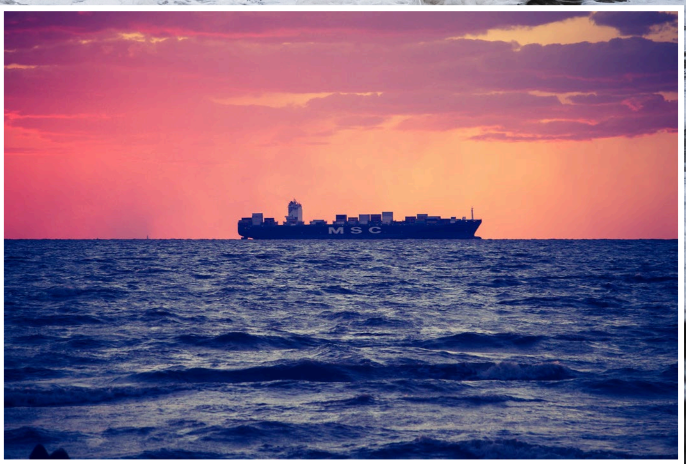
Book of Abstracts

Sea State Meeting

23-25 March 2021



Abstracts of Presentations at Sea State Meeting (23-25 March 2021)

Combining Observations

Tues 23rd March 09:15-10:45

Observing sea state climates and its evolution: the ESA Sea State CCI project in the context of other datasets, achievements and perspectives"

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& Sea State CCI team

Sea states have been measured continuously from space since the launch of ERS-1, 30 years ago. Both altimeters and synthetic aperture radars provide a unique global view of sea states, even if with a sparse time sampling that still offers a limited view of the wave climate, in particular when it comes to extremes. In this context, satellite measurements are highly complementary to other sources of sea state data: Voluntary Observing Ships, microseism records, in situ buoy data, and numerical model hindcasts. With 10 missions flying now, 9 completed and more at various stages of preparation and planning, there is a strong need for providing a uniform record that can be used for climate applications. Climate applications involve both detecting climate change and establishing the properties of this evolving wave climate for adaptation to climate change.
The project started off by extending and adjusting the Globwave dataset to produce the Sea State CCI V1 data set. The Sea State CCI project embarked on a much more ambitious effort to reprocess recent satellite altimeter and SAR wave mode missions with a specific goal of providing the most accurate wave height estimates. This V2 dataset is experimental and detailed validation will show the benefits and difficulties of applying the same processing approach across all satellite data. At the same time we are preparing the next phase of the project that will extend this effort in time, both in the past to go back to 1991 as done with CCI-V1, and in the future, including new missions and sensors such as the first real aperture wave spectrometer, the SWIM instrument on CFOSAT. In this formidable task we will have to prioritize our efforts with a view to maximizing the value of the dataset for climate users.
Possibly the widest pool of users is those using numerical model hindcasts such as ERA-5 which has assimilated most altimeters in the past, because they provide a continuous time coverage. We will thus work closely with producers of numerical model reanalyses and hindcasts to both help them ingest future CCI datasets and/or use satellite data for model post-processing such as bias corrections.
Besides, a full understanding of sea state evolution and variability is not possible without some understanding of its forcing agents: wind speed, sea ice concentration, surface currents. As we are dealing with satellite data that can also provide wind information, an important effort of future CCI work could be related to retrieving mean square slopes and/or wind speeds from altimeter data.
We count on this particular User Consultation Meeting to obtain important feedback on where we should place priorities so that we can best help users with their sea state climate needs.

Performance of CMEMS wave reanalysis WAVERYS in the Southern Ocean and challenges for next version 2.0

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The global wave reanalysis WAVERYS of the Marine Copernicus Service (CMEMS) responds to a strong request from users in order to implement several downstream applications related to wave climate in open oceans and coastal areas. The version 1.1 of WAVERYS has been implemented for the altimetry period from 1993 until present and includes the assimilation of Significant Wave Height (SWH) from altimeters missions and SAR directional wave spectra from Sentinel-1. WAVERYS is forced by 3-hourly surface currents from ocean reanalysis GLORYS and atmospheric forcing from ERA5 interpolated to 20 km grid size of the wave model MFWAM.
The validation of the wave reanalysis WAVERYS has shown a very good accuracy for integrated parameters such as SWH and mean period, thanks to the comparison with independent altimeter mission HY2A and buoys data (Law-Chune et al. 2020). In this talk we will present the rôle of using directional wave spectra in the Southern Ocean (SO) dominated by severe storms during four years from 2016 to 2019. The comparison with SWH from HY2A in the SO indicates a small scatter index and small bias of roughly 8 % and 6 cm, respectively. The scatter index of SWH decreases to 6.7% for high waves larger than 5 m which is correlated with severe storms. We nvestigated the impact of using SAR wave spectra for wind-waves generation and swell propagation in the Southern Ocean, as indicated in Aouf et al. (2021).
This talk will introduce the challenges for the next version 2.0 of WAVERYS which will lead to further improvements related to available data such the ones provided by CCI with EMD denoising skilled for smaller scales (Quilfen and Chapron 2019). In this framework we will compare such altimeters data from CCI with other improved altimeters data using deep learning technique as suggested by Wang et al. (2020). We will also investigate the use of directional wave spectra from past mission such as ENVISAT, that might be reprocessed with better algorithms in the framework of CCI sea state.
The conclusions will address the best configuration of the wave reanalysis to meet the requirements of European users. Further comments and discussions will be given during the final presentation.

References

Aouf L., et al. (2021): New directional wave satellite observations : Towards improved wave forecasts and climate description in Southern Ocean, GRL, https://doi.org/10.1029/2020GL091187.
Lawh-Chune S., et al (2020): WAVERYS A CMEMS wave reanalysis during altimetry period, Ocean Dynamics, DOI : 10.1007/s10236-020-01433-w

CMEMS satellite near-real-time wave products: recent upgrades and future developments towards delayed-time products

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A near-real-time wave service started in July 2017 in the frame of the Copernicus Marine Environment Monitoring Service (CMEMS). Handled by the WAVE-TAC (Thematic Assembly Center), a partnership between CLS and IFREMER, it provides near-real-time wave products derived from altimetry and SAR measurements. We will start this presentation with a brief description of the three types of near-real-time wave products currently distributed: the along-track Level-3 significant wave height, the gridded Level-4 significant wave height and the along-track Level-3 spectral (SPC) products. We will more particularly focus on the more recent Level-4 gridded SWH product and the SAR-derived spectral product. Then we will highlight the ongoing efforts on the product quality improvement with recent upgrades and validation methods. Finally, we will present the planned developments towards delayed-time products, the link with the ESA CCI+ Sea State project and we will detail the longer-term plans in terms of upstream research & developments and CMEMS expected service evolution.

New Sensors

Tues 23rd March
11:00-14:45

Ocean waves from space: What new information with the CFOSAT mission ?

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Since 2018, the new satellite CFOSAT (China France Oceanography SATellite) is in orbit. Thanks to its original concept, it allows simultaneous description of wind and waves with details on ocean wave properties (full directional spectra) that were not previously accessible systematically at the global scale. This brings new perspectives to study ocean / atmosphere exchanges, improve wind and wave forecasting, study the impacts of climate change on the ocean surface parameters. In this talk, I will present an overview on the latest results obtained from the CFOSAT observations.

Sea State Parameters from Sentinel-1 SAR

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An empirical algorithm was developed for estimation of wide spectrum of integrated sea state parameters from satellite-borne Synthetic Aperture Radar (SAR): total significant wave height, dominant and secondary swell wave height, windsea wave height, first and second moment wave periods, mean wave period and period of windsea. The algorithm was tuned and validated for C-band Sentinel-1 (S1) Wave Mode (WV) products consisting of multiple 20km×20km imagettes, for S1 IW (Interferometric Wide Swath Mode) and for S1-EW (Extra Wide). Whereas for S1 WV one integrated value per imagette has been estimated, for S1 IW and EW, sea state fields with any step raster for the scenes covering hundreds of kilometers can be processed.
The algorithm consists of two parts for estimation of sea state parameters: the initial part is based on linear regression and the second postprocessing part uses machine learning, i.e. the support vector machine technique (SVM), to improve the accuracy of the initial results. In this way, the accuracy of initial SWH estimated using linear regression with ~0.35m accuracy for S1 WV (CMEMS-hindcast validation) has been improved to ~0.26m accuracy by SVM postprocessing.
The combined algorithm is able to process S1 Level-1 SLC and GRD data in near real time (NRT). The complete archive of S1 WV since 2014 with ~60 overflights/day each including ~120 imagettes was processed. Validation was executed using CMEMS sea state hindcast within latitude of -60°<LAT<60° to avoid ice coverage. The total number of validated imagettes is around 3 Mio for 2018-2020 (2016-2017 data were used for training) and results into RMSE=0.25m for wv1 imagettes (incidence angle of 23°) and RMSE=0.28m for wv2 imagettes (incidence angle of 36°). The comparisons with NDBC buoys result into RMSE=0.41m. The derived state parameters and imagette information (geo-location, time, ID, orbit number) are stored in netcdf format for convenient use.

CFOSAT: possible contribution of the Sea State Dedicated mission to CCI project

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CFOSAT, the Sea State dedicated mission, was launched in end 2018 and its innovative instrument has already shown its reliability and data quality interest through several publications. Although the mission will last less than four years, its application for climate studies could be major thanks to its dual measurement system at nadir (fully comparable to the historical and long lasting nadir constellation) and off nadir, thus providing spectral information (direction, wavelength and height) fully comparable with the models and the Sentinel1 wave spectral content. Thanks to this, via an appropriate mission merging, both techniques could be linked together and improve the knowledge of sea state components at climate scales.
The official SWIM Calval Team (CNES, LATMOS, LOBS, MeteoFrance, CLS, ODL…) constantly works at improving the mission's data quality and plans several reprocessings for the users community. In January 2021, official data were fully reprocessed in a homogeneous version. The nadir time series shows very good performances and is ready to be included in the homogenization process of the CCI project. Off-nadir innovative data constantly improve and are qualified with respect to models and Sentinel 1 spectral data. Systematic Calval for SWIM CASYS project aims at promoting the calval expertises upstream. On Aviso web site, so called L2P times series are distributed to non expert users in a CMEMS Wave-TAC compliant format.
These products are available to any user and projects willing to have a simple access to the ground segment evolutions, sometimes before their inclusion in the official products. They aim at easing comparisons and fusion with other nadir missions and to SAR Wavemode products already in the CMEMS catalogue. This presentation describes their potential added value for the Sea State CCI project, and more largely for climate applications.

Ocean wave spectra in tropical cyclones with the Earth Explorer 10 candidate Harmony

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Tropical cyclones are commonly linked to devastation by hurricane force winds, storm surges and rainfall. They are also responsible for large exchanges of heat in the upper ocean and the atmosphere, and the transport of water from ocean to land. Due to the limited coverage of the microwave observations from planes and the limited resolution of spaceborne scatterometers, the dynamics inside these extremes are poorly sampled and understood. Synthetic Aperture Radar (SAR) overcomes these limitations, but is only able to recover one-dimensional information, which limits the accuracy of estimated quantities like wind speed, total surface current and wave spectra. Wave spectra in tropical cyclones can only partly be recovered, as the quickly changing sea surface limits the resolution of SAR in the azimuth direction. This presentation shows the benefit of having

Harmony's bi-static receivers flying in a StereoSAR configuration with Sentinel-1D for obtaining wave spectra. Wave trains in tropical cyclones are modeled using fetch laws and converted to wave spectra. Using SAR transforms, SAR spectra are estimated for monostatic and bistatic systems from the modeled wave spectra. The monostatic SAR spectra are compared to SAR observations over tropical cyclones. Based the bistatic SAR spectra, we demonstrate that Harmony's data allows for the retrieval of a larger fraction of the wave spectra. In the periphery of tropical cyclones Harmony will primarily enhance the recovery of medium-length (100-200 m) swell and wind waves, while Harmony improves the recovery of long (swell) waves (>200 m) near the eye of the storm.

Forward model simulation of swell effects in SMAP near-coastal high-resolution NRCS data

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Ocean waves play a major role in ocean circulation and impact coastal ecosystems and the associated human activities. Local wave observations typically show local wind-induced gravity waves (wind waves) that are modulated by longer swell waves generated by remote wind sources. In-situ measurement systems such as coastal buoys have historically played an important role in wave observations and forecasting. However, recent advancements in space-based radar remote sensing may have the potential to augment these observations at high spatial resolution and over a larger physical extent.

Ocean backscatter normalized radar cross section (NRCS) measurements are typically assumed to sensitive primarily to wind waves. However, several past studies have shown that the presence of swell waves can impact radar measurements. In this presentation, we examine the impact of swell waves on approximately 1 km spatial resolution backscatter NRCS measurements made by NASA's Soil Moisture Active/Passive (SMAP) radar at 1.26 GHz (L-band) at an incidence angle of 40 degrees via physics-based forward modeling of NRCS observations.

This study applies the widely used and computationally efficient two-scale (or composite surface) model (TSM) to model backscatter NRCS from the sea surface. The backscattered NRCS for the SMAP radar is dominated by resonant Bragg scattering (ocean wavelength = 18.5 cm) that is firmly within the gravity wave portion of the sea spectrum. A wind + swell model is used in which wind-driven waves are modeled using the fully-developed Durden-Vesecky spectrum while the impact of swell is represented as an excess slope variance contribution. The results demonstrate the capability of the wind + swell model to improve model predictions of SMAP measurements in HH-polarization and to observe swell waves at 1 km resolution. The presentation to be provided will describe the modeling approach, the resulting sensitivities to swell properties, the use of these datasets for inferring properties of swell waves on the sea surface, and recommendations for future application of the method.

Plans for long-term operational sea state monitoring by the Spire GNSS-R nanosatellite constellation

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Spire Global operates a large and rapidly growing constellation of nanosatellites performing GNSS-based science and Earth observation. Spire specializes in using science-quality observations of GNSS signals (e.g., GPS, GLONASS, Galileo, QZSS, etc.) to derive valuable information about the Earth environment. Beginning in 2018, Spire began an effort to design and build the first of many GNSS reflectometry (GNSS-R) missions for Earth observations for a variety of applications, including sea surface roughness and winds, sea ice characterization, soil moisture measurement, and wetlands and flood inundation mapping. In December 2019, Spire launched its first two GNSS-R satellites to complement its operational fleet of GNSS radio occultation (RO) satellites. These two GNSS-R satellites have undergone validation over 2020, and now these two satellites have entered an operational phase. Their data are now being developed into standard GNSS-R products, including sea state (e.g., L-band limited mean square slope) and ocean wind speed products. In this talk, we will give an update on the first two Spire GNSS-R satellites, their validation, and the initial sea state products derived from their observations. Additionally, Spire has designed and launched (in late January 2021) two follow-on GNSS-R satellites that improve upon the first two satellites by flying both a new, advanced, Spire-designed GNSS receiver and completely redesigned GNSS-R antennas. This talk will also detail this second set of Spire GNSS-R satellites, show first results from these satellites, and discuss plans to build a large constellation of GNSS-R satellites that will operationally monitor sea state over the long-term.

Challenges in assessing wave climate and trends therein

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Waves are key contributors to shoreline erosion and flooding, which can profoundly alter coastal ecosystems and disturb coastal communities. Wave information is also important to coastal and marine engineering, as waves can damage marine infrastructures and affect the safety of shipping, port and offshore operations. A realistic assessment and good understanding of the historical wave climate and its possible future changes is paramount to successfully address the challenges and opportunities posed by climate change.

Due to the lack of good spatial and temporal coverage/consistency of in-situ wave observations, simulations have been widely used to study the trends and variability in wave climate at global and regional scales. These include wave reanalysis, hindcasts, and simulations dynamically or statistically derived from climate models simulations of the atmosphere. However, they are affected by uncertainty arising from homogeneity problems, resolution issues (which particularly influence the representation of extremes), and model parameterizations. For example, there are large differences between trends derived from CFSR and ERA-interim reanalysis datasets. Additionally, an ensemble of realizations is needed to properly assess forcing signals due to internal climate variability. Nowadays, satellite records cover a sufficient period to assess climate statistics but changes of sensors over time could cause inhomogeneity problems. For example, altimeter data is still affected by uncertainty factors related to the filtering, correction and calibration methods used therein. There is need for consistent and homogeneous observation-based data products.

At regional scales, challenges exacerbate due to increased complexity of the physical processes involved and, in some cases, the limited number of observations. This is particularly relevant for the Arctic Ocean, where strongly interactive and complex processes take place in the atmosphere-ice-ocean boundary layer. For example, the parameterization of the complex interactions between waves and sea ice can lead to an additional uncertainty of up to 80%. The Arctic is also a hot spot for global climate change, as it is experiencing a warming rate that is three times the global average, with a rapid decline of the sea ice coverage. This can lead to an increase in extreme wave heights of up to 2 to 3 times the historical value along Arctic populated coastlines by the end of this century. Moreover, the implications of these changes extend beyond the high latitudes and can affect the global climate.

On the estimation of seasonal patterns using satellite, model, and measured data

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Since satellite altimeter data have a different time-space data structure, they cannot be a direct equivalent to time series of numerical models and/or buoy measurements. Nevertheless, by assuming that wave field is spatially homogeneous around a specific site of interest, one can obtain an estimate of the seasonal variability by calculating monthly mean values and standard deviations from all three sources of data.

The purpose of the present study is to investigate if seasonal patterns (mean values and standard deviations) estimated by means of all three sources (altimeters, models, buoys) are in a good

accordance. A fact that is suggested by previous studies. For this, the following data sources have been analyzed: a) satellite altimeter data from the archive of IFREMER covering the period 1992-2016 (partially coinciding with L3 ESA Sea State Product) from nine altimeter missions (ERS-1,2, ENVISAT, TOPEX/Poseidon, Jason-1,2, GEOSAT-FO, Cryosat-2, SARAL); b) hindcast data coming from two well-known reanalyses, namely Wavewatch III (30 years, 1979-2009) and ERA5 (40, 1979-2018).

Results for 13 locations around the globe are given, coming from 13 different non-overlapping subregions defined by Alves (2006), such that the wave conditions within each of them to be similar. The analysis has shown that satellite data exhibit large variability of available years per month and available months per year. The monthly mean values estimated by satellite altimeter data are in a good agreement with the ones estimated by other data. However, monthly standard deviations from satellite altimeters do not exhibit so much variation like the ones from the other sources. In the satellite data manual, a data screening procedure is described for the various altimeters. It seems that this procedure might have reduced the seasonal variability of the data. Further analysis of unfiltered raw satellite data is needed to find out more about that.

Projected future changes in tropical cyclone-related wave climate in the North Atlantic

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Tropical cyclones are a major hazard for numerous countries surrounding the tropical-to-subtropical North Atlantic sub-basin including the Caribbean Sea and Gulf of Mexico. Their intense winds, which can exceed 300 km h−1, can cause serious damage, particularly along coastlines where the combined action of waves, currents and low atmospheric pressure leads to storm surge and coastal flooding. This work presents future projections of North Atlantic tropical cyclone-related wave climate. A new configuration of the ARPEGE-Climat global atmospheric model on a stretched grid reaching ~ 14 km resolution to the north-east of the eastern Caribbean is able to reproduce the distribution of tropical cyclone winds, including Category 5 hurricanes. Historical (1984–2013, 5 members) and future (2051–2080, 5 members) simulations with the IPCC RCP8.5 scenario are used to drive the MFWAM (Météo-France Wave Action Model) spectral wave model over the Atlantic basin during the hurricane season. An intermediate 50-km resolution grid is used to propagate mid-latitude swells into a higher 10-km resolution grid over the tropical cyclone main development region. Wave model performance is evaluated over the historical period with the ERA5 reanalysis and ESA Sea State CCI data. Future projections exhibit a modest but widespread reduction in seasonal mean wave heights in response to weakening subtropical anticyclone, yet marked increases in tropical cyclone-related wind sea and extreme wave heights within a large region extending from the African coasts to the North American continent.

The importance of waves for coastal erosion and sediment transport

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Coastal erosion is a widespread and increasingly serious problem. It happens due to a range of causes, such as reduction of sediment supply by rivers to sand mining, blocking of longshore sediment transport by ports and other structures, sea level rise, particularly near tidal inlets, and land subsidence. It happens due to long-term processes, mainly related to longshore transport gradients, and short-term processes, mostly related to cross-shore transport.
For longshore transport, mean wave direction is key, followed by Hm0 wave height and peak wave period. Small variations in annual or seasonal mean wave direction can lead to beach rotation with important consequence for coastal erosion and accretion. Vast tracts of coastline go without any publicly available directional wave buoys and hence the combination of global wave hindcast models such as ERA5, which are assimilated with all available wave buoy and satellite wave data is the only reliable way to obtain reliable wave climate information.
For cross-shore profile evolution, skewness and asymmetry are important drivers of net transport due to orbital motions, and the horizontal and vertical return flow profiles are closely linked to the decay of wave energy. Short wave propagation models coupled with 2DH and 3D flow models are well able to describe the surf zone flow patterns, given accurate offshore wave spectra. During storms and large swell events, infragravity waves dominate the flow motions on the beach and against and over dunes and dikes; their strength depends strongly on the directional spreading of the wind and swell waves forcing them.
Waves do not only force changes in coastal bathymetry and in coastline evolution, but can also be good indicators of underwater morphology; by inverting the dispersion relation for different spectral bands, increasingly reliable and detailed maps of water depth and currents can be produced, from radar and visible-band imagery, both land-based and from satellites.
Thanks to freely available satellite imagery (e.g. Landsat, Sentinel) we are increasingly able to observe coastline changes with good accuracy; combined with wave models that are assimilated with satellite-based wave data, this allows us to hindcast and forecast coastal evolution in remote and ungauged areas, and to assess the effectiveness of coastal management strategies.

The impact of sea state: From coastal erosion to sailing

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Wind and wave conditions are a primary concern for many people living along the coastline, but when considering the partially frozen coastline in the Arctic, this concern is highlighted by the cascading detrimental thawing effects on indigenous cultural sites and subsistence practices. Media coverage has extensively shown cemeteries being washed away into the sea, ice cellars being inundated with floodwaters, and entire villages planning to relocate without having the funds to do so. If we take a look further offshore, sea state directly impacts the safety of subsistence hunters travelling by boat, leading to the fact that a lengthening open water season does not necessarily mean the same increase in the number of safely boat-able days. Beyond the scope of native communities, but still well within the lens of the media, professional sailors are constantly looking for products that improve their knowledge and forecasts of sea state to better inform which routes and actions they will take during months-long competitions. This talk will contain a broad overview of the specific uses of wave and wind information, citing specific examples from the authors' own experience on coastal erosion model development and interaction with Arctic native coastal communities. A main goal of this talk is also to illuminate the incentives for the scientific community to be actively engaged in improving operational sea state products, from Arctic indigenous coastal communities to professional sailors, particularly in light of the increasing media attention to the general public.

Towards nature-based solution design applications with marine seagrass for Emilia-Romagna coastal belt

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Nature-based solutions (NBS) find growing awareness as efforts to tackle societal challenges by utilizing environmentally safe operations for vulnerability and risk assessment processes. This study presents a simulated design methodology for the Emilia-Romagna coastal belt with marine seagrass as a highly recognised NBS, which has the capability to attenuate the impact of storm surges and coastal erosion. Under the OPEn-air laboRAtories for Nature baseD solUtions to Manage environmental risks (OPERANDUM) EU H2020 project, the NBS implemented in this study presents the assessment via validated numerical simulations for present climate and improved simulations with marine seagrass in the Emilia-Romagna coastal belt. To simulate the nearshore waves, unstructured WAVEWATCH-III (WW3) model was implemented with and without vegetation along the coastal belt. The simulated wave results (wave height and period) for the year 2017 were validated with buoy measurements (Nausicaa buoy in Cesenatico), which revealed that the model could reproduce the wave parameters at the buoy location with sufficient accuracy. To include the NBS as a promising mechanism for wave attenuation, the WW3 model was improved by incorporating the modified bottom dissipation stress due to submerged vegetation. The Zostera marina seagrass species selected for the coast was applied in different landscape designs across the coast. A combination of broken stripes and clusters of vegetation were seen to be highly capable in reduction of wave energy at the coast in comparison to other designs. This study points out to the high demand on coastal remote sensing, as an information provider for seagrass monitoring such that the factors causing a decline in seagrass at a coastal location can be identified and addressed with immediate solutions.

Keywords: Nature-based solutions, marine seagrass, storm surge, WW3, Zostera marina, remote sensing.

Advancing predictions of nearshore processes within coastal ecosystems

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Coastal ecosystems, such as coral reefs, mangroves, seagrass meadows and salt marshes, play a dominant role in shaping nearshore processes over a large portion of the world's coastline. Due to this capacity to naturally mitigate coastal flooding and erosion, the active use of such ecosystems within nature-based coastal protection initiatives is also being increasingly advocated. Despite the growing need to accurately predict how ecosystems modify nearshore processes, there still remain many challenges when predicting ecosystem-flow interactions that arise from diverse and complex properties of the organisms comprising ecosystems (e.g. three-dimensional roughness properties, porosity, flexibility, etc.). With existing theory and models for predicting nearshore processes having historically been developed and validated on sandy coastlines, as a consequence, there is usually much greater uncertainty in predictions of e.g. coastal hazard risk for coastlines fronted by ecosystems. With a focus on wave-driven nearshore processes, in this presentation I will provide an overview of recent research that is helping to improve our understanding of hydrodynamic interactions with ecosystems across a range of scales, from small-scale wave-canopy interactions to the dynamics of larger-scale wave transformation across ecosystems.

Coastal Modelling & Down-scaling

Wed 24th March 11:40-16:30

Characterizing the signature of a spatio-temporal wind wave field

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Jeseon Yoo (KIOST)
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This study aims at characterizing the distinctive features of a spatio-temporal random, moving, nonlinear wave surface. We analyze wind-generated 3-D wave fields observed during the passage of an atmospheric front, which led to a wide directional spreading of wave energy. Data were acquired from the Ocean Research Station Socheongcho-ORS (Yellow Sea) with a stereo wave imaging system. They include 2-D + time measurements of the sea surface elevation with high spatial and temporal resolution over a swath larger than any previous similar deployment. We examine the shape and the nonlinear properties of the 3-D wavenumber/frequency wave spectrum, and the characteristic spatial, temporal and spatio-temporal length scales of the wave field. We then focus on analyzing the probability of occurrence and the spatio-temporal size of the rogue waves we identified in the data. In particular, we provide for the first time an empirical estimate of the extent of the horizontal sea surface spanned by rogue waves. We also propose and assess a novel strategy to determine from the 3-D wave spectrum the vertical current profile, to be then used to map the spectrum on intrinsic frequencies.

HyWaves: A hybrid method to downscale swells in small Pacific islands

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Accurate wave hindcast and forecast systems are essential to reduce the vulnerability of Small Pacific Islands regularly exposed to distant-source swells inundation. Available global databases or buoy observations are usually the hydraulic boundary condition for the dynamic downscaling. However, simulating wave spectral energy from deep water to the continental shelf can be computationally expensive, being useful to approach this problem with hybrid (i.e., dynamical and statistical) methods.
Downscaling techniques frequently use the limited extend of information contained in the aggregated parameters of the directional spectra. This approach is especially unsuitable for coastal settings where concurrent seas and swells approach from different directions, and therefore, the average bulk parameters (e.g., Hs, Tp and Dir) can lead to unrealistic modeled results.
To overcome these limitations, a hybrid method (i.e., HyWaves) is proposed to downscale large-scale multimodal wave conditions by considering the characteristics of the individual wave systems. The methodology consists in 1) aggregate by directional sectors all the spectral wave energy surrounding the study site to minimize the shadowing effect produced by its own land presence.; 2) select representative cases based on MDA (Maximum Dissimilarity Algorithm); 3) dynamically downscale individual wave systems with the numerical wave model SWAN; and 4) reconstruct the multivariate series at particular points close to the coast using Radial Basis Functions (RBF) interpolation technique (Camus et al. 2011).
This general framework can be applied to both historical and emulated wave datasets, making it an efficient tool for risk management and the development of early warning systems, which has been highlighted as a current need for many Pacific Islands (Winter et al. 2020). HyWaves has been successfully validated on different small islands in the Pacific region (e.g., Roi-Namur, Kwajalein, Majuro, and Guam), demonstrating the flexibility and robustness of hybrid methods to improve our understanding of wave climate in small islands.

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The contribution of wave setup to sea-level variations: from the surfzone to lagoons and estuaries

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Wave setup corresponds to the increase in mean water level along the coast associated with the dissipation of short-waves. This process is of key importance for coastal dynamics, as it contributes to storm surges but also to the generation of bed-return flows, a process responsible for coastal erosion during storms. Although wave setup is overall well explained for several decades by the divergence of the momentum flux associated with short waves in the surf zone, several studies reported substantial underestimations along the coastline when using classical

2DH models. In this presentation, we first show that the accurate computation of wave setup requires that the dissipation of short waves is adequately reproduced, which is not the case at gently sloping beaches when using spectral wave models with default parameters. We also show that the 3D circulation driven by short waves in surfzones can contribute to wave setup, particularly when the sea-bottom is steep. Finally, we show that wave setup can extend spatially outside surfzones, such as in shallow coastal lagoons and even in large estuaries.

Monitoring the topography-bathymetry continuum from space

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With a large part of the world's population residing in coastal areas, and largely depending on the coastal environment, monitoring natural and human-induced coastal changes are paramount to understand the dynamic and vulnerability of these coastal systems/communities. To understand changes in coastal areas, e.g. environmental and social resilience to environmental change, local measurements are inadequate. Such large-scale issues can only be addressed with perhaps less accurate but large scale measurements from space. Considering vulnerability or exposure to coastal flooding, both the bathymetry (underwater) and topography (above water) are vital boundary conditions to understand and accurately estimate impacts on short (storms) and long (inter-seasonal) time-scales. In this work, we estimate the coastal bathymetry and topography with the optical VENµS satellite for every single overpass at the Field Research Facility of the US Army Corps of Engineers at Duck, NC. The experimental VENµS satellite enables estimation of the topography and bathymetry by two repetitive identical images with a small time-lag. This capability proofs to result in topographies with a few meters accuracy and the bathymetry estimation is at best a few decimetres accurate. As a base for future Earth Observation missions such as Landsat or Sentinel 2, VENµS shows that higher resolution imagery (5 m), repetitive bands and a revisit time of only 2 days, enables unprecedented land/sea monitoring.

Wave observations project on the west coast of Ireland

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Initially, the Wave Obs project started as an alert service for the engineering team of the HIGHWAVE project located in the West of Ireland. The idea was to obtain the weather and sea state forecast for the next few days, so that instrument deployment and other experimental activities could be planned. The first record was made on 12 January 2020, when storm Brendan was approaching Ireland. Since then the scope of the project has developed in all areas. As of today, Wave Obs have a daily record of forecasts from different models, including wind, waves, precipitation and other meteorological variables. In addition, four buoy campaigns have been organised. Two spotter buoys were deployed in August - October 2020 (Explorer) and June - September 2020 (Wanderer) in the area of interest. The two buoys are collecting data at present again - November 2020 deployment (Wanderer), December 2020 deployment (Explorer). This collected set of observations and forecast is currently being postprocessed, inspired by the work by Raftery (2005) on weather forecasts.
Future plan is to use this information as a baseline for developing forecast 'rating' and developing our own sea state forecast. This is part of HIGHWAVE mission "to develop an innovative approach

to include accurate wave breaking physics into coupled sea state and ocean weather forecasting model". Wave breaking is affected by environmental variables, and we have to look at how wind and rain affect wave breaking. The records from Wave Obs will allow to include these empirical measurements in the numerical models, to make them more accurate and close to the real-life ocean.

Statistical downscaling of the significant wave height

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Long-term climate characterization of sea state parameters, such as the significant wave height, is key for a wide number of maritime activities. General Circulation Models (GCMs) are indeed the main tools that provide future projections of atmospheric variables. However, on the one hand, these models generally do not provide ocean sea state parameters and on the other hand, GCMs provide simulations with coarse spatial resolution.
Due to their low computation cost, statistical downscaling models are used to construct a link function between large-scale and local-scale variables. At a given time, the sea state is characterized by a composition of a wind sea and swells. The wind sea is generated by local wind whereas swells are generated and propagated over large distances. As a result, statistical downscaling models have to take into consideration both wave systems. Therefore, given the non-instantaneous and-local relationship between wind and waves, more attention has to be given to the spatiotemporal definition of the predictors.
In this study, a transfer function between the atmospheric wind data and the significant wave height is constructed. The spatial coverage of the atmospheric predictors is defined based on the assumption that waves travel along great circle paths. Based on the same assumption, the wind components at each grid point are projected into the bearing of the target point in a great circle path. Subsequently, the temporal coverage of the predictor is defined by two parameters called travel time of waves and time window size, using a fully data-driven approach. Afterward, the generalized ridge regression is used to construct the link function between the predictor and the predictand.
The validation analysis proves the model's skill in predicting wave climate. Furthermore, the resulting model coefficients are spatially smooth making the wind-waves transfer function physically interpretable.

Significant wave height simulation using machine learning and remote sensing for offshore wind farms

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Significant wave height simulation is necessary for planning of maintenance operations of offshore wind farms. Subject to wave forecasts, 'go / no go' decisions are made on all operations and maintenance activities in offshore windfarms, in the days and hours preceding the mission. In this work a machine learning methodology was developed to extract significant wave information from satellite images. Synthetic aperture radar images, from European Space Agency Sentinel-1 satellites, were used together with CEFAS Wavenet wave buoy data from around the UK are used to train a set of artificial neural networks to predict sea state conditions. The trained networks were shown to provide an effective method for the estimation of the significant wave height having an r-squared of 0.89. The methodology enables information on the spatial distribution of wave height in very high resolution to be obtained. Burbo Bank and Burbo bank extension wind farm locations were further examined to understand the impact infrastructure on wave propagation and compare results with the higher-resolution, publicly available numerical model supplied by Copernicus (CMEMS-NWS-0.016°). Results had similar accuracy to CMEMS-NWS-0.016° model, but in higher-resolution which enable us to examine the significant wave height at almost a point location. This model can help towards improving downscaling of general sea state forecasts, locating hotspots of different wave height properties and correct prioritization of maintenance jobs in offshore wind turbines, reducing their maintenance cost.

A comparison between four different wind-wave hindcasts computed by forcing the WaveWatch III model

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Here, we present four global wind-wave hindcasts based on the third-generation spectral wave model WAVEWATCH III forced by ERA5, ERA-Interim, MERRA2, and NCEP CFSR reanalyses for 1980-2019. Absolute magnitudes of both 10-m wind speeds and significant wave heights are the largest in the CFSR reanalysis and CFSR-based hindcast, particularly in the extratropical regions. Hindcasts based on ERA5, ERA-Interim, and MERRA2 agree that a large part of the global ocean is characterized by statistically significant annual positive trends in wave heights from 1980-2019. The CFSR-based hindcast is generally consistent with other datasets in terms of annual linear trends in mean and extreme wave heights over the large regions of the Northeast Atlantic, Northeast Pacific, and South Indian Oceans; however, positive trends with lower magnitudes are seen in the Southern Hemisphere, and substantially stronger negative trends are seen in the Northern Hemisphere in comparison with other reanalyses. Magnitudes of long-term linear trends in significant wave heights in ERA5, ERA-Interim, and MERRA2-based hindcasts are more consistent than trends in 10-m winds in atmospheric reanalyses. Areas with significant linear trends in wave heights generally coincide with those for wind speeds; however, they have larger spatial coverage. The interannual variability in 10-m winds is the most consistent across different reanalyses in the eastern midlatitudes of both hemispheres and the least consistent in the equatorial Atlantic and Indian Oceans. The performed hindcasts contribute to the effort in understanding modern wave climate and in particular aid in constraining uncertainty in wave climate projections for the XXI century.

Seasonal to decadal scale wave induced shoreline changes along the Cameroonian coastline, Bay of Bonny (1986-2020)

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The Bay of Bonny along the Cameroon coastline is home to diverse ecosystems. It is under substantial pressure from large human activity, but remains very little studied, like much or the Gulf of Guinea. In order to understand its long-term shoreline variations and the role the wave regime plays in the evolution of the coastline, a study was conducted on the basis of optical image archives from Landsat 5/7/8 and Sentinel-2A/2B satellite missions acquired between October 1986 and May 2020, coupled with daily ERA-Interim wave re-analysis data covering the period from January 1986 to August 2019. Overall, the results show that the evolution of the coast is highly variable in space and time, as indicated by different levels of erosion (30.55 %), and accretion (27.7 %) on the decadal-scale, with the most significant variations occurring in estuarine areas. Nevertheless, 41.75% of the Cameroon shoreline remains stable during the study period. Three main periods during which the coast underwent significant changes a different location were identified, reaching a retreat rate of up to -10 m/year in the northern section during 1986-1999. The wave regime at the coast decreases from the southern part towards the north due to the shape of the coast and the presence of Bioko island. The annual trend of significant wave heights anomaly of the five segments (-5.6 to -4.1 mm/year) with wave height maxima of 1.46 ± 0.65 m observed in the summer months (July-August). Monthly shoreline changes inversely correlated with the wave climate in some segments. The relatively strong local influence of erosion and accretion caused by natural dynamics (waves, drift currents) associated with the disproportionate presence of estuaries (Wouri, Rio del Rey, Sanaga) accounts for 76.3% of the observed variability, as indicated by analyses of eigenvalue orthogonal decomposition (mode 1, Empirical Orthogonal Functions). These characteristics explain a complex pattern of coastline changes with an almost continuous retreat shoreline during the period 1986-2013 and a reversal in trend towards accretion during the period 2013-2020. EOF mode 2 explains 23.7% of variability associated with the gradual overall decline from south to north over the study period.

Visual wave observations for sea state analysis: possibilities and limitations

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The VOS data have three core advantages that make visual wave observations applicable for sea state research. These strengths include worldwide coverage, the fact that wind sea and swell parameters – heights, periods, and directions, – are estimated separately, and the continuity of time series of wave characteristics (1869 onwards, the longest of all datasets). The use of VOS data

in today's global wave analysis is, however, limited by their space-time inhomogeneity, making researchers choose altimetry measurements and/or model simulations instead.
VOS data are consistent with the alternative datasets on climatological scales while mostly failing to match individual records at a given point. The causes of this puzzling duality are discussed in the frame of the VOS – altimetry – WW3 comparison. The newly developed version of VOS wave database for the period 1970-2019 is presented in NetCDF format (https://sail.ocean.ru/gwdb/).

Retracking Sentinel-3 SAR altimeter waveforms with the ACDC algorithm

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In this work, a Delay-Doppler Processor for satellite altimetric data has been adjusted to include the Amplitude Compensation and Delay Compensation (ACDC) algorithm (Ray et al., 2015b) with the aim to improve the precision of geophysical parameter estimates retrieved from Sentinel-3 altimetric echoes over open ocean. This retracking algorithm, previously evaluated with synthetic aperture radar (SAR) mode oceanic CryoSat-2 data set (Makhoul et al., 2018), is based on a lower order approximation of the analytical model of the open ocean SAR altimeter backscattered power waveform developed in (Ray et al., 2015a). Two processing steps are applied to the Delay-Doppler map after a number of corrections, which correspond to the compensation of the variation in the maximum power of each beam (Amplitude Compensation) and the range-dilation of power in each Doppler beam with respect to the zero Doppler one (Dilation Compensation). A multilook echo is then obtained by averaging all power waveform samples in the resulting ACDC Delay-Doppler map, from which oceanic geophysical parameters can be inferred in a fitting procedure. The performance of the algorithm is evaluated in terms of its precision against an in-house conventional SAR altimeter retracker (Ray et al., 2015a) via the processing of Sentinel-3 data, showing a noticeable reduction of noise in the retrieved oceanic geophysical parameters.

Reliability of extreme significant wave height estimation from satellite altimetry and in situ measurements in the coastal zone

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Measurements of significant wave height from satellite altimeter missions are finding increasing application in investigations of wave climate, sea state variability and trends, in particular as the means to mitigate the general sparsity of in situ measurements. However, many questions remain over the suitability of altimeter data for the representation of extreme sea states and in particular applications that examine extremes in the coastal zone. In this paper, the limitations of altimeter data to estimate coastal Hs extremes (<10 km from shore) are investigated using the European Space Agency Sea State Climate Change Initiative (CCI) L2P altimeter data v1.1 product recently released. This Sea State CCI product provides near complete global coverage and a continuous record of 28 years. It is used here together with in situ data from moored wave buoys at a number of sites around the coast of the United States. The limitations of estimating extreme values based on satellite data are quantified and linked to several factors including the impact of data corruption nearshore, the influence of coastline morphology and local wave climate dynamics and the spatio-temporal sampling achieved by altimeters. The factors combine to lead to considerable underestimation of estimated Hs 10-yr return levels. Sensitivity to these factors is evaluated at specific sites, leading to recommendations about the use of satellite data to estimate extremes and their temporal evolution in coastal environments.

Waves in the marginal ice zone: insights from in situ observations and modeling

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Recent field campaigns provide rare measurements of ocean surface waves in partial sea ice cover. As the retreat of Arctic sea ice enables increased wave activity, wave-ice interactions will play an elevated role in the Arctic climate system. Current research is focused on understanding how waves and sea ice affect each other and including wave-ice physics in long-term climate simulations. Here, we interpret a collection of in situ observations from moorings and freely-drifting buoys spanning 2012-2019 in the Beaufort Sea that report wave activity beyond 100 kilometers inside the sea ice edge. Using satellite-derived ice concentrations, we group the in situ measurements based on distance from the ice edge and compare with a recent global climate model experiment that includes coupled interactions between waves and a sea ice floe size distribution. Comparisons of significant wave height, wave spectra, and nondimensional scaling for wind-generated waves illustrate how the wave field is altered by partial ice cover. These analyses highlight the impact of uncertainty in wave-ice physics on modeling the marginal ice zone, motivating further model development and future observational campaigns.

Recent developments in multi-mission altimeter sea state products: The ESA CCI dataset v2

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In 2018, the European Space Agency launched the Sea State Climate Change Initiative (CCI) project in the context of the CCI+ program. The objective of this 3-year initial phase is to reprocess and analyze sea state records from satellite altimeters (all ESA missions and the Jason series since 2002) and radar imagery (all wave mode from ERS to Sentinel 1), complemented and validated with in situ data, in order to provide the first sea state Climate Data Record needed for climate research. A primary concern of the project is the accuracy and stability of the multi-mission data sets. Algorithm developments are therefore carried out to ensure the best possible quality of wave products with a particular focus on consistency. These developments includes the reprocessing of conventional and Delay-Doppler altimeter missions with new waveform retracking algorithms, data editing and filtering methods for removing outliers and increasing the signal-to-noise ratio, mission calibration against quality-controlled in-situ measurements and mission inter-calibration at mission's crossover needed to ensure long-term consistency. In this poster, we present the current state of these developments in the new ESA CCI dataset version2, as well as a comparison of the performance with respect to the version1 dataset.

Marine Energy Sector- Industry use of wave data

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Wave data is critical to the safe and efficient design, installation and operation of marine energy sector assets. The data utilised to support these activities will vary over the lifetime of the project to meet the needs of the application. Applications include initial resource assessment (wave power), pre-licensing assessment to inform financial assessment, environmental assessment, preliminary engineering, final engineering, installation planning and execution, operation and maintenance planning and execution and repowering/decommissioning.
Each of the applications needs data of potential differing accuracy and duration. How the wave climate is characterised will also differ for each application. Spectral characterisation may be required for some applications whereas others require information on derived wave parameters such as directionality, spreading, sea and swell heights/periods.
The presentation will explore the types of wave data utilised for a number of the applications, and how the European Space Agency SeaState_cci may contribute to the enhancement of wave data available to support the Marine Energy Sector. This will be placed in the context of the value of the Marine Energy Sector, and how this sector can contribute to reducing global emissions.

Operational Forecasting of Winds and Waves at the NOAA Ocean Prediction Center

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The NOAA Ocean Prediction Center is responsible for issuing warnings and forecast for Metarea IV (North Atlantic) and XII (North Pacific) and partially meets the U.S. responsibilities under SOLAS. The OPC relies heavily on remotely sensed wave heights from satellite altimeters, moored buoys, and drifters and predictions and analyses from numerical models. Wave spectra data from observed sources remains an underutilized resource for data assimilation and forecast verification. This keynote will discuss operational wave prediction at NOAA from the coast to deep ocean, present day challenges, and future opportunities such as modernizing marine weather services in a digital age. Also, there will be discussion on the use of Automatic Identification System (AIS) from ships in near real time to better understand the impact environmental conditions have on safe and efficient passages.

Wind waves and coastal risk in Emilia Romagna Region: Monitoring and forecasting

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Arpae and ISPRA deeply collaborate in operational activities and research, involving protection, development and enhancement of coastal and marine environment. They provide technical and scientific support to policy makers and stakeholders for the environmental governance, through the collection, processing, management and dissemination of meteo-marine in situ and forecasting data.
ISPRA coordinates the National System of Environment Protection Agencies (SNPA) and has competences and responsibilities in the physical monitoring of the sea state, performed through national meteo-marine observation networks and forecasting operational systems, and it also has a long and deep experience in meteo-marine data analysis.
The Hydro-Meteo-Climate Service of Arpae Emilia-Romagna (Arpae-SIMC) is also the regional Civil Protection Support Centre as well as Centre of Competence for the meteorological and marine modelling for the Italian National Civil Protection system since 2005. Arpae daily runs an operational meteo-marine-coastal modelling chain that provides forecasts at different horizontal and temporal resolutions. These forecasts provide supporting information for navigation purposes as well as flood forecasting and the development of risk maps. As to define the risk thresholds required by the Civil Protection bulletins' daily emissions, in situ data and forecasting results have been used. Moreover Arpae manages since 2007 a wave buoy deployed just offshore the Municipality of Cesenatico, collecting real time data of physical parameters. Wave time series play a very useful and crucial role as for model calibration and validation as well as for statistical analysis and sea state climate characterization in the Emilia-Romagna region.
A detailed description and statistical analysis of wave data collected from 2007 to 2019 by the Cesenatico buoy is presented, with a focus on storm analysis, wave climate, return periods and joint distribution analysis.

The impacts of the sea on shipping operations and emergency response

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The Shipping industry has been evolving for hundreds of years but the environment in which it operates has remained relatively stable. The anticipated sea conditions have a significant impact on the design and structure of vessels as they are built. The variation in sea conditions impact the operations of vessels and has constantly provided challenges for seafarers for which they have had to continually adapt. This presentation explores the impacts of the sea on the following operational areas:

- Weather routing for shipping, the benefits, efficiencies and emissions. How this could change as new designs utilising wind technology are developed,
- Navigational safety (caused by visibility, vessel manoeuvring control and motions). Manoeuvring around Tropical Revolving Storms,
- Vessel safety (hull forces, Synchronous and Parametric rolling, Heavy Weather Damage),
- Shipping/Cargo operations impacted by weather (STS/Port Operations/cargo loss) etc, impact of sea temperature during floating storage of crude oils,
- Personal safety and fatigue caused by the impact of high sea states,

- Oil Spill and emergency response pros and cons in relation to sea state.

The industry has developed ways to adapt and respect the power of the oceans. As evolving vessel design pushes the boundaries of size and capacity, the demand for accurate data sources increases. Whilst taking all of this into consideration, there still remains a focus on seamanship and the skills of the crew who ultimately pay the price if something goes wrong.

Introduction to the CCI Tool

Sophie Hebden (ESA)

Abstract to follow

Partners