□ SCIENTIFIC REPORT

The main purpose of this STSM was to establish collaboration between the Estonian Marine Institute (EMI) and the Marine Institute in Ireland (MI) as well as to transfer knowledge between both institutions in the field of Earth Observation and marine optics. As an island nation the coastal ocean around Ireland plays an important role in the environmental, social and economic field. For this reason Ireland has a great involvement in the study and development of marine applications (e.g. real-time observations, marine forecast, seabed mapping or oceanography). MI is the Irish national agency for advice and implementation of marine research, technology, development and innovation (RTDI) as well as for marine research services that critically inform policy objectives, management and sustainable development strategies for marine resources. For this reason, this institution plays a relevant role in the development of marine applications. However, in spite of the advantages of remote sensing to provide information of marine environments, in the case of Ireland their use is not well established. The main engagement in the remote sensing field is by Universities, but only 17% of the activity relates to marine and coastal fields (Casal and Furey, 2014). Since 2014 MI is trying to build a remote sensing capacity that produce new data for marine and coastal ecosystems as well as promote use of this data as complement in ocean modelling, fisheries or coastal management. For this purpose an effort in attracting remote expertise to MI is being carried out and this STSM contributes in a major way to this fact. Taking into account this background the STSM was focused in the following tasks:

Task 1 Long term series of chlorophyll-a for the coast of Ireland. Chlorophyll-a concentration can be considered an estimation of phytoplankton biomass as it constitutes their main photosynthetic pigment. Phytoplankton regulate carbon dioxide and oxygen levels in the ocean and atmosphere and are the base of marine food chain. They sustain life in the oceans and their monitoring supports fisheries, aquaculture and marine resource management. Climate change with its increasing water temperatures and ocean acidification due to increasing CO_2 absorption is affecting phytoplankton, as eutrophication from land run-off. In Europe, the Water Framework Directive and the Marine Strategy Framework Directive impose the requirement on member states to routinely measure chlorophyll-a concentration and the clarity of water (turbidity) for assessment and monitoring of the Good Environmental Status by 2020.

During the STSM the time series analysis of the chlorophyll-a database for Irish waters was evaluated. The time series of data can serve to understand the past and predict the future trends of chlorophyll and consequently phytoplankton, enabling managers or policy makers to make properly informed decisions. The chlorophyll-a database (1998-2013) created using the ESA Ocean Colour Climate Change Initiative project (CCI) was analysed. In spite of this project provides merged products using different ocean colour sensors a problem with cloud coverage was detected in winter months (Fig.1). The areas of West of Scotland and Celtic Sea the phytoplankton peak takes place in spring and autumn while the Irish Sea presents much higher chlorophyll concentrations without any particular pattern due to the strong influence of runoff from rivers (Fig.2). The analysis of the time series could be done between March and October covering the two growing peaks and avoiding the cloud coverage especially important in winter months. As a first step , previous to the time series analysis, comparison with in situ chlorophyll measurements when possible was decided ensuring the quality of the products.

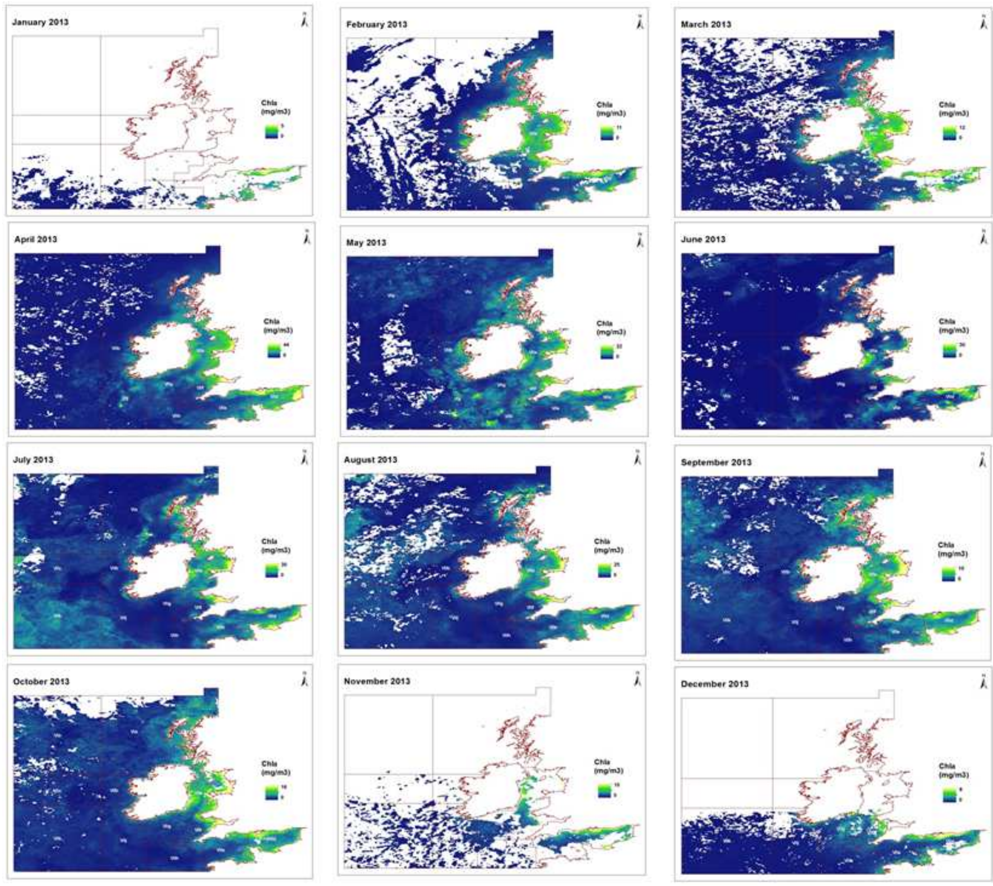

Fig 1 Monthly Chl-a concentration (mg/m3) for the year 2013

The analysis of the time series will be carried out using R software and seasonal effects, trends and random noise will be considered taking into account the specific packages. The use of an additive model could be a good approximation as the magnitude of the seasonal fluctuations not varies with the level of the time series.

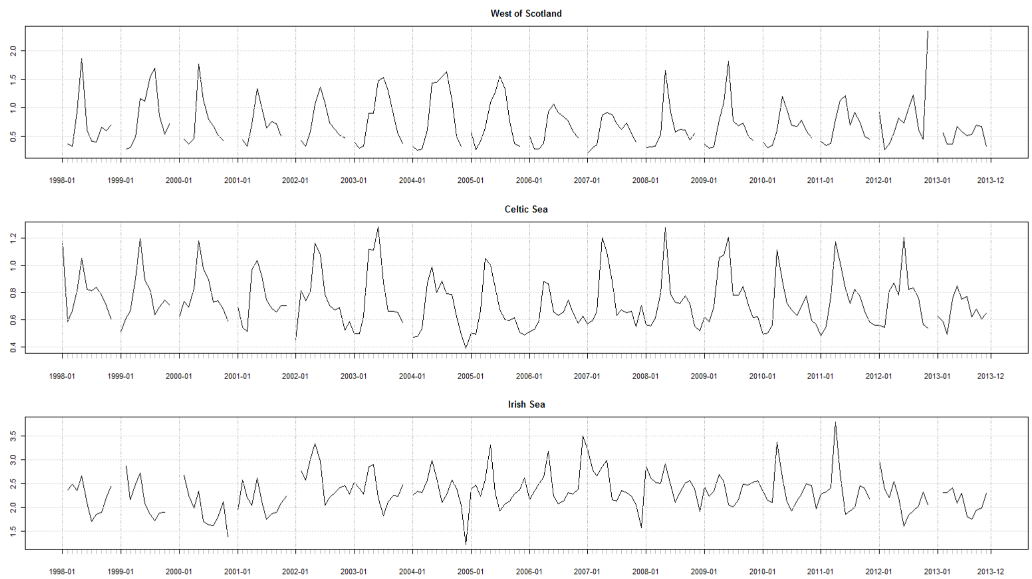

Fig 2 Chlorophyll-a concentration for the three main areas of study: West of Scotland, Celtic Sea and Irish Sea

The results obtained by analysis of the time series will be discussed with Dr. Kutser who will help to evaluate and interpret them and will contribute to the scientific publication resulting from the analysis of these data.

Task 2 Phytoplankton blooms. This task was the main activity discussed in this STSM with special focus in the Harmful Algae Blooms (HABs) produced by *Karenia mikimotoi*. The dinoflagellate *K. mikimoitoi* is a high biomass HAB species that has been identified in harmful concentrations in Irish waters (Silke, 2005). *K. mikimotoi* blooms can result in mortality of farmed fish and other marine animals through the production of haemolytic cytotoxins and the hypoxic conditions often created by high cell densities. As these blooms strongly modulate the colour of surface waters space-based platforms provide a robust means to reveal synoptic patterns in bloom formation and transport at various temporal and spatial scales. Due to this fact the number of studies to detect *K. mikimotoi* blooms has increased in the last years (e.g. Siswanto et al., 2013; Kurekin et al., 2014; Dwivedi et al., 2015). However, the new satellites Sentinel-2 (launched in 2015) and Sentinel-3 (expected launch February 2016) will offer improved spatial and temporal resolution with potential applications in the detection of HABs.

The images of Sentinel-2A were made available for users the 3rd December and although it was firstly designed as a terrestrial sensor the scientific community is reporting many potential applications in coastal and inland waters. For this reason the potential use of Sentinel-2 for the detection of *K. mikimotoi* blooms was evaluated. As a first step a bibliographic research was carried out during the STSM with the aim of stablishing the spectral characteristics of *K. mikimotoi*. In this quick bibliographic review was found that red-tide-type phytoplankton species, such as dinoflagellate *K. mikimotoi*, absorbs radiations in the blue and lower green regions (400-500 nm) in the blue and lower green regions (400-500 nm) of the visible spectrum while strongly reflecting radiations in the yellow region (570-580 nm) (e.g. Sasaki et al. 2008; Takahashi et al., 2009; Blondeau-Patissier et al., 2014). These assumptions are coincident with a specific study where the absorption spectra of *K. mikimotoi* were determined taking into accounts several nitrate and irradiance conditions. According to this study carried out by Stæhr and Cullen (2003) *K. mikimotoi* presents a high absorption between 410 and 460 nm approximately and a secondary absorption peak at around 670 nm. Conversely the absorption is much lower between 550 and 650 nm. These authors demonstrated that the absorption peaks are consisted with different environmental conditions at they vary in magnitude but not in location with the variation of nitrates and irradiance (Fig. 3).

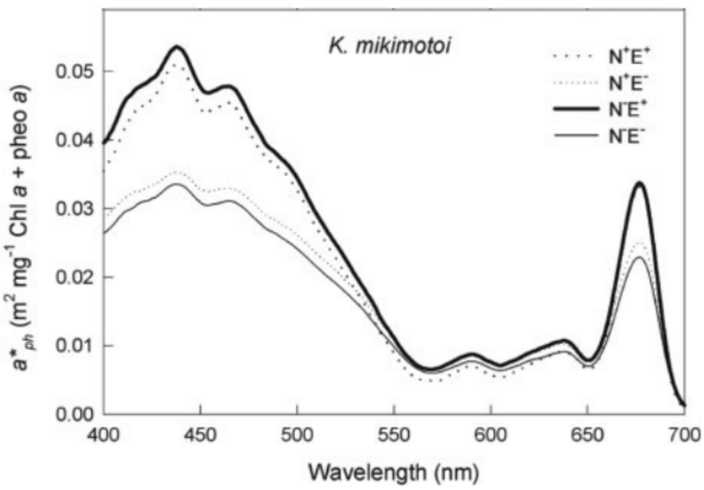

Fig 3. Acclimation of spectral Chl-a specific light absorption of K. mikimotoi exposed to different levels of nitrate (N) and irradiance (E) in a semi-continuous growth experiment. Each spectrum is the average of two replicates (Taken from Stæhr and Cullen (2003)

The comparison of these peaks and shoulders with the spectral bands of Sentinel-2 and taking into account its temporal (5-3 days depending on latitude) and spatial (10-20 m) resolution suggest that this sensor could be potentially used to detect and study *K. mikimotoi* blooms in Irish coast. For this reason, the second step carried out in the STSM was become familiar with the process of search, visualisation and download of Sentinel-2 images.

A strong *K. mikimotoi* was happened in the SW coast of Ireland during the 35th week of this year (23rd-29th August). At that moment Sentinel 2A was already registering images however images previous to 28th November are not available at the moment due to a reprocess analysis (Fig.4). Because of this issue other images over the coast of Ireland were searched but it was not possible to find one image free of clouds or with a low cloud coverage percentage. For this reason, the training exercises were carried out using a Sentinel-2A image taken over Estonia.

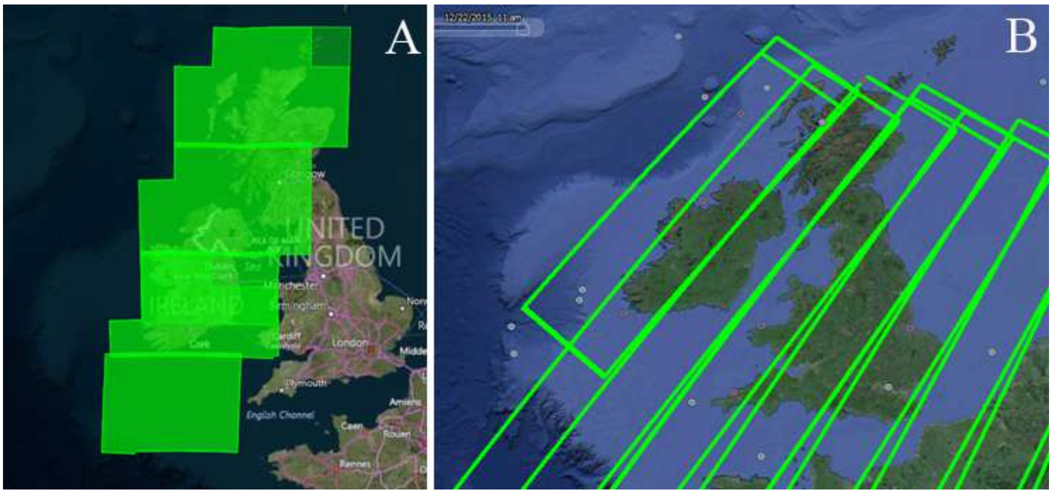

Fig 4 A) Sentinel- 2A images over the coast of Ireland on 2nd December 2015. B) Sentinel-2A coverage expected by 22nd December 2015

These training exercises consisted of the visualization of the image using SNAP software and the familiarisation with the basic processing tools. This analysis showed a promising use of these images in Irish coast not only for the detection of *K. mikimotoi* blooms but also for other coastal applications such as benthic mapping, water quality or coastal management. During the STSM a future collaboration for the assessment of Sentinel-2 data for detecting *K. mikimotoi* blooms was established.

Task 3 Radiometric Field campaigns. The MI has recently acquired hyperspectral radiance and irradiance sensors Trios-RAMSES. During the STSM protocols for using this equipment were discussed. EMI has a broad experience in the use of radiometers in the field and the recommendations and tricks given were much appreciated. Some exercises were also carried out to become familiar with the specific software and some configuration advises were given as well. Moreover, some training using some radiance and irradiance spectra registered by EMI was also carried out to learn about the processing and post-processing steps of radiometric data registered by this kind of sensors (Fig.5).

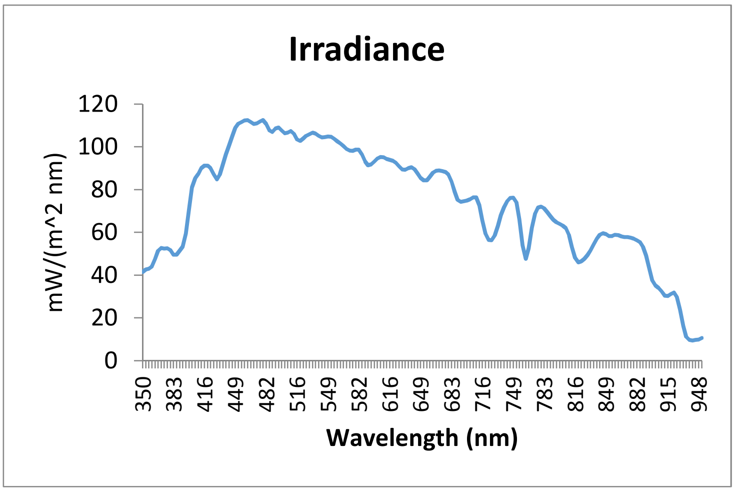

Fig 5 Example of an irradiance spectrum once it has been processed

Task 4 MERIS Validation and Algorithm 4th reprocessing - MERIS Validation Team (MVT). The STSM was coincident with the MERIS Validation Team (MVT) meeting (9^{th}-11^{th}) held and organised by Tartu Observatory (Tartu-Estonia). Taking the advantage of this opportunity attendance to some of the lectures was decided. The lectures were related with the variability and uncertainties of optical sensors such as radiometers and scattering meters and how their inherent variability can influence the measurements especially on inland and coastal waters. Atmospheric correction is also complex on water environments and some of the lectures were focus on how to face challenges. The lectures and following discussions were very useful in consideration for the future radiometric campaigns that MI will carried out in Irish waters. The attendance of this meeting allowed to extent MI networking as result of the interaction with members of referential institutions in the remote sensing field such as EUMESAT, Brockmann Consult, ARGANS, Tartu Observatory or JRC. Of special interest was the interaction with Dr. Ewa Kwiatkowska from EUMESAT, one of the persons in charge of the Sentinel-3 Valitation team (S3VT) for ocean colour. As result of this interaction the MI is evaluating to take part as member in this team where Ireland is not represented at the moment. The new Sentinel-3 is expected to be launched in January 2016 and will provide essential data for marine environments at high spatial and spectral resolution. Becoming part of S3VT would be very beneficial for Ireland to learn from experienced remote sensing groups around Europe and internationally. Moreover, it would promote the engagement and visibility of Ireland in the remote sensing community fostering new collaborations.

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