Accessing and developing the required biophysical datasets and data layers for Marine Protected Areas network planning and wider marine spatial planning purposes

Report No 20 Task 2F: Oceanic thermal fronts from Earth observation data - a potential surrogate for pelagic diversity

Summary Document

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Executive Summary

The UK is committed to the establishment of a network of marine protected areas (MPAs) to help conserve marine ecosystems and marine biodiversity. MPAs can be a valuable tool to protect species and habitats and can also be used to aid implementation of the ecosystem approach to management, which aims to maintain the ‘goods and services’ produced by the healthy functioning of the marine ecosystem that are relied on by humans.

A consortium\(^1\) led by ABPmer have been commissioned (Contract Reference: MB0102) to develop a series of biophysical data layers to aid the selection of Marine Conservation Zones (MCZs) in England and Wales under the Marine and Coastal Access Act and the equivalent MPA measures in Scotland. Such data layers would also be of use in taking forward marine planning in UK waters. The overall aim of the project is to ensure that the best available information is used for the selection of MPAs in UK waters, and that these data layers can be easily accessed and utilised by those who would have responsibility for selecting sites.

The Marine and Coastal Access Act allows for the designation of MCZs for biodiversity features of interest. To deliver this requirement, the project has been divided into a number of discrete tasks, one of which is to investigate the development of a marine diversity datalayer. Following a review of approaches and proposed methodologies two potential approaches were identified, one through the use of oceanic thermal fronts from earth observation data to provide a potential surrogate for pelagic diversity and the second through benthic diversity layers. This document describes the former and is published as a summary document as the findings will be incorporated into a final report covering all aspects of the production of marine diversity datalayers.

\(^1\) ABPmer, MarLIN, Cefas, EMU Limited, Proudman Oceanographic Laboratory (POL) and Bangor University.
1 Introduction

1.1 Biophysical Data Layers Project

1.1 The UK is committed to the establishment of a network of marine protected areas (MPAs) to help conserve marine ecosystems and marine biodiversity. MPAs can be a valuable tool to protect species and habitats and can also be used to aid implementation of the ecosystem approach to management, which aims to maintain the ‘goods and services’ produced by the healthy functioning of the marine ecosystem that are relied on by humans.

1.2 As a signatory of the OSPAR Convention the UK is committed to establishing an ecologically coherent network of well-managed MPAs. The UK is already in the process of completing a network consisting of Special Areas of Conservation (SACs) and Special Areas of Protection (SPAs), collectively known as Natura 2000 sites to fulfil its obligations under the EC Habitats Directive (92/43/EEC) and EC Birds Directive. Through provisions in the Marine and Coastal Access Act Marine Conservation Zones (MCZs) may be designated in English and Welsh territorial waters and UK offshore waters. The Scottish Government is also considering equivalent Marine Protected Areas (MPAs) in Scotland. These sites are intended to help to protect areas where habitats and species are threatened, and to also protect areas of representative habitats. For further information on the purpose of MCZs and the design principles to be employed see http://www.defra.gov.uk/marine/biodiversity/marine-bill/guidance.htm Defra, 2009.

1.3 MCZ selection will be undertaken via a participatory stakeholder engagement approach. Four regional MCZ projects have been established to lead this process and are expected to be fully functional by early 2010. The full stakeholder engagement process is anticipated to begin in February 2010, continuing until the end of 2011. A formal public consultation is expected in 2012.

1.4 Selection of MPAs should be based on the best available information from a wide range of sources including biological, physical and oceanographic characteristics and socio-economic data such as the location of current activities. To ensure such data are easily available to those who would have responsibility for selecting sites Defra and its partners2 commissioned a consortium lead by ABPmer Ltd and partners to take forward a package of work. New Geographical Information System (GIS) data layers to be developed included:

- Geological and geomorphological features;
- Habitats and species of conservation importance;

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2 Joint Nature Conservation Committee (JNCC), Countryside Council for Wales (CCW), Natural England (NE), Scottish Government (SG), Department of Environment Northern Ireland (DOENI) and Isle of Man Government.
• Fetch and wave exposure;
• Marine diversity layer;
• Benthic productivity; and
• Residual current flow.

1.5 In addition to the development of data layers, there is a need to ensure such information can be easily accessed through a webGIS given the participatory nature of the MCZ process that is currently being planned.

1.6 This summary document provides a detailed description of the development of the oceanic thermal fronts from earth observation data providing a potential surrogate for pelagic diversity. This summary will be incorporated into the final marine biodiversity report when the benthic datalayer associated with this task becomes available.

1.2 Aims and Objectives

1.7 The work follows on from the study of the 'Development of a marine diversity data layer: review of approaches and proposed method', Report 2 of this project issued in September 2009.

1.8 The recommendations from the Phase 1 work have been taken forward in two parts one covering the benthic datalayer, which is under development and the second being the development of a pelagic layer.

1.9 This summary document provides a description of the methodologies used to develop the second theme, namely the production of a surrogate for a pelagic layer translated from ocean thermal fronts derived from earth observation data.

1.3 Format of the Report

1.10 The report comprises 7 main sections:

• Section 1 delivers an Introduction;
• Section 2 provides a background to the work;
• Section 3 describes the methodology used;
• Section 4 presents the results;
• Section 5 provides an interpretation of ocean front data layers and describes how to interrupt the findings;
• Section 6 presents the conclusions; and
• Section 7 lists the references.
2 Background

2.1 Our knowledge regarding diversity patterns of pelagic organisms is scarce though the role of diversity in mediating and stabilising ecosystem function (through, for example, biomass production and elemental cycling) is becoming increasingly apparent (Duffy and Stachowicz, 2006). The earlier review of methodologies for mapping pelagic biodiversity appraised a series of metrics spanning different levels of ecological organisation of the pelagic system (Jackson et al., 2009). These included:

i. Diversity measures for different system components including phytoplankton, zooplankton and fish;
ii. Satellite earth observation (EO) surrogate measures (thermal fronts, sea surface temperature (SST) and ocean colour); and
iii. Indicators such as pelagic megafauna (e.g. basking sharks, cetaceans), seabirds and pelagic fish spawning areas.

2.2 EO oceanic fronts were selected for development to represent the pelagic diversity data layer, and this summary note describes the techniques used to exploit a long time-series of EO SST data to map frequently occurring thermal fronts within UK waters. The methodology closely follows the approach proposed in the review (Jackson et al., 2009).

2.3 Unlike most terrestrial and benthic systems, the pelagic ecosystem is not restricted by biotope boundaries (reef edge, change in substrate) and is mobile, constantly changing. This variability is manifest at a variety of spatio-temporal scales: from species fluctuations driven by short-term changes (including weather); to seasonal cycles, inter-annual and long-term change (such as climate change). It was important that this data layer captured some of this variability, and so it was decided that front maps would be presented seasonally, with indications of both spatial and temporal variability.
3 Methodology

3.1 Detection of Thermal Fronts

The source of data for this frontal analysis was the Advanced Very High Resolution Radiometer (AVHRR) archive acquired by Dundee Satellite Receiving Station, has made several passes per day over the UK continuously since August 1981. The maximum spatial resolution is 1.1 km, sufficient for detection of all scales of fronts relevant to pelagic diversity, including mesoscale and near-coastal fronts. Ten years of data were processed to encompass the interannual variability, from December 1998 to November 2008. If required in the future it would be possible to process the entire archive (currently 28 years) to provide greater confidence in describing interannual variability and long-term trends.

![Figure 1. Schematic diagram of composite front map technique. 30 AVHRR SST maps (three shown) of the Irish shelf within a 7-day window are processed to detect front locations, which are then composited to calculate the mean frontal gradient $F_{\text{mean}}$, the probability of detecting a front $P_{\text{front}}$, and the evidence for a feature in proximity $F_{\text{prox}}$. These weighting factors are combined as the composite front map $F_{\text{comp}}$ to provide optimal visualisation of all oceanic features observed during the period.](image-url)

3.2 The first stage was to convert the raw (Level 0) infrared AVHRR data into SST maps (Level 2). Plymouth Marine Laboratory (PML) have developed automated processing systems to allow AVHRR infrared data to be calibrated into SST values, navigated, cloud-masked and mapped consistently for the UK region (Miller et al., 1997). For the 10 year sequence, over 30,000 AVHRR passes were processed, totalling 2.4 Terabytes of input data. The characteristics of the mapped UK Continental Shelf region are as follows:

- Coordinate range: 48 to 64.4 °N, -25 to 4 °E.
- Image dimensions: 1600 x 1658 pixels.
- Map projection: Mercator.
- Datum: Sphere (later converted to WGS-84 ellipsoid).
- Spatial resolution: approx. 1.2 km/pixel in N-S direction. E-W resolution varies from 1.1 to 1.3 km/pixel from the top to bottom of the region according to the Mercator projection.

3.3 The second stage was to detect ocean fronts on every individual SST scene and combine them to generate monthly front maps. Algorithms developed by PML enable fronts to be located accurately and objectively. The composite front map technique combines the location, gradient, persistence and proximity of all fronts observed over a given period into a single map (Miller, 2009): this often achieves a synoptic view from a sequence of partially cloud covered scenes without blurring dynamic fronts, an inherent problem with conventional time-averaging methods (Figure 1).

3.4 It is important to emphasise that: (a) front detection is based on local window statistics specific to frontal structures, not simply on horizontal SST gradients; and (b) fronts are not detected on monthly SST composites, but rather on individual SST ‘snapshots’ that reveal the detailed thermal structure without averaging artefacts. The detailed methodology has been recently published (Miller, 2009).

3.2 Improved Detection of Near-Coastal Fronts

3.5 The standard composite front map algorithm was designed for open ocean and shelf-seas fronts, and would not detect fronts within approximately 5 km of the coast. Improvements to near-coast front detection have been made through the development of a new smoothing filter as outlined below.

3.6 The front detection algorithm employed a fast median smoothing filter to pre-process the SST map both to reduce noise and to generate more realistic frontal contour curves. This standard median filter included zero values (indicating cloud or land) in calculations, and so the smoothed SST map tailed off in the pixels neighbouring land or cloud, resulting in weaker front detection for those pixels. The median filter was improved to omit missing values, which resulted in an increase in the detection of near-coastal fronts (Figure 2). The change also resulted in greater likelihood of front detection in particularly cloudy regions in which the majority of valid pixels over the month are close to cloud. However the improvement was not universal, and in some areas the detection appeared to be degraded, probably due to the reduction in the effective size of smoothing filter close to coast and cloud. However,
there remains a coastal limit of detection due to the cloud-masking of SST data. There is a genuine increased likelihood of cloud cover at the coastal zone; but also the automated cloud masking algorithms are careful to avoid sub-pixel cloud contamination by extending the masked region by at least one pixel width around the detected cloud. The cloud-masking usually treats cloud and land similarly as 'non-sea' pixels, and so the pixels neighbouring the coast will rarely remain unmasked.

**Figure 2.** Improvement to near-coastal front detection: (a)-(c): Enlarged sections of monthly front maps using standard median smoothing filter, red circles indicate fronts detected only using standard filter; (d)-(f) Corresponding sections using improved median smoothing filter, green circles indicate improved near-coastal front detection.
3.3 Front Metrics

3.7 The next stage of analysis was to aggregate the monthly front maps into seasonal front climatologies to identify strong, persistent and frequently occurring features. Such frontal systems could be key factors influencing the distribution of productivity and diversity. An algorithm has been developed and tested to perform this aggregation, and estimates the percentage of time a strong front was observed within each grid location.

3.8 Monthly front maps from December 1998 to November 2008, for an area encompassing the UK continental shelf were employed. For each grid cell, each month \( j \) and year \( i \) the following quantities are determined:

- \( n_{i,j} \) valid observation;
- \( x_{i,j} \) strong front, above a specified threshold;
- \( c_{i,j} \) pixel clarity: number of clear observations in that month;
- \( m_{i,j} \) number of satellite passes in that month.

Note that both valid observation and strong front are outputs of the front detection algorithm and take values of either 0 or 1 for a particular month. Pixel clarity and number of satellite passes on the other hand give information on the input to the front mapping algorithm, rather than being one of its outputs. The threshold used to indicate a ‘strong’ front was \( F_{comp} \geq 0.015 \) (DN \( \geq 15 \)).

3.9 These quantities were used to generate seasonal maps of frequent fronts, interannual standard deviation and data quantity. These have been produced both at the full resolution of 1.2 km/pixel and at reduced resolution (where the data was averaged within each 4.8x4.8 km window). Although this reduces fine scale structure, it makes many features more prominent as small offsets of the same feature over the time-series will be accumulated. For easier visualisation these are enlarged to a resolution of 2.4 km/pixel with a nearest neighbour approach.

3.10 The aggregation method is explained in

3.11 Figure 3, and example metrics for summer are shown in

3.12 Figure 4. For a seasonal map we use all front maps of the \( M \) months of that season over all \( N \) years (where \( M=3 \) and \( N=10 \)). The following calendar seasons are used:

- Winter: December, January, February;
- Spring: March, April, May;
- Summer: June, July, August; and
- Autumn: September, October, November.
3.4 Frequent Fronts

3.13 Frequent front maps were created by averaging the ratio of strong fronts to valid observations for each pixel for a particular season over all years.

\[
\frac{1}{N} \sum_{i=1}^{N} \frac{\sum_{j=1}^{M} x_{i,j}}{\max(\sum_{j=1}^{M} n_{i,j}, 1)} \quad \text{(eq.1)}
\]

3.14 For computational reasons, we ensured that the denominator was always non-zero. The result was the percentage of time in which strong fronts occurred in that pixel in that season. As it was an average over all years for which data were available, any bias caused by \( n \), the validity of observations, was removed. Thus a year with only one valid winter observation for a particular pixel had an equal contribution to the final seasonal winter map as a year with valid observations on each month of the season.
Figure 4. Front metrics for summer season, UK continental shelf using 1999-2008 data: (a) Frequent front map at 1.2 km resolution; (b) same map at 4.8 km resolution; (c) Interannual standard deviation at 4.8 km resolution (d) Data quantity indicated by cloud-free observations as a percentage of total satellite passes.
3.4 Interannual Variability

3.15 Define \( f_i \), the percentage of strong fronts for a particular season in a particular year \( i \) as:

\[
 f_i = \frac{\sum_{j=1}^{M} x_{i,j}}{\max(\sum_{j=1}^{M} n_{i,j}, 1)} \quad (eq.2)
\]

3.16 This is the quantity averaged in equation 1. In a similar fashion, the standard deviation of \( f_i \) was computed over all \( N \) years:

\[
 \sigma_f = \sqrt{\frac{1}{N} \left( \sum_{i=1}^{N} f_i^2 \right) - \left( \frac{1}{N} \sum_{i=1}^{N} f_i \right)^2} \quad (eq.3)
\]

3.17 As the calculation was done on percentages of strong fronts observed, each year’s contribution was equally weighted in the final result. We used standard deviation rather than variance as it has the same units with \( f_i \), i.e. it is also a percentage.

3.18 In the examples provided in Figure 4, areas with persistent strong fronts (e.g. near-coastal fronts in the summer) show up as blue (very low standard deviation). Areas where there was a persistent front but with considerable variability in its location gave much higher values of standard deviation and are closer to red on the standard deviation map.

3.5 Data Quantity

3.20 All previous metrics are based on the monthly front maps, and so do not indicate the actual number of satellite observations. A data quantity metric was constructed to convey that information:

\[
 \frac{1}{N} \sum_{i=1}^{N} \frac{1}{M} \sum_{j=1}^{M} \frac{c_{i,j}}{m_{i,j}} \quad (eq.4)
\]

3.21 This shows seasonal and regional variation in cloud cover, as a percentage of satellite observations that were cloud-free. It can be considered a metric of how representative the front statistics are for each grid cell, and hence a relative measure of data confidence. Low percentage cloud-free means the other metrics have been based on a small subset of the satellite passes because of cloud cover, and so are less representative of that particular season.
3.6 Conversion of Front Metrics to Data Layers

3.22 The processing and front analysis was restricted to the UK Continental Shelf region of interest. Front metrics, originally created in an 8-bit binary format, have been converted into GeoTIFF to enable an easy import into any GIS. GeoTIFF is a public domain metadata standard which allows georeferencing information to be embedded within a TIFF file. An example GeoTIFF header taken from one of the front metric maps can be found in Appendix B.

3.23 The size of the images is 1600x1658 for full resolution and 800x829 for reduced resolution. All images are in a Mercator projection over the WGS-84 datum. This makes them easily readable by ArcGIS. The data are stored as 8-bit integers; to convert them into a metric percentage value simply multiply by 0.4. Pixel values of zero indicate missing data or areas outside the UK Continental Shelf region. Figure 5 shows the co-location match between a GeoTIFF image and the ABPmer 20km grid. A land mass mask has also been applied on this figure.

![Figure 5. Co-location match between front metric GeoTIFF map and ABPmer grid.](image)

3.24 Finally, the set of GeoTIFF metrics were imported by MBA into ArcMap and combined into a single ocean front data layer file in ESRI MXD format, as detailed in Appendix A.

\[ ^3 \text{Derived from ABPmer 20km grid.} \]
4 Results

4.1 Low resolution images of the final ocean front data layers are presented below for illustrative purposes only: frequent fronts (Figure 6), interannual variability (Figure 7), and data quantity (Figure 8).

![Winter, Spring, Summer, Autumn front maps](image)

**Figure 6.** Pelagic diversity ocean front data layer 1: Seasonal frequent front maps, indicating the percentage of time a strong front was observed at each location.

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Illustrations for this report are not for scientific usage, as it is only possible to accurately interpret and locate the front distributions in the final GIS resolution and format.
Figure 7. Pelagic diversity ocean front data layer 2: Seasonal interannual variability maps, indicating the temporal variability in frontal occurrence.
Figure 8. Pelagic diversity ocean front data layer 3: Seasonal data quantity maps, indicating the mean percentage of observations that were cloud-free at each location.
5 Interpretation of Ocean Front Data Layers

5.1 The following section provides direction on how the seasonal front metrics may be interpreted, and thus their application for marine conservation zone (MCZ) designation.

5.1 Limitations

5.2 Users of these ocean front layers should be aware of limitations of the approach. Firstly, ocean fronts are a proxy for enhanced biodiversity, not a direct measure. It is not currently possible to quantify the enhancement or to predict at what times the effect will be greatest. Satellites only observe surface fronts, though strong and persistent surface fronts usually indicate a depth profile through the whole surface layer. Therefore when considering MCZ designation, the major fronts may offer some indication of surface plankton and mobile pelagic species (and possibly seabirds), but not benthic fauna. Fronts should be considered alongside direct measures of biodiversity, for example to assist in assessing the spatial and temporal context of known hotspots.

5.3 Thermal infrared EO data are limited by cloud cover, though the SST processing and composite front maps techniques optimise the visualisation of fronts by combining all observations derived from sequences of partially cloudy scenes. Cloud cover may lead to biases in data analysis, for instance if features such as upwelling or stratification fronts are correlated with clear skies. Despite the improvements to near-coastal detection of fronts described, there remains a lack of usable SST data within a few kilometres of the coast. In any case the maximum 1 km resolution of AVHRR data prevents observation of small-scale fronts associated with coastal processes, estuaries and intertidal zones.

5.2 Irish Sea Area

5.4 The Irish Sea region has been extracted from all of the seasonal ocean front data layers at 4.8 km/pixel resolution (Figure 9). Starting with the top row, these are the frequent front maps for each season, and represent the percentage of time a strong front was observed at each location. This metric indicates the varying frequency of front occurrence, so the red zones highlight frontal systems that persist for 90-100% of the season. Spatial variability is indicated by a band of decreasing frequency surrounding the peak location of a front.

5.5 For example, the Celtic Sea front in summer in the south of the region shows a prominent meander in the peak shape, with a band of lower frequencies (40-80%) indicating the range of possible extent of this front. This front delineates the boundary between colder tidally-mixed water in the shallow Irish Sea and the warmer seasonally stratified water in the deeper Celtic Sea. Hence the front will tend to extend southwards in response to the greater tidal mixing according to the lunar cycle. The seasonal variability in this front is apparent: it is always absent in winter as both the Celtic and Irish Seas are
well mixed; it is present around 50% of the time during spring, depending on when the Celtic Sea stratifies; it is present 40% of autumn in a wide band.

5.6 The middle row of Figure 9 shows the corresponding interannual standard deviation, indicating the temporal variability in front locations. This metric can be used to discriminate front hotspots that occur only in certain years from those that occur every year. For instance, the band of low values at the Celtic
Sea front in summer shows there is little annual variability (±10%) in the frequency of fronts there. Indeed, the SD metric will tend to be low when the front frequency is very high or very low. High SD values indicate that frequent fronts are either present only in certain years, or are found in different locations in each year.

5.7 The data quantity was estimated using the cloud-free percentage of the available EO SST data. The bottom row of Figure 9 indicates that there is least cloud in spring; and in winter there is most cloud in the south but in summer there is most cloud in the north. Note that there is a band along the coast with low data quantity, due to limitations of the cloud-masking and front detection algorithms, and potentially genuine cloudiness close to the coast. It is possible to relate the data quality to confidence in the other front metrics. For instance less than 3% data quantity (purple in the data quantity maps) would indicate a region with only 1 cloud-free day each month on average, and hence a poor estimator of the front distribution for that season.

5.8 These sample metrics indicate many further frontal systems within the Irish Sea (less studied than the Celtic Sea front) which should be studied using the full GIS dataset in terms of their frequency and interannual variability. The higher resolution maps (1.2 km/pixels, not shown here) resolve smaller features and provide greater detail, but show individual front contours rather than a distribution. The lower resolution maps (4.8 km/pixel) aggregate contours to give a better statistical distribution, and a good trade off with detail: they appear to show the boundaries of each feature more clearly and more useful interannual statistics.

5.3 North Sea Area

5.9 Over the Dogger Bank in the North Sea there is striking seasonal variability, with highly frequent fronts observed in the summer (when the sea can stratify), and relatively low frequency at all other times. The most persistent fronts (observed in all seasons) in the UK Continental Shelf are located close to the coast in the central and eastern English Channel; these are likely to be influenced by the rivers in south England. Extending southwest of Shetlands (near 60°N 3°W) there is a narrow front observed in spring but rarely at other times.

5.4 West of Scotland Area

5.10 There is a surface front far out into the Atlantic that follows the western edge of the Rockall Bank (57°N 13°W), and is most often observed in spring. This may be the first identification of this front according to an initial literature survey (e.g. Pollard et al., 2004, Otto and vanAken, 1996, McMahon et al., 1995). We assume that currents across the Rockall Bank are causing the generation of internal waves, leading to enhanced mixing that sometimes reaches the surface. This is analogous to the well-studied band of cooler water observed along the Celtic shelf-break in summer (Huthnance et al., 2001). There is evidence of increased pelagic abundance and diversity at Rockall, for example in gelatinous zooplankton, fisheries and turtles (Newton et al., 2008, Witt et al., 2007), though this is more likely to be associated with the shelf-break currents than this particular surface front.
6 Conclusions

6.1 We have implemented a novel approach to the mapping of pelagic diversity for the UK continental shelf, using a long time-series of EO SST data to automatically detect thermal ocean fronts on a daily and then monthly basis, then aggregating observations into climatological seasonal metrics. Three selected metrics characterised the spatial, seasonal and interannual variability of fronts observed over a 10-year period. Many researchers have determined that fronts are related to the abundance and diversity of pelagic species (reviewed by Jackson et al., 2009), and hence may be considered a surrogate of pelagic diversity. EO data also have high spatio-temporal coverage and fine spatial resolution, which is lacking for many other diversity, abundance and habitat datasets.

6.2 Over 30,000 satellite passes were processed to generate the front climatology. The decision to segregate the analysis into seasons was clearly justified by the resulting maps, which showed considerable and consistent seasonal variation in the occurrence, location and frequency of fronts. This result raises the possibility that management measures should vary seasonally to account for seasonal changes in the water column and likely changes to species distributions.

6.3 These ocean front metrics could be readily applied to other geographical regions. Within the NW European receiving range of Dundee Satellite Receiving Station we have excellent coverage of AVHRR data since 1981. Outside this region it is possible to obtain AVHRR acquired by other receiving stations at full resolution or globally at reduced 4.4 km resolution; in addition MODIS SST data are available globally at 1 km resolution since 2002.

6.4 Future research in this area could consider ocean colour fronts in addition to thermal fronts. EO ocean colour products such as chlorophyll-a offer a number of benefits for observing fronts (Miller, 2004). The algae or suspended sediment acts as a tracer for physical processes, and hence may indicate fronts that only have a density gradient rather than a thermal gradient. Visible light is reflected back from several metres into the water column, compared to infrared which radiates only from the top millimetre of the sea surface; so ocean colour may observe fronts that would be easily obscured in SST by wind mixing or surface heating. However, ocean colour also observes biological processes such as the growth of algal blooms, the boundaries of which would be difficult to distinguish from ocean fronts. Also there would be less input data available from ocean colour, which normally is only acquired around local noon; though the combination of several sensors (Aqua-MODIS, Terra-MODIS and Envisat-MERIS) would counteract this.
7 References


Appendix A  Contents of Ocean Front Data Layer Files

The ocean front data layer is provided as a zip file ‘2F_FRONTS.zip’ that contains an ESRI ArcGIS project file named ‘2F_FRONTS.mxd’, together with 8 data directories named ‘<season>, <resolution>’ (e.g. ‘Autumn, 1km’). The user only needs to load the MXD file into ArcMap.

Each layer is provided with a palette attached; please note that the colours are not identical to the figures in this report. By clicking on the colour scale in ArcMap it is possible to change the contrast by modifying the minimum and maximum values.

Table 1 indicates the contents of the fronts data layer file, to clarify the correspondence with the thermal front metrics.

Table 1: Ocean front data layer names within ESRI MXD file

<table>
<thead>
<tr>
<th>Front metric type</th>
<th>Season</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasonal frequent front metric</td>
<td>Winter</td>
<td>1 km resolution</td>
</tr>
<tr>
<td>Seasonal front variability metric</td>
<td>Spring</td>
<td>4 km resolution</td>
</tr>
<tr>
<td>Seasonal front data quantity</td>
<td>Summer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Autumn</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B  GeoTIFF Header Information

An example GeoTIFF header taken from one of the front metric maps is shown below.

Geotiff Information:
Version: 1
Key_Revision: 1.0
Tagged_Information:
ModelTiepointTag (2,3):
  0    0    0
-2783996.75  9414576  0
ModelPixelScaleTag (1,3):
  2016.57922  2016.53467  0
End_Of_Tags.

Keyed_Information:
GMTModelTypeGeoKey (Short,1): ModelTypeProjected
GTRasterTypeGeoKey (Short,1): RasterPixelIsArea
GeographicTypeGeoKey (Short,1): GCS_WGS_84
GeogCitationGeoKey (Ascii,7): "WGS-84"
GeogLinearUnitsGeoKey (Short,1): Linear_Meter
GeogAngularUnitsGeoKey (Short,1): Angular_Degree
GeogSemiMajorAxisGeoKey (Double,1): 6378137
GeogSemiMinorAxisGeoKey (Double,1): 6356752.5
ProjectedCSTypeGeoKey (Short,1): User-Defined
ProjectionGeoKey (Short,1): User-Defined
ProjCoordTransGeoKey (Short,1): CT_Mercator
ProjLinearUnitsGeoKey (Short,1): Linear_Meter
ProjFalseEastingGeoKey (Double,1): 0
ProjFalseNorthingGeoKey (Double,1): 0
ProjCenterLongGeoKey (Double,1): 0
ProjCenterLatGeoKey (Double,1): 0
End_Of_Keys.
End_Of_Geotiff.

Projection Method: CT_Mercator
ProjNatOriginLatGeoKey: 0.000000 ( 0d 0' 0.00"N)
ProjNatOriginLongGeoKey: 0.000000 ( 0d 0' 0.00"E)
ProjScaleAtNatOriginGeoKey: 1.000000
ProjFalseEastingGeoKey: 0.000000 m
ProjFalseNorthingGeoKey: 0.000000 m
GCS: 4326/WGS 84
Datum: 6326/World Geodetic System 1984
Ellipsoid: 7030/WGS 84 (6378137.00,6356752.50)
Prime Meridian: 8901/Greenwich (0.000000/ 0d 0' 0.00"E)
Projection Linear Units: 9001/metre (1.000000m)

Corner Coordinates:
Upper Left (-2783996.750, 9414576.000)( 25d 0'32.65"W, 64d24'15.08"N)
Lower Left (-2783996.750, 6071161.521)( 25d 0'32.65"W, 47d58'34.82"N)
Upper Right (  442530.008, 9414576.000)(  3d58'31.13"E, 64d24'15.08"N)
Lower Right (  442530.008, 6071161.521)(  3d58'31.13"E, 47d58'34.82"N)
Center ( -1170733.371, 7742868.760)( 10d31' 0.76"W, 57d 5'28.14"N)