COMKISS - WP 5300 Surface Currents - Final Report

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1. Introduction

The need for better surface current information

Slow moving transports, and stationary or near-stationary offshore operations can be significantly affected by ocean surface currents. Unpredicted severe currents can cause delay, postponement or even abandonment of sensitive operations. Faster moving vessels are also affected by changing surface currents. Fuel is a major component in the costs of ocean transport, and potential savings from improved knowledge of surface currents are significant. For example if improved surface current information allowed a moderate 0.5 knot improvement on an average 10 knot speed over a 2000 NM voyage, the journey time would be reduced by10 hours. Assuming an average fuel consumption of 30 tonnes per day, consumption would be reduced by 12.5 tonnes. For slower or larger vessels the savings could be even more significant.
The larger stationary offshore operations are often supported by operational local surface and subsurface current prediction models, and by local *in situ* instrumentation. However many other offshore activities no not have access to reliable near real time surface current information. The major commercial ship routing organisations do include surface currents in their calculations. We understand that they update their surface current fields with satellite data twice weekly in areas with strong eddy driven currents (e.g. the Gulf Stream, the Kuroshio), otherwise the information is updated on a monthly or seasonal basis from climatological sources. The effect of wind driven currents in storms is calculated separately.
Whilst the behaviour of most current systems can be predictable in a general sense, there is much variability in the location and strength of ocean surface current systems, on time scales from days to years. Averaged climatologies are unable to represent this variability, which can take different forms and create different ship routing problems, as discussed below for two example regions.

The Indian Ocean

The general features of current system in the Indian Ocean (discussed in more detail later) are well known. The most significant characteristic is the reversal of the current flow between the Equator and 8°N from eastward during the NE Monsoon, and westward during the SW Monsoon. Thus in principle a ship can be routed to take advantage of the current system according to the season. However, the time of onset of the SW monsoon can vary from year to year, and a surface current climatology will not be able to provide useful information during these transition phases. A surface current data set updated with satellite derived information would be able to identify accurately the time (and surface currents patterns) of these transition periods.

The Gulf Stream

The Gulf Stream current system in the north-western Atlantic is a highly dynamic system with strong currents whose features (location of boundaries, connected eddies, and associated current directions and speeds) vary almost daily. Because of the high current speeds associated with the Gulf Stream it

is of great importance to a ship's master to know the vessel's position with respect to key features of the Gulf Stream. With the benefit of detailed information, a lateral movement of a few nautical miles can add several knots to the ship's speed.
Thus, for the Gulf Stream, a seasonal climatology is of particularly limited use. The key features do not stay in the same place over the period of a few weeks, never mind from year to year. Thus, ship's masters often apply their own techniques to assess their position with respect the Gulf Stream boundaries (for instance by measuring the water temperature). Satellite data provide a more reliable way of locating the key features and following their development on a weekly basis.

Aims

Satellite measurements offer the potential to generate near real time current information that could improve operational safety and contribute to significant savings of time and hence fuel on trans-oceanic routes. A number of pilot systems have been tried, but to our knowledge there is not as yet a global operational system with the potential to be integrated into a ship routing system.
The purpose of this work package is to establish the state of the art of the use of satellite data for monitoring surface currents, to identify those systems which offer the best opportunity for operational applications, and to establish the steps necessary to achieve such an operational system.

2. Satellite Data Sources for Surface Current Information

There are a number of satellite data sets which can be used to derive surface current information and so could contribute to an operational system.

1. Satellite altimeter sea surface height data. Provides derived (geostrophic) surface current magnitude and direction information.
2. Satellite radar backscatter measurements (altimeter, scatterometer, SAR). Can indicate the location of boundaries of current systems.
3. Satellite radiometer sea surface temperature and ocean colour data, can provide proxy "tracer" information of surface current systems.
4. Scatterometer wind vectors. Used to derive wind driven circulation (Ekman drift).
5. Large scale, or local, ocean circulation models, with assimilation of satellite data.

Altimeter Sea Surface Height Measurements

Whilst altimeter data can potentially provide near real time geostrophic currents, additional information is required to derive this information. Firstly an accurate background sea surface height field, and reference background current flow are required. The altimeter measurements of sea surface height on their own can only give the variability in surface currents about a reference mean. Secondly accurate orbit measurements are required, to fix the orbit height of the satellite at the time of the measurement. Whilst it generally takes six-eight weeks for the final orbits to be available, fast turn around orbits, based on laser tracking measurements, are available on a time scale of 1-2 weeks.

Resolution:

Time: 10 days/ 17 days based on TOPEX/ERS-1 repeat cycles, but updateable daily.
Space: ~100s km across track, 10s km along track
Current magnitude: ~10s cms^{-1} (0.2 knot)
Current Direction: >10°

Radar Backscatter (altimeter, scatterometer, SAR)

It has been observed that the ocean surface radar backscatter is affected in the presence of a strong current (see e.g. Topliss et al., 1994). However, the magnitude and even the sign of the change in backscatter depends on a number of other factors, and the physical processes involved are not well understood. Thus radar backscatter could only practicably be used to identify boundaries of strong current systems. Nonetheless, they offer a potentially high resolution localisation of current systems.

Resolution:

Time: Variable, perhaps daily
Space: 1-10 km along track (altimeter), < 1 km in all directions (SAR), 25 km in all directions (scatterometer)
Current magnitude: Not available
Current Direction: Not available

Sea Surface Temperature and Ocean Colour

Sea surface temperature (SST) and ocean colour are effective passive tracers of surface currents. There are many beautiful examples of high resolution radiometer data which indicate the presence of oceanic eddies, or loops and whirls in active systems such as the Gulf Stream. Whilst the direction of the current can be inferred from knowledge of the local systems and processes, it is not possible to extract any quantitative information on current speeds. Also, satellite SST or ocean colour measurements are not possible through cloud. As the strong current systems such as the Gulf Stream are often covered by cloud, an operational system would not have to place too much reliance on satellite derived SST input. It may also be difficult to develop an objective independent computer based system which is capable of interpreting the current signature in the image data reliably. However, as a secondary input, satellite SSTs offer a potentially high resolution localisation of current systems.

Resolution:

Time: Daily
Space: ~10 km or better
Current magnitude: Not available
Current Direction: Can be inferred from temperature signature

Wind Driven Surface Currents from Scatterometer Winds

Wind driven currents can be derived directly from directional scatterometer wind fields. The theoretical relationship between surface wind and the Ekman component of surface drift is well understood. Near real time scatterometer wind fields have for some time been available from ERS-2, and are now also available from Quikscat. Quikscat provides complete global coverage every 24 hours. Use of scatterometer data therefore offers a potentially useful system for offshore currents. Some averaging of data is required to reduce noise in the derived Ekman drift values.

Resolution:

Time: Daily
Space: ~50 km
Current magnitude: ~10s cms^{-1} (0.2 knot)
Current Direction: >10°.

Circulation Models

Ocean circulation models, coupled with atmospheric models, or forced by surface fields, can be used to derive surface currents. Up to now, large scale models have not been able to recreate reliably actual short term variability in circulation patterns, but localised models have been more successful. More recent applications, for example by Chevron in the Gulf of Mexico, have assimilated altimeter sea surface height data (also see e.g. Hetland et al, 1999, Dandin et al., 1999). The French MERCATOR project (Dandin et al., 1999) is a good example of a combined programme between operational services and (oceanographic and space) research institutes. The aim is to set up an operational high-resolution ocean circulation model that assimilates satellite and in situ data. The model will not work close to the coast, but should be capable of providing boundary conditions for very high-resolution coastal models. The objective is to have an operational implementation by the years 2004-2006.

Resolution:

Time: ? 6 hours
Space: ~1/6°
Current magnitude: 10 cms^{-1}.
Current Direction: 10° ?

3. Candidate Techniques

We understand that the climatological information used by ship routing companies is sourced from atlases derived from multi-year averages of surface drifter and ship measurements. Within COMKISS we are seeking potential satellite data sources which can provide information on large scale seasonal currents, and on highly dynamic current systems which can vary day by day. One independent commercial organisation which makes use of satellite information, and which is open about its data sources, is "Jenifer Clark's Gulfstream" (hereafter **JCG**). A number of other trial systems have been developed, usually with ocean circulation models assimilating satellite data, but these are mostly for localised scientific studies. At best they could be described as pre-operational. In this section we consider in detail the three techniques which are probably the best candidates to form the basis of an operational system.

"Jenifer Clark's Gulfstream" - JCG

Jenifer Clark worked at NOAA as a satellite oceanographer for 28 years. During that time she was responsible for giving official briefings to captains in the Newport to Bermuda yacht race. She started providing surface current data commercially in 1995. The main operational service she provides concentrates on the Gulf Stream off the Eastern US Coast, but she can also generate analyses for any location around the world.

Data Sources

The most important source for **JCG** is sea surface temperatures from NOAA AVHRR data. These data are drawn from composite images posted on the web by US universities. TOPEX altimetry data are also used for information on the location of cold and warm eddies, and *in situ* measurements (buoys and drifters) are also consulted to provide surface truth. These information sources are combined, and subjectively interpreted (using personal experience) to provide maps of Gulf Stream features (Figure 1).

Resolution

The estimated realistic spatial resolution on analyses based on NOAA AVHRR data is 8 km. **JCG** Charts (for the Gulf Stream) remain valid for an estimated 3-5 days. The area between 32°-35°N is the most active part of the Gulf Stream, and so the current features change most rapidly in this region.

Update Frequency

JCG update their maps every Monday, Wednesday and Friday.

Coverage

The areas routinely covered by **JCG** are the Gulf Stream (20°-45°N, 55°-85°W) and the Gulf of Mexico. However, analyses can in principle be prepared for any location. For instance **JCG** are offering a service to the British Telecom Global Challenge round the world yacht race.

Reported Time/Fuel Savings

Biggest usage is by yachts who have reported gaining up to 7 knots. A tug in the Gulf of Mexico reported a speed gain of 25% (from 6 knots to 7.5 knots). A tanker reported a saving of 10,000 US gallons of fuel every trip by using this service.

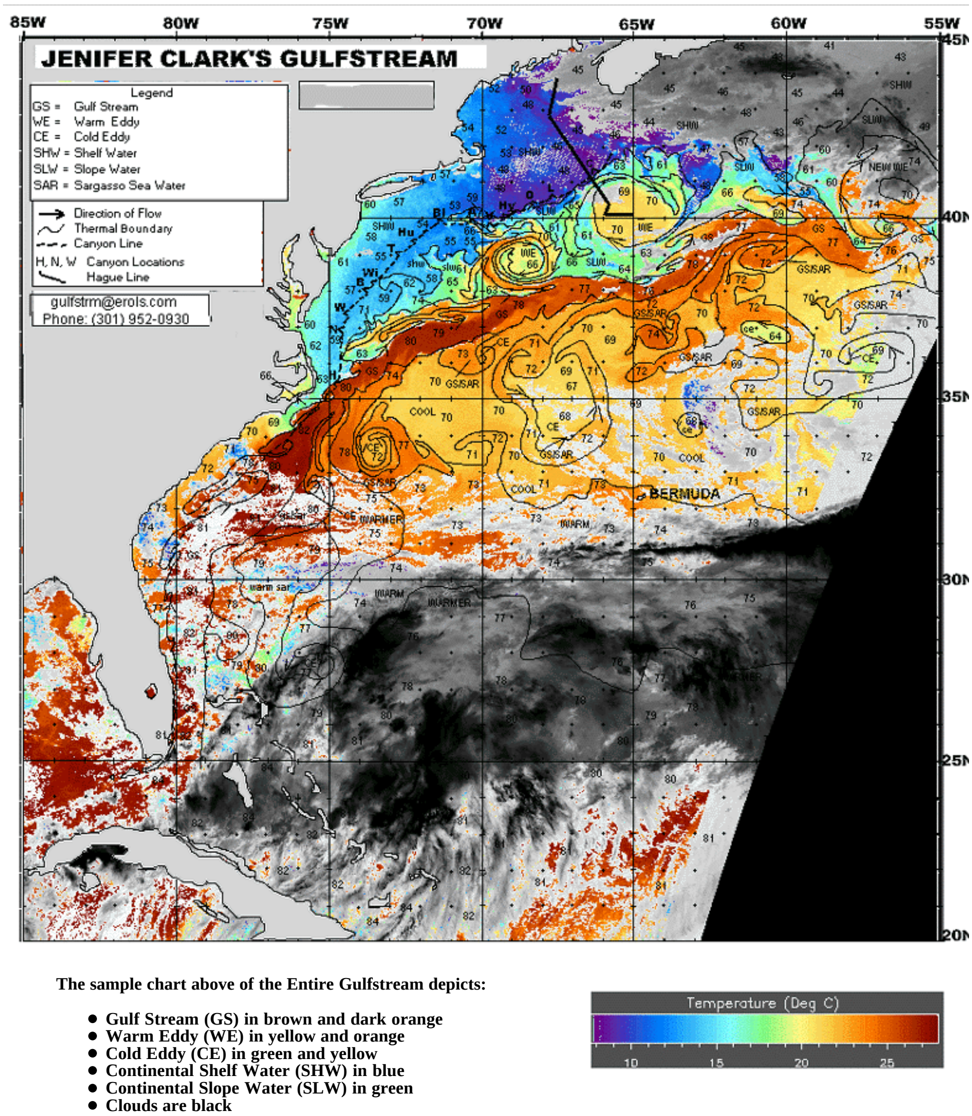

Figure 1. An example chart of the Gulf Stream off the eastern US coast, from "Jenifer Clark's Gulf Stream" service.

Surface Currents from Altimeter and Scatterometer Data

Earth and Space Research Seattle, WA, USA –ESR (http://www.esr.org.lagerloef/sfcV/sfcV.html)
Lagerloef et al., (1999) describes a technique which combines geostrophic velocities derived from altimeter sea surface height data and Ekman drift velocities derived from scatterometer wind fields. The combined surface current fields were then "tuned" using data from surface drifters. The aim of this study was to investigate the surface response of the Equatorial Pacific to El Niño. For this purpose a 1° x 1° monthly climatology was developed.

In a personal communication, Dr. Lagerloef commented that whilst surface drifter data are required for tuning the wind-driven component of the algorithms, and to establish whether the model coefficients vary with latitude, they are not necessarily needed on a regional basis. However, he has noted that the geostrophic current component computed from sea level gradients is somewhat underestimated relative to drifter measurements by up to 30%-40%. This is attributed to the smoothness of the mean dynamic topography derived from the Levitus Ocean Atlas data, and he is working on quantifying this problem.

ESR do not at present provide an operational service. However, they are developing a "near real time" operational system with a time resolution of 10 days (to match the TOPEX orbit cycle), and spatial resolution of 1°. Note that this technique will not resolve coastal or boundary currents well, but would be suitable for larger scale, open ocean, applications.

Ocean Circulation Models which assimilate altimeter data

A number of regional studies for commercial offshore operations have developed local circulation models which assimilate altimeter sea surface height and so derive surface and subsurface currents. The Caribbean Sea and Mexican Gulf in particular have received a lot of attention as has, more recently, the North Atlantic Ocean off north-western Britain. Cortis Cooper, of Chevron, has for years been using satellite altimetry extensively in the Gulf of Mexico to track the Loop Current (the precursor of the Gulf Stream) and the large eddies it spins off (300 km diameter). This application (supported under the CASE JIP) involves a numerical model with real-time data assimilation of altimeter data, and has been very successful in generating high quality nowcasts. Chevron routinely carry qualitative reviews of the major features like front positions, eddy centres, etc., which have indicated errors of order 50 km, or maybe 10% of the feature spatial scale.

The French MERCATOR project, which forms a contribution to GODAE (Global Ocean Data Assimilation Experiment) has ambitious aims to implement a high resolution global ocean circulation model, which will assimilate satellite and *in situ* data. As part of MERCATOR it is intended to develop a 1/12° circulation model of the eastern Atlantic and the Mediterranean Sea.

From Stennis Space Centre, the US military run an experimental Real Time North Pacific Ocean nowcast/Forecast system, based on a 0.25° resolution circulation model, with assimilation of altimeter and AVHRR data (http://www7320.nrlssc.navy.mil/npacnfs_www/NPACNFS.html)

4. COMKISS North Indian Ocean Study

Introduction

Within COMKISS we wished to compare a satellite derived data set, which could potentially be updated every ten days with a multi-year surface data based climatology, so that we could investigate the potential added commercial benefits offered by the satellite derived data set. The North Indian Ocean was selected for this study, in particular the shipping route from Aden to Singapore. This study comprised two parts, a comparison of the climatological and near real time data sets, and a trial ship routing exercise. Greater details of this study are given in another COMKISS report, so here we present a summary of the more important results.

Data Sets

The satellite derived data set (hereafter referred to as "ESR") was provided by Dr Lagerloef, of Earth and Space Research, Seattle, and the surface derived climatological data set (referred to as "RSMAS") by Dr. Mariano of the Rosenstiel School of Marine and Atmospheric Science, Miami. The ESR data set was provided as a series of 1° x 1° gridded data sets, each covering ten days (covering the period May 1998 to May 1999). The RSMAS climatology, derived from ship drift information, was provided on a 1° x 1° grid as climatological monthly averages.

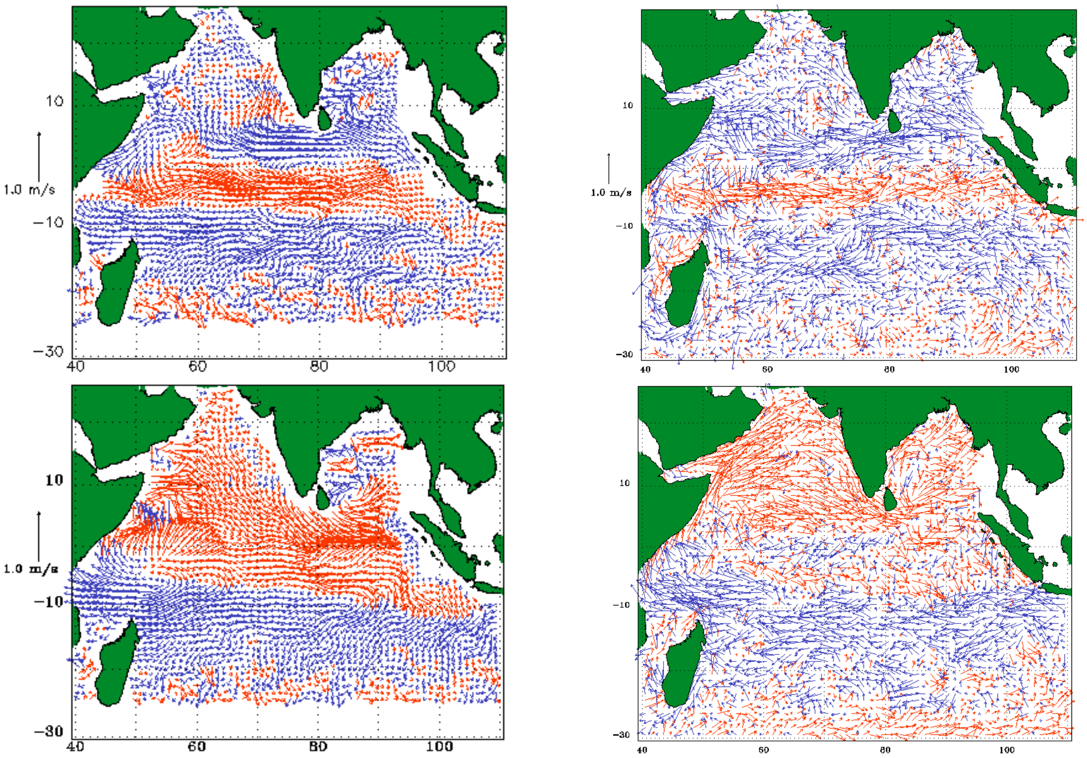

Figure 2. Top 2 panels: ESR (left) and RSMAS (right) surface current data for January. Bottom panels surface currents for July; Red arrows indicate eastward flowing currents, blue arrows indicate westward flow.

Comparison

RSMAS Climatology against Near Real Time ESR

The two data sets both show the expected seasonal current features related to the NE Monsoon (Figure 2 top panels) and the SW Monsoon (lower panels). During the NE Monsoon, there is a westward North Equatorial Current between the equator and 8°N, with an eastward flowing equatorial counter-current to the south (between 0° and 8° S), and another westward flowing current, the South Equatorial current south of this (between 8°S and 25°S). During the SW monsoon the flow to the North of the equator is reversed such that almost the entire flow north of 8°S is Eastward. This combined flow is known as the SW monsoon current.

Whilst there are clear similarities, there are also evident differences between the two data sets. The ESR data are more smoothed in appearance, and have smaller current magnitudes than the RSMAS data (note the scales in Figure 2). The ESR processing scheme forces some smoothing onto both the geostrophic and Ekman drift current fields, whereas (so far as we know) the RSMAS interpolation scheme does not carry out any similar smoothing. Also, Dr. Lagerloef has commented on the need to tune the satellite derived fields to surface data, because of the tendency of the untuned current fields to underestimate current strength.
The main conclusion that can be drawn is the rather unsatisfactory one that the ESR and RSMAS data sets are different, and that we are unable to say which gives the more realistic representation of the current systems of the Indian Ocean. There are two problems, which may be related:

1. In general, the current speeds in the RSMAS data are much larger than those in the ESR data. However, the size of this bias is not consistent between various regions within the Indian Ocean.
2. The RSMAS data are noisier in both speed and direction.

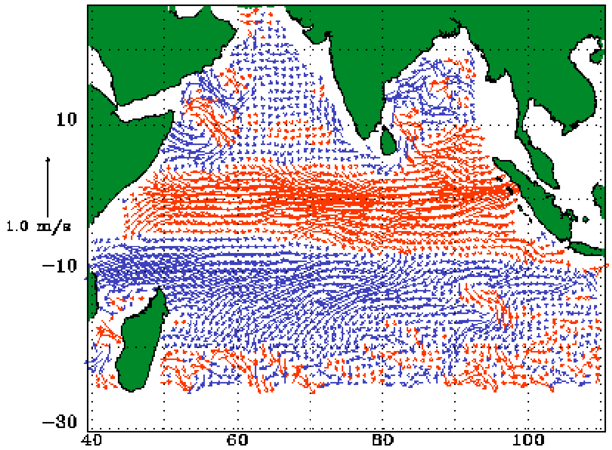

Figure 3. ESR currents for the 10 day period beginning 15/11/98.

With regard to point 1, the suspicion is that the ESR data are underestimating current speed. An increase in current speeds would also increase the variance in the data, but probably not to the extent that the large scale "smoothness" of the flow patterns would be affected. Some of the noisiness in the RSMAS data may be realistic, but may also be a consequence of the fact that different grid cells will have received different levels of sampling in different years, and so may have captured parts of current systems that were not consistent from year to year. In contrast, the ESR data, which may in their turn be overly smoothed, show up coherent, but transient, mesoscale features which the RSMAS data cannot hope to pick up. See, for instance, Figure 3, which shows gyres or large eddies in the Bay of Bengal and off the tip of the Horn of Africa. Such features are not seen in the RSMAS climatology.
It is concluded therefore that the ESR data are able to pick up short term events that the RSMAS data cannot, but that there may be unrealistic large scale smoothing and a tendency to underestimate currents speeds in these data. Thus it is important to verify the ESR data against surface truth measurements. In addition the use of sea surface temperature data (from satellite radiometers) would help to define the boundaries of different current systems and gyres, and may allow an improvement in the resolution of the derived current fields (1° resolution may be too coarse for some uses).

Near Real Time ESR against Drifting Buoy Data

We have noted that need to verify the derived data sets against direct measurements. Drifting buoy data are available from the US PODAAC (Physical Oceanography Distributed Active Archive Center - http://podaac-www.jpl.nasa.gov/). Therefore buoy measurements of surface currents in the North Indian Ocean, for 1998,were extracted from PODAAC. There are only a limited number of buoy measurements available, so it is not possible to compile gridded average measurements over a large region. Instead, PODAAC buoy data were averaged over a 10-day period, for regions where they were available, and ESR 10-day averages extracted for the same locations. Figure 4 gives an example for May 1998.

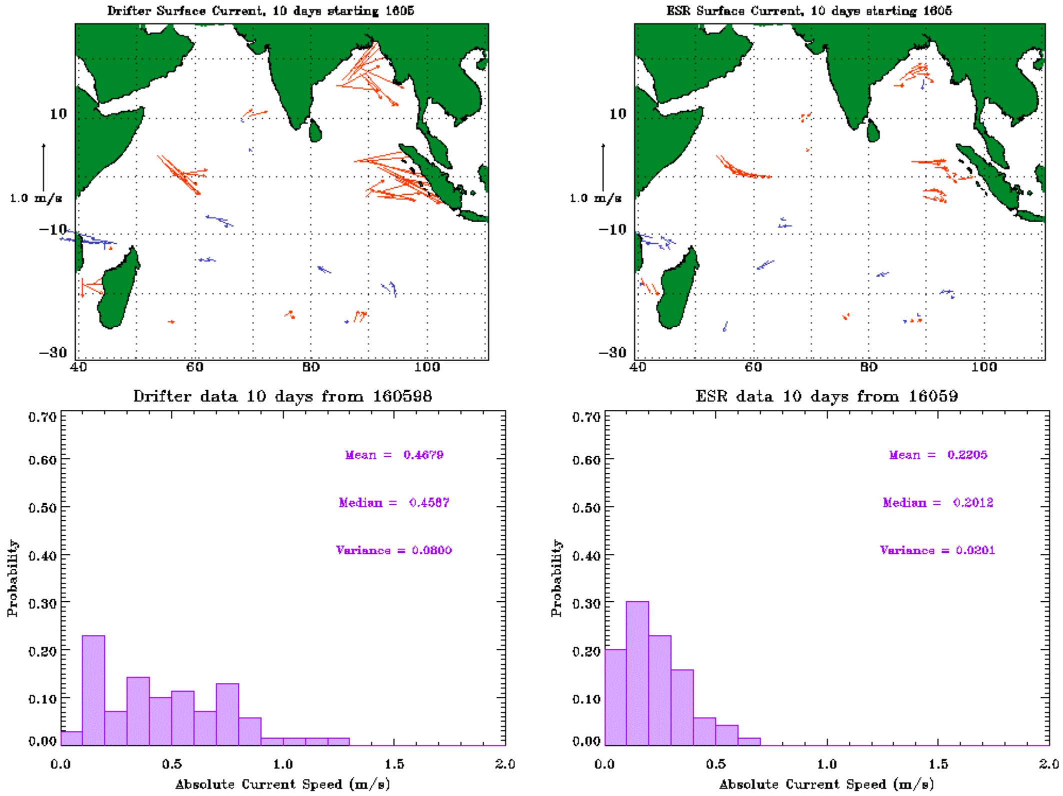

Figure 4. Top 2 panels: Drifting buoy (left) and ESR (right) surface current data for 10 days starting 16/05/98. Red arrows indicate eastward flowing currents, blue arrows indicate westward flow. Bottom panels contain absolute current velocity histograms for the se same data .

Figure 4 suggests that, whilst the “sense” of surface currents (as measured by the surface buoys) is well represented in the ESR data (top panels), the magnitude of absolute velocities is often too low (bottom panels). The buoy data show 10-day averaged velocities of up to 1.3 ms^{-1}, whereas the highest average velocity (for the same grid squares) from the ESR data is 0.7 ms^{-1}.

This observation confirms the need for ground truth corrections of measurements derived from remotely sensed data, and indicates that further work is required before the ESR data could be employed operationally.

Ship Routing Trial

In this trial the travel time for a vessel travelling at 5, 10 and 20 knots along the Singapore-Aden route was calculated. This calculation included the effect of surface current according to the (uncorrected) ESR data set. The "nominal" route ran from Socotra (12°36'N 53°59'E) to Banda Aceh (5°30'N 95°20'E passing to the south of the Maldive Islands (at 1°N, ~73°E). The active routing did not make use of a routing algorithm but simply consisted of a subjective visual analysis, the aim being to achieve an approximate measure of the possible time savings. Four test journeys were analysed, at different times of the year when different current regimes hold sway (Table 1). Under these conditions it might be expected that the optimum route might be different.

Results

The results were perhaps disappointing (Table 1). They indicated that routing, involving deviation away from the "nominal" route, increased journey times in all but one case (NE Monsoon, ship speed 5 knots, Table 1). However, one should recall that the ESR current speeds are suspected to be low. If these currents speeds were increased, more reductions in journey times might have been achieved.

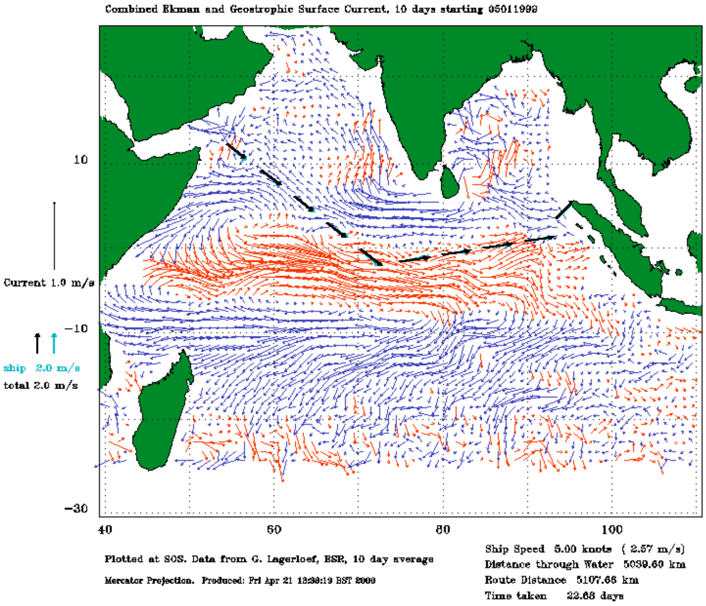

Figure 5. Ship routing trial for 05/11/98 (NE Monsoon). The ship (green) and combined ship and current vectors (black) are indicated by the heavy arrows. The underlying current fields are indicated by the red (east flowing) and blue (west flowing) arrows.

Season	date	Ship speed	Time saving (routed –unrouted)	Total Journey Time
SW Monsoon onset	16/05/98	5 knots 10 knots 20 knots	+0.10 day +0.23 day +0.19 day	19.3 days 10.2 days 5.2 days
SW Monsoon	26/06/98		*Routed and unrouted tracks identical*	
NE Monsoon onset	26/10/98	5 knots 10 knots 20 knots	+0.65 day +0.59 day +0.37 day	19.6 days 10.2 days 5.2 days
NE Monsoon	05/11/98	5 knots 10 knots 20 knots	+0.26 day +0.30 day +0.25 day	22.9 days 11.1 days 5.5 days

Table 1. Results of trial ship routing using ESR near real time surface currents.

Conclusions

There were significant differences between RSMAS climatology and ESR satellite derived currents. The climatology data were noisier and showed larger current speeds. A limited comparison of ESR data against drifting buoy measurements confirmed that ESR surface currents were too low. Thus there is a need for surface truth data to validate the ESR analysis

Different seasonal patterns could be identified in both data sets, but with only one year's data we were unable to establish whether there was year to year variation in the onset times of the current regimes associated with the different seasons. Current strengths are only locally large (for instance the Somali current runs at up to 4 knots during the SW monsoon).

It was possible to identify short term meso-scale eddies and local gyre systems in the ESR data, which cannot be seen in RSMAS climatology. The use of other data sets (e.g. AVHRR sea surface temperature data) would further improve temporal and spatial resolution.

In our study routing had benefit on only one occasion, but routing would have had more effect if the ESR current speeds were larger. It may be that routing may be most beneficial in the regions close to gyres, or at times close to the onset of SW/NE monsoons. In any case a gridded current data set could be valuable as it would enable accurate prediction of journey times.

Thus we suggest that the ESR technique of combining altimeter and scatterometer derived surface currents does show some potential, but requires some further development. The data set would benefit from integration with higher resolution sea surface temperature and/or ocean colour data, and must be subject to careful validation from surface truth information.

6. Conclusions

The aim of WP5300 was to define the state of the art, identify the techniques for processing satellite data that were most likely to lead to a useful operational system, and to define the steps necessary to develop an operational system.

State of the Art

Perhaps the most important point to be made is that we are not aware of any genuine operational near real time surface current nowcast systems presently on the market. It appears that the only near real time systems available are those which have been developed "in house" by offshore operators or by consortiums (e.g. OGP) for specific studies or regions. According to available product information, and some discussions with ship-routing consultants, the most widely used ship routing companies use a multi-year surface current climatology in their ship routing system, with twice weekly enhancements, derived from satellite imagery, in areas of strong and highly variable currents.

It is clear that it is possible to derive useful near real time analyses of surface currents based on interpretation of satellite data. The ship routing companies have clearly recognised this, as shown by their use of such data in areas of strong currents. The question we must ask within COMKISS is whether greater use could be made of satellite data. One commercial organisation which bases its entire sales around satellite derived surface current information is "Jenifer Clark's GulfStream". However, this company's product is quite specialised and because of its reliance on subjective visual analysis, their technique is perhaps not well suited to routine operational use, especially with regard to possible integration into computer based advice systems.

The feedback from users of ***JCG***, confirmed by simple calculations, suggests that potential cost and risk savings from improved near real time surface current information may be significant. However, it seems that the market for an operational near real time ocean surface current data system is not well developed or exploited. Consequently we suggest that it is worth investigating in more detail the potential market opportunity. We suggest that the two best candidate techniques for incorporation in a computer based advice system are:

a) Ocean circulation models which assimilate satellite data.
b) Surface current fields derived more directly from a number of satellite data sources, verified where possible against in situ measurements (altimeter geostrophic currents, plus wind driven currents derived from scatterometer data, complemented with further high resolution information derived from satellite radiometer sea surface temperature measurements and ocean colour images)

A number of national and international agencies are developing large scale circulation models which assimilate altimeter data. At least one of these (MERCATOR) is intended as an operational near real time system. However, it is not clear whether, or on what terms, these data may be publicly available. Our limited trials have indicated that whilst a simpler system may provide more immediate results, some further improvements to existing processing techniques are necessary.

Suggested Specifications

Ship routing and near stationary offshore operations have different requirements. A large scale perhaps weekly updated data set may be adequate for ship routing, but would not provide the high resolution information and early warning of severe currents required for stationary deep water operations. Whilst analysis of high resolution image data could well make a useful contribution in the latter situation, at this stage we suggest that the ship routing problem is most open to a marketable solution. One possibility would involve an intelligent advice system (ship or office based) which took as input a gridded or feature based surface current data file. This data file would be updated on a regular basis. As a starting point we suggest the following list of requirements for an operational system.

1.	Spatial resolution,	0.25° (global) or better (local ~10 km).	
2.	Temporal resolution	weekly (at least) updates.	
3.	Accuracy of current information	speed	25 cms^{-1} (0.5 knot)
		direction	30°
4.	Must improve upon climatology.		

Recommendations

We strongly recommend a further study which would investigate the commercial viability of an operational service coupled with an applications development programme to generate a near real time, satellite derived, surface current data system. Suggested key actions are given below:

Market Study

To define a commercially viable system (if possible), including:

- Preliminary Market Study
- Cost benefit assessment
- Outline System specification (data service only, or fully integrated ship advice system?)
- Delivery mechanisms.

Application Development

To develop, trial and cost an operational near real time surface current data service, including

- Secure end-user(s) as partner(s), define end-user requirements.
- Define initial technique and data set requirements.

- Generate initial data set and carry out detailed comparisons with climatology, as presently used in routing operations.
- Modify data processing techniques as necessary,
- Define service specifications.
- Carry out full scale operational trial, including transmission of data to offshore operation.
- Review trial.
- Cost various options of a fully operational service.

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Glossary

AVHRR – Advanced Very High Resolution Radiometer
CASE – A JIP study in the Caribbean
CNES – Centre Nationale d’Etudes Spatiales, France
ERS-1 – ESA first Earth Remote Sensing Satellite (1991-96)
ERS-2 – ESA second Earth Remote Sensing Satellite (1995-)
ESA – European Space Agency
ESR – Earth and Space Research, Seattle, WA, US
GODAE – Global Ocean Data Assimilation Experiment.
JCG – Jenifer Clark’s GulfStream
JIP – Joint Industry Programme (OGP)
MERCATOR – French Research Programme to Develop Operational Ocean Model
NOAA – National Oceanographic and Atmospheric Administration
OGP – The International Association of Oil and Gas Producers
PODAAC – Physical Oceanography Distributed Active Archive Center.
Quickscat – US scatterometer satellite (1999-)
SAR – Synthetic Aperture Radar
SST – Sea Surface Temperature
RSMAS – Rosenstiel School of Marine and Atmospheric Sciences, Miami, FL, US
TOPEX – US/French Altimeter Satellite, (1992-).