Development of spatial intercomparison within the operational wave forecast verification exchange

Adrian Hines
Met Office,
FitzRoy Road, Exeter, EX1 3PB, UK.
+44 1392 886509, adrian.hines@metoffice.gov.uk

Jean–Michel Lefèvre,
Météo France, France.

Dave Poulter,
National Oceanography Centre, Southampton, UK.

Abstract

The routine intercomparison of wave model forecast verification data that has been underway since 1995 has been developed around the exchange of model forecast data at an agreed list of moored buoy sites at which instrumented observations of significant wave height, wave period and wind speed are available. This exchange of data has proven invaluable, with a large number of centres now participating.

In considering the future development of the exchange the JCOMM Expert Team on Wind Waves and Storm Surges identified potential benefits in extending the exchange to include intercomparison of spatial fields from the model forecasts.

Techniques have been developed within the sea surface temperature (SST) community that allow the spatial intercomparison of model products alongside satellite observations, and collocated in situ observations. A sophisticated system of this nature has been developed within the GODAE High Resolution SST Pilot Project, based upon the concept of the High Resolution Diagnostic Data Set (HR-DDS).

The HR-DDS consists of a collection of small areas over which model, satellite and in situ data are presented together to allow straightforward comparison of spatial data over these selected areas. The data used in the HR-DDS can be delivered from multiple sources, are collated at a single centre, and are subsequently accessible via a map-based web interface. The HR-DDS approach is a complementary method to the validation statistics that potentially adds to the understanding of the differences in performance between forecast systems.

This paper will present an initial demonstration of the application of the HR-DDS system to wave model forecast verification, and will describe the potential for extension of the system to provide additional functionality and hence further insight into the performance of the operational wave forecast systems.

1. Introduction

A routine intercomparison of wave model forecast verification data was first established in 1995 to provide a mechanism for benchmarking and assuring the quality of wave forecast model products that contribute to applications such as safety of life at sea, ship routing and the Global Maritime Distress and Safety System.

This original intercomparison was developed around the exchange of model forecast data at an agreed list of moored buoy sites at which instrumented observations of significant wave height, wave period and wind speed are available over the WMO GTS. Five centres routinely running global wave forecast models contributed to the original exchange.

In subsequent years the verification exchange expanded with the inclusion of data from additional centres, with 12 operational centres now participating (see Appendix 1). Whilst access to the results from the intercomparison is restricted to the participating centres, the intercomparison work has been published (Bidlot et al., 2002; Bidlot et al., 2006) and presented at numerous international conferences (e.g. Bidlot et al., 2007).

The current exchange retains the methodology of the original exchange, with each centre providing a file of model data collocated with the buoy locations in an agreed format to ECMWF on a monthly basis. The datasets are collated and then processed to provide statistics for each centre at each buoy. Observation data are also collated at ECMWF, and are quality controlled, with wind speeds adjusted to 10m height.

A range of statistics are produced and plotted routinely as a function of forecast lead time, including:

- Bias
- RMS errors
- Correlation coefficient
- Scatter index (the standard deviation of the difference from the observations normalised by the mean of the observations)
- Symmetric slope (the ratio of the variance of the model and the variance of the observations)

In addition, time series of model and observation values, and scatter plots of model vs observation values are plotted. Each of these statistics is generated for significant wave height, peak period, and wind speed against individual buoys, and for groups of buoys by region. The verification data sets are also available to allow centres to calculate their own statistics to meet their specific requirements. Further details of the verification exchange can be found in Bidlot et al., 2007.

In 2003, the WMO/IOC Joint Commission on Oceanography and Marine Meteorology (JCOMM) endorsed the intercomparison exchange through the Expert Team on Wind Waves and Storm Surges (ETWS). The mandate of the JCOMM ETWS includes international coordination of validation work, and noting the value of the exchange the ETWS have taken responsibility for oversight of the work.

At a meeting in Geneva in March 2007 the ETWS discussed a number of proposals for future development of the exchange (JCOMM ETWS, 2007), and formed a working group to take forward the key recommendations. Alongside continuing to widen participation in the exchange, ETWS endorsed the expansion of the exchange in three principal areas:

- Validation against altimeter wave height data

- Validation against spectral buoy data
- Intercomparison of spatial data

Working group members were assigned to take forward each of the three areas, and in particular the Met Office and Meteo France were tasked with developing the intercomparison of spatial data.

2. Spatial intercomparison

The motivation for development of spatial intercomparison arises from recognition of some of the limitations of the summary statistics in terms of providing insight into the differences in performance between the operational systems. The existing summary statistics have provided an invaluable assessment of the relative performance of the systems, but, due to the necessary time and space averaging required to provide robust statistics, are limited to broad scale assessments.

To some extent this limitation can be overcome by examination of time series at particular buoy locations. However, the in situ buoy observations are sparse and unevenly distributed, and hence the sampling is limited. Furthermore, comparison of information at single points does not provide any context in relation to the prevailing conditions. For example, a front or low pressure system that is displaced by a small distance in its representation in the driving NWP fields could lead to significant differences at a point close to the edge of the system, whilst the prevailing meteorological conditions could be relatively consistently represented. Figure 1 shows a schematic example of a low pressure system passing a validation point. An accurate representation of the strength of the system but with a displacement of the trajectory (Figure 1b) would lead to reduced wave height estimates, as would an accurate trajectory, but with an underestimate of the strength (Figure 1c). Whilst these two errors could not necessarily be distinguished through examination of data at the validation point, comparison of spatial fields would allow such situations to be easily diagnosed and understood.

Similar considerations apply to the representation of swells that travel over long distances. Differences between the operational systems that lead to small differences in the direction of travel, dissipation, or speed of travel may be magnified over the long distances involved, leading to differences in arrival time or magnitude of the swell at a particular point location. Spatial intercomparisons can potentially help to provide insight into these differences, and can provide some context for the differences observed at the point locations in such circumstances.

Whilst the potential advantages of spatial intercomparisons are clear, the practicalities of routine, effective intercomparison are not necessarily straightforward. Figure 2 shows an example of intercomparison of fields from three different centres for a case of a typhoon off of Japan. Whilst using Figure 2 to identify the most significant differences between the models is straightforward, more in depth analysis is hampered by differences in presentation between the three fields. Firstly, the fields in Figure 2c are plotted using a different colour scale, making visual intercomparison difficult. Secondly, the fields are overlaid with different items (wind vectors in Figure 2a, in situ observations in Figure 2b). Whilst each of these issues is straightforward to address, this example illustrates the need for a systematic methodology for intercomparison of spatial data.

Methodologies for systematic intercomparison of data have been developed in other areas. For ocean forecasting models intercomparison of estimates of the full ocean state were developed within the Marine Environment and Security for the European Area (MERSEA) Strand 1 project (Johannessen et al., 2003; http://strand1.mersea.eu.org) and are continuing within the MERSEA Integrated

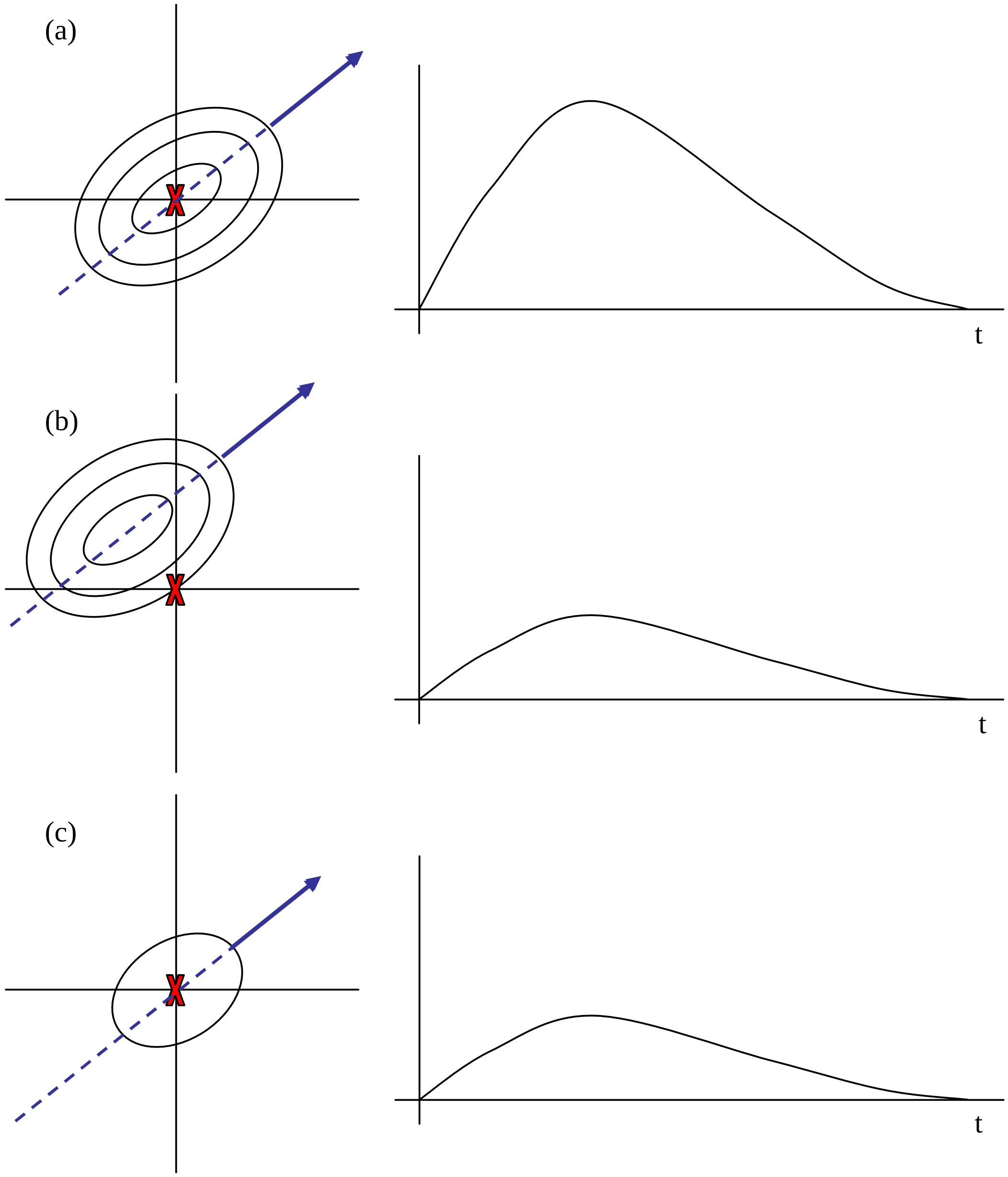
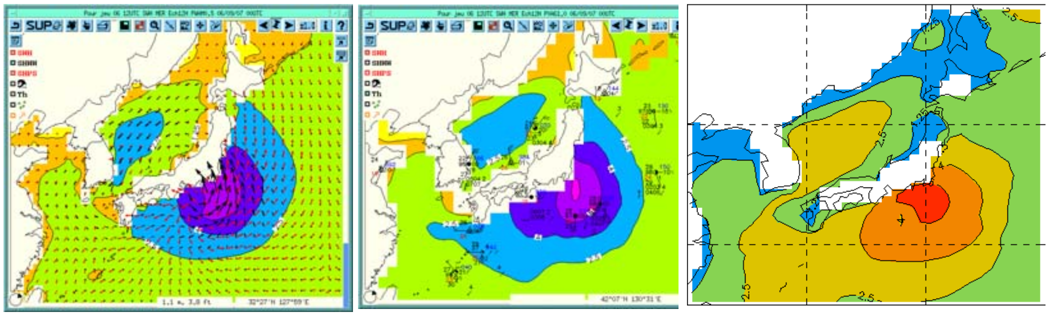


Figure 1: Schematic illustration of the limitation of point validation. Representation of a low pressure system, and associated wave height response (a) with path and magnitude correctly forecast; (b) with correct magnitude but incorrect trajectory forecast; (c) with correct path, but underestimated magnitude.



(a) (b) (c)

Figure 2: Intercomparison of spatial fields from three wave forecast systems.

Project (http://www.mersea.eu.org). These intercomparisons were seen to be extremely effective, aiding with the diagnosis of issues with particular systems, and consequently contributing to overall improvement in the quality of products provided by the ocean forecasting systems. The success of this intercomparison work was largely attributed to the significant effort devoted to standardisation of outputs and presentation (Crosnier and Le Provost, 2007).

A more sophisticated methodology for intercomparison has been developed within the sea surface temperature (SST) community, in particular within the GODAE High Resolution SST Pilot Project (GHRSST-PP, Donlon 2004). The motivation for development of an SST intercomparison system is the requirement to reconcile the various data records provided by the range of satellite SST sensors in order to provide a consistent set of satellite SST data products, and to compare these to various analysis and model products.

This requirement has led to the development of a comprehensive intercomparison system within GHRSST-PP, the High Resolution Diagnostic Data Set (HRDDS, www.hrdds.net) system. The basic philosophy behind the HRDDS system is to define a number of small, representative areas over which all available data are provided for comparison, with data presented in a consistent format through a web interface. The system is designed to retain the underlying numerical data for each area, allowing the potential to calculate statistics for each of the HRDDS areas. The use of a number of small areas is aimed at making intercomparisons more tractable than when dealing with full global fields.

The potential to develop the HRDDS system for use in wave model intercomparisons was recognised by the ETWS, given the similarities in the nature of surface wave data to that of SST data. ETWS endorsed development of a prototype Waves HRDDS system as a complementary approach to the on-going verification exchange based on buoy data.

3. The High Resolution Diagnostic Dataset System

The high resolution diagnostic data set system is an integrated sea surface temperature analysis and archive system hosted by the National Oceanography Centre, Southampton (NOCS). It was created to provide an archive of diagnostic SST data extracted from GHRSST-PP data products and to provide users with a web-based set of tools for displaying and comparing the statistics of the diagnostic data.

3.1 HRDDS system architecture

The HR-DDS system comprises a number of independent system components brought together through two linked databases. The major system components are described in the following text.

Registration database

The registration database is a MySQL relational database with the purpose of linking each HRDDS granule with the source file from which it was derived. It also records such information as the processing and ingestion times, the location of the produced files within the archive system, along with a description of each of the available input sources. Since this information is stored for each source file, and because each HRDDS granule is referred to one unique entry within this database, it becomes easy to establish the history and status of each and every entry within the HRDDS system.

Statistical database

The statistical database is a MySQL relational database that records, for every geophysical field in every produced HRDDS granule, the following statistical results:

- Arithmetic mean field value.
- Quadratic mean field value (RMS).
- Median field value.
- Standard deviation of field.
- Maximum and minimum value of field.
- Kurtosis and skew of field distribution.

There are presently almost 6 million individual statistics within the statistical database. Each item of statistical data is linked, through relational mapping within the database, to the HRDDS granule from which they where derived, and hence also to the original source file. This allows for extremely fast and efficient analysis of the performance of individual datasets.

Ingestion system

The HR-DDS ingestion system is capable of ingesting any netCDF based product, providing the product is suitably documented. Additionally, other sources (e.g. GRIB) may be ingested when a conversion routine specific to that dataset is provided or developed. The ingestion system can be configured either to pull the data from an FTP server, or to access files that have been delivered to the HRDDS FTP server.

The ingestion system records the relative performance and reliability of each of these interfaces and is capable of sending automatic email reports to each provider in the event of an error or poorly performing connection.

Processing system

The purpose of the processing system is to receive temporary files provided by the ingestion system and produce HRDDS granules, quick look imagery and XML metadata records. The original data fields are resampled into the granules at a spatial resolution of 1/100°, irrespective of the original resolution, using nearest neighbour substitution.

Archive system

The HRDDS archive system periodically analyses the temporary output archive and determines the correct location for each file within the FTP archive linked to the web portal. Files are uploaded and verified, and their details modified within the registration database.

Dissemination system

All HRDDS granules are also made available via OPeNDAP, a reworked version of the DODS protocol. This allows for automatic ingestion of data over the web into clients such as MATLAB or IDL as if the remote file were a local variable.

3.2 HRDDS system user interface

The user interface to the HRDDS (www.hrdds.net) is provided by a clickable map of the HRDDS areas (Figure 3). Clicking on an area within the map links to a data access page for the data valid in that area.

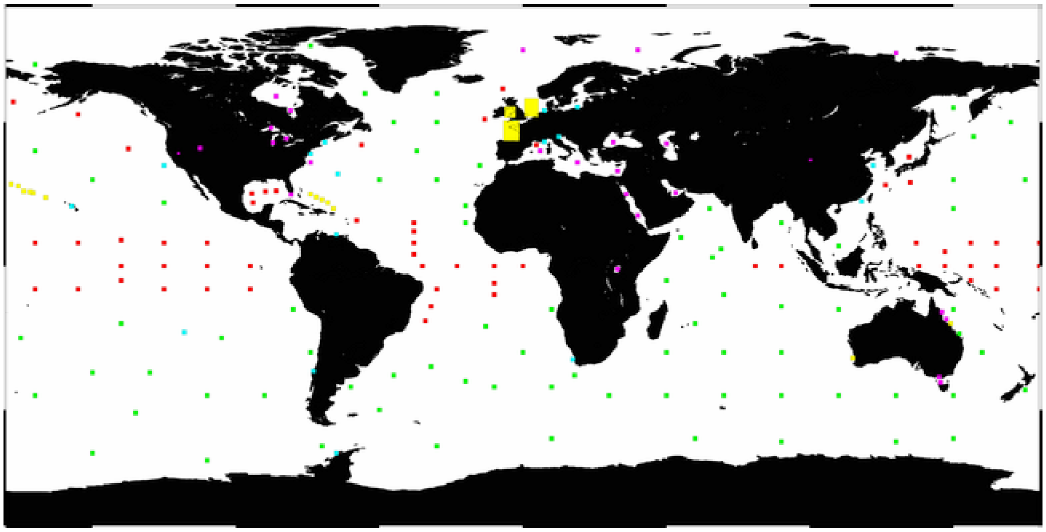


Figure 3: Map of HR-DDS areas. Each coloured box represents one area. Clicking on a box provides access to the data valid for that box.

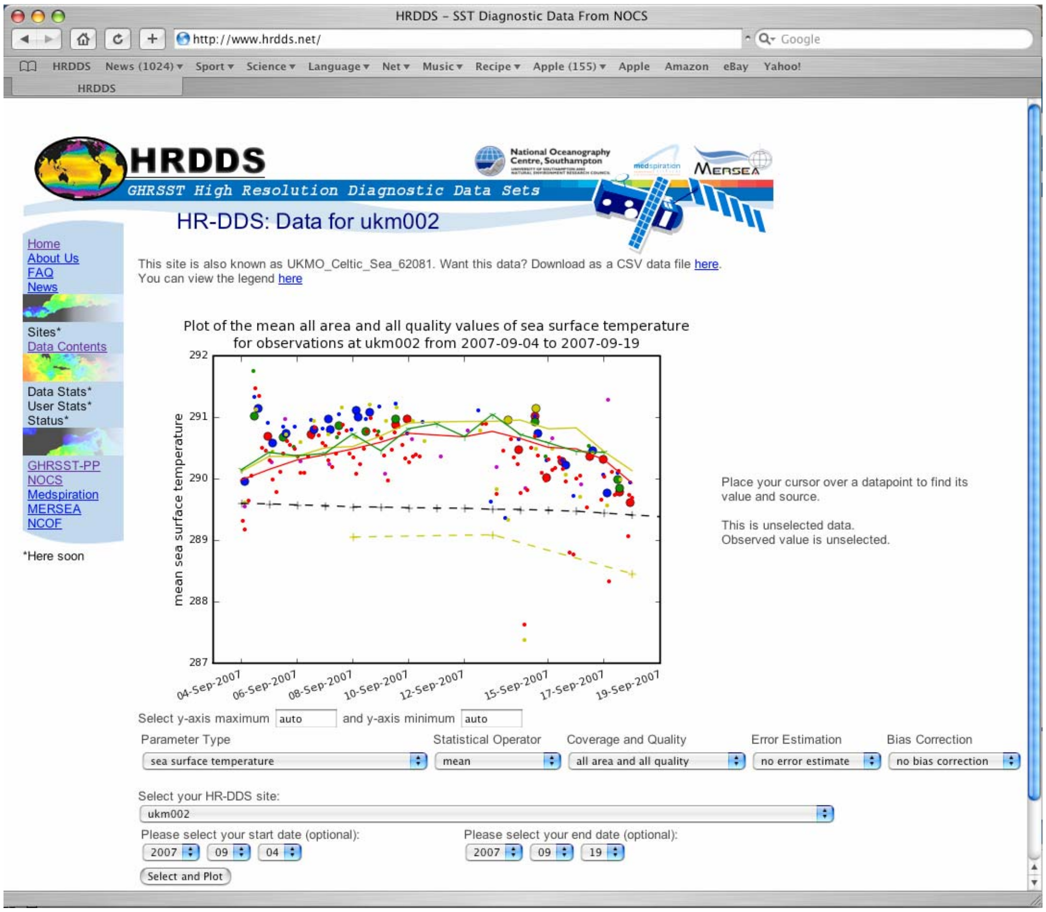
The data access page (Figure 4) provides a basic plot of a recent time series of the mean of the various data sets over the area, together with the functionality to generate plots of additional parameters, for different statistics (e.g. rms, max / min values) or for different time series dates.

Within the plots on the data access page, each point is clickable, and leads to the spatial observations for the HR-DDS area (Figure 5). All observations received within that day for all available platforms are presented.

4. Waves HRDDS system

The HRDDS approach could be applied for intercomparison and verification of gridded wave model output, with inclusion of appropriate in situ and satellite data, and would provide an ideal methodology for extension of the wave forecast verification exchange. Given the expertise built up at NOCS, the Met Office has provided funding to them to develop an initial demonstration of the Waves HRDDS.

The initial demonstration will primarily focus on model intercomparisons, in particular comparison on integrated parameters, to include significant wave height, wave period (precise diagnostic to be defined), wave direction, and wind speed and direction. This list of parameters could clearly be extended in the future to include additional fields such as maximum wave height and wave steepness.



HR-DDS: Data for ukm002

This site is also known as UKMO_Celtic_Sea_62081. Want this data? Download as a CSV data file here.
You can view the legend here

Plot of the mean all area and all quality values of sea surface temperature for observations at ukm002 from 2007-09-04 to 2007-09-19

Place your cursor over a datapoint to find its value and source.

This is unselected data.
Observed value is unselected.

Select y-axis maximum: auto
and y-axis minimum: auto

Parameter Type: sea surface temperature
Statistical Operator: mean
Coverage and Quality: all area and all quality
Error Estimation: no error estimate
Bias Correction: no bias correction

Select your HR-DDS site: ukm002

Please select your start date (optional): 2007 09 04
Please select your end date (optional): 2007 09 19

Figure 4: HR-DDS data access page.

Inclusion of satellite altimeter wave height data is viewed as a high priority as this provides the best potential for comparisons over the global ocean. Inclusion of along-track wave height data within each HRDDS area is a natural step, to provide some ground truth as a reference with which to compare the model outputs. Innovative altimeter data derived products, such as wave period (e.g. Mackay et al, 2007), could be included as a subsequent enhancement of the system.

In situ data provide another key data set for inclusion, though the sparse distribution of the data means that in situ observations would not be available in many of the HRDDS areas. Work is currently underway to develop techniques for inclusion of in situ SST data in the SST HRDDS, and these techniques could readily be adapted for use with in situ wave height and period data.

Full 2D spectral data, both in situ and satellite derived, potentially presents a greater challenge, not only due to the data volumes involved, but also due to the nature of the data which is not ideally suited to spatial intercomparisons. However, the flexibility of the HRDDS would enable spectral data to be made available at another level within the system, for example clicking a particular point in an HRDDS area could link to the spectral data for that point. This would enable inclusion of in situ spectral data, and Synthetic Aperture Radar (SAR) derived spectral data. A further interesting possibility would be inclusion of SAR imagettes within the system to provide comparisons that would be of interest to the community developing SAR retrieval methods.

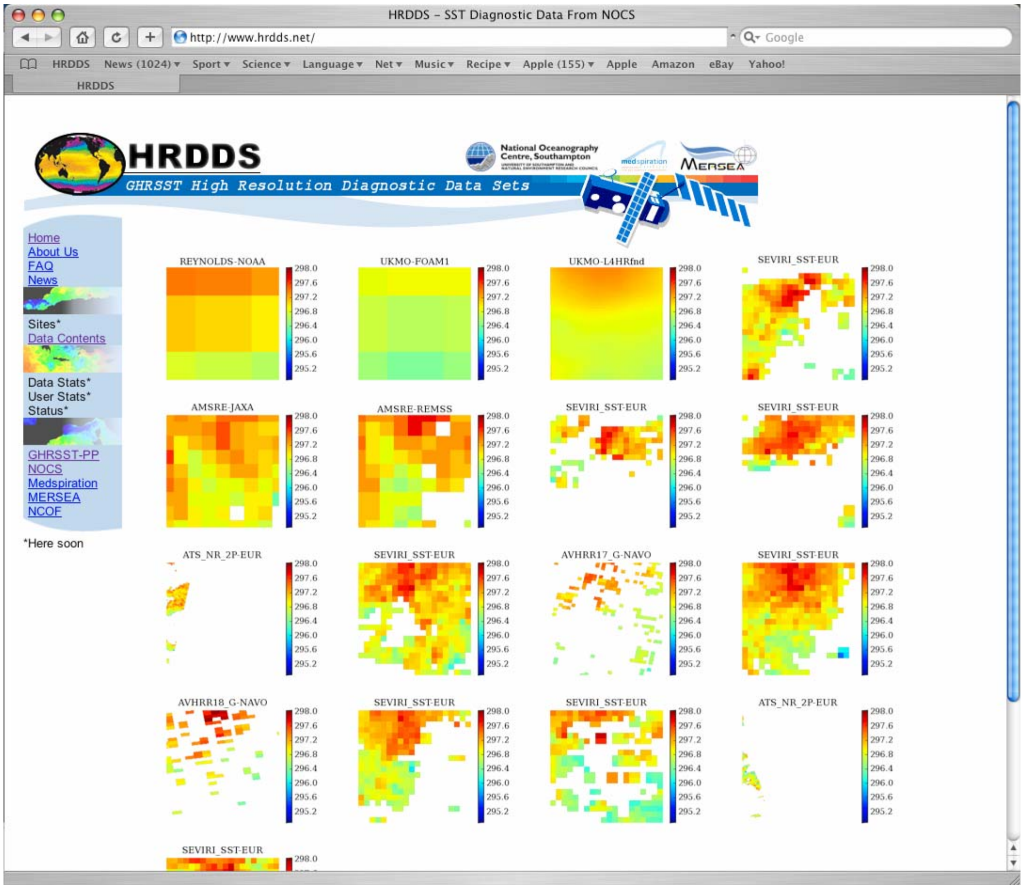


Figure 5: HR-DDS spatial data comparison page.

In order to develop the demonstration system, a small number of participants have been identified to provide initial data sets, with the expectation that the system will subsequently be made available to all participants. Participating centres will be required to provide files in an agreed standard format, which could potentially involve routine delivery of large data volumes.

There are a number of issues that would ideally need to be addressed prior to the full establishment of the Waves HRDDS as a component of the operational wave forecast verification exchange. Most notably, exchange of full fields of real-time data may pose issues with data policy for operational centres, hence suitable agreements need to be in place. Initially access to the Waves HRDDS system would be limited to the participating centres, although in the longer term ETWS is exploring options for making the intercomparison exchange outputs more widely available in a manner that protects the interests of the participants.

Finally, whilst the initial development of a demonstration system has been funded by the Met Office, the subsequent development and support for a full Waves HRDDS system will be dependent upon appropriate sustainable funding being identified. European opportunities for this are currently being explored.

5. Summary

The operational wave forecast verification exchange that has operated for over a decade has provided an invaluable tool for evaluation of the performance of the operational wave forecasting systems. Under the auspices of the JCOMM ETWS, work is underway to build upon this success by expanding the exchange to include comparison to altimeter data and to spectral buoy data, and intercomparison of spatial fields. The latter is motivated by the additional insight that can be gained through examining fields of data, providing context that cannot be given through point comparisons.

Previous intercomparison projects, such as work within Mersea, have highlighted the challenges in intercomparing outputs from diverse systems, and have noted the advantage of ensuring consistency in data presentation.

The High Resolution Diagnostic Data Set system used for comparison of sea surface temperature data from a variety of sources has been designed to provide systematic intercomparisons with consistent data presentation. The system has the flexibility to deal with model data, satellite data, and in situ observations, and provides access to data visualisation and manipulation tools through a web interface.

The potential to apply the HRDDS system to the intercomparison of wave forecasts has been identified, and the development of a demonstration system is underway. The inclusion of satellite altimeter and in situ buoy wave height data, and spectral data from in situ buoys and Synthetic Aperture Radar, have been identified as natural future developments to the system, with the potential to also include innovative products such altimeter derived wave period.

Whilst there are some issues to be overcome, most notably in terms of data policy, in order to establish the waves HRDDS as part of the intercomparison exchange, the system has the potential to provide additional insight into the performance of the operational wave forecasting systems.

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Appendix 1: Participants in the verification exchange.

As of September 2007 the following twelve centres were participating in the operational wave forecast verification exchange:

- European Centre for Medium range Weather Forecasts
- The Met Office
- Fleet Numerical Meteorology and Oceanography Centre
- Meteorological Service of Canada
- National Centers for Environmental Prediction
- Météo France
- Deutscher Wetterdienst
- Bureau of Meteorology
- Service Hydrographique et Océanographique de la Marine
- Japan Meteorological Agency
- Korea Meteorological Administration
- Puertos del Estado

For further details of the participating systems see Bidlot et al., 2007.