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Summary

Tropical Cyclone Heat Potential (TCHP) is a measure of the integrated vertical temperature from the sea surface to the depth of the 26°C isotherm, approximately to 50m depth. It is computed globally from altimeter-derived vertical temperature profiles. Unlike sea surface temperature (SST) it is a measure of the subsurface ocean thermal structure, which is strongly correlated with sea surface height and plays a strong role in the intensification of tropical cyclones.

The TCHP product provided via eSurge has been made available through the Atlantic Oceanographic and Meteorological laboratory1, and has been funded by NASA and NOAA at different stages of the project. The sea surface height and temperature products incorporated in the TCHP are supplied by the CLS Space Oceanography division2, France, and Remote Sensing3, USA, respectively. The eSurge project gratefully acknowledges NOAA for making this data available to us.

This product handbook was compiled for the eSurge Project, funded by the European Space Agency under the ESA Data User Element (DUE) Programme. It provides a broad introduction to the product and specifications, indicating the further literature sources where more advanced and comprehensive knowledge can be obtained.

For more information on the eSurge project go to http://www.storm-surge.info/.

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1 www.aoml.noaa.gov/phod/cyclone
2 www.cls.fr
3 www.remss.com/tmi/
Abbreviations and Acronyms

Table 0-1 lists the acronyms and abbreviations used within this document.

Table 0-1: Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
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<tr>
<td>AOI</td>
<td>Area of Interest</td>
</tr>
<tr>
<td>AOML</td>
<td>Atlantic Oceanographic and Meteorological Laboratory</td>
</tr>
<tr>
<td>BODC</td>
<td>British Oceanographic Data Centre</td>
</tr>
<tr>
<td>BOOS</td>
<td>Baltic Sea Operational Oceanographic System</td>
</tr>
<tr>
<td>CMRC</td>
<td>Coastal and Marine Research Centre</td>
</tr>
<tr>
<td>DMI</td>
<td>Danmarks Meteorologiske Institut (Danish Meteorological Institute).</td>
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<tr>
<td>DUE</td>
<td>Data User Elements</td>
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<td>DUP</td>
<td>Data User Programme</td>
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<tr>
<td>EO</td>
<td>Earth Observation</td>
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<tr>
<td>EOEP</td>
<td>Earth Observation Envelope Programme</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>EUMETSAT</td>
<td>European Organisation for the Exploitation of Meteorological Satellites</td>
</tr>
<tr>
<td>KNMI</td>
<td>Koninklijk Nederlands Meterologisch Instituut (Royal Netherlands Meteorological Institute)</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<tr>
<td>NERC</td>
<td>Natural Environment Research Council (UK)</td>
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<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<tr>
<td>NOC</td>
<td>National Oceanographic Centre</td>
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<tr>
<td>NOOS</td>
<td>North West Shelf Operational Oceanographic System</td>
</tr>
<tr>
<td>SSA</td>
<td>Sea Surface Anomaly</td>
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<tr>
<td>SSH</td>
<td>Sea Surface Height</td>
</tr>
<tr>
<td>SST</td>
<td>Sea Surface Temperature</td>
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<tr>
<td>TCHP</td>
<td>Tropical cyclone heat potential</td>
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<tr>
<td>UCC</td>
<td>University College Cork</td>
</tr>
<tr>
<td>WOND</td>
<td>The weather research section of the Royal Netherlands Meteorological Institute</td>
</tr>
<tr>
<td>OSI SAF</td>
<td>Ocean and Sea Ice Satellite Application Facility (of EUMETSAT)</td>
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</table>
1. THE TROPICAL CYCLONE HEAT POTENTIAL DATA PRODUCT (HP1)

1.1 Introduction

Tropical Cyclone Heat Potential (TCHP) is a measure of the integrated vertical temperature from the sea surface to the depth of the 26°C isotherm, approximately to 50m depth. It is computed globally from altimeter-derived vertical temperature profiles. Unlike sea surface temperature (SST) it is a measure of the subsurface ocean thermal structure.

The TCHP product provided via eSurge has been made available through the Atlantic Oceanographic and Meteorological laboratory\(^4\), and has been funded by NASA and NOAA at different stages of the project. The sea surface height and temperature products incorporated in the TCHP are supplied by the CLS Space Oceanography division\(^5\), France, and Remote Sensing\(^6\), USA, respectively. The eSurge project gratefully acknowledges NOAA for making this data available to us.

![Figure 1-1: altimeter-derived estimates of Tropical Cyclone Heat Potential (TCHP) for August 28, 2005 (Hurricane Katrina)](image)

1.2 Tropical Cyclone Heat Potential (TCHP) Data - the principals behind the data

Sea surface temperature (SST) provides a measure of the surface ocean conditions, however no information about the subsurface ocean thermal structure (approximately the upper 50 m of the ocean) can be derived from SST alone. For instance, it is known that the oceanic skin temperature

\(^4\) [www.aoml.noaa.gov/phod/cyclone](http://www.aoml.noaa.gov/phod/cyclone)
\(^5\) [www.cls.fr](http://www.cls.fr)
\(^6\) [www.remss.com/tmi/](http://www.remss.com/tmi/)
erodes when the sea surface is affected by strong winds, creating a well-mixed layer that can reach depths of several tens of meters. Moreover, warm ocean features, mainly anti-cyclonic rings and eddies, are characterized by a deepening of the isotherms towards their centers with a markedly different temperature and salinity structure than the surrounding waters. Several studies have shown that observations of sea surface height (SSH) are strongly correlated with the thermal structure of the upper ocean (e.g. Goni et al. 1996; Gilson et al. 1998; Mayer et al. 2001; Willis et al. 2004). Based in this virtually ubiquitous relationship, a methodology was developed to estimate fields of isotherm depth from the SHA fields derived from satellite observations.

The Tropical Cyclone Heat Potential (TCHP), is defined as a measure of the integrated vertical temperature from the sea surface to the depth of the 26°C isotherm. The TCHP can be considered as the anomalous heat storage associated with temperatures larger than 26°C. This parameter is computed globally from the altimeter-derived vertical temperature profiles estimates in the upper ocean (Shay et al., 2000). Different methods have been developed to calculate this vertical thermal structure of the upper ocean.

### 1.3 From Data to Product

The methodology used (version 2.1) to estimate the TCHP is described fully on NOAA’s TCHP page. The algorithm steps are the following:

- In-situ temperature profiles obtained mostly from eXpendable BathyThermograph and profiling-float observations from 1992 to 2006 are grouped in 3°×3° bins with a 1°×1° resolution.
- The depth of the 26°C to 28°C isotherms is estimated from each profile.
- The weekly SHA gridded fields derived by AVISO are interpolated into the location and time of the temperature profiles.
- In each 1°×1° bin the depth of each isotherm is linearly regressed onto the corresponding SHA value.
- Only regression parameters that are statistically significant within a 1-sigma level are considered. Any small gaps in the resulting fields of regression parameters are interpolated.
- In each 1°×1° bin a synthetic temperature profile is derived from the regression parameters and the daily real-time SHA fields distributed by AVISO. These synthetic profiles are completed with global TMI-AMSR-E SST fields for the z = 0 temperature.
- The TCHP field, the anomalous heat storage associated with temperatures larger than 26°C, is computed from each synthetic temperature profile.

To prepare the data for import into eSurge database, the NOAA data have been transferred into standard NetCDF format. (They were originally provided as ASCII files.)
1.4 Product Validation

The satellite derived TCHP measurements provided in this product have been validated by Nagamani et al. against in-situ measurements in the North Indian Ocean\(^9\). No independent validation has been performed by the eSurge project, as such it is highly recommended that users consult the validation work by Nagamani et al.

1.5 Potential Uses of Tropical Cyclone Heat Potential (TCHP) Data in Storm Surge Applications

TCHP is very relevant for the study of surges caused by tropical cyclones. It is highly correlated to sea surface height and is also related to storm intensity, making it an important parameter for modelling surges and their generation accurately\(^10\).

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\(^9\) [http://www.aoml.noaa.gov/phod/docs/tchp-val.pdf](http://www.aoml.noaa.gov/phod/docs/tchp-val.pdf)
\(^10\) [http://www.aoml.noaa.gov/phod/docs/I-Ilin.pdf](http://www.aoml.noaa.gov/phod/docs/I-Ilin.pdf)
2. PRODUCT DETAILS

2.1 Technical Description

2.1.1 File Type

Each DEM file is a NetCDF (.nc) file.

More information on NetCDF can be found in the NetCDF users guide\textsuperscript{11}.

2.1.2 File Names

TCHP data are computed daily. The filenames made available are of the format

\{year\}{month}\{day\}_TCHP.nc

For example 20071114_TCHP.nc is a TCHP file relating to cyclone Sidr.

2.1.3 File Sizes

The file sizes of the data vary, but are typically ~500MB/image.

2.1.4 Global Attributes

Only the netCDF convention (1.4) and the data date are saved as global attributes.

2.2 Technical Description

2.2.1 Parameters

Each file contains the variables:

- Latitude (array of M points)
- Longitude (array of N points)
- TCHP (grid of MxN points)

2.2.2 Latitude and Longitude

Latitude and longitude are given in degrees north (range -40 to +40) and degrees east (-180 to +180) respectively.

2.2.3 Tropical Cyclone Heat Potential

The TCHP is given in units of KJ/cm\textsuperscript{2}. A value of NaN signifies that the point is over land.

\textsuperscript{11} \url{https://www.unidata.ucar.edu/netcdf/docs/netcdf.html}
2.3 Accessing the Product

For many storm cases (events) where storm-surges are reported to have arisen, data have been collected and made available through the eSurge web-service (see www.storm-surge.info shown in figure 2-1). We would encourage users to look up these events and the suite of data products contained on the facility database.
2.3.1 Viewing the product in the eSurge website

The eSurge web-service provides users with a number of ways to explore and assess the utility of data they are interested in. Upon navigating to a storm surge event of interest (e.g. Cyclone Sidr shown in figure 2-3), the individual datasets can be previewed (figure 2-4) using the preview tab alongside the dataset name as shown encircled in figure 2-3. Alongside the dataset name also lies the link to view global attributes and dataset information through the OPeNDAP viewer (figure 2-5).

Alternatively, users can quick link to the eSurge GIS web-viewer, where they can visualise and explore all the datasets available concerning the event (figure 2-6).

Figure 2-3: The Cyclone Sidr dataset inventory on the eSurge web-service. Preview option links are encircled.
Figure 2-4: Previewing a Cyclone Sidr inundation dataset using the Preview link.

Figure 2-5: Viewing dataset metadata and information using OPeNDAP.

Figure 2-6: Exploring Cyclone Sidr datasets in the eSurge GIS web-viewer.
2.3.2 Download the product

If users are satisfied that the product suits their purposes, there is an option to download the data using the OPenDAP dataset information window (figure 2-7). Simply click on the “Get ASCII” or “Get Binary” tab to download the data. Note that the ability to download requires registration.

![Image of OPenDAP dataset query form]

Figure 2-7: downloading data using the OPenDAP dataset information page (tabs encircled).

2.3.3 Accessing the product outside eSurge

In addition to the data available through eSurge, daily global and regional maps can be obtained via the AOML/NOAA website.

2.4 Using the Product

Useful tools to work with the NetCDF TCHP data are Python (with netCDF4 and matplotlib libraries) and IDV for plotting. For manipulating the data NCO offers many tools, and Python offers higher level tools as well as low level manipulation of the data. Of course commercial software as Matlab and IDL also provides all capabilities.

12 [http://www.aoml.noaa.gov/phod/cyclone/data/gl.html](http://www.aoml.noaa.gov/phod/cyclone/data/gl.html)
2.5 Constraints on Use

The TCHP data is made freely available by the Atlantic Oceanographic & Meteorological Laboratory (AOML), however they request that all publications that use this data add the following acknowledgement:

"The Tropical Cyclone Heat Potential (TCHP) is made freely available by the Atlantic Oceanographic and Meteorological Laboratory (www.aoml.noaa.gov/phod/cyclone) and has been funded by the NASA and NOAA at different stages of the project. The sea surface height and temperature products incorporated in the TCHP are supplied by the CLS Space Oceanography Division, France (www.cls.fr) and Remote Sensing, USA (www.remss.com/tmi/) respectively."

The Atlantic Oceanographic & Meterological Laboratory (AOML) project scientists would also appreciate it if you informed them of any publications or presentations that you prepare using this data. Continued funding of this project depends on being able to justify to NOAA the usefulness of this data. The AOML communications officer can be contacted at Erica Rule@noaa.gov

Under no circumstances should this free data be copied to third parties. Use of the data implies the user will register their intent to use it either when obtaining it from the eSurge web facility, or when obtaining it from the AOML project directly. For data obtained from the eSurge website, user registration is essential to assess the success and performance of the eSurge web-service as it allows monitoring of data use and future tailoring of product availability to user needs. Also note that use of the data obtained through eSurge implies that the user is agreeing to give proper accreditation to both the AOML as data originators and the eSurge project data providers in any publications arising from the data’s use.

A suggested accreditation would be:

"The Tropical Cyclone Heat Potential (TCHP) is made freely available by the Atlantic Oceanographic and Meteorological Laboratory (www.aoml.noaa.gov/phod/cyclone) and has been funded by the NASA and NOAA at different stages of the project. The sea surface height and temperature products incorporated in the TCHP are supplied by the CLS Space Oceanography Division, France (www.cls.fr) and Remote Sensing, USA (www.remss.com/tmi/) respectively. Data were obtained using the ESA-funded online eSurge data facility."
3. FURTHER INFORMATION AND CONTACTS

For queries regarding Tropical Cyclone Heat Potential (TCHP) Data, please do not hesitate to contact: the NOAA's Atlantic Oceanographic and Meterological Laboratory (AOML) project at the following points:

- For technical questions, please contact:
  - Joaquin Triananes (Joaquin.Triananes@noaa.gov)
  - Francis Bringas (Francis.Bringas@noaa.gov)
  - Ricardo Domingues (Ricardo.Domingues@noaa.gov).

- For scientific questions please contact:
  - Gustavo Goni (Gustavo.Goni@noaa.gov).

For queries regarding the eSurge Project, please do not hesitate to contact:

General eSurge contact: Phil Harwood (esurge@outlook.com)

Website http://www.storm-surge.info

For queries regarding the European Space Agency (ESA) Data User Elements (DUE) Programme, see http://due.esrin.esa.int/
4. REFERENCES AND RECOMMENDED FURTHER READING


ANNEX A: THE ESURGE PROJECT

A.1 About eSurge

Despite the potential utility of satellite data, the storm surge community has not made as much use of it as they could. Largely this is due to the lack of easy data access. Different datasets are stored in different locations, in different data formats and with different access requirements. eSurge aims to change this, bringing relevant datasets together in an easy to use, web-accessible database of data products, downloadable in a standardised format.

The eSurge project is being run in two phases. During the initial Development Phase (Phase 1) we have built the database, known as SEARS (Surge Event Analysis and Repository Service), and populated it with initial data for a selection of historical surge events. This will give a useful library that can be used for assessing and improving the performance of numerical models. Whilst most of the datasets are already available, and just need to be imported into the database, others are being created during the project.

Following the launch of the SEARS database, eSurge will move into a Service Demonstration phase (Phase 2). During this phase we will continue to add more historical data, but will also look at making data available for surge events as they occur. The aim is to show that it is feasible to provide satellite data in near real time, so that it could potentially be used in forecasting and warning systems.

It is important to note that eSurge is not itself a forecasting and warning system, it is a system to make data available to forecasters. There are dedicated agencies (such as the UK Environment Agency) whose role it is to warn of impending flooding.

Making the data available is just part of the process of getting people to use it; we must also show the value of the data. To this end our partners at DMI and NOC will perform a series of experiments, focussing on the North Sea and North Indian Ocean. These will take existing models, such as DMI’s HBM model and NOC’s operational CS3X surge model, and will look at how incorporating satellite data could improve the models’ hindcast accuracy. These experiments will also investigate the best way to incorporate satellite data into models. This is a complex subject, and we do not expect to be able to resolve it in this project, but we aim to pave the way for future work.
A.2 The eSurge Consortium

The eSurge consortium consists of CGI (UK), the National Oceanography Centre (UK), the Danish Meteorological Institute (DK), University College Cork’s Coastal and Marine Research Centre (IRL) and the Royal Dutch Meteorological Institute (NL).

Consultants to Government and Industry (CGI) was founded in 1976, and is a global IT and business process services provider delivering business consulting, systems integration and outsourcing services. With 72,000 professionals operating in 400 offices in 40 countries, CGI fosters local accountability for client success while bringing global delivery capabilities to clients’ front doors. CGI applies a disciplined and creative approach to achieve an industry-leading track record of on-time, on-budget projects and to help clients leverage current investments while adopting new technology and business strategies. As a result of this approach, our average client satisfaction score for the past 10 years has measured consistently higher than 9 out of 10. We have a dedicated international Space and Satcoms business with over 300 specialists and a long track record in delivering mission critical software systems across the Space sector, and in particular for Navigation and GNSS systems. We have worked on many ESA Earth Observation projects, including GlobWave, CCI, GECA, PALSAR and many others.

The National Oceanography Centre (NOC) is a wholly owned centre of the Natural Environment Research Council (NERC). The NOC was formed by bringing together the NERC-managed activity at Liverpool’s Proudman Oceanographic Laboratory and the National Oceanography Centre, Southampton, creating the UK’s leading institution for sea level science, coastal and deep ocean research and technology development. The NOC hosts both the National Tidal and Sea Level Facility, and the Permanent Service for Mean Sea Level (since 1933), and contributes to the Storm Tide Forecasting Service (STFS), developing operational tide-surge models that provide UK coastal flood warning (in partnership with the Met Office and the Environment Agency). It has been at the forefront in developing interfaces to data sources and information. NOC have been involved in ESA funded projects such as COASTALT, GlobColour and GlobWave.

The Danish Meteorological Institute (DMI) is a public institute, providing meteorological, oceanographic and related services for the people of the Kingdom of Denmark (Denmark, the Faroe Islands and Greenland). DMI’s area of activity comprises forecasting and warning services as well as continuous monitoring of weather, sea state, climate, and related environmental conditions in the atmosphere, over land and in the sea. As such, it has national responsibility for carrying out storm
surge model forecasts and issuing warnings for Danish areas to the Danish coastal authorities and the public in general. DMI is part of the Baltic Sea Operational Oceanographic System (BOOS) and North West Shelf Operational Oceanographic System (NOOS). DMI play the role as the real-time in-situ sea level centre for the BOOS and NOOS communities. In the MyOcean project DMI leads the Baltic Model Forecasting Centre providing real-time ocean forecasting for the Baltic Sea. DMI is part of the High Resolution Local Area Modelling (HRLAM) developing consortium within numerical weather predictions. DMI is operationally running a number of numerical forecast models for European and Arctic regions, alongside regional and large scale ocean models (HBM and HYCOM). DMI is part of a collaboration developing a coupled atmosphere, ocean and sea ice climate model (EC-Earth), whilst a high resolution coupled ocean and ice forecast model (HYCOM/CICE) is currently being developed at the institute.

The Coastal and Marine Research Centre (CMRC) in University College Cork was established in 1994 to undertake research into coastal and marine resource management. It is part of the Environmental Research Institute (ERI) and the Irish Maritime and Energy Resource Cluster (IMERC). Research and consultancy in the CMRC is undertaken by staff with a range of specialist backgrounds, all of whom work collaboratively in a project-oriented environment. The Centre’s expertise and skill sets are highly regarded both nationally and internationally. Fundamental and applied research in the CMRC is organised according to five specialist areas of interest: marine geomatics; applied remote sensing and GIS; marine and coastal governance; coastal processes and seabed mapping and marine ecology. The CMRC works with data from a wide range of satellite EO instruments including MERIS, MODIS, SAR and higher resolution optical datasets (e.g. Landsat, IRS, SPOT, and IKONOS) for land, coastal and marine applications. It lies at the forefront of geomatics research with Europe and internationally, with an ability to work with a variety of data in projects such as FP7 NETMAR, FP6 InterRisk and FP5 DISMAR. It has a track record of engaging end users and stakeholders in projects, organising the CoastColour users’ workshop in 2008 and, was part of the organising committee for the European Space Agency’s Space innovation Powering Blue Growth Conference held in Cork in April 2013. The CMRC is currently being merged with sister centres in University College Cork under the banner of Beaufort Research. For further information see www.beaufortresearch.ie.

The Koninklijk Nederlands Meteorologisch Instituut, KNMI, (Royal Netherlands Meteorological Institute) is a government agency operating under the responsibility of the Dutch Ministry of Transport. It provides weather observations, weather forecasts and vital weather information, whilst carrying out applied and fundamental research in support of its operational tasks and as a global change research centre. Skilled and experienced groups, specialising in diverse topics such as instrument development and electronic read-out, automation, computing, operations control and quality control are employed within the institute, providing quality controlled, and cost effective data acquisition and data processing services. As an operational meteorological data centre and research institute in one, KNMI combines its international networks and collaborative projects in a practical way. It is an active member of the World Meteorological Organisation (Geneva, CH), the European Centre for Medium-range Weather Forecasts (Reading, UK) and the European Organisation for the Exploitation of Meteorological Satellites (Darmstadt, G), and Eumetsat’s Ocean and Sea Ice Satellite Application Facility (SAF).
For more information on this product please contact the Gustavo Goni (scientific), or Joaquin Trinanes (technical) of the NOAA/AOML product team at:

   gustavo.goni-AT@-noaa.gov

or

   Joaquin.Trinanes-AT@-noaa.gov

For more information on eSurge please contact Phillip Harwood, eSurge Project Manager, at

   esurge@outlook.com