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# **Coastal Processes**

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**Note:** Course content

For this component of the unit, we will use:

1. a *learning website* where you will find all information relative to the lectures themselves: it contains some **notes**, **videos** and **exercises** for each weeks,
  2. a *web-based programming platform* based on **Jupyter notebooks** that contains all the materials for the **exercises** and **practicals**.
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This part of the course focuses on coastal systems analysis using both ocean data from a variety of sources (hindcast and forecast data, satellite observations, radar, moored buoys) and numerical models of shoreline changes, wave dynamics and coral reef evolution.

The emphasise will be on:

- **How to query and analyse numerical and ocean data?**
  - **What can we learn from ocean and wave models on coastal evolution?**
  - **How to use these models and what are their limitations?**
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**Note:** Today, numerical modelling and ocean data query techniques are routinely applied by governmental agencies, companies and research organisations to tackle complex coastal problems. It is based on advanced physical models and engineering approaches designed to describe and observe the connections between ocean dynamics and coastal evolution.

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Over the last 20 years, major improvements in our understanding of coastal processes have been related to (1) easier access to observational dataset and (2) improved coastal numerical models. **It is now critical for any graduates to have a sense of how to access these dataset efficiently, how to process them using simple coding tools and how to interpret them.**

During this course, we will learn how to do that using web-enabled open source technologies that you will be able to reuse in the future.

## Lectures content

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**Important:** We will do **computer-based exercises during both lectures and practicals** so you will need to bring an electronic device (preferably a laptop but a tablet with internet access could work). As there will be a lot to cover, it is also recommended to go through each chapter prior to the lecture to be well prepared and able to get the most of it during classes.

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- *Ocean Data Query*
- *Bibliography*



## OCEAN DATA QUERY

### 1.1 Coastal Ocean Observing Systems

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**Note:** Now, more than ever, there is a need for regional to global observing systems that can provide accurate real-time data and forecasts on coastal ocean conditions.

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The ocean plays a role in everyone's life. It affects weather and climate patterns around the globe, hosts an abundance of wildlife that support fishing industries and provide food for the world, serves as a highway for vessels that deliver everyday materials, and supports economies as a tourism destination.

The coastal ocean is the part of the earth system where land, water, air, and people meet together. Populations, businesses, and infrastructure are increasing along coastlines, which are all susceptible to changing coastal ocean conditions.

**Coastal ocean observing systems (COOS)** are necessary for advancing our understanding on the state of the coastal ocean worldwide and its impact on matters of societal importance. These systems integrate a network of people, organizations, technologies, and data to share advances, improve research capabilities, and provide decision-makers with access to information and scientific interpretations.

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**Important:** Data acquisition

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<!-- Data acquisition instruments -->
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Data, observations, and models integrated into the **COOS** come from a variety of
↳ platforms, including, for example, **moorings**, high-frequency (HF) **radars**,
↳ underwater **gliders** and profilers, **satellites**, and **ships**. The resulting
↳ data are used to better understand, respond to, and prepare for **short-term**
↳ events such as oil spills, harmful algal blooms, and fish kills, **longer term**
↳ changes in our oceans resulting in acidification, hypoxia, and sea level rise, and
↳ in everyday decisions related to maritime operations, public health, and management
↳ of healthy ecosystems.
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### 1.1.1 A bit of history

**Matthew Fontaine Maury** (1806/1873) was an American astronomer, Confederate Navy officer, historian, oceanographer, meteorologist, cartographer, author, geologist, and educator.

He was nicknamed **Pathfinder of the Seas** and **Father of Modern Oceanography and Naval Meteorology** and later, **Scientist of the Seas** for his extensive works in his books, especially *The Physical Geography of the Sea* (1855), the first such extensive and comprehensive book on oceanography to be published. *Maury made many important new contributions to charting winds and ocean currents, including ocean lanes for passing ships at sea.*

As a sailor, Maury noted that there were numerous lessons that had been learned by ship masters about the effects of adverse winds and drift currents on the path of a ship. The captains recorded the lessons faithfully in their logbooks, but they were then forgotten. At the US Naval Observatory, Maury uncovered an enormous collection of thousands of old ships' logs and charts in storage in trunks dating back to the start of the US Navy. He pored over the documents to collect information on winds, calms, and currents for all seas in all seasons. His dream was to put that information in the hands of all captains.

Maury became convinced that adequate scientific knowledge of the sea could be obtained only by international co-operation. He proposed for the United States to invite the maritime nations of the world to a conference to establish a **universal system** of meteorology, and he was the leading spirit of a pioneer scientific conference when it met in *Brussels in 1853*.

As a result of the Brussels Conference, a large number of nations, including many traditional enemies, agreed to co-operate in the sharing of land and sea weather data using uniform standards. It was soon after the Brussels conference that Prussia, Spain, Sardinia, the Free City of Hamburg, the Republic of Bremen, Chile, Austria, and Brazil, and others agreed to joined the enterprise.

Within a few years, nations owning three fourths of the shipping of the world were sending their oceanographic observations to Maury at the Naval Observatory, where the information was evaluated and the results given worldwide distribution.

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**Note:** Maury's idea set the scene for what is now a *Global Ocean Observing Infrastructure*! Over the 19th and early 20th century a lot of measurements were made by diverse communities for their **own needs** (scientists, fishermen, commercial navigators...). However as more and more data was collected by diverse communities, data was shared only among small communities and was not properly archived and it wasn't done in a organised way. In situ archeology is a hard job providing questionable databases!

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## 1.2 Why do we need ocean observing tools?

Until recently, the ocean was viewed as *being an unlimited resource to be exploited* (source: *US National Academies of Science report on Economic Benefits of Oceanographic Research, 1964*). Subsequent science, including that from national and international observing efforts, has changed what we know about the ocean.

Nowadays, we recognise that **the ocean is a finite and shared resource** that needs to be manage regionally, nationally, and worldwide.

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**Important:** Societal threats and challenges

There are a number of significant societal threats and challenges facing humans due to the changing ocean:

\* The increased frequency and intensity of coastal storms and resulting storm surges will affect our coastal communities and disrupt commerce, nationwide.

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- \* Sea level changes are threatening critical infrastructure worldwide.
- \* Harmful algal blooms and oxygen-deficient dead zones threaten water supplies, [fisheries](#), and coastal recreation.
- \* Ocean acidification is negatively impacting coral reefs and shellfish harvesting.
- \* The increasing size and number of vessels calling on ports present challenges for [our already inadequate maritime infrastructure](#), and pose potential environmental [risks](#) as well.
- \* The world's growing population will increasingly rely on the ocean for food, but [fishing must be done sustainably](#).

To be able to understand and manage the ocean, we need meaningful measures of the [ocean's state](#).

## 1.3 National & Global Ocean Observing Infrastructure

Observing systems are expensive; Australia invests billions of dollars in civil Earth observations to ensure that the nation's decision-makers and managers have the information they need about climate and weather, disaster events, land-use change, ecosystem health, natural resources, and many other characteristics of the planet.

The ocean is a harsh environment in which to operate an observing system, from corrosion due to salinity to bio-fouling. The costs of maintaining instrumentation in this environment, accessing remote locations, and establishing sufficient communications with deployed technologies are significant.

IMOS <http://imos.org.au> had as its prime focus improving scientific understanding of ocean conditions, but the information it generates is increasingly being used by government agencies and other users to inform decisions. The main activities of IMOS <http://imos.org.au> are based around:

- Deploying, maintaining, and developing advanced observations technologies
- Providing free and open access to data in support of a wide range of users
- Advancing modeling
- Focusing on education

In addition to providing observations and data to a large and growing number of research projects, student projects, and academic courses, IMOS <http://imos.org.au> is now recognised as an essential partner in large, multi-institutional research programs across multiple sectors. It has contributed to 180 postgraduate projects, over 400 journal publications, and 250 research projects.

### 1.3.1 Coastal ocean observing systems development

Most large-scale coastal ocean observing systems are funded through national governments for their own interests, often with different foci, but the world's oceans are connected, therefore partnering is the key to success. As an example, the U.S. Integrated Ocean Observing System (IOOS <https://ioos.noaa.gov>), **Australia's Integrated Marine Observing System** (IMOS <http://imos.org.au>), or European Ocean Observing System (EOOS <http://eurogoos.eu/eoos/>) are progressing in their respective regions and are working together to observe and compile ocean information in a way that is easily accessible to scientists and managers.

IMOS advances have benefited from an evolving set of ocean observing efforts. The envisioned concept was a coordinated national and international network of observations, data management, and analyses that systematically acquired and disseminated data and information on past, present, and future states of the oceans. The coastal ocean observing efforts are implemented via regional programs distributed around coastal regions.

Each program is designed to assess and predict the effects of weather, climate, and human activities on the state of the coastal ocean, its ecosystems and living resources, and on the world's economy.

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**Note:** The Australian IMOS <<http://imos.org.au>> was formed in 2007, with equipment deployed from the next year onward. Scientific 'nodes' were formed broadly around state boundaries with both nationally unified overarching science goals and local priorities. The **NSW-IMOS** is an example of a successfully implemented ocean observing system along the coast of southeastern Australia. The current observational array is designed around pertinent science questions, leveraged existing data streams, and opportunities for further oceanographic research.

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IMOS <<http://imos.org.au>> currently has a portfolio of **13 Facilities** that undertake systematic and sustained observing of Australia's marine environment, across scales (from open ocean, onto the continental shelf, and into the coast), and across disciplines (physics, biogeochemistry, and biology and ecosystems).

## 1.4 Ocean observing technologies

It is a complex task to measure the ocean in ways that deliver useful products for people. For example, to deliver a five-day weather forecast for any local region, meteorologists must sample the whole planet. **Satellites** are key tools that provide multispectral images, atmospheric soundings, and sea surface characteristics needed for these forecasts. While satellites enable us to see through the atmosphere, they can only measure the surface of the ocean, and this does not provide the detail needed for accurate weather prediction. Therefore, we also need a complement of in situ measurements that extend our reach to the depths of the oceans at all relevant scales of phenomena. In situ refers to systems that measure on or under the surface of the ocean in continuous and event-driven modes, automatically and by humans.

IMOS <<http://imos.org.au>> is a global leader in ocean observation. It has infrastructures that operate on continental scales, field observing technologies, shares best practices for a broad suite of variables, and generate masses of data. IMOS <<http://imos.org.au>> is partner with IOOS <<https://ioos.noaa.gov>> and OTN <<https://oceantrackingnetwork.org>> (this later is a global ocean research and technology development platform, in the area of animal tagging and tracking). To understand animal movements and survival, you also have to understand how the animals respond to changes in environmental conditions. Thus, the animal tracking effort is tightly integrated with the observation of the physical and chemical environment, and all networks depend on common platforms for oceanographic observations. Other observing technologies include Argo, moored buoys, high-frequency radar (HFR), and autonomous underwater vehicles known as gliders.

## 1.5 Access to ocean data

All the national systems that participate in the Global Ocean Observing System (GOOS <<https://www.goosocean.org>>) and the Group on Earth Observations (GEO <<http://www.earthobservations.org/index.php>>) subscribe to the principal of **free and open data**. It is **policy** within Australia that all observational data collected with governmental funding support are made freely and openly available, which makes sense from scientific, disaster response, and economic perspectives.

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**Important:** One challenge IMOS <<http://imos.org.au>> faces is the need to support operational systems, often with unique data formats, while simultaneously working to create mutually compatible data access systems and services, and common data formats and metadata standards, in order to facilitate access to this public resource through the internet.

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IMOS <<http://imos.org.au>> provides marine data such as *temperature, salinity, currents, wind speed/direction, waves*, and other primarily physical observations for model assimilation through the GTS (Global Telecommunication

System). For broader access, IMOS <http://imos.org.au> uses three standards to convey the information in an interoperable manner:

- Open-source Project for a Network Data Access Protocol (**OPeNDAP**),
- Sensor Observation Service (**SOS**) and Open Geospatial Consortium (**OGC**) Standard, and
- Web Map Services (**WMS**) OGC Standard.

## 1.6 Modeling and analysis

Prediction of future conditions is critical to deliver the full benefits of an ocean observing system. The Australian ocean and coastal modeling community is a partnership between multiple universities and national organisations (CSIRO, IMOS, GA, BOM to cite a few) that is being asked to provide greater resolution models that cover not only traditional physical water circulation, which remains a critical need, but also expand outputs to include inundation forecasting and ecosystem modeling.

In May 2014, IMOS <http://imos.org.au> published the **IMOS Strategy 2015-25** (source [http://imos.org.au/fileadmin/user\\_upload/shared/IMOS%20General/documents/IMOS/Plans\\_\\_\\_Reports/IMOS\\_Strategic\\_Plan\\_3Jun2014\\_low\\_res.pdf](http://imos.org.au/fileadmin/user_upload/shared/IMOS%20General/documents/IMOS/Plans___Reports/IMOS_Strategic_Plan_3Jun2014_low_res.pdf)). In this plan, one can read that:

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**Note:** IMOS <http://imos.org.au> has a concerted focus on making **data available** and **seeing that it is used**. IMOS <http://imos.org.au> has worked with the coastal modeling community to make sure that available data are informing numerical models. Going forward, IMOS <http://imos.org.au> will use its infrastructure to be a coordinating entity to advance the assimilation and further development of coastal modeling. IMOS <http://imos.org.au> has begun a structured engagement with the coastal and ocean modeling communities through development of joint products (e.g., in ocean reanalysis), national workshops, and targeted infrastructure investment at the model-data interface (such as virtual laboratories).

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## 1.7 Hands-on examples

As we just saw, access to quality data is **essential to understand marine processes**.

Over the last 20 years, **ocean data portals** have emerged and are routinely used to better understand the complexity of the ocean and its interactions with climate and life. These portals facilitate seamless access to marine data/services and promote the exchange and dissemination of ocean-related information.

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**Important:** The information that is stored, processed, and exchanged, is at the heart of modern marine science. Ocean scientists routinely perform *data crunching* to understand a particular system and need to *access* and *query* extensive lists of dataset. **Understanding how these data are stored, their origin and how to quickly retrieve particular information from them are crucial skills that you will need in your job!**

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Wave height measurements taken every day by a buoy offshore Sydney are data. A graph showing the evolution of the significant wave height over time, at a given place, is information. The fact that the number of extreme storms hitting Australian's coast increases as a result of climate change is knowledge. These three notions are very closely linked.

### 1.7.1 Exercises for the lecture

Roughly speaking, here is how you should use them:

- A piece of data provides a basic description, typically numerical for our purposes, of a given reality.
- Drawing on the collected data, information is obtained by organising and structuring data so as to derive meaning.
- By understanding the meaning of information, we obtain knowledge.

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**Note:** One of the great challenges for Ocean Data users is to understand **where** and **how** to find technologies that make it possible to evaluate, validate, verify, and rank information to help them in their jobs. This involves understanding how the ocean data providers are organised, the main standards, vocabularies and formats which are used by the community as well as the best approach for accessing and querying these information routinely.

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**Important:** Before starting the exercise, take some times to familiarise yourself with the environment. You will see in the StartHere ipython notebook in your main repository a link to an introduction notebook that I highly recommend to do!

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After following the video and the introduction notebook, you will open the workspace in **edstem** and from the bottom of the StartHere notebook you will click on the **Ocean Data Query** link. It will open a folder containing exercises and practicals:

- `OceanData1.ipynb` and `OceanData2.ipynb` are 2 exercises that complement what you learned during this lecture,
- `Oceanforecast.ipynb` and `Waverider.ipynb` are Python notebooks that you will use for your practicals.

### Loading and checking IMOS NetCDF dataset

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#### Exercise 1.1

In this first example (``OceanData1.ipynb``), we will work with the ``IMOS portal`  
↪ `<https://portal.aodn.org.au/search>`` using ``Python` `<https://www.python.org>`` via  
↪ ``Jupyter Notebooks` `<https://jupyter.org>``. There are several advantages of using  
↪ ``Python` as a general data analysis language and the notebook environment is a  
↪ versatile tool that is designed to be interactive, user-friendly, open-source and  
↪ sharable.

We will see how to load NetCDF data into a Python environment, and show how to use  
↪ the data once loaded.

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<!-- .. image:: https://mybinder.org/badge_logo.svg
:target: https://mybinder.org/v2/gh/TristanSalles/CoastProc/binder -->
```

## Querying and analysis Coastal Ocean Radar dataset

### Exercise 1.2

In this second example (`OceanData2.ipynb`), the Australian Coastal Ocean Radar Network (ACORN <https://portal.aodn.org.au/search>) facility comprises a coordinated network of HF radars delivering real-time ocean surface velocity data. We will export the dataset file (NetCDF) for a given region and then we will plot the velocity field at a given time in a latitude/longitude grid.

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.. admonition:: Quick view of buoy dataset for the Gold Coast :class: toggle

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      :target: https://mybinder.org/v2/gh/TristanSalles/CoastProc/binder
```

### 1.7.2 Exercise for the practical

You will run a series of examples that will introduce some aspects of marine data querying.

- Off-shore Sydney wave buoy data from Australian Integrated Marine Observing System (IMOS) and
- Different dataset from the Bureau of Meteorology, CSIRO as well as forecast model outputs from NOAA.
- Extract Ocean Radar dataset for Turquoise Bay from IMOS and plot them on a map.

Download the practical documentation from Canvas website and answer the questions using: the `Waverider.ipynb` notebook.

## 1.8 Summary

Working together, agencies like IMOS <http://imos.org.au> or IOOS <https://ioos.noaa.gov> help to manage our oceans by measuring them and connecting observations to people. Yet, ocean observing systems are only as good as our ability to observe and accurately model ocean systems.

**Finding the resources to sustain coastal observations over relevant time scales is a big challenge.**

**Important:** As coastal data users - we need to understand how ocean dataset are obtained, managed and stored. We also need to know how to efficiently load these dataset, query and analyse them.

As a growing population continues to stress our planet, quality observations will increase in importance. But it is not good enough to measure the planet, we also need to work to ensure this information comes into play in our communities, our economies, and in management decisions.



## BIBLIOGRAPHY

### 2.1 References