From the deep ocean to the coast:

Open issues for UK marine science in the Atlantic & the role of spaceborne Earth Observation

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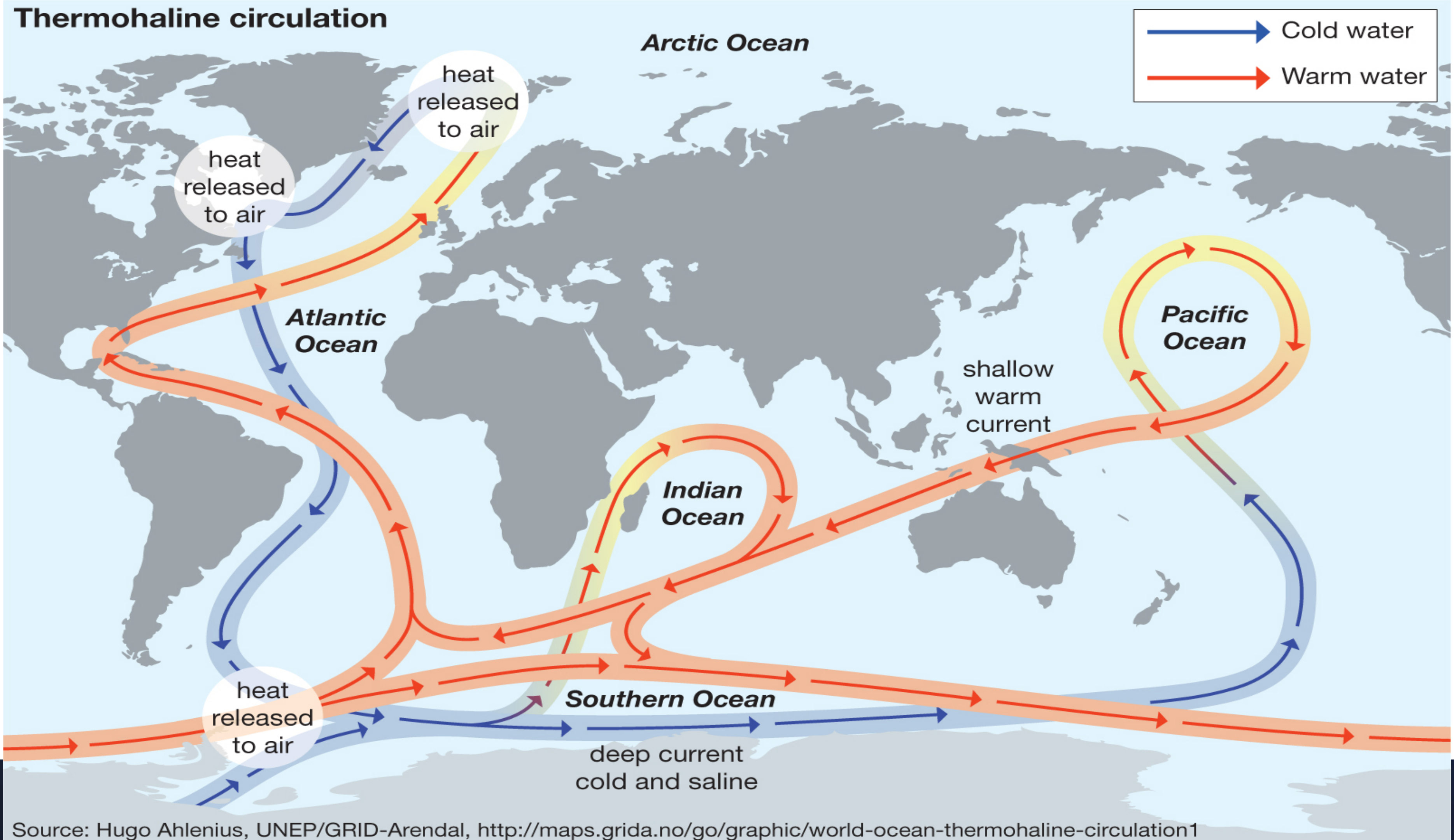
With grateful thanks to many colleagues at NOC and elsewhere

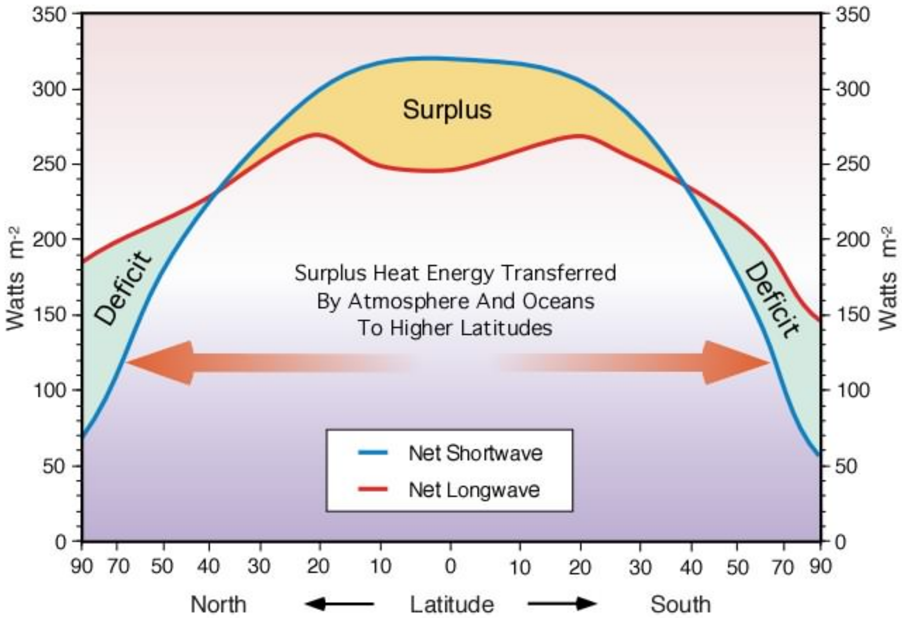
Content of this talk

- A journey around the Atlantic Ocean
  - *from the tropics to the poles*
  - *from the deep ocean to the coast*
  - *from large to small scales*
- As we go, we'll point out:
  - Open questions & issues
  - Ongoing activities and opportunities for satellite Earth Observations
- Summary & Recommendations

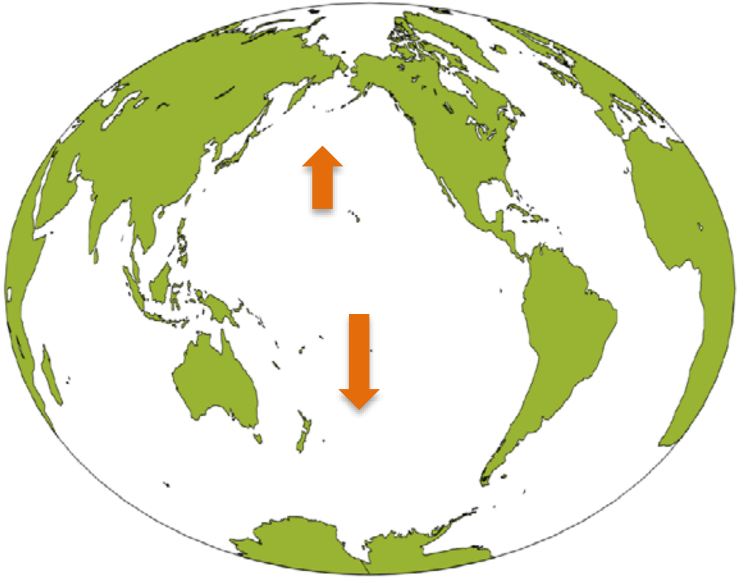

Thermohaline circulation
Cold water
Warm water
Arctic Ocean
heat released to air
heat released to air
Atlantic Ocean
Pacific Ocean
shallow warm current
Indian Ocean
heat released to air
Southern Ocean
deep current cold and saline
Source: Hugo Ahlenius, UNEP/GRID-Arendal, http://maps.grida.no/go/graphic/world-ocean-thermohaline-circulation1

The AMOC and its role in climate

Earth's Energy Balance



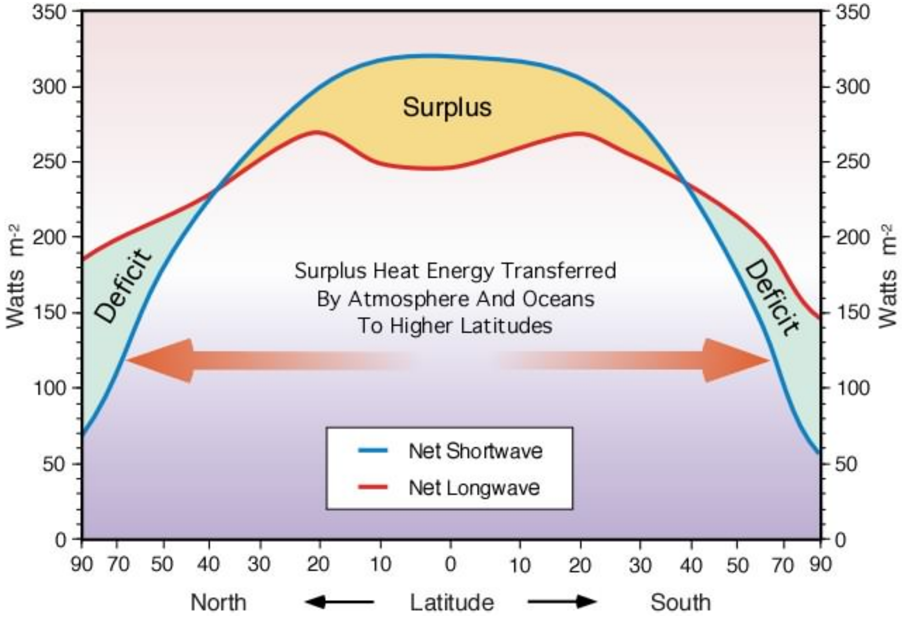
Ocean Heat Transport



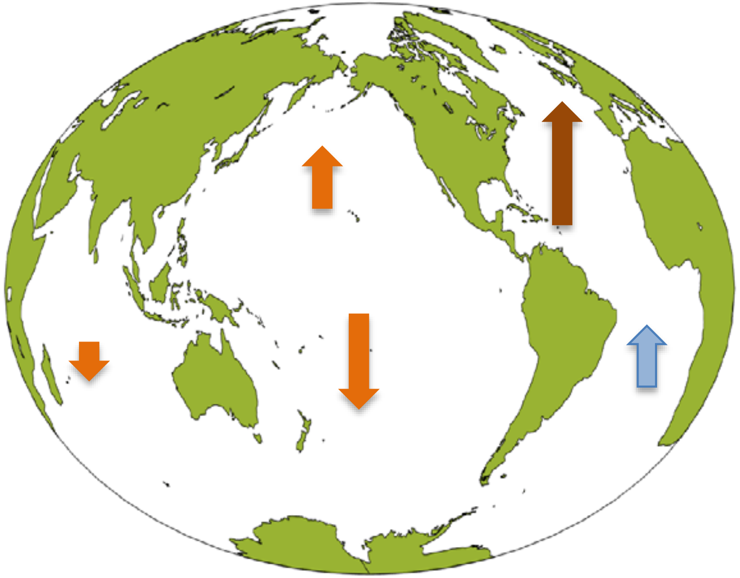
Courtesy of David Smeed, NOC

The AMOC and its role in climate

Earth's Energy Balance



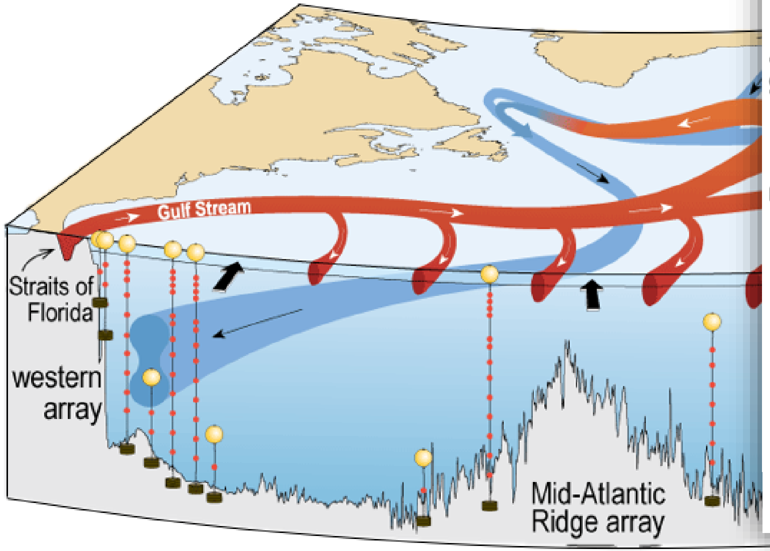
Ocean Heat Transport

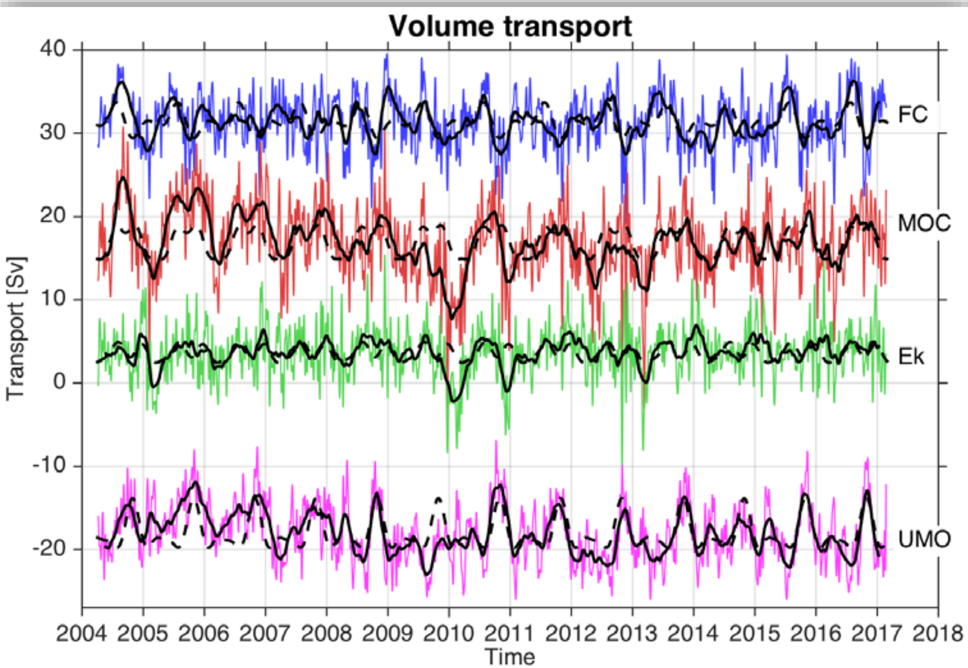


Courtesy of David Smeed, NOC

RAPID 26°N: Measuring the Atlantic Meridional Overturning Circulation *in situ*

In situ observations to measure the *full-depth* large-scale ocean circulation across 26°N.





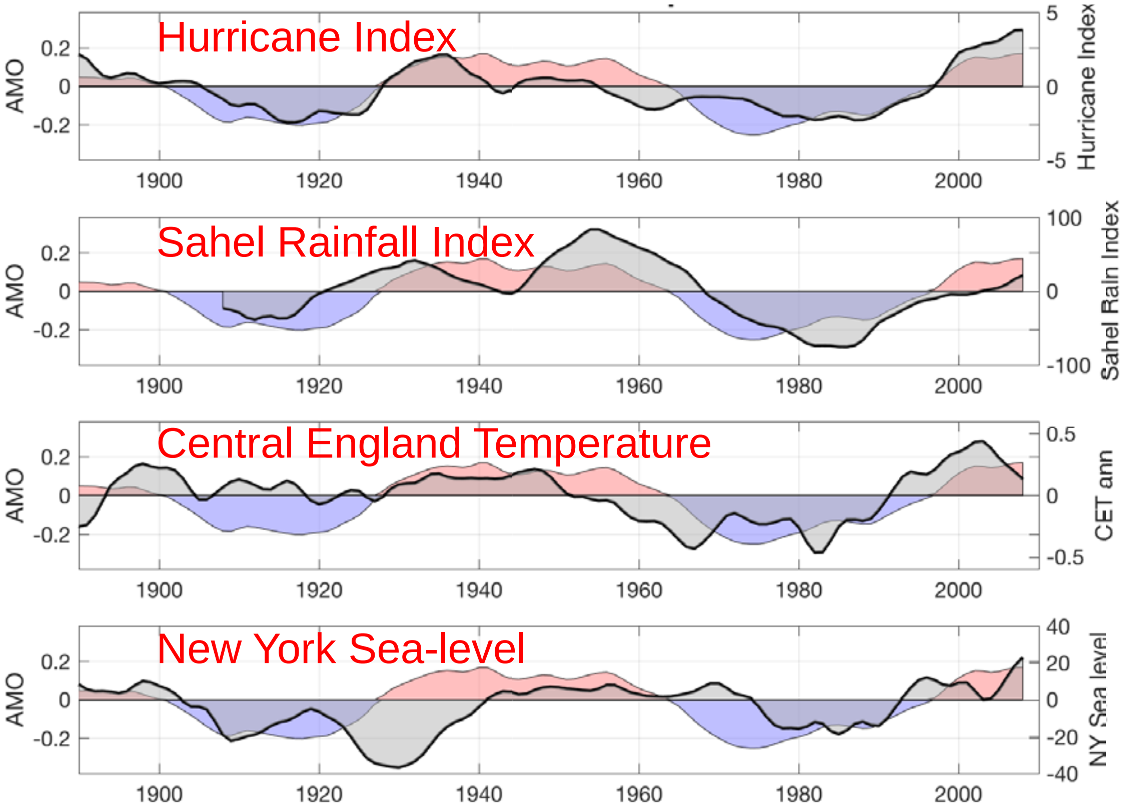
A benchmark for ocean & climate models

Courtesy of Eleanor Frajka-Williams, NOC

The AMOC and its role in climate

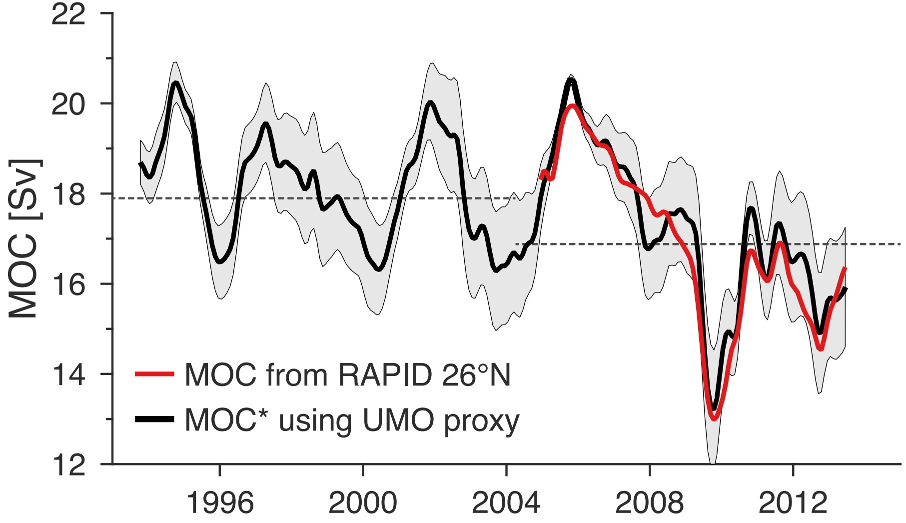
Colours show the Atlantic Multidecadal Variability index

Black lines show anomalies of four key climate indices



RAPID 26°N: Measuring the Atlantic Meridional Overturning Circulation *from space*

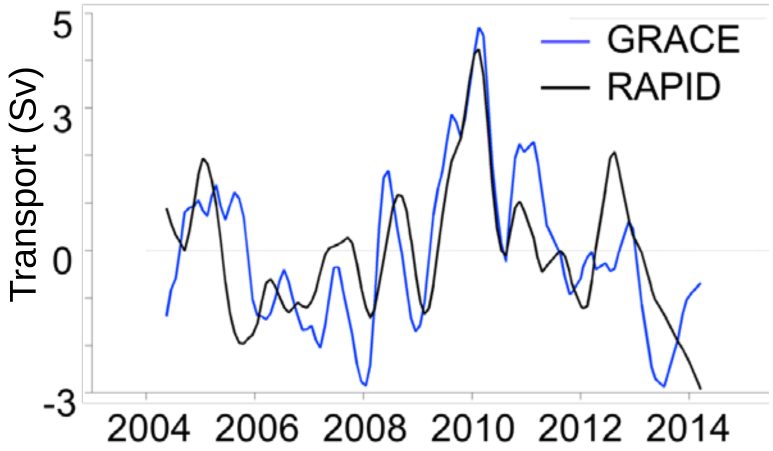
Proxy from altimetry reproduces the interannual variability of the measured MOC



How: *Uses statistical regression between altimetry and top 1000m (UMO) moored transports.*

Frajka-Williams (2015) *GRL*

Direct estimates of deep (3000-5000m) transports from GRACE match in situ.

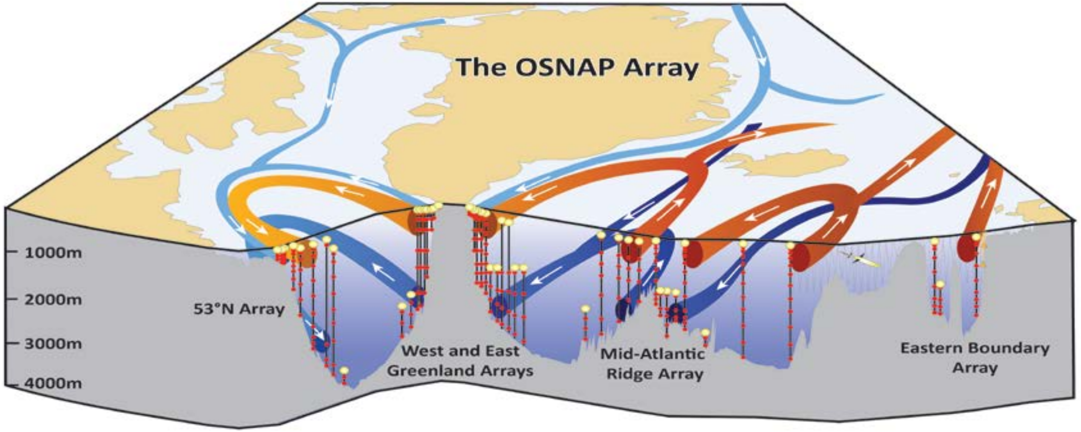


How: *Applies geostrophic balance to detrended GRACE bottom pressure at west & east endpoints of 26°N.*

Landerer et al. (2015) *GRL*

- **Meric Srokosz: 'Observing the AMOC from space', Thursday 17:00 Conference Room**
- **Eleanor Frajka-Williams et al.: 'Altimetry & Gravimetry for estimating the MOC', Poster #4**

Observing the subpolar MOC



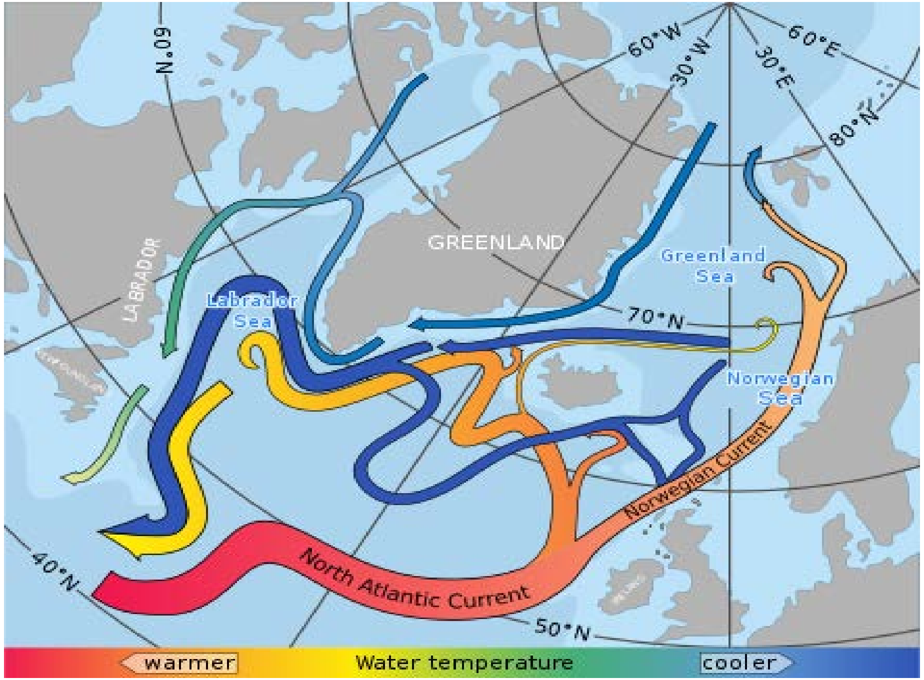
- Large international project to observe the subpolar MOC
  - UK: NOC, SAMS, Uni Oxford, Uni Liverpool
  - US, Canada, Germany, France, NL, China

OSNAP OVERTURNING IN THE SUBPOLAR NORTH ATLANTIC PROGRAM

Courtesy of Penny Holliday, NOC

- AMOC array in place since 2014, funded to 2020 (seeking extension to 2025)

North Atlantic & Arctic



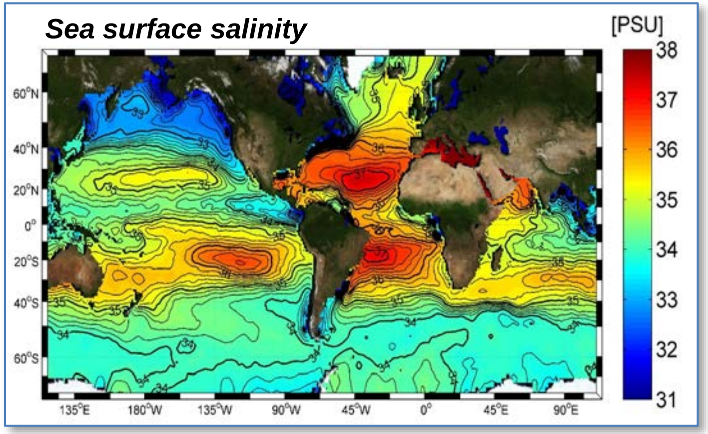
Wikimedia Commons

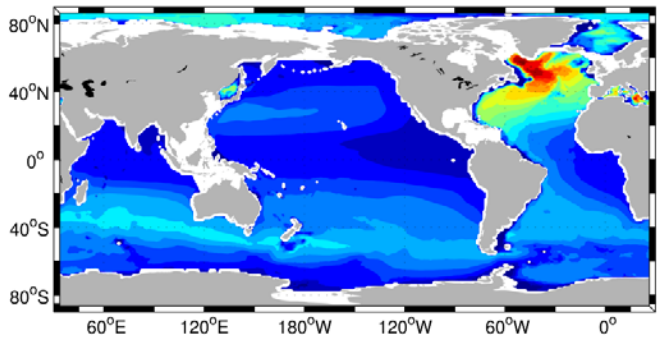
- AMOC expected to slow down over next decade
  - North Atlantic freshening (IPCC AR5)
- Influence of Arctic sea ice decline
  - export of freshwater to Atlantic
  - But Nordic pathways are complex and difficult to observe
    - *coastal Greenland current, Fram Strait, Canadian archipelago*
- Changing North Atlantic air-sea fluxes
  - subject to large variability on multiple scales, including changes in salinity, temperature and wind stress
- Open questions
  - relative roles of air-sea fluxes and ocean circulation in North Atlantic ?
  - Mechanisms driving convection & water mass transformation in Nordic seas ?

Simon Josey: 'Changing Air-Sea Freshwater Fluxes and Ocean Salinity: From Wet gets Wetter to the Big Fresh Blob', Thursday 12:00 Conference Room

CLASS: Climate Linked Atlantic Sector Science

- UK Marine Science National Capability programme (2018-2023)
  - Lead: Angela Hatton, NOC
- Underpinning Activities
  - Sustained Ocean Observations
  - Numerical Modelling
  - Technology Innovation
- Science Programme
  - Hydrological cycle and Atlantic Ocean Salinity
  - Atlantic carbon sink
  - Seafloor Disturbance
  - Ecosystem functioning and services
- Academic Engagement & training





C_{anth} storage – column inventory

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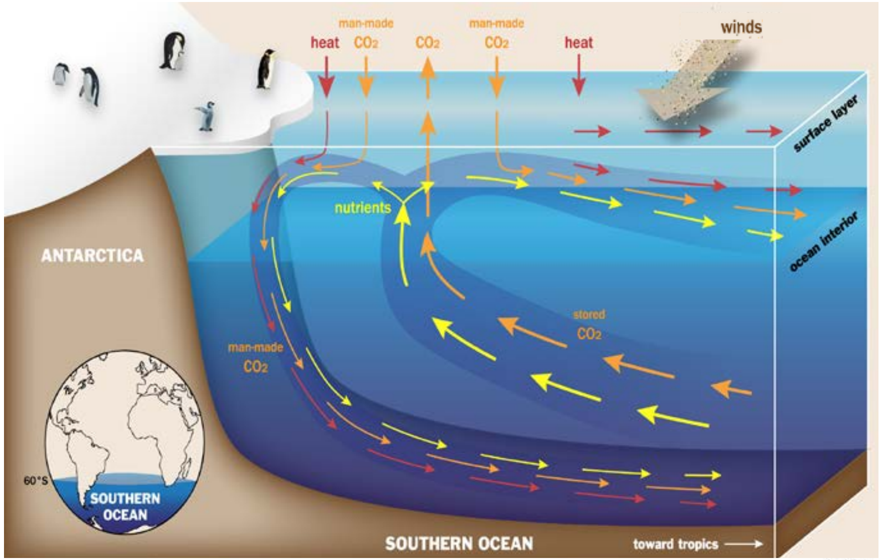
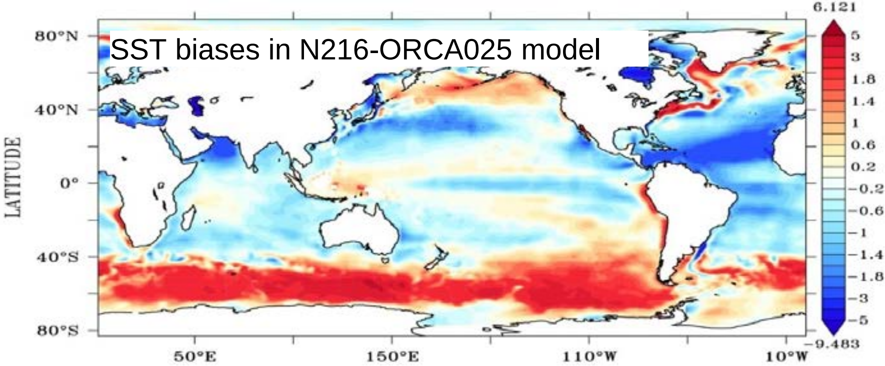
SAMS
PML Plymouth Marine Laboratory
The Marine Biological Association
Sea Mammal Research Unit

The Southern Ocean

- Disproportionately important for heat and anthropogenic carbon uptake by the ocean
  - Accounts for ~40% of oceanic uptake of anthropogenic carbon and >75% of the heat uptake (IPCC AR5)
- The Southern Ocean is the world's biggest data desert …
- … and it is notoriously hard to get right in models
- Buoyancy fluxes and surface winds directly impact ocean circulation
  - Wind stress plays major role as driver of Antarctic Circumpolar Current and upwelling of deep waters





Courtesy of Yvonne Firing, NOC

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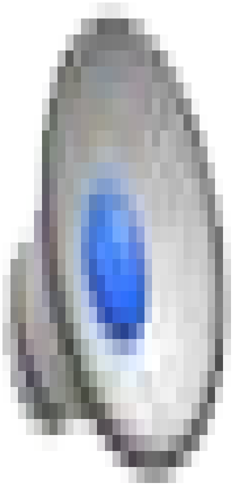
Sea Mammal Research Unit
cpom
PML Plymouth Marine Laboratory
Met Office
ORCHESTRA
OCEAN • CLIMATE • CARBON

Winds in the Southern Ocean

- Decadal trends in wind stress can change by up to 40% depending on storminess and wind fluctuations (Lin et al., J. Clim, 2018)
  - non-linear dependence on wind speed

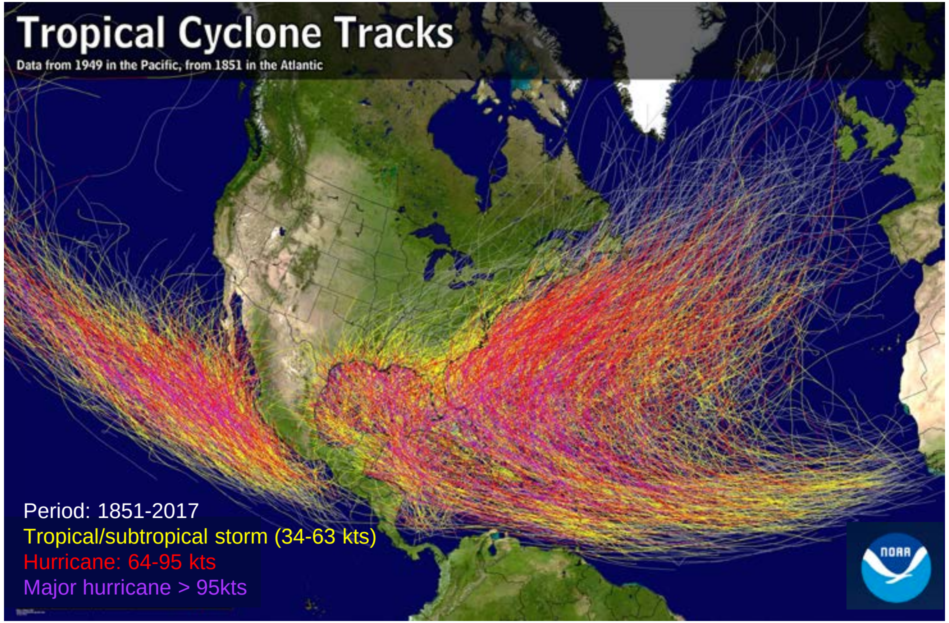
Winds in the Southern Ocean

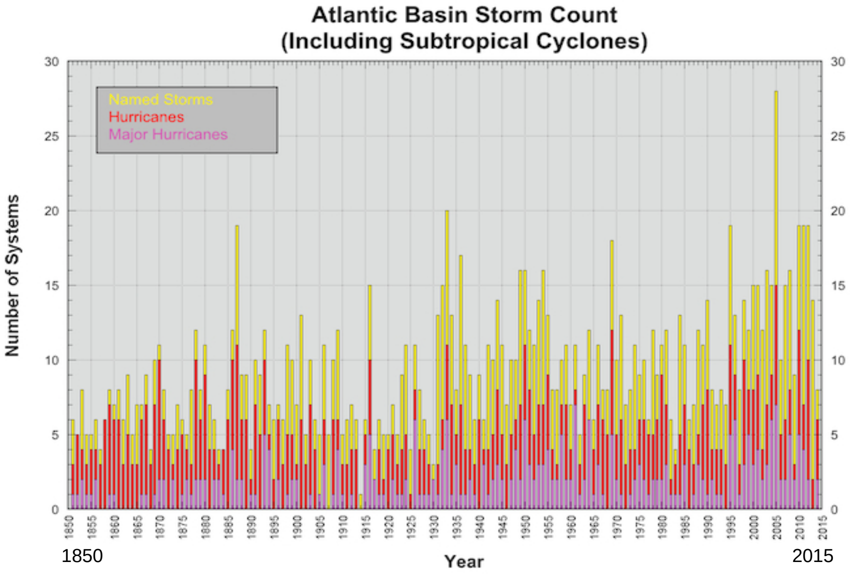
- Decadal trends in wind stress can change by up to 40% depending on storminess and wind fluctuations (Lin et al., J. Clim, 2018)
  - non-linear dependence on wind speed
- Importance of better and more frequent wind observations near the ice edge
  - e.g. using new space solutions like GNSS-Reflectometry
  - Here, showing surface reflectivity from the GNSS-R sensor on UK TechDemoSat-1 (one satellite)



Courtesy Giuseppe Foti, NOC

Hurricanes & storms





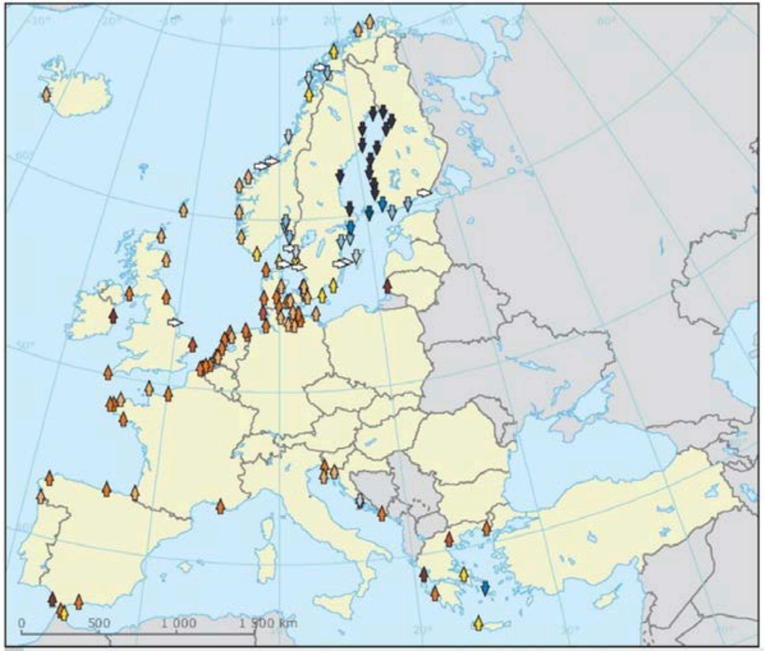
- Atmosphere-ocean feedbacks
- Better & more frequent high wind data needed to improve forecasts

Extreme sea level at the coast

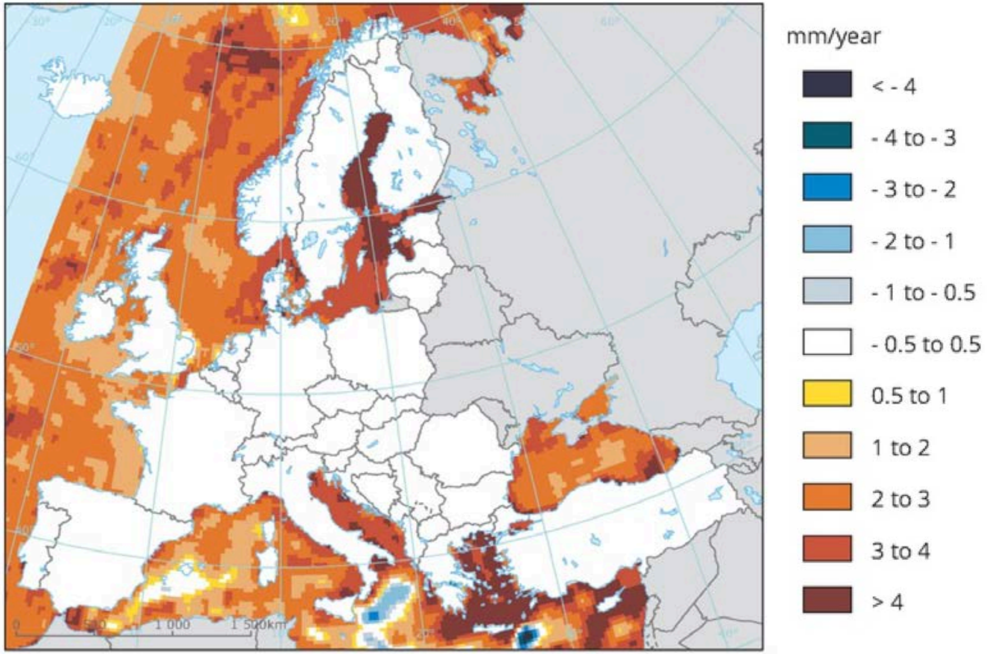
- Statement from WCRP/IOC Sea Level 2017 Conference, New York:

"Major immediate climate-related impacts of sea-level rise occur due to the increased likelihood of extreme sea-level events arising from the **combination of high tides, storm surges and waves on top of higher sea levels**. This increased frequency of extreme sea-level events, and increased impact of storm surges and waves, is already being observed, including routine flooding on spring tides at some locations. Hence it is important to **understand present and future occurrence of extreme conditions, in addition to mean sea-level rise**."

Coastal sea level, storm surges & waves



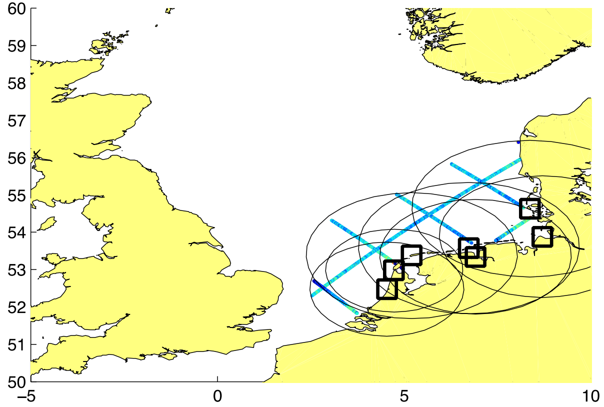
Trends in relative sea level from tide gauges 1970-2015 (Permanent Service Mean Sea Level)



Trends in absolute sea level from altimetry 1993-2015 (ESA Climate Change Initiative)

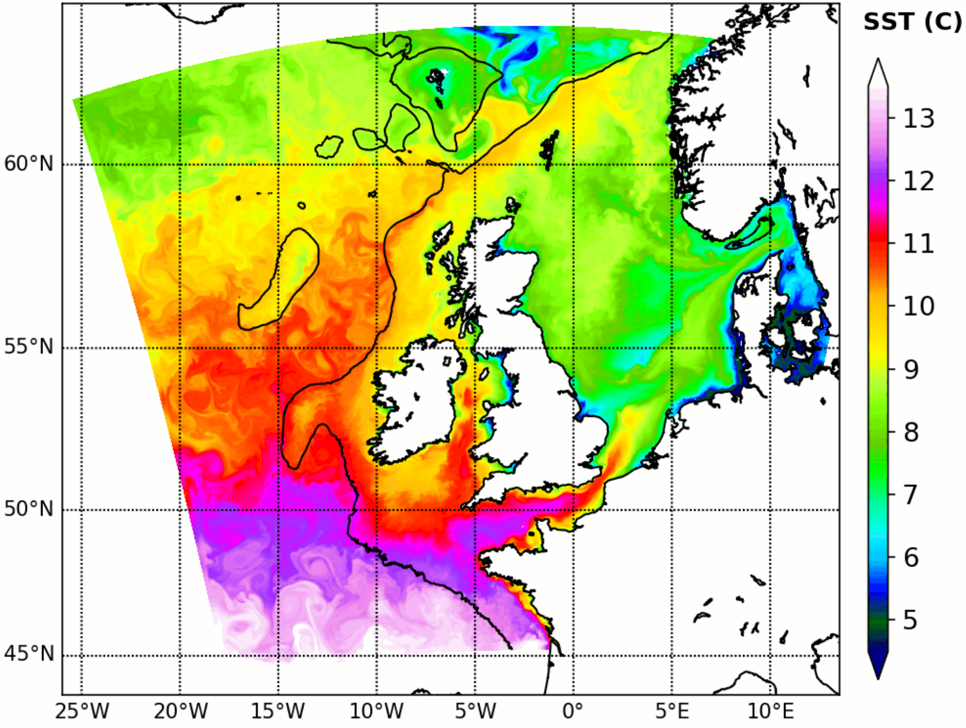
Quantifying coastal sea level change

- Better altimeter data in the coastal zone
  - Continued improvements of instrument performance (e.g. SAR mode altimetry on Cryosat-2 & Sentinel-3)
  - better corrections (e.g. tides, wet tropospheric delay, sea state bias)
  - Consistent multi-mission datasets for altimeter sea level AND waves
- New approaches to separate natural variability and trends by exploiting the different characteristics of tide gauges, satellite altimetry and models
- New multi-parameter methods that combine satellite altimetry with other spatial datasets and high-resolution models

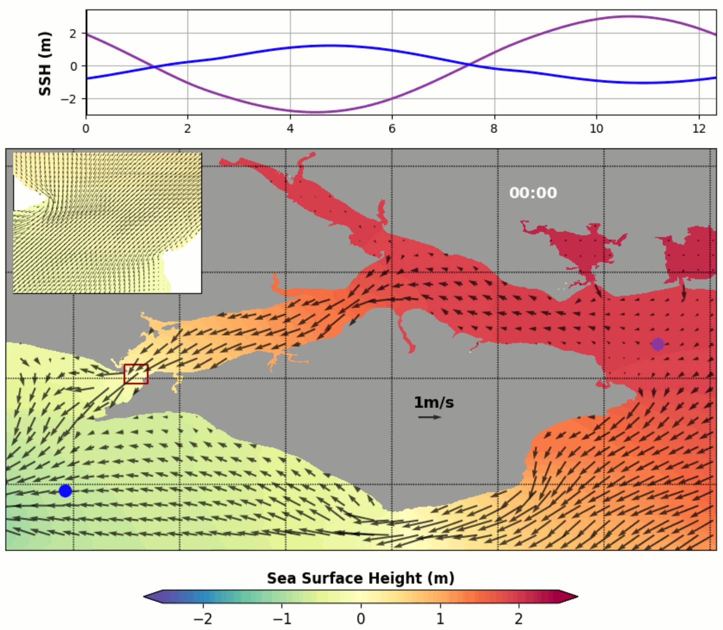


Courtesy of F. Calafat, NOC

Next generation high-resolution models

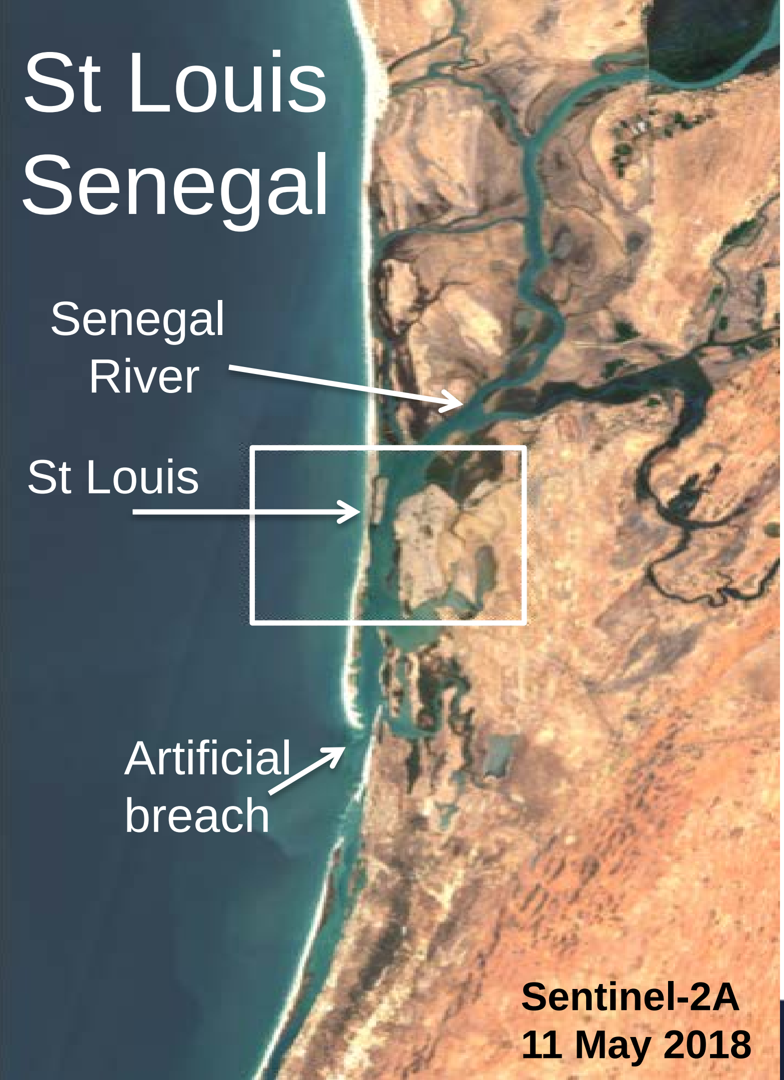


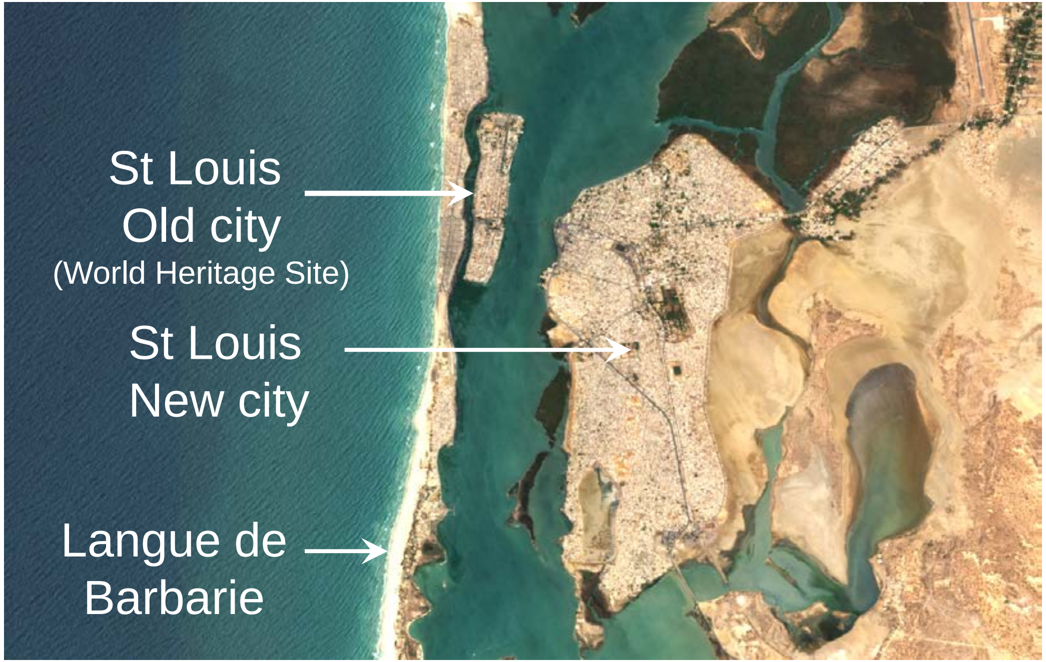
1.5km Coupled Ocean-Wave-Land-Atmosphere



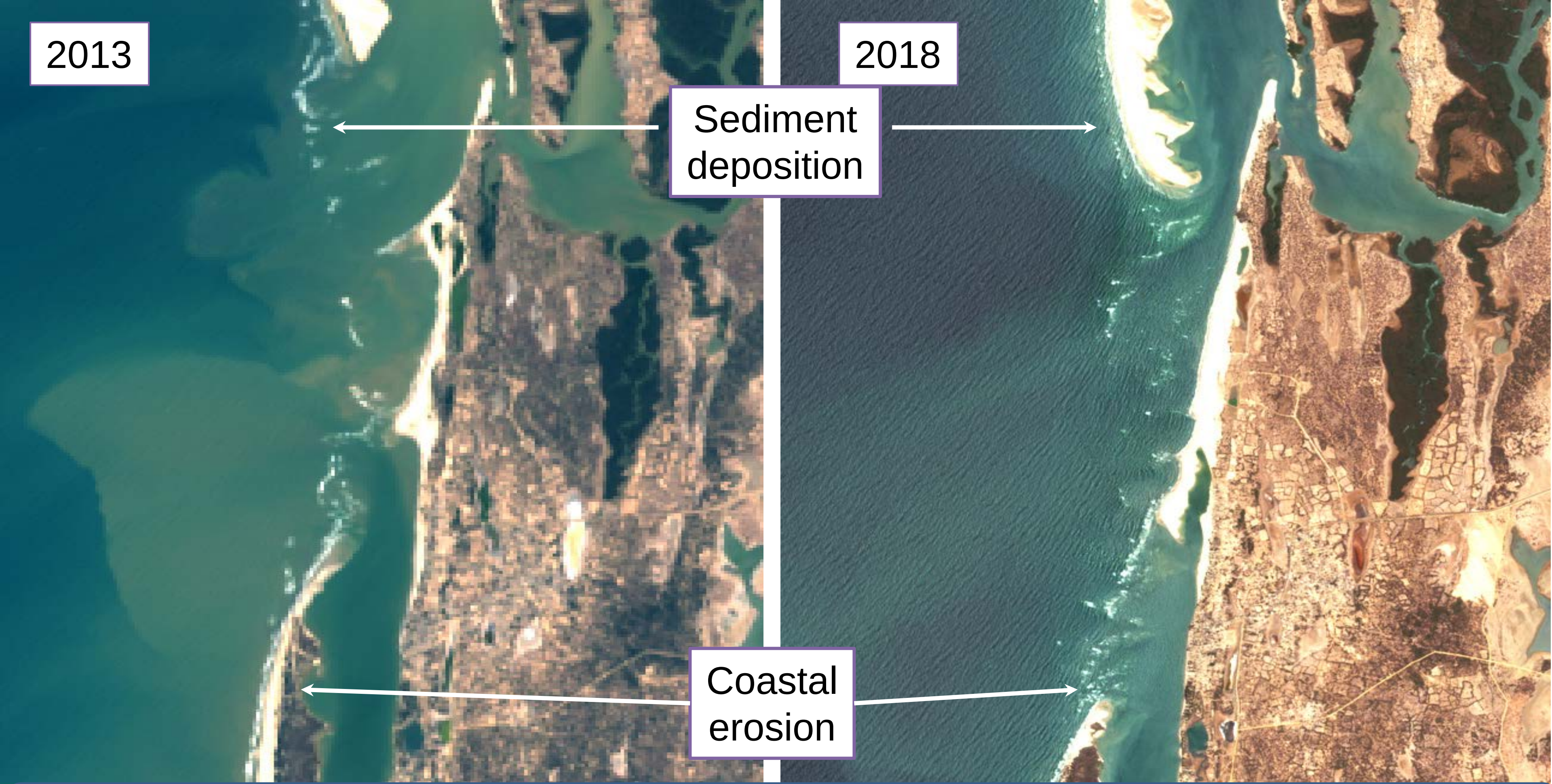
Sea surface height and total ocean currents in Southampton Water

Courtesy of J. Holt & J. Polton, NOC





Artificial breach in Langue de Barbarie sand bar to mitigate river flood risk tripled the tidal range & increased exposure of city to storms & sea level rise



Val Byfield: 'ESA EO4SD: Marine & Coastal Resources Management, EO-derived information for Blue Economies', **Thursday 17:15 Seminar Room**

Summary & Recommendations

- The Atlantic Ocean is characterised by a multitude of complex processes between the ocean, atmosphere, cryosphere and land on multiple spatial and temporal scales
- Open questions include:
  - AMOC, its variability and future changes
  - the relative role of air-sea fluxes and ocean circulation changes on the AMOC
  - Impact of changes at high latitudes, especially buoyancy & winds
  - Impact of high-energy processes on short temporal and spatial scales
- Significant efforts are underway in the UK and internationally to observe and model large-scale long-term processes in the Atlantic

Summary & Recommendations (2)

- Satellite Earth Observations offers many opportunities to complement existing observing and modelling efforts
  - Particular relevance of new satellite measurements of salinity, winds and coastal sea level and waves
- Combining satellite datasets with in situ and model data could help to quantify natural variability and trends
- New generation of high-resolution coupled models offer new opportunities to fully exploit the information content of new high-resolution satellite data from multiple sensors

Thank you