→ ESA ADVANCED OCEAN SYNERGY TRAINING COURSE 2019

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Investigating large scale ocean processes with a synergistic approach

Paolo Cipollini, ESA Climate Office

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Objectives

1. observe **large-scale propagating features** in satellite altimetry data
2. characterise the features

   (i.e, measure space/time scales and propagation speeds)
3. be able to observe the features in other satellite datasets: SST, Ocean Colour, Sea Surface Salinity…

   …and understand the mechanisms that make them visible
4. use the same **synergistic approach** to look at **El Niño / La Niña** effects in altimetry and Ocean Colour

The gist is: how to use the combination of different datasets to improve our knowledge of oceanic processes

The wider context of this lecture: large-scale processes

At scales larger than a few tens of Kms time-varying ocean dynamics is largely dominated by two kinds of westward propagating features:

- **eddies** (scales of order (100km) and greater, rotating)
- **planetary waves** (scales of order (500-1000km))

Satellites (especially altimetry, but also other datasets) have shaped up our knowledge of these important dynamic features:

- Their characteristics (spatial/temporal scales, propagation speed)
- How they affect ocean/atmosphere interactions
- How they affect biology in the oceans

Another large-scale feature is the **El Niño – Southern Oscillation (ENSO)** cycle

We will see that all these features show up clearly in the data!

Data we are using in this lecture

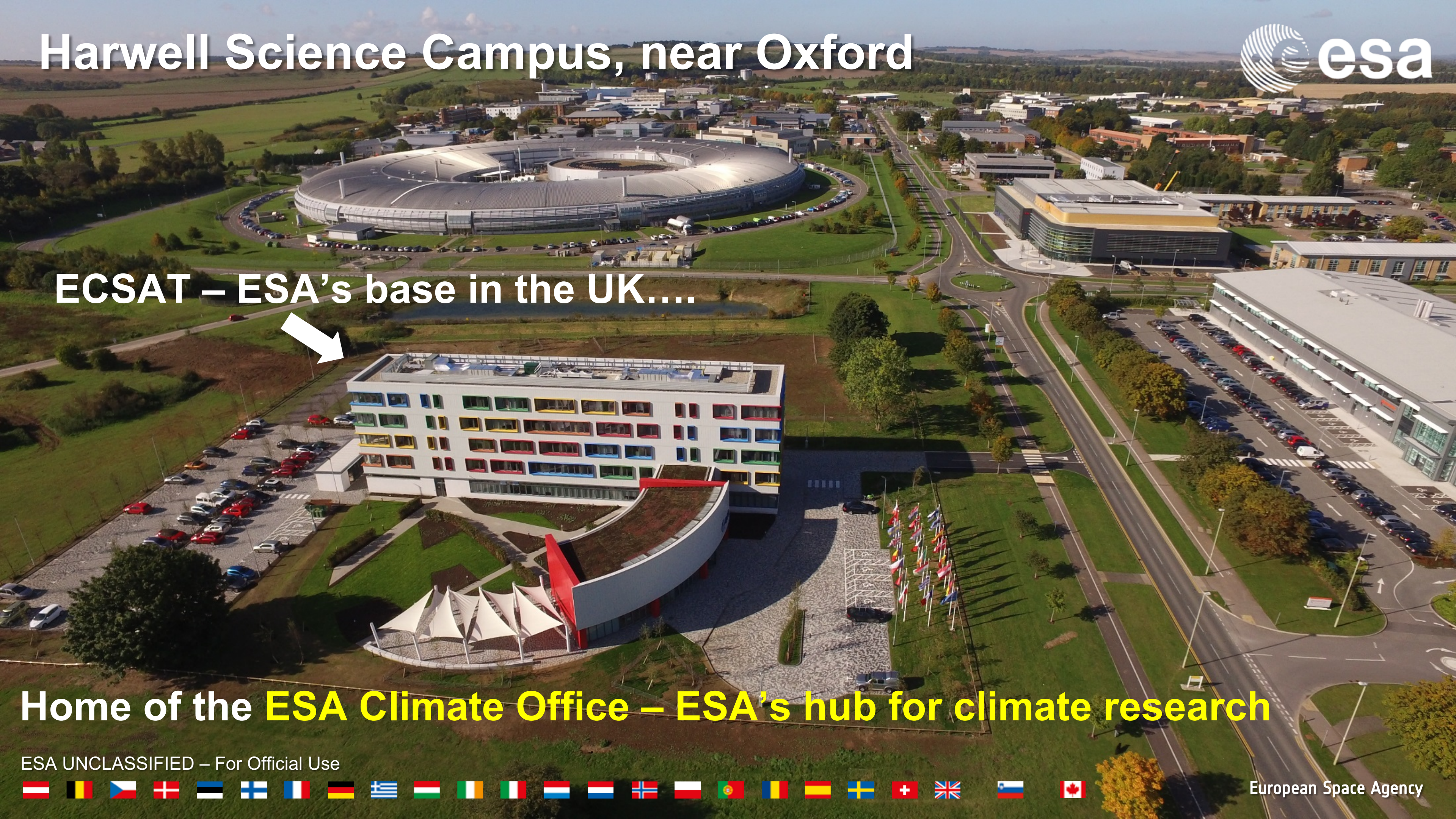
We will be using climate-quality data generated by the **ESA Climate Change Initiative (CCI)**

CCI

Climate Change Initiative

ESA's 165 MEuro R&D Programme (2010-2024)
to exploit the **full potential of Earth Observation**
in support of **Climate Research and Assessment**

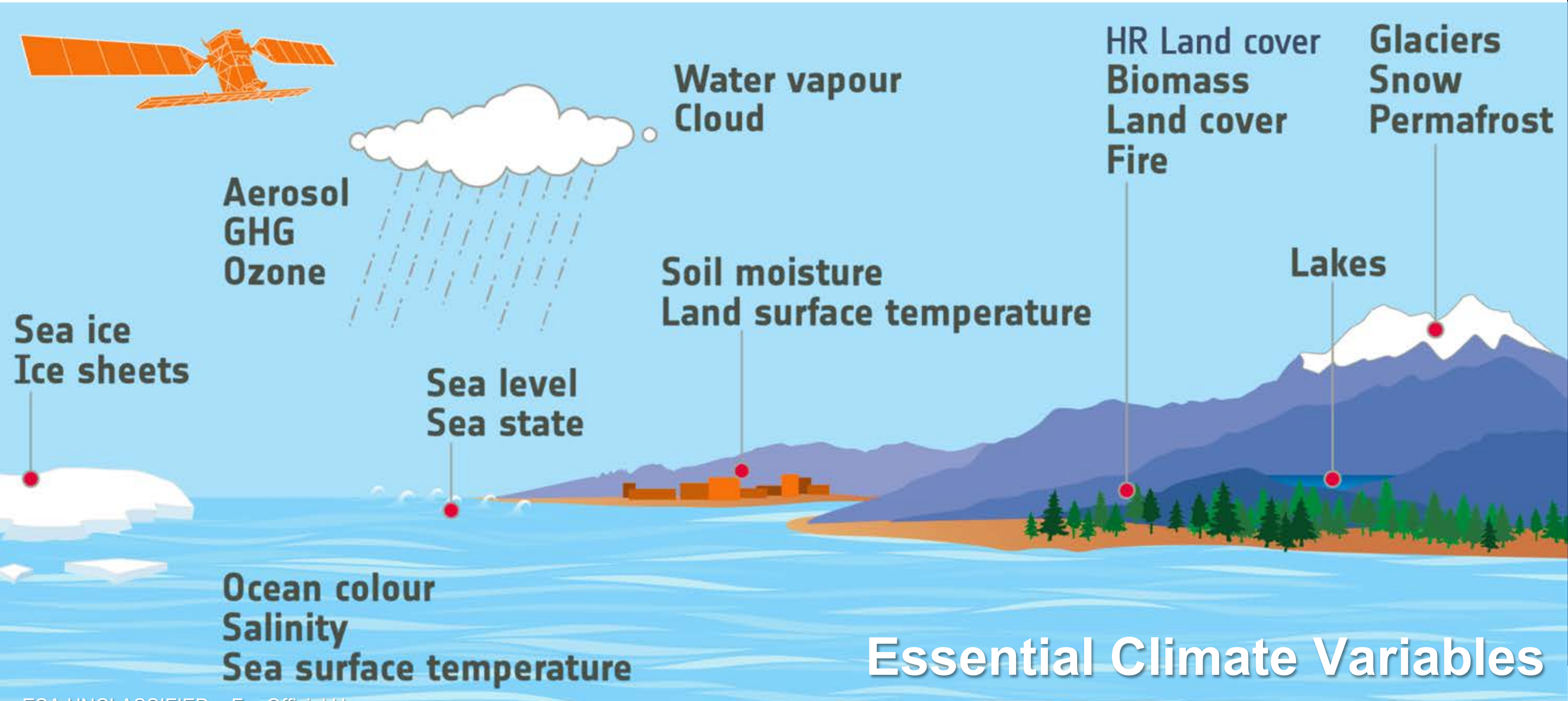
Produces long time series of **Essential Climate Variables** (ECVs)


Harwell Science Campus, near Oxford
esa
ECSAT – ESA's base in the UK….
Home of the ESA Climate Office – ESA's hub for climate research
ESA UNCLASSIFIED – For Official Use
European Space Agency

ESA Climate Office

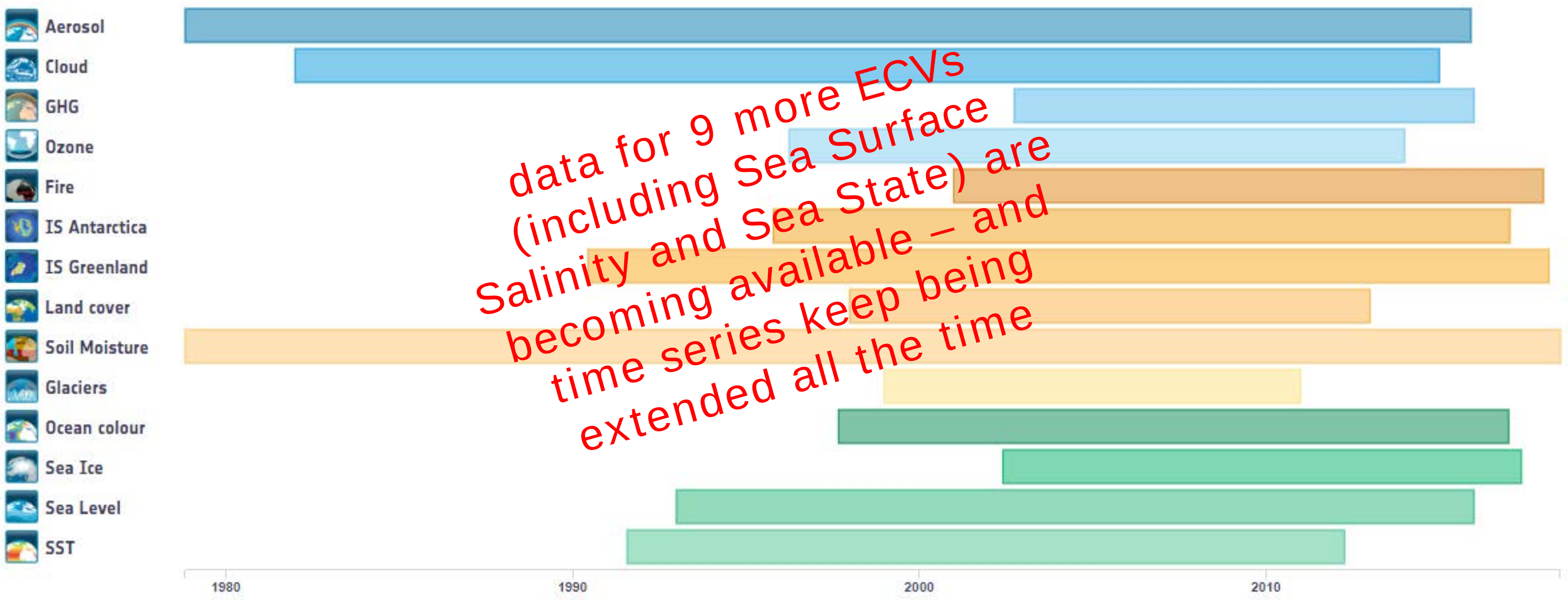
central point for coordinating all Earth Observation work conducted by ESA relating to **climate and climate change**

ESA Climate Change Initiative



CCI data products: time coverage

http://climate.esa.int/data



→ INTERACTIVE: 'Eddyspotting' in satellite images

Eddies in fields of Sea Surface Height

Open **SEAScope** and load SSH field from altimetry

Zoom on North Atlantic – what features do you see? Can you spot the eddies?

Then zoom on South Atlantic off the Southern tip of Africa – can you see some ring-like structures

Eddies in Sea Surface Temperature / Ocean Colour

Load SST/Ocean Colour in SEAscope – and have a look

Note that we so far we are looking at static images here. Let's move to examining propagation starting from a very peculiar class of propagating features: planetary waves

Planetary waves in the oceans

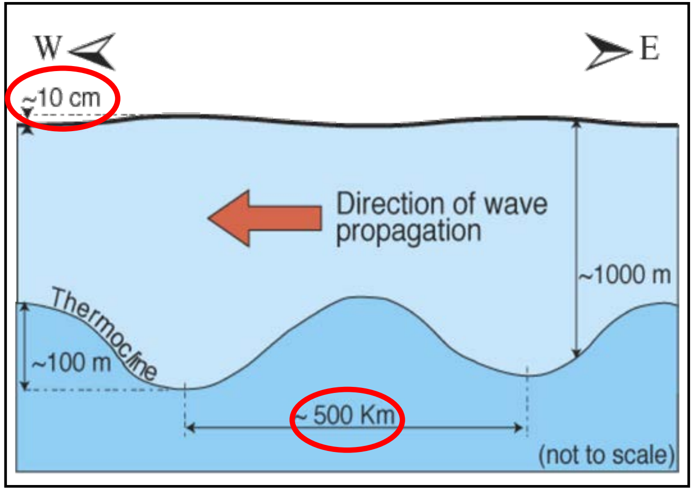
Large-scale internal waves with small surface signature

Due to shape and rotation of earth

Travel E to W at speeds of 1 to 20 cm/s (decreasing poleward)

Also known as **Rossby waves** (after C.-G. Rossby)

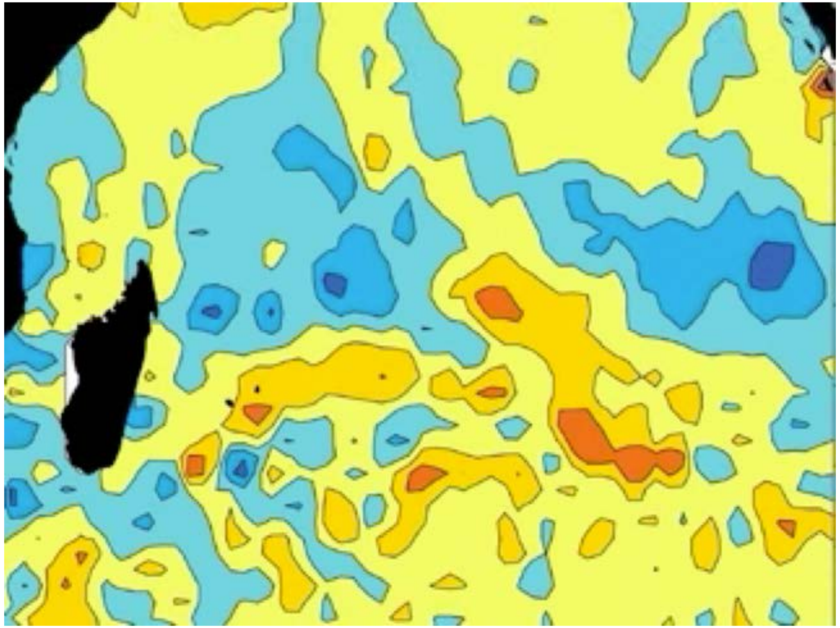
- Important mechanism of ocean adjustment to forcing
- Maintain western boundary currents
- Transmit information across ocean basins, on long (annual or longer) time scales



Seeing propagating features in satellite data

- As eddy and planetary waves tend to propagate to the west we see them by taking **longitude/time plots** of data

(also known as Hovmöller diagrams)



→ INTERACTIVE: Propagating features in SSH

We follow the Jupyter Notebook OTC2019_SSHA_ltplot.jpynb

- Extract monthly SSHA (SSH anomaly) data from the CCI archive, over 1993-2015
- Slice the data at ~34N in the North Atlantic (more precisely at 33.875N), over the longitude span 90W to 10W
- Can you see the propagating features? Can we measure a propagation speed and estimate the spatial scale (wavelength)?

- Then we repeat in the Indian Ocean, around 25S, 50E to 100E
- How do the result differ? Are the features propagating slower or faster?

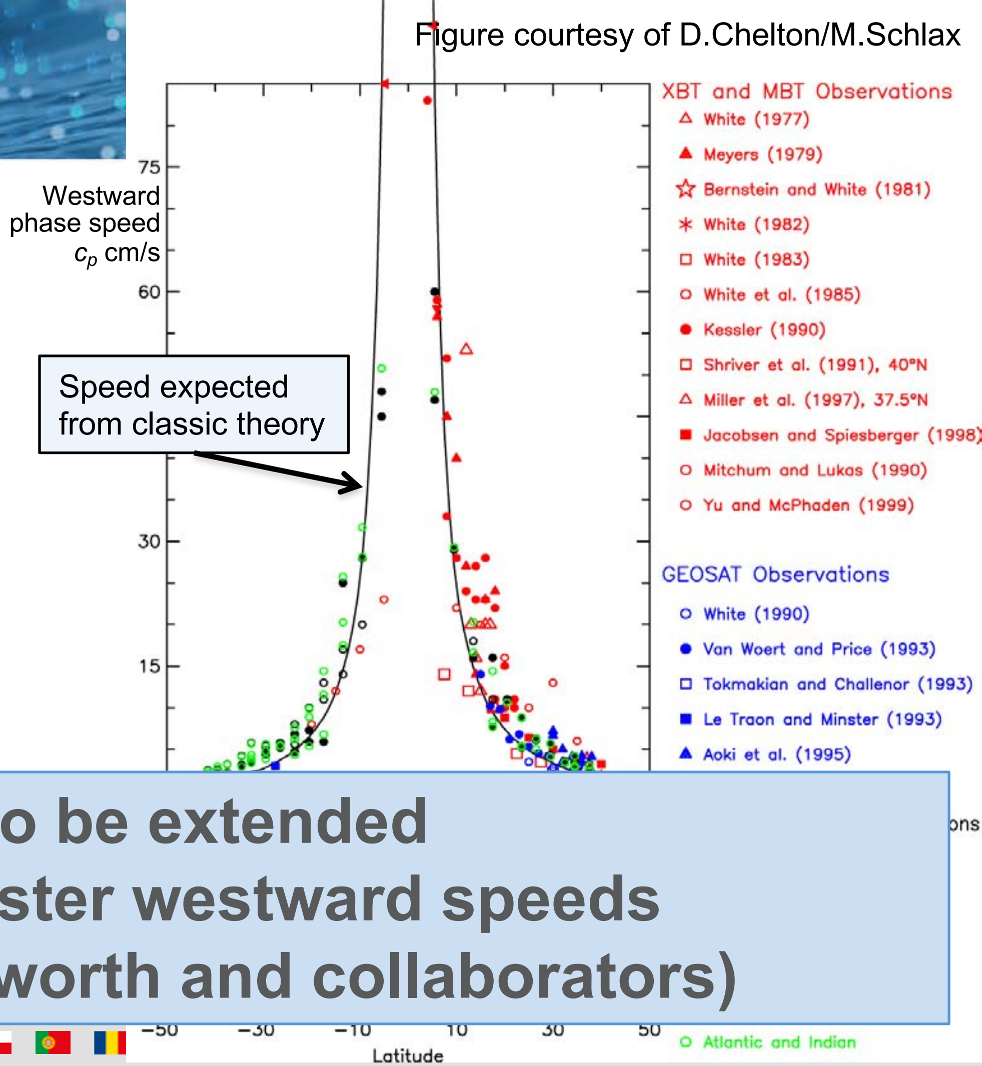
The speed of planetary waves

Observational quantum leap in the 1990s, thanks to altimetry.

Lots of papers in 1990s and 2000s characterizing planetary waves in observations

First truly global study: Chelton & Schlax, *Science*, 1996

Confirmed ubiquity of waves and **speed up w.r.t. classic theory of**

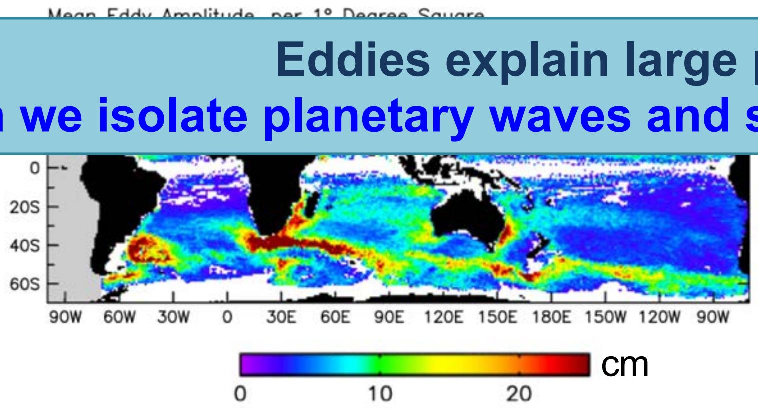


Theory had to be extended to account for the faster westward speeds (see work by Peter Killworth and collaborators)

Eddies everywhere - Chelton et al., 2011

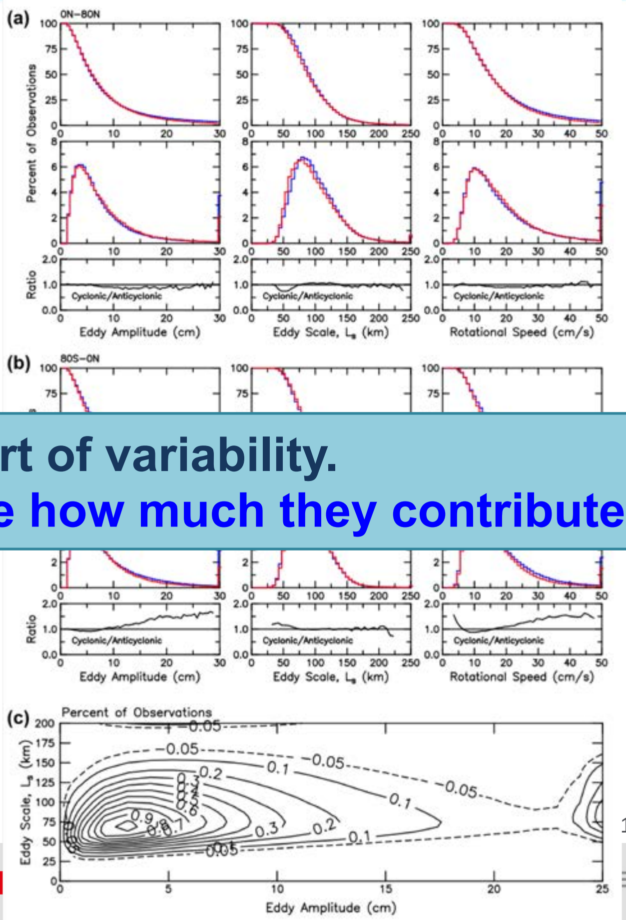
Identified **35891 eddies** (with lifetimes >=16 wks) in 16 years of two-mission altimeter data

averages: lifetime 32 weeks / propagation distance 550 km / amplitude 8 cm / radius 90 km



Eddies explain large part of variability.

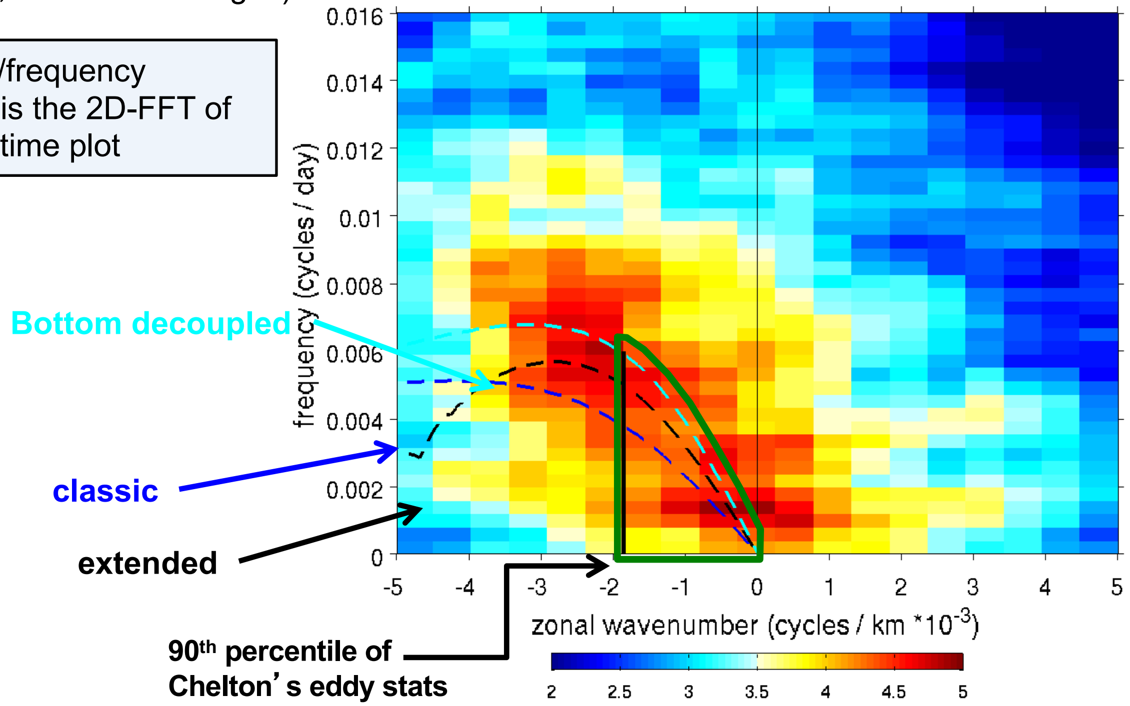
Can we isolate planetary waves and see how much they contribute ??



Spectral waves/eddies separation

Work by **Matthew Thomas**, (ESA YGT then UEA, then IFREMER, now Yale Univ), continued by **Anna Sutcliffe** (NOC Southampton, now FCT Portugal)

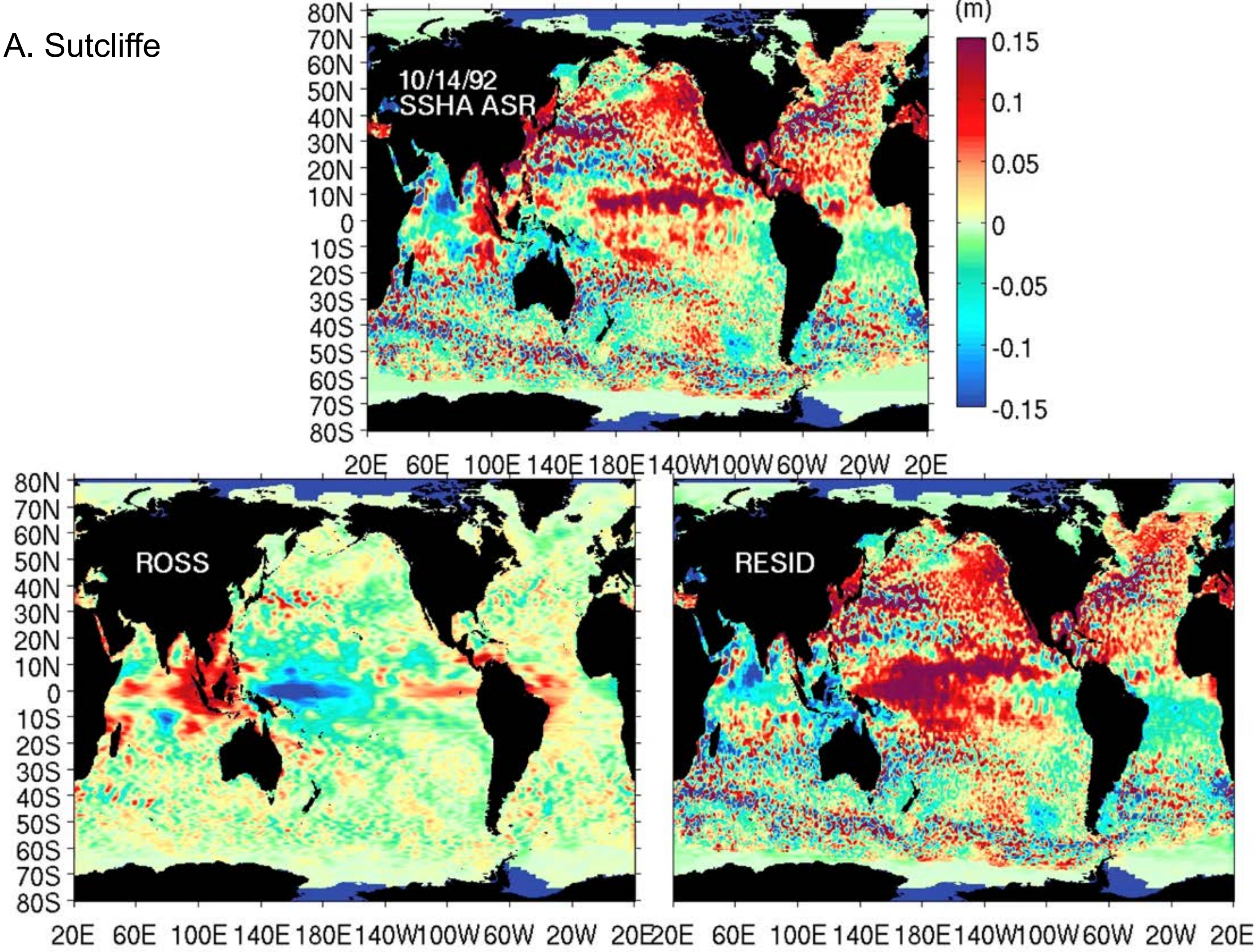
Wavenumber/frequency spectrum – it is the 2D-FFT of the longitude/time plot



31S 144W

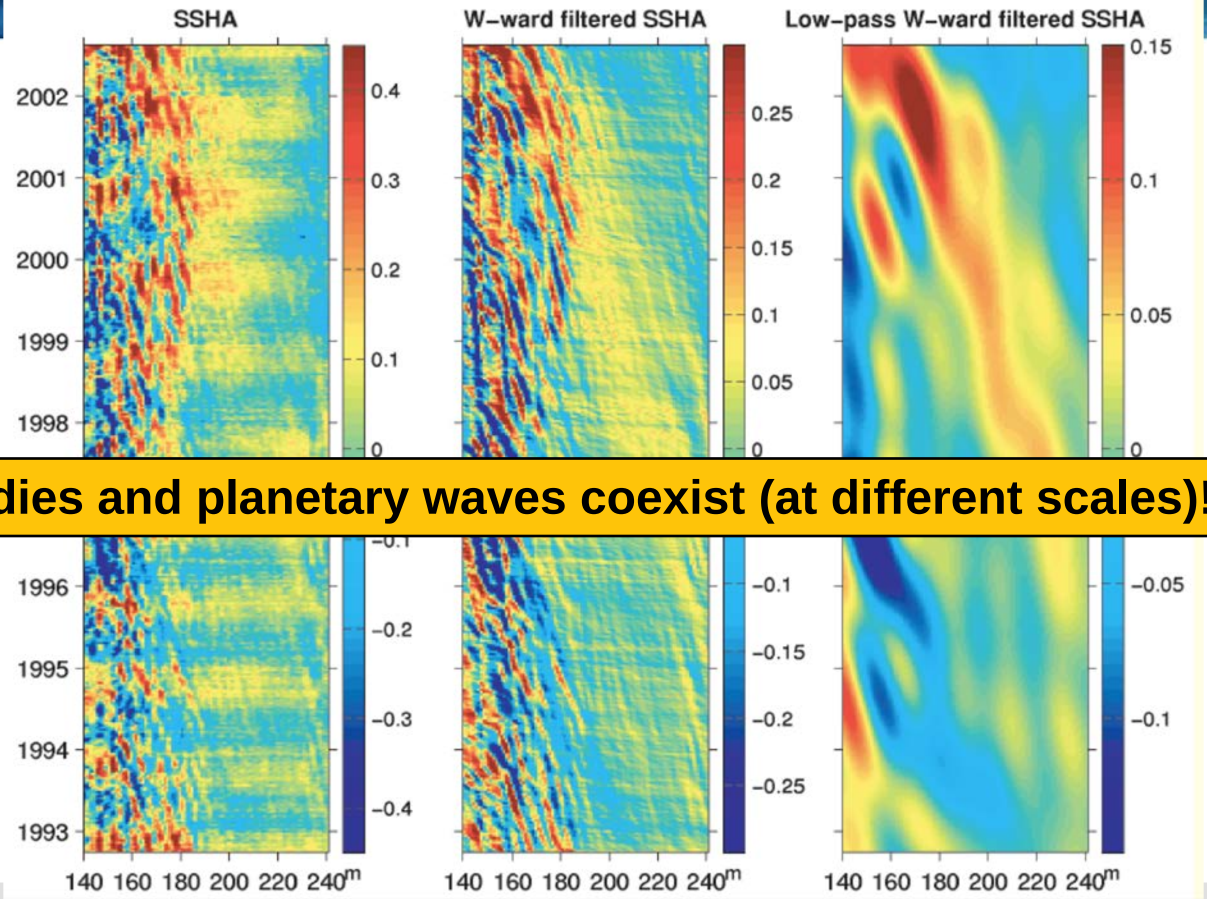
20° longitude span

M. Thomas / A. Sutcliffe



Example in the N Pacific

34° N



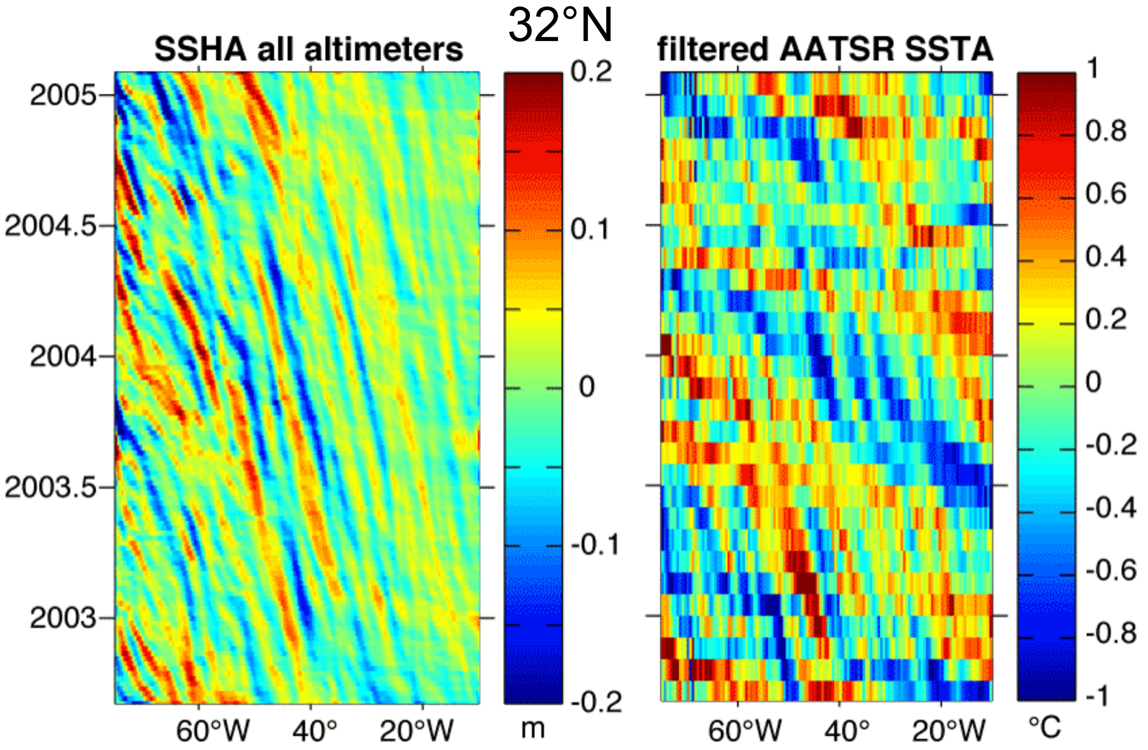
Eddies and planetary waves coexist (at different scales)!

Figure courtesy by Doug McNeall

Westward propagating features in other datasets

As eddies and planetary waves affect the density profile and the water column it is legitimate to expect that they may have a signature in other datasets

The most obvious is SST, which normally shows some degree of correlation with SSH



→ INTERACTIVE: Propagating features in SST

We follow the Jupyter Notebook OTC2019_SSTA_ltplot.jpynb

Extract monthly SSTA (SST anomaly) data from the CCI archive, over 1993-2015

Slice the data at ~25S in the Indian Ocean (more precisely at 25.125S), over the longitude span 50E to 100E

Can you see the propagating features?

They need to be highlighted this time – we use a simple filtering technique: first we filter (low-pass) the l/t plot with a gaussian kernel then we take the difference unfiltered minus filtered, which is equivalent to do a high-pass.

Can we measure a propagation speed and estimate the spatial scale (wavelength)?

How do the result compare with those from SSH?

→ INTERACTIVE: Propagating features in Ocean Colour

We follow the Jupyter Notebook OTC2019_OC_ltplot.jpynb

Extract monthly Chlorophyll-a data from the Ocean Colour CCI archive, over 1998-2016

Note this time the data are fetched in real time from the online server www.oceancolour.org

Slice the data at ~25S in the Indian Ocean and repeat analysis as before

Even this time we need to filter the data to highlight propagation - we use again the simple local anomaly filter

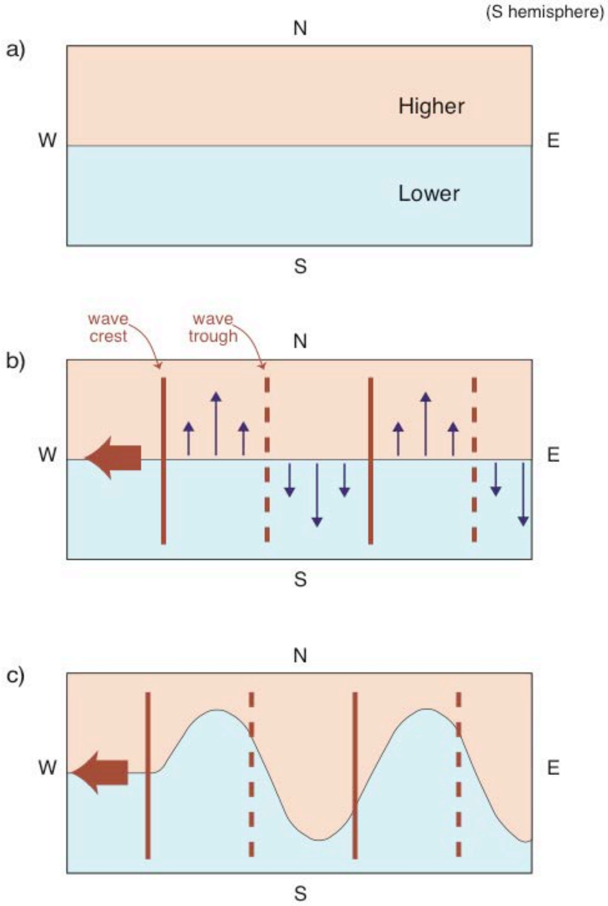
Compare results with those from SSH, SST

Why do you think we see the propagating features in Ocean Colour?

Possible mechanisms: 1 — horizontal advection

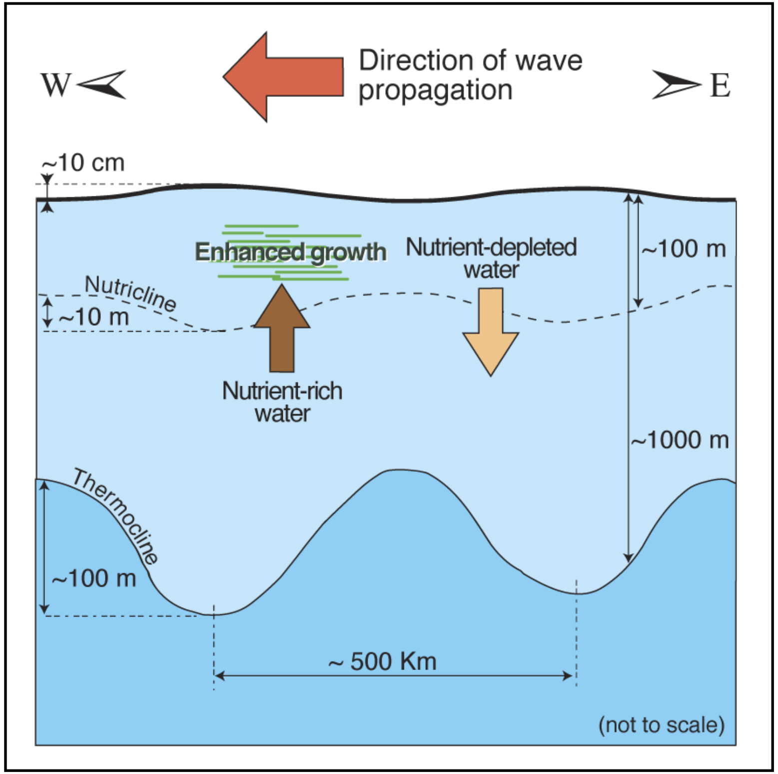
Phytoplankton is advected north-south by geostrophic currents associated with planetary waves

This mechanism works where there are north-south gradients of phytoplankton



Killworth et al, JGR, 2004

Possible mechanisms: 2 - Vertical advection of nutrients



Killworth et al, JGR, 2004

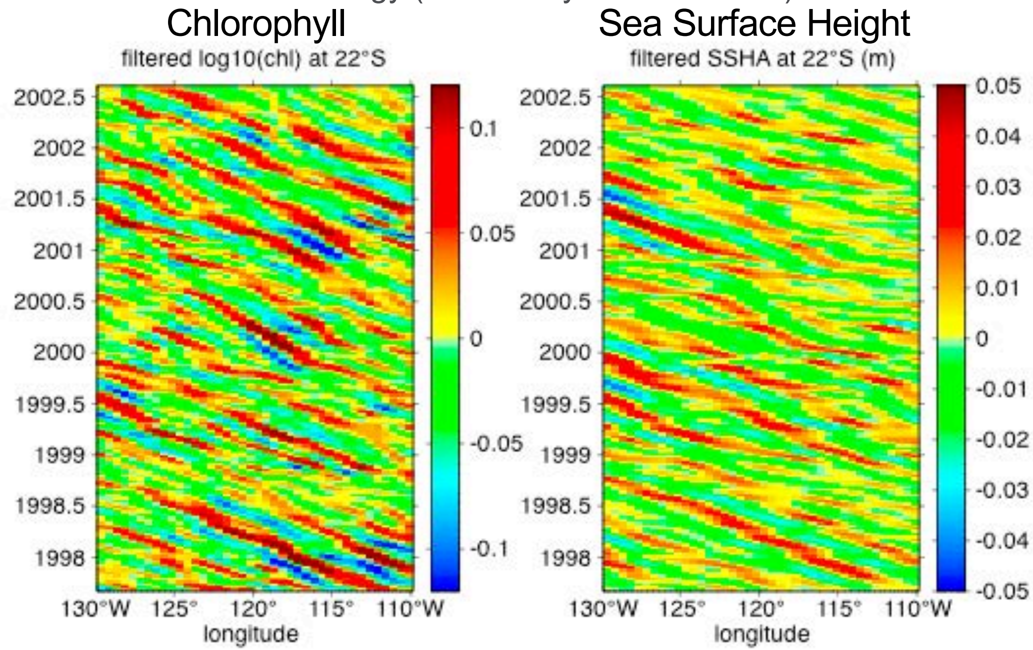
Nutrients would be upwelled along the whole wave propagation path

Would affect productivity & carbon cycle!!

Does it happen? Is it significant?

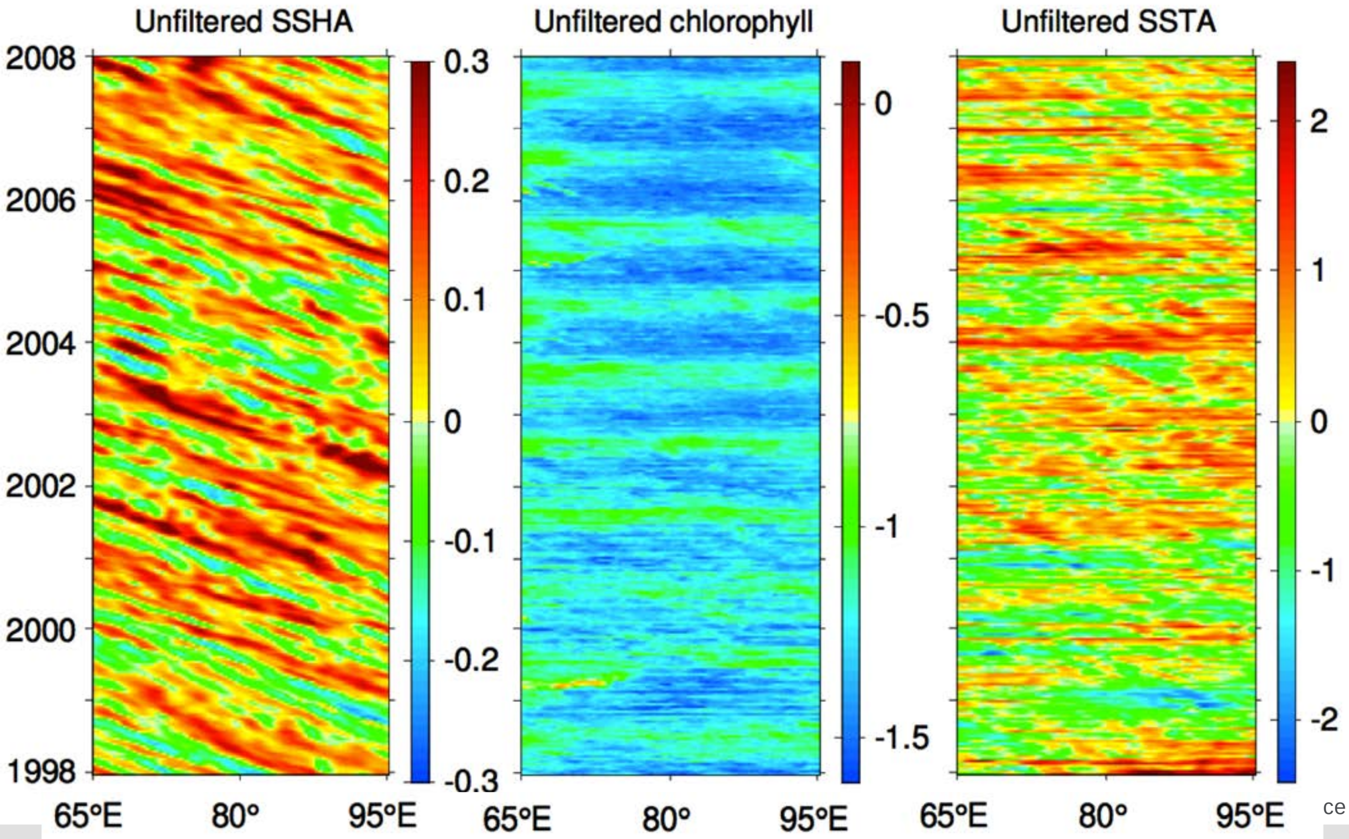
Planetary waves, eddies and biology

The signature of planetary waves and eddies in biology (as seen by Ocean Colour) has been the **subject of many studies**



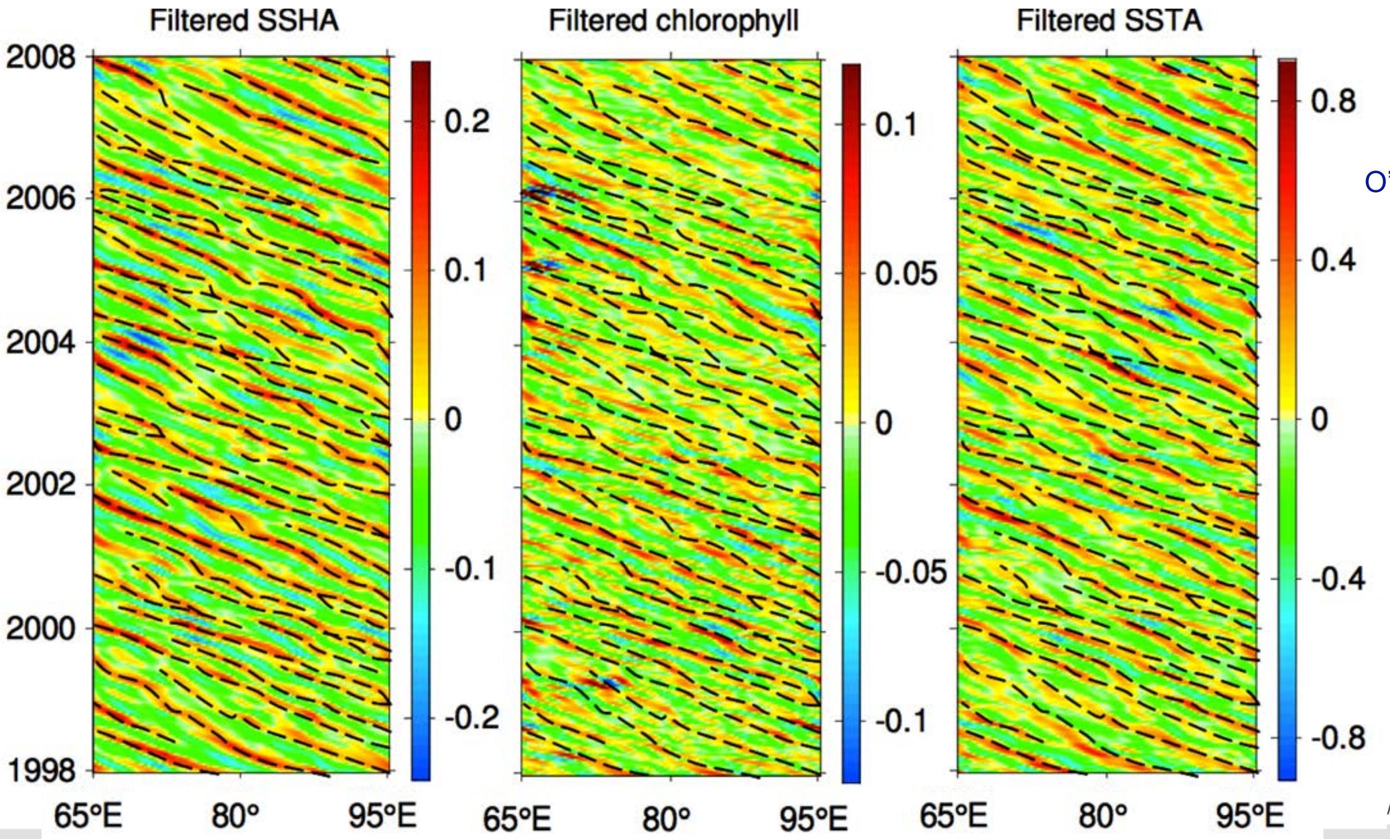
The **amplitude and phase relationships of the various signals** have been investigated (starting with Killworth et al., 2004) → **Horizontal advection** of chlorophyll gradients plays a significant role in the production of a signal; vertical processes are at most of local importance

Multiparameter Observations



O'Brien et al., 2013

Multiparameter Observations



O'Brien et al., 2013

→ INTERACTIVE: Propagating features in Sea Surf. Salinity

Finally we repeat the analysis with new Sea Surface Salinity data, following the Jupyter Notebook OTC2019_SSS_ltplot.jpynb

Extract monthly SSS data from the newly released Sea Surface Salinity CCI dataset, over 2010-2018

Slice the data at ~25S in the Indian Ocean and repeat analysis as before

We may filter the data to highlight propagation - we use again the simple filter approach. Actually this also highlights the different scales (broadly corresponding to eddies vs planetary waves)

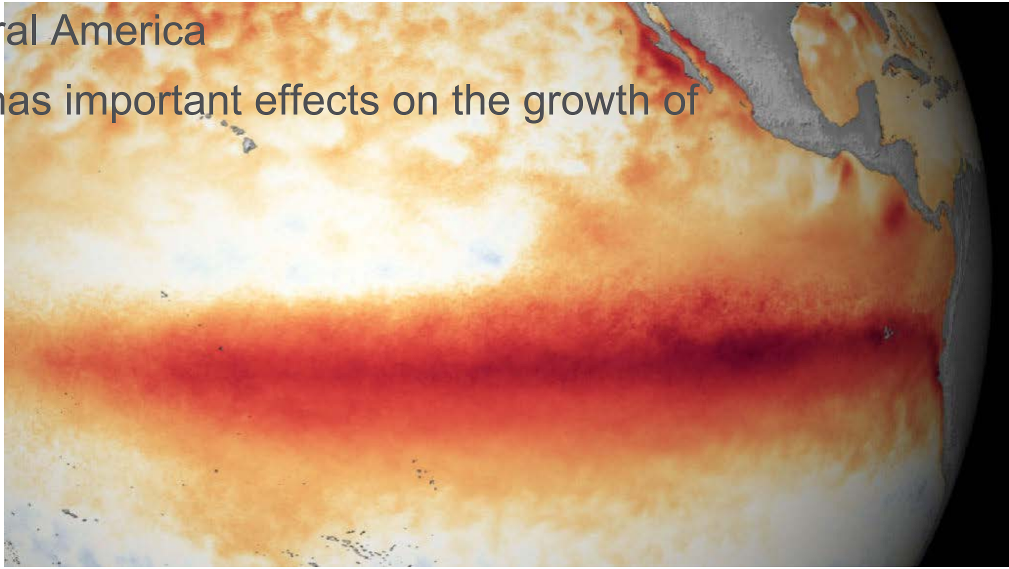
Compare results with those from SSH, SST, Ocean Colour

A synergistic look at El Niño – Southern Oscillation (ENSO)

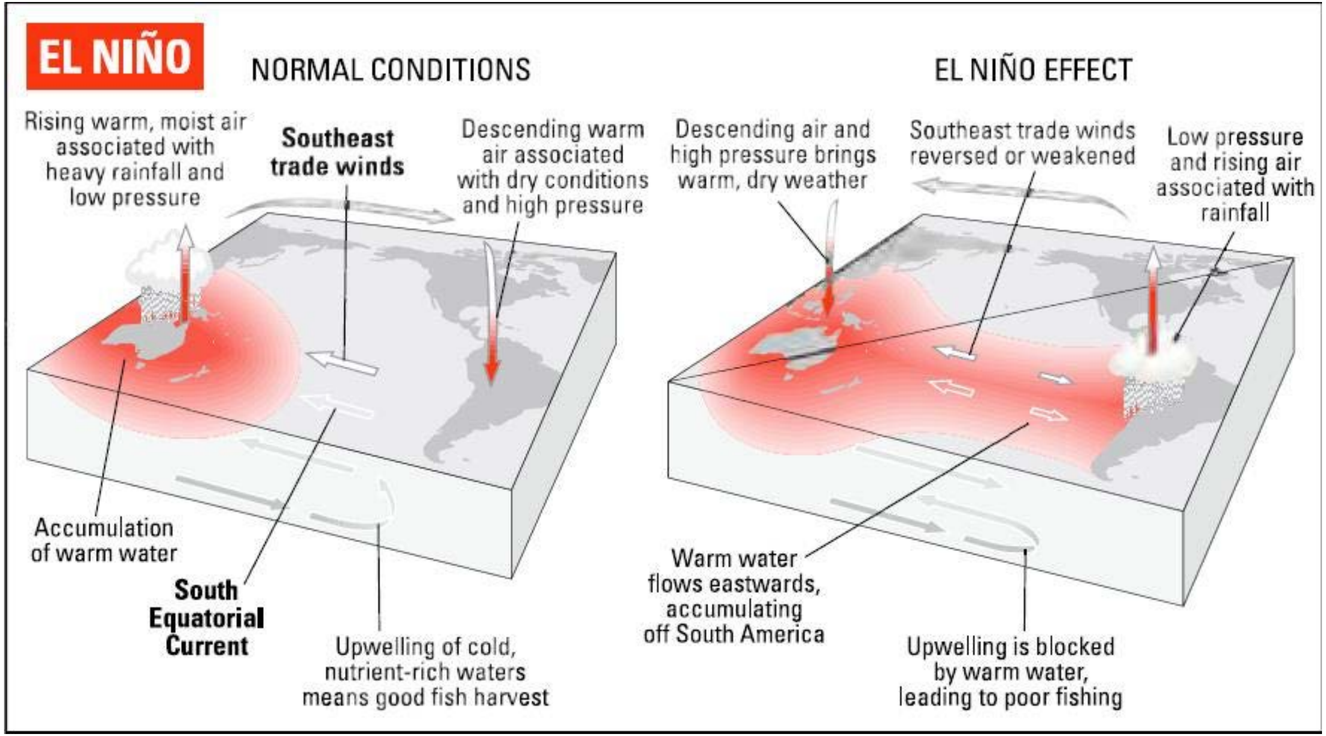
El Niño – Southern Oscillation is a major climate cycle in the equatorial Pacific Ocean that has repercussions and teleconnections globally

It surface manifestation is a region of abnormally warm water that extends in the Eastern Equatorial Pacific towards the coasts of Central America

It is clearly visible in SSH and SST, but also has important effects on the growth of phytoplankton



El Nino and its effect on phytoplankton



Graphics from geography.name

→ INTERACTIVE: ENSO and Phytoplankton

We follow notebook OTC2019_ENSO.jpynb

Load Multivariate ENSO index (MEI) from https://www.esrl.noaa.gov/psd/enso/mei/ – a multivariable index (mainly based on SST) recording the strength of the ENSO cycle. Strong positives are El Niño – Strong negatives are La Niña

Load CCI SSH data and extract the time series over the El Nino region, and plot it alongside MEI. What can you observe on the correlation?

Load CCI Ocean Colour data (from www.oceancolour.org) and extract the time series over the El Nino region, and plot it alongside MEI. What can you observe on the correlation this time?

Summary

We have looked at large-scale processes in the ocean: **eddies and planetary waves**

We have first observed them in satellite altimetry data

We have then measured space/time scales and propagation speeds

Then we have observed them in other satellite datasets: SST, Ocean Colour, Sea Surface Salinity, and discussed why they can be seen there

Finally we have used the same synergistic approach to look at **El Niño – Southern Oscillation (ENSO)** effects in altimetry, SST and Ocean Colour

All this using the long time series of climate-quality satellite data generated (and freely available) by the **ESA Climate Change Initiative** (climate.esa.int | @esaclimate)

Thanks for your interest and keep in touch! → paolo.cipollini@esa.int | @PaoloCipollini