Earth Sciences New Zealand

Welcome to

Earth Sciences New Zealand

On July 1, 2025 ***NIWA*** and ***GNS Science*** merged to become a new Public Research Organisation called ***Earth Sciences** New Zealand*

Earth Sciences New Zealand

Earth Sciences
New Zealand

Oceans and Climate

Phil Sutton

Physical Oceanographer

Outline

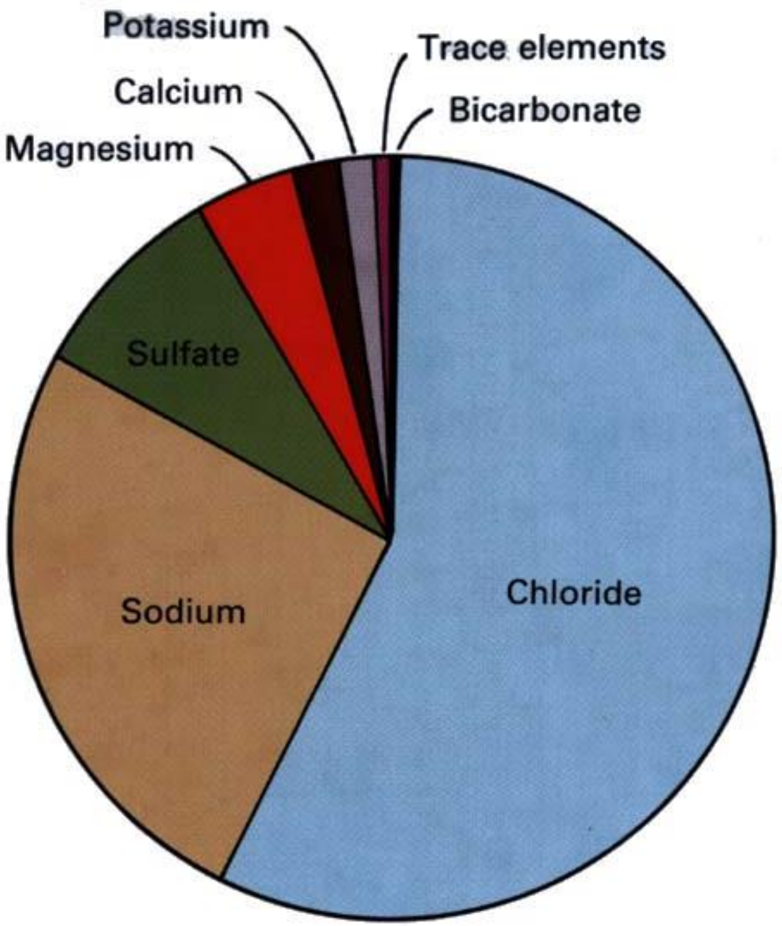
1) Background oceanography
2) Technology
3) The ocean's role in climate
4) Global and local ocean changes

The special properties of water

Properties	Comparison with other substances	Importance in physical-biological environment
Heat capacity	Highest of all solids and liquids except liquid ammonia	Prevents extreme ranges in ocean temperature. Heat transfer by currents is very large. Tends to maintain uniform body temperatures. 2.5m of water has the same heat capacity as the entire depth of the atmosphere
Latent heat of fusion	Highest except ammonia	Acts as thermostat at freezing point owing to absorption or release of latent heat.
Latent heat of evaporation	Highest of all substances	Extremely important in heat and water transfer of atmosphere.
Thermal expansion	Temperature of maximum density decreases with increasing salinity. For pure water it is at 4°C	Fresh water and dilute sea water have their maximum density at temperatures above the freezing point. Ice floats.
Surface Tension	Highest of all liquids.	Important of cell physiology. Controls certain surface phenomena (e.g. capilliary waves) and drop formation and behaviour
Dissolving power	Dissolves more substances and in greater quantities than any other liquid.	Implications in physical and biological phenomena
Transparency	Relatively high	Absorption of radiant energy is large in infrared and ultraviolet. In visible portion of energy spectrum there is relatively little selective absorption, hence is colourless.

Modified from Sverdrup, Johnson and Fleming 1942: “The Oceans: their Physics, Chemistry, and General Biology”

The special properties of seawater: salt



Major and minor constituents of seawater: almost constant throughout the world's oceans.

Seawater:

- about a 3.49% solution of salt, or about 96.5% freshwater.
- Salt concentration referred to as 'salinity' and expressed as parts per thousand or ‰.
- Ocean salinity ranges from ~32‰ to 38‰ with a mean of 34.9‰.
- Evaporation removes fresh water and makes the surface ocean saltier.
- Precipitation makes the surface ocean fresher.
- Sea ice is fresher than seawater.
- Salty water is denser.
- Fresher water is less dense.
- Below the surface, salinity is conserved, and so can be used to identify and track water masses.
- Salinity depresses freezing point: seawater freezing point is ~ -2°C.
- Routinely measured by conductivity

The mean state of the ocean: stratification

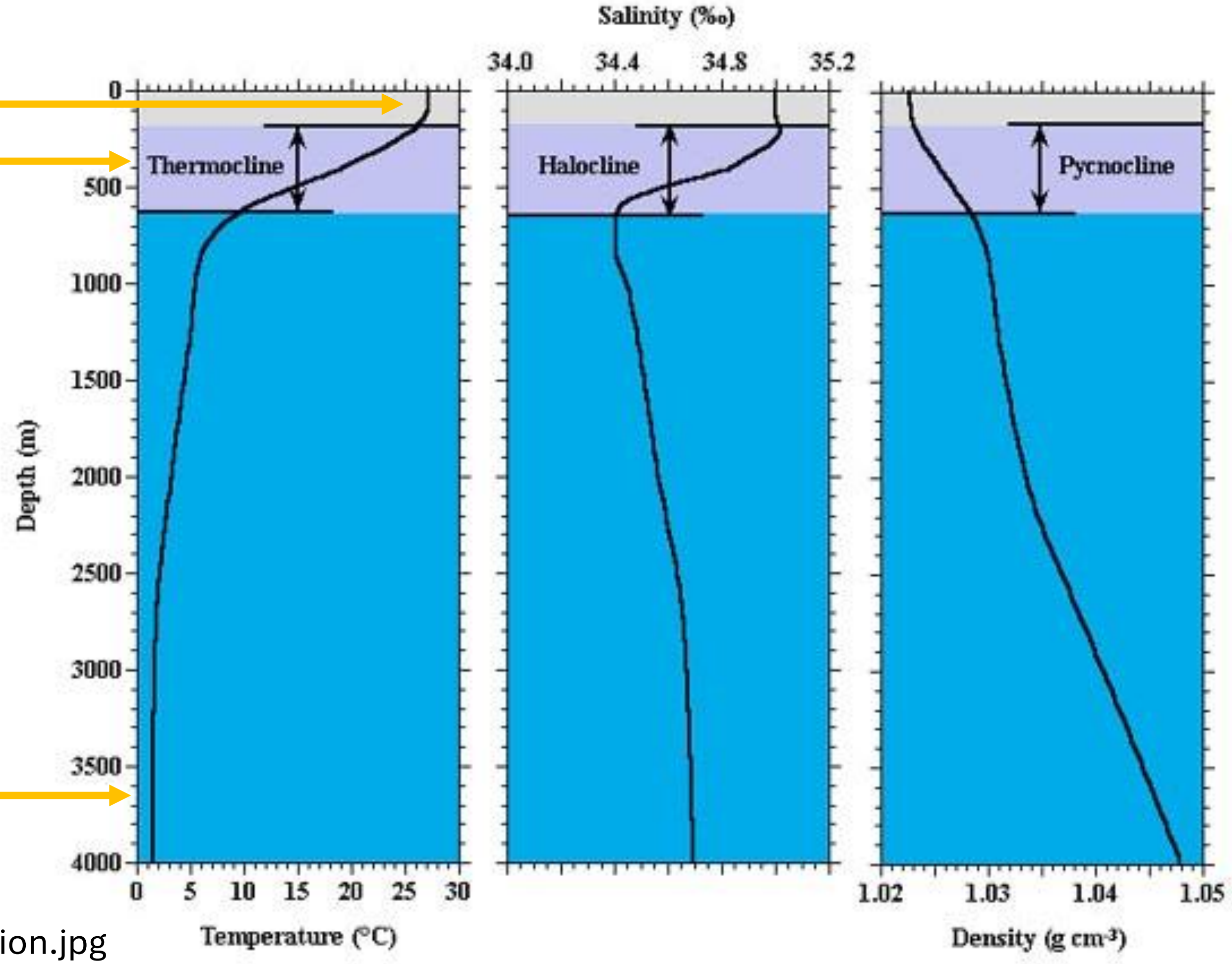
- **The ocean is stratified. Lighter water at the top, denser water at the bottom.**
- **Cold water is more dense than warm water; salty water is more dense than fresh water.**

Ocean layers:

1) Mixed layer
    - upper ocean
    - constant properties
    - well mixed
    - in contact with the atmosphere

2) Thermocline/Halocline/Pycnocline
    - decreasing temperature and salinity; increasing density
    - strong stratification

3) Deep ocean
    - weak gradients

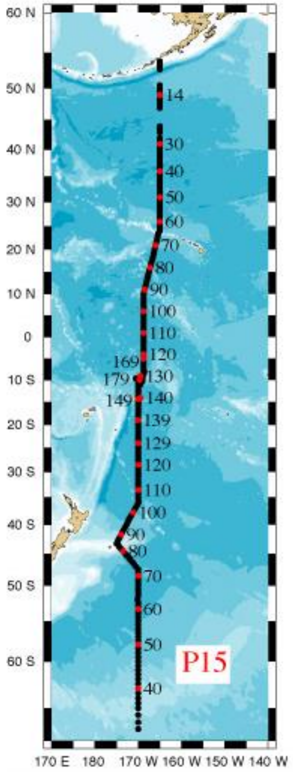


http://www.marinespecies.org/i/images/e/ed/Ocean_stratification.jpg

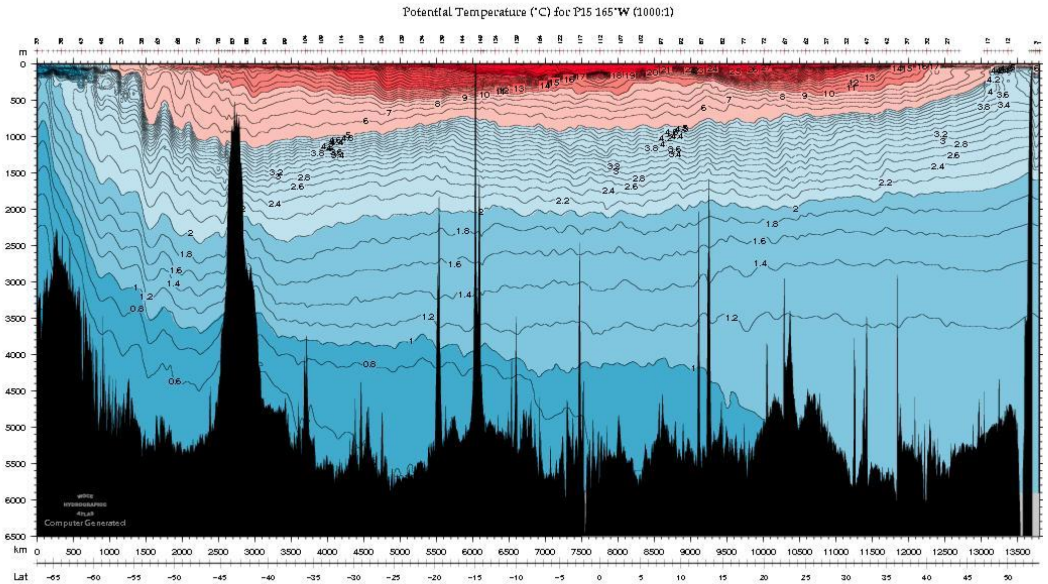
The mean state of the ocean: stratification

- **The ocean is stratified. Lighter water at the top, denser water at the bottom.**
- **Cold water is more dense than warm water; salty water is more dense than fresh water.**

Vertical sections of temperature and salinity across the Pacific Ocean at 170°W:



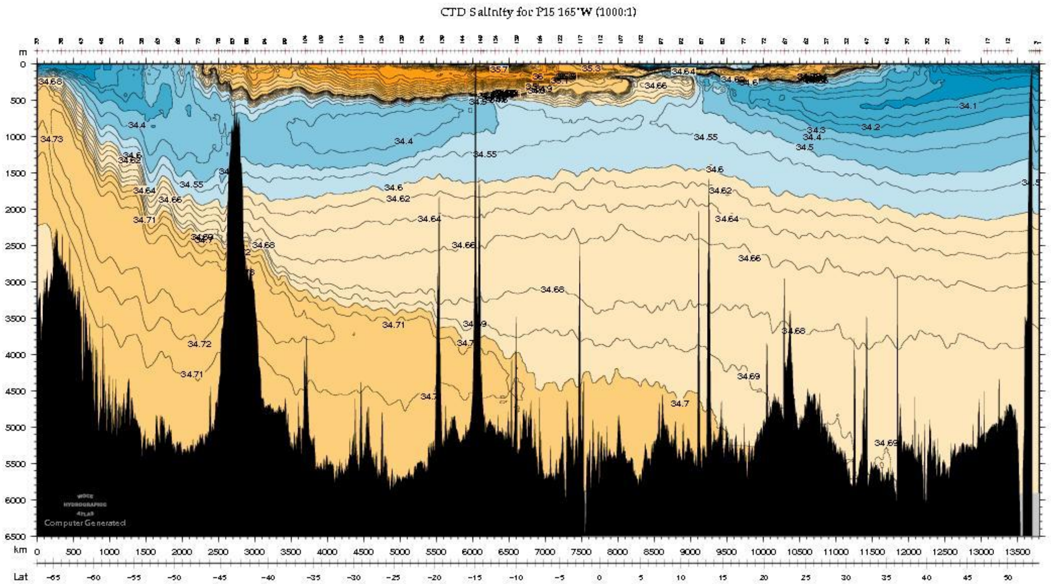
Temperature: from 0.6°C - 30°C



66° South

55° North

Salinity: from ~34.2 - 35.8ppt



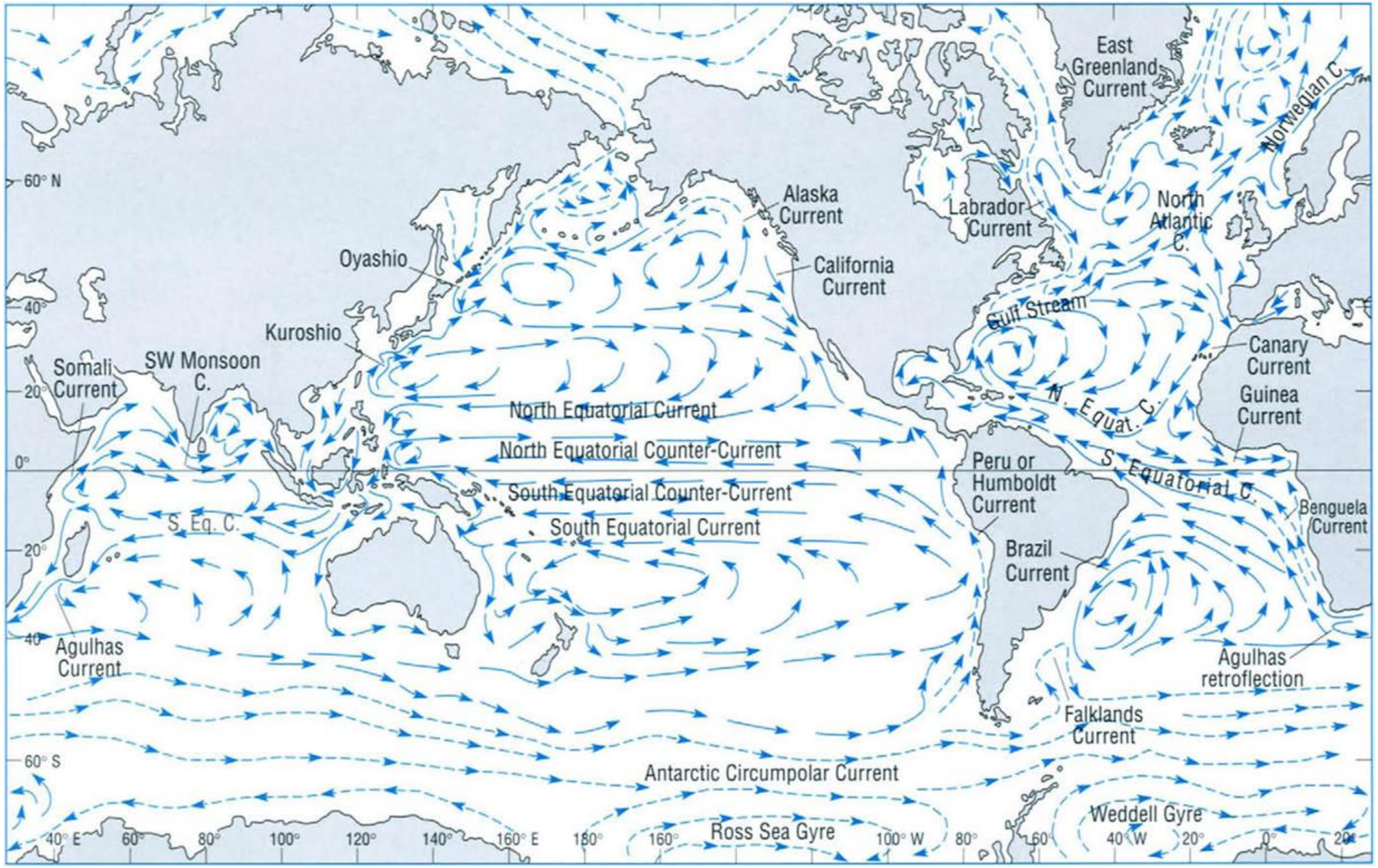
Chatham Rise

(from https://sam.ucsd.edu/whp_atlas/pacific/p15/sections/sct_menu.htm)

Upper ocean circulation

Upper ocean currents driven by the winds

Extend down from surface to about 1000 metres



- Subtropical gyres
- Western Boundary Currents
- Antarctic Circumpolar Current

From Ocean Circulation, 2001

Regional Oceanography: wind-driven currents

New Zealand spans from the subtropics to the subantarctic.

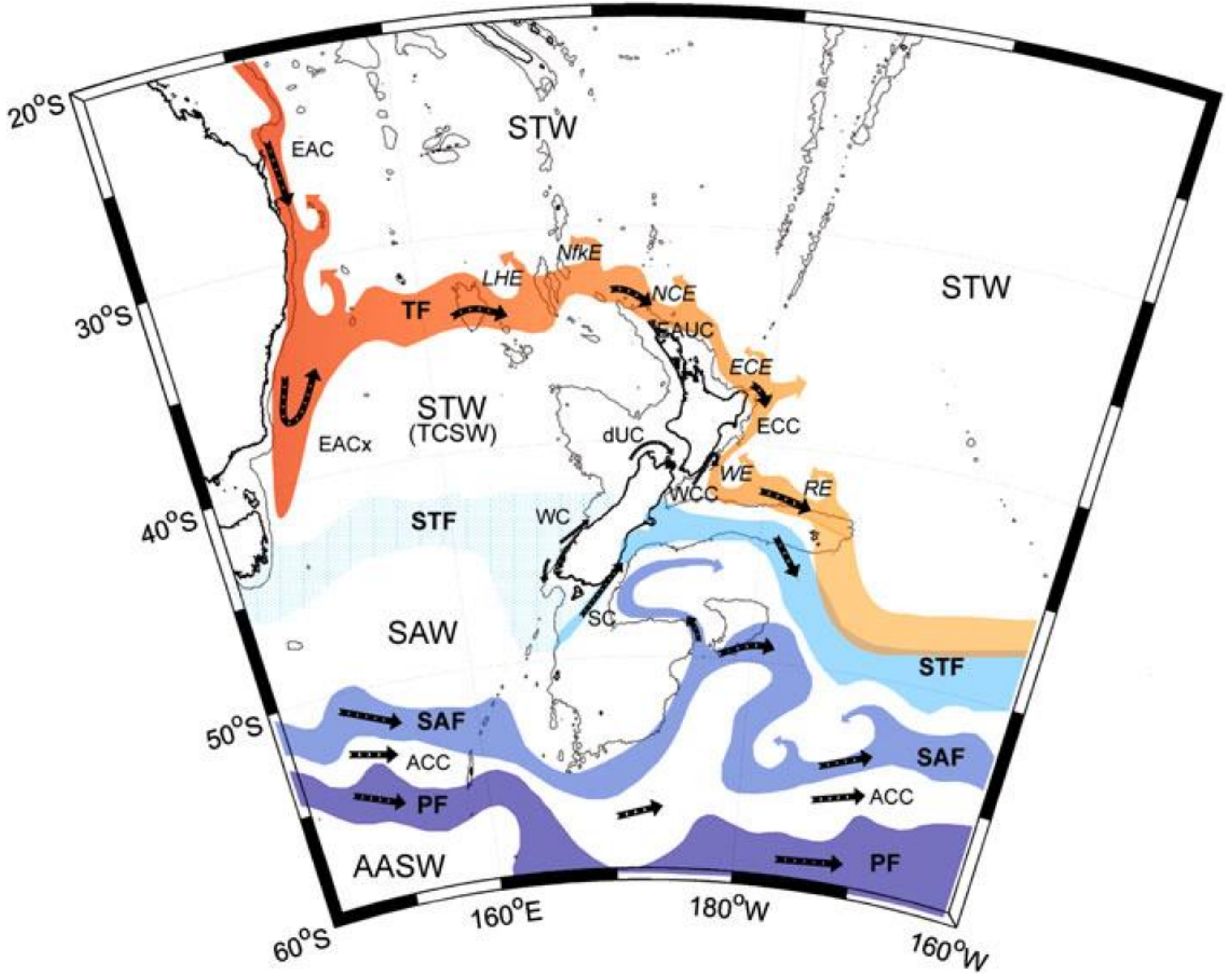
Two different current systems:

- South Pacific Subtropical Gyre
- Antarctic Circumpolar Current

Two different water masses:

- Warm, salty Subtropical Water
- Cold, fresh Subantarctic Water

separated by the Subtropical Front.



Chiswell et al. 2015. DOI: 10.1080/00288330.2014.992918

What about the deep ocean which isn't driven by the winds?

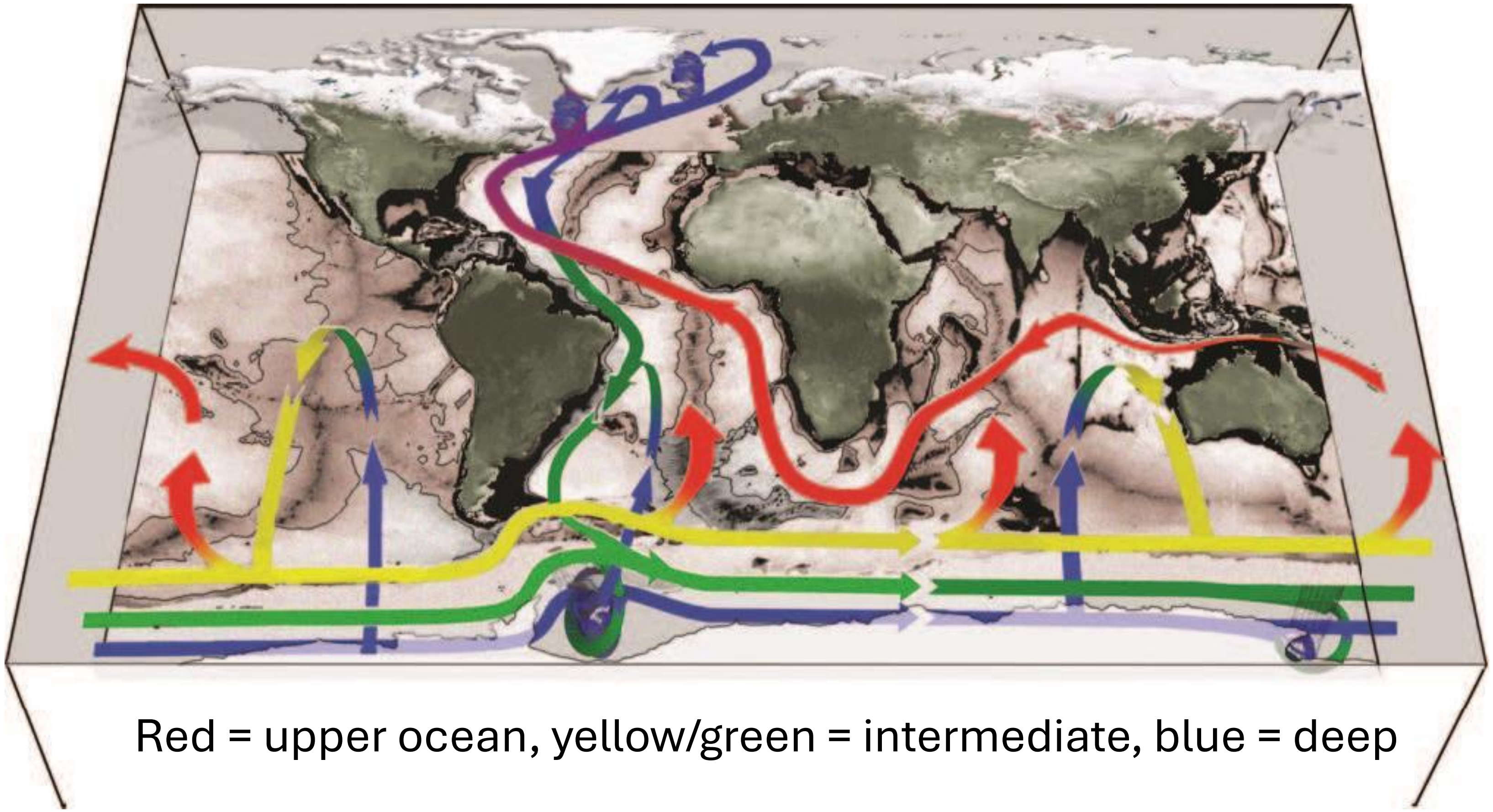
Thermohaline (density-driven) circulation

'Thermo' = temperature: cold water is denser

'Haline' = salinity: saltier water is denser

Currents result from density gradients

Thermohaline (density-driven) circulation



Red = upper ocean, yellow/green = intermediate, blue = deep

(Marshall and Speer, 2012)

- Salty water cooled in the North Atlantic becomes denser and sinks: **North Atlantic Deep Water (NADW)**.
- Cold water around Antarctica gains salt as ice is formed (brine rejection) and sinks: **Antarctic Bottom Water (AABW)**.
- These deep water masses travel around the world.
- Sequestration: deep water masses out of contact with the atmosphere for hundreds to thousands of years.
- Currents are on the western sides of the ocean basins because of the Coriolis Force

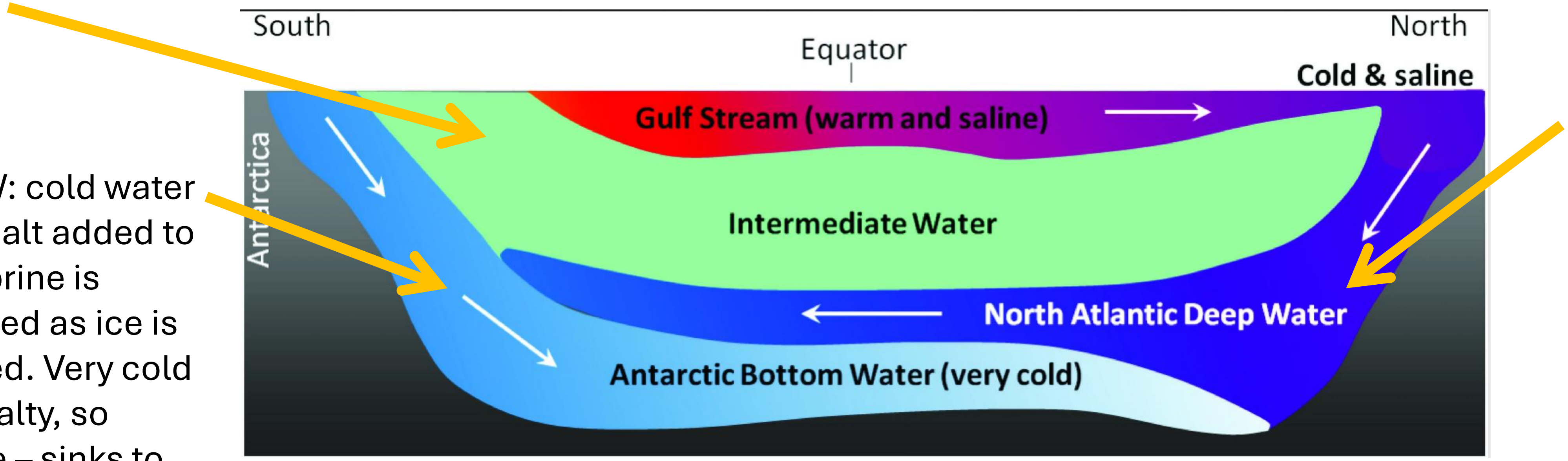
The mean state of the ocean: watermasses

Once water loses contact with the atmosphere (below the mixed layer) the temperature and salinity are largely conserved (there is some mixing).

- **Water can be identified and tracked by its temperature and salinity characteristics: watermasses.**
- **Watermasses often named by where they are 'formed': where they are last in touch with the atmosphere.**

AAIW: fresh water forms in deep winter mixed layers at the Subantarctic Front and is subducted.

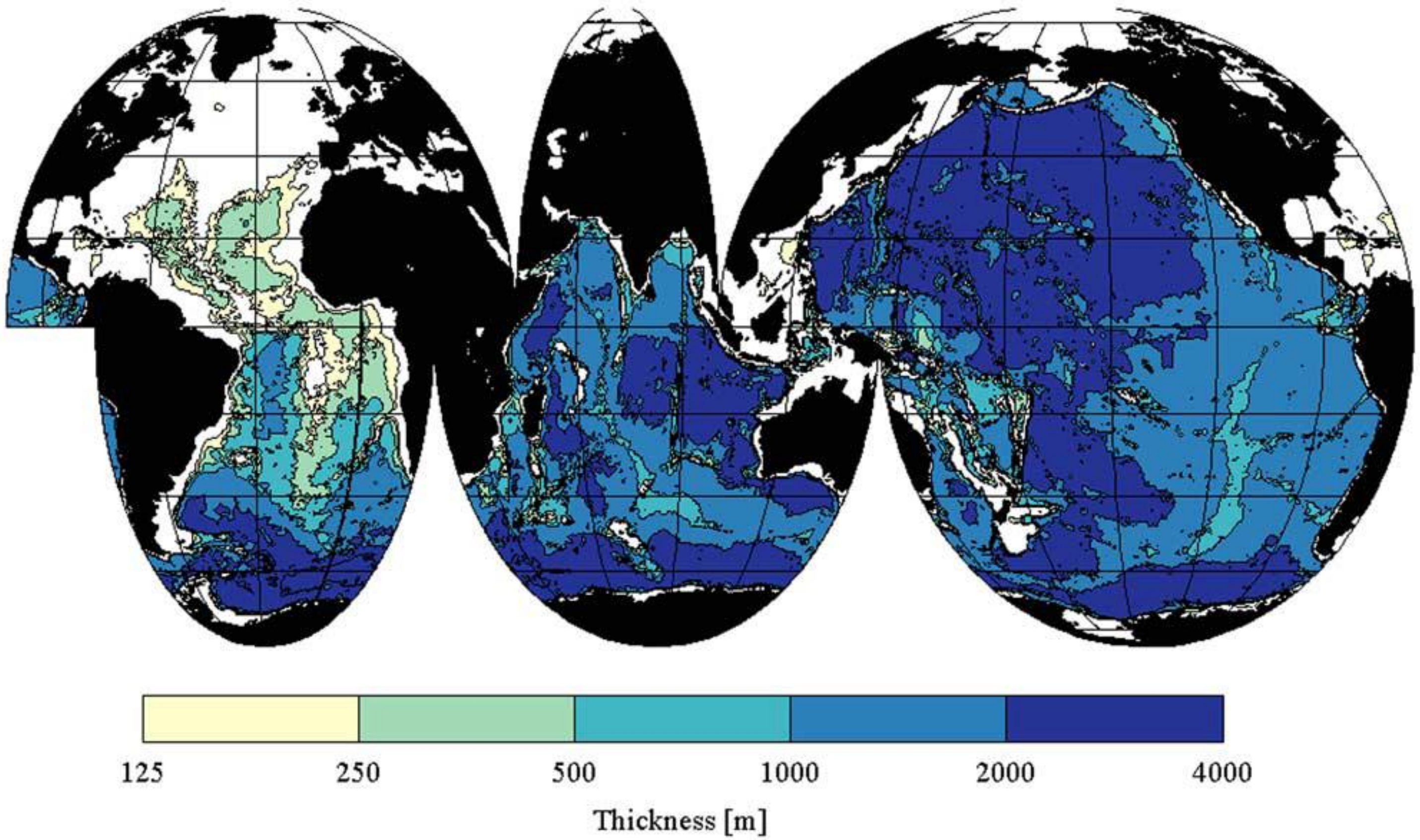
AABW: cold water gets salt added to it as brine is rejected as ice is formed. Very cold and salty, so dense – sinks to sea floor.



A section through the Atlantic Ocean

NADW: warm, salty water carried into the North Atlantic gets cooled. Cold and salty so dense- sinks to the deep ocean.

Antarctic Bottom Water (AABW)



(Johnson, 2008)

- Bottom water of Antarctic origin occupies 40% of the world ocean.
- Replacement time ~900 years

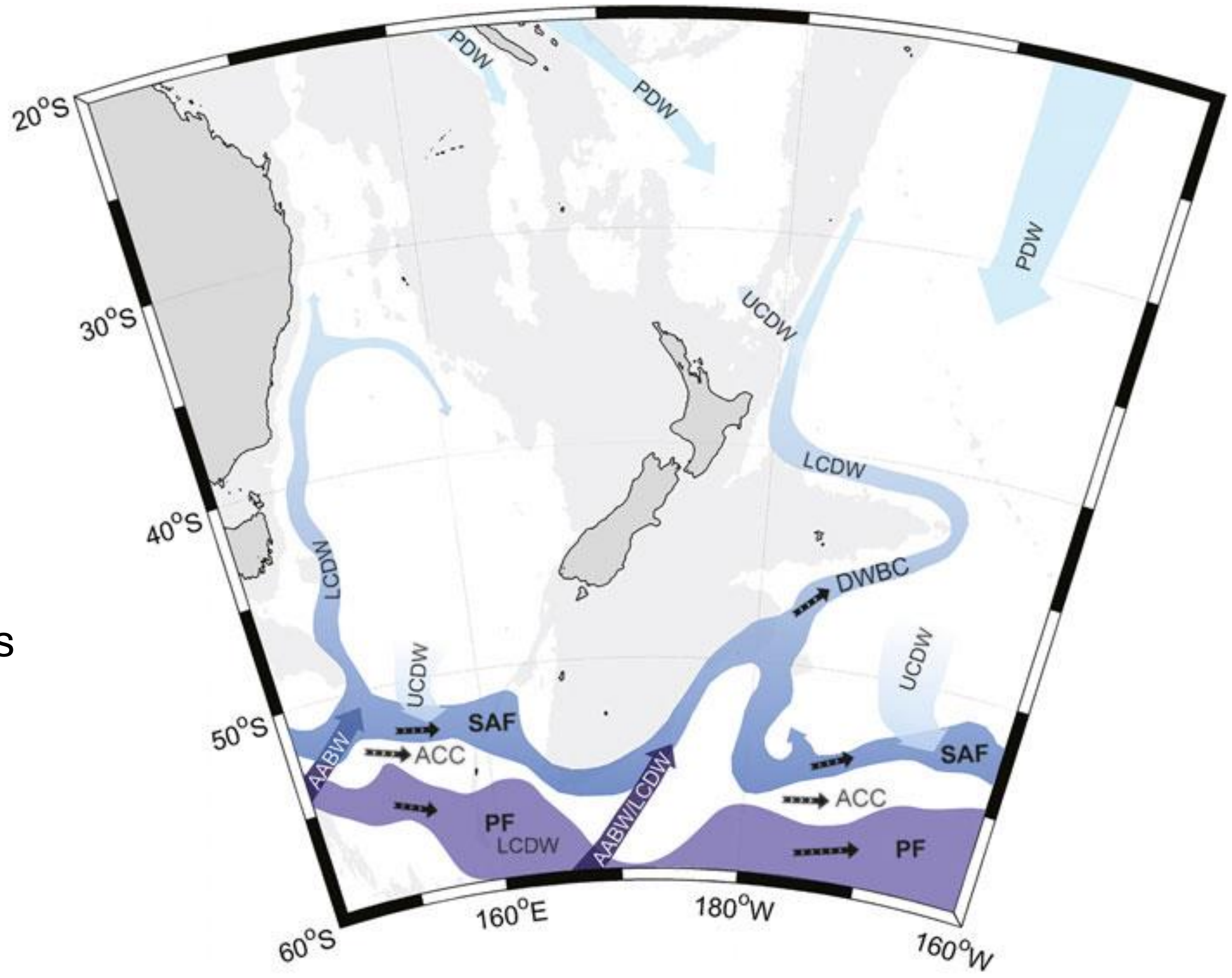
Regional deep currents

The western boundary of the deep South Pacific is east of New Zealand.

The **Deep Western Boundary Current (DWBC)** flows northward to the east of NZ and then east of the Kermadec Ridge, ultimately flowing into the North Pacific.

The water at ~3000m depth east of NZ was last in contact with the atmosphere in the Greenland Sea (NADW).

The water below 4000m in the Kermadec Trench was last in contact with the atmosphere around Antarctica.



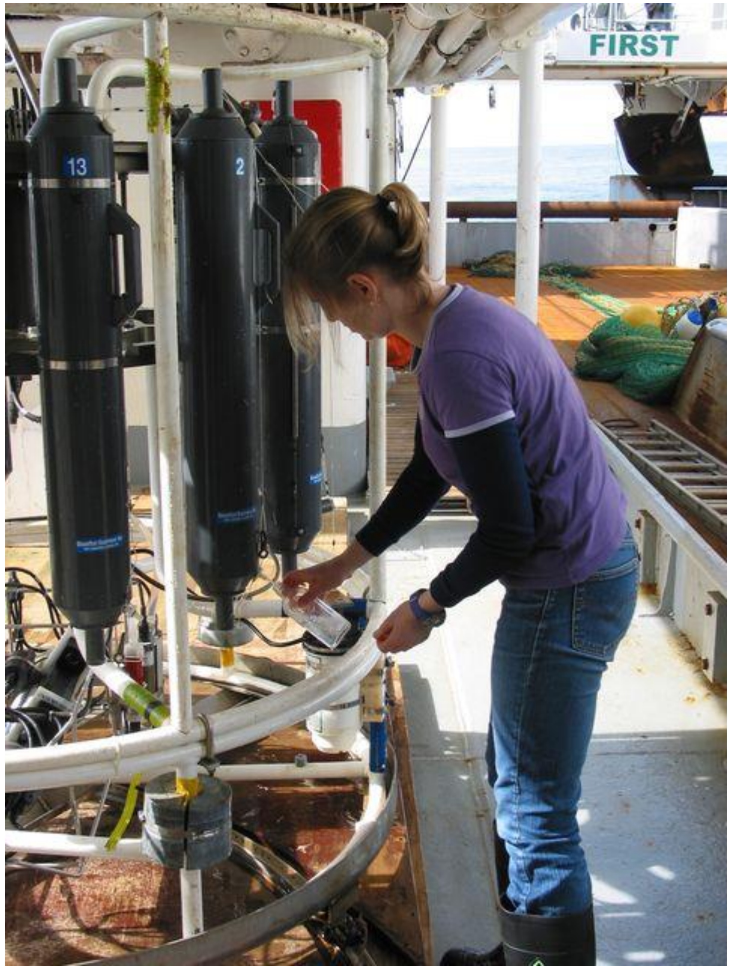
Chiswell et al. 2015. DOI: 10.1080/00288330.2014.992918

Technology and Data

- CTD
- Satellite (altimeter and SST)
- Argo

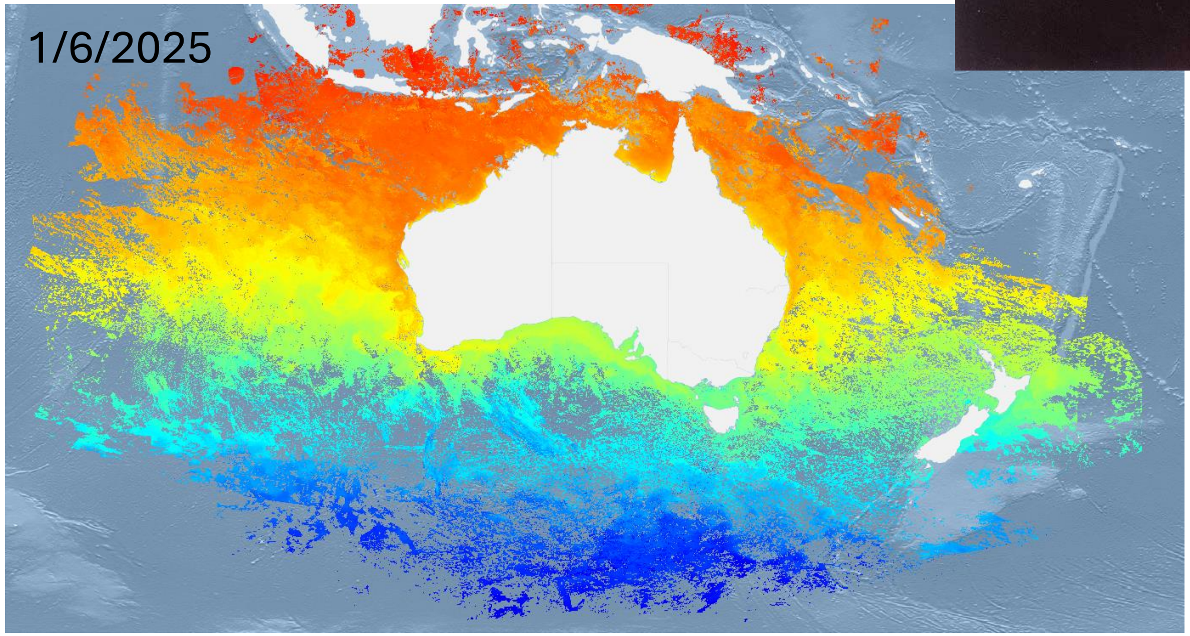
Technology and Data: CTD (Conductivity/Temperature/Depth)

- Lower from a ship on a conductive cable.
- ~1m/s wire speed: a 6000m cast takes ~4 hours
- Electronic measurements
- Water samples



Technology and Data: Satellite altimetry and Sea Surface Temperature

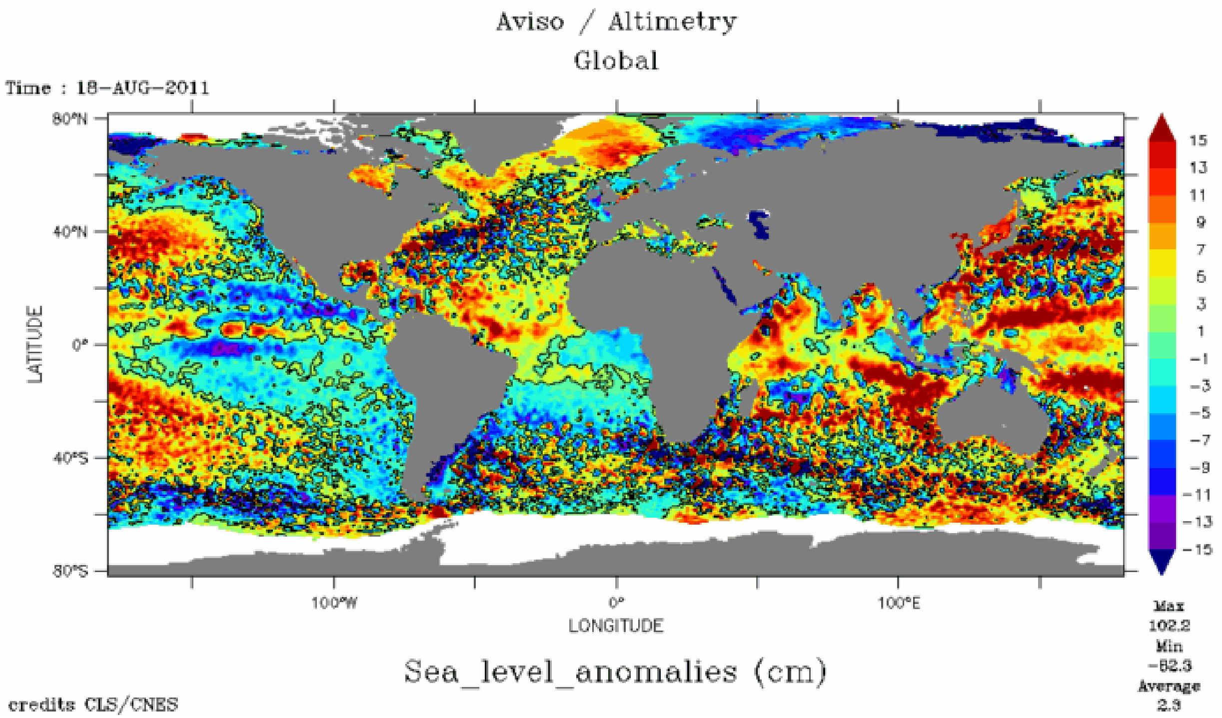
Sea Surface Temperature



IMOS-Satellite Remote sensing _SST-L3S Single sensor 6 day, day and night time. From https://portal.aodn.org.au/search

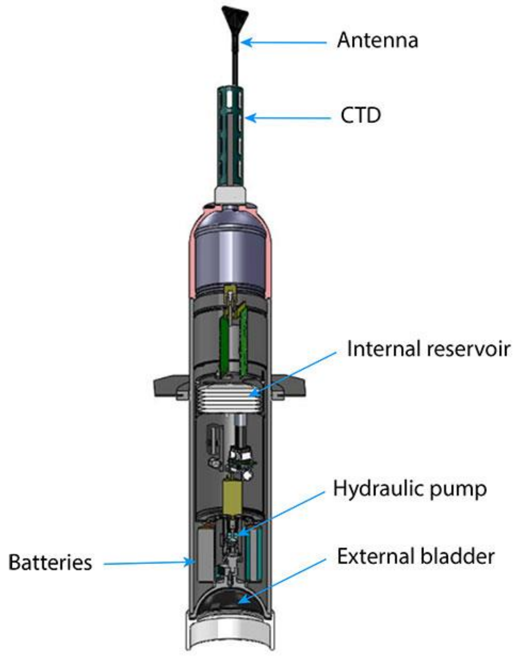
Satellite altimetry

Measure sea surface height anomalies from space and use for heat content and dynamical studies.



Technology and Data: Argo

A global array of profiling floats measuring the temperature and salinity of the upper 2000m of the ocean.

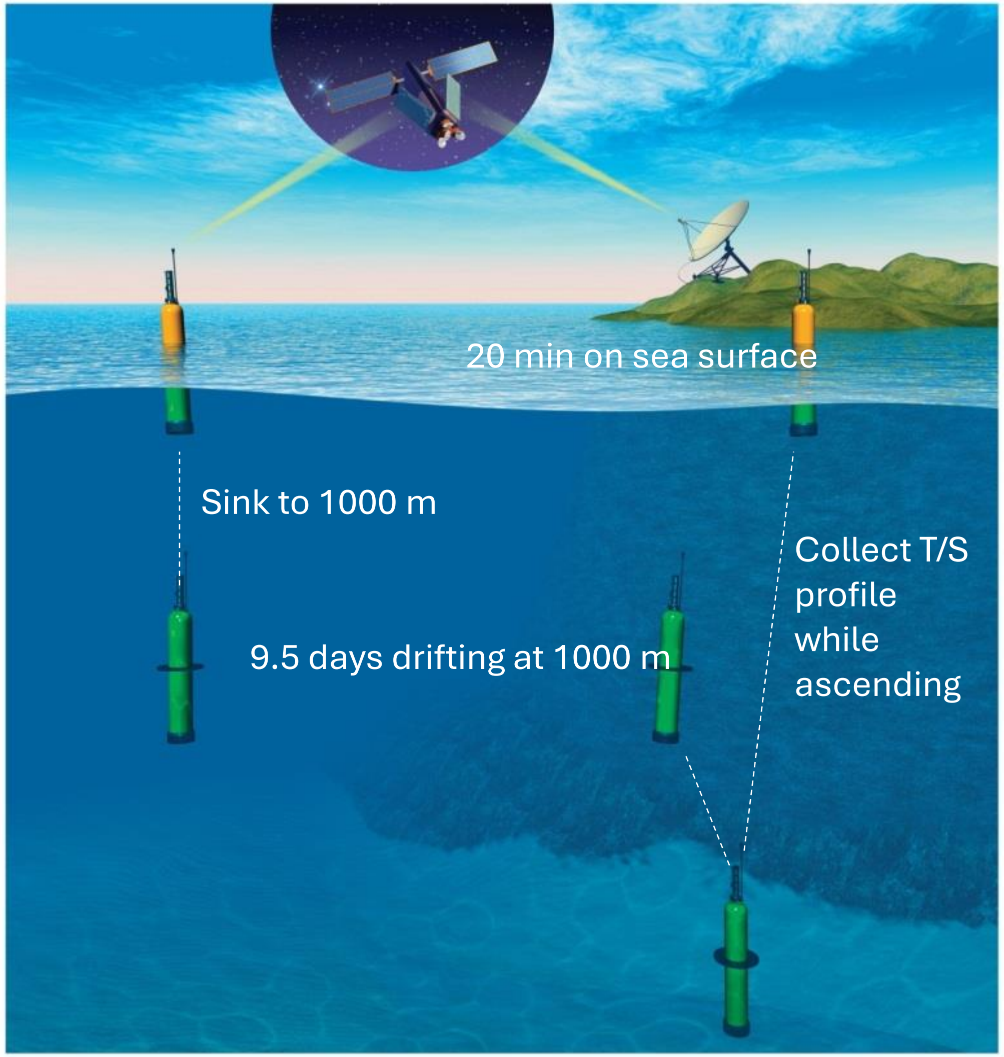


After deployment, a float:

- Sinks to 1000 m
- Drifts for 9.5 days
- Sinks to 2000 m
- Rises to the sea surface measuring T, S, P
- Collects GPS position
- Transmits data, position, and engineering (15 minutes)
- Repeat up to 300 times.

All data freely available in near-real time.

One cycle in the life of an Argo float



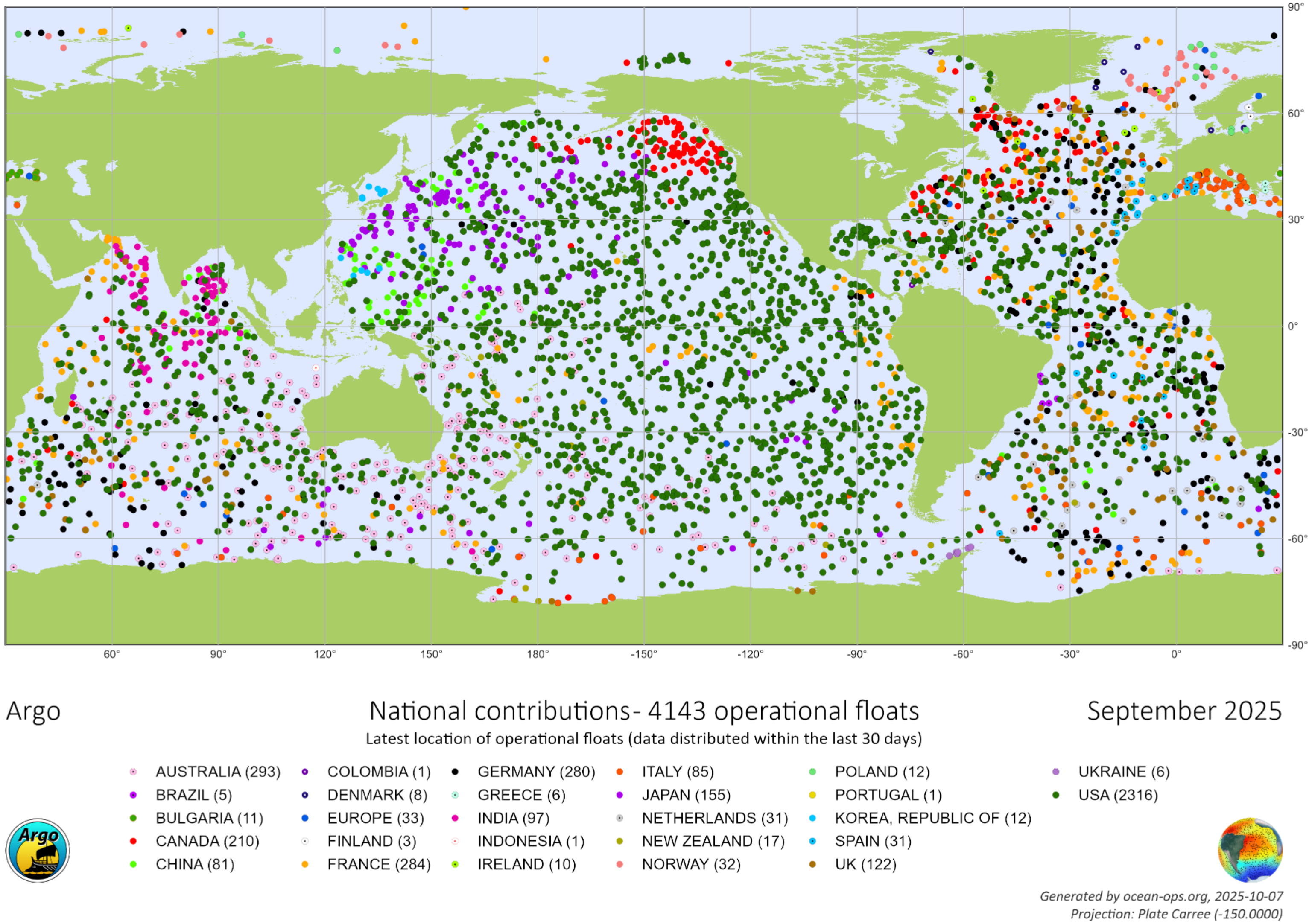
www.argo.ucsd.edu for information

Technology and Data: Argo

Kaharoa in Valparaiso, Chile 2004.

Kaharoa 2

Currently 4143 floats: 26 countries + Europe



Technology and Data: Argo

NZ has deployed the second most floats

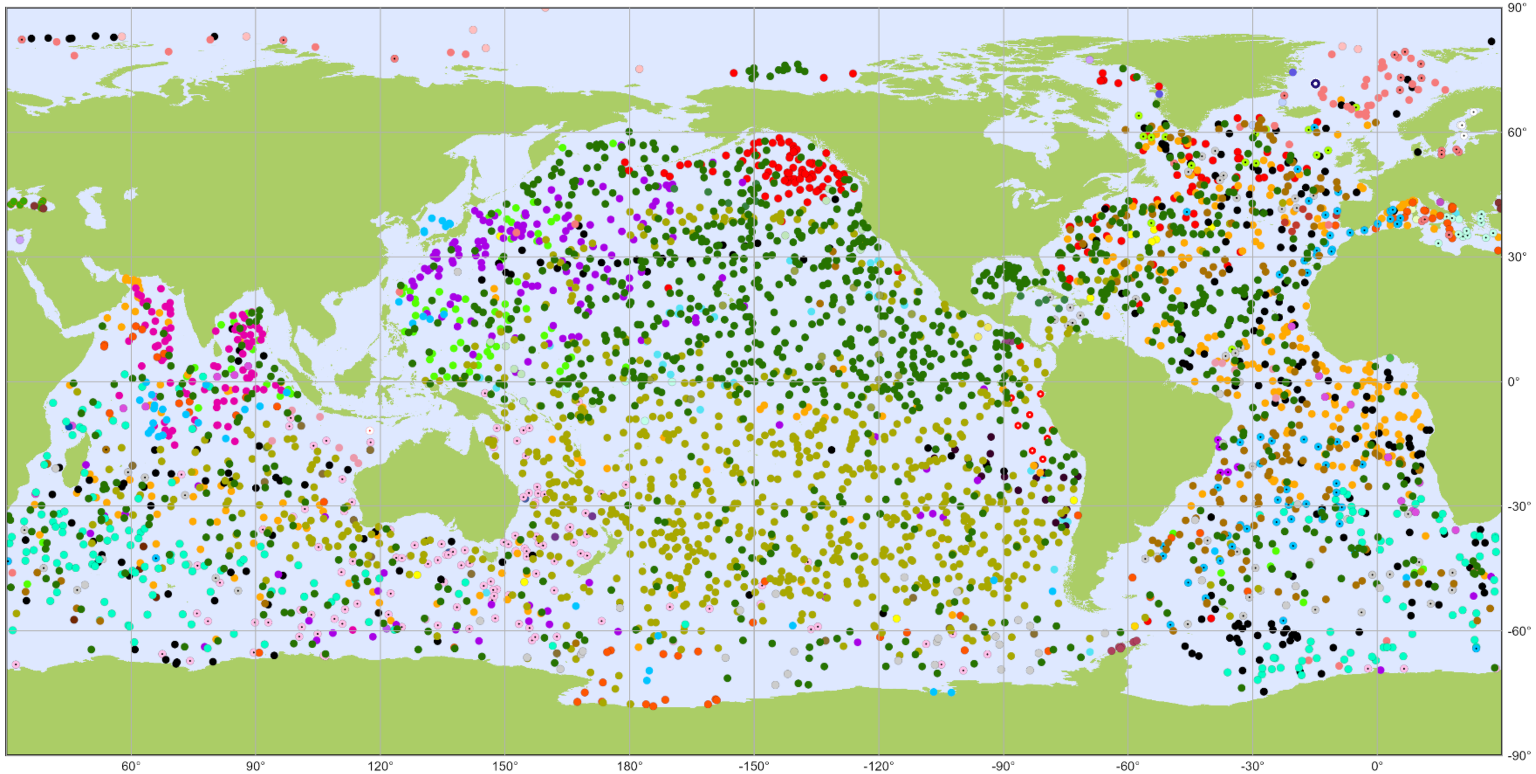
Extensions: **1. Deep Argo**:

In the Ocean, Clues to Change

AUG. 11, 2014

The research vessel Tangaroa deployed devices capable of recording conditions all the way to the bottom, then surfacing to relay the data to a satellite. Learnz

A few weeks ago, some 300 miles off the coast of New Zealand, scientists aboard the research vessel Tangaroa gently lowered two funky-looking orange orbs into the sea. Soon they disappeared, plunging of their own accord toward the depths of the Pacific Ocean.



Argo | Operational float latest locations | September 2025

Latest locations of all operational profiling floats, by ship country/flag

ANTIGUA&BARBUDA (2), ARGENTINA (1), AUSTRALIA (129), BAHAMAS (11), BELGIUM (2), BRAZIL (5), BULGARIA (8), CANADA (152), CAYMAN ISLANDS (32), CHILE (20), CHINA (81), COOK ISLANDS (14), COSTA RICA (3), CROATIA (1), CYPRUS (2), DENMARK (1), FALKLAND IS. (4), FINLAND (4), FRANCE (327), GHANA (1), GERMANY (262), GREECE (13), GREENLAND (2), HONDURAS (2), ICELAND (2), INDIA (90), INDONESIA (1), IRELAND (15), ITALY (64), JAMAICA (1), JAPAN (167), LIBERIA (3), MALTA (5), MARSHALL IS. (18), MAURITIUS (2), NETHERLANDS (57), NEW ZEALAND (857), NORWAY (48), PALAU (1), PANAMA (11), PERU (8), POLAND (18), PORTUGAL (6), ROMANIA (4), SEYCHELLES (1), SINGAPORE (11), SOUTH AFRICA (175), SOUTH KOREA (42), SPAIN (69), ST. VINCENT&GR. (11), TUNISIA (16), UK (162), UKRAINE (6), USA (1144), WALLIS/FUTUNA (8), UNKNOWN (36)

Generated by ocean-ops.org, 2025-10-07
Projection: Plate Carree (-150.0000)

Extensions: **2. BGC Argo**:

Floats with biogeochemical sensors:

Oxygen, Nitrate, pH, Chlorophyll, Suspended particles, Downwelling irradiance

Oceans and climate: oceans are climate!

- 71% of the earth is covered by ocean.
- 2.5m of water has the same heat capacity as the entire depth of the atmosphere.
- Even sluggish ocean currents can carry warm or cold water parcels great distances over long time scales.
- The ocean has high thermal inertia: temperatures are relatively constant over the ocean and in coastal regions.

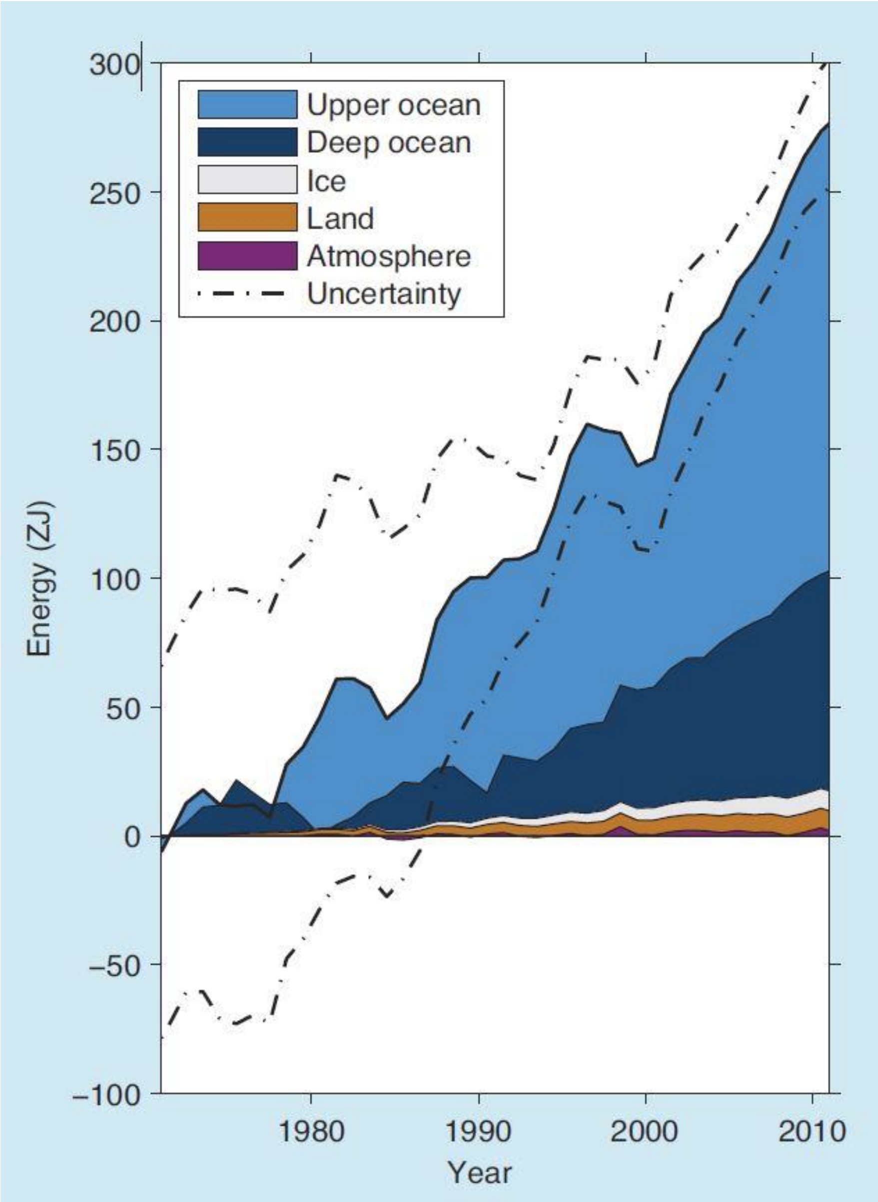
Global warming ≈ Ocean warming

Total global energy change 1971-2010:

- Ocean: 93%
- 0-700m ocean: 64%
- Melting ice: 3%
- Warming continents: 3%
- Warming atmosphere: 1%

The dominance of the ocean is because of the high specific heat of water.

(1 ZJ = 10^{21} J)



Rhein, M., et al., 2013

Ocean heat content (OHC)

Estimates from a number of different products all show warming through all ocean depths.

Heat gain by the 0-700m ocean:

0.39±0.06 W/m^2 to 0.46±0.07 W/m^2

Heat gain by the 700-2000m ocean:

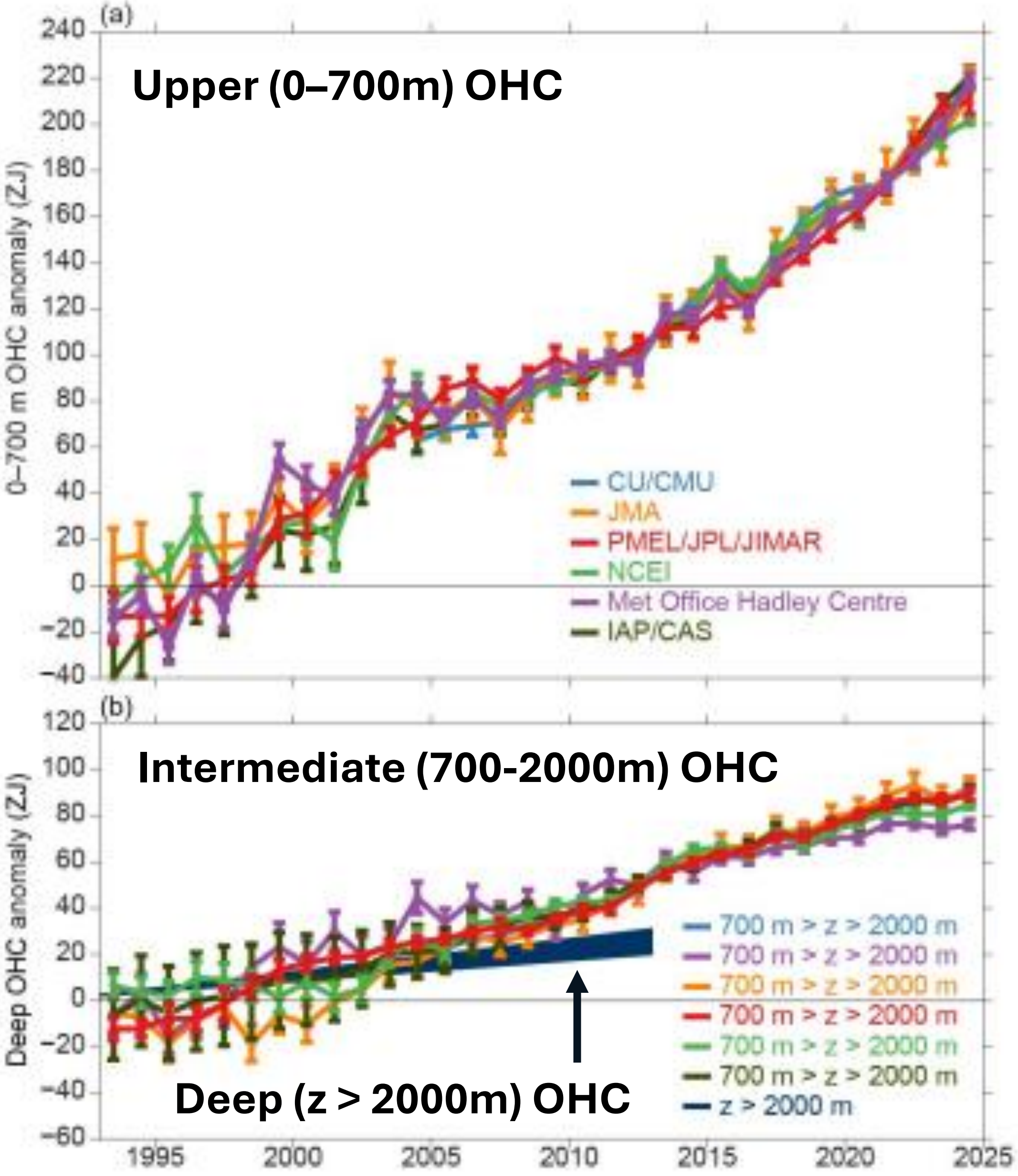
0.17±0.03 W/m^2 to 0.24±0.04 W/m^2

Heat gain deeper than 2000m:

0.070±0.016 W/m^2 from 1/1988 to 10/2014

Total: 0.66 W/m^2 to 0.74 W/m^2.

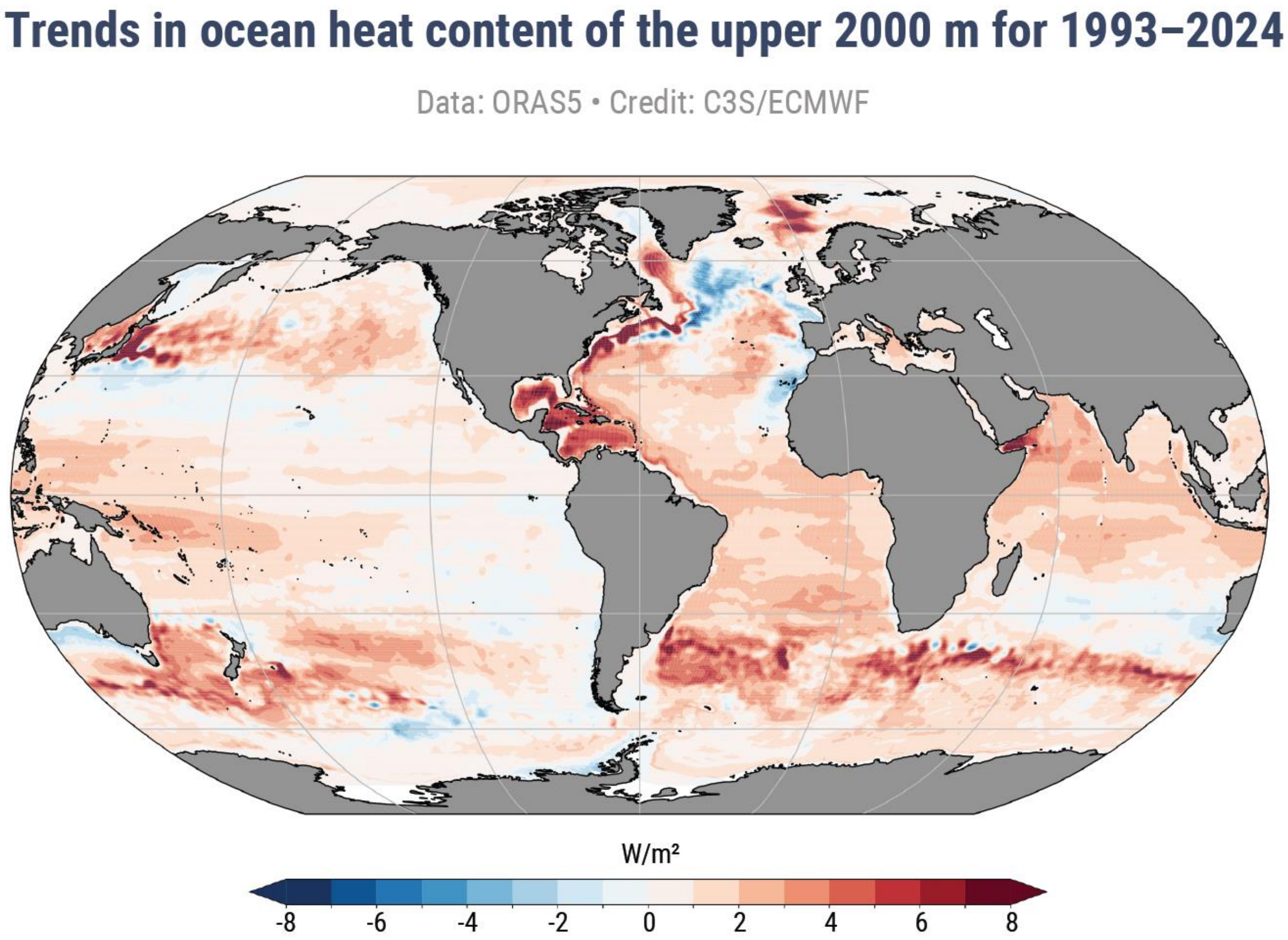
(Averaged over the surface area of the earth: not the surface area of the oceans).



Johnson, G. C. and R. L. Lumpkin, Eds., 2025: Global Oceans [in "State of the Climate in 2024"]. Bull. Amer. Meteor. Soc., 106 (8), S173–S232, https://doi.org/10.1175/BAMS-D-25-0074.1.

1 ZJ = 10^{21} Joules

Heat Content Changes 1993-2024: spatial pattern.



Note the peak in change at ~40°S.

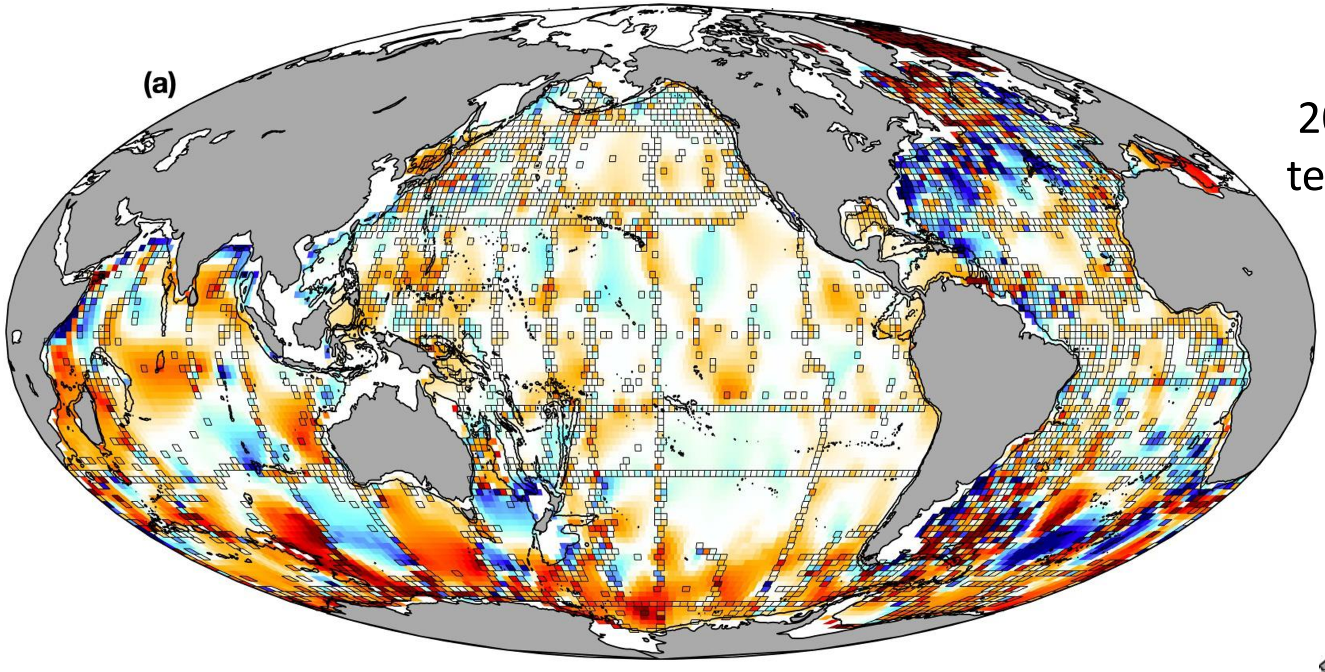
~half of the total heat gain is south of 30^{o}S.

The oceans are warmer to mid-depth at high latitudes in both hemispheres, but the increase in heat content is much greater in the southern hemisphere where the ocean area is larger.

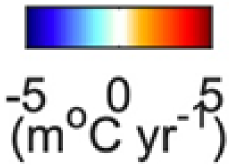
PROGRAMME OF THE EUROPEAN UNION · Copernicus Europe's eyes on Earth · Climate Change Service · IMPLEMENTED BY ECMWF

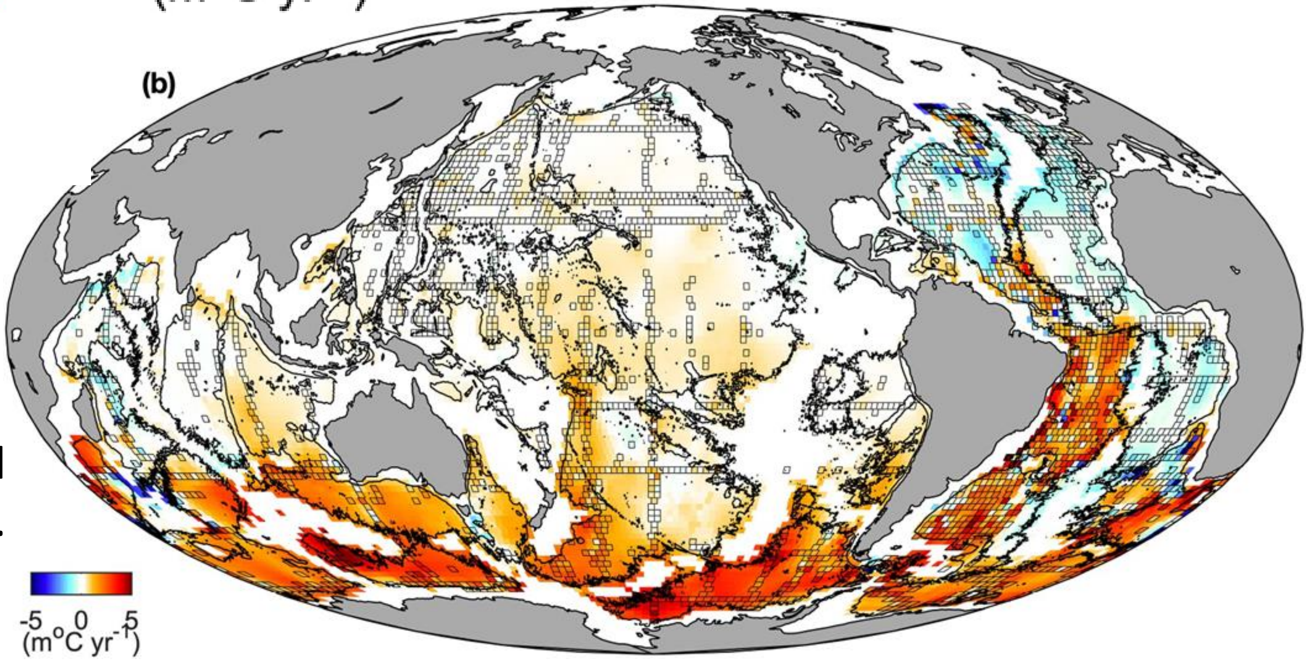
https://climate.copernicus.eu/climate-indicators/ocean-heat-content

What about the deep ocean? Deep temperature trends



2000-4000 dbar (~m) pressure-averaged decadal temperature trends and 2000 dbar isobath.

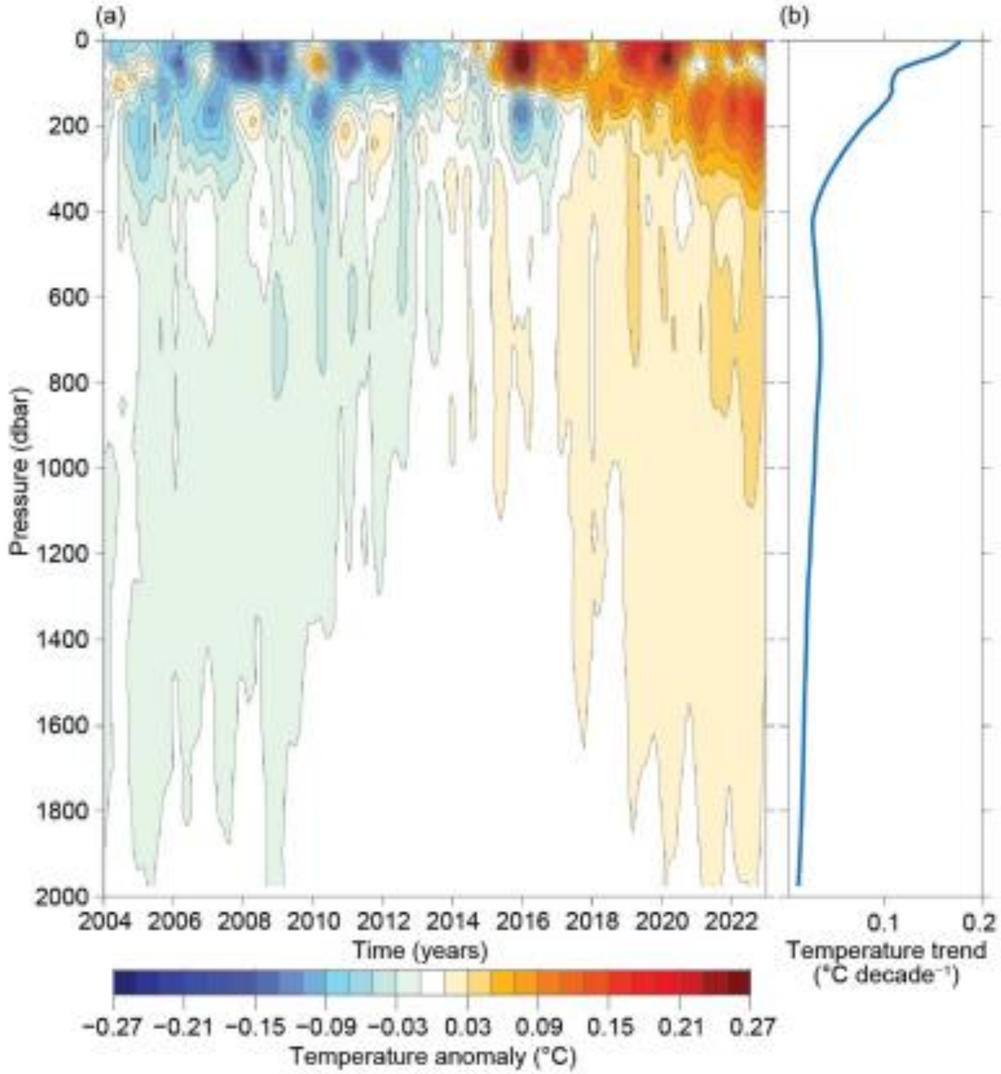




4000-6000 dbar (~m) pressure-averaged decadal temperature trends and 4000 dbar isobath.

Johnson and Purkey, GRL 2024

Where is the warming in the vertical?



Near global (65°S-80°N) ocean* average monthly temperature anomalies and the linear trend. (5 month smoothing).

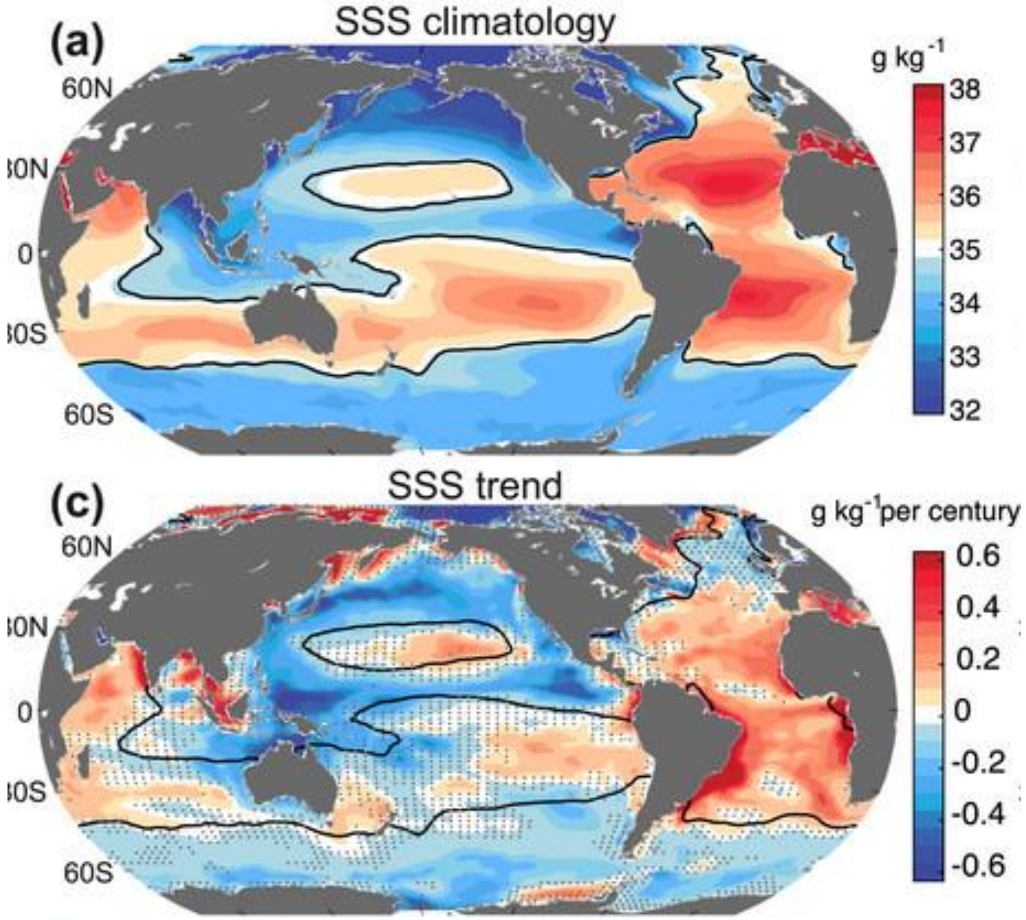
* Excluding continental shelves, Indonesian Seas and the Sea of Okhotsk.

Note the interchange between the 0-100m and 100-300m. The subsurface heat accumulation was masked from the surface analyses and explains the apparent ‘hiatus’ in warming in 1998-2013.

Roemmich, D., Church, J., Gilson, J. *et al.* Unabated planetary warming and its ocean structure since 2006. *Nature Clim Change* **5**, 240–245 (2015). https://doi.org/10.1038/nclimate2513

Johnson, G. C. and R. Lumpkin, Eds., 2023: Global Oceans [in “State of the Climate in 2022“]. Bull. Amer. Meteor. Soc., 104 (9), S146–S206, https://doi.org/10.1175/BAMS-D-23-0076.2.

Salinity Changes: (1960-2017)



Dry places are getting drier.

Wet places are getting wetter.

Accelerated hydrological cycle:

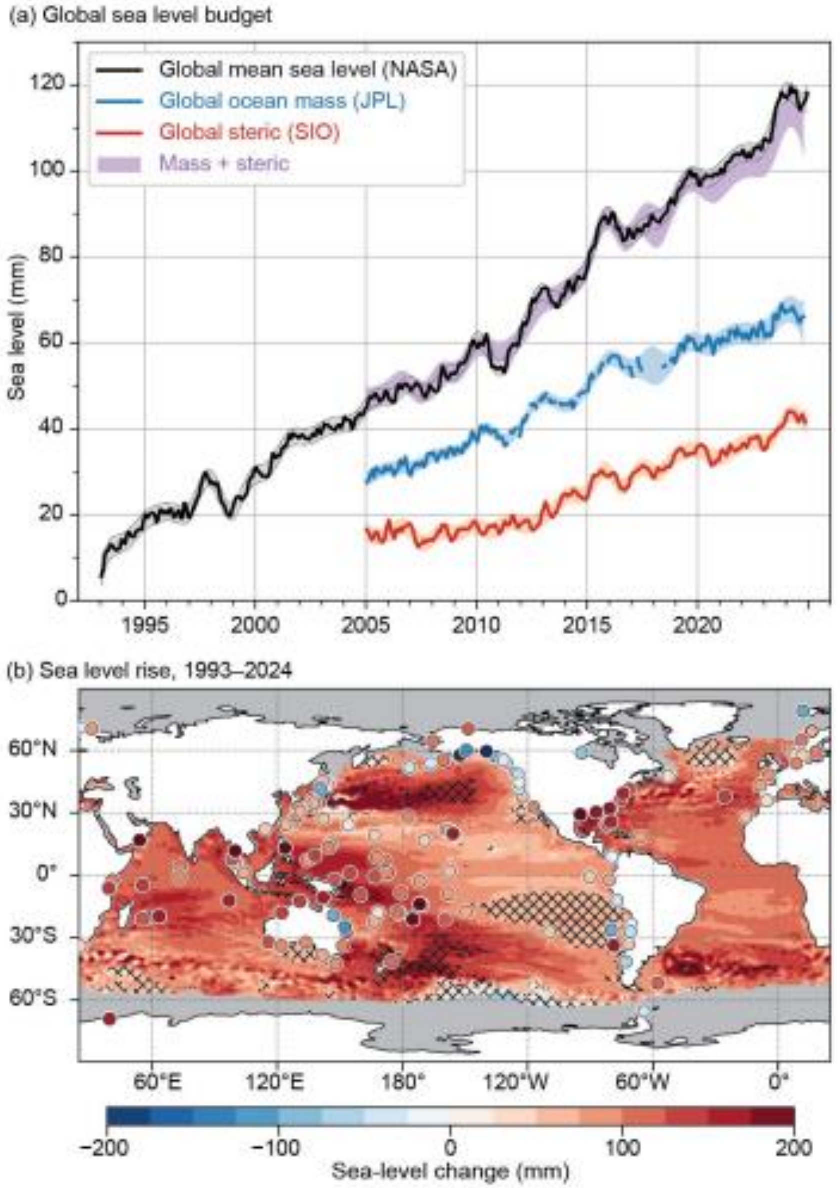
~4% since 1960

or 2-4% per °C warming

(consistent with model predictions)

Cheng et al., 2020. Journal of Climate. https://doi.org/10.1175/JCLI-D-20-0366.1

Sea level change and Ocean warming: Steric height



Sea level and its components (with 95% confidence intervals)

Black: global mean sea level from satellite altimeters.

Blue: global ocean mass from the Gravity Recovery and Climate Experiment

Red: global mean steric sea level (2004–18) from Argo.

Purple: Mass plus steric.

The global system balances.

Warm water stands taller because it is less dense.

- Global average sea level rise: 3.6 mm/yr from 2006-2015
  1.4 mm/yr for most of 20th century
- ~1/3 of this rise is due to steric expansion (~0.7 mm/yr)
- The other ~2/3 is due to more water (mass) in the ocean from less water on land and melting land-based ice.

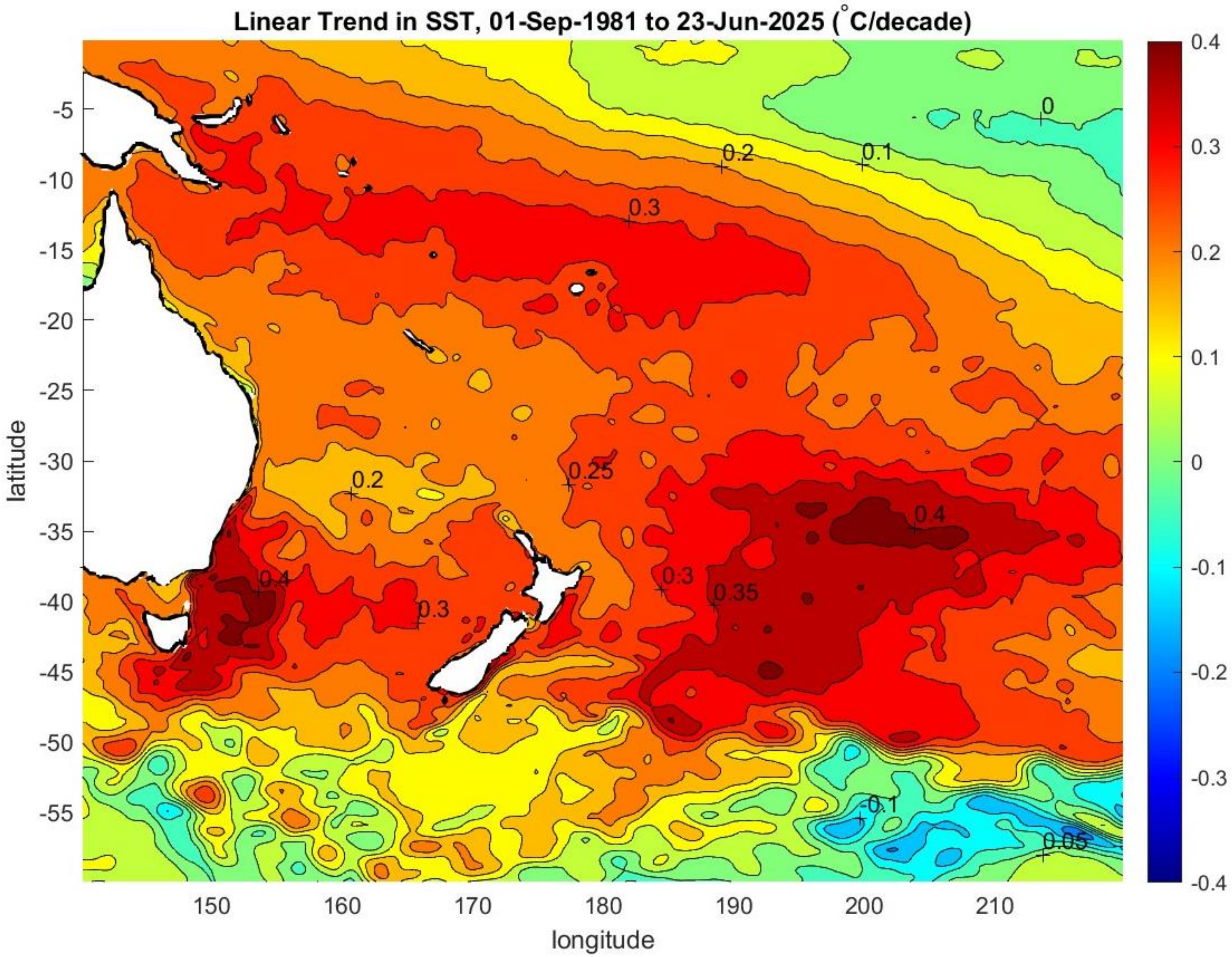
(Note large changes ~40°N&S)

Johnson, G. C. and R. L. Lumpkin, Eds., 2025: Global Oceans [in “State of the Climate in 2024“]. Bull. Amer. Meteor. Soc. Domingues et al., 2008; Levitus et al., 2009.

Ocean temperature change around New Zealand since 1981: SST trend

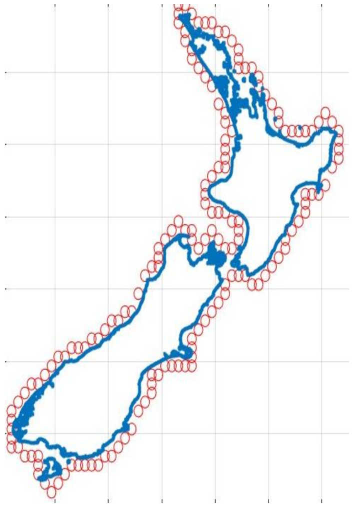
Linear trend in Sea Surface Temperature (1981–2025)

- Calculated from the NOAA OI SST V2 High Resolution Dataset (Reynolds et al. 2007; Banzon et al. 2016).
- Contour intervals are 0.05°C/decade.
- Around NZ: 0.25-0.3°C/decade
- c.f. global average ~0.2°C/decade.

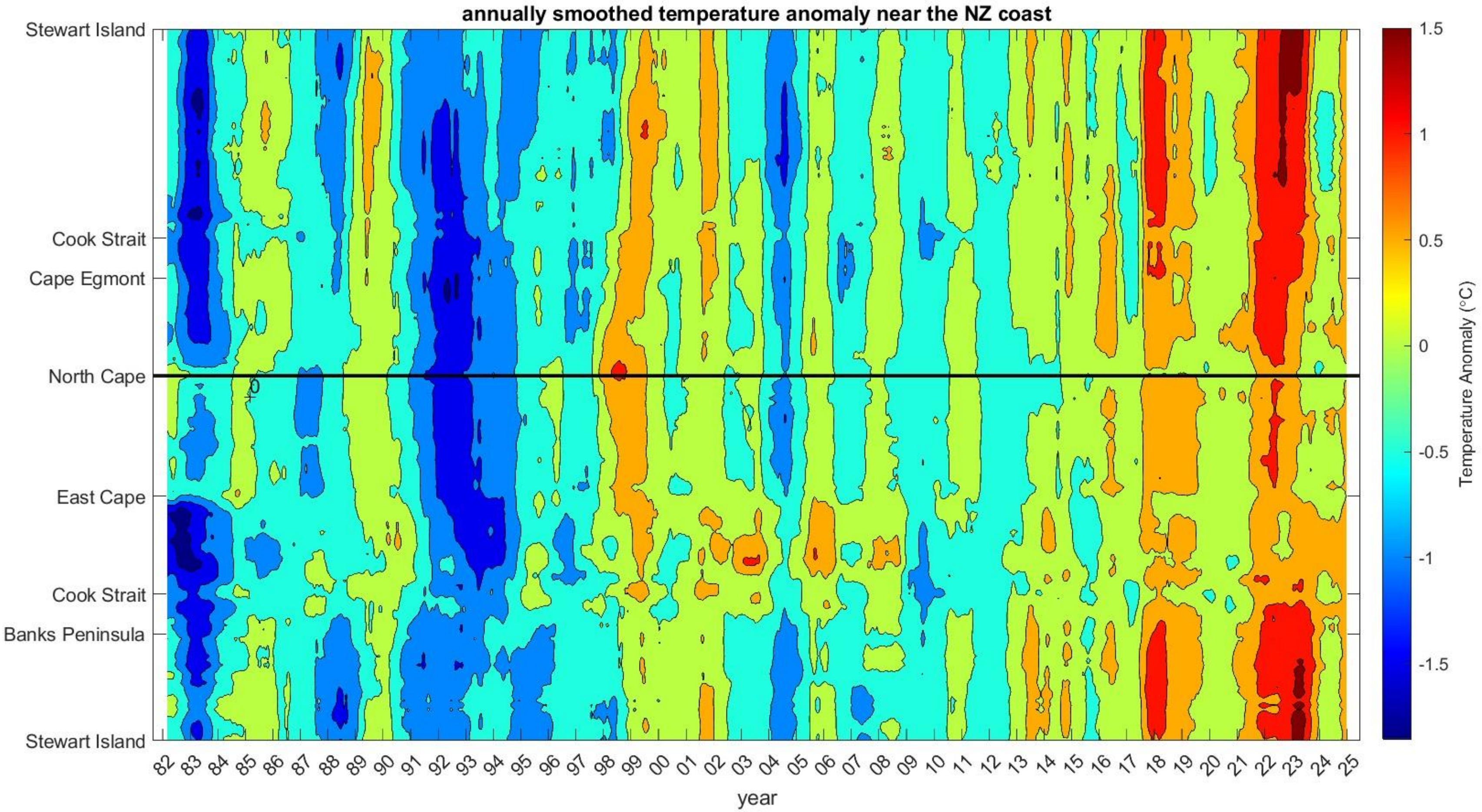


Updated from Sutton, P., Bowen, M., 2019: https://doi.org/10.1080/00288330.2018.1562945.

Ocean temperature change around New Zealand: variability around the coast



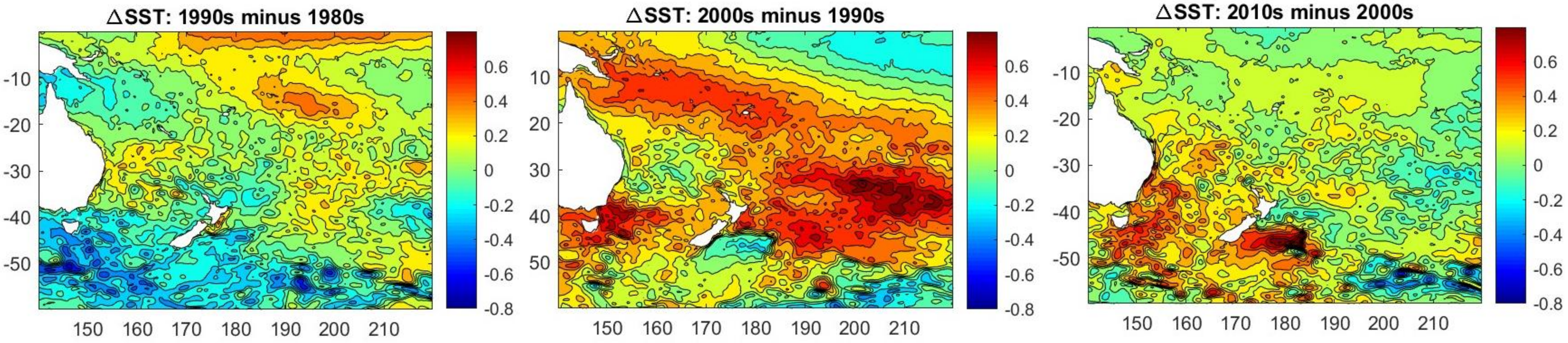
Coastal locations selected to build the timeseries.



Annually-smoothed temperature anomaly near the NZ coast. The y axis begins at the southern-most location south of Stewart Island, then runs north along the east coast to North Cape (shown by the black line) before running south along the west coast.

Updated from Sutton, P., Bowen, M., 2019: https://doi.org/10.1080/00288330.2018.1562945.

Ocean temperature change around New Zealand: decadal changes



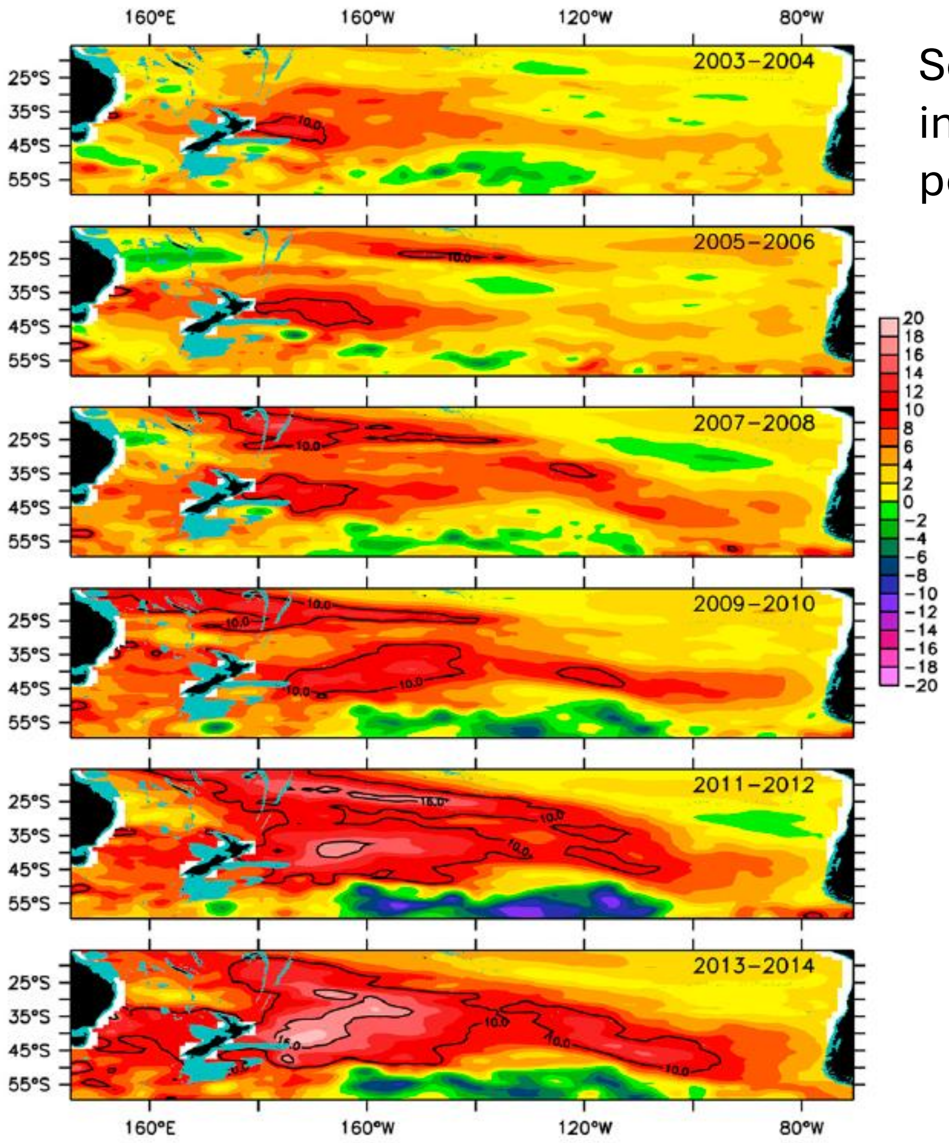
- Warming in western Tasman
- Cooling in subantarctic
- Patchy around NZ
- Warming off Wairarapa

- Warming in subtropical water
- Cooling in subantarctic
- Warming off Wairarapa

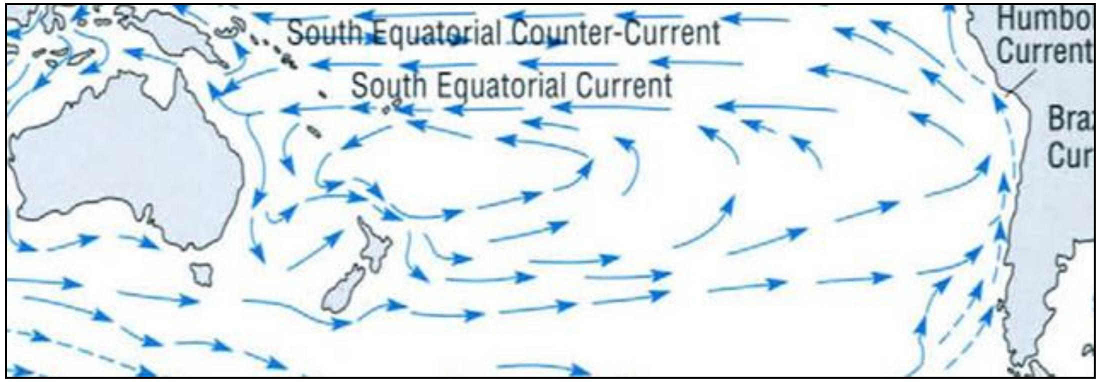
- Warming in western Tasman
- Warming south of Chatham Rise
- Cooling off Wairarapa/Hawke Bay

Lots of variability: not a simple linear trend.
Each decade has had distinctly different temperature changes

Why are there large changes ~40°S? South Pacific Gyre spinup.

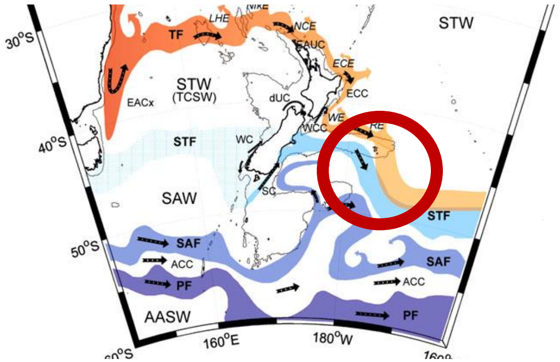


Sea surface height anomaly (cm) for 2-yr averaging periods, as labeled in the upper right corner of each panel; all are relative to the base period 1993 to 1994. Contour lines are drawn for 10 and 16 cm.

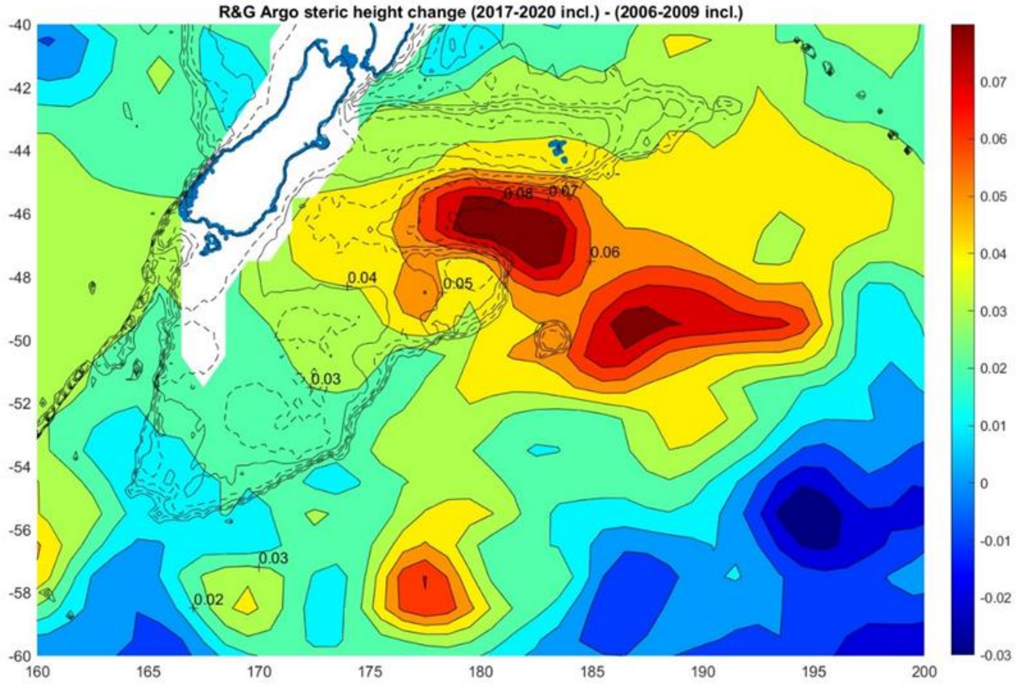


- Strong trend in sea level rise centred at ~45°S east of New Zealand.
- Strong, upper ocean warming.
- Driven by changes in the wind stress curl.
- South Pacific Gyre has ‘spun up’.

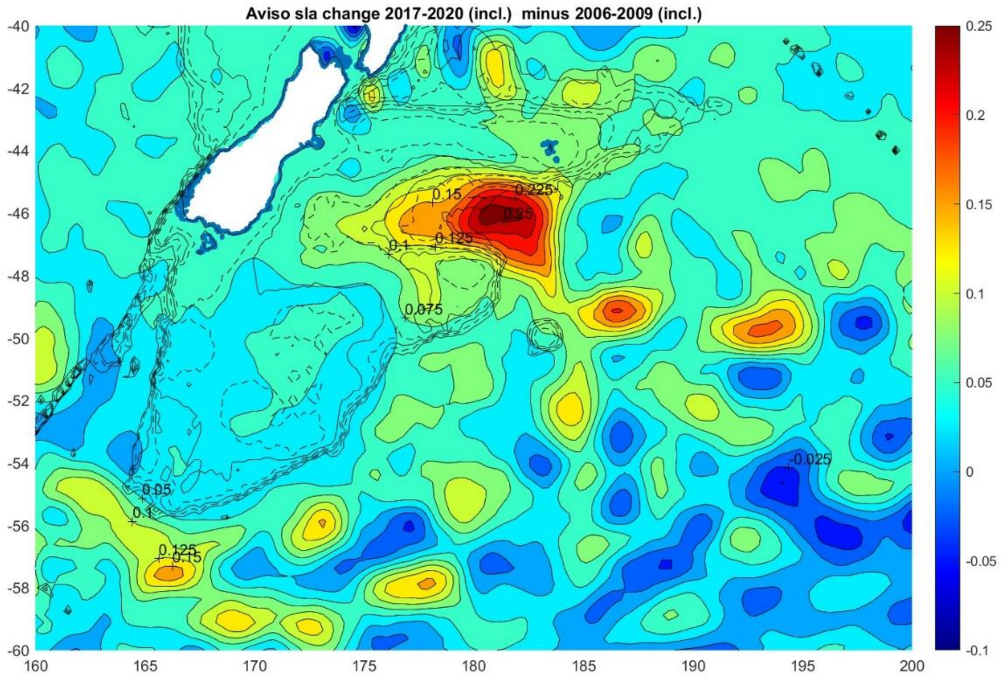
Full-depth warming in Bounty Trough



Changes: (2017-2020 incl.) minus (2006-2009 incl.)



Steric Height (0_2000m) (like ocean heat content)

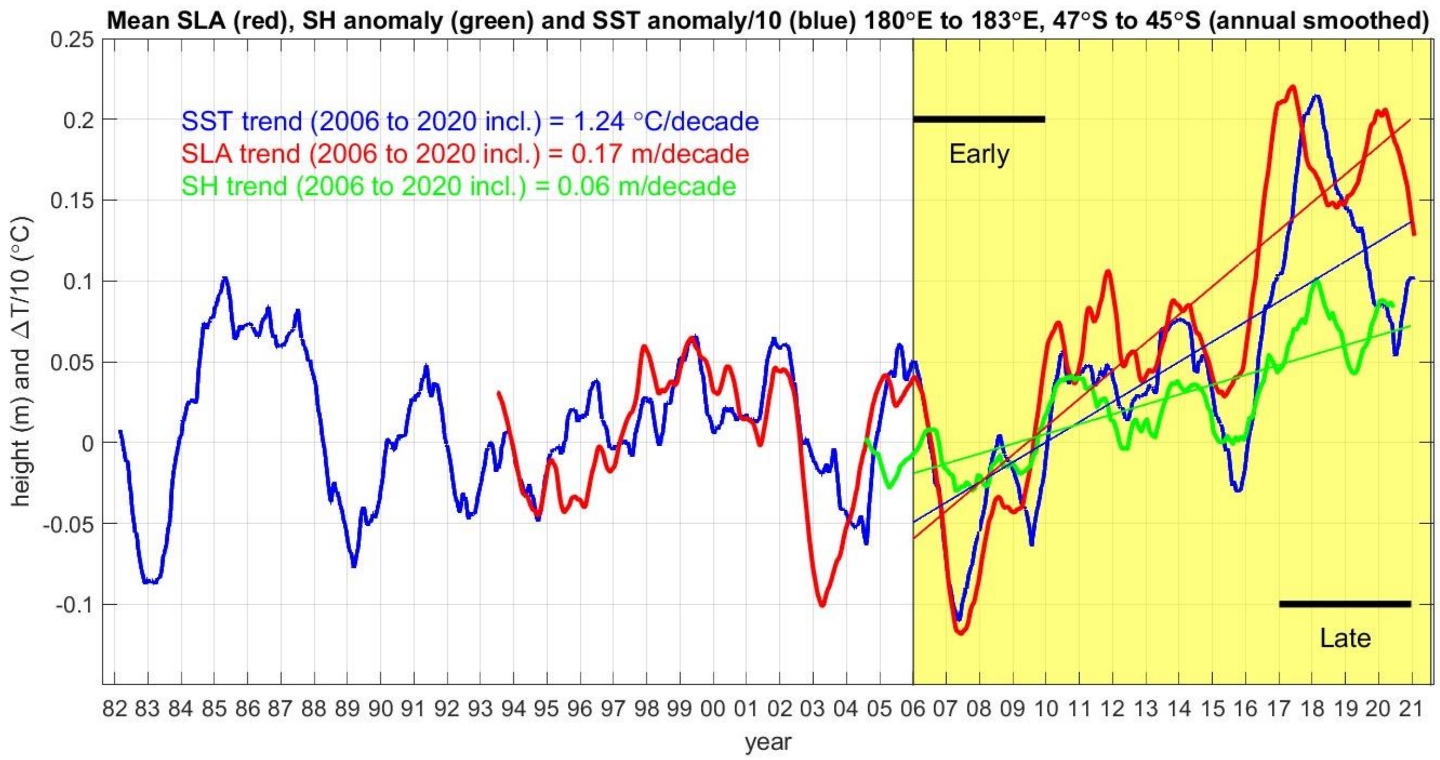


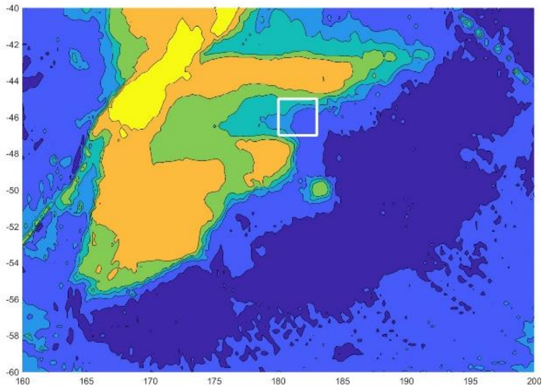
Sea Surface Height

(Bathymetry contours are 3000m, 2000m, 1000 m (solid) and 2500m, 1500m, 500 m dashed)

Temporal Changes in SST, Steric height and Sea Surface Height

Timeseries for SST, SSH and SH averaged over area 180°-183°E, 47°-45°S.





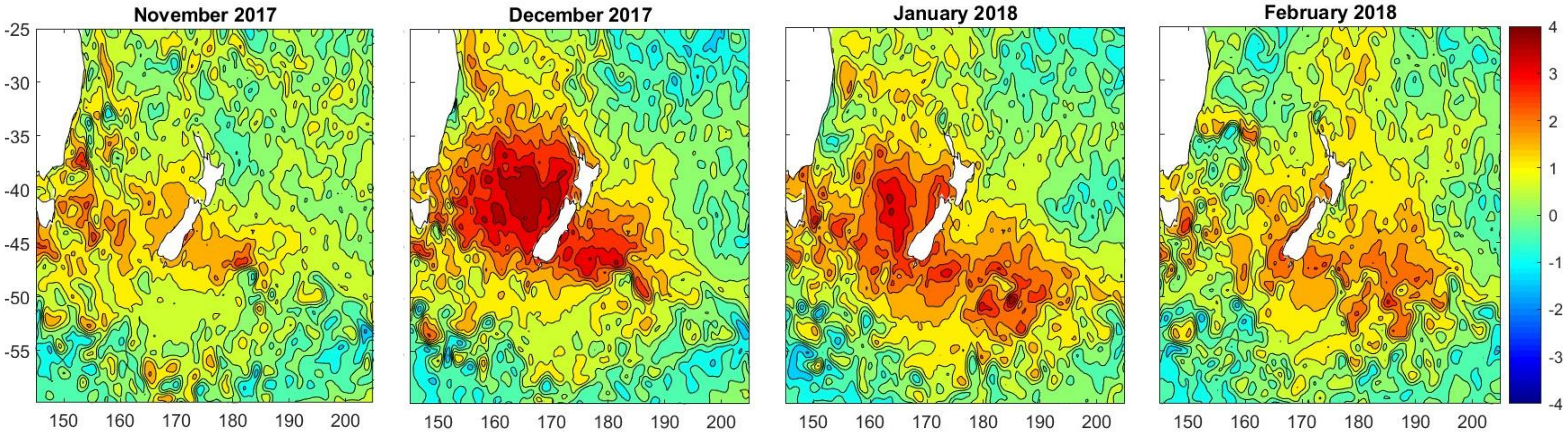
Current conditions unprecedented in the satellite era and are consistent with models.

- The local T and S changes are consistent with the Subtropical Frontal Zone moving ~50 km to the west.
- Drivers appear to be a change in local sea level pressure and windstress and a tendency in large scale wind changes since 2017.

Recent marine heatwaves

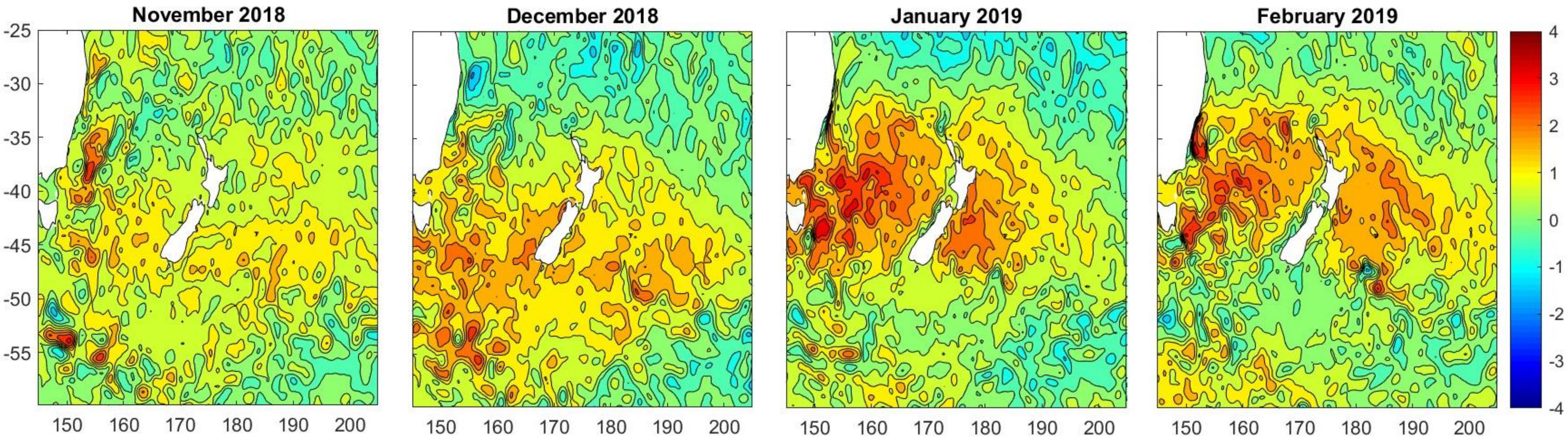
MHW definition: “An anomalously warm event that lasts for five or more days, with temperatures warmer than the 90th percentile based on a 30-year historical baseline period”.

1) SST anomalies summer 2017/2018



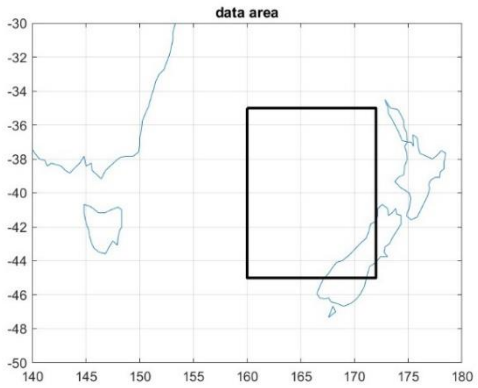
Recent marine heatwaves

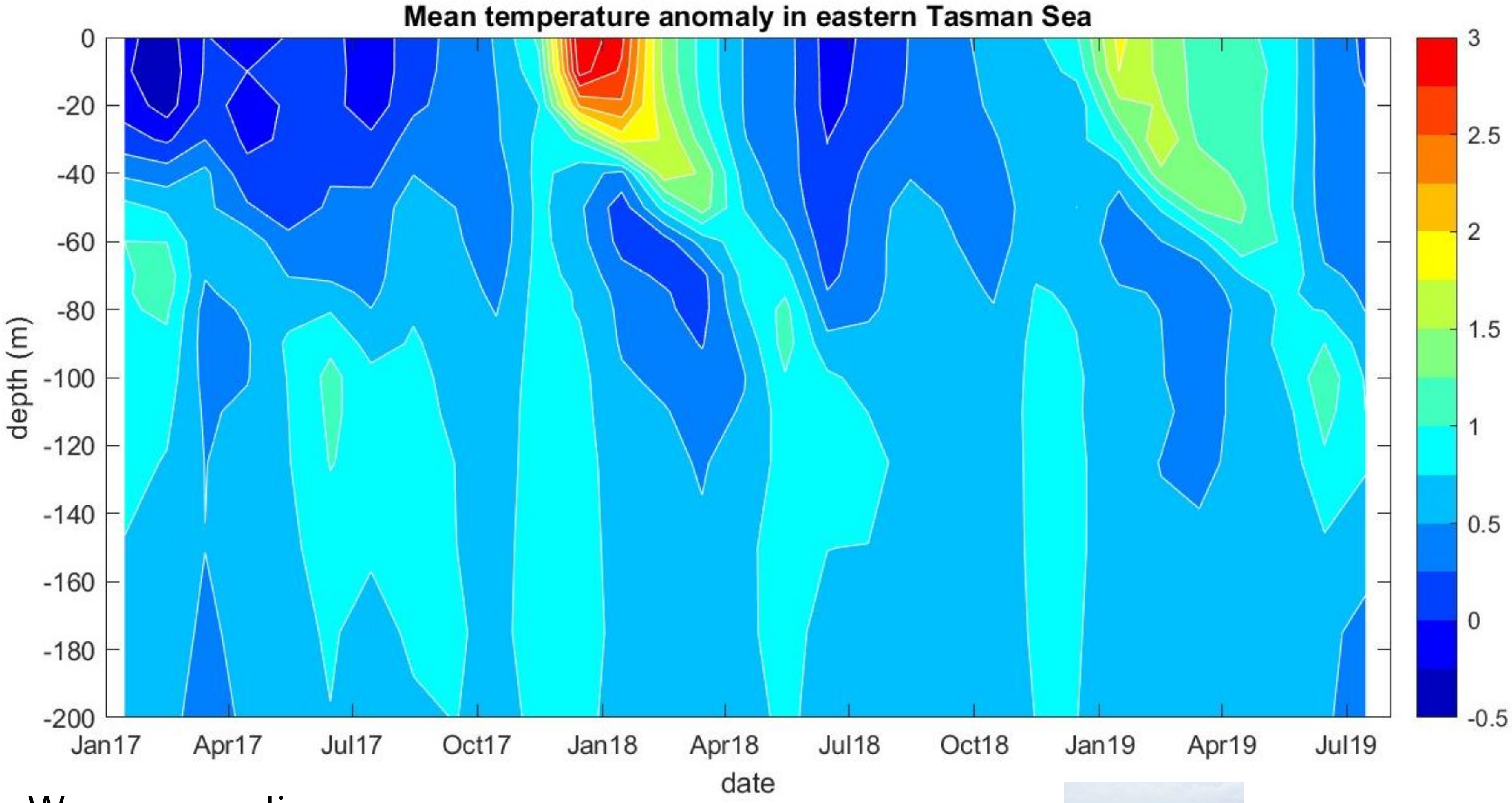
2) SST anomalies summer 2018/2019



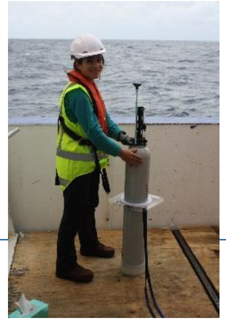
Recent marine heatwaves: depth extent

- Extracted Argo profile data for the eastern Tasman
- Calculated temperature anomaly relative to CARS climatology
- Averaged over each month (50-60 profiles)





Warm anomalies:
- started in December 2017, 2018
- surface intensified
- mainly shallower than 60m



Conclusions:

- The oceans are taking up more than 90% of the increased energy in the global system.
- Ocean heat content is increasing almost everywhere.
- The strongest warming is at the surface, but it extends to at least 2000m and to the bottom in the southern hemisphere.
- Trends are very small compared with the annual cycle and interannual variability.
- The strongest changes are centred on ~40° North and South and are a result of the subtropical gyres spinning up.
- The hydrological cycle has accelerated.
- There are clear changes around NZ.
- There is an increase in the number of MHWs in recent summers. Largely limited to the upper 30-60m of the water column (around NZ).
- The warming in Bounty Trough may be the first structural change in how the ocean behaves around NZ.

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