The massive South Australian Harmful Algal Bloom of 2025

A citizen science and wide boundary perspective*

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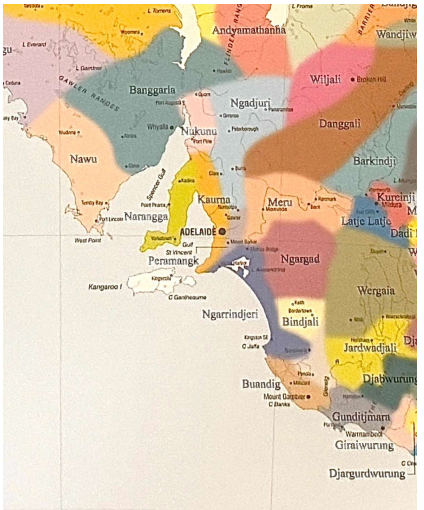
Adelaide, South Australia

*a personal non-peer reviewed perspective

Thank you; it's an honour to present at CaCOR Live. This is an attempt at a very wide boundary and dot-connecting perspective of the harmful algal bloom which has been widely described as an ongoing ecological catastrophe. Hopefully, at the end you will be able to discern the real significance of the moribund canary and the mountain goat from our planetary flightdeck.

Acknowledgement of Country

We meet on the lands of the Kaurna people, or wherever you may be located, and acknowledge that sovereignty to this land was never ceded. We acknowledge the centuries of resistance that indigenous people have led against the unsustainable and inhumane practices of colonisation. We pay our respect to Elders, past, present, and emerging, and recognise their continuing connection to land, waters, culture, language and community. We commit to learn from indigenous knowledge systems and wisdom that have been developed and used by the Kaurna custodians for countless generations, and express gratitude for their stewardship of these lands. We commit to walk together toward peace, justice and reconciliation.



We'll start with an Acknowledgment of Country.

Wide Boundary/Big Picture

- Nate Hagens
- Charles Hall
- Richard Heinberg
- William E Rees

ABC NEWS

South Australians urged to contribute as citizen scientists amid algal bloom 'devastation'

By Caroline Horn

Tue 29 Apr 2025

A dead globe fish at Waitpinga, south of Victor Harbor, has been uploaded to iNaturalists to form part of the data. *(ABC South East SA: Caroline Horn)*

This algal bloom, which the public first became aware of in March 2025, has spurred a lot of community interest in various aspects of citizen science. This attempt at a wide boundary perspective draws heavily on the writings, presentations and insights of these 4 people I've listed who are no doubt very familiar to many of you – I strongly recommend them. I'll present what I think is a plausible timeline-based narrative, drawing on indigenous, scientific and spiritual perspectives but this is a personal account and not in any way peer-reviewed and should be treated as such. I'd also like to thank the many people who have given up their time and very generously helped me better my understanding of the following.

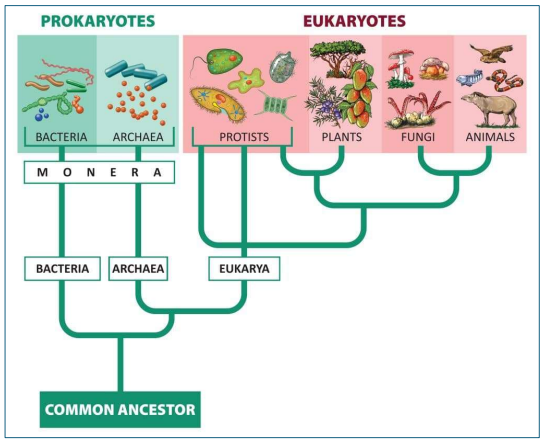
Key Messages of this talk

- The South Australian Harmful Algal Bloom (HAB) is a story of odd, extreme and unprecedented variance beyond expectations which needs to be seen as a marker of ecosystem tipping and treated as such. It's a true "Canary in the Coalmine" and is linked in broader ways to the following critical issues:
- Climate change is accelerating and we are losing a grip on what is happening
  - Earth Energy Imbalance (EEI) is increasing significantly beyond model predictions
  - being expressed in linked changes seen in the Southern Hemisphere especially in Southern Ocean and Antarctica
- There is clear evidence of tipping/regime shift/abrupt change including in Antarctica. I'll highlight:
  - Reduced Antarctic sea ice extent
  - Thwaites Glacier melting and collapse
- Bottom Line:
  - Immediate, drastic cuts to fossil fuels are essential and the only way out - if Gaia or Mother Earth is willing at this very late stage....
  - This will necessarily involve a transformation in the way we live

So the key messages of this talk are as follows:
- The South Australian Harmful Algal Bloom

What are algae?

- single (microalgae) or multi-cellular (macroalgae eg seaweed) organisms that **photosynthesise** (contain chlorophyll)
- mainly aquatic based – marine and freshwater; very widespread
- mainly in the "protists group" but also "bacteria" e.g. **cyanobacteria**



As there are a lot of slides, I'll only be summarizing the important parts and takeaway messages and they will be uploaded for any future use you may have for them such as references. Algae, plural, is an informal grouping. While single or multicellular aquatic organisms, the ones we will be considering today are photosynthetic, single-celled and marine-based organisms - and from the protist group and the bacteria group.

Plankton

- aquatic organisms that “wander” or “drift” with currents; but some move vertically
- “canary in the coalmine” as very sensitive to environmental disturbance
- classified into **phytoplankton** (plant-like **photosynthetic** producers [contain chlorophyll]) and **zooplankton** (animal-like consumers)
- Foundation or base of aquatic food webs
- **Phytoplankton** produce > 50% of the oxygen we breathe
- **Harmful Algal Blooms** (HABs) basically involve **phytoplankton** – mainly diatoms, dinoflagellates and cyanobacteria

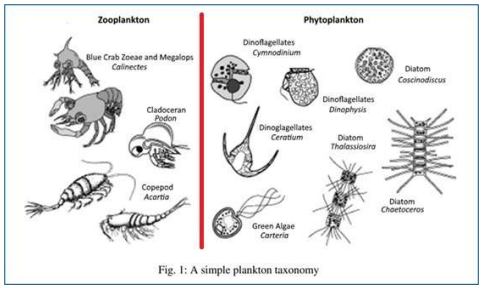
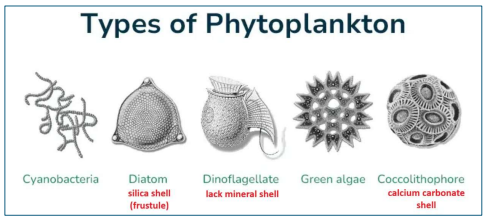


Fig. 1: A simple plankton taxonomy

Lumini A, Nanni L. Ocean ecosystems plankton classification. InRecent Advances in Computer Vision: Theories and Applications 2018 Dec 15 (pp. 261-280). Cham: Springer International Publishing.



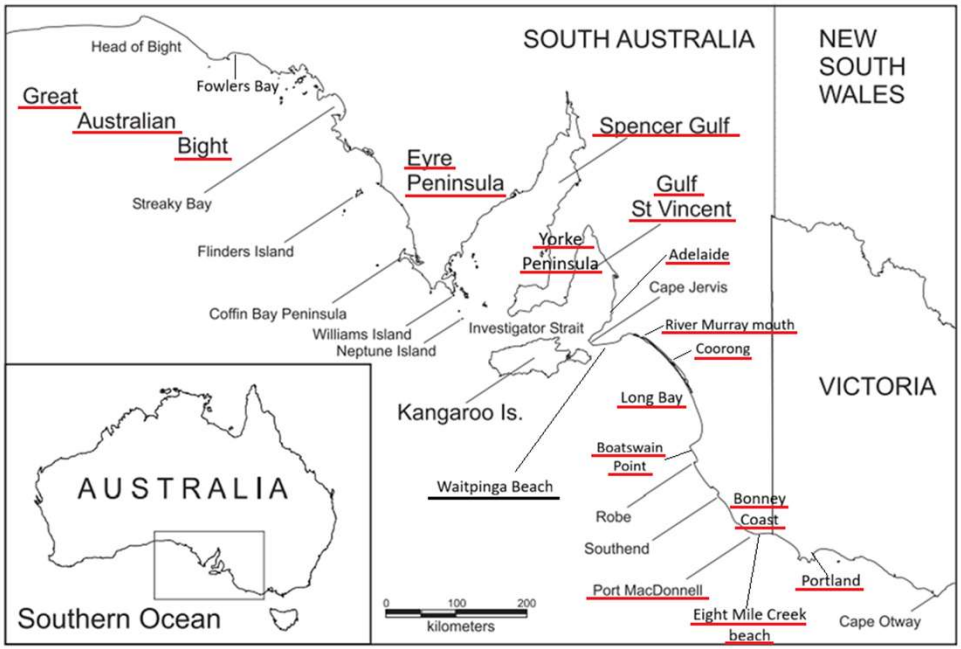
Plankton is another related and informal grouping. They are the “wanderers” or “drifters” of the waters and move with the currents. They are vulnerable to subtle environmental changes and therefore regarded as “canaries in the coalmine” and indicators of environmental stress or shifts.

The subgroup of phytoplankton are mostly microscopic, single-celled photosynthetic organisms, are the foundation of the marine food web, generate at least 50% of the oxygen we breathe, and are part of the microalgae group – they include cyanobacteria, diatoms and dinoflagellates, all of which can potentially cause harm, as well as coccolithophores.

Bloom and Harm

- For a specific alga (or mix of them), there is faster growth and/or less loss, leading to population increase or "bloom"
- Many factors, often interacting, can result in a bloom. Access to useful energy flows is key.
- "Harm":
    - toxin producing (toxic algal bloom): the SA HAB is caused by a mix of karenia genus dinoflagellates, dominated by karenia cristata species
    - hypoxia-generating through decomposition
    - food web altering;
    - ecosystem disruption; loss of biodiversity
    - not all blooms are "harmful" and many go unnoticed by humans and are the basis of marine productivity

A "bloom" occurs when there is significantly faster growth and/or less population loss than adjacent communities and while there can be multiple interacting factors involved, as we shall see, the bloom species or species mix is the one best able to absorb useful energy flow for survival and reproduction. A "harmful" bloom can be harmful at different levels and in different ways. Generation of lethal hypoxia, alterations to ecosystems and food webs, and production of biotoxins are some mechanisms. This South Australian bloom is caused by a mix of karenia genus dinoflagellates, dominated by the karenia cristata species – we'll be coming back to this. Many blooms are not overtly "harmful" and are the basis of marine productivity.



In terms of a very quick geographical tour, South Australian coastal geography includes 2 large peninsulas, the Eyre and Yorke Peninsulas, and their adjacent gulfs, Spencer Gulf and Gulf St Vincent, the capital city, Adelaide on the eastern coast of Gulf St Vincent at 35 deg latitude, Kangaroo Island, the Bonney Coast in the state's southeast region and the eastern part of the Great Australian Bight to the west. We'll come back to this map later.

Causes given for the HAB: Climate Change

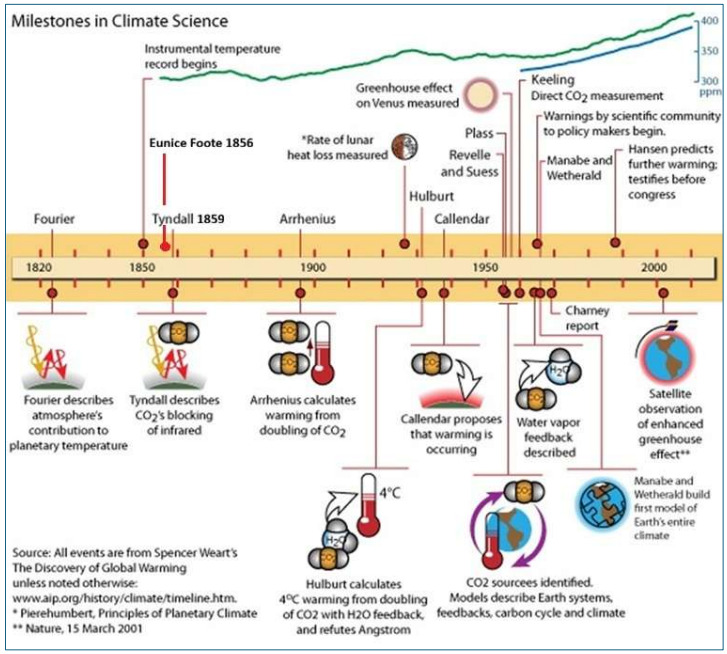
- Nicola Spurrier (Chief Public Health Officer, SA Health) JOINT COMMITTEE ON HARMFUL ALGAL BLOOMS IN SOUTH AUSTRALIA, 3 Dec 2025
  - "we have experienced this terrible algal bloom and it has been catastrophic for our marine life, but if we look at this from a systems point of view, this is climate change." "…. climate change is the biggest threat to human health. It's not in the future: it's happening now."
- Susan Close (SA Govn Climate/Environment/Water Minister: 2022 - 2025)
  - "This is not just a one-off tragedy. It's a warning of what lies ahead if we don't act fast on climate," Close said. "Our marine ecosystems are incredibly vulnerable, and they're telling us something loud and clear.
  - "So, unfortunately, as the world fails to fully come to grips with climate change, we are likely to see more of this kind of experience."
  - monitoring shows "a full-scale climate emergency in our coastal waters",
  - "We can't hide our head in the sand and pretend that this is somehow a phenomenon that might have somehow happened without climate change."

The messages related to the overarching cause of this algal bloom have been made explicity – it's climate change. Nicola Spurrier noted: and Susan Close said ….

Sequence

- EEI is increasing due to anthropogenic GHG emissions. Climate models are significantly underestimating this rise and the reasons are incompletely understood.
- Results in:
  - increasing global energy trapping
  - global surface air and sea surface temperature increases (TD)
  - changes to the way that surplus energy is distributed across the planet by wind and ocean currents (Circulation)

So let's review anthropogenic climate change and what's been going on. Firstly, the Earth Energy Imbalance is ....



Spencer Weart/AIP https://history.aip.org/climate/timeline.htm

Anthropogenic GHG emissions have been increasing mainly through the combustion of FF, and also land use changes. I won't go through this historical chart but the summary is that the atmospheric influence on planetary temperature has been known for about 200 years and Eunice Foote and then John Tyndall worked out the role of the greenhouse gases in the 1850s. The rest is history, so to speak ....

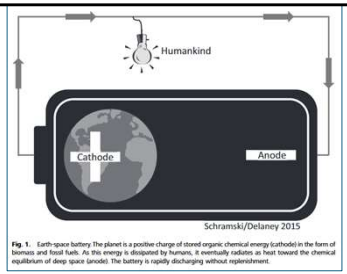
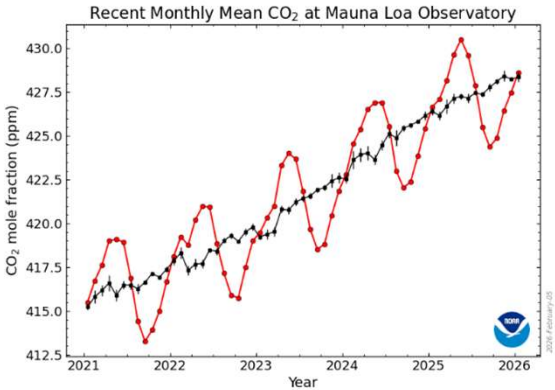
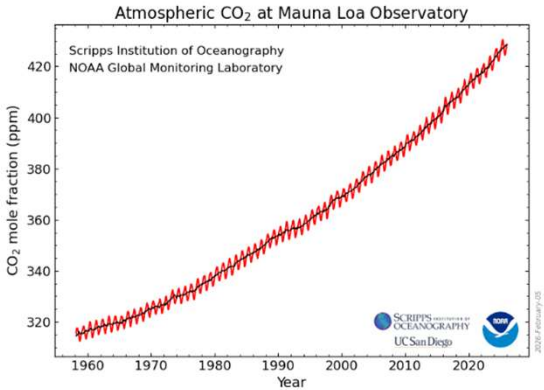


Fig. 1. Earth-space battery. The planet is a positive charge of stored organic chemical energy (cathode) in the form of biomass and fossil fuels. As this energy is dissipated by humans, it eventually radiates as heat toward the chemical equilibrium of deep space (anode). The battery is rapidly discharging without replenishment.

January 2026: 428.62 ppm
January 2025: 426.65 ppm
Last updated: Feb 05, 2026



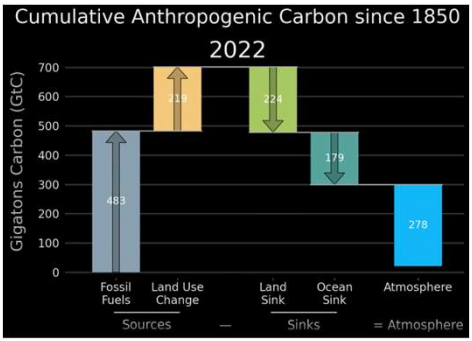


https://gml.noaa.gov/ccgg/trends/

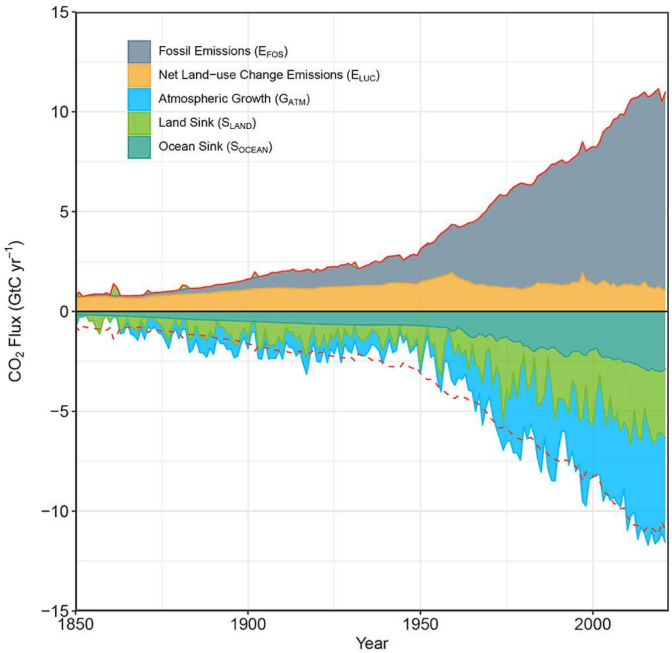
Here's the steady rise in atmospheric CO2 currently nearly 430ppm from a pre-industrial level of 280ppm, the result of humanity's unabated discharge of the earth-space battery.

Carbon Budget

- Oceans take up 30% of anthropogenic carbon
- Southern Ocean takes up about 20-40% of this making it the largest marine sink



https://svs.gsfc.nasa.gov/31270/



https://essd.copernicus.org/articles/14/4811/2022/

The result along with land use change is an extra 700 gigatons of carbon since 1850, and 30% of this is taken up by the oceans – and up to 40% of this by the important Southern Ocean.

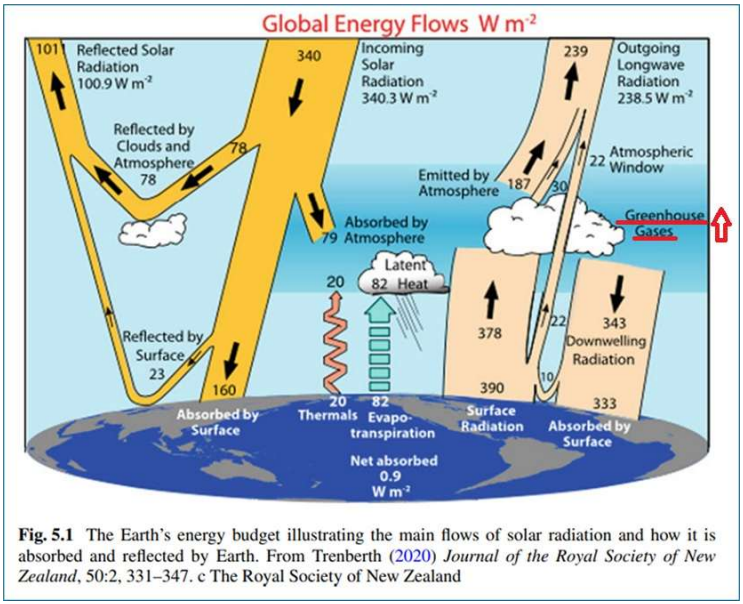


Fig. 5.1 The Earth's energy budget illustrating the main flows of solar radiation and how it is absorbed and reflected by Earth. From Trenberth (2020) *Journal of the Royal Society of New Zealand*, 50:2, 331–347. c The Royal Society of New Zealand

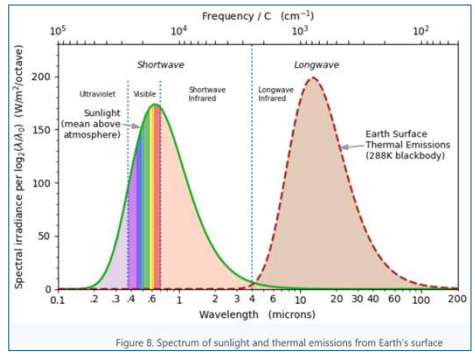
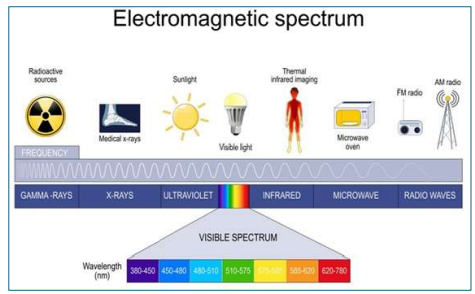
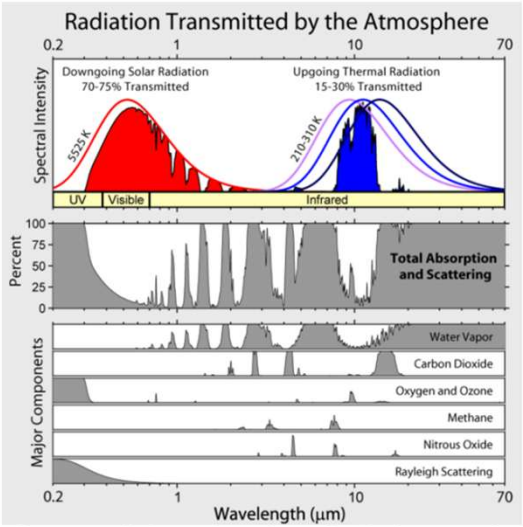


Figure 8. Spectrum of sunlight and thermal emissions from Earth's surface

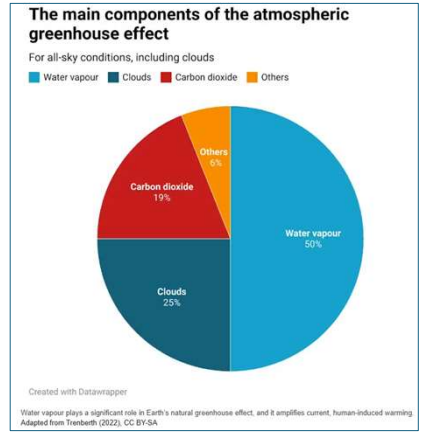
Robert Wentworth https://climatepuzzles.org/2023/03/spectrum-sun-vs-earth/



The Earth Energy Imbalance (EEI) is the most fundamental global climate indicator that we can use a monitor of what's happening and what's needed because it all gets back to energy. The Earth Energy Budget is shown on the left – energy must be conserved and can only be transformed, losing quality in the process. The high quality solar radiation enters the planet as this spectrum on the left, including shortwave infrared. Some is reflected by clouds and atmosphere and the earth's surface; some is also absorbed at the atmosphere (by water vapour) and earth's surface and re-emitted as low quality longwave IR shown on the spectrum on the right. So that's the fate of the incoming solar radiation. The longwave IR's fate is shown on the right of the diagram. Note the role of GHGs in the downwelling of radiation, ensuring a planetary surface air temperature of about 15 degrees C (but rising due to increasing anthropogenic GHG emissions). The subtraction of the energy flows out from the energy flows in at the top of atmosphere is the Earth energy imbalance and this has been increasing meaning energy is being trapped.

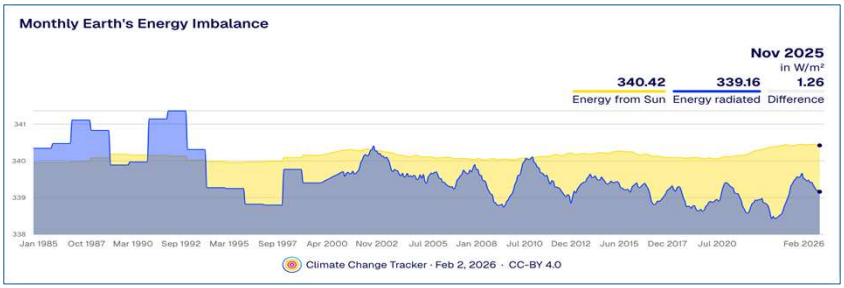


Radiation transmitted by the atmosphere as a function of wavelength. Downgoing solar radiation is on the left, and upgoing thermal radiation is on the right, with the percentage of radiation absorbed and scattered by the Earth's atmosphere below. Finally, the percentage of radiation absorbed and scattered is then divided by the major greenhouse gases in the panels at the bottom (CC BY-SA 3.0).

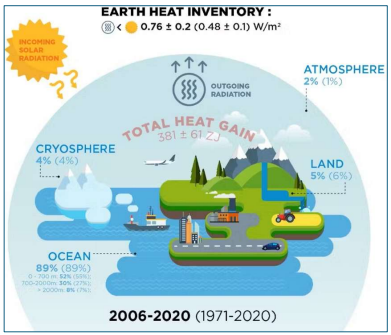


Carbon Dioxide and the other non-condensable GHGs drive the greenhouse effect while the condensable gases (water vapor) provide the feedback which provides 75% of the total greenhouse effect. Without the non-condensable GHGs, there is no greenhouse effect and average earth temp is -18 deg C (cf. 15 deg C).

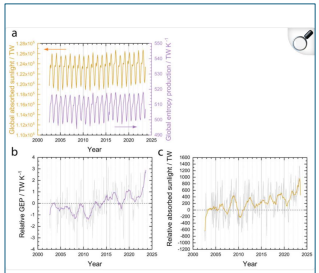
Here's the spectrum diagram again on the left. 75% of the greenhouse effect is done by the condensable water vapor as shown on the right. But this is a feedback GHG driven by the non-condensable GHG of which carbon dioxide is the most important. Note that water vapour is the GHG that absorbs the incoming solar radiation while the non-condensables absorb and scatter the longwave IR.



https://climatechangetracker.org/global-warming/monthly-earths-energy-imbalance



https://essd.copernicus.org/articles/15/1675/2023



Global absorbed sunlight and entropy production rate. (**a**) Global absorbed sunlight (orange) and entropy production rate (purple). Global entropy production rate (**b**) and absorbed sunlight (**c**) relative to 2003. Colored lines in (**b**,**c**) are moving averages with a 12 month window, grey lines are raw data.

Thimsen E. Planetary Energy Flow and Entropy Production Rate by Earth from 2002 to 2023. *Entropy*. 2024; 26(5):350

Anthropogenic EEI increase:

- 400 ZJ + accumulated over past 50 years, and accelerating
- annual total anthropogenic energy consumption = 600 EJ = 0.6 ZJ
- 90% into oceans; most into Southern Ocean

Here's the highly concerning thing. The Earth Energy Imbalance (Energy In – Energy Out) is growing substantially faster than climate models predict. It's unclear why but it looks like perhaps some positive feedback loops involving solar absorption might be involved with albedo, clouds and water vapour in the mix. The trapping is about 1.3 W/sqm as of November 2025 which equates to a huge amount of energy, currently around 14 ZJ per year. As a comparison, the total global human enterprise consumes 0.6 ZJ each year. Very importantly, 90% of that trapped energy, which is about 400 ZJ over the past 50 years, goes into the oceans and the Southern Ocean does the heavy lifting absorbing 90% of that.

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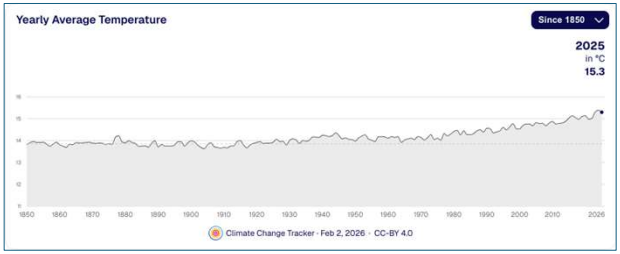
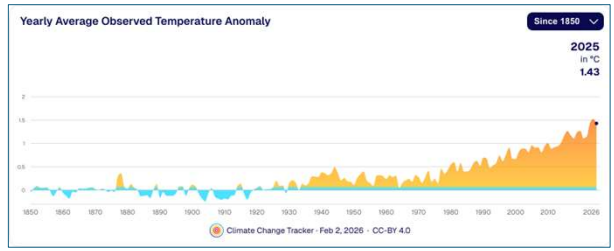
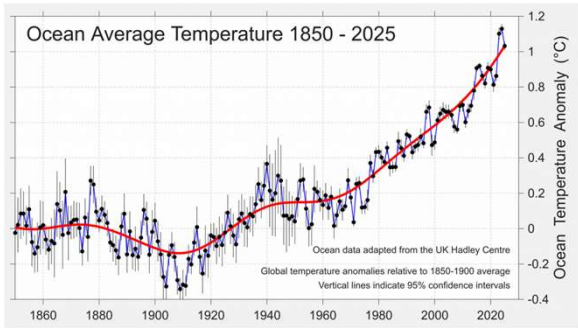
The results of this increasing EEI are thermodynamic with rising global air and sea surface temperatures ....



https://climatechangetracker.org/global-warming/yearly-average-temperature



https://climatechangetracker.org/global-warming/yearly-average-temperature-anomaly



https://berkeleyearth.org/global-temperature-report-for-2025/

Surface air and ocean temperature continue to rise. I noted yesterday's global sea surface temperature was almost at a record high.

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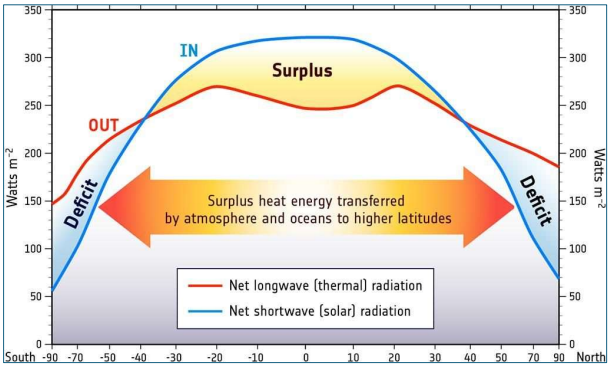
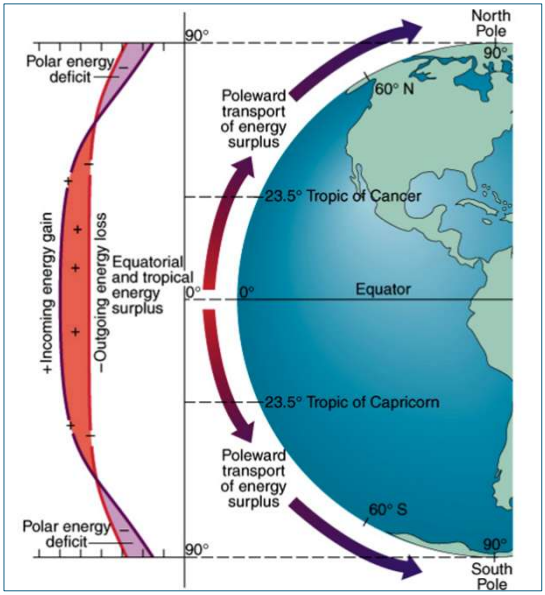
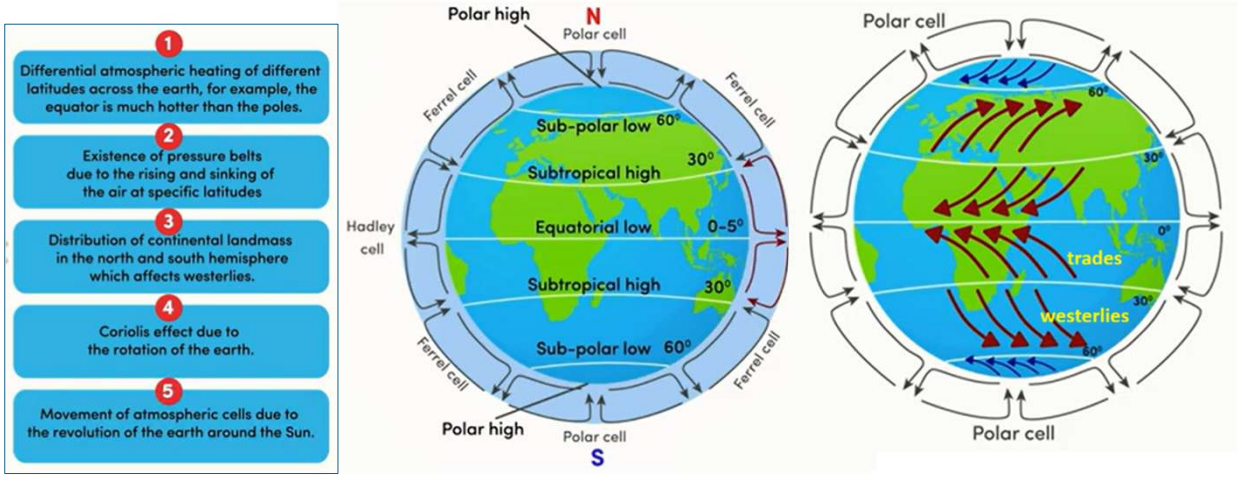
And there are major implications related to how the planet is handling the redistribution of all this extra trapped energy from tropics to poles via wind and ocean currents.





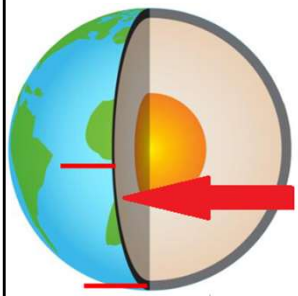
https://www.paleo.bristol.ac.uk/~ggxrk/Jalbums/test/Ocean%20Circulation_final.pdf

Here are some diagrams of this energy equilibration noting an excess of shortwave over longwave IR energy at the tropics and a deficit at the poles. This means that the atmosphere and oceans transfer the surplus to the poles.



Colin Price, TAU: Climate Change, the science behind the crises

However, the atmospheric circulation cell from equator to pole is divided into three in each hemisphere by the Coriolis force, namely the Hadley, Ferrel and Polar Cells. The winds and currents are also deflected by the Coriolis force – to the right in the NH and left in the SH. Note the position of the Southern Ocean Westerly winds in the Ferrel cell.



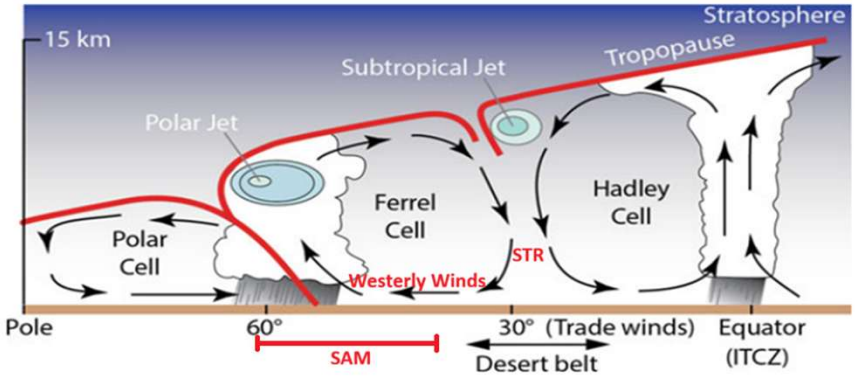


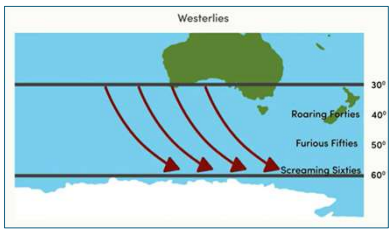
Fig. 5.6 A cross-section of the Hadley, Ferrel and Polar cells in the Southern Hemisphere. Note the position of the ITCZ, Tropopause, Stratosphere, Subtropical and Polar jets, and the descending dry air between the Hadley and Ferrel cells, that cause the desert belt and the Trade winds. From Lovegrove (2021) *The Living Deserts of Southern Africa (2nd Edition)*. Penguin Random House. *Artwork* John Warren

Note: Hadley Cell, STJ, PJ, Subtropical Ridge (STR) of High Pressure, Westerly Winds, Southern Annular Mode (SAM)

Here's a cross section through the 3 circulating atmospheric cells from tropics on the right to the south pole on the left. Note the Hadley Cell, the subtropical ridge of high pressure from dry descending air, the subtropical and polar jets high up, the westerly winds which are actually being deflected towards you and something extremely important called the Southern Annular Mode or SAM. This is the sea level pressure difference between 40 deg and 65 deg latitude.

Some specific important Circulation changes in the Southern Hemisphere driven by rising EEI

- Surface winds, and surface ocean currents which they drive, are generally strengthening
- Specific trends in Southern Hemisphere
  - Polewards expansion of Hadley Cell and tropics
  - Subtropical ridge intensification
  - polewards movement of STJ/PJ
  - Positive Southern Annular Mode trend
  - Strengthening Southern Hemisphere Westerly winds
- These changes have huge implications – which we are now directly experiencing as EEI increase accelerates



Coriolis Force – to the left in SH

So what's the impact of this rising EEI as a result of anthropogenic climate change. The surface winds and the surface ocean currents they drive are strengthening generally. In the Southern Hemisphere, where we will be focusing, there is polewards expansion of the Hadley Cell and tropics, subtropical ridge intensification, polewards movement of the subtropical and polar jets.

Expansion of the Southern Hemisphere Hadley Cell in Response to Greenhouse Gas Forcing

H. NGUYEN, C. LUCAS, A. EVANS, B. TIMBAL, AND L. HANSON

Bureau of Meteorology, Melbourne, Australia

(Manuscript received 15 February 2015, in final form 25 June 2015)

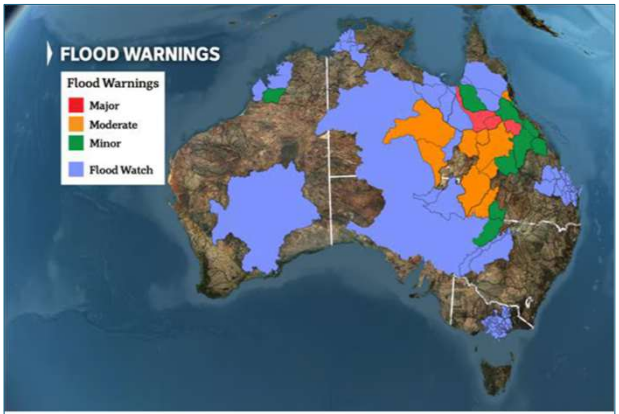
ABSTRACT

Changes of the Southern Hemisphere Hadley cell over the twentieth century are investigated using the Twentieth Century Reanalysis (20CR) and coupled model simulations from phase 5 of the Coupled Model Intercomparison Project (CMIP5). Trends computed on a 30-yr sliding window on the 20CR dataset reveal a statistically significant expansion of the Hadley cell from 1968 forced by an increasing surface global warming. This expansion is strongly associated with the intensification and poleward shift of the subtropical dry zone, which potentially explain the increasing trends of droughts in the subtropical regions such as southern Australia, South America, and Africa. Coupled models from the CMIP5 do not adequately simulate the observed amount of the Hadley expansion, only showing an average of one-fourth of the expansion as determined from the 20CR and only when simulations include greenhouse gas forcing as opposed to simulations including natural forcing only.

"With the majority of arid regions across Earth located beneath the subsiding branches of the Hadley cells, such an expansion suggests a broadening of the subtropical dry zone leading to a drier subtropical climate."
"The underestimation of intensification of subtropical ridge relates to the underestimation of the Hadley cell expansion by the models, and opens up the possibility that future projections of rainfall declines in the subtropical regions are underestimated."

Polewards expansion of the Hadley Cell means a drying trend for regions that tend to have Mediterranean type climates. This paper suggest climate models have underestimated future rainfall declines.

Tropical expansion into Australia's interior



Flood watches have been issued across nearly half the country. *(ABC News)*

Rare:

1. long duration event
2. extreme tropical moisture extending south


NEWS

Half the country on flood watch as summer storms bring deluge of rain

By weather reporter Tyne Logan

Weather 24 Feb 2026

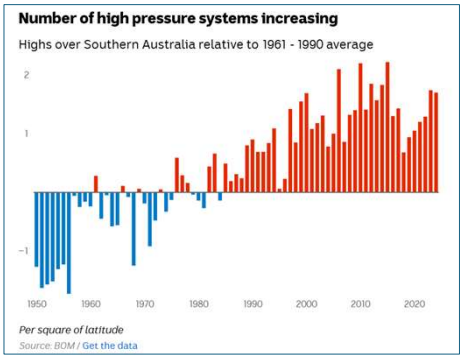
Dark storm clouds gather over Benalla, in north-eastern Victoria. *(Supplied: Rene Martens/Weather Obsessed)*

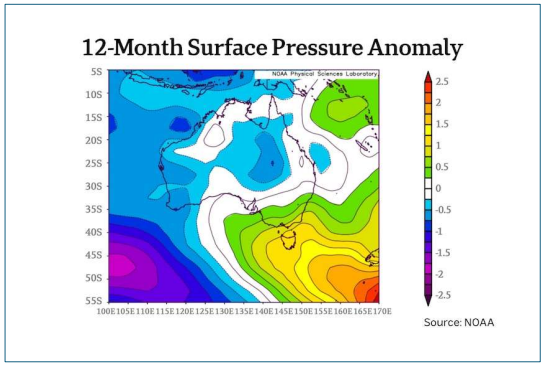
abc.net.au/news/flo... Share

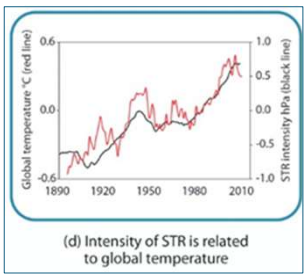
Nearly half of Australia is on flood watch, with warnings of severe storms for multiple states and territories today, as rare outback drenching continues across central Australia.

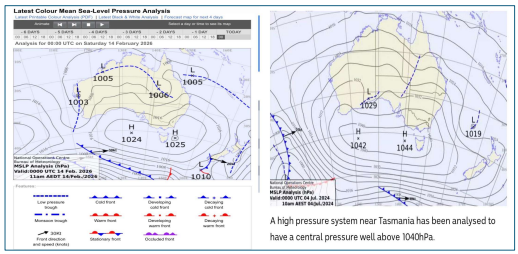
https://www.abc.net.au/news/2026-02-24/flood-watch-severe-summer-storms-rain-deluge/106380770

At the same time, at the other end of the Hadley Cell, the tropics are expanding into Australia's interior and there is currently an extreme rain and flood event underway which is notable for its long duration and extreme tropical-fed moisture.





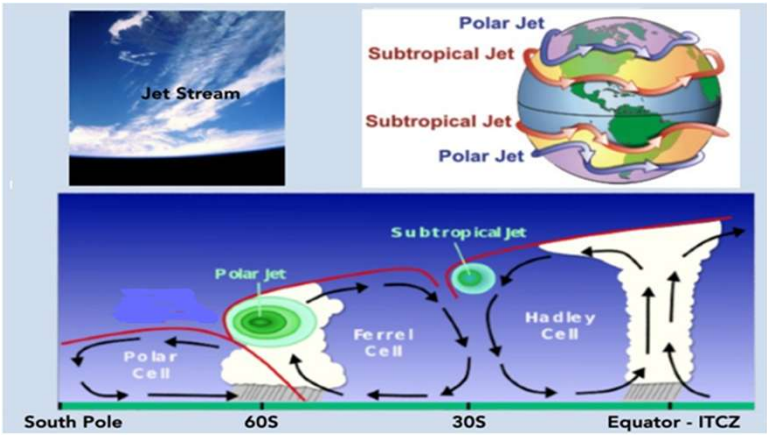




https://www.abc.net.au/news/2025-05-08/southern-australias-heat-and-drought-explained/105264074

The Subtropical Ridge intensification is important and the number of high pressure systems is increasing which is correlated with global temperatures. There is also anomalous high barometric pressure.

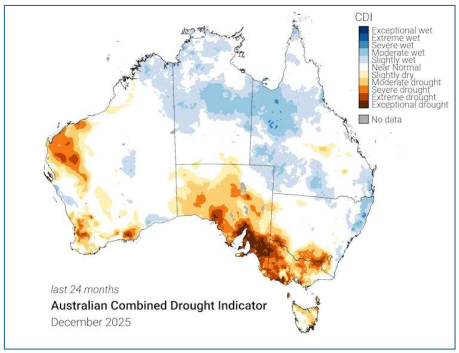
Jet movements

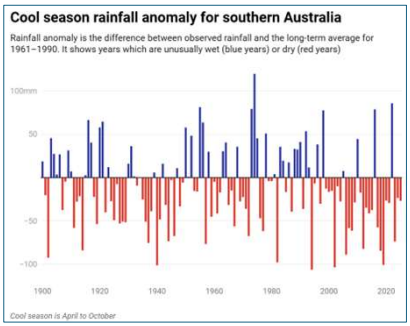


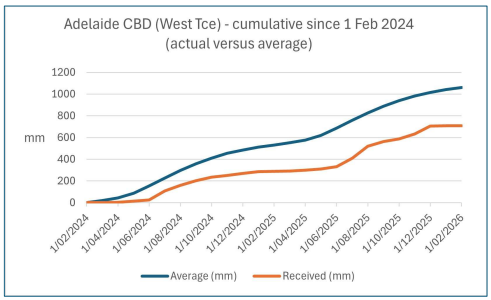
- "…. there is a dramatic change in position and structure of the STJ branch of the split jet, between the 1965 to 2015 and the 2016 to 2025 anomalies. The split jet structure has shifted approximately 10◦ poleward, causing rain producing systems to track south of the Australian continent."

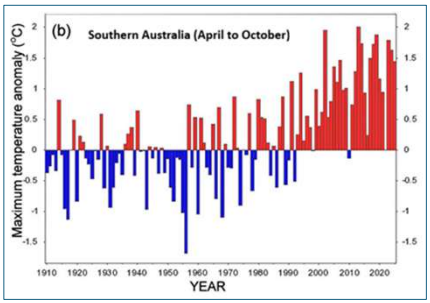
Speer M, Leslie L. Declining Rainfall in Southern Coastal Australia Signals a Return to Drought, Low Dam Levels, Declining Stream Flows, and Catastrophic Bushfires. Climate. 2026 Feb 10;14(2):52.

The Jet streams are also changing dramatically. They are the high-speed, narrow air currents that form at the top of the Hadley and Ferrel cells. The STJ is not present over Australia in summer. Recently found is a dramatic poleward shifting of the jet by approximately 10◦ comparing 1965-2015 data with the last 10 years and this causes rain producing systems to track south of the Australian continent.

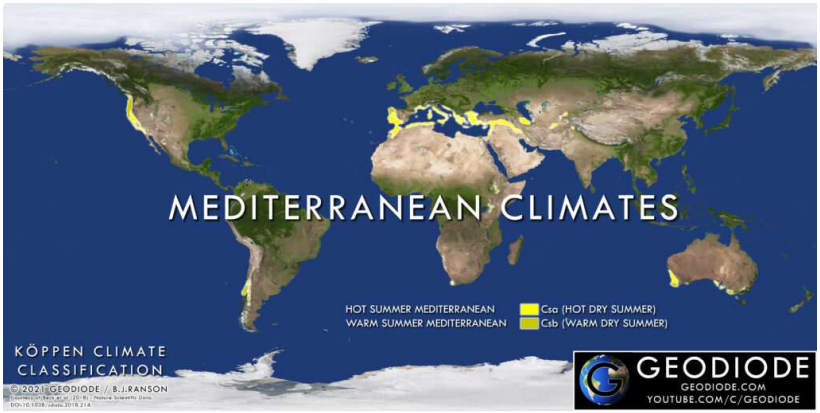








The result is a progressive drying and heating trend. On the left are shown the severe drought conditions impacting South Australia over the past 2 years. Adelaide's cumulative rainfall deficit has continued to increase, with totals now down 30%. Cool season rainfall is reducing and maximum temperatures are increasing.



Turton. S. M. (2025). Australia on the frontline of global climate change. *South Australian Geographical Journal.*

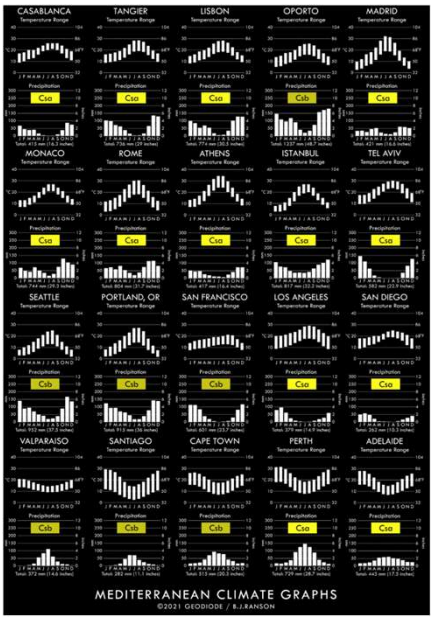
SPECIAL ISSUE - GEOGRAPHY FUTURES PAST

Australia on the Frontline of Global Climate Change

Stephen M. Turton[1]

[1] Research Division, Central Queensland University

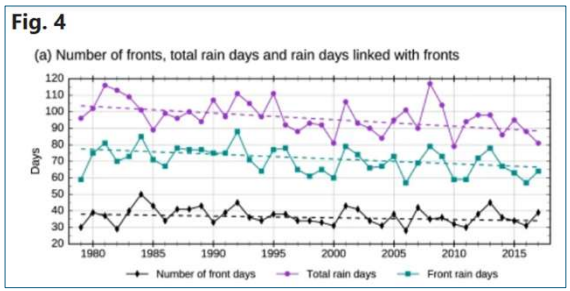
Keywords: arid subtropics, climate change, climate extremes, global warming, Hadley circulation, hydroclimate whiplash, tropical expansion, weather extremes, anthropocene



Here are the places impacted by these changes in the Mediterranean belts. In the Southern Hemisphere, it's southern Australia, southwestern Africa and Chile.

Southern Hemisphere – other frontlines

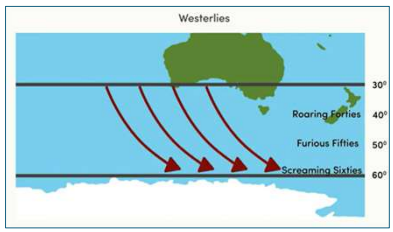
- Chile
- South Africa
  - Cape Town: Day Zero (May 2018 – 21% reservoir capacity)
  - Burls, N.J., Blamey, R.C., Cash, B.A. *et al*. The Cape Town "Day Zero" drought and Hadley cell expansion. *npj Clim Atmos Sci* **2**, 27 (2019).



We may be aware of the Cape Town Day Zero event of May 2018 that was ultimately averted. Reservoir levels fell to 21%.

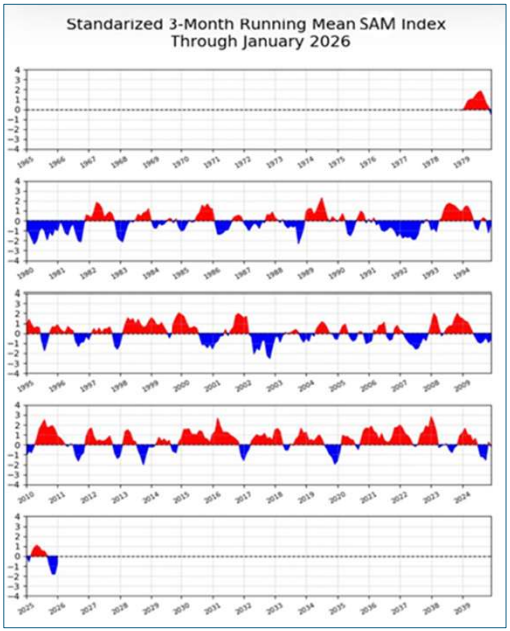
Some specific important Circulation changes in the Southern Hemisphere driven by rising EEI

- Surface winds, and surface ocean currents which they drive, are generally strengthening
- Specific trends in Southern Hemisphere
- Specific trends in Southern Hemisphere
  - Polewards expansion of Hadley Cell and tropics
  - Subtropical ridge intensification
  - polewards movement of STJ/PJ
  - Positive Southern Annular Mode trend
  - Strengthening Southern Hemisphere Westerly winds
- These changes have huge implications – which we are now directly experiencing as EEI increase accelerates

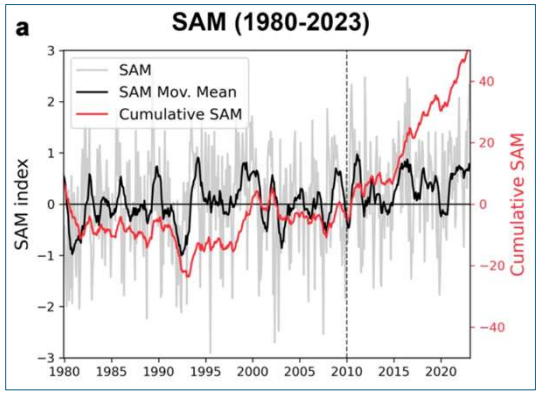


Coriolis Force – to the left in SH

Another really important trend in the Southern Hemisphere is the trend to a positive Southern Annular Mode or SAM.



Southern Annular Mode (1979-2026)



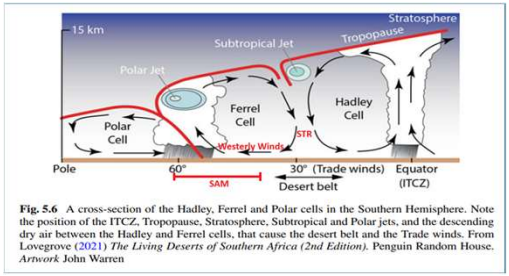


Fig. 5.6 A cross-section of the Hadley, Ferrel and Polar cells in the Southern Hemisphere. Note the position of the ITCZ, Tropopause, Stratosphere, Subtropical and Polar jets, and the descending dry air between the Hadley and Ferrel cells, that cause the desert belt and the Trade winds. From Lovegrove (2021) *The Living Deserts of Southern Africa (2nd Edition).* Penguin Random House. *Artwork* John Warren

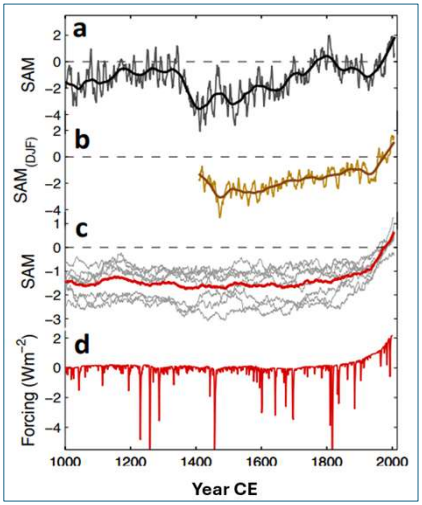
As I mentioned, the SAM is the difference in the zonal mean sea level pressure at 40°S (mid-latitudes) and 65°S (Antarctica). Changes in air pressure distribution cause changes in the strength and position of the westerly winds. A positively trending SAM means an increase in the strength of the Southern Hemisphere Westerly Winds which also move polewards. The graph on the left shows the trend towards this positivity from 1979 to 2026, with red areas increasingly greater than blue. This can also be shown cumulatively on the right upper graph.

SAM has an important paleoclimate linkage

- In colder climates, it's negative
- In hotter climates, it's positive
- May be linked to climate state tipping/transition points
  - via linkage to glacier melting
  - via linkage to carbon dioxide outgassing into atmosphere

    Menviel L, Spence P, Yu J, Chamberlain MA, Matear RJ, Meissner KJ, England MH. Southern Hemisphere westerlies as a driver of the early deglacial atmospheric CO2 rise. Nature Communications. 2018 Jun 27;9(1):2503.
  - View this SAM YouTube (Sarah Gaskin, 2021 UNSW student)

    https://www.youtube.com/watch?v=02Fkc2cpif0&list=UUnXvYIsrfCW1t9zVCfih2_w&index=2



Abram NJ, Mulvaney R, Vimeux F, Phipps SJ, Turner J, England MH. Evolution of the Southern Annular Mode during the past millennium. Nature Climate Change. 2014 Jul;4(7):564-9.

Concerningly, SAM has paleo or ancient climate linkages. It appears it may be a proximate mediator mechanism of climate transitions as the impact of strengthening SO Westerly winds can be very significant and related to the impact on ocean upwelling as well as carbon dioxide absorption or release from the ocean. When it's positive, it tends to be associated with warmer paleoclimates. It's worth taking a look at the YouTube created by a university student, and listed at the bottom of the slide, for an introduction to the significance of the SAM. The SAM is the most positive it has been for the last 1000 years and this is linked to GHG emissions.

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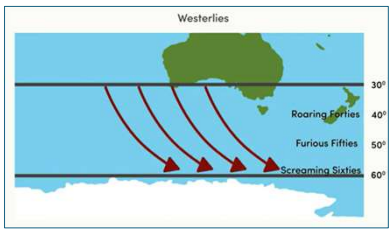
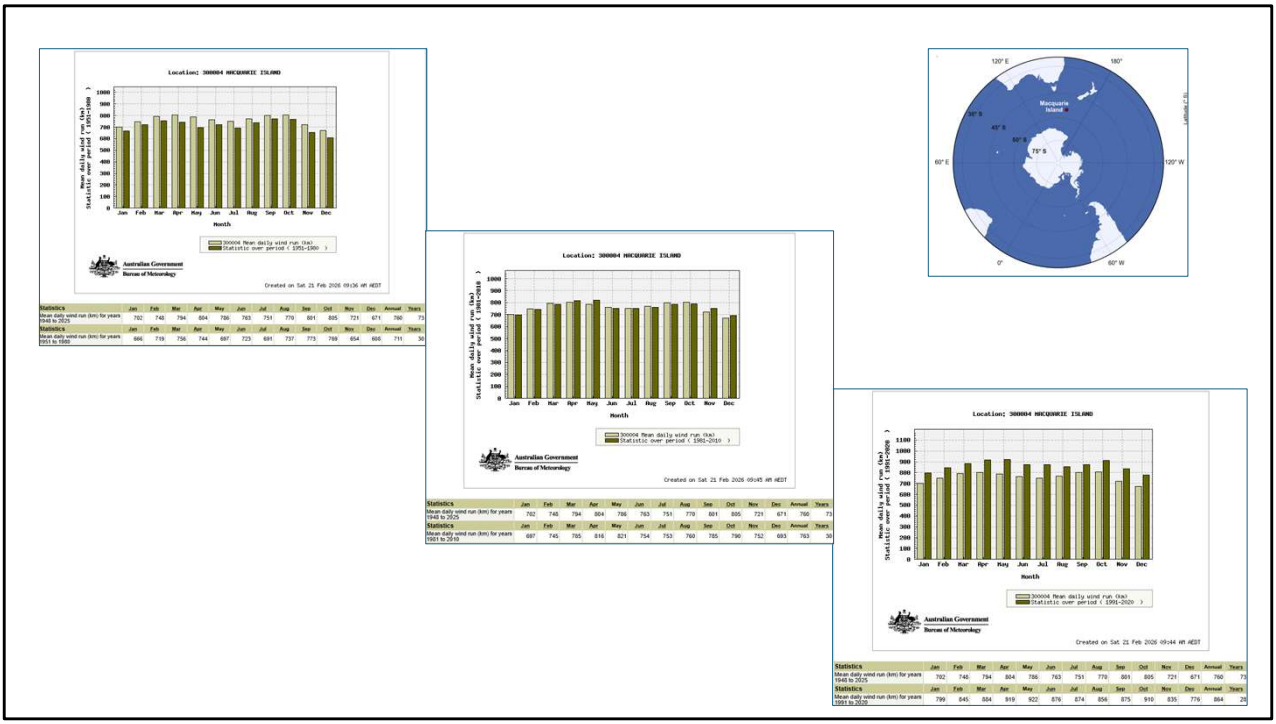


Coriolis Force – to the left in SH

The strengthening of the Westerly winds is linked to the positive SAM trend and is reliably reproduced across climate models. It's also possible to directly measure them at just a few sites in the Southern Ocean



This BOM Macquarie Island weather station data confirms recent increase of the westerly average wind average speed, the column graph on the bottom right showing a clear overall increase in average wind speeds across all months, comparing the 1991-2020 data with the average across the entire dataset from 1948-2025.

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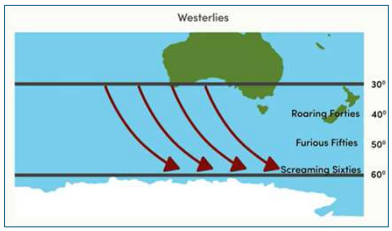


Coriolis Force – to the left in SH

So clearly these Southern Hemispheric changes driven by an increasing EEI have huge implications which we are now experiencing in real time.

So how does all this relate to the HAB?

- "Experts believe there are three plausible contributing factors to the bloom:
  - The ongoing marine heatwave impacting southern Australian waters since September 2024, with water temperatures 2.5°C warmer than usual, as well as relatively calm marine conditions with little wind and small swells.
  - The 2022–23 River Murray flood washing extra nutrients into the sea.
  - An unprecedented cold-water upwelling that occurred in the summer of 23–24, which has brought nutrient-rich water to the surface."

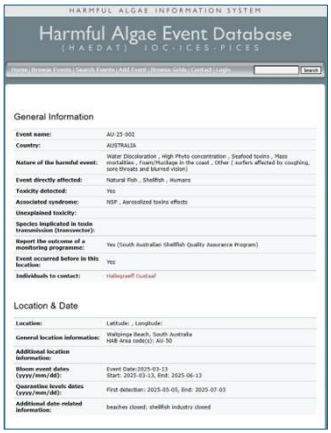
https://pir.sa.gov.au/news/news/sardi/collaboration_to_tackle_harmful_algal_bloom

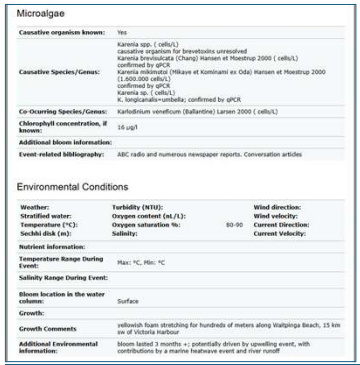
So getting back to the Algal Bloom – besides climate change, what else was said. The public was told in 2025 by the Government that there were 3 plausible contributors .... read

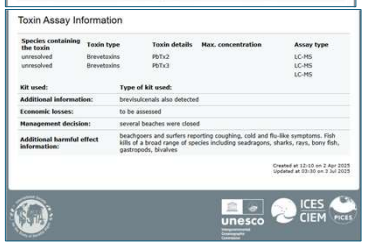
Upwelling Initiation: Gustaaf Hallegraeff, UTAS, IMAS

- “this is a frightfully complex scenario of a mixture of Karenia species most likely initiated by an offshore nutrient upwelling event”
- Algal Bloom Federal Senate Inquiry submission #52 (Gustaaf Hallegraeff, UTAS, IMAS)

- “potentially driven by upwelling event, with contributions by a marine heatwave event and River [Murray flood] runoff”
- https://haedat.iode.org/viewEvent.php?eventID=14543







Gustaaf Hallegraeff, a globally recognized HAB expert, identified an upwelling event as a likely initiator and driver. We’ll now look at this critically important phenomenon in more detail. What is upwelling?

Sequence

- Upwelling is an oceanic process whereby deep, cold water is brought to the surface. It occurs in the open ocean and also in coastal areas. It is caused by various mechanisms linked to surface winds, ocean currents and underwater topography known as being “upwelling favorable”. The water is typically nutrient rich which drives marine food web productivity and sustains biodiversity. It represents a large source of chemical and kinetic energy.
- The Eastern Boundary Upwelling Systems (EBUS) of the world are located along western continental boundaries and are very productive
- Off Southern Australia is a Northern Boundary Upwelling System named the Great Southern Australian Coastal Upwelling System (GSACUS) which shares many features of the EBUSs
- EBUSs are impacted by anthropogenic climate change in different ways and there are very serious concerns

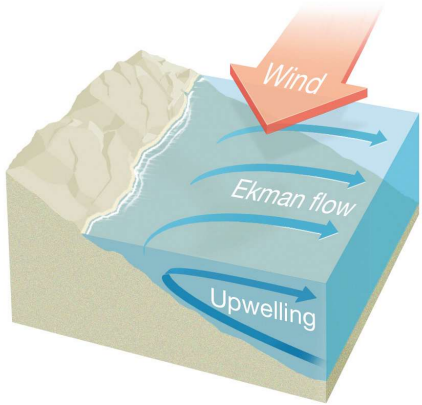
Read.....

Mechanisms

(i) Ekman transport/flow from upwelling-favorable alongshore wind stress (SouthEasterly winds in South Australia)

(ii) offshore vertical Ekman pumping from wind stress curl or vorticity, and Sverdrup transport

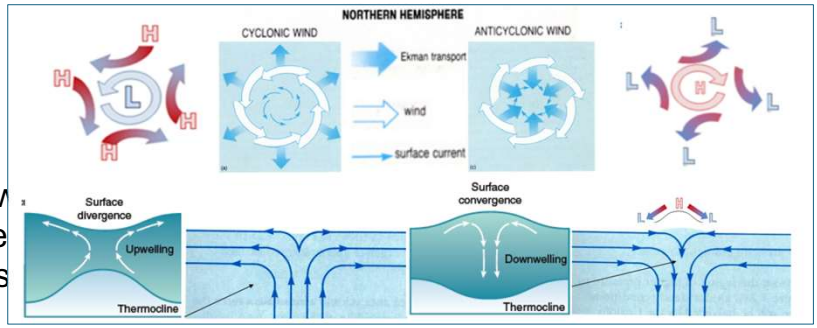
(iii) dynamic shear/uplift from shelf-edge currents (Flow-Topography interaction)



BOM, Australian Government

There are 3 main upwelling mechanisms which can be divided into wind-driven and ocean current-driven. Firstly, sustained winds in a consistent direction over the ocean move the top layer horizontally, so-called Ekman flow. In the southern hemisphere, the seawater layer moves to the left of the wind direction, due to the Coriolis effect. As the top layer of water is moved, it needs to be replaced. If the coast is to the right of the wind direction, an 'upwelling' process draws up colder and more nutrient-rich water from the depths of the ocean to the surface. The longer the winds persist, the greater the so-called alongshore wind stress.

Mechanisms



(i) Ekman transport/flow favorable alongshore (SouthEasterly winds Australia)

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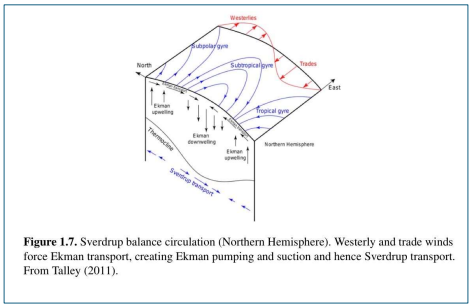

Figure 1.7. Sverdrup balance circulation (Northern Hemisphere). Westerly and trade winds force Ekman transport, creating Ekman pumping and suction and hence Sverdrup transport. From Talley (2011).

This is complicated but another mechanism involves wind blowing across the open ocean away in an offshore location and away from the coast. A wind stress curl is set up resulting in associated vertical water motion – either Ekman suction (upwelling) or Ekman pumping (downwelling) depending on wind direction and Ekman transport. To balance out water movement, water flow occurs at the bottom called Sverdrup transport which can then feed into ocean currents and strengthen them.

3 Mechanisms

(i) Ekman transport/flow from upwelling-favorable alongshore wind stress (SouthEasterly winds in South Australia)

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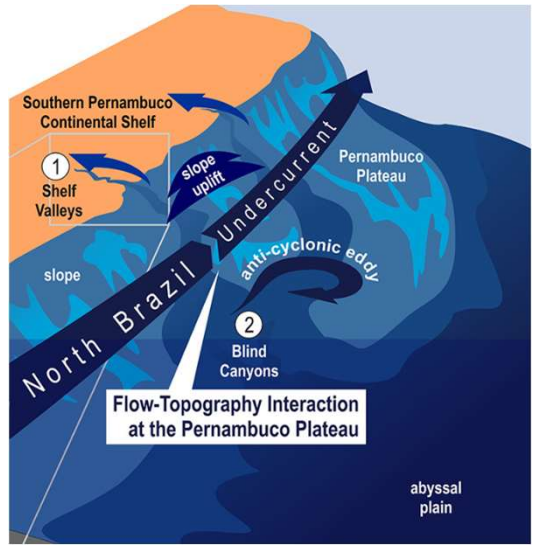

https://ars.els-cdn.com/content/image/1-s2.0-S0924796321001846-ga1_lrg.jpg

The third upwelling mechanism involves the interaction between the ocean current at the shelf and the topography of the adjacent shelf. For example, canyons and valleys can facilitate the storage of water closer to the surface for later upwelling as well as steer and funnel the water to the surface.

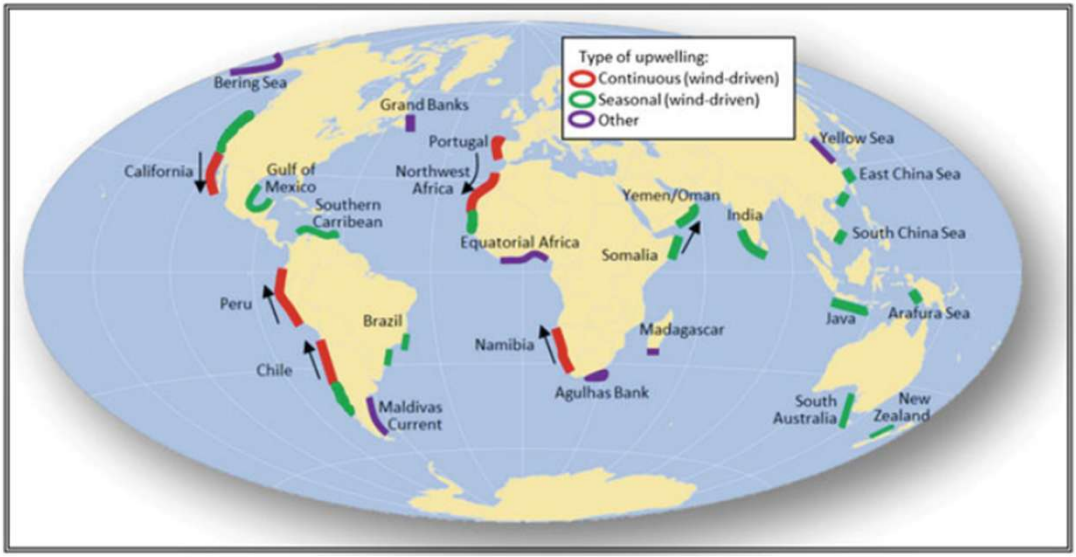

Fig. 2.14 Locations of significant coastal upwelling regions in the world ocean

So where does coastal upwelling occur? Here's a map of the major areas of coastal upwelling which includes the Great Southern Australian Coastal Upwelling System extending from the west coast of Tasmania to Eyre Peninsula. At these upwelling systems, you'll find a vast marine food web and associated biodiversity related to the large nutrient loads upwelled to the ocean surface and into the photic zone.

Sequence

- Upwelling is an oceanic process whereby deep, cold water is brought to the surface. It occurs in the open ocean and also in coastal areas. It is caused by various mechanisms linked to surface winds, ocean currents and underwater topography known as being “upwelling favorable”. The water is typically nutrient rich which drives marine food web productivity and sustains biodiversity. It represents a large source of chemical and kinetic energy.
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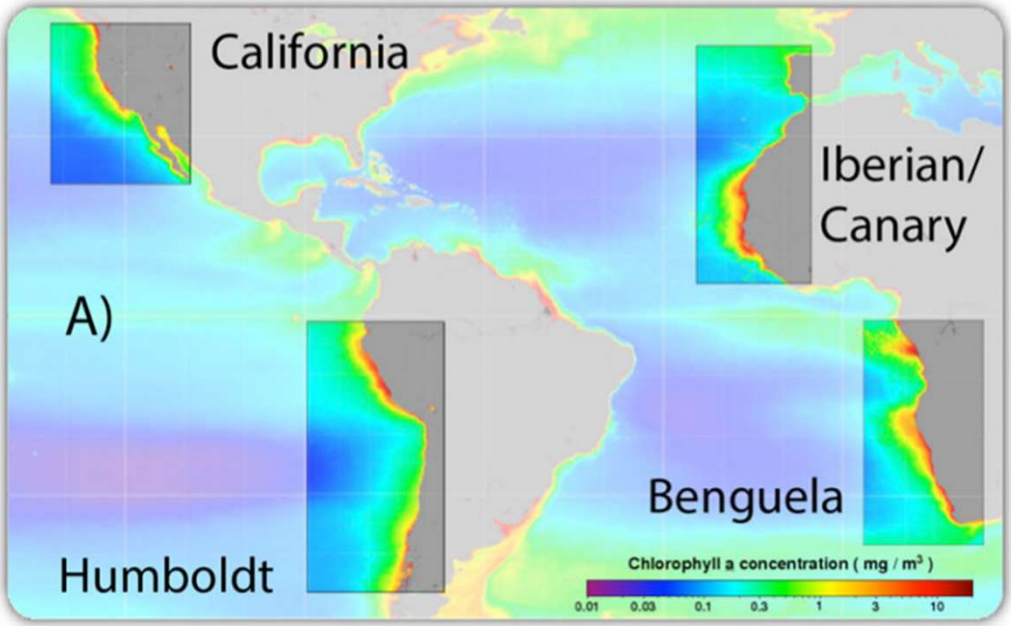
Read:



Bakun A, Black BA, Bograd SJ, Garcia-Reyes M, Miller AJ, Rykaczewski RR, Sydeman WJ. Anticipated effects of climate change on coastal upwelling ecosystems. Current Climate Change Reports. 2015 Jun;1(2):85-93

These are the 4 major Eastern Boundary Systems associated with the Californian, Humboldt, Canary and Benguela currents. They share a common feature – a regular, predictable coastal upwelling of nutrient-rich water driven by alongshore, equatorward surface winds and the Ekman transport mechanism we discussed. The resultant productivity is seen here on satellite imagery where chlorophyll a concentrations are colour-coded, red being the greatest – we'll be reviewing these types of images soon.

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- Upwelling is an oceanic process whereby deep, cold water is brought to the surface. It occurs in the open ocean and also in coastal areas. It is caused by various mechanisms linked to surface winds, ocean currents and underwater topography known as being “upwelling favorable”. The water is typically nutrient rich which drives marine food web productivity and sustains biodiversity. It represents a large source of chemical and kinetic energy.
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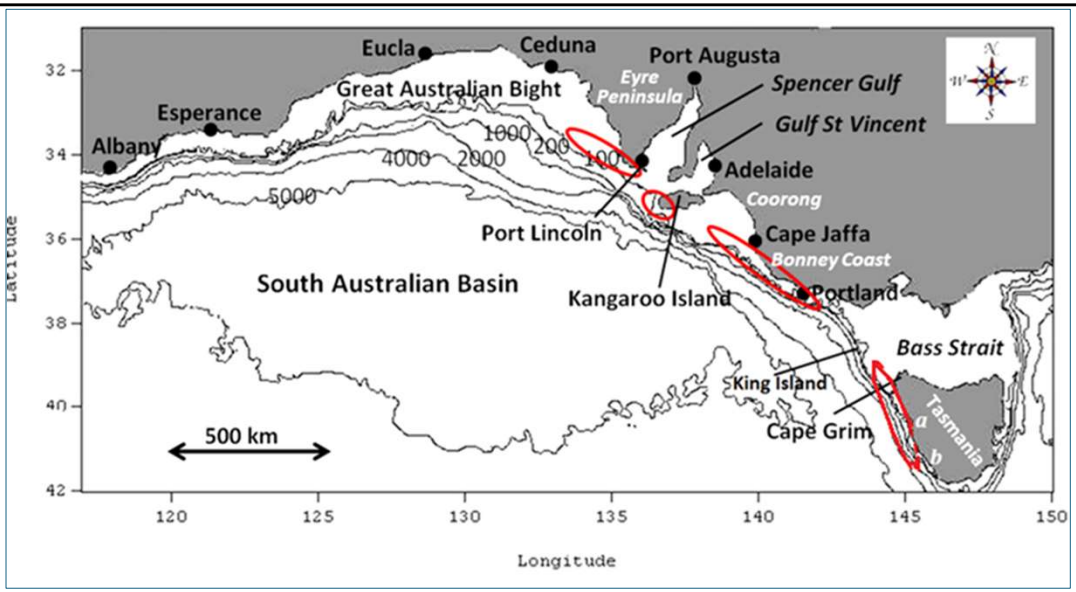
- Off Southern Australia is a Northern Boundary Upwelling System named the Great Southern Australian Coastal Upwelling System (GSACUS) which shares many features of the EBUSs
- EBUSs are impacted by anthropogenic climate change in different ways and there are very serious concerns

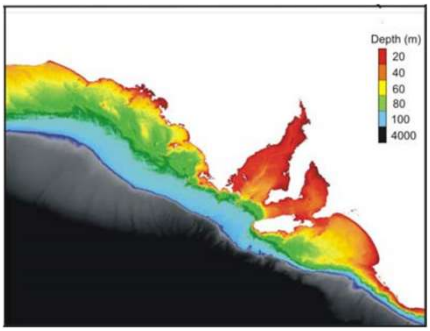
Read:



Great Southern Australian Coastal Upwelling System: 1500 kms from Tasmania to Eyre Peninsula, South Australia

Kämpf J. Phytoplankton blooms on the western shelf of Tasmania: evidence of a highly productive ecosystem. Ocean Science. 2015 Jan 5;11(1):1-1.

The Great Southern Australian Coastal Upwelling System comprises 4 upwelling centres shown here in red, the largest and most consistent being the Bonney upwelling off South Australia's Southeast region. While the productivity is less than the overall EBUS, it still rivals some of the least productive Eastern Systems.



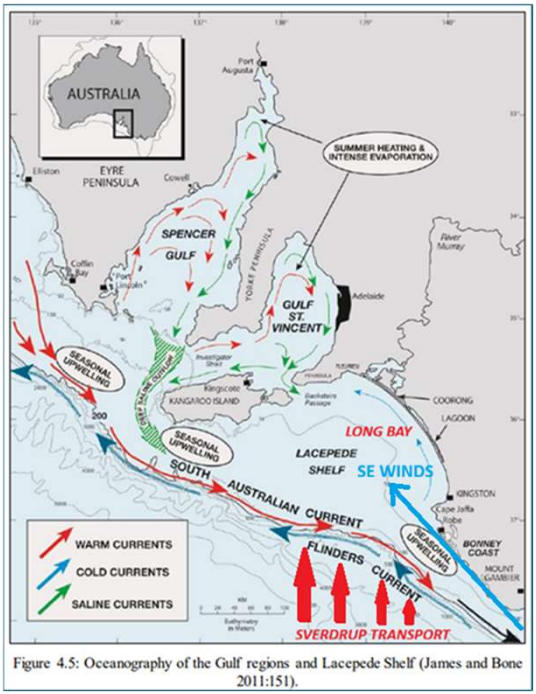


Figure 4.5: Oceanography of the Gulf regions and Lacepede Shelf (James and Bone 2011:151).

So here are the essential features of this System: firstly, the alongshore upwelling favorable SE winds, secondly, the upwelling favorable cold nutrient rich Flinders Current running east to west below the shelf at a depth of around 500m and fed by the Sverdrup water transport associated with the offshore wind stress curl we reviewed, and lastly the interactions of the Flinders Current with the shelf edge and its valleys, headlands and canyons. There is an intermittent warm west-to-east flowing current as well (the Leeuwin current) which is not upwelling favorable. Note that Long Bay, shown here on the Lacepede Shelf, is quite shallow and we'll be discussing this Bay soon.

"Cold, nutrient-rich water upwells from depth .... in the four main eastern boundary upwelling systems.... At the heart of these regional upwelling systems is wind forcing along the coast, with alongshore winds driving .... a persistent supply of nutrients that fuels photosynthesis and accounts for high levels of productivity. However, wind driven coastal upwelling is not confined to eastern boundary upwelling systems and is observed in .... southern Australia (Kämpf & Chapman 2016)]."

Largier JL. Upwelling Bays: How Coastal Upwelling Controls Circulation, Habitat, and Productivity in Bays. Ann Rev Mar Sci. 2020 Jan 3;12:415-447.

This important overlap between the EBUSs and the Southern Australian system was noted by John Largier who wrote:

Shelf waters of the eastern GAB and the Bonney Coast have oceanographic and ecological similarities to the eastern boundary current systems off the west coasts of northern and southern Africa and North and South America (Mann and Lazier, 1996). Southern Australia has the world's only northern boundary current. The Flinders Current that flows westward along the shelf slope (Bye, 1972, 1983; Middleton and Cirano, 2002) is analogous to the poleward undercurrents that flow over the shelf and/or shelf slope in the other ecosystems (Mann and Lazier, 1996). The Flinders Current and the regime of south-easterly winds that facilitate coastal upwelling during summer and autumn is comparable to the temporally variable longshore winds that drive surface flows offshore in the Canary, Benguela, California and Humboldt current systems (Mann and Lazier, 1996; Middleton, 2000; Middleton and Platov, 2003.

Ward, T.M., Goldsworthy, S., Rogers, P.J., Page, B., McLeay, L.J., Dimmlich, W.F., Baylis, A., Einoder, L., Wiebkin, A., Roberts, M., Daly K., Caines, R. and Huveneers, C., (2008). Ecological importance of small pelagic fishes in the Flinders Current System. Report to Department of the Environment, Water, Heritage and the Arts. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/001194-1.

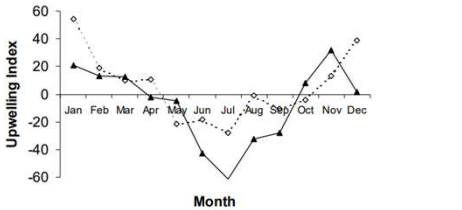


Figure 3. Mean upwelling indices for each month during 1999 (open diamonds) and 2000 (closed triangles) based on 30 minute averaged records of wind strength and direction from Neptune Island. Data provided by the Australian Bureau of Meteorology (Adelaide).

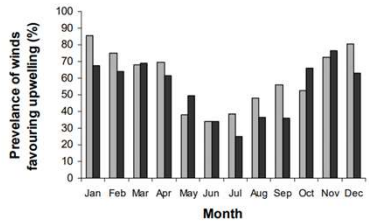
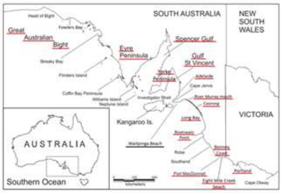


Figure 2. Proportion of 30 minute averaged wind records from Neptune Island during 1999 (shaded bars) and 2000 (solid bars) that favoured upwelling (i.e. were from directions between 45° and 225°). Data provided by the Bureau of Meteorology (Adelaide).

Local scientists have also reported this similarity. In this 2007 state government report, it was noted that ....

The graphs at the bottom show the seasonal variation of the upwelling favorable SE winds which can feed into a so-called Upwelling Index



The Upwelling Festival Portland is a community celebration of the Bonney Upwelling, presented by the Upwelling Festival Incorporated and a partnership with other community groups.

The Upwelling Festival celebrates what is unique about Portland and the community and showcases an important environmental phenomenon – the Bonney Upwelling.

The Bonney Upwelling is a unique and epic natural ocean phenomena where the spring winds shift to the south-east driving a change in ocean currents that powers a seven month feeding frenzy of tuna, crayfish, giant crabs, squid, fish, seabirds, seals, krill and blue whales. An incredibly rich ecological food web, the Upwelling is at its greatest off the coast of Portland and is the cornerstone of the lucrative local fishing and tourism industry.

The annual upwelling season is actively celebrated particularly along the Bonney Coast; here's an example of the Portland Upwelling Festival. This emphasizes that while upwelling is a physical process, it has many varied downstream consequences at all scales.

Sequence

- Upwelling is an oceanic process whereby deep, cold water is brought to the surface. It occurs in the open ocean and also in coastal areas. It is caused by various mechanisms linked to surface winds, ocean currents and underwater topography known as being “upwelling favorable”. The water is typically nutrient rich which drives marine food web productivity and sustains biodiversity. It represents a large source of chemical and kinetic energy.
- The Eastern Boundary Upwelling Systems (EBUS) of the world are located along western continental boundaries and are very productive
- Off Southern Australia is a Northern Boundary Upwelling System named the Great Southern Australian Coastal Upwelling System (GSACUS) which shares many features of the EBUSs
- EBUSs are impacted by anthropogenic climate change in different ways and there are very serious concerns

It is now well recognized that EBUSs are impacted by anthropogenic climate change in different ways and there are very serious concerns

CLIMATE CHANGE PROJECTIONS IN THE EASTERN BOUNDARY UPWELLING SYSTEMS

Temperature

- Coastal warming modulated by upwelling trends
- Stronger cross-shore SST gradient
- Enhanced stratification

Wind

- Poleward displacement of subtropical highs
- Stronger alongshore wind stress in poleward regions; weaker to no trend in equatorial regions
- Stronger offshore wind-stress curl

Upwelling

- Upwelling intensification (weakening or no trend) in poleward (equatorward) regions
- Later spring transition (northern CalCS)
- Longer upwelling season in poleward regions (HumCS, CanCS, and BenCS)

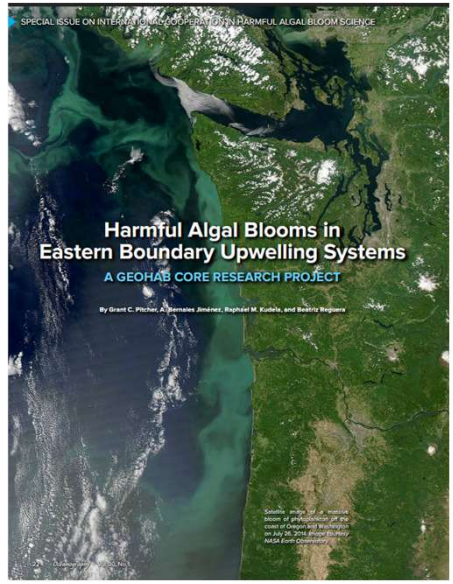
Nutrients

- Permanent aragonite undersaturation by 2050 (CalCS) or 2100 (HumCS)
- Deoxygenation and higher nutrient content (CalCS and HumCS)

Productivity

- Increased offshore transport of phytoplankton (CanCS and BenCS)
- Nonlinear productivity response to upwelling intensification (CalCS)
- Uncertain directional change in productivity

Steven J. Bograd, Michael G. Jacox, Elliott L. Hazen, Elisa Lovecchio, Ivonne Montes, Mercedes Pozo Buil, Lynne J. Shannon, William J. Sydeman, Ryan R. Rykaczewski. 2023. Climate Change Impacts on Eastern Boundary Upwelling Systems. *Annual Review Marine Science*. 15:303-328



Pitcher, G.C., A.B. Jiménez, R.M. Kudela, and B. Reguera. 2017. Harmful algal blooms in eastern boundary upwelling systems: A GEOHAB Core Research Project. Oceanography 30(1):22–35

Indeed significant work has been going on in this area. The 2023 publication on the left lists these areas of concern including upwelling intensification at the poleward parts of the EBUSs due to the 3 upwelling mechanisms we looked at, namely stronger alongshore winds, stronger offshore wind-stress curl which leads to stronger currents, and the resulting greater current-topography interaction at the shelf edge. Other concerns relate to upwelling of more nutrients and alterations to the characteristics of the upwelled water, greater stratification due to increasing sea surface temperature, the issue of generation of hypoxia (that is, low water oxygen levels) and dead zones, and the impact of all these factors on the ecosystems and marine life.

A further major concern, shown on the right of the slide, is the finding that HABs are becoming more common in the Eastern Upwelling Systems and this issue forms a core research project of the GlobalHAB initiative. For example, many of us may have heard of the recent increasingly severe and extensive toxic algal blooms in the Californian Current Upwelling System. A particular focus of the research is the importance of bays in upwelling systems.

ANNUAL REVIEWS

Annual Review of Marine Science

Upwelling Bays: How Coastal Upwelling Controls Circulation, Habitat, and Productivity in Bays

John L. Largier[1,2]

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[2]Coastal and Marine Sciences Institute, University of California, Davis, Bodega Bay, California 94923, USA; email: jlargier@ucdavis.edu

Annu. Rev. Mar. Sci. 2020. 12:415–47

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The *Annual Review of Marine Science* is online at marine.annualreviews.org

https://doi.org/10.1146/annurev-marine-010419-011020

Keywords

upwelling shadow, upwelling trap, headland, wind forcing, stratification, phytoplankton bloom, ocean acidification, hypoxia, larval dispersion

Abstract

Bays in coastal upwelling regions are physically driven and biochemically fueled by their interaction with open coastal waters. Wind-driven flow over the shelf imposes a circulation in the bay, which is also influenced by local wind stress and thermal bay–ocean density differences. Three types of bays are recognized based on the degree of exposure to coastal currents and winds (wide-open bays, square bays, and elongated bays), and the characteristic circulation and stratification patterns of each type are described. Retention of upwelled waters in bays allows for dense phytoplankton blooms that support productive bay ecosystems. Retention is also important for the accumulation of larvae, which accounts for high recruitment in bays. In addition, bays are coupled to the shelf ecosystem through export of plankton-rich waters during relaxation events. Ocean acidification and deoxygenation are a concern in bays because local extrema can develop beneath strong stratification.

"Much attention has been given to harmful algal bloom species that favor the sheltered and stratified bay waters (Pitcher et al. 2010), consistent with the importance of dinoflagellates as harmful algal bloom species (in addition to Pseudo-nitzschia, which also favors warmer stratified waters). This is a persistent local issue, e.g., in northeast Monterey Bay (Ryan et al. 2009), St. Helena Bay (Pitcher & Weeks 2006), and historically in Drakes Bay (Lewitus et al. 2012). These bay blooms also act as an inoculum for more widespread harmful algal blooms outside of bays, which may occur during relaxation events (Ryan et al. 2009), such as the Gonyaulax bloom in the Sonoma Coast embayment in August 2011 that originated in Drakes Bay (Rogers-Bennett et al. 2012)."

Largier JL. Upwelling Bays: How Coastal Upwelling Controls Circulation, Habitat, and Productivity in Bays. Ann Rev Mar Sci. 2020 Jan 3;12:415-447.

This is a really important publication by John Largier in 2020 and highlights the critically important functions and wider consequences of some bays found in upwelling systems, particularly those in the EBUSs – although the findings are generalizable beyond the EBUSs. He notes in relation to algal blooms in bays ....

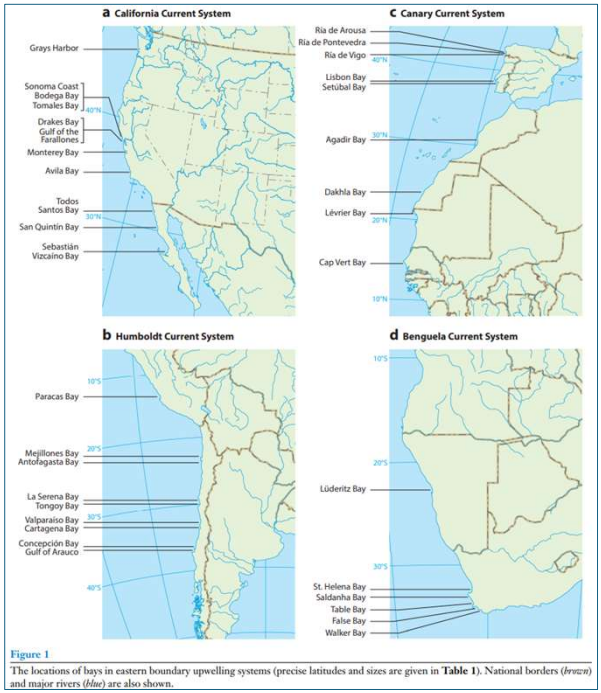
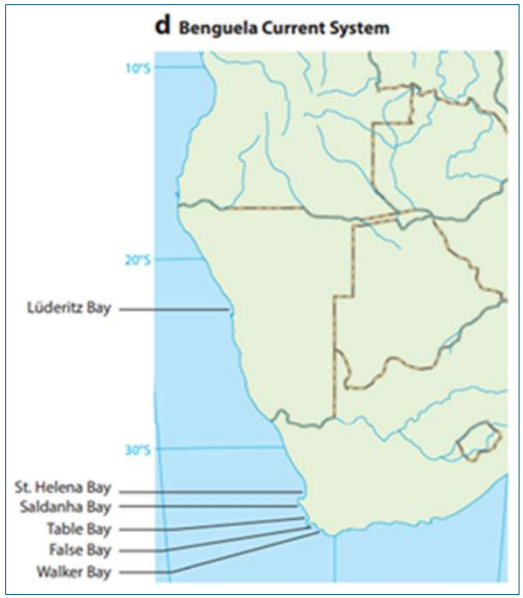


Figure 1

The locations of bays in eastern boundary upwelling systems (precise latitudes and sizes are given in **Table 1**). National borders (*brown*) and major rivers (*blue*) are also shown.



Largier JL. Upwelling Bays: How Coastal Upwelling Controls Circulation, Habitat, and Productivity in Bays. Ann Rev Mar Sci. 2020 Jan 3;12:415-447.

Some important bays are noted in each EBUS. On the right, I want to highlight some of the bays in the Southern Benguela system as we will be coming back to this as these are the only bays in the world that have ever had a confirmed karenia cristata algal bloom which is the one we are seeing in South Australia at the moment.

www.nature.com/scientificreports

scientific reports

Check for updates

OPEN

Widespread and increasing near-bottom hypoxia in the coastal ocean off the United States Pacific Northwest

John A. Barth[1✉], Stephen D. Pierce[1], Brendan R. Carter[2,3], Francis Chan[4,5], Anatoli Y. Erofeev[1], Jennifer L. Fisher[6], Richard A. Feely[3], Kym C. Jacobson[6], Aimee A. Keller[6], Cheryl A. Morgan[5], John E. Pohl[6], Leif K. Rasmuson[7] & Victor Simon[6]

The 2021 summer upwelling season off the United States Pacific Northwest coast was unusually strong leading to widespread near-bottom, low-oxygen waters. During summer 2021, an unprecedented number of ship- and underwater glider-based measurements of dissolved oxygen were made in this region. Near-bottom hypoxia, that is dissolved oxygen less than 61 μmol kg^{-1} and harmful to marine animals, was observed over nearly half of the continental shelf inshore of the 200-m isobath, covering 15,500 square kilometers. A mid-shelf ribbon with near-bottom, dissolved oxygen less than 50 μmol kg^{-1} extended for 450 km off north-central Oregon and Washington. Spatial patterns in near-bottom oxygen are related to the continental shelf width and other features of the region. Maps of near-bottom oxygen since 1950 show a consistent trend toward lower oxygen levels over time. The fraction of near-bottom water inshore of the 200-m isobath that is hypoxic on average during the summer upwelling season increases over time from nearly absent (2%) in 1950–1980, to 24% in 2009–2018, compared with 56% during the anomalously strong upwelling conditions in 2021. Widespread and increasing near-bottom hypoxia is consistent with increased upwelling-favorable wind forcing under climate change.

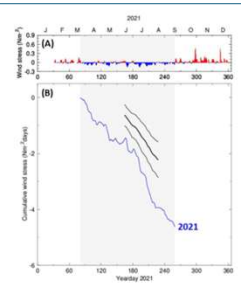


Figure 2. Winds during 2021. (**A**) North–south wind stress from Newport, OR; upwelling(downwelling)-favorable, south(north)ward wind is shaded blue(red); gray shaded region denotes the summer upwelling season. (**B**) Cumulative wind stress during 2021 (blue curve) compared with data from 1985 to 2022 (mean is thick curve, ± one standard deviation denoted by thin curves).

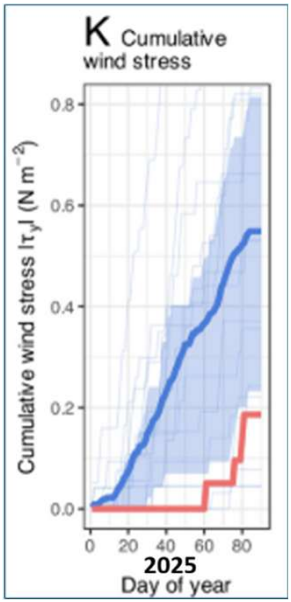
"Upwelled waters… are low in oxygen but still has enough to stay above the hypoxic threshold of <61 μmol kg−1 (1.4 mL L−1) … These upwelling source waters are declining in oxygen …. under the effects of climate change. Dissolved oxygen (DO) in near-bottom coastal waters is further decreased to below the hypoxic threshold by respiration of falling organic matter and in seafloor processes over the shelf …. [also in other EBUSs]"

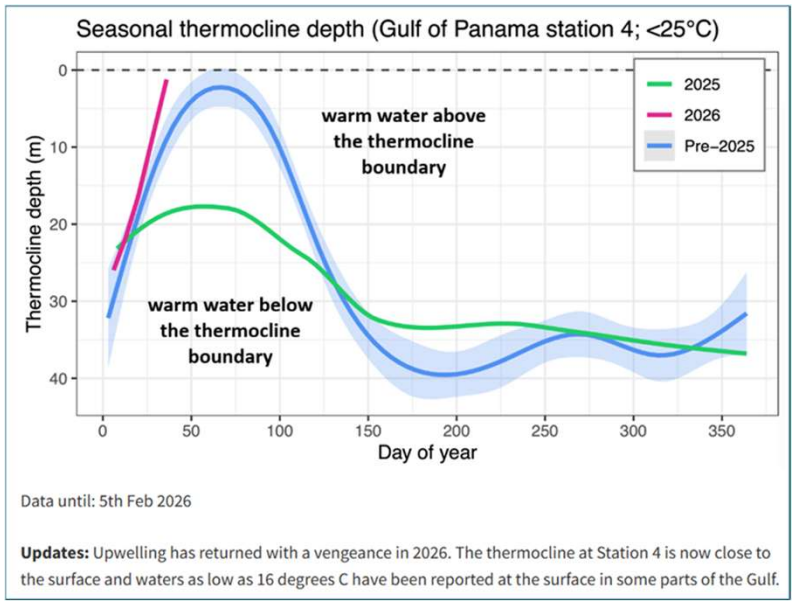
Barth, J.A., Pierce, S.D., Carter, B.R. *et al.* Widespread and increasing near-bottom hypoxia in the coastal ocean off the United States Pacific Northwest. *Sci Rep* **14**, 3798 (2024).

Short Film: https://www.oregonconservationstrategy.com/success-story/strategy-spotlight-hypoxia

Some extreme upwelling events are now showing up globally and, as we shall see, are loud and clear warning signs of tipping points. On the top right is the extreme 2021 event in the US Pacific NW which was prolonged and intense. The graph shows the anomalous cumulative alongshore wind stress for that season compared with the mean and standard deviation of the 1985-2022 seasons. There has been a steady increase in the hypoxia (low oxygen) levels in the near-bottom shelf waters off the US Pacific Northwest during the upwelling season, from the 1950 to 1980 period, when it was nearly non-existent, to the 2009 to 2018 period during which is averaged 24% - and in this extreme 2021 upwelling event, about 50% of the near-bottom water was hypoxic. The hypoxia is related to decreasing oxygen levels in the upwelled water but particularly to the increasing nutrient loads which are upwelled, under the influence of climate change, and retained on the shelf which then drives phytoplankton productivity which eventually decomposes consuming oxygen in the process. BTW a link at the bottom of the slide to an excellent short film of this issue.

Panama Upwelling https://odealab.com/upwelling-updates





Meanwhile, in 2025 in the Panama upwelling system, there was a near complete upwelling failure as shown by the red line on the cumulative wind stress graph on the left. On the other graph, the blue thermocline line marks the boundary between warm surface waters and the cold, nutrient-rich waters below for the typical seasonal pattern along with the 95% confidence intervals. When the thermocline moves upwards close to the sea surface, it's upwelling. The green line shows the failure of the 2025 upwelling while the red line shown the anomalously vigorous 2026 upwelling. So we again have this highly concerning pattern of events way outside expectations.

Climate Change and the GSACUS

Cai et al (2005): Climate models predict an upward trend of the Southern Annular Mode (SAM) in response to increasing atmospheric CO2 concentration…. This change in the wind stress curl causes a spin-up of the entire southern midlatitude ocean circulation including a southward strengthening of the subtropical gyres …. The pan-Southern Ocean scale suggests a broad impact on the marine ecosystem of the entire southern midlatitude ocean.

What about the Southern Australian upwelling system and climate change? There have been several very important warnings and reports over the past 20 years mainly related to the positive SAM trend with the associated strengthening of Southern Ocean Westerly winds, the increasing wind stress curl, the related strengthening of the nutrient rich and upwelling favorable Flinders Current, and the strengthening of the alongshore upwelling-favorable southeasterly winds. The wider ecosystem implications of these major changes have also been considered. For example, Cai ….

Hobday et al (2009): In southern Australia, the most important current is arguably the Flinders Current, which is … upwelled during summer-autumn between Cape Otway and the head of Great Australian Bight … anthropogenic climate change may result in increases in the strength and frequency of the southeasterly winds that … drive upwelling. The increase in nutrient enrichment … from upwelling supports the highest levels of … production in Australian waters (Ward et al. 2006). The strongest upwelling events recorded in the Flinders Current system have occurred during the last decade. Increased strength of upwelling favourable [southeasterly] winds could … could cause a major shift in ecosystem structure ….. increased upwelling can also have negative impacts (Bakun and Weeks 2004), including changes in community structure (e.g. phytoplankton and zooplankton) ….

Cetina-Heredia et al (2017): These results suggest that a positive SAM .... could facilitate the supply of more nutrient rich Subantarctic Mode Water (SAMW) to the GAB and enhance primary productivity.

.... a strengthening of the Flinders Current ... could increase primary productivity ... through enhanced current driven upwelling and nitrate supply into the euphotic zone.

... in addition to localized wind-induced upwelling, topographical upwelling may lead to considerable phytoplankton growth... Supporting this hypothesis, water-cooling events in the absence of upwelling favorable winds have been reported ...

Feng et al (2016):

Major ocean boundary current systems around Australia .... [including] the Flinders Current have strengthened during 1979–2014.

The invigorating ocean boundary current systems have induced extreme oceanographic conditions along the Australian coastlines in recent years .... primarily driven by large scale wind patterns.

Strengthening of the Flinders Current is driven by the increasing trend of the wind stress curls south of Australia. The poleward shift and strengthening of the westerlies in the Southern Ocean have increased the winds stress curls...

Understanding long-term trends .... of the ocean boundary currents is crucial to project future changes of the coastal marine systems under the influence of human-induced greenhouse gas forcing.

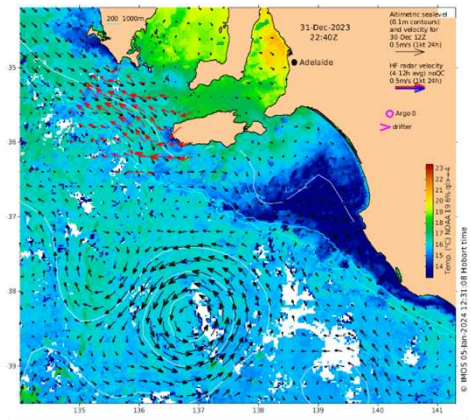
Hugo Bastos de Oliveira (PhD thesis 2018): *Upwelling dynamics in Southern Australia - Numerical Modelling and Observations*

We show .... the importance of alongshore variations in topography and the role of remote forcing on the shelf circulation.

We show that more upwelling favourable winds occur .... when a strong and positive Southern Annular Mode (SAM) phase develops.

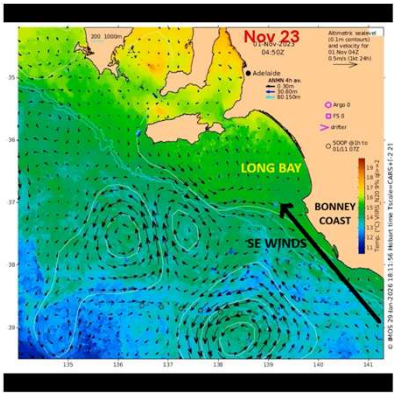
SA HAB Sequence/Timeline

- The unprecedented southern Australian upwelling of 2023-4 (intensity, duration, cold water temp) resulted in the upwelling of very large nutrient loads and was both wind and current driven although this can't be quantified

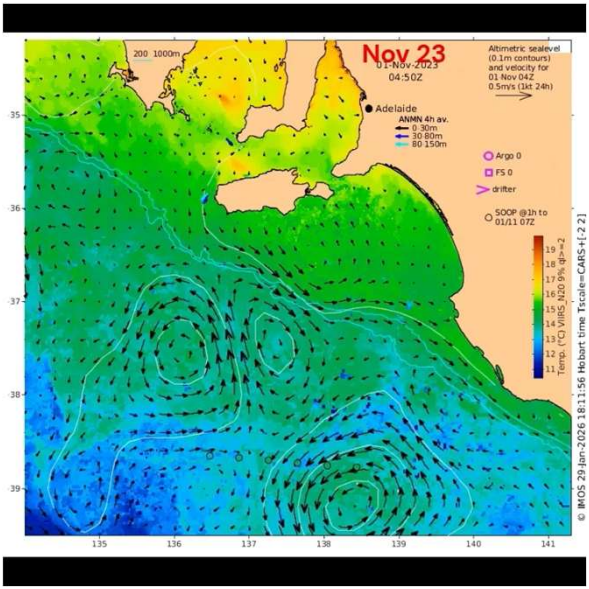


So back to the South Australian bloom timeline. We can start in November 2023 with the onset of an unprecedented upwelling across the Southern Australian upwelling system, both in terms of intensity and duration.

Video 2023-24 upwelling season (Nov 23-Jun 24)



satellite imagery:
- cold = blue
- warm = red
- watch for large plume from Bonney UW and smaller KI and EP plumes
- cold UW water is associated with nutrients



Satellite imagery can show us the cold upwelled water displayed as a blue colour. Deep blue is about 11 deg C. As we start the video on Nov 23, watch for a large cold water plume from the Bonney Upwelling project into Long Bay and the Lacepede shelf. This cold water is associated with nutrient loads. Other smaller upwelling centres are off the SW tip of KI and the tip of EP. This lasted until about June 2024.

This was noted in 2024 media reports:

- *“We're having a cracker upwelling this year. It's a bumper," he stated, attributing the phenomenon to sustained southeast winds that have been stronger and more persistent than usual.* (https://greatsouthernreef.com/upwelling)

- *He also noted the filters on the boats … were being changed every few days due to the presence of algae from the upwelling. "It's something I've never seen in 20 years of operating out there," he said. "To do that every other day is quite exceptional. So it just goes to show the load of plankton in the water.”* (https://www.abc.net.au/news/2024-02-02/ocean-upwelling-brings-deep-sea-visitors-eyre-peninsula-coast/103387184)

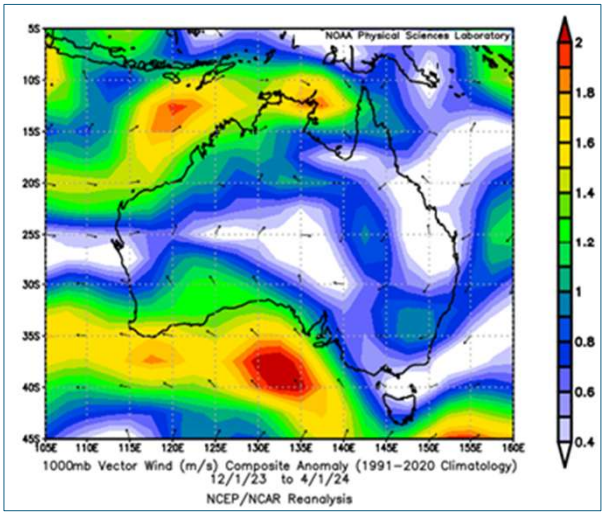
Those on the water reported very strong upwelling with sustained southeasterly winds and plankton blooms fouling boat filters

Surfers:

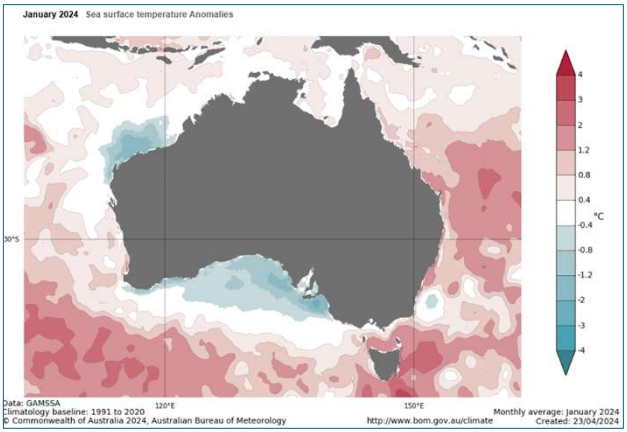
- *“Worst summer for surf on the mid and south coasts in living memory. Howling S.E. winds and bugger all swell for two months”*
- *“definitely the strongest SE'lies I've ever experienced”*
- *“coldest summer of surf, weather I have had, ice cream headaches, freezing hands and feet.”*

https://www.swellnet.com/news/swellnet-analysis/2024/01/11/cool-streaks-in-south-oz

Surfers reported cold water conditions and very strong southeasterly winds

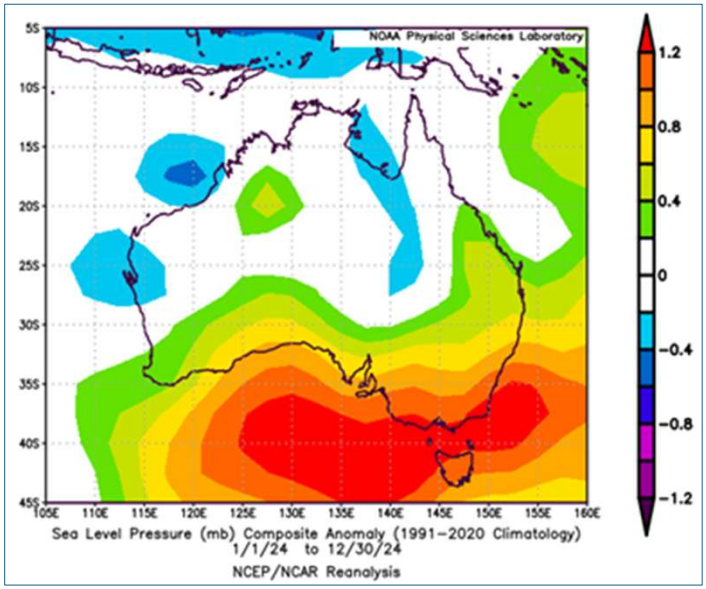


Craig Brockensha (Swellnet): Wind anomaly Dec 2023-April 2024



SST anomaly January 2024 (BOM)
https://www.bom.gov.au/climate/ocean/sst/#/anom/australia/monthly/20240101

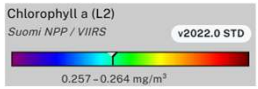
Charts confirmed anomalously strong winds in South Australian ocean basin from December 2023 to April 2024; and anomalously cold water across southern Australia extending to the coast.



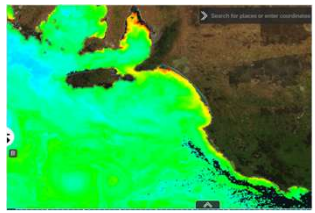
NOAA: https://psl.noaa.gov/data/composites/day/

Anomalously high sea level pressures were present in calendar year 2024 across southern Australia consistent with a strong subtropical ridge or descending branch of the Hadley Cell.

https://worldview.earthdata.nasa.gov/



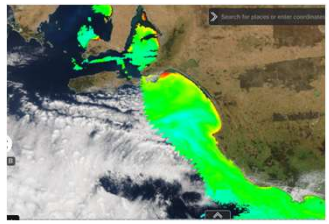
17 Oct 2023



17 Oct 2023

4 Nov 2023

True Color Corrected Reflectance



4 Nov 2023

Chlorophyll a

We'll now observe the biological response to this cold water upwelling by reviewing some more satellite imagery. The true color (on the left) and chlorophyll a (on the right) satellite imagery data stored on the NASA Worldview website is a great resource. In mid-October and November 2023, things looked quiescent. Upwelling had not yet commenced.

Pipis

- *"I have a good mate who is a commercial fisho…. not that long ago there were so many pipies on the beach you couldn't see the sand, now nothing"*
- *"Local fishos blame sudden cold water for pipies/cockles die-off. In the Discovery Bay vicinity, if they are there, they are dead and black inside"* (https://www.swellnet.com/news/swellnet-analysis/2024/01/11/cool-streaks-in-south-oz)
- *local recreational Pipi fishers in Discovery Bay, in South West Victoria, have not been able to find any Pipis. One Nelson resident said that he had not seen anything like this in his lifetime* (Jess Bourchier, Ecologist, https://natureglenelg.org.au/ocean-temperature-roller-coaster-and-its-local-legacy/)

But soon after the onset of this upwelling event in late November, concerning reports began to appear. Absent or dead and blackened pipis (a bivalve mollusc similar to a cockle) were noted at Discovery Bay, in western Victoria. Fishers blamed the cold water.

Eight Mile Creek Beach marine kill

- on 8 January, 2024, a marine kill event was reported at Eight Mile Creek Beach, just east of Port Macdonnell, in Riddoch Bay
- Mainly impacted “bottom-dwellers”
- some sick seals reported and some dead freshwater spiny crays and freshwater eels
- ocean water brown/dirty a week prior; out to 200m; current upwelling event noted

Read:






"At the moment, most of the species involved seem to be associated with rocky reef systems," Ms McSkimming said. "They're species that don't tend to move very far and stick to one location."

https://www.abc.net.au/news/2024-01-11/fish-kill-south-australia-pirsa-sharks-stingrays-water-salinity-/103308656

Here's some photos of the mortality event. It was noted .....

- “Local fishos …. blame red algae blooms for de-oxygenating the water for in-close fish” (https://www.swellnet.com/news/swellnet-analysis/2024/01/11/cool-streaks-in-south-oz)

PIRSA says rainfall runoff likely cause behind fish kill, including sharks, stingrays, in regional South Australia

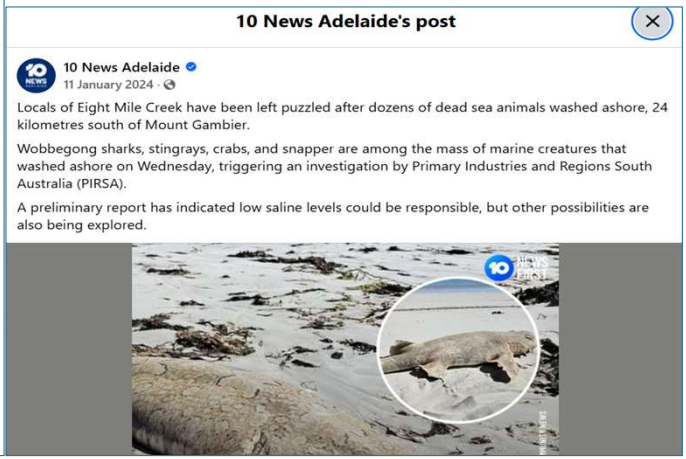
By Sam Bradbrook · ABC South East SA · Fish

Thu 11 Jan 2024

A popular beach along SA's Limestone Coast is littered with dead Wobbegong sharks. (ABC South East SA: Sam Bradbrook)

abc.net.au/news/fish-kill-south-australia-pirsa-sharks-stingr... Share article

Heavy rainfall and a rapid fall in water salinity are believed to be behind a sudden fish-kill event along a beach in South Australia's south-east.



10 News Adelaide's post

10 News Adelaide

11 January 2024 ·

Locals of Eight Mile Creek have been left puzzled after dozens of dead sea animals washed ashore, 24 kilometres south of Mount Gambier.

Wobbegong sharks, stingrays, crabs, and snapper are among the mass of marine creatures that washed ashore on Wednesday, triggering an investigation by Primary Industries and Regions South Australia (PIRSA).

A preliminary report has indicated low saline levels could be responsible, but other possibilities are also being explored.

Report:
https://pir.sa.gov.au/__data/assets/pdf_file/0005/466610/Determination_letter_16-5-2024_and_documents_released_-_CORP_F2024-000351.pdf

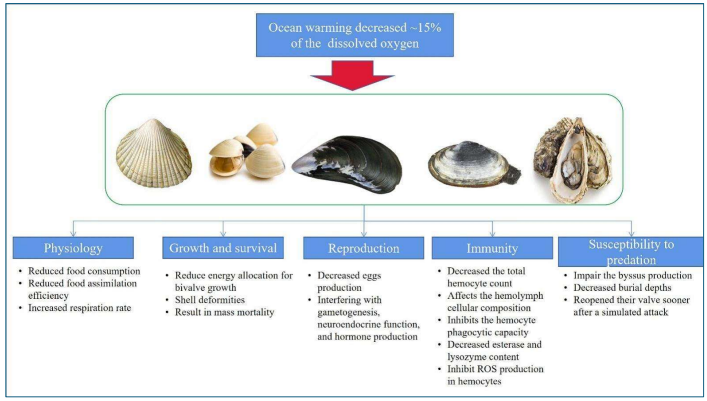
The initial investigation of the incident suggested rainfall has entered the bay through the Eight Mile Creek and caused a low salinity event in the adjacent ocean leading to the marine kill. You can read the details of the investigation on the link at the bottom of the slide.

https://natureglenelg.org.au/ocean-temperature-roller-coaster-and-its-local-legacy/

https://www.swellnet.com/news/swellnet-analysis/2024/01/11/cool-streaks-in-south-oz

But there was skepticism about this conclusion, for example, as noted on the commentary at these 2 sites. Personally, I wonder about a hypoxic event involving both this marine kill and the pipi issue, but perhaps there are audience opinions about this? And perhaps an associated harmful algal bloom with the Eight Mile Creek incident?

Bivalves and hypoxia



Song J, Farhadi A, Tan K, Lim L, Tan K. Impact of anthropogenic global hypoxia on the physiological response of bivalves. Science of the Total Environment. 2024 May 20;926:172056.

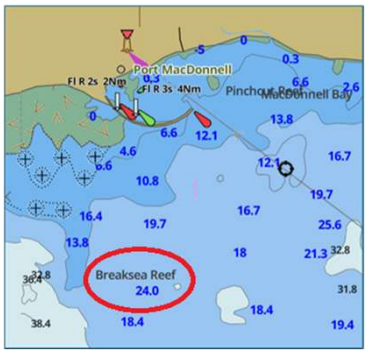
Mass Mortality of Asari Clams (Ruditapes philippinarum) Triggered by Wind-Induced Upwelling of Hypoxic Water Masses

As an aside, bivalves, such as pipis, have been found to be variably susceptible to hypoxia including through exposure to hypoxic upwelling

Fishing restrictions implemented after deadly abalone viral ganglioneuritis disease detected at Port MacDonnell

By Becc Bird | By Samuel O'Brien | By Josh Brine | ABC South East SA | Fishing and Aquaculture Industry

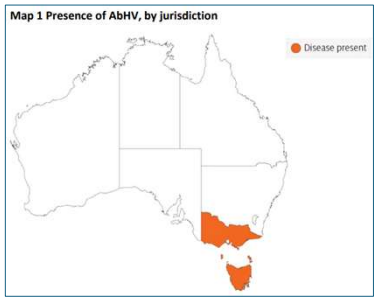
Mon 26 Feb 2024



- In February 2024, abalone viral ganglioneuritis was responsible for wild abalone kill on a reef 2.4 km offshore from Port Macdonnell
- New to South Australia, but present in western Victoria and Tasmania

A month later, there was an outbreak of abalone viral ganglioneuritis (or AVG) leading to a wild abalone kill on a reef 2.4 kms off Port Macdonnell. This was the first time this had been detected in South Australia but was known to be present in Victoria and Tasmania.

- Q: could this represent viral spread by particles and/or plankton in strong upwelling currents?
- Q: could this be analogous to the Pacific Oyster Mortality Syndrome (POMS) which is caused by herpes-like virus and spread by particles and plankton in ocean currents (and monitored in SA)?
- AVG is also caused by a herpes-like virus although abalone are gastropods (herbivores) rather than filterers
- https://media.bom.gov.au/social/blog/2619/ocean-modelling-combats-deadly-oyster-virus
- Whittington RJ, Hick P, Fuhrmann M, Liu O, Paul-Pont I. Removal of oyster pathogens from seawater. Environment International. 2020;410(25):106258.



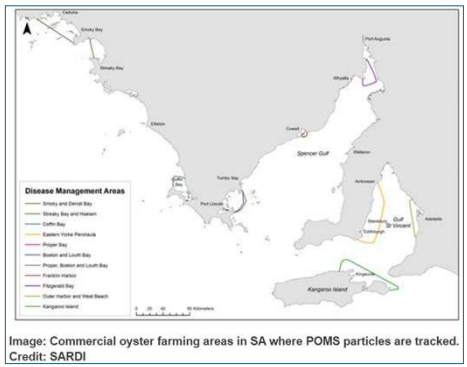
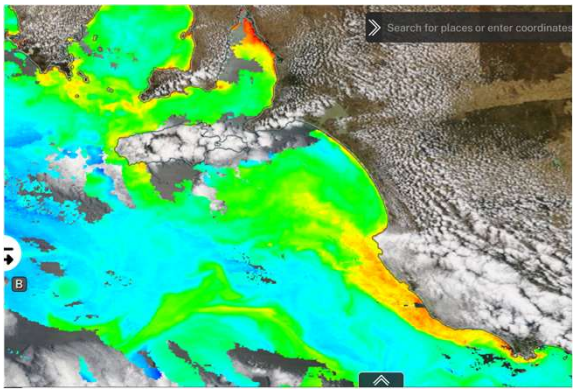


Image: Commercial oyster farming areas in SA where POMS particles are tracked.
Credit: SARDI

Which made me think -

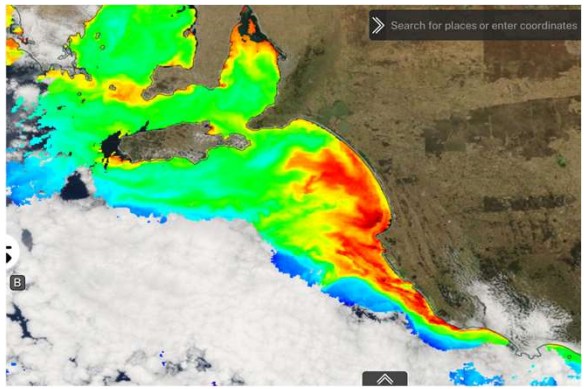
14 Dec 2023



14 Dec 2023

Turning back to the possible hypoxia I mentioned earlier: what could cause such hypoxia? While a change to the source water of the upwelling is possible, that is, a change to a deoxygenated state, extensive blooms, their decomposition and resultant hypoxia seems more likely. The 2023-2024 upwelling associated satellite imagery is very helpful and demonstrates a large amount of chlorophyll consistent with unspecified phytoplankton photosynthesis over a prolonged period over a very large area off the Bonney Coast, and other upwelling centres, and extending onto the Lacepede shelf and into Long Bay. Here's the situation in December 2023 shortly after the upwelling commenced showing blooming along the Bonney coast with a plume onto the shelf.

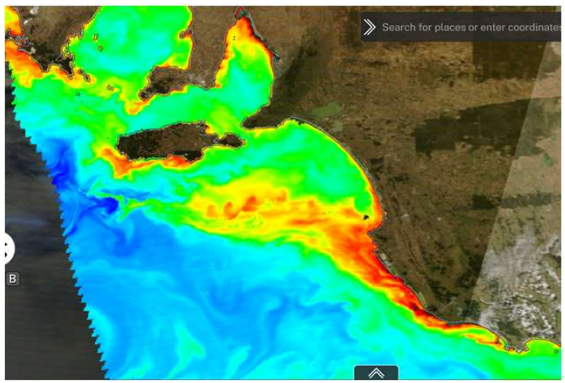
30 Dec 2023



30 Dec 2023

Later in December, it’s marked - and this continues into January where the blooms are evident on the True Color image on the left.

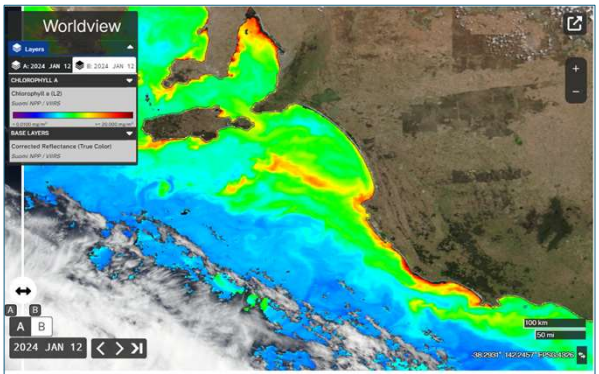
22 Jan 2024



22 Jan 2024

These blooms look almost white

True-color corrected reflectance image of a phytoplankton bloom in Long Bay, Australia, on January 12, 2024, acquired by the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) satellite. The true-color image is overlaid with Chlorophyll *a*, which provides the near-surface concentration of chlorophyll *a* in milligrams of chlorophyll pigment per cubic meter (mg/m^3) in the ocean.



True-color corrected reflectance image of a phytoplankton bloom in Long Bay, Australia, on January 12, 2024, acquired by the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) satellite. The true-color image is overlaid with Chlorophyll *a*, which provides the near-surface concentration of chlorophyll *a* in milligrams of chlorophyll pigment per cubic meter (mg/m^3) in the ocean.

This image is NASA Earth Observatory's Image of the Day for 15 January 2024

https://science.nasa.gov/earth/earth-observatory/filaments-of-phytoplankton-in-australia-152322/

These make NASA Earth Observatory's Image of the Day on 15 January 2024

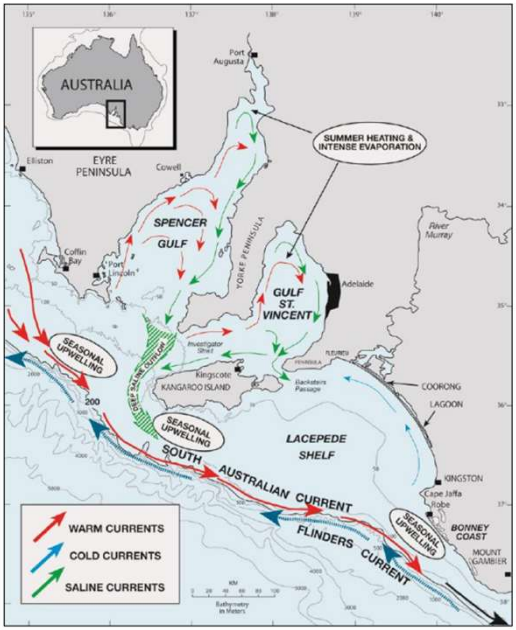


Figure 4.5: Oceanography of the Gulf regions and Lacepede Shelf (James and Bone 2011:151).

Photo by Kirsten Rough, marine scientist, Jan 2024, Lacepede Shelf

At this time, marine scientist, Kirsten Rough was in a plane over the area and captured this photo of the massive bloom on Lacepede shelf – possibly coccolithophore given the white/turquoise colour.

Todd Dickenson

- 6th generation scale fisher from the Southeast
- based at Boatswain Point
- extensive experience in SA waters
- great grandmother was a First Nations fisher
- knows this ocean “like the back of my hand”


Todd Dickenson says fish in the local waters are not acting in a way he recognises. (*ABC South East SA: Elsie Adams*)

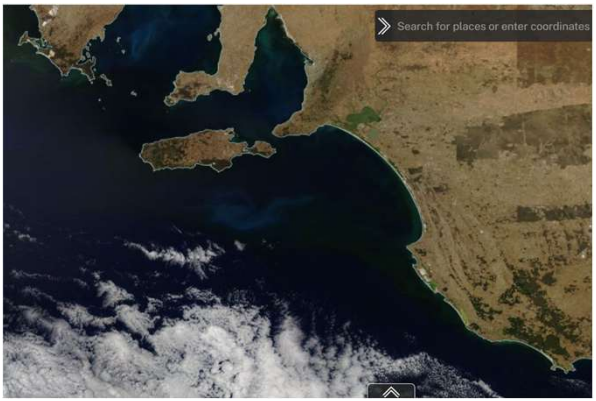
https://www.abc.net.au/news/2025-03-21/boatswain-point-water-quality-concerns-fisher-livelihood-at-risk/105077318

Also, at this time, Todd Dickenson, from Boatswain Point off the Bonney Coast, noted that the state of Long Bay starting in early 2024 was not as expected and he documented his experiences during the year. Todd is a very experienced 6th generation fisher; his great-grandmother was a First Nations fisher. He says he knows this area like the back of his hand.

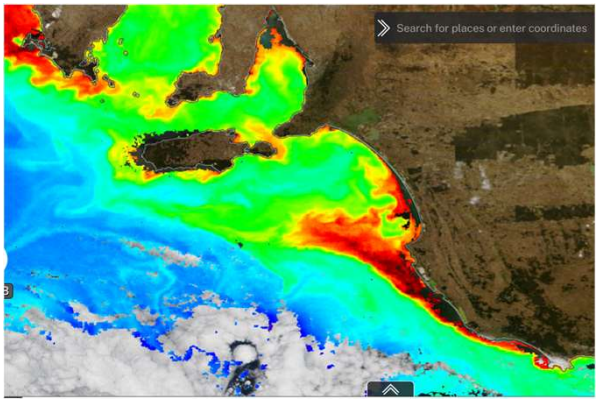
…. “need to recognize this timeline”

- noted an extended strong upwelling in 2024 lasting 8 months (Dec ‘23 to Aug ‘24)
- Summer 2023-2024: marine kill at Port MacDonnell (“very odd”)
- Jan 21, 2024: Robe – no fish catch, very unusual, unexplained
- Jan 23, 2024: discolored water, very cold water 11 deg C, no fish
- Late Jan 2024: Wright’s Bay: echosounder, fish taking shelter from dirty SE currents, no bites though
- Brown water, no bubbles, water looked “terrible”, SE winds howling
- Feb/March/April/May 2024: no fish caught. Fish hiding, weed everywhere. 11 degree water. Different fish species brought in by upwelling – some not seen before. Persisting upwelling

Todd’s strong point is that the timeline of events has not been understood or acknowledged but that’s its crucial. The 2023-2024 upwelling was intense and prolonged. This is what he recorded in a personal account of his time on the water in 2024 and into early 2025. He understood the January marine kill at Port MacDonnell to be very odd. In January, he noted fish were hiding from dirty SE ocean currents, not biting and the water was cold at 11 deg C. The SE winds were howling, the water looked terrible with no bubbles. In February and March, fish were hiding, weed everywhere, cold water, different fish not seen before.



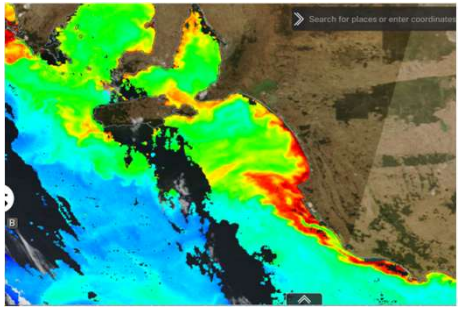
15 Feb 2024



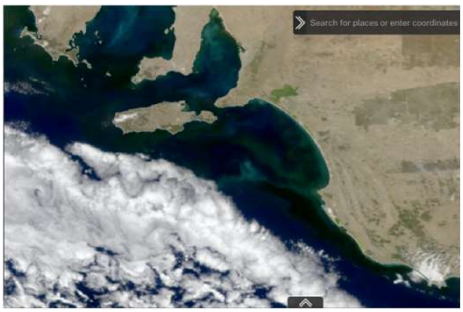
15 Feb 2024

In February through to June, there is plenty of photosynthesis underway extending onto the shelf and into Long Bay as well as at other upwelling sites.

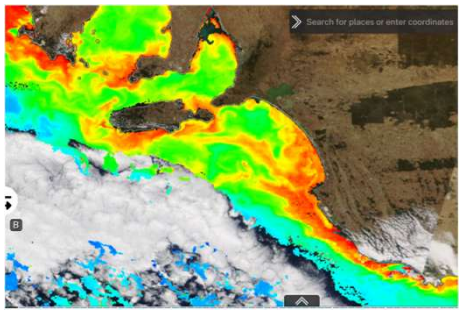
8 March 2024



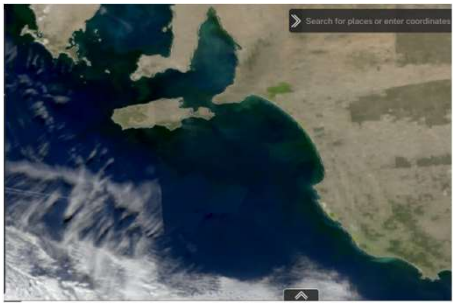
8 March 2024



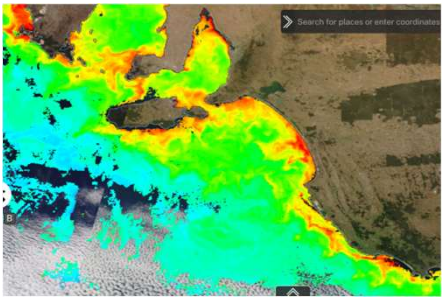
20 March 2024



20 March 2024

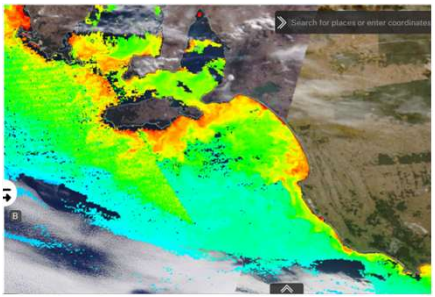


21 April 2024



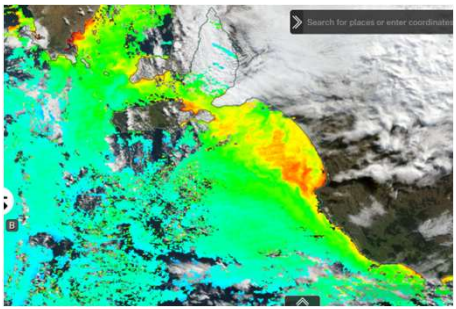
21 April 2024

15 May 2024



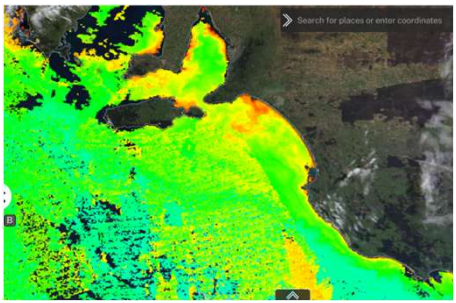
15 May 2024

14 June 2024



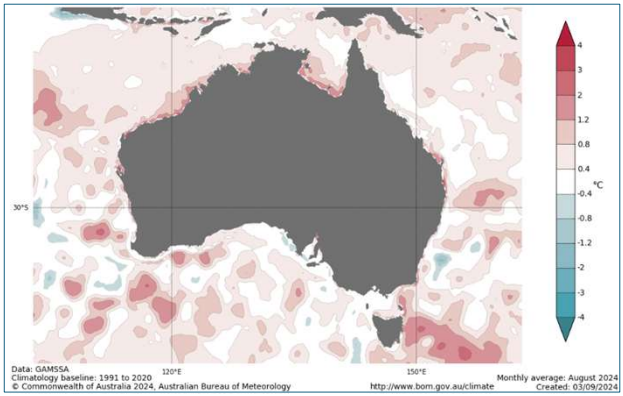
14 June 2024

29 July 2024



29 July 2024

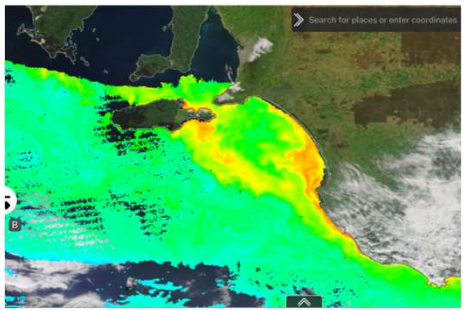
- July: strong tides
- August: upwelling stopped.
- September: Water temp increased to 14.8 deg C, water became clear; but no squid. Instead, countless crabs never seen before



August 2024

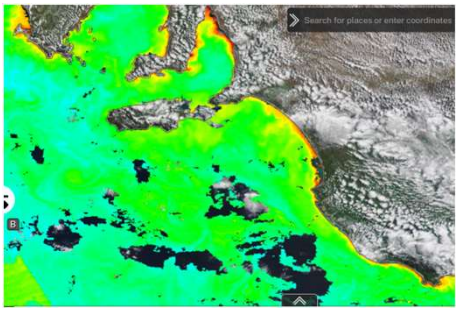
In July, strong tides were notes and in August, the upwelling had stopped and in September the water started to clear. No squid to be found but many crabs never seen before. Water temperatures normalized.

23 August 2024



23 August 2024

30 Sept 2024



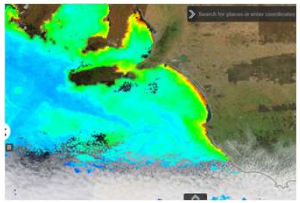
30 Sept 2024

Quiescent by September

- Oct/Nov/Dec 2024:
  - increasing water temp, water clearer.
  - Snapper reappeared. Scavenging sharks plentiful. But poor catches.
  - Beach undertow and tidal swell were very strong.
  - Large amount of dead weed washing up on beaches with foul odour.
  - Water temperature increased to 23 deg C.
  - Dead and stunned baby octopus on sea floor and washed up; also, leather jacket fish, deep sea fish, sea cucumbers washed up

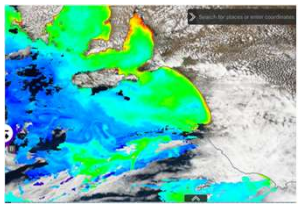
Over the last 3 months of the year, water temperatures increased to 23 degrees, the water was clearer but catches were poor. Dead washed-up fish and hypoxic appearing octopus. Large amount of foul smelling dead weed washes up.

28 Oct 2024



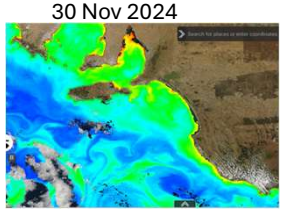
28 Oct 2024

30 Nov 2024



30 Nov 2024

17 Dec 2024

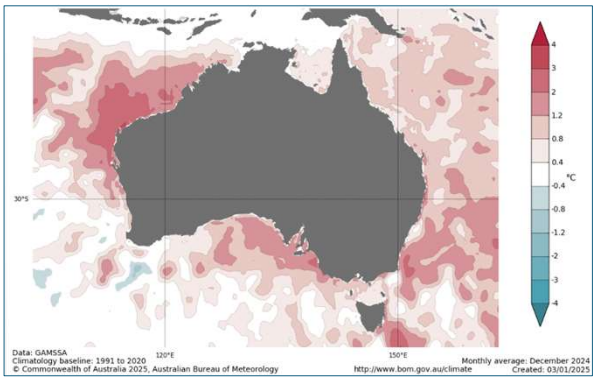


17 Dec 2024

Not much to see on the satellite images of Oct, Nov and Dec but the direct observations suggest that there were serious problems in these waters

- Dec 2024/Jan 2025: Boatswain Point beaches stinking with rotting seaweed. Fish acting strangely, hard to catch. [Sick and dead seals on beach; water discoloration (ABC report)]. Warm water temperatures.

A dead seal washed up on Long Beach, north of Robe. *(ABC South East SA: Elsie Adamo)*



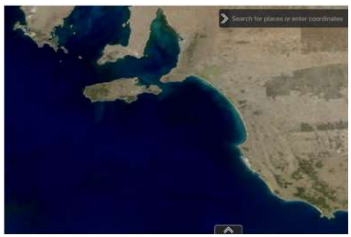
SST Anomaly December 2024

- Jan 2025: absent Goolwa pipis. Decaying mud cockles found. Skin irritation from contact with water.
- February/March 2025: poor catches.
- March 2025: Faith Coleman, Marine Ecologist:
  - shore-based phytoplankton testing at Boatswain Point, Cape Jaffa:
  - no live phytoplankton
  - remains of unarmoured dinoflagellates (not identifiable)
  - rotting weed

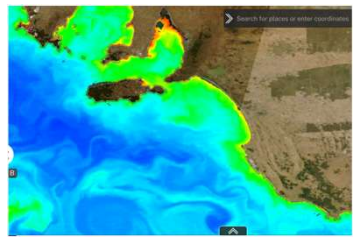
A summary of a possible interpretation of Todd's 2024-5 observations:

- unprecedented, intense, long duration cold water upwelling leading to
- very large upwelled, retained and recycled nutrient loads onto Long Bay on Lacepede shelf, with phytoplankton blooming
- subsequent decomposition of blooms
- resultant hypoxia in Lacepede shelf/Long Bay
- Cessation of upwelling/relaxation around mid-year with shift in water temperatures to an anomalously warm 23 deg C by late 2024
- later marine mortality and ecosystem shifts
- possible co-existing toxic algal bloom later in 2024 with mammal sickness and death

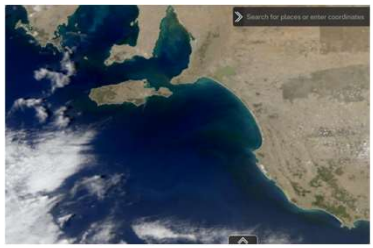
Timeline continued …. the lead-up



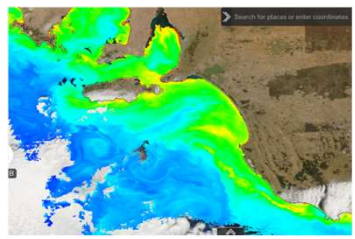
17 Jan 2025



17 Jan 2025



9 Feb 2025



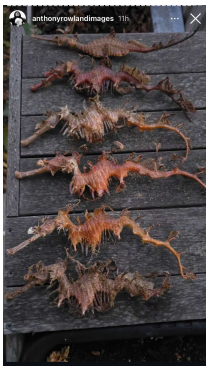
9 Feb 2025

Continuing the timeline …..the 2024-2025 upwelling season was delayed and weak. It doesn't seem to have really started until early February 2025. I don't have an upwelling index or cumulative wind stress to show but that would be interesting. Satellite imagery suggests that phytoplankton blooms related to the Bonney upwelling were very sparse on the Lacepede shelf during this 2024-2025 season in very dramatic contrast to 2023-2024. It is these extreme expressions of variance that are very concerning.

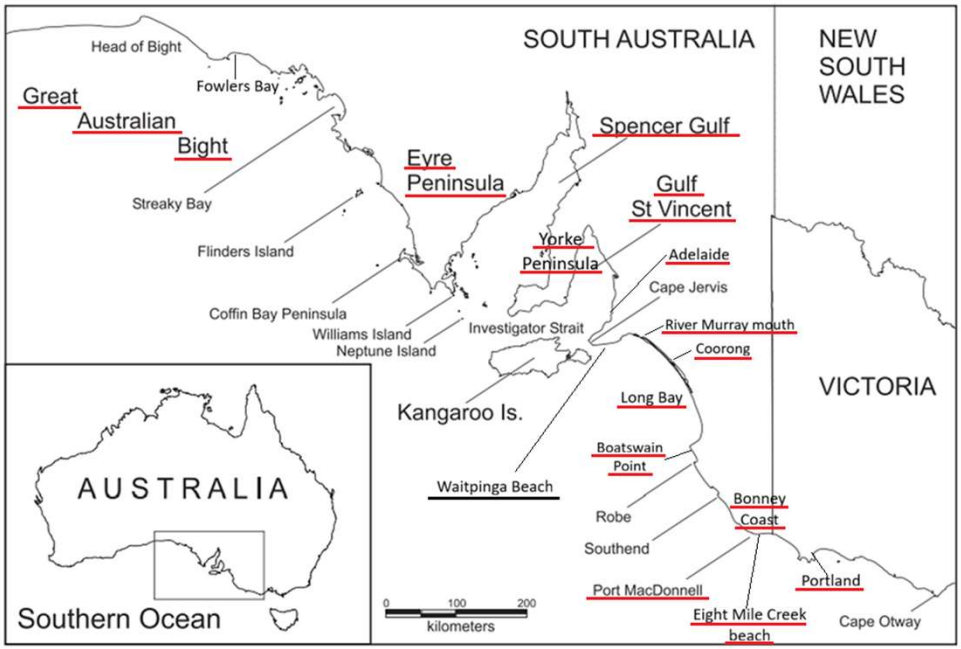
14-17 March 2025: the public becomes aware of the HAB

We now arrive at the time when the general public became aware of the harmful algal bloom that would go on to become an ecological catastrophe. Surfers at Waitpinga Beach, northwest of Long Bay and off the south coast of the Fleurieu Peninsula, noted extensive brown foam on the water, a marine kill and they experienced eye and skin irritation and coughing.

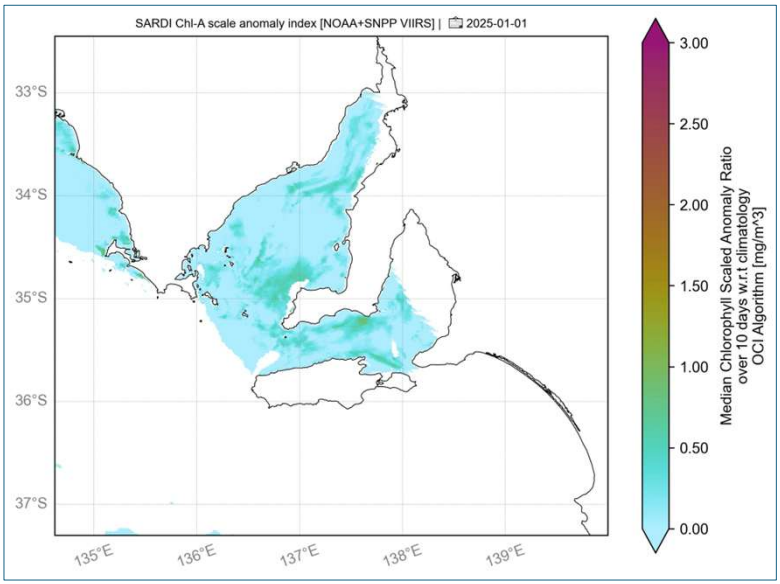
kangaroos: phalaris grass toxicity



Nearby kangaroos were noted to be staggering and ataxic but after investigations this was attributed to phalaris grass toxicity although low levels of sub-lethal brevetoxins were also detected in their systems. The marine kill included South Australia's iconic marine emblem, the Leafy Seadragon shown at bottom right.



From here, the spread of the bloom was rapid. It moved westwards towards Kangaroo Island and then into both Gulfs (Gulf St Vincent and Spencer Gulf) which are in effect, inverse estuaries, with limited exchange with the open ocean and hence sluggish flushing particularly in summer. The bloom also moved eastwards and entered the Murray River mouth and the northern lagoon of the Ramsar-listed Coorong.



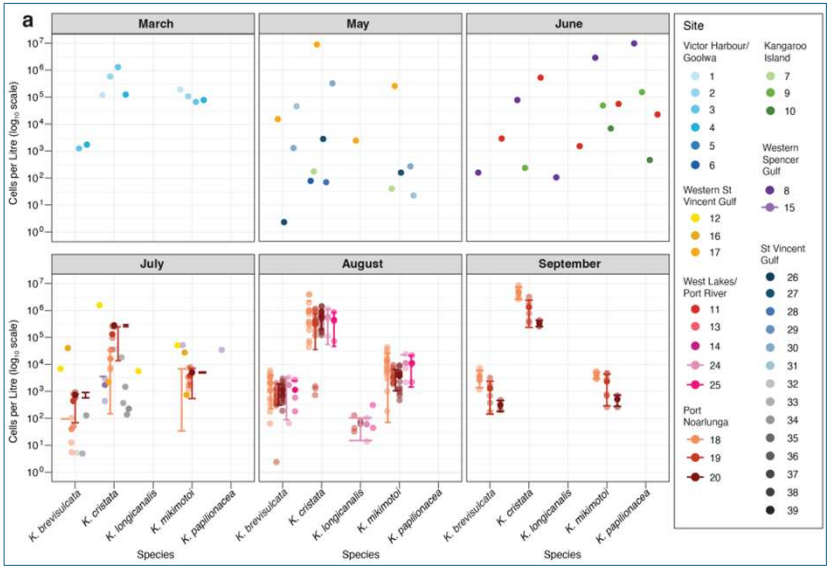
Chlorophyll anomaly ratio (Jan 2025-Dec 2025)

[Hugo Bastos de Oliveira, Oceanographer/Research Scientist (SARDI/PIRSA)]

Here are a few representative images of the devastation that was caused by this event and which continues. It has taken a toll at many different levels and scales.

- Ngarrindjeri elder Mark Koolmatrie has likened the devastation of South Australia's toxic algal bloom to watching Uluru being destroyed. **"It would be something like Uluru being destroyed right in front of our eyes, and we can do nothing about it.**
- "We have a responsibility to look after the things that belong to the south coast — now, when they are sick, so are we," he said.
- Mr Koolmatrie also urged the government to take stronger action and to work with the Indigenous community to find solutions to protect marine life.
- "Science and Indigenous values can work together side by side," he said.

https://www.abc.net.au/news/2025-08-13/sa-elder-describes-algal-bloom-devastation-akin-to-watching-ulur/105646282



Of Karenia species present, approximately 90% of samples contained a majority of K. cristata compared to other Karenia spp, at abundances of 10^3 - 10^6 cells L^{-1}. So thousand fold variation.

Cells L^{-1} (in log10 scale) is shown for samples collected at 35 distinct sites in March, May, June, July, August, and September 2025, for each of the detected species of:
K. brevisculcata,
K. cristata,
K. longicanalis,
K. mikimotoi,
K. papilionacea

Ref: Shauna A. Murray et al. A catastrophic marine mortality event caused by a complex algal bloom including the novel brevetoxin producer, Karenia cristata (Dinophyceae) bioRxiv 2025.10.31.685766 (preprint)

This HAB is caused by a karenia mix of 5 species, variably represented but dominated by the brevetoxin-producing karenia cristata in 90% of samples.

Biotoxins

https://www.iangibbins.com.au/science/citizen-science/south-australian-harmful-algal-bloom-2025/effects-of-the-toxins-on-humans/

Table 2
Classification of HAB clinical syndromes and associated toxins considered in the review (Adapted from Berdalet, 2015, Tubaro 2011).

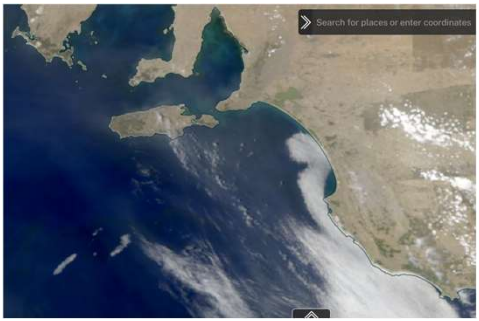
Clinical Syndrome	HAB toxin*	Notes
Amnesic Shellfish Poisoning (ASP)	Domoic acid	
Azaspiracid Shellfish Poisoning (AZP)	Azaspiracid	
Ciguatera Poisoning (CP)	Ciguatoxin	
Diarrhetic (Diarrheic) Shellfish Poisoning (DSP)	Okadaic acid (dinophysistoxins)	
Neurotoxic Shellfish Poisoning (NSP) and brevetoxin associated respiratory irritation	Brevetoxins	
Palytoxicosis	Palytoxin	Refers to seafood intoxication only
Effects of Palytoxin-like toxins or "*Ostreopsis* spp. algal syndrome"	Attributed to Palytoxin-analogues.	Respiratory and cutaneous irritation after postulated exposure to seawater and/or aerosol during *Ostreopsis* spp. blooms
Paralytic Shellfish Poisoning (PSP)	Saxitoxin	

* Including toxin-derivatives

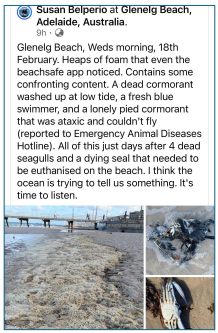
Young N, Sharpe RA, Barciela R, Nichols G, Davidson K, Berdalet E, Fleming LE. Marine harmful algal blooms and human health: A systematic scoping review. Harmful Algae. 2020 Sep 1;98:101901.

I won't go into the toxicology other than to note that Ian Gibbins has a good site listed at the top of the slide. Brevetoxins can cause respiratory irritation when aerosolized and can also get concentrated in shellfish and cause a neurotoxic shellfish poisoning when ingested. The causes of the marine mortality are varied and include direct brevetoxin toxicity, including that ingested in the food webs, but also hypoxia from bloom decomposition, starvation, and gill inflammation.

Video: Metropolitan Adelaide beach; October 2025
Aerosolized karenia HAB

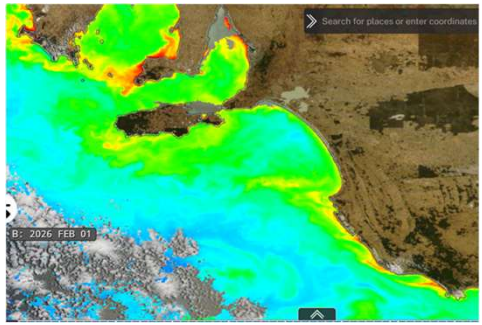


1 Feb 2026



Susan Belperio at **Glenelg Beach, Adelaide, Australia.**
9h ·

Glenelg Beach, Weds morning, 18th February. Heaps of foam that even the beachsafe app noticed. Contains some confronting content. A dead cormorant washed up at low tide, a fresh blue swimmer, and a lonely pied cormorant that was ataxic and couldn't fly (reported to Emergency Animal Diseases Hotline). All of this just days after 4 dead seagulls and a dying seal that needed to be euthanised on the beach. I think the ocean is trying to tell us something. It's time to listen.



1 Feb 2026

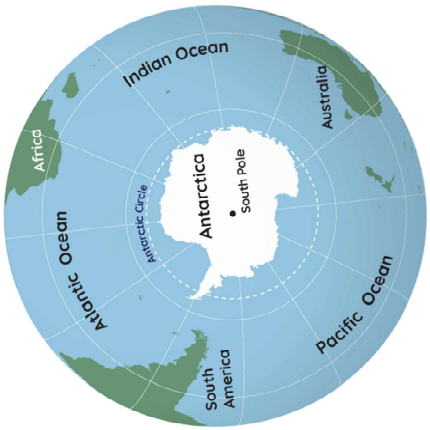
Currently, the bloom has moved into the eastern part of Spencer Gulf along the west coast of Yorke Peninsula where it is moving northwards.

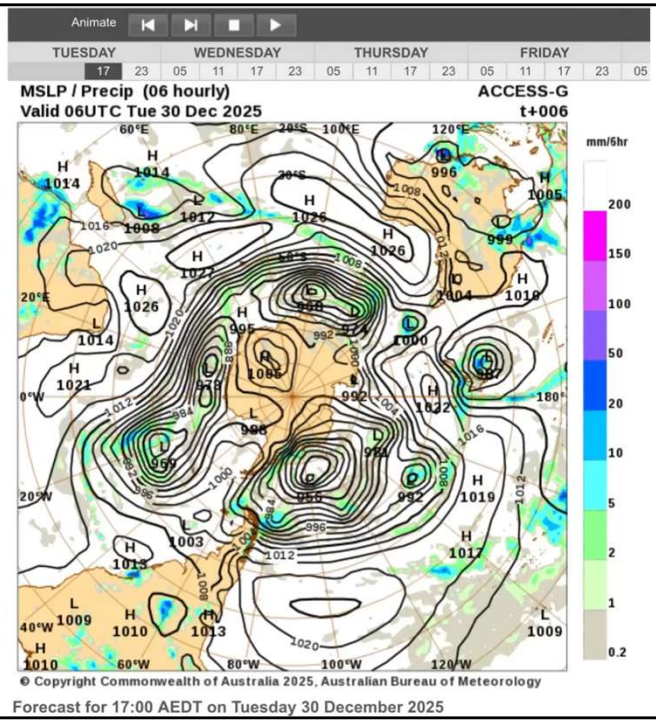
Comparison of the South Australian HABs with EBUSs HABs – any validity or value?

- Southern Benguela upwelling system. Similarities include:
  - Geography/climate, ecological and topographical
  - Upwelling mechanisms, drivers, climate correlates (e.g. SAM, subtropical highs)
    - Jury MR. Wind Vorticity and Upwelling along the Coast of South Africa. *Coasts*. 2024; 4(3):619-637
  - Climate change impacts
    - Hadley Cell expansion, SAM etc
    - Upwelling/winds > ecosystem regime shift
  - Upwelling bays, nutrient trapping/retention/recycling with susceptibility to:
    - Hypoxia
    - HABs (including karenia cristata) – increasing in the Benguela

Is there any validity or value in comparing the Benguela with the Southern Australian upwelling systems? At first glance, there are strong similarities as listed; and perhaps Benguela has already experienced some climate change impacts in advance of here such as ecosystem shifts, HABs and hypoxia?

cine movie
Dec 2025/Jan 2026





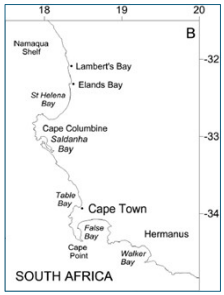
For example, you can see how these high pressure systems result in the upwelling favorable SE winds

Upwelling Bays: St Helena, Long Bay

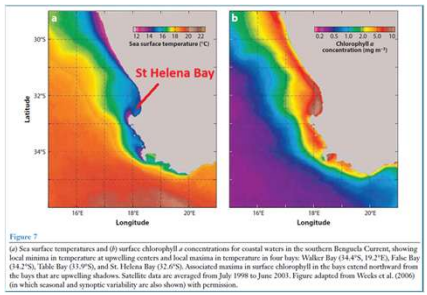
- The embayments of upwelling systems in particular create sites favorable for harmful algal bloom (HAB) initiation, development, and retention …. [and innoculation …. see Largier, 2020]

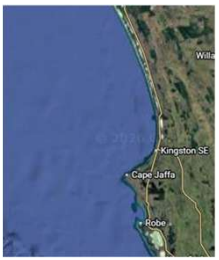
Pitcher, G.C., S. Bernard, and J. Ntuli. 2008. Contrasting bays and red tides in the southern Benguela upwelling system. *Oceanography* 21(3):82–91

Kämpf J. Phytoplankton and zooplankton production in the Bonney Coast upwelling, Australia: A coupled physical-biological model investigation. Continental Shelf Research. 2025 Feb 1;285:105373.



St Helena Bay





Long Bay

In terms of retentive upwelling bays, there appear to be strong similarities between St Helena Bay and Long Bay. Long Bay has been assessed as being consistent with such as a bay in a recent publication.

FIGURE 3. In the southern Benguela, episodic events of low oxygen following the decay of red tides have had major impacts on living marine resources within the region. In February and March 2015, St Helena Bay was once again subject to large marine mortalities, with a total of 415 tons of rock lobster (*Jasus lalandii*), 21 tons of molluscs (mostly the white mussel *Donax serra*), and seven tons of various fish species removed from the beaches (D. van Zyl, Department of Agriculture, Forestry and Fisheries, *pers. comm*., 2016). The causative dinoflagellate was identified as *Prorocentrum triestinum*. The events of 2015 provide the first records in the southern Benguela of mortalities of marine life linked to anoxia following the decay of *P. triestinum* blooms. *Photo credits: J. Foord, S. Sym, and G. Pitcher*

Hypoxic mortality event, 2015, St Helena Bay, Southern Benguela US

Pitcher GC, Louw DC. Harmful algal blooms of the Benguela eastern boundary Upwelling system. *Harmful Algae*. 2021;102:101898

Hypoxic mortality events are now seen at St Helena Bay

Southern Benguela: retention/recycling of upwelled nutrients with hypoxia

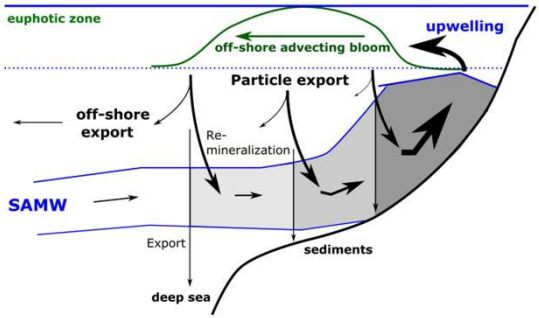


FIGURE 2 | Schematic illustration of nutrient trapping. The figure shows the supply of Sub-Antarctic Mode Water (SAMW), its upwelling at the coast, the development of an offshore advecting bloom due to the utilization of upwelled nutrients and the export of organically bound nutrients within sinking particles. The remineralization of organic matter within the onshore flowing SAMW increases the nutrient concentrations and lowers oxygen concentrations in the upwelling water and prevents the export of nutrients into the open ocean, the deep sea and sediments. The darkening gray areas indicate decreasing oxygen and increasing nutrient concentrations.

Hypoxia in the Southern Benguela upwelling system is also being evaluated by examining the impact of upwelling and nutrient trapping and recycling.

"The southern Benguela is a wind-driven, pulsed upwelling system .... dominated by primarily large celled diatoms (Hutchings et al., 2012) that thrive in the nutrient-rich turbulent environment of upwelling systems (Sathyendranath et al., 2014). Succession within the system generally follows known conceptual frameworks (Margalef, 1987) where diatoms dominate during turbulent upwelling phases, followed by a shift to dinoflagellate dominance during quiescent periods. A decrease in upwelling-favorable winds toward the end of austral summer (between January and May) are usually associated with more frequent dinoflagellate dominance in the near-shore waters of the southern Benguela during the latter stages of the upwelling season (Pitcher and Calder, 2000). HABs within the southern Benguela are largely attributable to dinoflagellates."

Smith ME, Bernard S. Satellite ocean color based harmful algal bloom indicators for aquaculture decision support in the Southern Benguela. Frontiers in Marine Science. 2020 Feb 14;7:61.

A typical phytoplankton succession cycle is noted in the Benguela where diatoms initially dominate turbulent upwelling phases followed by dinoflagellate domination in quiescent periods. The HABs are mainly due to dinoflagellates.

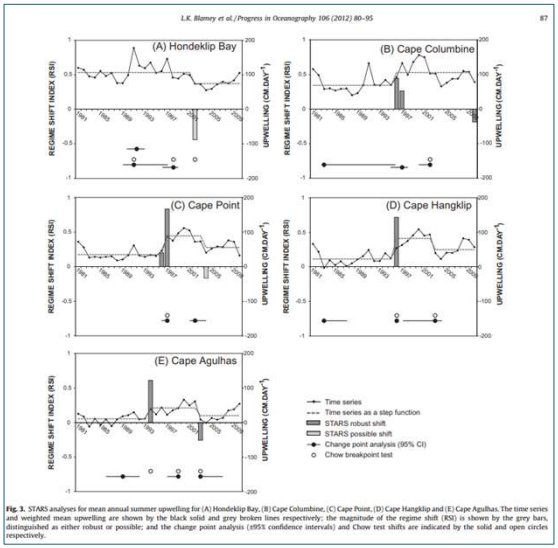


Fig. 3. STARS analyses for mean annual summer upwelling for (A) Hondeklip Bay, (B) Cape Columbine, (C) Cape Point, (D) Cape Hangklip and (E) Cape Agulhas. The time series and weighted mean upwelling are shown by the black solid and grey broken lines respectively; the magnitude of the regime shift (RSI) is shown by the grey bars, distinguished as either robust or possible; and the change point analysis (±95% confidence intervals) and Chow test shifts are indicated by the solid and open circles respectively.

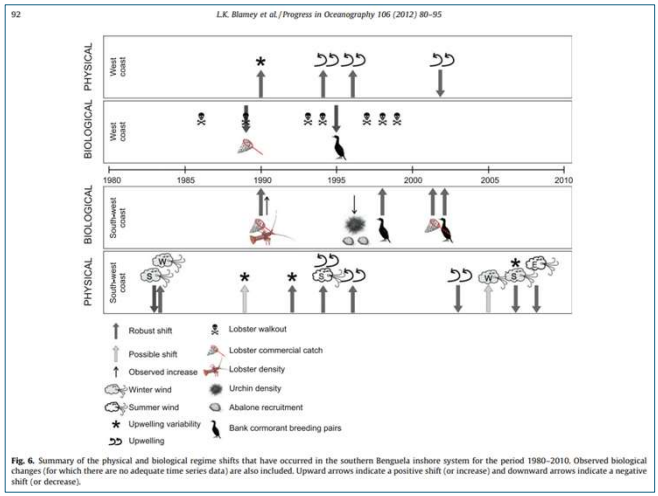


Fig. 6. Summary of the physical and biological regime shifts that have occurred in the southern Benguela inshore system for the period 1980–2010. Observed biological changes (for which there are no adequate time series data) are also included. Upward arrows indicate a positive shift (or increase) and downward arrows indicate a negative shift (or decrease).

Laura K. Blamey, James A.E. Howard, Jacobus Agenbag, Astrid Jarre, Regime-shifts in the southern Benguela shelf and inshore region, Progress in Oceanography, Volume 106, 2012, Pages 80-95

From 1980 to 2010, the effects of changing upwelling and wind patterns in the Southern Benguela were studied and a regime shift in the ecosystem was documented involving both physical and biological components.

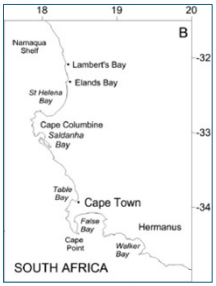
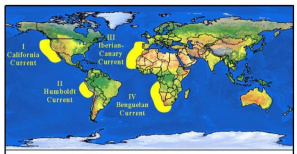


Table 1
Iconic HAB events in the Benguela Upwelling System attributed to known species of harmful algae.

YEAR	HAB	LOCALITY	IMPACT	HAEDAT Code and REFERENCE
1940	*Alexandrium catenella* (known at the time as *Gonyaulax catenella*)	Cape Town (Blouberg Beach)	First confirmed cases of PSP in several groups of people; included the death of a man having eaten toxic mussels	ZAF-40-001 Sapeika, 1948
1950	*Karlodinium veneficum* (described at the time as *Gymnodinium galatheanum*)	Walvis Bay	Large fish mortality	NAM-50-001 Brasrud, 1957
1950	*Alexandrium catenella* (known at the time as *Gonyaulax catenella*)	West coast of SA (Paternoster)	Several cases of PSP including the death of a man attributed to the consumption of toxic black mussels *Choromytilus meridionalis*	ZAF-50-001 Sapeika, 1950
1962	*Gonyaulax polygramma*	False Bay	Mortality of marine life attributed to anoxia; included 100 tons fish	ZAF-62-001 Grindley and Taylor, 1964
1966	*Protoceratium reticulatum* (described at the time as a new species *Gonyaulax grindleyi*)	West coast of SA	Mortality of hundreds of thousands of white mussels *Donax serra*	ZAF-66-001 Grindley and Nel, 1968
1967	*Alexandrium catenella* (known at the time as *Gonyaulax catenella*)	West coast of SA (Elands Bay to Olifants River)	Mortality of entire white mussel *Donax serra* population attributed to PST	ZAF-67-001 Horstman, 1981
1978	*Alexandrium catenella* (known at the time as *Gonyaulax catenella*)	West coast of SA	Seventeen cases of PSP in Cape Town; a further 13 cases outside of Cape Town; attributed to consumption of black mussels *Choromytilus meridionalis*; also large mussel and seabird mortalities	ZAF-78-002 Popkiss et al., 1979
1978	*Mesodinium rubrum*	St Helena Bay	Mortality of marine life attributed to anoxia; included hundreds of rock lobster, fish and thousands of sea urchins	ZAF-78-001 Horstman, 1981
1989	*Karenia cristata* (reported at the time as *Gymnodinium* sp.)	South-west coast of SA; Betty's Bay	Mortality of marine life including 40 tons of abalone	ZAF-89-001 Horstman et al., 1991
1991–92	*Dinophysis acuminata*	West and south coasts of SA	Widespread reports of human illness attributed to DSP following the consumption of mussels; first detection of DST (Okadaic Acid) in shellfish on SA coast	ZAF-91-001 ZAF-92-00 Pitcher et al., 1993
1994	*Prorocentrum micans* and *Tripos furca*	St Helena Bay	Mortality of marine life attributed to anoxia; included 1500 tons fish (mostly the mullet *Liza richardsoni*) and 60 tons of rock lobster *Jasus lalandii*	ZAF-94-001 Matthews and Pitcher, 1996
1995–96	*Karenia cristata* (reported at the time as *Gymnodinium* sp.)	False Bay and Walker Bay	Human respiratory problems and skin irritations attributed to production of an aerosol toxin	ZAF-95-001 Pitcher and Matthews, 1996
1997	*Alexandrium catenella*	West coast of SA	Twenty-two cases of PSP following the consumption of shellfish, including the death of 2 persons	ZAF-97-003 Muller et al., 1998
1997	*Tripos furca*	St Helena Bay (Elands Bay)	Mortality of marine life attributed to anoxia; included 2000 tons of rock lobster *Jasus lalandii*	ZAF-97-005 Cockcroft et al., 2001
1997–99	*Aureococcus anophagefferens*	Saldanha Bay, Langebaan Lagoon	Reduction in shellfish growth rates severely impacting oyster and mussel culture facilities through reduced sales	ZAF-97-001 ZAF-98-00 Probyn et al., 2001
1998	*Tripos lineatum* and *Tripos belechii*	St Helena Bay (Dwarskersboo)	Mortality of marine life attributed to anoxia and pH <7	ZAF-98-003 Pitcher and Probyn, 2012
1999	*Alexandrium catenella*	West coast of SA	First detection of PST in wild and farmed abalone *Haliotis midae*; major implications for abalone farms on west coast	ZAF-99-002 Pitcher et al., 2001
2000	*Alexandrium catenella*	Cape Town (Blouberg Beach)	Mortality of 100 tons of Otter Shells *Lutraria hiavia* attributed to PST	ZAF-00-001 Pitcher, 2000
2003	*Alexandrium minutum*	Cape Town harbour	First detection of PST in shellfish on SA coast attributed to *A. minutum*	ZAF-03-001 Pitcher et al., 2007
2005	*Protoceratium reticulatum*	Saldanha Bay	First impact of YTXs on aquaculture industry; 5 month closure of mussel harvesting	ZAF-05-001 Fawcett et al., 2007; Pitcher per. obs.
2011	*Gonyaulax spinifera*	Walvis Bay	First detection of YTXs attributed to *G. spinifera*; maximum shellfish toxins of 5.4 mg YTX eq kg^{-1}	NA-11-001 Chikwililwa, 2014
2014	*Lingulodinium polyedrum*	South and south-west coasts of SA	Extensive high biomass bloom; negatively impacting sardine catches in Algoa bay	ZAF-14-003 Van der Lingen et al., 2016
2015	*Prorocentrum triestinum*	St Helena Bay	Mortality of marine life attributed to anoxia; included 415 tons rock lobster *Jasus lalandii*, 21 tons molluscs, 7 tons fish	ZAF-15-001 Ndlovu et al., 2017
2017	*Gonyaulax spinifera* and *Lingulodinium polyedrum*	Walker Bay	Mortality of >250 tons of farmed abalone attributed to attributed to YTXs	ZAF-17-001 Pitcher et al., 2019



- *Lingulodinium polyedrum*
- *Pseudo-nitzschia* spp.
- *Ceratium furca*
- *Ceratium fusus*
- *Ceratium dens**
- *Ceratium lineatum*
- *Alexandrium catenella*
- *Gymnodinium catenatum*
- *Akashiwo sanguineum*
- *Protoceratium reticulatum*
- *Prorocentrum micans*
- *Prorocentrum rostratum*
- *Prorocentrum balticum*
- *Prorocentrum triestinum*
- *Prorocentrum minimum*
- *Gonyaulax polygramma*
- *Gyrodinium zeta*
- *Dinophysis acuta*
- *Dinophysis acuminata*
- *Dinophysis fortii*
- *Cochlodinium fulvescens*
- *Heterosigma akashiwo*
- *Scrippsiella trochoideum*
- *Karenia bicunaiformis*
- *Karenia cristata*
- *Karenia mikimotoi*
- *Karlodinium micrum*
- *Alexandrium minutum*
- *Noctiluca scintillans*

CCS I III Iberian-Canary
Humboldt II IV Benguela

And the Benguela upwelling system is the only other location where Karenia Cristata blooms have occurred.

Why this mix of karenia phytoplankton?

- The emergence of this HAB and its persistence indicate this karenia mix is the best at efficiently absorbing useful power for survival and reproduction. Advantages include:
  - Wide range of temperature tolerance
  - Some are mixotrophic
  - Swim up and down the water column accessing nutrients which may be limited by thermal stratification
  - Feed on dead weed in Long Bay
  - Toxins can kill marine life and provide nutrients
  - May suppress other organisms (allelopathic)
  - Low silicate in upwelled water favors dinoflagellates
  - Hypoxia may favor some karenia sp

Why are we seeing this particular mix of phytoplankton species in the South Australian bloom?

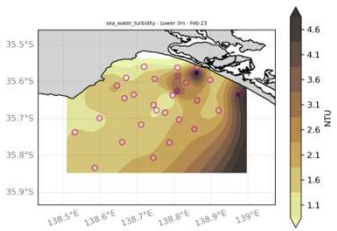
Other possible contributors:

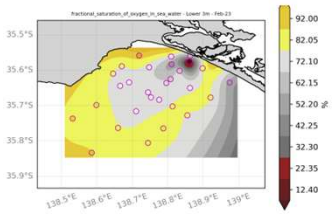
- Unclear contributions of:
  - The 2022-2023 Murray River floods,
  - Marine heat waves in late 2024, early 2025

Floods linked to climate change (positive SAM and repeated La Nina), with nutrient plume discharge north of Long Bay and associated non-karenia HAB

Murray River Flood: There was an associated HAB and confirmed hypoxic event

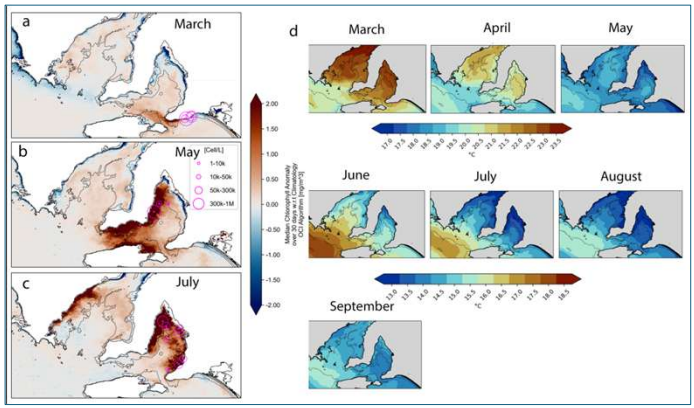
- pers. comm (2026):
  - Hugo Bastos de Oliveira (PIRSA/SARDI)
- HAB was mixed and non-karenia
- “Murray flood plume may have invoked changes within the bottom sediment resulting in changes to characteristics/communities of the ecosystems".





An important point here is that a nutrient load and bloom on the Lacepede shelf can result in hypoxia.

? Marine heat wave



- the associated thermal stratification may have favored the karenia species being dinoflagellates
- in terms of growth, the highest Karenia abundances coincided with lower temperature conditions in May and July

Shauna A. Murray et al. A catastrophic marine mortality event caused by a complex algal bloom including the novel brevetoxin producer, Karenia cristata (Dinophyceae) bioRxiv 2025.10.31.685766 (preprint)

In terms of the impact of the marine heatwaves, the associated thermal stratification may have favored the karenia species being dinoflagellates.
In terms of karenia growth ....

The other HAB (2024/5)

Cyanobacterial HAB (blue green algae): Cylindrospermopsis raciborskii (aka *Raphidiopsis raciborskii*

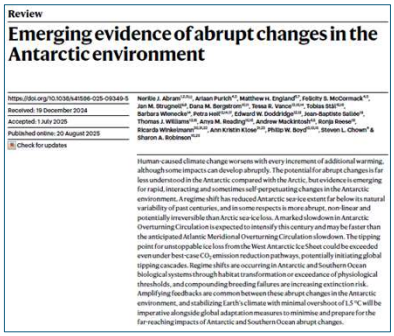
"This was new ground," Dr Cunliffe [principal water advisor, SA Health] said.
"This is the largest bloom of this organism we've seen in South Australia and certainly the largest bloom of this type in the lake."
Professor Saint said increasing numbers of clear winter days and hotter summer temperatures helped the algae to thrive. "We're unwittingly creating these conditions that favour these things," he said.

https://www.abc.net.au/news/2024-07-02/toxic-algae-bloom-still-problem-south-australia/104036958

Lastly, I should note that in 2024, there was another large scale HAB in the region – a freshwater cyanobacterial, or blue green algae bloom affecting the Lower Lakes region. This was "new ground" according the SA Health's principal water advisor – climate change seems responsible as well.

Wider implications of this HAB

- Commonalities with abrupt changes in Antarctica mediated via anthropogenic positive SAM trend:
  - Strengthening Westerly winds driving ….
  - More intense upwelling seen on both sides (poleward, equatorward) of Westerly wind belt
  - Poleward, in Antarctica, see:
    - upwelling of warm, saline Circumpolar Deep Water (CDW)
    - Massive sudden reduction in Antarctic Sea Ice extent
    - Glacier melting (Thwaites > WAIS)
  - Equatorward
    - greater wind stress curl/Ekman & Sverdrup transports
    - Stronger ocean currents, some upwelling favorable
    - Greater alongshore wind stress


Review

Emerging evidence of abrupt changes in the Antarctic environment

https://doi.org/10.1038/s41586-025-09349-5

Received: 19 December 2024

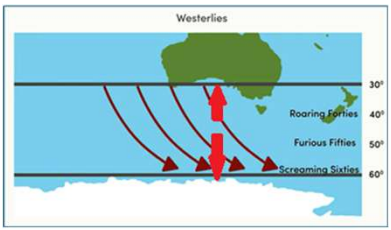
Accepted: 1 July 2025

Published online: 20 August 2025

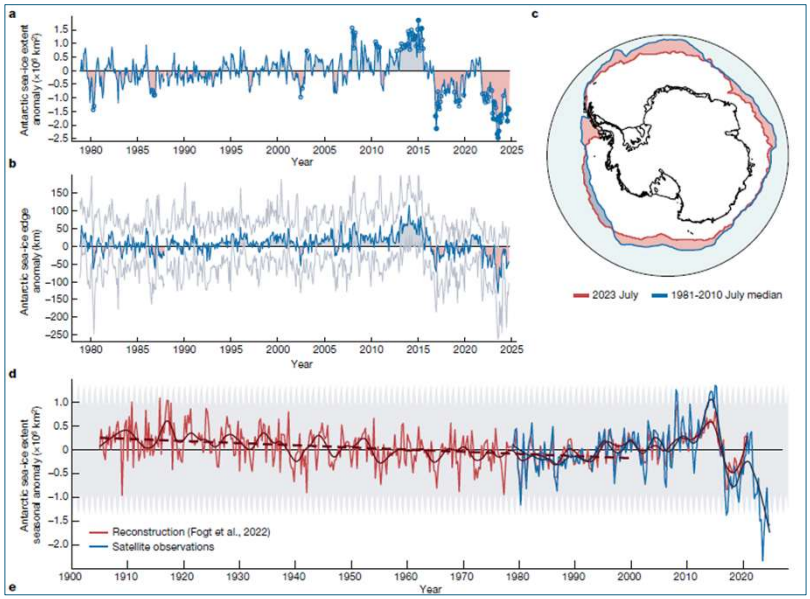
Check for updates

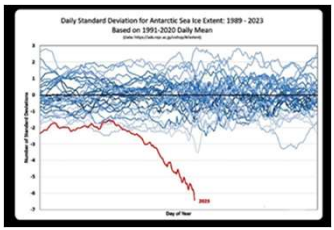
Human-caused climate change worsens with every increment of additional warming, although some impacts can develop abruptly. The potential for abrupt changes is far less understood in the Antarctic compared with the Arctic, but evidence is emerging for rapid, interacting and sometimes self-perpetuating changes in the Antarctic environment. A regime shift has reduced Antarctic sea ice extent far below its natural variability of past centuries, and in some respects is more abrupt, non-linear and potentially irreversible than Arctic sea ice loss. A marked slowdown in Antarctic Overturning Circulation is expected to intensify this century and may be faster than the anticipated Atlantic Meridional Overturning Circulation slowdown. The tipping point for unstoppable ice loss from the West Antarctic Ice Sheet could be exceeded even under best-case CO_2 emission reduction pathways, potentially initiating global tipping cascades. Regime shifts are occurring in Antarctic and Southern Ocean biological systems through habitat transformation or exceedance of physiological thresholds, and compounding breeding failures are increasing extinction risk. Amplifying feedbacks are common between these abrupt changes in the Antarctic environment, and stabilizing Earth's climate with minimal overshoot of 1.5 °C will be imperative alongside global adaptation measures to minimise and prepare for the far-reaching impacts of Antarctic and Southern Ocean abrupt changes.

Abram NJ, Purich A, England MH, McCormack FS, Strugnell JM, Bergstrom DM, Vance TR, Stål T, Wienecke B, Heil P, Doddridge EW. Emerging evidence of abrupt changes in the Antarctic environment. Nature. 2025 Aug 21;644(8077):621-33.



So turning back to my Takeaway Messages, how is this karenia algal bloom in South Australia related to wider and abrupt changes in the Southern Ocean and Antarctica – what is the link? This next section connects the dots looking at Antarctic Sea Ice and the Thwaites Glacier. The linkage is largely via the Southern Annular mode which is trending positive. As we have seen, this means stronger SO westerly winds and more intense upwelling seen poleward and equatorward of the Westerly wind belt. Polewards, we see increasing upwelling of warm, saline Circumpolar Deep Water which interacts with Antarctic Sea Ice and glaciers at grounding lines like Thwaites; and equatorward, we see stronger upwelling favorable currents. A positive SAM trend also correlates with greater upwelling favorable alongshore wind stress.

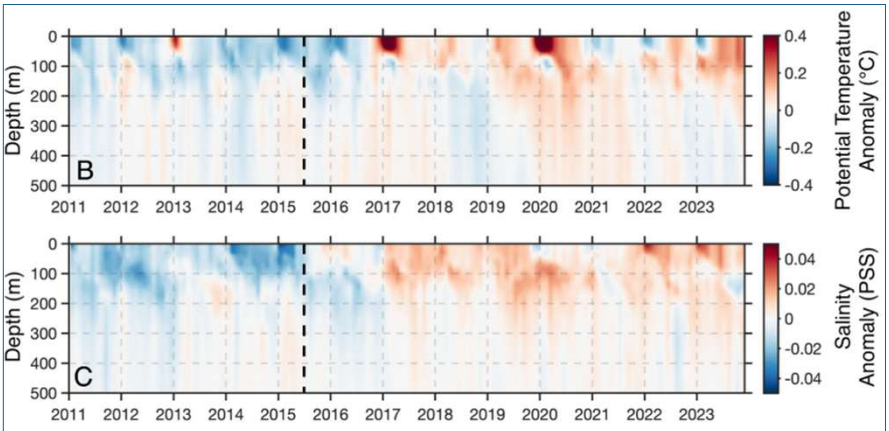




Abram NJ, Purich A, England MH, McCormack FS, Strugnell JM, Bergstrom DM, Vance TR, Stål T, Wienecke B, Heil P, Doddridge EW. Emerging evidence of abrupt changes in the Antarctic environment. Nature. 2025 Aug 21;644(8077):621-33.

The Antarctic Sea ice decline has been remarkable. The decline commenced around 2016, but in 2023 the decline was sudden, dramatic and shocked scientists.

Silvano A, Narayanan A, Catany R, Olmedo E, González-Gambau V, Turiel A, Sabia R, Mazloff MR, Spira T, Haumann FA, Naveira Garabato AC. Rising surface salinity and declining sea ice: A new Southern Ocean state revealed by satellites. Proceedings of the National Academy of Sciences. 2025 Jul 8;122(27):e2500440122.



(A) Mean vertical profile of potential temperature (°C, black) and potential density referenced to the surface (kg m^{-3}, red) from Argo float observations. Salinity follows the same structure as potential density. (B) Argo-derived potential temperature anomaly (°C) in the top 500 m of the water column. The vertical dashed black line marks winter 2015, when sea ice retreat began. (C) Same as (B), but for salinity. Argo-based observations are spatially averaged between 55°S and 65°S to capture the seasonally ice-covered Southern Ocean. Panel (A) also applies a time average over the 2011–2023 period. Monthly anomalies are calculated by removing the mean seasonal cycle.

In 2025, a very important paper was published documenting a marked increase in surface salinity and temperature across the circumpolar Southern Ocean since 2015 coinciding with start of the sea ice decline. This shift has weakened upper-ocean stratification, coinciding with the dramatic decline in Antarctic sea ice coverage.

Response to Silvano et al findings (2025)

https://www.sciencemediacentre.co.nz/2025/07/07/sea-ice-loss-linked-to-salty-southern-ocean-surface-expert-reaction

- **Melissa Bowen, Oceanography, University of Auckland, NZ**
  - These changes have global implications: the ocean around Antarctica is a hub for ocean circulation because the density of water is transformed here and it moves to different depths, taking heat and gases with it. These changes in the Southern Ocean, and our lack of understanding about why they are occurring, set off alarm bells about how well we can anticipate future climate
- **Wolfgang Rack, glaciologist, University of Canterbury, NZ**
  - this new study shows a significant increase in surface salinity, exactly starting at the time of sea ice loss. On the observed scale, this is best explained by the upwelling of warm and salty deep water. It prevents sea water from freezing and once frozen it can melt the ice more easily from below. It is the classic example of a positive feedback process.
- **Natalie Robinson, Marine Physicist, Victoria University of Wellington, NZ**
  - "We are moving into uncharted climate territory, and Antarctica is responding. What happens in Antarctica has implications for the entire globe. The Southern Ocean is a critical player in our global climate. Although it covers only 17% of the globe, it absorbs more than half of the additional heat, and ~2/5 of the excess carbon dioxide, that result from human activities
  - In order to secure a liveable future for ourselves and our children, it is imperative that we drastically reduce our reliance on fossil fuels.
- **Inga Smith, sea ice physicist, University of Otago, NZ**
  - extremely important short paper "Rising surface salinity and declining sea ice" contains shocking results
- **James Renwick, physical geography, Victoria University of Wellington, NZ**
  - The new paper provides more evidence of a major change in the way the southern oceans are working, following publications of changes in upper-ocean heat content and analyses of how the southern oceans respond to changes in overlying westerly winds. The research all suggests that climate change is really starting to be expressed throughout the southern oceans.. The implications are very worrying.

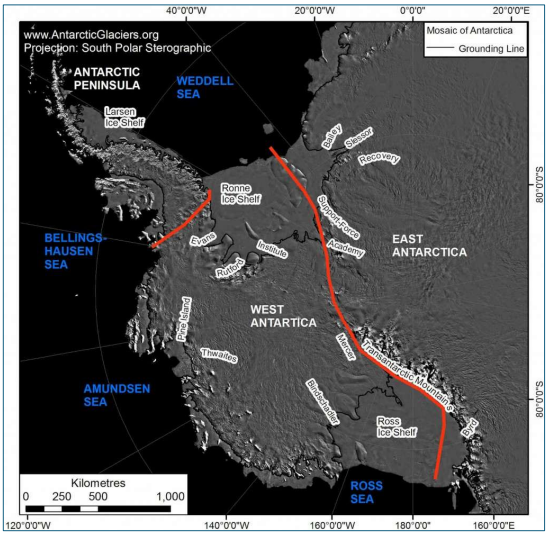
The response from scientists in NZ was one of shock and deep concern as these comments show ….

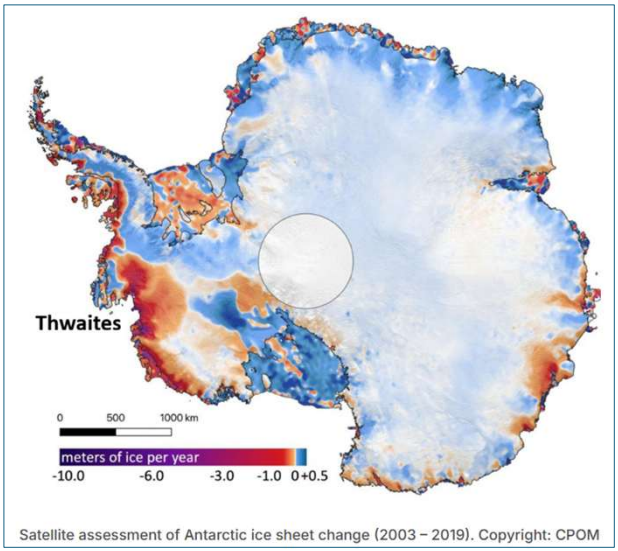
- "The subpolar Southern Ocean has experienced a long-term intensification of wind curl over both East and West Antarctica. Additionally, the westerlies have shown a sustained positive trend, reaching their highest magnitudes during the period from 2010 to 2023. The long-term trends in the winds indicate an intensification in the processes that induce upward transport of heat and salt from the subsurface ocean."
- "…. there is good reason to believe that upwelling-favourable conditions, driven by an enhanced [positive] SAM and intensified cyclonicity, are likely to persist under the influence of greenhouse gas emissions and the ozone hole. These conditions are expected to facilitate upward mixing of CDW heat into the upper ocean, reinforcing the present low sea ice state."

Preprint 10 Feb 2026:
Aditya Narayanan, Holly Ayres, Matthew H England, Alexander Haumann, Matthew R, Mazloff, Alessandro Silvano, Theo Spira, Shenjie Zhou, Alberto C. Naveira Garabato
Compound Drivers of Antarctic Sea Ice Loss https://doi.org/10.31223/X51V0B

And a recent pre-print release states there is good reason to believe that the positive SAM trend under greenhouse gas forcing will drive more warm saline CDW upwelling into the upper ocean where it will reinforce the current low sea ice state.

Thwaites Glacier/West Antarctic Ice Sheet

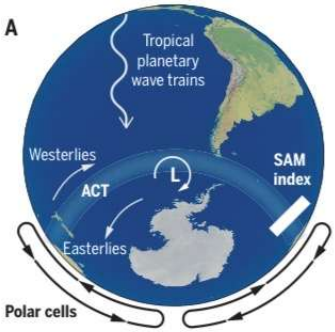




Satellite assessment of Antarctic ice sheet change (2003 – 2019). Copyright: CPOM

https://www.antarcticglaciers.org/glaciers-and-climate/southern-annular-mode/

The Thwaites “Doomsday” Glacier is the most consequential on the planet. It’s melting fast and is a keystone glacier holding back the WAIS. It also has vulnerable siting. If Thwaites melts or collapses, it adds 65 cm of SLR, and a complete associated WAIS melt equates to 3m SLR.



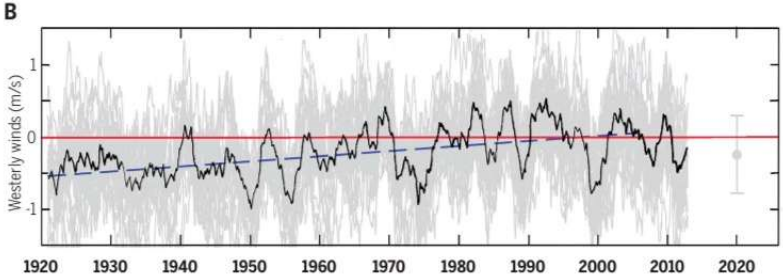
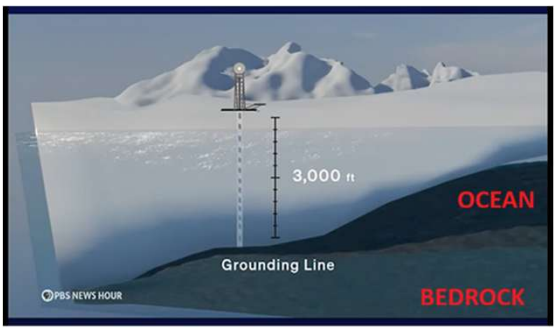


Fig. 4. Atmospheric context wind variability. (**A**) The approximately east-west oriented Antarctic Circumpolar Trough (ACT) supports a band of westerly winds to the north of the trough, and easterlies to the south. Coriolis force causes the westerlies and easterlies to drive the upper ocean waters to the north and south, respectively, creating a divergence of surface waters all along the ACT. This creates an upwelling of the subsurface CDW, which can cause it to rise above the depth of the continental shelf break in places and allow the possibility of it crossing onto the shelf and interacting with the AIS. Whether or not the CDW gets onto the continental shelf is determined by processes sketched in Fig. 2, A and B. (**B**) A time series of westerly winds in the Amundsen Sea adjacent to Thwaites Glacier (*36*). Positive values indicating westerly winds favor a greater transport of warm CDW into the cavity below Thwaites Ice Shelf, thereby increasing melting and consequently grounding-zone retreat. Negative values indicating easterly winds represent the opposite behavior. The winds were created using a global climate model that simulates large, natural, decadal variability in the climate system, principally originating in the tropics. Superimposed on this variability is a centennial-scale trend in positive wind values that is likely being forced by anthropogenic sources. The study suggests that this upward trend will lead to an increase in warm waters at Thwaites Ice Shelf, and hence increased melting and retreat.

David M. Holland et al. ,The Southern Ocean and its interaction with the Antarctic Ice Sheet.Science367,1326-1330(2020)

Again, there's a link with the Positive SAM trend. The stronger Westerly winds move polewards and warm CDW upwelling and transport into the cavity below Thwaites is favored.

Thwaites Glacier drilling: bore hole reached ocean at 4pm, Jan 30, 2026



https://milesobrien.substack.com/

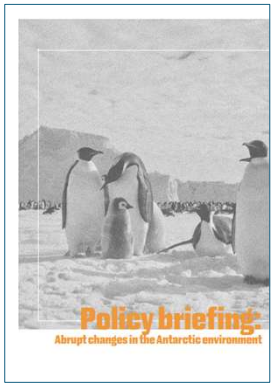
In January 2026, hot water drilling was performed at the level of the Thwaites Glacier grounding line in order to assess the ocean water in this location. On 30 January, the ocean was accessed at a depth of 900m.

Recent 2026 Thwaites Glacier drilling results summary: (Ref: https://milesobrien.substack.com)

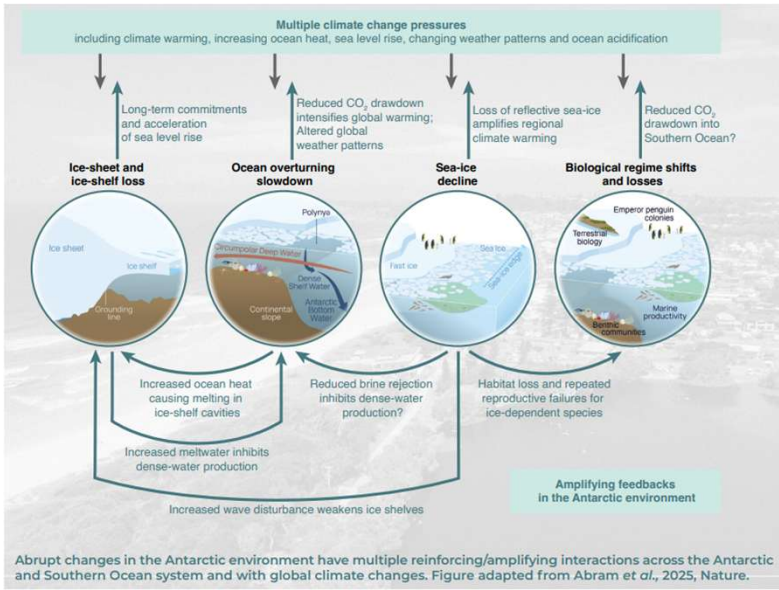
- The water temperature is 33.98°F, 5.58°F warmer than the freezing point of glacier ice in seawater (28.4°F) That represents 3.1 degrees Celsius of thermal driving force
- the water at the grounding line is turbulent due to prominent subglacial water discharge causing churn and dramatically enhancing energy transfer and melting (Jamin Greenbaum: https://www.thepocketlab.com/video/antarctica-virtual-field-trip-2026)
- 50% of the problem is glacial melting; the other 50% is the less understood glacier fracturing, cliff collapse. It's a chaotic environment, with the glacier advancing 10 m a day into the ocean, and accelerating (https://milesobrien.substack.com)

The summary of the drilling results is shocking – the thermal driving force is 3.1 degrees C and the water at the grounding line is turbulent due to subglacial water discharge which is very buoyant. This dramatically increases energy transfer and melting. These figures are fixed and non-negotiable and procrastination is not an option.

Antarctic Abrupt Change: summary



AAPP September 2025
https://antarctic.org.au/wp-content/uploads/2025/08/ACAE-Briefing-DIGITAL.pdf
This briefing is based on the following publication:
Abram, N.J., Purich, A., England, M.H., McCormack, F.S., Strugnell, J.M., Bergstrom, D.M., Vance, T.R., Stål, T., Wienecke, B., Heil, P., Doddridge, E.W., Sallée, J.-B., Williams, T.J., Reading, A.M., Mackintosh, A., Reese, R., Winkelmann, R., Klose, A.K., Boyd, P.W., Chown, S.L. and Robinson, S.A. (2025). Emerging evidence of abrupt changes in the Antarctic environment.
Nature, https://doi.org/10.1038/s41586-025-09349-5.

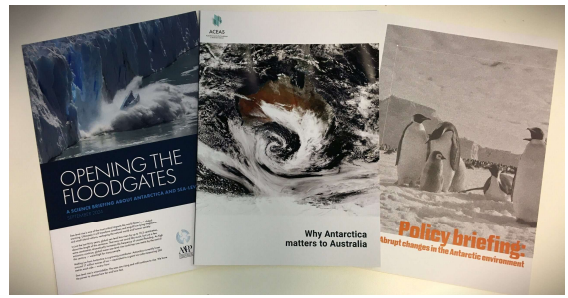


Abrupt changes in the Antarctic environment have multiple reinforcing/amplifying interactions across the Antarctic and Southern Ocean system and with global climate changes. Figure adapted from Abram *et al.*, 2025, Nature.

This dire and urgent Antarctic situation led to public awareness campaigns and briefings in the latter half of 2025.

Reactions to the Antarctic/SO abrupt changes

- Nerilie Abrams; https://theconversation.com/from-sea-ice-to-ocean-currents-antarctica-is-now-undergoing-abrupt-changes-and-well-all-feel-them-262615
  - The stakes could not be higher.
  - Antarctica is often seen as a symbol of isolation and permanence. But the continent is now changing with disturbing speed – much faster than scientists anticipated
  - The only way to avoid further abrupt changes is to slash emissions rapidly....
- Kubiszewski I, Costanza R, Fulton EA, King MA, Leane E, Stoeckl N. Protect Antarctica—or risk accelerating planetary meltdown. Nature. 2025 Aug 21;644(8077):605-7
  - Preventing irreversible change in the Antarctic and Southern Ocean requires urgent, system-wide transformation .... as well as the rapid reduction of global emissions to curb climate change
- Australian Antarctic Program Partnership (Sept 2025)
  - drastic greenhouse gas emission reductions is the only certain way to reduce the risk of triggering multiple abrupt changes and passing tipping points



https://aappartnership.org.au/antarctic-research-shared-with-australian-politicians-and-policymakers/

AAPP leader Professor Delphine Lannuzel said it is vital to keep Antarctica and the Southern Ocean in the forefront when making decisions about climate policy.
"Often regarded as the 'bottom of the world', our research demonstrates that Antarctica and the Southern Ocean are in fact central to the Earth's climate system, while at the same time acutely vulnerable to global heating", she said.

The leader of the Australian Antarctic Program Partnership noted: ....
Nerilie Abrams and others noted the stakes could not be higher, that changes were occurring with disturbing speed and much faster than scientists anticipated, and that drastic urgent reduction in GHG emissions was essential .....
There was absolutely no wriggle room in this commentary.

Wide Boundary/Big Picture perspectives: The Bottom Line

- Partner with Gaia (if Gaia is willing) to (re)build and promote Holocene Basin stability in a simple, prosocial, bioregional context
- Immediate, drastic reduction in fossil fuel use
  - Hothouse #1: W. Steffen, J. Rockström, K. Richardson, T.M. Lenton, C. Folke, D. Liverman, C.P. Summerhayes, A.D. Barnosky, S.E. Cornell, M. Crucifix, J.F. Donges, I. Fetzer, S.J. Lade, M. Scheffer, R. Winkelmann, & H.J. Schellnhuber, Trajectories of the Earth System in the Anthropocene, Proc. Natl. Acad. Sci. U.S.A. 115 (33) 8252-8259, https://doi.org/10.1073/pnas.1810141115 (2018).
  - Hothouse #2: William J. Ripple, Christopher Wolf, Johan Rockström, Katherine Richardson, Nico Wunderling, Jillian W. Gregg, Thomas Westerhold, Hans Joachim Schellnhuber, The risk of a hothouse Earth trajectory, One Earth, 2026,101565
- Too much of a good thing is pervasive and ubiquitous - the “Inverted U” Curve. Driven by the Maximum Power Principle.
- First Nations/Indigenous knowledge, wisdom, governance

Which brings us to the last section and one where we examine through our widest angle lens. So what to do? The first essential is the need to ….

What do we mean by Gaia?

- James Lovelock/Lynn Margulis (1970s)
- Earth/"Gaia" is a ***dissipative structure*** – "far from equilibrium" structure dissipating energy to self-organize order (negentropy) from chaos and generating low quality heat (entropy) in the process
- The earth's ecosphere forms a living self-organizing, self-regulating, complex system with emergent properties

James Lovelock with Lynn Margulis in 1983 at Lovelock's home at the time (next to a statue of Gaia). *(Supplied: Betsey Dexter Dyer)*

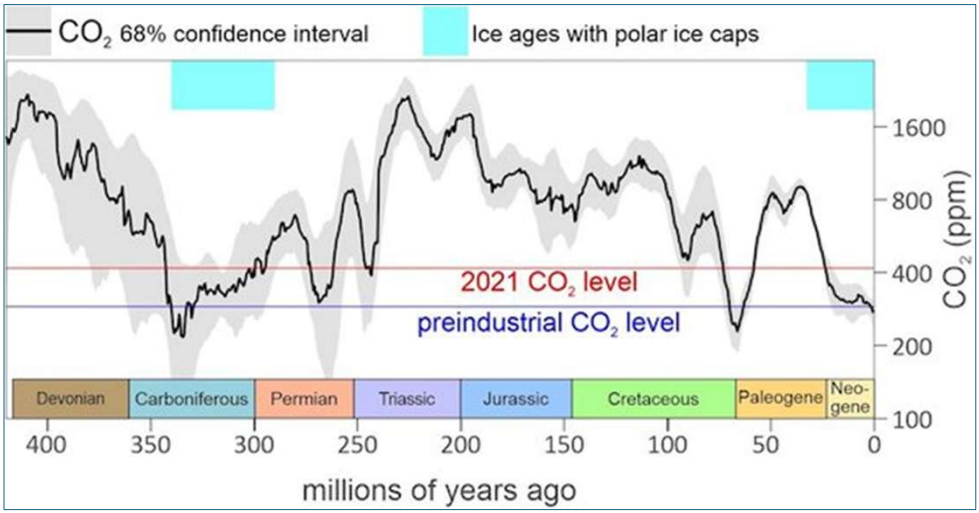
https://www.abc.net.au/news/science/2022-08-06/james-lovelock-legacy-gaia-climate-science-lynn-margulis/101297574

Gaia is a really powerful and resonating concept from James Lovelock and Lynn Margulis in the 1970's. So is the concept of all-encompassing dissipative structures and I recommend Bill Rees' writings for a good overview. The idea that Planet Earth forms a living self-organizing, self-regulating system with emergent properties using real-time solar energy flux is a remarkable thing.

Homeostasis/Allostasis

- Self-regulation can involve homeostatic mechanisms in a retrospective attempt to keep a stable internal environment within tolerable limits e.g. temperature, pH
- It can also include allostasis that is a more generalized adaptation in response to environmental change and involves a change in state ("stability through change") – this can involve changing the set points of homeostasis ahead of the change.
- Both mechanisms can generate wear-and-tear and have consequences, so-called "loads"

Self-regulation can involve homeostatic mechanisms ....



Earth is about 4.3 billion years old and things haven't always been as they are now - as shown on this graph of the past 400 million years, there was a lot of variation. BTW dinoflagellates are about 500 million years old and have seen a lot. And cyanobacteria are about 3.5 billion old evolving to oxygenic photosynthesis 2.4 billion years ago leading to the disruptive Great Oxidation Event.

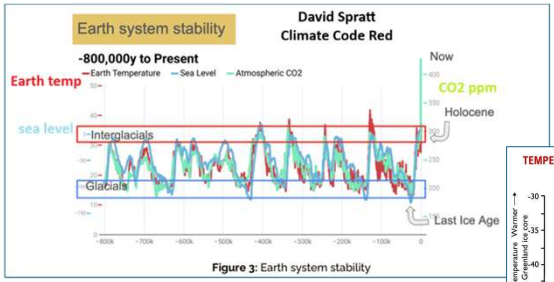
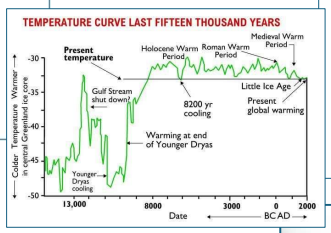
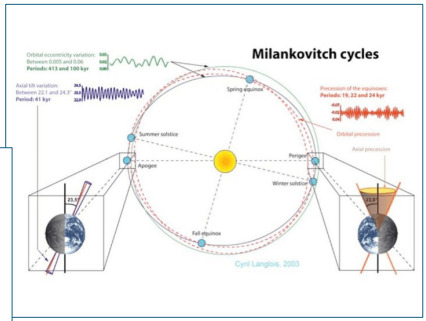
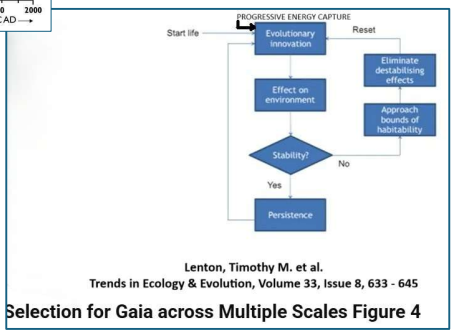


Figure 3: Earth system stability





https://theconversation.com/scientists-finally-have-an-explanation-for-the-gaia-puzzle-99153



Lenton, Timothy M. et al.
Trends in Ecology & Evolution, Volume 33, Issue 8, 633 - 645

Selection for Gaia across Multiple Scales Figure 4

And the last few million years or so have been increasingly stable as Gaia has "evolved through persistence" (see bottom right diagram) a toolkit of sophisticated
coupled physical and biogeochemical responses to perturbations, including the Milankovitch cycles which triggered the interglacial/glacial periods. The Holocene period over the past 10000 years has been a truly remarkable period of stability. But these have evolved in response to very slowly changing environmental conditions, in marked contrast with the GHG emissions spike over the past 200 years. We can expect Gaia's homeostatic and allostatic responses to this GHG spike to be both insufficient but also associated with partial masking of the true underlying severity of the crises and also "unintended" consequences or "paybacks".

Homeostatic/Allostatic loads

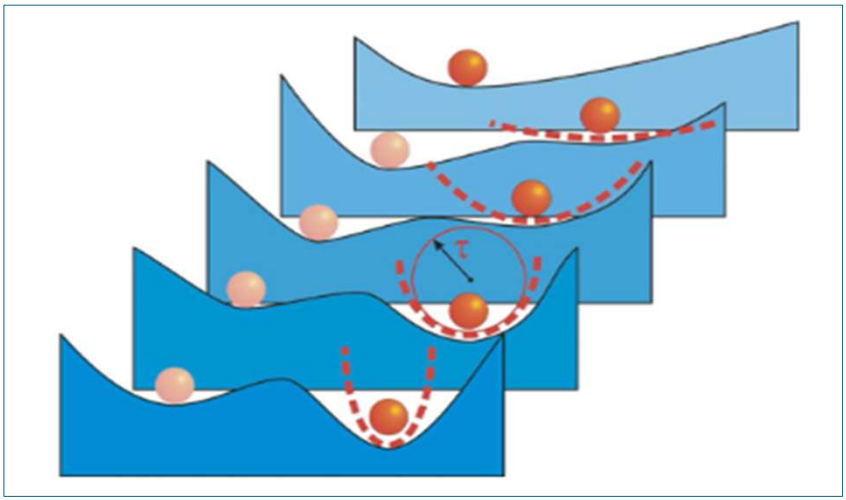
“A new world order

At no time in Earth’s history, giant meteorites and super-volcanos aside, has our climate system been jolted by changes in atmospheric gas composition like what we are imposing today by our unabated burning of fossil fuels.

The oceans are the flywheel of Earth’s climate, slowing the pace of change by absorbing heat and carbon in vast quantities. But there is payback, with sea level rise, ice melt, and a significant slowdown of the Atlantic overturning circulation projected for this century.”

Matthew England: https://theconversation.com/a-huge-atlantic-ocean-current-is-slowing-down-if-it-collapses-la-nina-could-become-the-norm-for-australia-184254

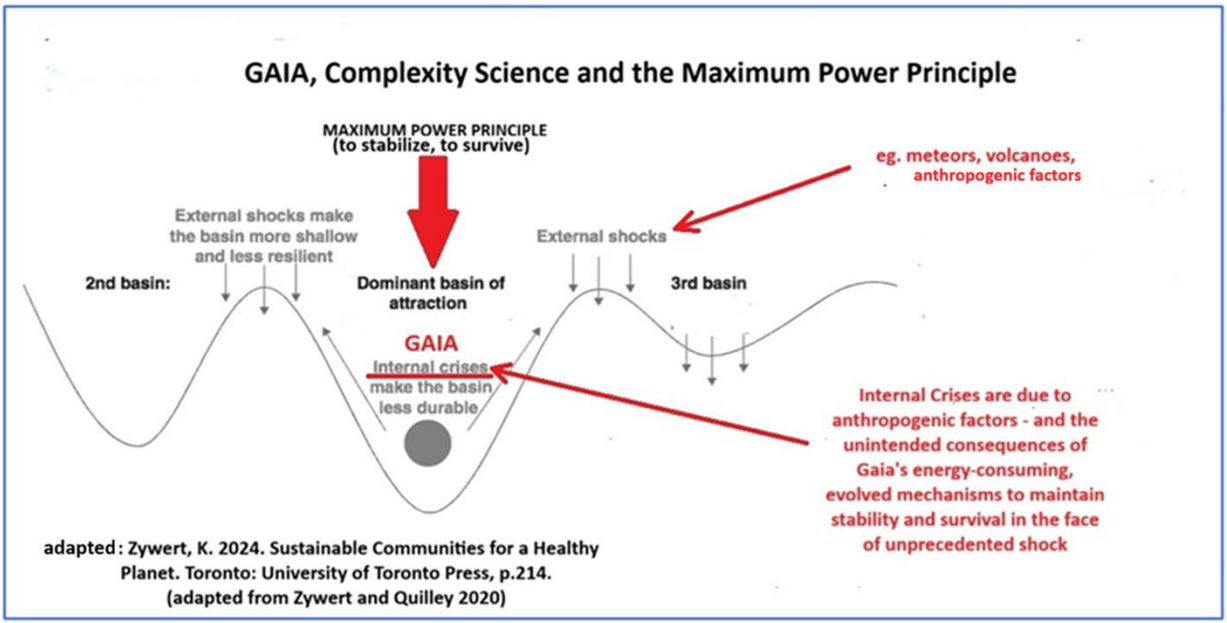
This concepts of paybacks was observed by Matthew England, UNSW, who observed ….. I think this is a really important concept.



The potential wells represent stable attractors, and the ball, the state of the system. Under gradual anthropogenic forcing (progressing from dark to light blue potential), the right potential well becomes shallower and finally vanishes (threshold), causing the ball to abruptly roll to the left. The curvature of the well is inversely proportional to the system's response time to small perturbations

Lenton TM, Held H, Kriegler E, Hall JW, Lucht W, Rahmstorf S, Schellnhuber HJ. Tipping elements in the Earth's climate system. Proceedings of the national Academy of Sciences. 2008 Feb 12;105(6):1786-93.

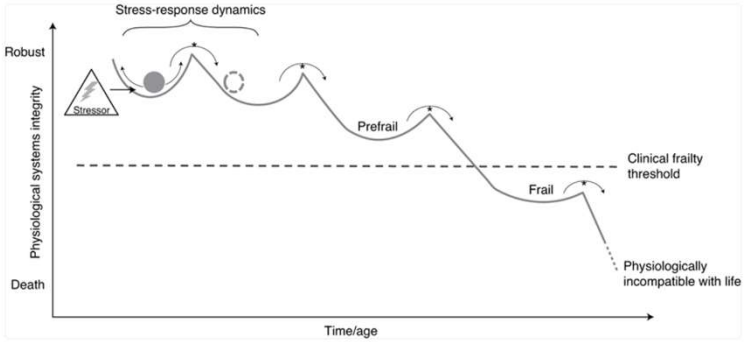
Another really important concept is that of attractor states and the marble in a basin. Complex systems, and their possible states shown here as the ball, build order and stability as energy flows through them and tend to settle into preferred states or attractors using self-regulation to maintain a position in a basin. When perturbed, for example with GHG emissions, they try to stay in the same basin but lose resilience as the basin become shallower. Eventually, a tipping occurs and the ball rolls into another basin. But before that happens, note the increasing oscillations and response times of the ball – we are seeing plenty of evidence of this right now, for example, the upwellings.



So if Gaia is currently in the stable Holocene basin using energy flows to maintain order and stability, we should be a partner in this process, Gaia willing, not actively pushing the ball into another basin - because we know Gaia and many life forms with be fine in the other basin but we humans will very likely struggle at the very least.

Human Health and Frailty

Fig. 3 |. Hypothesized natural history of frailty: deterioration of physiological integrity in response to repeated stressors and natural aging.



Frailty: the outcome of life course stressors resulting in allostatic load, and also age-related dysregulation of a complex dynamical system. Emerges when the dysregulation of multiple interconnected physiological and biological systems crosses a threshold to critical dysfunction, severely compromising homeostasis

Fried LP, Cohen AA, Xue QL, Walston J, Bandeen-Roche K, Varadhan R. The physical frailty syndrome as a transition from homeostatic symphony to cacophony. Nat Aging. 2021 Jan;1(1):36-46.

BTW, very interesting extension of these marble-in-basin concepts in relation to human frailty which you may like to review ....

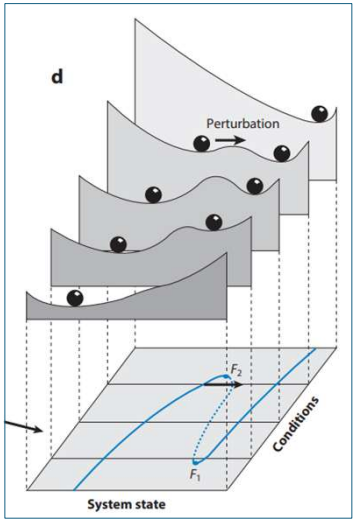
Early Warnings of Regime Shifts: A Whole-Ecosystem Experiment

S. R. Carpenter,[1*] J. J. Cole,[2] M. L. Pace,[3] R. Batt,[1] W. A. Brock,[4] T. Cline,[1] J. Coloso,[3] J. R. Hodgson,[5] J. F. Kitchell,[1] D. A. Seekell,[3] L. Smith,[1] B. Weidel[1]

Catastrophic ecological regime shifts may be announced in advance by statistical early warning signals such as slowing return rates from perturbation and rising variance. The theoretical background for these indicators is rich, but real-world tests are rare, especially for whole ecosystems. We tested the hypothesis that these statistics would be early warning signals for an experimentally induced regime shift in an aquatic food web. We gradually added top predators to a lake over 3 years to destabilize its food web. An adjacent lake was monitored simultaneously as a reference ecosystem. Warning signals of a regime shift were evident in the manipulated lake during reorganization of the food web more than a year before the food web transition was complete, corroborating theory for leading indicators of ecological regime shifts.

Carpenter SR, Cole JJ, Pace ML, Batt R, Brock WA, Cline T, Coloso J, Hodgson JR, Kitchell JF, Seekell DA, Smith L. Early warnings of regime shifts: a whole-ecosystem experiment. Science. 2011 May 27;332(6033):1079-82.

Peter Lake: *"Brock used a branch of applied mathematics known as bifurcation [tipping] theory to show that the odd behavior was in fact an early warning of catastrophic change. In short, he devised a way to sense the transformation of an ecosystem by detecting subtle changes in the system's natural patterns of variability."*



Scheffer M, Carpenter SR, Dakos V, van Nes EH. Generic indicators of ecological resilience: inferring the chance of a critical transition. Annual Review of Ecology, Evolution, and Systematics. 2015 Dec 4;46(1):145-67.

https://news.wisc.edu/scientists-detect-early-warning-signal-for-ecosystem-collapse

The Peter Lake experiment was a really important one where they manipulated a lake ecosystem by introducing bass fish to change to food web. They noted odd behaviour, a measurable increase in variance and longer times to recover after perturbations as early warning signs that an ecosystem would tip to another state. The latter occurs because a system's internal stabilizing forces — whatever they might be — become weaker near the point at which they suddenly propel the marble into another basin. We are seeing plentiful evidence of warning signs which are flashing red.

SUSTAINABILITY

Gaia 2.0

Could humans add some level of self-awareness to Earth's self-regulation?

By **Timothy M. Lenton**[1] *and* **Bruno Latour**[2]

Lenton TM, Latour B. Gaia 2.0. Science. 2018 Sep 14;361(6407):1066-8.

This article is really interesting and proposes we partner up with Gaia by introducing our consciousness and awareness into Gaia's Holocene basin, Gaia willing of course. We would need to become a responsible and reliable habitant of the Gaia Holocene basin, rather than a disruptor, and commit to continual care and attention – in other words, an ecological conversion.

Implications

- Partner with Gaia (if Gaia is willing) to (re)build and promote Holocene Basin stability in a simple, prosocial, bioregional context
- Immediate, drastic reduction in fossil fuel use
  - Hothouse #1: W. Steffen, J. Rockström, K. Richardson, T.M. Lenton, C. Folke, D. Liverman, C.P. Summerhayes, A.D. Barnosky, S.E. Cornell, M. Crucifix, J.F. Donges, I. Fetzer, S.J. Lade, M. Scheffer, R. Winkelmann, & H.J. Schellnhuber, Trajectories of the Earth System in the Anthropocene, Proc. Natl. Acad. Sci. U.S.A. 115 (33) 8252-8259, https://doi.org/10.1073/pnas.1810141115 (2018).
  - Hothouse #2: William J. Ripple, Christopher Wolf, Johan Rockström, Katherine Richardson, Nico Wunderling, Jillian W. Gregg, Thomas Westerhold, Hans Joachim Schellnhuber, The risk of a hothouse Earth trajectory, One Earth, 2026,101565
- Too much of a good thing is pervasive and ubiquitous - the “Inverted U” Curve. Driven by the Maximum Power Principle
- First Nations/Indigenous knowledge, wisdom, governance

We’re heard and reviewed the pleas of the scientists for immediate drastic reductions to fossil fuel use. The recently published update from Ripple et al also leaves no uncertainly as to the dire state of the situation.

- “…. quickly and drastically reducing anthropogenic emissions [is required]”
- “Uncertainty about where tipping thresholds lie is therefore not a reason for delay, but a compelling reason for immediate precautionary action.”
- “Earth’s climate is now departing from the stable conditions that supported human civilization for millennia.”
- “Uncertain tipping thresholds make precaution essential, as crossing them could commit the planet to a hothouse trajectory with long-lasting and potentially irreversible consequences.”

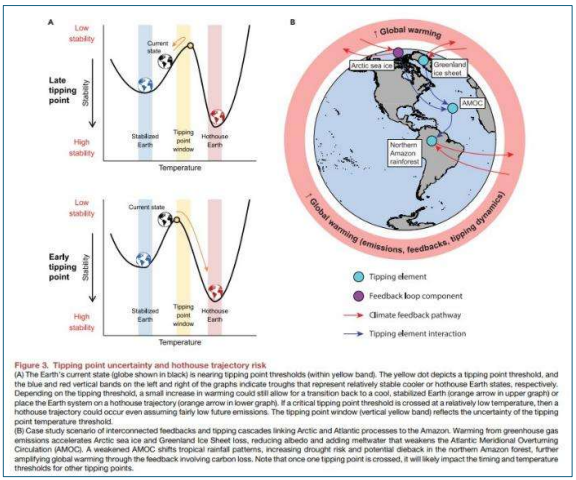


Figure 3. Tipping point uncertainty and hothouse trajectory risk

(A) The Earth’s current state (globe shown in black) is nearing tipping point thresholds (within yellow band). The yellow dot depicts a tipping point threshold, and the blue and red vertical bands on the left and right of the graphs indicate troughs that represent relatively stable cooler or hothouse Earth states, respectively. Depending on the tipping threshold, a small increase in warming could still allow for a transition back to a cool, stabilized Earth (orange arrow in upper graph) or place the Earth system on a hothouse trajectory (orange arrow in lower graph). If a critical tipping point threshold is crossed at a relatively low temperature, then a hothouse trajectory could occur even assuming fairly low future emissions. The tipping point window (vertical yellow band) reflects the uncertainty of the tipping point temperature threshold.

(B) Case study scenario of interconnected feedbacks and tipping cascades linking Arctic and Atlantic processes to the Amazon. Warming from greenhouse gas emissions accelerates Arctic sea ice and Greenland Ice Sheet loss, reducing albedo and adding meltwater that weakens the Atlantic Meridional Overturning Circulation (AMOC). A weakened AMOC shifts tropical rainfall patterns, increasing drought risk and potential dieback in the northern Amazon forest, further amplifying global warming through the feedback involving carbon loss. Note that once one tipping point is crossed, it will likely impact the timing and temperature thresholds for other tipping points.

William J. Ripple, Christopher Wolf, Johan Rockström, Katherine Richardson, Nico Wunderling, Jillian W. Gregg, Thomas Westerhold, Hans Joachim Schellnhuber, The risk of a hothouse Earth trajectory, One Earth, 2026,101565

The image on the right uses the explanatory “marble-in-basin” model and shows that tipping point position uncertainty within the tipping point window is a critical issue and underlines the need for immediate precautionary action.

Implications

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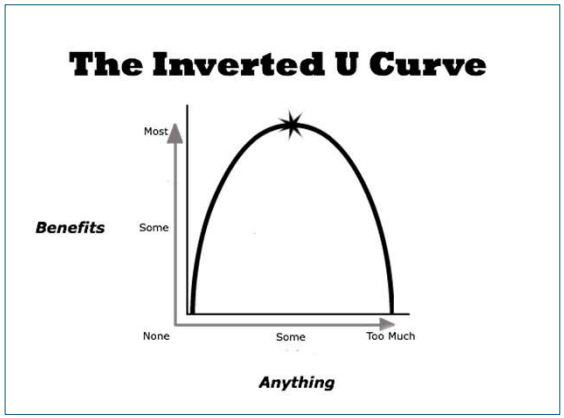
  - Hothouse #2: William J. Ripple, Christopher Wolf, Johan Rockström, Katherine Richardson, Nico Wunderling, Jillian W. Gregg, Thomas Westerhold, Hans Joachim Schellnhuber, The risk of a hothouse Earth trajectory, One Earth, 2026,101565
- "Too much of a good thing" is pervasive - the "Inverted U" Curve often driven rightwards by the Maximum Power Principle. This includes **Energy Flow.**
- First Nations/Indigenous knowledge, wisdom, governance

Thirdly, Too Much of a Good Thing is pervasive. The Inverted U curve, which applies to basically everything, is under pressure to move rightwards from the Maximum Power Principle – this applies to Energy Flows although modern societies in particular have not seen it this way.

Wide Boundary Implications

- Also known as “No such thing as an unmitigated good”. “Two-edged sword”. “Everything in moderation”.



Here’s the graph – it encapsulates the sayings – no such thing as an unmitigated good; a two-edged sword, everything in moderation

Maximum Power Principle

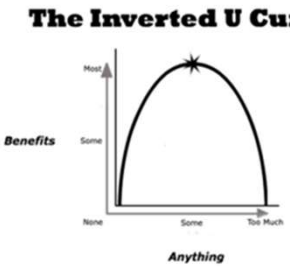
- ". . . the designs that prevail in self-organizing systems are those that maximize useful power" (HT Odum 1982)
- it is not the energy captured nor the energy dissipated that is important, rather it is the useful energy that is absorbed by the organism and that is used for survival and reproduction. The high rate of entropy production is selected for, but only incidentally (Hall, McWhirter 2023)
- In the work of Nietzsche, Lotka, Odum and many who have followed them, we find this provocative assertion—this world and all of us in it are the products of a fundamental tendency to maximize power (Hall, McWhirter 2023)

Charles A. S. Hall, Timothy McWhirter; Maximum power in evolution, ecology and economics. Philos Trans A Math Phys Eng Sci 2 October 2023; 381 (2256): 20220290.

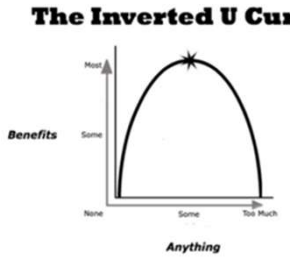
But it's hard to push back against the Maximum Power Principle. Building on the work of Alfred Lotka, HT Odum noted that .....
(note that it's useful or net power)

Charlie Hall and Tim McWhirter make the sobering observation that in these prevailing systems, the absorption of useful energy is used for survival and reproduction and is selected for. And that we and the planet are the products of this fundamental tendency to maximise power.

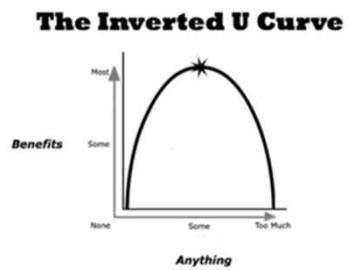
Maximum Power Principle



Upwelling and Climate Change



humans and endosomatic energy balance



humans and exosomatic energy

So how does the Maximum Power Principle apply in the context of an environmental energy flux which is above the evolutionary level which the system has evolved with and adapted to? We can look at the issues of upwelling and climate change (we could just as well look at Gaia and the response to current increasing EEI). And to humans and their relationship with their endosomatic energy – or food. And also the Great Human Enterprise.

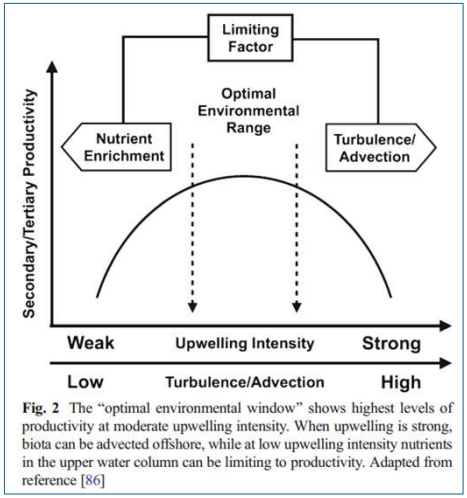
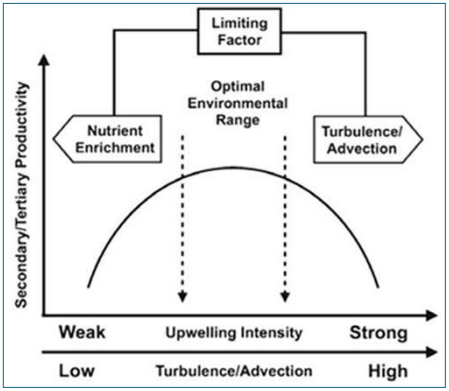


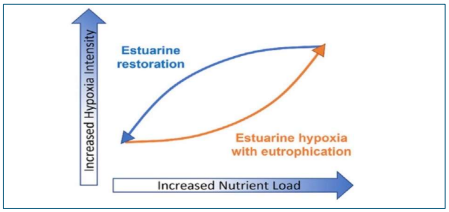
Fig. 2 The "optimal environmental window" shows highest levels of productivity at moderate upwelling intensity. When upwelling is strong, biota can be advected offshore, while at low upwelling intensity nutrients in the upper water column can be limiting to productivity. Adapted from reference [86]

Bakun A, Black BA, Bograd SJ, Garcia-Reyes M, Miller AJ, Rykaczewski RR, Sydeman WJ. Anticipated effects of climate change on coastal upwelling ecosystems. Current Climate Change Reports. 2015 Jun;1(2):85-93.



Strong Upwelling - potential impacts

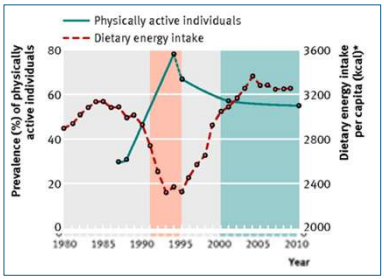
1.hypoxia
2. HABs
3.change in physical and biogeochemical properties
4. changes to selection pressures and ecosystem communities
5. bioinvasion

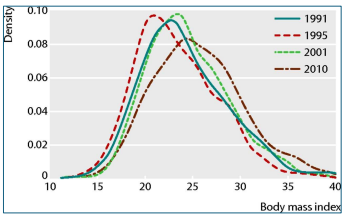


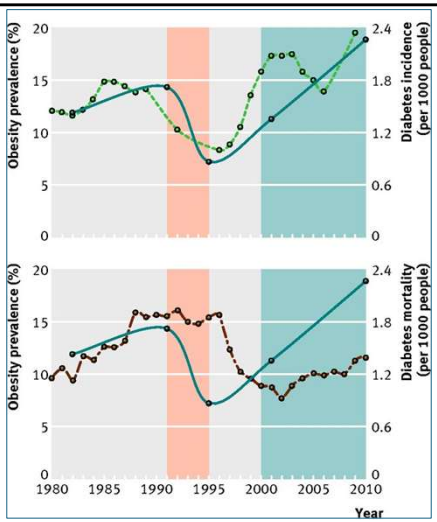
Ni W, Li M. What drove the nonlinear hypoxia response to nutrient loading in Chesapeake Bay during the 20th century?. *Sci Total Environ*. 2023;861:160650. doi:10.1016/j.scitotenv.2022.160650

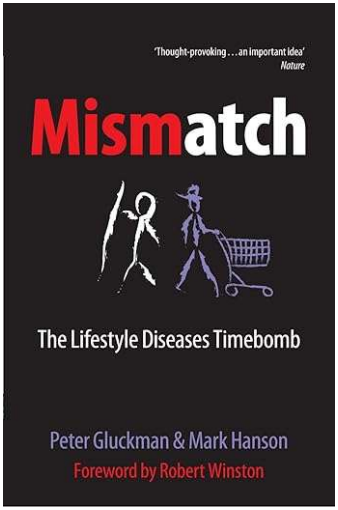
The inverted U of upwelling was noted quite a few years back. You need some, but too much upwelling causes excess turbulence and advection. With the climate change energy turbocharge, other downsides include excessive algal blooms, causing hypoxia, or the emergence of an otherwise harmful bloom including biotoxicity. Strong upwelling can change the characteristics of upwelled water, or selection pressures and ecosystem communities, as well as facilitate bioinvasion.

The bottom graph reminds us of the non-linear "marble in a basin" dynamics at play..... nutrients can be continually added, for example by upwelling, without any hypoxia developing, and everything looks OK – until it's not. This could explain the increasing hypoxia seen at the Southern Benguela upwelling system as upwelling intensity has been increasing there and nutrient upwelling, combined with retention and recycling, could reach tipping.





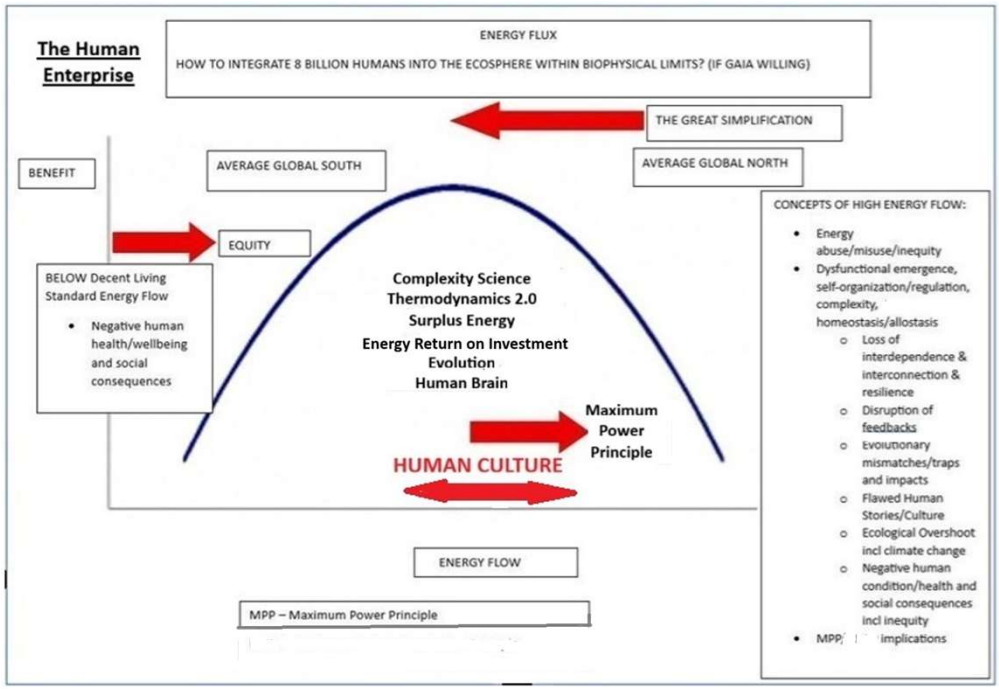




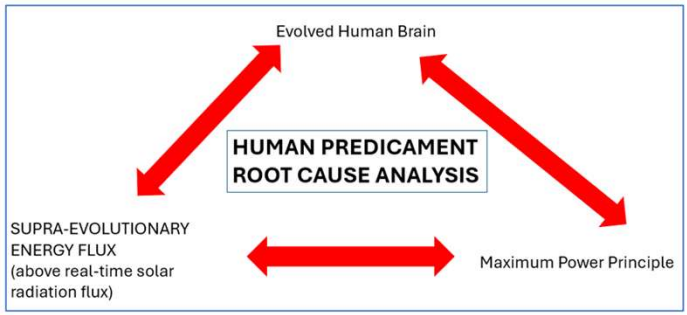
In relation to the Cuban experience in 1980-2010, there is an association at the population level between weight reduction and death from diabetes and cardiovascular disease; the opposite effect on the diabetes and cardiovascular burden was seen on population-wide weight gain.

Franco M, Bilal U, Orduñez P, Benet M, Morejón A, Caballero B, Kennelly JF, Cooper RS. Population-wide weight loss and regain in relation to diabetes burden and cardiovascular mortality in Cuba 1980-2010: repeated cross sectional surveys and ecological comparison of secular trends. Bmj. 2013 Apr 9;346.

When it comes to food, the Cuban experience at the time of the embargo and economic crisis of the 1990s showed that a rebalancing of energy balance with a combination of increased physical activity and a less energy-dense, nutrient rich diet led to weight reduction and reduced rates of diabetes and cardiovascular death – but that a return to initial conditions led to weight gain and reversal of gains. All this is discussed in much more detail in books examining our evolutionary mismatches, of which there are many. An important concept is the role of homeostatic and allostatic responses and loads on exposure to large energy flows.



Turning to the modern technoindustrial Human Enterprise, historically there has been a failure or reluctance to see an Inverted U function when it comes to energy flow. Rather it's been a case of the more the better. Things did change when quality of life issues were factored in, and the curve was deemed to have a plateau as energy flows increased. But a downwards trajectory as energy flow increases has been unthinkable, consistent with the Growth Paradigm – and the Maximum Power Principle. This is a busy graph but obviously we have energy requirements for descent basic living. Human culture may be able to alter energy flows and consumption but is swimming against the MPP tide. Nate Hagens' Great Simplification is at the top. The box on the right is important and the cause of the downward trajectory of the Inverted U. Energy has been abused, misused. As Richard Heinberg writes, it's been used to create vertical social power and inequity. And there's a whole list of other consequences which you can access at your leisure but are often not considered or poorly understood.

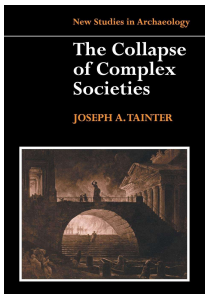


"To summarize, humans play the same game as life — we use efficiency to catalyze sprawl. And for most of human history, we played the game within tight constraints, using only the energy made available by the sun. But our exploitation of fossil fuels obviously changed everything, supercharging our activity beyond what the solar budget could maintain. It's this lack of constraint that converts the Jevons paradox [a MPP expression] from a blessing into a curse." (THINK ALGAL BLOOM)

Fix, Blair (2024) : A Tour of the Jevons Paradox: How Energy Efficiency Backfires, Economics from the Top Down, Toronto, https://economicsfromthetopdown.com/2024/05/18/a-tour-of-the-jevons-paradox-how-energyefficiency-backfires/ , https://bnarchives.yorku.ca/828/

The fundamental issues are related to the interactions of the evolved human brain with supra evolutionary energy flows operating under the maximum power principles with all the emergent implications of this. Blair Fix summarizes this wonderfully .... read

Joseph Tainter: Energy-Complexity Spirals



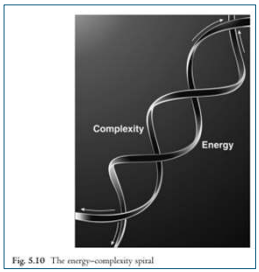
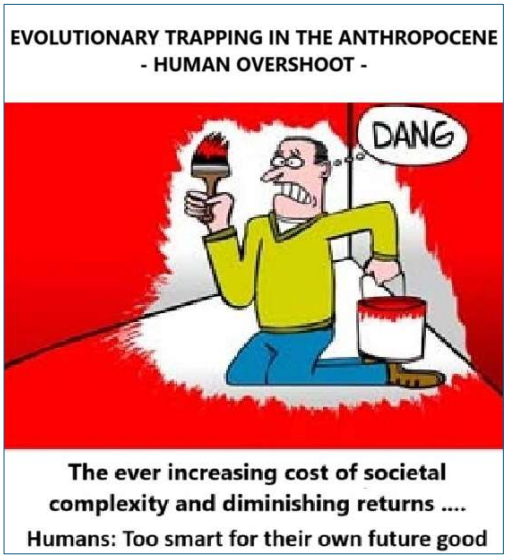


Fig. 5.10 The energy–complexity spiral

"The fact that complexity grows to solve problems leads to the sobering realization that there may be no way out of this spiral, or at least no way that we would find desirable. What happens to a society when it grows more and more complex on the basis of resources that become harder and harder to supply?"



And Joseph Tainter's work, I'm sure, resonates with everyone once they have the opportunity to get off the MTI dancefloor. Read quote…. We've literally painted ourselves into a corner with our "quote smartness end quote". The more complex things get, the more energy we use to try to incompletely solve the inevitable problems while generating more complexity, unintended consequences and energy demand.

Implications

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- Immediate, drastic reduction in fossil fuel use
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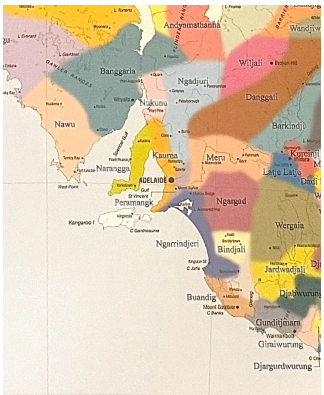
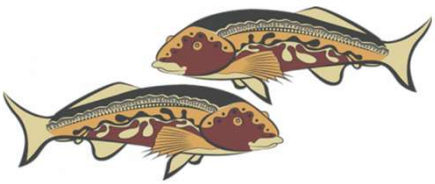
  - Hothouse #2: William J. Ripple, Christopher Wolf, Johan Rockström, Katherine Richardson, Nico Wunderling, Jillian W. Gregg, Thomas Westerhold, Hans Joachim Schellnhuber, The risk of a hothouse Earth trajectory, One Earth, 2026,101565
- Too much of a good thing is pervasive and ubiquitous - the “Inverted U” Curve. Driven by the Maximum Power Principle.
- First Nations/Indigenous knowledge, wisdom, governance

Finally, and very importantly, First Nations knowledge wisdom and governance must be a cornerstone and at the centre of the path forwards from here. The devastation that this algal bloom has caused First Nations people is difficult to understand but perhaps Ngarrindjeri elder Mark Koolmatrie’s likening to watching Uluru being destroyed gives us some idea. To paraphrase his words, when nature is sick, so are we. We have responsibility to nature.

Narungga Nation Aboriginal Corporation (Garry Goldsmith, Senate Enquiry Algal Blooms in South Australia, Submission 47)

- "My people [Narungga people, traditional owners of Guuranda] have been living on this country for millennia and our sea connection is very strong today as it was then
- our waters have been affected by the algal blooms
- we are known as the butterfish mob, the dusky Morwong, a fish that have fed our people for thousands of years. We also have dreaming stories of our sea creatures and the environment in which these two gulfs that are affected were formed
- we are very concerned about the algal blooms for our people
  - our identity as country people is at risk - many of the other Aboriginal nations know us as the butterfish mob ….
  - the effects of global warming that our people have not contributed to, yet we are the most vulnerable."





https://www.abc.net.au/news/2022-06-27/gynburra-butterfish-yorke-peninsula-research-preserve-protect/101186756

The Narungga people, the traditional owners of Guuranda or Yorke Peninsula, have also been greatly impacted by this algal bloom. In a submission to the Algal Bloom Enquiry, they wrote about the enduring and ancient connection to sea country and the importance of the butterfish or dusky morwong fish to their identity amongst other Aboriginal nations. This fish and the Gulfs are part of their dreaming stories but both have been greatly harmed. The Narungga people note their vulnerability to climate change, yet they have not contributed to it. Surely many lessons here. Thank you.