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1-5 December 2025
Manila, Philippines (Hybrid)

Climate and Ecosystem Indicators Update

WCPFC22-2025-16
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Climate and ecosystem indicators update

Oceanic Fisheries Programme
Pacific Community (SPC)

WCPFC
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Manila, Philippines

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Agenda Item 10
WCPFC22-2025-16

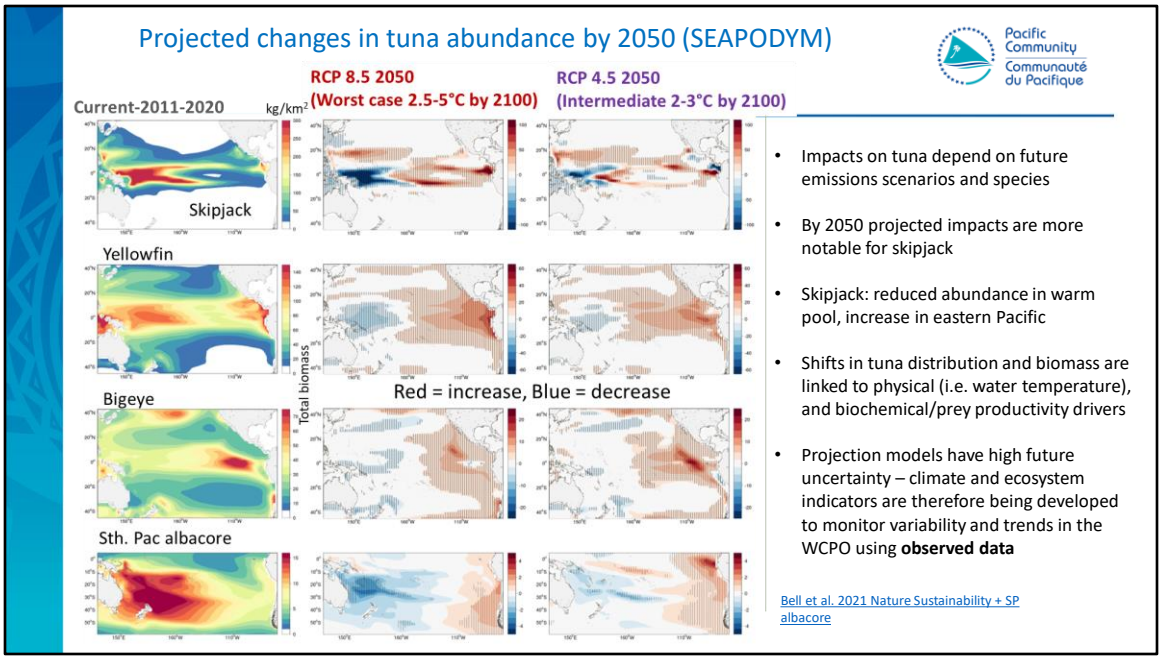
Presented by Paul Hamer

Background

- Anthropogenic climate change caused by increased greenhouse gas emissions
- Leading to several impacts:
  - Increasing ocean temperatures
  - Sea level rise
  - Increasing acidity of ocean
- WCPFC Resolution 2019-01 on climate change
  - Consider impacts of climate change
  - Support research
  - Consider climate change in decision making
  - Develop a set of WCPFC-CA relevant climate and ecosystem indicators for annual reporting

While the drivers and impacts of climate change are now familiar, how climate change is impacting the western and central Pacific Ocean (WCPO), Pacific Island Countries and Territories (PICTs), and associated fisheries is less well known. In response to this, the WCPFC agreed to Resolution 2019-01 outlining the importance and impacts of climate change, and the need to better understand and monitor climate change in the context of WCPFC member countries, fisheries and species of interest.

This presentation provides an update on the ongoing work to develop a core set of relevant climate and ecosystem indicators and presents the trends in various indicators that have so far been selected for annual reporting to SC and WCPFC.



This slide shows projections of changes in total spatial biomass levels by 2050 across the Pacific under two representative greenhouse gas concentration pathways, RCP 8.5 – an extreme/worst case scenario where emissions continue unabated for the rest of the century and global ave. temperatures rise by up 4-5˚C by 2100. RCP 4.5 a more moderate scenario where emissions start declining by approximately 2045 and reach roughly half of the levels of 2050 by 2100, as fossil fuel reserves are exhausted, with a global ave. temperatures rise of 2- 3˚C by 2100.

The panel on the far left shows the relative biomass levels for each tuna species estimated for the recent decade, and the two panels to the immediate right show the predicted changes in biomass; **red indicates increase in biomass, blue indicates decrease in biomass.**

Current projections from SEAPODYM suggest a shift/decline in the biomass of tunas in the WCPO by 2050. Projection models have a fair bit of future uncertainty, therefore, it is important to monitor various climate and fisheries indicators to determine if change is occurring, the rate of change, and if it is in line with SEAPODYM or other climate/ocean model projections.

Climate & ecosystem indicators –progress

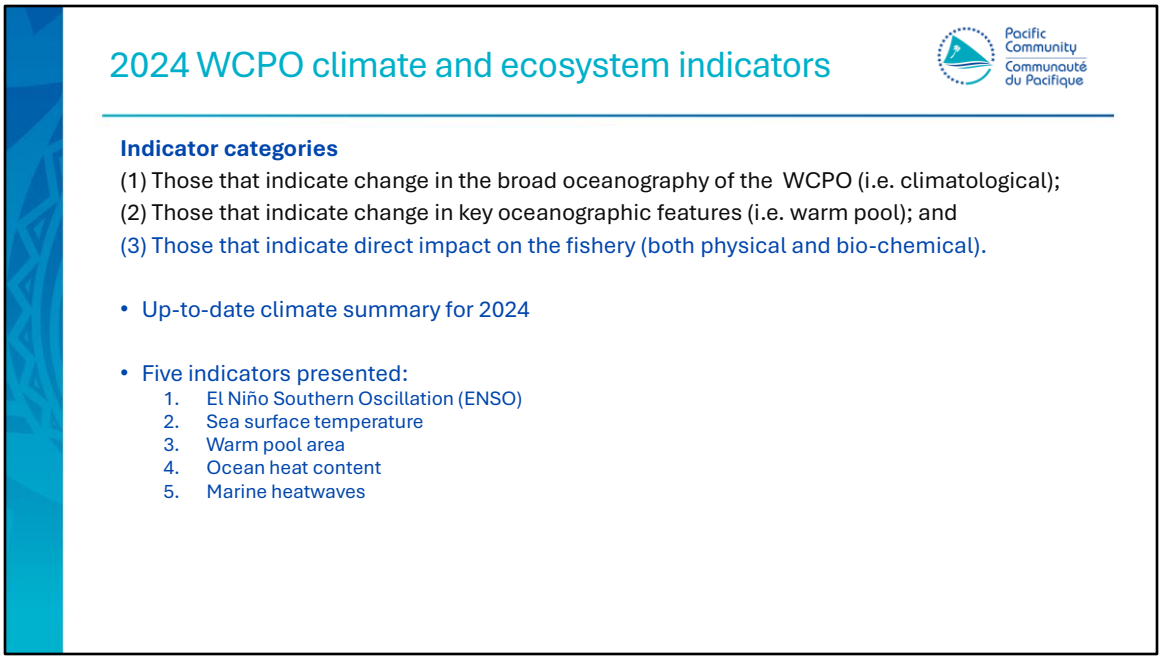
- WCPFC requested development of ecosystem & climate indicators
- Completed:
  - Expert workshop held in late 2024
  - 2025 report produced for SC WCPFC-SC21-2025/EB-IP-01
  - Improved candidate indicators developed/ongoing
- Ongoing:
  - Adoption workshop (prior SC22)
  - SC22 and ongoing review and evaluation

Task	Activity	Schedule			
		SC20	SC21	SC22	SC23
Initial screening of candidate indicators	Apply criteria endorsed at SC12 to candidate indicators that are relevant for monitoring impacts on purse seine and long-line fisheries and tuna species productivity				
Test candidate indicators	Fully develop methodology for developing and testing candidate indicators ✓				
	Test candidate indicators ✓				
	Expert Workshop ✓				
	Adoption Workshop		→		
Indicator validation	SC review and evaluation that adopted				
Communication tools	Report cards				
	Dashboards				
	TFAR (see https://fame1.spc.int/resources/documents/tuna-fisheries-assessment-report)				

Link to testing criteria - https://meetings.wcpfc.int/node/19391

As part of addressing this Resolution, SPC is in the process of developing and testing climate and ecosystem indicators to be presented to SC as a regular paper or "report card" each year to support management advice for WCPFC. Several indicators were developed across 2024/2025 and have been presented to this year's Scientific Committee, and are summarized in the Tuna Fisheries Assessment Report No. 25 (draft version available – https://www.spc.int/digitallibrary/get/af4wr) (still be uploaded at time of writing). Testing and review of these indicators is ongoing as well as the exploration of other potential indicators for SC22 review in 2026, which should present an improved, consolidated format for this report and these indicators going forward.

An expert workshop was held in Suva in **November 2024** to discuss the selection and testing of these indicators, and an **Adoption Workshop** is still to be planned prior to SC22. The report on indicator selection from the Suva workshop was provided to SC21 (WCPFC-SC21-2025/EB-IP-01) in Tonga, accessible here: https://meetings.wcpfc.int/node/26648
For this presentation, a summary will be provided of the indicators selected thus far, the current climate in the WCPO, and any underlying long-term trends apparent in those indicators.



The development of the WCPO climate and ecosystem indicators is ongoing and focussed on three broad categories :
(1) Those that indicate change in the broad oceanography of the WCPO (i.e. climatological);
(2) Those that indicate change in key oceanographic features (i.e. warm pool); and
(3) Those that indicate direct impact on the fishery (both physical and bio-chemical).

Useful indicators for category (3) are still being developed/explored and we focus on the first two categories.

Based on passing the selection criteria previously developed (WCPFC-SC21-2025/EB-IP-01), five indicators are presented herein. Indicator selection was based on:

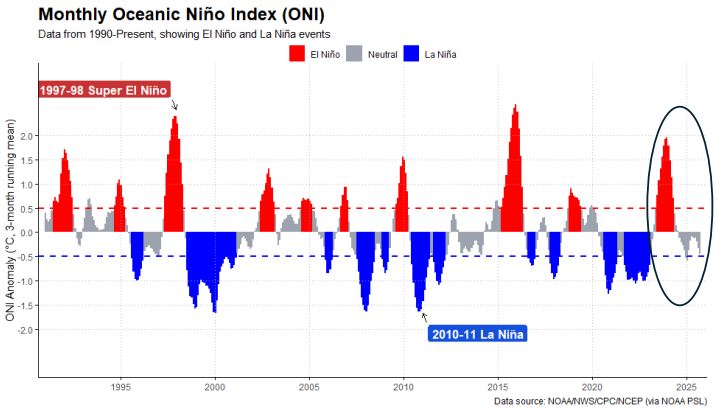
- their ability and relevance in monitoring the WCPO climate,
- ability to measure these indicators and update them regularly – not reliant on reanalysis models,
- their capacity to capture long-term, inter-annual and intra-annual variability in the climate, and;
- their relevance to member countries, fisheries and ecosystems.

The five indicators selected thus far are:

1) **El Nino Southern Oscillation Index (ENSO**) – which is the primary driver of inter-annual variability in the climate in the western Pacific and has known relationships with tuna dynamics and associated purse seine fishing dynamics.
2) **Sea surface temperature (SST)** - is a key index of the ocean climate and impacts a range of ecological processes such as species distribution. SST is also one of the most observable measures of tracking the marine environment and a key indicator of anthropogenic climate change.
3) **Warm pool area** – the Pacific warm pool is the dominant oceanographic feature of the WCPO, is important tuna feeding and spawning grounds, and is predicted to be impacted by climate change and so is an important feature to monitor.
4) **Ocean heat content** - The world's oceans are central to the transport and absorption of heat, with the ocean storing more than 90% of the excess heat energy trapped in the Earth's climate system from greenhouse gases. Ocean heat content will track this storage of heat as well as any change in current strength or trajectory. Ocean Content is less subject to interannual climate variability which can influence SST and warm pool area, and is therefore a better indicators of long-term trends in ocean warming.
5) **Marine heatwaves (MHWs**) – MHWs can have detrimental impacts on marine ecosystems and with the impacts of climate change MHWs are predicted to increase in frequency, duration, and intensity.

1. ENSO

- Current conditions: neutral/slight La Niña
- 2023-24 short, but strong El Niño
- Climate implications 2024:
  - Above-average SST in western Pacific
  - Below average SST in central and eastern Pacific
  - Westerly contraction of warm pool
- Fishery implications:
  - Westerly contraction of tuna and PS effort compared to 2023

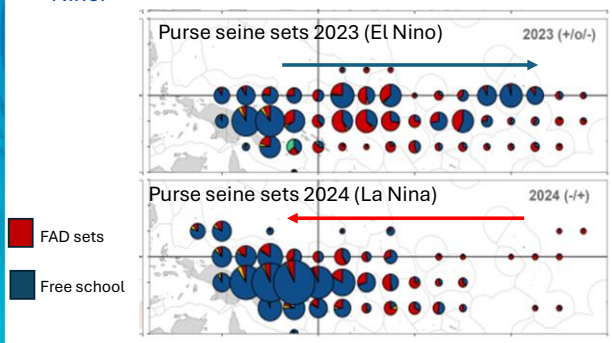


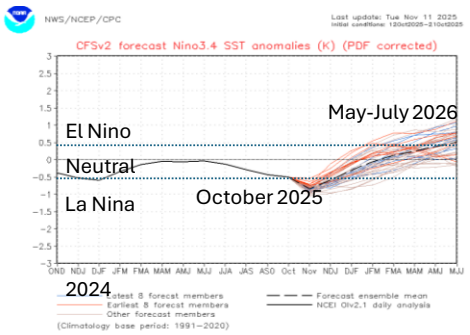
ENSO is the main driver of inter-annual climate variability in the Pacific, influencing weather, ocean circulation, and ecosystems. The Nino 3.4 index tracks sea surface temperature (SST) anomalies in the equatorial Pacific Ocean (i.e. corresponds to region 5 on slide 7). It captures the area where temperature changes have the strongest global climate impacts. Temperature anomalies (differences from average) in this region:+0.5°C or warmer = El Niño conditions and -0.5°C or cooler = La Niña conditions. Between -0.5°C and +0.5°C = Neutral conditions.

From 2020-2023, the WCPO experienced near continuous La Niña conditions, an anomalously long-term ENSO event. This was followed by a short, intense El Niño event that occurred between May 2023 and April 2024. Since this time, ENSO has expressed neutral to slight La Niña like conditions with above average surface temperature in the western Pacific and average to below average SST in the central and eastern Pacific. This shift in ENSO conditions was reflected in recent purse seine fishing effort dynamics as seen on the next slide.

1. ENSO - outlook

- Forecast is for neutral ENSO conditions into early 2026, with weak El Niño likely forming towards the middle of 2026
- Impact on fleet distribution – bit more spread back to east, more FADs sets?? Depends on strength of El Niño.





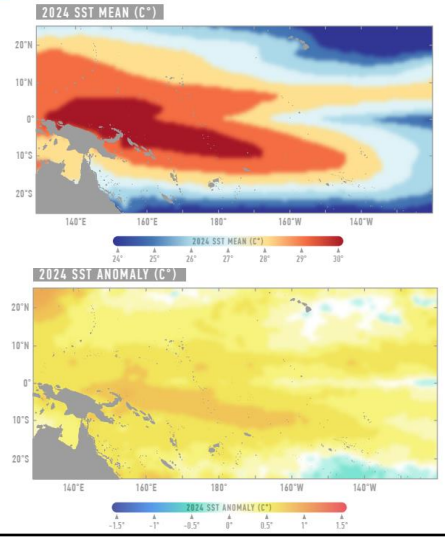
The shift to La Nina conditions from 2023-2024 resulted in a westerly contraction of the warm pool and therefore purse seine effort. Looking forward, we can see the recent observed (single black line) and multi model forecasts (coloured lines, median – dashed line) of the Niño 3.4 index.

The figure shows the weak La Nina conditions in later 2024 and the neutral conditions through 2025. The forecast models predict that El Nino conditions might start to form by mid 2026, and further La Nina conditions are very unlikely from late 2025 onwards. We would expect purse seine activity to have been less concentrated in the west of the warm pool in 2025, and likely to spread back further towards the central equatorial Pacific into 2026, where FAD sets will become more common again. Purse seine bigeye catch might be predicted to increase from 2025 through 2026.

2. Sea surface temperature (SST)

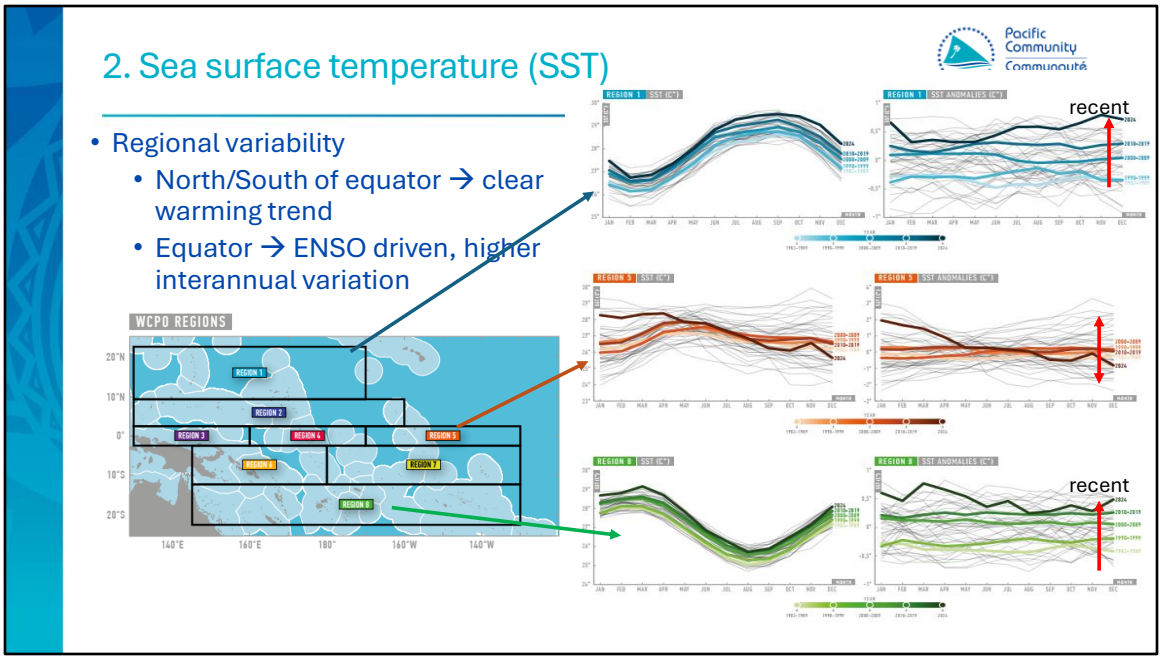
- 2024 was one of the hottest years on record globally
- Anomalously warm in western Pacific, closer to average in central/eastern pacific (ENSO)

SST anomaly relative to average 1982-2024



The next indicator is SST which is a key index of the ocean climate and impacts a range of ecological processes such as species distribution. SST is also one of the most **observable** measures of tracking the marine environment and a key indicator of anthropogenic climate change.

Overall, 2024 was an anomalously warm year in the WCPO relative to the climatological mean of 1982-2024. Temperature anomalies were highest in the western equatorial pacific which coincides with the warm pool, and closer to the long-term average in the central and eastern equatorial pacific which aligns with La Nina conditions. This data represents monthly SSTs and their anomaly relative to the climatological mean from the NOAA OISST product from 1982-2024.



The WCPO is a large and complex region and how climate change and variability impact the region will vary spatially. For this reason, the WCPO was divided into eight regions which are each influenced by different underlying oceanographic dynamics and conditions for the SST indicator.

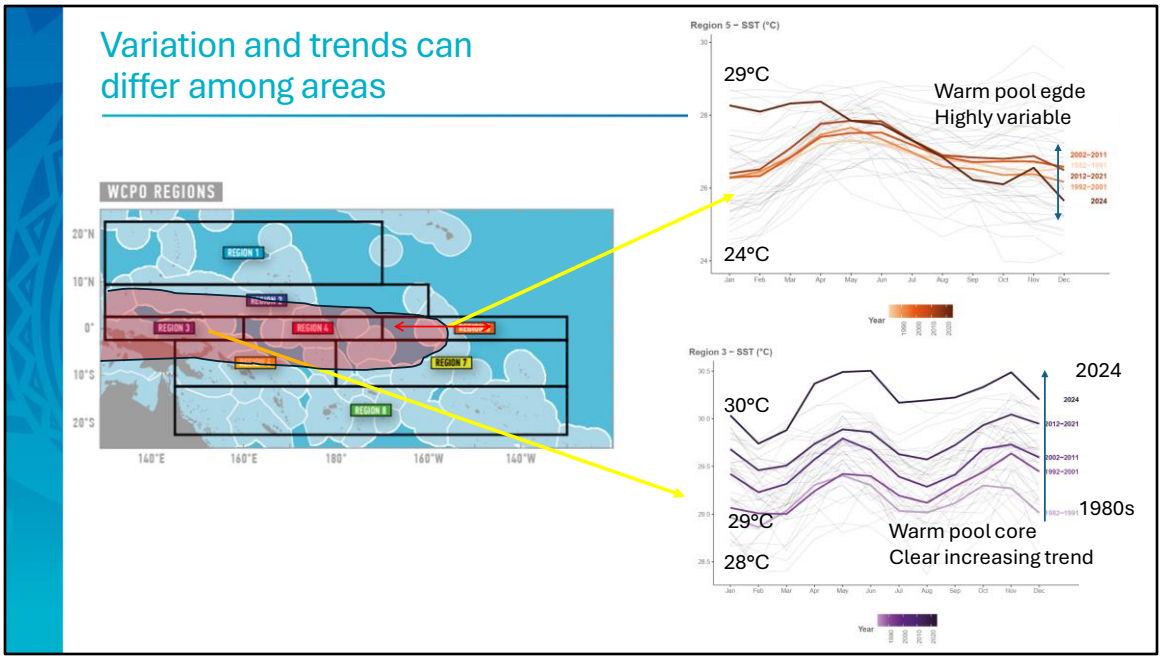
The line plots (right) show the seasonal temperature cycles for each year since 1982 (grey lines) and the thick coloured lines represent the decadal averages with darker colours representing the more recent decades. Left plots are the actual SST and the right plots are anomalies compared to1982-2024.

In regions 1 and 8, north and south of the equator (top and bottom plots), there is evidence of a long-term warming trend overlain on the seasonal cycle with each decadal average warmer than the previous one. **For both regions 1 and 8, the top 10 hottest years have all occurred since 2010 with 2024 the third and fourth hottest year on record for regions 1 and 8 respectively**.

In the central equatorial Pacific (region 5), temperatures are driven by the east-west movement of the warm pool which shifts with ENSO interannual variability. In 2024, temperatures in region 5 were near their long-term mean linked to the

current neutral ENSO conditions. This region has low seasonal variability and shows high interannual variability due the extension and contraction of the surface warm pool, which tends to dominate any long-term trends.

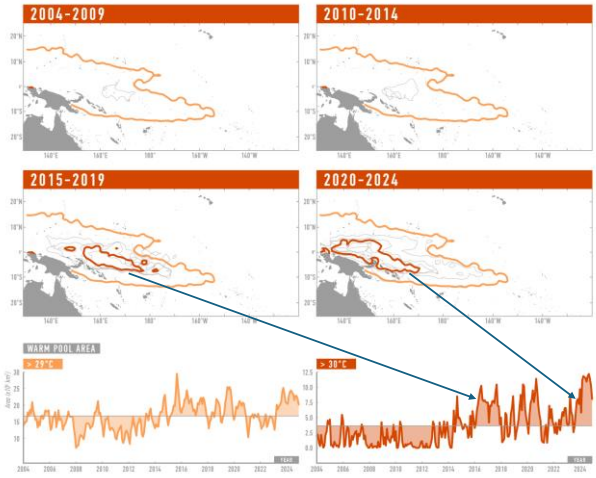
These regional differences in SST trends emphasises the point that some ocean areas are characterised by high short-term variability in SST and longer-term trends are less clear (region 5, middle plots), whereas other areas have less short-term variability but clearer long-term trends (region 1 and 8, top and bottom). Thus, different parts of the WCPO, PICTs, and associated fisheries are likely to be impacted differently by climate change.



This slide emphasis the point that some ocean areas are characterised by high short-term variability in SST and longer-term trends are less clear (region 5, top right), whereas other areas have less short-term variability but clearer long-term trends (region 3, bottom right). Region 3 is in the core of the warm pool where interannual variability is low (it's always warm), but the long term-trend is clearer – with around a 1°C increase in observed SST since the 1980s. Region 5 is a region on the east boundary of the warm pool and as the easterly extent of the warm pool fluctuates this area can regular shift from warm to cooler SST. This is indicated by the almost 5°C range in SST compared to around 2°C for region 3 in the warm pool core.

3. Warm pool area

- Near average in 2024 due to neutral ENSO conditions
- Warm pool ENSO driven with no clear long-term trend apparent for 29°C from 2004-2024 (yellow line)
- BUT, there is an increasing trend in water **>30°C** from 2004-2024 within the warm pool (red line)
- Need longer observational time series, long term increase (since 1970s) in warm pool (29°C) is indicated by re-analysis models

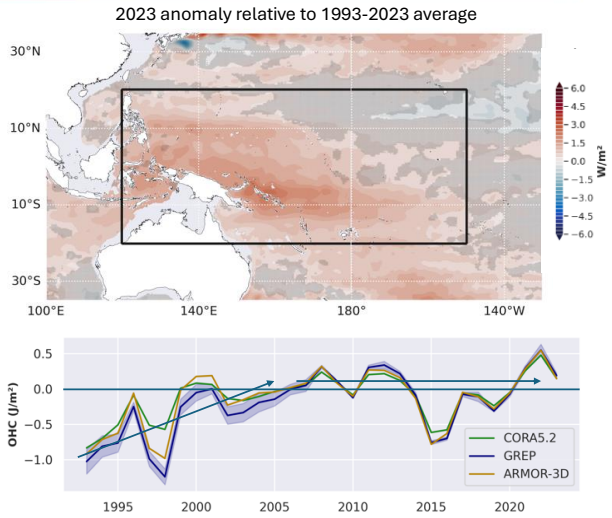


The area of the warm pool (waters >29°C) is characterised by ENSO-driven inter-annual variability with no clear long-term trend from 2004-2024, and the 2024 value is only slightly above the timeseries average. In contrast, there is a long-term increase in waters >30°C within the warm pool from 2004-2024. From 2004-2014, waters >30°C varied from approximately 0-5 million km^2, representing on average 10% of the warm pool. Since 2014, waters >30°C have represented on average 30% of the warm pool area and as high as 55% in August 2024. However, a longer timeseries is needed to monitor the impacts of decadal climate forcings such as Pacific Decadal Oscillation (PDO).

The area of the warm pool was calculated monthly between January 2004 – December 2024 using the Roemmich and Gilson Argo climatology product which represents observational data rather than a reanalysis product (noting that reanalysis products do show increased area of the warm pool (waters >29°C) since the 1970s) . Solid yellow lines on the map indicates the mean 29°C warm pool area for the 2004-2024 timeseries, red lines are 5-year averages of the area of waters >30°C. Grey lines represent annual 30°C area and coloured lines the mean 30°C area for each time period.

4. Ocean heat content (OHC) (0-300m)

- Ocean absorbs ~90% of excess heat
- Heat content increasing from 1993-2023, but variable since 2000s
- Greater increase in western Pacific – linked to warm pool
- Need a longer timeseries



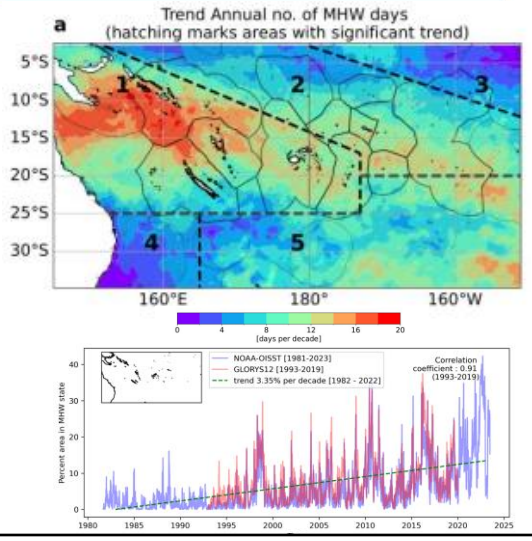
Ocean heat content (OHC) tracks the absorption and storage of heat in the ocean, the climate's primary heat sink, as well as any change in current strengths or trajectory. As mentioned in the earlier slide on indicators, ocean heat content is less sensitive to short-term variability in atmospheric/climate conditions and provides a more robust indicator of any long-term ocean warming.

Ocean heat content for 0-300m depth of the WCPO appears to have increased from 1993-2023. Most of this warming was recorded in the 1990s, with no clear trend in ocean heat content from approximately 2005 onwards. The map shows greater warming in the western equatorial region of the Pacific Ocean adjacent to Papua New Guinea and the Solomon Islands, which coincides with the position of the warm pool core area.

The map represents ocean heat content anomaly for the year 2023 relative to the 1993-2023 mean across three data products: CORA5.2, GREP, and ARMOR-3D. The line plot represents this data as a timeseries.

5. Marine heatwaves (MHWs)

- From 1981-2023 MHWs are:
  - Increasing in frequency
  - Longer lasting
  - Larger in area
  - Less intense
- Mean duration of MHW has doubled each decade
- PICTs impacted differently
- From Lal et al. 2025



Marine Heatwaves (MHWs) can have detrimental impacts on marine ecosystems and as a result of climate change are potentially increasing in frequency, duration, and intensity. MHWs were defined in this analysis as daily SSTs above the 90th percentile of the 1993-2019 climatological mean using NOAA-OISST and GLORYS12 data products. The plots in this slide show that in the south Pacific the number of MHW days, mean duration of MHWs, and their depth (i.e. how deep does the heatwave penetrate in the water column) have all increased from 1982-2022. The percentage of the south equatorial Pacific Ocean in a MHW state has increased 3.5% per decade over this same period. Over the past decade, there has not been a single day when at least part of the region was not exposed to a MHW event.

Lal, S., Cravatte, S., Menkes, C., Macdonald, J., Legendre, R., Mangolte, I., Dutheil, C., Holbrook, N. and Nicol, S., 2025. Characterization of past marine heatwaves around south Pacific Island countries: What really matters? *EGUsphere [preprint]*.

Summary

- Up-to-date climate summary for WCPFC22
- Five indicators presented:
  1. El Nino Southern Oscillation (ENSO) → Neutral through 2025, El Nino possible for 2026
  2. Sea surface temperature → Increasing
  3. Warm pool area → Variable/increasing – more area >30˚C
  4. Ocean heat content → Increasing
  5. Marine heatwaves → Increasing

Observations are qualitatively consistent with expectations from models

This presentation summarises climate indicators to date developed by SPC and collaborators to provide to WCPFC in support of Resolution 2019-01. The development of these indicators has included testing, and reviewing a range of candidate indicators that have been presented at recent SC meetings, and several are incorporated into TFAR reports for Commission meetings.

A snapshot of this progress including the completion of an expert workshop in late 2024, the development of several candidate indicators summarised in this talk, and of the recent ocean climate in the WCPO have been presented. This work should help SC and WCPFC be more informed on the recent trends of climate and ocean system change in the WCPO which can be considered in relation to management decisions and CMM that are vulnerable to climate change.

Overall, the indicators – from observational data – support the warming trend of the western Pacific, with increased SST of the core warm pool area, increased ocean heat content, and increase frequency, duration and depth penetration of marine heatwaves in the southwest Pacific.