Module 15/16/17 Oceans

- Module 15
    - Ocean variability in seasonal models
        - SST and Sea Level
    - Climate drivers and the ocean
    - Past and future coastal flooding for Pacific Small-Island Nations

- Module 16
    - Marine Applications of Ocean Outlooks

- Module 17
    - ACCESS-S Ocean Outlooks and websites
    - ACCESS-S Ocean Skill

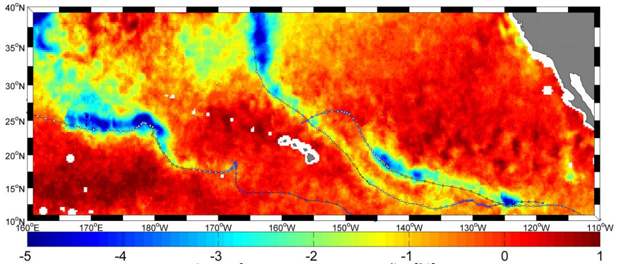
Module 15: Ocean Dynamics

Climate and Oceans Support Program in the Pacific
COSPPac

Australian Government
Department of Foreign Affairs and Trade
Bureau of Meteorology

Ocean variability in seasonal models

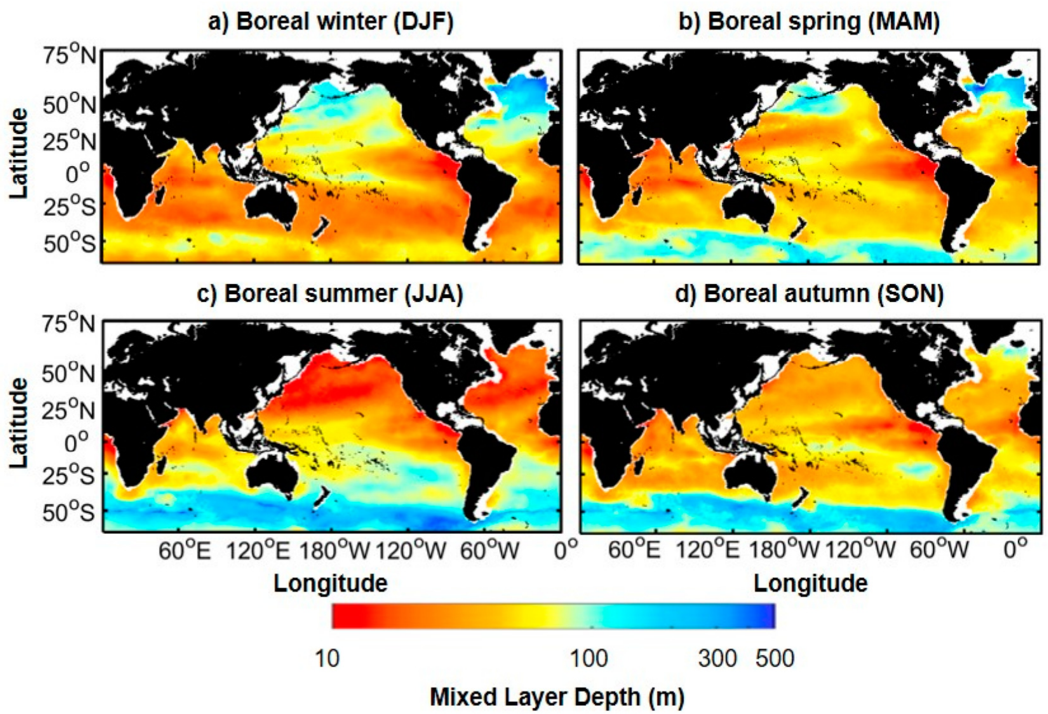
- Sea surface temperature
  - Current changes (wind and density driven)
  - Wind changes impacting mixing (cyclones)

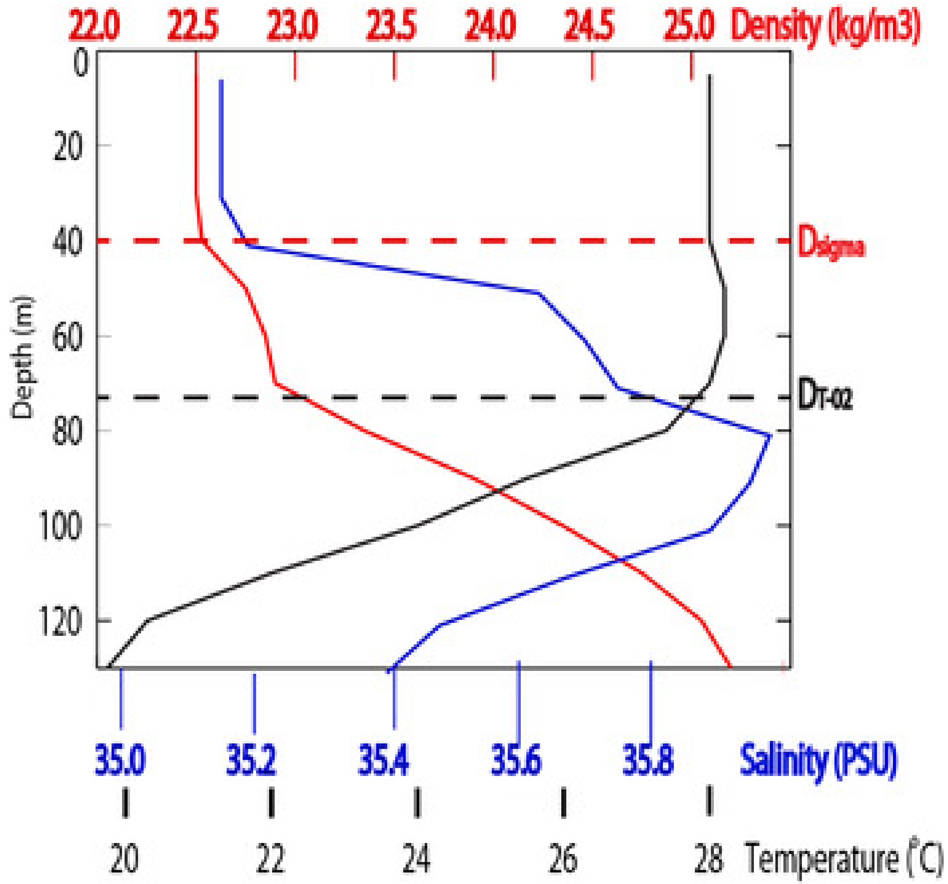


  - Subsurface downwelling/upwelling movements
  - Cloudiness/Rainfall

Ocean variability in seasonal models

- Mixed Layer Depth



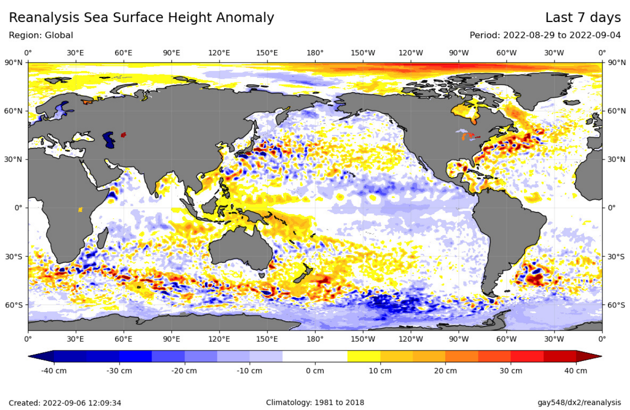


Sea Level Modelled in ACCESS-S

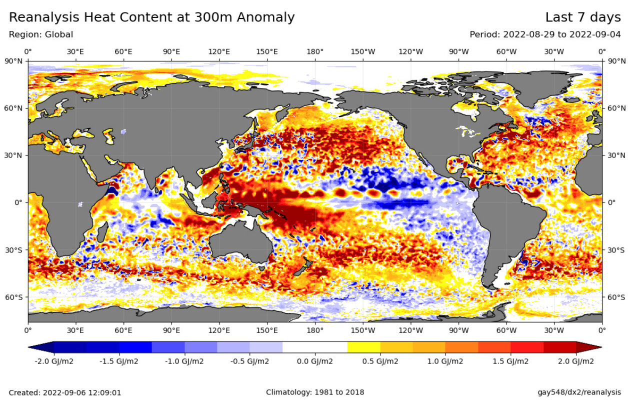
	CAUSES	TIME SCALE	SPACE SCALE
Wave Runup	Swell / wind waves	seconds	Shoreline/ reef 10s to 100s of metres
Wave Setup		Hours	
Storm Surge	Storms (pressure, wind stress)	Hours to days	Shelf areas 10s to 100s of kilometres
Astronomical Tides	Lunar & solar gravity	Hours to decades	
Oscillations (Seasonal / Inter-annual)	ocean/ atmosphere climate oscillations	Weeks to Months	Ocean basin 1000s of kilometres

Ocean variability in seasonal models

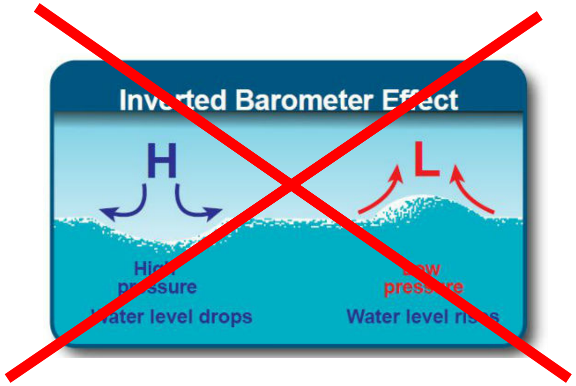
- Sea level
  - Subsurface density changes from temperature and salinity variation
  - Sea level mainly attributed to subsurface warming in most places



Sea level anomaly



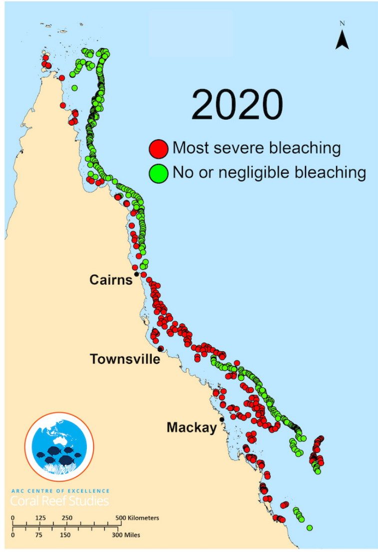
Heat Content Anomaly (300 m)

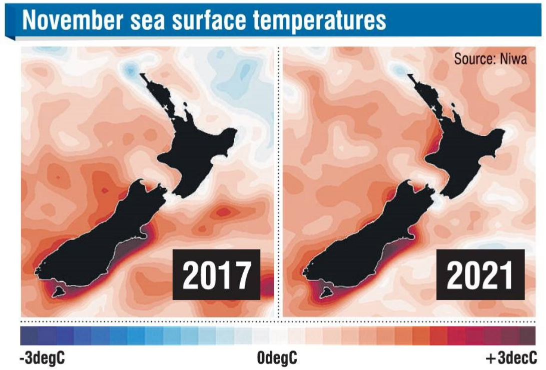


- Not included: Inverse Barometer effect

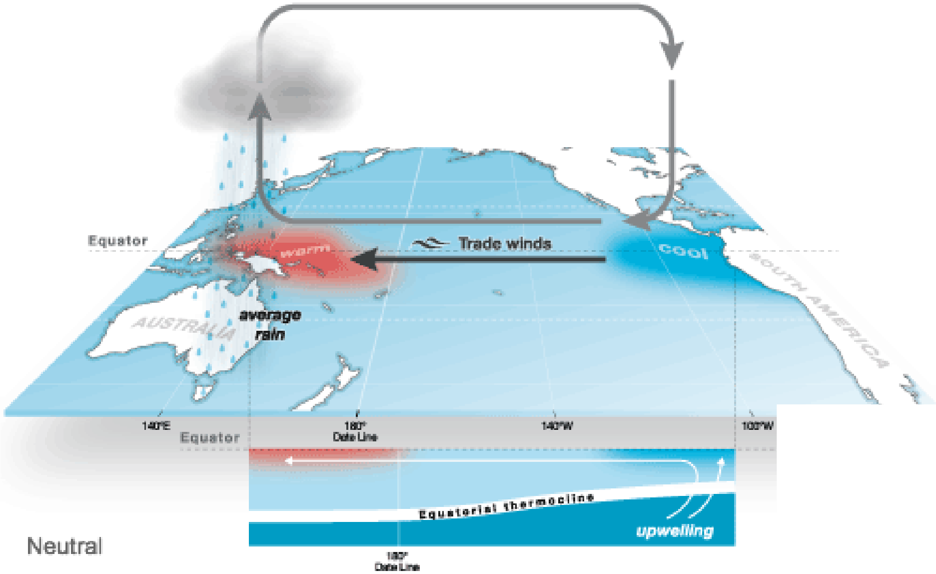
Ocean variability: climate drivers

- El Niño Southern Oscillation (ENSO)
  - SST and Sea level changes in the tropics
- MJO
  - Rainfall/Cloudiness and wind impacts on SST
- ITCZ/SPCZ
  - Cloudiness decreases insolation (sun shining on the ocean)

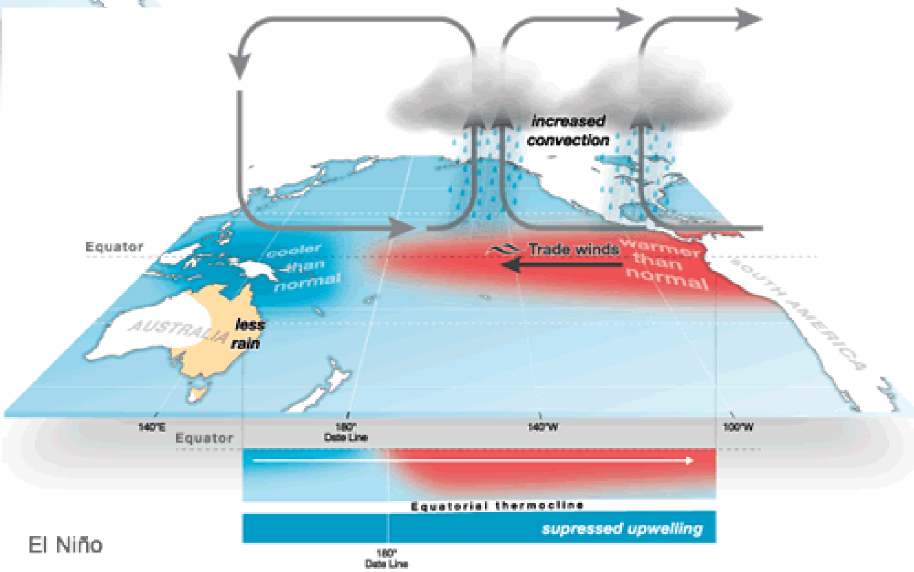




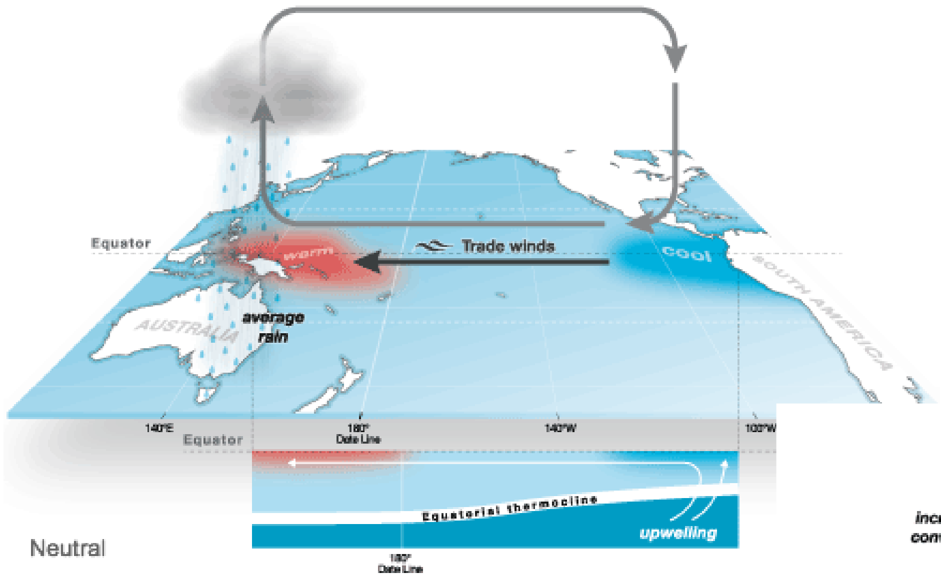
El Niño Southern Oscillation (ENSO):
El Niño Events

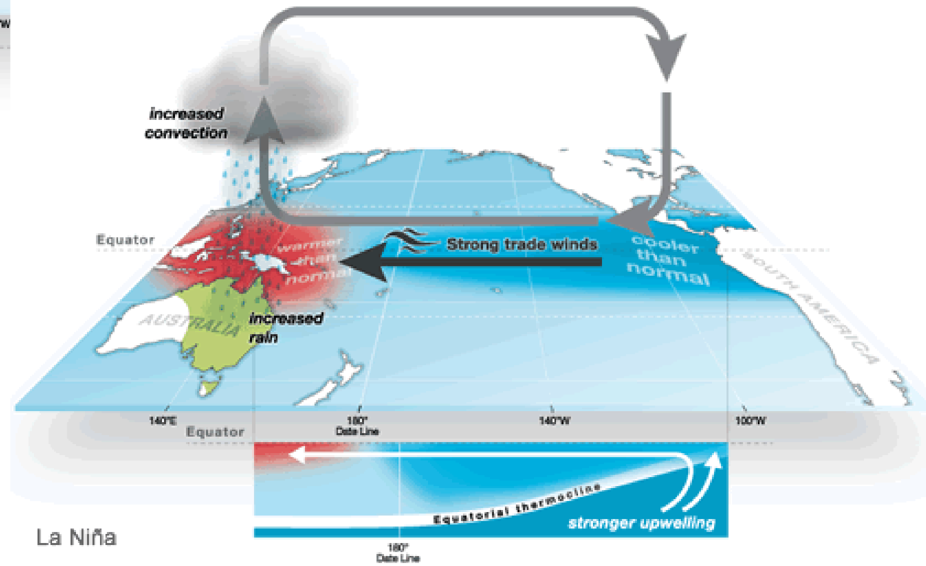


http://www.bom.gov.au/climate/enso/history/ln-2010-12/three-phases-of-ENSO.shtml



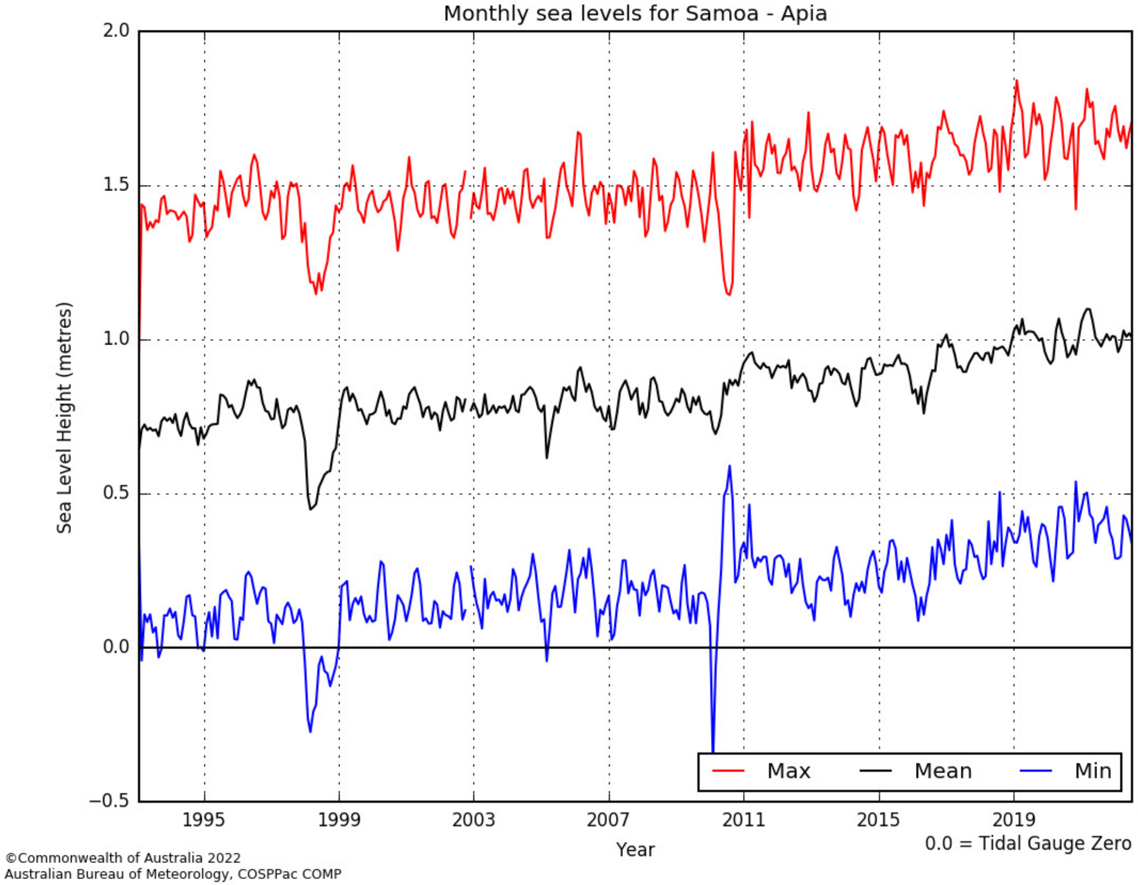
El Niño Southern Oscillation (ENSO): La Niña Events

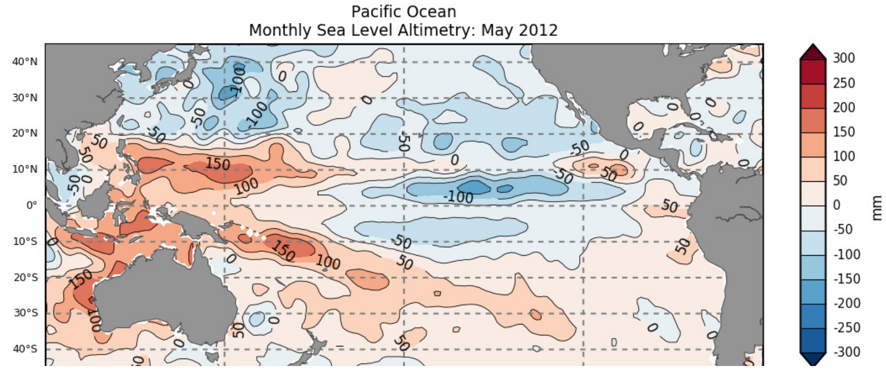


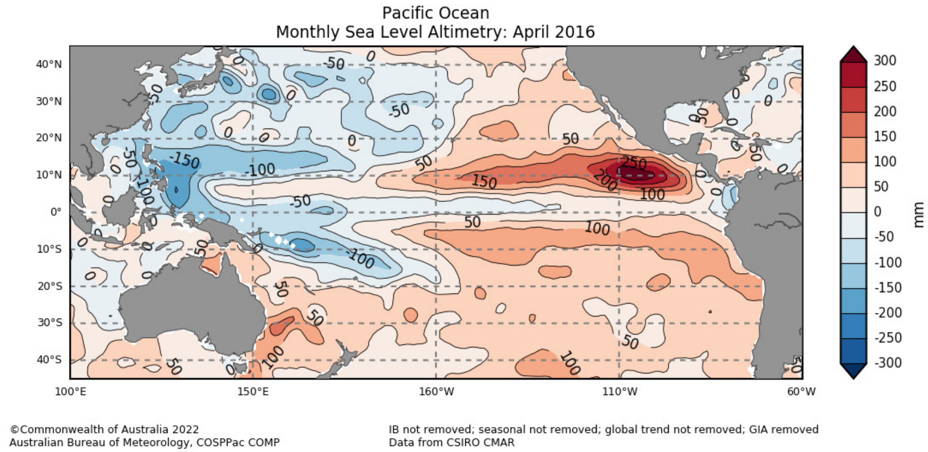


http://www.bom.gov.au/climate/enso/history/ln-2010-12/three-phases-of-ENSO.shtml

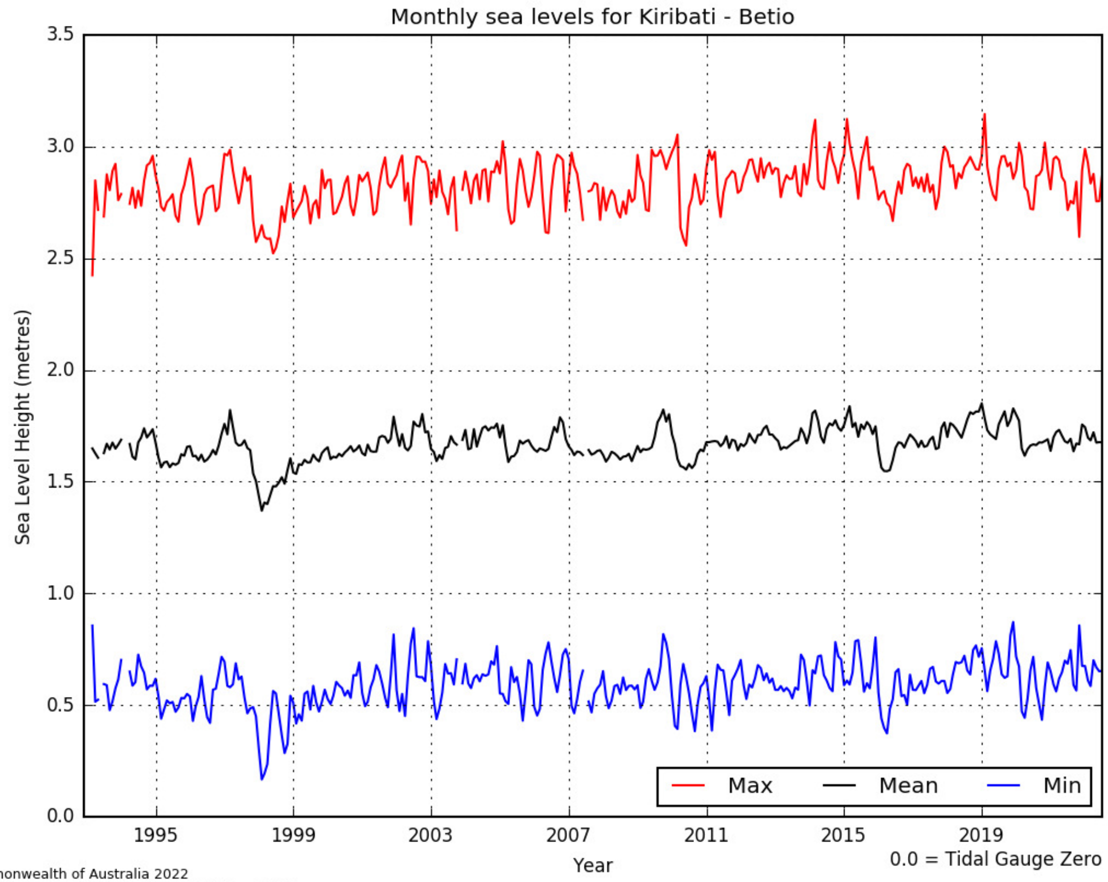
ENSO cycles and Sea Level

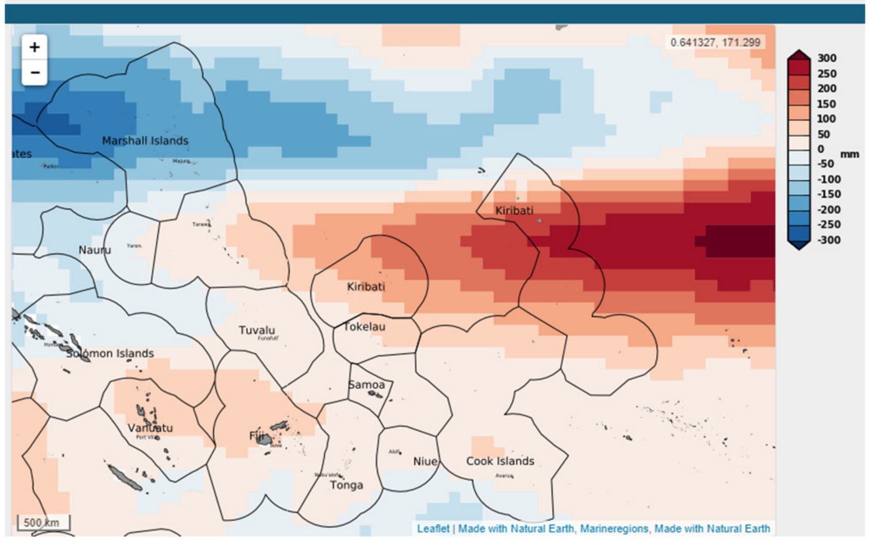


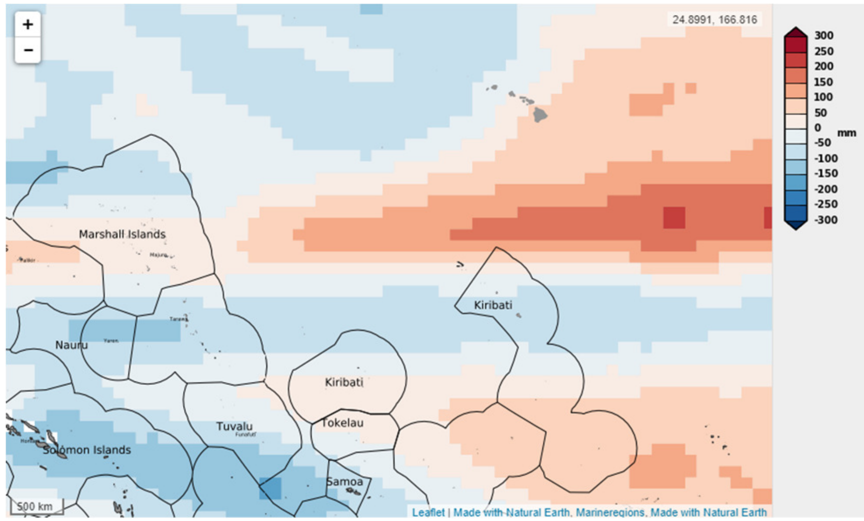




ENSO cycles and Sea Level



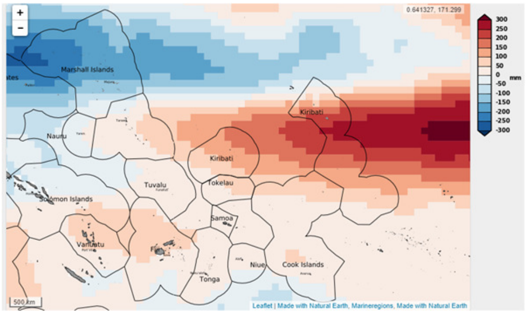


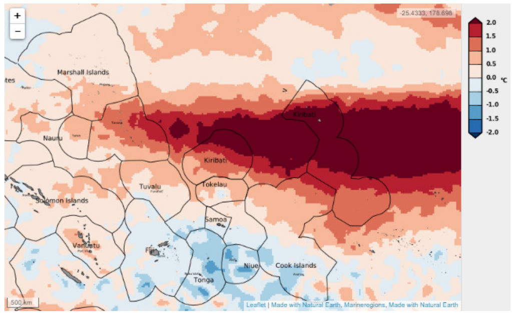


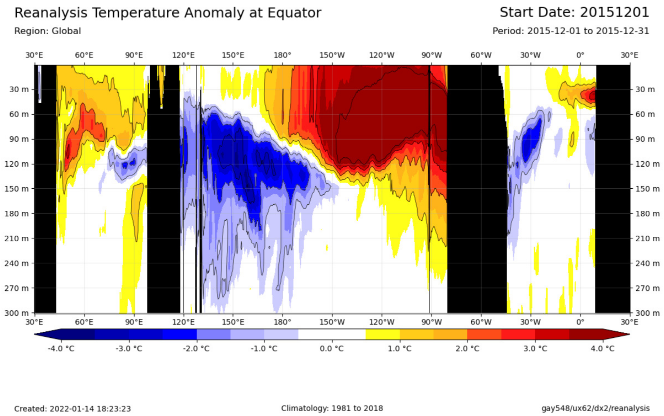
ENSO cycles and Sea Level

Sea Level Anomaly | SST Anomaly | Subsurface Anomaly

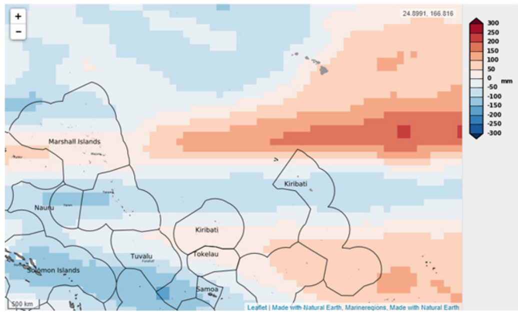
December 2015

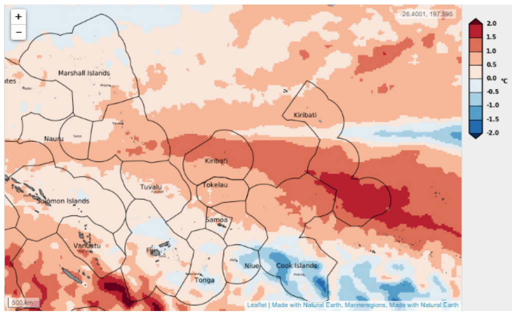


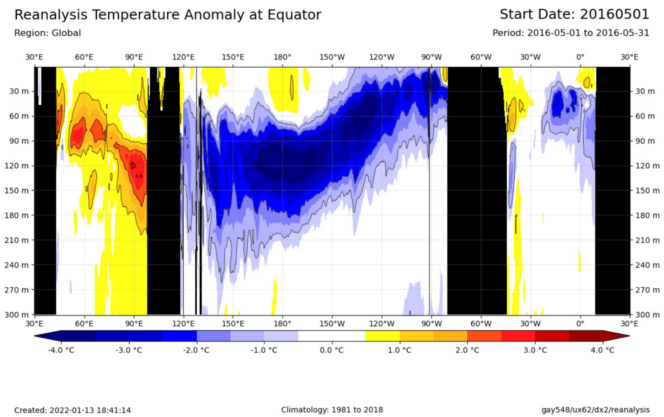




April 2016

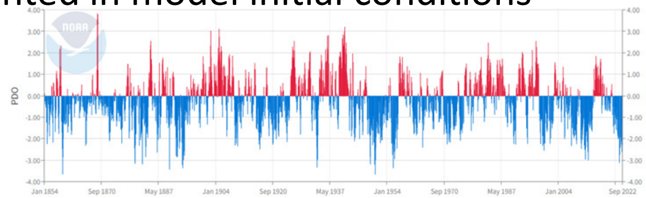


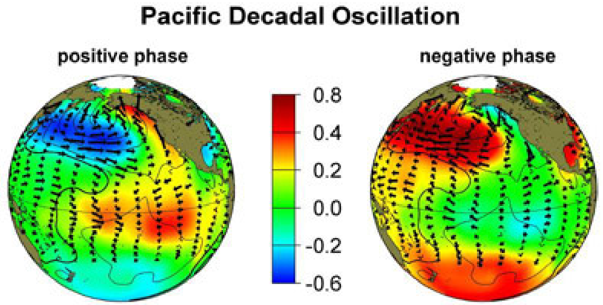




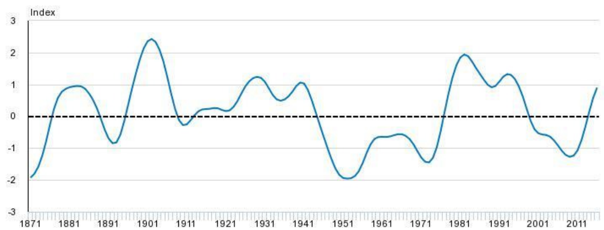
Ocean Variability: Years to decades

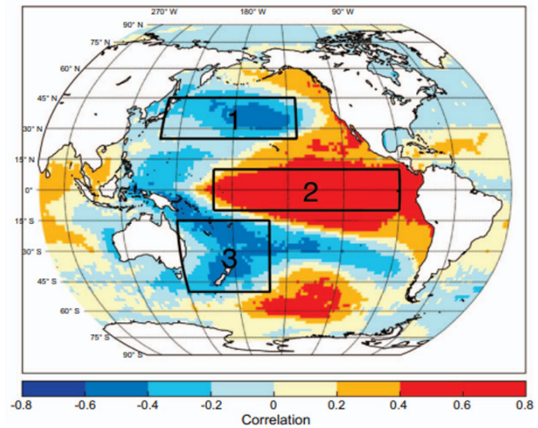
- PDO – Pacific Decadal Oscillation
  - Index compares North Pacific SST patterns to equatorial Pacific
  - Usually oscillates around 5 to 10 year intervals
  - Represented in model initial conditions





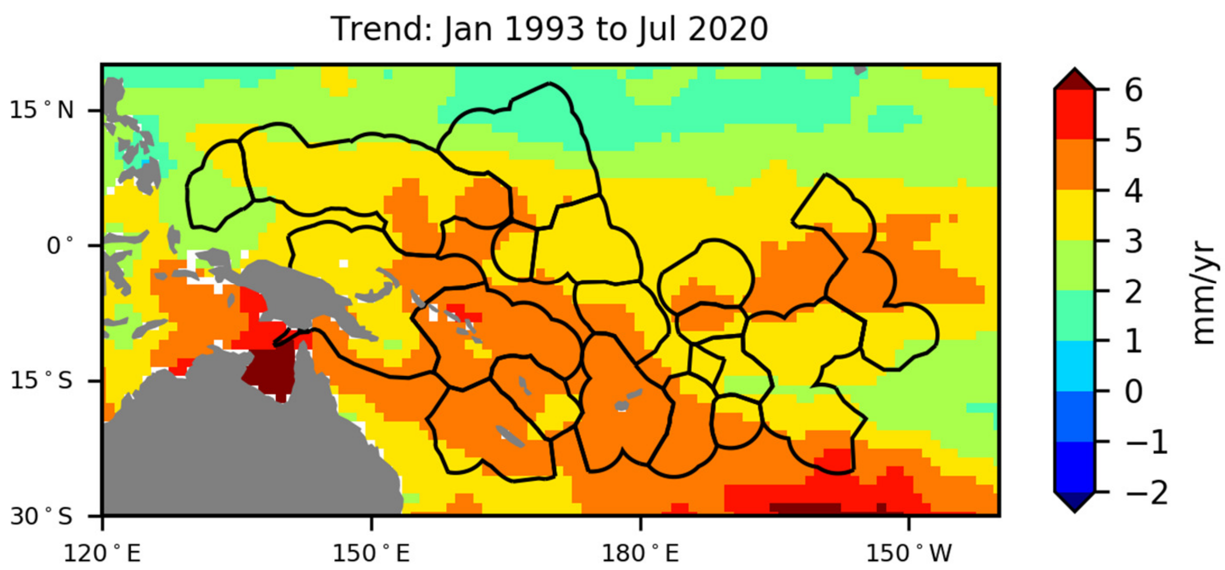
- IPO – Interdecadal Pacific Oscillation
  - Index compares both north and south Pacific SST to equatorial Pacific
  - 15 to 30 year oscillations
  - Represented in model initial conditions





Ocean Variability: Years to decades

- Climate Change – Sea Level Rise
  - Current global trend is +3.40 mm/year
  - Sea level observations not part of ACCESS-S initial conditions
  - Removed ACCESS-S2 post processing (detrended)



Past and future coastal flooding for Pacific Small-Island Nations

Mathilde Ritman

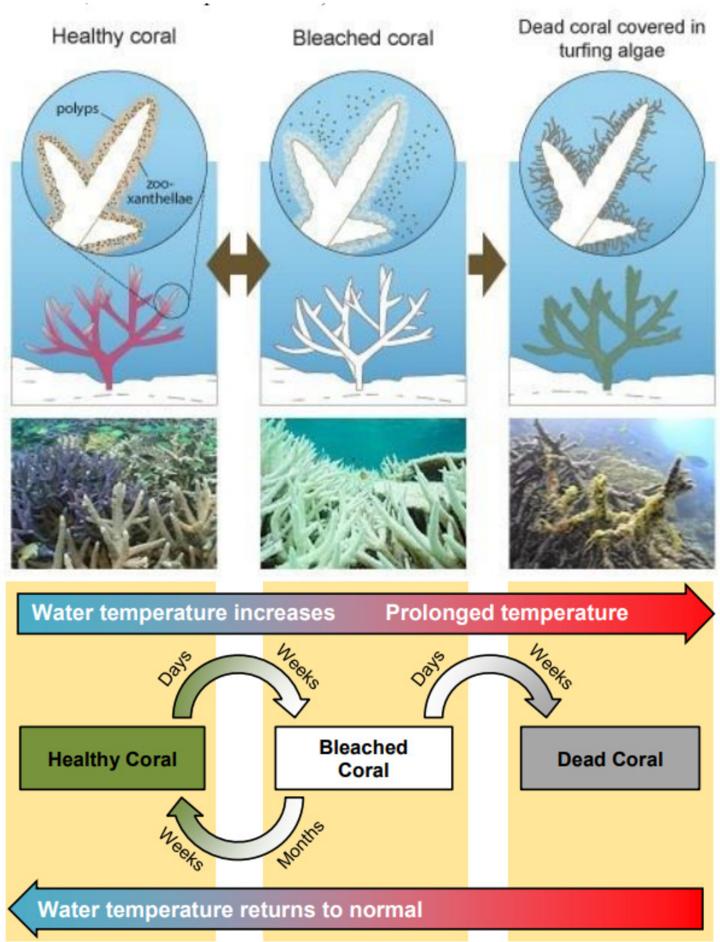
Module 16: Marine Applications

Climate and Oceans Support Program in the Pacific
COSPPac

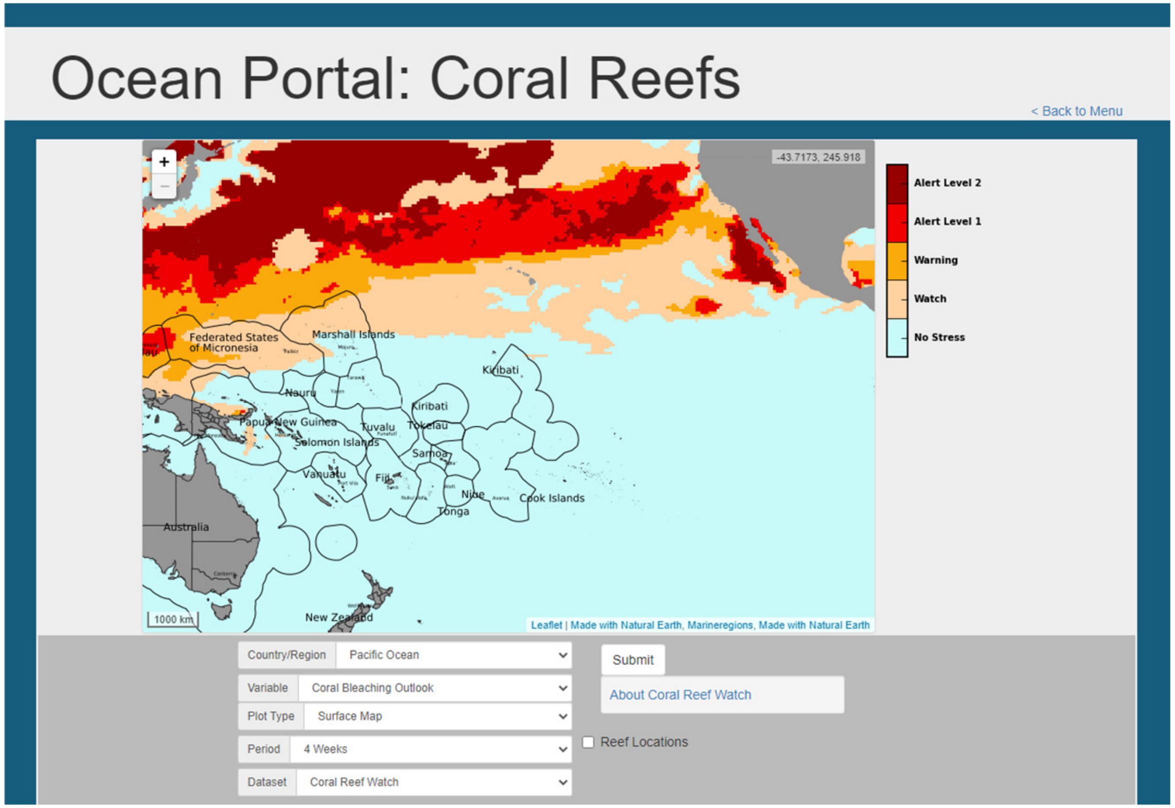
Australian Government
Department of Foreign Affairs and Trade
Bureau of Meteorology

Sea Surface Temperature

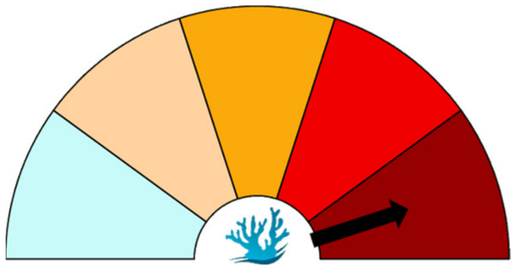
- Environmental health
  - Coral bleaching
  - Lagoon health (deoxygenation)
- Fisheries/Aquaculture
  - Pelagic fish migrations
  - Aquaculture site selection & management



Sea Surface Temperature: Coral bleaching



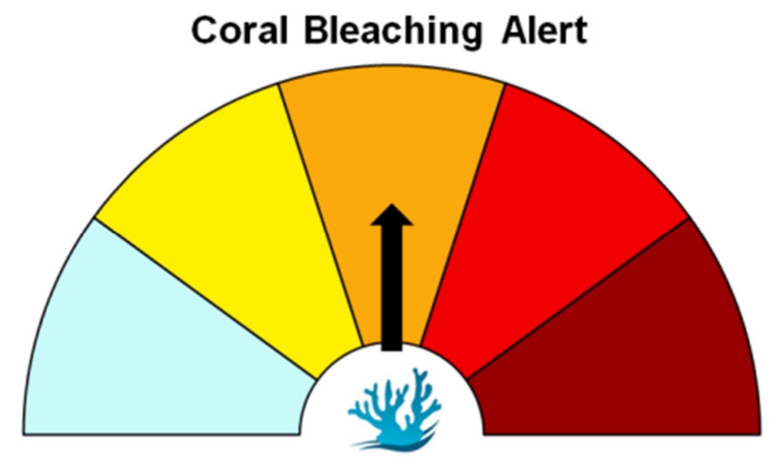
- Coral Bleaching outlooks available in the ocean portal
- Derived from SST outlooks from NOAAs CFSv2



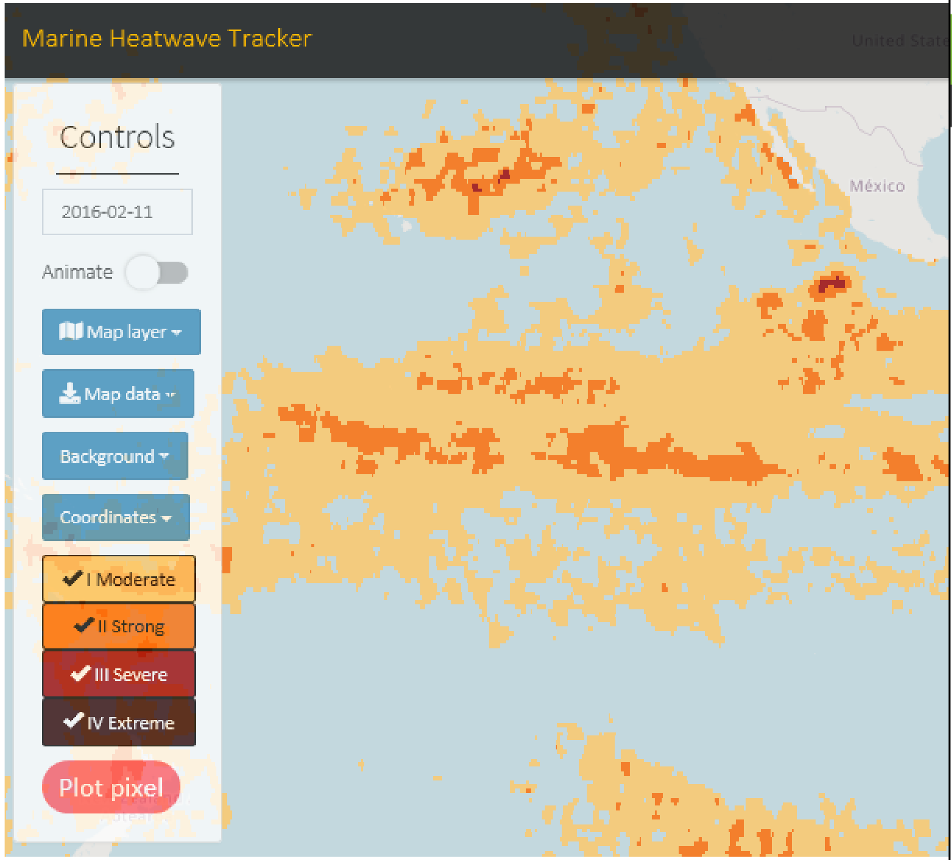
Sea Surface Temperature: Coral bleaching

Alert Level	Level Definition	Effect
No Stress	HotSpot ≤ 0.0	No thermal stress
Bleaching Watch	Watch 0.0 < HotSpot < 1.0	Low-level thermal stress
Bleaching Warning	1.0 ≤ HotSpot and 0.0 < DHW < 4.0	Coral bleaching possible
Bleaching Alert Level 1	1.0 ≤ HotSpot and 4.0 ≤ DHW < 8.0	Coral bleaching likely
Bleaching Alert Level 2	1.0 ≤ HotSpot and 8.0 ≤ DHW	Coral mortality likely

Alert Level	Effect
No Data	No alert data available
No Stress	No thermal stress
Bleaching Watch	Low-level thermal stress
Bleaching Warning	Coral bleaching possible
Bleaching Alert Level 1	Coral bleaching likely
Bleaching Alert Level 2	Coral mortality likely

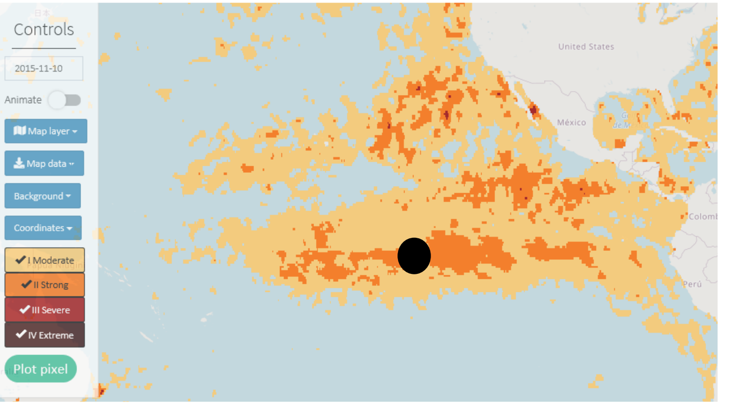


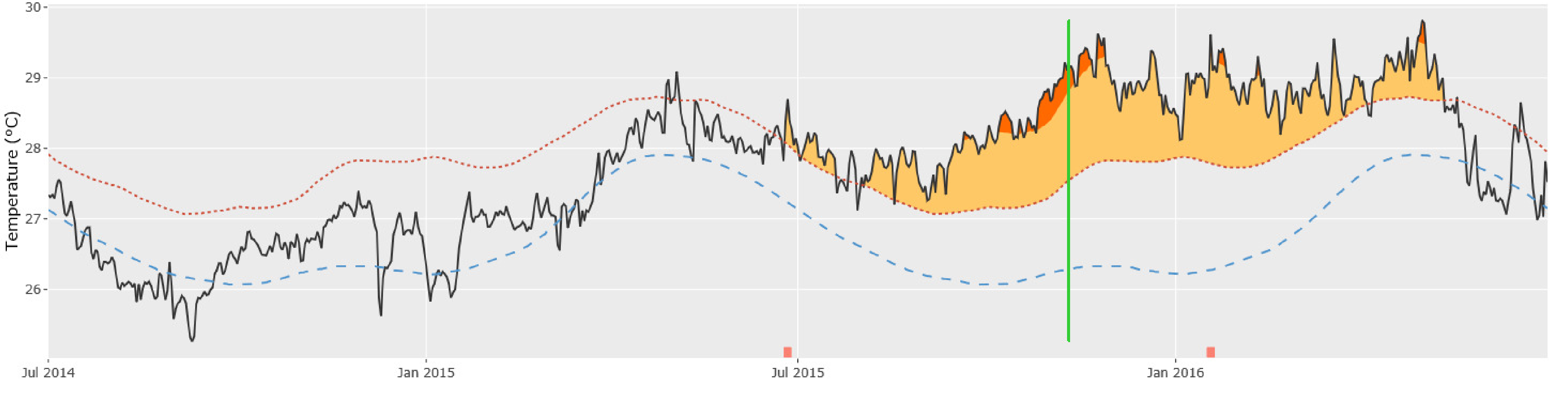
Marine Heatwaves: Impacts (Kiribati)



Marine Heatwaves: Impacts

- Almost 3 years of anomalously warm temperatures
- Peaking during the 2015-2016 El Niño at Category 2 - Strong





Marine Heatwaves: Impacts

HUFFPOST

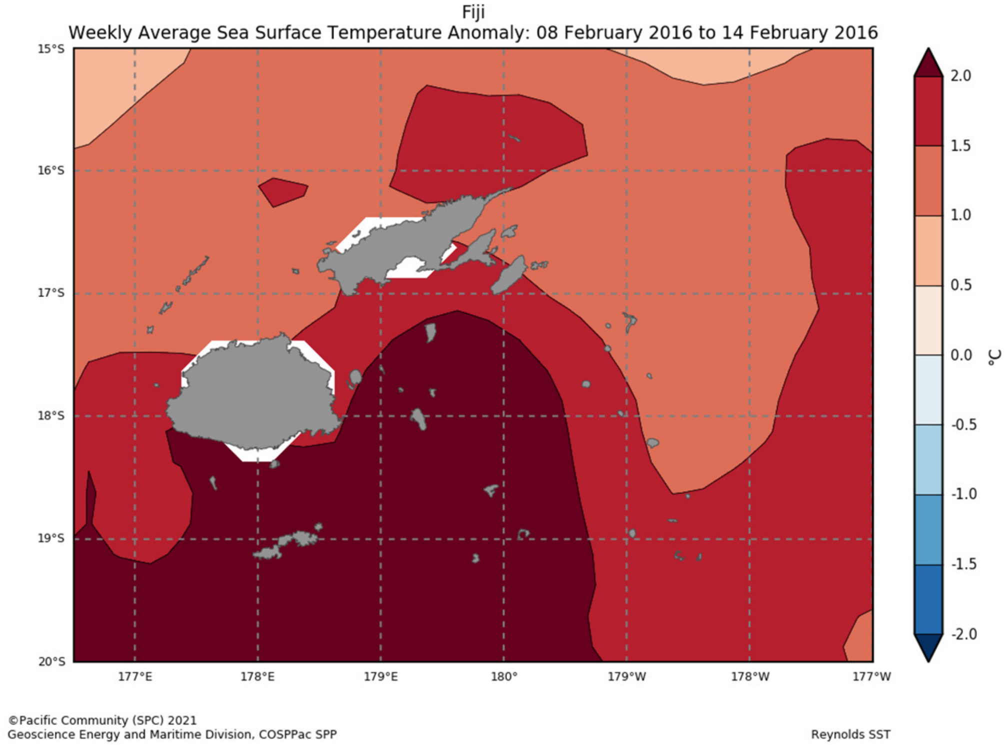
NEWS CORONAVIRUS POLITICS 2020 ELECTIONS ENTERTAINMENT LIFE PERSONAL VIDEO SHOPPING

Lagipoiva Cherelle Jackson, Contributor
Independent Samoan Writer

Fish Kills Reported in Fiji and Vanuatu

02/15/2016 03:43 pm ET | **Updated** Dec 06, 2017

You know how we talk about worst case scenario of climate change impacts? Well, it's happening now in some Pacific islands. All across the Pacific, high temperatures have been recorded and residents reported the hottest months they have ever experienced. For some islands however, the impacts have gone beyond a daily nuisance to a serious marine threat. Last week reports from Vanuatu and Fiji showed fish kills by the thousands as a result of the temperatures.



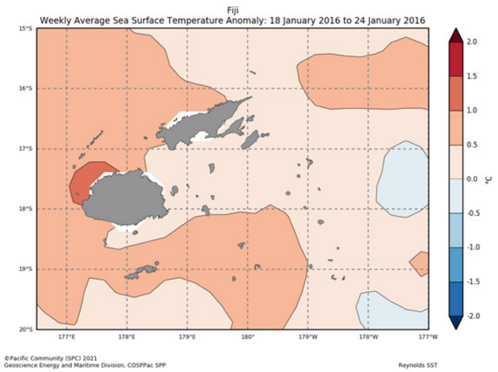
Marine Heatwaves: Impacts (Fiji)

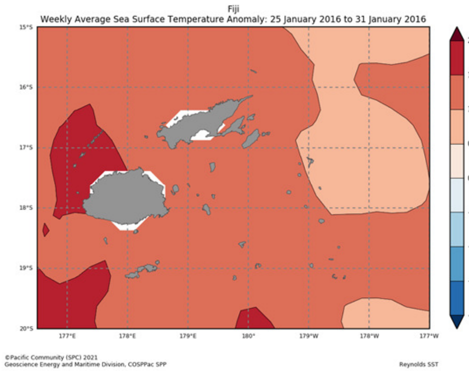
- 21 January 2016

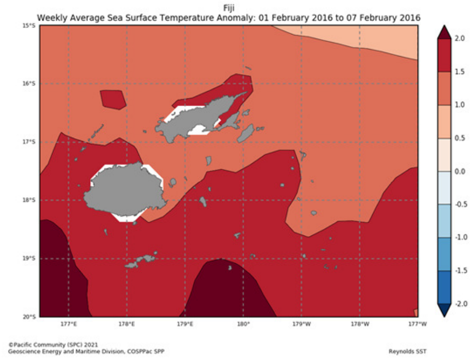
28 January 2016

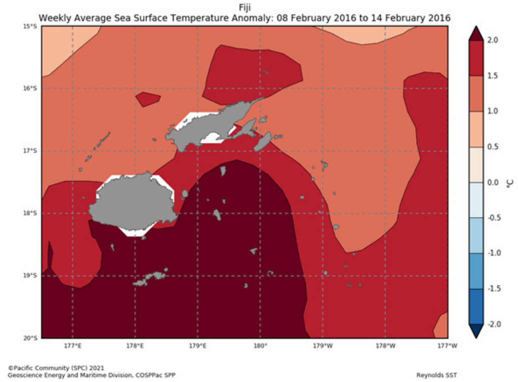
4 February 2016

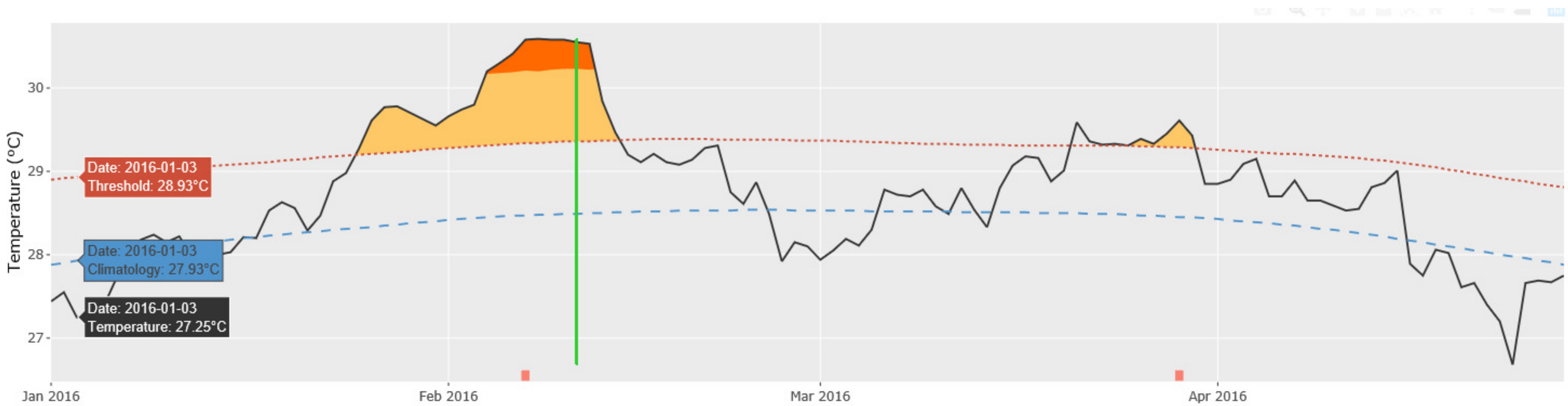
11 February 2016









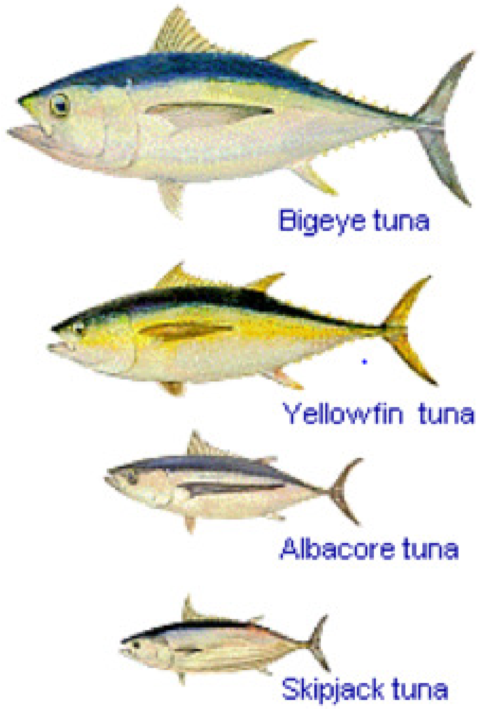


Fisheries in the Pacific

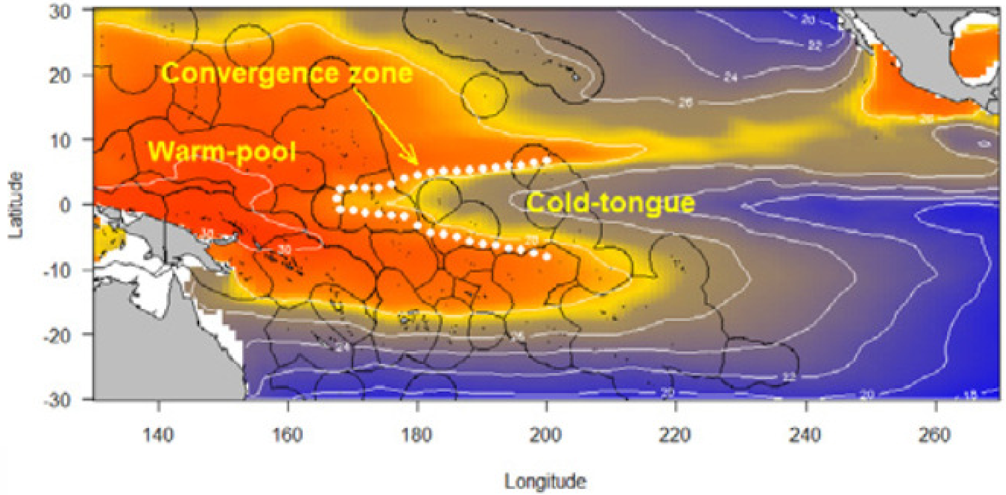
- Major source of animal protein in the diet of most Pacific Islanders (1 billion people worldwide)

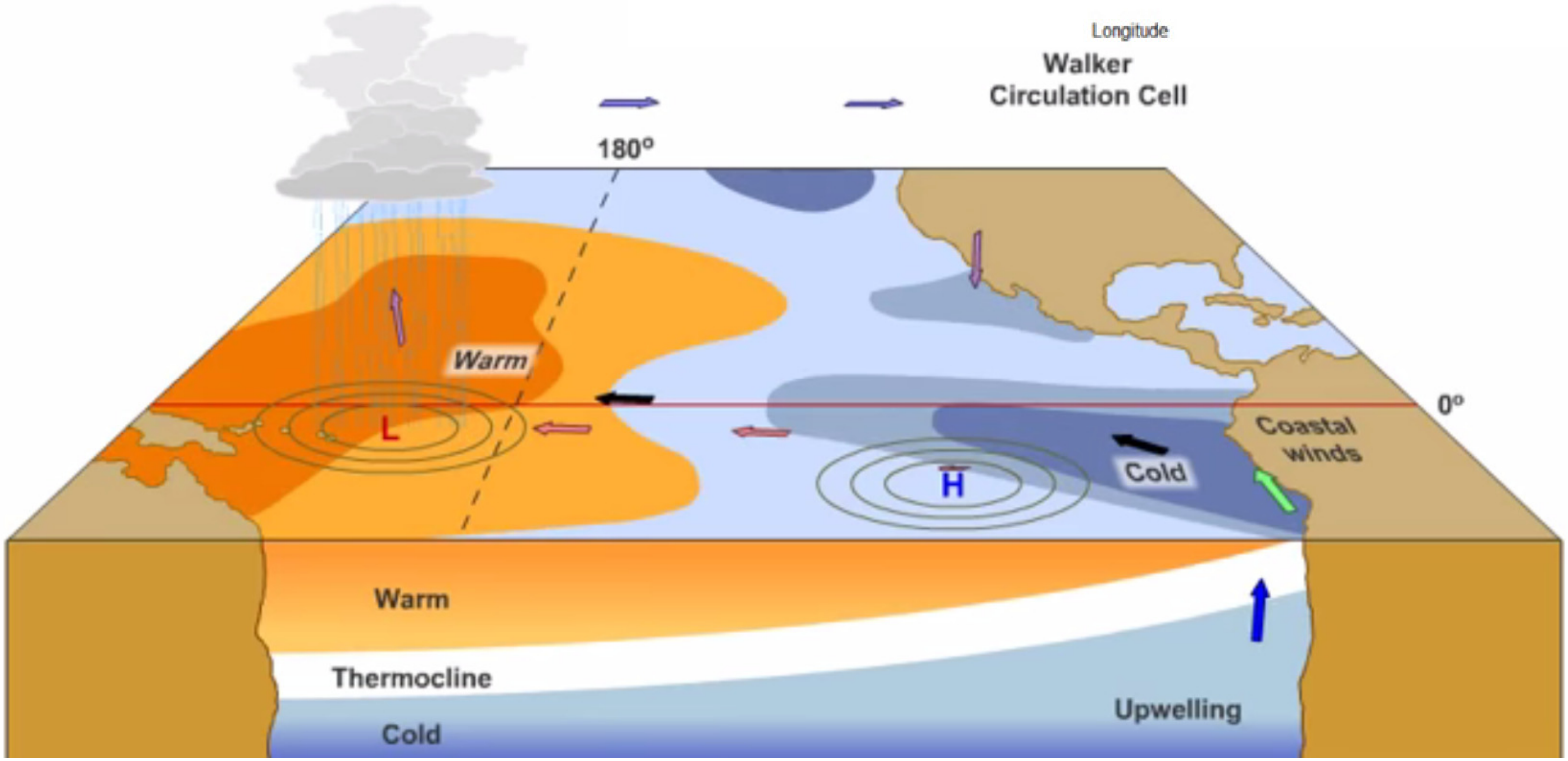
- Primary source of cash income (tuna)

- Primary source of food security (tuna and reef fish)



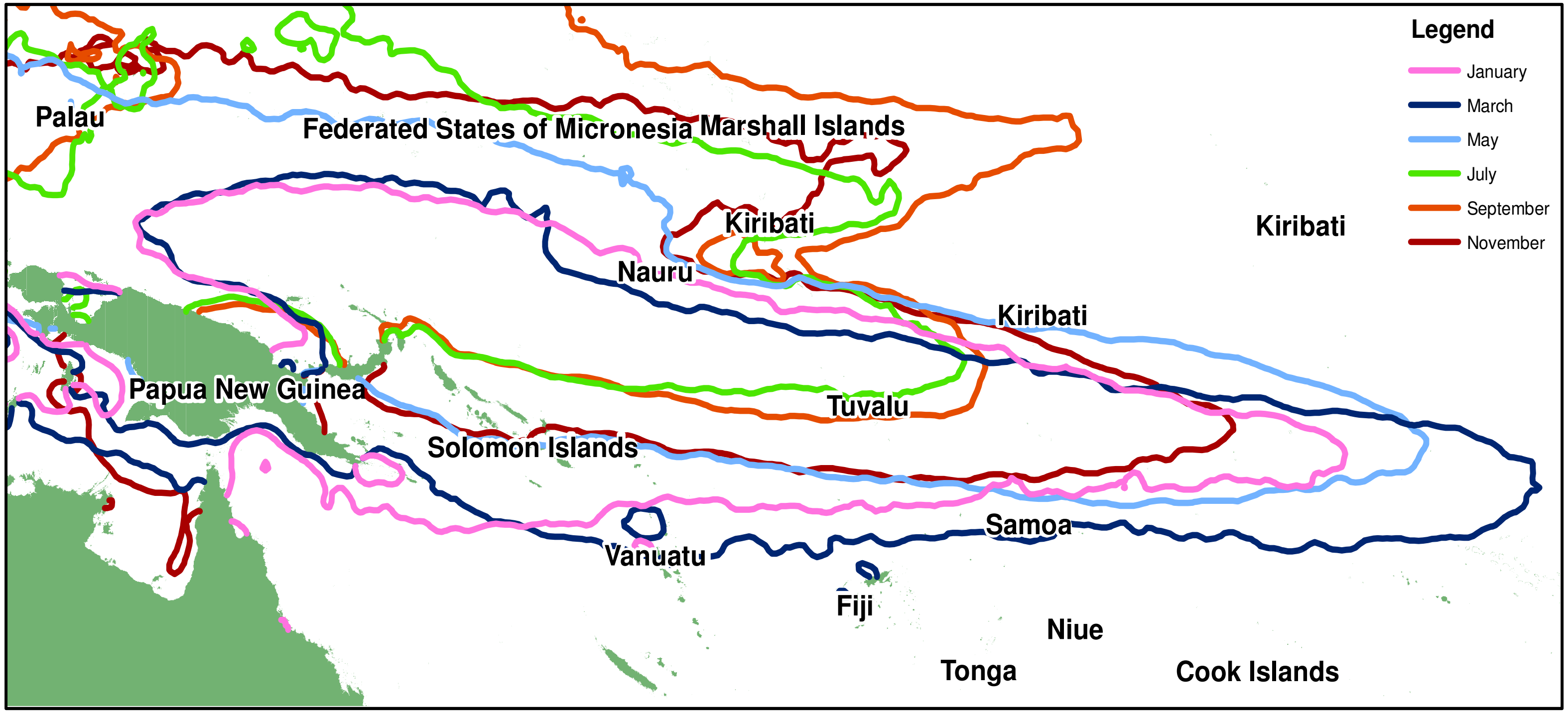
Distribution of Tuna



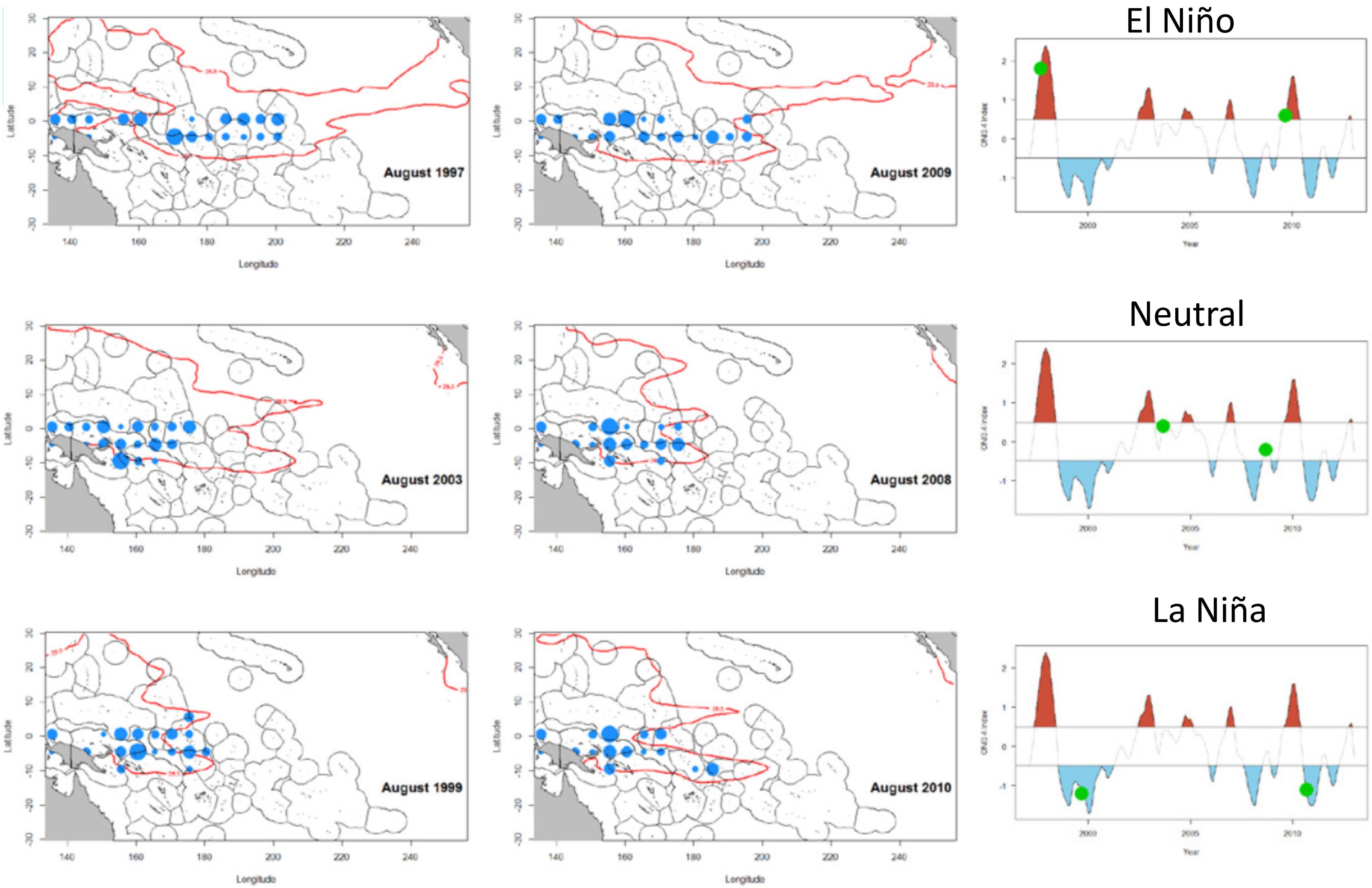


Fisheries: Convergence Zone

- The convergence zone is a well-defined salinity front that surrounds the western Pacific warm pool.



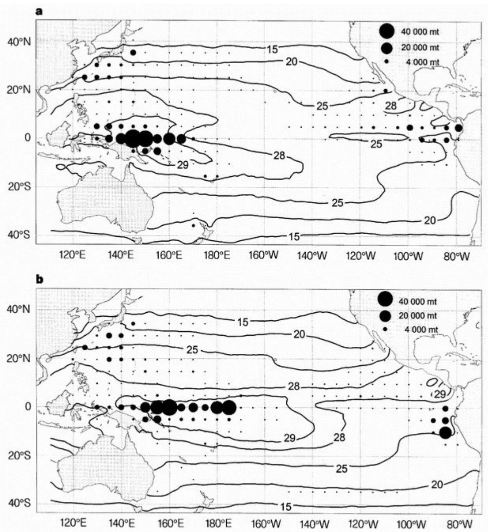
SPC Tuna factsheet

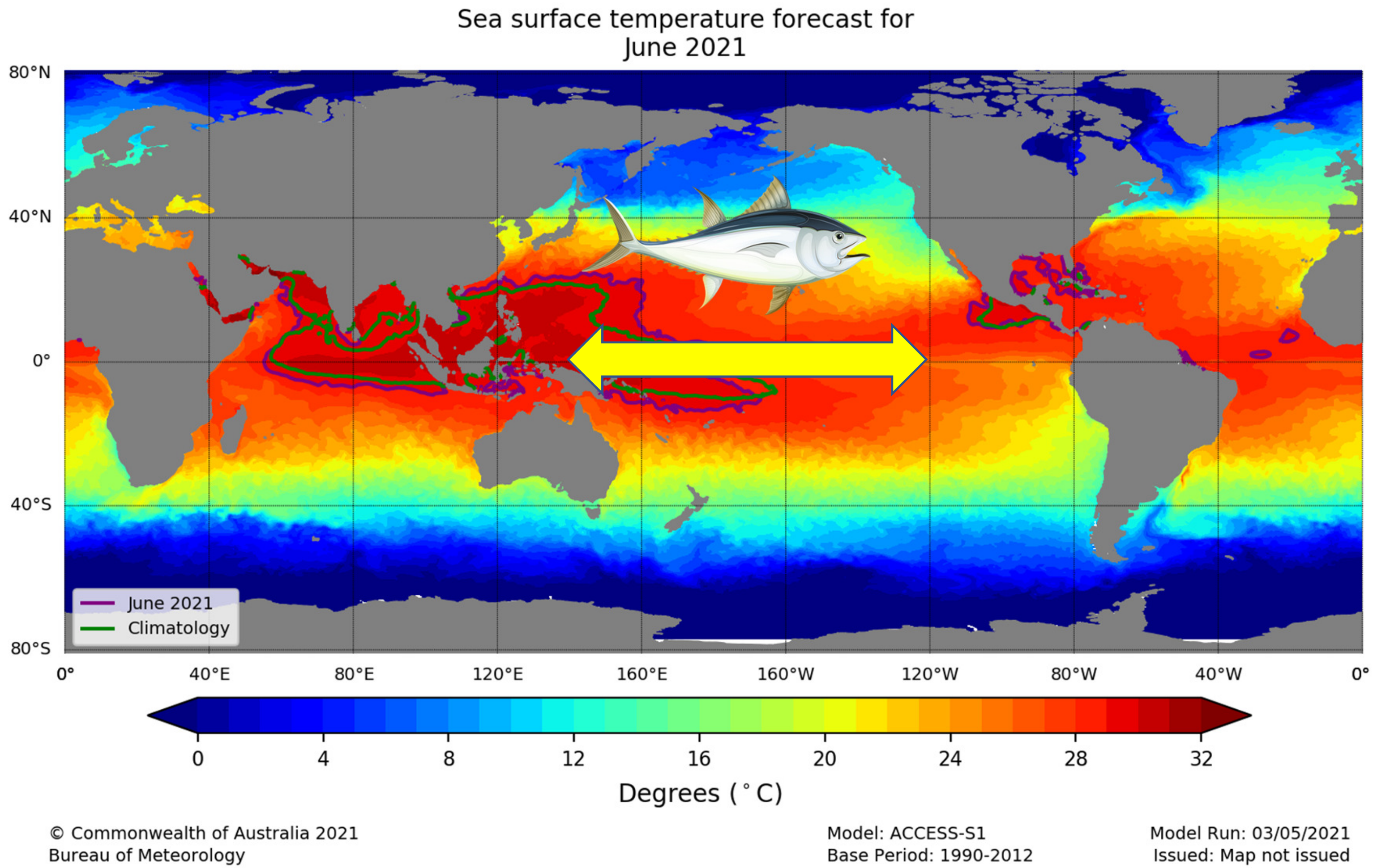


Seasonal Outlooks For Fisheries

SeasOF

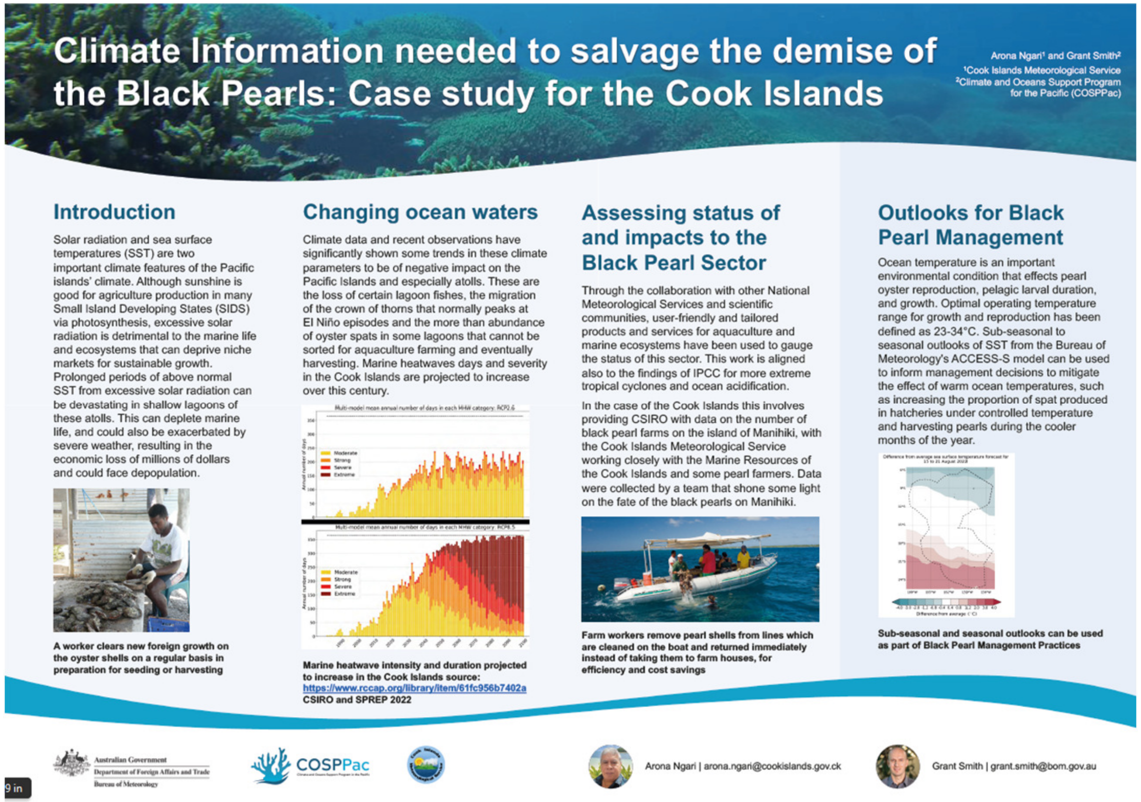
- Tuna (skipjack in below example) drifts with the Western Warm Pool boundary





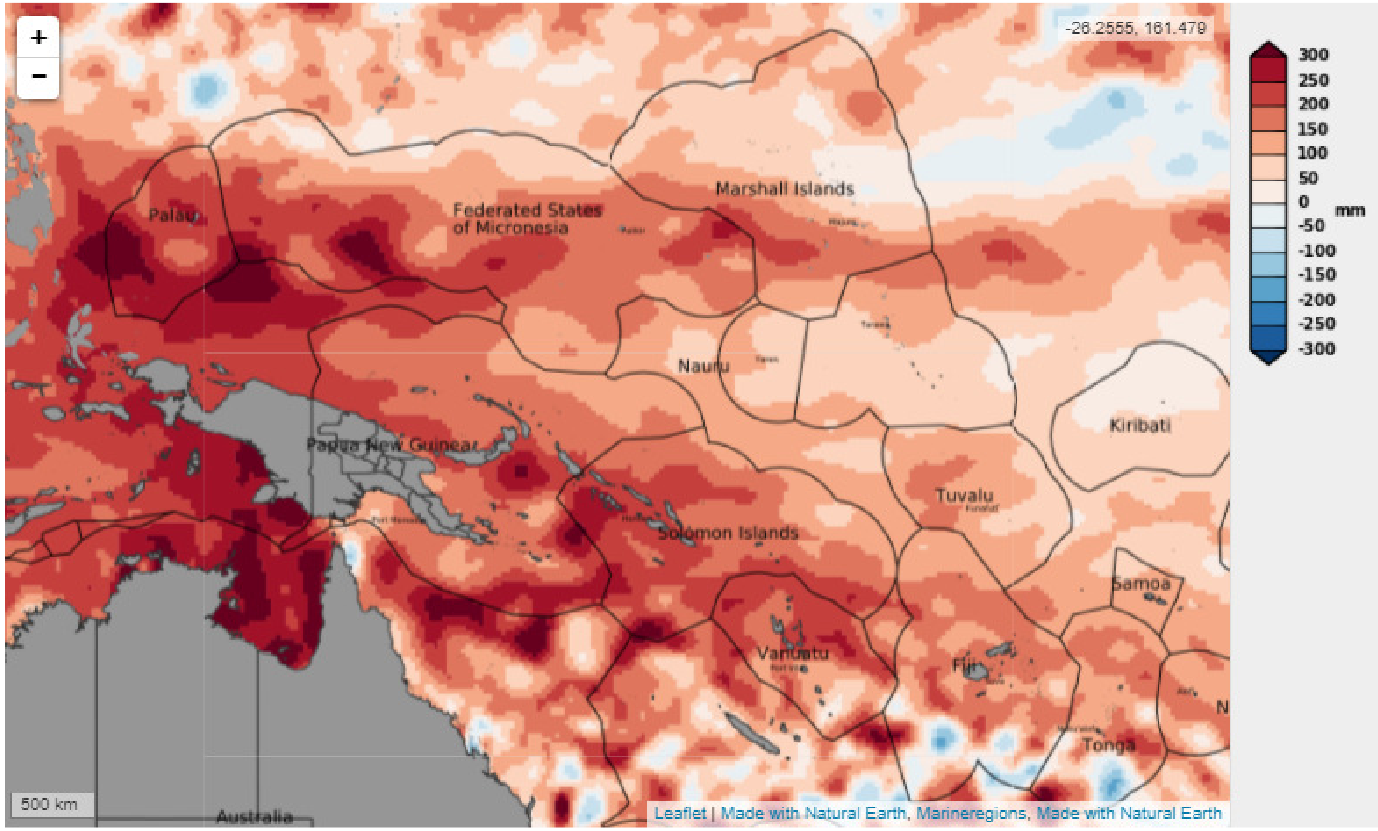
Sea Surface Temperature: Management of aquaculture

Ocean temperature is an important environmental condition that effects pearl oyster reproduction, pelagic larval duration, and growth. Optimal operating temperature range for growth and reproduction has been defined as 23-34°C. Sub-seasonal to seasonal outlooks of SST from the Bureau of Meteorology's ACCESS-S model can be used to inform management decisions to mitigate the effect of warm ocean temperatures, such as increasing the proportion of spat produced in hatcheries under controlled temperature and harvesting pearls during the cooler months of the year.



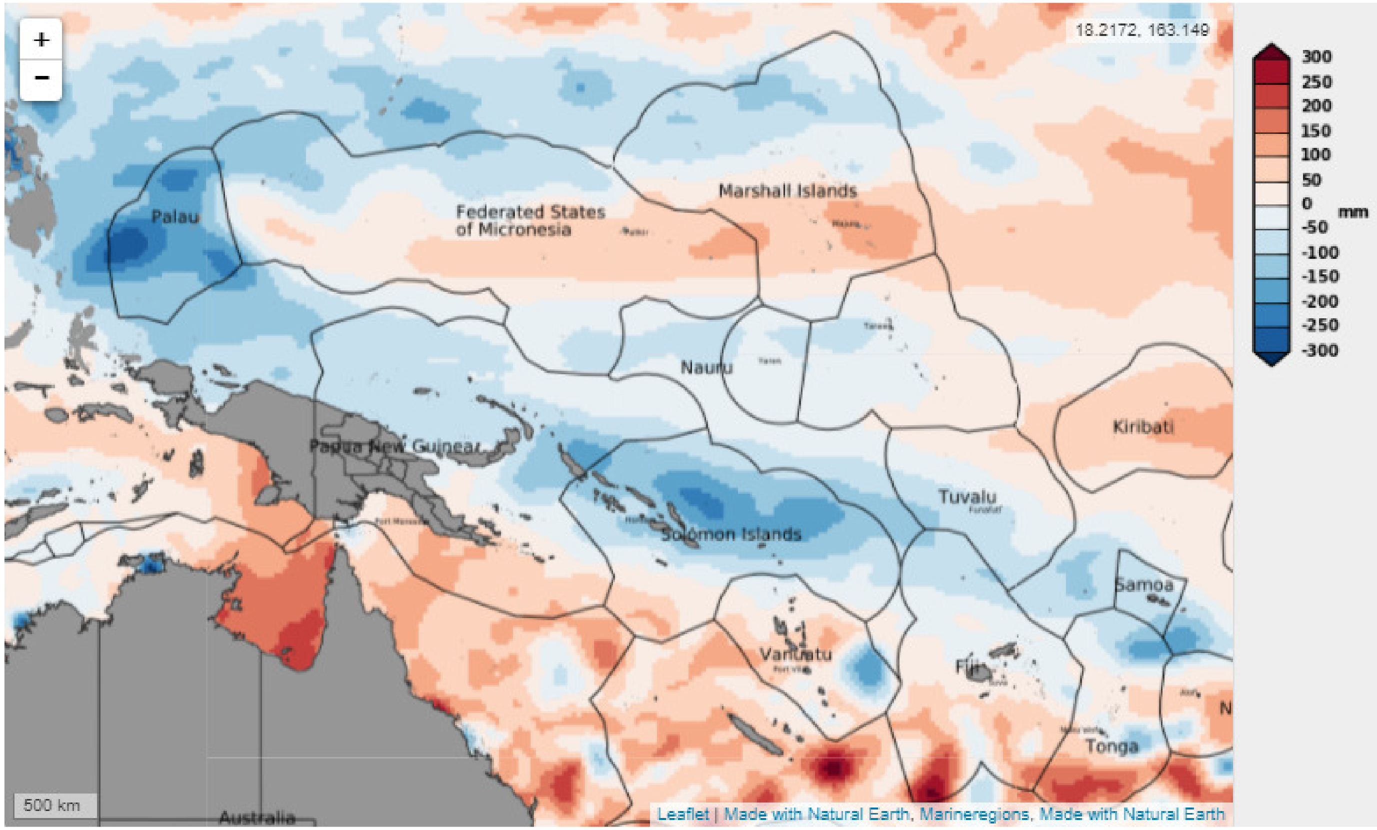
Sea level: Coastal hazards

Pictured Above: An island suffers from saltwater inundation

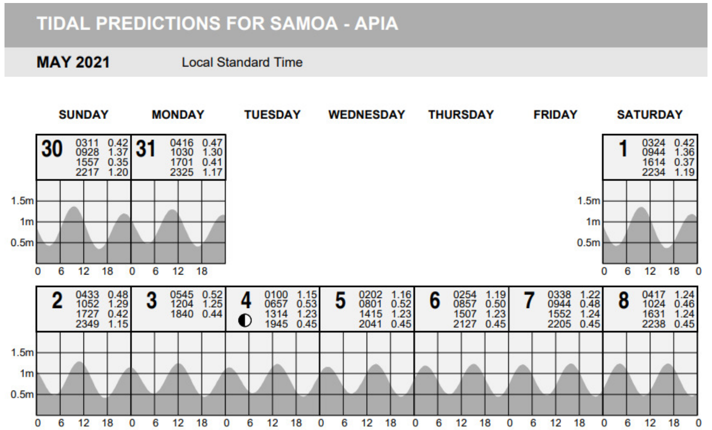


Sea level: Low water standings

- Taimasa



Inundation or Reef Exposure Risk



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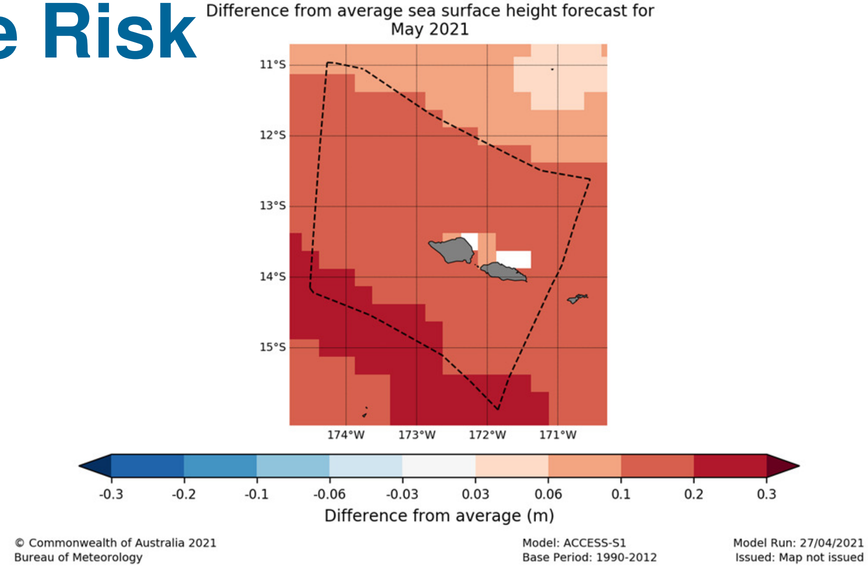

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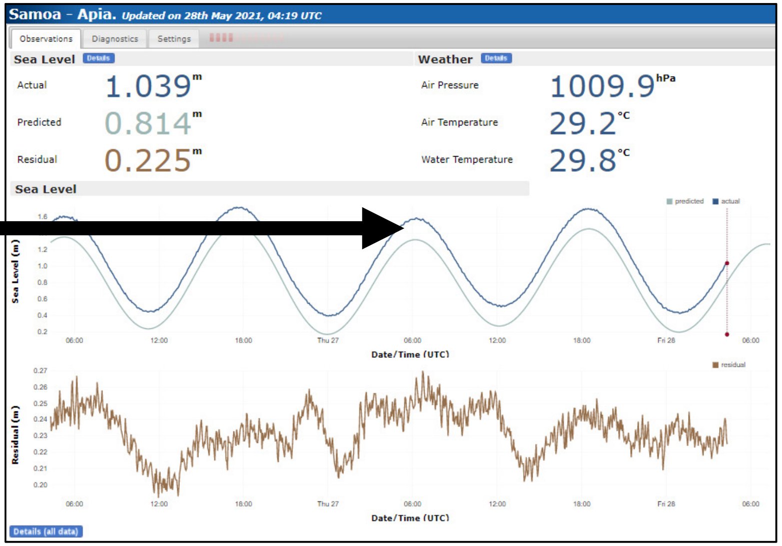

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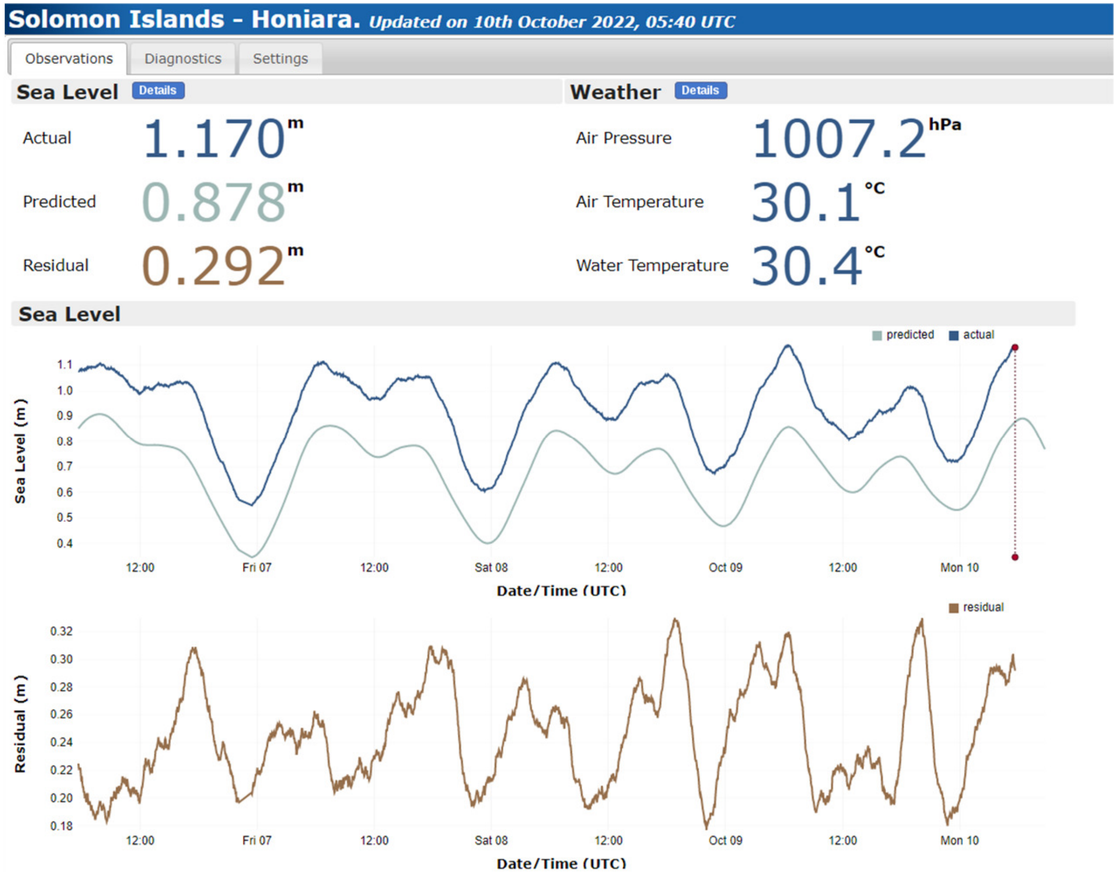
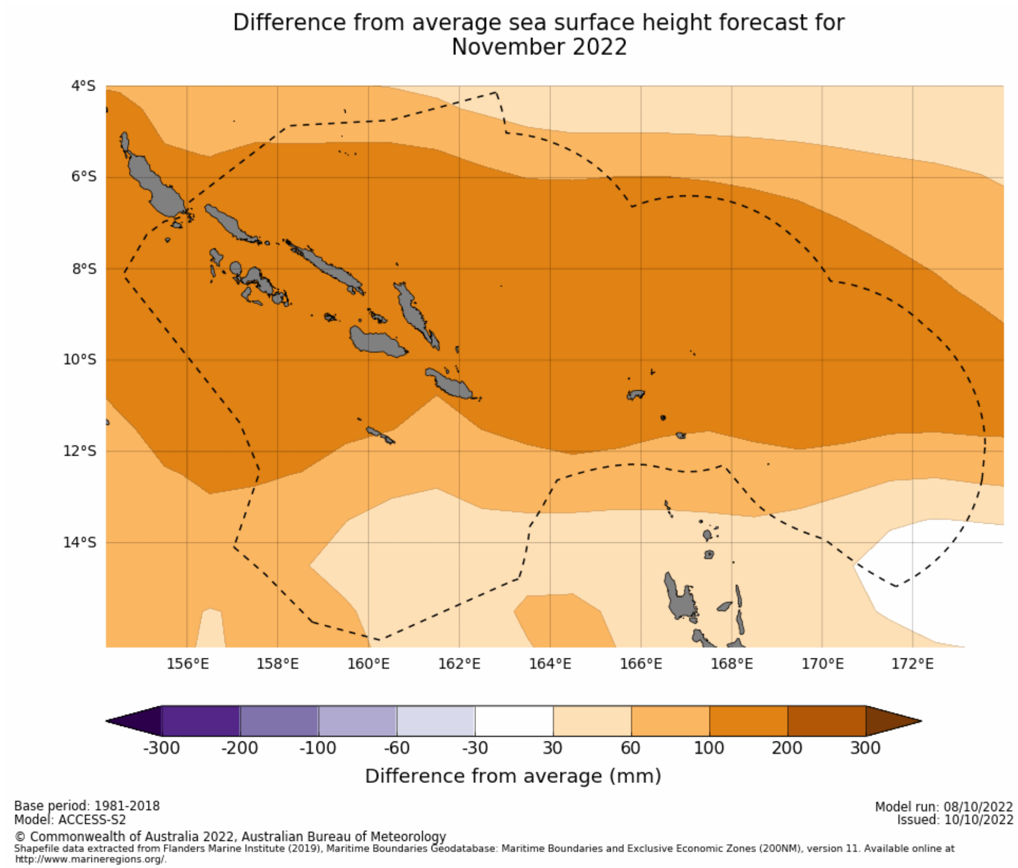
How good is the tides + anomaly method?





PNG Case Study: December 2021

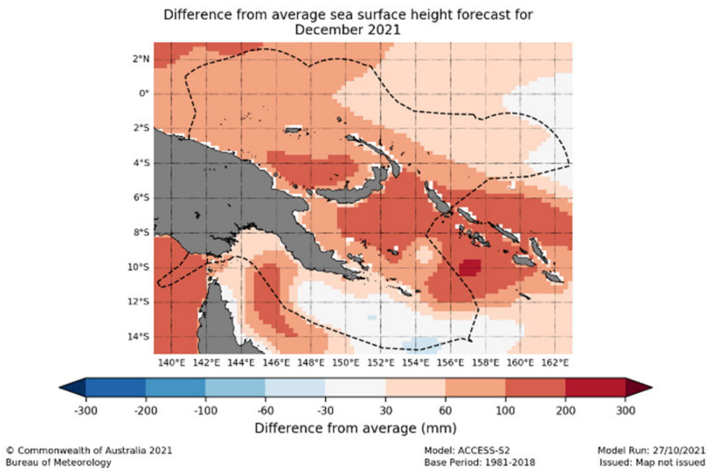
PNG Case Study

2021

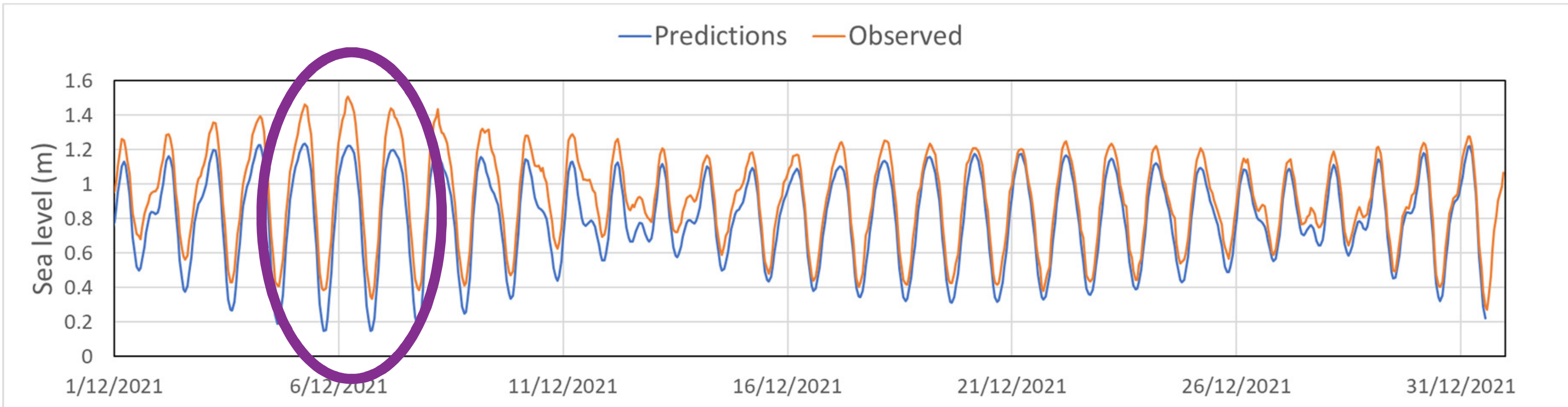
Time Zone –1000

DECEMBER

Day	Time	m	Day	Time	m
1 WE	0409 0807 1505 2306	0.82 0.72 1.13 0.50	**16** TH	1504	1.09
2 TH	0610 0809 1512 2347	0.84 0.83 1.17 0.37	**17** FR	0011 1413	0.38 1.10
3 FR	1522	1.20	**18** SA	0037 1341	0.34 1.13
4 SA ●	0035 1534	0.26 1.23	**19** SU ○	0106 1346	0.32 1.16
5 SU	0128 1544	0.18 1.24	**20** MO	0137 1407	0.31 1.18
6 MO	0224 1526	0.14 1.22	**21** TU	0213 1432	0.32 1.18
7 TU	0323 1445	0.14 1.20	**22** WE	0253 1454	0.33 1.17

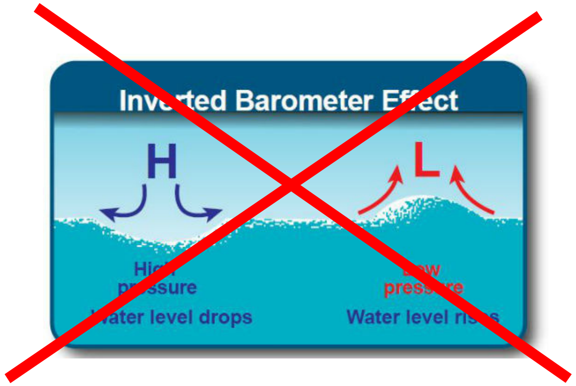


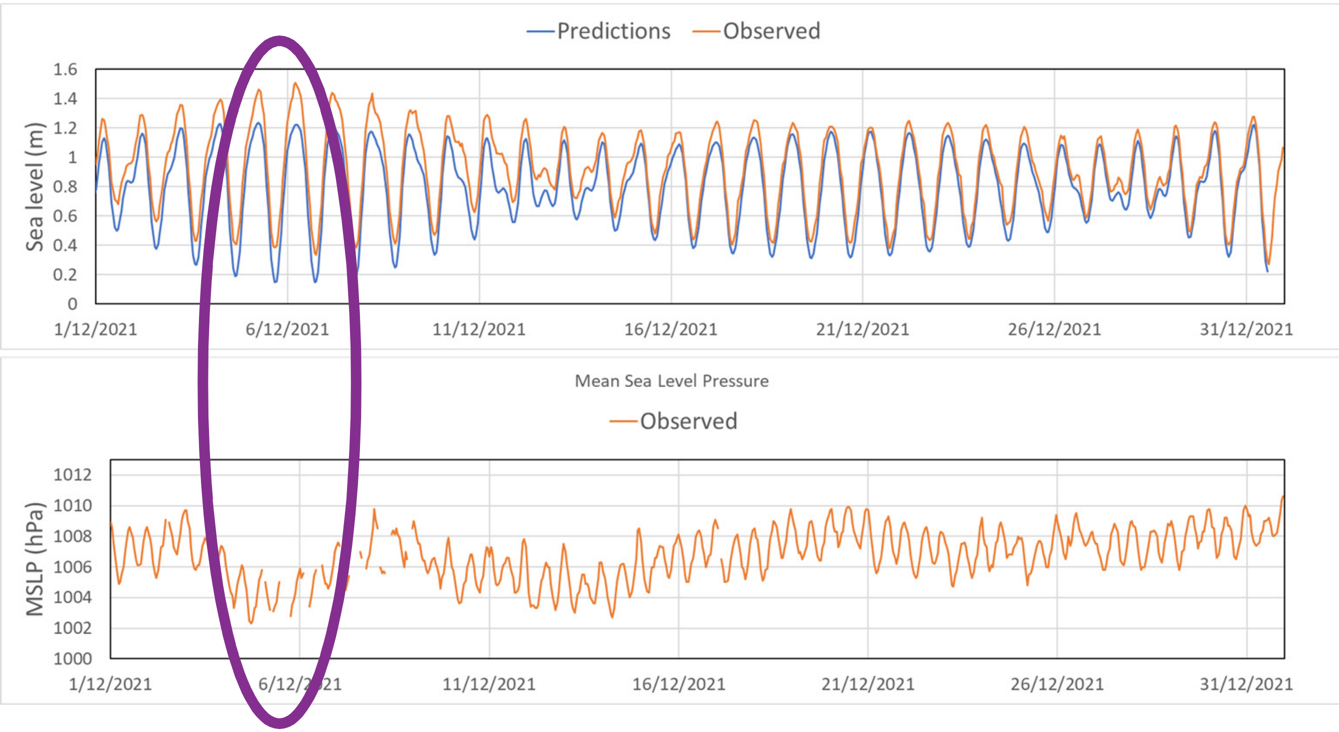
1.24m tide + ~0.1m =1.34m Measured SL was 1.48m

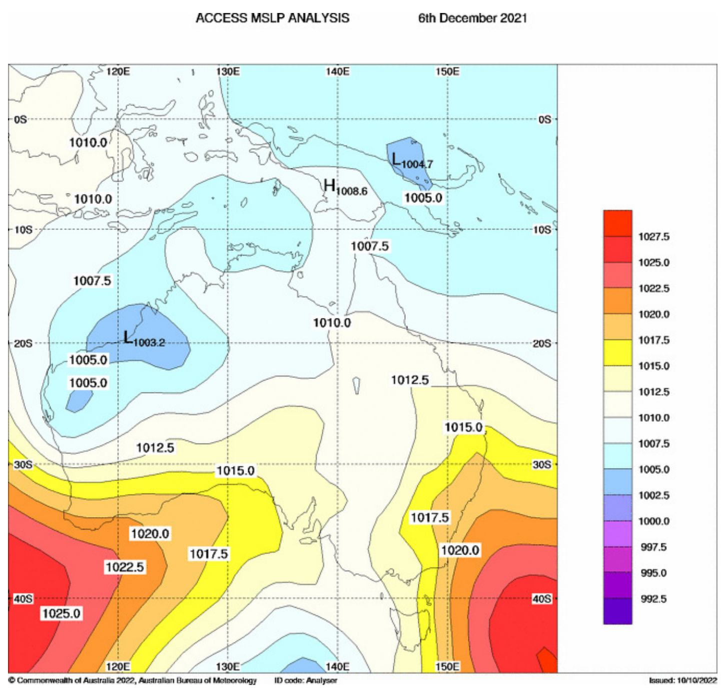


Inverse Barometer effect

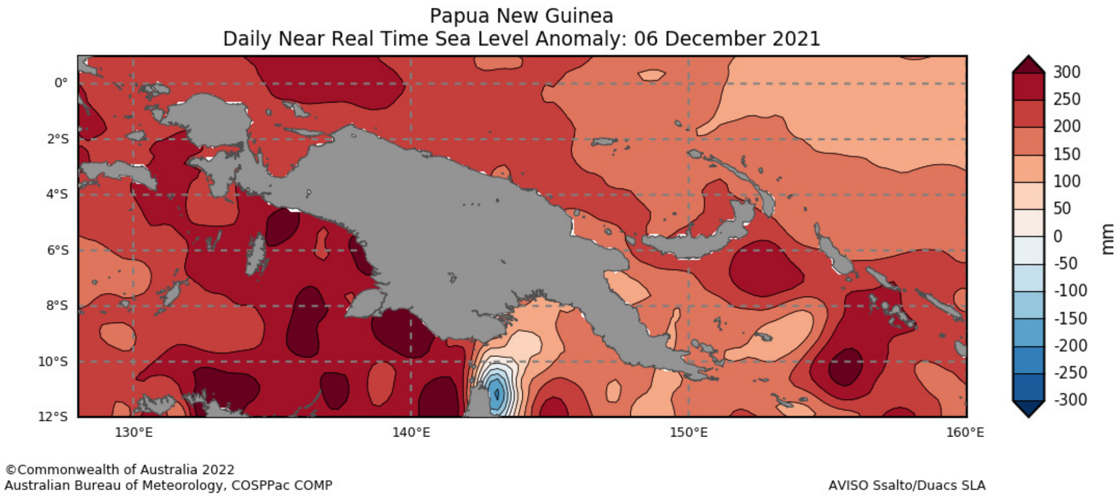
- IB accounts for several centimetres of sea level, approximately **1 cm** per hPa below average.
- About 10 cm still remains unaccounted for.
- The forecast is monthly, which averages the daily data over the month, lessening the peaks.







PNG Case Study: Conclusion

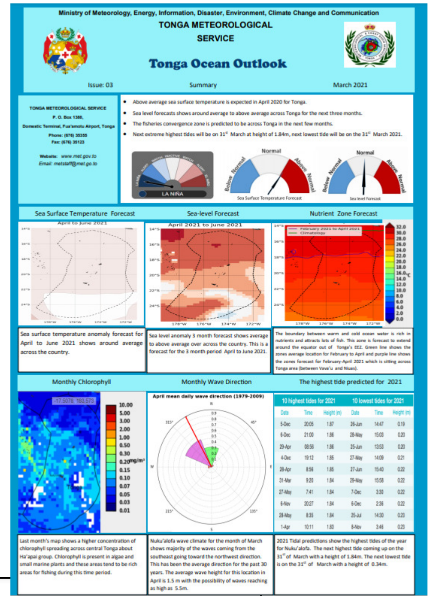


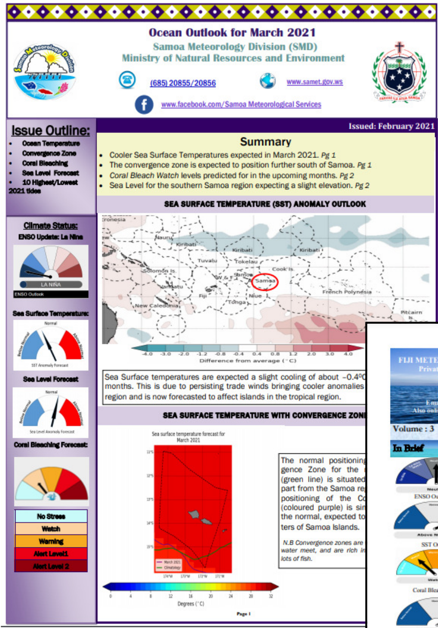
- In hindsight looking at satellite observations, we'd expect a total sea level of 1.44 m, which is still 4 cm below the tide gauge observations.

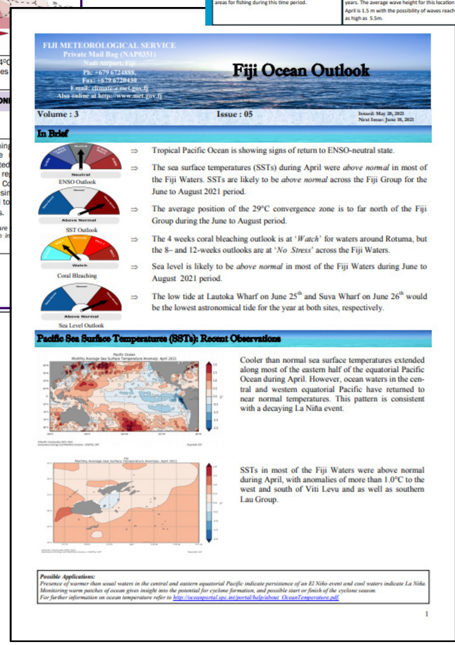
- Limitations in forecasting the full scale of the inundation event
- Monthly average forecasts lessen the daily peaks
- Inverse Barometer effect not included in ACCESS-S
- Small scale local coastal amplification effects

Ocean Outlooks

- Seasonal outlooks for Ocean Outlook Bulletins
- Commonly use SST Anomaly, Sea Level, Coral Bleaching, SST for Fisheries
- Released on monthly or 3-monthly timeframes
- Also include recent observations and tide predictions





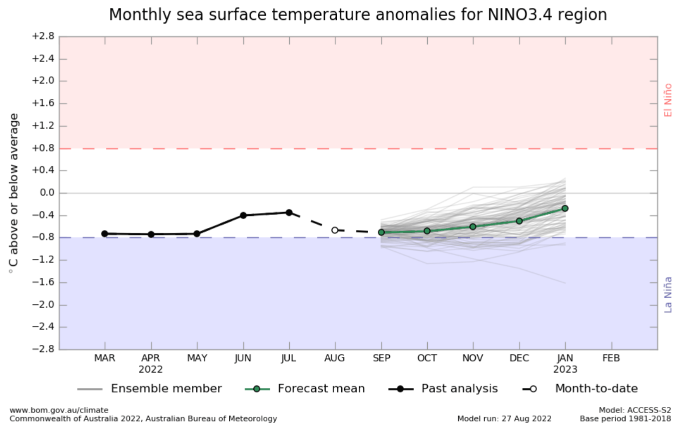


Module 17: ACCESS-S Ocean Outlooks & Skill

Climate and Oceans Support Program in the Pacific
COSPPac

Australian Government
Department of Foreign Affairs and Trade
Bureau of Meteorology

ACCESS-S Skill Information



- Ocean outlook maps from ACCESS-S are an **ensemble mean** anomaly
- An ensemble mean is an average of all model ensembles
- Ocean parameters such as SST and Sea Level usually have good skill in tropical pacific when showing outlooks as the ensemble mean
- Different types of forecasts need different methods of verification
- Skill metrics used are **Correlation Coefficient** and **Root Means Squared Error**

Operations with the mean

$$mean = \frac{Sum\ of\ all\ the\ observations}{Number\ of\ all\ observations}$$

Means can be added if variable is cumulative (like rainfall)

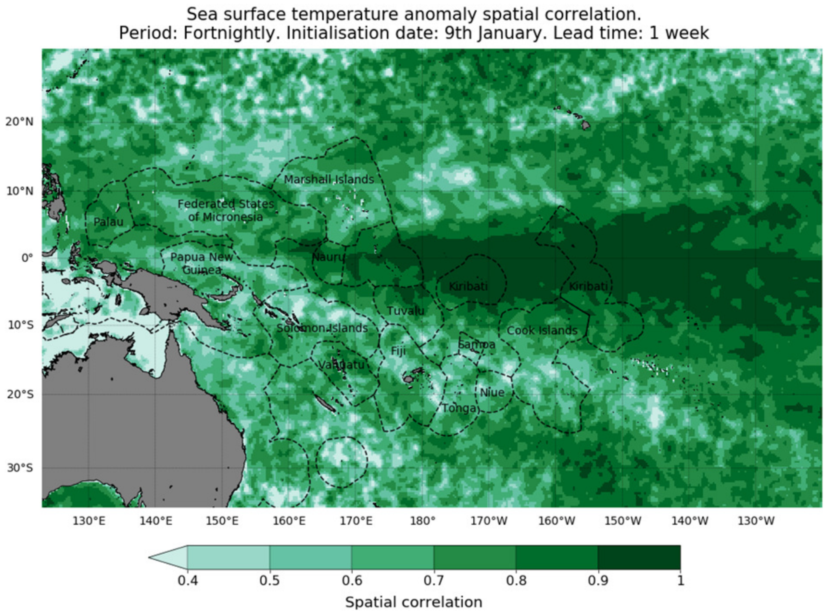
$$Mean\ Jan\ to\ March\ rainfall = Jan\ mean + Feb\ mean + March\ mean$$

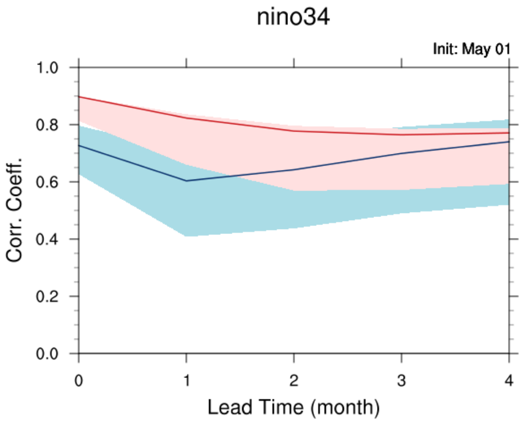
Means can be averaged if variable is not cumulative (like temperature)

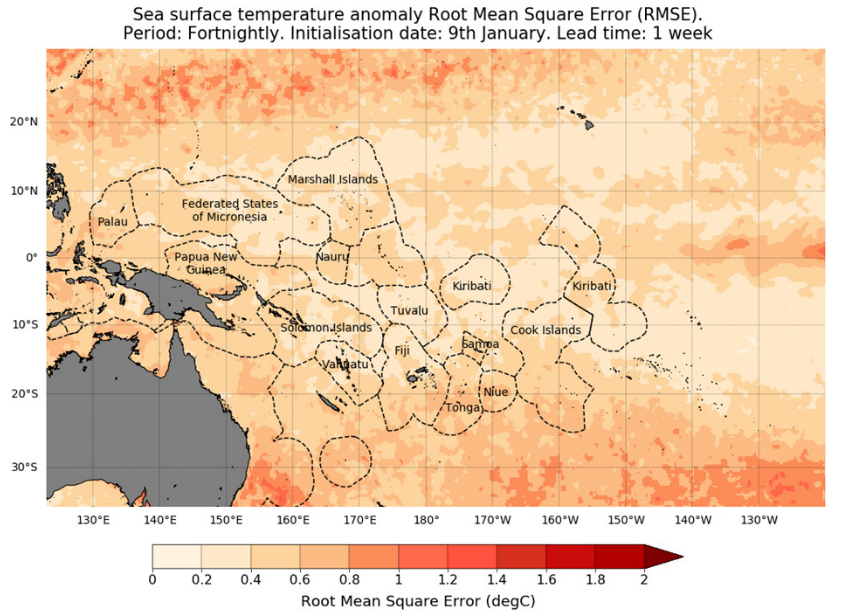
$$Mean\ Jan\ to\ March\ maximum\ temperature = \frac{Jan\ mean + Feb\ mean + March\ mean}{3}$$

Hindcast skill: How good is ACCESS-S at prediction?

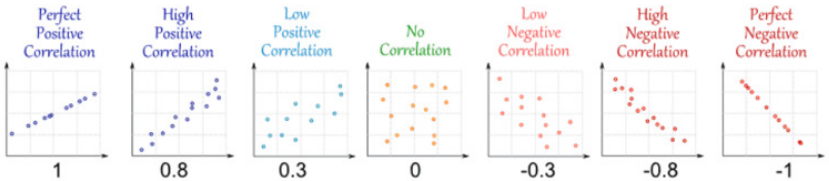
Different types of forecasts need different methods of verification







Correlation coefficient: measures how strong a relationship is between the model and real world over time

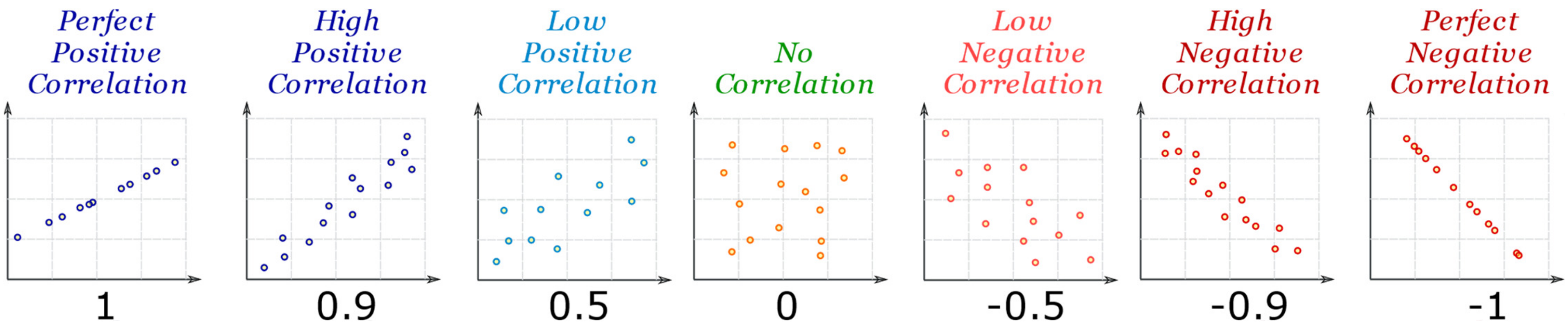


Root Mean Squared Error: often used alongside correlation, it's a measure of the average magnitude of the forecast error, *i.e.* how concentrated the data is around the line of best fit between the model and observed.

Correlation – how related are two variables?

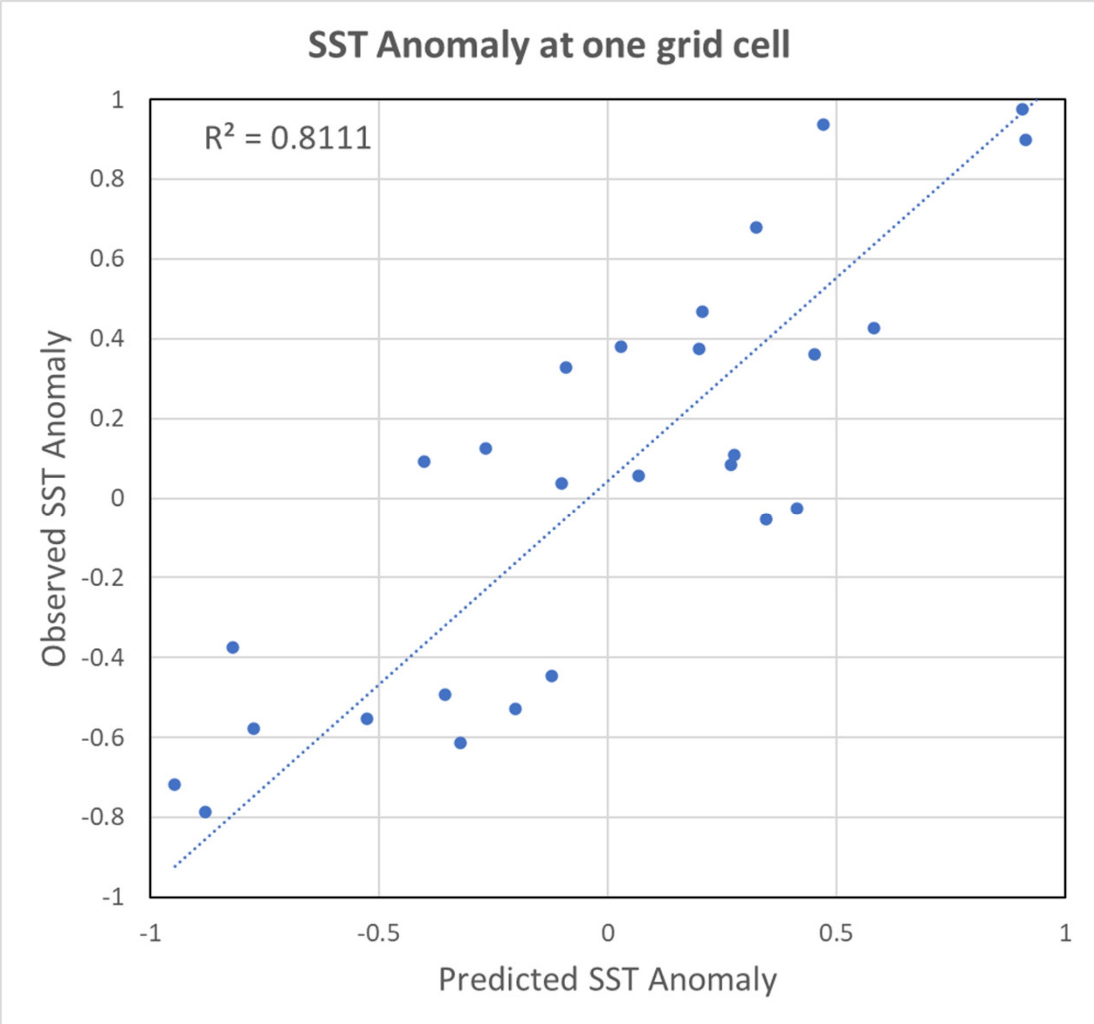
- We test a **dependent** variable's relationship with an **independent** variable
- The **Correlation Coefficient (r)** measures the strength of the relationship – it can vary between –1 and +1
- Values of –1 and +1 are **perfect** in which all the observations lie on a straight line
- **Positive** correlation: dependent variable increases as the independent variable increases
- **Negative** correlation: dependent variable decreases as the independent variable increases
- **r** relates to the **scatter** of observations about the regression line of best fit
- Correlation does **not** imply Causation
- Correlation can be used to calculate model skill

Correlation coefficient examples



The number below each graph is the value of **r**, the correlation coefficient

Using excel to calculate the correlation



What is the correlation between SST predicted by ACCESS-S and satellite observations of SST

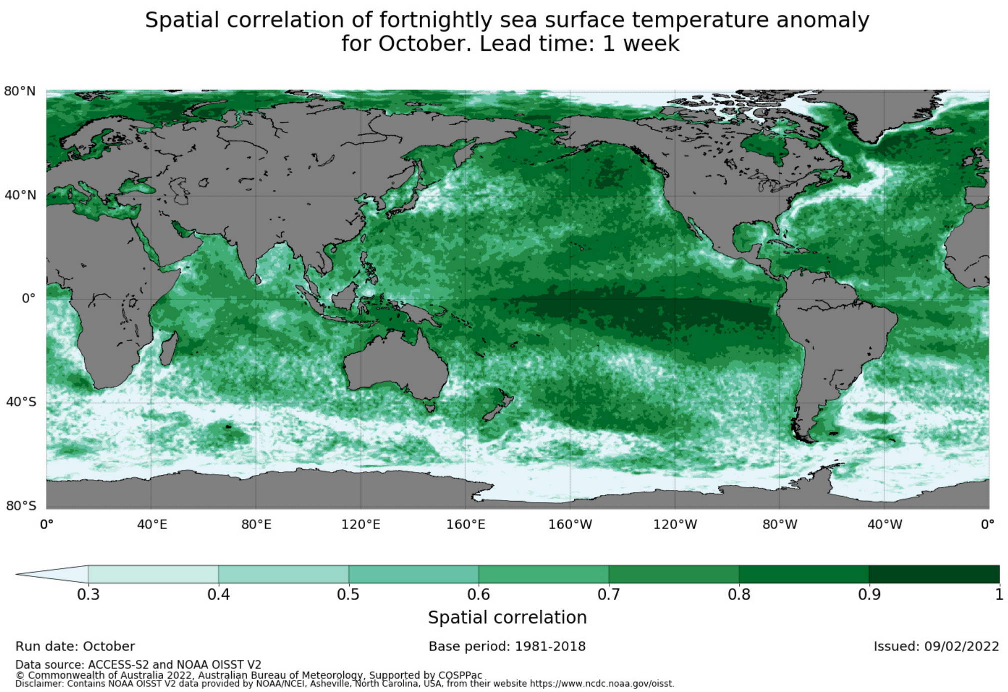
Use Excel to test the correlation. To calculate the correlation coefficient between two arrays of numbers: the formula is **=Correl(array1:array2)**

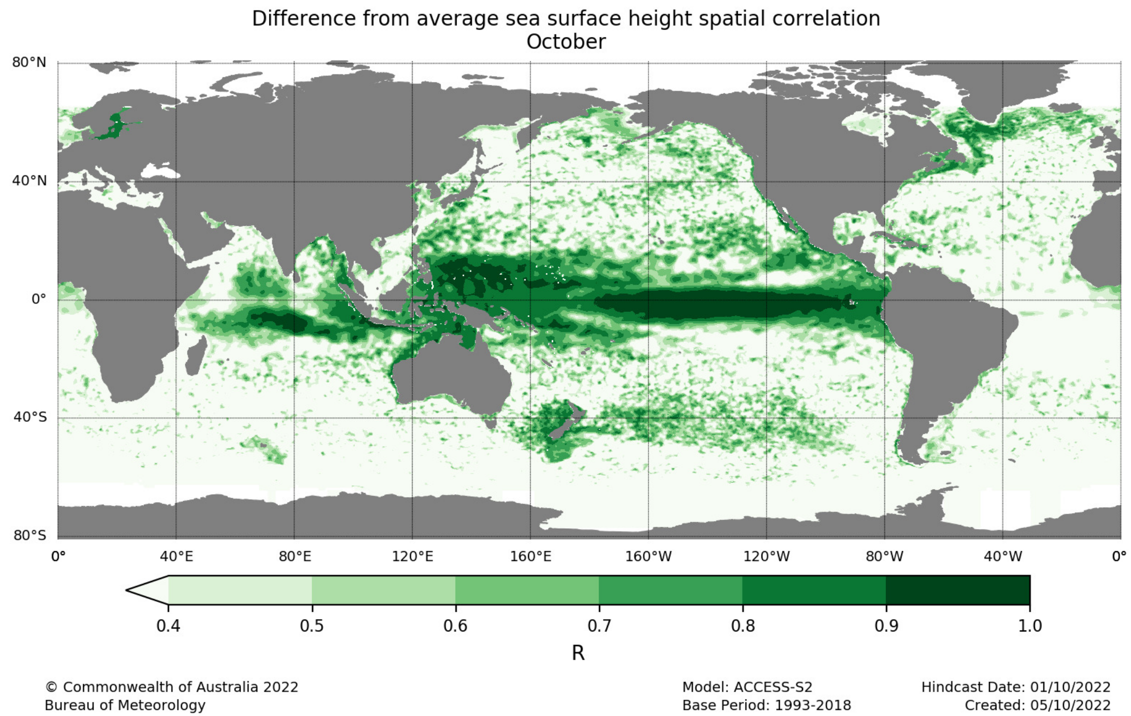
There is a positive correlation between the two datasets, very good news for a model (a negative correlation would mean the model is well underperforming.

Excel calculates 0.9 for **r**. If we square this, we get the **R^2** value shown on the graph.

But is it **statistically significant**?

Statistical significance





Using significance tables for correlation significance

The correlation coefficient (**r**) can be checked against a table of **critical r** values for **different levels of significance** [e.g. 0.05 (5%) or 0.01 (1%)] and **degrees of freedom (df)**

degrees of freedom (df) = n – 1, where n is the number of points on the graph, i.e. the sample size

df\α	0.2	0.1	0.05	0.02	0.01	0.001
1	0.951057	0.987688	0.996917	0.999507	0.999877	0.999999
2	0.800000	0.900000	0.950000	0.980000	0.990000	0.999000
3	0.687049	0.805384	0.878339	0.934333	0.958735	0.991139
4	0.608400	0.729299	0.811401	0.882194	0.917200	0.974068
5	0.550863	0.669439	0.754492	0.832874	0.874526	0.950883
6	0.506727	0.621489	0.706734	0.788720	0.834342	0.924904
7	0.471589	0.582206	0.666384	0.749776	0.797681	0.898260
8	0.442796	0.549357	0.631897	0.715459	0.764592	0.872115
9	0.418662	0.521404	0.602069	0.685095	0.734786	0.847047
10	0.398062	0.497265	0.575983	0.658070	0.707888	0.823305
11	0.380216	0.476156	0.552943	0.633863	0.683528	0.800962
12	0.364562	0.457500	0.532413	0.612047	0.661376	0.779998
13	0.350688	0.440861	0.513977	0.592270	0.641145	0.760351
14	0.338282	0.425902	0.497309	0.574245	0.622591	0.741934
15	0.327101	0.412360	0.482146	0.557737	0.605506	0.724657
16	0.316958	0.400027	0.468277	0.542548	0.589714	0.708429
17	0.307702	0.388733	0.455531	0.528517	0.575067	0.693163
18	0.299210	0.378341	0.443763	0.515505	0.561435	0.678781
19	0.291384	0.368737	0.432858	0.503397	0.548711	[illegible]
20	0.284140	0.359827	0.422714	[illegible]	[illegible]	0.652378
21	0.277411	0.351531	0.413247	0.481512	0.525620	0.640230
22	0.271137	0.343783	0.404386	0.471579	0.515101	0.628710
23	0.265270	0.336524	0.396070	[illegible]	[illegible]	[illegible]
24	0.259768	0.329705	0.388244	0.453413	0.495808	0.607360
25	0.254594	0.323283	0.380863	0.445078	0.486932	0.597446
26	0.249717	0.317223	0.373886	0.437184	0.478511	0.587988
27	0.245110	0.311490	0.367278	0.429693	0.470509	0.578956
28	0.240749	0.306057	0.361007	0.422572	0.462892	0.570317
29	0.236612	0.300898	0.355046	0.415792	0.455631	0.562047
30	0.232681	0.295991	0.349370	0.409327	0.448699	0.554119

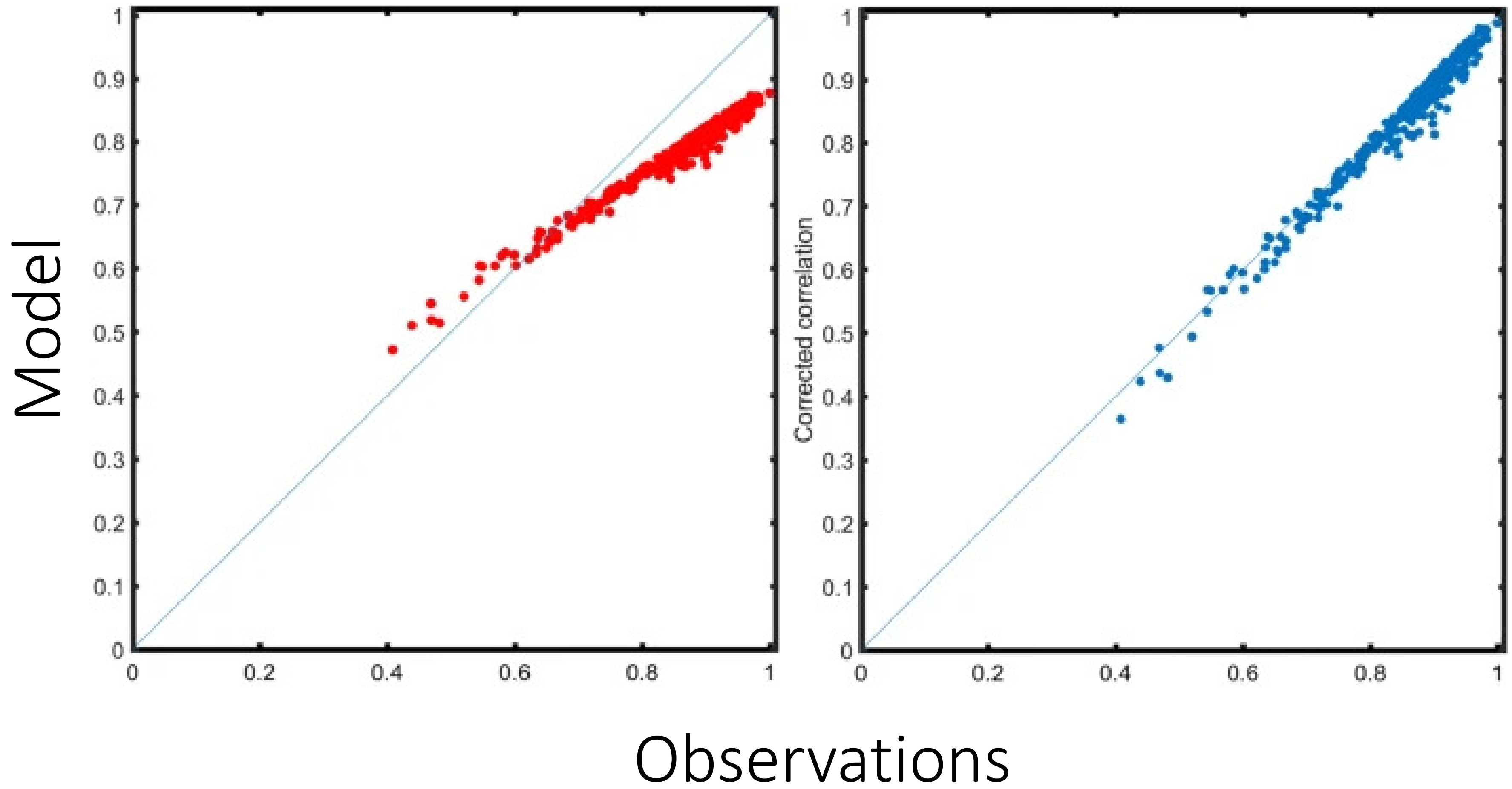
df\α	0.2	0.1	0.05	0.02	0.01	0.001
35	0.215598	0.274611	0.324573	0.380976	0.418211	0.518898
40	0.201796	0.257278	[illegible]	[illegible]	0.393174	0.489570
45	0.190345	0.242859	0.287563	0.338367	[illegible]	0.464673
50	0.180644	0.230620	0.273243	0.321796	0.354153	[illegible]
60	0.164997	0.210832	0.250035	0.294846	0.324818	0.407865
70	0.152818	0.195394	0.231883	0.273695	0.301734	0.379799
80	0.142990	0.182916	0.217185	0.256525	0.282958	0.356816
90	0.134844	0.172558	0.204968	0.242227	0.267298	0.337549
100	0.127947	0.163782	0.194604	0.230079	0.253979	0.321095
125	0.114477	0.146617	0.174308	0.206245	0.227807	0.288602
150	0.104525	0.133919	0.159273	0.188552	0.208349	0.264316
175	0.096787	0.124036	0.147558	0.174749	0.193153	0.245280
200	0.090546	0.116060	0.138098	0.163592	0.180860	0.229840
250	0.081000	0.103852	0.123607	0.146483	0.161994	[illegible]
300	0.073951	0.094831	0.112891	[illegible]	[illegible]	0.188431
350	0.068470	0.087814	[illegible]	0.123957	0.137131	0.174657
400	[illegible]	0.082155	0.097824	0.115997	0.128339	0.163520
450	0.060391	0.077466	0.092248	0.109397	0.121046	0.154273
500	0.057294	0.073497	0.087528	0.103808	0.114870	0.146436
600	0.052305	0.067103	0.079920	0.094798	0.104911	0.133787
700	0.048427	0.062132	0.074004	0.087789	0.097161	0.123935
800	0.045301	0.058123	0.069234	0.082135	0.090909	0.115981
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1000	0.040520	0.051993	0.061935	0.073484	0.081340	0.103800
1500	0.033086	0.042458	0.050582	0.060022	0.066445	0.084822
2000	0.028654	0.036772	0.043811	0.051990	0.057557	0.073488
3000	0.023397	0.030027	0.035775	0.042457	0.047006	0.060027
4000	0.020262	0.026005	0.030984	0.036773	0.040713	0.051996
5000	0.018123	0.023260	0.027714	0.032892	0.036417	0.046512

ACCESS-S2 (1981-2018)
38 years –2 = N = 36

ACCESS-S1 (1990-2012)
23 years – 2 = N = 21

ACCESS-S2 (1993-2018)
25 years – 2 = N = 23

Correlation can be misleading....



Root Mean Square Error

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}}$$

$\hat{y}_1, \hat{y}_2, \ldots, \hat{y}_n$ are predicted values

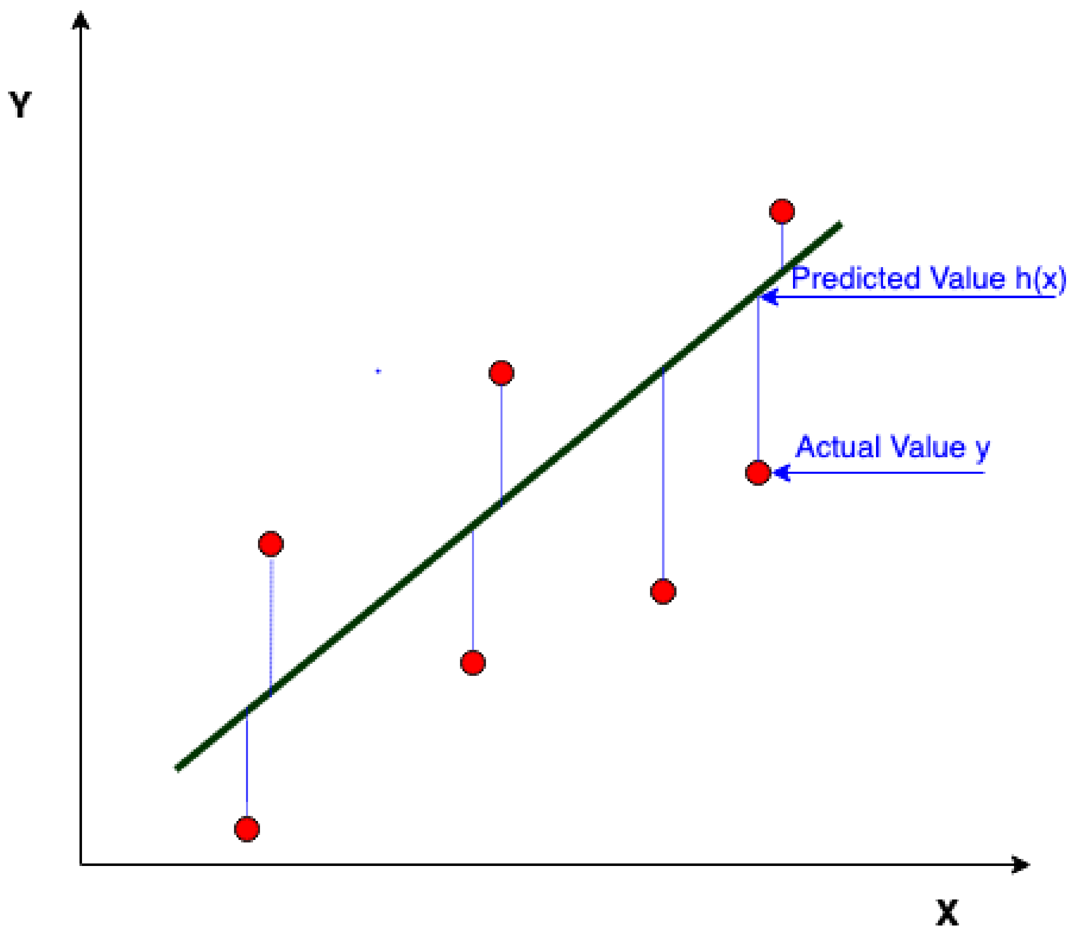
$y_1, y_2, \ldots, y_n$ are observed values

n is the number of observations

- RMS stands for **Root Mean Squared**
- It looks similar to the Standard Deviation
- Measures the error of a **model** in **predicting** data
- n = Sample size
- $\hat{y}_i - y_i$ is the **error** (anomaly or residual) between the model prediction and the observation
- Each error is **squared**
- We calculate the **sum** (∑) of all the squared errors
- This sum is divided by the number of observations to create the **mean** of the squared errors
- Finally, calculate the square **root** of the mean

- This is a common method used in ACCESS-S model verification

ACCESS-S Skill: Root means squared error



Tells you how different the outlooks are on average to reality in the parameters actual units (°C for SST and mm for Sea Level)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (Predicted_i - Actual_i)^2}{N}}$$

ACCESS-S Skill Calculations

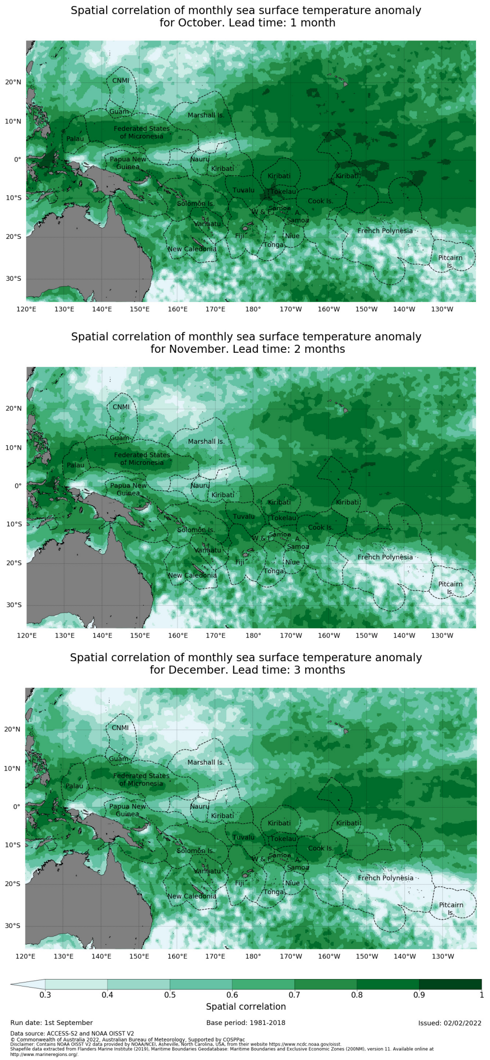
- ACCESS-S has a 38-year hindcast
- A hindcast is a set of retrospective forecast over the past few decades
- We use the hindcast to assess how good the model forecasts because we know what happened
- The model forecasts are compared to observations
- For SST, we used satellite observations (1982 to 2018)
- For Sea Level, we used satellite altimetry (1993 to 2018)

Model skill reduces with lead time…

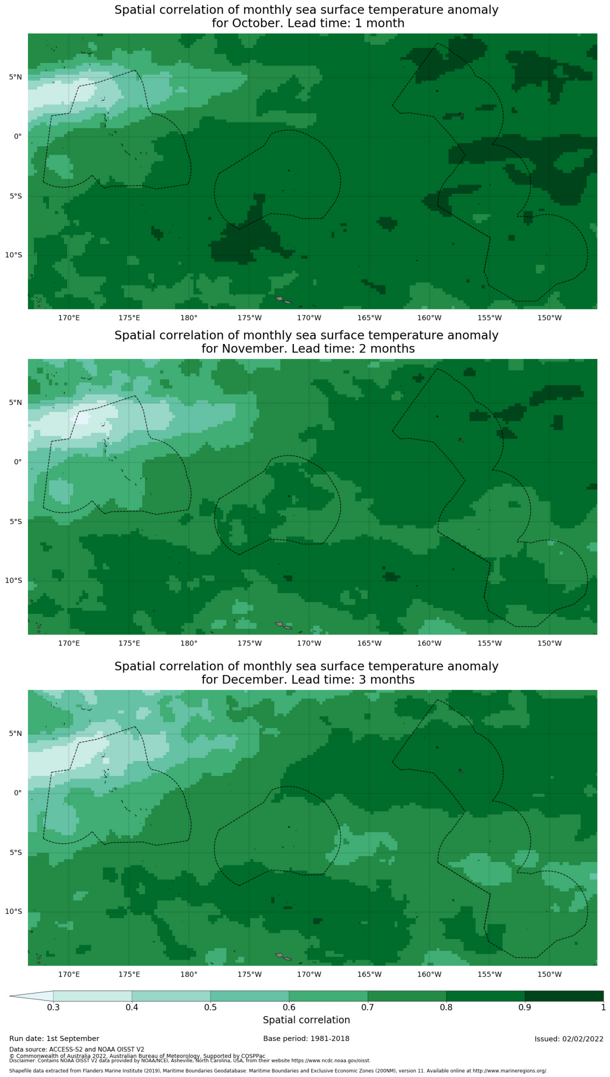
Lead 0

Lead 1

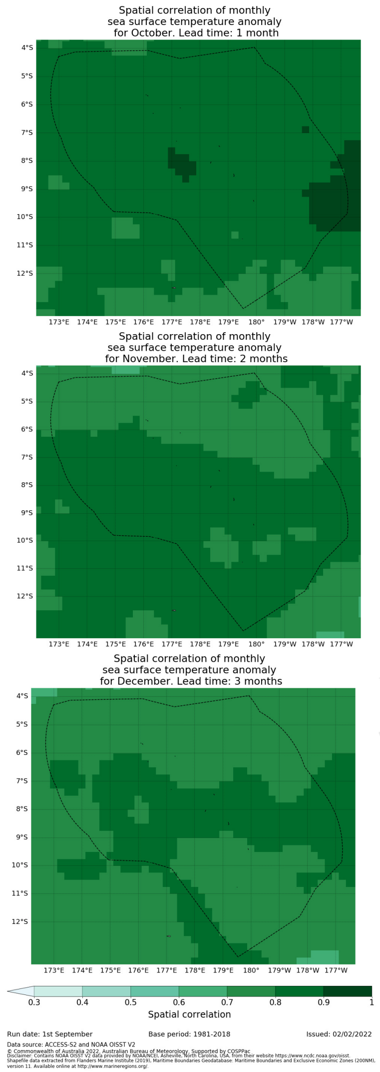
Lead 2



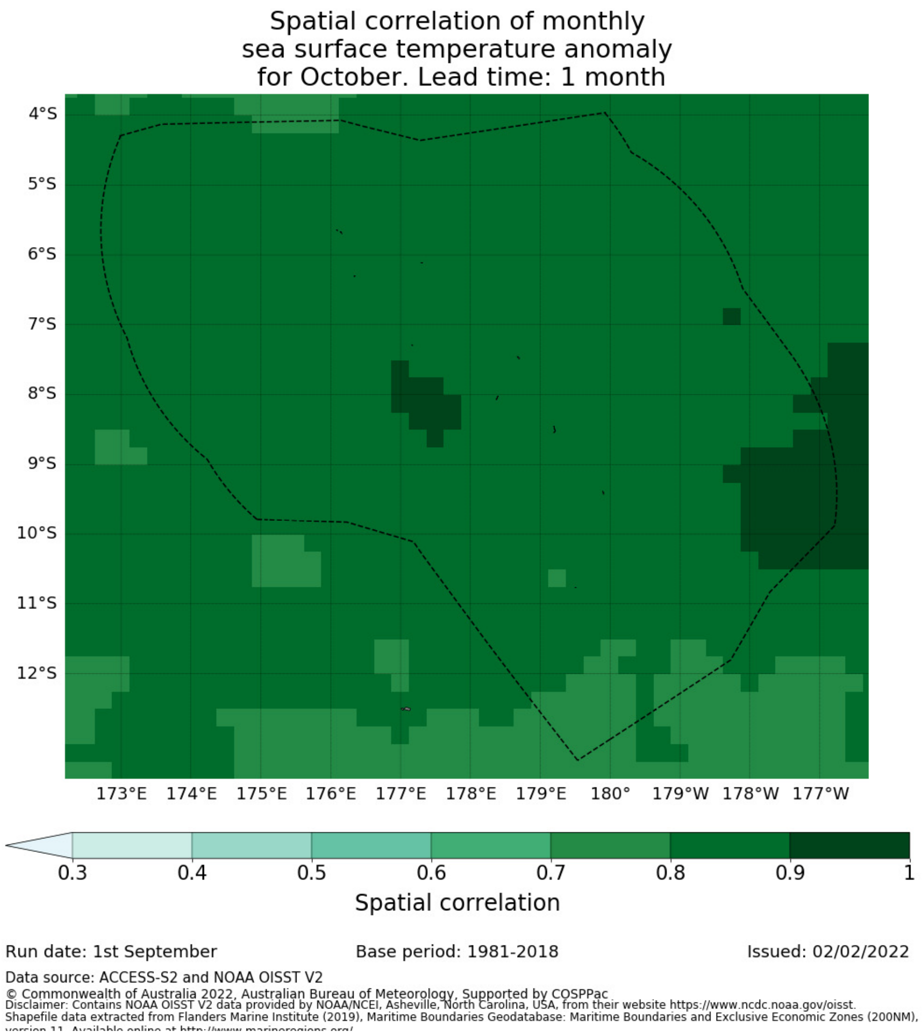
Kiribati

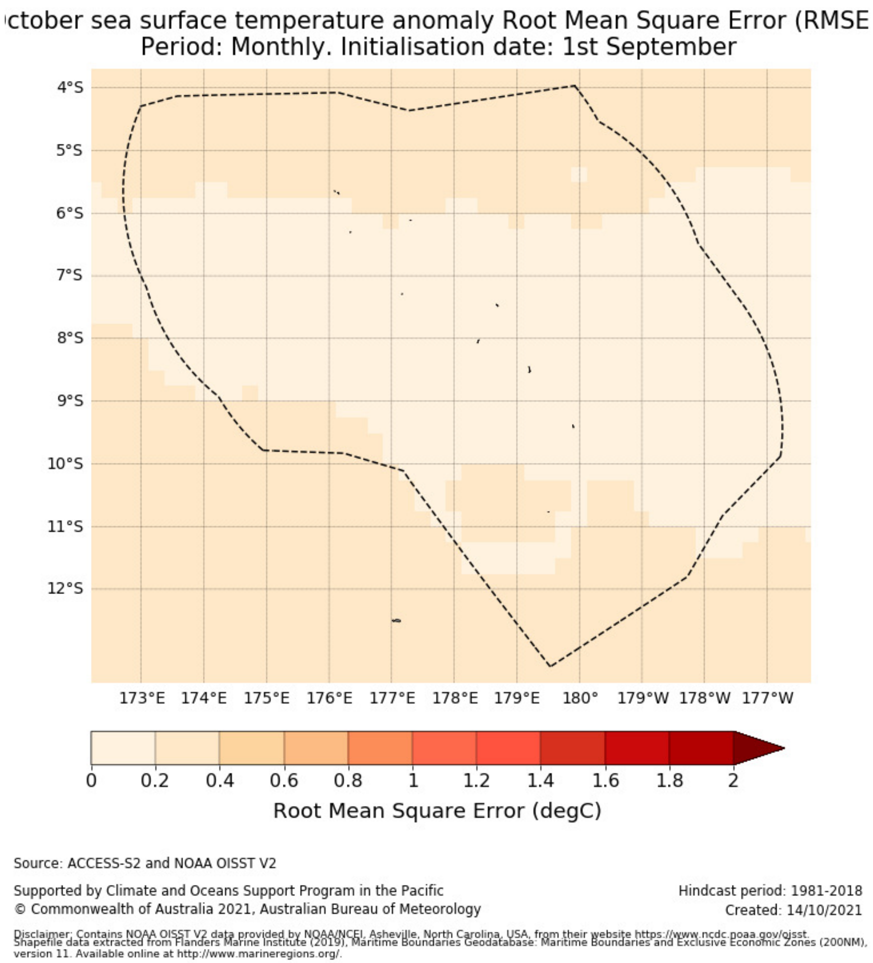


Tuvalu

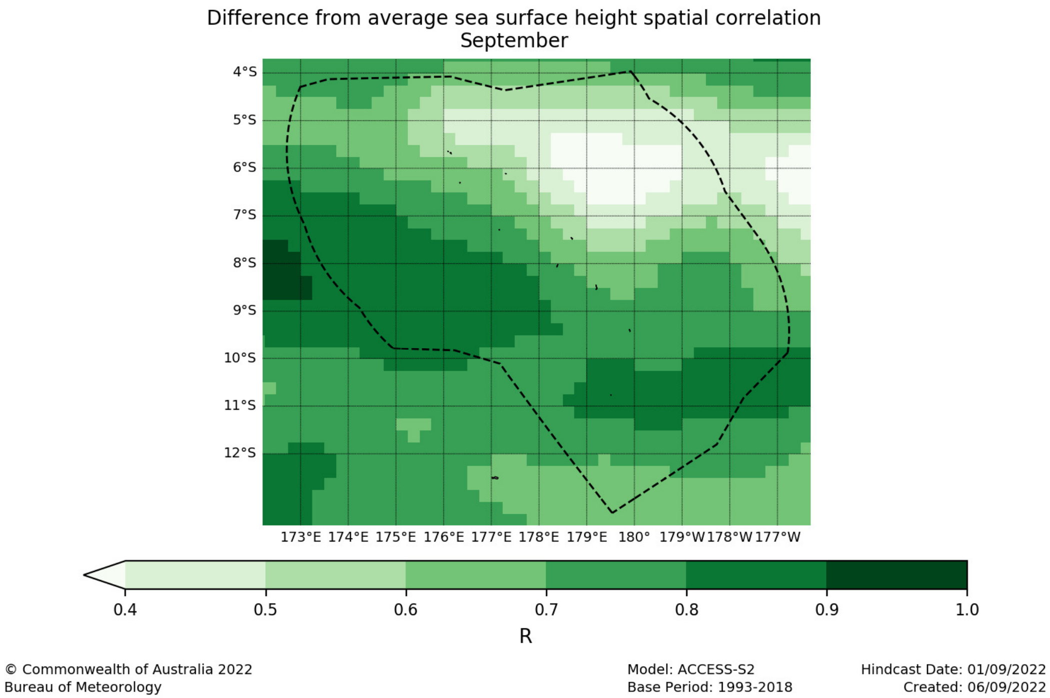


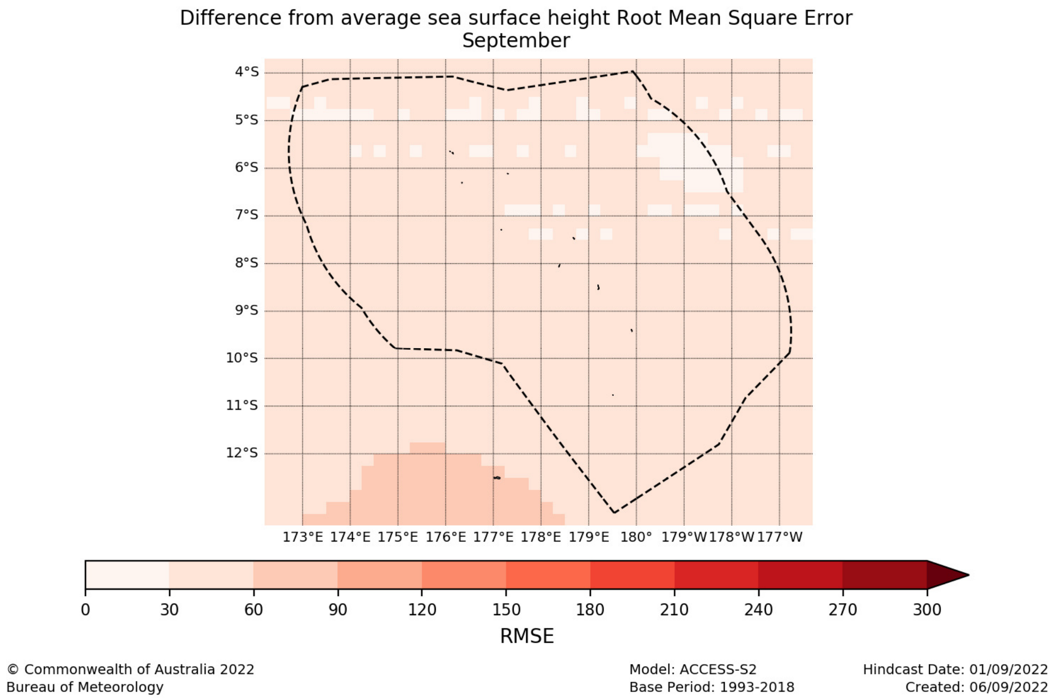
Tuvalu SST Skill Example



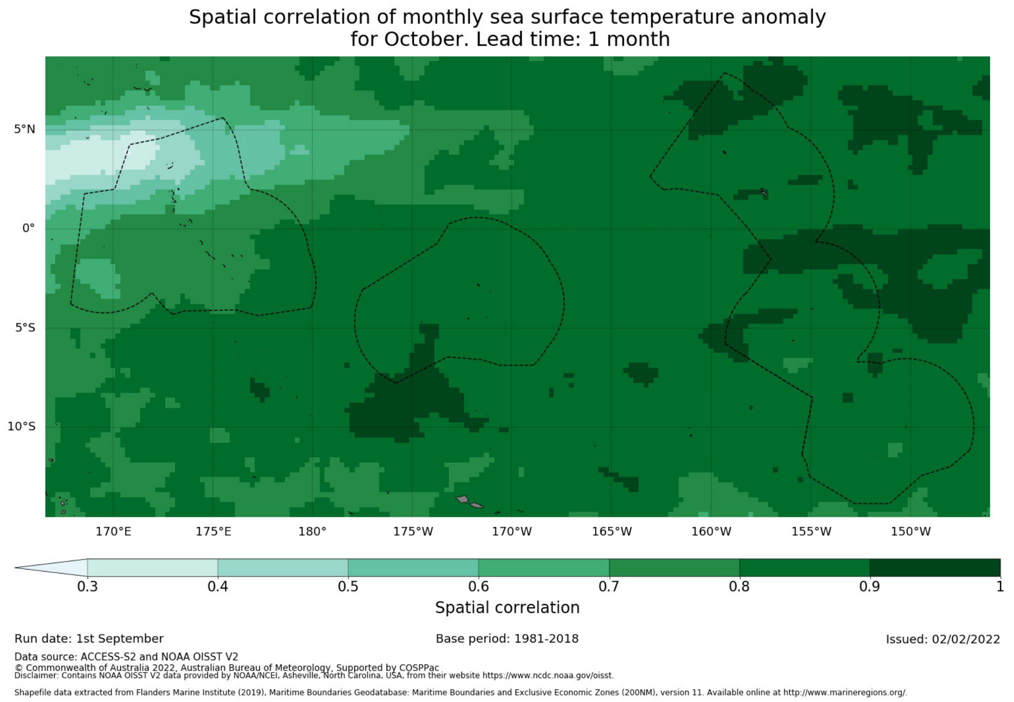


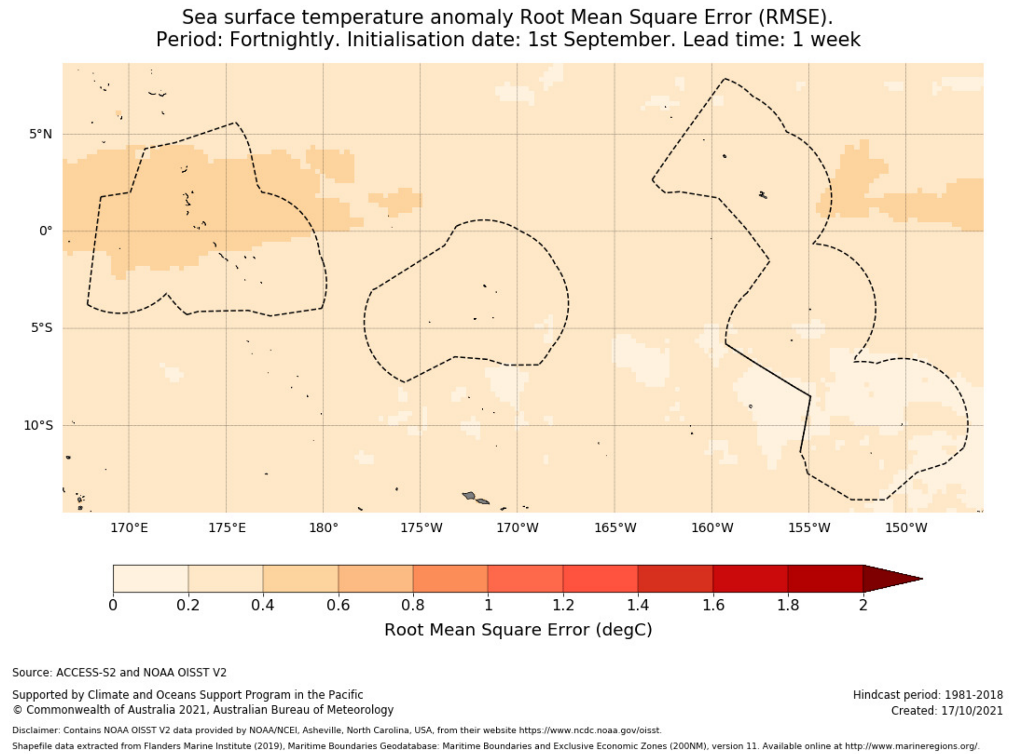
Tuvalu Sea Level Skill Example



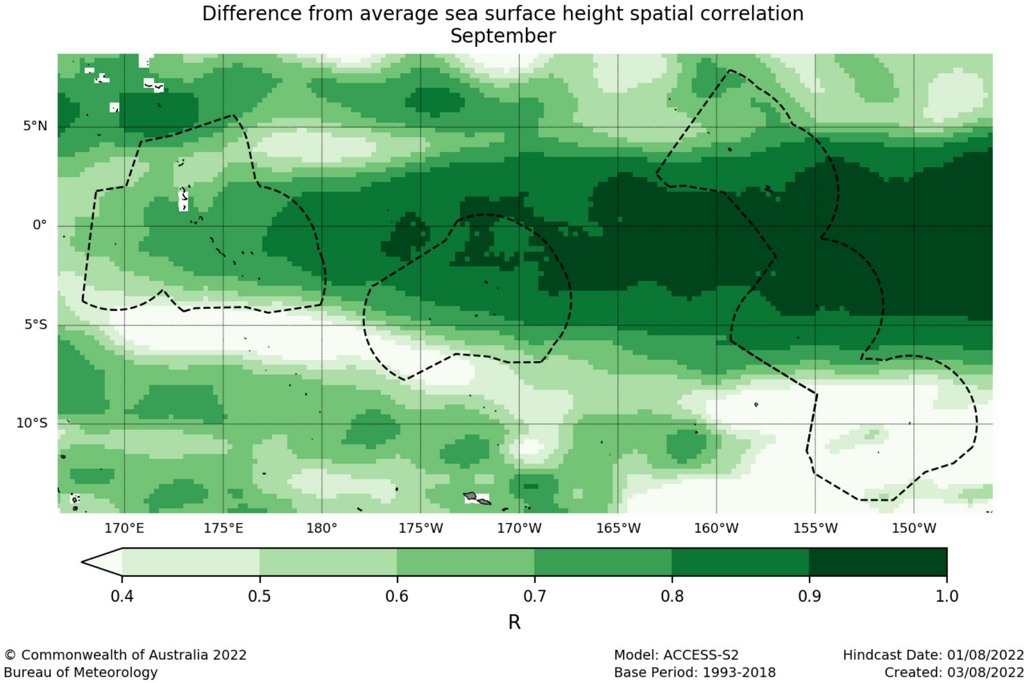


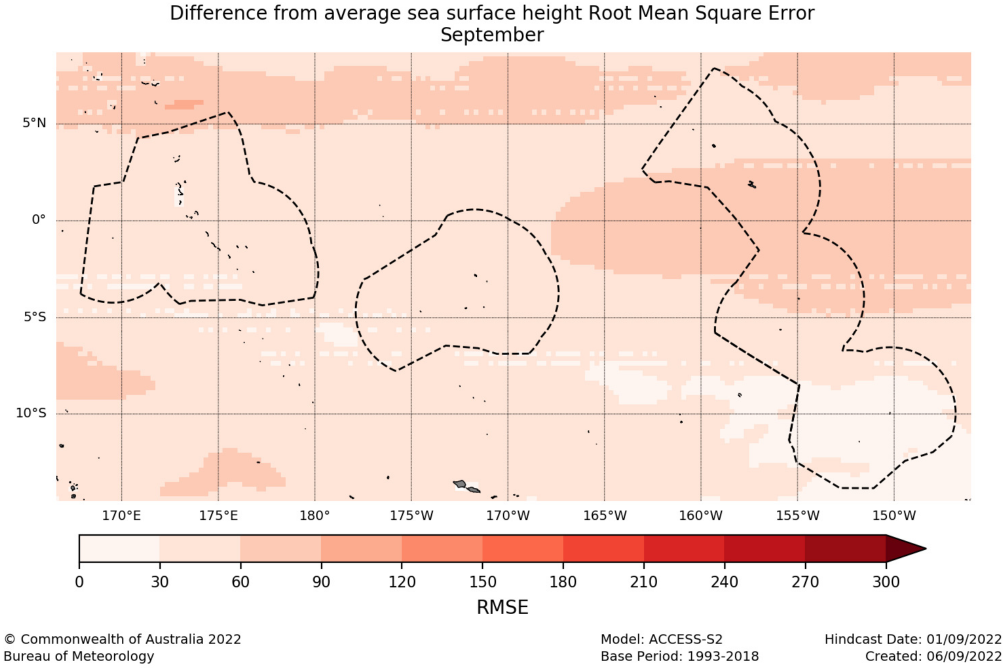
Kiribati SST Skill Example



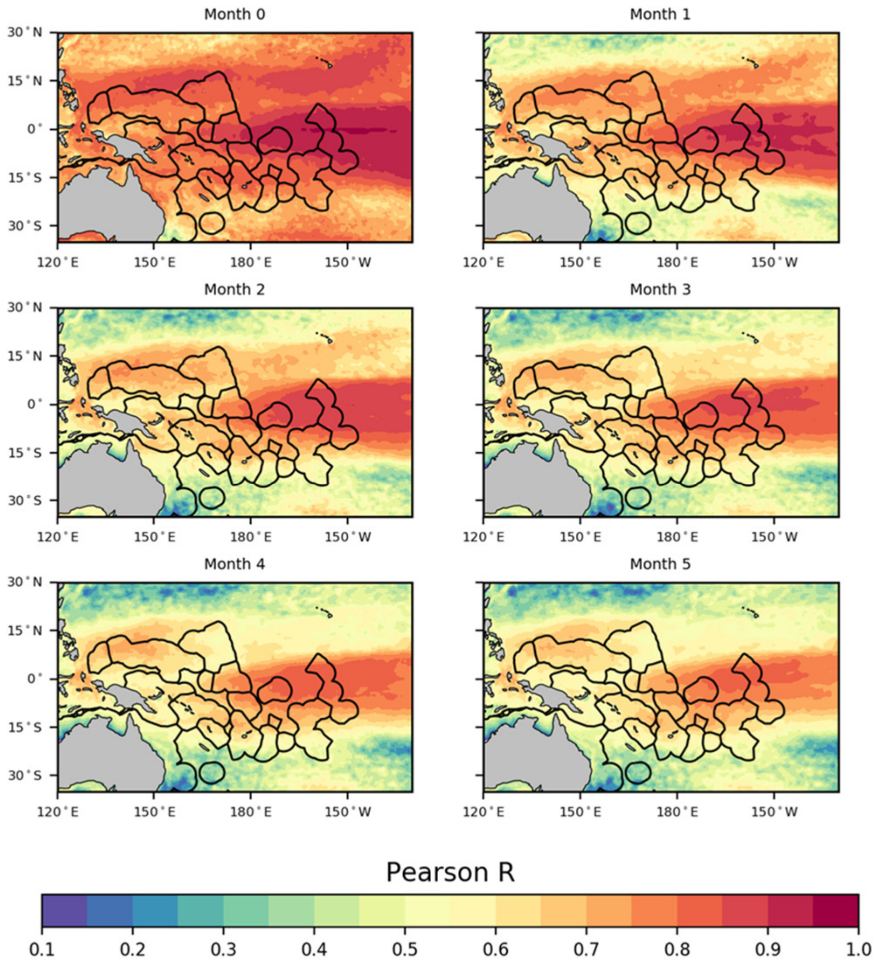


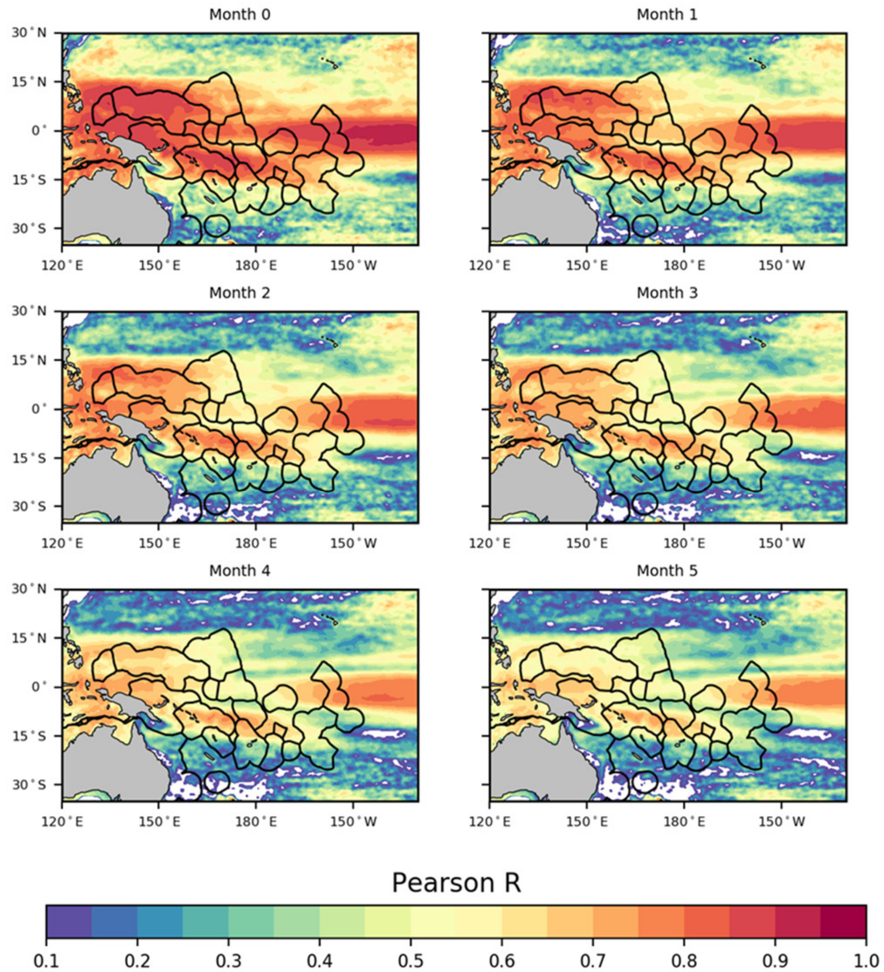
Kiribati Sea Level Skill Example





Skill in Ocean Portal Help Files

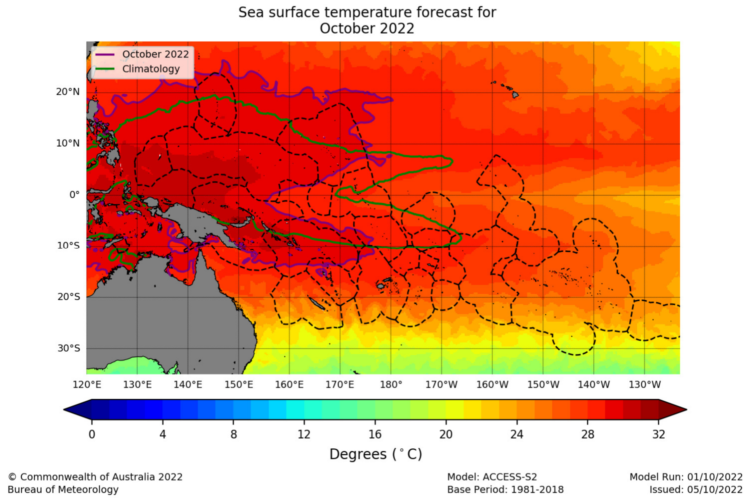


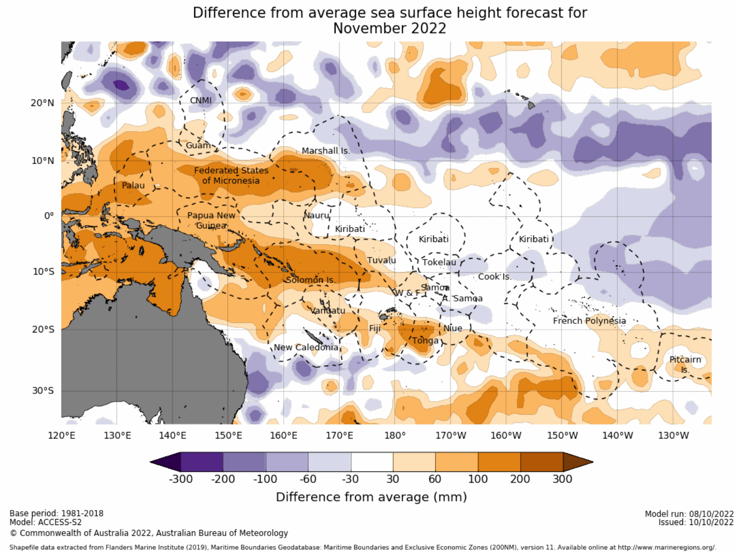


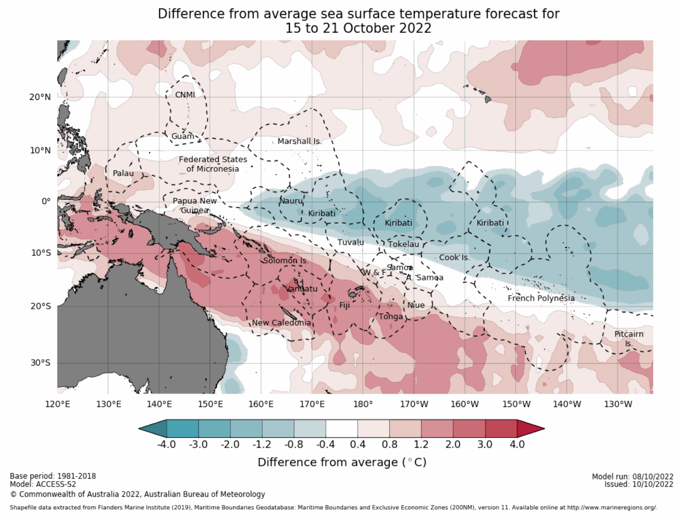
Important take home messages...

- Three main products: SST anomaly, sea level anomaly, SST with convergence zone.
- The most comprehensive resource for outlooks is the ACCESS-S webpage which includes regional/national maps and skill for all time scales.
- Pacific Ocean Portal provides an interactive view of monthly outlooks
- Model skill is represented by correlation with observations, and root means squared error.
- Use correlation to determine if there is skill, and use RMSE to see how different the model is to observations on average.
- Check skill for your country when issuing outlooks to ensure outlooks are trustworthy.

Pacific Forecasts – oceanic variables



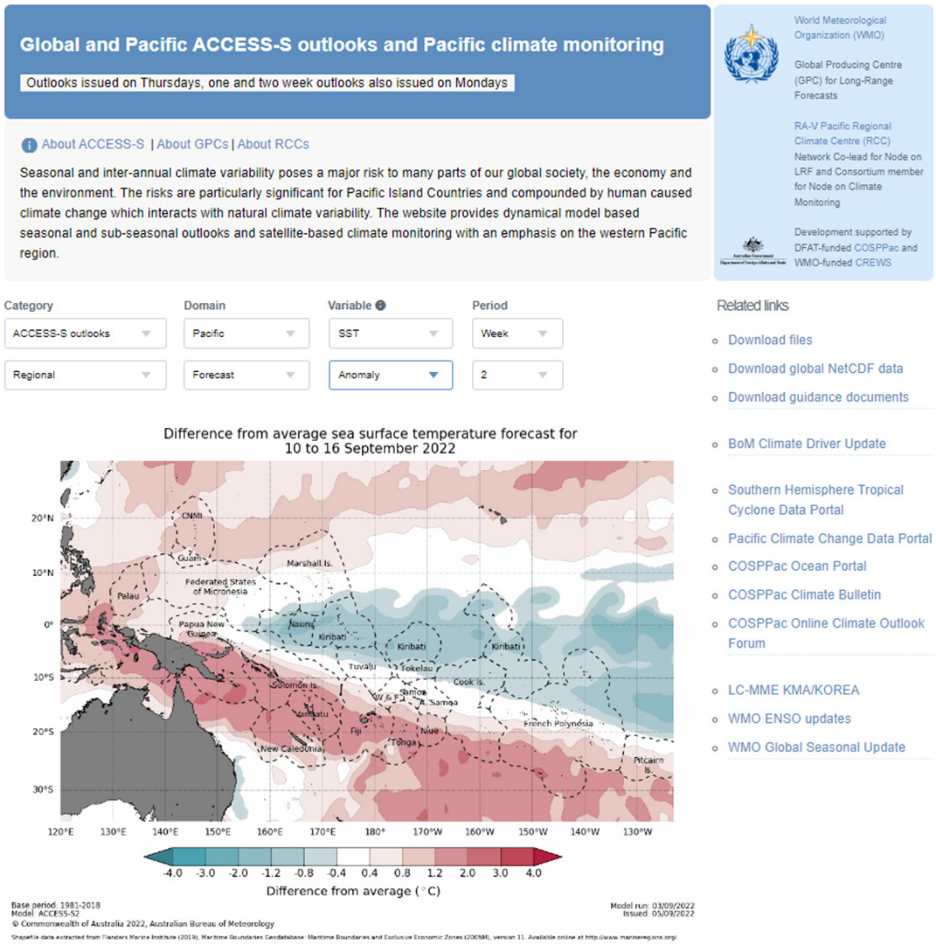




Outputs for:

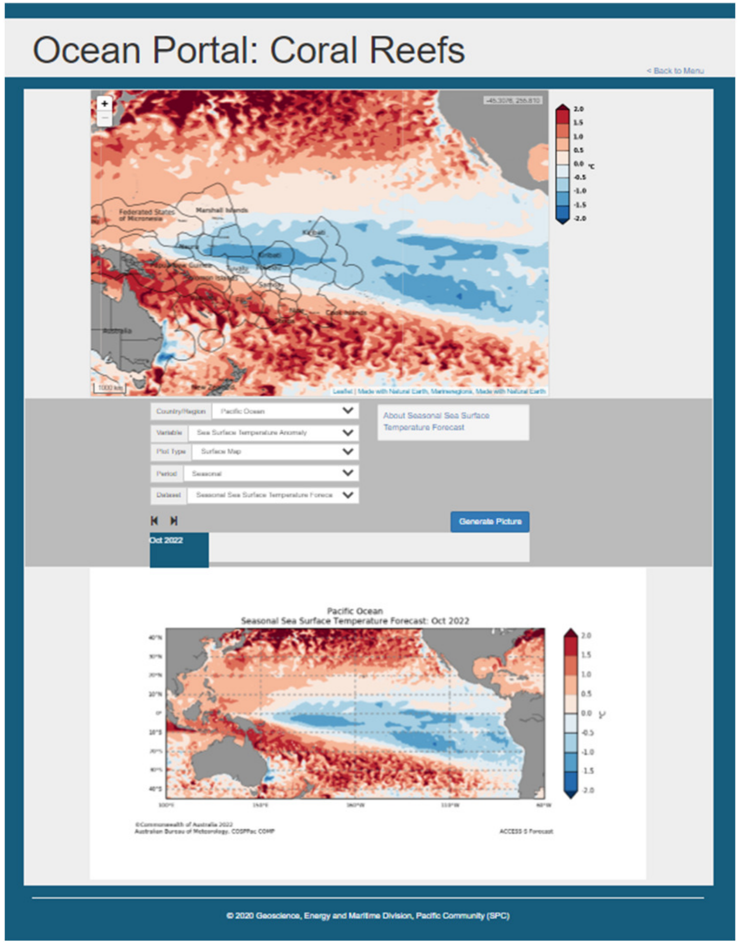
- Sea surface temperature (both full field and anomaly)
- Sea surface height

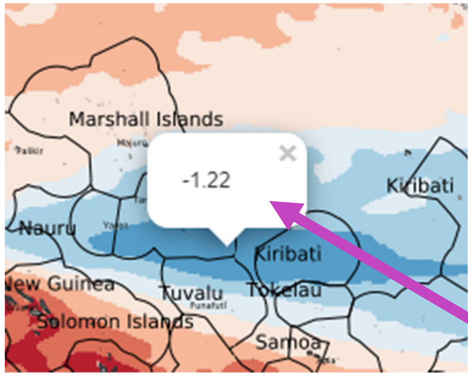
ACCESS-S Ocean Outlooks: website

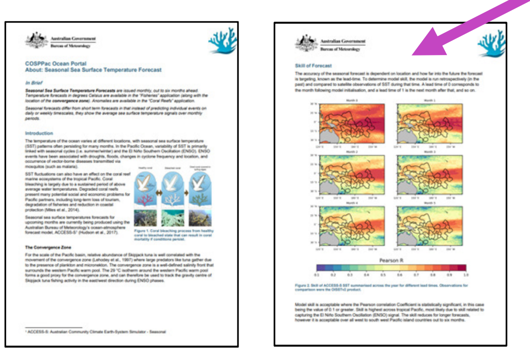


- http://www.bom.gov.au/climate/pacific/outlooks/
- Weekly/fortnightly/monthly/seasonal available for SST anomaly
- Skill maps
- Forecast out to 3 weeks, 3 fortnights, 3 months, 2 seasons

ACCESS-S Ocean Outlooks: Ocean Portal

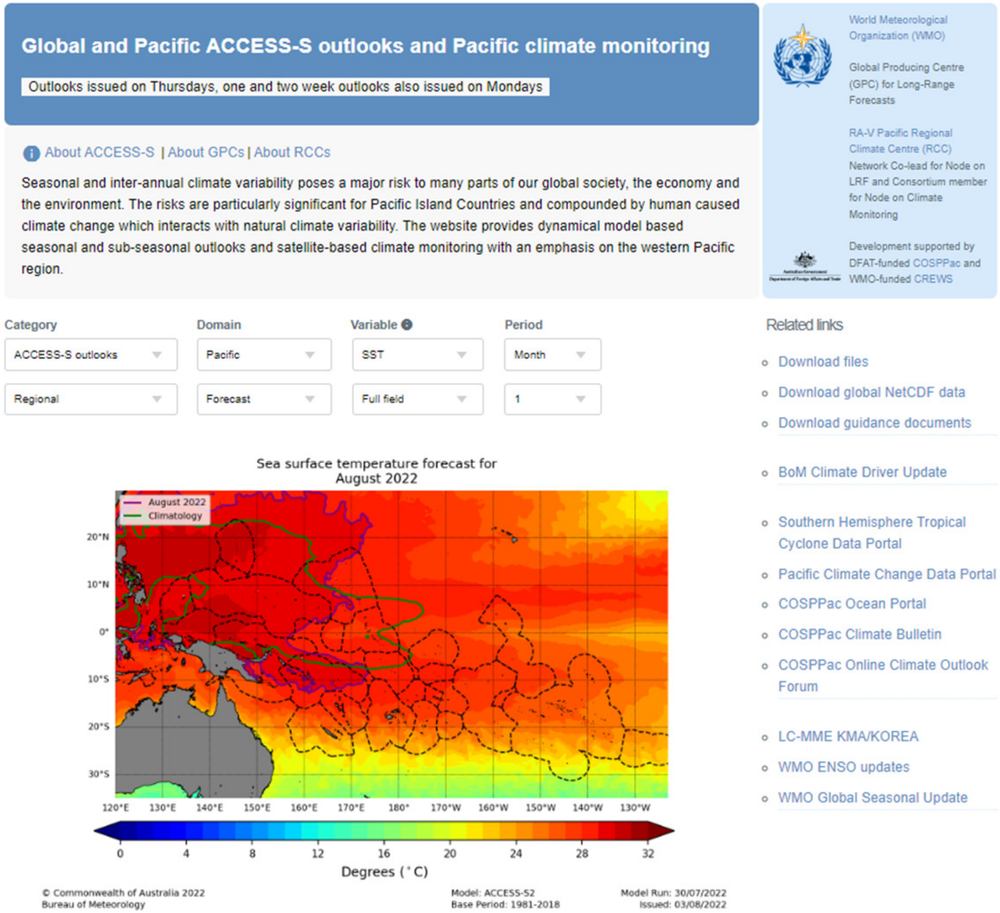


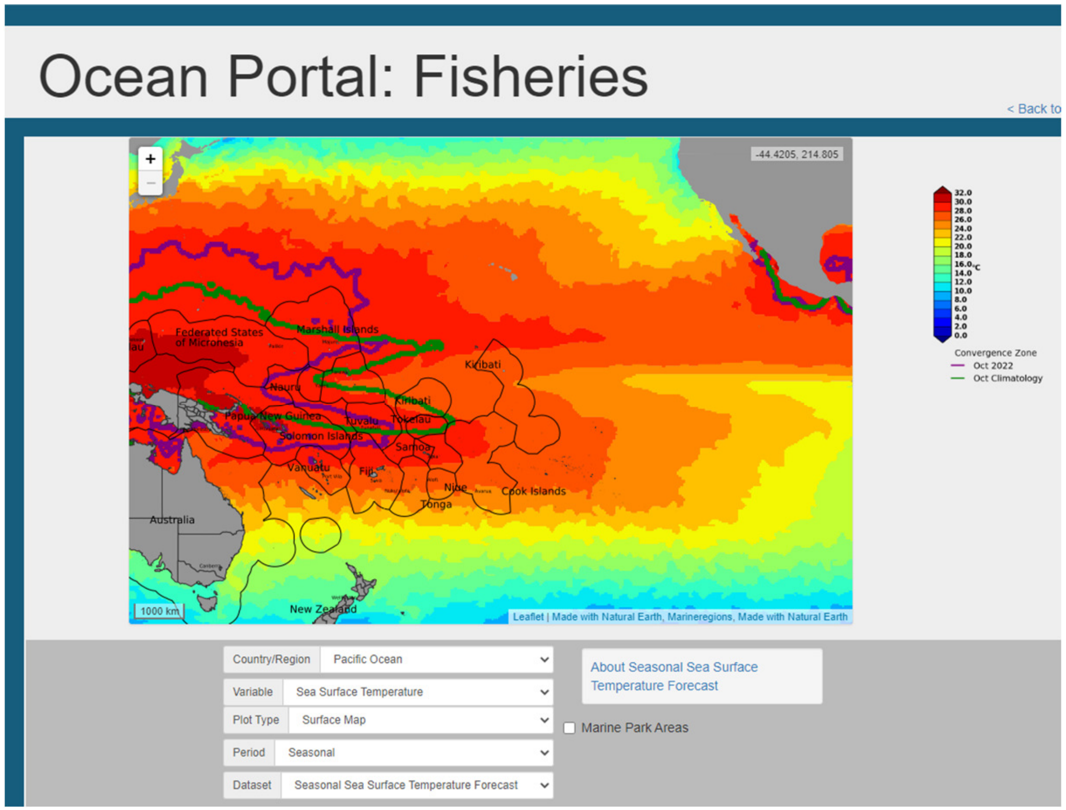




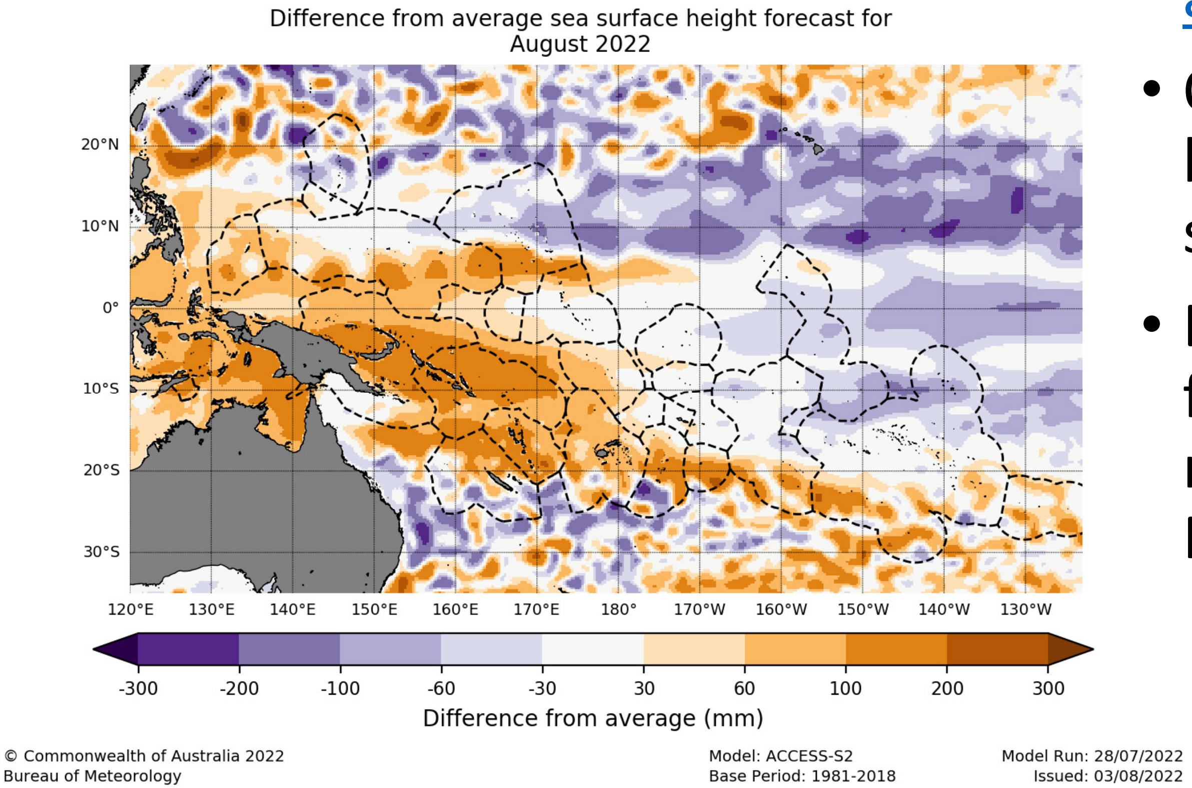
- http://oceanportal.spc.int/portal/ocean.html
- Monthly only
- Right click to discover real values down to two decimal places
- Help files available (with monthly skill maps included)
- Interactive map window
- Available out to six months

ACCESS-S Ocean Outlooks: SST full field



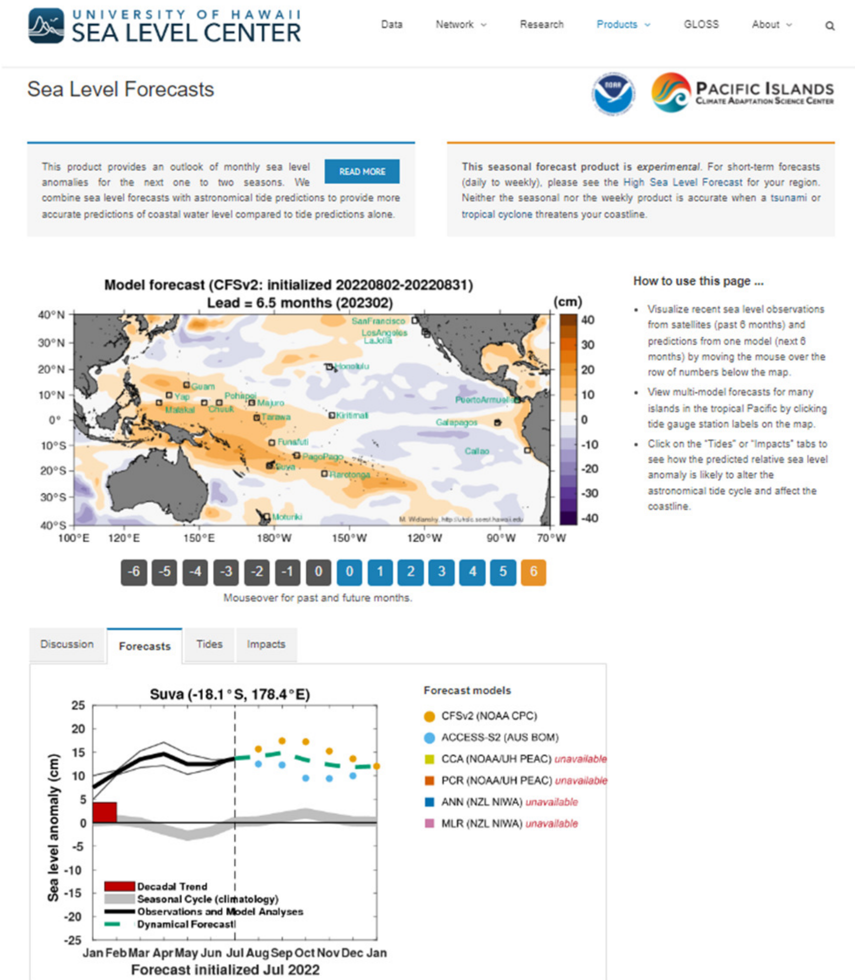


ACCESS-S Ocean Outlooks: Sea level

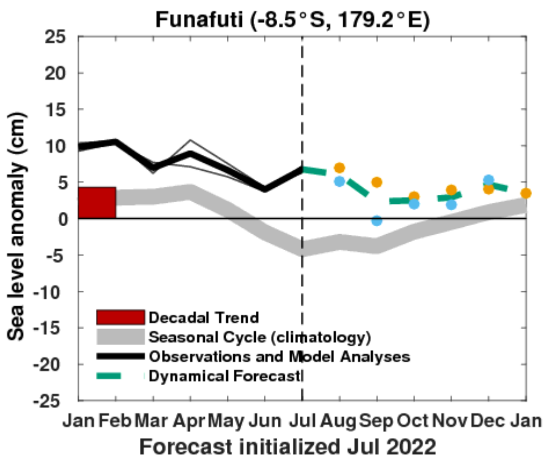


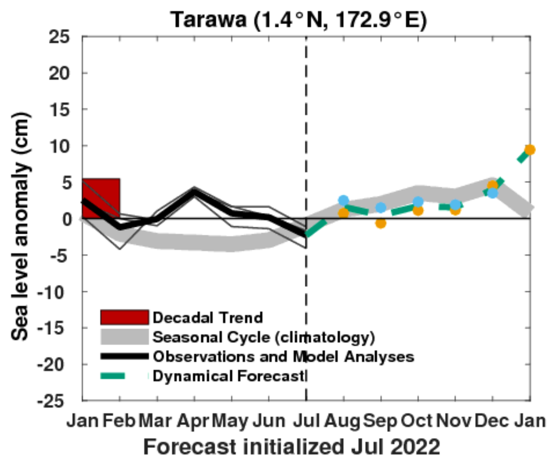
- http://www.bom.gov.au/climate/pacific/outlooks/
- Only available on the website (will be available in the ocean portal soon)
- Difficult to find sea level outlooks from global seasonal climate models (only other one available is NOAA CFSv2....)

CFSv2 and ACCESS-S MME

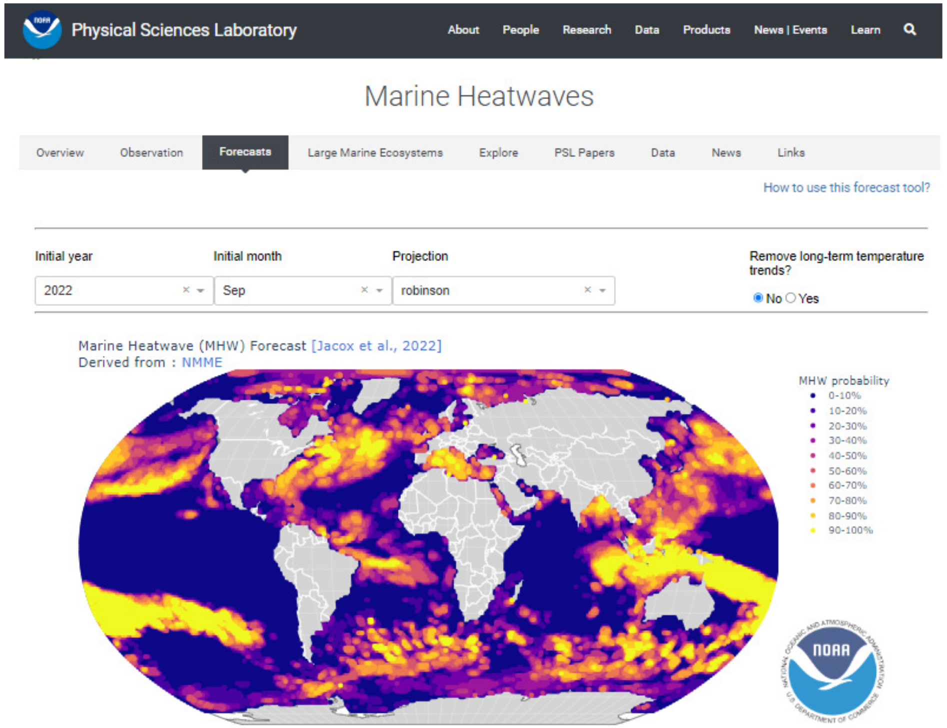


- https://uhslc.soest.hawaii.edu/sea-level-forecasts/
- Time series available (one location per Pacific country only)





Marine Heatwaves Outlooks



- https://psl.noaa.gov/marine-heatwaves/
- Marine Heatwave outlooks on a monthly time scale
- Probabilistic outlooks
- From NOAA's North American Multi-Model Ensemble
- Includes skill maps