OCEAN FORECASTING IN DATA-SPARE ENVIRONMENTS

Operational 3D Ocean Circulation Models for Pacific Island Resilience

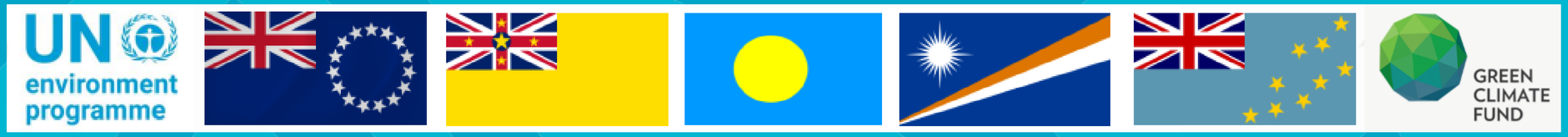
Bridging Models, Observations, and Societal Applications

Claudia Gabriela **(Gaby) Mayorga Adame**
Kunal Singh, Anuj Divesh, Moritz Wandres, Bipen Prakash, Jerome Aucan, Herve Damlamian
Oceanography Team
Geophysics, Energy and Maritime (GEM) Division

Enhancing Climate Information and Knowledge Services for Resilience (ECIKS) in 5 island countries of the Pacific Ocean (UNEP CIS-Pac5)

&

SPC Climate Change Flagship



Max Altitude:	652 m	68 m	242 m	10 m	5 m

Pacific Small Island Developing States (SIDS) face escalating ocean risk

Pacific Community
Communauté du Pacifique

Climate-driven hazards are intensifying — and early warning depends on ocean data of inadequate resolution

1

Tropical Cyclones

Increasing intensity threatens coastal communities and infrastructure

2

Marine Heatwaves

Drive coral bleaching and disrupt marine ecosystems

3

Coastal Flooding

Compounded by storm surge and sea-level rise

4

Drought

Affects freshwater security across small island nations

5

Sea-Level Rise

A chronic, compounding threat to low-lying atolls

6

Data Scarcity

Few in-situ observations exist to inform early warning

MOTIVATION

Coastal flooding do to Local Tropical Cyclones

Niue





TC TINO, Photo taken at Sir Roberts Wharf on Saturday morning 18th January 2020. P.C – Coral Pasisi



TC TINO, Photo taken at Avatele Beach on Saturday morning 18th January 2020. P.C – Tifaga Tupuiliu



Birdseye view of the destruction caused to the Huanaki Cultural Centre in Niue after Tropical Cyclone Heta.

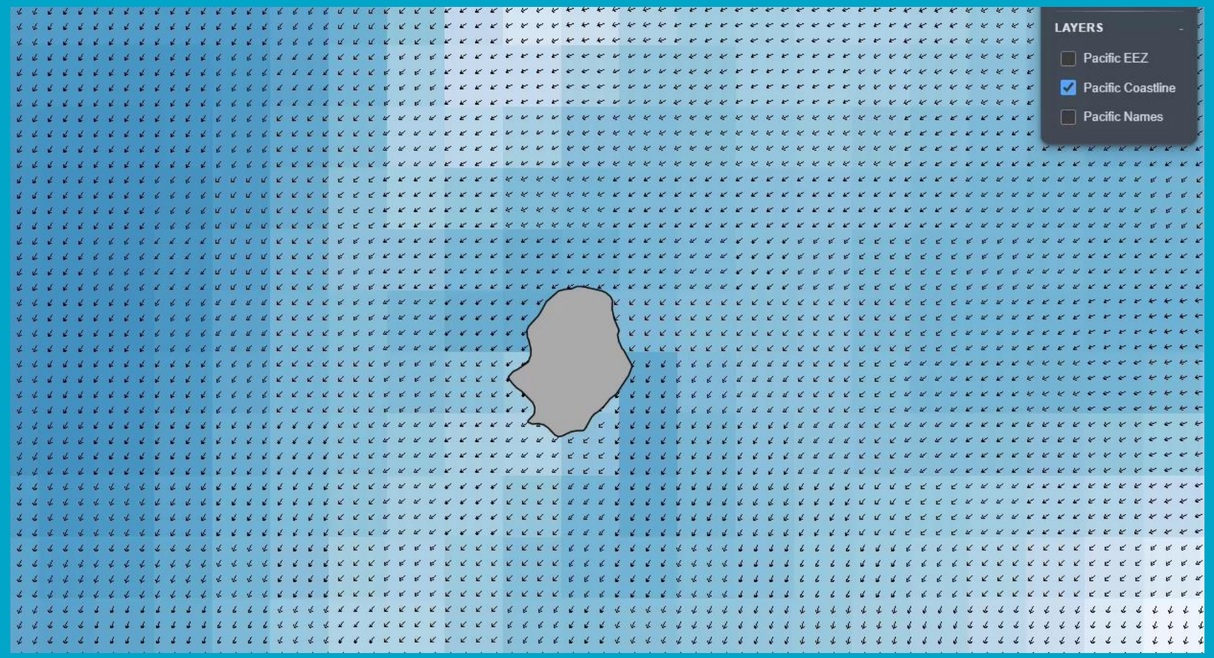
MOTIVATION

Why do we need regional downscaled high-resolution models?

Niue



Sea surface currents -Global Copernicus Forecast

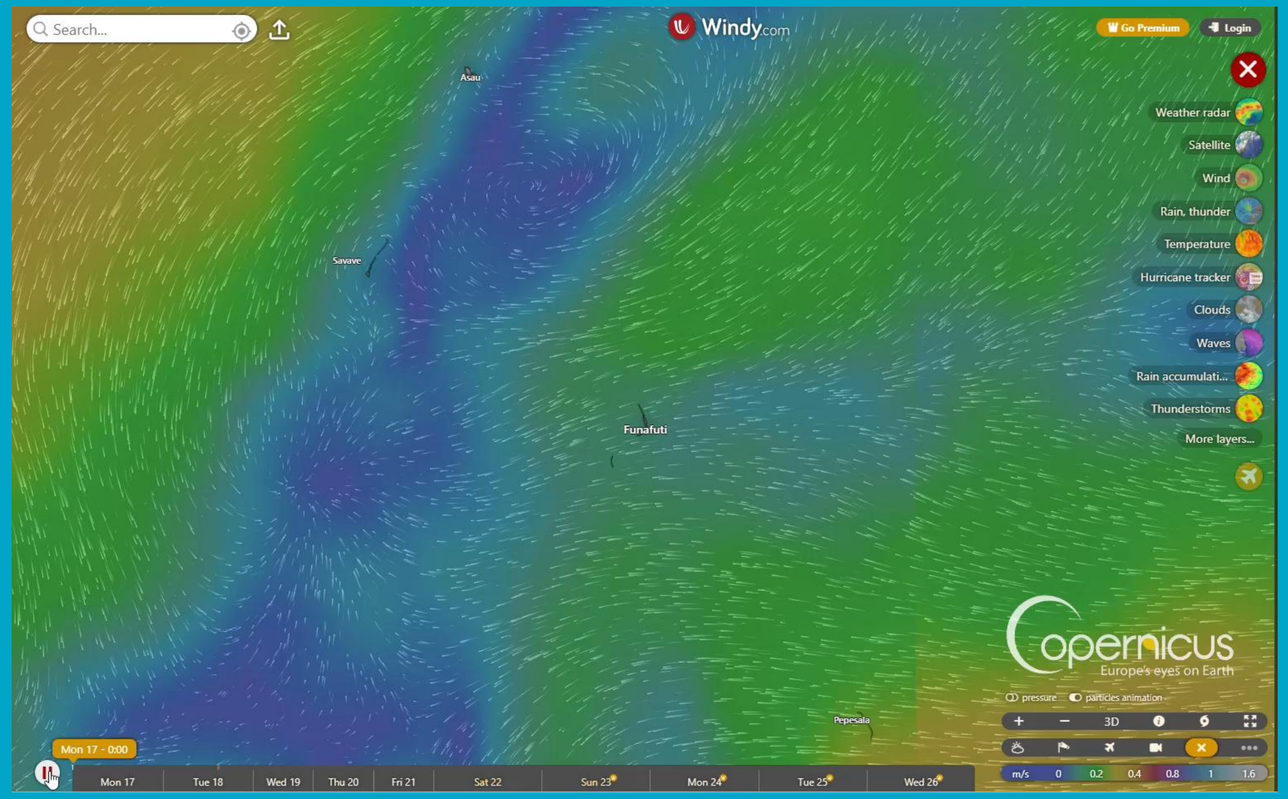


In most global datasets, small islands are not really present into the models as dry land, modifying the circulation.
The islands polygons are just overlaid on top of the data for geographic reference…

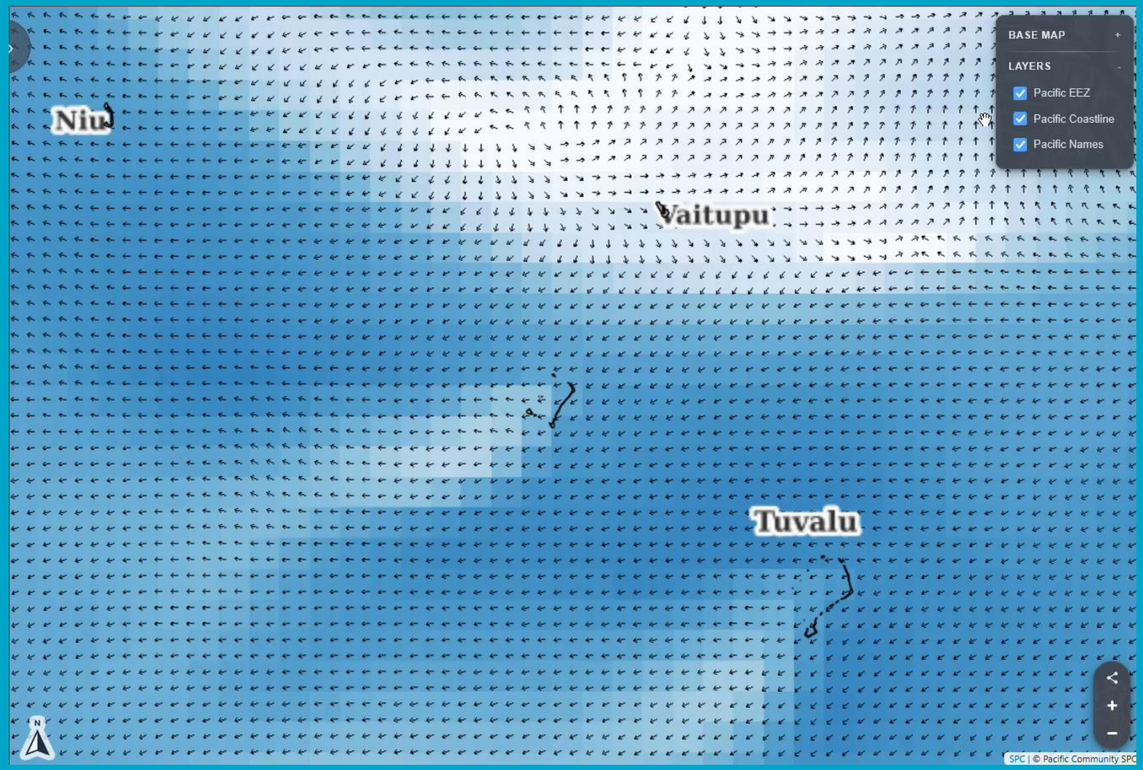
MOTIVATION

Why do we need regional downscaled high-resolution models?

Tuvalu



Sea surface currents -Global Copernicus Forecast



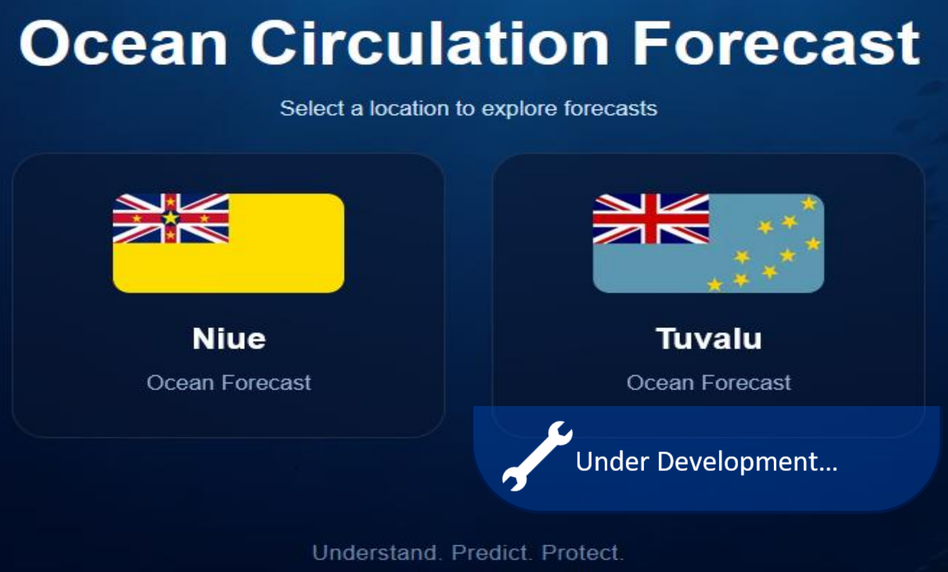
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The islands polygons are just overlaid on top of the data for geographic reference…

RESULTS

3D Coastal Ocean Circulation CROCO Models

1 km resolution 5-day forecast of ocean currents, salinity and temperature at different depths now available at:

https://opmthredds.gem.spc.int/current

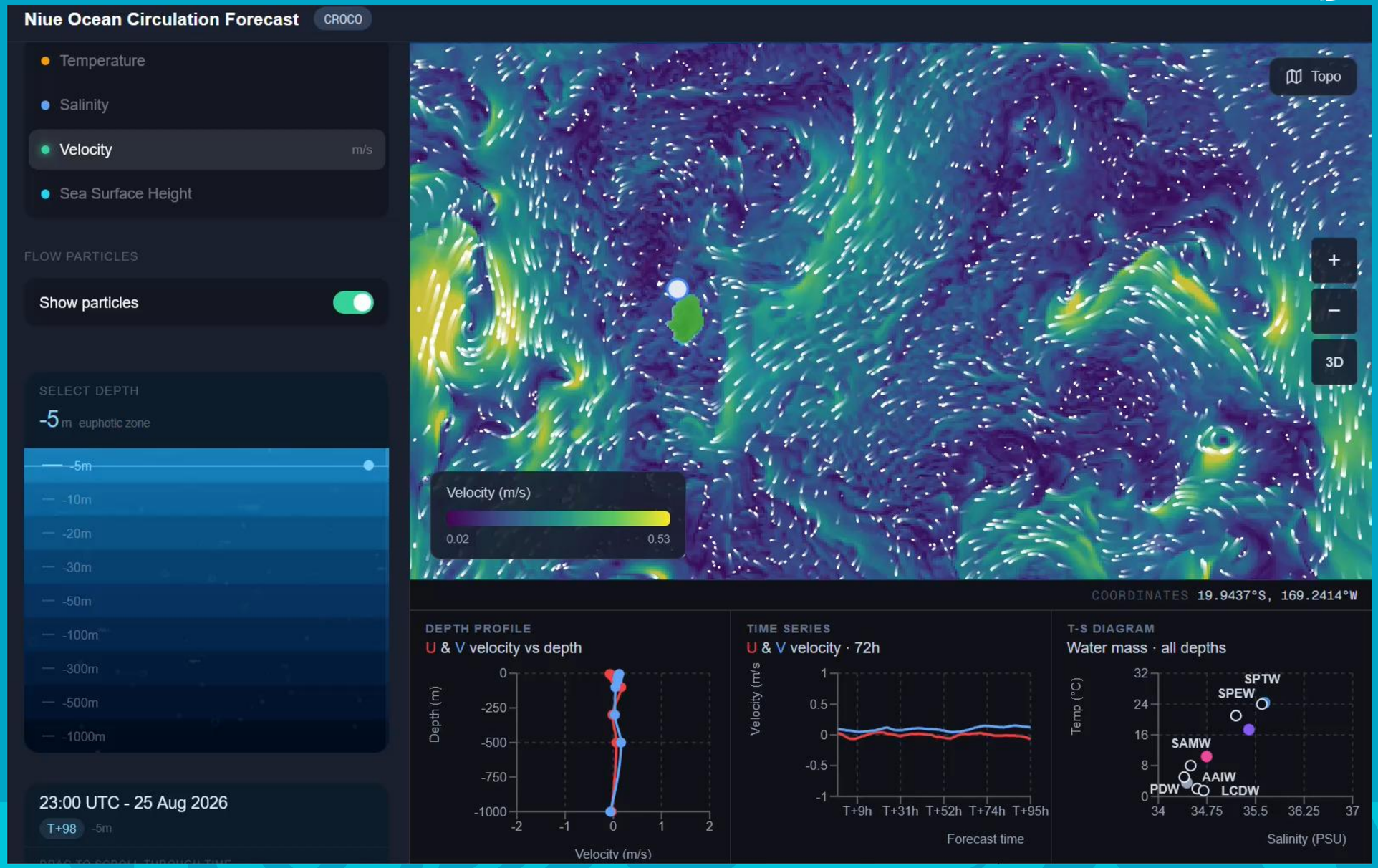


Mobile friendly

RESULTS

3D Coastal Ocean Circulation CROCO Models

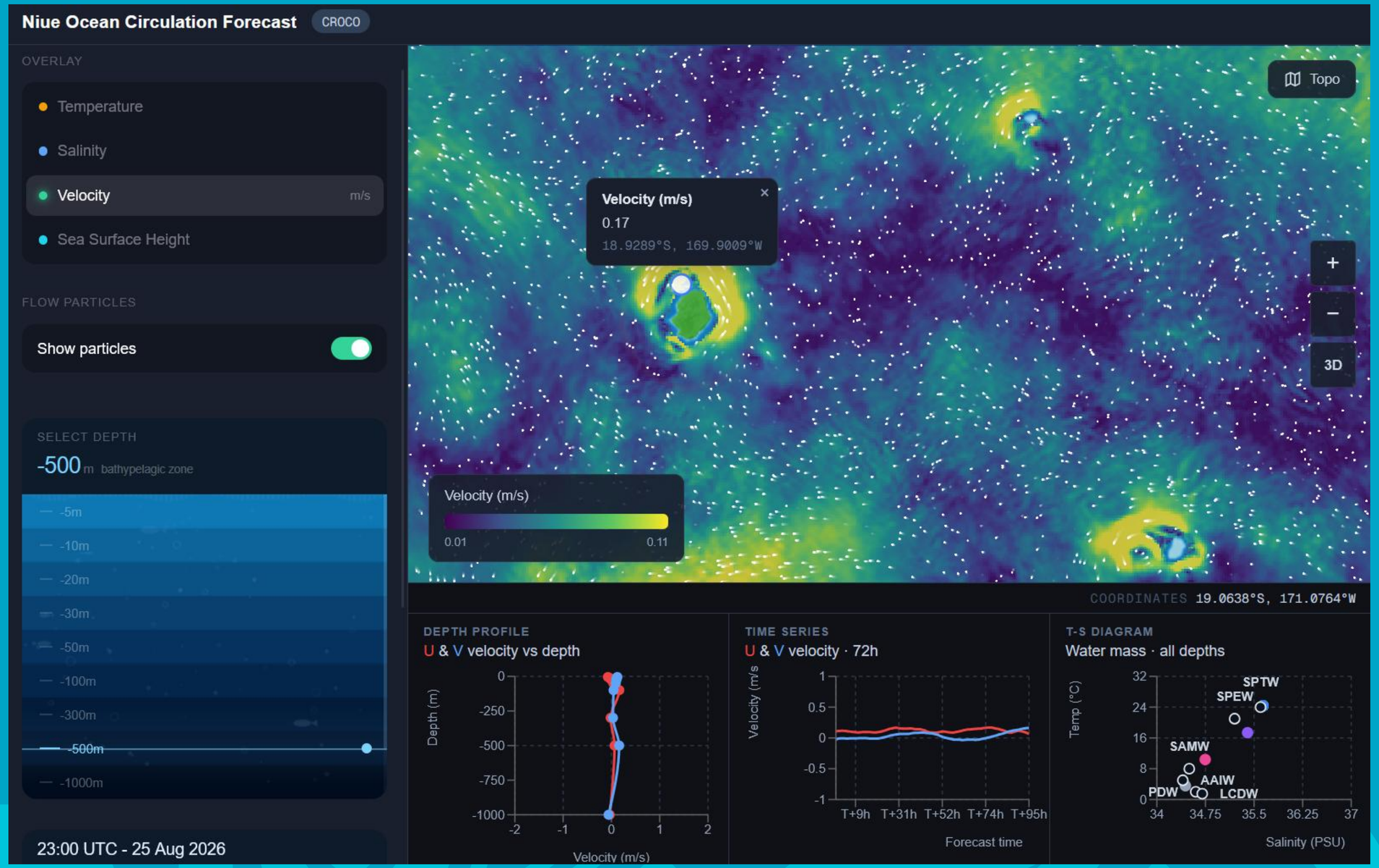
Pacific Community
Communauté du Pacifique



RESULTS

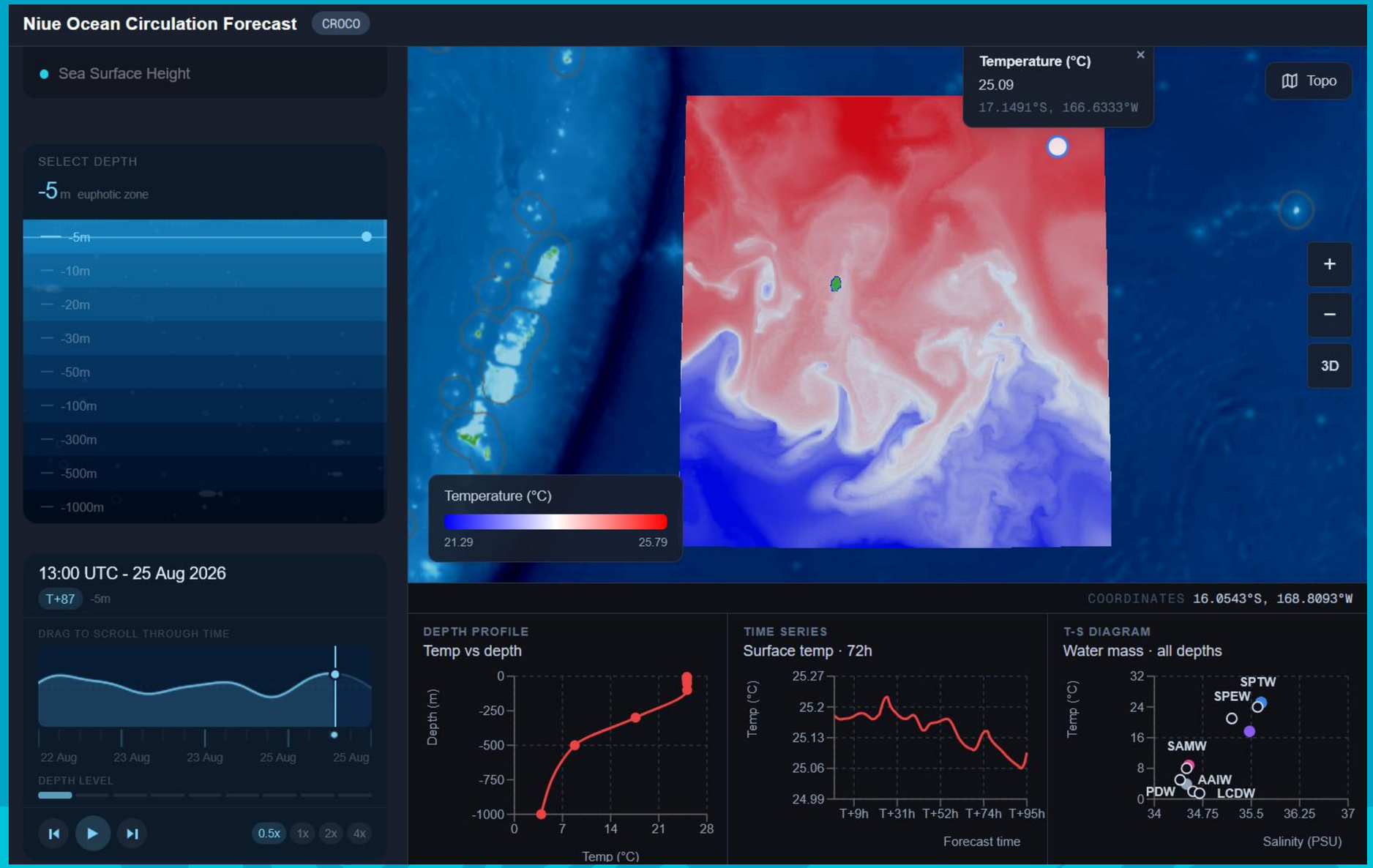
3D Coastal Ocean Circulation CROCO Models

Pacific Community
Communauté du Pacifique



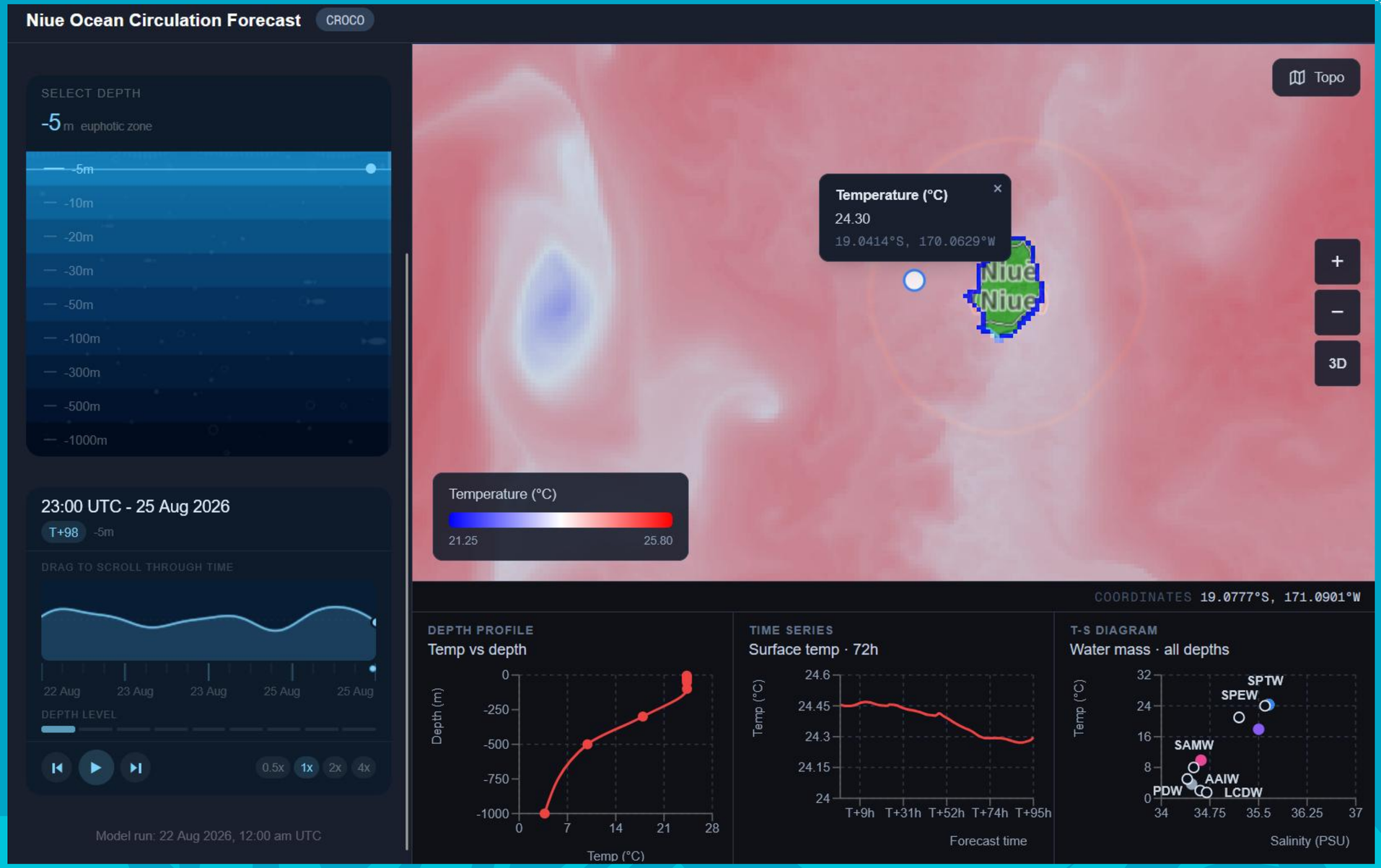
RESULTS

3D Coastal Ocean Circulation CROCO Models



RESULTS

3D Coastal Ocean Circulation CROCO Models

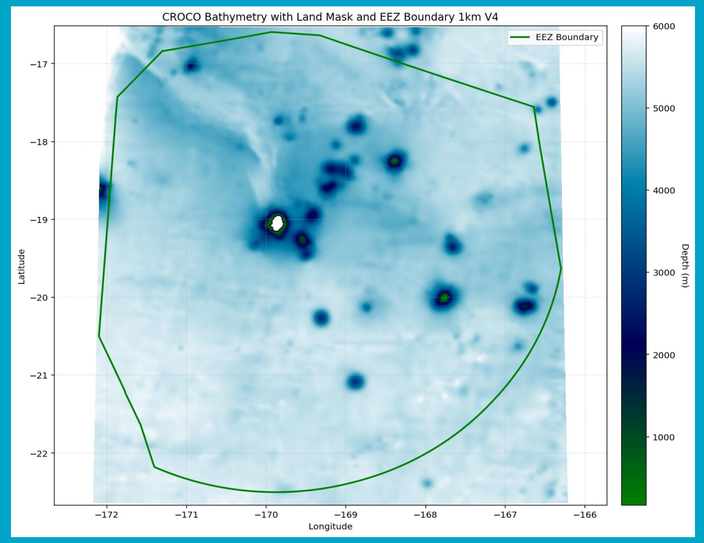


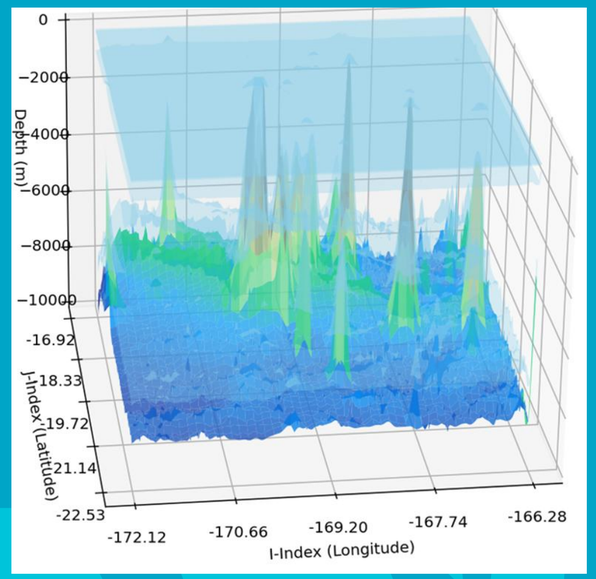
MODELS SET-UP

3D Coastal Ocean Circulation Models

Pacific Community
Communauté du Pacifique

Niue: 650x690 cells





Runing time:

20 min/day on 18 processors Linux desktop

4 min/day modelled on 60 CPUs MPI on NeSI

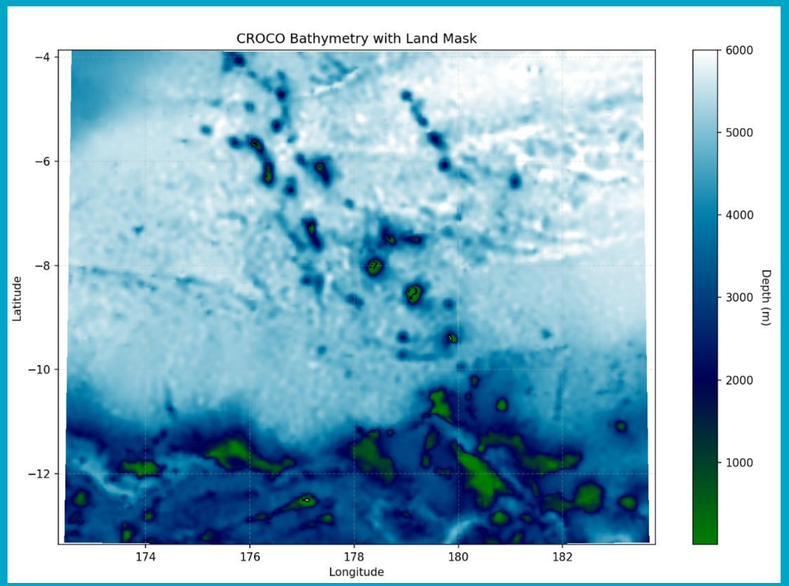
CROCO

- Bathymetry: Lidar-Multibeam-GEBCO24
- 1 km resolution
- 50 sigma stretched vertical layers
- **Operational/Hindcast- Climate**
- Mercator / PacCROCO ini and BC
- GFS / ERA5 Atmospheric forcing
- TPXO / FES tidal components

Progress

- Niue and Tuvalu configurations & inherited Solomon's system
  - ❑ operational version providing a 5 day forecast
  - ❑ Hindcast model
- **Prototype data products & applications**

Tuvalu: 1218x1052 cells

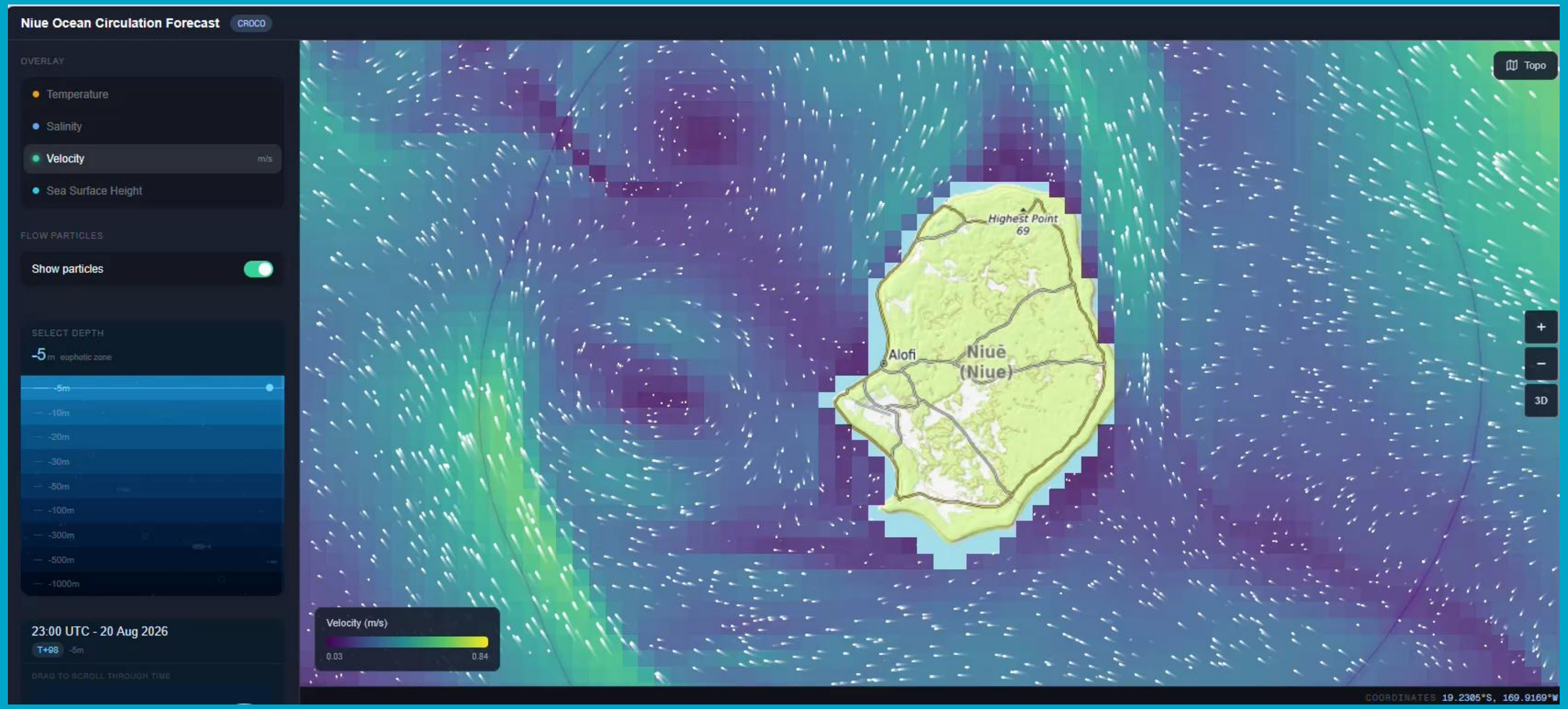


Runing time:

30 min/day on 100 processors DMZ server
<1hr serial pre-processing workflow
1-2 days hindcast +5 days forecast

RESULTS

3D Coastal Ocean Circulation Models

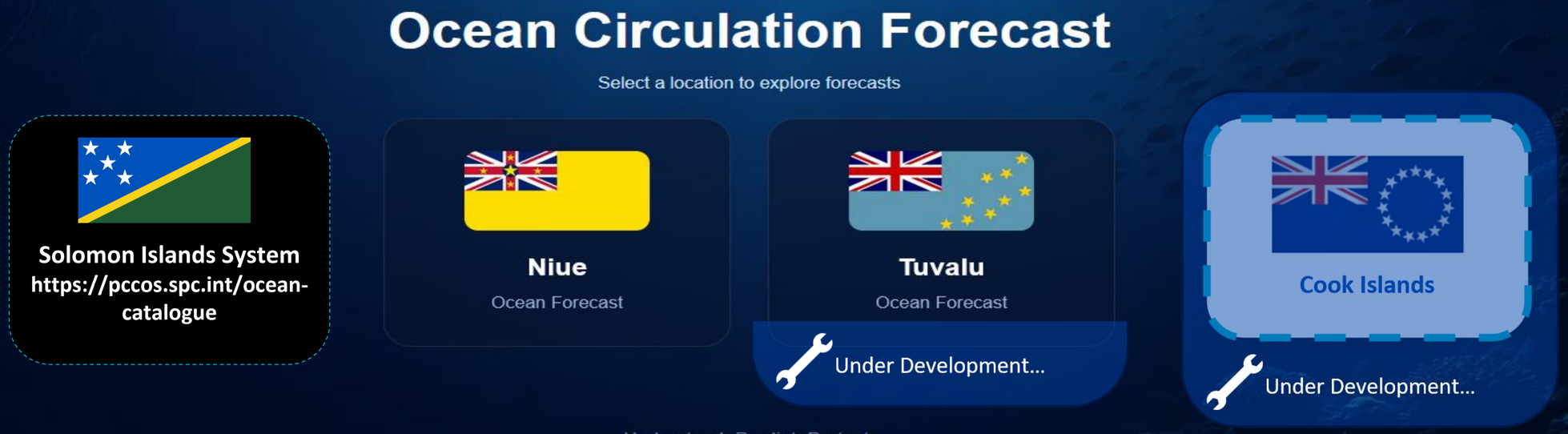


When the islands are really present they modify the circulation generating complex and highly variable 3D submesoscale structures. The impact on MLD, Ocean Heat Content, and MHWaves must be significant!

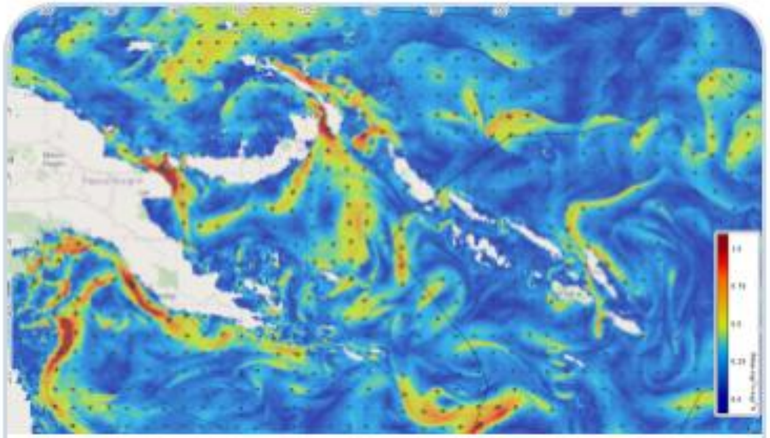
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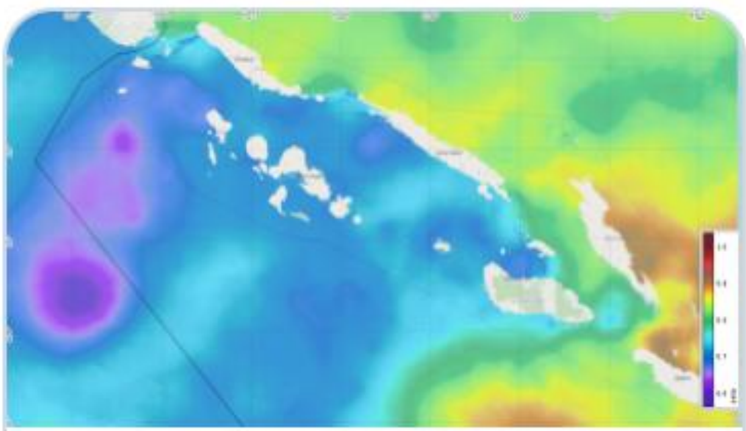


PNG / SOLOMON CROCO Forecasting system



Solomon Sea ocean circulation forecast at 1/36°

Ocean circulation forecast of the Solomon Sea developed by PCCOS.

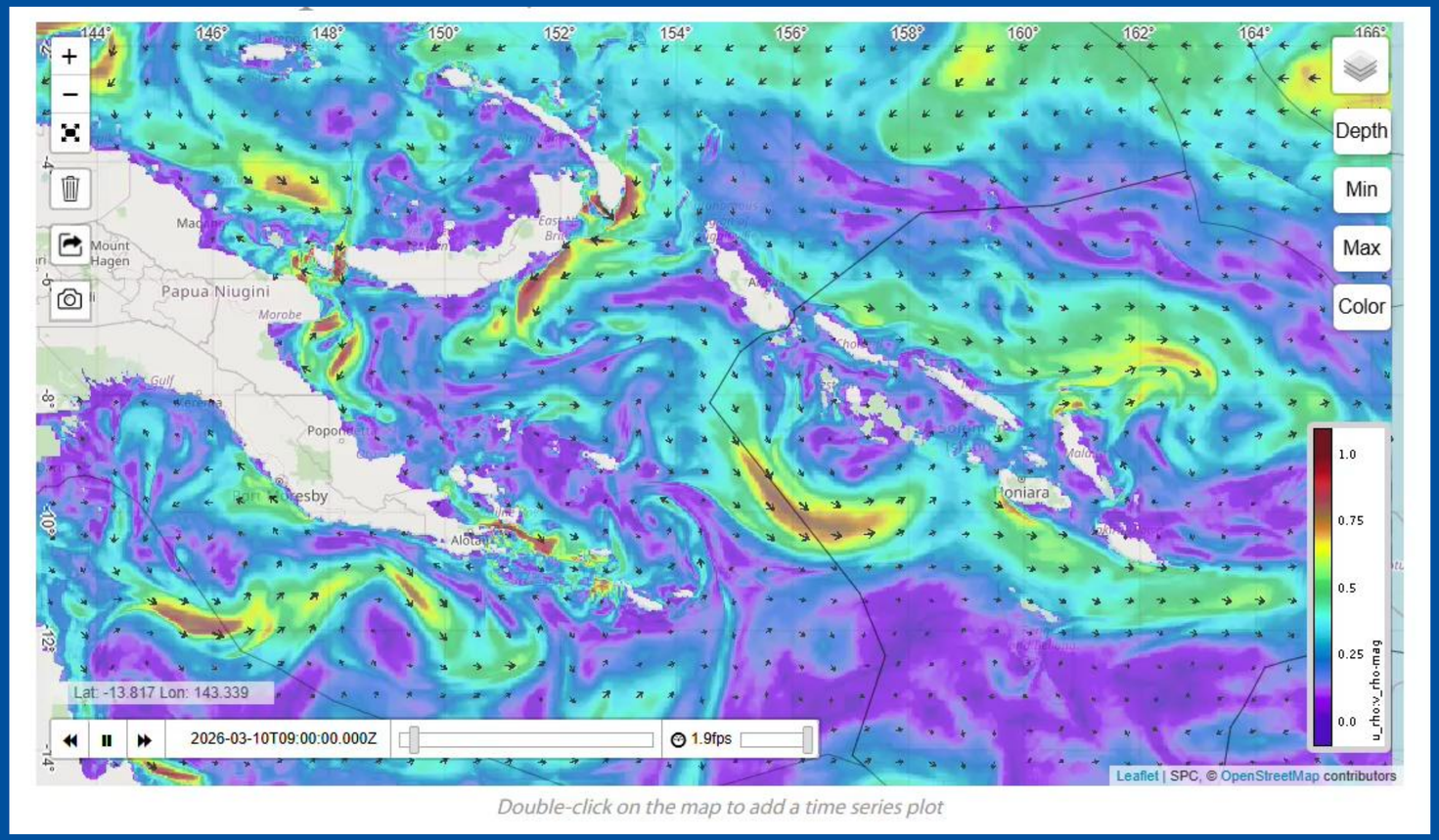


Solomon Islands ocean circulation forecast at 1/100°

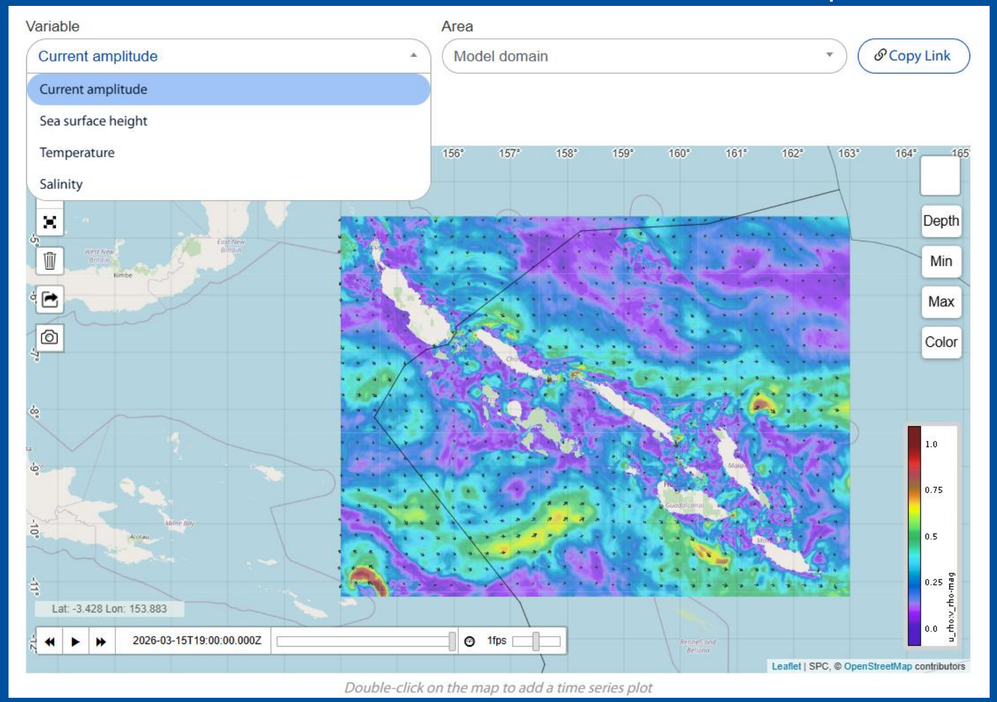
Ocean circulation forecast of the Solomon Islands developed by PCCOS.

https://pccos.spc.int/ocean-catalogue

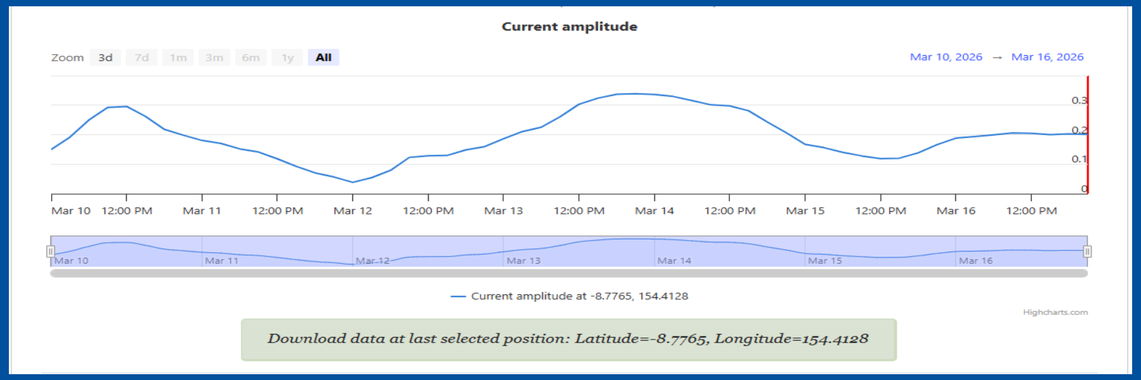
Set up by: Francois Dufois
Maintained by: Gaby Mayorga-Adame & Anuj Divesh



Double-click on the map to add a time series plot



Double-click on the map to add a time series plot



Download data at last selected position: Latitude=-8.7765, Longitude=154.4128

https://pccos.spc.int/ocean-catalogue

Models set up: This is an offline coupled system running sequentially once daily

Model	Solomon Sea	Solomon Islands
Resolution:	1/36 degree ~ 3 km	1/100 degree ~ 1km
Area covered:	Part of PNG & Solomon Is	Solomon Islands
Grid size:	845 x 518	901 x 667
Boundary Forcing:	GLORYS Copernicus Marine	Solomon Sea
Tides:	No	Yes (FES 33 components)
Atmospheric Forcing:	Global Forecast System	Global Forecast System
Hindcast:	2 days	2 days
Forecast:	5 days	5 days
Vertical levels:	40	40
Postprocessing:	6 depths	6 depths
Output:	3 hourly	1 hourly

Computational requirements:

The 7 days forecasting cycle including pre & postprocessing takes ~10 hrs on 32 cpus in the mahi-mahi server (SPC Noumea).

Observational components

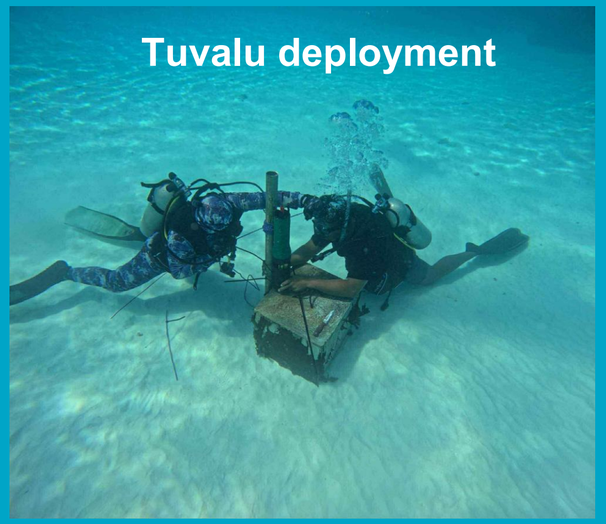
❑ WiMo Multiparameter probes nearshore deployments

- Pressure (sea surface elevation)
- Temperature
- Salinity (conductivity)
- Chl-a (photosynthetic pigment)
- Dissolved Oxygen
- pH (acidification)
- Turbidity (particles in the water)

WiMo Multiparameter probes



Tuvalu deployment



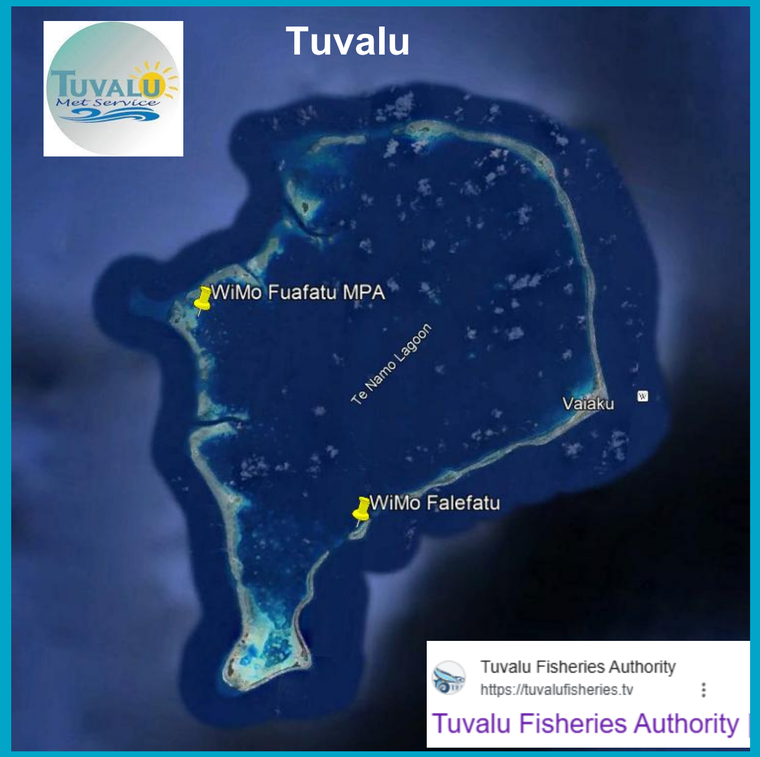
Niue deployment



- ✓ Stakeholder training completed in Tuvalu, Cook Islands and Niue, Jun 2025
- ✓ Deployed in 2 sites in Tuvalu since Jul 2025
- ✓ Ongoing deployments in Cook Islands, since Sep 2025
- ✓ Deployment in 3 sites in Niue: Utuko beach, Hikutavake rock pools & Liku, since 7 May, 2026

Observational components

❑ WiMo Multiparameter probes nearshore deployments

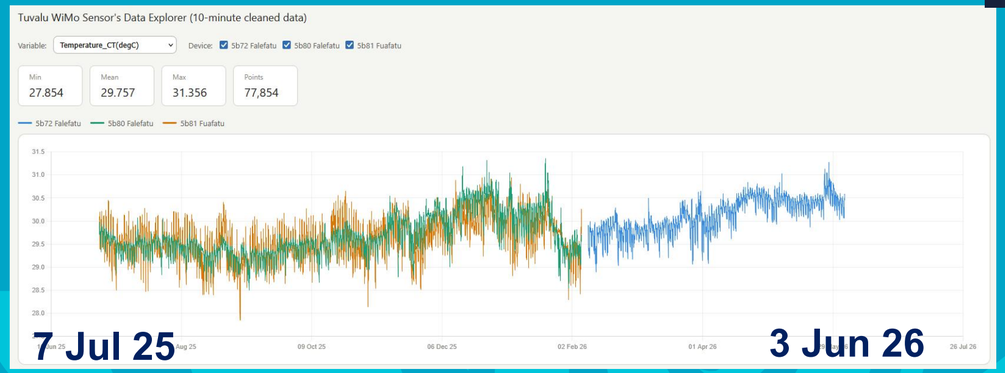




1st deployment since May 7th 2026



Deployments since Aug 7th 2025



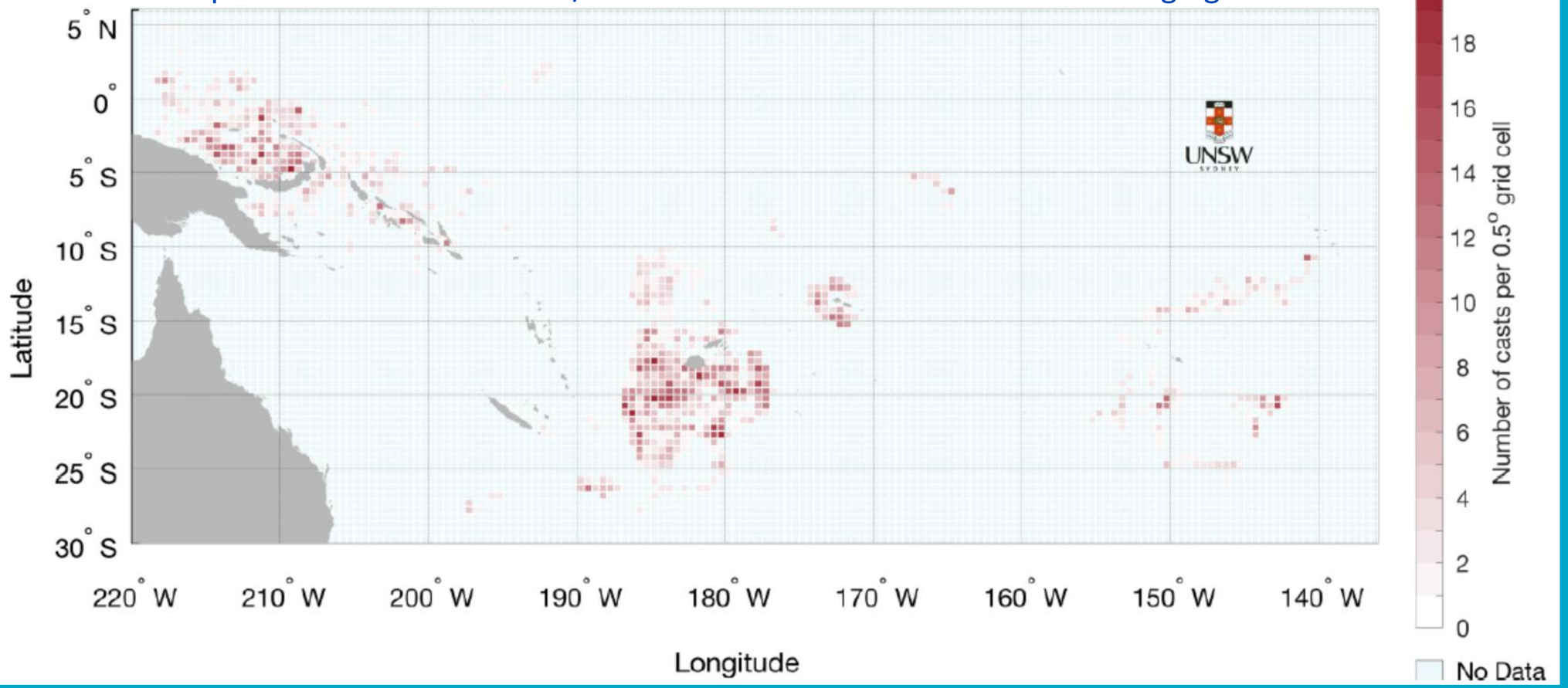
- Real time WiMo probes soon to be installed in Tuvalu and Cook Islands

Observational components

❑ Fishing Vessel Observing Network

- **Temperature profiles**

- Partnership between SPC and IMOS/UNSW
- Endorsed GOOS Emerging Network



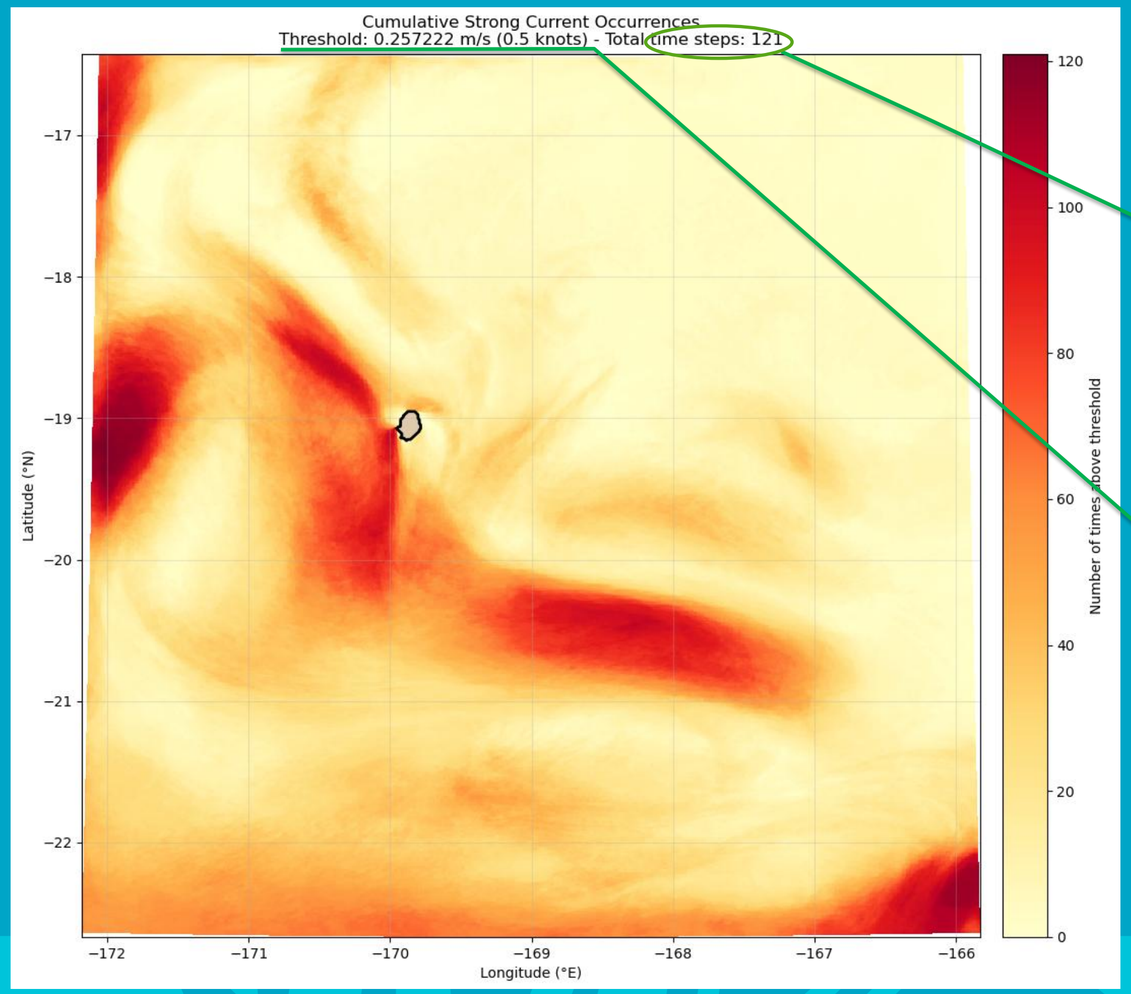
- QC data becomes available to vessels immediately, data exchanged through GTS



- Partnering with the commercial fishing sector in the Pacific for sub-surface temperature monitoring program – low-cost sensor
- 40 vessels installed, with 70 deployments by end of 2026

Safer Seas…

Interactive comulative maps of **strong currents** can inform if the ocean conditions are adequate for different activities and highlight areas to avoid in order to stay safe at sea (i.e. red areas > ½ knot).



A time window of interest can be selected

Speed threshold can be adjusted for different activities / vessel types

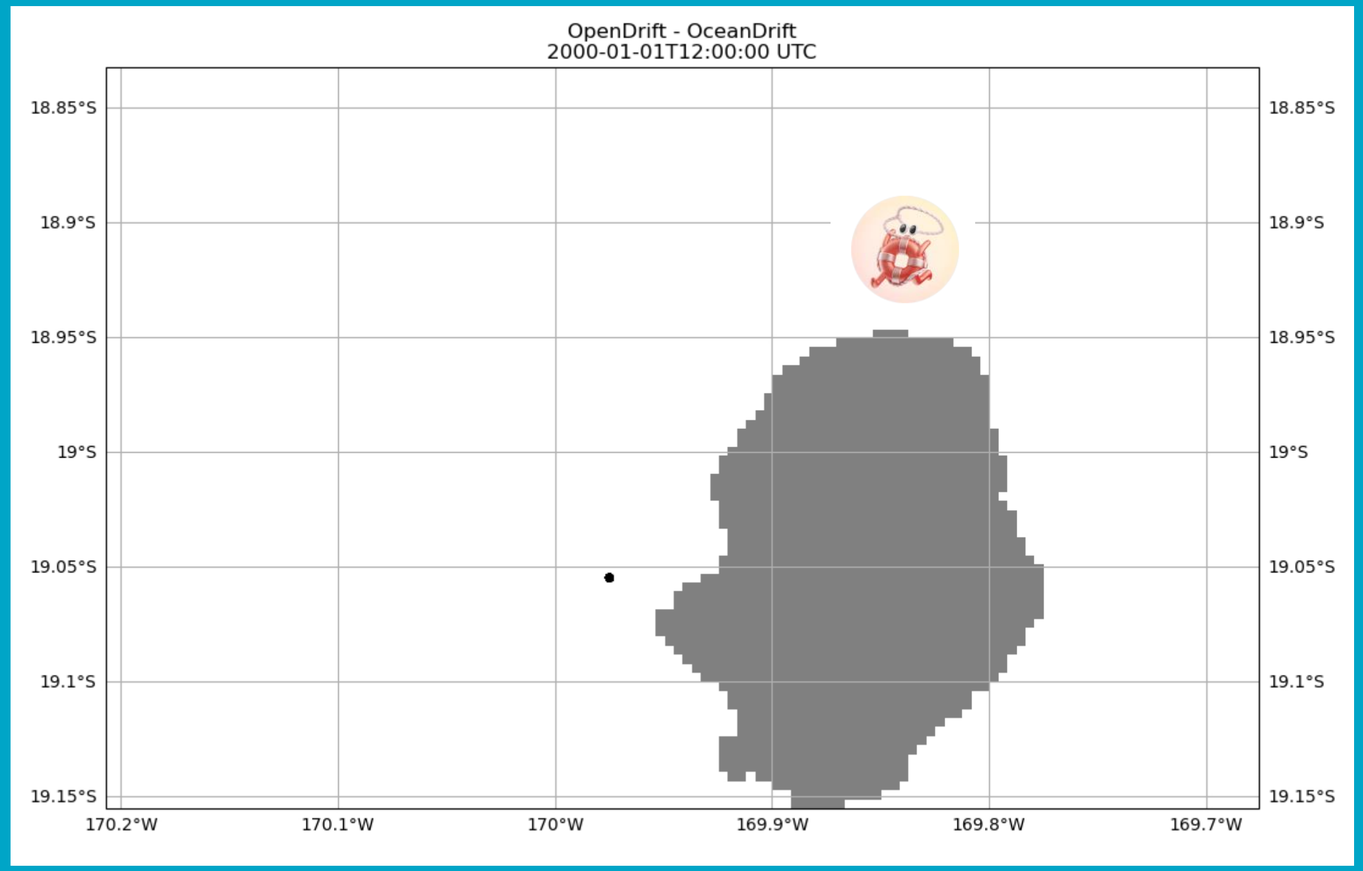




SOCIETAL APPLICATIONS

Safer Seas...

Search and rescue applications



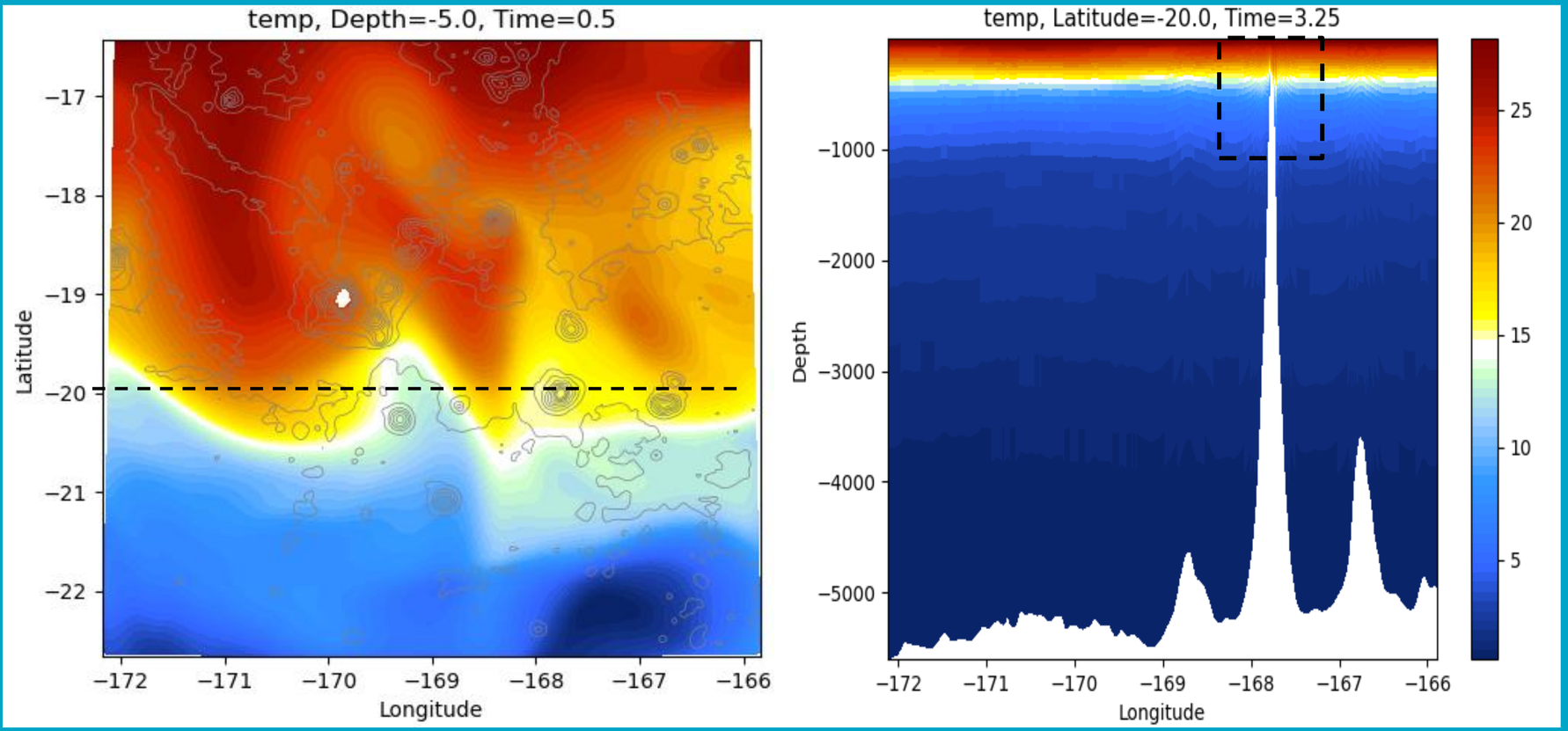
An OpenDrift particle tracking simulation uses the forecasted currents to find out the potential **drift path** of a floating object specifying the last know location and time.

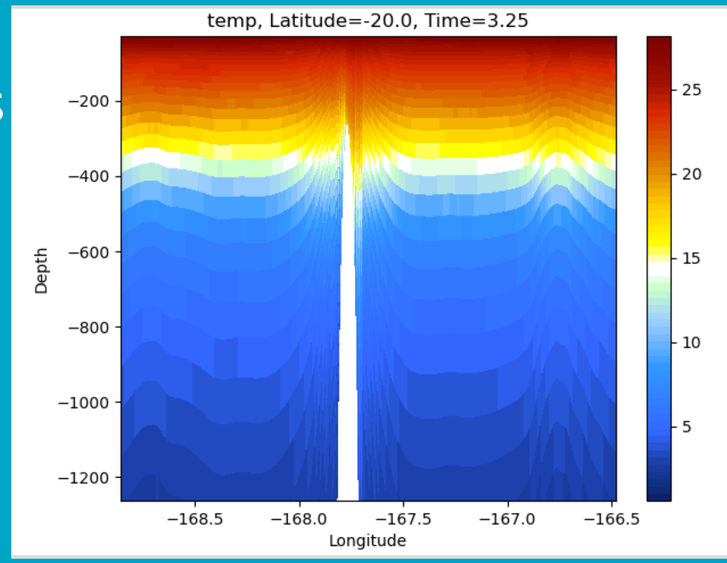
This animation shows the **2 days** trajectory of particles released 5 km offshore from Alofi.

SOCIETAL APPLICATIONS

Fisheries Management

Vertical slices of temperature help detect highly **productive upwelling regions**; important areas to fish, place FADs, or Marine Protected Areas

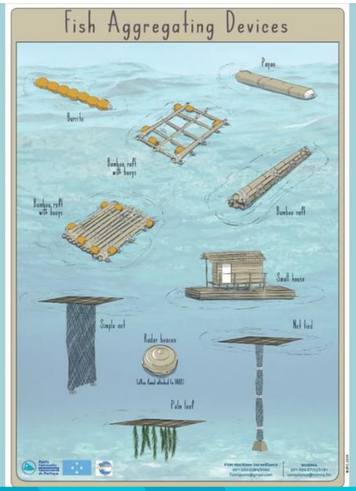




Fish Aggregating Devices

FADs are man-made structures deployed in coastal and offshore waters to attract and concentrate fish, enhancing fishing efficiency and sustaining coastal livelihoods.

Source: Anon. 2019. Fish aggregating devices [Poster] - Noumea, New Caledonia: Pacific Community. https://www.spc.int/digitallibrary/get/btqgi

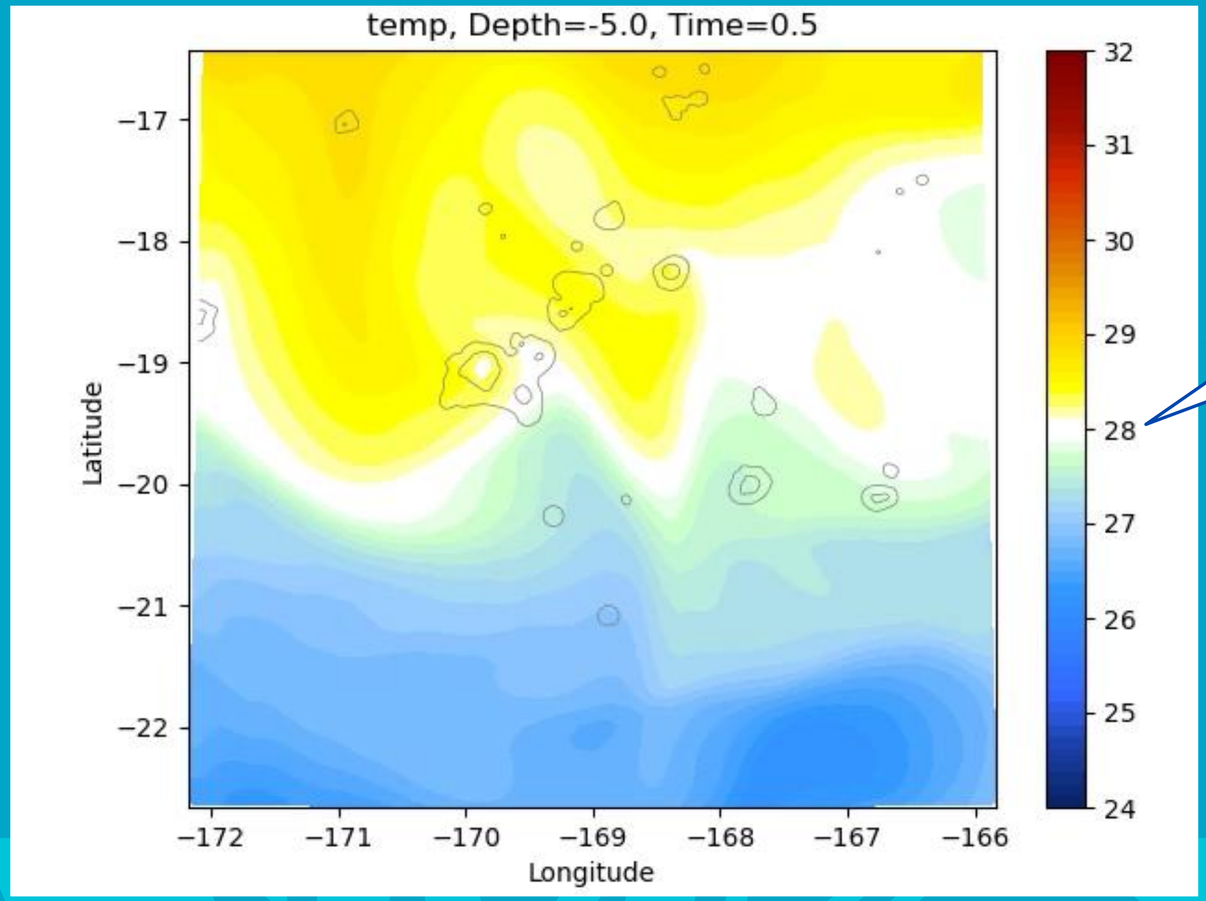


SOCIETAL APPLICATIONS

Fisheries Management

Subsurface temperature maps help us detect where and when to fish more efficiently; potentially minimizing costs, fishing pressure and by-catch.

It can also help identify sites worth protecting



Yellowfin tuna



Table 1. Preferable thermal ranges for albacore, bigeye, and yellowfin tuna.

Tuna	Species Name	Lower Limit (°C)	Upper Limit (°C)	Reference
Yellowfin	*Katsuwonus pelamzs*	18	33	[51]
Albacore	*Thunnus germo*	12–14	22	[52]
Bigeye	*Thunnus obesus*	16	22	[53]

* Weinberg, H.; Bhardwaj, J.; Watkins, A.B.; Kuleshov, Y. **The Impact of Marine Heatwaves on Isotherm Displacement and Tuna Distribution in Vanuatu**. Climate 2024, 12, 181. https://doi.org/10.3390/ cli12110181

Climate Resilience

Look into the future ocean conditions under different climate change scenarios (i.e. different levels of CO_2 emissions or atmospheric warming scenarios, “degrees of heating”)

- ❑ Sea Level
- ❑ Coastal ocean circulation patterns
- ❑ Ocean temperature and salinity conditions
- ❑ Extreme events i.e. **Subsurface marine heat wave** analysis

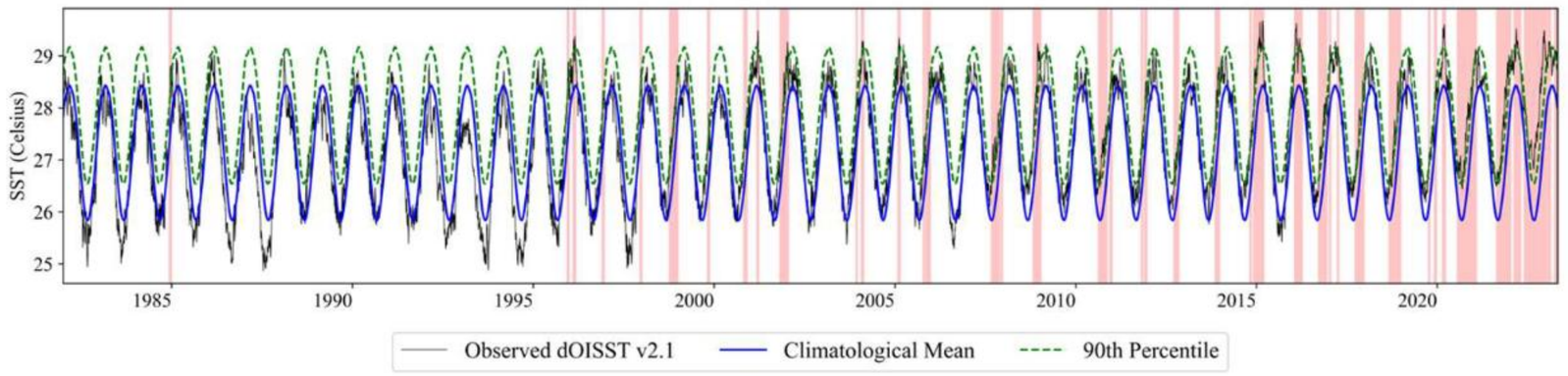


Figure 3. MHW events identified in the study period (1982–2022). MHW events are depicted in the red shaded areas with the dOISST (black line), the climatological mean (blue line), and the 90th percentile threshold (dashed green line).

* Weinberg, H.; Bhardwaj, J.; Watkins, A.B.; Kuleshov, Y. **The Impact of Marine Heatwaves on Isotherm Displacement and Tuna Distribution in Vanuatu**. Climate 2024, 12, 181. https://doi.org/10.3390/ cli12110181

CLIMATE CHANGE FLAGSHIP

Regional Pacific CROCO Model 1980-2020

Pacific Community
Communauté du Pacifique

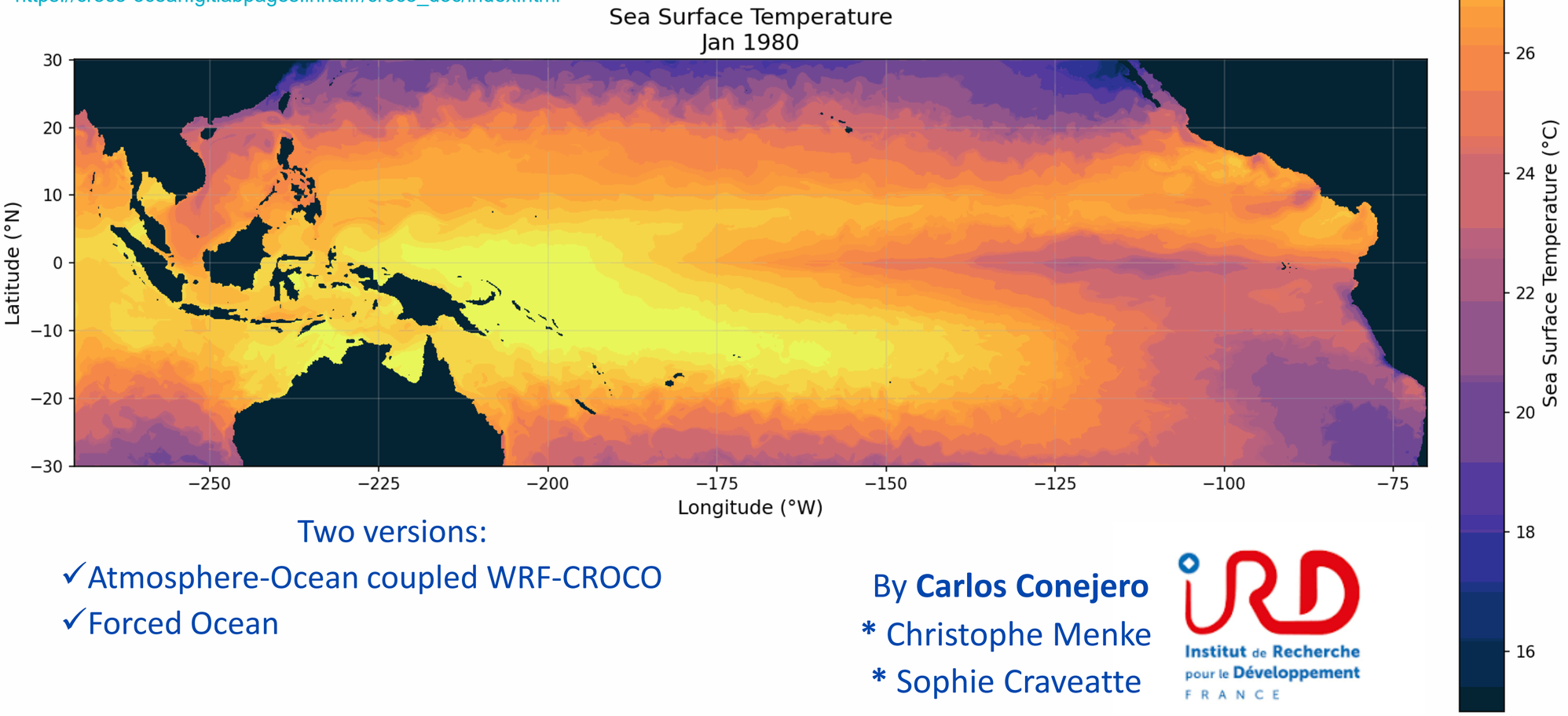
CROCO
Coastal and Regional Ocean COmmunity model

https://croco-ocean.gitlabpages.inria.fr/croco_doc/index.html

Hindcast run 1980-2020

Horizontal resolution: 1/12 degree ~ 10 km

50 vertical layers



Two versions:

- ✓Atmosphere-Ocean coupled WRF-CROCO
- ✓Forced Ocean

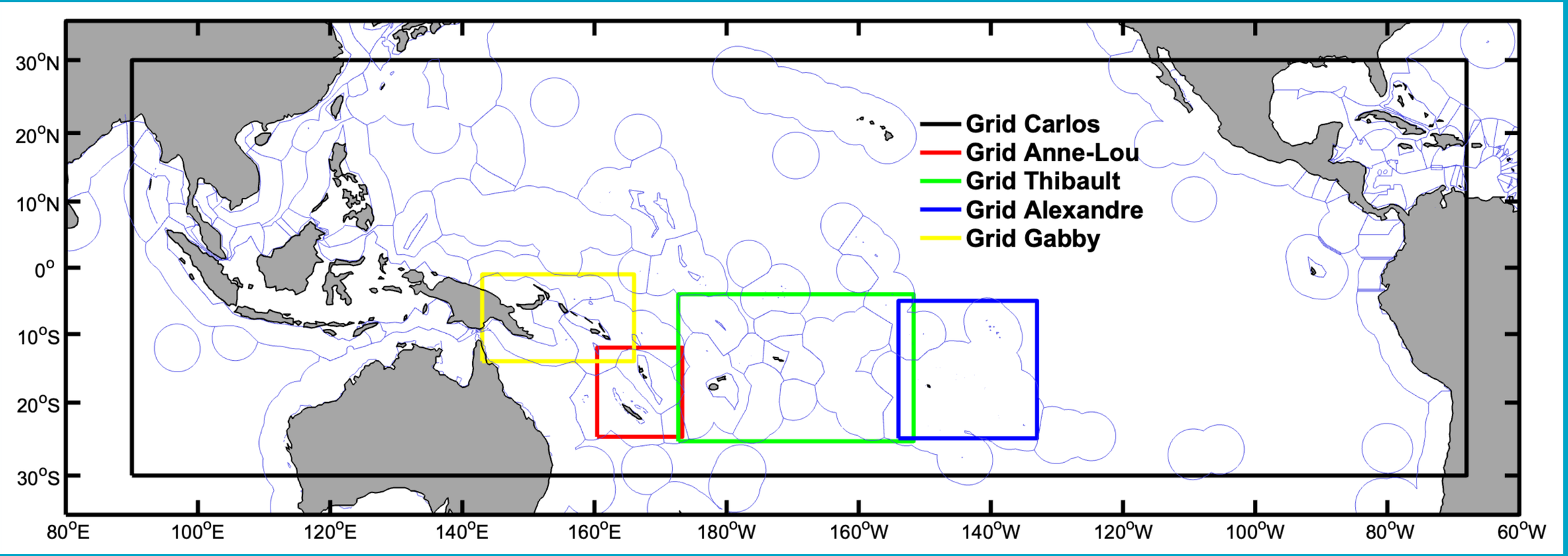
By **Carlos Conejero**

* Christophe Menke

* Sophie Craveatte

Institut de Recherche pour le Développement
FRANCE

Regional downscale domains for climate change run



Bias corrected CNRM trend + ERA5 variability forcing for the future 2025-2100

Future work: The Validation Challenge

Data-sparse regions make it hard to know if the models are right — especially near the coast and in the subsurface

Why It's Hard

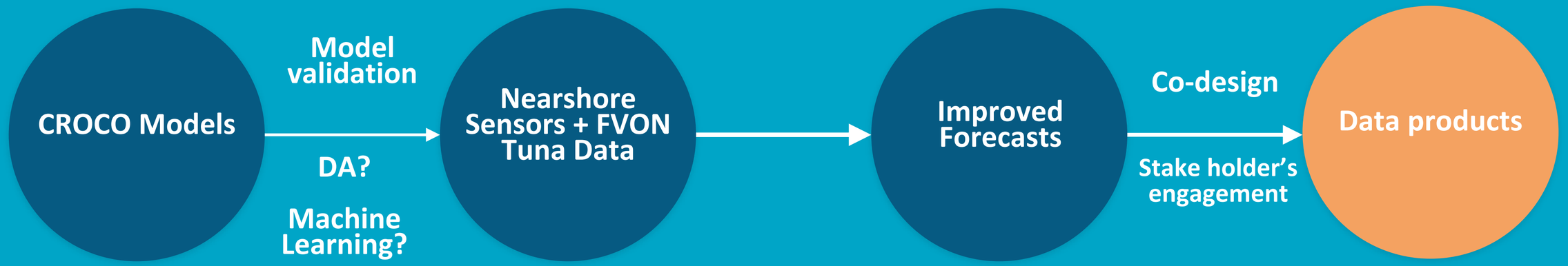
- Sparse in-situ observations across the wider Pacific ocean
- Coastal zones are the least observed, yet most societally critical
- Remote, resource-limited settings constrain sensor deployment
- Near shore process (i.e. waves, sea breeze) NOT yet included on CROCO models
- Model skill near shore is hardest to verify and improve

Closing the Gap

- Nearshore water quality sensors: temperature, salinity, pH, turbidity, chlorophyll, dissolved oxygen
- FVON tuna-industry temperature-at-depth data validates Solomon Islands model
- Use machine learning to link coastal model outputs to nearshore observations
- Identified observing gaps will become priorities for future deployment
- Data Assimilation…

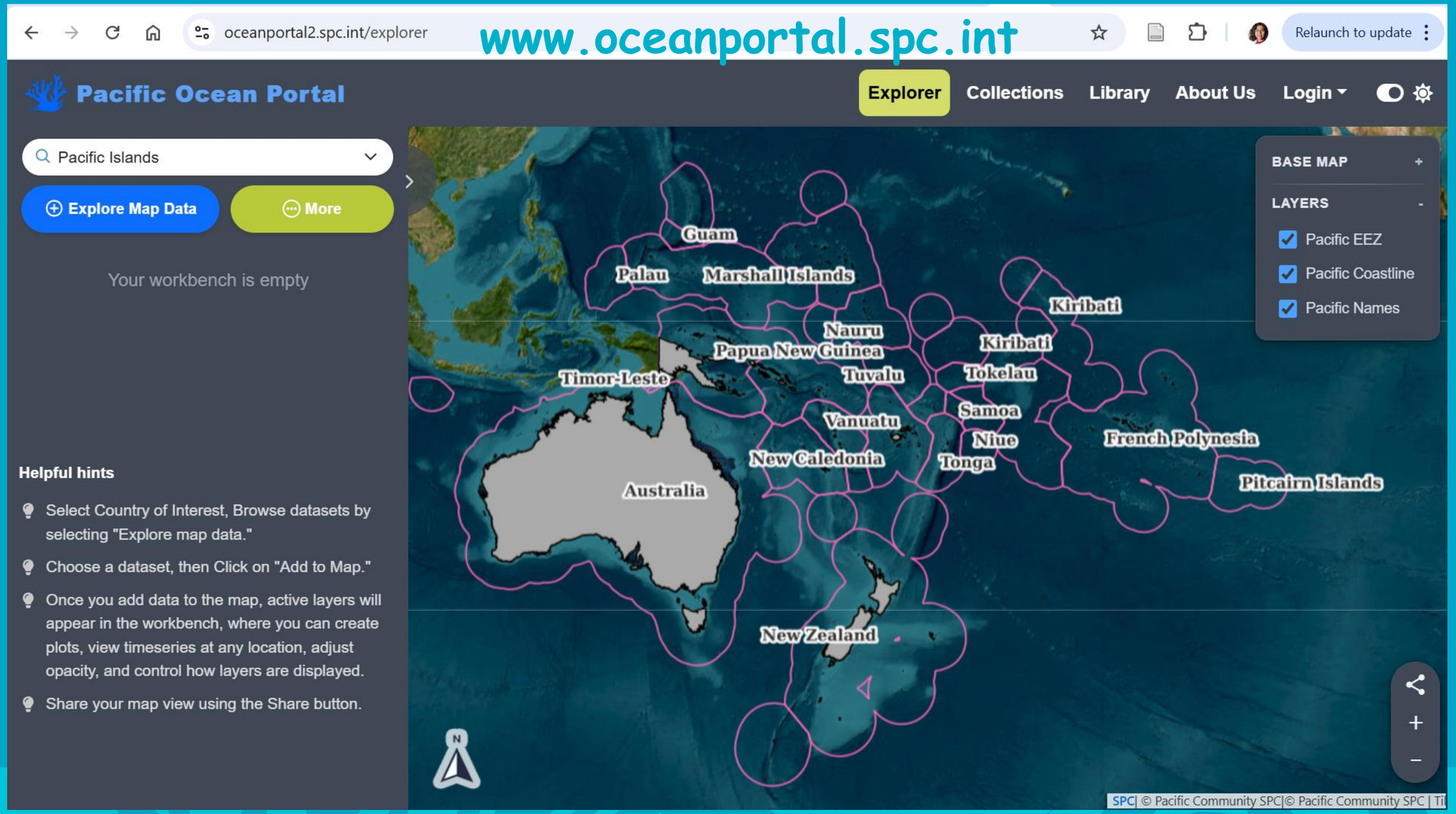
A Practical Feedback Loop

In-situ data improve the models; models help target where new observations are needed most



& a Co-Designed Path to Resilience for Pacific SIDS

Future work: Integration into the Ocean Portal



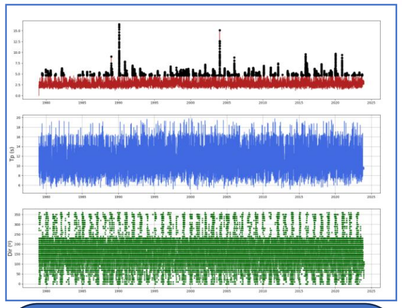
Dōmo arigatō gozaimasu

claudiaa@spc.int

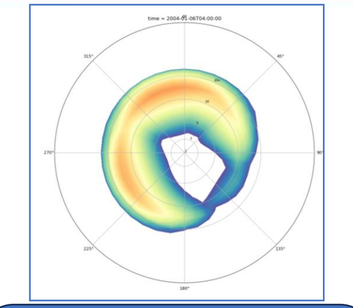
www.spc.int

Niue Croco Forecast

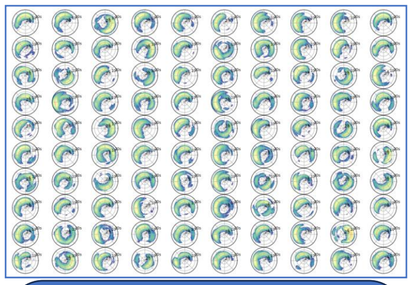
Wave Modelling & Inundation forecasting



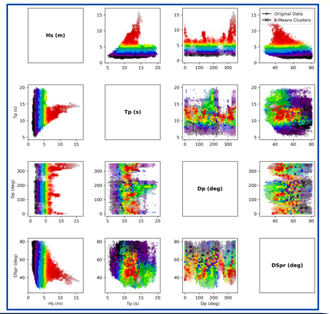
Multi-decadal wave hindcast



Generate superpoint wave spectrum



Monte-Carlo emulator to generate synthetic extreme wave spectra



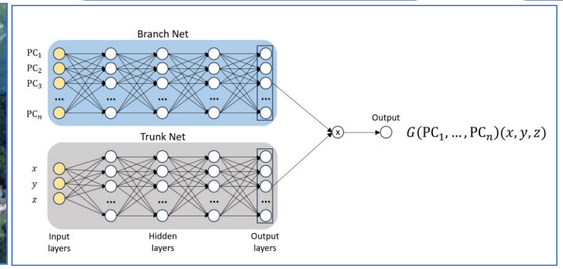
K-means clustering of wave spectra

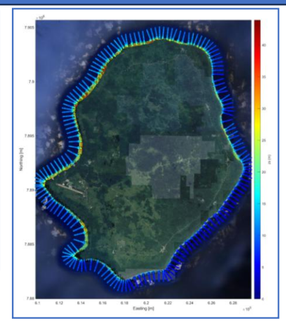
Simulate clusters with Xbeach-NH and SFINCS

Deep-learning with the simulated clusters

Use neural network to predict inundation







By Moritz Wandres