International Climate Change Adaptation Initiative

Tropical cyclones in the Western Pacific

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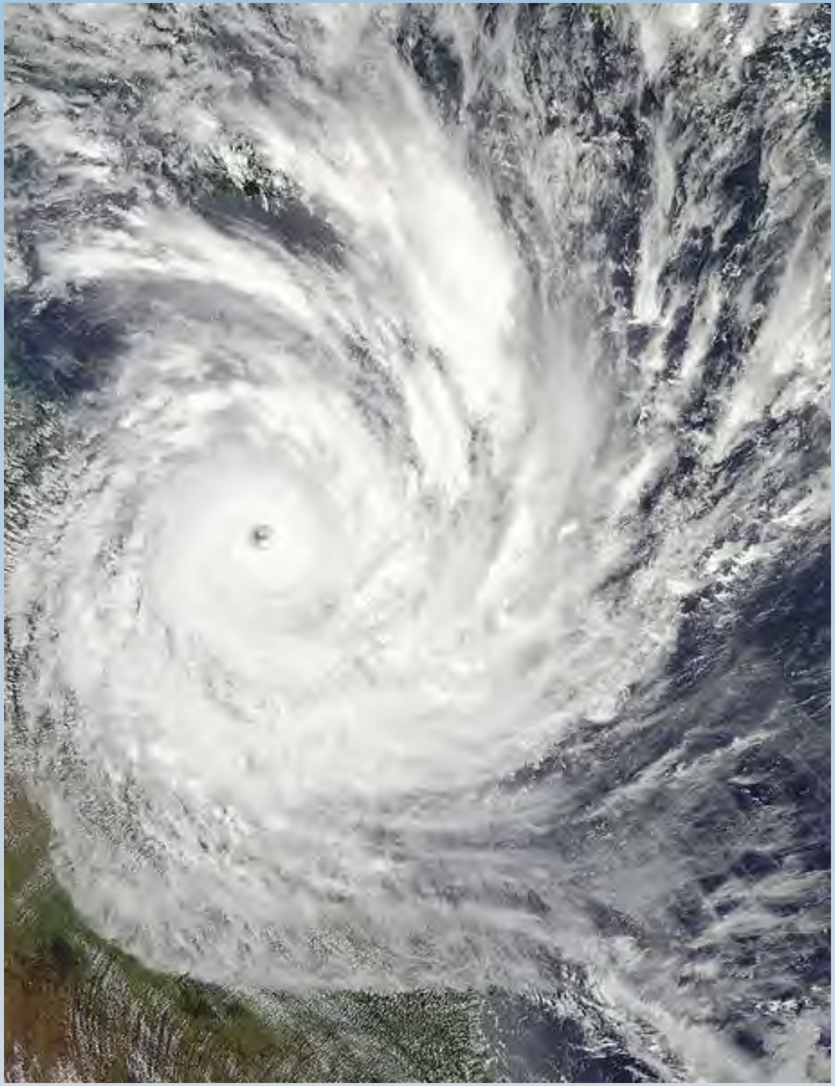
Outline

- Tropical cyclones – the most extreme severe weather events
- Tropical cyclone research
  - Historical data
  - Climatology
  - Seasonal prediction

Tropical cyclones



Cyclone *Yasi* approaching Queensland on 2 February 2011

Tropical cyclones

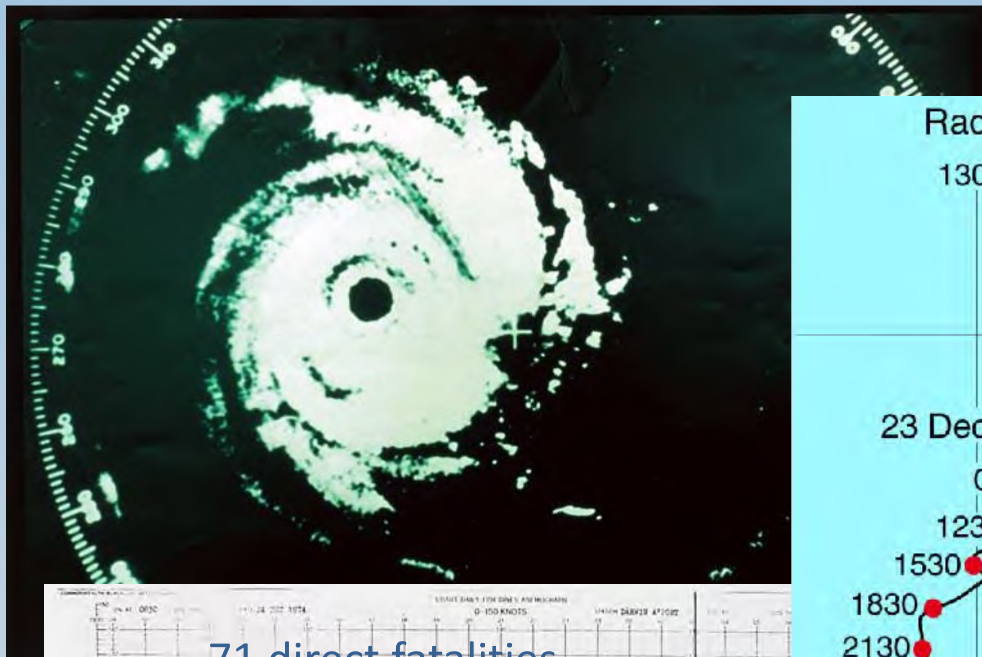
Tropical cyclones are the most extreme severe weather events which impact coastal communities and island nations.

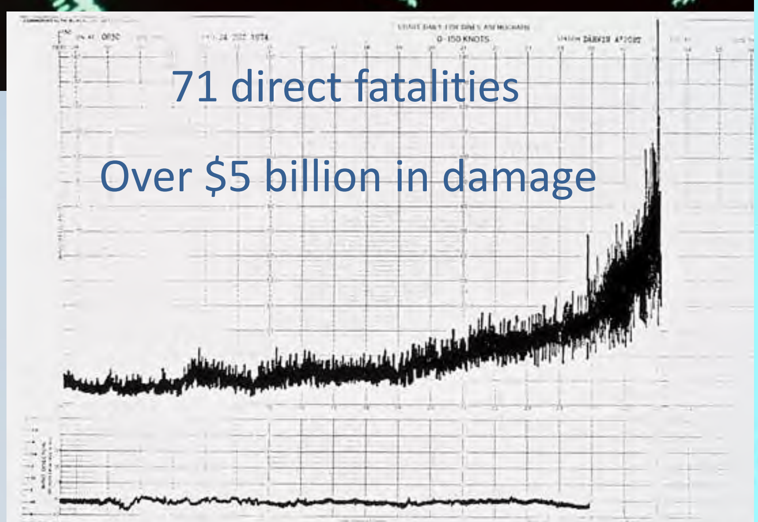
There is an ongoing research

(i) on accurate analysis of observed trends in tropical cyclone occurrences, and

(ii) how to improve skill of tropical cyclone forecasting, including seasonal prediction of cyclone activity to assist with preparedness and risk reduction for coastal communities.

Cyclone *Tracy*, Darwin, Australia, 1974





71 direct fatalities

Over $5 billion in damage

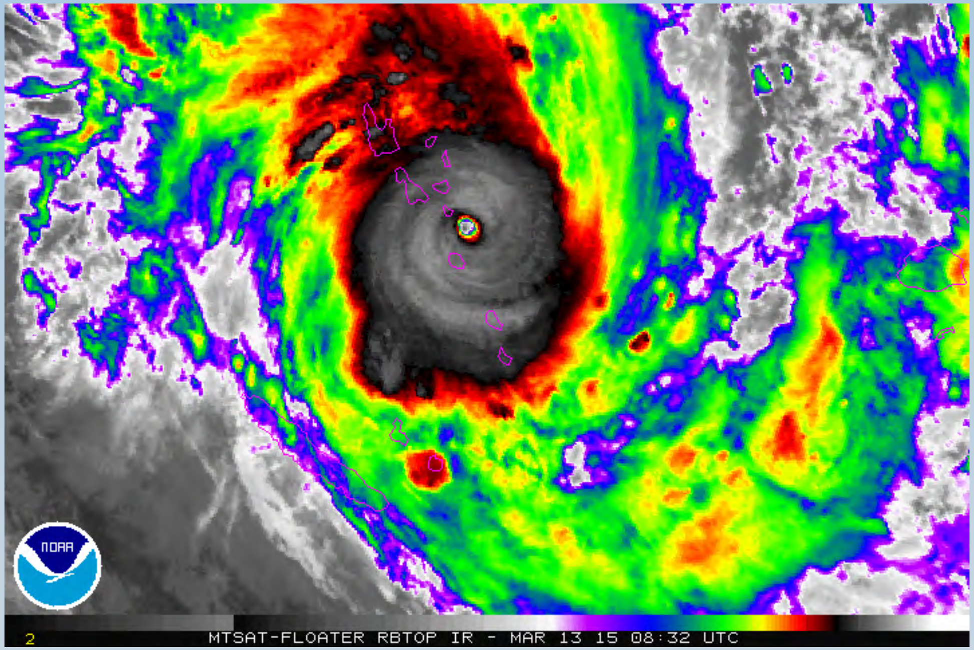
Fig 11 An approximate reproduction of the Dines anemograph record, reproducing only the information which is known to be inferred. The wind speeds may be low by as much as 6 km per h (3 knots) because of a possible zero error, The maximum gust is subject to verification

Cyclone *Tracy*, Darwin, Australia, 1974

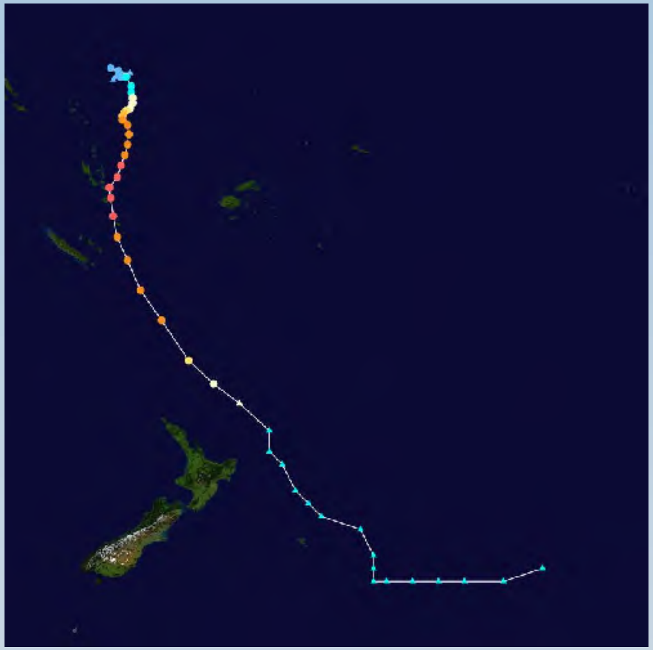
- 70% of Darwin's buildings were destroyed
- *Tracy* was described as "disaster of the first magnitude … without parallel in Australia's history".

Cyclone *Pam*, March 2015

Severe tropical cyclone *Pam* was considered to be the worst natural disaster in the history of Vanuatu. A tropical depression developed on 6 March 2015 east of Solomon Islands. On 13-14 March *Pam* attained category 5 cyclone intensity with highest winds 250 km/h and lowest pressure 896 hPa.



Satellite image of category 5 tropical cyclone *Pam* on 13/3/2015



Track of tropical cyclone *Pam*

Cyclone *Pam*, March 2015

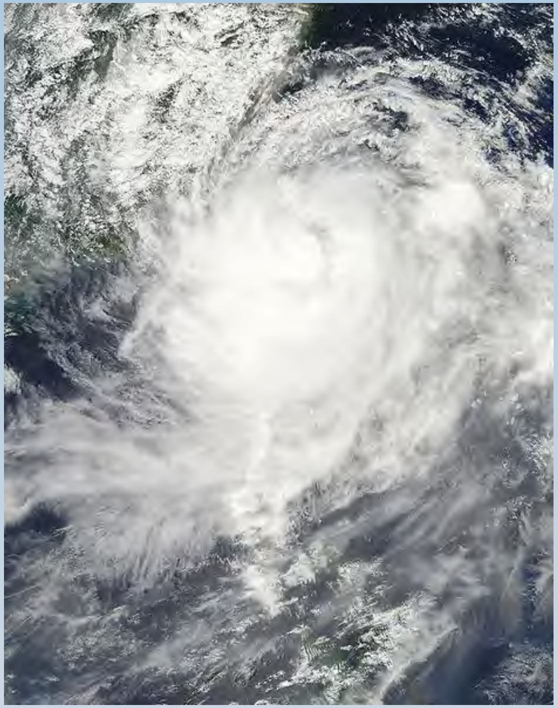
After all the development we have done for the last couple of years and this big cyclone came and just destroyed... all the infrastructure the government has... built. Completely destroyed. Vanuatu President Baldwin Lonsdale.

At least 16 people are confirmed to have died, and 30 others were reported injured; at least 132,000 people have been impacted (Vanuatu population is estimated at 267,000, July 2014)

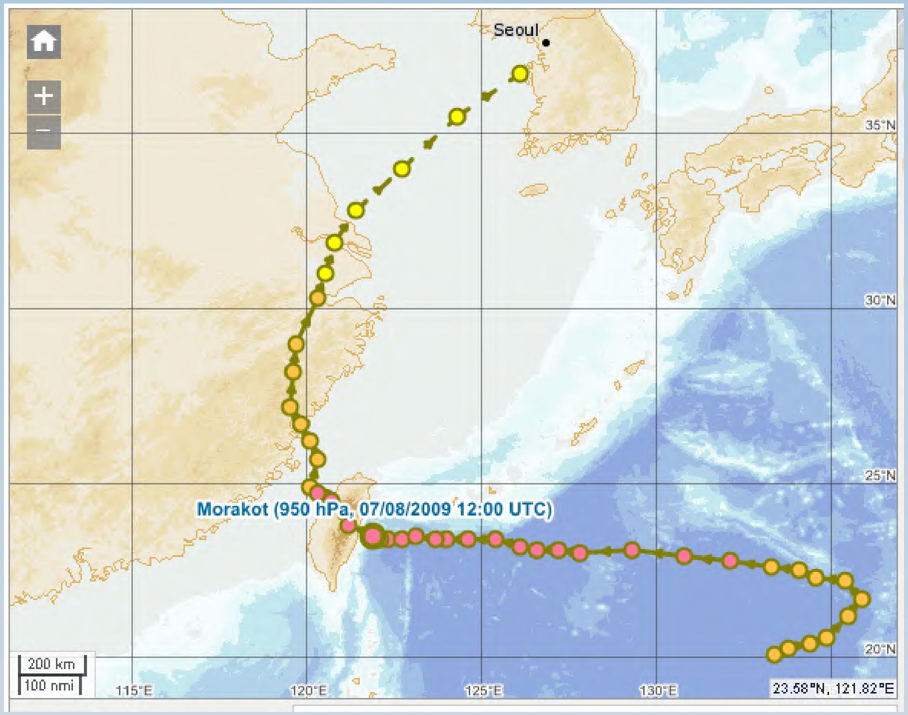
~ 70% of houses destroyed

Typhoon *Morakot*, August 2009

Morakot was the deadliest typhoon to impact Taiwan in recorded history leaving 677 people dead and 22 others missing, and approximately NT$110 billion ($3.3 billion USD) in damages.



Satellite image of typhoon *Morakot* on 7 August 2009



Track of typhoon *Morakot* displayed in the Pacific Tropical Cyclone Data Portal over Elevation and Bathymetry layer

How climate change affects tropical cyclone activity – globally and regionally?

Cyclone *Vance* approaching Western Australia on 21 March 2009

IPCC AR5 – Tropical Cyclone Trends

- *Current datasets indicate no significant observed trends in global tropical cyclone frequency over the past century.*

- *It is likely that the global frequency of occurrence of tropical cyclones will either decrease or remain essentially unchanged, concurrent with a likely increase in both global mean tropical cyclone maximum wind speed and precipitation rates.*

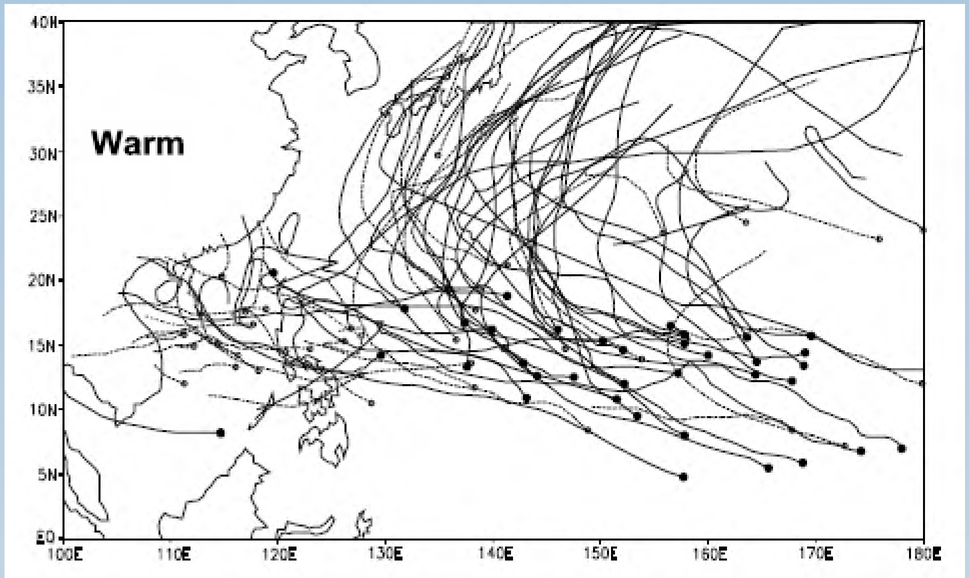
IPCC Fifth Assessment Report (AR5): Climate Change 2013

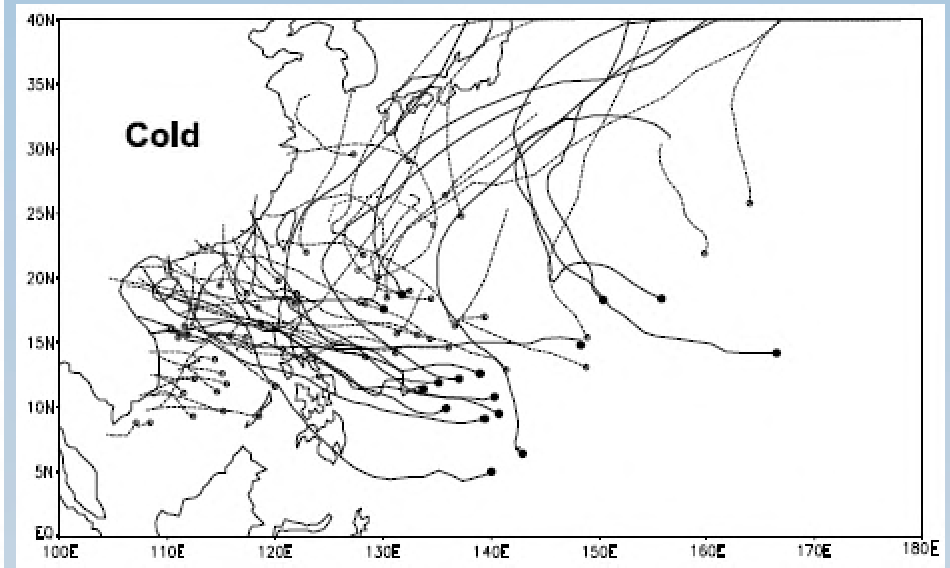
Phenomenon and direction of trend	Assessment that changes occurred	Likelihood of further changes (Late 21st century)
Increases in intense tropical cyclone activity	***Low confidence*** in long term (centennial) changes *Virtually certain* in North Atlantic since 1970	***More likely than not*** in the Western North Pacific and North Atlantic

Climate is changing on a global scale and consequently it is important to monitor changes in ***global*** *as well as in* ***regional*** *tropical cyclone frequencies, intensities and tracks.*

Tropical Cyclones in the western North Pacific

Chan, J. C. L., 2005: Interannual and interdecadal variations of tropical cyclone activity over the western North Pacific. Meteor. Atmos. Phys., 89, 143–152.





Tropical Cyclones in the western North Pacific – Seasonal prediction

Less Typhoons due to La Niña, While Two to Four Expected to Hit Taiwan in 2016

Taipei, Taiwan--June 28, 2016 – The Central Weather Bureau (CWB) has predicted 19 to 23 typhoons/tropical storms (TYs/TSs), which is less than the climate mean (25.7), may occur over the western North Pacific (WNP) in 2016.

Two (2) to four (4) TYs/TSs are most likely to invade Taiwan this year, anticipated by the CWB, while the climate average number is three point six (3.6).

NB. The 2016 season has so far produced a total of 25 named storms, 12 typhoons and five intense typhoons.

Tropical Cyclones in the western North Pacific – Seasonal prediction

PAGASA issues TC seasonal outlook twice a year

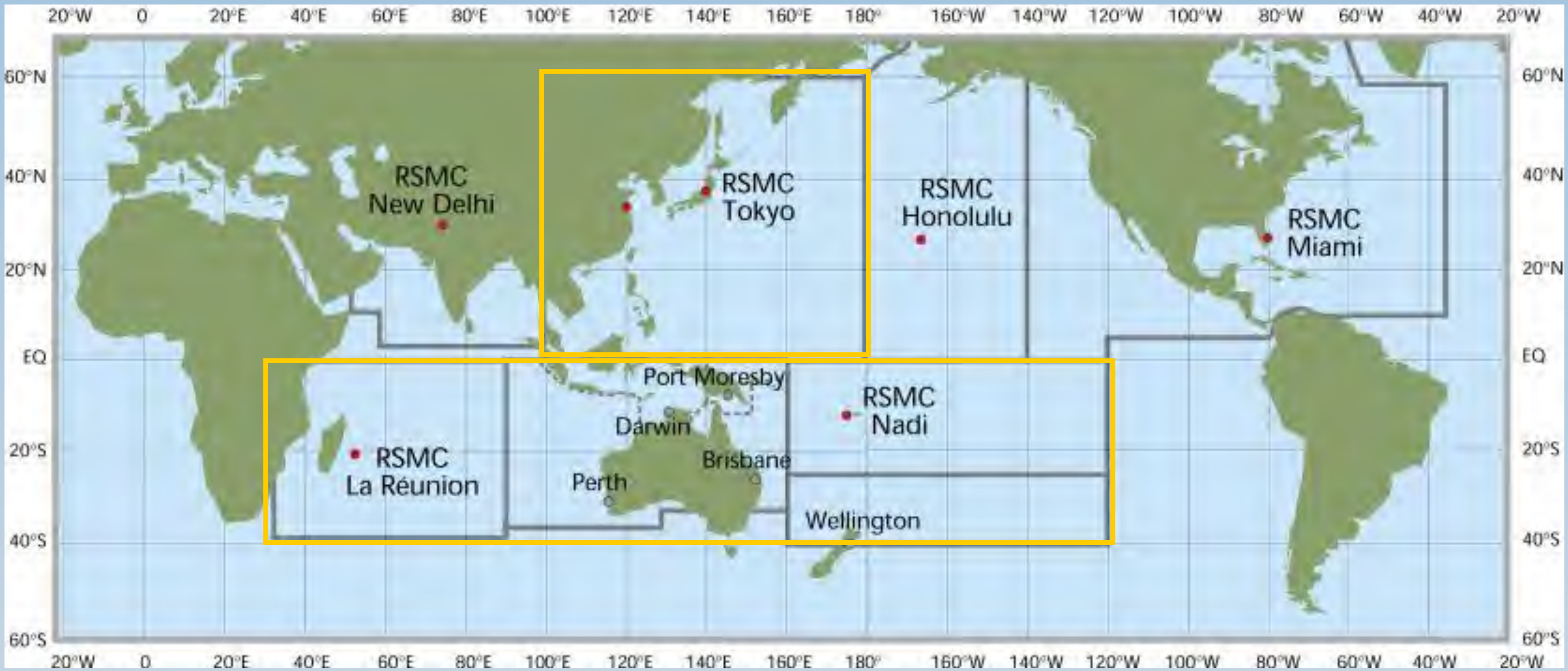
(to develop / enter the Philippines Area of Responsibility)

Jan 8, 2016	Jan - March	1-2 TCs
Jan 8, 2016	Apr – June	1-3 TCs
July 15, 2016	July – Sept	5-11 TCs
July 15. 2016	Oct - Dec	4-9 TCs

"*Climate Change and Southern Hemisphere Tropical Cyclones*" initiative

- High-quality tropical cyclone database for the South Pacific and the South Indian Oceans, covering tracks and intensity.
- Tropical cyclone archive extended to the Western North Pacific (in collaboration with RSMC Tokyo).
- Tropical cyclone climatology for the Southern Hemisphere.
- Web-based information tools to support the use and dissemination of data and analyses.
- Statistical and dynamical climate model-based seasonal tropical climate prediction.

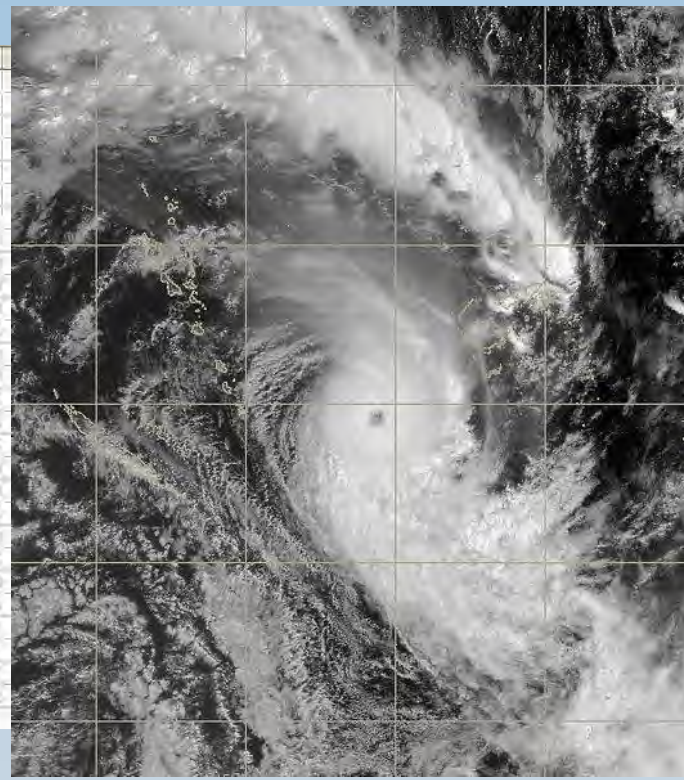
Tropical cyclone archive for the Southern Hemisphere and the Western Pacific Ocean

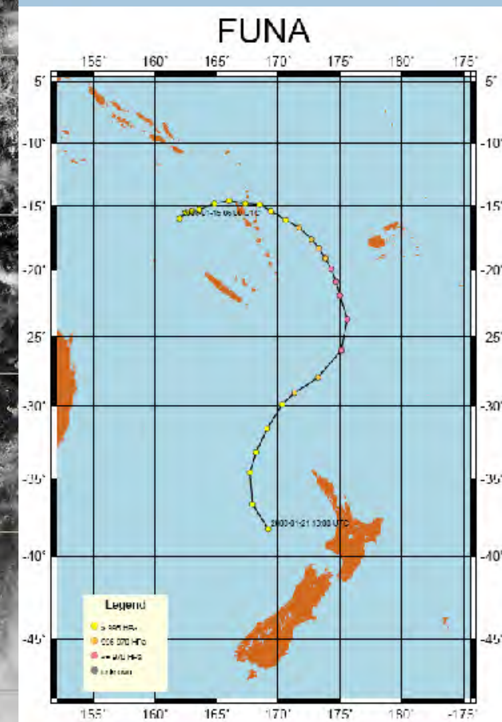


Original data from the Regional Specialised Meteorological Centres (RSMC) Nadi, La Reunion and Tokyo, and Tropical Cyclone Warning Centres (TCWCs) in Brisbane, Darwin, Perth and Wellington for 1969-1970 to 2012-2013 tropical cyclone seasons have been revised.

Tropical cyclone archive for the Southern Hemisphere and the Western Pacific Ocean

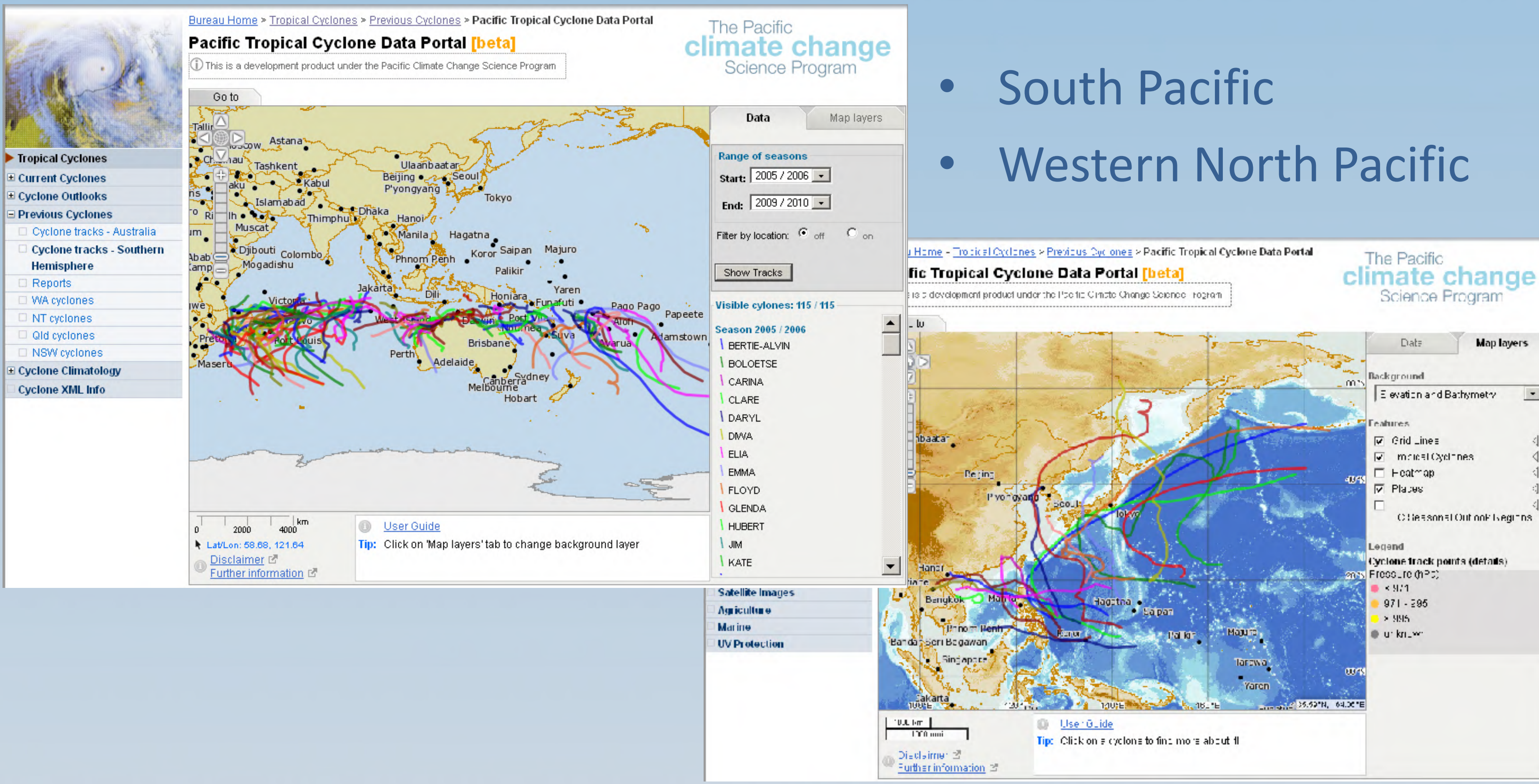
	A	B	C	D	E	F	G
1	year	seq	name	datetime	lat	lon	pressure
2	2007	12	FUNA	15/01/2008 6:00	-16	162	999
3	2007	12	FUNA	15/01/2008 12:00	-15.5	162.5	997
4	2007	12	FUNA	15/01/2008 18:00	-15.4	163	997
5	2007	12	FUNA	16/01/2008 0:00	-15.3	163.6	995
6	2007	12	FUNA	16/01/2008 6:00	-14.8	164.8	990
7	2007	12	FUNA	16/01/2008 12:00	-14.6	166	987
8	2007	12	FUNA	16/01/2008 18:00	-14.8	167.3	980
9	2007	12	FUNA	17/01/2008 0:00	-14.9	168.5	970
10	2007	12	FUNA	17/01/2008 6:00	-15.4	169.4	970
11	2007	12	FUNA	17/01/2008 12:00	-16.1	170.6	970
12	2007	12	FUNA	17/01/2008 18:00	-16.7	171.7	965
13	2007	12	FUNA	18/01/2008 0:00	-17.6	172.7	960
14	2007	12	FUNA	18/01/2008 6:00	-18.3	173.3	960
15	2007	12	FUNA	18/01/2008 12:00	-19.1	173.8	955
16	2007	12	FUNA	18/01/2008 18:00	-19.9	174.3	945
17	2007	12	FUNA	19/01/2008 0:00	-20.9	174.7	935
18	2007	12	FUNA	19/01/2008 6:00	-21.9	175	930
19	2007	12	FUNA	19/01/2008 12:00	-23.7	175.6	930
20	2007	12	FUNA	19/01/2008 18:00	-26	175.1	945
21	2007	12	FUNA	20/01/2008 0:00	-28	173.2	950
22	2007	12	FUNA	20/01/2008 6:00	-29.1	171.3	965
23	2007	12	FUNA	20/01/2008 12:00	-29.9	170.3	970
24	2007	12	FUNA	20/01/2008 18:00	-31.6	169.1	975
25	2007	12	FUNA	21/01/2008 0:00	-33.2	168.2	981
26	2007	12	FUNA	21/01/2008 6:00	-34.6	167.7	987
27	2007	12	FUNA	21/01/2008 12:00	-36.7	167.9	987
28	2007	12	FUNA	21/01/2008 18:00	-38.3	169.2	992
29							





- Historical tropical cyclone best track data have been examined and a new satellite-era data set has been prepared to be subsequently displayed through the enhanced tropical cyclone data portal for the Southern Hemisphere and the Western Pacific Ocean.

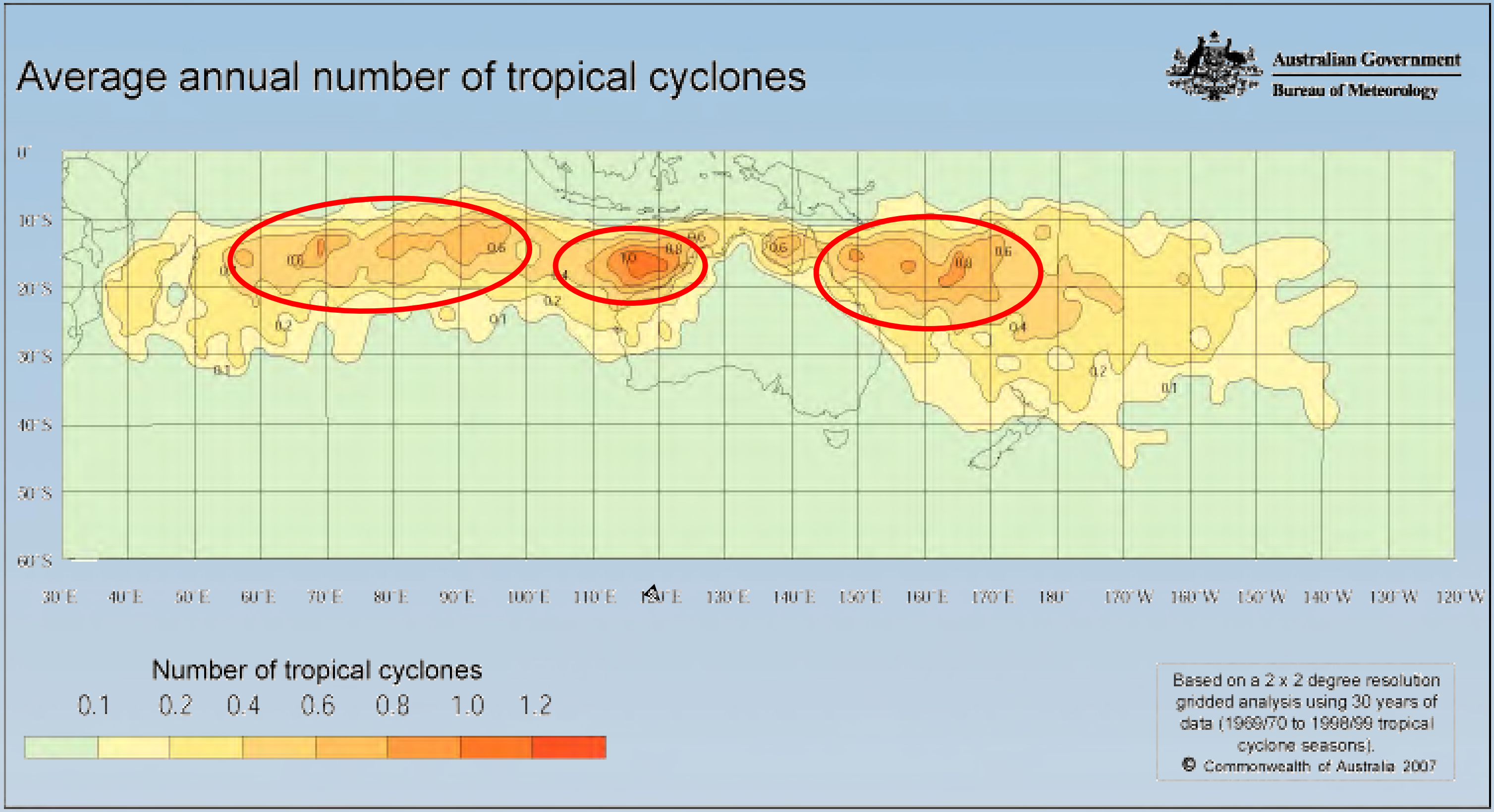
Tropical cyclone data portal



- South Pacific
- Western North Pacific

Kuleshov, Y., 2012: *Southern Hemisphere tropical cyclone climatology*, Chapter 1, in book "*Modern Climatology*", Intech, ISBN 979-953-307-337-7, pp. 1-44.

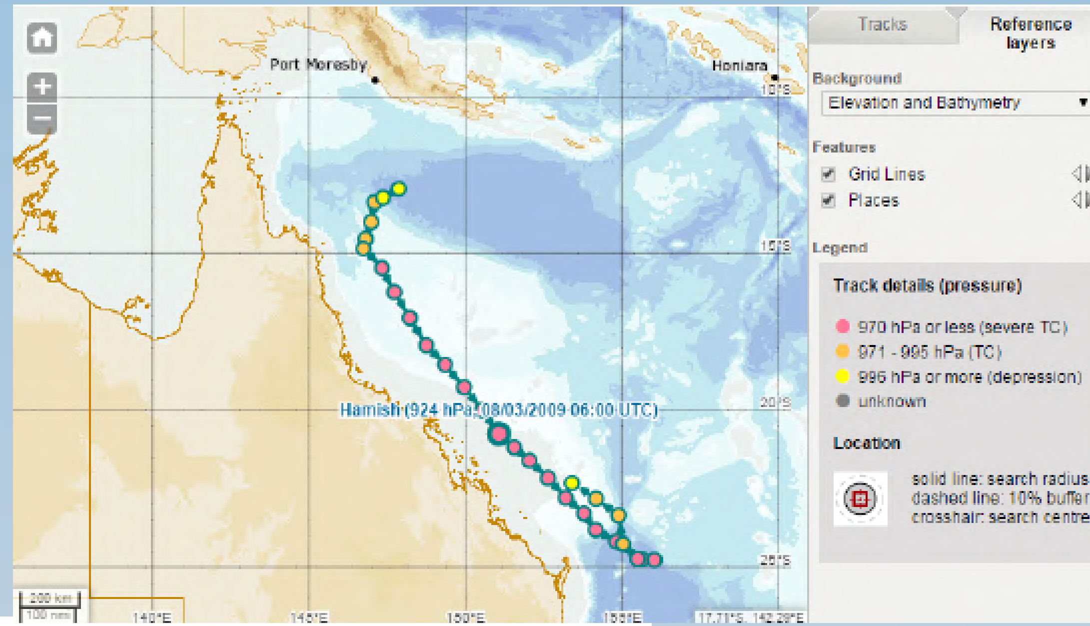
Tropical cyclones climatology



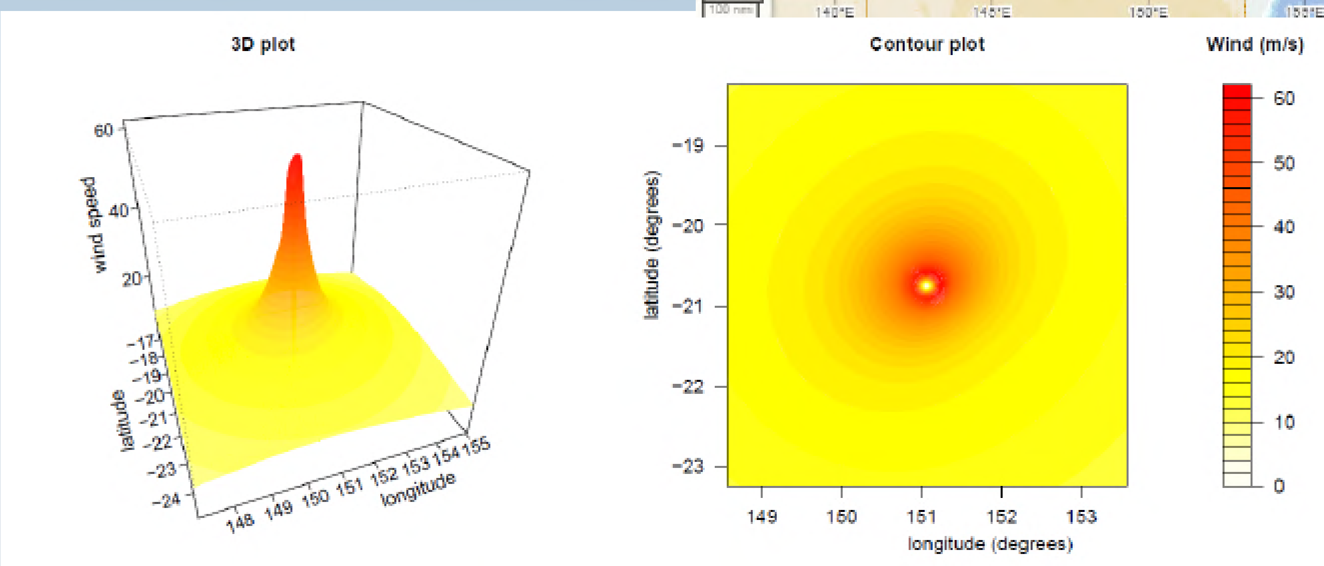
Kuleshov, Y., L. Qi, R. Fawcett, and D. Jones, 2008: On tropical cyclone activity in the Southern Hemisphere: Trends and the ENSO connection, *Geophysical Research Letters*, **35**, L14S08, doi:10.1029/2007GL032983.

Wind field model

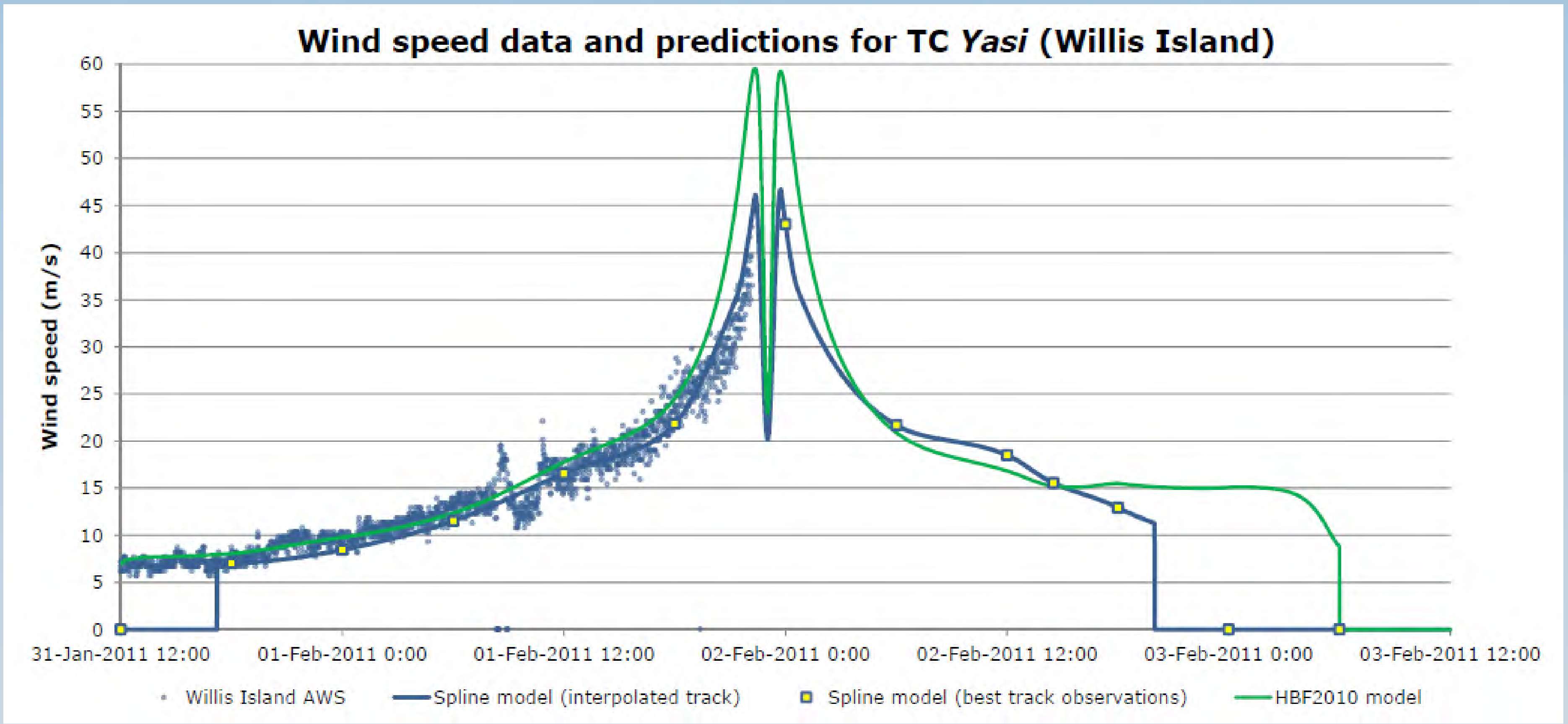
Best track of tropical cyclone *Hamish*



Tropical cyclone *Hamish* as a category 5 cyclone at peak intensity (central pressure 924 hPa).

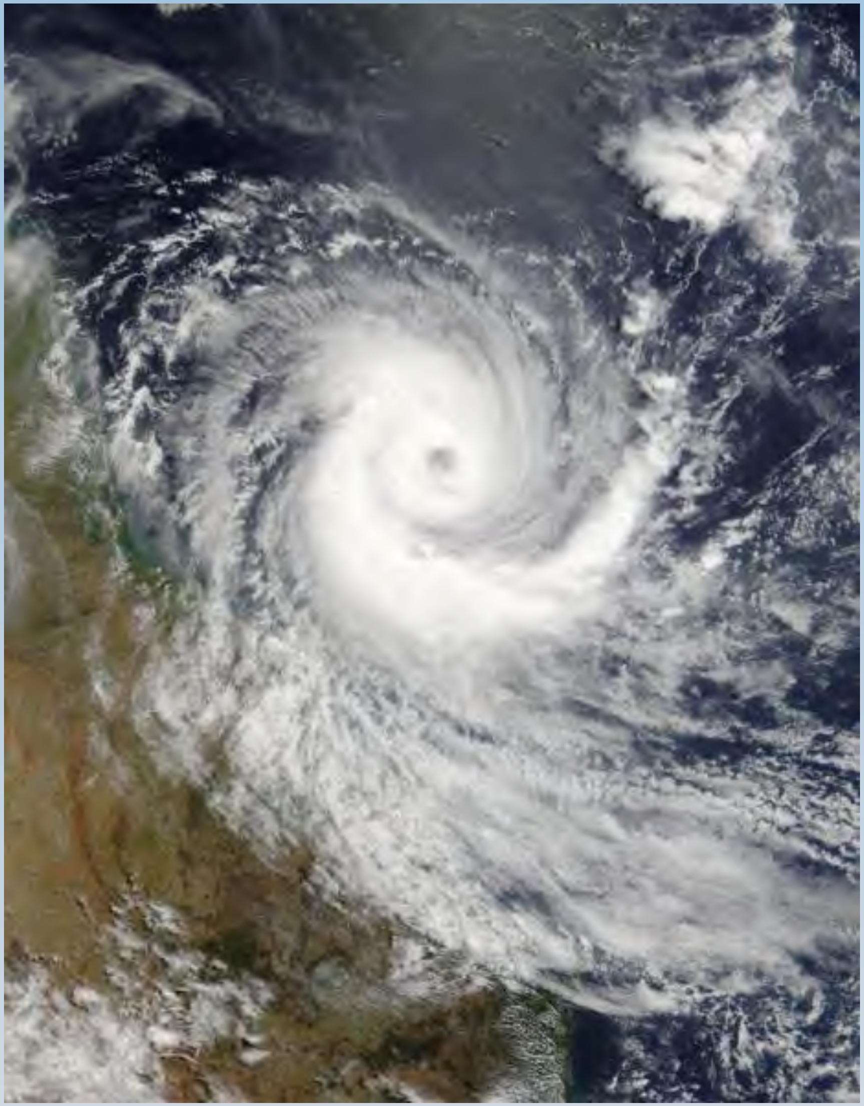


Wind field model



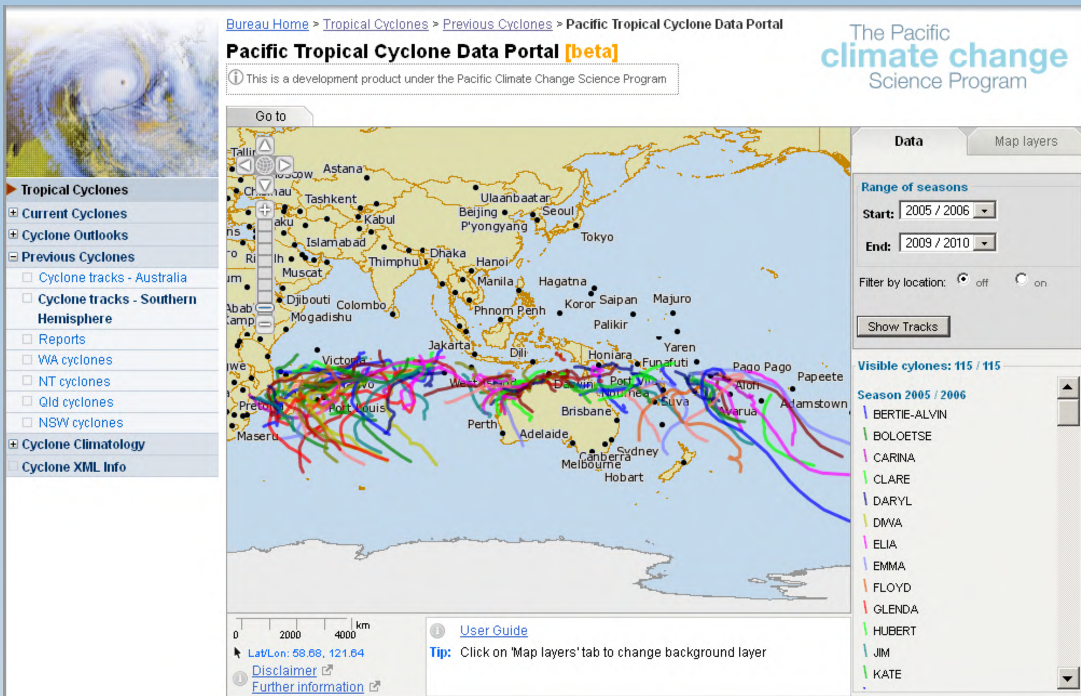
Comparison of modelled wind speeds of the spline model and HBF2010 model at Willis Island when tropical cyclone *Yasi* passed the AWS

Tropical cyclone data portal

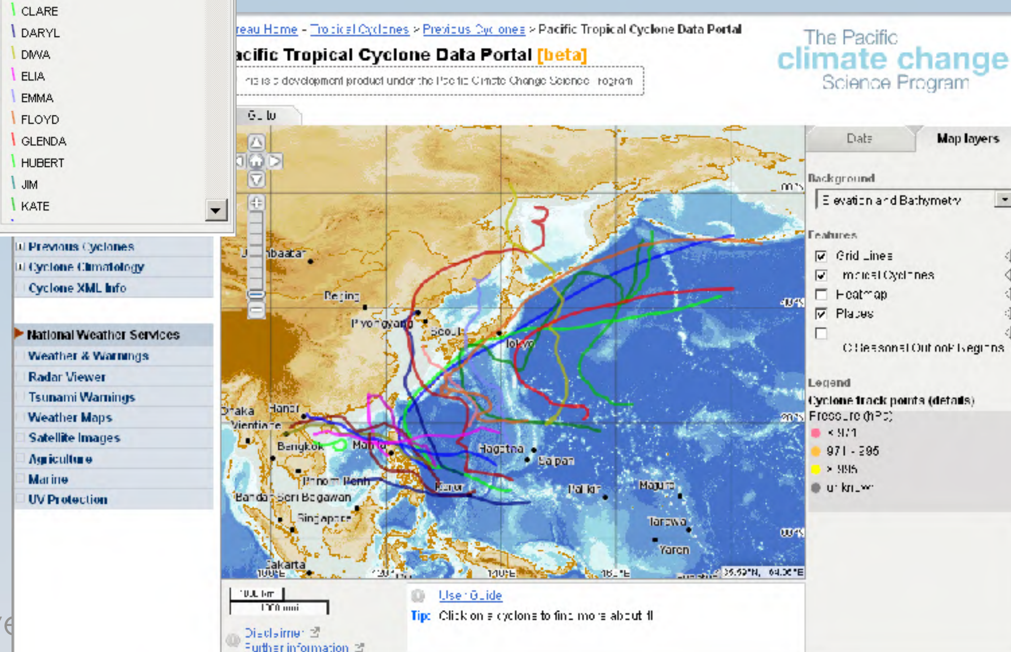


Cyclone *Larry* approaching Queensland on 19 March 2006

Tropical Cyclone Data Portal

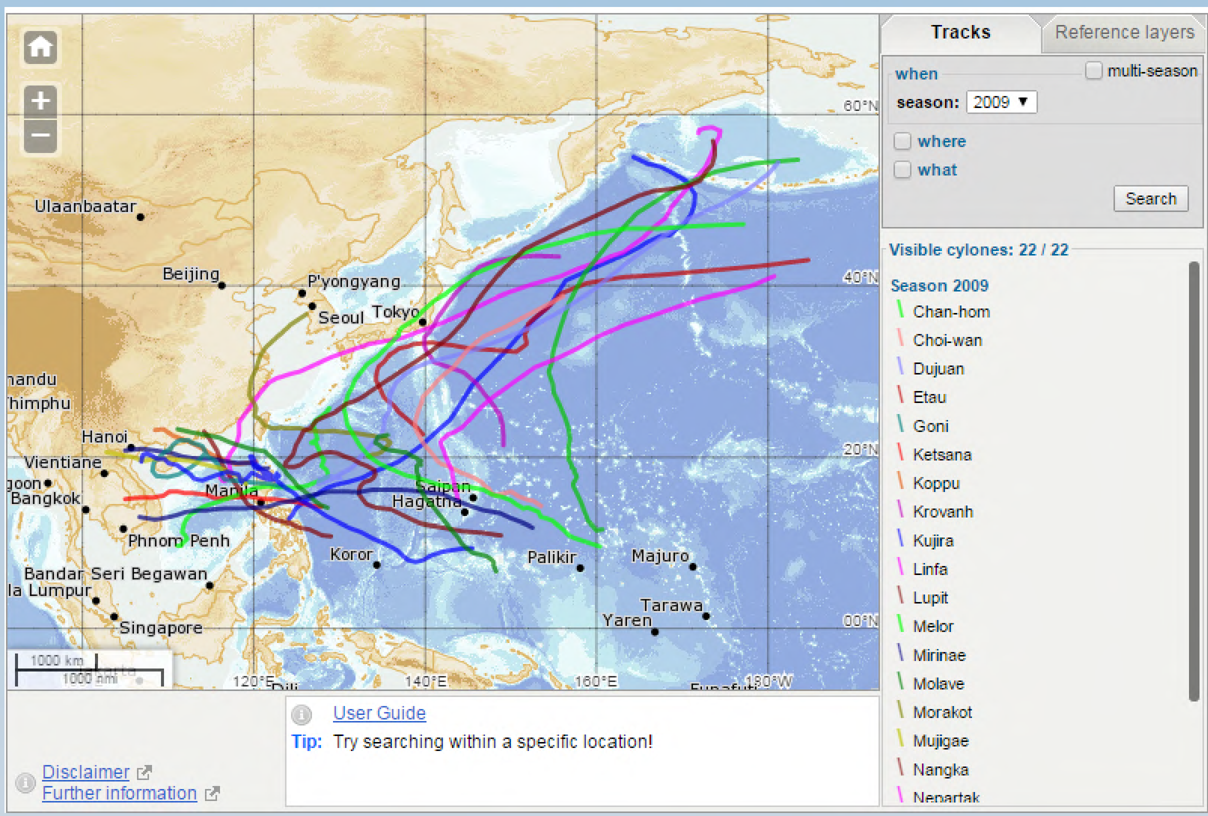


Southern Hemisphere – Regional Specialised Meteorological Centres Nadi, Fiji and La Reunion, France; Tropical Cyclone Warning Centres in Brisbane, Darwin and Wellington



Western North Pacific – Regional Specialised Meteorological Centre Tokyo, Japan

Tropical cyclone data portal

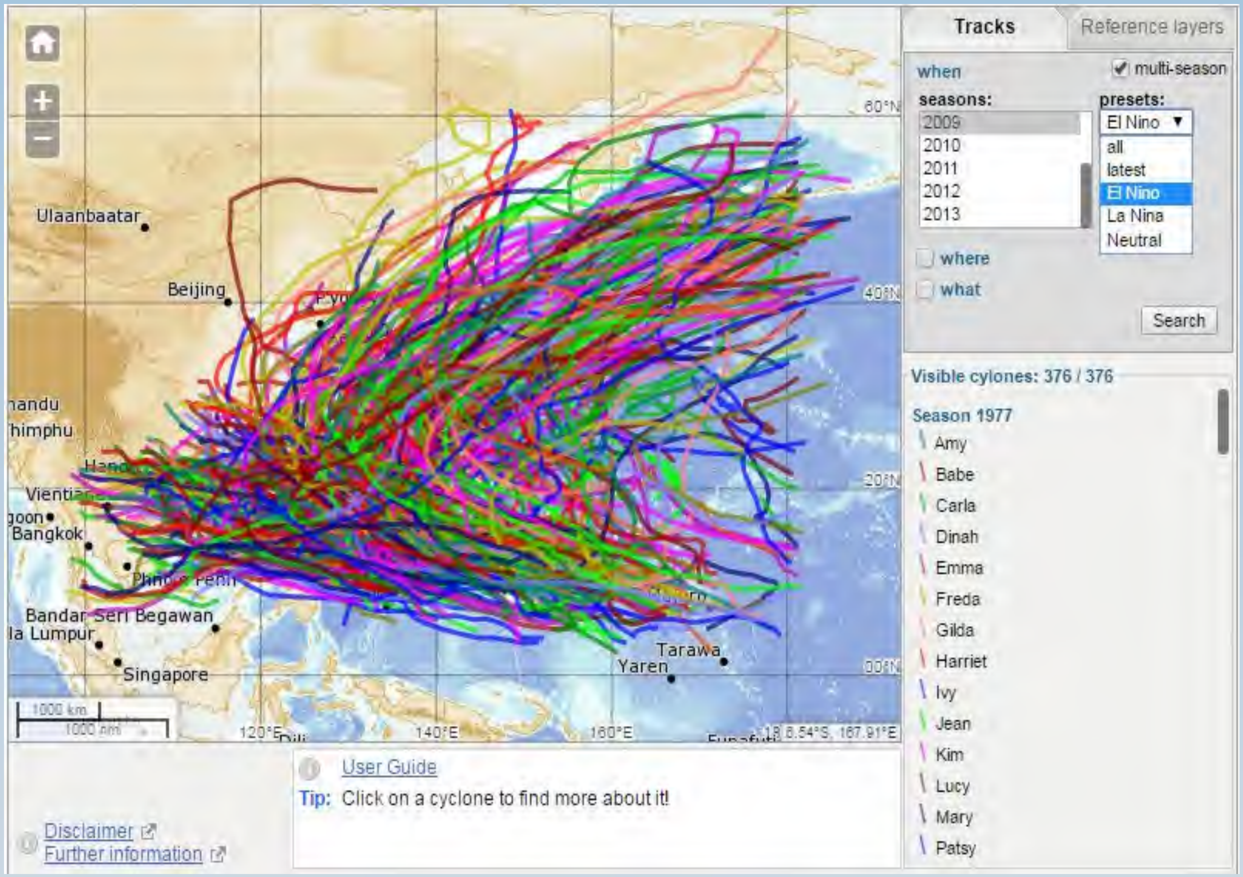


Temporal selection:

'when'

- Season (e.g. 2009)

Tropical cyclone data portal



Temporal selection:

'when'

- Multi-season

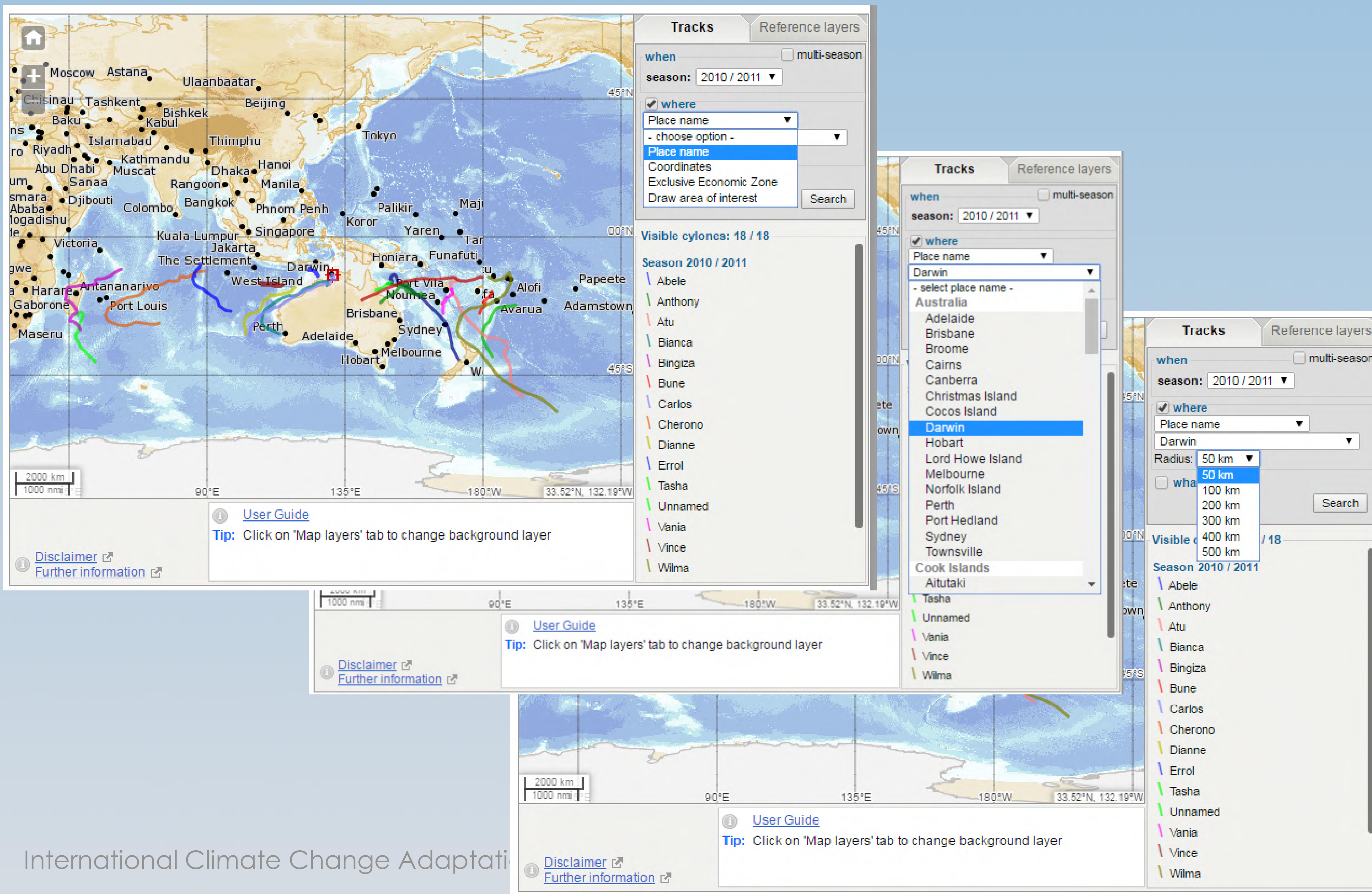
Tropical cyclone data portal

Spatial selection:

'where'

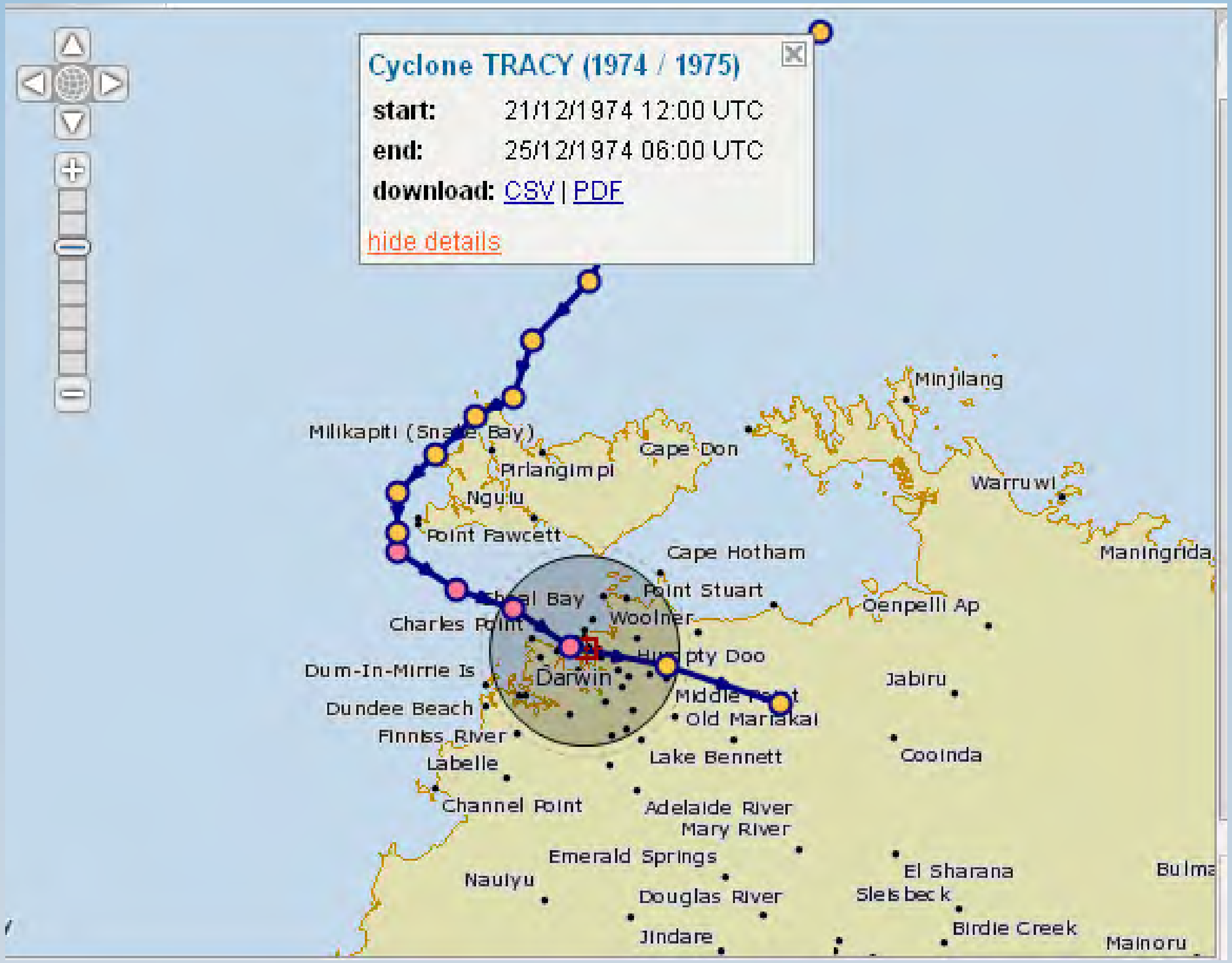
- Place name
- Coordinates
- Exclusive Economic Zone
- Draw area of interest

Tropical cyclone data portal



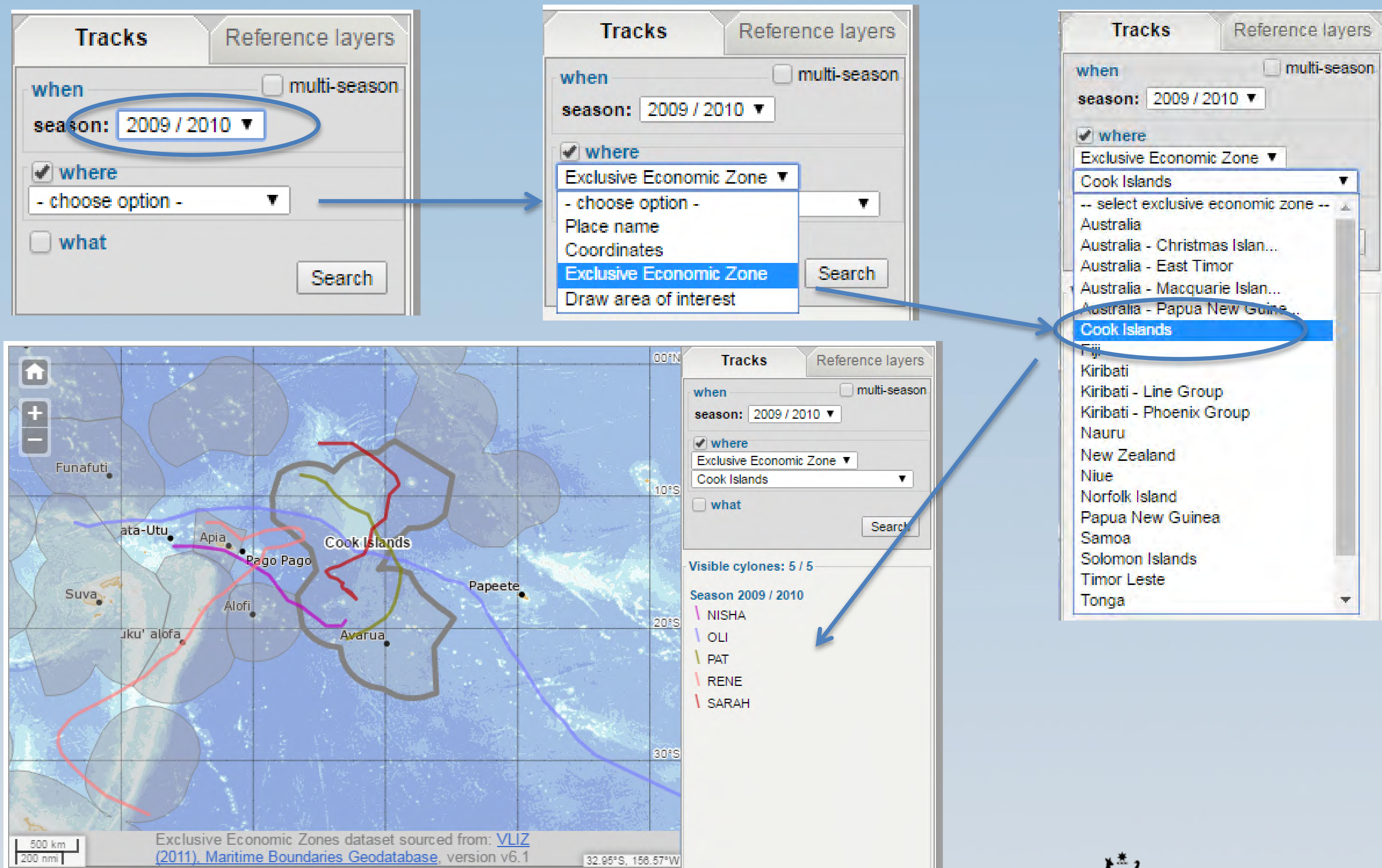
International Climate Change Adaptati

Pacific Tropical Cyclone Data Portal



'season' – 1974/75; 'where' - 50 km of Darwin, Australia

Tropical cyclone data portal



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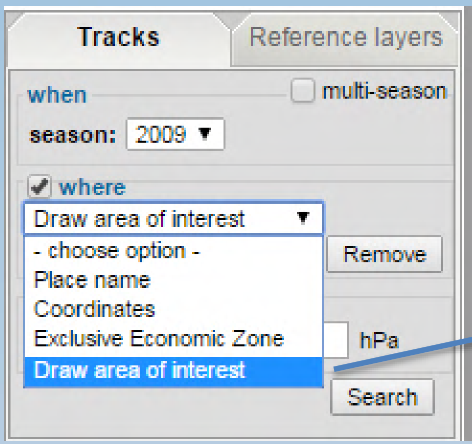
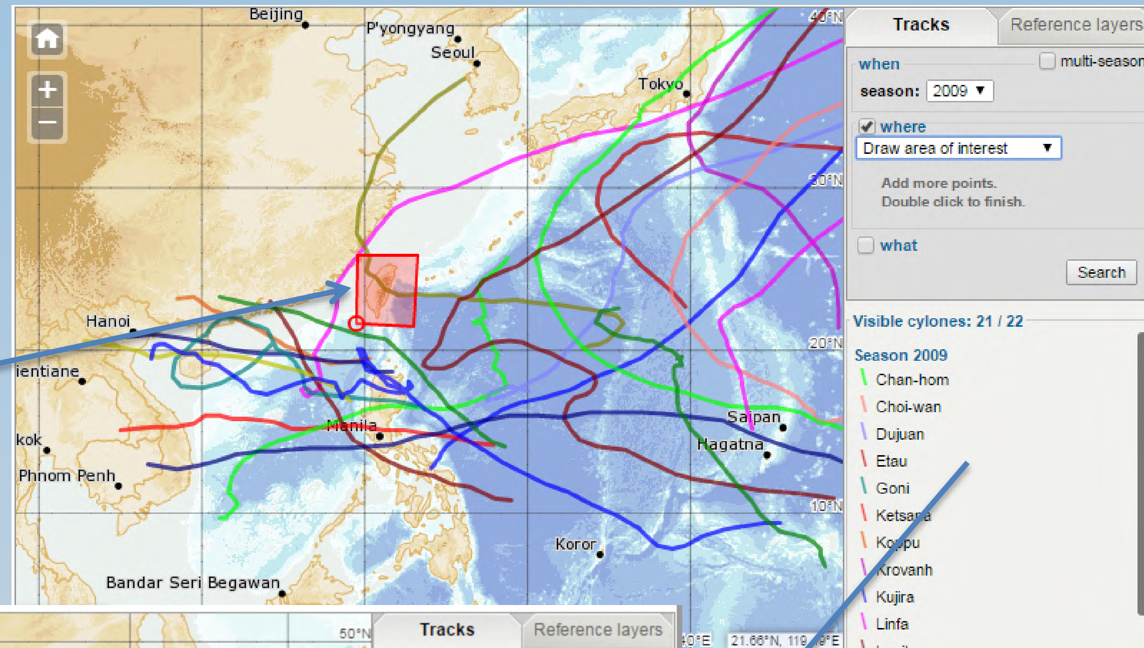
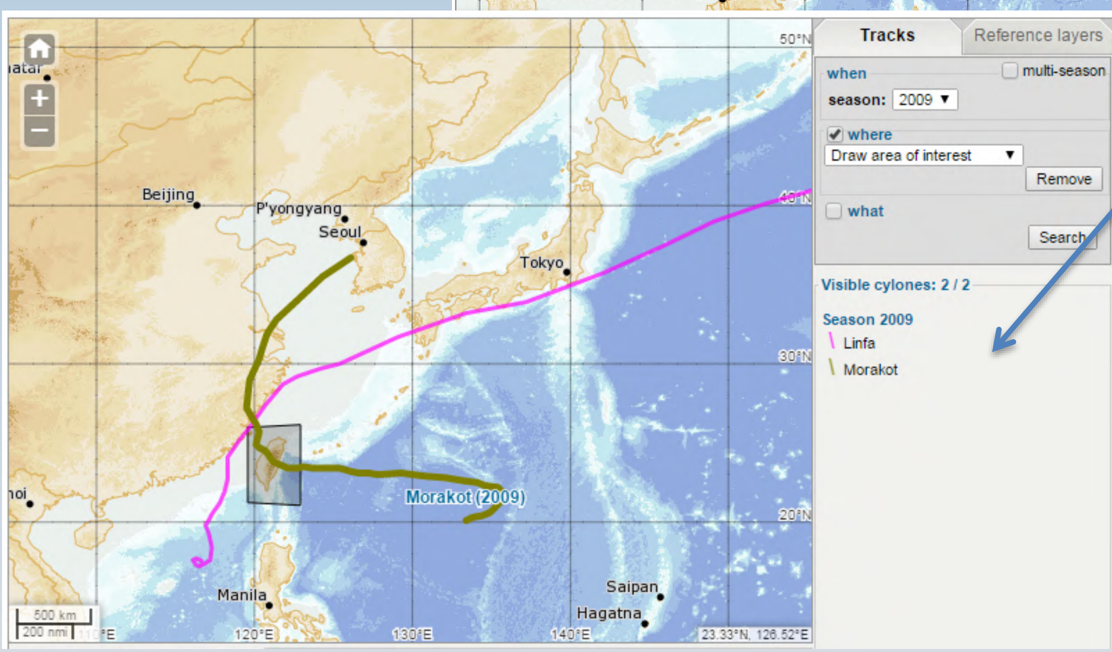


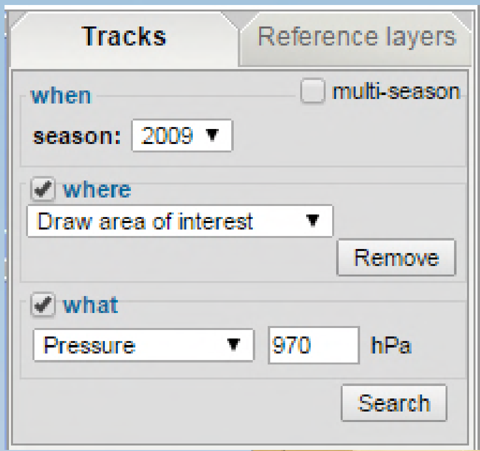


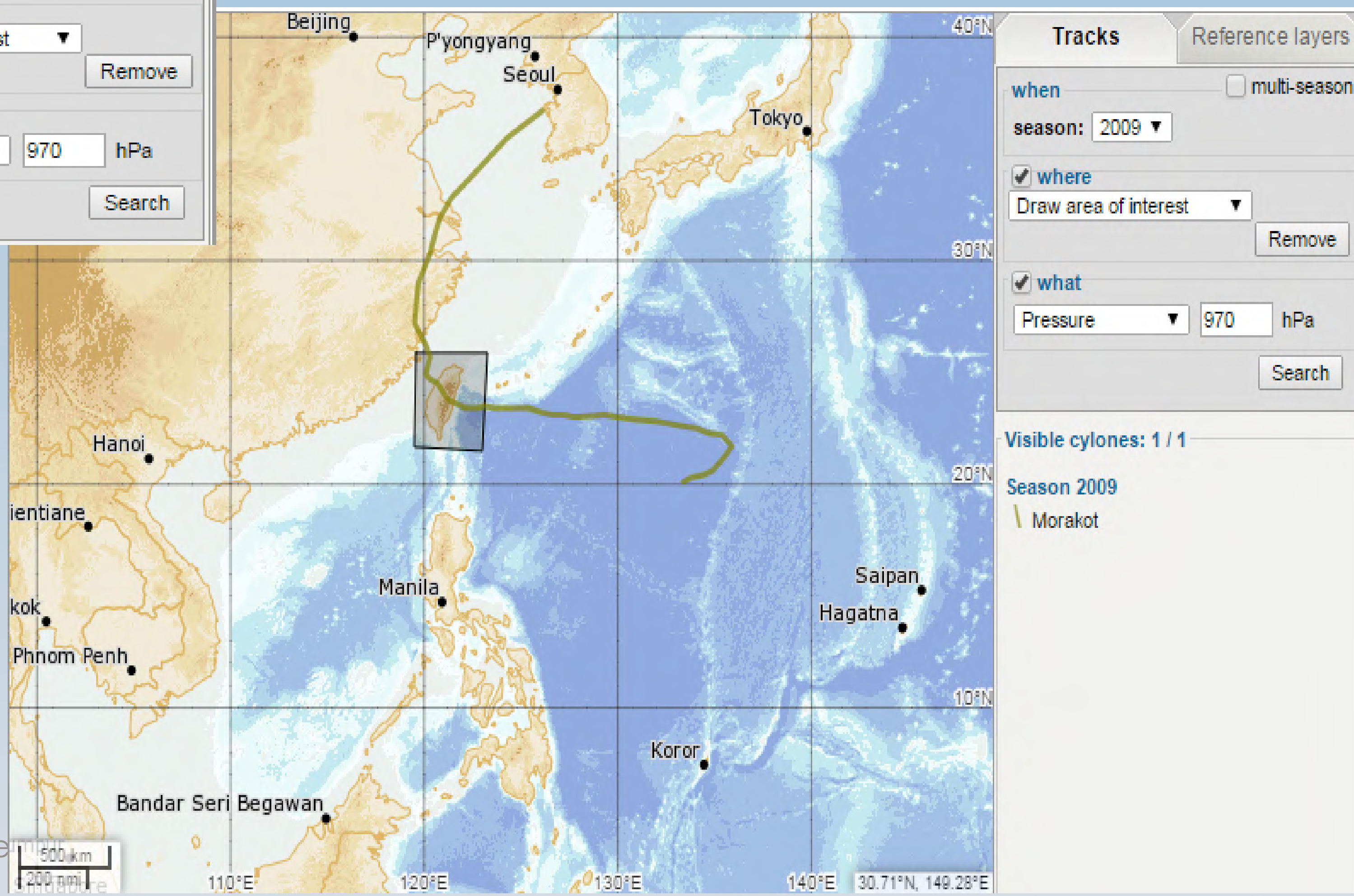


Tropical cyclone data portal

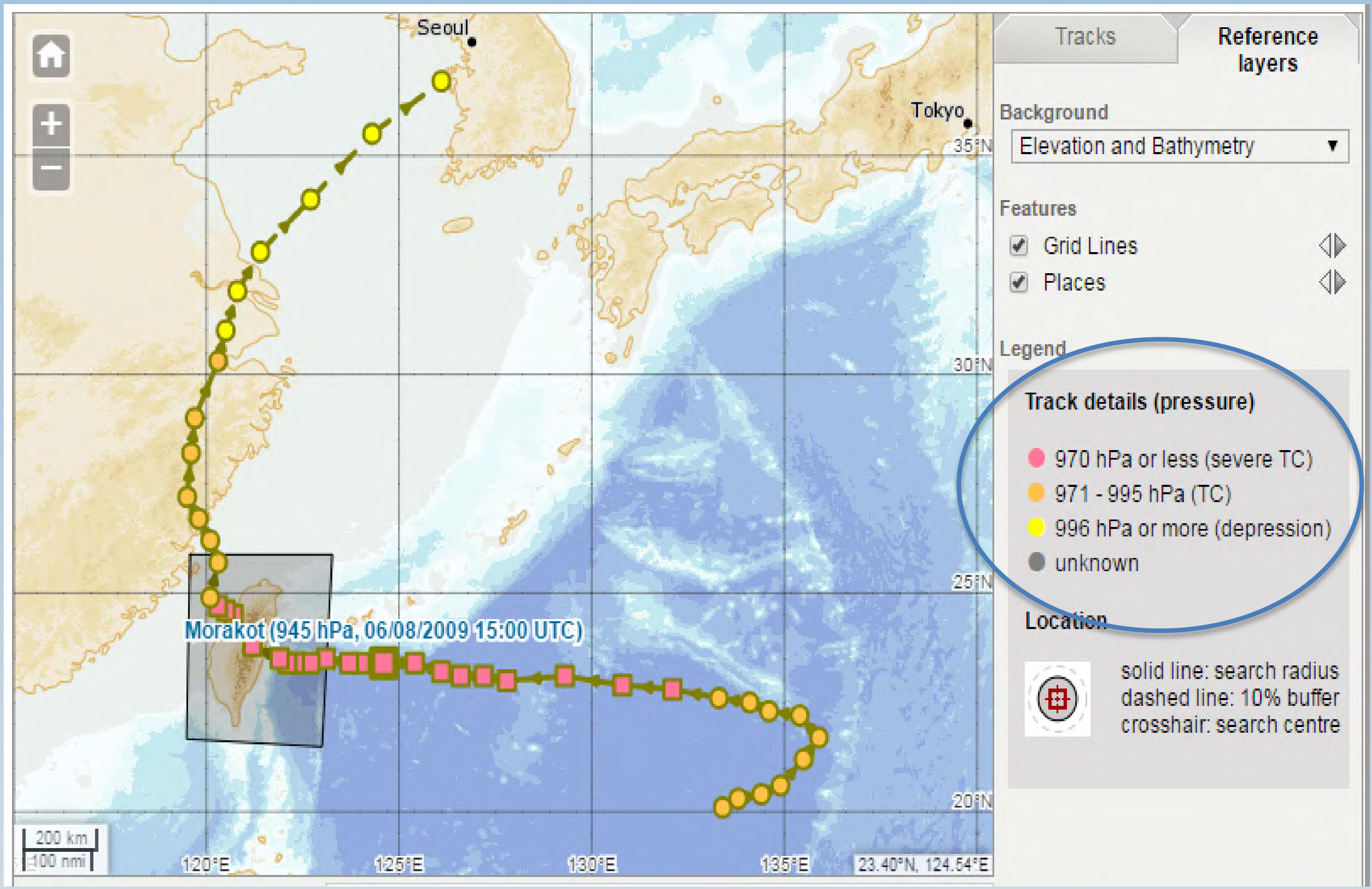
Selection: 'what'

- Pressure
- Name





Tropical cyclone data portal



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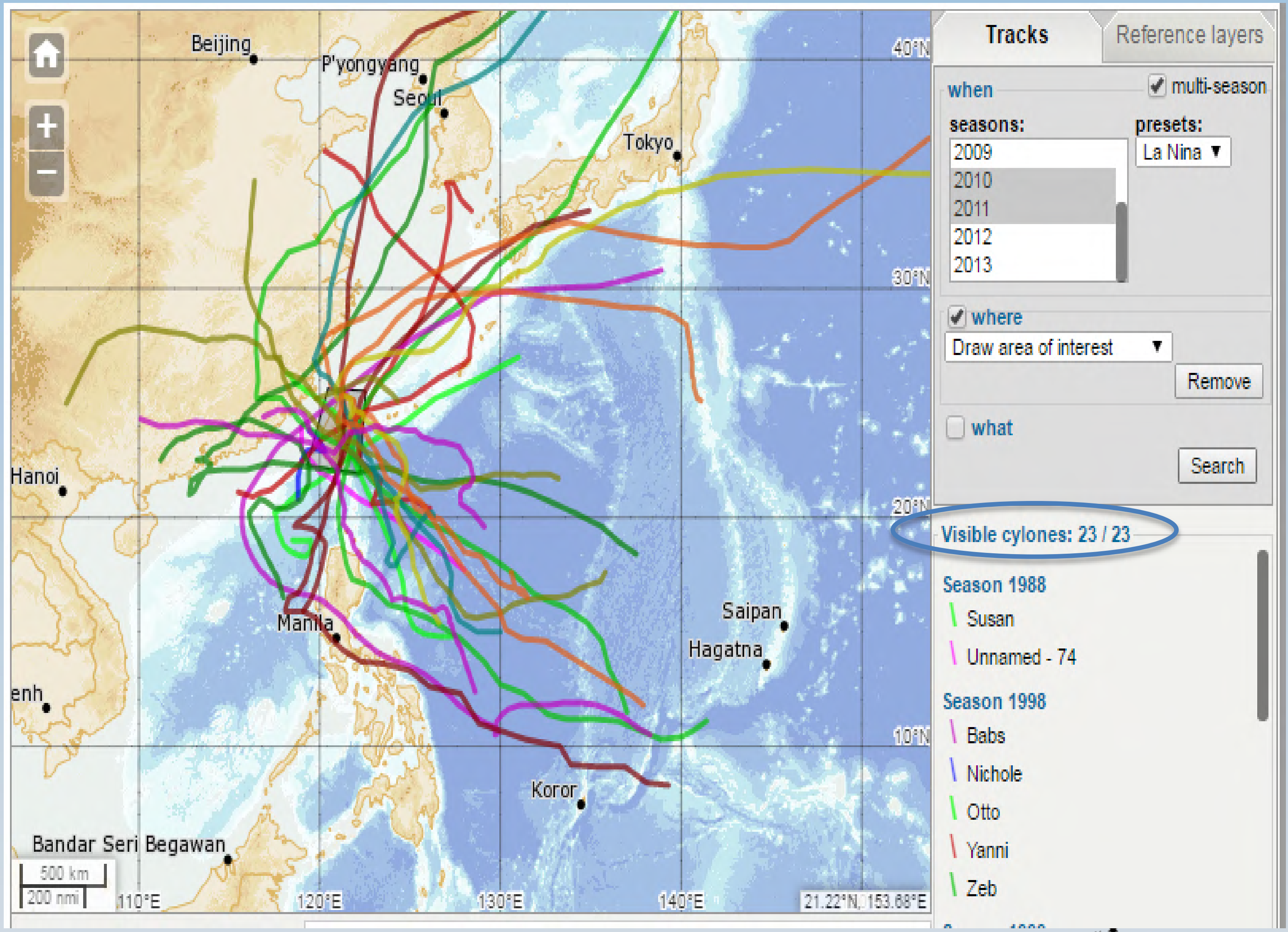

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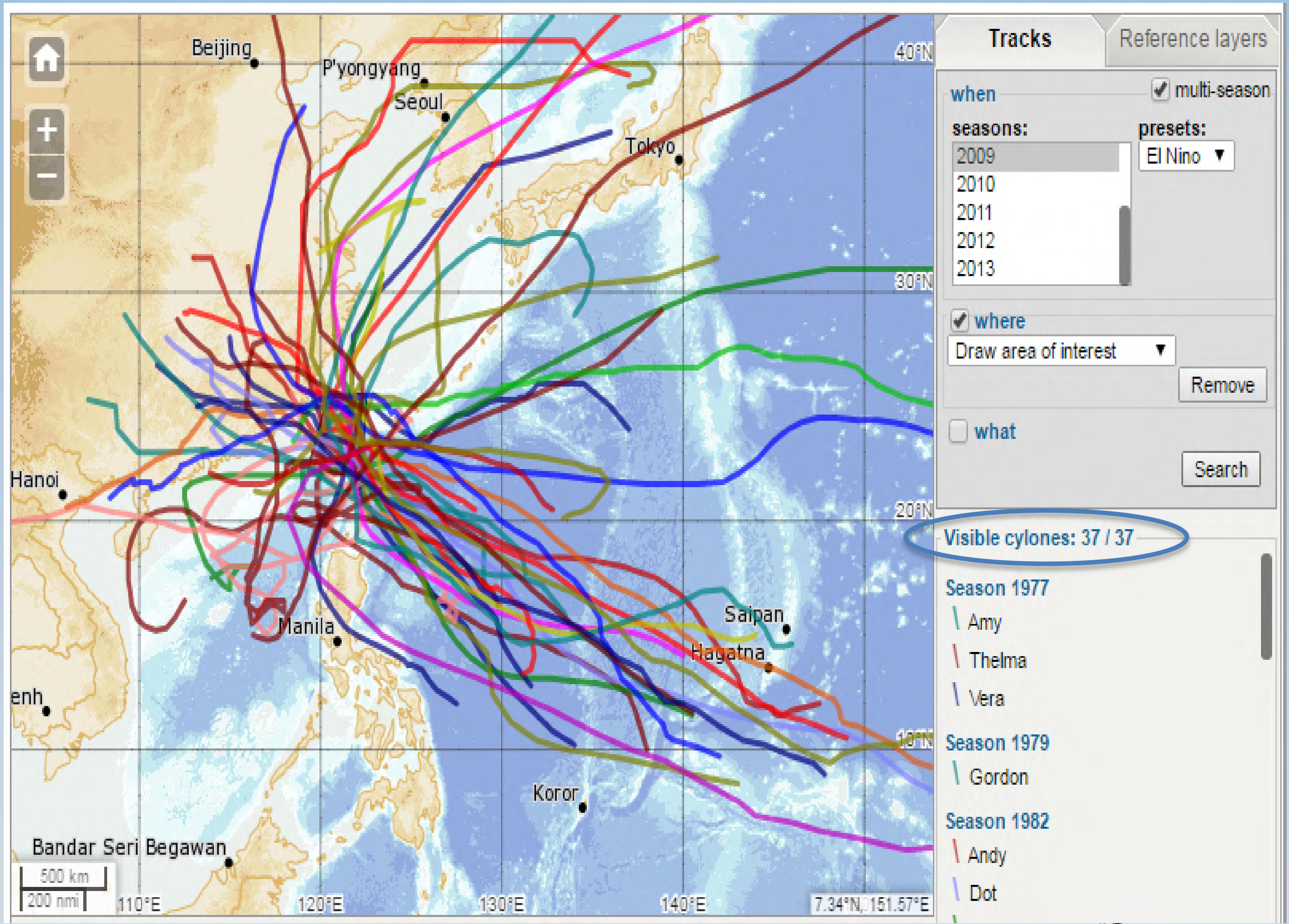
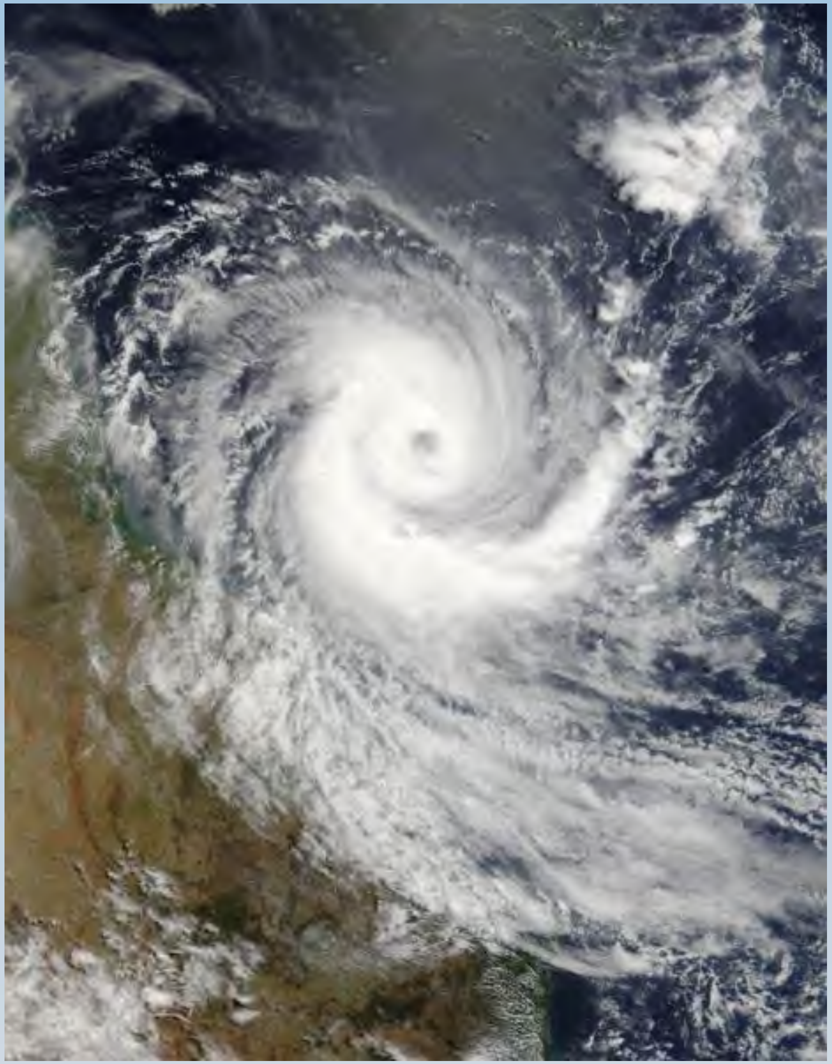


Tropical cyclone climatology and seasonal prediction



Cyclone *Larry* approaching Queensland on 19 March 2006

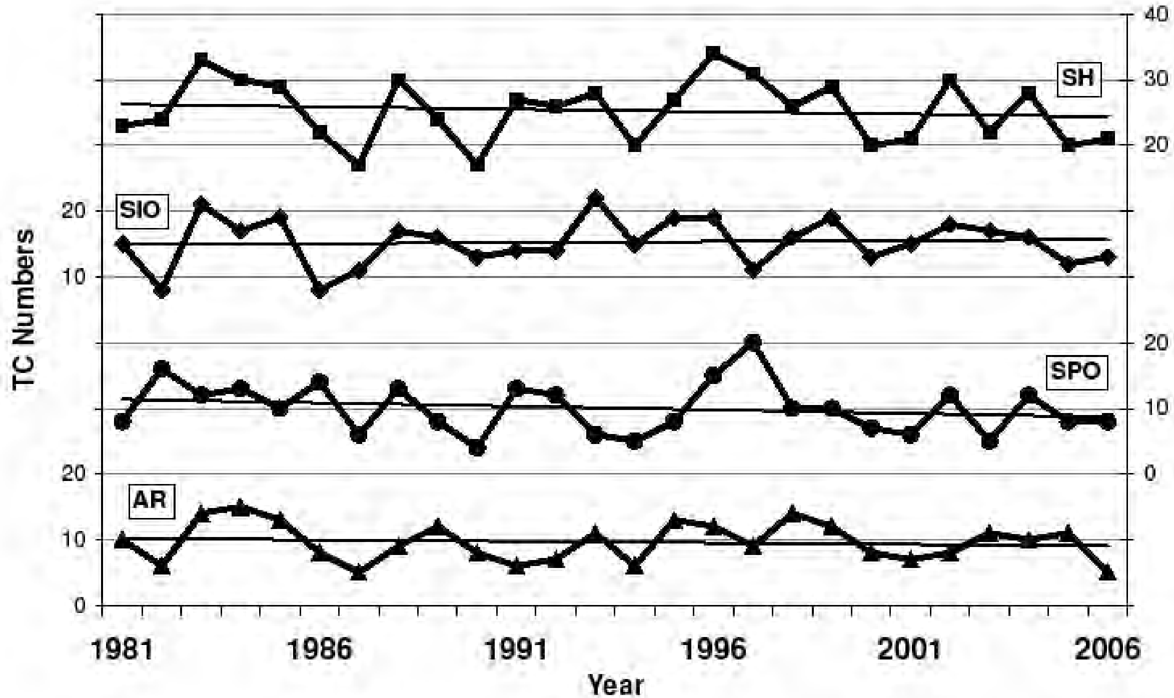
Trends in tropical cyclones in the South Pacific Ocean

- The statistical significance of trends in tropical cyclones in the South Pacific Ocean has been examined

- For the 1981/82 to 2010/11 tropical cyclone seasons, there are no apparent trends in the total numbers of tropical cyclones, nor in numbers of *severe* tropical cyclones in the South Pacific Ocean

Kuleshov, Y., R. Fawcett, L. Qi, B. Trewin, D. Jones, J. McBride, and H. Ramsay, 2010: Trends in tropical cyclones in the South Indian Ocean and the South Pacific Ocean, *Journal of Geophysical Research*, **115**, D01101, doi:10.1029/2009JD012372.

Trends in tropical cyclones in the South Pacific Ocean



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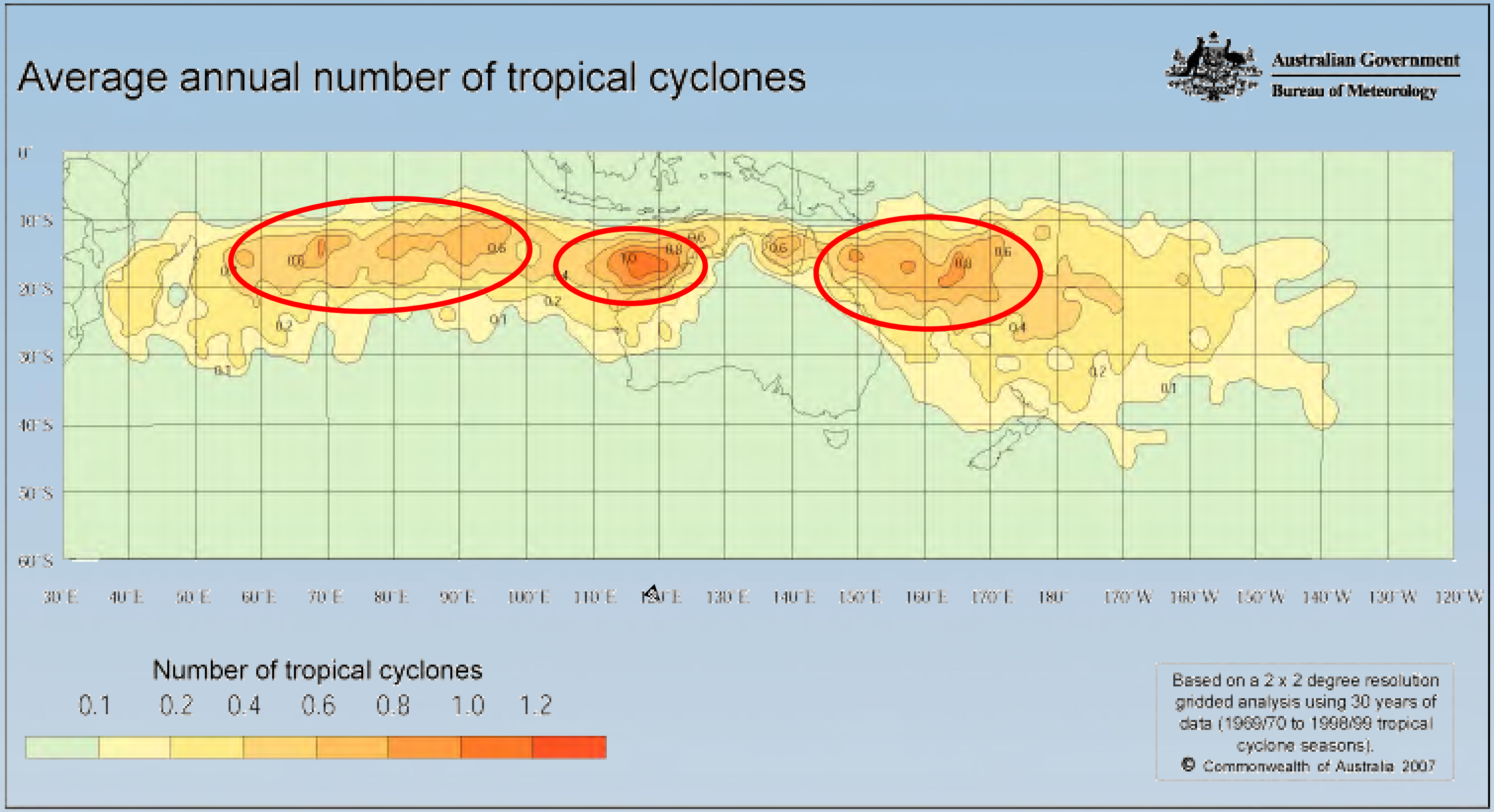
Tropical cyclones climatology – maps



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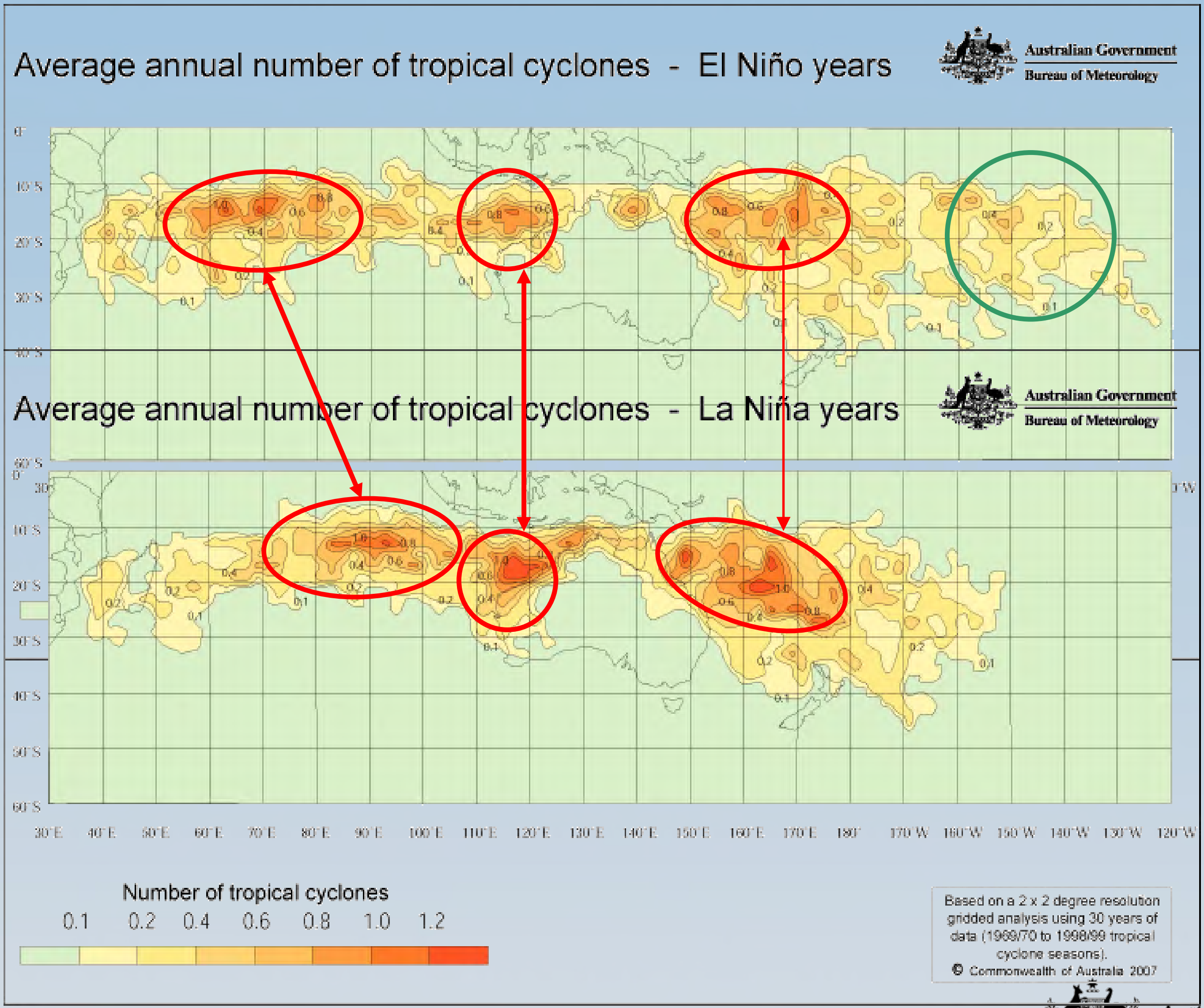
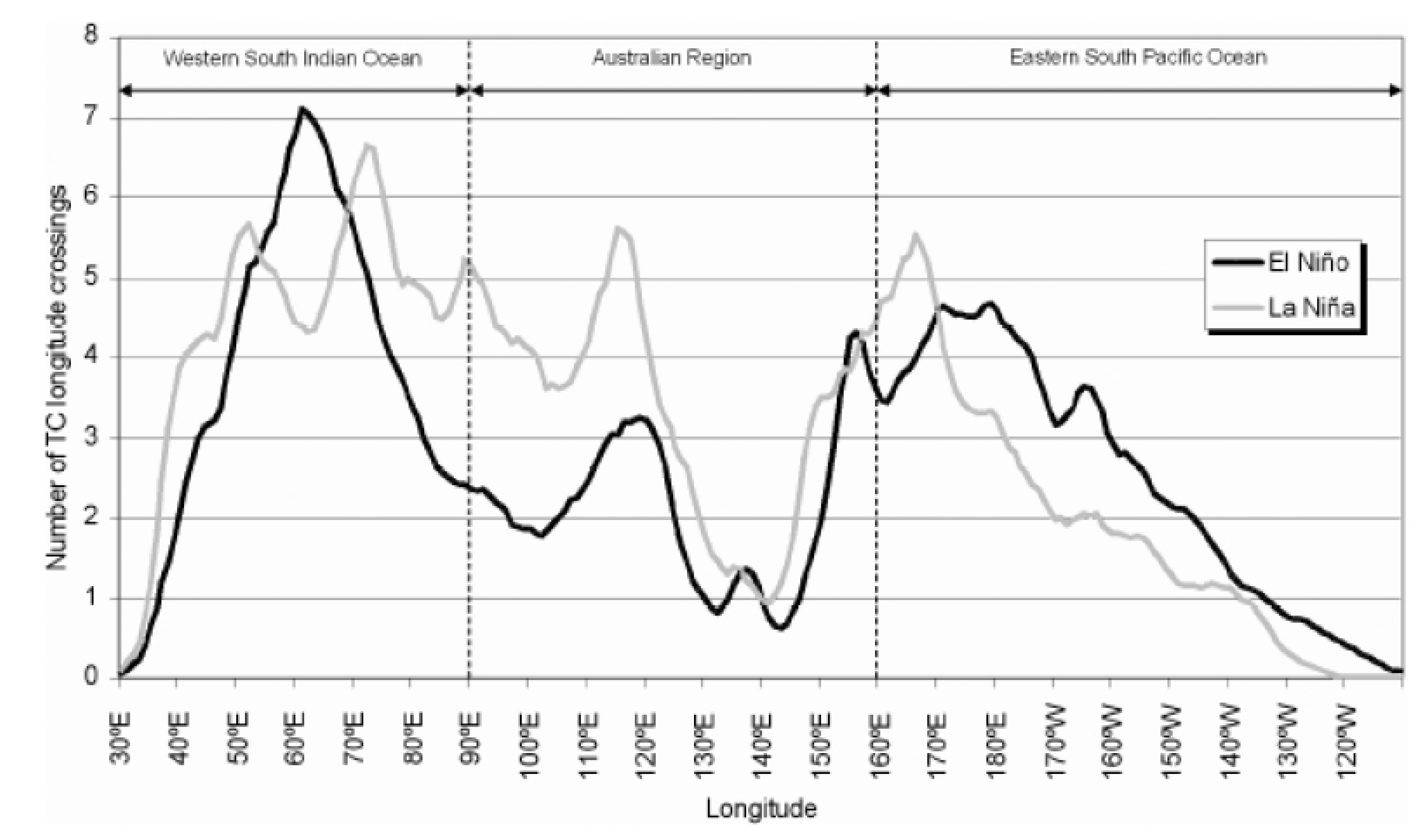
Tropical cyclones climatology – maps



Seasonal prediction models

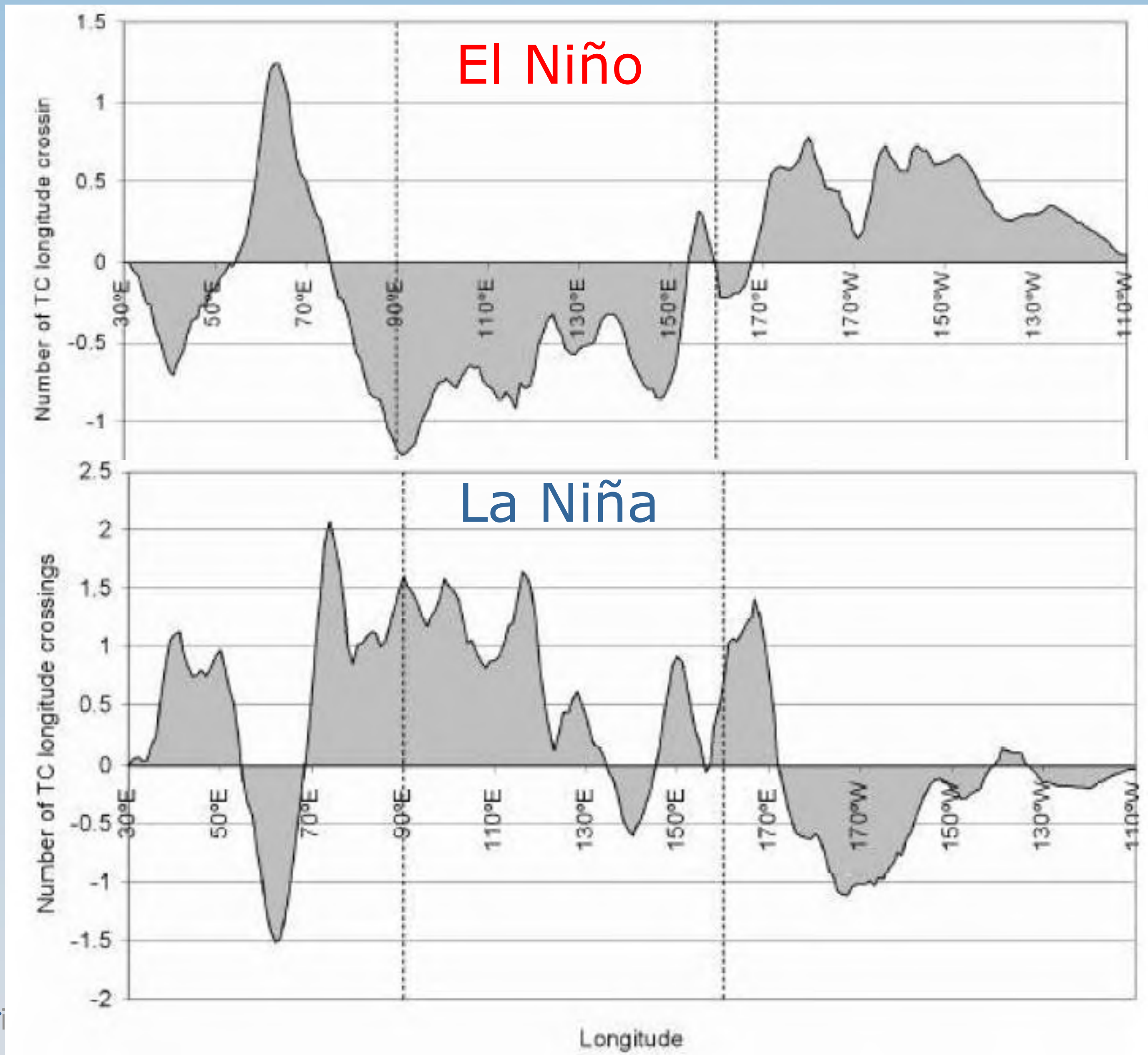
- Forecast models vary tremendously in structure and complexity. They can be simple enough to run in a few seconds on an ordinary computer, or complex enough to require a number of hours on a supercomputer.
- Dynamical models, also known as numerical models, are the most complex and use high-speed computers to solve the physical equations of motion governing the atmosphere.
- **Statistical models**, in contrast, do not explicitly consider the physics of the atmosphere but instead are **based on historical relationships** between storm behavior and storm-specific details such as location and date.
- Statistical-dynamical models blend both dynamical and statistical techniques by making a forecast based on established historical relationships between storm behavior and atmospheric variables provided by dynamical models.
- Finally, ensemble or consensus models are created by combining the forecasts from a collection of other models.

Tropical cyclones: El Niño and La Niña



Kuleshov, Y., L. Qi, R. Fawcett and D. Jones, 2009: *Improving preparedness to natural hazards: Tropical cyclone seasonal prediction for the Southern Hemisphere*, Advances in Geosciences, Vol. 12, pp. 127-143.

Tropical cyclones: departure from climatology



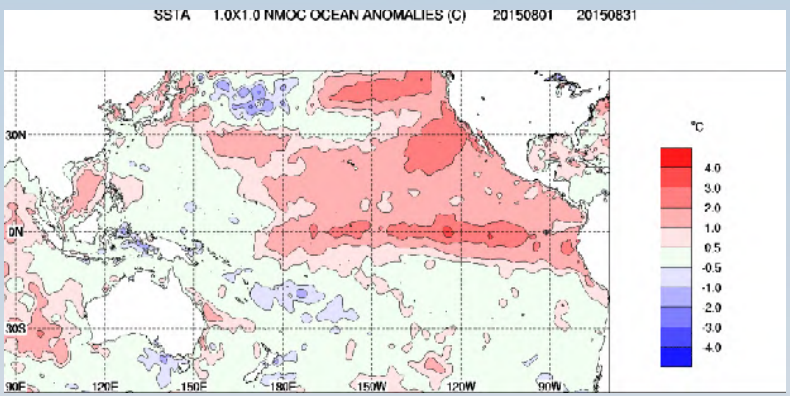
El Niño – Southern Oscillation (ENSO)

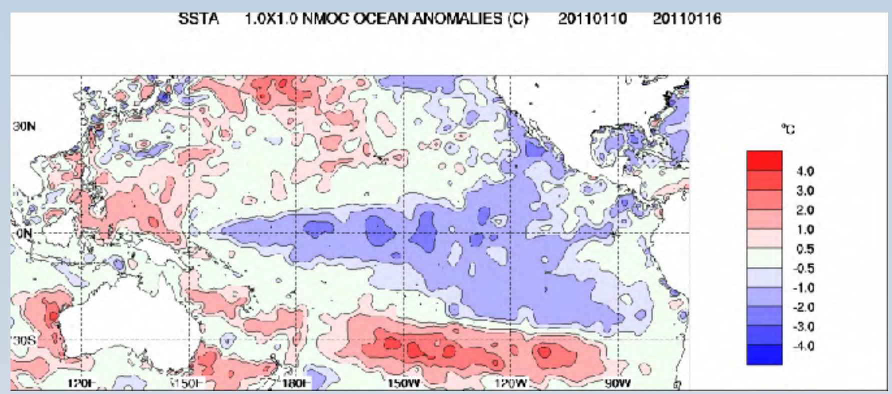
- El Niño–Southern Oscillation (ENSO) is an irregularly periodical variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean, affecting much of the tropics and subtropics.

- The oceanic warming phase is known as *El Niño* and the cooling phase as *La Niña*.

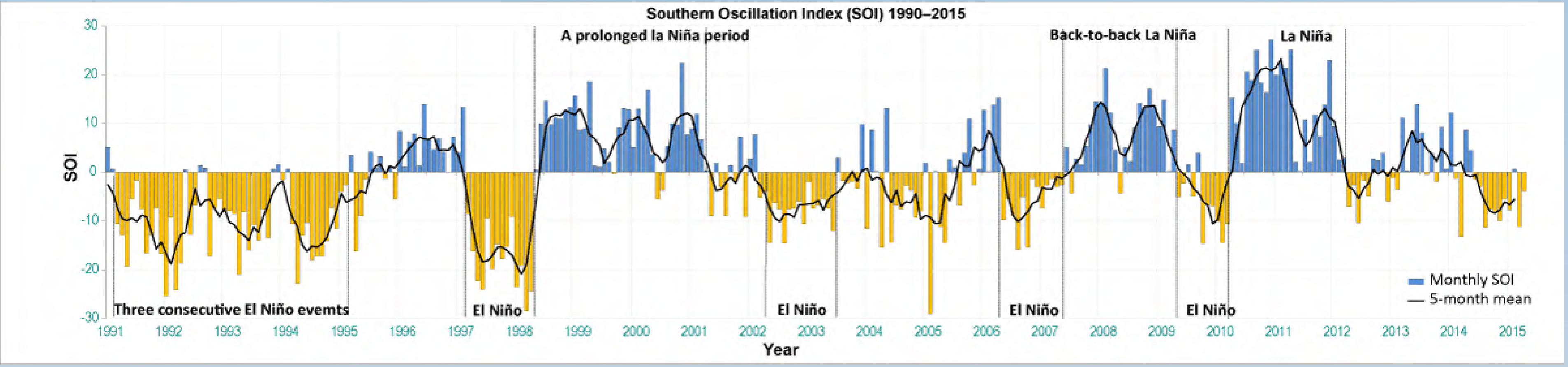
- *Southern Oscillation* is the accompanying atmospheric component, coupled with the sea temperature change: *El Niño* is accompanied with high, and *La Niña* with low air surface pressure in the tropical western Pacific.

- The two periods last several months each (typically occur every 2-7 years) and their effects vary in intensity.



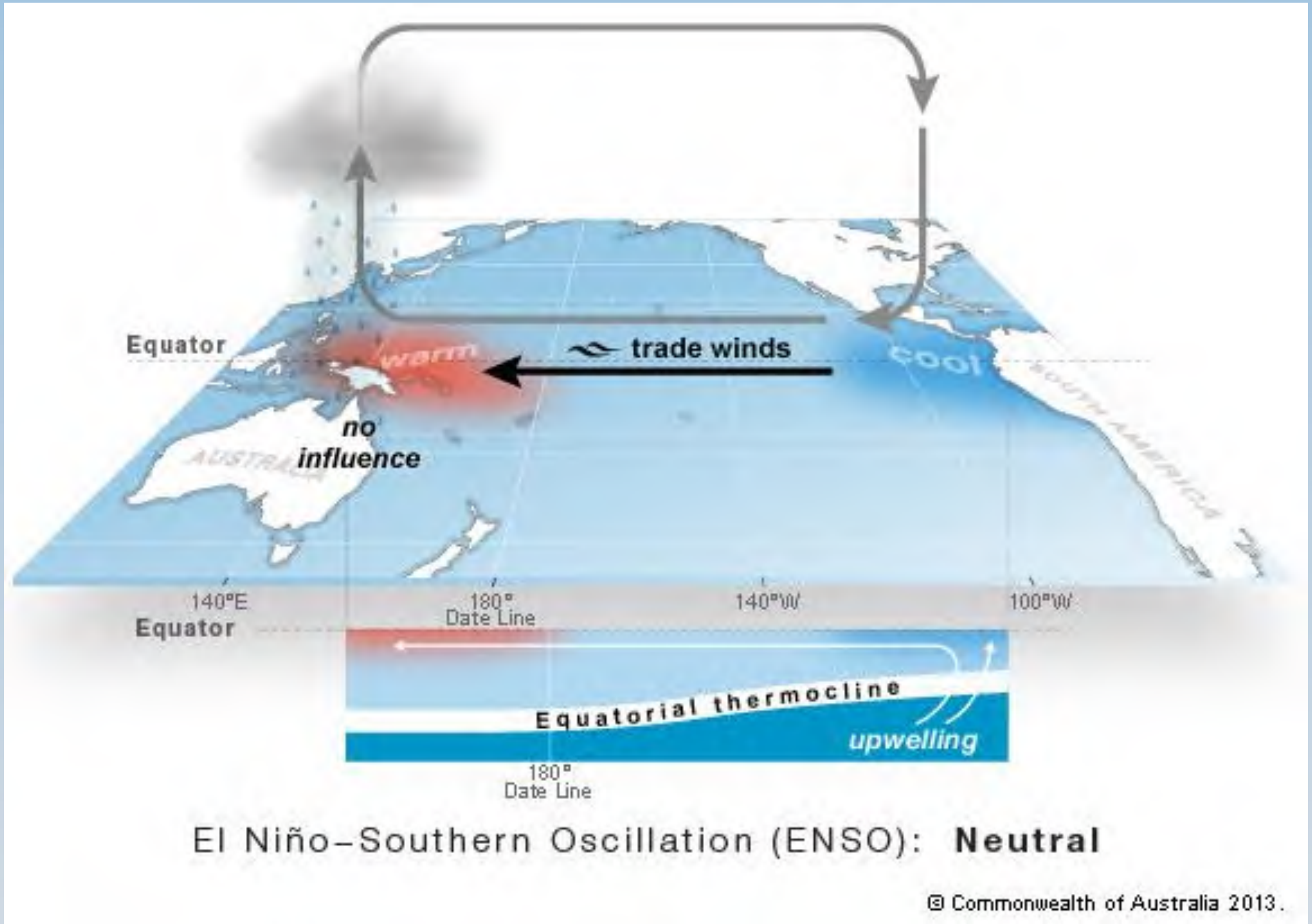


Southern Oscillation Index (SOI)

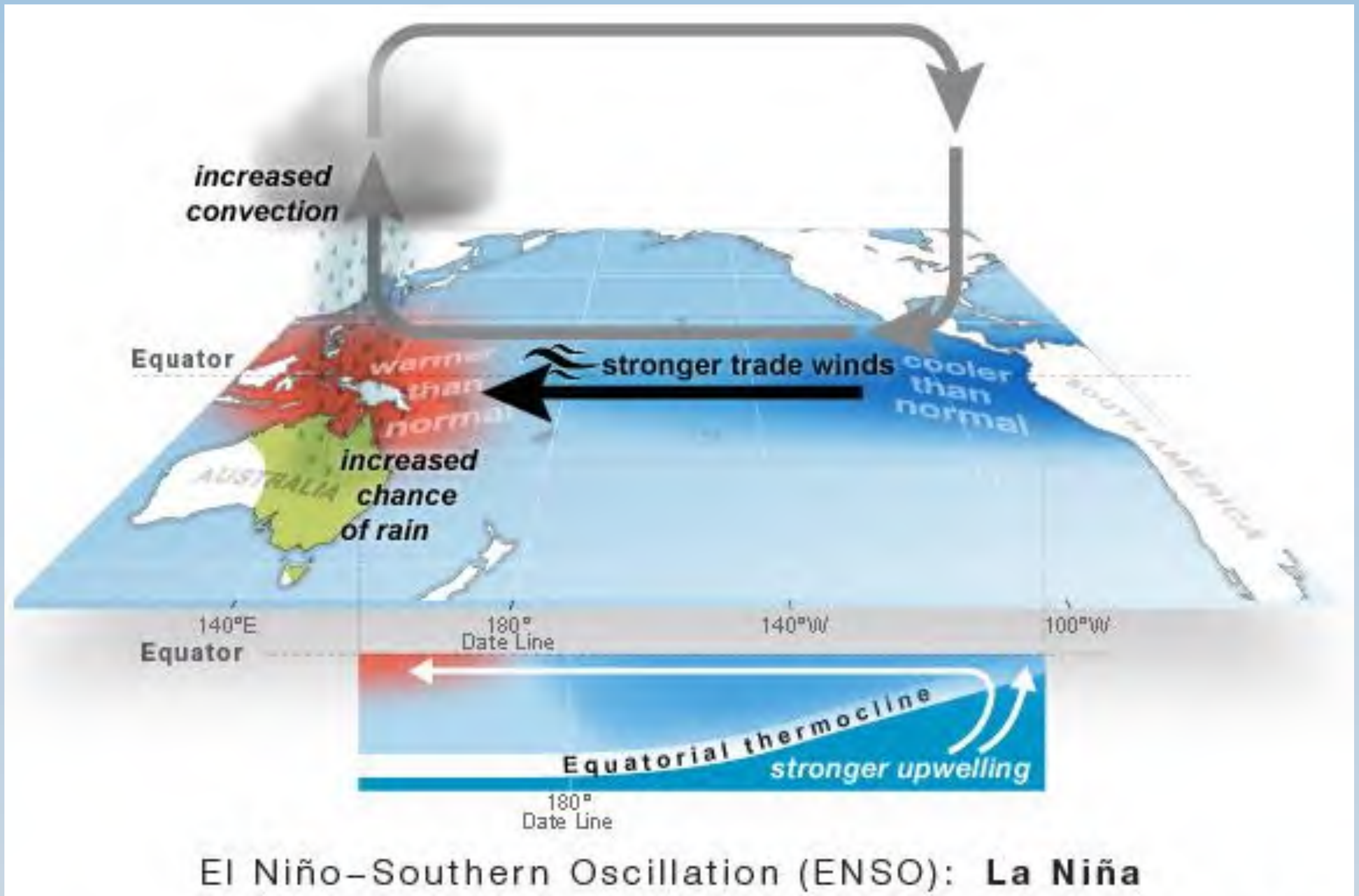


- The Southern Oscillation Index (SOI) provides an indication of the development and intensity of El Niño or La Niña events.
- The SOI is calculated using the pressure difference between Tahiti and Darwin.
- Sustained negative SOI values (blue) are indicative of El Niño conditions, and sustained positive SOI values (orange) are indicative of La Niña conditions.

El Niño – Southern Oscillation (ENSO)

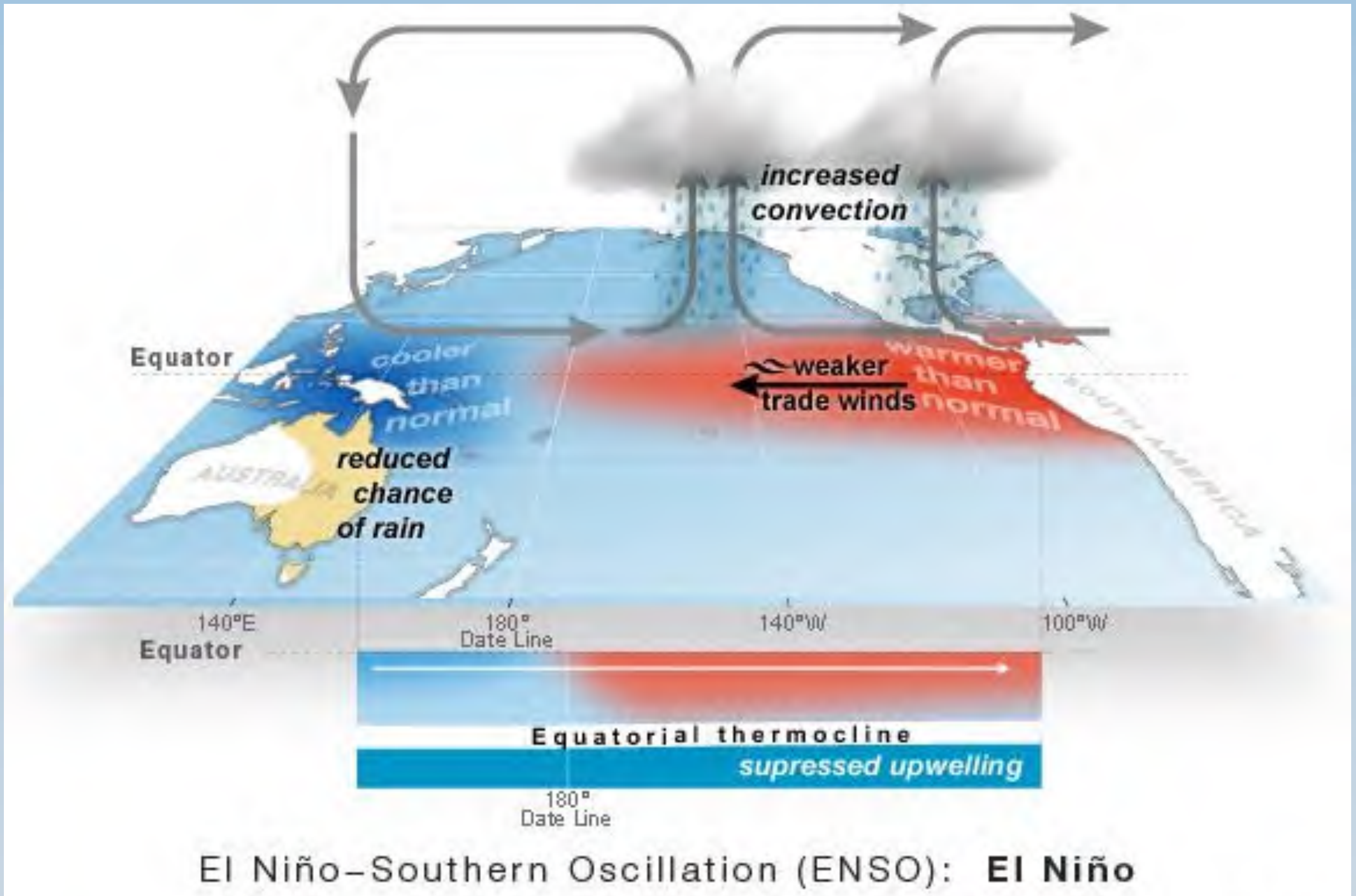


La Niña



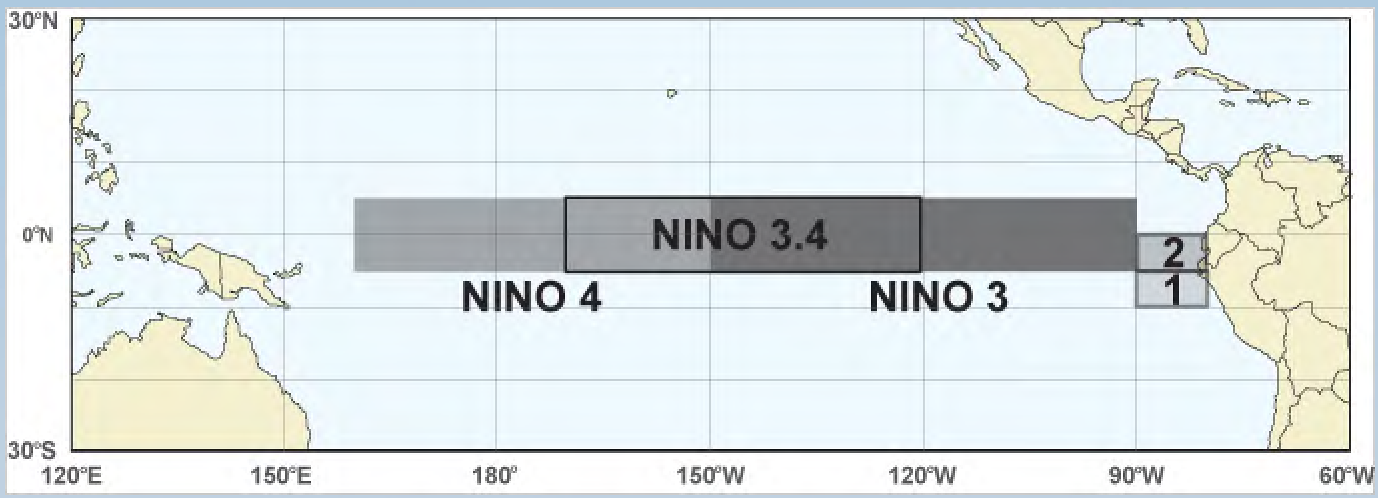
During La Niña events, as well as a sustained period of positive SOI, SSTs in the western tropical Pacific Ocean are warmer than normal while the SSTs across the central and eastern Pacific are cooler than normal; convection over the Maritime continent is increased; and trade winds (easterlies) are stronger than normal.

El Niño



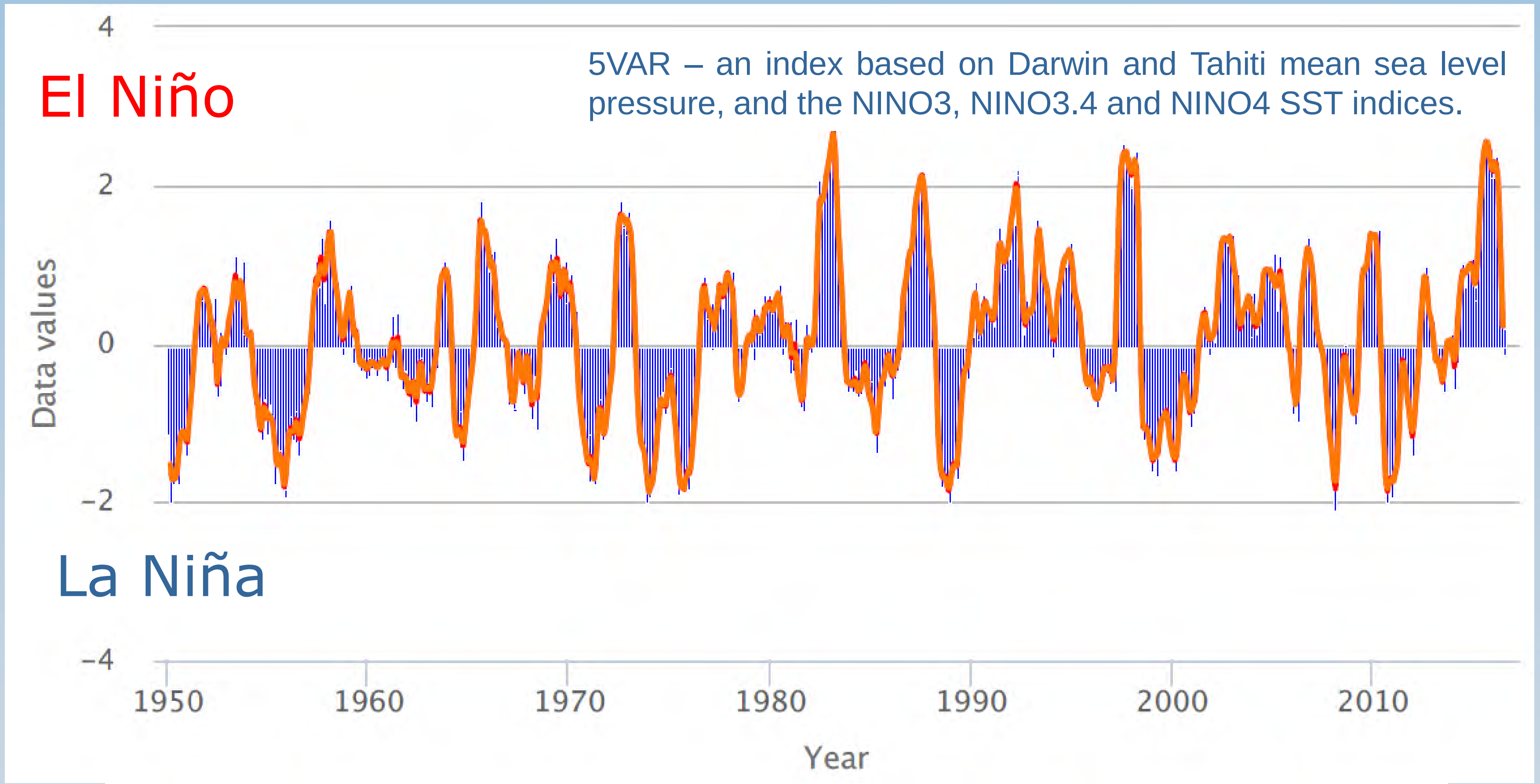
During El Niño events, as well as a sustained period of negative SOI, SSTs in the central and eastern tropical Pacific Ocean are warmer than normal; the focus of convection migrates from the Australian/Indonesian region eastward towards the central tropical Pacific Ocean; and trade winds (easterlies) are weaker than normal.

Sea Surface Temperatures (SSTs)



In addition to the SOI, climatologists use several NINO indices to monitor the Pacific Ocean. These indices refer to the difference from the long term mean of the SSTs in several regions located along the equatorial Pacific. Generally, the National Climate Centre uses NINO3.4 as the most informative index for the Australian region.

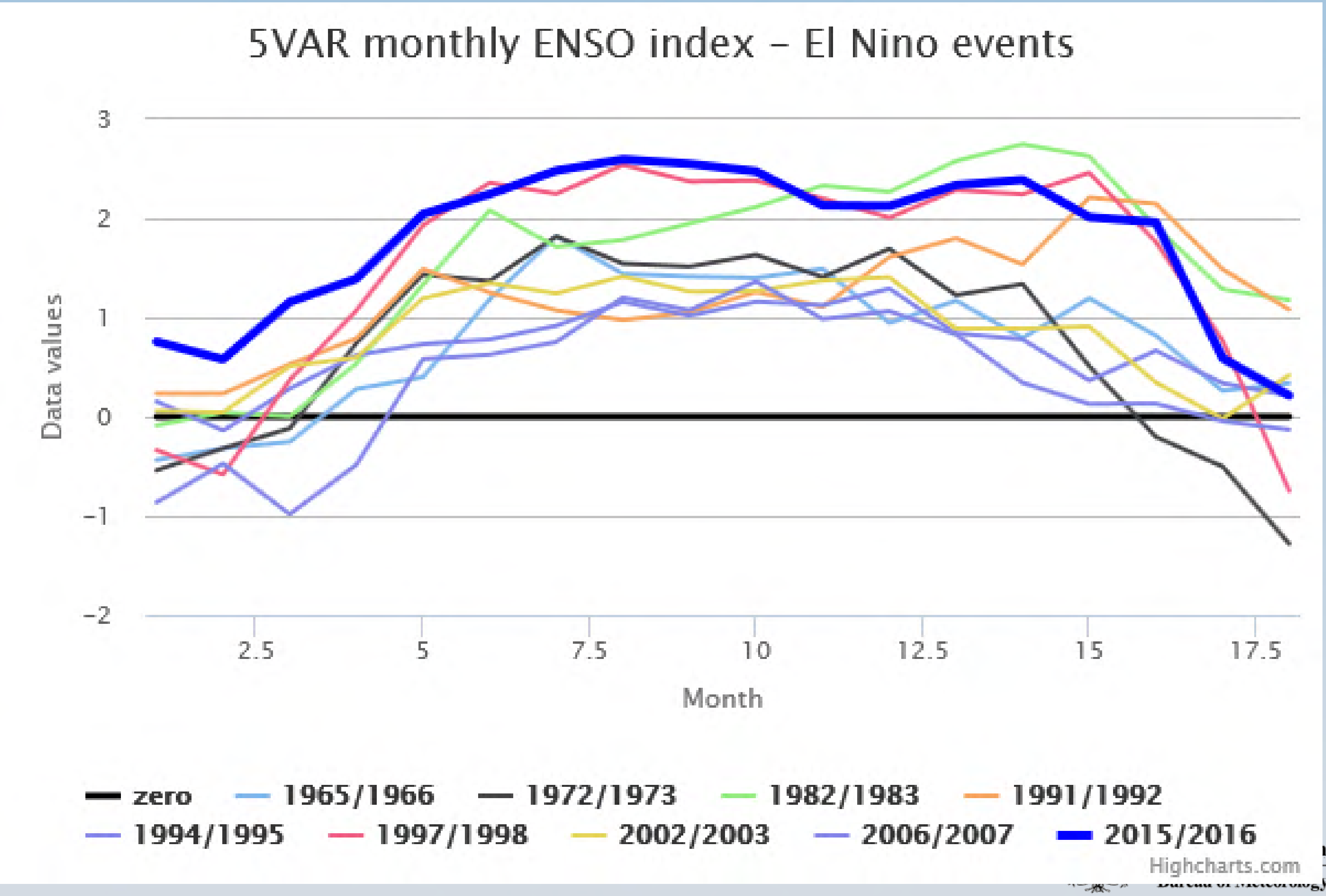
5VAR Index



- Sustained positive 5VAR values are indicative of El Niño conditions, and sustained negative 5VAR values are indicative of La Niña conditions.

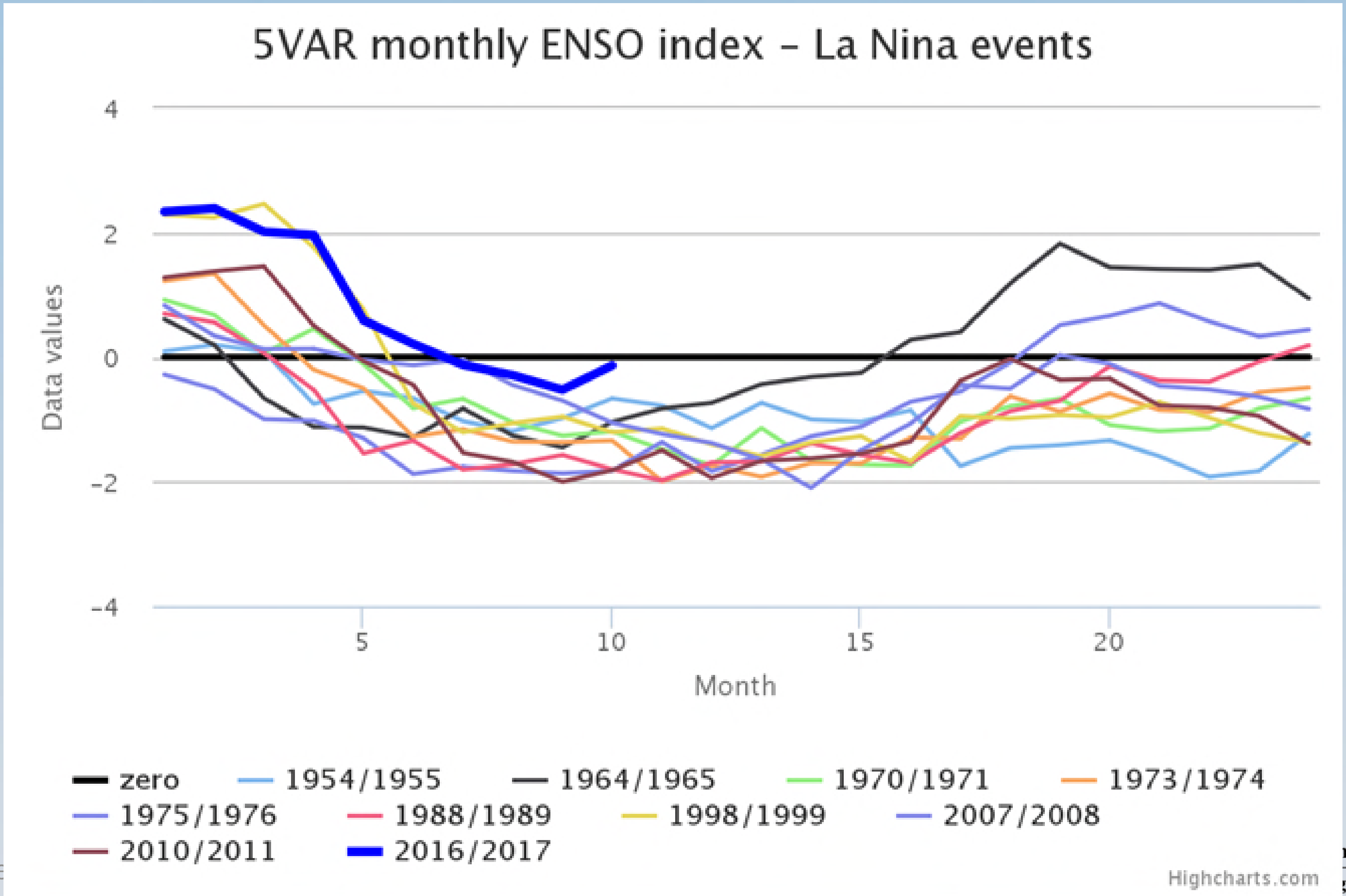
Kuleshov, Y., L. Qi, R. Fawcett and D. Jones, 2009: *Improving preparedness to natural hazards: Tropical cyclone seasonal prediction for the Southern Hemisphere,* Advances in Geosciences, Vol. 12, pp. 127-143.

5VAR Index



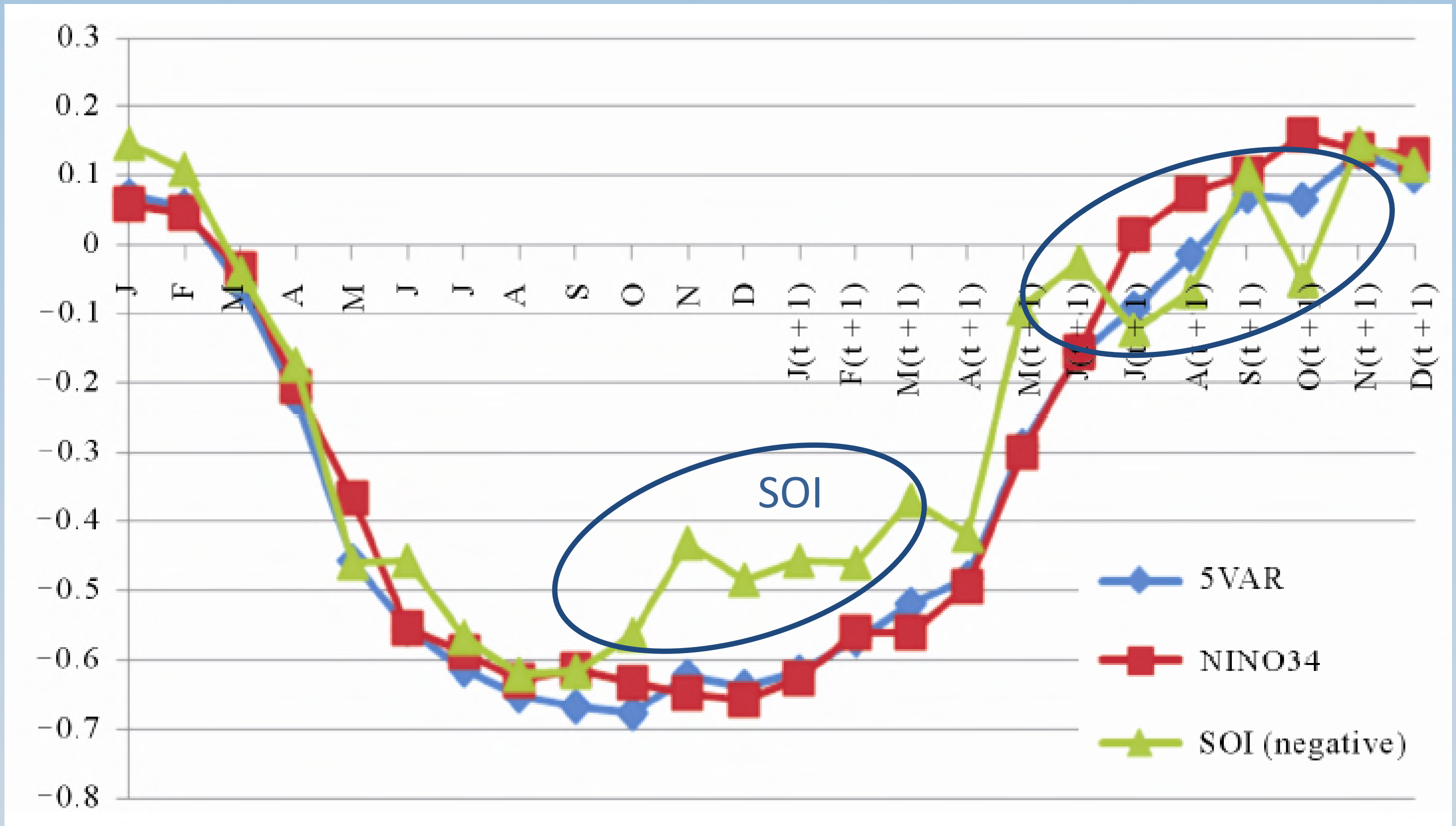
Interi

5VAR Index



Inte

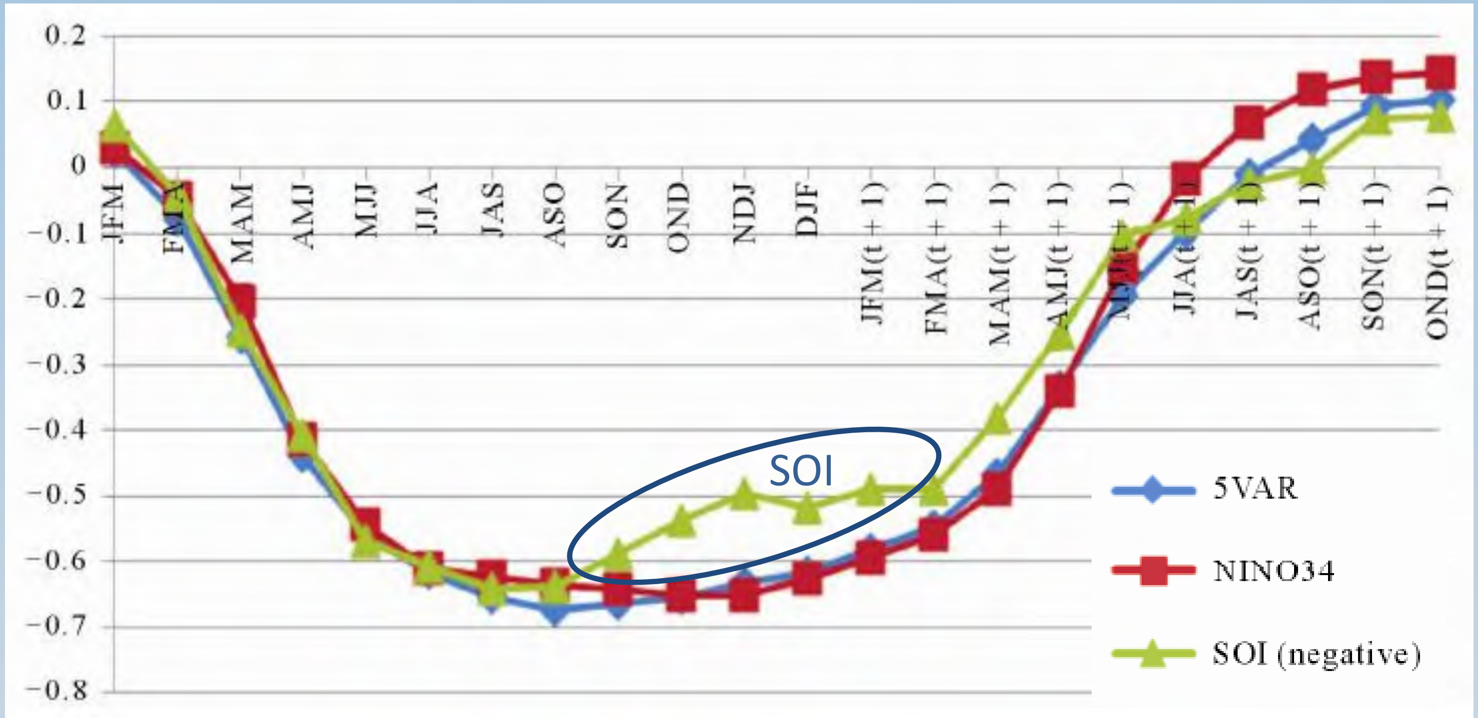
Seasonal prediction of tropical cyclones – statistical methodology



Correlation between annual number of tropical cyclones in the Australian region and the monthly 5VAR, NINO3.4 and SOI indices

Kuleshov, Y., Y. Wang, J. Apajee, R. Fawcett and D. Jones, 2012: *Prospects for improving operational seasonal prediction of tropical cyclone activity in the Southern Hemisphere*, Atmospheric and Climate Sciences, 2, 298-306.

Seasonal prediction of tropical cyclones – statistical methodology



Correlation between annual number of tropical cyclones in the Australian region and tri-monthly 5VAR, NINO3.4 and SOI indices

Kuleshov, Y., Y. Wang, J. Apajee, R. Fawcett and D. Jones, 2012: *Prospects for improving operational seasonal prediction of tropical cyclone activity in the Southern Hemisphere*, Atmospheric and Climate Sciences, 2, 298-306.

Seasonal prediction of tropical cyclones – statistical methodology

The SH TC season is typically from November to April and therefore seasonal prediction would be most valuable if issued in October, prior to the start of the TC season.

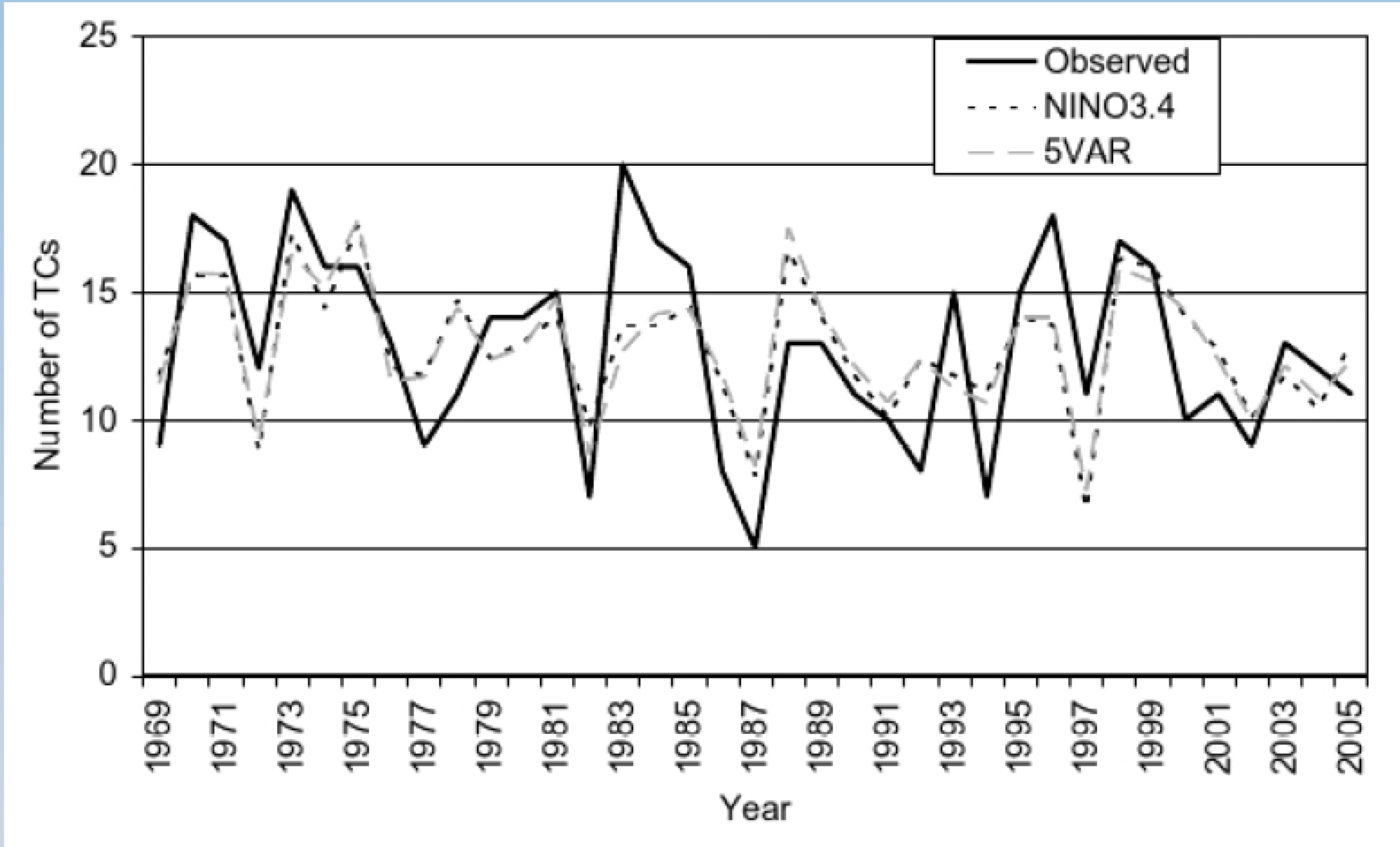
We evaluated the SOI, and the NINO3.4, NINO4 and 5VAR indices (tri-monthly, ASO) as possible predictors using ordinary least squares (OLS) linear regression.

The analogous bi-variate OLS linear regression method, with the SOI and NINI3.4 indices as simultaneous predictors, was also explored.

$$
\begin{aligned}
N_{\mathrm{SOI}} &= 0.26 \times \mathrm{SOI} + 13.21, \\
N_{\mathrm{NINO3.4}} &= -3.28 \times \mathrm{NINO3.4} + 13.04, \\
N_{\mathrm{NINO4}} &= -4.59 \times \mathrm{NINO4} + 13.33, \\
N_{\mathrm{SOI\&NINO3.4}} &= 0.12 \times \mathrm{SOI} - 2.00 \times \mathrm{SSTA} + 13.13, \\
N_{\mathrm{5VAR}} &= -1.31 \times \mathrm{5VAR} + 13.24.
\end{aligned}
$$

Kuleshov, Y., L. Qi, R. Fawcett and D. Jones, 2009: *Improving preparedness to natural hazards: Tropical cyclone seasonal prediction for the Southern Hemisphere*, Advances in Geosciences, Vol. 12, pp. 127-143.

Seasonal prediction of tropical cyclones – statistical methodology



Time series of total annual number of TCs in the Australian region as observed and predicted using NINO3.4 and the 5VAR indices.

Kuleshov, Y., L. Qi, R. Fawcett and D. Jones, 2009: *Improving preparedness to natural hazards: Tropical cyclone seasonal prediction for the Southern Hemisphere*, Advances in Geosciences, Vol. 12, pp. 127-143.

Seasonal prediction of tropical cyclones – statistical methodology

Support Vector Regression (SVR) has been identified as a skilful machine learning algorithm for application to TC seasonal prediction.

Using non-parametric and non-linear regression approach, annual total number of TCs expected to be formed in the coming season (Y) has been generated using nine variables as the model's input.

Selected input variables (X_1-X_9) were the following indices:

X_1 - Dipole Mode Index;

X_2 - NIÑO4;

X_3 - NIÑO3.4;

X_4 - NIÑO3;

X_5 – NIÑO1.2;

X_6 – El Niño Modoki index;

X_7 – 5VAR index;

X_8 – Multivariate ENSO index; and

X_9 - SOI.

Wijnands, J.S., Qian, G., Shelton, K.L., Fawcett, R.J.B., Chan, J.C.L., and Kuleshov, Y., 2015: *Seasonal forecasting of tropical cyclone activity in the Australian and the South Pacific regions*, Mathematics of Climate and Weather Forecasting, pp. 21-44.

Seasonal prediction of tropical cyclones – statistical methodology

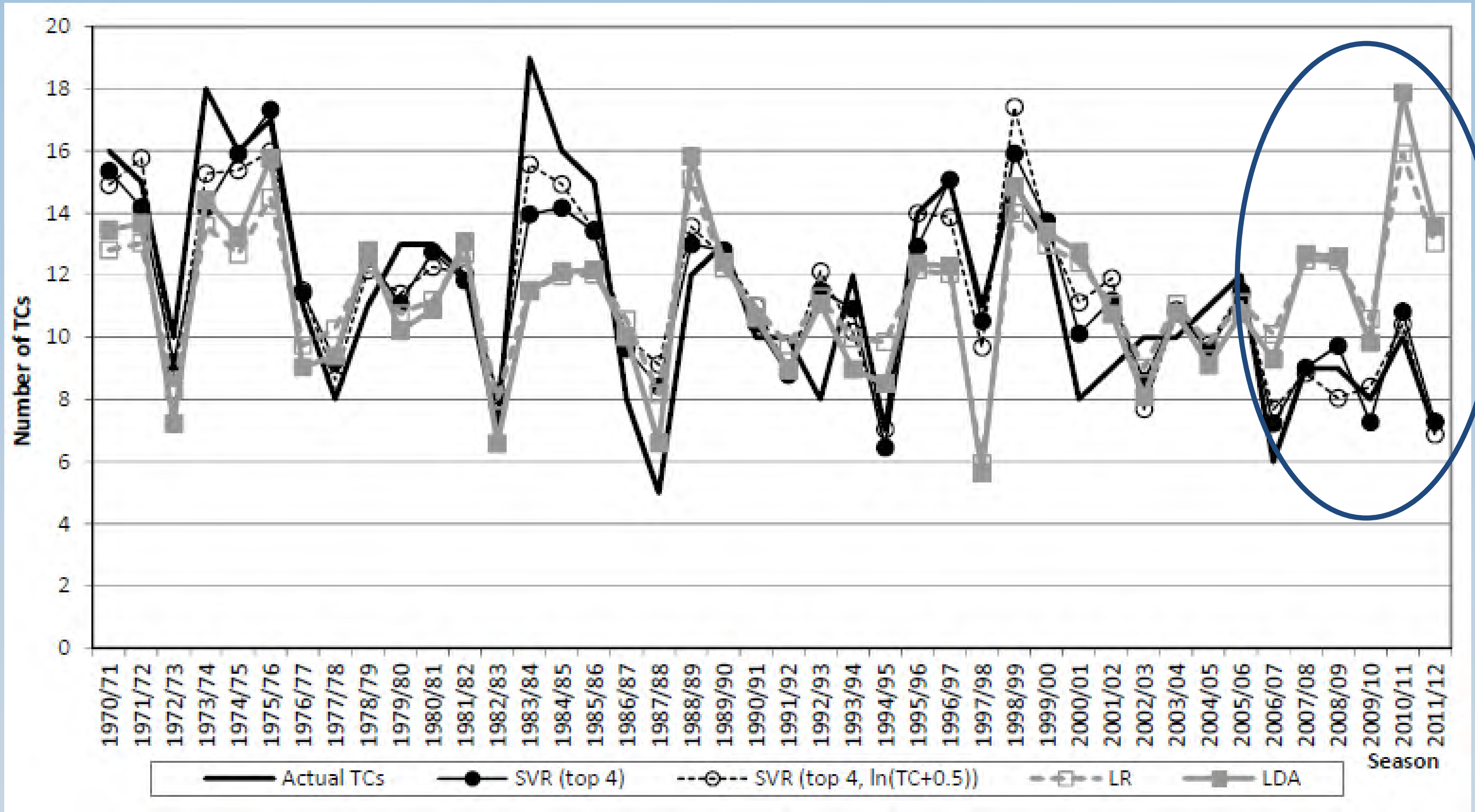
Table 2: nRMSE for various options of model averaging. The smallest (i.e., best) nRMSE for each region is underlined. Grey shading indicates a deviation of less than 0.01 from the best result.

	AR	AR-W	AR-NW	AR-N	AR-E	SPO	SPO-W	SPO-E
Best model	0.540	0.568	0.804	0.791	0.736	0.744	0.627	0.660
Top two	0.493	0.556	0.798	0.764	0.722	0.660	0.623	0.622
Top three	0.501	0.571	0.789	0.757	0.700	0.659	0.613	0.628
Top four	0.474	0.563	0.797	0.756	0.703	0.666	0.615	0.635
Top five	0.478	0.565	0.798	0.773	0.706	0.648	0.623	0.643
Top six	0.482	0.571	0.798	0.773	0.706	0.629	0.632	0.643
Top seven	0.484	0.574	0.796	0.783	0.703	0.629	0.639	0.650
Top eight	0.487	0.568	0.799	0.788	0.702	0.628	0.641	0.648
Top nine	0.488	0.573	0.800	0.794	0.700	0.631	0.642	0.628
Top ten	0.488	0.566	0.800	0.799	0.696	0.634	0.641	0.635

For all regions, model averaging yields better results than using the best model itself. Averaging top two to four models works well for most regions.

Wijnands, J.S., Qian, G., Shelton, K.L., Fawcett, R.J.B., Chan, J.C.L., and Kuleshov, Y., 2015: *Seasonal forecasting of tropical cyclone activity in the Australian and the South Pacific regions*, Mathematics of Climate and Weather Forecasting, pp. 21-44.

Seasonal prediction of tropical cyclones – statistical methodology



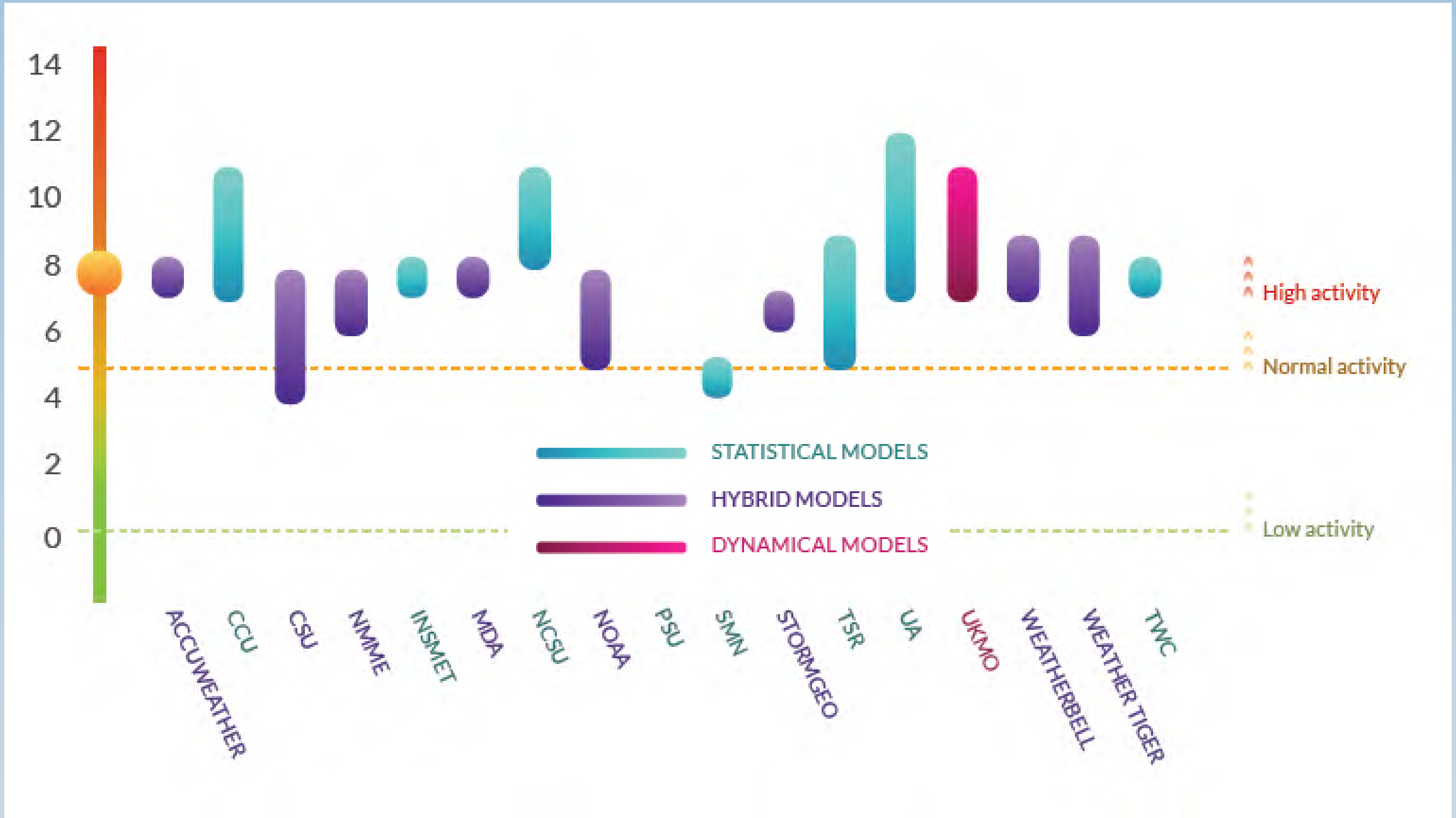
Wijnands, J.S., Qian, G., Shelton, K.L., Fawcett, R.J.B., Chan, J.C.L., and Kuleshov, Y., 2015: *Seasonal forecasting of tropical cyclone activity in the Australian and the South Pacific regions*, Mathematics of Climate and Weather Forecasting, pp. 21-44.

WMO activities of seasonal prediction of tropical cyclones

- Seasonal Hurricane Predictions has been created to pool predictions by the main centers carrying out forecasts on the hurricane season, which usually runs from early June to late November, and to make them available to the wider public.

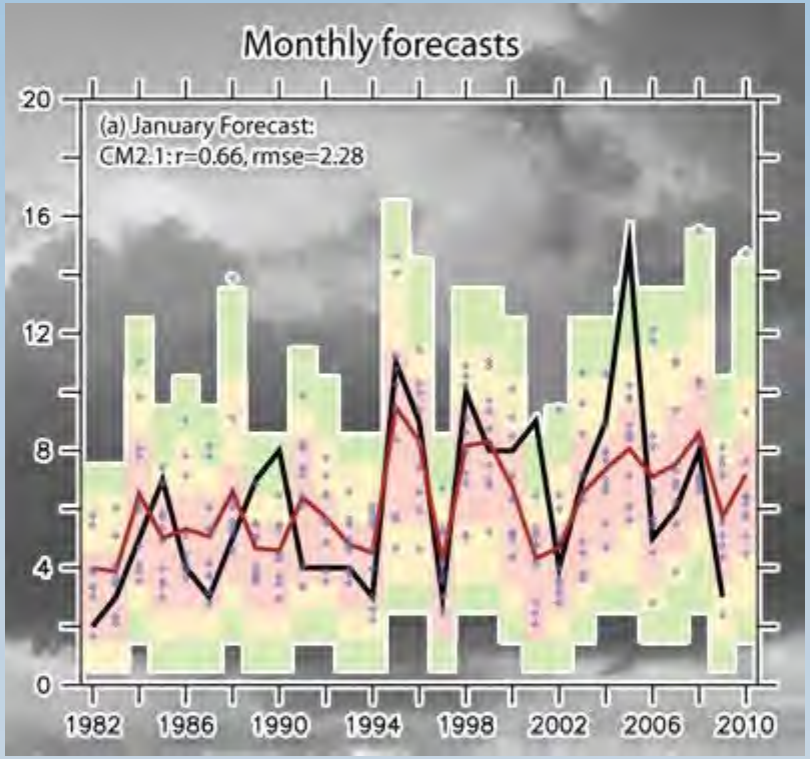
- The 17 centers whose forecasts are presented on the website are: Accu Weather, Coastal Carolina University, Colorado State University, MDA Weather Services, NC State University, NMME, **the National Oceanic and Atmospheric Administration (NOAA)**, Penn State University, The University of Arizona, Weatherbell Analytics, The Weather Company, WeatherTigger (all based in the U.S.), the Servicio Meteorológico Nacional of México, the Instituto Cubano de Meteorología (Cuba), StormGeo (Norway), Tropical Storm Risk at University College London, and **the UK Met Office (United Kingdom)**.

The Atlantic basin hurricane season prediction



- Statistical, hybrid and dynamical (Met Office, United Kingdom) models

Seasonal prediction of tropical cyclones – hybrid (statistical-dynamical) methodology

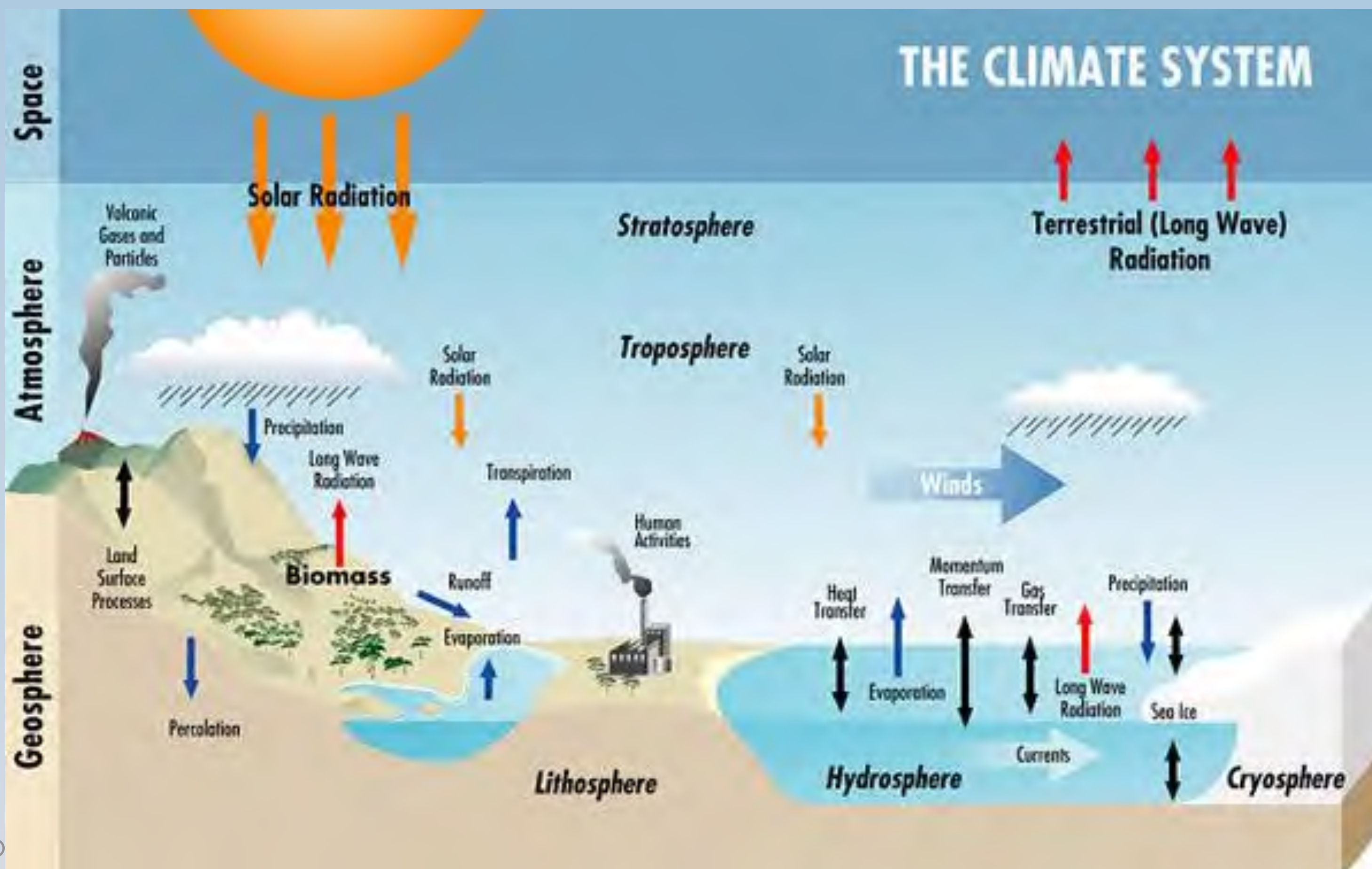


Retrospective (1982-2009) performance of HyHuFS predictions of hurricane frequency initialized in January (adapted from Vecchi et al. 2011). Black line shows the observed hurricane frequency. Red line shows the predicted expected value. The pink, yellow and green shaded areas show the predicted 50%, 75% and 90% confidence range on the predictions, respectively.

Vecchi, G.A., M. Zhao, H. Wang, G. Villarini, A. Rosati, A. Kumar, I.M. Held, R. Gudgel (2011): Statistical-Dynamical Predictions of Seasonal North Atlantic Hurricane Activity. /Mon. Wea. Rev.

Introduction to dynamical coupled models

- Ocean Model + Atmosphere model + Land surface/soil model + Sea ice model
- Models represent basic variables on a 3D grid. Typical grid resolutions 100 - 200km
- Use laws of physics to evolve variables forward in time and continuous in space - These represent the exchange of properties between the different variables



About POAMA

Predictive Ocean Atmosphere Model for Australia (POAMA), version 2.4.

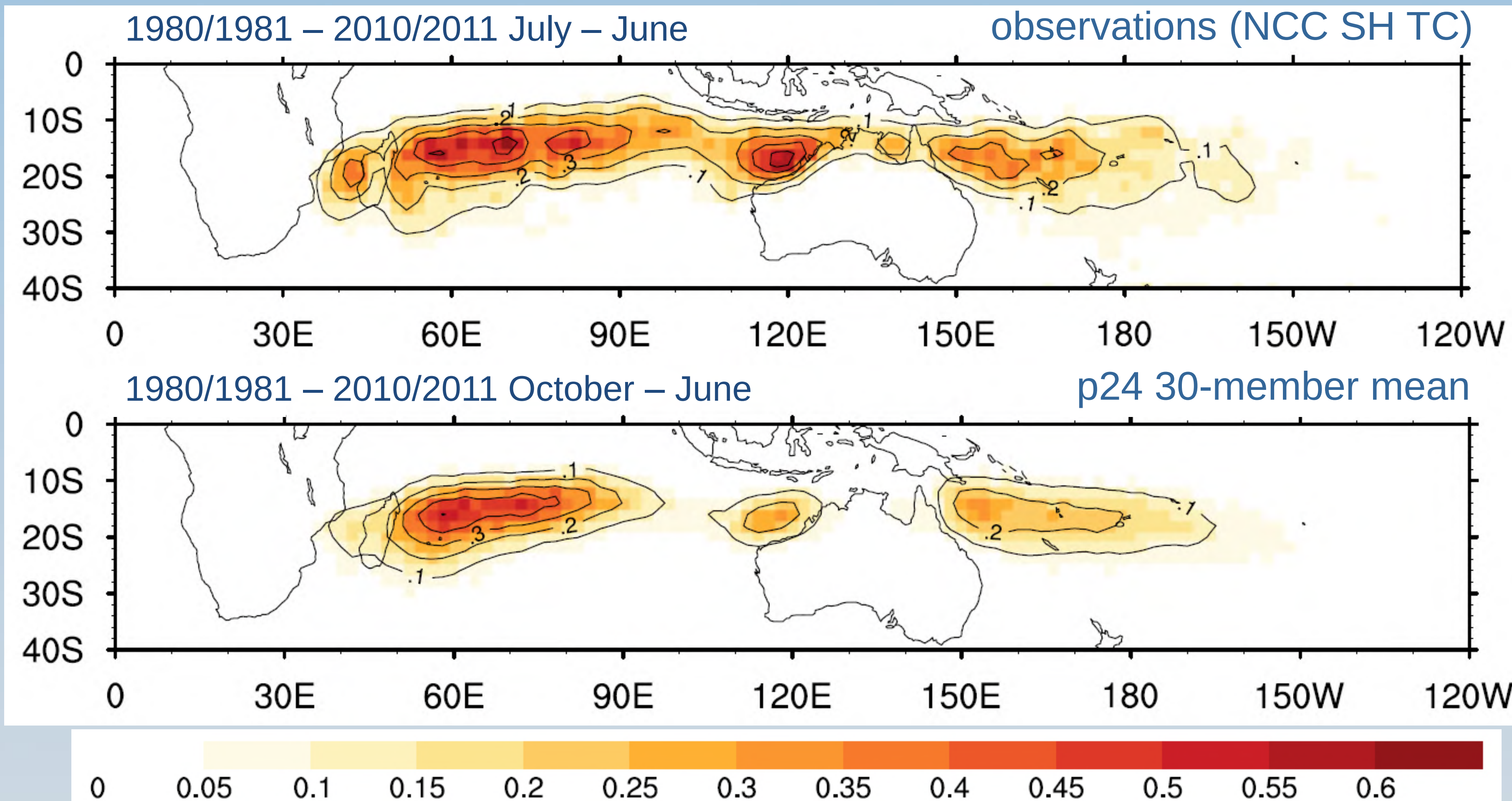
- Coupled atmosphere-ocean GCM developed by BoM and CSIRO.
- Components: ACOM2 (Australian Community Ocean Model version 2); BAM3 (the Bureau of Meteorology Research Centre Atmospheric Model version 3); OASIS3 (Ocean Atmosphere Sea Ice Soil version 3) coupler.
- Vital statistics: 30 member ensemble; T47 (~2.5°) L17 atmospheric model; L25 oceanic model.
- Seasonal version is initialised on 1st of every month and run for 9 months. For current analysis use Oct run to cover Nov-Apr TC season.

About ACCESS-S1

The Australian Community Climate and Earth-System Simulator-Seasonal prediction system (ACCESS-S1).

- ACCESS-S1 built upon the latest climate model Global Seasonal forecast system version 5 using the Global Coupled configuration 2 (GloSea5-GC2) from the UK Met Office (UKMO) along with locally developed system enhancements.
- The ACCESS-S1 system is planned to become operational, replacing the BoM's current operational system POAMA2 by mid-2017.
- The UKMO's GloSea5-GC2 includes a number of state-of-the-art features compared to POAMA2, such as substantially higher horizontal (~60 km) and vertical resolution, improved model physics and parameterization, a multi-level land surface model, and an interactive multi-level sea-ice model.

POAMA – tropical cyclone track density

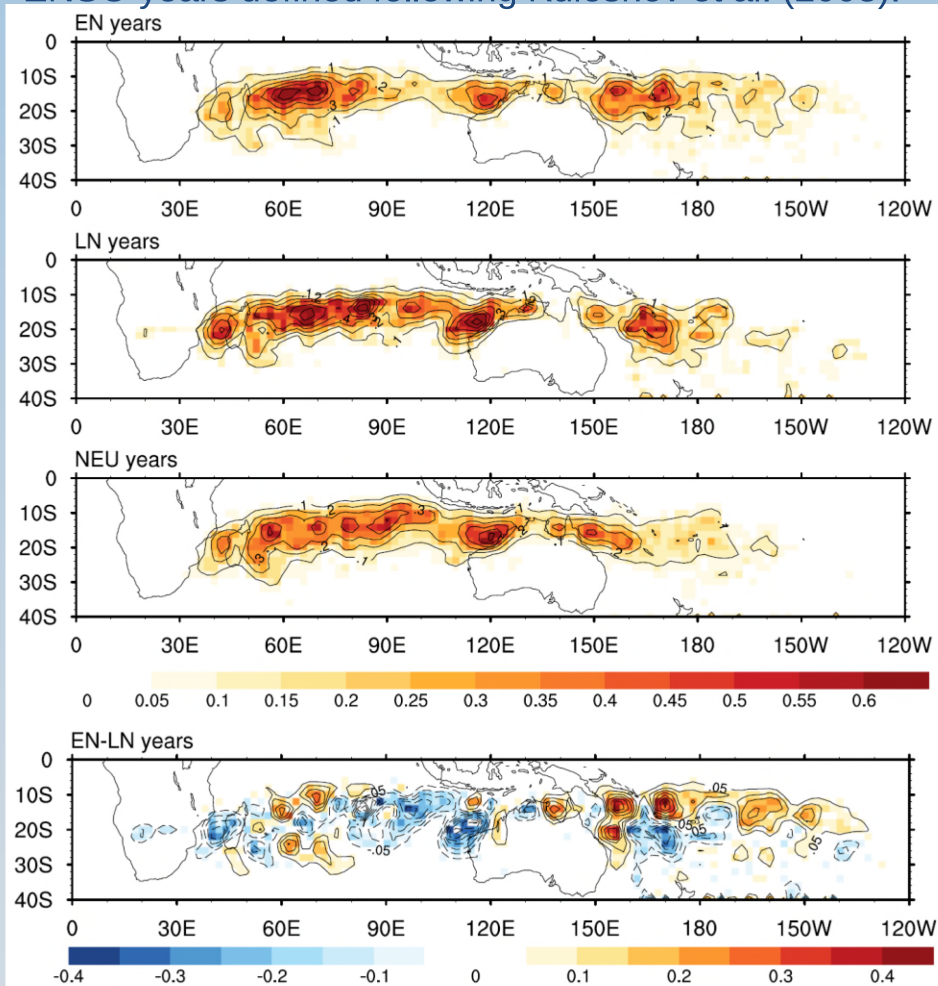


Number of TCs per 2° x2° grid box per season
[Obs. TC locations once per day to agree with POAMA]

POAMA – tropical cyclones & ENSO

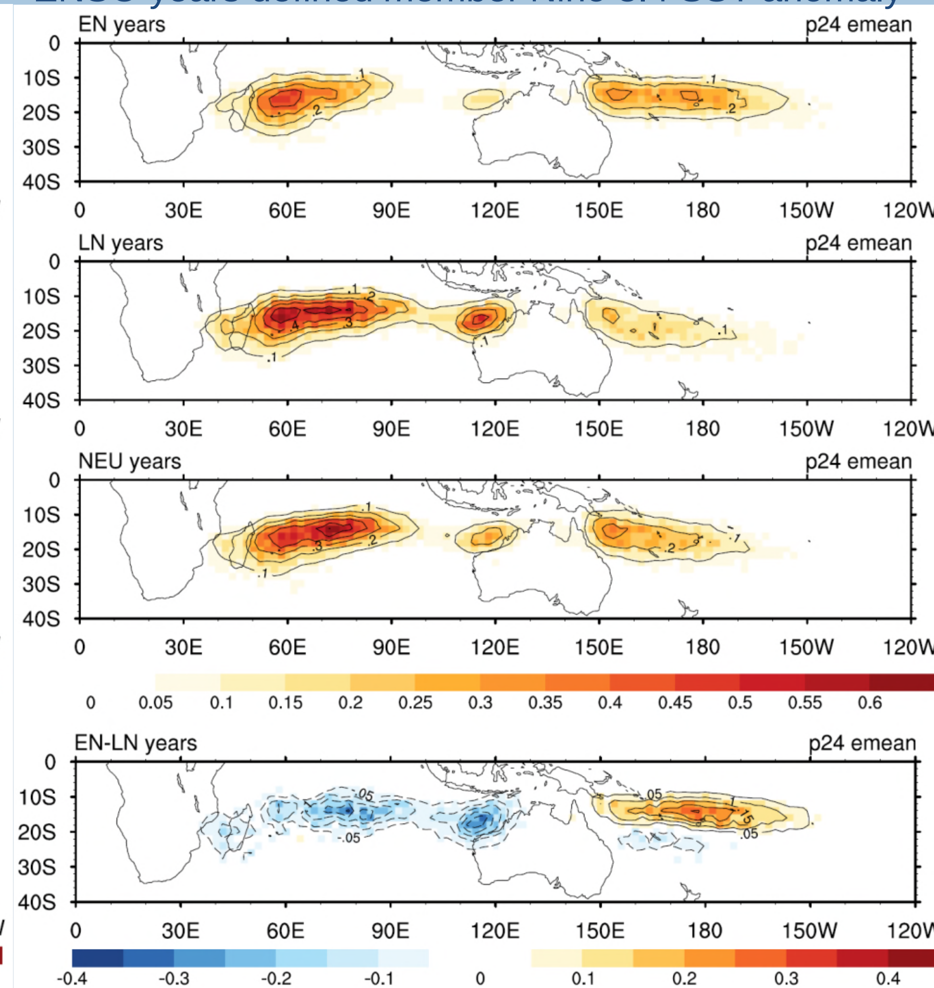
Observations

ENSO years defined following Kuleshov et al. (2008).



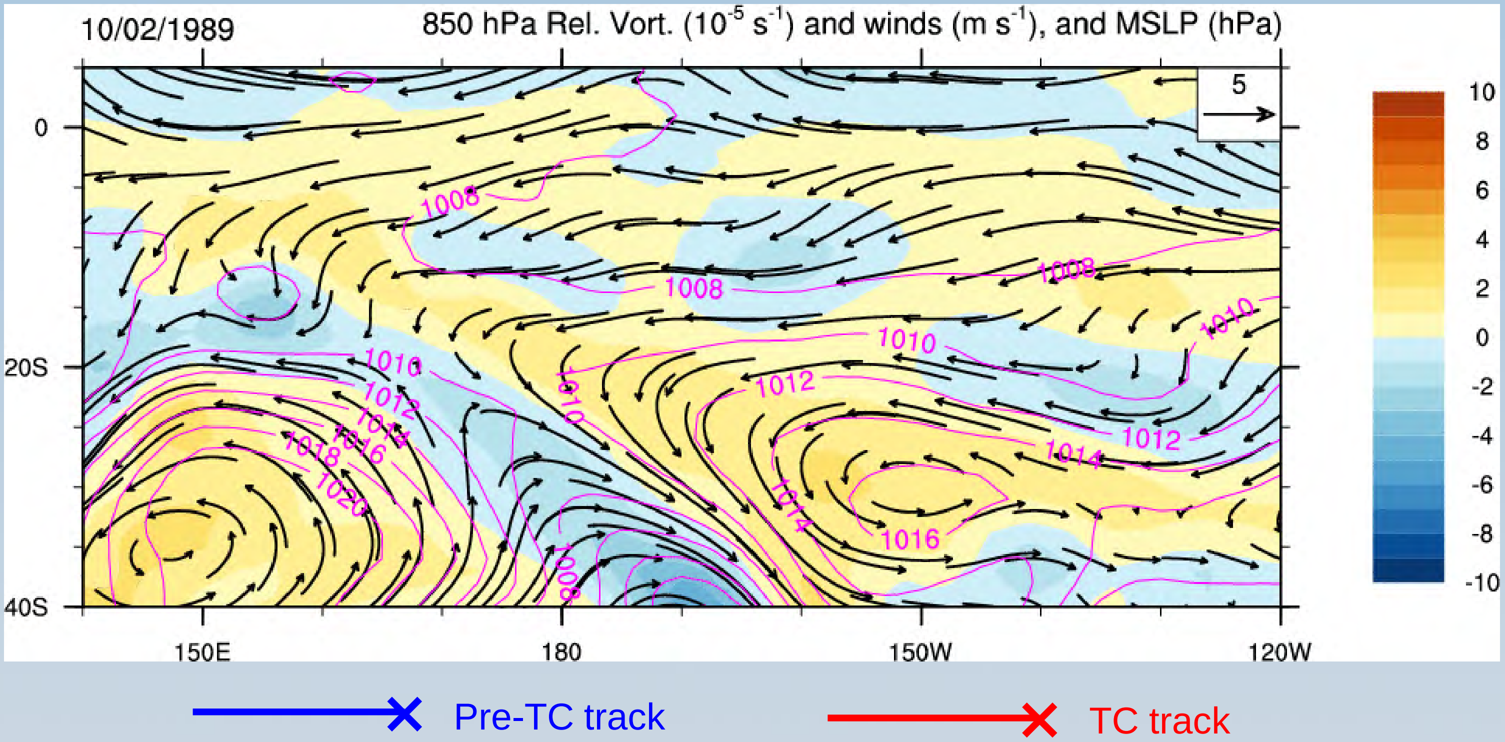
POAMA

ENSO years defined member Niño 3.4 SST anomaly



Tropical cyclone seasonal prediction

- Tropical cyclones are tracked every day for the entire Southern Hemisphere tropical cyclone season (Nov-Apr) in each member of the climate model ensemble.

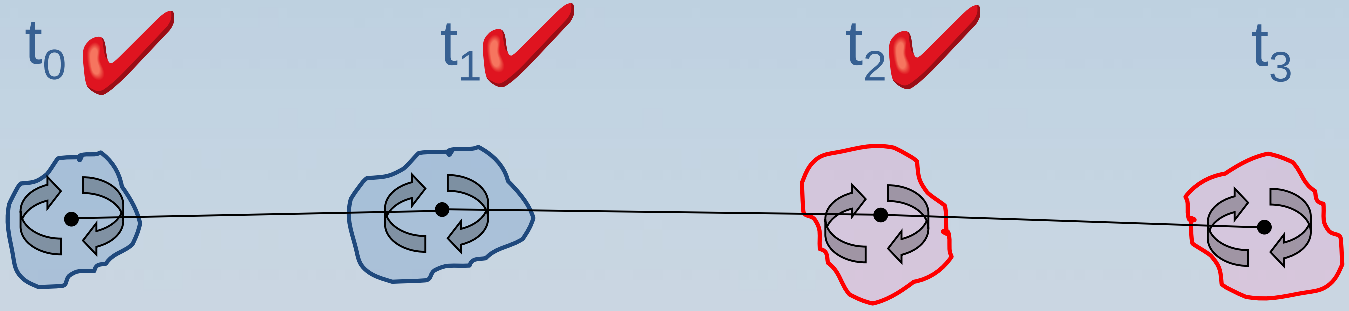


Kuleshov, Y., C. Spillman, Y. Wang, A. Charles, R. de Wit, K. Shelton, D. Jones, H. Hendon, C. Ganter, A. Watkins, J. Apajee, and A. Griesser, 2012: Seasonal prediction of climate extremes for the Pacific: Tropical cyclones and extreme ocean temperatures, *Journal of Marine Science and Technology*. Vol. 20, No. 6, pp. 675-683, doi: 10.6119/JMST-012-0628-1.

Tropical cyclone seasonal prediction

Use dynamical climate model and objective cyclone tracking scheme:

- Identify disturbances in the model at each time,
- Join these disturbances together to form a track,
- When certain threshold criteria have been met for 3 successive times, the disturbance is declared a tropical cyclone.



Tory, K.J., Chand, S.S., Dare, R.A. and McBride, J.L. 2013. The development and assessment of a model-, grid- and basin-independent tropical cyclone detection scheme. *J. Climate*, doi: 10.1175/JCLI-D-12-00510.1

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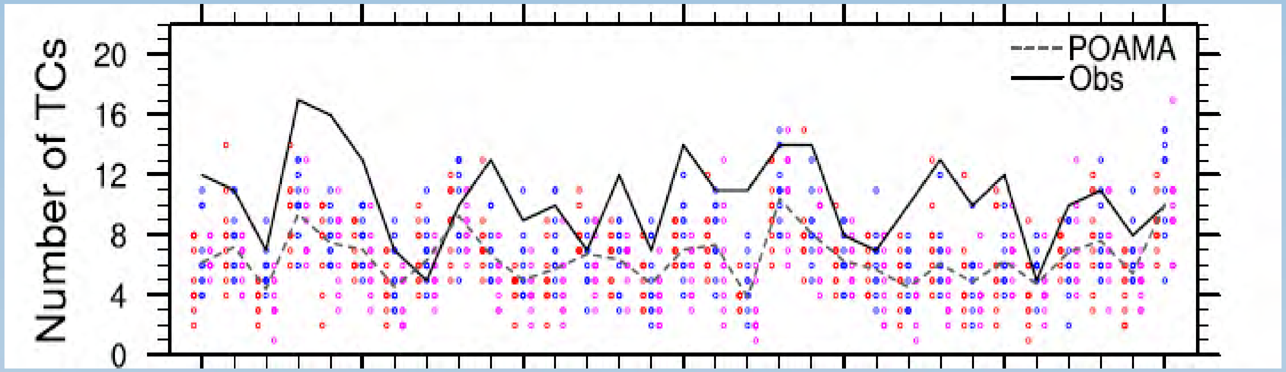
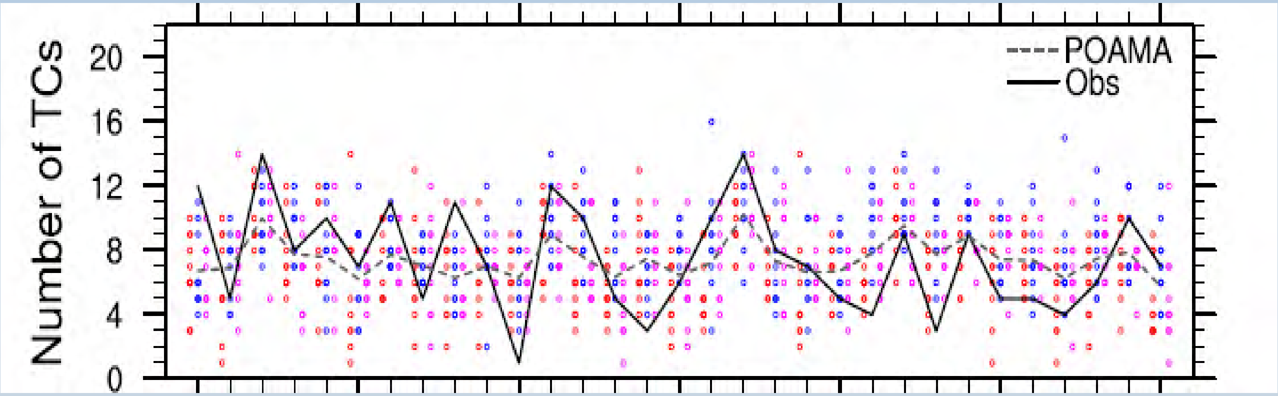
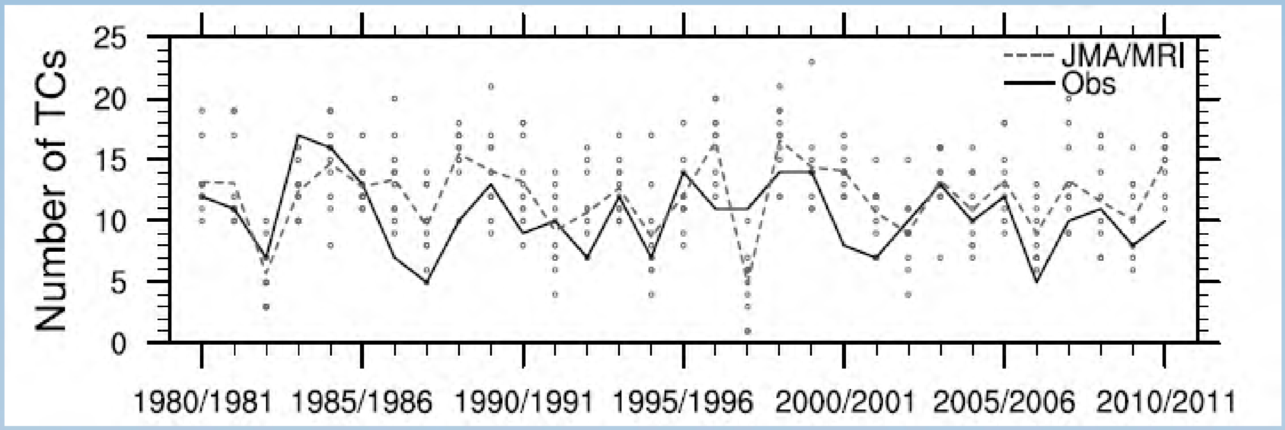
Tropical cyclone seasonal predictions

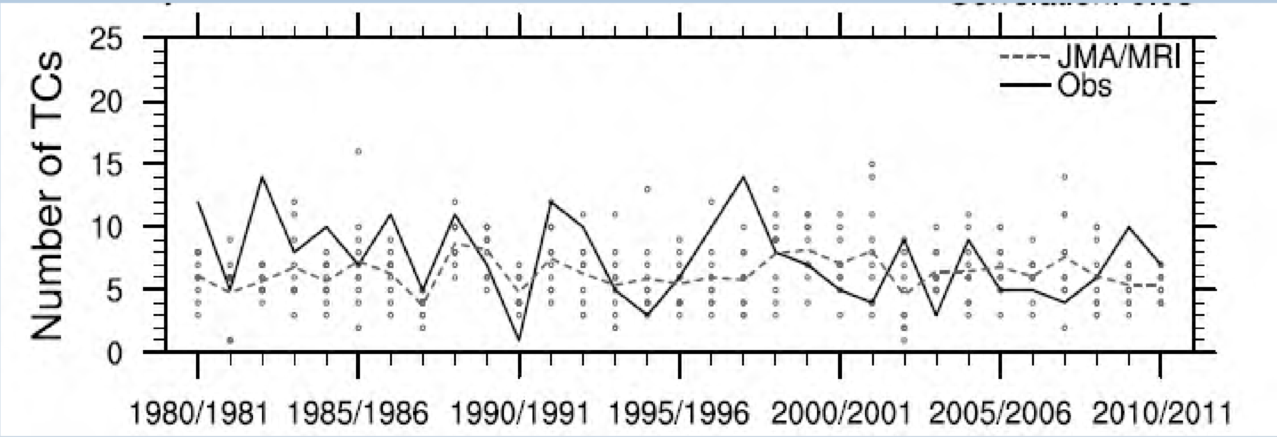




Time series of annual (NDJFMA) number of TCs in POAMA for the Australian (top panel) and South Pacific (bottom panel) regions. TC numbers are shown for observations (solid black line) and ensemble mean (dashed grey line). Ensemble members are shown as coloured circles.

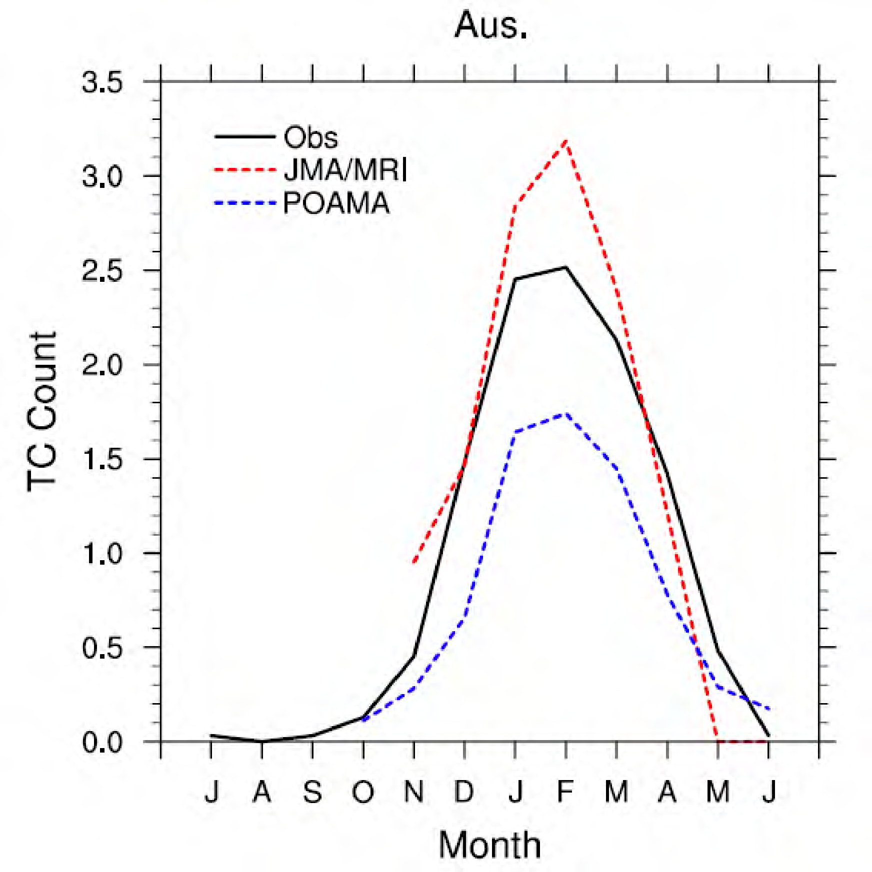
Tropical cyclone seasonal predictions

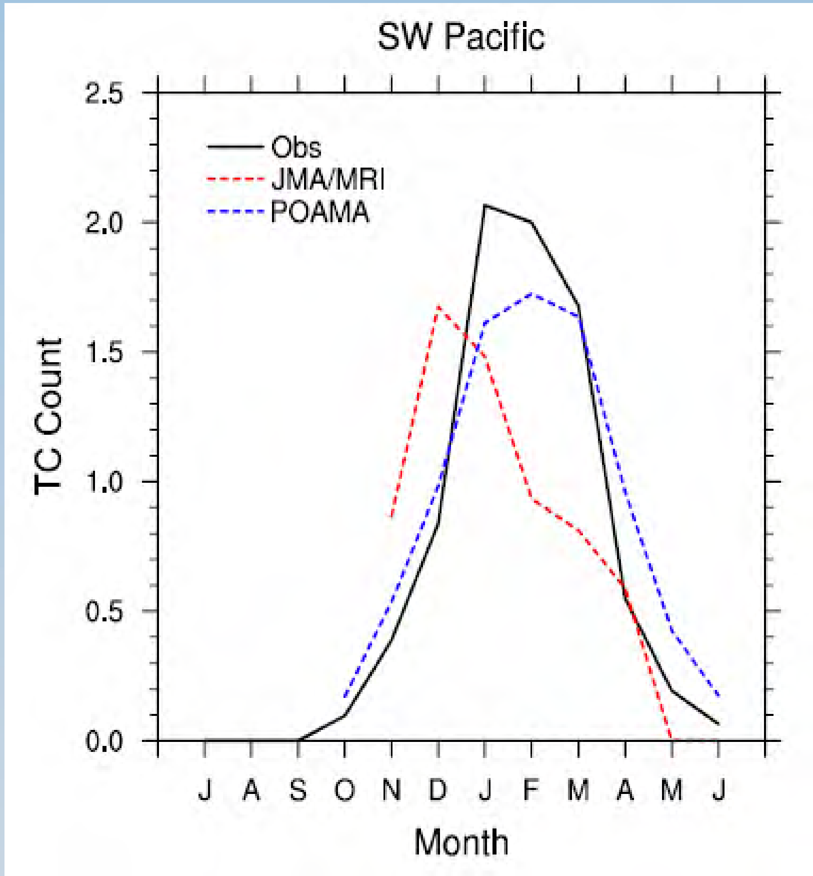




Time series of annual (NDJFMA) number of TCs in JMA/MRI-CGCM for the Australian (top panel) and South Pacific (bottom panel) regions. TC numbers are shown for observations (solid black line) and ensemble mean (dashed grey line). Ensemble members are shown as grey circles.

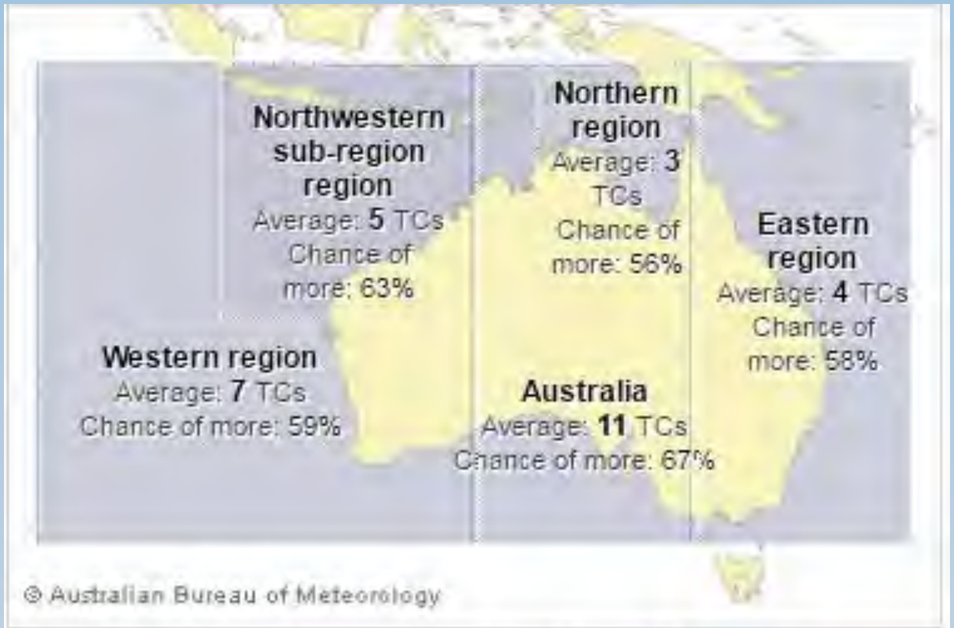
Tropical cyclone seasonal predictions





Climatological number of TCs as a function of month for observations (solid black line), POAMA (blue dashed line) and JMA/MRI-CGCM (red dashed line) in the Australian (left panel) and South Pacific Ocean (right panel) regions.

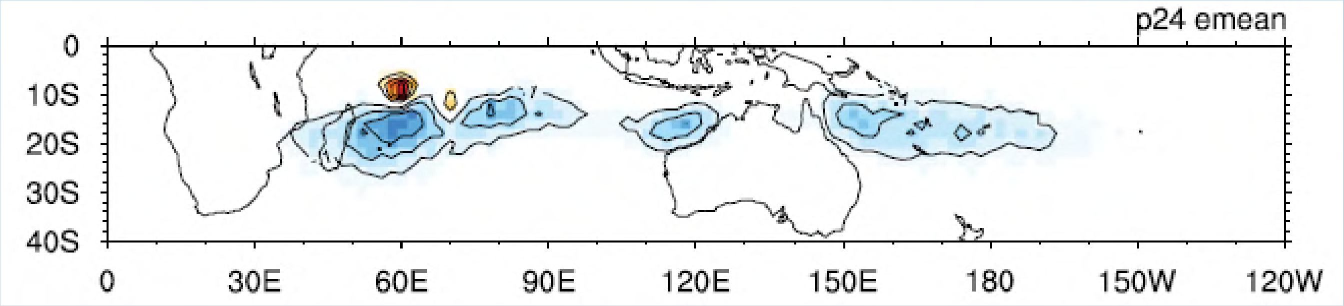
Tropical cyclone seasonal predictions



% Chance of more tropical cyclones than average

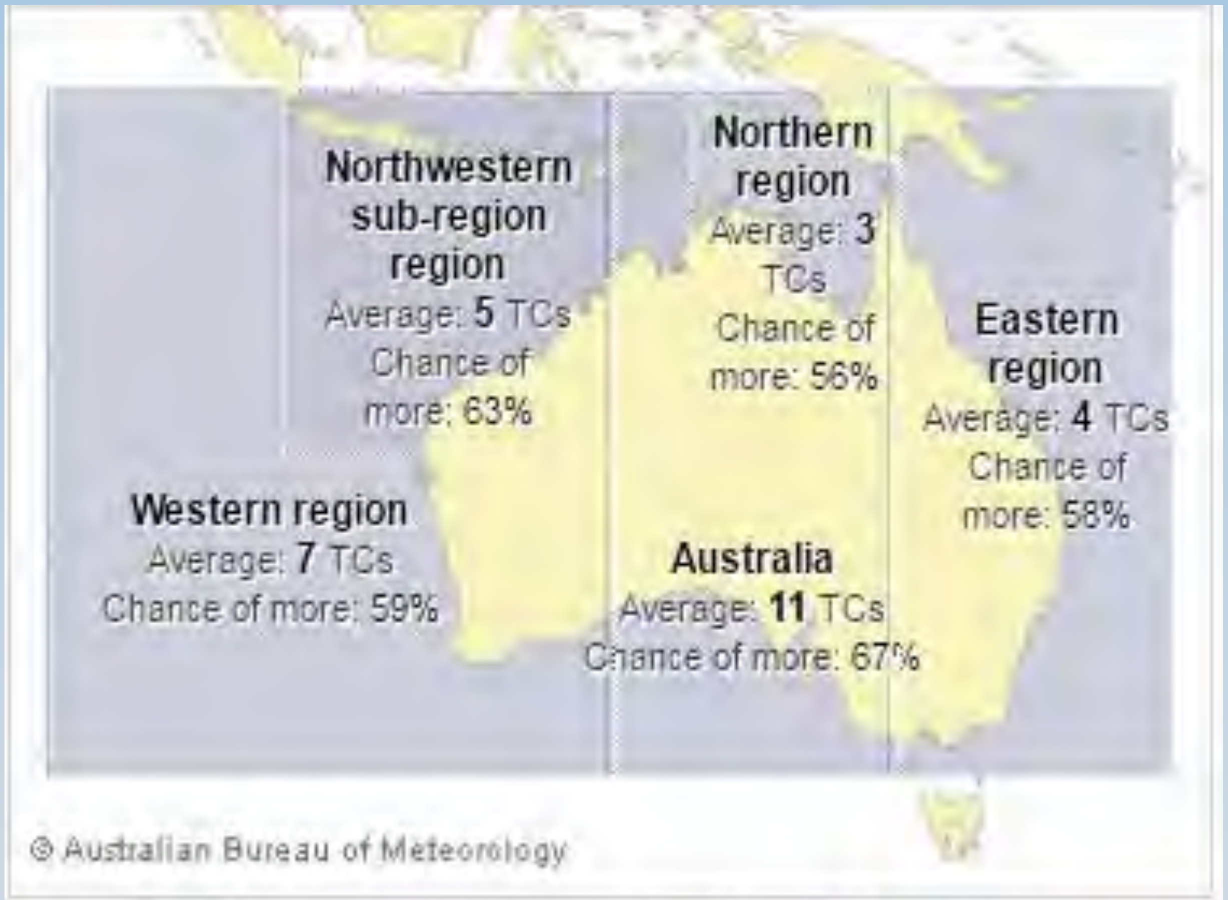
Based on climate model outputs, we could provide

- Regional probabilistic tropical cyclone predictions.
- Geographic distribution of tropical cyclone activity.



Australian Tropical Cyclone Outlook for 2016 to 2017

More cyclones than average likely for Australia



% Chance of more tropical cyclones than average

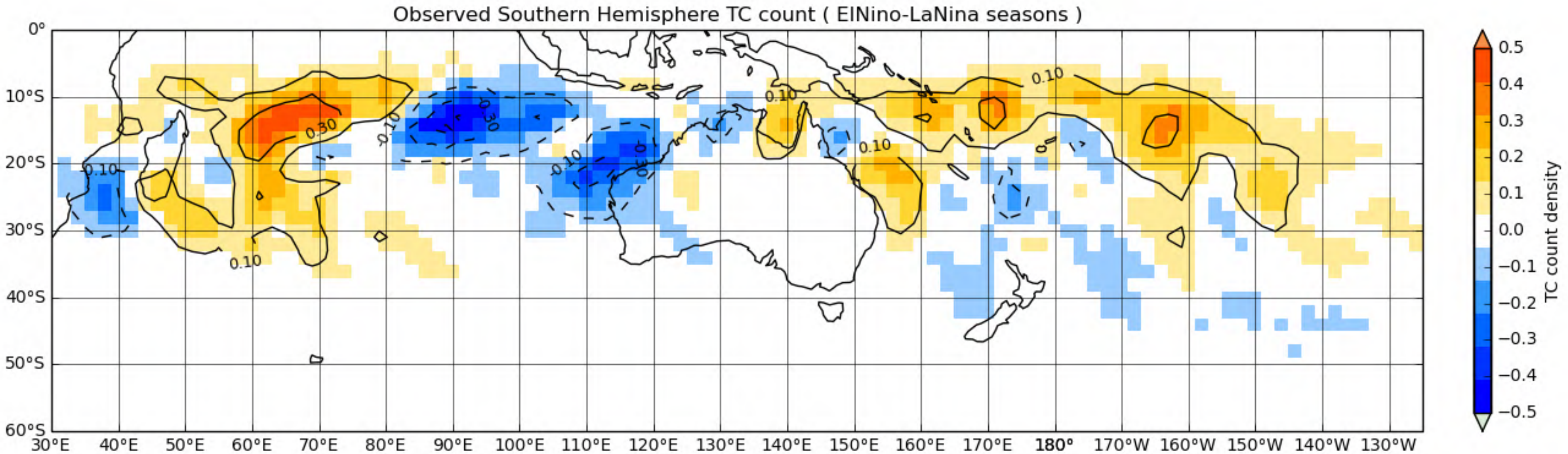
Australian Government
Bureau of Meteorology

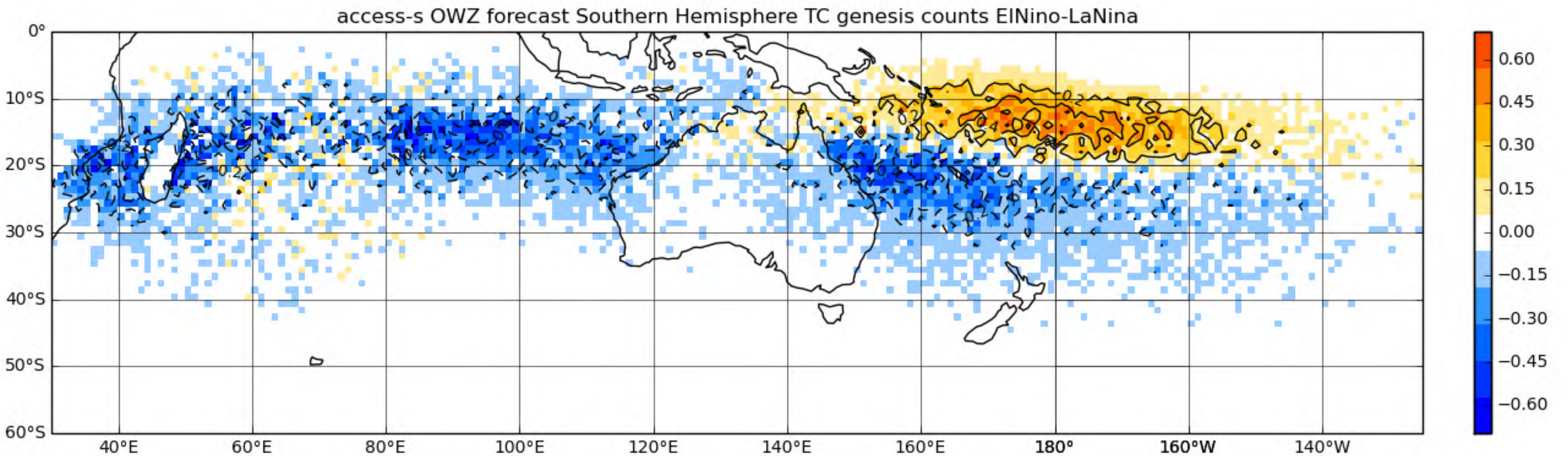
Australian Tropical Cyclone Outlook for 2016 to 2017

More cyclones than average likely for Australia

- An average to above-average number of cyclones are expected for the 2016–17 Australian tropical cyclone season (November–April).
- Neutral to weak La Niña conditions in the tropical Pacific Ocean and warmer than average ocean temperatures to the north and east of Australia have influenced this year's tropical cyclone outlook.
- During neutral years, the first tropical cyclone to make landfall typically occurs in late December. In La Niña years, the first cyclone to make landfall over Australia typically occurs earlier, around the first week of December.
- The Australian region typically experiences more tropical cyclone activity during La Niña years

TC seasonal predictions: ACCESS





Tropical cyclone seasonal prediction

- In summary, POAMA and JMA/MRI-CGCM both represent the large-scale environment relevant to TCs reasonably well, although possible deficiencies exist in the Australian region.
- The monthly TC climatologies in both models is reasonably realistic.
- Both models capture some of the interannual variability in the Australian region, although POAMA performs better in the South Pacific.
- Probabilistic NDJFMA TC number predictions both models, evaluated over the 31-year hindcast, show skill over random chance.
- With further development of dynamical climate models (e.g. ACCESS) and improving of their skill it is expected that both statistical and dynamical models will be used in operational TC seasonal prediction in the Australian and South Pacific regions, to complement each other.

Thank you

Tropical Cyclones in the western North Pacific

Lin, I.-I. and Chan, J. C. L. Recent decrease in typhoon destructive potential and global warming implications. *Nat. Commun.* 6:7182 doi: 10.1038/ncomms8182 (2015).