Global Ocean Monitoring: Recent Evolution, Current Status, and Predictions

Prepared by

Climate Prediction Center, NCEP/NOAA

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http://www.cpc.ncep.noaa.gov/products/GODAS/

This project, to deliver real-time ocean monitoring products, is implemented by CPC in cooperation with NOAA's Global Ocean Monitoring and Observing Program (GOMO)

Outline

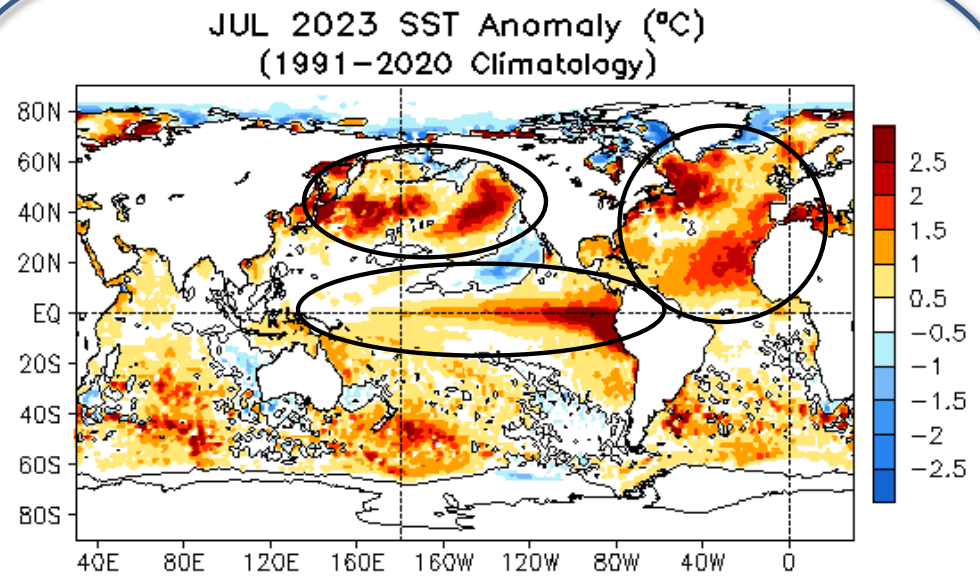
- Overview
- Recent highlights
  - Pacific Ocean
  - Arctic & Antarctic Oceans
  - Indian Ocean
  - Atlantic Ocean (NOAA Coral Watch)
- Global SSTA Predictions

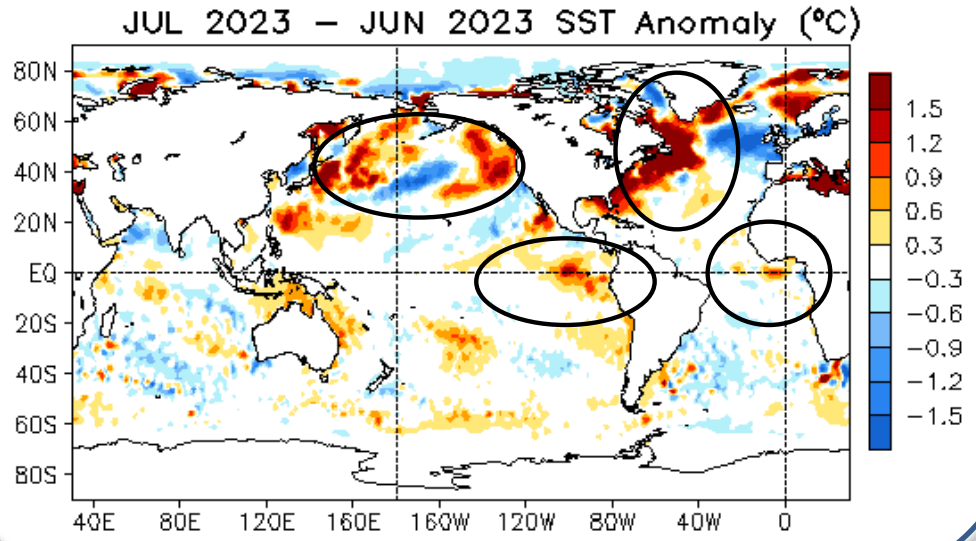
Overview

- Pacific Ocean
  - The warming in the central and eastern equatorial Pacific increased in Jul 2023 with Niño3.4 = 1.1^{o}C
  - A strong coastal El Niño has developed since Feb 2023 and continued to grow with Niño1+2= 3.3^{o}C in Jul 2023.
  - NOAA "ENSO Diagnostic Discussion" on 10 Aug 2023 stated "*El Niño is anticipated to continue through the Northern Hemisphere winter (with greater than 95% chance through December 2023 -February 2024)*".
  - The PDO has been in a negative phase since Jan 2020 with PDOI = -1.9 in Jul 2023.
  - Strong subsurface warming has persisted in the central north Pacific Ocean since 2020.
- Arctic and Antarctic Oceans
  - Average Arctic sea ice extent during Jul 2023 ranked the 12th lowest Jul in the satellite record.
  - Antarctic sea ice extent continues to track at historical low values.
- Indian Ocean
  - Positive SSTA dominated most of the tropical Indian Ocean in Jul 2023.
- Atlantic Ocean
  - SST warming during Jun-Jul 2023 hit the historical high of the same season since 1982.
  - Hurricane activity was relatively quiet in Jul 2023.
  - Ongoing mass marine heatwave starting in June/July 2023 caused mass coral bleaching in Caribbean, Gulf of Mexico, and Florida Keys.

Global Oceans

Global SST Anomaly (°C) and Anomaly Tendency



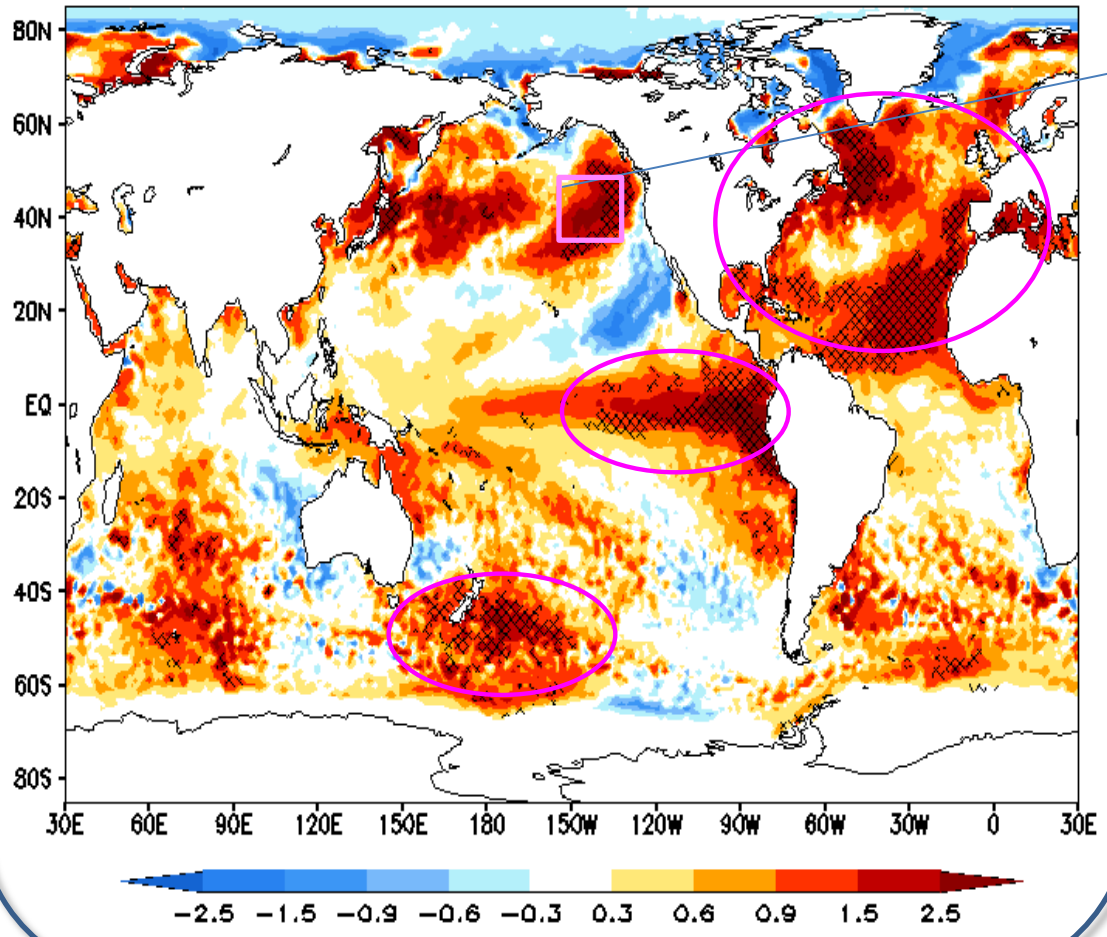


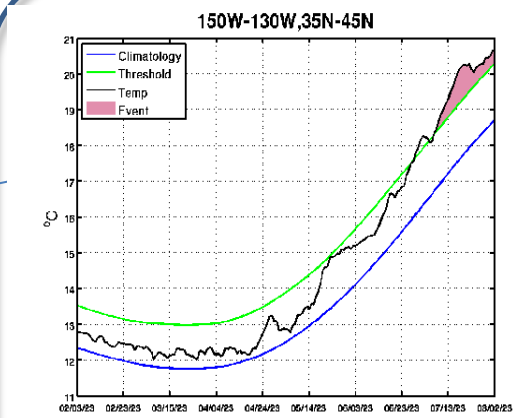
- SSTs were above average across most of the equatorial Pacific Ocean.
- The coastal El Niño continued to grow in Jul 2023.
- Strong positive SSTAs were persisted in the North Pacific and the the eastern North Atlantic Ocean.

- Large SSTA tendencies were present in the mid-high latitudes of North Pacific Ocean.
-Strong positive SSTA tendencies were observed along the east coast of North America.
-Positive SSTA tendencies were present in the eastern equatorial Pacific Ocean.

SSTAs (top) and SSTA tendency (bottom). Data are derived from the OIv2.1 SST analysis, and anomalies are departures from the 1991-2020 base period means.

Global Monthly SST anomaly and Marine Heat Waves

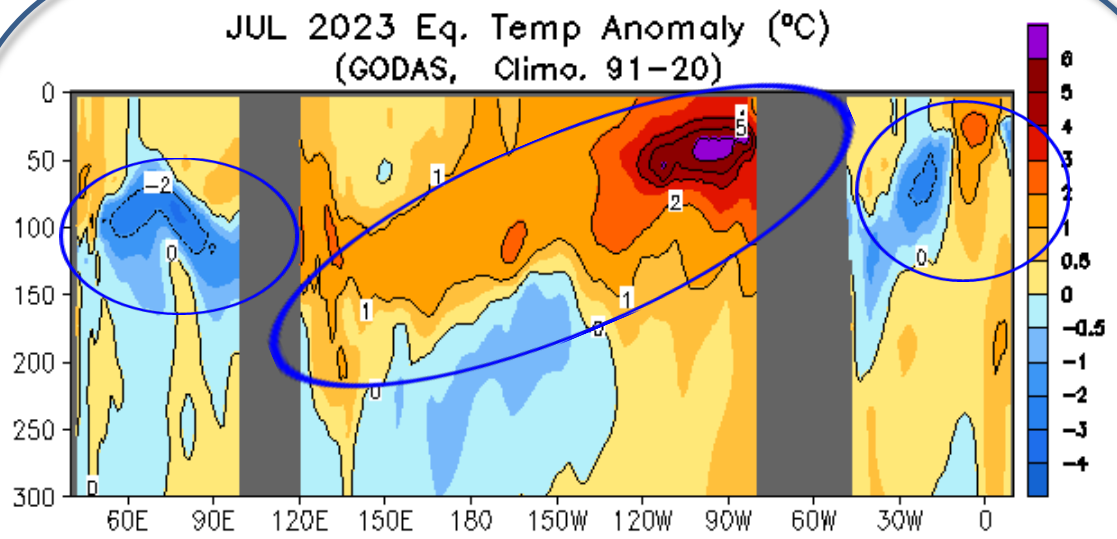


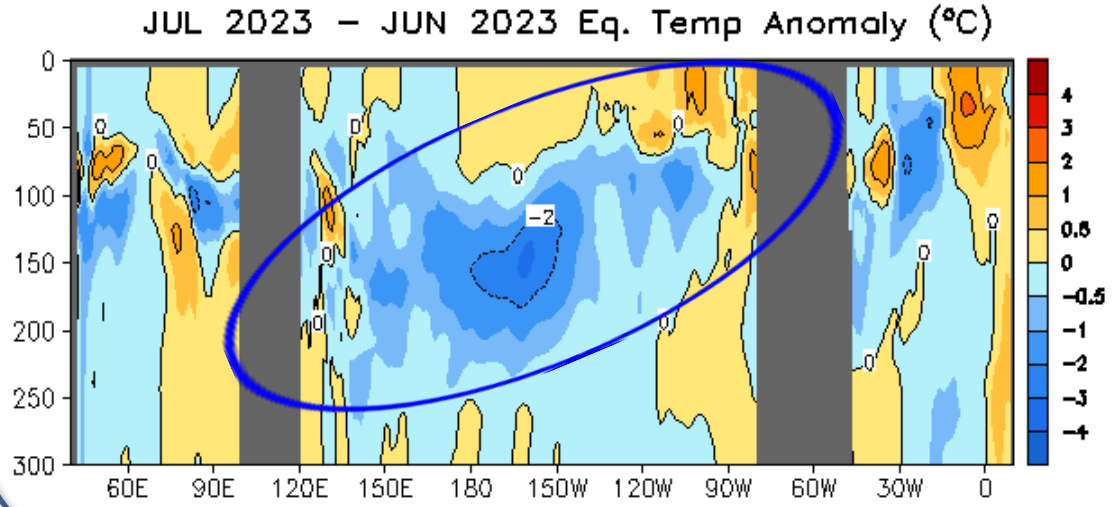


- MHWs were observed in the Northeast Pacific, eastern equatorial Pacific , Southwest Pacific near New Zealand, Northeast Atlantic, Gulf of Mexico and Labrador basin.

((Left panel) Monthly SST anomaly (shaded) and locations experiencing marine heat waves (hatched) by the end date labelled in the plot. (right panel) SST evolution at a specific location. Green line and blue line are the 90th percentile and daily climatology, respectively. Shaded area denotes the periods experiencing MHW. MHW is defined as a prolonged warming exceeding 90th percentile of daily SST for at least 14 consecutive days. Data is derived from NCEI OISSTv2.1 and the reference period is 1991-2020

Longitude-Depth Temperature Anomaly and Anomaly Tendency in 2°S-2°N





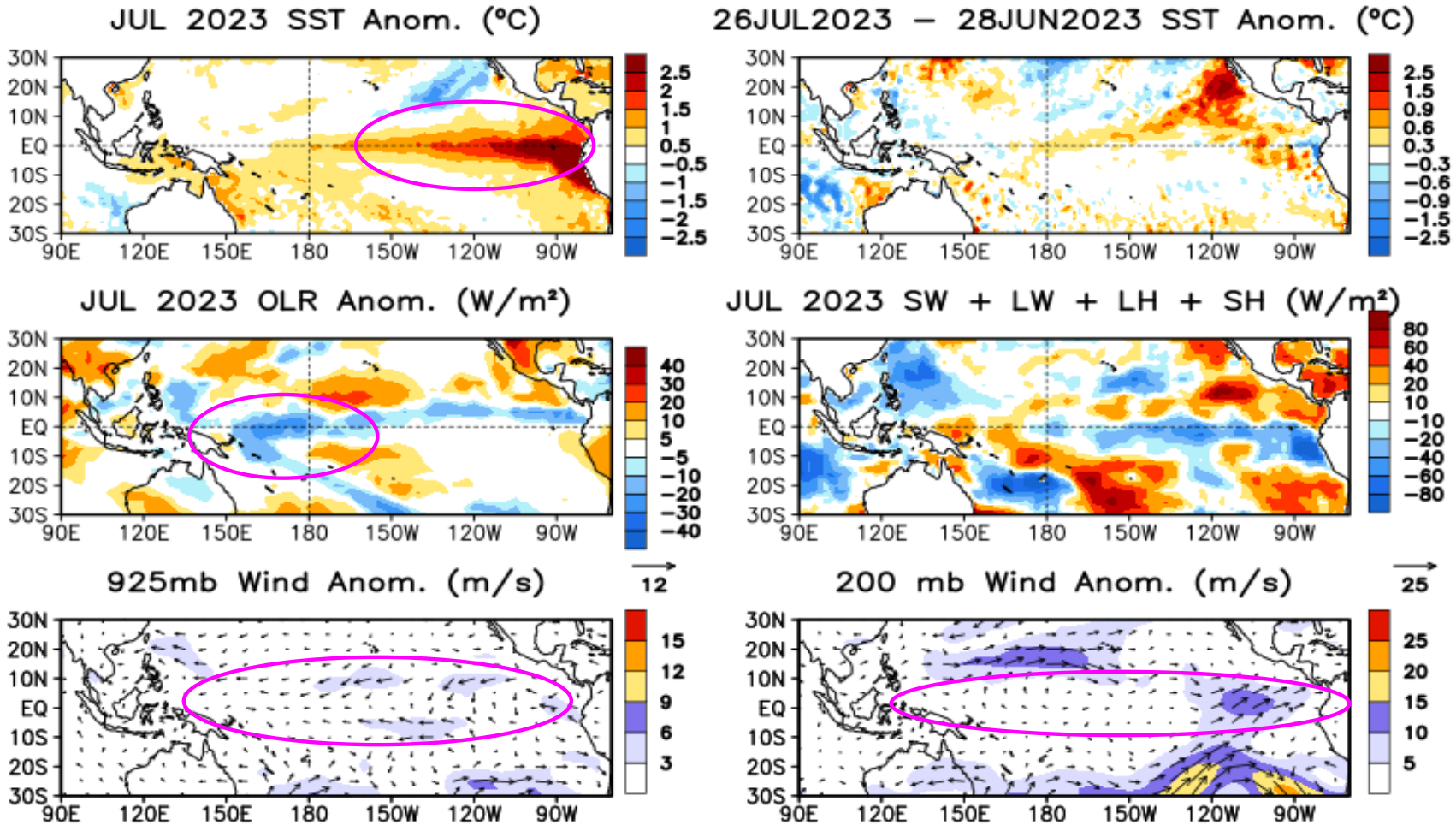
- Positive temperature anomalies were present along the thermocline in the Pacific.
- Negative temperature anomalies dominated the upper 50-150m of the Indian Ocean.
- Negative (positive) temperature anomaly was present near the western (eastern) thermocline in the Atlantic Ocean.

- Temperature anomaly tendency was negative (positive) along the thermocline in the western-central (far eastern) Pacific.

Equatorial depth-longitude section of ocean temperature anomalies (top) and anomaly tendency (bottom). Data is from the NCEP's GODAS. Anomalies are departures from the 1991-2020 base period means.

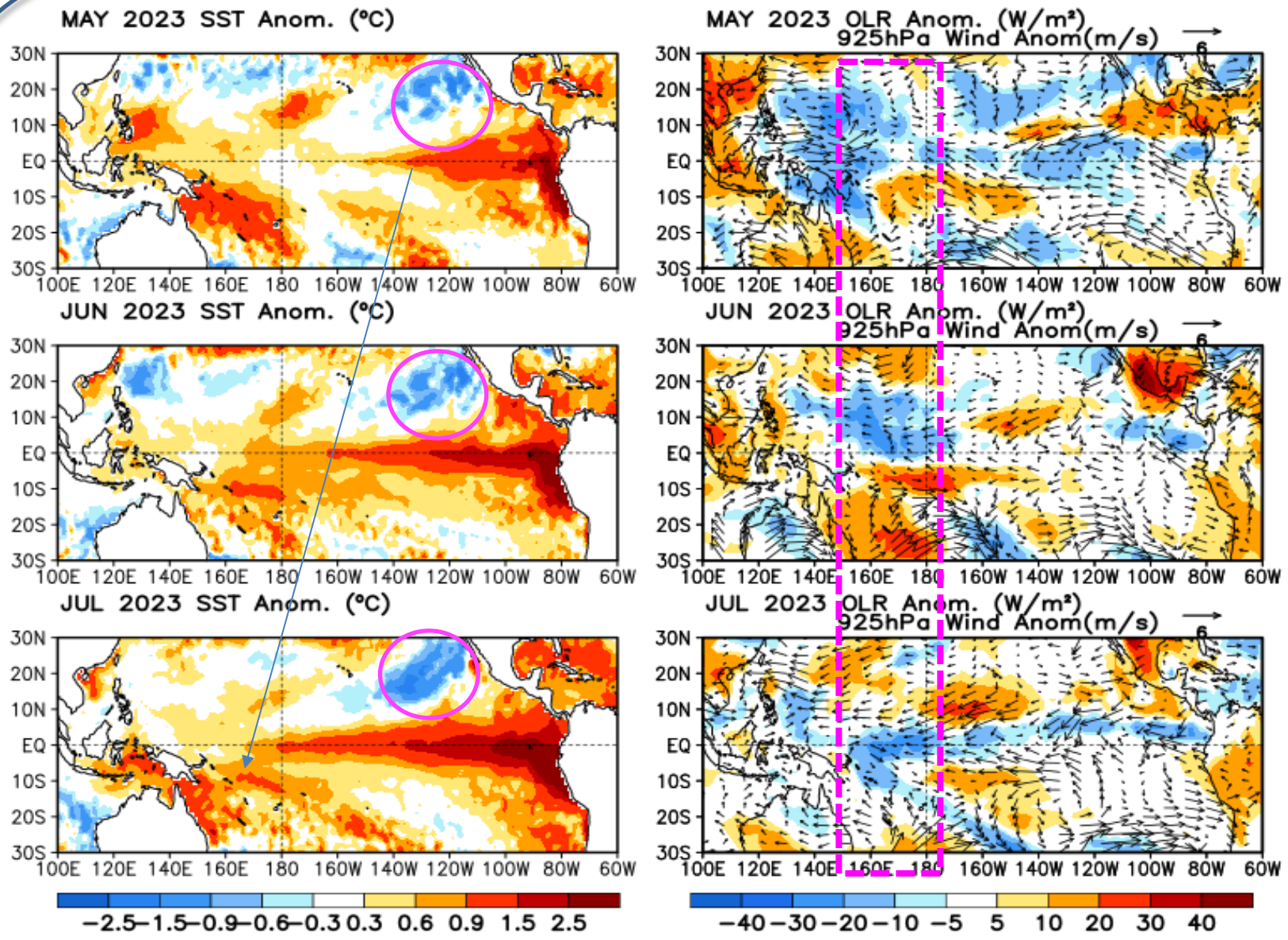
Tropical Pacific Ocean and ENSO Conditions

Tropical Pacific: SSTA, SSTA Tend., OLR, Sfc Rad, Sfc Flx, 925-mb & 200-mb Winds

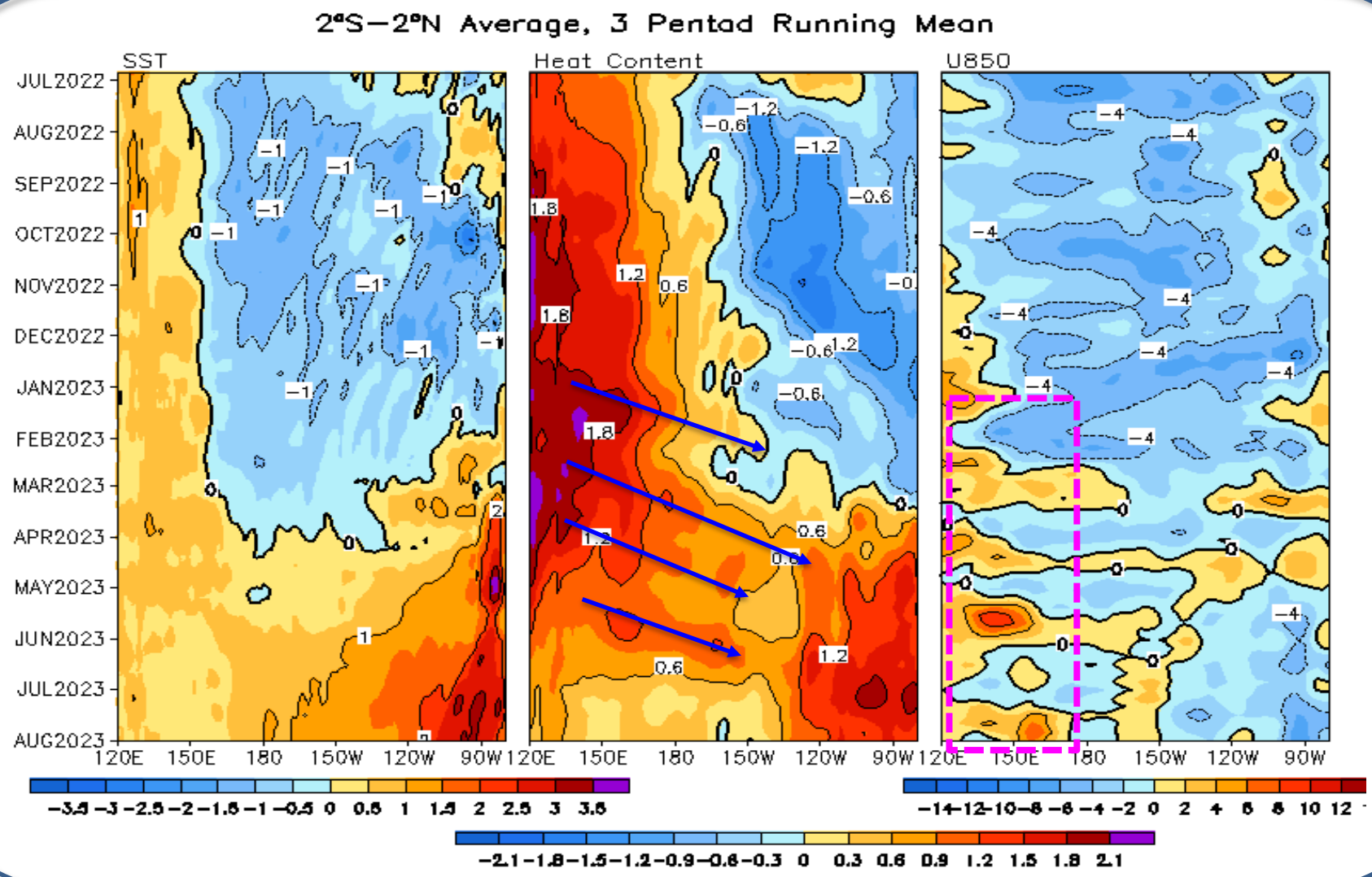


SSTAs (top-left), SSTA tendency (top-right), Outgoing Long-wave Radiation (OLR) anomalies (middle-left), sum of net surface short- and long-wave radiation, latent and sensible heat flux anomalies (middle-right; positive means heat into the ocean), 925-mb wind anomaly vector and its amplitude (bottom-left), 200-mb wind anomaly vector and its amplitude (bottom-right). SST are derived from the OIv2.1 SST analysis, OLR from the NOAA 18 AVHRR IR window channel measurements by NESDIS, winds and surface radiation and heat fluxes from the NCEP CDAS. Anomalies are departures from the 1991-2020 base period means.

Westward Expansion & Evolution of Coastal El Niño



Equatorial Pacific SST (°C), HC300 (°C), u850 (m/s) Anomalies

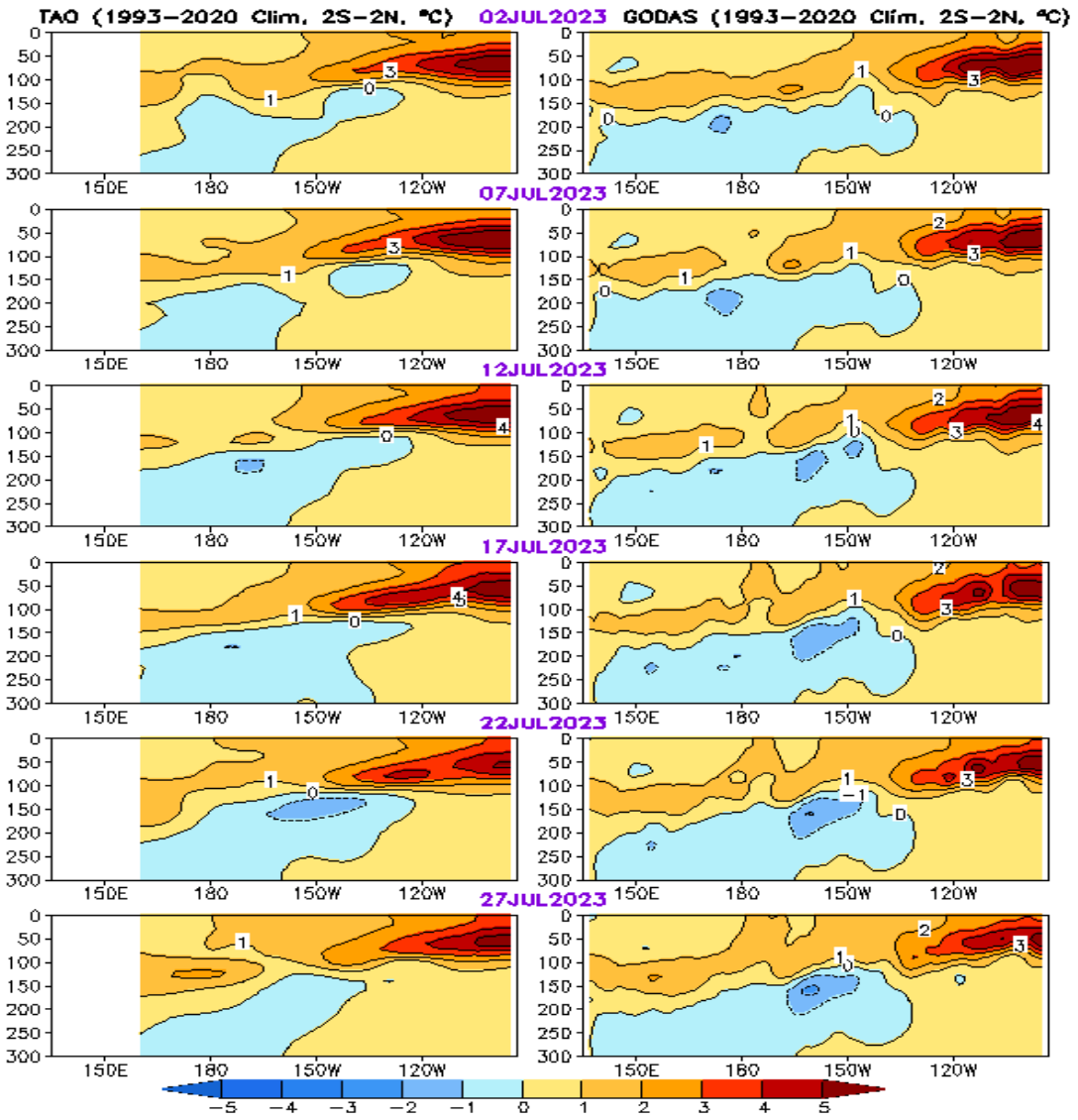


-Since Feb 2023, a set of westerly wind surges triggered downwelling Kelvin waves, helping to reinforce the subsurface warming in the central-eastern Pacific.

- Positive SST anomalies continued to strengthen and expanded westward.

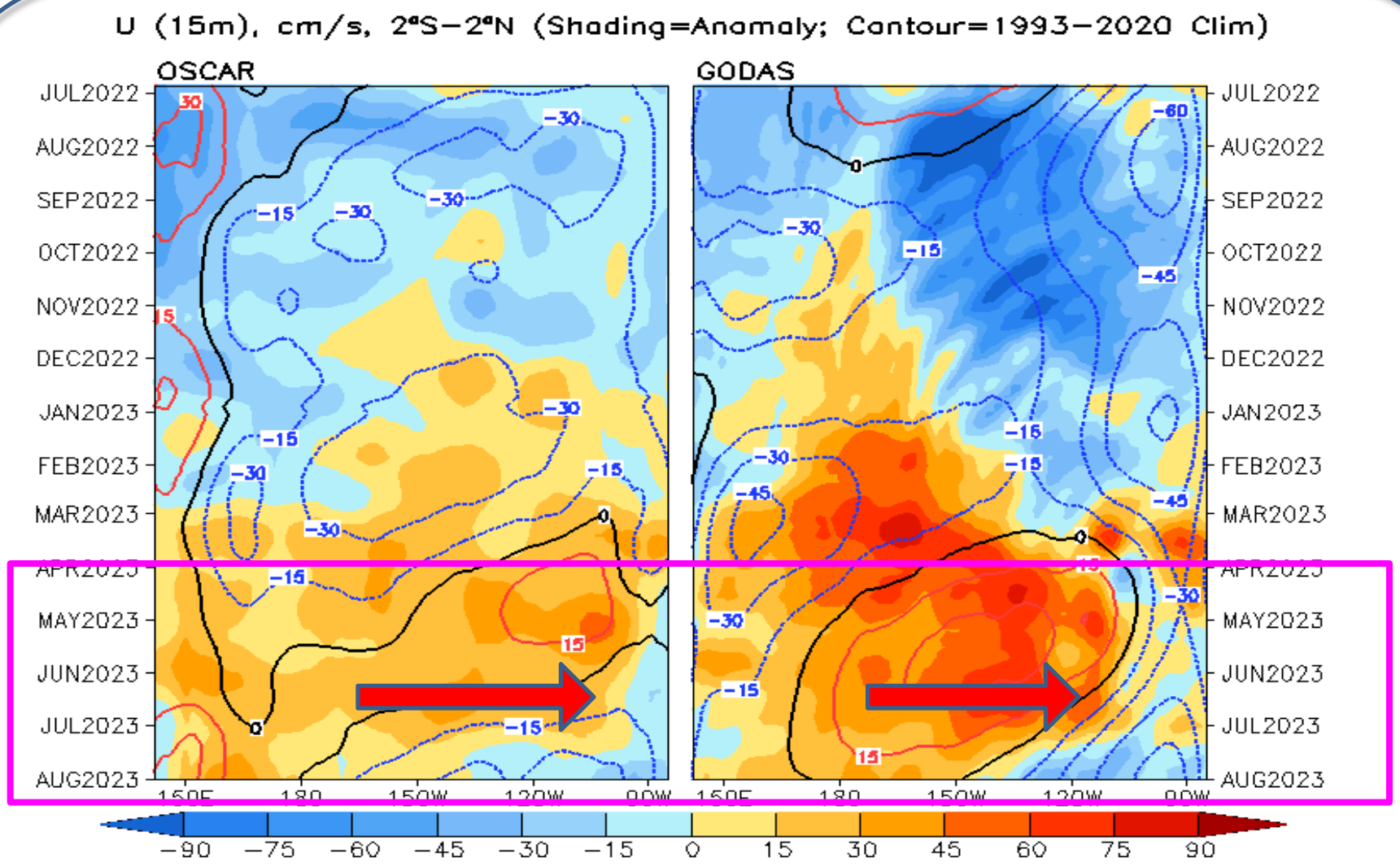
Equatorial Pacific Ocean Temperature Pentad Mean Anomaly

TAO GODAS



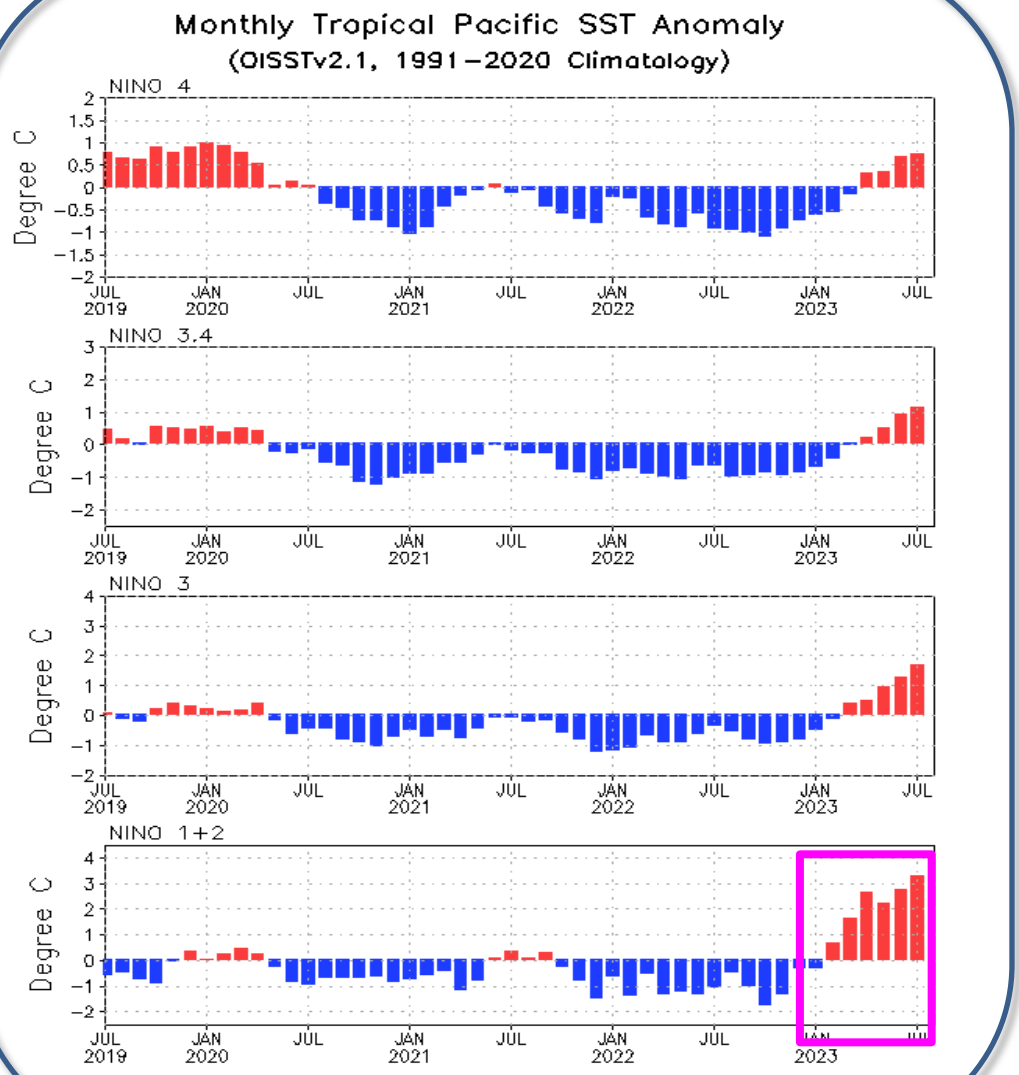
- Subsurface temperatures were warmer than average in the upper 100m.
- Strong positive temperature anomaly persisted in the far eastern Pacific.
- Negative temperature anomaly were present near the thermocline in the central-eastern Pacific.
- The features of the ocean temperature anomalies were similar between GODAS (model based) and TAO (objective) analysis.

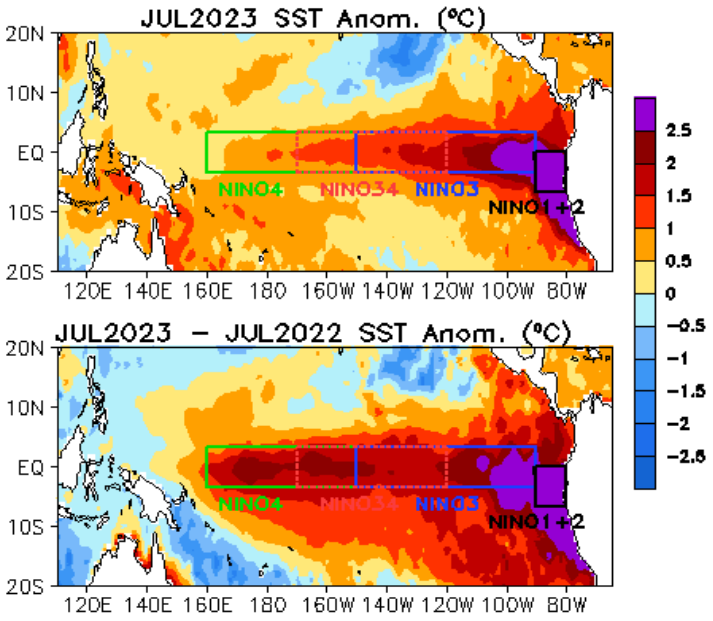
Evolution of Equatorial Pacific Surface Zonal Current Anomaly (cm/s)



- Anomalous eastward currents were present in the equatorial Pacific in both OSCAR and GODAS since Feb 2023, which were consistent with the growth of the positive SSTA.

Evolution of Pacific Niño SST Indices





- All Niño indices strengthened in Jul 2023, with Niño3.4 = 1.1°C.

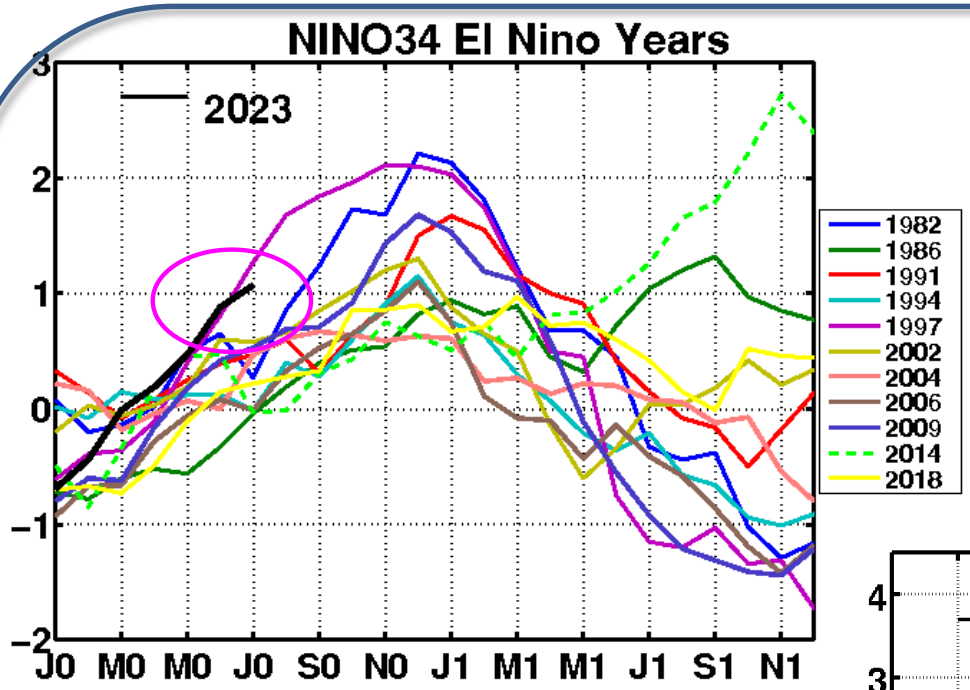
- A coastal El Niño has developed since Feb 2023 and continued to grow with Niño1+2= 3.3°C in Jul 2023.

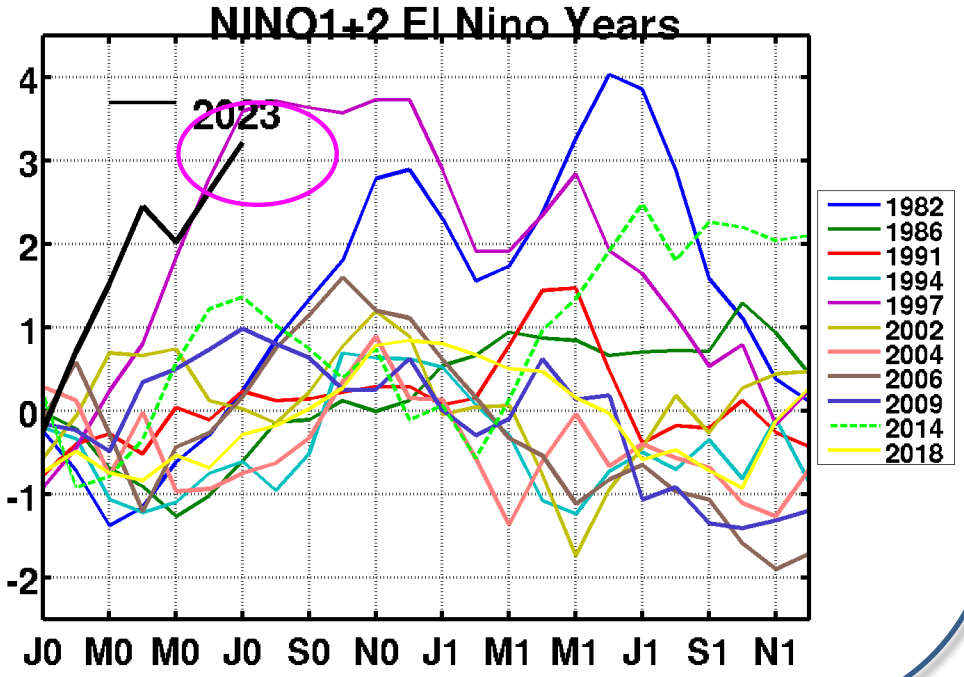
- Compared with Jul 2022, the tropical Pacific was much warmer in Jul 2023.

- The indices may have differences if based on different SST products.

Niño region indices, calculated as the area-averaged monthly mean SSTAs (°C) for the specified region. Data are derived from the OIv2.1 SST analysis, and anomalies are departures from the 1991-2020 base period means.

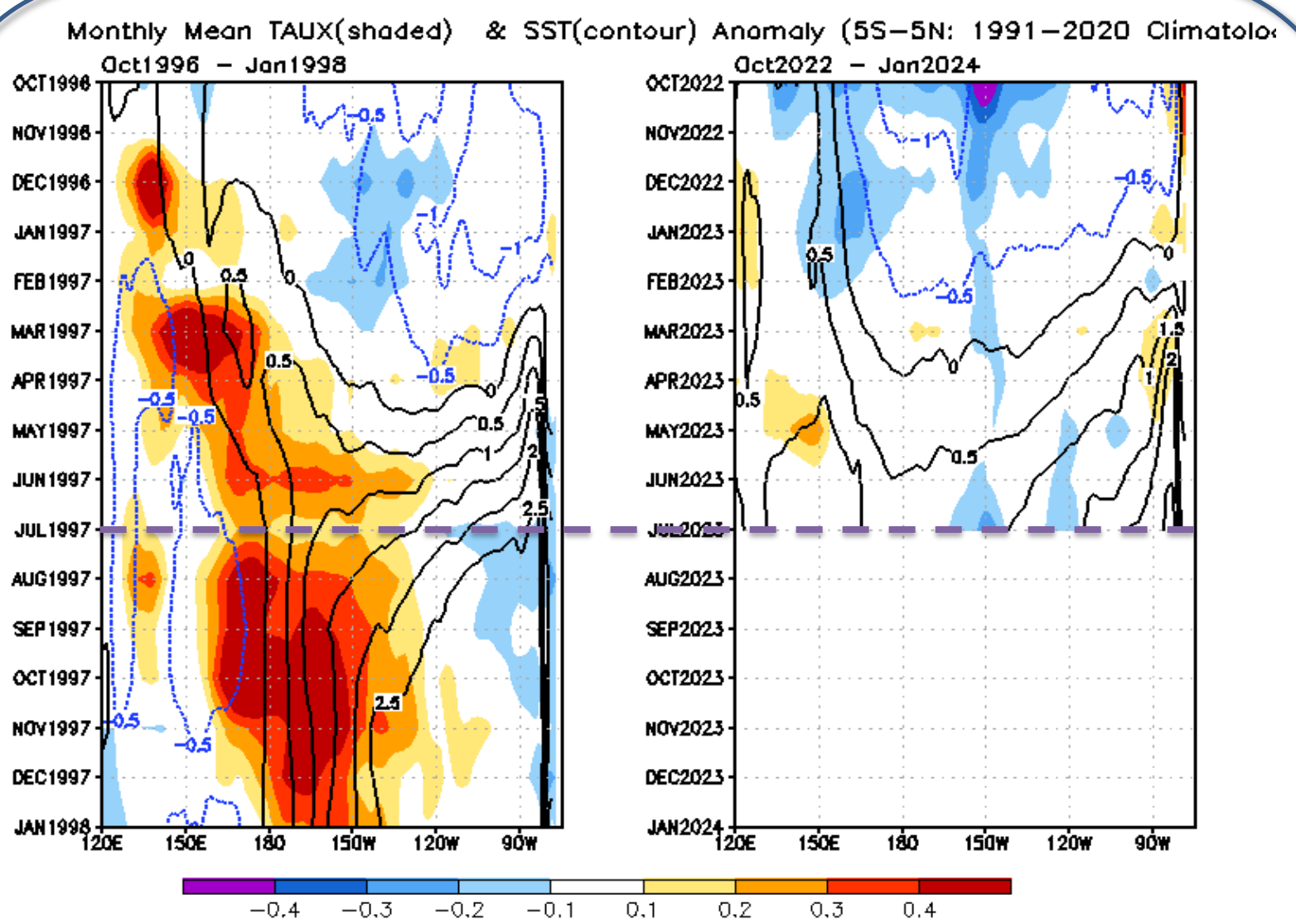
Evolution of NINO34 & NINO1+2 in El Niño Years





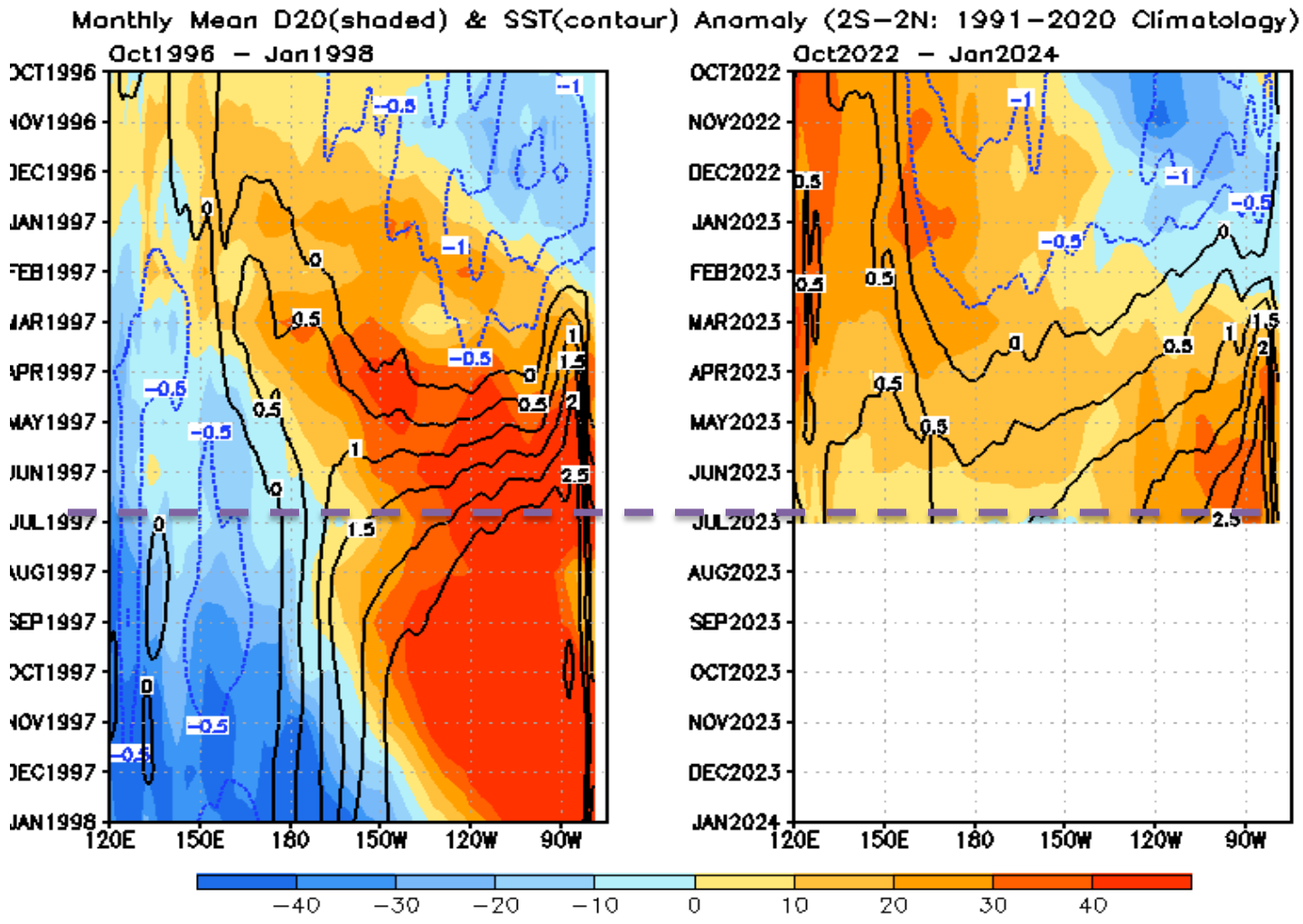
Nino 34 iand NINO1+2ndex is derived from the NCEP OI SST analysis, and anomalies are departures from the 1991-2020 base period means

Evolution of Monthly Mean Zonal Wind Stress Anomaly across [5S-5N]



Data source: NCEP R2 reanalysis

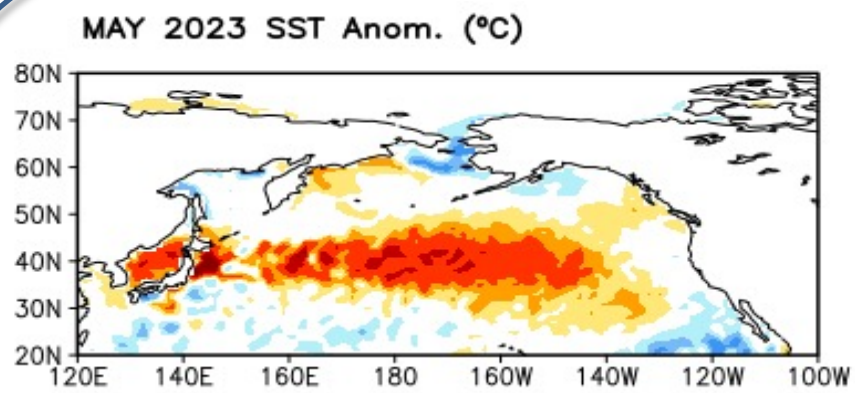
Evolution of Monthly Mean D20 Anomaly across [2S-2N]

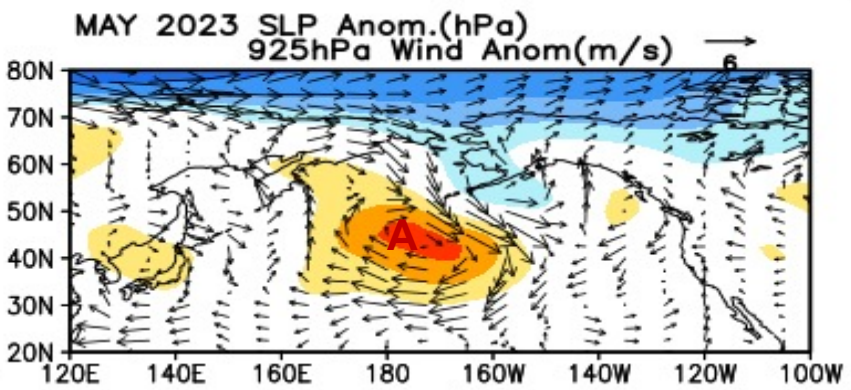


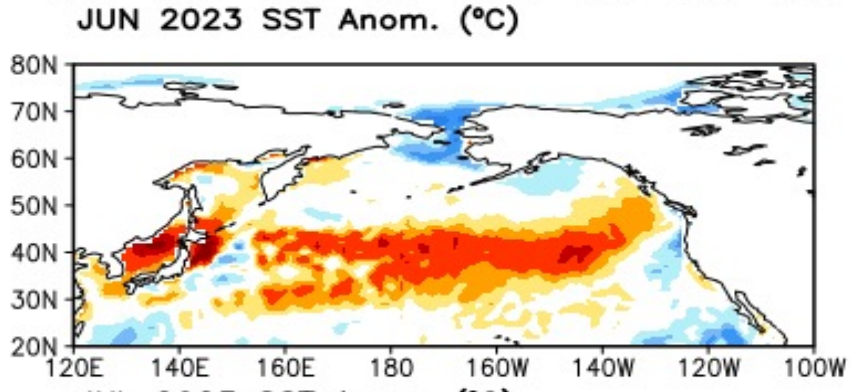
Data source: NCEP GODAS

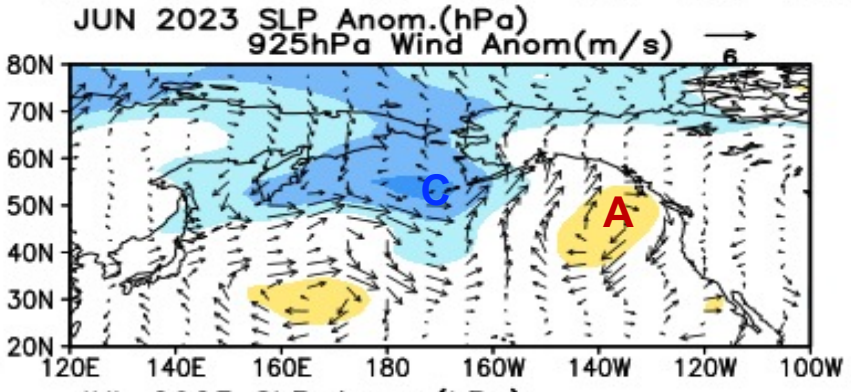
North Pacific & Arctic Oceans

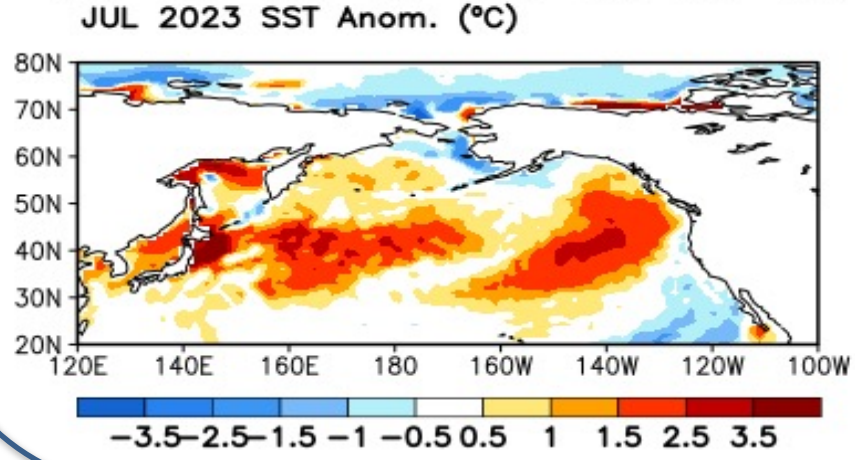
Last 3- month North Pacific SST, SLP, and uv925 anomalies

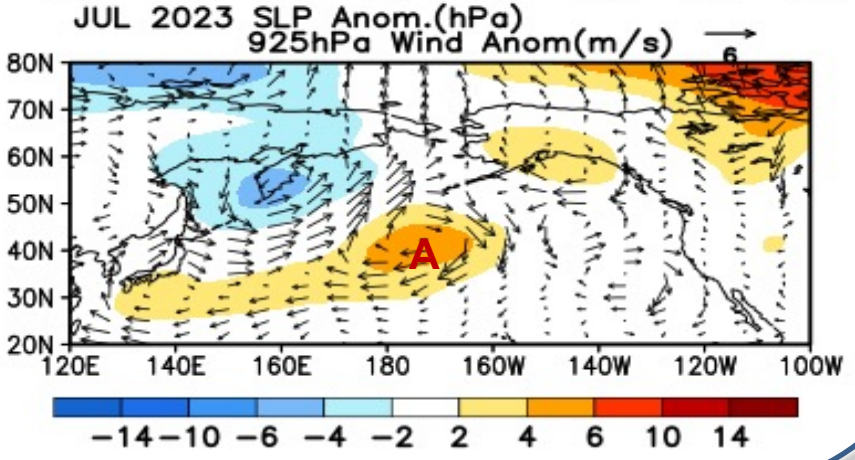




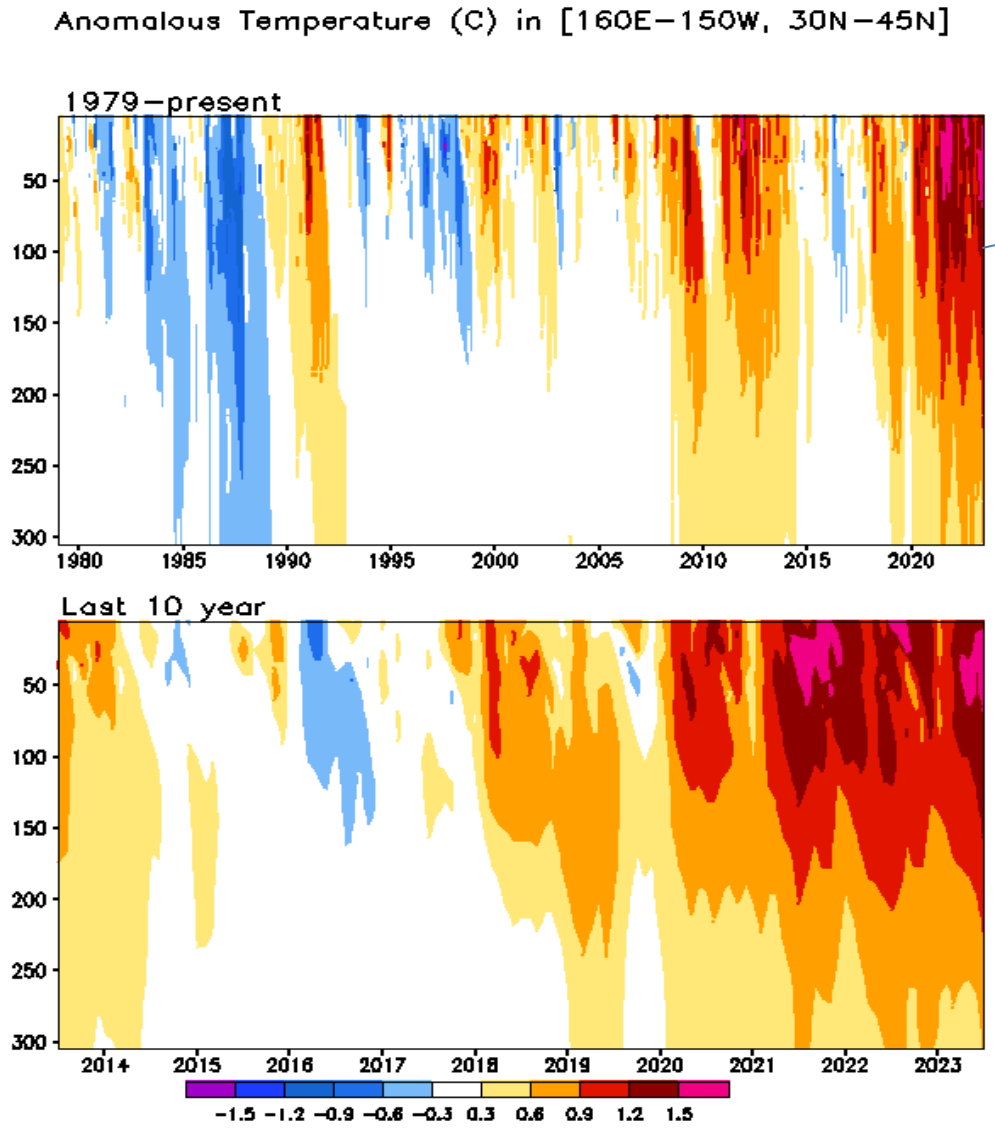


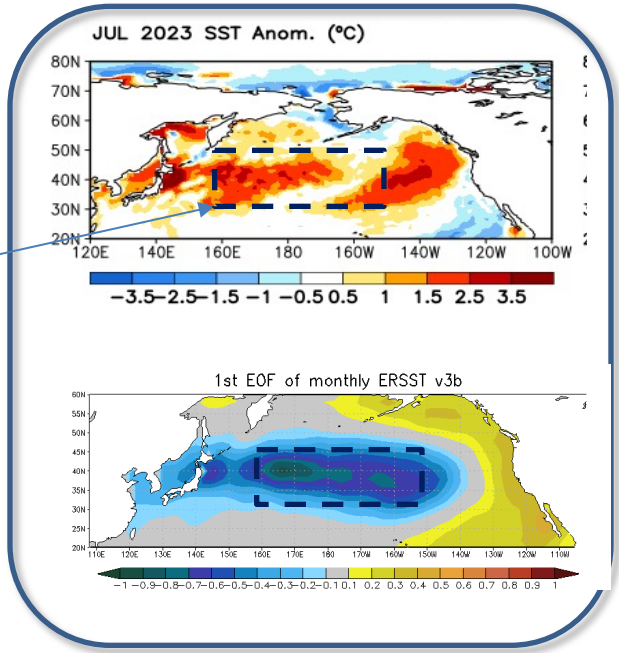






Subsurface Temperature Anomaly in the Northcentral Pacific

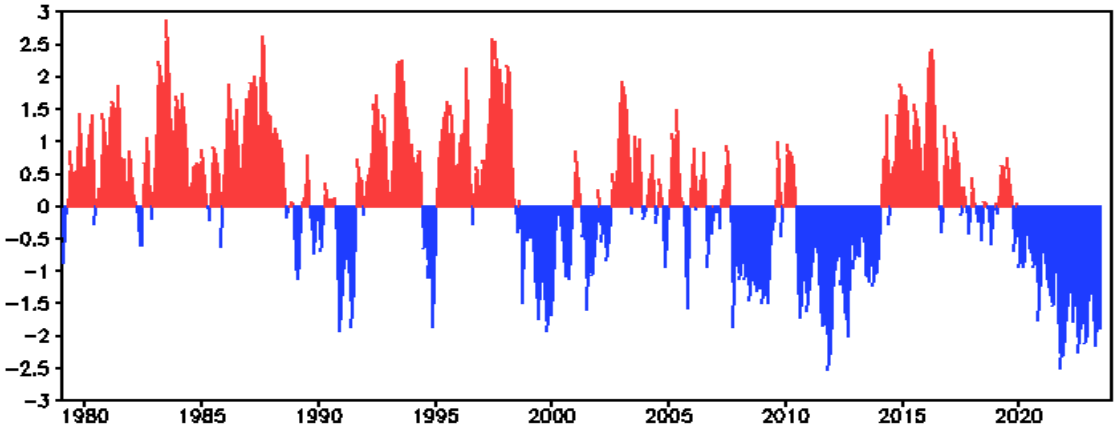




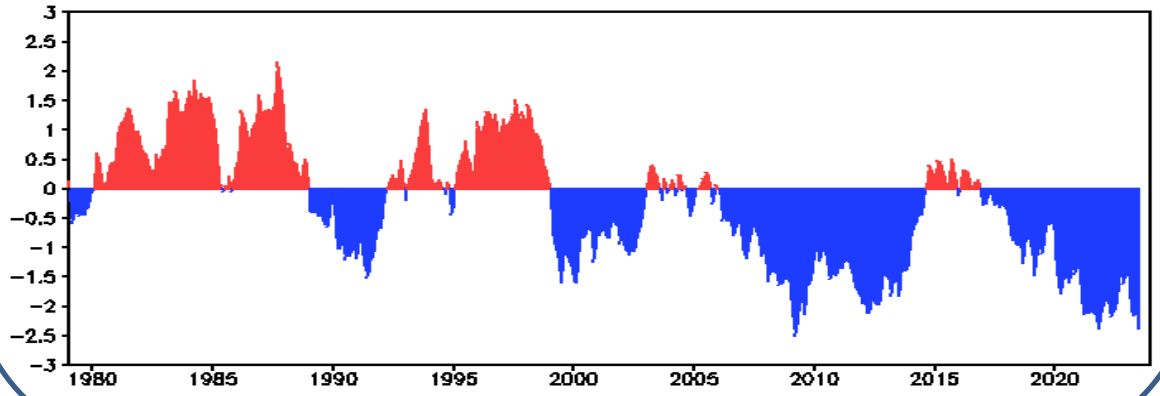
- Positive temperature anomaly (>0.9ºC) penetrated to 100m and persisted since 2020.
- Subsurface warming in the last three years is the strongest event since 1979.

Two Oceanic PDO indices

SST-based PDO (Wen et al. 2014: GRL)



H300-based PDO (Arun and Wen 2016:Mon.Wea.Rev.)



- The negative phase of PDO has persisted since Jan 2020 with PDOI = -1.9. in Jul 2023.

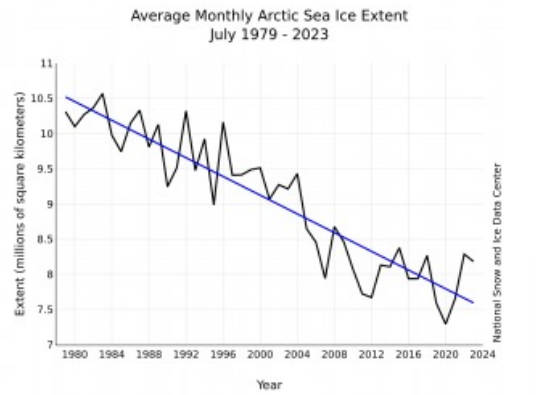
- Negative H300-based PDO index has persisted since Nov 2016, with HPDO = - 2.4 in Jul 2023.

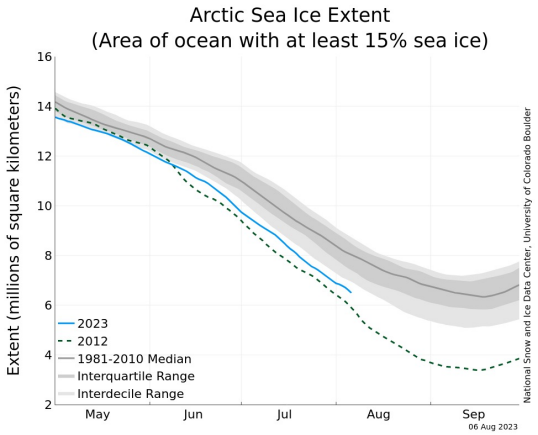
- SST-based PDO index has considerable variability both on seasonal and decadal time scales.

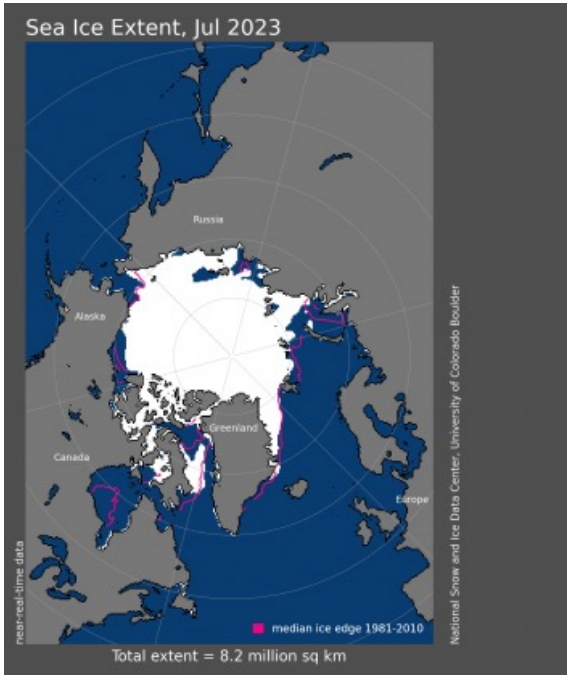
- H300-based PDO index highlights the slower variability and encapsulates an integrated view of temperature variability in the upper ocean.

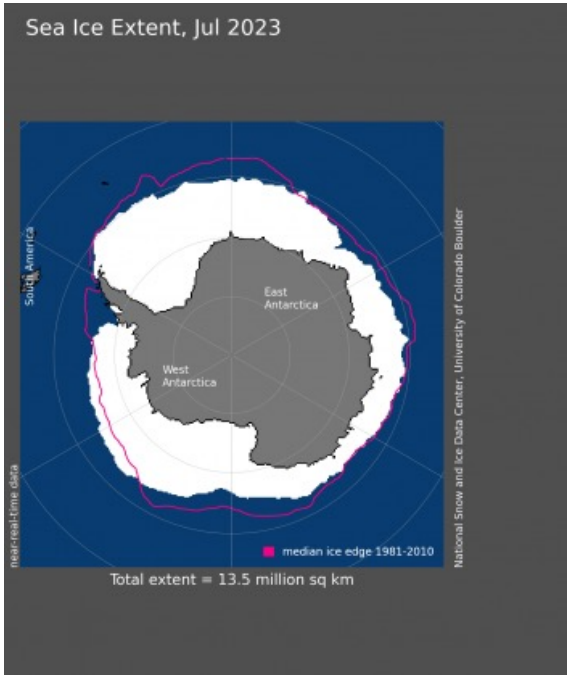
SST-based PDO is defined as the 1st EOF of monthly ERSST v3b in the North Pacific for the period 1900-1993. PDO index is the standardized projection of the monthly ERSSTv5 SST anomalies onto the 1st EOF pattern. H300-based Pacific Decadal Oscillation is defined as the projection of monthly mean H300 anomalies from NCEP GODAS onto their first EOF vector in the North Pacific. PDO indices are downloadable from https://www.cpc.ncep.noaa.gov/products/GODAS/ocean_briefing.shtml.

Sea Ice; NSIDC (https://nsidc.org/arcticseaicenews/)





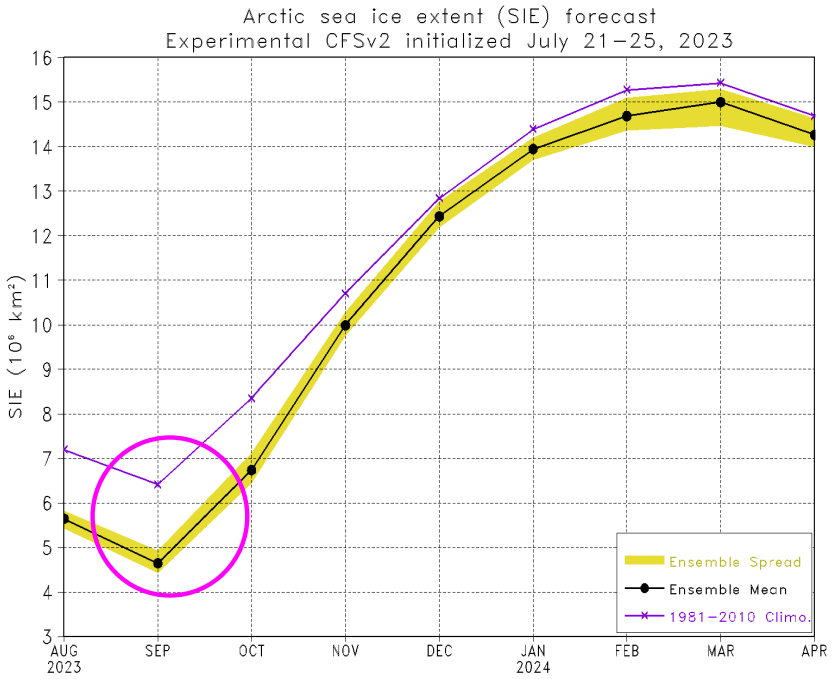




- Average Arctic sea ice extent during Jul 2023 was 8.18 million square kilometers, the 12th lowest Jul in the satellite record.
- Antarctic sea ice extent is continuing to track at extreme record low levels at record low levels since 1979.

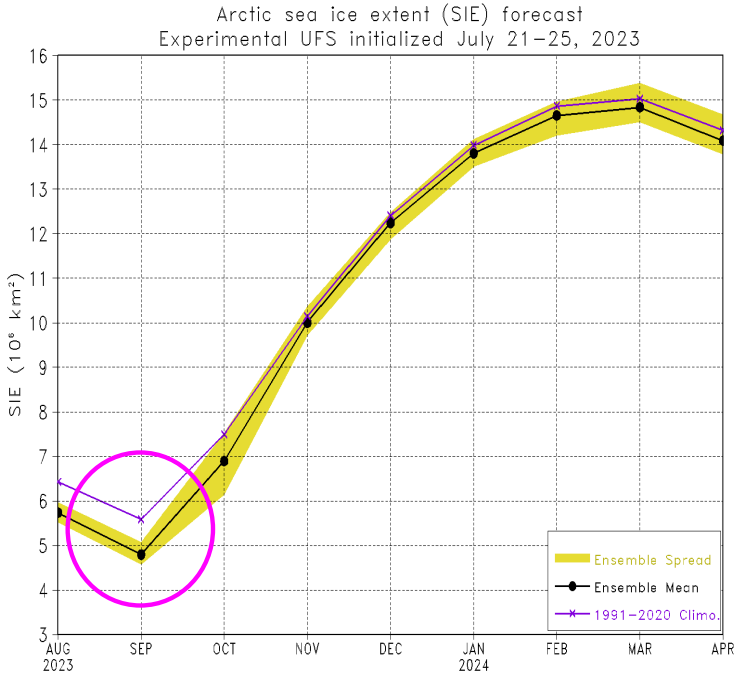
NCEP/CPC Arctic Sea Ice Extent (SIE) Forecast

CFSm5



https://www.cpc.ncep.noaa.gov/products/people/wwang/seaice_seasonal/index.html

UFS

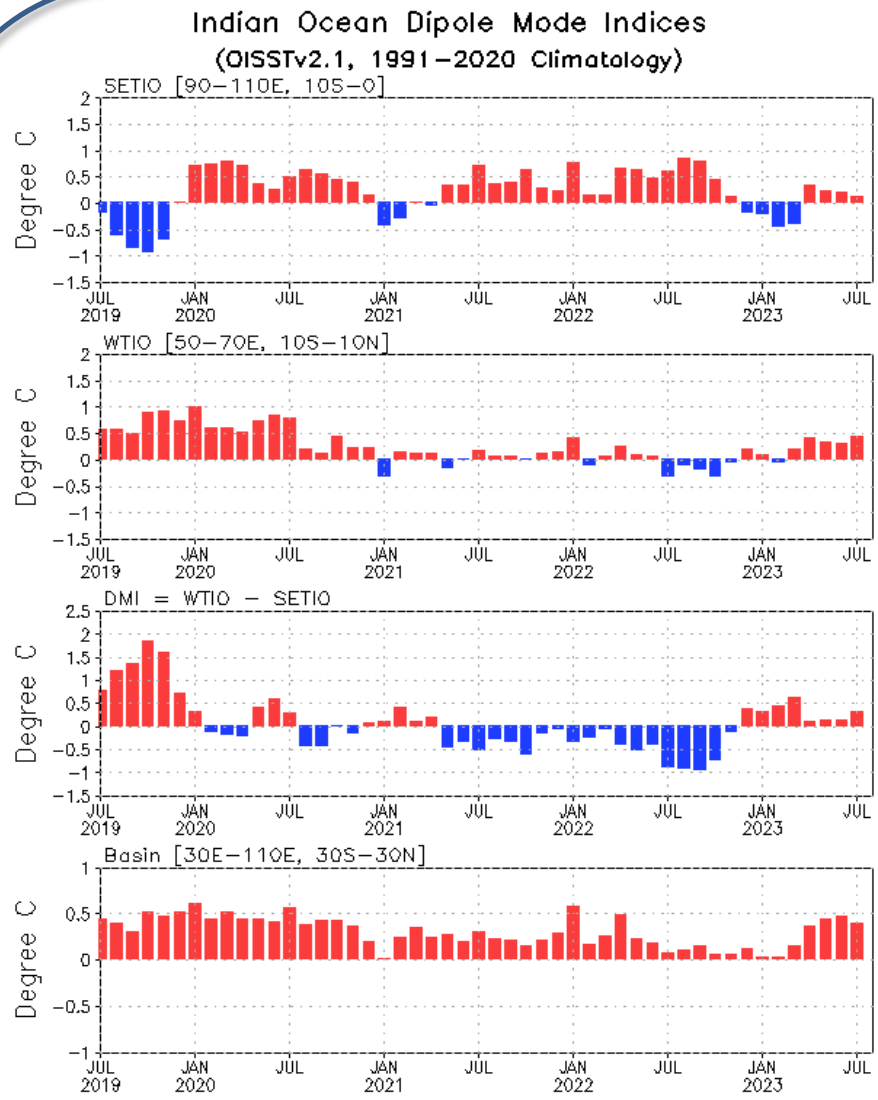


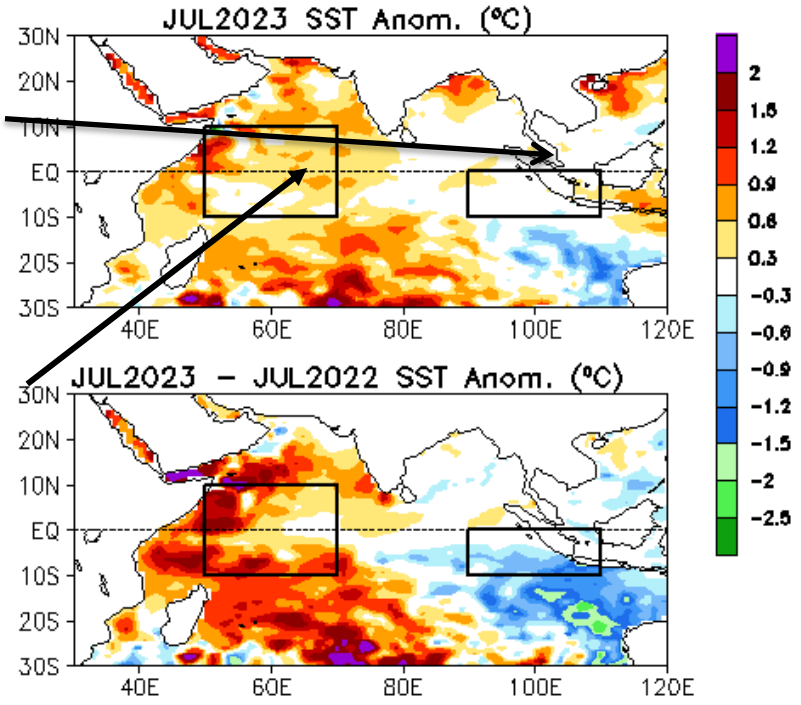
https://www.cpc.ncep.noaa.gov/products/people/jszhu/seaice_seasonal/index.html

- Both CFSm5 and UFS forecasts suggest SIE will be around 5 million square kilometers in Sep 2023.

Indian Ocean

Evolution of Indian Ocean SST Indices



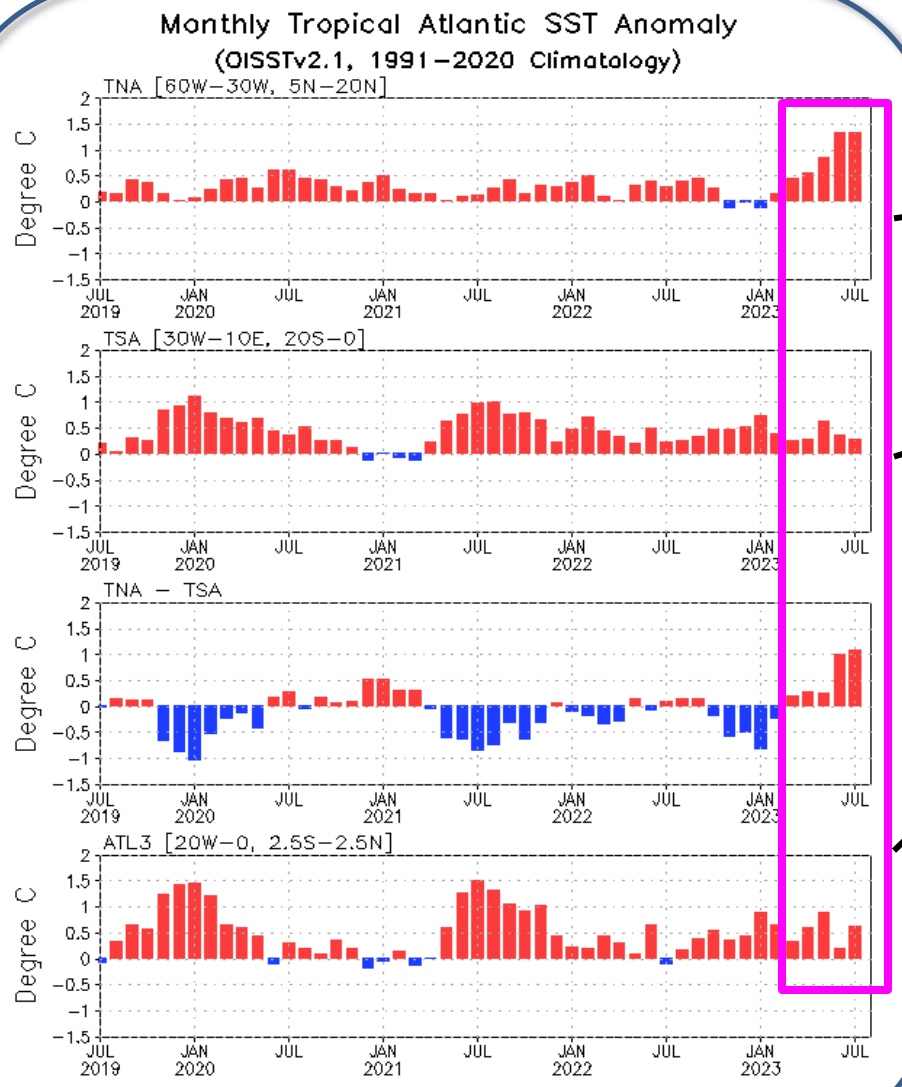


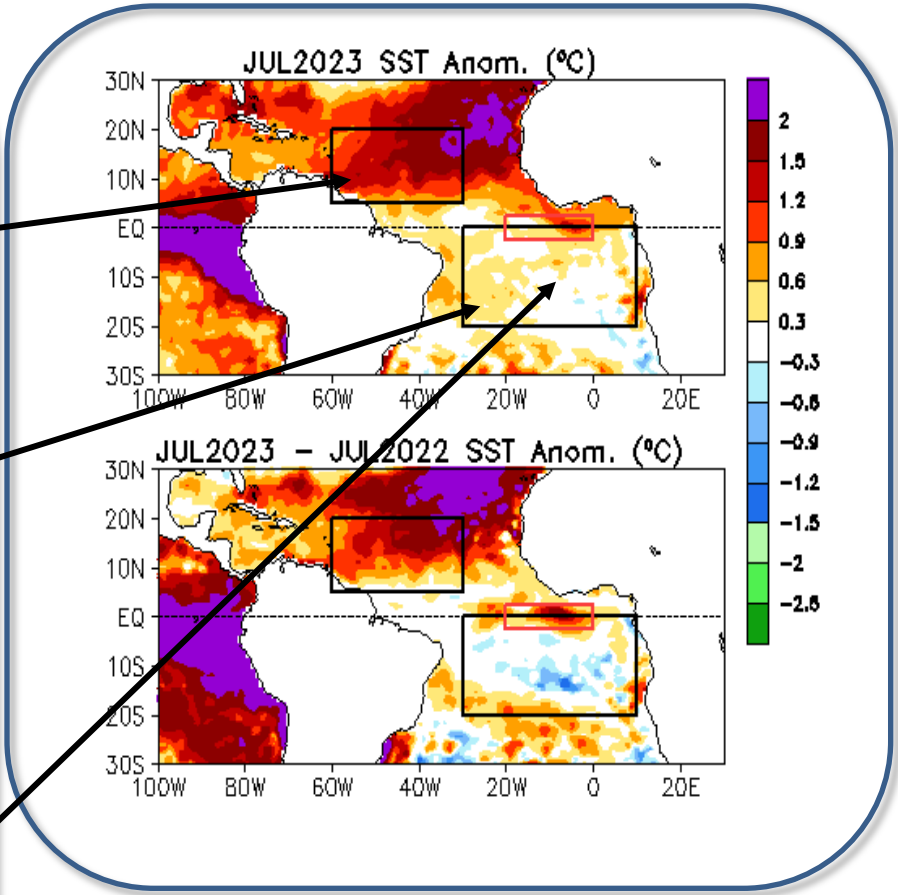
- Positive SSTAs dominated most of the tropical Indian Ocean basin in Jul 2023.

Indian Ocean region indices, calculated as the area-averaged monthly mean SSTA (OC) for the SETIO [90ºE-110ºE, 10ºS-0] and WTIO [50ºE-70ºE, 10ºS-10ºN] regions, and Dipole Mode Index, defined as differences between WTIO and SETIO. Data are derived from the OIv2.1 SST analysis, and anomalies are departures from the 1991-2020 base period means.

Tropical and North Atlantic Ocean

Evolution of Tropical Atlantic SST Indices

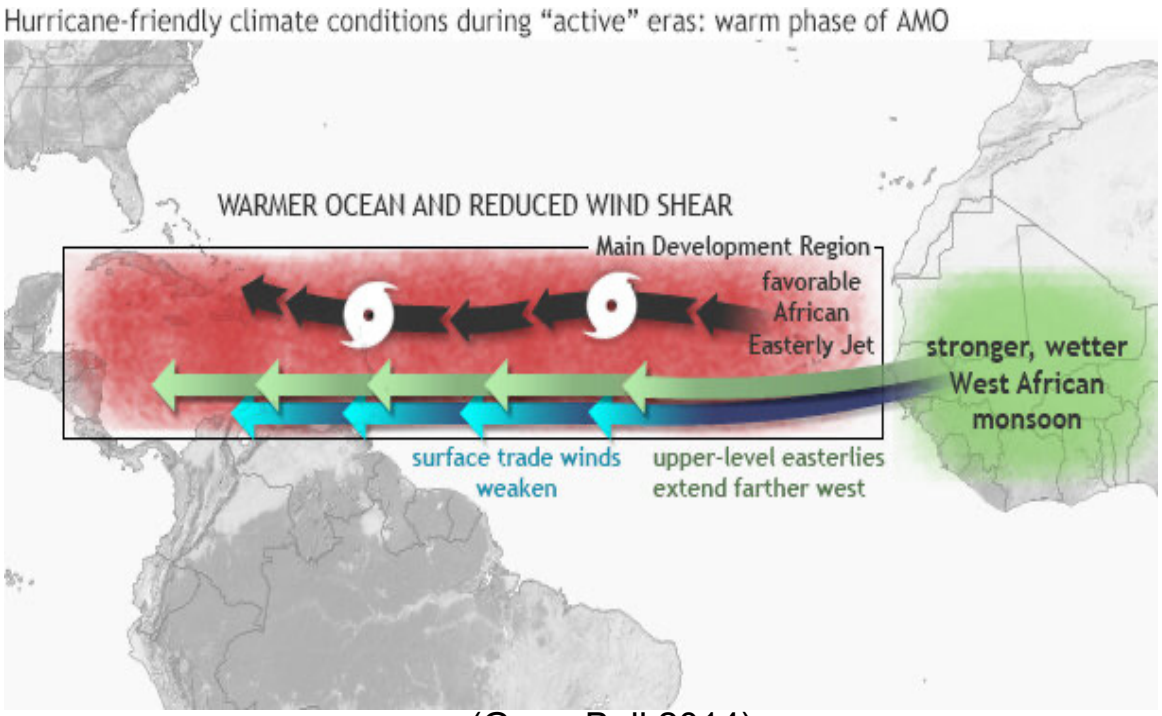




- Strong positive SSTA in the tropical north Atlantic persisted in Jul 2023, contributing to the large value of meridional mode index.
- Positive ATL3 index strengthened in Jul 2023.

Tropical Atlantic Variability region indices, calculated as the area-averaged monthly mean SSTAs (^{O}C) for the TNA [60^{O}W-30^{O}W, 5ºN-20^{O}N], TSA [30^{O}W-10^{O}E, 20^{O}S-0] and ATL3 [20^{O}W-0, 2.5^{O}S-2.5^{O}N] regions, and Meridional Gradient Index, defined as differences between TNA and TSA. Data are derived from the OIv2.1 SST analysis, and anomalies are departures from the 1991-2020 base period means.

Hurricane-friendly Climate Conditions



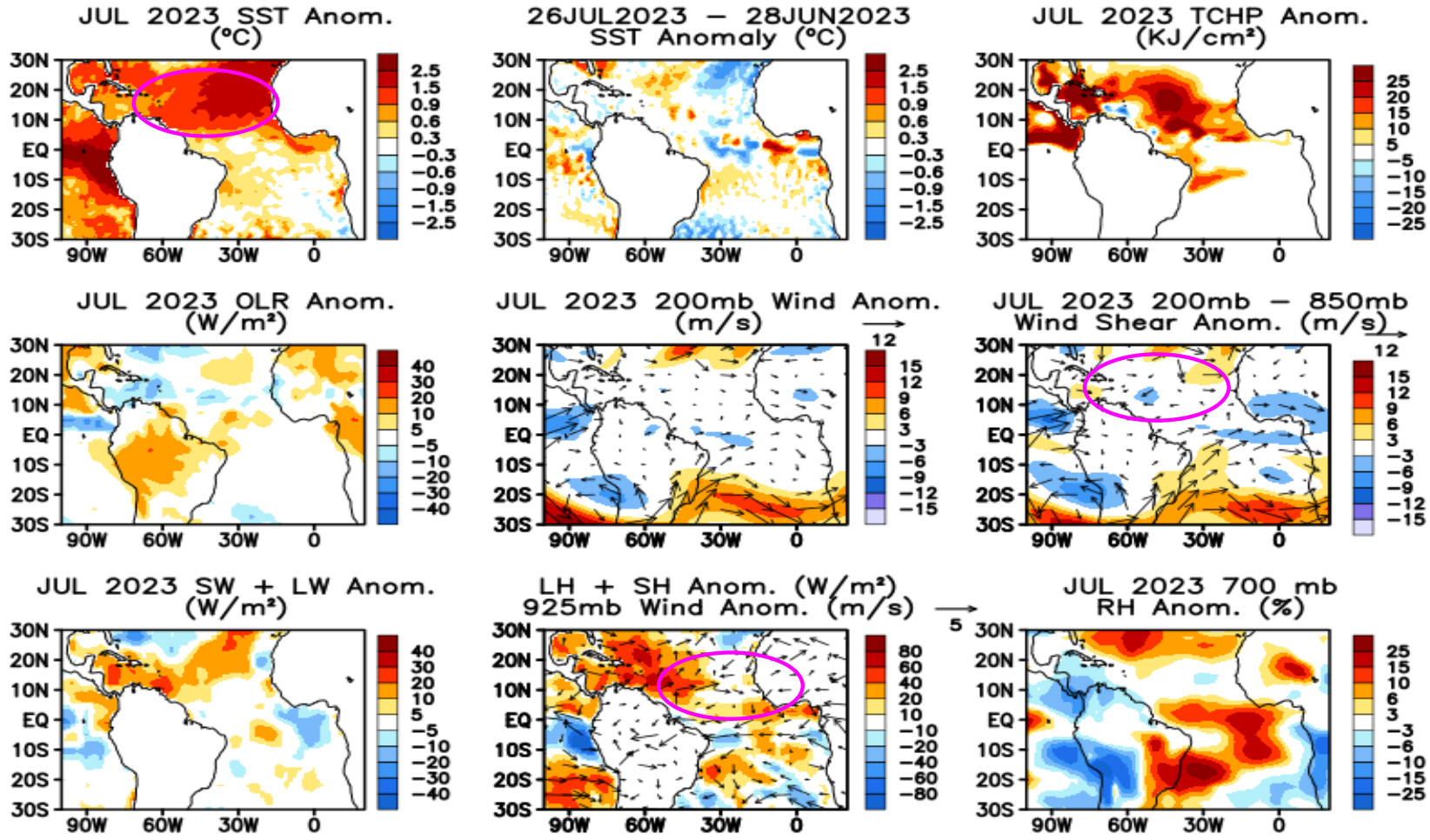
(Gerry Bell,2014)

https://www.climate.gov/news-features/blogs/enso/impacts-el-ni%C3%B1o-and-la-ni%C3%B1a-hurricane-season

Established theories:

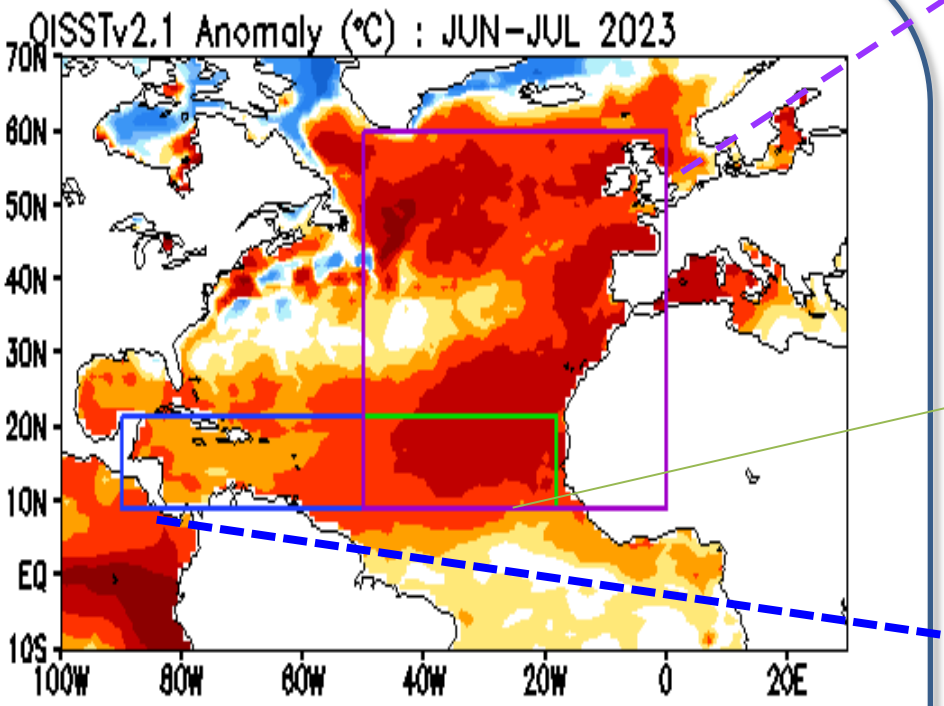
- Warm phase of Atlantic Multi-decadal Oscillation (AMO)
- Warmer SSTs across the Atlantic hurricane main development region
- Reduced wind shear (i.e ENSO impact)
- Stronger West African monsoon

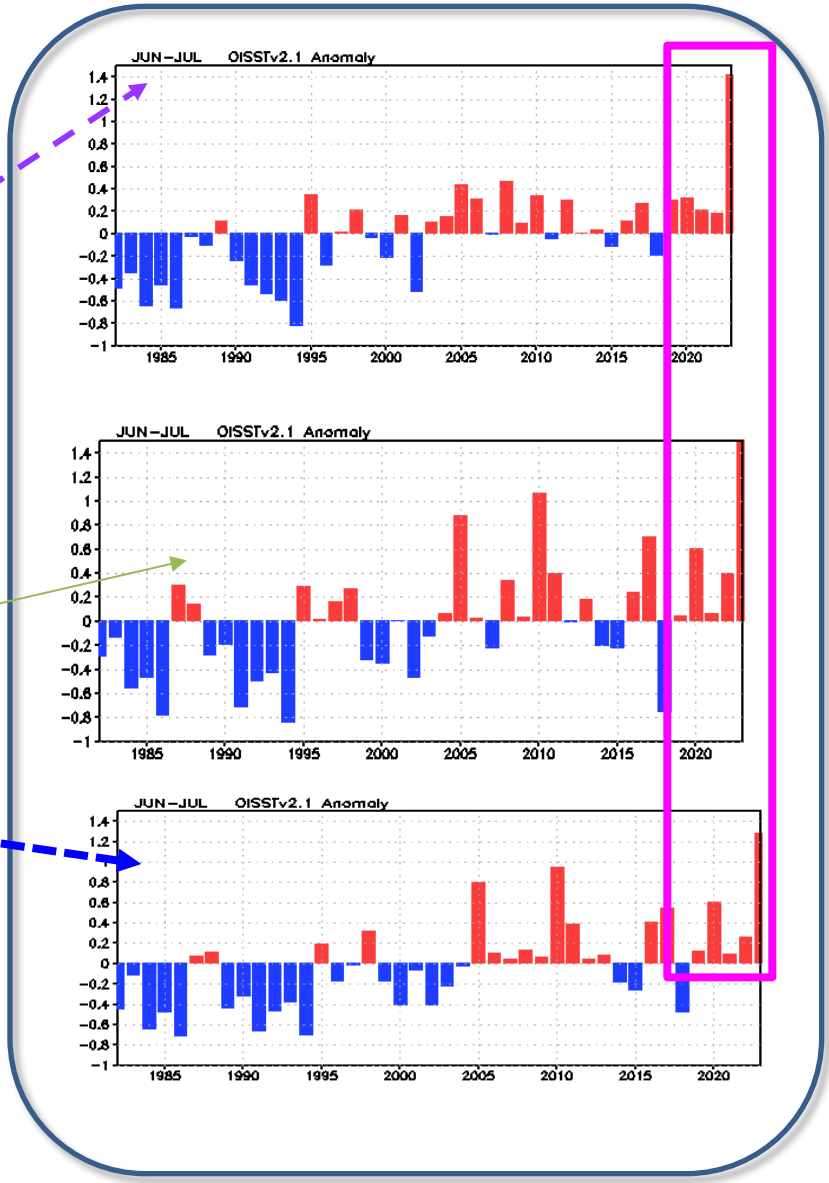
Tropical Atlantic: SST, SST tend., TCHP, OLR, 200 hPa wind, wind share, heat flex, & RH anom.



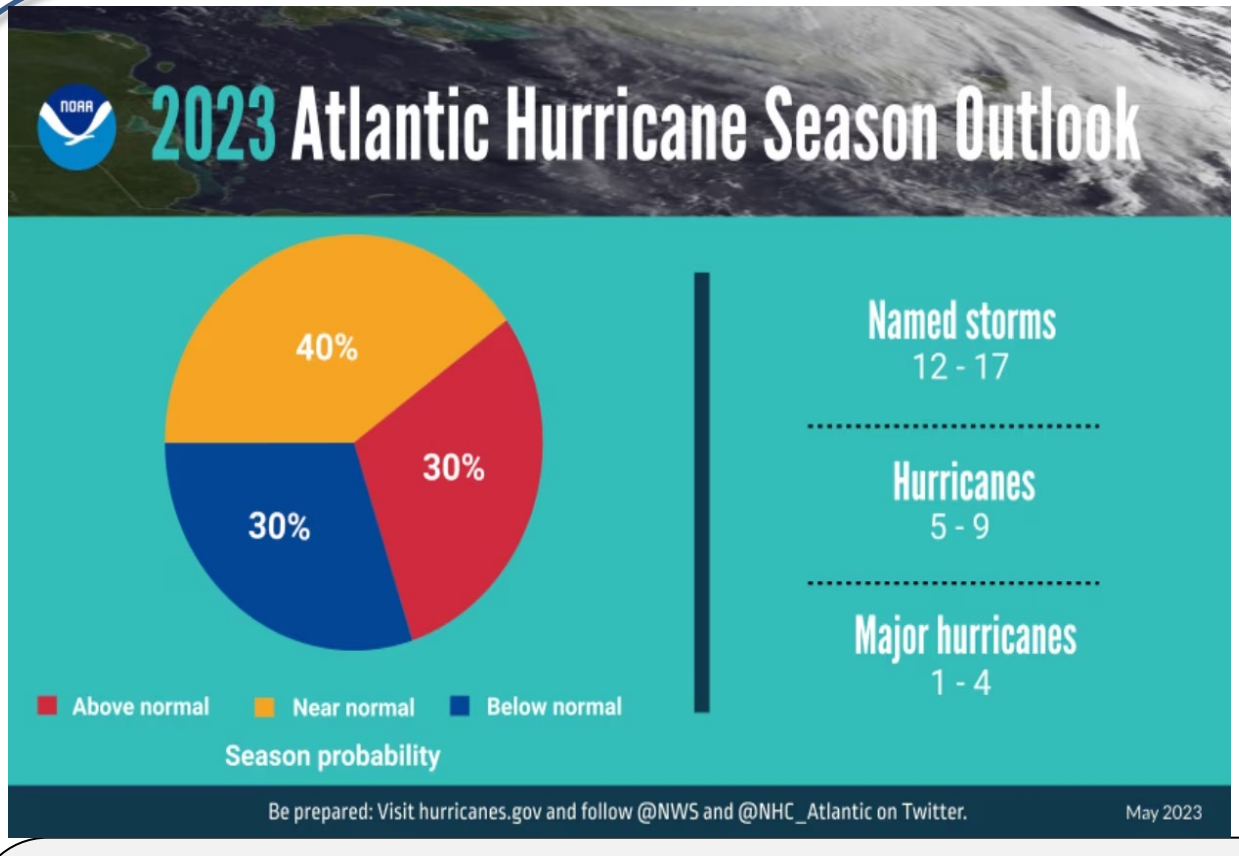
Top Row: SSTA (left; OI SST), SSTA tendency (central), Tropical Cyclone Heat Potential anomaly (right; GODAS).
Middle row: OLR (left; NOAA 18 AVHRR IR), UV200 (central; NCEP CDAS), UV200-UV850 (right; NCEP CDAS) anomalies.
Bottom row: SW+LW (left), LH+SH (central), Relative humidity at 700 hPa (right; NCEP CDAS) anomalies.
Anomalies are departures from the 1991-2020 base period means.

Evolution of SST anomaly in the North Atlantic





2023 Atlantic Hurricane Season Outlook



- May 25, 2023: NOAA CPC forecast a range of 12 to 17 total named storms. Of those, 5 to 9 could become hurricanes, including 1 to 4 major hurricanes (category 3, 4 or 5). NOAA has a 70% confidence in these ranges.

"…. NOAA scientists predict a high potential for El Nino to develop this summer, which can suppress Atlantic hurricane activity. El Nino's potential influence on storm development could be offset by favorable conditions local to the tropical Atlantic Basin. Those conditions include the potential for an above-normal west African monsoon, which produces African easterly waves and seeds some of the stronger and longer-lived Atlantic storms, and warmer-than-normal sea surface temperatures in the tropical Atlantic Ocean and Caribbean Sea which creates more energy to fuel storm development. These factors are part of the longer term variability in Atlantic atmospheric and oceanic conditions that are conducive to hurricane development — known as the high-activity era for Atlantic hurricanes — which have been producing more active Atlantic hurricane seasons since 1995. …."*(https://www.noaa.gov/news-release/2023-atlantic-hurricane-season-outlook)*

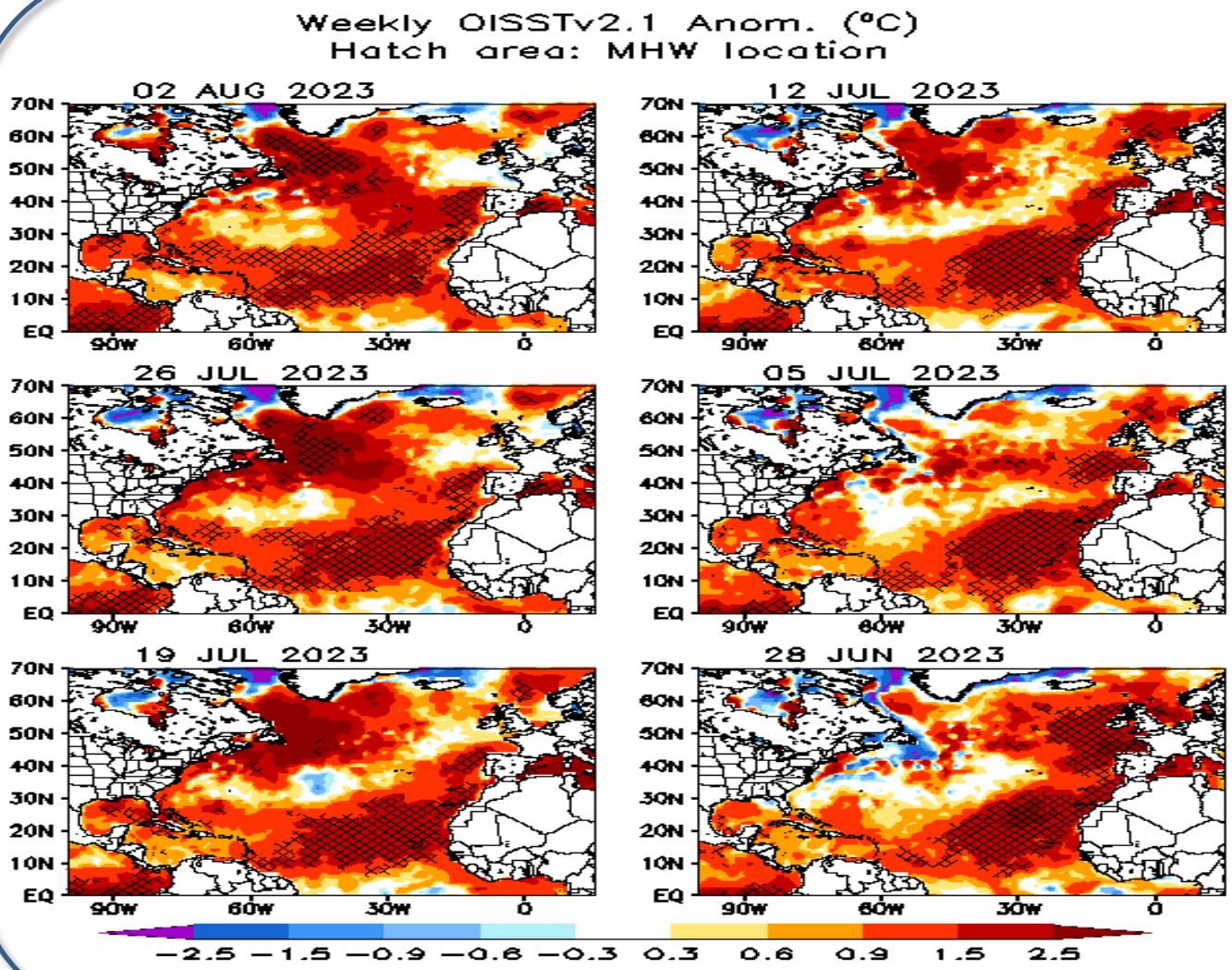
2023 Atlantic Hurricane Season Activities

https://en.wikipedia.org/wiki/2023_Atlantic_hurricane_season

- By 10 Aug 2023, five tropical storms formed, with one developing into hurricane.

Atlantic	Observations (By Aug 10)	Outlook (May 25) 40% near-normal	(1991-2020)
Total storms	5	12-17	14
Hurricanes	1	5-9	7
Major hurricanes	0	1-4	3

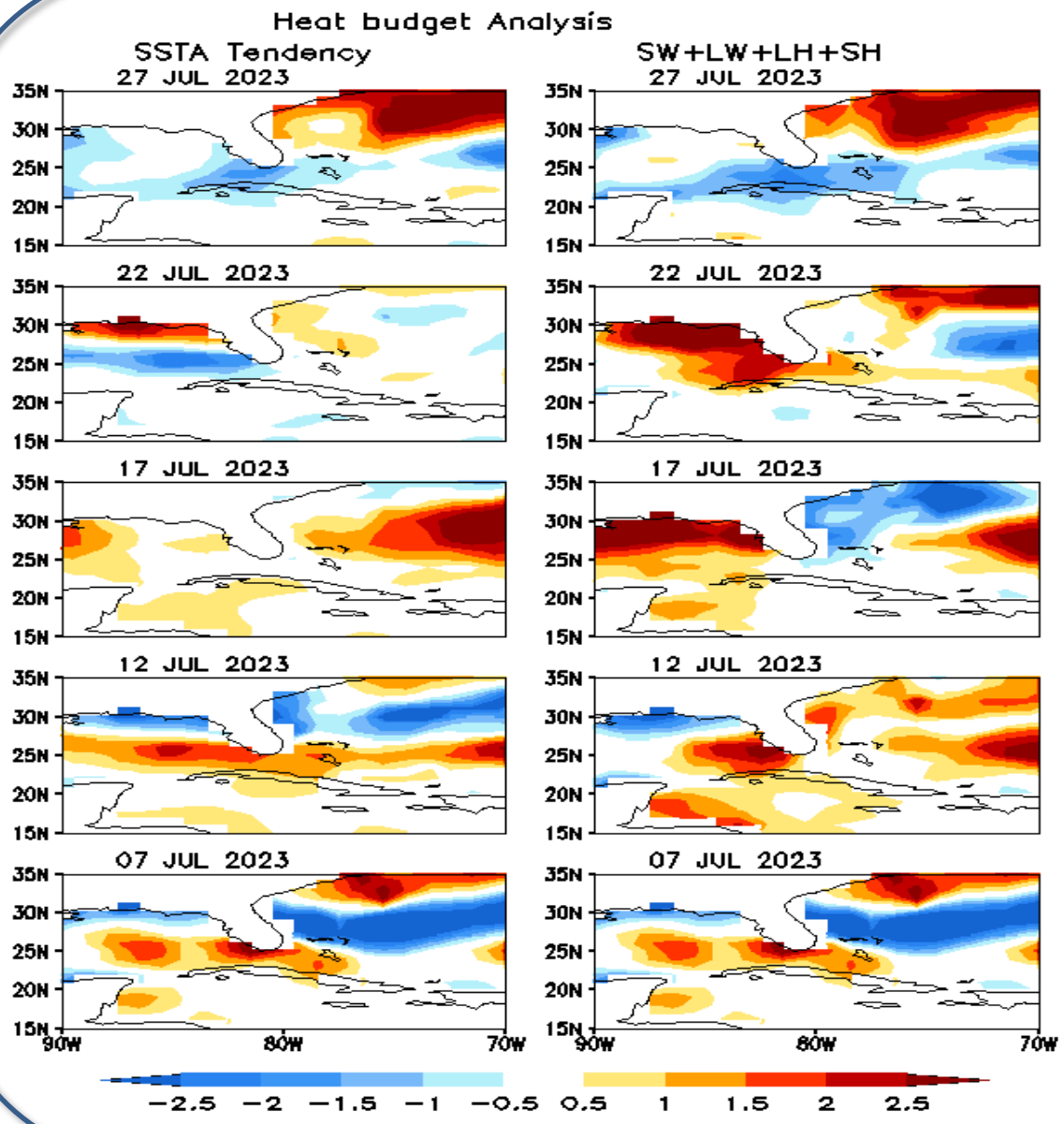
Weekly SST anomaly and MHWs in the North Atlantic



- Strong MHWs continued near the west coast of North Africa.
- MHWs developed near the Caribbean, Gulf of Mexico in early July.
- MHWs emerged near the Larbrador basin in late July.

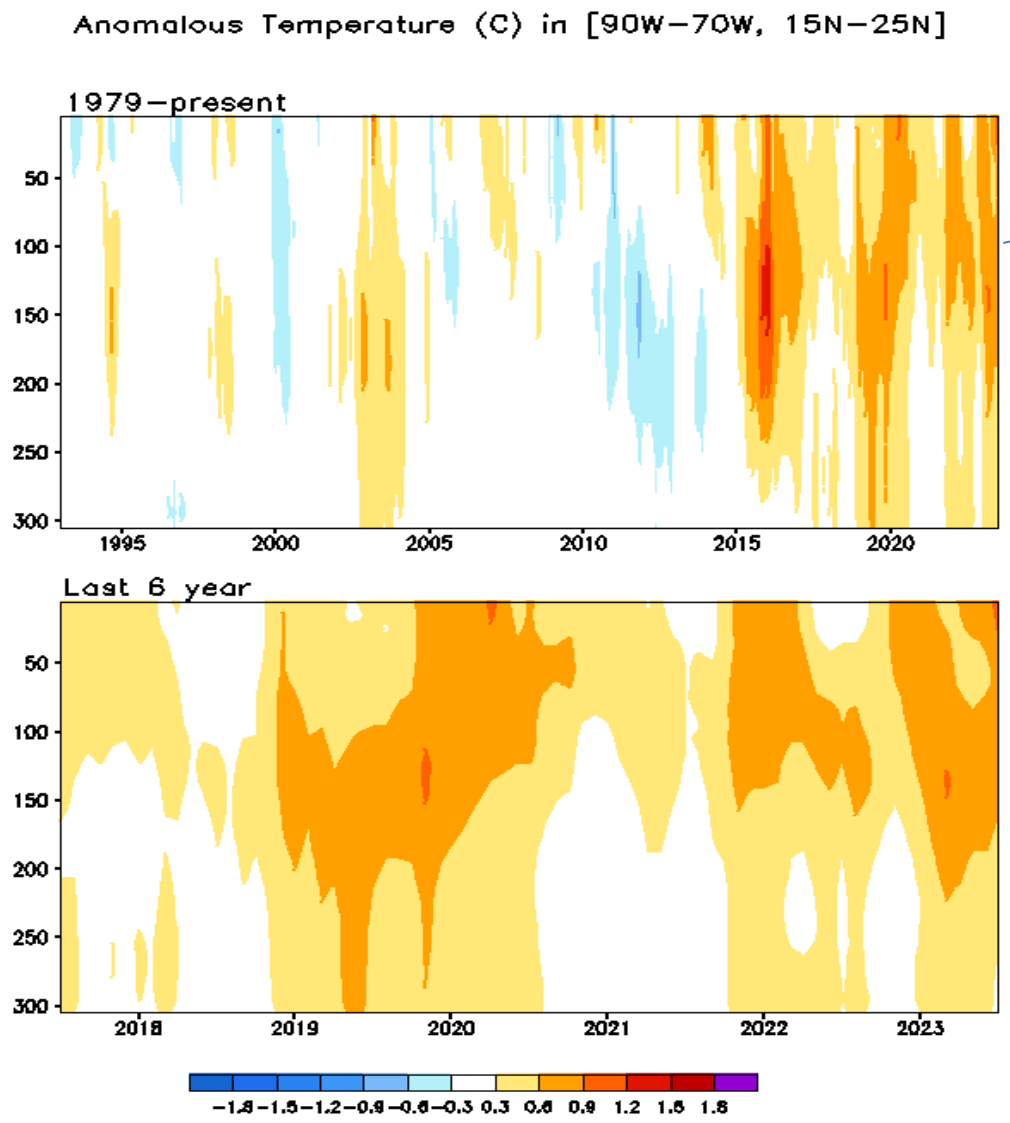
(Left panel) Weekly SST anomaly (shaded) and locations experience Marine heat waves (hatched) by the date labelled in the plot. (right panel) SST evolution at a specific location. Green line and blue line denote the seasonal 90th percentile and daily climatology, respectively. Shaded area denotes the periods experiencing MHW. MHW is defined as a discrete prolonged warmer than 90th percentile of daily SST for at least 14 days. Data is derived from NCEI OISSTv2.1 and the climatology reference period is 1991-2020

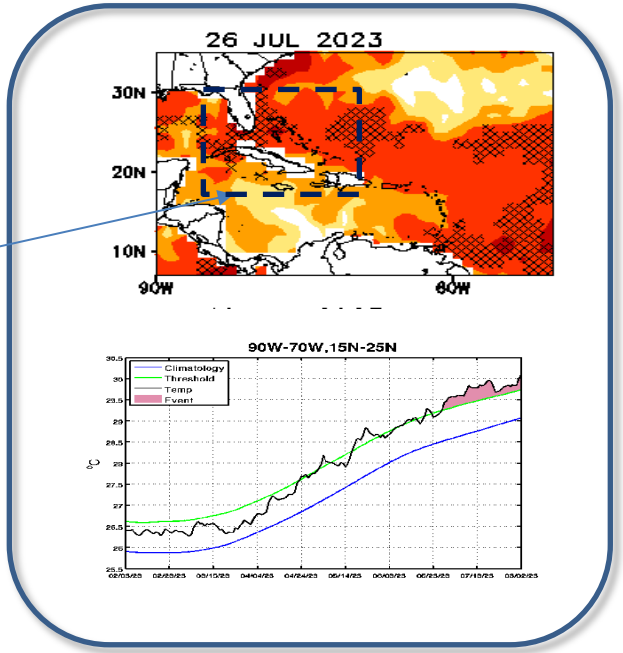
Mixed Layer Heat Budget Analysis



- Surface heat flux is the primary factor modulating SST tendency near the southern Gulf of Mexico.

Subsurface Temperature Anomaly in southern Gulf of Mexico





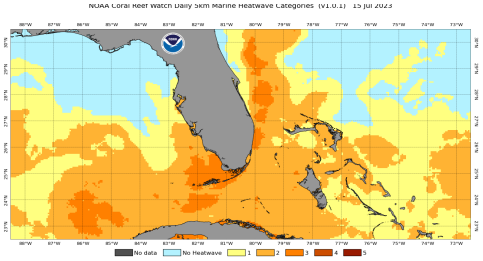
- Subsurface warming near the Florida has persisted since 2014.

Impact of MHWs on Corals and Marine ecosystems in Florida

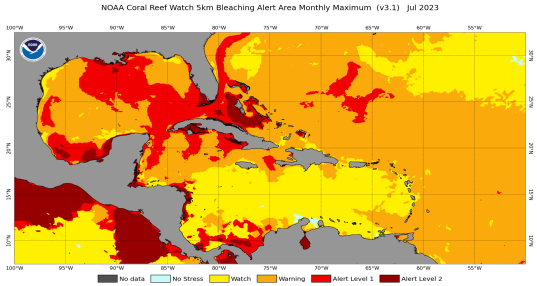
(Courtesy of Dr. Gang Liu)

NOAA Coral Reef Watch

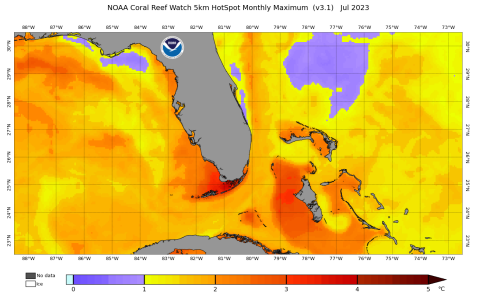
MHWs Categories (July 15)

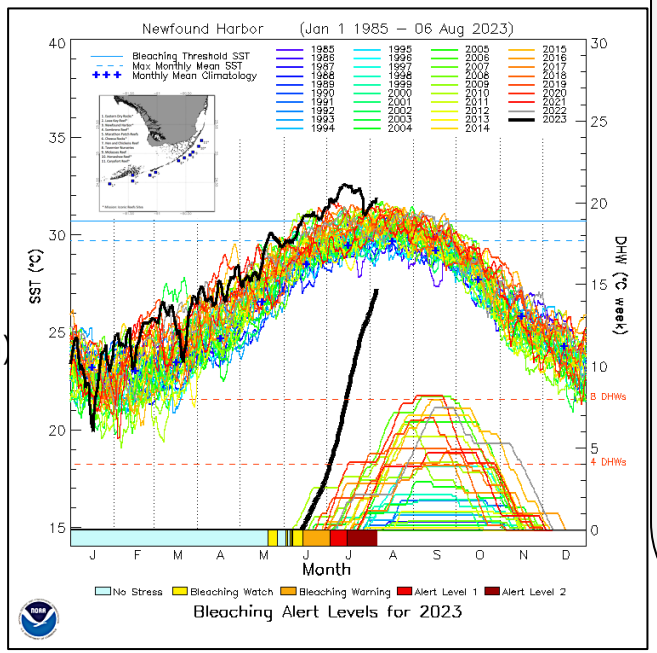


Coral Bleaching Alert Areas (July Maximum)

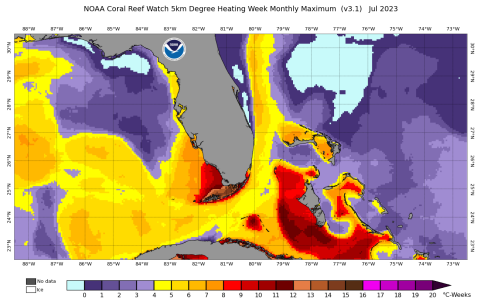


Coral Bleaching HotSpots (July Maximum)





Degree Heating Weeks (July Maximum)



- Mass coral bleaching in the eastern equatorial Pacific, Caribbean, Gulf of Mexico, and Florida Keys resulted from ongoing marine heatwave starting in June/July 2023.

- Situation in the Florida Keys is unprecedented in its severity & extent for so early in the summer season.

https://coralreefwatch.noaa.gov/product/marine_heatwave/

Impact of MHWs on Corals and Marine ecosystems in Florida

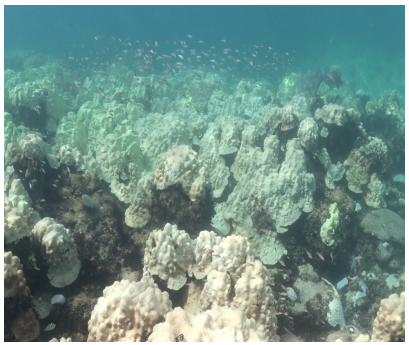
(Courtesy of Dr. Gang Liu)

Unprecedented (month before usual peak of heat stress/bleaching): Ongoing marine heatwave across South Florida, the Gulf of Mexico, and the greater Caribbean has caused widespread, significant bleaching since June. Since early July, widespread, severe bleaching and significant mortality have been reported in many locations in the Florida Keys.

Example: Complete bleaching at Cheeca Rocks, Florida was observed July 31- August 1 by NOAA AOML scientists & partners. Cheeca Rocks had some of the highest coral cover in the Florida Keys and had demonstrated persistence in the wake of the 2014 and 2015 bleaching events.

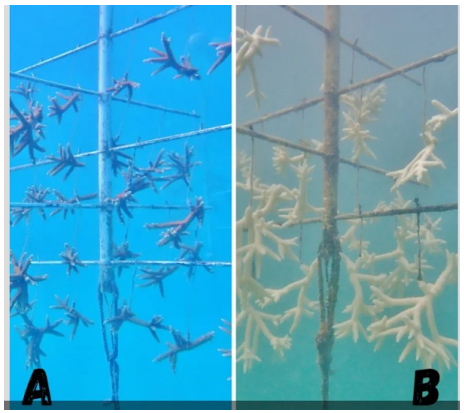
Actions: NOAA and its partners have conducted rescue missions to protect local genets and ensure coral survival, including evacuating live corals from wild habitats and natural coral nurseries to land-based facilities. NOAA and the State of Florida have issued Interim Protocols for the Management of In-Water Nurseries, Coral Transport, and Coral Outplanting.

Credit: Coral Restoration Foundation



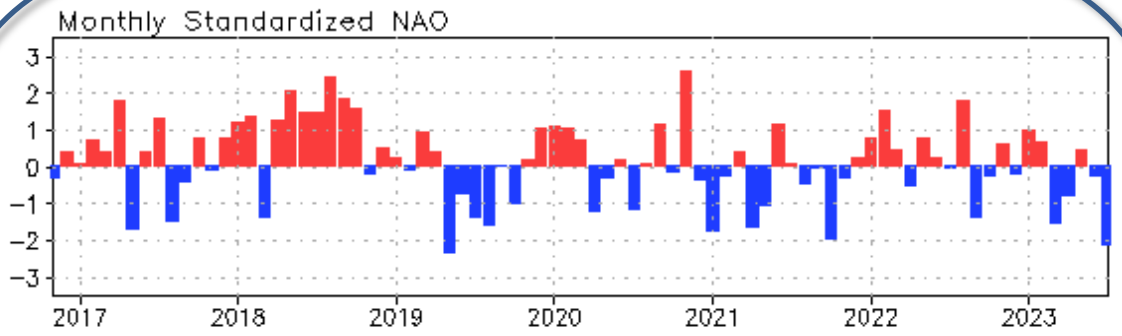
Credit: NOAA AOML

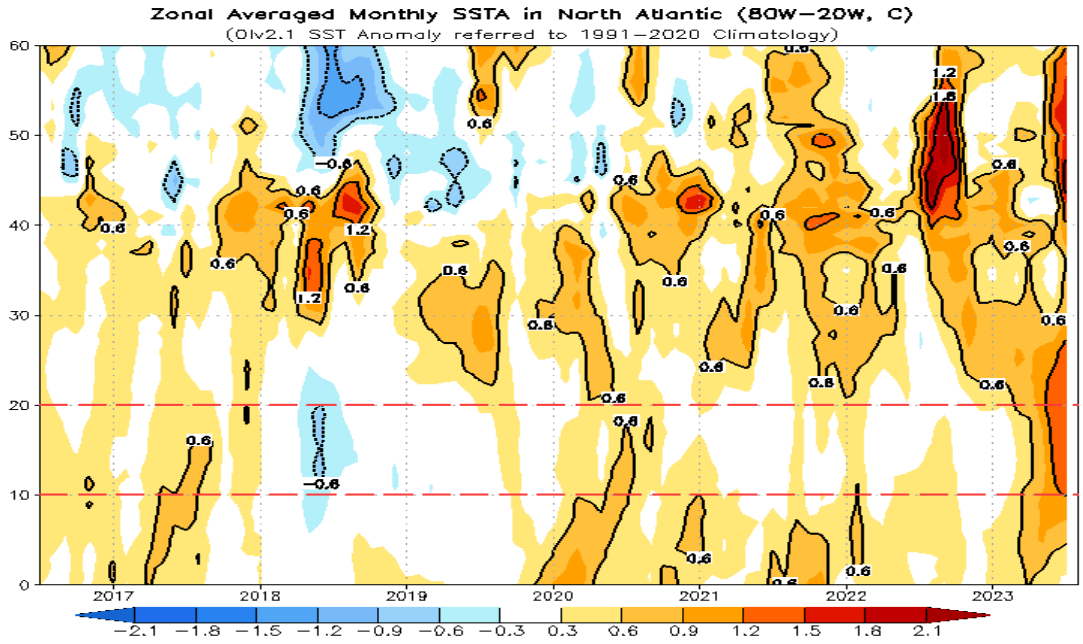
Credit: NOAA AOML

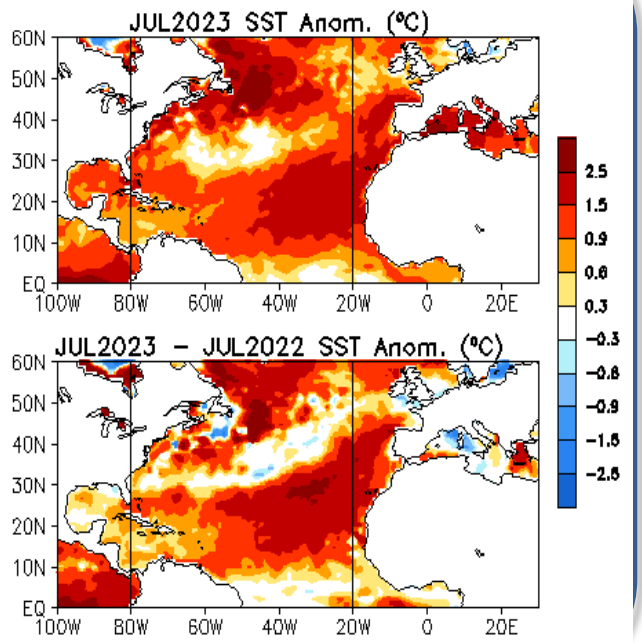


Credit: Florida FWCC

NAO and SST Anomaly in North Atlantic





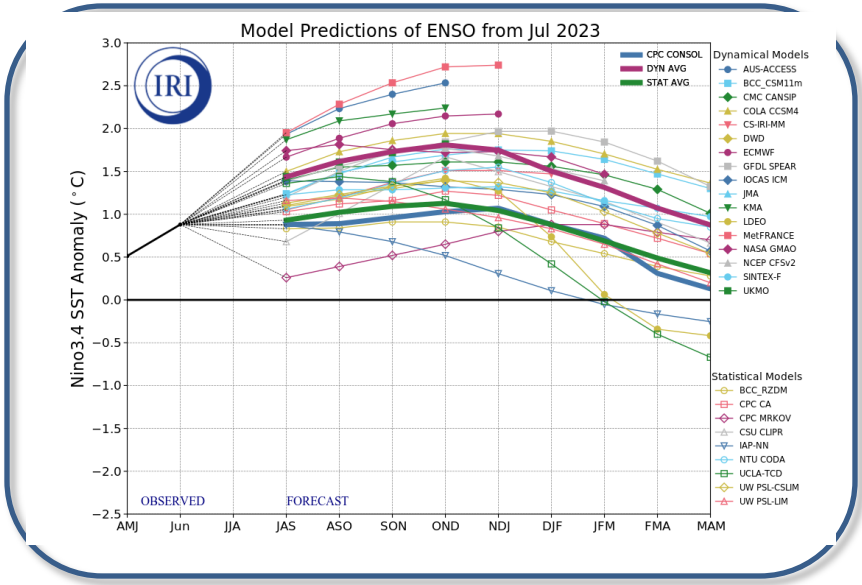


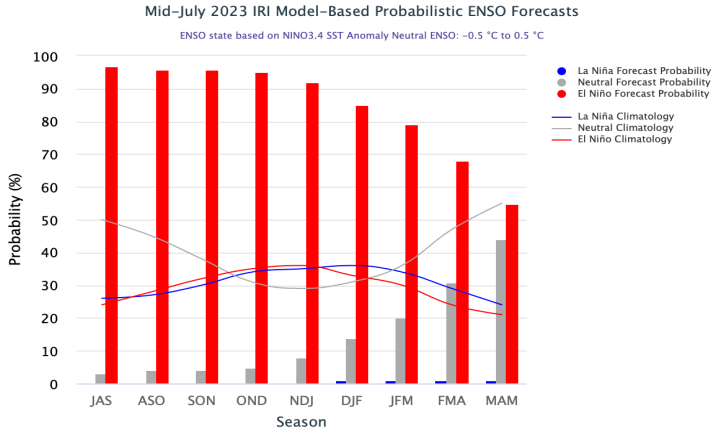
- Negative NAO strengthened substantially in Jul 2023.
- Strong warming continued in the eastern North Atlantic Ocean.
- The prolonged positive SSTAs in the middle latitudes were evident, due to dominance of the positive phase of NAO during the last 5-6 years.

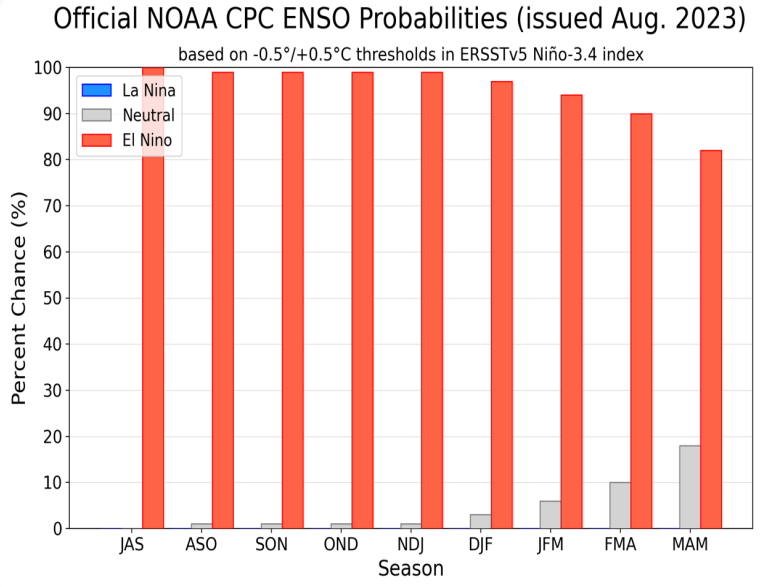
Monthly standardized NAO index (top) derived from monthly standardized 500-mb height anomalies obtained from the NCEP CDAS in 20°N-90°N. Time-latitude section of SSTAs averaged between 80ºW and 20ºW (bottom). SST are derived from the OIv2.1 SST analysis, and anomalies are departures from the 1991-2020 base period means.

ENSO and Global SST Predictions

IRI/CPC Niño3.4 Forecast





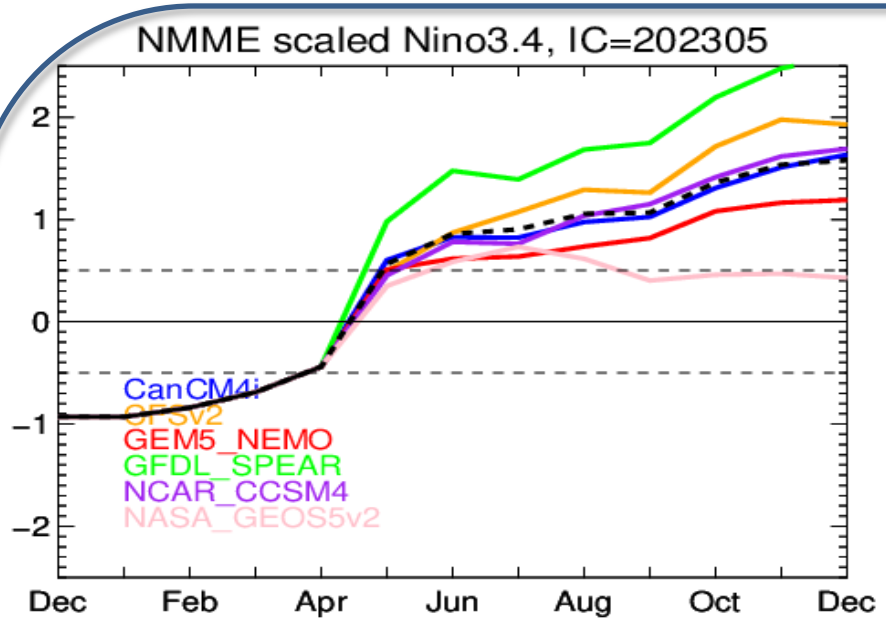


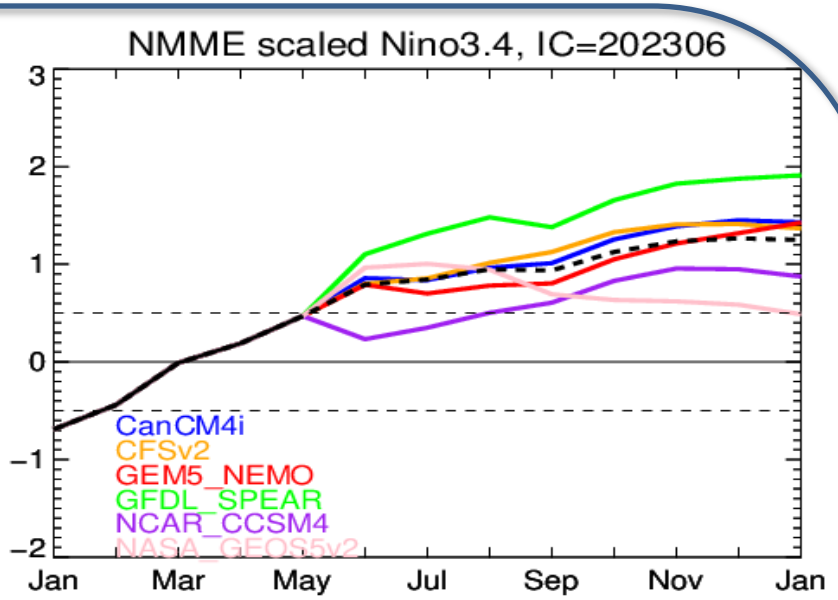
- Most of models forecasted that El Niño conditions will continue through the Northern Hemisphere winter 2023-24.

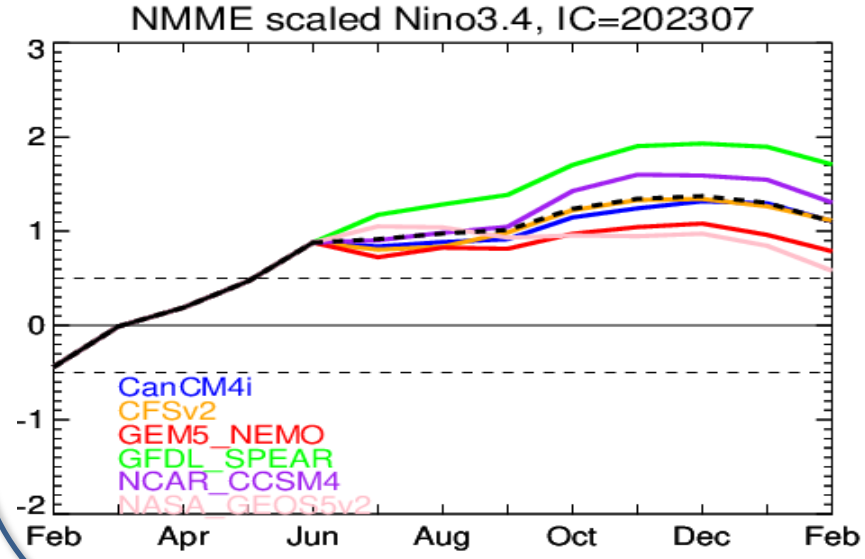
-**ENSO Alert System Status issued on 10 Aug 2023: El Niño Advisory**

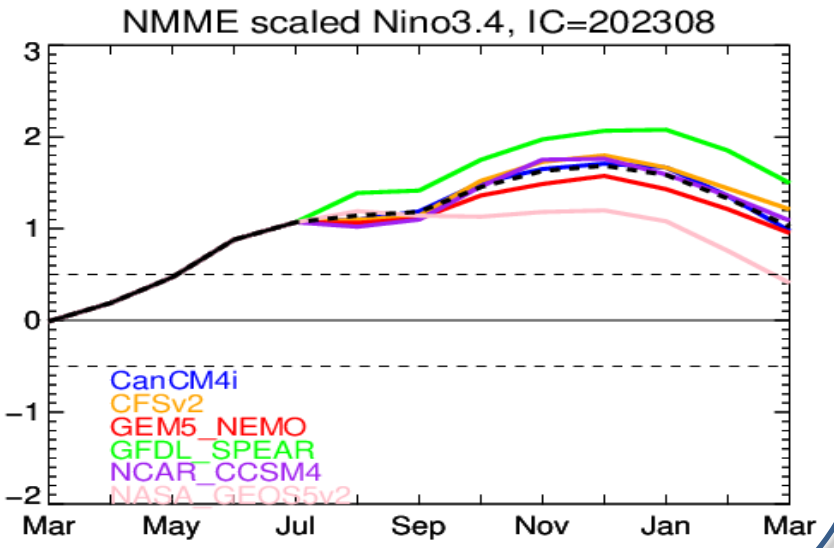
- Synopsis: *"El Niño is anticipated to continue through the Northern Hemisphere winter (with greater than 95% chance through December 2023 - February 2024"*

NMME forecasts from different initial conditions



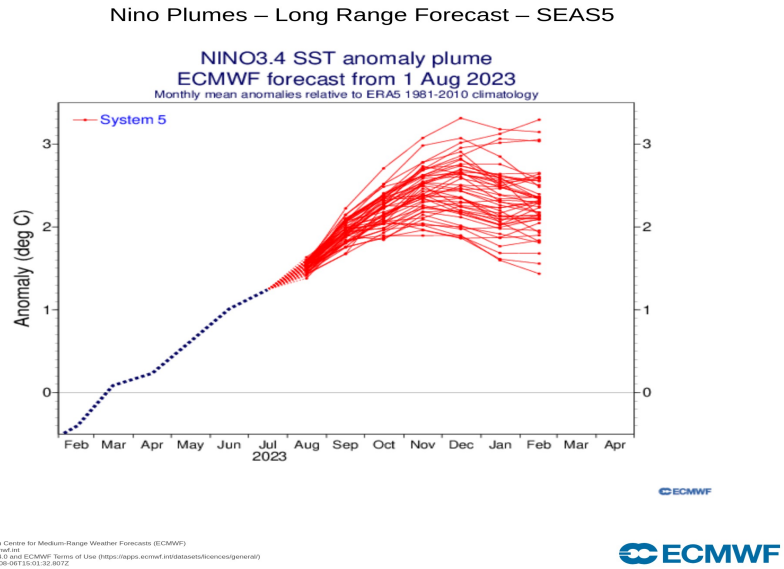




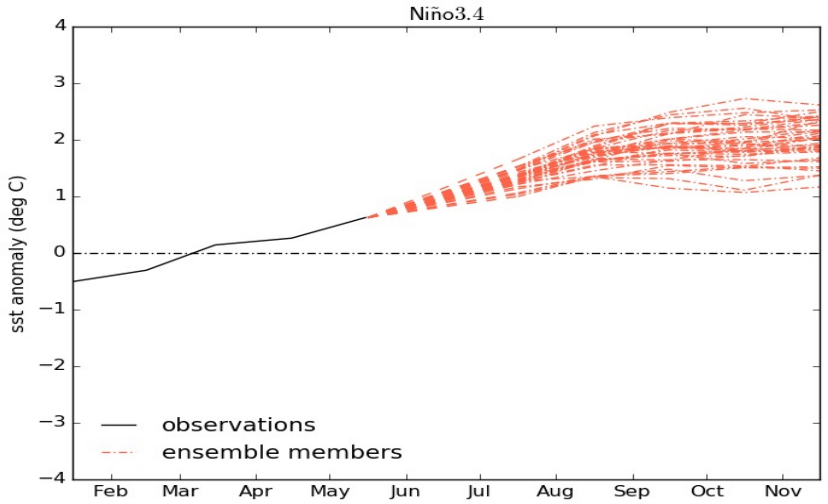


Individual Model Forecasts: A strong El Niño in 2023

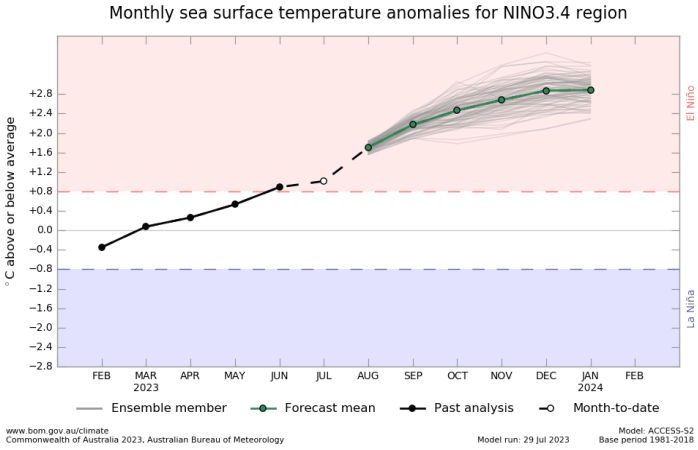
EC: Niño3.4, IC= 1 July 2023



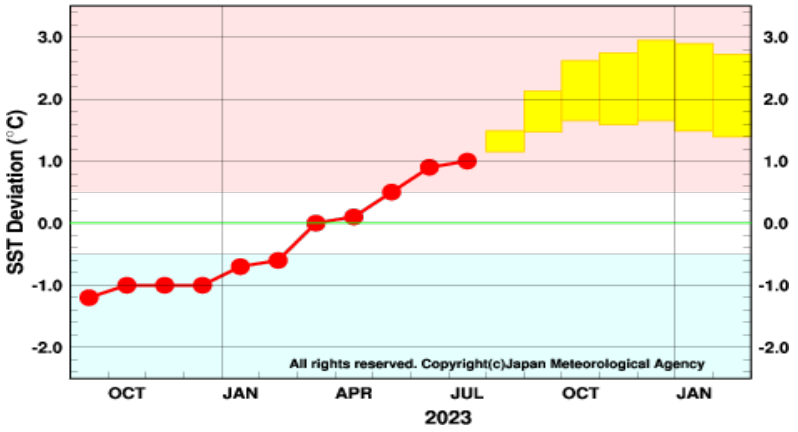
UKMO: Niño3.4, Updated 16 Jun 2023



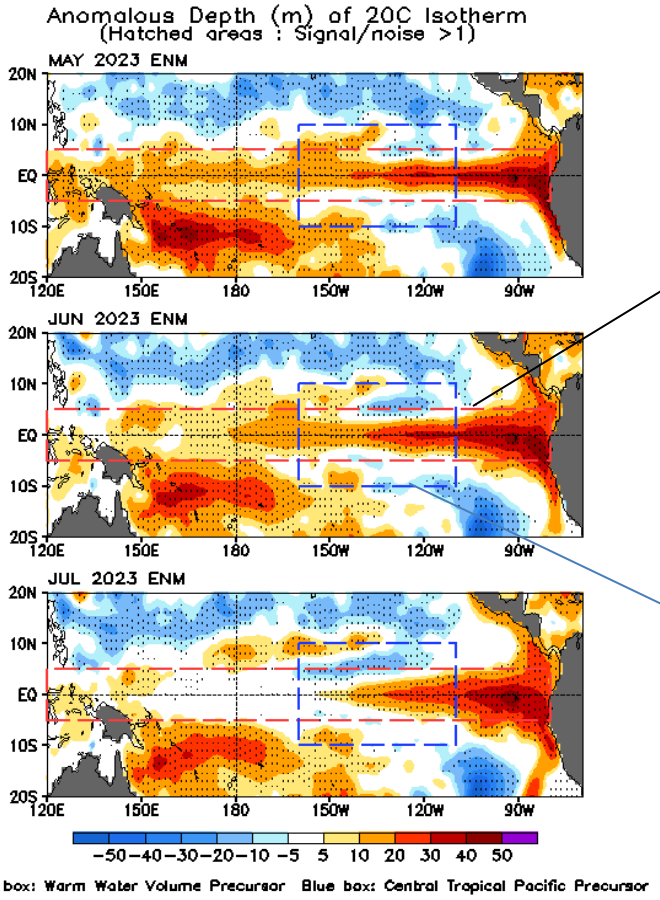
BOM: Niño3.4, Updated 29 July 2023

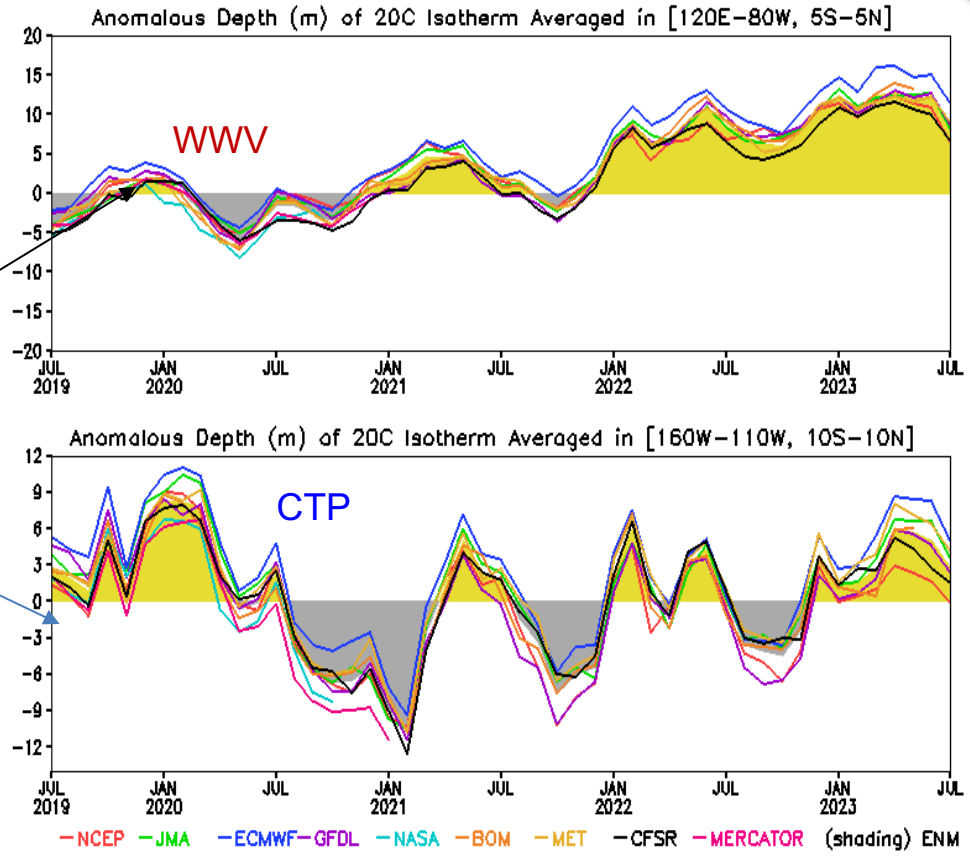


JMA: Niño3.4, Updated 10 August 2023



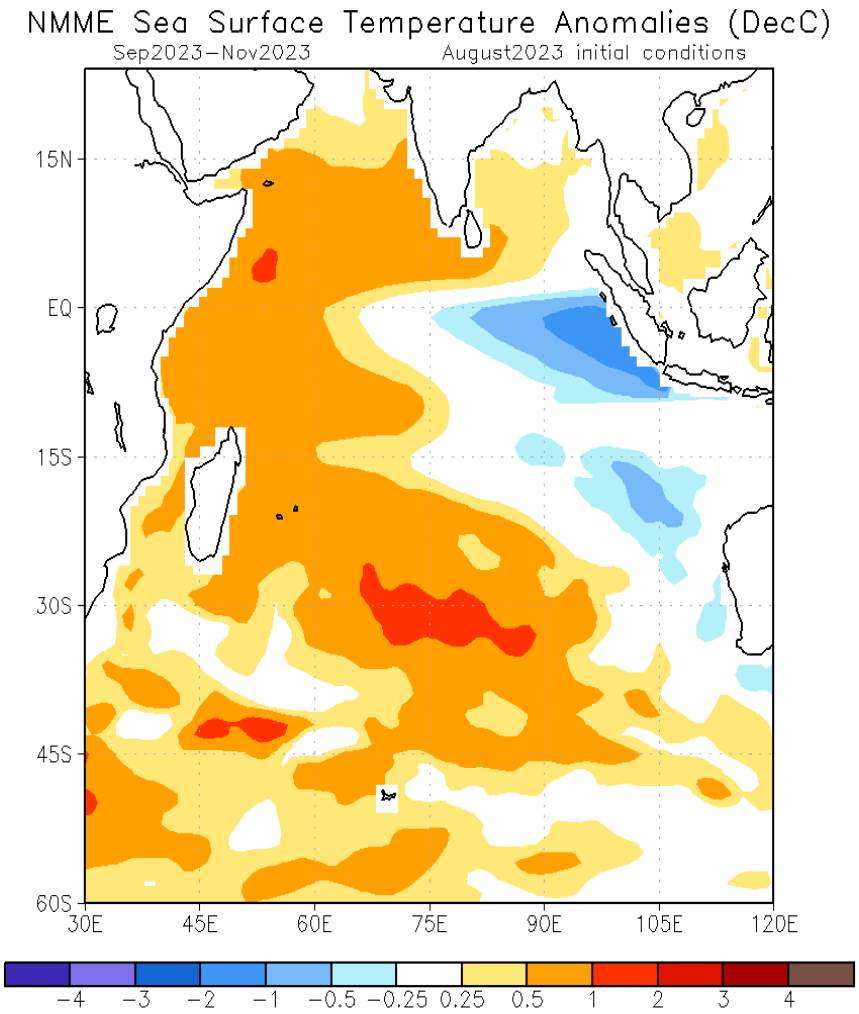
Oceanic ENSO Precursors: WWV & CTP



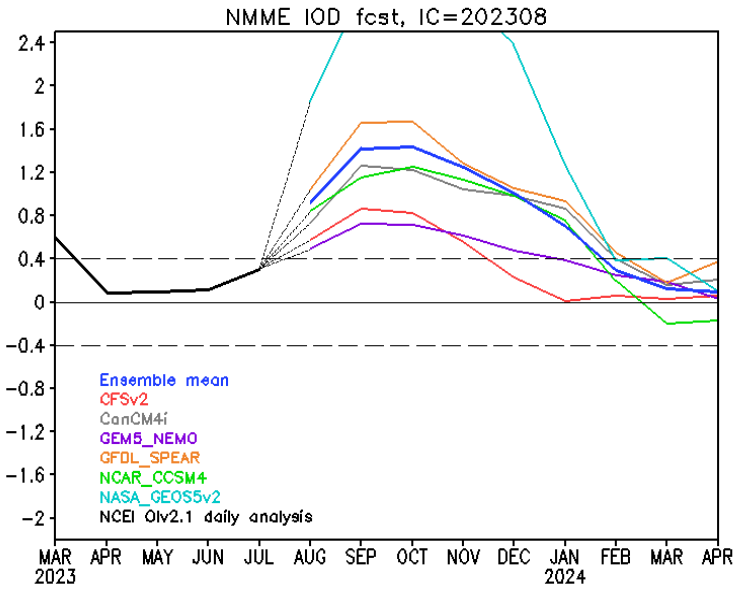


Warm water volume (WWV) is defined as an average of D20 anomaly across the equatorial Pacific (120° E – 80° W, 5° S-5° N) (Meinen and McPhaden 2000). Central tropical Pacific (CTP) index is calculated as the averaged D20 anomaly in the central tropical Pacific (160° W-110° W, 10° S-10° N) (Wen et al. 2014). The monthly D20 data is obtained from the Real-time Ocean Reanalysis Intercomparison Project(https://www.cpc.ncep.noaa.gov/products/GODAS/multiora93_body.html).

NMME Forecasts in the Indian Ocean

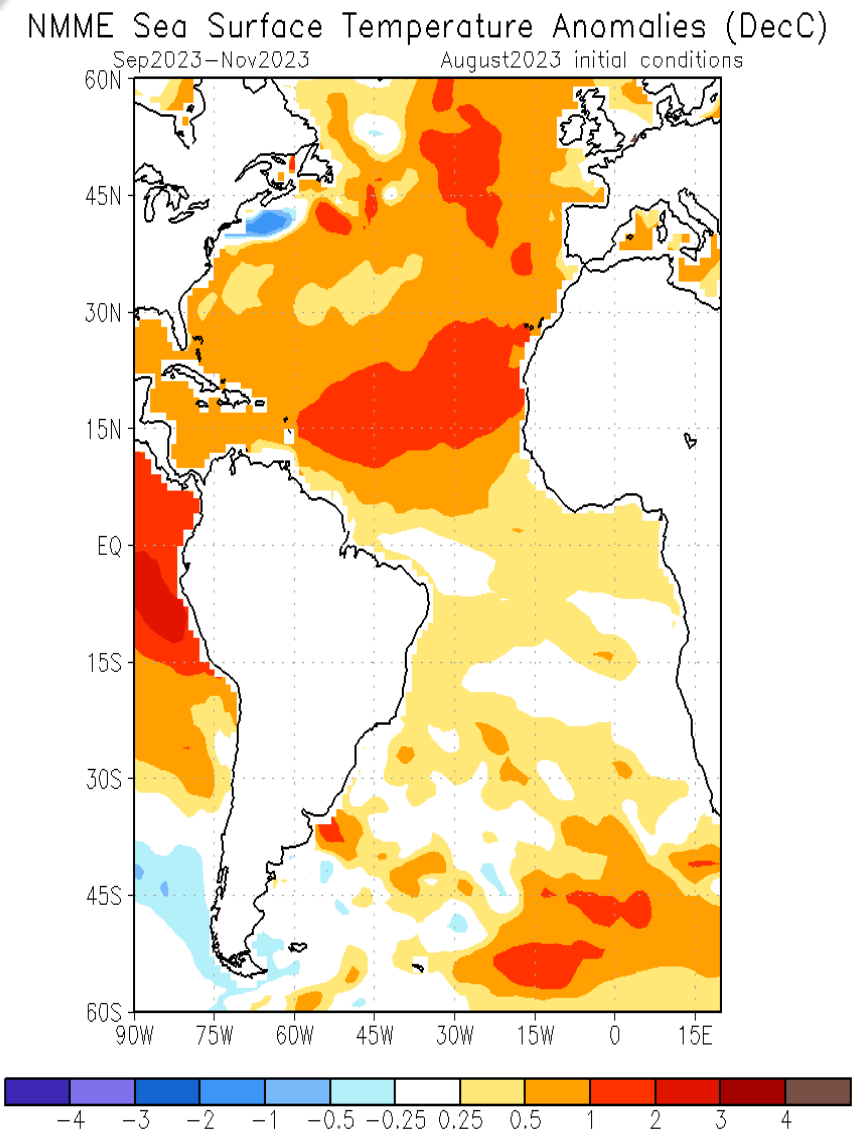


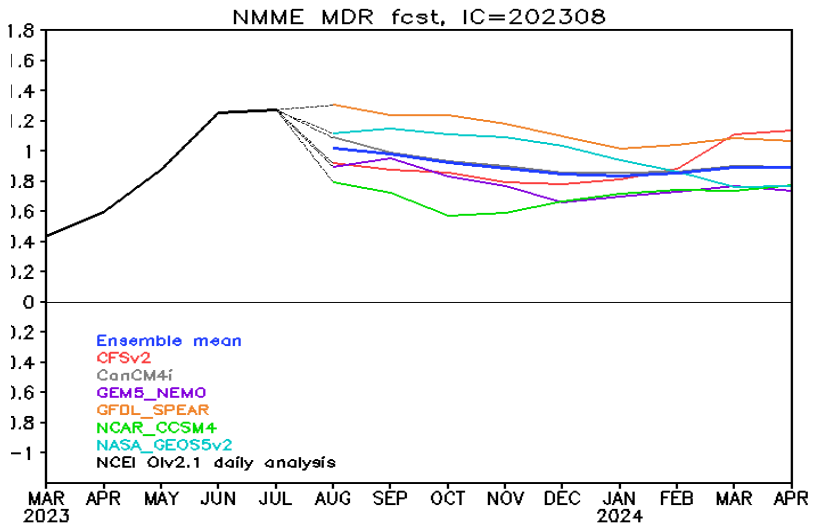
https://www.cpc.ncep.noaa.gov/products/international/ocean_monitoring/IO_monitoring_fcsts/io_index.shtml

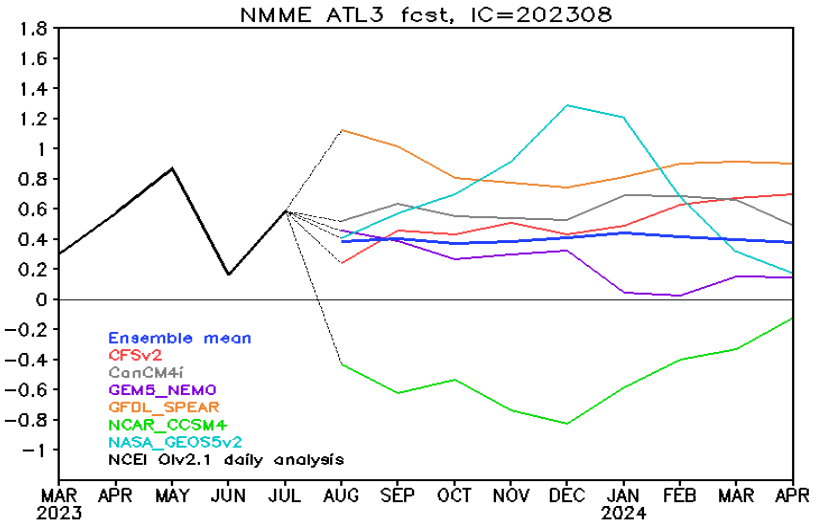


- All NMME members predict a positive IOD event will develop in August and last through winter.

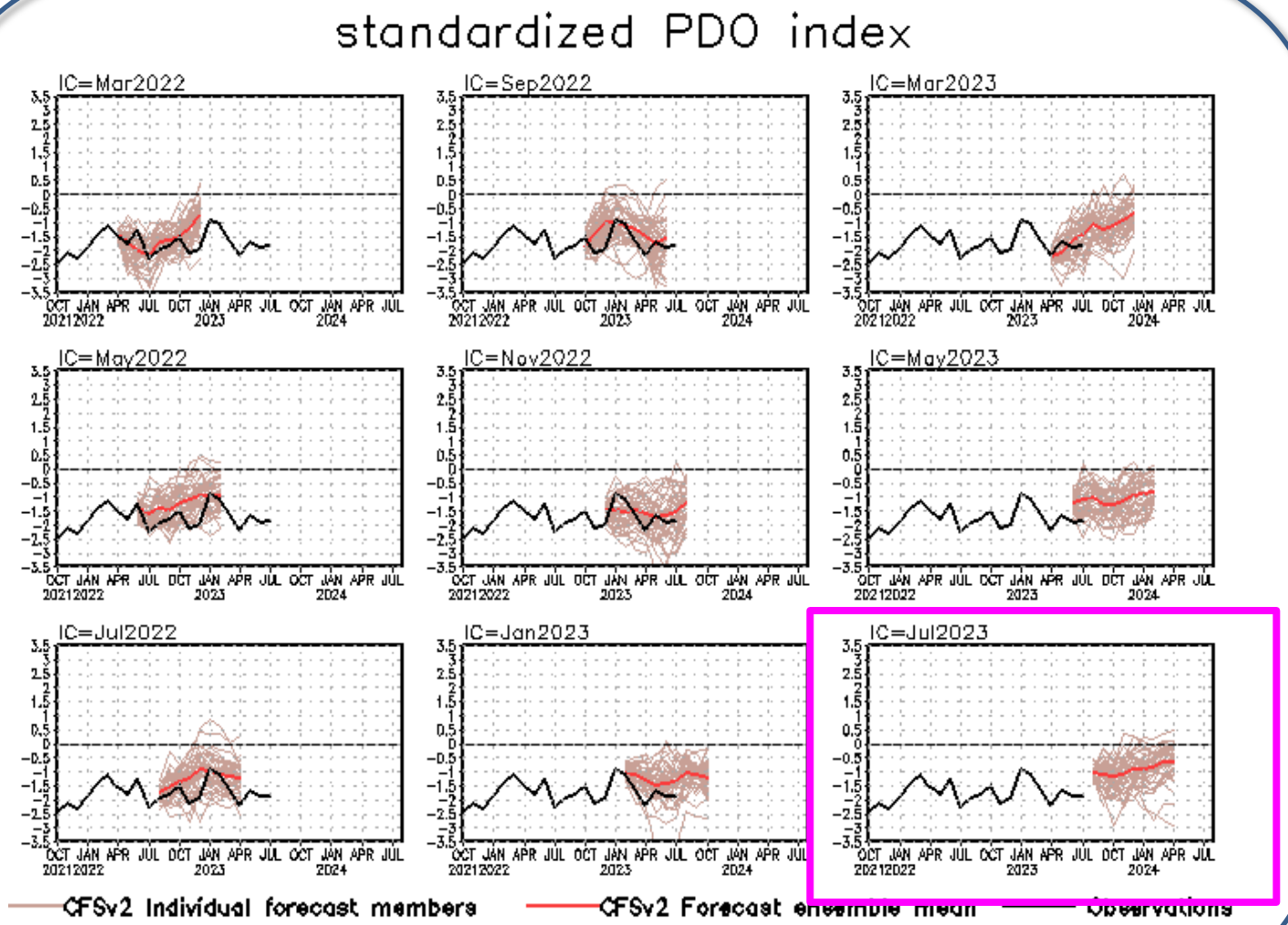
NMME Forecasts in the Atlantic Ocean







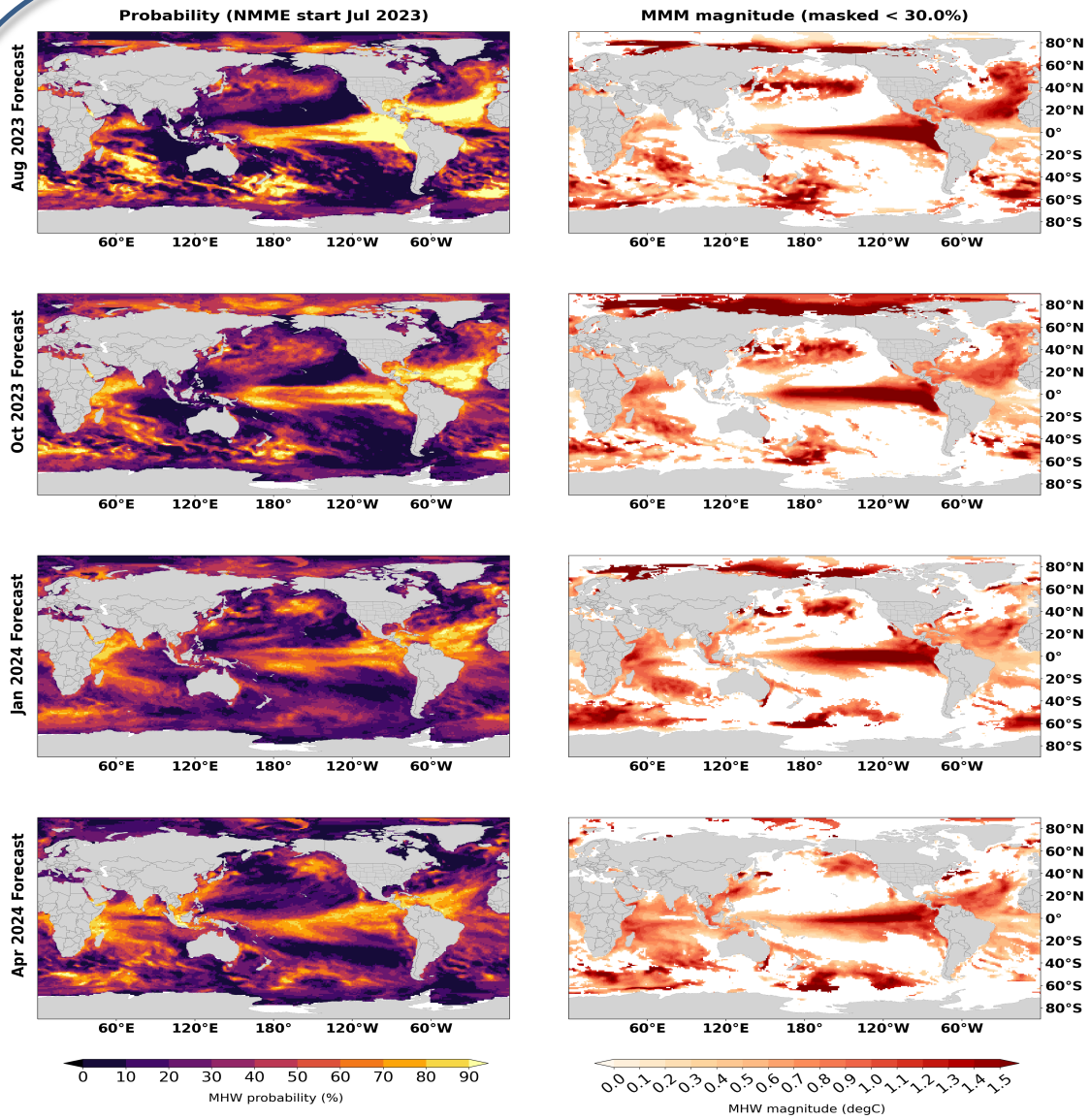
CFS Pacific Decadal Oscillation (PDO) Index Predictions from Different Initial Months



- CFSv2 predicts the negative phase of PDO will continue through spring 2024.

CFS Pacific Decadal Oscillation (PDO) index predictions from the latest 9 initial months. Displayed are 40 forecast members (brown) made four times per day initialized from the last 10 days of the initial month (labelled as IC=MonthYear) as well as ensemble mean (blue) and observations (black). Anomalies were computed with respect to the 1991-2020 base period means. PDO is the first EOF of monthly ERSSTv3b anomaly in the region of [110°E-100°W, 20°N-60°N]. CFS PDO index is the standardized projection of CFS SST forecast anomalies onto the PDO EOF pattern.

NOAA PSL Marine Heat Wave Forecasts



- NMME forecasts suggest that MHW coverage will increase to about 50% of the global oceans in Sep-Oct 2023.
- MHW conditions are expected to persist in the eastern tropical Pacific, central North Pacific and tropical North Atlantic through the end of year.
- MHW condition will persist in the Caribbean Sea and southern Gulf of Mexico through October 2023.

https://psl.noaa.gov/marine-heatwaves/#report

Acknowledgement

- Drs. Arun Kumar, Zeng-Zhen Hu, Jieshun Zhu reviewed PPT, and provide insightful suggestions and comments
- Dr Gang Liu provided the slides of NOAA Coral Reef Watch.
- Dr. Pingping Xie provided the BASS/CMORPH/CFSR EVAP package
- Drs. Jieshun Zhu and Wanqiu Wang provided the upgraded sea ice forecasts

Please send your comments and suggestions to:

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Caihong.Wen@noaa.gov
Jieshun.Zhu@noaa.gov
Zeng-Zhen.Hu@noaa.gov

Data Sources (climatology is for 1991-2020)

- **NCEP/CPC Ocean Monitoring & Briefing Operation (Hu et al., 2022, BAMS)**
- **Weekly Optimal Interpolation SST (OIv2.1 SST; Huang et al. 2021)**
- **Extended Reconstructed SST (ERSST) v5 (Huang et al. 2017)**
- **Blended Analysis of Surface Salinity (BASS) (Xie et al. 2014)**
- **CMORPH precipitation (Xie et al. 2017)**
- **CFSR evaporation adjusted to OAFlux (Xie and Ren 2018)**
- **NCEP CDAS winds, surface radiation and heat fluxes (Kalnay et al. 1996)**
- **NESDIS Outgoing Long-wave Radiation (Liebmann and Smith 1996)**
- **NCEP's GODAS temperature, heat content, currents (Behringer and Xue 2004)**
- **Aviso altimetry sea surface height from CMEMS**
- **Ocean Surface Current Analyses – Realtime (OSCAR)**
- **In situ data objective analyses (IPRC, Scripps, EN4.2.1, PMEL TAO)**
- **Operational Ocean Reanalysis Intercomparison Project**

http://www.cpc.ncep.noaa.gov/products/GODAS/multiora_body.html

http://www.cpc.ncep.noaa.gov/products/GODAS/multiora93_body.html

Backup Slides

Global Sea Surface Salinity (SSS): Anomaly for July 2023

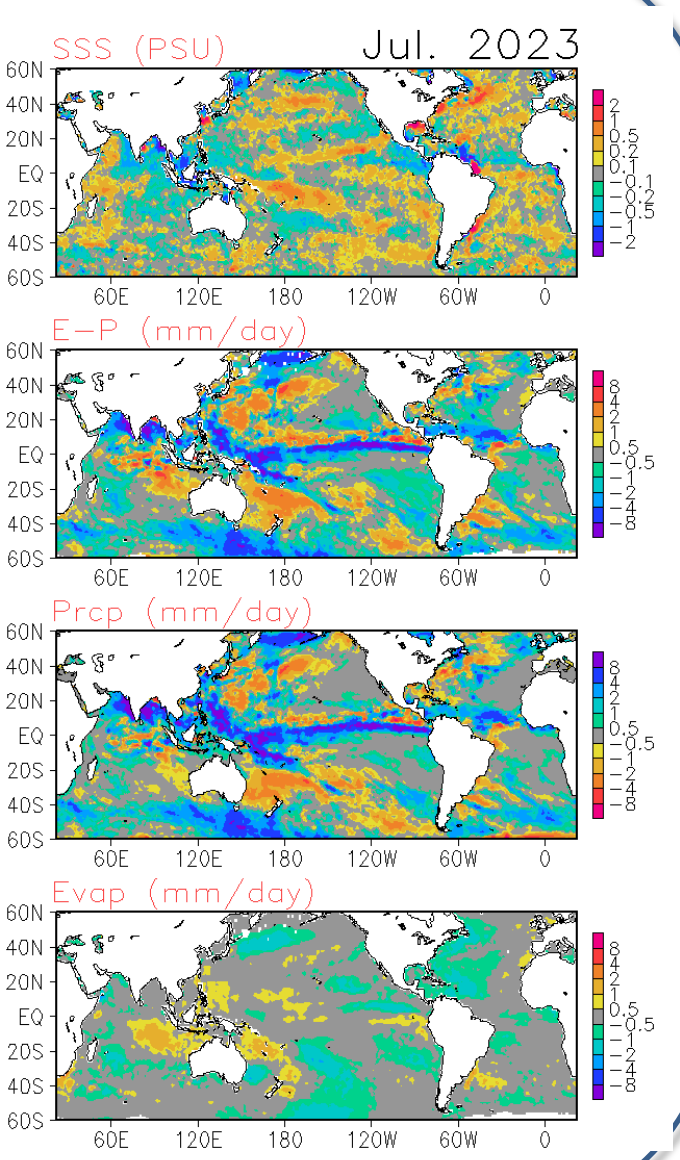
New Update: The NCEI SST data used in the quality control procedure has been updated to version 2.1 since May 2020;

ITCZ is further enhanced and positioned south of its climatological latitudes across the pacific and over the Maritime continent, causing freshening SSS anomalies there and saltier anomalies north of it. In particular, a belt of strong positive precipitation / negative E-P / freshening SSS anomalies is observed over the tropical /sub-tropical western Pacific where typhoons have been active during July. Over the Atlantic sector, enhanced ITCZ is observed slightly north of its mean position, resulting in freshening SSS anomalies. Indian monsoon precipitation is also above normal during July.

SSS : Blended Analysis of Surface Salinity (BASS) V0.Z
(a CPC-NESDIS/NODC-NESDIS/STAR joint effort)
ftp.cpc.ncep.noaa.gov/precip/BASS

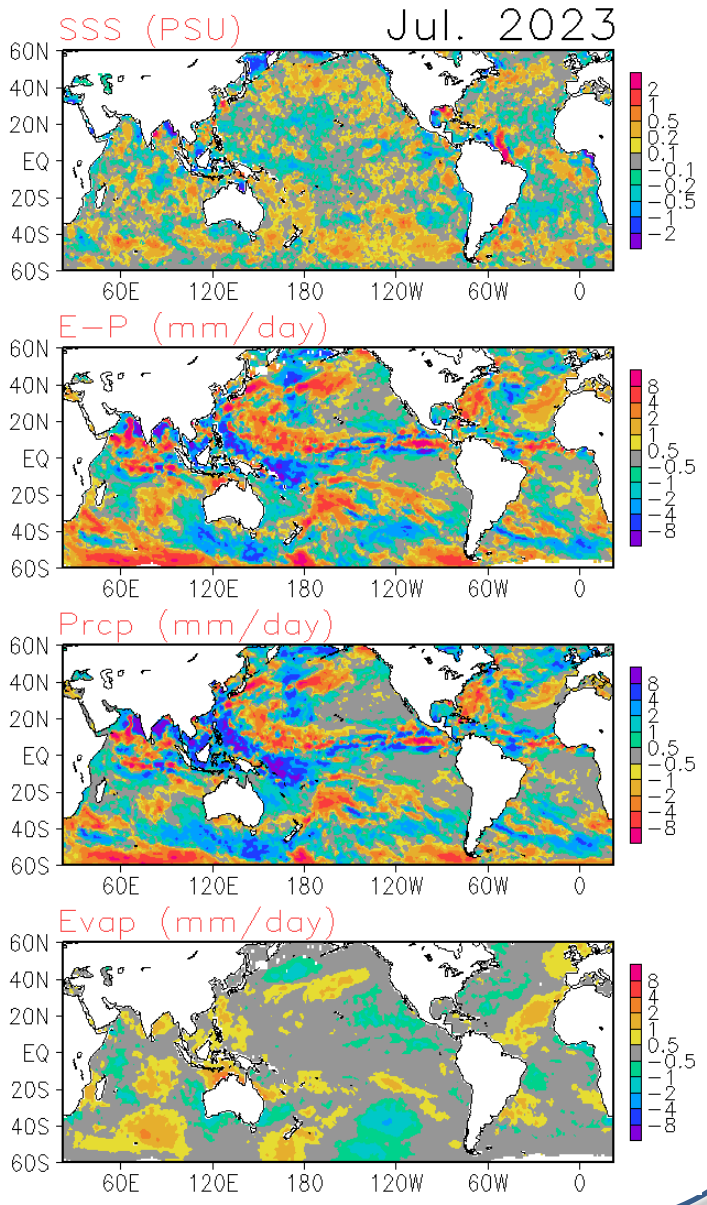
Precipitation: CMORPH adjusted satellite precipitation estimates

Evaporation: Adjusted CFS Reanalysis



Global Sea Surface Salinity (SSS): Tendency for July 2023

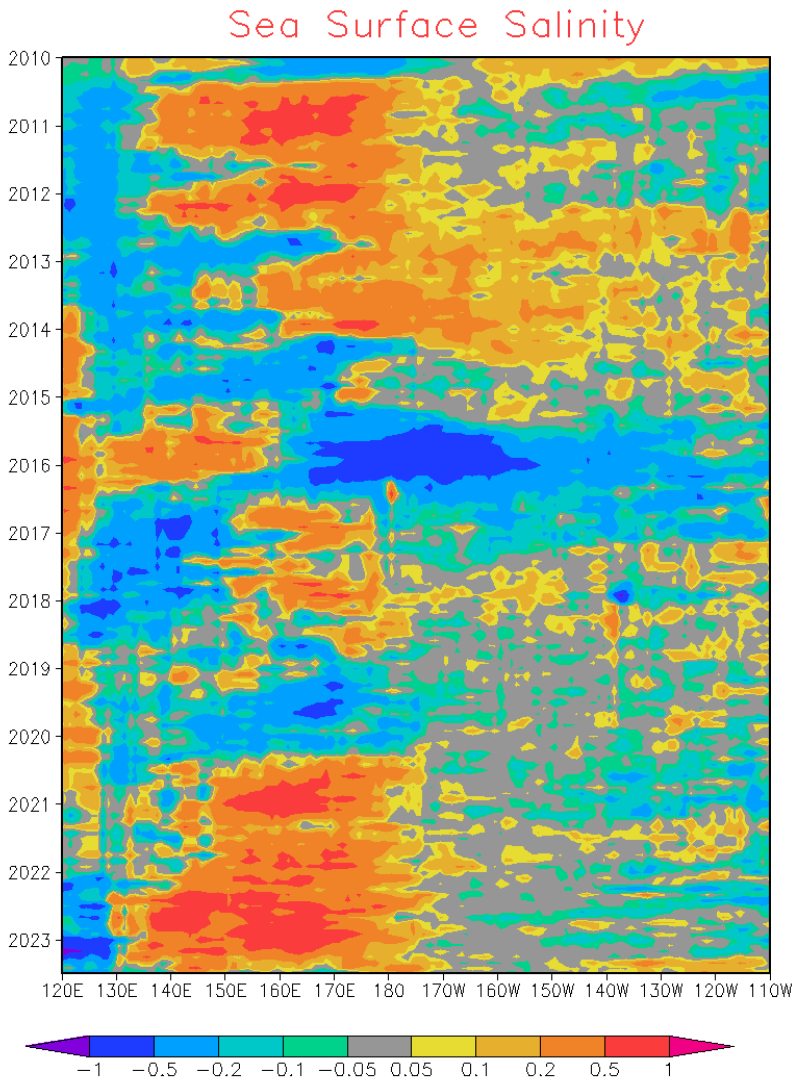
Enhanced ITCZ precipitation (convection) / freshening SSS tendency is observed across the Pacific and located south of its climatological positions. In particular, a large portion of the tropical western pacific east of the Maritime Continent and off the Asian continent coasts shows negative SSS tendency. Freshening SSS tendency also appears over the northern Indian Ocean and the Bay of Bengal, a reflection of an enhanced Monsoon during July.



Monthly SSS Anomaly Evolution over Equatorial Pacific

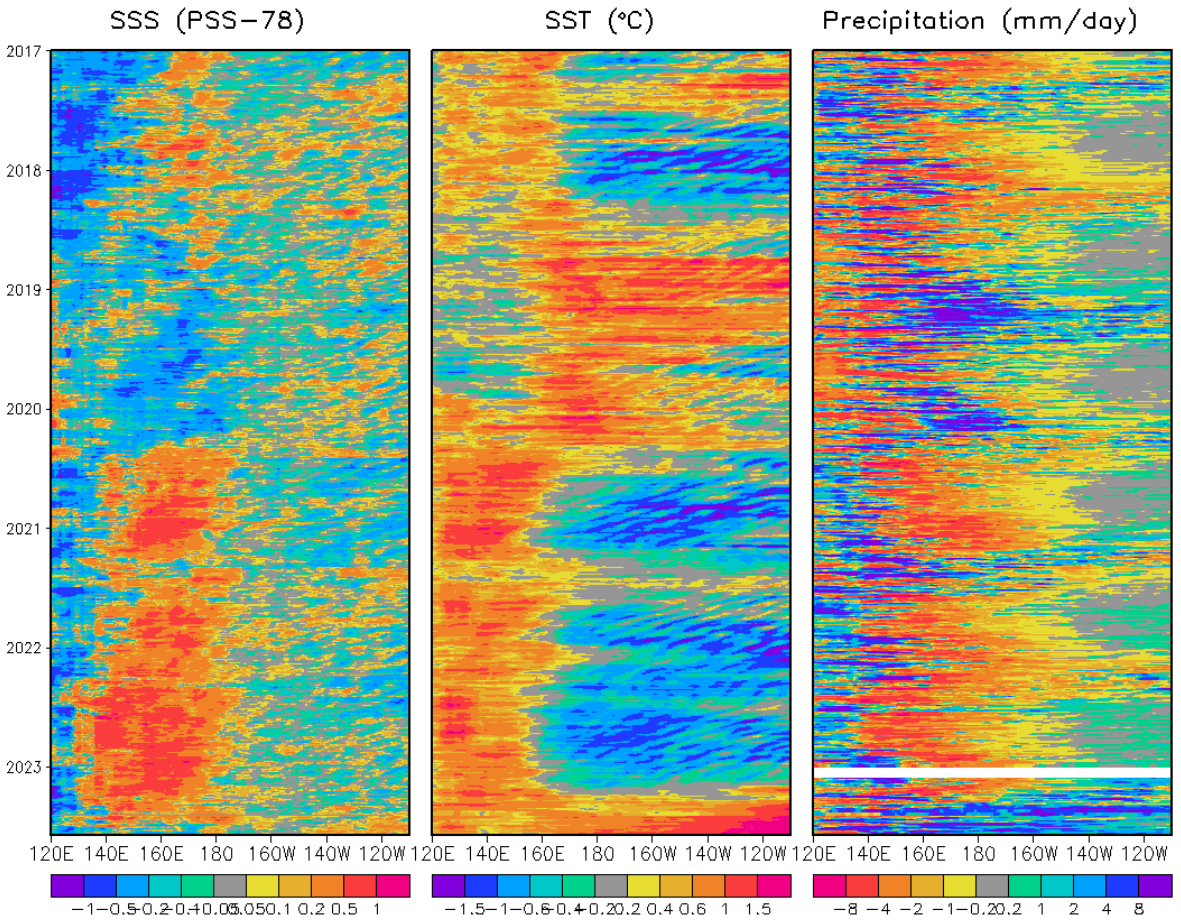
NOTE: Since June 2015, the BASS SSS is from in situ, SMOS and SMAP; before June 2015,The BASS SSS is from in situ, SMOS and Aquarius.

- Hovermoller diagram for equatorial SSS anomaly **(5˚S-5˚N);**
- Positive SSS anomalies over the western and central equatorial Pacific (130ºE-180º) is mostly gone, replaced by the negative SSS anomalies. Alternating signs of the weak SSS anomalies over the eastern Pacific is a reflection of the multiple zonally oriented bands of +/- SSS anomalies over the region.

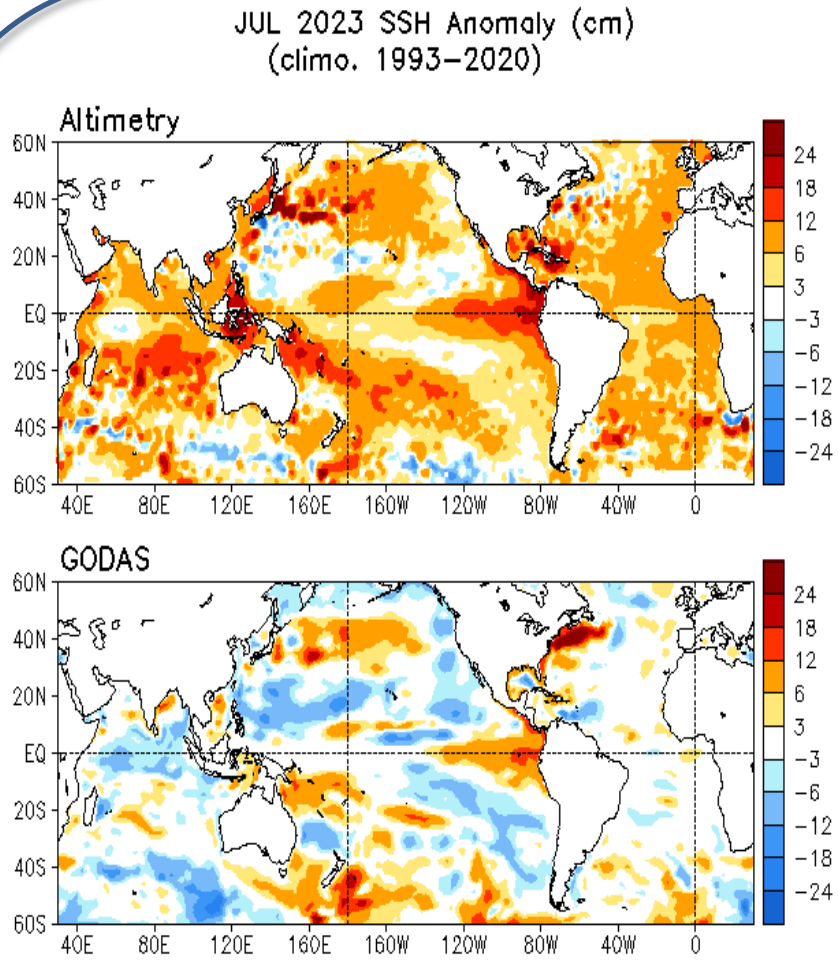


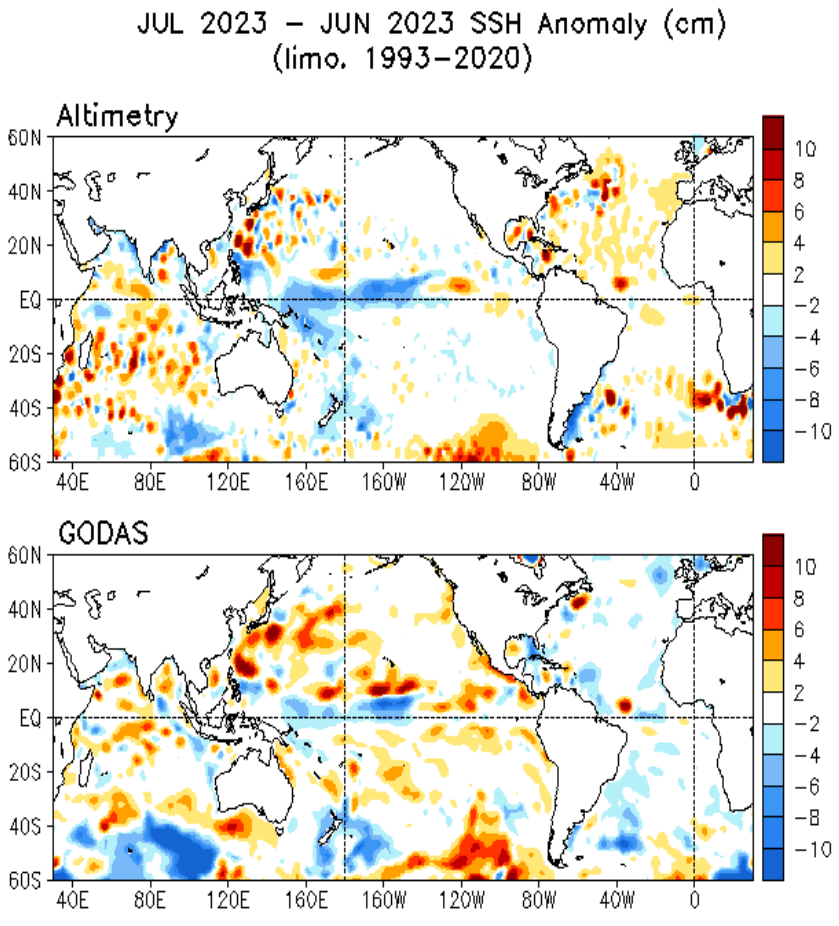
Pentad SSS Anomaly Evolution over Equatorial Pacific

Figure caption: Hovermoller diagram for equatorial (5°S-5°N) 5-day mean SSS, SST and precipitation anomalies. The climatology for SSS is Levitus 1994 climatology. The SST data used here is the OISST V2 AVHRR only daily dataset with its climatology being calculated from 1985 to 2010. The precipitation data used here is the adjusted CMORPH dataset with its climatology being calculated from 1999 to 2013.



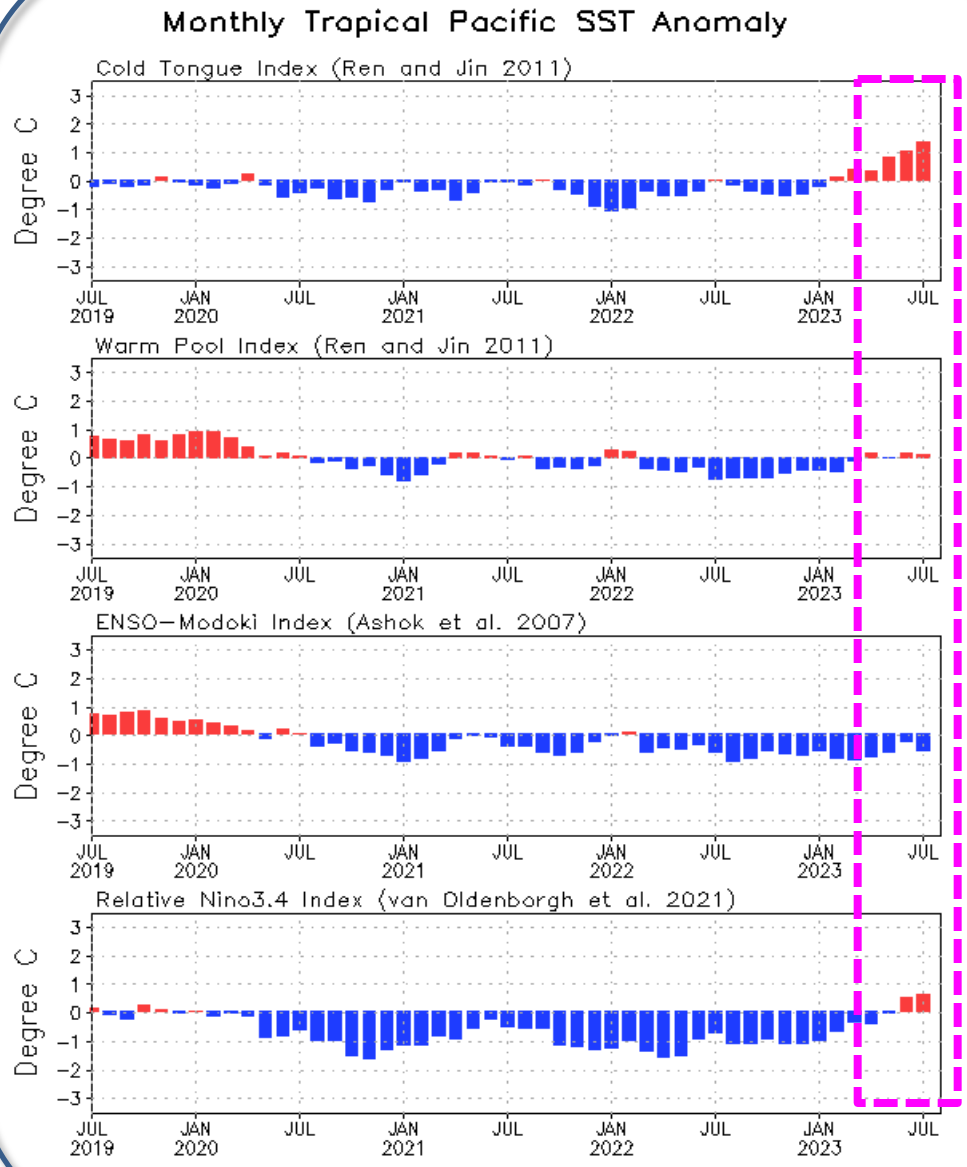
AVISO & GODAS SSH Anomaly (cm) and Anomaly Tendency

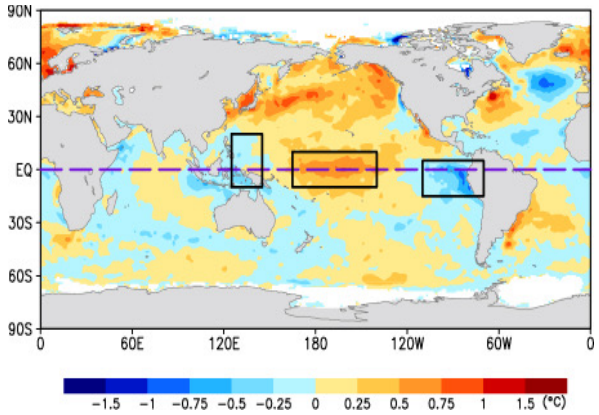




- SSHs were above normal in the equatorial Pacific in GODAS & AVISO.
- The tendencies indicated an increase (decrease) of SSH in the eastern (western) tropical Pacific.

Evolution of Pacific Niño SST Indices



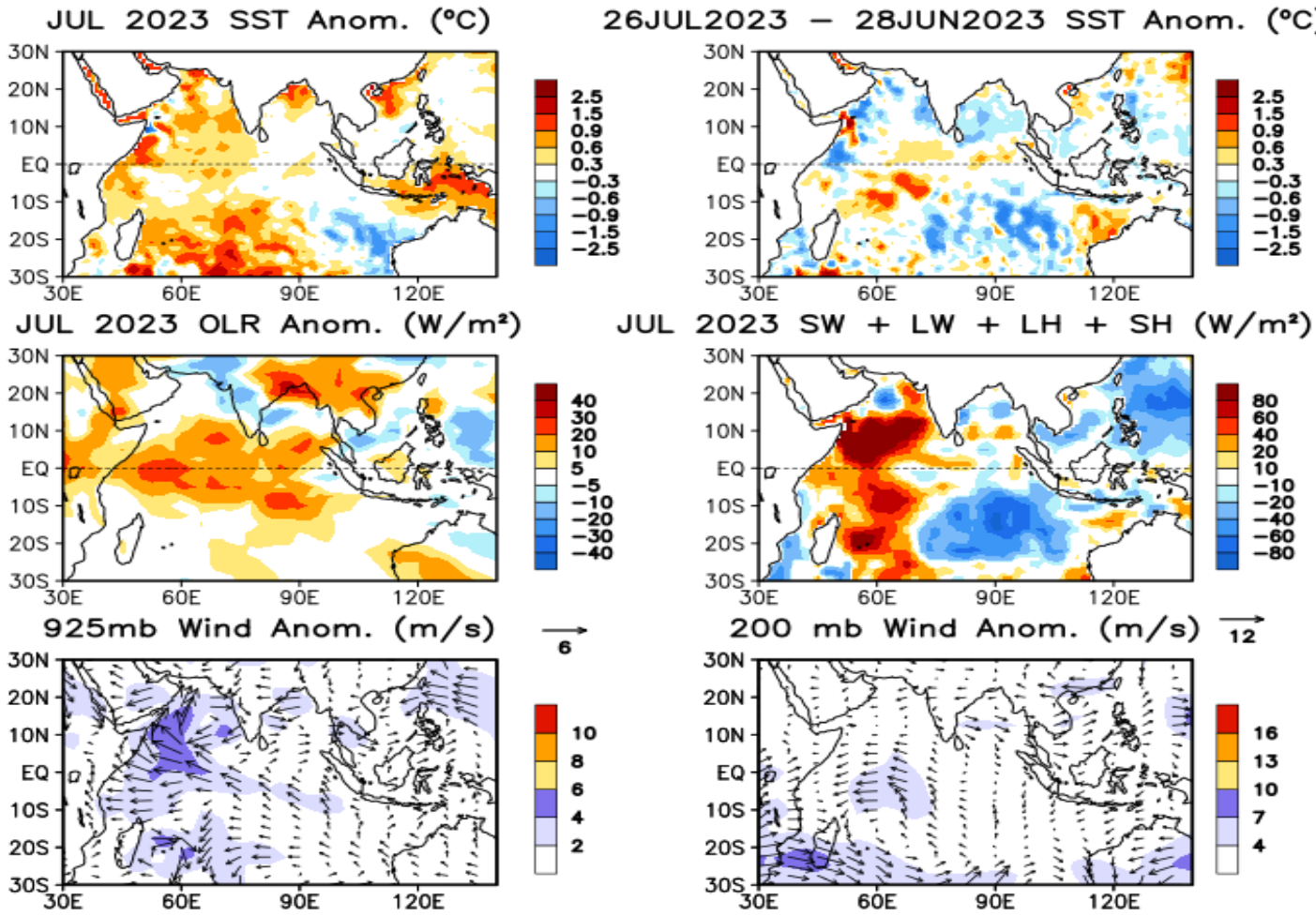


- Relative Niño3.4 index is now included in ENSO monitoring, which is defined as the conventional Niño3.4 index minus the SSTA averaged in the whole tropics (0º-360º, 20ºS-20ºN), in order to remove the global warming signal. Also, to have the same variability as the conventional Niño3.4 index, the relative Niño3.4 index is renormalized (van Oldenborgh et al. 2021: ERL, 10.1088/1748-9326/abe9ed).

Relative Niño3.4 data updated monthly at:

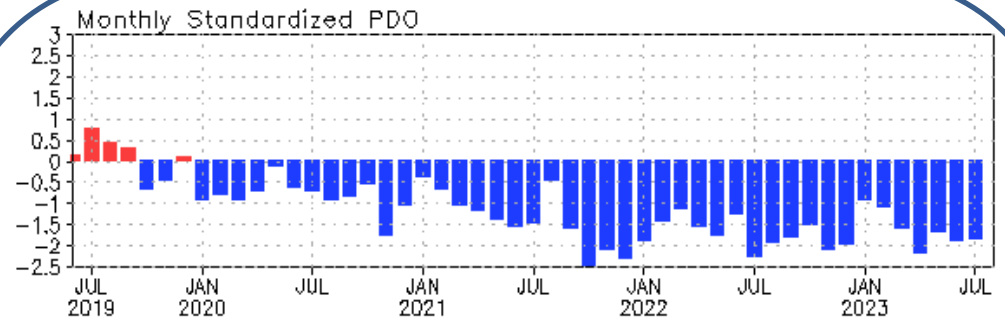
https://www.cpc.ncep.noaa.gov/data/indices/RONI.ascii.txt

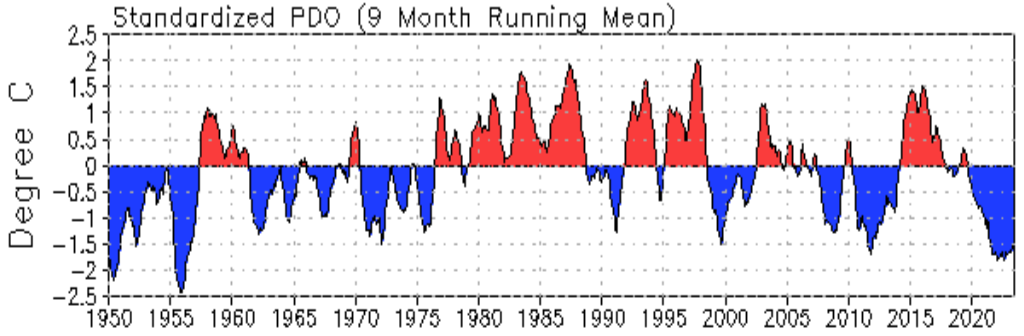
Tropical Indian: SSTA, SSTA Tend., OLR, Sfc Rad, Sfc Flx, 925-mb & 200-mb Wind Anom.

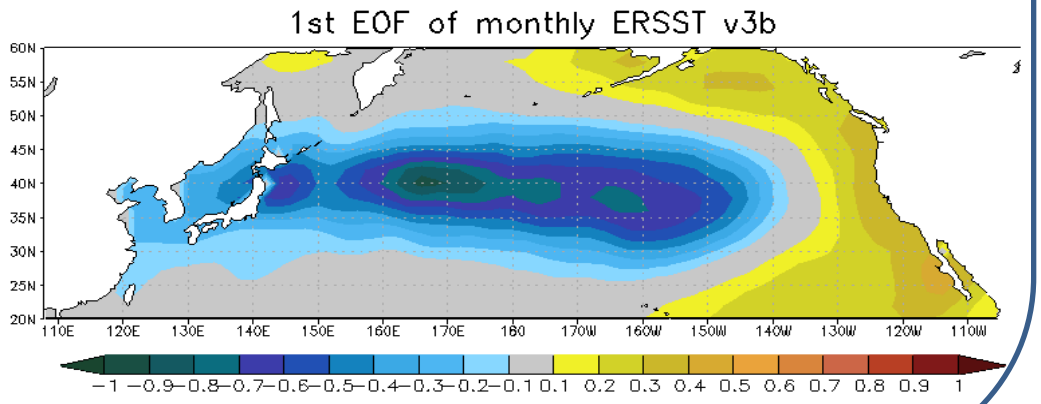


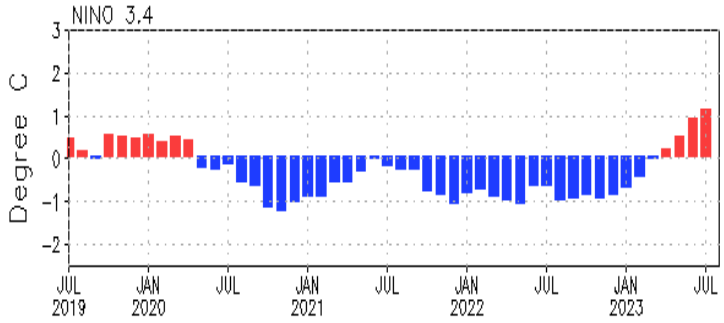
SSTAs (top-left), SSTA tendency (top-right), OLR anomalies (middle-left), sum of net surface short- and long-wave radiation, latent and sensible heat flux anomalies (middle-right), 925-mb wind anomaly vector and its amplitude (bottom-left), 200-mb wind anomaly vector and its amplitude (bottom-right). SST are derived from the OIv2.1 SST analysis, OLR from the NOAA 18 AVHRR IR window channel measurements by NESDIS, winds and surface radiation and heat fluxes from the NCEP CDAS. Anomalies are departures from the 1991-2020 base period means.

Pacific Decadal Oscillation (PDO) Index









- The PDO has been in a negative phase since Jan 2020 with PDOI = -1.9 in Jul 2023.

- Statistically, ENSO leads PDO by 3-4 months, through teleconnection via atmospheric bridge, with El Niño (La Niña) associated with positive (negative) PDO Index.

• PDO is defined as the 1st EOF of monthly ERSST v3b in the North Pacific for the period 1900-1993. PDO index is the standardized projection of the monthly SST anomalies onto the 1st EOF pattern.

A potential predictor for seasonal outlook: Atlantic Niño

(Courtesy of Dongmin Kim)

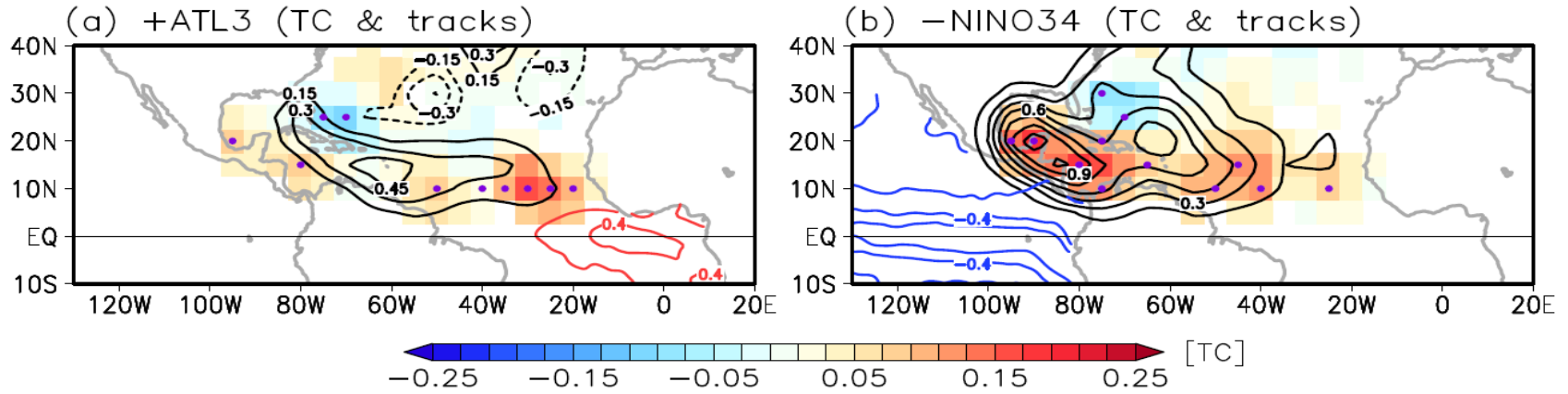
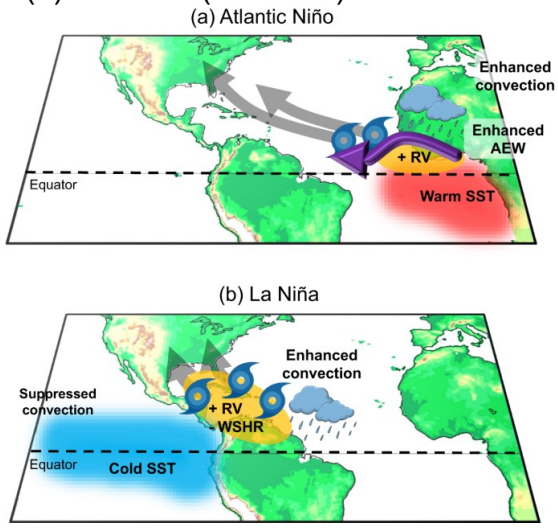


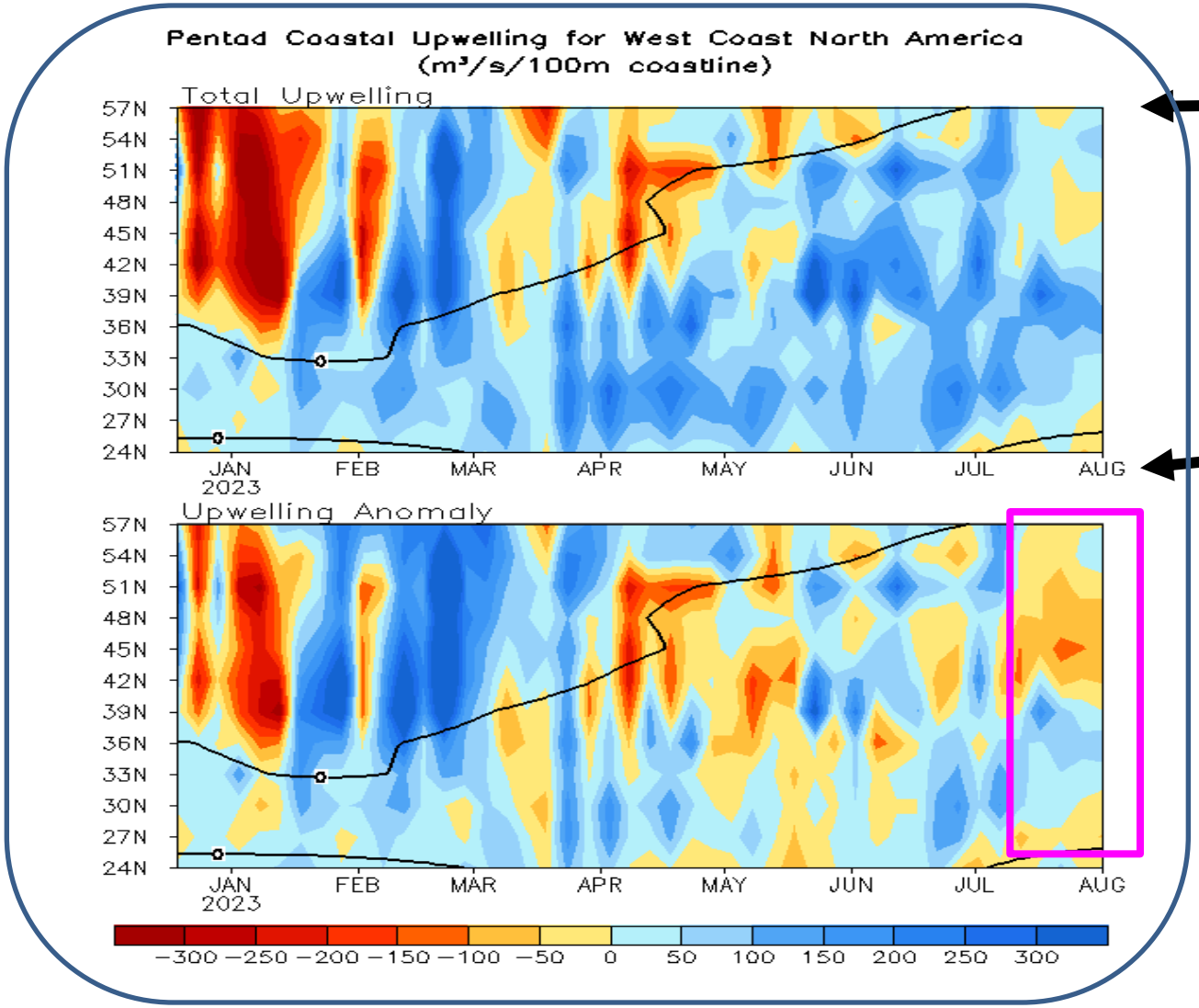
Fig. Partial regressions of tropical cyclone genesis (shaded), track density (black contours), and sea surface temperature anomalies (red and blue contours, interval is 0.2 K) onto (a) Atlantic Niño (ATL3) and (b) Niño 3.4 (NINO3.4) indices

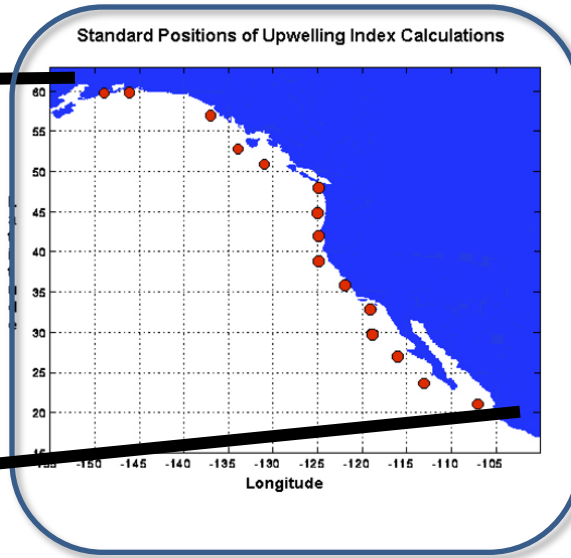
- Atlantic Niño/Niña is a dominant climate mode during Atlantic hurricane season (June–November).
- Atlantic Niño, by strengthening the Atlantic inter-tropical convergence zone rainband, enhances African easterly wave activity and low-level cyclonic vorticity across the deep tropical eastern North Atlantic. These conditions increase the likelihood of hurricanes developing in the deep tropics near the Cape Verde islands
- Atlantic Niño/Niña may serve as an additional predictor to improve seasonal Atlantic hurricane outlooks, especially when ENSO and AMM are in near-neutral phases



Kim, D. et al. (2023): Increase in Cape Verde hurricanes during Atlantic Niño. *Nat Commun* **14**, 3704 https://doi.org/10.1038/s41467-023-39467-5

North America Western Coastal Upwelling

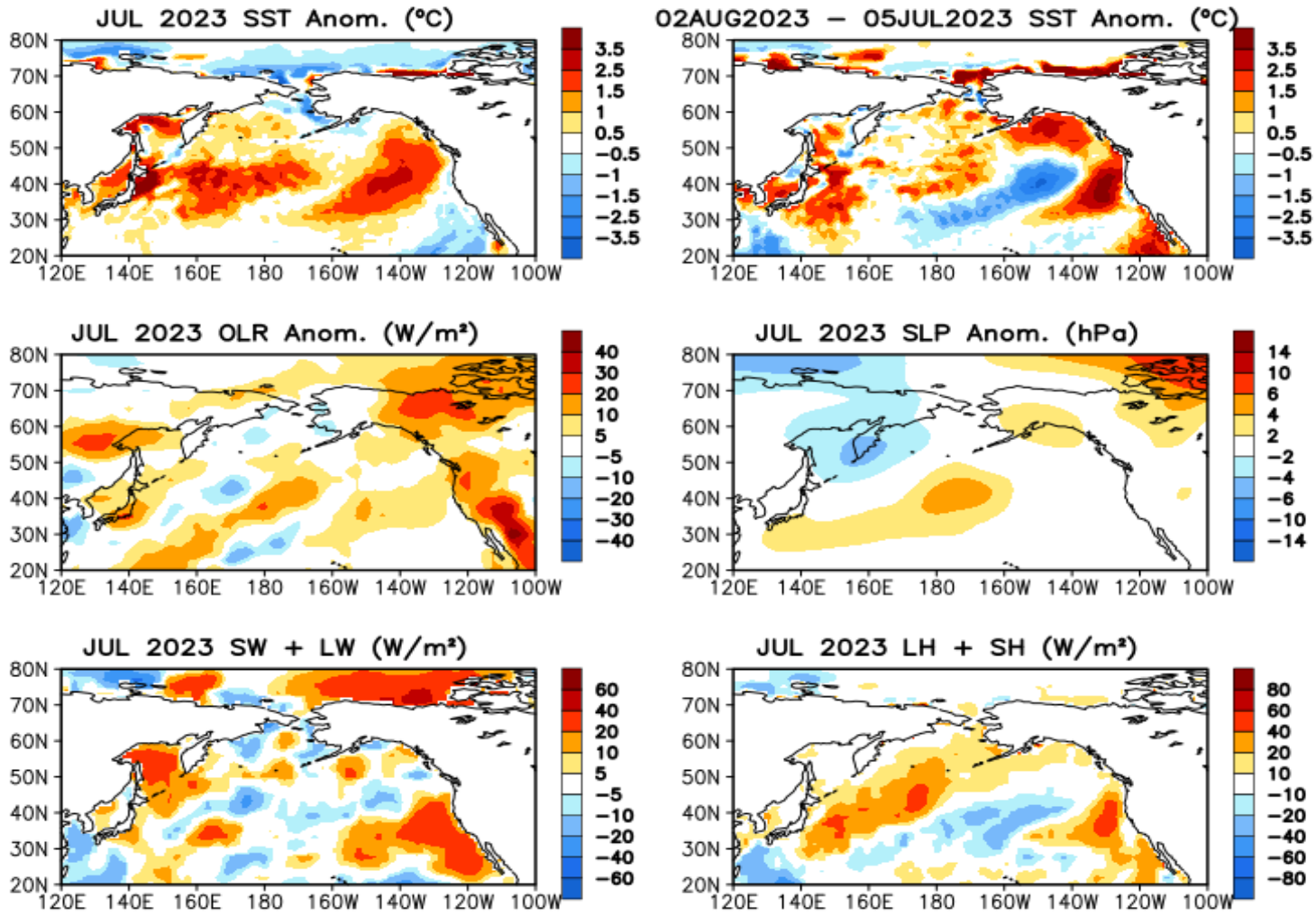




- Coastal (39º-54ºN) anomalous upwelling and downwelling were observed in Jul 2023.

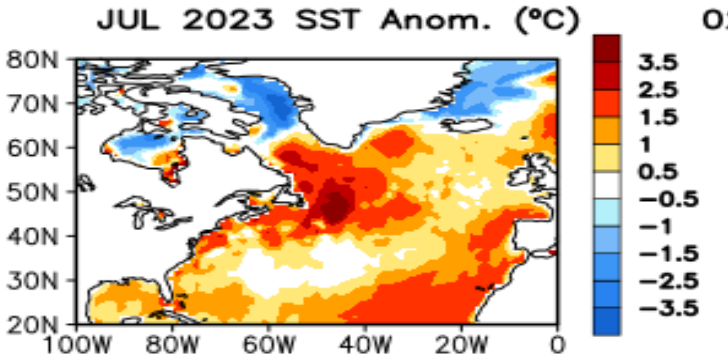
(top) Total and (bottom) anomalous upwelling indices at the 15 standard locations for the western coast of North America. Derived from the vertical velocity of the NCEP's GODAS and are calculated as integrated vertical volume transport at 50-meter depth from each location to its nearest coast point (m³/s/100m coastline). Anomalies are departures from the 1991-2020 base period pentad means.
- Area below (above) black line indicates climatological upwelling (downwelling) season.
- Climatologically upwelling season progresses from March to July along the west coast of North America from 36ºN to 57ºN.

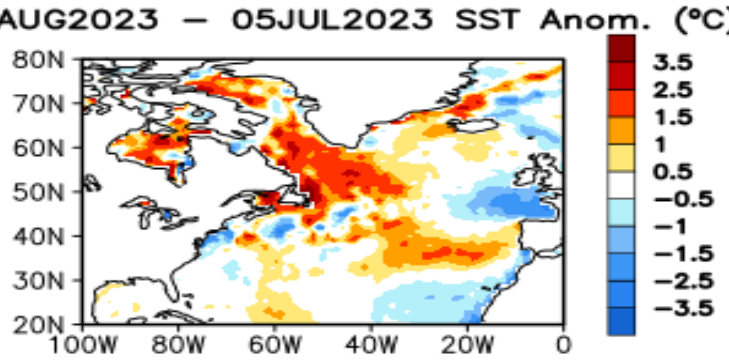
North Pacific & Arctic Ocean: SSTA, SSTA Tend., OLR, SLP, Sfc Rad, Sfc Flx Anomalies

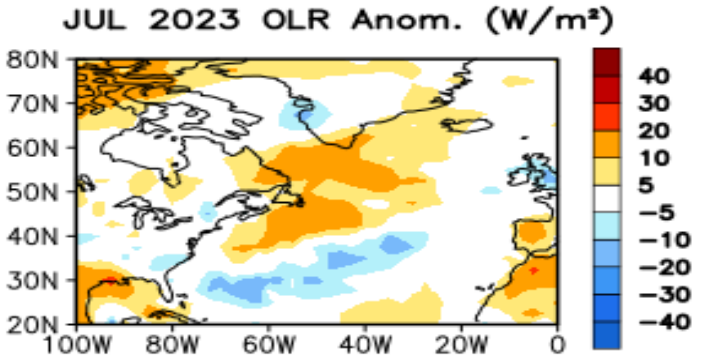


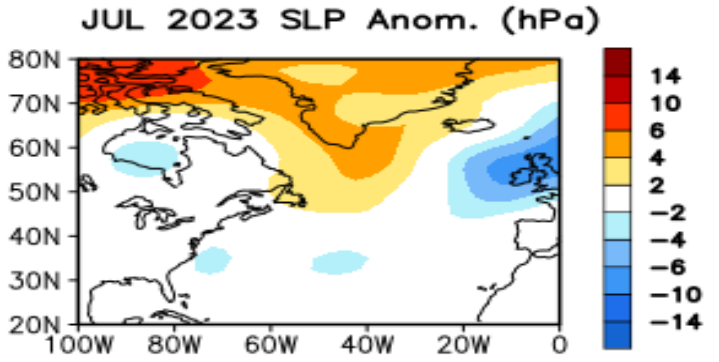
SSTA (top-left; OIv2.1 SST Analysis), SSTA tendency (top-right), Outgoing Long-wave Radiation (OLR) (middle-left; NOAA 18 AVHRR IR), sea surface pressure (middle-right; NCEP CDAS), sum of net surface short- and long-wave radiation (bottom-left; positive means heat into the ocean; NCEP CDAS), sum of latent and sensible heat flux (bottom-right; positive means heat into the ocean; NCEP CDAS). Anomalies are departures from the 1991-2020 base period means.

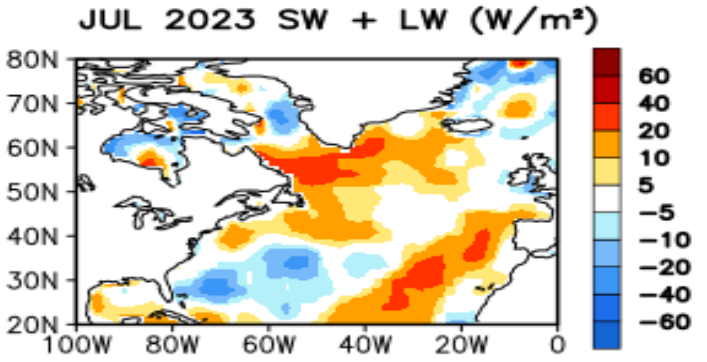
N. Atlantic: SST, SST tend., OLR, SLP, & heat flex anom.

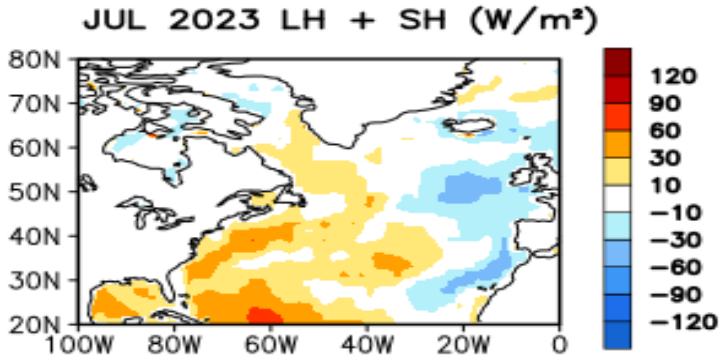




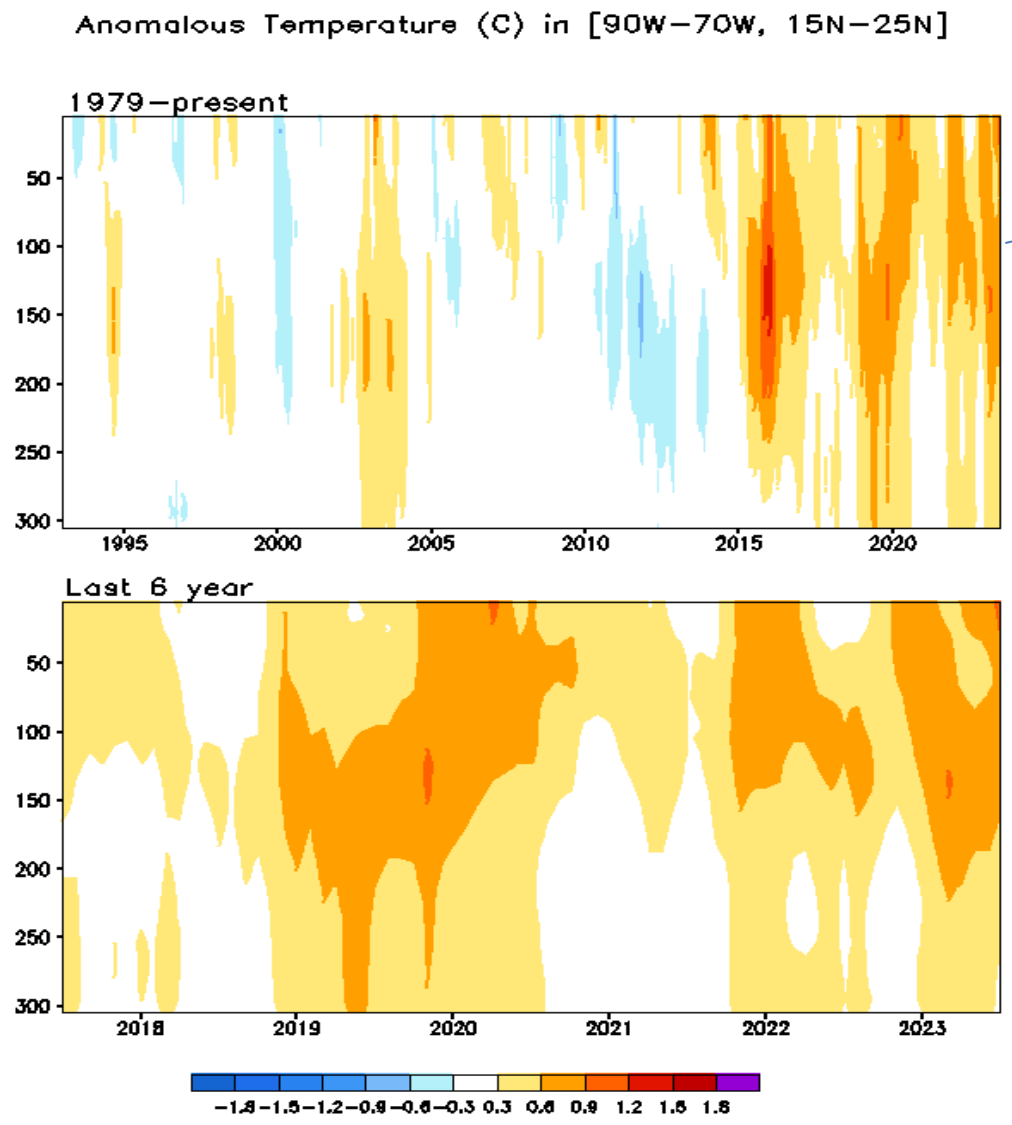


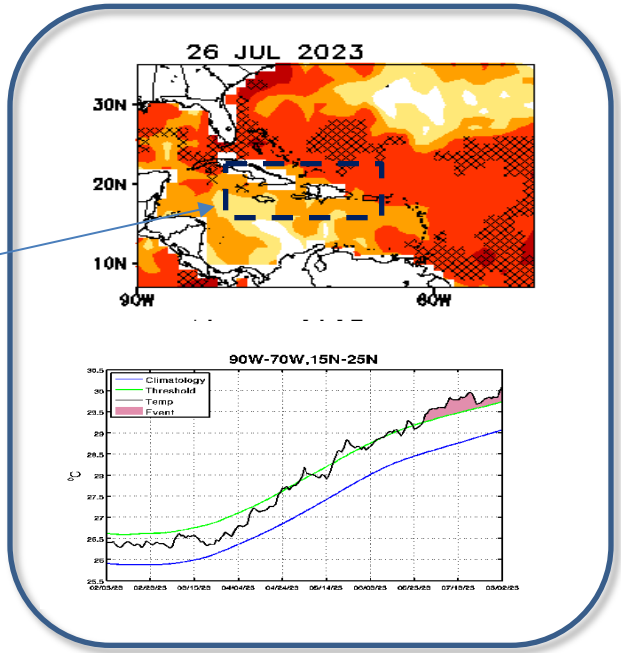






Subsurface Temperature Anomaly in the Northcentral Pacific

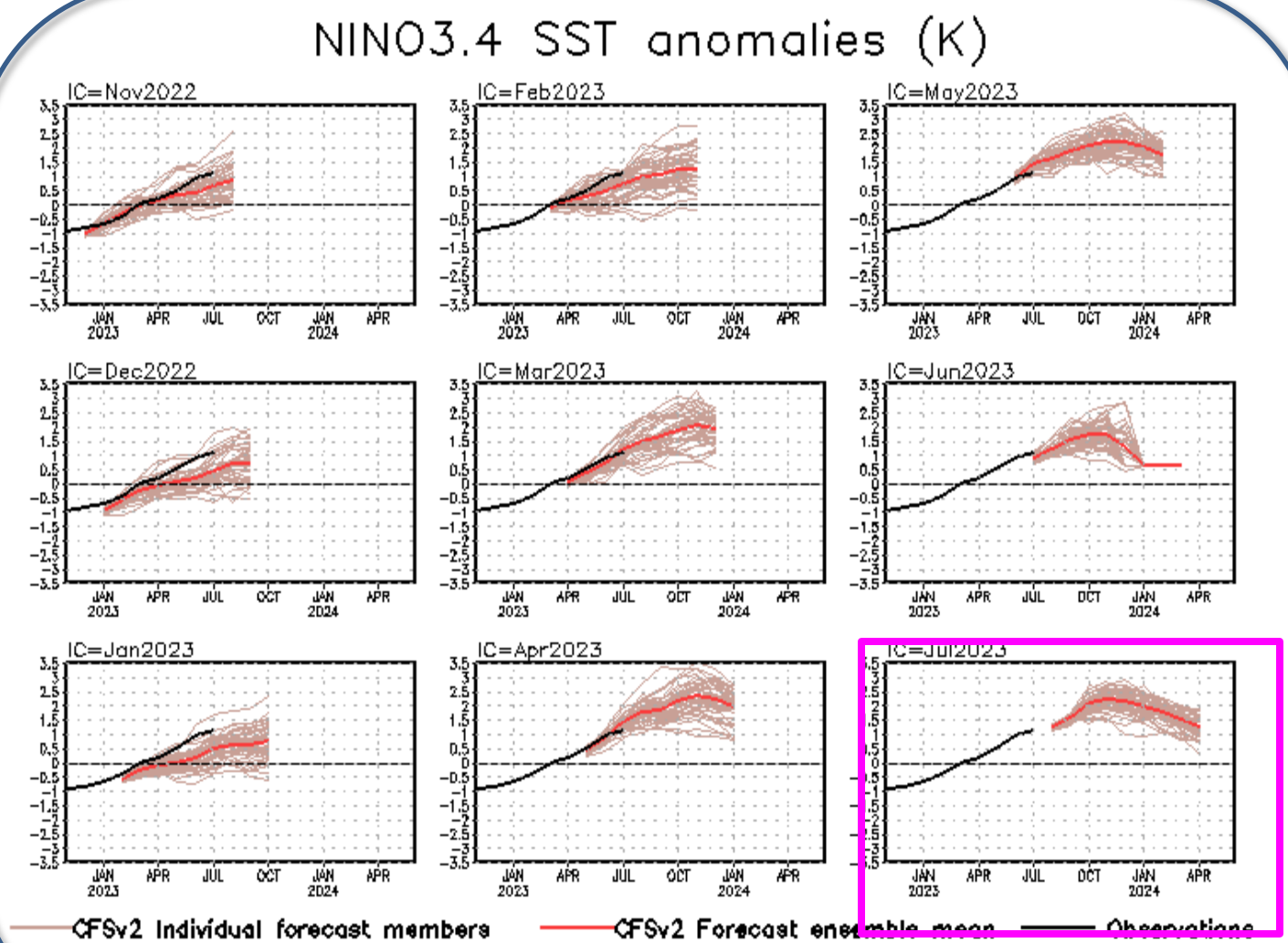




- Positive temperature anomaly (>0.9ºC) penetrated to 100m and persisted since 2020.

- Subsurface warming in the last three years is the strongest event since 1979.

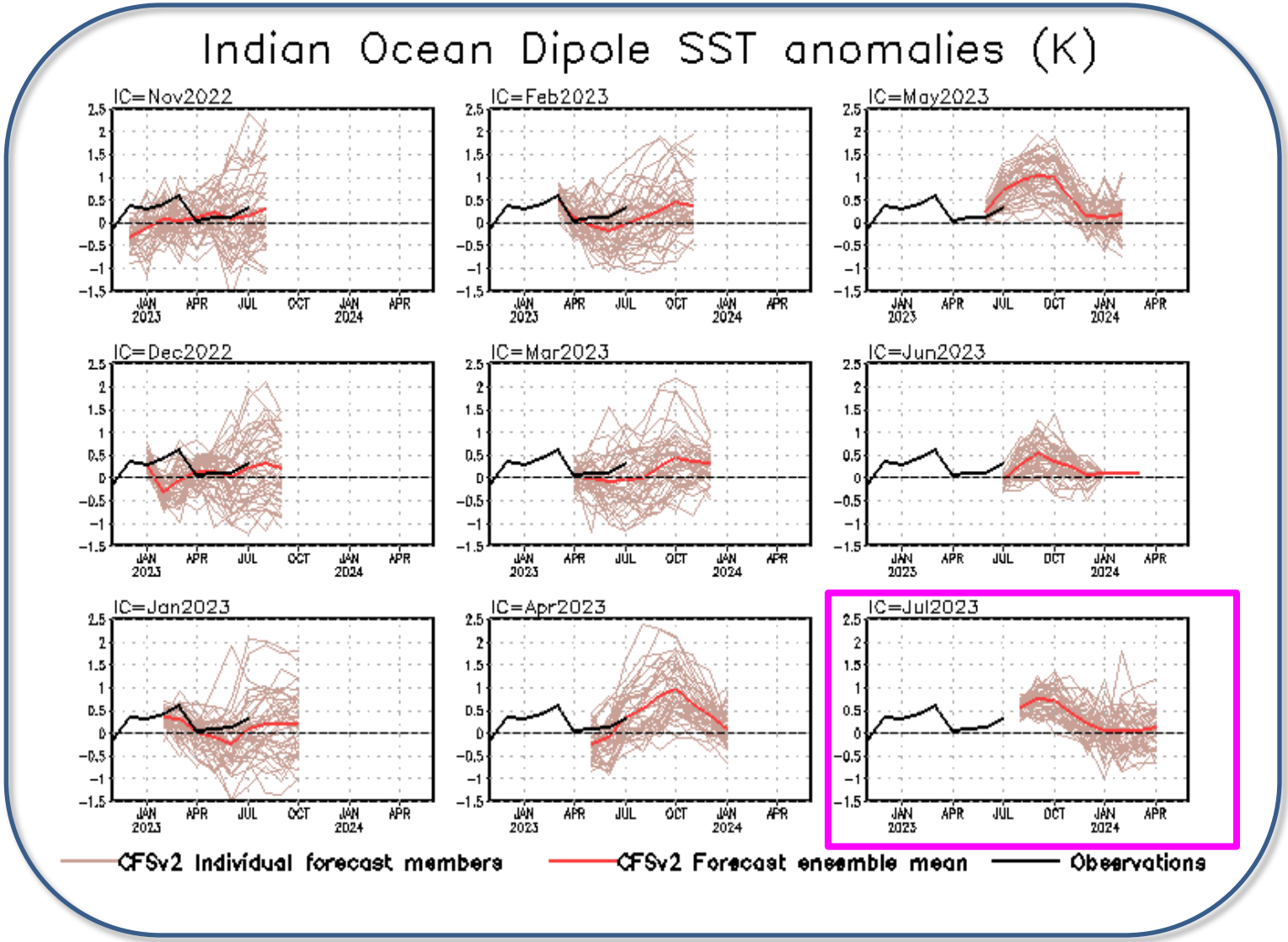
CFS Niño3.4 SST Predictions from Different Initial Months



- The latest CFSv2 forecasts call for an El Niño in the second half of 2023.

CFS Niño3.4 SST prediction from the latest 9 initial months. Displayed are 40 forecast members (brown) made four times per day initialized from the last 10 days of the initial month (labelled as IC=MonthYear) as well as ensemble mean (blue) and observations (black). Anomalies were computed with respect to the 1991-2020 base period means.

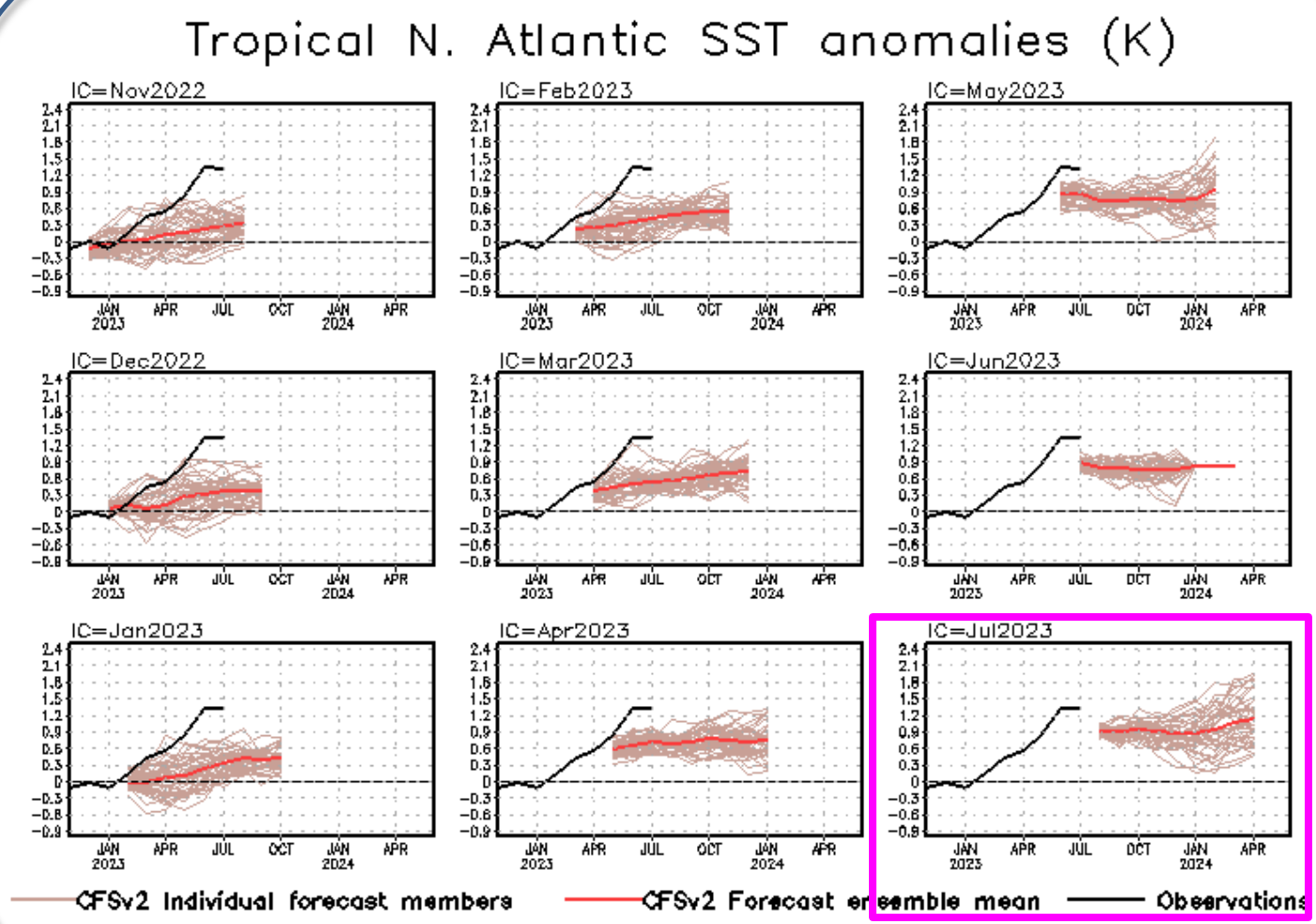
NCEP CFS DMI SST Predictions from Different Initial Months



- CFSv2 predicts a positive phase of IOD in the 2nd half of 2023.

CFS Dipole Model Index (DMI) SST predictions from the latest 9 initial months. Displayed are 40 forecast members (brown) made four times per day initialized from the last 10 days of the initial month (labelled as IC=MonthYear) as well as ensemble mean (blue) and observations (black). The hindcast climatology for 1981-2006 was removed, and replaced by corresponding observation climatology for the same period. Anomalies were computed with respect to the 1991-2020 base period means.

CFS Tropical North Atlantic (TNA) SST Predictions from Different Initial Months



- Latest CFSv2 predictions call for above-normal SST in the tropical North Atlantic.

CFS Tropical North Atlantic (TNA) SST predictions from the latest 9 initial months. Displayed are 40 forecast members (brown) made four times per day initialized from the last 10 days of the initial month (labelled as IC=MonthYear) as well as ensemble mean (blue) and observations (black). Anomalies were computed with respect to the 1991-2020 base period means. TNA is the SST anomaly averaged in the region of [60oW-30oW, 5oN-20oN].