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Research Article

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The-Cyclone-Freddy-in-The-Southwest-Indian-Ocean-(2022-2023-Cyclone-Season)

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1. Introduction

The-conditions-for-the-formation-of-cyclones-formulated-by-Palmen,-cited-by-G.-Donque,-are-present-in-the-southwest-Indian-Ocean.-The-first-frequent-formation-area-is-in-the-center-of-the-Indian-Ocean,-at-the-level-of-Agalega-and-near-Diego-Garcia.-These-cyclones-move-from-east-to-west-and-cross-the-extreme-north-of-the-island-to-exit-into-the-Mozambique-Channel:-this-type-of-trajectory-represents-14%-of-the-trajectories-from-1959-89.-Cyclones-with-this-type-of-trajectory-appear-at-the-beginning-of-the-austral-summer:-from-October-to-December.-The-second-preferred-formation-area-in-the-Indian-Ocean-is-near-the-island-of-Tromelin,-where-cyclones-enter-the-east-coast-south-of-Toamasina.-In-this-case,-cyclones-can-climb-the-eastern-slope,-cross-the-Highlands-south-of-Antananarivo,-and-exit-the-island-between-Morondava-and-Toliara.-This-type-of-trajectory-represents-12%-of-the-trajectories-from-1959-89.-A-third-type-of-trajectory-was-observed-entering-Madagascar-at-Mananjary-to-exit-near-Faux-Cap.-They-represent-9%-of-cyclones-from-1959-89,-and-a-fourth-type-of-trajectory-only-concerns-the-east-coast-of-Madagascar,-where-cyclones-run-along-the-eastern-slope-to-exit-on-the-side-of-Farafangana-(9%)-or-by-taking-a-maritime-trajectory-off-the-east-coast-(22%).-Currently,-the-first-type-of-trajectory-remains-the-most-important.-Out-of-24-cyclones-born-in-the-Indian-Ocean,-7/24-have-this-first-type-of-trajectory.-The-second-type-has-occurred-only-twice,-2/24,-the-third-type-only-once,-1/24-in-20-years.-However,-the-fourth-type-of-trajectory-is-still-the-most-followed-by-cyclones,-with-a-frequency-of-7/24.

Cyclones-in-the-Indian-Ocean-have-four-types-of-trajectories,-illustrated-in-Fig.1.-

The-second-formation-area-is-the-Mozambique-Channel-at-Cap-St-André.-J.-Randrianarison,-1991,-showed-that-cyclones-coming-from-the-Mozambique-Channel-have-three-trajectories:-the-first-type-is-shown-by-cyclones-born-north-of-Cape-Amber-and-entering-the-NW-coast-"to-cross-the-island-from-NW-to-SE-and-exit-into-the-Indian-Ocean-near-Mahanoro-and-Vatomandry":-"they-often-circulate-south-of-Antananarivo"-by-J.-Randrianarison,-1991.

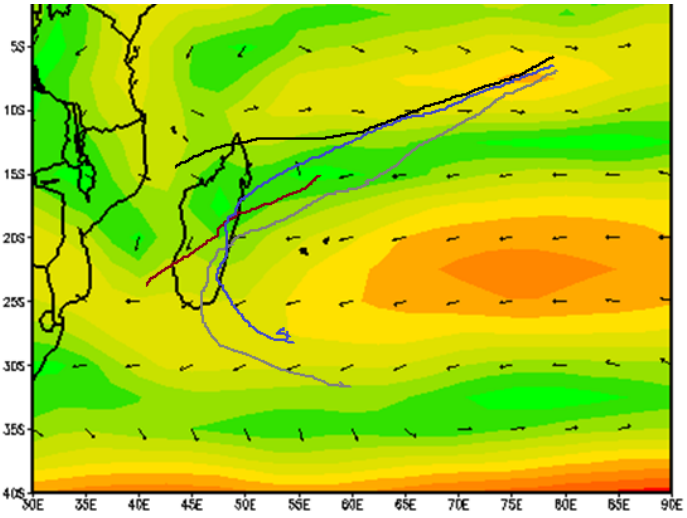


Figure 1: Trajectories-of-cyclones-born-in-the-Indian-Ocean
Source-:-DGM
_____-:-1st-trajectory-type
_____-:2nd-trajectory-type
_____-:-3rd-trajectory-type
_____-:4th-trajectory-type

The-second-type-of-trajectory-corresponds-to-cyclones-that-enter-between-Morondava-and-Toliara-and-exit-into-the-Indian-Ocean-between-Farafangana-and-Fort-Dauphin,-and-the-third-type-where-cyclones-do-not-touch-the-island.-On-average,-the-lifespan-of-a-cyclone-is-a-few-days-to-a-week,-yet-Cyclone-Freddy-lasted-for-more-than-a-month,-from-February-7th-to-March-13th.-The-system-generating-Cyclone-Freddy-formed-on-February-7th-around-116°E-and-10°S-off-the-coast-of-Australia-and-continued-to-exist-on-March-13th-on-the-Mozambican-coast.-The-trajectory-of-Cyclone-Freddy-initially-followed-the-third-type-of-trajectory-and-the-second-type-during-its-final-

phase,-touching-the-Tropic-of-Capricorn,-then-it-returned-to-the-intertropical-zone-and-descended-in-latitude-before-returning-to-the-latitude-at-the-borders-of-the-tropical-zone-and-descending-again-in-latitude.-This-trajectory-is-shown-in-Figure-2,-as-of-March-11th.-Additionally,-Cyclone-Freddy-is-an-exceptional-cyclone-due-to-its-trajectory,-long-lifespan,-and-the-human-and-material-damage-it-caused.

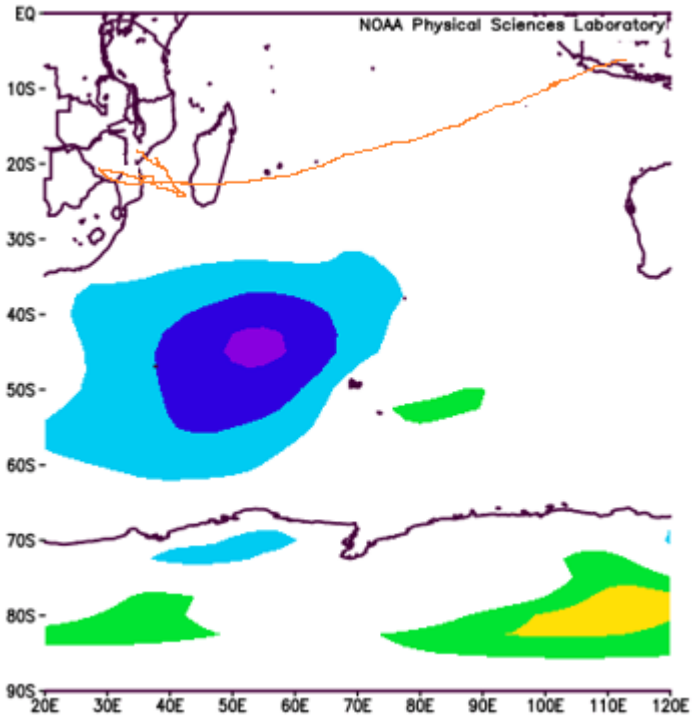


Figure 2: Trajectory-of-cyclone-Freddy

The-chosen-problem-is-to-investigate-the-effects-of-synoptic-environment-that-determine-the-trajectory-and-lifespan-of-Cyclone-Freddy.-Based-on-the-observation-of-global-climate-oscillations,-the-primary-factor-that-determined-these-phenomena-was-atmospheric-pressure.-Therefore,-the-main-objective-is-to-demonstrate-that-Cyclone-Freddy-evolved-within-a-context-of-variability-of-pressure-fields-in-the-Southwest-Indian-Ocean-(SWOI).-The-secondary-objectives-are-to-investigate-the-oscillations-affecting-this-area-of-the-Indian-Ocean-and-the-influence-of-air-and-sea-surface-temperatures.-The-hypotheses-are-that-the-Antarctic-Oscillation-has-effects-on-Cyclone-Freddy,-the-jet-stream-blocks-depressions-at-tropical-latitudes,-and-the-Mozambique-Channel-remains-a-warm-sea.

2. Methods and-Data

The-Chosen-Parameters

Based-on-these-assumptions,-the-choice-of-climate-parameters-is-based-on-sea-level-pressure,-geopotential-altitudes-at-700-hPa,-500-hPa,-270-hPa,-and-50-hPa,-vector-wind-at-270-hPa,-and-sea-surface-temperature-in-the-SWOI. The-isobaric-field-at-sea-level-is-used-to-observe-depression-and-anticyclone-zones,-fronts,-and-also-the-direction-of-wind-flow.-Considering-sea-level-pressure-plays-a-role,-firstly-to-facilitate-comparison-of-pressure-values-and-secondly,-to-provide-an-overall-view-of-the-pressure-gradient-(G.T.-Trewartha,-1954).-The-interest-of-this-level-is-also-its-direct-relationship-with-the-underlying-sea-surface-(T.-Delworth,-1996);-and-thirdly,-it-allows-the-observation-of-variations-in-pressure-gradient-in-relation-to-changes-in-the-thermal-field-structure,-which-causes-the-variation-in-the-position-of-cellular-movements-(B.-Fontaine-et-al.,-1996).-In-addition-to-the-horizontal-distribution-of-pressure,-there-is-also-its-vertical-distribution.-This-is-represented-by-geopotential-altitudes-that-depend-on-the-thermal-and-hygrometric-properties-of-the-air-mass.-Half-of-the-air,-500-hPa,-is-confined-to-the-first-third-of-the-troposphere-thickness-(5.6-km)-and-two-thirds-of-this-pressure,-about-700-hPa,-and-one-fourth-of-the-pressure,-250-hPa,-in-the-two-thirds-of-this-thickness.-Moreover,-it-is-at-this-level-that-the-subtropical-jet-stream-oscillates. As-for-the-270-hPa-level,-it-is-the-level-of-the-polar-jet-axis-and-the-50-hPa-level-is-considered-as-the-location-of-the-manifestation-of-the-polar-vortex,-a-low-pressure-zone,-and-which-is-represented-by-cyclonic-fluxes.

The-sea-surface-temperature-indicates-the-air's-moisture-supply-role-if-the-conditions-of-evaporation-are-present.

For-each-of-the-parameters,-the-observation-is-made-on-their-anomaly-because-it-informs-about-their-situation-which-implies-the-state-of-the-observed-phenomenon.-The-Hachette-Encyclopedic-Dictionary-in-2001-speaks-of-anomaly-as-

"a-peculiarity-that-makes-something-different-from-what-it-should-be"-and-according-to-the-Glossary-of-noaa-cires/cdc,-the-anomaly-is-"the-difference-between-the-value-of-a-variable-at-a-given-location-and-its-long-term-average-at-that-location."
These-parameters-are-observed-at-American-and-Australian-sites.
The-daily-images-are-from-www.bom.gov.au
The-observed-images-are-downloaded-from-Bureau-Home->Antarctic-and-southernocean-weather>Indian-ocean-MSLPAnalysis>AnalysisChart-archive-from-February-7-to-March-11;
The-daily-composite-images-are-from-www.cdc.noaa.gov
The-dates-range-from-February-7th-to-March-11th,-2023.

3. Results

1-The-Antarctic-Oscillation-is-the-first-factor-in-Freddy's-trajectory.

At-the-ground-level,-negative-anomalies-of-sea-level-pressure-were-observed-in-the-Mozambique-Channel,-the-southern-half-of-Madagascar,-Australia,-the-NW-part-of-Australia,-and-generally-from-30°S-50°S-in-the-Indian-Ocean-and-the-western-part-of-the-southern-Pacific.-This-drop-ranges-from-l-to--3-hPa,-as-shown-in-Figure-3.

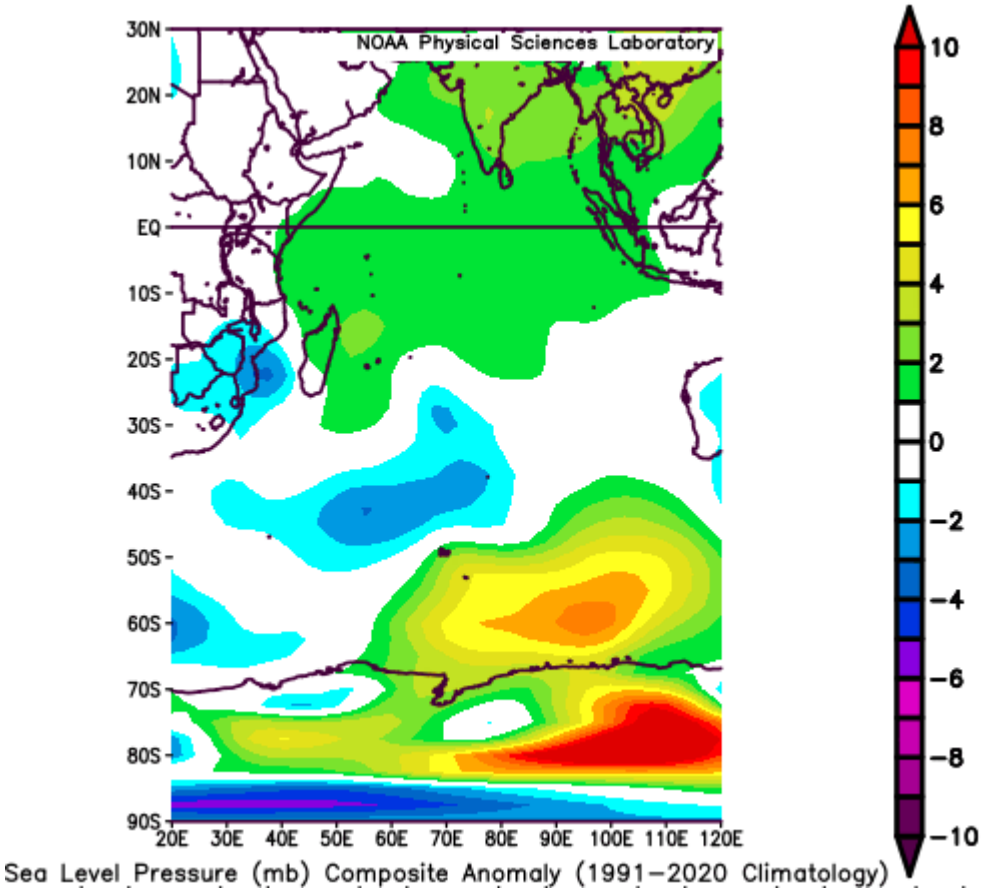


Figure 3: Pressure-anomalies-in-the-southwest-Indian-Ocean.

The-pressure-difference-at-the-surface,-shown-in-Fig.3,-helps-to-direct-the-system-towards-the-Mozambique-Channel-and-to-represent-the-exceptionally-meridional-position-of-the-ITCZ:-the-values-of-anomalies-from-+1hPa-to-+3hPa-are-an-extension-of-the-anticyclonic-situation-in-the-northern-hemisphere,-and-the-anomalies-from-+1-to-+8-hPa-indicate-the-strengthening-of-mobile-anticyclones-pushed-further-south,-at-the-level-of-the-polar-circle,-and-the-negative-anomalies-from--3hPa-to-0hPa-indicate-the-low-pressure-zone-becoming-a-convergence-zone.-Fig.4-confirms-this-position-of-the-ITCZ,-which-extends-into-the-extratropical-zone.

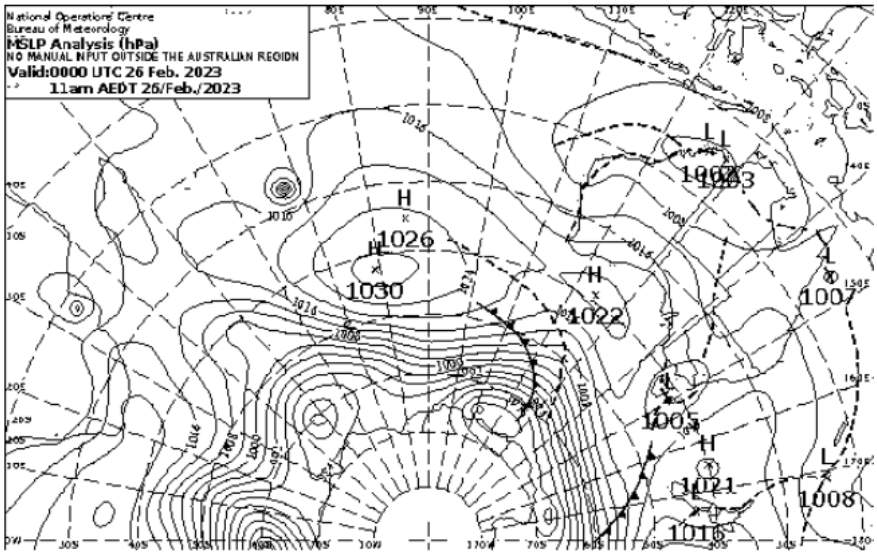


Figure 4: Southern-position-of-the-ITCZ

The-movement-of-the-ITCZ-further-south-was-observed-from-February-14th-to-16th-and-then-from-February-22nd-to-March-1st.-Therefore,-the-February-26th-Fig.4-is-chosen-to-represent-the-other-days-when-the-ITCZ-occupied-northern-positions.-On-this-date,-two-depression-cells-are-located,-one-at-Mozambique-(weakened-Cyclone-Freddy)-and-the-other-at-around-30°S-and-70°E.

Furthermore,-at-700-hPa-altitude-shown-in-Figure-5a,-there-are-negative-anomalies-of-0-to-more-than--10-m-in-the-southern-Indian-Ocean-between-approximately-20°S-50°S-and-20°E-120°E-continuously,-sometimes-interrupted-by-advances-of-high-pressure-coming-also-from-the-northern-hemisphere.-This-situation-also-shows-the-more-southern-position-of-the-ITCZ-at-altitude,-up-to-500-hPa,-Fig.5b.-The-negative-anomalies-indicate-an-atmosphere-with-warm-and-humid-air-mass,-hence-unstable,-with-lower-density-and-subsequently-lower-pressure-compared-to-other-areas-with-positive-anomalies.-The-movement-of-the-Freddy-system-is-directed-towards-this-low-pressure-zone-from-its-place-of-formation-(10°S,-116°E)-towards-the-SW,-crossing-the-southern-part-of-Madagascar.-Overall,-the-cyclone's-trajectory-is-also-directed-by-the-700-hPa-altitude-situation.-Due-to-the-stationary-situation-of-the-negative-anomalies-at-500-hPa,-Figure-5b,-over-Mozambique-and-its-surroundings,-the-system-moved-further-inland.

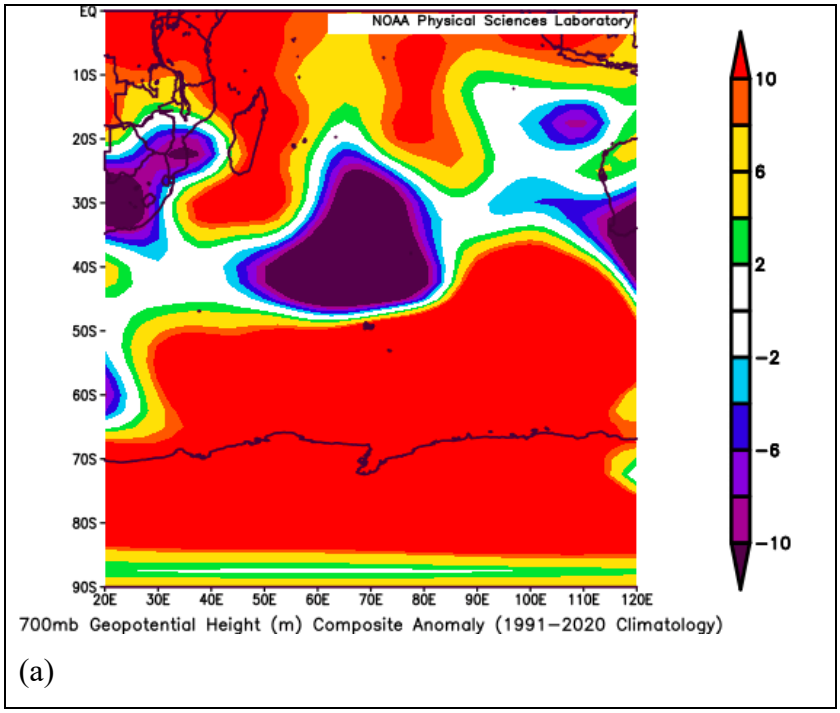
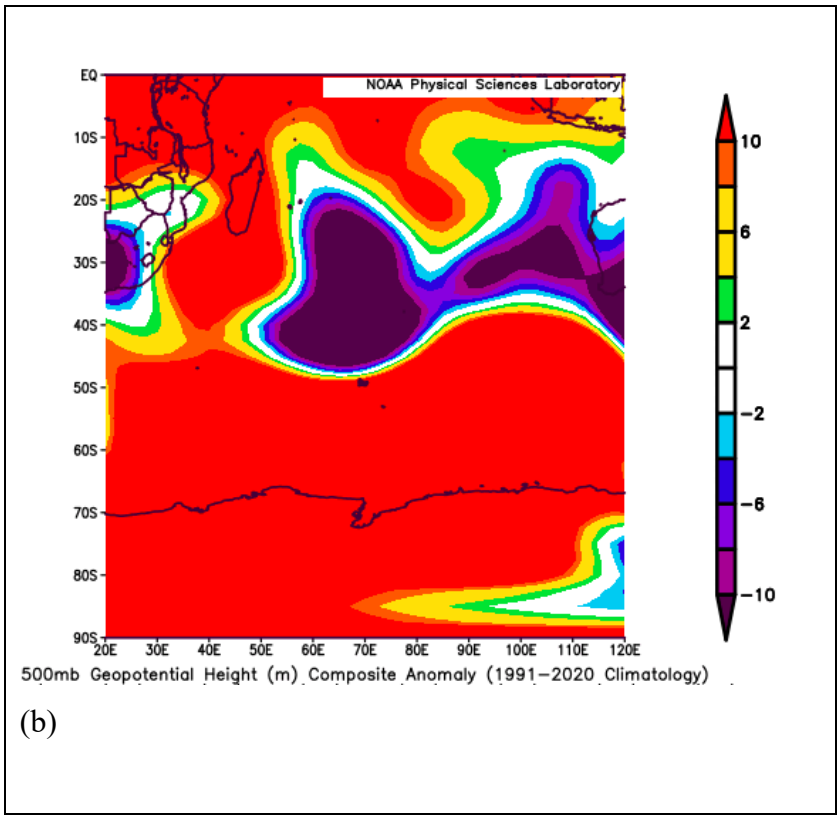


Figure 5a: The-extension-of-the-ITCZ-at-altitude.



(b)

Figure 5b and Figure 3: shows-that-the-southern-hemisphere-between-0°-45°S-is-experiencing-negative-pressure-anomalies-at-sea-level:-the-HPOI-has-weakened,-the-thermally-induced-centers-of-action-have-become-depressions-with-negative-anomalies,-and-mobile-depressions-occupy-lower-latitudes-instead-of-moving-towards-the-pole.

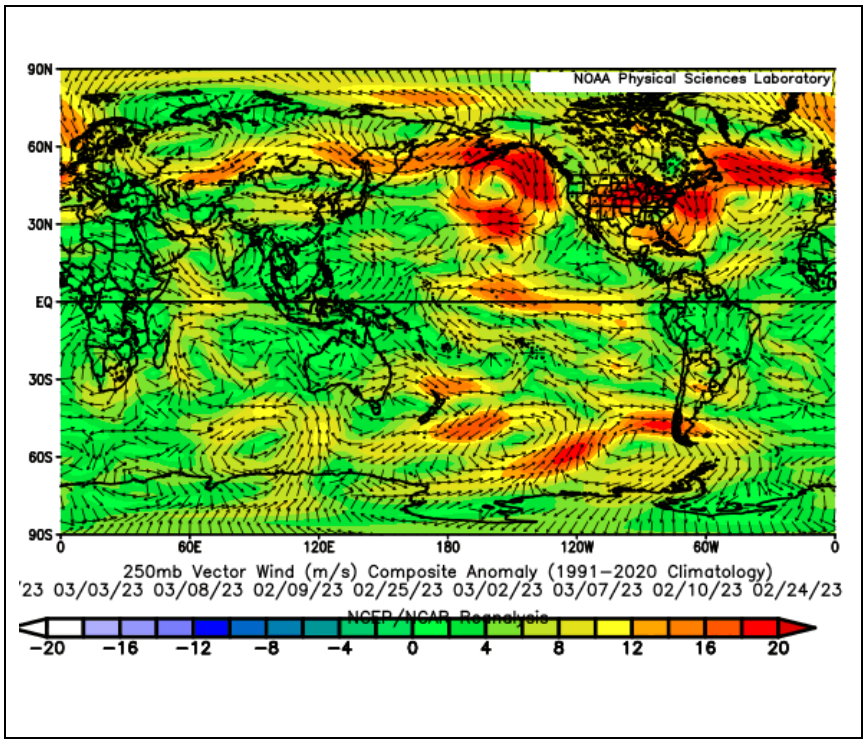


Figure 6: Anomalies-in-westward-jet-velocity-at-250-hPa-altitude.

These-low-pressures-continue-in-altitude-up-to-250-hPa-above-southern-Africa-and-the-southeastern-part-of-Australia,-as-shown-by-the-cyclonic-flow-in-Fig.-6.-In-the-hot-season,-the-high-altitude-jet-stream-should-be-meandering,-and-during-this-period-of-observation,-this-state-is-more-pronounced-due-to-its-extension,-from-25°S-to-65°S,-and-the-strengthening-of-the-linear-rotational-speed-of-the-centers-of-action,-from-+4m/s-to-+14m/s,-Fig.-6.

All-these-situations-lead-to-the-conclusion-that-the-southern-hemisphere-is-in-a-negative-phase-of-the-Southern-Oscillation:-mobile-low-pressures-shift-towards-the-equator,-and-low-pressure-anomalies-from-thermally-driven-centers-of-action-persist-even-up-to-500-hPa.

2- East-Phase-of-the-Quasi-Biennial-Oscillation

The-daily-composite-image-of-the-velocity-vector-at-50-hPa,-from-the-date-of-the-formation-period-of-Cyclone-Freddy-until-March-9th,-shows-the-existence-of-a-low-value-cyclonic-flow-zone-above-Antarctica,-ranging-from-6-12m/s,-which-also-splits,-as-shown-in-the-figure,-Fig.-7a.

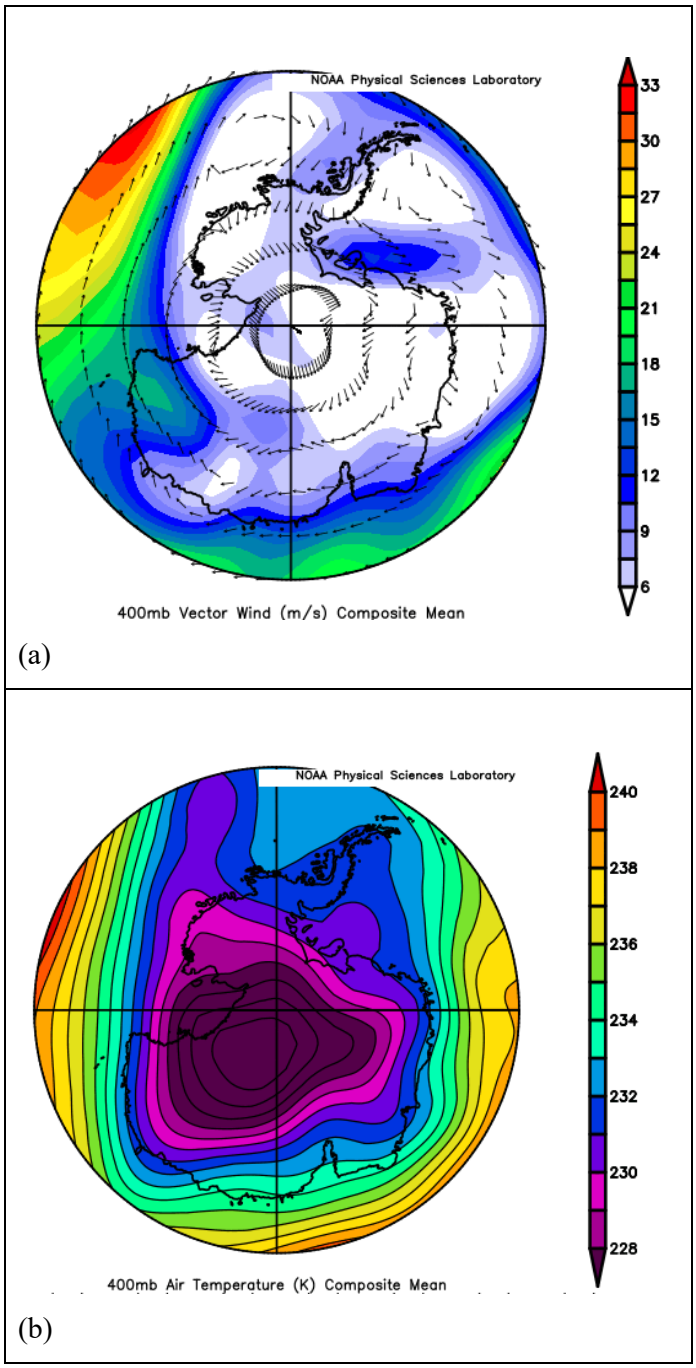


Figure 7: Cyclonic-flow-at-400hPa

Its-temperature-ranges-from--46°C-to--43°C-above-the-Ross-Ice-Shelf,-which-is-much-lower-than-the-temperature-of-the-polar-tropopause-at--30.5°C.-This-results-in-stable-air-masses-at-this-level.-Using-the-761-skew-T-diagram,-its-potential-temperatures-range-from-21°C-to-26°C,-and-those-of-the-surrounding-atmosphere-would-be-higher-than-those-of-the-vortex.-This-stable-vortex-over-the-South-Pole-is-slow-moving,-and-the-jet-stream-is-also-weakening,-as-shown-in-Fig.6.-

Therefore,-the-atmospheric-environment-in-which-Cyclone-Freddy-is-evolving-is-related-to-the-East-phase-of-the-QBO.

3- Thermal-and-Isobaric-Situations-in-the-Mozambique-Channel

The-Mozambique-Channel-is-a-sea-passage-open-to-both-the-Antarctic-and-the-Equator.-It-is-warm-throughout-the-year-due-to-the-presence-of-the-warm-ocean-current,-the-Agulhas,-flowing-from-north-to-south.-Moreover,-a-positive-anomaly-in-sea-surface-temperature-makes-it-a-basin-for-the-formation-or-passage-of-cyclones.

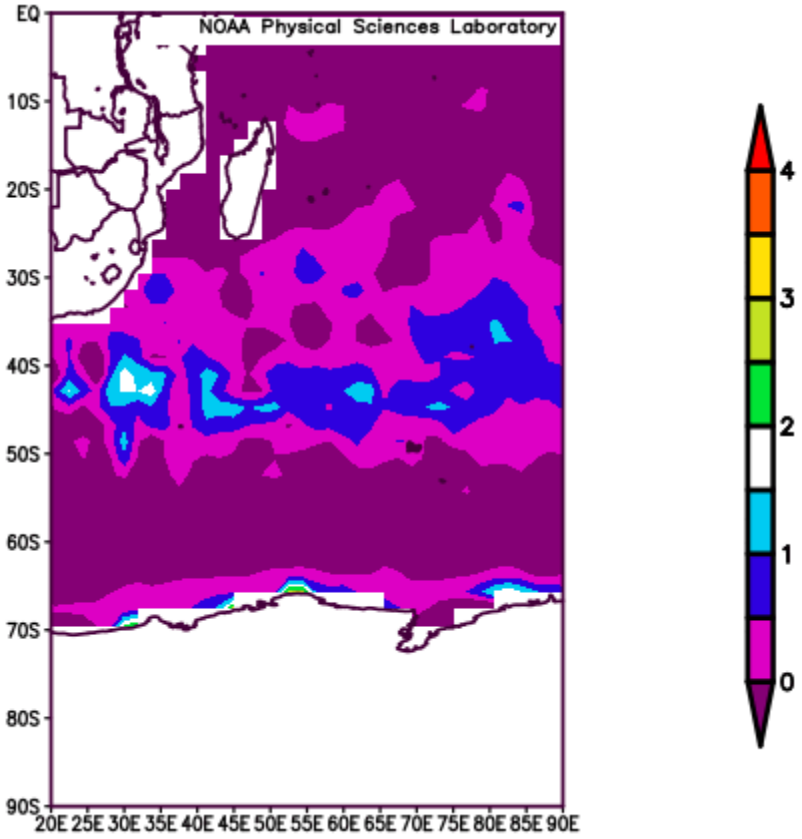


Figure 8: Sea-surface-temperature-in-the-Mozambique-Channel.

According-to-Fig.8,-the-SST-anomaly-varies-between-+0.5°C-and-+2°C-during-the-observation-period-from-February-7-to-March-9,-and-sustained-Cyclone-Freddy-during-its-passage-through-the-Mozambique-Channel,-which-is-supported-by-previous-observations-in-the-Atlantic-Ocean-where-a-0.5°C-increase-in-SST-led-to-a-40%-increase-in-the-number-of-hurricanes-during-1996-2005.-In-addition-to-this-favorable-zone,-the-surface-isobaric-conditions-also-played-a-role-in-explaining-the-trajectory-of-this-cyclone.-Surface-pressure-maps-from-February-7th-to-March-12th,-observed-by-www.bom.gov.au,-indicate-two-situations-that-persisted-over-the-Mozambique-Channel.-The-first-is-that-the-Mozambique-Channel-and-the-eastern-part-of-Southern-Africa-are-in-a-barometric-col-that-introduces-a-trough,-and-the-second-is-that-the-subzonal-isobar-1012-hPa-prevents-the-cyclonic-system-from-getting-lost-in-the-temperate-zone-and-directs-it-into-the-Mozambique-Channel.-This-was-the-case-from-March-7th-to-February-24th.-19/33-observations-showed-these-situations,-as-seen-in-the-example-of-February-20th-and-February-24th-in-Fig.8a-and-Fig.8b.

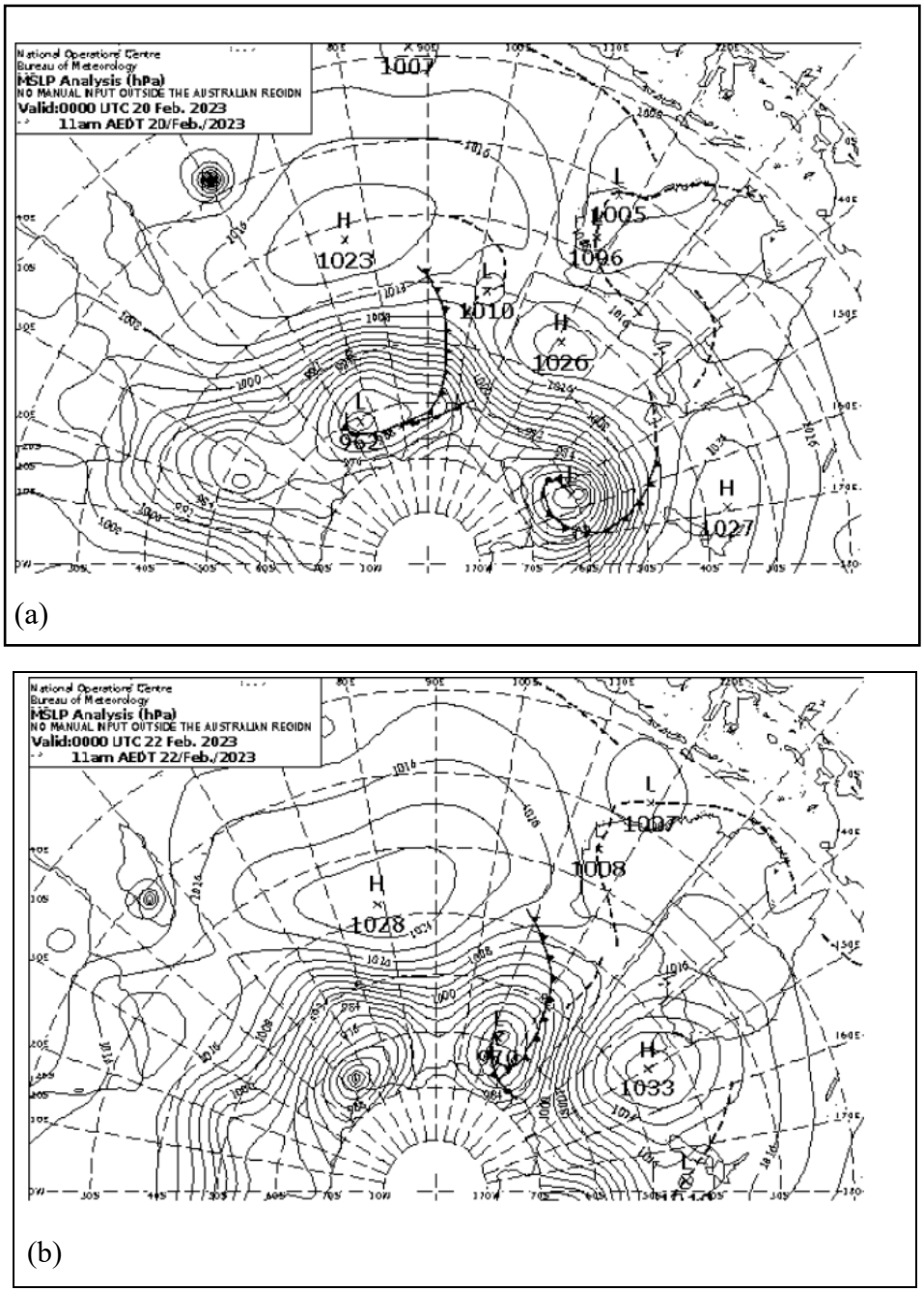


Figure 9: Surface-isobaric-situations-of-the-SWOI.

Also,-the-isobaric-situations-at-altitude-direct-the-system-in-its-movement,-assisted-in-the-surface-direction-by-the-barrier-role-of-the-1012-hPa-isobar.

4- The-impacts-of-Cyclone-Freddy's-passage-on-Madagascar

The-passage-of-the-cyclone-on-the-eastern-part-of-Madagascar-is-always-seen-in-its-negative-impacts.-The-reasons-lie-in-the-data-on-relief-and-population.-The-eastern-part-of-Madagascar,-or-the-eastern-slope,-is-formed-by-successions-of-faults-giving-a-topography-of-mountains-and-low-plateaus-dissected-into-hills-and-narrow-plains.-Moreover,-the-eastern-slope-constitutes-the-population-center-with-its-high-potential-for-cash-crops-and-tropical-fruits.-Consequently,-the-rise-of-water-is-felt-quickly,-Fig.10,-and-subsequently-the-destruction-of-houses,-losses-of-crop-lands,-infrastructure,-and-also-human-lives.-It-has-also-been-observed-that-a-river-sees-its-waters-rise-rapidly-when-the-eye-of-the-cyclone-is-directed-towards-its-mouth,-Randrianarison,-1991.-This-is-the-case-for-the-12,083-people-affected-in-a-single-region-of-the-eastern-slope-compared-to-a-total-of-16,660-in-all-six-regions-crossed-by-the-cyclone,-a-provisional-assessment-by-BNGRC-as-of-February-22.

Figure 10: The-rise-of-rivers-and-the-Pangalanes-canal-in-the-city-of-Mananjary.
----------Source:-zinfos974.com

This-figure-shows-the-situation-in-the-city-of-Mananjary.-Being-located-at-the-mouth-of-the-river-of-the-same-name-and-at-the-same-time-at-the-edge-of-the-Pangalanes-canal,-the-city-is-not-immune-to-flooding.-It-should-be-noted-that-this-city-was-the-landing-place-on-February-20th-of-the-cyclone-coming-from-the-Indian-Ocean,-climbing-the-eastern-slope-and-then-descending-the-western-slope.

While-the-eastern-slope-is-densely-populated,-the-western-slope-is-sparsely-occupied-except-along-rivers-and-their-mouths.-Cyclone-Freddy,-during-its-passage-over-the-southwest-(western-slope)-of-Madagascar,-brings-rainwater-to-this-part-of-the-island,-which-is-formed-of-plateaus-with-low-annual-rainfall.-The-main-city-in-this-southwestern-part-of-the-island-receives-an-average-annual-precipitation-of-344-mm-from-1977-to-2017,-according-to-the-General-Directorate-of-Meteorology.-This-cyclone-brought-a-significant-amount-of-rainfall-and,-as-a-result-of-sediments,-allowed-for-the-renewal-of-cultivated-lands-along-the-major-river-beds-of-this-western-slope.-Fig.11-shows-the-coastal-city-of-Morombe-in-this-part-of-the-island,-which-was-the-point-of-exit-for-Cyclone-Freddy-on-February-22nd-and-is-experiencing-flooding-due-to-heavy-rainfall-and-rising-sea-levels.

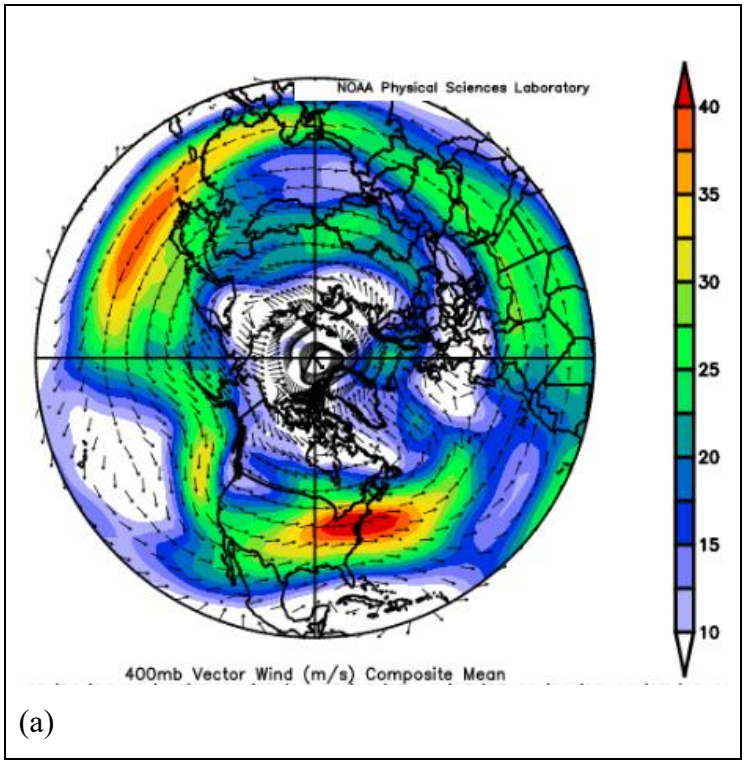
Figure 11: Flooding-in-the-city-of-Morombe.
----------Source-:-Le-quotidien-Midi-Madagasikara,-07/03/2023

As-cyclone-Freddy-passed-upstream-of-the-Mangoky-river-basin,-its-downstream-part-experienced-flooding.-Figure-12-shows-that-a-large-part-of-the-plain,-one-of-the-rice-granaries-of-Madagascar,-is-underwater-and-the-breach-in-the-dike-is-under-surveillance.-Given-that-the-SWOI-is-a-favorable-zone-for-cyclogenesis-and-that-Madagascar-is-hit-annually-by-cyclones,-cyclone-Freddy-is-atypical-in-its-round-trip-to-the-southwest-of-the-island.

Figure 12: The-lower-Mangoky,-an-irrigated-perimeter-zone.
----------Source-:-Le-quotidien-L'Express-de-Madagascar,-08/03/2023

4. Discussion

1-If-we-observe-the-decrease-in-wind-speed-in-the-Arctic,-that-of-Antarctica-is-even-much-lower,-Fig.7a-and-Fig.11a.-The-surface-covered-by-the-polar-low-with-a-wind-speed-less-than-10m/s-is-respectively-10%-between-60°N-90°N-and-80%-between-60°S-90°S.-Moreover,-the-air-temperature-at-this-level,-400hPa-and-at-the-center-of-the-depression-(above-Baffin-Island)-is--30°C,-and-the-temperature-varies-between--48°C-and--30°C.-Also-at-the-center,-the-vortex-temperature-equalizes-with-that-of-the-ambient-air-and-becomes-cooler-and-more-stable-as-it-moves-away-from-the-center.-This-Arctic-vortex-configuration-corresponds-to-a-more-or-less-straight-jet-stream-occupying-latitudes-from-75°N-to-15°N,-due-to-the-fact-that-the-centers-of-action-are-extended.-Figure-6-shows-that-their-speeds-are-higher-than-normal-(1991-2020),-with-positive-anomalies-of-12-to-20-m/s,-except-for-lower-speeds-above-Siberia-and-Eastern-Europe.



(a)

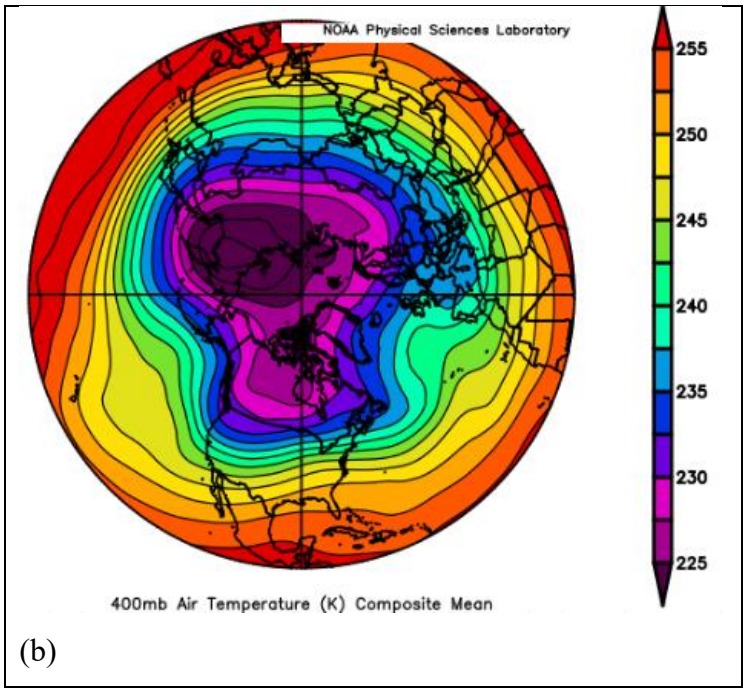


Figure 13: Vector-wind-and-air-temperature-at-400hPa.

As-a-result,-a-strong-depression-affects-North-America-at-ground-level,-as-shown-by-the-snowstorm-in-Fig.14.-Siberia-and-Eastern-Europe-experience-a-slight-increase-in-high-pressure,-while-it-is-stronger-over-Western-Europe.

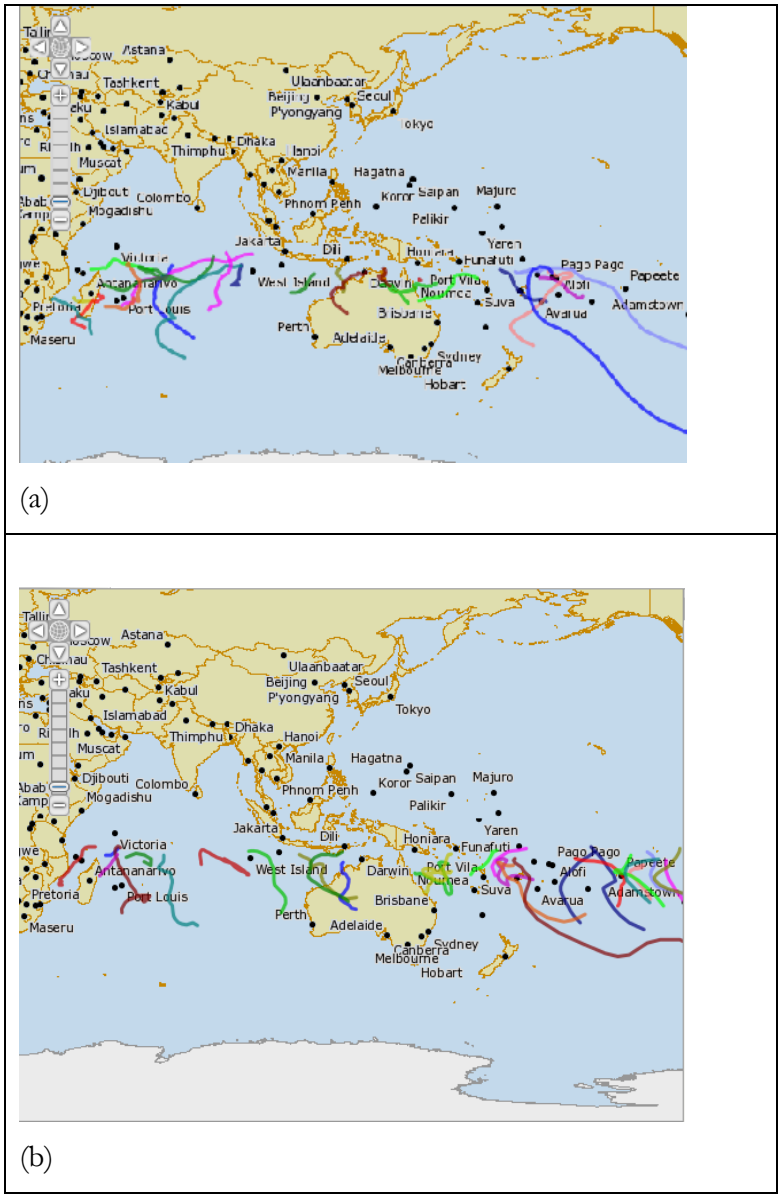
Figure 14: Snowstorm-in-the-United-States-(California)-on-February-24th,-2023.
Source: Ouest-France-AFP-(French-news-agency)

We-can-see-from-Fig.-13b-and-Fig.-7b-that-during-winter,-the-polar-vortex-narrows-(Arctic-polar-vortex)-and-during-summer,-it-widens-(Antarctic-polar-vortex).-**Thus,-during-the-East-phase-of-the-QBO,-the-northern-winter-experiences-vigorous-dynamic-depressions-due-to-the-decrease-in-pressure-and-the-extent-of-its-isobaric-field,-while-the-southern-summer-sees-depressions-reaching-the-tropopause-and-mobile-depressions-occupying-low-latitudes-and-intensified-thermal-depressions-due-to-negative-anomalies.-The-QBO-East-and-the-Antarctic-Oscillation-are-in-**

agreement-in-the-southern-hemisphere.-One-theme-to-investigate-is-whether-during-these-phases,-the-centers-of-action-will-migrate-abnormally-to-low-latitudes-and-anticyclones-will-weaken-for-the-following-season,-i.e.,-the-next-southern-winter.

It-is-observed-that-the-QBO-and-the-Antarctic-Oscillation-have-caused-heavy-rains-in-the-southern-half-of-Madagascar.-

2-Despite-the-temperature-difference-between-the-Arctic-and-the-Antarctic,-Figures-13b-and-7b-show-that-the-QBO-East-cools-the-southern-pole-much-more-than-the-northern-pole,-and-depressions-have-marked-both-hemispheres.-What-about-El-Nino,-which-has-impacts-on-global-climates?-According-to-Fig.-15,-during-the-strong-El-Nino-periods-of-1982-83-and-1997-98,-no-cyclones-from-the-Indian-Ocean-and-Mozambique-Channel-hit-Madagascar,-and-the-number-of-systems-decreases-significantly-in-the-SWOI.-During-the-1982-83-cyclone-season,-6-systems-passed-through-the-SWOI,-but-only-one-cyclone-affected-the-weather-in-Madagascar.-In-a-normal-period,-such-as-the-2007-2008-cyclone-season,-5-out-of-10-systems-that-pass-through-the-Indian-Ocean-and-the-Mozambique-Channel-affect-the-island.



(a):-During-normal-period-2009-2010

(b):-During-ENSO-period,-1982-1983-from-Oceanweather.

Figure 15: Cyclones-in-the-SWOI-during-El-Nino-and-normal-years.

This-means-that-during-the-El-Nino-phenomenon,-we-can-expect-positive-anomalies-of-700-hPa-and-500-hPa-geopotentials-over-Madagascar-and-the-Mozambique-Channel.

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