

Tropical Weather Systems - a review

REVIEW OF TROPICAL WEATHER SYSTEMS

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The following is a summary of some significant tropical synoptics and events which can influence the weather encountered by yachts in the South Pacific. An overriding influence in the tropics and subtropics is the Subtropical Jet (SJT). It's a semi-permanent feature near the poleward margin of the tropics and its strong baroclinic field, especially in winter, can and does supply energy for weather disturbances in low latitudes.

EQUATORIAL TROUGH AND INTER TROPICAL CONVERGENCE ZONE

The ET is an area of confluence between the northern hemisphere and southern hemisphere trade winds. The ET is referred to as the ITCZ when the trade winds converge, causing extensive cloud and rain. When the trade winds do not merge directly, the ET may be associated with little or no cloud. In the eastern Pacific it always lies north of the equator mainly due to cooler SST anomalies off the west coast of South America, caused by upwelling and the Humboldt current. From 160W to 10E it lies north of the equator and runs through India, and north Africa during the northern summer (May-Oct), but south of the equator during the southern summer (Nov-Apr).

Australians call the ET in this southern position the 'Monsoon Trough', as it moves over the top end of Australia and South Africa. The Australian northwest monsoon results from northern hemisphere northeast trades crossing the equator and turning due to the Coriolis effect. The resulting trough is located equatorward of the 200mb ridge. The monsoon is active when westerlies extend from the surface to 500mb or higher, overlain by easterly winds.

Looking more closely at the Island groups affected, from late June to early October the ITCZ lies entirely north of the equator giving disturbed weather over the Caroline, Marshall and Northern Gilbert Islands. By late October or early November the front first appears south of the equator and begins to affect the weather over northern Papua New Guinea, and through the southern Gilberts. The Solomons and Tuvalu usually come under its influence during December, but this can vary a month either way. Throughout January, February, and March the front is in its southern-most position and coexists with the South Pacific Convergence Zone, with disturbed weather over northern Queensland, southern Papua New Guinea, Vanuatu and oscillating as far south as New Caledonia, Fiji and Samoa. Throughout April and May the front retreats northward again allowing the southeast trades to extend progressively northward. Movement is irregular in that it can oscillate north or south 50-100 miles in a day.

LINEAR DISTURBANCES

These are systems in which vorticity or divergence, or both, are concentrated along a line whose length is larger than the width.

A SHEAR LINE is a term that in practice is applied to zones of cyclonic shear. It can occur when two airstreams of nearly opposite direction lie on either side of a line parallel to the flow; or variations in wind speed across an airstream of constant direction.

A shear line can occur in the upper troposphere in summer between two anticyclones. They're associated with extensive areas of mid to high cloudiness and convection. Another shear can occur in the vicinity of the equatorial trough when it's displaced far enough from the equator where equatorial westerlies are found. These shear lines can contain a series of cyclonic vortices.

ASYMPTOTES are defined as a streamline in the wind current in which neighbouring streamlines converge. Convergent zones in the low levels are very common and are accompanied by long lines or narrow zones of cumulus congestus, Cb's, and showers. These clouds and showers are usually organized in well defined lines parallel with the trades, are called cloud streets. Cloud streeting is also formed by the overturning in Cumulus cloud. Each cumulus is surrounded by a moat of descending air and this turns a field of cumulus into streets aligned by the wind. The streets tend to drift to the left of the mean surface wind.

Still another shear line is a remnant of a cold front moving into the tropics. The temperature contrast diminishes rapidly near 30S but the confluence of wind flow is marked by moderate to strong cyclonic shear. These modified cold fronts propagate NE toward New Caledonia, Fiji, Samoa and the Southern Cooks and when they approach 15 S a remnant of the front strings out in an east-west orientation. The fronts that make it to Samoa usually stall in what's known as the 'frontal graveyard'. They are best positioned by satellite imagery and the bunching of 850 mb isotherms.

SURGES

Sudden accelerations occur in tradewinds and the monsoon flow. Downstream of the surge, convergence and increased cyclonic shear occur to the right of the wind maximum's axis resulting in convection, and on occasion cyclogenesis. Throughout the tropics wind currents locally accelerate and decelerate usually without apparent cause but with significant effect on weather.

Sometimes an anticyclone in the subtropics intensifies creating a surge of cooler air on the eastern side of the High. When this surge advances into the tradewind region it may form a line of convergence accompanied by a band of showers- another version of a 'shear line'. This is common in the dry season (April-Sep) where a line of active thunderstorms ushers in a renewed burst of the SE trade winds.

WESTERLY WIND BURSTS

The equatorial western and central Pacific sometimes experiences 'bursts' of westerly winds that replace the normal easterlies and persist for a few days to up to three weeks. Twenty knots is common and sometimes up to forty knots is

experienced. Exact origins are probably related to the monsoon in Asia. These westerly wind bursts are associated with ‘twinning’, or tropical cyclones forming equidistantly on either side of the equator.

MESOSCALE CONVECTIVE SYSTEMS

An MCS consists of a group of deep cumulonimbus cells connected by extensive mid and upper level Stratiform cloud and a large cirrus shield shaped by the outflow generated by Cb’s. Often the Cb’s are at the leading edge of the MCS with the stratiform trailing behind. MCS’s usually form in areas of pre-existing cyclonic vorticity, for example in the ITCZ or SPCZ.

Low level convergence triggers isolated Cb’s. These cells organize into bands with varying shapes. Individual cells grow and merge to form a single large area of rain with intense falls connected by larger areas of lighter rain. A large mid to upper level stratiform shield develops as long as new cells keep developing. Cold pools associated with severe downdrafts in mature Cb’s flow downward and outward, undercut existing air, with resulting further uplift. Thus the system is self sustaining so long as there is a supply of moist air near the surface.

The system can last a few hours to a few days and starts to end when new cells stop forming. This is usually because the down drafts creating the gust front creates a strengthening mesohigh (a contained small high pressure system) which pushes the gust front well out in front of the system cutting off inflow. When this occurs new convection in front of the system is weaker and the MCS begins to collapse.

In order for a strong MCS to occur, the environment needs to have a moderate amount of buoyant air (as measured by a parameter called CAPE), dry air in mid levels so rising moist air evaporates and cools, and a moderate amount of vertical wind speed shear to balance the forward push of the gust front from the convective downdrafts – so that a parcel lifted at the gust front is allowed to sustain deep lifting and not immediately advected to the rear of the system.

WAVE DISTURBANCES.

It is common to have troughs (and ridges) traveling eastwards in the westerlies of the middle and upper troposphere. Regions of low level convergence and deep cloud bands develop just downstream from these traveling upper troughs; the clouds travel eastward with the trough counter to the low level easterly flow. Surface frontal symbols are not drawn for these features.

Similar to the above is a cyclonic perturbation in subtropical easterlies, which is shallow easterlies that are overlain by westerly winds, that are an extension of a trough in the mid-latitude westerlies. Cloud and precipitation may not be well organized, but any existing disturbances already in the easterly flow will become more active.

On some occasions this extended upper trough in the westerlies can fracture. There is latitudinal shearing with the mid-latitude part separating, while the low latitude part moves with the low level easterlies. Such systems are often quasi-stationary and sometimes they move westward. There is usually some amount of

vertical shearing occurring as well with higher clouds moving eastward. Anyway, wave disturbances produce a deep cloud mass.

Strong shear on the edge of the sub tropical jet stream (STJ) can also lead to the creation of vast cloud sheets in the middle and upper troposphere. Sometimes these sheets develop and later decay without there being more than a weak trough at the surface. At other times a jet max will create a surface trough, and even a hook shaped cloud pattern, first in the middle and upper troposphere and then later extending to the surface which then can develop into a Low.

VORTICES

These can be cyclonic or anti-cyclonic. Here we will focus on cyclonic rotations at different levels in the troposphere. Weather satellites show cyclonic cloud patterns occurring much more frequently in the tropics than previously believed.

There are three types of vortices: Low, mid, and upper tropospheric.

Low Tropospheric.

Usually found within the SPCZ and monsoon trough. Monsoon troughs are characterized by westerly winds on their equatorward side and easterly winds poleward. Maximum cloud and rain occur in the westerly flow but spreads poleward of the trough line when circulation develops. Most of these Lows don't develop into tropical cyclones due to strong wind shear between 850mb and 200mb; usually at least 30 knots. These vortices extend to 180 degrees and generally occur from November through May and most common from January through March. For yachts in the western north pacific, the frequency of cyclone formation appears to be greatest when the monsoon trough is north of its normal position or extends further eastward to the dateline or beyond thus causing cyclone formation in the Marshall Islands area. This is most common from July to October, the northern hemisphere tropical cyclone season.

Mid Tropospheric.

These originate when a closed upper Low in the sub tropics becomes cut-off from the mainstream westerlies and becomes trapped in the low latitudes due to a blocking High.

An upper tropospheric disturbance gradually causes it's cyclonic circulation to work its way down to the surface. The most well know are the 'Kona' storms of Hawaii which can last up to two weeks before being absorbed by a trough in the westerlies. It's possible that mid-tropospheric vortices provide an environment for the development of mesoscale convective complexes.

Upper Tropospheric

These upper Lows, at 200mb, start off as cold upper lows, and sometimes can build down to the surface and trigger tropical cyclones while other upper lows don't. They can also produce an easterly wave sometimes seen in French Polynesia. They are prevalent in the warm season. The clouds associated with upper cyclones depend on their penetration to low levels. If this is achieved a vortex cloud pattern (spiraling lines of cumulus clouds) is observed in satellite pictures. The cloud is normally found equatorward of the upper trough line. Surface penetration is inhibited if cold sea

surface temperatures and a strong trade wind inversion is present. Once achieved however, surface systems move in conjunction with the upper low, which typically track westward at about 10-12 knots or 5 degrees per day. In some cases the upper low moves eastward so the induced surface trough or vortex moves upstream against the low-level easterlies.

A train of these cold lows can form what is known as a Tropical Upper Tropospheric Trough, or TUTT.

TUTT. Tropical Upper Tropospheric Trough.

A summer feature in all oceans except the Indian. It consists of a train of cold lows that form the TUTT and is most intense just after mid-summer. It's usually oriented WNW to ESE and can be found from approximately the equator at 180 Longitude and runs to approximately 28 S 110 W as a mean location. This position is typical for January.

As a short wave trough in the upper tropospheric westerlies passes poleward of the TUTT, a jet like surge of cold air sweeps westward and then equatorward around the TUTT, where the resulting increase of cyclonic vorticity causes a cold low to develop. These lows are colder than their environment and the majority don't extend their vortex down to 700mb.

Once on the surface, however, deep short lived Cumulonimbus can develop in the center of the low, but they usually have a short life. Usually though, as stated earlier, satellite imagery shows a central surface core relatively cloud free with a cloudy ring surrounding the center; a radius of 125 NM has been observed.

Upper cold lows may possess an annulus of cirrus around a clear center. Often the cirrus is only in one quadrant or semicircle with a very sharp edge where it lies next to a jet.

Since the low level monsoon trough in the South Pacific seldom extends east of the dateline it may be likely that tropical storm development east of this meridian stems from these cold lows.

CLOUDS IN THE TRADE WINDS

Cumulus predominates in the tropics. Heat from the sun over the tropical ocean produces low level water vapor which, being less dense and thus buoyant, rises to form the trade cumulus so commonly seen. Differentials in sea surface temperatures can also cause pressure differentials which can induce convection. As a function of the persistent inversion layer these clouds seldom rise very high. Because upper level winds are stronger than those at the surface, the clouds take on a 'lean' with altitude due to the vertical shear.

Occasionally cumulus can overcome the inversion and grow rather tall to become cumulonimbus. In the tropics a cloud must extend above 16,000 feet for ice to form, and since ice is a necessary ingredient for electrical gradients that cause lightning, thunderstorms usually extend well beyond this to above 30,000 feet. The

cold downflow from these Cb's may trigger more upward motion and new convective cells initiating a self sustaining process.

The potential for Cb development and accompanying squalls over the ocean is more prevalent at night because upper atmospheric cooling allows for a greater temperature differential between upper levels and the surface where temperature is maintained by the sea surface. The approaching Cb will generally track to the left of the prevailing surface wind looking downwind. In addition the wind will shift left to the mean surface wind.

Stratus and stratocumulus will prevail on the eastern side of travelling anticyclones while deeper convection is possible on its western side.

Alto cumulus and altostratus in the tropics are typically associated with disturbed weather conditions. They accompany mid to upper tropospheric vortices or from large scale orographic lifting. Nimbostratus, a gray thick cloud with rain, is also observed with these mid to upper level vortices.

Cirrus or cirrostratus result from leftover Cb activity or formed independently. Thin cirrus is prevalent in the tropics, found on the equatorward side of the subtropical jet and with upper level vortices. This thin cirrus can produce the sun halo, which may not indicate anything of itself, however if there is a sun halo and dropping pressure then its time to brace for something.

THE SOUTH PACIFIC CONVERGENCE ZONE .. SPCZ

The SPCZ contains one of the earth's most expansive and persistent convective cloud bands. It's zonal barotropic part (the pressure difference marker) extends from 150 E to 170 W, and is formed by moisture convergence, and its diagonal part is orientated approximately NW to SE. This part is baroclinic (the density difference marker) and extends from about 170 W to 130 W and is formed predominantly between the easterly to northeasterly flow from the trapped semi-permanent anticyclone in the eastern south pacific and the cooler southeasterly flow from traveling anticyclones. It's mean position is from Papua New Guinea east-southeastward to about 30S 120W.

In January, the most prominent feature is the trough of low pressure that extends eastward from the monsoonal low centered over northern Australia across the Pacific to a location near the equator and 130W. The western part of this equatorial trough is commensurate with the zonal portion of the SPCZ.

In July, the pattern changes drastically. The trough of low pressure is now located along a line that stretches from the low centered over southeast Asia, associated with their summer monsoon, east-southeastward across the Pacific to just east of the dateline where it then remains close to the equator. In contrast to January, there is a high pressure center located over southern Australia, and in winter the SPCZ is much less noticeable but located slightly north of its summer position, near Samoa to between Northern and Southern Cooks.

In short the SPCZ is more active in the southern summer than at other times of the year.

There are a number of theories for the zonal portion of the SPCZ. One which is generally accepted is that the zonal area of the SPCZ owes its existence to sea surface

temperatures (SST). SST gradients impose pressure gradients that in turn drive low level winds that result in convergence. The diagonal portion of the SPCZ is generated by convergence from two different mid-latitude influences as previously mentioned.

It's further noted that when the SPCZ interacts with transient surface troughs the zone becomes the preferred storm track should a low develop. Certainly transient troughs tend to 'activate' the SPCZ.

Looking at upper levels there is generally a 200mb ridge collocated with the diagonal surface cloud band, a position favorable for providing divergent outflow to sustain convection.

Interaction with the Madden-Julien Oscillation. A noteworthy observation is that when the MJO phase is more or less over Indonesia look for activation of the SPCZ. An upper high develops over this phase near Indonesia and outflow from this high turns equatorward on its eastern side, which in turn develops into an upper trough. This upper trough induces deep ascent to its east, which is directly over the SPCZ.

ENSO events. During an El Nino the SPCZ is generally north and east of its average position, as the pressures are lower over the central south pacific and higher over northern Australia. A stronger than normal 200mb ridge develops over the SPCZ and more convective outflow results in the SPCZ being more active in this phase of ENSO. Conversely during La Nina the SPCZ is south and west of its mean position and generally is less active as upper cyclonic conditions inhibit outflow.

Tropical Cyclones. The zonal portion of the SPCZ is where tropical cyclones are often observed particularly during the Australian summer monsoon season. Once formed the tropical cyclones tend to track along the SPCZ . One study showed cyclones to remain in the zonal portion and others showed southeastern tracks along It's diagonal portion. The tracks seem to be influenced by the 200mb streamlines. And initiation of the cyclones may be associated with the equatorward entrance of a jet max.

THE MADDEN-JULIEN OSCILLATION... MJO

The MJO is a wave oscillation traveling around the equatorial region of the globe on an average of 40 days. To lend support to this mean time frame it's been shown that enhanced wet spells in the Australian monsoon occur about 40 days apart in conjunction with MJO pulse. The pulse originates in the western Indian Ocean and moves east at about 10-20 knots. Moving with the pulse is an area of deep convection. In front and behind the convective area is suppressed convection with typically stronger trade winds. The MJO is strongest during the southern summer and influences the activity of the SPCZ and ET.

OLR stands for Outgoing Longwave Radiation or the amount of radiation lost to space, something which satellites can easily measure, and this is greatest where the air is clearest. So OLR is an inverse measure of cloudiness. OLR measurement charts are one means to track the MJO phase propagation. When OLR is minimal it indicates that convective cloud activity is prevalent and more clouds mean less outgoing

radiation. Chart color coding from source to source can be different so ensure you identify the key, but usually 'yellow is mellow and blue is bubbly'. Some charts use OLR anomalies or the difference between that observed and the mean. Other methods of forecasting the MJO are velocity potential charts which isolates the divergent component of the wind at upper levels; upper level and lower level wind anomalies (low level weakening easterlies or westerly wind bursts and high level cyclonic and anticyclonic circulations); and 500mb height anomalies which represents the atmospheres response to the wave.

The structure of a Madden-Julian wave has two regimes. One regime has upper level divergence, and low level convergence which leads to rising motion and the visible convection seen in satellite imagery. Super cloud clusters, and mesoscale convective complexes (MCC), can be seen moving along with the wave. The clusters have a life of one to two days while the MCS's within the clusters have a life of 6-12 hours. The other regime has upper level convergence and lower level divergence, leading to sinking air and suppressed convection. Suppressed convection leads to clearer skies and higher surface pressures, and as stated before stronger than normal trades. This set of regimes travel eastward however as the pulse encounters colder water in the eastern pacific the convective activity diminishes greatly, but even if clouds and rain are not visible the wave is still there, propagating eastward.

Strong MJO activity is often observed during weak La Nina years or during ENSO-neutral years. Weak or absent MJO activity is typically associated with strong El Nino episodes. For more information : Madden,R.A., and P.R. Julian, 1971: Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific. J. Atmos. Sci., 28, 702-708.

This summary is by design just a brief overview of papers presented by numerous research meteorologists. Tropical meteorology is a fascinating topic where unfortunately very little data is available. As a result many of the features described are not fully understood but study continues aided by satellite imagery. Tropical cyclones have not been included as this topic is an enormous subject of its own.

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