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TROPICAL STORM TALAS
FORMATION AND IMPACTS AT KWAJALEIN ATOLL

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1. INTRODUCTION

Tropical Storm (TS) 31W (later named Talas) developed rapidly and passed just to the south of Kwajalein Island (hereafter referred to as "Kwajalein"), on 10 December 2004 UTC. Kwajalein is the southern-most island of Kwajalein Atoll in the Marshall Islands (see figure 1). Despite having been a minimal tropical storm as it passed, TS Talas had a significant impact not only on the residents of Kwajalein Atoll, but on mission operations at United States Army Kwajalein Atoll (USAKA)/Ronald Reagan Test Site (RTS).

This paper will describe the development and evolution of TS Talas and its impacts on Kwajalein Atoll and USAKA/RTS. Storm data, including radar, satellite, and surface and upper air observations, and a summary of impacts will be presented. A strong correlation between Tropical Cyclone (TC) frequency and the phase of the El Niño Southern Oscillation (ENSO) has been observed for the Northern Marshall Islands. Therefore, the environment in which TS Talas formed will also be discussed.

The name "Talas" was submitted to the World Meteorological Organization's Typhoon Committee by the Philippines and means "sharpness" or "acuteness". TS Talas was the most significant TC to affect the Kwajalein Atoll, USAKA, and RTS since Typhoon Paka in 1997 and TS Zelda in 1991.

2. ABOUT KWAJALEIN ATOLL

2.1 *Location*

Kwajalein Atoll is part of the Ralik (meaning sunset or western) chain of the Northern Marshall Islands. Kwajalein Atoll is approximately 4,000 km southwest of Hawaii, 1,350 km north of the equator, or almost exactly halfway between Hawaii and Australia. Kwajalein is the largest of the approximately 100 islands that comprise Kwajalein Atoll and is located at 8.7° north and 167.7° east.

2.2 *Topography/Bathymetry*

The islands that make up Kwajalein Atoll all lie very near sea level with an average elevation of approximately 1.5 m above mean sea level. The highest elevations are man-made hills which top out at approximately 6 m above mean sea level.

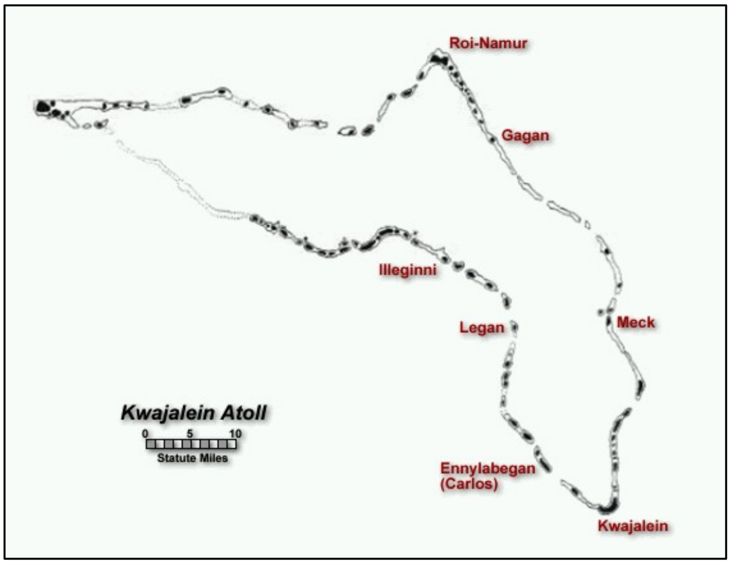

Figure 1: Kwajalein Atoll Map

The bathymetry of Kwajalein Atoll is one of dramatically rising sea floors and a relatively shallow, but large lagoon. Although Kwajalein Atoll's bathymetry doesn't lend itself to dramatic storm surges, even relatively small storm surges of 1 to 2 m have been documented and were devastating.

2.3 *Population & Vulnerability*

Kwajalein Atoll is home to approximately 18,000 people. The vast majority (approximately 14,000) of those people are Marshallese citizens who live on Ebeye Island, about 8 km north of Kwajalein. More than half of Ebeye's residents are under the age of 18. Kwajalein's population

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is approximately 2,500 and made up almost entirely of U.S. military and civilian contractor personnel for USAKA/RTS.

Kwajalein Atoll's population is extremely vulnerable to the effects of TCs. This is largely due to the physical characteristics of the atoll, but native poverty and the resulting lack of adequate shelter play a significant role in increasing the vulnerability. For example, it is estimated that Ebeye has adequate emergency shelters for only about 2,000 of its 14,000 residents[1].

3. KWAJALEIN CYCLONE HISTORY

Kwajalein Atoll is located on the far eastern edge of the West Pacific TC generation zone. While tropical depressions occasionally form near Kwajalein Atoll, tropical storms are relatively rare and typhoons rarer still. It is estimated that a tropical storm affects Kwajalein Atoll on average once every three to five years with typhoons occurring every six to ten years.

Since the United States took control of Kwajalein Atoll (c. 1945) there have been 17 TCs of tropical storm force or greater that had a direct impact on Kwajalein Atoll. With the exception of a storm in 1955, none of those storms have had a devastating effect on the atoll. The 1955 storm "put water to a depth of 1 ½ to 2 feet on the island (Kwajalein)" (Heine and McKay, 1964, pg. 1).

However, there is anecdotal evidence dating back to the 19th century indicating that devastating storms have occurred. In 1875, a typhoon was reported to have produced a storm surge large enough to sweep Kwajalein Atoll clean (Spennemann and Marschner, 1994, pg. 12). Local residents reported that a storm hit Kwajalein in 1914 which produced a "4-foot storm surge that swept one woman to her death, uprooted all trees on the island, and destroyed every structure except the church, which was of sound construction" (Heine and McKay, 1964, pg. 1).

The three most recent storms to affect Kwajalein Atoll were TS Zelda (1991), Typhoon Paka (1997) and TS Talas (2004). Paka posed the most risk to Kwajalein as it was already at typhoon strength as it passed by. Fortunately, its closest point of approach (CPA) was approximately 140 km to the south and thus damage was minimal.

4. TS TALAS

4.1 *Background Conditions*

4.1.1 *Global Scale Patterns*

As with Paka, Zelda, and a number of other storms, TS Talas occurred during an El Niño event. Table 1 shows selected past storms and the strength of the corresponding El Niño (if present). The strength of the El Niño shown in Table 1 is a subjective estimate made by the author based on Niño 4 region water temperature anomalies. Further discussion regarding the role of ENSO in TC development will be presented in Section 6.

Storm Name	Month/Year	El Niño Strength
Talas	Dec/2004	Strong
Paka	Dec/1997	Strong
Gay	Nov/1992	Weak
Axel	Jan/1992	Strong
Zelda	Nov/1991	Moderate
Page	Nov/1990	Weak
Roy	Jan/1988	Strong
Norris	Dec/1986	Moderate
Freda	Mar/1981	None
Alice	Jan/1979	Weak
Rita	Oct/1978	None
Mary	Dec/1977	Weak
Ophelia	Jan/1958	Strong
Mamie	Nov/1957	Moderate
Lola	Nov/1957	Moderate
Kit	Nov/1957	Moderate
Unnamed	Mar/1955	None

Table 1: Past storms and corresponding El Niño strength based on ocean temperature anomalies from Niño region 4.

Water temperatures were running from 0.5° to 1.5°C above normal in the vicinity of Kwajalein Atoll during much of 2004, helping to fuel convective development. Despite the abnormally warm ocean waters in the central equatorial Pacific, the 2004 event was still considered a developing El Niño because the warm pool had not yet extended into the Niño 3.4 region of the East Pacific.

It has been noticed that the Central Pacific region generally tends to experience more frequent westerly surface wind events, between

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[1] Estimate obtained by author from personal communication with the Honorable Johnny Lemari, Ebeye Mayor, September, 2005.

approximately 5°N and 10°N, during El Niño episodes. These westerly wind events may also be enhanced by the Madden-Julian Oscillation (MJO) as it moves across the Pacific. In December 2004, the Outgoing Longwave Radiation (OLR) product showed a potential MJO moving through the Central Pacific. However the 200-millibar (mb) velocity potential product did not corroborate the existence of a MJO. More about the possible connection between the MJO and TC development in the Marshall Islands will be presented in Section 7.

4.1.2 *Synoptic Scale Patterns*

As the dry season begins to set in over the Central Pacific and the subtropical ridge to the north of Kwajalein strengthens, strong northeasterly trades develop in the region between 10°N and 20°N. When much weaker, or even opposing (westerly) wind fields set up over the southern Marshall Islands, an increased tendency for cyclonic rotation develops on a broad scale.

As convection and convergence associated with disturbances moving through the easterlies intensifies, this broad-scale cyclonic tendency can aid in or possibly even cause low-level cyclogenesis. If upper-level patterns are conducive, the low-level cyclone can become organized to the point of becoming a full-fledged tropical storm or typhoon.

4.2 *Formation of TS Talas*

The necessary elements came together during the first half of December 2004. A strong El Niño in the Niño 4 region added fuel to the atmosphere in the form of very warm ocean water temperatures surrounding the Marshall Islands; westerly surface wind bursts had occurred several times during the months leading up the formation of Talas (and were possibly aided by a MJO); upper-level conditions were conducive to cyclone formation; strengthening surface trade winds to the north added the push necessary for cyclonic rotation; and finally, a disturbance in the easterlies provided the spark that spawned TS Talas.

Not surprisingly, the winds with TS Talas were strongest in the northern part of the storm where the pressure gradient between the subtropical ridge to the north, and typical lower pressures near the equator, was the greatest.

Talas' progression from an area of apparently disorganized convection into a tropical storm was surprisingly quick, taking less than 12 hours.

4.3 *Chronology Of TS Talas*

A Tropical Cyclone Formation Alert (TCFA) was issued at 2200 UTC 09 December 2004 by the

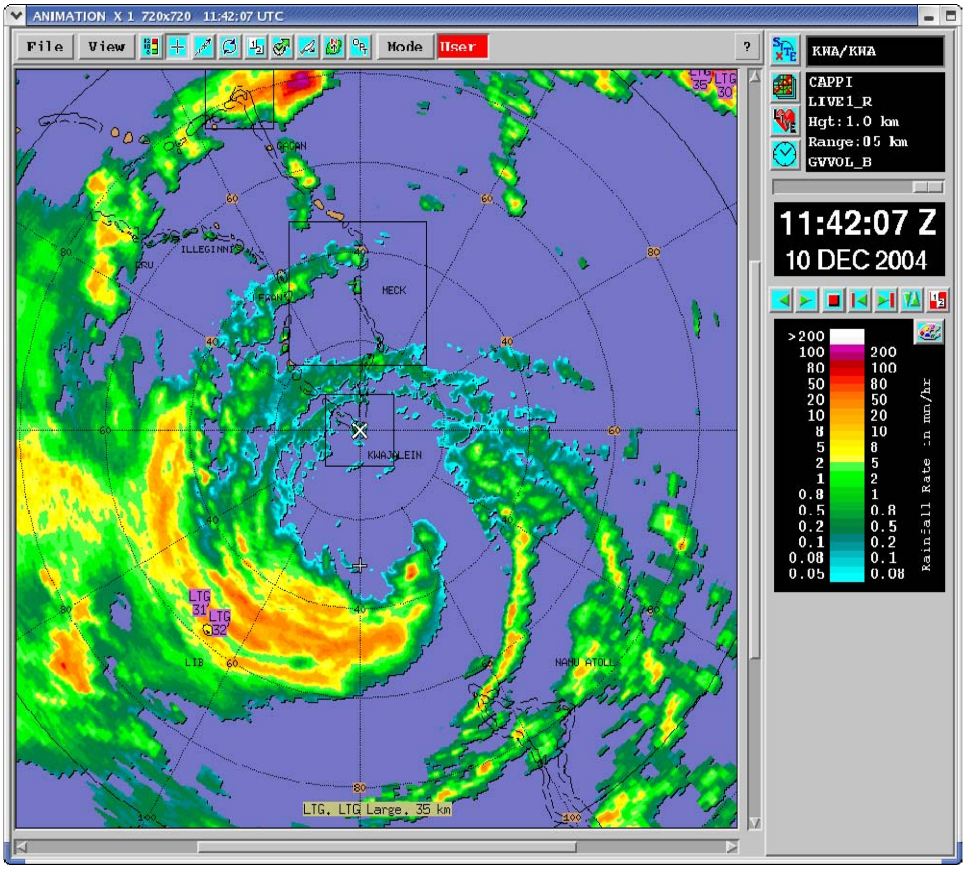

Figure 2: Radar Image from 1142 UTC, 10 December 2004 as TS Talas made its CPA to Kwajalein.

Joint Typhoon Warning Center (JTWC) for a cyclone forming near Majuro, or approximately 250 nautical miles (n mi) ESE of Kwajalein. The storm was upgraded to Tropical Depression (TD) 31W by the JTWC at 0300 UTC 10 December 2004, and was expected to move toward Kwajalein and gradually intensify over the following 24 hours.

At 0400 UTC 10 December 2004 the National Weather Service (NWS) in Guam issued a Tropical Storm Warning for Kwajalein. The storm, now called Talas, was approximately 220 n mi ESE of Kwajalein, packing sustained winds of 35 mph with gusts to 45 mph, and estimated to be moving toward Kwajalein (toward the WNW) at 15-20 mph.

TS Talas continued to strengthen as forecasted on its trek toward Kwajalein, however it also began to pick up speed. The storm made its CPA to Kwajalein at approximately 1145 UTC 10 December 2004, about two hours ahead of schedule. As seen on the 1142 UTC 10 December 2004 Kwajalein radar image (Figure 2, previous page), the center of the storm passed about 16 n mi to the south of Kwajalein.

After lashing Kwajalein, TS Talas meandered westward across the West Pacific over the next nine days. It finally dissipated about 370 n mi east of Kadena Airbase, Japan on 19 December 2004, never having reached Typhoon strength.

4.4 *Observed Weather & Storm Data*

4.4.1 *CPA Conditions*

As is usually the case with TCs, the conditions were the worst as TS Talas made its CPA to Kwajalein Atoll. Since TS Talas passed by closest to Kwajalein, conditions there were naturally the worst. Winds exceeded tropical storm force at Kwajalein for about an hour and a half (1130-1300 UTC 10 December 2004). Table 2 summarizes the worst conditions at Kwajalein at the CPA of TS Talas.

Time / Date (UTC)	Condition	Observed Value
1145/10 December 2004	CPA to Kwajalein	16 nmi
1202/11 December 2004	Maximum Wind Gust	64 mph
1145/10 December 2004	Maximum Sustained Wind	46 mph
1130/10 December 2004	Minimum Surface Pressure	1002.9 mb
1230/11 December 2004	Maximum Winds (Radar Indicated)	92 mph
Entire Event	Rainfall attributed to storm	0.33 inches

Table 2: Worst conditions seen at Kwajalein during TS Talas.

4.4.2 *Barometric Pressure*

Figure 3 shows the pressure trace captured by the weather station micro-barograph during the passage of TS Talas. The pressure scale is not visible on the image but the time scale, in local time, runs across the top.

Although not a dramatic V-shaped pressure pattern, there was a noticeable decrease in surface pressure just before midnight (00) local (L). The pressure dip is more impressive when one considers the fact that midnight local is close to the normal time for a diurnal maximum in pressure at Kwajalein.

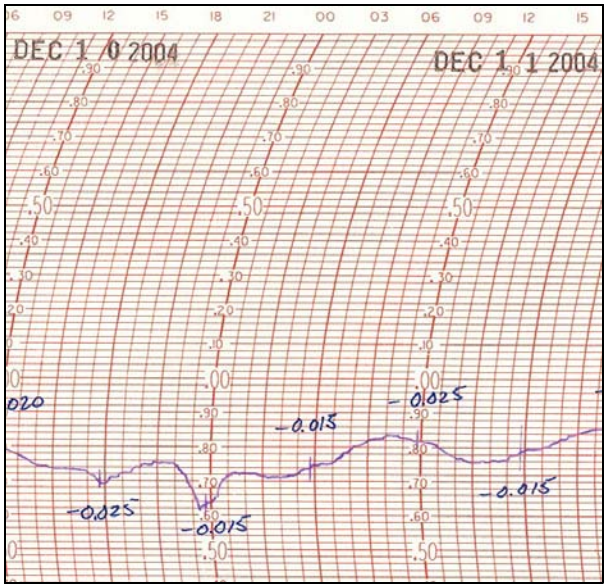

Figure 3: Microbarograph trace from 10/11 December 2004 L. Dip in trace near 00L indicates passage of TS Talas.

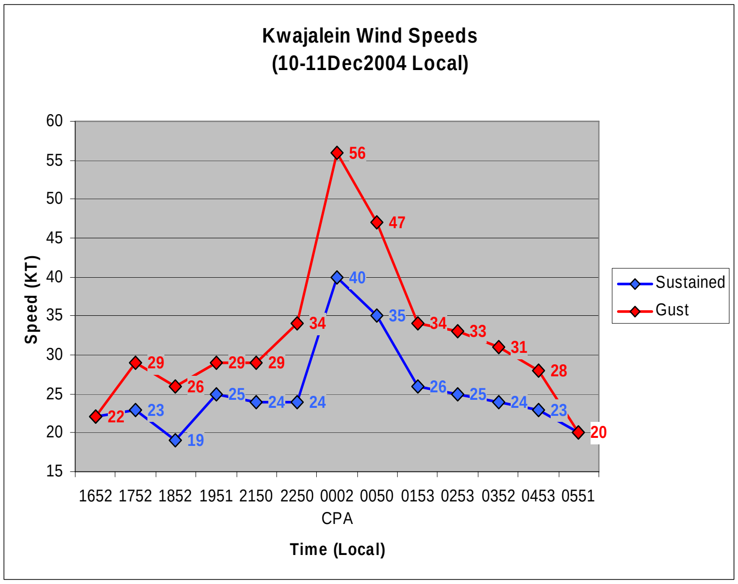

Figure 4: Sustained wind speeds (blue) and gusts (red) at Bucholz Airfield, Kwajalein for 10/11 December 2004 L.

Normal pressure for Kwajalein at midnight in December is approximately 1009.5 mb. The minimum pressure recorded during the passage of TS Talas was 1002.9 mb, resulting in a net pressure drop of 6.6 mb.

4.4.3 *Surface Winds*

Figure 4 shows the evolution of wind speed at Kwajalein during the passage of TS Talas, based on manual surface observations collected at the weather station.

Wind direction was NNE at 0452 UTC 10 December 2004 and as can be seen from the manual surface observations taken from Kwajalein around the CPA of TS Talas (Figure 5), winds gradually shifted to ENE through approximately 1200 UTC and then made an abrupt shift to the E and ESE as the storm passed around midnight.

4.4.4 *Conditions At Other Sites Around Kwajalein Atoll*

Kwajalein Atoll has a network of surface observing stations (known as the "mesonet") which includes stations on Kwajalein, Illeginni, Meck, Legan and Roi-Namur Islands (Figure 1). Figure 6, next page, shows wind gusts for mesonet sites located throughout Kwajalein Atoll for each 30-minute period beginning at the time indicated.

Based on Kwajalein Atoll Mesonet data, it is estimated that tropical storm force winds extended over the southern one-third of Kwajalein Atoll during the CPA.

While some of the gusts in Figure 6 were in excess of tropical storm force, all sustained winds measured at sites other than Kwajalein were less than 34 knots.

4.5 *Impacts At Kwajalein Atoll*

Overall, damage from TS Talas was light to moderate across Kwajalein Atoll and concentrated over the southern one-third of the atoll. There were no reports of injuries or fatalities on any of the islands. The overall cost to USAKA/RTS of preparing for, enduring, and cleaning up after the storm was estimated at $1 million.

4.5.1 *Damage*

There were a few structures on Kwajalein that sustained significant structural damage from TS

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METAR PKWA 101050Z 02024G34KT 4SM SHRA BKN020 OVC035 27/25 A2969 RMK PK WND
03034/45 SLP053 T02740251

METAR PKWA 101154Z 07040G53KT 4SM BKN020 OVC035 28/26 A2963 RMK PK WND 07053/55
SHRAE25 PRESFR SLP033

METAR PKWA 101250Z 11035G47KT 070V140 6SM -SHRA BLPY BKN012 OVC035 27/25 A2970 RMK
PK WND 08056/02 OCNL LTG DSNT SW SHRAB12 PRESRR SLP056 CENTER OF TROPICAL
DEPRESSION 31W APPROX 27NM SW T02700254
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Figure 5: Surface observations, in raw METAR format, from Kwajalein near the CPA of TS Talas (10 December 2004 UTC).

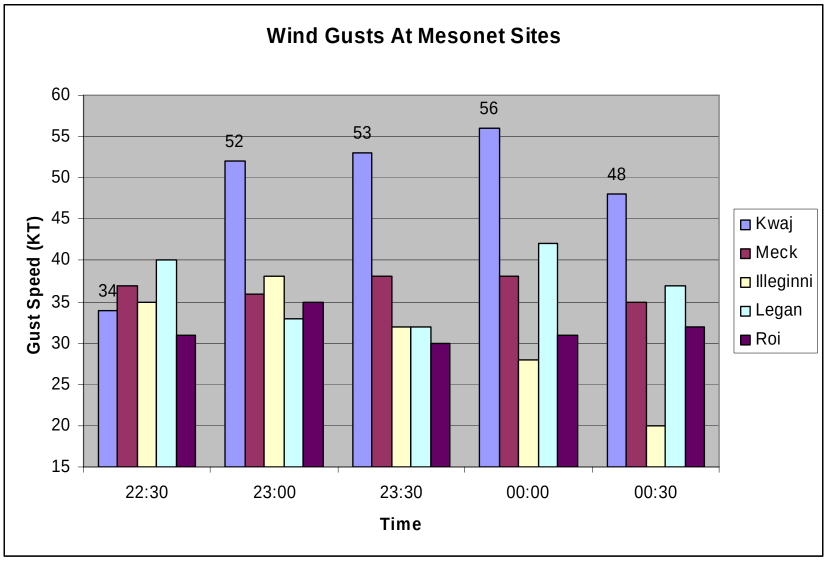

Figure 6: Maximum wind gusts at Kwajalein Atoll mesonet sites for each 30-Minute period indicated.

Talas, however, the storm's overall impact was not great. The most significant damage was to the new sandblast shelter at the marine department. The shelter appeared to have gyrated in the wind and collapsed straight down onto itself. Other damage reported to or observed by 3D Research Corporation/RTS Weather Station personnel included:

- Widespread palm frond and coconut debris strewn about
- Numerous medium and large, leafy trees uprooted
- East-end metal doors on the high school blown off
- Roof damage to the high school
- Several metal buildings with collapsed walls or roof damage
- Two barges broke loose from their moorings (which had to be corralled by tug boats) and one of the barges bumped into a private sailboat

There were no reports of water washing over any of the islands. This was probably due in part to the fact that the water level at the time of CPA, as indicated by data collected from Echo Pier, was only about two feet. While there were no reports of any damage to housing on Kwajalein, reports did indicate that Ebeye Island fared worse with many roofs blown off and houses damaged.

4.5.2 *Mission Operations*

TS Talas had a significant impact on mission operations that were underway for the U.S. Missile Defense Agency at USAKA/RTS. Mission Operations had to be suspended on 10 December 2004 and were not resumed until 12 December 2004. The additional cost to the government for suspending the mission for 48 hours remains unknown, but was likely significant.

5. COMPARISON OF TS TALAS WITH OTHER STORMS AT KWAJALEIN

As was discussed in section 4.1 and shown in Table 1, the environment in which TS Talas formed was very similar to that of most storms that have impacted the Northern Marshall Islands. Table 3 shows a comparison of various parameters from TS Talas with those of the worst historical storms on record that have affected Kwajalein Atoll (items not listed are not available).

A quick scan of Table 3 shows that TS Talas ranked first for CPA to Kwajalein, a close third for highest wind gust, fourth for minimum surface pressure and fifth for sustained wind speed. Overall, TS Talas would probably rank as third or fourth worst since there were several

Storm	Date	CPA (n mi)	Min Pressure	Sustained Wind	Wind Gust
Talas	Dec 2004	16 S	1002.9 mb	46 mph (20.6 ms^{-1})	64 mph (28.6 ms^{-1})
Paka	Dec 1997	83 SW	1003.1 mb	45 mph (20.1 ms^{-1})	54 mph (24.1 ms^{-1})
Gay	Nov 1992	110 N	1001.0 mb	29 mph (13.0 ms^{-1})	35 mph (15.6 ms^{-1})
Zelda	Nov 1991	19 SW	990.1 mb	60 mph (26.8 ms^{-1})	82 mph (36.7 ms^{-1})
Roy	Jan 1988	35 S	991.5 mb	49 mph (21.9 ms^{-1})	66 mph (29.5 ms^{-1})
Pamela	Nov 1982	18 S	n/a	49 mph (21.9 ms^{-1})	n/a
Alice	Jan 1979	40 E	n/a	48 mph (21.5 ms^{-1})	n/a

Table 3: Comparison of TS Talas with other storms at Kwajalein (based on Kwajalein observations).

storms that were more intense (based on the fact that they produced worse conditions at Kwajalein and yet were further away).

6. THE ENSO/TC CONNECTION IN THE NORTHERN MARSHALLS

As indicated in Table 1, it has been observed that the vast majority of TCs that affect the Northern Marshall Islands occur during a positive phase of the ENSO (El Niño).

Attempts have also been made to quantify the increased likelihood of a TC during an El Niño over the Marshall Islands. One estimate is that TCs over the Marshalls are 2.6 times more likely to occur during El Niño than during neutral or La Nina conditions (Spennemann, 1998). Another estimate indicates a 100 percent increase in TCs at Kwajalein during an El Niño (Fujita and Fujita, 1998).

The purpose of this section and the research conducted therefore is to quantify the increased threat to USAKA/RTS posed by TC activity due to the occurrence of an El Niño.

6.1 *How ENSO Affects TC Formation In The Marshall Islands*

Considerable research has been conducted into the eastward shift of the TC generation area of the West Pacific due to the presence of an El Niño. It is widely accepted that the shift occurs and that it is caused by El Niño. However, since the water temperatures of the tropical Pacific are normally sufficiently high for tropical cyclone formation year-round, the actual mechanism responsible for the shift is not thought to be the local increase in water temperature.

In fact, it was concluded by Wang and Chan that no relationship exists between local sea-surface temperature and the location of TC formation (Wang and Chan, 2002). Rather, it is believed to be changes in the Walker circulation associated with El Niño that create favorable conditions for TC development (Chan, 1985).

In its normal state, the Walker circulation is characterized by easterly low-level flow (the trades) from the East Pacific toward the West Pacific and a return flow (the westerlies) aloft. The Walker Circulation is disrupted during an El Niño such that the low-level easterlies are either weakened or reversed near the equator (generally below 10°N). As the normal trades continue north of 10°N and the trades to the south weaken or reverse, a general cyclonic vorticity is induced over a broad area.

This setup of broad-scale, low-level cyclonic vorticity over the eastern West Pacific that occurs during El Niño is an extension of the monsoon trough of the West Pacific. The monsoon trough in the West Pacific is normally the favored area for TC development and it shifts from its normal location in the western West Pacific into the eastern West Pacific during an El Niño. Certainly the increased ocean water temperature helps to fuel the cyclone once it develops, but it is not the cause of the development.

6.2 *Storm Sample*

In an attempt to quantify the impact of El Niño on TC frequency for Kwajalein Atoll in general, and range operations at USAKA/RTS in particular, only TCs (including depressions) that occurred within 300 miles of Kwajalein were considered. The set of storms to be evaluated was narrowed further by eliminating those storms that occurred west of 166°E. In choosing these limits, it was reasoned that if a storm occurred within 300 miles of Kwajalein and east of 166°E, it could have just as easily been right over Kwajalein as not (it was merely a matter of chance that it was not over Kwajalein Atoll).

This area (300 mile radius of Kwajalein, east of 166°E) will be called the Kwajalein Area Of Concern (AOC). Between 1956 and 2004 there were 79 TCs that occurred in the Kwajalein AOC, creating a sample of sufficient size to be considered statistically significant (Nicholls and Young, 2006).

6.3 *ENSO Indices Considered*

Three indices were used in this analysis: Niño 3.4 Region water temperature anomalies (Niño 3.4), Niño 4 Region water temperature anomalies (Niño 4), and the Southern Oscillation Index (SOI).

Given that the Niño 3.4 covers much of the East Pacific, water temperature anomalies from this region are widely used to measure the occurrence and strength of ENSO. However, since the Marshall Islands are well west of the Niño 3.4 region, it is likely to be the least reliable measure to use for the purposes of this study.

The SOI is used to monitor changes in the air pressure between Darwin, Australia and Tahiti that result from changes in the Walker

Circulation and ocean water temperatures. Since the SOI is closely related to Niño 3.4 (i.e. if the anomalously warm waters don't extend into the Niño 3.4 region, the air pressure change at Tahiti will probably not be realized), and to a large extent mirrors its tendencies, it is also not considered to be the best measure of local ENSO conditions in the Marshall Islands.

Niño 4, by contrast, includes the southern Marshalls and stretches from west of Kwajalein to well out into the East Pacific. It is therefore much more likely to be indicative of local ENSO conditions in the Marshalls.

During positive ENSO phase	**ENSO index**		
	3.4	**SOI**	**4**
Number of Storms (out of 79)	52	61	68
Percentage of storms	66%	77%	86%
During negative or neutral ENSO phase	**ENSO index**		
	3.4	**SOI**	**4**
Number of storms (out of 79)	27	18	11
Percentage of storms	34%	23%	14%
Ratio of storms during positive ENSO phase to negative/neutral ENSO phase	**1.9**	**3.4**	**6.2**

Table 4: Breakdown of the number of storms that have occurred in the Kwajalein AOC during the positive and negative/neutral (non-positive) phase of ENSO for the three indices considered. Also shown is the ratio of storms that occurred during a positive ENSO phase to those that occurred during a non-positive ENSO phase. The standard definitions of El Niño are used for Niño 3.4 and SOI, however, the definition of El Niño used in Niño 4 was ±0.3° C (see section 6.3 for explanation).

Because the water temperatures in the Central Pacific are generally much warmer than those of the East Pacific, the magnitude of warming in Niño 4 that is indicative of an El Niño need not be nearly as high as those in Niño 3.4. For example, the very strong El Niño of 1997/1998 exhibited maximum water temperature anomalies of +2.5°C in the Niño 3.4 region while the maximum anomalies in Niño 4 region were barely above 1°C. Certainly, the 1997 El Niño in Niño 4 was every bit as strong as it was in Niño 3.4.

Similar comparison of other ENSO events indicates that anomalies of +1°C (-1°C) or greater in Niño 4 is indicative of strong El Niño (La Nina) conditions. Furthermore, the standard National Oceanic and Atmospheric Administration definition of El Niño (anomalies of 0.5°C, or greater) do not necessarily apply in Niño 4.

It is estimated by the author, based on comparison with other ENSO events, that an El Niño (La Nina) is indicated in Niño 4 with anomalies as low as 0.3° C (-0.3° C). Further, it was noted in Trenberth (1997) that anomalies of +0.4° C might be an even better indicator of El Niño in Niño 3.4. So this author's estimate of 0.3° C anomalies being sufficient to indicate El Niño in Niño 4 is justified.

6.4 *Results*

6.4.1 *For All Storms (Depressions Included)*

Table 4 shows how often storms have occurred in the Kwajalein AOC during positive ENSO events for the three indices considered.

The likelihood of having a storm that affects Kwajalein based on Niño 3.4 and SOI are similar to the findings by Spennemann (1998) and Fujita and Fujita (1998) mentioned earlier. Table 4 suggests, however, that when Niño 4 is in a positive ENSO state (as defined in this paper) the likelihood of a TC of at least depression strength affecting Kwajalein increases to over 6 times higher than normal. Of all the storms that have occurred over the last 50 years in the Kwajalein AOC, 86% have occurred during a positive phase of ENSO in Niño 4.

For the case when the ENSO phase is negative or neutral there is a very low chance of a cyclone developing in the Kwajalein AOC. Only 11 of the 79 storms considered (14%) occurred when ENSO was negative or neutral in Niño 4.

Also of importance is to note that the vast majority of storms that occur in the Marshalls do so during the latter part of the rainy season (August-December). Of the 79 storms considered here, 72 (91%) occurred between August and early January. Therefore it is clear that even though storms can occur in the West Pacific any time of year, a positive ENSO signal in Niño 4 would be of most concern between August and January.

It is interesting to note that during La Nina, storms in the Marshall Islands have occurred most frequently during the month of March. This is an unexpected finding to be sure, but the sample size of storms during La Nina (11) is quite small and thus not statistically significant (Nicholls and Young, 2006).

6.4.2 *Considering Only Strong Storms (Tropical Storm Force Or Greater)*

Of the 79 storms considered in the previous section, 29 reached tropical storm force or greater while still in the Kwajalein AOC. Of those 29 storms, 24 (83%) occurred during an El Niño as indicated by both SOI and Niño 4 and 20 (69%) occurred during El Niño as indicated by Niño 3.4.

Five storms reached typhoon strength in the Kwajalein AOC and all 5 occurred during an El Niño as indicated by both SOI and Niño 4. Four of the 5 typhoons occurred during an El Niño as indicated by Niño 3.4.

6.5 *Conclusions*

While some of the information presented in this section was already covered by other research, four important conclusions can be drawn. First, the Niño 4 region appears to be a much better indicator of the potential for increased TC development over the Marshall Island than other commonly used indicators. Second, the likelihood of a storm occurring in the Kwajalein AOC is significantly higher when Niño 4 is in a positive ENSO state than when it is neutral or negative. Third, storms of tropical storm strength or greater are well correlated with the presence of El Niño. Finally, typhoons are virtually non-existent in the Kwajalein AOC when ENSO is negative or neutral.

These findings have obvious implications for U.S. Government agencies with bases of operations in the Marshall Islands as well as the Government of the Republic of the Marshall Islands itself. The data indicate that Niño 4 region water temperature anomalies should be monitored locally even when El Niño is not indicated by standard indices (particularly between the months of August and January).

7. MJO'S ROLE IN MODULATING TC FREQUENCY IN THE MARSHALL ISLANDS

The westerly wind bursts and the eastward displacement of the West Pacific monsoon trough associated with El Niño are important factors that contribute to increased numbers of tropical cyclones over the Marshall Islands. However, there is anecdotal evidence suggesting that the MJO also plays an important role. The author was unable to obtain data to properly quantify the MJO in time for this paper, but evaluation of the 200 mb velocity potential products at the Climate Prediction Center's Website indicates that the MJO was rather active over the Central and East Pacific during the strong El Niño of 1997. In fact, the MJO signal was present over much of the Central and East Pacific east of 140°E from July through early December of 1997.

During 1997, the Kwajalein AOC experienced its most active tropical cyclone year on record with 12 cyclones! While no other single year came close to 1997 in terms of numbers of cyclones, there were 22 cyclones in the Kwajalein AOC during the long-lived El Nino event between 1992 and 1995. Perhaps not coincidentally, there were at least weak MJO signals present in temporal proximity to most of those cyclones.

Chan (2004) indicated that the MJO induces conditions favorable to the formation of tropical cyclones. Further study into what role the MJO plays in modulating tropical cyclone activity in the Marshall Islands is needed.

8. INVESTIGATING TS TALAS WITH DUAL-POLARIZED (DP) RADAR DATA

TS Talas was the first cyclone in the Kwajalein AOC to form almost entirely within the range of the Kwajalein Polarimetric Radar (KPOL). KPOL is a DP S-band weather radar. Interrogation of TS Talas during its formative stage use DP radar data may provide useful insights into tropical cyclone formation. A complete set of standard and DP radar data, which covers the entire period that TS Talas was within range, was collected and archived. 3D Research Corporation/RTS Weather would be interested in working with universities and/or other research institutions to study the formation of TS Talas using DP radar data.

9. CONCLUSION

TS Talas was not a particularly destructive storm, but it served to remind residents, weather forecasters, and emergency managers alike, not only of the fact that cyclones are possible near Kwajalein, but of how vulnerable the region is to their effects. While the specific occurrence of TS Talas could not have been predicted with much advanced notice, the signals that pointed to the increased potential for cyclone development in the Marshalls were noticed well ahead of time. TS Talas was not completely unexpected and perhaps the information presented in this paper can assist forecasters in recognizing the increased (decreased) TC potential during El Nino (La Nina) in the future.

Further research, including better or more advanced statistical analysis, into the correlation of Niño 4 region water temperature anomalies and the increased potential for TC development is warranted in this case. Of particular interest is whether a certain stage of El Niño is important and what other factors (MJO, mid-latitude systems, upper air patterns, etc) might be modulating TC frequency in the Kwajalein AOC.

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