Fractal Analysis of Sea Surface Temperature Anomaly and Tropical Depression Occurrence

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Abstract

The study analyzes the fractal image of sea surface temperature (SST) anomalies that were taken from the Pacific Ocean and relates this to the tropical depressions and cyclones in the Pacific basin. Previous studies indicate a significant statistical correlation between tropical cyclone power dissipation and SSTs, although it is not clear on what aspect of SSTs affects the cyclone forming. SSTs are calculated from infrared pictures that the polar-orbiting satellites take twice a week around the globe. The National Oceanic and Atmospheric Administration, NOAA, defines anomalies in SST against a long-term mean SST. A positive anomaly means that the current SST is warmer than average, and a negative anomaly means it is cooler than mean SST. This study reveals that the high fractal dimensions of the upper range of the SST anomaly and the low mean barometric pressure on the cyclone basin closely correlates to the frequency and intensity of tropical depressions and tropical cyclones.

Keywords: cyclone, sea surface temperature, fractal dimension

1.0 Introduction

Studies relating Sea Surface Temperatures (SST) and tropical cyclones (TC) have produced varied conclusions. For example, there exist a significant statistical correlation between the Atlantic SSTs and tropical cyclone power dissipation but also states a weaker or no correlation on the NW Pacific SSTs and the number of category 4-5 typhoons (Knutson et al 2010). Sea surface temperature (SST) plays an important role in determining the intensity of tropical cyclones (Berg, 2002). Furthermore, regarding Atlantic tropical cyclones, the recent increase in TC activity can be linked to Atlantic SSTs, however, Faghmous, Liess et al, 2012, recommends looking at smaller regions, or centers of action, instead of basinwide trends.

Previous to this, a study has concluded that SST alone is an inadequate predictor of tropical cyclone intensity and SST does not seem to be the overriding factor in determining the maximum storm intensity (Evans, 1992). While there is a significant relationship between overall sea-surface temperature (SST) and tropical cyclone intensity, the relationship is much less clear in the upper range of SST normally associated with these storms (Michaels, Knappenberger and Davis 2006).

Obviously, more studies are necessary. These studies will draw attention to the factors of SST and how the factors relate to the formation of TCs. This study analyzes the fractal dimension of SST anomalies and relates this to the occurrence of tropical cyclone.

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2.0 Literature

Water is an excellent reservoir for heat, this makes the ocean a large storage battery that stores heat during the day and releases such heat on a cooler atmosphere (Deser, Alexander, et al, 2010). This large thermal inertia of the oceans is a key factor in stabilizing Earth's climate (Pidwirny, 2013). The average flux striking the earth's surface is 174.7 W/m2 (Tsao, 2006), with the pacific ocean coverage of an approximate 1.62 x 10^8 km^2, the approximate energy striking the ocean is 2.83 x 10^{13} kJ/sec in direct sunlight. The heat from the sun does not only warm the water but also evaporates surface waters and builds up moisture on the atmosphere.

According to the National Oceanic and Atmospheric Administration, NOAA, near real time SST is produced from night time-only data, to eliminate the effect of solar glare and reduce variability caused by heating during the day. Sea surface temperature is defined as the skin temperature of the ocean surface water. The persistence of SST anomalies is caused largely by the thermal inertia of the ocean mixed layer. These infrared images taken at night, therefore, are remnants of the displaced warm sea waters carried by the ocean current. These are effectively a trace of the intensity of the heat of the ocean, an indicator of how much heat is absorbed by the ocean during the day. As the thermal footprints gets larger, the intense the heat absorbed by the ocean.

The amount of heat can be proportionately related to the amount of water that may be evaporated for the day or to the amount of moisture in the atmosphere. The time to raise enough atmospheric moisture is a significant consideration in the development of the tropical depressions.

Air capacity to absorb moisture depends on its temperature and barometric pressure. The rate of water holding capacity of air increases by about 7% per 1°C. (Trenberth, 2011) In the atmospheric strata, cooler air, which is denser, stratifies at the lower level and the water vapor carrying hot air rises to the higher level. This continuous rise of water vapor carrying air causes the thermal column. Barometric pressure and temperature drop approximately 1.2 kPa every 100 m and 6.5° C with every 1 kilometer height respectively (Russell, 2009). The pressure drop increases kinetic activity of the hot air and water vapor due to volumetric expansion. The heat from the rising hot air dissipates to the cooler atmosphere and the water vapor condenses. The condensed water vapor has far less volume, these collapses the atmospheric pressure. The low atmospheric pressure causes more water vapor, and hot air to rise. This cycle continues until the atmosphere is saturated or the pressure equalizes. As enough mass forms in the atmosphere tropical depression (TD) appears. The high velocity updrafts of thermal columns cause a vacuum; in turn, the vacuum attracts sideways winds. The winds increase the size of the column and develop the cyclonic effect. For a fairly slow moving and symmetrical winds an atmospheric TD forms just above a high SST area after a period of time, and at a highly active and asymmetric winds TD forms at relative displaced locations.

Tropical cyclones are intense, cyclonically-rotating, low-pressure weather systems that form over the tropical oceans. Intense means that near surface sustained wind speeds exceed 17 m/s (60 km/h, 32 kn). Severe tropical cyclones with near surface sustained wind speeds equal to or exceeding 33 m/s (120 km/h, 64 kn) are called hurricanes over the Atlantic Ocean, the East Pacific Ocean and the Caribbean Sea, and Typhoons over the Western North Pacific Ocean. (Smith 2006)

2.1 Fractal dimension

Fractal is a general term used to describe both the geometry and the processes which exhibit self-similarity, scale invariance, and fractional dimension (Mandelbrot, 1983). Two of the core properties of fractals are self-similarity and scale invariance. Formally, self-similarity is defined as a property where a subset, when magnified to the size of the whole, is indistinguishable from the whole (Mandelbrot, 1967).

Mandelbrot (1967) shows that classical geometry deals with shapes or objects described in integral dimension. A point is 0-dimensional, a line having 1-dimension, a plane figure with 2-dimensions and the 3-dimensional solid. However, many phenomena are appropriately described in terms of a dimension between any two dimensions. A straight line has dimension d = 1 and a zigzag of this will have a dimension between one and two for the curve is more than a line but less than a 2-dimensional figure. Here, the dimension manifested is referred to as a fractional dimension - a dimension whose value lies between integral values.

Nature, natural growth and many geographic features are said to be fractal. Fractal dimension quantifies an otherwise difficult natural occurrence, especially those captured in images. Fractal dimension offers a convenient method of measuring the thermal footprint of the SST anomaly on the ocean surface. This process of determining the fractal dimension of an image is also called fractal image analysis.

2.2 Fractal Image Analysis

According to Zmeskal et al (2013), fractal analysis means the determination of fractal dimension and fractal measure of the image. Fractal dimensions and fractal measures are obtained by using the Box Counting Method. Traditionally, box counting method works by laying meshes of different sizes r and then counting the number of boxes N needed to cover tested object completely. Using the values of r and N, the slopes D of the linear portion of function $\log N(r) = D (\log (1/r)) + \log k$ converge to be the box fractal dimension of the tested image, and the converging values of k intercept is the fractal measure.

HarFA is a software compiled to perform harmonic and wavelet analysis of digitized images and calculations their fractal parameters. It can be freely downloaded from http://www.fch.vutbr.cz/lectures/imagesci.

HarFA uses a modified Box Counting. Squares, which are completely black, are counted separately from squares, which border black and white, and those that are completely white. By this modification, HarFA obtains three fractal dimensions DB, DBW, DW, which characterize properties of black plane DB, black-white border of black object DBW and properties of white background DW.

The practice for obtaining these dimensions is the same as classical Box-Counting. The following individual fractal dimensions are established as slopes of functions:

$$NB(r) = DB(\log(1/r)) + kB$$

$$NBW(r) = DBW(\log(1/r)) + kBW$$

$$NW(r) = DW(\log(1/r)) + kW$$

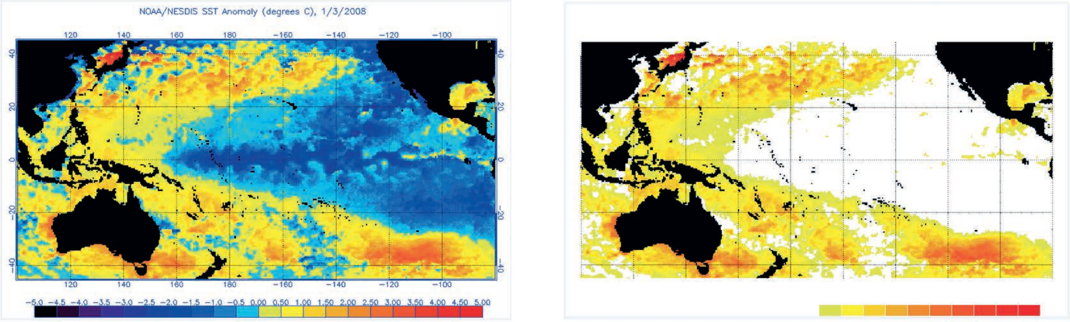
By this technique, HarFA can examine black and white fractal structures which come into existence during the process called "thresholding". Thresholding transforms colored image object into black and white. There are many criteria that can be changed, to derive many different fractal structures from one image. Thus, it is possible to obtain various fractal dimensions and measures for one image. (Zmeskal et al. 2013)

3.0 Methodology

Data images of the SST anomalies were retrieved from the NOAA website. The images were preprocessed: a.) the removal of ocean cold spots, the blue region. It is necessary to retain only the hot and warm spots, see figure 1. This is done with the use of an image processor that is capable of hue - lightness – saturation. The necessary fractal dimensions must come from the warm waters only; b.) the division of the Pacific into the three major basins, West Pacific Basin (latitude 0 to 40 and longitude 120 to -160), East Pacific Basin (latitude 0 to 40, longitude -80 to -160), and South Pacific Basin (latitude 0 to -40, longitude 120 to -160). This is done with an image processor capable of object selection or cropping. Figure 2 shows the latitudes and longitudinal dimensions for each cyclone basin.

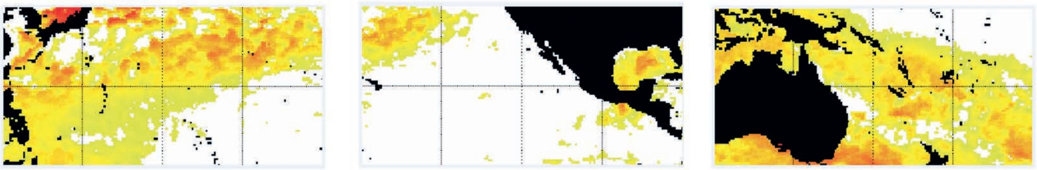
The resulting images were subjected to fractal image analyses using the Harmonic and Fractal Image Analyzer (HarfA 5.5.3 Demo Version). Thresholding the images for the specific of 1 °C to 2.5°C, 2.5 °C to 3.5 °C and 3.5 °C to 5 °C SST anomalies generates the desired thermal footprints, see figures 3, 4, and 5. The fractal dimensions of the images of the thermal footprints are calculated using the same software, figure 6. Table 1 shows the tabulated fractal dimensions of the different SST anomalies under each basin in chronological order.

A time series graph was generated for each basin figures 7, 8 and 9. Each graph includes the fractal dimensions of the SST anomalies and tropical cyclone data including TC intensity and barometric pressure.



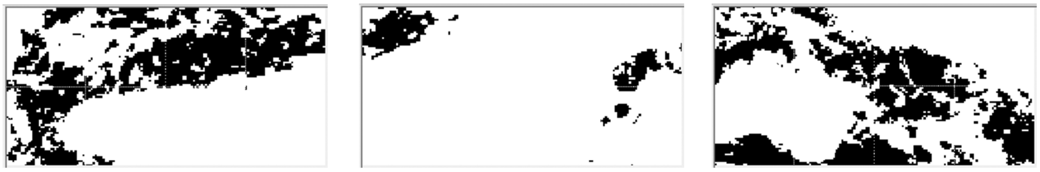
a.) Original NOAA image b.) After removal of cold regions

Figure 1. Image Preprocessing: Ocean Cold Spots Removal



a.) West Pacific Basin b.) East Pacific Basin c.) South Pacific Basin

Figure 2. Image Preprocessing: Dividing the Basins of the Tropical Cyclones



a.) West Pacific Basin b.) East Pacific Basin c.) South Pacific Basin

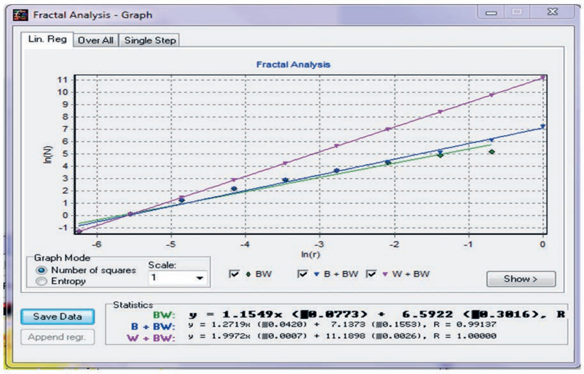
Figure 3. Image Processing: HarFA Thresholding the range of 1°C to 5°C Temperature Anomaly

a.) West Pacific Basin b.) East Pacific Basin c.) South Pacific Basin

Figure 4. Image Processing: HarFA Thresholding the range of 2.5°C to 3.5°C Temperature Anomaly

a.) West Pacific Basin b.) East Pacific Basin c.) South Pacific Basin

Figure 5. Image Processing: HarFA Thresholding the range of 3.5°C to 5°C Temperature Anomaly



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      BW:  y = 1.1549x (█0.0773) +  6.5922 (█0.3016), R
  B + BW:  y = 1.2719x (▓0.0420) +  7.1373 (▓0.1553), R = 0.99137
  W + BW:  y = 1.9972x (▓0.0007) + 11.1898 (▓0.0026), R = 1.00000
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Figure 6. Fractal Analysis using HarFA Software

4.0 Results and Discussion

Figures 7, 8 and 9 are the time series graphs of the fractal dimensions of the SST anomaly, TCs and TDs developed in the three cyclone basins in the Pacific Ocean. These basins are the west Pacific basin, where the Philippines and Japan are included, the east Pacific basin where California and Mexico are included, and the south Pacific basin where Australia faces the Pacific Ocean.

Figure 7 is the time series graph for the West Pacific Basin. There are five line graphs, the uppermost line A is the barometric pressure graph limited to the available data in connection with the occurrence of TD's and TC's. It is scaled to fit the graph with the maximum value 1010 mbar, and the minimum value is 905 mbar. The second line graph, B, is the fractal dimension of the 1 °C to 2.5 °C SST anomaly. These dimensions show little variations throughout the year. The next two lines C and D are the fractal dimensions of the 2.5 °C to 3.5 °C and 3.5 °C to 5 °C SST anomalies respectively. The two ranges are sensitive to the thermal changes of the ocean. On the basis of sensitivity test, these two graphs are the variables that can show the state of

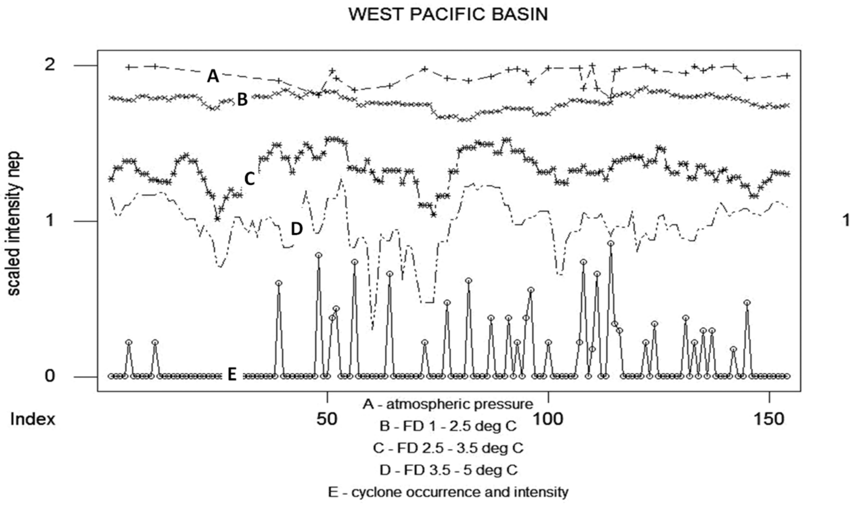


Figure 7. Time Series Graph of the West Pacific Basin

the ocean thermal energy. If the thermal energy is greater, the fractal dimensions are also relatively bigger. The three temperature graphs are on the same ordinate scale with the maximum fractal dimension of 2.

The spikes at the lowermost line, line graph E, represent tropical depressions and cyclones. The heights of the spikes are scaled TC intensities. The base line is nil or non occurrence, the shorter spikes are the cyclones, depressions with category 0, the tallest spike in this graph is a category 5 cyclone. The abscissa totals 154 observations from January to December. This includes SST anomaly observations recorded according to dates the images are taken, TDs and TCs events recorded according to the dates of occurrence.

Figure 7 reveals a significant correlation between the fractal dimension size and frequency and intensity of the tropical cyclones, line graphs D and E. The persistence of the large fractal dimensions, line graph D, for a number of days, prior to any TD, and TC occurrences showed a significant

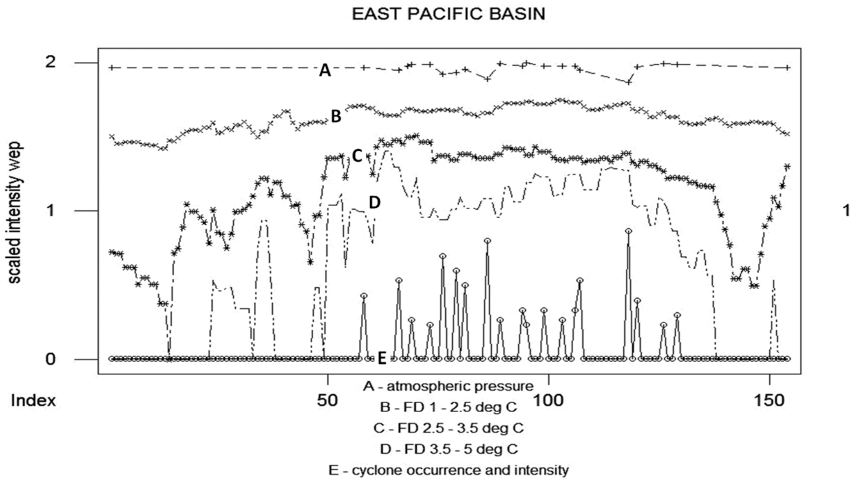


Figure 8. Time Series Graph of the East Pacific Basin

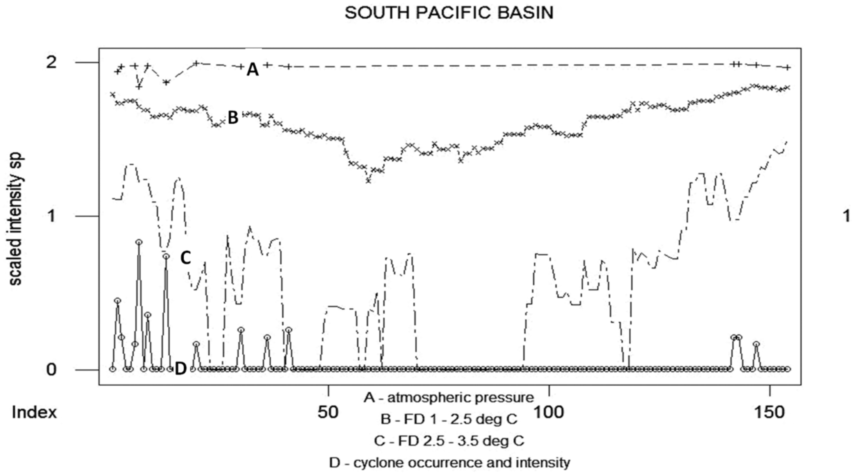


Figure 9. Time Series Graph of the South Pacific Basin

correlation to the TC intensity. The magnitudes of the atmospheric pressure drops that are coincident to the TCs are directly proportional to the TC intensity. In addition, figure 7 line graph D show drops in the fractal dimensions that are consistent with the dates of non occurrence of TD and TC. There are no significant atmospheric activities when the fractal dimensions are smaller. These observations are also apparent in the East, and South Pacific Basins, figures 8 and 9.

The East Pacific Basin figure 8, reveals a series of tropical depressions and cyclones developed during the period from May to November, line graph E. The graph shows an erratic fractal dimension of the 2.5 °C to 3.5 °C and of 3.5 °C to 5 °C SST anomaly, line graphs C and D. The persistent high SST anomaly over the basin is found in May. It becomes discernible and attains the peak on September. Then, it gradually disappears in November. The temperature graph curves at the peaks of the tropical cyclone intensities and frequencies in the region. The highest spike is a category 4 cyclone. The highest and lowest barometric pressures are 1010 mbar and 945 mbar respectively, line graph A.

The South Pacific Basin figure 9 shows a relatively different seasonal cycle. The occurrence of TDs and TCs start on December of the previous year and ends in May in the succeeding year, line graph D. Line graphs A and C are the fractal dimensions of 1°C to 2.5°C, 2.5°C to 3.5°C SST anomalies, respectively. The South Pacific Basin has a lower thermal inertia than the other basins. The lowest barometric pressure is 930 mbar, line graph A.

5.0 Findings

A tropical cyclone grows from a span of days to weeks. For a tropical cyclone to develop fully, a significant amount of moisture must be accumulated in the atmosphere. The presence of moisture in the atmosphere can upset the balance of the atmospheric pressures. This pressure difference drives the winds from one region to another. The moisture build-up and the significant pressure drop in the atmosphere determine whether a tropical depression will grow to be a tropical cyclone or simply dissolves.

This study is aimed at investigating how the SST anomalies relate to the frequency of tropical cyclones and depressions by fractal image analysis. The following are the findings:

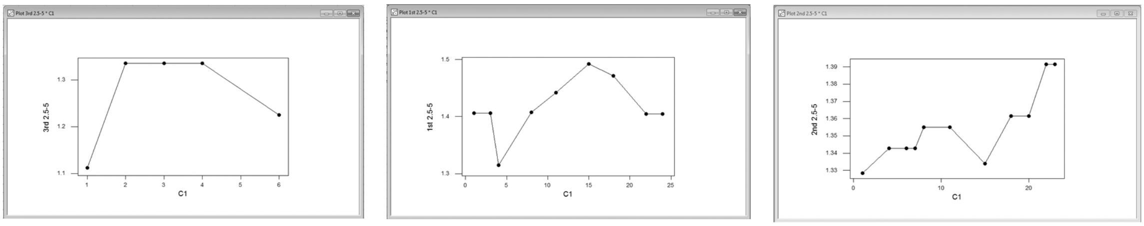
1. The high fractal dimension of SST anomaly and the low mean atmospheric pressure

on the cyclone basin are the important determinant of the frequency and intensity of tropical cyclones.

2. The higher the fractal dimensions of SST anomaly over a period of time becomes the higher frequency of TD and TC. The time for moisture to build-up in the atmosphere is an important consideration for the growth of a TD and TC.
3. The fractal dimension of the 2.5°C to 3.5°C and 3.5°C to 5°C SST anomalies reflect the thermal energy that the ocean has received from the sun during the day. These SST anomalies are the sensitive values. These could appear and disappear accordingly with the strength of the thermal inertia of the ocean.
4. The sizes of the fractal dimensions of the 2.5 °C to 3.5 °C and 3.5°C to 5°C SST anomalies correlate closely with the growth and dissolution of the of a tropical cyclone. The large fractal dimensions of the 2.5 °C to 3.5 °C and 3.5°C to 5°C SST anomalies occur as a precursor to tropical depressions in the region see figure 10. Figure 10.a. shows a 24-days high fractal dimension of the 3.5°C to 5°C SST anomaly prior to an intense cyclone Butchoy category 4 (PAGASA Weather, 2008). Figure 10.b shows Funa (Australian Severe Weather, 2008) with a 6 days lead time of high fractal dimension of the 2.5°C to 3.5°C SST anomaly. Figure 10.c shows Norbert (National Hurricane Center,2008) with 23 days high fractal dimension of the 3.5°C to 5°C SST anomaly prior to the occurrence.

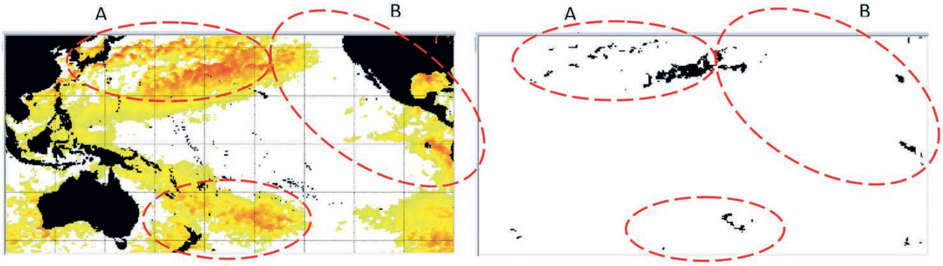
Relating to the actual locations of determinant SST: (see figure 11)

1. Latitude 20 to 40, northern part of Pacific Ocean, figure 11, A, is the persistent location of the 2.5°C to 3.5°C, 3.5°C to 5°C SST anomaly thermal footprint. The fractal dimension of this footprint closely correlates with the frequency and intensity of the TCs and TDs of the West Pacific Basin.
2. The northeastern Pacific between the latitude 20 to 40 and longitude -160 to -140 and the east Pacific longitude -100 to -80, figure 11, B is the persistent location of the 2.5 °C to 3.5°C and the 3.5°C to 5°C SST anomaly thermal footprint. The fractal dimension of this footprint closely correlates with the frequency and intensity of the TCs and TDs of the East Pacific Basin.
3. The South Pacific between the latitude -20 to -40 and longitude 160 to -160 is the persistent location of the 2.5°C to 3.5°C SST anomaly thermal footprint, figure 11, C. The fractal dimension of this thermal footprint closely correlates with the frequency and intensity of the TCs and TDs of the South Pacific Basin.



a.) Typhoon Butchoy b.) Cyclone Funa c.) Hurricane Norbert

Figure 10. High Fractal Dimension of the 2.5°C to 5°C SST Anomaly prior to Cyclone Occurence



a.) Pacific Ocean SST anomaly

b.) image of 2.5°C to 3.5°C SST anomaly footprint

Figure 11. Relevant Locations of SST Anomalies

6.0 Conclusions

The sun is a major source of energy that initiates atmospheric disturbances on earth. The solar energy is the main contributor to the thermal energy of the ocean. This is manifested by the SST anomalies. Ocean thermal evaporates water that builds up moisture in the atmosphere. Water with its significant latent heat capacity contributes largely to the atmospheric pressure imbalance and the tropical depressions. Assessing the results of the fractal image analyses and the time series analyses, the study asserts the following:

The fractal dimensions of the 2.5°C to 3.5°C and 3.5°C to 5°C SST anomaly are the scaled reflection of the thermal energy of the ocean. The fractal dimensions of these SST anomalies vary in size with the thermal inertia of the ocean.

The fractal dimensions of the 2.5°C to 3.5°C and 3.5°C to 5°C SST anomaly reveals a close correlation with TCs and TDs frequency and intensity in a per cyclone basin basis. The magnitudes of the atmospheric pressure drops that are coincident to the TCs are directly proportional to the TC intensity. As the fractal dimension of SST anomaly gets higher and as the atmospheric pressure drops lower the more the frequency and the higher the intensity of the TDs and TCs. In addition, the time for moisture to build-up in the atmosphere is an important consideration for the growth of a TD and TC. The large fractal dimensions of the 2.5 °C to 3.5 °C and 3.5°C to 5°C SST anomalies occur as a precursor to tropical depressions in the region.

The 2.5°C to 3.5°C and 3.5°C to 5°C SST anomaly thermal footprints are consistently located at the North Pacific region(the latitude 20 to 40 and longitude -160 to -140), East Pacific (longitude -100 to -80) and the South Pacific (latitude -20 to -40 and longitude 160 to -160) as indicated in figure 11. The fractal dimensions of these thermal footprints closely correlate with the frequency and intensity of the TCs and TDs.

Moreover, this study shows that it is possible to predict the frequency and intensity of tropical cyclones, by fractal image analyses of the SST anomalies of the ocean.

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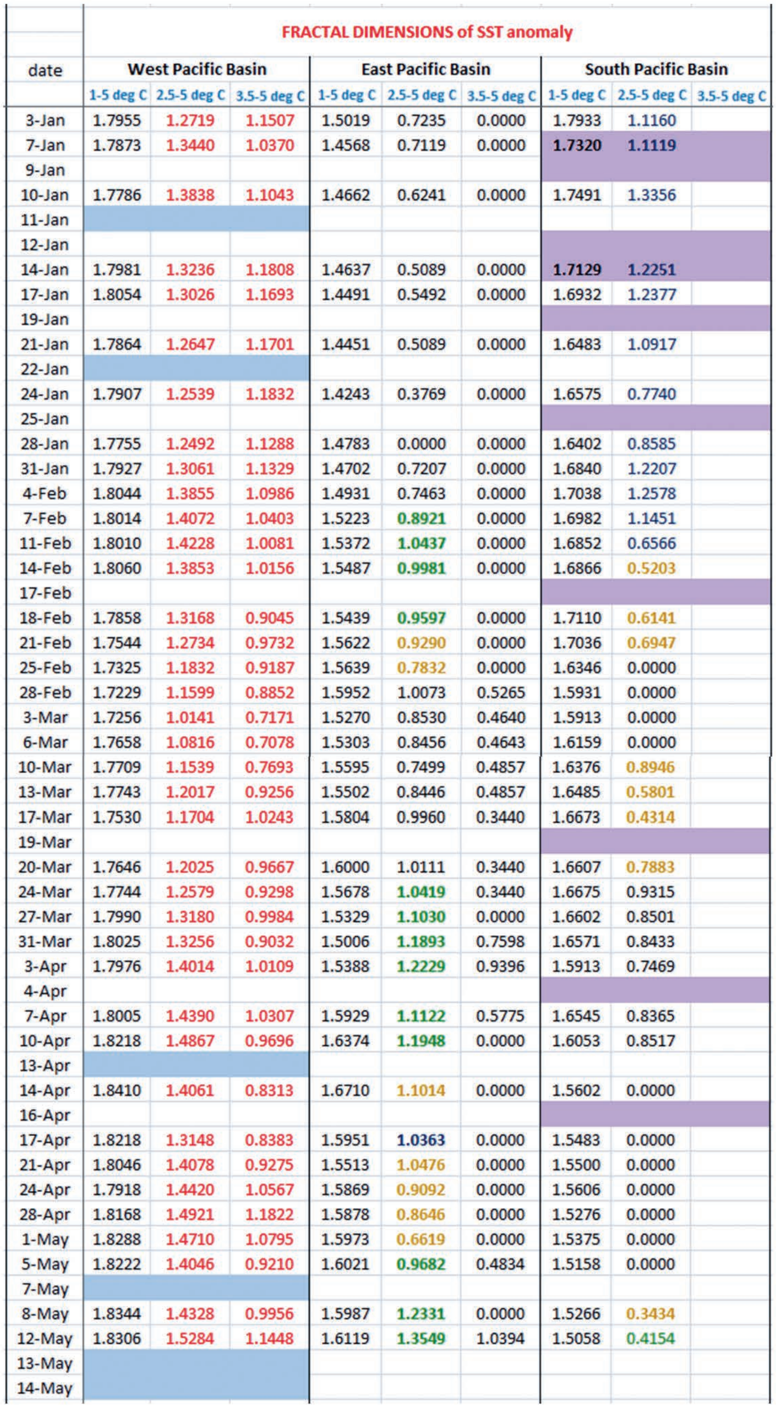
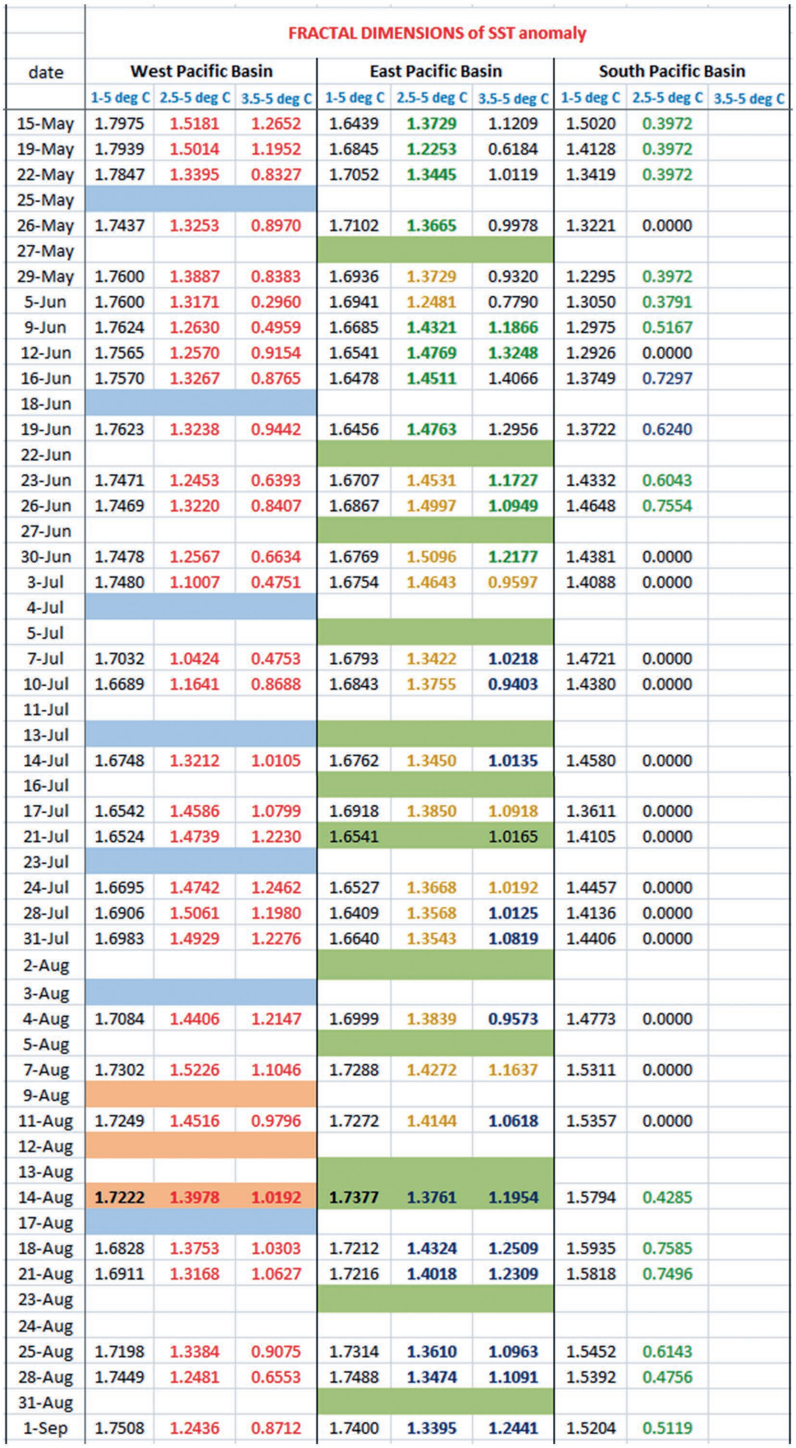
APPENDIX

Table 1. Fractal Dimensions of SST Anomaly



	FRACTAL DIMENSIONS of SST anomaly								
date	West Pacific Basin			East Pacific Basin			South Pacific Basin		
	1-5 deg C	2.5-5 deg C	3.5-5 deg C	1-5 deg C	2.5-5 deg C	3.5-5 deg C	1-5 deg C	2.5-5 deg C	3.5-5 deg C
3-Jan	1.7955	1.2719	1.1507	1.5019	0.7235	0.0000	1.7933	1.1160	
7-Jan	1.7873	1.3440	1.0370	1.4568	0.7119	0.0000	1.7320	1.1119	
9-Jan									
10-Jan	1.7786	1.3838	1.1043	1.4662	0.6241	0.0000	1.7491	1.3356	
11-Jan									
12-Jan									
14-Jan	1.7981	1.3236	1.1808	1.4637	0.5089	0.0000	1.7129	1.2251	
17-Jan	1.8054	1.3026	1.1693	1.4491	0.5492	0.0000	1.6932	1.2377	
19-Jan									
21-Jan	1.7864	1.2647	1.1701	1.4451	0.5089	0.0000	1.6483	1.0917	
22-Jan									
24-Jan	1.7907	1.2539	1.1832	1.4243	0.3769	0.0000	1.6575	0.7740	
25-Jan									
28-Jan	1.7755	1.2492	1.1288	1.4783	0.0000	0.0000	1.6402	0.8585	
31-Jan	1.7927	1.3061	1.1329	1.4702	0.7207	0.0000	1.6840	1.2207	
4-Feb	1.8044	1.3855	1.0986	1.4931	0.7463	0.0000	1.7038	1.2578	
7-Feb	1.8014	1.4072	1.0403	1.5223	0.8921	0.0000	1.6982	1.1451	
11-Feb	1.8010	1.4228	1.0081	1.5372	1.0437	0.0000	1.6852	0.6566	
14-Feb	1.8060	1.3853	1.0156	1.5487	0.9981	0.0000	1.6866	0.5203	
17-Feb									
18-Feb	1.7858	1.3168	0.9045	1.5439	0.9597	0.0000	1.7110	0.6141	
21-Feb	1.7544	1.2734	0.9732	1.5622	0.9290	0.0000	1.7036	0.6947	
25-Feb	1.7325	1.1832	0.9187	1.5639	0.7832	0.0000	1.6346	0.0000	
28-Feb	1.7229	1.1599	0.8852	1.5952	1.0073	0.5265	1.5931	0.0000	
3-Mar	1.7256	1.0141	0.7171	1.5270	0.8530	0.4640	1.5913	0.0000	
6-Mar	1.7658	1.0816	0.7078	1.5303	0.8456	0.4643	1.6159	0.0000	
10-Mar	1.7709	1.1539	0.7693	1.5595	0.7499	0.4857	1.6376	0.8946	
13-Mar	1.7743	1.2017	0.9256	1.5502	0.8446	0.4857	1.6485	0.5801	
17-Mar	1.7530	1.1704	1.0243	1.5804	0.9960	0.3440	1.6673	0.4314	
19-Mar									
20-Mar	1.7646	1.2025	0.9667	1.6000	1.0111	0.3440	1.6607	0.7883	
24-Mar	1.7744	1.2579	0.9298	1.5678	1.0419	0.3440	1.6675	0.9315	
27-Mar	1.7990	1.3180	0.9984	1.5329	1.1030	0.0000	1.6602	0.8501	
31-Mar	1.8025	1.3256	0.9032	1.5006	1.1893	0.7598	1.6571	0.8433	
3-Apr	1.7976	1.4014	1.0109	1.5388	1.2229	0.9396	1.5913	0.7469	
4-Apr									
7-Apr	1.8005	1.4390	1.0307	1.5929	1.1122	0.5775	1.6545	0.8365	
10-Apr	1.8218	1.4867	0.9696	1.6374	1.1948	0.0000	1.6053	0.8517	
13-Apr									
14-Apr	1.8410	1.4061	0.8313	1.6710	1.1014	0.0000	1.5602	0.0000	
16-Apr									
17-Apr	1.8218	1.3148	0.8383	1.5951	1.0363	0.0000	1.5483	0.0000	
21-Apr	1.8046	1.4078	0.9275	1.5513	1.0476	0.0000	1.5500	0.0000	
24-Apr	1.7918	1.4420	1.0567	1.5869	0.9092	0.0000	1.5606	0.0000	
28-Apr	1.8168	1.4921	1.1822	1.5878	0.8646	0.0000	1.5276	0.0000	
1-May	1.8288	1.4710	1.0795	1.5973	0.6619	0.0000	1.5375	0.0000	
5-May	1.8222	1.4046	0.9210	1.6021	0.9682	0.4834	1.5158	0.0000	
7-May									
8-May	1.8344	1.4328	0.9956	1.5987	1.2331	0.0000	1.5266	0.3434	
12-May	1.8306	1.5284	1.1448	1.6119	1.3549	1.0394	1.5058	0.4154	
13-May									
14-May									

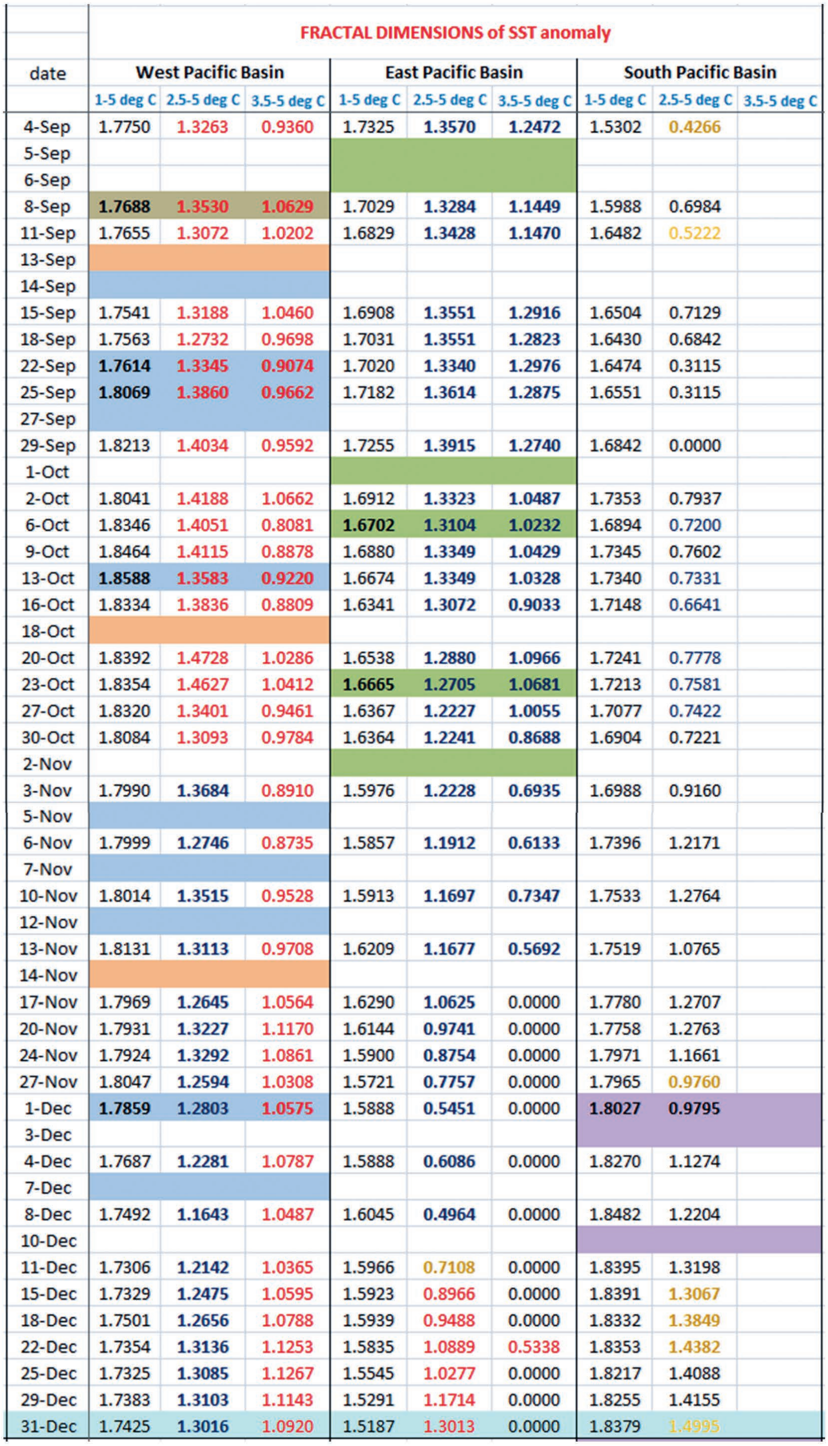
Continuation. Fractal Dimensions of SST Anomaly



FRACTAL DIMENSIONS of SST anomaly

date	West Pacific Basin			East Pacific Basin			South Pacific Basin		
	1-5 deg C	2.5-5 deg C	3.5-5 deg C	1-5 deg C	2.5-5 deg C	3.5-5 deg C	1-5 deg C	2.5-5 deg C	3.5-5 deg C
15-May	1.7975	1.5181	1.2652	1.6439	1.3729	1.1209	1.5020	0.3972	
19-May	1.7939	1.5014	1.1952	1.6845	1.2253	0.6184	1.4128	0.3972	
22-May	1.7847	1.3395	0.8327	1.7052	1.3445	1.0119	1.3419	0.3972	
25-May									
26-May	1.7437	1.3253	0.8970	1.7102	1.3665	0.9978	1.3221	0.0000	
27-May									
29-May	1.7600	1.3887	0.8383	1.6936	1.3729	0.9320	1.2295	0.3972	
5-Jun	1.7600	1.3171	0.2960	1.6941	1.2481	0.7790	1.3050	0.3791	
9-Jun	1.7624	1.2630	0.4959	1.6685	1.4321	1.1866	1.2975	0.5167	
12-Jun	1.7565	1.2570	0.9154	1.6541	1.4769	1.3248	1.2926	0.0000	
16-Jun	1.7570	1.3267	0.8765	1.6478	1.4511	1.4066	1.3749	0.7297	
18-Jun									
19-Jun	1.7623	1.3238	0.9442	1.6456	1.4763	1.2956	1.3722	0.6240	
22-Jun									
23-Jun	1.7471	1.2453	0.6393	1.6707	1.4531	1.1727	1.4332	0.6043	
26-Jun	1.7469	1.3220	0.8407	1.6867	1.4997	1.0949	1.4648	0.7554	
27-Jun									
30-Jun	1.7478	1.2567	0.6634	1.6769	1.5096	1.2177	1.4381	0.0000	
3-Jul	1.7480	1.1007	0.4751	1.6754	1.4643	0.9597	1.4088	0.0000	
4-Jul									
5-Jul									
7-Jul	1.7032	1.0424	0.4753	1.6793	1.3422	1.0218	1.4721	0.0000	
10-Jul	1.6689	1.1641	0.8688	1.6843	1.3755	0.9403	1.4380	0.0000	
11-Jul									
13-Jul									
14-Jul	1.6748	1.3212	1.0105	1.6762	1.3450	1.0135	1.4580	0.0000	
16-Jul									
17-Jul	1.6542	1.4586	1.0799	1.6918	1.3850	1.0918	1.3611	0.0000	
21-Jul	1.6524	1.4739	1.2230	1.6541		1.0165	1.4105	0.0000	
23-Jul									
24-Jul	1.6695	1.4742	1.2462	1.6527	1.3668	1.0192	1.4457	0.0000	
28-Jul	1.6906	1.5061	1.1980	1.6409	1.3568	1.0125	1.4136	0.0000	
31-Jul	1.6983	1.4929	1.2276	1.6640	1.3543	1.0819	1.4406	0.0000	
2-Aug									
3-Aug									
4-Aug	1.7084	1.4406	1.2147	1.6999	1.3839	0.9573	1.4773	0.0000	
5-Aug									
7-Aug	1.7302	1.5226	1.1046	1.7288	1.4272	1.1637	1.5311	0.0000	
9-Aug									
11-Aug	1.7249	1.4516	0.9796	1.7272	1.4144	1.0618	1.5357	0.0000	
12-Aug									
13-Aug									
14-Aug	**1.7222**	**1.3978**	**1.0192**	**1.7377**	1.3761	1.1954	1.5794	0.4285	
17-Aug									
18-Aug	1.6828	1.3753	1.0303	1.7212	1.4324	1.2509	1.5935	0.7585	
21-Aug	1.6911	1.3168	1.0627	1.7216	1.4018	1.2309	1.5818	0.7496	
23-Aug									
24-Aug									
25-Aug	1.7198	1.3384	0.9075	1.7314	1.3610	1.0963	1.5452	0.6143	
28-Aug	1.7449	1.2481	0.6553	1.7488	1.3474	1.1091	1.5392	0.4756	
31-Aug									
1-Sep	1.7508	1.2436	0.8712	1.7400	1.3395	1.2441	1.5204	0.5119	

Continuation. Fractal Dimensions of SST Anomaly



	FRACTAL DIMENSIONS of SST anomaly								
date	West Pacific Basin			East Pacific Basin			South Pacific Basin		
	1-5 deg C	2.5-5 deg C	3.5-5 deg C	1-5 deg C	2.5-5 deg C	3.5-5 deg C	1-5 deg C	2.5-5 deg C	3.5-5 deg C
4-Sep	1.7750	1.3263	0.9360	1.7325	1.3570	1.2472	1.5302	0.4266	
5-Sep									
6-Sep									
8-Sep	1.7688	1.3530	1.0629	1.7029	1.3284	1.1449	1.5988	0.6984	
11-Sep	1.7655	1.3072	1.0202	1.6829	1.3428	1.1470	1.6482	0.5222	
13-Sep									
14-Sep									
15-Sep	1.7541	1.3188	1.0460	1.6908	1.3551	1.2916	1.6504	0.7129	
18-Sep	1.7563	1.2732	0.9698	1.7031	1.3551	1.2823	1.6430	0.6842	
22-Sep	1.7614	1.3345	0.9074	1.7020	1.3340	1.2976	1.6474	0.3115	
25-Sep	1.8069	1.3860	0.9662	1.7182	1.3614	1.2875	1.6551	0.3115	
27-Sep									
29-Sep	1.8213	1.4034	0.9592	1.7255	1.3915	1.2740	1.6842	0.0000	
1-Oct									
2-Oct	1.8041	1.4188	1.0662	1.6912	1.3323	1.0487	1.7353	0.7937	
6-Oct	1.8346	1.4051	0.8081	1.6702	1.3104	1.0232	1.6894	0.7200	
9-Oct	1.8464	1.4115	0.8878	1.6880	1.3349	1.0429	1.7345	0.7602	
13-Oct	1.8588	1.3583	0.9220	1.6674	1.3349	1.0328	1.7340	0.7331	
16-Oct	1.8334	1.3836	0.8809	1.6341	1.3072	0.9033	1.7148	0.6641	
18-Oct									
20-Oct	1.8392	1.4728	1.0286	1.6538	1.2880	1.0966	1.7241	0.7778	
23-Oct	1.8354	1.4627	1.0412	1.6665	1.2705	1.0681	1.7213	0.7581	
27-Oct	1.8320	1.3401	0.9461	1.6367	1.2227	1.0055	1.7077	0.7422	
30-Oct	1.8084	1.3093	0.9784	1.6364	1.2241	0.8688	1.6904	0.7221	
2-Nov									
3-Nov	1.7990	1.3684	0.8910	1.5976	1.2228	0.6935	1.6988	0.9160	
5-Nov									
6-Nov	1.7999	1.2746	0.8735	1.5857	1.1912	0.6133	1.7396	1.2171	
7-Nov									
10-Nov	1.8014	1.3515	0.9528	1.5913	1.1697	0.7347	1.7533	1.2764	
12-Nov									
13-Nov	1.8131	1.3113	0.9708	1.6209	1.1677	0.5692	1.7519	1.0765	
14-Nov									
17-Nov	1.7969	1.2645	1.0564	1.6290	1.0625	0.0000	1.7780	1.2707	
20-Nov	1.7931	1.3227	1.1170	1.6144	0.9741	0.0000	1.7758	1.2763	
24-Nov	1.7924	1.3292	1.0861	1.5900	0.8754	0.0000	1.7971	1.1661	
27-Nov	1.8047	1.2594	1.0308	1.5721	0.7757	0.0000	1.7965	0.9760	
1-Dec	1.7859	1.2803	1.0575	1.5888	0.5451	0.0000	1.8027	0.9795	
3-Dec									
4-Dec	1.7687	1.2281	1.0787	1.5888	0.6086	0.0000	1.8270	1.1274	
7-Dec									
8-Dec	1.7492	1.1643	1.0487	1.6045	0.4964	0.0000	1.8482	1.2204	
10-Dec									
11-Dec	1.7306	1.2142	1.0365	1.5966	0.7108	0.0000	1.8395	1.3198	
15-Dec	1.7329	1.2475	1.0595	1.5923	0.8966	0.0000	1.8391	1.3067	
18-Dec	1.7501	1.2656	1.0788	1.5939	0.9488	0.0000	1.8332	1.3849	
22-Dec	1.7354	1.3136	1.1253	1.5835	1.0889	0.5338	1.8353	1.4382	
25-Dec	1.7325	1.3085	1.1267	1.5545	1.0277	0.0000	1.8217	1.4088	
29-Dec	1.7383	1.3103	1.1143	1.5291	1.1714	0.0000	1.8255	1.4155	
31-Dec	1.7425	1.3016	1.0920	1.5187	1.3013	0.0000	1.8379	1.4995	