Statistical Nature of Cold Fronts Within the Gulf of Mexico and Their Potential Influence on OTEC Operations

S. L. Ulanski

December 1978

**Prepared for the U.S. Department of Energy
under Contract EY-76-C-06-1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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UNITED STATES DEPARTMENT OF ENERGY
Under Contract EY-76-C-06-1830

Printed in the United States of America

Available from

National Technical Information Service

United States Department of Commerce

5285 Port Royal Road

Springfield, Virginia 22151

Price: Printed Copy \$ ____*; Microfiche \$3.00

*Pages	NTIS Selling Price
001-025	\$4.00
026-050	\$4.50
051-075	\$5.25
076-100	\$6.00
101-125	\$6.50
126-150	\$7.25
151-175	\$8.00
176-200	\$9.00
201-225	\$9.25
226-250	\$9.50
251-275	\$10.75
276-300	\$11.00

3 3679 00053 2095

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STATISTICAL NATURE OF COLD FRONTS WITHIN THE GULF OF MEXICO AND THEIR POTENTIAL INFLUENCE ON OTEC OPERATIONS

INTRODUCTION

This study was undertaken to quantify selected aspects of cold fronts as they penetrate southward into the Gulf of Mexico region. A need arises to statistically define the nature of these cold fronts since the Department of Energy's Ocean Thermal Energy Conversion (OTEC) program is geared for determining the feasibility of utilizing the temperature difference between the tropical ocean surface and depths of approximately 1500 m for the production of power. However, severe winters are known to significantly decrease the normal sea surface temperature by approximately 7.2 °F as well as cause deepening of the mixed layer (Leetmaa, 1977). With an OTEC plant operating at efficiencies of only 2 to 3 percent, the plant could become marginally operational during the winter months. This potential shutdown is in result of the sea temperature difference becoming less than that normally required for plant operation.

Upon the passage of a cold front, the sea surface will exchange heat to the atmosphere through the fluxes of latent and sensible heat. Garstang (1969) has shown that these fluxes can increase more than an order of magnitude upon the passage of a moderate cold front.

PROCEDURE

Long term, greater than 25 years, meteorological data from the National Climatic Center was used as the basis for determining the impact of cold fronts in the Gulf of Mexico region. In particular, surface air temperature and wind direction were analyzed daily during the months of December, January and February. The drop in temperature as well as the directional wind shift were the criteria for the frontal passage. Surface observation data from Tampa and Key West, Florida were used in the study.

RESULTS

Throughout the period of record (1948-1976), the number of cold fronts passing Tampa, Florida (Table 1) on a yearly basis range from 9 to 15 fronts, with the average being 12 fronts. January had the most fronts (127) throughout the record and February the least (93).

Though there is a gap in the data record for Key West (1953-1957), the total number of fronts reaching Key West is 250 compared to 293 which passed Tampa over the same period. In other words, 85 percent of the fronts which reach Central Florida penetrate as far southward as Key West. The fronts failing to reach Key West are dissipated due to warming and modification of the underlying sea and land.

Table 2 shows the average interval in days between the occurrence of fronts at Tampa. Though there exists a positive relationship between the number of fronts occurring during a particular year (Table 1) and the interval in days between the passage of consecutive fronts, more interesting is the characteristic (entire record) period, 6.4 days, between fronts. This value falls in between the theoretically determined periods of cyclone (1 wave per day) and Rossby (1 wave per 10 days) waves.

The maximum temperature change of the 0100 LST reading before and after the passage of a cold front was arbitrarily chosen as an indicator of cold front intensity (Tables 3, 4 and 5). As to be expected, not only is there much variation in the temperature drop associated with the passage of consecutive fronts, but there also exists large yearly variations for particular months (Figure 1).

A closer examination of Figure 1 shows that the yearly peaks and troughs for the three months do not coincide. This observation then leads to the question if one month was characterized by particularly strong or weak cold fronts in a certain year did the following month exhibit similar characteristics? As evidenced by the scatter about the one to one fit (Figure 2), there exists only a weak relationship between the frontal temperature changes for December and January. Figure 3, for January and February, depicts a similar relationship to that of Figure 2 in that there

TABLE 1. Number of Cold Fronts for Tampa, Florida

<u>Year</u>	<u>December</u>	<u>January</u>	<u>February</u>	<u>Total</u>
1947-1948	-	5	3	8*
1948-1949	4	4	2	10
1949-1950	3	3	3	9
1950-1951	4	3	2	9
1951-1952	4	3	3	10
1952-1953	5	3	4	12
1953-1954	3	5	4	12
1954-1955	5	6	2	13
1955-1956	5	5	3	13
1956-1957	4	4	3	11
1957-1958	4	6	4	14
1958-1959	4	6	2	12
1959-1960	5	5	3	13
1960-1961	3	5	3	11
1961-1962	4	5	2	11
1962-1963	5	4	6	15
1963-1964	4	5	4	13
1964-1965	3	4	3	10
1965-1966	3	5	4	12
1966-1967	4	4	4	12
1967-1968	3	3	4	10
1968-1969	4	4	5	13
1969-1970	6	4	4	14
1970-1971	3	5	4	12
1971-1972	2	4	3	9
1972-1973	3	5	3	11
1973-1974	5	3	4	12
1974-1975	5	5	2	12
1975-1976	6	4	3	13
1976-	6	-	-	6*

*partial record

TABLE 2. The Average Interval in Days Between the Passage of Cold Fronts at Tampa, Florida

<u>Year</u>	<u>December-February</u>
1947-1948	7.0*
1948-1949	8.5
1949-1950	9.5
1950-1951	7.0
1951-1952	7.3
1952-1953	5.4
1953-1954	5.2
1954-1955	5.0
1955-1956	5.0
1956-1957	7.1
1957-1958	4.6
1958-1959	5.5
1959-1960	5.8
1960-1961	6.5
1961-1962	6.0
1962-1963	4.8
1963-1964	5.4
1964-1965	8.0
1965-1966	6.2
1966-1967	5.5
1967-1968	8.2
1968-1969	6.0
1969-1970	5.2
1970-1971	6.0
1971-1972	8.6
1972-1973	6.1
1973-1974	6.0
1974-1975	6.7
1975-1976	6.0
1976-	3.4*

*partial record

TABLE 3. December Frontal Temperature Drop
at 0100 LST for Tampa

<u>Year</u>	<u>$\Delta T(^{\circ}\text{F})$</u>	<u>Avg. $\Delta T(^{\circ}\text{F})$</u>
1947-1948		
1948-1949	8,21,16,14,17	15.2
1949-1950	11,14	12.5
1950-1951	17,23,22,18	20.0
1951-1952	10,23,16,23	18.0
1952-1953	21,15,13,19,20	17.6
1953-1954	27,10,21	19.3
1954-1955	9,25,15,29	19.5
1955-1956	21,16,8,19	16.0
1956-1957	21,3,28,19	17.8
1957-1958	10,26,15,8	14.8
1958-1959	23,21,3,12	14.8
1959-1960	4,8,10,15,5	8.4
1960-1961	30,16,15	20.3
1961-1962	5,19,22,23	17.3
1962-1963	10,18,24,3,18	16.2
1963-1964	5,12,24,19	15.0
1964-1965	28,18,2	16.0
1965-1966	9,20,23	17.3
1966-1967	28,15,28,20	22.8
1967-1968	22,30,21	24.3
1968-1969	21,20,29,29	24.8
1969-1970	9,20,8,10,17,24	13.0
1970-1971	5,19,29	17.7
1971-1972	12,15	13.5
1972-1973	4,6,13	14.3
1973-1974	32,11,27,22,7	19.8
1974-1975	24,25,27,13,12	20.2
1976-1977		

TABLE 4. January Frontal Temperature Drop
at 0100 LST for Tampa

<u>Year</u>	<u>$\Delta T(^{\circ}\text{F})$</u>	<u>Avg. $\Delta T(^{\circ}\text{F})$</u>
1947-1948	19,22,16,22,25	20.8
1948-1949	25,4,2,7	9.5
1949-1950	12,5,5	7.1
1950-1951	25,21,6	17.3
1951-1952	23,19,24	22
1952-1953	23,16,16	18.3
1953-1954	8,23,11,16,10	13.6
1954-1955	2,9,17,19,19,15	13.5
1955-1956	7,18,12,12,14	12.6
1956-1957	12,14,28,2	14
1957-1958	19,27,17,8,5,9	14.2
1958-1959	31,23,22,18,6	21.2
1959-1960	17,2,18,24,14	15
1960-1961	25,12,11,15,11	14.8
1961-1962	20,21,11,22	18.5
1962-1963	10,14,25,15	16
1963-1964	20,19,35,17,14	21.0
1964-1965	10,22,30,29	25.5
1965-1966	24,20,21,29,19	22.6
1966-1967	31,20,17,29	24.3
1967-1968	12,22,24	19.3
1968-1969	25,20,14,18	19.3
1969-1970	28,11,23,22	21
1970-1971	9,4,22,22,28	17
1971-1972	24,29,15,11	19.8
1972-1973	4,18,7,8,22	11.8
1973-1974	7,4,3	4.7
1974-1975	10,11,34,19,17	18.2
1975-1976	16,30,30,30	26.5

TABLE 5. February Frontal Temperature Drop
at 0100 LST for Tampa

<u>Year</u>	<u>$\Delta T(^{\circ}\text{F})$</u>	<u>Avg. $\Delta T(^{\circ}\text{F})$</u>
1947-1948	17,19,3	13
1948-1949	15	15
1949-1950	6,23,12	13.7
1950-1951	27,18	22.5
1951-1952	20,16,19	18.3
1952-1953	12,14,15	13.7
1953-1954	18,12,12,16	14.5
1954-1955	13,31	22
1955-1956	12,19,19	16.7
1956-1957	20,10,12	14
1957-1958	27,19,19,12	19.3
1958-1959	8,20	15
1959-1960	11,26,9	15.3
1960-1961	10,15,19	14.7
1961-1962	13,18	15.5
1962-1963	17,10,19,14,5,10	12.5
1963-1964	13,13,16,23	16.3
1964-1965	20,21,12	17.7
1965-1966	13,7,20	13.3
1966-1967	14,20,34	22.7
1967-1968	18,15,10,17	15
1968-1969	34,22,8,20	21
1969-1970	37,16,13	22
1970-1971	12,30,26,13	20.3
1971-1972	25,16,17	19.3
1972-1973	29,27,23	26.3
1973-1974	25,27,13,20	21.3
1974-1975	21	21.0
1975-1976	11,21,25	19.0

FIGURE 1. Winter Frontal Temperature Drop at Tampa, Florida from 1973 to 1976.

FIGURE 2. Comparison of Frontal Temperature Changes for December versus January at Tampa, Florida.

FIGURE 3. Comparison of Frontal Temperature Changes for January versus February at Tampa, Florida.

is no evidence of strong monthly persistence with regard to the intensity of the cold fronts.

With regard to the average frontal temperature change over the entire period of record, there was very little difference from month to month. In particular, the average for December was 17.3 °F compared to 17.1 °F and 17.8 °F for January and February respectively.

For Tampa, the temperature change intervals 11-15 °F, 16-20 °F and 21-25 °F exhibit the highest frequency and probability of occurrence (Table 6). Almost 70 percent of the fronts fall within this 15 degree interval. However, of potential interest to planners of the OTEC project is the time period for which on the average a particular event, in this case strong frontal temperature drops, will be equaled or exceeded. Figure 4 shows the return period in years for temperature changes greater than 20 °F. The return period increases logarithmically for increasing temperature changes. That is, very large drops in temperature may occur only once or twice within the proposed lifetime of the project. For example, the temperature interval 35-40 °F has a return period of 28 years. Metz (1977) has pointed out that OTEC proponents are counting on the plants to operate satisfactorily with virtually no shutdown for 20 to 40 years. With this proposed design horizon as a benchmark, the chance that a severe temperature depression due to a cold front passage will be equaled or exceeded in the project's lifetime is calculated. That is

$$P = 1 - (1 - (1/T))^n$$

where

P = probability of event occurring

T = return period of event

n = lifetime of project

TABLE 6. Frequency and Probability of Frontal
Temperature Change for Tampa

	$\Delta T(^{\circ}\text{F})$							
	<u>0-5</u>	<u>6-10</u>	<u>11-15</u>	<u>16-20</u>	<u>21-25</u>	<u>26-30</u>	<u>31-35</u>	<u>>35</u>
f	21	35	64	79	61	31	7	1
P(%)	7.0	11.7	21.4	26.4	20.4	10.4	2.3	.3

Probability = (# of particular events/total # of events)

FIGURE 4. Return Period for Cold Front Changes Greater than 20 $^{\circ}\text{F}$.

Let $T = 28$ years and $n = 20$ years

$$P = 1 - (1 - (1/28))^{20}$$

$$P = 0.52$$

That is there is a 52 percent chance that the severe temperature (35° - 40°) drop with the 28 year return period will be equaled or exceeded sometime during the lower limit for the proposed existence of the OTEC plant. For 40 years, the risk value is 77 percent.

Tables 7, 8 and 9 present the decrease in temperature (0100 LST reading) after the passage of a cold front at Key West. The values are lower than for Tampa as would be expected because of modification of the southward moving front. The monthly average values for the period of record are 10.3° , 11.2° and 10.7° F for December, January and February respectively. For each of the months, these values are approximately 7° F less than for Tampa.

In Table 10, note that more than 60 percent of the fronts fall within the temperature bracket of 6° - 15° F. Furthermore, while the data for Tampa showed that 13 percent of the fronts were characterized by temperature drops of greater than 25° F, this large temperature change was not in evidence as far south as Key West.

CONCLUSIONS

An analysis of the long term winter air temperatures within the Gulf of Mexico area has provided statistical information with regard to the frequency, number, intensity and southward penetration of cold fronts.

Hopefully, this information may be of use to OTEC planners when assessing feasibility of operating a sea based power plant for the production of power.

Directly, cold fronts have the effect of changing the thermal budget of the sea surface and the mixed layer. Indirectly, the winter wind stress increases the vertical mixing changing the depth of the well-mixed top layer of water.

TABLE 8. January Frontal Temperature Drop
at 0100 LST for Key West

Year	$\Delta T(^{\circ}\text{F})$	Avg. $\Delta T(^{\circ}\text{F})$
1947-1948	14,22,12,8	14
1948-1949	8,3,3	4.7
1949-1950	4,2	3
1950-1951	14,17	15.5
1951-1952	8,16	12
1952-1953	14,14,4	10.7
1953-1954	Missing	
1954-1955	Missing	
1955-1956	Missing	
1956-1957	Missing	
1957-1958	Missing	
1958-1959	Missing	
1959-1960	Missing	
1960-1961	13,10,17,7	11.8
1961-1962	16,14,13	14.3
1962-1963	12,6,7,3	7
1963-1964	9,22,11,3	11.3
1964-1965	4,12,11	9
1965-1966	11,12,15,20,19	15.4
1966-1967	18,6,13	12.3
1967-1968	4,6,14	8
1968-1969	7,8,8,7	7.5
1969-1970	7,24,5,9,11	11.2
1970-1971	13,23,9	15
1971-1972	6,14	10
1972-1973	7,16	11.5
1973-1974	No fronts	No fronts
1974-1975	16,3	9.5
1975-1976	18,21,17	18.7

TABLE 7. December Frontal Temperature Drop
at 0100 LST for Key West

<u>Year</u>	<u>$\Delta T(^{\circ}F)$</u>	<u>Avg. $\Delta T(^{\circ}F)$</u>
1947-1948		
1948-1949	2,9,16	9
1949-1950	4,2	3
1950-1951	10,16,10,13	12.3
1951-1952	8,8,8	8
1952-1953	13,12,6,6,19	11.2
1953-1954	Missing	
1954-1955	Missing	
1955-1956	Missing	
1956-1957	Missing	
1957-1958	Missing	
1958-1959	Missing	
1959-1960	Missing	
1960-1961	17,10,13	13.3
1961-1962	8,14,12	11.3
1962-1963	8,16,13	12.3
1963-1964	8,4,15,14	10.3
1964-1965	8,8	8
1965-1966	6,11,9	8.7
1966-1967	14,8,9,4	8.8
1967-1968	7,20,8	11.7
1968-1969	12,19,15	15.3
1969-1970	4,20,9,11	11
1970-1971	2,1,12	5
1971-1972	6,5	5.5
1972-1973	18,12	15
1973-1974	12,15,15,20	15.5
1974-1975	5,11,13,5	8.5
1975-1976	2,6,7,10,7,8	6.7
1976-	8,9,15,14,7	10.6

TABLE 9. February Frontal Temperature Drop
at 0100 LST for Key West

<u>Year</u>	<u>$\Delta T(^{\circ}F)$</u>	<u>Avg. $\Delta T(^{\circ}F)$</u>
1947-1948	1,5	3
1948-1949	3	3
1949-1950	4,15,4	7.7
1950-1951	21,10	15.5
1951-1952	17,12,4	11
1952-1953	7,8,7,13	8.8
1953-1954	Missing	
1954-1955	Missing	
1955-1956	Missing	
1956-1957	Missing	
1957-1958	Missing	
1958-1959	Missing	
1959-1960	Missing	
1960-1961	5,11,12	9.3
1961-1962	4,11	7.5
1962-1963	10,14,12,4	10.0
1963-1964	5,18,16	13
1964-1965	7,18	12.5
1965-1966	16,10,3	9.7
1966-1967	9,10	9.5
1967-1968	10,12	11
1968-1969	11,10,5,14,7	9.4
1969-1970	22,7,9,12	12.5
1970-1971	2,24,15,5	11.5
1971-1972	17,6,17	13.3
1972-1973	11,17,13	13.7
1973-1974	10,16,8,24	14.5
1974-1975	11,8	9.5
1975-1976	11,10,11	10.7

TABLE 10. Frequency and Probability of Frontal
Temperature Change for Key West

	$\Delta T(^{\circ}\text{F})$				
	<u>0-5</u>	<u>6-10</u>	<u>11-15</u>	<u>16-20</u>	<u>21-25</u>
f	31	66	56	32	7
P(%)	16.1	34.4	29.2	16.7	3.6

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