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Data Tabulations and Analysis of Diurnal Sea Surface Temperature Variability Observed at LOTUS

by

Clarke M. Bowers, James F. Price, Robert A. Weller and Melbourne G. Briscoe

February 1986

Technical Report

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Robert C. Beardsley, Chairman  
Department of Physical Oceanography
Air/sea measurements from the Long-Term Upper Ocean Study (LOTUS) buoy in the Sargasso Sea are analyzed to learn how the diurnal response of sea surface temperature, $\Delta T_s$, is related to the surface heating, $H$, and the wind stress, $S$. Data are taken from the LOTUS-3 and LOTUS-5 records which span the summers of 1982 and 1983. The basic data are shown in monthly plots, and the analyzed daily values of $\Delta T_s$, $H$, and $S$ are given in tables and in figures.

Analyzed data show a clear trend of $\Delta T_s$ increasing with $H$ and decreasing with $S$. A best-fit, three-parameter, empirical function can account for 90% of the variance in a screened subset of the LOTUS data (172 days) and 81% of the variance of the full data set (361 days).

The analyzed data are also compared with a theoretical model function now used for ocean predictions in the Diurnal Ocean Surface Layer model (DOSL) of Fleet Numerical Oceanography Center. The DOSL model function was derived from the assumption that wind-mixing occurs by a mechanism of shear flow instability. It is fully predictive and shows a parameter dependence consistent with the LOTUS data over a wide range of $H$ and $S$. The DOSL model function can account for almost as much variance as the best-fit empirical function.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>2</td>
</tr>
<tr>
<td>List of Tables</td>
<td>4</td>
</tr>
<tr>
<td>List of Figures</td>
<td>4</td>
</tr>
<tr>
<td>I. Introduction</td>
<td>5</td>
</tr>
<tr>
<td>II. LOTUS Data and Analysis Methods</td>
<td>5</td>
</tr>
<tr>
<td>A. Sea Surface Temperature Response</td>
<td>6</td>
</tr>
<tr>
<td>B. Daily Averages</td>
<td>6</td>
</tr>
<tr>
<td>C. Insolation</td>
<td>7</td>
</tr>
<tr>
<td>1) Maximum Observed Insolation</td>
<td>7</td>
</tr>
<tr>
<td>2) Integrated Insolation</td>
<td>7</td>
</tr>
<tr>
<td>3) Least Squares Fit to Insolation</td>
<td>8</td>
</tr>
<tr>
<td>D. Horizontal Advection</td>
<td>8</td>
</tr>
<tr>
<td>III. Results</td>
<td>9</td>
</tr>
<tr>
<td>IV. Fit to and Comparison with Models</td>
<td>14</td>
</tr>
<tr>
<td>A. Empirical Model</td>
<td>14</td>
</tr>
<tr>
<td>B. Positive Bias of Analyzed ΔT_{S}</td>
<td>15</td>
</tr>
<tr>
<td>C. Theoretical Model</td>
<td>15</td>
</tr>
<tr>
<td>V. Conclusions</td>
<td>20</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>22</td>
</tr>
<tr>
<td>References</td>
<td>23</td>
</tr>
<tr>
<td>Appendix A, Monthly Time-Series Plots of LOTUS Data</td>
<td>24</td>
</tr>
<tr>
<td>Appendix B, Listing of Analyzed Data</td>
<td>38</td>
</tr>
<tr>
<td>Appendix C, FORTRAN Listing of DOSL Model Function</td>
<td>48</td>
</tr>
</tbody>
</table>
LIST OF TABLES

1. Statistics of Data / Model Comparisons ........................................ 16

LIST OF FIGURES

1. Analyzed, full data set ................................................................. 10
2. Data set with advection periods omitted ....................................... 12
3. Screened data set ............................................................................. 13
4. Screened data and best-fit model function ..................................... 17
5. Sea surface temperature response
   at very low values of heating ......................................................... 18
6. Screened data set and DOSL model function .................................. 19
7. Residuals from the screened data set and DOSL model function ... 21
A.1-
A.13 Monthly time-series plots of LOTUS data ................................. 25
I. INTRODUCTION

In this study we use oceanographic and meteorological field observations to examine the response of sea surface temperature to diurnal heating and wind stress. The data were acquired by the Long-Term Upper Ocean Study (LOTUS) buoy which was deployed in the northwestern Sargasso Sea (34°N, 70°W) from 1982 to 1984 (Briscoe and Weller, 1984; Deser, Weller and Briscoe, 1983; Tarbell, Montgomery and Briscoe, 1985). The LOTUS data are well suited for this study because the signal of local heat storage is generally large compared to the effects of horizontal advection, and because the LOTUS data provide high accuracy and temporal resolution.

The aim of the analysis is, first, to reduce the time series data to daily values of the heating, $H$, wind stress, $S$, and surface temperature response, $\Delta T_s$, and second, to determine the dependence of $\Delta T_s$ upon $H$ and $S$. There is a practical value to this result --- the function $\Delta T_s(H,S)$ defined or verified by these data can be used to forecast or hindcast the diurnal cycle, and a scientific value --- these data show how a rotating fluid responds to a stabilizing heat flux and an imposed stress.

The primary purpose of this technical report is to provide time series plots of the original LOTUS data, a tabulation of the analyzed data, and a listing of the FORTRAN program which evaluates a theoretical model function.

II. LOTUS DATA AND ANALYSIS METHODS

The LOTUS data used for this analysis are time series measurements of wind speed, insolation and ocean temperatures at 0.6, 5, 10, 15, 25, 50 and 75 m at 15 min intervals (Deser et al., 1983; Tarbell, Pennington and Briscoe, 1984). Estimates of the wind stress, $\tau$, and surface heat flux, $Q = I + L$, where $I$ is insolation and $L$ is the heat loss, were made as described by Stramma et al. (1986). The data sets analyzed are from the deployments LOTUS-3 (May 14, 1982 through October 20, 1982) and LOTUS-5 (April 15, 1983 through October 30, 1983). Monthly plots of the full data set are in Appendix A. In Appendix B we list the analyzed daily values of the wind stress, wind speed, insolation, etc., so that other investigators will have ready access to our intermediate results.
A. Sea Surface Temperature Response

The ocean's response to the forcing of the winds and solar heating is characterized here by the amplitude of the sea surface temperature response, \( \Delta T_s \), where \( T_s \) is the LOTUS temperature at 0.6 m depth, and \( \Delta \) indicates the change (increase) over a day. If the diurnal cycle is the dominant signal in \( T_s \), then the lowest \( T_s \) of the day will occur between 0500 and 0900 hours (all times quoted in the text are local solar; local noon is 1730 Z), and the highest \( T_s \) will occur between 1100 and 1800. We have estimated the diurnal response of sea surface by subtracting the lowest temperature observed between 0500 and 0900 from the highest temperature observed between 1100 and 1800. The result is listed in Appendix B as "DEL T".

This process of subtracting the lowest from the highest temperature will alias high frequency noise (compared to diurnal) into larger \( \Delta T_s \). In Section IV.B we will evaluate the resulting bias in the analyzed \( \Delta T_s \) by inspection of the estimates available at very low values of surface heating.

B. Daily Averages

In the following analysis we compute a "daily" value as an average over the period during each day when \( Q > 0 \). Let \( t_1 \) be the time when \( Q \) first becomes positive, and let \( t_2 \) be the time when \( Q \) becomes negative at sunset. Daily average is defined here as

\[
\bar{Q} = \frac{1}{2P_Q} \int_{t_1}^{t_2} Q(t) \, dt,
\]

where \( P_Q = 1/2 (t_2 - t_1) \). (On some days \( Q \) may become negative within the time interval \( t_1 < t < t_2 \) when increased cloud cover causes the insolation to drop below the value of the heat loss. A second, alternate, time scale, \( P_{Q2} \), (not used here) was defined to be literally the half time that \( Q \) was positive for each day.)

Daily average values are tabulated in Appendix B as:

"U", daily average wind speed (m s\(^{-1}\)),
"TAU", daily average wind stress (Pa),
"L", average heat loss (W m\(^{-2}\)).
Standard deviations are also listed as "SD U", "SD TAU", and "SD L". In computing SD TAU we sum the standard deviations of the east and north components to take account of varying wind direction. In some of the later comparisons with models we will screen out those days having highly variable or irregular forcing and retain the days which have comparatively steady forcing.

C. Insolation
The amplitude of insolation has been estimated in three ways.

1) Maximum Observed Insolation
The maximum insolation observed on each day was extracted from the records, and is listed as $I_1$. If there were no clouds, then $I_1$ together with the duration of the insolation, $D$, would completely characterize the insolation for any day. However, cloud-free days are the exception rather than the rule, and we have therefore defined two other more useful measures of insolation.

2) Integrated Insolation
The integral of the insolation has been used to define $I_2$ as

$$I_2 = \frac{\int_{t_3}^{t_4} I \, dt}{D \Gamma}$$

where

$I$ = observed insolation,
$t_3$ = the start of insolation,
$t_4$ = the end of insolation,
$D$ = duration of the insolation, $t_4 - t_3$,

$$\Gamma = \frac{1}{DF_m} \int_{t_3}^{t_4} F(t, \phi, \alpha) \, dt = 0.57, \text{ a constant}$$

$F(t, \phi, \alpha)$ = theoretical clear sky insolation; function of year day, $t$,
latitude $\phi = 34^\circ N$, and clear sky transmittance, $\alpha = 0.8$.

$F_m$ is the daily maximum (List, 1958).
Because the insolation records have some slight noise, \( t_3 \) was estimated to occur a half hour before \( I \geq 30 \text{ W m}^{-2} \), and similarly \( t_4 \) was taken to be a half hour beyond \( I \leq 30 \text{ W m}^{-2} \) in late afternoon. The error in defining the period of insolation in this manner is \( \pm 15 \) minutes for most days, which gives about 4 percent error in the computed amplitude \( (I_2) \) of the insolation.

3) Least Squares Fit to Insolation

As an alternative measure of insolation, we have also carried out a least squares fit of the normalized theoretical insolation function \( F \) onto observed insolation to compute the amplitude "\( I_3 \)" (Appendix B). The standard deviation of the fit, listed as "\( SD \ I_3 \)", provides a convenient, objective measure of the variability of insolation due to cloud cover. In a later analysis we screen out days with highly variable insolation by setting an upper limit on the ratio, \( SD \ I_3/I_2 \).

D. Horizontal Advection

The analysis thus far has been concerned only with the vertical fluxes of heat and momentum. Our implicit assumption of a local balance is valid as long as there is no horizontal advection occurring in the water column. However, the effects of horizontal advection are evident in the LOTUS data as occasions when the water column (above 75 m) underwent depth-independent temperature changes. Since we were unable to account for the effects of horizontal advection explicitly, we sought to identify at least the most obvious occurrences of horizontal advection so that we could eliminate the corresponding days from the analysis.

A local heat balance analysis was performed by comparing the net surface heat flux with the observed heat storage in the water column,

\[
EPS = \frac{\int_{t_1}^{t_2} Q \, dt - \Delta B}{\int_{t_1}^{t_2} Q \, dt},
\]
where $B$ is the observed heat storage to 25 m depth, and $\Delta B = B(t_2) - B(t_1)$. The values of EPS are listed in Appendix B. This alone does not effectively identify horizontal advection since vertical advection can also cause significant changes in heat storage without changing $T_s$ (note especially the period 10 to 30 September 1983, Figure A.12, when there were very large changes in temperature at 25 m and deeper, but no corresponding changes in the near surface). We have therefore used the tabulated EPS values as a guide, and proceeded to subjectively identify periods where horizontal advection seemed to be important. These were noted by setting the flag $A = 1$ (Appendix B), and included only 44 days (two periods in 1982 and three in 1983), or about 12 percent of the complete data set.

III. RESULTS

Our analysis of the full data set is presented graphically in Figure 1 where the diurnal response of sea surface temperature is plotted against independent variables proportional to the heating and wind stress. The "heating" variable was computed as:

$$H = \frac{Q P Q}{\rho_o C_p} \,(C \, m)$$

where

$$Q = I_2 + \bar{L} \,(W \, m^{-2}),$$
$$\rho_o = 1023 \,(kg \, m^{-3}), \text{ and}$$
$$C_p = 4183 \,(J \, kg^{-1} \, C^{-1}).$$

The product $Q P Q$ is proportional to the (warming) heat flux supplied to the ocean; division by $\rho_o C_p$ gives kinematic units, $C \, m$, which are more readily interpreted. In a similar way the "stress" variable was computed as:

$$S = \frac{\tau P}{\rho_o} \,(m^2 \, s^{-1}),$$

where

$\tau$ = daily average wind stress (Pa),
$P$ = acceleration time scale $= 1/[2 - 2 \cos(fP Q)]^{1/2}$ (s), and
$f$ = Coriolis parameter (s$^{-1}$).
Figure 1: The complete LOTUS-3 and LOTUS-5 data sets, one data point per day (361 days). (Note that what we term "stress" has the units of volume transport per unit length.)
In this final regard the scaling begins to follow the theory developed by Price, Weller and Pinkel (1986; hereafter, PWP) where the vertical mixing due to wind stress was presumed to occur through shear flow instability caused by wind-driven currents. [The amplitude of the wind-driven current (or diurnal jet) was estimated to be \( W/D \) where \( D \) is the trapping depth, and \( \Delta T_s = H/D \).] The \( f \)-dependence of \( P_T \) takes account of rotation which in this case is small enough that \( P_T \approx P_Q \). In effect, the heating rate \( Q \) and the wind stress \( \tau \) are multiplied by nearly the same time scale (which does vary from day to day).

While there is a good deal of scatter in the data of Figure 1, it is also apparent that there is a significant functional dependence of \( \Delta T_s \) upon \( H \) and \( S \). Within the variable range sampled here, \( \Delta T_s \) increases with increasing \( H \) and with decreasing \( S \) -- the qualitative result expected.

Before we attempt to define or test a model function, we first screen the data to omit the days which one would expect, a priori, to be unsuitable for defining a function \( \Delta T_s(H,S) \). That is, we assume that if the wind was steady during the day and \( H \) was regular (not intermittent due to cloud cover), then some function \( \Delta T_s(H,S) \) should obtain. On the other hand, if the wind, say, were highly variable during a day, then there are additional degrees of freedom present, and a function dependent upon \( S \) alone might not be appropriate. The LOTUS data set is large enough that we can omit days with irregular or variable forcing and still retain a large sample spanning a wide parameter range.

In Figure 2 we have omitted the days identified as showing some effects of horizontal advection (discussed in Section II.D), and in Figure 3 we have also omitted days having either highly variable insolation, \( SD I_3/I_2 \geq 1/2 \), or highly variable wind stress, \( SD TAU/TAU \geq 1/2 \). The result of this screening is to eliminate some of the points which lie furthest from the mean trend of the data. The last version, Figure 3, will be used for model definition and testing, but we also make comparisons with the full data set.
Figure 2: Same as Figure 1 but omitting time periods identified as showing effects of horizontal advection (316 days remaining).
Figure 3: Same as Figure 2, but also omitting individual days having highly variable wind stress or irregular insolation (172 days remaining). This is referred to as the screened data set.
IV. FIT TO AND COMPARISON WITH MODELS

These data may be used to define purely empirical model functions and to test theoretical model functions. To quantify data/model comparisons, we have calculated statistics of the deviations,

\[ T' = \Delta T_S - \Delta T_m, \]

where \( \Delta T_m \) is \( \Delta T \) evaluated by the best fit or theoretical model at the \( H, S \) of the corresponding, observed \( \Delta T_S \). The ensemble Average Deviation is

\[ AD = \langle T' \rangle = \frac{1}{N} \sum T', \]

where \( N \) is the number of days;

the Percentage of Variance accounted for by the model is

\[ PV = 100 \left[ 1 - \frac{\langle T'^2 \rangle}{\langle \Delta T_S^2 \rangle} \right]; \]

and the Correlation Coefficient is

\[ CC = \frac{\langle \Delta T_m \Delta T_S \rangle \sqrt{\langle \Delta T_m^2 \rangle \langle \Delta T_S^2 \rangle}}{\langle \Delta T_m^2 \rangle \langle \Delta T_S^2 \rangle}, \]

where (\( \hat{\cdot} \)) indicates departure from the ensemble mean. (PV and CC differ in that CC is independent of bias error. Here the bias error is small compared to random errors, and we emphasize PV in our discussion.)

A. Empirical Model

A purely empirical model function is defined from the data by maximizing PV for the three parameter function,

\[ \Delta T(H, S) = \alpha H^8 \exp(-S/\gamma). \]
This functional form was chosen by inspection of the data, and under the assumption that $\Delta T$ should vanish as $H \to 0$, and should be finite as $S \to 0$. Values of $\alpha, \beta, \gamma$ which maximize $PV$ were found by a searching method to be:

$$\alpha = 0.20 \pm 0.03 \; (C),$$
$$\beta = 1.40 \pm 0.1 \; \text{and}$$
$$\gamma = 0.80 \pm 0.05 \; (Pa).$$

These give $PV = 90$ (see also Table I), showing that there is indeed a strong dependence of $\Delta T_S$ upon the presumed independent variables, $H$ and $S$. This best fit function is plotted as a surface along with the screened data in Figure 4.

B. Positive Bias of $\Delta T_S$

A consistent result of the data/model comparisons is that $AD$ tends to be positive, i.e., on average the observed $\Delta T_S$ lie slightly above the model prediction (as can be seen in Figure 4). This is at least partially a result of a bias error inherent in the day-night differencing procedure used to estimate the diurnal response of surface temperature (Section II.A). To check this we have plotted the $\Delta T_S$ available at small values of $H$, Figure 5. Note that $\Delta T_S$ tends to remain slightly positive as $H$ goes to zero; $\langle \Delta T_S \rangle = 0.07 \; C$ for $H < 0.05 \; C \; m$, which is unphysical, and presumed to be a bias error of the analysis.

C. Theoretical Model

A theoretical model function derived by PWP and now in use at Fleet Numerical Oceanography Center as part of the Diurnal Ocean Surface Layer (DOSL) model may be tested using these data. The only additional parameters needed to evaluate the model (see Appendix C for model listing) are those that define the optical properties of the water. For the LOTUS site we use Type I parameters appropriate for very clear ocean waters (Stramma et al., 1986; Paulson and Simpson, 1977: long wave extinction scale, $\beta_1 = 0.35 \; m$; short wave extinction scale, $\beta_2 = 23 \; m$, and the fraction of long wave insolation, $R = 0.58$).

The statistics of this model/data comparison are in Table I, and the result is plotted in Figure 6. Note that $AD$ is again slightly positive and
Table I

Statistics of Data / Model Comparisons

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<th>Best Fit, Empirical Model</th>
<th>DOSL Model</th>
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<td>Full Data Set</td>
<td>Screened Data Set</td>
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<tr>
<td>Number of Days</td>
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<td>172</td>
</tr>
<tr>
<td>Average Deviation, C</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>Percent Variance</td>
<td>81</td>
<td>90</td>
</tr>
<tr>
<td>Cross-Correlation</td>
<td>0.82</td>
<td>0.91</td>
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</tbody>
</table>
Figure 4: Screened data set and the best-fit empirical model function shown as a surface. Data points which lie above the surface are solid, those below are open. Vertical lines connect the points to the model surface.
Figure 5: Sea surface temperature response at very low values of heating. Note that the estimates have a small mean value, ~0.07°C, as heating vanishes, probably because of a bias error inherent in the day/night differencing method used to define the diurnal response.
Figure 6: Screened data set and the DOSL model function.
that $PV = 87$, or nearly as successful as the best-fit empirical function. The empirical model function and the DOSL model function differ significantly only in the limit of very large $H$ and vanishing $S$ where there are not enough data to tell which is better.

The DOSL model function appears to follow the trend of the data reasonably well (suggested also by large $PV$). To check explicitly whether there may be coherent structure in the deviations, we have smoothed and interpolated $T'$ to a regular grid, and plotted the resulting local average $T'$ (local in $H,S$) as a surface in Figure 7 left. This surface lies slightly above 0 almost everywhere (by about 0.05 to 0.1 C), consistent with the bias noted before. There is no obvious low mode structure to the surface, which suggests that the model function dependence upon $H$ and $S$ is reasonably consistent with the $H,S$ dependence of the LOTUS data. Said differently, the deviations do indeed appear to be random (aside from the bias of the analysis).

In a similar way the local average root mean square deviation was computed and plotted in Figure 7 right. This surface does have a significant low mode structure with the rms $T'$ increasing as does $\Delta T'_S$. In the range where $\Delta T'_S = 2$ C, the rms $T' = 0.4$ C. (In the limit of small $H$, large $S$, the rms $T' = 0.1$ C, which is essentially the statistics of the data itself.) A random error which increases with the signal might result from variable wind stress or insolation (recall that SD TAU/TAU is allowed to be as large as 1/2 here).

A statistical comparison of the DOSL model with the full data set shows that there is still a significant dependence of $\Delta T'_S$ upon $H$ and $S$ ($PV = \frac{1}{4}$, Table I), though on some specific days the deviation may be quite large.

V. CONCLUSIONS

The LOTUS-3 and LOTUS-5 data sets have been used to define and test model functions that relate the diurnal response of sea surface temperature to the imposed surface heat flux and wind stress. Either a best fit empirical function or the DOSL model function developed by PWP can account for roughly 80% of the $\Delta T'_S$ variance observed in the LOTUS data set. The DOSL
Figure 7: The average (top) and root mean square (bottom) field of the deviations, $T'$, from Figure 6. The surfaces were constructed by smoothing over neighboring values. The heavy border shows where deviation = 0.

Note that the average value tends to be about 0.1°C throughout the full range of $H$ and $S$, with little evidence of low mode structure. On the other hand, the rms value is largest where $\Delta T_S$ is also largest. This suggests that there may be a "hidden variable" not accounted for by the present scaling and model assumptions (e.g., using only the daily mean value to represent the wind stress).
function has the advantage of showing explicit dependence upon sea water optical properties and latitude, while in the empirical function this dependence is implicit in the parameter values.

The DOSL model function was based upon the idea that the currents generated by wind stress cause vertical mixing by a mechanism of shear flow instability. The resulting function $\Delta T_s(H,S)$ which follows from this idea has a parameter dependence consistent with the LOTUS field data. This is indirect evidence that the mixing assumption was a good one (but to make a strong test requires sensitivity testing and alternate model testing not attempted here).

The tests of the DOSL model function made here do suggest that that function is appropriate physically. That is, if given accurate forecasts of heating and wind stress, the DOSL model should return an accurate upper ocean forecast. Of course, on any specific site or day, the ocean's response could be dominated more by advection, or by sub-mesoscale variability of the winds, than by the forecast diurnal response (recall the larger scatter in the full data set compared to the screened data set.) It may be that the large scale (atmospheric mesoscale) patterns of diurnal warming will be forecast more successfully than will the point-wise response studied here.

The most readily observable quantities are the cloud cover (needed to calculate $H$) and the sea surface temperature itself. This suggests that an inversion of $\Delta T_s(H,S)$ to estimate $S$ (or wind speed) might be useful at least in the low $S$ regime where there is some sensitivity. As a qualitative example, Stramma et al. (1986) have shown that regions of large $\Delta T_s$ are coincident with regions of weak sea surface pressure gradient, e.g., ridges of the marine high pressure systems. Thus, given a map of $H$ and $\Delta T_s$ a forecaster, or an analysis program, could easily sketch in the locations and perhaps some measure of the width of low wind speed regions over the world ocean.

Acknowledgments

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References


APPENDIX A

Monthly Time-Series Plots of LOTUS Data
Figure A.1: Monthly time series from May, 1982. The periods during which advection appears to be important (discussed in Section II.D) are denoted by the bar labelled A.
Figure A.2: Monthly time series from June, 1982.
Figure A.3: Monthly time series from July, 1982.
Figure A.4: Monthly time series from August, 1982.
Figure A.5: Monthly time series from September, 1982.
Figure A.6: Monthly time series from October, 1982.
Figure A.7: Monthly time series from April, 1983.
Figure A.8: Monthly time-series from May, 1983.
Figure A.9: Monthly time-series from June, 1983.
Figure A.10: Monthly time-series from July, 1983.
Figure A.11: Monthly time-series from August, 1983.
Figure A.12: Monthly time-series from September, 1983.
Figure A.13: Monthly time series from October, 1983.
APPENDIX B

Listing of Analyzed Data
APPENDIX C

FORTRAN Listing of the DUCL (PWP) Model Function
SUBROUTINE DAYSCL(QI,QL,PQ,TAU,DSC,TSC,USC,ICON)
C
C THIS SUBROUTINE COMPUTES THE AMPLITUDE OF THE DIURNAL
C CYCLE FROM THE FOLLOWING INPUT DATA:
C QI, SOLAR INSOLATION MAXIMUM, WATTS PER METER SQUARED
C QL, HEAT LOSS, WATTS PER METER SQUARED (USUALLY NEGATIVE)
C PQ, HALF THE TIME INTERVAL DURING WHICH QI + QL > 0, SECONDS
C TAU, WIND STRESS, PASCALS
C
C OUTPUT VARIABLES ARE:
C DSC, MINIMUM TRAPPING DEPTH, METERS
C TSC, DIURNAL RANGE OF SEA SURFACE TEMPERATURE, CENTIGRADE
C USC, AMPLITUDE OF THE DIURNAL JET, METERS PER SECOND
C ICON, FLAG = 1 IF CONVECTION LIMIT WAS REACHED (VANISHING TAU)
C
C REFERENCE TO THEORY IS IN PRICE, WELLE AND PINKEL, JGR, 1986
C DOCUMENTED BY J. F. PRICE, JULY 2, 1985, W.H.O.I.
C
COMMON/APLANE/BETA1,BETA2,R,F,ALPHA,G,CPW,RO
C
THE COMMON APLANE DELIVERS PARAMETERS WHICH ARE SITE SPECIFIC:
C
BETA1, EXTINCTION COEFFICIENT FOR LONGWAVE INSOLATION, METERS
C BEAT2, AS ABOVE FOR SHORTWAVE
C R, THE FRACTION OF INSOLATION ASCRIBED TO BETA 1, NON-D
C F, CORIOLIS PARAMETER, INVERSE SECONDS
C ALPHA, THERMAL EXPANSION COEFFICIENT, KILOGRAMS PER METER CUBED
C PER DEGREE CENTIGRADE (IN A LINEAR STATE EQUATION)
C G, ACCELERATION DUE TO GRAVITY, METERS PER SECOND SQUARED
C CPW, HEAT CAPACITY OF SEA WATER, JOULES PER KILOGRAMS SECOND
C RO, DENSITY OF SEA WATER, KILOGRAMS PER METER CUBED (CONSTANT)
C
ICON = 0
C
COMPUTE PS, THE ACCELERATION TIME SCALE
C
PS = (SQRT(2.)/F)*SQRT(1. - COS(F*PQ))
C
QNET = QI + QL
C
CHECK THAT QNET AND PQ ARE > 0. IF NOT, RETURN
C
IF(QNET.LT.0.OR.PQ.LT.0.1) THEN
   TSC = 0.
   USC = 0.
   DSC = 999.
   ICON = 9
   RETURN
END IF
CONST = (1/RO)*SQRT(-ALPHA*G/CPW)

EVALUATE THE SCALES IN THE STRESS-DOMINATED REGIME

USC = 1.5*SQRT(QNET*PQ)*CONST
DSC = 0.45*(1/RO)*TAU*PS/(SQRT(QNET*PQ)*CONST)

TSC = 1.5*(QNET*PQ)**1.5*CONST/(TAU*PS*CPW)

TAKE ACCOUNT OF THE EFFECT OF PENETRATING INSOLATION

RS1 = (1 - R)*(QI - QL)/QI
HLAM = (1 - RS1*EXP(-DSC/BETA2))

TSC = TSC*HLAM**1.5
USC = USC*HLAM**0.5
DSC = DSC/HLAM**1.5

NOW, CHECK TO SEE IF CONVECTION LIMIT IS REACHED

CALL CDEP(QI,QL,R,BETA1,BETA2,CDZ,QDC,RIC)

TCON = PQ*QDC/(RO*CPW)

IF(TCON.LT.TSC) THEN

IF CONVECTION LIMIT WAS REACHED, THEN USE CONVECTION SCALES

ICON = 1
TSC = TCON
USC = TAU*PS/(RO*CDZ)
DSC = CDZ + (PQ/(RO*CPW))*RJC/TSC

END IF

RETURN

END
SUBROUTINE CDEP(QI,QL,R,B1,B2,CD,QDC,RIC)

C THIS SUBROUTINE COMPUTES THE CONVECTION DEPTH FOR THE 
C DIURNAL CYCLE.

C INPUT DATA ARE:
C QI, THE MAXIMUM SOLAR INSOLATION, WATTS PER METER SQUARED
C QL, HEAT LOSS, WATTS PER METER SQUARED
C R, FRACTION OF INSOLATION IN LONG WAVE COMPONENT, NON-D
C B1, EXTINCTION SCALE FOR LONG WAVE INSOLATION, METERS
C B2, EXTINCTION SCALE FOR SHORT WAVE INSOLATION, METERS

C THE OUTPUT DATA ARE:
C CD, THE DAILY MINIMUM CONVECTION DEPTH, METERS
C QDC, HEAT FLUX ABSORBED ABOVE CD, WATTS PER METER CUBED
C RIC, THE SOLAR INSOLATION AT DEPTH CD, WATTS PER METER SQUARED

C

JIM PRICE, 1 JULY 1985, W.H.O.I.

C

DZ = 0.05

C SET DEFAULT VALUES
CD = 26.
QDC = 0.1

C

DO 4 J=1,500
Z = FLOAT(J)*DZ
RIZ = QI*(1. - (R*EXP(-Z/B1) + (1.-R)*EXP(-Z/B2)))
DIDZ = QI*(R*EXP(-Z/B1)/B1 + (1.-R)*EXP(-Z/B2)/B2)
ELS = (RIZ + QL)/Z

C IF(ELS.GE.DIDZ) GO TO 5

4 CONTINUE
GO TO 9
5 CONTINUE

CD = Z
QDC = (ELS + DIDZ)/2.
RIC = RIZ

C

9 CONTINUE
RETURN
END

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