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A METHOD OF CORRECTION FOR DIEL EFFECTS ON OBSERVATIONS, IN ASSESSING THE ANNUAL VARIATIONS OF A PARAMETER*

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ABSTRACT

The ship-survey data, especially those controlled by solar heating during day and nocturnal cooling during night, necessitate diel corrections in their observed values for accurate seasonal variations. Based on harmonic analysis, an analytic method is envisaged and worked out for seasono-diel variations applicable for assessing more accurately the annual variations of a parameter in the Indian region.

INTRODUCTION

CERTAIN parameters in oceanography, meteorology and marine biology, especially those which are governed by solar radiation and nocturnal cooling, like the sea surface temperature, barometric pressure and so on exhibit clearly systematic variations in a day (diel variations) superimposed on their sesonal variations. As practised by India Meteorological Department, if observations are made in fixed hour of the day, it is easy to get the mean value of the parameter for the month and henceforth its seasonal (month to month) variations. However, such monthly mean value does not take care of the entire diurnal variations. Information based on ship-survey is much more restricted from the synoptic point of view, as it is impossible to vist a particular station or region always at a particular hour of the day in the regular surveys by research vessels. It is inevitable to involve different hours of the day in such data of observations over a year.

As the curve of seasonal variations of the parameter proceeds from month to month in its annual march, the dirunal oscillations bring changes in the actual observations made. Therefore observations conducted at different times of the day require correction for the study of their seasonal variations, the amount of correction being dependent upon the actual time (hr) of observing the parameter.

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TECHNIQUE OF CORRECTION FOR DIEL OSCILLATIONS

Let a parameter Y in a month T be represented by Y_T (monthly mean) in its annual march and Y_t the diel fluctuation value at the hour t of the day and $Y_{T,\,t}$ the actual observation at the hour t in the same month T. Then,

$$Y_{T,\,t} = Y_T + Y_t \text{ or}$$
$$Y_{T,\,t} - Y_t = Y_T \qquad (1)$$

Therefore $-Y_t$ is the required diel correction to be applied to the actual observation $Y_{T,\,t}$ in order to get the annual march Y_T of the parameter Y.

Y_T is constant for a given value of T and Y_t oscillates on Y_T with a duration of 24 hrs.

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The mean diel cycle for each month is prepared by pooling up the data of the month taken at different hours. Of all the diel oscillations, the diurnal and semidiurnal waves are important. Therefore, eq. 1 can be represented as

$$Y_{T,t} - \left(+ \sum_{p=1}^{2} a_p \cos p \frac{2\pi t}{24} + \sum_{p=1}^{2} b_p \sin p \frac{2\pi t}{24} \right) = Y_T \quad (2)$$

where a and b are harmonic coefficients. Over 24 hrs, the diel oscillations will get nullified. It is therefore clear that

$$Y_T = \frac{1}{24} \sum_{t=0}^{23} (Y_{T,t}) \quad (3)$$

which is the mean value of $Y_{T,t}$ for the 24 hrs of the day.

16-ordinate scheme for diel variations

The hour-wise mean value of the parameter for 24 hrs is prepared for each month by pooling up the available data of observations of the parameters for the month. The primary period (24 hr) is divided into 16 equal parts starting from t=0 (mid night) and the corresponding 16 ordinates are chosen. Let the ordinates in the order be Y_0, Y_1, Y_2, ... Y_{14} and Y_{15}. As the 16-ordinate scheme brings out the diurnal wave and semi-diurnal wave effectively from the diel variations, it is the best suited for treatment of the diel variations (Murty, 1987). The scheme is as follows :

Arrange the Y series as

$$\begin{array}{llllllllll}
 & Y_0 & Y_1 & Y_2 & Y_3 & Y_4 & Y_5 & Y_6 & Y_7 & Y_8 \\
 & & Y_{15} & Y_{14} & Y_{13} & Y_{12} & Y_{11} & Y_{10} & Y_9 & \\
\hline
\text{Sum} & P_0 & P_1 & P_2 & P_3 & P_4 & P_5 & P_6 & P_7 & P_8 \\
\text{Diff.} & & q_1 & q_2 & q_3 & q_4 & q_5 & q_6 & q_7 &
\end{array}$$

Rearrange p and q series as

$$\begin{array}{lllll l llll}
p_0 & p_1 & p_2 & p_3 & p_4 & & q_1 & q_2 & q_3 & q_4 \\
p_8 & p_7 & p_6 & p_5 & & & q_7 & q_6 & q_5 & \\
\hline
r_0 & r_1 & r_2 & r_3 & r_4 & \text{Sum} & m_0 & m_1 & m_2 & m_3 \\
s_0 & s_1 & s_2 & s_3 & & \text{Diff.} & n_0 & n_1 & n_2 &
\end{array}$$

and the r series as

$$\begin{array}{llll}
 & r_0 & r_1 & r_2 \\
 & r_4 & r_3 & \\
\hline
\text{Sum} & v_0 & v_1 & v_2 \\
\text{Diff.} & w_0 & w_1 &
\end{array}$$

Tabulate the results as follows :—

TABLE 1. *Summary of coefficients for diel variations*

Multiplier					
0.383	..	s_3		m_0	
0.707	..	s_2	w_1	m_1	n_0+n_2
0.924	..	s_1		m_2	
1	..	s_0	w_0	m_3	n_1
sum =	..	$8a_1$	$8a_2$	$8b_1$	$8b_2$

If each set of the diurnal waves and semidiurnal waves for the twelve months of the year show reasonable closeness in their respective amplitudes and phases which could be determined by the closeness of each of the corresponding coefficients a_1, a_2, b_1 and b_2 for the twelve months, then the diel correction for the entire year can be represented by a single expression. In case there is significant disparity in the values of the diel coefficients from month to month, it is required to consider the diel oscillation for each month or at least for each season. In either case, the parameter $Y_{T,t}$ observed at time t (hr) in the month T would become, after diel correction, Y_T as expressed by equation 2.

SEASONAL VARIATIONS

As Y_T is the mean value of the parameter for the month, its variations from month to month are considered for the study of seasonal variations of the parameter. From the climatic view-point of the waters around India, the period of the year may be broadly divided into three main seasons, namely, the monsoon season from June to September, the winter season from October to January followed by the hot-weather season from February to May. The annual variations of Y_T may be represented by the first three harmonics which are determinable from the variations of Y_T during the the year.

$$\therefore\ Y_T = A_0 + \sum_{n=1}^{3} A_n \cos n \frac{2\pi T}{12} + \sum_{n=1}^{3} B_n \sin n \frac{2\pi T}{12} \qquad (4)$$

where A_1, A_2, A_3, B_1, B_2 and B_3 are coefficients of harmonics. T is in months (T=0 or 12 refers to December so that the digital counting of months follows the conventional rule)

$$A_0 = \frac{1}{12} \sum_{T=0}^{11} Y_T \qquad (5)$$

which is the annual mean of Y_T for the 12 months of the year.

12-ordinate scheme for seasonal variations

The 12 values of Y_T, each representing a particular month of the year, constitute the 12 ordinates required for the scheme to express the seasonal variations in the form of the first three harmonics.

Arrange the twelve Y_T values as

$$\begin{array}{llllll} & Y_0 & Y_1 & Y_2 & Y_3 & Y_4 & Y_5 \\ & Y_6 & Y_7 & Y_8 & Y_9 & Y_{10} & Y_{11} \\ \hline \text{Sum} & p_0 & p_1 & p_2 & p_3 & p_4 & p_5 \\ \text{Diff.} & q_0 & q_1 & q_2 & q_3 & q_4 & q_5 \end{array}$$

Arrange p series as

$$\begin{array}{llll} & p_0 & p_1 & p_2 \\ & p_3 & p_4 & p_5 \\ \hline \text{Diff.} & r_0 & r_1 & r_2 \end{array}$$

Arrange q series as

$$\begin{array}{llll} & q_0 & q_1 & q_2 \\ & q_3 & q_4 & q_5 \\ \hline \text{Sum} & s_0 & s_1 & s_2 \\ \text{Diff.} & t_0 & t_1 & t_2 \end{array}$$

Rearrange r, s and t series as

$$\begin{array}{lllllll} & r_0 & r_1 & s_0 & s_1 & t_0 & t_1 \\ & & r_2 & & s_2 & & t_2 \\ \hline \text{Sum} & u_0 & u_1 & w_0 & w_1 & m_0 & m_1 \\ \text{Diff.} & & v_1 & & l_1 & & n_1 \end{array}$$

Arrange the terms in the following Table 2.

TABLE 2. *Summary of coefficients for seasonal variations*

Multiplier						
0.5	$-l_1+m_1$	v_1		w_1+n_1		
0.865	l_1+m_1			w_1-n_1	u_1	
1	w_0+m_0	u_0	$w_0+m_0+l_1-m_1$	w_0-m_0		$w_1+n_1-w_0+m_0$
Sum=	$12A_1$	$6A_2$	$12A_3$	$12B_1$	$6B_2$	$12B_3$

From the above Table and from eq. 5, the values of the harmonic coefficiencts A_1, A_2, A_3, B_1, B_3 and A_0 required for eq. 4 are determined.

The total seasono-diel effects on the observed parameter can be rewritten, by combining eq. 2 and 4 as,

$$Y_{T,t} - \left[a_1 \cos\left(\frac{2\pi t}{24}\right) + a_2 \cos 2\left(\frac{2\pi t}{24}\right) + b_1 \sin\left(\frac{2\pi t}{24}\right) + b_2 \sin 2\left(\frac{2\pi t}{24}\right) \right]$$
$$= A_0 + A_1 \cos\left(\frac{2\pi T}{12}\right) + A_2 \cos 2\left(\frac{2\pi T}{12}\right) + A_3 \cos 3\left(\frac{2\pi T}{12}\right)$$
$$+ B_1 \sin\left(\frac{2\pi T}{12}\right) + B_2 \sin 2\left(\frac{2\pi T}{12}\right)$$
$$+ B_3 \sin 3\left(\frac{2\pi T}{12}\right) \qquad \ldots (6)$$

their mean value is treated to represent the value at 0700 hrs. The mean diel cycle is prepared for each month.

Taking the mean diel cycle for December (0=T=12), for example, the 16-ordinate scheme for diel variations worked out as described below :

The ordinates are

Y_0	Y_1	Y_2	Y_3	Y_4
77.95	77.90	77.70	77.70	77.60
Y_5	Y_6	Y_7	Y_8	Y_9
77.64	78.10	78.62	79.20	79.61
Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y_{14}
79.70	79.25	78.90	78.65	78.50
and	Y_{15}			
	78.05			

Arranging the ordinates

	77.95	77.90	77.70	77.70	77.60	77.64	78.10	78.62	79
		78.05	78.50	78.65	78.90	79.25	79.70	79.61	
p	77.95	155.95	156.20	156.35	156.50	156.89	157.80	158.23	79
q		—0.15	—0.80	—0.95	—1.30	—1.61	—1.60	—0.99	

EXAMPLE

To cite as an example, data on surface temperature (°F) of the nearshore waters at Waltair for the period from February 1960 to January 1961 from a Ph.D. thesis (Murty, 1965) are utilised here, as the coverage of the same in terms of diurnal cycles was excellent. One hundred and fifteen diel cycles in all, with not less than five diel cycles in any month were covered in those observations which were taken at alternate hours of the day starting from 0700 hrs and ending by 0700 hrs the next day in each cycle. As the initial and final readings of each diel cycle are clubbed together,

Rearranging p series

	77.95	155.95	156.20	156.35	156.50
	79.20	158.23	157.80	156.89	
r	157.15	314.18	314.00	313.24	156.50
s	—1.25	—2.28	—1.60	—0.54	

Rearranging q series

	—0.15	—0.80	—0.95	—1.30
	—0.99	—1.60	—1.61	
m	—1.14	—2.40	—2.56	—1.30
n	0.84	0.80	0.66	

Rearranging r series

157.15	314.18	314.00
156.50	313.24	
313.65	627.42	314.00
0.65	0.94	

Tabulating the results

Multi-plier				
0.383	—0.54		—1.14	
0.707	—1.60	0.94	—2.40	0.84+0.66
0.924	—2.28		—2.56	
1	—1.25	0.65	—1.30	0.80
Sum=	—4.6847	1.3146	—5.7989	1.8605
	$8a_1$	$8a_2$	$8b_1$	$8b_2$

$a_1=-0.586$; $a_2=+0.164$; $b_1=-0.725$; $b_2=+0.233$

Therefore for December (T=12 or 0), the diel correction ($-Y_t$) for the observed surface temperature (in °F) at any hour t of the day is given by

$$-Y_t = +0.586 \cos\left(\frac{2\pi t}{24}\right) - 0.164 \cos 2\left(\frac{2\pi t}{24}\right) + 0.725 \sin\left(\frac{2\pi t}{24}\right) - 0.233 \sin 2\left(\frac{2\pi t}{24}\right) \quad \ldots (7)$$

Applying the procedure for dirunal and semidiurnal waves of the mean diel cycle for each month, the coefficients thereby obtained are enlisted in the following Table 3.

The coefficients a_1, a_2, b_1 and b_2 are the required constants for each month for estimating the diel fluctuation Yt at any hour t of the day in the respective month.

TABLE 3. *Coefficients of diel variations in all the 12 months*

Month		a_1	a_2	b_1	b_2
0/12	..	—0.586	0.164	—0.725	0.233
1	..	—0.532	0.185	—0.817	0.249
2	..	—0.749	0.176	—1.171	0.325
3	..	—0.962	0.258	—1.286	0.167
4	..	—1.143	0.254	—1.511	0.333
5	..	—0.741	—0.076	—0.633	0.154
6	..	—0.613	0.078	—0.626	—0.144
7	..	—0.648	0.323	—0.826	0.231
8	..	—0.377	0.191	—0.532	0.206
9	..	—0.278	0.163	—0.557	0.305
10	..	—0.633	0.221	—0.373	0.091
11	..	—0.659	0.320	—0.529	0.165

The diel fluctuations for the three distinct seasons as in Table 4 (monsoon, winter and hot weather season) are obtained from the mean values of each of the coefficients a_1, a_2, b_1 and b_2 for the months corresponding to the respectives easons from Table 3.

From the values presented in above Table.

$$Y_{t\,(m)} = -0.479 \cos \frac{2\pi t}{24} + 0.189 \cos 2 \frac{2\pi t}{24} - 0.635 \sin \frac{2\pi t}{24} + 0.150 \sin 2 \frac{2\pi t}{24} \quad ..8\text{ (a)}$$

$$Y_{t\,(w)} = -0.603 \cos \frac{2\pi t}{24} + 0.223 \cos 2 \frac{2\pi t}{24} - 0.611 \sin \frac{2\pi t}{24} + 0.185 \sin 2 \frac{2\pi t}{24} \quad ..8\text{ (b)}$$

$$Y_{t(h)} = -0.899 \cos \frac{2\pi t}{24} + 0.153 \cos 2 \frac{2\pi t}{24} - 1.150 \sin \frac{2\pi t}{24} + 0.254 \sin 2 \frac{2\pi t}{24} \quad ..8\ (c)$$

where $Y_{t\,(m)}$, $Y_{t\,(w)}$ and $Y_{t\,(h)}$ are the amounts of fluctuations at hour t in the monsoon, winter and hot weather seasons respectively. The diel fluctuation coefficients of the Table 4

Table 4. *Seasonal mean coefficients of diel variations*

coef. / Season	a_1	a_2	b_1	b_2
Monsoon .. (June-Sept.)	—0.479	+0.189	—0.635	+0.150
Winter .. (Oct.-Jan.)	—0.603	+0.223	—0.611	+0.185
Hot weather .. (Feb.-May)	—0.899	+0.153	—1.150	+0.245

or the equation 8 provide means for diel correction in the observed surface temperature (°F) of the nearshore waters of Waltair.

Seasonal Variations

The average of the monthly mean values is 81.297 ($=A_0$). Proceeding with 12-ordinate scheme on the monthly mean values which are equal to Y_T values (°F) as shown at the bottom.

Arranging p series

	160.96	159.62	162.55
	165.63	164.50	162.30
r	—4.67	—4.88	+0.25

Arranging q series

	—4.08	—3.96	—3.89
	—4.33	—4.24	+1.16
s	—8.41	—8.20	—2.73
t	+0.25	+0.28	—5.05

Arranging r series

	—4.67	—4.88
		+0.25
u	—4.67	—4.63
v		—5.13

T (month)	0	1	2	3	4	5	6	7	8	9	10	11
Y_T	78.44	77.83	79.33	80.65	80.13	81.73	82.52	81.79	83.22	84.98	8 84.37	80.57

Arranging the 12 ordinates

	78.44	77.83	79.33	80.65	80.13	81.73
	82.52	81.79	83.22	84.98	84.37	80.57
p	160.96	159.62	162.55	165.63	164.50	162.30
q	—4.08	—3.96	—3.89	—4.33	—4.24	+1.16

Arranging s series

	—8.41	—8.20
		—2.73
w	—8.41	—10.93
l		—5.47

Arranging t series

	+0.25	+0.28
		—5.05
m	+0.25	—4.77
n		+5.33

The tabular form corresponding to Table 2 is

Multiplier						
0.5	5.47−4.77	−5.13		−10.93+5.33		
0.866	−5.47−4.77			−10.93−5.33	−4.63	
1	−8.41+0.25	−4.67	−8.41+0.25	−8.41−0.25		−10.93+5.3
			−5.47+4.77			+8.41+0.25
Sum =	−16.6778	−7.235	−8.86	−25.5412	−4.0096	+3.06
	$12A_1$	$6A_2$	$12A_3$	$12B_1$	$6B_2$	$12B_3$

from which

$A_1 = -1.390$; $A_2 = -1.206$; $A_3 = -0.738$
$B_1 = -2.128$; $B_2 = -0.668$; $B_3 = +0.255$

The annual variations (monthly means) are given by

$$Y_T = 81.297 - 1.393 \cos \frac{2\pi T}{12} - 1.206 \cos 2 \frac{2\pi T}{12} - 0.738 \cos 3 \frac{2\pi T}{12} - 2.128 \sin \frac{2\pi T}{12} - 0.668 \sin 2 \frac{2\pi T}{12} + 0.255 \sin 3 \frac{3\pi T}{12} \quad ..(9)$$

Assuming that the diel fluctuations are the same in each month of the same season, eqs. 8 b, c provide correction factors ($-Y_t$) for the observed values ($Y_{T,,t}$) at the hour t in the month T.

From eqs 8 and 9, for monsoon months

$$Y_{T,t} - \left(-0.479 \cos \frac{2\pi t}{24} + 0.189 \cos 2 \frac{2\pi t}{24} - 0.635 \sin \frac{2\pi t}{24} + 0.150 \sin 2 \frac{2\pi t}{23} \right)$$

$$= 81.297 - 1.390 \cos \frac{2\pi T}{12} - 1.206 \cos 2 \frac{2\pi T}{12} - 0.738 \cos 3 \frac{2\pi T}{12} - 2.128 \sin \frac{2\pi T}{12} - 0.668 \sin 2 \frac{2\pi T}{12} + 0.255 \sin 3 \frac{2\pi T}{12} \quad ..(10a)$$

for winter months

$$Y_{T,t} - \left(-0.603 \cos \frac{2\pi t}{24} + 0.223 \cos 2 \frac{2\pi t}{24} - 0.611 \sin \frac{2\pi t}{24} \right.$$

$$+ 0.185 \sin 2 \frac{2\pi t}{24}\Big)$$

$$= 81.297 - 1.390 \cos \frac{2\pi T}{12}$$

$$- 1.206 \cos 2\frac{2\pi T}{12}$$

$$- 0.738 \cos 3\frac{2\pi T}{12} - 2.128 \sin \frac{2\pi T}{12}$$

$$- 0.668 \sin 2 \frac{2\pi T}{12}$$

$$+ 0.255 \sin 3\frac{2\pi T}{12} \quad ..(10b)$$

and for hot weather season

$$Y_{T,t} - \Big(- 0.899 \cos \frac{2\pi t}{24}$$

$$+ 0.153 \cos 2\frac{2\pi t}{24} - 1.150 \sin \frac{2\pi t}{24}$$

$$+ 0.245 \sin 2 \frac{2\pi t}{24}\Big)$$

$$= 81.297 - 1.390 \cos \frac{2\pi T}{12} - 1.206$$

$$\cos 2 \frac{2\pi T}{12} - 0.738 \cos 3 \frac{2\pi T}{12}$$

$$- 2.128 \sin \frac{2\pi T}{12}$$

$$- 0.668 \sin 2 \frac{2\pi T}{12}$$

$$+ 0.255 \sin 3\frac{2\pi T}{12} \quad ..(10c)$$

In order to realise the significance of diel corrections, let us consider Y_{Tt} for t=0100 hr. In this case, the diel correction (from eq. 10 will become +0.336, 0.414 and +0.826 for monsoon, winter and hot weather seasons respectively. The annual march of the concerned parameter (surface temperature in °F) for 0100 hr before and after correction for diel effects and the monthly mean values of the parameter are shown in Table 5 for comparison.

The closeness of the corrected figures with the corresponding monthly mean values (Table 5) indicates that the diel correction

TABLE 5. *Comparison of the annual march of surface temperature (°F) with the mean 0100 hr observation*

Month T	Value of $Y_{T,t}$ for t=0100 hr. (without correction for diel effects)	Value of $Y_{T,t}$ for t=0100 hr with diel correction (adopting the seasonal corection)	Value of $Y_{T,t}$ for t=0100 hr with diel correction (adopting the monthly correction)	Monthly mean value Y_t
0/12 ..	78.0	78.41	78.45	78.44
1 ..	77.3	77.71	77.69	77.83
2 ..	78.7	79.52	79.34	79.33
3 ..	79.4	80.22	80.23	80.65
4 ..	78.9	79.72	79.90	80.13
5 ..	81.0	81.82	81.85	81.73
6 ..	81.9	82.23	82.55	82.52
7 ..	81.4	81.73	81.78	81.79
8 ..	83.0	83.33	83.19	83.22
9 ..	84.9	85.23	85.01	84.98
10 ..	83.9	84.31	84.34	84.37
11 ..	80.1	80.51	80.47	80.57

method is very effective in bringing out the seasonal character of variation of the parameter.

CONCLUSIONS

Even though the methodology of diel corrections (eq. 2 or 6) is the same for any region, the actual values of the coefficients differ from region to region and from parameter to parameter. The split-up of seasons is made in such a manner, in the example, that seasonwise determined coefficients are more suited for tropical areas dominated by monsoon system. The diel correction coefficients evaluated in the example (eq. 10) are applicable only for the surface temperature of the nearshore waters off Waltair (Visakapatnam). Evidently, the more the number of observations with uniform spread over hours and months, the more accurate would be the evaluated constants involved in the expression of seasono-diel variations of a chosen parameter in a region.

It may be said that the expression for seasono-diel variatons serves a useful purpose for time-series analysis of environmental parameters in general and in the field of oceanography in particular. It provides a correction factor for observations made at different times of the day (day and night) in the study of seasonal variations of a parameter in a chosen region. Different sets of constants are required for different regions, if their characters differ.

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