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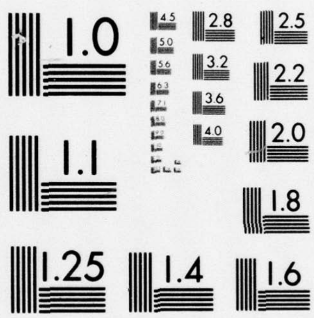

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A METHOD FOR MANUALLY CALCULATING THE LOCAL WIND CURRENT

Oceanographic Unit Technical Report 78-2

A METHOD FOR MANUALLY CALCULATING THE LOCAL WIND CURRENT.

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by

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ABSTRACT

A method to manually calculate the local wind current in deep water is developed. The method is based on time-dependent Ekman dynamics. The method is tuned and tested against a 2 1/2 month long current and wind record in the North Atlantic.

ABSTRACT

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INTRODUCTION

The local wind current is that current in the ocean which is generated solely by the action of the local wind field acting on the ocean surface. The ability to calculate this local wind current by a manual method is an important aspect in SAR Planning. The development of a manual method presents a two fold problem: (1) the selection of an appropriate model to determine the local wind current and (2) the adaption of the model to a manual method.

THE MODEL

Most of the models to determine the local wind current are extensions of Ekman's (1905) work. Ekman's (1905) model for the determination of the local wind current for an unbounded infinitely deep ocean is based on the following assumptions:

a. The fluid is hydrostatic

b. The fluid is homogeneous

c. The eddy viscosity is constant

d. The lateral stresses are neglected

e. The non-linear interaction terms are neglected

With these assumptions the equations of motion in complex notation can be written:

$$\frac{\partial w}{\partial t} = -ifw + \nu \frac{\partial^2 w}{\partial z^2} \qquad (1)$$

where

$w = u+iv$, horizontal components of velocity

f = Coriolis parameter

ν = vertical eddy viscosity coefficient

This equation states that the acceleration of the fluid is balanced by the Coriolis force and the frictional force due to vertical shearing stresses.

With the boundary conditions that there is no flow at the bottom of the ocean, that the stress at the fluid's surface matches the wind stress and that the velocity at t=0 equals 0, equation (1) can be solved by the method of Laplace transforms. This solution as derived by Jelesnianski (1970) is then:

$$w(z,t) = \frac{2}{\rho_w H}\sum_{n=0}^{\infty} \cos\left[\left(n+\frac{1}{2}\right)\pi\frac{z}{H}\right]\int_0^t F(T)e^{-\theta_n(t-T)}dT \qquad (2)$$

where

ρ_w= density of the water

H = depth of the ocean

F = F_x + iFy, complex wind stress

Jelesnianski's (1970) solution was selected because it is an exact solution to the equations of motion under the stated assumptions.

To implement equation (2) it is necessary to choose a relationship between the wind stress and the wind velocity. For ease of computation it was assumed that the wind stress was linearly proportional to the wind velocity, i.e.

$$F(T) = \rho_a C_D W(T) \qquad (3)$$

where

ρ_a = density of air

C_D = wind drag coefficient

W = W_x + iWy, complex wind velocity

Substituting equation (3) into equation (2), a relation between the local wind current and the local wind velocity is obtained:

$$w(z,t)=\frac{2\rho_a C_D}{\rho_w H}\sum_{n=0}^{\infty}\cos\left[(n+\tfrac{1}{2})\pi\frac{z}{H}\right]\int_0^t W(T)e^{-\beta_n(t-T)}dT \qquad (4)$$

Equation (4) essentially states that the present wind current is determined by a weighted average of the previous wind history.

ADAPTATION OF THE MODEL TO A MANUAL METHOD

To determine the local wind current, it is necessary to compute the integral in equation (4). To facilitate this computation, assume that the wind record is composed of a series of step functions, that is, the wind is assumed constant in speed and direction over an interval $2\Delta t$ centered at some time T_j. Equation (4) can then be written:

$$w(z,t)=\frac{2\rho_a C_D}{\rho_w H}\sum_{n=0}^{\infty}\cos\left[(n+\tfrac{1}{2})\pi\frac{z}{H}\right]\sum_{j=1}^{N}W(T_j)\int_{T_j-\Delta t}^{T_j+\Delta t} e^{-\beta_n(t-T)}dT \qquad (5)$$

where

$N = \dfrac{t}{2\Delta t}$, number of time intervals in the wind record.

Now write the complex local wind current as a sum of a series of the form:

$$w(z,t)=\sum_{j=1}^{N}w_j(z,t)=\sum_{j=1}^{N}\left[u_j(z,t)+iv_j(z,t)\right] \qquad (6)$$

Substitution of equation (6) into equation (5) and elimination of the summation signs yields:

$$w(z,t) = \frac{\alpha\rho_a C_D}{\rho_w H} W(T_j) \sum_{n=0}^{\infty} \cos\left[(n+\tfrac{1}{2})\pi \frac{z}{H}\right] \int_{T_j-\Delta t}^{T_j+\Delta t} e^{-\theta_n(t-T)}\, dT \quad (7)$$

Now orient the axes so that for the time period centered at Tj the wind blows in the x direction. Also write the x and y components of the complex local wind current contribution for the time period center at Tj as:

$$u_j(z,t) \equiv \frac{\alpha\rho_a C_D}{\rho_w H} C_j^{(1)} W(T_j) \quad (8)$$

$$v_j(z,t) \equiv \frac{\alpha\rho_a C_D}{\rho_w H} C_j^{(2)} W(T_j) \quad (9)$$

Note that these components are relative to the direction of the wind over each particular time interval. Substitution of equations (8) and (9) into equation (7) yields the following expressions for $C_j^{(1)}$ and $C_j^{(2)}$:

$$C_j^{(1)} = \mathrm{Re}\left\{ \sum_{n=0}^{\infty} \cos\left[(n+\tfrac{1}{2})\pi \frac{z}{H}\right] \int_{T_j-\Delta t}^{T_j+\Delta t} e^{-\theta_n(t-T)}\, dT \right\} \quad (10)$$

$$C_j^{(2)} = \mathrm{Im}\left\{ \sum_{n=0}^{\infty} \cos\left[(n+\tfrac{1}{2})\pi \frac{z}{H}\right] \int_{T_j-\Delta t}^{T_j+\Delta t} e^{-\theta_n(t-T)}\, dT \right\} \quad (11)$$

The integrals in equations (10) and (11) can be computed explicitly:

$$C_j^{(1)}=\sum_{n=0}^{\infty}\cos\left[\left(n+\tfrac{1}{2}\right)\pi\frac{z}{H}\right]\frac{e^{-\nu\beta_n^2\tau_j}}{\nu^2\beta_n^4+f^2}\Big[-\nu\beta_n^2 e^{-\nu\beta_n^2\Delta t}\cos f\tau_j^{(+)} + \nu\beta_n^2 e^{\nu\beta_n^2\Delta t}\cos f\tau_j^{(-)} + f e^{-\nu\beta_n^2\Delta t}\sin f\tau_j^{(+)} - f e^{\nu\beta_n^2\Delta t}\sin f\tau_j^{(-)}\Big] \quad (12)$$

$$C_j^{(2)}=\sum_{n=0}^{\infty}\cos\left[\left(n+\tfrac{1}{2}\right)\pi\frac{z}{H}\right]\frac{e^{-\nu\beta_n^2\tau_j}}{\nu^2\beta_n^4+f^2}\Big[f e^{-\nu\beta_n^2\Delta t}\cos f\tau_j^{(+)} - f e^{\nu\beta_n^2\Delta t}\cos f\tau_j^{(-)} + \nu\beta_n^2 e^{-\nu\beta_n^2\Delta t}\sin f\tau_j^{(+)} - \nu\beta_n^2 e^{\nu\beta_n^2\Delta t}\sin f\tau_j^{(-)}\Big] \quad (13)$$

where

$Tj = t - Tj \quad Tj^{(+)} = t - Tj + \Delta t \quad Tj^{(-)} = t-Tj-\Delta t$

The derivations for equations (12) and (13) are given in Appendix I.

The magnitude of the local wind current contribution for each interval is:

$$U_j=(u_j^2+v_j^2)^{1/2} = \frac{2\rho_a C_D}{\rho_w H}\left\{\left[C_j^{(1)}\right]^2+\left[C_j^{(2)}\right]^2\right\}^{1/2} W(\tau_j) \equiv K_j W(\tau_j) \quad (14)$$

where

$$K_j=\frac{2\rho_a C_D}{\rho_w H}\left\{\left[C_j^{(1)}\right]^2+\left[C_j^{(2)}\right]^2\right\}^{1/2} \quad (15)$$

If αj is the direction from which the wind blew over the interval centered at Tj, then the direction of the local wind current contribution for that period is:

$$\alpha_j + \phi_j = \alpha_j + 180° - \mathrm{TAN}^{-1}\frac{v_j}{u_j}$$
$$= \alpha_j + 180° - \mathrm{TAN}^{-1}\frac{C_j^{(2)}}{C_j^{(1)}} \quad (16)$$

Thus from a knowledge of $Cj^{(1)}$ and $Cj^{(2)}$ the contributions to the local wind current can be determined.

The local wind current can be determined by summing up the contributions from each interval:

$$u = \sum_{j=1}^{N} K_j N(\tau_j)\, \mathrm{SIN}(\alpha_j + \phi_j) \quad (17)$$

$$v = \sum_{j=1}^{N} K_j N(\tau_j)\, \mathrm{COS}(\alpha_j + \phi_j) \quad (18)$$

The speed and direction of the local wind current is then:

$$U = (u^2 + v^2)^{1/2} \quad (19)$$

$$\phi = \mathrm{TAN}^{-1}(u/v) \quad (20)$$

TESTING AND TUNING OF THE METHOD

Except for C_D, the wind drag coefficient, and ν, the vertical eddy viscosity, the parameters necessary for the determinations of Kj and ϕj are accurately known. The drag coefficient and the eddy viscosity can thus be used to tune the model.

The model was tuned against a time series of wind and current measurements made with current meters and wind recorders by the Woods Hole Oceanographic Institution during June, July and August of 1970 in the Northwestern Atlantic at 39° 07.6'N and 70° 02.3"W (see Pollard and Tarbell, 1975). The current measurement were made at a depth of 12 meters in water of depth 2682 at a site designated 339D. The length of the records are 50 days, 20 hours, 30 minutes.

The wind and current measurement were averaged over 6 hour time periods as this was assumed to be the most realistic time interval for which wind measurements could be obtained in a practical situation. Using a time record of length 48 hours, t = 48 hours in equations (12) and (13), Kj and ϕj were calculated for various values of C_D and ν. A time record of 48 hours makes N = 8. The various Kjs and ϕj's were then used in equations (17) through (18) to reproduce the current record. The distance between the calculated drift distance and the observed drift distance for each 6 hour time interval was then used as a measure of the accuracy of the calculated velocities. This distance can be calculated from the equation:

$$d = 6\left[U^2 + U_0^2 - 2UU_0\cos(\phi - \phi_0)\right]^{1/2} \qquad (21)$$

where U and ϕ are the calculated values of the current speed and direction and U_o and ϕ_o are the observed values of the current speed and direction. A minmum average value for d was obtained for $C_D = 1.9 \times 10^{-3}$ cm/sec and $\nu = 50\ cm^2/sec$. These values are realistic values for the drag coefficient and eddy viscosity. The average drift error for these values was 1.5 nm.

FORMUALTION OF THE METHOD

The values of Kj and ϕj can now be calculated as a function of latitude. These calculated values are shown in Table 1. To calculate the local wind current at a specific latitude one now simply has to multiply the local wind speed at that latitude by the appropriate Kj's for each period and add the appropriate ϕj's to the local wind direction for each period. The resultant contributions for each period are then added vectorially to obtain the calculated local wind current. An example of how this method can be used is given in Appendix II.

APPENDIX I

Derivation of explicit expressions for $Cj^{(1)}$ and $Cj^{(2)}$

The expression for $Cj^{(1)}$ from equation (10) in the text is:

$$C_j^{(1)} = Re\left\{\sum_{n=0}^{\infty} \cos\left[(n+\tfrac{1}{2})\pi\tfrac{z}{H}\right]\int_{T_j-\Delta t}^{T_j+\Delta t} e^{-\theta_n(t-T)}\,dT\right\} \qquad \text{I-1}$$

$$= Re\left\{\sum_{n=0}^{\infty} \cos\left[(n+\tfrac{1}{2})\pi\tfrac{z}{H}\right] \frac{e^{-\theta_n(t-T_j-\Delta t)} - e^{-\theta_n(t-T_j+\Delta t)}}{\theta_n}\right\} \qquad \text{I-2}$$

$$= Re\left\{\sum_{n=0}^{\infty} \cos\left[(n+\tfrac{1}{2})\pi\tfrac{z}{H}\right] \times \frac{e^{-(if+\nu\beta_n^2)(t-T_j-\Delta t)} - e^{-(if+\nu\beta_n^2)(t-T_j+\Delta t)}}{if+\nu\beta_n^2}\right\} \qquad \text{I-3}$$

$$= Re\left\{\sum_{n=0}^{\infty} \cos\left[(n+\tfrac{1}{2})\pi\tfrac{z}{H}\right] \frac{\nu\beta_n^2 - if}{\nu^2\beta_n^4+f^2} \left[e^{-\nu\beta_n^2(t-T_j-\Delta t)}\left(\cos f(t-T_j-\Delta t) - i\sin f(t-T_j-\Delta t)\right) - e^{-\nu\beta_n^2(t-T_j+\Delta t)}\left(\cos f(t-T_j+\Delta t) - i\sin f(t-T_j+\Delta t)\right)\right]\right\} \qquad \text{I-4}$$

$$= Re\left\{\sum_{n=0}^{\infty} \cos\left[(n+\tfrac{1}{2})\pi\frac{z}{H}\right] \frac{e^{-\nu\beta_n^2(t-T_j)}}{\nu^2\beta_n^4 + f^2}\right.$$

$$\times\left[\nu\beta_n^2 e^{\nu\beta_n^2\Delta t} \cos f(t-T_j-\Delta t)\right.$$

$$-\nu\beta_n^2 e^{-\nu\beta_n^2\Delta t} \cos f(t-T_j+\Delta t)$$

$$-f e^{\nu\beta_n^2\Delta t} \sin f(t-T_j+\Delta t)$$

$$+f e^{-\nu\beta_n^2\Delta t} \sin f(t-T_j+\Delta t)$$

$$-i f e^{\nu\beta_n^2\Delta t} \cos f(t-T_j-\Delta t)$$

$$+i f e^{-\nu\beta_n^2\Delta t} \cos f(t-T_j+\Delta t)$$

$$-i\nu\beta_n^2 e^{\nu\beta_n^2\Delta t} \sin f(t-T_j-\Delta t)$$

$$\left.\left.+i\nu\beta_n^2 e^{-\nu\beta_n^2\Delta t} \sin f(t-T_j+\Delta t)\right]\right\} \quad \text{I-5}$$

$$= \sum_{n=0}^{\infty} \cos\left[(n+\tfrac{1}{2})\pi\frac{z}{H}\right] \frac{e^{-\nu\beta_n^2(t-T_j)}}{\nu^2\beta_n^4+f^2}\left[-\nu\beta_n^2 e^{\nu\beta_n^2\Delta t} \cos f(t-T_j-\Delta t)\right.$$

$$-\nu\beta_n^2 e^{-\nu\beta_n^2\Delta t} \cos f(t-T_j+\Delta t) - f e^{\nu\beta_n^2\Delta t} \sin f(t-T_j-\Delta t)$$

$$\left.+f e^{-\nu\beta_n^2\Delta t} \sin f(t-T_j+\Delta t)\right] \quad \text{I-6}$$

The expression for $C_j^{(1)}$ can be obtained by taking the imaginary part of equation (I-5):

$$C_j^{(2)} = \sum_{n=0}^{\infty} \cos\left[\left(n+\tfrac{1}{2}\right)\pi \frac{z}{H}\right] \frac{e^{-\nu\beta_n^2(t-T_j)}}{\nu^2\beta_n^4+f^2} \Big[-f e^{\nu\beta_n^2\Delta t}\cos f(t-T_j-\Delta t)$$
$$+ f e^{-\nu\beta_n^2\Delta t}\cos f(t-T_j+\Delta t) - \nu\beta_n^2 e^{\nu\beta_n^2\Delta t}\sin f(t-T_j-\Delta t)$$
$$+ \nu\beta_n^2 e^{-\nu\beta_n^2\Delta t}\sin f(t-T_j+\Delta t)\Big] \qquad \text{I-7}$$

Equations (I-6) and (I-7) are the same as equations (12) and (13) in the text.

APPENDIX II

The following problem is intended to illustrate that various computational procedures described in the text.

Given: Present time is 2300Z on the 15th. Information is received that a distress occurred at 1600Z on the 15th. Position of the distress is 44° -15'N, 58°-25'W. The search is expected to commence at 0800Z on the 16th and to be completed by 1600Z on the same day. The following wind information is obtained:

Day	Time	Wind Direction	Wind Speed
16	1800Z	(°T)	(kts)
16	1200Z	340	15
16	0600Z	330	20
16	0000Z	320	35
16	0000Z	320	30
15	1800Z	260	35
15	1200Z	240	30
15	0600Z	230	25
15	0000Z	230	20
14	1800Z	230	20
14	1200Z	230	20
14	0600Z	220	15
14	0000Z	220	15

In order to calculate the local wind current which is valid for the time period from 1200Z to 1800Z on the 15th, the time history extending from 0000Z on the 14th to 1800Z on the 15th is used. The appropriate winds are recorded on a wind current computation sheet, a typical example of which is shown in Figure 1. The column labeled 45°N latitude is then located in Table 1. The figures from this column are recorded on the wind current computation sheet as shown in Figure 1. The necessary additions and multiplications are then made to determine the wind current contributions from each time period. For example the wind current direction appropriate for period 1 is obtained by the following addition:

$$260°+221° = 481° = 121°T$$

The wind current speed appropriate for period 1 is obtained by the following multiplication:

$$35x0.023 = 0.80 \text{ knots}$$

These values are recorded on the wind current compulation sheet. For period 2 the wind current direction is obtained from the addition:

$$240°+007° = 247°T$$

and the wind current speed from the multiplication:

$$30x0.010 = 0.30 \text{ knots}$$

Theve values are recorded on wind current computation sheet. This procedure is repeated for periods 3 through 8:

Period 3	WC direction	= 230°+136° = 366° = 006°T
	WC speed	= 20x0.007 = 0.14 knots
Period 4	WC direction	= 230°+264° = 494° = 134°T
	WC speed	= 20x0.006 = 0.12 knots
Period 5	WC direction	= 230°+031° = 261°T
	WC speed	= 20x0.005 = 0.10 knots

Period 6	WC direction	= 230°+150°	= 389° = 029°T	
	WC speed	= 20x0.005	= 0.10 knots	
Period 7	WC direction	= 220°+286°	= 506° = 146°T	
	WC speed	= 15x0.004	= 0.06 knots	
Period 8	WC direction	= 220°+053°	= 273°T	
	WC speed	= 15x0.004	= 0.06 knots	

These values are recorded on the wind current computations sheet. There is now a wind current direction and speed for all eight periods. These values must be added vectorially in order to obtain the wind current direction and speed which is valid during period 1. It should be noted that the wind current direction and speed for each period is not the wind current which existed during that period, but is only the contribution from that time period to the wind current which is valid during period 1.

There are two possible methods to add the contributions. The first method is to add the vectors head to tail on a maneuvering board. The second method, which is convenient if a calculator is available, is to separate each contribution into its east-west and north-south components, add these components and then reassemble the components into a vector. In both cases the resultant vector is the local wind current valid for period 1. Both methods yield a resultant vector of 136° at 0.63 knots.

In order to calculate the local wind current which is valid for the time period from 1800Z on the 15th to 0000Z on the 16th, the time history extending from 0600Z on the 14th to 0000Z on the 16th is used. Employing procedures the same as those described above a local wind current of 203° at 0.67 knots is calculated.

Similar procedures can be used to calculate the local wind currents for the time periods 0000Z to 0600Z on the 16th, 0600Z to 1200Z on the 16th and 1200Z to 1800Z on the 16th. The results of the calculations for all the desired time periods are:

Day	Time Period	Current Direction (°T)	Current Speed (kts)
16	1200Z-1800Z	228	0.27
16	0600Z-1200Z	204	0.36
16	0000Z-0600Z	185	0.49
15	1800Z-0000Z	203	0.67
15	1200Z-1800Z	136	0.63

This is all the data necessary to calculate the drift due to the local wind current during the period of interest.

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VALID FOR TIME 151200Z-151800Z LAT. 44°15'N LONG. 58°25'W

PERIOD	WIND HISTORY	COEFFICIENTS	CONTRIBUTION TO WIND CURRENT	LOCAL WIND CURRENT
1	260° 35	221° 0.023	121° 0.80	186° 0.63
2	240° 30	007° 0.010	247° 0.30	
3	230° 25	136° 0.007	006° 0.14	
4	230° 20	264° 0.006	134° 0.12	
5	230° 20	031° 0.005	261° 0.10	
6	230° 20	159° 0.005	029° 0.10	
7	220° 15	286° 0.004	146° 0.06	
8	220° 15	053° 0.004	273° 0.06	

WORKED UP BY: Al Smith

CHECKED BY: Frank White

DATE June 15 1977

Figure 1 Wind Current Computation Sheet

	LATITUDE													
PERIOD	0°	5°N	10°N	15°N	20°N	25°N	30°N	35°N	40°N	45°N	50°N	55°N	60°N	65°N
ϕ_1	180°	185°	190°	196°	200°	205°	210°	214°	217°	221°	224°	226°	228°	230°
K_1	0.029	0.029	0.028	0.028	0.027	0.027	0.026	0.025	0.024	0.023	0.022	0.021	0.020	0.020
ϕ_2	180°	203°	226°	249°	271°	292°	312°	332°	350°	007°	072°	036°	049°	059°
K_2	0.012	0.012	0.012	0.012	0.011	0.011	0.011	0.011	0.010	0.010	0.009	0.009	0.009	0.008
ϕ_3	180°	219°	258°	296°	333°	009°	043°	076°	107°	136°	162°	186°	207°	224°
K_3	0.009	0.009	0.009	0.009	0.009	0.008	0.008	0.008	0.008	0.007	0.007	0.007	0.007	0.006
ϕ_4	180°	235°	289°	342°	035°	085°	134°	180°	223°	264°	301°	334°	003°	028°
K_4	0.008	0.008	0.008	0.008	0.007	0.007	0.007	0.007	0.006	0.006	0.006	0.006	0.006	0.005
ϕ_5	180°	250°	320°	029°	096°	162°	224°	283°	339°	031°	079°	121°	159°	192°
K_5	0.007	0.007	0.007	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.005	0.005	0.005	0.004
ϕ_6	180°	266°	352°	076°	158°	238°	314°	027°	095°	159°	217°	269°	315°	355°
K_6	0.006	0.006	0.006	0.006	0.006	0.006	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004
ϕ_7	180°	282°	023°	123°	220°	314°	044°	130°	211°	286°	355°	056°	111°	158°
K_7	0.006	0.006	0.006	0.006	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.003	0.003
ϕ_8	180°	298°	054°	169°	281°	030°	134°	233°	327°	053°	132°	204°	267°	321°
K_8	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003

Table 1. Coefficients relating drift current speed and direction to wind speed and direction.

	LATITUDE													
PERIOD	0°	5°S	10°S	15°S	20°S	25°S	30°S	35°S	40°S	45°S	50°S	55°S	60°S	65°S
ϕ_1	180°	175°	170°	164°	160°	155°	150°	146°	143°	139°	136°	134°	132°	130°
K_1	0.029	0.029	0.028	0.028	0.027	0.027	0.026	0.025	0.024	0.023	0.022	0.021	0.020	0.020
ϕ_2	180°	157°	134°	111°	089°	068°	048°	028°	010°	353°	338°	324°	311°	301°
K_2	0.012	0.012	0.012	0.012	0.011	0.011	0.011	0.011	0.010	0.010	0.009	0.009	0.009	0.008
ϕ_3	180°	141°	102°	064°	027°	351°	317°	284°	253°	224°	198°	174°	153°	136°
K_3	0.009	0.009	0.009	0.009	0.009	0.008	0.008	0.008	0.008	0.007	0.007	0.007	0.007	0.006
ϕ_4	180°	125°	071°	018°	325°	275°	226°	180°	157°	096°	059°	026°	357°	332°
K_4	0.008	0.008	0.008	0.008	0.007	0.007	0.007	0.007	0.006	0.006	0.006	0.006	0.006	0.005
ϕ_5	180°	110°	040°	331°	264°	158°	136°	077°	021°	329°	281°	239°	201°	168°
K_5	0.007	0.007	0.007	0.007	0.006	0.006	0.006	0.006	0.006	0.005	0.005	0.005	0.005	0.004
ϕ_6	180°	094°	008°	284°	202°	122°	046°	333°	265°	201°	143°	091°	055°	005°
K_6	0.006	0.006	0.006	0.006	0.006	0.006	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004
ϕ_7	180°	078°	337°	237°	140°	046°	316°	230°	149°	074°	005°	304°	249°	202°
K_7	0.006	0.006	0.006	0.006	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.003	0.003
ϕ_8	180°	062°	306°	191°	079°	330°	226°	127°	033°	307°	228°	156°	093°	039°
K_8	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003

TABLE 1 (cont)