

FAST AND ACCURATE GEOMETRIC CORRECTION OF NOAA AVHRR IMAGERY

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ABSTRACT:

NOAA AVHRR imagery is very suitable for monitoring global vegetation change because of the wide swath, visible and near infrared wavelength, short observation interval. For such an application, a huge number of images have to be corrected precisely both radiometrically and geometrically. So the fast and accurate correction method should be desirably developed. This paper is focused on the geometric correction.

The system correction is not sufficient for this purpose. Ground control points(GCPs) are utilized for more accurate correction. The correction with GCPs has some problems that it is time consuming as they have been acquired by human interaction, and very few GCPs can be obtained in the open ocean or on the cloudy image. In this paper, the algorithm for the fast and accurate geometric correction of NOAA AVHRR imagery with few GCPs is introduced. The fast process is mainly achieved by automated GCP acquisition which can do without human interaction. The accurate correction is achieved by adopting colinearity condition in photogrammetry.

KEY WORDS: AVHRR, Geometric correction, GCP acquisition, Colinearity condition

1. INTRODUCTION

In general, the geometric correction of NOAA AVHRR imagery is systematically carried out by using the satellite ephemeris data or the orbital element data which are transmitted every day from NOAA. This method is called the system correction and is very simple and fast. However, there remain some distortions in the image by the system correction, which results from the errors of the ephemeris data, the disregard of satellite attitude, the error between the onboard clock and the clock at a receiving station, etc. For more accurate correction, these distortions will be eliminated using ground control points(GCPs). One problem of this method is that very few GCPs can be obtained in the open ocean or on the cloudy image. Another problem is that the acquisition of GCPs from an image is conventionally made by interactive procedures, which results in a long processing time.

The algorithm introduced in this paper enables to correct the orbital elements and the satellite attitude by using colinearity condition in photogrammetry. In the algorithm, the position and attitude of a satellite are treated as the exterior orientation parameters and they are determined by using GCPs. From the examination which orientation parameters should be corrected, the system is modified to be adaptable to the case of only few GCPs.

2. MATHEMATICAL MODEL FOR GEOMETRIC CORRECTION

2.1 Colinearity Condition

The satellite position and attitude are determined by using the colinearity condition used in photogrammetry, where

they are treated as the exterior orientation parameters. The satellite position (X_o, Y_o, Z_o) on the geocentric coordinates is expressed using the distance between the geocenter and satellite(R), the inclination(i), the latitude of ascending node(Ω), the angle between ascending node and satellite on the orbital plane(u). All parameters are functions of a line number as they vary with time.

The orientation is carried out on the geocentric coordinates system where the earth is expressed a reference ellipsoid. The image coordinates system is selected so that x-axis is along track and z-axis along the normal of satellite orbit. Under such a condition, The colinearity condition is expressed as Fig. 1.

The parameters (R, i, Ω, u) at any time (t) can be expressed by Keplerian's theory using the epoch time(t_o) and the following six kinds of orbital elements [semi-major axis(a), inclination(i), eccentricity (e), right ascension of the ascending node(Ω), argument of perigee(w), mean anomaly(M)] which are announced by NOAA. By treating the satellite position estimated by the ephemeris data as initial values, the exterior orientation parameters can be determined with GCPs.

Consequently the parameters to be determined are the orbit elements (a, i, e, Ω, w, M) and the satellite attitude (ω, ϕ, κ)

2.2 Orientation Parameters to be Unknown

Two colinearity equations can be made from one GCP. The number of unknowns to be solved is limited in case of few GCPs. The order of priority which parameter should be an unknown is decided by the following conditions.

- (a). When some parameters have a big correlation, a representative among them is selected as the unknown and the others are fixed.
- (b). The parameters which vary greatly with time will be unknown in prior.

For evaluating the condition (a), the residual patterns on the image induced by a forced error were calculated by using colinearity equations. The correlation analysis was carried out between these residual patterns. The result (see Table 1) proved that there were high correlations between M_0 , w_0 and ϕ , M_1 and w_1 , Ω_0 and ω , respectively (the subscripts represent the order of polynomials). The residual caused by e_0 was excellent along the track far from the perigee or the apogee, and highly correlated with those by M_0 or M_1 .

And for the condition (b), the actual ephemeris data from NOAA were statistically analyzed for two different two weeks, supposing that the bigger variations of them had the more influences had on the residuals on the image. From this result (see Table 2), the degree of the influences on the direction of along-track (V_x) and cross-track (V_y) is

$$\begin{aligned} V_x &: w_0, M_0 > w_1, M_1 > e_0 \\ V_y &: \Omega_0 > i_0 > M_0 > e_0 \end{aligned}$$

The order of priority to be an unknown is decided as follows by the analyses mentioned above.

$$\begin{aligned} M, \Omega &> \kappa, e, i > a; \\ w, \omega, \phi &\text{ are fixed.} \end{aligned}$$

2.3 Parameters to be Determined with Few GCPs

The examinations were performed using simulation data and LAC (Local Area Coverage) data in order to decide which parameter should be determined with few GCPs. Two kinds of LAC data were examined, one was Southeast Asia region as the low latitude area, the other was the neighborhood of Japan as the mid-latitude area. In case of simulation data, both ground and image coordinates of GCPs had no errors and the inclinations of satellite attitude were zero. This case showed the theoretical adaptability of this system. In case of LAC data, there were probably some errors of coordinates and some inclinations of attitude. This case showed the practical adaptability. The selection of examination case, or the selection of parameters to be unknowns, was carried out with respect to the result mentioned in section 2.2. The estimation was made by the residuals of check points.

Table 3 shows the result. In case of simulation data, the higher the order of polynomial is, the higher the accuracy is. Otherwise, in case of LAC data, the accuracy does not increase or becomes worse in spite of making the order higher. This seems to result from the error of coordinates of GCPs. The order of priority of parameters to be unknowns in section 2.2 are reasonable except semi-

major axis (a). This seems to result from the correlation between parameters, because (a) is not so correlated with the others.

From the examination, the parameters to be unknowns are decided with respect to the number of GCPs as shown in Table 4. The eccentricity (e_0) is adopted only over the area scanned near from the perigee or the apogee.

2.4 Automated GCP acquisition

The acquisition of GCPs by human interaction is very time consuming. For the fast process, GCPs are automatically acquired by image matching between an original image piece and a shoreline. The shoreline is prepared in advance and entitled as a candidate for GCP. The GCPs are not searched from the limb regions of an original image as they are very distorted,

The distribution of GCPs depends greatly on the accuracy of geometric correction. It is most desirable that GCPs are distributed widely and homogeneously on the whole image. With respect to this problem, the whole image without limb regions is divided into some rectangles as shown in Fig. 2. Only one GCP is acquired from every rectangle if it contains candidate shorelines and is not cloudy.

3. RESAMPLING

3.1 General Overview

The transformation from output image coordinates (x, y) to original image coordinates (u, v) is generally difficult to be determined analytically, so the iteration method is adopted, which results in a long process time. To accelerate the resampling process, two methods have been reported. One is called here 'four points interpolation', the other is 'scan function method'. It is hereafter analysed which method is more suitable for the resampling of AVHRR imagery.

The analysis is performed for latitude/longitude grid system, Mercator's projection and polar stereo projection which are widely utilized by AVHRR users. The nearest neighbor interpolation is used.

3.2 Four Points Interpolation

The process of this method is as follows. Firstly, an output image is divided into some rectangles. Then the coordinate transformation of only four corner points are calculated by the iteration. The coordinate of any point in the rectangle is interpolated from four points. The interpolation function is generally used pseudo Affin's transformation or bi-linear transformation.

The size of rectangle depends greatly on the accuracy and process time. The relationship between the rectangle size and the interpolation error is analyzed for latitude/longitude grid system and polar stereo projection (Mercator's

projection can be treated as same as latitude/longitude grid system). The interpolation error is checked at a center of the rectangle. The error of less than 0.5 pixel is judged to be adaptable.

Table 5 shows the result. In the case of latitude/longitude grid system, the area of a rectangle should be constant all over the regions and the aspect ratio be almost linear. Otherwise, in the case of polar stereo projection, the aspect ratio should be constant and the area be variable with respect to the latitude.

3.3 Scan Function Method

In this method, some mesh lines are drawn on the output image coordinates. Firstly, the attention is paid to one horizontal line among them. The original image coordinates (u,v) corresponding to output image coordinates (x,y) on the grid points along the line can be expressed by the polynomials of (x) as follows;

$$u = P_0 + P_1x + P_2x^2 + P_3x^3 + \dots$$

$$v = Q_0 + Q_1x + Q_2x^2 + Q_3x^3 + \dots$$

All horizontal lines are expressed in the same manner. Then every coefficients (Pi, Qi) are expressed by the polynomials of (y). The transformation of (x,y) to (u,v) of any point can be calculated by these polynomials.

The number of mesh lines and the orders of polynomials have the great effect on the accuracy and process time. After some examination, it was found out that the number of lines should be selected about 0.5 degree interval in both latitude and longitude. The relationship between the orders of polynomials and the interpolation error is analyzed for

latitude/longitude grid system in the same manner as four points interpolation. The analysis on the polar stereo projection has not been made because this method is less suitable than the four points interpolation as mentioned in section 3.4.

The analysis proved that the orders of polynomials should be higher in proportional to the area of mapped region in the low and middle latitude. Otherwise, in the higher latitude, the division of the mapped region is more effective than the higher ordered polynomials.

3.4 Process Time

Both methods are compared each other about process time. A full scene image and a sub scene image are resampled by each method into the latitude/longitude grid system on SUN SPARK STATION 379GXP. Table 6 shows the process time of these resampling. In both image sizes, the four points interpolation took less time than the scan function method.

4. CONCLUSION

The characteristics of the algorithm introduced here are as follows;

- (a) The system can correct the orbital elements and the attitude of the satellite by using colinearity condition in photogrammetry.
- (b) The system has become adaptable to the case of few GCPs.
- (c) GCPs are acquired automatically by image matching.
- (d) Resampling procedure is carried out by the four points interpolation. The suitable parameters of this method are determined, which leads to fast and accurate process.

Table 5 Number of GCPs vs. the Unknowns to be Corrected

No. of GCPs	Unknowns to be Corrected
1	Mo, Ωo
2	Mo, Ωo, M1 or Ω1,
3	Mo, M1, Ωo, Ωo, io or ao
4	Mo, M1, Ωo, ao, κo, κ1
5	Mo, M1, Ωo, Ω1, io, (eo), ao, κo, κ1
6 -	Mo, M1, M2, Ωo, Ω1, io, (eo), ao, κo, κ1

Table 6 Process Time of Resampling (Latitude/Longitude Grid System)

Difference Lat. Long.	Output image size	Method	Process Time (sec.)	CPU Time (sec.)	Remarks
50' 40'	2500L x 2000P	4 points scan func.	460. 655.	98. 113.	3,525 areas all 4th polynomials
10' 10'	500L x 500P	4 points scan func.	46.3 54.8	11.5 12.1	200 areas all 2nd polynomials

$$G_x = -x - f \frac{w_{11}(X-X_0(L))+w_{12}(Y-Y_0(L))+w_{13}(Z-Z_0(L))}{w_{31}(X-X_0(L))+w_{32}(Y-Y_0(L))+w_{33}(Z-Z_0(L))} = 0$$

$$G_y = -y - f \frac{w_{21}(X-X_0(L))+w_{22}(Y-Y_0(L))+w_{23}(Z-Z_0(L))}{w_{31}(X-X_0(L))+w_{32}(Y-Y_0(L))+w_{33}(Z-Z_0(L))} = 0$$

f : assumed focal length

(X, Y, Z) : ground coordinates of object

(X₀, Y₀, Z₀) : ground coordinates of satellite

(x, y) : image coordinates ; for (L line, P pixel) ;

$$x = 0, \quad y = f \cdot \tan \theta$$

$$\theta = (P - 2049/2) \cdot \Delta \theta \quad \Delta \theta : \text{step angle}$$

(w_{ij}) : rotation matrix

$$W = K_X(\omega) K_Y(\phi) K_Z(\kappa) K_Y(u^*) K_X(i^*) K_Z(\Omega^*) = \begin{bmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{31} & w_{32} & w_{33} \end{bmatrix}$$

$$\begin{bmatrix} X_0(L) \\ Y_0(L) \\ Z_0(L) \end{bmatrix} = K_Z(-\Omega^*) K_X(-i^*) K_Y(-u^*) \begin{bmatrix} 0 \\ 0 \\ R \end{bmatrix}$$

$$= \begin{bmatrix} (\cos \Omega \cos u - \sin \Omega \cos i \sin u) R \\ (\sin \Omega \cos u + \cos \Omega \cos i \sin u) R \\ \sin i \sin u R \end{bmatrix}$$

K_M(N) : rotation matrix of angle N around M axis

$$u^* = u - 90^\circ, \quad i^* = 90^\circ - i, \quad \Omega^* = \Omega - 180^\circ$$

$$K_X(N) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos N & \sin N \\ 0 & -\sin N & \cos N \end{bmatrix}, \quad K_Y(N) = \begin{bmatrix} \cos N & -\sin N & 0 \\ 0 & 1 & 0 \\ \sin N & 0 & \cos N \end{bmatrix}, \quad K_Z(N) = \begin{bmatrix} \cos N & \sin N & 0 \\ -\sin N & \cos N & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

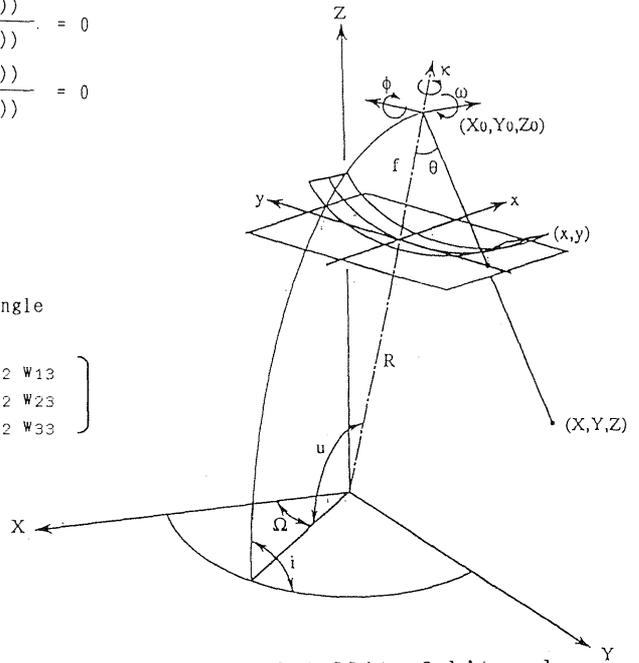


Fig. 1 Satellite Orbit and Colinearity Condition

Table 1 Correlation Coefficients Table between Parameters

	e ₀	i ₀	a ₀	w ₀	Ω ₀	M ₀	w ₁	Ω ₁	M ₁	κ	φ	ω
e ₀	1.00000											
i ₀	-.00002	1.00000										
a ₀	.27768	.00095	1.00000									
w ₀	.80284	-.00017	-.00001	1.00000								
Ω ₀	-.13923	.23960	.00033	-.17351	1.00000							
M ₀	.80326	-.00017	-.00001	.99999	-.17351	1.00000						
w ₁	.41464	-.00007	-.00001	.84608	-.14686	.84561	1.00000					
Ω ₁	-.06784	-.18759	.00004	-.13849	.89783	-.13842	-.16373	1.00000				
M ₁	.41500	-.00007	.00025	.84624	-.14688	.84577	.99999	-.16373	1.00000			
κ	.00073	-.14591	.00125	.00073	.01826	.00073	.00085	-.00963	.00085	1.00000		
φ	-.80239	.00020	-.00055	-.99951	.17340	-.99951	-.84545	.13838	-.84561	-.00100	1.00000	
ω	-.00039	.33536	-.00123	-.00000	.91650	-.00000	-.00001	.78644	-.00001	-.00000	.00000	1.00000

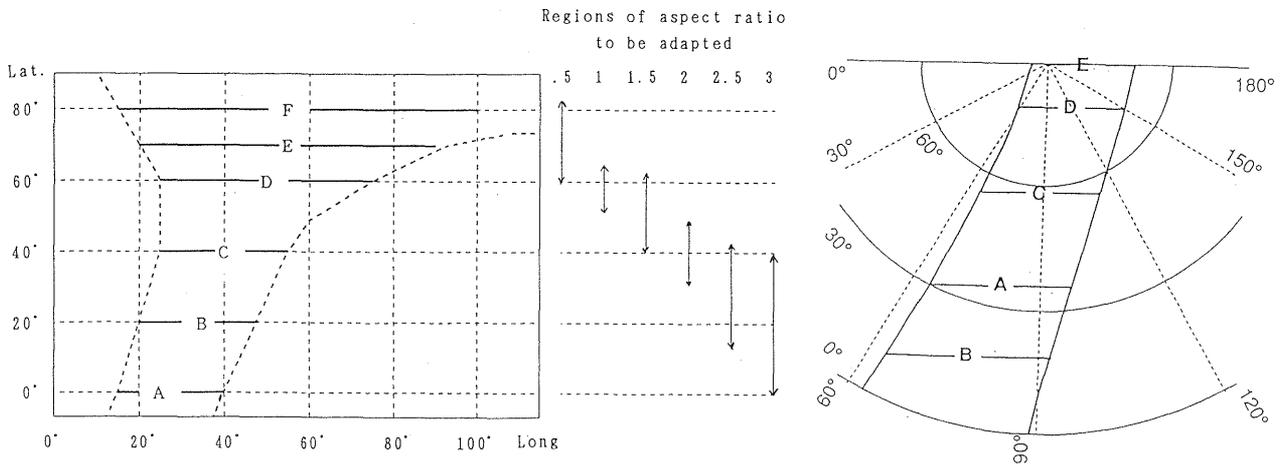
Table 2 Variations of Orbital Elements and their effects on Residuals

Para-meter	Unit	around meanage		Linear Regression		Residual on Image(Unit:Pixel)		
		S.D.	max	S.D.	max	(input)	Vx	Vy
e ₀		.1282E-4	.2108E-4	.4408E-5	.8443E-5	.2108E-4	.1909	.0358
i ₀	deg	.001050	.001975	.3968E-3	.7658E-3	.001975	.0130	.0901
a ₀	km	.04155	.06948	.003340	.006968	.06948	.0000	.0329
w ₀	deg			.23323	.39446	.39446	39.0314	.0711
Ω ₀	deg			.01261	.01296	.01296	.2065	1.0222
M ₀	deg			.23319	.39511	.39511	39.0385	.0974
w ₁	deg/d	.07357	.17612			.17612	9.9516	.0046
Ω ₁	deg/d	.1257E-3	.1815E-3			.1815E-3	.0016	.0082
M ₁	deg/d	.06407	.12026			.12026	6.7857	.0067

Table 3 Number of Unknown Parameters vs. Maximum Residuals

Number of GCPs	Number of Unknown						Simulation		Southeast Asia		Japan	
	M	Ω	i	e	a	κ	Vx	Vy	Vx	Vy	Vx	Vy
0	System Correction						4.752	1.7671	10.812	2.6040	15.052	4.5027
1	1	1	0	0	0	0	.1409	.0434	2.3636	1.6245	.5818	1.8651
2	2	1	0	0	0	0	.1048	.0447	1.1374	1.7982	.5795	1.4662
	1	2	0	0	0	0	.1493	.0782	1.4257	1.5242	.5742	.9849
3	2	2	1	0	0	0	.0208	.0777	1.0302	1.3547	.4413	1.0011
	2	2	0	0	0	1	.0086	.0249	1.0310	1.3602	.4373	.9985
	2	1	1	0	0	1	.0106	.0229	1.0274	1.3618	.4125	.9830
	2	1	0	0	1	1	.0103	.0464	1.0368	1.0606	.4137	1.2137
4	2	1	0	1	0	1	.0066	.0480	.9417	1.2764	.4090	1.1475
	2	2	1	1	0	1	.0006	.0019	1.1631	.4582	.5782	.5186
	2	2	0	1	1	1	.0049	.0156	1.9291	1.9207	.3185	.6650
	2	2	1	0	1	1	.0047	.0151	1.2860	.6707	.5726	.5315
	2	1	1	1	1	1	.0003	.0007	1.9302	1.9242	.3196	.6767
5	2	1	1	0	1	2	.0215	.0170	.9210	.9237	.3149	.4849
	2	1	1	1	0	2	.0025	.0017	.9602	1.1636	.3146	.5824
	2	2	1	1	1	1	.0003	.0012	.8176	.6756	.5028	.3472
	2	2	1	1	1	2	.0002	.0012	.4583	.4561	.3342	.3336
	3	2	1	2	0	1	.0001	.0002	1.0211	.6640	.5915	.3874
6	3	2	1	0	1	2	.0005	.0186	.6189	.3917	.2967	.7553
	3	2	1	1	0	2	.0003	.0014	.5151	.3118	.2968	.8354
	3	2	1	1	1	1	.0003	.0012	1.0396	.4562	.5438	.2367
	3	2	1	1	1	1	.0002	.0009	.9108	.7756	.6512	.3429
7	2	2	1	1	1	2	.0002	.0008	.4589	.4549	.3919	.3553
	3	2	1	1	1	2	.0002	.0008	.4522	.4032	.3255	.2773
	3	2	1	0	1	2	.0005	.0190	.6178	.3935	.3302	.7561
	3	2	1	1	1	2	.0002	.0011	.4398	.3837	.8260	.3897
7	3	2	1	1	1	1	.0003	.0011	* * *	* * *	* * *	* * *
	3	2	1	0	1	2	.0601	.0152	.6813	.5499	.4232	.2950
	3	2	1	1	1	2	.0002	.0011	.5031	.3605	.3431	.2283
	3	2	1	2	1	2	.0001	.0001	.6745	.4934	.5946	.3941

(* * * : not calculated or very big residual (Unit : Pixel)



Latitude/Longitude Grid System

Polar Stereo Projection

(see Table 4)

Table 4 Residuals of Center by 4 Points Interpolation
(1) Latitude/Longitude Grid System

section	differences				residuals (unit:pixel)			
					pixel		line	
	lat.	long.	aspect	area	S.D.	max	S.D.	max
A	1.19'	0.47'	2.53	.56	.3451	.5152	.0138	.0317
	1.3'	0.43'	3.0	.56	.3260	.4849	.0163	.0384
	1.4'	0.4'	3.45	.56	.3167	.4707	.0215	.0454
	1.51'	0.37'	4.1	.56	.3192	.4518	.0237	.0497
	1.6'	0.35'	4.57	.56	.3214	.4617	.0263	.0573
B	1.1'	0.5'	2.2	.55	.3453	.5149	.0127	.0319
	1.19'	0.47'	2.53	.56	.3286	.4976	.0136	.0330
	1.3'	0.43'	3.0	.56	.3169	.4752	.0146	.0347
	1.4'	0.4'	3.45	.56	.3151	.4700	.0166	.0383
	1.51'	0.37'	4.1	.56	.3149	.4743	.0210	.0517
C	0.93'	0.6'	1.55	.56	.3182	.4848	.0325	.0497
	1.1'	0.5'	2.2	.55	.2795	.4469	.0217	.0426
	1.19'	0.47'	2.53	.56	.2851	.4547	.0212	.0423
	1.3'	0.43'	3.0	.56	.2871	.4615	.0211	.0423
	1.4'	0.4'	3.45	.56	.2943	.4851	.0239	.0480
D	0.6'	0.93'	0.65	.56	.2776	.4582	.0690	.0901
	0.75'	0.75'	1.0	.56	.2493	.4260	.0429	.0613
	0.93'	0.6'	1.55	.56	.2588	.4612	.0255	.0451
	1.1'	0.5'	2.2	.55	.2978	.5455	.0216	.0397
E	0.6'	0.93'	0.65	.56	.2372	.4128	.0451	.0662
	0.75'	0.75'	1.0	.56	.2803	.5329	.0290	.0479
F	0.6'	0.93'	0.65	.56	.1005	.2159	.0261	.0386
	0.75'	0.75'	1.0	.56	.1514	.3290	.0201	.0325
	0.93'	0.6'	1.55	.56	.2278	.5256	.0186	.0337

(2) Polarstereo Projection

sevtion	size of small rectangles				residuals (unit:pixel)			
					pixel		line	
	ver.*	hor.*	apsect	area	S.D.	max	S.D.	max
A	10.	5.	2.0	50.	.3328	.4963	.0645	.0846
	11.	4.55	2.4	50.	.3149	.4806	.0915	.1118
	12.5	4.	3.1	50.	.3107	.4775	.1289	.1557
	13.2	3.8	3.5	50.	.3160	.4833	.1454	.1760
	13.3	4.5	3.0	60.	.3749	.5676	.1437	.1733
B	12.2	4.9	2.5	60.	.2821	.4389	.0956	.1005
	13.3	4.5	3.0	60.	.2857	.4485	.1204	.1216
	14.6	4.1	3.6	60.	.3035	.4808	.1516	.1570
C	12.5	4.	3.1	50.	.3258	.5434	.1100	.1521
	13.2	3.8	3.5	50.	.3196	.5288	.1252	.1720
	11.	3.65	3.0	40.	.2658	.4290	.0830	.1169
	11.8	3.4	3.5	40.	.2542	.4320	.0991	.1385
	5.	5.	1.0	25.	.3197	.4861	.0034	.0097
D	11.	3.65	3.0	40.	.2588	.4333	.0387	.0653
	11.8	3.4	3.5	40.	.2379	.4195	.0451	.0780
	5.	5.	1.0	25.	.3682	.5498	.0027	.0082
	4.5	4.5	1.0	20.	.2999	.4481	.0027	.0079
E	11.	3.65	3.0	40.	.2350	.4192	.0132	.0346
	11.8	3.4	3.5	40.	.2183	.4019	.0171	.0415
	4.5	4.5	1.0	20.	.2958	.4510	.0022	.0069

*) The lengths of vertical & horizontal lines are measured in per mill of the radius.