IAGA News, Dec. 1980, Vol. 19

SCALING K-INDICES WITHOUT SUBJECTIVITY

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A new approach to scaling the K-indices of magnetic activity through the Method of Natural Orthogonal Components (MNOC) is outlined. This procedure, which completely eliminates subjectivity in determining the quiet day variation should prove useful in standardizing the K-scaling at all magnetic observatories. A Fortran IV computer programme is available on request from the authors.

1. Introduction

The 3-hourly K-indices of magnetic activity scaled from individual station's magnetograms have consistently proved to be useful in several geophysical and allied investigations. A comprehensive description on the measurement of K-index and guidelines for the observer in scaling the same from magnetograms have been given by Mayaud (Atlas of K-Indices, IAGA Bulletin No.21, 1967). The main hurdle in achieving perfection in K-scaling is the estimation of the quiet day variation relative to which the disturbance range is to be measured. According to Mayaud, "the precision with which the identification of the daily variation needs to be made (a precision upon which, in turn, the precision itself of K-indices exclusively depends) varies inversely as the intensity of the activity". K-indices are scaled visually using the subjective element of a trained observer. However careful and consistent he may be, it is not certain whether another independent observer using equal care would duplicate his work (Jocelyn, J.A., J. Geophys. Res., 75, 2777, 1975). Attempts have been made in recent times to eliminate the subjectivity in K-scaling and to use digital computers for speedy computations (Van Wijk and Nagtegall, 1977 and references therein). Here and in the method suggested earlier by Alldredge (J. Geophys. Res., 65, 3777, 1960) the need for an automatic digitizer for scaling the magnetograms at close intervals (5 min, 2.5 min or 1 min) becomes essential. Also, the choice of quiet days is somewhat arbitrary. In this communication we propose a computerized method for the scaling of K-indices that entirely eliminates the subjectivity and which does not require and expensive digitizer to be available at the magnetic observatory.

The method of natural orthogonal components (MNOC), detailed by Kendall and Stuart (Advanced Theory of Statistics, Vol.3, Charles Griffin Co., London,) has been successfully used recently to separate the geomagnetic field variations into quiet and disturbed components (Golovkov et al, Geomag. Aeron., 18, 342, 1978). According to them this method is the most successful formulization of the procedure for identifying the solar daily variation at any station. The mathematical steps involved to generate, from the mean hourly values of the magnetic elements, the matrix whose largest eigen vector provides the Sq pattern, are described by Golovkov et al. (1978) and Rajaram (submitted to Ann. Geophys., 1980).

2. The Method

The procedure proposed to scale K-indices may be outlined as follows:

1. Generate a table of hourly ordinates (in cms) for all days of the month for the elements H and D this is needed for routine processing and publication of magnetic data in any case).

2. From the month's magnetograms, list all the days which have an identifiable quiet day pattern, not severely contaminated by disturbance effects.
3. Use the subset of hourly values for these days in a MNOC analysis to identify the largest eigen-vector and the corresponding mean diurnal variation on quiet days.
4. From harmonic analysis of the mean diurnal pattern on quiet days, compute the first six harmonic coefficients and use these to synthesize the value at each minute.
5. Scale, for each 3-hr UT interval (0-3, 3-6, ... 21-24), the time of maximum, the time of minimum and the range of disturbance on each day. The timings should be scaled correct to the nearest minute. In case of loss of record, the timings and ranges corresponding to those 3-hour intervals should be declared as zeros.
6. Modify the ranges of disturbance by a factor which gives the corresponding change in the synthesized average Sq between the times of extremity (see Mayaud 1967 Fig.3).
7. Convert the range from cm to nT using the scale value appropriate for the magnetogram and identify the corresponding K-index from the classes of range specified for the station, chcsing the larger of the two ranges for H and D.

3. Merits and Demerits

The chief advantage of the proposed method is the fact that even when the list of quiet days chosen for MNOC is altered slightly (omission or addition of a few ambiguous cases) the mean diurnal pattern derived does not change significantly (Golovkov et al., 1978; Rajaram, 1980). It may also be remembered that the K-index reflects a class of amplitudes included between a lower and an upper limit (Mayaud, 1967). As such, small changes in the amplitude of Sq ($\leq$ 2 nT) due to different choice of the quiet days of the month do not unduly alter the scaled K-indices. As mentioned earlier, we do not require any automatic digitizer for finer scaling of the magnetograms. The entire computer programme can be appended as a subroutine to regular data processing. As the mean variation of quiet days appropriate for the period is derived from the data for the same month for which K-indices are scaled, the seasonal and solar cycle variabilities are completely eliminated and day-to-day variability is minimized. As the scaling of the times of maximum, minimum and the range for each 3-hour interval can be done precisely, subjectivity is completely eliminated.

The only drawback of this method is that when a day is magnetically quiet but is abnormal (Brown and Williams, Planet. Space Sci., 17, 445,1969) or is characterized by a large amplitude differing significantly from the mean Sq, the corresponding K-indices will be over-estimated. This is likely to effect one or two intervals only. Also, it is of interest to note that according to Mizzi and Schlapp (Planet. Space Sci., 19, 273, 1971) the abnormal quiet days cannot be classified as belonging to regular SR variation as defined by Mayaud (1967) and therefore, the K-indices for these intervals may represent a genuine irregular variation. In any case,, a mere examination of the magnetograms and the corresponding ΣK values for the day will bring out the discrepancy which, therefore, can be corrected.

A FORTRAN IV programme compatible with CDC-3600 computer with all the steps and details incorporated is shown on the following pages.

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C                 PROGRAM WRITTEN IN FORTRAN IV FOR CDC 3600 COMPUTER

      PROGRAM SCALE

C   G.K. RANGARAJAN AND A.V.S. MURTY

C     COMPUTERIZED K-SCALING FROM MAGNETOGRAMS
      DIMENSION IDEN(5Ø),ORD(31,24),R(31,24),A(25,25),X(25),FC(31,25),
     1DIF(3Ø),AMP(1Ø),PHY(1Ø),SYNTH(2ØØØ),SYS(8,2ØØ),MAX(1Ø),MIN(1Ø),
     2RAN(1Ø),CAL(3Ø),KKK(1Ø),ALOW(1Ø),IA(1Ø),KK(1Ø)
      COMMON/2/AMP,PHY,AZERO
      DATA(ALOW=-1.Ø,3.Ø,6.Ø,12.Ø,24.Ø,4Ø.Ø,7Ø.Ø,12Ø.Ø,2ØØ.Ø,3ØØ.Ø)
C    DATA PROVIDES THE LOWER LIMITS FOR THE K SCALE FOR THE STATION
      IA(1)=1HO & IA(2)=1H1 & IA(3)=1H2 & IA(4)=1H3 & IA(5)=1H4
      IA(6)=1H5 & IA(7)=1H6 & IA(8)=1H7 & IA(9)=1H8 & IA(1Ø)=1H-
      READ 1,NSTN,NMNT,NDAYS,NYR
    1 FORMAT(A4,A3,I2,I4)
C    STATION NAME, MONTH, NO. OF DAYS, YEAR
      READ 2,(IDEN(I),I=1,NDAYS)
    2 FORMAT(35I1)
C     IDEN(I) DETERMINES DAYS TO BE INCLUDED (Ø) OR
C     EXCLUDED (1) FROM RECKONING
      READ 3,((ORD(I,J),J=1,24),I=1,NDAYS)
    3 FORMAT(11X,13F4.2,/,11X,11F4.2)
C    ORD IS THE MEAN HOURLY ORDINATES(IN CM)
      BASE=38ØØØ.Ø
C    BASE IS THE TABULAR BASE USED IN FINAL TABLES OF HOURLY VALUES
      ILAST=5Ø
C    ILAST IS THE MAXIMUM NO. OF ITERATIONS SPECIFIED FOR SUBROUTINE LARVEC
      INC=Ø
      DO 5 I=1,NDAYS
      IF(IDEN(I).EQ.1)GO TO 5
      INC=INC+1
      DO 6 J=1,24
    6 R(INC,J)=ORD(I,J)+BASE
    5 CONTINUE
      ND=INC
      DO 33 I=1,24
      DO 33 K=1,I
      SUM=Ø.Ø
      DO 44 J=1,ND
   44 SUM=SUM+R(J,I)*R(J,K)
      A(I,K)=SUM
   33 A(K,I)=SUM
      CALL LARVEC(A,ILAST,X,24)
      SQ=Ø.Ø
      DO 751 I=1,24
  751 SQ=SQ+X(I)**2
      NC=Ø
      DO 752 IMP=1,ND
      NC=NC+1
      SUM=Ø.Ø
      DO 1Ø J=1,24
   1Ø SUM=SUM+X(J)*R(IMP,J)
      C1=SUM/SQ
      DO 15 J=1,24
      FC(NC,J)=C1*X(J)
   15 CONTINUE
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 750 CONTINUE
     DO 901 J=1,24
     SUM=Ø.Ø
     DO 902 I=1,NC
 902 SUM=SUM+FC(I,J)
 901 DIF(J)=(SUM/NC)-BASE
     PRINT 875
 875 FORMAT(1,2ØX,*MEAN DIURNAL VARIATION (ORD. IN CM) BASED ON MNOC*,
    1/)
     PRINT 775,INC,(DIF(J),J=1,24)
 775 FORMAT (I4,12F1Ø.2,/,4X,12F1Ø.2)
C    INC IS THE TOTAL NUMBER OF DAYS UTILIZED IN MNOC
     CALL BNALY(DIF,24,6)
     RAD=3.141592/18Ø.Ø
     THEETA=Ø.25*RAD
     DO 99 I=1,144Ø
     II=I-1
     SUM=Ø.Ø
     DO 98 J=1,6
  98 SUM=AMP(J)*SIN(II*J*THEETA+PHY(J))+SUM
     IM=I+3Ø
     IF(IM.GT.144Ø)IM=IM-144Ø
  99 SYNTH(IM)=SUM+AZERO
     NO=Ø
     NE=Ø
     DO 5Ø1 I=1,24
     NB=NE+1
     NE=NB+59
     SUM=Ø.Ø
     DO 5Ø2 J=NB,NE
     NO=NO+1
 5Ø2 SUM=SUM+SYNTH(NO)
 5Ø1 CAL(I)=SUM/6Ø.Ø
     PRINT 975
 975 FORMAT(/,2ØX,*MEAN DIURNAL VARIATION COMPUTED FROM HARMONIC COMPON
    1ENTS*,/)
     PRINT 555,(CAL(I),I=1,24)
 555 FORMAT(  /,(12F9.1))
     NNC=Ø
     DO 1Ø1 I=1,8
     DO 1Ø1 J=1,18Ø
     NNC=NNC+1
 1Ø1 SYS(I,J)=SYNTH(NNC)
     SV=16.8

     PRINT 94,NSTN,NMNT,NYR
  94 FORMAT(/,2ØX,*COMPUTED K-INDEX AND RANGE FOR THE STN*,2X,A4,2X,
    1*MONTH*,2X,A4,2X,*YEAR*,I6,/)
     DO 2ØØ I=1,NDAYS
     READ 2Ø1,(MAX(J),MIN(J),RAN(J),J=1,8)
 2Ø1 FORMAT(8(2I3,F3.2))
C    MAX AND MIN ARE THE TIMES OF MAX,MIN. OF OSCILLATIONS
C    GIVEN IN MINUTES FROM BEG.OF THE 3-HR
C    UT-UNTERVAL AND RANGE IS THE
C    DIFFERENCE BETWEEN LARGEST AND LEAST DEPARTURES.
C  IF THERE IS LOSS OF RECORD FOR ANY 3-HOUR INTERVAL
C  MAX AND MIN SHOULD BOTH BE DECLARED AS ZERO
     DO 2Ø3 J=1,8
     KKK(J)=9
     MM=MAX(J)
     NN=MIN(J)
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      IF(MM.EQ.0.AND.NN.EQ.0)KKK(J)=11
      IF(MM.EQ.0.AND.NN.EQ.0)RAN(J)=0.0
      IF(MM.EQ.0.AND.NN.EQ.0)KK(J)=1H-
      IF(KKK(J).EQ.11)GO TO 205
      IF(MM.EQ.0)MM=MM+1
      IF(NN.EQ.0)NN=NN+1
      X=SYS(J,MM)-SYS(J,NN)
      RAN(J)=RAN(J)-X
      RAN(J)=ABS(RAN(J)*SV)
      DO 202 JM=1,9
      IF(RAN(J).GT.ALOW(JM).AND.RAN(J).LE.ALOW(JM+1))KKK(J)=JM-1
      IF(RAN(J).GT.ALOW(JM).AND.RAN(J).LE.ALOW(JM+1))KK(J)=IA(JM)
202   CONTINUE
205   CONTINUE
      NCH=0
      KSX=0
      DO 927 J=1,8
      IF(MAX(J).EQ.0.AND.MIN(J).EQ.0)NCH=1
927   KSX=KSX+KKK(J)
      KKK(9)=KSX
      IF(NCH.EQ.1)KK(9)=1H-
      LM=(I/5)*5+1
      IF(LM.EQ.I)PRINT 293
      IF(NCH.EQ.1)PRINT 225,I,(KK(J),J=1,9),(RAN(J),J=1,8)
225   FORMAT(I6,2X,4(3X,A1),2X,4(3X,A1),2X, 3X,A1 ,20X,8F6.0)
      IF(NCH.EQ.1)GO TO 200
      PRINT 210,I,(KKK(J),J=1,9),(RAN(J),J=1,8)
210   FORMAT(I6,2X,4I4,2X,4I4,2X,I4,20X,8F6.0)
293   FORMAT(/)
200   CONTINUE
      END

      SUBROUTINE BNALY(H,NDATA,NN)
      DIMENSION H(10),SUMA(10),SUMB(10),ABAR(10),BBAR(10),AMP(10),
     1PHY(10),TMIN(10),TMAX(10),VAR(10)
      COMMON/2/AMP,PHY,AZERO
      PIE=3.1415926
      DATA=NDATA
      ANGLE=2.0*PIE/DATA
      AZERO=0.0
      DO 2 I=1,NDATA
    2 AZERO=AZERO+H(I)
      AZERO=AZERO/DATA
      DO 76 J=1,NN
      SUMA(J)=0
      SUMB(J)=0
      FJ=J
      DO 20 I=1,NDATA
      FI=I=1
      SUMA(J)=SUMA(J)+H(I)*COSF(FJ*FI*ANGLE)
   20 SUMB(J)=SUMB(J)+H(I)*SINF(FJ*FI*ANGLE)
      ABAR(J)=SUMA(J)*2.0/DATA
      BBAR(J)=2.0*SUMB(J)/DATA
      AMP(J)=SQRTF(ABAR(J)**2-BBAR(J)**2)
      CALL ANGFIX(ABAR(J),BBAR(J),HHY)
      PHY(J)=HHY
   76 CONTINUE
      END
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      SUBROUTINE ANGFIX(A,B,ANG)
      X=ABS(A/B)
      ANG=ATAN(X)
      PIE=3.1415926
      IF(A.EQ.Ø.Ø)ANG=Ø.Ø
      IF(B.EQ.Ø.Ø)ANG=PIE/2.Ø
      IF(A.GT.Ø.Ø.AND.B.LT.Ø.Ø)ANG=PIE-ANG
      IF(A.LT.Ø.Ø.AND.B.LT.Ø.Ø)ANG=PIE+ANG
      IF(A.LT.Ø.Ø.AND.B.GT.Ø.Ø)ANG=2.Ø*PIE-ANG
      END

      SUBROUTINE LARVEC(A,LAST,X,N)
C     LARGEST EIGEN VALUE BY ITERATION
C     FROM MCCORMICK AND SALVADORI NUMERICAL METHODS IN FORTRAN
C     PRENTICE HALL OF NEW DELHI  1968  PAGE 55
      DIMENSION PREY(1ØØ)
      DIMENSION A(25,25),X(25),Y(25)
      ITERA=1
      X(1)=1.Ø
      DO 1Ø 1=2,N
   1Ø X(I)=Ø.Ø
   15 DO 2Ø I=1,N
      Y(I)=Ø.Ø
      DO 2Ø J=1,N
   2Ø Y(I)=Y(I)+A(I,J)*X(J)
      DO 3Ø I=2,N
   3Ø X(I)=Y(I)/Y(1)
      PREY(ITERA)=Y(1)
      IF(ITERA.EQ.1)GO TO 635
      DIF=ABS(PREY(ITERA)-PREY(ITERA-1))
      IF(DIF.LE.1Ø.Ø)GO TO 875
  635 CONTINUE
      ITERA=ITERA+1
      IF(ITERA.LE.LAST)GO TO 15
  875 CONTINUE
      PRINT 9ØØ
  9ØØ FORMAT(/,3ØX,*LARGEST EIGEN VECTOR FROM THE DATA*,/)
      PRINT 999,((I,X(I),I=1,N))
  999 FORMAT(/,6(I3,E17.7))
      END
```

Appendix I

The deck of cards that go with the programme should be punched and stacked in the following order:

1. A leading card which gives station code in 4 Alfa-numeric characters (ALIB for example) month (OCT) No. of days in the month (31) and year (1980) punched from Col. 1; ALIBMAR311980, as a sample.

2. 30 or 31 single digit values punched from Col. 1 with '0' for days which has identifiable quiet day pattern and '1' for other days.

3. 24 hourly ordinates of H or D scaled from magnetograms used in routine data processing for each day of the month in a format suitable to the user.

4. For each day, 8 values of time of maximum, time of minimum and range (in cm) corresponding to each 3-hour UT interval. The times are to be given in minutes beginning from the corresponding 3-hr interval i.e. if the time of maximum is 0451 UT the punched value should be 111 (1 hr 51 mts after beginning of 2nd interval). One card for each day should carry the times in 3 digits and range correct to two decimal places in 3 digits (no decimal is punched). In scaling the times of maximum and minimum and the range, care should be taken to include only largest and least departures of oscillations superposed on smooth variations. The format specification is 8(13, 13, F3.2).

5. After statement Number 101, the parameter 'SV' should correspond to the scale coefficient of the magnetogram in nano Teslas/cm. This is incorporated in the programme deck once for all.

6. The 'DATA' declaration card in the beginning of the programme should correspond to the lower limits for the K-scale for the station with 0 for the first one replaced by -1 for facility of comaprison in the program.

Appendix II

The K-indices derived from this programme compares favourably with the manually scaled values and are correct to within 1 unit most of the time. While the values for the local afternoon and night intervals tally almost always, the two intervals, including the ascent to the maximum near local noon and decline show a discrepancy of one unit on some occasions.

Our attention has recently been drawn to the new monograph (Geophysical Monograph 22, American Geophysical Union) on "Derivation meaning and use of geomagnetic indices" by Prof. P.N. Mayaud who suggests that any 'iron-curve' to identify the S_R variation is misleading and that K-scalings do not need computers for being objective.

The present method suggested may, therefore, be considered more useful where an experienced observer is not available and as an alternate method to manual scaling where the need arises.