

Technical Report

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**Error Growth Estimates for Operational Forecasts Produced  
by the Canadian Meteorological Centre Numerical Weather  
Prediction Model**

by

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## Objectives

The objective of this project is to calculate error growth and predictability estimates for the operational numerical weather prediction model used by the Canadian Meteorological Centre (CMC) and to compare the results with similar estimates for the global prediction model used at the European Centre for Medium-Range Weather Forecasts (ECMWF).

## Background

This project is part of the ensemble Kalman filter (EnKF) project that aims at providing an ensemble of four-dimensional analyses for the operational Ensemble Prediction System (EPS) at CMC. For the EnKF, it is important to have a better understanding of the activity of the Global Environmental Multi-Scale (GEM) model used at CMC. The improved understanding of error dynamics that will result from the completion of the project is expected to have an impact on future development projects for the GEM forecast model (in particular for the diffusive processes in the forecasting system and for the numerical precision of the calculations) and on the design of the EPS (in particular for the simulation of the model error component).

## Methodology

Due to the chaotic nature of the dynamics regulating the evolution of atmospheric fields, a small error in the initial conditions of a realistic model, or a misrepresentation of some atmospheric phenomena (an imperfect model), can lead after a few days to numerical solutions with little resemblance to the instantaneous state of the real atmosphere. In order to help quantify the level of predictability of the atmosphere for some given length scale range, the model error dynamics must be studied. In particular, one can take advantage of the routinely archived analyses and prognoses to perform error growth rate studies and to learn more about atmospheric predictability.

The error growth rate of an atmospheric model can be visualized with the help of what is called a “Lorenz diagram” (Lorenz 1982). These diagrams sketch a measure of the space average discrepancy between two fields as a function of the forecasting range (say, in days) averaged over a given period of time (say, a month). The main curve of a Lorenz diagram is a measure of the forecast skill of the model (say,  $E_{0k}$ ) as a function of the forecast time  $k$ . More specifically,

$$E_{0k}^2 = S^{-1} N^{-1} \sum_{i=1}^N \int_S (\Phi_{pki}(\lambda, \varphi) - \Phi_{ai}(\lambda, \varphi))^2 dS$$

where  $S$  is some area of the globe,  $N$  is the number of days of the analyzed period,  $\lambda$  is longitude,  $\varphi$  is latitude,  $\Phi_{pki}$  is the  $k$ -day prognosis valid for date  $i$ , and  $\Phi_{ai}$  is the analysis valid for date  $i$ .

The subsequent curves of a Lorenz diagram constitute branches to the main curve. These branches are measures of error growths as a function of the forecasting time. For example, one can plot the mean difference between the one-day forecasts and the two-day forecasts (valid for the same dates), the mean difference between the two-day forecasts and the three-day forecasts (valid for the same dates), the mean difference between the  $k$  day forecasts and the  $(k+1)$ -day forecasts (valid for the same dates). This is the first branch of the Lorenz diagram.

More generally, the  $j$ th branch of a Lorenz diagram is a plot (as a function of  $k+j$ ) of the mean difference  $E_{jk}$  between the  $k$ -day forecasts and the  $(k+j)$ -day forecasts (valid for the same dates). The  $x$ -axis of the  $j$ th branch extends from  $j$  to  $D$  days. In mathematical terms,

$$E_{jk}^2 = S^{-1} N^{-1} \sum_{i=1}^N \int_S (\Phi_{pki} - \Phi_{pji})^2 dS$$

The reader is referred to Lorenz (1982) for the original presentation of the Lorenz diagrams. Their interpretation within the framework of the GEM model will be discussed later in this report. Similar analyses applied to the ECMWF forecast system were made in Lorenz (1990) and in Simmons *et al.* (1995).

## Data

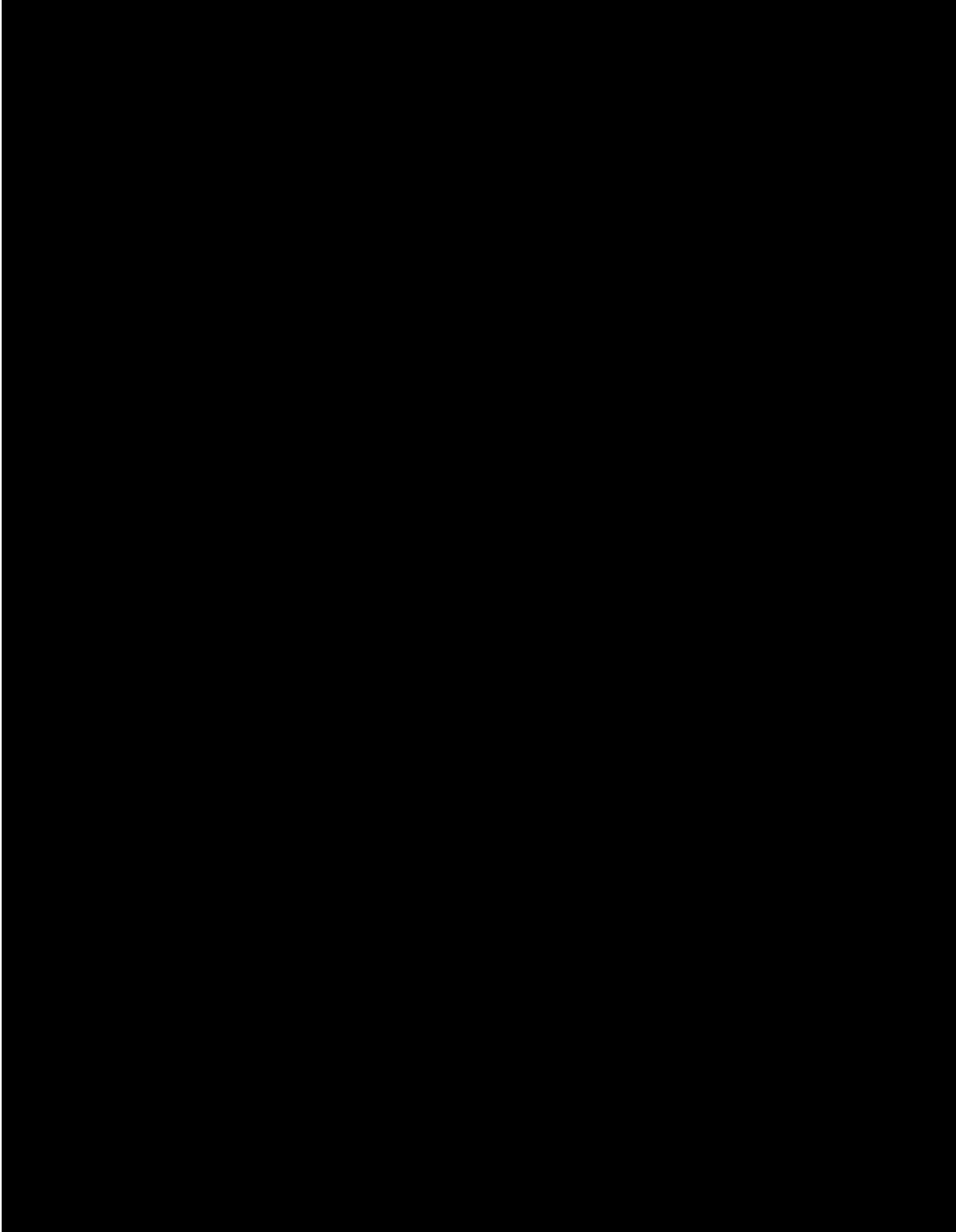
The months that have been analyzed separately in the context of the present study are January, April, July, and October of the year 2002. For forecast periods ranging from 0 to 10 days and valid for each day of the abovementioned months at 0000 UTC, the geopotential at 500 hPa produced by the global GEM model has been extracted from the archive. Note that the zero day forecasts are the analyses that served as initial conditions for the GEM model.

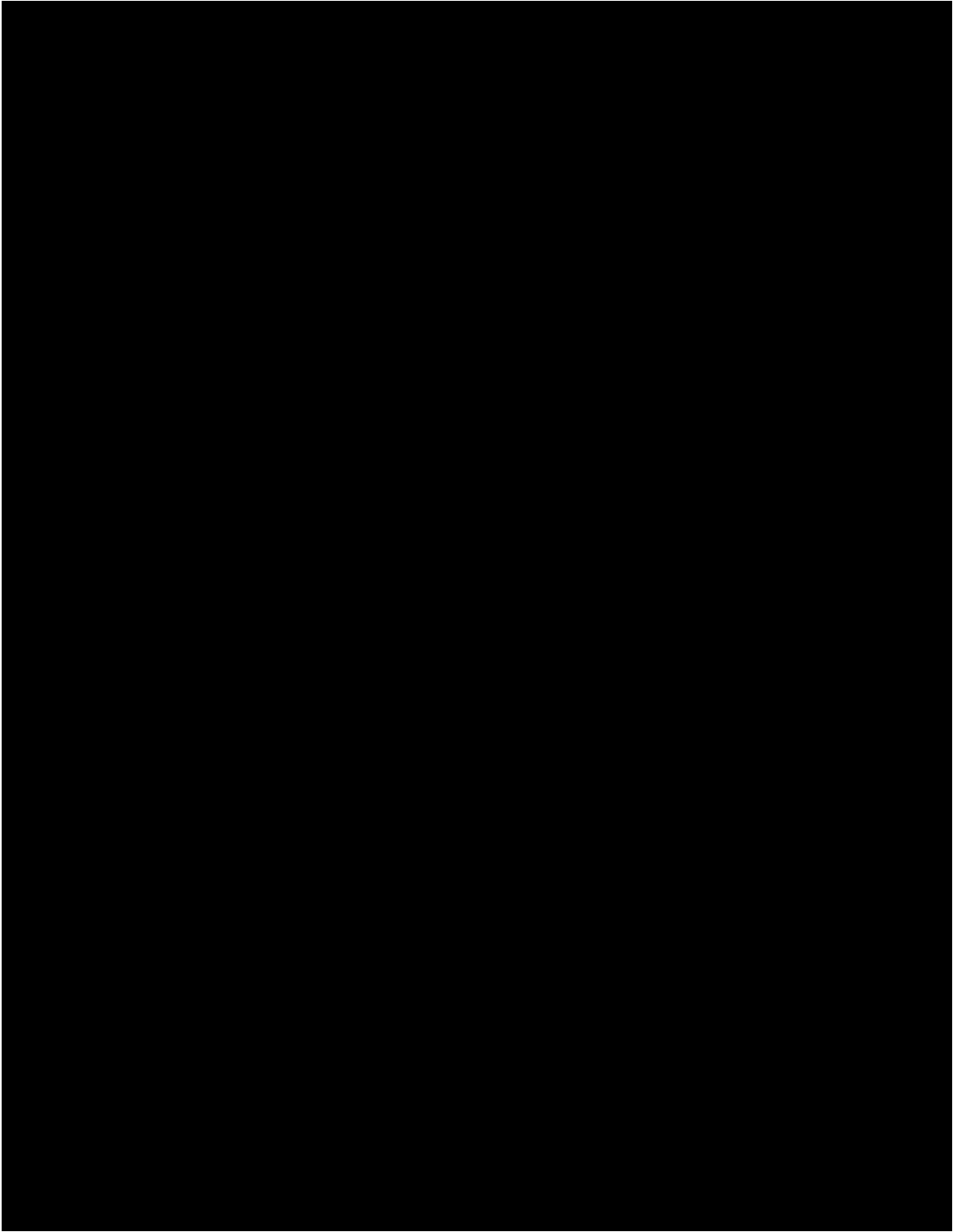
The reader is referred to Appendix A for an example of the listing of commands executed to extract the relevant data.

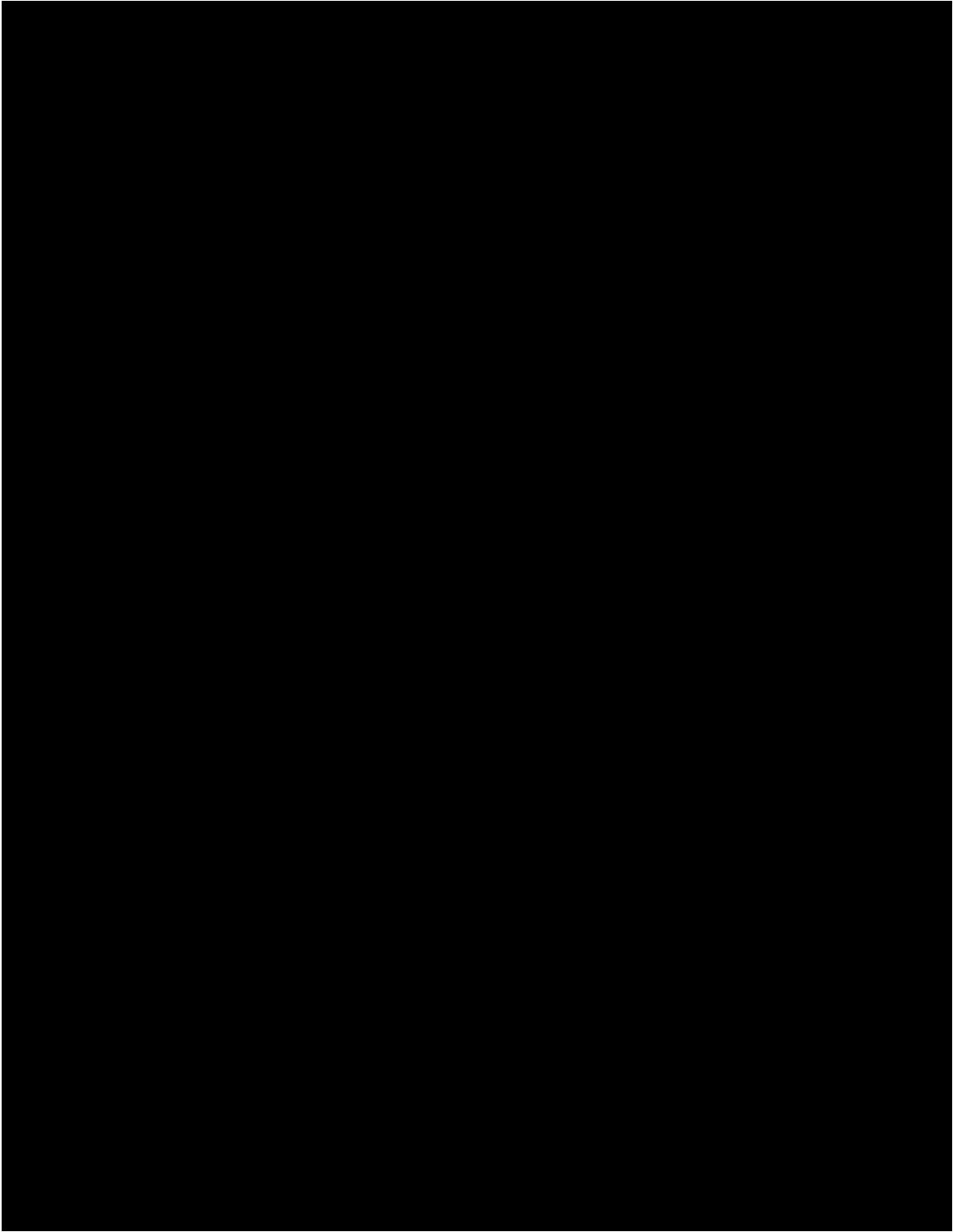
The Lorenz diagrams were built with the full resolution of 400x200 grid points (referred to as T199), as well as with a reduced resolution equivalent to a triangular truncation T40. This smoothing of the data was performed in order to compare directly with Lorenz (1982) in which a dataset with resolution T40 was used. Moreover, the diagrams for three different areas  $S$  over the globe were drawn: the global surface (referred to as Global), the area north of 30N (referred to as NH), and the area south of 30S (referred to as SH).

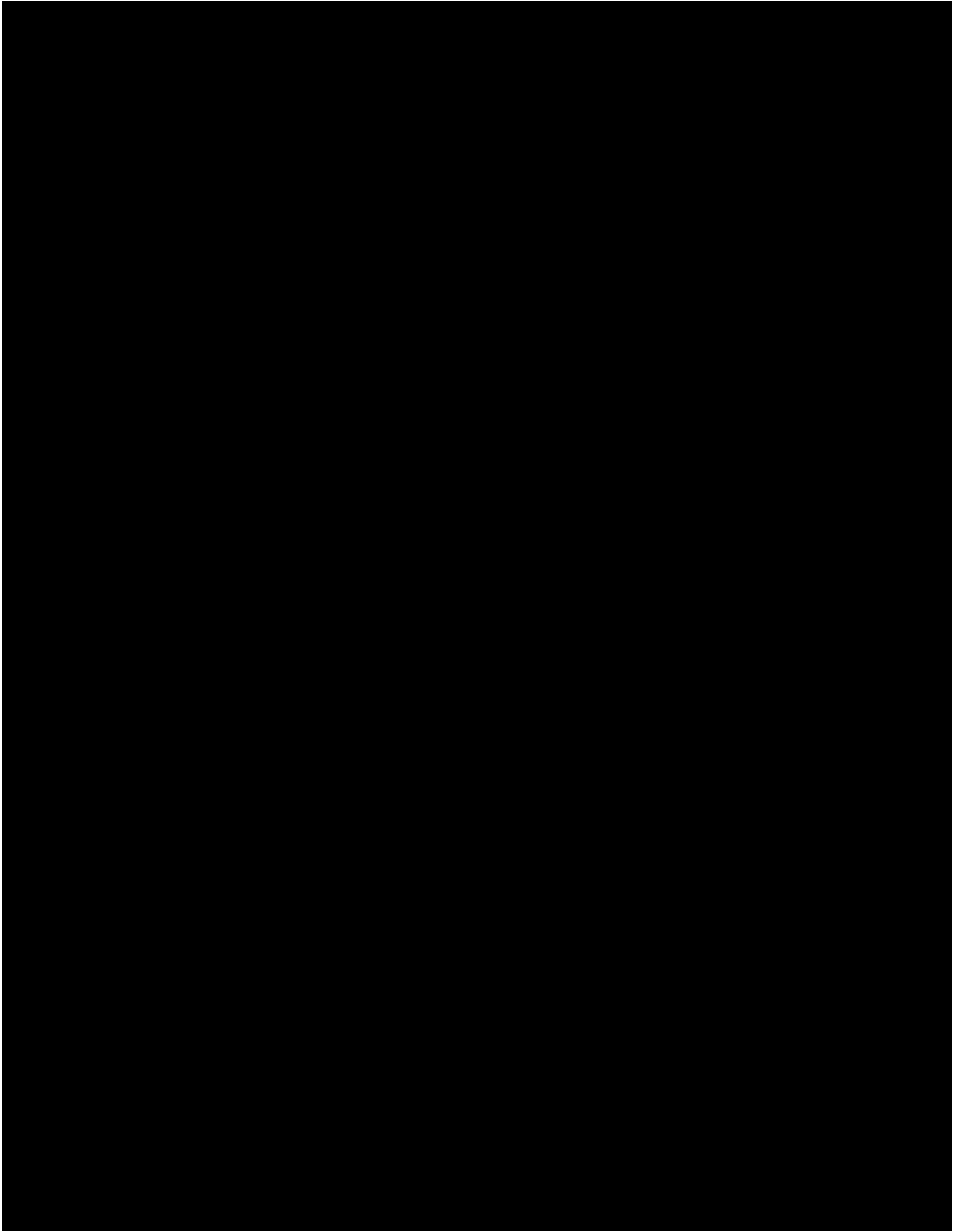
## Results

The following figures are the Lorenz diagrams for the 500 hPa geopotential in January (Jan), April (Apr), July (Jul), and October (Oct) for 2002 at resolution T40 and T199. Extratropical northern and southern hemispheres, and global data are shown.



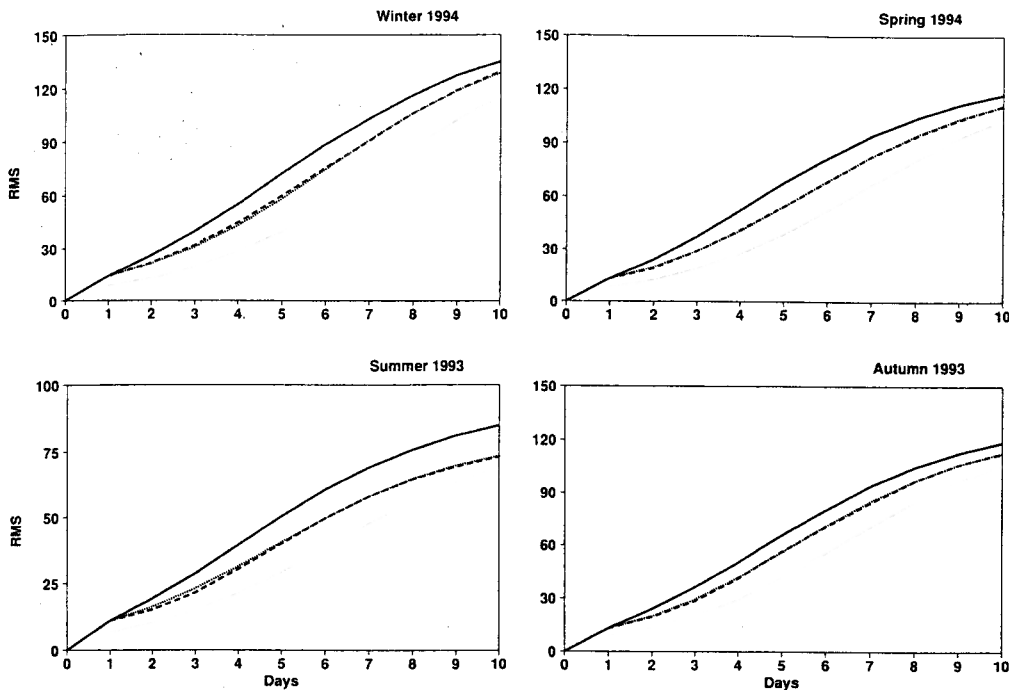






## Discussion

In a Lorenz diagram, the error growth rate of the internal dynamics plus the model error caused by the model's deficiencies is described by the main branch (which is a general measure of model performance). The GEM model can be directly compared with the ECMWF model of 1993-1994. Simmons *et al.* (1995) performed the same type of analyses for the northern hemisphere extratropical region for the ECMWF model of 1993-1994. It turns out that the one-day forecast skill of the 500 hPa geopotential of the ECMWF model of 1993-1994 is very close to the forecast skill of the GEM model of 2002. The following figure is adapted from Figure 4 of Simmons *et al.* (1995).



It shows the main branch, as well as the lowest branch, of the ECMWF model of 1993-1994 for the four seasons in the northern hemisphere extratropics. Winter stands for the period covering December to February, Spring for the period covering March to May, Summer for the period covering June to August, and Autumn for the period covering September to November. The 500 hPa geopotential 10-day forecast skill of the ECMWF model of 1993-1994 is slightly better than the one of the GEM model of 2002 in spring and fall, but equivalent in winter and summer. To give an estimate, the extratropical northern hemisphere fall r.m.s. error of the ECMWF model for the 500 hPa geopotential is about 120 meters (as compared with 135 meters for the GEM model).

A first estimate of the doubling time of small errors in the case of a perfect model can be made as follows. In a Lorenz diagram, the connection of the lowest branch with the main branch is a mean measure of the difference between a one-day forecast and an analysis valid for the day of the forecast. If this difference is considered relatively small, then the analysis and the one-day forecast (valid for the same day) can be considered as two different, but similar, initial conditions. By following how these two different initial



conditions diverge as the integrations go by, one is in fact following the lowest branch of a Lorenz diagram. For the GEM model in January for the global case, the connection of the first branch with the main branch is at about 12 meters (day one). Following the lowest branch, one finds that an error of 24 meters arises at around day three, giving a **doubling time of two days**. In fact, a doubling time of small errors of nearly two days (or even a bit less in April) seems to occur in all the cases presented in the previous section.

From the previous figure, the doubling time of small errors in the ECMWF model of 1993-1994 can be estimated, with the present method, to be very close to two days.

This way of calculating small error doubling time does not exactly reveal the doubling time of very small errors. A second estimate of the doubling time of very small errors, due to Lorenz (1982), is to model the evolution with time of the lowest branch as a simple nonlinear process:

$$\frac{dE}{dt} = aE(1 - E/E_\infty) ,$$

with a solution:

$$E(t) = \frac{E(t_1)E_\infty}{E(t_1) + [E_\infty - E(t_1)]e^{-a(t-t_1)}}$$

Such a solution will reach a steady state at  $E = E_\infty$ . One can note that the time it takes for  $E/(E_\infty - E)$  to double is independent of time (in fact,  $E/(E_\infty - E)$  increases exponentially with time). For small  $E/E_\infty$ ,

$$\frac{E}{E_\infty - E} \approx \frac{E}{E_\infty} ,$$

and the time it takes for small  $E/E_\infty$  to double is approximately the same as the time it takes for finite amplitude  $E/(E_\infty - E)$  to double. For example, the time it takes for finite amplitude  $E/E_\infty$  to go from 1/3 to 2/3 (equivalently,  $E/(E_\infty - E)$  goes from 1/2 to 2) is approximately twice the doubling time of small errors. When applied to the Lorenz diagrams of the previous section, it means that the time it takes for  $E_{ij}$  to go from 1/3 to 2/3 of the saturated  $E_{ij}$  (very large forecast time) is twice the doubling time of small errors. From the figures of the previous section, one can make a **second estimate for doubling time of small errors of about 1.5-2.0 days** for the GEM model.

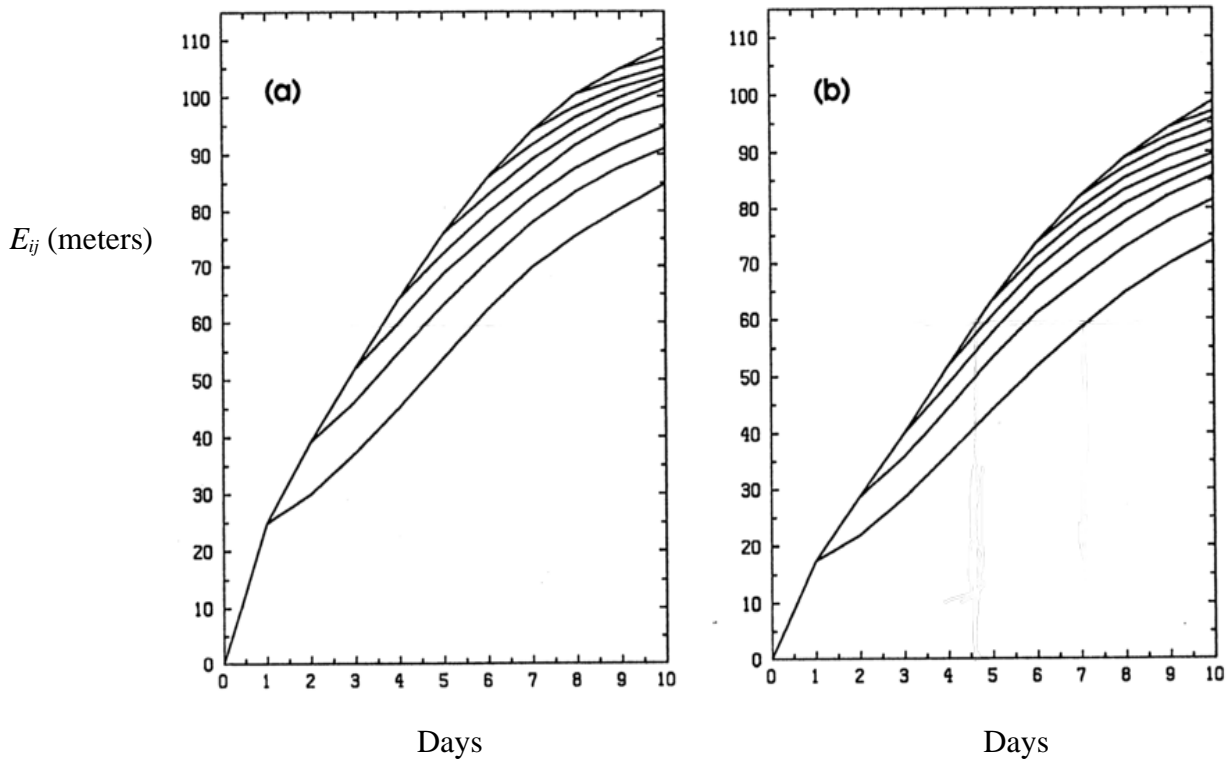
Another way of estimating the doubling time of small errors is to perform a least square fit of  $E(t)$ , provided by the Lorenz model, for a chosen  $E_\infty$ . One can thus estimate  $a$  from

$$\ln\left(\frac{E(t)}{E_\infty - E(t)}\right) = \ln\left(\frac{E(t_1)}{E_\infty - E(t_1)}\right) + a(t - t_1)$$

with the doubling time of small errors given by  $\tau = (\ln 2)/a$ . The following table gives the doubling time of small errors calculated from the least square fit. The first number is the doubling time in days and the number in parenthesis is the chosen  $E_\infty$  in meters.

	January	April	July	October
Global	2.0 (120)	1.7 (110)	1.7 (100)	1.6 (110)
NH	1.7 (160)	1.7 (160)	1.7 (100)	1.6 (150)
SH	2.1 (160)	1.8 (160)	1.8 (180)	1.5 (160)

These estimates for the 2002 GEM model are smaller than those made by Lorenz (1982). He quoted the doubling time of small errors to be 2.5-3.5 days (ECMWF model of 1980 and 1986). The next figure shows Lorenz diagrams for the ECMWF model of 1980 (a) and 1986 (b) in winter for the global case.



Simmons *et al.* (1995) also evaluated the doubling time of small errors from the Lorenz simple nonlinear model. Their Table 2 shows that the doubling time is between 1.5 and 2 days in the ECMWF model of 1993-1994.

In Lorenz (1982), it is argued that the distance between the main branch and the lowest branch of a Lorenz diagram is a measure of the possible room for improvement of a model. Indeed, if a model is unbiased and has the same daily variability as the atmosphere, it would follow the lowest branch if it were suddenly perfect after one day of

integration. So, improving a model should bring the main branch closer to the lowest branch. The previous picture shows that things are more complicated. In six years, the ECMWF model main branch went down, but the lowest branch went down as well, leaving as much room for improvement. Lorenz (1990) argues that a better analysis will bring all the branches closer to zero.

For the case of the GEM model, it appears that the room for improvement is slightly smaller than what is reported in Lorenz (1990), but equivalent to what is reported in Simmons *et al.* (1995).

## Summary of main results

- The one day 500 hPa geopotential forecast skill of the 2002 GEM model is similar to the forecast skill of the 1993-1994 ECMWF model.
- The ten day 500 hPa geopotential forecast skill of the 2002 GEM model is slightly inferior to the forecast skill of the 1993-1994 ECMWF model for spring and fall, but equivalent for winter and summer.
- In the GEM model in the northern hemisphere, the initial 500 hPa geopotential mean error growth rate due to internal dynamics and model deficiencies ranges from 10 meters per day (in July) to 18 meters per day (in January).
- A first estimate of the doubling time of small errors in a “perfect” GEM model is about 2 days (the small error being the difference between a one-day forecast and an analysis valid for the same day). This is very similar to what is observed in the 1993-1994 ECMWF model.
- A second estimate of the doubling time for small errors in a “perfect” GEM model based on a simple nonlinear modelisation of the error growth (Lorenz, 1982) is 1.5-2 days. This is also very similar to what is observed in the 1993-1994 ECMWF model.

## References

- Lorenz, E., 1982: Atmospheric predictability experiments with a large numerical model. *Tellus*, **34**, 505-513.
- Lorenz, E., 1990: Effects of analysis and model errors on routine weather forecasts, in Vol. 1 of the *Proceedings of 1989 ECMWF Seminar on ‘Ten Years of Medium-Range Weather Forecasting’*, pp. 115-128.
- Simmons, A. J., R. Mureau, and T. Petroliaqis, 1995: Error growth and estimates of predictability from the ECMWF forecasting system. *Quart. J. Roy. Meteor. Soc.*, **121**, 1739-1772.

## Appendix A: rarc commands to extract the data from the archive

In order to demonstrate which data were extracted from the archive (the branch), the code that has been used is presented here (example for January). `get_data.txt` reads as follows.

```
#!/bin/sh

set -x

progdir=/users/dor/armn/028/data1/extrac_prog

cat << EOT > ${progdir}/dirrarc
target=$BIG_TMPDIR
filter = copy
branche=operation.forecasts.glbpres
ext=000,024,048,072,096,120,144,168,192,216,240
date=2002,1,1,2002,1,31
heure=0
postprocess=nopost
priority = online
inc=1
EOT

rarc -i ${progdir}/dirrarc

rm ${progdir}/dirrarc
```

Then, the geopotential at 500 hPa is extracted with `get_gz.txt` (example for January). Since the data are archived with rotated poles, `get_gz.txt` also rotates back the poles to their original position.

```
#!/bin/ksh

for month in 01
do

for day in 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 26 27 28 29 30 31
do

for forecast in 000 024 048 072 096 120 144 168 192 216 240
do

editfst2000 -s 2002${month}${day}00_${forecast} -d 2002${month}${day}
00_gz500r_${forecast} << DTS
desire(-1,"GZ",-1,-1,500,${forecast})
desire(-1,[">>","^^"])
DTS

/usr/local/env/armnlib/modeles/diag/bin/r.diag_5.0.1 llagg 2002${month}
${day}00_gz500r_${forecast} /
tmp/armn028/101012965/operation.forecasts.glbpres/2002${month}${day}
00_gz500_${forecast} -lon 400 -lat 200 -npg =-32

done
```

done

done

These codes, as well as other codes not shown here that served to prepare the data before the final analysis, are available at /users/dor/armn/028/3043.

## Appendix B: Fortran 77 code generating the data suitable for producing the Lorenz diagrams

The following Fortran 77 code performs the analysis and writes the results in a format suitable for plotting with GrADS. It reads the data from IEEE unformatted files.

```
PROGRAM analyse
IMPLICIT NONE

INTEGER      i, j, day
INTEGER      maxlag, maxday
INTEGER      month, lat, lon
CHARACTER*2  reg

C
C maxlag : longest forecast in days
C maxday : number of days in the analyzed month + maxlag
C month  : month number (from 1 to 12)
C lat    : number of latitudes
C lon    : number of longitudes
C reg    : GL for Global, NH for North. Hemis., SH for South. Hemis.
C
PARAMETER(maxlag = 10      )
PARAMETER(maxday = 31+maxlag)
PARAMETER(month   = 10     )
PARAMETER(lat     = 200    )
PARAMETER(lon     = 400    )
PARAMETER(reg     = 'SH'   )

C
C cmonth   : month number (character)
C cforecast : forecast length in hours from 000 (the analysis)
C           to 24*maxlag (the 'maxlag' day forecast)
C cday     : day of the month + maxlag
C
CHARACTER*3 cforecast(0:maxlag)
CHARACTER*2 cmonth(12)
CHARACTER*2 cday(maxday)
DATA cmonth /'01','02','03','04','05','06'
&           , '07','08','09','10','11','12'/
DATA cforecast /'000','024','048','072','096','120'
&           , '144','168','192','216','240'/
REAL dist2, tau, gz1(lon, lat), gz2(lon, lat)
REAL dist2_moy(0:maxlag, 0:maxlag), res(maxlag+1, maxlag)
CHARACTER*2 cdum
CHARACTER*18 cfile1, cfile2
INTEGER dum, ii, jj

DO day=1, maxday
  dum=day
  DO i=2, 1, -1
```

```

        cdum(i:i)=ACHAR(MOD(dum,10**(3-i))/10**(2-i)+48)
        dum=day-MOD(dum,10**(3-i))
    ENDDO
    cday(day)=cdum
ENDDO

DO i=0,maxlag
    DO j=0,maxlag
        dist2_moy(i,j)=0.
    ENDDO
ENDDO

DO i=0,maxlag-1
    DO j=i+1,maxlag
        DO day=maxlag+1,maxday
            cfile1=cmonth(month)//'_'//cday(day-i)//'_GZ500_'
&                //cforecast(i)//'.GR'
            cfile2=cmonth(month)//'_'//cday(day-j)//'_GZ500_'
&                //cforecast(j)//'.GR'
            OPEN(10,FILE=cfile1,FORM='UNFORMATTED')
            OPEN(11,FILE=cfile2,FORM='UNFORMATTED')
            READ(10) ((gz1(ii,jj),ii=1,lon),jj=1,lat)
            READ(11) ((gz2(ii,jj),ii=1,lon),jj=1,lat)
            dist2_moy(i,j)=dist2_moy(i,j)+dist2(gz1,gz2,lon,lat,reg)
&                /REAL(maxday-maxlag)
            CLOSE(10)
            CLOSE(11)
        ENDDO
    ENDDO
ENDDO

DO i=1,maxlag+1
    DO j=1,maxlag
        res(i,j)=0.
    ENDDO
ENDDO

DO i=1,maxlag+1
    res(i,1)=SQRT(dist2_moy(0,i-1))*10.
ENDDO
DO j=2,maxlag
    DO i=j,maxlag+1
        res(i,j)=SQRT(dist2_moy(i-j,i-1))*10.
    ENDDO
    DO i=1,j-1
        res(i,j)=res(i,1)
    ENDDO
ENDDO

OPEN(12,FILE='october_'//reg//'_T199',FORM='UNFORMATTED')
DO i=1,maxlag
    WRITE(12) (res(j,i),j=1,maxlag+1)
ENDDO
CLOSE(12)

WRITE(*,17) tau(res,maxlag)
17  FORMAT('Doubling time for small errors: ',F5.2,' days')

END PROGRAM analyse

```

C-----

```
FUNCTION dist2(a,b,ni,nj,reg)
IMPLICIT NONE

INTEGER ni,nj,i,j,n1,n2
REAL a(ni,nj),b(ni,nj),dist2
REAL pi,dphi(nj),phi(nj),phi1,phi2,phib(200)
CHARACTER*2 reg
DATA phib/ -89.313,-88.423,-87.527,-86.630,-85.733,-84.836
&          ,-83.938,-83.041,-82.143,-81.246,-80.348,-79.450
&          ,-78.553,-77.655,-76.757,-75.860,-74.962,-74.064
&          ,-73.166,-72.269,-71.371,-70.473,-69.576,-68.678
&          ,-67.780,-66.882,-65.985,-65.087,-64.189,-63.291
&          ,-62.394,-61.496,-60.598,-59.700,-58.803,-57.905
&          ,-57.007,-56.109,-55.212,-54.314,-53.416,-52.518
&          ,-51.621,-50.723,-49.825,-48.927,-48.030,-47.132
&          ,-46.234,-45.336,-44.439,-43.541,-42.643,-41.745
&          ,-40.848,-39.950,-39.052,-38.154,-37.257,-36.359
&          ,-35.461,-34.563,-33.666,-32.768,-31.870,-30.972
&          ,-30.075,-29.177,-28.279,-27.381,-26.484,-25.586
&          ,-24.688,-23.790,-22.893,-21.995,-21.097,-20.199
&          ,-19.302,-18.404,-17.506,-16.608,-15.711,-14.813
&          ,-13.915,-13.017,-12.120,-11.222,-10.324, -9.426
&          ,-8.529, -7.631, -6.733, -5.835, -4.938, -4.040
&          ,-3.142, -2.244, -1.347, -0.449,  0.449,  1.347
&          ,  2.244,  3.142,  4.040,  4.938,  5.835,  6.733
&          ,  7.631,  8.529,  9.426, 10.324, 11.222, 12.120
&          , 13.017, 13.915, 14.813, 15.711, 16.608, 17.506
&          , 18.404, 19.302, 20.199, 21.097, 21.995, 22.893
&          , 23.790, 24.688, 25.586, 26.484, 27.381, 28.279
&          , 29.177, 30.075, 30.972, 31.870, 32.768, 33.666
&          , 34.563, 35.461, 36.359, 37.257, 38.154, 39.052
&          , 39.950, 40.848, 41.745, 42.643, 43.541, 44.439
&          , 45.336, 46.234, 47.132, 48.030, 48.927, 49.825
&          , 50.723, 51.621, 52.518, 53.416, 54.314, 55.212
&          , 56.109, 57.007, 57.905, 58.803, 59.700, 60.598
&          , 61.496, 62.394, 63.291, 64.189, 65.087, 65.985
&          , 66.882, 67.780, 68.678, 69.576, 70.473, 71.371
&          , 72.269, 73.166, 74.064, 74.962, 75.860, 76.757
&          , 77.655, 78.553, 79.450, 80.348, 81.246, 82.143
&          , 83.041, 83.938, 84.836, 85.733, 86.630, 87.527
&          , 88.423, 89.313 /

pi=2.*ASIN(1.)

DO j=1,nj
  phi(j)=phib(j)*pi/180.
ENDDO

dphi(1)=0.5*pi+0.5*(phi(1)+phi(2))
DO j=2,nj-1
  dphi(j)=0.5*(phi(j+1)-phi(j-1))
ENDDO
dphi(nj)=0.5*pi-0.5*(phi(nj-1)+phi(nj))

IF (reg.EQ.'GL') THEN
  phi1=-pi/2.
  phi2= pi/2.
  n1=1
  n2=nj
```

```

ELSE IF (reg.EQ.'NH') THEN
  phi1= pi/6.
  phi2= pi/2.
  DO n1=nj,nj/2+1,-1
    IF (phi(n1).LT.phi1) GOTO 1
  ENDDO
1  n2=nj
ELSE IF (reg.EQ.'SH') THEN
  phi1=-pi/2.
  phi2=-pi/6.
  DO n2=1,nj/2-1
    IF (phi(n2).GT.phi2) GOTO 2
  ENDDO
2  n1=1
ENDIF

dist2=0.
DO i=1,ni
  DO j=n1,n2
    dist2=dist2+(a(i,j)-b(i,j))**2
&          *COS(phi(j))*dphi(j)/REAL(ni)
&          /(SIN(phi2)-SIN(phi1))
  ENDDO
ENDDO

END FUNCTION dist2

FUNCTION tau(res,maxlag)
IMPLICIT NONE

INTEGER maxlag
REAL res(maxlag+1,maxlag)
REAL xbar,x2bar,ybar,xybar,einf
REAL tau
INTEGER i

einf=180.

xbar=0.
ybar=0.
x2bar=0.
xybar=0.

DO i=1,maxlag
  xbar=xbar+REAL(i)/REAL(maxlag)
  x2bar=x2bar+REAL(i*i)/REAL(maxlag)
  ybar=ybar+LOG(res(i+1,2)/(einf-res(i+1,2)))/REAL(maxlag)
  xybar=xybar+REAL(i)*
&          LOG(res(i+1,2)/(einf-res(i+1,2)))/REAL(maxlag)
ENDDO

tau=LOG(2.)*(x2bar-xbar*xbar)/(xybar-xbar*ybar)

END FUNCTION tau

```

This code, as well as the code used to convert the extracted data from RPN Standard file format to IEEE format (fst2grads.f), are available at / users/dor/armn/028/3043.



## Appendix C: GrADS code producing the Lorenz diagrams

The plotting tool that has been used to generate the Lorenz diagrams is GrADS (freely available from the World Wide Web). The following example code is valid for the January panels.

```
enable print january
open january_GL_T40.ct1
open january_NH_T40.ct1
open january_SH_T40.ct1
open january_GL_T199.ct1
open january_NH_T199.ct1
open january_SH_T199.ct1
set grads off
set grid off
set parea 1.25 4. 8.0 10.5
set vrange 0 160
set xaxis 0 10 1
set ccolor 1
set cmark 1
set lev 0
d e.1
set ccolor 1
set cmark 1
set lev 1
d e.1
set ccolor 1
set cmark 1
set lev 2
d e.1
set ccolor 1
set cmark 1
set lev 3
d e.1
set ccolor 1
set cmark 1
set lev 4
d e.1
set ccolor 1
set cmark 1
set lev 5
d e.1
set ccolor 1
set cmark 1
set lev 6
d e.1
set ccolor 1
set cmark 1
set lev 7
d e.1
set ccolor 1
set cmark 1
set lev 8
d e.1
set ccolor 1
set cmark 1
set lev 9
```

```

d e.1
*draw xlab Days
draw ylab E`bij`n (meters)
draw title Jan. Global T40
set parea 1.25 4. 4.5 7.
set vrange 0 160
set xaxis 0 10 1
set ccolor 1
set cmark 1
set lev 0
d e.2
set ccolor 1
set cmark 1
set lev 1
d e.2
set ccolor 1
set cmark 1
set lev 2
d e.2
set ccolor 1
set cmark 1
set lev 3
d e.2
set ccolor 1
set cmark 1
set lev 4
d e.2
set ccolor 1
set cmark 1
set lev 5
d e.2
set ccolor 1
set cmark 1
set lev 6
d e.2
set ccolor 1
set cmark 1
set lev 7
d e.2
set ccolor 1
set cmark 1
set lev 8
d e.2
set ccolor 1
set cmark 1
set lev 9
d e.2
*draw xlab Days
draw ylab E`bij`n (meters)
draw title Jan. NH T40
set parea 1.25 4. 1.0 3.5
set vrange 0 160
set xaxis 0 10 1
set ccolor 1
set cmark 1
set lev 0
d e.3
set ccolor 1
set cmark 1
set lev 1
d e.3

```

```

set ccolor 1
set cmark 1
set lev 2
d e.3
set ccolor 1
set cmark 1
set lev 3
d e.3
set ccolor 1
set cmark 1
set lev 4
d e.3
set ccolor 1
set cmark 1
set lev 5
d e.3
set ccolor 1
set cmark 1
set lev 6
d e.3
set ccolor 1
set cmark 1
set lev 7
d e.3
set ccolor 1
set cmark 1
set lev 8
d e.3
set ccolor 1
set cmark 1
set lev 9
d e.3
draw xlab Days
draw ylab E`bij`n (meters)
draw title Jan. SH T40
set parea 5. 8. 8.0 10.5
set vrange 0 160
set xaxis 0 10 1
set ccolor 1
set cmark 1
set lev 0
d e.4
set ccolor 1
set cmark 1
set lev 1
d e.4
set ccolor 1
set cmark 1
set lev 2
d e.4
set ccolor 1
set cmark 1
set lev 3
d e.4
set ccolor 1
set cmark 1
set lev 4
d e.4
set ccolor 1
set cmark 1
set lev 5

```

```

d e.4
set ccolor 1
set cmark 1
set lev 6
d e.4
set ccolor 1
set cmark 1
set lev 7
d e.4
set ccolor 1
set cmark 1
set lev 8
d e.4
set ccolor 1
set cmark 1
set lev 9
d e.4
*draw xlab Days
*draw ylab E`bij`n (meters)
draw title Jan. Global T199
set parea 5. 8. 4.5 7.0
set vrange 0 160
set xaxis 0 10 1
set ccolor 1
set cmark 1
set lev 0
d e.5
set ccolor 1
set cmark 1
set lev 1
d e.5
set ccolor 1
set cmark 1
set lev 2
d e.5
set ccolor 1
set cmark 1
set lev 3
d e.5
set ccolor 1
set cmark 1
set lev 4
d e.5
set ccolor 1
set cmark 1
set lev 5
d e.5
set ccolor 1
set cmark 1
set lev 6
d e.5
set ccolor 1
set cmark 1
set lev 7
d e.5
set ccolor 1
set cmark 1
set lev 8
d e.5
set ccolor 1
set cmark 1

```

```

set lev 9
d e.5
*draw xlab Days
*draw ylab E`bij`n (meters)
draw title Jan. NH T199
set parea 5. 8. 1.0 3.5
set vrange 0 160
set xaxis 0 10 1
set ccolor 1
set cmark 1
set lev 0
d e.6
set ccolor 1
set cmark 1
set lev 1
d e.6
set ccolor 1
set cmark 1
set lev 2
d e.6
set ccolor 1
set cmark 1
set lev 3
d e.6
set ccolor 1
set cmark 1
set lev 4
d e.6
set ccolor 1
set cmark 1
set lev 5
d e.6
set ccolor 1
set cmark 1
set lev 6
d e.6
set ccolor 1
set cmark 1
set lev 7
d e.6
set ccolor 1
set cmark 1
set lev 8
d e.6
set ccolor 1
set cmark 1
set lev 9
d e.6
draw xlab Days
*draw ylab E`bij`n (meters)
draw title Jan. SH T199
print

```

This GrADS script, as well as the files with the extension “.ctl”, can be found at / users/dor/armn/028/3043.