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GLOBAL SURFACE TEMPERATURE TIME SERIES CHARACTERISTICS FOR THE EARTH, IN RELATION TO CO_2 PERTURBATIONS

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Összefoglalás – A tanulmány célja a globális felszínhőmérséklet idősor néhány statisztikai jellemzőjének tanulmányozása. A lineársi trendanalízis nem mutatott ki hosszú tartamú szignifikáns trendeket. Az esetleges rövid tartamú (legfeljebb hatelemű) trendek a legnagyobb gyakorisággal a D(QTH, QTM) globális felszínhőmérséklet differencia idősor középső harmadában fordulnak elő. A vizsgált idősorra alkalmazzuk a Makra-tesztet, mely a kétmintás próba egy új interpretációja. A próba alapkérdése: kimutatható-e szignifikáns különbség a vizsgált idősor egy tetszőleges részmintájának, illetve a teljes idősornak az átlagai között. A próba alkalmas arra, hogy szignifikáns töréseket mutassunk ki az idősorban, meghatározva annak erősségét, hosszát és tartamát, azaz kezdő és záró időpontját. A Makra-próba segítségével meghatároztuk a D(QTH, QTM) globális felszínhőmérséklet differencia idősor szignifikáns részperiódusait. Két szignifikáns részperiódust mutattunk ki: Pozitív törést 1861-1900 között, míg negatív törést 1881-1958 között tapasztaltunk. További célunk az volt, hogy tanulmányozzuk a megnövekedett CO_2 szint hatását a globális felszínhőmérséklet változásaira. A D(QTH, QTM) idősor legjobb görbeillesztései az adatsor varianciájának (teljes négyzetes hiba = total squared error) jelentős részét megmagyarázzák: $R^2 > 80$ %; RMSE (becsült szórás) < 0.5. Az RMSE értéke igen hasonló a referencia szimulációra kapott RMSE értékhez. Az adatsorhoz illesztett görbék futása az időszak elején növekvő, majd 10-15 éves futást követően eléri maximumát, s később fokozatosan csökken. Ugyanakkor az illesztett görbék számos esetben emelkedő tendenciát jeleznek a vizsgált 100 éves periódus végén, mely meglehetősen leronthatja a hosszútávú előrejelzéseket.

Summary – The aim of the study was to analyse some statistical characteristics of the global surface temperature time series. Linear trend analysis did not reveal any significant long-range trends. Significant sporadic short term trends (with not more than 6 elements) can only be observed with higher frequency in the middle third of the D(QTH, QTM) temperature difference times. The Makra-test, as a new interpretation of the two-sample test, was also applied to the global surface temperature time series. The basic question of this test is whether or not a significant difference can be found between the mean of an arbitrary sub-sample of a given time series and that of the whole series. This test is suitable to detect breaks in the data set, along with their strength, length and time interval, namely their starting and ending date. With the help of the Makra-test two significantly different sub-periods in the global temperature difference time series of D(QTH, QTM) were detected. In the here-mentioned data set a significant positive break were found between 1861-1900 and a significant negative break relating to the term around 1881-1958. A further aim was to study the effect of the increased CO_2 level on the changes of the global temperature. The curves best fitting to the D(QTH, QTM) global surface temperature difference time series explain changes (total squared error) of the data set in fairly high ratios. The value of the R-square generally exceeds 80 %. The estimated standard deviations (RMSE) are rather low, mostly below 0.5. These RMSE values are very similar to those of standard deviation in the reference simulation. The fitted curves adjusted to the data show an increasing tendency in the first period; then, after 10-15 years run reaches its maximum and later is gradually decreasing. However, the fitted curves in several cases indicate slight increasing tendencies at the end of the 100-year period, which may rather ruin long-range forecasts.

Key words: QTM simulation, QTH simulation, D(QTH, QTM) global surface temperature difference time series, linear trend analysis, Makra-test, curve fittings

1. INTRODUCTION

The aim of the study was to analyse some statistical characteristics of surface temperature time series; namely, to perform linear trend analysis, as well as to show the Makra-test, as a new interpretation of the two-sample test with its application to the global surface temperature times series. The basic question of this test is whether or not a significant difference can be found between the means of an arbitrary sub-sample of a given time series and the whole sample (*Makra et al.*, 2002, 2005).

A further aim was to study the effect of the increased CO_2 level on the changes of the temperature of the Earth and its separate regions. The data of three simulations, concerning a 100-year long period, were used in the analysis. Among them the first one was a reference simulation, for which the background data were adjusted on the basis of a period preceding industrialization. The original temperature data set was distorted by the supposed high level of CO_2 the effect of which gradually decreased by 20-year periods from the beginning till the end of the time series.

2. DATABASE

The original data come from the research team CAIAC (Atmospheric Chemistry and its Interactions with Climate), METEO-FRANCE, CNRM (Centre National de Recherches Météorologiques, Toulouse, France. They were derived from a simulation of 100 years. Each year contains 12-monthly mean fields. There are data for the unperturbed run and the pulse perturbations of CO_2. The pulses started at January 1^{st} 1860 and the relaxation time was 20 years. The results of the simulation were stored in netCDF format. NetCDF (network Common Data Form) is an interface for array-oriented data access and a library that provides an implementation of the interface. The netCDF library also defines a machine-independent format for representing scientific data. The interface, library and format together support the creation, access and sharing of scientific data. The netCDF User's Guide and the Interface Guides (*http://www.unidata.ucar.edu/software/netcdf/docs/*) were most useful in the course of our work.

The database can be divided in two parts:

The first part contains the surface air temperature at 2 m height, with monthly mean values for the years from 1860 till 1959. Every file contains one three-dimensional field with the following dimensions: longitude (128) latitude (64) and months (12). The surface air temperature fields are given on a Gaussian grid with 128 x 64 points, 128 longitudes and 64 latitudes. A Gaussian grid is one where each grid point can be uniquely accessed by one-dimensional latitude and longitude arrays (i.e. the coordinates are orthogonal). The longitudes are equally spaced, while the latitudes are unequally spaced according to the Gaussian quadrature. Gaussian grids do not have points at the poles. Typically, the number of longitudes is twice the number of latitudes (i.e. 128 longitudes and 64 latitudes). A MATLAB function Gauss2lats can be useful to compute the latitude coordinates. The function determines the Gaussian latitudes by finding the roots of the ordinary Legendre polynomial of degree NLAT using Newton's iteration method. The only input required is the number of latitude lines in the Gaussian grid. The outputs are Gaussian latitudes, latitude spacing and cosine of latitude. The land-sea mask is given as a two-dimensional array of 128 x 64 values, (= 1 if land; = 0 if sea). However we have to admit that the mask and the grid with the atmospheric data are not identical to the grid used during the simulations. The grid used during the simulation is a "reduced" Gaussian grid with 128 x 64 points, while the grid with the results is a Gaussian grid with 128 x 64 points. So there is already an interpolation step. However, during this interpolation, the influence of the different masks has been accounted for.

The second part contains the ocean temperature monthly mean values for the years from 1860 till 1959. Every file contains one four-dimensional field with the following dimensions: longitude (182), latitude (152), level (31) and month (12). This data is given on an irregular grid of 182 x 152 x 31: 182 longitude, 152 latitude, and 31 levels. In the southern hemisphere, this grid is in fact still regular, but in the northern hemisphere it is irregular. The latitude grid is given as a Gaussian grid. The 1st and 2nd longitudes are identical to the 181st and 182nd longitudes: in fact there are only 180 distinct longitudes. The longitudes vary between 90° and 450°.The vertical grid is described by the following fields: depth is a one-dimensional array (31) of the depth below the oceanic surface of the centre of the layer, and bounds (2 x 31) is a two-dimensional array (2 x 31) of the depth below the oceanic surface of the upper and lower bound of the layer. The mask of the ocean is described by a three-dimensional field (182 x 152 x 31), where 1 means that the given grid is ocean.

There were two different simulations: The QTM simulation is a simulation with ordinary pre-industrial climate conditions, i.e. the CO_2 concentration is constant at 282.6 ppbv that can be used as a reference run. This simulation starts at 1 December 1859 and goes on for 50 years. The QTH (CO2_20Y) simulation also starts at 1 December 1859, where from 1 January 1860 the CO_2 concentration is multiplied by 6.5. This perturbation then also fades away with a relaxation time of 20 years. This simulation goes on for 100 years.

3. SIMULATIONS

On the basis of the original land-sea mask, another file converted to continents was prepared. The co-ordinates of the original mask-file were calculated on the basis of a "Gaussian grid". For each grid it was checked whether land or sea was found in the place of the co-ordinate belonging to the centre of the grid, and also which continent the land belonged to. If land was found on the given co-ordinate, then the number belonging to the adequate continent was written into the mask-file. On the other hand, if sea was found on the given co-ordinate, then 0 was written in the given grid in the database. Seven continents were distinguished, namely Europe, Africa, Asia, Australia, North-America, South-America and the Antarctic. America, together with North- and South-America, was also considered. Then it was looked up in GoogleEarth, whether, on the basis of the position of the middle of the grids, a given point was land or sea.

3.1. The differences of the simulations

A netCDF database was prepared from the surface temperature files for the period, which comprises yearly averages for each co-ordinates and a global mean value for the database over the lands, which were computed with the help of the land-sea mask.

The reference simulations have also been examined by continents and, they seem to run fairly horizontal. From this, we conclude that at the end of the period the difference between data of the pulse and the reference simulations mainly shows the residual response and that is not the result of long term variability. For this reason the method was changed, according to which the difference of the pulse simulations is to be considered in relation to the 50-year average of the reference simulation.

3.2. The curve-fitting

In a second step curves were fitted to the data. The suggested curve corresponds (to some extent) with a simple model of the atmosphere. The following curves were fitted to the time series:

Those curves were tried to be fit to the data sets that contain only one exponential component: one with a decay time of 20 years:

$$a \cdot e^{-\frac{x-1859.5}{20}} \qquad \text{(“exp”)}$$

one with an unknown decay time:

$$a \cdot e^{-\frac{x-1859.5}{b}} \qquad \text{(“exp2”)}$$

and one with a linear factor:

$$a \cdot (x-1859.5) \cdot e^{-\frac{x-1859.5}{20}} \qquad \text{(‘tau’)}$$

At these fittings a weighting factor was used and the weight of the first 20 years was defined as 0.

Then the curves were tried to be fit to the database with the difference of two exponential components: one with a decay time of 20 years and another one with an unknown decay time. The first curve “2dvar” was a simple difference:

$$a \cdot \left(e^{-\frac{x-1859.5}{20}} - e^{-\frac{x-1859.5}{b}} \right) \qquad \text{(“2dvar”)}$$

The second curve “3dvar” contains a constant factor:

$$a \cdot \left(e^{-\frac{x-1859.5}{20}} - c \cdot e^{-\frac{x-1859.5}{b}} \right) \qquad \text{(“3dvar”)}$$

The next curve, namely “3dvarlin” has a linear component:

$$a \cdot \left(e^{-\frac{x-1859.5}{20}} - e^{-\frac{x-1859.5}{b}} + c \cdot (x-1859.5) \right) \qquad \text{(“3dvarlin”)}$$

The curve "4dvarlin" combines the previous two curves and contains a constant factor and a linear component, too:

$$a \cdot \left(e^{-\frac{x-1859.5}{20}} - c \cdot e^{-\frac{x-1859.5}{b}} + d \cdot (x-1859.5) \right) \qquad \text{("4dvarlin")}$$

The "5dvarlin" curve adds a constant component to the previous formula:

$$a \cdot \left(e^{-\frac{x-1859.5}{20}} - c \cdot e^{-\frac{x-1859.5}{b}} + d \cdot (x-1859.5) + e \right) \qquad \text{("5dvarlin")}$$

The last two formulas have an unknown offset, namely the "6dvarlin" with one unknown decay time:

$$a \cdot \left(e^{-\frac{x-f}{20}} - c \cdot e^{-\frac{x-f}{b}} + d \cdot (x-f) + e \right) \qquad \text{("6dvarlin")}$$

and "7dvarlin" with two unknown decay times:

$$a \cdot \left(e^{-\frac{x-f}{g}} - c \cdot e^{-\frac{x-f}{b}} + d \cdot (x-f) + e \right) \qquad \text{("7dvarlin")}$$

The number of free parameters to fit varies from 1 to 7. Some of these parameters have to be initialized for the fit to converge: giving the correct sign is generally enough; sometimes other parameters also need a starting value.

3.3. The goodness of the curve-fitting statistics

After using graphical methods to evaluate the goodness of fit, some goodness-of-fit statistics were examined, namely, the Sum of Squares Due to Error statistics, *R*-Square statistics, adjusted *R*-square statistics and the Root Mean Squared Error statistics (*http://www.mathworks.com/access/helpdesk/help/pdf_doc/curvefit/curvefit.pdf*).

4. RESULTS

4.1. Linear trends

It was examined whether or not linear trends of the 100-year long temperature difference time series of D(QTH, QTM) were significant, considering all three-element sub-periods, for all four-, five-, ... , 98- and at last 99-element sub-periods. Student's *t*-distribution was considered to be the basis of the significance analysis, which was performed at the 1% probability level and with a degree of freedom of $n - 2$ (where n is the element number of the time series).

The D(QTH, QTM) time series show very few significant trends with not more than 6-element sub-periods. Relatively high frequency of significant trends can be observed between 1877-1914, a 38-year period in the D(QTH, QTM) data set (14 of all the 20 significant trends: 70.0%); however, they are distributed rather sporadically in the data sets. Higher frequency of the significant trends indicates higher variability of the time series for the period and region examined. Nevertheless, no clear tendencies of the temperature difference time series have been experienced.

4.2. Significant sub-periods (breaks) (Makra-test)

With the help of the Makra-test significant sub-periods in the global surface temperature difference time series of D(QTH, QTM) were detected (*Figs. 1-4*).

The time series examined shows two significant breaks with the highest significant value of the probe statistics. Namely, between 1861 and 1893 there is a 33-element significant positive sub-period, while between 1895 and 1958 a 64-element significant negative one (first-type two-dimensional figure, *Fig. 1*).

Though the second-type two-dimensional figure (*Fig. 2*) does not indicate the strength of the significant sub-periods (that is to say the difference of their means from the whole sample mean); however, it shows all the significant breaks, either distinct or overlapping) (positive breaks: light-grey block, lower part of the figure; negative breaks: dark-grey block, upper part of the figure, *Fig. 2*).

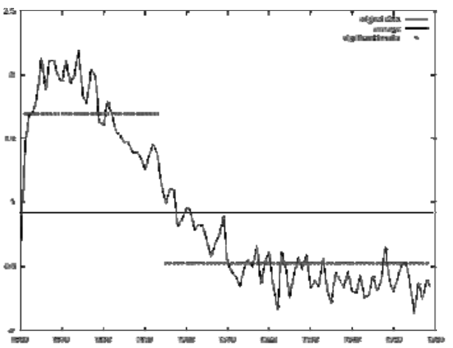

Fig. 1 Significant breaks in the D(QTH, QTM) temperature difference time series, 1860-1959, Earth, first-type two-dimensional presentation

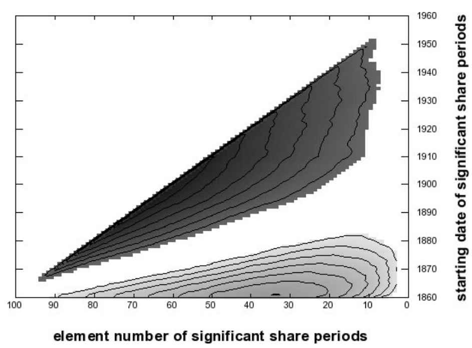

Fig. 2 Sub-periods of which the means differ significantly from that of the D(QTH, QTM) temperature difference time series, 1860-1959, Earth, second-type two-dimensional presentation

The three-dimensional figure (*Fig. 3*) comprises the most complete information on the significant breaks in the data set examined. Namely it consists of all the significant sub-periods with their (1) time interval, namely their starting and ending date (axis x); (2) element number (axis y); and (3) strength.

The maximum and minimum values of the significant probe statistics concerning all the sub-periods (the highest value belonging to the 32-element sub-period, while the lowest one to the 62-element sub-period), as well as frequency of the significant breaks with different element number (maximum frequencies belong to the 11-element significant positive and the 12-element significant negative breaks) were also computed (*Fig. 4*).

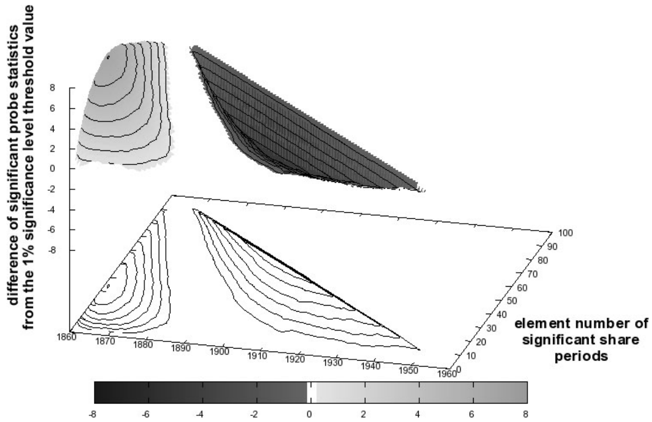

Fig. 3 Sub-periods of which the means differ significantly from that of the D(QTH, QTM) temperature difference time series, 1860-1959, Earth, three-dimensional presentation

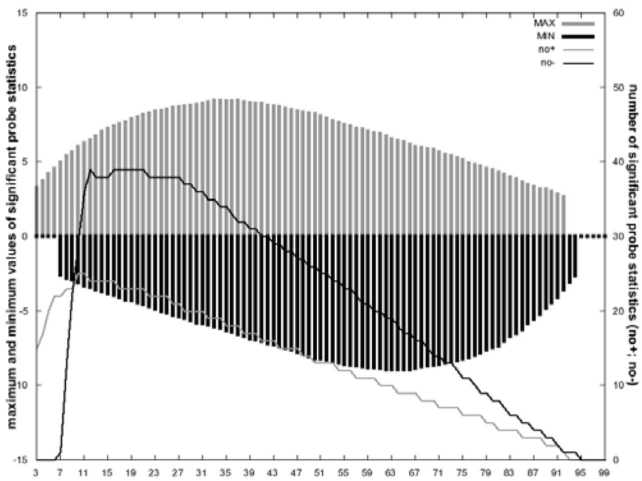

Fig. 4 Sub-periods of which the means differ significantly from that of the D(QTH, QTM) temperature difference time series, 1860-1959, Earth, values and number of significant probe statistics

4.3. Curve-fitting

In order to characterise the differences in the data sets of the simulations, curve-fittings were made. The curves to be fitted were generated on the basis of an exponential function or the difference of two exponential functions (the latter ones seem to be more useful) and different numbers of freely variable parameters were used in the formulas.

Among the curve-fittings applied, generally those of "4dvarlin", "5dvarlin" and "6dvarlin" proved to be the best ones; hence, their analysis will be emphasized in the following. The first six curve-fittings (“exp”, “exp2”, “tau”, “2dvar”, “3dvar”, “3dvarlin”) comprised only a few parameters; consequently, they were not very good. Adding a new parameter to the curve-fitting of “7dvarlin” did not result in a clear improvement compared to that of “6dvarlin”. Generally, the values of SSE and R-square statistics in curve-fitting are nearly identical or even better than those of “6dvarlin”. On the other hand, values of the adjusted R-square and the RMSE statistics did not indicate improvement.

4.3.1. QTH global surface temperature time series fits

The curve-fitting of “6dvarlin” seemed to be the best one for this data set. It shows better values for each statistics than those of “4dvarlin” and “5dvarlin”. Still out of these latter two fittings “4dvarlin” is better; the adjusted R-square and the RMSE statistics also indicate this. Nevertheless the other two statistics do not show important differences (SSE, R-square) (*Figs. 5-6*).

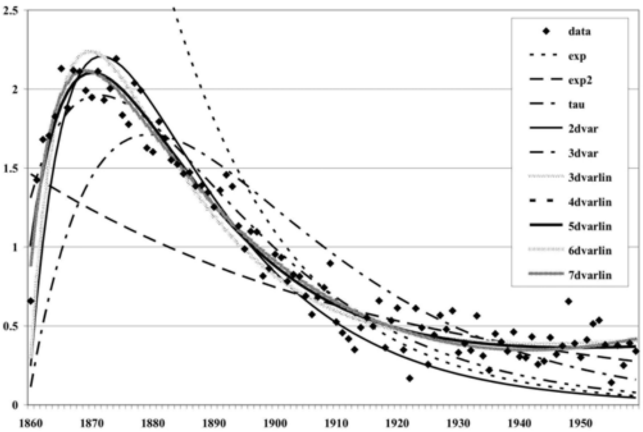

Fig. 5 Curve-fittings, QTH global surface temperature time series1860-1959

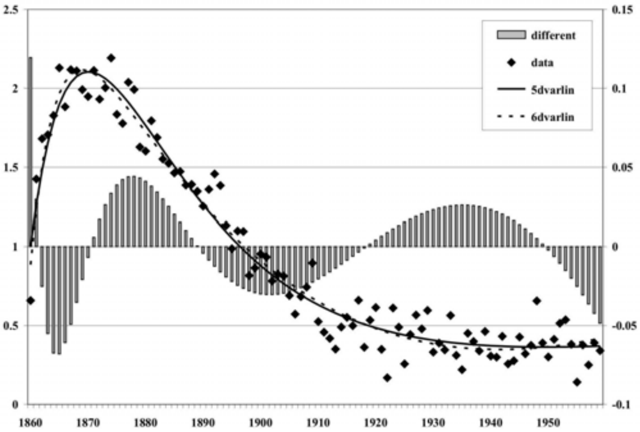

Fig. 6 Comparison of the two best curve-fittings, QTH global surface temperature time series, 1860-1959. Vertical axis on the left shows the original values of the data set; while vertical axis on the right indicates the D(6dvarlin; 5dvarlin) difference

5. CONCLUSION

The more detailed trend analysis applied to all the possible sub-periods of the data sets did not detect any long-range significant trends for the regions examined. The short term significant trends (with not more than 6 elements) can only be observed with higher frequency in the middle third of the D(QTH, QTM) temperature difference times series and in the last fifth of the D(QTK, QTM) times series. The linear trends received can be considered sporadic ones, which are mostly due to the higher variability of the data compared to the temperature anomalies between the simulations. In this way, decreasing tendency in the data sets could not be detected by the trend analysis.

The Makra-test makes it possible to determine whether or not significant differences can be found between the means of two non-independent time series. At a global level the highest significant value of the probe statistics belongs to a 33-element significant positive sub-period between 1861 and 1893, while the lowest significant value refers to a 64-element significant negative one between 1895 and 1958. According to the Makra-test, the difference of the temperature time series proved to be significantly higher at the beginning of the period examined (around 1861-1900), while this effect substantially decreased by the end of the term (around 1881-1958). This near-uniform distribution of the significant breaks in each region considered assumes that the effect of increased CO_2 concentration (QTH) and solar perturbation (QTK) have similar time interval.

The curve-fittings presented in the paper represent the data sets fairly well; however, the best fittings could neither be determined for each case and formula nor could be found to produce definitely the best result for each data set. The curve-fittings found best explain changes (total squared error) of the data sets in fairly high ratios. In some cases, the value of R-square reaches approximately 95%, and its value is generally 80% or so; while its lowest value, only in a few cases, is about 70%. The estimated standard deviations (RMSE) are rather low. They rarely exceed the value of 0.5; in some cases, their values are even below 0.2. These RMSE values are very similar to those of standard deviation in the reference simulation. The run of the fitted curves adjusts to the data: it is increasing in the first period; then, after 10-15 years it reaches its maximum and later is gradually decreasing. However, it should be noted that the fitted curves in several cases indicate slight increasing tendencies at the end of the 100-year period. Therefore, they may rather ruin long-range forecasts. The temperature differences of the simulations should disappear with time, since effects resulting in temperature-increase decline. On the basis of the above results, curve-fittings applied in the paper can be considered fairly good ones; however, better fittings might also be found for long-range forecast.

REFERENCES

Makra, L., Horváth, Sz., Pongrácz, R. and Mika, J., 2002: Long term climate deviations: an alternative approach and application on the Palmer drought severity index in Hungary. *Phys. Chem. Earth B - Hydrology, Oceans and Atmosphere 27,* 1063-1071.

Makra, L., Mika, J. and Horváth, Sz., 2005: 20th century variations of the soil moisture content in East-Hungary in connection with global warming. *Phys. Chem. Earth 30,* 181-186.

http://www.mathworks.com/access/helpdesk/help/pdf_doc/curvefit/curvefit.pdf

http://www.unidata.ucar.edu/software/netcdf/docs/