Free software in Meteorology

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Abstract: In meteorology, the importance of open science and open data is recognized. Huge amount of data is needed for weather and climate forecast. Traditionally, GFortran is used for development of Numerical Weather Prediction models and number crunching. One of the most applied free software packages is the Grid Analysis and Display System (GrADS), that has been developed for manipulation and visualization of meteorological data. The University of Belgrade - Faculty of Physics is the only educational and research institution in Serbia where the meteorology is studied. Students learn about processes in the atmosphere by applying free software in several courses. The application of free open source software in education and research in meteorology is presented.

Keywords: Meteorology; GFortran; Xmgr; GrADS; LibreOffice.

I. Introduction

Meteorology applies physical and mathematical methods to understand and forecast the processes in the atmosphere that determine a weather and climate. Meteorology makes extensive use of the high-performance computing and tools of mathematics and physics, adapted to analyse atmospheric phenomena using large datasets.

The Faculty of Physics in Belgrade is the oldest national and leading educational and research institution in the field of physical and meteorological sciences in Serbia. The Faculty of Physics is organizing four undergraduate and master groups of studying: General Physics, Theoretical and experimental Physics, Computer and applied Physics, and Meteorology. About 25 students enroll meteorology each year, which encourage individual work on computers.

II. Free Software for Meteorology Calculation, Visualization, and Modelling

There is a computer laboratory equipped with 16 personal computers in Institute of Meteorology at the Faculty of Physics. Linux 4.9 and LibreOffice 5 are installed at all computers. Free software is applied at the following courses: Statistics in Meteorology, Fortran in Meteorology, Micrometeorology, Modelling of the Atmosphere I, Modelling of the Atmosphere II, Climatology, Applied Meteorology and Weather Forecast. Students use LibreOffice Calc, LibreOffice Writer, Xmgr, GrADS and GFortran to complete their works.

LibreOffice is a free and open-source office suite, a project of the Document Foundation (https://www.libreoffice.org/). It was forked in 2010 from OpenOffice.org, which was an open-sourced version of the earlier StarOffice. The LibreOffice suite consists of programs for word processing, creating and editing of spreadsheets, slideshows, diagrams and drawings, working with databases, and composing mathematical formulae.

The GNU General Public License (GNU GPL or simply GPL) is a series of widely-used free software licenses that guarantee end users the freedom to run, study, share, and modify the software. Historically, the GPL license family has been one of the most popular software licenses in the free and open-source software domain. Prominent free software programs licensed under the GPL include the Linux kernel and the GNU Compiler Collection (GCC).

The purpose of the **GNU Fortran (GFortran)** project is to develop the Fortran compiler front end and run-time libraries for GCC, the GNU Compiler Collection (https://gcc.gnu.org/fortran/). GFortran development is part of the GNU Project. It is suitable for free number crunching to a broad spectrum of platforms and users. The GFortran compiler is fully compliant with the Fortran 95 Standard and includes legacy F77 support. GFortran development follows the open development process.

Xmgr (an early name for Grace) is one of the two most prominent graphing packages for Linux (https://en.wikipedia.org/wiki/Grace_(plotting_tool). The name stands for "**GRaphing, Advanced Computation and Exploration of data**". The Grace project was started as a fork, released under the GPL. **Xmgr** is a 2D plotting tool for workstations or X-terminals. A few of its features are:

- User defined scaling, tick marks, labels, symbols, line styles, colors;
- Batch mode for unattended plotting;
- Read and write parameters used during a session;
- Polynomial regression, splines, running averages, DFT/FFT, cross/auto-correlation;
- Hardcopy support for PostScript, HP-GL, jpeg, pdf, png format.

While **Xmgr** has a convenient point-and-click interface, most parameter settings and operations are available through a command line interface. Weakness is that is no undo feature.

The Grid Analysis and Display System (GrADS) is an interactive desktop tool that is used for easy access, manipulation, and visualization of earth science data (http://cola.gmu.edu/grads/). GrADS, developed and supported at COLA/George Mason University, is freely available. GrADS supports many data file formats, including binary (stream or sequential), GRIdded Binary or General Regularly-distributed Information in Binary form (GRIB), Network Common Data Form (NetCDF), and the Binary Universal Form for the Representation of meteorological station data (BUFR). GrADS has been implemented worldwide on a variety of commonly used operating systems and is freely distributed over the Internet. GrADS uses a 5-Dimensional data environment:

the four conventional dimensions (longitude, latitude, vertical level, and time) plus an optional fifth dimension for grids that is generally implemented but designed to be used for ensembles. Data from different data sets may be graphically overlaid, with correct spatial and time registration. Operations are executed interactively by entering FORTRAN-like expressions at the command line. A rich set of built-in functions are provided, but users may also add their own functions as external routines written in any programming language. GrADS has a programmable interface (scripting language) that allows for sophisticated analysis and display applications.

For example, to create a plot of wind field in GrADS, one can use commands similar to these:

```
ga-> sdfopen uwnd.mean.nc
Found displayable variable uwnd with 0 levels in SDF file
Data file uwnd.mean.nc is open as file 1
LON set to 0 360
LAT set to -89 89
LEV set to 0 0
Time values set: 1980:1:1:0 1980:1:1:0
ga-> d uwnd
```

III. Free Software in Meteorology Education

A. Statistics in Meteorology

Students use LibreOffice Calc and LibreOffice Writer for completing their homework. Precipitation and temperature data are downloaded from the European Climate Assessment & Dataset site (https://eca.knmi.nl/dailydata/predefinedseries.php).

Example of precipitation distribution for Belgrade during the period 1951-2000 is shown in Fig. 1. Absolute frequency obtained from observations is presented with solid line, while theoretical distribution (Normal pdf) with dashed line. It can be seen that the Normal pdf can be used to describe distribution of the annual precipitation sums in Belgrade.

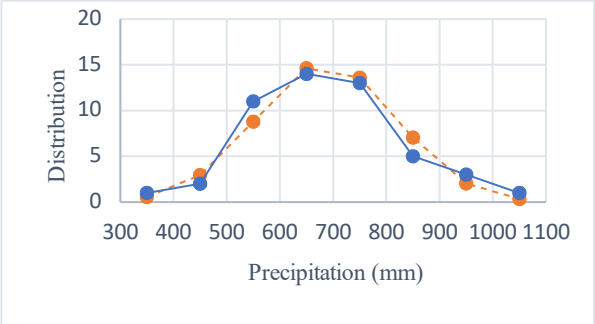

Figure 1: Frequency distribution (solid line) and Normal probability density function (dashed line) of annual precipitation sums in Belgrade.

Precipitation regime, i.e., monthly distribution of precipitation in Belgrade, using the LibreOffice spreadsheets, is presented in Fig. 2. The continental regime is characterized with a maximum of precipitation in June.

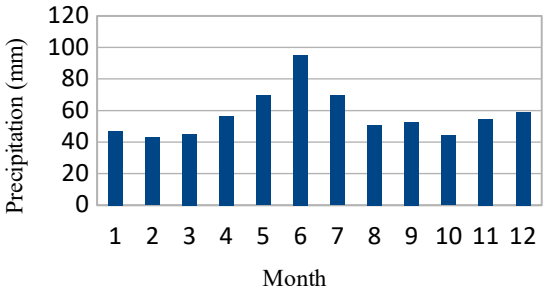

Figure 2: Precipitation regime in Belgrade during the period 1961-2018.

B. Climatology

Climatology describes the complex interrelations between the atmosphere, land, oceans, ice and the biosphere. It is defined as weather conditions averaged over a period of time. Temperature and precipitation are the main factors determining regional climate.

Students run codes in GFortran, and use Xmgr for visualization of obtained results. Example of the annual mean temperature along with a trend for Belgrade during the period 1961-2018 is shown in Fig. 3. Applying the Mann-Kendall test, the significant increase of the annual mean air temperature in Belgrade is found [1].

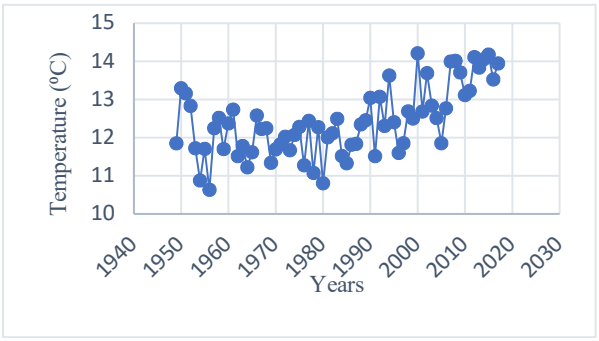

Figure 3: Annual mean temperature in Belgrade with linear regression trend during the period 1961-2018.

C. Modelling of the Atmosphere

While many different methods for numerical solution of partial differential equations are available, the approach that is followed in the course “Modelling of the Atmosphere” is a traditional, Eulerian, grid-point, finite-differencing method. This course is concerned almost exclusively with dynamics, i.e., the approximations of those processes that govern motion of the air [2]. One of examples that students solve at the end of the course is to derive an approximation for the one-dimensional linear advection equation using the Adams-Bashforth scheme for time differencing, and centered and backward finite difference quotient of the first-order of accuracy for space differencing. Then, the advection of the initial perturbation should be calculated and displayed for different time step.

Consider the one-dimensional linear advection equation

$$\frac{\partial u}{\partial t} + c\frac{\partial u}{\partial x} = 0 \quad ,$$

where $u = u(x, t)$ is a function of two independent variables space and time, and c = const.

The Adams-Bashforth scheme is a time scheme,

$$\frac{U^{n+1} - U^n}{\Delta t} = \frac{3}{2} f^n - \frac{1}{2} f^{n-1} \quad , \quad \frac{\mathrm{d}U}{\mathrm{d}t} = f(U,t) \quad , \quad U = U(t) \quad .$$

Centered finite difference quotient over two grid intervals represents an approximation of the spatial derivative in the form

$$\left(\frac{\partial u}{\partial x}\right)_{j,t_0} \approx \frac{u(x_{j+1},t_0) - u(x_{j-1},t_0)}{2\Delta x}$$

Approximation of the spatial derivative by the quotient backward over one grid interval is

$$\left(\frac{\partial u}{\partial x}\right)_{j,t_0} \approx \frac{u(x_j,t_0) - u(x_{j-1},t_0)}{\Delta x}$$

Initial perturbation in one point (top) and in three points (bottom) is advected without change in shape (Fig. 4). Centered finite difference quotient (CKKR) better preserved amplitude of initial perturbation than the backward quotient (UKKR). However, CKKR produced negative values.

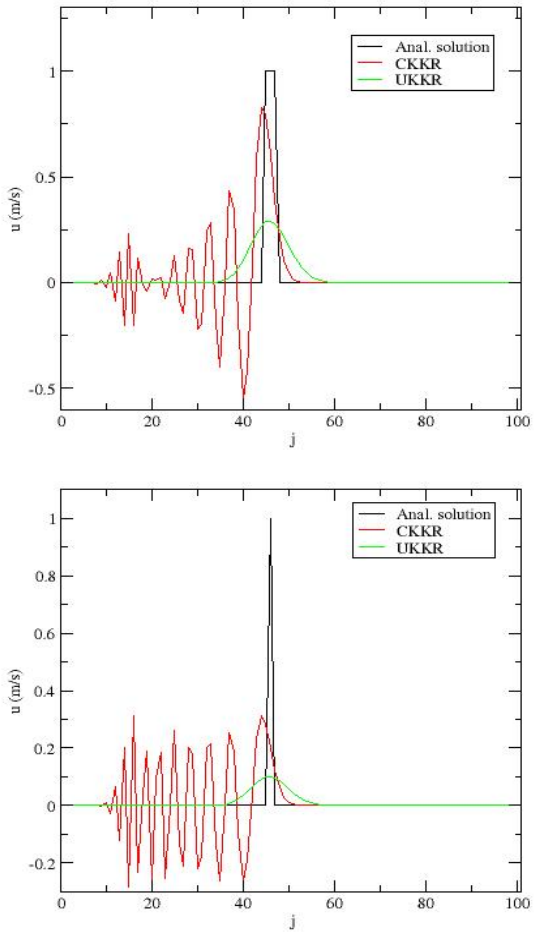

Figure 4: Analytical solution (black), centered finite difference quotient (CKKR, red) and backward quotient (UKKR, green) for initial perturbation in: one point (top) and three points (bottom).

IV. Free Software in Meteorological Research

The Institute of Meteorology pursues a wide range of research topics ranging from data analysis and numerical forecasting to regional climate research.

GrADS is extensively used free software in meteorological research for displaying meteorological fields. Daily values of air temperature, geopotential height, and vector wind are obtained from the gridded dataset of the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis Project (https://psl.noaa.gov/data/composites/day/). All gridded values are saved as the Network Common Data Form (NetCDF) and imported in GrADS for a mapping. An extraordinary heat wave occurred in Serbia from July 14 to July 24 in 2007 [3]. Record values of the maximum temperatures were observed over almost the whole territory of Serbia and in Smederevska Palanka, a temperature of 44.9 ºC was registered, which was the absolute maximum value ever recorded. Temperature anomaly observed on 24 July 2007 based on the period 1981-2010 is shown in Fig. 5. The atmospheric circulation at 500 hPa (not shown) resulted in the horizontal advection of warm air masses from northern Africa across central and eastern Mediterranean towards the Balkans.

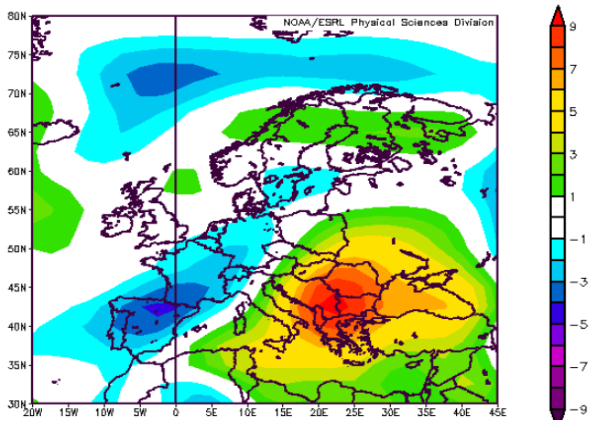

Figure 5: Temperature anomaly of 24 July 2007 at 1000 hPa over Europe, based on the 1981–2010 reference period.

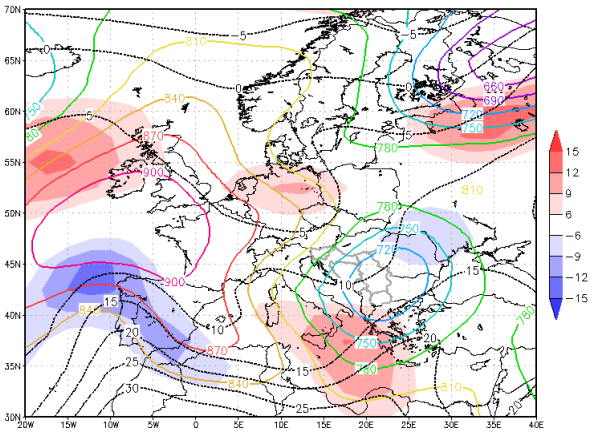

Figure 6: Synoptic situation on 14 May 2014: a geopotential height (gpm, continuous line), temperature (ºC, dashed line) and horizontal wind speed (shaded) at 925 hPa.

Extreme precipitation was recorded in May of 2014 in western Serbia [4]. On 15 May 2014, the daily rainfall broke previous historical records in Belgrade (109.8 mm), Valjevo (108.2 mm) and Loznica (110 mm) as a result of the cyclonic activity. Precipitation exceeded 200 mm in 72 h, producing the most catastrophic floods in the recent history of Serbia. Synoptic situations were analysed in [4] and presented in Fig. 6.

Interdisciplinary research such as the study of long-range transport is a good example for application of GrADS [5]. Although the phenomenon of long-range dust transport is generally present, North Africa, more precisely the Sahara, is the largest source of mineral dust, with about 0.8 x 10^9 tons per year. In the Sahara region, air currents lead to dust build-ups, which are then transported to the Mediterranean [6, 7] and further north to Arctic regions or west to the Atlantic. A composite geopotential height and wind flow map for synoptic situations that favored a long-range dust transport from Sahara towards the Balkans is presented in Fig. 7. As a consequence, colored rain can be observed in Belgrade and Serbia.

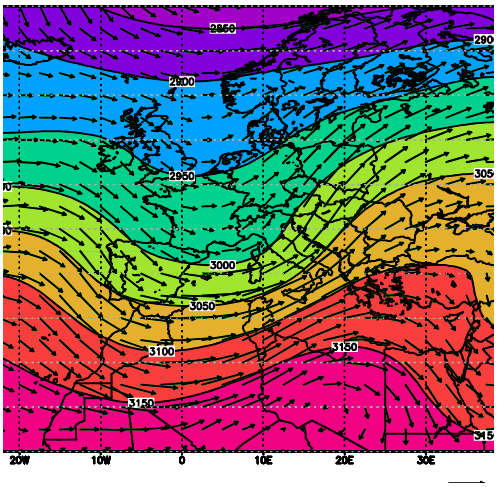

Figure 7: A composite geopotential height (m) and wind flow (m/s) map for days of 18 events analysed from March 2012 to December 2013.

V. Conclusion

Meteorology is a geophysical science and a good example of a discipline that relays on complex visualization of scientific data. Consequently, free open source software might be good candidate for both students and researchers in the field of data calculation and visualization. There are many free software programs that are applied for calculation and visualization of meteorological data. Xmgr is a 2D plotting tool for X-terminals used in education. GrADS is extensively applying in visualization of meteorological fields in education and research. Students in Meteorology use free software at several courses at the Faculty of Physics in Belgrade. However, there is a space for incorporation of other free software, for example Python, which will be done in the near future.

References

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