A Guide to Dynamical Downscaling of Climate and Scenario generation using climate models

PREFACE

IGAD Climate Prediction and Applications Centre (ICPAC) under the Planning for Resilience in East Africa through Policy, Adaptation, Research, and Economic Development (PREPARED) project, held its first training of scientists from the region on dynamical downscaling of climate in Nairobi, Kenya, 27 April-01 May 2015.

The main objective of this training was to build capacity of National Meteorological and Hydrological Services (NMHSs) climate scientists from East Africa member countries on downscaling techniques of low resolution Global Climate Models (GCMs) using high resolution Regional Climate Models (RCMs). The participants were also trained on analysis of daily rainfall and temperature extremes for their respective countries using observed in-situ data.

The training guidelines were modified and developed into a training manual on dynamical climate downscaling and scenario development. This was in response to participants request for a follow-up tool to help scientists from the region learn on their own skills and knowledge on climate downscaling. The manual is simple and straight forward for a beginner to use and become expert without necessarily participating in a formal training.

This manual is composed of four main parts. The first part introduces users to the basics of Linux commands, its structure, where files and directories are located to enable navigate around, giving one a better idea of how Linux systems works. The second part gives guidance on how to format climate data and carry out basic analysis using the Climate Data Operator (CDO). The third part is on data analysis and visualization using Ferret. The fourth part is dedicated to creating future climate scenarios and analyzing change (using CDO and ferret). The fifth part is based on the use of R- software in constructing climate extremes indices for use in climate change monitoring and detection studies. This is through computation of daily rainfall and temperature extreme indices using observed in-situ data.

The basic scripts used for the computations of the regional climatology, mean annual cycle and the models bias from mean observed data are provided in the annexes. All other downscaling procedures can be built from these basic scripts.

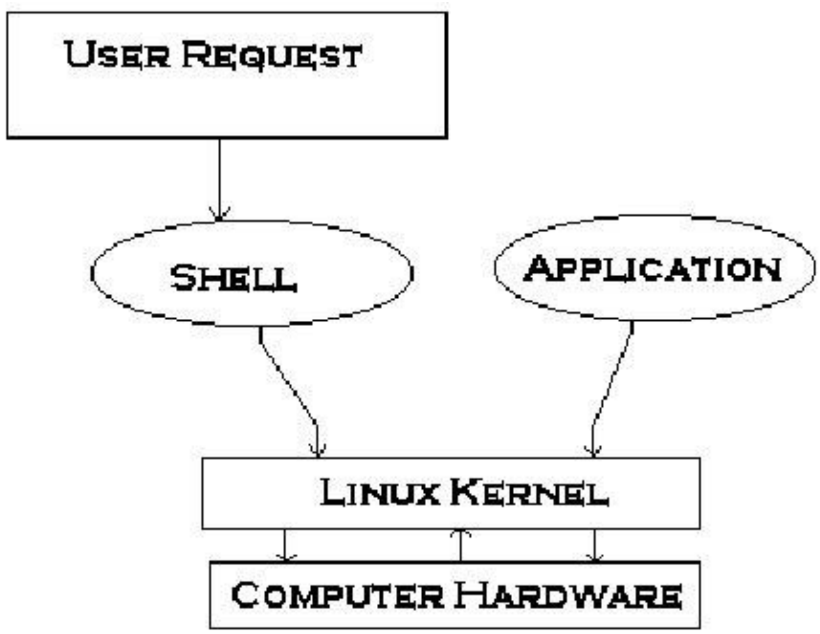
Part I: Linux Commands and Administration for Beginners

The goal of this article is to help introduce new users to the basics of Linux. After reading this article you will have an understanding of how the Linux system is structured, where files and directories are located making it easier for you to navigate around, giving you a better idea of how your systems works. We'll then move on to some basic Linux navigation, copy, showing your files and directories, etc.

Whether you're new to Linux or already using it, you'll need to have some basic knowledge of the Shell, the Kernel, the Terminal, and File Hierarchy Standard (FHS), among others. There's actually quite a bit of other things you'll need to know, but let's start with the basics.

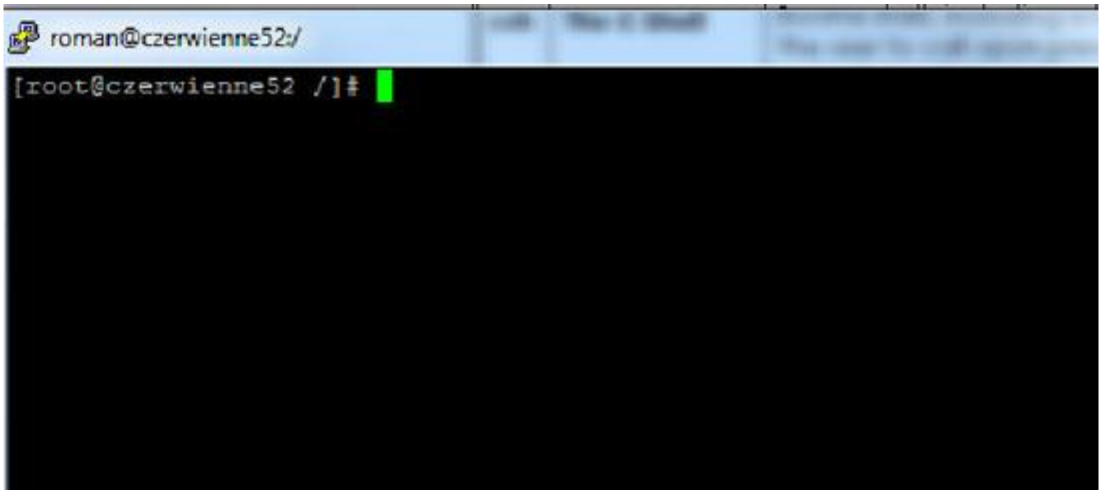
The Kernel

The Kernel is what controls everything on a system; think of it as the heart of Linux. It performs tasks that create and maintain the Linux environment. The Kernel receives instructions from the shell and engages the appropriate hardware (processors, memory, disks, enforces security, etc.). It is a bridge between applications and the actual data processing done at the hardware level.



The Shell

The shell is the interface between you and Linux. We issue commands through the command line interface which is interpreted and passed on to the kernel for processing. When we log onto the computer the shell will automatically start. It will then monitor the terminal for any commands.



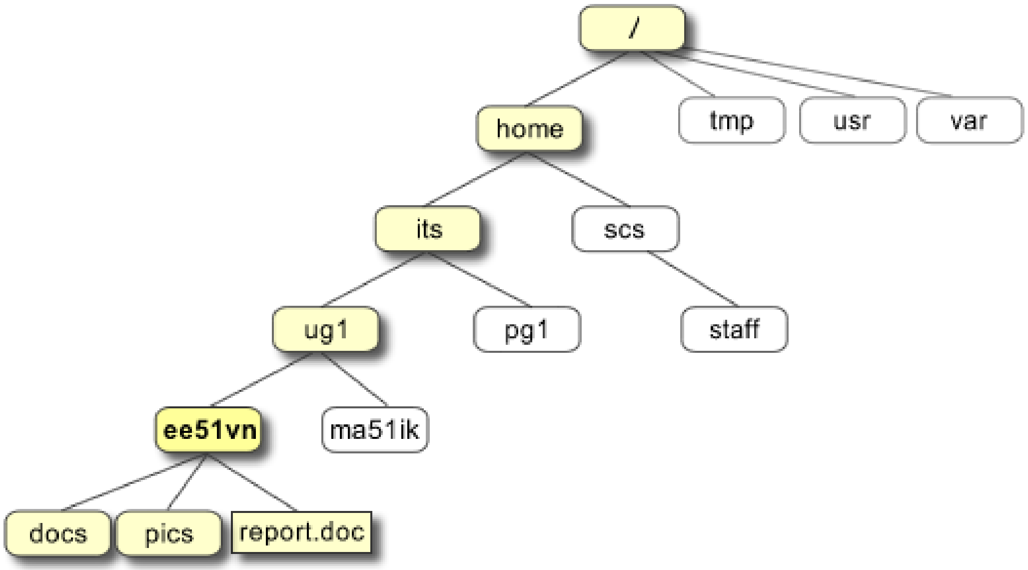
This is the Terminal (command line interface).

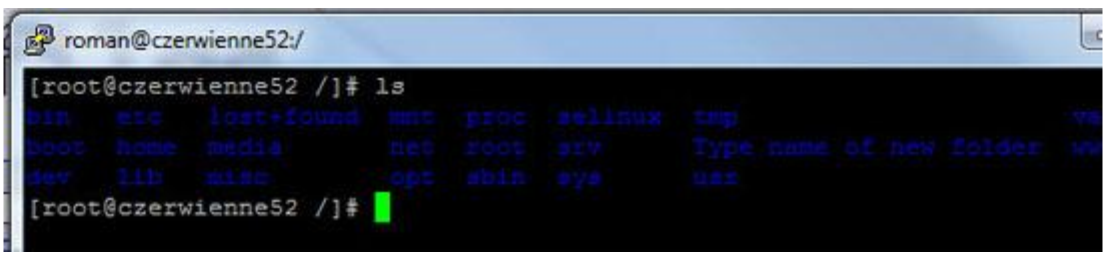
There are a number of shells you can use, each differing slightly. Most Linux distros use Bourne-Again shell (bash) but support various others: Korn Shell, Bourne shell, C shell, etc. For all intensive purposes you can just stick with bash but I will show you how to change this if you want to. As you advance you can use shells to create scripts to automate tasks, making your daily routine all the more easier.

Filesystem Hierarchy Standard

Next important aspect is the FHS. Everything in Linux is either a file or a directory. The Filesystem Hierarchy Standard (FSH) is the way that these files and directories are structured. More importantly though is how they are structured. Looks intimidating at first glance but when you realize that there is a method to this madness, you will find it's so much simpler because everything is organized in the proper place and you can find where you want go much easier.

/ – The root directory. This is where your directory structure starts. Everything is housed under the root directory.





/bin – Essential user command binaries used for general operations: Copy, show directory, etc. (ls, cp, and cat – we'll get to these commands soon)

/boot – Static files of the boot loader. Files here are necessary for a Linux system to start (Kernel & GTUB information)

/dev – Where the device files are located

/etc – Configuration files for all programs. Things like an apache web server, users & groups on your system, or printer configuration. Think of this as a control panel for Windows users. We will edit these text files later (These files should remain static and text based).

/home – Home directories for all the users to store personal files (i.e. /home/roman) – Windows equivalent of Documents & Settings.

/lib – Essential shared libraries and kernel modules

/media – Mount point for removable media

/mnt – Temporary mounted file systems

/opt — Add on application software packages – (i.e. Program files for windows users)

/sbin — Essential system binaries

/tmp – Programs write their temporary files here.

/usr – Multi-user utilities & Applications. It contains application source codes, documentation, & config files they use. It's the largest directory on the system.

/var – Variable data on a system. Data that will change as the system is running (Log files, backups, cache, etc.)

/root – Home directory for root

/proc – Virtual directory containing process information (system memory, hardware configuration, devices mounted, etc.)

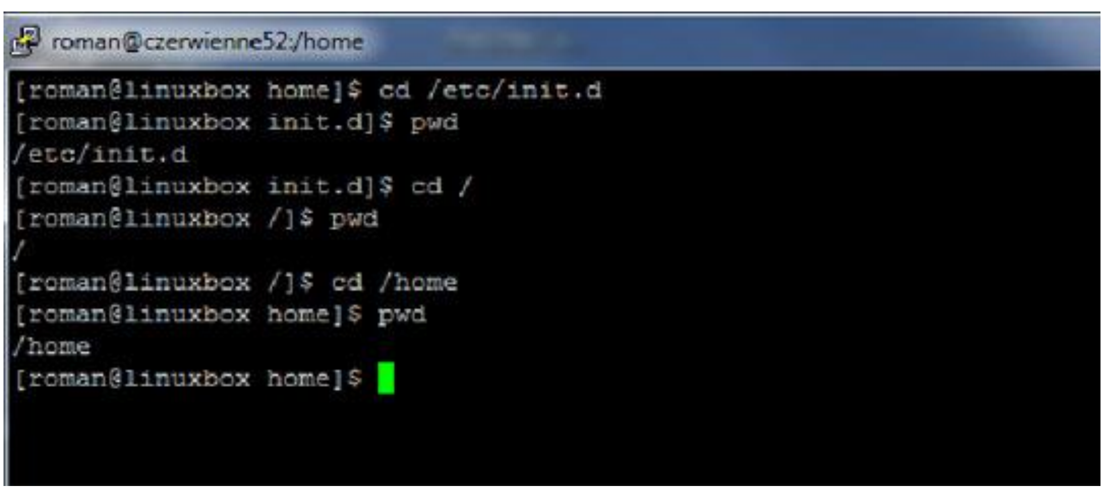
The directories that one would be most concerned in starting with are /etc, /home, /dev, /mnt and as your skills progress you'll venture off into other areas. There are directories that extend, but those will come later.

Navigation and Issuing Commands

The first thing you want to do is open a terminal. Depending on the distribution you are using this may differ but you should find it in Utilities. If one is new to Linux, it is recommended that you download a distro and try it Live without having to install. Check out the blog's Linux section and other lists of Linux distros.

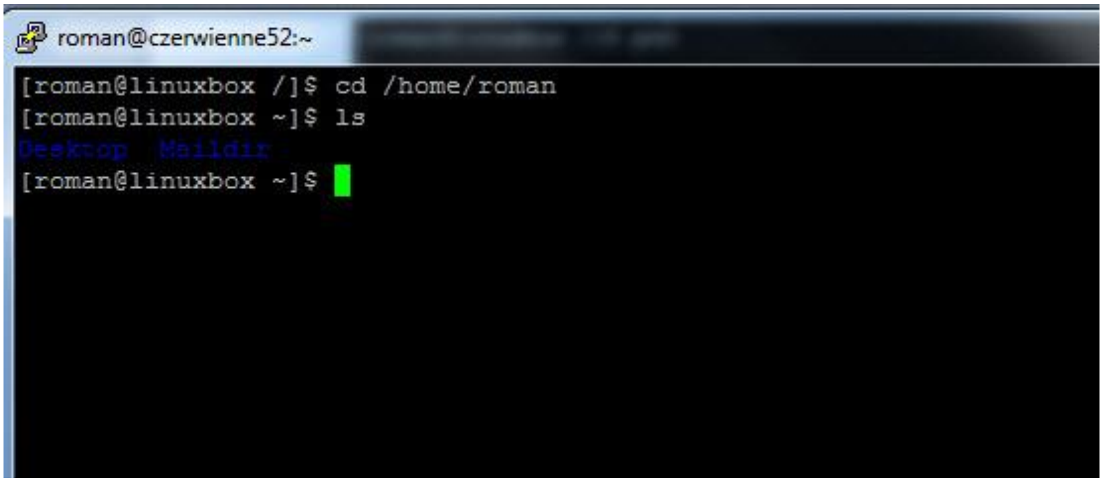
Let's start with some basic commands

pwd – Print working directory will tell you what directory you are in.



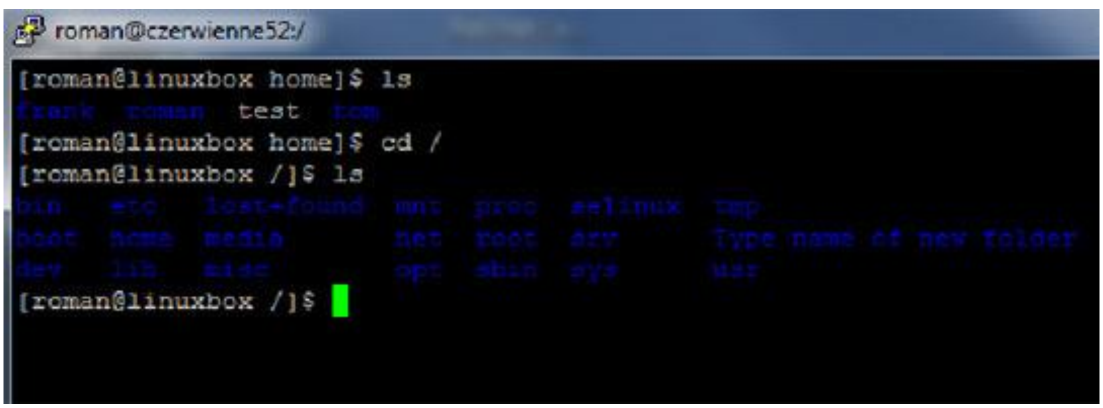
Notice that the use of pwd to tell where one is while cd (change directory) is used to move into another folder.

cd – Change Directory. Can be used with "/" and then the folder you want to go to. For example, cd /home/roman will take you to the directory that exits for user Roman.

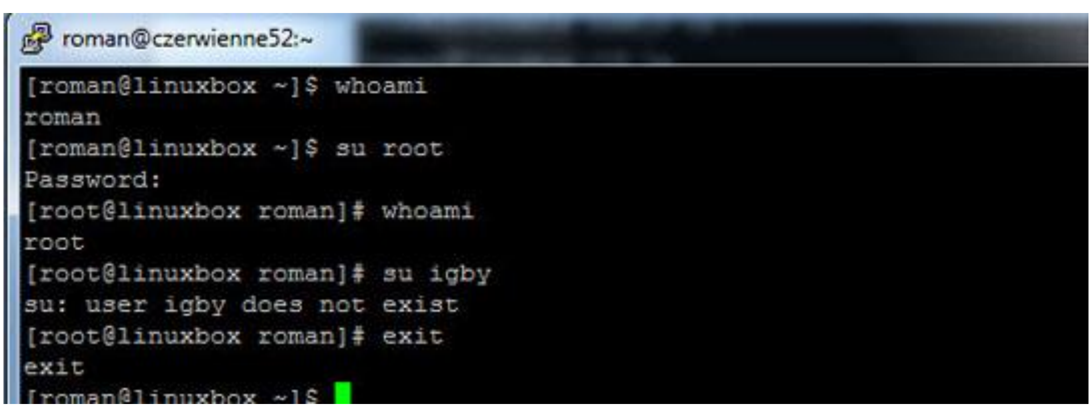


ls – Lists files and directories that you are in.

It may help to use the ls command to list what files and directories exist in the directory you are in. It's vital to know the difference between ls & pwd. pwd tells you where are, ls tells you what you have to work with.



whoami – Tells you which user is logged in



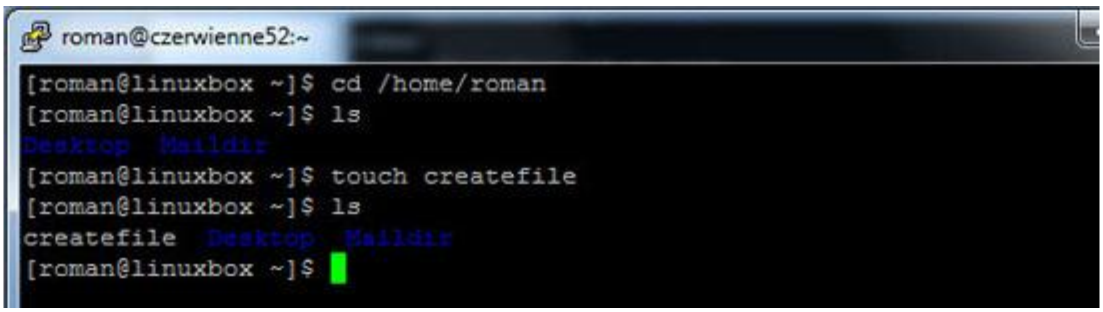
You'll notice the use of the *su* command to change from user roman, to root, then to igby, though igby does not exist. Use "exit" to go back to user roman.

su – Substitute user. There are some rules and additional features that we'll be explored in the next session.

Let's go to your home directory and finish off a few other commands. This will be cd /home/roman.

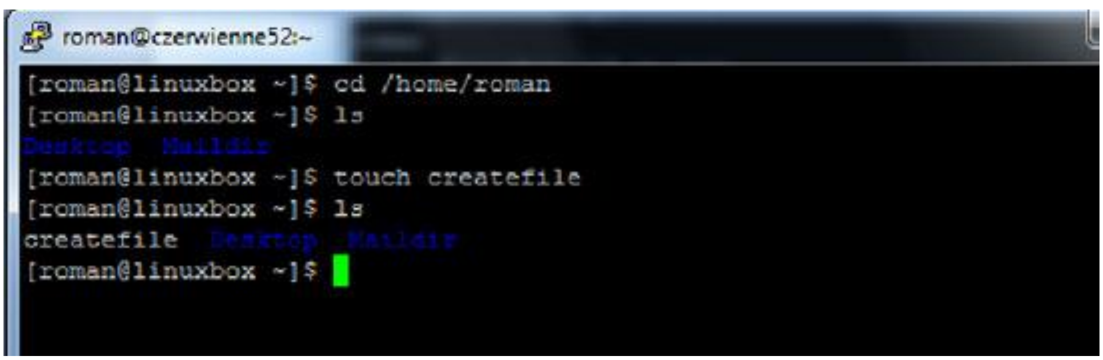
Let's make a file and delete it.

touch – A command you can use to quickly create a file that you can also "touch" on existing files.



You'll notice that "createfile" wasn't there before but when is used with the "touch" command it will be created. Nothing is in createfile but it exists.

rm – Removes the file for you



clear – Clears the terminal for you

Those are some of the basic commands. There are plenty more where that came from. Hopefully this article has been informative and insightful. The next article will follow up on this one with more information on Linux as well as commands to really get you going.

Useful shortcuts

To copy double click with left mouse button and paste by pressing middle mouse button.

ctrlA	Control + A to go to beginning of typed line.
ctrlE	Control + E to go to the end of typed line.
ctrlK	Control + K deletes the line
ls e*	lists all files that start with e
ls *.nc	lists all files that end in pdf
ls file?.dat	list files such as file1.dat and file7.dat but will not list file001.dat
cat	Concatenate and display
less	Can move through a file when viewing it
man	Manual
touch	Makes a new file
clear	Clears the terminal screen
emacs	Editor
pico	Editor
vi	Editor
acroread	Acrobat Reader

Some useful websites:

i. Doctor Bobs Lowfat Linux http://lowfatlinux.com/
ii. Getting started with Linux http://www.linux.org/lessons/beginner/toc.html
iii. Unix Tutorial for beginners http://www.ee.surrey.ac.uk/Teaching/Unix/index.html

Part II: Climate data formats and analysis tools

Contents

- Formats used for climate data
- Software for climate data analysis
- Introduction to ***netCDF*** and ***ncdump***

1. Formats used for climate data

Different types of data formats are used in climate/atmospheric science. The most commonly used data format types are *ASCII*, *Binary* and *Self-describing* data formats.

1.1 ASCII data formats:

Data usually organized in rows and columns

Advantages:

- Easy to look at: can use tools like Excel, Notepad, or any UNIX editor to look at files
- Can print it out

Disadvantages:

- Inefficient way to store data
- Hard to tell what kind of grid the data is on
- Can get unwieldy very quickly
- No standards
- Potential lack of descriptive info

1.2 Binary data formats

Examples: “Fortran sequential”, “Fortran direct”

Advantages:

- Usually smaller file sizes than ASCII

Disadvantages:

- Not easily portable across computers – need to know “big endian” versus “little endian”
- Need special program to look at binary data
- What happens if you lose description of what’s on the file? You won’t know how to read it.
- No standards

1.3 Self-describing data formats

Self-describing data is data that has descriptive data (“metadata”) associated with it. The metadata is optional, but highly useful. Metadata can include information about the file itself and about the variables on the file.

Metadata generally consists of three features:

- Attributes (descriptive information about file or variables)
- Named dimensions (names for dimensions in arrays)
- Coordinate arrays (one-dimensional arrays that indicate lat/lon locations, levels, time, etc, of data points).

Advantages:

- Well-written files have all the information you need, hence easier to share with others
- You can query what's on the file before reading the whole file
- You can easily ask for subsets of data: "Give me all the rainfall values for this lat/lon range"

Disadvantages:

- Files can get large if you have lots of variables and/or lots of metadata
- Some standards, but not always adopted

Global attributes– Information about the file itself

- "title" : one-line description of what's in the file
- "institution": where original data file was created
- "source": method used to produce the data file
- "history": history of mods to the data, timestamps
- "references": publications, web-based references for data
- "comment" : miscellaneous information

Variable attributes – Information about the variable

- "units": one-line description of what's in data
- "long_name": a long descriptive name
- "standard_name": shorter name with no spaces
- "_FillValue": special attribute value that represents missing values (-9999.9 etc)
- "scale_factor" and "add_offset": used for packing data, making it more compact

Dimension names – naming each dimension of an array

- "time", "lev", "lat", "lon" are very common
- E.g. "This variable is dimensioned time x lev x lat x lon (1 x 194 x 201 x 300)"

Coordinate variables – gives the coordinate values for a particular dimension of an array

- Has the same name as dimension it represents

Examples of self-describing data formats

- NetCDF (Network Common Data Form) - most commonly used in climate sciences
- HDF (Hierarchical Data Format) - used by NASA and common format for satellite data
- GRIB (Gridded Binary) - Historical and forecast weather data; WMO standard highly compressed. Can be complicated to read, requires supplemental files

2. Software for climate data analysis

- CDO (http://www.mpimet.mpg.de/fileadmin/software/cdo/)

- Ferret (http://www.ferret.noaa.gov/Ferret/)
- GrADS (http://www.iges.org/grads/)
- IDL (http://www.ittvis.com/ProductServices/IDL.aspx)
- Matlab (http://www.mathworks.com/)
- ncdump (http://www.unidata.ucar.edu/software/netcdf)
- NCL (http://www.ncl.ucar.edu/)
- NCO (http://nco.sourceforge.net/)
- R (http://www.r-project.org/)
- Panoply (http://www.giss.nasa.gov/tools/panoply/)
- gnuplot (http://www.gnuplot.info/)
- wgrib (http://www.cpc.noaa.gov/products/wesley/wgrib.html)

3. Introduction to netCDF and ncdump

netCDF - the acronym stands for network Common Data Form (not Format). It's self-describing, portable, metadata friendly, supported by many languages including fortran, C/C++, Matlab, ferret, GrADS, NCL, IDL; viewing tools like ncview/ncdump; and tool suites of file operators (NCO, CDO).

ncdump - is a netcdf utility that allows one to dump the contents of the netcdf file to screen or file. Files are often too big to dump to screen, but one can look at subsets of the file using the different ncdump options.

ncdump options

$ *ncdump input.nc* - dump entire contents of netCDF to screen (generally not used: too much information)

$ *ncdump –h input.nc* - dump header from netCDF file to screen (see the next E.g.)

$ *ncdump –v input.nc* - dump the variable to the screen, after the header

$ *ncdump –v time input.nc | less* - display the time array using the UNIX command less, which allows one to page up/down using the arrows on the keyboard

Example: output using ncdump –h input.nc

```
netcdf AFRICA_GPCC_CTL_GPCC5_MM_50km_1981-2005_pr {
dimensions:
        lon = 194 ;
        lat = 201 ;
        time = UNLIMITED ; // (300 currently)
        nb2 = 2 ;
variables:
        double lon(lon) ;
                lon:standard_name = "longitude" ;
                lon:long_name = "longitude" ;
                lon:units = "degrees_east" ;
                lon:axis = "X" ;
        double lat(lat) ;
                lat:standard_name = "latitude" ;
                lat:long_name = "latitude" ;
                lat:units = "degrees_north" ;
                lat:axis = "Y" ;
        double time(time) ;
                time:standard_name = "time" ;
                time:bounds = "time_bnds" ;
                time:units = "days since 1950-01-01 00:00:00" ;
                time:calendar = "standard" ;
        double time_bnds(time, nb2) ;
                time_bnds:units = "days since 1950-01-01 00:00:00" ;
                time_bnds:calendar = "standard" ;
        float pr(time, lat, lon) ;
                pr:standard_name = "precipitation_flux" ;
                pr:long_name = "Precipitation" ;
                pr:units = "kg m-2 s-1" ;
                pr:_FillValue = 1.e+30f ;
                pr:cell_methods = "time: mean" ;

// global attributes:
                :CDI = "Climate Data Interface version 1.6.0 (http://code.zmaw.de/projects/cdi)" ;
                :Conventions = "CF-1.4" ;
                :history = "Wed Jun 12 10:56:40 2013: cdo setgrid,griddescription.txt AFRICA_GPCC_CTL_GPCC5_MM_50km_1981-2005_pr.nc AF
RICA_GPCC_CTL_GPCC5_MM_50km_1981-2005_pr_new.nc\n",
                        "Mon May 27 20:42:51 2013: ncks -d time,0,299 /terra/data/cordex/Observational_Datasets/GPCC/MM/AFRICA_GPCC_CT
L_GPCC5_MM_50km_1981-2009_pr.nc AFRICA_GPCC_CTL_GPCC5_MM_50km_1981-2005_pr.nc\n",
                        "Tue Mar 19 11:19:38 2013: cdo mergetime AFRICA_GPCC_CTL_GPCC5_MM_50km_1981-1990_pr.nc AFRICA_GPCC_CTL_GPCC5_M
M_50km_1991-2000_pr.nc AFRICA_GPCC_CTL_GPCC5_MM_50km_2001-2009_pr.nc AFRICA_GPCC_CTL_GPCC5_MM_50km_1981-2009_pr.nc" ;
                :institution = "GPCP" ;
                :title = "GPCC Full Data Reanalysis Version 5" ;
```

4. Data manipulation and analysis using CDO

The following data manipulation procedures shall be covered using CDO under part B of this manual

- Introduction to CDO
- Installation and usage
- Explore data Information
- Climatological mean calculation
- Mean annual cycle calculation
- Computing statistical values
- Interpolation

4.1 Introduction to CDO

CDO – stands for *climate data operators*. It is a Collection of command line operators to analyze and manipulate climate and numerical weather prediction model output. It can be used for netCDF, GRIB and other data formats (like SERVICE, EXTRA & IEG).
CDO was developed at the Max Planck Institute for Meteorology in Hamburg. It is a free open source tool, can be run on Linux, Windows and MacOS. Documentation and support forums can be found at https://code.zmaw.de/projects/cdo

5. Installation and usage

5.1 Installation

First go to the download page (http://code.zmaw.de/projects/cdo) to get the latest distribution.

After downloading CDO from internet, performing the following steps to compile and install:

$ gunzip cdo.tar.gz # uncompress the archive

$ tar xf cdo.tar # unpack it

$ cd cdo

$. /configure

$. /configure --with-netcdf=/usr/local/lib # type ncdump to know where netCDF is

$ make   #compile the program

$ make install

N.B: Additional libraries (netCDF, GRIB_API, HDF5) should be installed and compiled to take full advantage of cdo.

5.2 Usage

$ cdo <options><operator> input.nc output.nc # This is all you need to know about CDO

5.2.1 Options

All options have to be placed before the first operator.

Here are some of the options available for operators:

-h   help information for the operators

$ cdo -h <operator>

-f<format> Set the output file format

$ cdo -f nc copy input.grb out.nc

-g <grid> Define the default grid description by name or from file

-m<missval> Set the default missing value (default: -9e+33).

-a converts from relative to absolute time axis

$ cdo –a –f nc copy input.grb out.nc

-r converts from absolute to relative time axis

$ cdo –r –f nc copy input.grb out.nc

5.2.2 Operators

There are more than 600 operators available. The table below shows some of the operators and their description. A full list of operators can be found from the manual.

Categories*	Descrip. on	Example
File information (Info, sinfo, diff, nvar, …)	Print information about datasets	cdo sinfo file.nc
File operators (copy, merge, split ...)	Copy, merge and split datasets	cdo mergetime f2001.nc f2002.nc out.nc
Selection (selcode, selvar, sellevel, seltimestep, ...)	Select parts of a dataset	cdo seldate,2001-08-15 f2001.nc out.nc
Comparison (eq, ne, le, ge, gt, …)	Compare datasets	cdo eq
Arithmetic (add, sub, mul, div, …)	Arithmetically process datasets	cdo sub f2002.nc f2001.nc out.nc
Missing values (setmissval, setctomiss, setmisstoc, setrtomiss, …)	Set missing value	setmissval,newmiss ifile.nc out.nc
Mathematical functions (sqrt, exp, log, sin, cos, …)	Standard mathematical functions	cdo sqrt ifile.nc out.nc
Field interpolation (remapbil, remapcon, remapdis, …)	Interpolate datasets in space	cdo remapbil,n32 ifile.nc out.nc
Time interpolation (intime, intyear)	Interpolate datasets in time	cdo intyear,2002,2003 f2001.nc f2004.nc year

6. Explore data Information

Now let's see the structure and content of the netcdf file you have: *infov* and *sinfo* operators write information about the structure and content of the netCDF file to screen. Go to the directory where the data is, and then apply these operators, and see what comes out.

bash$ cdo info file.nc

```
hussenseidendris@MacBook-Pro:~/Desktop/Training_workshop$ cdo info test.nc
   -1 :       Date     Time   Level Gridsize    Miss :     Minimum        Mean     Maximum : Parameter ID
    1 : 1980-01-16 12:00:00       0    38994       0 :      0.0000  1.8312e-05  0.00044887 : -1
    2 : 1980-02-15 12:00:00       0    38994       0 :      0.0000  1.9585e-05  0.00059224 : -1
    3 : 1980-03-16 12:00:00       0    38994       0 :      0.0000  2.1490e-05  0.00051283 : -1
    4 : 1980-04-16 00:00:00       0    38994       0 :      0.0000  2.1516e-05   0.0014011 : -1
    5 : 1980-05-16 12:00:00       0    38994       0 :      0.0000  2.0761e-05  0.00085891 : -1
    6 : 1980-06-16 00:00:00       0    38994       0 :      0.0000  1.5107e-05  0.00050233 : -1
    7 : 1980-07-16 12:00:00       0    38994       0 :      0.0000  1.4281e-05  0.00064682 : -1
    8 : 1980-08-16 12:00:00       0    38994       0 :      0.0000  1.5379e-05  0.00069933 : -1
    9 : 1980-09-16 00:00:00       0    38994       0 :      0.0000  1.5825e-05  0.00059557 : -1
   10 : 1980-10-16 12:00:00       0    38994       0 :      0.0000  1.5346e-05  0.00050480 : -1
   11 : 1980-11-16 00:00:00       0    38994       0 :      0.0000  1.7797e-05  0.00053030 : -1
   12 : 1980-12-16 12:00:00       0    38994       0 :      0.0000  1.8862e-05  0.00069348 : -1
```

bash$ cdo sinfo file.nc

```
hussenseidendris@MacBook-Pro:~/Desktop/Training_workshop$ cdo sinfo test.nc
   File format : netCDF
    -1 : Institut Source   Ttype    Levels Num    Points Num Dtype : Parameter ID
     1 : unknown  unknown  instant       1   1     38994   1  F32  : -1
   Grid coordinates :
     1 : curvilinear              : points=38994 (194x201)
                              lon : -24.64 to 60.28 degrees_east
                              lat : -45.76 to 42.24 degrees_north
   Vertical coordinates :
     1 : surface                  : levels=1
   Time coordinate :  372 steps
     RefTime =  1949-12-01 00:00:00  Units = days  Calendar = standard  Bounds = true
  YYYY-MM-DD hh:mm:ss  YYYY-MM-DD hh:mm:ss  YYYY-MM-DD hh:mm:ss  YYYY-MM-DD hh:mm:ss
  1980-01-16 12:00:00  1980-02-15 12:00:00  1980-03-16 12:00:00  1980-04-16 00:00:00
  1980-05-16 12:00:00  1980-06-16 00:00:00  1980-07-16 12:00:00  1980-08-16 12:00:00
  1980-09-16 00:00:00  1980-10-16 12:00:00  1980-11-16 00:00:00  1980-12-16 12:00:00
```

You may compare these results with the result from NCO operator (i.e ncdump)
$ ncdump –h input.nc

7. Climatological mean calculation

Let's calculate the annual and seasonal mean (JJAS, OND, MAM) values for the period of 1989 to 2008. Note: First you need to go to the directory where you stored the data.

selyear allow you to select years

timmean calculates the mean over all timesteps in a file (e.g. annual mean clim)

selmon allow you to select months

yearmean calculates yearly mean

7.1 Computing the annual mean step by step:

$ cdo selyear,1989/2008 input.nc out_1989_2008.nc

$ cdo timmean out_1989_2008.nc out_1989_2008_clim.nc

Piping: All operators with a fixed number of input streams and one output stream can pipe the result directly to another operator. The operator must begin with ”–”, in order to combine it with others. This can improve the performance by reducing unnecessary disk I/O and parallel processing.

Piping:

$ cdo timmean –selyear,1989/2008 input.nc out_1989_2008_clim.nc

Note sometimes commands are too long to fit on one line. If a line does not start with $, the command is continued on the next line and you should not press enter until it is complete.

7.2 Computing the seasonal mean (JJAS) step by step:

Step-by-step computation of JJAS mean season:

$ cdo selyear,1989/2008 input.nc out_1989_2008.nc

$ cdo selmon,6,7,8,9 out_1989_2008.nc out_1989_2008_jjas.nc

$ cdo timmean out_1989_2008_jjas.nc out_1989_2008_jjas_clim.nc

Or use Piping:

$cdo timmean -selmon,6/9 -selyear,1989/2008 out_1989_2008_jjas_clim.nc

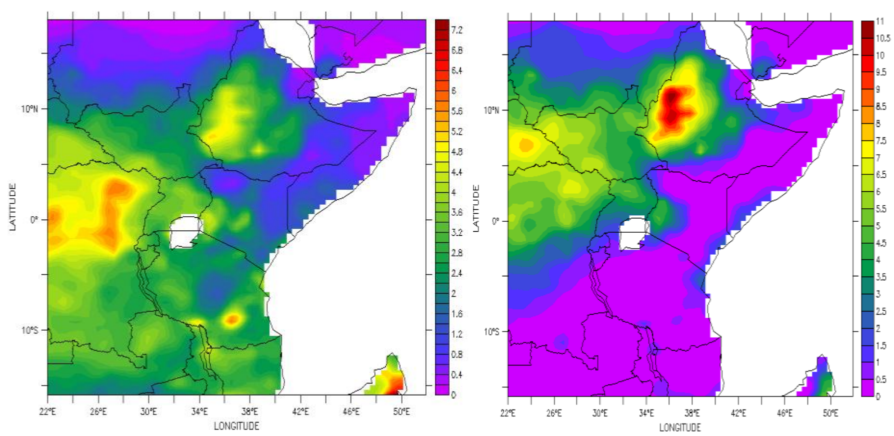


Figure 1: Annual mean (left) and seasonal mean (right) rainfall over East Africa, units in mm/day

Note that we will use ferret for the visualization, not cdo. We will start the ferret session once we complete the cdo tutorial.

8. Mean annual cycle calculation

sellonlatbox allows you to extract an area from fields by choosing lon1,lon2,lat1,lat2.
fldmeancalculates field mean (e.g area average)
ymonmean computes the mean of all the time steps of multiple years in each month (e.g. annual cycles)

Step-by-step computation of mean annual cycle:

$ cdo sellonlatbox,33.75,40.25,7.25,15.25 input.nc out_box.nc
$ cdo fldmean out_box.nc out_box_fldmean.nc
$ cdo ymonmean out_box_fldmean.nc out_box_ymonmean.nc
Piping:
$ cdo ymonmean –fldmean -sellonlatbox, 33.75,40.25,7.25,15.25 input.nc out_box_ymonmean.nc

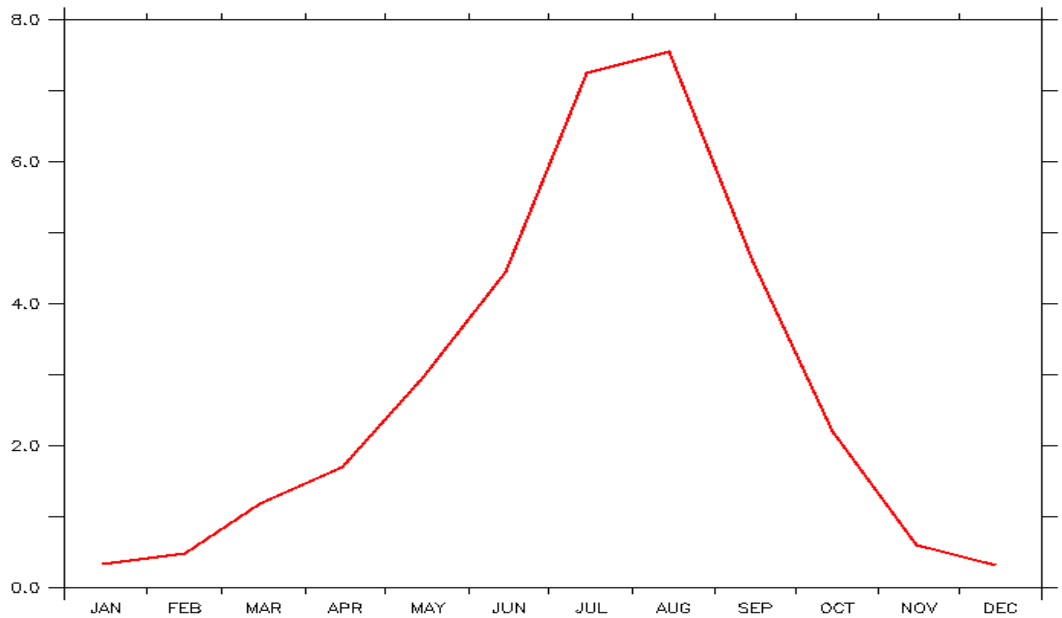


Figure 2: Annual Cycle of Rainfall over Ethiopian highlands

9. Computing statistical values

This section contains some of the operators to compute statistical values of datasets.
Standard deviation

bash$ cdo timstd input.nc output.nc#Twime standard deviation with divisor n
bash$ cdo timstd1 input.nc output.nc#Time standard deviation with divisor is n-1
Bash$ cdo fldstd input.nc output.nc#Field standard deviation with devisor n

Correlation and covariance

bash$ cdo timcor input1.nc input2.nc output.nc#Correlation over time
bash$ cdo fldcor input.nc input.nc output.nc#Correlation in grid space
bash$ cdo timcovar input.nc input.nc output.nc#Covariance over time

Bash$ cdo fldcovar input1.nc input2.nc output.nc#Covariance in grid space

Climate indices

bash$ cdo eca_cdd input.nc output.nc#Consecutive dry days index per time period
bash$cdo eca_cwd input.nc output.nc#Consecutive wet days index per time period
bash$cdo eca_r10mm input.nc output.nc#Heavy precipitation index per time period
bash$ cdo eca_rr1 input.nc output.nc #Wet days index per time period

10. Interpolation/regridding

Note that to compare spatial model and observation fields they must firstly be on the same grid. So we will regrid the datasets to the same grid. Theobserved datasets we use for this training (i.e GPCC) isat 0.5-degree resolution. The resolution of the CORDEX simulations is 0.44-degree so we will regrid the model data onto the observation grid.

There are several operators to interpolate horizontal fields to a new grid (E.g. remapbil, remapbic,remapdis …)

Thefollowing example shows you how to remap all model fields to an observed horizontal grid using griddes and remapbil.

$ cdo griddes obs_data.nc > obsgrid

$ cdo remapbil,obsgrid mod_data.nc mod_data_obsgrid.nc

* griddes prints a description of the input field(s) grid (i.e the observed grid in this case)
* remapbil - remaps all input fields to a new horizontal grid using bilinear interpolation.

Note: obsgrid is used as the target grid for remapping.

Alternatively, you can remap all input fields to a new horizontal grid by using the following command.

Bash$ cdo remapbil, griddescription.txt inputfile.nc outputfile.nc

The file “griddescription.txt” must look like the following:

gridtype=lonlat
xsize=194
ysize=201
xfirst=-24.64
yfirst=-45.76
xinc=0.44
yinc=0.44

Part III: Data analysis and visualization using Ferret

Contents:

- Introduction to ferret
- Most common and useful commands
- Importing and manipulating data
- Create maps
- Saving output
- Writing your own script

1. Introduction to ferret

Ferret is an interactive analysis and visualization environment that allows users to explore large and complex gridded data sets.It is a free open source tool; can be run on Linux, Windows and MacOS.It can be used for netCDF, GRIB, ASCII and other binary formats. Download and documentation can be found at: http://www.ferret.noaa.gov/Ferret/.

NB: Ferret User's Group provides a venue to ask experienced ferret users for advice solving problems.

Note that ferretis not case-sensitive, i.e., commands and variable names may be entered in upper or lower case. Commands may be entered either entered interactively at the prompt or by a script file (filename.jnl in Ferret).

2. Most common and useful commands

Here's a list of the most common and useful commands:

Command	***Description:***
USE	Names the data set to be analyzed (alias for "SET DATA")
SHOW DATA	Produces a summary of variables in a data set
SHOW GRID	Examines the coordinates of a grid
SET REGION	Sets the region to be analyzed/plotted
LET	Defines a new variable
PLOT	Produces a plot
CONTOUR	Produces a contour plot
FILL	Produces a color-filled contour plot
SHADE	Produces a shaded-area plot
VECTOR	Produces a vector arrow plot
GO	Executes Ferret commands in a .jnl file
STATISTICS	Produces summary statistics about vars and expressions
SAVE	Saves data in NetCDF format
LIST	Produces a listing of data (also outputs to a file)
!	Comment in a .jnl file

The sequence of operations in ferret is simply:

- ✓ Specify the data set
- ✓ Specify the region
- ✓ Define the desired variable or expression (optional)
- ✓ Request the output

3. Getting started

To start ferret, type "ferret" at the Unix prompt. Once you do that, you will see the ferret "yes?" prompt.

```
home@icpaclab:~$ ferret
NOAA/PMEL TMAP
FERRET v6.82
Darwin 9.8.0 – 08/06/12
28-Apr-15 12:36
cancel mode journal sp rm –f ferret.jnl
yes?
```

To execute a journal file (filename.jnl), which is just a sequence of Ferret commands in a file, type *GO* filename at the Ferret prompt. A quick way to get to know ferret is to run the tutorial provided with the distribution.

yes? go tutorial

The tutorial demonstrates many of ferret's features, showing the user both the commands given and ferret's textual and graphical output.

4. Importing and manipulating data

Let's look at an example using the COADS (Comprehensive Ocean/Atmosphere Data Set), and suppose we want to shade the sea surface temperature in the equatorial Indian Ocean using this climatology.
First, we load or specify the data set:

yes? use coads_climatology! you can use "set data" instead of "use"

What variables are contained in this data set? What is the resolution of the data?
To answer these questions, the commands: *SHOW DATA* and *SHOW GRID* variable are useful. These commands should also be used for diagnosing problems and debugging.
yes? show data! produces a summary of a variable

```
yes? show data
     currently SET data sets:
    1> /usr/local/ferret/fer_dsets/data/coads_climatology.cdf  (default)
 name     title                             I         J         K         L         M         N
 SST      SEA SURFACE TEMPERATURE          1:180     1:90      ...       1:12      ...       ...
 AIRT     AIR TEMPERATURE                  1:180     1:90      ...       1:12      ...       ...
 SPEH     SPECIFIC HUMIDITY                1:180     1:90      ...       1:12      ...       ...
 WSPD     WIND SPEED                       1:180     1:90      ...       1:12      ...       ...
 UWND     ZONAL WIND                       1:180     1:90      ...       1:12      ...       ...
 VWND     MERIDIONAL WIND                  1:180     1:90      ...       1:12      ...       ...
 SLP      SEA LEVEL PRESSURE               1:180     1:90      ...       1:12      ...       ...
```

yes? show grid sst !produces the coordinates of the variable

```
    GRID GSQ1
 name        axis              # pts   start                end
 COADSX     LONGITUDE          180mr   21E                  19E(379)
 COADSY     LATITUDE            90 r   89S                  89N
 normal     Z
 TIME       TIME                12mr   16-JAN 06:00         16-DEC 01:20
 normal     E
 normal     F
```

5. Create maps

Now we know what the variables are and that the resolution of the data, we can define a region which is in the tropical Indian ocean for the month of January and then shade the sea surface temperature (sst) for that region. Note: A region can be defined either in terms of the X, Y, Z or T value, or in terms of the corresponding indices, I, J, K and L.

yes? SHADE SST [X=30E: 80E,Y=30S: 30N,L=1]

yes? go land 1 “” 1

The purpose of the “go land” command is to overlay the continental and national boundaries.

Exercise:

a. Analyse and plot the observed seasonal rainfall climatology over Greater Horn of Africa (JJAS, MAM and OND)?
b. Analyse and plot the observed annual cycle over three homogeneous rainfall sub-regions?

You have already calculated the climatology and annual cycle using cdo before, so you just use ferret only for visualization.

6. Saving output

Graphical Output:

A quick way to save images in ferret is using the frame qualifier:

yes?frame/file=filename.gif

To create a publication-quality postscript file, type the following command in ferret, prior to creating the plot

yes? SET MODE METAFILE

This creates a file called metafile.plt in the current directory. Once you exit Ferret and have a Unix prompt, type:

Fprint -o filename.ps metafile.plt

This Unix command creates a postscript file called filename.ps from the metafile.plt.
Data file:
Data or computations from ferret may be saved into files using the LIST command, e.g.:

yes? LIST/file=precipitation.output/format=(20E11.3)/order=xy/L=7 pr

The file qualifier lets you specify a filename for the output. The format qualifier lets you specify a format for ASCII output. Format can also be "UNFORMATTED", which creates a fortran-compatible binary file, or "CDF" which produces NetCDF formatted output.

7. Write your own ferret script

It is not necessary to re-type Ferret commands every time you want to generate a plot. Especially if you are analyzing large climate model outputs, typing ferret commands into ferret command line would be very time very time consuming. So we will write a ferret script instead. A script contains a series of Ferret commands and comment lines (lines beginning with!). A Ferret script can be identified by a file name ending in .jnl. To run a script, use the go command.

Example:

To start with, open an empty file using a gedit editor (a different editor) with a *.jnl extension. You can use a different edior other than gedit if you are comfortable with it.

gedit filename.jnl & # this will open an empty file

Now you can write the computation within the script

! Example Type the following commands:

use file.nc !N.B use quotation marks if you are importing files from a different directory.

sh d

shade var[x=x1:x2,y1:y2,l=1]

go land 1 “” 1

frame/file=filename.gif

To run the script:

yes? go myscript.jnl

8. Comparing models and observation(s)

At this stage, we believe the basic syntaxes of CDO and ferret analysis of climate data are understandable. Thus our next task is to evaluate the performance of CORDEX models in reproducing the recent-past climate over the region.

First we will evaluate the Era-Interim driven CORDEX RCMs (10 RCMs) in simulating climate of the region. Secondly we will assess the performance of one regional climate model (i.e RCA model) driven by different CMIP5 GCMs in representing the climate of the region.

Exercise 1: Evaluating Era-Interim driven CORDEX RCMs over the region

How the models reproduce the seasonal mean rainfall over GHA (JJAS, OND, MAM)?

How the models represent the annual cycles over different homogeneous rainfall sub-regions (NEA, EEA, and SEA)? NEA (lon=33.75, lon2= 40.25 lat1=7.25, lat2= 15.25), EEA (lon1=44.25, lon2=51.75, lat1=2.25, lat2=11.75), SEA (lon1=28.75, lon2=35.25, lat1=-15.25, lat2=-2.25). Some portion of EEA fall over the ocean, so you may apply a land mask to EEA region (a value of 0 for water, 1 for land using a file landmask.nc, $cdo mul model.nc landmask.nc out.nc)

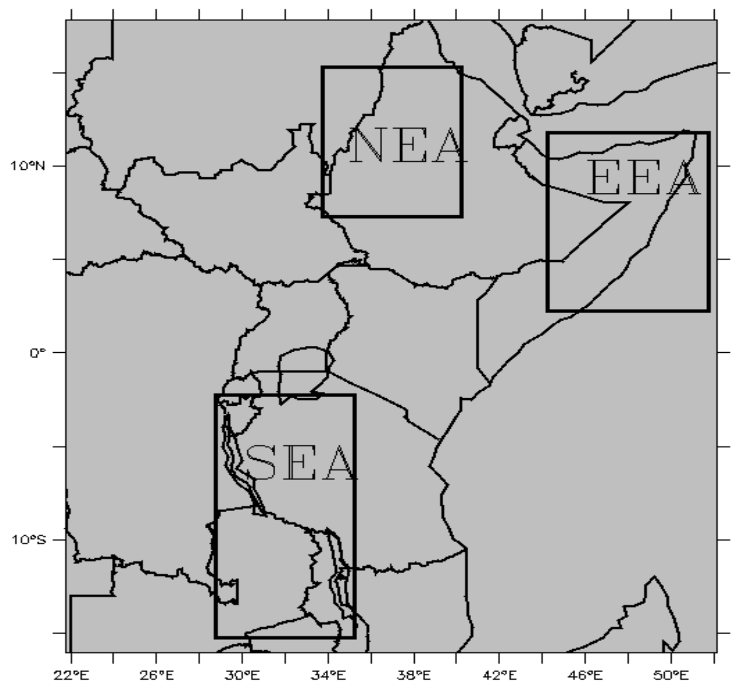


Figure 3: Rainfall sub-regions over Greater Horn of Africa

Do the models show a wet or dry bias from observation over the GHA region?

Exercise 2: Evaluation of historical simulations (RCA driven by different CMIP5 GCMs)

How different boundary forcing from GCMs affects the RCM's ability in reproducing the regional climate?
To see the effect of boundary condition, compare GCM driven results (RCM(GCM) –

GPCC) with ERA-interim driven results (RCM(ERA) – GPCC)

Assess the added value by RCM. To assess the added value by the RCM use this following formula

RCM AV = (GCM-GPCP)**2 - (RCM(GCM)-GPCP)**2

9. More ferret commands

Setting up the plot window:

set window n — Send graphics to window n
set window/size=1.0 — Resize window to 1.0 of full
set window/aspect=0.7 — Change aspect ratio to 0.7

Plot layout:

set viewport ll — Lower left of window [also: lr, ul, ur]
set viewport left — Left half of window [also: right]
set viewport upper — Upper half of window [also: lower]

Colour palettes:

palette blue_darkred — User colour palette blue_darkred
spawn Fpalette '*' — List all available palettes
go try_palette blue_darkred — Display palette blue_darkred

Customizing plots:

shade/set_up/options data — Set up a plot
ppl commands — Customise the plot using ppl
ppl shade — Generate the plot

fill, plot and shade options:

shade/hlimits=0:10:1 — Horizontal axis range and interval
shade/vlimits=0:10:1 — Vertical axis range and interval
fill/title="My title" — Specifies a plot title
contour/over/nolab — Overlay contours without adding a label
go land — Overlay continental boundaries
contour/over — Overlay contours

ppl commands:

ppl labset Sets character heights for labels
ppl axlsze Sets axis label heights
ppl shakey Controls the shade key
ppl axlint Sets numeric label interval for axes
ppl xfor Sets format of x-axis numeric labels
ppl yfor Sets format of y-axis numeric labels
ppl xlab Sets label of x-axis
ppl ylab Sets label of y-axis

Much more ferret commands found at:
http://ferret.pmel.noaa.gov/Ferret/documentation/users-guide

Part IV: Creating future climate scenarios and analyzing change (using CDO and ferret)

Contents

- Creating climate change fields
- Future time series
- Creating a future scenario

1. Creating climate change fields

In this section we will calculate the climate change signals for the nearer future (2031-2060) and the end of the 21st century (2070-2099) with respect to thebaseline (1976–2005)

Example:Calculate the future change in OND precipitation (2070-2099)in rcp4.5 projection.

$ cdo remapbil,obsgrid -mulc,86400 -timmean -selmon,10/12 -selyear,1976/2005model1_baseline.nc model1_baseline_1976_2005_OND_timmean_rg.nc

$ cdo remapbil,obsgrid -mulc,86400 -timmean -selmon,10/12 -selyear,2070/2099model1_future_rcp45.nc model1_future_rcp45_2070_2099_OND_timmean_rg.nc

Now find the change
$ cdo sub model1_future_rcp45_2070_2099_OND_timmean_rg.nc model1_baseline_1976_2005_OND_timmean_rg.ncmodel1_future_baseline_OND_diff.nc

Calculate the future change in OND precipitation as a percentage.

Calculate 100*(diff/baseline)

$ cdo mulc,100 -div model1_future_baseline_OND_diff.nc model1_baseline_1976_2005_OND_timmean_rg.nc model1_future_baseline_OND_diff_perc.nc

Exercise:

Calculate the seasonal climate change signals (JJAS, OND, MAM)in each model for the nearer future (2031-2060) and the end of the 21st century (2071-2099) with respect to the baseline (1976 – 2005) in both rcp4.5 and rcp8.5 projection.

Modify and use the bash script that you used for historical simulations.

2. Future time series

Now let’s calculate 2070-2099 monthly time series of precipitationrelative to the 1976-2005 baseline monthly mean.

ymonsub command subtracts multi-year monthly time series

$cdo ymonsub model1_future_rcp45.nc -ymonmean
model1_baseline_1971_2000.nc model1_future_rcp45_tseries_diff.nc

$ cdo mulc,86400 -fldmean -sellonlatbox,33.75,40.25,7.25,15.25
model1_future_rcp45_tseries_diff.nc model1_future_rcp45_tseries_diff_NEA.nc

3. Creating a future scenario

There are several different possible approaches to create climate change scenarios from model projections. This is just one example to demonstrate how CDO tools can be implemented to do this.

For example let's create a climate change scenario over east Africafor 2070 to 2099, which comprises a timeseries of monthly mean rainfall which has a mean derived from the observed mean plus the modelled change but has variability directly simulated by the model.

Note: This example assumes that model biases are systematic.

The first step is to create the monthly mean annual cycle from both observation and model baseline.

Create the monthly mean annual cycle from the model baseline.

$ cdo ymonmean model1.nc model1_ymonmean.nc

Create the monthly mean annual cycle from the observation

$ cdo ymonmean obs.nc obs_ymonmean.nc

Calculate the monthly mean annual cycle model bias (model minus observations).

$ cdo sub model1_ymonmean.nc obs_ymonmean.nc model_ymonmean_bias.nc

Remove the monthly mean bias from the modelled future monthly (daily) timeseries

$ cdoymonsub model_future.nc model_baseline_ymonmean_bias.nc
model_future_scinario.nc

Note: If you use daily data the first step is to put all of each month's daily fields into one file.
To create the climate change scenario for eastern Africa(blue nile) is to find the model bias by subtracting the model monthly means from the observation monthly means.

$ cdo model_monmean_baseline.degC.nc > mygrid
$ cdo remapnn,mygrid cru_monmean_baseline.nccru_monmean_baseline_rg.nc
$ cdo sub cru_monmean_baseline_rg.ncmodel_monmean_baseline.degC.nc
run_mod_bias.nc

Now from the future time series of monthly precipitation, take the monthly model bias. You will also need to extract the blue nile area and convert from K into degrees C. This can all be done in one command:

$ cdo ymonsub -subc,273.15 -sellonlatbox,lon1,lon2,lat1,lat2
model_rcp45.nc run_mod_bias.ncrun_ccscenario.nc

$ cdo infov model_ccscenario.nc

2) Plot the climate change scenario for temperature over eastern Africa/blue nile.
Can you explain another method which could be used to produce a future temperature scenario?

Part V: R- User Manual

1.0 Introduction

R is a powerful statistical program and environment for computing graphics. It can be run on Windows and Linux and other platforms and is freely available. You can download the program and user manuals from the Comprehensive R Archive Network (CRAN) website: http://cran.r-project.org/.

1.1 Installation Guide

From the CRAN website, download R by double clicking on the icon of choice and follow the instructions:

- Download R for Linux
- Download R for (Mac) OS X
- Download R for Windows.

Ensure you install the latest version (R-3.2.0 for Windows -32/64 bit)

- For linux installation you can install R in Ubuntu (Others include: open suse, linux mint etc). Press Ctrl+Alt+T to launch the terminal and type the following;

```
> sudo apt-get install r-base-core ##step 1 is to ensure that the internet is connected to your system
> sudo apt-get install r-base-dev  ##Enter this command if you want more than the standard packages
> R  ## You can now type R to launch the program.
> update.packages ()        ## This will update your packages.
```

R prompts you to type the commands using the greater than (>) symbol on the RConsole. For example, to quit R, the command is > q ( ). On quitting you will be asked whether you want to save the data from your R session. Say know unless you need the data.

[The RConsole allows command editing through left and right arrow keys, home, end, backspace, insert, and delete keys and a command history through the up and down arrow keys]

1.2 Installing Tinn-R editor

The Tinn-R is an editor/word processor ASCII/UNICODE generic for the Windows operating system, very well integrated into the R, with Graphical User Interface (GUI) and Integrated Development Environment (IDE). Tinn-R can be freely available from: http://sourceforge.net/projects/tinn-r/. Download and save in your computer and then install.

The R-Language recognizes Rgui.exe and Rterm.exe which simply put are the two alternative RConsoles. A screen-shot of the R Editor, Console (RGui) and Graphics Inter-phase is shown below.

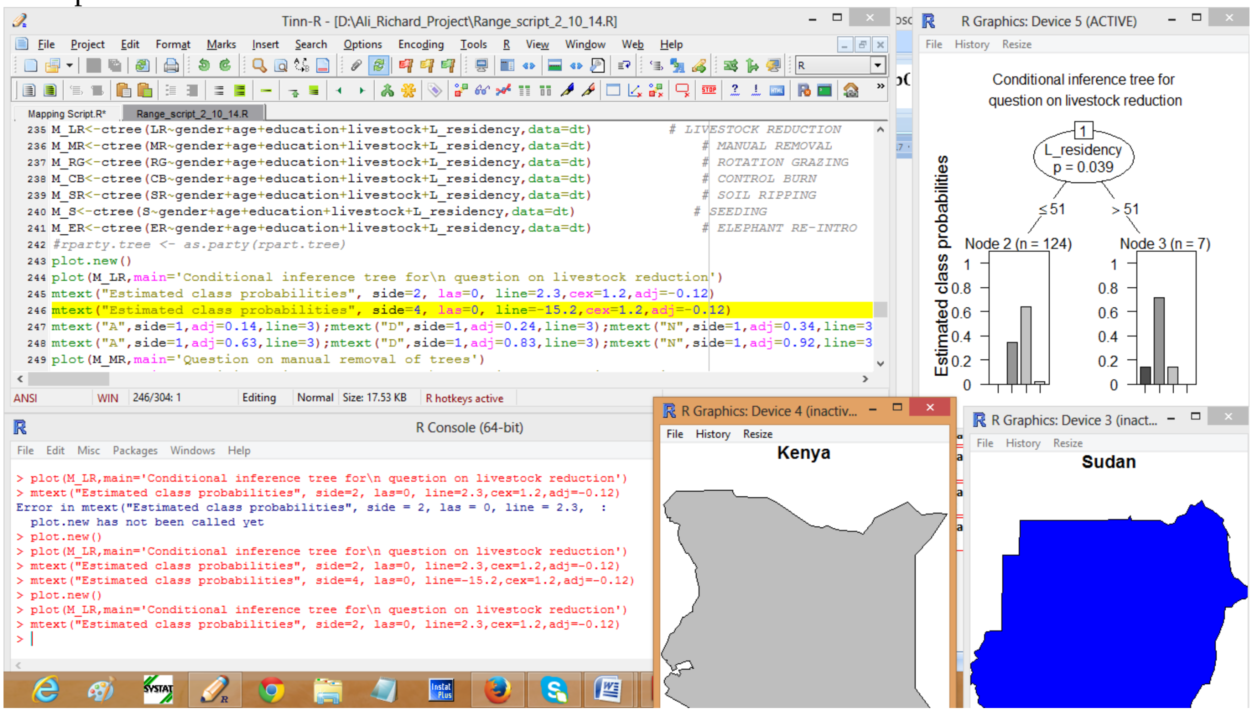
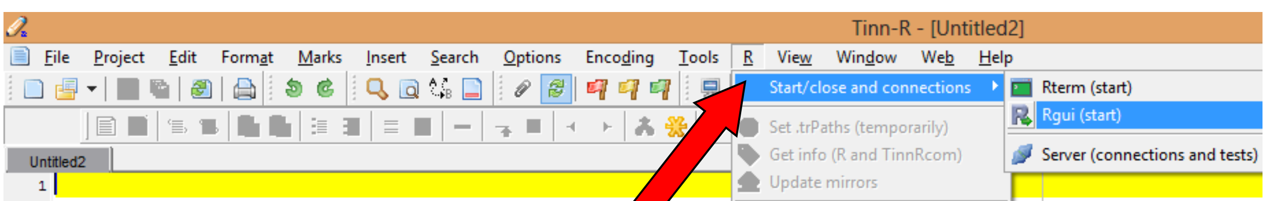


Figure 3: R working Space, Console and Graphics interface

1.3 Starting R

<u>Step1</u>

After completing the installation process, you should see a "Tinn-R" icon on your desktop (you should have saved this during installation). Clicking on this would start up the standard Tinn-R editor interface, from where you can launch the RConsole (see below).



Alternatively, one may download and install RStudio ((http://rprogramming.net/download-and-install-rstudio/). It is similar to the above only that it comes "all in one window" but with some slight modifications.

<u>Step 2</u>

Once you have the two panels ready, you can start a new working space from the Tinn-R editor…File menu …New. You can write down your commands/scripts in this and save as a file for future use.

1.3.1 Expressions and Assignments

The basic operators in R are '+', '-', '/', '*', '^', which stands for addition, subtraction, division, multiplication and the exponent (power). You can enter expressions directly in RConsole the way one does in the calculator. For example,

> 5*10 # multiplication

Note that for more extensive/complex analysis you need to write/type the commands in the editor in order to edit, review and store for future reference or use.

You can assign a value, a vector, table, data series, or matrix of values to a variable (name). R is case sensitive i.e. x ≠ X,

Basic Data Types: You can have or create

1. Vectors and assignment to a variable (x)

```
> x <- c(10.4, 5.6, 3.1, 6.4, 21.7)    # assigns the values to x
> y <- c(x, 0, x)                      # assigns the values to y
```

Using the function c ()

The vectors above can also be used in arithmetic expressions (x & y) i.e.

```
>  v <- 2*x + y + 1                    # assigns the arithmetic to v
> v
 [1] 32.2 17.8 10.3 20.2 66.1 21.8 22.6 12.8 16.9 50.8 43.5
```

Calculating the mean of the vector x you can simply use the function mean ()

```
> mean(x)                          > sum(x)/length(x)
[1] 9.44    This is same as:       [1] 9.44
```

Character vector

```
> State <- c("Kenya", "Tanzania",  "Uganda", "Djibouti", "Sudan", "Zambia",  "Ethiopia",  "Burundi",
+ "Eritrea", "Zimbabwe", "South Africa", "Egypt", "Ivory Coast", "Libya")
```

Can be converted to factors by using the function factor () : > factor (State)

2. Data frames

```
> d <- data.frame(Red=1:6, Blue=4:9, Green=10:15)
> d
  Red Blue Green
1   1    4    10
2   2    5    11
3   3    6    12
4   4    7    13
5   5    8    14
6   6    9    15
```

You can add another variable/Column to the data frame as follows:

```
> d$Yellow<-c(yellow=16:21)
> d
  Red Blue Green Yellow
1   1    4    10     16
2   2    5    11     17
3   3    6    12     18
4   4    7    13     19
5   5    8    14     20
6   6    9    15     21
```

If you are interested in selecting the first column only you can use the "**[ ]**" or the **"$"** operator to slice off the first column as follows:

```
> d[,1]
[1] 1 2 3 4 5 6
> d$Red
[1] 1 2 3 4 5 6
```

To retrieve elements from the first column of the data frame-'d', you add **"[[**]]" operator after selecting the column (d [,1]) and then define which element you want to select e.g. for the first element choose…. **"[[1**]]" .

```
> d[,1][[1]]
[1] 1
> d$Red[[1]]
[1] 1
```

Create a data frame from vector and calculate mean

```
> State <- c("Kenya", "Tanzania",  "Uganda", "Djibouti", "Sudan", "Zambia",  "Ethiopia",  "Burundi",
+ "Eritrea", "Zimbabwe", "South Africa", "Egypt", "Ivory Coast", "Libya")
> Rain <- c(500,678,541,370,398,429,560,590,1004,340,499.3,720.5,359.8,520.3)
> df <- data.frame(State, Rain)
> tapply(df$Rain, list(State=State), mean)
State
     Burundi     Djibouti        Egypt      Eritrea     Ethiopia  Ivory Coast        Kenya        Libya South Africa        Sudan     Tanzania       Uganda
       590.0        370.0        720.5       1004.0        560.0        359.8        500.0        520.3        499.3        398.0        678.0        541.0
      Zambia     Zimbabwe
       429.0        340.0
```

***** We can try this out with own data e.g. rainfall for MAM, JJA or any other data

3. Matrix

A matrix is a collection of data elements arranged in a two-dimensional rectangular layout. The following is an example of a matrix with 2 rows and 3 columns. We reproduce a memory representation of the matrix in R with the matrix function. The data elements must be of the same basic type.

```
> A <- matrix( c(2, 4, 3, 1, 5, 7), # the data elements
+ nrow=2,              # number of rows
+ ncol=3,              # number of columns
+ byrow = TRUE)        # fill matrix by rows
> A # print the matrix
     [,1] [,2] [,3]
[1,]    2    4    3
[2,]    1    5    7
```

Retrieving Elements of a Matrix

An element at the m^{th} row, n^{th} column of A can be accessed by the expression A [m, n].

```
> A[2,3]      # element at 2nd row, 3rd column
[1] 7
> A[2,]       # the entire 2nd row
[1] 1 5 7
> A[,3]       # the entire 3rd column
[1] 3 7
> A[,c(1,3)]  # extracting more than one  column
     [,1] [,2]
[1,]    2    3
[2,]    1    7
```

1.4 Loading your data into R

Step 1: Set your working directory to where all your data and script should be stored.

Type in the command window:

`setwd("directoryname")`. e.g.

```
setwd("C:\\Documents and Settings\\user\\My Documents\\my_Climate_DATA")
```

Step 2: Load the file you wish to use

R can read a wide range of data input files / formats including text (.txt), excel (.xlsx), comma separated values (.csv) files, SYSTAT (.dta), STATA, SPSS files and even netcdf (.nc) files.

To read a text or .csv file type:

```
> mydata <- read.table("filename.txt", header=TRUE, sep=",",row.names="id")
```

To read in the worksheet named mysheet (excel) you first need to install the package / library “xlsx” and then load the file:

```
> install.packages("xlsx")
> library(xlsx)
> mydata<-read.xlsx("filename.xlsx",header=TRUE, sep=",",,sheetName="mysheet")
```

```
> mydata<-read.csv("filename.csv",header=TRUE, sep=".",)
```

Similarly, for NetCDF file require the library “ncdf”

install.packages (“ncdf”)

```
> library(ncdf)
> file <- open.ncdf(ncfilename.nc)
```

Summarizing DATA

You can summarize your data with mean, standard deviation, etc.), broken down by group and so on. To view some statistics you can use the function summary ().
Recall: data “d”, and data frame “df”

```
> d
  Red Blue Green Yellow
1   1    4    10     16
2   2    5    11     17
3   3    6    12     18
4   4    7    13     19
5   5    8    14     20
6   6    9    15     21
> summary(d)
      Red              Blue            Green             Yellow     
 Min.   :1.00   Min.   :4.00   Min.   :10.00   Min.   :16.00  
 1st Qu.:2.25   1st Qu.:5.25   1st Qu.:11.25   1st Qu.:17.25  
 Median :3.50   Median :6.50   Median :12.50   Median :18.50  
 Mean   :3.50   Mean   :6.50   Mean   :12.50   Mean   :18.50  
 3rd Qu.:4.75   3rd Qu.:7.75   3rd Qu.:13.75   3rd Qu.:19.75  
 Max.   :6.00   Max.   :9.00   Max.   :15.00   Max.   :21.00  
```

```
7       Ethiopia  560.0
8        Burundi  590.0
9        Eritrea 1004.0
10      Zimbabwe  340.0
11  South Africa  499.3
12         Egypt  720.5
13   Ivory Coast  359.8
14         Libya  520.3
> summary(df)
         State         Rain       
 Burundi     :1   Min.   : 340.0  
 Djibouti    :1   1st Qu.: 405.8  
 Egypt       :1   Median : 510.1  
 Eritrea     :1   Mean   : 536.4  
 Ethiopia    :1   3rd Qu.: 582.5  
 Ivory Coast:1   Max.   :1004.0  
 (Other)     :8                   
```

1.5 Plotting in R

Once the data has been loaded, one can plot the raw data or output from the analysis of the data

To plot data, use the plot ( ) function.

For example, you may wish to plot the monthly rainfall data file. You will go like

plot(Rain, Years, type='l', col="blue",lwd=0.9, lty=1, xlab="Years", ylab="Seasonal Rainfall (mm)", main="Plot of Monthly rainfall for Kitale")

You may wish to do the seasonal sums and plot

> First do seasonal sum for MAM and then plot

> MAM=rowSums(Kitale[,3:5]) ## Performs the seasonal sum for MAM (y data)

> Years=Kitale$Years ## Defines the x-values and reads the years column in Kitale

> To plot

plot(MAM, Years, type='l', col="blue", xlab="Years", ylab="Seasonal Rainfall (mm)", main="Plot of MAM rainfall for Kitale")

Resources for further reading

1. http://cran.r-project.org/doc/manuals/R-intro.pdf
2. http://www.r-tutor.com/r-introduction
3. http://www.computerworld.com/article/2497143/business-intelligence-beginner-s-guide-to-r-introduction.html
4. http://cran.r-project.org/doc/contrib/usingR.pdf

Annexes I: To compute climatology of GHA region

```
define view/ylim=0.56,1.000  /xlim=0.00,0.30 A1
define view/ylim=0.56,1.000  /xlim=0.23,0.53 A2
define view/ylim=0.56,1.000  /xlim=0.46,0.76 A3
define view/ylim=0.56,1.000  /xlim=0.69,0.99 A4

define view/ylim=0.28,0.72  /xlim=0.00,0.30 B1
define view/ylim=0.28,0.72  /xlim=0.23,0.53 B2
define view/ylim=0.28,0.72  /xlim=0.46,0.76 B3
define view/ylim=0.28,0.72  /xlim=0.69,0.99 B4

define view/ylim=0.00,0.44  /xlim=0.00,0.30 C1
define view/ylim=0.00,0.44  /xlim=0.23,0.53 C2
define view/ylim=0.00,0.44  /xlim=0.46,0.76 C3
define view/ylim=0.00,0.44  /xlim=0.69,0.99 C4

use
"/Volumes/External/Training_workshop/data_analysed/GPCC/1986_2005/pr_GPCC_MM_50km_1
986-2005_mam_timmean_rg.nc" !d=1
use "/Volumes/External/Training_workshop/data_analysed/RCA/climatology/pr_AFR-
44_CCCma-CanESM2_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_mam_timmean_rg.nc"!d=2
use "/Volumes/External/Training_workshop/data_analysed/RCA/climatology/pr_AFR-
44_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_mam_timmean_rg.nc" !d=3
use "/Volumes/External/Training_workshop/data_analysed/RCA/climatology/pr_AFR-
44_ICHEC-EC-EARTH_historical_r12i1p1_SMHI-RCA4_v1_mon_1986-2005_mam_timmean_rg.nc"
!d=4
use "/Volumes/External/Training_workshop/data_analysed/RCA/climatology/pr_AFR-
44_MIROC-MIROC5_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-2005_mam_timmean_rg.nc"!d=5
use "/Volumes/External/Training_workshop/data_analysed/RCA/climatology/pr_AFR-
44_MOHC-HadGEM2-ES_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-2005_mam_timmean_rg.nc"
!d=6
use "/Volumes/External/Training_workshop/data_analysed/RCA/climatology/pr_AFR-
44_MPI-M-MPI-ESM-LR_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-2005_mam_timmean_rg.nc"
!d=7
use "/Volumes/External/Training_workshop/data_analysed/RCA/climatology/pr_AFR-
44_NCC-NorESM1-M_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-2005_mam_timmean_rg.nc"
!d=8
use "/Volumes/External/Training_workshop/data_analysed/RCA/climatology/pr_AFR-
44_NOAA-GFDL-GFDL-ESM2M_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_mam_timmean_rg.nc" !d=9
use "/Volumes/External/Training_workshop/data_analysed/RCA/climatology/pr_AFR-
44_ECMWF-ERAINT_evaluation_r1i1p1_SMHI-RCA4_v1_mon_1986-2005_mam_timemean_rg.nc"
!10


SET WINDOW/SIZE=1.0
SET WINDOW/ASPECT=0.74

!ppl tics,0,0,0,0
!ppl axlsze,0,0

SET VIEWPORT A1
fill/nolabel/nokey/level=(-inf)(2,30,2)(inf)
pr[d=1,x=24.20E:51.92E,y=12.32S:18.04N]
!ppl fill
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as GPCC
```

```
SET VIEWPORT A2
ppl tics,0,0,0,0
ppl axlsze,0,0
fill/nolabel/nokey/level=(-inf)(2,30,2)(inf)
pr[d=2,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(CCCma-CanESM2)

SET VIEWPORT A3
fill/nolabel/nokey/level=(-inf)(2,30,2)(inf)
pr[d=3,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(CNRM-CM5)

SET VIEWPORT A4
fill /nolabel/nokey/level=(-inf)(2,30,2)(inf)
pr[d=4,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(EC-EARTH)

SET VIEWPORT B1
fill /nolabel/nokey/level=(-inf)(2,30,2)(inf)
pr[d=5,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(MIROC5)

SET VIEWPORT B2
fill /nolabel/nokey/level=(-inf)(2,30,2)(inf)
pr[d=6,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(HadGEM2-ES)

SET VIEWPORT B3
fill /nolabel/nokey/level=(-inf)(2,30,2)(inf)
pr[d=7,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(MPI-ESM-LR)

SET VIEWPORT B4
fill /nolabel/nokey/level=(-inf)(2,30,2)(inf)
pr[d=8,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(NorESM1-M)

SET VIEWPORT C1
fill /nolabel/nokey/level=(-inf)(2,30,2)(inf)
pr[d=9,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(GFDL-ESM2M)

SET VIEWPORT C2
fill /nolabel/set_up/level=(-inf)(2,30,2)(inf)
pr[d=10,x=24.20E:51.92E,y=12.32S:18.04N]
PPL SHAKEY 1, 0, 0.18, 1, 3, 12,  -2.8, 11.2, 0.75, 1.1
PPL fill
```

```
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(ERAINT)


frame/file=climatology_historical_mam_pr_historical.gif
```

Annexes II: To compute mean annual cycle of GHA region

```
use
"/Volumes/External/Training_workshop/data_analysed/GPCC/1986_2005/pr_GPCC_MM_50
km_1986-2005_annualcycle_EEA.nc" !d=1
use "/Volumes/External/Training_workshop/data_analysed/RCA/annual_cycle/pr_AFR-
44_CCCma-CanESM2_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_annualcycle_EEA.nc"!d=2
use "/Volumes/External/Training_workshop/data_analysed/RCA/annual_cycle/pr_AFR-
44_CNRM-CERFACS-CNRM-CM5_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_annualcycle_EEA.nc" !d=3
use "/Volumes/External/Training_workshop/data_analysed/RCA/annual_cycle/pr_AFR-
44_ICHEC-EC-EARTH_historical_r12i1p1_SMHI-RCA4_v1_mon_1986-
2005_annualcycle_EEA.nc" !d=4
use "/Volumes/External/Training_workshop/data_analysed/RCA/annual_cycle/pr_AFR-
44_MIROC-MIROC5_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_annualcycle_EEA.nc"!d=5
use "/Volumes/External/Training_workshop/data_analysed/RCA/annual_cycle/pr_AFR-
44_MOHC-HadGEM2-ES_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_annualcycle_EEA.nc" !d=6
use "/Volumes/External/Training_workshop/data_analysed/RCA/annual_cycle/pr_AFR-
44_MPI-M-MPI-ESM-LR_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_annualcycle_EEA.nc" !d=7
use "/Volumes/External/Training_workshop/data_analysed/RCA/annual_cycle/pr_AFR-
44_NCC-NorESM1-M_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_annualcycle_EEA.nc" !d=8
use "/Volumes/External/Training_workshop/data_analysed/RCA/annual_cycle/pr_AFR-
44_NOAA-GFDL-GFDL-ESM2M_historical_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_annualcycle_EEA.nc" !d=9
use "/Volumes/External/Training_workshop/data_analysed/RCA/annual_cycle/pr_AFR-
44_ECMWF-ERAINT_evaluation_r1i1p1_SMHI-RCA4_v1_mon_1986-
2005_annualcycle_EEA.nc" !10


!SET MODE METAFILE:seasonal-R4.plt
SET WINDOW/SIZE=1.0
SET WINDOW/ASPECT=0.65

let pr1=pr[d=1]
let pr2=pr[d=2]
let pr3=pr[d=3]
let pr4=pr[d=4]
let pr5=pr[d=5]
let pr6=pr[d=6]
let pr7=pr[d=7]
let pr8=pr[d=8]
let pr9=pr[d=9]
let pr10=pr[d=10]

plot/vlimits=0:6:0.5/nolabel/line=13 pr1
plot/vlimits=0:6:0.5/over/nolabel/line=14 pr2[gt=pr1@asn]
plot/vlimits=0:6:0.5/over/nolabel/line=15 pr3[gt=pr1@asn]
plot/vlimits=0:6:0.5/over/nolabel/line=16 pr4[gt=pr1@asn]
plot/vlimits=0:6:0.5/over/nolabel/line=17 pr5[gt=pr1@asn]
plot/vlimits=0:6:0.5/over/nolabel/line=18 pr6[gt=pr1@asn]
plot/vlimits=0:6:0.5/over/nolabel/line=14/dashed pr7[gt=pr1@asn]
```

```
plot/vlimits=0:6:0.5/over/nolabel/line=15/dashed pr8[gt=pr1@asn]
plot/vlimits=0:6:0.5/over/nolabel/line=16/dashed pr9[gt=pr1@asn]
plot/vlimits=0:6:0.5/over/nolabel/line=17/dashed pr10[gt=pr1@asn]

LET tt = T[GT=pr1]         ! tt is the coordinates along the T axis
! place an "X" at the value exactly at 7-aug
! "@ITP" causes interpolation to exact location
LET t0   = tt[T="01-JAN-2005"@itp]
LET t1   = tt[T="15-FEB-2005"@itp]
!LET t2   = tt[T="20-OCT-2005"@itp]
LET t2=10000

plot /over/vs/nolabel/line=13 {`t0`,`t1`},{4.75,4.75}; label `t2`, 4.75,-
1,0,0.11 @AS GPCC
plot /over/vs/nolabel/line=14 {`t0`,`t1`},{4.5,4.5}; label `t2`, 4.5,-1,0,0.11
@AS RCA(CCCma-CanESM2)
plot /over/vs/nolabel/line=15 {`t0`,`t1`},{4.25,4.25}; label `t2`, 4.25,-
1,0,0.11 @AS RCA(CNRM-CM5)
plot /over/vs/nolabel/line=16 {`t0`,`t1`},{4,4}; label `t2`, 4,-1,0,0.10 @AS
RCA(EC-EARTH)
plot /over/vs/nolabel/line=17 {`t0`,`t1`},{3.75,3.75}; label `t2`, 3.75,-
1,0,0.11 @AS RCA(MIROC5)
plot /over/vs/nolabel/line=18 {`t0`,`t1`},{3.5,3.5}; label `t2`, 3.5,-1,0,0.11
@AS RCA(HadGEM2-ES)
plot /over/vs/nolabel/line=14/dashed {`t0`,`t1`},{3.25,3.25}; label `t2`,
3.25,-1,0,0.11 @AS RCA(MPI-ESM-LR)
plot /over/vs/nolabel/line=15/dashed {`t0`,`t1`},{3,3}; label `t2`, 3,-1,0,0.11
@AS RCA(NorESM1-M)
plot /over/vs/nolabel/line=16/dashed {`t0`,`t1`},{2.75,2.75}; label `t2`,
2.75,-1,0,0.11 @AS RCA(GFDL-ESM2M)
plot /over/vs/nolabel/line=17/dashed {`t0`,`t1`},{2.5,2.5}; label `t2`, 2.5,-
1,0,0.11 @AS RCA(ERAINT)


label/nouser  -0.5, 2.0, 0, 90, 0.15 @AS mm/day


frame/file=annual_cycle_EEA.gif
```

Annexes III: To compute RCM bias from observed

```
define view/ylim=0.56,1.000  /xlim=0.00,0.30 A1
define view/ylim=0.56,1.000  /xlim=0.23,0.53 A2
define view/ylim=0.56,1.000  /xlim=0.46,0.76 A3
define view/ylim=0.56,1.000  /xlim=0.69,0.99 A4

define view/ylim=0.28,0.72  /xlim=0.00,0.30 B1
define view/ylim=0.28,0.72  /xlim=0.23,0.53 B2
define view/ylim=0.28,0.72  /xlim=0.46,0.76 B3
define view/ylim=0.28,0.72  /xlim=0.69,0.99 B4

define view/ylim=0.00,0.44  /xlim=0.00,0.30 C1
define view/ylim=0.00,0.44  /xlim=0.23,0.53 C2
define view/ylim=0.00,0.44  /xlim=0.46,0.76 C3
define view/ylim=0.00,0.44  /xlim=0.69,0.99 C4

use "/home/icpaclab/Downscaling/data_analysed/RCA/pr_CCCma-CanESM2-
45_ond_timmean_rg_diff.nc"
use "/home/icpaclab/Downscaling/data_analysed/RCA/pr_CNRM-CERFACS-CNRM-CM5-
45_ond_timmean_rg_diff.nc"
use "/home/icpaclab/Downscaling/data_analysed/RCA/pr_ICHEC-EC-EARTH-
45_ond_timmean_rg_diff.nc"
```

```
use "/home/icpaclab/Downscaling/data_analysed/RCA/pr_MIROC-MIROC5-
45_ond_timmean_rg_diff.nc"
use "/home/icpaclab/Downscaling/data_analysed/RCA/pr_MOHC-HadGEM2-ES-
45_ond_timmean_rg_diff.nc"
use "/home/icpaclab/Downscaling/data_analysed/RCA/pr_MPI-M-MPI-ESM-LR-
45_ond_timmean_rg_diff.nc"
use "/home/icpaclab/Downscaling/data_analysed/RCA/pr_NCC-NorESM1-M-
45_ond_timmean_rg_diff.nc"
use "/home/icpaclab/Downscaling/data_analysed/RCA/pr_NOAA-GFDL-GFDL-ESM2M-
45_ond_timmean_rg_diff.nc"
use "/home/icpaclab/Downscaling/data_analysed/RCA/pr_ENSEMBLE-
45_ond_timmean_rg_diff.nc"

SET WINDOW/SIZE=1.0
SET WINDOW/ASPECT=0.74

!ppl tics,0,0,0,0
!ppl axlsze,0,0


SET VIEWPORT A1
ppl tics,0,0,0,0
ppl axlsze,0,0
fill/nolabel/nokey/pal=purple_orange/level=(-inf)(-10)(-8)(-6)(-5)(-4)(-3)(-
2)(-1)(0)(1)(2)(3)(4)(5)(6)(8)(10)(inf) pr[d=1,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(CanESM2)

SET VIEWPORT A2
fill/nolabel/nokey/pal=purple_orange/level=(-inf)(-10)(-8)(-6)(-5)(-4)(-3)(-
2)(-1)(0)(1)(2)(3)(4)(5)(6)(8)(10)(inf) pr[d=2,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(CNRM-CM5)

SET VIEWPORT A3
fill /nolabel/nokey/pal=purple_orange/level=(-inf)(-10)(-8)(-6)(-5)(-4)(-3)(-
2)(-1)(0)(1)(2)(3)(4)(5)(6)(8)(10)(inf) pr[d=3,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(EC-EARTH)

SET VIEWPORT A4
fill /nolabel/nokey/pal=purple_orange/level=(-inf)(-10)(-8)(-6)(-5)(-4)(-3)(-
2)(-1)(0)(1)(2)(3)(4)(5)(6)(8)(10)(inf) pr[d=4,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(MIROC5)

SET VIEWPORT B1
fill /nolabel/nokey/pal=purple_orange/level=(-inf)(-10)(-8)(-6)(-5)(-4)(-3)(-
2)(-1)(0)(1)(2)(3)(4)(5)(6)(8)(10)(inf) pr[d=5,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(HadGEM2-ES)

SET VIEWPORT B2
fill /nolabel/nokey/pal=purple_orange/level=(-inf)(-10)(-8)(-6)(-5)(-4)(-3)(-
2)(-1)(0)(1)(2)(3)(4)(5)(6)(8)(10)(inf) pr[d=6,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(MPI-ESM-LR)
```

```
SET VIEWPORT B3
fill /nolabel/nokey/pal=purple_orange/level=(-inf)(-10)(-8)(-6)(-5)(-4)(-3)(-
2)(-1)(0)(1)(2)(3)(4)(5)(6)(8)(10)(inf) pr[d=7,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as RCA(NorESM1-M)

SET VIEWPORT B4
fill /nolabel/nokey/pal=purple_orange/level=(-inf)(-10)(-8)(-6)(-5)(-4)(-3)(-
2)(-1)(0)(1)(2)(3)(4)(5)(6)(8)(10)(inf) pr[d=8,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as UC-WRF311

SET VIEWPORT C1
fill /nolabel/nokey/pal=purple_orange/level=(-inf)(-10)(-8)(-6)(-5)(-4)(-3)(-
2)(-1)(0)(1)(2)(3)(4)(5)(6)(8)(10)(inf) pr[d=9,x=24.20E:51.92E,y=12.32S:18.04N]
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as UCT-PRECIS

SET VIEWPORT C2
fill /nolabel/set_up/pal=purple_orange/level=(-inf)(-10)(-8)(-6)(-5)(-4)(-3)(-
2)(-1)(0)(1)(2)(3)(4)(5)(6)(8)(10)(inf)
pr[d=10,x=24.20E:51.92E,y=12.32S:18.04N]
PPL SHAKEY 1, 0, 0.18, 1, 3, 12,  -2.8, 11.2, 0.75, 1.1
PPL fill
go focean 5 white
go land 1 " " 1
label 38,18.7,0,0,0.19 @as UQAM-CRCM5


frame/file=bias_historical_ond_pr.gif
```