

Risk Mapping of El Niño Impacts on Climate, Seasonality and Society Using Köppens Geiger Classification Maps: A Guidebook.

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A practical guide to assessing El Niño's ability to disturb the regional and national climates worldwide. A tool to increase our knowledge and support the efforts on Disaster Risk Reduction (DRR) and strategic preparedness plans on hydrometeorological risks related to El Niño.

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Acronyms

CCB	Consortium for Capacity Building.
DRR	Disaster Risk Reduction.
ENRN	El Niño Ready Nations.
MATLAB	MATrix LABoratory.
NMHSs	National Hydrometeorological Services.
NaN	Non available data.

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1. Forward

The results presented in this guide are part of a project, funding by USAID/Office of Foreign Disaster Assistance, named “El Niño-Ready Nations” that seeks to enhance the value of National Meteorological and Hydrological Services (NMHSs) to their societies.

"El Niño-Ready Nations" (ENRN) is more than a name; it is a concept proposed by Dr. Michael Glantz from the Consortium of Capacity Building at the University of Colorado. In this sense, an "El Niño-Ready Nation" search for proactive actions focused on a multidisciplinary concept of El Niño that involves science, impacts, policy, economics, ethics & equity issues. The concept of El Niño ready nations (ENRN) is part of the broader concepts of "Weather Ready Nation"¹.

One of the key tasks was the mapping of "El Niño Climate", a study of El Niño and its capacity to disturb the "normal" regional climate worldwide, to increase knowledge and support Disaster Risk Reduction (DRR) and strategic preparedness efforts for related hydro-meteorological hazards.

Information about El Niño Ready Nation can be found in <http://elniñoreadynations.com/>

¹ <https://www.weather.gov/wrn/>

2. Background.

Usually, when working with El Niño impacts, specialists and stakeholders rely on existing impacts maps to get relevant information for their needs. Most of those maps are versions of the first maps designed by Ropelewski and Halpert² in the mid 1980s. El Niño impact maps can be important sources of awareness and knowledge for decision-makers and the public. Frequently, however, this information is not enough to capture changes at the national or subnational scales. This issue constitutes one of the main challenges along with forecasting uncertainty.

Seeking to highlight the value of using El Niño climate information for decision making, an important issue arises: How we can make El Niño impact maps more usable at the regional, national or sub-national levels?

Two important constraints that should be considered, using the traditional view of El Niño Impact maps, are:

- Impacts over a region or country usually are not uniform and tend to be concentrated in very localized areas.
- Interactions of El Niño-teleconnection with other regional circulation patterns create a strong variability of the impacts over certain areas.

These facts along with the current uncertainties in the El Niño forecast impose important challenges for the NHMSs' actions in their dealings with civil society and for the development of adequate DRR policies.

The idea behind this methodology considers that the more significant El Niño's impacts should leave their fingerprint over the climate of a region and country, creating a "disturbed" climate that can be visualized using the Köppen-Geiger classification system³. If the "normal" climate maps were compared against new climate maps that consider El Niño effects, one could describe a picture of those potential impacts and their spatial and temporal variability. This also would permit one to estimate frequencies and generate risk maps.

This approach has important innovative characteristics such as providing information, not only about the direction of change in a climate regime but also about indicating the

² Ropelewski, C. F. and Halpert, M. S. (1987). Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. *Monthly Weather Review*, 115(8), 1606-1626.

³ Naranjo, L., M.H. Glantz, S. Temirbekov, I.J. Ramírez. 2018. El Niño and the Köppen-Geiger classification: a prototype concept and methodology for mapping impacts in Central America and the Circum-Caribbean. *International Journal of Disaster Risk Science*. DOI: 10.1007/s13753-018-0176-7. <https://rdcu.be/TB3H>.

magnitude of change. These changes can have devastating and long-lasting consequences on the economy, agriculture, food insecurity, public health, and human welfare.

The main reason why the Köppen-Geiger climate classification, was used in our study, is its simplicity in comparison with others accepted climate classification schemes. It uses the temperature and precipitation statistics in its climate classification. These two climate elements are easy to measure and require a minimum amount of calculation.

Classification of the climate is based on statistical parameters; each climatic region can be defined using a shorthand code of letters for the climatic types. All the major climate groups, sub-groups, and further subdivisions are described by a combination of letters making it very simple. An important added value is that temperature and precipitation tend to affect other aspects of the physical environment such as vegetation, more directly than any other meteorological element.

Our question could be stated as follows: is an **El Niño signal strong enough to modify the Köppen-Geiger climatic classification of a region?**

2.1. The Köppen Geiger classification.

The Köppen Geiger classification creates a code of letters to identify major climate groups, sub-groups (Figure 1).

Five major climate groups are designated by capital letters:

A—Tropical Rainy Climate: The average temperature of every month is over (18°C). Annual rainfall is large and exceeds annual evaporation.

B—Dry Climate: Potential evaporation exceeds precipitation throughout the year. No water surplus.

C—Mild Temperate Climates: Coldest month has an average temperature under (18°C), but above -3°C; at least one month has an average temperature above 10°C). The sea climates have both a summer and a winter season.

D—Snowy (Continental) Climates: Coldest month has an average temperature under -3°C. The average temperature of the warmest month is above 10°C

E—Polar Climates: The average temperature of the warmest month is below 10°C. The climates have no true summer.

Four of these five groups (A, C, D and E) are defined by the temperature averages, whereas one (B) is defined by the precipitation to evaporation ratios.

Sub-Groups are designated by a second letter, applied only to the dry B climates according to the following codes: -

S—Steppe Climate: A semi-arid climate with about 15-30 inches (38-76 cm) of rainfall annually at low latitudes.

W—Desert Climate: Arid climate. Less than 10 inches (25 cm) of rainfall annually.

The letters S and W yield two combinations BS and BW.

Second Letter (Seasonal Precipitation)

f:- Moist. precipitation in all months. No dry season. This modifier is applied to A, C, and D groups, creating combinations Af, Cf, and Df. w:- Dry season in the winter of the respective hemisphere. This modifier is applied to A, C, and D groups, yielding combinations Aw, Cw and Dw.

s:- Dry season in the summer of the respective hemisphere (high sun season).

m:- Monsoon climate. Short, dry season. Applies only to A climates (Am).

To differentiate more variations in temperature, Koppen added a third letter to the code group. Meanings are as follows:

Thirds letter (Temperature patterns)

a: With hot summer; the warmest month over 22°C. Used for C and D climates.

b: With warm summer; the warmest month below 22°C. Used for C and D climates.

c: With cold, short summer; less than 4 months over 10°C. Used for C and D climates.

d: With a very cold winter; the coldest month below –38°C. Used for D climates only.

h: Dry, hot; mean annual temperature over 18°C. Used for B climates only.

k: Dry, cold; mean annual temperature under 18°C. Used for B climates only.

World map of Köppen-Geiger climate classification

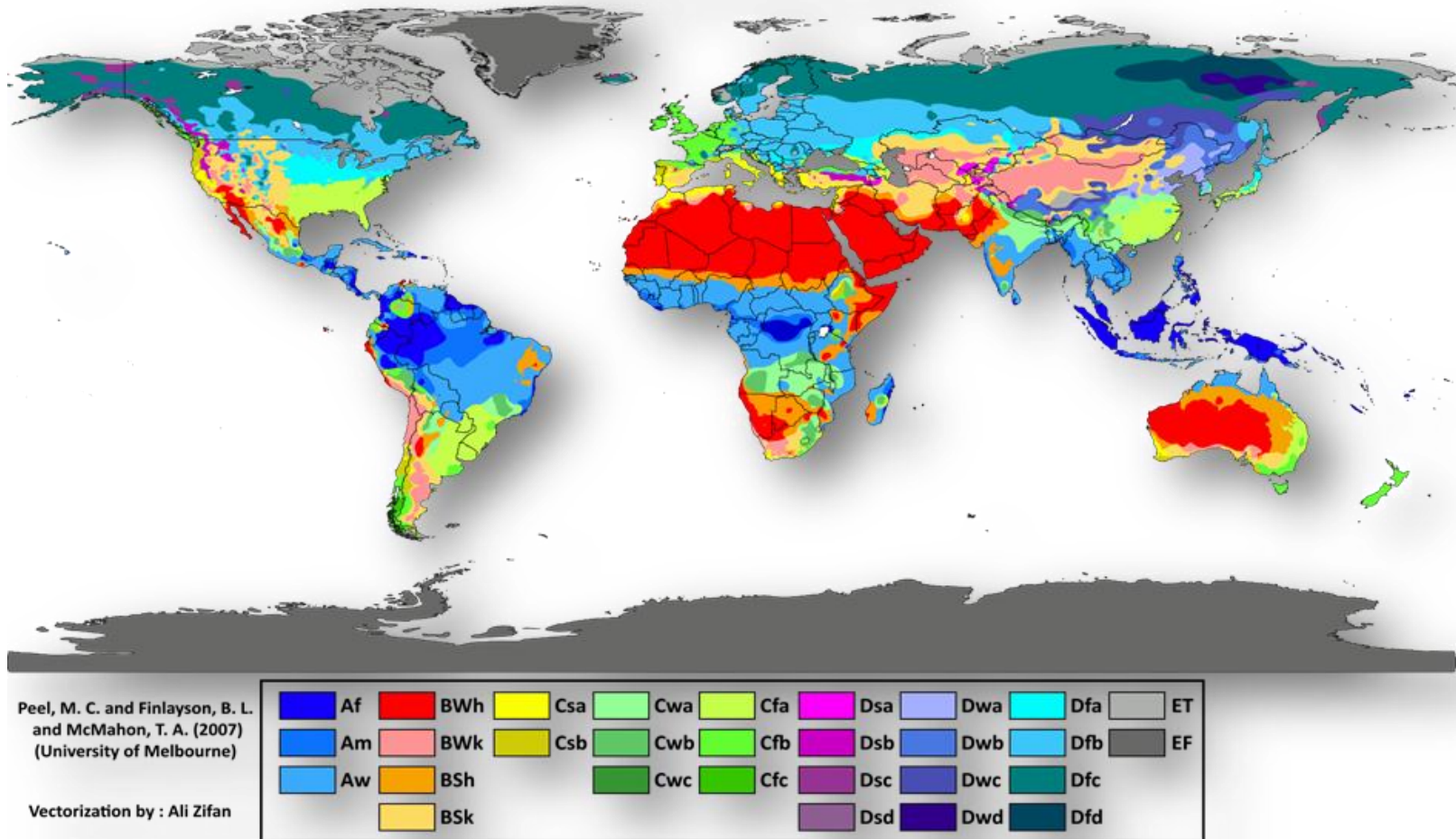


Figure 1. Global map, Köppen-Geiger climate classification.

From the combination of the letters, distinct climates groups emerge. As examples:



Figure 2. Rain forest climate

Af Called rain forest climate where rainfall of the driest month is 60 mm or more. These climates usually occur within 10° latitude of the equator. This climate is dominated by the intertropical low-pressure system all year round, so it has no natural seasons in terms of thermal and moisture changes.



Figure 3. Tropical Savannah Climate

Aw, It is the Tropical Savannah with dry winters. At least one month has rainfall less than 60 mm and less than 4% of the total annual precipitation. The dry season is strongly developed. As is used in place of Aw if the dry season occurs during the time of higher sun and longer days (during summer.



Figure 4. Steppe Climate

BSh Hot semiarid or Steppe Climate: A semi-arid climate characterized by grasslands. It occupies an intermediate position between the desert climate "BW" and the more humid climates of A, C, and D groups.



Figure 5. Hot Desert Climate

BWh. Is the Hot Desert Climate with the annual precipitation below 50% of the certain limit and average annual temperature above 18 °C. (the coldest month has an average temperature above 0 °C.)

2.2. The onset to the decay of El Niño is actually a cross-annual cycle (El Niño Year).

All Climate classifications are based on the usual Calendar Year (January-December), However, El Niño events often begin in one year and end in the next year or two, eg. they are a cross-annual event typically lasting 9 to 12 months. El Niño events tend to develop during the Northern Hemisphere (NH) Spring (March-June), reach peak intensity during the late fall or winter (November-February), and then weaken and return to neutral conditions during late spring or early summer (March-June) of the following year.

In terms of impacts, most of El Niño's impacts on the regional or national climate occur in the NH winter of the First Year and spring of following Year, where teleconnection patterns are fully developed and stronger in the higher latitudes. Additionally, NH summer could be considered a "starting point" in terms of institutional responses to an El Niño forecast, because in this season the ability of the prediction models becomes increasingly better after the so-called "Spring Barrier"⁴.

Consequently, in our approach, we define an El Niño Year as a 12-month period that begins in July of the first calendar year (onset of the event or year) and ends in June of the following calendar year (year + 1). For example, to construct the 1982-83 El Niño non-calendar year, it is necessary to consider the 12 months from July 1982 to June 1983.

3. The procedure:

3.1. Defining a data set

The calculation of Köppen-Geiger climate types and the shifts in those types associated with El Niño depend on the existence of a reliable monthly rainfall and temperature data sets with adequate spatial and temporal resolutions. The big challenge is that almost all available long-term global data sets have resolutions too coarse regarding regional, national, and subnational scales. So, in a "Perfect World" we should expect that NHMSs can develop their reliable high-resolution data. However, in the Real World, observational networks, with long-term climate data, are very scarce in those regions and countries that are particularly vulnerable to El Niño's impacts. We should consider that as El Niño has a sub-decadal multiyear frequency, we need not only reliable but also long enough data sets.

One option could be the Global observational dataset of Terrestrial Precipitation and Temperature:1900-2017 Gridded Monthly Time Series from the Department of the Geography University of Delaware (http://climate.geog.udel.edu/~climate/html_pages/download.html), which combines data from several sources interpolated into a 0.5 ° longitude × 0.5 ° latitude grid. However, although resolution could be acceptable for the use of big regions, its use is not recommended for a National or sub-national Level.

A higher resolution data option is the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) (ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/global_monthly/tifs/), a quasi-global rainfall dataset with a 0.05° resolution. Results with this dataset have been very encouraging. However, one important issue is that a similar high-resolution data set for temperature is still lacking, so it is necessary to combine with

⁴ The "Spring Barrier" is a springtime predictability barrier that causes forecasts initialized prior to May to be less skillful.

other national temperature datasets. In case there is no available temperature data the month of, it might be possible to use high-resolution climatology (such as at www.worldclim.org/). In this case, the temperature will be considered as an invariant and any calculated shift will be due only to changes in precipitation regime. This kind of approximation would be mostly valid in the Tropical belt.

3.2. Calculating Shifts Maps

Once the data set has been defined, the calculations of El Niño Köppen-Geiger classification and shifts are based on two separate processings:

1. **Calculation of the long-term average Köppen-Geiger classification for the nation or region. It is recommended to consider a 30 year or more data series.**
2. **Calculation of El Niño Köppen-Geiger classification shifts for the country or region. The El Niño year is constructed by taking 12 months from July Year 0 to June Year +1.**

The method is a very straightforward task using a matrix manipulation and processing software like MATLAB.

1. Using data of temperature and precipitation two Köppen gridded maps are constructed: A "Normal" Köppen map and an El Niño Köppen map. To calculate El Niño Köppen maps, you should use only the available El Niño years, e.g. [1982, 1997, 1986, 2002, 2009, 2015]. Each gridded map defines a matrix of Köppen values into the working space.
2. The matrix with "Normal" Köppen Values is subtracted from the El Niño Köppen matrix into the defined geographical area. As output, a gridded map of changes will be displayed. A matrix "C" with the numerical code of the changes should be saved in a file.

Although the method seems to be simple, to obtain the "shift" maps requires a logical analysis of what the observed changes mean. For example, if at a certain point, if we detect a shift from the Köppen type **Am** to type **Aw**. We must ask, what it means?

3.3. Shift Typology System (STS)

Based on the nature of the observed Köppen-Geiger climate shifts during El Niño, a classification was developed, focused on the result of what a shift means in terms of "drier" or "wetter" and "cooler" or "warmer" climate types. The classification is divided into two main groups with type and subtypes of climate shifts.

1. **Group 1: Climate shifts where the most significant changes occur over the precipitation regime**

- 1.1. Shift towards a drier climate
- 1.2. Severe dryness, likely drought conditions
- 1.3. Shift towards a wetter climate
- 1.4. Shift towards an increased contrast between the wet and dry seasons.
- 1.5. Shift towards a seasonal reversal in the occurrence of the rainfall minimum month.

2. Group 2: Climate shifts that are more significant in the temperature regime.

- 2.1. Shift towards a warmer climate.
- 2.2. Shift towards a colder climate.

Group 1 Includes climate shifts where the most significant changes occur over the precipitation.

This includes three types of traditional "wet to dry" impacts (1.1, 1.2 1,3) but with the other two giving information about seasonality. One example is the climate shift from Tropical Monsoon (Am) to Tropical Savanna (Aw). The most significant characteristic is a reinforcement of the dry season which is clearly a shift to a drier climate (type 1).

Two types of climate shifts are related to changes in the seasonal regime: 1.4 "shift towards an increased contrast between the wet and dry seasons" and 1.5 "a shift towards a rainfall seasonal reversal in the rainfall minimum month". The first of these two types indicates changes that are not necessarily linked to a drier or a wetter climate but are related to changes in rainfall in one or more seasons that increase the seasonal contrast between the wet and dry seasons. One example is the climate shift from Humid Subtropical (Cfa) to the Mediterranean (Csa). In this shift, the very stable Humid Subtropical climate changes, when anomalous rainy conditions appear in the winter season. This is a typical change in the SE of the United States.

"Seasonal reversal" appears when the monthly rainfall minimum, usually defined into the dry season shift toward one month of the rainy season. In savanna climate, a seasonal reversal means a shift from Aw type to As (savanna with a dry summer) or vice versa. Causes that lead to a seasonal reversal could be: abnormally heavy rains in the winter season followed by a dry summer (which seems to be the case of Western Cuba) or an extremely dry summer or "canicula" with drought conditions as is the case in the "Dry Corridor" area of Central America.

Group 2. More common in High and Middle latitudes in tropical areas tends to be concentrated in the continental highlands. This group is composed of two types of climate shifts. The first is a "cool to warm" type, for example, we can find a climate shift from Subtropical Highland (Cwb) to Monsoon-influenced Humid Subtropical (Cwa), in the mountainous areas of Guatemala. The second is a "warm to cool" type. An example is the climate shift from Hot Semiarid (Bsh) to Cold Semiarid (Bsk), which is basically because of

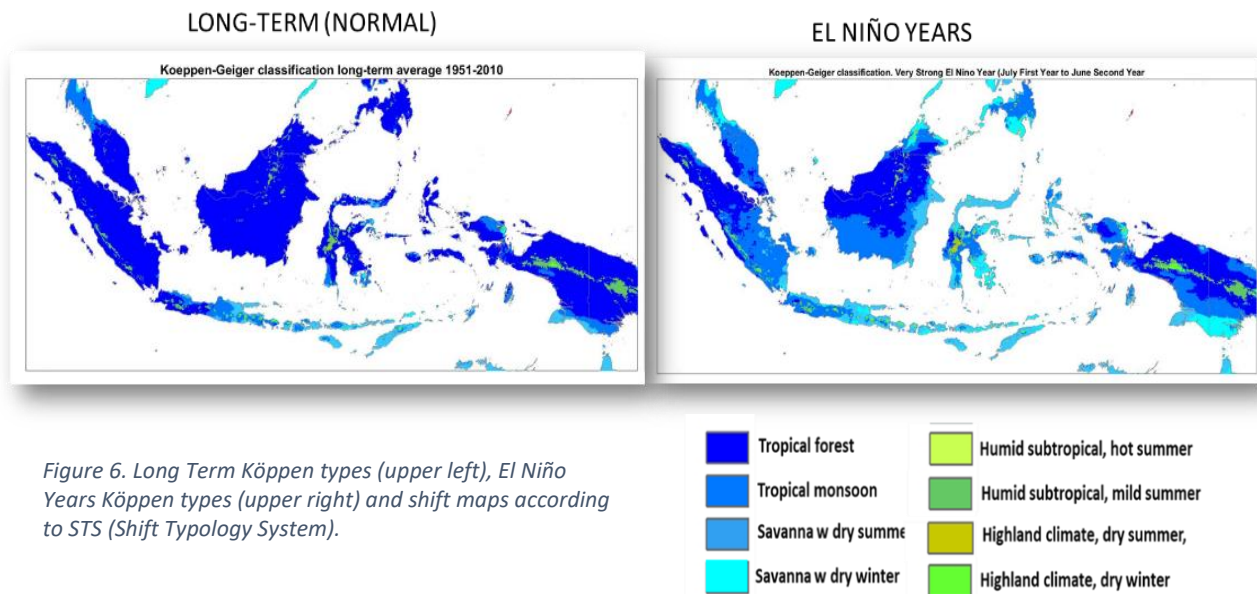
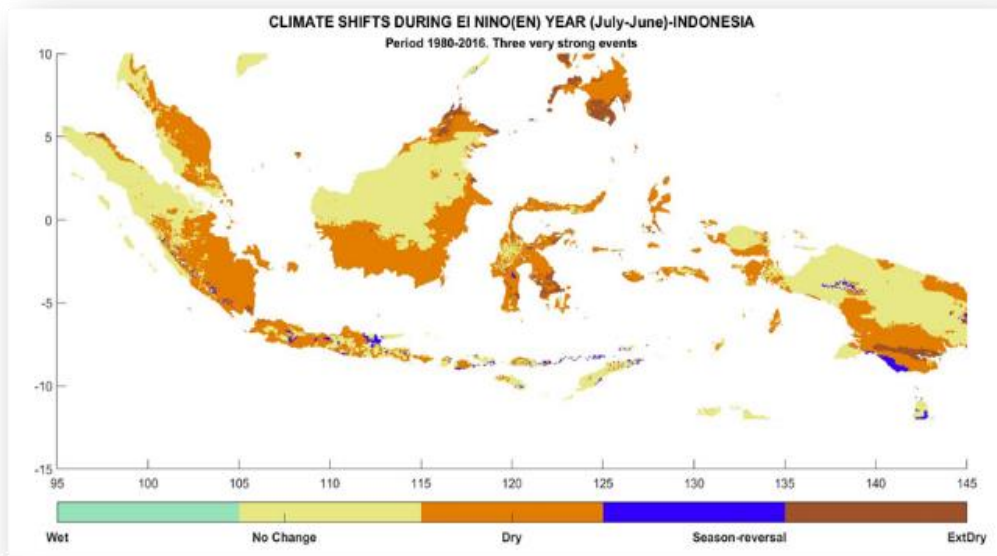


Figure 6. Long Term Köppen types (upper left), El Niño Years Köppen types (upper right) and shift maps according to STS (Shift Typology System).



the abnormal irruption of cold air masses that are found in the semiarid areas in northern Mexico.

To illustrate how it works we are showing here an example with Indonesia using the Climate Hazard Group database (figure 6).

Indonesia's climate is almost entirely tropical, dominated by the tropical rainforest climate found in every major island of Indonesia, followed by the tropical monsoon climate that

predominantly lies along Java's coastal north, Sulawesi's coastal south and east, and Bali, and finally the tropical Savanna climate, found in isolated locations of Central Java, lowland East Java, coastal southern Papua and smaller islands to the east of Lombok. Cooler climate types do exist in mountainous regions. On the average, as we can see in the figure El Niño disrupts the rainforest climate of all the majors islands particularly South of Java, South of Borneo and Celebes, moving to drier versions of the tropical climate. This means an abnormal seasonal rainfall regime with dry conditions in the rainy season. The map of the bottom right in the figure, describe these changes, based on our STS.

3.4. Why we should not rely only on average pictures?

Although average El Niño impacts maps can be important sources of knowledge and tools for decision makers, they give only a general view about what to expect and sometimes could lead to confusion and even miscalculations in DRR activities. This is due not only to the internal variability of the El Niño event but is also due to the interactions of El Niño's teleconnection patterns with other regional circulations. Keeping Indonesia as an example in figure 7 we show a shift in the precipitation regime in 1982-83 at the left and in 1986-87 to the right. Although the general pattern of El Niño's impact is similar, there are

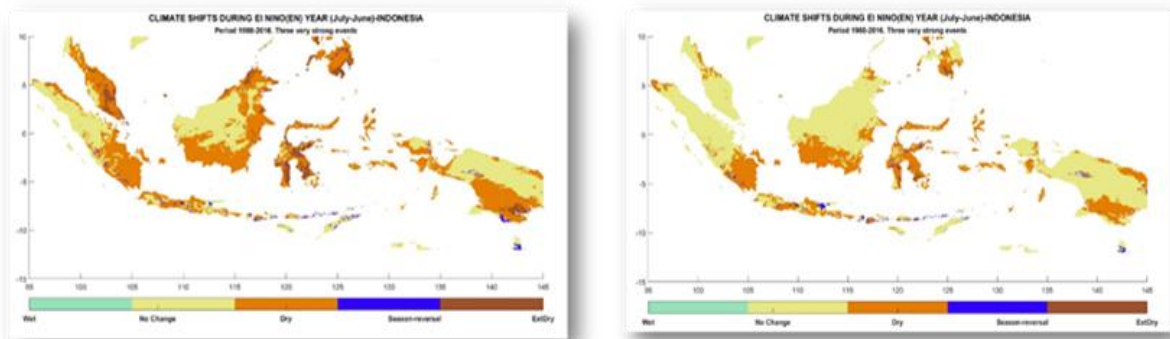


Figure 7. Climate shift in Indonesia during El Niño 1982-83 (left) and 1986-87 (right).

important differences in the extension of affected areas and the magnitude of the impacts.

So, it is important to visualize our uncertainty in terms of impact. Where impacts are more expectable, we should calculate the Frequency maps.

Frequency of impacts maps would give an important tool to policymakers and specialists. To obtain these maps, we should process El Niño Years individually to create references of variability. This step is a little more time consuming, because you will need to replicate many times the same processing, but results are encouraging. To create a year to year Köppen maps for each El Niño year we will perform steps described earlier in section 4.2, taking care that the input matrix will be one El Niño year each time, e.g. [1982], [2015].

The gridded data matrix for each year should be saved and then is compared with the long-term average classification to get individual climate shift maps. Once the year-to-year calculations are finished, frequency maps are calculated for each shift type you want as:

$$F_i^t = S_i^t/N$$

Where F_i^t is the frequency at the point "i" for a specific shift type "t" (e.g. drier climate shift, wetter climate shift etc). S_i^t is the number of El Niño Years having those shift type "t" and N the number of available El Niño years. For example if in 10 available El Niño Years (N), six of these years (S_i^t) are associated to drier climate conditions (t), then, the frequency of drier conditions (F_i^t) for this sample will be 0.6.

3.5. Why a frequency map is important

Frequency maps provide important additional information. It is a tool to identify the more vulnerable areas in a country or region and it is a quantitative measure of our uncertainty in terms of impacts. But also, maps of the frequency of dry/wet impacts open the door to the calculation of risk maps.

There is a different way to calculate a risk map. Risk estimation in a social context represents the damage or the fatalities that are statistically expected, due to the hazard impact in a certain scenario. Societal risk can be defined as the "product of the expected damage in a scenario and the frequency of this scenario".

In the context of El Niño, the societal risk is the potential economic and population losses that are anticipated with the forecast of a warm event and its related anomalies (e.g., floods and droughts). In its simplest form, the frequency map itself could be considered a measure of risk, otherwise, if we combine this information with other information such as the cost of damage, level of a disease outbreaks or simply the severity of the hazard, we can construct different risk maps.

4. How to... (Practical steps).

We designed a set of MATLAB scripts that can be classified into 3 groups:

<u>Input data.</u>	<u>Köppen Maps Calculation</u>	<u>Shifts and frequencies</u>
<i>read_multiple_temp.m</i>	<i>classKoppenNN.m</i>	<i>diferencia2.m</i>
<i>read_multiple_precip.m</i>	<i>classKoppenElNiñoY.m</i>	<i>risknew2.m</i>
<i>read_multiplerasterT1.m</i>	<i>combine.m</i>	
<i>read_multiplerasterT2.m</i>		
<i>read_mltiple_prec1.m</i>		

Input Data: Basically, we could use two types of input data, tabular data with longitude and latitude as the first columns and Gridded data. Both types have specific scripts for reading and processing, the output will be in each case three matrixes:

“loc” (coordinates),
“temp” (monthly temp) and
“precip” (monthly precipitation).

Using gridded data, we are assuming that grid dimensions and resolution of both temperature and precipitation are the same. If this is not the case, you would need to fix this issue. We created an auxiliary script called “**combine.m**”. Basically what “combine” does is to homogenize the cells size in both data sets.

Köppen Maps Calculation: For further calculations, it is necessary to calculate the Köppen maps: A “Normal” Köppen map and an El Niño Köppen map. For this step, we use an adaptation of “classKöppen” function from the toolbox “MeteoLab” from The University of Cantabria (Spain). To Calculate “Normal” Köppen maps we run “**classKoppenNN(temp,precip,loc)**”. The program will create a map with the Köppen classification for the area under study, which can be saved as .jpg or .pdf format. A vector file with a numerical representation of the Köppen classes will be saved as well into the file named “KöppenN.mat”.

For calculating, the Köppen maps of El Niño years “**classKoppenElNiñoY(temp,precip,loc)**” should be run, considering as the input data only the available first El Niño years e.g. [1982, 1997, 1986, 2002, 2009, 2015]. It will save as a vector file with a numerical representation of the Köppen classes in “KöppenEN.mat”.

Shifts and frequencies: To Calculate the climate type shift due to El Niño impacts, the script “diferencia2.m” should be used. As output, a map with the changes will be displayed. The map can be saved as .jpg or .pdf. A matrix “C” with the numerical code of the changes should be saved in a file.

To calculate frequencies, each El Niño year Köppen maps should be calculated separately e.g. [1982], [2015], etc., running the script `diferencia2` each time and taking care that resulting matrix C be saved in the workspace with a different name each time. Once all El Niño years have been processed separately, the script “**risknew2.m**” will calculate a map of the observed frequency for the selected shift (by default to a drier climate). Additionally, a map with a risk calculation is displayed.

4.1. Scripts process and process2

Scripts called “process” and “process2” have been designed to merge the functionality of all programs in “all in one” design. The first one performs the data input and the calculation of the basic data matrixes and the following one performs all the other processes, calculating shift, frequency and displaying maps. Please use these scripts as follow:

- **process** and **process2**: Calculations with gridded datasets.
- **process_mask** and **process2_mask**: Calculations with gridded datasets and masks (see below).
- **processT** and **process2T**: Calculations with tabular datasets.

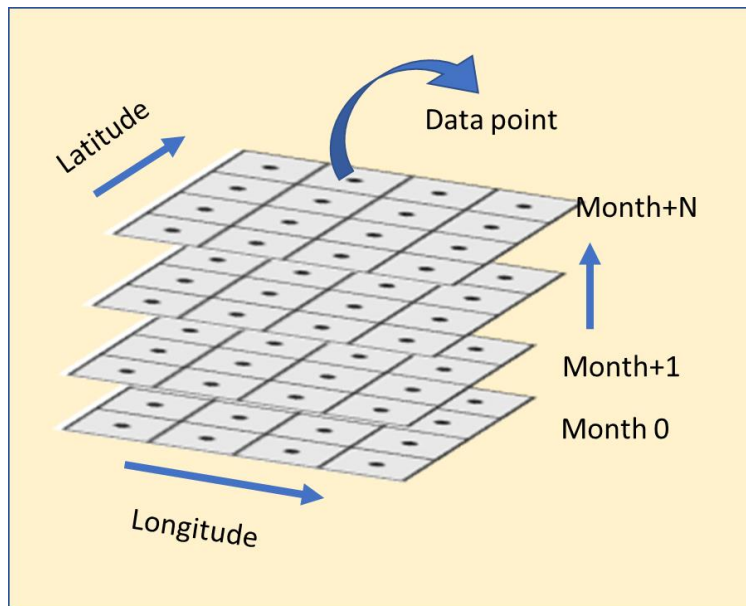


Figure 8. Schematic representation of a gridded dataset specifications.

The methodology for a gridded dataset was designed to work with monthly mean temperature and precipitation data separately. A month of each variable is represented by a two-dimensional array, where the location of each point is described by latitude and longitude in decimal degrees (figure 8).

These scripts allow to run all the steps as an “all in one” to simplify the task.

All the programs’ package can be accessed freely at the address: <https://bit.ly/2v6fmZS>. Additionally, this guidebook will help you to clarify and follow our method.

It is important to be clear that these ARE NOT recipes to be used without changes. Some parameters had to be modified according to each specific circumstance. So, you should understand every step and be creative.

Scripts are presented “as is” and they are not optimized.

4.2. Using the methodology⁵

Be sure you have installed MATLAB in your computer before you start to run the scripts. Additionally, we used a package named **MeteoLab** developed by The University of Cantabria, Spain. In our previous link we provide all the necessary programas from this

⁵ This is an ongoing activity. Programs are periodically revised to find bugs or to improve their performance. If you find any issue when follow this guide, please contact us at: lino.naranjo@gmail.com

package but for further details it can be accessed at:

https://meteo.unican.es/svn/repos/toolboxes/branches/MLToolbox_R2013.

4.2.1. Getting Ready

Before running the scripts, you should modify some lines in the scripts according with the data you are going to use, the area you are going to process, etc.

To be ready follows these steps:

1. **Define your dataset.** If you are using gridded data, your files should be in “.tif” format while tabular data are usually in text format. Name of files should be in the form “name.YEAR.MONTH.tif” where YEAR is the year in 4 digits (e.g. 1980, 1991 etc) and MONTH the two-digit month number (01 for January; 10 for October etc). Due to the number of years to be processed, YEAR is defined as a raw vector called anno1, e.g. [1982:1991] for the period 1982 to 1991.

2. **Edit the program for precipitation data acquisition.** These programs should be placed in the same folder where the dataset files are. For a gridded data, edit “read_multiple_prec1.m”; go to lines 51 to 73 and 208 to 230 and change names of the data files. Note that years are a variable defined by a numeric string array.

Additionally, in line 3 and 4 you should edit the total number of grid points in your dataset in the north-south direction (m) and in the west-east (n). In lines 10 to 13, you should edit the boundary coordinate of your dataset. For the tabular data script “read_multiple_precip.m” go to lines 7 and 14 to edit names and edit boundary coordinate on lines 23 to 27.

3. **If you have a temperature dataset, make the changes in** “read_multiple_rasterT2.m” and “read_multiple_precip.m” in the same way as with precipitation, If you are working with gridded datasets and you don’t have monthly temperature data, so you should use the long term climatology, to do this, use the script “read_multiple_rasterT1.m” changing the files name in lines 30 to 52. In the same fashion than precipitation, these programs should be allocated where in the file where the temperature datasets are.

3.2.2. Getting ready. The scripts **process** and **process2**.

1. **Once you are defined the dataset and the working region, the scripts should be modified as needed.** Change lines 1 to 4 for the latitude-longitude limits of your

working region. On line 10 you should define your raw vector for the years, called “anno1”. Be aware that on lines 11, 15, 17, 24, 33 and 53 there are defined the paths where the dataset is allocated, you should change it to your convenience. Check the path on line 1 of “process2.m” as well. Path in line 126 is the place where you are going to save some output.

2. **If you are going to use a temperature dataset** deactivate line 12 and activate lines 27, 28 and 38, 39. Default option of these scripts is the use of the temperature climatology.
3. **The scripts were designed considering 8 El Niño events** in the period 1980-2017, (1982-83, 1986-87, 1987-88, 1991-92, 1997-98, 2001-02, 2009-10, 2015-16). If you need to add new events or modify the existing years, you will have to make changes in vector on line 8.
4. Note that in the script “**process2.m**”, lines 14 to 36 some **outputs are saved in excel files** to be ready for further processing. If you don’t want to get this option, you may deactivate.
5. By default, the processing is designed to calculate the frequency maps of drier conditions. If it would be convenient to calculate frequency of wetter conditions go to the script “**risknew2.m**” and edit it changing all “>” signs to “<”. This will modify the logical loops from line 12 to 22. Run this script separately, if previously the drier condition frequency maps were calculated using “process2”.

5.2.3. Running an example. Madagascar.

To make the processing clearer, we are going to develop an example using a geographical area corresponding with Madagascar in the Southern Hemisphere.:

1. Defining our dataset. We use the Climate Hazards Group InfraRed Precipitation with Station data, CHIRPS. So the files name are in the form “'chirps-v2.0.' num2str(j) '.month_number.tif', e.g. 'chirps-v2.0.' num2str(j) '.01.tif' for monthly data of January.
2. Grid point number m=2000 and n=7200. Boundary coordinates: SL=-50, NL=50, WL=-180, EL=179.85. grid size 0.05X0.05.

3. As the available CHIRPS year-to-year dataset is only for precipitation we will use the temperature climatology dataset 'MONTH_meantemp.tif' and the script **“read_multiple_rasterT1.m”**.
4. As our working area is the Island of Madagascar, we define the boundary as: nl=-10, sl=-27, wl=42, el=52. Note that latitude in degree have negative values

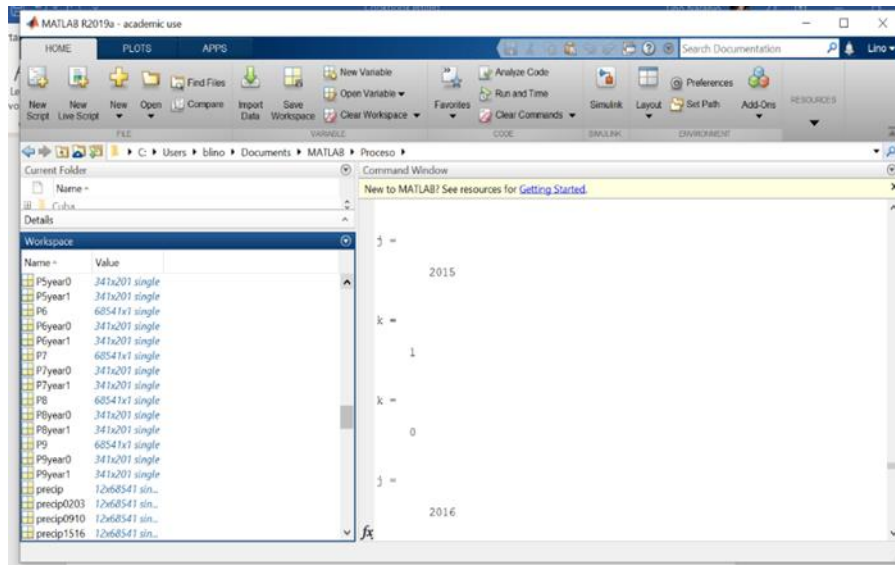


Figure9.Screen capture with the output of the script "process".

corresponding to the Southern Hemisphere and the longitude positive values corresponding to the East side of the Greenwich meridian.

5. Our available dataset is from 1980 to 2016, so our “anno1” vector is [1981:2015] and we activate the line 10 option in “process .m”.

Once our preliminary steps are finished, we run the script process.m. In the figure 9 it can be see how all matrixes and data needed for the processing are saved in the workspace.

Once “process.m” is finished run “process2.m”. This script displays 21 figures with average and year-to-year Köppen classification and shifts and frequency and risk maps. An excel file “FreqDry.xlsx” with all data has been saved in the working folder.

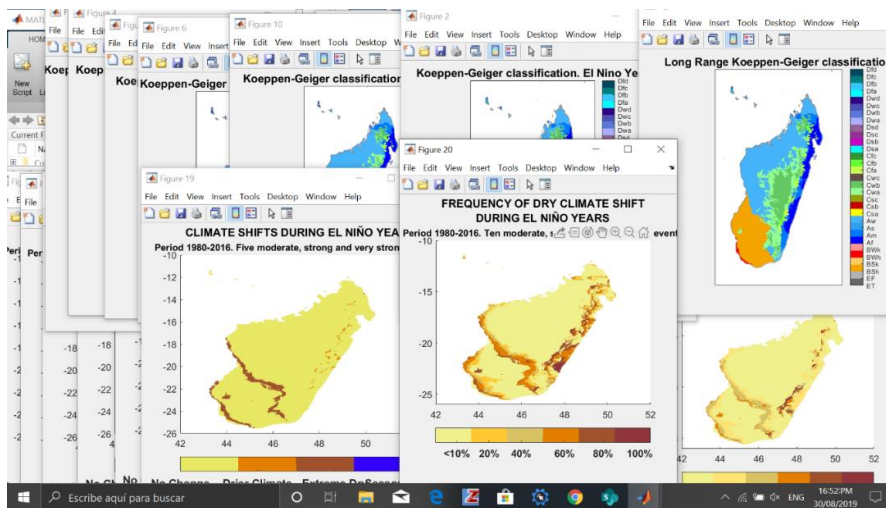


Figure 10. Screen capture with the output of the script "process2".

You can may save maps displayed by “process2.m” for further editing, using the following list:

Köppen-Geiger Classification Maps.

- Fig1: Long Range Average Köppen classification.
- Fig2: Köppen Classification for El Niño Year 1982-83.
- Fig3: Köppen Classification for El Niño Year 1986-87.
- Fig4: Köppen Classification for El Niño Year 1987-88.
- Fig5: Köppen Classification for El Niño Year 1991-92.
- Fig6: Köppen Classification for El Niño Year 1997-98.
- Fig7: Köppen Classification for El Niño Year 2001-02.
- Fig8: Köppen Classification for El Niño Year 2009-10.
- Fig9: Köppen Classification for El Niño Year 2015-2016.
- Fig10: Average El Niño Years Köppen classification.

Shift and Other Derivatives Maps.

- Fig11: Climate shift for El Niño Year 1982-83.
- Fig12: Climate shift for El Niño Year 1986-87.
- Fig13: Climate shift for El Niño Year 1987-88.
- Fig14: Climate shift for El Niño Year 1991-92.
- Fig15: Climate shift for El Niño Year 1997-98.
- Fig16: Climate shift for El Niño Year 2001-02.
- Fig17: Climate shift for El Niño Year 2009-10.
- Fig18: Climate shift for El Niño Year 2015-16.
- Fig19: Average Climate shift for El Niño Year.

Fig20: Frequency Map for Drier Climate Shift during El Niño Years.

Fig21: Estimated Risk Map for Drier Climate Shift.

5.2.4. Working with masks.

Working with a region at a national or sub-national level, usually it is convenient to consider the political boundaries or other specifications to highlight a specific working region or an inland country. So, it could be adequate to isolate the information of the country from its neighborhood. To do this you will need to define a mask with the region you are going to study. A “mask” is a (m, n) two-dimensional array with the same dimension of our working data where all point lying outside the country/region boundary are considered no-data point “NaN”.

There are different ways to design a mask to be used in our methodology. Basically, the method could be the following:

- Get a shape file “.shp” of the geographical area you are going to process. There are many web pages that you can access freely to shape files of countries.
- Using a geospatial processing program such as ArcGis or similar, convert the shape file to a raster in .tif format with a desired resolution.

We designed a set of scripts for processing, using masks with same names of the original version plus the word “mask” (e.g. “process_mask”, diferencia2_mask etc). Before starting a process, you have to upload in the MATLAB workspace a file PT.tif with the mask, then to perform all steps described in section 5.2.1 and 5.2.2. Be careful in defining the dimensions of the working region which must match the one defined by the mask file.

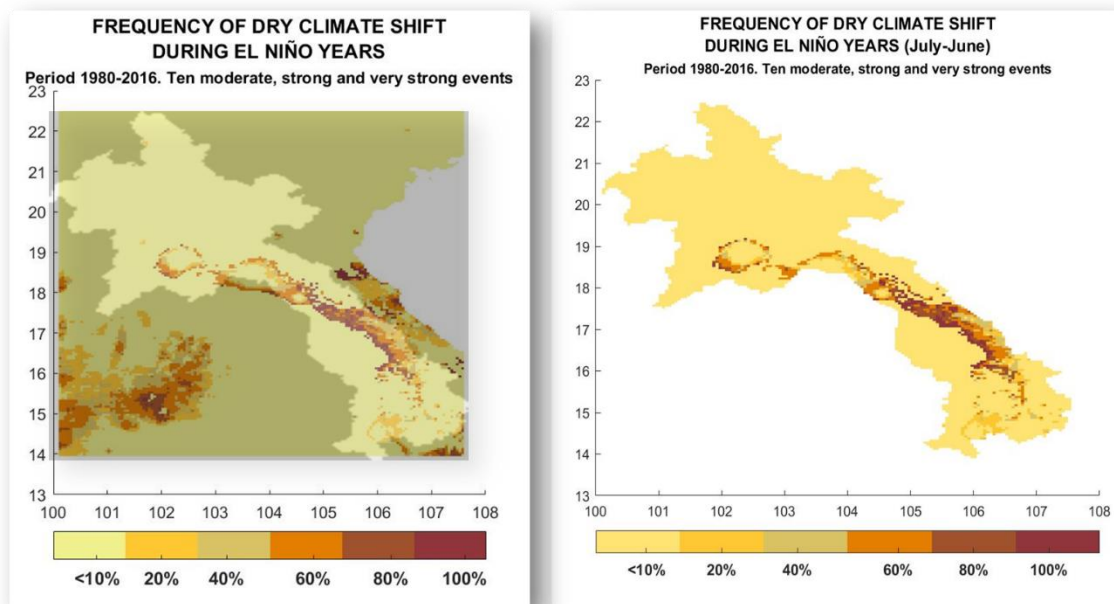


Figure 61. Use of a mask in an example with People’s Democratic Republic of Lao (see text).

For example, figure 11 left panel, shows the dry climate shifts maps obtained from the CHSRP dataset using the script “process” and “process2” for the geographical area bounded 13.95-22.5° N and 100.1-107.6° W, corresponding with the location of the People’s Democratic Republic of Lao. In the right panel the same area is presented but has been processed with “process_mask” and process2_mask” scripts. Evidently, if we want to focus on an inland country, it would be convenient to apply a “mask” to get a clearer result.

5. Final Considerations

Although results obtained with this methodology should be considered as a preliminary effort, with a wide field for improvements, they can be considered the first method as well to obtain realistic El Niño impacts maps applied to a National perspective with a direct application for Disaster Risk Reduction planning efforts. They reflect indeed the most significant consequences of El Niño in terms of social and economic impacts, accounting

for the effects of the climate anomalies generated by El Niño teleconnection patterns with devastating and potentially long-lasting consequences over agriculture, health and human welfare.

Our approach has important innovative characteristics such as being comprehensive, giving information not only about the direction of shifts in climate regime but also about their magnitude. The maps reflect the spatial variability of the impacts at a sub-national level and can account for their intrinsic time variability. Calculating, analyzing and comparing individual events permit us to visualize how the spatial structure changes and to design frequency maps of dry-wet impacts that opens the door to the calculation of risk maps.

Processing tools were designed in such a way that they could be reproduced in other countries or regions with a capability to develop high resolution data sets. As the resulting field are gridded data, they are able to be assimilated in a GIS.

While this approach and methodology has potential for DRR planning efforts, there is room for improvement. Firstly, more accurate results could be obtained, if reliably measured high-resolution precipitation and temperature data were available, which unfortunately is very unlikely in the near future for most El Niño hazards-prone countries. Secondly, in countries with remote (e.g. teleconnected) impacts, such as those in mid-latitudes, the utility of our approach has yet to be tested. The CCB Köppen-Geiger-based maps are most effective in places where El Niño-related impacts (drought, heavier rains than normal in the rainy season etc.) clearly affect the normal seasonal flow regime.

The MATLAB scripts were designed at a “user level.” We were more focused in obtaining our goals than in getting optimized structures or more adequate syntaxes. Therefore, there remains work to do to enhance the methodology. Making available all of this information in the most accessible, reliable and fastest way to the users is crucial to fulfill the urgent need, at different levels of policy and decision making, to improve the efficiency of DRR planning.