Briefing:

UNDERSTANDING CLIMATE VARIABILITY: USEFUL METHODOLOGY FOR STAKEHOLDERS

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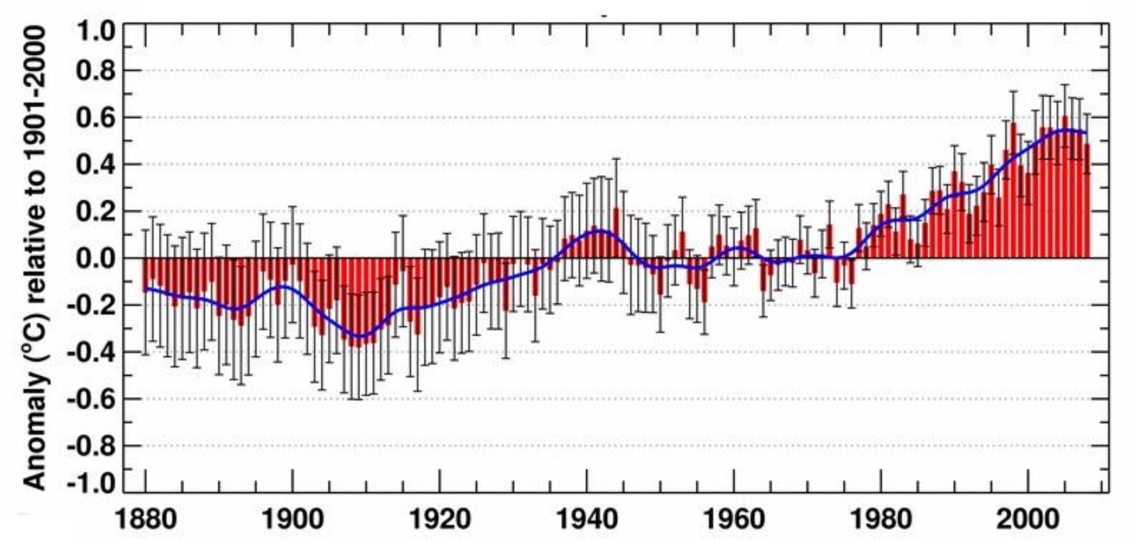
1 Introduction

There is an international consensus in the scientific community that we are in the presence of a global warming produced by the increased concentrations of Greenhouse Gases (GHGs) and aerosols (Figure 1). According to the Intergovernmental Panel on Climate Change (IPCC) in 20th Century the Earth surface increased its temperature in almost 0.7 ºC (IPCC, 2007). The estimation of how this global warming can affect regional climates is difficult and, in some cases, it has a very low reliability. We still do not know how changes in climate may vary and how the future socio-economic and environmental conditions will evolve due to its effects. However, since it is possible to provide some information on how climate change will affect ecosystems and human economy, we therefore can analyze what measures can be taken to prevent it or decrease the damages. The analysis of future climate scenarios for determining when a system or a specific sector is potentially vulnerable to climate change can be provided to the society. The limits within which the impacts will become negative or severe can also be recognized.

Figure 1. Anomalies considering January- December mean temperature over land and ocean.



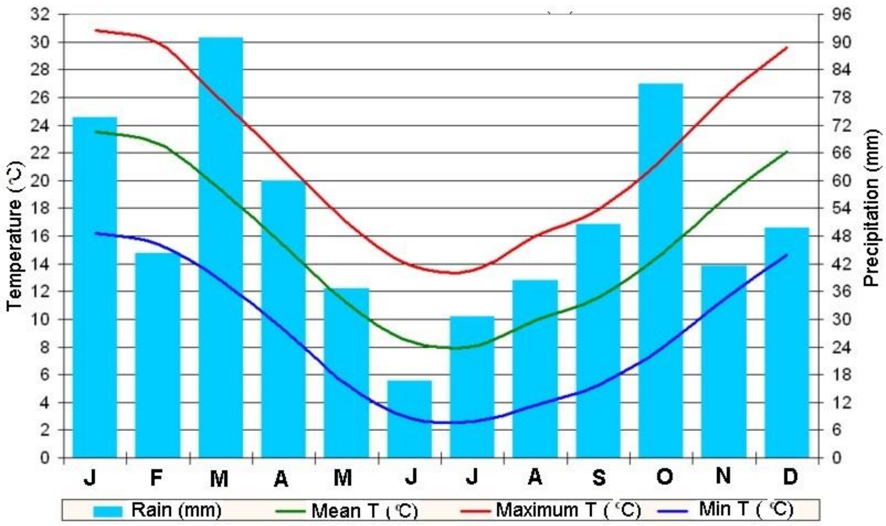
Source: NCDC/NESDIS/NOAA

There is often confusion in the general public about the difference between the climate and the weather. Weather involves the description of the atmospheric condition at a single instant of time for a single occurrence. They are short lasting meteorological events and the characteristic time scale is of a few days. Examples of an atmospheric condition are a storm, the passage of a low pressure system, strong winds, the passage of a high pressure system generating clear skies, scarce clouds, etc.

Climate may be thought of as an average of weather conditions over a period of time including the probability for distributions from this average (Houghton, 2002). The classic definition of climate indicates that it is the average state of the atmosphere for a given time scale (month, season, year, decade, etc.) and in general for a specified geographical region. The average-state statistics for a given time scale including all deviations from the mean are obtained from the ensemble of conditions recorded for many occurrences for the specified period of time (Houghton, 2002). As an example, Figure 2 shows two principal elements of the climate of Bahia Blanca city located at 10 km of the Bahia Blanca Estuary, where the COMET LA Argentine coastal study sites are located. The figure shows the mean temperatures and the annual mean monthly precipitation considering a period of 30 years.

The average-state description involves a wide range of variables depending on what is of interest. Temperature and precipitation are the most commonly variables used; however, the list may include wind, cloudiness and sunshine, pressure, visibility, humidity and elements with noteworthy human impacts such as severe storms, excessively high and low temperatures, fog, snow and hail. The description method focuses on statistical parameters, the mean and measures of variability in time such as the range, standard deviation, etc. (Houghton, 2002).

Figure 2. Monthly mean precipitation and temperature for the Bahia Blanca city. Period 1961-1990.

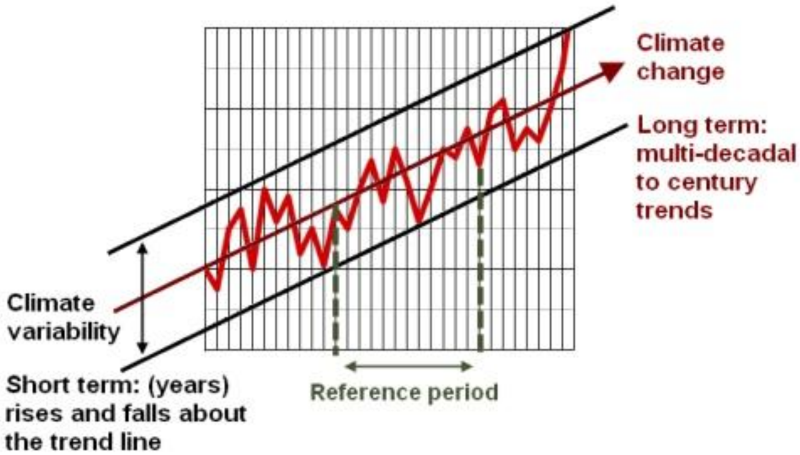


Data from the National Argentine Meteorological Service, figure adapted from Wikipedia.

If we focus only on climate processes, then we must define what is meant by climate change and climate variability. Society must make different decisions to prevent possible damages from climate change and/or climate variability. According to the time scale considered, the variations observed in meteorological parameters acquire a different denomination. Climate Change is defined as a difference over a period of time (with respect to a baseline or a ***reference period***) and corresponds to a statistical significant trend of mean climate or its variability, persistent over a long period of time (e.g. decades or more). Climate change may be due to both natural (i.e. internal or external processes of the climate system) as well as anthropogenic forcing (Environment Canada, 2012).

On the other hand, Climate Variability is defined as a deviation from the overall trend or from a stationary state, and refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales. Climate variability can be thought as a short term fluctuation superimposed on top of the long term climate change or trend (Figure 3). During a particular year, there are recorded values above or below normal. The Normal Climatological or normal value is used to define and compare the weather and generally represents the average value of a continuous series of measurements of climatic variable over a period of at least 30 years. The difference between the carrying value of the variable and its average is called *Anomaly*. In different years, the values of the climate variables (temperature, precipitation, etc.) fluctuate above or below normal. The sequence of these oscillations around the normal, known as variability and its evaluation is accomplished by determining anomalies.

Figure 3. Climate change and variability concepts.



Source: Elaine Barrow, Environment Canada, 2012

The climatic system alteration appears around the world in different ways such as floods, droughts, heat and cold waves, etc. In the last decades there are evidences that these phenomenons are more frequent and their severity is increasing (ONU, 2013). The atmospheric variability in a particular time scale is often linked to a specific set of dynamical and physical processes. It is essential then to understand the nature and origin of atmospheric variability on different time scales (Grimm, 1999). Cycles of high and low values of weather events (e.g., drought, floods) are not considered climate change unless prolonged over many decades. Therefore, it is important to analyze the inter-annual variation of the meteorological variables. The climatic statistics show significant variability from year to year, above the intrinsic random variability, associated with patterns that have characteristic properties in space and time (ie., EL Niño-Southern Oscillation (ENSO)).

The climate variability can be of low or high frequency. Low frequency variability refers to phenomena such as the North Atlantic Oscillation (NAO) or El Niño which occur at a decadal scale or longer. High frequency variability refers to meteorological events and their distribution (for example, frequency, duration and intensity of strong winds) at yearly, seasonal or monthly timescales (Environment Canada, 2012).

The largest impacts come through the meteorological parameters of precipitation and temperature. However, the atmospheric variability is intimately linked to the behavior of other components of the climate system (Grimm, 1999). For this situation, different adaptation strategies through policies and practices should be prepared to generate the necessary conditions to deal with the effects of climate variations (ONU, 2013).

2 Proposed methodology

The main objective of this work is to propose a common methodology to determine and compare the climate variability of the study sites of the COMET LA project. The main task is to understand the vulnerability of the different study sites to climate phenomena and develop possible scenarios of future weather conditions. Each study site is located in different climatic zones, different cultures and different ideas about how to focus science, etc. But the purpose of this work is to suggest easy ways to analyze meteorological information to establish the typical climate and climate variability of each region. To achieve the general objective, the following methodology is proposed. To study the climate of a given region the use of in situ data and numerical models are described. To analyze the climate variability, the different times scales that range from days to decades are briefly describe with some examples. Depending of the time series of the available meteorological data of each region, it will be possible to estimate the different climate variability.

2.1 Climate

2.1.1 From in situ data (meteorological stations)

To determine the climate of a region we must obtain a long time series of meteorological information. If there is no meteorological station in the study site, normally there is one nearby or in the region. With standard statistical methods we can analyze the information and obtain the mean values of each meteorological variable (atmospheric pressure, temperature, precipitation, relative humidity, solar radiation, winds) to describe the climate of the study zone. National Meteorological Services or any other private or government agency can provide national data. We must take in account that there are diverse meteorological data sources. Data collection varies according to each season, may be in months, days and even minutes. If we find a significant number of measuring stations in the study area, all the information should be studied to obtain a best possible climate characterization of the region.

The amount of data available will determine the type of analysis we can apply in a given region. If we have a continuous monthly data series of 50-100 years, it is possible to determine very precisely the climate and the climate variability of the region. Anomalies on the order of decades or more for any meteorological parameter may be defined. If we have a short time series of meteorological information, we still can perform the statistical analysis, but the data should be complemented with other techniques, such as the use of numerical models to determine the climate of the study area.

One of interesting theme to analyze is the behavior of the temperature and precipitation in each study site to know if they are experiencing changes related to global warming.

2.1.2 From numerical models

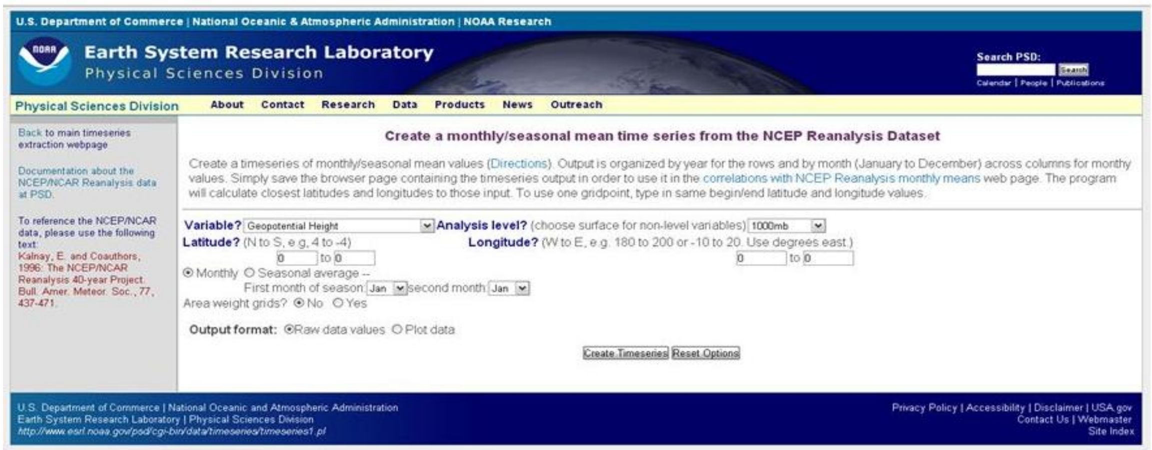
The use of numerical models to obtain climate data is increasingly used by scientists. Spatially interpolated climate data on grids are used in many applications, particularly in environmental, agricultural and biological sciences. Therefore, numerical models are useful tools to use in the COMET LA project. In literature we found several numerical models that provided climate data. Hijmans et al. (2005) describe the different ones. For the scientist that uses Geographical Information System, the Worldclim, Global Climatic data, is a free climate data model for ecological modeling. Bioclim (http://www.worldclim.org) is a model that provides bioclimatic variables that are derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). The knowledge of GIS is necessary to use the Bioclim.

Another very functional model to obtain climatic information from various meteorological parameters is the Reanalysis (NCEP / NCAR) from Kalnay et al. (1996). This model is the result of a joint project from the National Center for Environmental Prediction (NCEP), the National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration/Climate Diagnostics Center (NOAA/CDC) (http://wesley.wwb.noaa.gov/Reanalysis.html). The method is based on numerical weather prediction worldwide from various meteorological parameters from 1948 to the present (Kalnay et al., 1996, Klister et al., 2001). The spatial resolution is 2.5 ° latitude and longitude. Reanalysis data may not be accurate in subtropical latitudes and mountain areas.

Use of Reanalysis is very simple. Upon entering the website you must complete the latitude and longitude of the area of interest (with a negative sign before the number if the location is on the South hemisphere and in the Western) (Figure 4). Then you must select the variable you want to study (for example temperature, humidity, precipitation, etc. (Figure 5). These variables may be those obtained at sea level, 1000 mb, 850 mb, etc. Once completed the preference options, you must press the button "Create timeseries" to access the data.

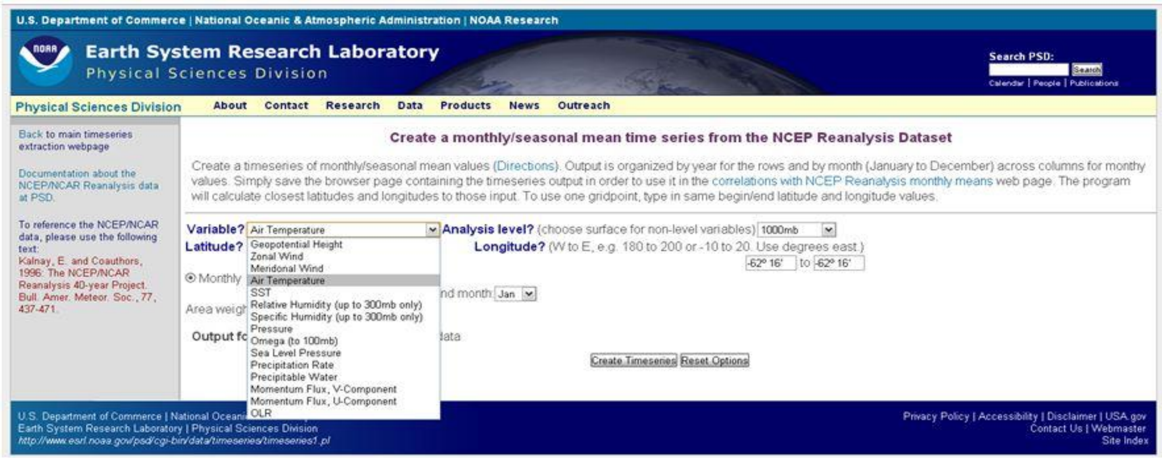
When the latitude and longitude of the study area, the meteorological variable and, the atmospheric height you want to work with is incorporated in the model, the data set is created and in the screen you can obtain the data chart from 1948 to date. The row represents the year and the columns, from left to right, the months from January to December (Figure 6).

Figure 4. Access Page to the Reanalysis model..



Source: www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl

Figure 5. Access Page to the Reanalysis model. List of variables the model offers.



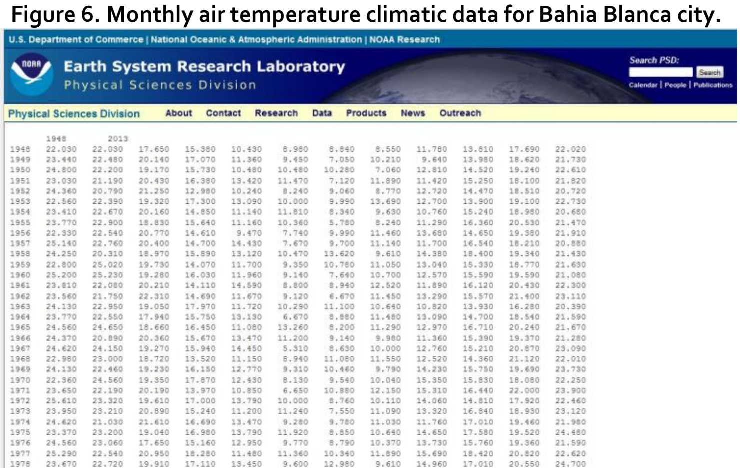
Source: www.esrl.noaa.gov/psd/cgi-bin/data/timeseries/timeseries1.pl

According to the results of different investigations, the model is not always accurate for all sites. Therefore, it is important to validate the model data with in situ measurements, if available. Figure 7 presents an example of the comparison between the temperatures measured in situ (and the calculated the mean monthly value) in Monte Hermoso coastal city (Buenos Aires Province, Argentina) and the monthly data from the reanalysis model. The seasonal temperature patterns are well represented in almost all the seasons, except in summer, where the model overestimates the temperature. One possible explanation is the low resolution of the model (2.5°) and the influence of the sea that is not incorporated in the model. The model does not represent very well the monthly behavior of the relative humidity of Monte Hermoso (Figure 7). Undoubtedly, the influence of the sea is important in the water content of the air of the coastal site.

2.2 Climate Variability

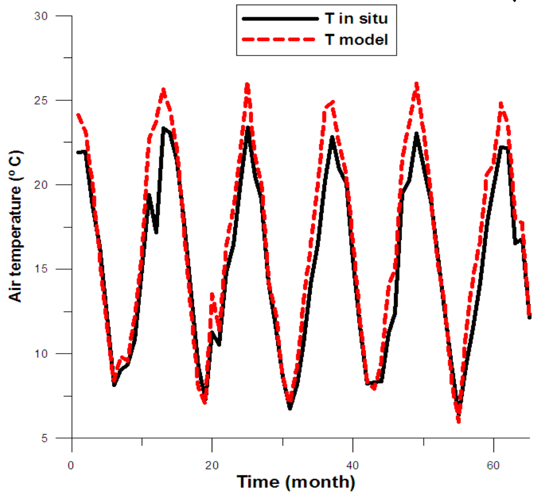
The climate variability presents different time scales. Therefore, to study the different atmospheric processes (daily, monthly, seasonal or annual), it is fundamental to generate the different manners of adaptation or mitigation to these changes. The different times scales are (Grimm, 2009):

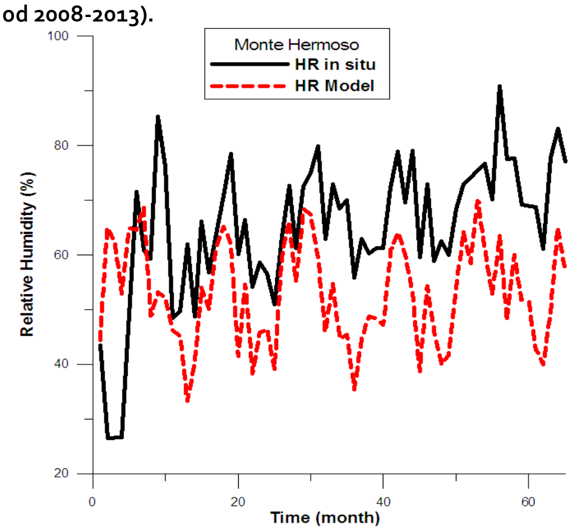
Figure 6. Monthly air temperature climatic data for Bahia Blanca city.



	1948	2013										
1948	22.030	22.030	17.650	15.380	10.430	8.980	8.840	8.550	11.780	13.810	17.690	22.020
1949	23.440	22.480	20.140	17.070	11.360	9.450	7.050	10.210	9.640	13.980	18.620	21.730
1950	24.800	22.200	19.170	15.730	10.480	10.480	10.280	7.060	12.810	14.520	19.240	22.610
1951	23.030	21.190	20.430	16.380	13.420	11.470	7.120	11.890	11.420	15.250	18.100	21.820
1952	24.360	20.790	21.250	12.980	10.240	8.240	9.060	8.770	12.720	14.470	18.510	20.720
1953	22.560	22.390	19.320	17.300	13.090	10.000	9.990	13.690	12.700	13.900	19.100	22.730
1954	23.410	22.670	20.160	14.850	11.140	11.810	8.340	9.630	10.760	15.240	18.980	20.680
1955	23.770	22.900	18.830	15.640	11.160	10.360	5.780	8.240	11.290	16.360	20.530	21.470
1956	22.330	22.540	20.770	14.610	9.470	7.740	9.990	11.460	13.680	14.650	19.380	21.910
1957	25.140	22.760	20.400	14.700	14.430	7.670	9.700	11.140	11.700	16.540	18.210	20.880
1958	24.250	20.310	18.970	15.890	13.120	10.470	13.620	9.610	14.380	18.400	19.340	21.430
1959	22.800	25.020	19.730	14.070	11.700	9.350	10.780	11.050	13.040	15.330	18.770	21.630
1960	25.200	25.230	19.280	16.030	11.960	9.140	7.640	10.700	12.570	15.590	19.590	21.080
1961	23.810	22.080	20.210	14.110	14.590	8.800	8.940	12.520	11.890	16.120	20.430	22.300
1962	23.560	21.750	22.310	14.690	11.670	9.120	6.670	11.450	13.290	15.570	21.400	23.110
1963	24.130	22.950	19.050	17.970	11.720	10.290	11.100	10.640	10.820	13.930	16.280	20.390
1964	23.770	22.550	17.940	15.750	13.130	6.670	8.880	11.480	13.090	14.700	18.540	21.590
1965	24.560	24.650	18.660	16.450	11.080	13.260	8.200	11.290	12.970	16.710	20.240	21.670
1966	24.370	20.890	20.360	15.670	13.470	11.200	9.140	9.980	11.360	15.390	19.370	21.280
1967	24.620	24.150	19.270	15.940	14.450	5.310	8.630	10.000	12.760	15.210	20.870	23.090
1968	22.980	23.000	18.720	13.520	11.150	8.940	11.080	11.550	12.520	14.360	21.120	22.010
1969	24.130	22.460	19.230	16.150	12.770	9.310	10.460	9.790	14.230	15.750	19.690	23.730
1970	22.360	24.560	19.350	17.870	12.430	8.130	9.540	10.040	15.350	15.830	18.080	22.250
1971	23.650	22.190	20.190	13.970	10.850	6.650	10.880	12.150	15.310	16.440	22.000	23.900
1972	25.610	23.320	19.610	17.000	13.790	10.000	8.760	10.110	14.060	14.810	17.920	22.460
1973	23.950	23.210	20.890	15.240	11.200	11.240	7.550	11.090	13.320	16.840	18.930	23.120
1974	24.620	21.030	21.610	16.690	13.470	9.280	9.780	11.030	11.760	17.010	19.460	21.980
1975	23.370	23.200	19.040	16.980	13.790	11.920	8.850	10.640	14.650	17.580	19.520	24.480
1976	24.560	23.060	17.650	15.160	12.950	9.770	8.790	10.370	13.730	15.760	19.360	21.590
1977	25.290	22.540	20.950	18.280	11.480	11.360	10.340	11.890	15.690	18.420	20.820	22.620
1978	23.670	22.720	19.910	17.110	13.450	9.600	12.980	9.610	14.960	17.010	20.550	24.700

Figure 7. In situ and numeric model (Reanalysis) monthly air temperature and relative humidity at Monte Hermoso (Period 2008-2013).



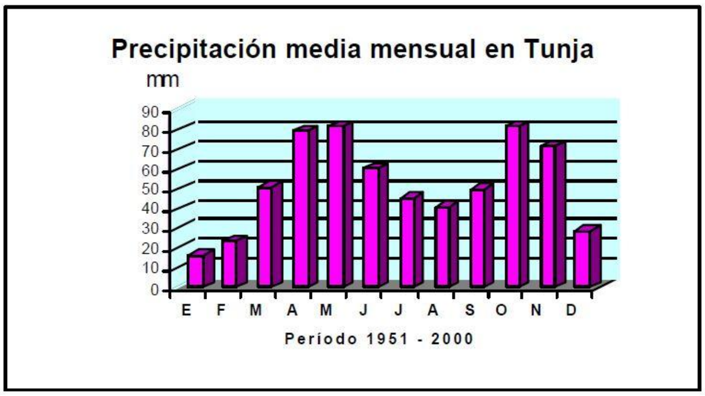


2.2.1 Seasonal and Intraseasonal variability

This variability involves processes that have periods ranging from about 10 days to a season. These processes are relevant to medium and long-range weather forecasting. Processes may vary within the seasons, generating oscillations that determine the weather conditions for weeks and even one or two months. Since its amplitude is small compared to the annual cycle, most of the time, these oscillations go unnoticed by the general public. This variability was unknown until very recently. Intraseasonal oscillations have been detected in the convective activity of the Eastern Tropical Pacific (ETP) and in the precipitation of tropical America. The Madden-Julian Oscillation, discovered in 1971, is the largest component of the intraseasonal variability (30–90 days) in the tropical atmosphere associated to the ETP and precipitation in tropical Americas. Other examples are the persistent high pressure centers in the extra tropics (blocking), intraseasonal variations with periods of 10-30 days, etc.

The seasonal scale corresponds to the monthly level while the determination of the annual cycle from the climate elements is a key stage in climate variability. In middle latitudes, the common sequence of winter, spring, summer and fall is essential for the planning of activities that depends from this alternation, while in tropical latitudes, it is more important to know how frequent the occurrence of rainy and dry seasons are. The planning of activities, particularly agriculture, energy and transport, depend on the knowledge of such periodic sequence. The migration of the Intertropical Confluence Zone - ITCZ (rainfall producing system) is considered one of the most important climatic fluctuations at seasonal scale and its dynamics explains a large percentage of the variability of rainfall. In Colombia, Montealegre Bocanegra and Pabon Caicedo, (2001) studied the annual cycle of precipitation in Tunja (Figure 8) and they show the occurrence of two rainy seasons (April-May and October-November) and two relatively dry periods (January-February and July-August).

Figure 8. Annual rainfall distribution in Tunja (seasonal variability).



Source: Montealegre Bocanegra and Pabon Caicedo, 2001.

To study seasonal and interseasonal variability in our study sites, we can use daily meteorological information and analyze the intensity and frequency of the weather extremes (storms, strong winds, etc.), heat and cold waves, etc. by standard statistical methods.

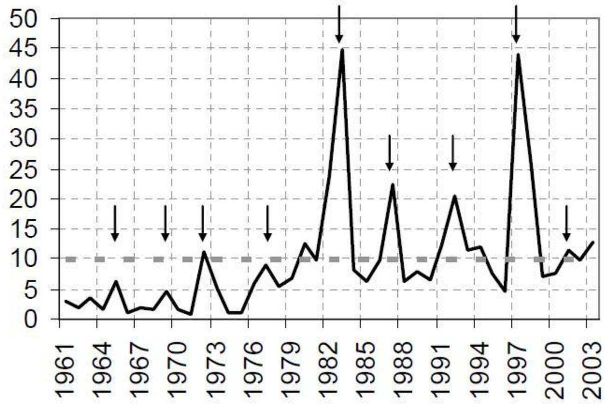
2.2.2 Interannual variability

It is represented for processes of periods of several years and it is mostly related to interactive processes taking place at the air-sea and air-land interfaces, in view of the long memory embedded in many maritime and land processes. This variability is very well documented.

At this scale variables change from year to year. Normally, we perceive that the precipitation of the rainy season in a certain site is not always the same from one year to another, but fluctuates above or below normal. Climate variability, framed within this scale, could be related to changes in the global balance of radiation. A typical example of interannual climate variability corresponds to the frame within the phenomena cycle El Niño - La Niña - Southern Oscillation. The ENSO phenomenon is the main example of interannual variability, but there are several significant works that shows different evidences of this variability. Following, two clear results of interannual variability are discussed.

In Chile an increase in the percentage of minimum temperatures (Conama, 2006) could be observed in five coastal stations between 18° and 30° S (Figure 9). Daily series of temperature extremes (maximum and minimum) in 16 Chilean stations were analyzed. Changes in the frequency of extreme thermal conditions such as occurrence of a maximum temperature below the 10 percentile (cold day) or above the 90 percentile (warm day), or a minimum temperature less than 10% (cold night) or above the 90 percentile (warm night) were evaluated. Preliminary results show that changes in the occurrence of this type of thermal conditions is strongly modulated by climate variability associated with the Pacific Decadal Oscillation (PDO). Thus, the phase shift of the PDO in the mid-1970s led to a relatively abrupt increase in temperature and an increase in the frequency of El Niño events which has had a strong impact on extreme indices of thermal frequency such as warm evenings as shown in Figure 9.

Figure 9. Percentage of minimum temperatures in five coastal stations of Chile between 18° and 30° S.

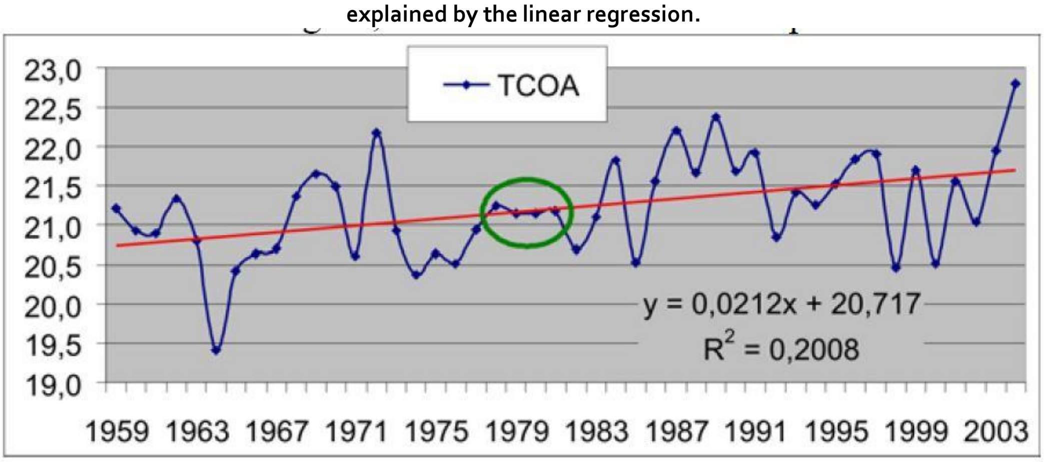


Source: Conama, 2006.

On the other hand, Agosta and Martin (2008) studied the interannual fluctuations of the summer temperatures in West-Central Argentina (COA). They calculated the temperature index series and found that the air temperature shows significant cuasi-oscillations in the spectral bands of roughly 11-yr and 18-yr (Figure 10). The former was linked to the solar forcing, the latter to the effects of the climate transition of the summer 1976/77 (IPCC 2001).

Different statistical methods are used to study the interannual variability of the different meteorological parameters: Empirical Orthogonal Functions, Fast Fourier transforms Wavelets, etc.

Figure 10. Temperature index series in the COA (TCOA). In circle: "plateau" between 1978-1981. R^2: variance explained by the linear regression.



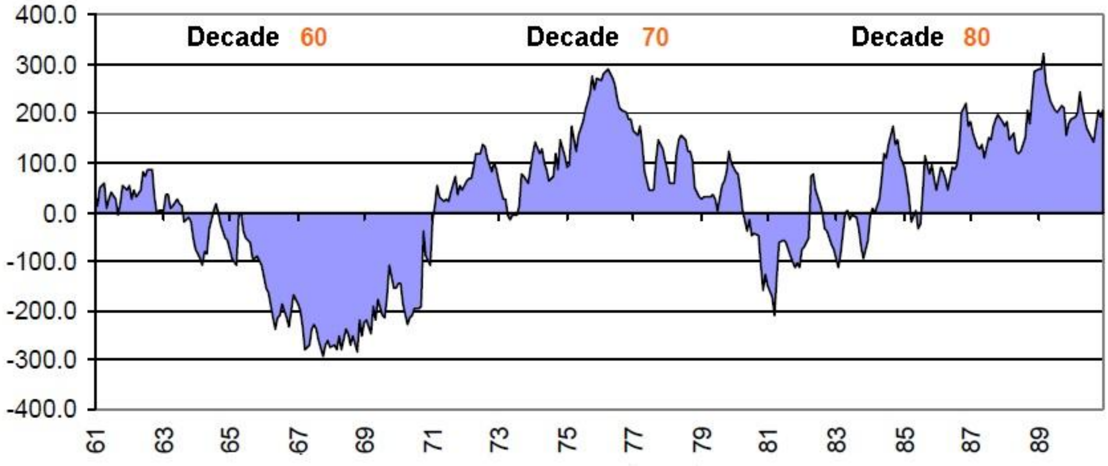
Source: Agosta and Martin, 2008.

2.2.3 Decadal / Interdecadal variability

This type of variability can be studied if we have a long time series of data. They consist of processes with long characteristic time scales, such as interactions with the deep ocean (thermohaline circulation) or the cryosphere, secular changes in the concentration of chemical constituents in the atmosphere and variations in the Earth's orbital parameters (Grimm, 2009).

On this scale, climate fluctuations manifest at the level of decades. Compared to the interannual variability, the amplitude of these oscillations is lower. This is one reason why this type of variability goes unnoticed for common people. However, these long-term fluctuations significantly influence the activities of society and decadal cycles are very important in determining possible trends in climate variables. Figure 11 shows the cumulative rainfall anomalies recorded at a meteorological station located in Funza (Cundinamarca) since 1961, with periods of near 10 years of rainfall (70s and 80s) and of deficit (early 60s).

Figure 11. Anomalies of precipitation in Funza, Colombia in three decades.



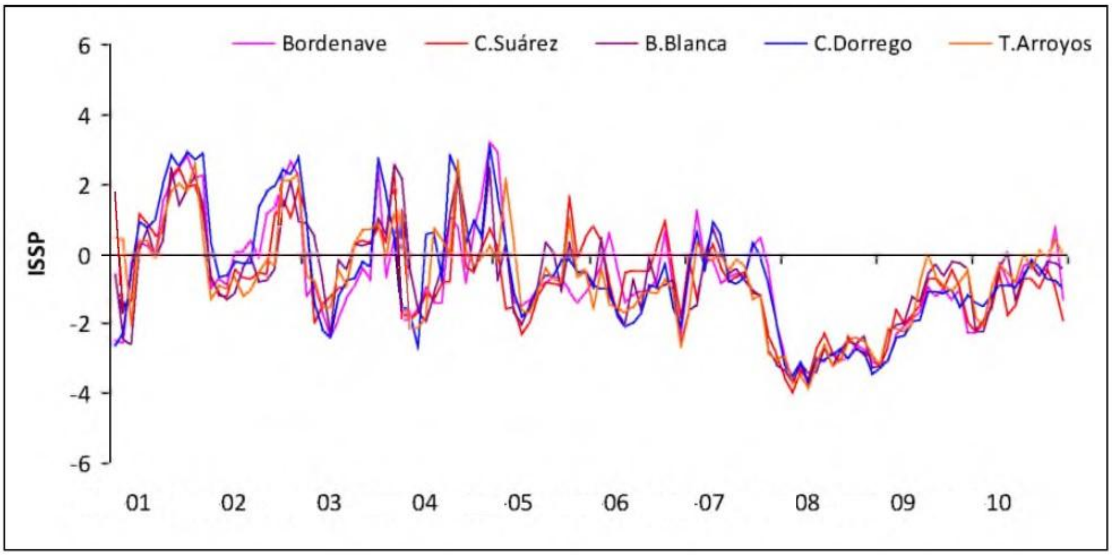
Source: Montealegre Bocanegra and Pabon Caicedo, 2001.

2.3 Drought Indices

For all human activities it is essential to know the interannual and decadal variability of precipitation. Several indices were written to determine periods of inundation or drought. Table 1 shows a review of these indexes (Hayes, M, 2002). The ***Palmer Drought Severity Index (PDSI, ISSP)*** (known operationally as the *Palmer Drought Index (PDI)*) is the most frequently used (http://www.drought.noaa.gov). The Palmer Drought Index, sometimes called the Palmer Drought Severity Index and often abbreviated PDSI, is a measurement of dryness based on recent precipitation and temperature. It attempts to measure the duration and intensity of the long-term drought-inducing circulation patterns. Long-term drought is cumulative, so the intensity of drought during the current month is dependent on the current weather patterns plus the cumulative patterns of previous months.

Since weather patterns can change almost literally overnight from a long-term drought pattern to a long-term wet pattern, the PDSI (PDI) can respond fairly rapidly. The index varies between positive and negative values. Values of the drought index greater than + 4 mean extreme humidity and values less than – 4 means extreme drought. Figure 12 shows the index for several cities of the Southern Buenos Aires province for the period 2001-2010 (Forneron, 2013). The years 2001, 2003 and 2004 were with a moderate humidity, but years 2008 and 2009 were years of extreme drought. Therefore, the figure clearly shows the extreme variability that a region can suffer in only one decade.

Figure 12. Palmer drought index in several cities of the Southern Buenos Aires province, Argentina. Period 2001-2010.



Source: Forneron, 2013.

In summary, there are many methods that can be applied to study the climate and climate variability at different time scales. Depending of the meteorological information available to us we can apply certain methodology**.** The main objective is to identify predictors associated with climate variability, allowing seasonal, medium and long term climate forecasts to obtain the most successful adaptation measures and mitigate the damage that might be caused by hydro-meteorological phenomena. As a final result, we may develop climate scenarios, using numerical models for each study site for the years 2050 and 2100.

3 Acknowledgements

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Table 1. Review of draught indices.

Indices	Method	Application
Percent of Normal	Percent of Normal is a simple method to detect drought. It is calculated by dividing actual precipitation by normal precipitation –typically a 30-year mean and multiplying it by 100% for each location. Data are not normalized.	**Pros**: Percent of Normal is effective in single region or season. **Cons**: Percent of Normal cannot determine the frequency of the departures from normal or compare with different locations. Also, it cannot identify specific impact of drought or the inhibition factor for drought risk mitigation plans.
Standardized Precipitation Index (SPI)	SPI is a simple index which is calculated from the long term record of precipitation in each location (at least 30 years). The data will be fitted to normal distribution and be normalized to a flexible multiple time scale such as 3-,6-,12-,24- 48- and etc .	SPI is used to identify the meteorological drought or deficit of precipitation. **Pros**: SPI can provide early warning of drought and its severity because it can specify for each location and is well-suited for risk management. **Cons**: The data can be changed from the long term precipitation record. The long time scale up to 24 month is not reliable.
Palmer Drought Severity Index(PDSI)	PDSI complexity is calculated from precipitation, temperature and soil moisture data. Soil moisture data has been calibrated to the homogeneous climate zone. PDSI has an inherent time scale of 9 months. PDSI treats all forms of precipitation as rain.	**Pros**: PDSI has been widely used to trigger agricultural drought. PDSI can be used to identify the abnormality of drought in a region and show the historical aspects of current conditions.. **Cons**: The PDSI may lag in the detection of drought over several months because the data depend on soil moisture and its properties which have been simplified to one value in each climate division. The PDSI will not present accurate results in winter and spring due to the effects of frozen ground and snow. PDSI also tends to underestimate runoff conditions.
Palmer Hydrological Drought Index	PHDI has been derived from the PDSI index to quantify the long term impact from hydrological drought.	**Pros**: The PHDI has been officially used by NCDC to determine the precipitation needed for drought termination and amelioration which has a PHDI equal to -0.5 and -2.0 consecutively. It has been used Indiana for drought monitoring. **Cons**: The PHDI is developed from precipitation, outflow, and storage. PHDI may change more slowly than PDSI and it has sluggish response for drought.
Crop Moisture Index (CMI)	CMI is a derivative of PDSI which was developed from moisture accounting procedures as the function of the evapotranspiration anomaly and the moisture excesses in the soil. It also can be present as	**Pros**: CMI is used to monitor crop condition. It is effective for the detection of short term agricultural drought while the Z index determines drought on a monthly scale. It can detect drought sooner than PDSI and PHDI.

	the monthly moisture anomaly or Z index (ZNDX) as a product from PDSI calculation. CMI looks at the top 5 feet of the soil layer.	**Cons:** CMI is limited to use only in the growing season; it can not determine the long term period of drought.
Surface Water Supply Index(SWSI)	SWSI is used for frequency analysis to normalize long-term data such as precipitation, snow pack, stream flow, and reservoir level.	**Pros:** The SWSI is very useful for indicating snow pack conditions in mountain areas to measure the water supplied for community **Cons:** The index of different basins can not be compared with each other and has been computed seasonally. States such as Colorado, Oregon, Montana, Idaho, and Utah have used SWSI.
Reclamation Drought Index (RDI)	The RDI index is similar to the SWSI index. It combines the functions of supply, demand and duration. RDI also combines temperature features and duration in the index.	**Pros:** The RDI is used as the trigger to evaluate drought reclamation plans and to release drought emergency funds. **Cons:** The disadvantage of RDI is the same as the SWSI index. The state such as Oklahoma has used RDI.
Deciles	Deciles have been developed to use instead of percent of normal. Deciles are calculated from the number of occurrences distributed from 1 to 10. The lowest value indicates conditions drier than normal and the higher value indicates conditions wetter than normal.	**Pros:** The deciles index has been used in Australia; it provides accurate precipitation data for drought response. **Cons:** However, it's use requires a long climatology record to accurately calculate the deciles index.
Experimental Objective Blends of Drought Indicators	Drought Blend Indicators are divided into short-term and long-term blends. The short term blend includes PDSI, Z, SPI 1, 3-month, and soil moisture. The long-term blend includes PHDI, SPI 06 12 24 and 60-month, and soil moisture. The drought blend method has been used for US drought monitoring: http://www.drought.unl.edu/dm/monitor.html	In the short-term blend method, the indicators are weighted to the precipitation and soil moisture which use to identify the impacts of no irrigated agriculture, wildfire dangers, top soil moisture, and pasture conditions. The long blend index indicates the impacts of hydrological drought such as reservoir and well levels and irrigated agriculture. The drought indicator used in Drought Monitor provides the most widely used map for drought conditions across United States (and is suitable for Indiana).

Source: *Drought Indices, Michael J. Hayes, National Drought Mitigation Center (http://www.drought.unl.edu/whatis/indices.htm). With modifications by Dev Niyogi and Umarporn Charusambot, Indiana State Climate Office, Purdue University (http://iclimate.org)*