UNIVERSITÀ DEGLI STUDI DI MILANO
FACOLTÀ DI SCIENZE MATEMATICHE, FISICHE E NATURALI
DOTTORATO DI RICERCA IN FISICA, ASTROFISICA E FISICA APPLICATA

1961-90 HIGH RESOLUTION TEMPERATURE, PRECIPITATION, AND SOLAR RADIATION CLIMATOLOGIES FOR ITALY

Settore Scientifico disciplinare FIS/06

Coordinatore: Prof. Marco Bersanelli

Tutore: Prof. Maurizio Maugeri

Co-Tutore: Prof. Guido Parravicini

Tesi di Dottorato di:

Jonathan Spinoni

Ciclo XXIII

Anno Accademico 2009-2010

UNIVERSITY OF MILAN – FACULTY OF SCIENCES
Doctorate School in Physics, Astrophysics, and Applied Physics
(XXIIIrd cycle)

1961-90 HIGH RESOLUTION TEMPERATURE, PRECIPITATION, AND SOLAR RADIATION CLIMATOLOGIES FOR ITALY

Director of the School: Prof. Marco BERSANELLI

First Supervisor: Prof. Maurizio MAUGERI

Second Supervisor: Prof. Guido PARRAVICINI

Referee: Prof. Carla TARICCO

Ph.D. Thesis by:

Dr. Jonathan SPINONI

Matr. No. R07883

PACS 92.60.R

Academic Year 2009-2010

Abstract

This PhD thesis focuses on the construction of monthly 30-arc-second resolution temperature, precipitation, and solar radiation 1961-90 climatologies for Italy and on the superimposition of the information of the secular anomaly records to these climatologies. The minimum, mean, and maximum temperature climatologies are based on a quality-checked new 1961-90 dataset for Italy that includes 1,493 T_M records and 1,138 T_N-T_X records; they have been obtained by means of a Multiple Linear Regression model, plus local and global improvements and a Geographical Inverse Distance Gaussian Weighting of the residuals. The final monthly average *MAE* is 0.65 °C for T_M, 0.91 °C for T_N, 0.81 °C for T_X. The precipitation climatologies are based on a quality-checked new 1961-90 dataset for Italy that includes more than 4,000 precipitation totals; they have been obtained by means of a *PRISM* model. The relative *MAE* for yearly total precipitation is approximately 10%. Further work is under development in order to improve both the database and the models. Examples of new reconstructed temperature and precipitation secular records for 1851-2010 are shown and the methodology used to obtain a secular record for each grid point is described. The solar radiation climatologies are obtained by means of a solar radiation model based on a quality-checked new dataset for Italy that includes more than 150 sunshine duration records. The solar radiation model is created on the basis of astronomical parameters, shading effects, albedo tables and turbidity Linke's factor: monthly 1961-90 grids for direct, diffuse, reflected, absorbed, and global radiation are obtained. The final monthly average relative *MAE* is 4.6%.

Keywords: **Climatology, High-Resolution Grids, Spatial Interpolation, Precipitation, Temperature, Solar Radiation, Climate Reconstruction.**

Index

1. Aims and development of the PhD project

In the last decades, an increasing attention has been focused on climate change on Earth; not only the scientific community but even the mass media have been dealing more and more with the possible causes and consequences of climate change.

Within this context, a research group based on a cooperation between The University of Milan (Department of Physics) and *ISAC-CNR* (Institute of Atmospheric Sciences and Climate, Consiglio Nazionale delle Richerche) was set up in the mid-1990s. In order to focus on the study of climate variability and change in Italy, it initially concentrated the scientific efforts on recovering and studying the secular records, which were available for Italy and for the surrounding area. The database of 111 precipitation, 67 mean temperature, and 48 minimum and maximum temperature secular records, used for this objective, allowed the evaluation of temporal trends and the understanding of their relations with large-scale atmospheric circulation. The available station density was however completely unsatisfactory to evaluate local-scale effects because temperature, and even more so precipitation, shows a high spatial variability.

To overcome such a deficit halfway through the years 2000 and 2010, a new project was set up. The main goal was to transfer the information on Italian climate variability and change it to a scale as close as possible to a local scale. This cannot be obtained by means of a trivial statistical approach, as the desired resolution is of the order of 1 km^2, while the actual meteorological series (even though very short records are also considered) are not nearly as spatially resolved. It is therefore necessary to proceed with an approach based on the integration of the actual meteorological data and the outputs of climate spatialization models, thus aiming at projecting the series on a number of grid-points at least two orders of magnitude higher than the number of the actual available series. Such an approach is based on the fact that the spatio-temporal structure of a meteorological variable over a given area can be described in terms of the superimposition of two fields: the normal values related to a standard time period, known as the climatologies, and the deviations from them, i.e. the anomalies. The projection of the latter onto a high-resolution grid is fully justified by the fact that the temporal fluctuations of meteorological variables, linked to the variability of climate, present a high spatial coherence. This leads to the fact that the data recorded in one station would not only be representative of the location of the station itself, but also of a wider portion of territory centred on the station. On the contrary, the climatologies are linked to the geographical characteristics of the territory. This implies very strong spatial gradients and, as a consequence, it clearly strengthens the need of a higher number of stations, though on a more limited temporal interval. The two fields can be reconstructed in a totally independent way from one another, and can also be based on two different datasets: a high spatial density and a short time interval for the climatologies, a low spatial density and a long time interval for the anomalies.

This 3-year PhD project has been realised within this project.

The first part of the PhD project has been dedicated to contributing to increasing the climatic database for Italy and for the neighbouring surroundings. The final goal is a station density of mean, minimum and maximum temperature and precipitation and eventually of new variables (sunshine duration, cloudiness, relative humidity and so on) that is enough to create monthly high-resolution climatologies.

The second part of the PhD has been dedicated to the construction of monthly high-resolution temperature climatologies (30-arc-second horizontal resolution) related to a 30-year period (i.e. 1961-90). According to the World Meteorological Organization's recommendations, a time interval of 30-years is a good choice to evaluate climate norms (the averaged values on the 30-year period), which are useful in evaluating spatial effects on the physical variables. We developed mathematical models and computational codes to obtain monthly 1961-1990 high-resolution grids and maps for precipitation, mean, minimum and maximum temperature for the whole of Italy. In order to improve the temperature spatial model, we also created a high-resolution spatial model for solar radiation (solar radiation and temperature are supposed to be correlated physical quantities), starting from sunshine duration records, which can be considered a self-consistent climate model for Italy.

The third part of the PhD has been dedicated to obtaining new secular records, as a contribution to the framework of The University of Milan and *ISAC-CNR* projects. These records describe the evolution of climate at a local scale in Italy from 1850 to 2010. This information can be inferred by superimposing the temporal information (from the homogenised secular records database and the low-resolution anomaly grids - a homogenised dataset is a dataset subjected to statistical procedures that fill the data gaps and eliminate the non-climatic noise or errors) and the spatial information (the high-resolution climatologies for the 1961-90 period). This procedure is usually known as the "anomaly" approach *(New et al., 2000)*. The local secular records (for temperature and precipitation), expressed in absolute values, provide a valuable scientific tool to evaluate climate change in Italy over the last two centuries and can be achieved for each single grid point. Such records can be updated monthly with new data.

Thus, this PhD project has contributed to increasing the Italian temperature and precipitation database, to implementing and improving the spatial interpolation models that lead to monthly high-resolution 1961-90 temperature and precipitation climatologies, to the better understanding of the distribution of solar radiation over Italy, and to the extraction of a secular record in absolute values for each cell of a high-resolution grid covering Italy for the cited variables.

2. The reconstruction of climate: state of art

2.1 Climate change: a general overview and latest results

Climate is defined as the statistical description, in terms of the mean and the variability, of relevant meteorological quantities (such as temperature, precipitation, wind and so on) over a period of time that ranges from months to millions of years *(IPCC, 2007; AMS Glossary website).* The typical period for averaging climate variables is 30 years, as stated by the World Meteorological Organization *(WMO, 1989).*

The "climate system" is a complex system, which consists of six components: the Sun, the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere. External and anthropogenic forcings may cause a change in climate, that is, according to the last assessment report of the International Panel on Climate Change (*IPCC*): "A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods" *(IPCC, 2007)*.

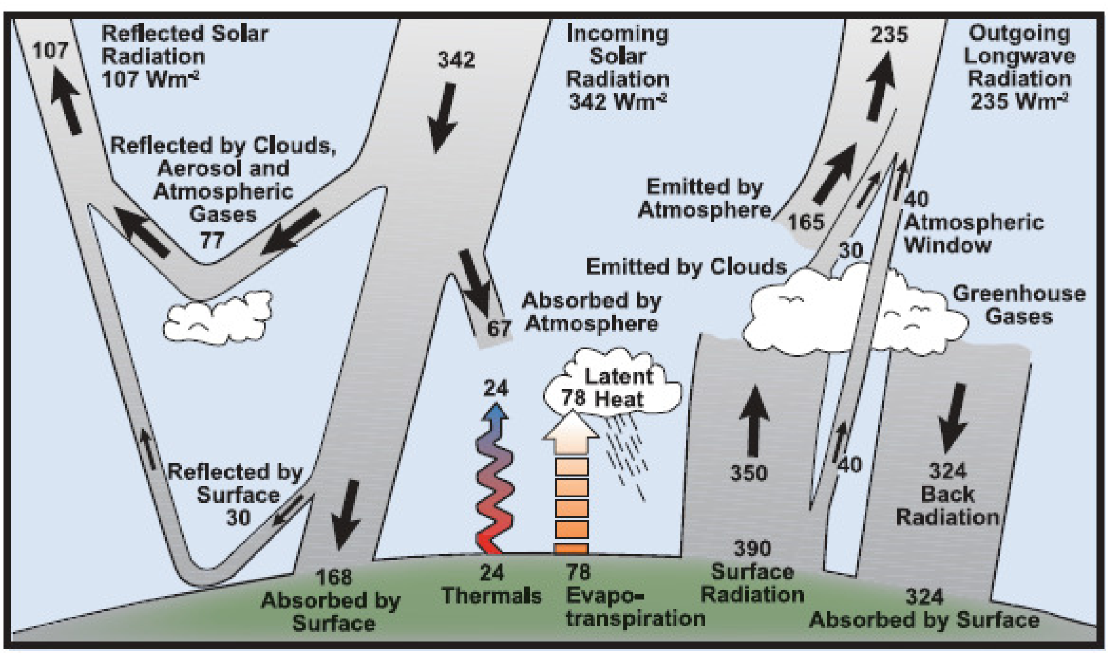

Fig.1 Estimate of the Earth's mean global energy balance (IPCC, 2007)

Solar radiation is the main energy that drives climate processes on Earth. The energy that is not reflected back to outer Space and that is absorbed by the Earth's surface or is trapped in the atmosphere by greenhouse gases causes an average air temperature on the Earth's surface of approximately *15* °C *(IPCC, 2007)*. Due to the Earth's axis inclination, the tropical regions receive more energy than the poles; this surplus of energy is transported to higher latitudes via atmospheric and oceanic circulations, during the Earth's rotation. These global processes, besides climate feedbacks and teleconnections, complicate models and give them an intrinsic degree of uncertainty.

Climate models, i.e. numerical representations of the climate system, are created to study, reconstruct and simulate the climate; such models are scientific tools used to detect climate changes. Global circulation models (*GCM*) and regional circulation models (*RCM*) should also consider many complex interactions between natural and anthropogenic factors to properly describe the climate at different space or time scales *(McGuffie et al., 2005).*

The Earth's climate changes on a wide range of time scales due both to forced and non-forced oscillations. Decadal or century-scale variability of climate can be related to many causes and we divide them up into natural and anthropogenic forcings.

Natural forcings:

- Milankovich variations: astronomical cycles such as the Earth's precession cycle (26,000 years), rotation of the Earth's elliptical orbit (22,000 years) and change in the angle between the Earth's axis and the normal to the plane of its orbit (41,000 years; *McGuffie et al., 2005);*
- Solar activities: Sunspots 11-year cycles, global dimming, early and late global brightening *(Crowley et al., 2004; Houghton et al., 2001; Frolich et al., 1998);*
- Plate tectonics: continental drift over millennia *(Forest et al., 1999);*
- Volcanic eruptions: emission of sulphuric aerosols into stratosphere causing a cooling effect *(Stenchikov et al., 1998; Kelly et al., 1996);*
- Change in the oceanic circulations: *(IPCC, 2002).*
- Oscillations: the Mediterranean area and the Alpine area are influenced by the *QBO* (Quasi-Biennal Oscillation), the *ENSO* (El-Nino Southern Oscillation), the *NAO* (North Atlantic Oscillation) *(Wanner et al., 1997; McGuffie et al., 2005; Hurrell et al., 1995; Hurrell et al., 1997; Beniston et al., 2002).*

Anthropogenic forcings:

- Greenhouse gases emission is increasing: it causes a warming effect and change in radiative forcing, the Kyoto Protocols (*UNFCCC website, 2010*) establish that the emissions, constantly increasing the half of the 20th century *(IPCC, 2007),* must be reduced;
- Tropospheric aerosols and clouds: cooling and feedbacks effects *(Houghton et al., 2002);*
- Reduction of Ozone in Stratosphere: *(IPCC, 2007);*
- Changes in land surface: deforestation, change in albedo of the Earth's surface, desertification and so on *(IPCC, 2007).*

The Earth's climate always changes throughout the millennia, and some evidence proves that present climate is also changing:

- Temperature is increasing: 0.6°C ± 0.2°C worldwide in 20th century *(IPCC, 2002)*; 0.2 / 10y in 1950-1993 for minimum temperatures; 0.74°C ± 0.18°C worldwide in 1906-2005, 11 of the 12 years between 1994 and 2005 were the warmest since instrumental measurements were set up *(IPCC, 2007; Brohan et al., 2006)*;
- Sea level is rising: the ocean stores 80% of the global warming; this leads to a sea level's increase of 1.8 mm/y in 1961-2003 and of 3.1 mm/y in 1993-2003 *(IPCC, 2007)* and of 3.2 mm/y ± 0.4 mm/y in 1993-2010 *(University of Boulder, Colorado, website, 2010)*;
- Snow/ice cover is decreasing: the average annual ice loss during 1980-1999 was 0.3 m.w.e./y (meters water equivalent) and it was 0.7 m.w.e/y in 2000-2007 *(WGMS website, 2007)*. Alpine glaciers are melting even at a faster rate *(Houghton et al., 2002; IPCC, 2007; Seiz et al., 2007; Haeberli et al., 1998)*;
- Extreme events are occurring more frequently: such as droughts, heat waves (e.g. summer 2003 in the Northern Hemisphere), heavy precipitation (+2/+4% in 20th century) *(IPCC, 2002; IPCC, 2007)*. Nevertheless, this data should be handled with care.

Apart from these findings, some key uncertainties remain. There is a lack of data from Africa and Central Asia. At local scale, some changes are contrary or not evident. At global scale, the listed facts are not taking place in the oceans of the Southern Hemisphere or in Antarctica, and the frequencies of the tropical thunderstorms and tornadoes are constant.

The evidence of significant changes, together with the atmospheric increase in greenhouse gases (GHG) *(IPCC, 1995; IPCC, 2002; IPCC, 2007)*, strongly contributed to forcing the study of the climate system. However, it is worth underlining that a deep knowledge of the Earth's climate system is a very important scientific task, regardless of the evaluation of the climate change, whether it is real occurring or not.

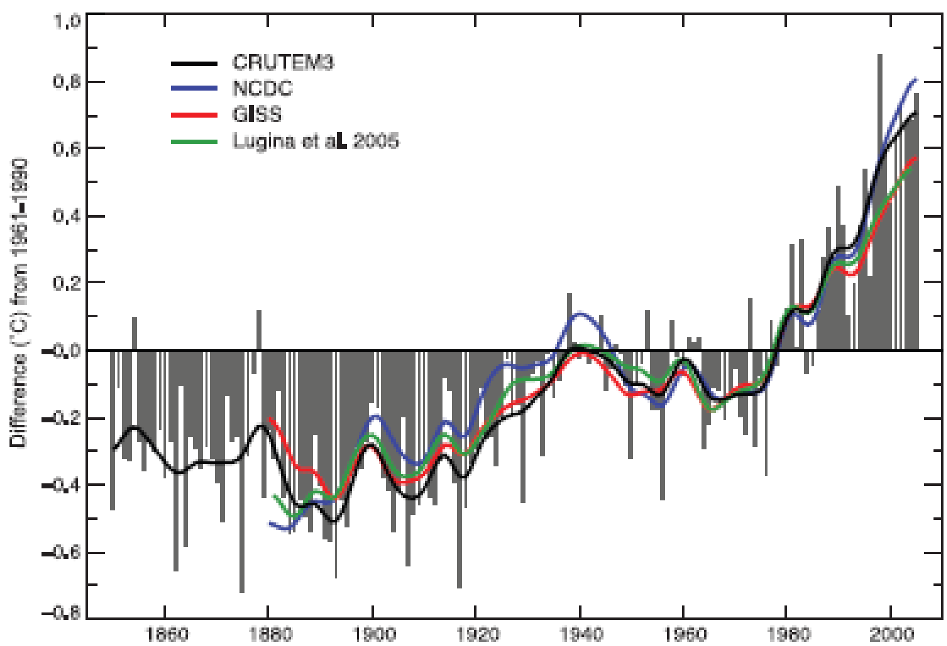

Fig.2 Annual anomalies of global land-surface air Temperature (°C) in 1850-2006 relative to 1961-90 mean from different databases: HadCRUTem3 (Brohan et al., 2006), NCDC (Smith et al., 2005), GISS (Hansen et al., 2001), Lugina (Lugina et al., 2006), (IPCC, 2007).

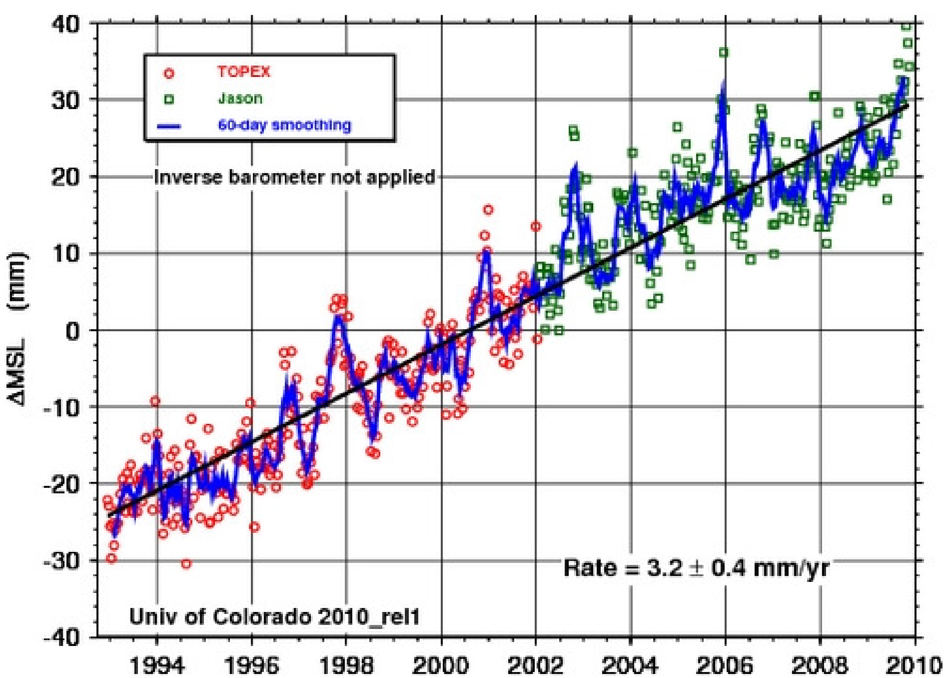

Fig.3 Monthly Sea level anomalies for 1993-2020 calculated on 1993-2010 mean (Univ. of Colorado, 2010)

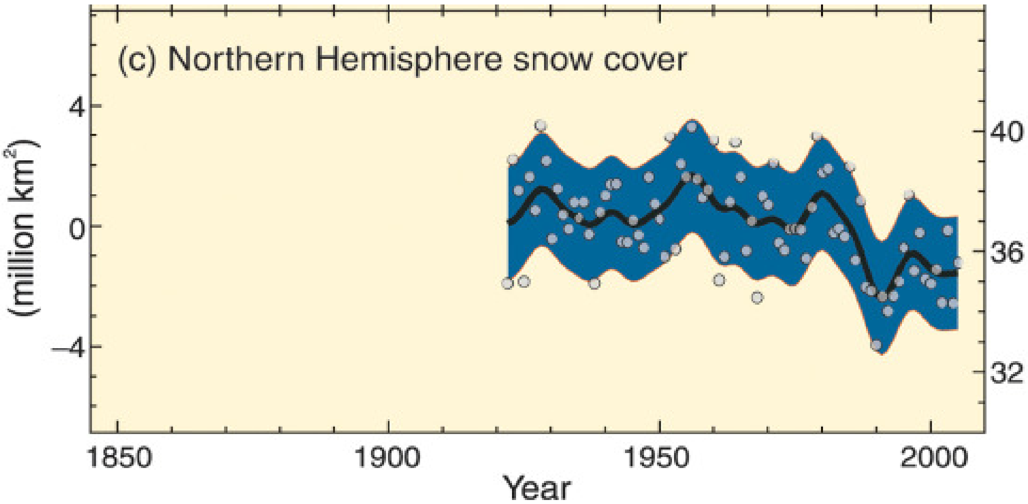

Fig.4 Monthly Northern Hemisphere snow cover anomalies calculated over 1961-90 mean (IPCC, 2007)

Climate change is best investigated combining spatial and temporal analyses of surface information *(Schmidli et al., 2001).*

As for the spatial scale, the resolution varies from the global scale (*Jones et al., 2003*) to the regional scale (e.g. Italy, *Brunetti et al., 2002*). Regional climate change can be different or opposite to the global climate change; the Mediterranean area and the Alps, e.g., are particularly involved in climate change, whose effects are more intense (see Chapters 2.2 and 2.3 and *Camuffo et al., 2010; Agnew et al., 2000; Jeftic et al., 1997; Wanner et al., 1997)* .

As for the temporal scale, studies are focused on three different time intervals: the far past, the recent past (as far as present), and the future.

With the exception of the extent of some secular records in Europe (in particular in Central England and Northern Italy), the instrumental measurement of climatic variables began after 1850. In order to reconstruct climate over the past millennia, proxies must be used: tree rings *(Frank et al., 2005)*, pollen analysis *(Peyron et al., 1998)*, isotopic compositions of snow or ice cores, corals and stalactites *(Mann et al., 2003)*, and sea sediments (*Cini Castagnoli et al., 1993*).

For the recent past (the last two centuries), climate researchers use global or local databases of station records of temperature, precipitation and other variables *(Jones et al., 2002; Brunetti et al., 2002; IPCC, 2002).*

Future climate is simulated with modelled projections based on real trends or hypothesis; a scenario (e.g. emission scenario) is based on a coherent and internal set of assumptions about driving forces and key assumptions *(AMS Glossary website),* but uncertainties can be high. Many examples of climate scenarios can be found in literature *(Mitchell et al., 2004; McGuffie et al., 2005; Houghton et al., 2002)*.

2.2 Climate reconstruction based on spatial and temporal analysis. A bibliographic review

A large availability of instrumental records allows the reconstruction of the climate of the last century for a wide part of the Earth.

Many examples of spatial-temporal global databases (the most common variables studied are temperature and precipitation) can be found in literature: the *GPCP* database (Global Precipitation Climatology Project, global dataset of precipitation, *Huffman et al., 1997*), the *GHCN* database (Global Historical Climatology Network, global, precipitation, temperature, pressure, *Peterson et al., 1997*), the *CAMS* database (Climate Anomaly Monitoring System, global, precipitation, *Ropelewski et al., 1984*), the *CRU* and the *HadCRUT3*, *CRUTem* databases (Climate Research Unit of East Anglia University, land and marine data, global, wind, precipitation (two indices), mean temperatures, daily temperature range, wet days frequency, water vapour pressure, sunshine duration, ground frost days, relative humidity, *New et al., 2002; Jones, 1994; Jones et al., 2003; Brohan et al., 2006*). There are also hemispheric or regional datasets: the *HISTALP* database (Historical Instrumental climatological Surface Time series of the greater ALPine region, *GAR*, temperature, pressure, precipitation, sunshine duration, cloudiness, relative humidity, *Auer et al., 2007; Brunetti et al., 2009a; Efthymiadis et al., 2006*), the Australian database (precipitation and other variables, *Jeffrey et al., 2001*) and so on.

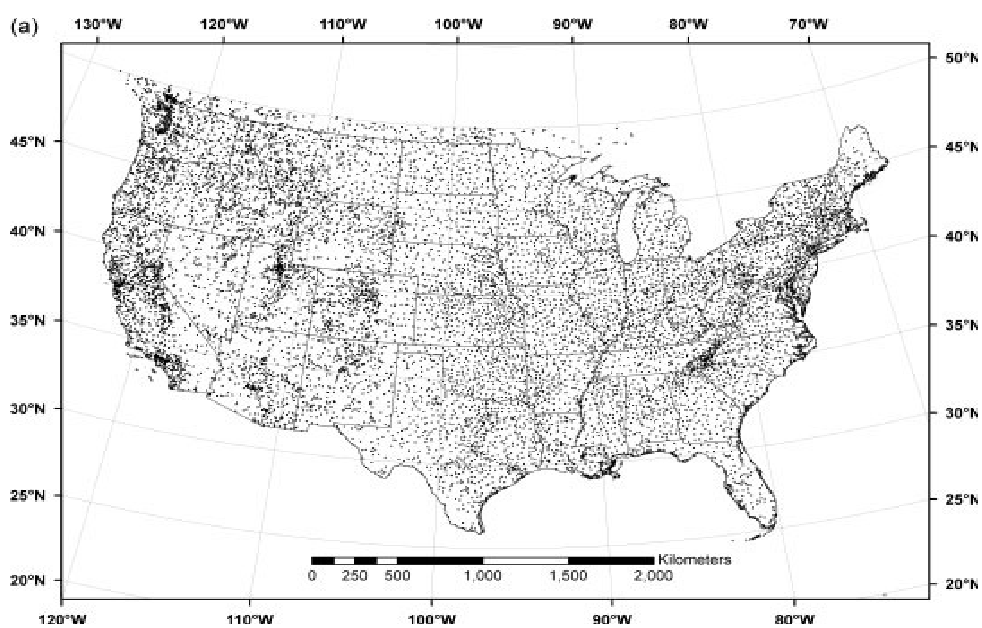

Fig.5 Example of dataset: precipitation normal records for 1971-2000 for USA (Daly et al., 2008).

Space-time datasets are also very important in assessing the impact of climate variability and change. There are a lot of recent applications in biogeochemical modelling *(Cramer et al., 1996)*, agriculture *(Nicholls, 1997)*, hydrology *(Arnell, 1999)*, forestry *(Booth et al., 1998)* and so on.

These datasets are used as the data basis for the so-called "**anomaly approach**". This procedure is based on the superimposition of spatial and temporal information onto regular grids and leads to fields of estimated climate surfaces (i.e. a continuous gridded representation of a variable) of a selected variable and to secular series in absolute values (*New et al., 1999)*.

First, the anomaly grids (holding the temporal information) must be derived. Such grids are low-resolution grids because anomalies (calculated as differences related to a standard 30-year period, 1961-1990 in our case) are linked to climate variability. They are generally characterised by a high spatial coherence and tend to be more influenced by large scale circulation patterns than physiographic control. The anomaly grids are used to quantify temporal trends of the climatic variable under investigation. However, the number of long secular quality checked and homogenised records is usually low, thus it is improper to suppose that a small number of stations used to create anomaly grids can actually be representative of the real average variable over the area under investigation *(Brunetti et al., 2006b)*.

The spatial gradients of a climatic variable need to be studied by means of spatially denser datasets and the number of archived and "easy" obtainable station normals is much greater than that of station time series *(New et al., 1999)*. These climate normals related to the 30-year chosen interval, 1961-1990 in our case, are the data basis for the construction of spatial "climatologies" (holding the spatial information), which are the spatial continuous representation of the studied climatic variable obtained by means of spatialization models that grid the discrete data *(New et al., 1999)*. The mean monthly high-resolution climatologies are linked to the geography of the territory and they contain the remarkable spatial gradients of the climatic variables as temperature *(New et al., 2000; Brunetti et al., 2009a; Mitchell et al., 2005).* The spatial climatologies are used to quantify such local-scale gradients.

The anomaly approach requires the projection of both the anomaly records and the normal values onto regular spaced grids (spatial climatologies and anomaly grids can be derived separately). In order to obtain continuous climate surfaces from discrete point data, mathematical models known as spatialization models are used. For details see Chapter 3.

Eventually, it is possible to reconstruct a secular record for each grid point. The anomaly (versus 1961-1990) series for the chosen grid point can be rescaled using the 1961-90 modelled value for the grid point itself.

Just to give an example, from the anomaly grids we can infer that two grid cells (grid cell "A" and grid cell "B"), only 3 km distant from one another, show a certain temperature trend that is quite identical (high spatial coherence of anomalies), from the spatial climatologies. We inferred information on the mean monthly 1961-1990 temperature values for grid cells "A" and "B" that are different because elevation, longitude, latitude, distance from the coast and other parameters are different for the two grid cells (high spatial gradients of absolute values). Let us suppose that grid cell "A" shows a mean temperature positive anomaly (referred to 1961-90 period) of 0.2 °C in May 1912 and the same anomaly applies to grid cell "B". If we know from the spatial climatologies that the mean temperature value is 8.8 °C for grid cell "A" and 5.7 °C for grid cell "B" in May in the 1961-1990 period, we can conclude that in May 1912, grid cell "A" was *8.6* °C and grid cell "B" was 5.5 °C. These calculations, repeated for each month from 1850 to 2010, give a new monthly secular record for each grid cell in absolute values.

Without measured data in May 1921 for grid cells "A" and "B", it would be impossible to obtain the temperature values for grid cells "A" and "B" without an approach that takes into account and combines the temporal trends (anomaly grids) of the variable and the spatial differences between two close points (climatologies).

Examples given where the anomaly approach was used include global areas with coarse resolution (0.5 °Lat x 0.5 °Lon, many variables, *New et al., 2002*), global areas with medium resolution (merging *GHCN* and *CAMS* datasets, precipitation, data from 1948-2007, *Fan et al., 2008*), the Alpine Region (precipitation, 1961-90 means and 1951-200 anomalies, *Gyalistras, 2003*), Switzerland (precipitation, dataset 1901-1990, *Schmidli et al., 2002*) and so on.

In some cases, where secular records are not available, only monthly spatial climatologies were realised. Examples given are precipitation climatologies for the Globe for 1951-1980 by *Hulme et al. (1992)*, for Iceland for 1971-2000 by *Crochet et al. (2003)*, for Denmark for 1961-1990 by *Frich et al. (1997)*, for Switzerland by *Frei et al. (1998)*, precipitation and temperature climatologies for Ireland for 1961-1990 by *Goodale et al (1998)*, for Catalunya by *Ninyerola et al. (2000)*, for the Globe by *Hijmans et al. (2005)*, for the conterminous USA for 1971-2000 (see fig.6) by *Daly et al. (2009)*, temperature climatologies for Iceland for 1961-1990 by *Bjornsson (2003)*, for Mediterranean area by *Agnew et al. (2000)*, multivariable climatologies for Scandinavia for 1961-90 by *Tveito et al. (2001)*, for Europe and for the Globe by *Mitchell et al. (2000)* and so on.

In other cases, if only secular data with low spatial resolution are available, only trend analysis with Mann-Kendall test *(Mann, 1945)* or similar statistical tests are performed. Examples given are global trends for minimum and maximum temperatures for the Globe by *Easterling et al. (1997)*, precipitation trends for the USA by *Karl et al. (1998)*, temperature and precipitation variability in 1750-2003 for the Alps by *Casty et al. (2005)*, for the Greater Alpine Area by *Böhm et al. (2001), Auer et al. (2007), Brunetti et al. (2009a)*.

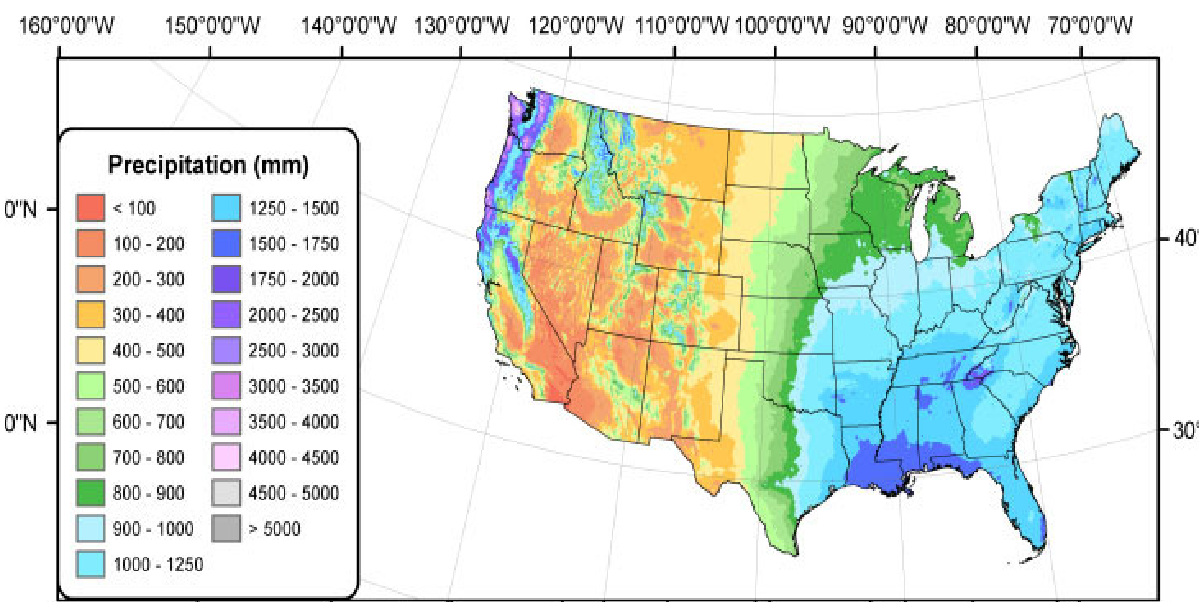

Fig.6 Example of mean annual precipitation climatology for 1971-2000 for USA (Daly et al., 2009)

2.3 Climate reconstruction for Italy and the surrounding regions

A cooperation between The University of Milan (Department of Physics) and *CNR* (Institute of Atmospheric Sciences and Climate) permitted to set up, around the mid-1990s, a research group which deals with the study of climate variability and change in

Italy. This research group initially focused on recovering and studying cloud cover, temperature and precipitation Italian data since 1870 *(Lo Vecchio et al., 1995; Nanni et al., 1998; Maugeri et al., 1998; Buffoni et al., 1999; Maugeri et al., 2001; Brunetti et al., 2000a; Brunetti et al., 2000b; Brunetti et al., 2002)*. The activities led to a database for Italy and surroundings, of 111 precipitation, 48 minimum and maximum temperature and 67 mean temperature quality-checked, homogenised (to avoid non-climatic noise in trends) and metadata-provided secular records. This activity is particularly important for Italy as it (and some surrounding countries) is a region very rich in secular records if compared with other European or Worldwide countries *(Brunetti et al., 2002; Brunetti et al., 2006b)*. Further collaborations between The University of Milan, *ISAC-CNR*, *ZAMG* (Zeltral-Anstalt fur Meteorologie und Geodinamik, Vienna, Austria), other universities, and national or European organizations, led to improving and including this dataset into the *HISTALP* dataset and in other datasets *(Bohm et al., 2001; Auer et al., 2005; Efthyamidis et al., 2006; Camuffo et al., 2010; Brunetti et al., 2009a; Auer et al., 2007).* A detailed synthesis of the results on the climate evolution (a multivariate analysis which includes temperature, precipitation, vapour pressure, cloudiness, sunshine duration) of the last two centuries for the GAR region can be found in *Brunetti et al. (2009a)*.

Temperatures show a positive trend (obtained using Mann-Kendall non-parametric test, *Sneyers et al., 1990)* over the whole Italy of about 1°C/100y in the 1800-2005 period (significant at >99%); it is generally higher for minimum temperature, but in the last 50 years, the behaviour has been the opposite. Daily temperature range (*DTR*) is negative over the whole period (-0.2°C/100y), but it is positive over the last 50 years, in contrast to the global negative trend for last 50 years. Precipitations show a low and rarely significant trend: -5%/100y, but the heavy precipitation events are increasing *(Brunetti et al., 2006b).* Daily temperature range is negatively correlated with precipitation (significant at >99%) and positively correlated with mean temperature (significant at >95%) *(Brunetti et al., 2002)*. If we compare Italy with Central Europe, we can conclude that, in both cases, temperature, heavy precipitations and long dry spells are increasing, whilst in Italy, cloud cover (strong decrease in Italy in 1951-96, *Maugeri et al., 2001*), daily temperature range and number of wet days are decreasing.

These climate patterns can be tentatively related to an increase in the North Atlantic Oscillation index *(Hurrell, 1995; Hurrell et al., 1997)* and to an increase in frequency of central and western Mediterranean anticyclones *(Brunetti et al., 2002)*.

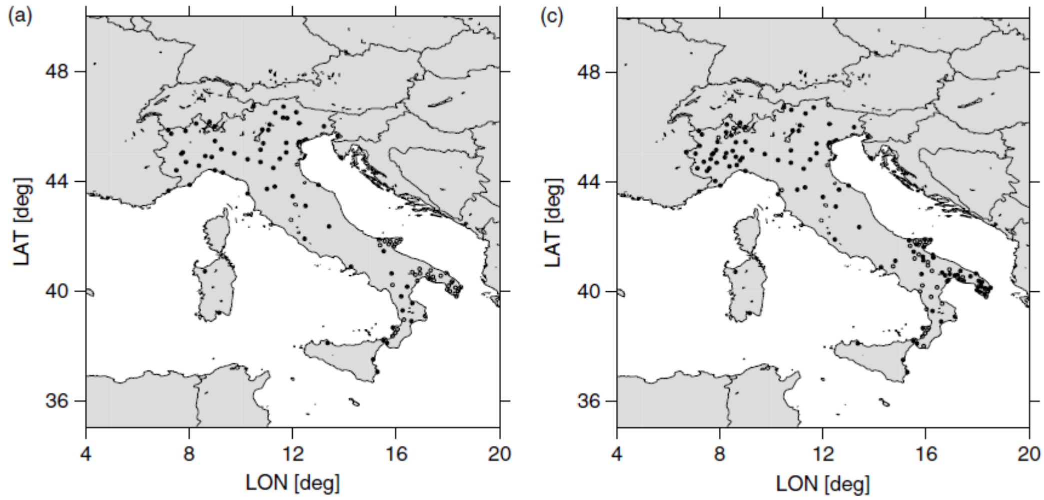

Fig.7 ISAC-CNR/UniMI secular database. Left: mean temperature; right: precipitation (Brunetti et. al., 2006b)

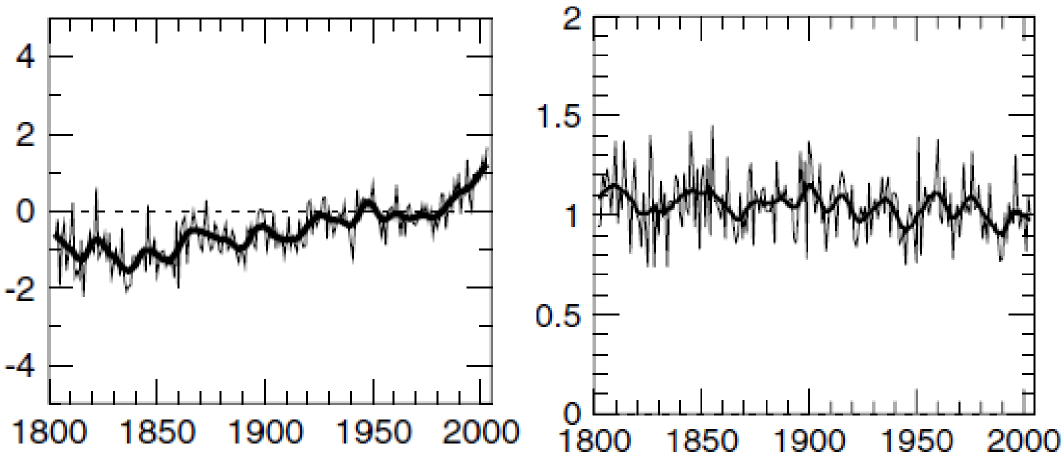

Fig.8 Average Italian temperature series (left) and precipitation series (right) (Brunetti et. Al., 2006b)

The secular Italian database was also used to create low-resolution (1° Lat x 1° Lon) anomaly grids for Italy and to evaluate precipitation and temperature trends for Italy and for the *GAR* region. The same method was applied to other climatic variables using the *HISTALP* dataset and gridded data can be freely downloaded at the official *HISTALP* website *(http://www.zamg.ac.at/histalp/).*

The main deficit of the Italian secular records, as well as of the *HISTALP* records, is that the available station density is unsatisfactory to evaluate local-scale effects because temperature, and even more so precipitation, show a high spatial variability.

In order to overcome such a deficit, a new project was set up in the mid-2000s. The main goal was to transfer the information on Italian climate variability and change it to a scale as close as possible to a local scale. This cannot be obtained by means of a trivial statistical approach as the desired resolution is of the order of 1 km^2. While the actual meteorological series (even if very short records are also considered) are not nearly as spatially resolved (the order of magnitude is approximately 1 station each 100 km^2). It is therefore necessary to proceed with an approach based on the integration of the actual meteorological data and the outputs of climate spatialization models. Thus aiming at projecting the series on a number of grid-points at least two orders of magnitude higher than the number of the actual available series. As we described in Chapter 2.2, such an approach (i.e. the anomaly approach) is based on the fact that the spatio-temporal structure of a meteorological variable over a given area can be described in terms of the superimposition of two fields: the climatologies and the deviations from them, i.e. the anomalies. The two fields can be reconstructed in a totally independent way from one another. They can also be based on two different datasets: a high spatial density and a short time interval for the climatologies, and a low spatial density and a long time interval for the anomalies, which are not only representative of the location of the station itself but also of a wider portion of territory centred on the station.

This 3-year PhD study was realised within this project. In particular, the research group in the last years focused on the issue of the 1961-1990 spatial climatologies.

For many years, there was a lack of interest in such an issue. As far as precipitation is concerned, the only available publications for the whole of Italy were cartographic hand-made maps of precipitations for 1921-1950 *(Servizio Idrografico, 1959)* and neither maps nor data which were used to construct them are available in digital form (*Brunetti et al., 2009a)*. In some cases, small parts of Italy were studied only, e.g. the areas of northern and central Italy, encompassed by the *1.25-arc-minute*-resolution Alpine precipitation climatology presented by *Schwarb (2000)*, but a very poor station density was used to realize the climatologies.

As far as temperature is concerned, the situation was not different. Once again, the only available publications for the whole of Italy were cartographic hand-made maps for 1926-55 *(Servizio Idrografico, 1966),* by the former "Servizio Idrografico Italiano" (Ministero dei Lavori Pubblici) and later, in 1999, *ENEA* (Ente Nazionale Energia e Ambiente) realised a simplified and low-resolution temperature and solar radiation atlas for Italy for 1961-1990 *(Petrarca et al., 1999; Petrarca et al., 2000)*.

Thus, the present PhD project was developed within a wide research project whose main goal was to get the chance to assign a temperature and a precipitation series for the last 150 years to each single gridded point on the Italian territory.