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The Italian air force sea level pressure data set (1951-2000)(*)

M. Maugeri(1)(**), M. Brunetti(1),(2), F. Monti(1) and T. Nanni(2)

(1) *Istituto di Fisica Generale Applicata, Università di Milano Via Brera, 28, 20121 Milano, Italy*

(2) *ISAC-CNR - Via Gobetti, 101, 40129 Bologna, Italy*

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Summary. — A set of 39 homogenised sea level pressure records, extracted from the Italian Air Force dataset (1951-2000), is introduced and analysed for trends. The data consist of 3-hourly observations. Daily mean pressures are obtained using a method that allows biases to be avoided due to the presence of a high fraction of days that do not have all 8 observations. Trend analysis is performed on seasonal and yearly basis and concerns both the individual station records and the series of their averages. The results show a highly significant positive trend in winter and yearly air pressure all over Italy. It is mainly due to a change-point around 1980. The Italian air pressure records are also compared with the NCAR/NCEP and UKMO gridded data sets. The results give evidence that gridded data capture most of the trend and variability of air pressure over Italy, even if NCAR/NCEP data display some significant inhomogeneities with respect to the station records.

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1. – Introduction

The reconstruction of air pressure records plays a primary role in understanding past climate, as changes in atmospheric circulation are one of the main causes of variations in climatic elements on a regional scale [1].

Most of the activity with observed air pressure has been aimed at the reconstruction of gridded Sea Level Pressure (SLP) data sets. They consist mostly of analysed data (see *e.g.* [2]), even if the most recent ones are adjusted in order to be strongly influenced by quality controlled observed records [3]. The analysed data are derived from hand-drawn analyses in the pre-computer era and more recently from routine General Circulation Model (GCM) operational analyses or reanalyses [4, 5].

(*) The authors of this paper have agreed to not receive the proofs for correction.

(**) E-mail: maurizio.maugeri@unimi.it

The availability of a wide number of high-quality observed long-term records is important especially in detecting trends, as it is very difficult to get homogeneous series using only data derived from SLP analyses. Unfortunately the state of the art of existing SLP secular records displays problems both in the number of series available in digital format and in their homogeneity. An example of the lower availability of SLP records compared to temperature and precipitation records is given by the GHCN, the Global Historical Climatology Network [6]: It includes SLP data for about 2500 stations, whereas temperature and precipitation data concern, respectively, about 6000 and 7500 stations. A discussion of the problems concerning the homogeneity of secular SLP records is given in [7] and in [8].

In recent years the situation has been improving rapidly. In Europe two EU funded projects (ADVICE and IMPROVE) involved air pressure: the former collected and analysed 51 secular European monthly records [9], the latter, besides recovering daily data for some of the oldest European records [8], allowed homogenisation of some of them using very detailed metadata [10-13]. However, in spite of important new research, at present a sound homogenisation on a regional basis such as the one carried out for Alpine region temperatures [14] is often hampered both by low station density and poor metadata.

Within this context the authors set up a program to construct and analyse high-quality Italian SLP records as much as possible. The program is in progress within National (COFIN 2001) and European (ALPIMP) projects; the paper reports the first results concerning the 1951-2000 period.

2. – Data and methods of pre processing

The first step in our research was to extract from the 3-hourly Italian Air Force (Aeronautica Militare, hereinafter AM) climatic dataset (1951-2000) a subset of SLP station records with the aim of i) obtaining less than 20% of days without observations and ii) considering only observatories located at an altitude less than 500 meters above sea level. These criteria were fulfilled by 41 of the 164 AM station records (table I and fig. 1).

AM stations are managed according to WMO standards; the records consist of synoptic data observed at 0, 3, 6, 9, 12, 15, 18 and 21 Greenwich Mean Time (GMT).

All the selected records were quality checked by a method already used for AM precipitation data [15, 16]. It consists of carrying out crossed comparison between the data and individually analysing all the values that markedly disagree with the ones of the surrounding stations. This procedure allowed the identification and elimination of about 5000 erroneous observations, corresponding to 0.1% of all available data.

Figure 2 shows the data availability of the quality controlled records. It highlights an important problem: for many stations, even if there is a small fraction of days without any observation, the fraction of days that does not have all 8 observations is rather large. Averaging over all stations the former fraction is 4.2%, whereas the latter one is 38.1%. So, if we calculated for each station daily SLP records by simply averaging all the available data of each day, 33.9% of the values would be obtained from less than 8 observations. This would cause great homogeneity problems as air pressure has a typical diurnal cycle [17] and missing data are not randomly located in the records, but mainly concern some periods without night time observations.

In order to avoid obtaining series biased by the time evolution of observation availability, we used a procedure similar to the one we used for AM cloud cover records [18]. It consists of first estimating the average daily SLP cycle of each station in each day of the

TABLE I. – *List of the 41 stations that were selected from the AM data set and relative identification codes. The station coordinates are also indicated.*

Code	Station	Latitude	Longitude
020	Bolzano	46.47	11.33
059	Torino Caselle	45.20	7.65
066	Milano Malpensa	45.63	8.73
076	Bergamo Orio Al Serio	45.67	9.70
080	Milano Linate	45.45	9.28
084	Piacenza	44.92	9.73
090	Verona Villafranca	45.38	10.87
094	Vicenza	45.57	11.53
098	Treviso Istrana	45.70	12.05
110	Trieste	45.65	13.75
140	Bologna Borgo Panigale	44.53	11.30
146	Ravenna	44.37	12.22
149	Rimini	44.02	12.62
158	Pisa	43.68	10.40
172	Arezzo	43.45	11.85
206	Grosseto	42.77	11.07
214	Civitavecchia	42.03	11.83
216	Viterbo	42.40	12.07
230	Pescara	42.43	14.18
232	Termoli	42.00	15.00
235	Roma Urbe	41.95	12.50
239	Roma Ciampino	41.80	12.60
261	Amendola	41.53	15.72
270	Bari	41.13	16.77
280	Ponza	40.92	12.95
289	Napoli Capodichino	40.88	14.28
310	Capo Palinuro	40.20	15.28
312	Gioia Del Colle	40.77	16.93
320	Brindisi	40.65	17.95
332	Lecce	40.23	18.15
350	Crotone	39.00	17.08
360	S.Maria Di Leuca	39.82	18.35
400	Ustica	38.70	13.18
420	Messina	38.20	15.55
422	Reggio Calabria	38.10	15.65
460	Catania Fontanarossa	37.47	15.07
470	Pantelleria	36.82	11.97
480	Cozzo	36.68	15.13
520	Alghero Fertilia	40.63	8.28
550	Capo Bellavista	39.93	9.72
560	Cagliari Elmas	39.25	9.05

year by using the days with all eight observations and then calculating from these cycles the differences between the daily averages obtained from the eight synoptic observation hours (these averages give an estimate of 24 h means) and from any given subset of them. These differences give the corrections to be applied in order to remove the biases induced by calculating daily means on the basis of any subset of observation hours.

Fig. 1. – Location of the 41 stations that were selected from the Italian Air Force data set. The station identification codes are also indicated.

The estimation of the daily average SLP cycles was based on the 1971-1980 period as it has the best data coverage; the results were then smoothed by a trigonometric filter. Figure 3 shows an example of the procedure: it displays in graphs A-D the estimated (smoothed) daily SLP cycles for station 080 (Milano Linate) corresponding to January 1st, April 1st, July 1st and October 1st with the mean values based on: i) all the eight synoptic observations (continuous line) and ii) only two observations performed at 6 and 18 GMT (dashed line), whereas graph E shows the differences between the means calculated according to i) and ii) for each day of the year.

After obtaining daily mean SLP records, monthly series were calculated for all months with at least 80% of daily data. Then the Craddock homogeneity test was applied [19]. In order to minimise errors, northern and southern Italy mean series were used as references. These mean series were calculated by excluding the series to be tested and weighing each series by the squares of its correlation coefficients with the series to be tested [20]. Moreover the series were tested against some Swiss and Austrian homogenised long-term series of the ALOCLIM dataset [21]. Testing homogeneity by means of records collected in stations that are not included in the AM network is useful, as using data from only one network apparent climatic signals can be present in the data due to changes in instruments or methods, or to any other homogeneity problem simultaneously affecting all the network stations [22].

Homogeneity tests suggested that 5 records were homogeneous. 34 of the remaining 36 were homogenised, whereas 2 (Milano Malpensa and Viterbo) were rejected. So the final dataset contains 39 station records. It is worth noticing that by averaging the differences between the homogenised and original records over all 34 stations subjected to homogenisation, a series without any trend, with 0.04 hPa average and 0.05 hPa standard deviation is obtained. So, the average SLP over all records had very low bias

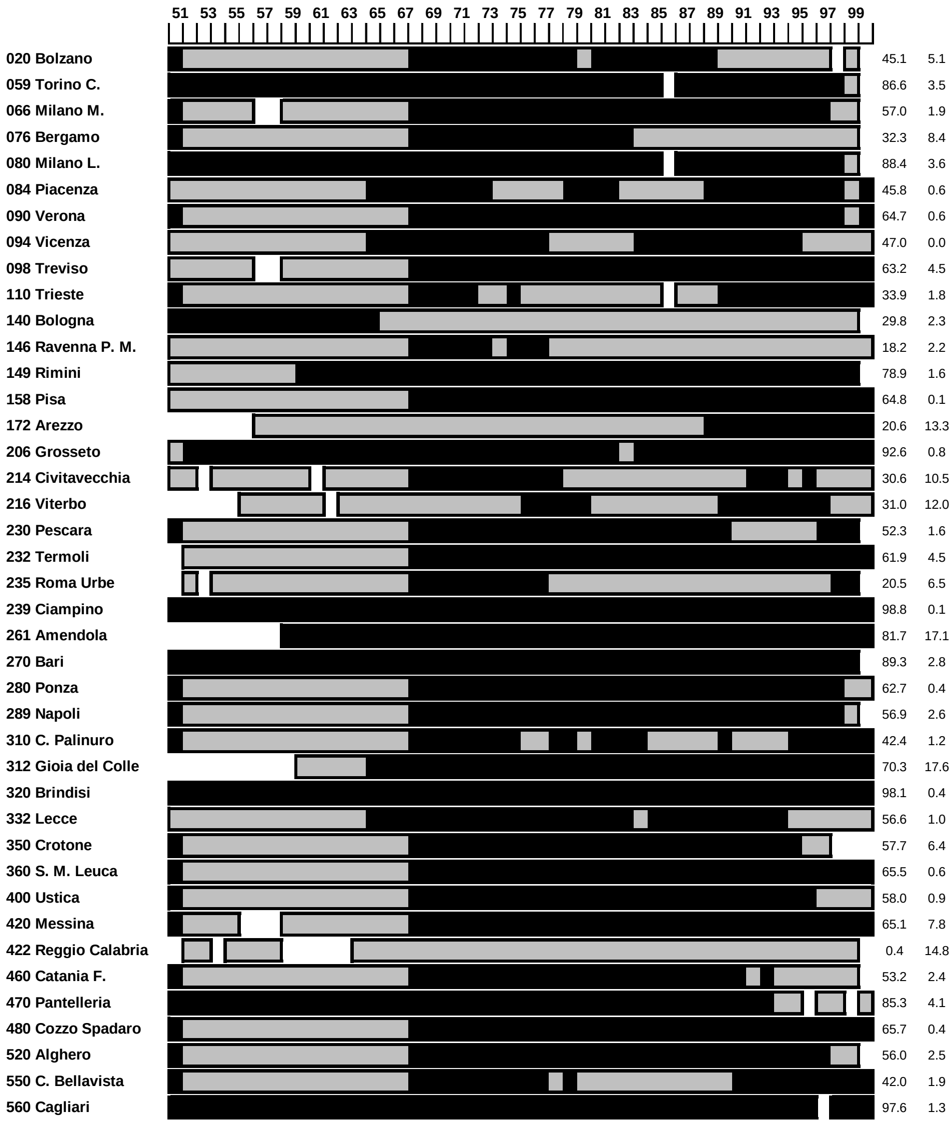

Fig. 2. – Details on data availability. Empty boxes: missing periods; grey boxes: periods with less than 8 observations per day; black boxes: periods with 8 observations per day. The percentages in the right part of the figure display, respectively, the fraction of days with all 8 and with no observations (missing periods).

also before homogenisation.

After homogenisation, the gaps in the station series were completed by means of the same series that were used as references for the application of the Craddock homogeneity test.

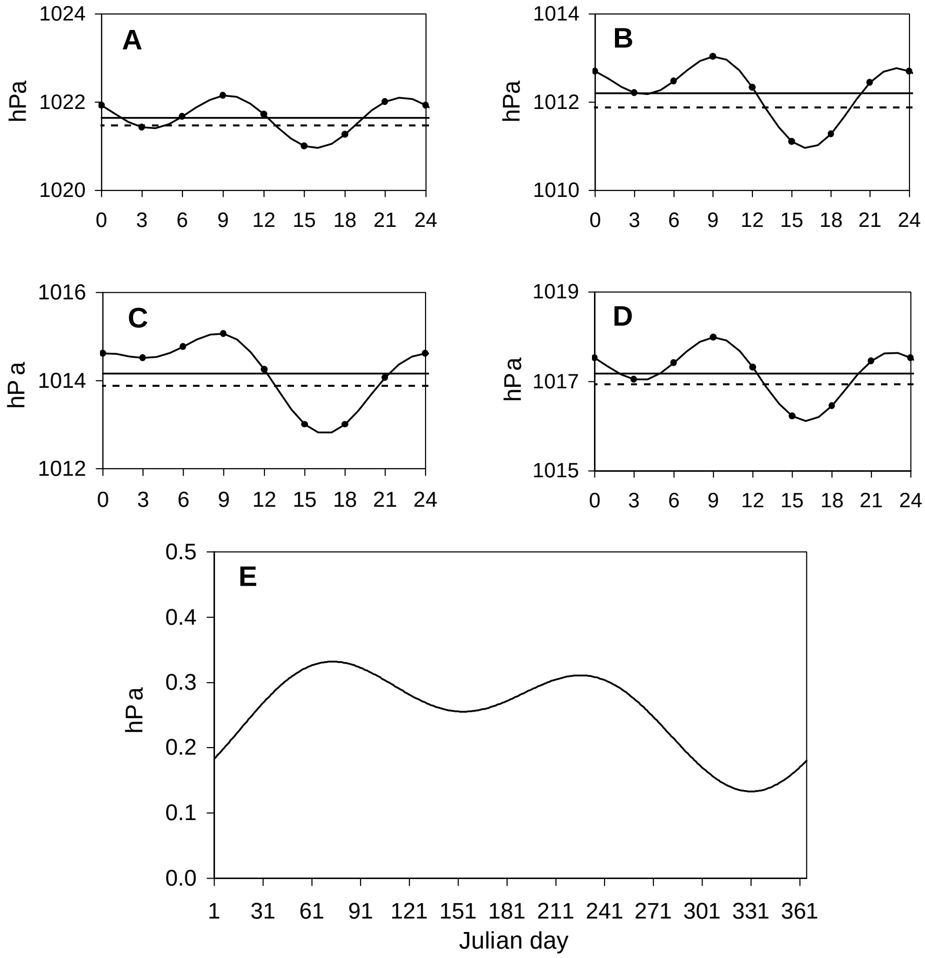

Fig. 3. – Graphs A-D display the average daily SLP cycles (smoothed) at station 080 (Milano Linate) on (A) January 1st, (B) April 1st, (C) July 1st and (D) October 1st. The horizontal lines represent the mean values obtained with i) 8 synoptic observations (continuous lines) and ii) only two observations performed at 6 and 18 GMT (dashed lines). Graph E displays the corrections to be applied to the Milano Linate daily averages obtained by means of two observations performed at 6 and 18 GMT in order to make them representative of the averages calculated by means of all the eight synoptic observations.

3. – Results and discussion

3˙1. *Station records and regional average series*. – The first step in analysing the data was the transformation of the 39 SLP series into SLP standardised anomalies series. They were calculated on a monthly basis by subtracting the monthly means over the 1961-1990 period and normalising by means of their standard deviations in the same period. This transformation removes the yearly cycle from the records, and allows evidence to be given only to displacements (in standard deviation units) from climatological monthly normals. Then, a correlation analysis was performed. The results showed that SLP data

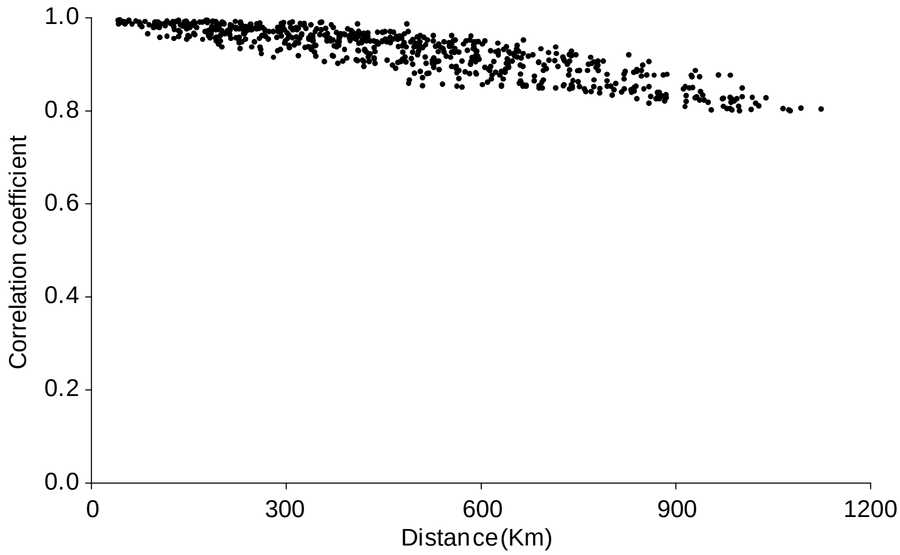

Fig. 4. – Correlation coefficients between monthly standardised anomalies series for all pairs of stations *vs.* their distance.

have a rather high spatial correlation with correlation coefficients around 0.9 for station distances around 500 km (fig. 4). This high spatial coherence suggested that most of the variability in the station data can be captured by a regional average series.

The possibility of representing most of the information contained in our data set by means of only one record was also verified by Principal Component Analysis [23, 24]. It showed that the first Principal Component (PC1) accounts for 93.2% of the variance of the SLP standardised anomalies and has very high correlation with all the station series (fig. 5). So it can be assumed to be approximately proportional to the mean of all SLP standardised anomalies series. Besides PC1, only one other PC (PC2) accounts for more variance than each of the original variables. It accounts for 4.2% of the variance of the dataset and seems to represent the differences between northern and southern Italy SLP.

So, considering the results of correlation analysis and PCA, an average series over all Italian station SLP records (AVIT) was introduced. It gives a synthetic description of the evolution of air pressure over Italy.

3·2. *Trend analysis*. – Trend analysis was performed both by considering the individual station records and the average over all Italian stations (AVIT). The first step was the calculation of seasonal and annual average series. Annual values correspond to the period from December to November and are dated by the year in which January is included. Winter values refer to the December-February interval, spring to March-May, summer to June-August and autumn to September-November. Then the slopes of the seasonal and yearly series were calculated by least-squares fitting, whereas the significance levels (SL) of the trends were tested by means of the Mann-Kendall non-parametric method [25].

Figure 6 displays the slopes of the seasonal station records expressed in hPa/50 years. The clearest signal is a marked increase in winter SLP all over Italy, with highest increases in the western areas and lower ones in the southeastern stations. In the other seasons, significant trends are present only in spring over central and southern Italy. Even if in

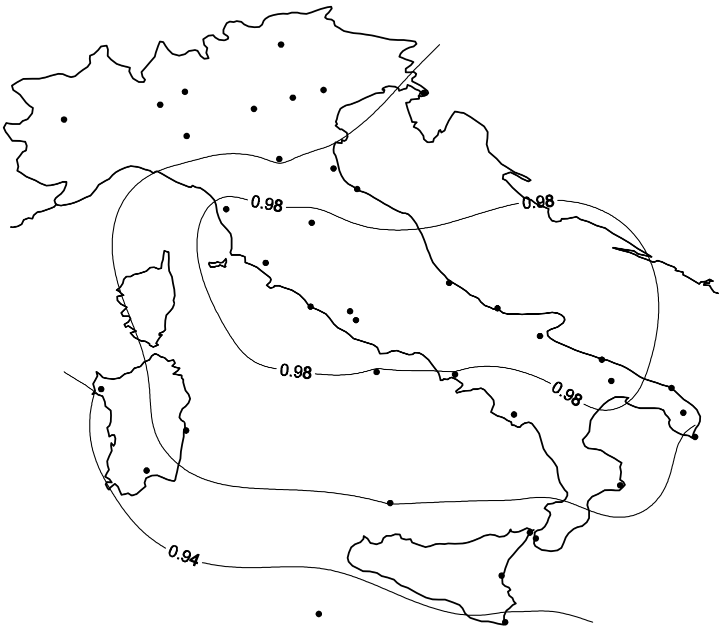

Fig. 5. – Geographical representation of PC1 loadings. They represent the correlation coefficients between PC1 and the station records, expressed in terms of monthly standardised anomalies.

many cases station trends are not significant, it is worth noticing that the only negative slopes concern northern Italy stations in autumn.

The strong positive trend of Italian winter SLP is well described by AVIT, that gives evidence of an increase of 5.7 ± 1.4 hPa/50 years (SL $>$ 99.9%). This increase, together with the general tendency toward positive trends in the other seasons (SL $<$ 90%), causes AVIT yearly series to display a positive trend of 1.8 ± 0.4 hPa/50 years (SL $>$ 99.9%). Figure 7 shows AVIT seasonal and yearly values in the 1951-2000 period. It gives evidence that the positive trend of Italian SLP seems mainly due to a change point around 1980. This result was also confirmed by the application of the non-parametric change-point detection Pettitt test [26]. This method, based on Mann-Whitney–type statistics, allowed us to establish a significance level greater than 99% both for the winter and for the yearly change-points.

3·3. *Comparison with gridded data sets.* – The AM data were also used to check the ability of two widely used gridded data sets (NCAR/NCEP and UKMO) to capture the variations of Italian SLP in the 1951-1998 period.

The first step was to obtain, starting from the AM homogenised records, three series representative of grid points 45°N-10°E, 40°N-10°E and 40°N-15°E. They were calculated using weighted averages, according to the distances from the grid points. Weights were calculated by a Gaussian function decreasing from 1 to 0.6 for distances from 0 to 700 km. No stations for distances greater than 700 km were used. For grid point 45°N-10°E, besides AM data, also Swiss and Austrian homogenised records were included [21]. Then the gridded AM SLP series and the corresponding NCAR/NCEP [4, 5] and UKMO [3] ones were averaged in order to obtain a series representative of grid point 42.5°N-12.5°E,

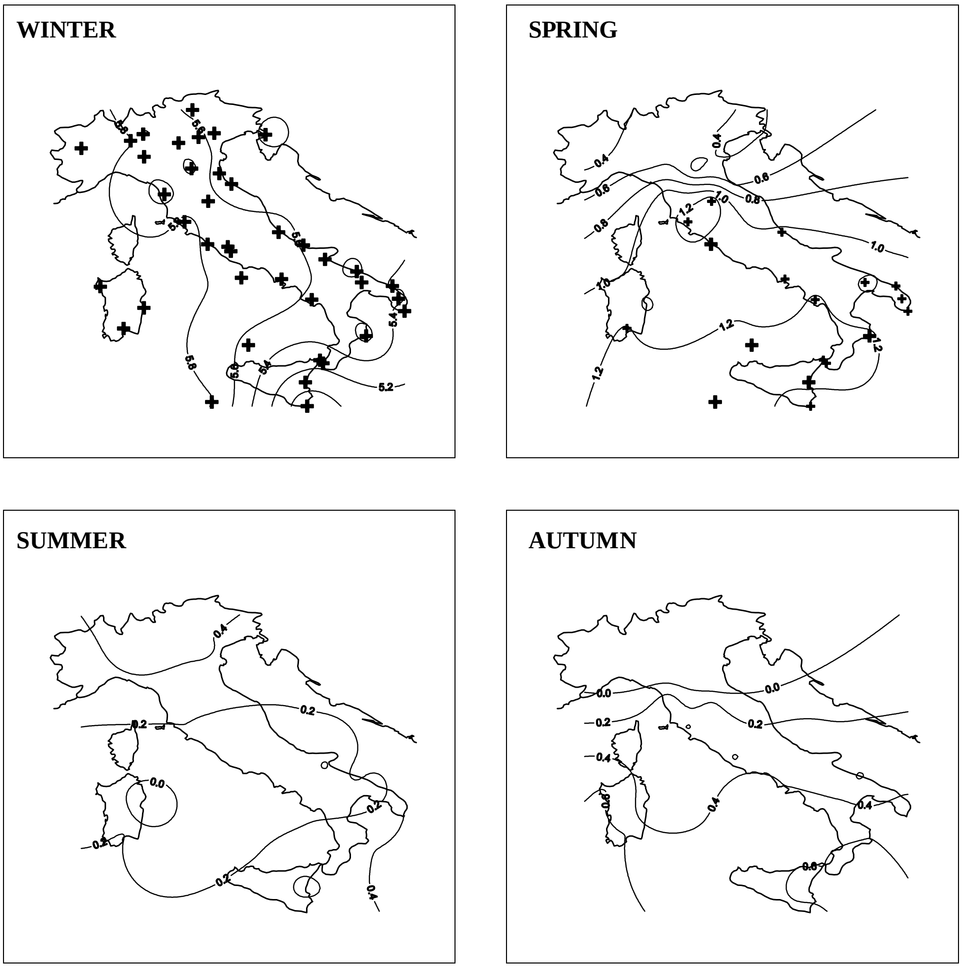

Fig. 6. – Spatial patterns of SLP trends for winter (upper left), spring (upper right), summer (bottom left) and autumn (bottom right). Trends are expressed in hPa/50 years. Station labels give information about significances. SL $<$ 90%: no label; 90% $\leqslant$ SL $<$ 95%: +/-; SL $\geqslant$ 95%: +/−.

that corresponds approximately to the centre of the region covered by our data set (CENIT). It is worth noticing that, even if obtained by different methods, the seasonal and yearly AM CENIT series are almost identical to the corresponding AVIT ones.

The first step in the comparison between the CENIT series obtained from the three data sets concerned trend analysis. It displayed a very good agreement between AM and UKMO data (table II), giving evidence that the spatial patterns of air pressure trends obtained by [27] for the 1951-1995 period by means of the latter data set are consistent with the AM records trends. Besides very similar results for AM and UKMO, table II gives evidence of important differences with NCAR/NCEP results, that display stronger positive trends with high significant increases in all the seasons. It is worth noticing that the strong positive NCAR/NCEP trends in all the seasons are not a particular feature

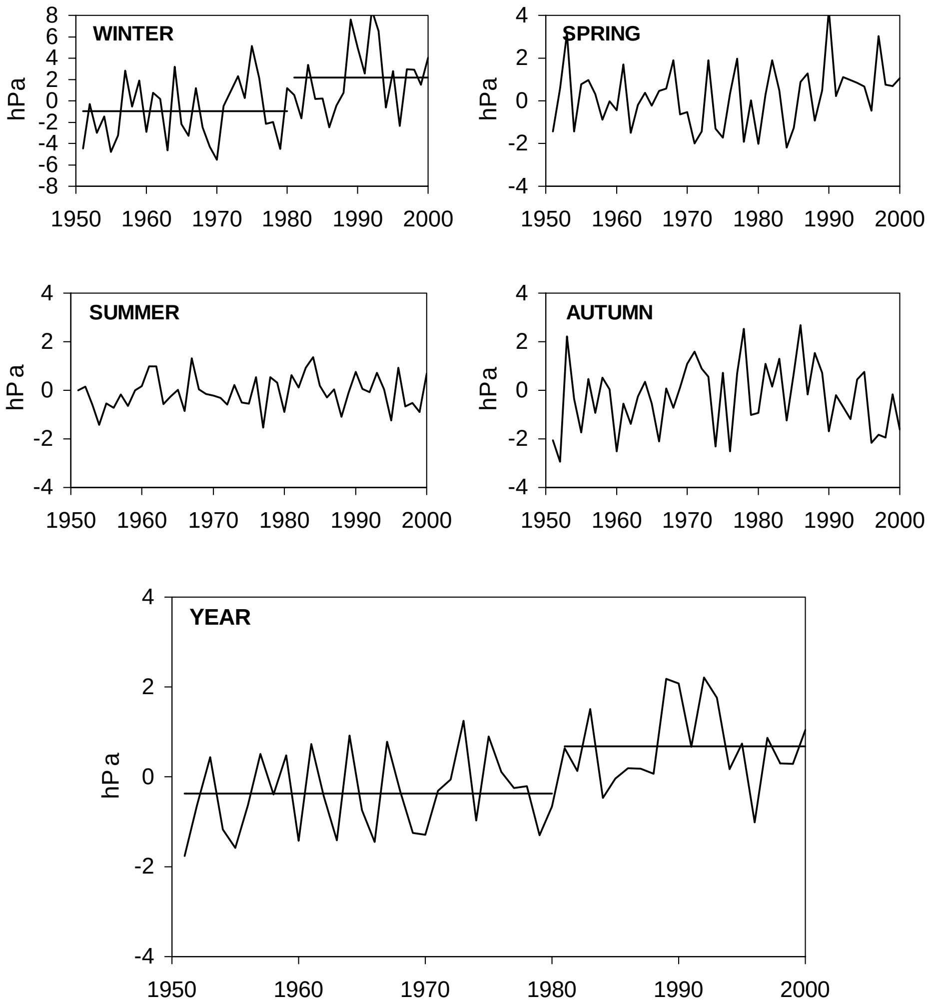

Fig. 7. – Seasonal and annual AVIT series (hPa) for the 1951-2000 period. In order to give better evidence of the amplitude of the 1980 change point, we also show the averages over the 1951-1980 and 1981-2000 periods for the winter and for the year.

of grid point 42.5°N-12.5°E, but concern all NCAR/NCEP grid points covering Italy (figure not shown).

In order to give better evidence of the results of the comparison between AM and NCAR/NCEP data, we display in fig. 8A the differences between the yearly AM and NCAR/NCEP CENIT series. This figure displays some evident steps that cause the differences between the AM and the NCAR/NCEP yearly mean values to pass from about 1 hPa in the 1951-1965 period to values near to 0 hPa in the last 15 years. On the contrary the differences between AM and UKMO CENIT yearly mean values are much more constant, with most values included in the interval $-0.8/-0.5$ hPa (fig. 8B).

Besides the presence of some steps, the comparison between the CENIT series obtained from the three data sets also gives evidence that there are differences up to 1 hPa

TABLE II. – *Results of the application of the non-parametric Mann-Kendall test and of least-squares linear fitting to the seasonal and annual AM, NCAR/NCEP and UKMO CENIT series. a is the estimated trend expressed in hPa/50 years, σ_{a} is the associated error.*

A: AM CENIT trends	$a \pm \sigma_{\mathrm{a}}$ (hPa / 50 y)	SL
Winter	5.7 ± 1.5	$> 99.0\%$
Spring	0.8 ± 0.8	$< 90.0\%$
Summer	0.3 ± 0.4	$< 90.0\%$
Autumn	0.4 ± 0.8	$< 90.0\%$
Year	1.8 ± 0.5	$> 99.9\%$
B: NCAR/NCEP CENIT trends	$a \pm \sigma_{\mathrm{a}}$ (hPa / 50 y)	SL
Winter	6.2 ± 1.5	$> 99.9\%$
Spring	2.2 ± 0.8	$> 99.0\%$
Summer	2.4 ± 0.4	$> 99.9\%$
Autumn	1.9 ± 0.8	$> 95.0\%$
Year	3.1 ± 0.5	$> 99.9\%$
C: UKMO CENIT trends	$a \pm \sigma_{\mathrm{a}}$ (hPa / 50 y)	SL
Winter	5.3 ± 1.6	$> 99.0\%$
Spring	0.9 ± 0.8	$< 90.0\%$
Summer	0.3 ± 0.4	$< 90.0\%$
Autumn	0.1 ± 0.8	$< 90.0\%$
Year	1.6 ± 0.5	$> 99.0\%$

in the long-term SLP averages. They could be caused by the fact that the different data sets are constructed using different observation hours, but probably also depend on data inhomogeneities.

In order to compare also the variability of monthly data, the grid point series were transformed into standardised anomalies using the same method adopted for studying the correlation between the AM station records. Then the agreement between the three CENIT records was studied both by analysing the correlation between the monthly stan-

TABLE III. – *Correlation coefficients among AM, NCAR and UKMO CENIT monthly standardised anomalies series. In order to allow the estimation of the influence of long-term inhomogeneities on the results, also the correlation coefficients among the first difference series are displayed.*

Anomalies series	CENIT (monthly standardized anomalies)
AM-NCAR/NCEP	0.94
AM-UKMO	0.96
UKMO-NCAR/NCEP	0.91
First differences series	CENIT (monthly standardized anomalies)
AM-NCAR/NCEP	0.98
AM-UKMO	0.96
UKMO-NCAR/NCEP	0.95

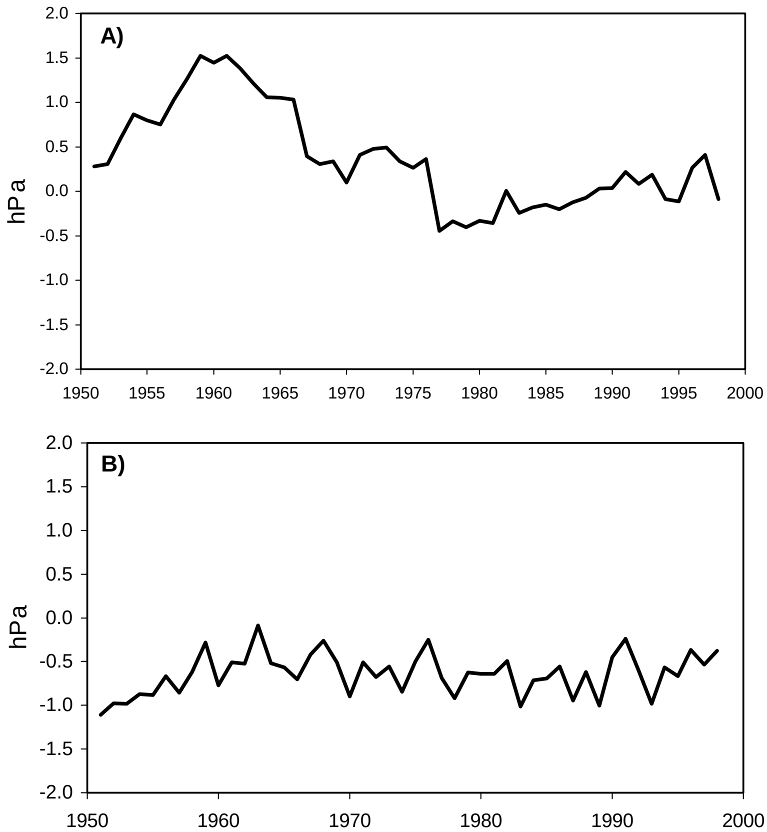

Fig. 8. – Differences between yearly CENIT series: A) AM-NCAR/NCEP; B) AM-UKMO.

dardised anomalies series and between their first difference series (table III). The latter ones are less influenced by inhomogeneities than the former, as in a first difference series any step change in methods or instrumental errors alters only one point, and not all the values after the event [28]. The results clearly showed that, considering the first difference series, NCAR/NCEP records have higher correlation with AM data than the UKMO ones.

The higher correlation of the NCAR/NCEP data and the better long-term agreement of the UKMO ones are clearly a result of the methods used to construct these two data sets and of their objectives: the first consists only of analysed data and aims to capture atmospheric circulation features, the second is also based on observed records and aims also to describe long-term evolution [3].

Globally our comparisons gave evidence that gridded data sets must be used carefully in studying long-term SLP evolution, especially if they are based only on analysed data. This may be a critical point as such data sets are often used to study long-term changes in atmospheric circulation.

4. – Conclusions

An analysis of a data set of 41 Italian 3-hourly records over a 50-year period was undertaken to identify air pressure trends. The main results are as follows:

– A method has been developed to obtain daily mean pressures avoiding biases due to missing observations. This point is particularly important as, even if only around 4% of the days have no observations, near 40% of them have at least one missing 3-hourly value.

– The application of correlation analysis and Principal Component Analysis displayed that only one PC accounts for more than 93% of the variance of the SLP standardised anomalies. It is very close to being proportional to mean SLP over Italy.

– Trend analysis displayed a highly significant positive trend in winter and yearly Italian mean SLP. The estimated magnitude of the winter trend is 5.7 ± 1.4 hPa/50 years, whereas for the year the estimated increase is 1.8 ± 0.4 hPa/50 years. Besides an increase in winter and yearly average SLP, central and southern Italy stations also displayed a weaker increase in spring SLP.

– The positive trend of Italian winter SLP seems mainly due to a change point around 1980. This result was also confirmed by the application of the non-parametric change-point detection Pettitt test.

All these results are in good agreement with the global picture displayed by the evolution of other parameters, such as cloud cover, total precipitation, rainy days and daily temperature range [15,18,29,30]. This good agreement confirms the hypothesis [27, 29-31] that the observed trends in Italian climate in the last decades are mainly due to a change in atmospheric circulation that has accompanied the recent warming and that has caused an increase and a northerly shift in the westerlies, with consequent advection of warm and moist air over large areas of central and northern Europe [32-34] and more frequent anticyclones over its southern part [35].

The AM data were also used to check the ability of two widely used gridded data sets (NCAR/NCEP and UKMO) to capture the variations of Italian SLP in the 1951-1998 period. The results showed that gridded data capture most of the trend and variability of air pressure over Italy, even if they also displayed that such data must be used carefully in studying long-term SLP evolution, especially if they are based only on analysed data.

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