Precipitation in the French Alps: Why Downscaling is required

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Introduction

Simulations of the climate of the end of the 21^{st} century are still performed using coarse grain resolution of **General Circulation Models** (GCMs), mostly for computer time consumption saving compared to **Regional Climate Models** (RCMs). However, a crucial question about Climate Change is that of its manifestations in local or sub-regional precipitation climatology, and especially that of changes in extreme precipitation or drought duration or severity. Present day operational models still suffer from frequent failures in sub-regional heavy precipitation forecasts like during the 8 september 2002 southern France flood when extreme precipitation affected the region of Avignon, Nîmes and Orange (there was a local record of 650 mm in 24 hours): on the 8 September morning, precipitation was still forecast to sweep the south-eastern part of France from the Cévennes to the Côte d'Azur whereas the actual exceptionally intense thunderstorms and rainfall did not move but stayed over the same small region for almost 24 hours; the consequences were catastrophic. In view of such failures, even with (almost) real time operational models, direct Climate Change investigations for small regions (like the Alpes Maritimes, Savoy, or Ticino...) are very unlikely to be confident with GCM output products alone (another extreme precipitation case, October 13, 1973, will be discussed below). However, many synopticians are aware that intense precipitation in a given sub-region like the Alpes Maritimes most often occur with one of a few types of Large Scale Circulations (LSCs) [Plaut et al., 2001], and this empirical (also dynamical!) link makes up a key feature for **Downscaling**.

If the simulation of large scale features by GCMs can be considered confident enough, then **Downscaling** algorithms could be "nested" in a GCM and provide a way to obtain precipitation forecasts at the sub-regional scale. Although these forecasts would unavoidably be (more or less) probabilistic in their nature, they could efficiently support Climate Change studies. To this purpose, we developed a stochastic **Downscaling** algorithm for precipitation over the french Alpes Maritimes (see CNRS STARDEX deliverable D10 for more details; a draft will soon be available on the STARDEX WeB site). Here, we test, in a *cross-validation* way, our algorithm using NCEP-ReAnalysis (NCEP-ReA) LSC data. NCEP-ReA may be interpreted as a **perfect GCM** for LSCs. A comparison of our algorithm outputs is then attempted with NCEP-ReA direct precipitation forecasts. Although these forecasts are coarser grained than the size of the Alpes Maritimes (and others) sub-region, important conclusions about the relevance of GCMs for Climate Change studies (and the necessity or not of a **Downscaling** type of approach) seem to emerge from this comparison.

Data and Methodology

- **Precipitation records.** Daily gridded precipitation data over the Alps were provided to us by Christoph Frei, a STARDEX partner from ETH Zürich. The "Alpine Precipitation Climatology" (APC hereafter, [Frei and Schär, 1998]) now runs from 1966 up to 1999 and covers the Alps area and the adjacent foreland. It offers very attractive opportunities for the development and validation of **Downscaling** algorithms which could be (hopefully) "exported" to the end of the 21^{st} century. Thousands of station records have been projected on a 25 km grid for each day of the period, and each gridpoint corresponds on average to 6 stations. Subdomains were extracted for the Alpes Maritimes (AM hereafter, 14 gridpoints), for Savoy (15 gridpoints), and for other sub-regions (Fig. 1 in [Plaut et al., 2001]). In this report, we deal with the average precipitation over the Alpes Maritimes (or Savoy) area, *i.e.* the average over the 14 (or 15) APC gridpoints covering these areas.

To demonstrate the necessity or not of **Downscaling**, we also use direct NCEP-ReA precipitation fields. Like reanalysed LSCs, daily precipitation forecasts are delivered on a 2.5x2.5 GCM grid. This is not a problem for LSCs, but some discussion will be needed for precipitation in order to ensure that a (partial) comparison with smaller scale observations can make sense. Alpine NCEP-ReA grid boxes may be seen on Fig.1 of STARDEX deliverable D11.

- **Large Scale Circulation (LSC).** As already mentioned in the Introduction, we use NCEP-ReA LSC fields. We indeed impose that our **Downscaling** scheme is really a **Downscaling** one and does not depend on anything else than (rather large scale) circulation. It is noteworthy that LSCs are often amongst the best forecast and analysed fields, whereas many other fields depend more or less on model *ad hoc* parametrisation schemes. We thus limit ourselves to the Z700 height field, the most appropriate LSC field for precipitation studies. In [Plaut et al., 2001] the Z700 maps (*i.e.* the LSCs) corresponding to **Intense Precipitation Events (IPEs)** were classified into clusters. These clusters are very appropriate tools for **Downscaling** algorithms since some of them were found to own a high **discriminating power** for **IPE** probabilistic forecasts (Fig. 2 in [Plaut et al., 2001]).

- **The Stochastic Downscaling Algorithm.** We limit ourself here to a brief description; the algorithm will soon be described more extensively in deliverable D10. At a first stage, a **"Potential Precipitation Circulation Index" (ppci)** is looked for through a linear regression of daily precipitation against the **anomaly pattern correlation (apc)** of any day's LSC (*i.e.* Z700 height field) with the (above mentionned) IPE LSC clusters of [Plaut et al., 2001] which we now call **"Precipitation Regimes" (PR)**, a natural extension of the name: **"Weather Regimes" (WR)** in use when all daily LSCs are classified. We moreover introduce in our **ppci** a linear dependence on **apc**'s with **WR**'s, which allows some improvement of the performance of the algorithm. Since the **ppci**'s is the result of a linear regression, there exists no deterministic link between its value on a given day and the correponding precipitation; however, for the same reason, there exists a statistical link, and, the higher its value, the higher the probability of occurence of an **IPE**. Separation of dry and wet days and classification of the *learning period* **ppci** values into 20 categories (*vingtiles*) allows us to develop a nice stochastic **Downscaling** algorithm. The main steps are the followings: we start from the LSC of the involved day and compute its **ppci**. We then randomly choose an analog within the set of (*learning period*) days having their **ppci**'s belonging to the same *vingtile*. In this way, given a set of daily circulations, many precipitation series may be generated. When interested in seasonal precipitation, we typically generate 100 (daily) precipitation series and take the mean of the 100 seasonal accumulations obtained. This mean appears to be extremely **robust**. Seasonal accumulations are also extremely **robust** with regards to many details of our scheme. There are typically 2 or 3 **PR**s and 4 or 5 **WR**s: therefore the model only depends on 6 to 8 parameters (the corresponding linear coefficients within the **ppci**), whereas the linear regression is constrained by thousands of daily precipitation records. As a consequence, the **ppci** one obtains is so robust that, at the monthly or the seasonal level, the *cross-validation* forecasts are almost indistinguishable from the *single validation* ones.

The case of the Alpes Maritimes.

Figs 1 and 2 compare observed seasonal precipitation (red circles) over the Alpes Maritimes (AM hereafter), with those forecasted either by our stochastic **Downscaling** scheme (blue squares, upper panels) or directly by NCEP-ReA (inverted green triangles, lower panels of the same figures).

- **Fall precipitation** We compare on Fig.1 the observed automn precipitation heights over the AM and the forecasts of our **Downscaling** model with the daily **ppci** values computed using Z700 fields from NCEP-ReA. The blue squares show the remarkably **robust** seasonal precipitation heights obtained when one considers the mean of 100 **Downscaling** forecasts using the same daily observed **ppci** (computed from NCEP-ReA). Each **Downscaling** forecast affects a daily precipitation height to any day between September 1 and November 30 of each year. The corresponding seasonal accumulation is then computed; finally, for each year between 1966 and 1999, we compute the mean of the 100 forecasts. The blue squares on the Figures display these means. At a first sight, one can remark that 3 out of the 5 highest values of the automn precipitation are very well simulated (1966, 1976, and 1993), whereas two out of them are underestimated (1979 and 1994). A more detailed inspection (not shown) reveals that very heavy accumulations occured during short periods of the later automns, due to the development and persistance of rather small size systems providing intense prolonged precipitation. The exceptional character of these systems and the associated precipitation cannot be fully accounted for by our **ppci** approach which depends only on LSCs.

  We touch here a limitation of our statistical **Downscaling** algorithm based on the computation of a circulation index depending only on LSCs. Describing these smaller scale systems is merely out of its scope. The **Dynamical Downscaling** through **RCM**s like **Limited Area Models** nested in a GCM or some coarse grained operational model is intended for this purpose; a few case studies are described in [C. Marsigli et al., 2001] where the Bologna Limited Area Model (BOLAM) was nested in representative members selected from the ECMWF ensemble prediction system; in 2 out of 4 case studies, the high resolution runs nested on the representative member of the most populated cluster of the ensemble predicted to a very good degree of spatial and temporal accuracy the heavy rainfall which actually occured. In the 2 other cases, one high resolution run predicted either the precise location of the event or the precipitation rate, but it was a run nested to a poorly populated cluster, so only enabling the issue of probabilistic flood alerts. In all the ways, such an approach is still under studies, and it will take time before it can be applied to Climate Change studies in a confident way. We mention **Dynamical Downscaling** at the end of our conclusion below. It is worth noticing that since **Dynamical Downscaling** is currently nested on ensemble forecast representative members, it shares in some way the stochastic nature of ... **Stochastic Downscaling** approaches like ours.

  By contrast, the precipitation of the 3 dryest automns is somewhat overestimated. However, our model quite accurately describes the interannual variability, with only some underestimation of the variance. The mean($\approx$ 300 mm) is perfectly well reproduced, whereas the observed slight increasing trend ($\approx$ + 100 mm in 34 years) is somewhat underestimated.

Of course, a direct comparison with NCEP-ReA direct precipitation forecasts is *a priori* excluded. One can nevertheless observe that seasonal precipitation at both grid points closest to the AM is highly correlated (corr $\approx$ 0.8) with that actually observed for the AM, although the AM area is quite tiny when compared to the area attached to any NCEP gridpoint. On Fig.1b we tentatively compar the AM area averaged automn rainfall with the corresponding mean (green inverted triangles) between the 2 closest NCEP gridpoint precipitation (7.5E 42.5N and 7.5E 45N). The correlation (0.81) between the 2 curves is striking. But the increasing relative bias represents an unexpected feature: at the beginning of the period, NCEP fall precipitation amounts to $\approx$ 80% of observed AM one, whereas it drops to $\approx$ 45% at the end. No conclusion can of course be drawn at this stage: we have to examine whether such an intriguing behaviour occurs for other seasons and other sub-regions. We may however already point out that this huge model precipitation decrease, if confirmed, would **definitely mask** the end of the 21^{st} century tendencies; and the investigation of these tendencies makes actually the ultimate purpose of STARDEX!

> In order to enlarge our inquiries about the relevance of the precipitation fields generated through the reanalysis process for past extreme events, we also briefly turned to the **ERA 40** precipitation field. Let us give here a brief insight of the description by **ERA 40** of the **heaviest** (since 1949) daily precipitation both in Nice and over the whole AM area, with, on October 13, 1973 , an average 96 mm accumulation over the 14 AM gridpoints, and 191 mm in Nice airport station. Since the AM area, with its 14 APC gridpoints, is far from being a small area ($\approx 9000 km^2$), such an extreme precipitation would be expected to affect in some way the ReA precipitation field. **ERA 40** precipitation map are now available on the ECMWF WeB site. Although such maps suffer from the scarcity of the interpolation procedure, those for October 13, 1973 may be looked at. It is amazing to observe that the most intense 6H forecast for this overall extreme event over the AM only amounted to $\approx$ 15 mm, mainly from large scale precipitation: we actually touch a **severe limitation of the present day GCM reanalysis precipitation fields** relevance concerning extreme events; this limitation must be considered all the more because October 13, 1973 was a spatially extended extreme event, not at all a local or small extension one!

- **Winter precipitation** On Figs 2a,b we perform the same comparison for the winter season over the AM. The excellent quality of the **Downscaling** model seasonal accumulations of Fig.2a is striking, especially for the last 20 years. The mean and the variability are very well accounted for; many annual values of the downscaled winter precipitation even lie very close to observations, pointing to the importance and relevance of the link between heavy precipitation and circulation (the **ppci** is nothing more than a rather crude description of this link). Even the slight negative trend ($\approx -$ 100 mm in 34 years, the reverse of the automn trend), is quite well reproduced.

  The comparison with NCEP-ReA is again amazing: the correlation between the red circles and the green triangles of Fig.2b is excellent (0.84). The absolute bias remains constant, but the increase of the relative bias is again problematical: the direct NCEP forecasts for winter precipitation drop from about 70% of the observed one at the beginning, down to $\approx$ 50% at the end of the period. It's worth mentionning that the same drop occurs separately at both involved gridpoints, wich strongly suggests that this bias has **nothing to do** with the larger scale of the NCEP-ReA grid.

  We do not show spring NCEP-ReA forecasts for brevity, but the same observations could be done. As to summer, there would be nothing to compare since truely heavy precipitation is actually almost absent from records during summer in the AM.

Observations and NCEP-ReA forecasts for Savoy

We have not yet used our **Downscaling** algorithm for Savoy, since **PR**s depend on the Alpine sub-region [Plaut et al., 2001]. However, in view of the strange behaviour of NCEP-ReA precipitation for the AM, we had to check over another sub-region whether the discrepancy observed in the case of the AM was an isolated problem... or if a similar behaviour was observed elsewhere (intense precipitation occurs with very different kinds of LSC patterns over the AM and Savoy which lie on opposite flanks of the Alpine massifs). 4 NCEP gridpoints lie around the Savoy area; the best correlated precipitation occurs at the gridpoint (7.5E 47.5N) lying to the NE. We display on Fig. 3a (resp. 3b) the observed fall (resp. winter) precipitation over Savoy and the corresponding NCEP-ReA precipitation forecasts at this gridpoint. Before making any comment, let us specify that equivalent trends are found for the 3 other surrounding gridpoints, making **our conclusions very general**, at least for the west Alpine regions.

The qualitative features of Figs 3a and 3b are the same as those of Figs 1b and 2b, with a yet stronger decrease of NCEP-ReA precipitation relative to the observations for both fall and winter: NCEP-ReA seasonal precipitation heights drop each time from $\approx 80\%$ down to $\approx 35\%$ of observed ones. This is not a minor problem since it has as a direct consequence that one can in no way be confident in the precipitation rate of NCEP-ReA **direct** precipitation forecasts. Had the attenuation between the observations and the NCEP forecasts been stationary in time, attenuation had not been a major problem! But the missing fraction of precipitation increases by more than a factor 2 between the mid sixties and the late nineties and this **non-stationarity** truely makes up a serious problem: **direct precipitation simulated by NCEP-ReA**, theoretically a perfect GCM, **is unusable** for Climate Change studies. This unambiguously **demonstrates the necessity to use some Downscaling algorithm** in order to get somewhat confident results about future changes in precipitation and extreme precipitation climatology.

Indeed, unless these tremendous spurious negative trends found for NCEP-ReA precipitation fields all over the western Alps (**to the North like to the South**) is due to some coarse problem which could be remedied before long, they set a serious problem. The investigation of extreme precipitation events changes at the end of the 21^{st} century actually aims to enquire whether extreme precipitation is expected to get more intense and (or) more frequent or not. In other words, the **trends** in extreme precipitation are the **main** parameters to be investigated, and these huge biases in the trends of the presently available NCEP-ReA precipitation fields discard their use in any prospective study about the future of extreme precipitation; they are indeed too large when compared to any expected change!

Conclusion

We developed a **Downscaling** algorithm and began to **validate** it using the gridded precipitation data basis of the **Alpine Precipitation Climatology** (APC) over the french Alpes Maritimes (AM), together with the **NCEP-ReA (Large Scale) Z700 height field**. At the seasonal time scale, the correlation is high between forecasts and observations. The magnitude of the interannual mean is exact, the interannual variability is also nicely reproduced, while the trend is only somewhat underestimated, either not large enough when positive, or a bit too pronounced when negative. However, this last discrepancy remains very small, especially for winter: the model only fails to account for a minor amount of the trend and we can infer that our **Downscaling** algorithm, although very simple, could provide the basis of an **appropriate**

tool for Climate Change studies.

We also looked at NCEP-ReA direct precipitation forecasts at gridpoints over the Alps, for comparison. Although the spatial scale is larger than that of the sub-regions we are looking at, we were first surprised by the very good correlation between observed and NCEP-ReA (forecasted) seasonal precipitation. This was true for Savoy as wel as for the AM, and for winter and spring (not shown) as well as for automn. However, **a very serious problem arises with a strong decrease of the NCEP precipitation relative to the observed one**. This **increasing relative bias** was observed **everywhere over the western Alps** and seems therefore to have **nothing to do with the larger spatial scales of NCEP-ReA**.

As a consequence, this particular GCM precipitation field appears fully irrelevantt for Climate Change studies: even the present day order of magnitude for trends are problematic, and any prospective study could be confident in no way since trends are really the most important feature for prospective studies... The fact that this report limits itself to seasonal precipitation cannot seriously be raised as an objection, at least for the AM where seasonal precipitation is highly correlated with the occurence of extreme precipitation. And highest damages mostly occur after repeated intense precipitation episodes, always leading to high seasonal accumulations, like was the case during October and November 2000.

To conclude, our limited study demonstrates the **feasability** of a **Downscaling** approach for precipitation forecasts or studies, at least for the AM and similar sub-regions. It could provide the basis of an **appropriate tool for Climate Change perspective investigations about sub-regional precipitation**. On the contrary, the **very serious problems** we were faced with when **using direct NCEP-ReA precipitation forecasts** seem to **exclude, at least at the present state of the art, any direct use of such a precipitation field**.

The question whether other GCMs suffer from similar problems is out of the scope of D11. However, the analysis of outputs from other models will be very instructive (see D13 to come next year). In all the ways, we have verified that like statistical **Downscaling**, GCM precipitation fields seem to suffer from severe limitations which inherently prevent them from describing particular extreme events like October 13, 1973 torrential rain over the AM. A very promising and (likely) much more reliable approach may be the nesting in a GCM of **high resolution ensemble prediction** techniques like in [Marsigli et al., 2001] who apply these techniques to a few famous case studies like Vaison-la-Romaine (1992) or the Piemonte flood (1994). But such techniques are time consuming, and, in a near future, we only hope to systematically compar **Empirical Downscaling** precipitation forecasts, like those obtained through our **ppci** approach, with deterministic **Dynamical Downscaling** precipitation forecasts. Unfortunately, **Dynamical Downscaling** products like **Regional Climate Model** (RCM) Re-Analysis outputs are still difficult to access, and the comparison could not be performed in this report.

References

[**Plaut et al., 2001**]: Plaut, G., Schuepbach, E. and Doctor, M., Heavy precipitation events over a few Alpine sub-regions and the links to large-scale circulation, 1971-1995, *Climate Research* **17**, CR Special 9 **ACCORD: Atmospheric Circulation Classification and Regional Downscaling**, pp 285-302, 2001.

[**Marsigli et al., 2001**]: Marsigli, C., Montani, A., Nerozzi, F., Paccagnella, T., Tibaldi, S., Molteni, F. and Buizza, R., A strategy for high resolution ensemble prediction. II: Limited-area experiments in four Alpine flood events, *Quarterly Journal of the Royal Meteorological Society* **127**, pp 2095-2115, 2001.

[**Frei and Schär, 1998**]: Frei, C. and Schär, C., A precipitation climatology for the Alps from high-resolution rain-gauge observations, *Int. J. Climatol.*, **18** pp 873-900, 1998.

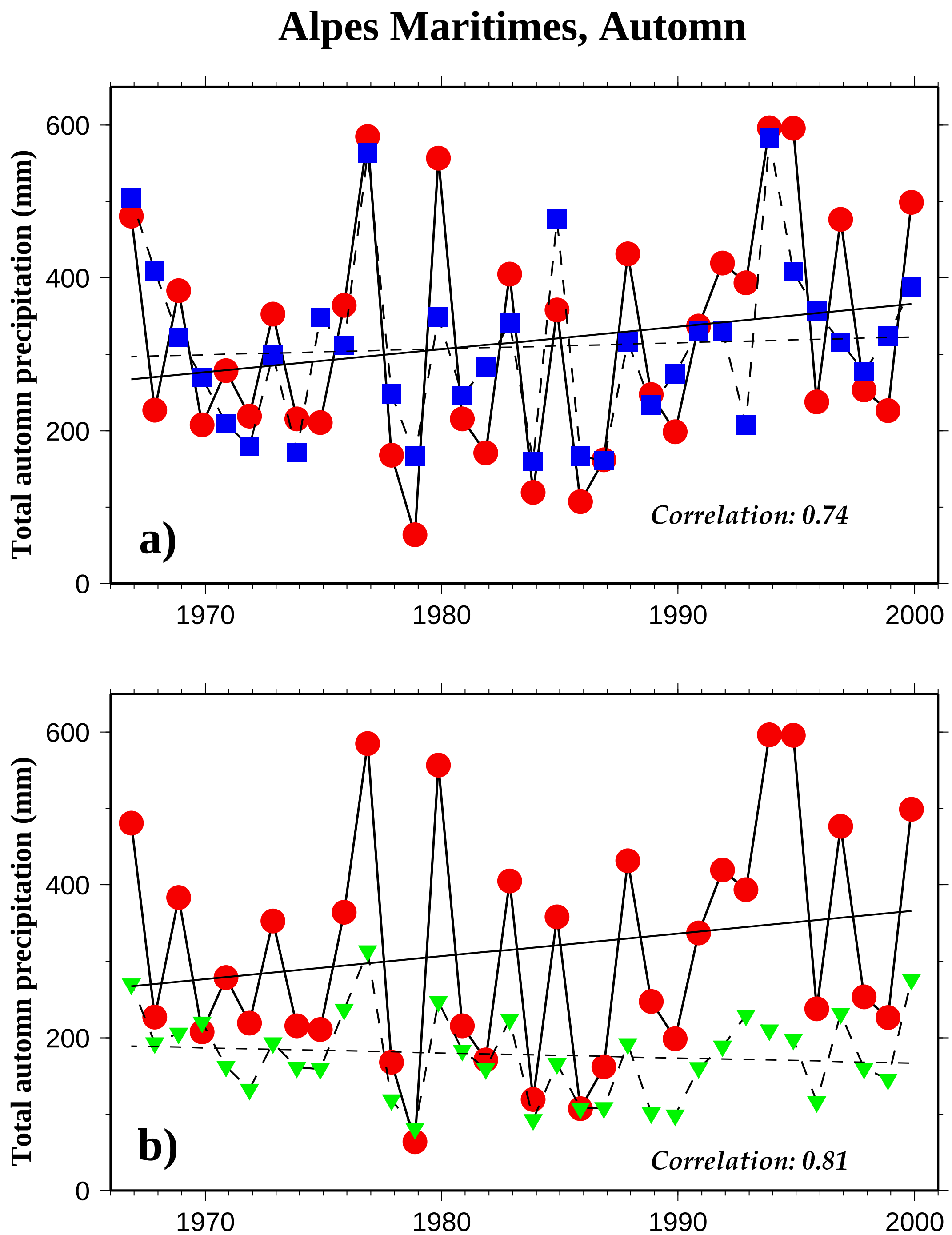

Figure 1: Area averaged total Fall precipitation for the Alpes Maritimes. Red circles and full lines: Observations. a) Blue squares and dashed lines: mean of 100 Downscaling forecasts starting from the Z700 height field of NCEP-ReA; b) Green inverted triangles: mean of the raw NCEP-ReA forecasts at the 2 gridpoints closest to the Alpes Maritimes (see text for more details). The straight lines display the corresponding tendencies.

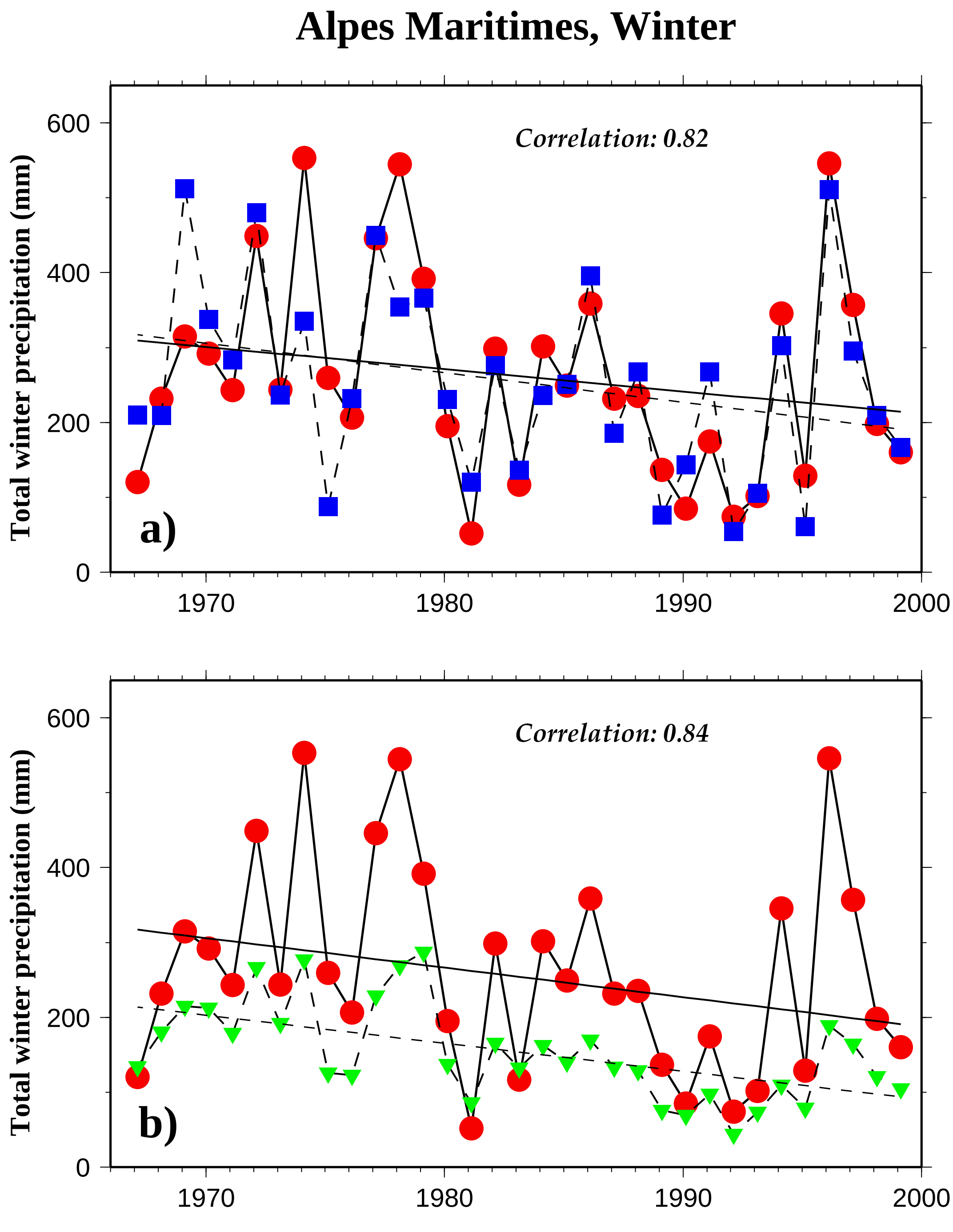

Figure 2: Same as Fig. 1, but for winter precipitation.

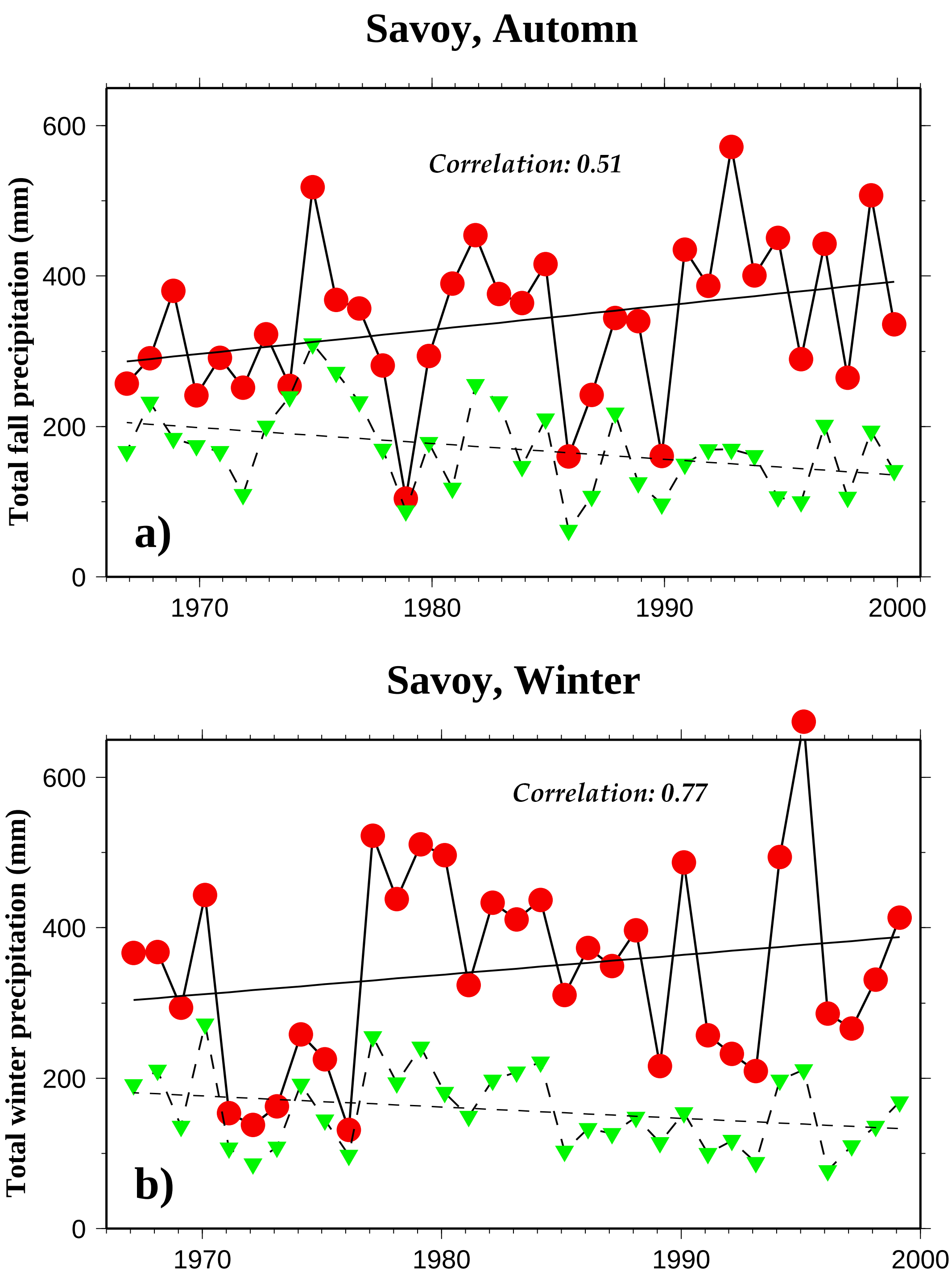

Figure 3: Same as Figs 1b and 2b, but for Savoy a) Automn; b) Winter. Green inverted triangles: precipitation forecasts at the NCEP-ReA gridpoint 7.5E 47.5N (see text for more explanations).