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Impact of land use and precipitation changes on surface temperature trends in Argentina

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[1] The "observation minus reanalysis" (OMR) method has been used to estimate the impact of changes in land use (including urbanization and agricultural practices such as irrigation) by computing the difference between the trends of the surface observations (which reflect all the sources of climate forcing, including surface effects) and the NCEP/NCAR reanalysis (which only contains the forcings influencing the assimilated atmospheric trends). In this paper we apply the OMR method to surface stations in Argentina for the period 1961–2000. In contrast to most other land areas, over most of Argentina there has been net cooling, not warming (about −0.04°C/decade). Observations also show a very strong decrease in the diurnal temperature range north of 40°S. This is associated with an observed strong reduction in the maximum temperature (−0.12°C/decade) together with a weak warming trend in the minimum temperature (0.05°C/decade). The OMR trends show a warming contribution to the mean temperature (+0.07°C/decade) and a decrease in diurnal temperature range (−0.08°C/decade), especially strong in the areas where the observed precipitation has increased the most and where, as a consequence, there has been an exponential increase of soy production in the last decade. The increase in precipitation is apparently associated with an increase in the moisture transport from the Amazons to northern Argentina by the low-level jet.

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1. Introduction

[2] Trends on the timescale of decades are due to either natural climate variability or to anthropogenic factors, and their attribution is quite difficult [e.g., *Intergovernmental Panel on Climate Change*, 2001]. Long-term trends can be masked by decadal changes in circulation. Furthermore, two of the most important anthropogenic actions that impact surface temperatures are the increase of greenhouse gases, and changes in land surface physical properties due to land use changes such as urbanization, agricultural practices, deforestation, etc., and their impacts are also very difficult to separate. It has been a hard task to detect a clear climate signal attributable to land cover change, except for a distinct warming in mega cities, likely due to urbanization.

[3] Temperature analyses show that in the last decades, the extratropical regions in the Southern Hemisphere, and in particular southern South America, have undergone much less warming than the Northern Hemisphere (Figure 1a).

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[4] Figures 1b–1d show the decadal trends over 20 years, from 1961 to 1980, 1971 to 1990 and 1981 to 2000 respectively. The strongest cooling occurred between the first two decades (Figure 1b), and in the last two decades the trend is rather neutral. As discussed in section 2 we do not include in this study the trends across 1971–1990 (Figure 1c) because of the large changes that occurred in the observing systems with the introduction of satellite data.

[5] It is not clear what causes this lack of apparent warming in this region, whether it is natural variability in the climate, including changes in oceanic circulation or in precipitation [*Karoly and Braganza*, 2005], or changes in the land surface properties. Local surface forcing of climate change is hard to detect but recent studies suggest that the impact of widespread land use changes should not be ignored [e.g., *Pielke et al.*, 2002; *Kalnay and Cai*, 2003; *Marshall et al.*, 2004]. Other studies [*Lim et al.*, 2005, 2008] indicate that the response to global warming may be strengthened or weakened by the type of vegetation cover, with surface warming stronger than expected from greenhouse gases warming in barren or urban areas, and weaker warming in broad-leaf forests.

[6] In this paper we attempt to estimate the impact of land surface changes on climate change in Argentina. We compare trends observed at surface stations with surface temperatures derived from the NCEP/NCAR reanalysis [*Kalnay et al.*, 1996]. *Kalnay and Cai* [2003] (hereinafter referred to as

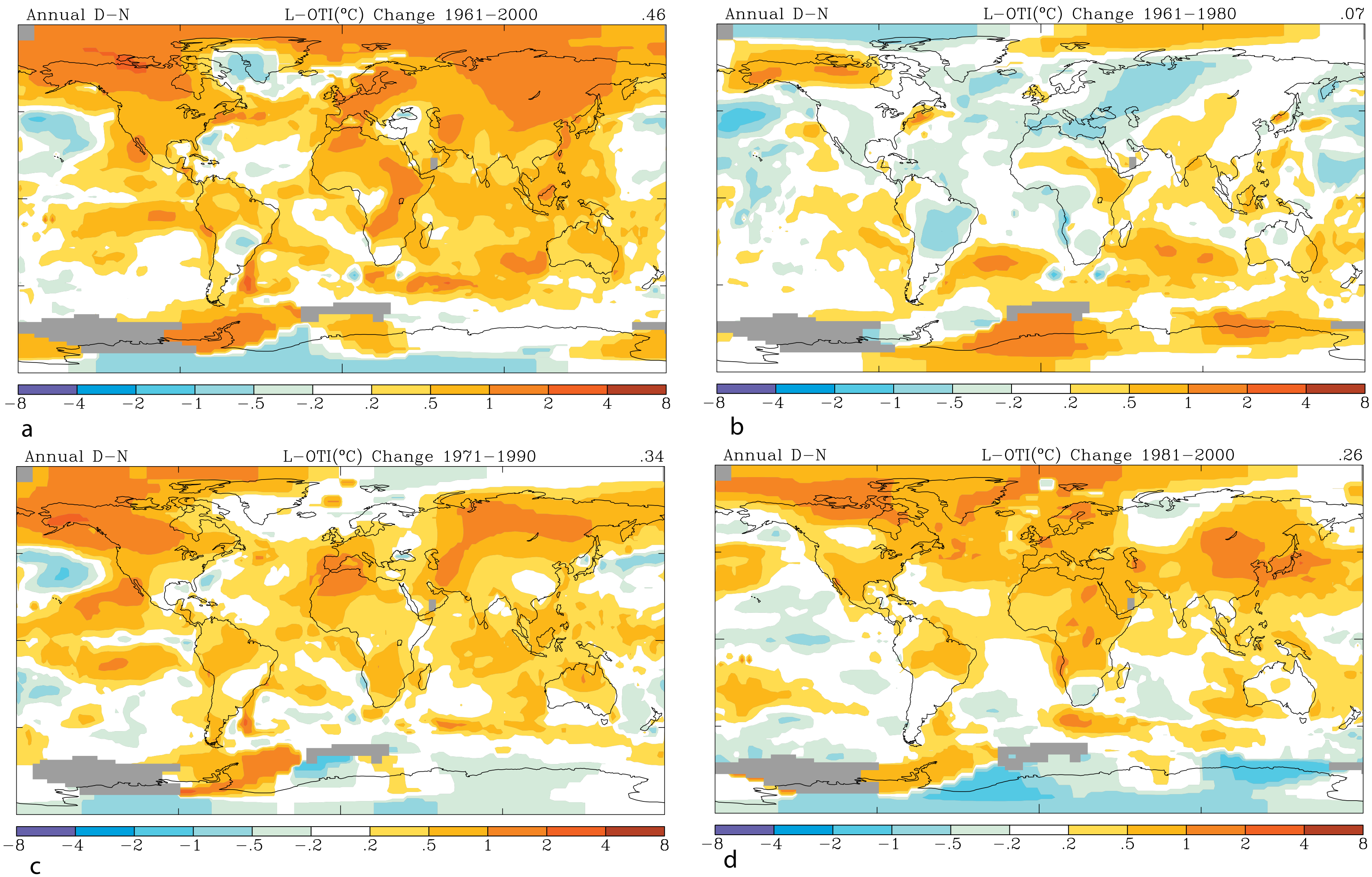

Figure 1. (a) Estimated change of the surface temperature between 1961 and the end of 2000 obtained from http://data.giss.nasa.gov/gistemp/maps/, with a smoothing parameter of 1200 km. The estimated global average trend is 0.45°C/4 decades = 0.11°C/decade. (b) As Figure 1a but for 1961 to 1980. (c) As Figure 1a but for 1971 to 1990. (d) As Figure 1a but for 1981 to 2000.

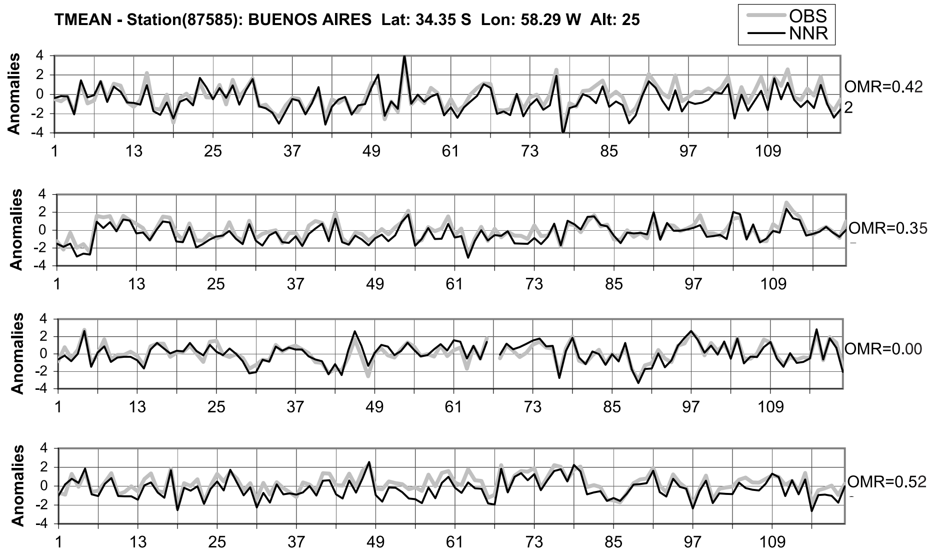

Figure 2. Comparison of the monthly averaged temperature anomalies for the NNR (black) and stations (gray), shifted so that they have the same average during the 1980s, for Villa Ortúzar in the city of Buenos Aires. The observation minus reanalysis (OMR) on the right is the decadal average (valid nominally at the center of the decade), so that the OMR trend between the 1980s and the 1990s is 0.52°C/decade.

KC) proposed to estimate the impact of all changes in land use (including urbanization and agricultural practices such as irrigation) as well as land surface changes due to precipitation, aerosols, etc., by comparing trends from surface observations and from the NCEP/NCAR reanalysis (NNR). The essence of the method proposed by KC to at least partially identify the impact of land use and other surface effects is to compute the difference between the trends of the surface observations (which reflect all the sources of climate forcing, including surface effects) and the NNR (which only contains the forcings influencing the assimilated atmospheric trends). KC suggested this approach, taking advantage of the fact that the NNR does not use surface observations, so that it is insensitive to land surface properties or their changes, but because it assimilates atmospheric temperatures, it is sensitive to atmospheric climate changes. The difference of observation minus reanalysis (OMR) surface temperature trends should be at least partly attributable to the characteristics and changes in land surface properties, including urbanization and agricultural practices, aerosols, and changes in precipitation which may be due to natural variability. An advantage of the OMR method is that climate changes associated with changes in atmospheric circulation with decadal timescales are essentially filtered out from the trend because they are present in both the observations and the reanalysis. This method has been applied by *Zhou et al.* [2004] to estimate urbanization impacts over southern China. *Kalnay et al.* [2006] showed that the OMR results are regional in nature, both positive and negative, and agree well with the "urbanization" trends obtained by *Hansen et al.* [2001] over the United States using satellite nightlights. *Lim et al.* [2005] showed that the OMR trends are strongly dependent on the type of land cover, as estimated by MODIS, and that the results obtained

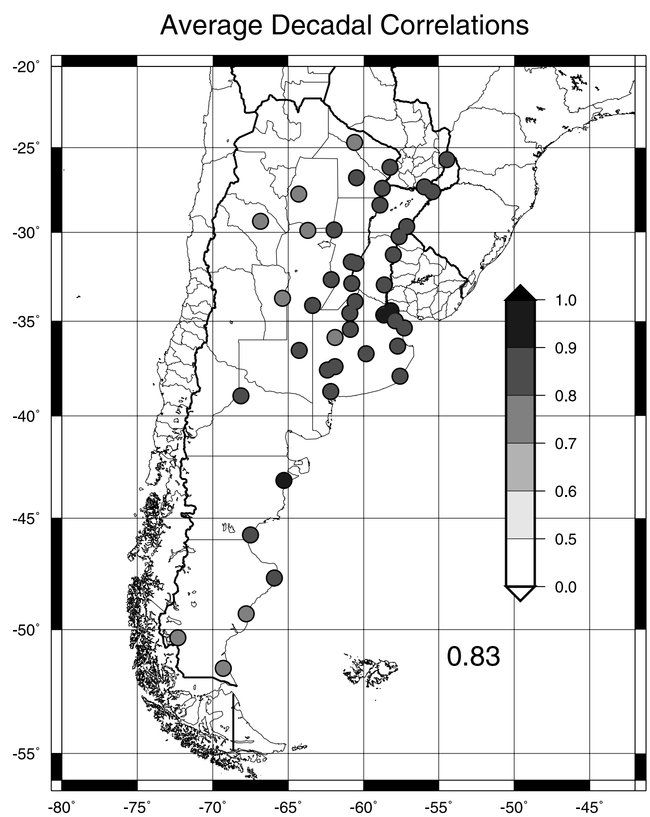

Figure 3. Correlation between the surface temperatures anomalies with respect to the 40-year annual cycle for stations and for the NNR. The correlation for each of the 4 decades is averaged in order to avoid the jump between the 1970s and the 1980s due to addition of satellite data. The value 0.83 represents the average correlation.

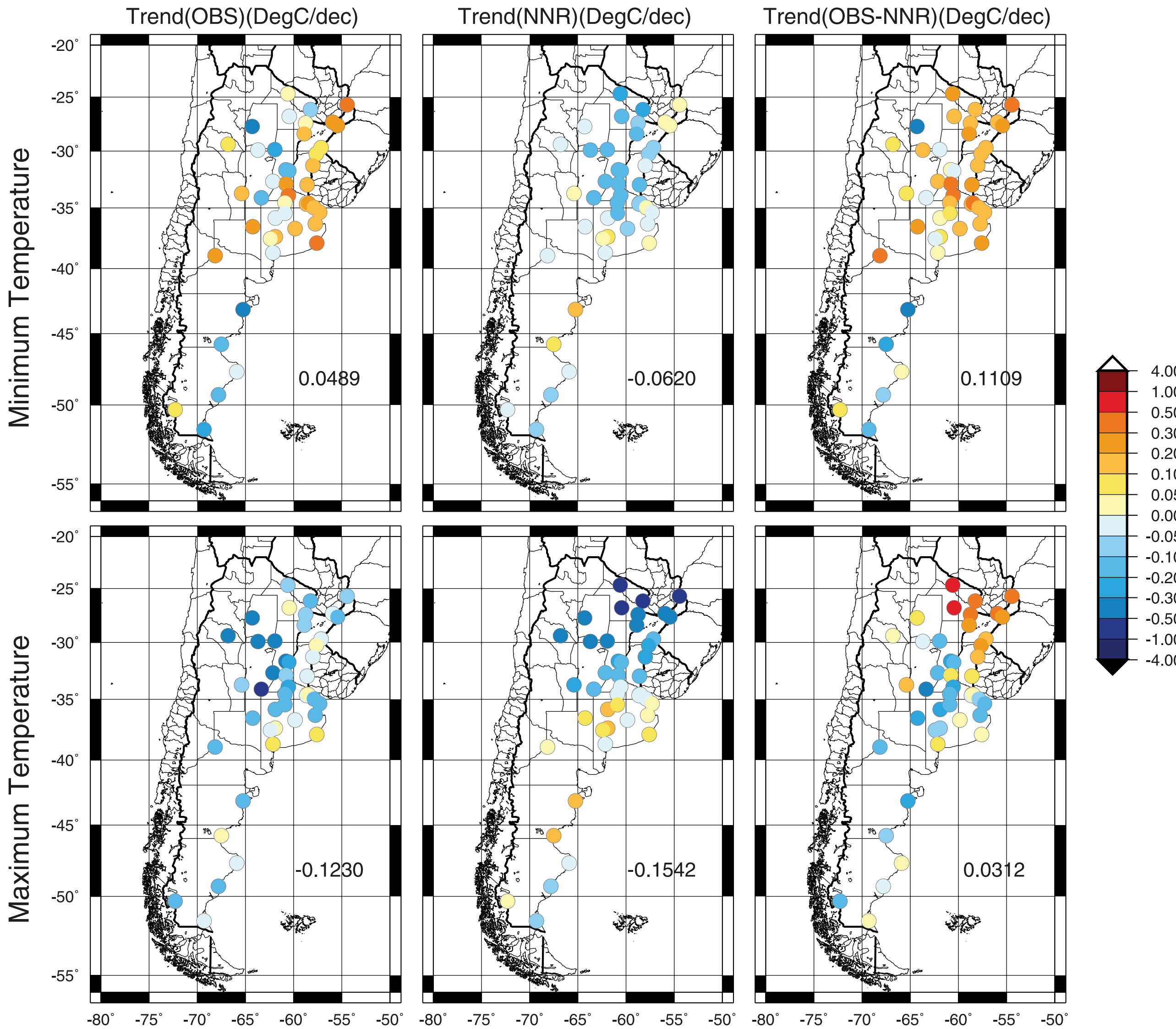

Figure 4. The 40-year (top) minimum temperature and (bottom) maximum temperature trends for Argentina (in °C/decade) over stations located below 500 m. Trends (left) from stations and (middle) from the NNR and (right) observations minus NNR trend. The number represents the average trend of all stations in the study.

using the NNR are similar to those obtained the ECMWF reanalysis (ERA40) although the latter OMR trends are generally smaller because (unlike NNR) ERA40 uses surface air temperatures in the initialization of soil temperature and moisture. *Lim et al.* [2008] found a strong anticorrelation of the OMR trends with the independently estimated Normalized Difference Vegetation Index (NDVI), with a stronger response to greenhouse warming in arid regions than in highly vegetated regions. Readers may also consult with *Pielke et al.* [2007a, 2007b] for a comprehensive review on this subject as well as discussions on applying the OMR method for assessing the nonclimate biases in the surface station data.

[7] In this paper we present trends obtained from station data in Argentina, both for temperature and precipitation over the decades 1961–2000, and the corresponding NNR reanalysis temperature trends. Section 2 discusses the data and method, section 3 presents the results, and section 4 is a summary and discussion.

2. Data and Method

[8] For the surface observations, we use the daily surface maximum and minimum surface stations temperatures from the National Weather Service (SMN) of Argentina over most Argentinean provinces for 1961–2000. For the NNR, we use the global daily surface maximum and minimum temperatures at the Gaussian grid, also for the period 1961–2000. No attempt to correct station measurements for nonclimatic changes such as station location or time of observations was made (beyond standard quality control). *Kalnay et al.* [2006] have shown that corrections for such changes, though large in magnitude, do not affect the regional distribution of observation or OMR trends over the United States.

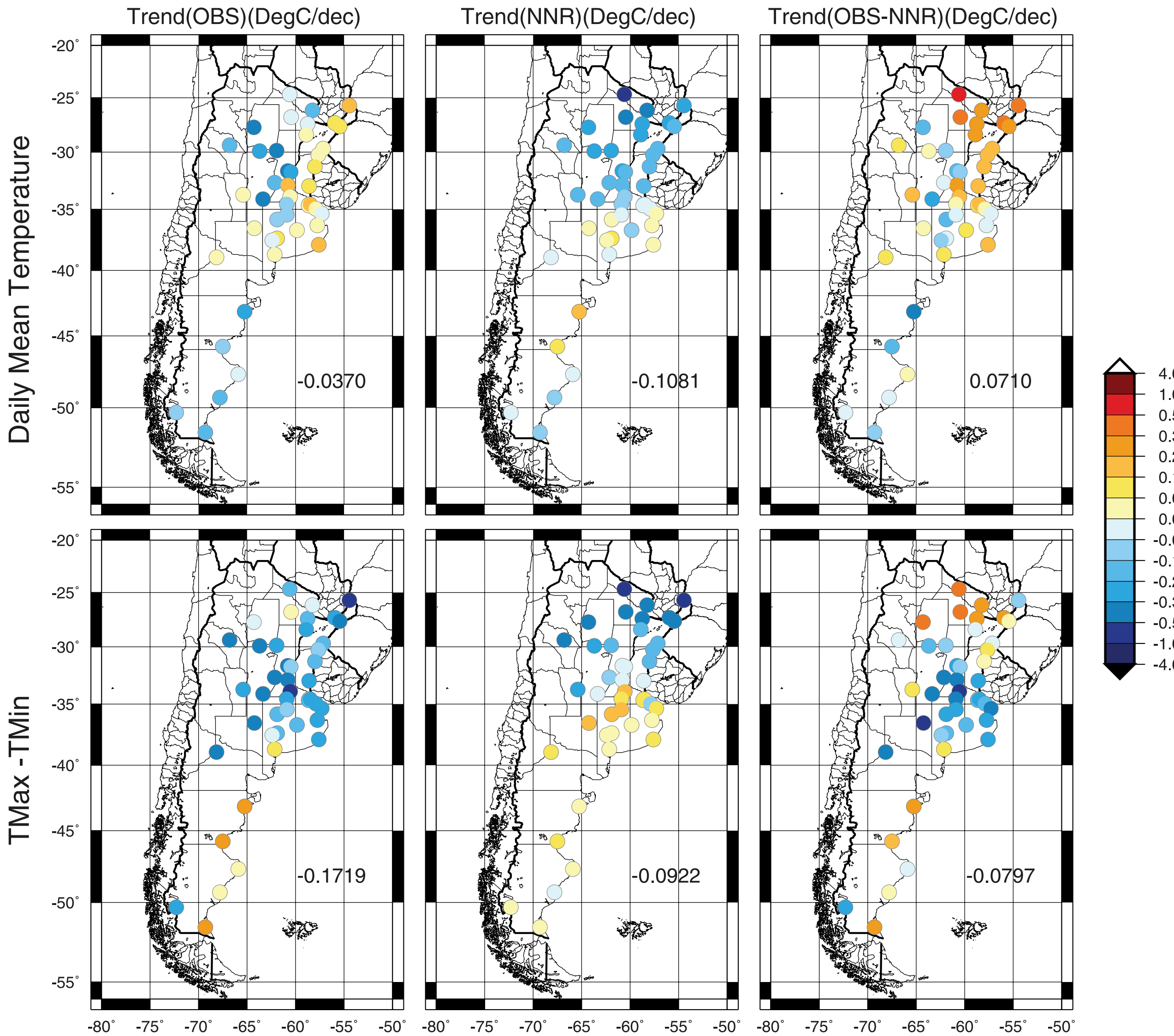

Figure 5. The 40-year (top) mean temperature and (bottom) diurnal temperature range trends for Argentina (in °C/decade) over stations located below 500 m. Trends (left) from stations and (middle) from the NNR and (right) observations minus NNR trend. The number represents the average trend of all stations in the study.

[9] The analysis method is to interpolate linearly the gridded reanalysis data to observational sites and obtain monthly data means by averaging daily data. We only consider sites that have available at least a total of 70% of months of observations per decade. We compare the daily maximum and minimum temperatures of 45 surface stations located below 500 m in the contiguous provinces of Argentina, and the daily surface maximum and minimum temperatures on a Gaussian grid from the NNR interpolated to the stations locations, both for the period 1961–2000. Sites above 500 m showed correlations below 0.7 between observations and reanalysis therefore have not been considered (not shown).

[10] Temperature anomalies with respect to the 40-year mean annual cycle for each site and each data set have been computed. This eliminates most of the systematic errors that appear in the annual cycle in the NNR. Following KC, trends were computed as changes in decadal averages in the anomalies in order to reduce the impact of random errors but this does not affect the results. The NNR has been constructed with a model and data assimilation system kept unchanged, but it is affected by changes in the observing systems, especially the introduction of the satellite observing system in 1979. Therefore, in the computation of temperature trends we exclude changes from the decade of the 1970s to the 1980s. The decadal trend averaged over two separate periods (1981–2000 and 1961–1980) is computed for every station, with an overall areal average computed for all the stations with a cosine latitude weight.

[11] For precipitation, we also use the daily precipitation data from SMN over most Argentinean provinces for 1961–2000. Since the precipitation varies widely in absolute value with location, we have introduced a normalization showing the percentage contribution of each decade to the total

Table 1. Summary of the 40-Year Trends (Computed as Discussed in the Text) for the Four Seasons and the Annual Average[a]

	Total [(70 − 60) + (90 − 80)]/2				
	Year	Summer	Fall	Winter	Spring
DTR					
OBS	−0.1719	−0.3340	−0.2387	−0.0753	−0.0348
NCEP	−0.0922	−0.2599	−0.1659	0.0367	0.0038
OBS-NCEP	−0.0797	−0.0741	−0.0728	−0.1120	−0.0386
Tmax					
OBS	−0.1230	−0.4133	−0.0793	0.0188	−0.0434
NCEP	−0.1542	−0.3933	−0.0730	0.0017	−0.1864
OBS-NCEP	0.0312	−0.0200	−0.0063	0.0171	0.1430
Tmin					
OBS	0.0489	−0.0793	0.1594	0.0942	−0.0086
NCEP	−0.0620	−0.1335	0.0929	−0.0350	−0.1902
OBS-NCEP	0.1109	0.0542	0.0665	0.1291	0.1816
Tmean					
OBS	−0.0370	−0.2463	0.0401	0.0565	−0.0260
NCEP	−0.1081	−0.2634	0.0099	−0.0166	−0.1883
OBS-NCEP	0.0710	0.0171	0.0301	0.0731	0.1623

[a]Unit is °C/decade.

precipitation, allowing the intercomparison of the precipitation trends at different stations. We also present the trends and total area planted with soy in Argentina with data from the Secretaría de Agricultura, Ganadería, Pesca y Alimentos de la República Argentina (SAGPyA).

3. Results

3.1. Temperature Trends

[12] Figure 2a compares time series of 40 years of monthly mean temperatures anomalies for a station (Villa Ortuzar) situated in a park within the city of Buenos Aires, the largest city of Argentina, including the average decadal difference between observations and the NNR. The correlation between both series is 0.91. To help visualize the difference in trends, we added a constant to make the temperature average for the 1980s the same for both station and NNR, but this does not affect the trends. It can be seen that the NNR captures very well the intraseasonal, interannual and interdecadal variability but there is a growing gap between the NNR estimate and the station observations, so that for the last two decades the OMR trend is 0.52°C/decade. Even before 1979 there is also good agreement between the two data sets but problems are observed over regions with topography (KC [*Rusticucci and Kousky*, 2002]). There is a large negative jump between the 1970s and 1980s (before and after the advent of satellite data) associated with the impact of the change in observing systems on the reanalysis climatology, which is much larger in the Southern than in the Northern Hemisphere. This negative jump in OMR of more than 0.2°C took place in essentially all stations north of 40°S, and is much larger in the reanalysis over South America than over the United States, where KC did not find a significant jump in the OMR trends. For this reason, we do not include the trend between the 1970s and the 1980s in the computations. Figure 3 shows that the 40-year correlation for all the stations located below 500 m averages 0.84. In mountainous regions (not shown), the correlation is lower than 0.7, so that these stations have not been included in the analysis.

[13] Figure 4 shows the 40-year trend (in °C/decade) for the minimum (top) and maximum (bottom) temperatures for all the stations included in this study. Figure 4 (left) shows the trend of the station observations, the center panels show the NNR trend, and the right panels show their OMR differences, attributed at least partially to land surface properties and changes, including land use and precipitation. The decadal trends averaged over two separate 20-year periods (1981–2000 and 1961–1980) are computed for every station and averaged in circles centered in each station site with a cosine latitude weighted average computed over all the stations.

[14] The observations (Figure 4, left) indicate that in Argentina the minimum temperature increased slightly over these 40 years, on the average by about 0.05°C/decade, with some cooling in Patagonia. However, the NNR, which reflects the changes associated with atmospheric temperature changes (both due to changes in circulation and greenhouse warming) indicates that the lower atmosphere over Argentina underwent relative cooling of about −0.06°C/decade. The observation minus reanalysis (OMR) minimum temperature trends indicates strong warming (except in Patagonia) with an average of +0.11°C/decade, which would be attributable to changes in the land surface properties not included in the NNR.

[15] The maximum temperatures show a strong cooling trend in the observations of about −0.12°C/decade, stronger in the north than in Patagonia. The NNR trend (reflecting changes in circulation and greenhouse warming) shows

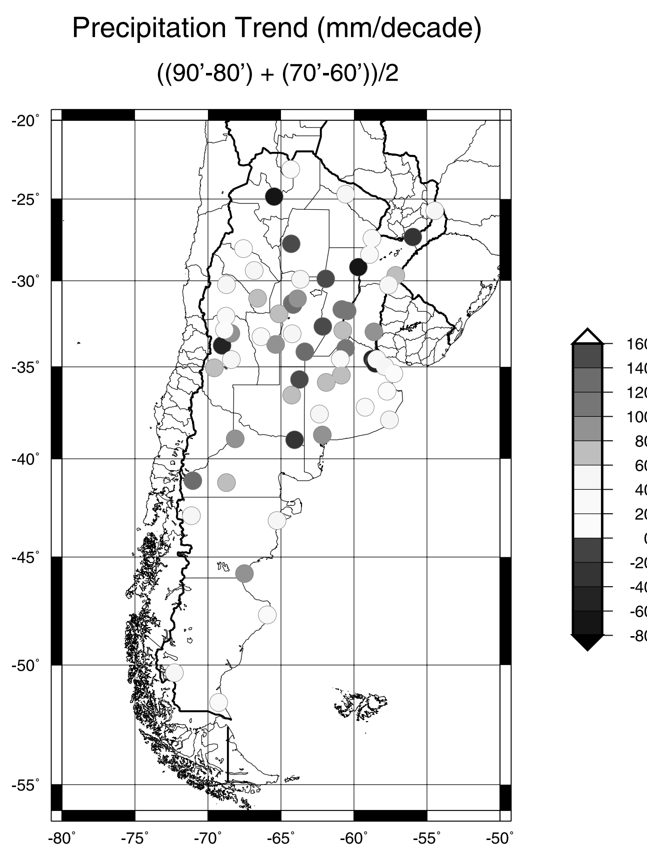

Figure 6. Decadal precipitation trend (mm/decade) computed as the temperature trends.

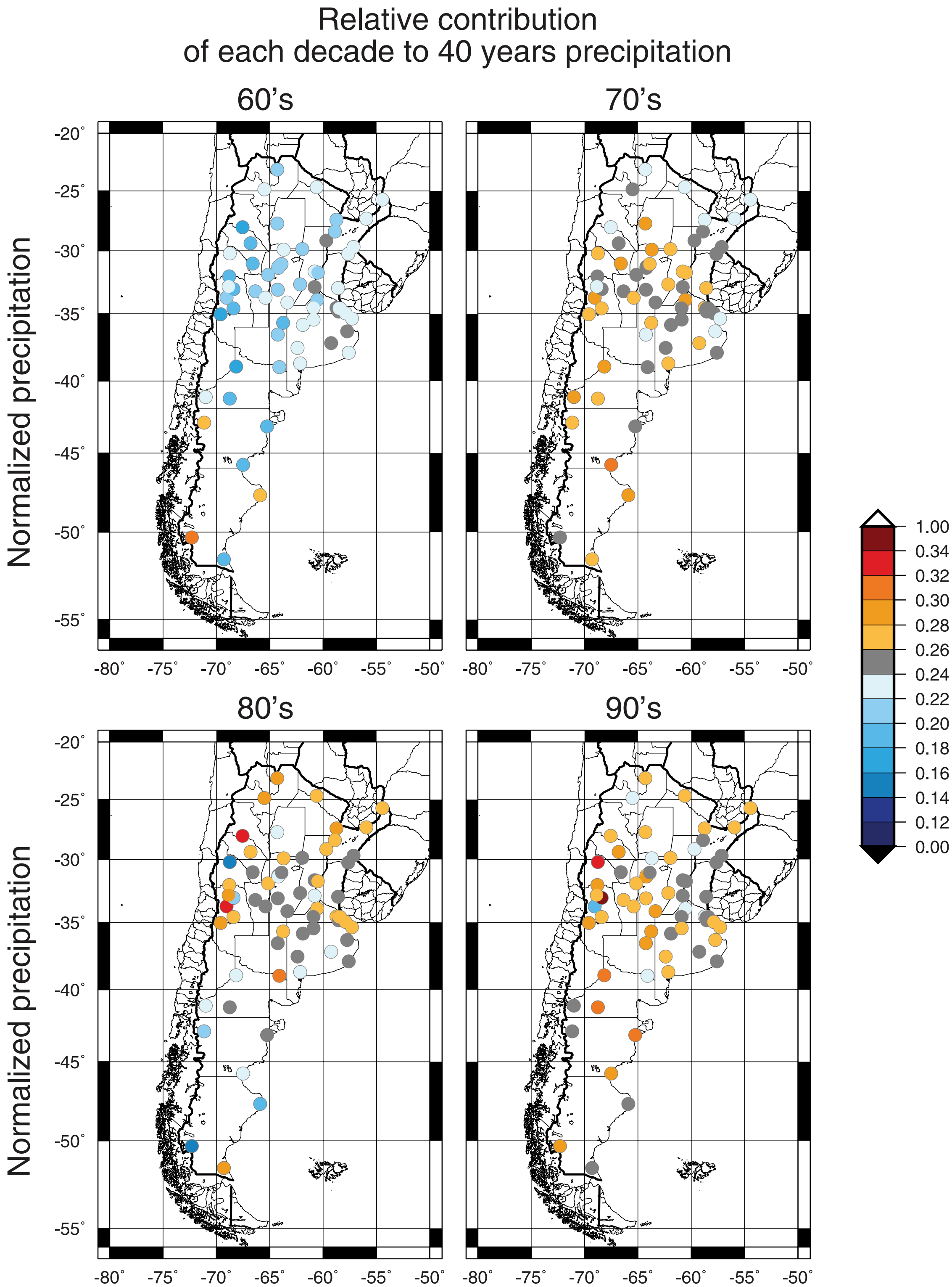

Figure 7. Relative contribution of each decade to the total precipitation. A value of 0.25 indicates that the precipitation over that decade was one quarter of the four decades total.

warming south of 35°S, and strong cooling to the north, with an average of −0.15°C/decade. The OMR trend, which could be attributable to changes in the surface, shows warming in the maximum temperature in the northeast of Argentina, and cooling elsewhere, with an average of +0.03°C/decade.

[16] Figure 5 shows on the top the 40-year trend of the mean temperature, indicating an overall negative trend, moderate for the observations (−0.04°C/decade) and much stronger for the NNR (−0.11°C/decade). The trend in the observations is similar to that of Figure 1, even though in our case the trends do not include the difference between the

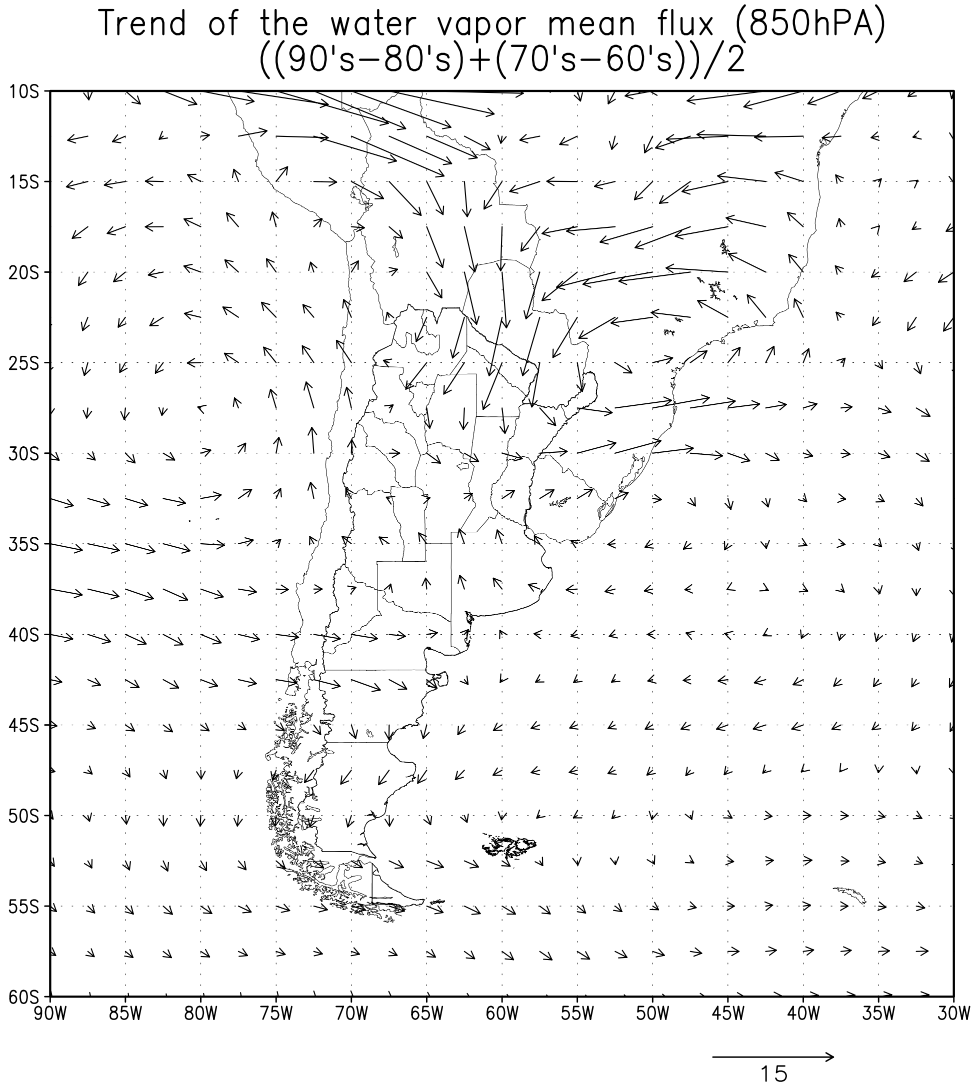

Figure 8. Trend of the mean flux of water vapor from the NNR, estimated as the trend in precipitation in Figure 6. Units are in m s^{-1} g kg^{-1}/decade.

1980s and the 1970s (Figure 1c). The OMR trend suggests that surface changes have resulted in warming north of 40°S and cooling in the south, with an average of +0.07°C/decade.

[17] The diurnal temperature range (DTR, Figure 5 (bottom)) has a very strong negative trend of about −0.17°C/decade in the observations, but an increase in DTR in Patagonia. The NNR trends are similar but the increase in DTR extends further north, with an average of −0.09°C/decade. The corresponding OMR trends are very negative over the wet pampas and mostly positive in Patagonia, with an average of −0.08°C/decade, suggesting that land changes and greenhouse warming contribute almost equally to the overall decrease in DTR.

[18] Table 1 presents the summer (DJF), fall (MAM), winter (JJA), spring (SON) and annual average trends for the observations, reanalysis and their OMR differences. The amplitude of the annual cycle in the trends is smaller than over the United States [*Kalnay et al.*, 2006]. The observations show that Tmax has decreased very strongly in summer and Tmin increased in fall and winter, so that Tmean decreased in the summer and increased slightly in fall and winter. The observations show a decrease in the diurnal temperature range throughout the year, but it is strongest in the summer and fall.

[19] In the OMR trends, the annual cycle is also smaller than over the United States, and suggests that the surface effects have contributed positively to the temperature trend and to the decrease in diurnal temperature range throughout the year.

3.2. Precipitation Trends, Agricultural Changes, and Possible Relationship With the Temperature Trends

[20] Since precipitation varies widely with location, we present both an absolute trend and a normalized tendency showing the contribution of each decade to the total precipitation for different stations, allowing a comparison of precipitation trends in different stations. The absolute trends in Figure 6 are computed using observed precipitation, with the same method as indicated for temperature. The decadal percentage contributions of Figure 7 are computed by dividing at each station the decadal precipitation by the total precipitation over 40 years, so that normal

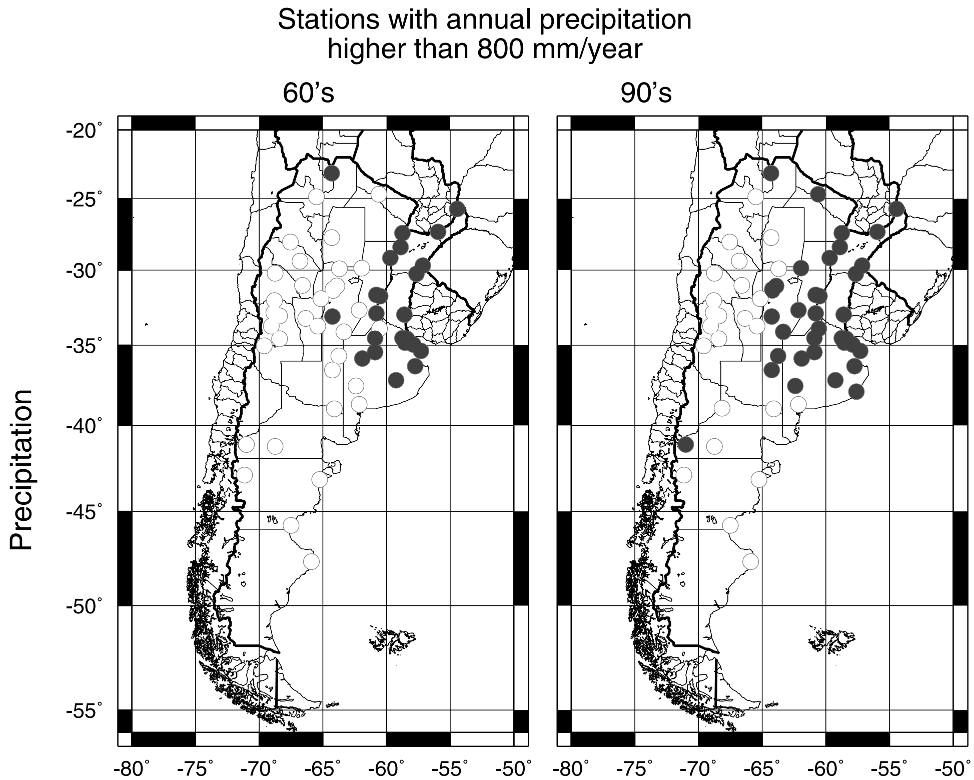

Figure 9. Stations with annual precipitation higher than 800 mm, during the 1960s and 1990s decades.

decadal precipitation appears as about 0.25, in grey, and cold and warm colors represent below and above normal decadal precipitation respectively. The annual precipitation trend (mm/decade) presented in Figure 6 indicates an increase in most of the country with maximum values in the center of the country. The normalized precipitation contribution of each of the four decades, clearly indicates that the 1960s were considerably drier than the 1970s, not much change between the 1970s and the 1980s, and a further increase of rain in the 1990s, which had the highest level of precipitation throughout the country.

[21] The South American low-level jet is a major source of moisture for northern and central Argentina [*Vera et al.*, 2006]. We have checked for trends in this source of moisture using the NNR, and found that except in high latitudes the flux of moisture $(\mathbf{v}q)_{total} = \mathbf{v}_m q_m + \mathbf{v}' q' \approx \mathbf{v}_m q_m$ is dominated by the mean flux term $\mathbf{v}_m q_m$, and that the eddy fluxes $\mathbf{v}' q'$are an order of magnitude smaller. Figure 8 presents the vector of mean moisture flux trend for South America, computed, as in the temperature trends, without the trends from the 1970s to the 1980s. It indicates a very clear increase in moisture transport from the Amazon to northern and central Argentina, suggesting that this is a major cause of the observed increase in precipitation.

[22] This increase in precipitation has been accompanied by a very significant increase in agricultural production, especially the intensive cultivation of soy. In Argentina the border of the region devoted to crops has extended westward by more than 300 Km in the last years (see Figure 9 showing the displacement of the 800 mm/a isohyet between the 1960s to the 1990s), and the land productivity has also increased substantially in the 1990s, with the use of fertil-

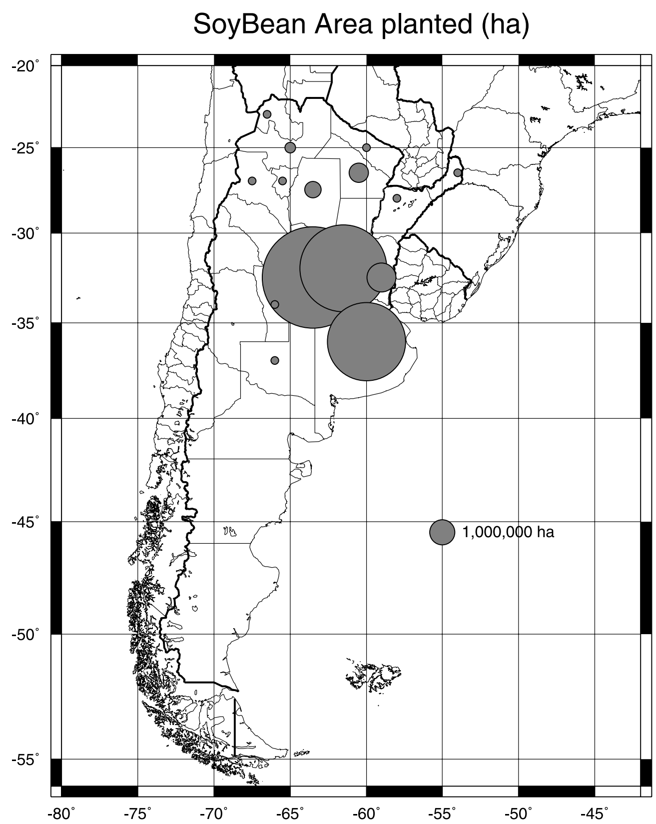

Figure 10. Total area planted with soy in 2003 (from SAGPyA).

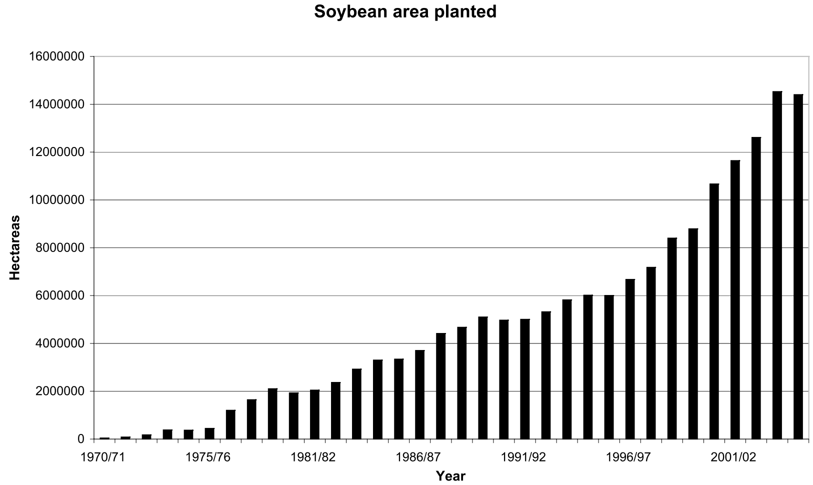

Figure 11. Number of hectares planted with soy since 1970 (from SAGPyA).

izer increasing from about 5 Kg/hectare of cropland in the 1980s to over 30 Kg/hectare in the late 1990s. Figure 10 shows the areas planted with soy in Argentina (data corresponding to 2003) and Figure 11 shows the number of hectares planted with soy since 1970 in the country. The area with the maximum increase in precipitation generally coincides with the area with maximum total area planted with soy, as well as the area with the maximum estimated decrease of diurnal temperature range associated with surface changes using OMR (Figure 5, bottom right).

[23] These observations suggest that a possible explanation for the observed and OMR temperature trends can be related to the changes in precipitation and agricultural practices. The anomalous lack of warming in the center of Argentina over the last four decades (Figure 1a) can be associated with the increased precipitation, which, as shown in Figure 8, is probably associated with an increase in the inflow of moisture from the Amazon by the low-level jet. This is because the increase in precipitation should result in a decrease in maximum temperature (due to increased evaporation and more cloud cover during the day) and possibly an increase in minimum temperature (due to the increase in soil heat capacity). *Nicholls* [2003] found similar negative correlations between observed maximum temperature and precipitation and smaller positive correlations for the minimum temperatures over Australia. *Karoly and Braganza* [2005] found similar correlations in model simulations.

[24] Surface effects and changes in precipitation are not well represented in the NCEP-NCAR reanalysis. To the extent that OMR trends reflect these factors missing in the NNR, they suggest that the observed increase in precipitation and changes in agricultural productivity resulted in net warming and a strong reduction in diurnal temperature range.

4. Summary

[25] We have carried out a comparison of 40-year trends in the surface temperature observation anomalies and NCEP-NCAR reanalysis anomalies over Argentina. In contrast to most other land areas in the world, there has been net cooling over most of Argentina (about −0.04°C/decade), and a very large decrease in the diurnal temperature range north of 40°S. This is associated with an observed strong reduction in the maximum temperature (−0.12°C/decade) together with a weak warming trend in the minimum temperature (0.05°C/decade). The observation minus reanalysis (OMR) trends show a warming contribution to the mean temperature (+0.07°C/decade) and a decrease in diurnal temperature range (−0.08°C/decade), especially strong in the areas where the observed precipitation has increased the most, and where, as a consequence, there has been an exponential increase of soy production in the last decade. The annual cycle of the observed and OMR trends has a weaker annual cycle over Argentina than over the United States, where the atmospheric greenhouse warming is most apparent in the winter, and the OMR surface effects dominate in the summer.

[26] Although it is not possible to definitively attribute the differences between the observation and the NCEP-NCAR reanalysis temperature trends solely to surface effects not included in the reanalysis, such as the observed increase in precipitation and changes in land use, the results obtained are not incompatible with such an interpretation. To the extent that increased precipitation, urbanization and irrigated agriculture contribute to an increase in the heat storage capacity of the surface, they should contribute to an increase in the minimum temperature, a decrease in the maximum temperature, and to a reduction in the diurnal temperature range shown in our OMR estimates over most of Argentina. The anomalous cooling observed in Argentina, is also present in the NCEP-NCAR reanalysis during these decades, and is consistent with a change in circulation leading to the observed increase in precipitation. An understanding of the origin of this change requires a detailed analysis of the NCEP and the ERA-40 reanalyses, but a preliminary analysis indicates that there has been a significant increase in the inflow of moisture by the low level into this region. However, more studies are needed, including a comparison of the NCEP-NCAR reanalysis and observed precipitation, a diagnostic study of the mean and eddy fluxes of heat and moisture, as well as changes in population, urbanization, irrigated and natural rain agriculture, in order to complete an attribution of the observed temperature trends over Argentina.

[27] **Acknowledgments.** This work was made possible by the support of NOAA grant NA04OAR4310129. We are grateful to Remor Chavez, from Bolivia, for his suggestion that the observed increase in precipitation was due to an increase in the strength of the low-level jet.

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