Impacts of urbanization and land surface changes on climate trends

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By now there is little doubt that the increase in greenhouse gases (GHG) is producing global warming. The question we addressed in this project is whether the regional response to the GHG effect is uniform or depends on the land characteristics and use. In this report we summarize results we obtained showing that the response is very much dependent on the type of land cover and use, and that desertic and urban areas get more than their "fair share" of GHG warming, whereas broadleaf forested areas have locally reduced warming.

1. The Observation Minus Reanalysis (OMR) method

We use the Observation Minus Reanalysis (OMR) surface temperature trends method suggested by Kalnay and Cai (*Nature*, 2003) to provide an estimate of the impact of surface effects on regional warming (or cooling). It takes advantage of the insensitivity of the NCEP-NCAR Reanalysis (NNR) to land surface type, and eliminates the natural variability due to changes in circulation (since they are also included in the reanalysis), thus separating surface effects from greenhouse warming. Kalnay *et al.* (*JGR*, 2006) showed that over the US the OMR *average* is small, but it has different regional signs, in good agreement with the regions of "urban heating and cooling" obtained by Hansen *et al* (JGR, 2001) when using nightlights to discriminate between urban and rural regions (Fig. 1). Kalnay *et al.* (2006) also showed that the results obtained with OMR were not qualitatively affected by the NCDC corrections of non-climatic effects (e.g., change of observation time and station location), which increase the overall warming trend in the US (compare Fig. 2c with Fig. 2d, obtained using the USHCN observations corrected for nonclimatic effects).

2. Relationship between OMR and land vegetation type

Lim *et al.* (GRL, 2005) compared two global observation-based data sets (CRU and GHCN) and two different global reanalyses (NCEP-NCAR and ERA40) and MODIS-derived land classes. The results (Figure

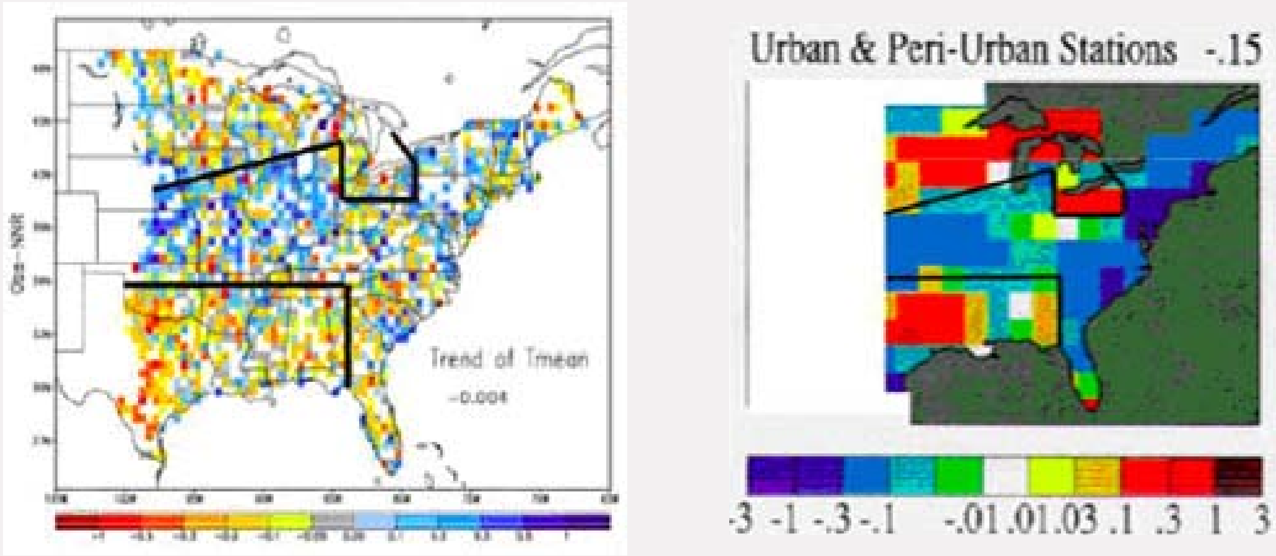

Figure 1. Left: OMR trend difference for the mean temperature with the scale of colors having been reversed so that warming appears as blue, in units of °C/decade. Right: Urban *correction* (opposite of the trend) obtained by Hansen *et al.* (2001) in units of °C/century.

3a) showed that the OMR trends have a strong dependence on the type of land-surface, and that this dependence is similar using either the NCEP-NCAR or the ERA-40 Reanalyses. The ERA40 OMR trends are smaller than those of the NCEP reanalysis OMR (about half), as could be expected since the ERA40 uses air surface temperature observations indirectly, from an off-line OI analysis of surface temperature, to initialize the soil temperature and moisture. As a result the ERA40 analysis is partially influenced by surface observations, which are affected by land surface properties, and the OMR is correspondingly smaller (Figure 3b).

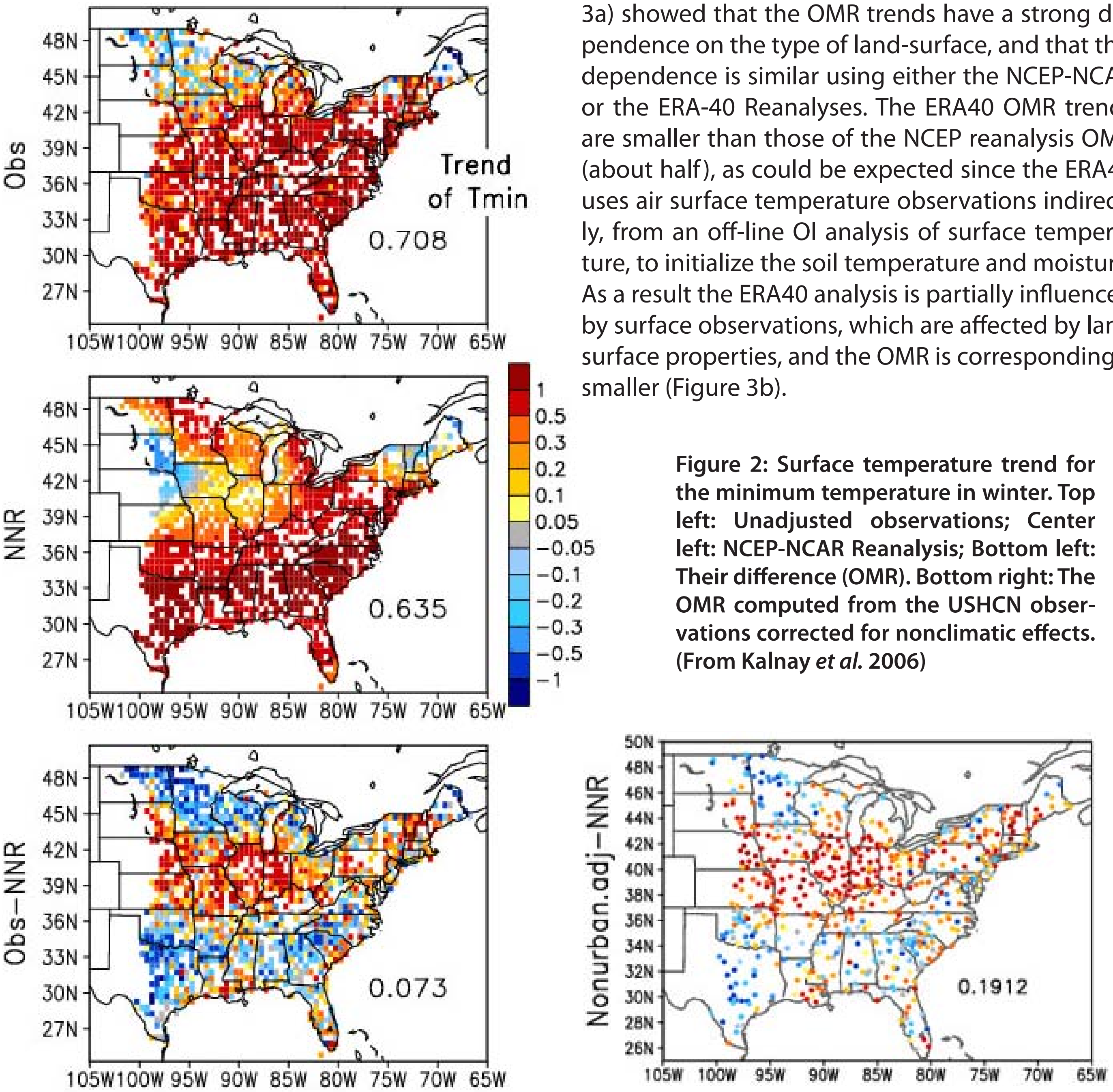

Figure 2: Surface temperature trend for the minimum temperature in winter. Top left: Unadjusted observations; Center left: NCEP-NCAR Reanalysis; Bottom left: Their difference (OMR). Bottom right: The OMR computed from the USHCN observations corrected for nonclimatic effects. (From Kalnay *et al.* 2006)

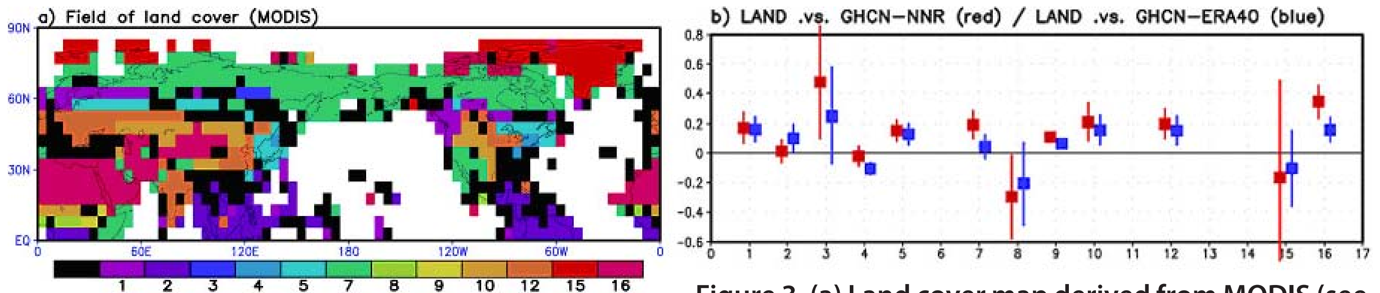

Figure 3. (a) Land cover map derived from MODIS (see Table 1). Grid boxes in which the dominant land cover type covers less than 40% are colored black and not used in the analysis presented in Figure 2b. (b) The mean OMR trend of "GHCN-minus-NNR" (red), and "GHCN-minus-ERA40" (blue) per decade (°C/decade) over the NH as a function of land types. Filled squares represent the mean OMR trends and vertical lines the error bars at 95% significance level. The OMR trend per decade is obtained by taking the average of two decadal mean difference (90s-80s and 70s-60s). (From Lim *et al.* 2005)

Table 1. 16 Land-Cover Categories From MODIS and the Number of 5°x5° Grid Boxes Used for the Calculation of OMR Trends Per Decade

Land Cover Category		Number of Grid Boxes
1	Evergreen needle-leaf forest	29
2	Evergreen broadleaf forest	42
3	Deciduous needle-leaf forest	4
4	Deciduous broadleaf forest	3
5	Mixed forest	31
6	Closed shrubland	0
7	Open shrubland	81
8	Woody savannah	6
9	Savannah	6
10	Grassland	36
11	Wetland	0
12	Cropland	51
13	Urban	0
14	Natural vegetation mosaic	0
15	Snow and ice	3
16	Barren or sparsely vegetated	56

The results show that OMR warming over barren areas is larger than most other land types, and that urban areas show a large warming second only to barren areas. Croplands with agricultural activity show a larger warming than natural broadleaf forests. The overall assessment indicates surface warming is larger for areas that are barren, anthropogenically developed, or covered with needle-leaf forests (see also Figs. 4 and 5).

3. Relationship between OMR and NDVI

Lim *et al*. (*JAMC*, 2008) extended this study to establish the dependence of OMR on the Normalized Difference Vegetation Index (NDVI), and hence on the Leaf Area Index, LAI (Figure 6).

The trend of the observations (Global Historic Climate Network, GHCN) does not show a dependence on the vegetation index (Fig. 6a). Both the ERA-40 and the NCEP-NCAR Reanalysis show a positive correlation in the temperature trends and the vegetation index. For both reanalyses, the OMR decreases with NDVI (Figs. 6c and e).

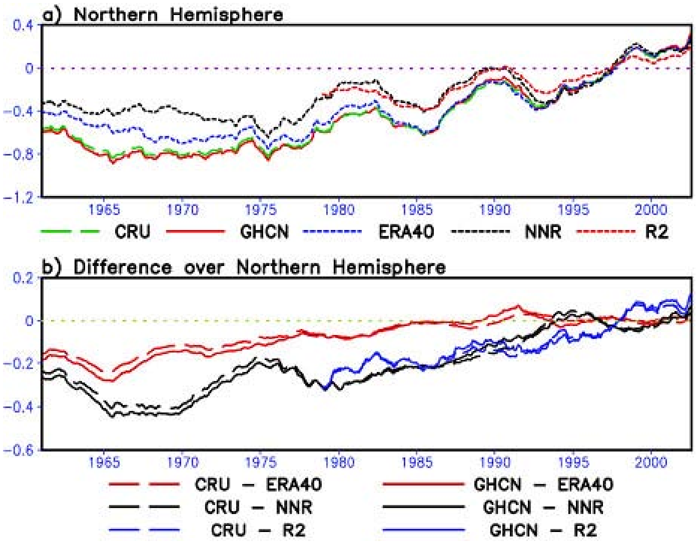

Figure 4. Time series (three-year running mean) of (a) land surface temperature anomalies (°C) derived from CRU, GHCN, ERA40, NNR, and R2 and (b) the OMRs. Anomaly values are obtained by removing the 30-yr mean from 1961 to 1990 and they are further adjusted to have zero mean over the last 10 years (1993–2002). (From Lim *et al*. 2005)

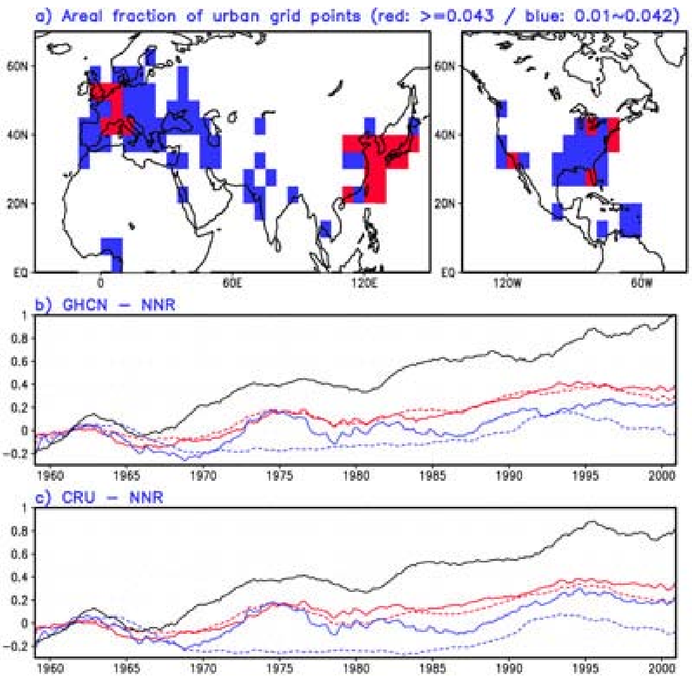

Figure 5. (a) Geographical distribution of urban grids (5°x5°). Grid boxes where the fractional area of 1 km x 1 km urban pixels is greater than 0.043 (in red), and between 0.01 and 0.042 (in blue) are categorized respectively as big and small urban areas. Time series (°C) of (b) GHCN-NNR, and (c) CRU-NNR, for the areas of big urban areas (red solid), small urban areas (red dashed), agriculture (blue solid), natural broadleaf (blue dashed), and barren areas (black solid), respectively. (From Lim *et al*. 2005)

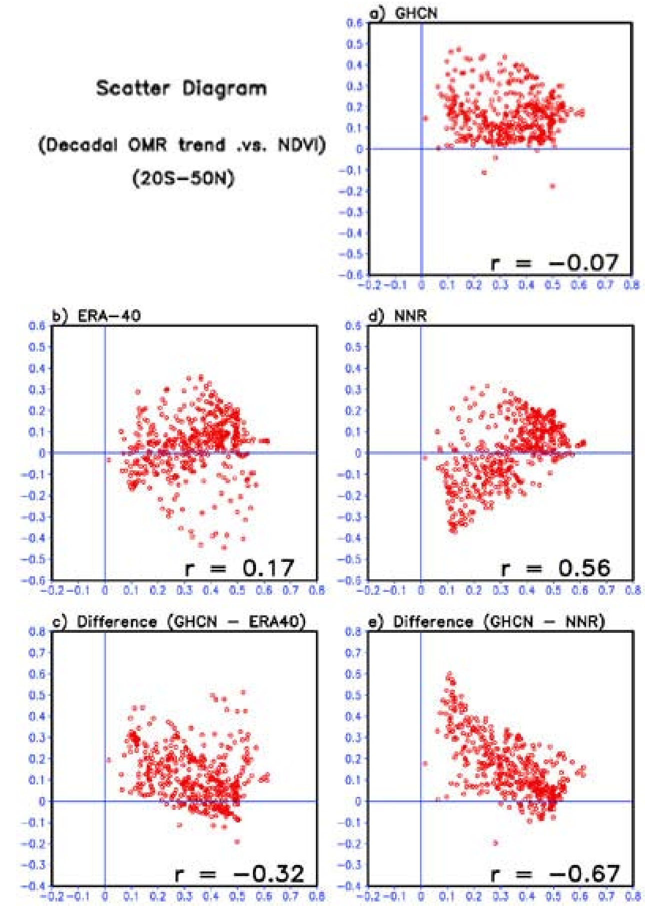

Figure 6. Scatter diagram between the NDVI and the decadal surface temperature trend of a) GHCN, b) ERA40, c) GHCN – ERA40, d) NNR, and e) GHCN – NNR over (0°-360°E)x(20°S-50°N) region. Data have been spatially smoothed to remove the extreme outliers. Abscissa denotes the NDVI whereas the ordinate the decadal trend. Here r is the correlation coefficient of all the data points. (From Lim *et al*. 2006)

4. Impact of land-use and precipitation changes on surface teemperature trends in Argentina

In this paper (Nunez *et al*., JGR, 2008) we applied 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) (Figs. 7 and 8, left). Observations also show a very strong decrease in the diurnal temperature range north of 40°S latitude. 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 the diurnal temperature range (-0.08°C/decade) (Figs 7 and 8, right). This decrease is especially strong in the areas where the observed precipitation has increased the most (Figure 9). 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 (Figure 10).

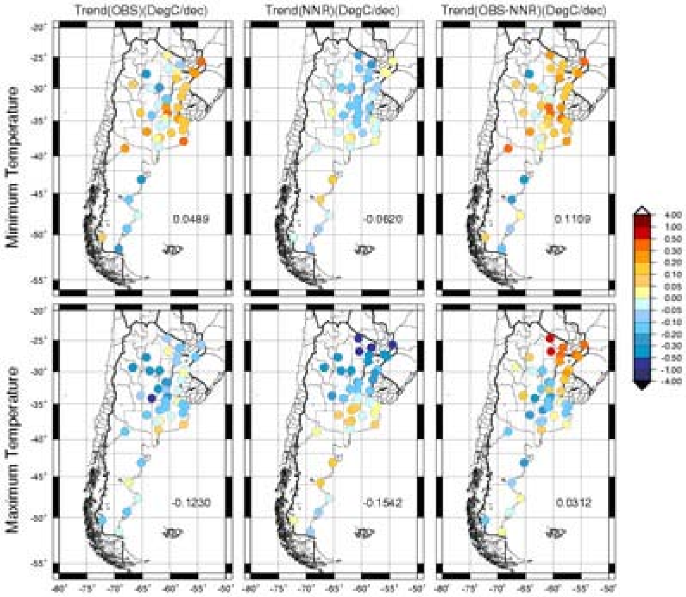

Figure 7: 40-year minimum temperature (top) and maximum temperature (bottom) trends for Argentina (in °C/decade) over stations located below 500m. Left: trends from stations, Center: from the NNR, Right: observations minus NNR trend. The number represents the average trend of all stations in the study.

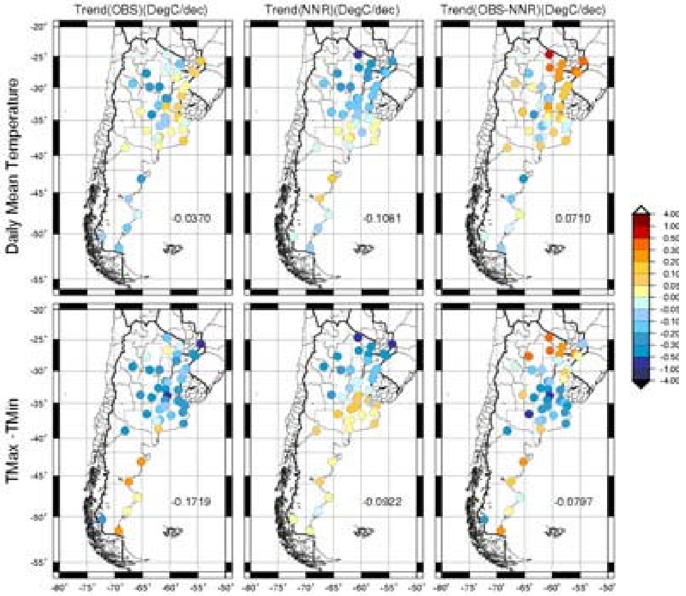

Figure 8: As figure 7 but for the daily mean temperature and the diurnal temperature range.

The maximum precipitation increase also corresponds with the area where there has been an exponential increase of soy production in the last decade.

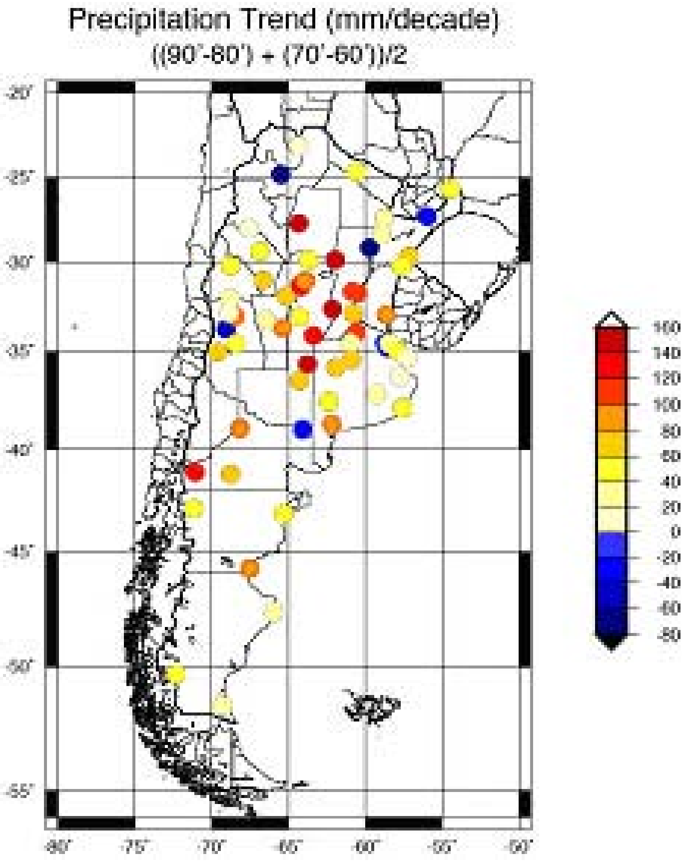

Figure 9: Decadal precipitation trend (mm/decade) computed as the temperature trends.

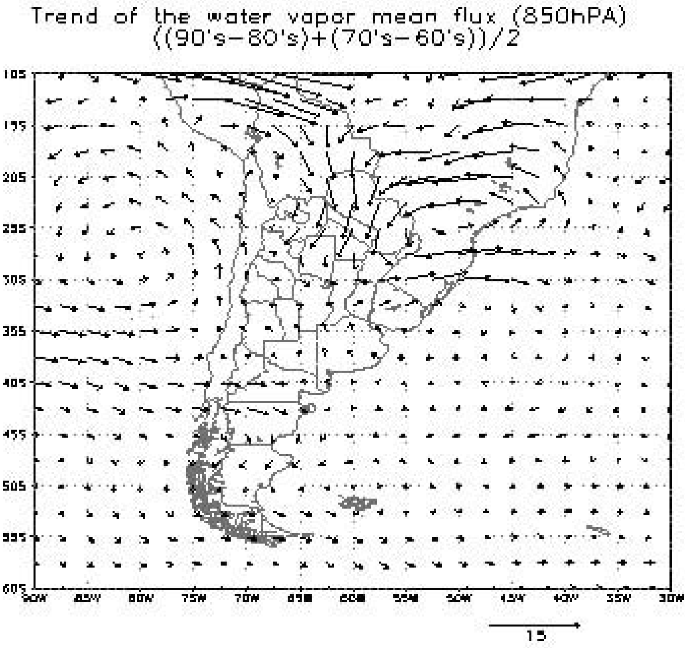

Figure 10: Trend of the mean flux of water vapor from the NNR, estimated as the trend in precipitation in Figure 6. Units are in ms^{-1}gkg^{-1}/decade.

5. Summary

The Observation Minus Reanalysis trend (OMR) method has been proposed to estimate the impact of surface and near surface effects on the temperature trends, to the extent that these effects are not included in the Reanalysis and do affect the observations. The results suggest that these effects are regional and depend on the type of land cover. Areas with little vegetation suffer from warming higher than their "fair greenhouse gases warming share", as estimated from reanalysis, whereas for highly vegetated zones, the OMR is small or negative indicating that high vegetation cover can help ameliorate the impact of global warming. In central-northern Argentina, where there has been an exponential growth in the planting of soy beans in an area of increased precipitation, possibly due to an increase in water vapor transport from the Amazons, there is a strong negative OMR trend of diurnal temperature range.

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6. References

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