J5.2 IMPACT OF LAND-USE CHANGE AND URBANIZATION ON CLIMATE

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1. INTRODUCTION

The two most important anthropogenic activities that impact climate are the increase of greenhouse gases and the changes in land use. They both tend to produce surface warming so that their impacts are very difficult to separate. The impacts of changes in land use have generally been regarded as "noise" compared to impacts of increase of greenhouse gases. So far, the approach for "correcting" for urbanization effects on climate trend has been based on the comparison of observations in cities/suburbs with those in surrounding rural areas. The key of these methods has been to classify meteorological stations using either population data (Easterling et al, 1997) or satellite measurements (Gallo et al, 1999, Hansen et al, 2001). The estimated urban impacts over the US have been small (0.006C/dec. and 0.015C/dec.), and do not include the impact of other land-use changes such as those related to agriculture that can change the landscape over much larger areas.

2. NEW METHOD USING REANALYSIS

In this approach (Kalnay and Cai, 2003) we take advantage of the fact that the NCEP/NCAR Reanalysis (NNR, Kalnay et al, 1996, Kistler et al, 2000) *is insensitive to surface observations over land* . This is because surface observations (except surface pressure) are not used over land, and because the model transports information making the analysis less local than it is in reality. The reanalysis does reflect the trends of the atmospheric observations assimilated, such as rawinsondes and satellite soundings, and even though it does not include the forcing due to the increase in greenhouse gases in the model, the trend from the greenhouse effects should be present in the model at essentially the full strength of the observations (Cai and Kalnay, 2003b).

The essence of our method is that we would attribute at least part of the difference between the climate trends between the observations (which reflect all the sources of climate forcing) and the NNR (which only contains the forcings influencing the atmospheric temperature trends) to the impact of land-use changes. This includes not only urbanization effects but also changes in agricultural practices, such as irrigation, and deforestation.

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The surface data that we have used are the daily surface T_{max} and T_{min} from NCDC "Cooperative Summary of the Day" dataset over the 48 contiguous United States (CONUS) for 1950-1999. These are "raw" data that have not been adjusted for several non-climatic changes such as station location and time of observation. We also used the global daily surface air T_{max} and T_{min} (which were computed "on-the-fly") from the NNR gaussian grid (with about 2.5^o resolution) for the same period.

The analysis method is to interpolate the gridded reanalysis data to observational sites, and obtain monthly averages by averaging daily data. We only consider observational sites that have at least 480 whole months of observations. We remove from both observations and NNR data the annual cycle at each site, and only consider anomalies. This has the advantage that it eliminates systematic errors that can be quite significant, but are assumed not to contain trends in the NNR. The model orography and the real orography can be quite different, requiring vertical extrapolations. We found that as a result, the correlation between the NNR and surface observations was lower over the Rockies than east of the Rockies, so that we did not include in our analysis stations with elevations above 500m. Over the West Coast, where the station elevation is low, the model elevation may be higher, so that the results in this are may not be so reliable. We have recently developed more accurate approaches to the vertical interpolation that may allow for the extension of our method to more mountainous regions.

It is well known that the NNR (and other reanalyses) are affected by changes in the observing systems. We did not include the 1950's decade in our analysis, because there were important changes in the density and time of observation of the rawinsondes, making it less reliable (Kistler et al, 2000). In addition, the most important change in observing systems was the introduction of satellite observing systems in 1979. Because this major change can result in a spurious jump in the climatology, and hence in artificial trends, we opted for separating the trend calculations into two essentially homogeneous periods: the two decades of 1960-1979, with an observing system based on rawinsondes, and the two decades 1980-1999, with an observing system based on both satellite and rawinsondes. The trends presented here are the average of the two twenty year trends, and are presented in units of C/decade.

3. RESULTS

Fig. 1 has examples of 50 year monthly means of temperature anomaly series for two stations (Baltimore, MD and Owing Ferry Landing, MD, together with the same time series for the NNR. We added a constant to make the 1950s temperature average be the same for both station and NNR (without affecting the trend). 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, especially in urban stations.

Fig. 2 shows the 40 year trend for the minimum and maximum temperatures (top panel: stations, middle panel: NNR, bottom panel: difference attributed at least partially to land-use change). The trends in each 0.5^o by 0.5^o box have been averaged, and the number is the average trend (C/dec.) of the boxes with stations over the CONUS, weighted by the cosine latitude. Our results suggest that land-use changes may explain:

- About 40% of the observed increase in Tmin
- Most of the observed slight decrease in Tmax
- Half of the observed decrease in diurnal temperature range (-0.14 out of –0.27C/dec.)
- 0.035C/dec. increase in mean temperature.

Fig. 3 shows the seasonal trend in summer and winter, and it indicates that the greenhouse warming seems to be dominant in the winter, at which time the land impact is rather small. In the summer the greenhouse warming is smaller and the estimated land-surface impact larger.

Table 1 provides a summary of the 4-decade trend suggesting that the greenhouse warming is largest in the winter for both maximum and minimum temperatures, and this is reflected in the NNR, whereas the land-use impact is strongest in the spring and summer seasons, the growing seasons with maximum sunshine.

4. DISCUSSION

Although it is not possible to definitively attribute the differences between the observation and the NN-Reanalysis temperature trends solely to land use, including urbanization, agriculture and irrigation, the results obtained are compatible with such an interpretation. Both urbanization and agriculture effects could be consistent with the general increase in the minimum temperature and the small change observed in the maximum temperature, and contribute to the reduction in the diurnal temperature range shown in our estimates east of the Rockies. These effects should be maximum in the growing seasons (spring and summer), when the surface heating by the Sun is strongest, as observed in Table 1. This suggests that the comparison of urban and rural stations, without including agricultural effects would underestimate the total impact of land use changes. More studies are necessary, including a comparison of geographical distribution of NN-Reanalysis trends with other upper air observations, such as rawinsondes and satellites, a more precise definition of the urban and rural observing stations, and the impact of other human activities such as contrails and aerosols that can also reduce the diurnal temperature range.

Since the model used in the NNR has constant greenhouse gases and aerosols, and has other known deficiencies such as imperfect cloud cover, it might be assumed that the NNR necessarily underestimates the greenhouse impact, and that our procedure could be attributing this difference to surface effects (Trenberth, 2003). However, we have recently shown analytically that a reanalysis reproduces essentially the full strength of trend present in the observations. This happens after a short transient, even if the forecasts used as first guess are made with a model that does not contain the forcings responsible for the observational trends. The ratio of the trend per time step in the analysis $T_A(N\Delta t) - T_A((N-1)\Delta t)$ divided by the observed trend (WΔt) is given by

$$\frac{T_A(N\Delta t) - T_A((N-1)\Delta t)}{W\Delta t} \simeq \left[1 - \frac{a\dfrac{\Delta t}{\tau}}{1 - a(1 - \dfrac{\Delta t}{\tau})} \right]$$

where a is the relative weight given to the forecast. Fig. 4 shows that the ratio between analyzed and observed trend is close to one even if the observations are given relatively low weights. Such analysis is supported by the fact that Andersen et al (2001) were able to detect the heating impact of volcanic eruptions in the ECMWF reanalysis even though the model does not include volcanic aerosols.

It should be noted that we used raw (unadjusted) observations. The Historical Climatological Network data, which has been adjusted for a number of factors two of which are the change in the time of observations and the impact of changes in the location of the stations (Vose et al, 2003, Cai and Kalnay, 2003a). These adjustments for the four decades that we have used are positive and rather large (0.112C/ dec., or half of the estimated mean US temperature trend). If we use the HCN data we have to add this adjustment to our estimate giving a larger estimate of the land-use impact of 0.147C/dec, an impact larger but of the same order as those found by Gallo et al (1999) and Kukla et al (1986). The results in Fig. 1 suggest that the NNR could also be used as an alternative method to estimate the station adjustments, since it provides an accurate proxy of the expected station values, and the impact of a known sudden change in the station can be therefore estimated.

5. REFERENCES

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		year	spring	summer	fall	winter
Tmax	Obs	-0.0214	-0.1396	-0.2248	-0.2199	0.4983
	NNR	0.0096	-0.1440	-0.1758	-0.1411	0.4994
	Obs-NNR	-0.0310	0.0044	-0.0491	-0.0788	-0.0011
Tmin	Obs	0.2500	0.1853	0.1729	0.0004	0.6412
	NNR	0.1441	0.0506	0.0343	-0.0988	0.5904
	Obs-NNR	0.1059	0.1347	0.1385	0.0992	0.0508
Tmean	Obs	0.1143	0.0229	-0.0260	-0.1098	0.5698
	NNR	0.0769	-0.0467	-0.0708	-0.1200	0.5449
	Obs-NNR	0.0375	0.0696	0.0447	0.0102	0.0249
DTR	Obs	-0.2714	-0.3249	-0.3977	-0.2203	-0.1429
	NNR	-0.1345	-0.1946	-0.2101	-0.0423	-0.091
	Obs-NNR	-0.1369	-0.1303	-0.1876	-0.178	-0.0519

Table 1: Seasonal average and annual average of the trends of the observations, NNR and their difference, computed as an average of the trends in the 1960s-1970s and in the 1980s-1990s.

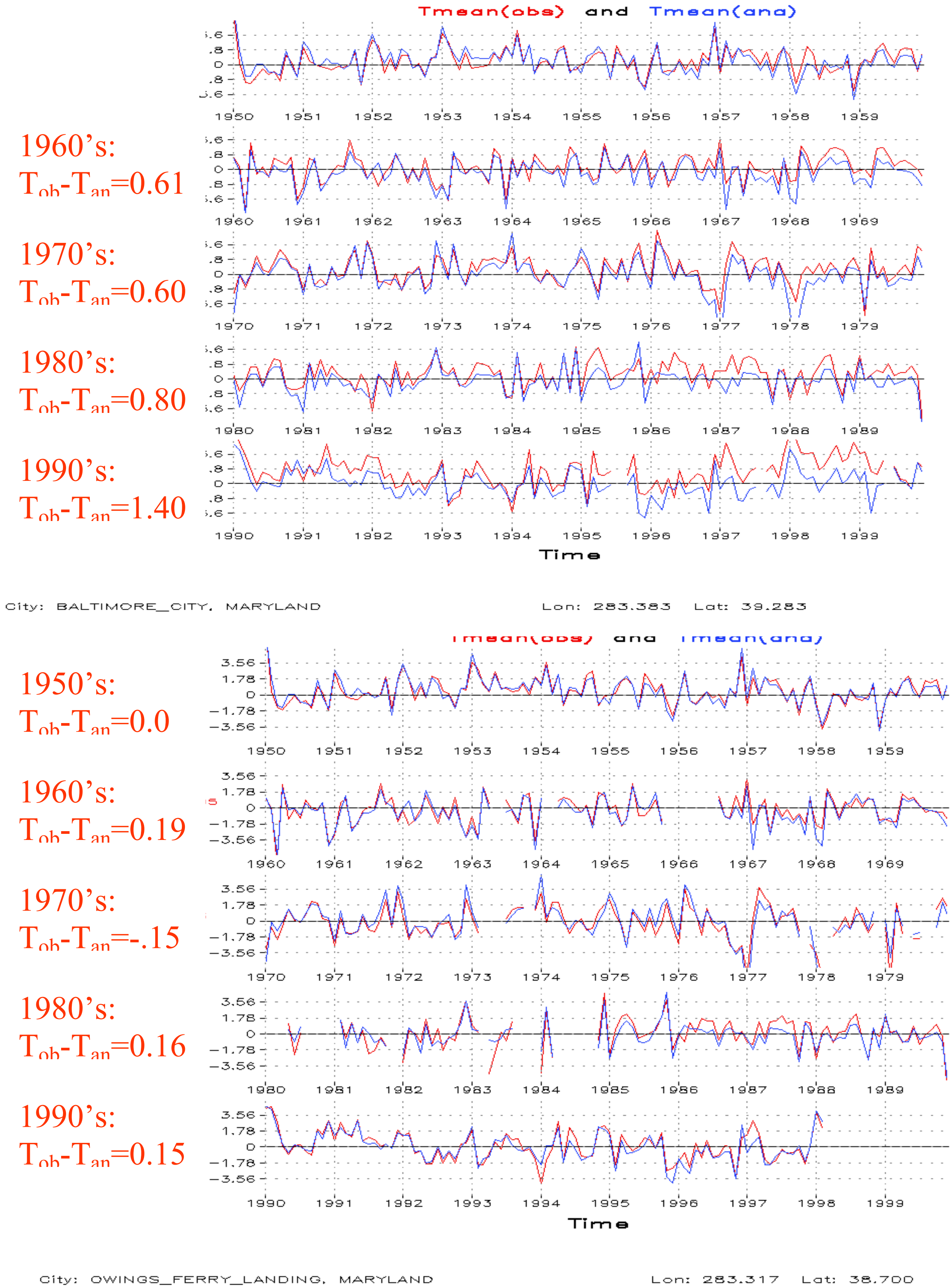

Fig. 1: Comparison of the monthly averaged temperature anomalies for the NNR (blue) and stations (red), shifted so that they have the same average during the 1950's. The stations are Baltimore and Owings Ferry Landing, both in Maryland.

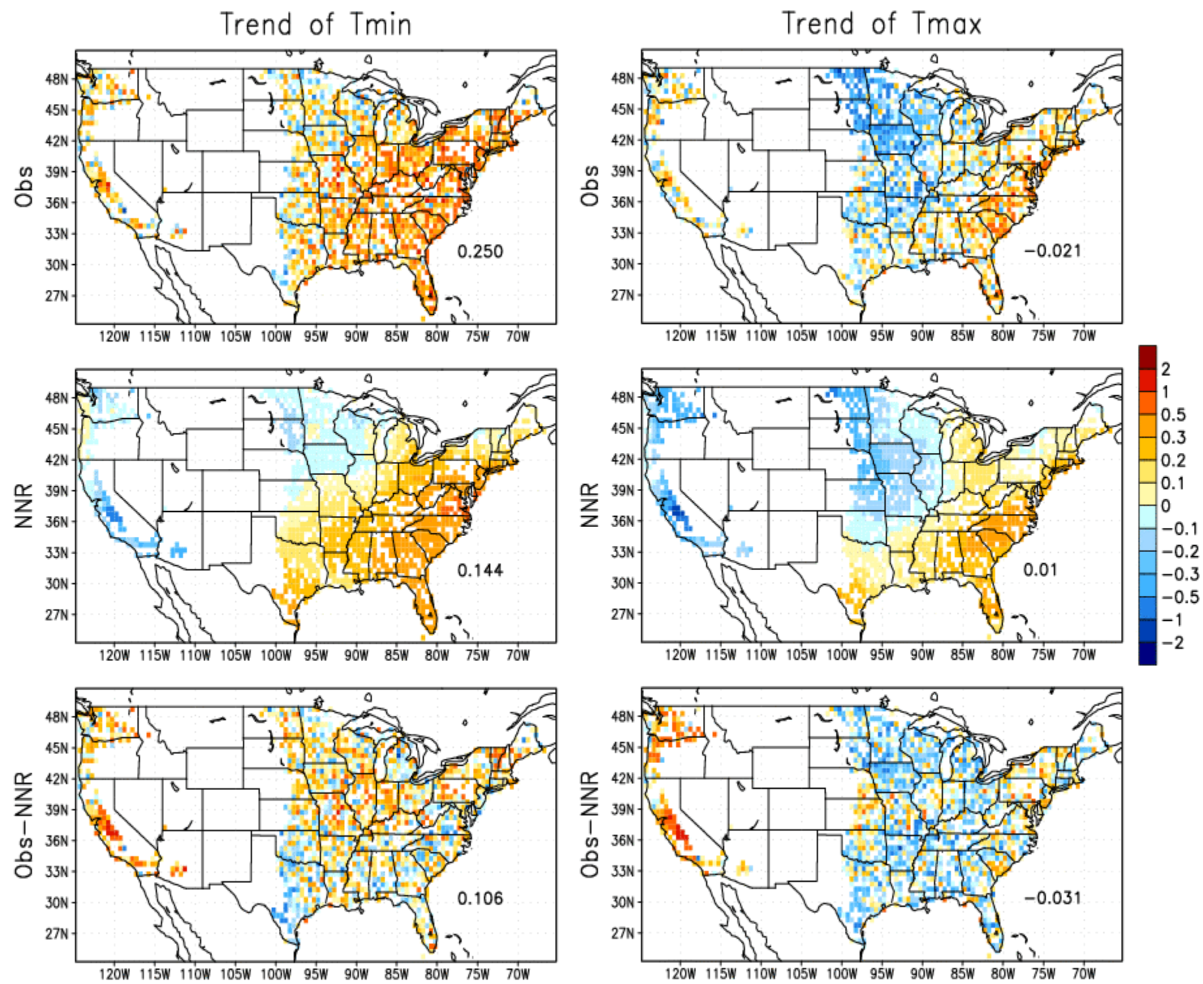

Fig. 2 40-year yearly temperature trends for the US over stations located below 500m. Top panel: from stations, middle panel: from the NNR, bottom panel: observations minus NNR trend. Left: trend of minimum temperature, right, trend of maximum temperature.

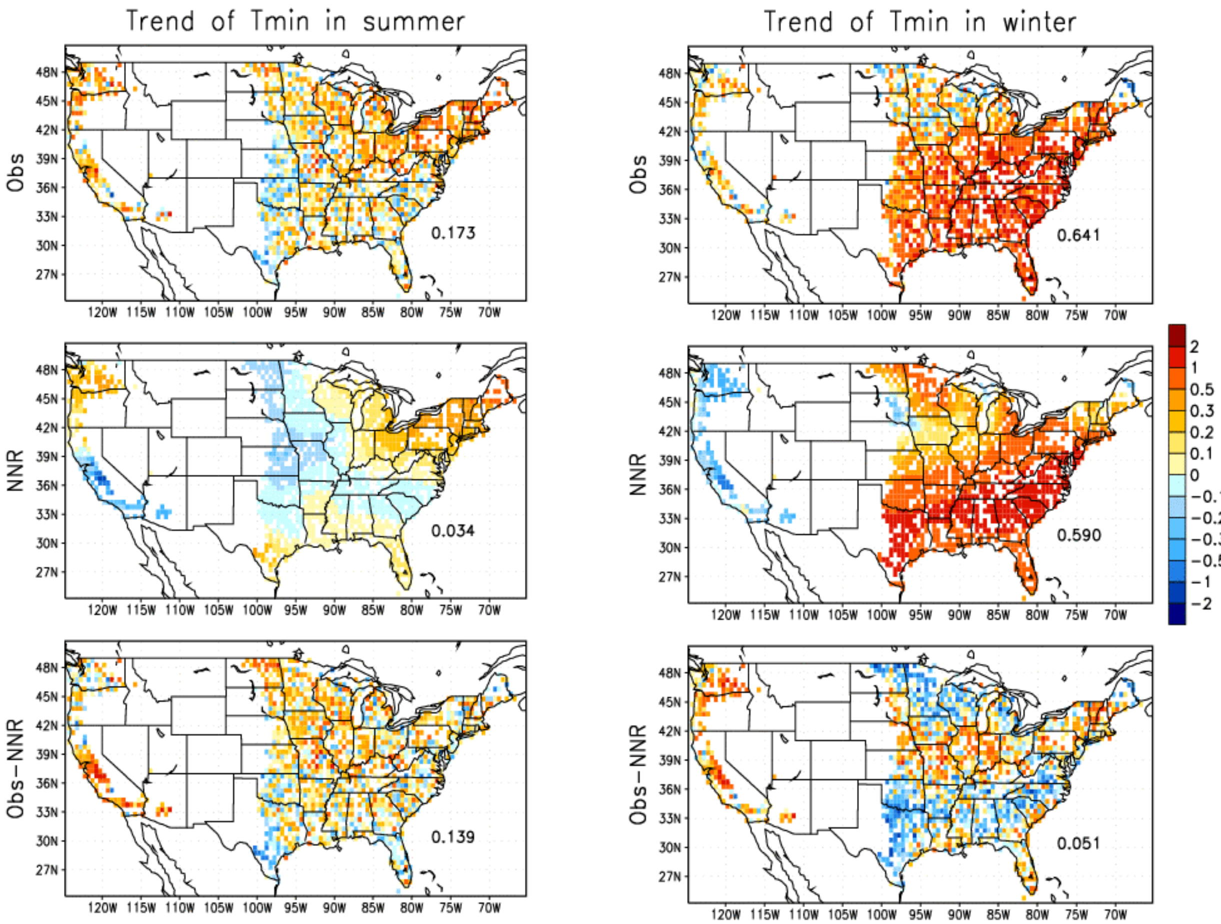

Fig. 3 40-year minimum temperature trends in the summer and in the winter for the US over stations located below 500m. Top panel: from stations, middle panel: from the NNR, bottom panel: observations minus NNR trend. Left: trend of minimum temperature in the summer, right, trend of minimum temperature in the winter.

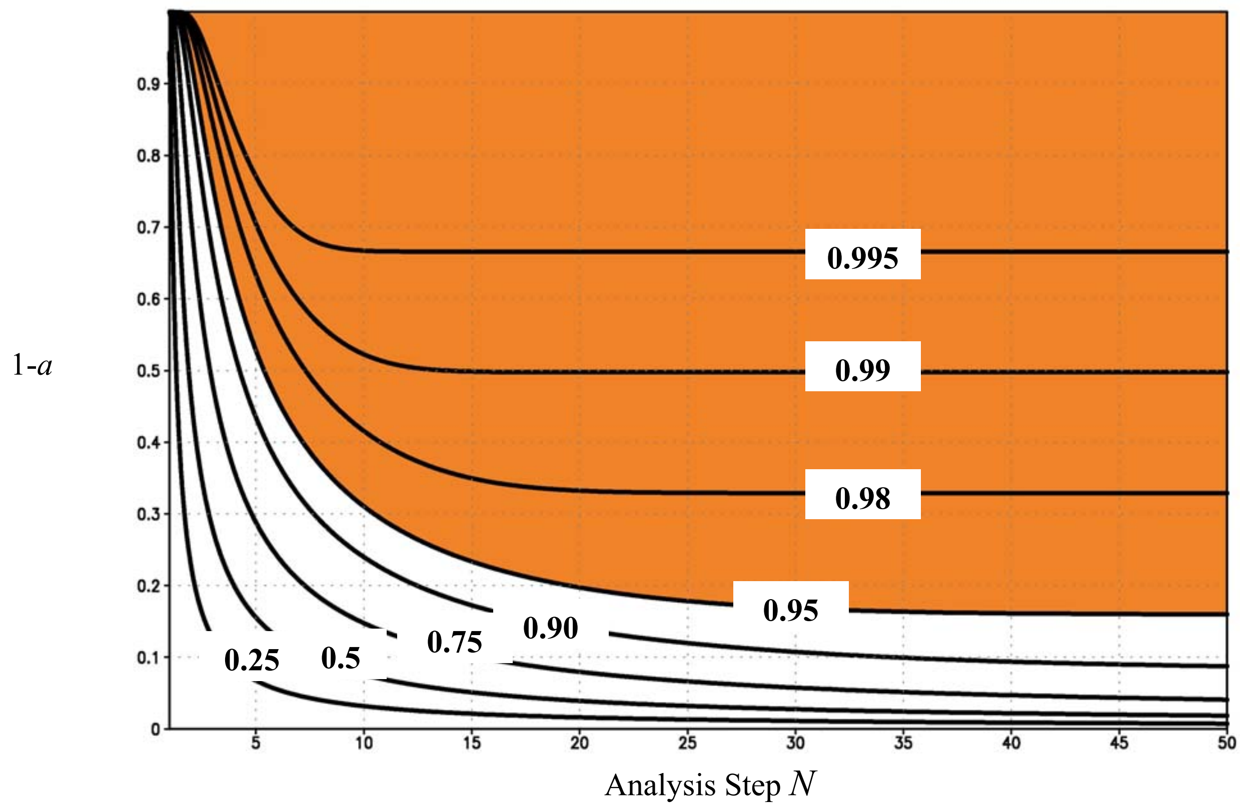

Fig. 4 Ratio of the trend between two consecutive analysis cycles to the trend in the observation as a function of *N*, the analysis step starting from *N*=1, and *(1-a)*, the weight assigned to the observation in the data assimilation procedure. We assume that the ratio between the analysis time step and the radiative relaxation time is 0.01. (From Cai and Kalnay, 2003b).