Trends and inhomogeneities in the NCEP/NCAR Reanalysis 1948 - 1998: implications for interannual correlation analysis and appropriate detrending methods

Andreas Philipp & Jucundus Jacobeit

Department of Geography, University of Wuerzburg, Am Hubland, D-97074 Würzburg, Germany
(andreas.philipp@mail.uni-wuerzburg.de, jucundus.jacobeit@mail.uni-wuerzburg.de)

Abstract

The study gives a broad overview of trends and abrupt shifts in the geopotential height (GPH) field of the NCEP/NCAR Reanalysis dataset in the period 1948 - 1998, discusses appropriate detrending methods and points out the impacts on interannual correlation analysis for which the application of highpass filtering techniques is recommended.

Introduction

The global NCEP/NCAR Reanalysis dataset covering the period from January 1948 up to the present is one of the most widely used datasets for climatological monitoring and investigations at synoptical to global scales. While some of the reconstructed climatological parameters in the dataset are indicated to be less reliable (e.g. precipitation rate), others are expected to provide a high level of quality. This is true especially for the GeoPotential Heights (hereafter GPH) of 17 pressure levels ranging from 1000 hPa to 10 hPa (Kalnay et al., 1996). The main improvement of the global reanalysis datasets stems from the data assimilation system which is kept constant in order to eliminate artificial jumps in the time series (Kistler et al., 2001). Nevertheless there are some systematic and some individual constraints leading to biases in the resulting data sets. The systematic biases are due to differences in the availability and quality of observational data. The most distinctive changes are the enhanced availability of upper air observations since the year 1957 and the use of satellite based data since 1979. Non-sytematic biases are resulting from individual errors (e.g. the "Problem with PAOBS", NOAA, 1999). Beside these artificial changes in the dataset global changes in the climate system take place in the period 1948 until now, i.e. the observed global warming and a higher frequency of stronger El Niño events since the mid 1970s, known as "climate shift" (Trenberth & Stepaniak, 2001). Due to the major incisions in the observation system about 1957 and 1979, studies on long term variability are not recommended for this dataset whereas "Reanalysis can be used for daily to seasonal and interannual timescales." (Kistler et al., 2001, p. 262). This recommendation suggests that studies on interannual variability are largely unaffected by the constraints described above. Nevertheless there are significant impacts in particular concerning interannual correlation analysis in the GPH field which are examined in this study.

Data

NCEP/NCAR Reanalysis GPH data has been selected for the seven tropospheric levels at 1000, 850, 700, 500, 300, 200 and 100 hPa (spatial resolution 2.5°x2.5°). As a particular example for influences of long term variability on interannual correlation analysis the October-April mean GPH is used.

Since the major changes in the reanalysis period occurred around 1957 and 1979, the 1948 - 1998 period (sample size of 50 years) is well sufficient for this study.

Trends and abrupt shifts in the dataset

In order to describe linear trends in the GPH timeseries, Fig. 1 shows the Z-statistics of the nonparametric Mann-Kendall trend test (Hollander & Wolfe, 1999) being able to detect trends which are established only in subsections of the whole period. At the 1000 hPa level (Fig. 1a) significantly negative trends are shown for northeastern North-America, northeastern Asia, the North-Pacific, and the vicinity of Antarctica where data quality is rather low. The latter are known to be artificial (Hines et al., 2000). Significantly positive trends predominate the tropics - except of the Indian Ocean - with extensions to the subtropics around Africa, Asia and Australia. At the high tropospheric 100 hPa level (Fig. 1b) the positive trends in the tropics spread out over most of the globe while negative trends predominate the arctic region. In order to distinguish between linear trends and abrupt changes in the timeseries, additional SMWD (Split Moving Window Dissimilarity) analyses has been applied. This method is able to detect jumps in timeseries by performing an t-test between the first and the second half within a running time window of several (here 10) years (Camberlin et al., 2000). Fig. 2a shows the number of gridpoints for which jumps are detected as a function of time.

a) b)

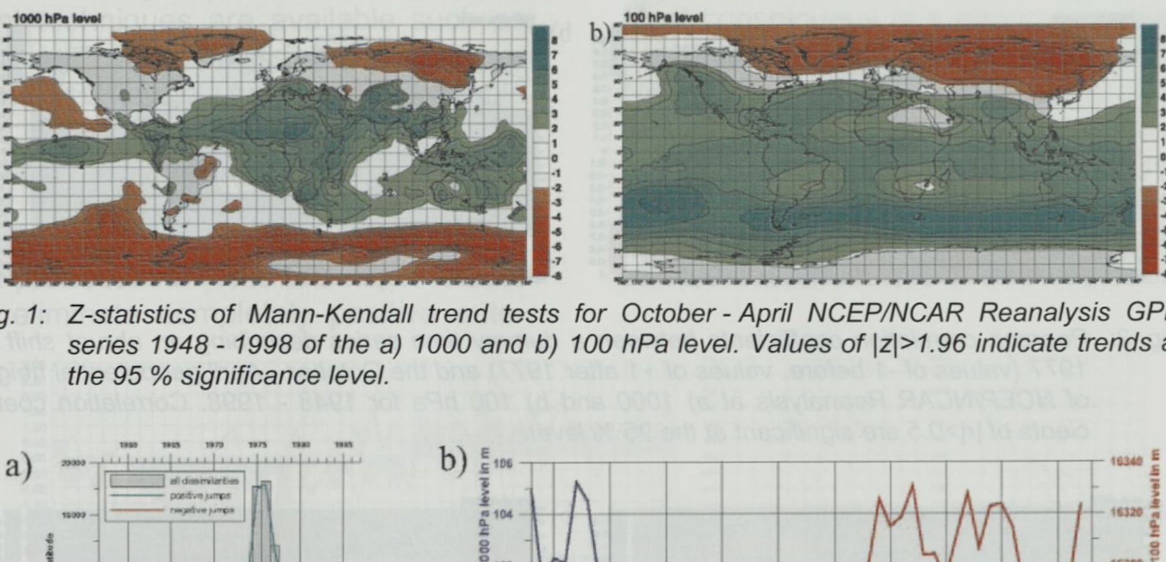

Fig. 1: Z-statistics of Mann-Kendall trend tests for October - April NCEP/NCAR Reanalysis GPH series 1948 - 1998 of the a) 1000 and b) 100 hPa level. Values of |z|>1.96 indicate trends at the 95 % significance level.

a) b)

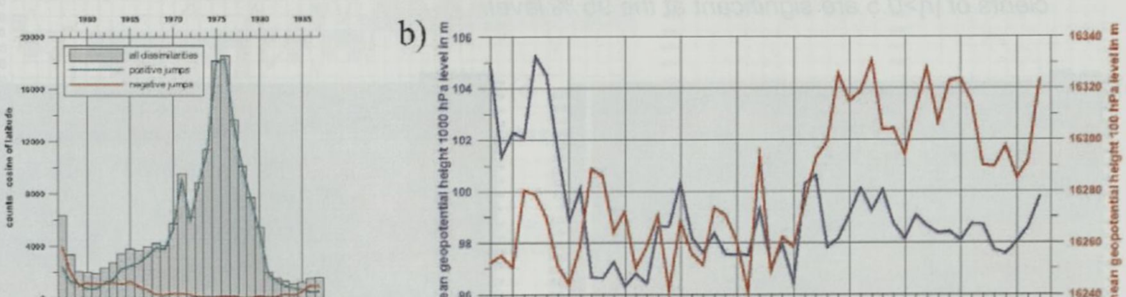

Fig. 2: a) Number of October - April GPH time series with dissimilarities inbetween a running time window of 10 years (SMWD analysis, see text) as a function of time 1948 - 1998. A detected jump is counted for the year immediately before the dissimilarity in the time series for one gridpoint and is weighted with the cosine of its latitude. b) October - April 1948 - 1998 time series of global mean GPH for the 1000 and the 100 hPa level.

While negative and positive jumps in the GPH time series show a peak at the beginning of the period in 1957 and a decrease afterwards, a huge amount of dissimilarities is detected in the 1970s with a peak in 1971 and further increasing number up to the maximum year 1976.

Fig. 2b shows the temporal evolution of the global mean GPH values of the 1000 and 100 hPa levels.

While there is a decline at the 1000 hPa level in the 1950s, the jump around the year 1977 predominates the whole global mean of the high troposphere, leading to a strong inhomogeneity. For the purpose of recording the spatial extent of this jump, each of the GPH time series has been correlated with a dummy variable describing just this jump by constant values of -1 before 1977 and values of +1 afterwards (Fig. 3). Strong correlation coefficients (r>+0.8) are recognized in tropical Africa and around Bangladesh at the 1000 hPa level. In the high troposphere most of the tropics and subtropics are affected by the abrupt change in the 1970ies leading to correlation coefficients of up to r>+0.9. Even if considering significant changes in the climate system in the 1970s this seems to be too high pointing to the impact of the initial use of satellite data at this time.

Detrending

In order to counteract biases introduced by long term variability, different detrending techniques are commonly used to reduce its influence on interannual analysis.

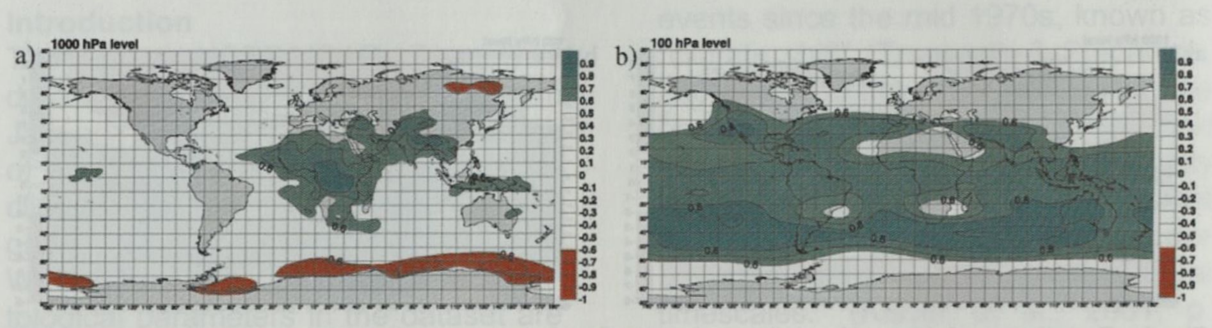

Fig. 3: Pearson correlation coefficients between a dummy time series describing an abrupt shift at 1977 (values of -1 before, values of +1 after 1977) and the October - April geopotential height of NCEP/NCAR Reanalysis at a) 1000 and b) 100 hPa for 1948 - 1998. Correlation coefficients of |r|>0.5 are significant at the 95 % level.

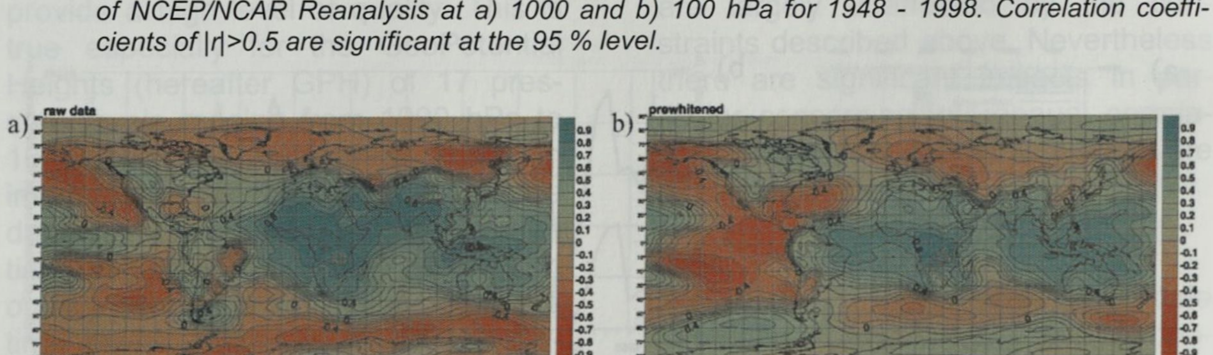

Fig. 4: Teleconnection map of correlations of the basepoint at 30° E/10° S (Africa, red circle) in the NCEP/NCAR Reanalyis 1000 hPa GPH field for October - April 1948 - 1998 a) using raw data, b) with prewhitened time series.

Concerning the time series jump in the mid or late 1970s an adjustment of the anomalies to two different long term mean values for the periods before and after 1977 seems adequate for trend assessments as suggested by Kistler et al. (2001, p. 261). However, this method inserts some artificial variability in cases where there is no jump in the late 1970s but rather a continuous trend. Thus, this technique may not be applied for studies on interannual variability. A second possibility for counteracting is the linear detrending approach using differences between raw data and trend regression values. This procedure will reveal the required results - but only for time series which are affected by stringent linear trends. In all other cases this technique inserts new types of artificial long term variability into the time series. A third method is offered by highpass filtering. Different techniques are available such as filtering with Gaussian weights or wavelet filtering. Another very simple but effective highpass filter is the so called "prewhitening" technique, i.e. the use of differences between each value of the time series and its temporal predecessor. This technique is able to eliminate completely positive autocorrelations without substantial shortenings of the time series (Brown & Katz, 1991) retaining, however, year-to-year variability. Therefore it is capable to remove all types of trends and shifts without inserting artificial biases.

Implications for interannual correlation analysis

The impact of long term variability on interannual correlation analysis is demonstrated by comparing the use of raw data and high pass filtered data. Fig. 4 shows the 1000 hPa GPH teleconnection map of a base point located in central Africa (30° E/10° S) including its correlation coefficients with all other GPH grid points. The raw-data correlation map is predominated by the distribution pattern of trends and abrupt shifts shown in Fig. 1 and 3 whereas the prewhitened-data correlation field depicts a pattern with large differences. Most conspicuous is a strong negative correlation (r<-0.6) with the primary El Niño/Southern Oscillation (ENSO) centers in the central and eastern Pacific and an increase of positive correlations in the Indonesian sector (r>+0.8). Furthermore, a negative correlation center in northeastern Brazil is now replaced

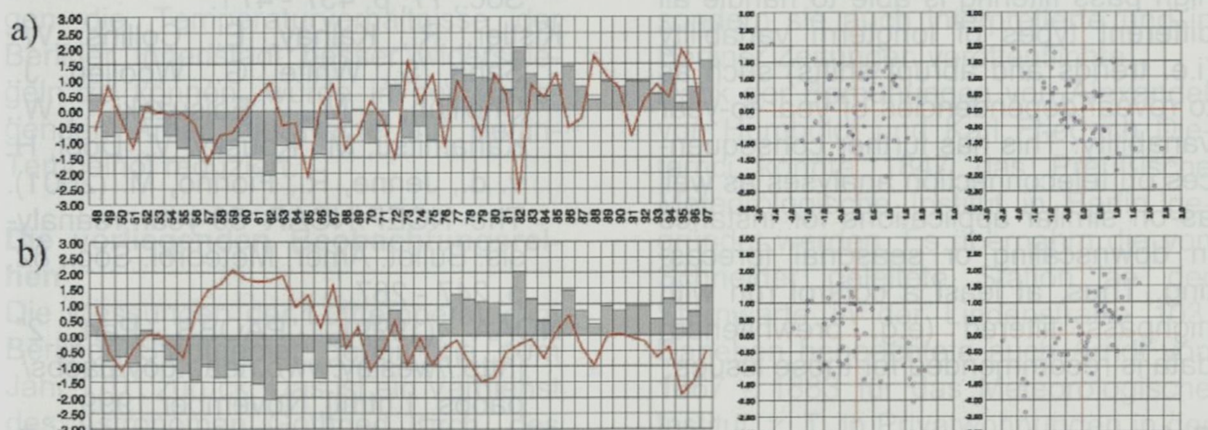

Fig. 5: a) left pannel: normalized October - April mean timeseries of 1000 hPa GPH at 30° E/10S (central Africa, bars) and at 100° W/0° N (eastern Pacific, red line). Right pannel: scatter plots between the two time series using normalized raw data (left) and with prewhitened normalized data (right). b) as a) but for 1000 hPa GPH at 42.5° W/5° S (NE Brazil, red line).

by a strong positive correlation of r>+0.7 in the eastern tropical Atlantic. The example time series in Fig. 5 point out the reasons for these differences. The negative year-to-year correlation between the central African gridpoint and the eastern Pacific time series is superimposed by a common positive shift in the 1970s which completely suspends the strong relationship. In the second example (north eastern Brazil) opposite anomalies of the late 1950s and early 1960s lead to a predominating total negative correlation while the underlying year-to-year variability is strongly correlated with positive sign. Similar examples confirm that interannual correlation analysis is highly affected by long term biases leading to incorrect assumptions about dependencies in the GPH field on high-frequency time scales.

Conclusions

Longterm variability may hide completely significant correlations in the NCEP/NCAR Reanalysis GPH field as well as it may pretend strong dependencies which, in fact, are caused by temporal autocorrelation. In contrast to various other methods of detrending, high pass filtering is able to handle all different types of longterm variability (i.e. trends and abrupt shifts) such as to reveal dependencies of year-to-year variability. This has further consequences on teleconnection analyses as well as on similar applications for instance in downscaling or seasonal forecasting. Thus, at least a control run with highpass filtered (e.g. prewhitened) data is recommended for those issues.

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