The Tropospheric Humidity Trends of NCEP/NCAR Reanalysis Before the Satellite Era

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Introduction

NCEP/NCAR Reanalysis (Kistler, et al., 2001, and Kalnay et. al, 1996), hereafter called the Reanalysis, currently is still the most comprehensive and coherent global analysis, which includes three decades of data before satellite measurements became available. The long history of the data are valuable for studies on climate variations, such as ENSO and inter-decadal variations. (proceeding of 1st and 2nd conf on reanalyses)

A figure similar to Fig. 1, showing a trend of Longwave Cloud Radiative Forcing (LWCF) from NCEP/NCAR Reanalysis was presented by Potter et al. '99, which was derived from the 50 year NCEP/NCAR Reanalysis (Kistler, et al, 2001). In that study, global LWCF was found to exhibit a significant trend of - 3 W/M^2 starting from 1949 through 1979. The trend spells for more than 10% of LWCF over 3 decades period. LWCF (Ramanathan, 1989) measures the thermal radiative heating in the atmosphere that modulated by clouds. In general, an increase of LWCF is offset by the accompanied shortwave cloud radiative forcing, SWCF, over the sunlit region, which alter the heating to the surface. Although the cancellation of these two terms would means the net cloud forcing on the earth-atmosphere stay near balanced, the distribution of the heating profile could be seriously changed, hence, the climate of the earth.

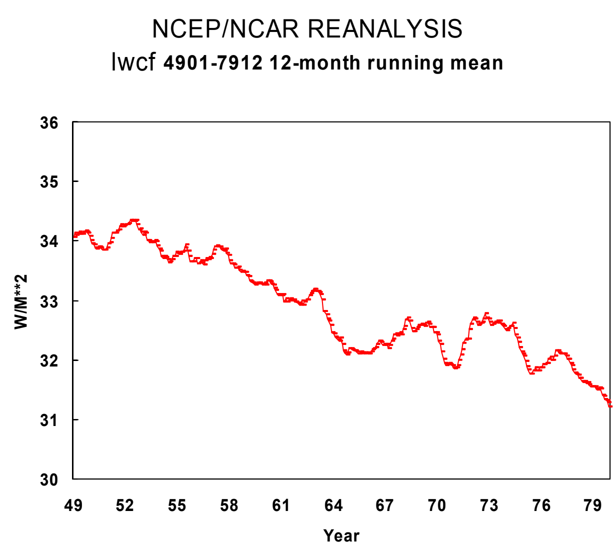


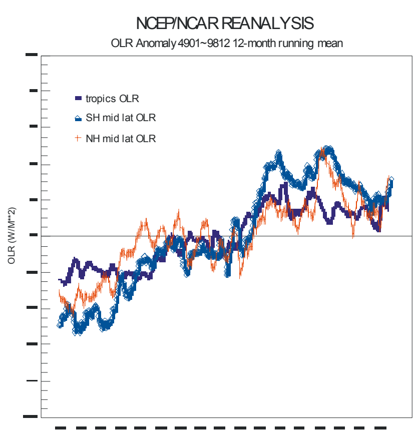
Figure. 1, Reanlsysis Global LWCF. The time series is a 12-month running mean.

This study, eventually, conclude that the cause of the LWCF trend originated from the Reanalysis humidity, in particular from the upper tropospheric humidity, UTH. This report presents the analyses that lead toward such a conclusion, and provide measurement information for theorizing the trends imbedded in the Reanalysis.

Longwave Cloud Radiative Forcing Analyses:

Figure 1 illustrates the time series of Reanalysis LWCF from 12-month running means from 1949 through 1979. Satellite observations from NOAA polar orbiters are operationally used starting from 1979. Thus all the data before this interested period are mainly from radiosondes, and other surface observations. LWCF is the difference between clear sky Outgoing Longwave Radiation, OLR, and total-sky OLR.

Figure 2 shows these two components of the LWCF, and clearly identifies that the trend is from the total-sky OLR. It also indicates that the trend over the higher latitudes are more pronounced than the tropics. As the total-sky OLR is highly modulated by the clouds, and the Reanalysis clouds is parameterized based on relative humidity, RH. This differentiation of clear-sky versus total-sky OLR reveals the core issue of upper-air humidity trend, as illustrated in the time series of 500 hPa RH anomalies, shown in Figure, 3, which reconfirms that the strongest trend is located in the tropics, and is anti-correlated with total-sky OLR. Although not shown, the trend is even stronger in the higher altitudes.



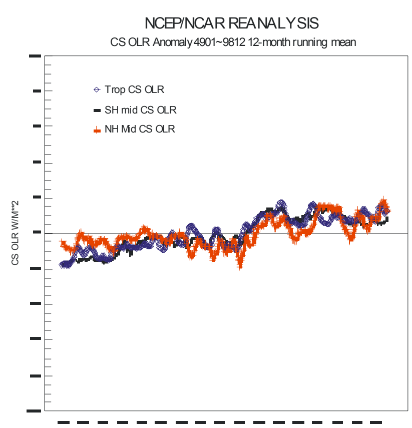


Fig. 2, Two components of LWCF. The left panel is the anomaly of total-sky OLR; the right panel is clear-sky OLR; both are 12-month running means, in W/m ^{2}.

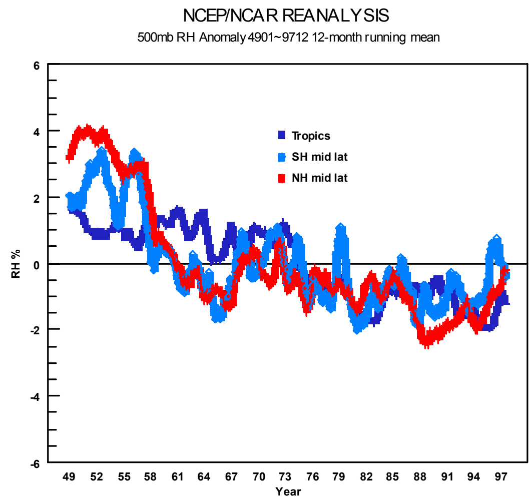


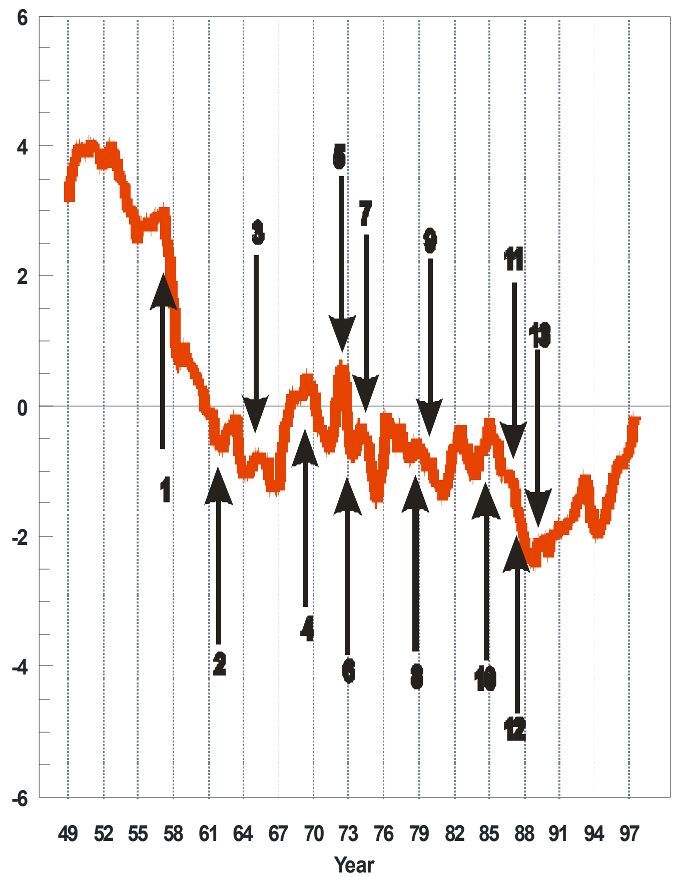
Fig. 3, 12-month running means of Reanalysis 500 hPa RH anomalies, in %.

Possible Causes for the Trend

A number of the possible causes for the trend have been examined, including 1) the instrument characteristics, 2) instrument and reporting algorithm/procedure changes over the years, 3) reporting station increases for the Reanlaysis, and possible 4) natural variations.

For the instrument characteristics, Nash and Schmidlin (1987), NS87, reports that the time constants for most hygrometer sensors used performs are rather short at the surface, 1-2 seconds for carbon hygristor and thin film. However, the goldbeater and hair sensors responses much slower, more than 10 seconds. The information about the sensor performance at altitudes are rather scarce. It is generally believed that the response time increase drastically. NS87 reports that goldbeater and hair's time constant at 300mb is about 5 minutes. As the balloon traveling at 15 ft/sec, the 5 minutes can be translated to more than 50 hPa in the mid to upper troposphere. Thus if one uses a sluggish sensor, the instrument will reports the higher reading toward the true value of the moister air of the lower altitudes. Although some sensor manufacture provided correction factors for the users, the derivation of the factors were proprieties, and the accuracies are still difficult to assess. More recent report from Miloshevich et al (2001) indicates that humidity measurement are not reliable in the cold temperature. Elliot and Gaffen (1991), EG91, summaries many of the instrument, as well as algorithm and reporting procedure changes. Mathews (1963) and Lott (1976) also documented some of the reporting practice when the instrument loses sensitivity in high altitudes. Those practice would biased to the higher value as well. The other major event is International Geophysical Year 1957, which change the reporting time, as well as more observations were initiated. Figure 4 is a chronology of instrument and algorithm change based on EG91, and plotted over Reanalysis LWCF anomaly. Although one can't draw any conclusion that this is the factor for the trend, it does show that instrument and algorithm changes do have significant impacts on the data.

Chronology of changes in the US Radiosonde Network



A Chronology of changes in the US Radiosonde Network from Elliott and Gaffen (1991) plotted on LWCF anomaly to demonstrate the probable impacts. 1: observaion time changd on IGY; 2: introduced white-coated temperature elements; 3: Introduced carbon humidity element; 4: changed from manual system to a time-share computer system; 5: redesigned relative humidity ducts introduced; 6: "motorboating" lower RH values as 19% when measured lower than 20%; 7: introduced semi-automatic mini-computer-based system; 8: Satellite measurements incorporated into Reanalysis; 9: New carbon hygristors introduced; 10: Introduced fully automatic mini-computer-based system; 11: Introduced Precalibrated hygristor replacing individual preflight calibration; 12: Introduced new VIZ sonde with new humidity duct; 13: Introduced fully automatic micro-computer-based system.

Reporting station increase, figure 5, for the Reanlaysis could also be a factor for the humidity trend. It is possible if that the new observations are heavily came from the lower latitudes with higher moisture, see figure 6. However, our study on the regions with major station increases, such as Western Europe and China, and found no strong evidence for causing a distinguishable trend.

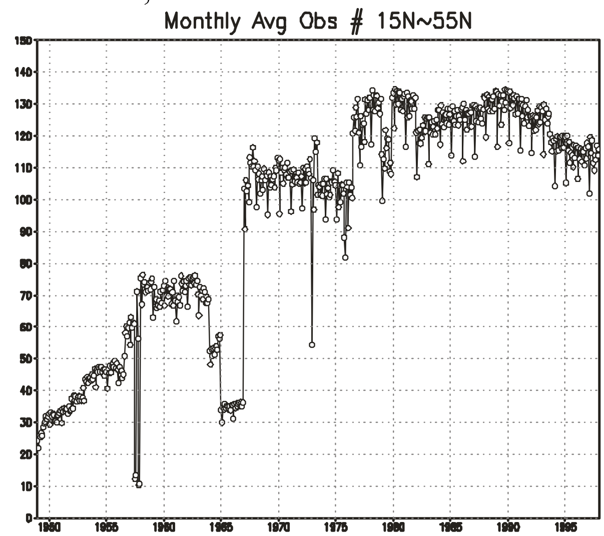


Figure 5, Monthly average number of the observations accepted by the Reanlaysis Global Data Assimilation System between 15 deg and 55 deg N.

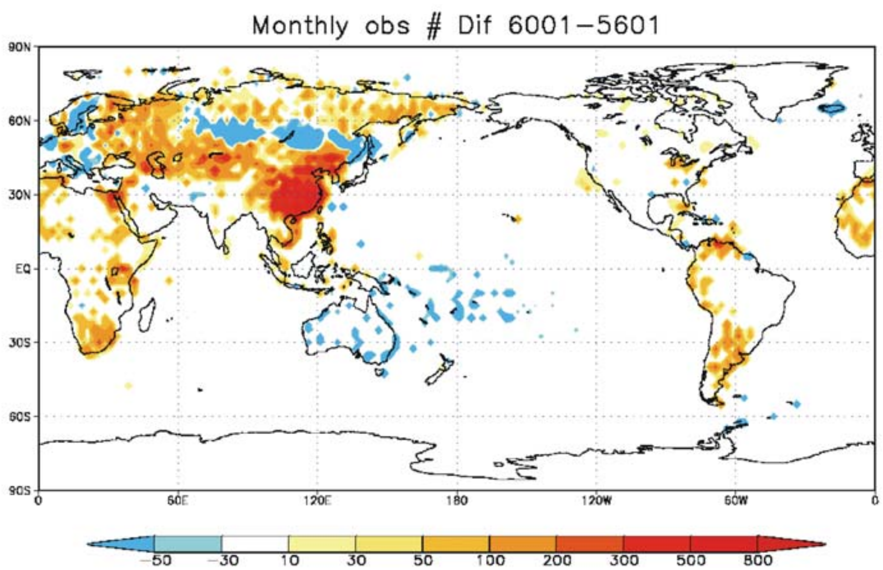


Figure 6, The difference of monthly observation number between January 1960 and January 1956. It shows the largest increase over central Eurasia and China.

To be sure that the natural variation, in particular ENSO, would not account for any of the trend, we perform a differential time series analysis with an AMIP simulation. Assumethat both the AMIP simulation and the Renalaysis contains the same ENSO signals, as both using the same SST of Reynold and Smith (1994), if the reminder between the two still show the trend, than it is an clear indication that ENSO is not a cause. Table 1 shows the attributes of the models used for the Reanalysis Global Data Assimilation System, and model used for the a 10-member AMIP simulations. The means of the 10 members are used for this analysis.

We assemble the RH time series on the locations of 30 stations given by John Christy (2000, personal communication) , see table 2. These US stations are known for quality operations, and spread through vast climate regions. The stations are sorted to high, mid latitudes and the tropics according to their latitudes. The results are presented in Figure 7, which again, shows the strong trends in the high altitudes, as well as latitudes, where the air is dry and cold. The lower panels of Figure 7 shows the time series after 1957, IGY. Large portion of the trends on the upper panel are since removed, which indicates most of the trends are in the earlier years of the 50-year Renalaysis. This analysis eliminates the possible cause from ENSO.

	Reanalysis	**AMIP-ensemble10**
Convection Scheme	**SAS**	**RAS**
SW Radiation	**Lacis & Hansen (1974)**	**Chou et al (1992, 1996)**
Boundary Layer	**Local Diff**	**Non-Local**
Orography	**Mean**	**Smooth Enhanced**
Resolution	**T62L28**	**T42L24**
Soil Moisture	**w/ nudging**	**interactive**
Snow	**Obs (fixed on '72)**	**Climatology**
Radiation Freq.	**124 (3-hourly)**	**128 (3-hourly)**

Table 1, the attributes of Reanalysis GDAS and the model used for AMIP runs

Station	Latitude	Longitude	Region
Majuro Marshall Is	7.05	171.23	T
Guam	13.33	144.5	T
Dodge City KS	37.46	-99.58	M
Oakland CA	37.46	-122.14	M
Barrow AK	71.18	-156.47	H
Key West FL	24.33	-81.45	T
Jackson MS	32.19	-88.45	M
Brownsville TX	25.54	-97.26	M
Corpus Christi TX	27.46	-97.3	M
Del Rio TX	29.22	-100.55	M
Nashville TN	36.15	-86.34	M
Albuquerque NM	35.03	-106.37	M
Mercury NV	36.37	-116.01	M
Pittsburgh PA	40.32	-80.14	M
Medford OR	42.22	-122.52	M
Green Bay WI	44.29	-88.08	M
Caribou ME	46.52	-68.01	H
Bismarck ND	46.46	-100.45	H
Glasgow MT	48.13	-106.37	H
Great Falls MT	47.29	-111.22	H
San Juan PR	18.26	-66	T
St Paul AK	57.09	-170.13	H
Annette Is	55.02	-131.34	H
San Diego CA	32.51	-117.07	M
Spokane WA	47.38	-117.32	H
Quillayute WA	47.57	-124.33	H
Belize	17.32	-88.18	T
Barbados	13.09	-59.37	T
Hilo HI	19.43	-155.04	T
Grand Cayman	19.17	-81.21	T

T: Tropics $< 25^0$, 8 stations

M: Mid Lat. $25^0 \sim 45^o$, 13 stations

H: High Lat. $> 45^0$, 9 stations

Table 2, Locations of the 30 US stations provided by J. Christy (2000, personal communication) where quality observations have been consistently reported. The stations are sorted by latitudes to: T for tropics, M for mid latitudes and H for high latitudes.

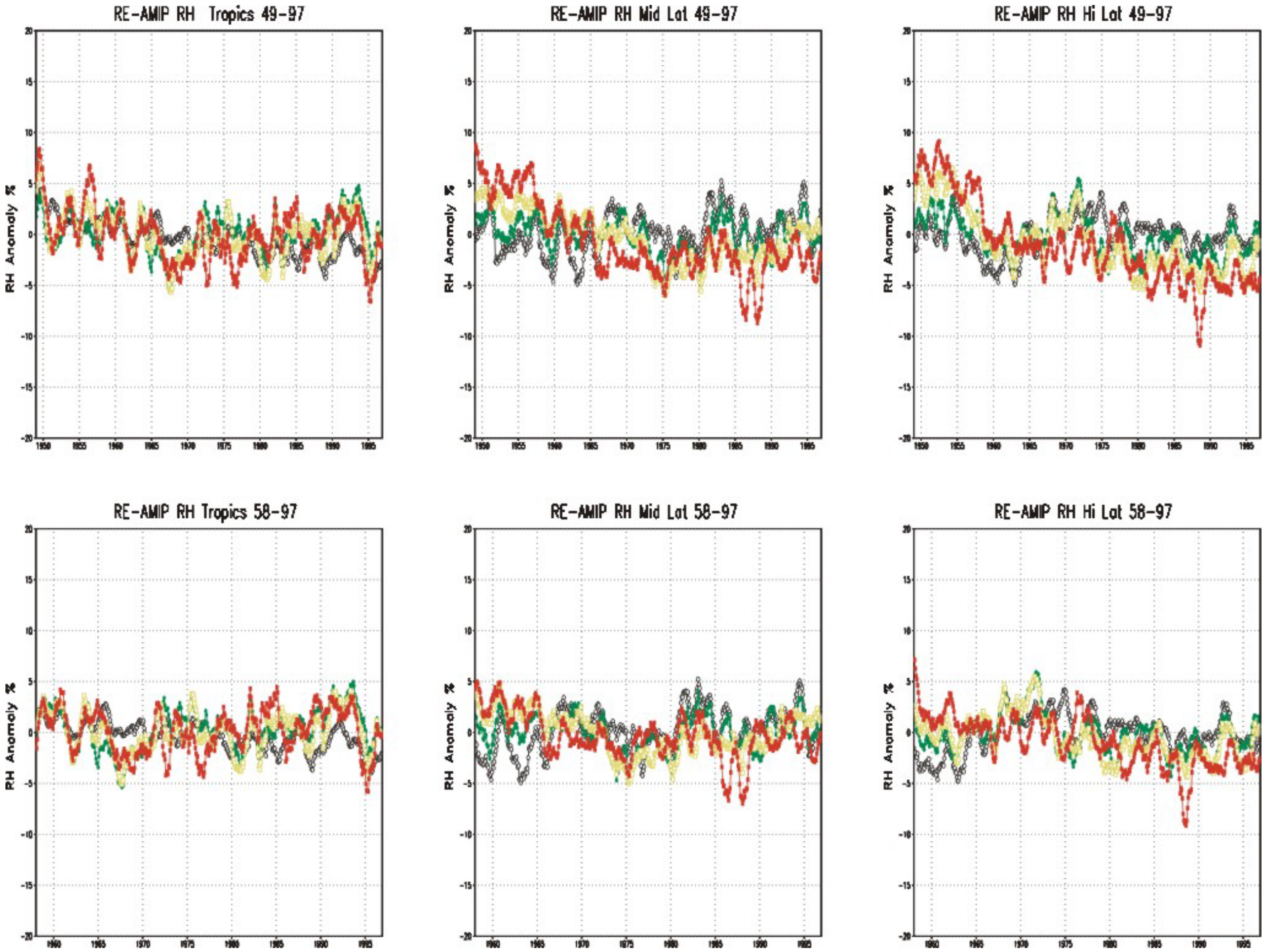


Figure 7, Time series of RH anomaly differences between the REanlaysis and AMIP simulations; black for 850 hPa; green 700 hPa, yellow 500hPa, and Red 300hPa.

Conclusion and Suggestions:

The analyses from this study indicate that the drying humidity trend of the Reanalysis, that 1st identified by Potter et al. (1999) from LWCF, is an artifact. The trends is mild in the lower troposphere, and become more severe from the mid to upper troposphere. The trend is also more pronounced in the high latitudes, and less severe toward the tropics due to the less gradient of humidity in altitude. From the AMIP simulation, and analysis on a number of well-maintained stations, it is also clear that the trend is not associated with ENSO.

Based on the available information about the instrument characteristics and the sampling, we strongly believe that the major reason for the trend is caused by the long response time of hygrometers from the earlier years. The early humidity measurements by Goldbeater with hair element has fairly long time constant, more than 10 seconds on the surface, and 5 minutes at 300 hPa. As the instrument ascending at a speedy 15 ft/sec from the moist surface toward dryer altitudes, the sluggish instrument response reports the higher moisture biased toward the true value of the lower altitudes. The sharper the vertical moisture gradient, the worse the problem. Which explains why the trend is stronger in the high latitude UTH, and subsides toward the tropics. This also reflects the known difficulty of radiosonde measurements in the cold temperature.

The key objective for doing Reanalysis is to eliminate the artificial anomalies which is not avoidable as the operational systems being upgraded. This study suggest that the future Reanalyses includes a sub-analysis using only the limited well-known, high quality, fixed number stations for GDAS, such that a baseline reference analysis for the full analysis can be established. Meanwhile, it is indispensable to conduct the parallel processes for extended period whenever a new instrument, or processing system, is introduced, such that the impact from the new instrument/process can be understood.

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