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Did the global temperature trend change at the end of the 1990s?

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Abstract

The apparent leveling of the global temperature time series at the end of the 1990s may represent a break in the upward trend. A study of the time series measurements for temperature, carbon dioxide, humidity and methane shows changes coincident with phase changes of the Atlantic and Pacific Decadal Oscillations. There are changes in carbon dioxide, humidity and methane measurement series in 2000. If these changes mark a phase change of the Pacific Decadal Oscillation then it might explain the global temperature behaviour

1 Introduction

The apparent leveling of the global temperature time series (Brohan et al., 2006) at the end of the 1990s may represent a break in the upward trend. But the methodology is widely disputed. For example in a long editorial comment in the journal Climate Change, Terence Mills (Mills, 2010), a UK econometrician who has written at length on temperature trend analysis, concludes that “Statistical arguments alone are unlikely to settle issues such as these, but neither are appeals to only physical models or the output of computer simulations of coupled general circulation models….it is a case of *you pays your money and you takes your choice*”.

The approach adopted here is to look at the time development of global temperature and other atmospheric variables to see if there is supporting evidence of a significant change. Further the Great Pacific Climate Shift (GPCS) (Mantua et al., 1997) of 1976-77 a part of the Pacific Decadal Oscillation (PDO) and the identification of a phase change in the Atlantic Decadal Oscillation (ADO) related to changes in the concentration of atmospheric CO_2 (Wang et al., 2010), may offer a test bed of global indicators for the late 1990s.

Thus atmospheric carbon dioxide (CO_2), humidity and atmospheric methane are examined below using the Chow Break Test (Chow 1960).

The Chow Break Test compares the residual sum of squares for a least squares fit, $S_{(1,n)}$, for the total time series of length n years with the sum of the two fits $S_{(1,k)}$ and $S_{(k+1,n)}$) from two straight line segments where the data is divided at the break point of year k and R is the number of segments plus the base case fit to the entire time series, in this case 3. F is defined as:

$$F = 1/R \{ S_{(1,n)} – (S_{(1,k)} + S_{(k+1,n)}) \}/\{(S_{(1,k)} + S_{(k+1,n)}) /(n-2R) \}$$

The test statistic follows the F distribution with R and n − 2R degrees of freedom. The null hypothesis, no break, gives F = 0 with 100% probability of no break. A maximum in the F Statistic indicates the best choice of break point in the time series. For the data analysed here the presence of a break in the time series is where Chow F Statistic values have a greater than 98% statistical significance for the presence of a break.

2 Global Temperature

The starting point is of course the global temperature series. The decade 2000 to 2010 has seen the interpretation of the global temperature measurements subjected to much argument. The measurements can be presented in a number of ways from monthly to yearly to 10 year values. Monthly data has seasonal effects that are not relevant to this study but a comparison of annual and 10 year values illustrates the problem of assessing the temperature trend. As an example, the global temperature anomaly calculated by the Hadley-CRU group (Brohan et al. 2006) is show in Figure 1. The 10 year average values show a break in the trend in the 1970s but offer no evidence of a further break after 1980. The annual values show the global temperature started increasing in the mid 1970s and the question is whether there is a temperature plateau starting in the late 1990s?.

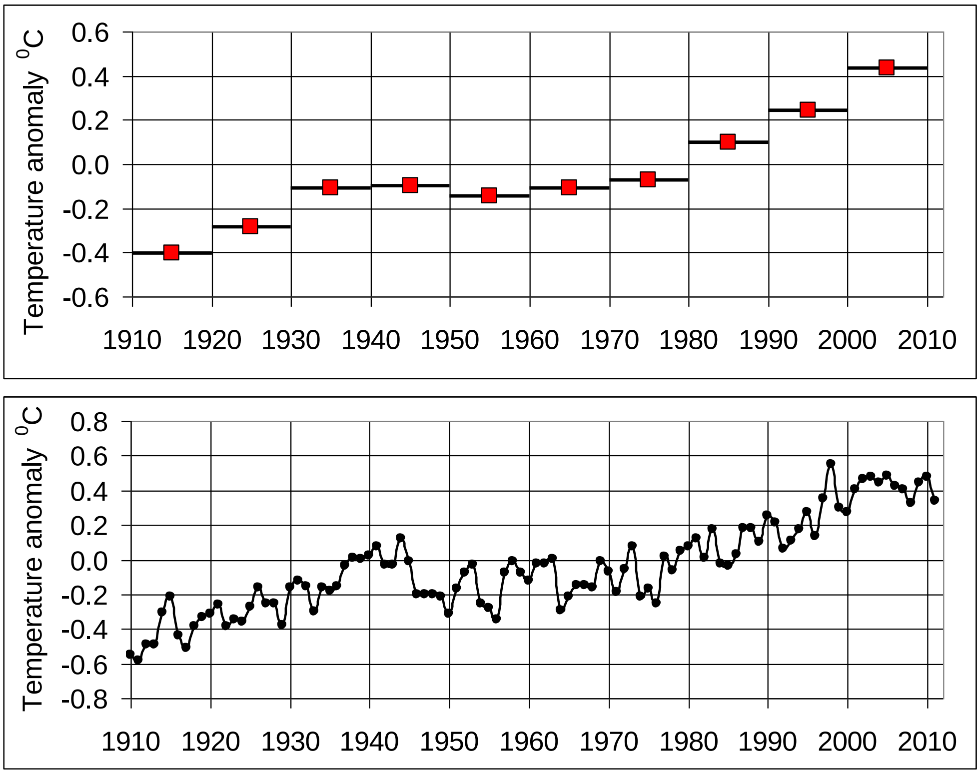

Figure 1: *Global temperatures estimated derived from the HadCRUT3 global temperature series of the Hadley Centre of the UK Met Office.* ***Upper****: 10 year averages of annual temperatures (IPCC presentations).* ***Lower:*** *Annual values from HadCRUT3*

There are three other time series available for global temperatures. These are the National Climate Data Center (NCDC) and Goddard Institute of Space Science (GISS) using ground based measurements and satellite measurements from the University of Alabama at Huntsville (UAH) and Remote Sensing Systems (RSS).

The data used in this analysis are the global temperature anomalies from the Hadley-CRU, NCDC (Smith et al.), GISS (Hansen et al., 2006) and satellite measurements of the lower troposphere from UAH (Christy et al., 2000).

When the Chow Break Test is applied to annual global temperature measurements although there are detectable breaks, there is a measurement standard deviation of 0.1 ^{0}C about the lines of best fit and the

Chow F statistic does not meet the 98% significance test. The data has therefore been analysed taking 5 year running means which gives a measurement standard deviation of 0.04 ^{0}C about the lines of best fit.

The results of applying the Chow Break Test are given in Table 1 and two examples, those of the HadCRUT3 and GISS annual global temperatures series are shown in Figure 2.

Table 1 Breaks identified in global temperature anomaly series.

	HadCRUT3		**NCDC**		**GISS**		**UAH**	
Chow Test Period	**F Test Maximum Probability**	**Peak Year**	**F Test Maximum Probability**	**Peak Year**	**F Test Maximum Probability**	**Peak Year**	**F Test Maximum Probability**	**Peak Year**
1965-1996	98.9%	1977-8	99.9%	1977	99.6%	1977-8		
1978-2009	>99.9%	1995	99.9%	1995	>99.9%	1995	>99.9%	1995

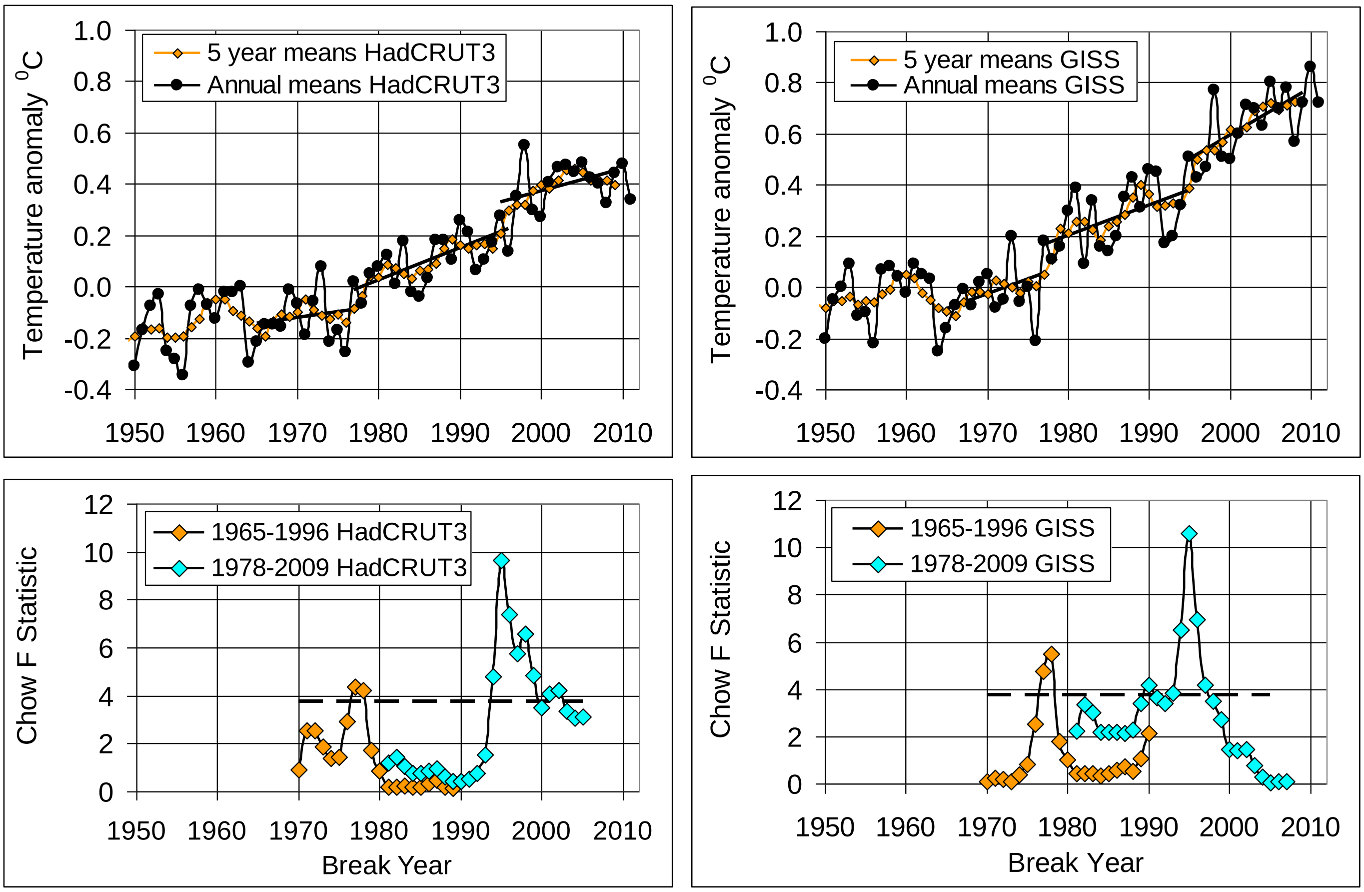

Figure 2 Upper*: Annual and 5 year running mean global temperatures from HadCRUT3 and GISS. The solid lines are least squares straight line fits giving the largest F Statistic value as described in Table.* ***Lower:*** *Chow F Statistic where the dashed lines indicate 98% statistical significance.*

The conclusion from the global temperature analysis is that there are breaks at 1977-78 and at 1995 but not beyond this point where there is limited data.

3 Carbon Dioxide

The longest continuous time series for atmospheric CO_2 are measurements made at the South Pole and Mauna Loa in Hawaii. Figure 3 shows the atmospheric CO_2 concentrations measured at the South Pole from 1957 to 2009 (Keeling et al., 2005). A least squares straight line fit has been made to measurements from 1959 to 2007 in the series and the residual differences of the annual measurements from the fit line are shown in Figure 4. In addition the solid lines in Figure 4 are least squares straight line fits giving the largest

F Statistic value for the breaks at 1966, 1975, 1995 and 2002 that are listed in Table 2. All identified breaks have probabilities greater than 98% with the exception of the break in 2002 where the probability is 97.6%.

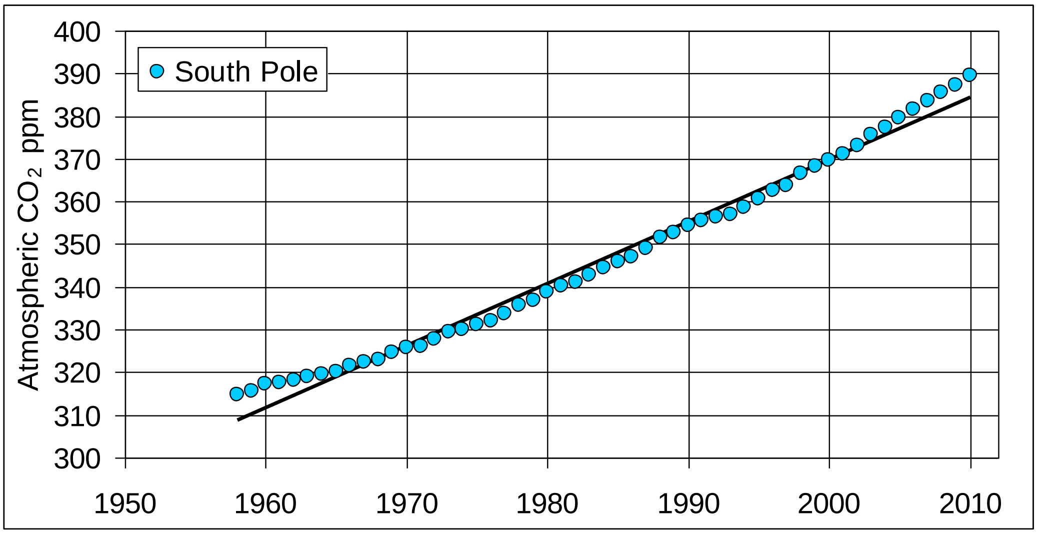

Figure 3: Annual CO_2 measurements at the South Pole. The solid straight line is least squares fit to measurements from 1959 to 2007. For each year, the difference of the measurement from the fit line is shown in Figure 3. Source Scripps Institute

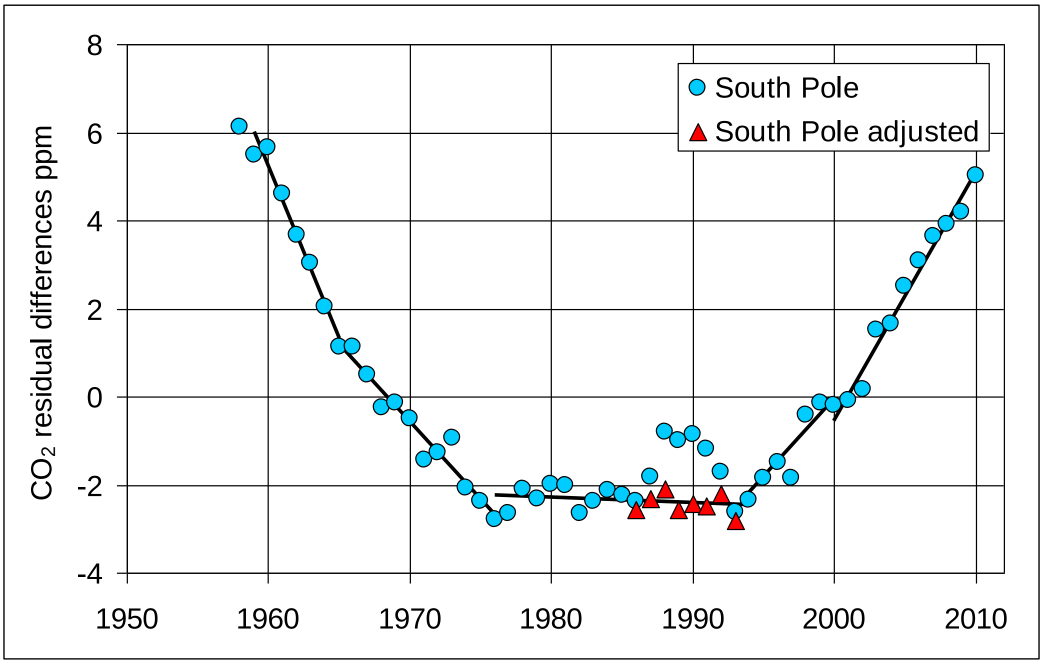

Figure 4: *Residual differences for each year of CO_2 measurement from the trend line. The adjusted values from 1986 to 1993 are a correction for a CO_2 contribution from Arctic ocean warming. The solid lines are least squares straight line fits giving the largest F Statistic value as described in Table 1.*

Figure 5 shows the CO_2 residual time series for the South Pole, Mauna Loa and Point Barrow and confirms the breaks as global in extent. The break analysis has been repeated for the residual differences for Mauna Loa. Breaks have been identified at 1966, 1975, 1994 and 2001 that are listed in Table 2.

Beyond 1987 there is a more complicated structure in the CO_2 residual differences. The peaking of the residuals in 1990 is latitude dependent. The behaviour of the structure is at a maximum at Point Barrow (71^0 N) and at a minimum at the South Pole. For this analysis the structure is assumed to be an effect arising from the sea surface warming in the Arctic Circle (Polyakov et al. 2011) and not a part of the Atlantic or Pacific Decadel Oscillations. Therefore measurements between 1986 and 1993 have been reduced by a bell curved shape peaking at 1989.5 with a 1.6 ppm maximum and a 0.6 ppm standard deviation.

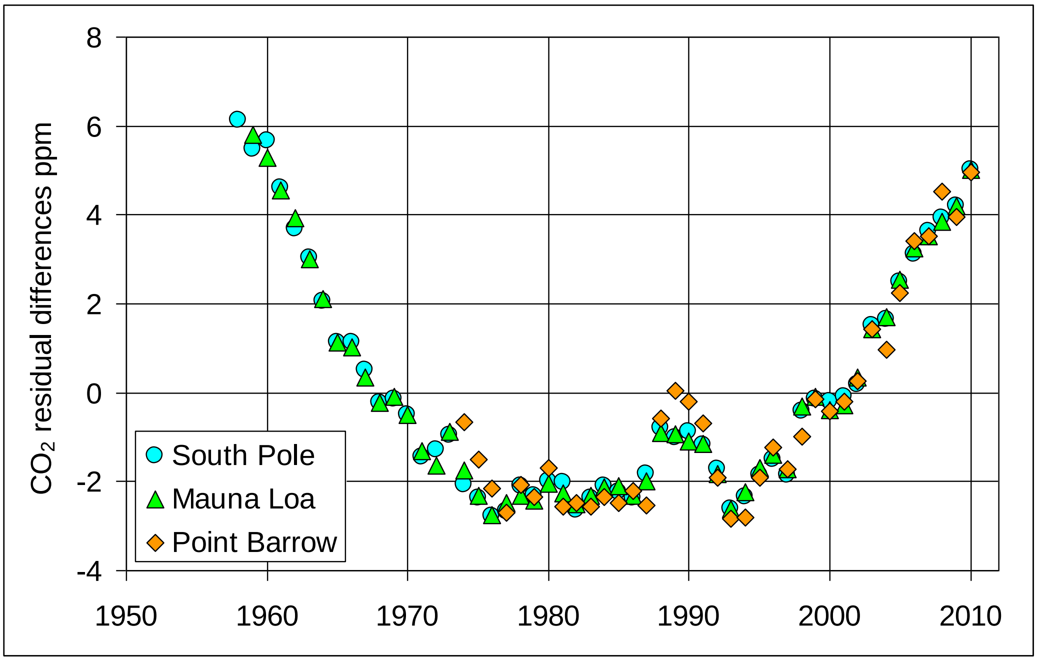

Figure 5: *CO_2 concentration residual differences from straight line fits from 1958 to 2007 for the South Pole (90^0 S) and Mauna Loa (19^0 N). The residual differences for Point Barrow (71^0 N) come from the use of the fit for Hawaii and a 1.4 ppm addition for the mean difference of Point Barrow from Mauna Loa.*

Table 2 Breaks identified in South Pole and Mauna Loa CO_2 measurement series

Nominal Year		**South Pole**		**Mauna Loa**	
	Chow Test Period	**F Test Maximum Probability**	**Peak Year**	**F Test Maximum Probability**	**Peak Year**
1965 ADO	1960 -1975	99.9%	1966 ± 2	99.9%	1966 ± 2
1976 PDO	1965 - 1996	99.9%	1975 ± 2	99.9%	1975 ± 2
1995 ADO	1977 - 2010	99.9%	1995 ± 2	99.9%	1994 ± 2
2001	1994 - 2010	97.6%	2002 ± 1	98.7%	2001 ± 2

The behaviour of the Atlantic Decadel Oscillation as summarized by Wang et al shows the end of a warm phase in 1965 and the start of a new warm phase in 1995. This change in 1995 would explain the increased annual rise in atmospheric CO_2 from out-gassing or reduced absorption in the North Atlantic after 1995. The Pacific Decadal Oscillation identified with the Great Pacific Climate Shift marked the start of a warm phase in 1976-77 in the Pacific. .A sea surface temperature change would lead to a rebalancing of CO_2 in the oceans and atmosphere. These breaks signify the changes. The breaks in 2001 and 2002 are more problematic as can be seen from the F test probabilities of near 98% in Table 2.

However the role of the oceans must be complex. The “warm phase” of the Pacific Decadal Oscillation commenced in 1977 and from 1977 to 1997 shows a CO_2 increase of 0.46 +/- 0.03 ppm per year over 1965 to 1976 but the change after 1995 and through to 2009 is an overall further increase of 0.43 +/- 0.03 ppm per year from 1977 to 1997. This is a result of the phase change of the Atlantic Decadel Oscillation. However the statistical probability is marginal for the start of a cool phase of the Pacific Decadal Oscillation in 2000.

4 Water Vapour

There are extensive measurements of atmospheric water vapour available from the ESRL database as relative and specific humidity (Kalnay et al., 1996). This analysis uses specific humidity notionally at the ocean surface. Yearly data on specific humidity at 1000mb pressure has been used for the Atlantic and Pacific Ocean areas as defined by latitude and longitude in Table 3.

Table 3 Ocean limits used for humidity data

Ocean	Hemisphere	Latitude	Longitude	Time span
Atlantic	Northern	60 N to 0	60 W to 10 W	1948-2010
	Southern	0 to 60 S	30 W to 10 E	1948-2010
Pacific	Northern	60 N to 0	150 E to 220 E	1948-2010
	Southern	0 to 60 S	150 E to 220 E	1948-2010

For the Northern Hemisphere (Figure 6) break changes in humidity occur in the Pacific Ocean in 1963, 1976 at the time of the Great Pacific Climate Shift and in 2000. However when the period 1948 to 1975 is analyzed there is no significant break in 1963 while there is a break at 1976 for the period 1963 to 2000. For the Atlantic Ocean there is a break in 1994 at the time of a phase change of the Atlantic Decadel Oscillation.

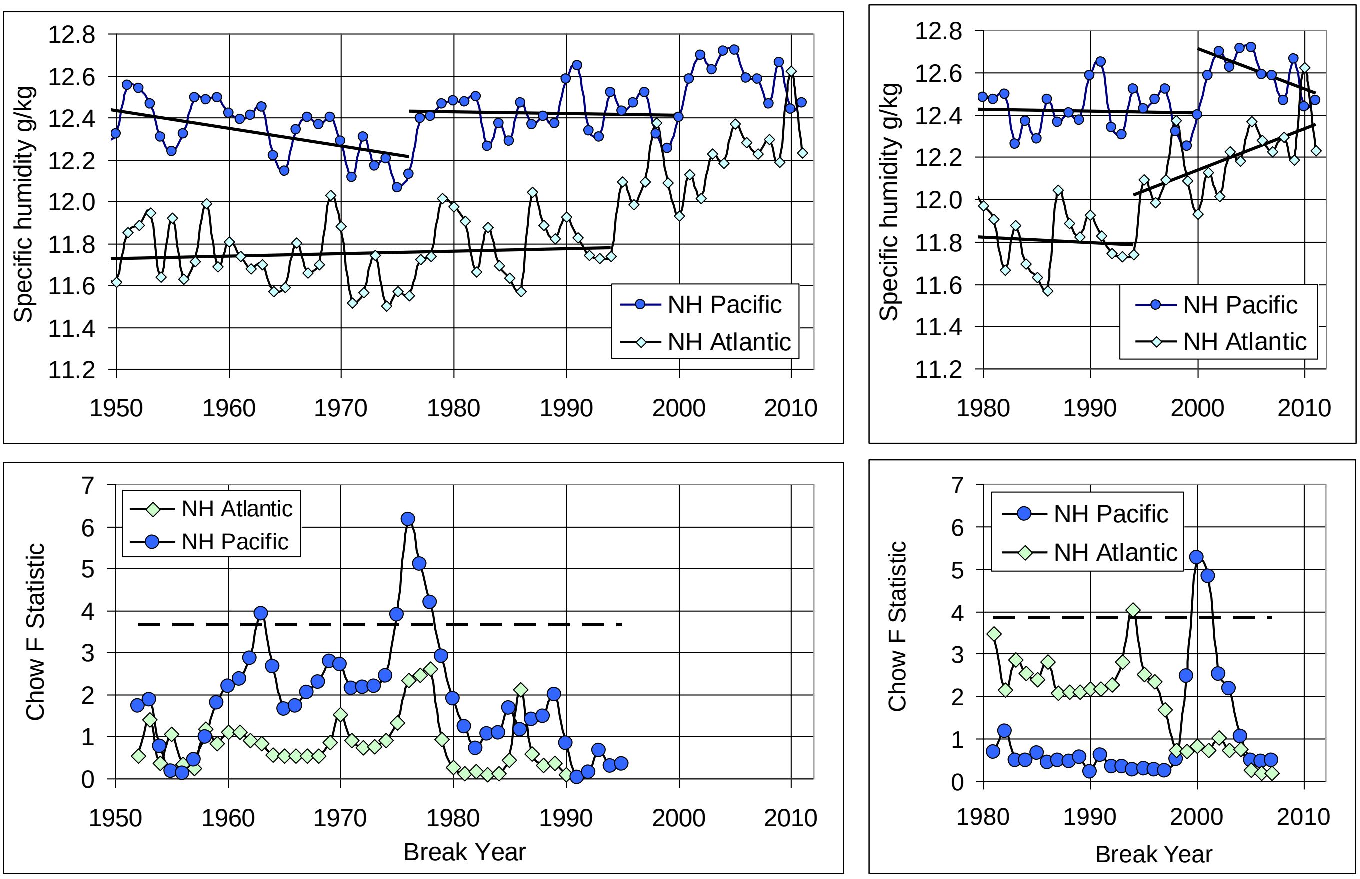

Figure 6 *1948-2010 Northern Hemisphere* ***Upper:*** *Specific humidity for the oceans at 1000 mb. The solid lines are least squares straight line fits giving the largest F Statistic value.* ***Lower:*** *Chow F Statistic where the dashed lines indicate 98% statistical significance*.

For the Southern Hemisphere (Figure 7) a break change in humidity occurs in the Pacific Ocean in 2000. For the Atlantic Ocean there is a break in 1971. .

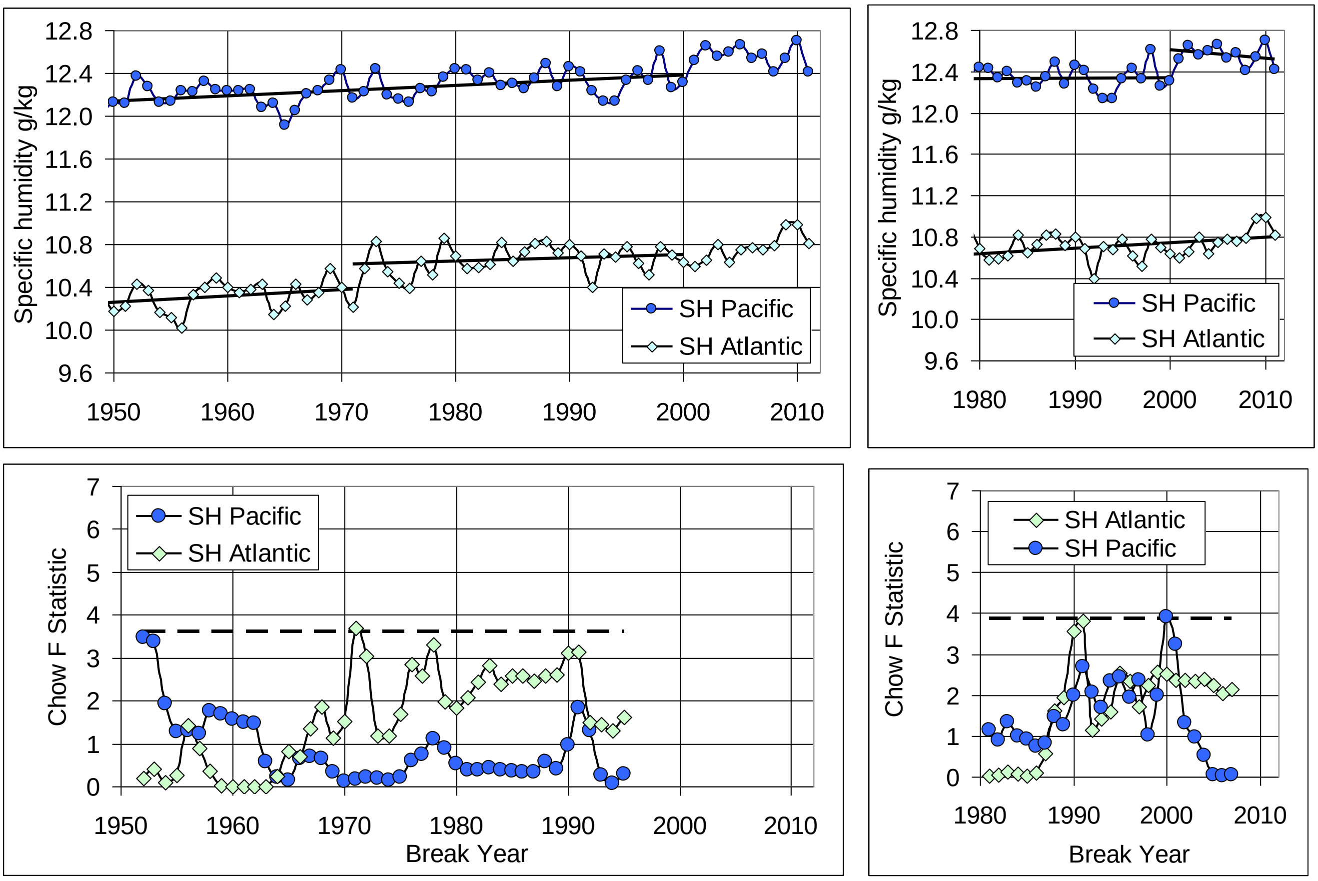

Figure 7 *1948-2010 Southern Hemisphere* ***Upper:*** *Specific humidity for the oceans at 1000 mb. The solid lines are least squares straight line fits giving the largest F Statistic value.* ***Lower:*** *Chow F Statistic where the dashed lines indicate 98% statistical significance*

The humidity data shows the influence of the Atlantic Decadel Oscillation in 1994 and Pacific Ocean decadel oscillation in 1976. There is also a strong signal in 2000 for both hemispheres of the Pacific Ocean

5 Methane

Atmospheric methane concentrations have been directly measured systematically since 1983 (Cunnold et al, 2002) so it is not possible to see any changes before that time. There are ice core data available covering this period (MacFarling Meure et al., 2006) but atmospheric gases trapped in the ice bubbles are averaged over a number of years and detail is lost. There is a further problem with methane measurements prior to 1990. They may well be contaminated by natural gas leakage from pipelines (Quirk, 2010).

The level of methane in the atmosphere is understood to be controlled by the interplay of natural and anthropogenic sources with an atmospheric sink of OH radicals that removes methane. The level of OH radicals is controlled by ultraviolet solar radiation, ozone and the amount of water vapour present (Bousquet et al. 2006).

The major (95%) sink for methane is OH radicals in the troposphere. These are concentrated in the Tropics as water vapour is their source and water vapour is at a maximum concentration in the Tropics. If there is a change in humidity at about the year 2000 then there should be a change in the rate of removal of methane from the atmosphere. An increase in humidity implies an increase in OH radicals and a consequent increase in the rate of removal and a reduced rate of increase of methane. Figure 8 shows just this effect. For the period 1991 to 2009 the annual increase in methane falls from 5.8 +/- 0.4 ppb per year before 1999 to 1.3 +/- 0.4 ppb per year after 1999.

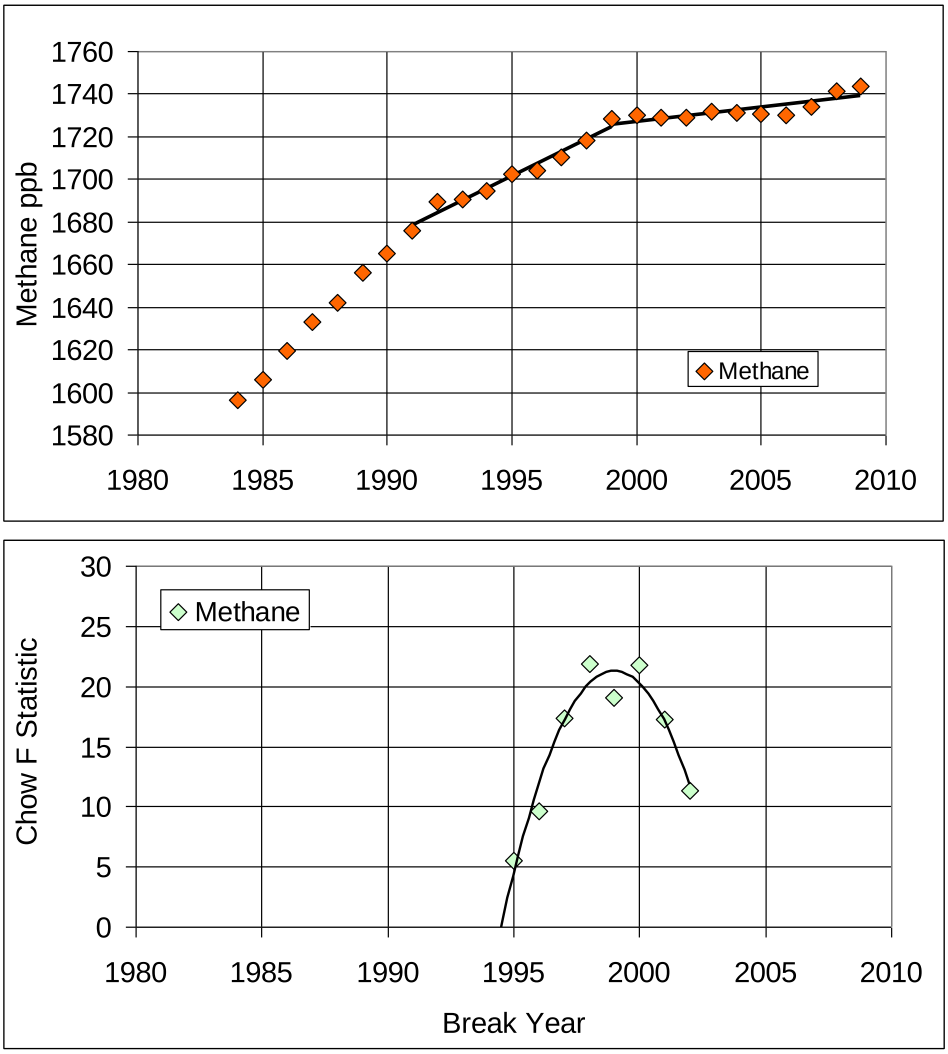

Figure 8 *1991- 2010* ***Upper:*** *Atmospheric methane concentrations at Cape Grim (Latitude 40 S). Values before 1991 are affected by fugitive natural gas from pipeline leakage. The solid lines are least squares straight line fits for the maximum F Statistic value at 1999.* ***Lower:*** *Chow F Statistic where points over 4 have a better than 98% statistical significance*

Methane like other components of the atmosphere has a break in its time series in 1999 +/- 1 year.

6 Conclusion

One of the most useful analytical techniques where there is timing information is the use of coincidence to separate signal from noise.

This can be seen looking at the timing of changes in temperature, CO_2, humidity for the period 1959 to 2010 and from 1983 to 2010 for methane. Figure 9 shows the timing of breaks in the various time series identified from the Chow break analysis where the Chow statistic indicates greater than 98% significance.

This analysis has identified a series of coincident changes that are unlikely to be a random coincidence of events since it is possible to understand that the Pacific and Atlantic Decadal Oscillations cause breaks in global temperatures, a rebalancing of ocean and atmosphere exchanges of CO_2, consequent changes in humidity and indirectly changes in the annual increases of atmospheric methane. Some random breaks might be expected to arise from the number of data points analyzed with a 98% probability level. The break identified in the Southern Hemisphere Atlantic Ocean humidity time series (Figure 7) in 1972 may simply be a random break.

This analysis shows:

- coincident changes in temperature, CO_2 and humidity at the time of the Atlantic Decadal Oscillation phase change in 1995. There is also a hint of the change in 1965 from the atmospheric CO_2 measurements;

- coincident changes in temperature, CO_2 and humidity at the time of the Pacific Decadal Oscillation phase change in 1976-77, the time of the Great Pacific Climate Shift; and

- coincident changes of CO_2, humidity and methane for 1999-2002. If these changes mark a phase change of the Pacific Decadal Oscillation then it could explain the global temperature behaviour.

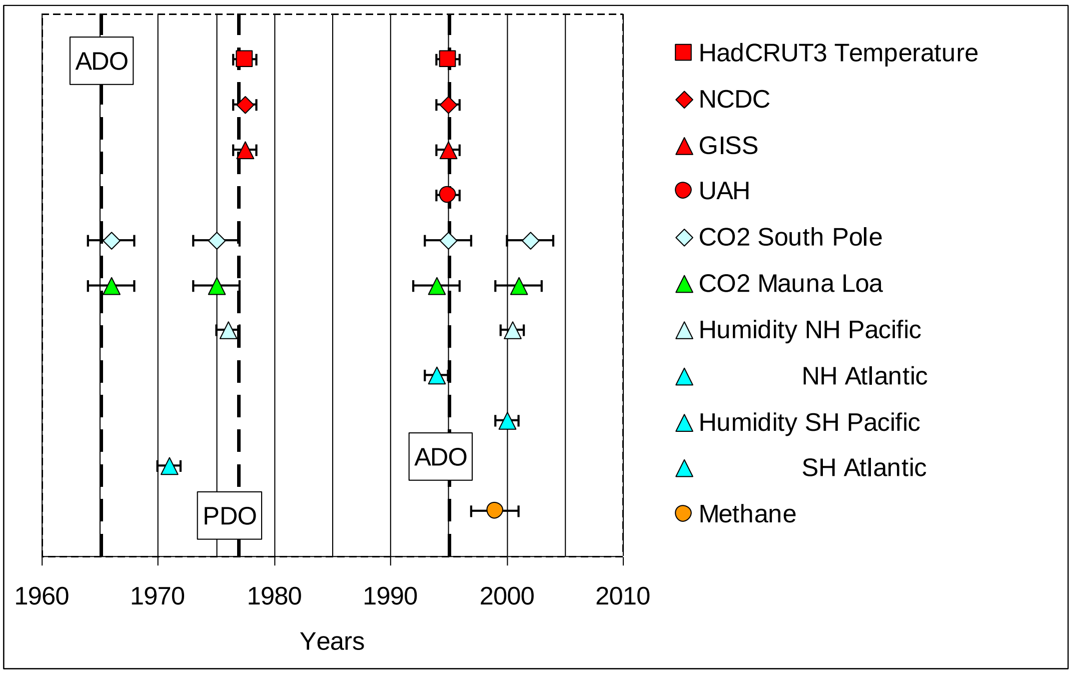

Figure 9: *Timing of breaks in the various atmospheric measurement time series. Global temperatures,* CO_2 *, humidity and methane series breaks are identified when the Chow statistic is at a maximum and indicates greater than 98% significance. The dashed vertical lines mark the identified phase changes of the Atlantic (ADO) and Pacific (PDO) Decadel Oscillations.*

There is a strong set of coincident events at or around 2000 that suggest the onset of a cool phase of the Pacific Decadal Oscillation. This is supported by the decreasing humidity in the Northern Pacific Ocean after the break in 2000 (Figure 6) where the probability of the straight line fit showing no decrease is 3%. However for the global surface temperature this analysis has not established whether the cool phase of the Pacific Decadal Oscillation dominates the warm phase of the North Atlantic Decadal Oscillation.

The variations in global temperature, atmospheric CO_2, water vapour and atmospheric methane all indicate the importance of the Atlantic and Pacific Decadal Oscillations. This is not easily taken into account in General Circulation Models and until there is a better understanding of the long term behaviour of the oceans, it must be a significant difficultly in projecting future temperatures.

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