Intercomparison of Temperature Trends in IPCC CMIP5 Simulations with Observations, Reanalyses and CMIP3 Models

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ABSTRACT

On the basis of the fifth Coupled Model Intercomparison Project (CMIP5) and the climate model simulations covering 1979 through 2005, the temperature trends and their uncertainties have been examined to note the similarities or differences compared to the radiosonde observations, reanalyses and the third Coupled Model Intercomparison Project (CMIP3) simulations. The results show noticeable discrepancies for the estimated temperature trends in the four data groups (Radiosonde, Reanalysis, CMIP3 and CMIP5) although similarities can be observed.

Compared to the CMIP3 model simulations, the simulation in some of CMIP5 models were improved. The CMIP5 models displayed a negative temperature trend in the stratosphere closer to the strong negative trend seen in the observations. However, the positive tropospheric trend in the tropics is overestimated by the CMIP5 models relative to CMIP3 models. While some of the models produce temperature trend patterns more highly correlated with the observed patterns in CMIP5, the other models (such as CCSM4 and IPSL_CM5A-LR) exhibit the reverse tendency. The CMIP5 temperature trend uncertainty was significantly reduced in most areas, especially in the Arctic and Antarctic stratosphere, compared to the CMIP3 simulations.

Similar to the CMIP3, the CMIP5 simulations overestimated the tropospheric warming in the tropics and southern hemisphere and underestimated the stratospheric cooling. The crossover point where tropospheric warming changes into stratospheric cooling occurred near 100 hPa in the tropics, which is higher than in the radiosonde and reanalysis data. The result is likely related to the overestimation of convective activity over the tropical areas in both the CMIP3 and CMIP5 models.

Generally, for the temperature trend estimates associated with the numerical models including the reanalyses and global climate models, the uncertainty in the stratosphere is much larger than that in the troposphere, and the uncertainty in the Antarctic is the largest. In addition, note that the reanalyses show the largest uncertainty in the lower tropical stratosphere, and the CMIP3 simulations show the largest uncertainty in both the south and north polar regions.

1. Introduction

The fifth phase of the Coupled Model Intercomparison Project (CMIP5) provided quantitative data sets for estimating climate change based on a suite of climate models (Taylor et al., 2011). Compared to the third phase of the Coupled Model Intercomparison Project (CMIP3), conventional atmosphere-ocean global climate models (AOGCMs) and Earth System Models of Intermediate Complexity (EMICs) are for the first time being joined by more recently developed Earth System Models (ESMs). The reliability of the new climate model products is an important question for the climate change detection. Evaluating climate model results using observational data sets is necessary to understand the capabilities and limitations of climate change simulations.

As the models get more complicated, they must handle a greater number of complex processes that often interact. Subtle changes can lead to unintended results. Also, it is difficult to rigorously test each process, each pathway in the software, and understand the way it is represented in the model and how it interacts with the other modeled processes.

Temperature trend is an important component for measuring global climate change. It provides evidence of both natural impacts and those from anthropogenic forcing. However, a lot of evidence was found in the literature (Santers et al., 1999; Seidel et al., 2004; Christy et al., 2006; Sakamoto and Christy, 2009; Xu and Powell, 2010) that the temperature trend estimation is sensitive to the data source (radiosondes, satellite observations, and reanalysis products). Radiosonde coverage extends back to the late 1950s. However, radiosondes only reach altitude levels below 20 hPa and do not provide data over the ocean, Arctic and Antarctic zones. Also, due to discontinuous observations caused by instrumentation changes, the raw radiosonde record includes remarkable inhomogeneities (Lanzante et al., 2003; Seidel et al., 2004).

The first generation of reanalysis products created by NCEP, NASA and ECMWF were successfully used in the study of global atmospheric and oceanic processes and their dynamics, especially over the data-sparse poles, southern hemisphere, and ocean regions. The updated or second-generation reanalyses have been implemented by several weather and climate prediction centers. However, the reanalysis products showed a number of uncertainties and deficiencies (Kanamitsu *et al.* 2002, Trenberth 2001).

Because of these and other difficulties involved with complex data implementation, observation systems, and processing algorithms, objectively identifying one or more reliable data sets is a difficult task. This paper compares three types of data sets with the CMIP5 simulations on the basis of the same fundamental analyses. The goal is to understand the similarities or differences between the temperature trends in the CMIP5 simulations and those from the (1) radiosonde observations, (2) reanalyses, and (3) the CMIP3 climate simulations.

To evaluate the capability of the CMIP5 climate models for simulating the historic climate, an ensemble analysis for the temperature trends and spread will be implemented. The data sets used here are described in the section 2. The analysis includes inter-comparisons between the stratosphere and troposphere (section 3), and inter-comparisons between the tropics, Arctic and Antarctic (section 4). Section 5 provides a final summary.

2. Data and calculations

The purpose of this research was to compare the temperature trends in the CMIP5 climate model simulations with three groups of products: radiosonde observations, reanalysis products and the CMIP3 model simulations. All data sets spanned the period from 1979 through 2005 between the levels of 850 and 30 hPa.

2.1 Reanalysis and radiosonde data sets

The eight reanalysis products used in this study include NCEP-R1, NCEP-R2, NCEP-CFSR, ERA-40, ERA-Interim, JRA-25, MERRA and 20CR. The detailed information about these reanalyses can be found in our previous publication (Xu and Powell, 2011). The five radiosonde data sets used in this study include HadAT2, RATPAC, IUK, RAOBCORE and RICH. More information about these radiosonde products can be also found in our previous publication (Xu and Powell, 2010).

2.2 The CMIP3 simulations

The CMIP3 model simulations were introduced in the study by Meehl (2007). To get a comparable number of climate and reanalysis products, eight climate models (Table 1) were selected from the larger group and were matched with eight reanalyses using temperature fields from the climate of the 20th century experiments (20C3M) (selected from 1979 through 1999) and the committed experiment (COMMIT) (selected from 2000 through 2005).

2.3 The CMIP5 simulations

Similar to the CMIP3 experiments, the CMIP5 simulations provide a framework for coordinated climate change experiments aimed at evaluating climate simulations of the recent past, providing projections of climate change, and quantifying climate feedbacks (Taylor et al., 2011). Compared to CMIP3, the CMIP5 simulations include more comprehensive and higher spatial resolution models. Corresponding to the selected CMIP3 models, eight models from the same group (Table 1) in the "historical" run in CMIP5 are used in this study. The "historical" run (1860–2005) is forced by observed atmospheric composition changes (reflecting both anthropogenic and natural sources) including time evolving land cover.

2.4 Trend and Spread Calculation

The annually-averaged data is first calculated based on the monthly dataset listed above. In order to be consistent with the radiosonde data sets location, the annual data is then processed by zonal-mean for land coverage only in the resolution of 10 latitudes.

The trend is computed with the methodology of linear least squares fitting. The ensemble spread is described by the standard deviation among these data sets listed on Table 1. The t-test analysis was employed to calculate the statistical significance of the temperature trends.

3. Intercomparison of temperature trends between the stratosphere and troposphere

3.1 Vertical structure

In terms of the linear least squares fitting of the temperature time series in the period from 1979 through 2005 for the four data groups, Fig. 1 displays the vertical and latitudinal distribution of the temperature trend for the levels between 850 hPa and 30 hPa.

First, the vertical and latitudinal distributions of temperature trend in all five radiosonde data sets (left panel in Fig.1) match quite well. Strong maximum cooling is clearly observed in the tropical and subtropical stratosphere, while strong warming appeared in the lower troposphere in the northern middle and high latitudes and the tropical upper troposphere. The temperature trend switched from positive to negative at approximately 150 hPa. The strongest warming in RAOBCORE was on the order of 0.5°C/decade, which occurred in the lower northern high latitudes and was higher than that in the other four radiosonde data sets. The largest cooling trend in the stratosphere reached -1.2°C/decade in the southern tropical stratosphere in IUK. The results confirmed the high consistency among the five radiosonde data sets revealed in our previous study (Xu and Powell, 2011) although there are some differences in these five data sets. Unfortunately, based on current understanding, we cannot identify which one is closest to the true observational temperature.

Second, within the group of reanalysis (left middle panel in Fig. 1), 20CR and JRA-25 reanalyses do not display the feature of tropospheric warming and stratospheric cooling that is consistently seen in the other six reanalyses. The maximum cooling on the order of -1.6°C /decade in the tropical tropopause layer is observed in the NCEP-R1 and NCEP-R2, which is much stronger cooling than the other six reanalyses and all the radiosonde observations. Relatively strong warming appeared in the upper tropical troposphere in the ERA40 and NCEP-CFSR, while the warming at the lower northern high latitudes is comparable to the magnitude in the radiosondes. Note the cooling in the northern stratosphere in 20CR shows abnormal values compared to the other seven reanalyses. It is worth noting significant discrepancies can be found between the different reanalyses, and it is hard to say which one best reproduces the true atmospheric trends even with the new data sets and algorithms used in new data assimilation systems. For example, the NCEP-CFSR is a new generation data assimilation system from NCEP developed from NCEP-R1 and NCEP-R2. However, according to the radiosonde observation measurements, the NCEP-CFSR reanalysis overestimated the tropospheric warming compared to the previous system in NCEP-R1 or NCEP-R2.

Third, the CMIP3 simulations (right middle panel in Fig.1) show a similar transition from tropospheric warming to stratospheric cooling in all eight models except for the tropical zone in the CNRM_CM3 and the high latitudes in IPSL_CM4 and MRI_CGCM2. However, four of the eight models (CCSM3, CNRM_CM3, CSIRO_MK3.5 and UKMO_HADCM3.1) indicated relatively strong stratospheric cooling outside the tropical and subtropical areas, in contrast to the radiosonde observations.

Compared to the CMIP3 simulations, the CMIP5 simulations (right panel in Fig.1) display a better vertical and latitudinal structure, and all eight models show a relatively strong cooling in the tropical and subtropical stratosphere, which matches the distribution in the radiosonde observations. Similar to the reanalysis and CMIP3 simulations, the CMIP5 simulations portrayed stronger warming in the upper tropical troposphere than in the radiosonde data sets.

The statistical significance at the 99% level, according to a T-test, shows (the line with the value of ±2.5 in Fig. 1) that the trends are believable in most of the troposphere and stratosphere. However, the ~~a weak~~ significance cannot be found in the tropopause layer.

The vertical and latitudinal structure indicates four significant characteristics. 1) The temperature trends show noticeable discrepancies in the four data groups although commonalities can be observed. 2) Most of the data sets exhibit a sharp cooling in the tropical and subtropical stratosphere with a stronger warming in the lower troposphere in the northern middle and high latitudes and the tropical upper troposphere. 3) Compared to the CMIP3 simulations, the CMIP5 simulations display a relatively strong cooling in the tropical and subtropical stratosphere, which matches the distribution in the radiosonde observations. 4) The height of the crossover point where tropospheric warming changes into stratospheric cooling depends on the individual data set ranging from ~100 hPa in tropics to ~200 hPa in extratropics.

3.2 Similarities and differences

To quantify similarities and differences between these data sets, the global mean temperature trend and spatial correlations between model simulations and observations were calculated. The mean of all five radiosonde data sets is used to represent the observations.

In the troposphere (500 hPa), the radiosonde trends range from 0.106°C/decade to 0.129°C/decade (Table 2), which reflects consistency among the radiosonde data sets. The trends in the reanalysis group show a significant divergence with the largest warming reaching 0.24°C/decade in the NCEP-CFSR while the trend value went down to 0.04°C/decade in the ERA40. However, compared to the radiosondes, the value in all eight CMIP3 simulations are increased within values from 0.15°C/decade in HADCM3 to 0.29°C/decade in CCSM3. The magnitude of the warming in the CMIP5 simulations is higher than the CMIP3 simulations except for the MRI model and the temperature trend ranged from 0.17°C/decade in MRI-CGCM3 to 0.47°C/decade in IPSL_CM5A-LR.

The mean trend and standard error show (Fig. 2a) that the tropospheric mean trend in the CMIP5 (0.293°C/decade) is much larger than in the radiosonde observations (0.12°C/decade) and the CMIP3 simulations (0.215°C/decade) while the divergence in the eight CMIP5 models is also larger than the other three data groups. In other words, the CMIP5 simulations show not only the greatest tropospheric warming, but also the largest uncertainty for the temperature trend estimation.

In contrast, in the stratosphere (50 hPa), the cooling trend in all the radiosonde data sets are larger than -0.70°C/decade (Table 2), which shows a strong similarity among the five radiosonde data sets. Most of the reanalyses have a cooling trend larger than -0.60°C/decade except for the estimation from the 20CR and JRA25. However, the cooling trends in the CMIP3 simulations are significantly reduced except for the HADCM3 model, and five of the eight CMIP5 models show that their cooling trend exceeds -0.50°C/decade, which is closer to the radiosonde observations than the cooling trends of the CMIP3 simulations. It is worth noting that the uncertainty for the stratospheric cooling trend estimates in the CMIP5 models is significantly decreased (Fig. 2b).

Similar to the CMIP3, the CMIP5 simulations overestimated the tropospheric warming and underestimated the stratospheric cooling although the stratospheric estimates were improved in comparison with the radiosonde observations (Figs. 2a,b). In addition, the large uncertainty for the stratospheric cooling trend estimates in the reanalysis group is mainly due to the 20CR and JRA25.

Furthermore, the spatial correlations between the model simulations and the radiosonde observations indicate (Fig.3) that the temperature trend in most of the reanalyses is in very good agreement with the radiosonde observations in both the stratosphere (100-30 hPa) and troposphere (850-300 hPa), but the stratospheric trends in the 20CR, ERA40 and JRA25 significantly differ from the observations.(Fig. 3a). The CMIP3 simulations (Fig. 3b) have a worse structure than the analyses especially in the stratosphere, four of the eight models show negative correlations with the radiosonde observations. The correlations of the CMIP5 simulations with the radiosonde observations (Fig. 3c) in the stratosphere are higher than that in the previous version in the CMIP3 simulations except for CCSM4 and IPSL_CM5A-LR (Fig. 3b). However, three of the eight CMIP5 models in the troposphere have negative correlations with the radiosonde observations.

To summarize, while similar to the CMIP3 models, the CMIP5 simulations overestimated the tropospheric warming and underestimated the stratospheric cooling. The tropospheric mean temperature trend in the CMIP5 models is much larger than those in the radiosonde observations and the CMIP3 simulations. The discrepancy among the eight CMIP5 models is also the highest of all four data groups. In other words, the CMIP5 models show not only the biggest tropospheric warming, but also the largest uncertainty for the temperature trend estimates. Based on the spatial correlation with radiosonde observations, most of CMIP5 simulations have higher correlations in the stratosphere but lower correlations in the troposphere compared to the CMIP3 simulations.

3.3 Ensemble mean and spreads

Fig. 4 shows the height-latitude distribution of the ensemble mean of temperature trends for the four data groups. All exhibit predominant warming in the troposphere with cooling in the stratosphere. However, the discrepancy among these data sets is very clear although the mean temperature trends are in reasonable agreement. In the radiosondes (Fig. 4a), the cooling center appeared in the tropical stratosphere (30-50 hPa), while the warming center is observed in the northern middle and high latitudes. Compared to the radiosondes, the stratospheric cooling in the tropics and the northern tropospheric warming in high latitudes is slightly decreased in the reanalyses (Fig.4b). In contrast, the strongest cooling is found over the Antarctic in the stratosphere in CMIP3 (Fig. 4c), and the tropical upper tropospheric warming over the southern hemisphere significantly increased. Similar to the CMIP3, the additional strong warming center in CMIP5 (Fig. 4d) is observed over the southern tropical upper troposphere, and the cooling structure in the stratosphere is improved.

At the same time, the ensemble spread among the radiosondes (Fig. 5a) remains nearly constant near ~0.1°C/decade from the troposphere to the stratosphere except for part of the southern hemisphere and Arctic zone in the stratosphere, which displays high consistency among the five radiosonde observation sets. However, the ensemble spread in the reanalyses (Fig. 5b) is substantially increased in the stratosphere. The maximum spread value reached 0.4°C /decade in the tropics in the lower stratosphere. The large ensemble spread mainly is due to the overestimated cooling in both the NCEP-R1 and NCEP-R2 reanalyses around 100 hPa. The stratospheric warming in the 20CR and JRA25 and the overestimated upper tropospheric warming in the ERA-40 reanalysis (left middle panel in Fig. 1) contribute most to the discrepancies with the radiosondes. In the CMIP3 climate model simulations, the ensemble spread (Fig. 5c) in the tropical stratosphere is much smaller than in the reanalyses. It is worth noting the ensemble spread is large over both polar regions in the stratosphere. This result indicates that the CMIP3 models contain large uncertainties in the polar stratosphere. In contrast, the discrepancy in the CMIP5 simulations is significantly reduced except for a small portion of the southern high latitudes in the stratosphere.

Generally, the tropospheric warming is overestimated in the tropics of the southern hemisphere in both the CMIP3 and CMIP5 simulations compared to the radiosonde observations. The reanalyses show a large uncertainty in the trend estimates in the lower tropical stratosphere, and the CMIP3 simulations show a large uncertainty in both the south and north polar regions in the stratosphere. The recent effort in the CMIP5 simulation indicates that the uncertainty is significantly reduced for most areas especially in the tropical and the northern high latitudes.

4 Intercomparison Between Tropics, Arctic and Antarctic

Fig. 6 shows the vertical profiles of the temperature trend that represents the three latitudinal bands including the Arctic (60-90°N), tropics (15°S-15°N) and Antarctic (60-90°S) in the four data groups. The distribution is zonally averaged, and the period of 1979–2005 is used with altitudes ranging from the 850 to 30 hPa. The five radiosonde data sets agree reasonably well with each other in the Arctic and tropics (Fig.6a, e) in both the troposphere and stratosphere. However, a large discrepancy can be found in the Antarctic (Fig. 6i), where the Hadat2 shows a noticeable difference from the other two available data sets in the stratosphere.

For the reanalyses, the trends in the tropics and Antarctic (Fig. 6f,j) displayed a large divergence, and the discrepancy among the eight reanalyses is much larger than shown in the radiosondes. In the tropical tropopause layer (~100 hPa), the trend ranges from ~ 0.3°C/decade in the ERA40 to ~ -1.4°C/decade in the NCEP-R1 and NCEP-R2 (Fig. 6f). In the tropics, the JRA-25 shows a significant warming in the stratosphere while the 20CR exhibits a warming in the study domain from troposphere to stratosphere. In the Antarctic (Fig. 6j), most of the reanalyses show cooling in the troposphere except for the ERA40, and the warming trend is observed again in the stratosphere in JRA25. However, the trends are highly consistent in the Arctic except for the 20CR reanalysis (Fig. 6b).

For the CMIP3 simulations, the trends are in very good agreement in the tropics (Fig. 6g) but don't show similar agreement in the stratosphere in both polar areas (Figs. 6c, k). For example, in the Arctic, the CNRM_CM3 and MRI_CGCM2 simulations displayed a warming in the stratosphere compared to the cooling in the other six models (Fig. 6c), with the UKMO_HadCM3 simulation having the most extreme stratospheric cooling of -1.4°C/decade in the Antarctic (Fig. 6k). Compared to the CMIP3 simulations, the CMIP5 simulations have very good agreement in the three selected regions (Figs. 6d,h,l) except for the strong cooling (-1.4°C/decade) in the Antarctic lower stratosphere in the GISS_E2-R simulation (Fig. 6l) and a strong warming (0.7°C/decade) in the tropical upper troposphere in the IPSL_CM5A-LR (Fig. 6h). The trend range in the stratospheric Arctic and Antarctic zone among the CMIP5 models is significantly reduced; these results imply that the uncertainty in the CMIP5 models was improved, especially in the stratosphere.

Furthermore, the vertical profile of the ensemble mean and spread show (Fig. 7) that there is a clear difference among the three regions in the vertical trend structure (Fig. 7a-d) and the ensemble spreads (Fig. 7e-h). First, in the radiosondes, the warmest trend appeared in the lower tropospheric Arctic zone and the coldest occurred in the tropical middle stratosphere (Fig. 7a). In contrast, in the reanalyses, the whole atmospheric layer in the Antarctic shows a cooling with the coldest trend occurring in the lower stratosphere (Fig. 7b). The tropospheric vertical trend profile in the Antarctic looks reasonable in the CMIP3 simulation (Fig. 7c) but the stratospheric cooling is much higher than in the radiosonde and reanalysis data sets. In the CMIP5 simulation, the vertical trend structure in the Antarctic is slightly improved, but the upper tropospheric warming exceeds the other three data groups (Fig. 7d). Second, the crossover point, that expresses the transition from tropospheric warming to stratospheric cooling, is largely different in the tropics. The crossover point in the CMIP3 and CMIP5 simulations occurs near 100 hPa, which is higher than in the radiosonde and reanalyses. The high crossover point is likely related to an overestimation of convective activity over the tropical areas in both the CMIP3 and CMIP5 models.

Finally, the ensemble spread among the radiosondes (Fig. 7e) remains nearly constant near ~0.1°C/decade from the troposphere to the stratosphere except for the lower stratosphere in the Antarctic. However, in the reanalyses, the ensemble spread (Fig. 7f) increases substantially with height reaching a maximum value of 0.6°C /decade in the tropical lower stratosphere. The large ensemble spread mainly is due to overestimating the cooling in both the NCEP-R1 and NCEP-R2 around 100 hPa, the warming in the 20CR, ERA40, and JRA-25. Note that the uncertainty for the trend in the Antarctic is much larger than the Arctic in the stratosphere. In the CMIP3 simulations, the trends (Fig. 7g) show a substantial spread with 0.8°C /decade in the Antarctic stratosphere. The spread at both poles is significantly reduced in the CMIP5 simulations (Fig. 7h). It is worth noting that the spread in the tropics retains similar values in the CMIP3 and CMIP5 simulations. This result implies that the uncertainty in the CMIP5 simulation over the Arctic and Antarctic was significantly improved compared to the CMIP3 simulations.

In summary, the CMIP5 model trend uncertainty in the Arctic and Antarctic zones in the stratosphere is improved compared to the CMIP3 models. The crossover point in the CMIP3 and CMIP5 simulations occurs near 100 hPa, which is higher than in the radiosonde and reanalysis data sets. The result is likely related to overestimated convective activity over the tropical areas in both the CMIP3 and CMIP5 models.

5. Summary

Based on the four data groups (Radiosonde, Reanalysis, CMIP3 and CMIP5) from 1979 through 2005 at levels between 850 and 30 hPa, the results are summarized as follows:

1) The temperature trends show a noticeable discrepancy in the four data groups although similarities can be observed. Most of the data sets exhibit a sharp cooling (~-1.0°C/decade) in the tropical and subtropical stratosphere and a strong warming (~0.6°C /decade) in the lower troposphere in the northern middle and high latitudes and the tropical upper troposphere. The CMIP5 simulations display a relatively strong cooling in the tropical and subtropical stratosphere, which matches the distribution in the radiosonde observations.

2) Similar to the CMIP3, CMIP5 models overestimated the tropospheric warming and underestimated the stratospheric cooling. The eight CMIP5 simulations show not only the largest tropospheric warming, but also the largest uncertainty for the estimated temperature trend. The uncertainty in the CMIP5 simulations was improved in the stratosphere but worse in the troposphere compared to the CMIP3 simulations.

3) The tropospheric warming is overestimated in the tropics in the southern hemisphere by the CMIP3 and CMIP5 simulations compared to the radiosonde observations. The reanalyses

show a large uncertainty in the estimated trends in the lower tropical stratosphere, and the CMIP3 simulations show a large uncertainty in the Arctic and Antarctic stratosphere.

4) The trend uncertainty in the stratospheric Arctic and Antarctic zones among CMIP5 models was improved compared to the CMIP3 models. The crossover point in the CMIP3 and CMIP5 simulations occurs near 100 hPa in the tropics, which is higher than in the radiosonde and reanalysis data sets. The result is likely related to overestimating the convective activity over the tropical areas in both CMIP3 and CMIP5 models.

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Caption of Figures

Fig.1 Vertical - latitude distribution of zonal mean temperature trend (ºC/decade) from 1979 to 2005. Radiosonde: left panel; Reanalysis: left middle panel; CMIP3 models: right middle panel; CMIP5 models: right panel. The dashed line with the value of ±2.5 indicates the statistical significance t-test at 99% level

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Fig.3 The spatial correlation of temperature trends between reanalysis, CMIP3, CMIP5 and the radiosonde mean trends from 1979 to 2005. (a) reanalysis; (b) CMIP3; (c) CMIP5.

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Fig.7 Vertical profile of the ensemble mean trends and spreads (ºC/decade) for the Arctic, tropics and Antarctic temperature from 1979 through 2005.

Ensemble mean trends: (a) radiosonde, (b) reanalysis, (c) CMIP3 and (d) CMIP5; Ensemble spread trends: (e) radiosonde, (f) reanalysis, (g) CMIP3 and (h) CMIP5.

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