Estimation of the absolute surface air temperature of the Earth

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Received 22 January 2013; revised 20 March 2013; accepted 22 March 2013; published 29 April 2013.

[1] Average temperatures for the hemispheres and the globe are generally expressed as anomalies from a base period. Most users of these data and the underlying constituent gridded datasets do not require the values in absolute degrees, but a number of users might require this additional detail. An example group of users are climate modellers, who want to directly compare their simulations with reality in absolute units. Reanalysis datasets offer opportunities of assessing earlier absolute temperature estimates, but until recently their quality over data-sparse regions of the world was questionable. Here, we assess the latest Reanalysis (ERA-Interim) which is available from 1979 to the present against earlier direct estimates. Globally averaged ERA-Interim and the earlier direct estimates of absolute surface temperatures across the world are about 0.55°C different for the 1981–2010 period, with ERA-Interim cooler. The difference is only 0.29°C for the Northern Hemisphere, but larger at 0.81°C for the Southern Hemisphere. Spatially, the largest differences come from the Polar Regions, particularly the Antarctic.

Citation: Jones, P. D., and C. Harpham (2013), Estimation of the absolute surface air temperature of the Earth, *J. Geophys. Res. Atmos.*, *118*, 3213–3217, doi:10.1002/jgrd.50359.

1. Introduction

[2] Most analyses producing time series of global and hemispheric averages of surface air temperatures show results relative to a base period such as 1961–1990 [e.g., *Jones et al.*, 2012 and *Morice et al.*, 2012]. The base period may differ [e.g., the 1901–2000 used by *Vose et al.*, 2012], but the key aspect is that the series are shown as anomalies. For use in climate monitoring, anomalies are perfectly adequate, but a small number of users are interested in the absolute temperature value for the base period even though the addition of this constant doesn't alter the characteristics of the time series. Hence, although rarely used, the most widely quoted value for the global average for the 1961–1990 period is 14.0°C developed by *Jones et al.* [1999], where the derivation is extensively discussed. This involved producing values for all 5° by 5° latitude/longitude grid boxes. Over land areas, the absolute values relate to the average elevation of each grid box and also to how individual Met Services calculate monthly averages, while for the ocean, they relate to the absolute values of marine air temperatures. Spatial interpolation of the 1961–1990 averages (12 monthly fields) was undertaken, using elevation over land to infill all the missing grid boxes [see complete discussion in *Jones et al.*, 1999]. Average values for the hemispheres are 14.6°C for the Northern Hemisphere (NH) and 13.4°C for the Southern Hemisphere (SH). This was not the first attempt to derive such a value from observational data. *Crutcher and Meserve* [1970] and *Taljaard et al.* [1969] derived hemispheric averages from atlases nominally based on earlier periods (~1931–1965). Their results for hemispheric averages were 14.9°C for the NH and 13.3°C for the SH. When combined, these give a value for the globe of 14.1°C. As the difference in the global average time series between the two base periods is about 0.2°C (1961–1990 warmer than ~1931–1965), the difference between the two estimates (with *Jones et al.*, 1999 cooler) is 0.3°C (0.1°C + 0.2°C). Assuming the 0.2°C time series offset applies equally to both hemispheres, it is surprising to note that the two estimates differ more in the much better sampled NH than the less sampled SH. The earlier work from 1969 and 1970 did not estimate errors, but *Jones et al.* (1999) estimated that their global value of 14°C should be within 0.5°C of the true value.

[3] Reanalyses offer possibilities for additional means of estimating absolute surface air temperature averages for the NH, SH, and Globe. The second generation of these [NCEP/NCAR and ERA-40, *Kistler et al.*, 2001 and *Uppala et al.*, 2005, respectively] had potentially serious shortcomings in the estimation of surface temperatures in both Polar Regions, especially the Antarctic. The latest reanalysis [ERA-Interim, *Dee et al.*, 2011, the third generation] is a considerable improvement in this regard, and the purpose of this article is to compare the absolute surface temperature estimates with those from *Jones et al.* [1999]. ERA-Interim learned a lot from ERA-40, particularly with respect to the input satellite, radiosonde, and surface datasets used, and was chosen principally for this reason. Additionally, ERA-40 and later ERA-Interim have already been compared with earlier versions of the CRUTEM and

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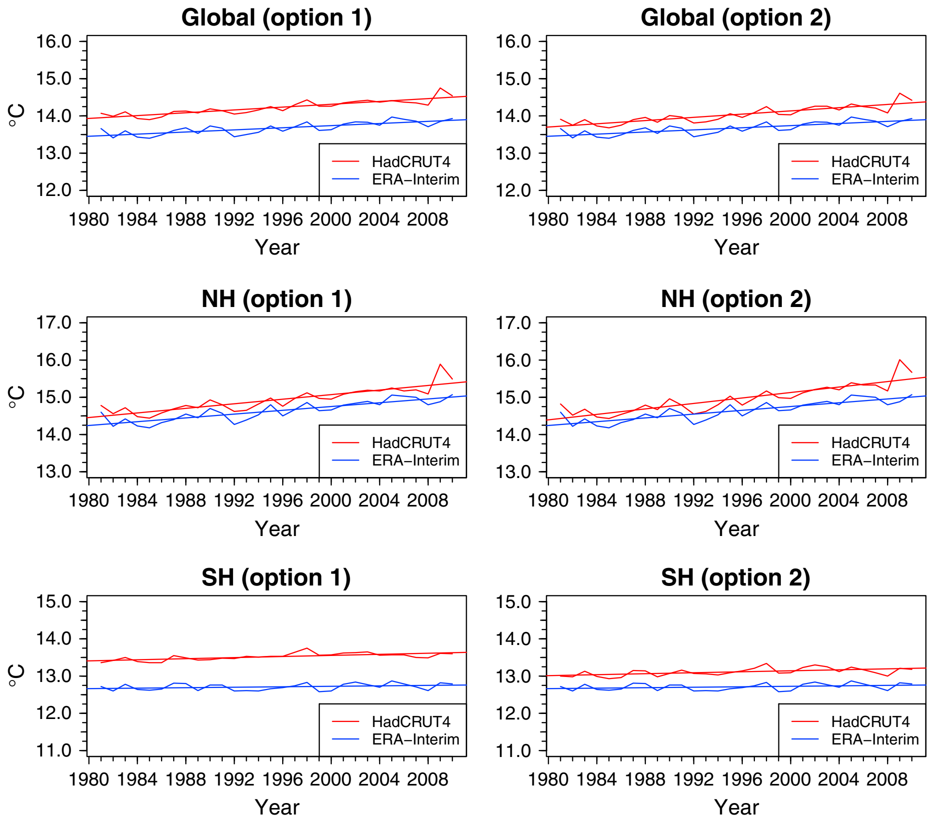

Figure 1. Large-scale averages of Absolute Temperatures for the Globe, NH, and SH estimated using Options 1 and 2 (see text for details) for HadCRUT4. Values are shown for each year from 1981 to 2010 for the annual average. The straight lines are linear fits to the 30 values for 1981 to 2010.

HadCRUT datasets [*Simmons et al*., 2004, 2010]. ERA-Interim is available from 1979 to the present, so we choose the base period 1981–2010. For this period, ERA-Interim is complete. ERA-Interim is available on a grid resolution of approximately 0.7° by 0.7° latitude/longitude, which was degraded to the 5° by 5° grid boxes used by *Jones et al*. [1999]. Section 2 discusses issues with updating the *Jones et al*. [1999] absolute analysis to the 1981–2010 period. Section 3 compares the two climatologies and discusses the differences, particularly in the context of the potential accuracy of ERA-Interim for the 1981–2000 period. Section 4 presents some conclusions.

2. Analyses

[4] *Jones et al*. [1999] discuss the development of the 1961–1990 climatology. Adjusting this to the more recent period (1981–2010) necessitates using time series data from the grid-box datasets of CRUTEM4 and HadCRUT4 [*Jones et al*., 2012 and *Morice et al*., 2012]. Neither CRUTEM4 nor HadCRUT4 undertake any extrapolation of anomaly data to neighbouring unfilled grid boxes. Both datasets are at their most complete during the period from 1951 to 2010, but they include missing areas, where there are no observations, which increase for earlier periods.

[5] By definition the average of the 30 years for 1961–1990 should be zero, but some grid boxes are missing or incomplete. Here we calculate averages for the two 30-year periods from HadCRUT4 and accept the offset of the two periods if there are at least 20 years of data in each period. In the first step, these calculations are undertaken monthly and result in adjustments for about 66% of the possible 5° by 5° grid boxes. In terms of the area, the grid boxes that cannot be estimated are a much smaller percentage of the total surface area of the Earth, than the 34% (100–66) would imply. Most of the grid boxes where adjustments between the two base periods cannot be undertaken are principally in the Polar Regions (more so in the Antarctic than the Arctic) and also some of the Southern Oceans. In later discussion, the ~34% of grid boxes where adjustments of base periods using HadCRUT4 could not be accomplished are referred to as AREAX. For the second step, estimates have to be made for the AREAX areas. There are a number of choices available to derive 1981–2010 averages from those for 1961–1990. The first two options are simply either retain the 1961–1990 average [i.e., *Jones et al*., 1999] or replace the 1961–1990 with the value from ERA-Interim for 1981–2010. We refer to these as Options 1 and 2.

[6] A third option would be to interpolate the difference field between the two 30-year periods to estimate values for the AREAX areas where direct calculation was not possible. Here, as the purpose of the exercise is to assess whether ERA-Interim is useful, we just consider the first two options. We present the results as annual time series in absolute degrees Celsius for the global average and for the NH and SH. In all cases, the global average is the simple average of the NH and SH.

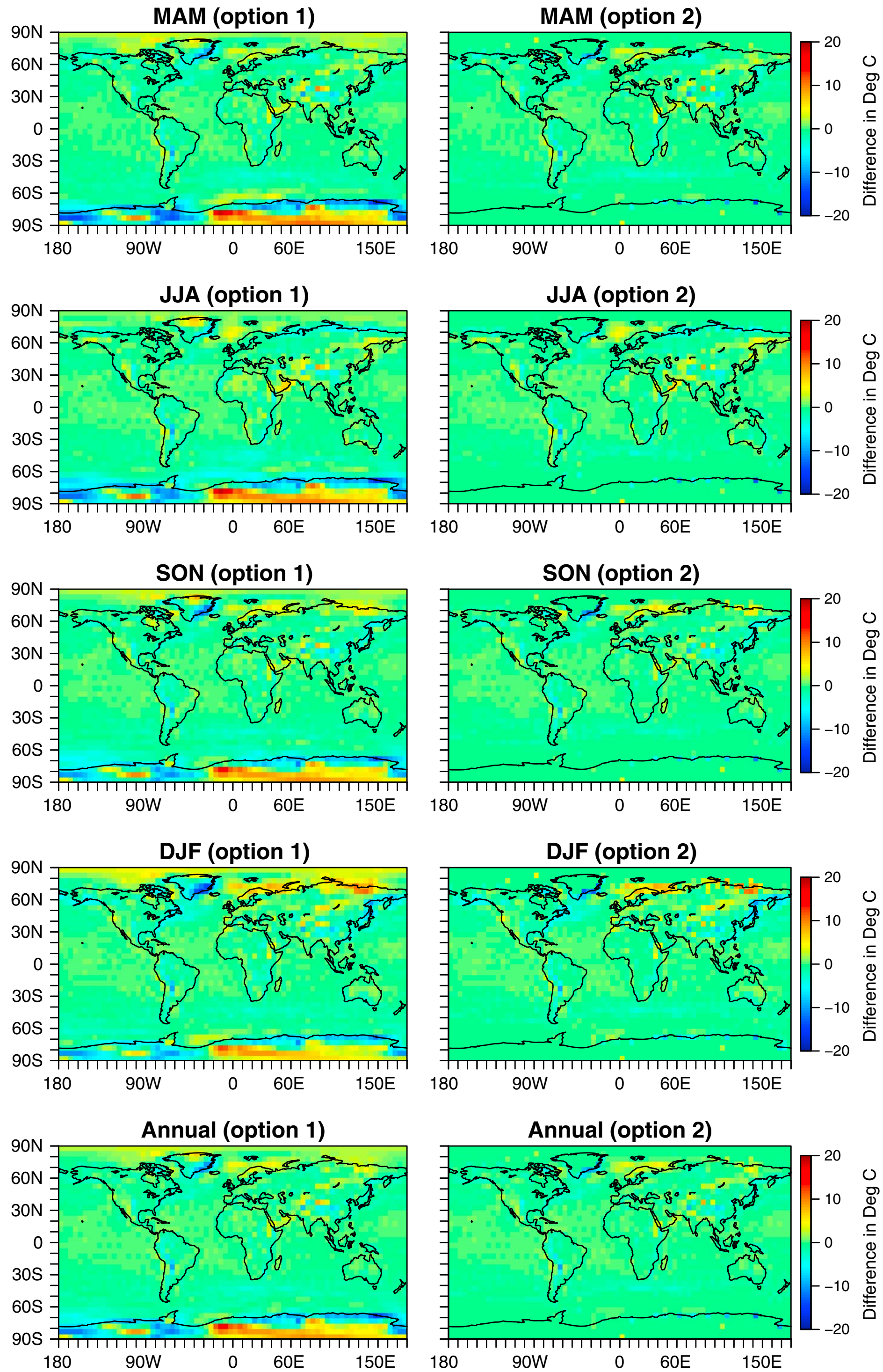

Figure 2. Spatial differences between *Jones et al*. [1999] climatology (referred to as HadCRUT4) and ERA-Interim for the period 1981–2010 for the four seasons and the year. Option 1—AREAX areas have retained their original 1961–1990 values from HadCRUT4 (see text for details). Option 2—where AREAX regions take absolute values from ERA-Interim.

3. Results

[7] In all the subsequent time series plots, hemispheric averages for HadCRUT4 and ERA-Interim are calculated as area-weighted values of all the 5° by 5° grid boxes in absolute degrees. For HadCRUT4, this involves adding the anomaly value for that month (and hence seasons and the year) to the absolute value using either Option 1 or 2. For grid boxes with missing anomaly values, this means assuming the anomaly value is zero for that month (i.e., using the appropriate 30-year average). For the complete ERA-Interim, the averaging is straightforward. For both datasets, global averages are the averages of the hemispheric values.

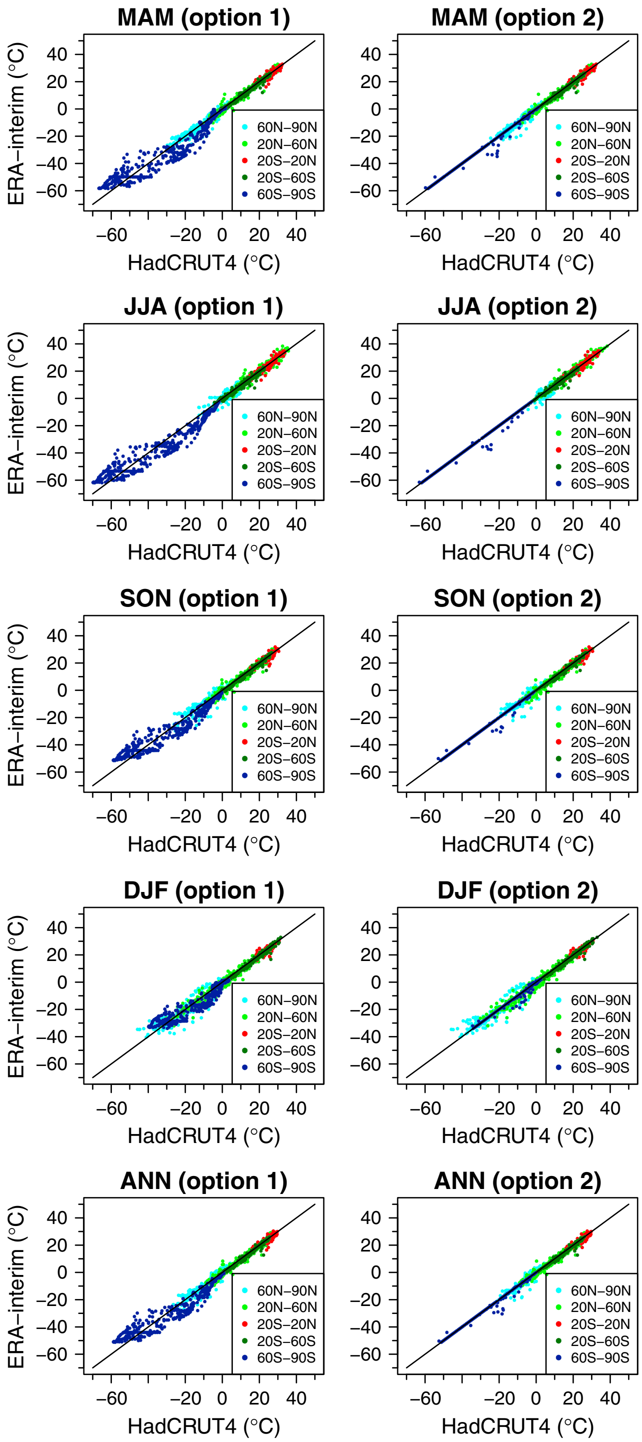

Figure 3. Scatterplots of the absolute values from ERA-Interim and HadCRUT4 for the seasons and the year for Options 1 and 2. Dots are color coded based on latitude ranges.

[8] Figure 1 shows annual averages for the NH, SH, and Globe for each year from 1981 to 2010 in absolute degrees Celsius for both options. The left side shows the results of calculating annual averages for the NH, SH, and Globe for each year from 1981 to 2010 using Option 1 (i.e., assuming all areas in the 1961–1990 climatology that cannot be estimated from HadCRUT4 using the 1981–2010 period—i.e., the AREAX areas, retain their 1961–1990 absolute value). The right side of Figure 1 shows similar series for Option 2 where AREAX areas take the 1981–2010 absolute values from ERA-Interim. In both series of plots, the absolute values for each year refer to 1981–2010, and for ERA-Interim (the blue lines) values are the same in both figures. There is little difference at these scales between the two red series in both plots, but Option 1 values tend to be slightly warmer than Option 2 for the series referred to as HadCRUT4. The differences are larger in the SH, and as will be shown in the next plots of spatial differences most of these differences come from the Antarctic.

[9] Figure 2 shows maps of the differences (for the 30-year average based on 1981–2010) between ERA-Interim and HadCRUT4 for Options 1 and 2, for the four seasons and for the year. For Option 1, differences between ERA-Interim and HadCRUT4 are larger and principally occur for AREAX areas so over the Antarctic and to a lesser extent over parts of Greenland. Over the Antarctic, the differences are positive over the higher elevation areas of the continent and negative around the coastal areas. The differences are slightly larger in MAM and JJA than in SON and DJF. Warmer ERA-Interim values during the northern winter (DJF) are evident over Northern Eurasia. For Option 2 where ERA-Interim absolute values have been used for AREAX areas, the differences are zero. For the remaining 66% of grid boxes, differences tend to occur at isolated grid boxes over the land areas or in regions around coastlines especially in higher northern latitudes. Sometimes the differences are seasonally specific (particularly in the northern winter, DJF, in northern Eurasia), but more often they are consistent between the seasons. The land differences are suggestive of possible differences in elevation (particularly over the Himalayas and the Andes) or due to differences between the surface (land, sea or ice) evident in *Jones et al*. [1999] and used by ERA-Interim. Over the Antarctic, the differences that do occur are at the locations of all the stations in the CRUTEM4 dataset over continental Antarctica. ERA-Interim is cooler for the coastal sites and warmer for the two inland sites.

Table 1. Average Annual and Seasonal Temperatures (°C) for the 1981–2010 Period for the NH, SH, and Globe Using Options 1 and 2

	ERA-Interim	HadCRUT4	
		Option 1	Option 2
Global			
Annual	13.68	14.23	14.04
MAM	13.58	14.12	13.95
JJA	15.43	16.00	15.66
SON	13.72	14.29	14.08
DJF	11.96	12.58	12.46
NH			
Annual	14.64	14.93	14.96
MAM	13.85	14.12	14.14
JJA	20.64	20.78	20.80
SON	15.59	15.95	15.98
DJF	8.47	8.88	8.91
SH			
Annual	12.71	13.52	13.11
MAM	13.31	14.11	13.75
JJA	10.23	11.07	10.52
SON	11.85	12.63	12.17
DJF	15.46	16.28	16.01

[10] Figure 3 shows scatterplots of the absolute temperatures by season and year, color coded by latitude band. These plots are another way of plotting the absolute differences between the two climatologies. For Option 1, the scatterplots show that the largest differences occur for the higher latitudes of the SH (60–90°S). The line of points with little difference in their very cold temperatures for ERA-Interim values (particularly in JJA) is due to HadCRUT4 having much larger spatial differences for the grid boxes in the 85–90°S zone. The least differences for Option 1 occur for DJF (summer season in the SH). For Option 2, where ERA-Interim has been assumed for the AREAX areas, the largest differences are for the DJF season. In this case, though, the areas showing the greatest differences are in the higher latitudes of the NH. The differences in the higher latitudes of the SH occur at the locations of the Antarctic station locations. The two dots left of the diagonal are for the South Pole and Vostok station, whilst those on the right are the coastal stations of East Antarctica.

[11] Table 1 gives the hemispheric and global averages for both datasets and Options 1 and 2 by seasons and the annual average. Option 1 for HadCRUT4 results in warmer temperatures for the SH compared to Option 2, but there is little difference for the NH. For Option 1, this SH difference comes principally from the cooler ERA-Interim over parts of Antarctica, countered to some extent by warmer ERA-Interim values in central parts of the continent. Assuming Option 1, the global average is 0.55°C warmer for HadCRUT4 compared to ERA-Interim. This is made up from 0.29°C for the NH and 0.81°C for the SH. For the NH, the difference is larger in the winter compared to the summer season, but there is little seasonal contrast for the SH. The accuracy of the surface temperature field is not specifically addressed by *Dee et al.* [2011] but a cold bias in the background field in the troposphere is noted. Based on an analysis of the typical temperature "increments" from the background forecast [see discussion in *Simmons et al.*, 2004] due to the land temperature observations (often referred to as SYNOP data) assimilated every 6 h, there is an overall global cold bias of ERA-Interim of between 0.2 and 0.3°C (A. J. Simmons, personal communication, 2013). This cold bias, which can be considered as the effect of the temperature observations on the model [*Simmons et al.*, 2004], is a global average that masks spatial and seasonal variations of up to ±1.5°C, which when averaged are larger in the SH compared to the NH. If we take this cold bias to be 0.25°C, the global difference in the climatologies is ~0.3°C.

4. Conclusions

[12] In this paper, we have discussed the issue of the absolute surface temperature of the Earth. The difference between the value developed for 1961–1990 by *Jones et al.* [1999] and that from ERA-Interim are within 0.55°C, a value that is marginally larger than the 0.5°C uncertainty estimate given by *Jones et al.* [1999] for their climatology. The two are easily within the uncertainty estimate if the 0.2–0.3°C cold bias in ERA-Interim is acknowledged. The absolute surface temperature of the world is likely to be between 13.7 and 14.0°C for the 1961–1990 period and 13.9 and 14.2°C for 1981–2010. The spatial detail reveals that most of this difference comes from Antarctica and to a lesser extent Greenland and the immediate coastal areas around these two landmasses. There are also large differences along the coastlines of northern Eurasia particularly in DJF. These differences are suggestive of issues over the two landmasses and their adjacent sea-ice areas, which for large parts of Antarctica makes ERA-Interim up to 10°C cooler. High-elevation areas of Antarctica are much warmer (5–6°C) than the two sites with long records. ERA-Interim, therefore, has markedly reduced temperature gradients between the interior and coastal sites than evident at the limited number of sites in eastern Antarctica.

[13] **Acknowledgments.** This work has been supported by the USDoE (Grant DE-SC0005689). The authors thank the reviewers, especially Russ Vose. The ERA-Interim data was downloaded from the BADC and ECMWF websites and the paper benefitted from discussions with Adrian Simmons and Dick Dee.

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