Estimating Ocean Subsurface Temperature Trends, 1950-2000

by D. E. Harrison and Mark Carson

Background: Many attempts have been made to estimate long-term subsurface temperature trends in the oceans. Due to the lack of long time series in vast regions of the ocean, most of these attempts have involved calculating anomalies, heavy interpolation, and bulk spatial and temporal averages. The research presented here attempts to calculate long-term temperature trends only where there is enough data to reasonably fit to a line. Spatial averaging has been kept to a minimum by only working with 1-degree square boxes having data within small depth intervals. Daily averages are calculated to help represent a number of CTD data points from a single cast as one value. No climatologies have been removed from the data, so these data are real in situ values and not anomalies.

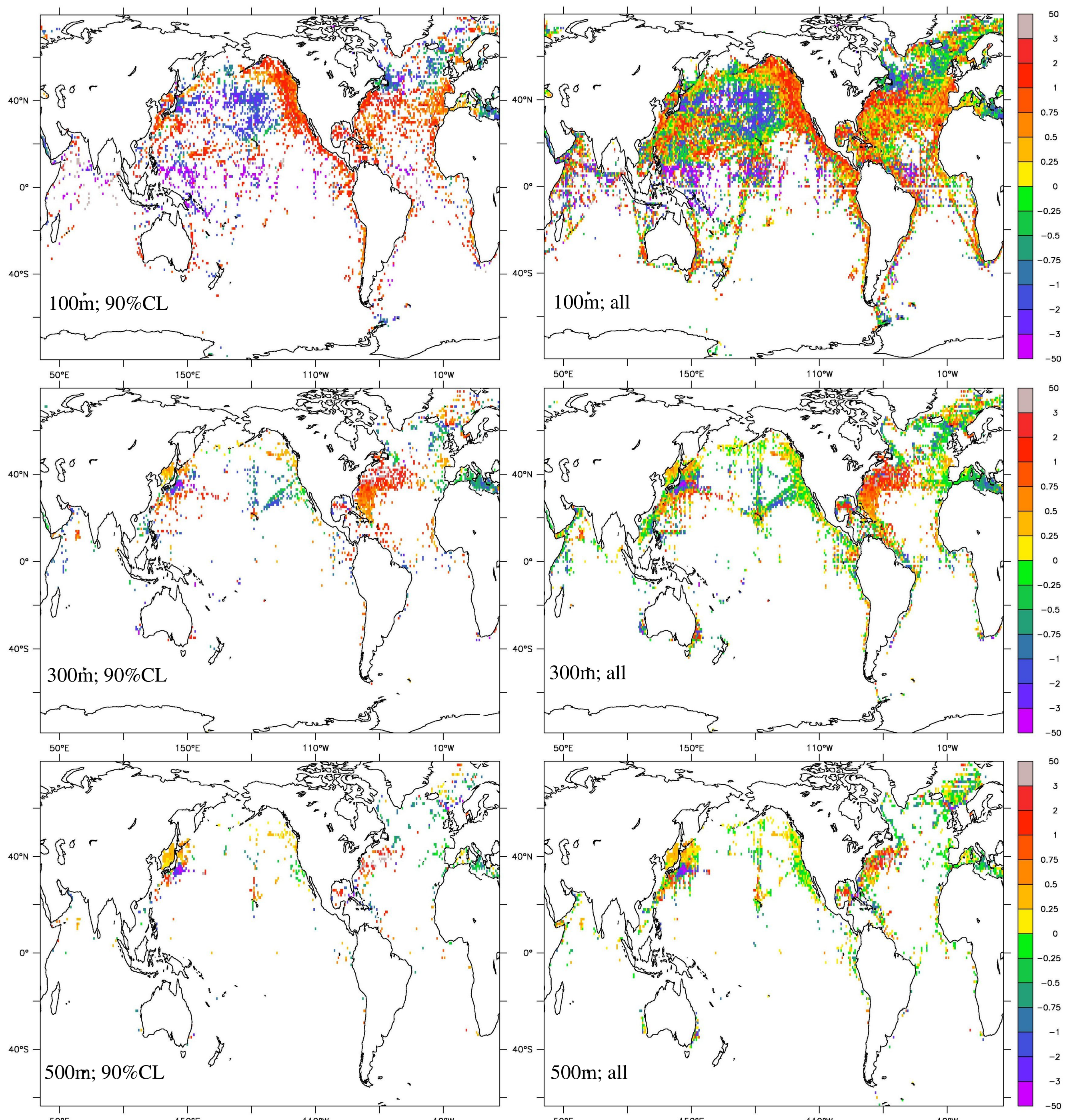
The 51-year trends

The maps in Figure 1 show the magnitudes of the trends for each 1-degree square region which were calculated using the fitted trend line (see the box below for details). Maps on the left show trends that pass the 90% CL; those on the right show trends in all regions which met the criteria of having 5 or more observations per decade for 4 of the 5 decades from 1950-2000.

A number of features can be gleaned from these maps, a few of which are listed here:

- Large-scale spatial patterns are evident at all depths and in all basins with enough regions,
- Some spatial structures are coherent with depth:
  - Cooling in the north central Pacific
  - Warming in the tropical and subtropical Atlantic
  - A "tripole" warming-cooling-warming pattern off of the coast of Japan
- The north Pacific pattern is similar to the positive phase of the PDO pattern (see Deser, et al. 1996). This seems to be the dominant picture of the north Pacific in part due to the 51-year trends only covering one "oscillation",
- There is very little data distributed well in time in regions south of 40ºS, and rarely in any open ocean regions south of 20ºS,
- At 100 m there is broad cooling in the tropical western Pacific and some warming in the tropical eastern Pacific may be due to changes in thermocline tilt (cf. Stephens, et al. 2001).

More recent analysis with 2º x 2º boxes and with removing the World Ocean Atlas 2001 climatology yield the same spatial patterns of warming and cooling. Also, the values of the trends are not meant to be indicative of the actual magnitude of temperature change due to the fact that these trends are linear least squares fits to data which have a lot of variance due to nonlinear processes.

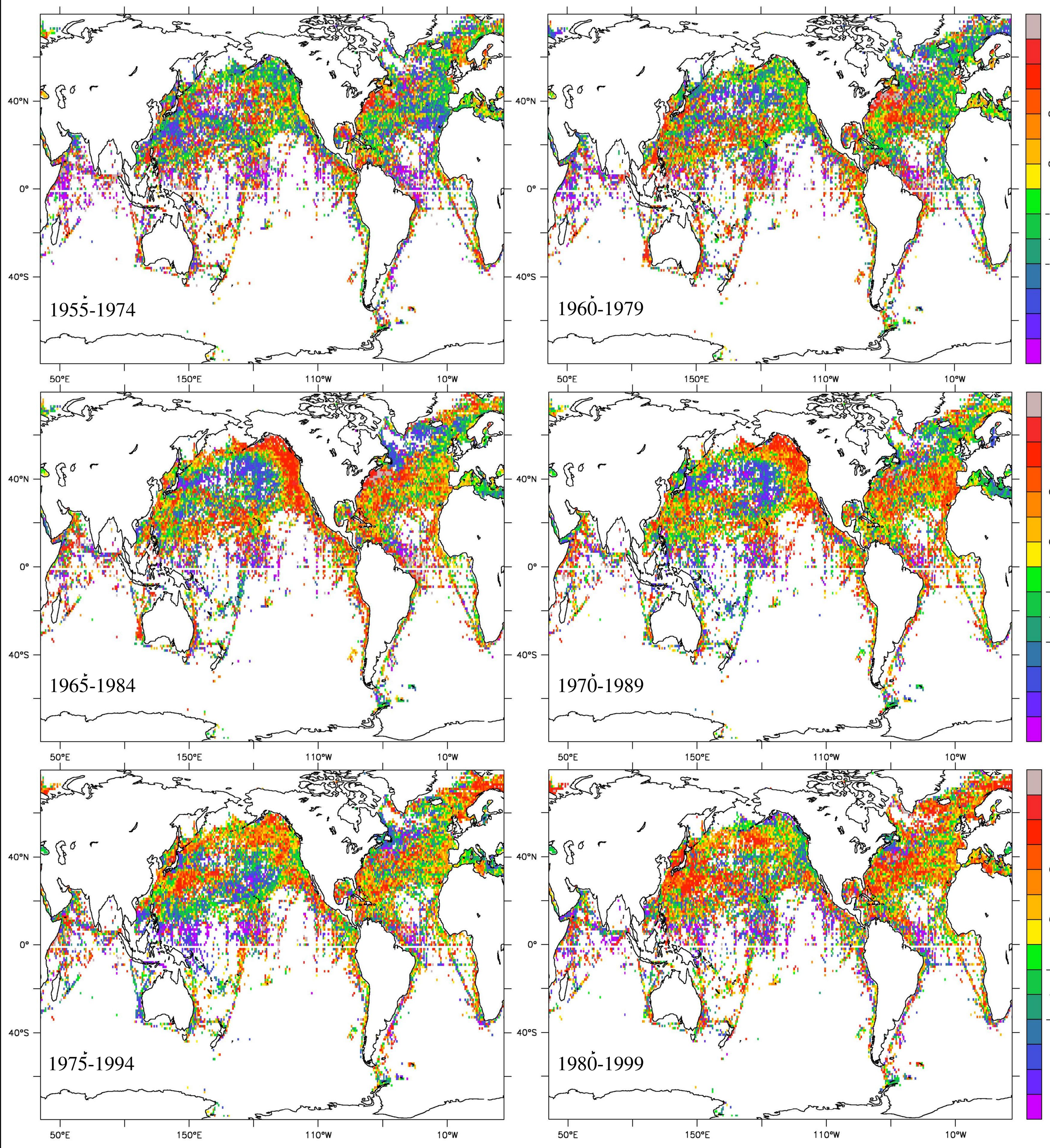


51-year temperature trends (degrees C per 51 years, based on linear fit) over 1950-2000 in regions meeting sampling criterion (at least 5 observations per decade in at least 4 of the 5 decades of the analysis period). Trends in the left panels pass 90% CL significance; trends over all regions are shown in the right panels (top, 95-105 m; middle, 280-320 m; bottom, 480-520 m depth).

The 20 year trends

To see how interdecadal variability contributes to the long term trends in ocean temperature, overlapping 20 year trends were calculated for 100 m data – due to the better data coverage at that depth. Some of the boxes, especially in the earlier parts of the records, have little data upon which the 20-year trends are based, and so some trends are pathological. There is also much more apparent noise. However, there are still recognizable broad spatial patterns in many places in all time periods, which include:

- An evolving PDO-like spatial structure in the north Pacific – negative phase in the earlier period a); positive phase in the later records c), d) and e); and perhaps a slight shift back towards the negative phase in f);
- The southwestern corner of the north Pacific subtropical gyre slowly shifting from cooling to warming;
- The portion of the north Pacific subtropical gyre near Hawaii going from cooling to warming to cooling;
- General warming in the north Atlantic throughout all periods with some cooling building in the last 3 periods along the coast around Nova Scotia;
- Numerous smaller scale sign changes in trends along the noisy tropics although there a background of mostly cooling throughout;
- Switching between warming and cooling trends off the western coast of Australia.



20-year temperature trends (degrees C per 20 years) at 100 m for different time periods: a) 1955–1975, b) 1960–1980, c) 1965–1985, d) 1970–1990, e) 1975–1995 and f) 1980–2000. Trends are shown for all regions satisfying the 51-year trend sampling criteria.

Data and Methods

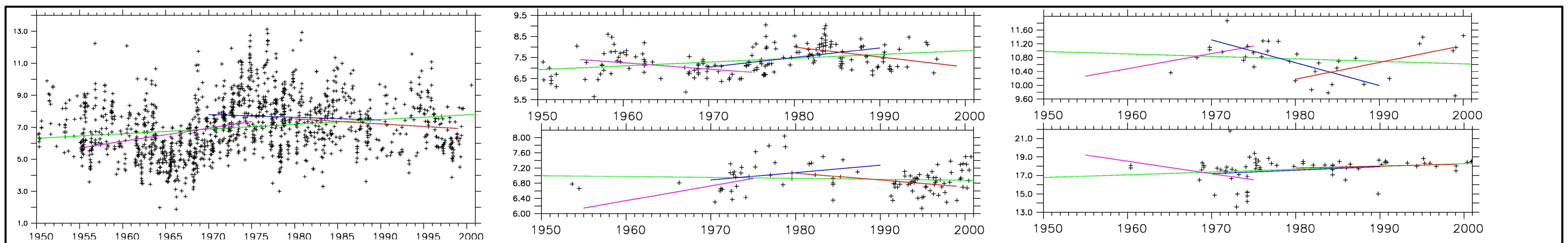
The dataset used was the World Ocean Database 2001 (WOD01) from which data in 1-degree square boxes were extracted and run through gross error-checking. Then, due to concerns that other data errors were not flagged correctly in the database, data were kept only that lie within 4 standard deviations from the mean. Comparisons showed that this filtering did not change the large-scale features of the trend maps.

Trends were then fitted to the data using the standard linear least-squares method. For the entire 51-year record, the magnitudes of the trends are calculated by the endpoints of the trend line in that interval; for the 20-year trends, the magnitudes of the trends are computed using the trend lines fitted only to the data within the period in question. This can be seen in the graphs of individual 1-degree square box data below. The green line is the 51-year trend line, but magenta line is the trend based on data from 1955-1974, the blue line 1970-1989, and the red line from 1980-1999. Taking the difference of the endpoints of the trend lines gives the magnitude of the trend over the period in question and these magnitudes are plotted in the planview maps above.

The boxes below demonstrate some of the features and some of the difficulties of doing long-term trend analysis on ocean data. The first graph is from a box in the north Atlantic at 100m and shows how large the interannual variability can be at this depth. This low-frequency variability can be found in many places at many depths as the other graphs demonstrate.

Discussion

The world ocean has evolved over the course of the last 50 years with spatial and temporal complexity. This is clear just from looking at the temperature fields alone. The patterns of interdecadal variability are robust and show up clearly in numerous analyses. These patterns make it problematic to quantify the extent to which the ocean has warmed in the 50-year interval especially when considering that it is unclear to what extent the variability has been adequately sampled. The PDO events in the central north Pacific have not been spatially sampled well enough before 1970 which increases the uncertainty of long-term trends in the region. The north Atlantic appears to have a strong warming signal in the subtropical gyre, but the cooling in the subpolar gyre dominates the entire record with warming there only in the last 20 years. It is possible that such a short-term warming trend is due to interdecadal variability in that region, and it will take longer records to resolve the evolution of the ocean temperature field.



References

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