National Aeronautics and Space Administration

Global Trends of Lake Temperatures Observed From Space

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Introduction

The temperatures of lakes and reservoirs worldwide are an excellent indicator of climatic change. In situ observations of lake surface temperature are very rare on a global scale, however thermal infrared imagery can be used to infer accurate, continuous and homogeneous water surface temperature of lakes and reservoirs worldwide (Schneider et al., 2009). In this study we utilize the existing archive of spaceborne thermal infrared imagery to generate multi-decadal time series of lake surface temperature for 169 of the largest inland water bodies worldwide. The data used for this purpose includes imagery from the Advanced Very High Resolution Radiometers (AVHRR), the series of (Advanced) Along-Track Scanning Radiometers ((A)ATSR), and the Moderate Resolution Imaging Spectroradiometer (MODIS). Used in combination, these data sets offer a gapless time series of daily to near-daily thermal infrared retrievals from 1981 through present. From this data we compute 25-year trends of nighttime summertime/dry-season surface temperature using linear regression. The results indicate that the surface temperatures of the studied water bodies have been rapidly warming with an average rate of 0.045 ± 0.011 °C/yr for the period 1985–2009 and rates as high as 0.13 ± 0.01 °C/yr. Worldwide, the data show far greater warming in the mid- and high latitudes than near the equator. The results provide a critical new independent data source on climate change that indicates lake warming in certain regions is greater than expected based on air temperature data.

Data & Methods

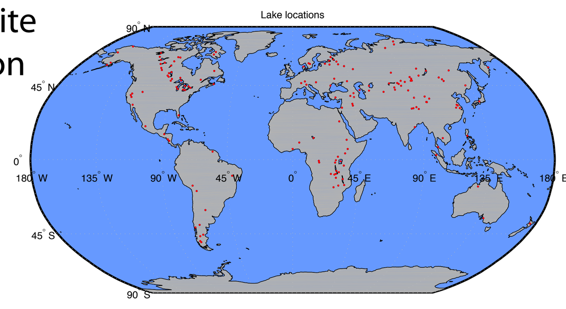
Data

- Entire global archive of ATSR-1, ATSR-2 & AATSR (1991 through 2009)
- AVHRR Pathfinder 4 km (1985 through 2009)
- MODIS Terra & Aqua (currently only used for validation)
- Only nighttime data used from all sensors to improve trend accuracy
- In situ data: 4 buoys at Lake Tahoe, 9 buoys at Great Lakes

Processing

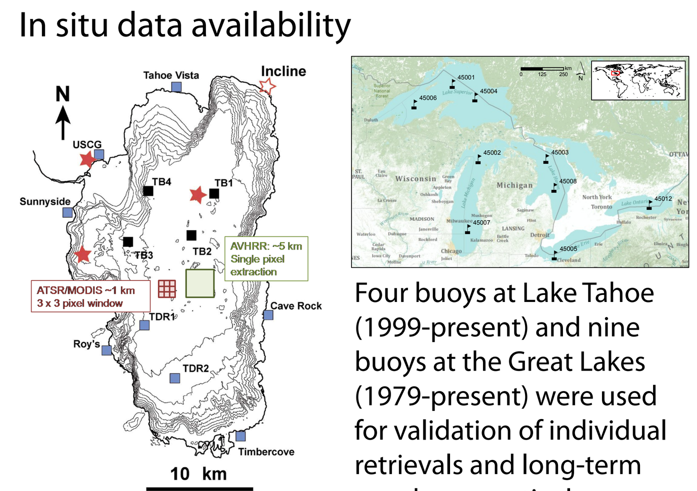
- Extraction of 3 x 3 pixel arrays(AVHRR: 1 pixel) over each site for all images
- Cloud masking using spectral cloud tests
- Atmospheric correction & skin temperature retrieval
- Used LOWESS smoothing for continuous estimate from irregularly obtained retrievals (Cleveland, 1979)
- Average temperature computed for July through Sept. and January through March dependent on latitude
- Linear regression analysis on seasonal means

Study site selection

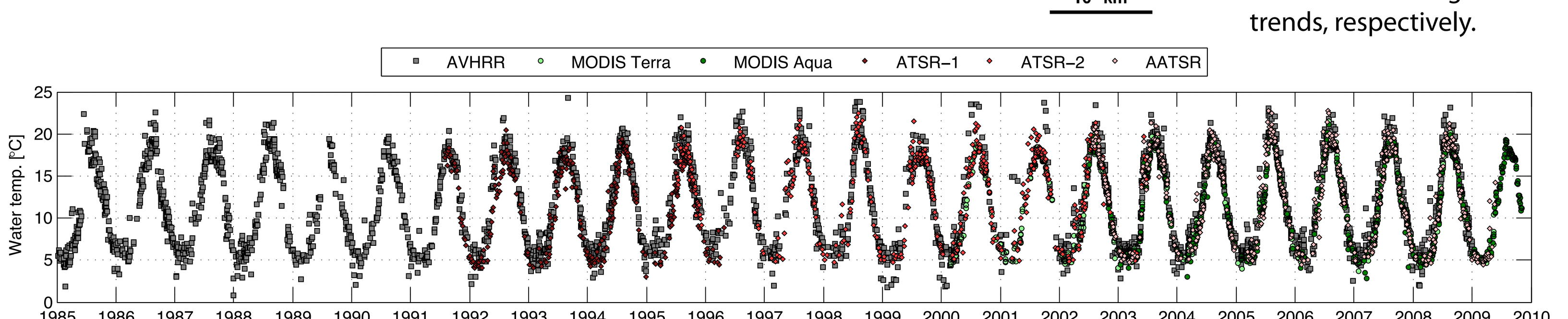


169 sites were selected based on total surface area (> 500 km^2) and the existence of a roughly 10 x 10 km pure water area (to eliminate potential bias from land surface pixels)

In situ data availability



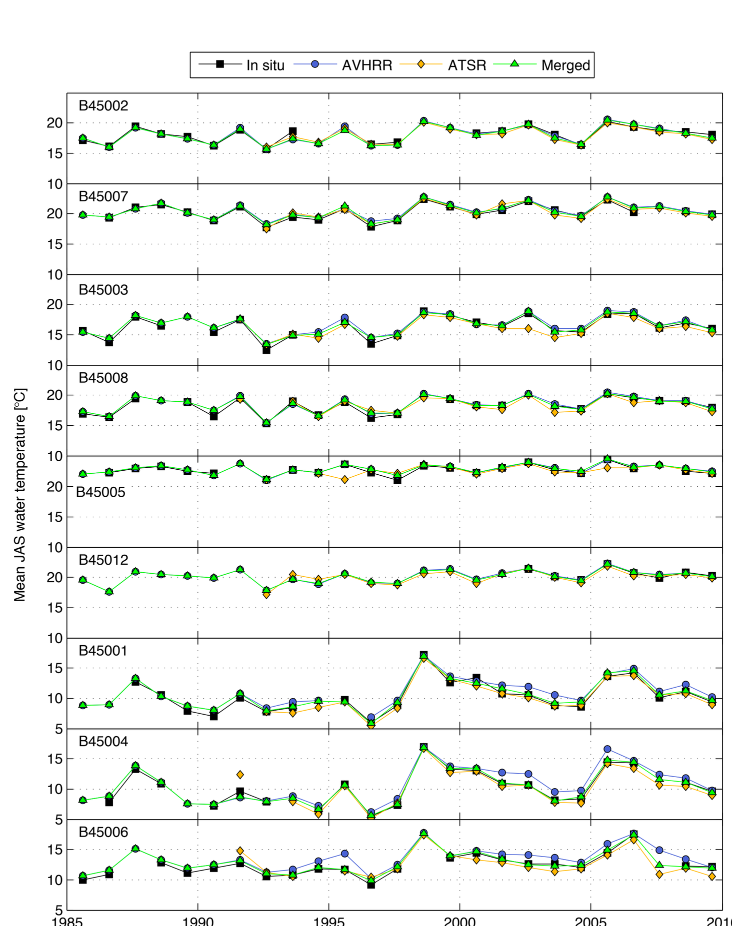
Four buoys at Lake Tahoe (1999-present) and nine buoys at the Great Lakes (1979-present) were used for validation of individual retrievals and long-term trends, respectively.



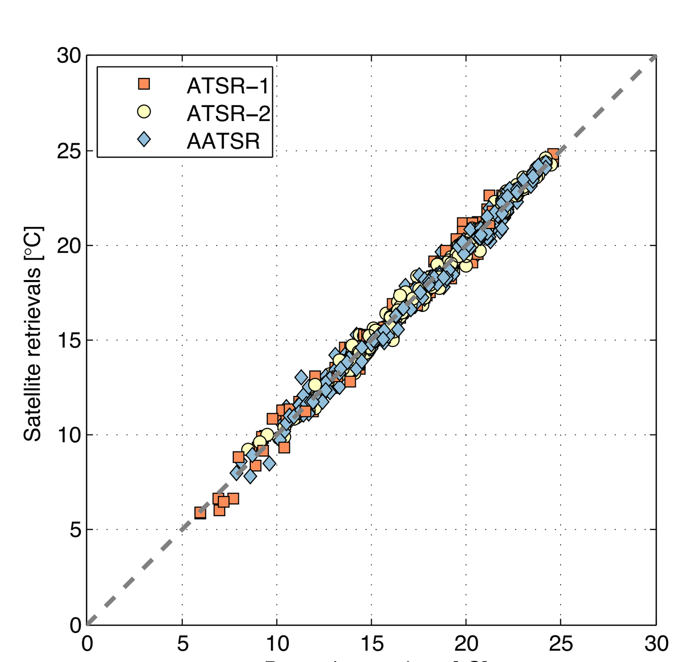
Example of a time series of all available surface water temperature retrievals (nighttime and daytime) from 7 AVHRRs, 2 MODIS sensors and 3 ATSR sensors, for Lake Tahoe, CA/NV.

Validation

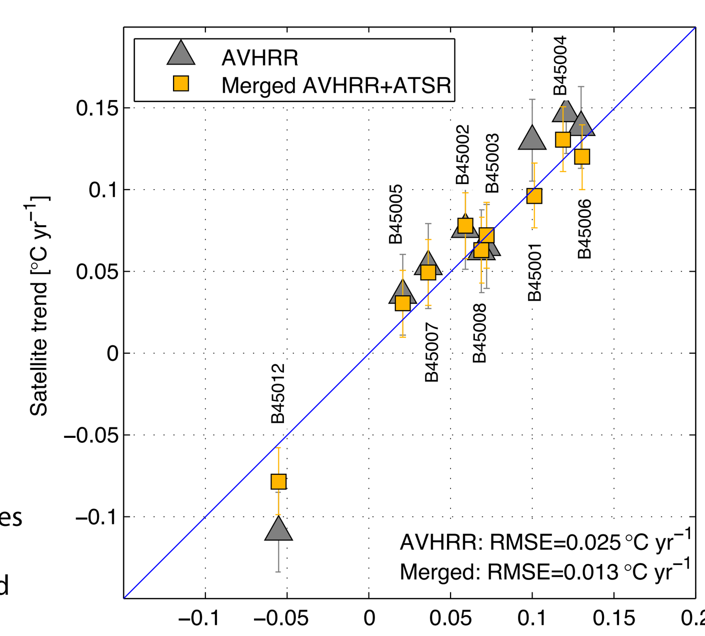
Extensive validation efforts were carried out in order to ensure that a) individual sensor retrievals are accurate b) time series of seasonal means follow in situ data and c) trends obtained from both data sources result in similar trends.



Comparison of mean JAS water surface temperature time series computed from the in situ data, AVHRR and ATSR data, and a merged time series from both satellites. Buoy 45012 measured data only since 2002. Absolute values of the y-axis are shifted for buoys 45001, 45004, and 45006 for display purposes, but its range is identical for all sites.

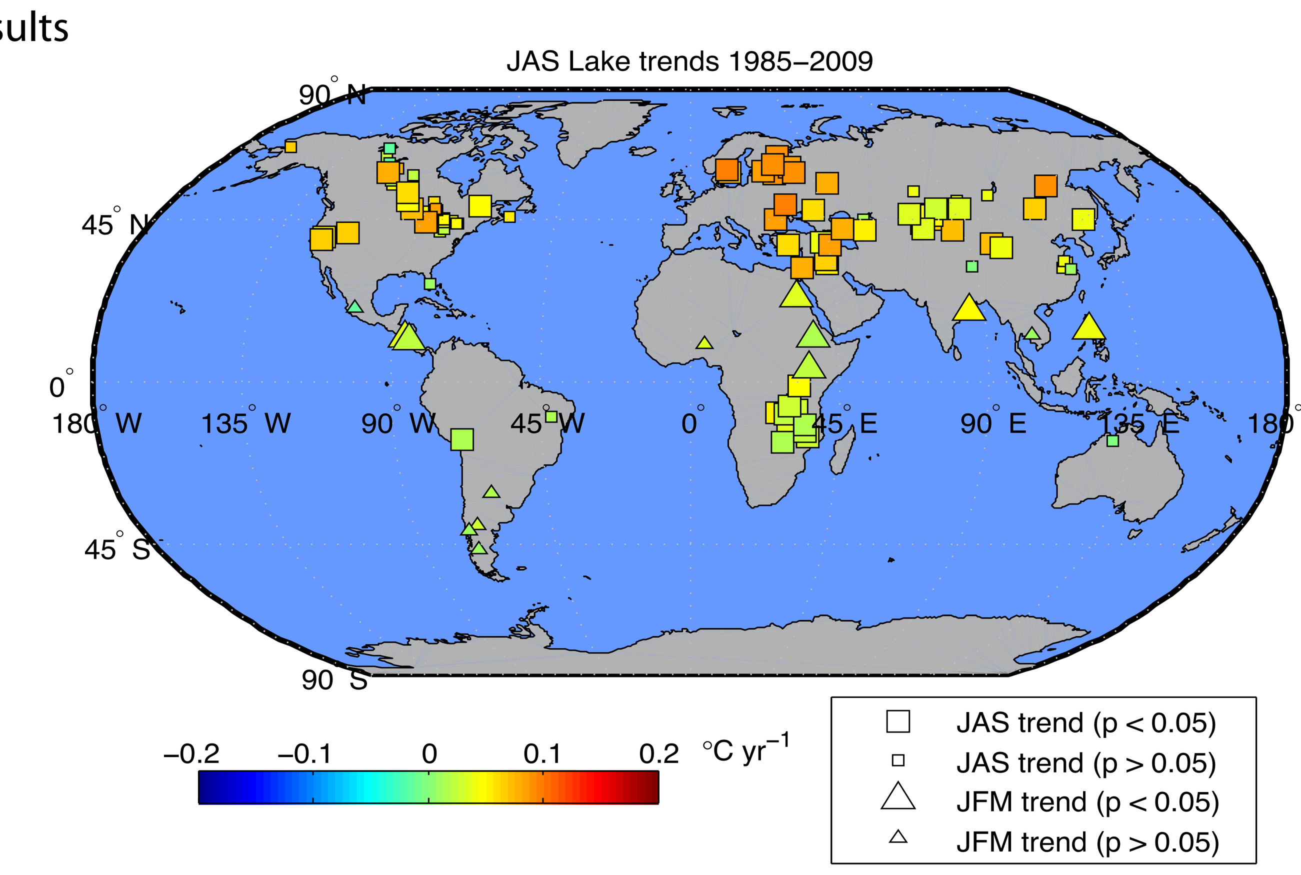


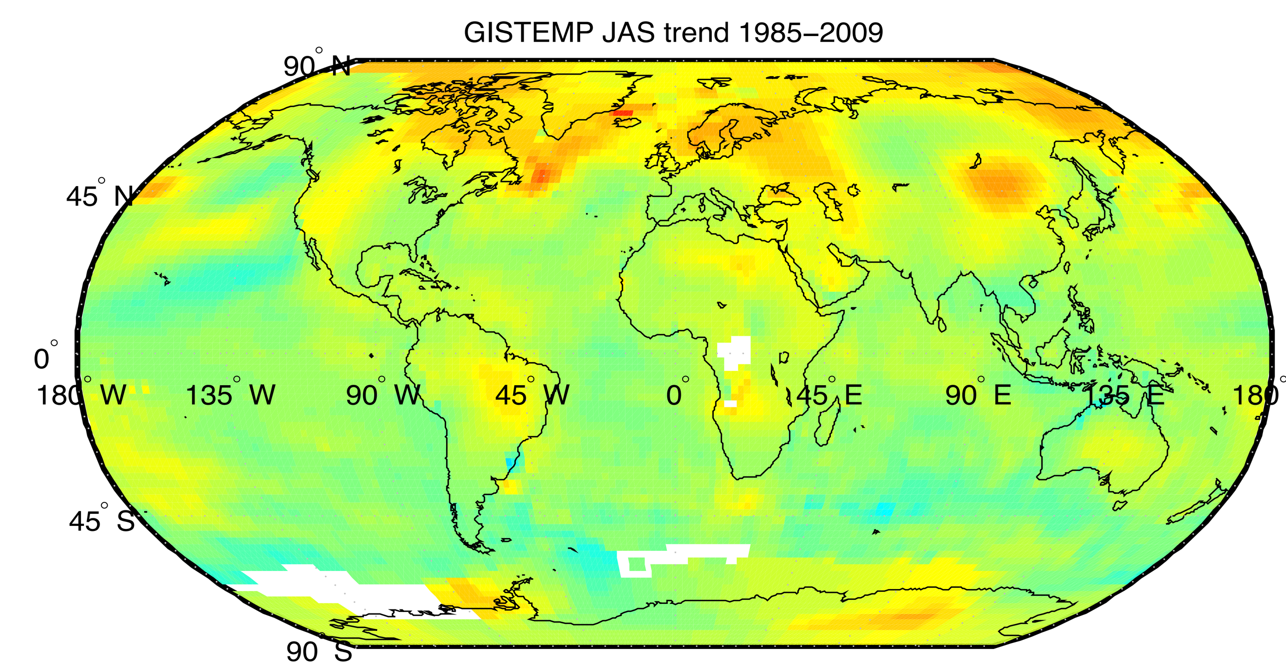
Validation of individual JAS lake surface temperature retrievals from all three ATSR sensors against in situ observations from nine buoys at the Great Lakes. Biases of all three sensors are < 0.1 K and RMSEs < 0.6 K.



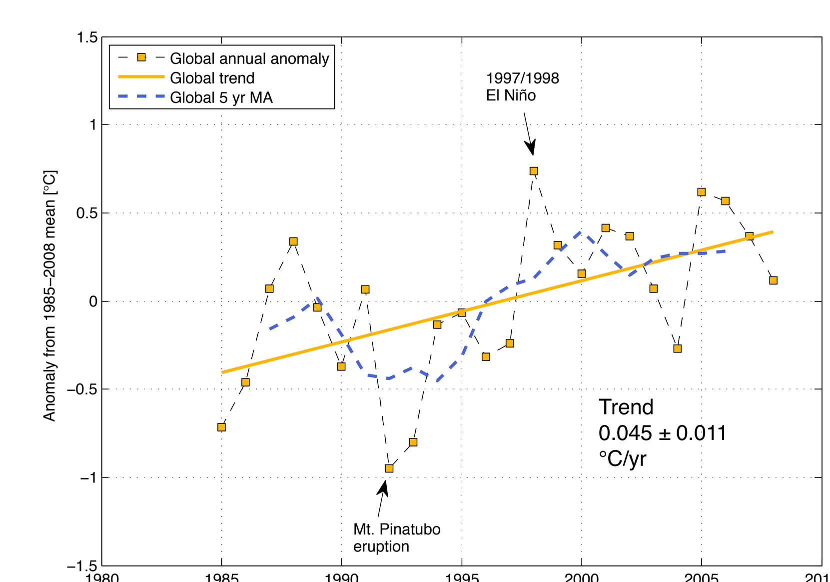
Direct validation of 25-year JAS surface temperature trends obtained from the merged AVHRR+ATSR dataset against those computed at nine NDBC buoys at the Great Lakes. Uncertainty estimates are standard errors of slope as estimated parametrically using linear regression.

Results

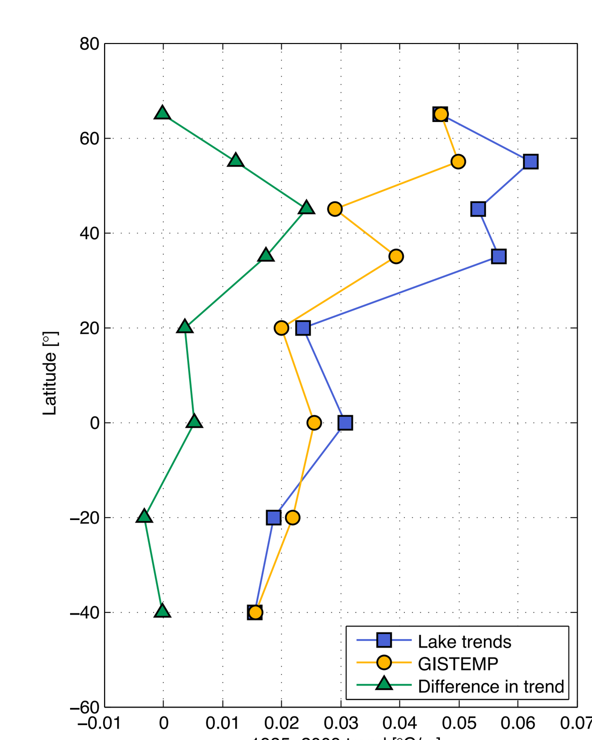




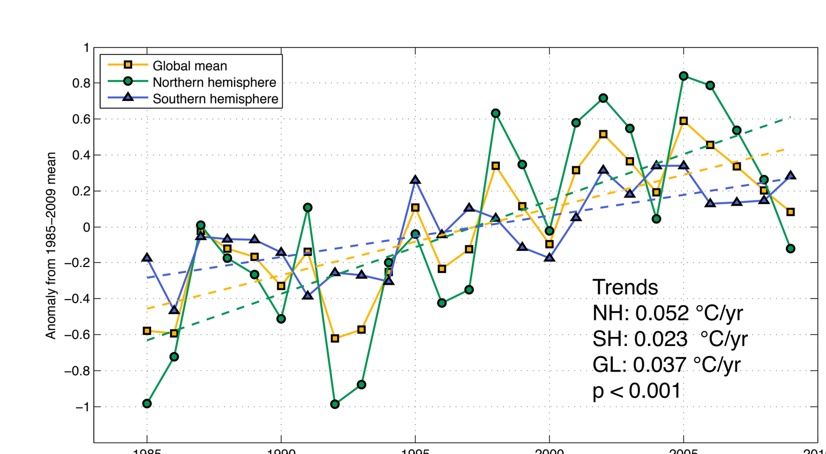
Global trends in nighttime lake surface temperature derived from merged satellite data (a) and the corresponding map of global JAS trends in surface air temperature from GISTEMP (Hansen et al. 1999) (b). JAS trends were computed for all sites located north of 23.5° N and between 0° and 23.5° S, while JFM trends were computed for all sites located south of 23.5° S and between 0° and 23.5° N. JFM GISTEMP map is not shown due to the small number of JFM sites.



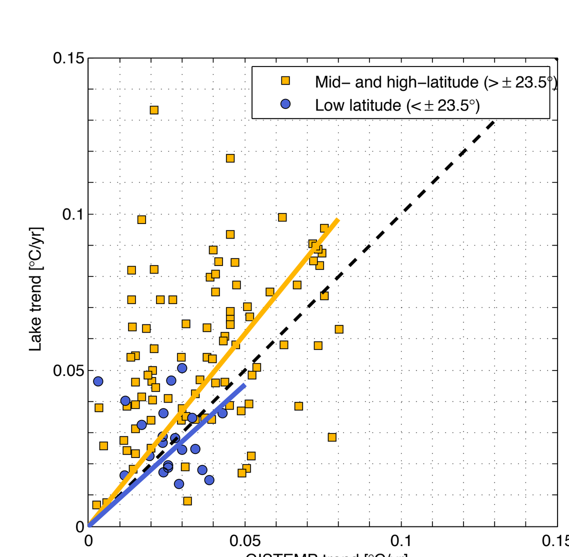
Anomaly time series of the global mean average over all study sites. The anomaly is computed as the difference from the 1985 to 2008 mean for each lake. All sites were weighted equally, thus the signal is dominated by the mid-latitudes of the northern hemisphere.



Zonal means of trends obtained from the merged satellite data set for lakes and from GISTEMP (Hansen et al. 1999), as well as the difference between the two parameters. The figure shows that the trends are most rapid in the mid-latitudes of the norther hemisphere, which is also where lake trends and trends of regional air temperature deviate the most.



Anomaly time series for northern and southern hemisphere and the global mean computed from both weighted equally. Anomaly computed as deviation from 1985-2009 mean.



Direct comparison of 1985-2009 surface water temperature trends for lakes worldwide with trends at the same locations obtained from the GISTEMP (Hansen et al., 1999) analysis for air temperature. Many mid- and high-latitude lakes warm more rapidly than regional air temperature.

Conclusions

- Lakes have excellent potential as indicators of a changing climate
- Availability of 30 years of thermal infrared remote sensing data permits the construction of a continuous record of lake temperatures worldwide and to complement the traditional surface air temperature records
- Individual retrievals accurate up to 0.2 K
- Long-term trends can be determined with an accuracy of ~0.013 °C/yr
- Average trend over all sites was found to be about 0.045 °C/yr (weighted global mean 0.037 °C/yr)
- Map of global trends shows distinct spatial patterns – generally agree with patterns from air temperature trends but in some regions lakes warm faster than surrounding air temperature
- Offers an independent dataset to verify global climate trends derived from air temperature data
- Rapid warming of lakes has a variety of implications on lake ecosystems, regional climate, and our understanding of how lakes react to climate change

References

Cleveland, W., 1979. Robust locally weighted regression and smoothing scatterplots. Journal of the American Statistical Association, 74(368), 829-836.

Hansen, J. et al., 1999. GISS analysis of surface temperature change. Journal of Geophysical Research, 104(D24), 30997-31022.

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