Rising Air and Stream-Water Temperatures in Chesapeake Bay Region, USA

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Introduction

- Global air temperature (AT) is rising
- Over the period 1951-2012, global mean surface temperature increased approximately 0.12°C per decade (IPCC 2013)
- Increasing trends in stream-water temperature (WT) have been observed in many regions and across the globe (e.g., Kaushal et al. 2010; van Vliet et al. 2011)
- The literature reflects disagreement regarding the control of AT on WT

Objectives

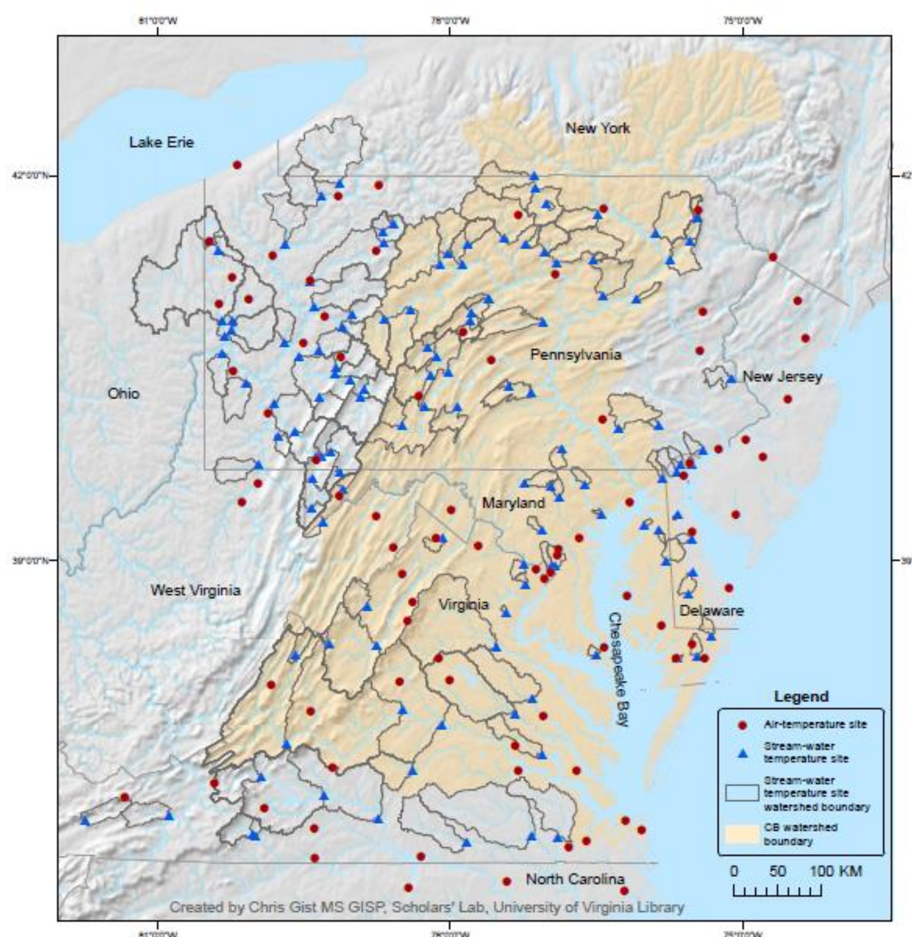
- Calculate temporal trends in AT and WT across the region for 1960-2010
- Calculate changes in the distribution of AT and WT anomalies compared to the climate normal base period of 1971-2000
- Evaluate influence of trends in streamflow on WT trends
- Evaluate relations among landscape factors and WT trends

Rationale

- Stream ecosystems and aquatic biota will be affected once WT reaches a critical threshold (e.g., Caissie 2006)
- Rising WT of source waters can affect industry, electricity, and drinking water, as well as recreation (van Vliet et al. 2013)
- Biological effects: rising WT of both freshwater and estuarine systems alters species ranges and community composition of phytoplankton, submerged aquatic plants, and fish (e.g., Short and Neckles 1999; Najjar et al. 2010)
- Physical effects: rising WT decreases dissolved oxygen and can cause changes in salinity, circulation patterns, and stratification (e.g., Scavia et al. 2002)
- Biogeochemical effects: rising WT is expected to increase eutrophication—one of the biggest problems of polluted estuaries worldwide, including Chesapeake Bay (e.g., Najjar et al. 2010; Rabalais et al. 2009)

Study Area

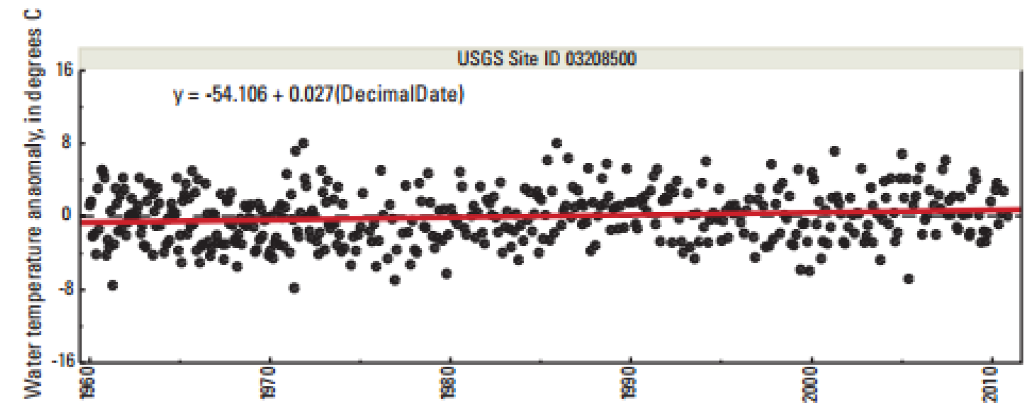
- Mid-Atlantic area of the eastern U.S.
- Includes most of Chesapeake Bay watershed (>166,000 km^2)
- 85 AT sites:
  - data completeness ranges from 87-100% (median 99%)
  - 51,012 values
  - elevation range: 3 - 1078 m
- 129 WT sites:
  - data in 90% of the 51 years
  - 48,960 values
  - elevation range: 2 - 719 m
  - watershed area range: 8 - 16,207 km^2
  - USGS streamgages, with 104 of the 129 sites being independent (not nested)



Methods

Trends:

- Calculated anomalies as observed monthly mean AT (or instantaneous WT) subtracted from the site-specific monthly mean AT (or WT) for the entire period (1960-2010)
- Fit a simple linear regression (SLR) to the AT and WT anomalies at each site
- Tested for serial correlation of residuals using Spearmans Rho of the lagged residuals
- Trends of the anomalies were calculated by:
  - SLR, if significant serial correlation of the residuals was absent ($p \geq 0.05$); or
  - Cochrane-Orcutt method, if serial correlation of the residuals was present ($p < 0.05$)
- Tested for significance of regional trends on the collection of trend slopes with Wilcoxon signed-rank test
- Calculated AT and WT anomalies for 1961-1985 and 1986-2010 using the climate normal period of 1971-2000, and plotted as pdfs
- Calculated correlations between WT trends and landscape factors with Kendall's tau
- Evaluated the influence of streamflow trends on WT trends

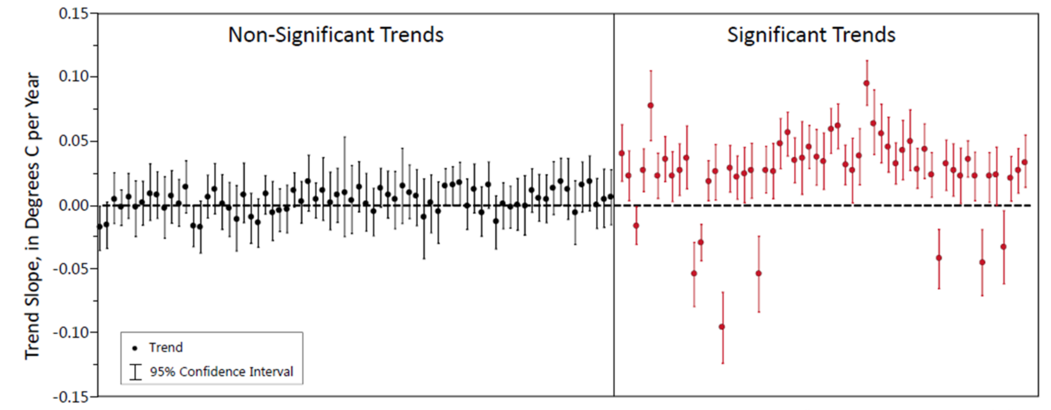


Example of SLR of WT anomalies at one site

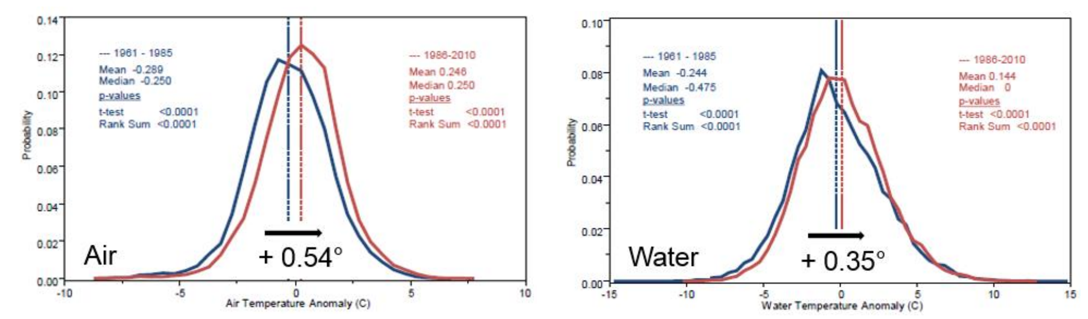
Suitability of irregular-interval WT data to evaluate trends was tested two ways:

1) bootstrapped the SLRs using 1,000 bootstrapped resamples of the WT data for each of the 129 sites; sensitivity of the trend results was evaluated using the bootstrapped 95% confidence interval of the trend slope, focusing on whether the confidence interval indicated non-significance of significant SLR trends, i.e., whether the confidence interval crossed zero; and
2) developed a synthetic 51-year dataset based on 8 years of measured continuous (15-min interval) WT data from USGS station 02035000 from 2005-2012; randomly selected a year of measured continuous data to represent each of the 51 years; applied a decreasing trend, and increasing trend, and no trend to the synthetic dataset; sampled the synthetic dataset using the actual date/time of the WT data collected at each of 28 of the original WT sties and calculated the 28 trends for each of the three groups

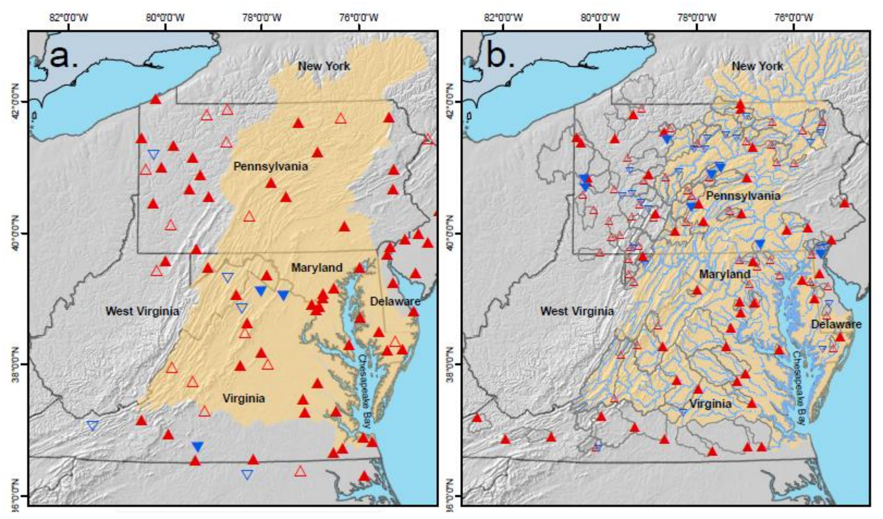
Results



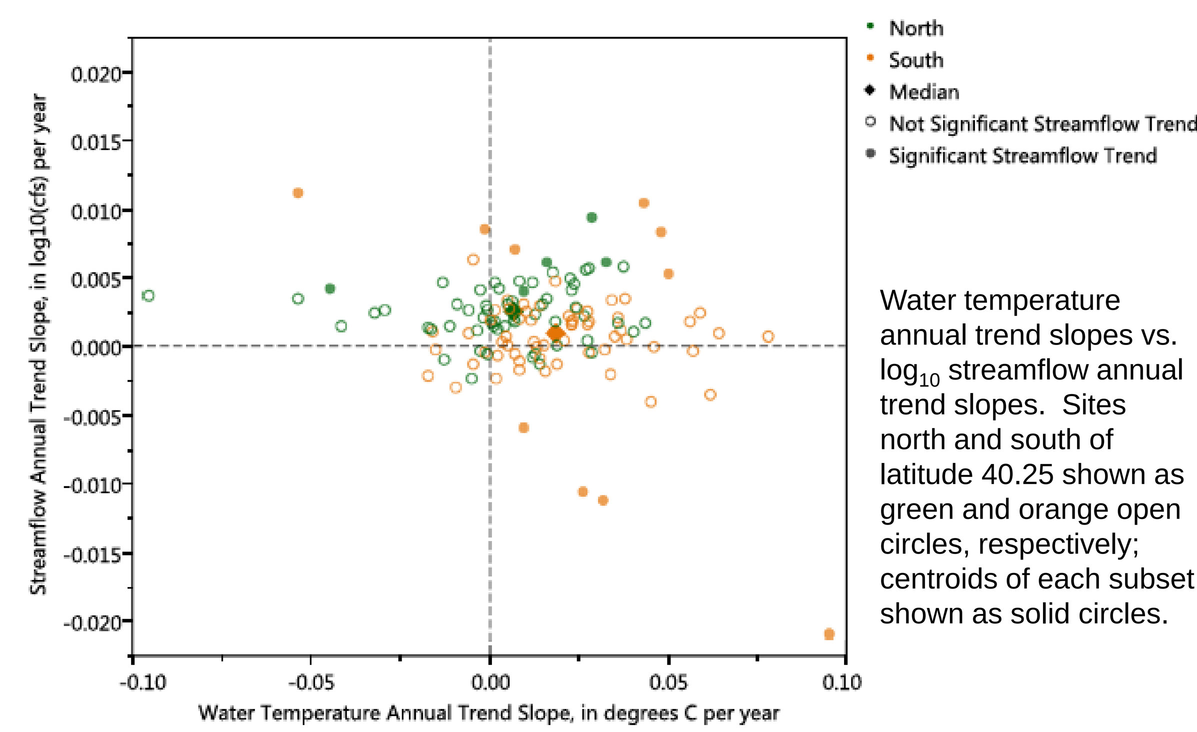
Bootstrapped WT trends; error bars show the 95% confidence interval for the bootstrapped results; none of the significant trends crossed zero.



Probability density functions (pdfs) of anomalies for 1961-1985 and 1986-2010 relative to 1971-2000 for AT and WT.



Temporal trends for 1960-2010 for a) monthly mean air temperature, and b) instantaneous stream-water temperature. Red symbols indicate increasing trends and blue symbols indicate decreasing trends. Solid and open symbols show trends that are statistically significant and not significant, respectively.



Water temperature annual trend slopes vs. $\log_{10}$ streamflow annual trend slopes. Sites north and south of latitude 40.25 shown as green and orange open circles, respectively; centroids of each subset shown as solid circles.

Findings

- Mean regional trends for 1960-2010 were:
  - 0.022°C per year for AT
  - 0.028°C per year for WT
- Anomalies showed a significant shift in mean annual AT of +0.54°C and in mean annual WT of +0.35°C
- Most sites had increasing trends in both instantaneous streamflow and WT
- Comparison of the centroids of streamflow and WT trends for sites north and south of latitude 40.25° shows:
  - streamflows are increasing at a greater rate in the northern part of the study area relative to those in the southern part
  - WT are increasing at a greater rate in the southern part of the study area
- As streams continue to warm, there will be shifts in floral and faunal species distributions
- Measures of watershed topography were inversely correlated with WT trends, indicating that warming trends are damped in higher-elevation settings
- Chesapeake Bay will be subject to changes in salinity, stratification, and eutrophication, in addition to shifts in floral and faunal species distributions
- Despite the wide variability of the streams with respect to watershed area, channel geometry, aspect, elevation, thermal capacity, riparian buffers, microclimate conditions, and land cover, on the whole, WT increased from 1960-2010
- Additional results can be found in Rice, K.C., and Jastram, J.D., 2015, Rising air and stream-water temperatures in Chesapeake Bay region, USA: Climatic Change: v. 128 (iss. 1), p. 127-138

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