Global Temperature Part 1: Observed Trends

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In this bulletin, we explore how the average global surface temperature has changed historically and how these changes have affected forest ecosystems. We discuss the challenge of projecting *future* temperature trends in next month's bulletin.

2014 Recap

It seems fitting to begin our first bulletin of the new year with a look back at how the previous year stacked-up in terms of temperature trends. You may have seen the recent headlines announcing that 2014 was a year of record-setting warmth on a global scale. There is, of course, some level of uncertainty with measuring the temperature of the planet, but it is very likely (90.4% probability) that last year was one of the five warmest years since people began keeping records (NOAA 2015) and it is at least in a statistical tie with 2010 and 2005 (Hansen et al. 2015). Four independent datasets from agencies in the U.S., the UK, and Japan have confirmed this updated temperature record, with 2014 at the top of the charts (Figure 1). Last year simply continued the upward trend that we have observed over the past several decades.

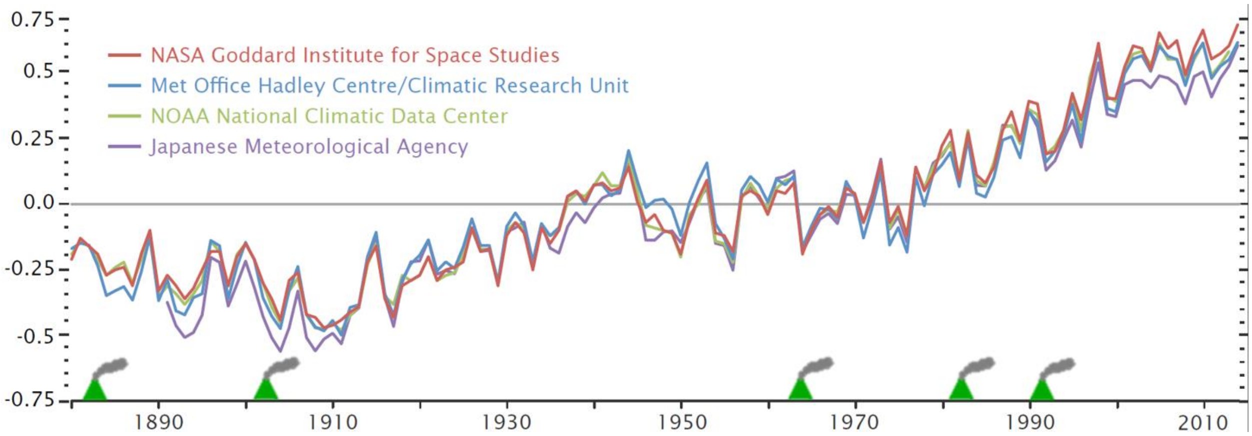

Figure 1: Annual Global Temperature Anomaly (°C), Source: Adapted from NASA, with major volcanic eruptions (producing extensive stratospheric aerosol layer and corresponding global cooling) added.

The Modern Temperature Record

The modern instrumental temperature record goes back to 1880 and is based entirely on direct measurements of land and ocean surface temperature from thermometers. It is only when we go further back in time that we need to rely on proxy temperature records from sources such as tree rings, lake and ocean sediments, ice cores, and others. What is more striking than any single record-breaking year, is the fact that 14 of the 15 warmest years in this record have occurred since 2000. This surface warming, as well as documented increases in the temperature of the *deep* oceans (Levitus et al. 2012), are the result of the earth’s current energy imbalance (more energy staying in than going out).

Over this entire period, the average global temperature rose around 0.85^{0}C (1.53^{0}F) (IPCC 2013). While that might not seem like much of a change, it is worth remembering that the difference between the world today and the depths of an ice age are on the order of 4^{0}C (7.2^{0}F) (Annan and Hargreaves 2015). When we talk about *global* average temperature, relatively small changes can actually mean a big difference in the state of the world.

A Regional View of Global Trends

When we view these temperature trends on a world map, it becomes immediately apparent that things have not changed uniformly across all regions (Figure 2).

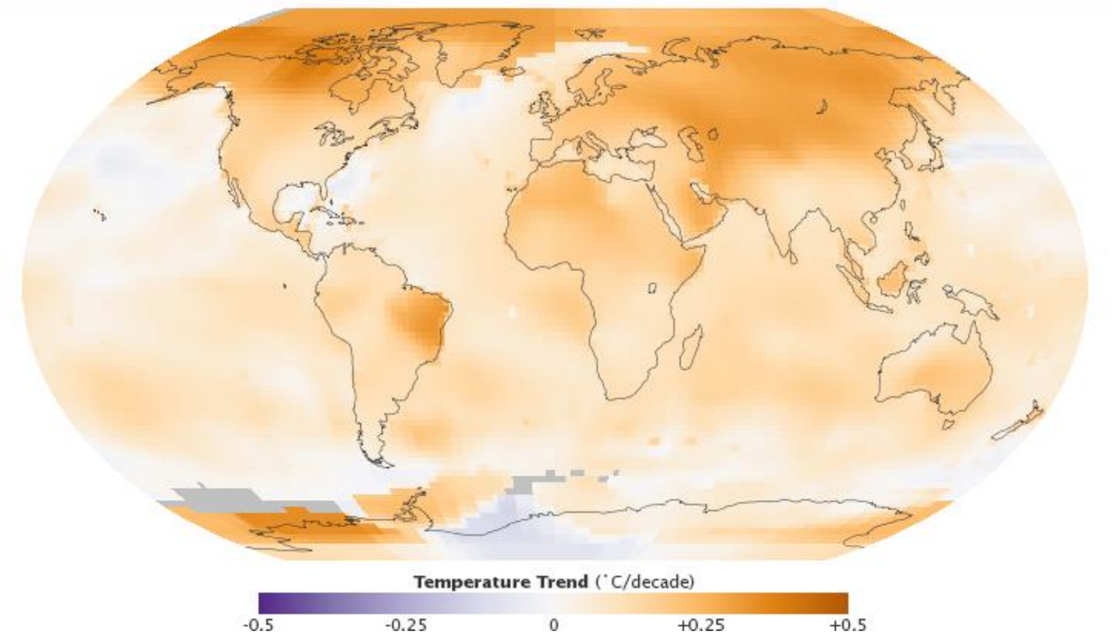

Figure 2: 1950 – 2014 Temperature Trend, Source: NASA/GSFC/Earth Observatory, NASA/GISS

In particular, we have observed greater warming at high latitudes and greater warming over land than oceans. You can see evidence of this spatial pattern in the map above. Most of this regional variation can be explained by three main factors:

1. Polar Amplification
   Warming temperatures lead to the loss of bright snow and ice cover, which exposes darker surfaces (e.g. ocean water) that absorb more solar radiation and create a feedback that accelerates warming at high latitudes.
2. Ocean Heat Capacity
   Oceans have a greater heat capacity than land, which means they warm much more slowly and absorb more energy per unit of temperature increase.
3. Internal Climate Variability
   There are a number of large-scale ocean-atmosphere circulation patterns that drive our regional weather and redistribute heat within the climate system, e.g. North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), El Niño – Southern Oscillation (ENSO), etc.

Ecosystem-Climate Interactions

Now we turn our discussion to where the rubber meets the road for forest managers – a look at how these observed trends affect forest ecosystems at various time scales.

Long-Term Trends

Long-term changes in temperature can profoundly affect vegetation composition across landscapes. One of the best natural experiments for examining this influence is the deglaciation of North America following the end of the last ice age around 10,000 years ago. Using pollen records, researchers have catalogued the ways in which forest composition and individual species abundance have changed over time (Jacobson et al. 1987).

Of course, temperature alone cannot explain all vegetation change, but taken with moisture balance, there is evidence to show that forest composition responded to these climate changes within centuries or less (Shuman et al. 2004) and it has been well-established that past vegetation distribution is an indirect but effective record of global and regional climate change (Williams 2009).

Short-Term Variability

Long-term temperature trends can have a tremendous effect on forest ecosystems, but it is shorter-term climate variability that is most important for the typical timescales of forest management. Perhaps one of the most well-known and influential examples of an internal cycle that drives short-term (year to year) climate variability is the El Niño – Southern Oscillation (ENSO). ENSO is essentially a change in the surface temperature of the equatorial Pacific Ocean that has a hugely important influence on temperature and precipitation throughout the globe.

It is so influential that when ENSO is in a warm phase, also known as an El Niño event, it tends to increase global average temperature for the duration of that phase (typically one to three years). In fact, circling back to the beginning of this post, it's worth mentioning that one of the most interesting aspects of the recent 2014 global temperature record is that it was the hottest year on record that was *not* an El Niño year. Consequently, it is not unreasonable to expect significantly warmer global temperatures when the next El Niño event materializes sometime in the next few years.

Other ramifications of ENSO vary across the globe, but the relatively short time span between the warm (El Niño) and cool (La Niña) phases means that we have been able to observe and study the effects of this phenomenon over many years and have a solid understanding of the weather patterns associated with each phase. Figure 3 displays the typical shifts in temperature and/or moisture that occur during an El Niño year.

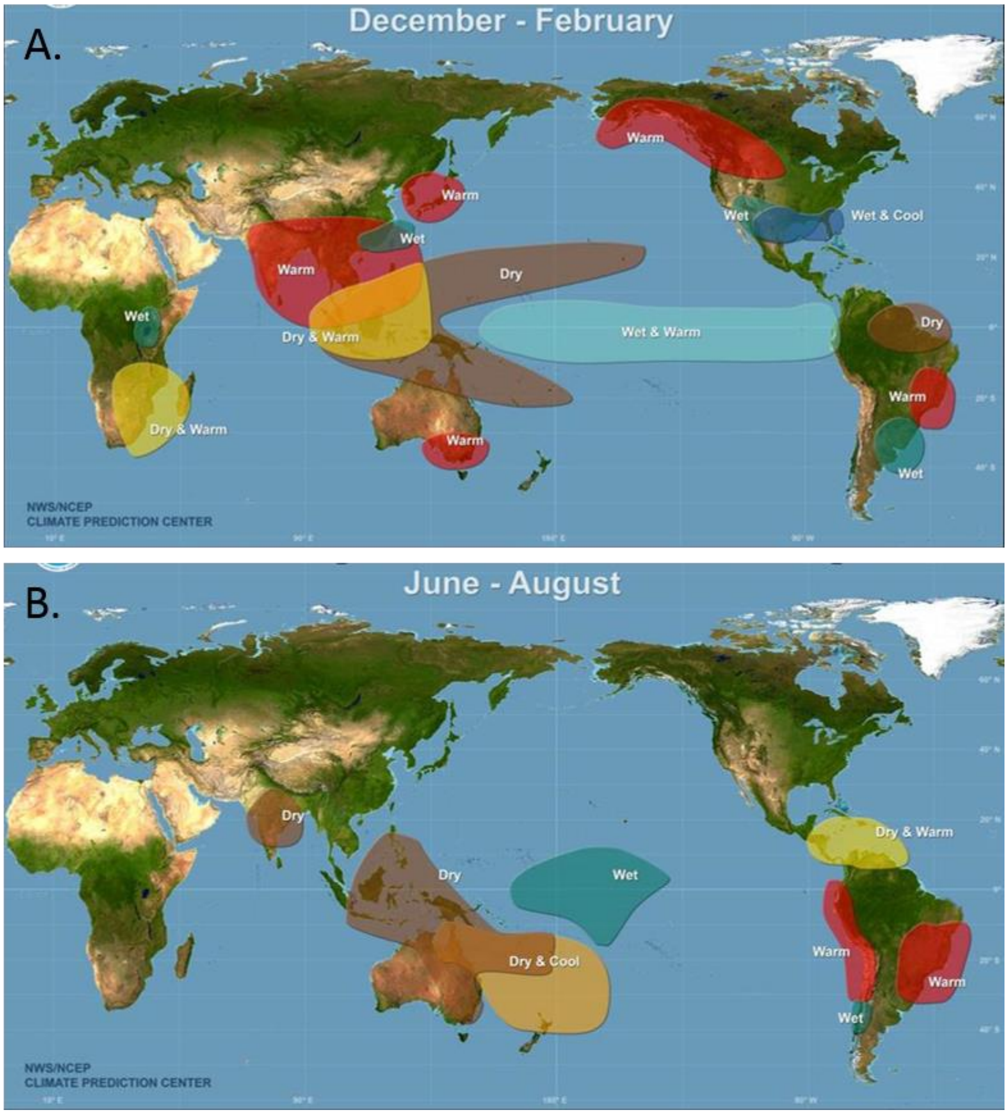

Figure 3: ENSO warm episode (El Nino) relationships in (A) winter and (B) summer, Source: NOAA http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/impacts/warm.gif

This ENSO influence has far-reaching impacts on forest ecosystems throughout the globe. In the boreal forests of North America, it has been shown to drive changes in fire regimes (particularly total area burned) through its effect on atmospheric weather patterns that control fuel moisture (Macias Fauria and Johnson 2008). Researchers have also linked ENSO-driven seasonal changes, specifically warmer springs during strong El Nino events, with significant increases in the rate of carbon sequestration in these boreal ecosystems (Black et al. 2000). Closer to the source, in equatorial forests, ENSO plays a big role in the variability of productivity and phenology from year to year (van Leeuwen et al. 2013; Asner et al. 2000).

Things to Consider

Variability in the earth's climate can be separated into two categories, *external variability* (due to natural and anthropogenic external forcing, e.g. sun cycles, enhanced greenhouse effect) and *internal variability* (due to natural internal processes within the climate system, e.g. ENSO) (IPCC 2001). This internal climate variability modulates the long-term upward global temperature trend that we have observed over the past century, and the interplay between external and internal sources of variability ultimately determines the unique climate conditions felt in each region, making it particularly relevant for land managers. In instances where the forces of internal variability create problematic conditions for forests, such as mild winter conditions that are more favorable to pests, the background trend of ever warming temperatures has the potential to exacerbate those stressors. The flip side will also be true – for example, an El Niño-induced precipitation increase, when combined with the backdrop of warmer temperatures, may lead to increases in plant productivity. In order to prepare for these risks and capitalize on these opportunities, it will be useful to anticipate how both the background trend and these interactions may play out in the future – a task we take on in next month's bulletin on global temperature projections.

Sources

Annan, J. D., and J. C. Hargreaves. 2015. “A Perspective on Model-Data Surface Temperature Comparison at the Last Glacial Maximum.” Quaternary Science Reviews 107 (0): 1–10. doi:http://dx.doi.org/10.1016/j.quascirev.2014.09.019.

Asner, Gregory P., Alan R. Townsend, and Bobby H. Braswell. 2000. “Satellite Observation of El Niño Effects on Amazon Forest Phenology and Productivity.” Geophysical Research Letters 27 (7): 981–84. doi:10.1029/1999GL011113.

Black, T. A., W. J. Chen, A. G. Barr, M. A. Arain, Z. Chen, Z. Nesic, E. H. Hogg, H. H. Neumann, and P. C. Yang. 2000. “Increased Carbon Sequestration by a Boreal Deciduous Forest in Years with a Warm Spring.” Geophysical Research Letters 27 (9): 1271–74. doi:10.1029/1999GL011234.

Bradley, R.S. and Eddy, J.A. (figure compiled by) based on J.T. Houghton et al., Climate Change: The IPCC Assessment, Cambridge University Press, Cambridge, 1990; published in EarthQuest, Vol 5, No 1, 1991.

Hansen, James, Makiko Sato, Reto Ruedy, Gavin A. Schmidt, and Ken Lo. 2015. “Global Temperature in 2014 and 2015.” Earth Institute | Columbia University - Climate Science, Awareness and Solutions. January 16. http://csas.ei.columbia.edu/2015/01/16/global-temperature-in-2014-and-2015/.

Intergovernmental Panel on Climate Change (IPCC). 2001. Appendix | Glossary in *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp. Accessed via: http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/518.htm

Intergovernmental Panel on Climate Change (IPCC). 2013. “Summary for Policymakers.” In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Jacobson, G.L., T. Webb III, and E.C. Grimm. 1987. “Chapter 13: Patterns and Rates of Vegetation Change during the Deglaciation of Eastern North America.” In The Geology of North America - North America and Adjacent Oceans during the Last Deglaciation, K-3:277–88. Boulder, Colorado: Geological Society of America.

Levitus, S., J. I. Antonov, T. P. Boyer, O. K. Baranova, H. E. Garcia, R. A. Locarnini, A. V. Mishonov, et al. 2012. “World Ocean Heat Content and Thermosteric Sea Level Change (0–2000 M), 1955–2010.” Geophysical Research Letters 39 (10): n/a – n/a. doi:10.1029/2012GL051106.

Macias Fauria, Marc, and EA Johnson. 2008. “Climate and Wildfires in the North American Boreal Forest.” Philosophical Transactions of the Royal Society B: Biological Sciences 363 (1501): 2317–29. doi:10.1098/rstb.2007.2202.

National Oceanic and Atmospheric Administration. 2015. “State of the Climate: Global Analysis - Annual 2014 | Calculating the Probability of Rankings for 2014.” NOAA National Climatic Data Center. January. http://www.ncdc.noaa.gov/sotc/global/2014/13/supplemental/page-1.

Shuman, B., P. Newby, Y. Huang, and T. Webb III. 2004. “Evidence for the Close Climatic Control of New England Vegetation History” 85 (5): 1297–1310.

Van Leeuwen, Willem J.D., Kyle Hartfield, Marcelo Miranda, and Francisco J. Meza. 2013. “Trends and ENSO/AAO Driven Variability in NDVI Derived Productivity and Phenology alongside the Andes Mountains.” Remote Sensing 5 (3): 1177–1203. doi:10.3390/rs5031177.

Williams, J. 2009. “Quaternary Vegetation Distributions.” Encyclopedia of Paleoclimatology and Ancient Environments. Dordrecht, The Netherlands: Springer.