



Twentieth century bipolar seesaw of the Arctic and Antarctic surface air temperatures

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[1] Understanding the phase relationship between climate changes in the Arctic and Antarctic regions is essential for our understanding of the dynamics of the Earth's climate system. In this paper we show that the 20th century detrended Arctic and Antarctic temperatures vary in anti-phase seesaw pattern – when the Arctic warms the Antarctica cools and visa versa. This is the first time that a bi-polar seesaw pattern has been identified in the 20th century Arctic and Antarctic temperature records. The Arctic (Antarctic) detrended temperatures are highly correlated (anti-correlated) with the Atlantic Multi-decadal Oscillation (AMO) index suggesting the Atlantic Ocean as a possible link between the climate variability of the Arctic and Antarctic regions. Recent accelerated warming of the Arctic results from a positive reinforcement of the linear warming trend (due to an increasing concentration of greenhouse gases and other possible forcings) by the warming phase of the multidecadal climate variability (due to fluctuations of the Atlantic Ocean circulation). **Citation:** Chylek, P., C. K. Folland, G. Lesins, and M. K. Dubey (2010), Twentieth century bipolar seesaw of the Arctic and Antarctic surface air temperatures, *Geophys. Res. Lett.*, 37, L08703, doi:10.1029/2010GL042793.

1. Introduction

[2] Although the polar regions comprise a relatively small fraction of the Earth's surface, the climate change in polar regions are of prime interest due to possible melting of the polar ice sheets and subsequent sea level rise. The polar regions are expected to be more susceptible to external climate forcing and to unforced natural variability due to the sea ice/snow albedo-temperature feedback. An open ocean absorbs more solar radiation and allows more heat to be transferred to the atmosphere than an ocean covered by sea ice.

[3] The Arctic has undergone a well documented rapid warming starting in the 1970s. Since the atmospheric carbon dioxide concentration increased from 339 ppm in 1980 to 387 ppm in 2009, it has been generally accepted that the Arctic warming represents a regional amplification of global warming which is primarily due to the increase in fossil fuel burning. This interpretation has been further strengthened by the fact that the recent Arctic warming has been about twice

the global average [Chylek *et al.*, 2009], in agreement with the results of the AOGCMs (Atmosphere Ocean General Circulation Models) simulations.

[4] However, there are still unanswered questions concerning the Arctic climate and its evolution that cast some doubt on the above explanation. The first problem is that the early 20th century (1910–1940) rate of the Arctic warming (0.63 K/decade) was at least as high as the 1980–2008 warming rate (0.60 K/decade), suggesting that natural climate variability can produce a warming similar to the present one. Furthermore, none of the AOGCMs used in the IPCC 2007 climate assessment report has been able to reproduce the early 20th century (1910–1940) Arctic warming followed by a sharp cooling period (1940–1970), although all models simulated the post 1970s warming trend [Gillett *et al.*, 2008]. Consequently our understanding of Arctic climate, its internal variability, its drivers and responses is not yet complete.

[5] In the following we show that the multidecadal scale variability of detrended Arctic and Antarctic temperature time series were highly anticorrelated during the 20th century. Consequently we suggest that the Atlantic Ocean may provide the physical link leading to the coherent multidecadal scale climate changes of opposite phases in the two polar regions. We further suggest the ocean variability contributed at least as much to the recent Arctic warming as the increase of atmospheric concentration of greenhouse gases (GHGs).

2. Seesaw Pattern of the Arctic and Antarctic Temperature

[6] In our analysis of the polar region temperature records (Figure 1) we use the annual averaged temperature from meteorological stations north from 64°N and south of 64°S as compiled by the NASA Goddard Institute for Space Studies (GISS) [Hansen *et al.*, 2006] and made available on its website (<http://data.giss.nasa.gov/gistemp/tabledata/ZonAnn.Ts.txt>). The 64°S–90°S time series starts in 1903. To compensate for scarcity of station data in the polar regions in the early records, the NASA GISS data set uses spatial correlations between stations within 1200 km of each other to interpolate and extrapolate the data [Hansen *et al.*, 1999]. This procedure affects predominantly the early 20th century Antarctic temperature and is likely responsible for its large variability as well as for an enhancement of its linear trend.

[7] We decompose the time series into a linear trend (presumably dominated by increasing concentrations of greenhouse gases) and a residual variability. To isolate multidecadal scale variability we smooth the residual detrended data by applying either an 11 year or a 17 year running average (Figure 2a). We find the residual detrended series to be highly anti-correlated reflecting the seesaw pattern. The

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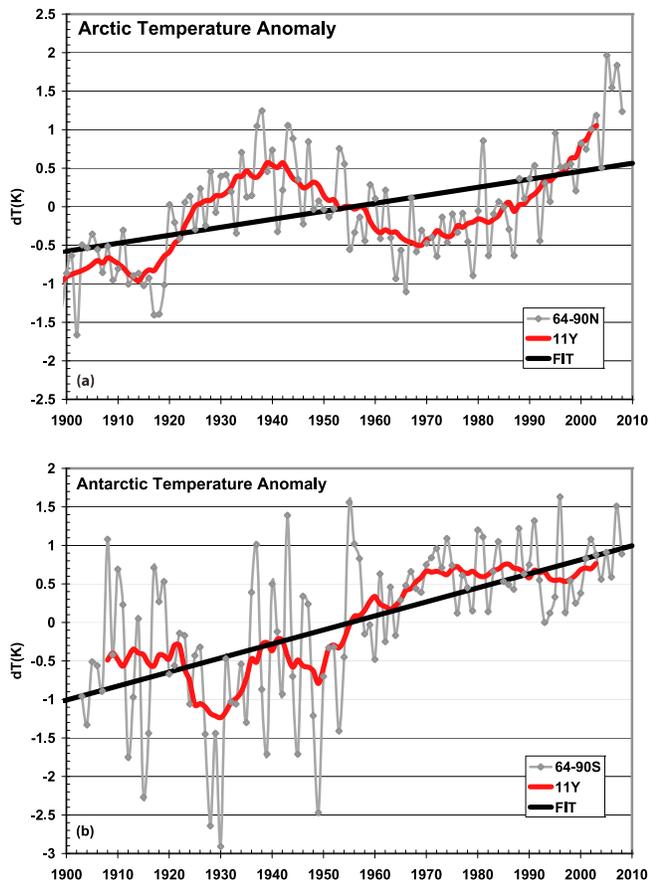


Figure 1. Temperature anomaly with respect to the 1903–2008 average, its 11 year running mean (red line) and the least square linear fit (thick black line) for the (a) Arctic and (b) Antarctic region. Temperature data used are from the NASA GISS compilation.

correlation coefficients are $r = -0.76$ for the 11 year averages and $r = -0.89$ for the 17 year averages. We use two different smoothing periods to show that the correlations remain robust independent of the averaging period. The correlation coefficient increases (in absolute value) monotonically with the length of the smoothing interval, however, at the same time the statistical significance decreases (Figure 3) due to decreasing degrees of freedom. The 17 year averaging has been found to provide the maximum anti-correlation while keeping the significance at the 95% confidence level ($p < 0.05$).

[8] Since the NASA GISS temperature time series especially in early years of the 20th century depends at least partially on the way the data set was formed (interpolation and extrapolation methods used), we provide an additional support for robustness of the observed anti-correlations by using the UK Met Office–University of East Anglia Climate Research Unit (CRU) temperature gridded dataset on a $5^\circ \times 5^\circ$ grid [Brohan *et al.*, 2006]. The HadCRUT3v dataset combines land and ocean monthly temperatures. It considers only the grid-points where measurements are available and does not extrapolate the data. We use the data for the time span from 1880–2008. To avoid the latitudinal belts with very few observations in the early years we consider the Southern Hemisphere data only north of latitude 55°S . We

calculate the average temperature time series within individual 5° wide latitudinal zones and then compute cross correlation coefficients between individual zonal de-trended time series. The results (Figure 4) show high anti-correlations between the polar regions and confirms that the anti-correlation is a robust feature which does not depend on the details or differences between the GISS and HadCRUT data sets.

[9] The strong anti-correlation of the multidecadal temperature anomalies in the Arctic and Antarctic regions suggests a common cause. The complete cycle of the 20th century residual de-trended temperature took about 70 years. The most likely component of the climate system whose state can persist for decades are oceans.

[10] The residual polar temperatures (Figure 2a) are unlikely to be dominated by solar activity since the changes in solar irradiance would lead to simultaneous warming or cooling in both the Arctic and Antarctic regions, instead of the observed seesaw pattern. The same applies to the solar modification of the cosmic ray flux. Although aerosols might have contributed towards the Arctic cooling between 1940 and 1970 and the following warming [Baines and Folland, 2007; Chylek *et al.*, 2007] it is unlikely that they were the dominant change agent during this period. Note, however, that from 1930 to 1940 simultaneous warming of both polar

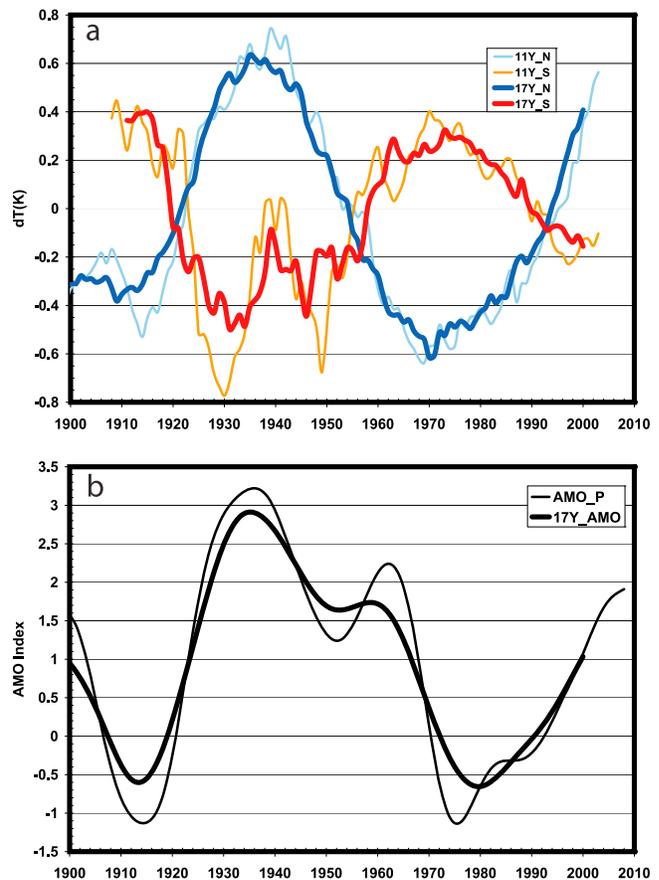


Figure 2. (a) De-trended Arctic (blue) and Antarctic (red) temperature time series smoothed by a 11 year running average (thin lines) or 17 year running average (thick lines), and (b) the AMO index [after Parker *et al.*, 2007] annual values (thin line) and 17 year running average (thick line).

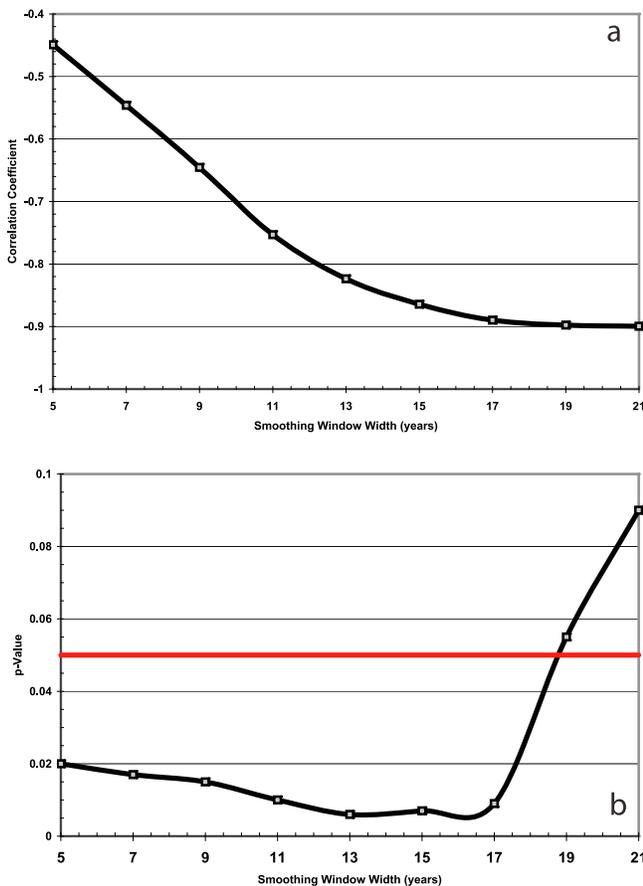


Figure 3. (a) Correlation coefficient between the GISS Arctic (64° – 90° N) and Antarctic (64° – 90° S) de-trended temperature anomalies for the years 1903–1908 as a function of the width of the smoothing window used, and (b) the corresponding p-value. The horizontal line at $p = 0.05$ indicates the limit of the 95% confidence level.

regions followed by a simultaneous cooling episode from 1940 to 1950 (visible on the 11 years averaged residual temperatures in Figure 2a) is consistent with a more globally uniform forcing such as changes in the solar irradiance or the solar modification of cosmic ray flux and cloudiness.

[11] The role of the Atlantic Ocean in the multidecadal scale variability of polar temperatures is further supported by the high correlation (or anticorrelation) of the residual temperature time series with the AMO (Atlantic Multidecadal Oscillation) index [Folland *et al.*, 1986; Knight *et al.*, 2006; Knight, 2009]. An increasing AMO index is associated with warming of the North Atlantic with especially pronounced warm anomalies in the subtropical North Atlantic (hurricane generation region) and in the northern part of the North Atlantic near the southern tip of Greenland [Goldenberg *et al.*, 2001; Grossmann and Klotzbach, 2009]. The origin of the AMO is generally ascribed to the variability of the Atlantic Meridional Overturning Circulation (AMOC), supported particularly by Knight *et al.* [2005]. They show that a clear AMO signal is strongly linked to natural variations in the model's overturning circulation on a near century time scale in a 1400 year control run of the HadCM3 coupled climate model. Although Mann and Emanuel [2006] suggested that the origin of the AMO may

be anthropogenic, and indeed recent fluctuations of the AMO are likely to have a near in phase anthropogenic component [Baines and Folland, 2007], a long-term ice core $\delta^{18}\text{O}$ data from the south-central Greenland [Stuiver *et al.*, 1995] indicates that similar quasi-periodic oscillations have existed for hundreds of years before the age of industrialization. This is supported by an analysis of proxy and instrumental climate data for the last 330 years showing a near 70 year fluctuation of surface temperature consistent in phase with AMO time series of Parker *et al.* [2007] in the Atlantic region of the Northern Hemisphere [Delworth and Mann, 2000].

[12] The AMO index based on an eigenvector analysis of worldwide sea surface temperature [Parker *et al.*, 2007] is shown in Figure 2b, together with its 17 year running average. Note that the Parker *et al.* AMO time series is quite similar to that of Trenberth and Shea [2006] even though the calculation details are different. The correlation coefficient with the Arctic temperature residual time series is $r = 0.71$ for the 11 year AMO index average and $r = 0.72$ for the 17 year averages, while the corresponding anti-correlations with the Antarctic temperature are $r = -0.69$ and $r = -0.80$.

3. Ocean Circulation

[13] While a high correlation between the AMO and the Arctic temperature and anti-correlation with the Antarctic temperature suggests a connection between the multidecadal temperature variability of the polar regions and the state of the Atlantic Ocean, it does not provide a physical mechanism through which the needed transfer of energy can be accomplished.

[14] One picture of the ocean thermohaline circulation is that by temperature-salinity buoyancy forces, wind and internal mixing. It consists of cold salty water sinking in the Nordic and Labrador sea and around Antarctica with upwelling over wide areas of the Indian and the Pacific Oceans.

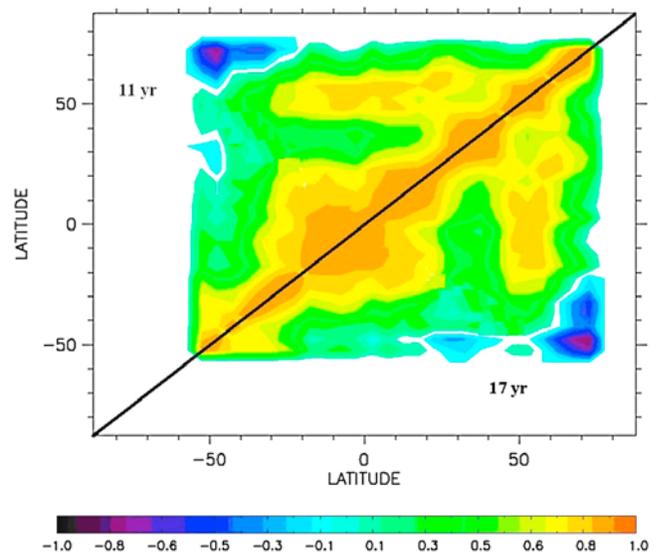


Figure 4. Cross-correlation coefficient between individual 5° wide latitudinal zones using 11 year (above the diagonal) or 17 year (below the diagonal) averaging of the de-trended HadCRUT3v temperature data. The dark blue indicates high anti-correlation between the two ends of polar region.

[15] In an alternate picture of ocean circulation [Toggweiler and Russell, 2008], the upwelling is dominated by wind stress along the Antarctic Circumpolar Current (ACC). It has been estimated [Wunsch, 1998] that about 70% of the wind energy transferred globally to the ocean takes place within the ACC. The deep and intermediate waters are drawn to the surface by the wind stress and are subsequently heated by the sun and contact with the atmosphere. Then the Atlantic surface current transports the warm waters away from the Antarctic region, northward towards the equator, with additional warming, and then further north towards the Arctic. In this way heat that would otherwise be available to the Southern Ocean and Antarctica is being exported to the northern hemisphere and northward to the Arctic. The more efficient this transport, the greater is the warming in the Arctic at the expense of the Antarctic. This model of ocean circulation with a return of deep water to the surface in the Southern Ocean followed by a transport towards the Arctic is consistent with the observed seesaw pattern of the Arctic and Antarctic multidecadal temperature variability.

[16] The Arctic and Antarctic temperature seesaw pattern has also been observed in paleo ice core records [Blunier et al., 1998; Blunier and Brook, 2001] and reproduced in paleoclimate modeling [Toggweiler and Bjornsson, 2000]. Thus polar seesaw patterns similar to the one observed during the 20th century may have indeed existed during the past centuries and millennia.

4. Summary

[17] A bi-polar seesaw pattern of the paleo temperature has been observed earlier in the Greenland and Antarctic ice core data. For the first time we identify a bi-polar seesaw pattern in the 20th century Arctic and Antarctic instrumental temperature records. The detrended multidecadal scale variability of the Arctic and Antarctic temperature time series are highly anticorrelated. When the Arctic warms Antarctica cools and vice versa. This multidecadal variability combines with the general warming trend (presumably dominated by anthropogenic GHGs) to produce the observed Arctic and Antarctic temperature patterns. The intense Arctic warming since the 1970s (Figure 1a) arises from an additive combination of the general global warming trend with the warming phase of the multidecadal climate oscillation, while in Antarctica the cooling phase of the multidecadal oscillation opposes the general warming trend leading to essentially no significant Antarctic temperature change since the 1970s (Figure 1b).

[18] The high correlation of the polar de-trended temperature time series with the AMO index suggests that the variability of the Atlantic ocean circulation might serve as a link with the bi-polar temperature seesaw pattern. The observed seesaw pattern is consistent with the model of the inter-hemispheric ocean circulation that includes a strong upwelling along the Antarctic Circumpolar Current.

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References

- Baines, P., and C. K. Folland (2007), Evidence for a rapid global climate shift across the late 1960s, *J. Clim.*, *20*, 2721–2744, doi:10.1175/JCLI4177.1.
- Blunier, T., and E. Brook (2001), Timing of millennial-scale climate change in Antarctica and Greenland during the last glacial period, *Science*, *291*, 109–112, doi:10.1126/science.291.5501.109.
- Blunier, T., et al. (1998), Asynchrony of Antarctic and Greenland climate change during the last glacial period, *Nature*, *394*, 739–743, doi:10.1038/29447.
- Brohan, P., J. J. Kennedy, I. Harris, S. F. B. Tett, and P. D. Jones (2006), Uncertainty estimates in regional and global observed temperature changes: A new dataset from 1850, *J. Geophys. Res.*, *111*, D12106, doi:10.1029/2005JD006548.
- Chylek, P., U. Lohmann, M. Dubey, M. Mishchenko, R. Kahn, and A. Ohmura (2007), Limits on climate sensitivity derived from recent satellite and surface observations, *J. Geophys. Res.*, *112*, D24S04, doi:10.1029/2007JD008740.
- Chylek, P., C. Folland, G. Lesins, M. Dubey, and M. Wang (2009), Arctic air temperature change amplification and the Atlantic Multidecadal Oscillation, *Geophys. Res. Lett.*, *36*, L14801, doi:10.1029/2009GL038777.
- Delworth, T. L., and M. E. Mann (2000), Observed and simulated multidecadal variability in the Northern Hemisphere, *Clim. Dyn.*, *16*, 661–676, doi:10.1007/s003820000075.
- Folland, C. K., T. Palmer, and D. E. Parker (1986), Sahel rainfall and worldwide sea temperatures, *Nature*, *320*, 602–607, doi:10.1038/320602a0.
- Gillett, N. P., et al. (2008), Attribution of polar warming to human influence, *Nat. Geosci.*, *1*, 750–754, doi:10.1038/ngeo338.
- Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nunez, and W. M. Gray (2001), The recent increase in Atlantic hurricane activity: causes and implications, *Science*, *293*, 474–479, doi:10.1126/science.1060040.
- Grossmann, I., and P. Klotzbach (2009), A review of North Atlantic modes of natural variability and their driving mechanism, *J. Geophys. Res.*, *114*, D24107, doi:10.1029/2009JD012728.
- Hansen, J., R. Ruedy, J. Glascoe, and M. Sato (1999), GISS analysis of surface temperature change, *J. Geophys. Res.*, *104*, 30,997–31,022, doi:10.1029/1999JD900835.
- Hansen, J., M. Sato, R. Ruedy, K. Lo, D. Lea, and M. Medina-Elizade (2006), Global temperature change, *Proc. Natl. Acad. Sci. U. S. A.*, *103*, 14,288–14,293, doi:10.1073/pnas.0606291103.
- Knight, J. R. (2009), The Atlantic Multidecadal Oscillation inferred from the forced climate response in coupled general circulation models, *J. Clim.*, *22*, 1610–1625, doi:10.1175/2008JCLI2628.1.
- Knight, J. R., R. J. Allan, C. K. Folland, M. Vellinga, and M. Mann (2005), A signature of the persistence natural thermohaline circulation cycle in observed climate, *Geophys. Res. Lett.*, *32*, L20708, doi:10.1029/2005GL024233.
- Knight, J. R., C. K. Folland, and A. A. Scaife (2006), Climate impact of the Atlantic Multidecadal Oscillation, *Geophys. Res. Lett.*, *33*, L17706, doi:10.1029/2006GL026242.
- Mann, M. E., and K. A. Emanuel (2006), Atlantic hurricane trends linked to climate change, *Eos Trans. AGU*, *87*(24), doi:10.1029/2006EO240001.
- Parker, D. E., C. K. Folland, A. A. Scaife, A. Colman, J. Knight, D. Fereday, P. Baines, and D. Smith (2007), Decadal to interdecadal climate variability and predictability and the background of climate change, *J. Geophys. Res.*, *112*, D18115, doi:10.1029/2007JD008411.
- Stuiver, M., P. M. Grootes, and T. F. Braziunas (1995), The GISP2 $\delta^{18}\text{O}$ climate record of the past 16,500 years and the role of the sun, ocean and volcanoes, *Quat. Res.*, *44*, 341–354, doi:10.1006/qres.1995.1079.
- Toggweiler, J. R., and H. Bjornsson (2000), Drake Passage and paleoclimate, *J. Quat. Sci.*, *15*, 319–328, doi:10.1002/1099-1417(200005)15:4<319::AID-JQS545>3.0.CO;2-C.
- Toggweiler, J. R., and J. Russell (2008), Ocean circulation in a warming climate, *Nature*, *451*, 286–288, doi:10.1038/nature06590.
- Trenberth, K. E., and D. J. Shea (2006), Atlantic hurricanes and natural variability in 2005, *Geophys. Res. Lett.*, *33*, L12704, doi:10.1029/2006GL026894.
- Wunsch, C. (1998), The work done by the wind on the oceanic general circulation, *J. Phys. Oceanogr.*, *28*, 2332–2340, doi:10.1175/1520-0485(1998)028<2332:TWDBTW>2.0.CO;2.
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