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Proceedings of the 2017 WMO Aeronautical Meteorology Scientific Conference

Commission for Aeronautical Meteorology
assisted by
Commission for Atmospheric Sciences
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AIRCRAFT OBSERVATIONS AND REANALYSIS DEPICTIONS OF TRENDS IN THE NORTH ATLANTIC POLAR FRONT JET STREAM WIND SPEEDS AND TURBULENCE

By J. Tenenbaum and P.D. Williams

(Presented by J. Tenenbaum)

Presentation

Introduction

Multiple model-based studies of the North Atlantic polar front jet stream have considered the effects of doubled CO_2 (Williams and Joshi 2013; Delcambre et al. 2013). Two key questions are whether any effects can already be seen in observations and whether any effects can be seen independent of computer models. A major tool in the climate change community is atmospheric reanalyses (NCEP-NCAR: Kalnay et al. 1996, Kistler at al. 2001; ERA: Uppala et al. 2005, Dee et al. 2011) which calculate an optimum depiction of the jet stream when the reanalysis model is held fixed for 40 to 50 years. But such reanalyses do depend on the underlying assimilation model. In addition, any secular trends must be disentangled from other oscillations that affect the North Atlantic: the North Atlantic Oscillation (NAO; Hurrell et al. 2003) and the Atlantic Multi-decadal Oscillation (AMO; Schlesinger 1994).

We have addressed these issues by using three separate data sources: the NCEP-NCAR reanalyses, the underlying AMDAR/ACARS aircraft wind observation archive (Moninger et al. 2003), and the Global Aircraft Data Set (GADS: Tenenbaum 1991, Cardinali et al. 2004, Gill and Buchanan 2013) archive. The reanalyses are somewhat correlated with AMDAR because those observations form a major component of cruise-level results. The 3 billion GADS observations (100 million over the North Atlantic during 2002-2017) taken from the flight data recorders of multiple carriers are independent of both reanalyses and AMDAR. They also provide direct measurements of the turbulence associated with the North Atlantic jet.

Discussion

The AMDAR observations archive represent automated real-time meteorological reports that are digitally transmitted from cruise levels of most of the world's long haul aircraft (referred to as ACARS over and near North America). Typical report spacing is 7.5 min (~110 km). Their value relative to manually radioed AIREP (PIREP) observations is that no additional errors are introduced by the voice transmission step. The GADS observation archive represents an alternate approach using flight data recorders. The underlying measurements are the same as AMDAR; only the data pathway changes. While not available in real time, they have spacing of 4 seconds (~1 km) and also include turbulence measurements similar to DEVG (derived vertical gust velocity, Gill, 2012). We are currently working on a comparison with the WMO aircraft independent standard of EDR (eddy dissipation rate, Sharman et al. 2014, Sharman and Lane 2016).

Delcambre et al. (2013) have studied the effects of doubled CO_2 by using models contributing to phase 3 of the Coupled Model Inter-comparison Project (CMIP3) ensemble. They summarize multiple previous studies that suggest anthropogenic climate change impacts on the eddy–jet system include an intensified mid-latitude jet stream, an elevated tropopause, and a poleward-shifted jet. To study the wind speed changes in more detail, they use 17 twenty-first-century projections of the ensemble mean zonal wind change at 300 hPa. They "predict … an overall expansion of the Atlantic jet … [and that] zonal winds are projected to decrease in the core of the … Atlantic jets, with increasing zonal winds located primarily in the jet exit regions and the meridional flanks of the jets."

To roughly match the Delcambre et al. analyses we have concentrated on the polar front jet exit region as illustrated in Fig. 1. It displays the turbulence associated with the pre-industrial jet which illustrates the polar front jet location. Superimposed are three rectangular boxes extending from 40°W to 10°W in longitude and ±4° in latitude centered on the mean latitude of the eastbound transatlantic routes [New York (JFK) to London (LHR)] used for the subsequent comparisons. Also depicted is the great circle route whose location is combined with the forecast winds to establish the North Atlantic Track System (NATS) on a twice-daily basis (Williams and Joshi, 2013). Because of the location of the great circle route between New York and London, these boxes contain large numbers of aircraft observations and are in the jet exit region described by Delcambre et al.

Our first result using NCEP reanalyses yields a tiny increase in the jet stream wind speeds over the period winter 1979-2017 (DJF) and is shown in Fig. 2. But that increase is not statistically significant and is possibly due to the flip in the strength of the AMO around 2000 as illustrated in Fig. 3. As a reminder, the AMO is a 65-70 year oscillation of Atlantic sea-surface temperatures independent of any secular changes (Schlesinger, 1994). We try to eliminate the effects of the AMO by concentrating on 2002-2017 when the AMO sign and magnitude were relatively stable and the AMDAR and GADS observations (JFK-LHR) were available. Our second result (Fig. 4), shows increases in wind speed which are statistically significant for the NCEP reanalysis at the 5% level (F value = 3.13) and marginally statistically significant for AMDAR (F value = 1.59), both with 14 degrees of freedom. Their geographical distribution – an increase in the jet exit region - is consistent with the modelling results of 21st century doubled CO_2 of Delcambre et al. (2013).

Because of the very large number of observations in the GADS archive, we are able to present results both for all flight levels and for only flight level 370. The former is most comparable to the NCEP reanalyses (effectively FL370 to FL320) while the latter can avoid changes due to changing air carrier procedures with respect to flight level. But the effects of a possibly rising tropopause (and jet) at a fixed flight level need further investigation. The GADS interval results also show wind speed increases but are only currently processed for 2002-2013 due to soon to be relaxed contractual limitations. Because the reanalysis and AMDAR changes are not independent, we also compare the NCEP reanalysis with the (currently) 13 year GADS observation sequence which *is* independent of any computer models. The NCEP reanalysis and GADS results for 2002-2013 are shown in Fig. 5 (all flight levels) and Fig. 6 (just FL370). Again the slopes are positive but the NCEP reanalysis and GADS observations are only weakly significant due in part to the shortness of the series (F value 0.46 and 0.36 for 10 degrees of freedom). We await the longer, 2002-2017 results.

The GADS turbulence measurement consists of the minimum and maximum vertical acceleration a_{zn} and a_{zx} during the one second preceding every four-second GADS observation. In our preliminary 2002-2013 interval results, there is no clear trend in "light" turbulence (not shown).

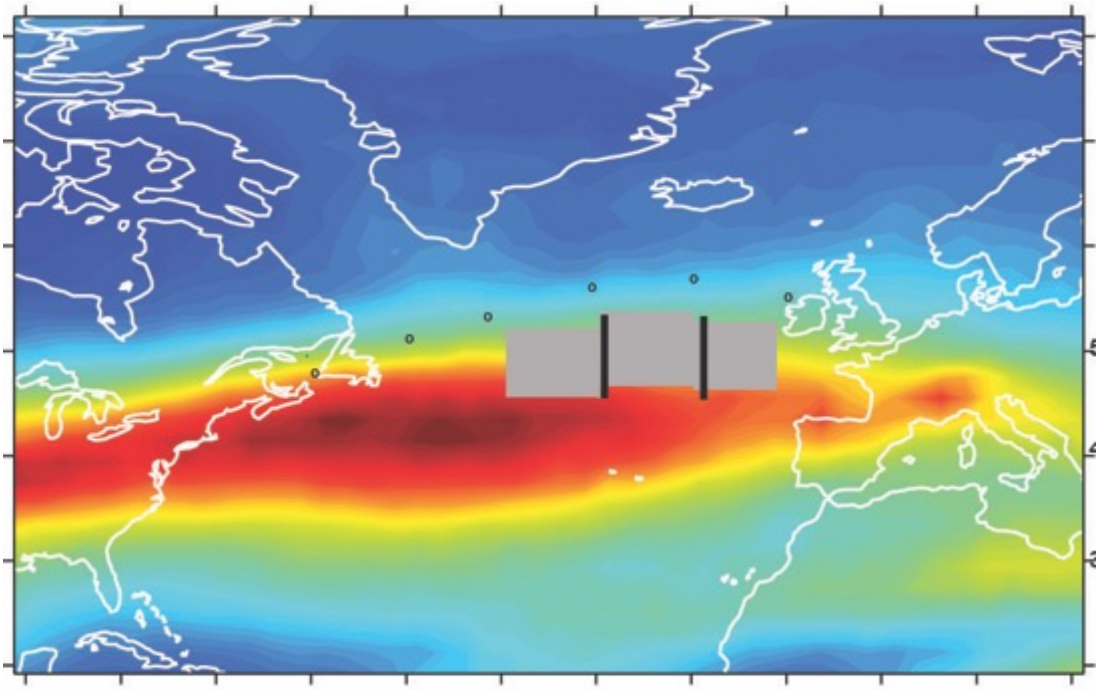

Figure 1. The turbulence associated with the pre-industrial polar front winter Atlantic jet stream (colour coded contours, 20 years of variant 1 of Ellrod's turbulence index at 200 hPa), the three aircraft observation (AMDAR, GADS) boxes in the jet exit region (grey rectangles), and some points on the Great Circle route across the Atlantic (black o's).

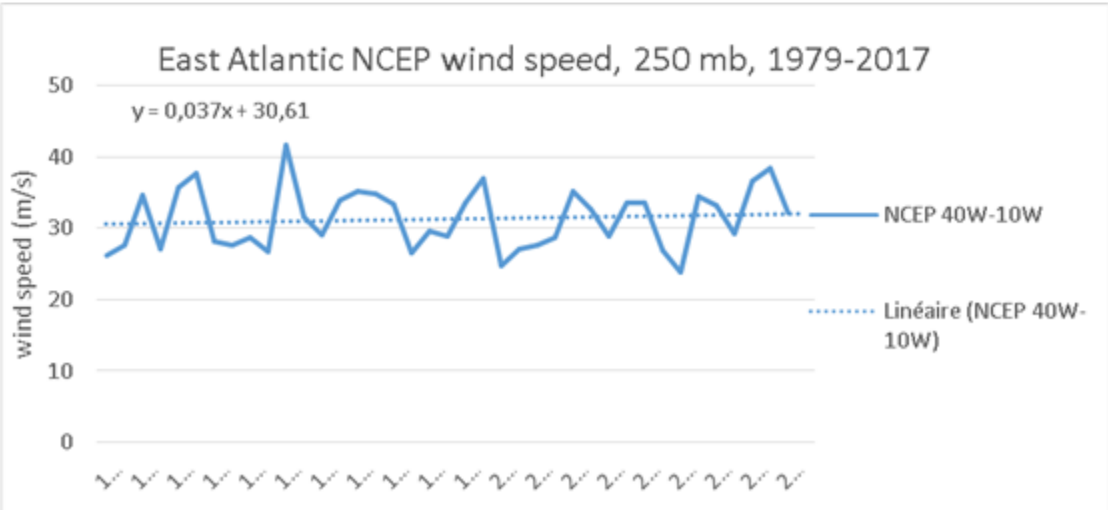

Figure 2. Wind speed versus year at the North Atlantic polar front jet exit region averaged over the three rectangular boxes shown in Fig. 1 at 250 hPa. The longitudes covered are from 40°W to 10°W and the periods covered are the Northern Hemisphere winter (DJF) with the winter labelled by the January year. The 39-year least square fit is superimposed and corresponds to an annual increase of 0.12% (NCEP reanalysis).

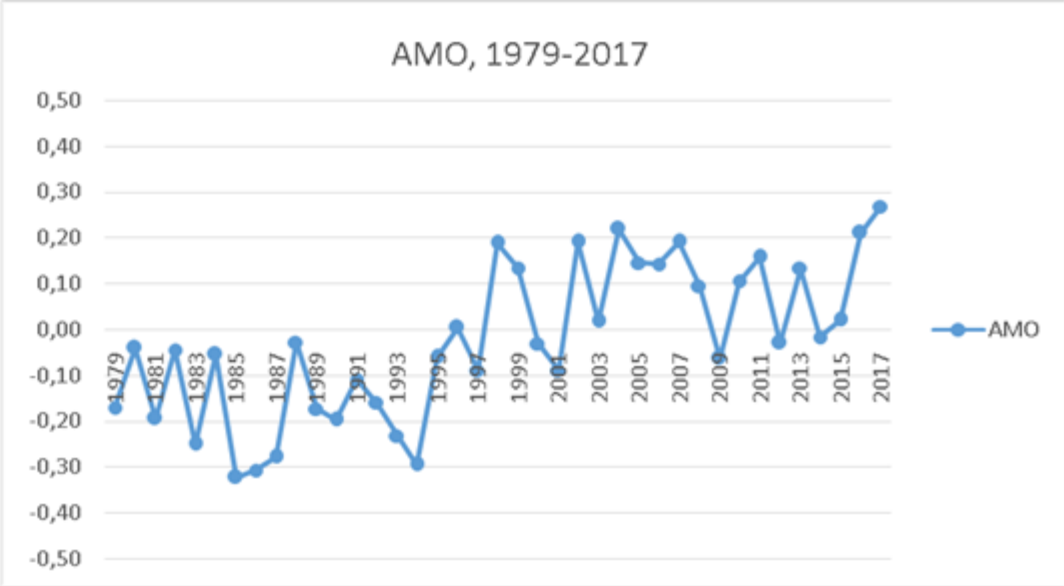

Figure 3. The Atlantic Multi-decadal Oscillation index for winter (DJF) 1979-2017 taken from https://www.esrl.noaa.gov/psd/data/correlation/amon.us.data. [Accessed 30 Sep 2017]

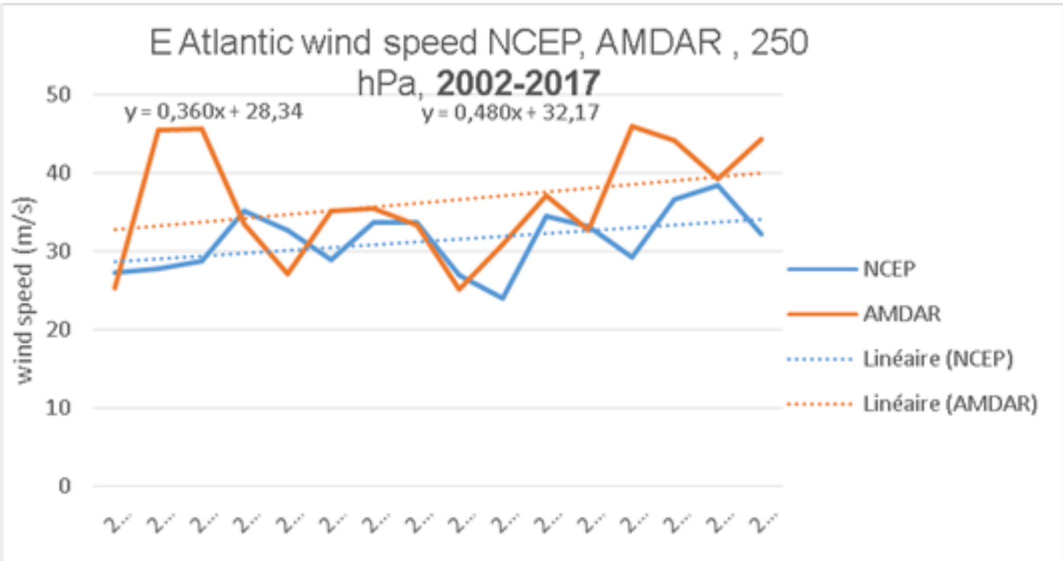

Figure 4. Secular change in wind speed for AMDAR observations and NCEP reanalysis near 250 hPa. Plot is of the winter (DJF) jet exit region for years (2002-2017) when AMO is relatively stable. Equations of least square fits are superimposed and correspond to annual increases of 1.49% (AMDAR) and 1.27% (NCEP reanalysis). In this and subsequent secular plots the least squares fits are listed in the order that they appear in the legend.

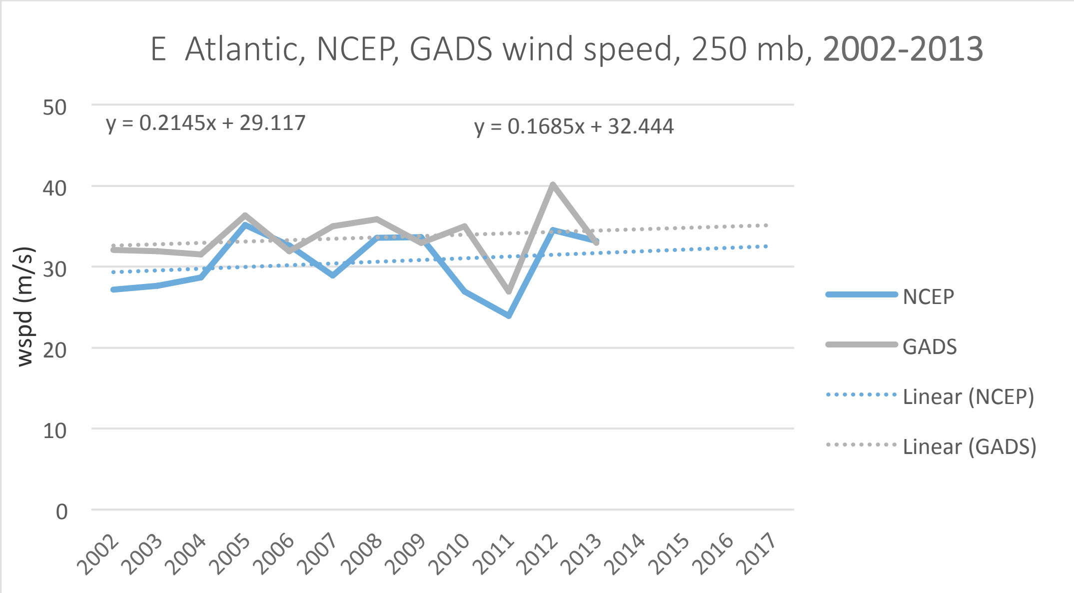

Figure 5. Secular change in wind speed for NCEP reanalysis and GADS observations for all flight levels. Plot is of the winter (DJF) jet exit region for years (2002-2013) when AMO is relatively stable and GADS observations are available and have been processed. Equations of least square fits are superimposed and correspond to annual increases of 0.73% (NCEP reanalysis) and 0.52% (GADS).

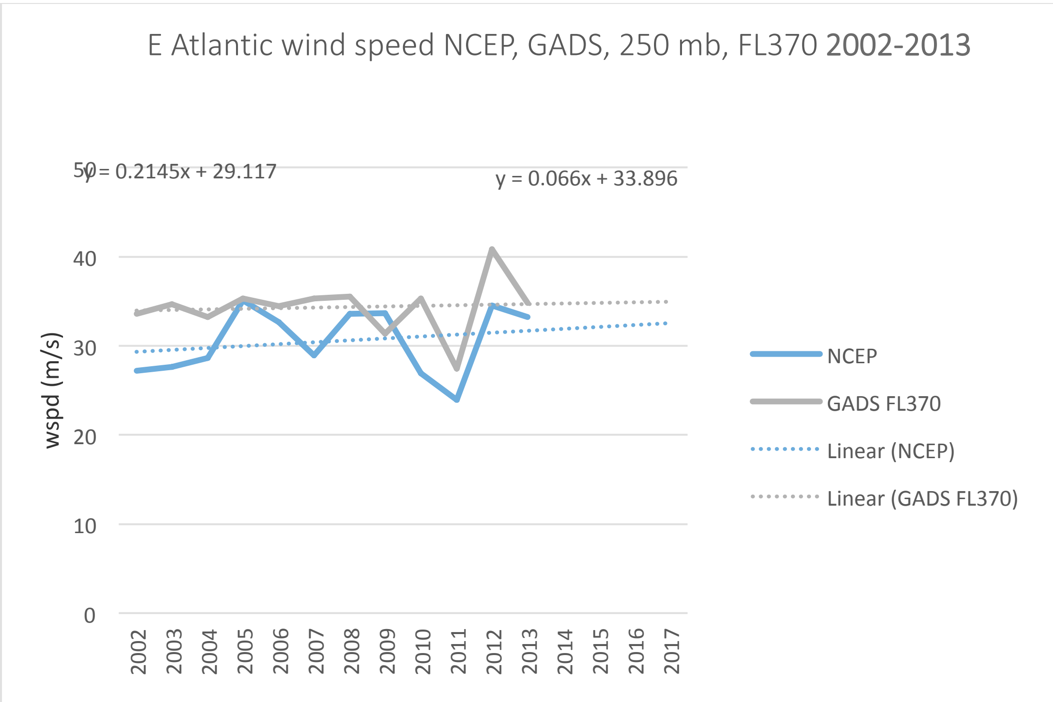

Figure 6. Secular change in wind speed for NCEP reanalysis and GADS observations near FL370. Plot is of the winter (DJF) jet exit region for years (2002-2013) when AMO is relatively stable and GADS observations are available and have been processed. Equations of least square fits are superimposed and correspond to annual increases of 0.7% (NCEP reanalysis) and 0.02% (GADS).

Table 1 below summarizes the results for the three intervals. Within each interval (1979-2017, 2002-2017, and 2002-2013) they are consistent on an order of magnitude basis. Whether the difference in the annual percent increase really substantially changed between 1979-2017 and 2002-2017 remains to be seen. A key question will be whether the 2002-2017 GADS results confirm the AMDAR and NCEP-NCAR values.

Table 1. Secular annual percent increase of wind speed in the North Atlantic polar jet exit region (see Figure 1) for the several annual intervals studied. The detailed comparability, especially with respect to CMIP5, is debatable but the order of magnitude values are probably indicative.

Note. – Statistically significant F values shaded.

Years	Source	Reference	Flight levels	Annual percentage increase	F value	Degrees of freedom
1979-2017	CMIP5	Delcambre et al. 2013	~250 hPa (FL340)	0.06	-	-
	NCEP-NCAR	Kistler et al. 2001	FL320-FL370	0.12	0.20	37
2002-2017	NCEP-NCAR	as above	FL320-FL370	1.27	3.13	14
	AMDAR	Moninger et. al 2003	FL320-FL370	1.49	1.54	14
2002-2013	NCEP-NCAR	as above	FL320-FL370	0.73	0.46	10
	GADS	this study	FL all	0.52	0.36	10
	GADS	this study	FL370	0.02	0.06	10

The CMIP5 value is taken from the winter zonal mean wind speed averages for 1980-1999 in the longitude sector 120°W-0° and the change after 100 years of doubled CO_2, 2080-2099 versus 1980-1999. Delcambre et al. define winter as NDJFM (also labelled by the January year) and the 100 years change values have been taken from the zonal mean graphs at 250 hPa and 50°N – the approximate height and latitude of the three easternmost jet exit regions studied. Her choice of 120°W-0° is only an approximate longitude match for the three easternmost GADS jet exit regions sectors which are centered at 25°W.

The NCEP reanalysis, AMDAR, and GADS values are taken from the average of the 40°W-10°W jet exit region sectors at 250 hPa for DJF. The range FL320 to FL370 includes the vast bulk of the observations. For the case labelled GADS FL370, all wind speed readings between flight levels 365 and 375 are accepted approximately corresponding to 217 hPa in the international standard atmosphere.

In summary, once we limit our time series to a fixed AMO phase (2002-2017) our results for secular changes in the jet exit region wind speeds are statistically significant. They are also consistent with the Delcambre et al. model predictions of the increase of the jet stream speed in the exit regions due to doubled CO_2 but too short a series to definitively prove the case at this time.

Acknowledgements

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