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Wind- and turbulence-related aviation impacts caused by strong cold fronts crossing the Washington D.C. – New York City corridor

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Abstract

During the cold seasons (15 October – 15 April) of 2014-15, 2015-16, 2016-17 and 2017-18, 30 strong cold fronts passed through the Washington D.C. (DC) – New York City (NYC) corridor during the late morning – late evening hours. All 30 of these strong cold fronts caused wind-related ground stops and/or ground delay programs at two or more of the following airports within the DC – NYC corridor: John F. Kennedy International Airport, LaGuardia Airport, Newark Liberty International Airport, Philadelphia International Airport, Baltimore-Washington International Thurgood Marshall Airport, Ronald Reagan Washington National Airport, Washington Dulles International Airport, Teterboro Airport and Westchester County Airport. These strong cold fronts also generated several other significant wind- and turbulence-related impacts that affected air traffic in the DC – NYC corridor. This technical attachment identifies atmospheric and surface patterns associated with these strong cold fronts and highlights the significant wind- and turbulence-related impacts they created.

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1. Introduction

Throughout the cold season – defined here as 15 October through 15 April – strong cold fronts can generate significant wind and turbulence impacts on air traffic in the Washington D.C. (DC) – New York City (NYC) corridor. This corridor is sensitive to cold front-related wind and turbulence impacts because it is home to 7 of the Federal Aviation Administration (FAA)'s [Core 30 airports] – those airports through which the largest amount of air traffic flows within the National Airspace System (NAS) – and two of the nation's busiest general aviation airports. It is also comprised of a tightly-packed, intricate array of air traffic routes that extend from the surface to heights greater than Flight Level (FL450 or 45000 ft mean sea level). Due to the air traffic complexity within this corridor, impacts due to wind and turbulence can quickly ripple throughout the NAS. As volume within the NAS is [projected to increase] in the coming years, air traffic in this already-congested air corridor will become even more vulnerable to cold front-related wind and turbulence impacts.

This technical attachment (TA) provides results of an analysis of strong cold fronts that passed through the DC – NYC corridor (Fig. 1), causing turbulence and wind-related aviation impacts during the study period (2014/15, 2015/16, 2016/17 and 2017/18 cold seasons). This TA 1) highlights atmospheric and surface flow/pressure patterns associated with these fronts and 2) spotlights several different types of aviation impacts (and their frequencies) that resulted from the passage of these strong cold fronts. Taken together, these cold front-related patterns and resultant aviation impacts will provide operational meteorologists a foundation on which to build and refine aviation-related impact-based decision support services (IDSS) both prior to and during strong cold frontal passages through the DC – NYC corridor.

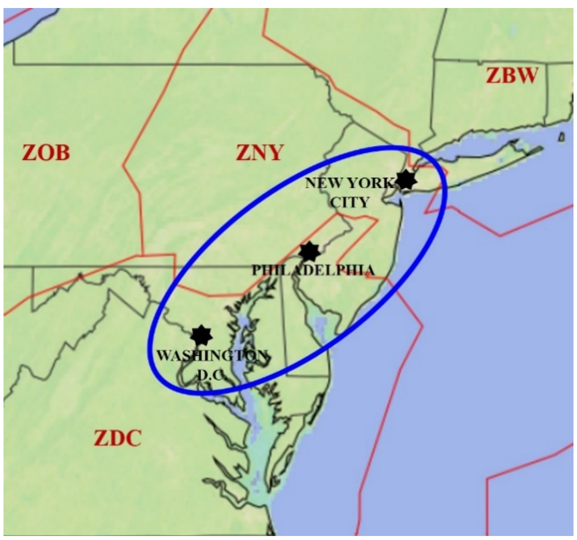

Figure 1: The DC – NYC corridor, outlined by the blue oval. FAA Air Route Traffic Control Center (ARTCC) airspaces are labeled in red and separated by the solid red lines.

2. Data and Methodology

Seven of the FAA's Core 30 airports are located in the DC – NYC corridor and are referenced throughout this TA. These Core 30 airports include John F. Kennedy International Airport (JFK), LaGuardia Airport (LGA), Newark Liberty International Airport (EWR), Philadelphia International Airport (PHL), Baltimore-Washington International Thurgood Marshall Airport (BWI), Ronald Reagan Washington National Airport (DCA) and Washington Dulles International Airport (IAD). Collectively, JFK, LGA and EWR comprise the New York (NY) Metros, while BWI, DCA and IAD constitute the Washington D.C. (DC) Metros. Teterboro Airport (TEB), in northern New Jersey, and Westchester County Airport (HPN), in southern New York, are the two busy general aviation airports in the DC – NYC corridor and are also referred to throughout this TA.

Wind and turbulence impact data during the period of study were compiled from daily FAA Northeast Recap logs (with a focus on the seven Core 30 airports in the DC – NYC corridor, including TEB and HPN). Once daily impacts were collected, cold frontal passages were determined using NOAA/NWS Weather Prediction Center (WPC) analyzed 3-hr North American surface charts and time-stepped NOAA/NWS Storm Prediction Center (SPC) Hourly Mesoscale Analysis Archive (HMAA) surface charts. Only cold fronts passing through the DC – NYC corridor between 15 UTC and 03 UTC were included in this study, since air traffic/air operations peak during these hours. To qualify as a "strong" cold front, at least two of the DC Metros, NY Metros, PHL, TEB and/or HPN had to be affected by ground stops and/or ground delays programs caused by cold front-related wind shifts/wind gusts/turbulence. This process resulted in 30 strong fronts throughout the study period.

More detailed investigation of FAA Northeast Recap logs led to further delineation of several other cold front-related impact categories within the DC – NYC corridor:

a. *Wind compression* – (unplanned for) change of wind direction and/or speed with altitude, or wind shear, in critical airspace regions with sufficient air traffic demand, resulting in the loss of required separation between aircraft (Reiche et al. 2015) – on final approach into the NY Metros only, due to the airports' close proximity

b. *Air traffic management initiatives (TMIs)* initiated due to unfavorable wind/turbulence; some examples include increased miles-in-trail (increased separation between aircraft along a particular jet route/landing path), jet route closures and aircraft re-routing

c. *Refusal by pilots to use certain runways and runway go-arounds* (where an aircraft has to fly around a runway)/missed runway approaches due to unfavorable crosswinds/wind shear/turbulence at any of the 7 Core 30 airports, TEB and/or HPN

d. *Aircraft diverts* to other airports due to unfavorable wind/turbulence at any of the 7 Core 30 airports, TEB and/or HPN

Composite figures were created using the NOAA/Earth System Research Laboratory (ESRL) 6-hr National Center for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) Reanalysis Data Composites website.

3. Analysis and Discussion

a. Cold front-related turbulence

Aircraft-scale turbulent eddies can cascade down from much larger, synoptic-scale motions (Dutton and Panofsky 1970, Koshyk and Hamilton 2001). Some synoptic-scale phenomena that may produce these eddies include jet streams and their associated wind shear (Reiter 1969, Uccellini and Koch 1987), baroclinic waves, upper-level fronts and surface fronts. Upper-level fronts are favored for turbulent eddy generation due to the presence of Kelvin-Helmholz instabilities (vertical shear zones between two atmospheric layers with different densities) and gravity waves, both of which may be initiated by frontogenesis and/or flow deformation (e.g. Mancuso and Endlich 1966, Kennedy and Shapiro 1980, Keller 1990). Frontal lift can enhance fluctuations in gravity waves, especially at higher levels in the atmosphere (Fritts and Nastrom 1992). Gravity waves and low-level wind shear associated with low-level (frontal) boundaries can also create turbulence strong enough to cause aircraft accidents (Bieringer et al 2004). Behind cold fronts, strong low-level wind increases the turbulence potential. Physical and mechanical processes contributing to the strong wind and increased turbulence potential include isallobaric flow (Niziol and Paone 2000; Crupi 2004), deep mixing of stronger wind aloft (Layer and Colle 2014), tropopause folding (Browning and Reynolds 1994; Schultz and Meisner 2009), sting jets (Martinez-Alvarado et al. 2012) and flow interacting with rough terrain, such as the Appalachian Mountains.

Figures 2a and 2b illustrate two different upper-level jet stream/trough patterns associated with surface cold fronts that can generate moderate to severe clear air turbulence (CAT) areas (shown in red shading). Figure 2c shows locations (blue shading) within an idealized upper-level frontal structure where moderate or greater turbulence is favored. All three of these turbulence-generating patterns occurred with strong cold fronts as they crossed the DC – NYC corridor.

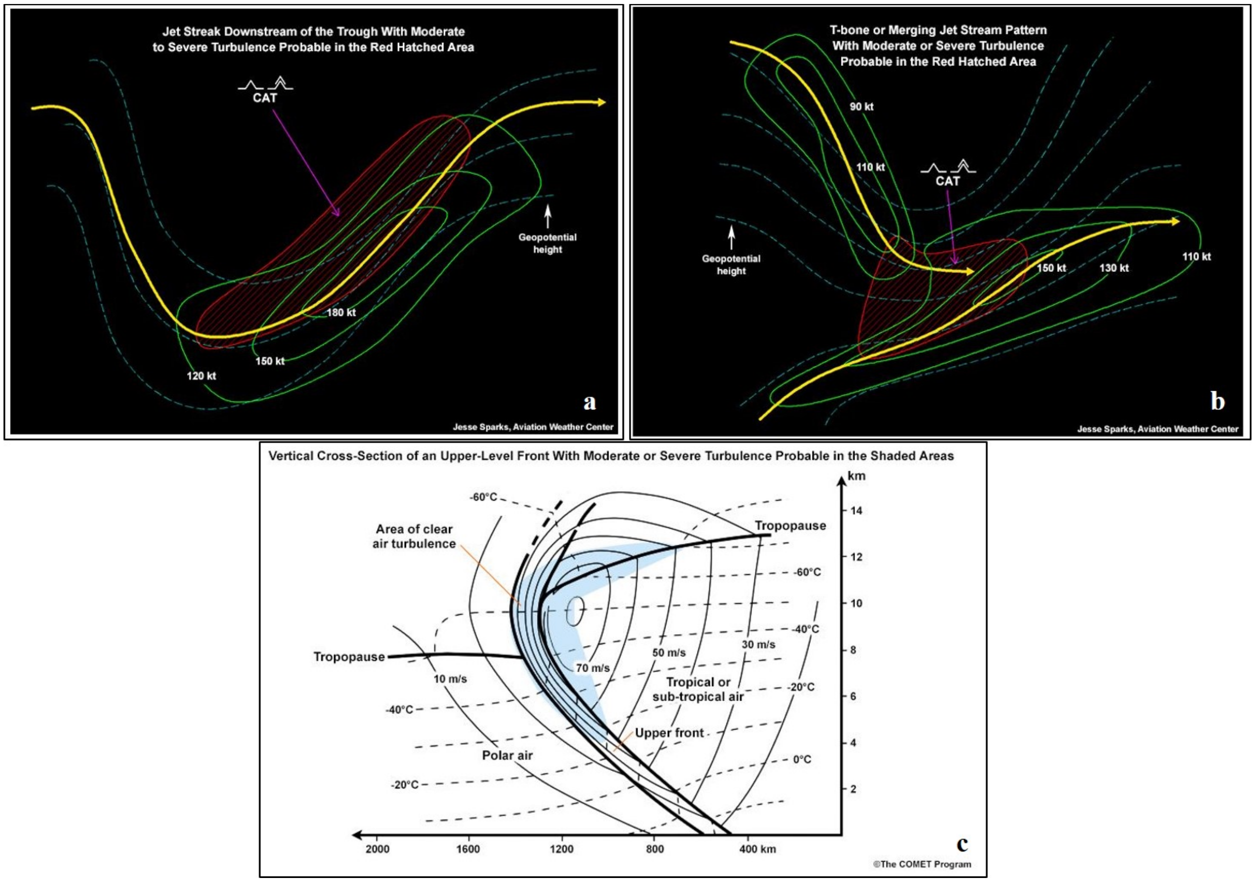

Figure 2. CAT-producing patterns: (a) sharp trough; (b) T-bone or merging jet stream and; (c) a vertical cross section of an upper-level front – all associated with moderate or severe turbulence. Adapted from the COMET Program module "Forecasting clear air turbulence for aviation".

b. Impacts of the Appalachian Mountains

When cold fronts approach the Appalachians (typically from the west), many of them slow down due to mountain-induced blocking effects. The northern portion of a cold front crossing the Appalachians may move quicker than the southern portion, since the steeper slopes and higher peaks of the southern Appalachians tend to block the initially shallow cold airmass directly behind the front. A front whose velocity may appear to be unaffected by the Appalachians may have a stronger pressure gradient force that works against the slowing of the flow caused by the interaction with the mountains. In some cases, a strong upper-level short-wave trough can generate a cross-mountain ageostrophic circulation vigorous enough to force the cold front over the Appalachians (Schumacher et al. 1996).

As cold fronts move down the eastern slopes of the Appalachians and into the DC – NYC corridor, many intensify and speed up. This occurs for a couple of reasons – increased mountain-generated frontogenesis and the coupling of this frontogenesis with ageostrophic zonal flow down the eastern slopes of the Appalachians (Zehnder and Bannon 1988). Cold fronts that pass over the Appalachians during the afternoon and early evening can have a more intense thermal gradient associated with them, which may be attributed to enhanced mountain-related frontogenesis (O'Handley and Bosart 1996). Such a process would lead to an increase in cold front-related mixing and turbulence.

Small, lee-side lows can develop and enhance turbulence and wind shear along cold fronts as they move east of the mountains. Preferred lee-side low formation locations include regions east of the central Appalachians in Virginia and southern New Jersey (O'Handley and Bosart 1996); both are close to or reside within the DC – NYC corridor. In the more stable airmass behind strong cold fronts, temperature inversions can develop above the tops of the Appalachian Mountains. These post-frontal temperature inversions are important because they can trap lee waves, cause mountain waves to propagate vertically and transfer stronger wind to the surface (e.g. Kapela et al 1995; Niziol and Paone 2000; Crupi 2004), all of which can negatively impact air traffic within the DC – NYC corridor.

c. Strong cold front patterns

This study looked at patterns of 30 strong cold fronts passing through the DC – NYC corridor between 15 UTC and 03 UTC (Table 1). As the strong surface cold fronts crossed through the region, the pattern aloft featured a supporting upper-level trough that extended from north of the central/eastern Great Lakes region southward into the southeastern United States. A southwest to northeast flowing jet stream was observed at both 300 hPa and 500 hPa, with wind maxima at both levels located directly over the study area (Figs. 3a, 3b).

In the low-levels, the trough supporting the strong cold fronts extended from north of the eastern Great Lakes region southward into Georgia and Florida. A strong west-southwest to east-northeast flow also maximized almost directly over the study area (Fig. 3c). The strong flow at all levels contributed to the turbulence and wind-related air traffic impacts, such as increased miles-in-trail, route closures and wind compression. The pressure trough (cold front) can easily be seen at 18 UTC, extending from the northeastern United States southward through the DC – NYC corridor, then extending southwestward into central Georgia and Alabama (Fig. 3d). Looking more closely at the surface pressure pattern (Fig. 3d), there are indications that the northern portion of the surface cold front moved east a bit faster than the southern portion of the surface cold front. This may be a result of both cold front-related and mountain-related dynamics described earlier in section 3b.

Table 1. Days during which strong cold fronts moved through the DC – NYC corridor. Those dates with a "*" were selected to create Figure 3, as the spacing between them and associated impacts allowed for an accurate "average" of all 30 cold fronts for illustration purposes.

6 November 2014*	17 November 2014	4 January 2015*
9 January 2015	12 February 2015*	8 March 2015*
17 March 2015	30 March 2015	31 March 2015*
12 November 2015*	27 December 2015*	10 January 2016
29 January 2016*	16 February 2016	25 February 2016*
25 March 2016	28 March 2016	7 April 2016*
11 November 2016*	18 December 2016*	22 December 2016
4 January 2017*	26 January 2017*	15 February 2017*
16 November 2017*	23 December 2017*	23 January 2018*
7 February 2018	16 February 2018*	4 April 2018*

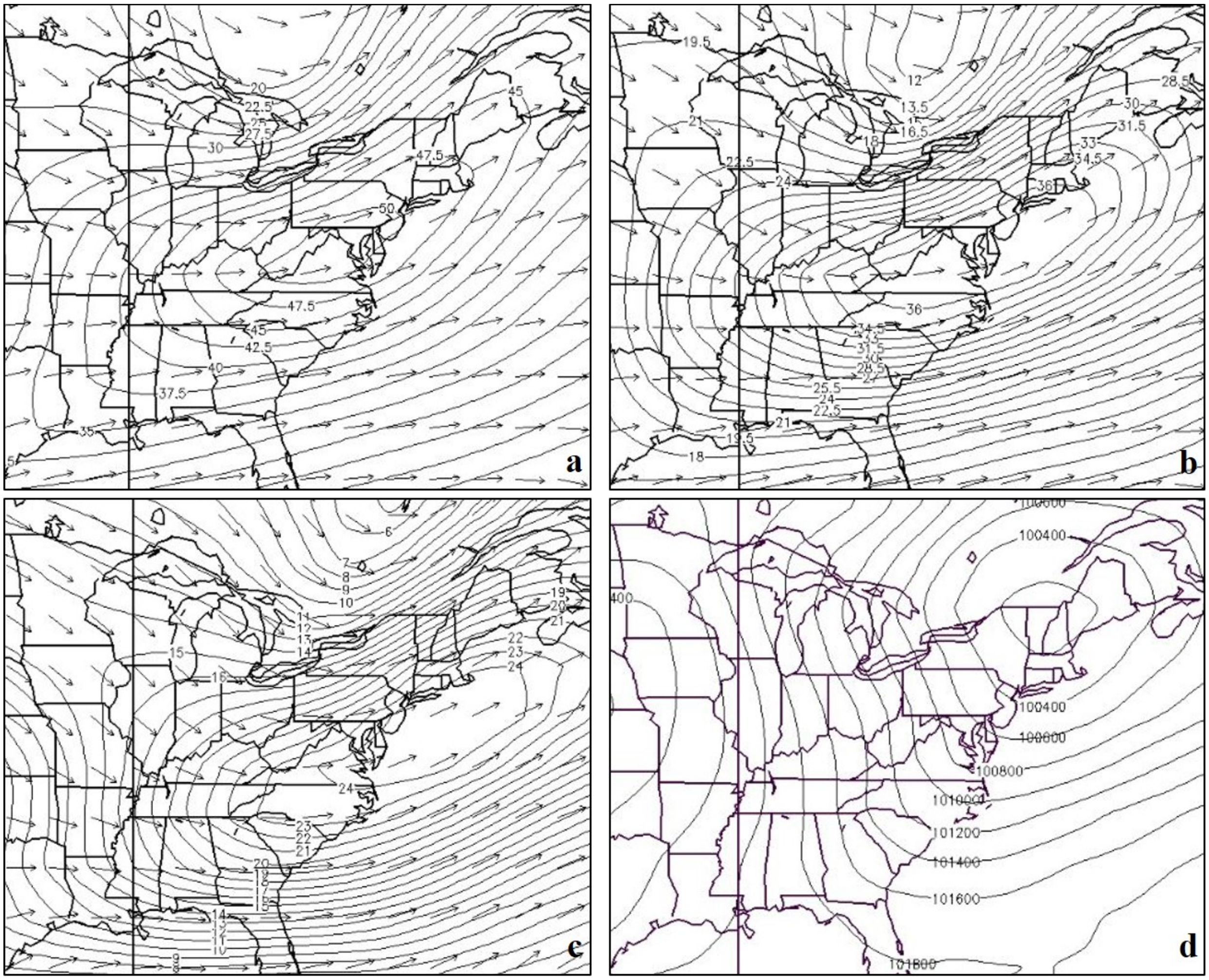

Figure 3. NCEP/NCAR 6-hr mean composite images of: (a) 300 hPa vector wind in m s⁻¹, (b) 500 hPa vector wind in m s⁻¹, (c) 700 hPa vector wind in m s⁻¹ and, (d) surface sea level pressure in pressure altitude (d) at 18 UTC based on the events in Table 1. Courtesy of NOAA/ESRL.

d. Aviation impacts

Commercial airliners flying north-northeast along the East Coast sometimes have to turn (bank) to the left at or below FL180, then fly in a westerly or southwesterly direction as they descend into the NY Metros to land. If the wind is westerly or southwesterly, what was a tailwind becomes a headwind as the planes bank into the wind and continue to descend. If the westerly or southwesterly wind is strong enough, as it can be ahead of strong cold fronts, the result is a compression of space between aircraft. Problems then arise because aircraft are required to maintain a certain spacing interval along the same flight path for safety reasons. Since JFK, EWR and LGA (TEB and HPN, too) are so close to each other, there tend to be air traffic volume-related issues, thus wind compression further exacerbates the challenges faced by pilots and air traffic controllers responsible for ensuring that aircraft land at and take-off from the NY Metros efficiently and safely.

Figure 4 shows wind flow/wind speed composites in the mid- and low-levels on 17 (57%) of the 30 mornings ahead of strong cold fronts when wind compression significantly affected the NY Metros. Assuming aircraft flying from the south or southwest needed to bank left between FL100 and FL180 to descend westward or southwestward into the NY Metros, any aircraft flying along that route experienced, on average, 46 – 63 m s⁻¹ (89 – 122 kts) of wind compression immediately as it banked left. Essentially, these planes flew into a "wave of wind" as they were already slowing during descent.

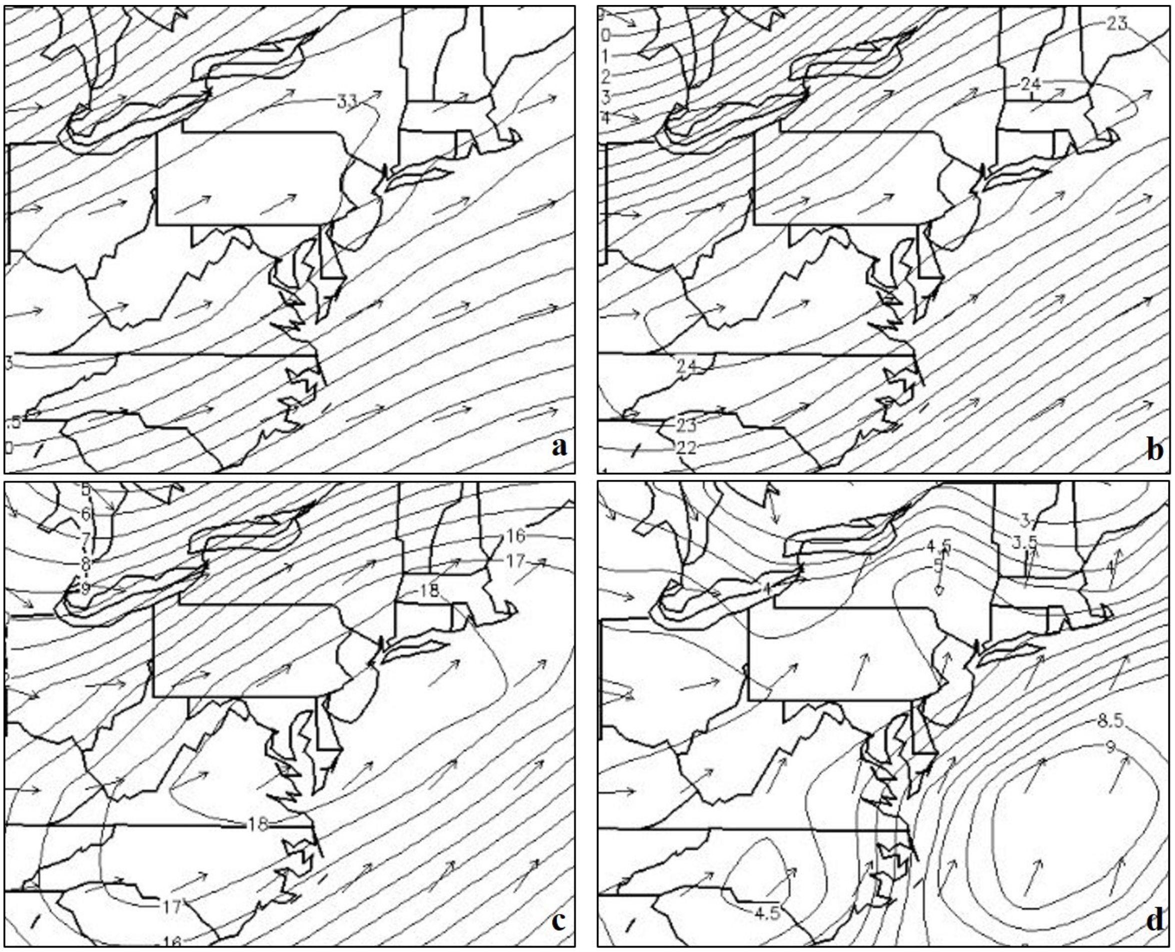

Figure 4. NCEP/NCAR 6-hr mean composite images of: (a) 500 hPa vector wind in m s^{-1}; (b) 700 hPa vector wind in m s^{-1}; (c) 850 hPa vector wind in m s^{-1} and; (d) surface vector wind in m s^{-1} at 12 UTC on days when cold front-related wind compression caused aviation impacts at the NY Metros, as noted in FAA Northeast Recap logs. Images courtesy of NOAA/ESRL.

Although ground stops and ground delays – the defining criteria for strong cold fronts in this study – comprise one set of TMIs, a review of FAA Northeast Recap Logs revealed another significant category of TMIs associated with unfavorable wind and turbulence generated by strong cold fronts. Included in this second category of TMIs (which were, at times, used to resolve aforementioned wind compression issues) are increased miles-in-trail for both en route aircraft and for aircraft taking off and landing at the 7 Core 30 airports (as well as TEB and HPN), jet route closures and aircraft re-routing. One or more of this second category of TMIs occurred as 25 (83%) of the 30 strong cold fronts crossed the area. Air traffic volume can be lighter on some days, so these additional wind- and turbulence-related TMIs may not have been required on five days due to low air traffic volume.

Another impact category associated with these strong cold fronts included refusal by pilots to use certain runways and runway go-arounds/missed runway approaches due to unfavorable crosswinds, wind shear, or turbulence at any of the 7 Core 30 airports, TEB and/or HPN. This impact category was mentioned in FAA Northeast Recap logs during the passage of 10 (33%) of the 30 strong cold fronts.

A final impact category included aircraft diverting to other airports due to unfavorable cold front-related wind/turbulence at any of the 7 Core 30 airports, TEB and/or HPN. These diversion impacts were noted during nine (30%) of the 30 strong cold front passages through the study area.

e. Example: 30 March 2015 cold front

On 30 March 2015, a strong surface cold front moved quickly though the DC – NYC corridor, exiting to the east after 21 UTC 18 (Figs. 5a, 5b, 5c). Ahead of and along the cold front, gusty wind caused a 52 minute ground stop at PHL and a 3 hour 42 minute ground delay program at EWR, which impacted inbound aircraft over 1000 nm away from these airports. Average departure delays reached 39 minutes at EWR, but departure delays as long as 1 hour 44 minutes occurred. After the cold front passed, northwest wind gusts to 39 kts were reported at EWR during the evening and wind shear was reported in the NY Metros region. The gusty northwest wind and wind shear forced runway go-arounds, which led to a period of holding (circling at a fixed altitude above an airport) for aircraft attempting to land at the NY Metros. A wind-related TMI to increase miles-in-trail restrictions of greater than 40 nm for aircraft flying into JFK and LGA was also implemented for over 2 hours.

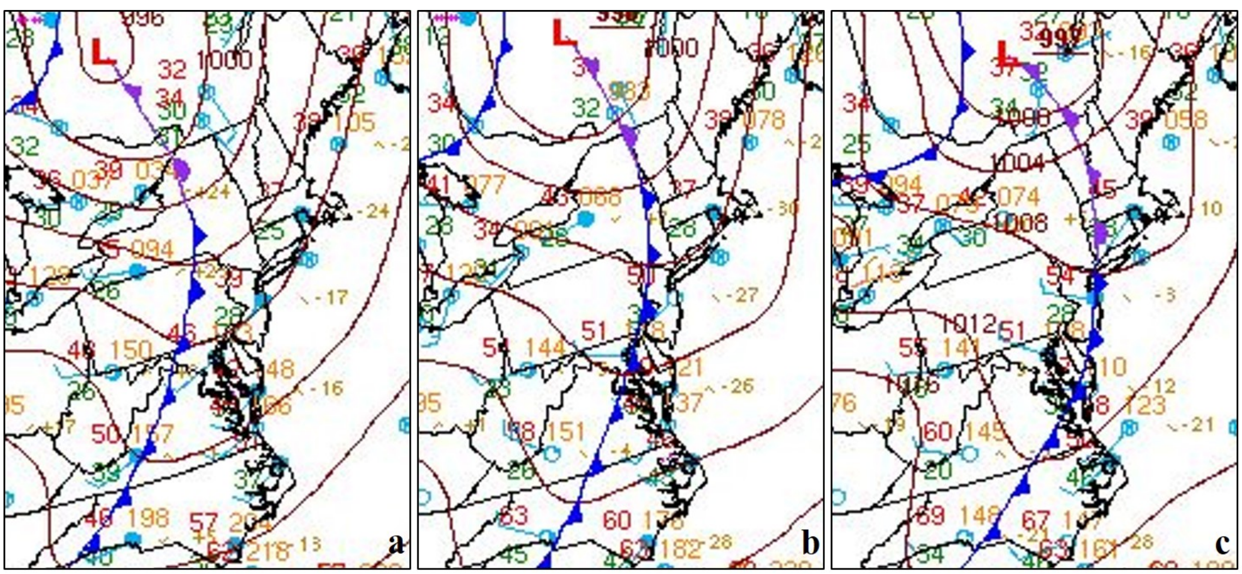

Figure 5. WPC surface analysis at (a) 15 UTC, (b) 18 UTC, and (c) 21 UTC on 30 March 2015.

As the surface cold front transited eastward, strong mid-level shortwaves (Figs. 6a, 6b) moving through the DC – NYC corridor worked in concert with instability in the low-levels (Fig. 6e) to help mix 25-40 kt northwest wind at 850 hPa (Figs. 6c, 6d) to the surface in the NY Metros region. It was this combination of meteorological factors that produced the wind shear and strong, gusty surface wind that ultimately led to the runway go-arounds, holding and increased miles-in-trail.

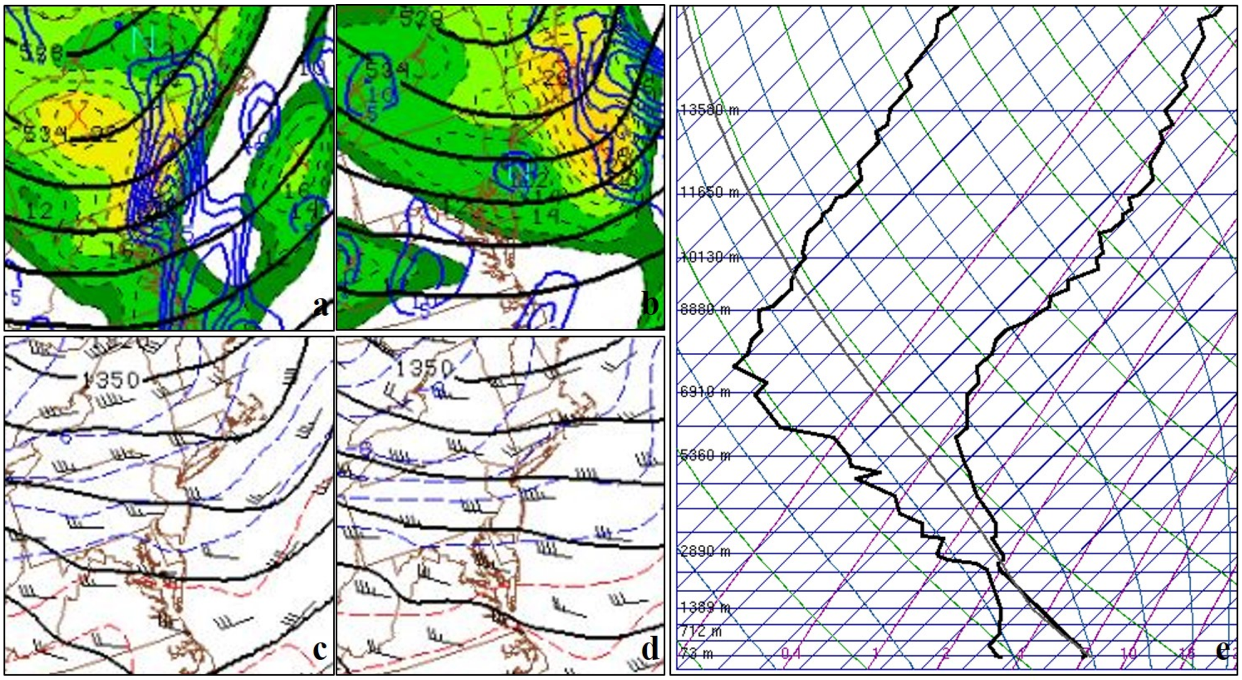

Figure 6. SPC HMAA 500 hPa height and vorticity (fill)/700-400 hPa differential (positive) vorticity advection in blue at (a) 21 UTC on 30 March 2015; (b) the same at 03 UTC on 31 March 2015; (c) 850 hPa height/temperature/wind at 21 UTC on 30 March 2015; (d) the same at 03 UTC on 31 March 2015 (d); (e) a portion of the upper-air sounding from OKX – Upton, NY at 00 UTC on 31 March 2015. Sounding courtesy of the University of Wyoming.

4. Summary

Strong cold fronts present unique safety hazards when crossing through the DC – NYC corridor, one of the busiest regions within the NAS, from late morning through the evening. Within this study period (the cold seasons of 2014/15, 2015/16, 2016/17 and 2017/18), 30 strong cold fronts that crossed though this corridor caused ground stops and/or ground delays at two or more of the following airports: DCA, IAD, BWI, JFK, EWR, LGA, PHL, TEB and HPN. Other significant impacts included:

a. Wind compression impacts for the NY Metros along/ahead of 57% (17 of 30) of the strong cold fronts

b. 83% (25 of 30) of the strong cold fronts resulted in TMIs such as increased miles-in-trail, jet route closures and aircraft re-routing due to unfavorable wind and turbulence in the DC – NYC corridor

c. Runway refusals, runway go-arounds and/or missed approaches at the DC Metros, PHL, NY Metros, TEB and/or HPN during 33% (10 of 30) of the cold frontal passages

d. Aircraft diverts to other airports during 30% of the strong cold frontal passages

5. Future Work

This TA is an initial step in documenting meteorological patterns and aviation-related wind/turbulence impacts associated with the passage of strong cold fronts through the DC – NYC corridor. Thus, there are certainly possibilities for future research and IDSS-related initiatives. One idea is to accomplish a more detailed analysis of how strong cold fronts affect each of the Core 30 airports located in the study region individually. These airports all have different runway layouts, so a portion of this research could help determine when less-than-optimal runway configurations caused by strong cold front-related wind/turbulence lead to lowered aircraft arrival rates (AARs). Incipient work on this subject matter has been accomplished, which led to the creation of basic post-cold front wind "impact reference aids" for IAD and BWI.

Additional research would help refine existing reference aids and expand the development of reference aids and tactical decision aids to the other Core 30 airports in the DC – NYC corridor. Another idea is to conduct studies on wind compression events and their impacts on not only the NY Metros, but on PHL and the DC Metros; initial work on determining wind compression thresholds at individual airports and assessing the usability of finer-scale models to create accurate wind compression forecasts has met with some success (Reiche et al. 2015).

Experimental computing programs that calculate potential wind compression using finer-scale model data for Core 30 airports within the DC – NYC corridor already exist and are primarily used by the New York ARTCC (ZNY) Center Weather Service Unit (CWSU) to create wind compression forecasts for the NY Metros and PHL. These wind compression graphics are available (when significant compression is expected) on ZNY CWSU's web page. Further research may result in the refinement of these forecasts and the development of more scenario-specific wind compression tactical decision aids.

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