OBSERVATIONS OF A 25 JANUARY 2010 GRAVITY WAVE IN THE NEW YORK CITY METROPOLITAN AREA AND ITS IMPACT ON AIR TRAFFIC

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1. INTRODUCTION

The New York City metropolitan area is one of the most heavily congested airspaces in the world with commercial, general aviation, and cargo aircraft, arriving, departing, or transiting local airports at a rate of approximately 6,000 operations per day or just under 2 million a year (N90, 2010). When significant weather develops in the Northeast United States, air traffic is quickly impacted due to restrictions in nominal jetway/airway usage, increased mile-in-trail spacing, reduced surface visibility, or any number of other factors. Although an approaching low pressure system was forecast to impact flights on 25 January 2010, the timing and severity of thunderstorms and winds on that day were not anticipated, consequently, large delays resulted and numerous aircraft ended up diverting, holding, cancelling, or encountering multiple hazards. The delays rippled through the National Airspace System (NAS) as the Federal Aviation Administration (FAA) tried to mitigate significant operational problems. Unbeknownst to controllers and managers at the time, a gravity wave had developed on the western edge of the New York Terminal Radar Approach Control (TRACON) and propagated through the area making an already dangerous situation even worse (Figure 1).

Analysis will show that a narrow but intense squall line formed quickly as a result of a gravity wave or buoyancy wave (Koch and O'Handley, 1997) and caused vertical shear of the horizontal winds from the surface up to cruise flight levels throughout all of TRACON airspace. Air traffic control planning procedures are examined because the extent and severity of the weather was underestimated; consequently, air traffic managers over-delivered aircraft which led to excessive airborne holding in regions of suspected turbulence.

Although not available to the operational aviation community at the time, evidence is presented that the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) experimental High-Resolution Rapid Refresh (HRRR) model accurately forecast the event (Weygandt et al., 2009). HRRR supplemental output fields could have provided the spatial and temporal resolution necessary for Managers to plan and execute an orderly reduction in air traffic demand; which, in-turn, would have improved safety and significantly reduced all categories of delays.

This paper will investigate the meteorological conditions leading up to the severe weather event, the effects the weather had on air traffic, and provide observations of the gravity wave itself as sensed by the FAA's Terminal Doppler Weather Radar (TDWR). Thoughts are presented on how future high wind events can be better managed through the integration of currently existing operational systems. A framework for incorporating HRRR data into Air Traffic Management (ATM) Decision Support Tools and specific ATM Collaborative Decision Making guidance is also offered.

2. METOROLOGICAL SYNOPSIS

A complex low pressure system moved through the Northeast United States on 25 January 2010. As the day progressed, a north-south line of convection formed ahead of an approaching cold front and intensified very rapidly as it passed over the four major New York City airports: Teterboro Airport, NJ (TEB), Newark Liberty International Airport, NJ (EWR), LaGuardia Airport, NY (LGA), and John F. Kennedy International Airport, NY (JFK) (Figure 1). At 1200 UTC, a low pressure center was located over northern Virginia with a cold front southward into the Gulf of Mexico. The warm front extended into Pennsylvania and southern New York State. At 1500 UTC, the low had moved into central PA (Figure 2) with the warm front remaining nearly stationary across Connecticut and western Massachusetts. At 1800 UTC, a National Weather

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Service (NWS) surface analysis placed the cold front south of the low with a squall line now evident about 100nm ahead of the main boundary – nearly overhead JFK Airport. The cold front pushes through NYC by 2100 UTC.

Upper air analyses indicates that at 1200 UTC, a 150-knot 300mb jet was advancing north-northeast around the base of a low pressure trough from the Southeast US - with divergence beginning over the mid-Atlantic states (Figure 3). At the same time, winds at 500mb over NYC were from the south-southwest at approximately 75-knots; and 850mb winds were southerly around 65-knots. Arrivals into the New York area reach the TRACON boundary below 24kft or at or below the 400mb - 500mb pressure levels. At 0000 UTC on 26 Jan 10, the 300mb maximum jet core had rotated directly overhead NYC at 140-knots. The 500mb and 700mb winds at 26/0000 UTC, respectively, were 200-deg/120-knots and 230-degs/35-knots. Strong vertical shear was apparent even on the synoptic scale.

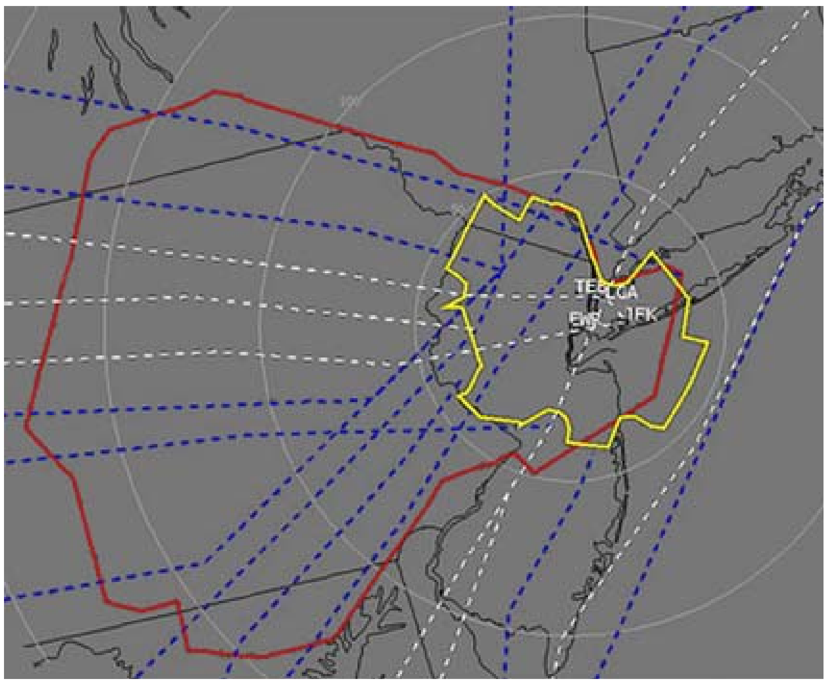

Figure 1: Overlays showing Northeast state outlines in black with 3-letter identifiers for the four major NYC metro-area airports in white (TEB, EWR, LGA, and JFK). The yellow polygon denotes the boundary of the New York TRACON (N90). New York Air Route Traffic Control Center airspace (ZNY) is shown in red. Blue dashed lines are major *departure* routes and primary *arrival* routes are dashed white. Range rings are drawn every 50nm.

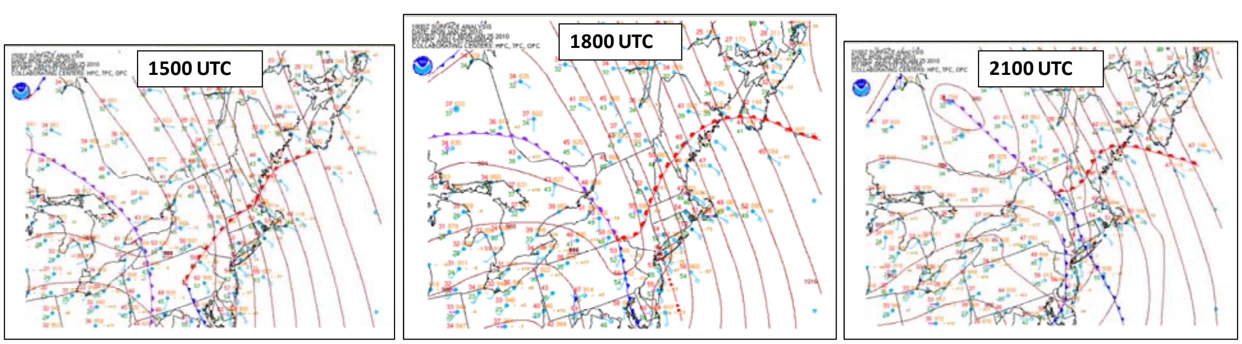

Figure 2: National Weather Service time progression of surface frontal boundaries showing squall line development over NYC at 1800 UTC.

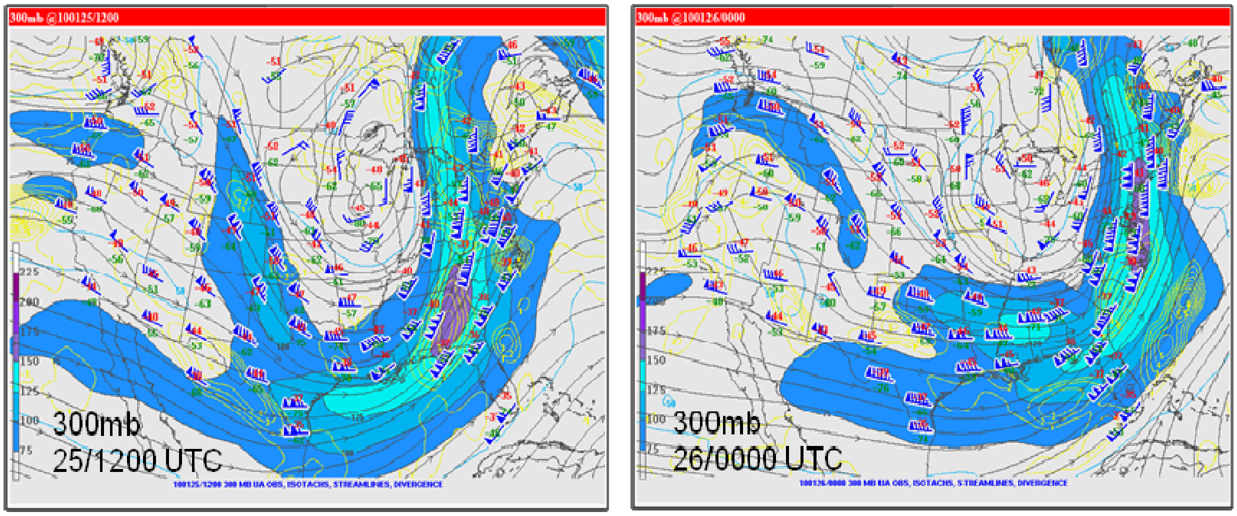

Figure 3: Strong 300mb jet stream evident at 25/1200 UTC and 26/0000Z over the Northeast US.

Brookhaven, NY (KOKX) Skew-T diagrams at 1200 UTC (25 Jan 10) and 0000 UTC (26 Jan 10) are shown in Figure 4. The morning sounding indicates a temperature inversion near the surface and at 700mb, with considerable dry air aloft up through approximately 550mb. Once the main cold front moved through by 26/0000 UTC, dry air penetrated most of the column and stability increased. Various stability indices did not indicate a significant threat for severe weather.

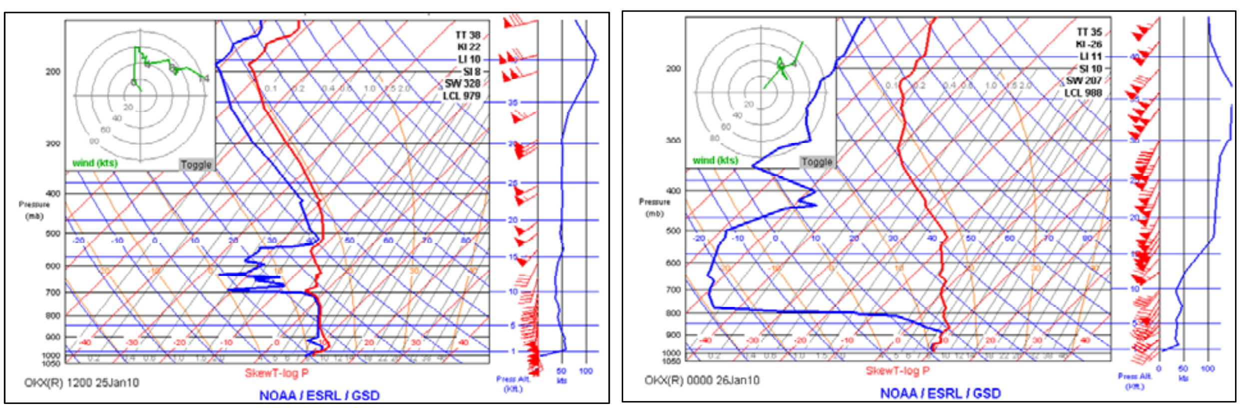

Figure 4: KOKX Skew-T plot valid 1200 UTC, 25 January (left) and 0000 UTC on 26 January 2010 (right)

Surface METAR observations (Figure 5) taken at JFK Airport show that as the squall line approached, winds gusted up to 40knots from the southeast and the cloud ceiling dropped to 1100 feet. Moderate rain began at 1437 UTC as the pressure continued to fall rapidly and visibility dropped to 1.5 miles. There was no thunderstorm or lightning reported all day at either JFK or LGA which are approximately 8nm apart. The peak surface wind gust of 45knots occurred at 1742 UTC which corresponds to the passage of the gravity wave. Surface pressure continued to fall rapidly until the wave passed east of JFK by 1751 UTC. Up until the 1751 UTC observation, surface wind direction was relatively constant out of the southeast to south-southeast. At 1756 UTC, the surface wind direction changed abruptly to 240 degrees and remained that way until 1806 UTC when it shifted back to the south. It is speculated that the gravity wave was reflected at the surface during this 15-minute period (Balachandran, 1980).

A plot of instantaneous surface wind speed and direction corresponding to each Record and

Special METAR observation is shown in Figure 6. The light green shading denotes light to moderate rain whereas dark green denotes a period of heavy rain. Green triangles indicate the maximum gust value. The small circles near the bottom axis represent the approximate times of detection of 40-knot, 35-knot, and 30-knot microbursts by the JFK Terminal Doppler Weather Radar. Wind direction remained nearly constant from about 140 degrees until the squall line began impacting the airport. Between 1742 UTC and1756 UTC, winds shifted rapidly to the southwest and gusted up to 45knots. A sudden 1-degree jump in surface temperature from 11 to 12 deg C at 1753 UTC suggests the disturbance was not caused by a convective gust front or density current and could be characterized as an atmospheric bore (Kingsmill, 2003 and Wakimoto, 1994).

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SPECI KJFK 251437Z  15028G40KT  1 1/2SM  RA BR SCT007 BKN013 OVC022 11/10  A2951 RMK AO2 PK WND 14040/1435  PRESFR P0004
METAR KJFK 251451Z  14029G37KT  1 1/2SM  R04R/6000VP6000FT  RA BR FEW008 OVC013 11/10  A2948 RMK AO2 PK WND 14040/1435  PRESFR SLP983
SPECI KJFK 251509Z  15025G35KT  1 1/2SM  R04R/6000VP6000FT  RA BR BKN006 OVC015 11/10  A2946 RMK AO2 PK WND 15035/1500  PRESFR P0005
METAR KJFK 251551Z  15028G38KT  2SM -RA BR BKN006 OVC018 11/10  A2941 RMK AO2 PK WND 15040/1524  SFC VIS 2 1/2 SLP958 P0012
SPECI KJFK 251621Z  15029G39KT  1 1/2SM  R04R/5500VP6000FT  RA BR OVC006 11/10  A2936 RMK AO2 PK WND 15040/1559  TWR VIS 2 PRESFR P0004
METAR KJFK 251651Z  15029G41KT  1SM  R04R/4500V6000FT  +RA BR OVC006 11/11  A2933 RMK AO2 PK WND 16041/1646  PRESFR SLP931 P0018
SPECI KJFK 251742Z  16036G45KT  3/4SM  R04R/6000VP6000FT  +RA BR OVC006 12/11  A2926  RMK AO2 PK WND 16045/1742  P0008
METAR KJFK 251751Z  17034G45KT  3/4SM  R04R/4000V6000FT  +RA BR BKN006 OVC022  12/11  A2935  RMK AO2 PK WND 16045/1742  PRESRR SLP939
SPECI KJFK 251806Z  19027G36KT  2SM R04R/2200VP6000FT  RA BR BKN008  OVC045 11/11  A2931  RMK AO2 PK WND 24043/1756  CIG 006V010  P0013
SPECI KJFK 251819Z  19024G34KT  2 1/2SM  -RA BR SCT005  BKN022 OVC045  11/10 A2930  RMK AO2 PK WND 24043/1756  P0014
METAR KJFK 251851Z  17024G34KT  2 1/2SM  RA BR FEW005 BKN026 OVC047 11/11  A2927 RMK AO2 PK WND 24043/1756  SFC VIS 3 SLP910 P0021
SPECI KJFK 251940Z  18026G32KT  2 1/2SM  -RA BR BKN003 OVC026  10/09  A2927  RMK AO2 PK WND 17036/1918  SFC VIS 4 P0004
METAR KJFK 251951Z  18021G30KT  2 1/2SM  BR BKN003 OVC026  10/09  A2927 RMK AO2 PK WND 17036/1918  SFC VIS 4 RAE41 SLP912 P0004
SPECI KJFK 252020Z  19016G25KT  1/8SM  R04R/4500VP6000FT  BR OVC003 10/09  A2928 RMK AO2 PK WND 19030/1957  SFC VIS 3/4
SPECI KJFK 252044Z  19016KT  1/8SM  R04R/1200V2200FT  FG BKN003  09/08  A2927  RMK AO2 PK WND 19030/1957  SFC VIS 1/4
METAR KJFK 252051Z  19020G25KT  1/8SM  R04R/1200V2200FT  FG BKN003  BKN030  09/08  A2926  RMK AO2  PK WND 19030/1957  SFC VIS 1/2  SLP908
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Figure 5: Abbreviated JFK surface observations, before, during, and after gravity wave passage.

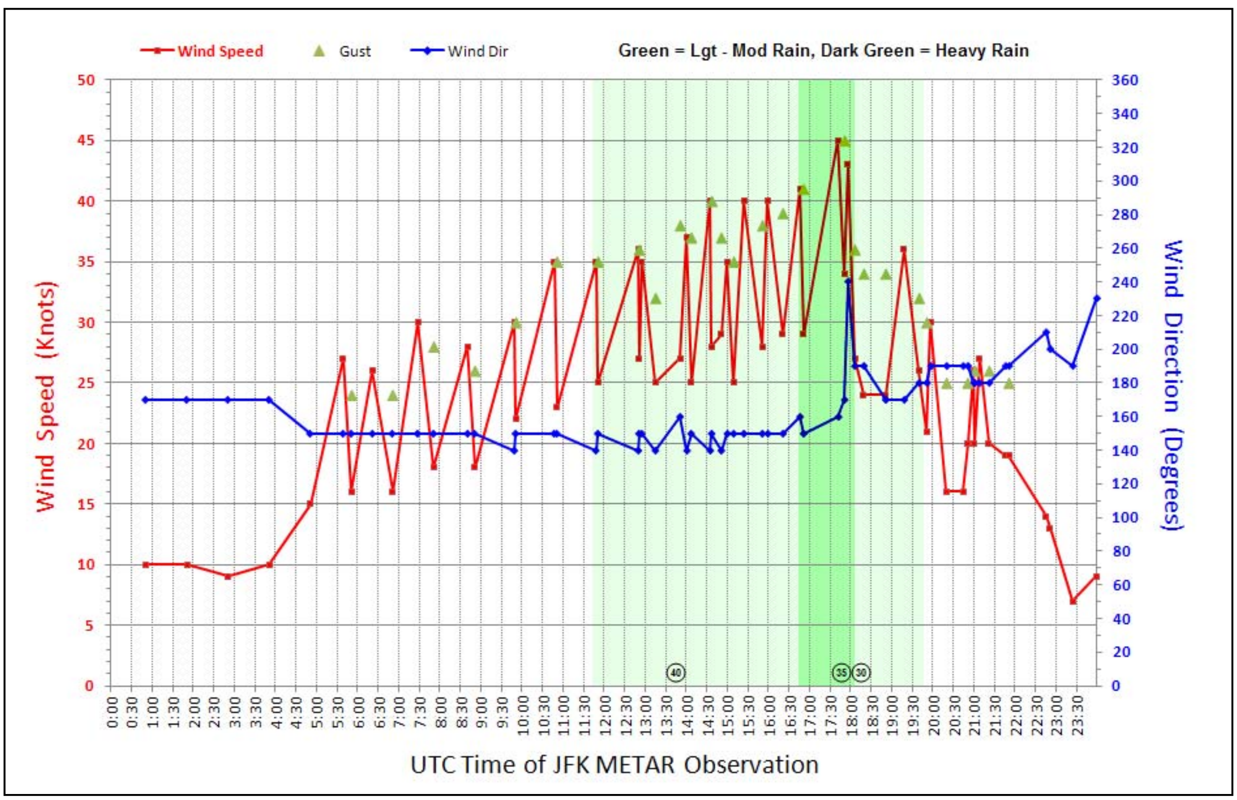


Figure 6: JFK Airport surface winds, precipitation, and wind shears, on 25 January 2010.

The NWS Terminal Aerodrome Forecast (TAF) issued at 1431 UTC on 25 January 2010 is shown in Figure 7. The amended forecast states that 60 to 70-knot wind shear is possible at 2000 feet with conditions as low as 300 feet and ½ mile in heavy rain and fog temporarily between 1700 UTC and 2000 UTC. The deteriorating weather trend is captured well; however, the extent and severity may not have been evident to air traffic controllers or managers.

A snapshot of aircraft turbulence reports taken just before the squall line/gravity wave impacted the NY terminals is shown in Figure 8. The 1519 UTC – 1642 UTC PIREP graphic clearly shows a high concentration of moderate to severe reports across the Northeast United States up through at least 34kft. The high incidence of turbulence corresponds to heavy air traffic and also curvature in the 300mb jet stream (Figure 3).

TAF AMD KJFK 251431Z 2515/2618 15030G40KT 3SM -RA BR SCT007 BKN015 OVC025 WS020/17060KT
TEMPO 2515/2517 1SM RA BR OVC007
FM251700 16032G45KT 1SM RA BR OVC007 WS020/16070KT
TEMPO 2517/2520 1/2SM +RA FG OVC003
FM252000 21018G25KT 5SM -SHRA BR OVC020 FM252200 25012KT P6SM SCT020 SCT050
FM260600 25010KT P6SM BKN050 FM261200 25015G22KT P6SM SCT050

Figure 7: Terminal Aerodrome Forecast (TAF) issued for JFK Airport at 1431 UTC, 25 January 2010.

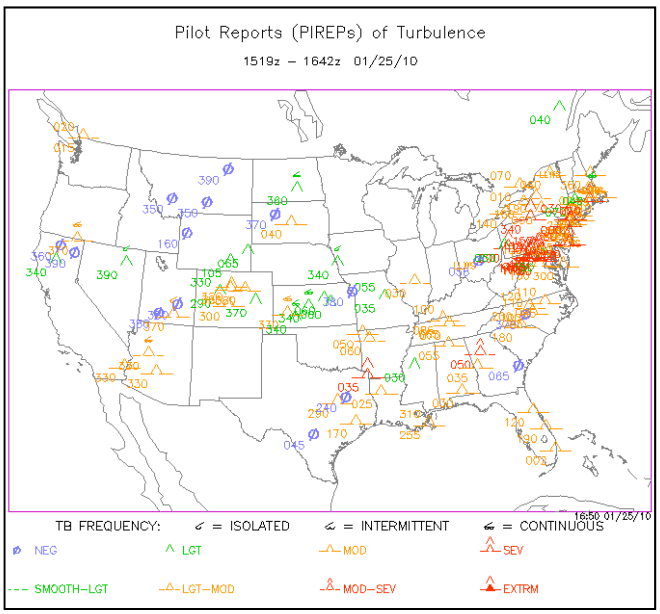


Figure 8: Pilot Reports from 1519 UTC – 1642 UTC, 25 January 2010, courtesy of NOAA's Aviation Digital Data Service.

3. ATC COMMENTS AND FAA PERFORMANCE METRICS

FAA National Traffic Management Logs were reviewed for significant statements to provide a sense of scale for the severe weather impacting Northeast operations (FAA NTML, 2009). ATC from Washington D.C. through New York and Boston reported numerous problems with enroute spacing, delays, turbulence, missed approaches, etc. Figure 9 provides an abbreviated look at some of the comments. N90 is the New York TRACON. ZNY refers to the New York Air Route Traffic Control Center (ARTCC) located in Ronkonkoma, NY on eastern Long Island. The overriding concern was high winds at the terminals and aloft which affected arrival spacing.

1208Z DCC/NE N90 Requested a LGA GDP at 1100 due to winds, ground and aloft. The winds aloft are 16060KTS at 2000FT creating significant compression issues.

1455Z DCC/NE DCC/N90/LGA...Lengthy discussion on plan for LGA. There have been no arrivals for about an hour due to strong/gusty winds.

1531Z DCC/NE RERTE: ZDC req ZNY to accept EWR arrvs via J220, svr to extreme turb on the ARD route.

1632Z HPN/HPNT PIREP RY 16: H25B reported mod to sev turb, wind shear or gain and loss of btw 15 and 25 knts. Wing roll btw 30 and 60 degrees.

1757Z N90/TMU JFK depts. are not departing due to wind.

1800Z DCC/NE N90 advised for JFK…front overhead, several go-arounds, multiple diverts.

1849Z DCC/NE JFK on the 22's. Asked airlines to consider alternates ahead of time as the situation looks very unlikely that we can land what is in the air.

1855Z N90/TMU Shift Summary: - WX:IFR/MVFR/VFR/Very high winds. Comment: Extremely difficult Monday day shift. Wx system from the south moved along coastline and thru N90. Winds out of the south sustained 30 with gusts to almost 50 kts. Many go-arounds at all the airports and many diversions due to excessive airborne holding and not enough A/C landing. Many GS's and starts, GDPs and adjusted GDPs and MIT and increased MIT all to try to keep up with this wx system that the TAF's could not keep up with. Many cancellations due to backlog of delays and diversions…we were operating with single rwys at LGA and extremely high winds at both the other two with A/C refusing to depart with the stated winds. Again, very difficult day.

Figure 9: Selected FAA National Traffic Management Logs for 25 January 2010.

The FAA's Aviation System Performance Metrics (FAA ASPM, 2010) provided additional insight into terminal operations at JFK and LGA Airports (Table 10). Prior to noon local time at JFK, the active runways were 13L and 13R; however, by 1300L, the airport was reconfigured for arrivals and departures on runways 22L and 22R due to winds shifting to the southwest. Actual departures dropped to a low of 10 aircraft per hour by 1400 local whereas the nominal *Airport Departure Rate* (ADR) was 32 (FAA TFM, 2009). Actual arrivals also dropped to only 10 aircraft per hour by 0900 local compared to the nominal *Airport Acceptance Rate* (AAR) of 38. Traffic flow problems were even worse at LaGuardia. LGA was in south operations on runway 13 during the morning up through approximately 1300 local when surface winds required the use of R22. Only one aircraft departed during the 1200L to 1300L hour and only two aircraft landed between 1100 – 1300L due to heavy rain, turbulence, and low-level wind shear. It is clear that the severe and rapidly changing winds and weather resulted in over-delivery of aircraft. Additional ASPM metrics indicated that for JFK, 60% of all aircraft departed on time while 44% arrived on time. Arrival delays neared 55 minutes while outbound gate delays averaged 42 minutes. For LGA, 51% of all aircraft departed on time and 36% arrived on time. Arrival delays averaged 63 minutes, and outbound gate delays averaged 53 minutes.

The Traffic Management Initiative summaries in Table 11 show that wind, weather, and turbulence, caused extensive ground delays and ground stops at all four major airports. Program rates in (red) are the planned aircraft arrival rates based on imposed restrictions. In several instances, the sent time of an advisory (ADVN) coincides with the scheduled time implying there was little if any chance for an orderly reduction in flow. Advisory number 52 for LGA resulted in no planes being scheduled for that period of time.

Table 10. ASPM Management Reports for JFK and LGA Airports on 25 January 2010.

Runway Configuration for JFK From 1/25/2010 To 1/25/2010						
Local Time	Configuration	ADR	Actual Departures	Cap AAR	Actual Arrivals	Weather Conditions
0	22L, 22R | 22R	34	13	48	14	V
1	22L, 22R | 22R	34	7	48	5	V
2	22L, 22R | 22R	34	1	48	0	V
3	22L, 22R | 22R	34	0	48	1	V
4	22L, 22R | 22R	34	0	48	7	V
5	13L | 13R	34	3	46	15	V
6	13L | 13R	34	15	38	23	V
7	13L | 13R	34	25	38	26	V
8	13L | 13R	34	37	38	19	I
9	13L | 13R	34	39	38	**10**	I
10	13L | 13R	34	21	38	**10**	I
11	13L | 13R	34	**13**	38	15	I
12	13L | 13R	34	15	38	12	V
13	22L, 22R | 22R	33	15	37	21	I
14	22L, 22R | 22R	32	**10**	36	32	I
15	22L, 22R | 22R	32	19	36	24	V
16	22L, 22R | 22R	32	20	36	35	I
17	22L, 22R | 22R	32	22	36	36	V
18	22L, 22R, 31L | 22R, 31L	46	31	36	30	V
19	22L, 22R, 31L | 22R, 31L	50	34	36	34	V
20	22L, 22R, 31L | 22R, 31L	50	44	36	35	V
21	22L, 22R, 31L | 22R, 31L	50	29	36	29	V
22	22L, 22R | 22R	34	30	48	23	V
23	22L, 22R | 22R	34	23	48	26	V

Runway Configuration for LGA From 1/25/2010 To 1/25/2010						
Local Time	Configuration	ADR	Actual Departures	Cap AAR	Actual Arrivals	Weather Conditions
0	13, 22 | 13	40	3	44	21	V
1	13, 22 | 13	40	3	44	4	V
2	13, 22 | 13	40	0	44	3	V
3	13, 22 | 13	40	0	44	0	V
4	13, 22 | 13	40	0	44	0	V
5	13, 22 | 13	40	1	44	0	I
6	13, 22 | 13	40	31	44	11	I
7	13 | 13	33	17	34	16	I
8	13 | 13	30	15	30	11	I
9	13 | 13	30	34	30	9	I
10	13 | 13	30	14	30	3	I
11	13 | 13	30	2	30	**1**	I
12	13 | 13	30	**1**	30	**1**	I
13	22 | 13	34	3	34	3	I
14	22 | 13	34	3	34	10	I
15	22 | 13	34	6	34	24	V
16	22 | 13	34	15	34	33	I
17	22 | 31	34	26	34	27	I
18	22 | 31	34	26	34	31	V
19	22 | 31	34	31	34	28	V
20	22 | 31	34	40	34	40	V
21	22 | 31	34	32	34	26	V
22	22 | 31	34	7	34	21	V
23	22 | 31	34	2	34	23	V

Table 11: FAA Ground Delay and Ground Stop summaries for the major New York City metro-airports on 25 January 2010.

GDP Daily Summary 1/25/2010 (Program Rate: Current plus 2 hours)

ADVN	AIRPORT	INITIATIVE	SENTTIME	ACTUALTIMES	SCHEDTIMES	REASON
37	EWR	GDP (28)	1331	1530-1800	1530-0459	WEATHER / WIND
70	EWR	GDP (25)	1756	1800-2100	1800-0659	WEATHER / WIND
84	EWR	GDP (30)	1957	2100-0155	2100-0459	WEATHER / WIND
97	EWR	GDP (36)	2239	0300-0155	0300-0359	WEATHER / WIND
8	EWR	GDP CNX	155	0155-0155	0155-0155	NF
49	JFK	GDP (35)	1547	1800-1800	1800-0359	WEATHER / WIND
60	JFK	GDP (30)	1641	1800-1942	1800-0359	WEATHER / WIND
83	JFK	GDP (34)	1942	1942-2135	1942-0359	WEATHER / WIND
92	JFK	GDP	2135	2135-0015	2135-0359	WEATHER / LOW VISIBILITY
2	JFK	GDP CNX	15	0015-0015	0015-0015	NF
22	LGA	GDP (30)	1129	1200-1240	1200-0414	WEATHER / WIND
29	LGA	GDP (25)	1240	1240-1601	1240-0459	WEATHER / WIND
52	LGA	GDP (0)	1601	1601-2052	1601-0759	WEATHER / WIND
90	LGA	GDP (32)	2052	2052-2159	2052-0459	WEATHER / WIND
94	LGA	GDP (44)	2159	2159-2357	2159-0359	WEATHER / WIND
99	LGA	GDP CNX	2357	2357-2357	2357-2357	NF
39	TEB	GDP (8)	1340	1340-1939	1340-1959	WEATHER / WIND
82	TEB	GDP (20)	1939	1939-2100	1939-0059	WEATHER / WIND
89	TEB	GDP (15)	2044	2100-2155	2100-0159	WEATHER / WIND
93	TEB	GDP CNX	2155	2155-2155	2155-2155	NF

GS Daily Summary 1/25/2010

ADVN	AIRPORT	INITIATIVE	SENTTIME	ACTUALTIMES	SCHEDTIMES	REASON
54	EWR	CDM GS	1602	1602-1644	1602-1700	WEATHER / WIND
62	EWR	CDM GS	1644	1644-1800	1644-1800	WEATHER / WIND
55	HPN	CDM GS	1610	1610-1705	1610-1715	WEATHER / WIND
63	HPN	CDM GS	1705	1705-1800	1705-1800	WEATHER / WIND
71	HPN	CDM GS CNX	1801	1801-1801	1801-1801	NF
50	JFK	GS	1551	1551-1639	1551-1700	DUE TO TURBULENCE IN THE TERMINAL AREA
58	JFK	GS CNX	1639	1639-1639	1639-1639	NF
64	JFK	CDM GS	1707	1707-1749	1707-1800	WEATHER / WIND
69	JFK	CDM GS	1749	1749-1834	1749-1900	WEATHER / WIND
74	JFK	CDM GS	1834	1834-1907	1834-1930	WEATHER / WIND
79	JFK	CDM GS	1907	1907-2000	1907-2000	WEATHER / WIND
91	JFK	CDM GS	2054	2054-2145	2054-2145	WEATHER / LOW VISIBILITY
25	LGA	CDM GS	1207	1207-1300	1207-1300	WEATHER / WIND
36	LGA	CDM GS	1320	1320-1404	1320-1415	WEATHER / WIND
41	LGA	CDM GS	1404	1404-1500	1404-1500	WEATHER / WIND
45	LGA	CDM GS	1502	1502-1551	1502-1600	WEATHER / WIND
50	LGA	GS	1551	1551-1639	1551-1700	DUE TO TURBULENCE IN THE TERMINAL AREA
58	LGA	GS CNX	1639	1639-1639	1639-1639	NF
26	TEB	CDM GS	1214	1214-1302	1214-1315	WEATHER / WIND
34	TEB	CDM GS	1302	1302-1415	1302-1415	WEATHER / WIND

4. NEXRAD RADAR DATA AND AIRCRAFT IMPACTS

Figure 12 is a short set of images from the MIT Lincoln Laboratory Corridor Integrated Weather System (CIWS) (Evans and Ducot, 2006) showing NEXRAD mosaiced Vertically Integrated Liquid water (VIL), echo top heights, and storm cell motion at 1500, 1800, and 2100 UTC. Dark red polygons denote Air Route Traffic Control Center (ARTCC) boundaries. The blue polygon around NYC is the New York TRACON boundary. Weak embedded level 3 - 4 intensity weather is present from 1500 – 2100 UTC. Motion is north-northeast at 60 – 70 knots and echo tops are relatively low at 20 – 30kft throughout the period.

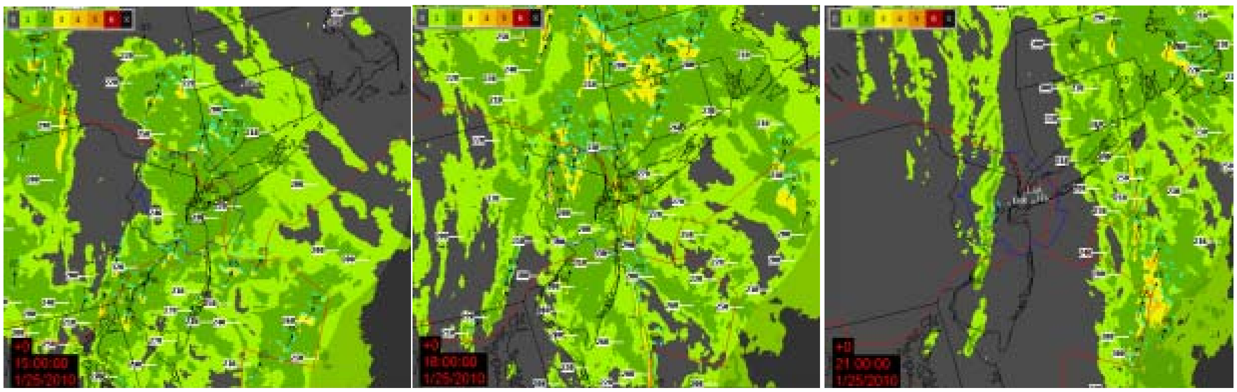


Figure 12: CIWS time series showing VIL before, during, and after, squall line passage at JFK.

Figure 13 is another time series showing a running 30-minute cumulative traffic flow into and out of JFK, LGA, EWR, and TEB airports. Arriving aircraft are shown in white and departing aircraft are blue. The heavy black polygon is the boundary of the New York TRACON (N90). The aircraft tracks and underlying 6-level VIL was obtained from the MIT Lincoln Laboratory Route Availability Planning Tool Post Event Analysis Tool (RAPT REPEAT). At 1100 UTC, arrivals and departures are mostly unimpeded. Within an hour, however, arrivals from the north and south enter holding; and by 1300 UTC, multiple holding orbits (denoted by white race track shapes) are needed to the west and southwest due to over-delivery. At 1700 UTC, all departures are nearly stopped in an attempt to land what's already airborne. As the squall line and gravity wave impact JFK around 1800 UTC, arrivals are held once again within enroute, TRACON, and terminal airspace. It is important to note that holding is being conducted in areas of known or suspected turbulence. Even after most of the convection has moved through the major airports, it takes several more hours to flush the departure queues and recover arrivals. Long-haul passenger traffic arriving over Pennsylvania is usually descending from approximately 33 - 39kft and reach the western edge of the NY TRACON between approximately 7 – 19kft.

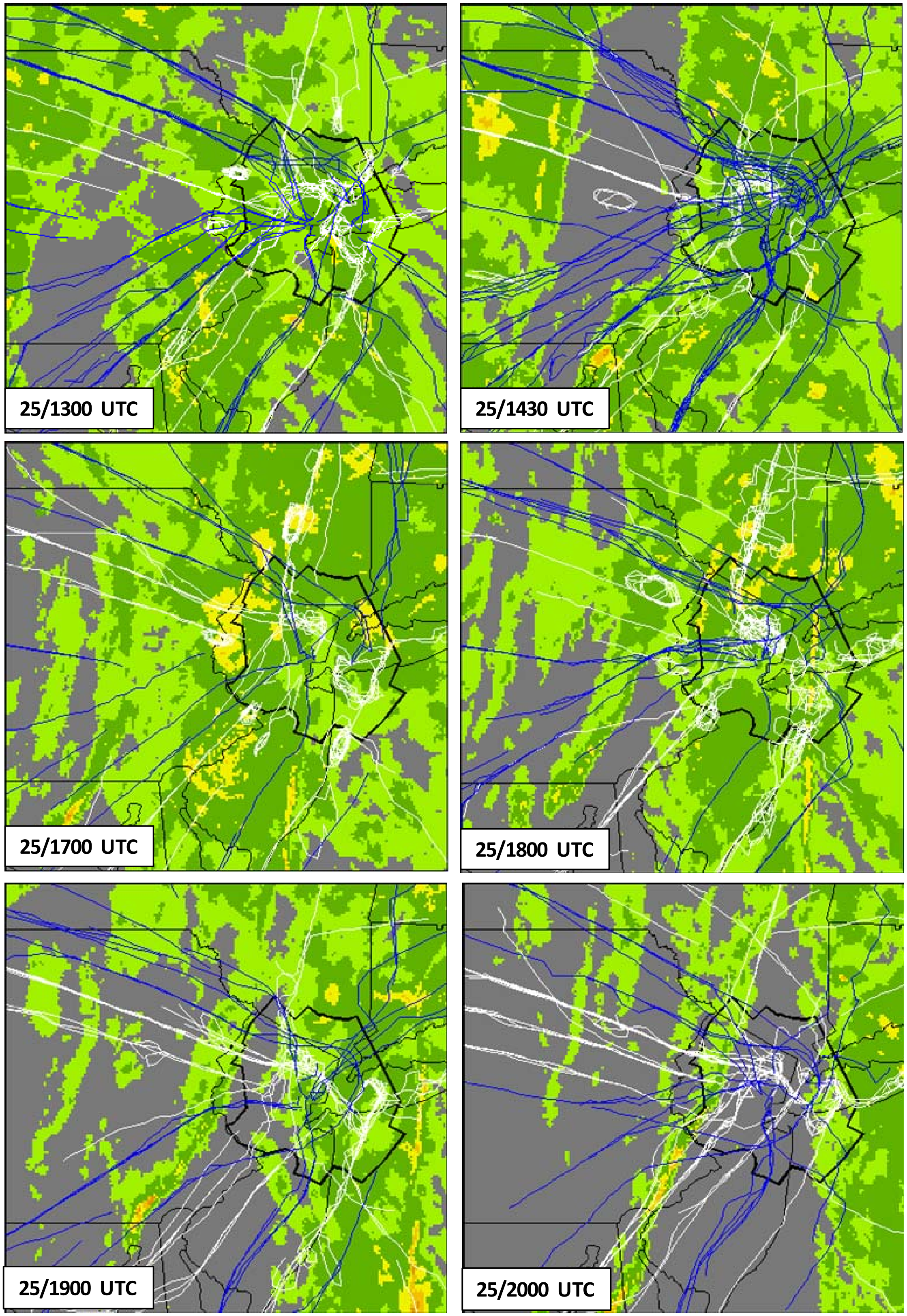


Figure 13: Time series of NYC area aircraft arrivals and departures on 25 January 2010. Departing traffic is blue and arrivals are white. White race track shaped lines show where aircraft are holding.

5. TERMINAL DOPPLER WEATHER RADAR DERIVED INFORMATION

The FAA's JFK Terminal Doppler Weather Radar (TDWR) is located on Floyd Bennett Field which is about 6 nm southwest of JFK Airport. The radar proved to be an excellent weather sensor not only for alerting controllers of surface wind shear and microburst hazards, but also for revealing significant vertical shear of the winds aloft. Velocity Azimuth Display analysis from JFK TDWR data showed evidence of strong turbulent mid-level winds being mixed downward from mid-levels of the atmosphere, especially after 1700 UTC. At the same time, boundary layer winds veered slowly to the southwest. The maximum low-level winds of 177 degrees at 96-knots were observed at 3000 feet at 1728 UTC. The maximum winds at altitude occurred at 30,000 feet at 1616 UTC: 214 degrees at 120-knots. Figure 14 shows selected output of VAD winds from the JFK TDWR from approximately 1658 UTC – 1948 UTC on 25 January 2010. The column on the far right within each image is the most current vertical profile; with the previous 1-hour history in 6-minute increments to the left. Height values range from 1,000 to 50,000 feet. Wind barbs in red indicate highly variable direction and speed. Winds within the black dashed oval at 1753 UTC most closely match the period of greatest gravity wave impact at JFK.

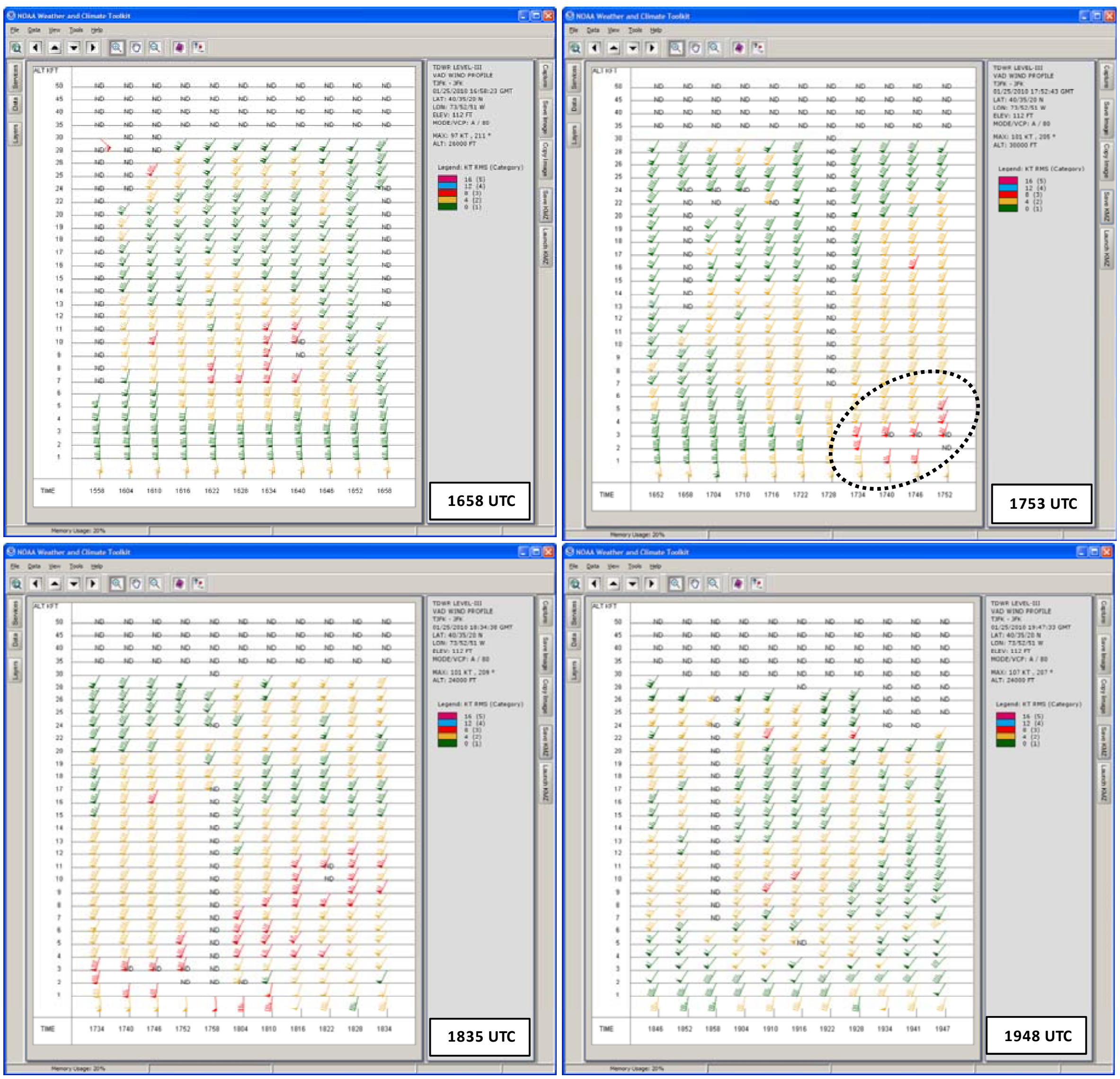
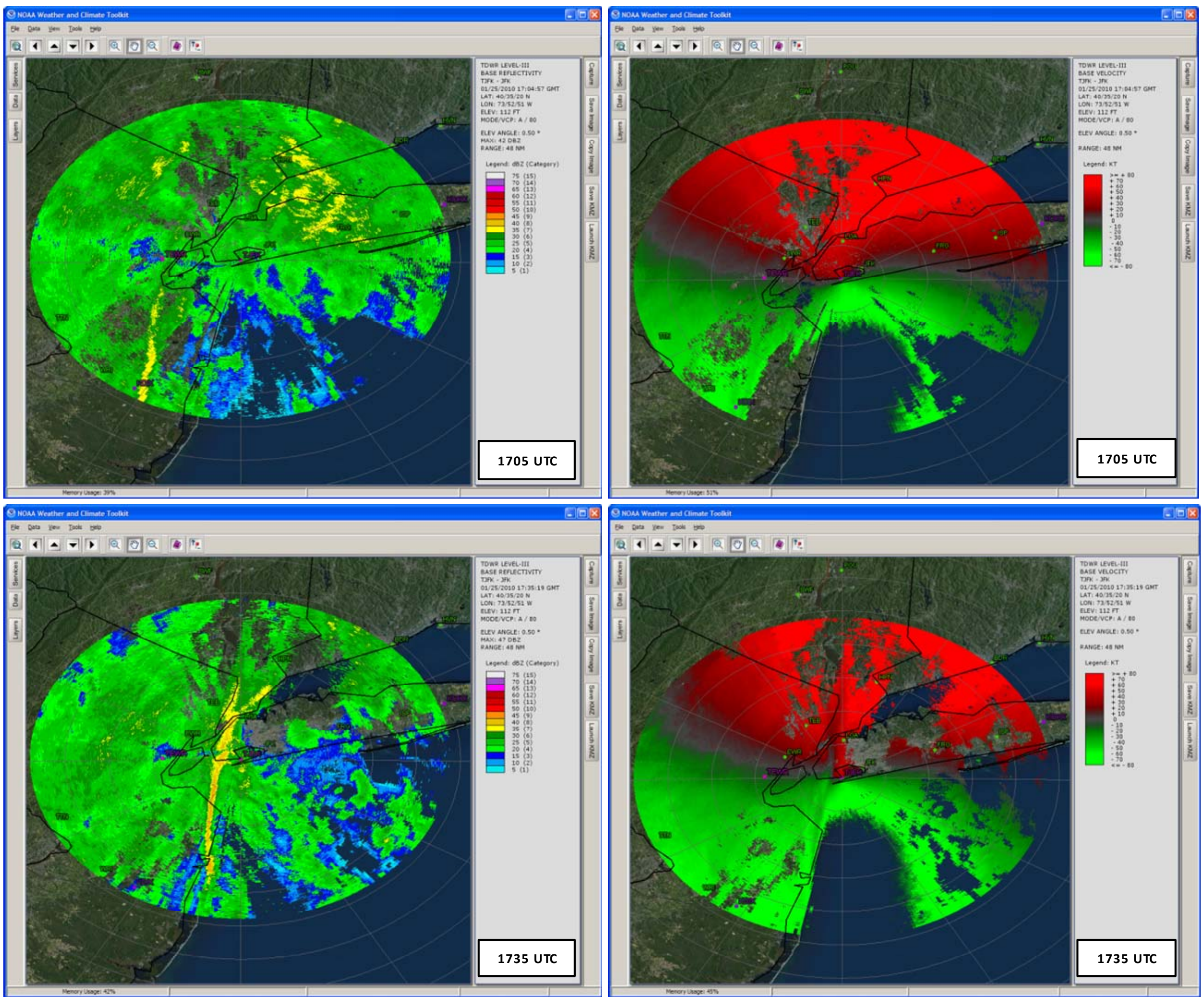


Figure 14: Velocity Azimuth Display derived from the JFK TDWR.

The JFK TDWR also provided invaluable reflectivity and velocity signatures that clearly indicated rapid squall line development and visual evidence of a gravity or buoyancy wave propagating from west to east through the TRACON. It is important to state that air traffic controllers and managers do not have access to raw NEXRAD or TDWR data and only see highly processed and filtered weather radar data through various display tools such as the FAA Traffic Situation Display and Integrated Terminal Weather System. The images in Figure 15 are snapshots of JFK TDWR Level III base reflectivity and velocity data within the effective detection range of approximately 48 nm. All images are taken at a 0.50 degree elevation angle and show the evolution of the transitory feature. Base reflectivity is on the left, and the corresponding velocity image is on the right. The dashed white oval in the 1823 UTC image encompasses a well defined wave train approaching Republic Airport in Farmingdale Long Island (FRG).



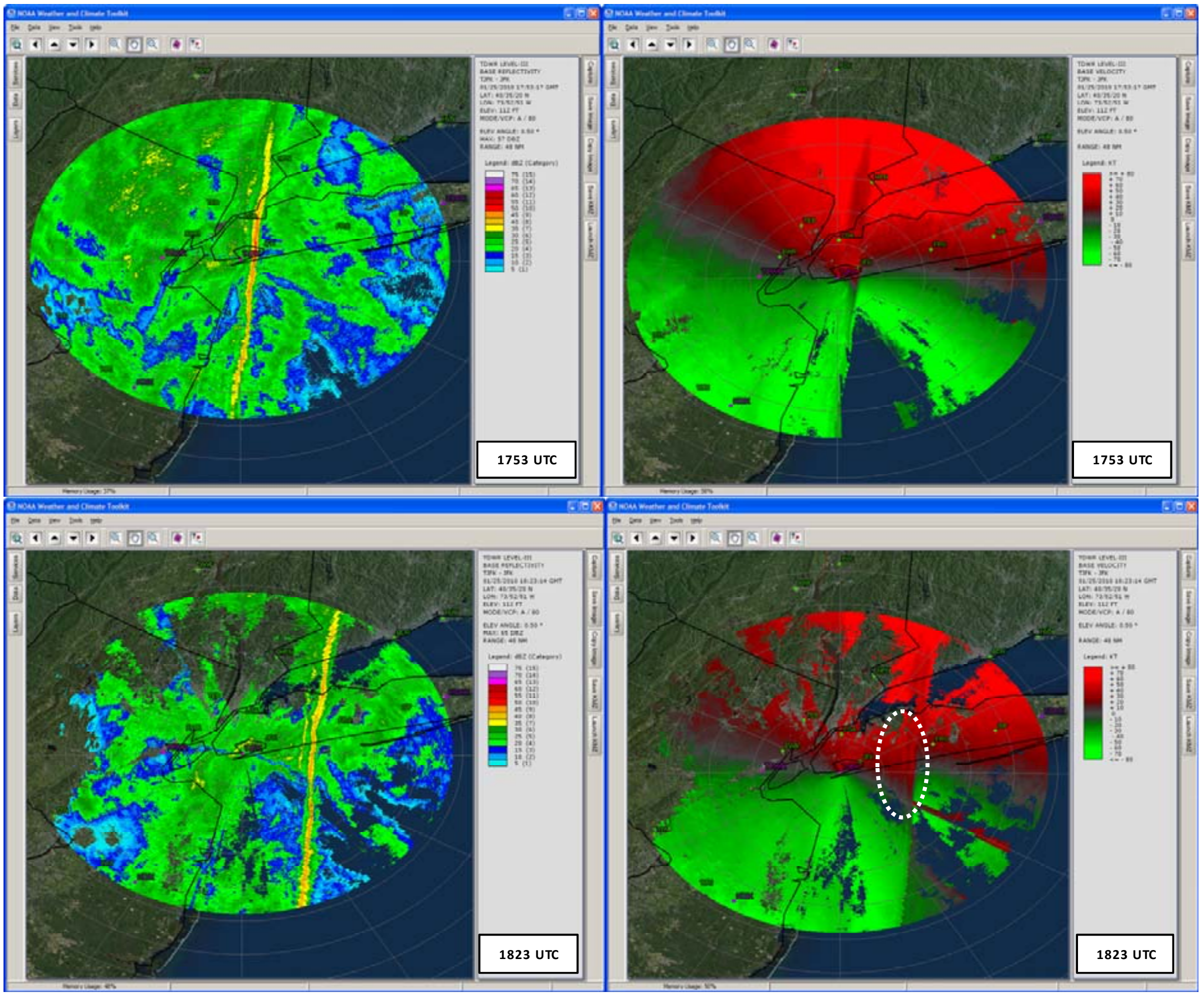


Figure 15: JFK TDWR base reflectivity (left) and velocity (right) showing evolution of squall line and gravity wave train within New York TRACON airspace. TEB, EWR, LGA and JFK airports are shown in green. The EWR and JFK TDWRs are marked in purple. Range rings are every 10 nm. The squall line developed very rapidly over New Jersey and intensified and elongated in a north-south direction as it moved east across Manhattan and Long Island. Doppler velocity signatures show a strong and fairly uniform region of southerly winds affecting air traffic ahead of the squall line. At 1735 UTC, the Doppler zero band is deformed due to increased vertical shear as the gravity wave becomes better established. For reference, Figure 16 (below) is the view from the KOKX WSR-88D taken at 1755 UTC. The KOKX NEXRAD is approximately 43nm east-northeast of JFK yet the 1.45 degree elevation angle was able to detect a prominent feature in spectrum width and velocity.

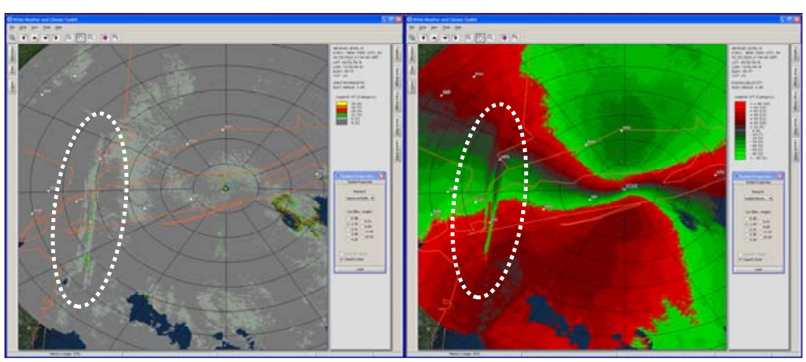


Figure 16: KOKX WSR-88D spectrum width (left) and velocity (right) at 1755 UTC, 25 January 2010.

The JFK TDWR did an excellent job detecting low-level shear throughout the day and provided alerts to air traffic controllers that dangerous winds were affecting aircraft on approach and departure. During the period from 1337 UTC to 1813 UTC, 3 microbursts and 58 wind shears were detected. The location and total distribution of shapes is shown in Figure 17. Purple dots represent all 15-knot, 20-knot, and 25-knot wind shears. Yellow dots represent microbursts of 40-knots, 35-knots, and 30-knots, respectively, from north, to south, to east of JFK Airport. A close inspection shows that the majority of detections were made over the open water and no shape directly impacted the runways. Figure 18 shows the shear regions relative to the narrow but intense squall line at 1753 UTC. It is accompanied by a velocity image taken one scan later at 1759 UTC. Wind shear detections slightly lag behind the trough/wave passage. Maximum echo top heights over the airport were 25kft.

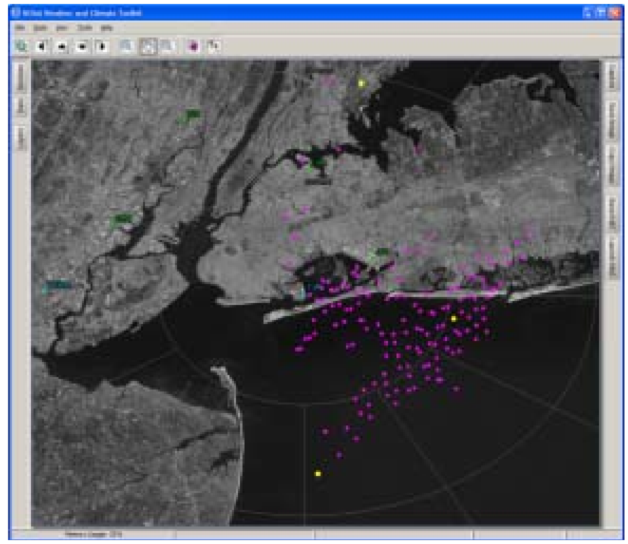


Figure 17: Wind shears and microbursts detected by the JFK TDWR on 25 January 2010.

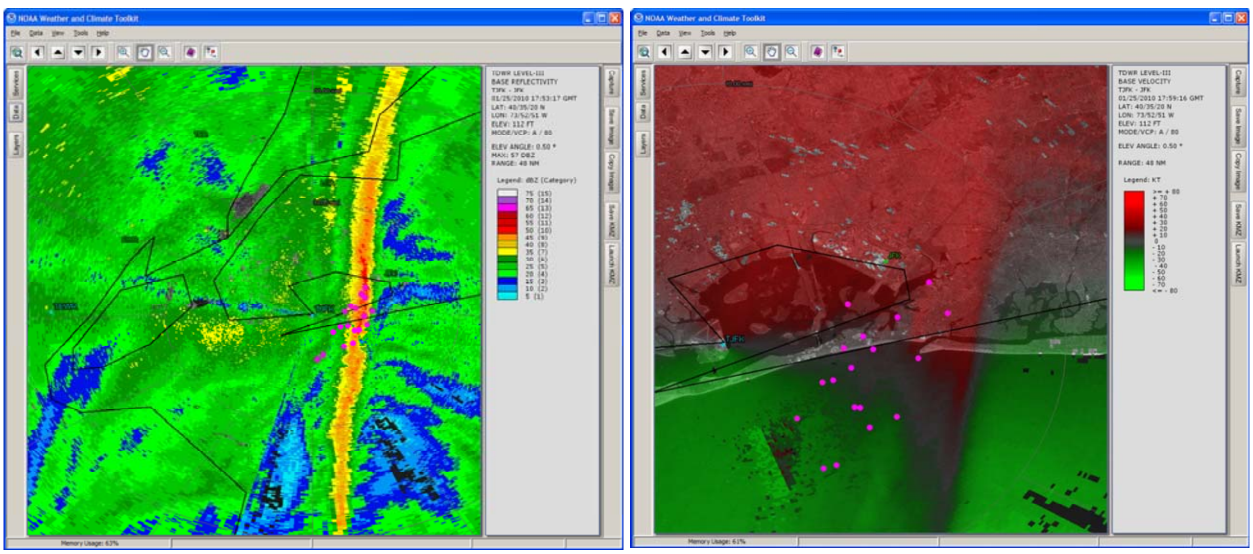


Figure 18: JFK TDWR base reflectivity and wind shears at 1753 UTC (left). The 0.5 degree tilt velocity field with wind shear overlay at 1759 UTC (right).

The dynamic storm system created a highly sheared environment for flying. The strong and gusty winds and speed divergence at the surface and aloft caused significant problems and delays for air traffic controllers and managers within the New York TRACON and at all four major airports. The JFK TDWR performed well and provided adequate warnings for over 60 low-level wind shear and microburst events. Most hazards were correlated with a narrow but intense pre-frontal squall line that exhibited gravity wave or buoyancy wave characteristics as it passed over JFK Airport at 1753 UTC. There were no thunderstorms or lightning reported during the passage and the extent of the severe weather resulted in many delayed arrivals and departures. Planning for the NY terminal areas was highly reactive and less effective than desired as traffic management initiatives were chasing events, and necessary restrictions were disseminated late. Moreover, there was excessive airborne holding in turbulent airspace and analysis of available forecasts suggests that more proactive planning may have been possible. The following section will examine a numerical weather model currently in development that predicted the severe weather conditions at least six hours in advance.

6. HIGH-RESOLUTION RAPID REFRESH MODEL

The High-Resolution Rapid Refresh (HRRR) model is hosted by NOAA's Earth System Research Laboratory (ESRL) (Weygandt, 2009). The 3-km resolution model is updated hourly and uses radar, aircraft winds and temperatures, and surface observations, to produce 0 to 15-hour forecasts across the entire continental United States. Although not used operationally at the present time, the forecasts and supplemental output fields are of great value to the aviation and air traffic control communities. ESRL's HRRR web site is freely accessible at *http://rapidrefresh.noaa.gov/hrrrconus*.

When the 25 January 2010 wind event case was examined after-the-fact through the use of HRRR data, fine details emerged regarding potential squall line development well before severe winds and convection impacted ATC operations in the NYC metro area. Figure 19 shows the HRRR 5-hour and 6-hour composite reflectivity forecasts valid at 1700 and 1800 UTC, respectively, based off the 1200 UTC model run. The corresponding VIL truth images are on the right. A thin line of strong convection was predicted from eastern Pennsylvania down the east coast just before and after the gravity wave passed over JFK Airport at 1753 UTC.

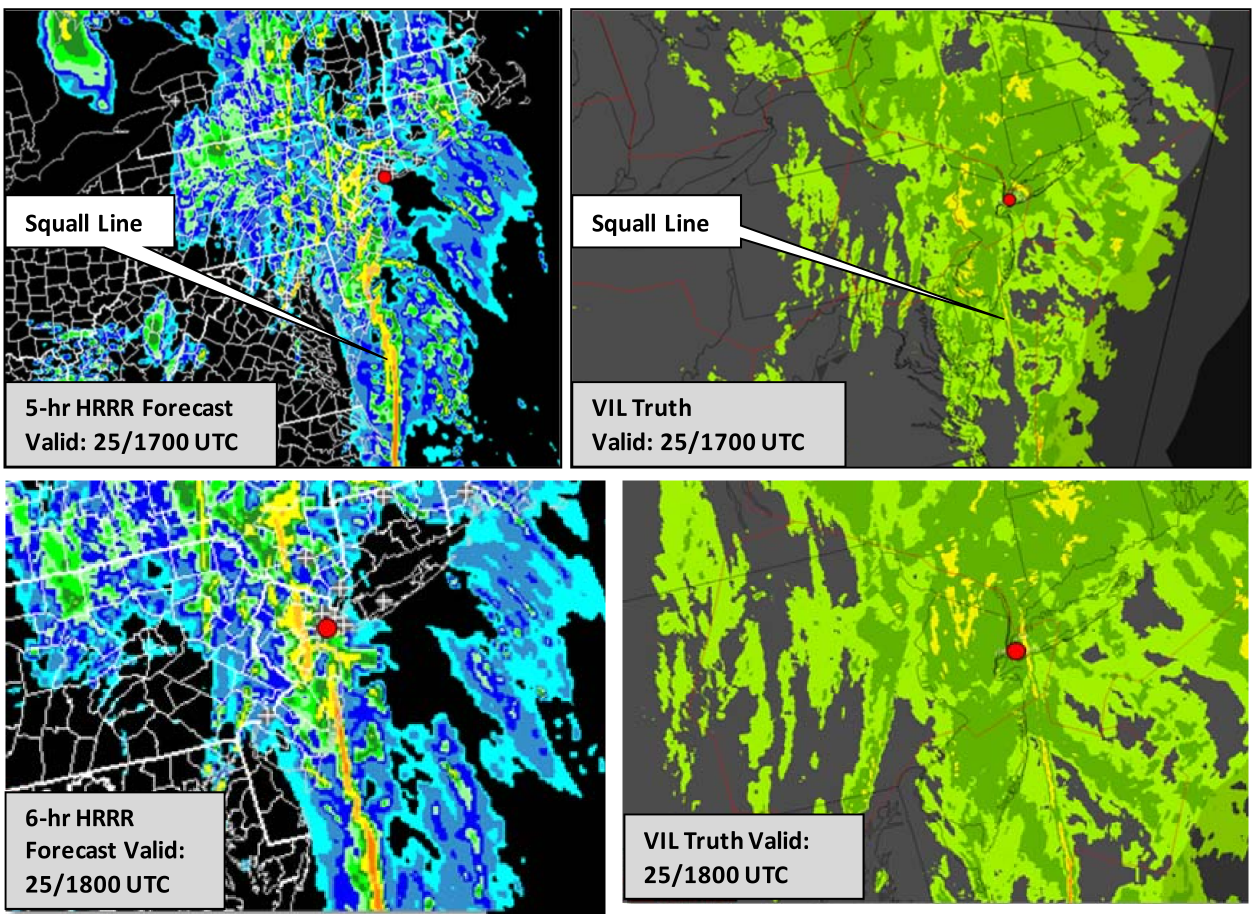


Figure 19: HRRR forecasts from the 1200 UTC, 25 January 2010 model cycle predicting a squall line impacting the NYC metro airports at 1700 and 1800 UTC. Corresponding VIL truth is on the right.

The HRRR web site also provides unrestricted access to over 50 separate model forecast fields that are viewable in hourly increments out to 15 hours. The supplemental output was very helpful in predicting the severe weather event in the New York area. For example, a sharp kink was visible in the 6-hour pressure field at 1800 UTC and a strong 30 to 50-knot jet core was noted at 10 meters. Surface visibility was predicted to drop below 1 mile and the maximum updraft/downdraft velocity regions were strong enough to signal turbulence. Overall, the raw HRRR forecasts resolved the instability line very well at 5 and 6 forecast hours in both timing and orientation. The supplemental forecast output fields appear to be extremely valuable for real-time decision making and post-event analysis. Unfortunately, the HRRR is not incorporated into any operational forecast and it is strongly recommended that the translation of these forecast output fields be incorporated into ATC decision support when it comes to arrival compression mitigation and severe terminal area turbulence avoidance.

7. PATH –BASED SHEAR DETECTION

Compression and expansion of arrival flows and aircraft encounters with hazardous turbulence significantly impacts airport capacity. The MIT Lincoln Laboratory Path-based Shear Detection (PSD) algorithm was developed in the mid-90's to compute headwinds and tailwinds along most major New York airport standard arrival corridors. The graphical display created for the NY TRACON indicates where along the paths significant gains or losses will be experienced since excessive gains lead to compression of aircraft and excessive losses lead to wider than desirable spacing between aircraft. The PSD was developed to ingest the ITWS Terminal Winds product at the New York airports but the algorithm is applicable to all airports where gridded winds forecasts have high enough spatial resolution to resolve shear regions. We believe that terminal domain subject matter experts, for example Traffic Management Coordinators, would be able to use PSD to quantitatively determine runway capacity estimates given minimum acceptable terminal area spacing.

8. TRANSLATION OF HRRR MODEL DATA INTO DECISION SUPPORT GUIDANCE

To optimize safety and to minimize avoidable delay, wind forecasts for air traffic management (ATM) during severe impact events need to be surgical in predicting the time, space, and severity of an event; and translated directly into explicit ATM impact predictions for objective collaborative planning. ATC-specific guidance currently provided by the National Weather Service; for example, Wind Compression Forecasts, Tactical Decision Aids, and Strategic Planning Aids, still require ATM to identify other pertinent weather conditions such as vertical shear to fully understand compression. Traffic managers need to pull NWS information back into an ATC model and determine the proper traffic management plan or response. The JFK Terminal Aerodrome Forecasts (TAF) for 25 January 2010 were good in accurately predicting a prolonged period of strong winds, but the wind shift was underestimated and the severe event was muted. The severe wind impact period had to be inferred subjectively, and translation of the forecast into an ATM plan was still required. A framework for translating HRRR data into weather-air traffic management decision support for wind impacts events is offered as a three-step process (Figure 20).

Step 1. The full suite of 0 – 15 hour HRRR forecast fields is used as initial model input for a set of ATM-specific algorithms. At the outset, a forecaster or human-in-the-loop would then examine the supplemental data for indications of any parameter that might impact terminal, TRACON, or enroute operations.

Step 2. An intermediate weather translation process identifies all meteorological conditions such as wind speed/direction, wind shifts, vertical shear, thin-line convection, frontal boundaries, etc. pertinent to air traffic management.

Step 3. The final step involves translating the previously identified weather parameters and producing explicit ATM impact guidance for strategic collaborative decision making. Explicit guidance such as when wind-defined runway configurations would be necessary, the location and intensity of arrival compression or expansion, the expected aircraft arrival rate and likelihood of a ground delay program, or the anticipated start and end time of a significant shear event at a terminal.

Augmenting the decision support chain to provide a more complete picture would be input provided by more mature tactically oriented systems such as ITWS, TDWR, and CIWS. TAFs, PIREPs, and PSD forecasts should also be used.

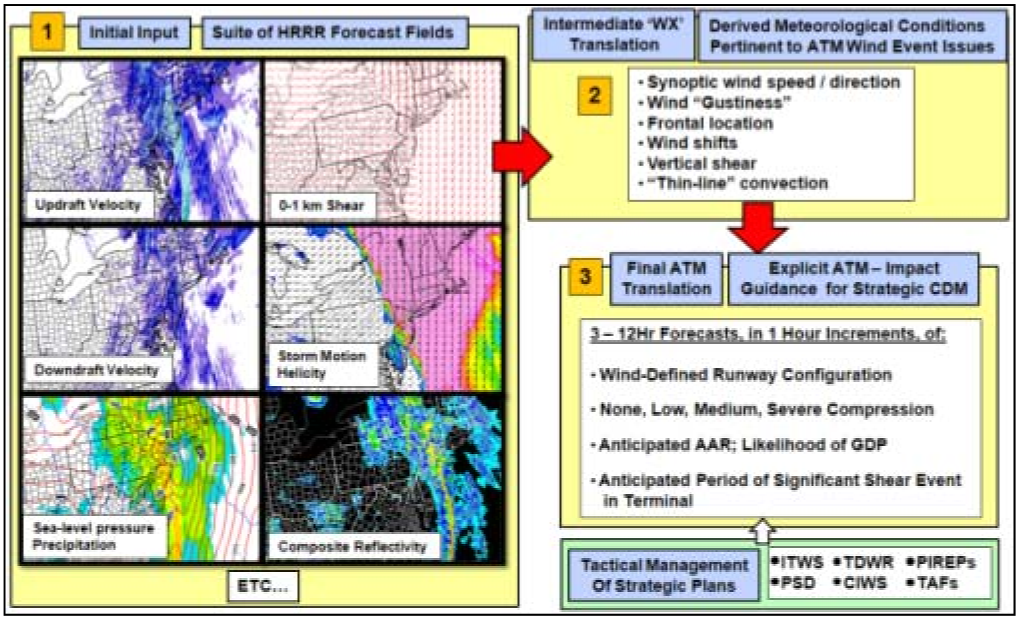


Figure 20: Framework for translating HRRR data into WX-ATM decision support for wind impact events.

9. CONCLUSIONS AND FUTURE WORK

A deep low pressure system moved across the Northeast United States on 25 January 20 and significantly disrupted air traffic at the NYC-metro area airports and throughout the surrounding airspace. The event was unusual because as the main cold frontal boundary approached from the west, a narrow but intense pre-frontal squall line and gravity wave developed unexpectedly that produced strong shear of the horizontal winds from the surface up to cruise flight altitudes. The gravity wave and low-level wind shears were detected well by the JFK TDWR, but many pilots ended up aborting their approach, cancelling takeoff, or holding aloft in less than optimum flying conditions. Air traffic managers were more reactive than proactive because of the rapidly changing severe weather and unplanned compression of arrival streams into the major airports. We have shown that the HRRR model accurately forecast the event at least 6-hours ahead of time. A case is made that the 15-hour HRRR forecast and supplemental output fields are extremely valuable for real-time decision making and post-event analysis. Since it is not currently incorporated into any operational product, a multi-stage framework is offered for translating the raw model data into actionable guidance for traffic managers and collaborative decision makers. It is obvious that many more observations and studies of terminal synoptic wind impact days need to be made - not only for the New York airports, but at other major airports across the country. Once a comprehensive first order assessment of avoidable weather delay days is identified, HRRR archive data can be reviewed to determine if similar forecast success stories can be told.

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