P1.4 TWO HISTORIC 2009-2010 BALTIMORE-WASHINGTON WINTER STORMS

Bryan A. Jackson* and Steven M. Zubrick
NOAA - National Weather Service, Sterling, Virginia

1. INTRODUCTION

The winter of 2009-2010 was the snowiest on record for the Baltimore-Washington metropolitan area. The bulk of the snow fell from three winter storms. Presented in this study are two of these cases, which produced snowfall at Washington DC on December 18-20 and February 05-06 (Figure 1a, b). In December, up to 80 cm of snow fell across west-central Virginia and eastern West Virginia, while 80 to 90cm of snow fell across the central Mid Atlantic states. Both of these snow events can be classified as major on the Northeast Snowfall Impact Scale (NESIS), a rating system for Northeast winter storms based on snowfall magnitude and coverage (Kocin and Uccellini 2004).

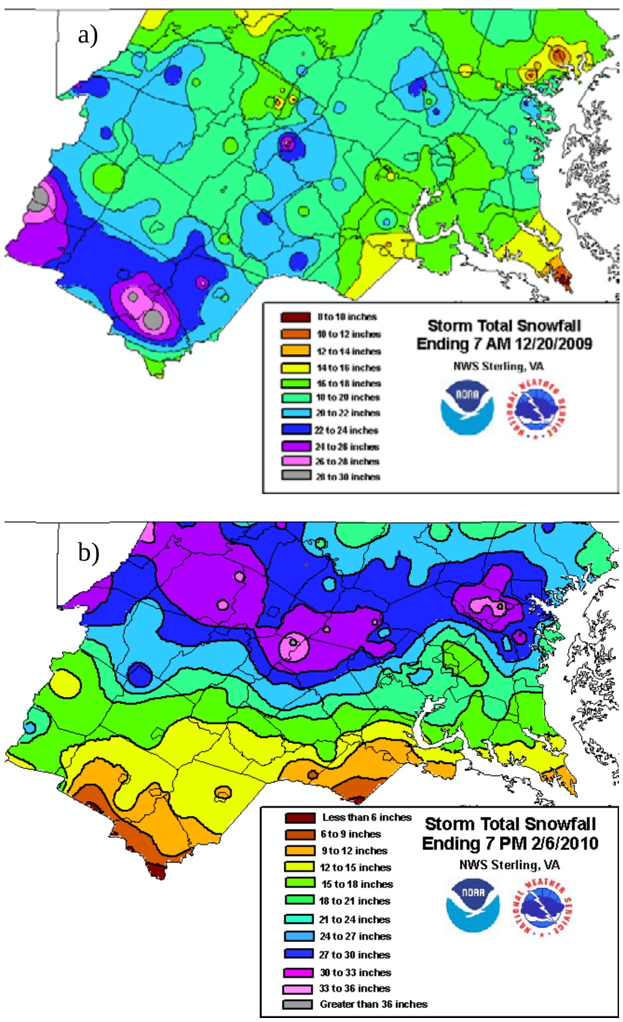

Figure 1. Storm total snowfall across NWS WFO LWX from (a) 18-20 December 2009 and (b) 05-06 February 2010.

The weather patterns leading up to and through the 19-20 December and 05-06 February storms were rather similar. During the 2009-2010 winter, a moderate to strong El Nino resulted in a very active southern jet stream. Also, during both cases the North Atlantic Oscillation (NAO) was in a negative phase with a strong ridge over Greenland and a deep trough over the Canadian Maritimes (Figure 2). This blocked pattern enabled northern and southern jet streams to phase over the eastern CONUS, allowing upper level northern stream energy to translate east to a coastal low across the southern Mid Atlantic. The location of this translation and the resultant forcing, along with abundant moisture, aided in the production of remarkable snowfall over the central Mid Atlantic. The key difference between the cases is the amplification of the jet streams. The more amplified February case had more intense jet streaks and

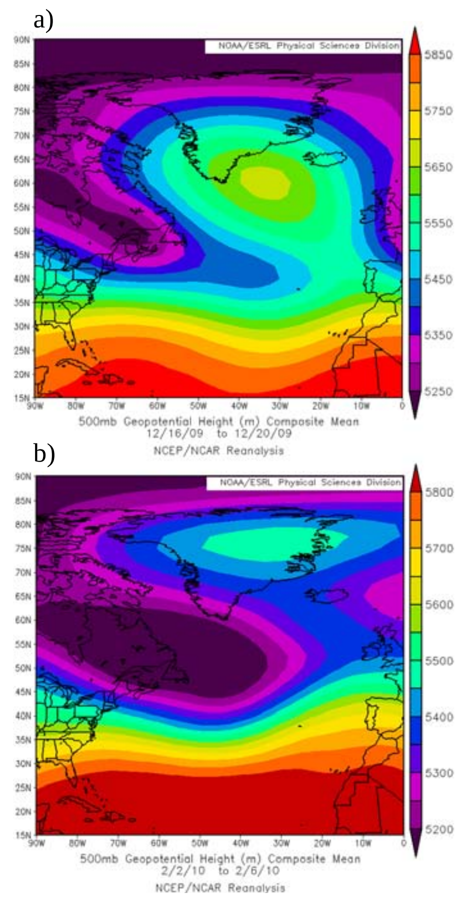

Figure 2. NCEP/NCAR Reanalysis Composite mean 500 hPa height (m) over the north Atlantic Ocean during the (a) December 2009 and (b) February 2010 winter storms.

much more available moisture and forcing, and thus greater snowfall. The more meridional nature of southern stream as it entered the CONUS in February also allowed a difference in the timing and completion of phasing between the two storms. Where the December storm phased over the eastern Tennessee Valley, allowing the already developed surface low to continue to track northeast along the coast (Figure 3a), the February storm had a more progressive and divergent southern stream that tracked north into the Midwest ahead of the northern stream, leading to an incomplete phasing and a more complicated west-to-east storm track (Figure 3b). The position of antecedent features such as surface high pressure and cold air also had an impact on the resultant snowfall for the Baltimore-Washington metro. Both of these winter storms produced moderate to heavy snow at Washington Reagan National Airport (KDCA) for roughly 24 hours (Table 1).

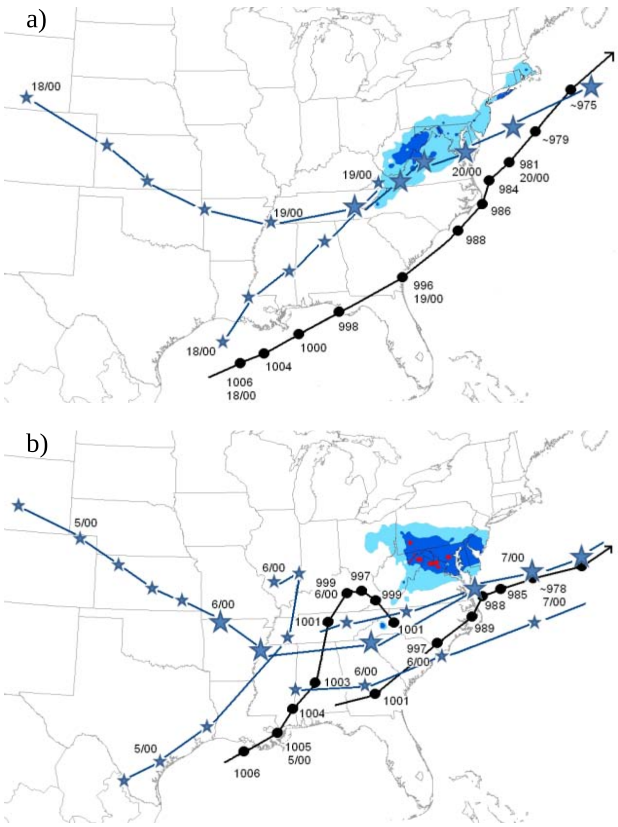

Figure 3. Tracks of 6 hourly 500 hPa vorticity maxima (blue stars) and surface low centers (black dots) from (a) 18-20 December; (b) 05-06 February. Shading is for snowfall of over: 25 cm (light blue), 50 cm (dark blue) and 75 cm (red).

An analysis of synoptic and mesoscale features depicted in standard weather charts and visible, water vapor (WV), and infrared (IR) satellite imagery available to National Weather Service operational forecasters in AWIPS for the two events begins approximately 24 hours prior to the onset of moderate snow at KDCA and continues through the Mid Atlantic portion of the event. Also used in the analysis were data from up to 48 hours before snow onset including full disk GOES-11 imagery, super rapid scan imagery from GOES-14 testing in December, and a derived moisture content product, the blended total precipitable water (TPW).

Table 1. Timing of light, moderate and heavy snowfall at KDCA as reported in METARs during both events.

December		**February**	
-SN began	0133 UTC 19th	-SN began	1544 UTC 05th
SN began	0242 UTC 19th	SN began	1700 UTC 05th
+SN began	1407 UTC 19th	+SN began	0319 UTC 06th
+SN ended	2039 UTC 19th	+SN ended	1752 UTC 06th
SN ended	2352 UTC 19th	SN ended	1825 UTC 06th
-SN ended	0505 UTC 20th	-SN ended	2224 UTC 06th
16.4 inches total		17.8 inches total	

2. STORM SUMMARIES

a. 18 to 20 December 2009

An early noticeable feature of the December case was an active southern jet stream that became stronger and more meridional over eastern Mexico as indicated in IR imagery at 0000 UTC 17 December by a plume of clouds that extended from Texas to the eastern Pacific just south of Mexico (Figure 4a). Over the next 24 hours, this feature tracked northeast across the Gulf of Mexico and by 0000 UTC on the 18th, a baroclinic leaf extending from the Yucatan to the Mid South was apparent (Figure 4b).

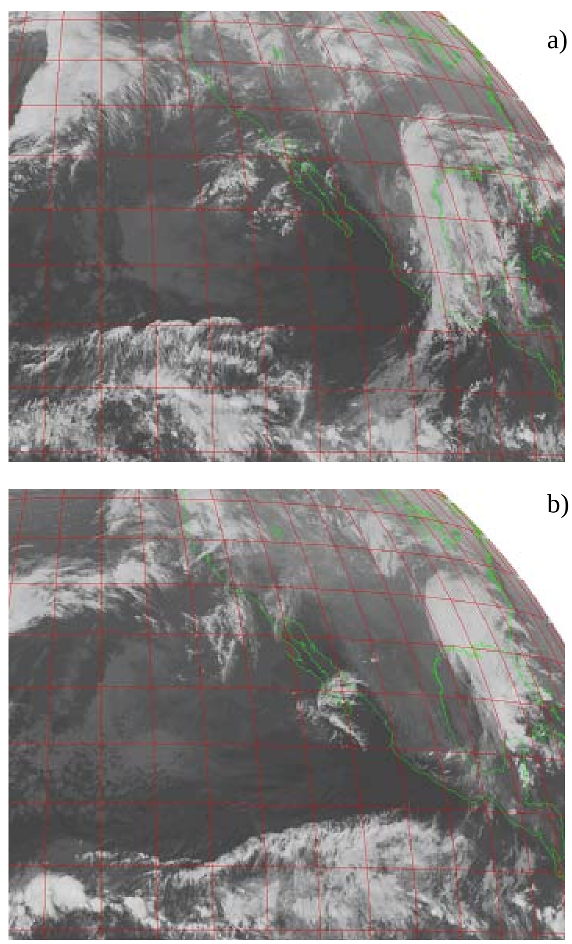

Figure 4. GOES-11 IR imagery (above) at (a) 0000 UTC 17 December and (b) 0000 UTC 18 December.

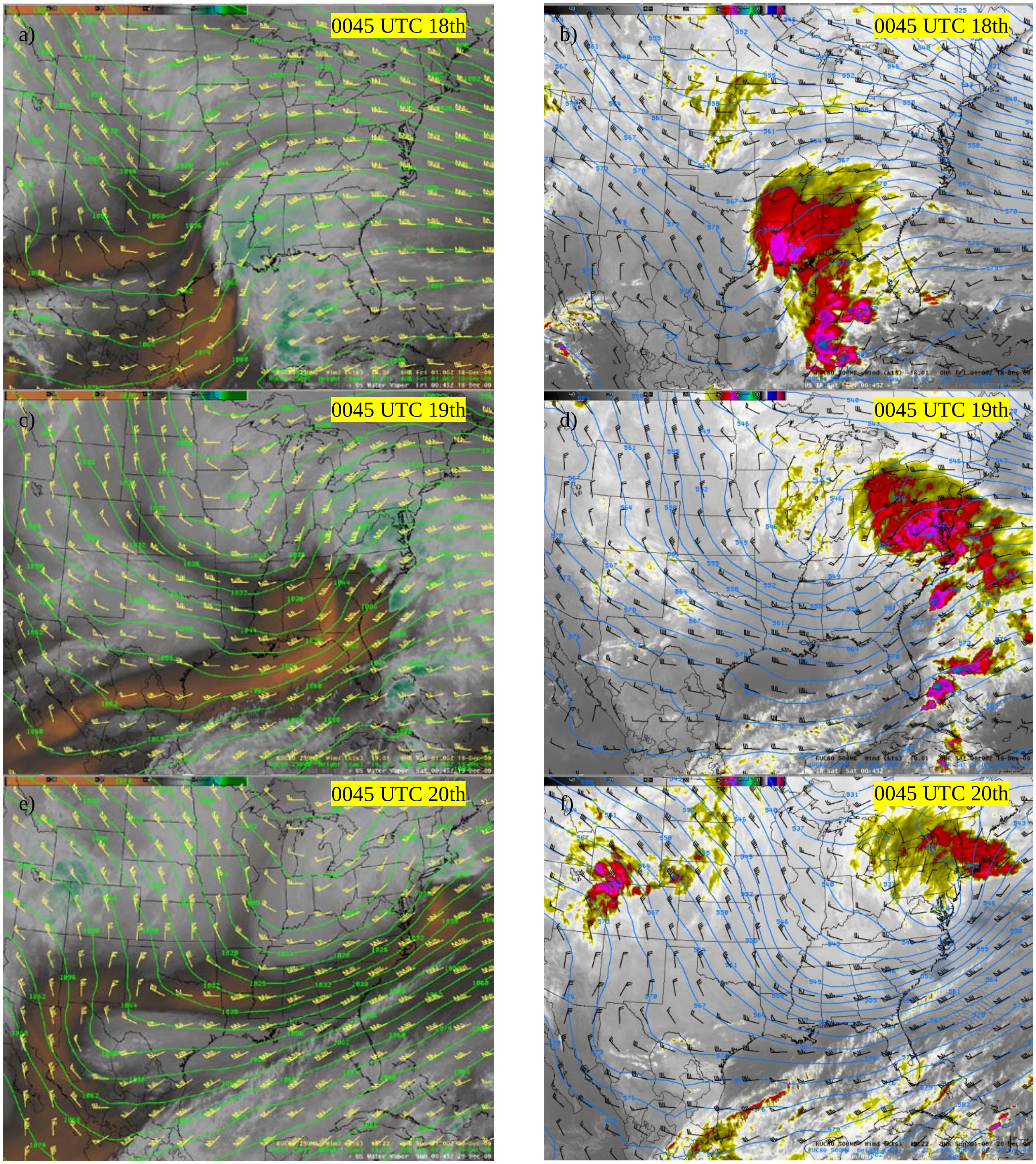

Figure 5. GOES-12 (left) WV imagery with RUC80 250 hPa geopotential height (dam) and wind (kt) and (right) IR imagery with RUC80 500 hPa geopotential height (dam) and wind (kt) at (a, b) 0045 UTC 18 December 2009, (c, d) 0045 UTC on the 19^{th}, and (e, f) 0045 UTC on the 20^{th}.

In a plot of 250 hPa geopotential height and wind from 0000 UTC 18 December, a deep trough extended down the Great Plains while a broad ridge was over the eastern CONUS (Figure 5a). Energy in the northern jet stream was pushing southeast over the Rocky Mountains in the lee of a ridge that had setup from British Columbia to Nevada. Southern stream energy was moving east-northeast along the Texas coast ahead of both the trough axis over the Great Plains and a positively tilted shortwave trough over Baja California. Downstream of the eastern CONUS ridge was a stationary 505 dam low at 500 hPa over the Canadian Maritimes and a very strong high over Greenland (Figure 2a). Notable magnitudes were associated with the jet streams through this wave pattern at 250 hPa: a northerly flow west of Baja California was greater than 25 ms^{-1}, a northwesterly jet max over the Intermountain West was greater than 45 ms^{-1}, a southwesterly jet max over the Mid South was greater than 55 ms^{-1}, and a west-northwesterly jet max over the northern Mid Atlantic was greater than 60 ms^{-1}. The confluence of the eastern CONUS ridge and the deep low over the Canadian Maritimes resulted in a 1031 hPa surface high centered over eastern Ontario that allowed cold air to spill south across the Eastern Seaboard (Figure 6). In both WV and IR imagery from 0045 UTC 18 December, a cusp in the baroclinic leaf south of the Texas and Louisiana border was apparent as dry southwesterly flow off the Sierra Madre interacted with a developing low on west side of the deep convective plume in the southern stream that covered the Deep South (Figure 5a, b). Also at this time, mid and high level clouds associated with the northern stream upper low were across the central Great Plains along with high clouds across the ridge over the Midwest to the Mid Atlantic (Figure 5b).

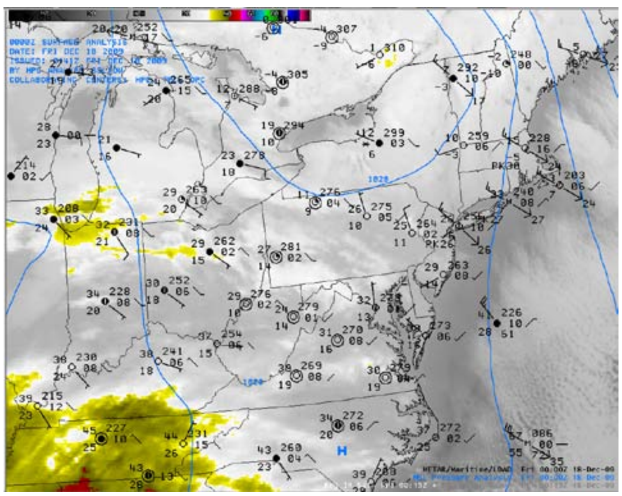

Figure 6. GOES-12 IR imagery with HPC surface pressure analysis and surface observations from 18 December at 0015 UTC.

Over the next 24 hours, the northern stream energy pushed southeast across the central Great Plains into the Mid South states while the developing southern stream low moved northeast across the southeastern states to the Georgia coast as the Canadian Maritime low remained stationary. As this southern stream low intensified, a surface low pressure center developed over the Gulf of Mexico. A large shield of stratiform rain, primarily due to isentropic lift, extended north of the surface low across the southeastern states with convective storms to the southeast. As the system moved north, it encountered cooler air that had invaded the eastern CONUS, which, along with dynamic and diabatic cooling processes, allowed a changeover to snow to begin [Asheville, North Carolina (KAVL) first reported snow around 1200 UTC on the 18th]. The central pressure of the surface low dropped below 1000 hPa near the Florida Panhandle coast around 1600 UTC on the 18th. This surface low steadily developed along a baroclinic zone over the Deep South through the daytime hours of the 18th, then along the southeastern US coast that night (Figure 3a).

By 0000 UTC on the 19th a reinforcing shortwave pushed south into the northern Great Plains, further deepening the northern stream trough and making it negatively tilted over the eastern CONUS (Figure 5c, d). With the downstream pattern still blocked, the northern stream and southern stream energy began to phase over the southern Tennessee Valley. In IR imagery from 0045 UTC on the 19th, the northern stream low had reached the Mid South while the southern stream comma head was over the southern Mid Atlantic where enhanced cloud tops were now apparent at the north end of the moisture plume that extended to the Bahamas (Figure 5c). From 0000 UTC to 0600 UTC, phasing of the two jet streams initiated with a great westward expansion of cooling clouds across the Ohio Valley, essentially stretching the comma head west (Figure 5d). This westward expansion of cooling tops is from both the cold conveyor belt transporting moisture from the Atlantic west along the north side of the low and the trough taking on a negative tilt. Through these six hours, the Canadian Maritime low began to retrograde to Quebec and the dry slot associated with the southwesterly jet expanded northeast across the southeastern states (Figure 5c). Ahead of the dry slot, the precipitation shield associated with the southern stream moved north through the Mid Atlantic with snowfall initiating at KDCA at 0133 UTC (Table 1). The interaction of instability from the dry slot over low level moisture with forcing from the phasing low resulted in heavy snow bands across the central Mid Atlantic later in the day.

In IR imagery from 0600 to 1200 UTC on the 19th, developing heavy snow bands began to appear as curved striations in the cloud shield from Ohio to North Carolina as the northern stream upper low translated energy toward the surface low along the Carolina coast (Figure 7a). Intense low level easterly flow, evident just north of the 850 hPa low transported Atlantic moisture and aided production of heavy snow from eastern Virginia to southern West Virginia with orographic effects enhancing snowfall totals for the central Appalachians (Figure 3a). With the westward expansion of the comma head and east-northeasterly progression of the original southern stream cloud plume in an increasing jet from the Gulf of Mexico, the comma head became very oblong by 1245 UTC on the 19th (Figure 5d).

From 1200 UTC on the 19th to 0000 UTC on the 20th, the storm continued to translate upper level energy southeast across the southern Mid Atlantic to the coastal low. A 986 hPa surface low near Cape Hatteras at 1200 UTC on the 19th intensified to about 981 hPa off the mouth of the Chesapeake Bay by 0000 UTC on the 20th (Figure 3a). Through this period, the southwesterly jet over the southern states drifted north and intensified as the northern stream trough moved east across the Midwest. Difluence associated with the left exit region of this jet increased, enhancing lift across the Mid Atlantic. Near the interface of the dry slot and cold conveyor belt on the north side of the low, the combination of frontogenetical forcing, lift, conditional instability, and ample moisture allowed several convective heavy snow bands to develop across central Virginia and track north in Pennsylvania (Figure 7a, b) with heavy snow first reported at KDCA at 1407 UTC (Table 1). During this time, an eye-like feature was visible at the surface low pressure center (Figure 8) which dropped to around 984 hPa by 1800 UTC (Figure 3a). Since this activity persisted over the same areas for around 12 hours while the storm contracted east, a swath of great snowfall occurred across the central Mid Atlantic (Figure 1a).

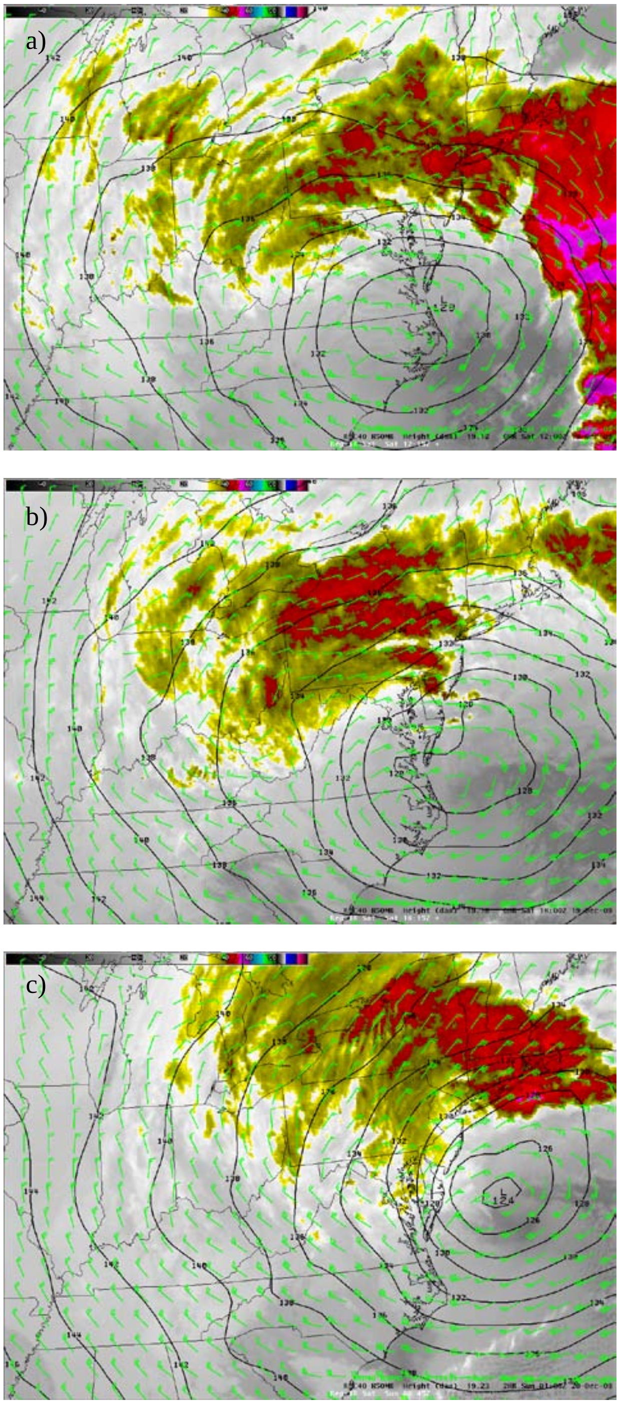

Figure 7. GOES-12 IR imagery with RUC40 850 hPa height and wind at (a) 1215 UTC and (b) 1815 UTC 18 December and (c) 0015 UTC 19 December.

Around 2100 UTC on the 19th, the coastal low and associated deformation zone/Trowal began to pull away from the Mid Atlantic coast. Cloud tops, as seen in IR imagery, warmed as the upper portion of the low quickly skirted east across Maryland toward the coastal portion of the storm (Figure 7c). Moderate snow ended at KDCA by 2352 UTC (Table 1). By 0045 UTC on the 20th, the downstream upper low had retrograded to over Quebec, allowing the storm to begin to eject northeast from the Mid Atlantic coast (Figure 4e, f). The storm then rapidly intensified as it became vertically stacked off the New Jersey coast by 0600 UTC on the 20th. The vertical stacking resulted in a narrower swath of more intense precipitation and wind that limited the greatest subsequent snowfall to Long Island and far southeastern New England (Figure 3a). Since most of the northeast corridor received less than 50 cm of snowfall, the NESIS rating of the December 18-20 2009 storm was limited to around 4.00, the minimum criteria for major classification.

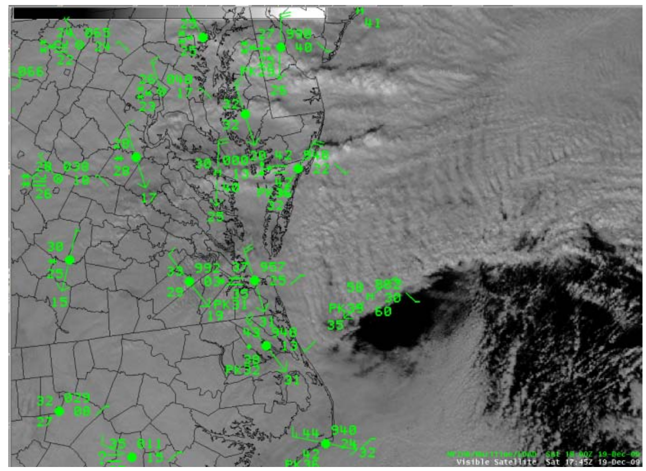

Figure 8. GOES-12 visible imagery and surface observations over the Mid Atlantic coast from 1745 UTC on 19 December.

GOES-14 Super Rapid Scan Test in December

As part of the science testing for GOES 14, super rapid scan mode (featuring continuous 1-minute data) was implemented for particular regions during December 2009; including the 18th and 19th for the Mid Atlantic. A loop of IR imagery over the Mid Atlantic from 1639 UTC December 18 to 1350 UTC on the 19th reveals incredible temporal detail to the development of mesoscale and storm scale features in this storm system. For instance, cloud tops associated with leading convective snow bands cooled about 10°C from the NC/VA border to northern Virginia between 2300 UTC on the 18th and about 0130 UTC on the 19th. The ability to see convective cloud bands associated with particularly heavy precipitation in the developing low system as it pushed northeast through North Carolina and Virginia after 0900 UTC on the 19th at a much more frequent rate than radar volume scans would be very useful to near term forecasting of heavy snow. In fact, depiction of these features from a single perspective compared to a mosaic of radars revealed a more precise location of features such as the low center between 500 hPa and the surface and the axis of convergence as the system contracted east. Super rapid scan in the GOES satellites enables real-time analysis of mesoscale and storm scale processes in developing severe weather and is an exciting prospect for the future of weather analysis and forecasting.

b. 05 to 06 February 2010

Very notable features were apparent as the elements leading up to the February case entered North America. At 0000 UTC 04 February, a deep cutoff low that had been over Baja California the day before was moving northeast into New Mexico with a very large comma shaped cloud. This was detailed in IR imagery that extended essentially from the eastern Pacific Inter-Tropical Convergence Zone (ITCZ) to the Great Plains (Figure 9a). Over the next 12 hours, this occluded low center diminished as it tracked northeast to Colorado, though a lingering trough continued to direct the southern jet stream into the tropics, stretching the comma cloud (and baroclinic leaf) from the eastern tropical Pacific to the Great Lakes (Figure 9b). Meanwhile, a northern stream trough developed an upper low as it moved east across Idaho and Wyoming.

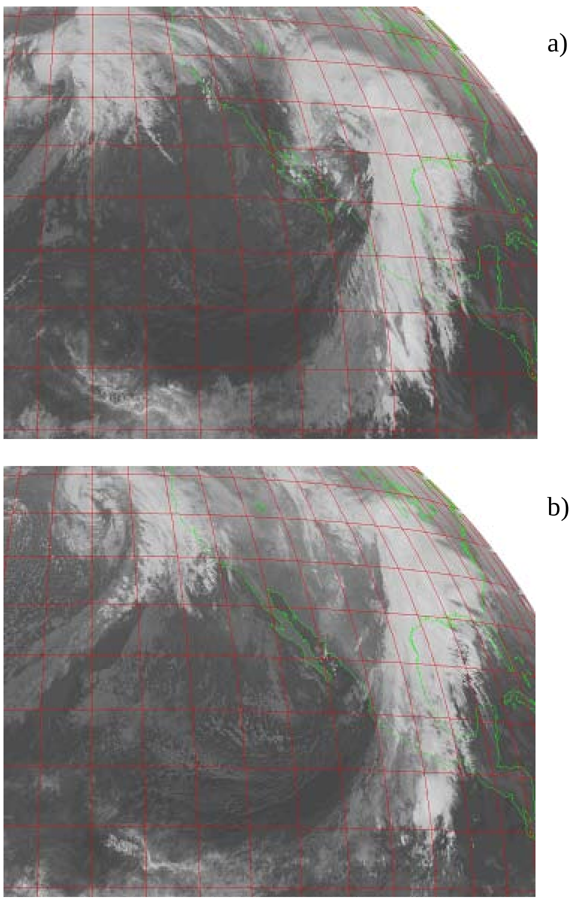

Figure 9. GOES-11 IR imagery (above) at (a) 0000 UTC 04 February and (b) 1200 UTC 04 February.

The highly amplified upper air pattern with this case is revealed in a plot of 250 hPa geopotential height and wind at 1800 UTC 04 February (Figure 10a, b). By this time the negatively tilted northern stream trough and the positively tilted southern stream trough curved down the Rocky Mountains into western Mexico. This stacked trough setup was upstream of a broad ridge axis that extended from the eastern Gulf Coast, across the Midwest, and all the way into the Canadian Prairies. Downstream of the northern portion of this ridge was a broad and deep area of low pressure across northeastern Canada (with two 505 dam low centers at 500 hPa near Labrador) that was blocked by a ridge over Greenland (Figure 2b). The northern stream trough and developing low were starting to turn southeast toward Colorado in the lee of a ridge that had set up from the British Columbia coast to southern California, while southern stream energy was moving north-northeast along the Texas coast (Figure 10b). Despite the similarity of jet stream location to the December case around 24 hours prior to the onset of snow at KDCA, the magnitudes in this more amplified regime were much greater: a northeasterly jet max west of Baja California was greater than 60 ms^{-1}, a northwesterly jet max over the Intermountain West was greater than 50 ms^{-1}, a south-southwesterly jet max from Texas to Iowa was greater than 80 ms^{-1}, and a east-southeasterly jet max over Long Island was greater than 100 ms^{-1}. Confluence between the eastern CONUS ridge and the Labrador lows resulted in a 1031 hPa surface high pressure centered over the eastern Great Lakes (Figure 11). This brought sunshine and 5°C air across the Mid Atlantic which melted the 10 to 20 cm of snow that fell across the Baltimore-Washington metropolitan area on February 02 and 03. WV and IR satellite imagery from 1731 UTC on the 04th show the large baroclinic leaf covering the central CONUS with clouds streaming from the positively tilted trough to over the ridge axis to the Mid Atlantic (Figure 10a, b). Cold cloud tops over the Deep South at this time were associated with a shield of moderate to heavy rainfall. Also apparent in the satellite imagery are two inflection points: one over northern Colorado ahead of the developing low, and one over Kansas ahead of the remnant low which combined to form an elongated comma head across the northern Great Plains (Figure 10a, b).

Over the next 24 hours, the northern stream upper low drifted southeast across the Front Range and the central Great Plains while a new low developed on the western edge of the baroclinic leaf over Texas. This development diverted some southern stream energy to the Tennessee Valley while the rest of the southern stream/warm conveyor belt cloud plume and precipitation shield tracked northeast into the southeastern states. Also during this time, persistent low pressure rotated around far eastern Canada, maintaining a blocked downstream pattern. On the evening of the 04th, a broad area of surface low pressure developed under the difluent zone in the southern stream over the northwestern Gulf of Mexico. Also that evening, the northern edge of the large precipitation shield encountered colder air drawn south from Canada and rain began to change over to snow (KAVL first reported snow around 2200 UTC on the 04th). The precipitation shield progressed north and snow began at KDCA at 1544 UTC and quickly increased to moderate intensity (Table 1). By 1731 UTC on the 05th, the northern stream upper low was over southeastern Kansas, the southern stream low had reached the western Tennessee Valley, while a second southern stream low had begun to form on the western edge of the baroclinic leaf over the Deep South (Figure 11c, d). The surface pressure of both southern stream lows dropped below 1000 hPa by 0000 UTC on the 6th, resulting in a dual low scenario that added to the complexity of the developing storm system as it approached the Mid Atlantic (Figure 3b).

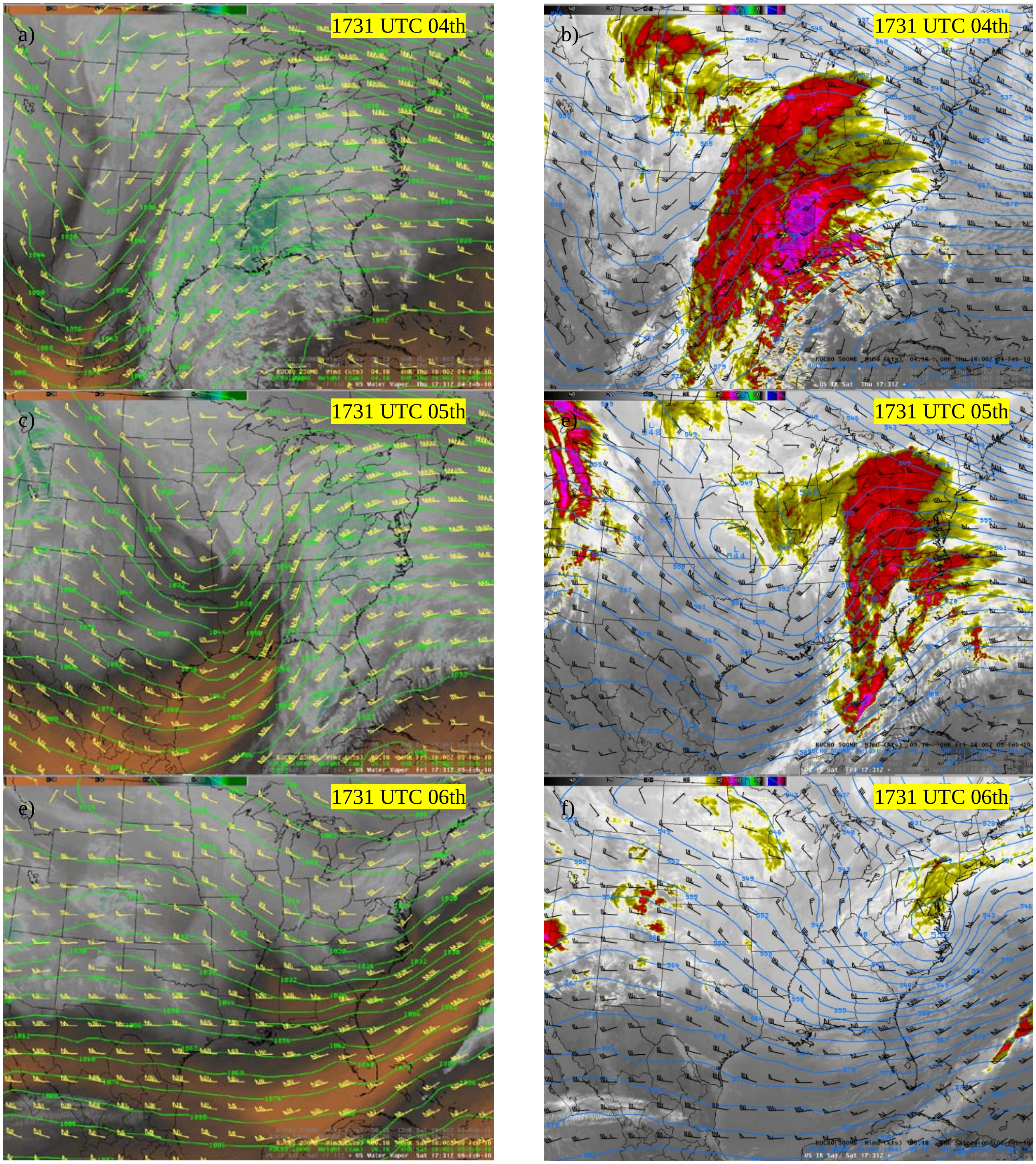

Figure 10. GOES-12 (left) WV imagery with RUC80 250 hPa geopotential height (dam) and wind (kt) and (right) IR imagery with RUC80 500 hPa geopotential height (dam) and wind (kt) at (a, b) 1731 UTC 04 February 2010, (c, d) 1731 UTC on the 05th, and (e, f) 1731 UTC on the 06th.

From around 1800 UTC on the 05th to 0600 UTC on the 06th, the first southern stream low phased with the northern stream upper low and became occluded, drawing the associated surface low center north into Kentucky (Figure 3b). Meanwhile, the northern jet stream wrapped around the phasing low, forcing the trough axis over the southeastern states to become negatively tilted and push the warm conveyor belt east across the Carolina Coast. During this period of cyclogenesis, bands of heavy snow developed across the central Mid Atlantic with heavy snow first reported at KDCA at 0319 UTC (Table 1). Furthermore, the persistent upper low over eastern Canada sank south to the Canadian

Maritimes, maintaining a low level ridge axis across New England. By 0600 UTC on the 06th, the second surface low had tracked northeast up the eastern Carolinas and intensified to 989 hPa in the coastal baroclinic zone (Figure 3b). 850 hPa analysis at 0615 UTC on the 06th showed the dual lows over the Virginia-North Carolina border and the central Ohio Valley (Figure 12a). This low pressure, combined with the high pressure ridge over New England, brought intense easterly flow to the central Mid Atlantic, which provided moisture, isentropic lift, and mid level frontogenetic forcing, enabling several bands of heavy snowfall. Over the next 12 hours, the easterly flow continued down the elongated occlusion to the north side of the western low, stretching the deformation zone/Trowal and associated swath of heavy snow to Ohio (Figure 3b). With the northward component of progression blocked, this pattern persisted for several hours with the western low translating east to the coastal low from roughly 1200 UTC (Figure 13b) to 1800 UTC (Figure 13c) on the 06th. By 1731 UTC on the 06th, the southwesterly jet south of the low center had pushed the warm conveyor belt well into the Atlantic, producing a very elongated comma shape to the clouds with the northwestern sector of the coastal low off the Delmarva forming the head (Figure 11e, f). The central pressure of the coastal low around this time was near 985 hPa and a small eye-like feature was apparent in visible imagery (Figure 13).

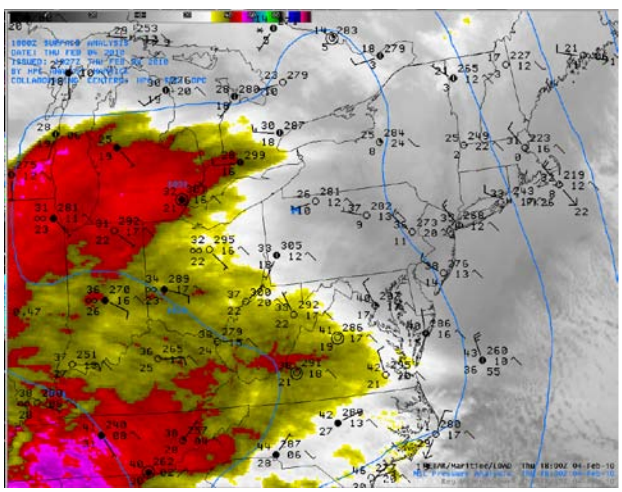

Figure 11. GOES-12 IR imagery with HPC surface pressure analysis and surface observations from 04 February at 1815 UTC.

Between 1800 UTC on the 06th and 0000 UTC on the 07th, the surface low rapidly intensified as upper portions of the system finished contracting east, making the system vertically stacked off the Delmarva coast. Wrap around snowfall persisted at KDCA until 2224 UTC. The storm total snowfall was quite impressive with an 80-90 cm swath from western Maryland and eastern West Virginia, east across northern Virginia to central Maryland (Figure 1b). With the block still in place to the north, the storm tracked east-northeast away from the coast, limiting significant snowfall to the Philadelphia metro area and central New Jersey, south to central Virginia and the Delmarva (Figure 3b). Since most of New York City and New England were spared significant snowfall, the NESIS classification for the 05-06 February 2010 storm is a low end major event with a rating around 4.40.

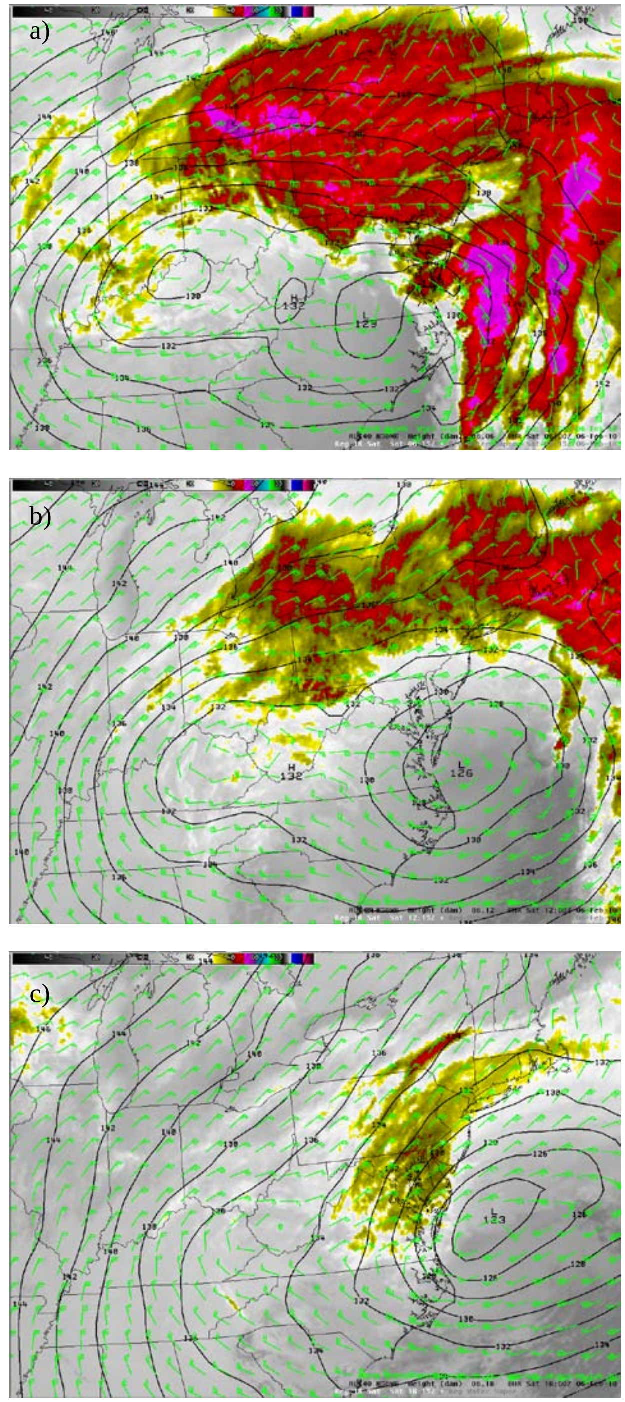

Figure 12. GOES-12 IR imagery with RUC40 850 hPa height and wind at 0615 UTC (a), 1215 UTC (b), and 1815 UTC (c) on 06 February 2010.

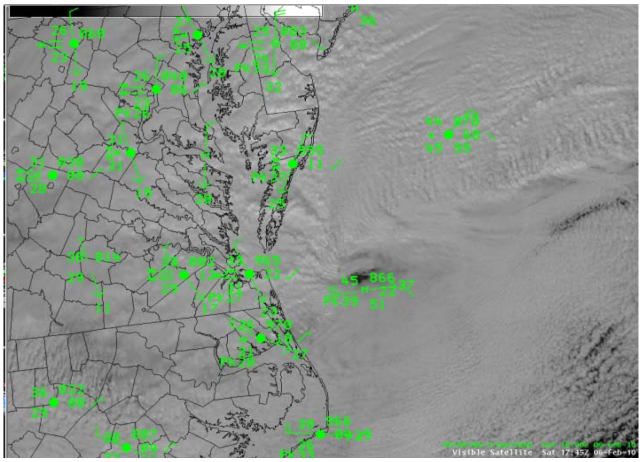

Figure 13. GOES-12 visible imagery and surface observations over the Mid Atlantic coast from 1745 UTC on 06 February.

3. MOISTURE DISCUSSION

WV imagery generally only depicts moisture from the upper levels of the atmosphere. A derived product, called blended total precipitable water (TPW), incorporates data from the passive microwave satellite sensors SSM/I and AMSU over ocean and from GPS communication signals along with some GOES soundings over land to quantify the TPW through the atmospheric column. The measure of atmospheric moisture is then compared to climatology to determine a percent of normal. Since blended TPW data comes from sensors that are ground based (GPS), in near polar orbit (POES and DMSP), and in geostationary orbit (GOES), the product delivery is inconsistent, though it is generally available to operational forecasters every two to four hours. This product is particularly useful for analyzing moisture transport, such as in these cases from the tropics to the mid-latitudes.

a. 18 to 20 December 2009

Blended TPW at 2305 UTC on the 16th (a little more than two days before snow onset at KDCA), was greater than 24 mm across south Texas, 36 to 48 mm across the western Gulf of Mexico, and 24 to 36 mm south of Mexico (Figure 16a). The TPW over the western Gulf was around 150% of normal while the TPW south of Mexico was right around normal (Figure 16b). Therefore, the moisture plume entering the early stages of the December storm derived mainly from subtropical sources. The moisture plume then expanded across the rest of the Gulf and north into the Deep South. As the storm phased and crossed the eastern CONUS, moisture surged toward the developing low. By 1753 UTC on the 18th, a TPW plume of 36 to 48 mm extended northward from the western Caribbean to Georgia with 12 to 24 mm up to the southern Midwest and across the southern Mid Atlantic (Figure 16c). This moisture content was over 200% of normal across Georgia and 150 to 200% of normal across the Tennessee Valley and the Carolinas (Figure 16d). As the surface low tracked northeast to the southern Mid Atlantic coast and translation of upper level energy from the northern stream began in earnest, the moisture plume entering the occluding system pushed east off the coast and over the Gulf Stream. Moisture continued to wrap into the occluding system off the Mid Atlantic coast even as the southwesterly jet pushed the moisture plume well into the Atlantic. At 0112 UTC on the 20th, TPW of 24 to 36 mm were derived off the Mid Atlantic coast with TPW around 12 mm across the Mid Atlantic (Figure 14e). These TPW values were around 200 percent of normal over the Atlantic and just above 100 percent of normal across the Mid Atlantic (Figure 14f).

b. 05 to 06 February 2010

The plume of tropical moisture with the southern stream in early February 2010 was very impressive. At 1142 UTC on the 3rd (a little more than two days before snow onset at KDCA), a plume with TPW of 48 to 60 mm extended north from the ITCZ to the Gulf of Mexico ahead of a deep low over Baja California (Figure 15a). As expected some of this moisture precipitated out over Mexico as TPW in the Bay of Campeche was in the 36 to 48 mm range. However, the moisture content of the plume was 150 to 200% of normal on both sides of Mexico (Figure 15b). As the jet streams approached each other, this plume was drawn north into the CONUS. As the southern stream/warm conveyor belt surged into the Midwest the derived moisture content was rather anomalously high. By 0806 UTC on the 5th, TPW of 48 to 60 mm extended northward from the ITCZ to southern Mexico, around 48 mm across the Gulf of Mexico, and 24 to 42 mm up to the southern Midwest (Figure 15c). This moisture content was 150 to 200% of normal around Mexico and over 200% of normal from the Gulf Coast to the Ohio Valley (Figure 15d). As the northern jet stream wrapped around the low and across the southeastern CONUS, the warm conveyor belt was pushed off the coast and over the Gulf Stream. However, the dual low development drew Atlantic moisture east across the central Mid Atlantic and into the Ohio Valley (not shown). The degree of occlusion is evident in a plot from 1928 UTC 06 February (shortly after moderate snow ended at KDCA) where 36 to 48 mm TPW extended from The Bahamas to Bermuda, 24 mm extended west from Bermuda to the Mid Atlantic coast, and around 12 mm remained over the eastern Mid Atlantic (Figure 15e). At this time, the TPW in the plume over the Atlantic were 150 to 200% of normal while the TPW over the Mid Atlantic was 100 to 150% of normal (Figure 15f).

4. SUMMARY

The overall pattern of the two cases were very similar with an active southern stream phasing with the upper level northern stream energy over the Tennessee Valley and subsequent translation of energy to a coastal low off the southern Mid Atlantic. Both storms phased over the southern Mid Atlantic because of a blocked pattern downstream of New England which lead to the abundant snowfall over the central Mid Atlantic. The December case had a nearly complete phasing since the timing allowed the northern stream upper low to converge directly with the southerly stream coastal low. The February case had two southern stream lows develop which lead to two phasings; one over the northern Tennessee Valley and the other across the southern Mid Atlantic. The greater meridional

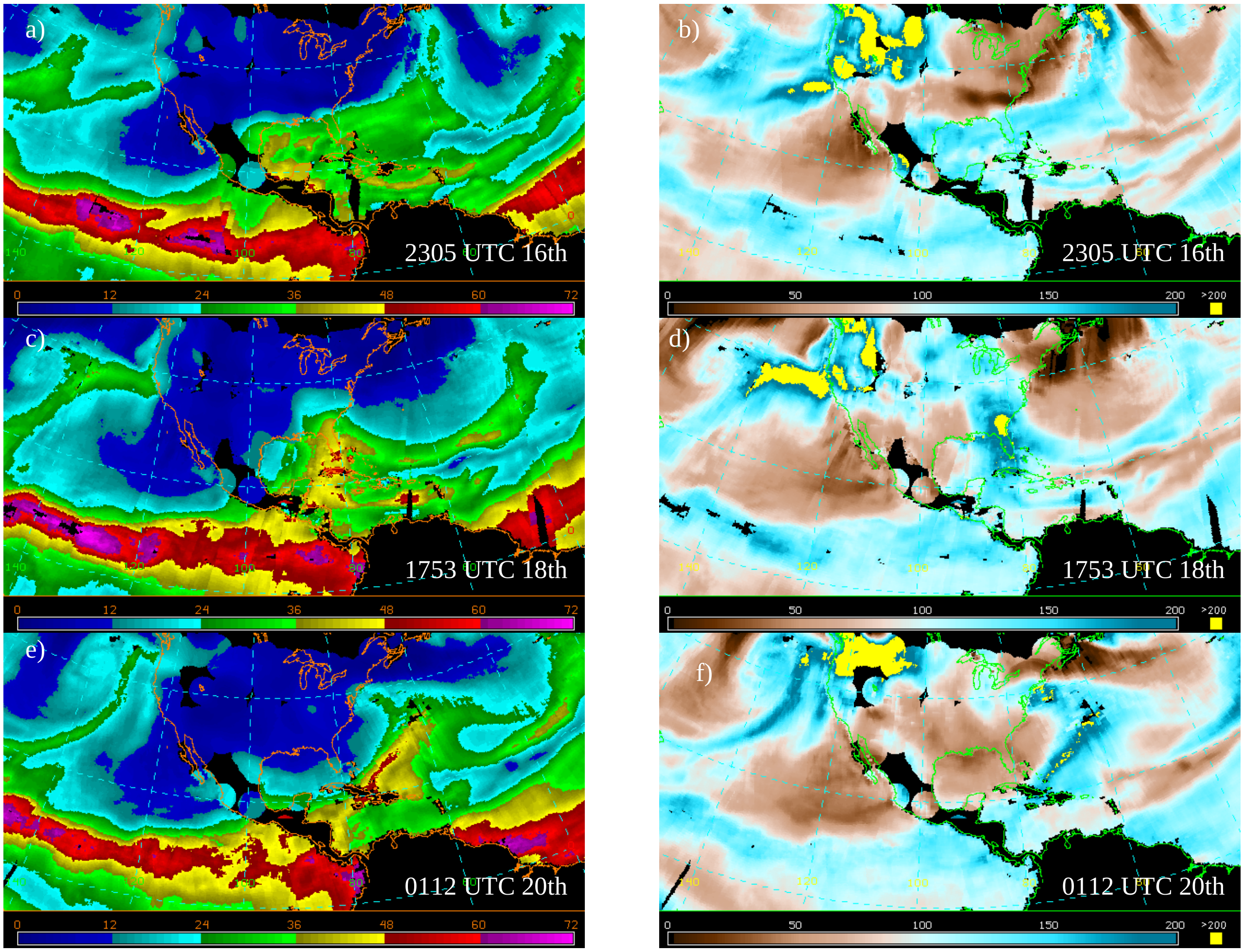

Figure 14. Plots of AMSR-SSM/I-GPS-GOES (left) blended TPW and (right) percent of normal from (a, b) 2305 UTC 16 December, (c, d) 1753 UTC on the 18th, and (e, f) 0112 UTC on the 20th.

nature of the upper air pattern in the February case drew much more tropical moisture into the system and enabled the southern stream to have a longer track through the southeastern CONUS which allowed the dual low to setup.

Moisture availability is essential to the development and quantity of precipitation in weather systems. The ability to analyze the moisture content through the atmospheric column and know the deviation of this value compared to normal across both land and ocean using the blended TPW product is very helpful to quantifying the capability of a developing storm system. Further improvements slated for the blended TPW product will only improve near real time analysis of moisture transport.

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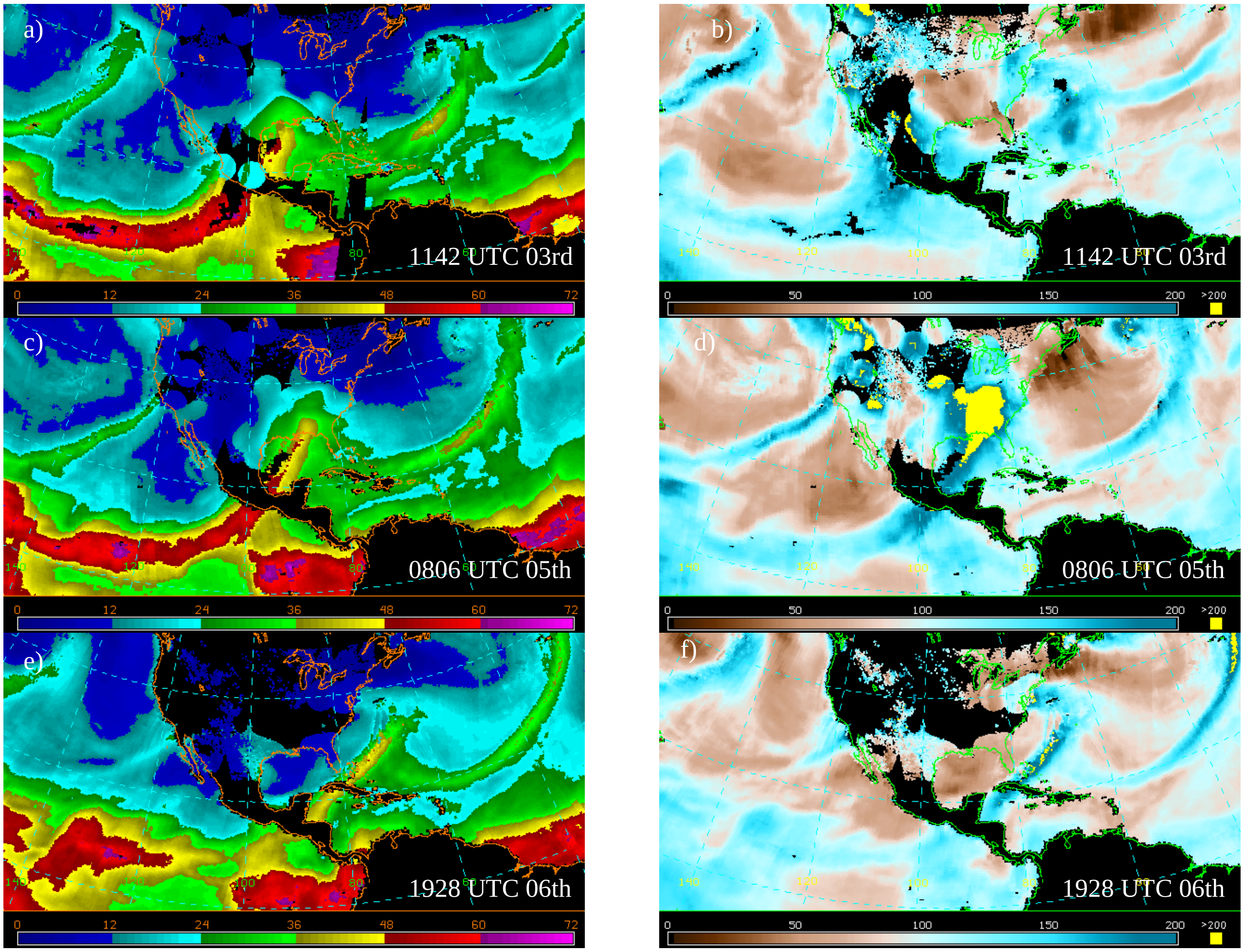

Figure 15. Plots of AMSR-SSM/I-GPS-GOES (left) blended TPW and (right) percent of normal from (a, b) 1142 UTC on 03 February, (c, d) 0806 UTC on the 05th, and (e, f) 1928 UTC on the 06th.