JP1.8 USING GOES SATELLITE PRODUCTS TO ENHANCE NATIONAL WEATHER SERVICE WARNING OPERATIONS

Samuel L. Lashley*
National Weather Service, Syracuse, Indiana

1. INTRODUCTION*

Geostationary Operational Environmental Satellites (GOES) have improved significantly since the early 1990s by being more efficient in gathering data, and having improved signal to noise ratios compared to the previous GOES Visible and Infrared Spin Scan Radiometer Atmospheric Sounder (VAS) (Menzel et al. 1998). These improvements have led to new and improved GOES products, some of which now arrive in National Weather Service forecast offices (NWSFOs) every 5 to 10 minutes, allowing them to be used in the warning decision process.

Most NWS offices now use a warning meteorologist to monitor radar information and make warning decisions, while a mesoscale analyst monitors the large amount of data from mesoscale models, local analysis programs, mesonet observations, and satellite. The mesoanalyst is responsible for notifying the warning meteorologist to changing atmospheric conditions that may affect storm development and evolution.

Delivery of real-time GOES products to NWS offices will help mesoanalysts identify features that may lead to changes in the near storm environment. This information can be relayed to the warning meteorologist to better anticipate storm evolution and strength.

This paper will briefly review some of the GOES instruments, products and improvements made over the last decade. Examples of Images and derived products that can aid in the warning process will be discussed, along with a case study showing their use in a real-time situation.

2. GOES INSTRUMENTS AND PRODUCTS

The first generation of GOES included satellites 1 through 7. Spacecraft in this series were spin stabilized and the VAS combined imaging and sounding, all limiting the effectiveness of instruments. The new generation of GOES began with GOES 8, launched 13 April 1994. This series of satellites began using three axis stabilization and carried separate instruments for imaging and sounding, capable of independent and simultaneous operation (Kidder and Haar 1995). This created a revolutionary change in how satellite images and derived products are delivered and used by operational meteorologists.

Prior to the mid-1990's, operational meteorologists had to wait between 30 and 60 minutes for new satellite images. This made satellite data nearly useless in warning operations. Since the mid-1990's, forecasters have been able to routinely receive images every 15 minutes through the Advanced Weather Interactive Processing System (AWIPS). During GOES Rapid Scan Operation (RSO), satellite images are received every 5 to 8 minutes.

Derived products are now available in real-time for operational use and can contribute significantly to mesoscale forecasting (Menzel and Purdom 1994). Derived products are available every hour, with atmospheric soundings possible from over 3,000 locations across the Continental United States (CONUS) and surrounding coastal waters. Access to these products can give meteorologists a very accurate depiction of the pre-storm environment in both time and space.

2.1 Imager

The imager is responsible for generating visible (VIS), infrared (IR) and water vapor (WV) images. Most operational meteorologists are familiar with the basic products generated by the imager and employ some type of observational techniques to monitor cloud development and movement during convective situations.

Convective cloud boundaries and their mergers and interactions have long been known to be potential pre-cursors to severe weather (Purdom 1973, 1974, 1976). The detailed resolution of the 1 km VIS product, combined with new images every 8 minutes, allows mesoscale meteorologists to accurately monitor convective

---

*Corresponding author address: Samuel Lashley
National Weather Service KIWX, 7506E 850N
Syracuse, IN 46567
email: Sam.Lashley@noaa.gov

cloud movements and anticipate boundary interactions. If warning meteorologists are made aware of potential boundary interactions prior to thunderstorm development, and atmospheric conditions are favorable for severe thunderstorms, warnings can be issued with increased lead times.

Infrared imagery at 4 km resolution does not have the detail that VIS imagery has, but it is useful in the warning decision process. Cloud top temperatures from IR imagery can be used to determine updraft strength and severe potential of thunderstorms. McCann (1983) discussed the enhanced V signature and demonstrated its usefulness as a reliable pre-cursor of severe thunderstorms. Using GOES 7 data with 30 minute intervals between images and broad temperature enhancement curves, the enhanced V signature showed high percent of detection of severe weather (POD), low false alarm rates (FAR), and 30 to 60 minute lead times before the first occurrence of severe weather (McCann 1983). With improved enhancement curves in AWIPS and GOES RSO, mesoscale analysts should watch satellite imagery closely for enhanced V signatures and inform radar meteorologists of their presence. This will help improve POD and lower FAR at many NWS offices.

Water vapor imagery at 8 km resolution has even less detail than IR images, but it too has its own benefits. Water vapor can yield important clues to large scale features such as vorticity centers, jet streaks, tropical moisture plumes, and areas of subsidence, which may impact ongoing or potential thunderstorm activity.

2.2 Sounder

Atmospheric profiles created by the sounder are similar to profiles generated from balloon radiosondes, but on a larger scale. Between 2,000 and 3,000 soundings can be generated by each GOES, each hour, over the United States and adjacent waters (Holt and Olsen 1999). This is about 150 times the number of profiles available from radiosondes (Menzel et al. 1998). The number of soundings generated varies depending on cloud cover since the sounder requires clear to partly cloudy skies to obtain accurate readings (Fig. 1).

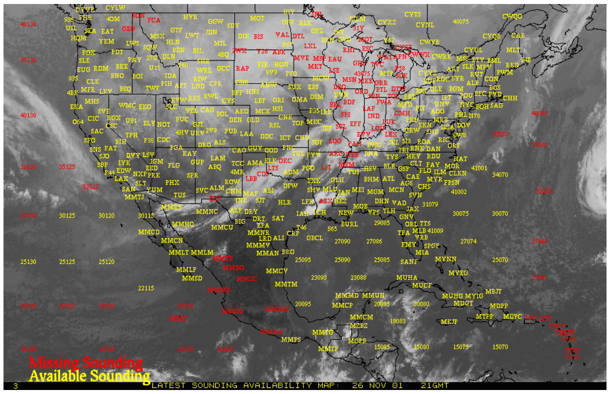


Fig. 1 Locations of GOES atmospheric soundings. Sites in yellow have a current sounding available while sites in red do not have a current sounding.

A sample sounding in Fig. 10 shows how similar a satellite derived sounding is compared to a traditional land based sounding. Important parameters in the forecasting of severe weather such as Convective Available Potential Energy (CAPE) Index, Convective Inhibition (CINH), Lifted Index (LI), Total Precipitable Water (TPW), and many others are computed each hour. The same parameters from the Eta model are shown with this sounding for a comparison of hourly GOES data to the current model run. An eleven month study of GOES sounding retrievals showed they were more accurate than NCEP short term forecasts for both temperature and moisture (Menzel et al. 1998). Thus operational meteorologists should have high confidence in GOES data when determining atmospheric stability.

Derived products from the sounder are not limited to vertical sounding profiles. Horizontal plots generated hourly are also available for CAPE Index (Fig. 3), LI (Fig. 7), CINH, TPW (Fig. 6) and WINDEX. WINDEX is a wind index designed to identify favorable environments for microbursts prior to thunderstorm development, using information from atmospheric soundings (McCann 1994).

Mesoscale analysts using GOES derived products will have an increased awareness and better understanding of the near storm environment than those simply relying on model output and sparse radiosonde data. This information will improve the ability of the warning meteorologist to anticipate storm structure and evolution, and improve the warning decision process.

3. CASE STUDY

On the afternoon of 11 September 2000, a severe weather outbreak occurred across the lower Great Lakes region, including the county warning area (CWA) of the NWS Northern Indiana Office, KIWX (Fig. 2). GOES satellite data provided helpful clues to atmospheric conditions before convection occurred and during the warning process.

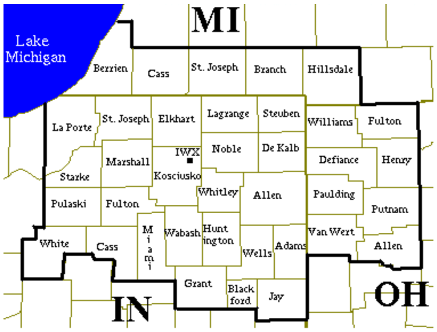


Fig. 2. NWS KIWX CWA

The morning weather pattern was dominated by two Mesoscale Convective Systems (MCS). A weak MCS was moving northeast along the Ohio river, and a much stronger MCS was moving northeast across Wisconsin and northern Michigan (Fig. 3). A large area of stratus from early morning fog was slow to dissipate across northwest Indiana and southern lower Michigan (Fig. 4a area A), leaving this area relatively stable during the morning hours. On the periphery of this stratus, surface temperatures were warming into the lower 80s with surface dew points in the lower 70s (Fig. 4a area B). Area C in Fig. 4a indicates the presence of a southwest to northeast oriented boundary in the cumulus cloud field, just west of Fort Wayne, Indiana (FWA). Loops of the RSO VIS images show this boundary moving north, likely a weak outflow from the southern MCS. This boundary is not evident in the KIWX WSR-88D radar imagery (Fig. 4b). Visible loops, surface observations, and radar imagery (Figs. 4a and 4b) also indicate a cold pool outflow boundary (Bader, et al. 1995) associated with the northern MCS at location D.

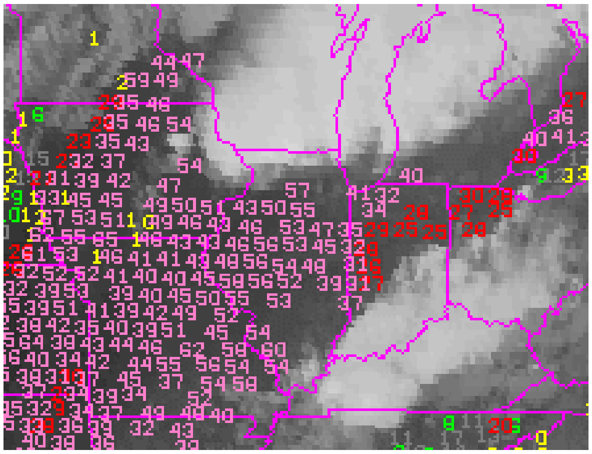


Fig. 3. Sounder and derived CAPE Index over Great Lakes region at 1800 UTC, 11 September 2000. Two distinct MCSs are visible.

The 1200 UTC run of the Eta numerical model indicated an axis of high instability north and west of the KIWX CWA by 1800 UTC, with less

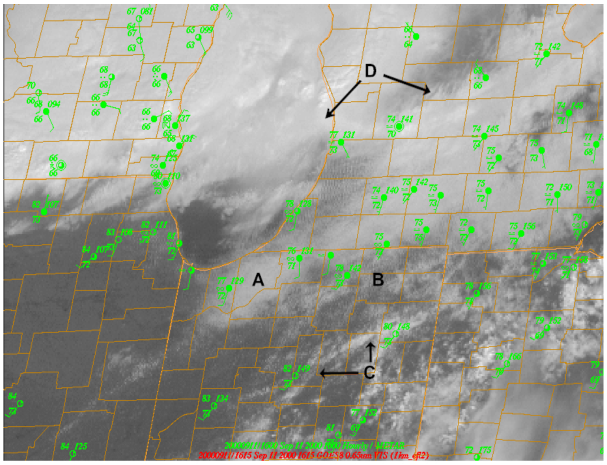


Fig. 4a. GOES 1 km VIS image at 1615 UTC depicting cloud boundaries at locations C and D.

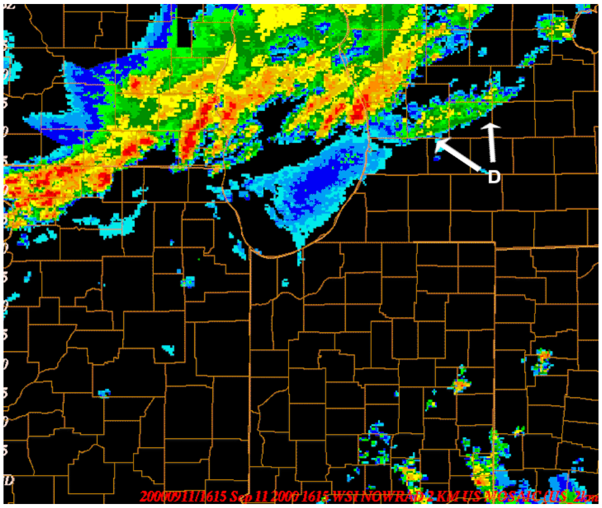


Fig. 4b. KIWX WSR-88D base reflectivity at 1615 UTC. Boundary D is visible but there is no indication of boundary C.

CAPE across northern Indiana and extreme southern lower Michigan (Fig. 5). High precipitable water values, near 1.5 inches (Fig. 5), were also forecast across the entire CWA and verified by GOES data (Fig. 6).

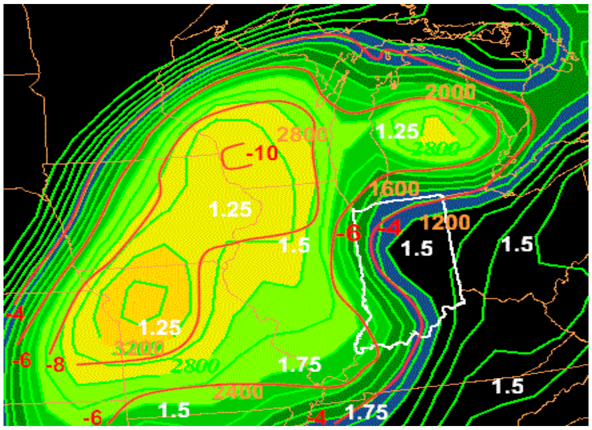


Fig. 5. Eta 6 hour forecast for 1800 UTC of CAPE (green contours and orange numbers), Best LI (red contours), and TPW in inches (white numbers).

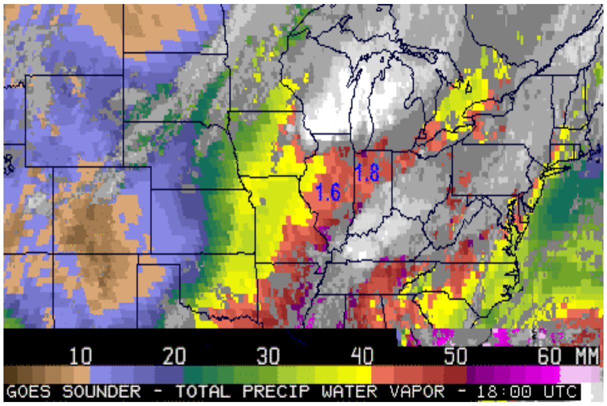


Fig. 6. GOES TPW product from 1800 UTC showing moisture axis from Arkansas to Indiana. Precipitable water values across northern Indiana are between 1.6 and 2.0 inches (blue numbers).

The GOES CAPE Index (Fig. 3) and GOES Lifted Index (Fig. 7) at 1800 UTC show much more instability over northern Indiana and southern lower Michigan than the Eta forecast. These products indicate CAPE values between 2000 and 4000 j/kg and lifted indices between -4 and -8. Forecast soundings from the 1800 UTC run of the Rapid Update Cycle (RUC) were used to determine which atmospheric conditions were actually prevailing. The initial forecast hour and 3 hour forecast from the RUC support the GOES data with CAPE values between 3000 and 4000 j/kg, and LI's of -7 to -10 across northern Indiana. In addition, surface temperatures and dew points in Fig. 8a would support higher CAPE values than the Eta forecast.

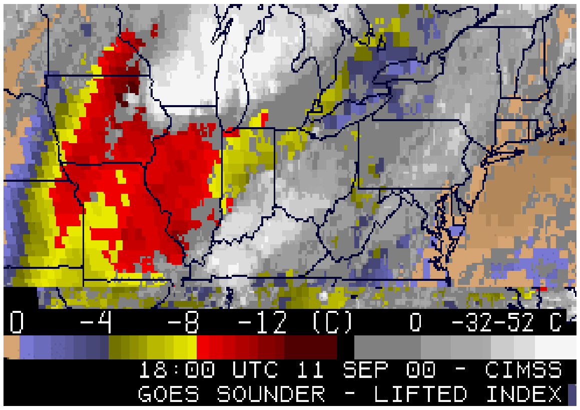


Fig. 7. GOES Lifted Index product at 1800 UTC. Lifted indices are between -4 and -8 across northern Indiana and lower Michigan.

Outflow boundary D can be seen in Fig. 8a at 1815 UTC as a very pronounced arc cloud (Purdom 1976) that has moved into southern Michigan. Meanwhile, the weak boundary that was near FWA has moved north, near the unstable atmosphere of area B, with an increase in convective clouds (Fig. 8a). Since intersections between outflow arc clouds and other boundaries have been shown to have a high potential for intense convective development and often severe weather (Purdom 1976), these features should be quickly recognized by mesoanalysts and the information passed on to warning meteorologists. It is also interesting to note that the stratus from area A in Fig. 4a has dissipated and convective cloud development has yet to occur in this region due to the inhibition of morning heating (Fig. 8a). Radar imagery from 1815 UTC (Fig. 8b) shows

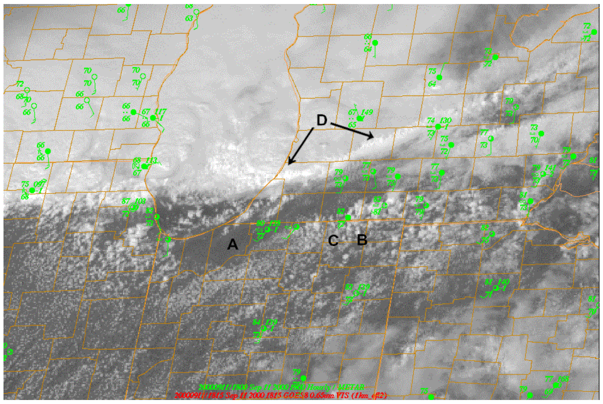


Fig. 8a. GOES 1 km VIS image at 1815 UTC. Boundary D is very evident and moving south. Boundary C has moved north into unstable region B.

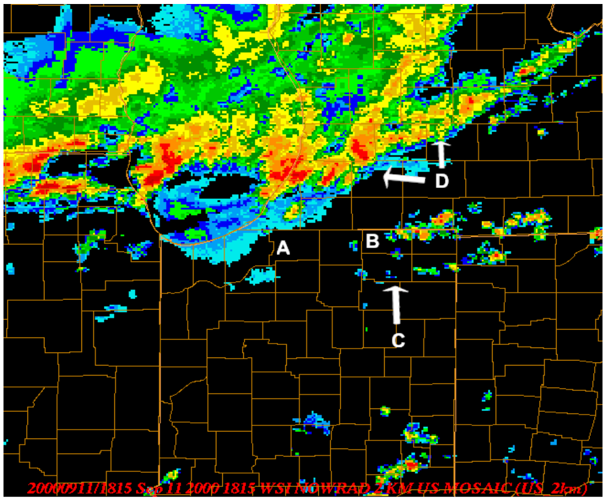


Fig. 8b. KIWX WSR-88D base reflectivity at 1815 UTC. Boundary C is now evident and convection is beginning in area B.

thunderstorms are indeed developing in region B while convection is being hindered in area A.

Once convection develops, GOES can still be useful in warning operations by providing real-time data to meteorologists about near storm environments (Weaver et al. 2001). At 2015 UTC, satellite shows the merger of boundaries C and D across northern Indiana (Fig. 9a). A Mesoanalyst monitoring visible imagery loops would have already alerted the warning meteorologist to this intersection. GOES soundings from 2000 UTC (Fig. 10) confirm that high instability and high liquid water content are present. With this knowledge, warning meteorologists can be confident in their warning decisions, which may lead to an increase in warning lead times.

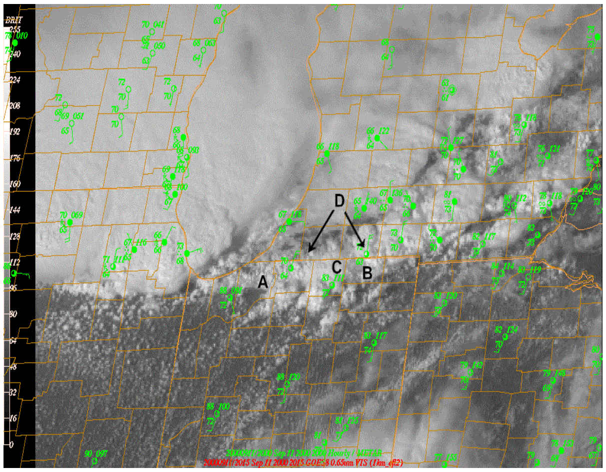


Fig. 9a. GOES 1 km VIS image at 2015 UTC. Boundaries C and D have merged in the unstable region B. Widespread severe thunderstorms are ongoing.

Severe thunderstorms with damaging winds and heavy rainfall are occurring in area B at 2015 UTC (Fig. 9b). Weaker convection has also developed in area A (Figs. 9a and 9b), but due to the morning cloudiness stabilizing the atmosphere (Weiss and Purdom 1974), severe thunderstorms were only observed near the edge of where the morning stratus was located (Fig. 15).

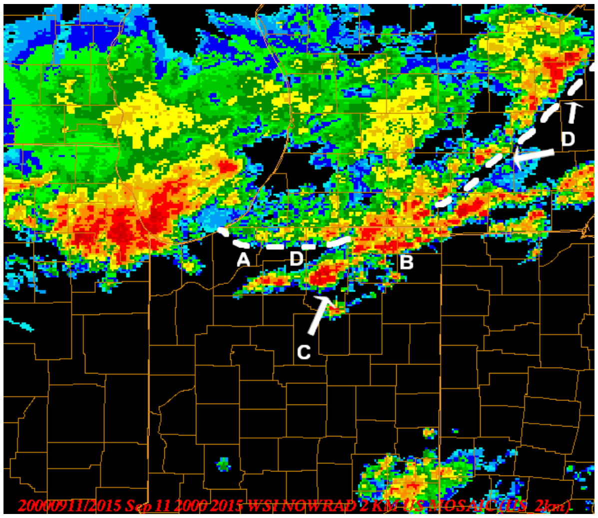
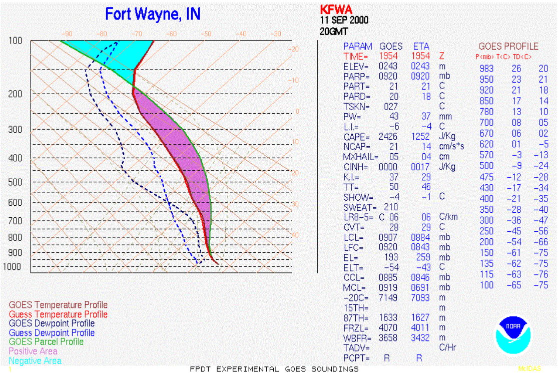


Fig. 9b. KIWX WSR-88D base reflectivity at 2015 UTC. Boundaries C and D have merged in region B where severe thunderstorms are ongoing. Area A is experiencing only weak thunderstorms.



KFWA
11 SEP 2000
20GMT

PARAM	GOES	ETA	
TIME=	1954	1954	Z
ELEV=	0243	0243	m
PARP=	0920	0920	mb
PART=	21	21	C
PARD=	20	18	C
TSKN=	027		C
PW=	43	37	mm
L.I.=	-6	-4	C
CAPE=	2426	1252	J/Kg
NCAP=	21	14	cm/s*s
MXHAIL=	05	04	cm
CINH=	0000	0017	J/Kg
K.I.=	37	29	
TT=	50	46	
SHOW=	-4	-1	C
SWEAT=	210		
LR8-5=	C 06	06	C/km
CVT=	28	29	C
LCL=	0907	0884	mb
LFC=	0920	0843	mb
EL=	193	259	mb
ELT=	-54	-43	C
CCL=	0885	0846	mb
MCL=	0919	0691	mb
-20C=	7149	7093	m
15TH=			m
87TH=	1633	1627	m
FRZL=	4070	4011	m
WBFR=	3658	3432	m
TADV=			C/Hr
PCPT=	R	R	

GOES PROFILE

P<mb>	T<C>	TD<C>
983	26	20
950	23	21
920	21	18
850	17	14
780	13	10
700	08	05
670	06	02
620	01	-5
570	-3	-13
500	-9	-24
475	-12	-28
430	-17	-34
400	-21	-35
350	-28	-40
300	-36	-47
250	-45	-56
200	-54	-66
150	-61	-75
135	-62	-75
115	-63	-76
100	-65	-75

Fig. 10. GOES derived sounding for FWA at 2000 UTC 11 September 2000.

Severe thunderstorms continued through the late afternoon hours as instability across northern Indiana remained high (Fig. 11). Mesoanalysts can monitor these GOES derived products each hour to determine if the instability is increasing or decreasing. In this case, lifted index values of -6 to -10 are being advected into the region of thunderstorm activity. This supports a continued threat of severe weather. The 2230 UTC VIS image supports the derived products with a large thunderstorm complex and overshooting tops across northeast Indiana (Fig. 12). Warning logs from the KIWX office show severe thunderstorm warnings were being issued for counties near these overshooting tops. Radar imagery from 2230 UTC (Fig. 13) shows the large area of severe thunderstorms that continue in the highly unstable region of area B.

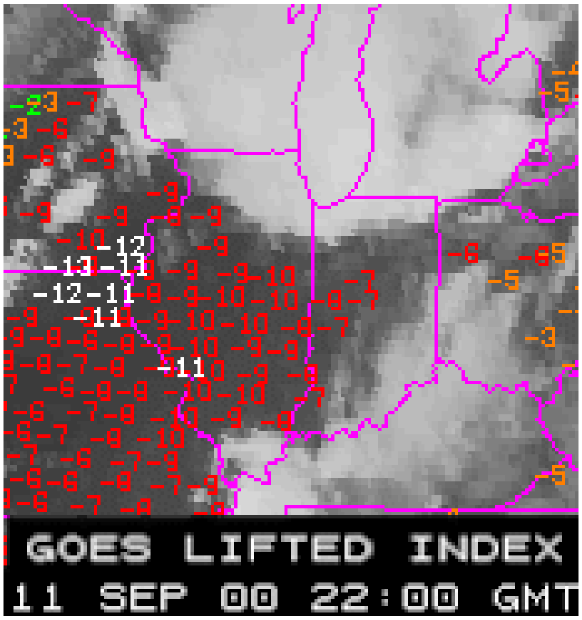


Fig. 11. GOES LI product from 2200 UTC showing the unstable atmosphere just south of the ongoing thunderstorm activity.

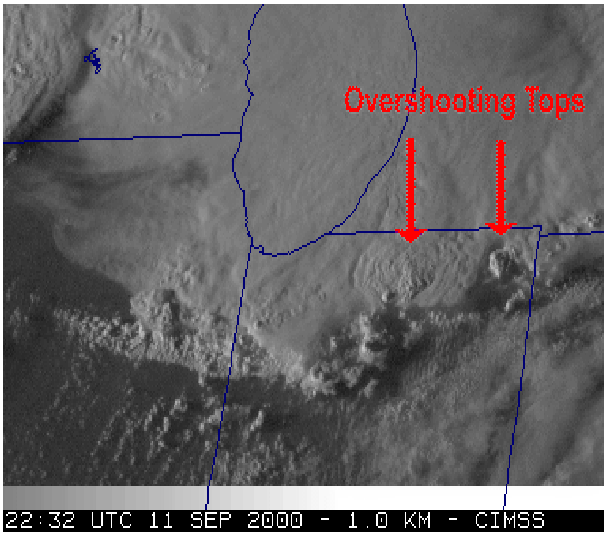


Fig. 12. GOES VIS image from 22:30 UTC. Overshooting tops can be seen across northeast Indiana. Severe thunderstorms and 3 to 5 inches of rain were observed with these thunderstorms.

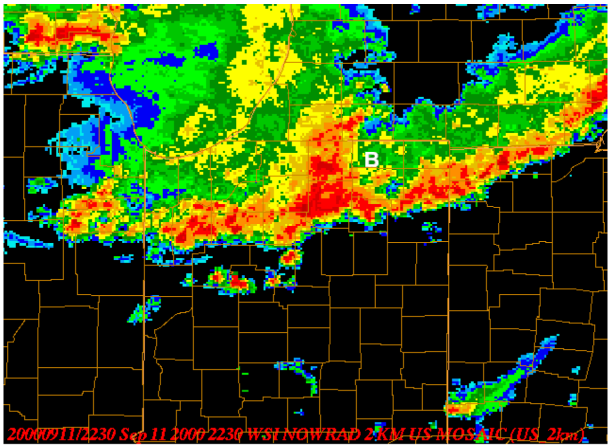


Fig. 13. KIWX WSR-88D radar image from 2230 UTC. Severe thunderstorms are occurring in region B. Thunderstorms are beginning to occur south of this area, where GOES derived products indicated high instability.

Damage reports obtained from the Storm Prediction Center (SPC) can be seen in Fig. 14. Several wind damage reports were received across northeast Indiana, near region B. Only a few severe weather reports were received from area A, mainly on the periphery of where the morning stratus was located. The atmosphere was unable to destabilize enough to support severe thunderstorms once the stratus dissipated.

Mesoscale analysts monitoring GOES satellite data can continually update warning meteorologists about the stability of the atmosphere near thunderstorms. In addition, VIS and IR images can be used to monitor enhanced V signatures, overshooting tops, and new outflow boundary interactions. Warning meteorologist can correlate this real-time information with radar trends. Results will be increased situational awareness and an enhanced warning decision process at NWS offices.

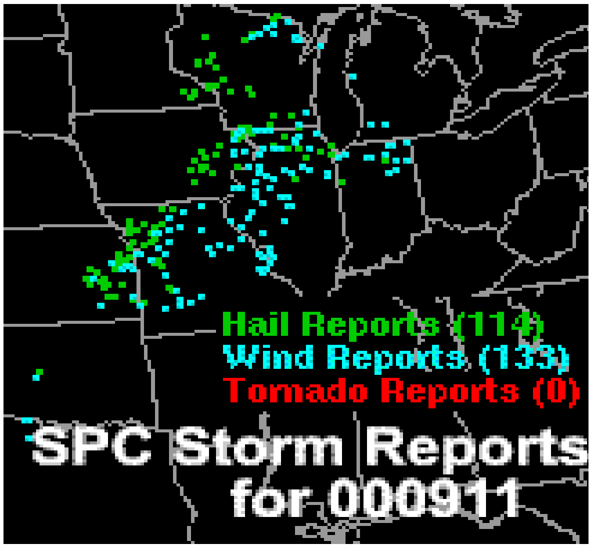


Fig. 14. Severe weather reports from SPC for 11 September 00. Several wind reports from northeast Indiana and area B, but few reports from northwest Indiana and area A.

4. SUMMARY

Improvements in satellite technology have made GOES products more valuable than ever before in NWS warning operations. GOES products can be used hourly to verify model forecasts and monitor changing atmospheric conditions. In areas away from radiosonde balloon launch sites, or during times between launches, GOES sounder data may actually be more representative of the atmosphere.

Mesoscale analysts and warning meteorologists should work together integrating GOES satellite images that arrive every 8 minutes in RSO, with WSR-88D radar images that arrive every 5 minutes in VCP 11. Satellite pre-cursors to severe weather, such as inverted V signatures in the IR (McCann 1983), overshooting tops, and boundary intersections in VIS images (Purdom 1976), can be recognized quickly and monitored with radar trends to improve lead times of severe weather warnings, lower FARs, and improve PODs.

Additional information, including loops of the VIS and radar imagery for the 11 September 00 case can be found on the World Wide Web at:

www.crh.noaa.gov/iwx/sllsatposter/preprint.html

5. ACKNOWLEDGMENTS

Special thanks to Jaime Daniels of NOAA/NESDIS, and staff at the University of Wisconsin/CIMSS for their work in obtaining archived satellite data used in this paper. Thanks also to Jeffrey Logsdon, Science and Operations Officer at KIWX for the many reviews of this paper.

6. REFERENCES

Bader, M.J., G.S. Forbes, J.R. Grant, R.B.E. Lilley, A.J. Waters, 1995: *Images in weather forecasting. A practical guide for interpreting satellite and radar imagery*. New York: Cambridge University Press, 499 pp.

Holt, Frances C., Steven R. Olsen, 1999: *GOES products and services catalog (second edition)*. U.S. Department of Commerce, Washington, D.C., 152 pp.

Kidder, S.Q., and T.H. Vonder Haar 1995: *Satellite Meteorology: An Introduction*. Academic Press, San Diego. 456 pp.

McCann, D.W., 1983: The enhanced-V, a satellite observable severe storm signature. *Mon. Wea. Rev.*, 111, 887-894.

McCann, D.W., 1994: WINDEX-A new index for forecasting microburst potential. *Wea. Forecasting,* 9, 532-541.

Menzel, W.P., Frances C. Holt, Timothy J. Schmit, Robert M. Aune, Gary S. Wade, Donald G. Gray, Anthony J. Schreiner, 1998: Application of GOES-8/9 soundings to weather forecasting and nowcasting. *Bull. Amer. Meteor. Soc*. 79, 2059-2078.

Menzel, W.P. and J.F. Purdom, 1994: Introducing GOES-I: the first of a new generation of geostationary operational environmental satellites. *Bull. Amer. Meteor. Soc*., 75, 757-781.

Purdom, J.F.W., 1973: Satellite imagery and the mesoscale convective forecast problem. *Preprints 8th Conf. Severe Local Storms*, Denver, Colo., Amer. Meteor. Soc., 244-251.

_____, 1974: Satellite imagery applied to the mesoscale surface analysis and forecast. *Preprints 5th Conf. Weather Forecasting and Analysis*, St. Louis, Mo. Amer. Meteor. Soc., 63-68.

____, 1976: Some uses of high-resolution GOES imagery in the mesoscale forecasting of convection and its behavior. *Mon. Wea. Rev.*, 104, 1474-1483.

Weaver, John F., John A. Knaff, Dan Bikos, Gary S. Wade, Jaime M. Daniels, 2002: Satellite observations of a severe supercell thunderstorm on 24 july 2000 made during the *GOES-11* science test. *Wea. Forecasting*: Vol. 17, No. 1, pp. 124-138.

Weiss, Carl E., James F. W. Purdom, 1974: The Effect of Early-Morning Cloudiness on Squall-Line Activity. *Mon. Wea. Rev.,* 102, No. 5, pp. 400—402.