

Transitioning Satellite Imagery from Research to Operations

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Abstract

At the present time, geostationary satellites provide the bulk of satellite information used by National Weather Service (NWS) offices. While these data are consistent and reliable, and quite beneficial to weather forecasters, at times data from polar orbiters may provide a better representation of the atmosphere. The Moderate-resolution Imaging Spectroradiometer (MODIS) instruments on board the Aqua and Terra satellites provide high, one-kilometer imagery at multiple bands. For certain situations this imagery can provide more detail about the current atmosphere than that rendered by the Geostationary Operational Environmental Satellite (GOES). In turn, this enhanced detail enables operational forecasters to more accurately predict future weather patterns and phenomena. To assist forecasters in their quest for greater accuracy, the Space Science and Engineering Center (SSEC) began sending MODIS imagery and products to NWS Forecast Offices in a format that could be displayed with the Advanced Weather Information Processing System (AWIPS), the primary display package of the NWS. This article describes the benefits of MODIS over GOES for specific situations and offers examples of several MODIS products and their use.

Introduction

Tasked with providing accurate weather forecasts and issuing timely warnings to save lives, NWS is the primary consumer of United States satellite data within an operational setting. The AWIPS software package allows NWS forecasters to render model data, plot surface and upper air observations, view radar slices, and display satellite imagery with Display Two Dimensions (D2D), a graphical user interface. Using AWIPS, meteorologists have the ability to load various channels from geostationary satellites, most notably GOES, on multiple scales, including, but not limited to, northern hemisphere, continental United States, and regional, specific to the location of the weather forecast office. AWIPS, the primary NWS forecast tool, retrieves nearly all relevant weather data (including satellite), from a satellite-based delivery system known as NOAAPORT, decodes it, and stores it in network Common Data Form (netCDF) format.

During a standard shift, a NWS forecaster may use satellite imagery to determine the movement of an upper-level cloud deck, watch fog formation and erosion, track particulate resulting from wildfires, check for the formation of a cumulus field, and discover features not well diagnosed with forecast models. To accomplish these tasks, the forecaster uses the visible, water vapor, and infrared window channels. Although geostationary satellites do not offer images at high, one-kilometer resolution across the United States and suffer from parallax error, the reliable and consistent nature of the imagery makes them a constituent part of the short-term forecast process. Other satellite products available in AWIPS include: scatterometer winds, valuable in hurricane forecasting; GOES Sounder lifted index, surface temperature, total precipitable water, and effective cloud amount, useful in evaluating thunderstorm potential; GOES operational wind vectors, for determining prevailing winds at different heights above ground; and GOES soundings, for vertically profiling the entire atmosphere at a given location.

GOES and MODIS

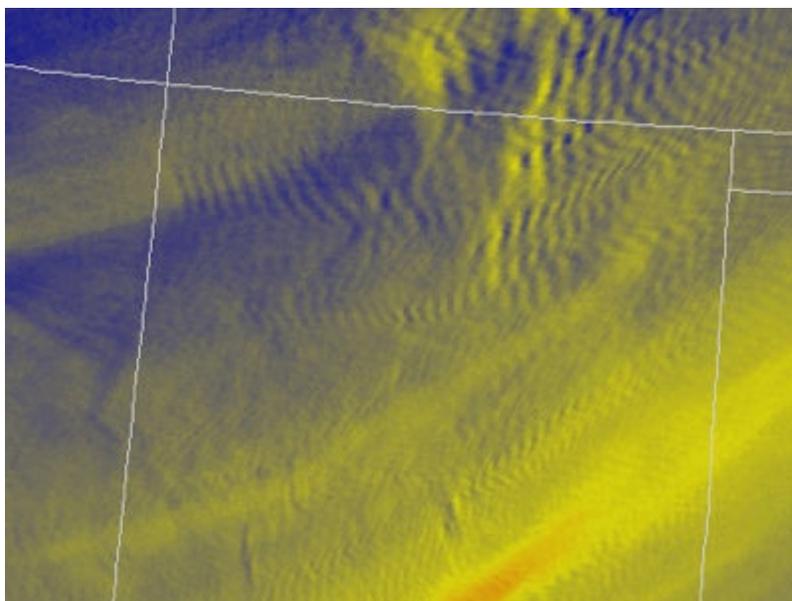
Although GOES provides data and imagery that are very useful to forecasters, compared to polar orbiters, it does not always provide the optimal perspective. Forecasters in Alaska and nearby polar regions cannot use geostationary satellites due to their degraded resolution at very high latitudes. Even in the middle latitudes, GOES does not render the nuances of deep convection with as much detail as some current polar orbiters. Additionally, the GOES satellites only have a limited number of channels. Satellites equipped with a MODIS can detect, among other features, mountain turbulence, eddies in sea surface temperature, thunderstorm signatures, surface moisture gradients, narrow valley fog, and surface ice accumulations (Bachmeier, 2007). Furthermore, products derived from MODIS can indicate cloud phase and more accurately represent the temperature of thin clouds. The two satellites that are equipped with such spectrometers are Aqua and Terra, both polar orbiting satellites. While their spatial coverage of polar regions is sufficient, their temporal resolution across the middle and equatorial latitudes is less than desirable for consistent use in operational settings. However, with proper training, forecasters can learn to use MODIS imagery and products in special situations.

Delivering MODIS

In 2006, the SSEC began providing select NWS forecast offices with imagery and products from the two MODIS satellites. The SSEC has an antenna which ingests data from Aqua and Terra as they pass across the United States and southern Canada. This data is then

processed into netCDF format, which can be read using AWIPS when in the proper structure, and then compressed. These compressed files are then distributed over the Unidata Local Data Manager (LDM) to the regional headquarters of the NWS. While this process is straightforward, there are time-consuming intricacies which complicate the process: AWIPS seeks netCDF files of a specific format, the netCDF files of MODIS data are large in size and cause bandwidth complications at NWS offices, and AWIPS cannot easily adapt to accept new products. NWS offices can then choose the MODIS data they wish to receive from their region's LDM feed. Following its capture, it takes approximately one hour for an image to arrive at a NWS office, depending on the image or the product.

In order to view the images in AWIPS, a NWS office must download the customization scripts provided by SSEC, and install the proper menu entries. Once the menu entries are installed, a forecaster can load the images in D2D. In AWIPS, forecasters can overlay numerical data or create four-panel displays to diagnose the conditions of the atmosphere more effectively.

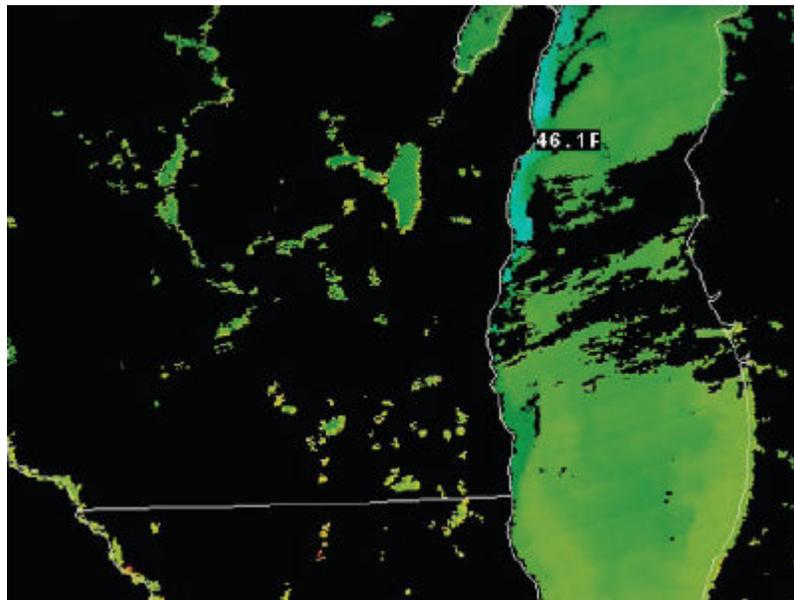


Above: As an example of the high resolution capabilities of MODIS, the water vapor band (band 27) from MODIS indicates intense turbulence across much of New Mexico.

Sea Surface Temperature

Since the arrival of MODIS imagery is delayed to NWS forecast offices, the product must have some operational longevity, remaining valid long enough to be useful in a forecast. The sea surface temperature image is a prime example. The NWS Forecast Office in Sullivan, Wisconsin, was the initial consumer and key advocate of the MODIS sea surface temperature

image. The image is useful in determining not only the general skin temperature of the water, but also regions of coastal upwelling and subtle contrasts in temperature resulting from sea currents on the western Great Lakes. In one extreme example, a pneumonia front not clearly distinguished with cloud features was caught sweeping south across Wisconsin's Lake Michigan shoreline by strong upwelling occurring in its wake. Since sea surface temperature tends to change gradually over the course of several weeks, the product's time of use extends several days instead of several hours. Furthermore, there is no GOES equivalent, or even a good analysis that can rival the detail produced by MODIS on a relatively clear sky day. Additional uses for the sea surface temperature product include tracking small eddies associated with the Gulf Stream and finding areas of relatively cool water on the Gulf of Mexico where previous tropical cyclones may have caused upwelling, which thus may cause subsequent cyclones to intensify more slowly than anticipated by forecast models (Bachmeier, 2007).

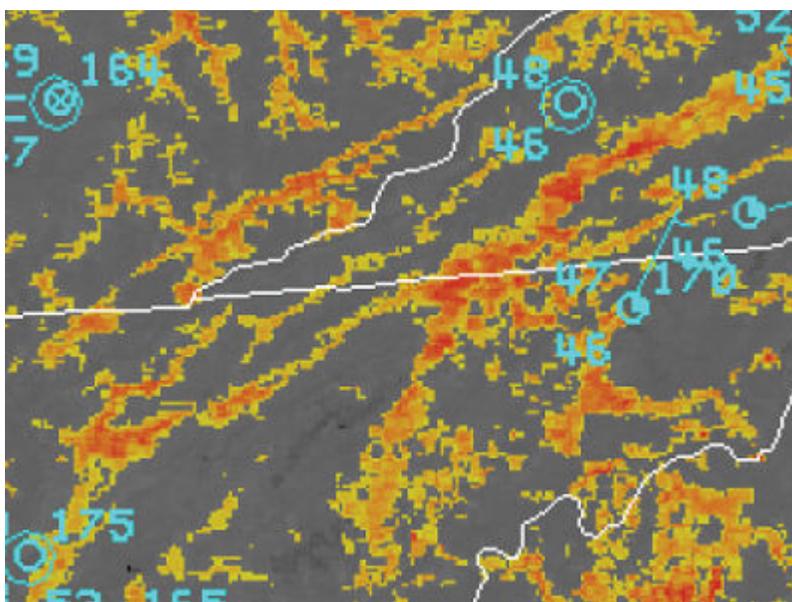


Above: A pneumonia front slides down Lake Michigan. Note the upwelling, indicated by cooler lake surface temperatures, that is occurring on the western side of Lake Michigan.

Fog Product

Another weather hazard affecting coastal and island communities alike is fog. Both GOES and MODIS offer a fog product, roughly derived from subtracting the standard IR window from the 3.9 or 3.7 micron band. The fog product not only serves as a useful indicator for the presence of fog and dense fog, but it can also be used to locate areas of thick stratus. A key benefit of the MODIS product is its high resolution, making it easy to locate narrow bands of

fog forming in river and mountain valleys. Additionally, MODIS can detect changes in the density of a low cloud deck due to the presence of manmade pollutants, such as power plants. Operational forecasters find these abilities significant for two reasons. First, it allows them to determine which portions of their area of responsibility susceptible to fog and dense fog. Second, forecasters may adjust temperatures in those regions as a result of the presence of fog or low cloud, which may inhibit the sun from providing daytime warming until later in the morning or earlier in the afternoon. The delay in receiving the MODIS product does not tend to hinder the forecast process as information about a cloud deck is usually not critical for weather warning purposes. As long as the product arrives by the time a forecast is due, it can be incorporated.



Above: The MODIS 11 – 3.7 micron fog product confirms regions of dense valley fog indicated by surface observations across parts of eastern Tennessee and western Virginia on September 27, 2006, at 7:07Z.

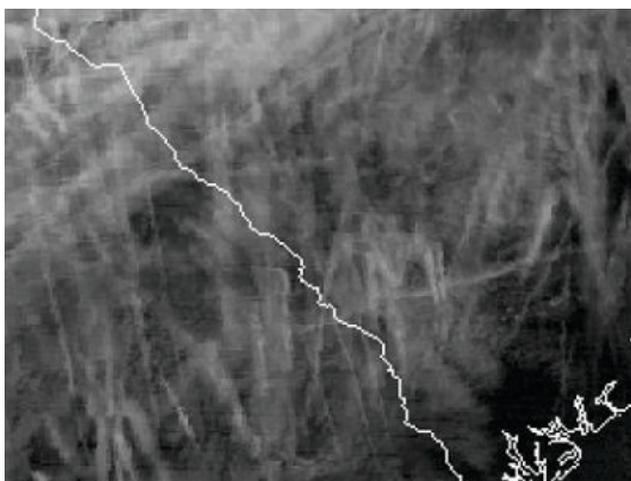
Cirrus Band

The cirrus band of MODIS provides another unique perspective not available on GOES. Thin clouds have a profound effect on temperature, particularly in the summer, when they serve as a filter for the sun. As a result, forecasters seek to determine how thin clouds may impact their area. In standard bands from GOES, such as the infrared window, thin clouds are difficult to detect, particularly in polar climates where there is snow on the ground, or in areas where there are multiple layers of clouds— for example, a layer of thin clouds above a stratus deck. While the life cycle of a cirrus cloud is unclear, thunderstorms are one of the key players in the production of cirrus clouds. Strong convection can produce cirrus, which may slowly dissipate

in the atmosphere as it is advected upstream following the demise of the complex. Since storms often diminish overnight, coincident with the formation of fog and low cloud, a forecaster must not only contend with how the morning fog will affect daytime heating and thunderstorm chances later in the day, but also how the cirrus cloud cover will limit the amount of sun reaching the low cloud deck to dissipate it. Since visible imagery and infrared bands may be contaminated with other cloud, a forecaster may seek to find an alternative source of determining the presence of cirrus cloud.

Examination of the cirrus band over time has uncovered examples where it has indicated other, non-cloud particulate in the atmosphere not indicated by other bands. In one case over the Central Plains during the winter, a notable region of dust or ash was seen traveling the northwest flow. The use of back-trajectory models indicated that this area of particulate was most likely attributed to a volcano that erupted in Alaska several days earlier. Similarly, this band is also useful in tracking areas of smoke from wildfires. The high resolution nature of the MODIS imagery is particularly beneficial in this case, since smoke and associated plumes are often small, sometimes disperse, and can go undetected until the fire has grown larger, at which time it poses a significantly greater threat to society.

The higher resolution of MODIS imagery can also be employed to find jet contrails. In one of the best examples, a MODIS pass over Georgia indicated a mixture of clouds on the visible band. However, the cirrus band display indicated several prominent contrails resulting from aircraft. Such contrails are usually not noted in GOES imagery. The impact of jet contrails on surface temperature is difficult to study, but contrails appear to cause notable impacts on high and low temperatures alike, and, since jet contrails are manmade, they are not forecasted by operational models or incorporated into temperature prediction schemes (Bachmeier, 2007).



Left: Jet contrails over eastern Georgia and southern South Carolina as seen on the cirrus band (band 26) from MODIS at 15:50Z on November 29, 2006.

Cloud Top Temperature Product

MODIS also offers a cloud top temperature product which can be utilized instead of the standard infrared window to determine the temperature of clouds that are not opaque, such as cirrus. In addition, the cloud top temperature product can be used to determine areas where high clouds exist, particularly at night when the cirrus band is not useful. This product is ultimately the best diagnostic tool in determining the temperature of a cloud, even though the IR window is capable for thick cloud.

Snow and Ice Band

Ground snow and ice also play a significant role in temperature. A heavy snow pack can prevent temperatures from warming strongly during the day, and can aid in a nighttime plummet. MODIS has a snow and ice band which can assist in finding areas of frozen precipitation that has already fallen and accreted on the surface. In contrast, GOES has no such band. However, fallen snow can be located quite easily on a visible band without a cloud deck above. In the event that there are clouds in the vicinity of the snow pack, the snow and ice band from MODIS can assist in determining areas where the surface is visible and contrast those with regions covered with cloud. Freezing rain accumulations are much more difficult to detect, yet the MODIS snow and ice band is able to successfully depict ice on the surface, which is useful in preparing a post-event analysis of a winter storm.

Cloud Phase Product

Winter storms are complicated to forecast, and due to their long duration, can impact society significantly. They bring numerous types of precipitation, which sometimes change throughout the life of the storm. MODIS data can be used to examine cloud phase in these situations (Baum, 2000). The MODIS cloud phase product can be used just before and during a winter weather event to determine whether there is ice crystal in the cloud to produce snow. If the cloud is determined to contain liquid nuclei, then the forecaster may consider adding freezing rain or freezing drizzle as opposed to snow. When a cloud contains both ice and water particles, such pixels are accordingly tagged as mixed or unknown, not a possibility with GOES. It is difficult to render precipitation type information based on the GOES imagery and sounder products currently available to forecasters.

Additional Uses

MODIS has several infrared bands which may render mesoscale details about a storm once it has formed. While the time delay with MODIS imagery does not make it a useful tool in real-time convective situations, it can be used in post-event analysis to examine aspects of the storm. MODIS captures enhanced-V signatures (Space Science and Engineering Center, 2007) and the temperature of the coldest core of the storm cell better. Additionally, the one-kilometer resolution of the MODIS imagery can indicate small undulations propagating away from the core of the storm. It is believed that these small undulations are a key player in the production of turbulence in the vicinity of thunderstorms, and can pose a significant threat to aircraft flying near thunderstorms. Forecasters may opt to overlay turbulence reports on top of MODIS imagery to determine whether or not they can draw a correlation between forming thunderstorms and turbulence. If they can, they may be able to send warning to pilots that areas upstream of storm cells may be hazardous for air travel. Forecasters may also be able to use MODIS water vapor imagery to find areas of turbulence in the vicinity of mountain ranges. While GOES can occasionally indicate significant examples of turbulence involving complex topography, MODIS imagery is much better for locating smaller events or showing the full extent of larger events.

Conclusion

Since the nature of the GOES satellite is to provide consistent and reliable data over a fixed region, it is useful for many operational forecasting tasks, especially with its several temporal scanning modes and despite the fact that the resolution of the imagery is not sufficient for resolving small-scale features in the atmosphere. While MODIS excels in its ability to render a very detailed look at weather disturbances, its nature as a polar orbiter does not make it the predominant choice at all stages of the forecast process. However, with sufficient training about how and when best to use MODIS imagery instead of GOES, the use of MODIS products can add significant value to a prediction. Furthermore, it expands the number of uses for a satellite which was originally intended to be used within the research realm. Lastly, it prepares forecasters for some of the imagery and products that will be available in the next generation of GOES (Bachmeier, 2007). Ultimately, the utilization of all resources available benefits the public at large through better predictions, thereby saving property and countless lives.

References

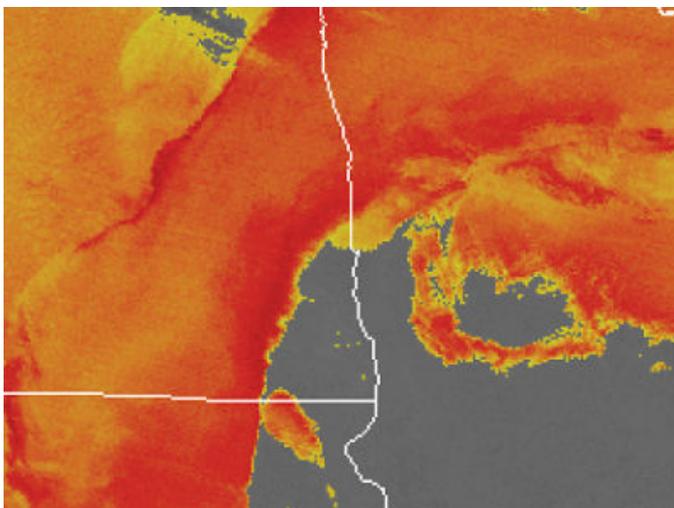
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All of these figures were captured using the Advanced Weather Information Processing System's graphical front-end, Display Two Dimensions.

Other Notes

When I started the process of developing AWIPS for use at SSEC during the fall of 2005, I never imagined where the project would take me. A year and a half later, I am proud to find that CIMSS and SSEC imagery, including that from MODIS, has found its place in NWS offices from Wyoming to Indiana. In the appendix, I have attached a recent Area Forecast Discussion (AFD) from a local NWS office, Milwaukee/Sullivan, which references both GOES and MODIS heavily. It certainly attests to the power of satellites in operational meteorology.

I would like to extend a special thanks to Steve Wanzong, Steve Ackerman, Tom Achtor, Robert Aune, Scott Bachmeier, Wayne Feltz, Kathy Strabala, Gary Wade, and many others at CIMSS and the University of Wisconsin for their assistance, leadership, and thoughtful guidance through this point in my academic career. I appreciate the opportunity to work with and learn from such a diversified group of scientists that have a dedicated interest in understanding our atmosphere through remote sensing.



Left: Thick and thin areas of low cloud observed over North Dakota and western Minnesota using the 11 – 3.7 micron product from MODIS on December 11, 2006, at 8:27Z.

Appendix

The bold text was added for emphasis.

AREA FORECAST DISCUSSION
NATIONAL WEATHER SERVICE MILWAUKEE/SULLIVAN WI
230 PM CDT WED JUN 13 2007

.SHORT TERM...

SURFACE HIGH OVER THE GREAT LAKES TO TO DOMINATE THROUGH FRIDAY. SHALLOW FAIR WEATHER CU WILL DISSIPATE RAPIDLY...GIVEN THE SHALLOW LAYER OF MOISTURE ON CURRENT RUC SOUNDINGS AND NAM FORECAST SOUNDINGS. SOME CONCERN ON FOG. HOWEVER LOW LAYERS DRY...AND WITH SHORT NIGHTS...ONLY CONCERN WOULD BE IN RIVER VALLEYS. **LAST NIGHTS MODIS 11UM - 3.9UM 1 KM RES FOG IMAGE DID NOT SHOW ANY FOG IN THE VALLEYS.** TODAYS GOES SOUNDER PRECIP WATER IMAGERY SHOWS DRIEST AIRMASS HAS PUSHED OFF TO THE WEST ACROSS THE MISSISSIPPI VALLEY REGION. WITH MORE MOISTURE...MAINLY AROUND 200-300 MB...EXPECT SOMEWHAT LESS RADIATION AL COOLING. GOES SOUNDER DATA IS MUCH DRIER IN THE MID LEVELS THAN RUC. GOES SOUNDER IS MORE IN LINE WITH NAM SOUNDINGS.

1 KM MODIS SEA SURFACE TEMP SHOWING MID 50 TO NEAR 60 MID LAKE SURFACE TEMPS...WITH NEAR SHORE TEMPS IN THE LOWER 60S. WITH CLEAR SKIES ACROSS THE GREAT LAKES 15Z MODIS IMAGE IS AN EXCELLENT DATA SOURCE.

MAIN FORECAST CHALLENGE IS THE TRANSITION FROM OMEGA BLOCK PATTERN TO MORE OF A ZONAL FLOW ACROSS THE NORTHERN TIER OF THE U.S. SURFACE FRONTAL POSITION SATURDAY IS THE QUESTION. GFS HAS A MORE SOUTHERLY POSITION...ACROSS SOUTHERN WI...WITH THE NAM SLOWER MAINLY ACROSS THE NORTH. WITH SOME RIDGING STILL EVIDENT...WILL TAKE MORE OF A NAM APPROACH FOR NOW...BUT WILL STILL INTRODUCE A SLIGHT CHANCE OF THUNDERSTORMS SATURDAY FOR THE MORE SOUTH POSSIBILITY.

GFS ALSO BRINGS A CHANCE OF THUNDERSTORMS INTO PLAY SUNDAY ...AS WARM AIR ADVECTION AND INCREASING 850 MB FLOW DEVELOPS AHEAD OF NEXT MAIN SHORTWAVE. OF COURSE IF NAM IS CORRECT...THIS PRECIP WOULD BE MAINLY TO OUR NORTH. WILL INTRODUCE A SLIGHT CHANCE FOR NOW SUNDAY TO ACCOUNT FOR THIS AND WAIT FOR FURTHER TRENDS IN THE NEW MODEL RUNS.

12Z ECMWF IS SIMILAR TO THE QUICKER GFS. ENSEMBLES WOULD ALSO SUPPORT AN INCREASE IN THE POPS. CRAS MODEL APPEARS TO SUPPORT THE NAM.

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.MKX WATCHES/WARNINGS/ADVISORIES...

NONE.

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HENTZ/KOCHIS