Deriving Atmospheric Winds from GOES-R ABI Measurements

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National Oceanic and Atmospheric Administration

Outline

- Atmospheric motion as observed from satellite imagery

- Importance of satellite wind observations

- How is atmospheric motion derived from satellite imagery?

- Product examples and assessing product quality

- Who are the users of the satellite derived motion winds product?

- High resolution satellite winds

Atmospheric Motion as Observed from Satellite Imagery

Longwave Infrared (11um) Band
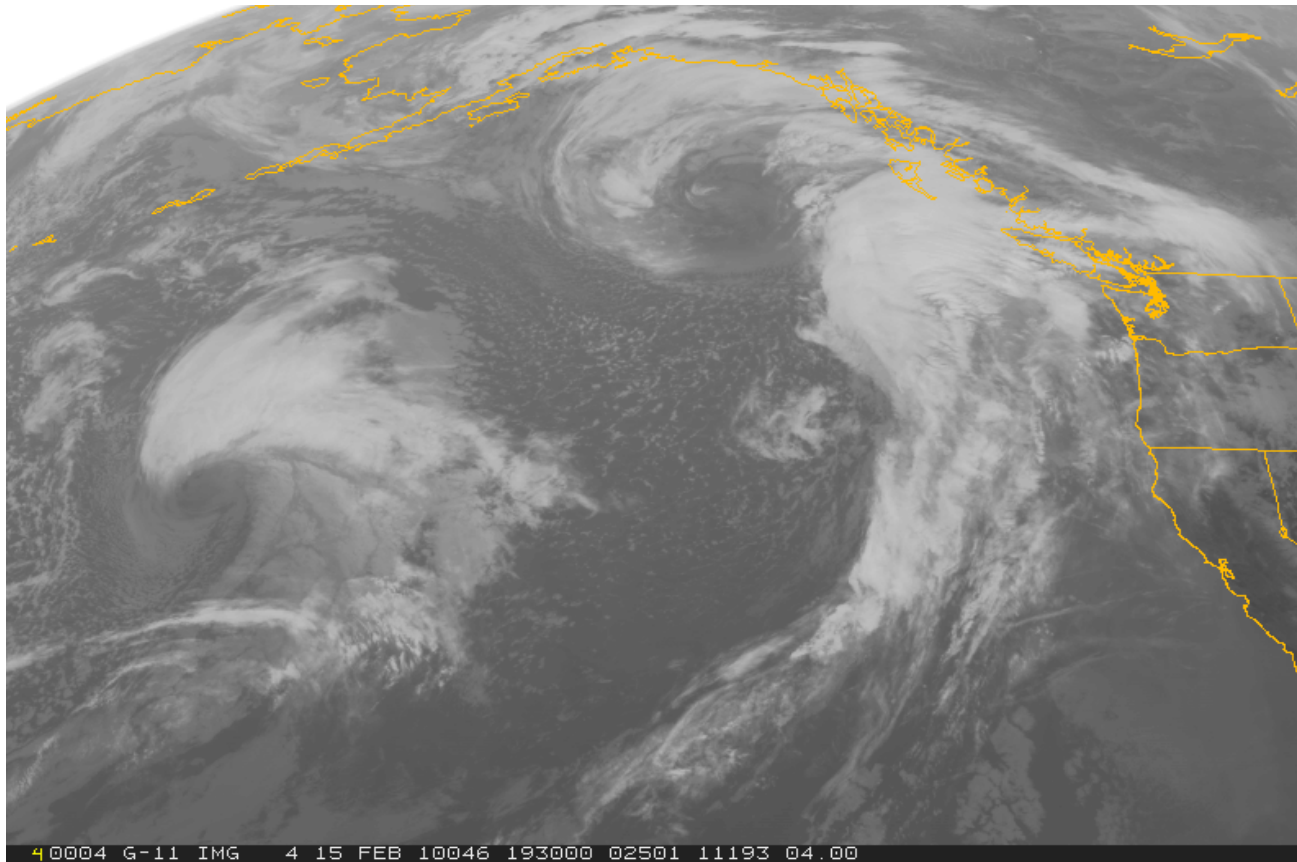
GOES


```
40004 G-11 IMG    4 15 FEB 10046 193000 02501 11193 04.00
```

The movement of clouds reflects atmospheric motion

Animation of a sequence of satellite images taken at different times reveals the motion

We see it everyday on our local weather TV broadcast, in our favorite weather app, on the internet, etc
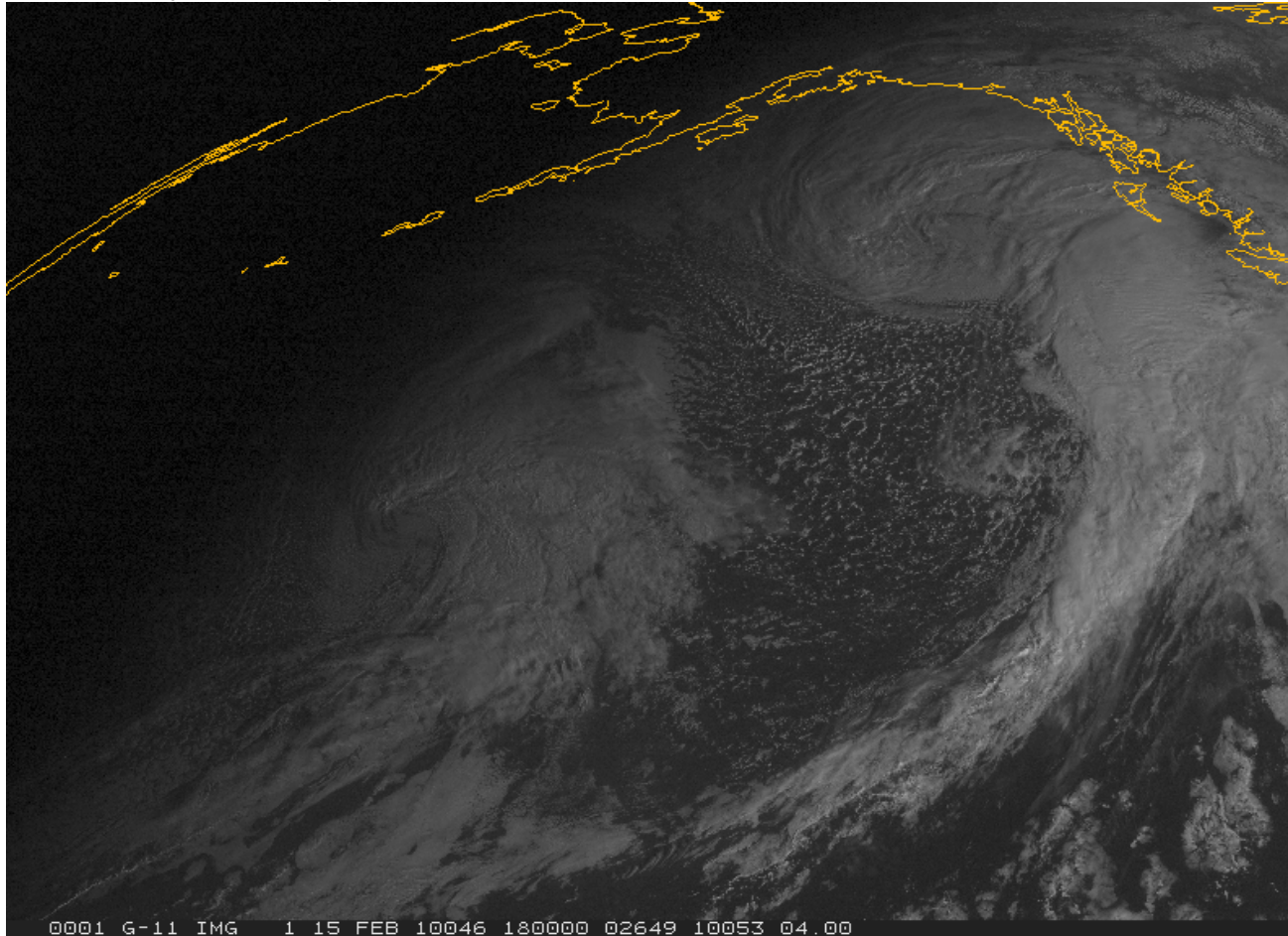
Or just looking up at the sky

Visible (0.64um) Band

GOES

0001 G-11 IMG   1 15 FEB 10046 180000 02649 10053 04.00

The movement of clouds reflects atmospheric motion

Animation of a sequence of satellite images taken at different times reveals the motion

We see it everyday on our local weather TV broadcast, in our favorite weather app, on the internet, etc
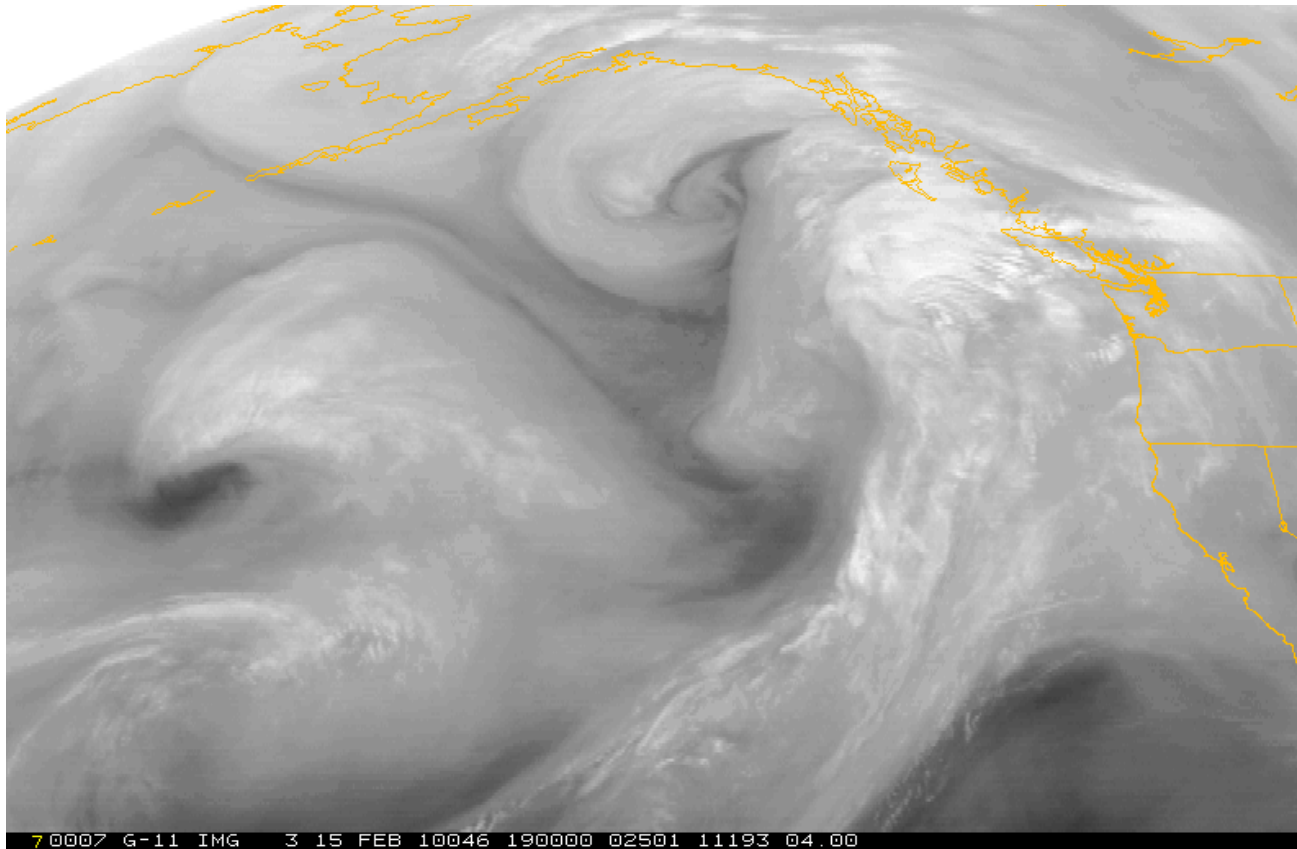
Or just looking up at the sky

Atmospheric Motion as Observed from Satellite Imagery

Water vapor (6.5um) Band

GOES

7 0007 G-11 IMG   3 15 FEB 10046 190000 02501 11193 04.00

The movement of clouds reflects atmospheric motion

Animation of a sequence of satellite images taken at different times reveals the motion

We see it everyday on our local weather TV broadcast, in our favorite weather app, on the internet, etc
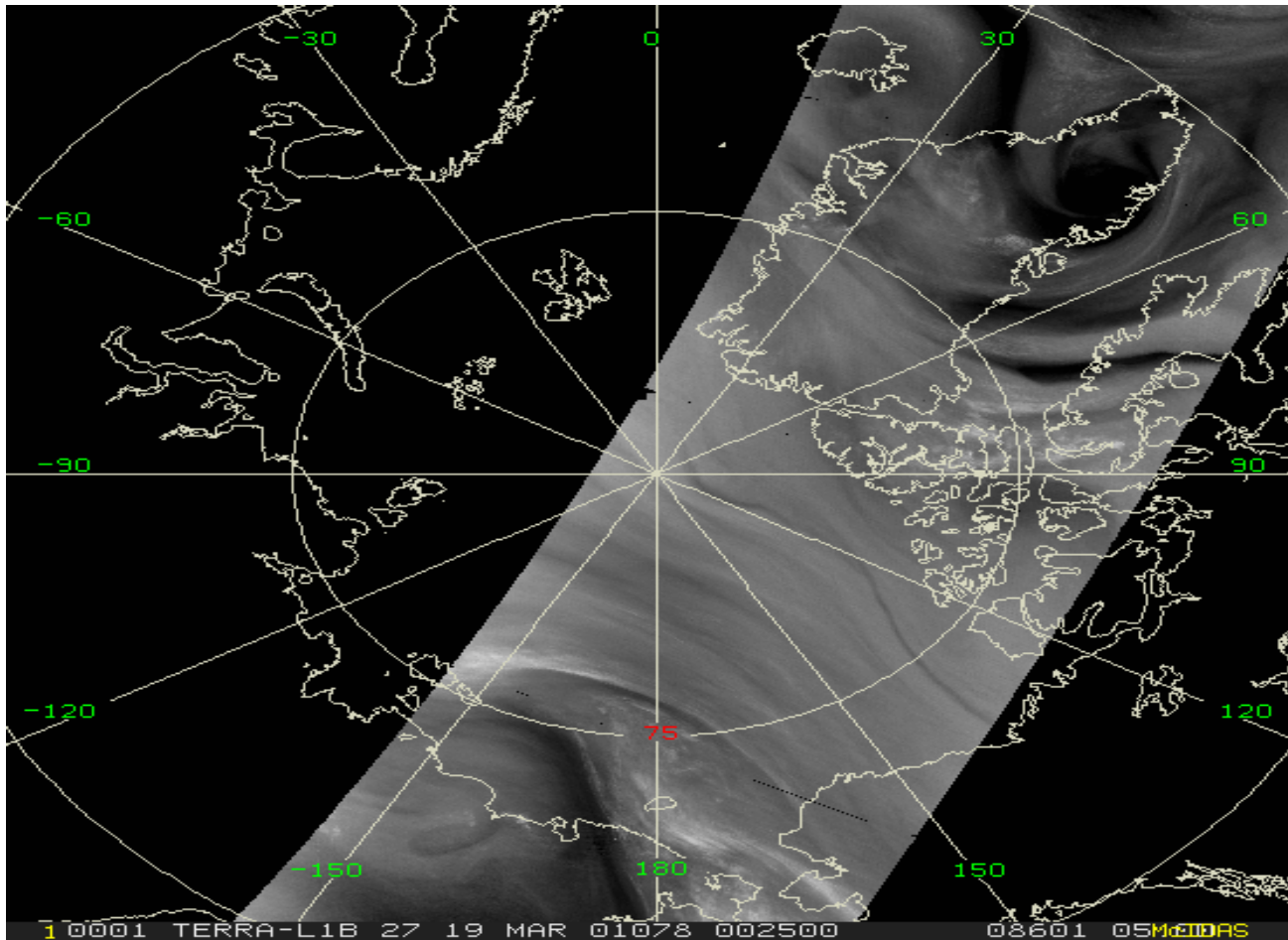
Or just looking up at the sky

Atmospheric Motion as Observed from Satellite Imagery

Water vapor (6.7um) Band

Terra/MODIS

The movement of clouds reflects atmospheric motion

Animation of a sequence of satellite images taken at different times reveals the motion
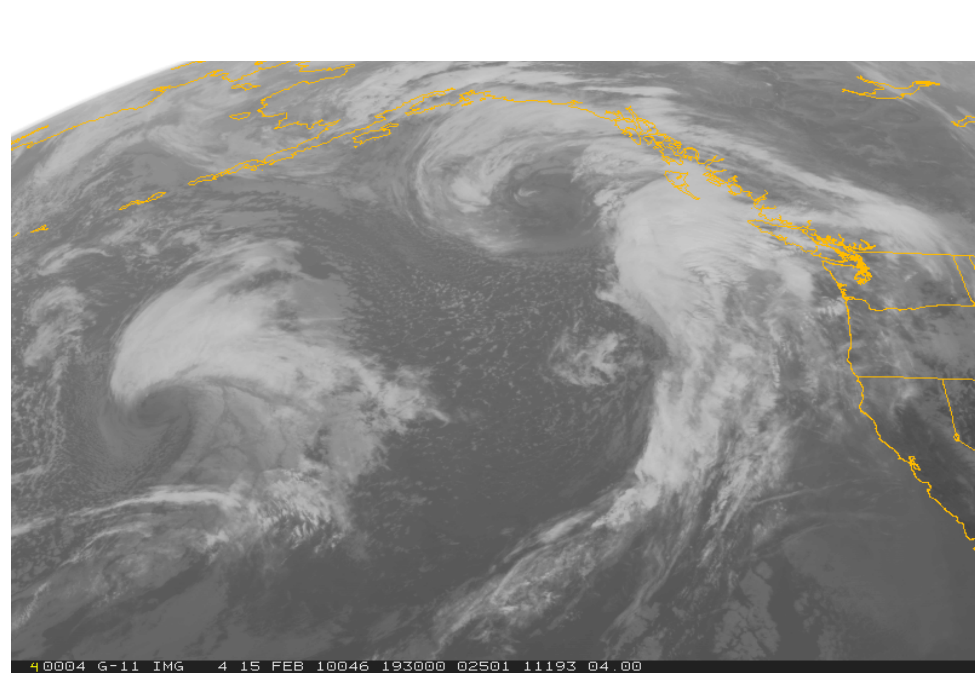
We see it everyday on our local weather TV broadcast, in our favorite weather app, on the internet, etc

Or just looking up at the sky

Strengths of Geostationary Imagery for Deriving Atmospheric Winds

- View same location on the earth

- Frequent observations!!!

- Improving spatial and spectral resolutions

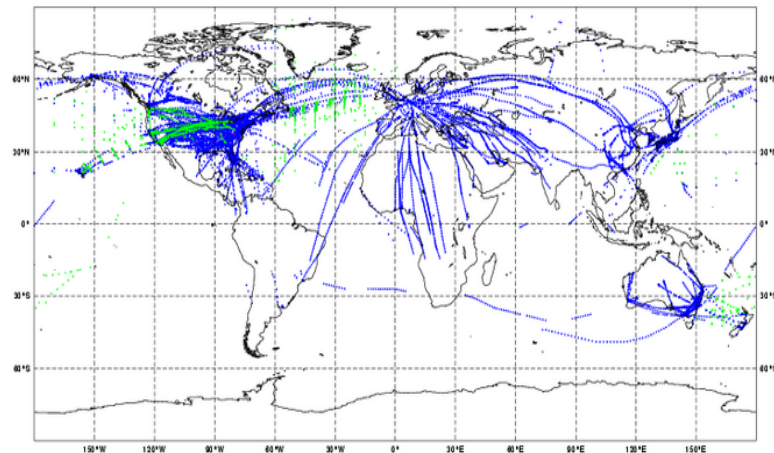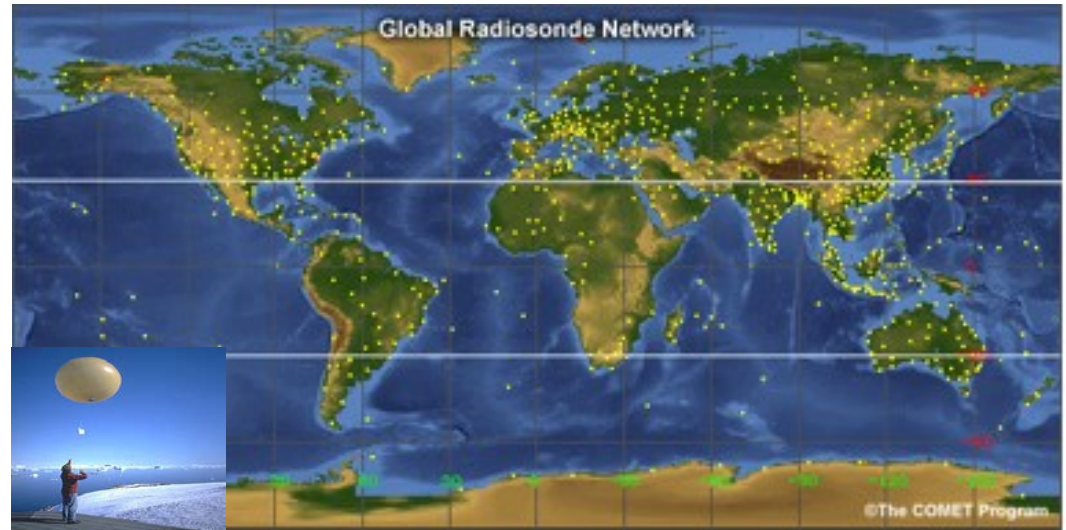`0004 G-11 IMG    4 15 FEB 10046 193000 02501 11193 04.00`

Importance of Satellite Wind Observations

Satellite Derived Winds are a Key Component of the Global Observing System (GOS)

- Provide vital tropospheric wind information over expansive regions of the earth that are devoid of in-situ wind observations that include oceans, polar regions, and Southern Hemisphere land masses.

- Provide key wind observations to operational NWP data assimilation systems where their use has been demonstrated to improved numerical weather prediction forecasts including tropical cyclones

- Provide improved guidance for NWS field forecasters

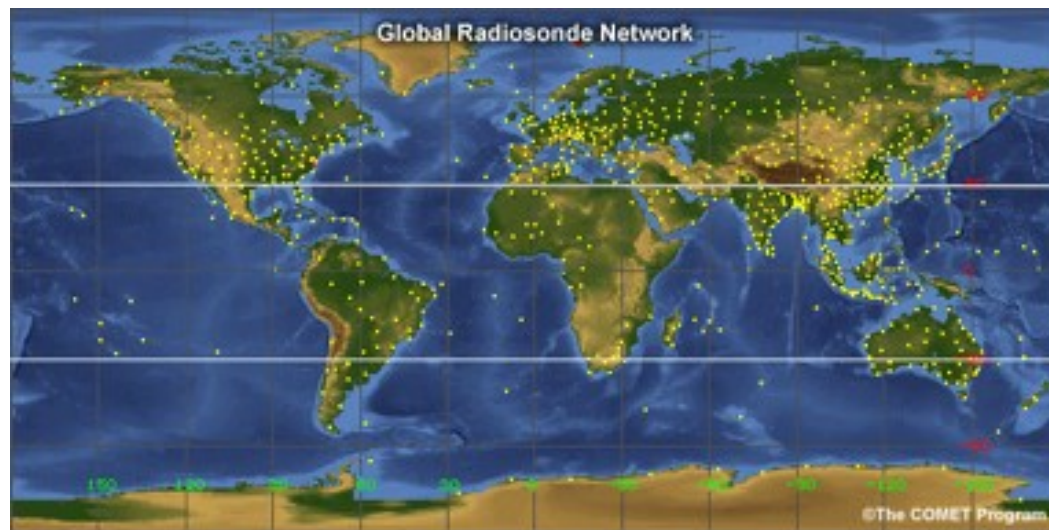## Global Radiosonde Network

Aircraft Winds
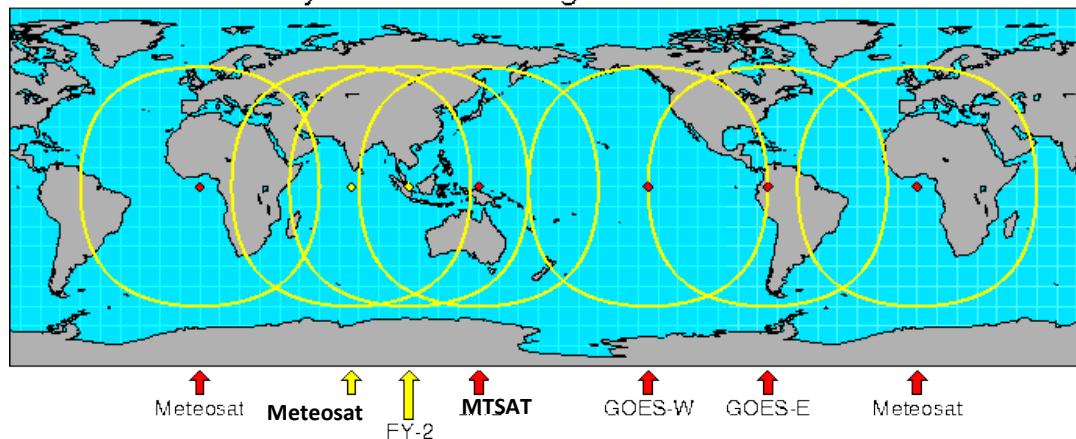
Importance of Satellite Wind Observations

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Global Radiosonde Network

Global Radiosonde Network
©The COMET Program

Global Geostationary Satellite Coverage

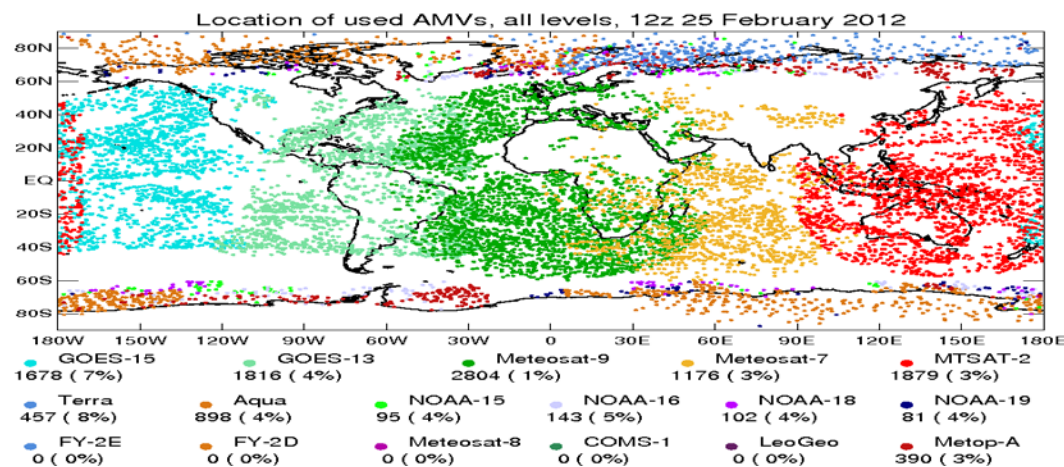Meteosat   **Meteosat**   FY-2   **MTSAT**   GOES-W   GOES-E   Meteosat

Importance of Satellite Wind Observations

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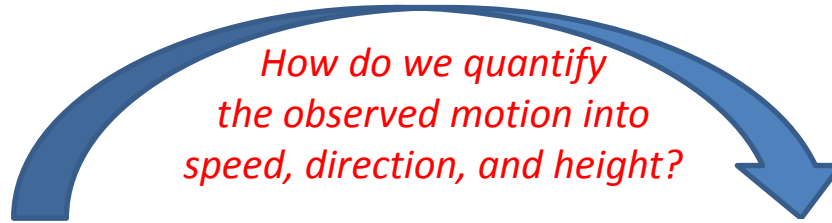- Provide improved guidance for NWS field forecasters

Global Radiosonde Network

Global Radiosonde Network

©The COMET Program

Location of used AMVs, all levels, 12z 25 February 2012

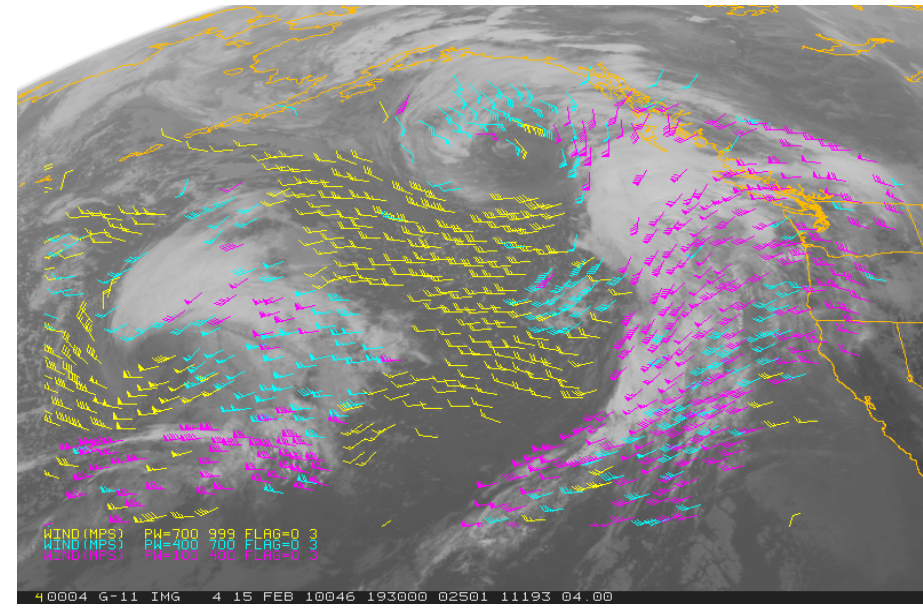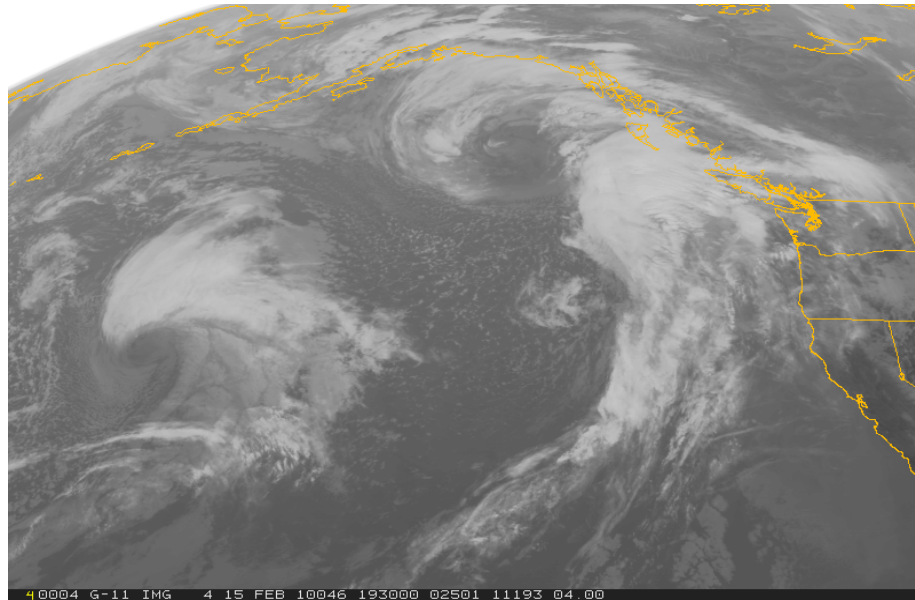|				
GOES-15 1678 (7%)	GOES-13 1816 (4%)	Meteosat-9 2804 (1%)	Meteosat-7 1176 (3%)	MTSAT-2 1879 (3%)
Terra 457 (8%)	Aqua 898 (4%)	NOAA-15 95 (4%)	NOAA-16 143 (5%)	NOAA-18 102 (4%)	NOAA-19 81 (4%)
FY-2E 0 (0%)	FY-2D 0 (0%)	Meteosat-8 0 (0%)	COMS-1 0 (0%)	LeoGeo 0 (0%)	Metop-A 390 (3%)

How is Atmospheric Motion Derived from Satellite Imagery?

How do we quantify the observed motion into speed, direction, and height?

Longwave Infrared (11um) Band

GOES

- Select a target

- Track the movement of each target over time

- Assign a height to each target

- Quality Control

- **Select a target**

- Track the movement of each target over time

- Assign a height to each target

- Quality Control

Temperature values

15 Lines

X

15 Elements

- *A "target" scene is a NxN array or patch of pixels*

- *This array of pixels is what is tracked over time to estimate the wind*

- *Cloud edges are good targets*

Steps Involved in Generating Satellite Winds

- Select a target

- **Track the movement of each target over time**

- Assign a height to each target

- Quality Control

- *A sequence of three images is used*

- *The speed and direction of each target can be computed since we know the location and time of the target in each image*

2nd Image: **Time = t_0**

- Targeting is performed on the <u>center</u> image of image triplet

- A target is a NxN scene of pixels

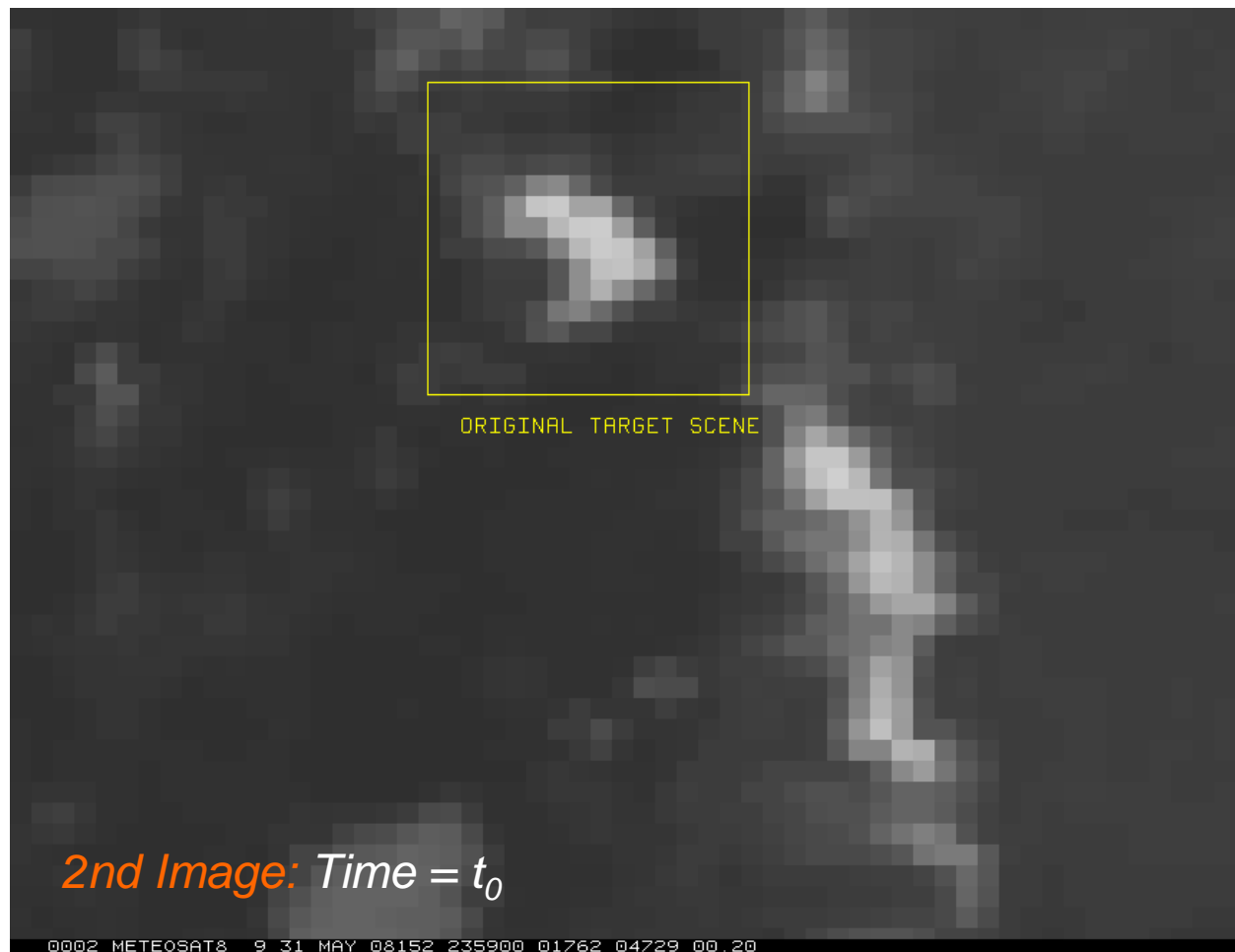

ORIGINAL TARGET SCENE

2nd Image: Time = t_0

0002 METEOSAT8   9 31 MAY 08152 235900 01762 04729 00.20

1st Image: **Time = t_0 - 10mins**

- Feature is found and tracked at an <u>earlier</u> time

MATCHING SCENE

ORIGINAL TARGET SCENE

SEARCH REGION

1st Image: Time = t_0 - 10mins

0001 METEOSAT8 9 31 MAY 08152 234900 01762 04729 00.20
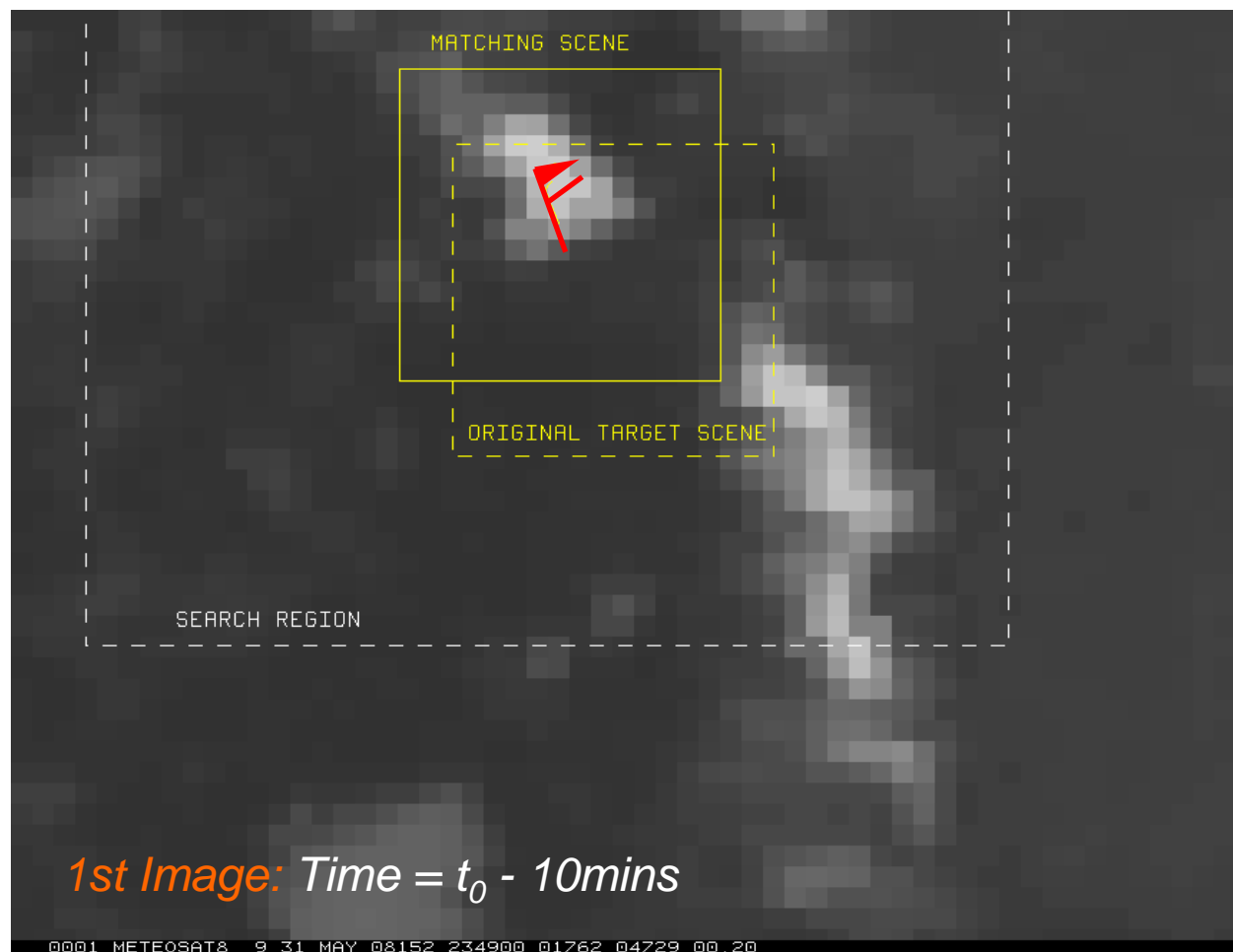
3rd Image: Time = t_0 + 10mins

- Feature is found and tracked <u>later</u> in time

ORIGINAL TARGET SCENE

MATCHING SCENE

SEARCH REGION

3rd Image: Time = t_0 + 10mins

3 0003 METEOSAT8 9 1 JUN 08153 000900 01762 04729 00.20

17

- Select a target

- Track the movement of each target over time

- **Assign a height to each target**

- Quality Control

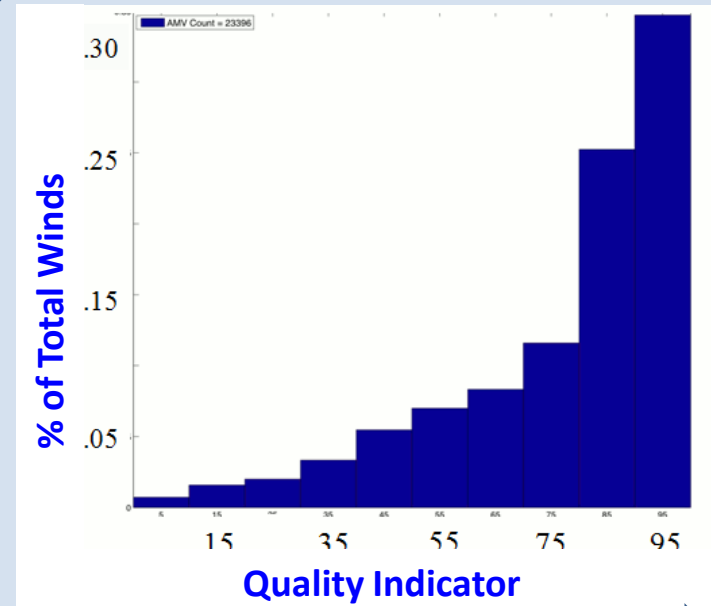- *Cloud top heights generated before the winds algorithm runs are used to assign heights to each target*

- Select a target

- Track the movement of each target over time

- Assign a height to each target

- **Quality Control**

Higher Quality

- *Flag suspect winds*
- *Compute and append quality indicators to each retrieved wind*

Improved Temporal Resolution *(Faster Scanning)*

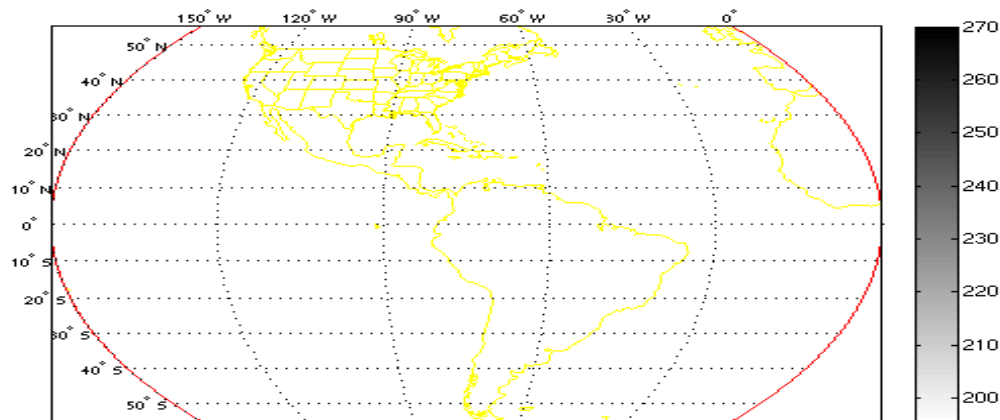In 15 Minutes the current GOES Imager can scan:
• Most (3/5) of a Full Disk (Hemisphere) Image

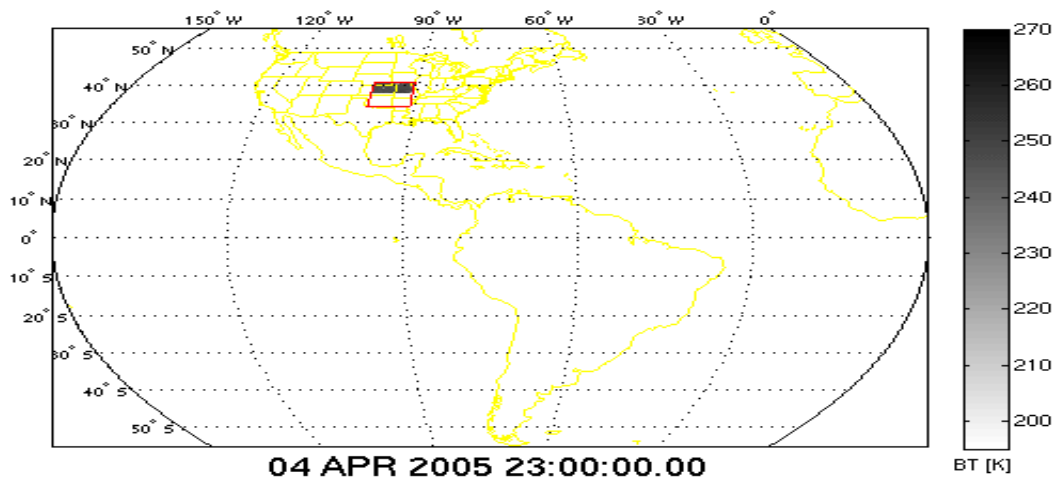**ABI scans about 5 times faster than the current GOES imager**

In 15 Minutes the ABI (Flex Mode) will scan:
• 30 Images of localized severe weather events
• 3 Images of the Continental US
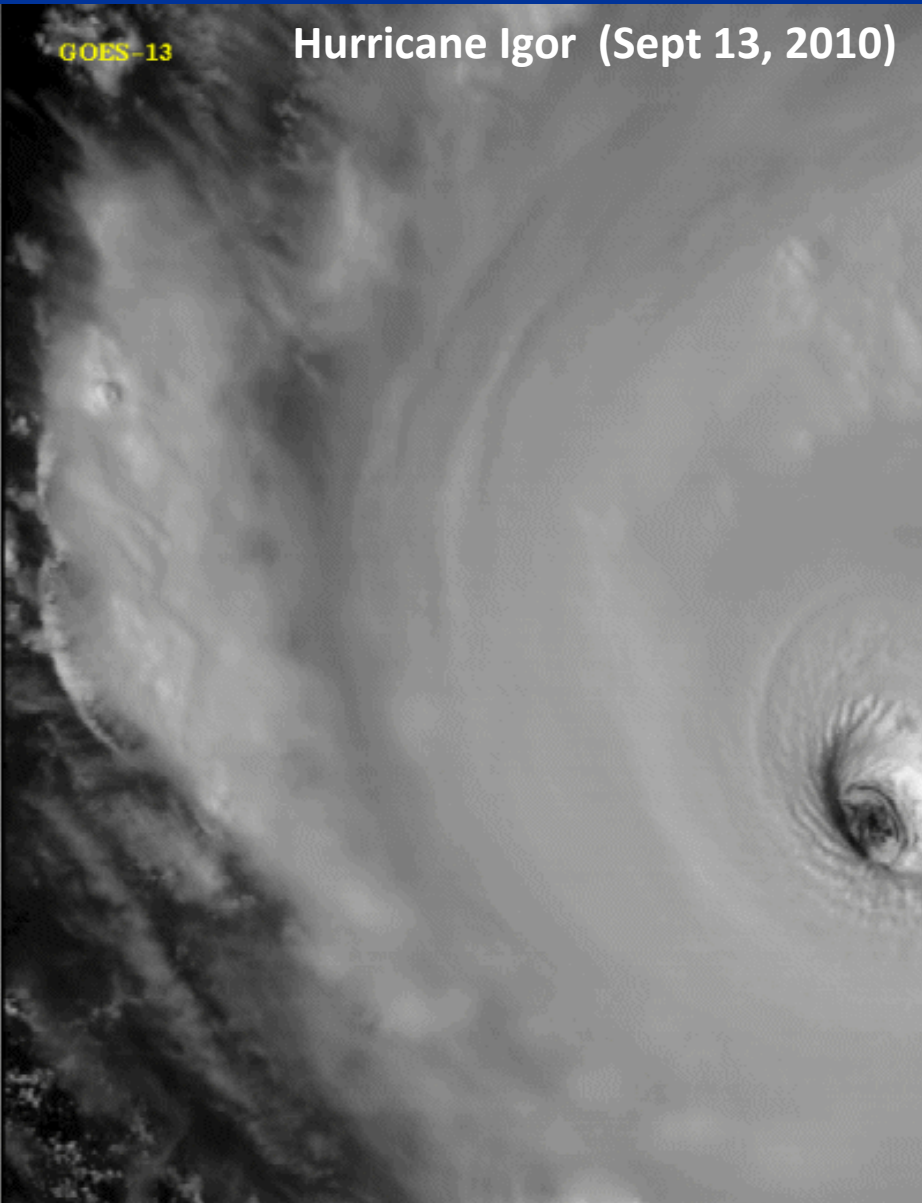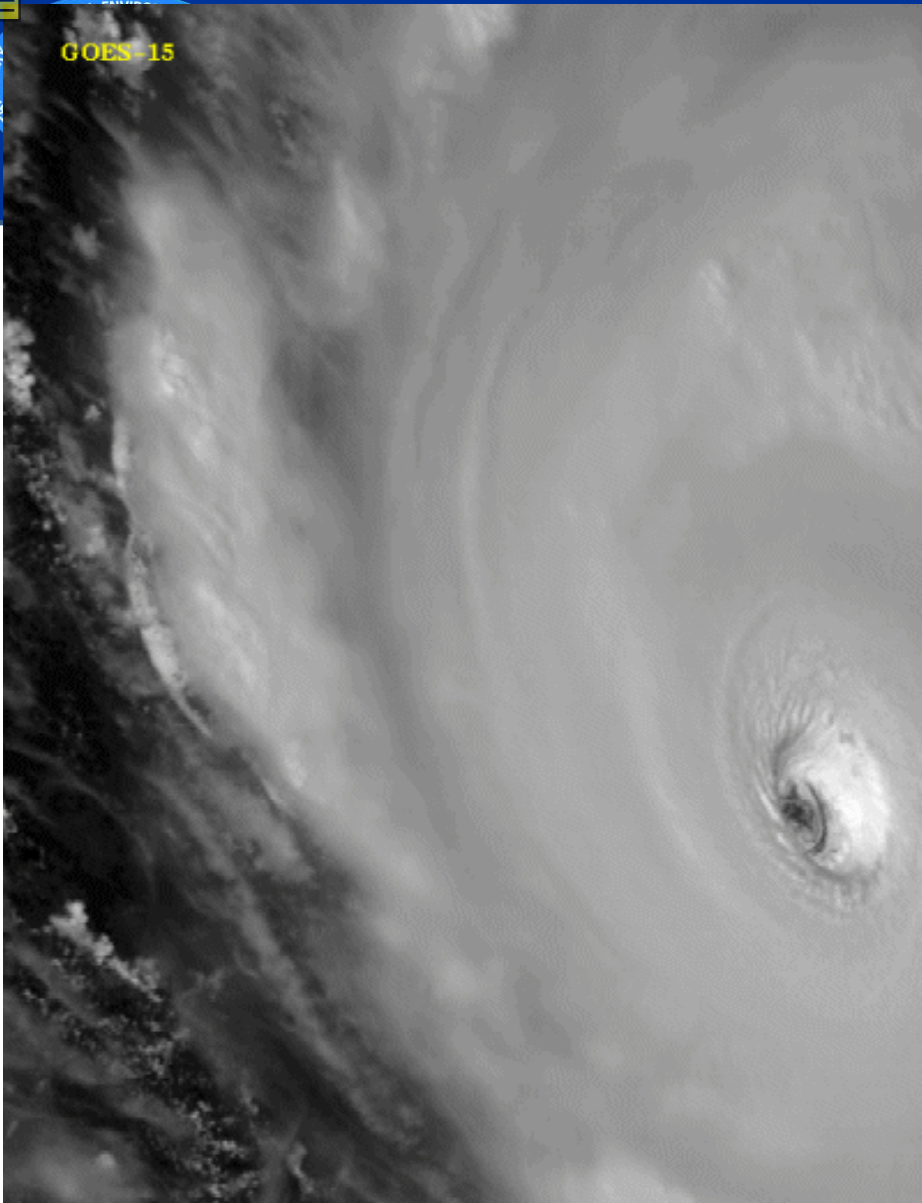• 1 Full Disk Image

Current GOES Imager

GOES-R ABI

04 APR 2005 23:00:00.00

Hurricane Igor (Sept 13, 2010)

A hint of what GOES-R will routinely provide!!...

Improved Navigation and Registration

Will lead to a more accurate wind product

GOES-15 provides a hint of ABI's INR quality...

GOES-11 IMAGER - VISIBLE 0.65 (CHANNEL 01) - 15:30 UTC 27 NOVEMBER 2011 - CIMSS

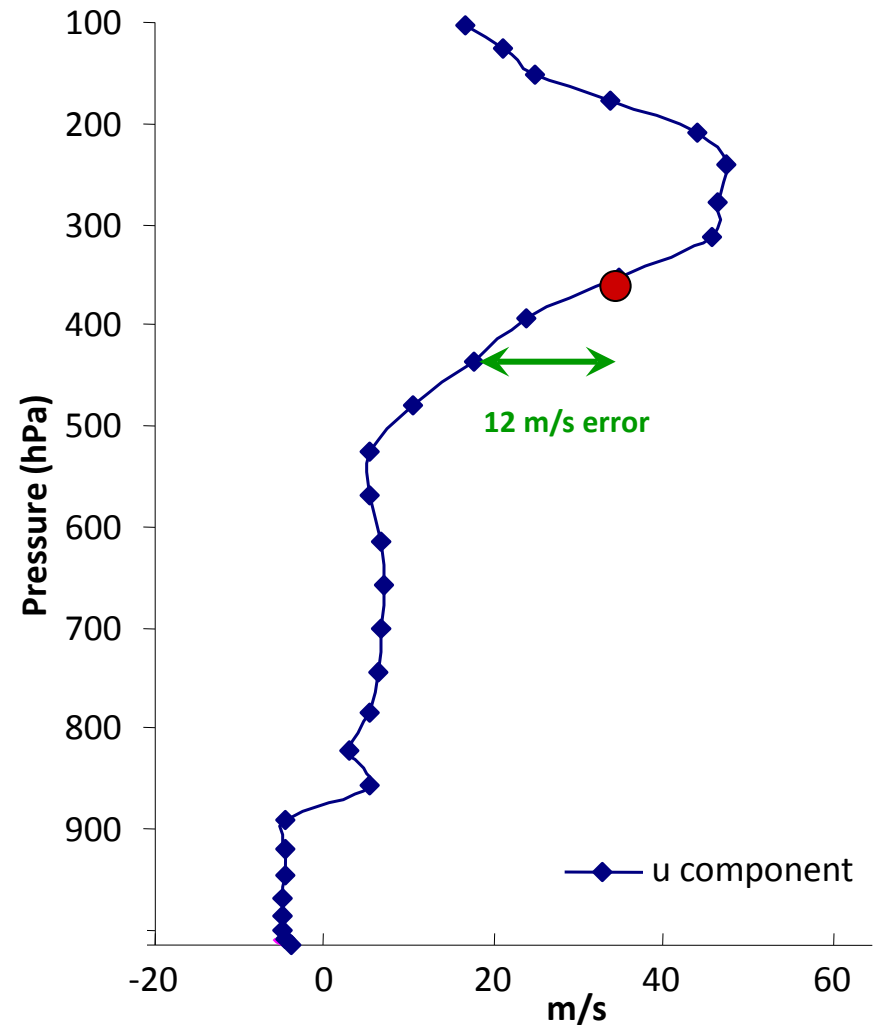GOES-15 IMAGER - VISIBLE 0.63 (CHANNEL 01) - 15:30 UTC 27 NOVEMBER 2011 - CIMSS

Improved Radiometric Performance together with Improved Spectral and Spatial Resolution

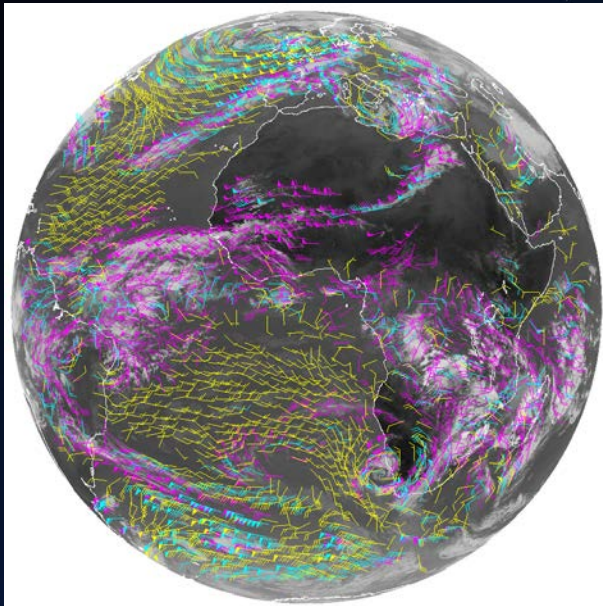**Will lead to improved wind height assignments and a more accurate wind product**

PRODUCT EXAMPLES

Meteosat-10/SEVIRI FD Winds

January 6, 2013)

LWIR (10.8um)

WVCT (6.2um)
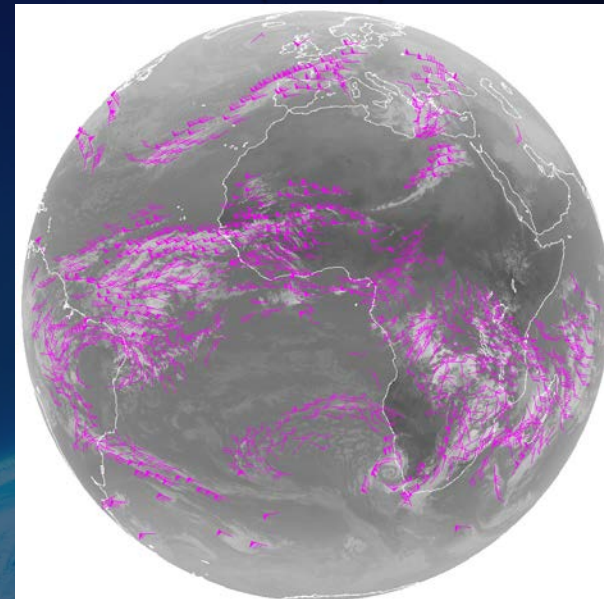
- New nested tracking algorithm introduced that makes use of a two-dimensional clustering algorithm to capture the dominant motion in each target scene
- Utilizes clear sky mask product
- Wind height assignment relies on the utilization of pixel level cloud heights generated upstream
- Running in real-time

High-Level 100-400 mb   Mid-Level 400-700 mb   Low-Level >700 mb

VIS (0.60um)

SWIR (3.9um)
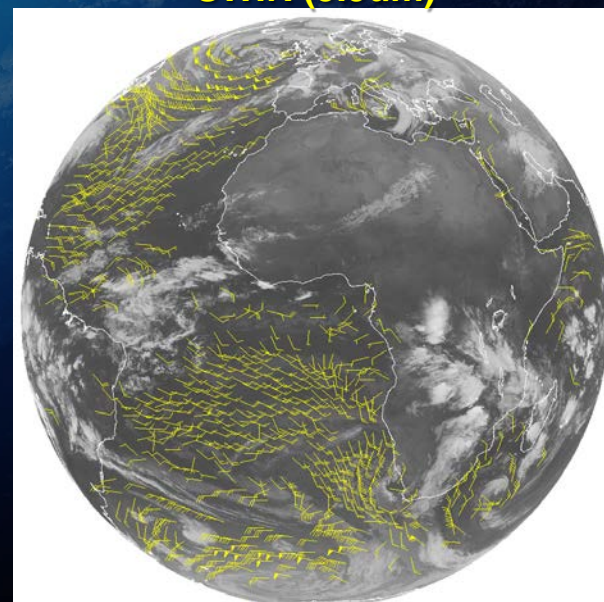
Application of GOES-R Winds Algorithm to Meteosat/SEVIRI
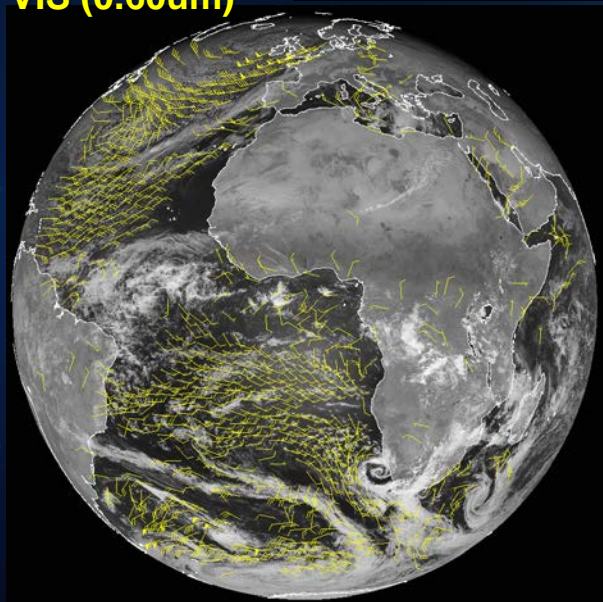
Loop of winds derived from hourly Full Disk Meteosat-9 SEVERI 10.8 μm imagery (22 UTC Apr 24 – 08 UTC Apr 25, 2012
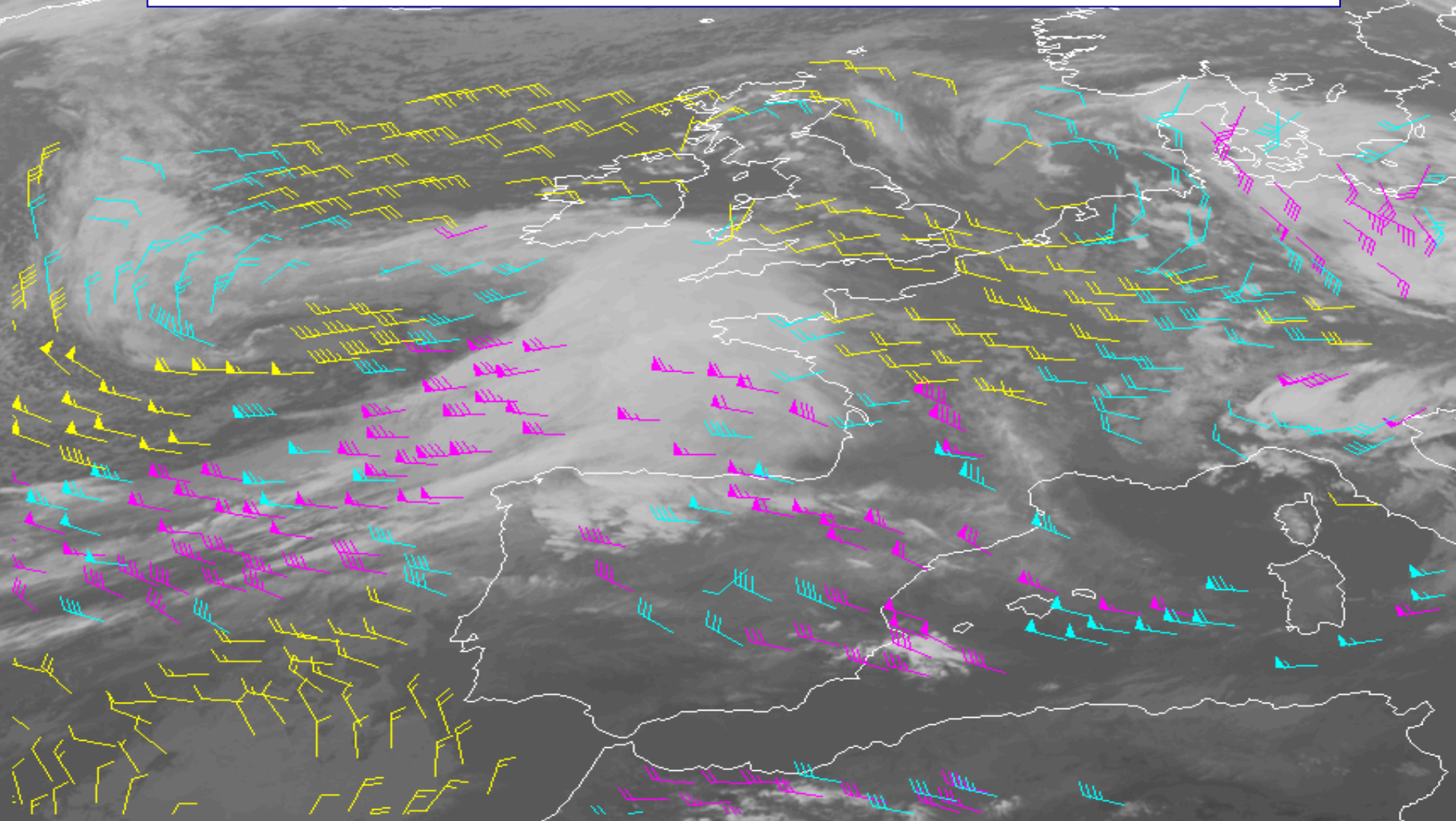
High-Level 100-400 mb   Mid-Level 400-700 mb   Low-Level >700 mb

Application of GOES-R Winds Algorithm to Current GOES

Cloud-drift winds derived from 15-min GOES-15 imagery over the East Pacific
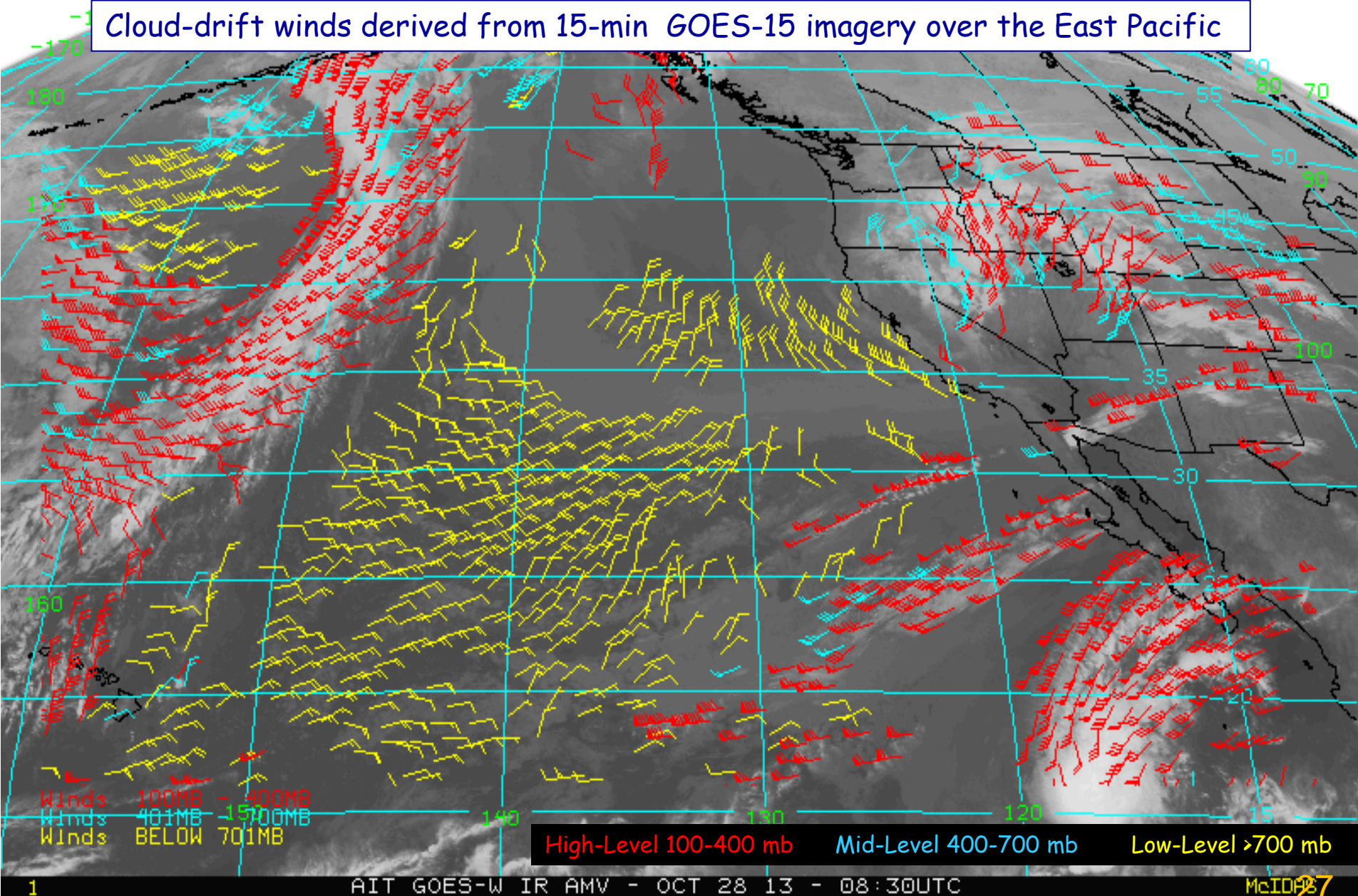
High-Level 100-400 mb   Mid-Level 400-700 mb   Low-Level >700 mb

AIT GOES-W IR AMV - OCT 28 13 - 08:30UTC

Application of GOES-R Winds Algorithm to Current GOES

Cloud-drift winds derived from 15-min GOES-13 imagery over Hurricane Sandy (4-day loop)

High-Level 100-400 mb   Mid-Level 400-700 mb   Low-Level >700 mb
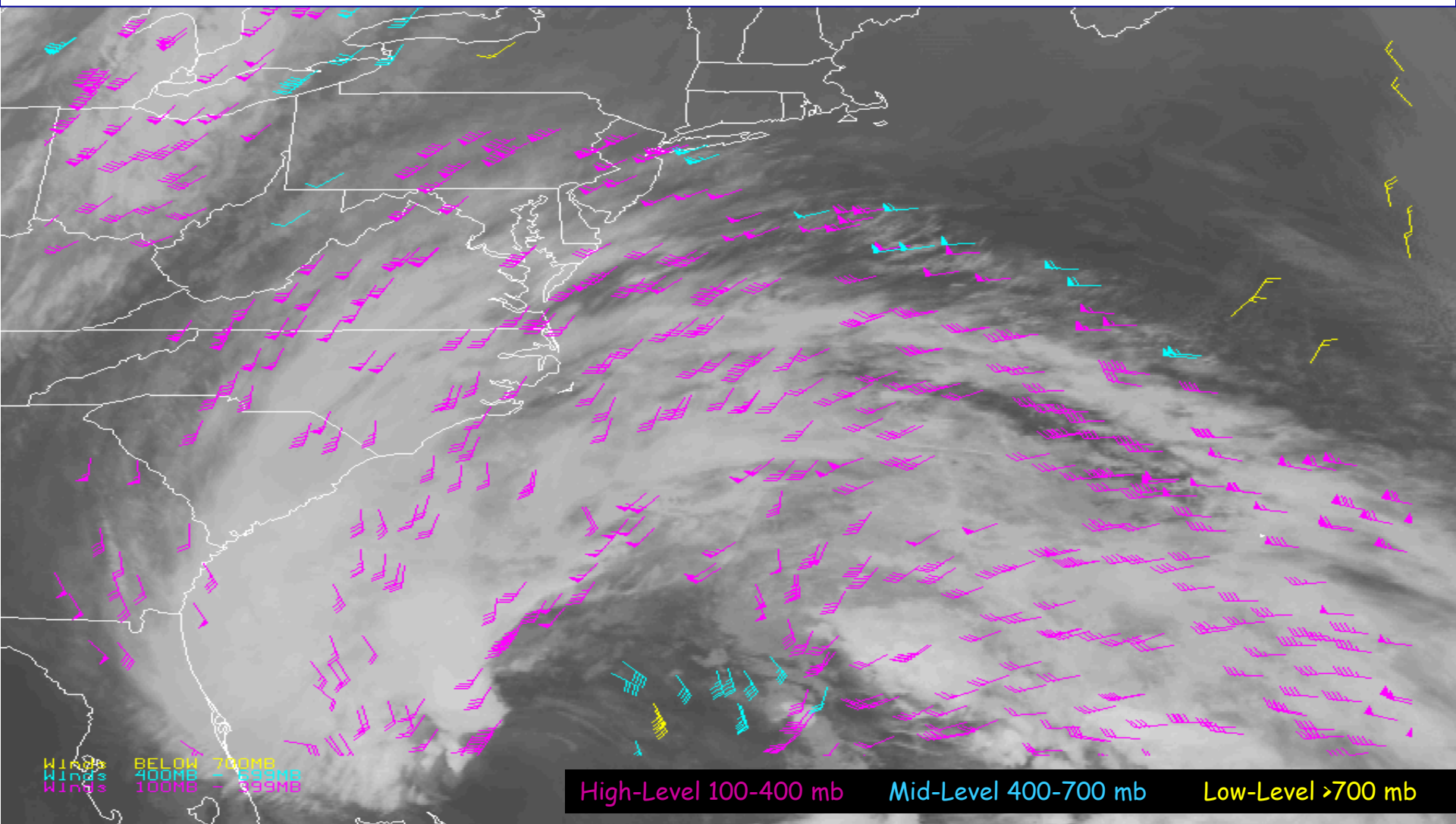
*The GOES-R Winds Team continues to routinely generate and validate ABI proxy winds from **GOES-13, GOES-15, Meteosat-10/SEVIRI, and NPP/VIIRS** using the GOES-R winds algorithm.*

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Application of GOES-R Winds Algorithm to Simulated GOES-R ABI Imagery

High-Level 100-400 mb   *Mid-Level 400-700 mb*   *Low-Level >700 mb*
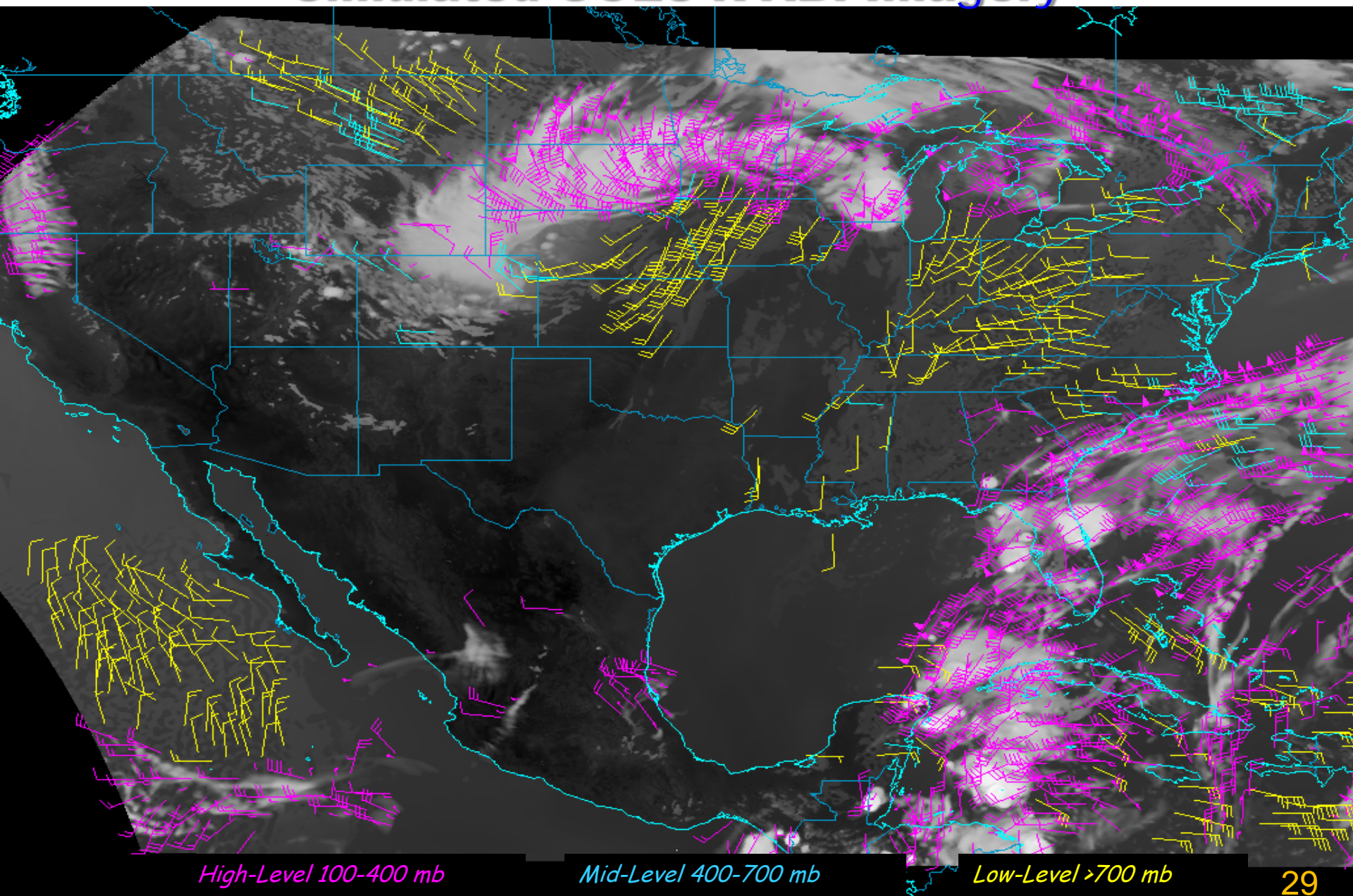
- The VIIRS polar winds product became <u>operational in NESDIS on 8 May 2014</u>.

- This is the first GOES-R algorithm to become operational.
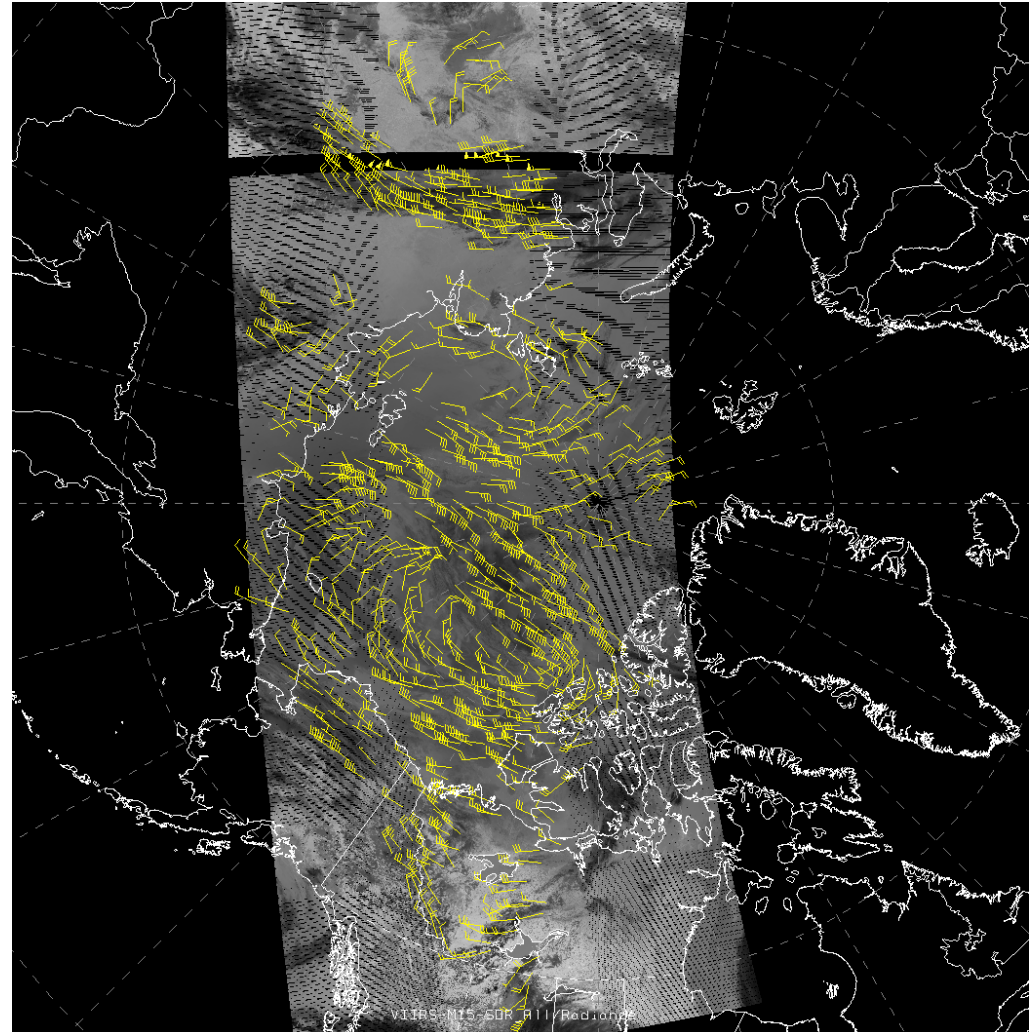
Assessing the Quality of Satellite Derived Winds

- **Radiosonde Wind Observations**
  - Used by all operational satellite processing centers that generate satellite derived motion winds

- **NCEP GFS Analyses Winds**
  - Useful over ocean

- **Aircraft Communications and Addressing System (ACARS) Wind Observations**

300 mb Height and Winds (kt) 2230 UTC 06/04/05
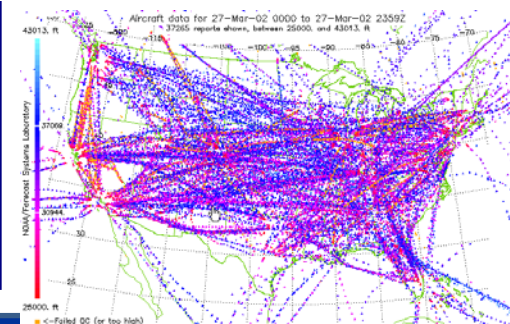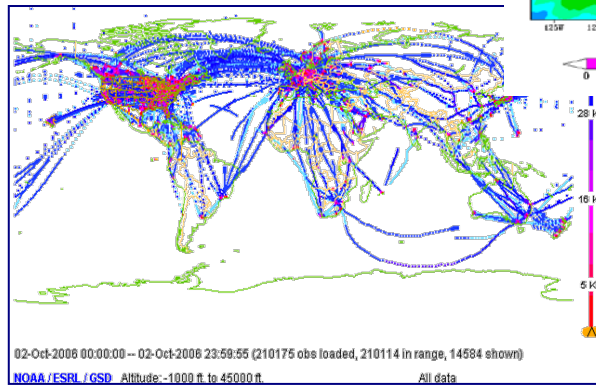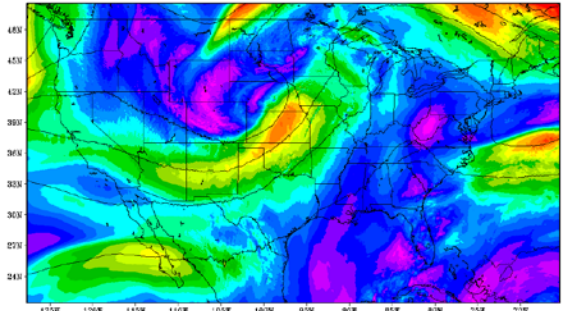
Assessing the Quality of Satellite Derived Winds *(vs radiosondes)*

Mean Vector Difference / **Bias (sat–rawinsonde)**

100-400 mb

Meteosat-10/SEVIRI Winds (10.8um)

Mean Vector Difference

Speed Bias

Overall Stats for Period:

MVD = 4.84 m/s
NRMS = 0.37
Speed Bias = -0.72 m/s
Avg Speed = 16.12 m/s
N = 23,400

Ground Truth: Radiosonde

Layer: 100 – 400 MB
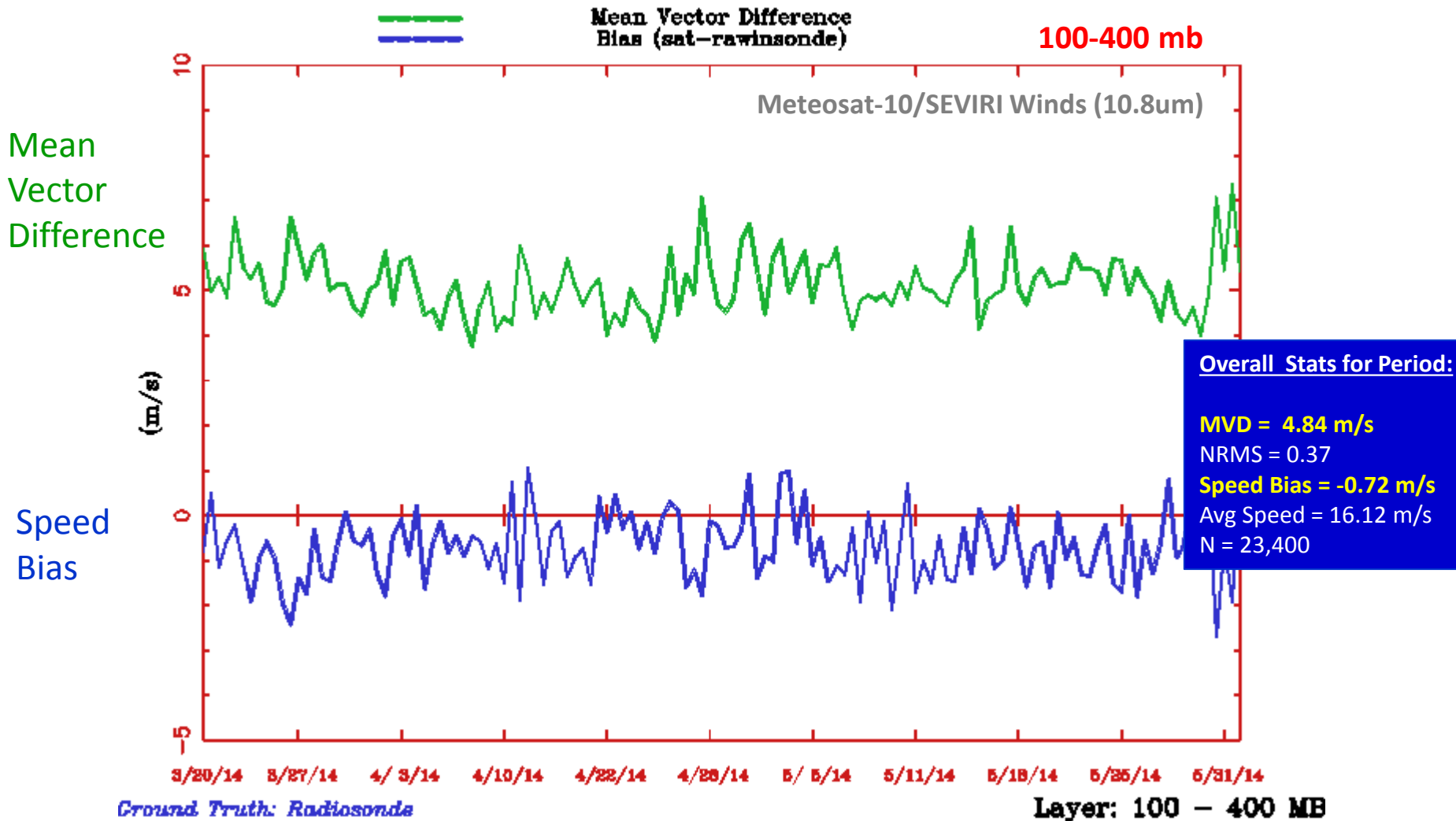
- **Field Forecasters (NWS WFOs and National Centers)**
  - Situational awareness of the atmospheric wind field
  - Verification of model guidance
  - Atmospheric monitoring

- **Numerical Weather Prediction Centers**
  - NWS/NCEP and international NWP centers are <u>primary users</u>
  - Satellite winds used to support the initialization of the atmospheric wind field in global and regional models

General Forecast Process: Observations to Human Forecast
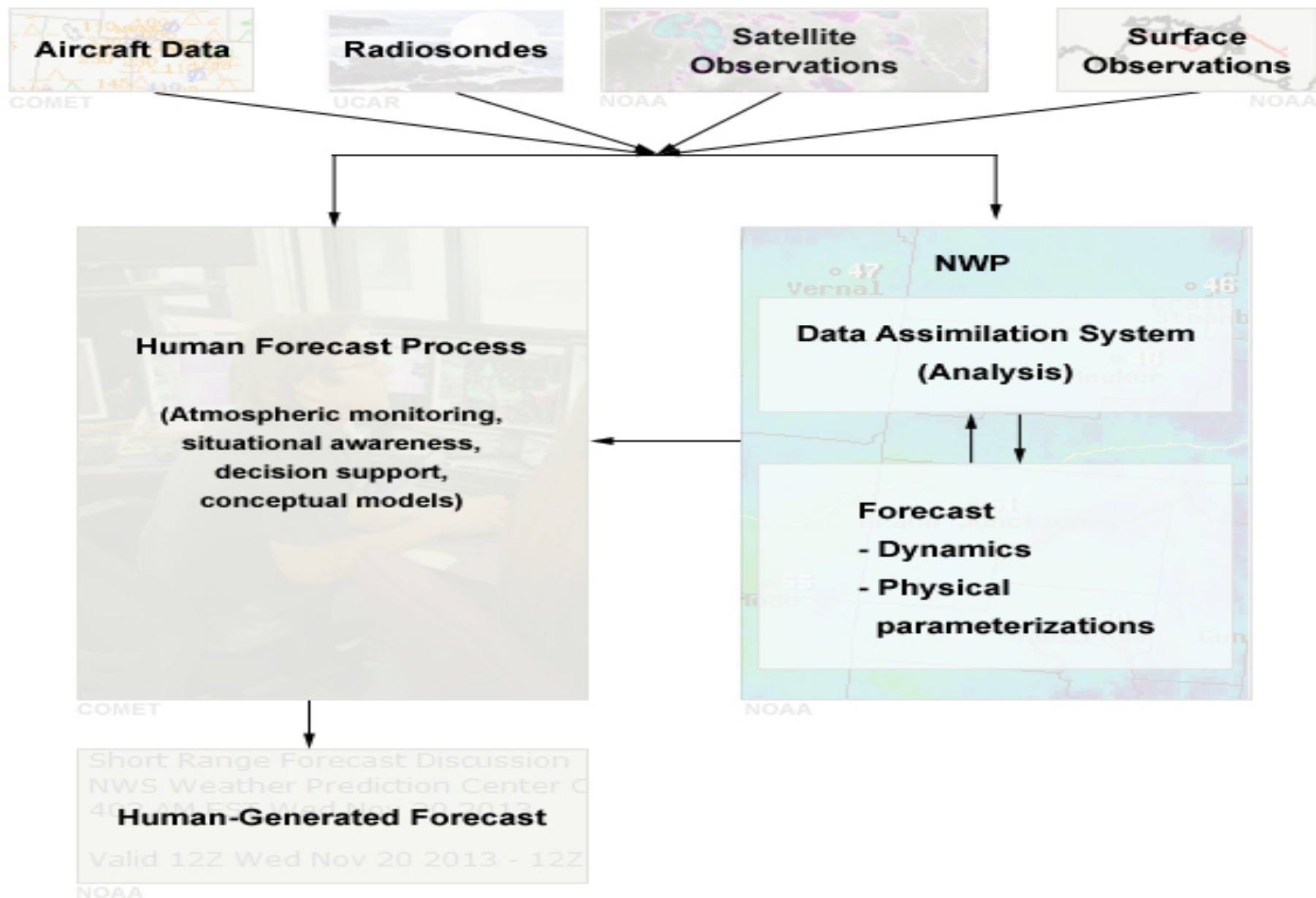
Aircraft Data

Radiosondes

Satellite Observations

Surface Observations

NWP

Human Forecast Process

(Atmospheric monitoring,
situational awareness,
decision support,
conceptual models)

Data Assimilation System

(Analysis)

Forecast
- Dynamics
- Physical
  parameterizations

Human-Generated Forecast
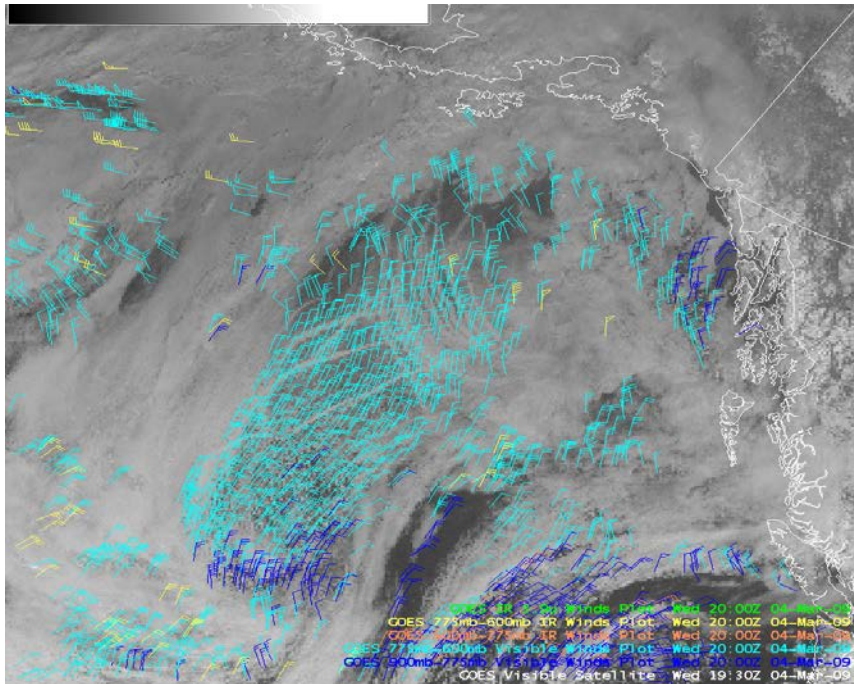
GOES winds as displayed in AWIPS

AWIPS enables easy integration of GOES AMVs with a multitude of other data sources

Verification of a Strong Polar Jet:

250mb GOES Water Vapor Winds, radiosonde winds, and NCEP NAM model forecast isotachs

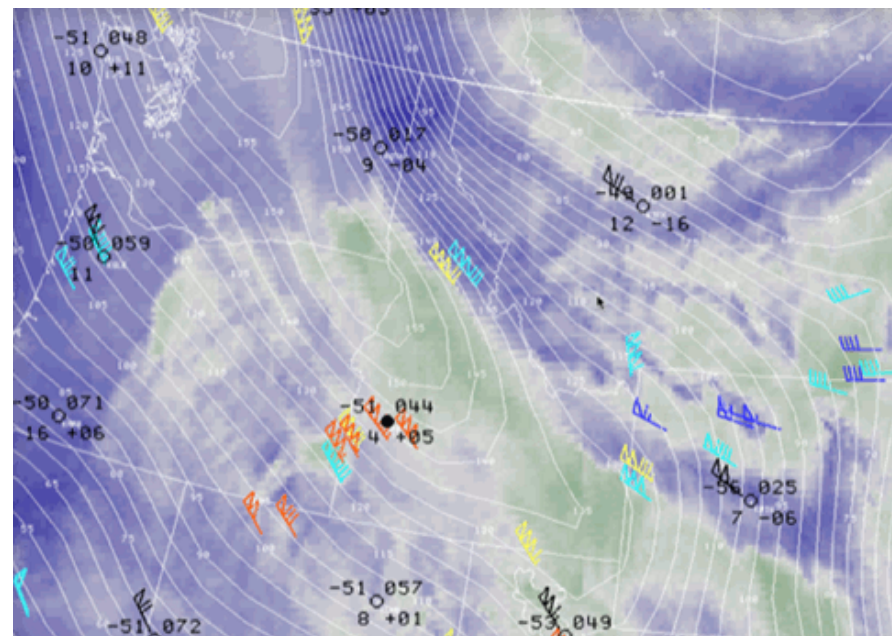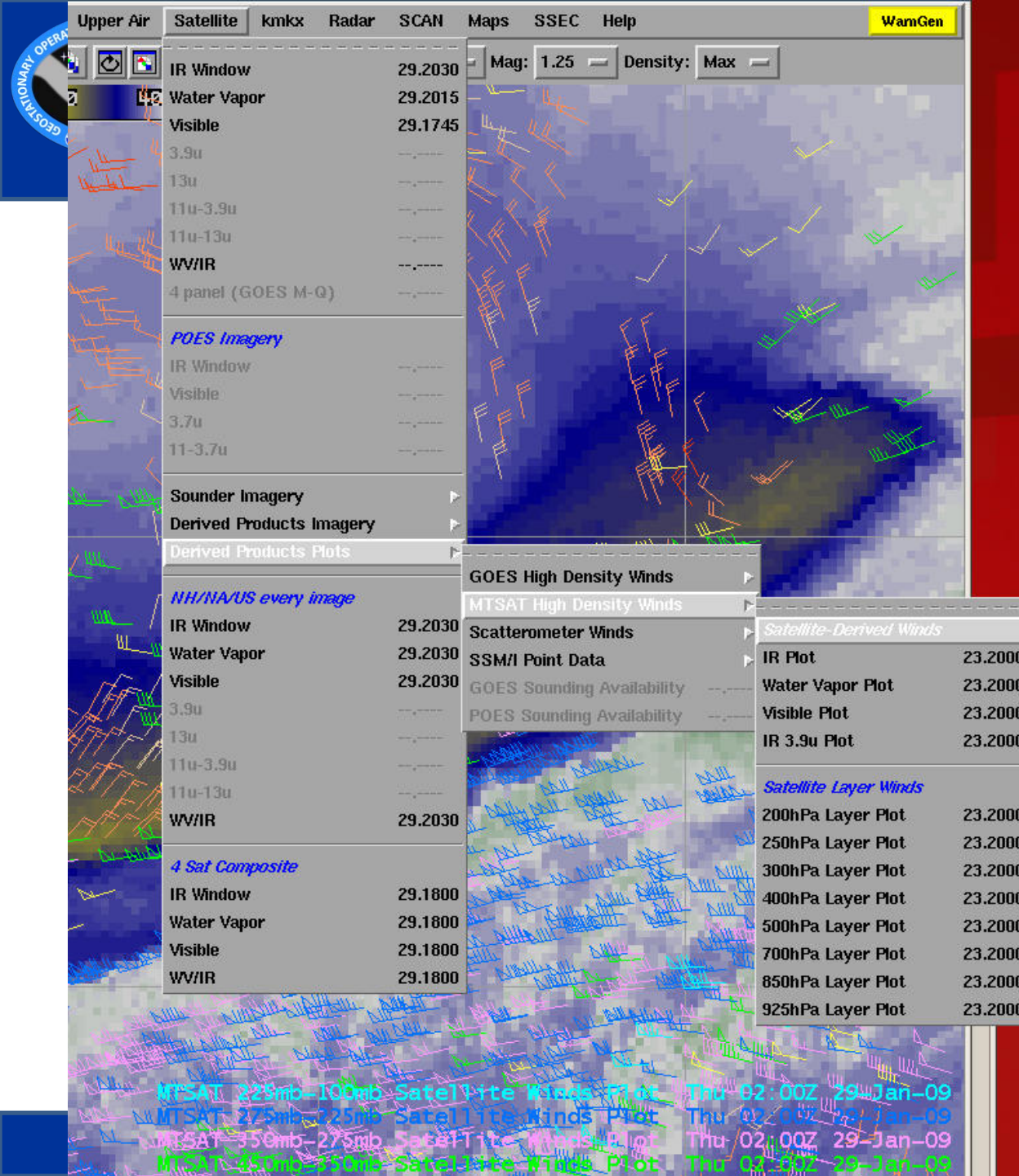Beginning in October 2008, "high density winds" (also known as Atmospheric Motion Vectors, or AMVs) derived from the Japanese geostationary Multi-functional Transport Satellite (MTSAT-1R, which is positioned over the Equator at 140º East longitude) were added to the NOAAPORT Satellite Broadcast Network (SBN). National Weather Service forecast offices localized as West CONUS sites (or OCONUS offices in the Alaska Region and the Pacific Region) that have installed AWIPS Operational Build 9.0 or higher will be able to access these new MTSAT satellite winds products from the AWIPS menu (above).

TECHNICAL IMPLEMENTATION NOTICE 08-61
NATIONAL WEATHER SERVICE HEADQUARTERS
WASHINGTON DC
317 PM EDT FRI AUG 1 2008

SUBJECT: NESDIS HIGH DENSITY GEOSTATIONARY WINDS TO BE
     ADDED TO SBN/NOAAPORT: EFFECTIVE OCTOBER 15 2008

EFFECTIVE WEDNESDAY OCTOBER 15 2008...BEGINNING AT APPROXIMATELY 1500 COORDINATED UNIVERSAL TIME /UTC/...THE NATIONAL ENVIRONMENTAL SATELLITE...DATA...AND INFORMATION SERVICE /NESDIS/ AND NWS START DISSEMINATING HIGH DENSITY GEOSTATIONARY /MTSAT/ WIND PRODUCTS VIA SBN/NOAAPORT.

THE MTSAT WINDS /FROM THE JAPANESE SATELLITE/ WILL AUGMENT THE CURRENT GOES EAST AND WEST HIGH DENSITY WINDS OVER SPARSE DATA REGIONS...MOST BENEFITING THE ALASKA AND PACIFIC REGIONS CENAND THE AVIATION WEATHER TER /AWC/.

100-250 mb
250-350 mb

The AMVs are used to help identify synoptic patterns, assess outflow and shear around tropical cyclones, and, when displayed on model fields, to help assess the reliability of the model initial conditions

GEN-100-250 140825/1300
GEN-250-350 140825/1300
140825/1315 GOES13   IR3
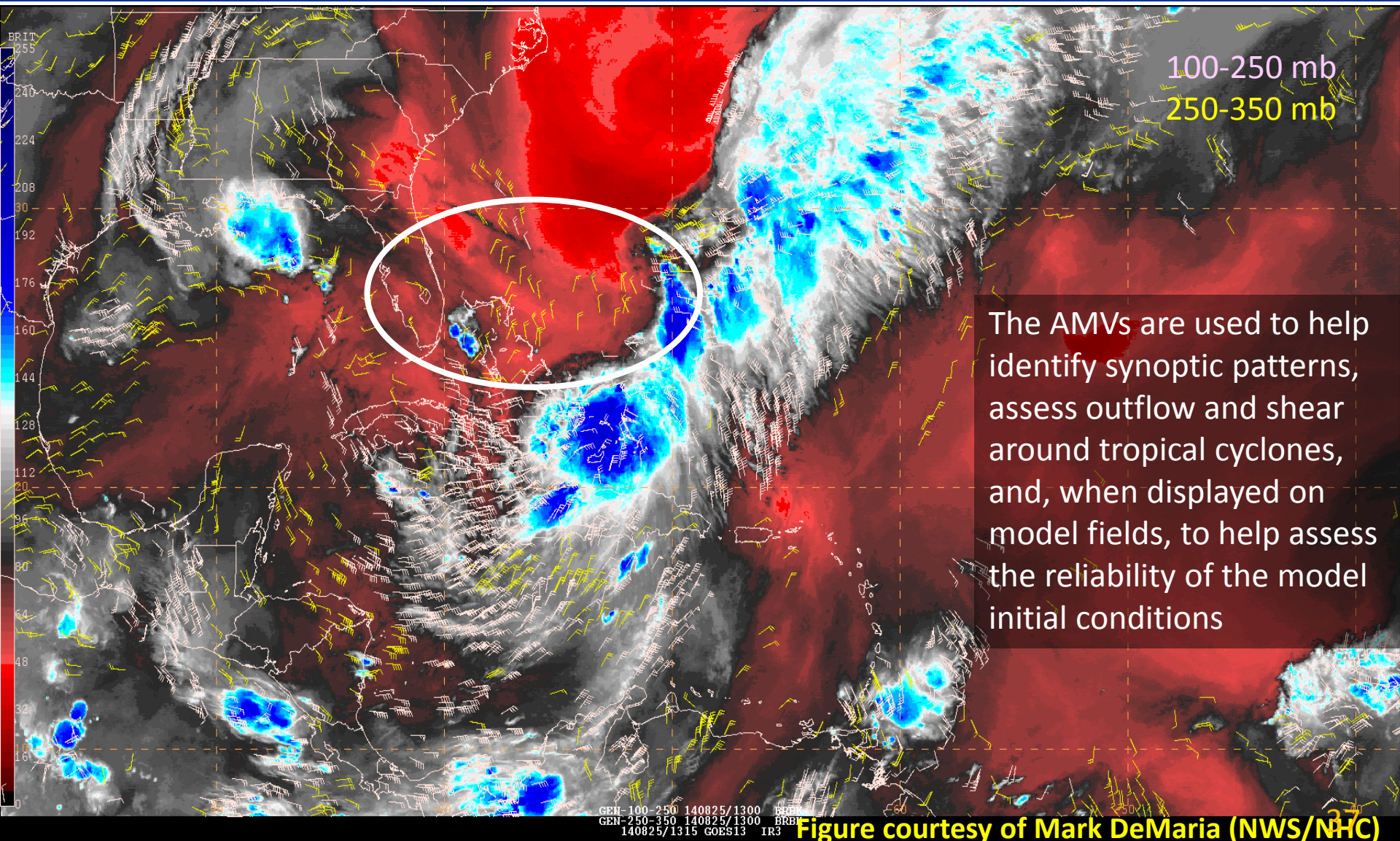
Figure courtesy of Mark DeMaria (NWS/NHC)

Forecast Sensitivity to Observations (FSO)

- Adjoint-based FSO method gives estimate of the contribution of each observation towards reducing the 24-hour forecast error

- Satellite winds reduce 24 hour forecast error on the order of 7-11% *(NRL was exception)*

- Places satellite winds among the top global observing system observations that contribute in a positive way to NWP global forecast impact
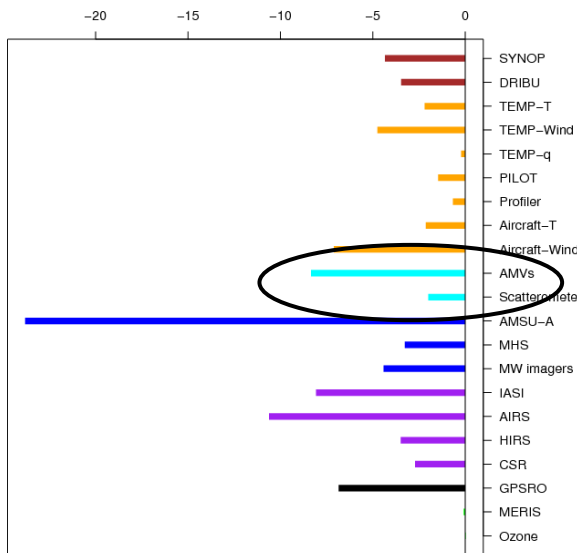
ECMWF   Met Office   NRL
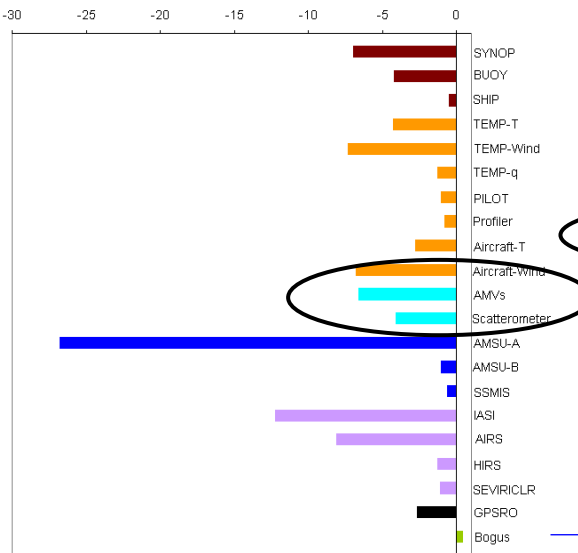
- Current AMV products generally designed to capture broad-scale to synoptic scale flow. However, NWP is moving to higher spatial resolution and more frequent assimilation cycles.

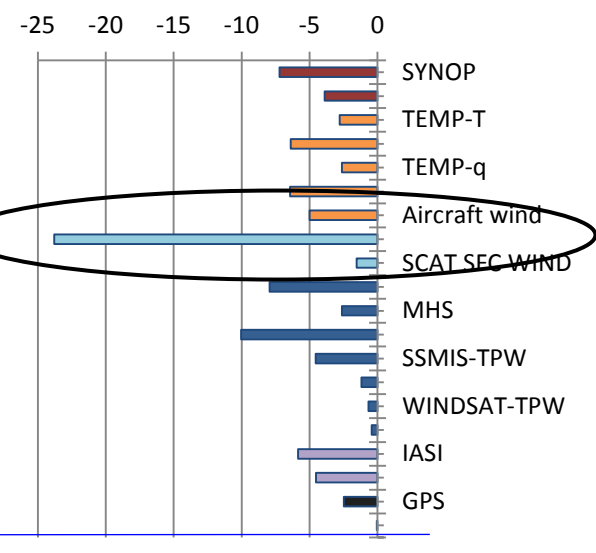- There is information available on smaller scales in the geo satellite imagery (i.e. ***clearly evident in rapid-scan animations***)

- Future instruments (GOES-R ABI, Himawari-8, etc) will bring improved spectral, spatial, and temporal resolution, all of which will enable the generation of higher resolution AMV products

- Can we derive more useful AMV information for nowcasting and mesoscale assimilation in high resolution models like NCEP's HWRF to help with forecasting high impact weather events like tropical cyclones??
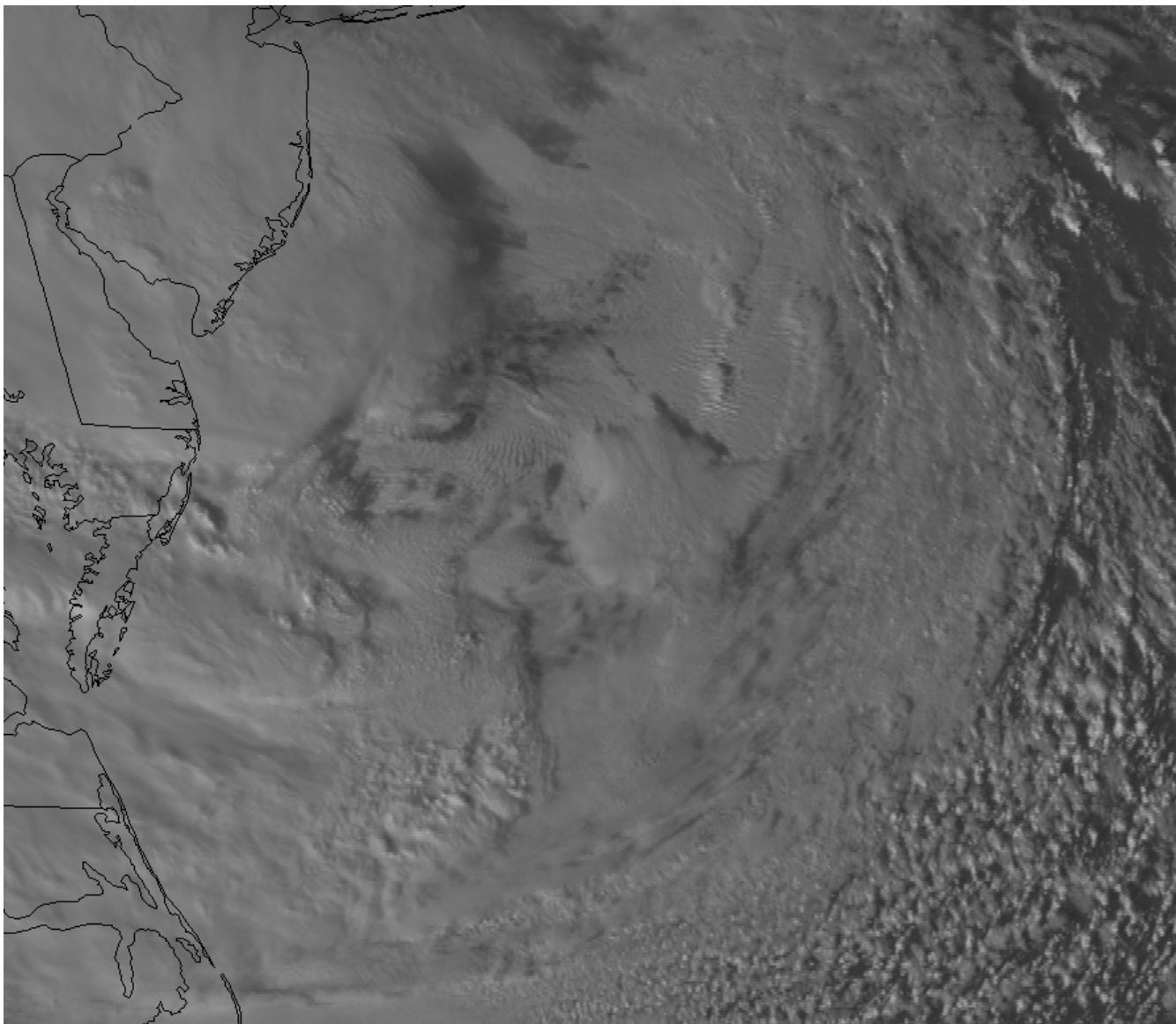
G-14 IMG   BAND=1 (0.62 UM)   29 OCT 12 (2012303)   20:15 UTC   NOAA UW/SSEC CIMSS   McIDAS

http://cimss.ssec.wisc.edu/goes/srsor/GOES-14_SRSOR.html

40

Hurricane force winds (> 75 mph)

Hurricane Sandy

2 0002 G-14 IMG 1 28 OCT 12302 160500 04117 16962 01.00
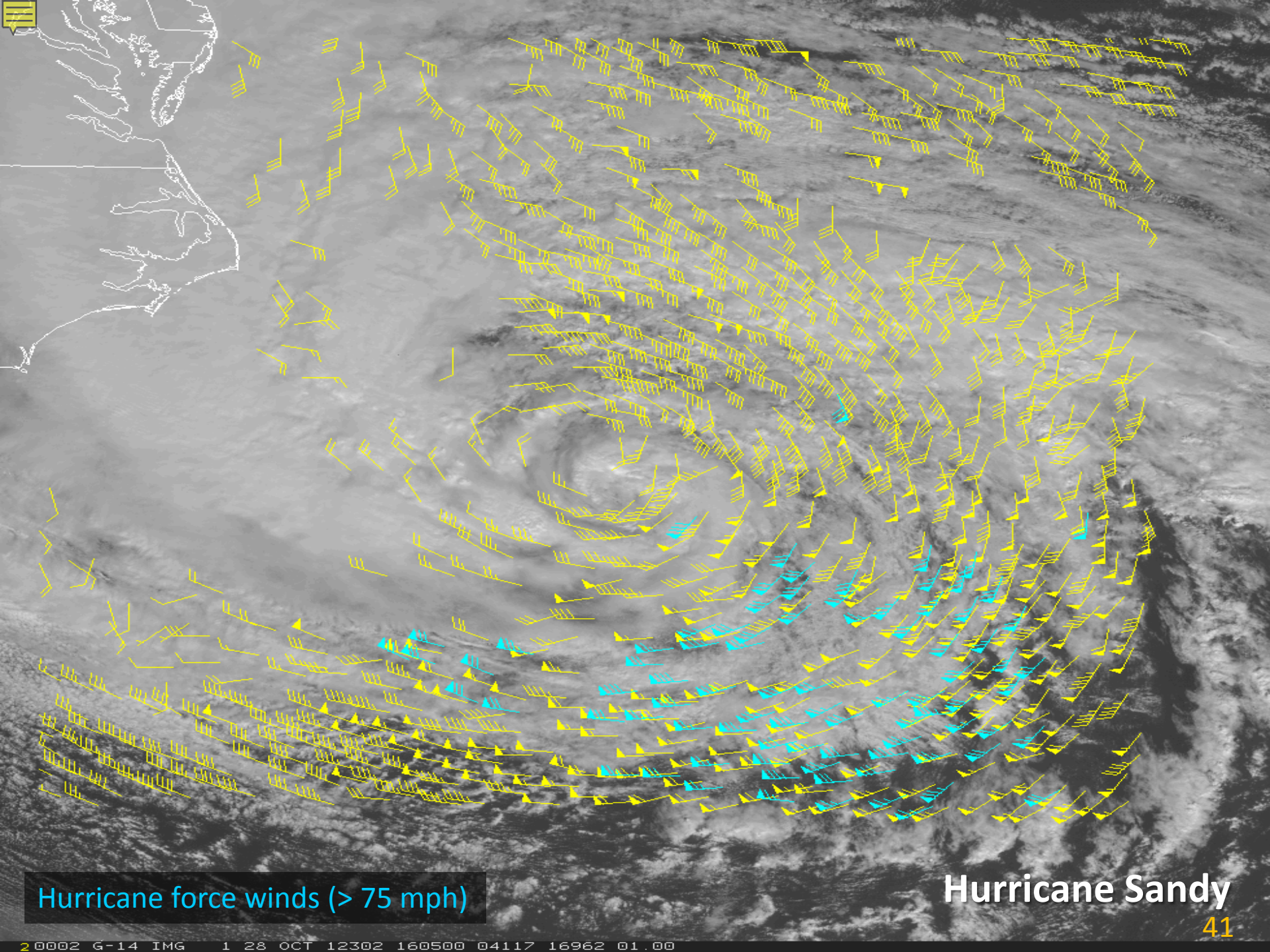
Summary

- Atmospheric motion is readily apparent in sequences of satellite imagery

- Satellite derived winds are a key component of the Global Observing System (GOS)

- GOES-R ABI will improve our ability to retrieve better wind products

- User community (NWP users, field forecasters) will benefit from better wind products

Questions
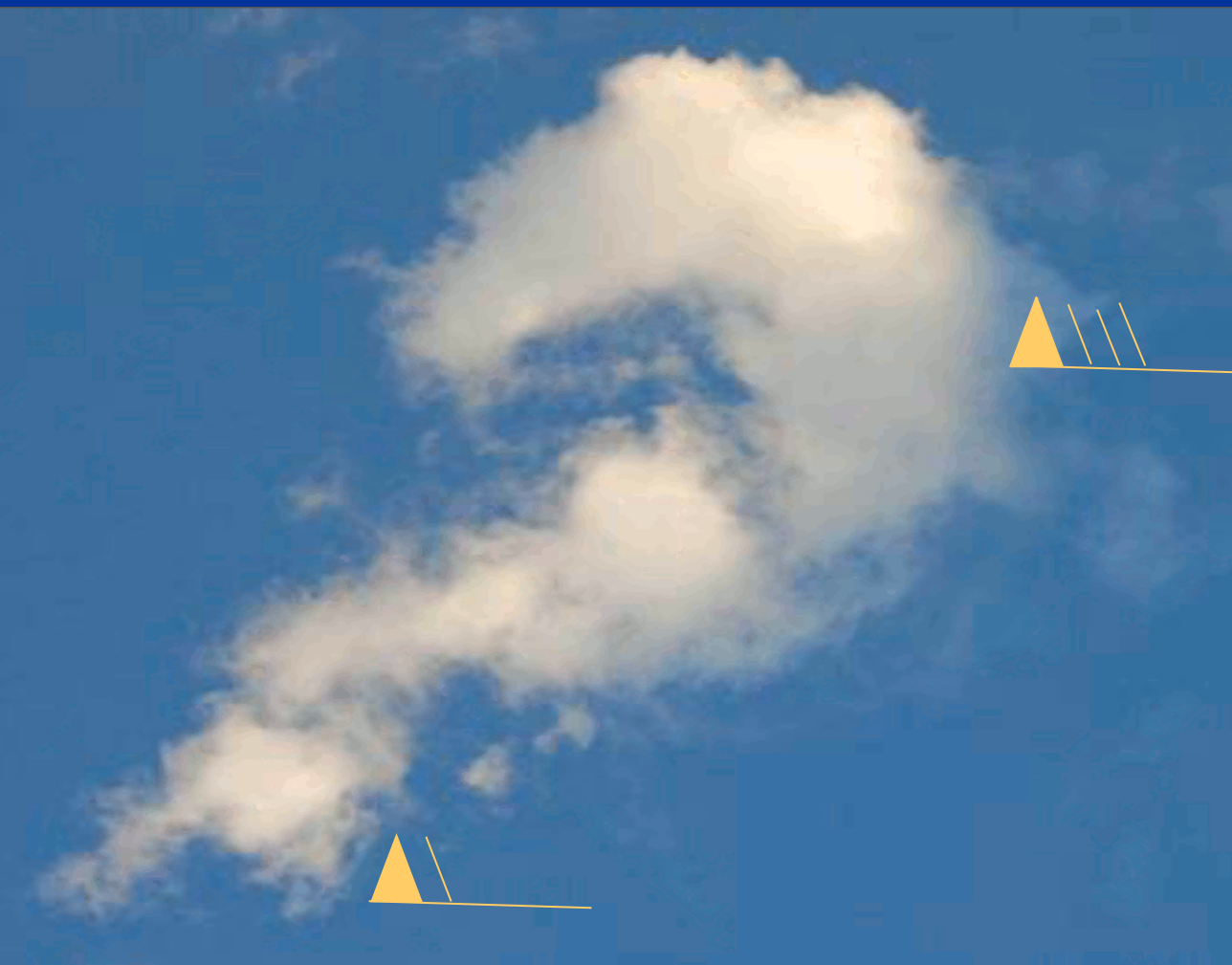
Jaime Daniels: jaime.daniels@noaa.gov

NESDIS STAR AWG web page: http://www.star.nesdis.noaa.gov/goesr

Hurricane force winds (> 75 mph)

Hurricane Sandy

20002 G-14 IMG   1 28 OCT 12302 160500 04117 16962 01.00
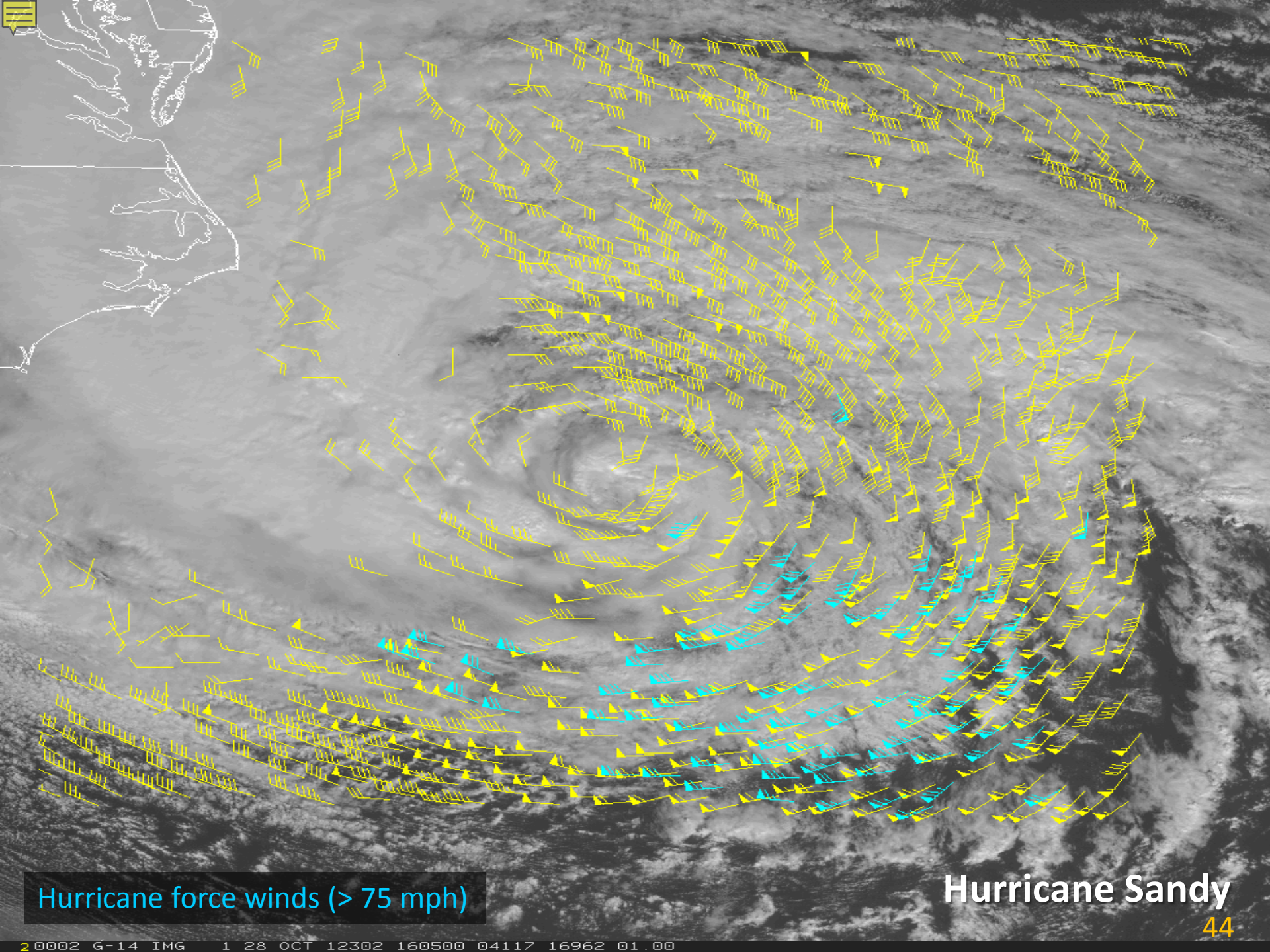
BACKUP

Validation Strategy
For satellite wind height assignments...

Using CALIPSO/CloudSat Data to Validate Satellite Wind Height Assignments

- Leverages unprecedented cloud information offered by CALIPSO and CloudSat measurements

- Enables improved error characterization of satellite wind height assignments

- Enables feedback for potential improvements to satellite wind height assignments

- Improvements to overall accuracy of satellite-derived winds
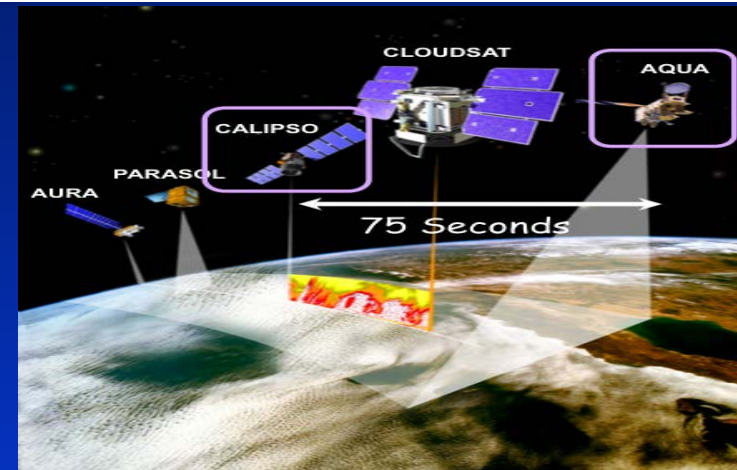
GOES-12 Cloud-drift Wind Heights Overlaid on CALIPSO total attenuated backscatter image at 532nm
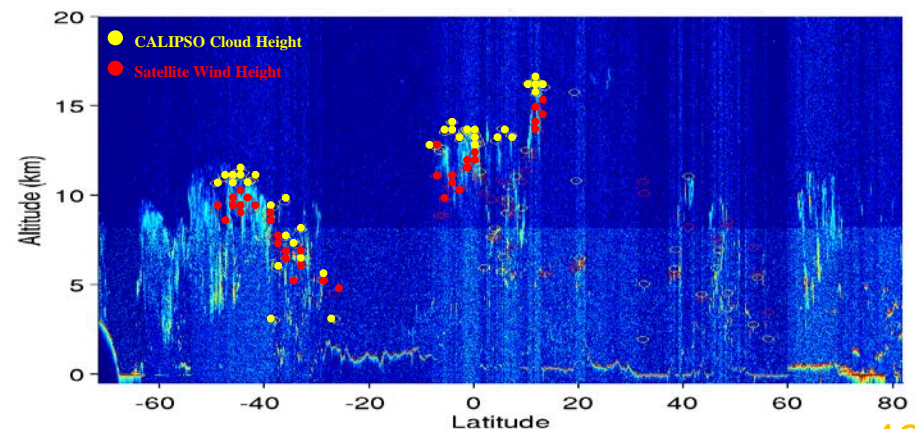
Hurricane Isabel

GOES-12 Vis imagery

12 Sept. 2003

Low-level AMVs in Isabel's eye derived from GOES-12 super-rapid-scan (3-min intervals used) VIS imagery

GOES-12 SRSO   12 SEP 03   13:07 UTC   HURRICANE ISABEL

GOES-12 SRSO   12 SEP 03   13:07 UTC   HURRICANE ISABEL

Data assimilation systems

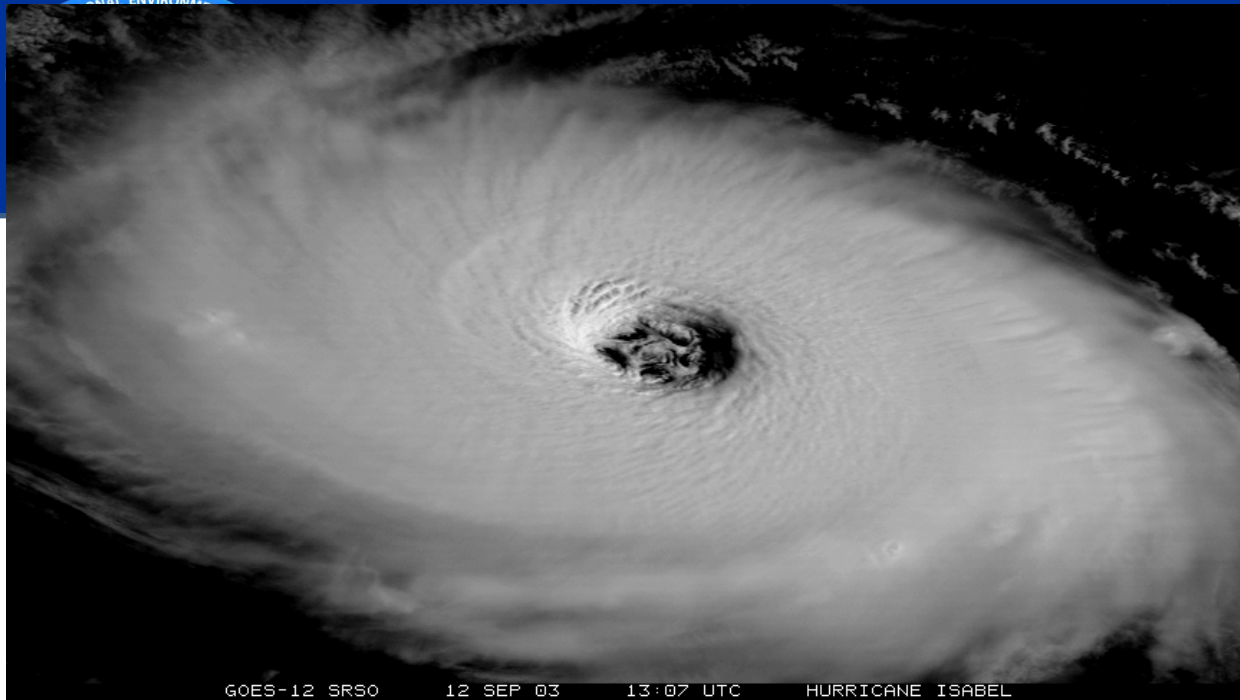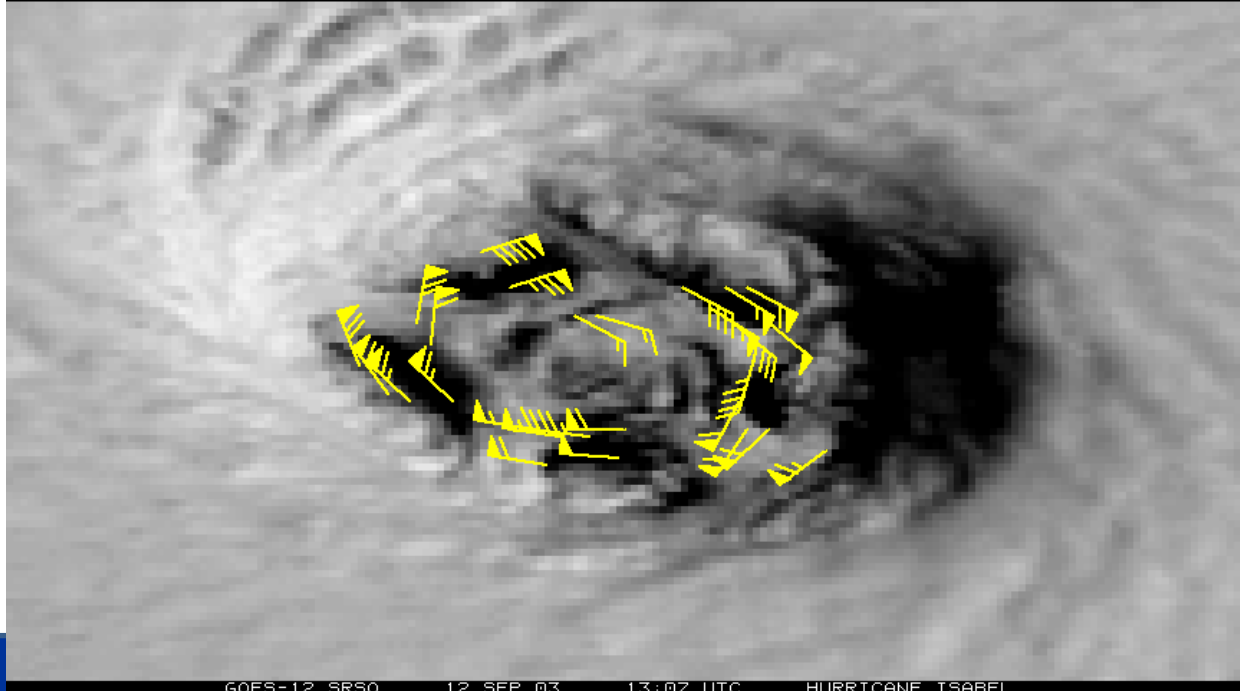Data assimilation systems produce the starting point or analysis for an NWP forecast. To do this, they take a short-range NWP forecast or first guess valid at the analysis time, and use observations within a time window centered on that time to adjust the first guess to the best analysis possible. This becomes the starting place for the current forecast cycle.

Forecast modules

The forecast part of the NWP model consists of two modules. One deals with dynamical equations, the other with physical parameterizations. Dynamical equations forecast processes that are large enough to be analyzed and forecast at the model's resolution, such as shortwave troughs. Physical parameterizations estimate the effect of processes that are smaller than the model can forecast directly, such as convection and atmospheric transmission of long- and shortwave radiation.

Observations from new instruments

The needs of DA systems and NWP help drive new instrument design. Observations from new instruments are quality tested before and after launch. They are then tested in the DA system, and NWP forecasts are run from these test analyses. If the quality of the forecasts improves or is maintained, the new data are accepted for operational use. Otherwise, they will not be used.

All satellite data are continuously monitored, even after they are accepted into operations. Any degradation in data quality is corrected if possible. Otherwise, the data are removed from the DA observational stream. Other satellites with the same or similar instruments may be considered to replace the lost data.

Satellite observations and retrievals

Satellite data are assimilated operationally in two forms, as observations and as retrievals. When retrieval products are used, they are compared directly to the matching first guess data to determine an analysis increment. When observations are used, the first guess data is converted into simulated satellite observations and adjusted to bring it and the actual observations as close to each other as possible. These adjustments are then used as analysis increments. From this point forward, observations and retrievals are handled in the same manner: weighted, buddy checked, and weight adjusted if they're significantly different from neighboring increments. In the last step, the increments from all observational platforms are combined to make the final analysis.

Satellite data are essential for making good forecasts in high-impact situations, and for improving overall model forecast skill. This is especially true in and downstream from data-sparse areas.

Future challenges

To improve satellite data and NWP and DA systems in the future, challenges need to be met in three areas. **NWP models** and their **DA systems** need to make better use of existing satellite data, particularly in the areas of clouds and precipitation, explicitly predicted convection, natural and human-made aerosols, and real-time surface conditions such as soil moisture and vegetation greenness. Preparatory work needs to continue so the satellite observations from GOES-R and the next generation of NOAA LEO satellites will be used effectively.

In the area of **satellite remote sensing**, we need to increase the resolution of microwave sounders, improve the usefulness of sounder data in areas of clouds and precipitation, increase the amount of satellite wind data, and add hyperspectral infrared instruments to geostationary satellites. In addition, we need to address the potential loss of U.S. LEO data if there's a gap between the decommissioning of any current satellites and the launch of next generation satellites.