Algorithm and Software Development of Atmospheric Motion Vector Products for the Future GOES-R Advanced Baseline Imager (ABI)

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TOPICS

- **GOES-R Program Information**
- **GOES-R Advanced Baseline Imager (ABI)**
- **GOES-R AMV Algorithm and Software Development Approach**
- **GOES-R AMV Algorithm Descriptions and Results from Early Testing**
- **Summary, Future Plans, and Opportunities**

GOES-R Program Information

- GOES-R is a collaborative development and acquisition effort between NOAA and the National Aeronautics and Space Administration (NASA).

- The GOES-R series acquisition includes:
  - Two spacecraft: GOES-R and GOES-S
  - Five different environmental instrument suites, spacecraft launch services, ground systems, and the end-to-end systems integration to support GOES-R design, fabrication, testing, launch, and operations.

- Instruments to be flown on GOES-R include:
  - ***Advanced Baseline Imager (ABI)***
  - Geostationary Lightning Mapper (GLM)
  - Space Environmental In-Situ Suite (SEISS)
  - Solar Ultra Violet Imager (SUVI)
  - Extreme Ultra Violet / X-Ray Irradiance Sensors (EXIS)
  - Magnetometer (MAG)

All instruments are now on contract;

Unfortunately, no Hyper-Spectral Sounder on GOES-R

- Launch Dates:
  - GOES-R: December 2014
  - GOES-S: April 2016

- GOES-R Algorithm Working Group
  - Formed to select, develop, and deliver Level-2 product algorithms to the GOES-R Ground Segment

GOES-R Algorithm Working Group

PURPOSE: To develop, test, demonstrate, validate and provide algorithms for end-to-end GOES-R Ground Segment capabilities and to provide sustained life cycle validation and product enhancements

- Executed from Center for Satellite Applications & Research
- Leverages nearly 100 scientists from NOAA, NASA, DOD, EPA, and NOAA's Cooperative Institutes (University partners)
- Apply first-hand knowledge of algorithms developed for POES, GOES, DMSP, AIRS, MODIS, MetOP and Space Weather.
- Facilitate algorithm consistency across platforms (maximizes benefits and minimizes integration)

GOES-R Algorithm Working Group - ***Application Teams***

GOES-R Products Mapped to Algorithm Application Teams

- **Soundings**
- **Aerosols / Air Quality / Atmospheric Chemistry**
- **Clouds**
- **Aviation**
- **Winds**
- **Hydrology**
- **Land Surface**
- **SST**
- **Ocean Dynamics**
- **Cryosphere**
- **Radiation Budget**
- **Lightning**
- **Space Environment**

Led by Government Scientists

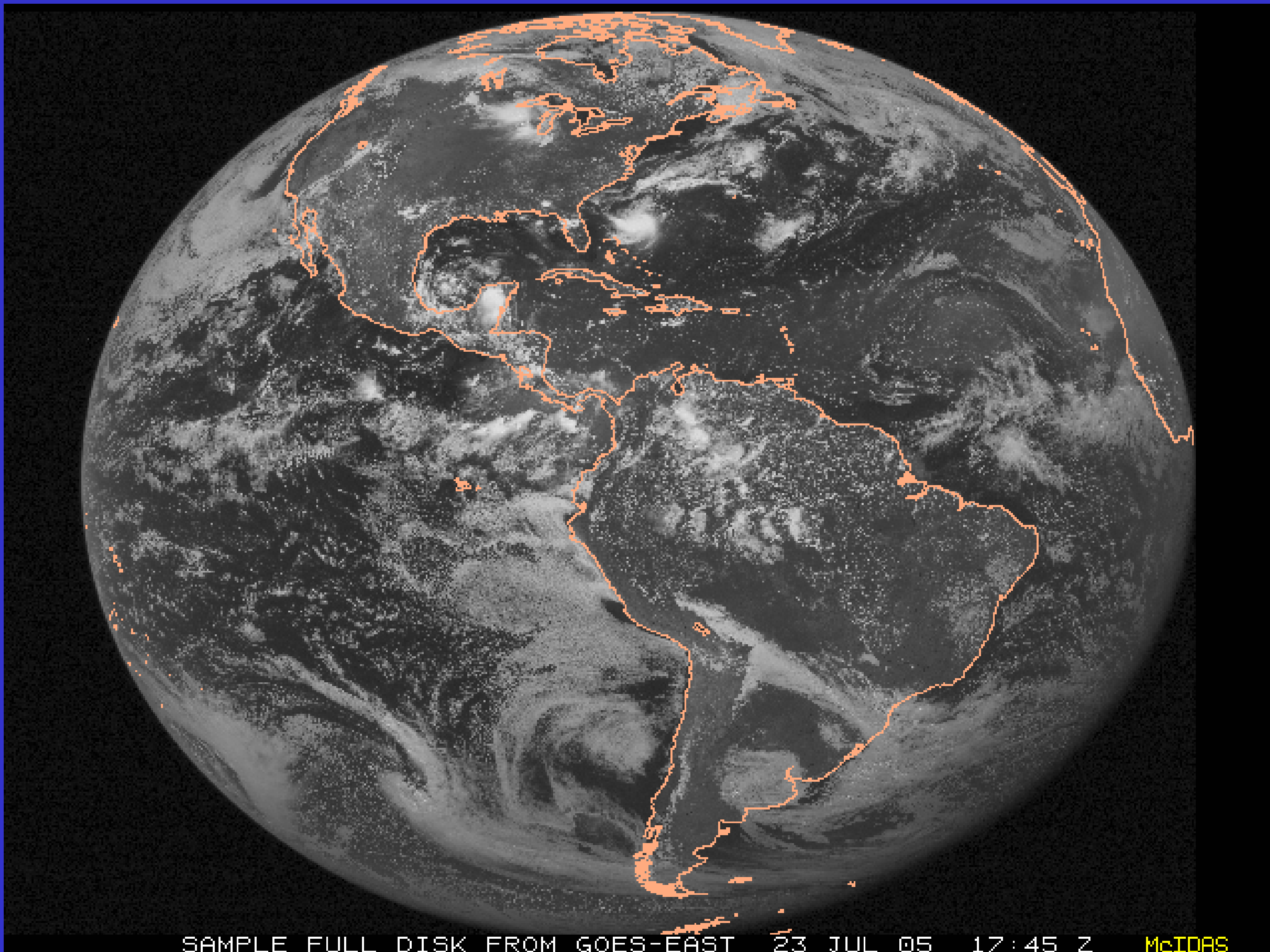
- **Proxy Data**
- **Cal/Val**
- **Algorithm Integration**
  - Product System Integration
  - Imagery/Visualization
  - Product Tailoring

Support Teams

GOES-R Advanced Baseline Imager

The Advanced Baseline Imager:

	ABI		Current GOES
Spectral Coverage			
	16 bands		5 bands
Spatial Resolution			
0.64 μm Visible	0.5 km		~ 1 km
Other Visible/near-IR	1.0 km		n/a
Bands (>2 μm)	2 km		~ 4 km
Spatial & Temporal Coverage	*(Mode 3)*	*(Mode 4)*	
Full disk	4 per hour	12 per hour	Every 3 hours
CONUS	12 per hour		~4 per hour
Mesoscale	Every 30 sec		n/a
Visible (reflective bands)			
On-orbit calibration	Yes		No



ABI will scan about 5 times faster than the current GOES imager

There are two anticipated scan modes for the ABI:

- Full disk images every 15 minutes+CONUS images every 5 mins+mesoscale every 30s.

or

- Full disk every 5 minutes.

ABI Visible/Near-IR Bands

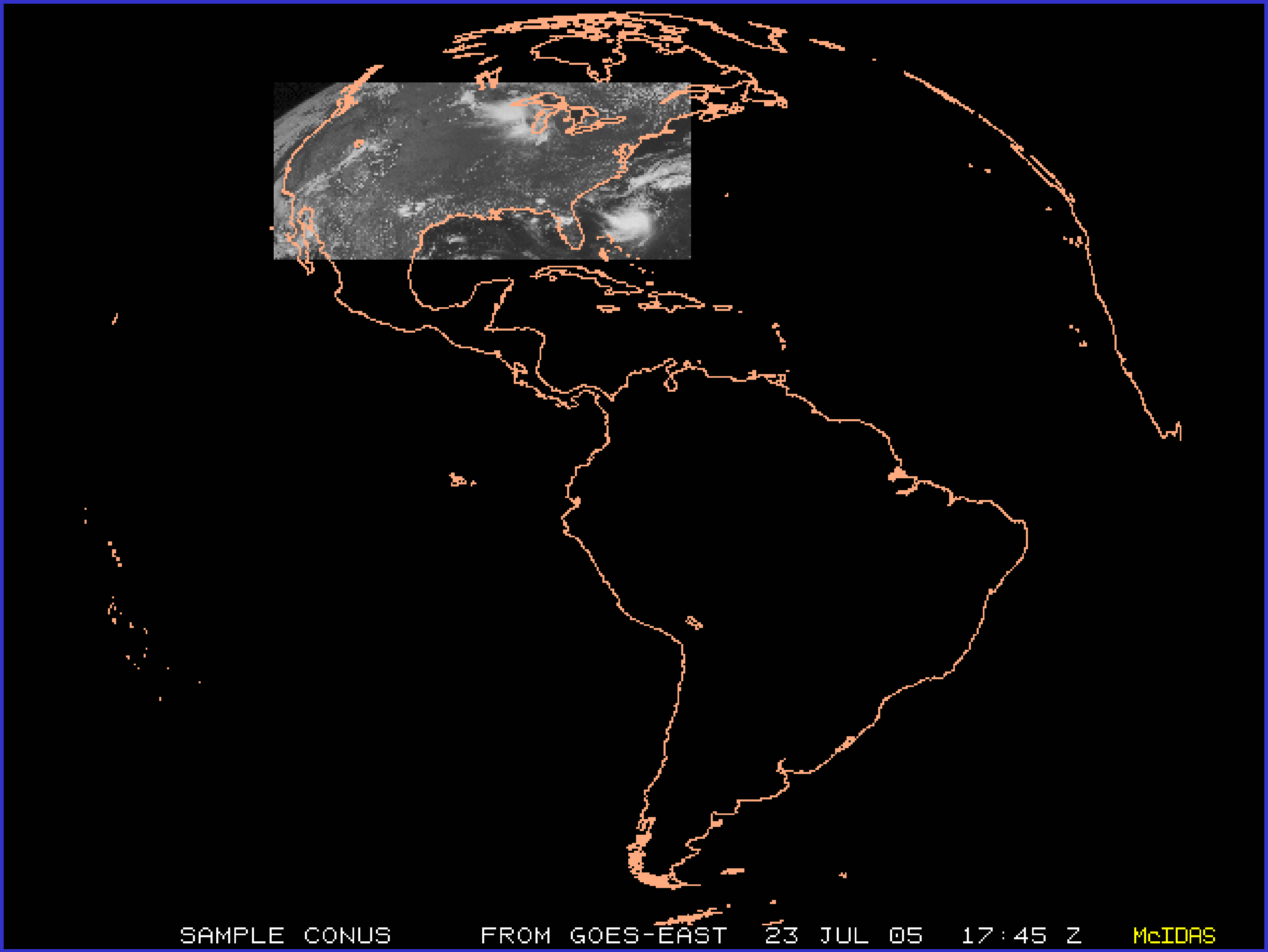
Future GOES imager (ABI) band	Wavelength range (µm)	Central wavelength (µm)	Nominal subsatellite IGFOV (km)	Sample use
1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping
2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds
3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds
4	1.371–1.386	1.378	2	Daytime cirrus cloud
5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow
6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow

Schmit et al, 2005

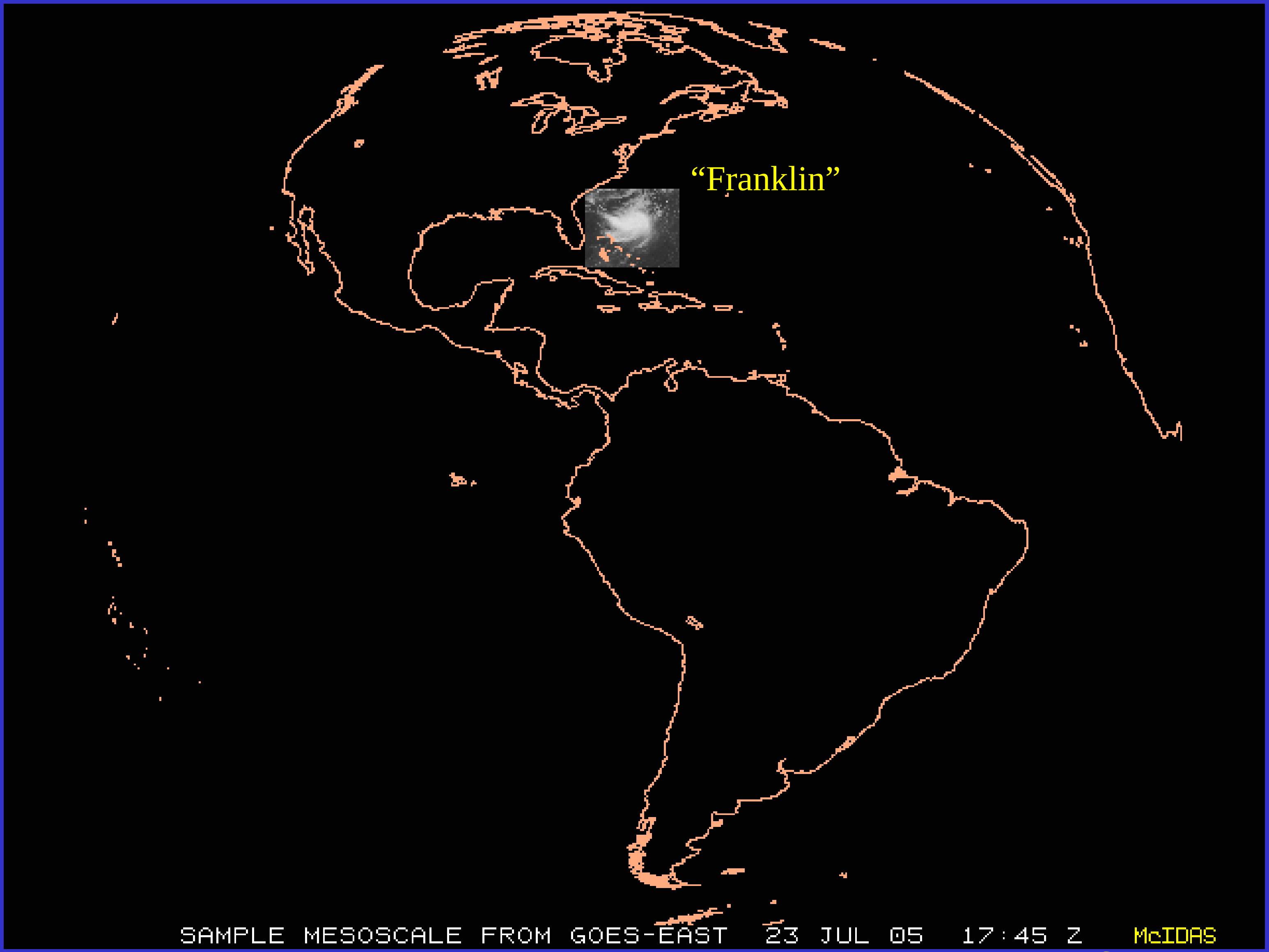
ABI IR Bands

7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds
8	5.77–6.6	6.19	2	High-level atmospheric water vapor, winds, rainfall
9	6.75–7.15	6.95	2	Midlevel atmospheric water vapor, winds, rainfall
10	7.24–7.44	7.34	2	Lower-level water vapor, winds, and SO_2
11	8.3–8.7	8.5	2	Total water for stability, cloud phase, dust, SO_2 rainfall
12	9.42–9.8	9.61	2	Total ozone, turbulence, and winds
13	10.1–10.6	10.35	2	Surface and cloud
14	10.8–11.6	11.2	2	Imagery, SST, clouds, rainfall
15	11.8–12.8	12.3	2	Total water, ash, and SST
16	13.0–13.6	13.3	2	Air temperature, cloud heights and amounts

Schmit, T. J., M. M. Gunshor, W. P. Menzel, J. J. Gurka, J. Li, and A. S. Bachmeier, 2005: Introducing the next-generation Advanced Baseline Imager on GOES-R. *Bull. Amer. Meteor. Soc*., **86**, 1079-1096.



ABI can offer Continental US images every 5 minutes for routine monitoring of a wide range of events (storms, dust, clouds, fires, winds, etc).
This is every 15 minutes with the current GOES in routine mode.



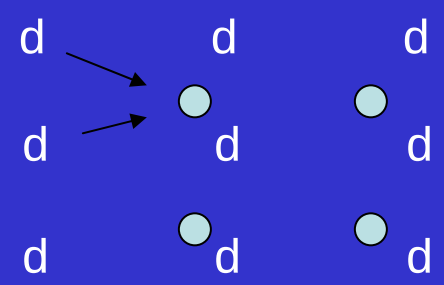
Mesoscale images every 30 seconds for rapidly changing phenomena (thunderstorms, hurricanes, fires, etc). Current GOES can not offer these rapid scans while still scanning other important regions

GOES-R ABI Image Requirement

Navigation and Registration

- The distributed, calibrated and navigationally corrected **image data will be rectified to a fixed grid**. The grid is defined relative to an ideal geostationary satellite viewpoint.

- The image pixels will have an angular separation of:
  - 14 microradians (0.5 km) in the 0.64 um channel;
  - 28 microradians (1 km) in the 0.47, 0.86 and 1.61 um channel;
  - 56 microradians (2 km) in all other channels.



GOES Image Navigation and Registration (INR)

SPECIFICATIONS (3σ); (CALCULATED)

	GOES 8-12	GOES 13,O,P	GOES-R
	KM D / N	KM D / N	KM D / E
ABSOLUTE NAVIGATION	4.0 / 6.0 (4.5 /5.0)	2.3	1.0 / 1.5
WITHIN IMAGE	1.6 / 1.6	2.0	1.0
I-TO-I (RD)			
5-7 MIN	-- (2.3 / 2.3)	-- (0.6/0.6)	0.75 1.0
15 MIN	1.5 / 2.5 (2.8 / 3.2)	1.3 (1.0/1.3)	0.75 1.0
90 MIN	3.0 / 3.8	1.8	0.75 1.0
24 HR	6.0 / 6.0	4.0	--

GOES-13 image-to-image registration accuracy is <u>substantially improved</u> over its predecessors – approaching GOES-R requirements ⇨ Very beneficial for generation of high quality AMVs…

Slide Courtesy: Gary Jedlovek (NASA/MSFC)

Upper Peninsula MI Fires

Figure courtesy of S. Bachmeier, CIMSS

GOES-R ABI Instrument

Expected Improvements to AMVs…

Higher spatial, spectral, temporal resolution together with increased radiometric performance and improved navigation/registration performance is expected to result in:

- Improved target selection
- Improved feature tracking
- Improved AMV heights
- Opportunities for applications of very high-resolution (spatial & temporal) winds in severe storm environments
- Opportunities for applications involved with feature tracking of volcanic ash, dust, etc…

AMV Algorithm and Software Development Approach

GOES-R AMV software development and testing is being done within a framework that supports a tiered algorithm processing approach that allows the output of lower-level algorithms to be available to subsequent higher-order algorithms while supplying needed data inputs to all algorithms through established data structures.

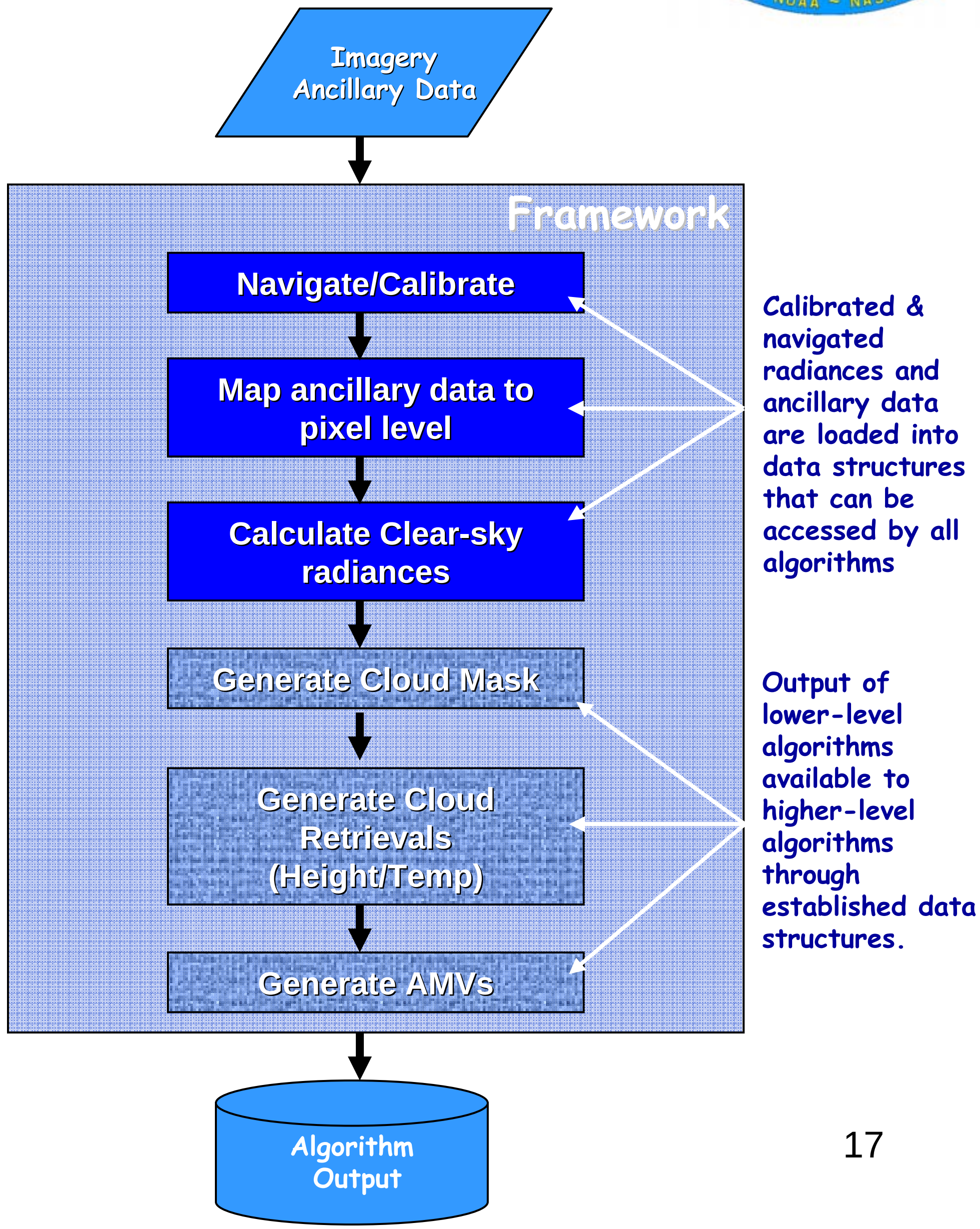
New AMV software has been written (Fortran 90) that conforms to strict coding standards

Leveraging and building upon existing target selection/quality control, feature tracking, and quality control algorithms used operationally today at NESDIS

Target selection and height assignment will rely on utilization of pixel level cloud mask and cloud heights generated upstream via algorithms delivered by AWG cloud application team

MSG/SEVERI, current GOES imager, and simulated ABI imagery are being used as proxy datasets for GOES-R ABI AMV development, testing, and validation activities. The SEVIRI imager on MSG offers 11 ABI channels at 3km horizontal resolution with a temporal resolution of 15 minute making it the best proxy data available today for our needs.

Algorithm Theoretical Basis Document (ATBDs) are being prepared



AMV Algorithm Descriptions and Results from Early Testing

1. Proxy Datasets
2. Target selection/QC
3. Height Assignment
4. Feature Tracking
5. Quality Control
6. Early validation results

MSG SEVIRI Data

Serving as a key ABI proxy data source…

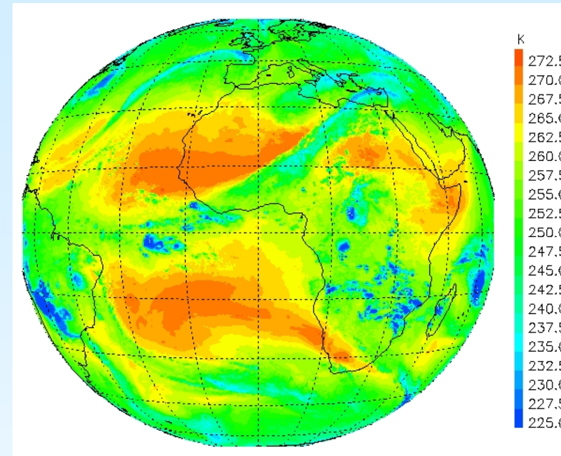
- **Meteosat Second Generation SEVIRI data**
  - » Full disk, 15-min resolution and 12 bands.
  - » (Entire dataset is available for August 2006)

- **Cloud Products to be Generated**
  - » Cloud mask, cloud type and cloud height at pixel level
  - » Cloud type/phase, optical and microphysical properties

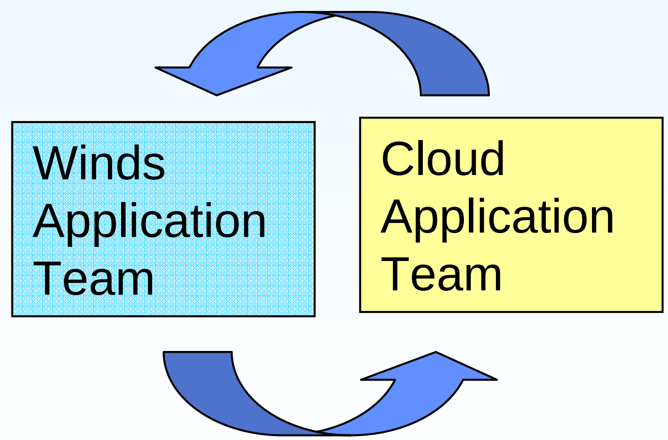
- **AMV Products to be Generated**
  - » IR & VIS cloud-drift winds; WV winds

- **Ancillary Data**
  - » GFS forecasts/analyses (u,v,T,RH,Z)
    - – Available

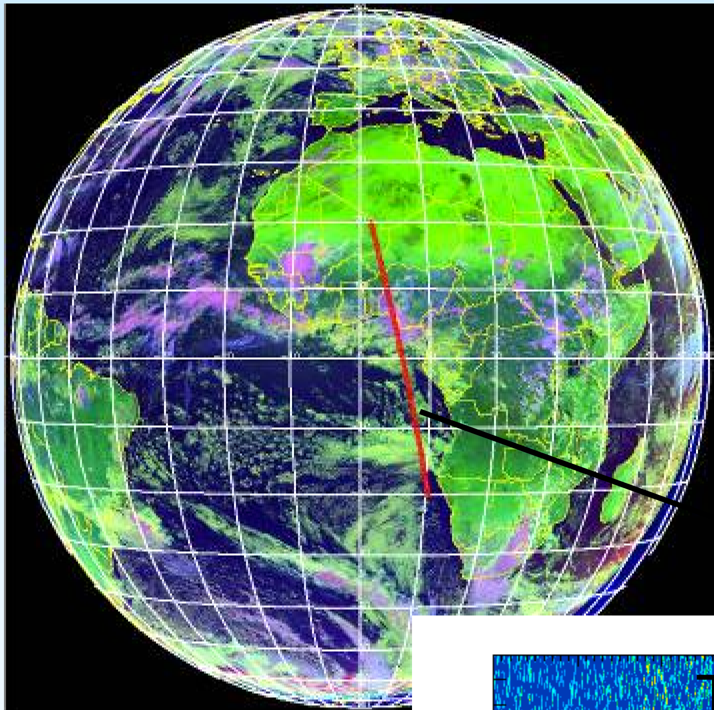
- **Validation Data**
  - » Co-located Calipso and Cloudsat observations
    - – Geometric cloud boundaries
    - – Available
  - » GFS analyses (u,v)
    - – Available
  - » Rawinsondes (u,v)
    - – Available
  - » AMVs generated from operational NESDIS winds software
    - – Available



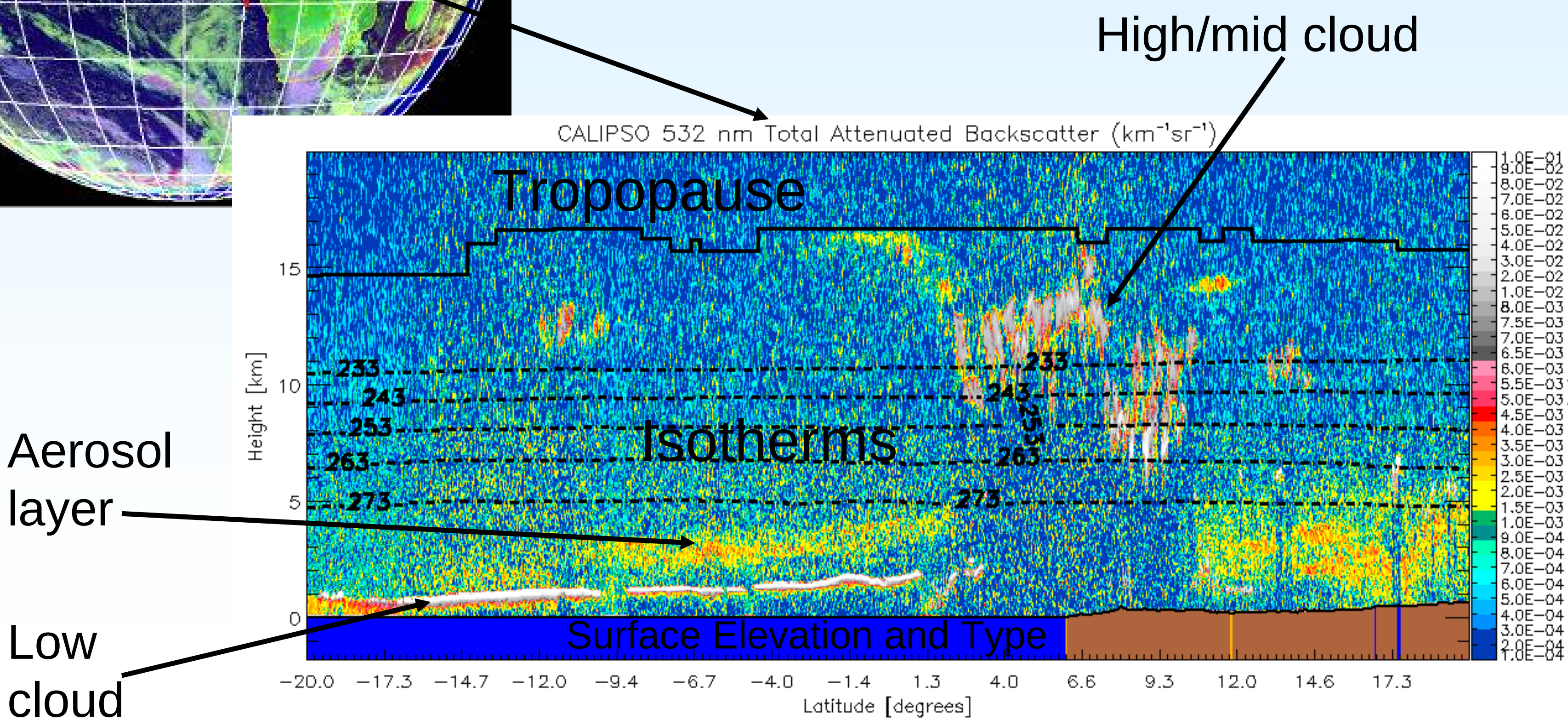
SEVIRI Observation



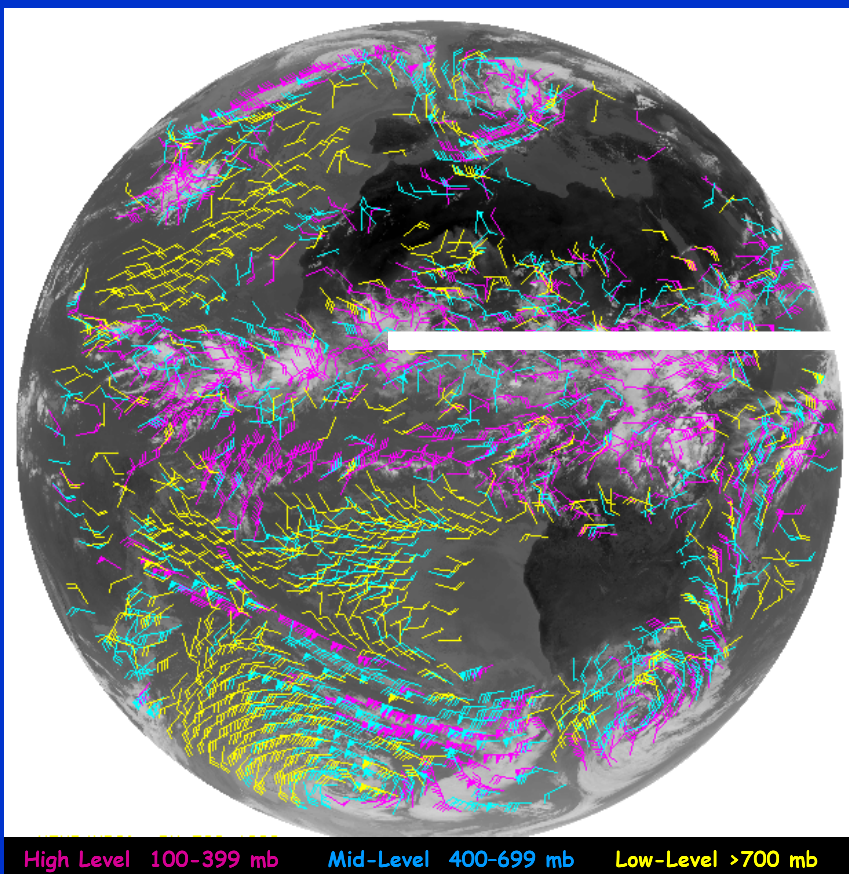
GOES-R Algorithm Validation



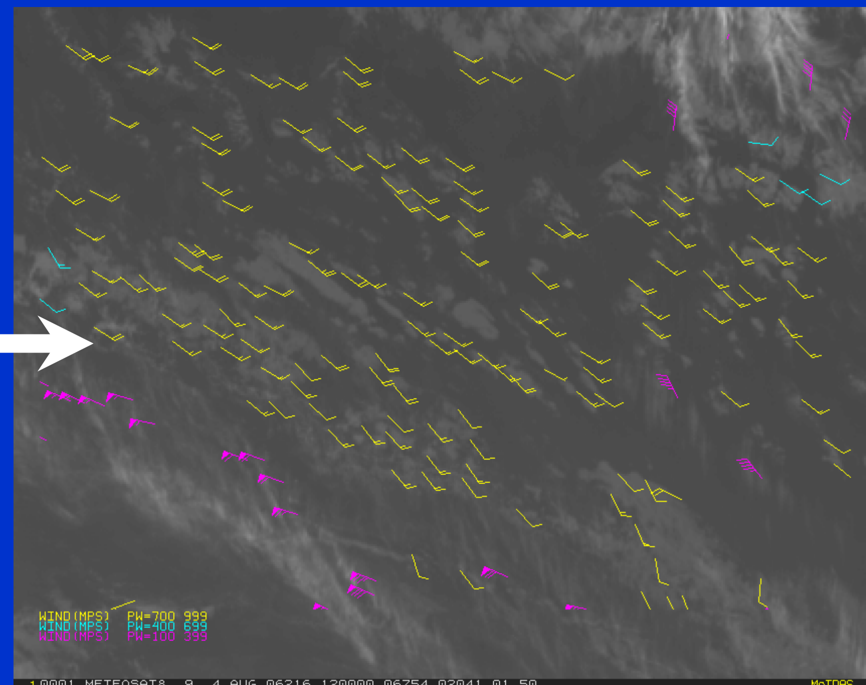
When co-located with SEVIRI, CALIPSO and CLOUDSAT are serving as a vital validation source for GOES-R cloud algorithms. Presently, the Cloud Application Team is actively using these data for their pre-launch cloud retrieval algorithm validation activities using the August 2006 SEVERI dataset.



MSG/SEVERI imagery are being used as proxy datasets for GOES-R ABI Atmospheric Motion Vector (AMV) algorithm development, testing, and validation activities.

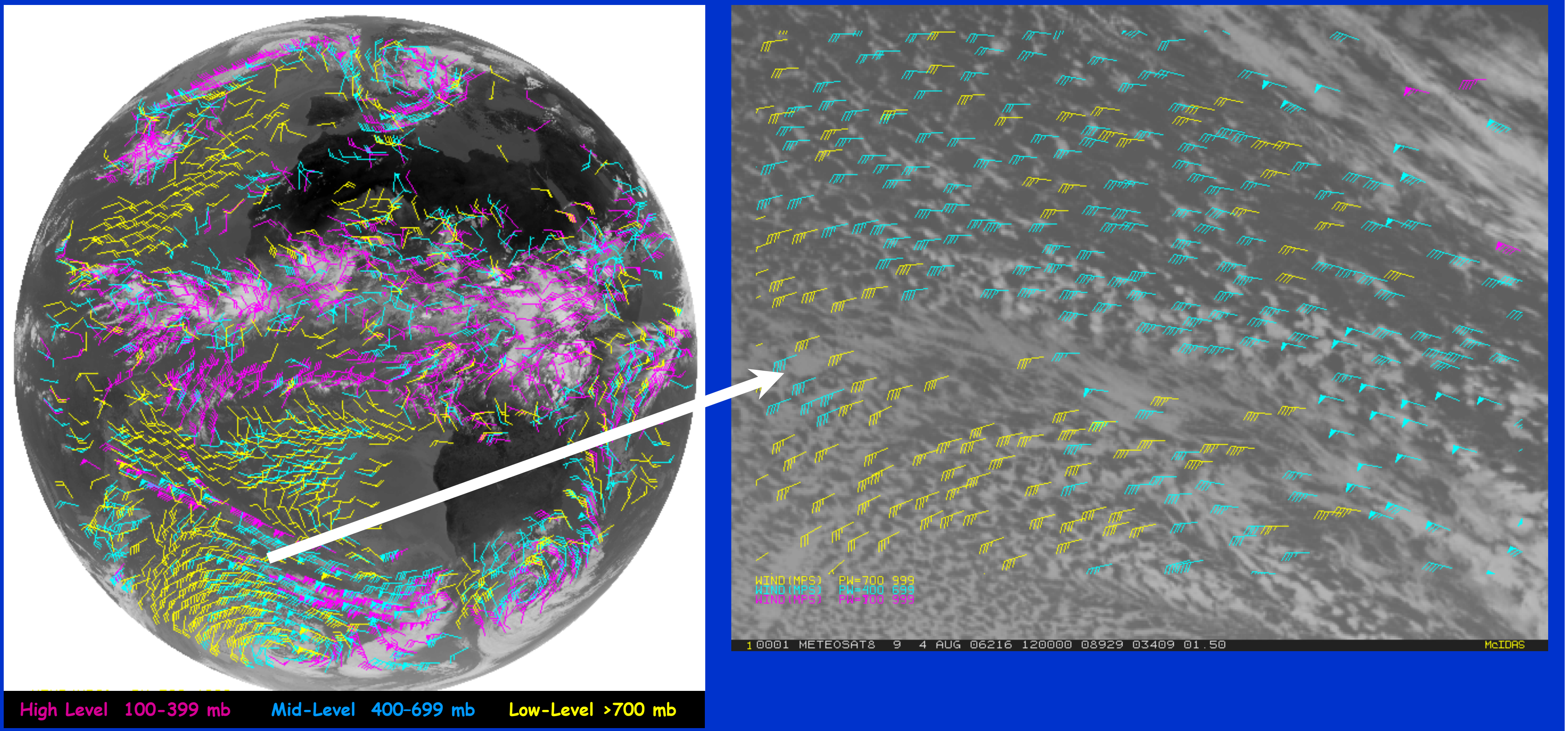


Cloud-drift AMVs derived from a Meteosat-8 SEVERI image triplet centered at 1215Z on 04 August 2006



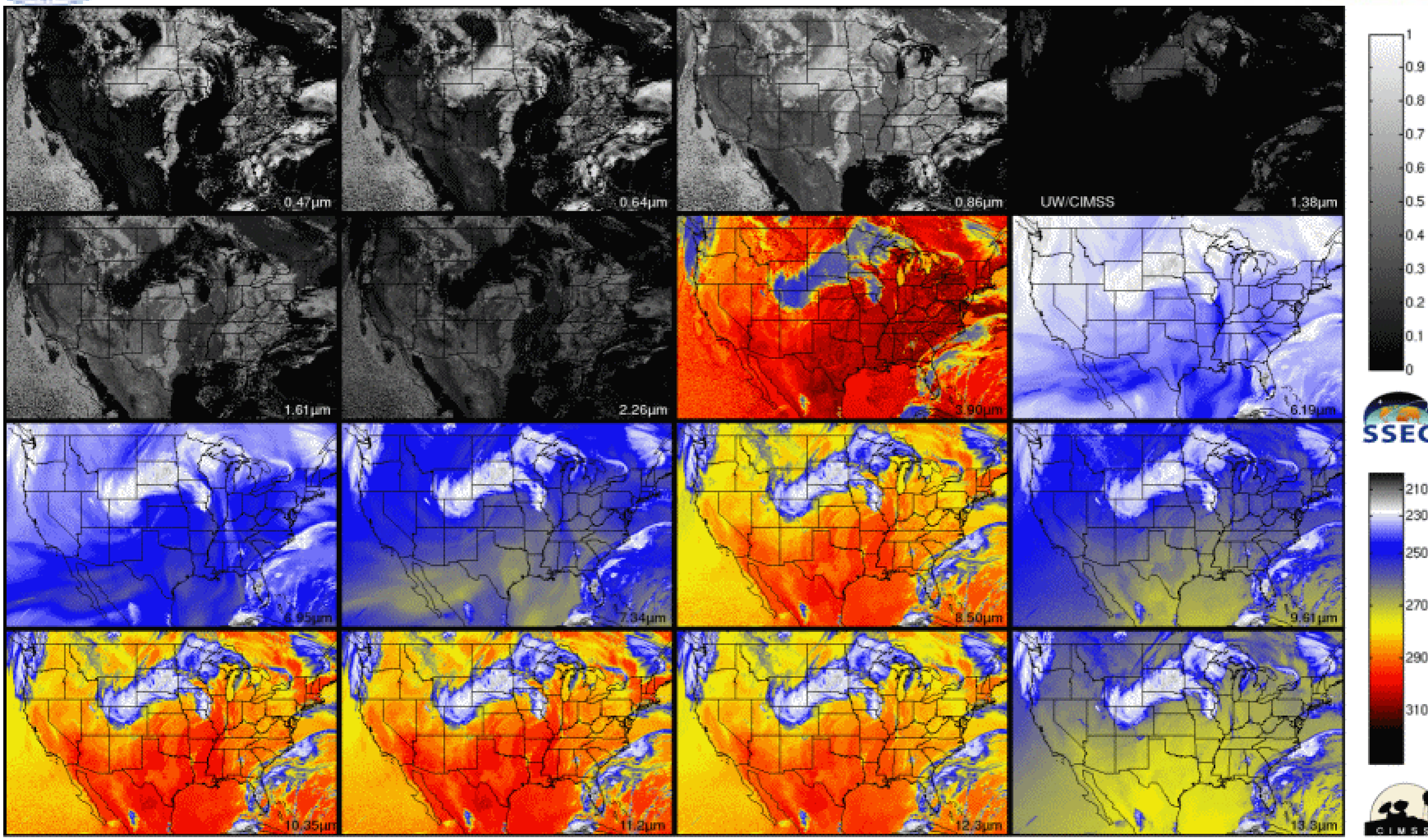
High Level Winds	100-399 mb
Mid-Level Winds	400-699 mb
Low-Level Winds	>700 mb

MSG/SEVERI imagery are being used as proxy datasets for GOES-R ABI Atmospheric Motion Vector (AMV) algorithm development, testing, and validation activities.



Cloud-drift AMVs derived from a Meteosat-8 SEVERI image triplet centered at 1215Z on 04 August 2006

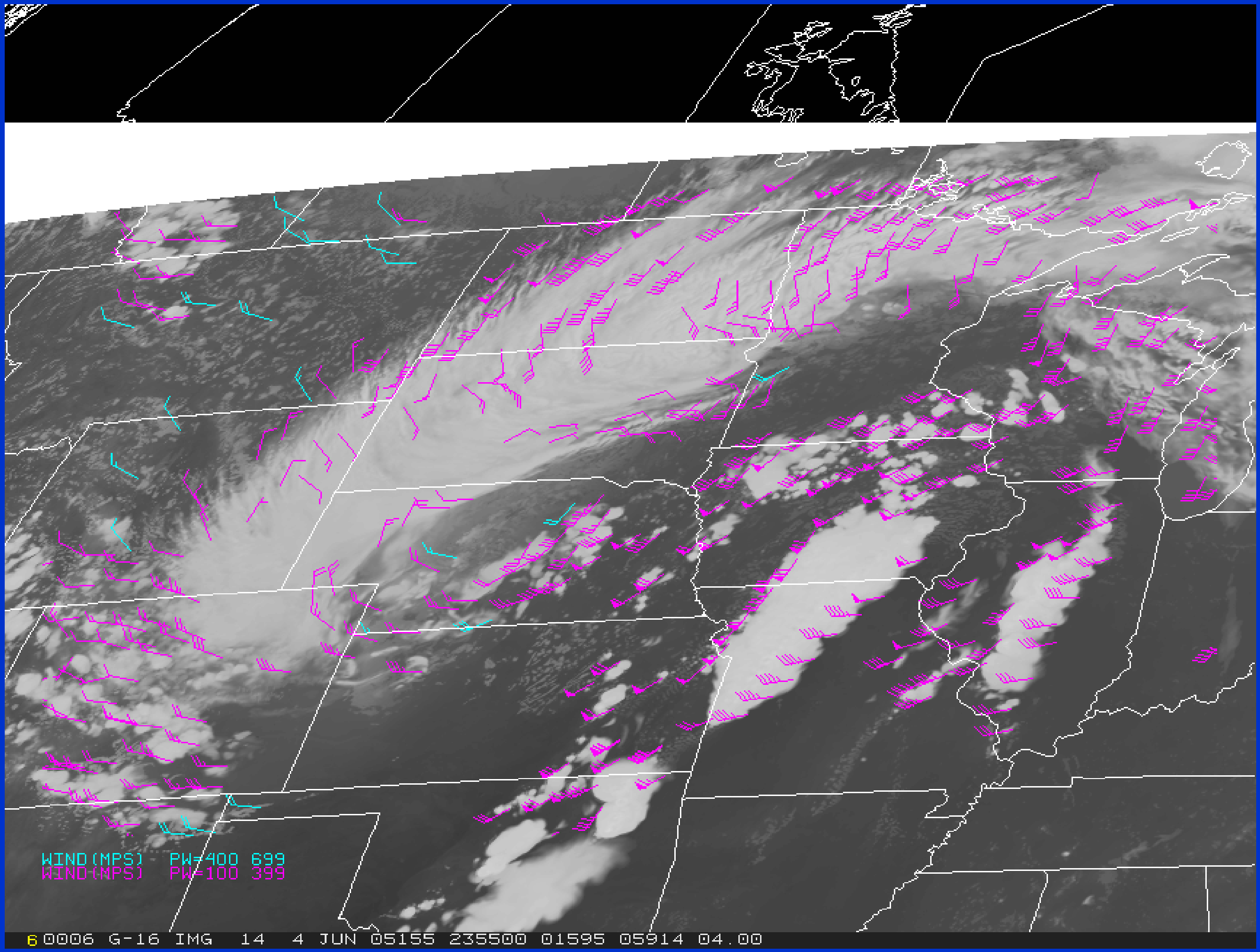
Animations of Simulated GOES-R ABI (16 channels) over CONUS



ABI band data for 2005 June 04 15:00 UTC

AWG Proxy Team members at CIMSS have developed the capability to provide high fidelity simulated datasets that will be critically important for algorithm development and validation activities

Simulated GOES-R ABI imagery are also being used for GOES-R ABI Atmospheric Motion Vector (AMV) algorithm development, testing, and validation activities.



Cloud-drift AMVs derived from a Simulated GOES-R ABI image triplet centered at 0000Z on 05 June 2005

AMVs generated by the GOES-R Algorithm Working Group (AWG) Winds Application Team

Simulated GOES-R ABI imagery generated by Proxy Data Team members at CIMSS

Target Selection/Quality Control

Radiance Gradient calculation…

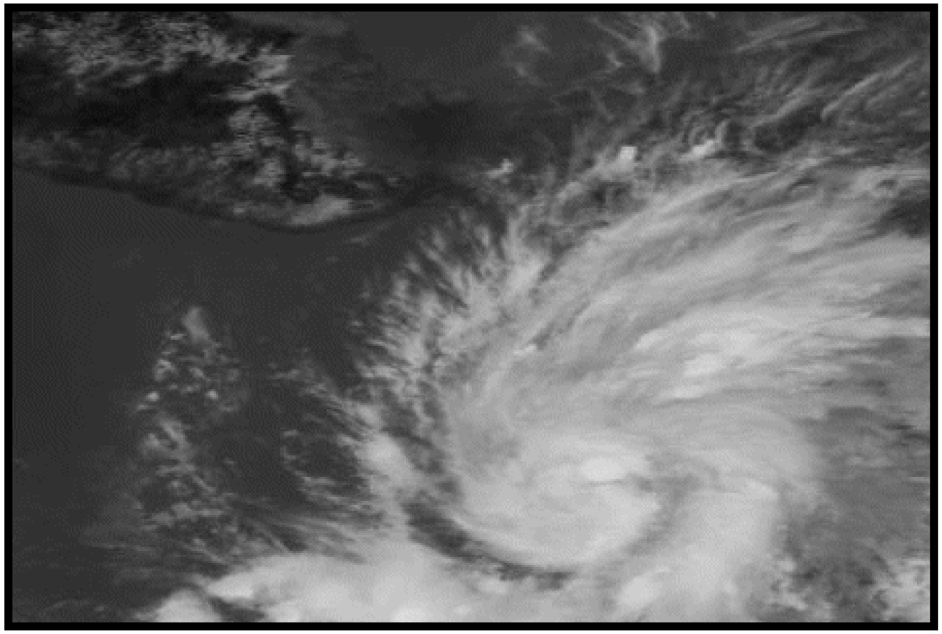


Image of corresponding GOES-12 11um Brightness Temperatures

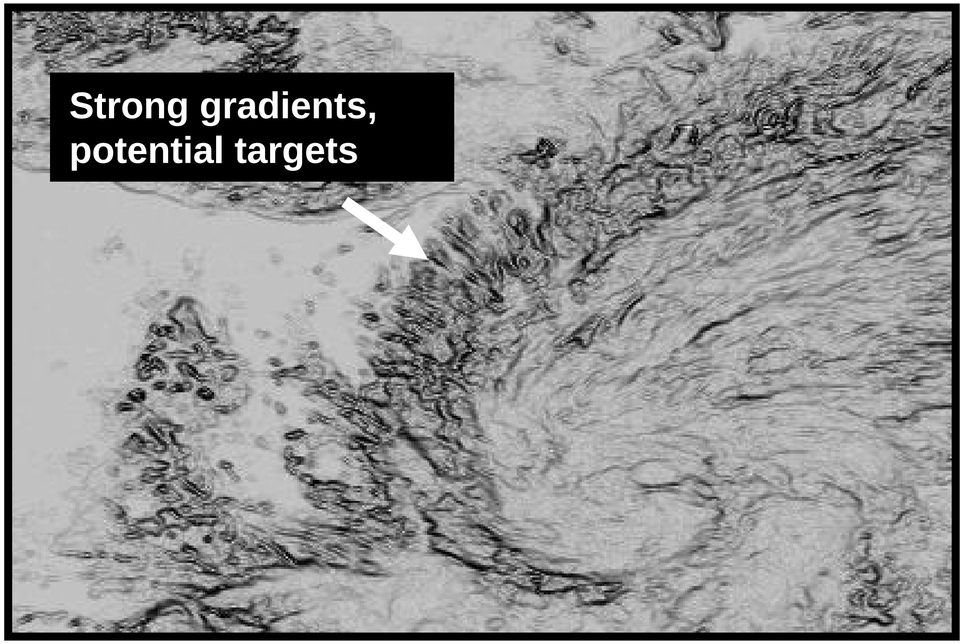


Image of GOES-12 11um pixel-level gradient magnitude used in target selection

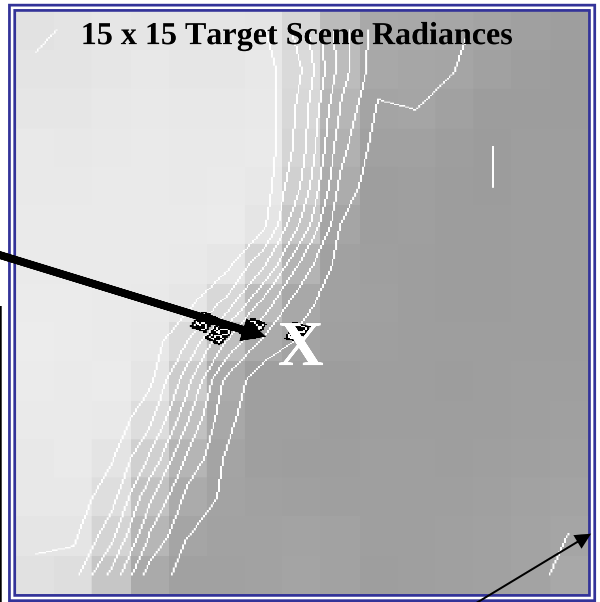
Pixel level gradient magnitudes derived at cloudy pixels (per cloud mask). A 4-point centered difference algorithm, that spans 5 pixels in the north/south and east/west direction, is used. A gradient mask is used to keep track of local maxima in the gradient magnitude field within each target scene.

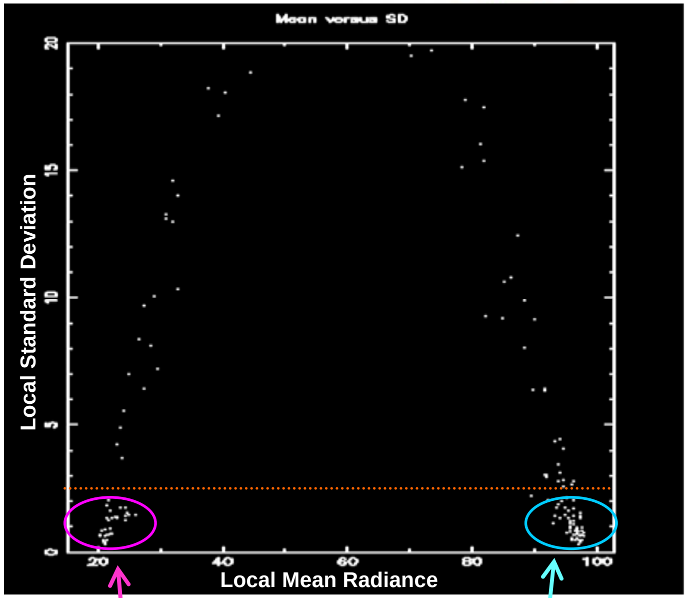
Target Selection/Quality Control

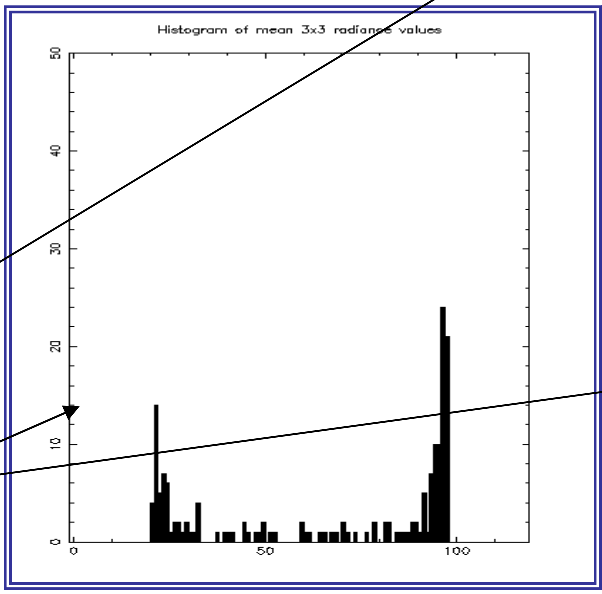
The target scene is re-centered at the maximum gradient, after which, quality control (QC) is applied to the target scene (see below). This ensures that the QC is applied to the actual target scene.

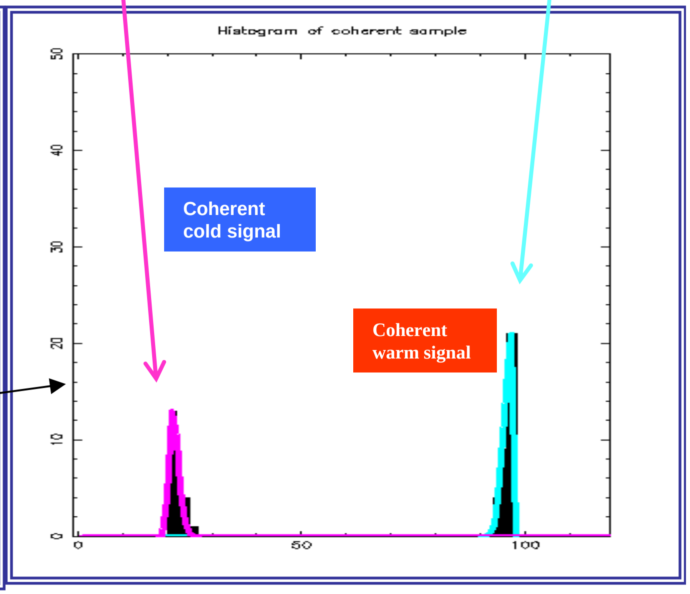
The following QC tests are performed on each target scene before determining a representative height for each:

- ❑ A minimum contrast (max BT – min BT) must exist (currently set to 4 K)
- ❑ Exclude earth edge (space)
- ❑ A minimum number of cloudy pixels must exist in the target scene (currently set to 10%)
- ❑ Exclude bad data (unreasonable data values)
- ❑ Perform spatial coherence analysis to find coherent signal *(Coakley & Bretherton, 1982)*
- ❑ Perform cluster analysis on mean 3x3 radiances passing spatial coherency - Look for and exclude multi-deck cloud scenes









Target Height Assignment

GOES-R AWG ABI Cloud Height Algorithm…

Heritage

- GOES-NOP CO_2 & IR Window algorithms.
- AVHRR CLAVR-x Split-window algorithm (*Heidinger, A. and M. J. Pavolonis, 2008: Gazing at cirrus clouds through a split-window Part I: Methodology. Submitted to JAMC September 2007.)*

Description of ABI Cloud Height Algorithm

- Uses 11, 12 and 13.3 μm observations to estimate cloud temperature/height/pressure, emissivity and a μ-physical index.

Motivation for this Approach

- The inability to account for the spectral variation of cloud emissivity from 11 to 13.3 μm was a limitation of the GOES-NOP algorithm. This approach uses the multiple window channels to estimate emissivity variations (cloud μ-physics) automatically.

- While the AVHRR split-window approach provided good information on cloud emissivity and cloud μ-physics, it exhibited little sensitivity to cloud height for thin cirrus. The use of the 13.3 μm channel improves performance over that seen with AVHRR (*though a stronger absorption channel would be preferable*).

Numerical Method

- Use an optimal estimation framework ***(Rodgers, 1976)*** to maximize impact of all channels. Method automatically weights observations and first guess to make "optimal" retrievals.
- CALIPSO observations and state-of-the-art scattering models used to derive forward model and first guesses.

Quality Information

- Error estimates provided for 1D-Var retrievals of cloud height and other retrieved cloud properties

Future Work

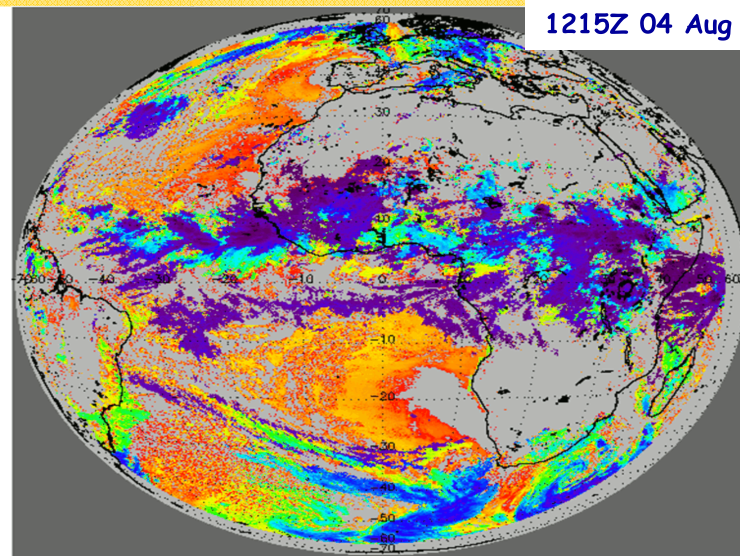
- Incorporate water vapor bands to increase sensitivity to height for thin cirrus.
- Incorporate 10.4 μm channel

Rodgers, 1976: Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation. *Rev. of Geophysics and Space Physics*, 14, 609-624.

Target Height Assignment *(cont'd)*

Approach for assigning heights to targets…

The goal is to derive a "representative" height **<u>that is consistent with and has ties to</u>** the features being tracked.

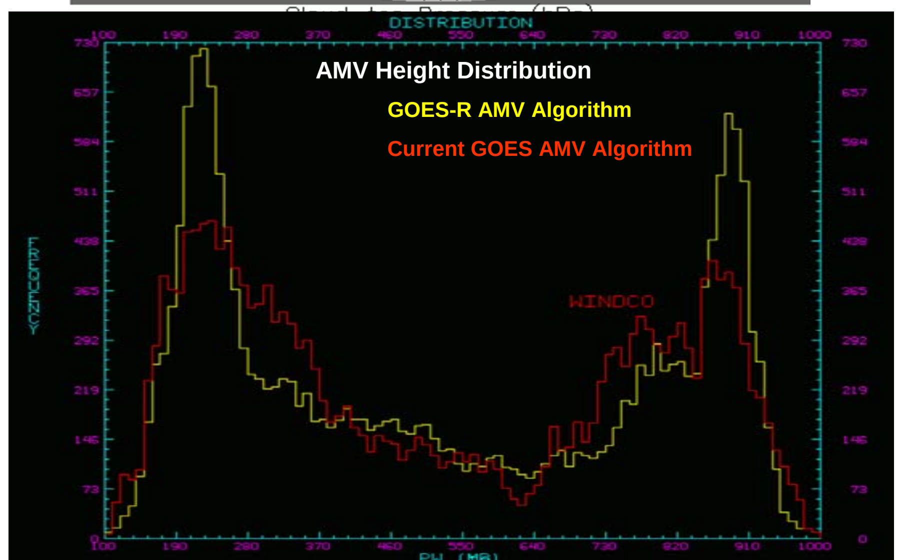


Current Implementation *(Work in Progress)*

- ❑ Heights are assigned to targets passing target selection and target quality control criteria
  - ➔ Done before feature tracking step
- ❑ **Upstream pixel-level cloud-top heights are used to arrive at a representative target height:**
  - **Big change from what we do now with current GOES AMVs!**
  - ➔ A 1-D histogram of 11um channel brightness temperature values is constructed. The cloud-top pressures associated with the coldest 25% of the cloud/probably cloudy pixels are sorted and the median pressure is determined. This pressure then serves as the representative height for the target scene.

Future Work and Investigations

- ❑ More validation of AMVs with a focus on their height assignment
- ❑ Implement cloud base algorithm for oceanic AMVs
- ❑ **<u>Option to look at:</u>** Perform height assignment AFTER feature tracking step using cloud height information from those pixels determined to be contributing to feature tracking solution (per R. Borde study)

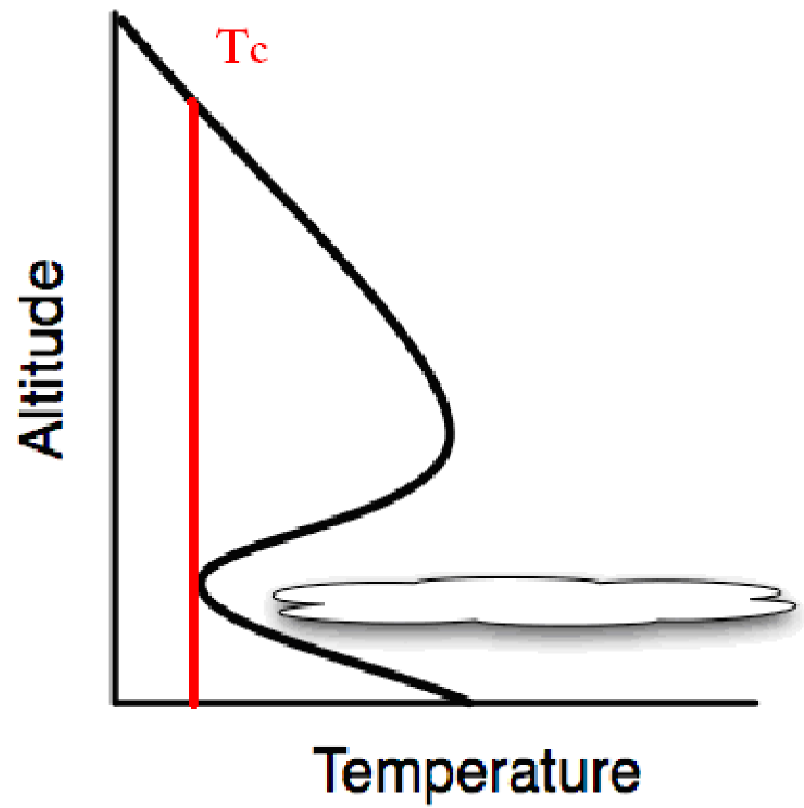


High Level 100-399 mb Mid-Level 400-699 mb Low-Level > 700mb

Target Height Assignment *(cont'd)*

Problem: Low-level Inversions…

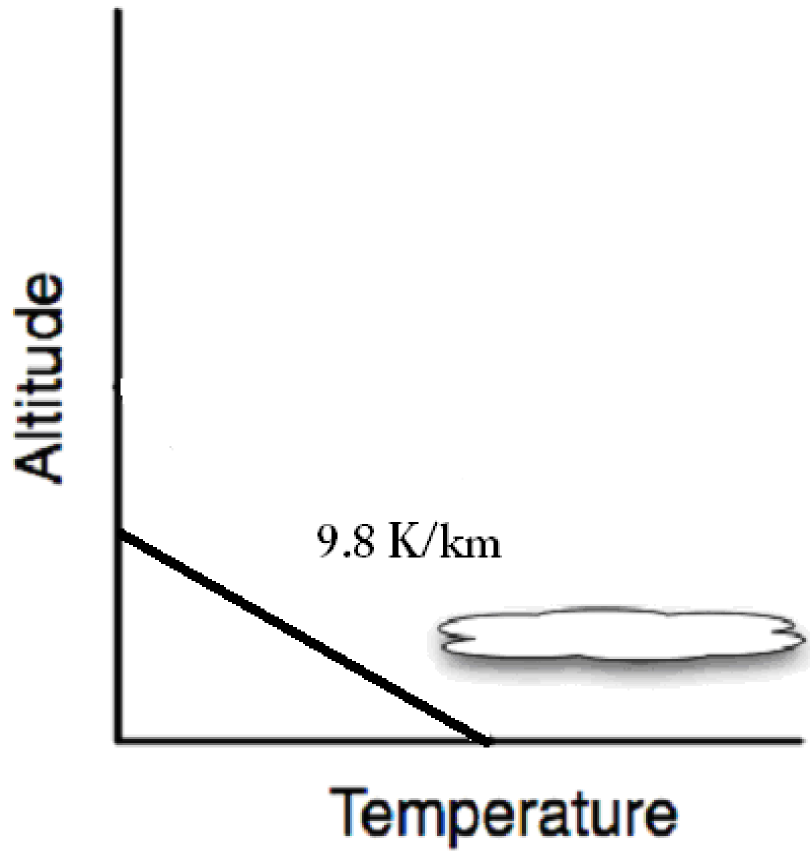
- Common over ocean in vicinity of sub-tropical high pressure systems characterized by the existence of an extensive Stratocumulus cloud deck
- Cloud temperature (Tc) found at 2 locations in profile
- Causes height assignment errors of 200 mb



Target Height Assignment *(cont'd)*

One Solution*…

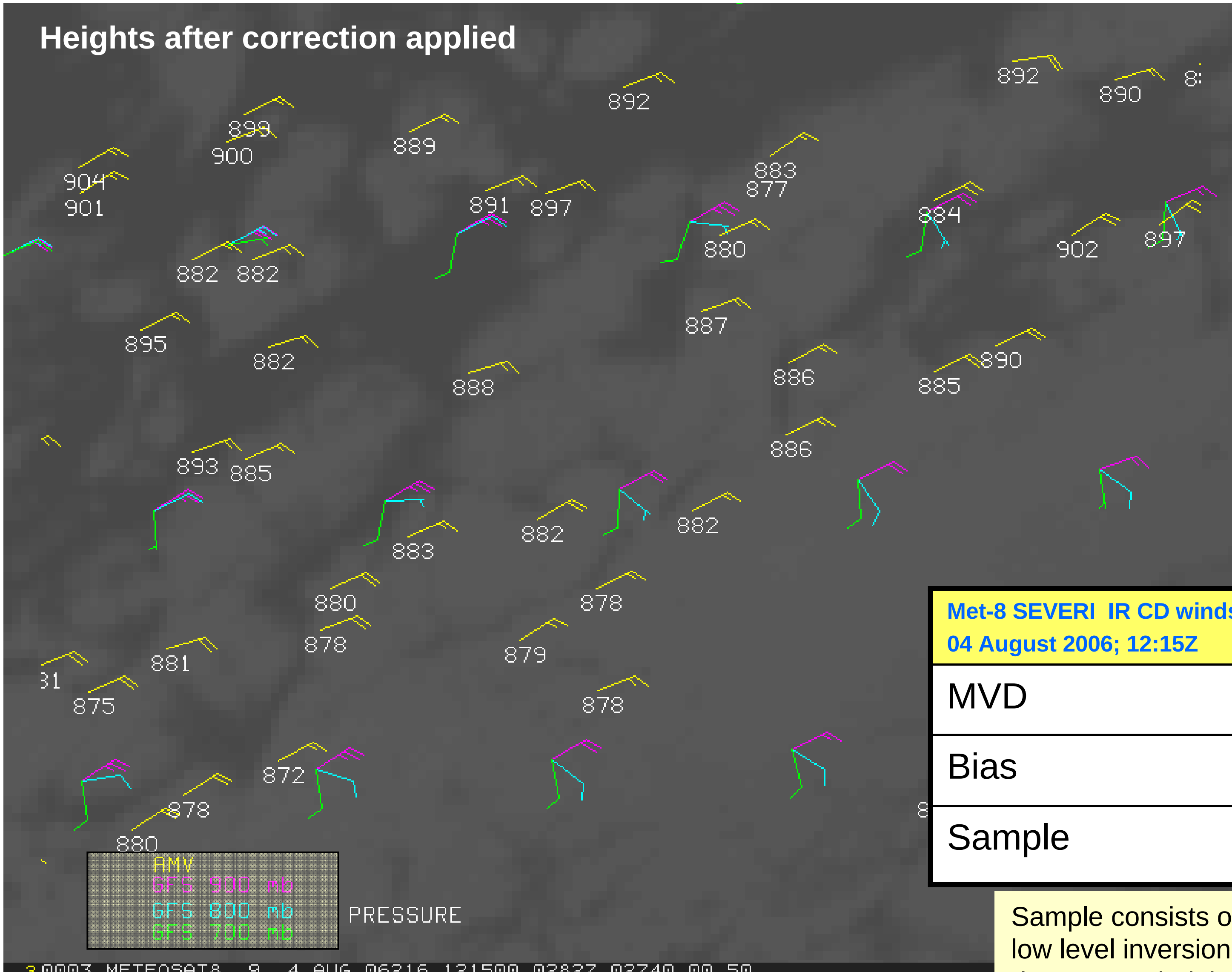
- Start with surface temperature from GFS forecast
- Assume dry adiabatic lapse rate
- Lift parcel & stop when parcel temperature matches cloud temperature
- Standard atmosphere lapse rate (6.5 K/km) insufficient



* Solution previously adopted by latest MODIS cloud height algorithm and is now part of latest release of the GOES-R cloud height algorithm

Impact

Comparison to GFS Forecast…



AMVs

GFS 900 mb

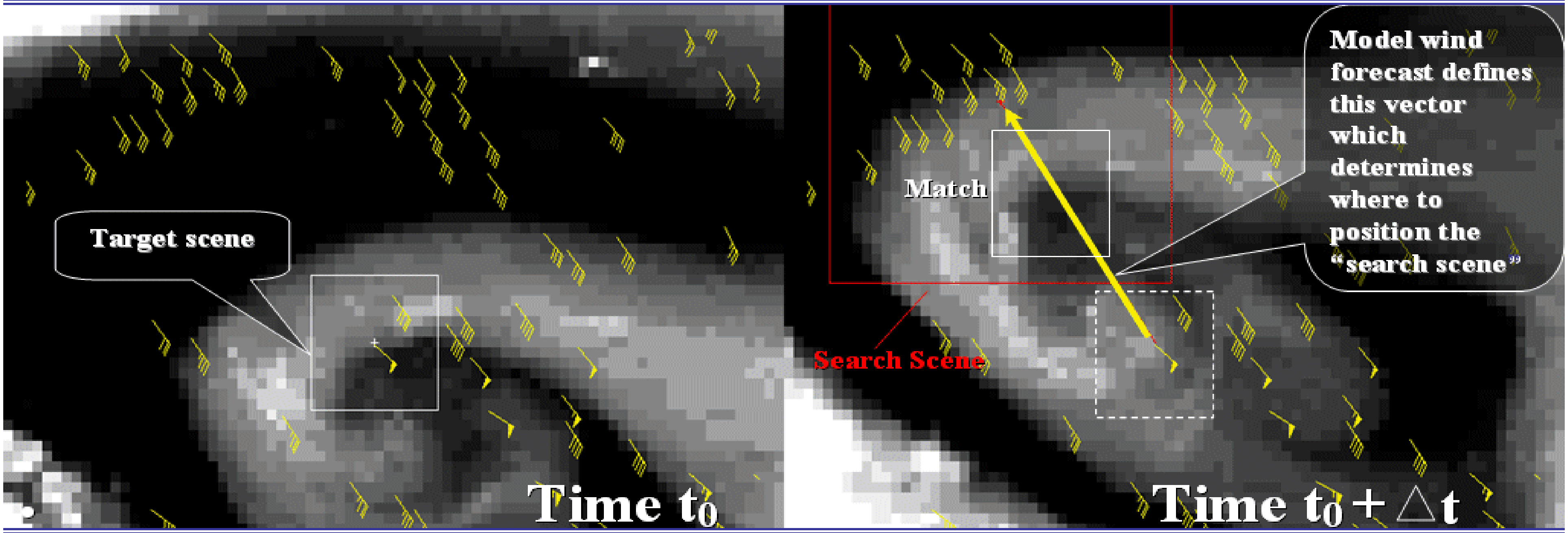
GFS 800 mb

GFS 700 mb

Met-8 SEVERI IR CD winds 04 August 2006; 12:15Z	Before	After
MVD	7.11	4.29
Bias	1.31	0.73
Sample	3658	3788

Sample consists of targets that contained a low level inversion and were eligible for the "bottom up" height correction.

Feature Tracking



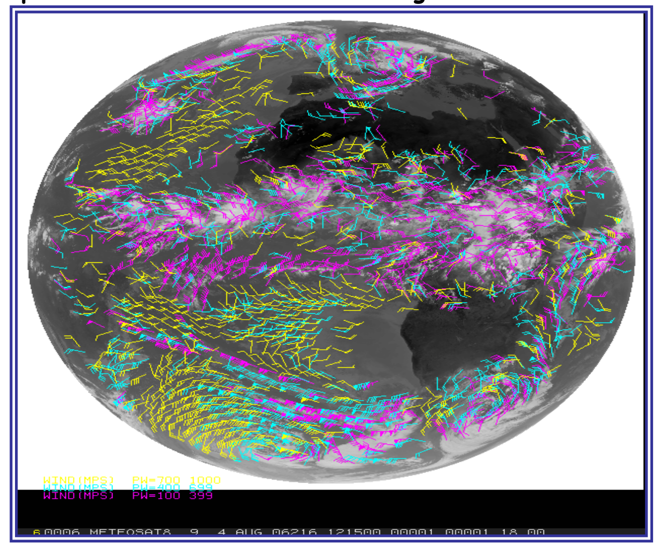
- ❑ Image triplets are currently being used; use of an image pentad is possible and will be tested
- ❑ Tracking algorithms available include:
  - ❑ Sum of Squared Differences (SSD)
  - ❑ Cross Correlation
- ❑ Forecast used to help guide search
- ❑ Interpolation of correlation surface to account for sub-pixel displacement
- ❑ Feature tracking with 16-bit REAL Brightness Temperature values; contrast this with feature tracking of current GOES which uses 8-bit data

AMV Quality Control

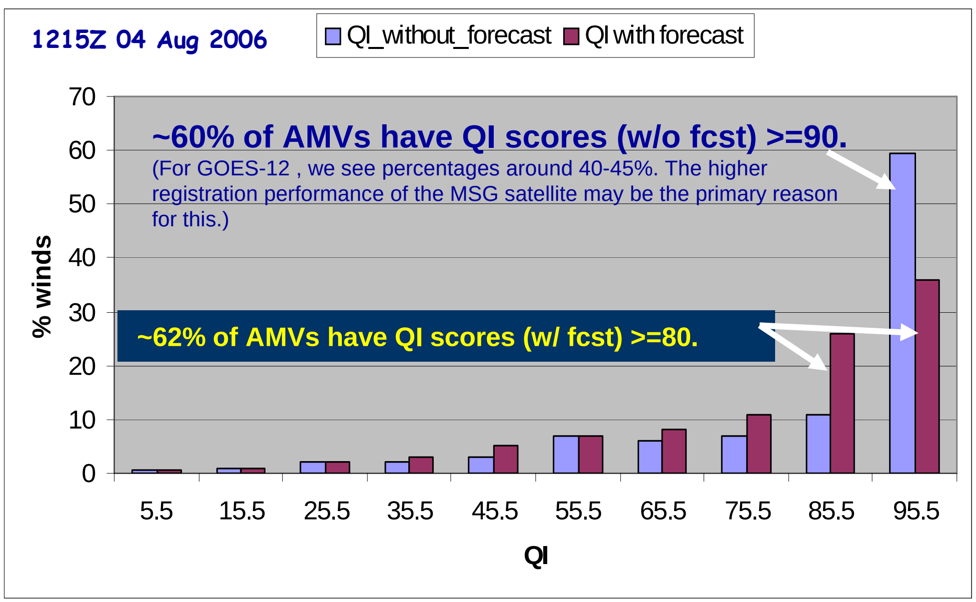
Current Implementation *(Work in Progress)*

- ❑ Acceleration checks on vector pairs
- ❑ Gross checks against model background
- ❑ Quality Indicator (QI) algorithm
- ❑ Expected Error (EE) algorithm
- ❑ Autoeditor is not being considered at this time

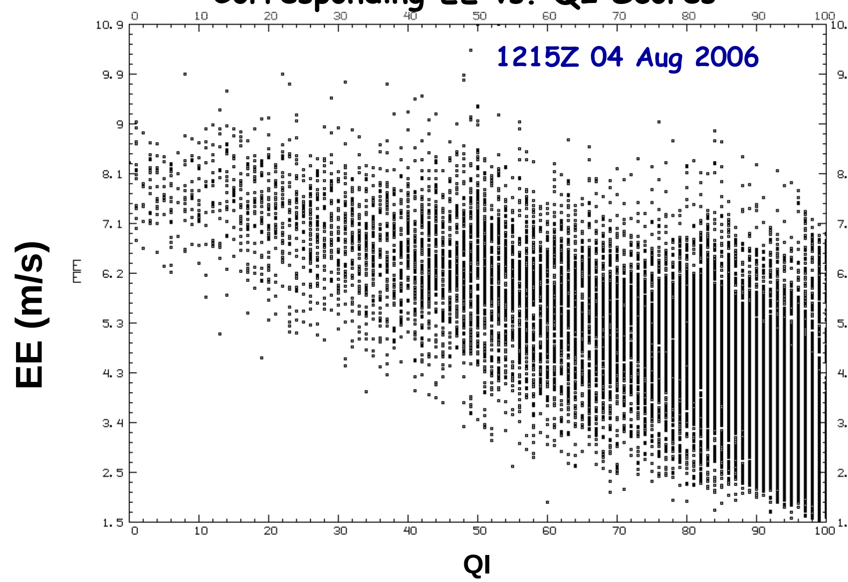
Cloud-drift AMVs derived from a Meteosat-8 SEVERI image triplet centered at 1215Z on 04 August 2006



Distribution of Quality Indicator (QI) Scores



Corresponding EE vs. QI Scores



Early Validation Results

Met-8 SEVERI IR Cloud-drift Winds vs. Radiosondes…

SEVERI Full Disk
IR Cloud-Drift Winds

Aug 2-9, 2006

QI >= 80

100 - 400mb

		Sat	Guess	Raob
HIGH	RMS DIFFERENCE	7.74	7.13	
	NORMALIZED RMS	0.40	0.37	
	AVG DIFFERENCE	6.27	5.89	
	STD DEVIATION	4.54	4.02	
	SPEED BIAS	-0.79	0.44	
	ABS.DIRECTION DIFF	12.22	13.16	
	SPEED	18.66	19.88	19.44
	SAMPLE SIZE	2009.0		

400 - 700mb

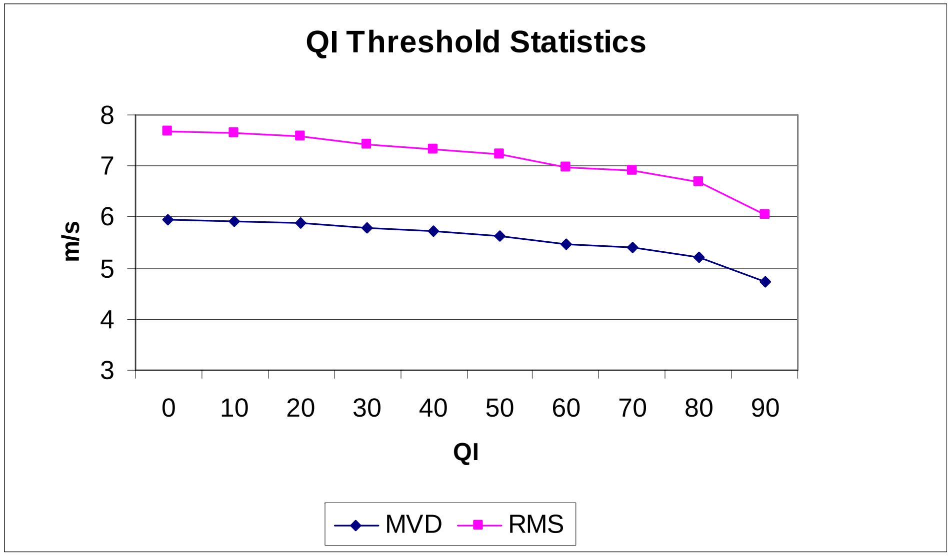
		Sat	Guess	Raob
MIDDLE	RMS DIFFERENCE	5.43	4.30	
	NORMALIZED RMS	0.42	0.34	
	AVG DIFFERENCE	4.38	3.55	
	STD DEVIATION	3.21	2.42	
	SPEED BIAS	-1.52	-0.37	
	ABS.DIRECTION DIFF	13.04	13.66	
	SPEED	11.31	12.45	12.82
	SAMPLE SIZE	968.0		

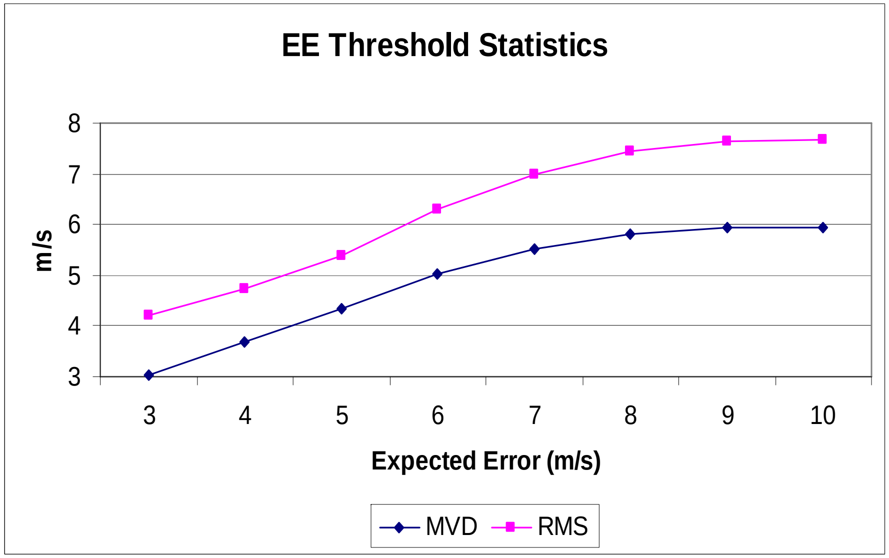
>700mb

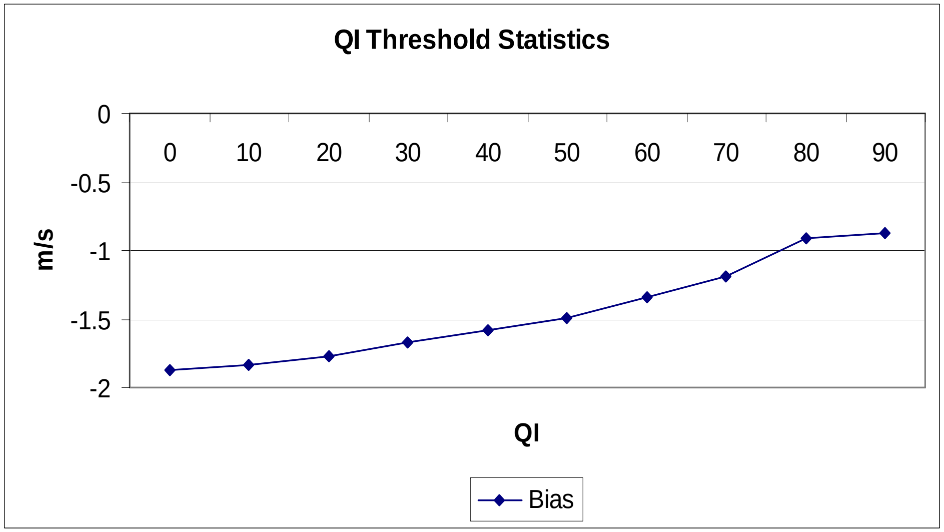
		Sat	Guess	Raob
LOW	RMS DIFFERENCE	4.96	5.11	
	NORMALIZED RMS	0.53	0.55	
	AVG DIFFERENCE	3.51	3.70	
	STD DEVIATION	3.51	3.53	
	SPEED BIAS	-0.45	-0.19	
	ABS.DIRECTION DIFF	14.46	15.64	
	SPEED	8.82	9.09	9.28
	SAMPLE SIZE	795.0		

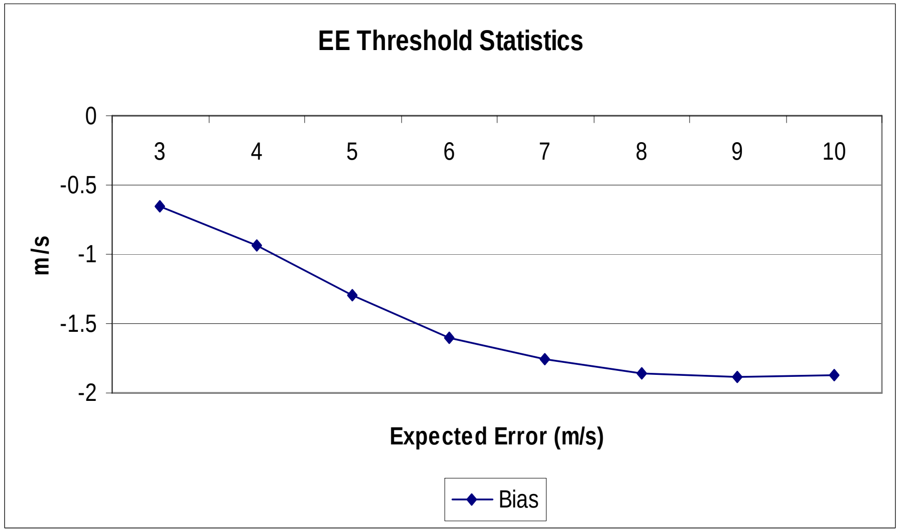
Early Validation Results

Met-8 SEVERI IR Cloud-drift Winds vs. Radiosondes…









Summary, Future Plans, and Opportunities

- GOES-R ABI is an improved imager and is expected to bring improvements to AMV quality
- GOES-R AWG Winds Application Team has made significant progress developing the AMV algorithms and software for the future GOES-R ABI
  - Using SEVERI imagery and simulated ABI imagery for pre-launch algorithm validation activities
  - GOES-R AMV software development and testing is being done within a framework that supports a tiered algorithm processing approach
  - Leveraging some of the current GOES AMV algorithms used today
  - New approach being used for cloud height assignment: Upstream pixel level cloud heights used to assign a representative target height.
- Near term focus: Validation, validation, validation
  - Leverage ABI proxy datasets
    - MSG/SEVERI
    - Simulated ABI
  - Assess AMV performance and make adjustments to algorithms as needed
    - Target selection/QC
    - AMV height assignment algorithm
    - AMV Quality Control
  - Perform tracking with other channels (Visible, SWIR, and WV)
- Setup real-time processing of AMVs from GOES and SEVERI using our new algorithms/software and processing framework
  - To provide a continuous diagnosis of our algorithms as they evolve.

Summary, Future Plans, and Opportunities *(cont'd)*

- Leverage our GOES-R Risk Reduction Program to investigate new opportunities/applications of AMVs derived from the ABI
  - Detailed analysis studies
  - Scene analysis/cloud classification for improved target selection
  - Use of non-heritage channels (1.38um, 8.5um, 9.6um)
  - Alternative tracking algorithms (ie., optical flow)
  - Applications of very high-resolution (spatial & temporal) winds in severe storm environments that take advantage of well navigated, higher spatial and temporal ABI imagery
    - Depiction of mesoscale flows indicating growth/dispersion of convective cloud systems
    - Depiction and monitoring of motions on top of thunderstorm anvils
    - Storm relative motion
  - New applications involved with feature tracking of volcanic ash, dust, etc