Atmospheric Motion Vectors Derived via a New Nested Tracking Algorithm Developed for the GOES-R Advanced Baseline Imager (ABI)

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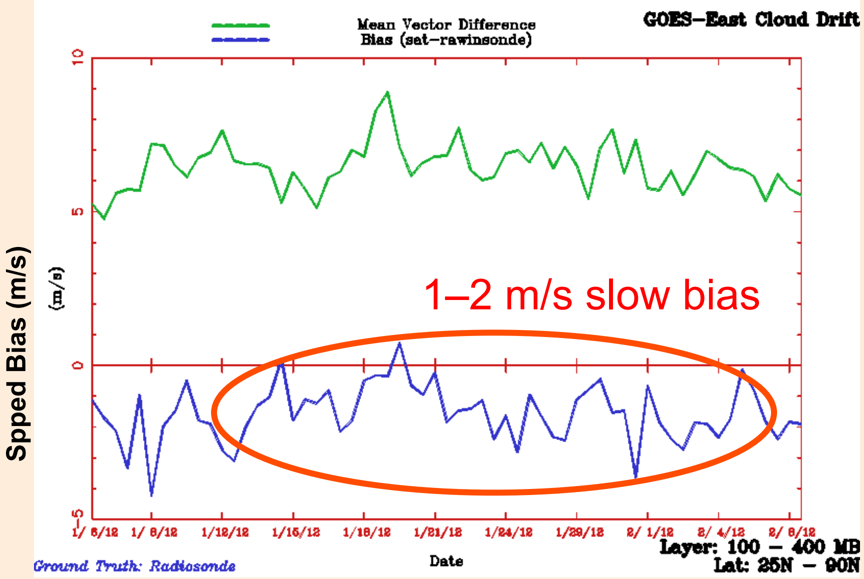
Topics

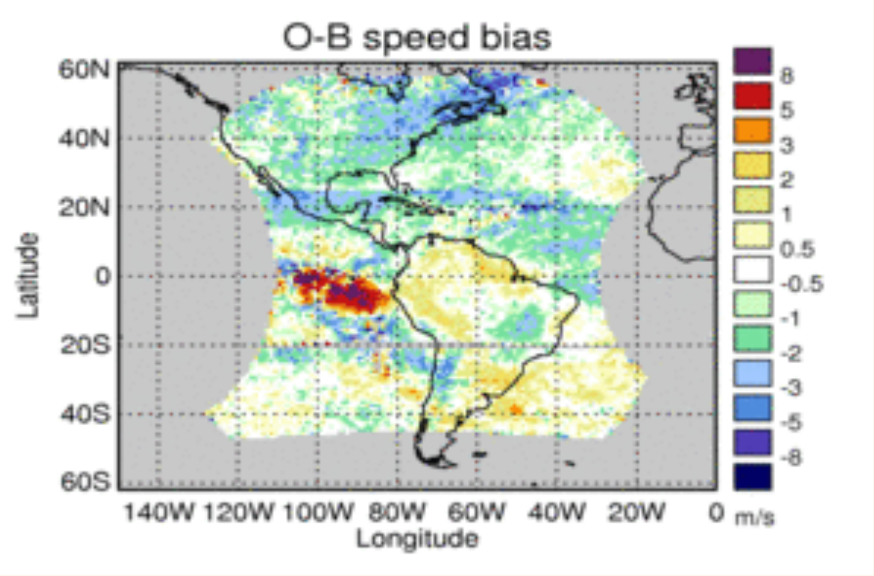
- Motivation
- Review of Nested Tracking Approach
- Some Examples and Results
- Ongoing Activities and Plans
- Summary

Motivation

- **Minimize the observed slow speed bias of satellite winds; *a significant concern of the NWP user community***

GOES-13 (100-400mb) January 2012





- **Two leading causes**
  - Poor heights assigned to AMVs (ie., too high)
  - Derived motion is an average of motion at multiple levels and/or different scales

Impact of Box Size and Time Interval on Magnitude of Speed Bias

- Earlier studies by Sohn and Borde (2008) have shown a link between box size and magnitude of slow bias. Their results showed:

  1. A smaller box produces faster winds
  2. A smaller box produces lower heights

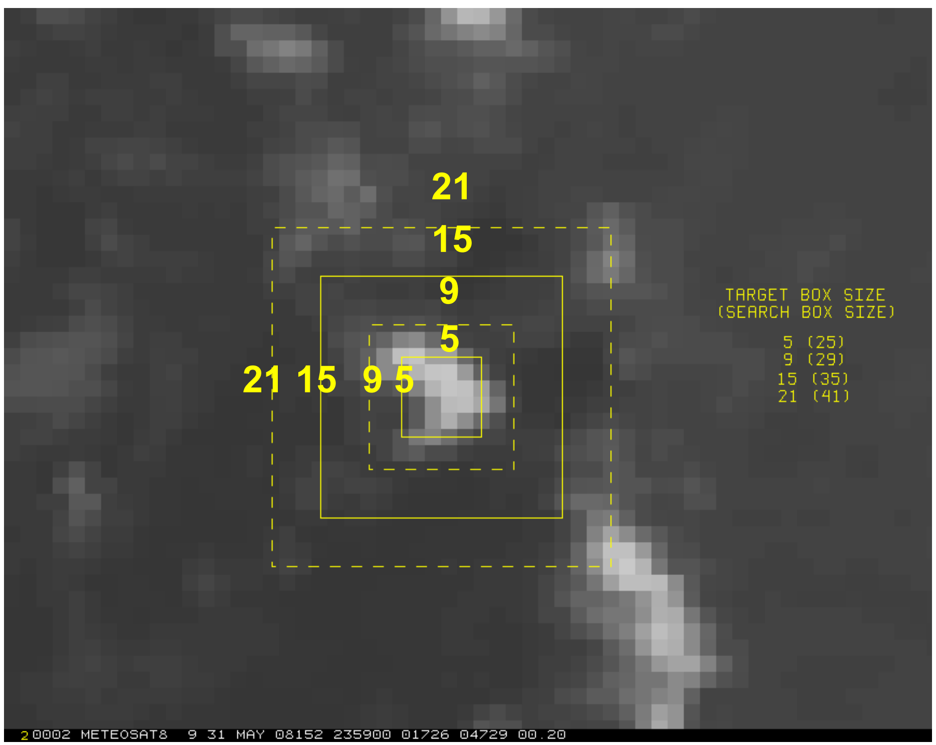
  Both factors reduce the slow bias!

- Above work was extended by present authors to include varying time intervals (5-, 10-, 15- and 30-minute intervals)

Impact of Box Size and Time Interval on Magnitude of Speed Bias

Setup of Study

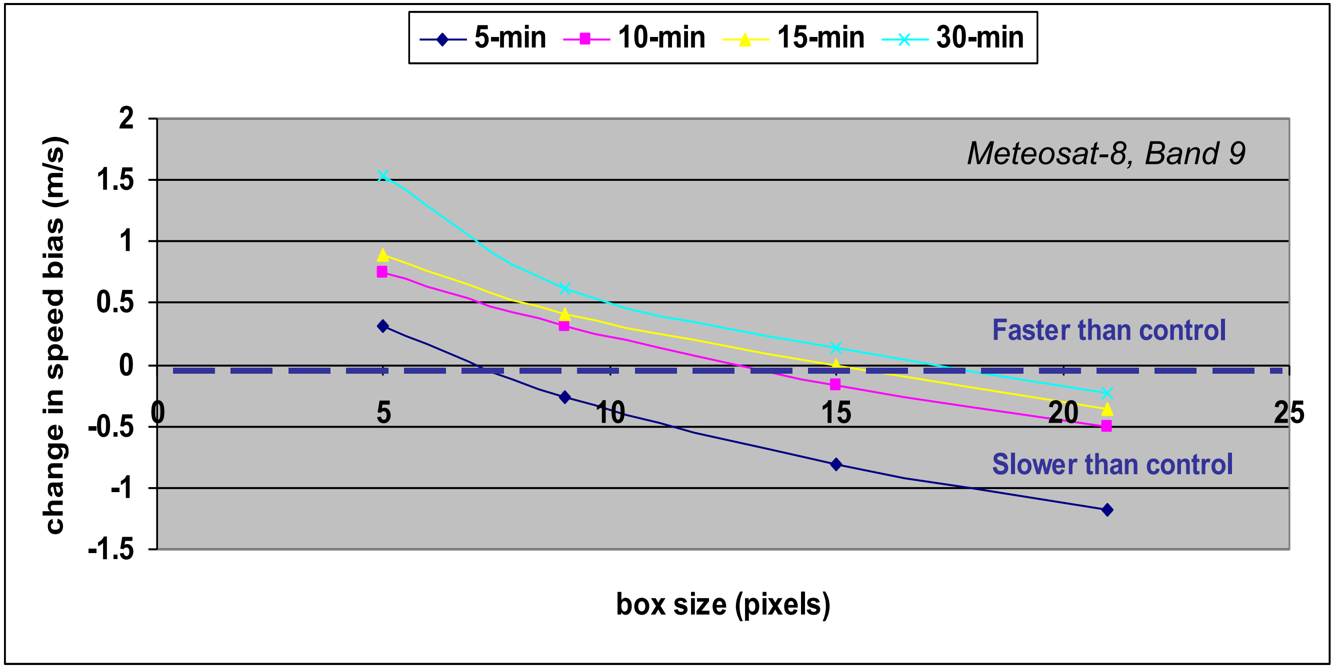
- Winds were generated using Meteosat-8 rapid scan imagery for the period June 1 – 8, 2008.
- Target locations were fixed while box size and time interval varied.



- **Target Box Sizes:**
  - 5x5, 9x9, 15x15, 21x21
- **Time Intervals:**
  - 5, 10, 15, 30 minutes

Impact of Box Size and Time Interval on Magnitude of the Speed Bias

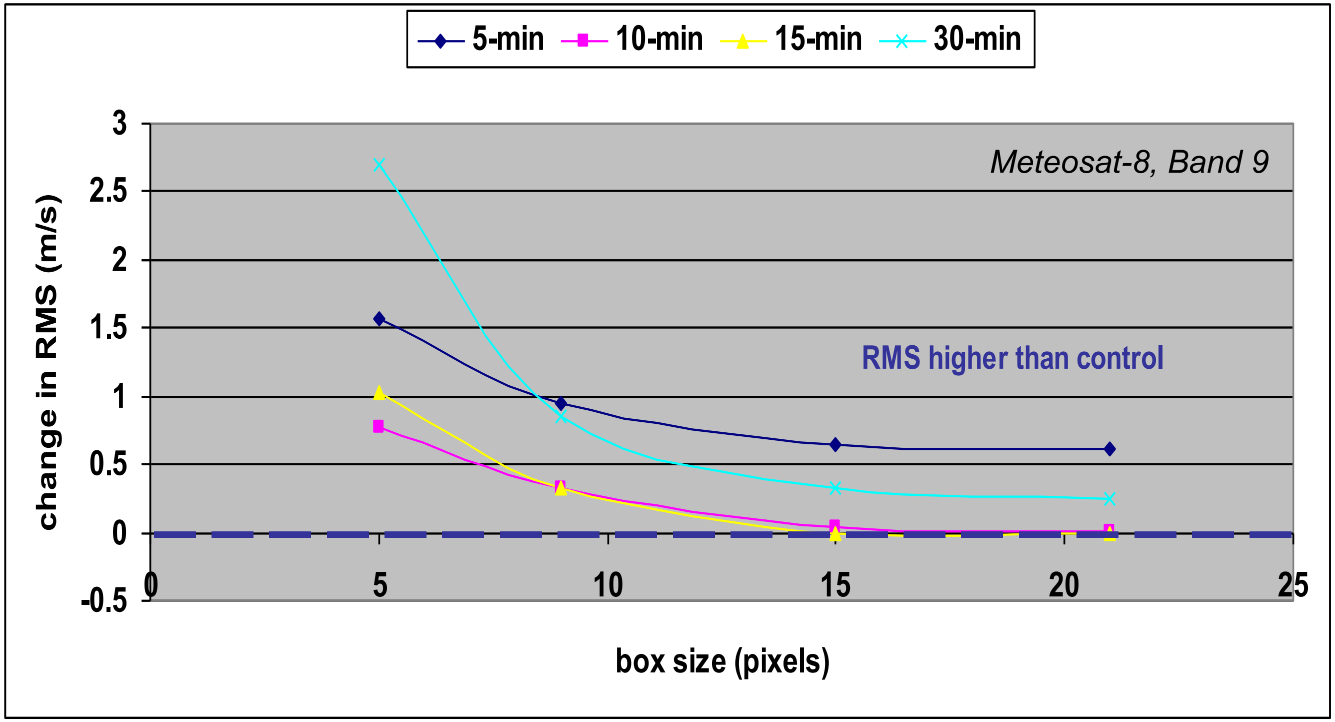
Results – *relative to control run (15x15 box, 15-minute loop interval)*



- **A larger box yields a larger slow bias – consistent with Sohn and Borde (2008)**
  - **Argues for using a small target box to reduce speed bias**
- Larger time interval also reduces slow bias
  - Believed to be resolution related

Impact of Box Size and Time Interval on the RMS

Results – relative to control run (15x15 box, 15-minute loop interval)



- **A larger box reduces the RMS** – largest box tested was 21x21 pixels
  - **Argues against using a small box**

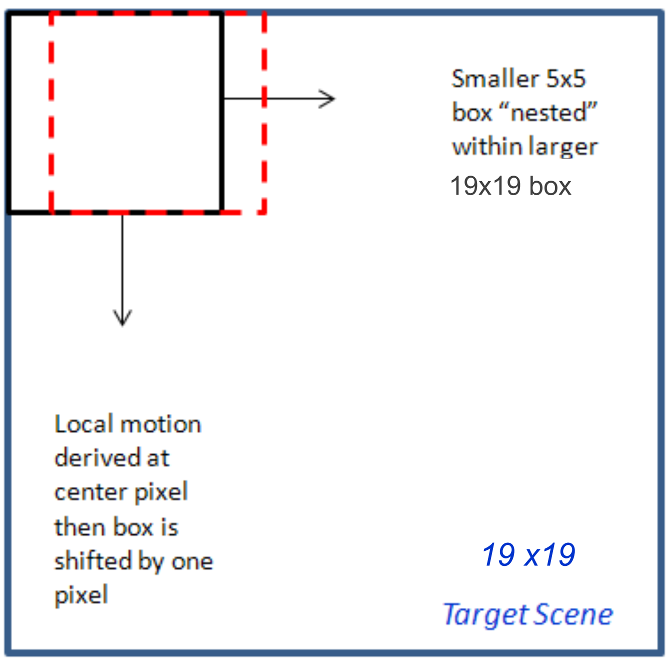
Nested Tracking Approach

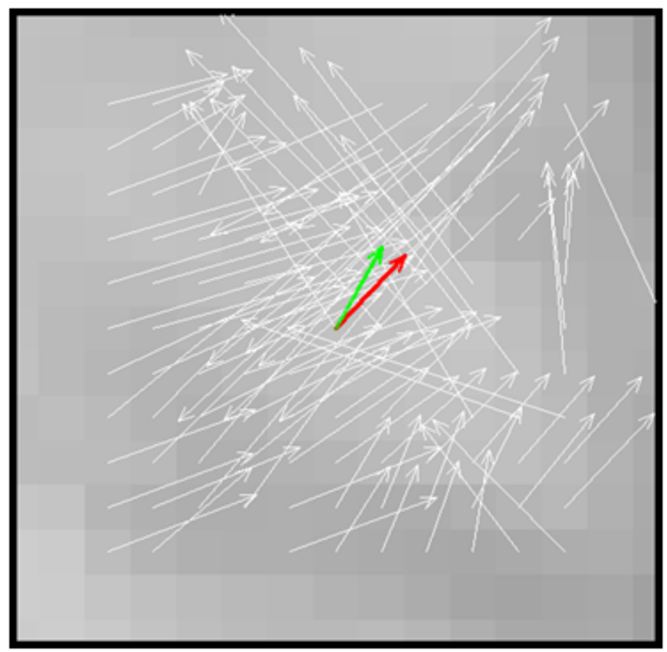
Challenge:

Use smallest box possible to retain fast wind speeds without increasing the RMS

Solution:

Use a small 5x5 box ***"nested"*** within larger target box and derive all possible local wind vectors *(retain those whose CC >= 0.8)*





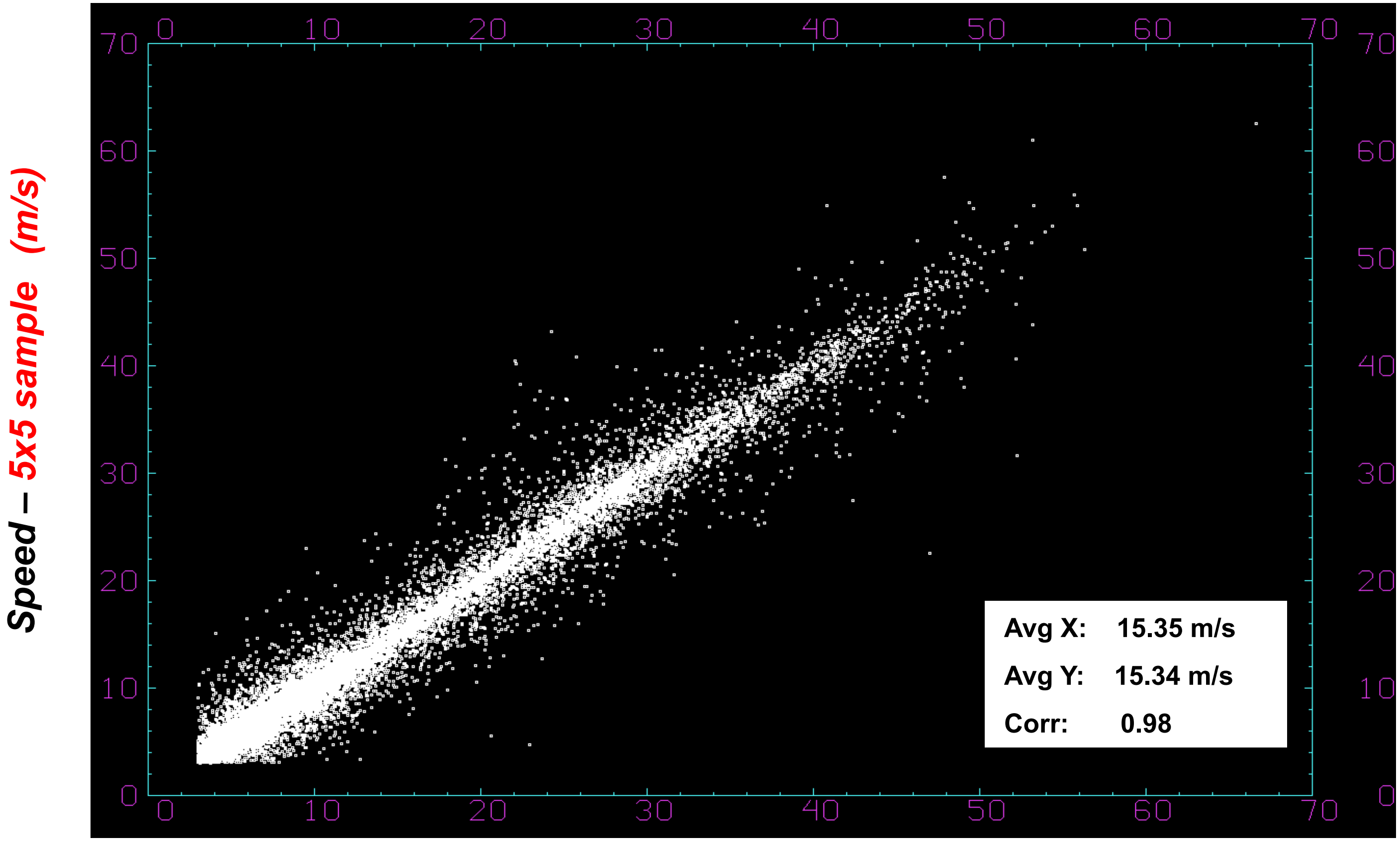
White arrows show local motion derived using 5x5 box centered at pixel location

Green arrow shows average of all local (white) vectors

Red arrow shows vector if larger target scene is tracked

Nested Tracking Approach

How does average speed of entire 5x5 sample compare to single solution from larger box?



Speed – 15x15 box (m/s)

Agreement indicates that speed estimate from larger target box is an *average of local motion*

- From different levels and/or
- From different scales

12Z Feb 1, 2007

Meteosat-8, Band 9

Nested Tracking Approach

- **How can we use local motion vector field?**
  - Need to be able to extract dominant motion from local motions
  - Want to link pixels driving the tracking solution with the height assignment
  - Same goal as Borde and Oyama (2008), but different approach

- **Perform cluster analysis of line and element displacements**
  - Use density-based cluster analysis scheme (DBSCAN**)
  - Locates regions of high density that are separated from one another by regions of low density
  - Very effective at identifying "noise"

** Ester, M., H.-P. Kriegel, J. Sander and X. Xu (1996): A Density-Based Algorithm for Discovering Clusters in Large Spatial Databases with Noise. In Proceedings of 2nd International Conference on Knowledge Discovery and Data Mining (KDD-96), Portland, Oregon, USA, 226-231

Nested Tracking & Clustering Details

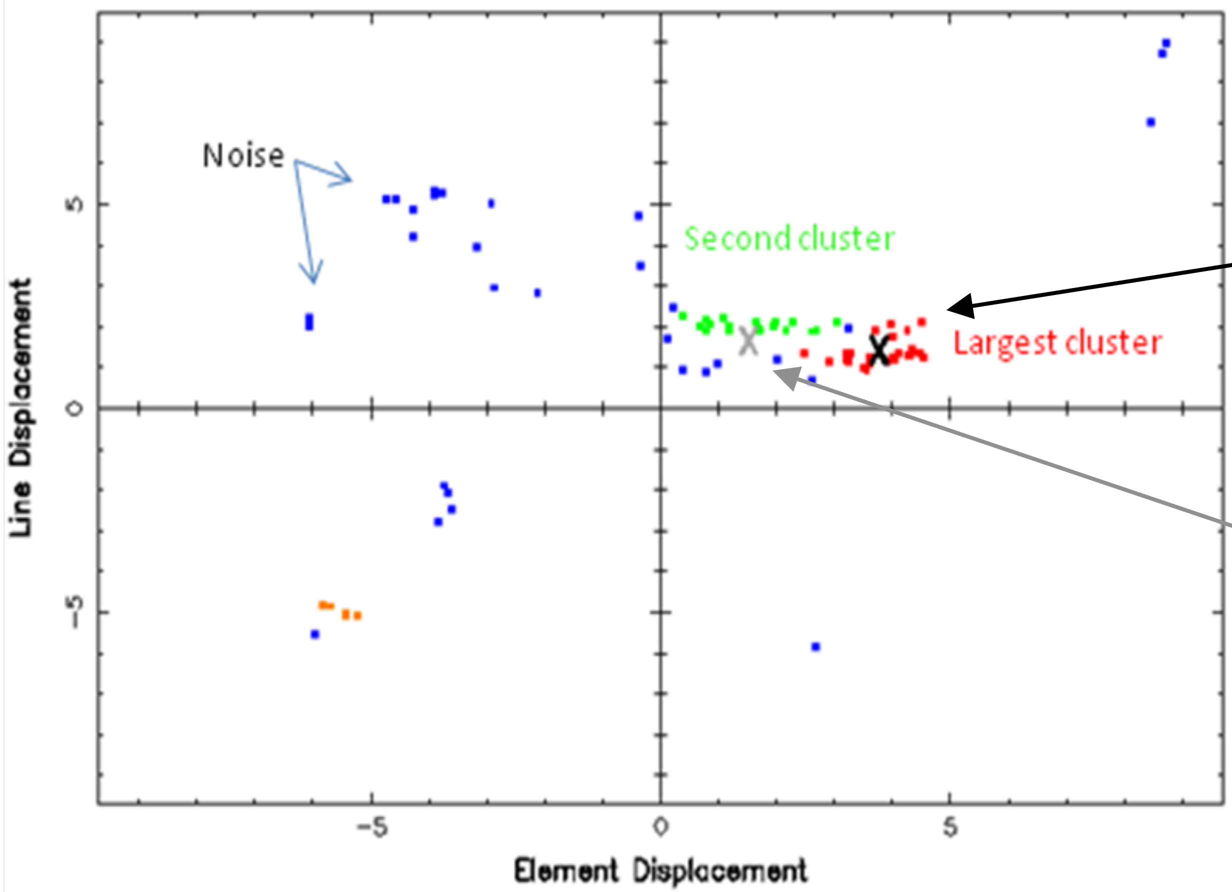
- **Size of outer target scene is 19x19 pixels**
  - 2-pixel offset is used that yields a maximum of 225 possible local motion estimates derived from nested 5x5 target scenes

- **An initial sample of local motion vectors is filtered by imposing a 0.8 correlation threshold**

- **Clustering (via DBSCAN)**
  - *Specification of two parameters to start*
    - Minimum number of points in a cluster (4)
    - Radius about each point to search for neighboring points (1/2 pixel)
  - *Each point (ie., displacement) is processed and given a classification based on nearby points*
    - <u>"Core" cluster point:</u> Has at least 4 points in neighborhood (radius)
    - <u>"Boundary" point:</u> Has fewer than 4 neighbors, but connected to neighborhood by at least one other point
    - <u>"Noise":</u> Point does not belong to any cluster

Nested Tracking Approach

Clustering is done on displacements in line/element space:

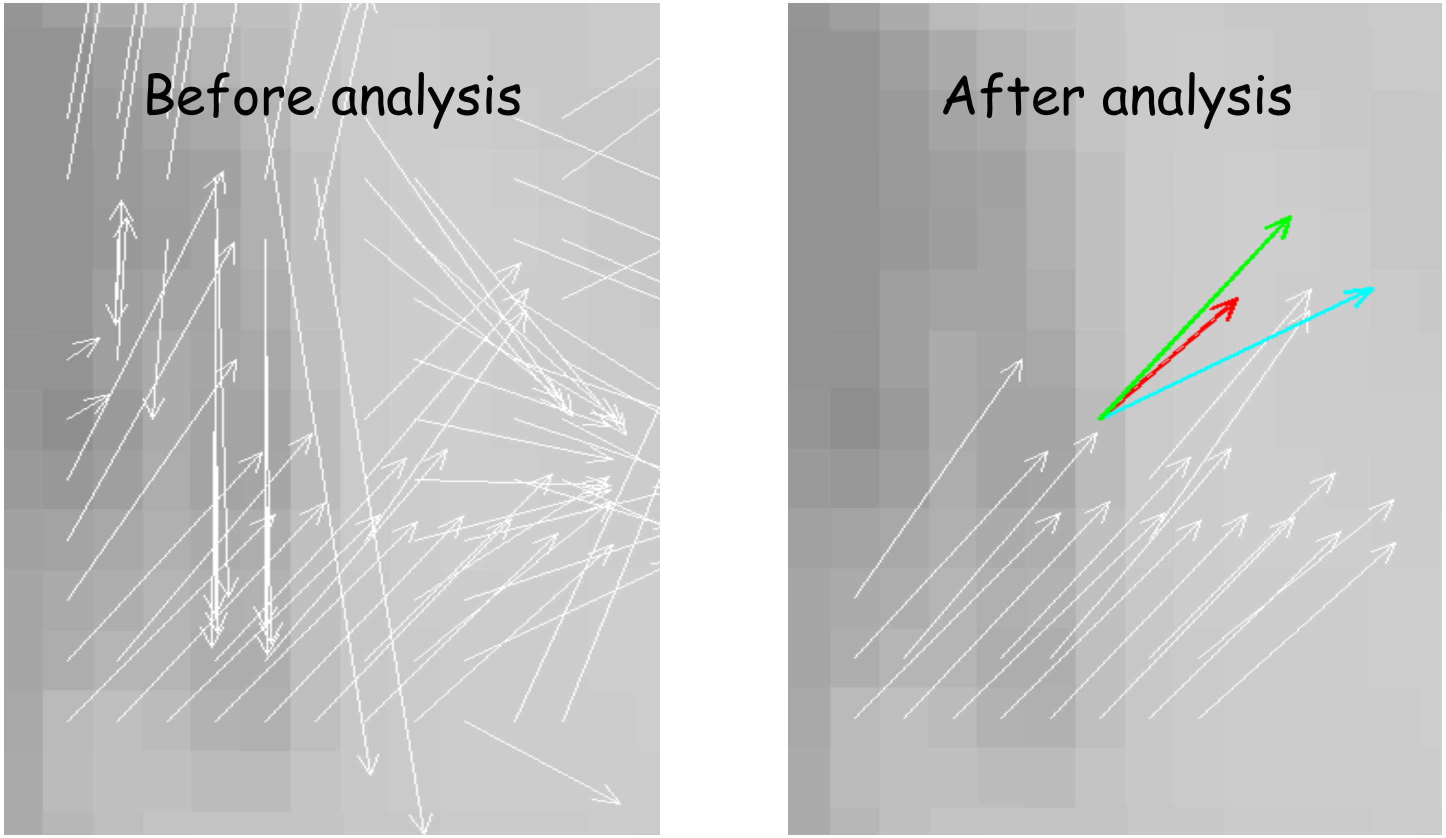


X – Average displacement of points in cluster

X – Displacement from tracking the entire 15x15 target scene

Nested Tracking Approach

Resulting vector field:



Motion of entire 15x15 box

SPD: 25.0

Average of largest cluster

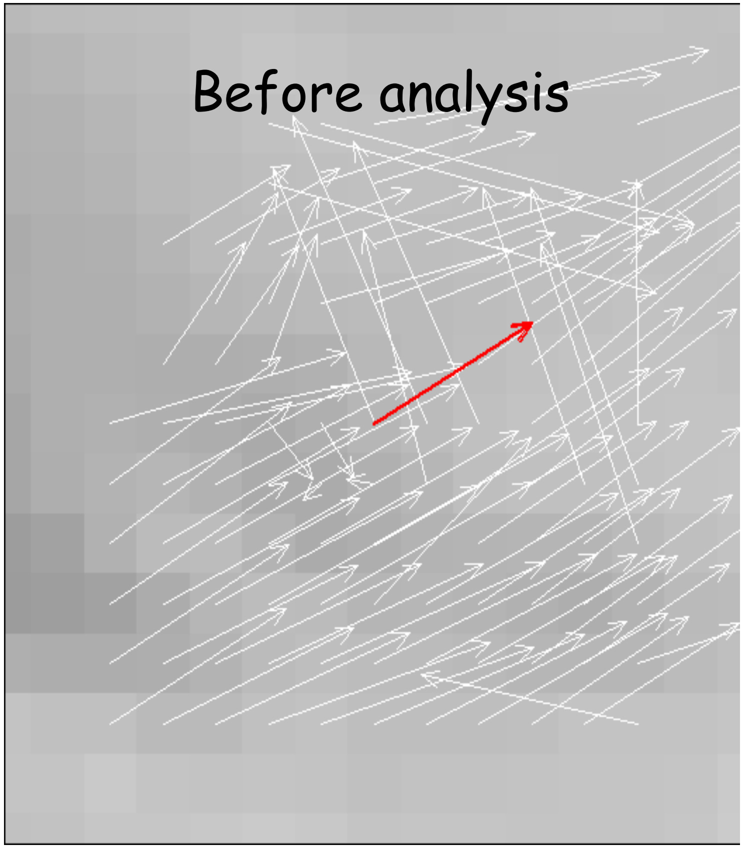
SPD: 39.8

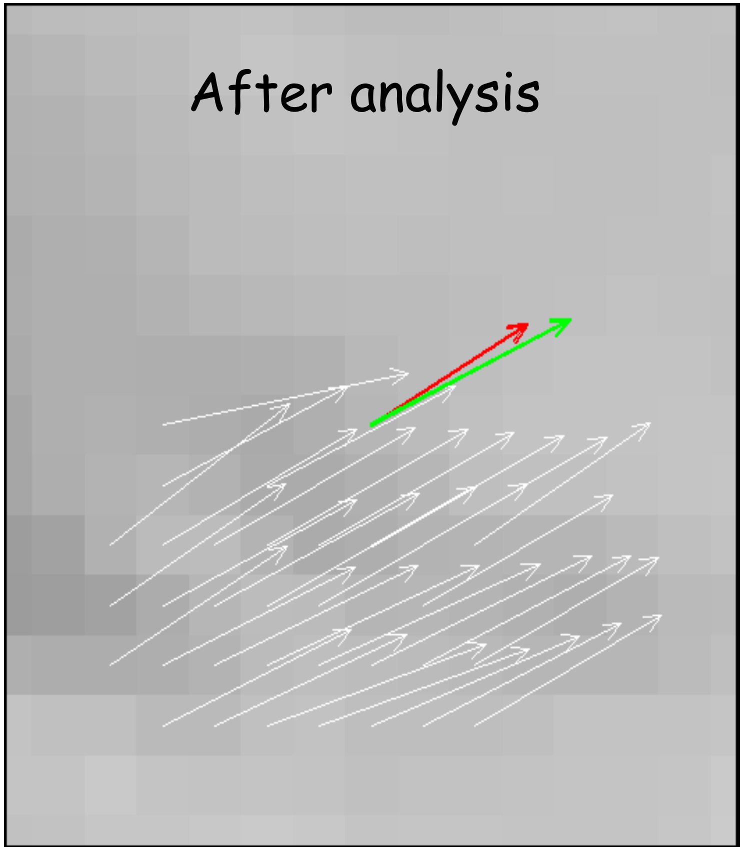
Forecast

SPD: 38.9

Nested Tracking Approach

Resulting vector field:





Motion of entire 15x15 box

SPD: 22.3

Average of largest cluster

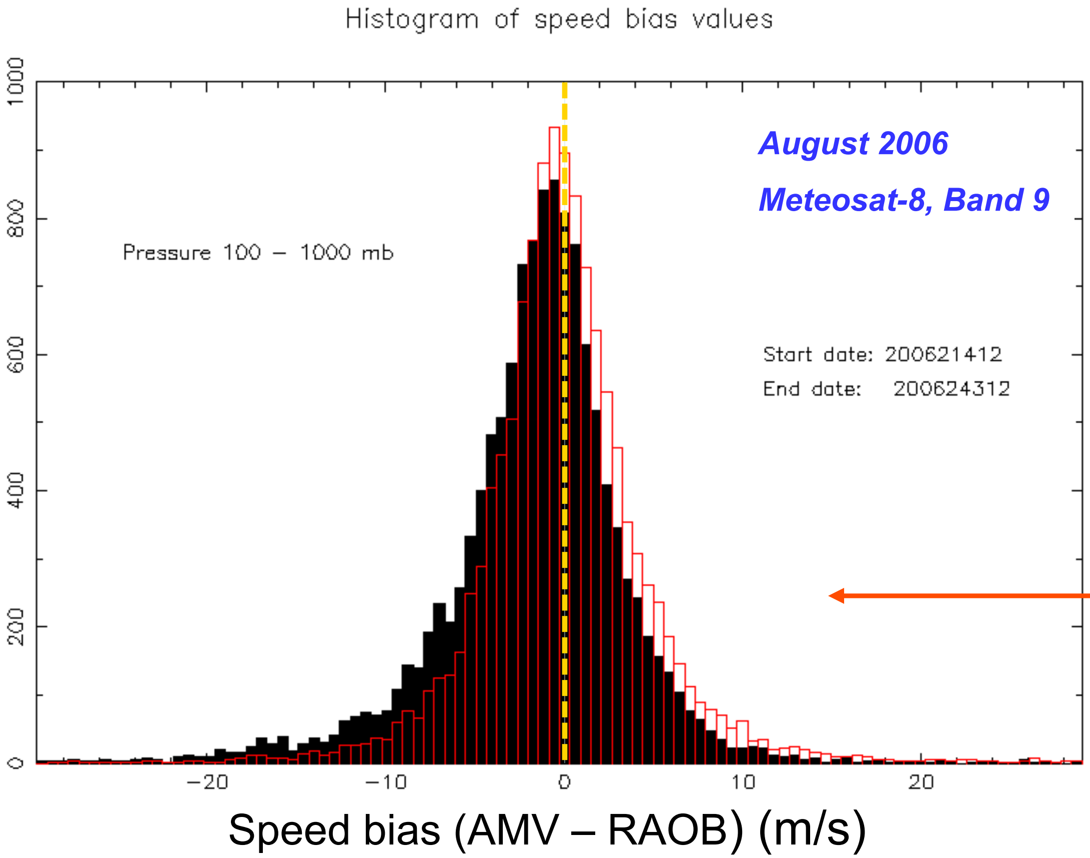
SPD: 27.6

Nested Tracking Approach

Impact on Speed Bias…

Nested tracking reduces slow speed bias of AMVs when compared to radiosonde winds!

Expect this to be beneficial to NWP…



Black histogram shows control

Red histogram shows test

Test distribution shifted right

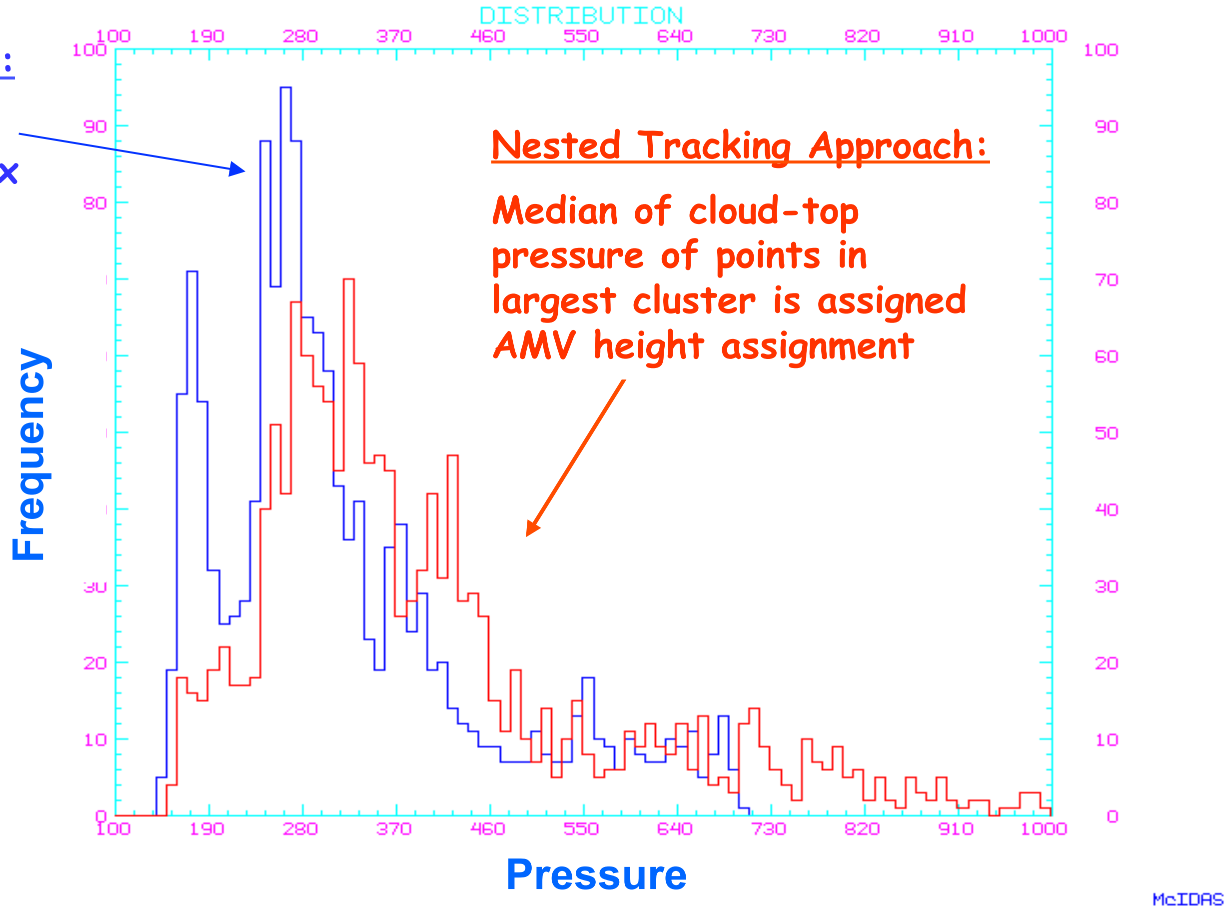
- faster AMVs and/or lower heights

Nested Tracking Approach

Linking Tracking to Height Assignment…

Heritage Approach:

Coldest 20% of pixels in target box used to compute AMV height assignment



Nested Tracking Approach:

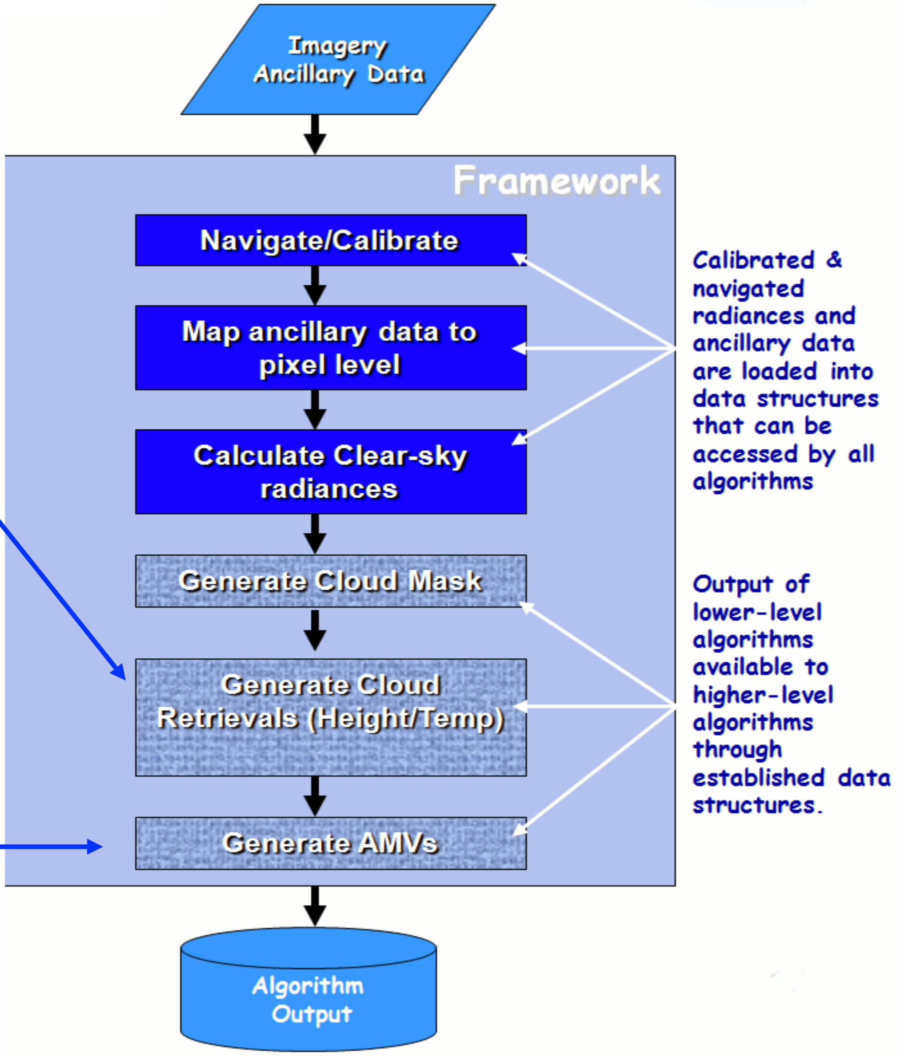
Median of cloud-top pressure of points in largest cluster is assigned AMV height assignment

Impact is to push AMV height assignments lower in the atmosphere

Nested Tracking Approach

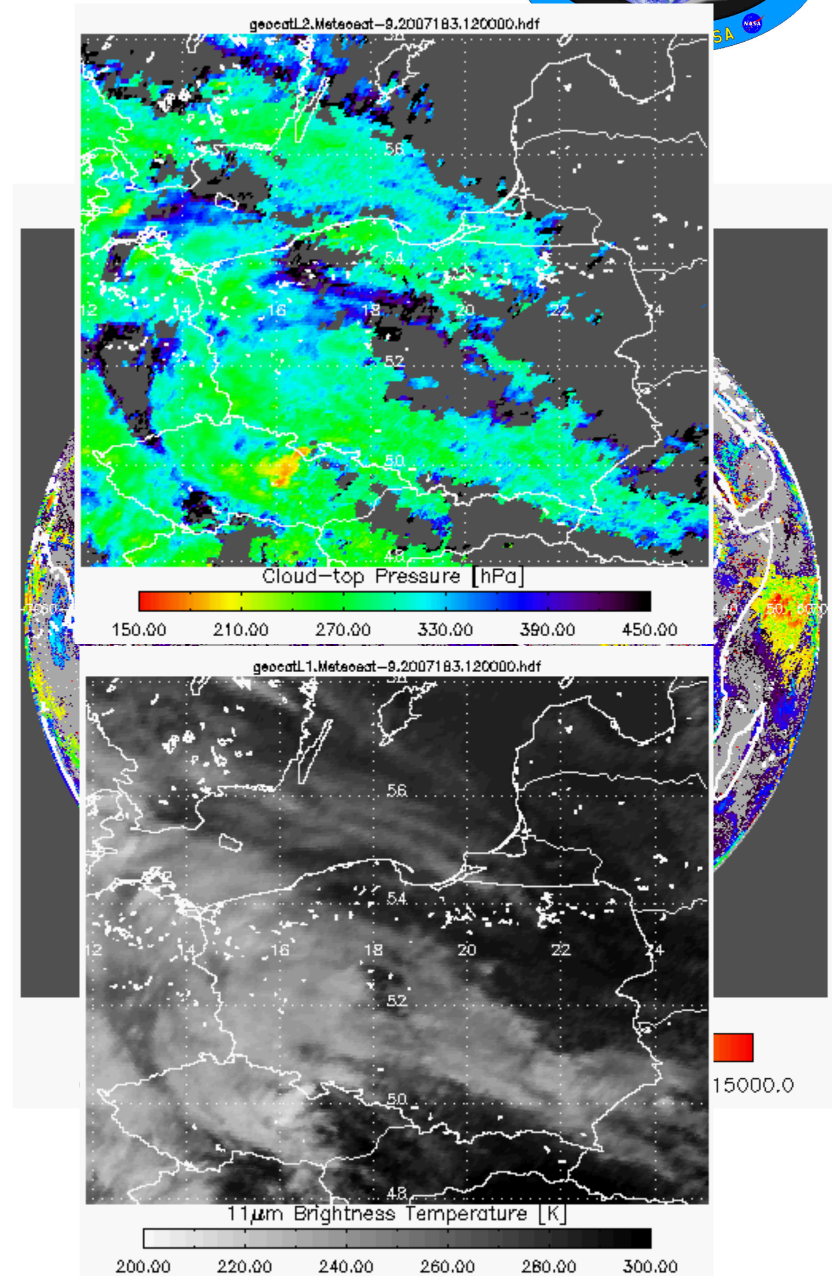
Linking Tracking to Height Assignment…

- Level-2 Cloud products
  - *Computed upstream of winds algorithm*
  - *Pixels belonging to the largest cluster are used to assign a representative height to the derived motion wind*
    - Cloud-top height/pressure
    - Cloud-top temperature
    - Cloud-top phase
    - Cloud-type
    - Cloud mask
- Nested tracking determines dominant motion in target scene



Cloud-Top Pressure Product

- **Cloud Height Algorithm Highlights**
  - Algorithm uses the 11, 12 and 13.3mm channels to retrieve cloud temperature, cloud emissivity and a cloud microphysics.
  - Algorithm uses an ***optimal estimation approach*** (Rogers, 1976) that provides error estimates (T_c).
  - State-of-the-art scattering calculations are used to model the variation of cloud emissivity between 11, 12 and 13.3 um.
  - Cloud emissivity (11um) and a microphysical index (β 11&12 um) are also generated automatically in the retrieval.
  - NWP forecast temperature profiles used to compute cloud-top pressure and height.
  - For multi-layer clouds, lower cloud height estimates obtained from surrounding pixels.
  - Cloud heights in the presence of low level inversions are handled using similar logic that is employed in the MODIS algorithms.



- **References**

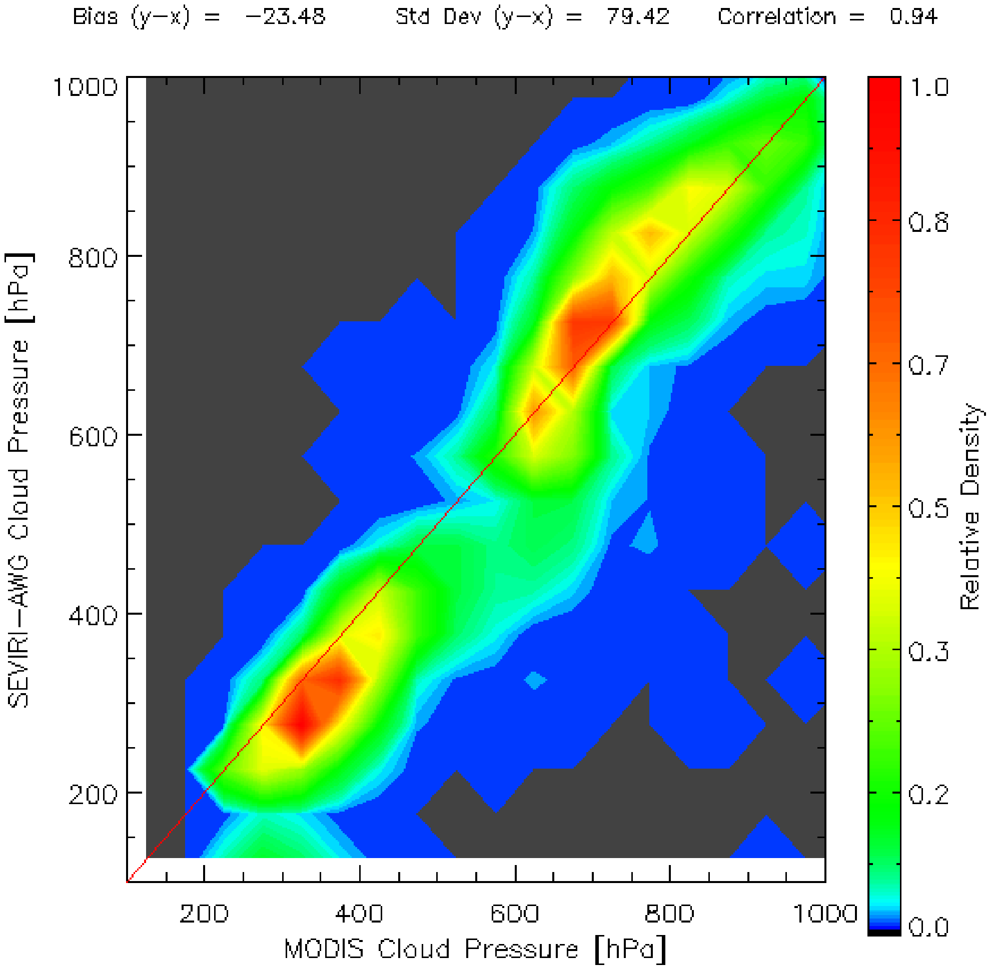
  - Heidinger, A., 2010: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document For Cloud Mask, GOES-R Program Office, www.goes-r.gov.
  - Rodgers, C.D., 1976: Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation. Rev. Geophys. Space Phys., 60, 609-624.

Andrew Heidinger, NOAA/NESDIS/STAR

Cloud-Top Pressure Validation

- MODIS cloud height product (MYD06) uses the CO_2 slicing approach that has been well-characterized

- The image on the right shows a comparison of the GOES-R Cloud Height Algorithm run on SEVIRI compared to MODIS results for simultaneously observed pixels.
  - Bias = -24 hPa (MODIS CTPs lower in the atmosphere)
  - Std. Deviation = 80 hPa



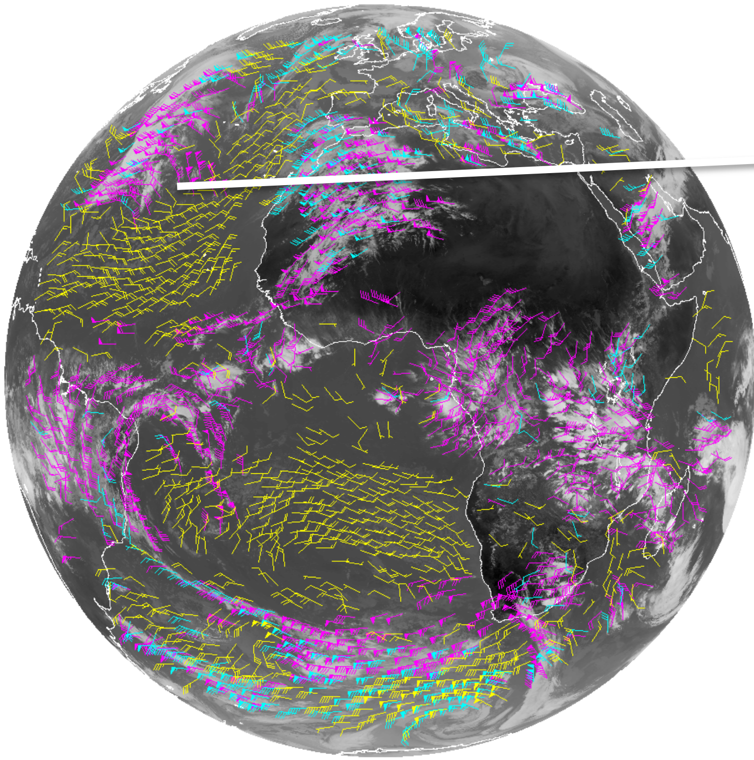
June 13, 2008 at 12:15 UTC

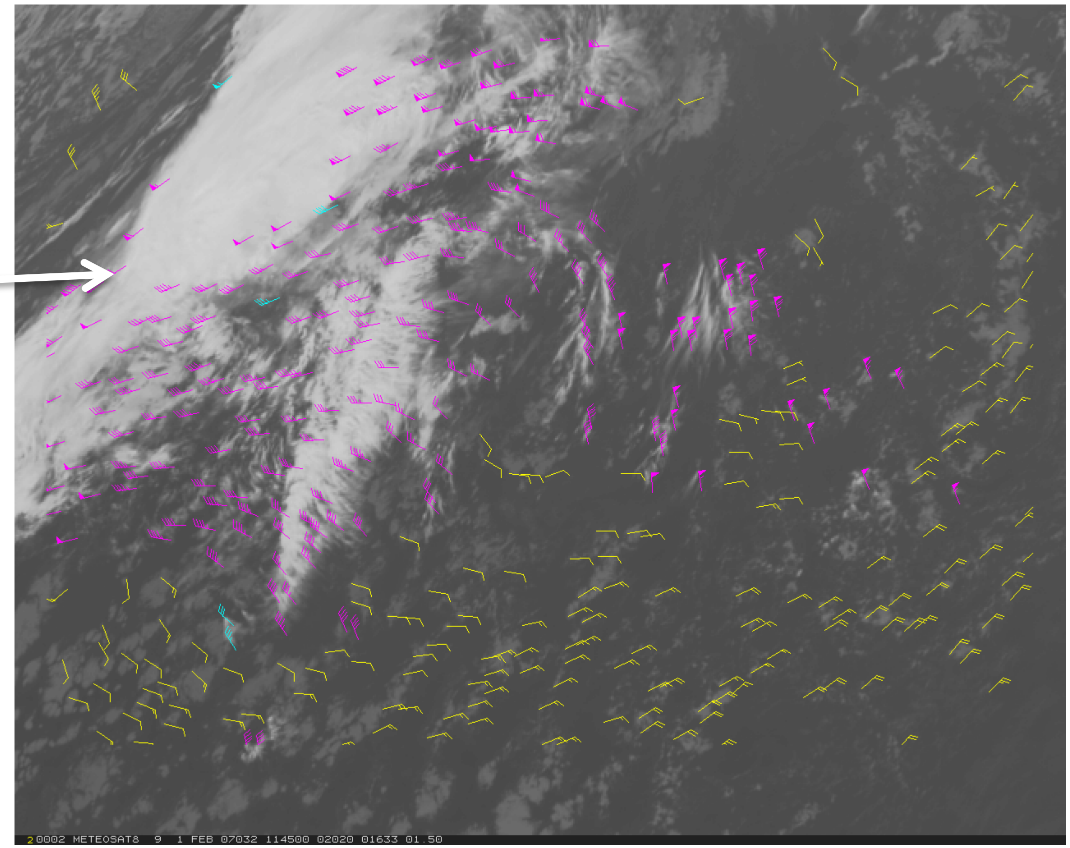
PRODUCT EXAMPLES

USING AVAILABLE ABI PROXY DATA…

Using SEVIRI as a Proxy for the Future GOES-R ABI

Cloud-drift Winds derived from a Full Disk Meteosat-8 SEVERI 10.8 µm image triplet centered at 1200 UTC   01 February 2007



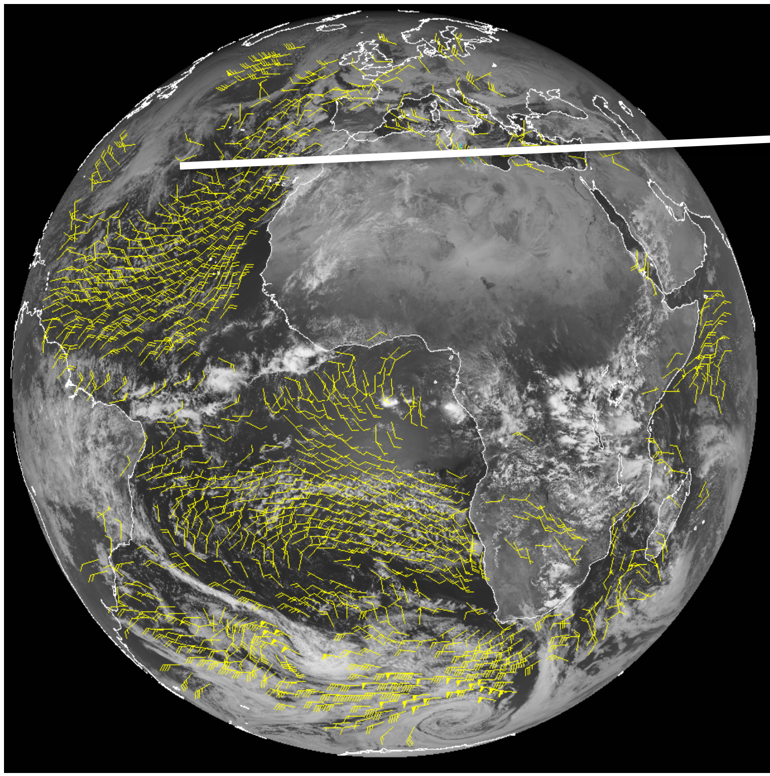


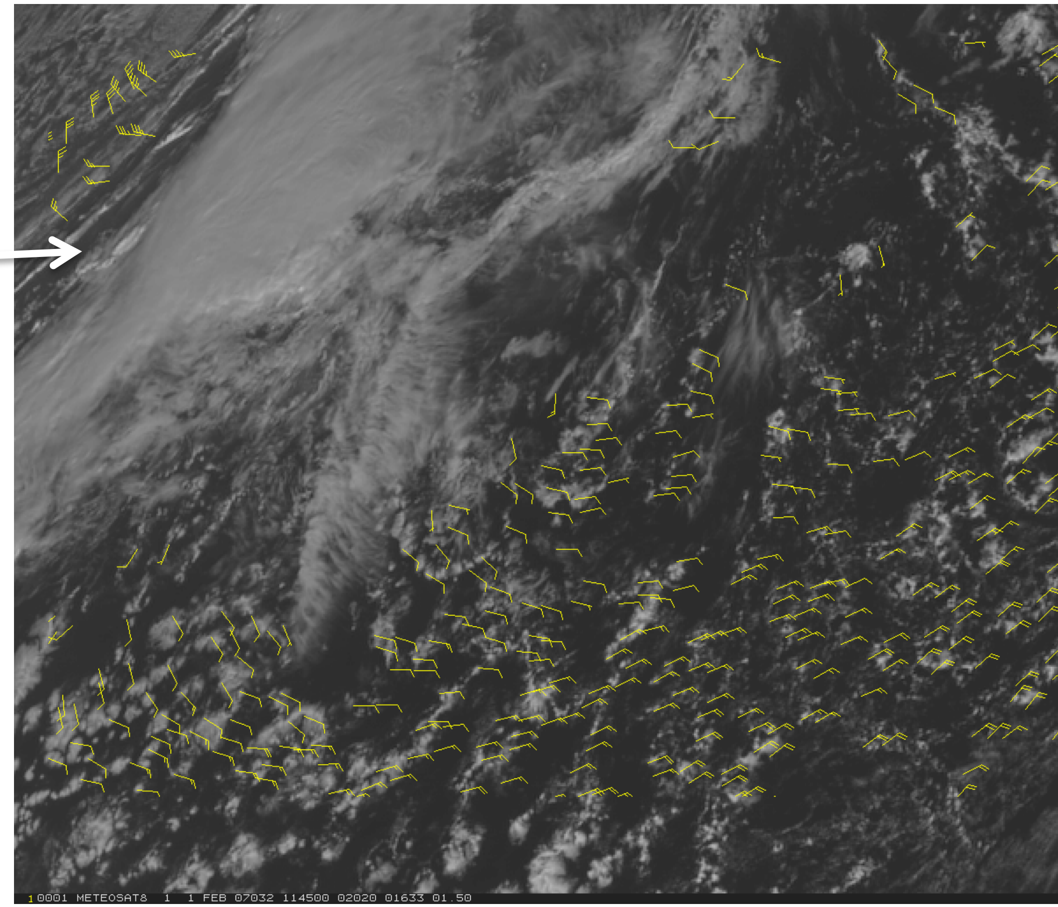
High-Level 100-400 mb   Mid-Level 400-700 mb   Low-Level >700 mb

Since February 2011, NESDIS/STAR has been routinely generating experimental winds from Meteosat-9/SEVIRI using the GOES-R winds algorithm (ie., nested tracking)

Using SEVIRI as a Proxy For the Future GOES-R ABI

Cloud-drift Winds derived from a Full Disk Meteosat-8 SEVERI 0.60 um image triplet centered at 1200 UTC   01 February 2007

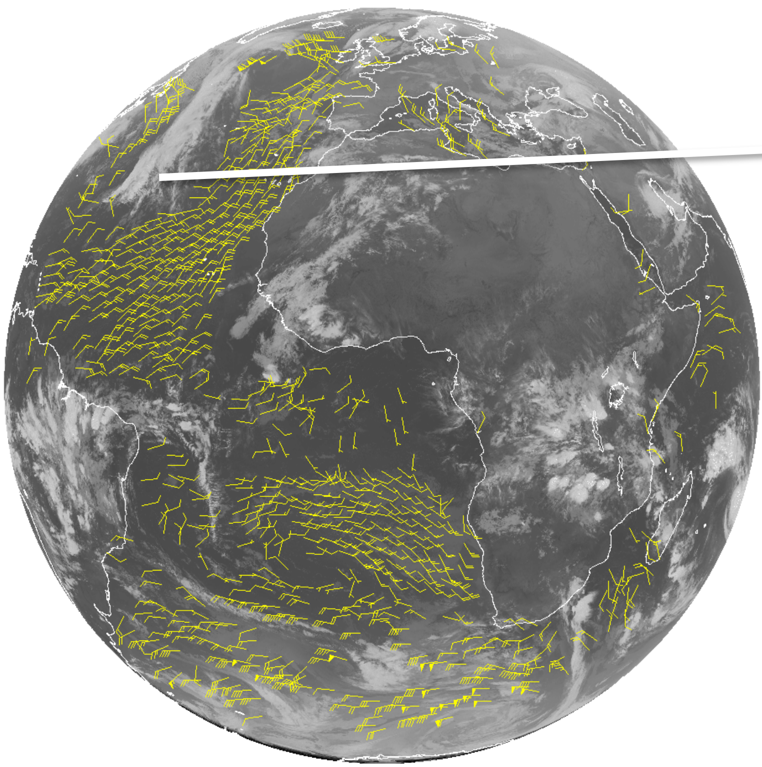


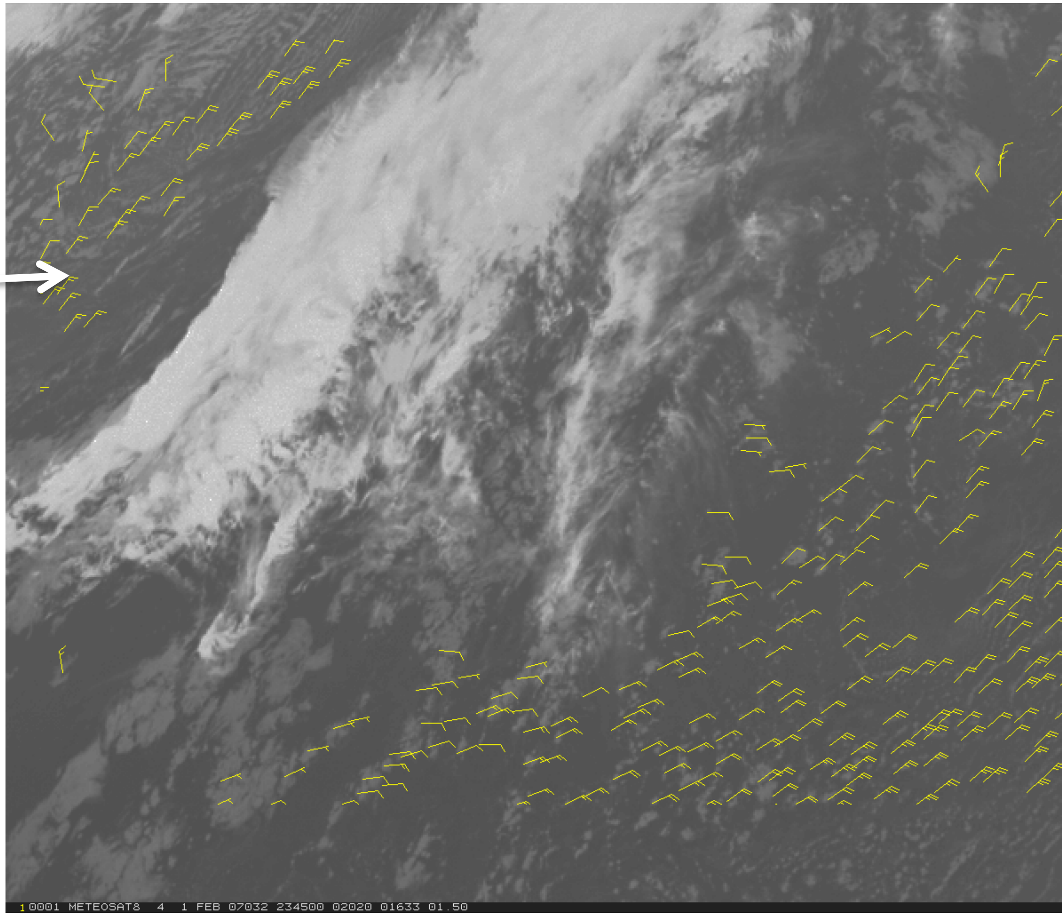


Low-Level >700 mb

Using SEVIRI as a Proxy For the Future GOES-R ABI

Cloud-drift Winds derived from a Full Disk Meteosat-8 SEVERI 3.9μm image triplet centered at 0000 UTC   02 February 2007

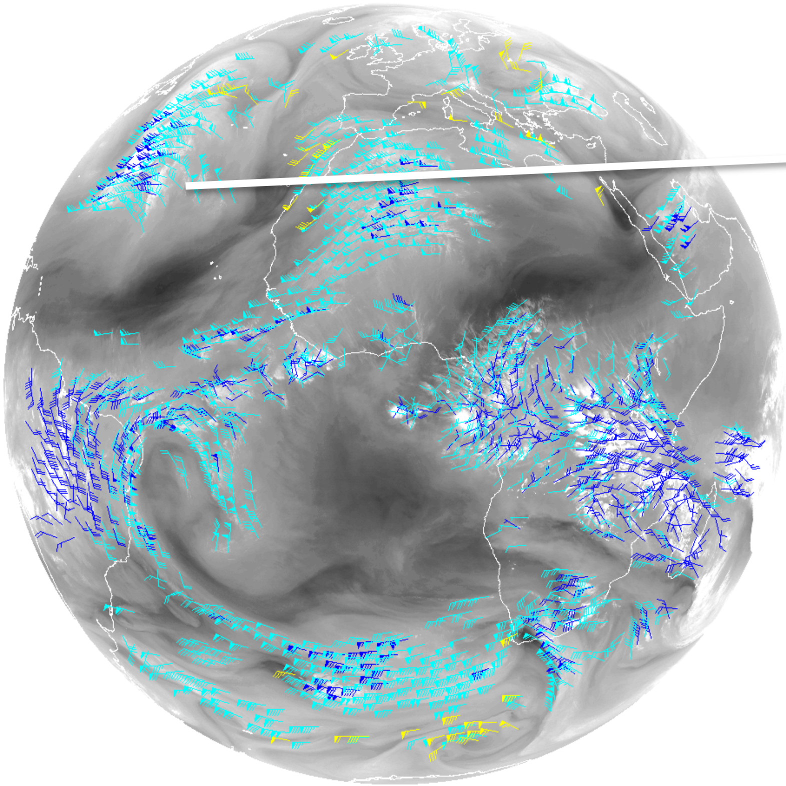


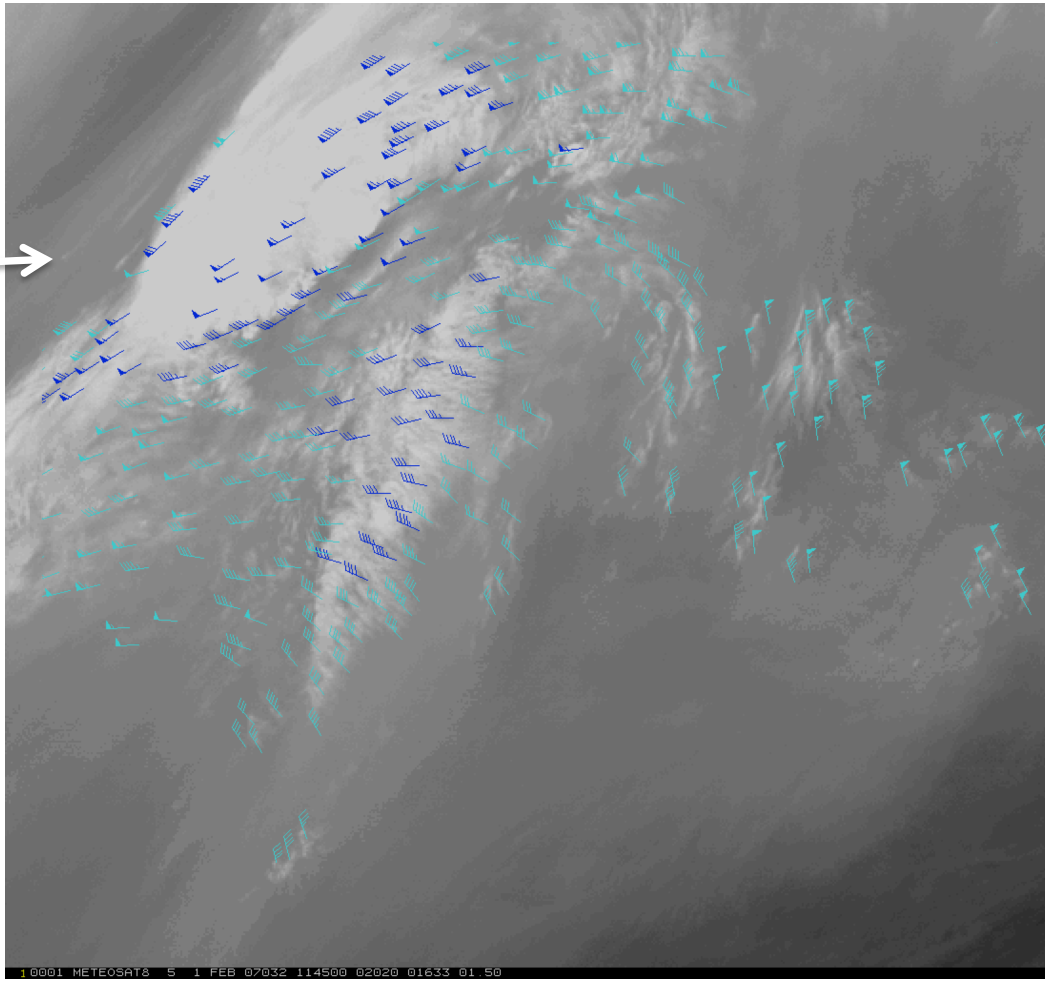


Low-Level >700 mb

Using SEVIRI as a Proxy For the Future GOES-R ABI

Cloud-top Water Vapor Winds derived from Full Disk Meteosat-8 SEVERI 6.2um image triplet centered at 1200 UTC 01 February 2007





100-400 mb | 250-350 mb | 350-550 mb

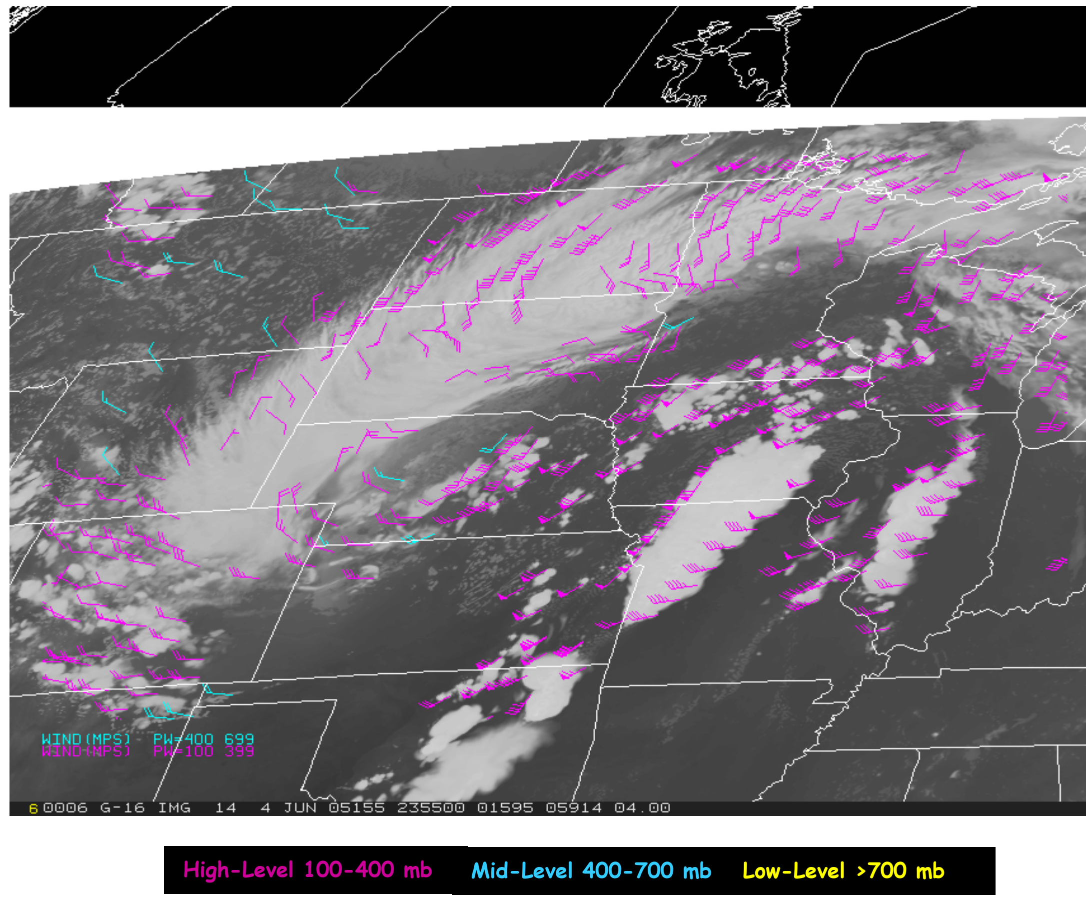
Application to Simulated ABI Imagery

- GOES-R AWG Data Proxy Team has generated a large number of simulated ABI datasets
  - All ABI bands
  - Various spatial and temporal resolutions

- Simulated datasets have been used by some of the algorithm teams to generate Level-2 products

- Simulated datasets will support a number of tests for elements of the GOES-R ground system segment

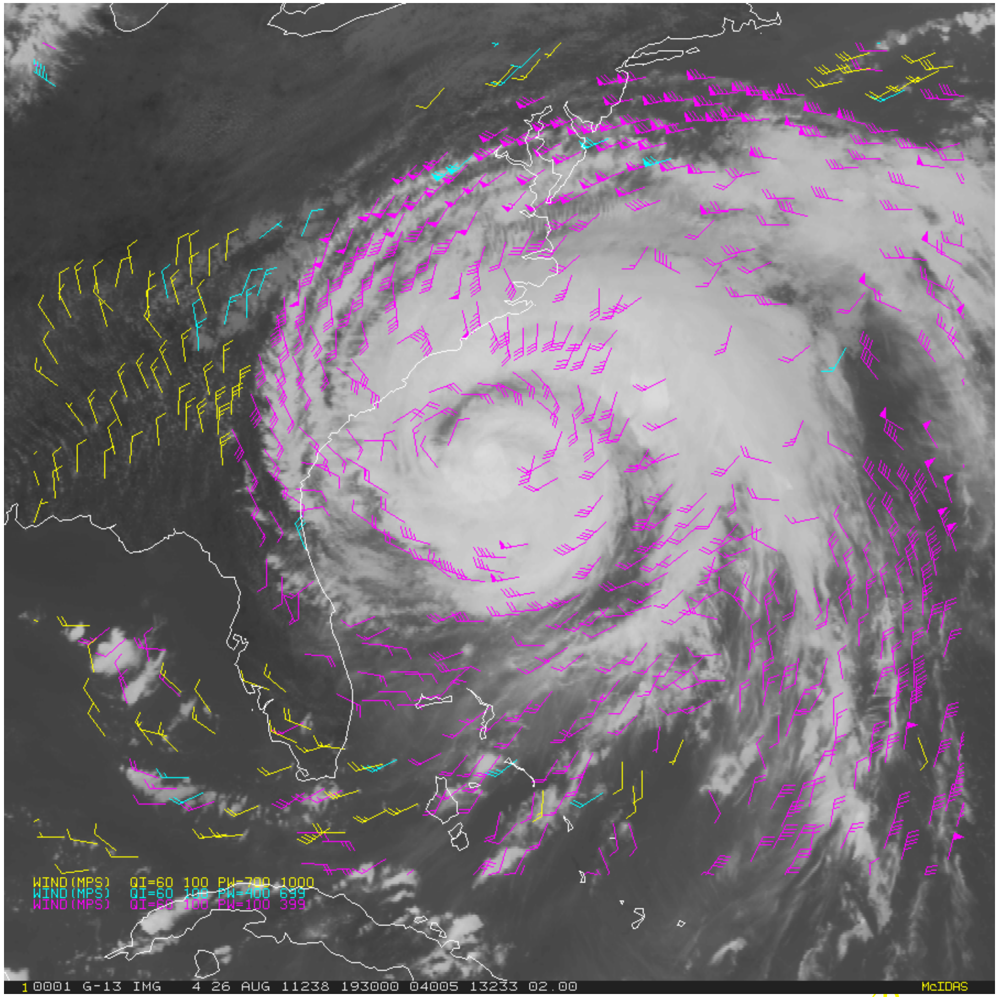
Cloud-drift AMVs derived from a Simulated GOES-R ABI image (Band 14; 11um) triplet centered at 0000Z on 05 June 2005



Application to Current GOES Imagers

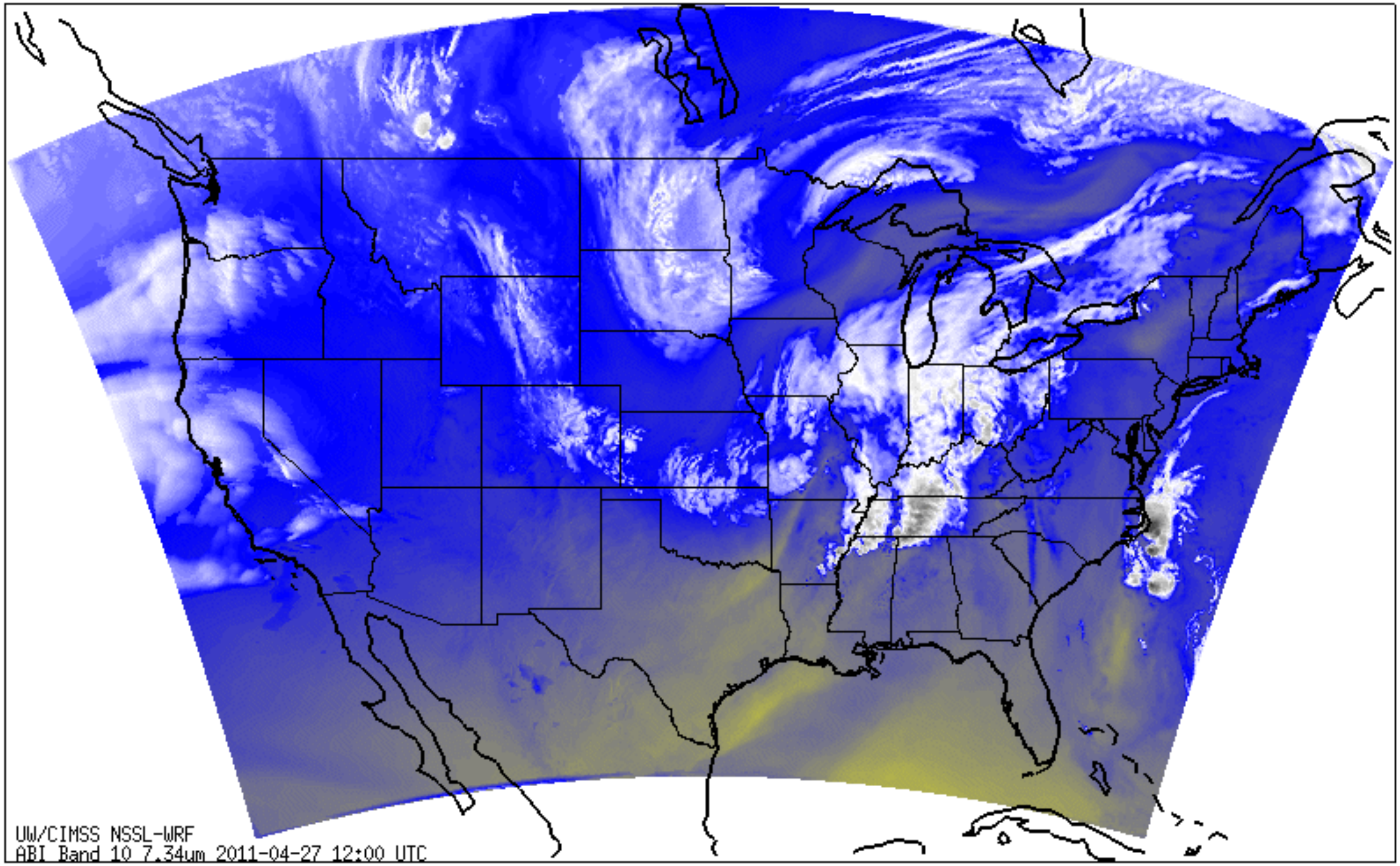
- Since September 2011, we have been routinely generating experimental winds from GOES-13 using the GOES-R winds algorithm (ie., nested tracking)
- Setting up processing of experimental winds for GOES-15 (Mar 2012)
- Goal is to replace heritage AMV algorithm running in NESDIS operations with AMV algorithm developed for GOES-R ABI
  - GOES (funded effort) – March 2013 (pre-Operational date)
  - VIIRS (funded effort) – Dec 2012
  - AVHRR (not funded yet)
  - MODIS (not funded yet)

Cloud-drift winds derived from 15-minute GOES-13 imagery over Hurricane Irene at 1930 UTC on 26 August 2011



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

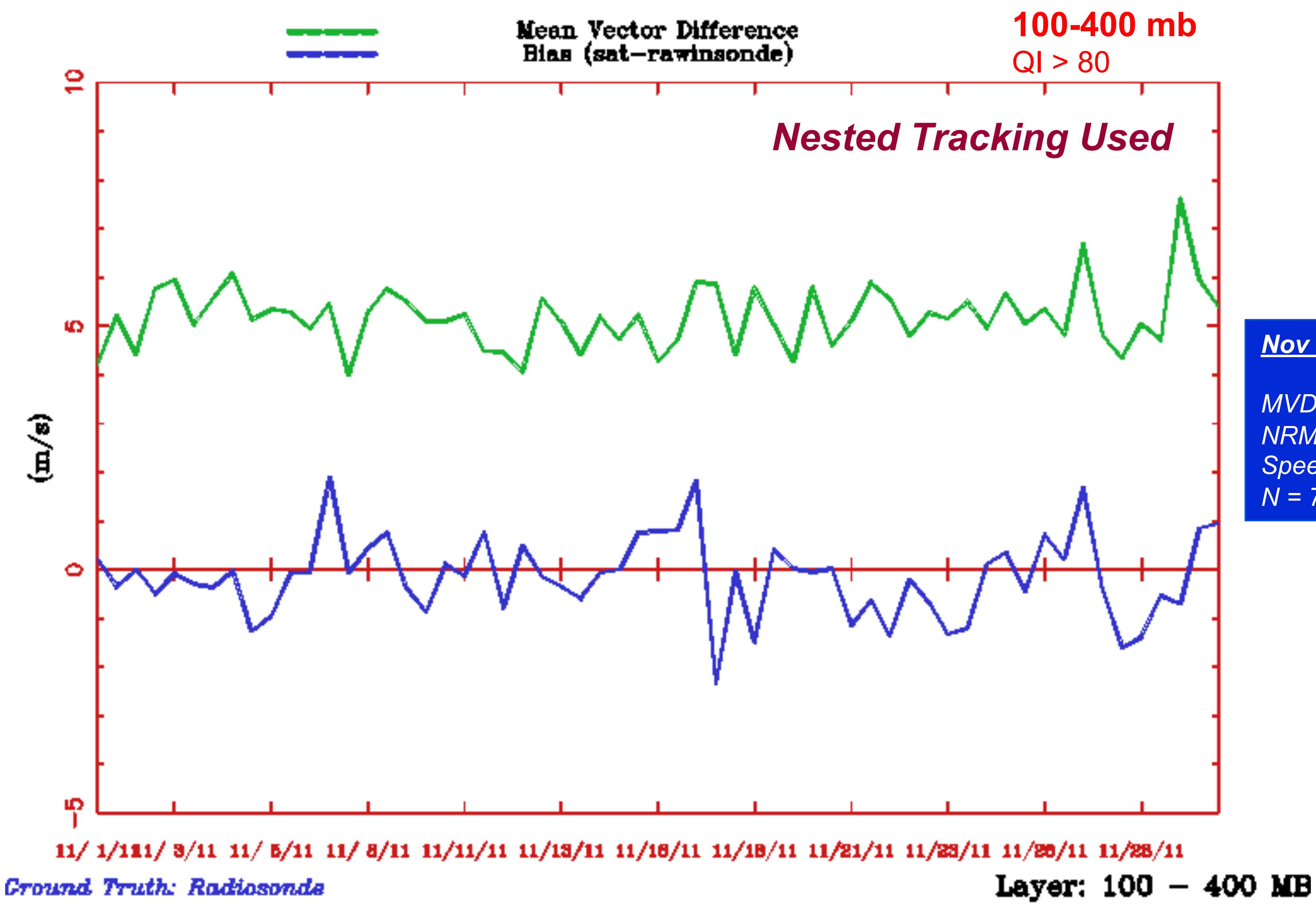
Simulated ABI band – NSSL WRF



- GOES-R AWG Proxy Team at CIMSS generates these in near real-time each day.
- Future plans call for all ABI bands to be simulated, currently only 8 or 9 are being generated and use these for end-to-end demonstrations, simulation studies, etc

http://cimss.ssec.wisc.edu/goes_r/proving-ground/nssl_abi/nssl_wrf_goes.html

Met-9/SEVIRI Winds (10.8um) vs Radiosondes

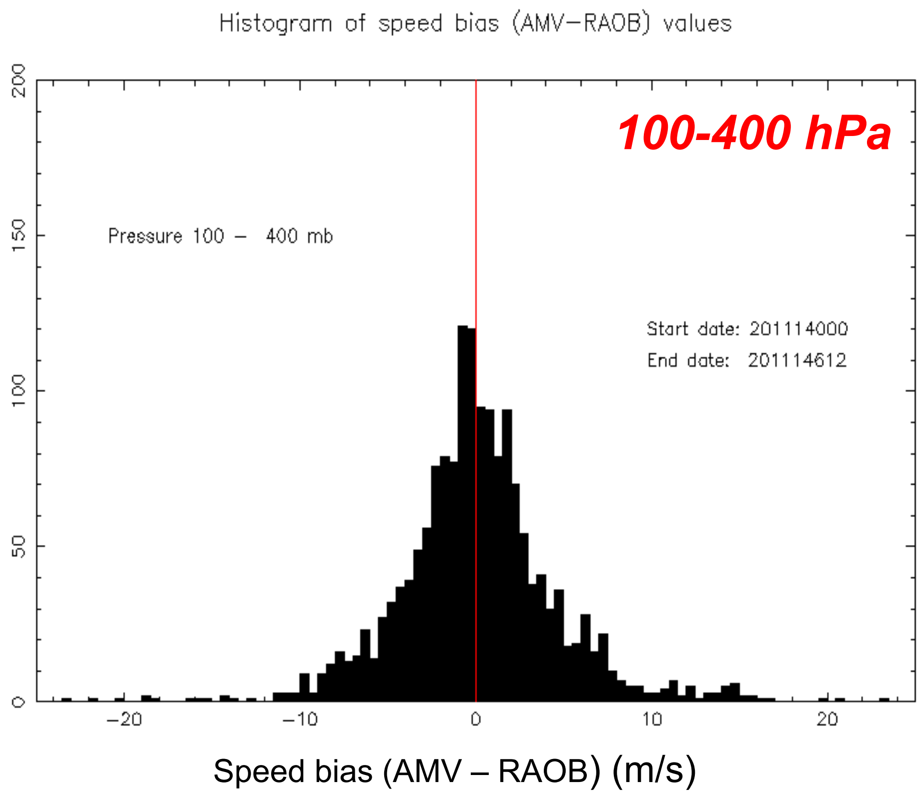


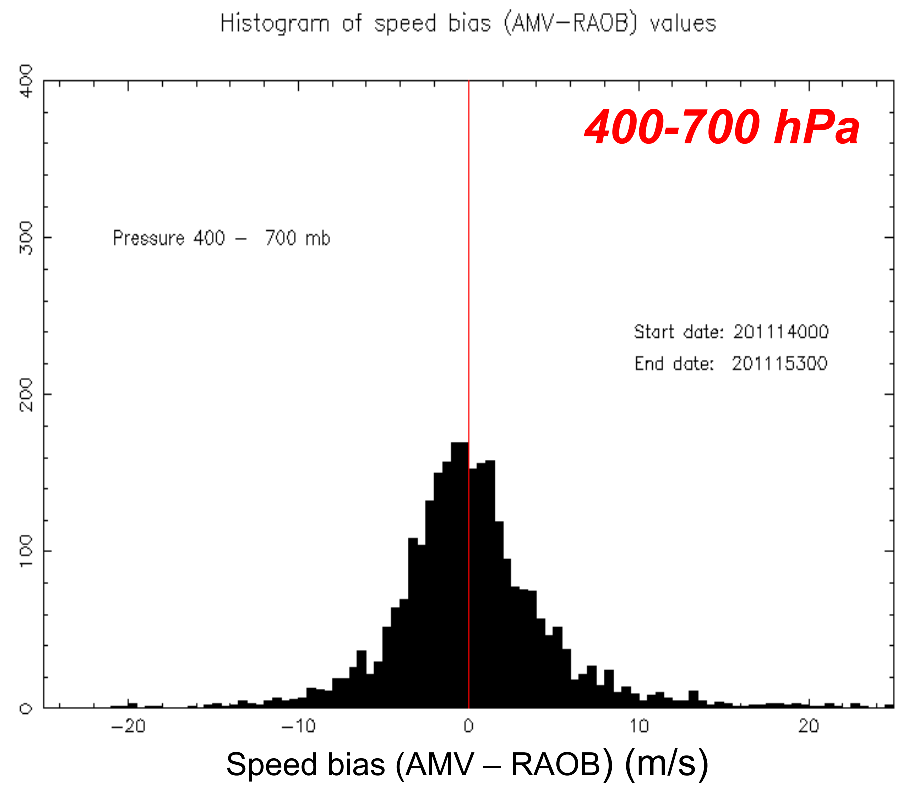
Nov 2011 Stats:

MVD = 5.05 m/s
NRMS = 0.31
Speed Bias = -0.31
N = 7295

Validation

Speed Bias…



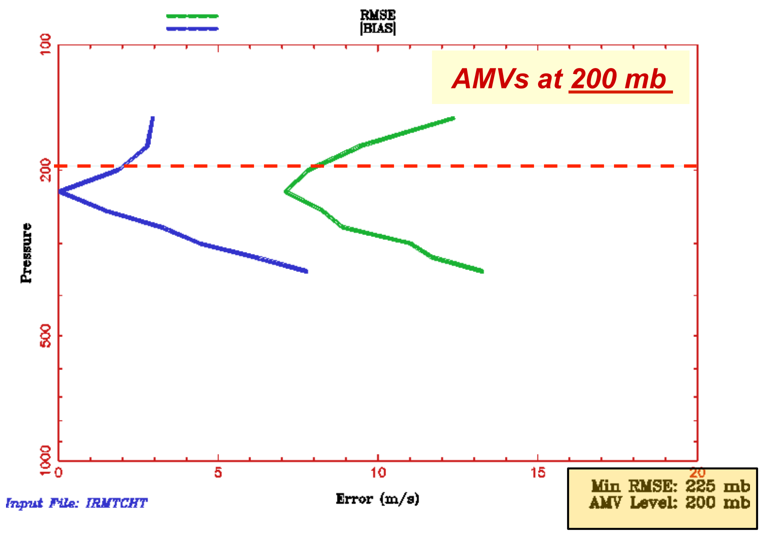


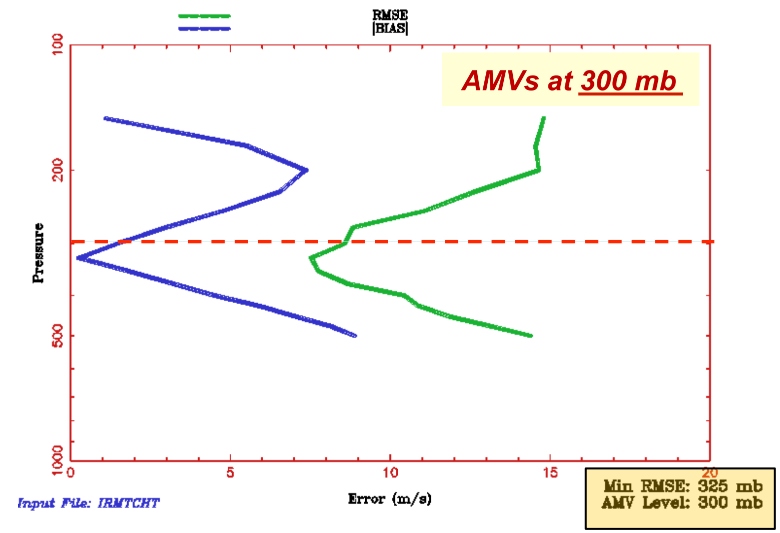
Meteosat-9/SEVIRI (10.8um) AMVs *(15 -21 March 2011)*

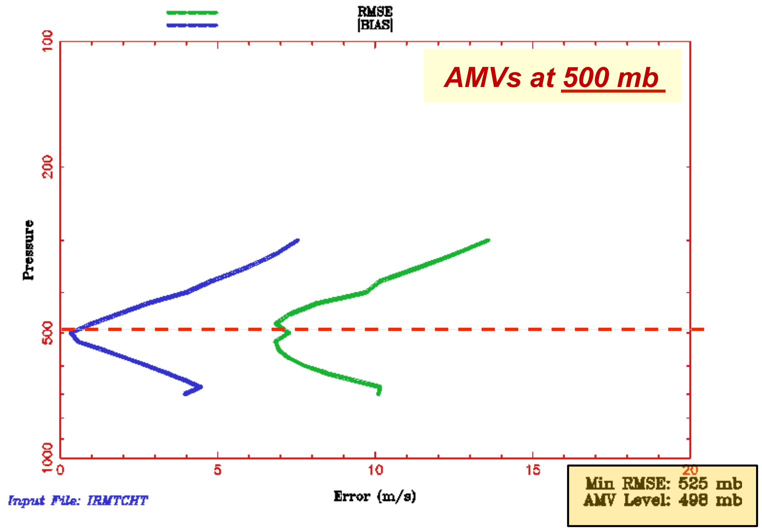
Validation

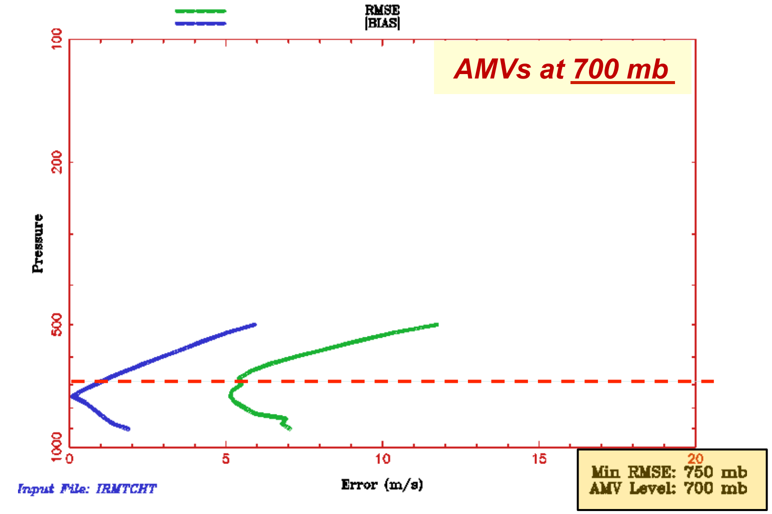
Height Assignment (Level-of-Best-Fit)…

Meteosat-9/SEVIRI (10.8um) AMVs (28 Nov 2011 – 06 Feb 2012)





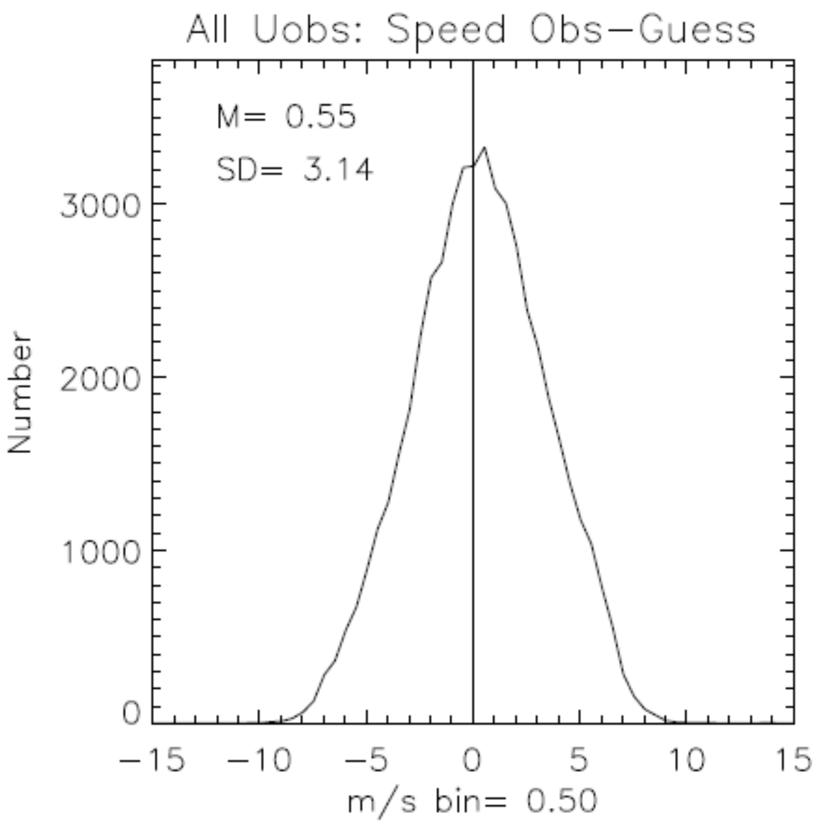




Assessing Impact of Nested Tracking Winds in NCEP's Global Forecast System (GFS)

- Meteosat-9/SEVIRI winds (10.8um) using GOES-R AMV algorithm

- Initial set of data assimilation stats (O-B) have been generated for 10 day period (July 2011)
  - Encouraged by what we see, especially with respect to the bias
  - Gaussian; centered at zero



Sharon Nebuda will talk more about this Tuesday afternoon

Nested Tracking Output Potentially Relevant for NWP Data Assimilation

- Number of distinct motion clusters (sample 1 – reverse vector)
- Size of largest cluster (sample 1 – reverse vector)
- Number of distinct motion clusters (sample 2 – forward vector)
- Size of largest cluster (sample 2 – forward vector)

- Minimum cloud-top pressure (hPa) in largest cluster
- Maximum cloud-top pressure (hPa) in largest cluster
- Minimum cloud-top temperature (K) in largest cluster
- Maximum cloud-top temperature (K) in largest cluster

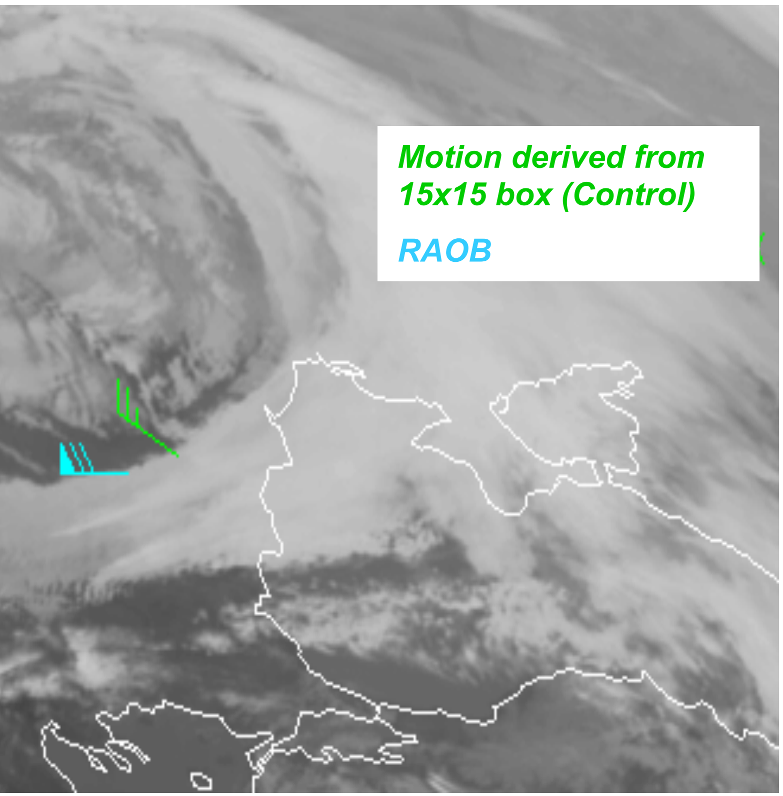
- Dominant cloud phase of target scene
- Dominant cloud type of target scene

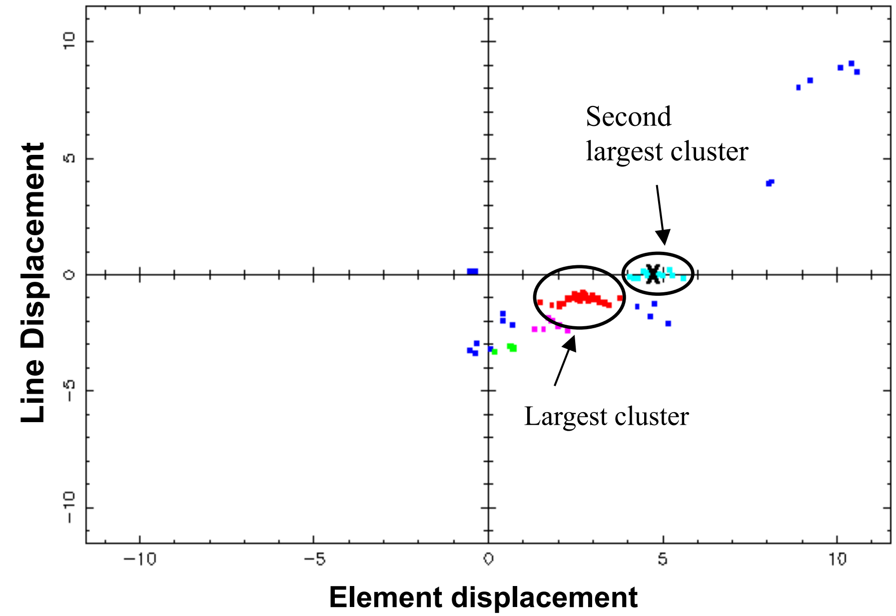
- Standard deviation of cloud top pressure values in target scene (hPa)

Sharon will talk more about this

Multiple Motion Solutions

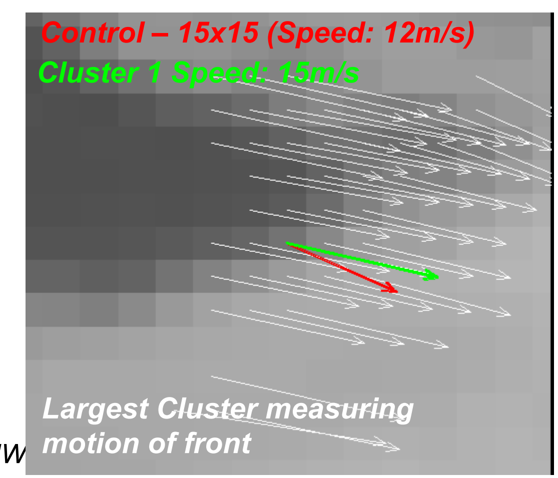
What motion is represented?...

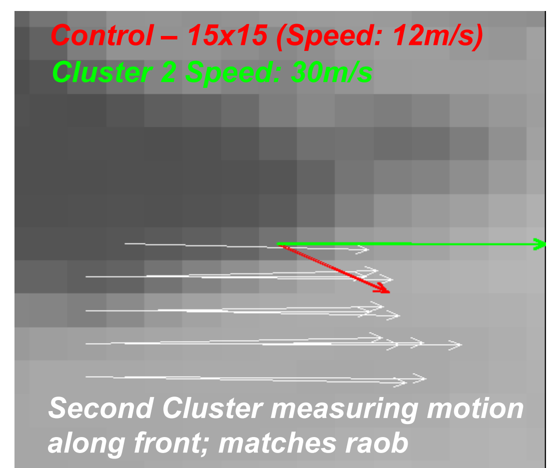




Red – motion of synoptic front

Light Blue – motion along front

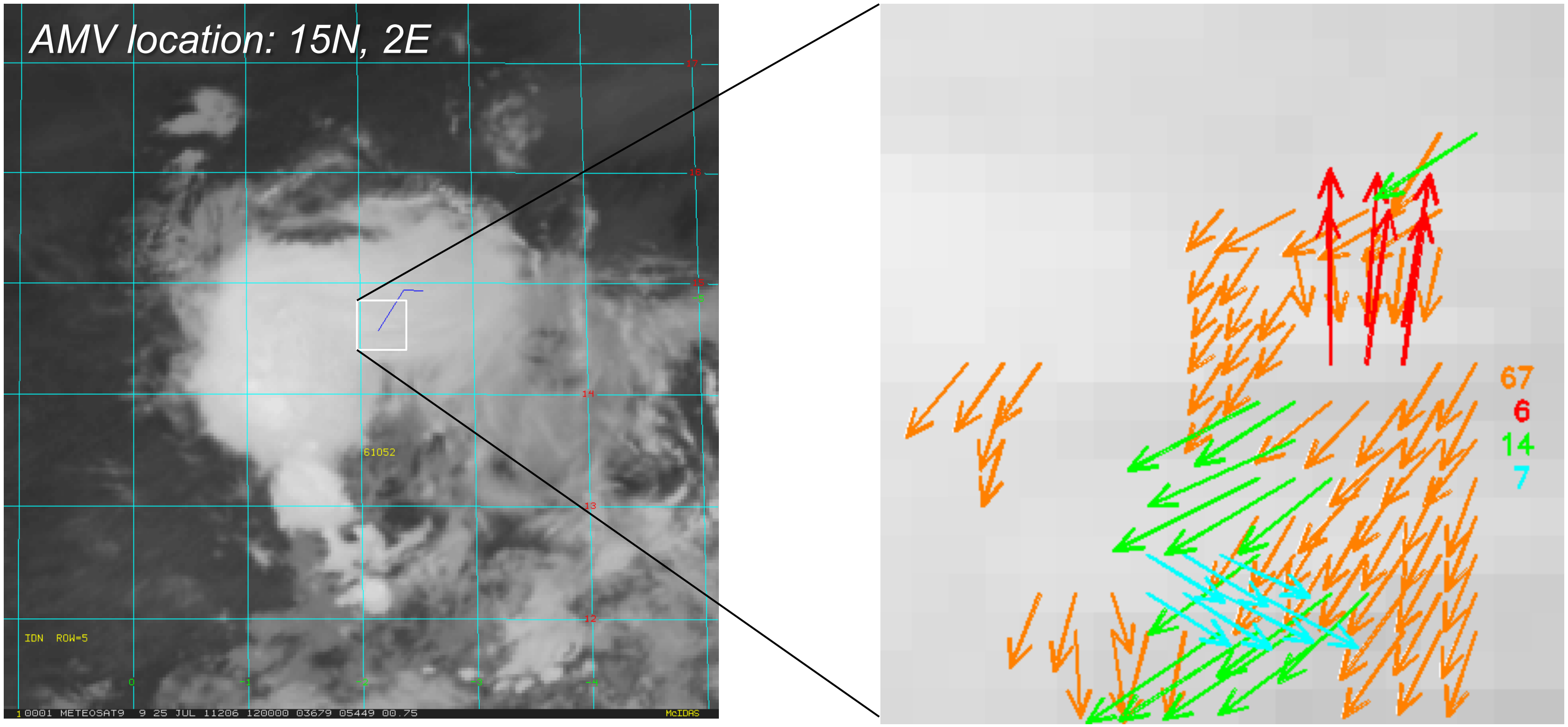




Divergent Flow Example in the Tropics

Derived AMV

Local Motion Clusters



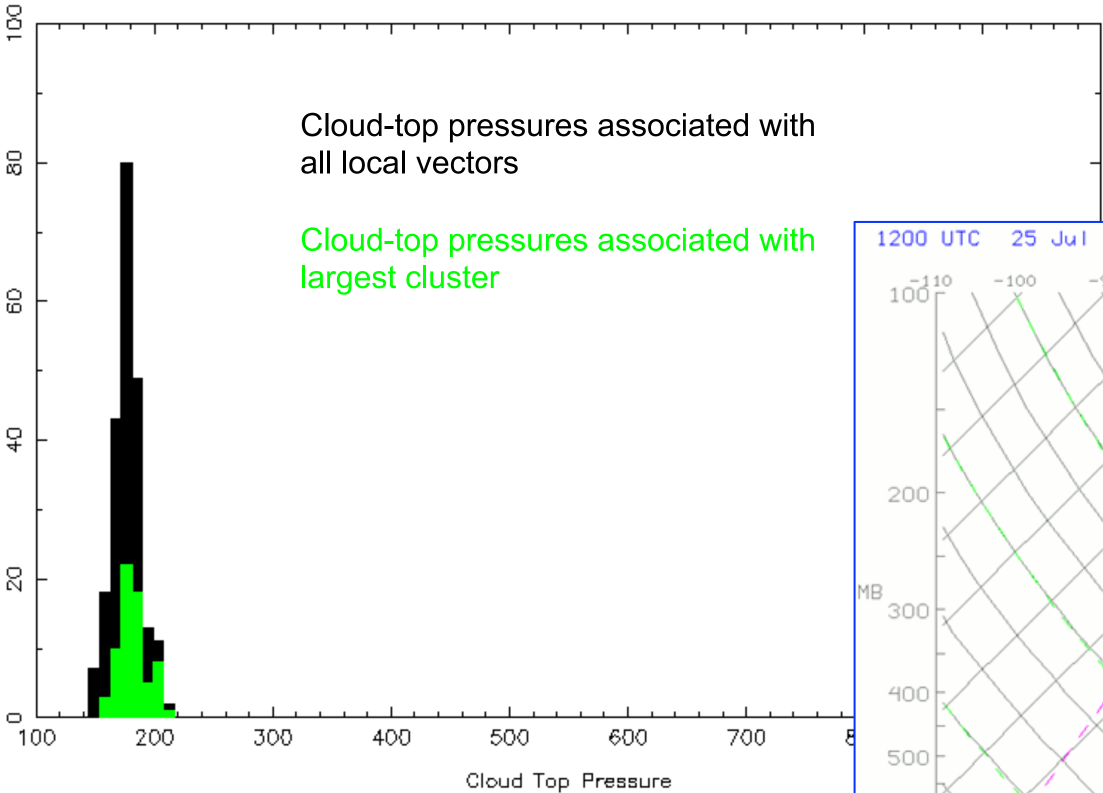
Derived AMV (left) is an average of local vectors from the orange (largest) cluster

AMV derived from Green cluster (2nd largest cluster) is a better fit to radiosonde wind at 200 mb

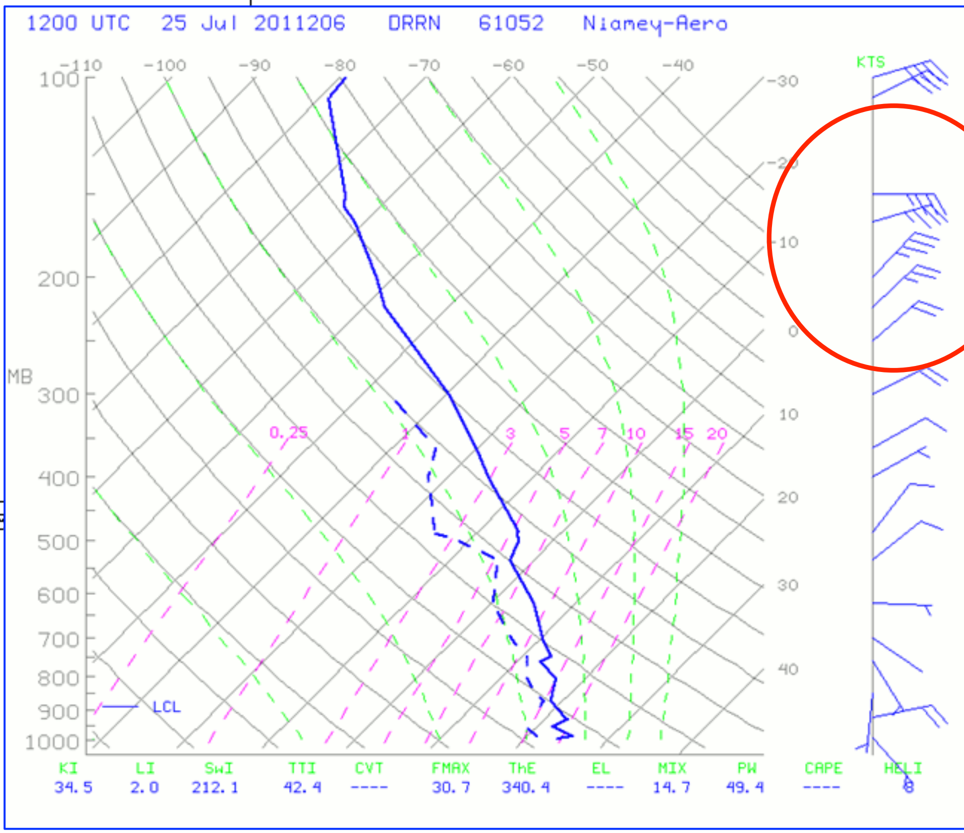
Case illustrates the challenge of deriving winds in the tropics where convection is very prevalent

Case illustrates ability of approach to extract motions at different scales

Divergent Flow Example in the Tropics



Nearby Radiosonde



AMV derived from Green cluster (2nd largest cluster) shown on previous slide is a better fit to radiosonde wind at 200 mb

Ongoing Activities and Plans

- **Submitted a journal article on nested tracking algorithm to JAMC (in review)**
- **Supporting industry's implementation of GOES-R Winds algorithm into the GOES-R Ground System**
- **Continuing our Validation Related Activities**
  - Continue routine processing (hourly) of winds using Meteosat-9/SEVIRI imagery (VIS, SWIR, WV, LWIR) for continuing validation of nested tracking algorithm
  - Search for outliers, analyze, and understand (case studies)
  - Develop, test, and validate algorithm adjustments
  - Validation tool development **(Steve Wanzong will talk more about this Wed morning)**
- **Assessing Nested Tracking Winds in the NCEP GFS Data Assimilation System**
  - Use Met-9 winds first, then GOES-13/15
  - Derive initial data assimilation stats (O-B) and develop assimilation quality control procedures that make use of new information (quality indicators, cluster size, cloud phase, cloud type, etc)
  - Conduct forecast impact studies **(Sharon Nebuda will talk more about this Tues afternoon)**
- **Funded projects underway to transition nested tracking algorithm into NESDIS operations for:**
  - Current GOES series. Goal: Replace heritage AMV algorithm. (Spring 2013 – running in operations)
  - VIIRS winds (Dec 2012) **(Jeff Key will talk more about this Tues morning)**

Summary

- **Nested tracking approach effectively minimizes the slow speed bias**
  - Most speed “adjustments” are small, but some can exceed 10 m/s
  - Smaller bias a result of lower heights and faster winds
  - Expected to benefit NWP

- **Nested tracking approach also significantly reduces RMSE**
  - Greatest benefit seen at upper levels for IR winds
  - Smaller improvements for cloud-top WV

- **Identified opportunities with the nested tracking approach**
  - Additional clusters may contain useful wind information in the target scene
  - Use pixel level heights from cluster analysis to report layer information.
  - Clustering metrics may enable new quality control to be employed
    - Number of points in cluster
    - Number of clusters
    - mean distance of points in cluster
  - Extend cluster analysis to include height

- **Funded to extend new approach to current GOES and VIIRS winds processing**

- **Funded to assess impact of nested tracking winds in NCEP’s GFS System**

Backup Slides

GOES-R ABI vs. GOES Imager

	ABI	GOES Imager
Spectral Coverage		
	16 bands	5 bands
Spatial resolution		
0.64 μm Visible	0.5 km	Approx. 1 km
Other Visible/near-IR	1.0 km	n/a
Bands (>2 μm)	2 km	Approx. 4 km
Spatial/Temporal coverage		
Full disk	4 per hour	Scheduled (3 hrly)
CONUS	12 per hour	~4 per hour
Mesoscale	Every 30 sec	n/a
Visible (reflective bands)		
On-orbit calibration	Yes	No

ABI Level-2 product algorithms will take advantage of the ABI's improved spectral coverage, higher spatial resolution, and improved temporal coverage.

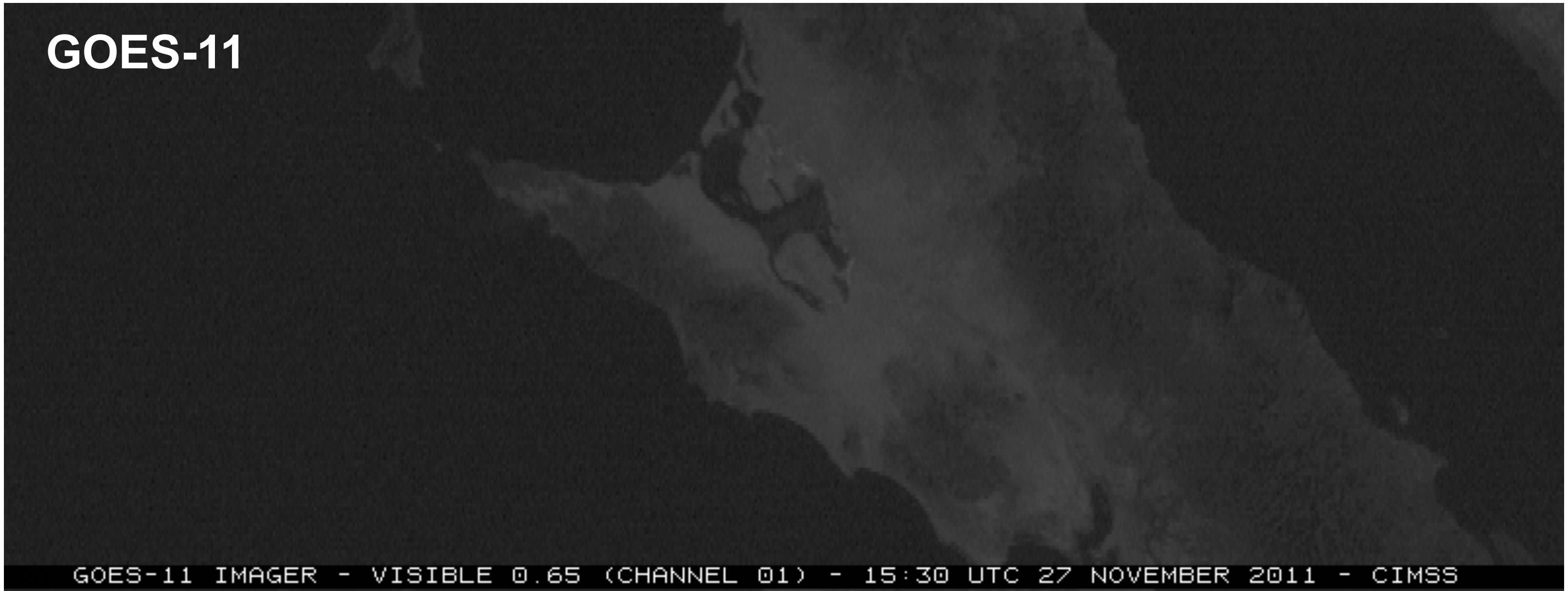
Channel Noise Comparison

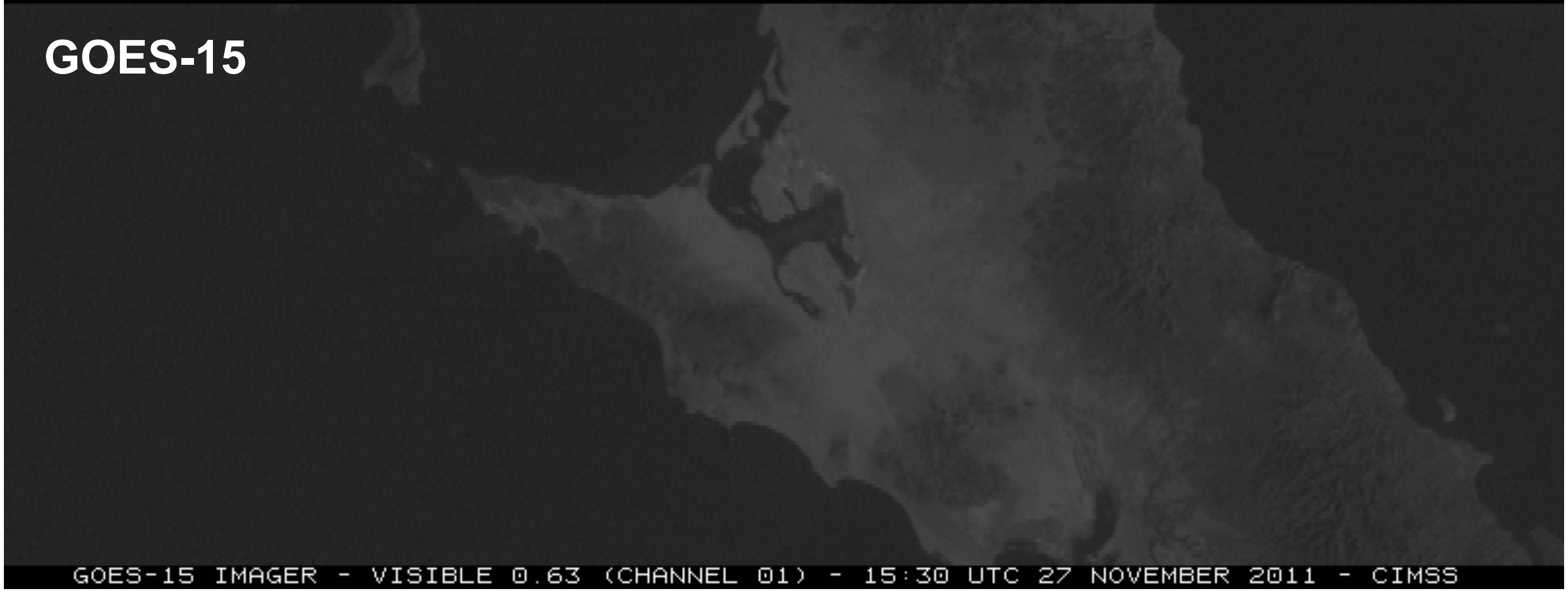
GOES-R ABI			GOES Imager			GOES-12	GOES-15
Channel	Freq.(um)	Spec	Channel	Freq. (um)	Spec	Measured (PLT)	Measured (PLT)
7	3.9	0.1	2	3.9	1.4	0.130	0.063
8	6.185	0.1					
9	6.95	0.1	3	6.x	1.0	0.15	0.17
10	7.34	0.1					
11	8.5	0.1					
12	9.61	0.1					
13	10.35	0.1					
14	11.2	0.1	4	10.7	0.35	0.11	0.06
15	12.3	0.1	5	12.0	0.35	-	-
16	13.3	0.3	6	13.3	0.32	0.19	0.13

GOES-R ABI: Instrument noise will be similar to that measured for current GOES even with the much finer spatial resolutions!

Improved Navigation & Registration

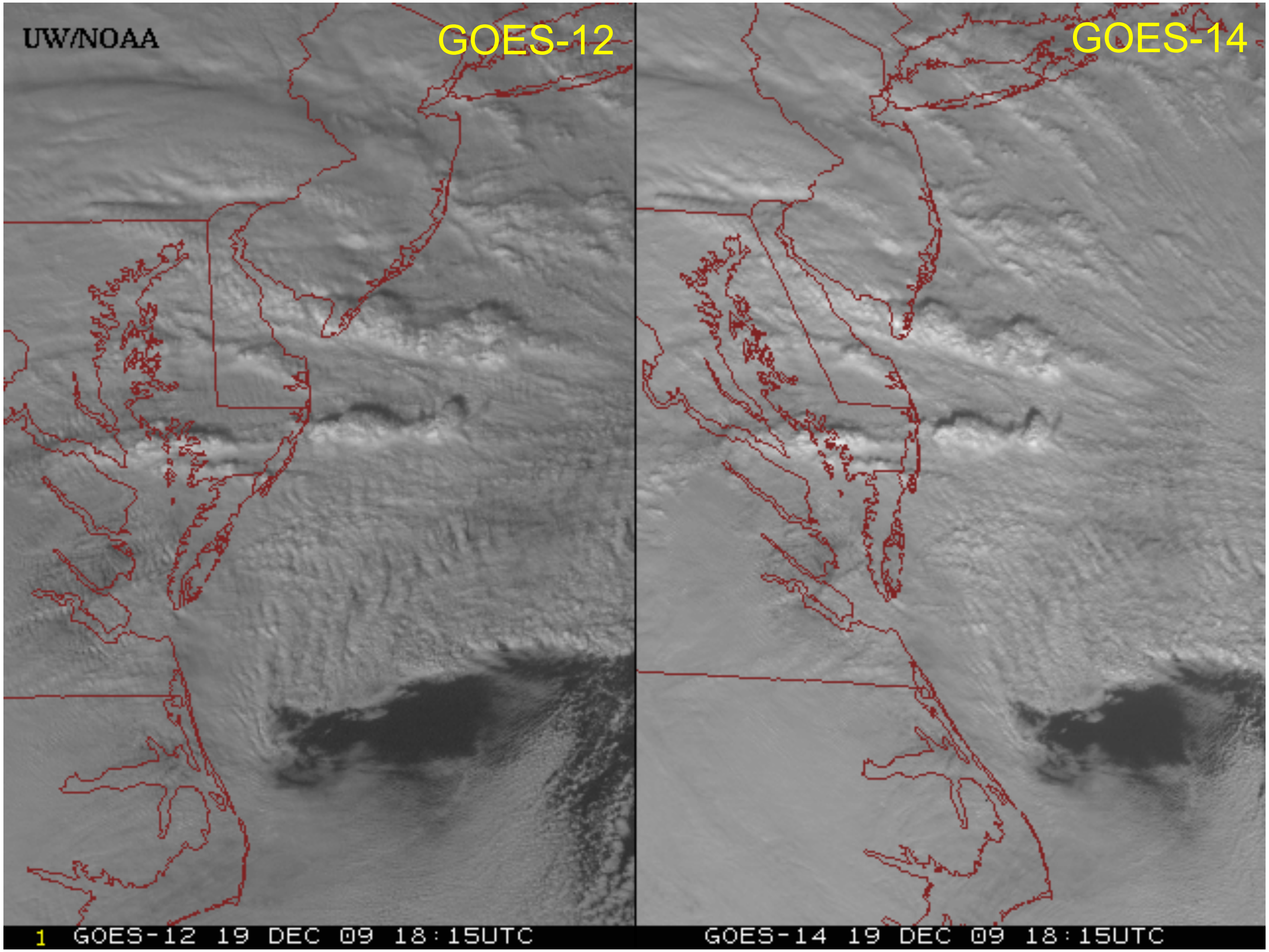
GOES-15 provides a hint of ABI's INR quality…





GOES-14: Sample "1-min" imagery

A hint of what GOES-R will routinely provide…



Visible data from the GOES-14 NOAA Science Test, lead by Hillger and Schmit