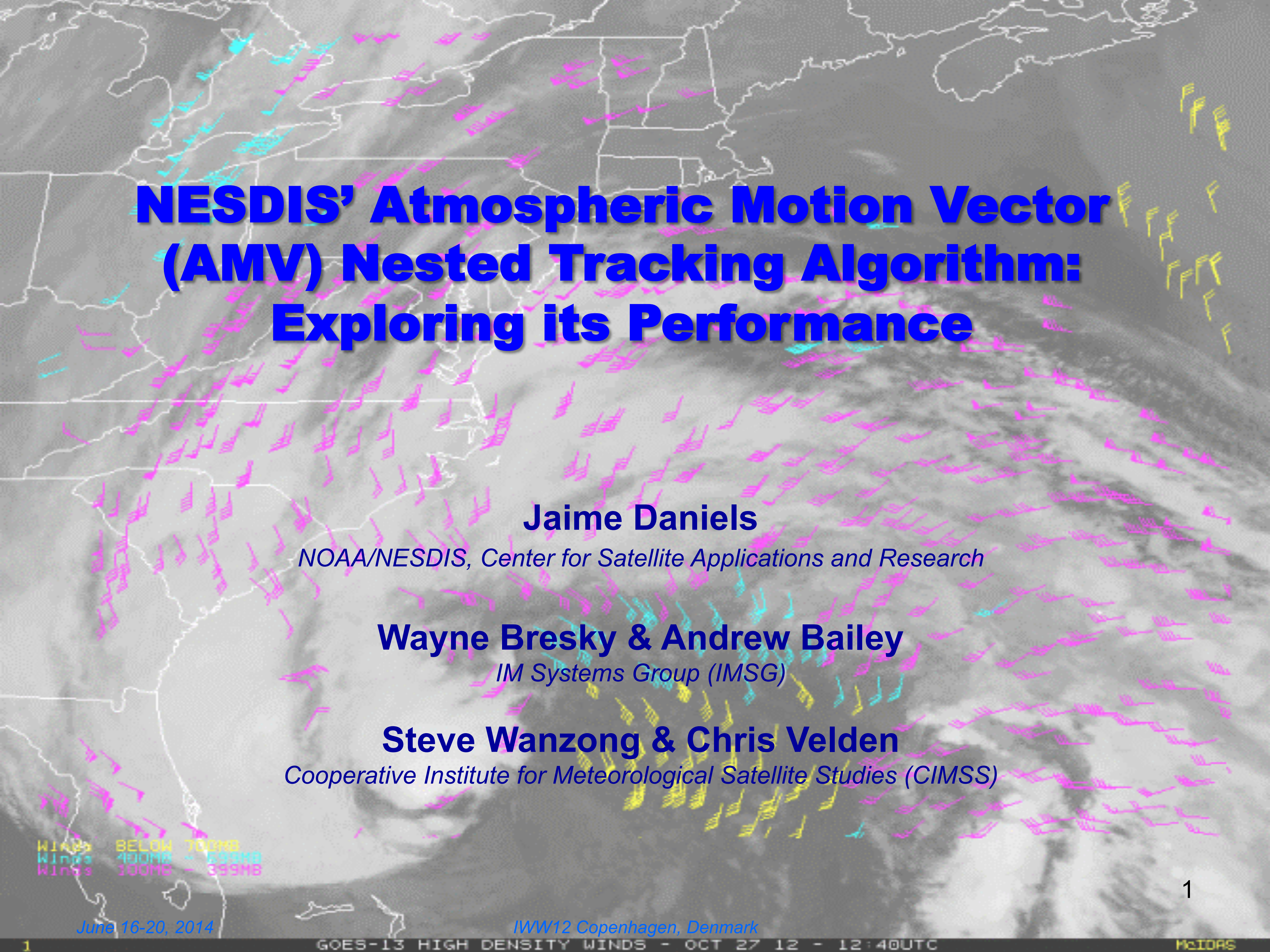

NESDIS' Atmospheric Motion Vector (AMV) Nested Tracking Algorithm: Exploring its Performance

Jaime Daniels
NOAA/NESDIS, Center for Satellite Applications and Research

Wayne Bresky & Andrew Bailey
IM Systems Group (IMSG)

Steve Wanzong & Chris Velden
Cooperative Institute for Meteorological Satellite Studies (CIMSS)

Topics

- Some GOES-R Information
- Review of Nested Tracking Approach
- Some Examples: Application to an Assortment of Imagers
  - *Using Available ABI Proxy Data…*
- Performance
  - *Overall, individual cases, experimentation with new ideas*
- Ongoing Activities and Plans
- Summary

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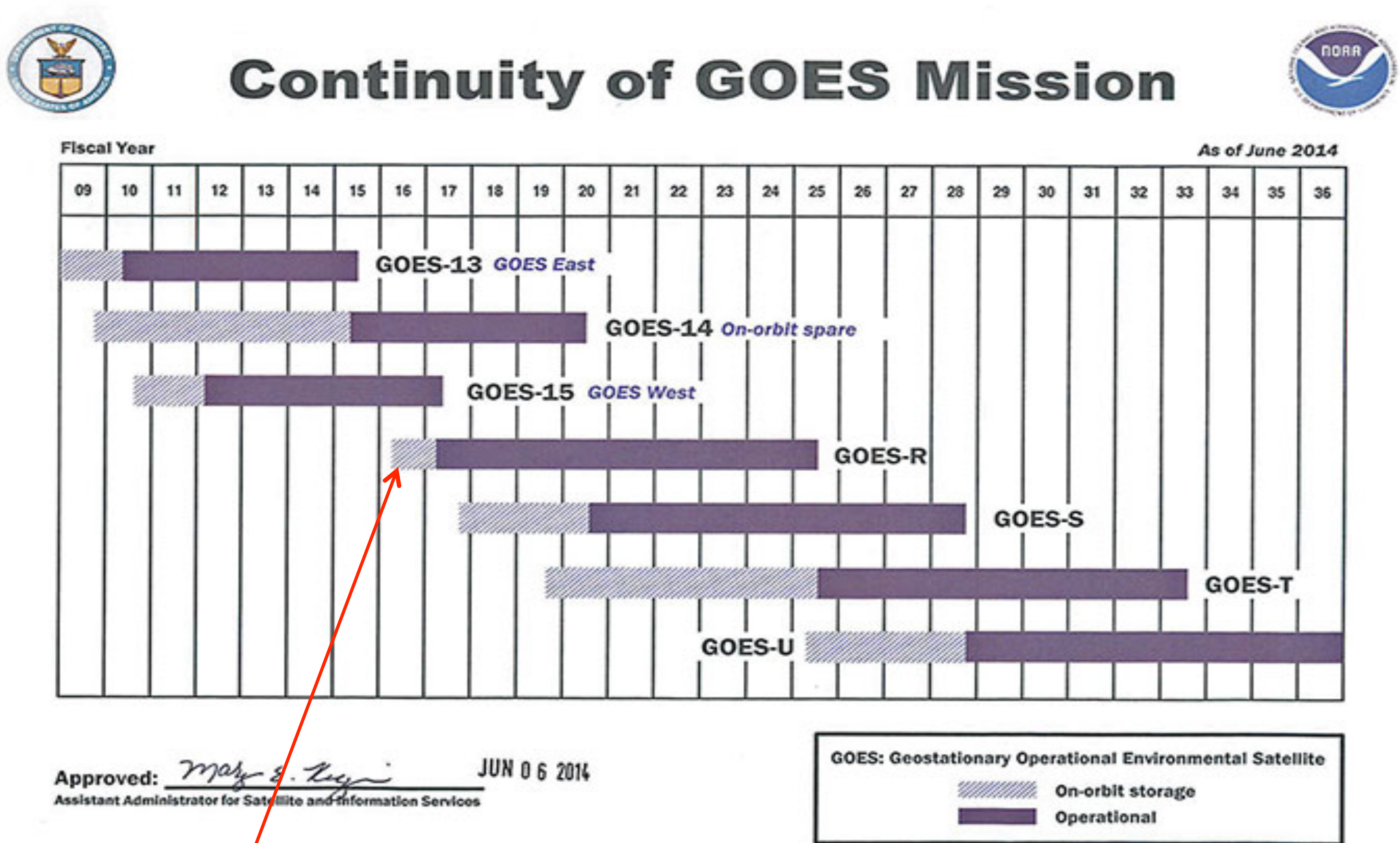

GOES-R Launch Date: *No later than March 31, 2016*

The Advanced Baseline Imager

	ABI		Current 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 coverage	*Scan Mode 3*	*Scan Mode 4*	
Full disk	**4 per hour**	**12 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 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, 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 IR Bands

Future GOES imager (ABI) band	Wavelength range (µm)	Central wavelength (µm)	Nominal subsatellite IGFOV (km)	Sample use
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

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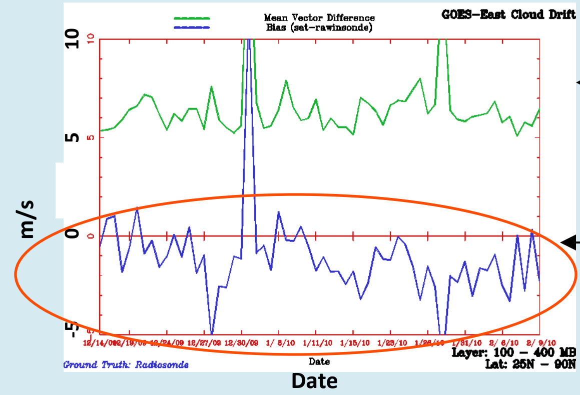
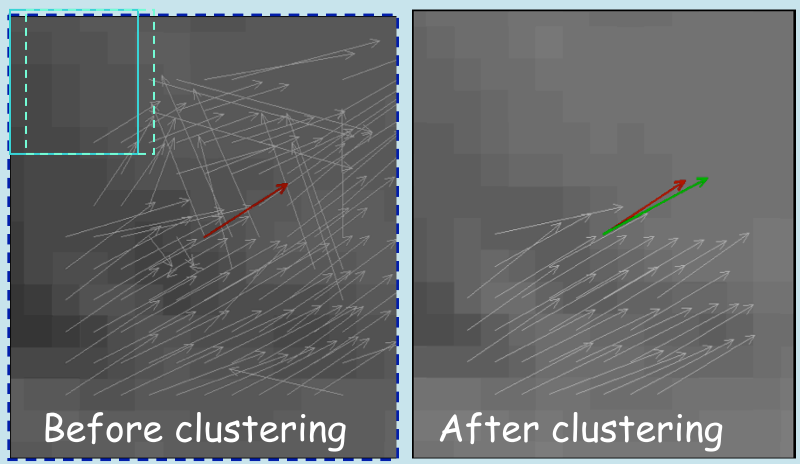
Nested Tracking Approach

- Designed to minimize observed slow speed bias of satellite winds; *<u>a long standing concern of the NWP community</u>*
- Computes local motions (nested) within a larger target scene, together with a clustering algorithm, to arrive at a motion solution(s)
- Potential for determination of motion at different levels and/or different scales
- Cloud heights at pixels belonging to the largest cluster are used to assign a representative height to the derived motion wind

GOES-12 Satwinds vs. Rawinsonde (100-400 hPa)





Nested Tracking Approach*

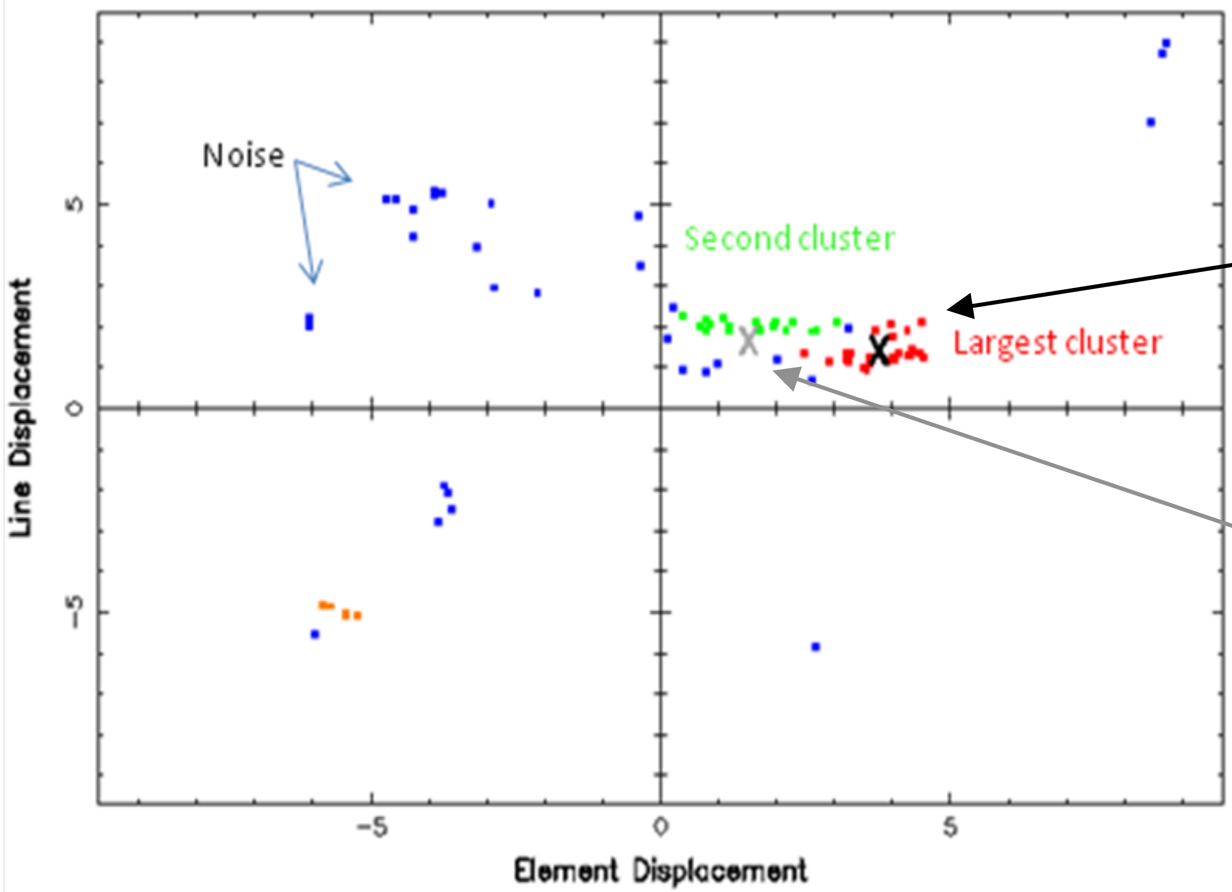
- **Use local motion vectors to extract dominant motion(s)**
  - Perform cluster analysis of line and element displacements
  - Use a density-based cluster analysis scheme (DBSCAN**)
- **Link pixels driving tracking solution(s) to final height assignment**
  - Use the median of pixel level cloud heights associated with each cluster.

***** Bresky, W., J. Daniels, A. Bailey, and S. Wanzong, 2012:** *New Methods Towards Minimizing the Slow Speed Bias Associated With Atmospheric Motion Vectors (AMVs). J. Appl. Meteor. Climatol., 51, 2137-2151*

****** 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 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

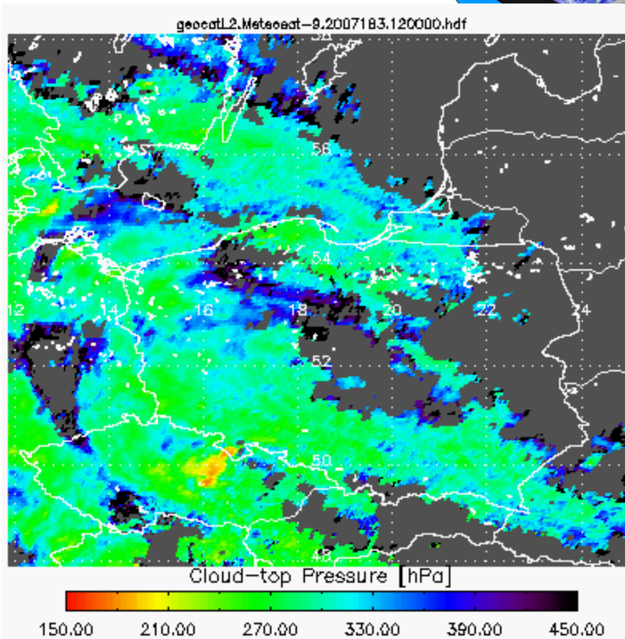
Nested Tracking & Clustering Details

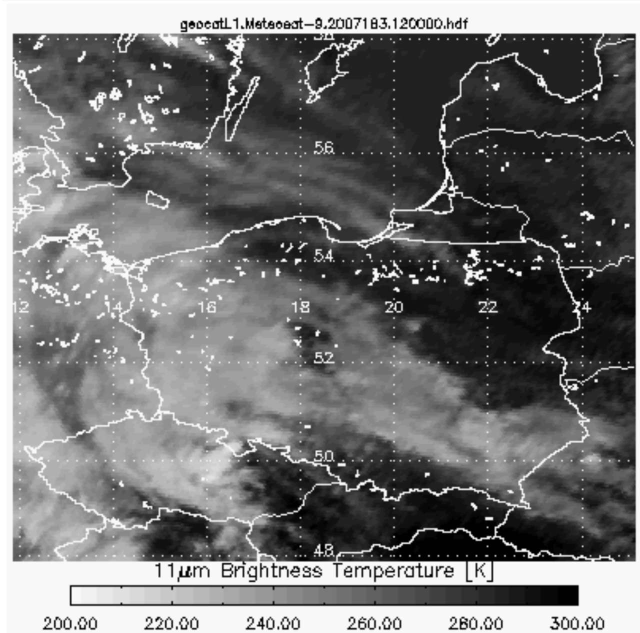
- **Size of outer target scene is 19x19 pixels**
  - 2-pixel offset is used that yields a maximum of 225 possible local motion estimates derived from nested 5x5 target scenes

- **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*
    - "Core" cluster point: Has at least 4 points in neighborhood (radius)
    - "Boundary" point: Has fewer than 4 neighbors, but connected to neighborhood by at least one other point
    - "Noise": Point does not belong to any cluster

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).
  - NWP forecast temperature profiles used to compute cloud-top pressure and height.
  - For pixels typed as containing multi-layer clouds, a multi-layer solution is performed.
  - Special processing occurs in the presence of low level temperature inversions.

- **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.

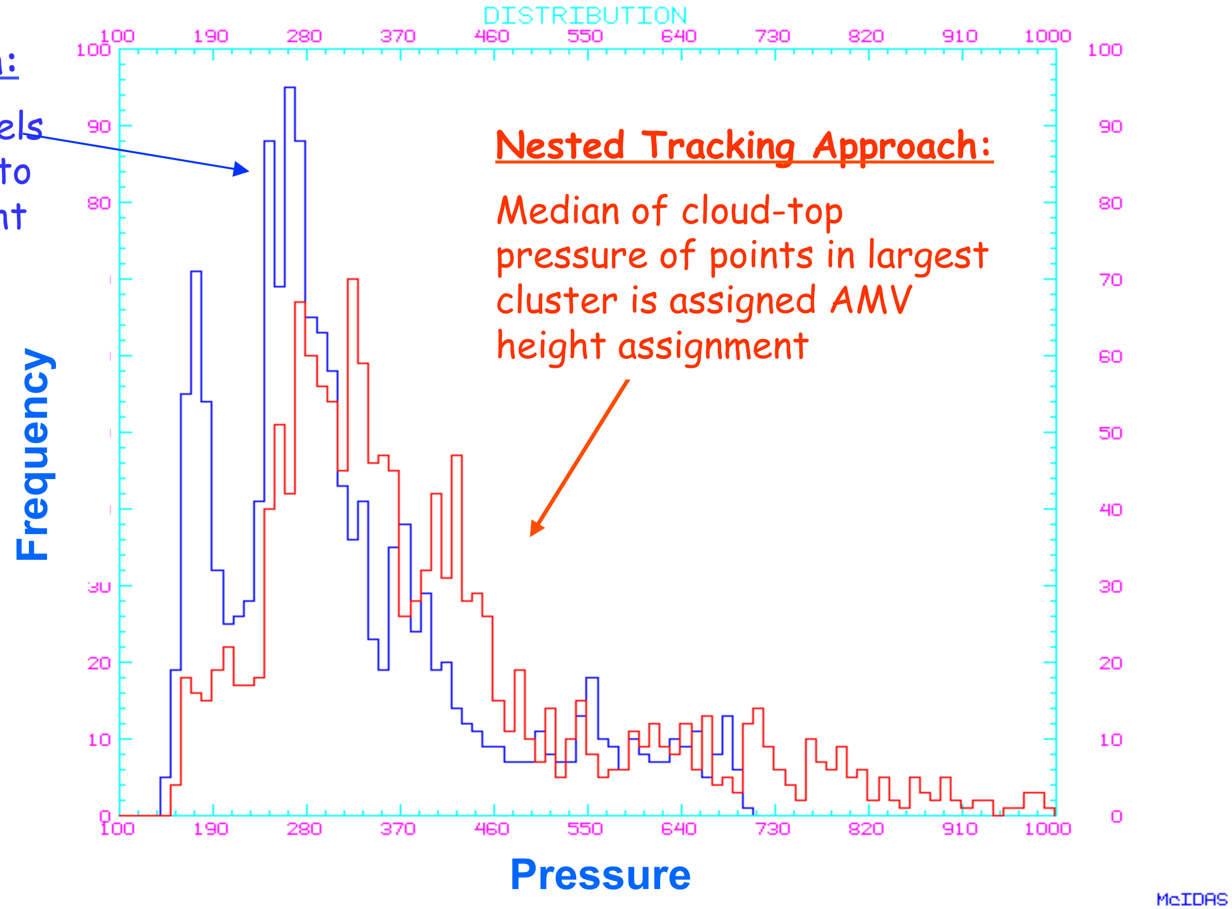
Please visit Andy Heidinger (NOAA/NESDIS) at his poster to learn more about this cloud height algorithm!!

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

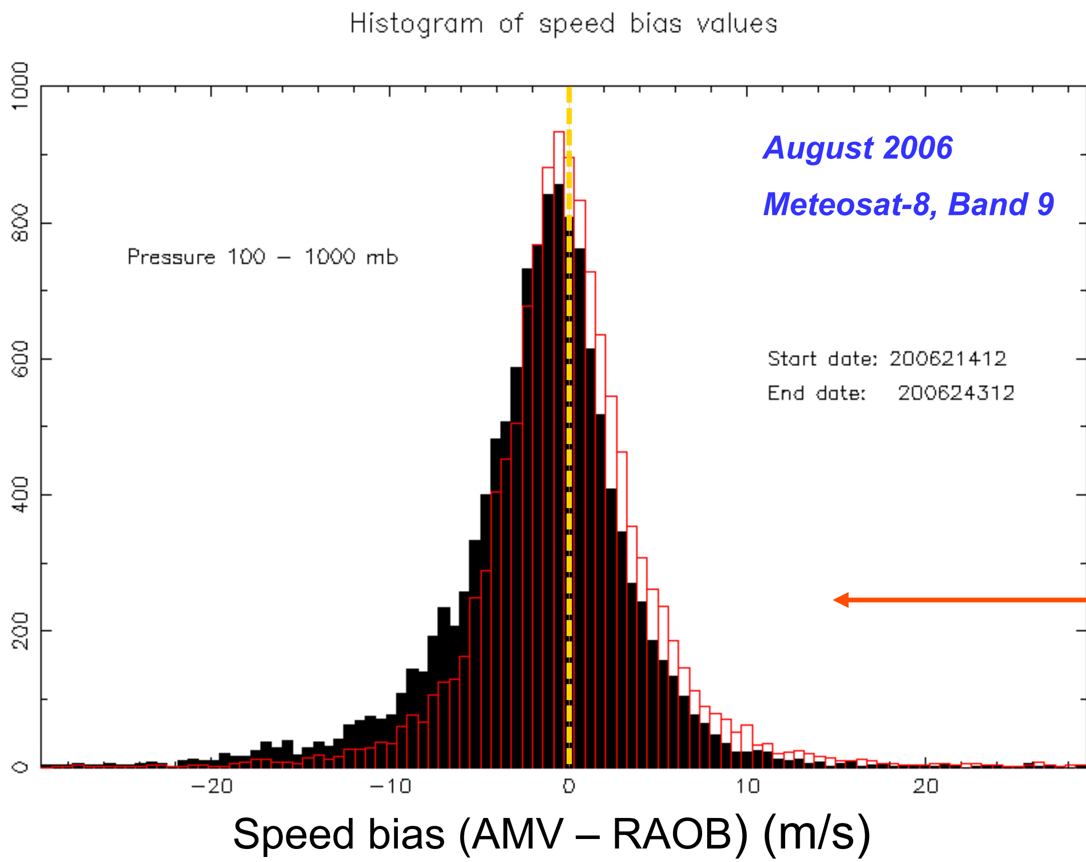
Impact is to push AMV height assignments lower in the atmosphere

Nested Tracking Approach

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 conventional tracking

Red histogram shows nested tracking

Test distribution shifted right

- Due to faster AMVs and/or lower heights

Nested Tracking Output

- **Standard deviation of displacements (in pixels) in largest cluster**
  - Sample 1 (reverse vector), Sample 2 (forward vector)
- **Standard deviation of displacements divided by magnitude of average displacement**
  - Sample 1 (reverse vector), Sample 2 (forward vector)
- **Size of largest cluster**
  - Sample 1 (reverse vector), Sample 2 (forward vector)
- **Median, Minimum, and Maximum cloud-top pressure (hPa) in largest cluster**
- **Median, Minimum , and Maximum cloud-top temperature (K) in largest cluster**
- **Median, Minimum , and Maximum cloud optical depth 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 about the parameters she tested with and found useful.
These variables are part of the new proposed winds BUFR sequence

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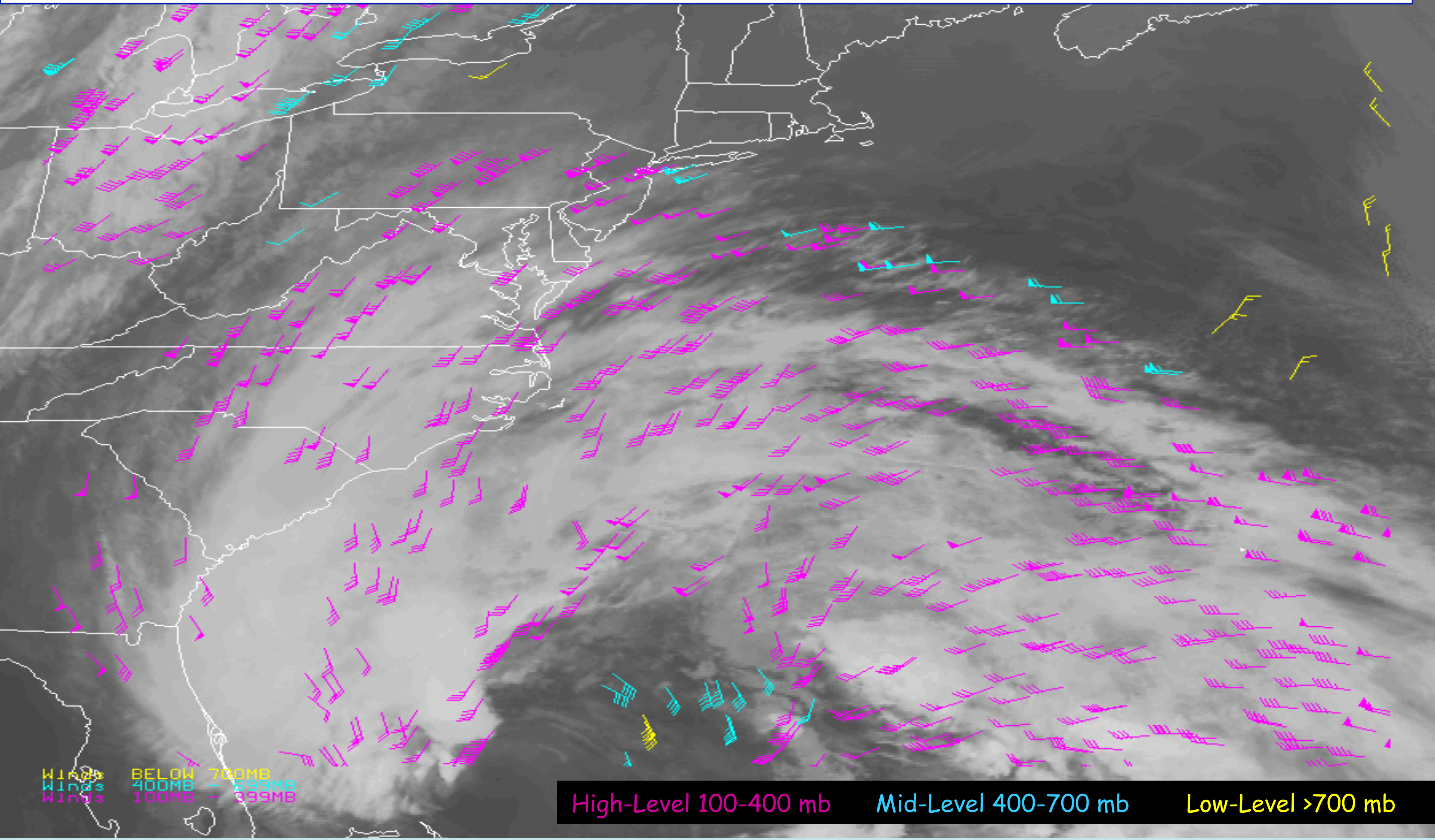
Application to Current GOES

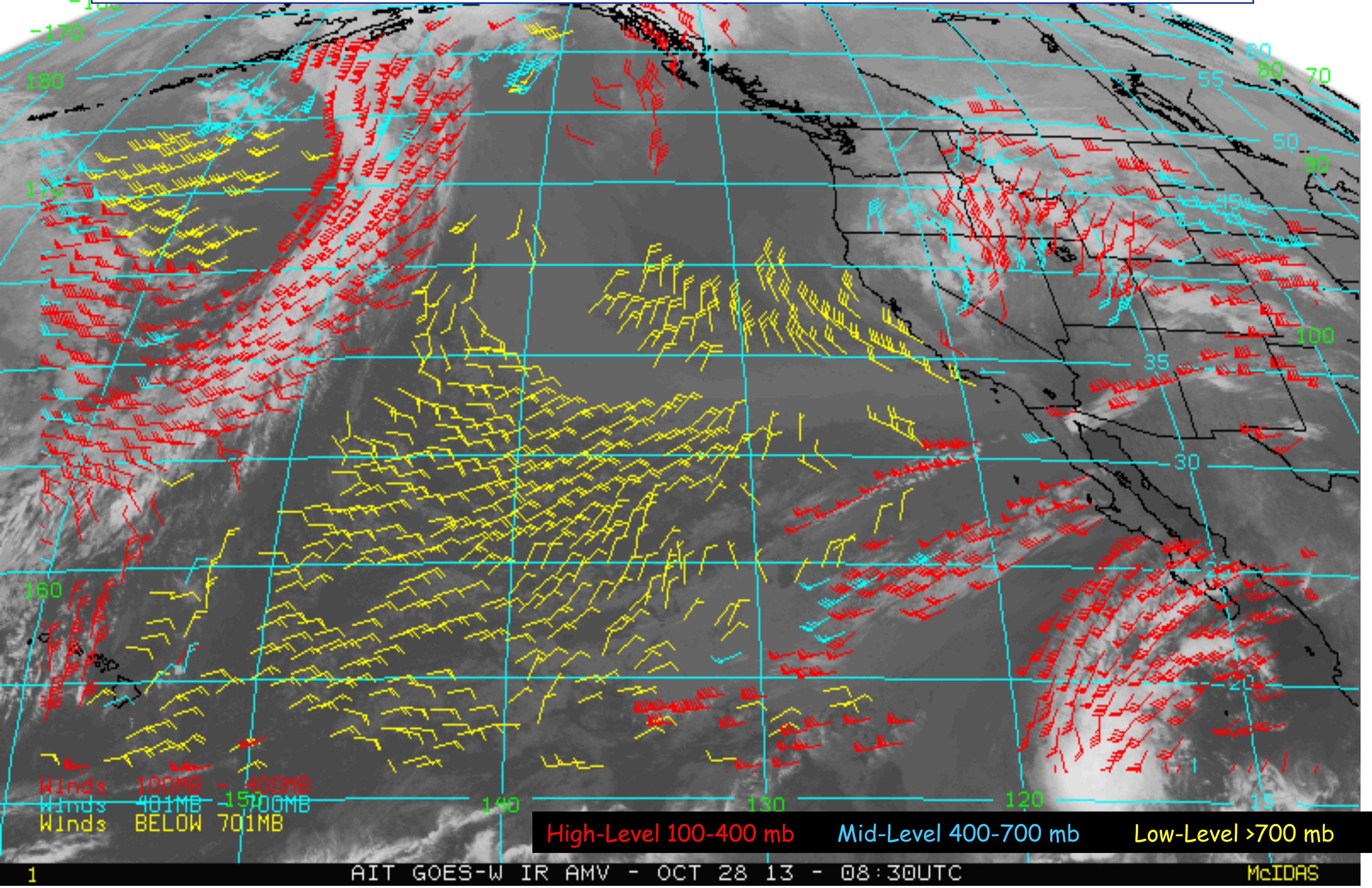
Cloud-drift winds derived from 15-min GOES-13 imagery over Hurricane Sandy (4-day loop)



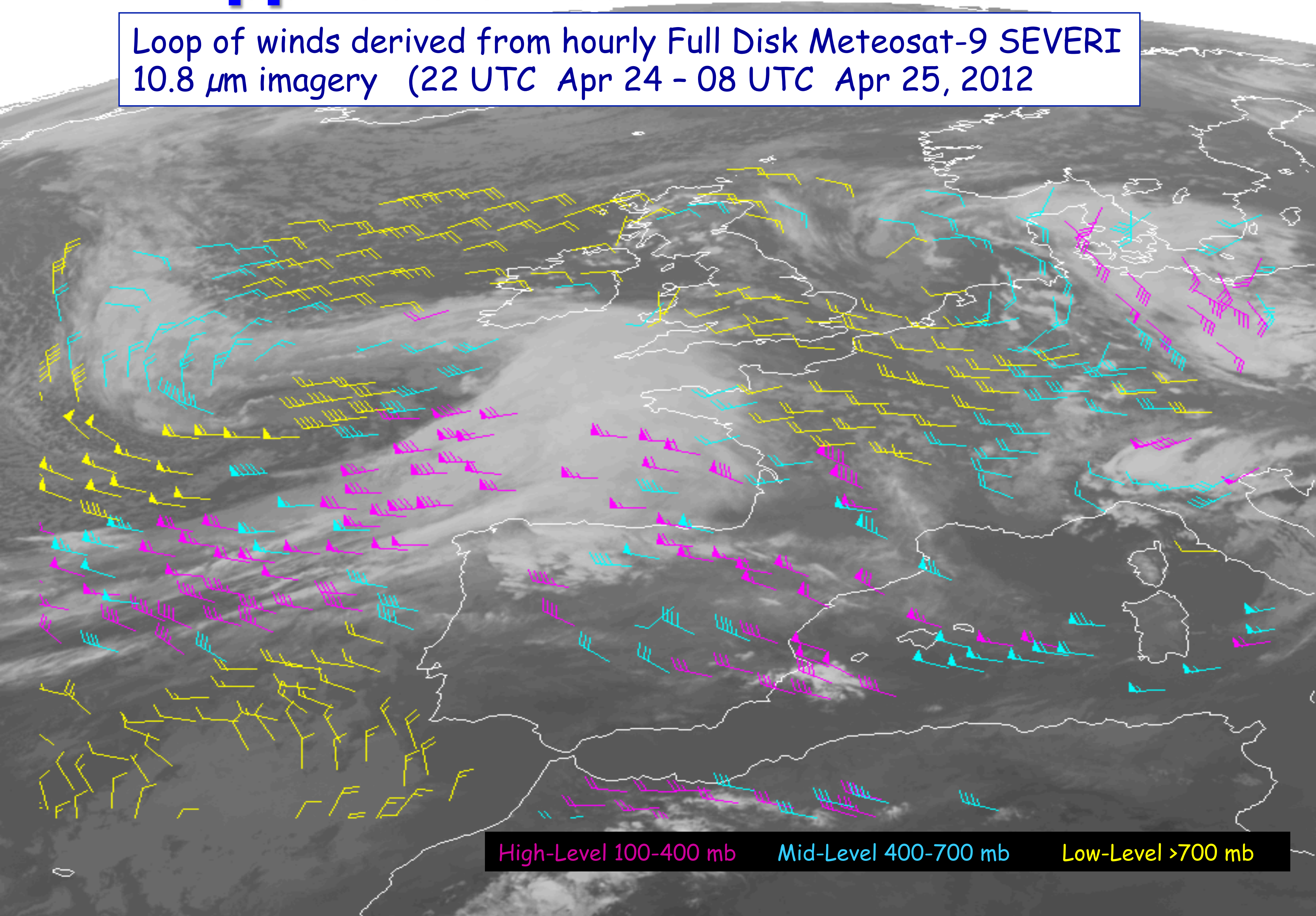
*The GOES-R Winds Team continues to routinely generate and validate ABI proxy winds from **GOES-13, GOES-15, Meteosat-10/SEVIRI, and NPP/VIIRS** using the GOES-R winds algorithm.*

Application to Current GOES

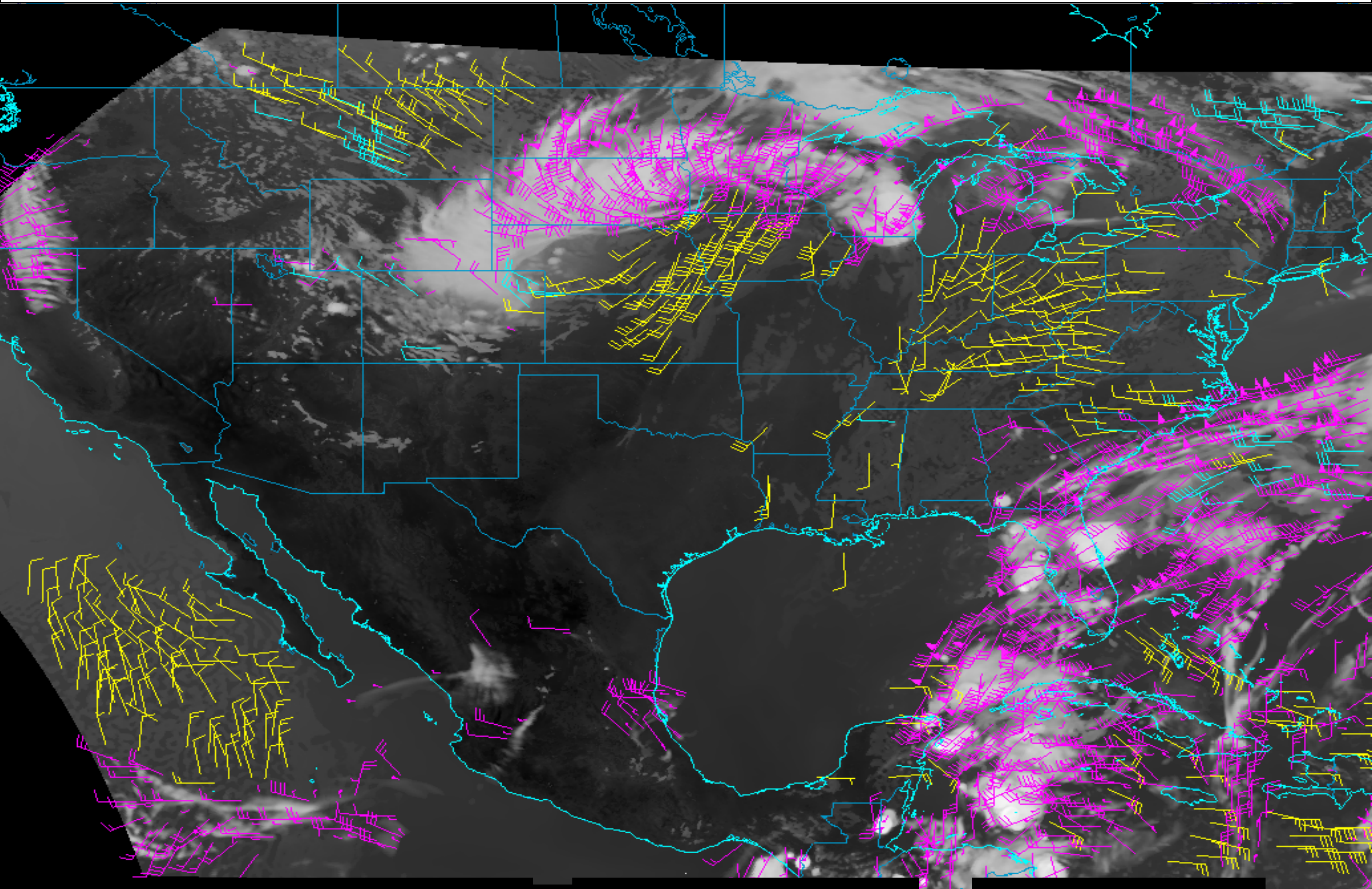
Cloud-drift winds derived from 15-min GOES-15 imagery over the East Pacific



Application to Meteosat/SEVIRI



Application to Simulated ABI Imagery

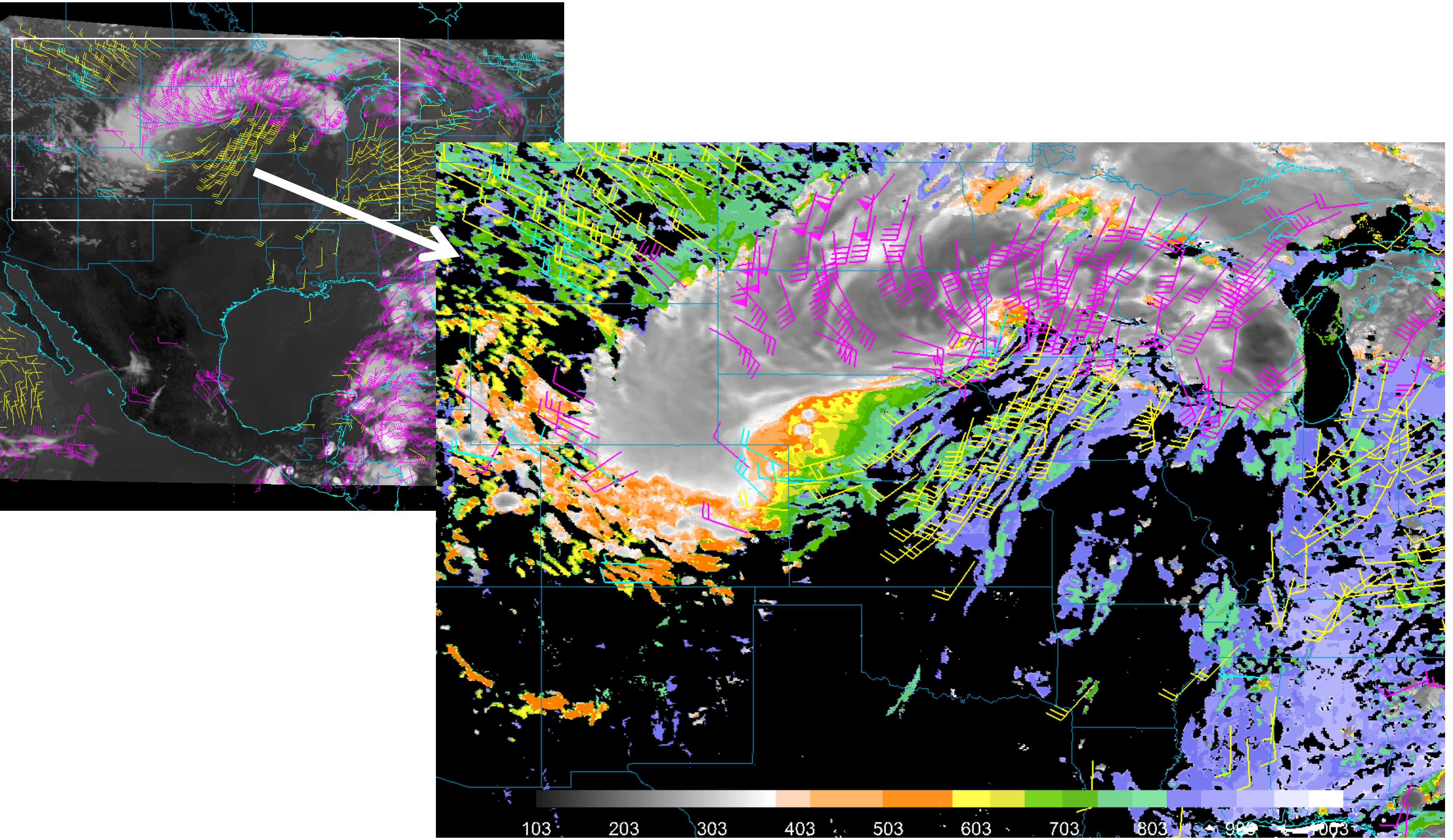


High-Level 100-400 mb

Mid-Level 400-700 mb

Low-Level >700 mb

Application to Simulated ABI Imagery



High-Level 100-400 mb

Mid-Level 400-700 mb

Low-Level >700 mb

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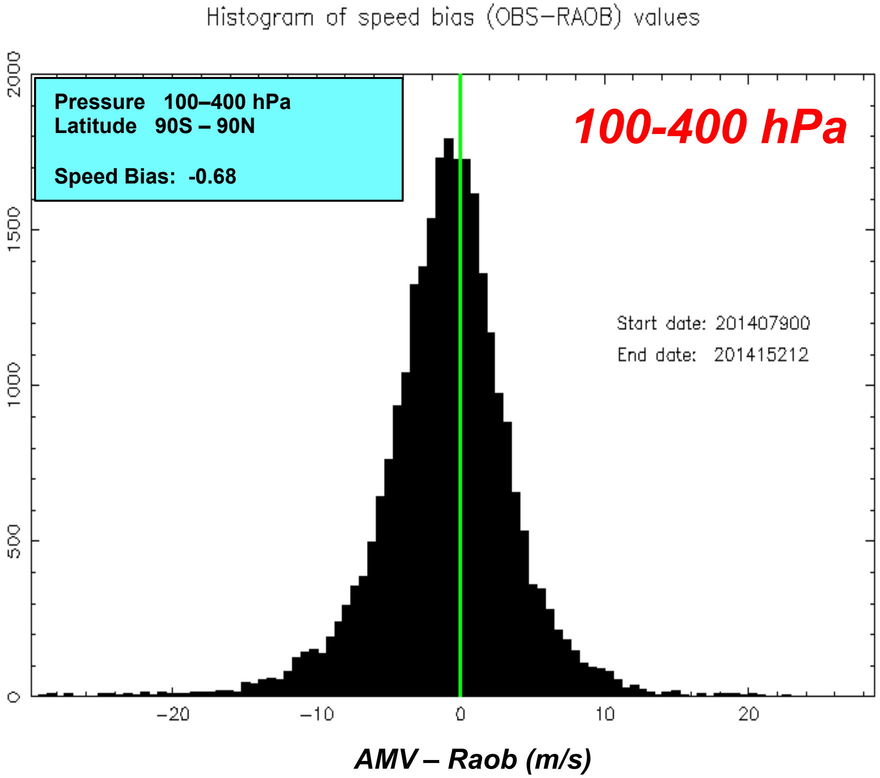
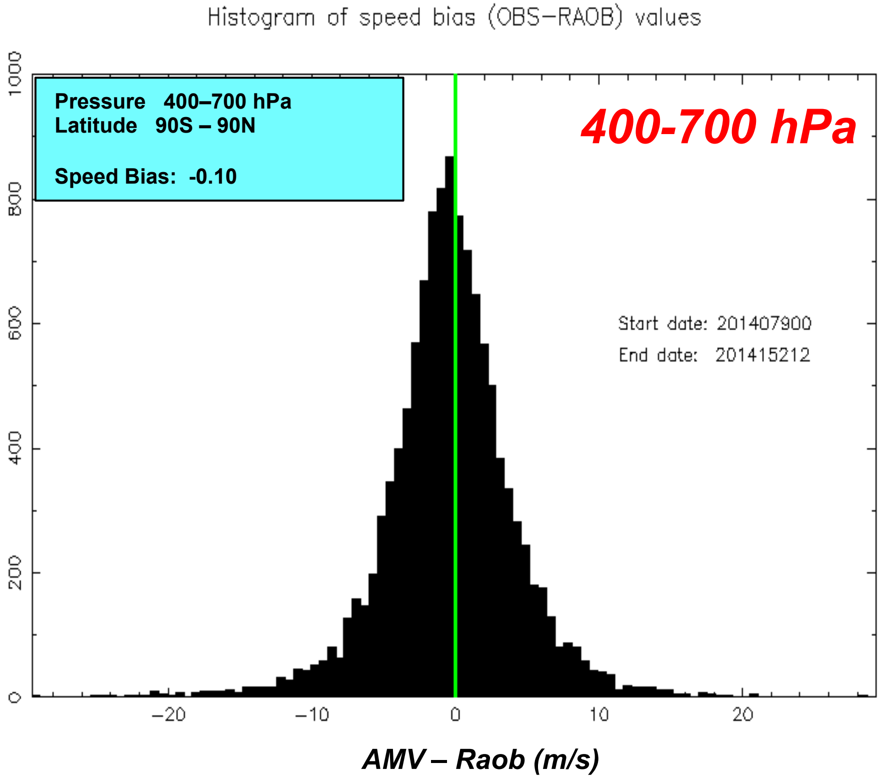
Validation

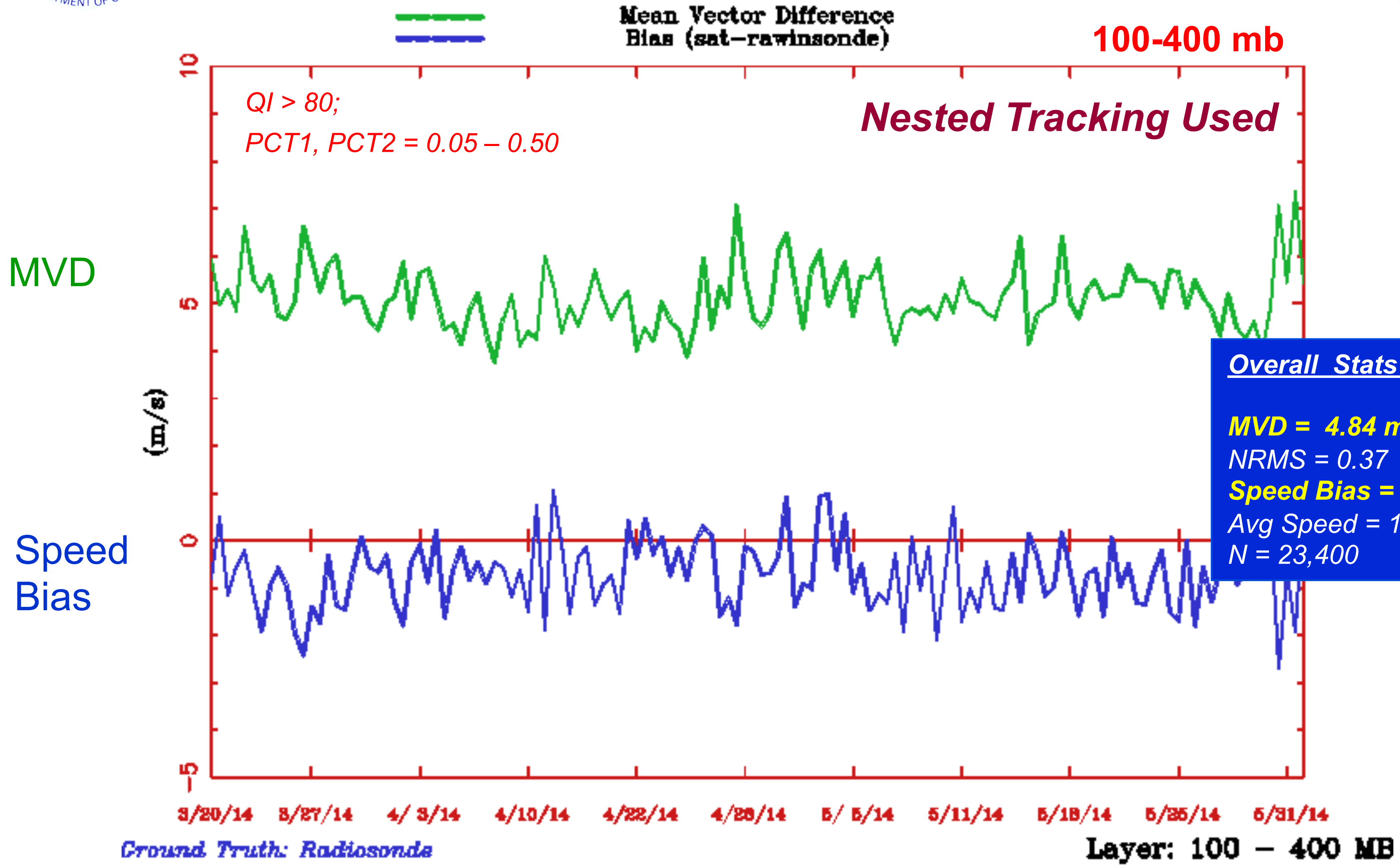
Speed Bias…





Meteosat-10/SEVIRI (10.8um) AMVs *(March 20 - June 2, 2014)*

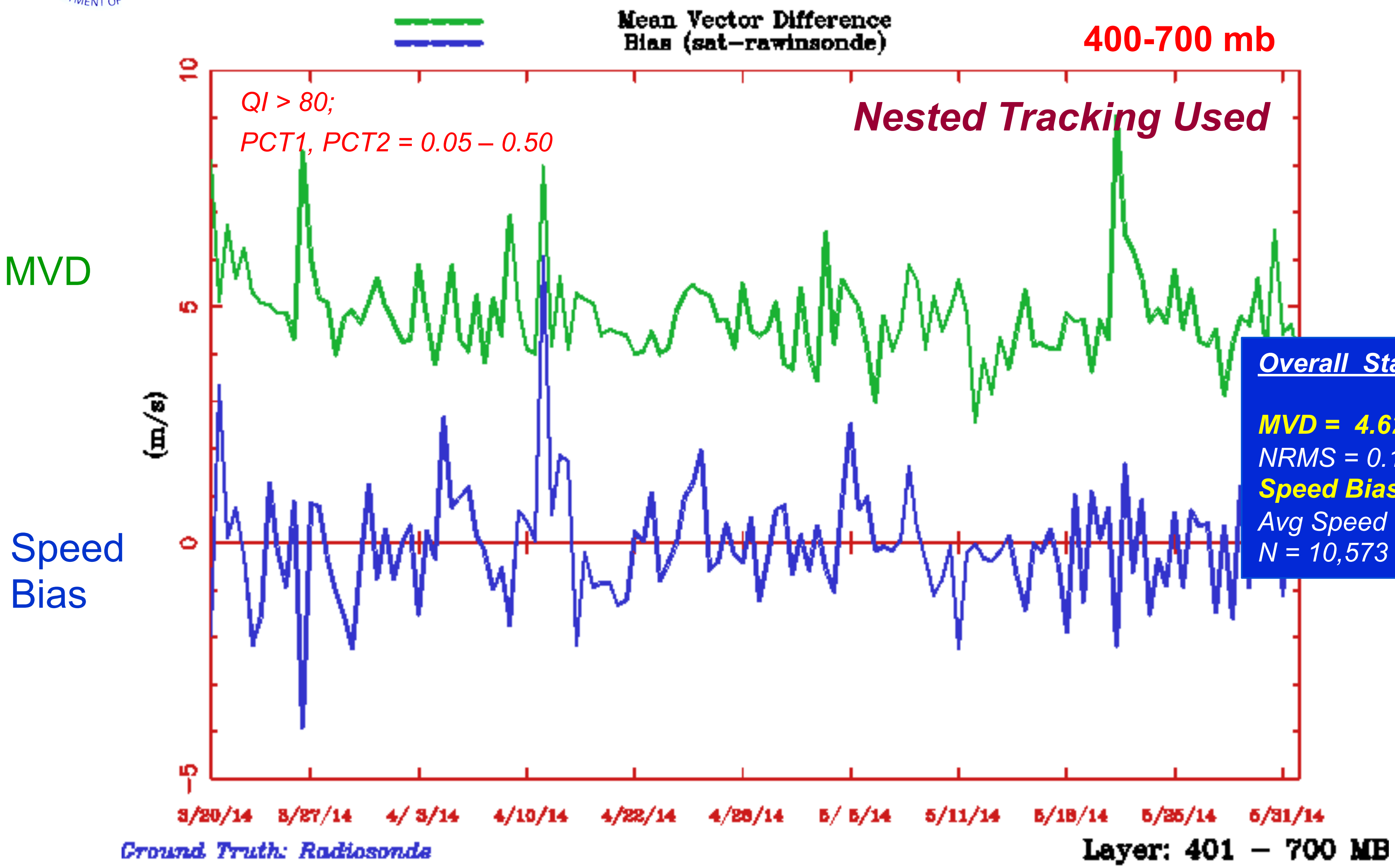
Meteosat-10/SEVIRI Winds (10.8um) vs Radiosondes



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

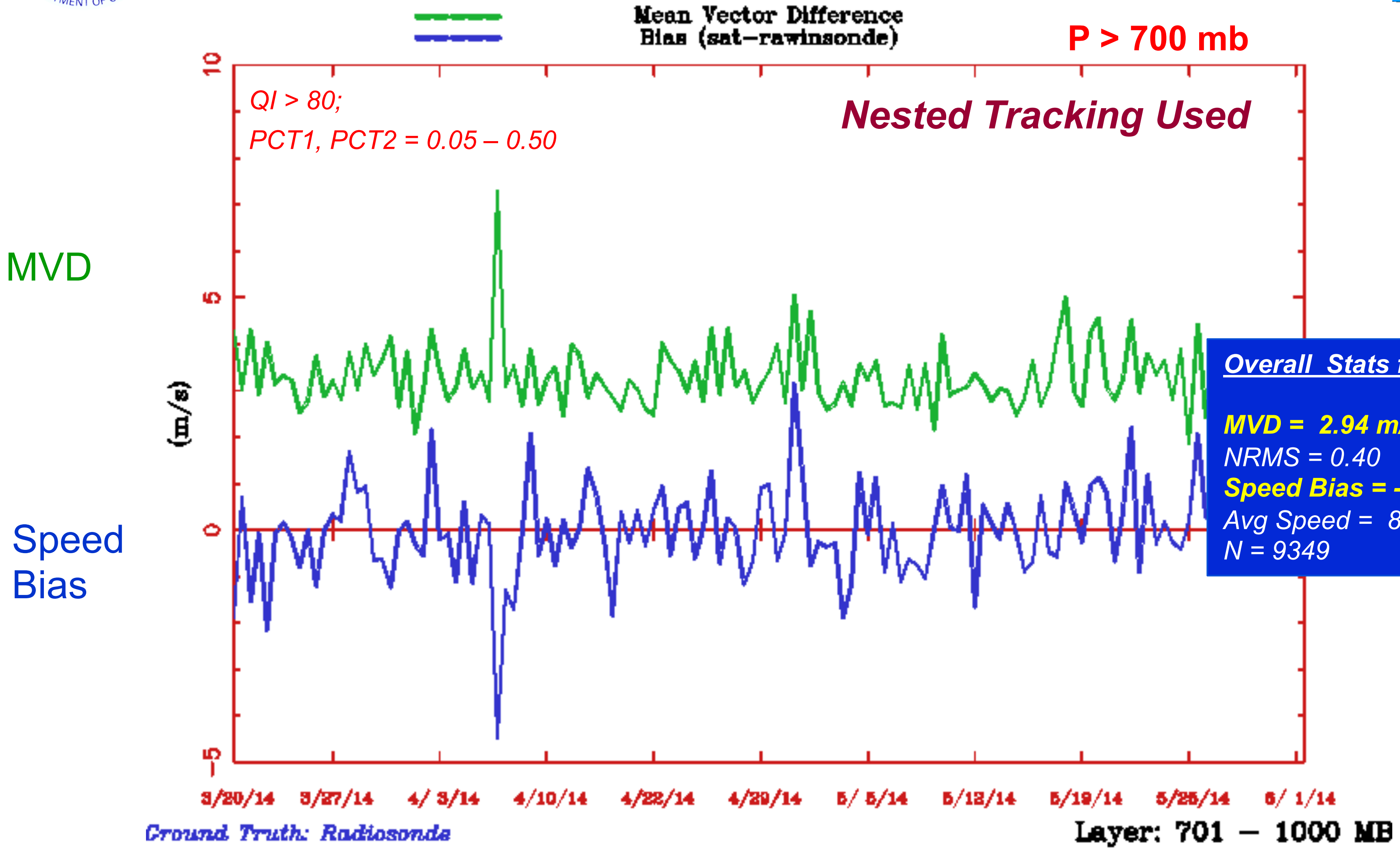
Meteosat-10/SEVIRI Winds (10.8um) vs Radiosondes



Overall Stats for Period:

MVD = 4.62 m/s
NRMS = 0.19
Speed Bias = -0.19 m/s
Avg Speed = 13.31 m/s
N = 10,573

Meteosat-10/SEVIRI Winds (10.8um) vs Radiosondes



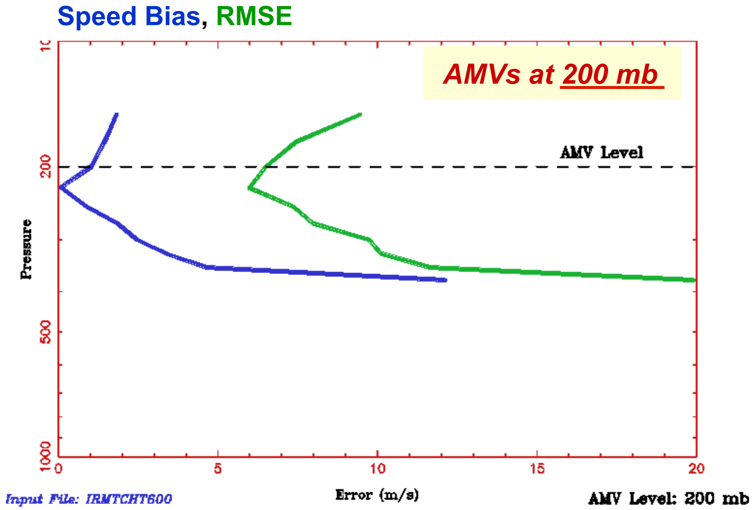
Overall Stats for Period:

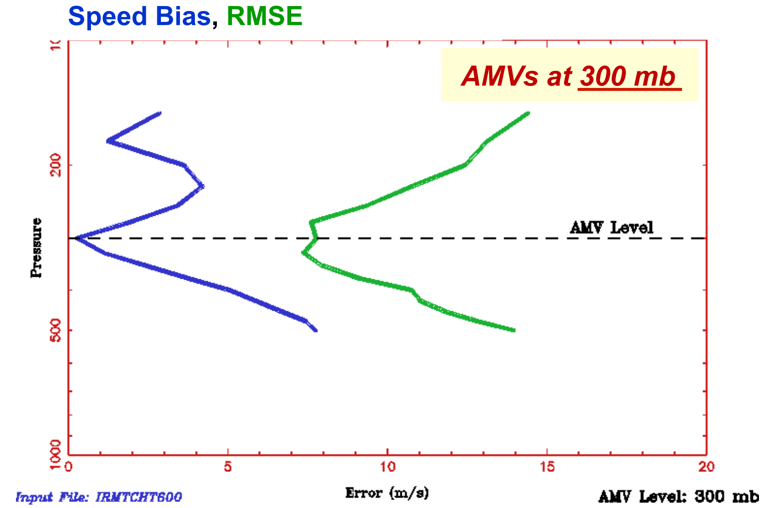
MVD = 2.94 m/s
NRMS = 0.40
Speed Bias = -0.04 m/s
Avg Speed = 8.68 m/s
N = 9349

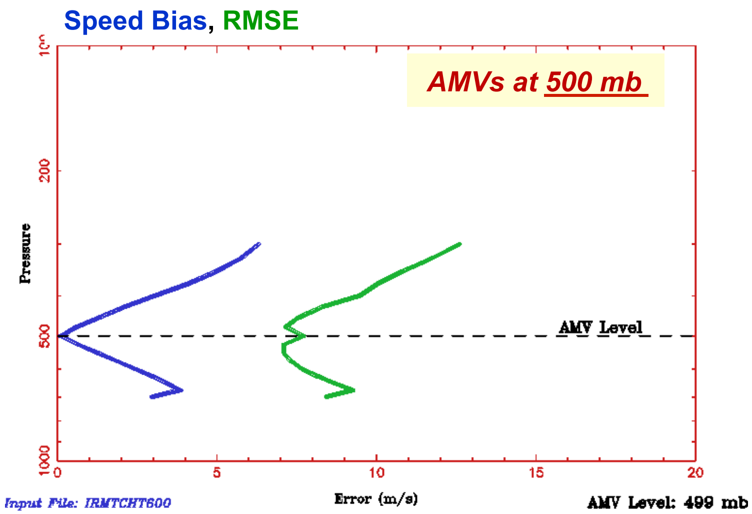
Validation

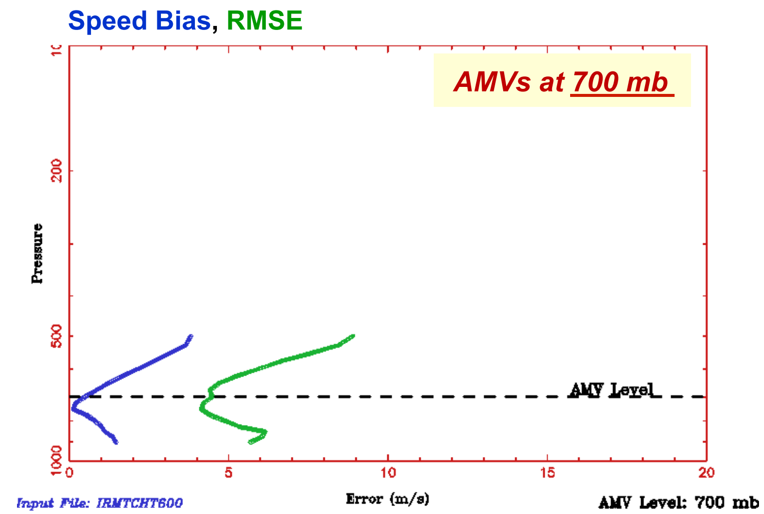
Height Assignment (Level-of-Best-Fit)…

Meteosat-10/SEVIRI (10.8um) AMVs (22 March 2014 – 02 June 2014)





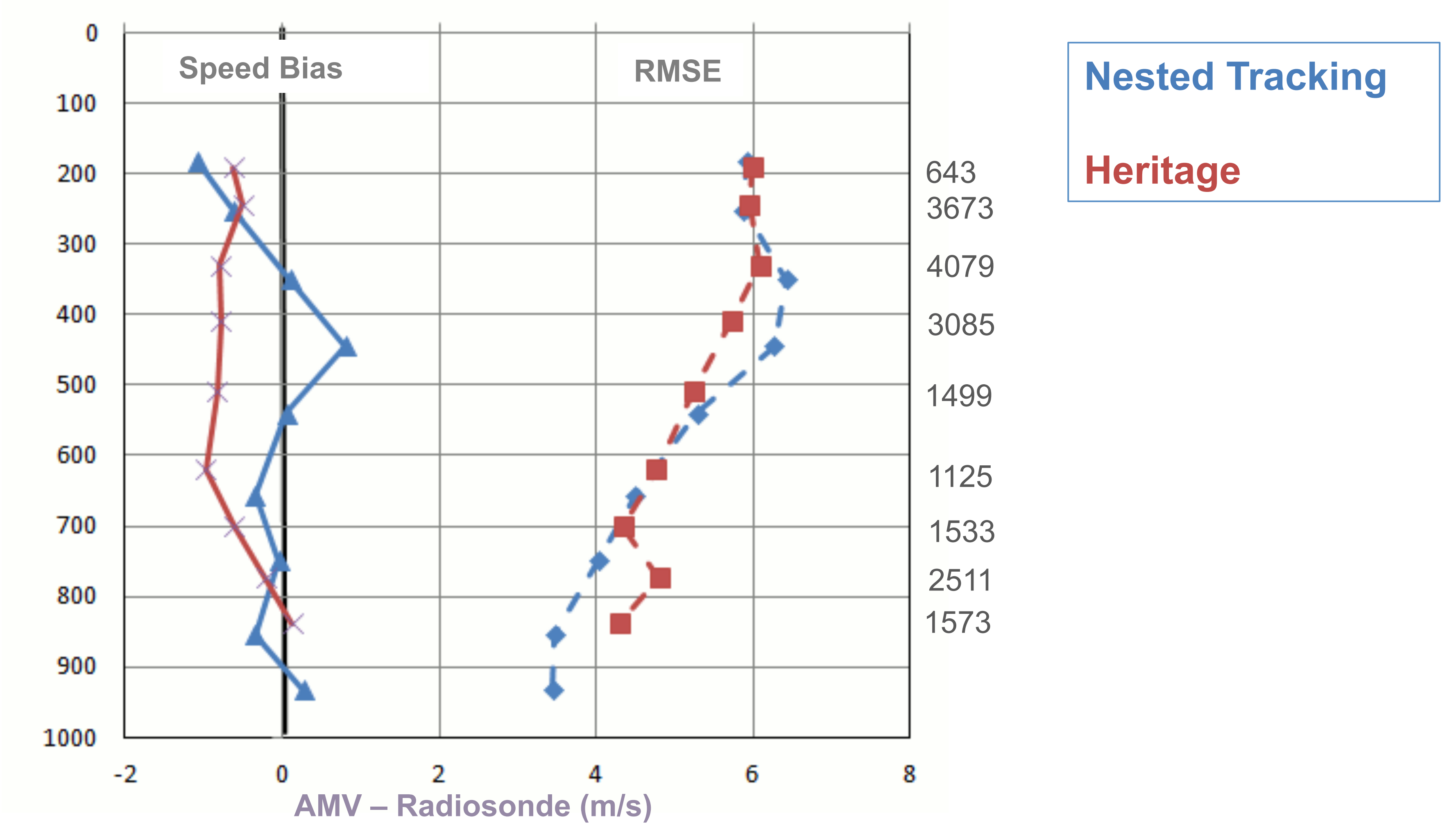




New vs. Heritage AMV Algorithm

Comparing Performance…

Meteosat-8, 11 um
Aug 2006 and Feb 2007



Testing EUMETSAT's CC_{ij} Approach

Meteosat-8 11 micron winds Feb 1-28, 2007 100-400 hPa	Comparisons to Radiosondes (QI > 80)	
	Nested tracking 23x23 box Median pressure of largest motion cluster	**Traditional tracking** 23x23 box CC_{ij} height assignment
Vector RMSE (m/s)	7.76	8.15
Speed Bias (m/s)	-1.37	-2.74
Mean speed (m/s)	22.85	22.44
Mean AMV Height (hPa)	277	267
Sample Size	3268	3268

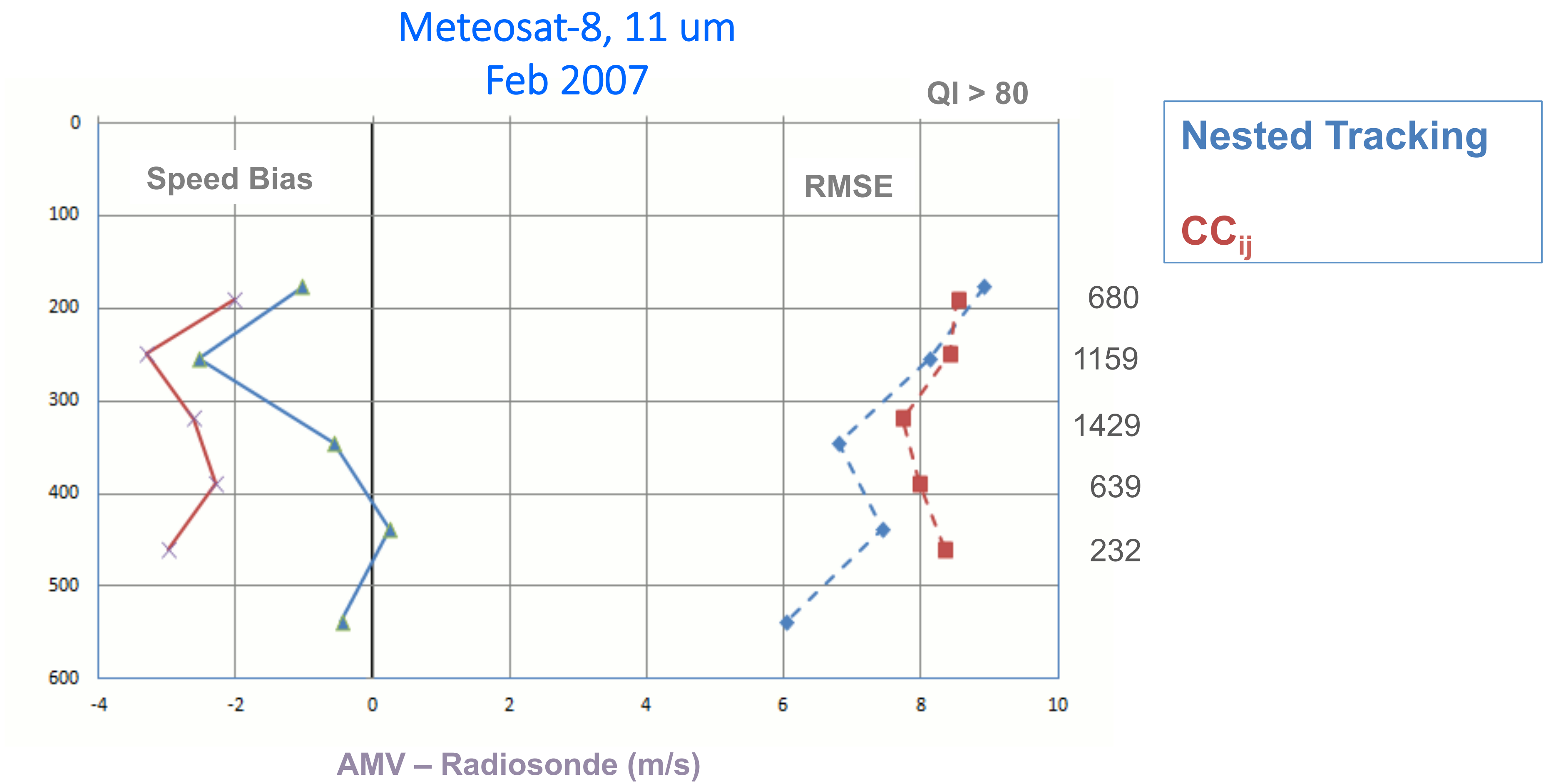
- CC_{ij} approach tested in GOES-R AMV algorithm for 1 month (Feb 2007)
- Result: Higher heights and slightly slower winds; increased slow bias

Testing EUMETSAT's CC_{ij} Approach

Meteosat-8 11 micron winds Feb 1-28, 2007 400-650 hPa	Comparisons to Radiosondes (QI > 80)	
	Nested tracking 23x23 box Median pressure of largest motion cluster	Traditional tracking 23x23 box CC_{ij} height assignment
Vector RMSE (m/s)	7.02	7.97
Speed Bias (m/s)	0.12	-2.46
Mean speed (m/s)	18.30	18.01
Mean AMV Height (hPa)	480	418
Sample Size	951	951

- CC_{ij} approach tested in GOES-R AMV algorithm for 1 month (Feb 2007)
- Result: Higher heights and slightly slower winds; increased slow bias

Testing EUMETSAT's CC_{ij} Approach

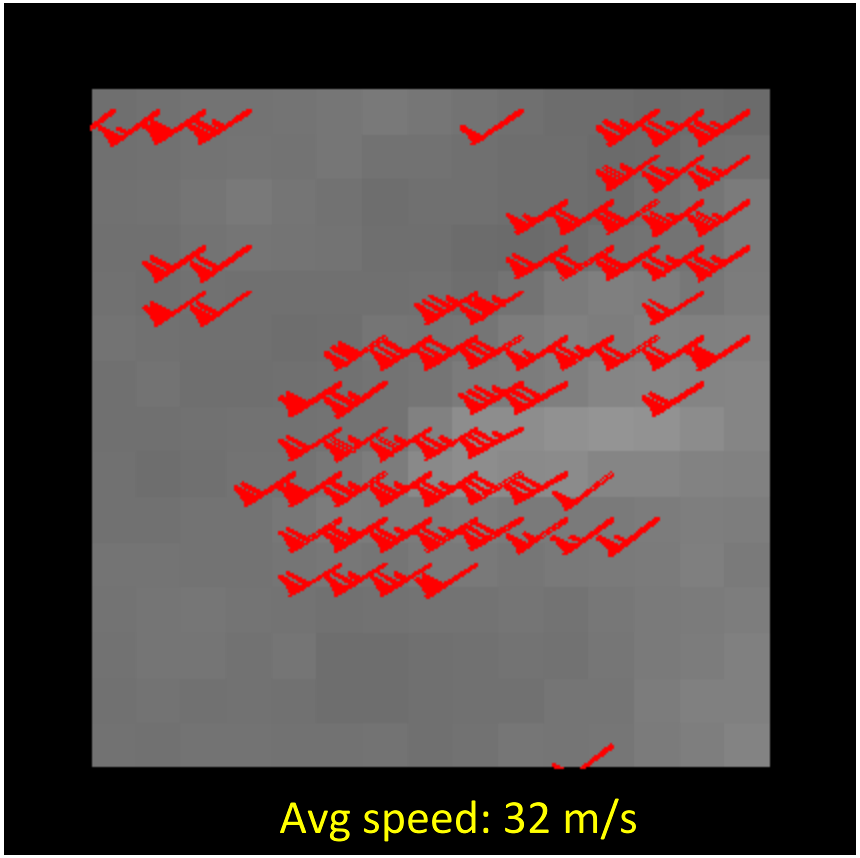


- CC_{ij} approach tested in GOES-R AMV algorithm for 1 month (Feb 2007)
- <u>Result:</u> Higher heights and slightly slower winds; increased slow bias

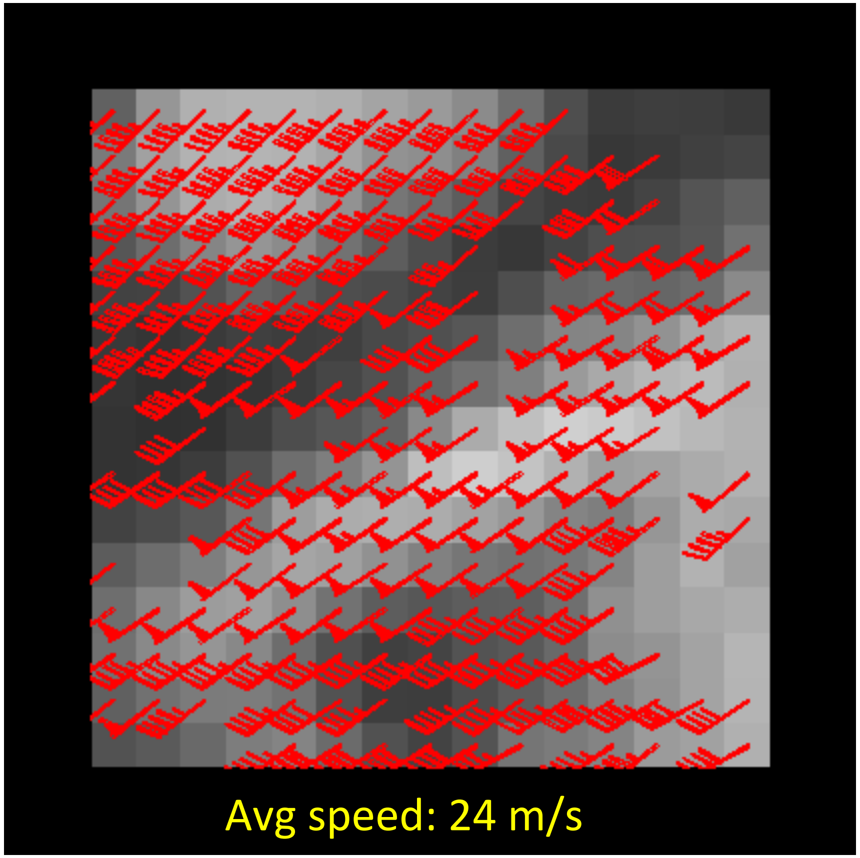
Feature Tracking

WV band vs. LWIR Window…

Tracking Clouds with the **6.2um** band



Tracking Clouds with the **10.8um** band

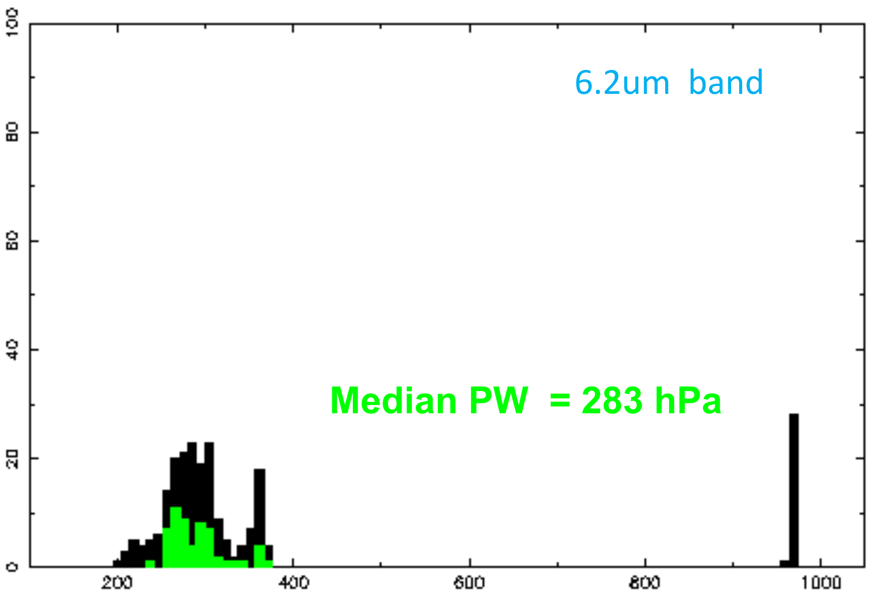


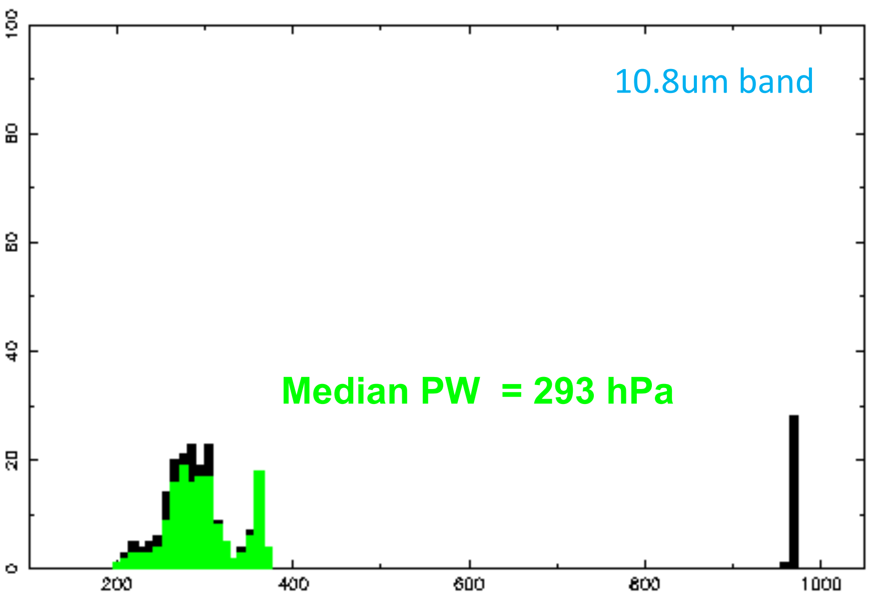
- WVCT wind (6.2um) almost always faster than IR (10.8um) cloud-drift wind
- LWIR channel tracking features over greater depth of the atmosphere
  - Greater shear evident leading to more smoothing and slower wind estimate

Height Assignment

WV band vs. LWIR Window…

Histograms of cloud top pressure





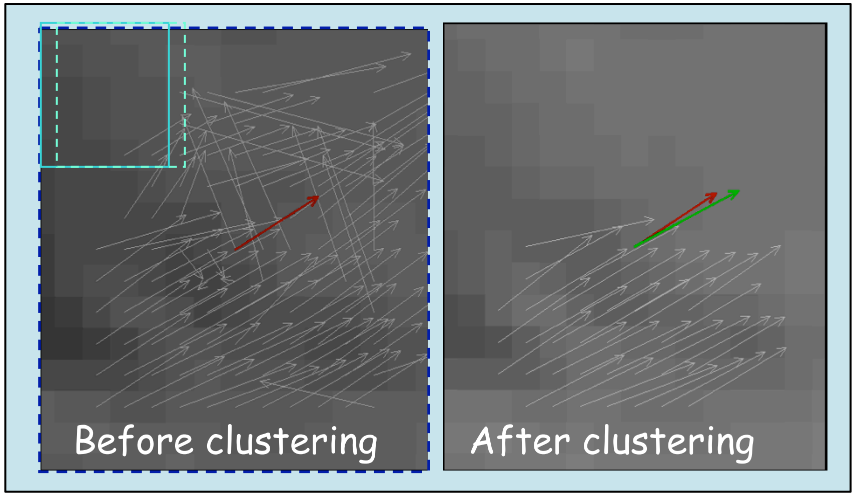
- Black histogram is for entire scene, green histogram is largest motion cluster
- 10.8um channel tracking more points over greater depth of the atmosphere

Note the interesting fact that for this case we have two AMVs within 10 hPa of each other, but with very different speeds. Which AMV is more correct?

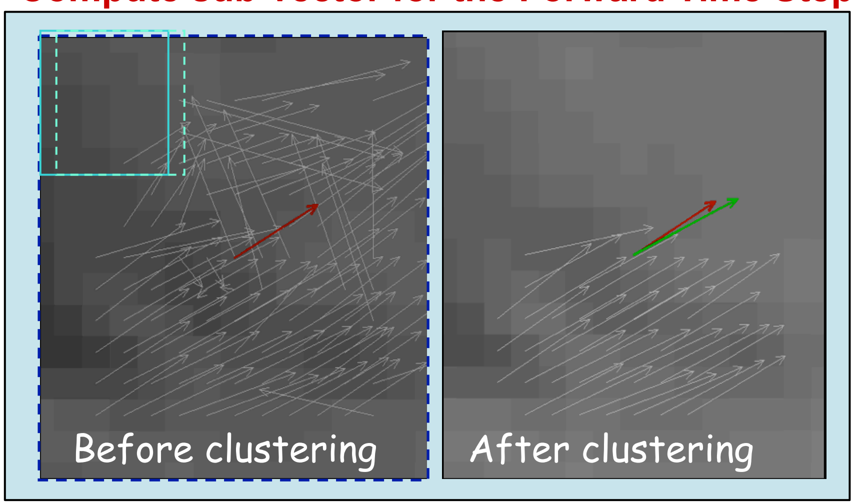
Testing the Idea of Combining the Displacements of Each Time Step

This is our current implementation

Compute sub-vector for the Reverse Time Step



Compute sub-vector for the Forward Time Step



Sub-vector 1

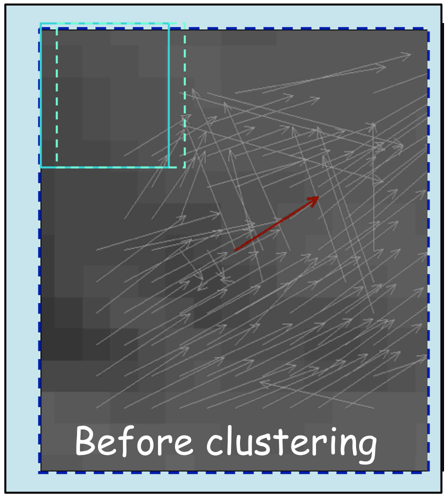
Sub-vector 2

Average sub-vectors

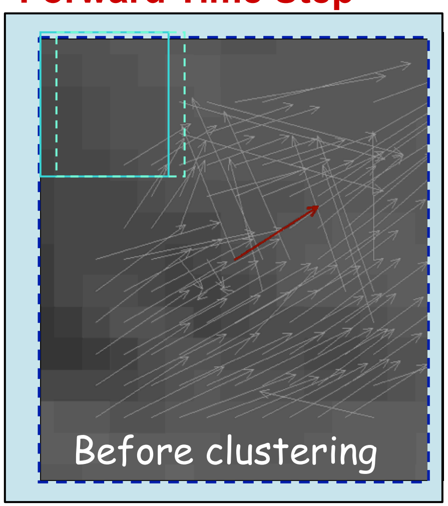
Final Vector

Testing the Idea of Combining the Displacements of Each Time Step

Reverse Time Step



Forward Time Step



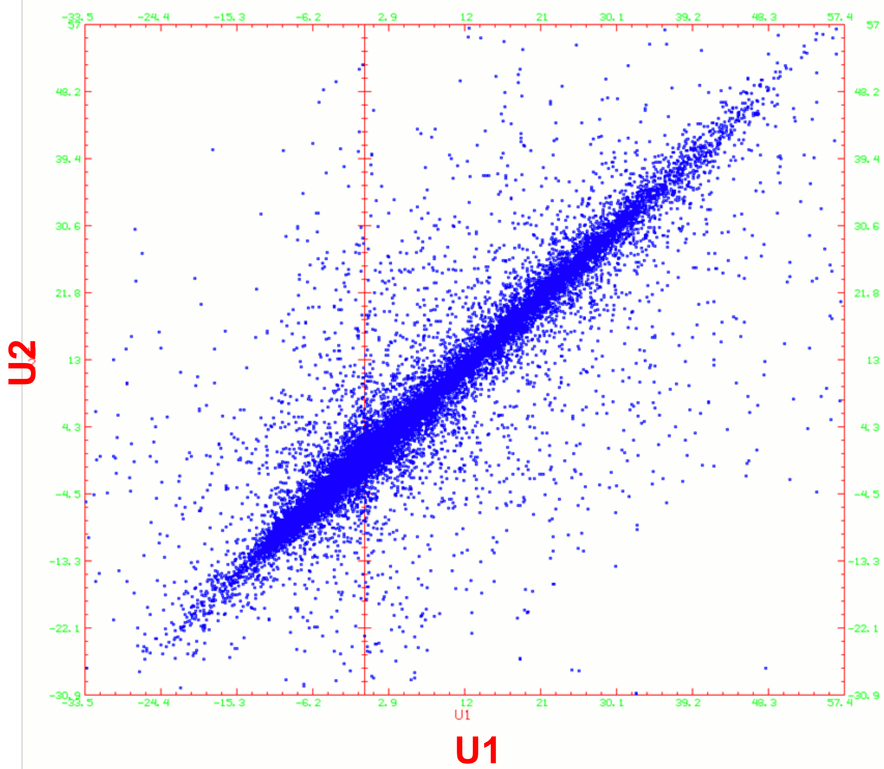
Apply clustering to local displacements <u>from both time steps</u>

→

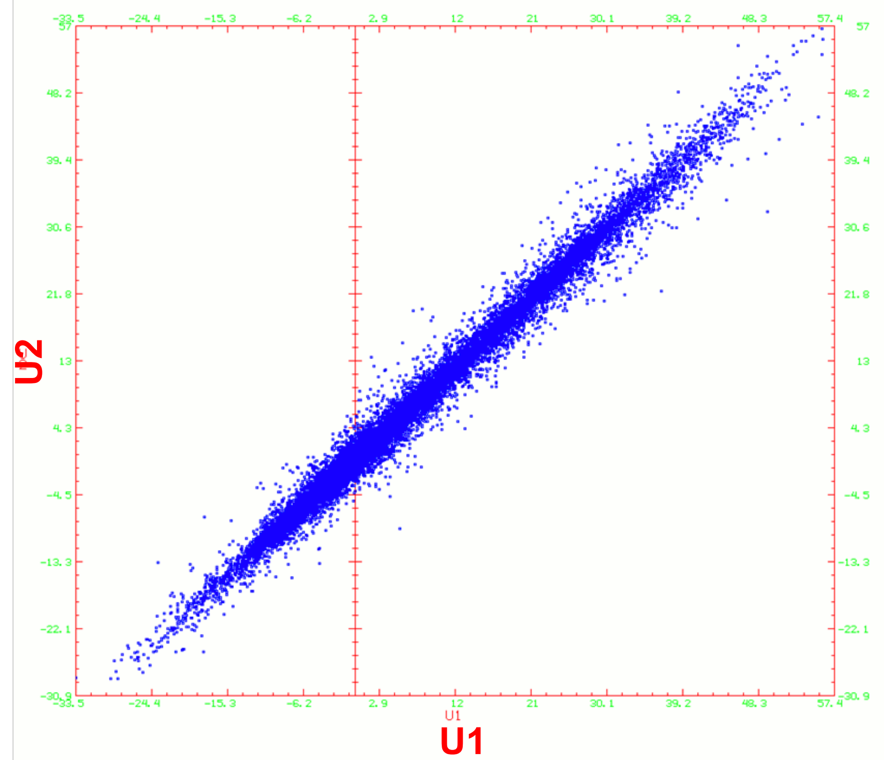
Final Vector

Testing the Idea of Combining the Displacements of Each Time Step

U1 vs U2

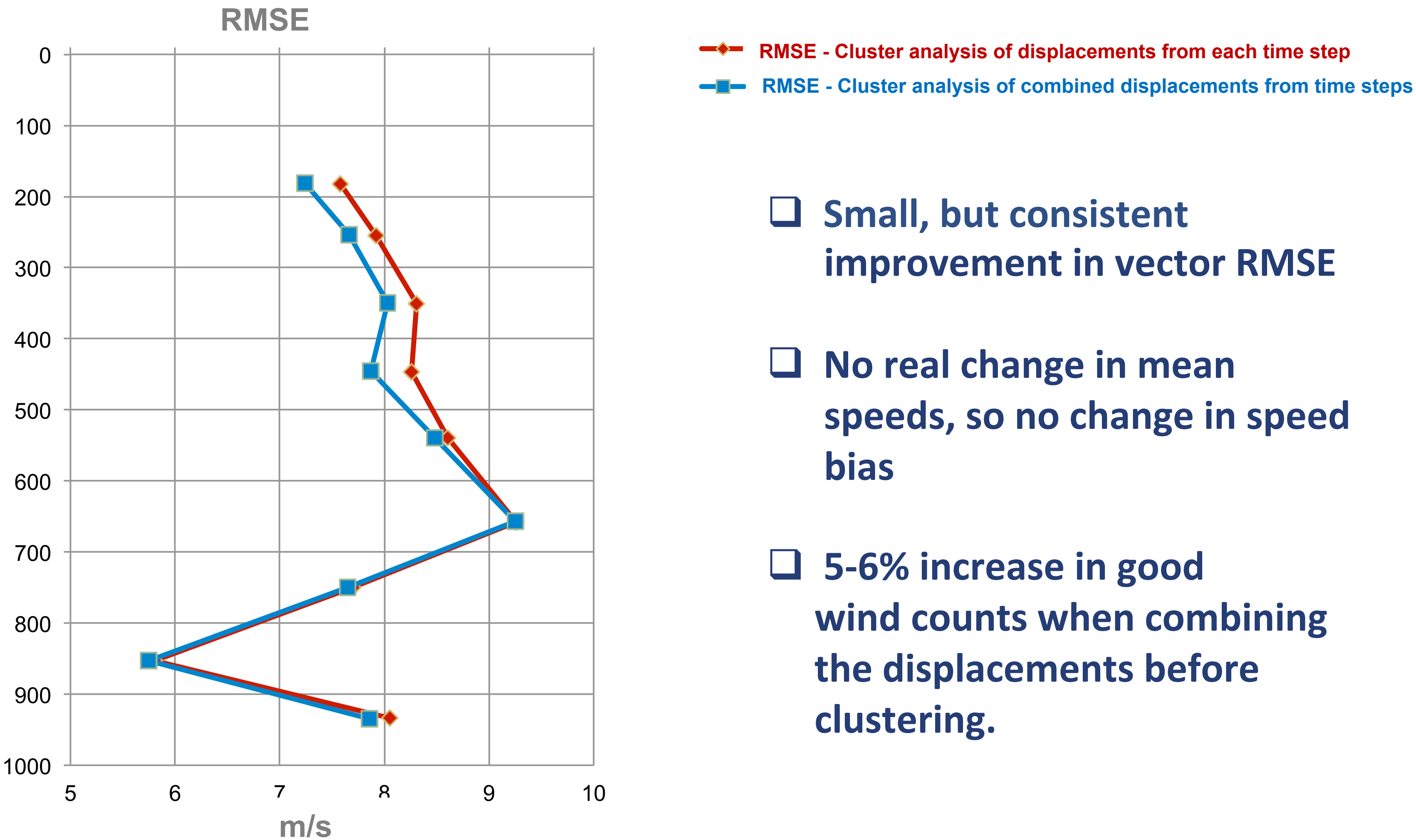


Points from each time step when analyzed *separately*



Points from both time steps when analyzed *together*;

Testing the Idea of Combined Displacements



- Small, but consistent improvement in vector RMSE
- No real change in mean speeds, so no change in speed bias
- 5-6% increase in good wind counts when combining the displacements before clustering.

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  - *Using Available ABI Proxy Data…*
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Ongoing Activities and Plans

- **Supporting industry's implementation of GOES-R Winds algorithm into the GOES-R core ground system**

- **Continuing our Validation Related Activities Using Available ABI Proxy Data**
  - Meteosat-9/10/SEVIRI imagery, GOES-13/15, NPP/VIIRS, and **Himawari-8**
    - Case studies: Search for outliers, analyze, and understand
    - Develop, test, and validate algorithm adjustments
    - Validation tool development

- **Supporting development of a new BUFR sequence for satellite winds** **(Thurs morning discussion)**
  - Our routine (ie., hourly) experimental GOES-13/15 winds (all types) are placed in latest version of this new BUFR sequence and made available on our ftp server.

- **Assessing Impact of Nested Tracking Winds in the NCEP GFS Data Assimilation System**
  - Meteosat/SEVIRI **(Sharon Nebuda will talk more about this Tues afternoon)**
  - GOES-13/15 **(Iliana Genkova is working on this at NCEP)**

- **Latest information on transition of nested tracking algorithm into NESDIS operations:**
  - **NPP/VIIRS:** Operational as of May 8, 2014 **(Jeff Key will talk more about this later today)**
  - **GOES-13/15:** September 2014 – running in operations in parallel with existing GOES winds for a 9 month period to help ensure a smooth transition for NWP users
  - **MODIS:** November 2015
  - **AVHRR:** November 2015
  - **GOES-R/ABI**: Late 2016/Early 2017

Topics

- Some GOES-R Information
- Review of Nested Tracking Approach
- Some Examples: Application to an Assortment of Imagers
  - *Using Available ABI Proxy Data…*
- Performance
  - *Overall, individual cases, experimentation with new ideas*
- Ongoing Activities and Plans
- Summary

Summary

- **Developed, tested, and validated nested tracking approach using a variety of available ABI proxy data** *(Meteosat/SEVIRI, GOES-13/15, NPP/VIIRS, and Himawari-8, when available)*

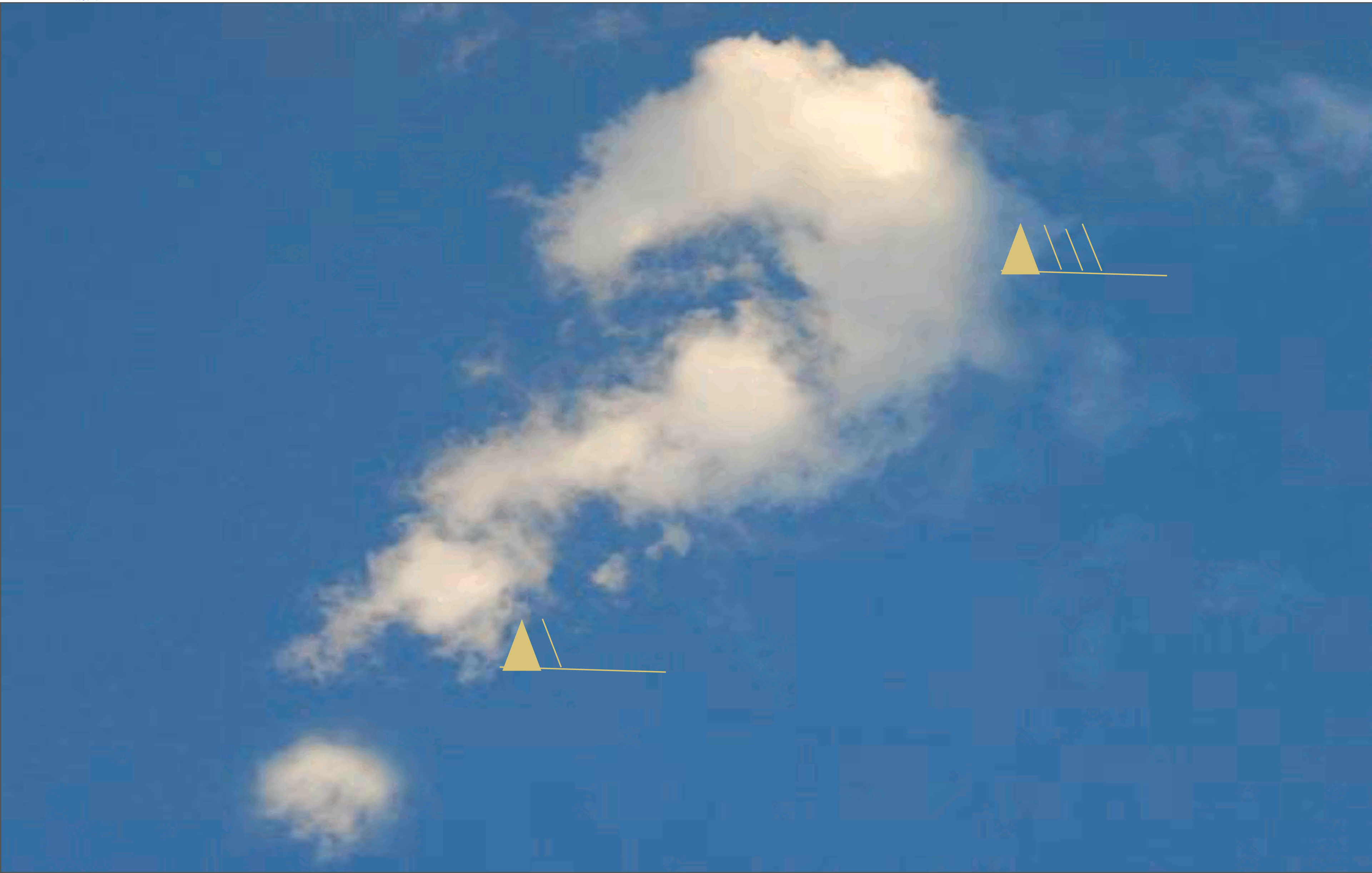
- **Nested tracking approach effectively minimizes the slow speed bias**
  - Most speed "adjustments" are small, but some can exceed 10 m/s
  - Smaller bias a result of lower heights and faster winds
  - Improvement over heritage approach
  - Expected to benefit NWP

- **Opportunities with the nested tracking approach**
  - Additional clusters may contain useful wind information in the target scene
  - Clustering output enables new quality control to be employed in NWP data assimilation

- **Nested tracking being implemented in NESDIS operations:**
  - GOES-13/15 (soon), VIIRS (now), Terra/Aqua/MODIS (soon), AVHRR (soon), and GOES-R/ABI

- **Impact testing of nested tracking winds in NCEP's GFS System in progress**

Questions

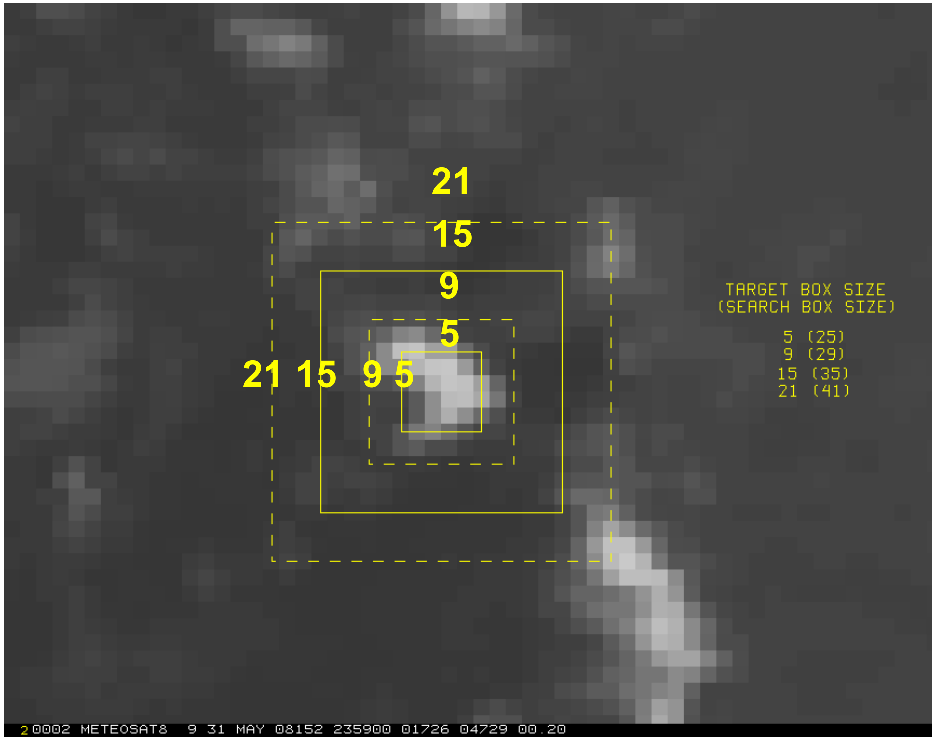


Backup Slides

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

Setup of Study

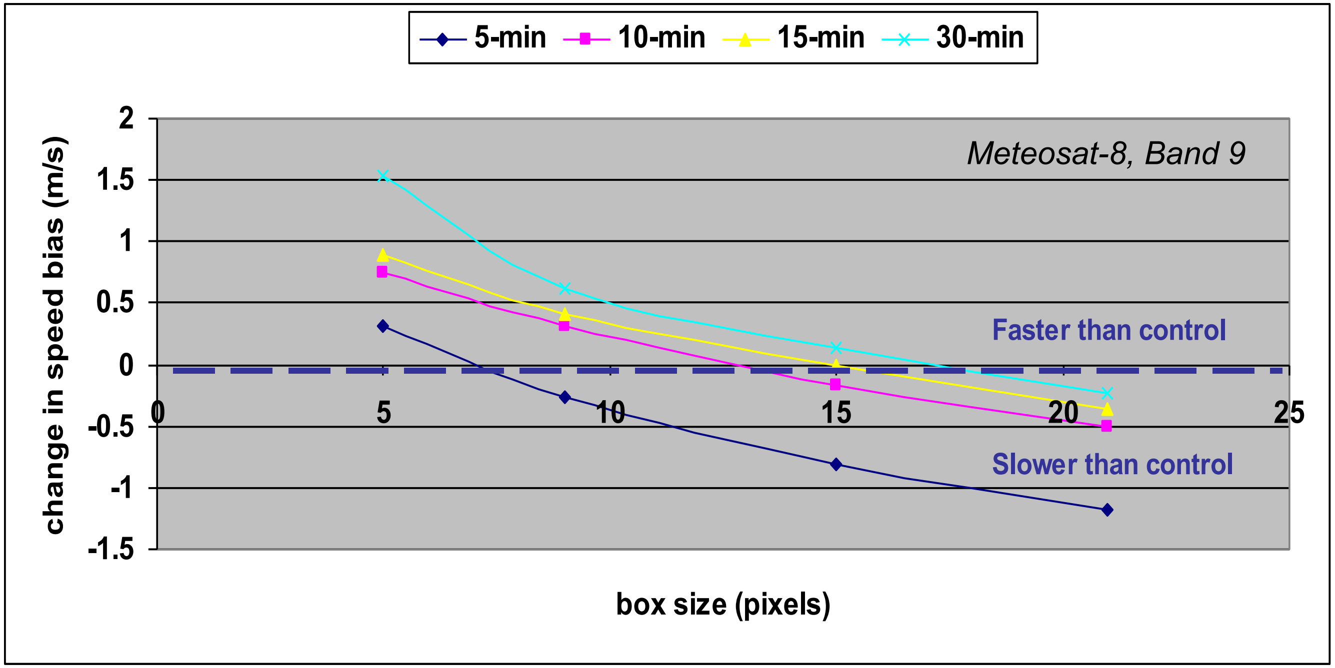
- Winds were generated using Meteosat-8 rapid scan imagery for the period June 1 – 8, 2008.
- Target locations were fixed while box size and time interval varied.



- **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

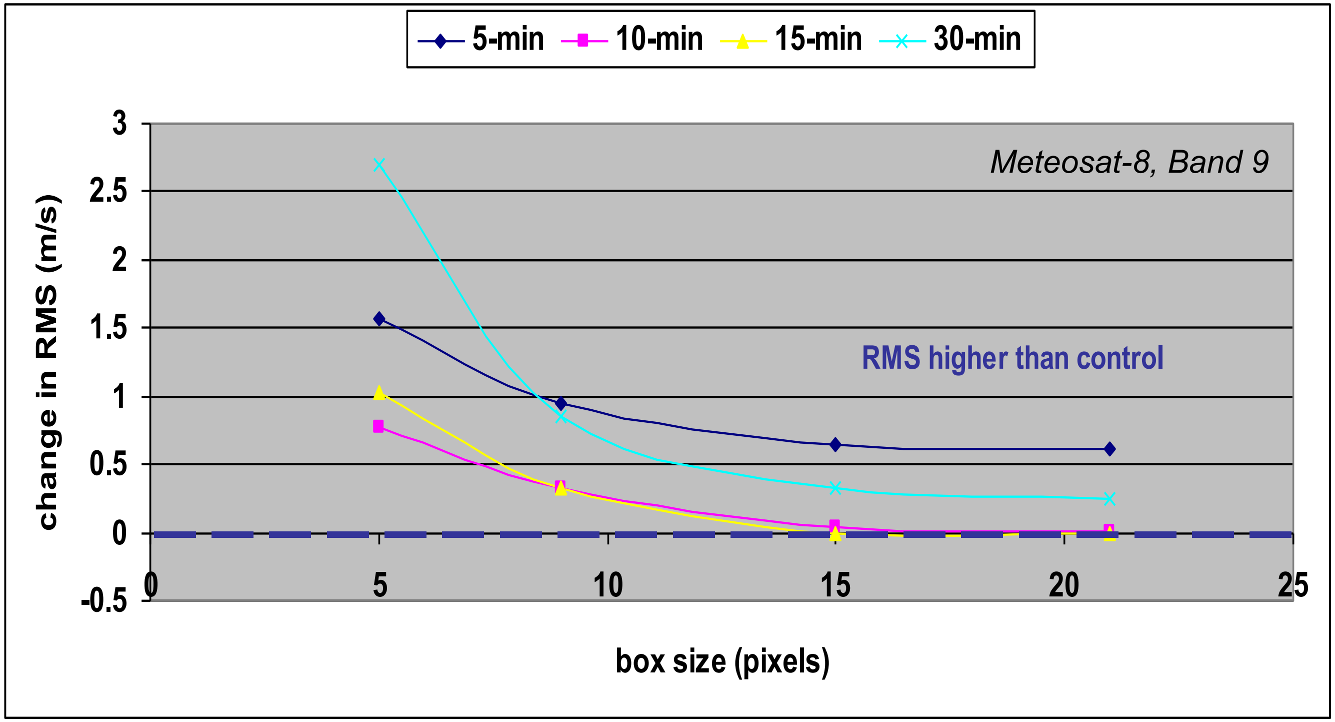
Results – *relative to control run (15x15 box, 15-minute loop interval)*



- **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 <u>against</u> using a small box**