Feature-tracked 3D Winds from Satellite Sounders: Derivation and Impact in Global Models

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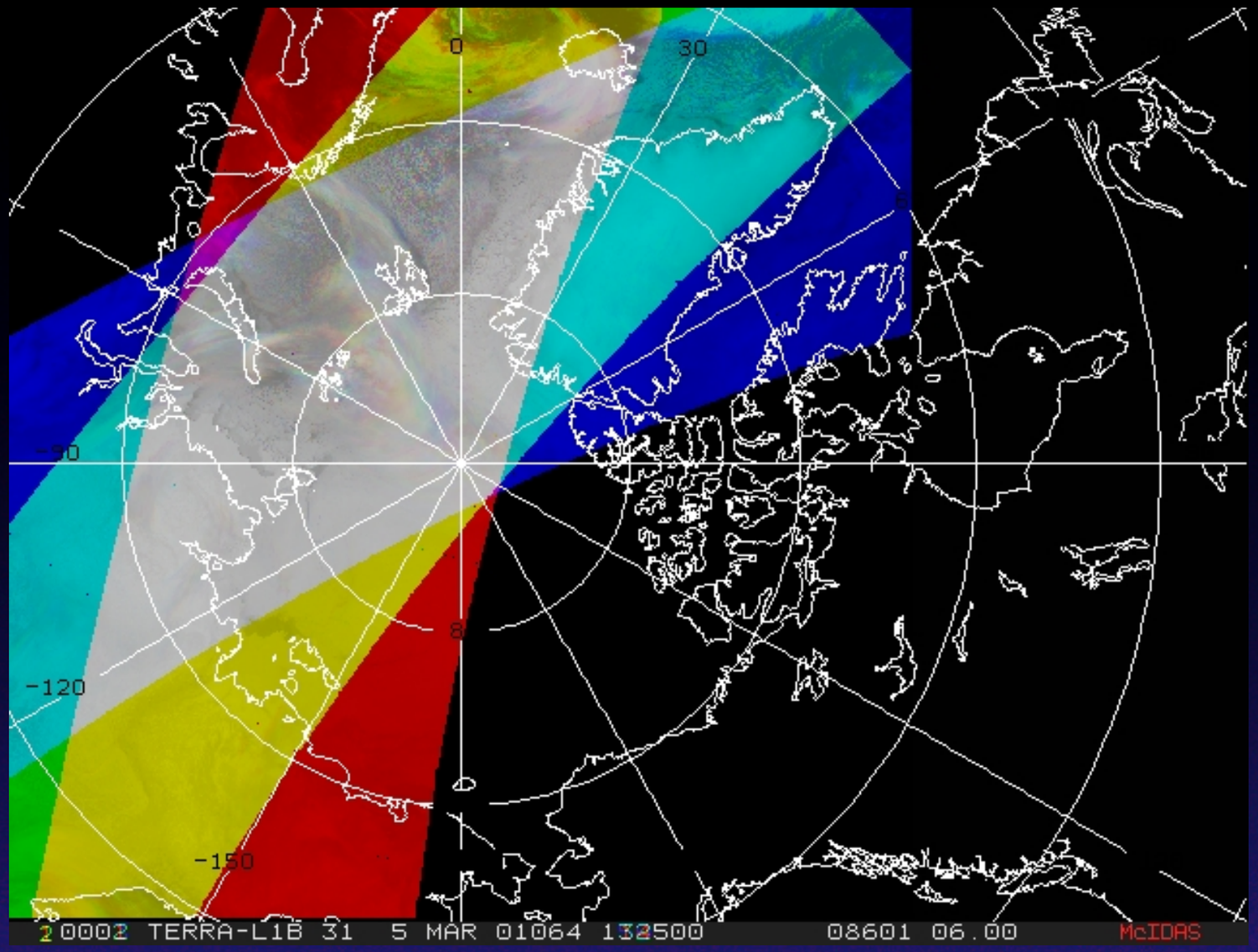
Outline

1) Apply feature tracking to retrievals of moisture
2) Product generation
    a) 2012 case study
    b) Real-time
3) Assimilation and forecast impact
4) Future: Global coverage from satellite constellations

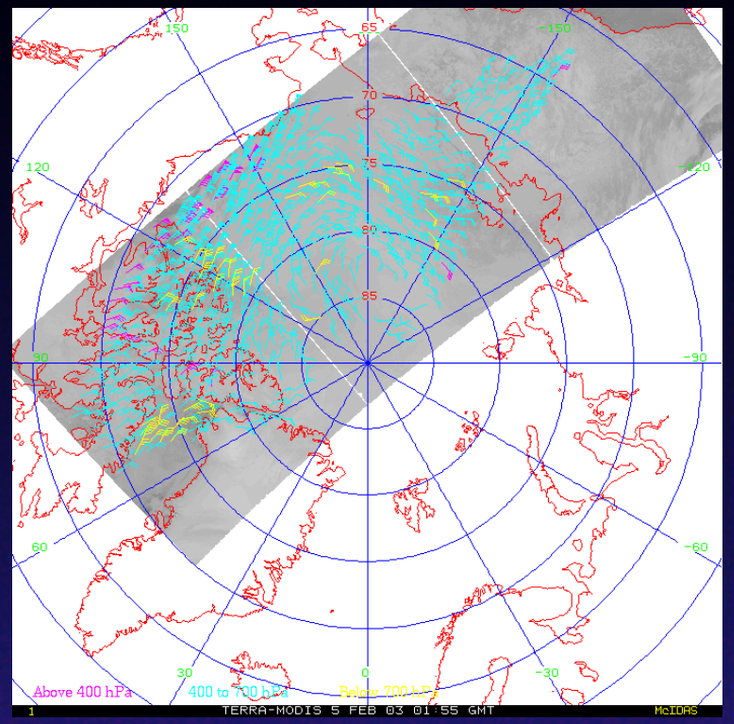
MODIS Satellite-derived Polar Winds



Unlike geostationary satellites at lower latitudes, it is not be possible to obtain complete polar coverage at a snapshot in time. Winds must be derived for areas that are covered by three successive orbits. The gray area is the overlap between three orbits.

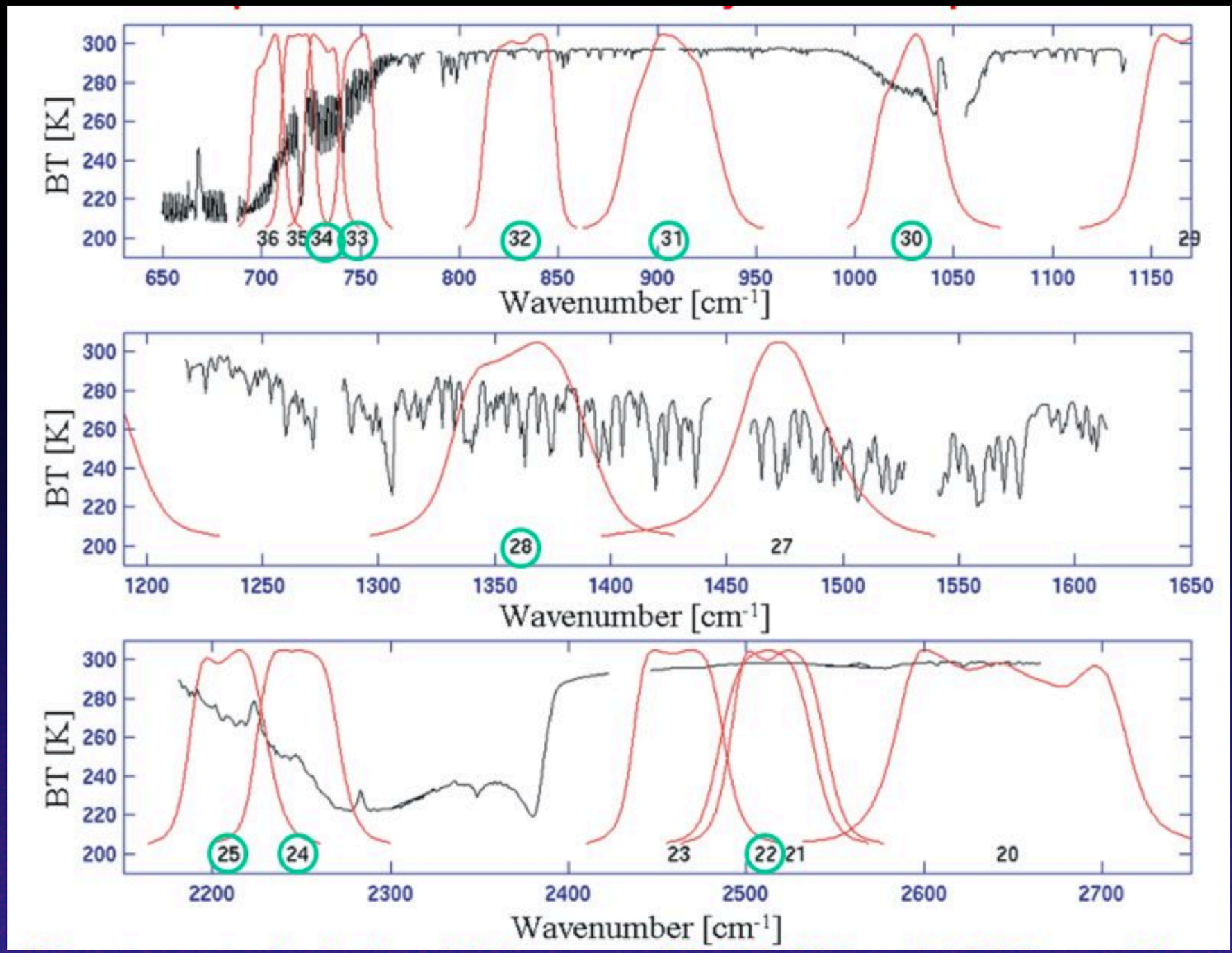
Polar Winds in Numerical Weather Prediction

European Centre for Medium-Range Weather Forecasts (ECMWF)
NASA Global Modeling and Assimilation Office (GMAO)
National Centers for Environmental Prediction (NCEP/EMC)
Japan Meteorological Agency (JMA), Arctic only
Canadian Meteorological Centre (CMC)
(UK) Met Office
Deutscher Wetterdienst (DWD)
Meteo France
Australian Bureau of Meteorology (BoM)
National Center for Atmospheric Research (NCAR)
China Meteorological Administration (CMA)
Hydrological and Meteorological Centre of Russia (Hydrometcenter)
US Navy, Fleet Numerical Meteorology and Oceanography Center (FNMOC)

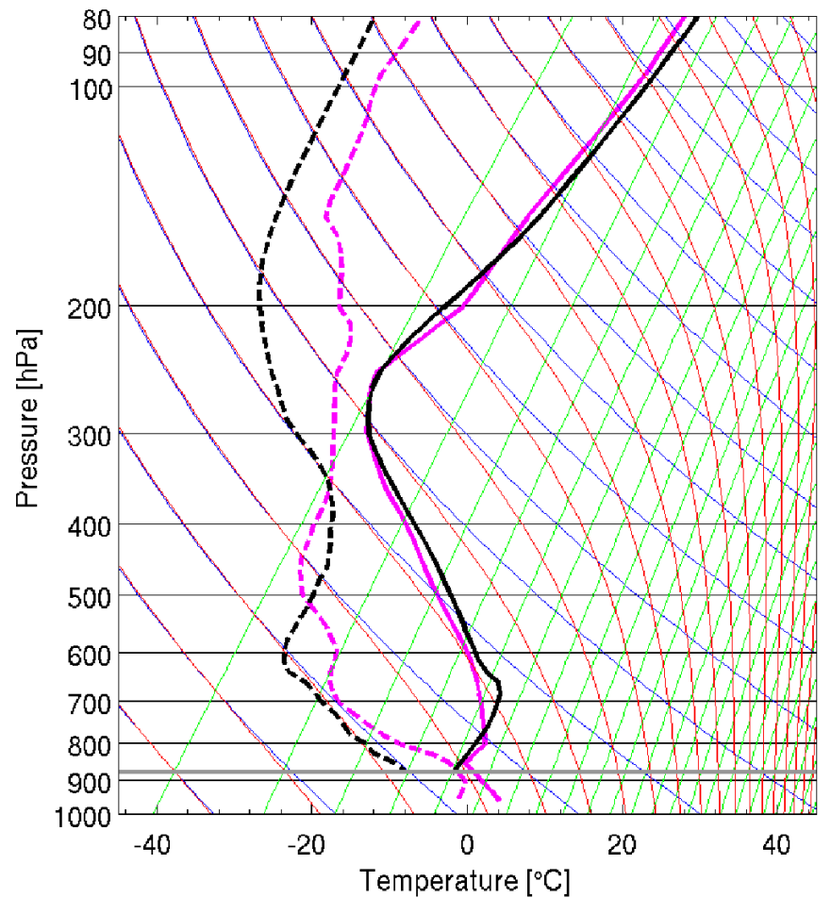


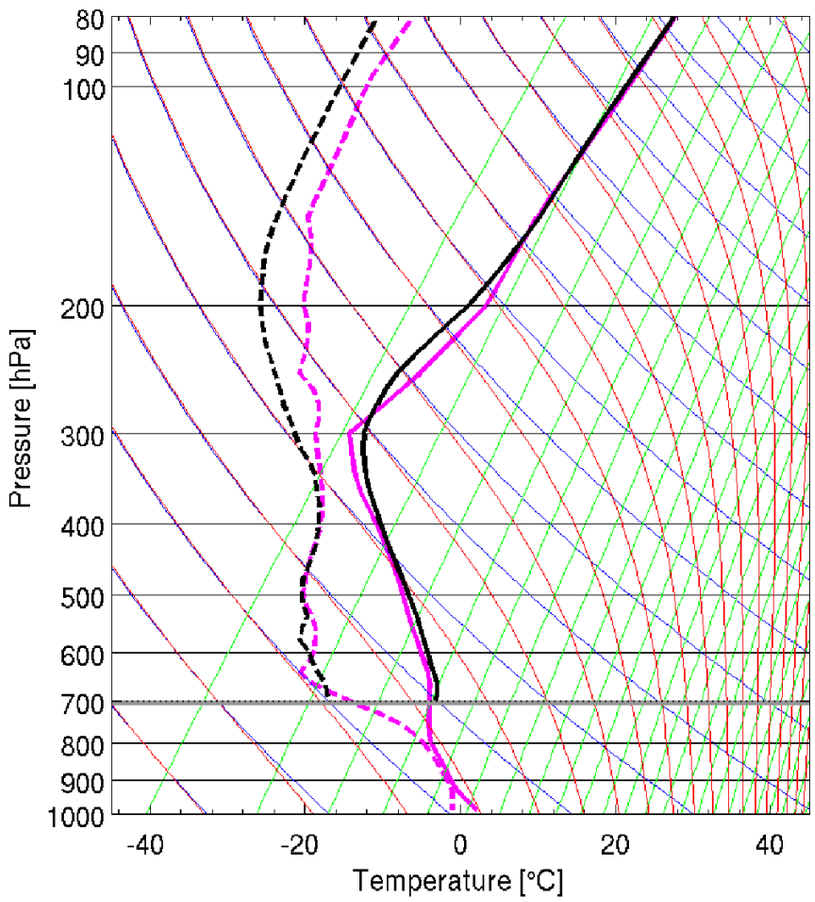
Hyperspectral sounder vs. Imager

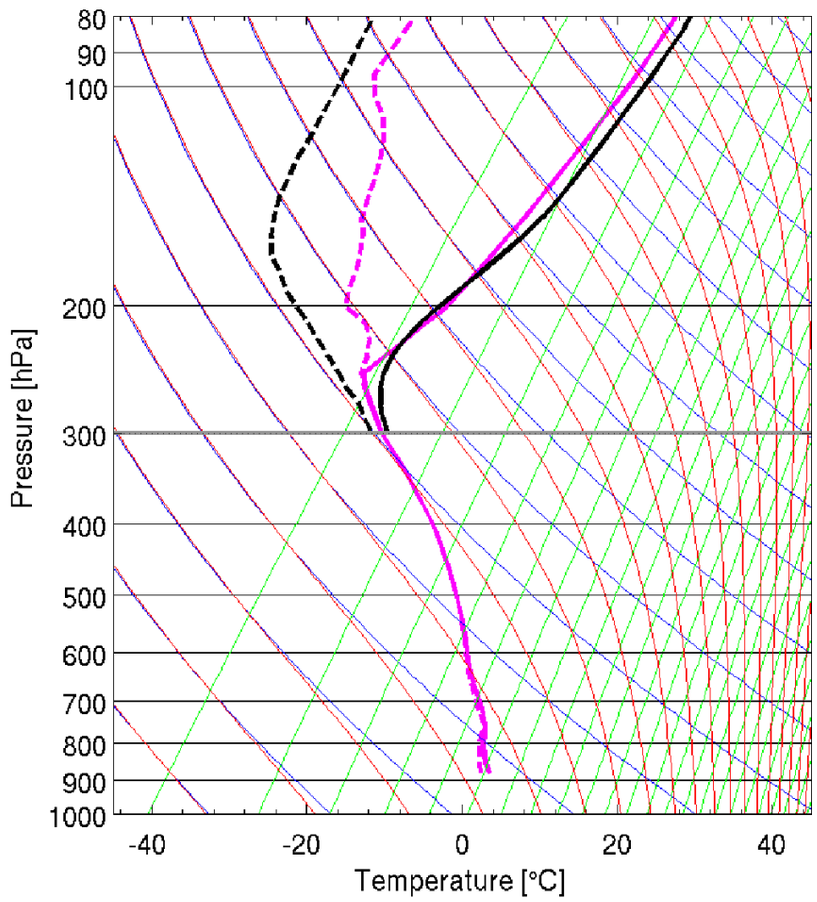
- Hyperspectral sounder: Atmospheric Infrared Sounder (AIRS) on Aqua
- 2378 channels in the IR band vs. 36 MODIS bands



Retrieved profiles of temperature and humidity







Example of temperature and dewpoint profiles for clear sky (left), low cloud (middle), high cloud (right). Retrievals (black) and NCEP/GFS (magenta).

What are 3D winds from satellite sounders?

- Create images horizontal fields of humidity
- Track humidity features over time

- Advantages:
  a) 3D wind distribution
  b) Implicit AMV height
  c) Clear sky and above cloud

- Disadvantages:
  - Lower spatial resolution compared to MODIS (13.5 vs. 1 km)
  - Narrower swath

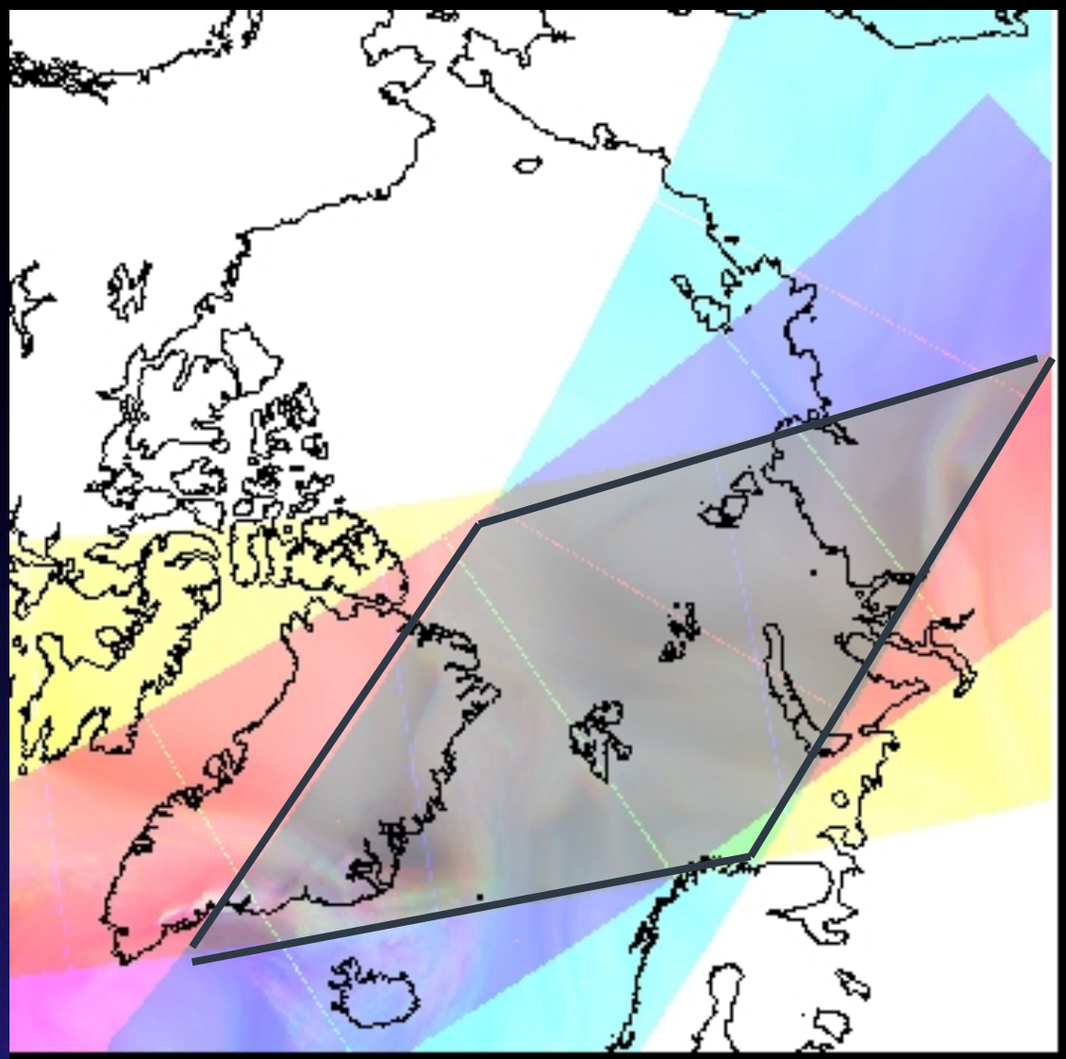
AIRS Retrieval

- Use the CIMSS SFOV AIRS retrieval algorithm
  a) Need highest possible resolution
  b) Retrievals of moisture and ozone mixing ratio at 101 pressure levels:
     i. Away from tropopause and surface for AMVs
     ii. Ozone: 103 to 201 hPa
     iii. Moisture: 359 to 616 hPa
  c) Elisabeth Weisz and Bill Smith, Sr.

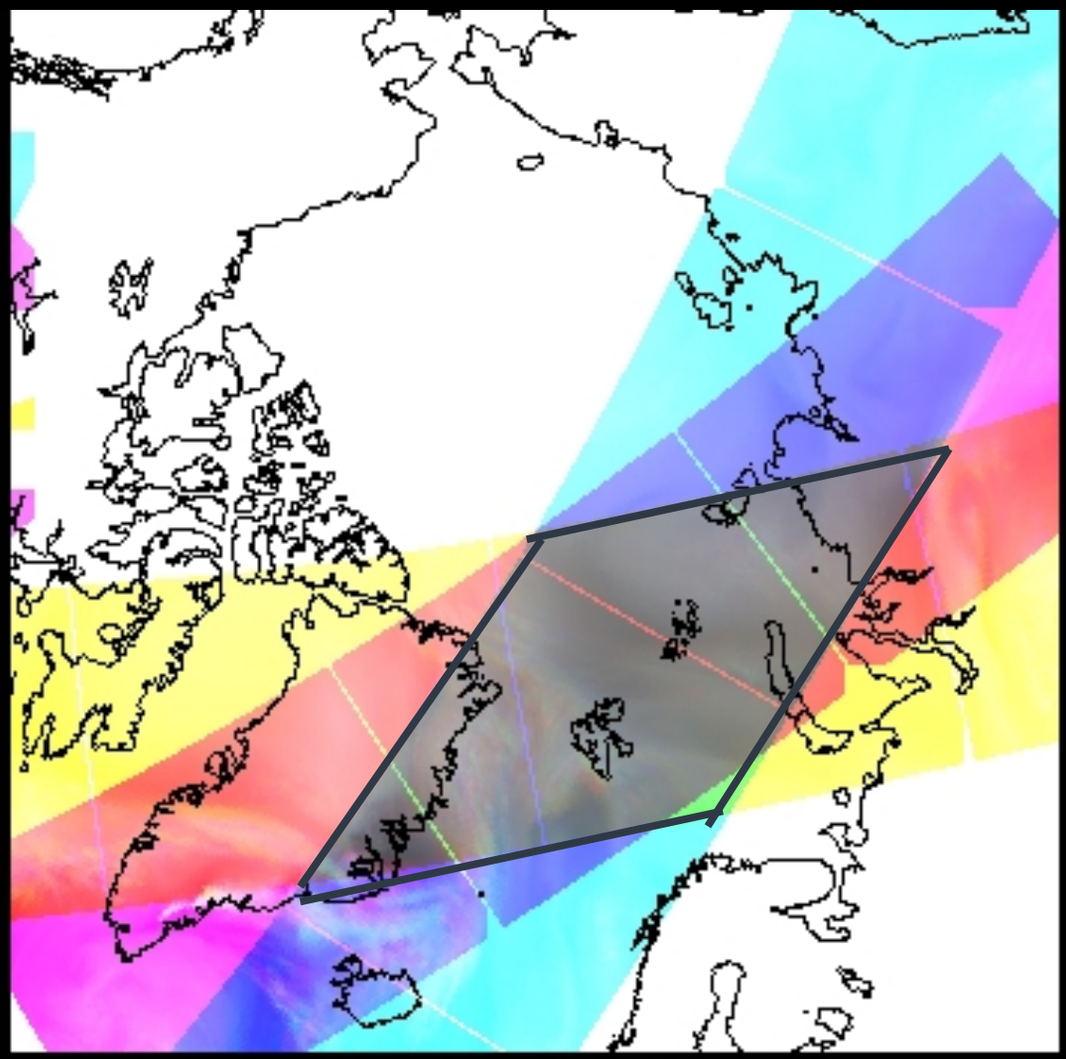
New Challenge: Lower resolution

- AIRS: 13.5 km; MODIS: 1 km
- Images at 16 km (AIRS) and 2 km (MODIS)
- Magnify images with bi-linear interpolation
  a) Increase winds algorithm parameters to match magnification
  b) Cross correlation for tracking features behaves much better
- Narrower swath

Polar Winds Coverage
MODIS vs. AIRS

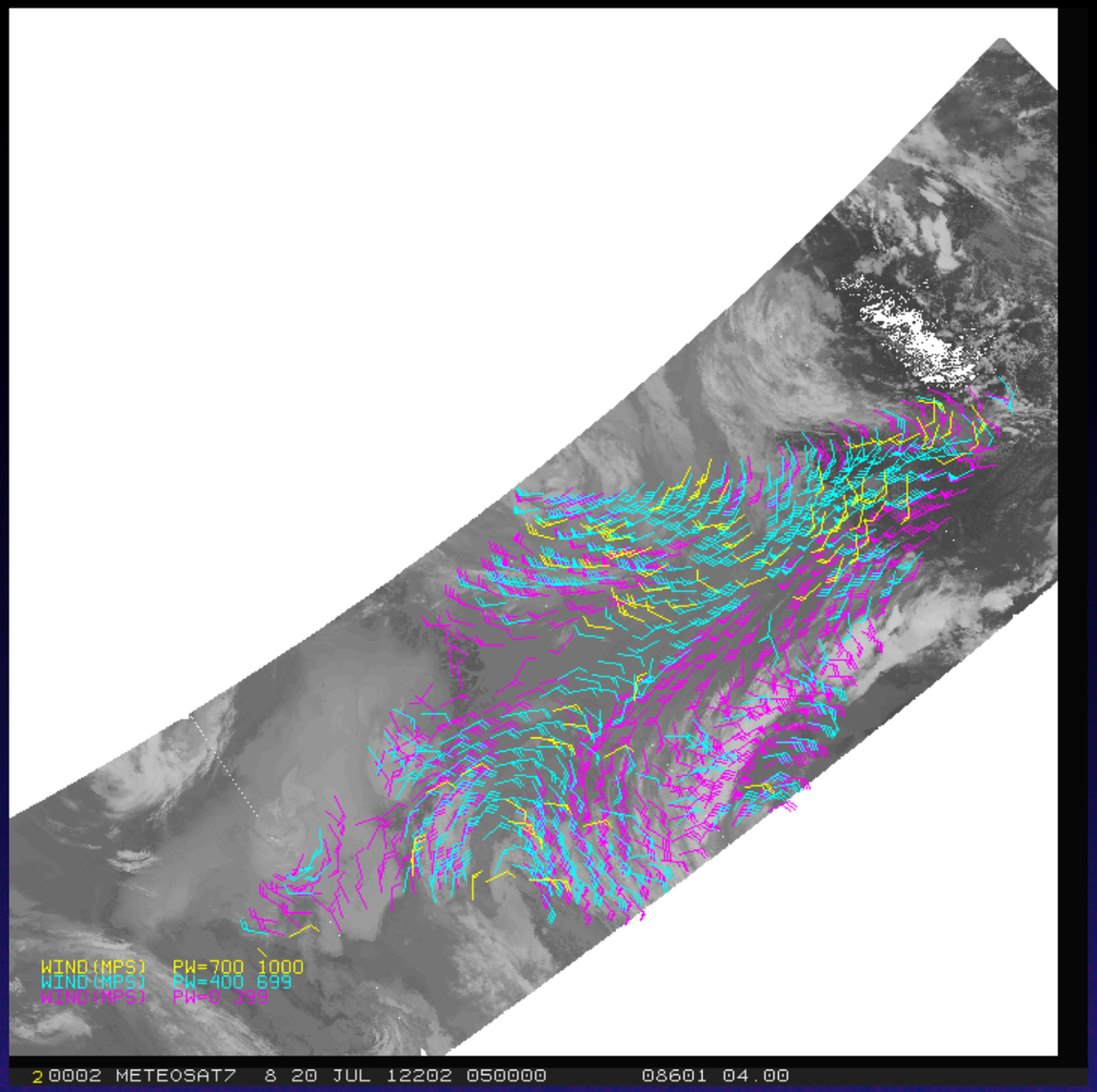


AQUA MODIS COVERAGE

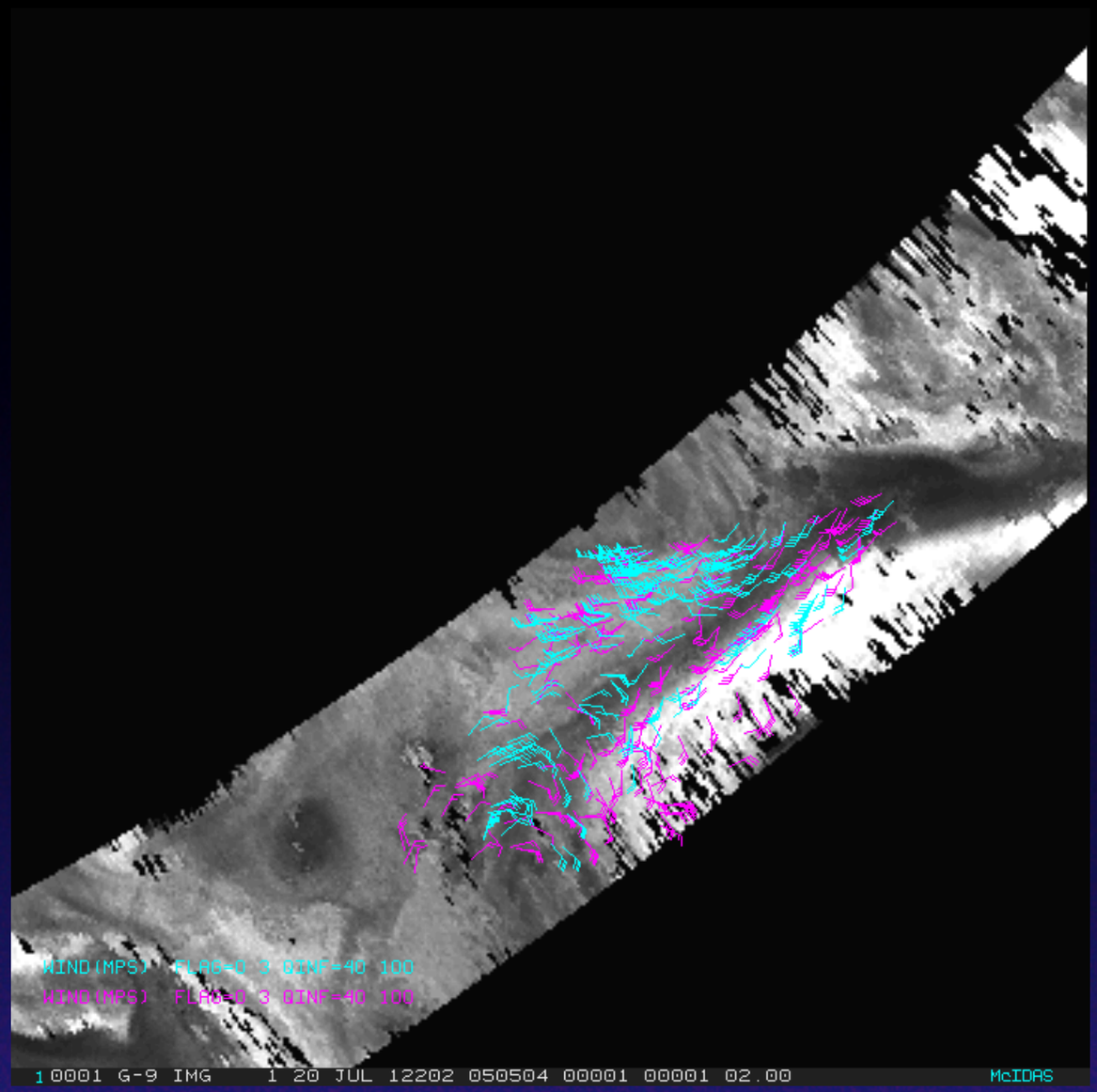


AQUA AIRS COVERAGE

Aqua MODIS AMVs
AIRS Retrieval AMVs at All Levels

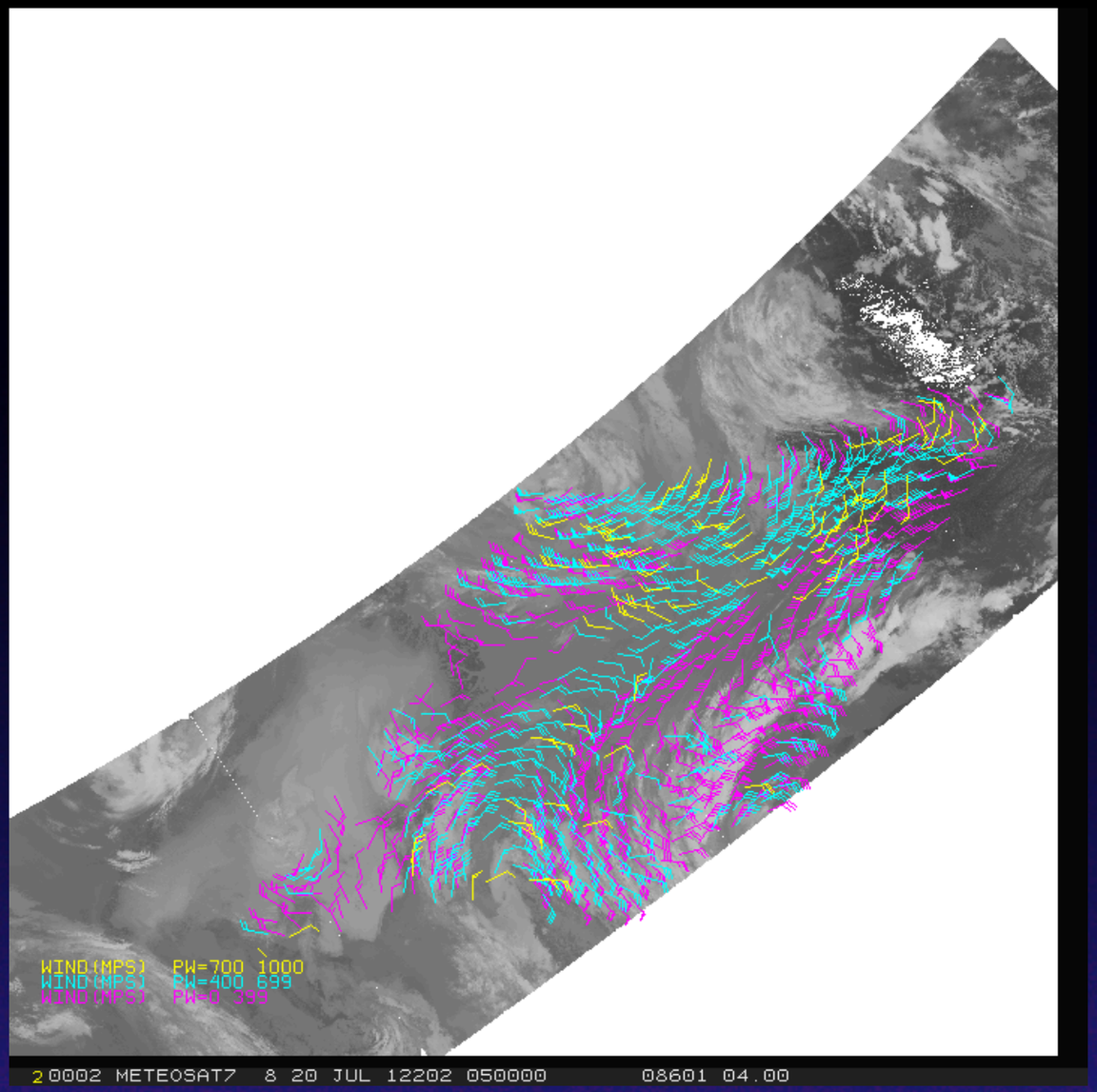


MODIS 20 July 2012 0551 UTC
Infrared and Water Vapor
(including clear sky)



AIRS 20 July 2012 0505 UTC
Ozone: 103 to 201 hPa Moisture:
359 to 616 hPa

Aqua MODIS AMVs
AIRS Retrieval AMVs at All Levels



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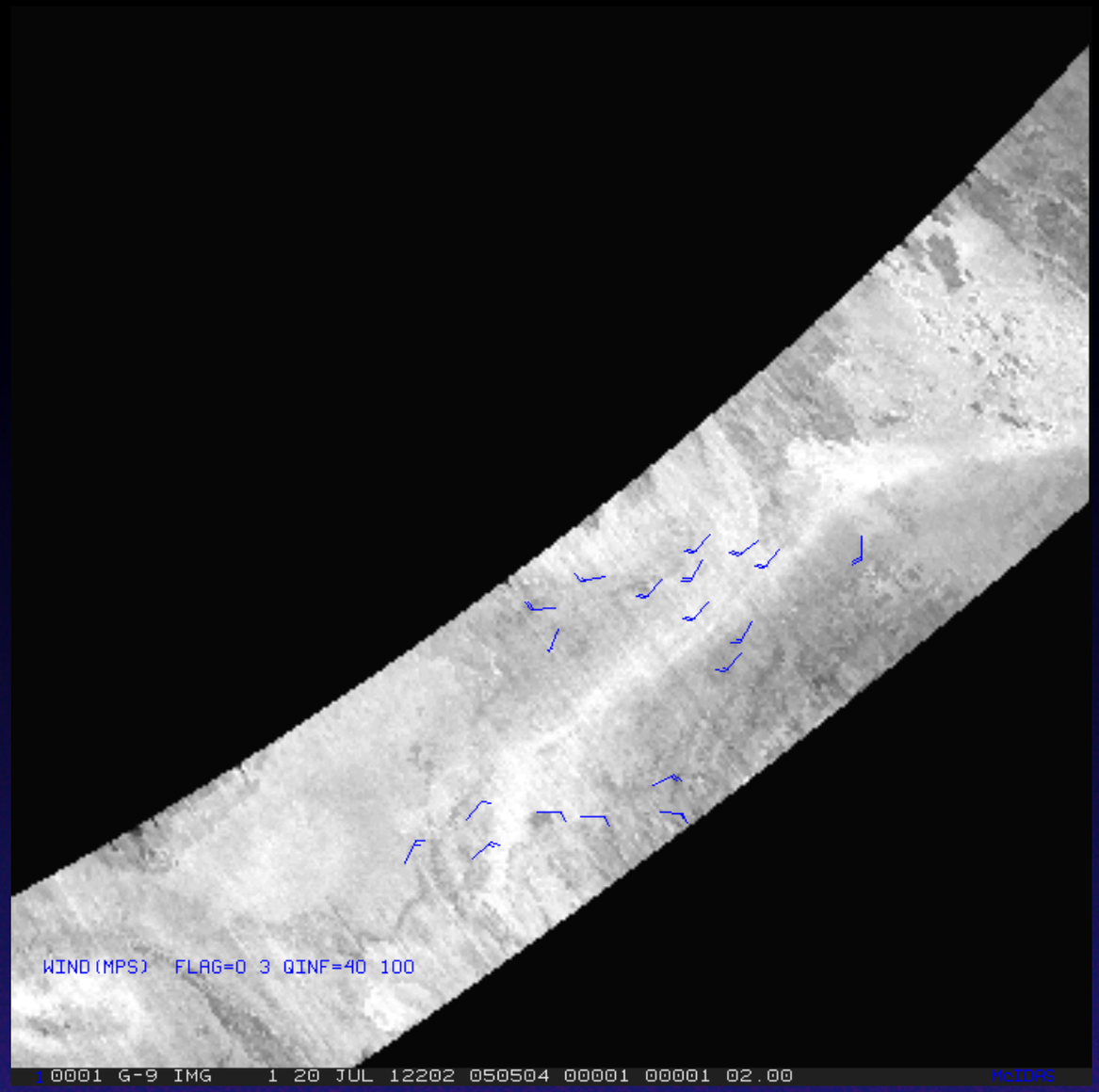


AIRS 20 July 2012 0505 UTC
Ozone: 103 to 201 hPa Moisture:
359 to 616 hPa

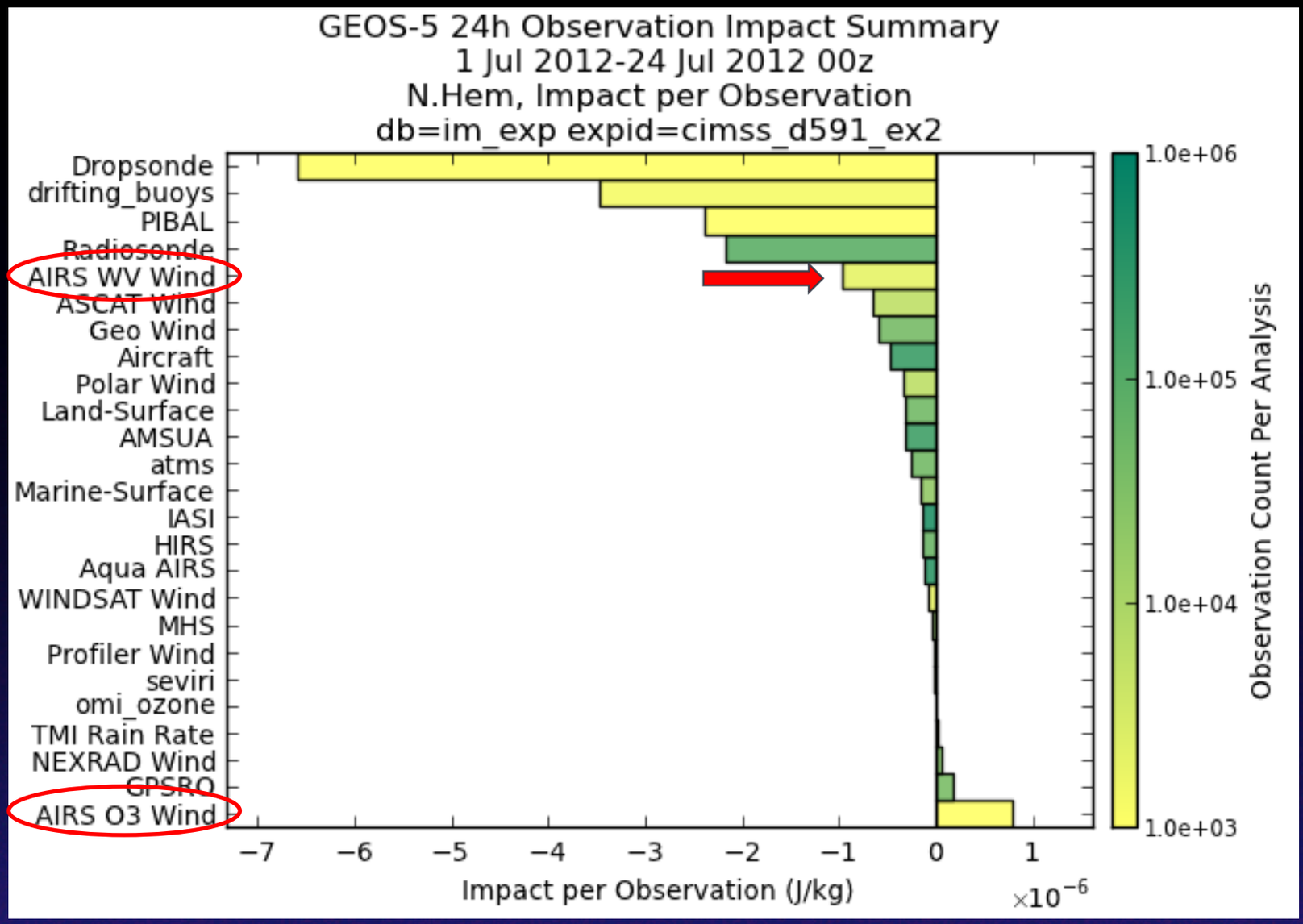
Experiments

GEOS-5 Forecast System (reduced resolution)
- GEOS-5 AGCM + GSI analysis (~½° L72)
- 3DVar
- 6-h assimilation cycle
- 7-day forecasts, adjoint-based 24h obs
- Impacts at 00z (dry energy norm, sfc-150 hPa)
- QI > 40; increased the observation error

Dates: 14 June – 31 July 2012

Experiments
1. Control
2. + AIRS winds
3. + AIRS winds - MODIS WV winds
4. - AIRS winds - MODIS all winds

Impact per observation



1 – 24 July 2012 00 UTC

GEOS-5 Forecast Impact: ACC

Two experiments

Control in black.

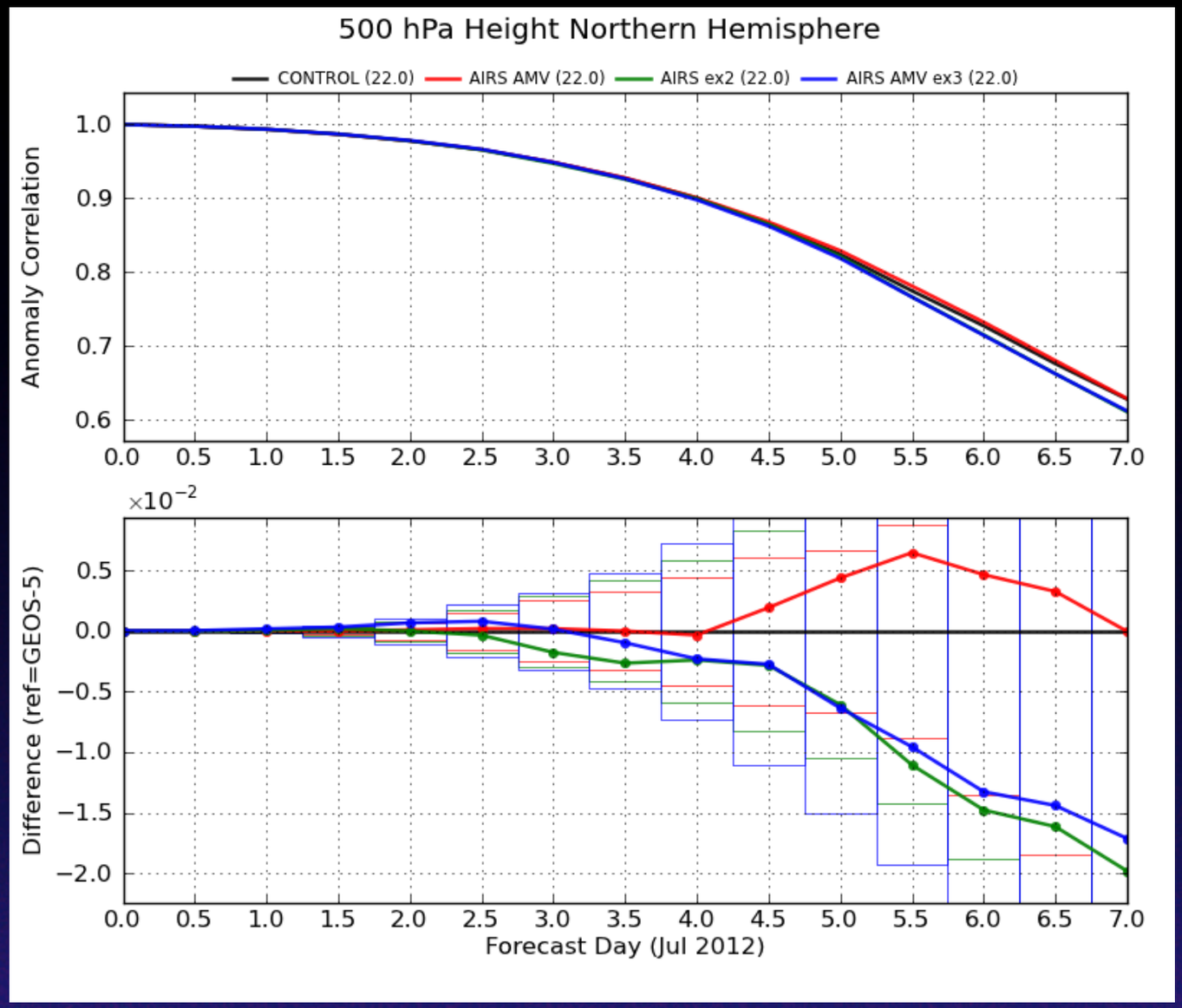
Red: Addition of AIRS AMVs. Slight improvement after Day 4 (not statistically significant).

Blue: Removal of the MODIS AMVs decreases ACC score:

- AIRS AMVs can not offset loss of MODIS AMVs

AIRS AMVs complement the MODIS AMVs

AIRS AMVs are in clear sky or above cloud regions; MODIS AMVs include cloud-tracked features.



500 hPa Northern Hemisphere
1 – 24 July 2012 00 UTC

Summary of AIRS AMVs

- Impact per AIRS moisture AMV is ranked higher than all other satellite-derived wind datasets
- Neutral, or slightly positive, forecast impact due to the addition of the AIRS retrieval AMVs is encouraging:
  - AMVs only in polar region: poleward 70° latitude
  - Impact in the longer range forecast over the entire northern hemisphere (20° – 90° N)

Follow-on NASA Project

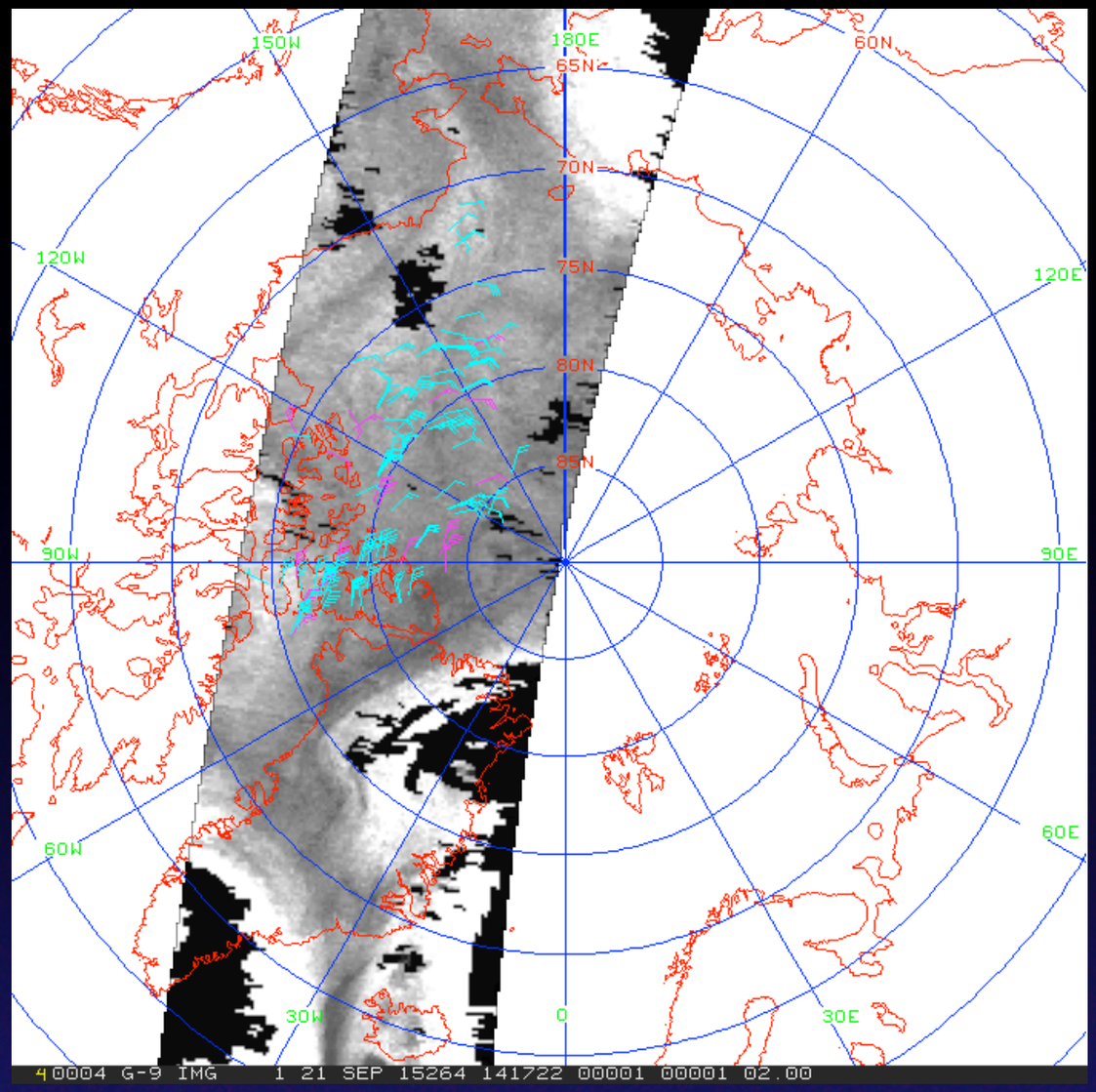
Real-time Generation of Atmospheric Motion Vectors from AIRS Retrieval Data

Goals

1. Automate procedures to generate AIRS AMVs in near realtime
2. Blend AIRS and Aqua MODIS AMVs
3. Collaborate with NWP partners for monitoring and assimilating the AMVs
4. Product available since May 2015

Real-time AIRS winds

- Three to four 6-minute granules are reprojected to a polar stereographic projection:
  - 16 km resolution
  - Composited
- Bi-linear interpolation used to smooth gradients
- Winds are computed on 22 levels (343 to 753 hPa)
- Product is available in near real-time
  - Delayed by several hours
  - Similar delay to other polar winds products
  - 13-15 AIRS datasets per day at each pole
- AMVs generally cover the area poleward of 70° latitude over the course of a day



Preview: http://stratus.ssec.wisc.edu/cgi-bin/polarwinds?airs

Winds product: ftp://stratus.ssec.wisc.edu/pub/winds/retrieval_winds/airs/

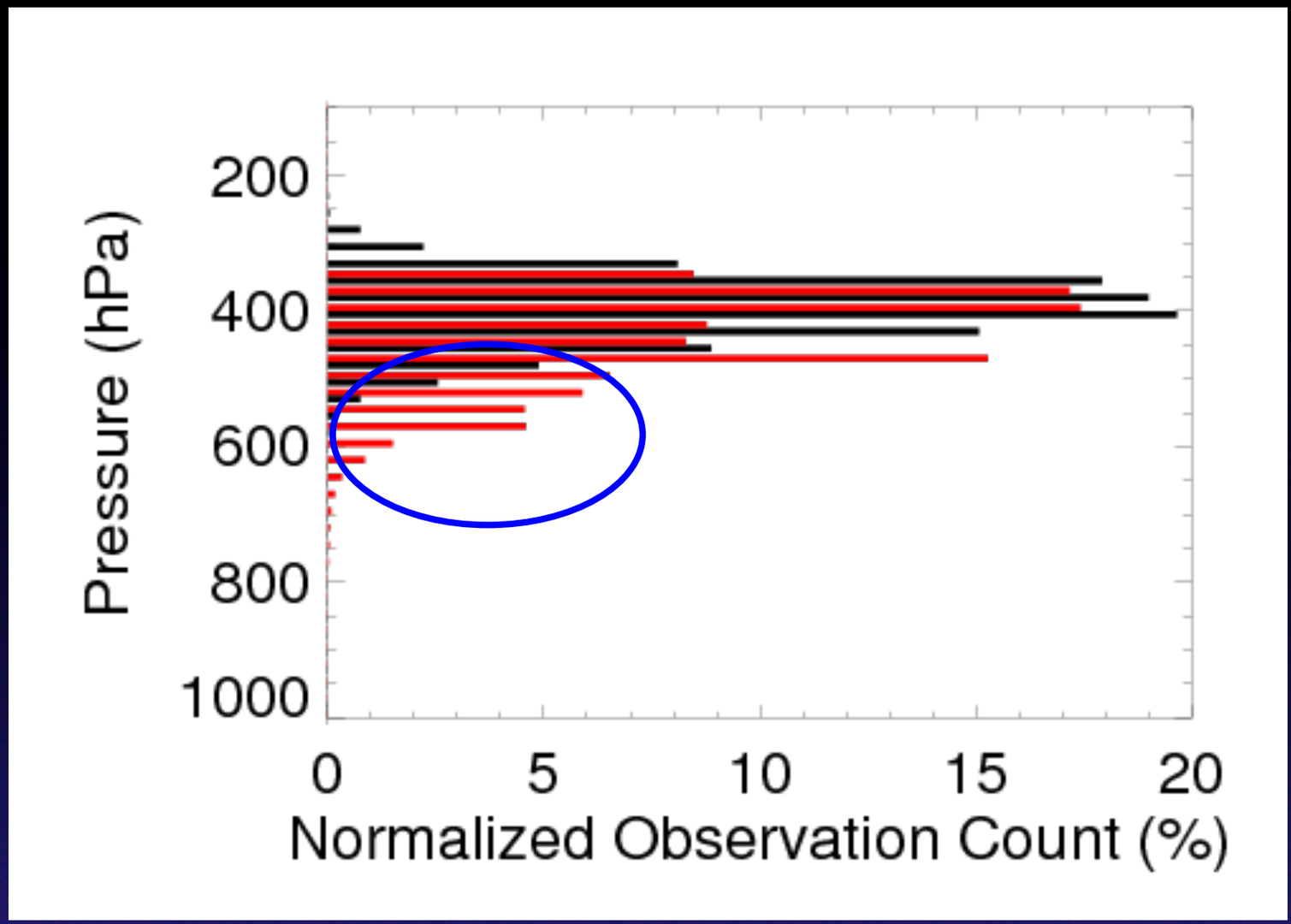
AIRS winds preliminary evaluation

FNMOC (Randy Pauley)

- Observation impact looked good
- They are comparable to other polar winds in impact per observation and innovation statistics
- However, data volume low
  - Low resolution hyperspectral instruments
  - Only in the polar regions (dry atmosphere)

AIRS winds preliminary evaluation

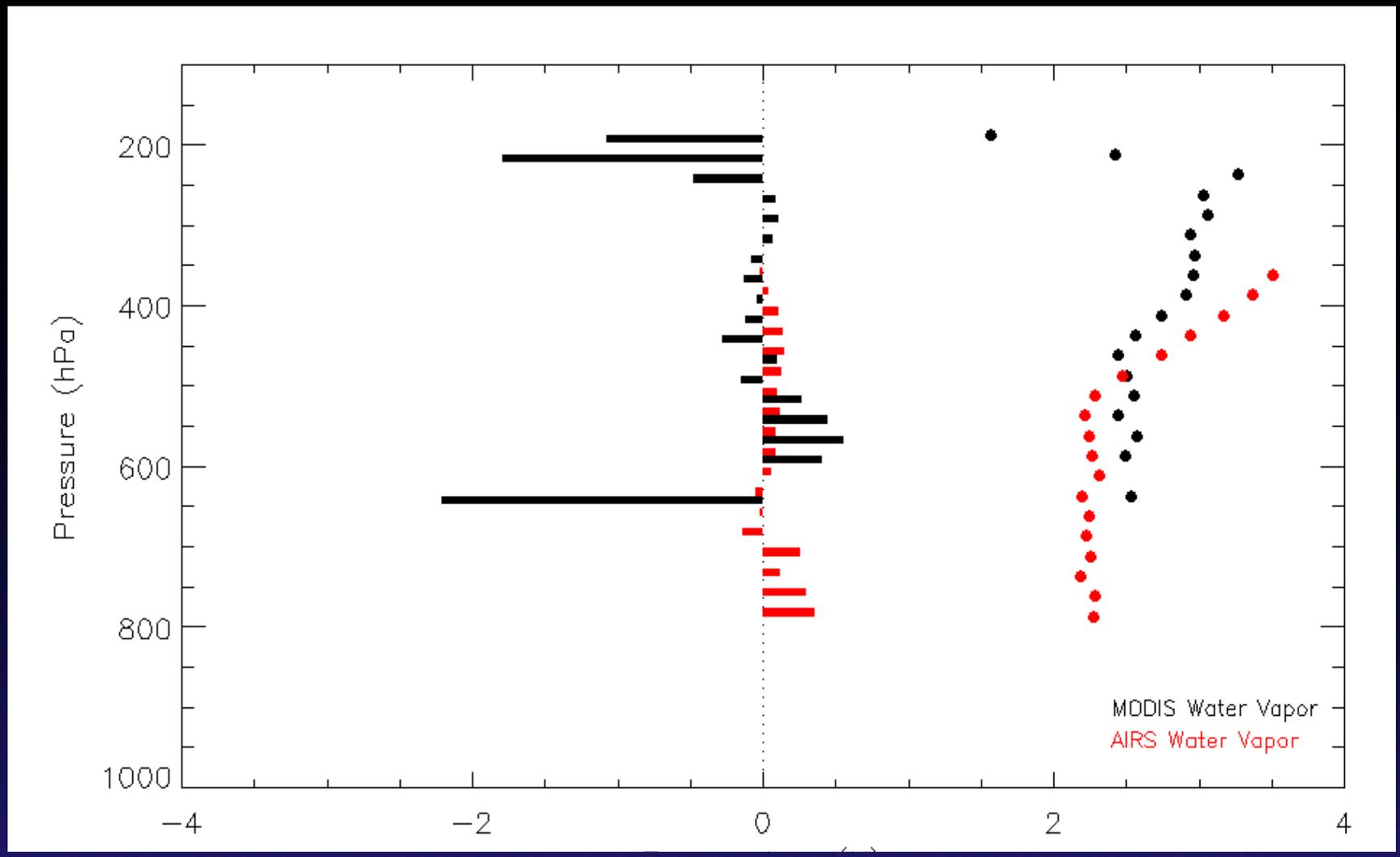
NASA/GMAO (Will McCarty)



Observation Counts: Histogram of averaged normalized counts for 6-hour cycles for AIRS (red) and MODIS (black) water vapor winds.
May to July 2015

AIRS winds preliminary evaluation

NASA/GMAO (Will McCarty)



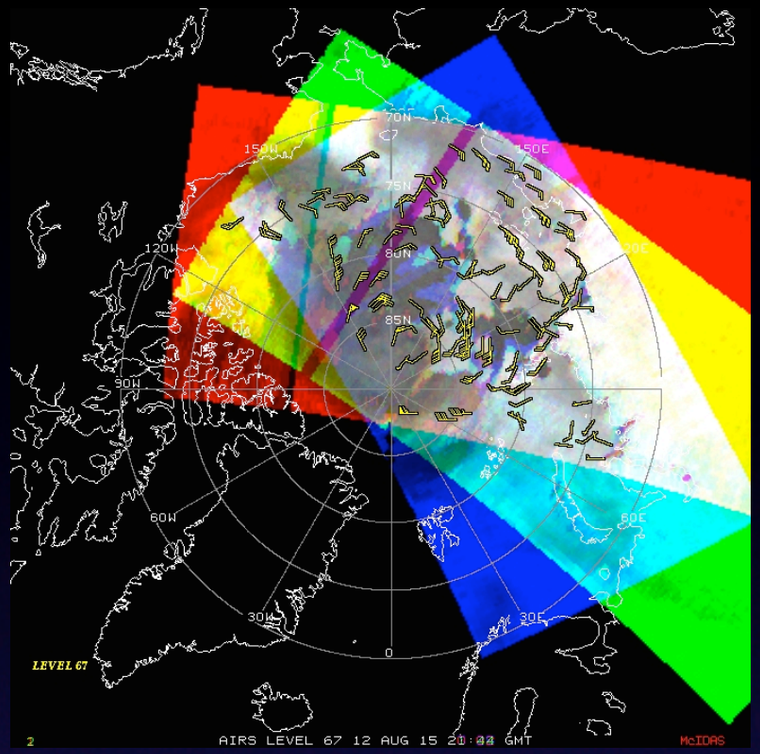
Observation Departures: Mean and standard deviation (ms^{-1})
for AIRS (red) and MODIS (black) water vapor winds
May to July 2015

Future Application of Technique

Technique can be applied to other satellites:

- Polar imagery winds are currently being generated from AVHRR (Metop-A and –B) and VIIRS (S-NPP)
- SSEC SFOV retrieval algorithm has been applied to IASI and CrIS
- Therefore, blended AMV products could be generated for:
  - AVHRR/IASI on Metop-A and -B
  - VIIRS/CrIS on S-NPP and JPSS
- Investigate cross-platform humidity feature tracking:
  - Shorter time interval between images
  - Coverage would extend further south
- And, perhaps other sounding instruments….

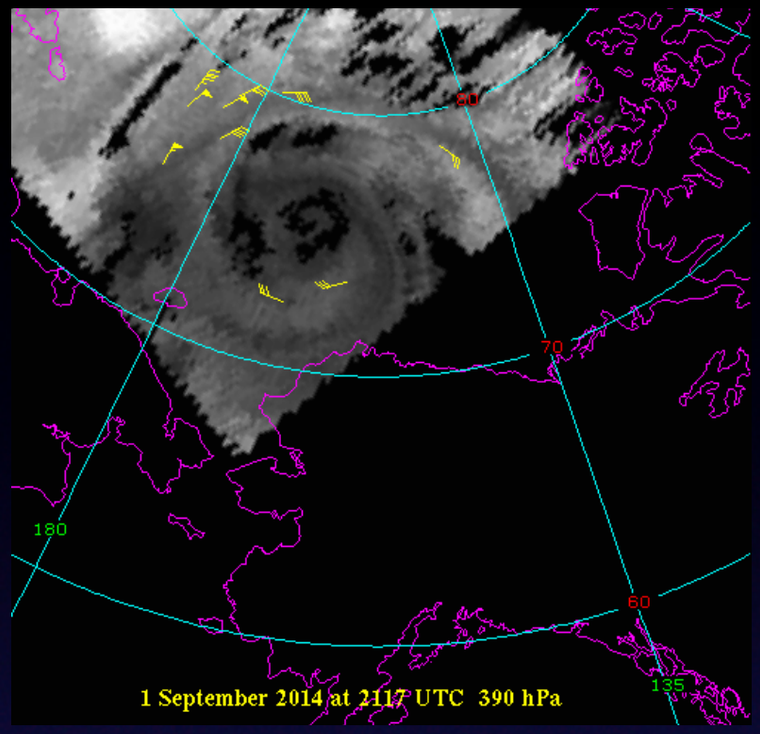
Winds from ATMS, IASI, and CrIS
In development



ATMS

Advanced Technology Microwave Sounder

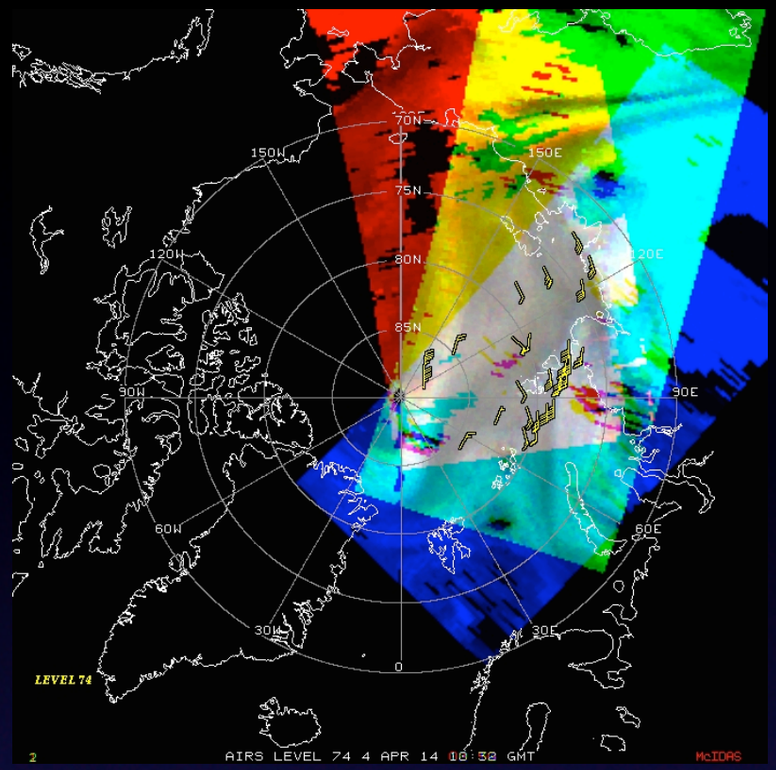
Suomi NPP



CrIS

Cross-track Infrared Sounder

Suomi NPP

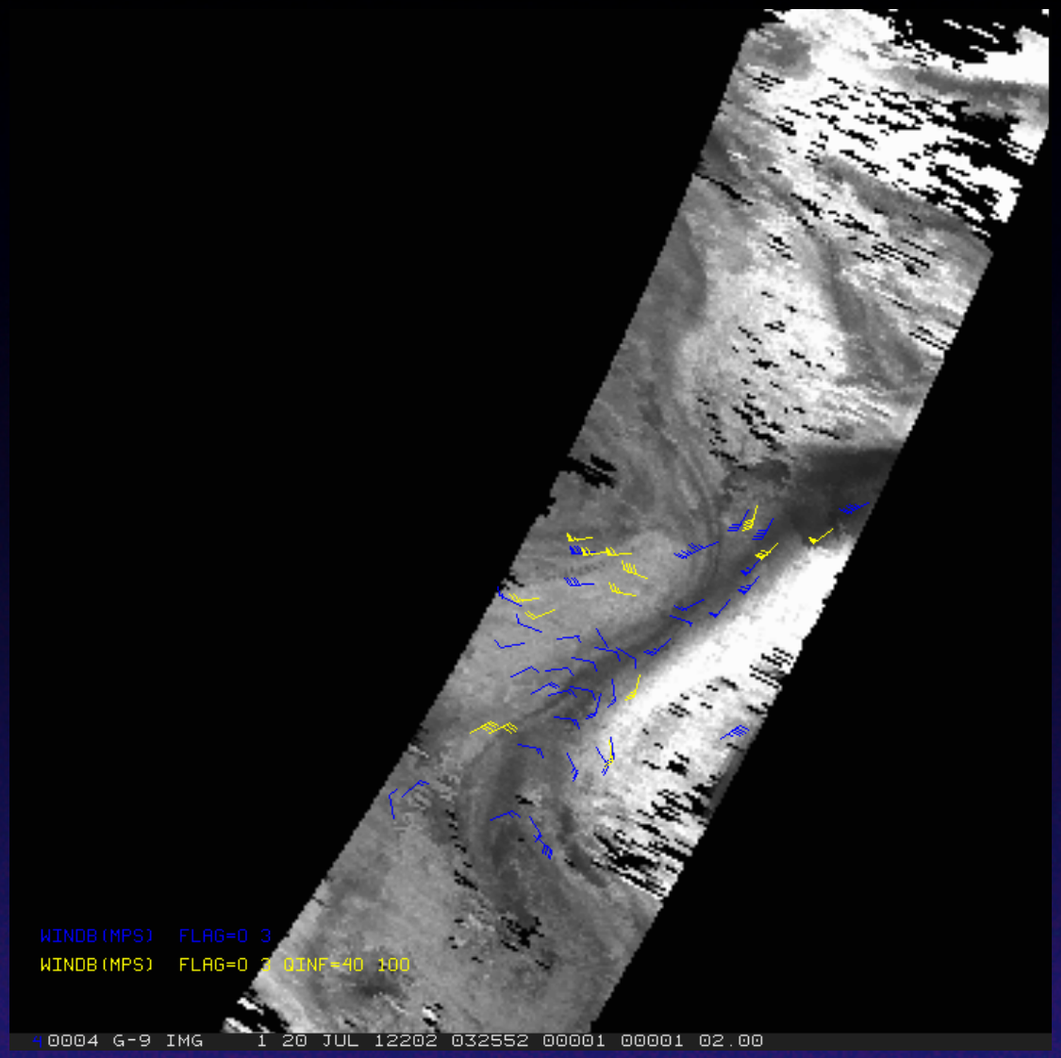


IASI

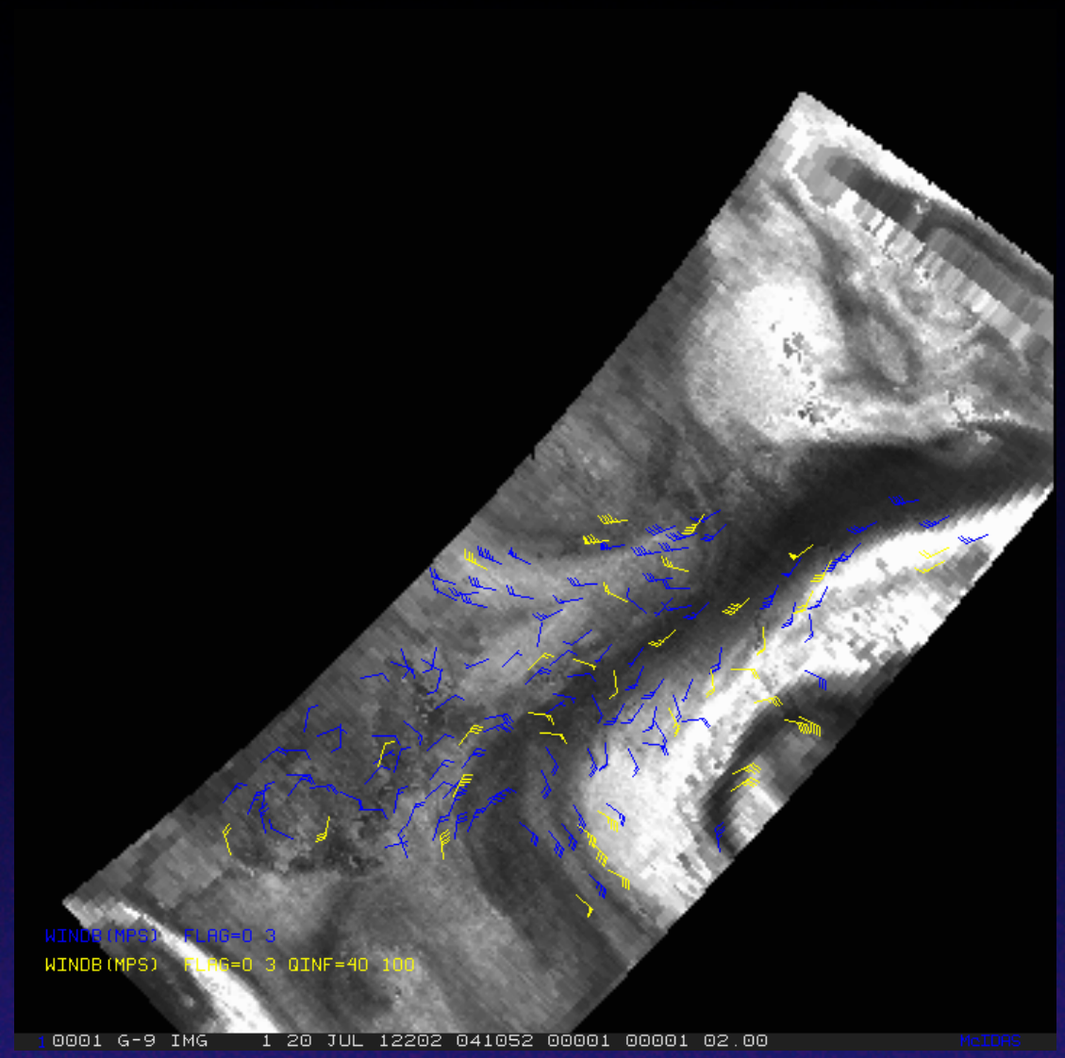
Infrared Atmospheric Sounding Interferometer

Metop-A, -B

AIRS and ATMS Retrieval Images at 400hPa



AIRS 20 July 2012 0505 UTC



ATMS 20 July 2012 0551 UTC

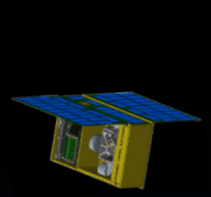
Specific humidity retrievals.
All winds (blue); Quality controlled winds(yellow)

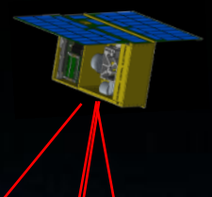
Future: 3D Wind Measurements Using Constellation of Small-Sats

Concept: Time-Separated Moisture Field Soundings By Multiple Small Satellites Can Provide Winds at Multiple Vertical Layers

Leading Small-Sat

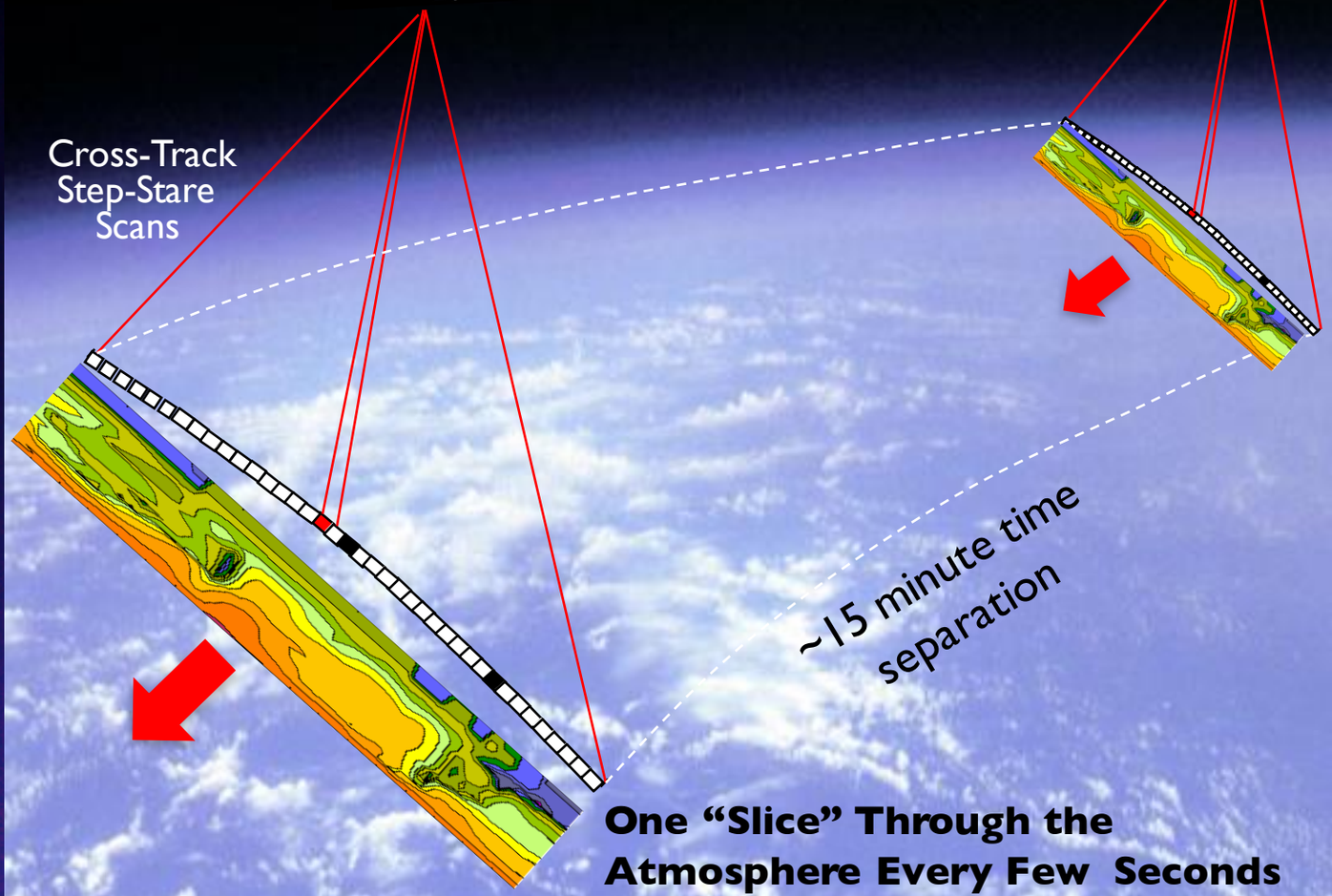
Trailing Small-Sat





MWIR FTS is Optimized for Moisture Soundings

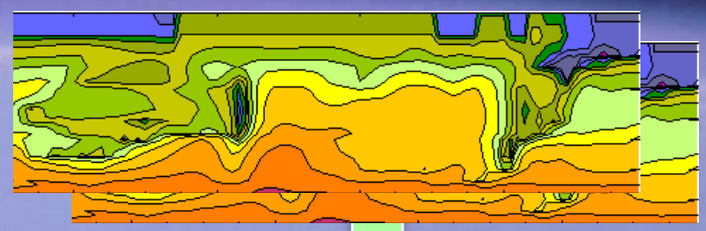
Cross-Track Step-Stare Scans

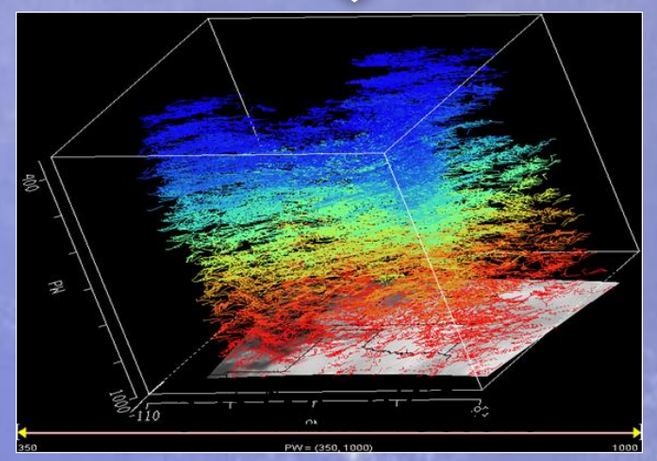


~15 minute time separation

One "Slice" Through the Atmosphere Every Few Seconds

Two 3-D Moisture Data Cubes





Observing System Simulation Experiment (OSSE)

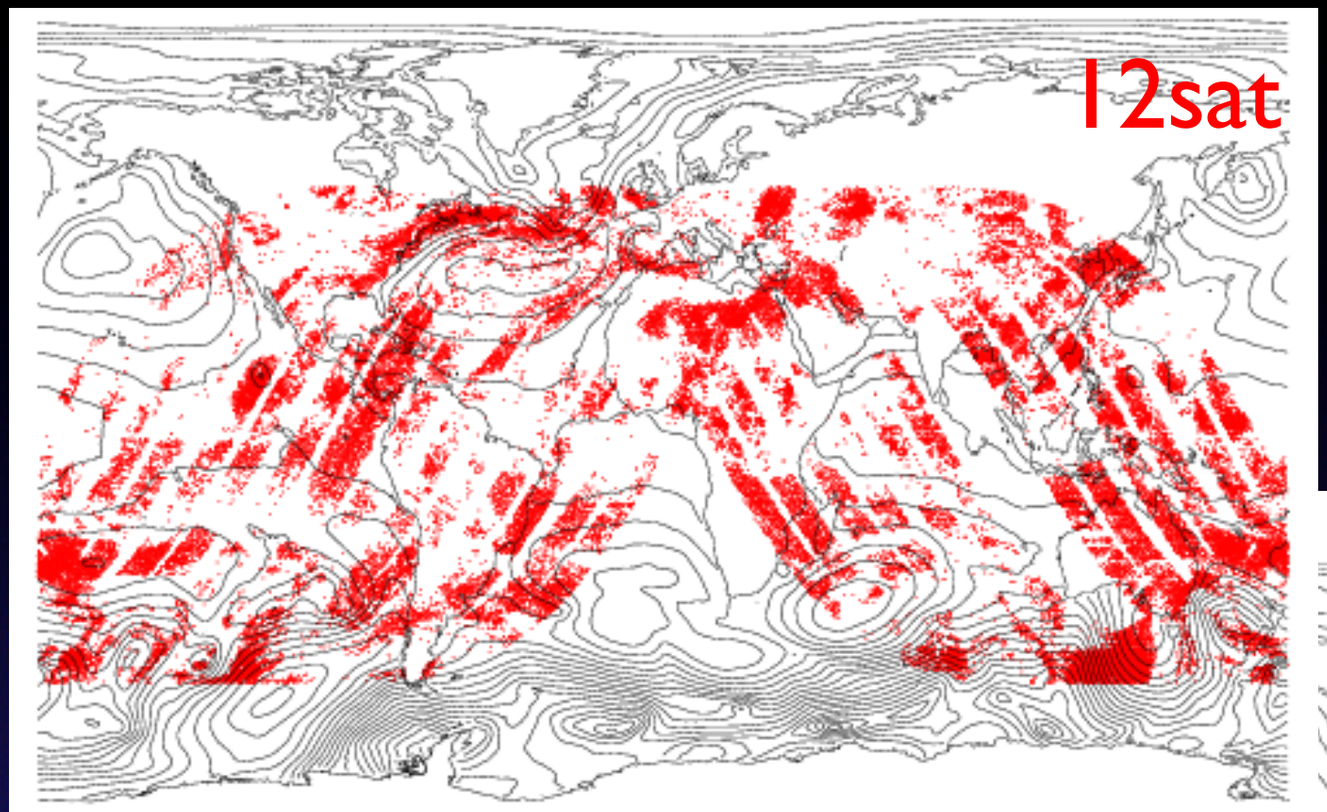
Nature run:

- 7 km GEOS-5 from the NASA/GMAO
- 2-year period, circa 2012
- A simulator was developed which probabilistically determines the 3D AMV fields at a given point along the swath of the orbital planes

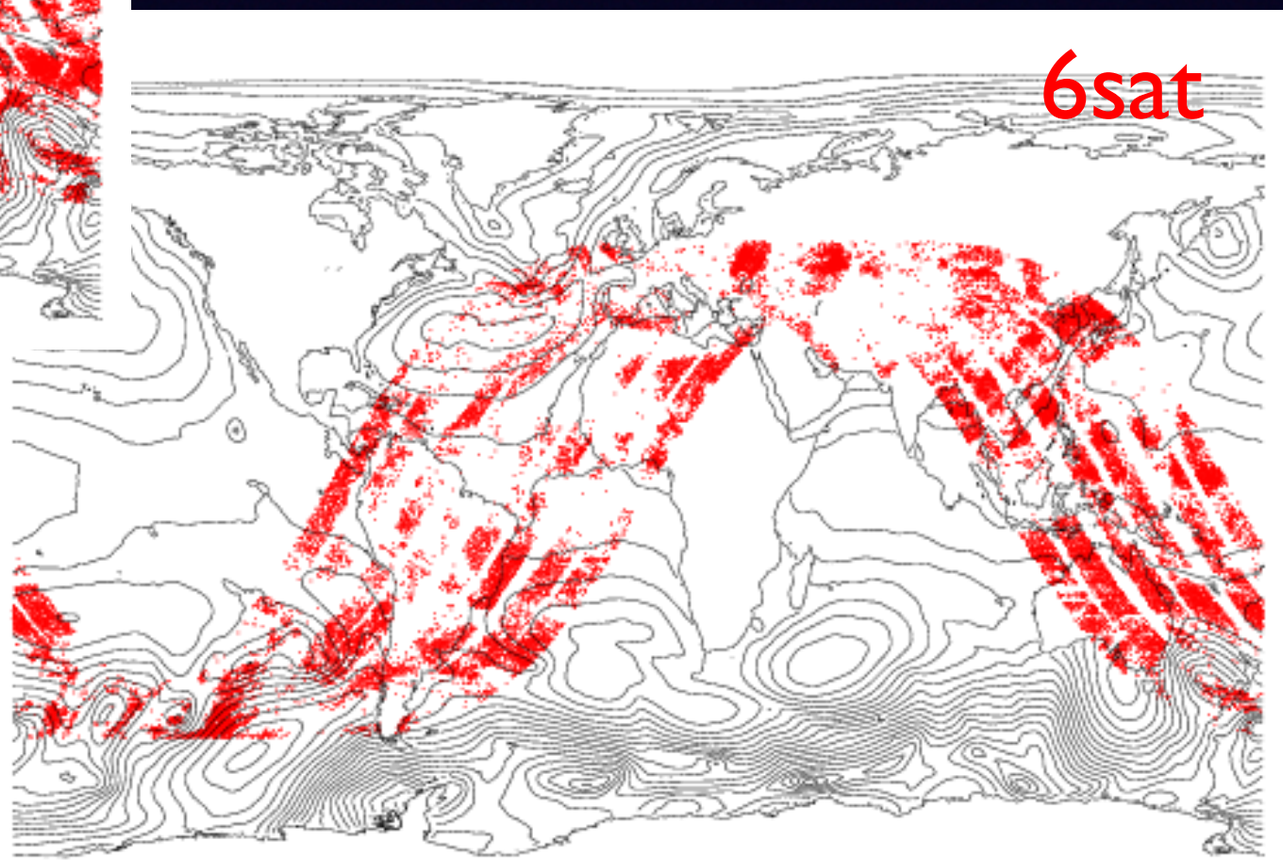
Assimilation:

- GEOS-5 data assimilation system
- 0.5° x0.625° horizontal resolution globally
- 72 vertical levels; surface to 0.01 hPa
- Cycled for a month
- Analyses every six hours

Simulated Observations (12- and 6- satellite constellations)



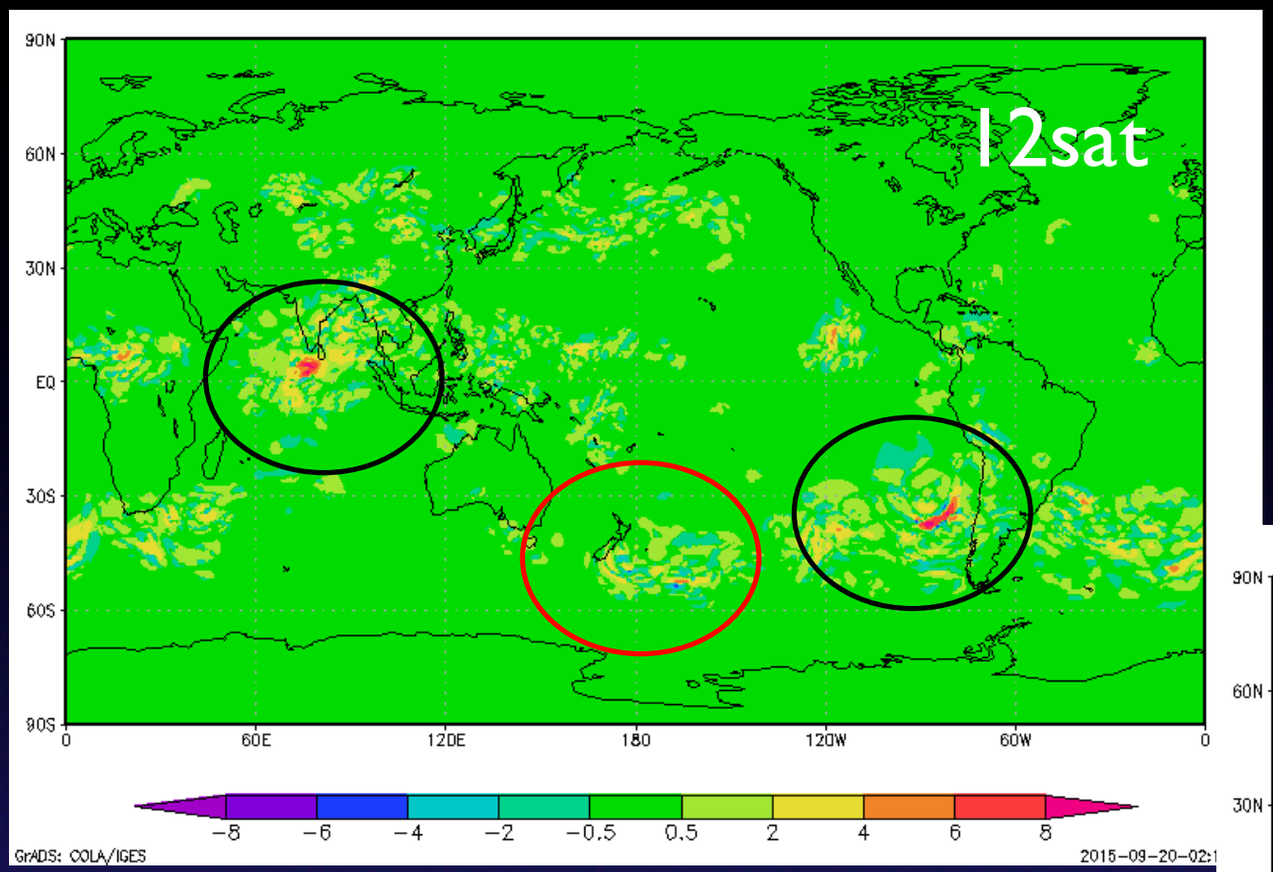
High inclination orbit to maximize mid- and low-latitude coverage



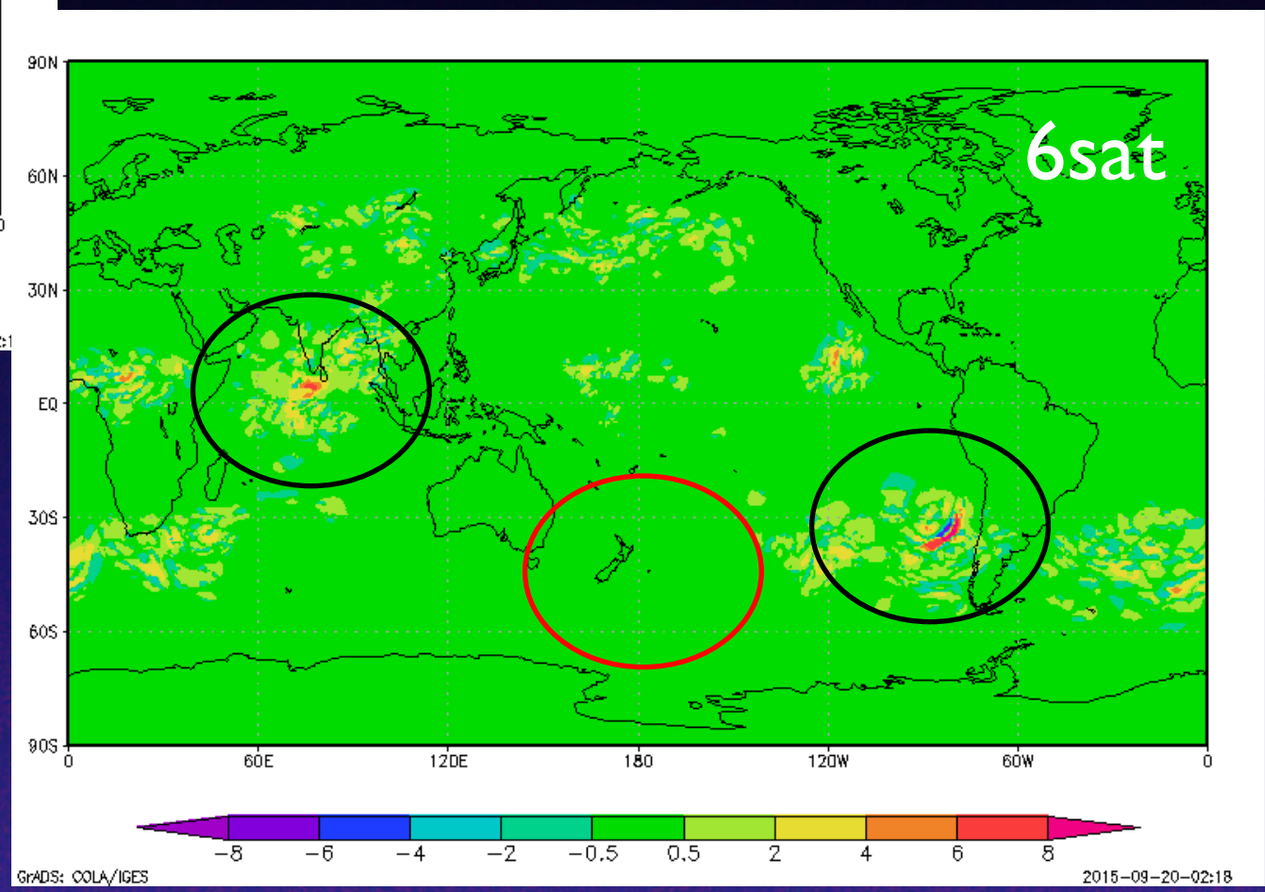
Simulated AMVs valid for 6-hour assimilation window

Black contours are surface pressure over ocean

Error Reduction



Reduction in wind speed error (ms^{-1}) at 300 hPa for a single analysis time in July



Positive impact (yellow to red)
Negative impact (blue to purple)

☐Summary

- AIRS retrieval polar AMVs are being produced routinely
- Interest in using other retrievals for winds:
  - CrIS, IASI: SSEC SFOV retrieval
  - ATMS: NOAA Unique CrIS/ATMS Processing System (NUCAPS)
- Global 3D winds from LEO satellite constellation:
  - 6-satellite: Minimum for demonstration mission
  - 12-satellite: Minimum for operational applications

NASA Grants NNX11AE97G and NNX14AI77G
NOAA Grant NA14NES4830004