Impact, Quality and Benefits of AMDAR Data

Ralph Petersen[1,2]

[1]Cooperative Institute for Meteorological Satellite Studies (CIMSS)
Space Science and Engineering Center (SSEC)
University of Wisconsin – Madison
[2]Representing the WMO AMDAR Panel

A combination of:

An overview of the work of a lot of other people

and

A discussion of new AMDAR data and other applications

(with the help of Lee Cronce and others)

AMDAR stands for Aircraft Meteorological Data Relay.

It provides flight-level reports and profiles of Temperature, Wind and Humidity (increasing amount) from the surface to ~40,000 feet

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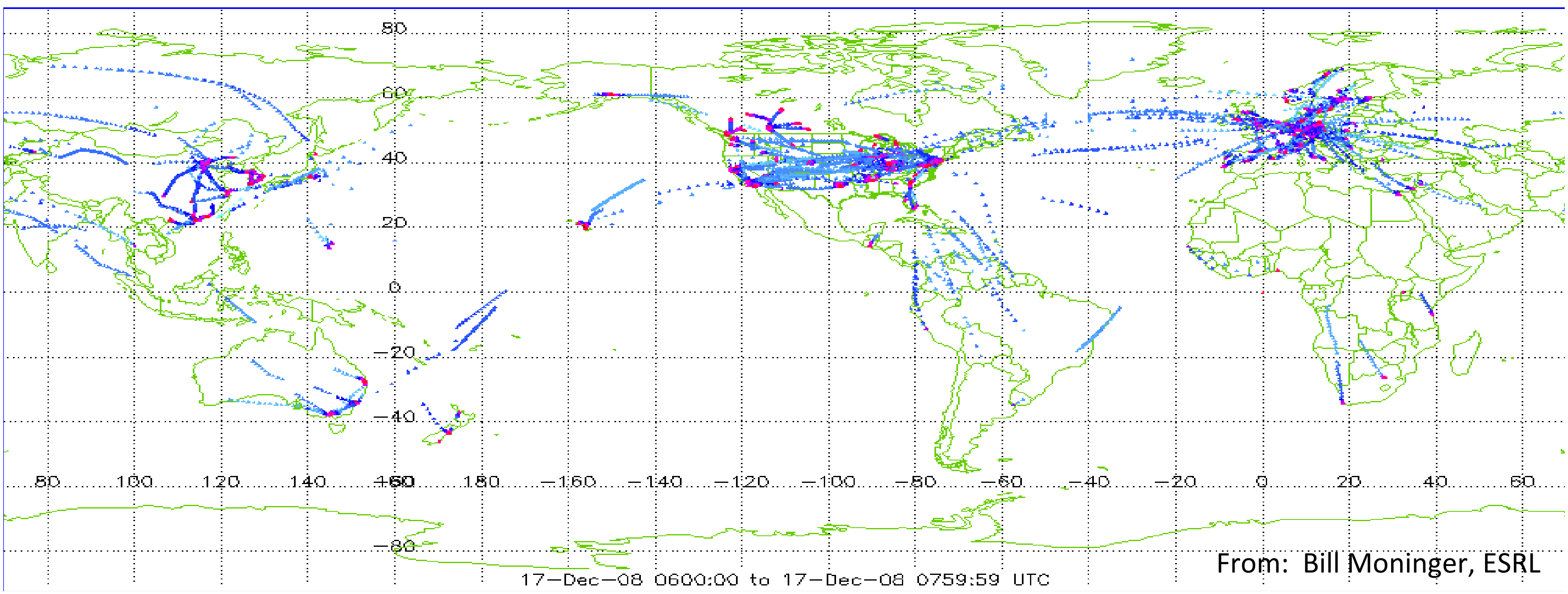
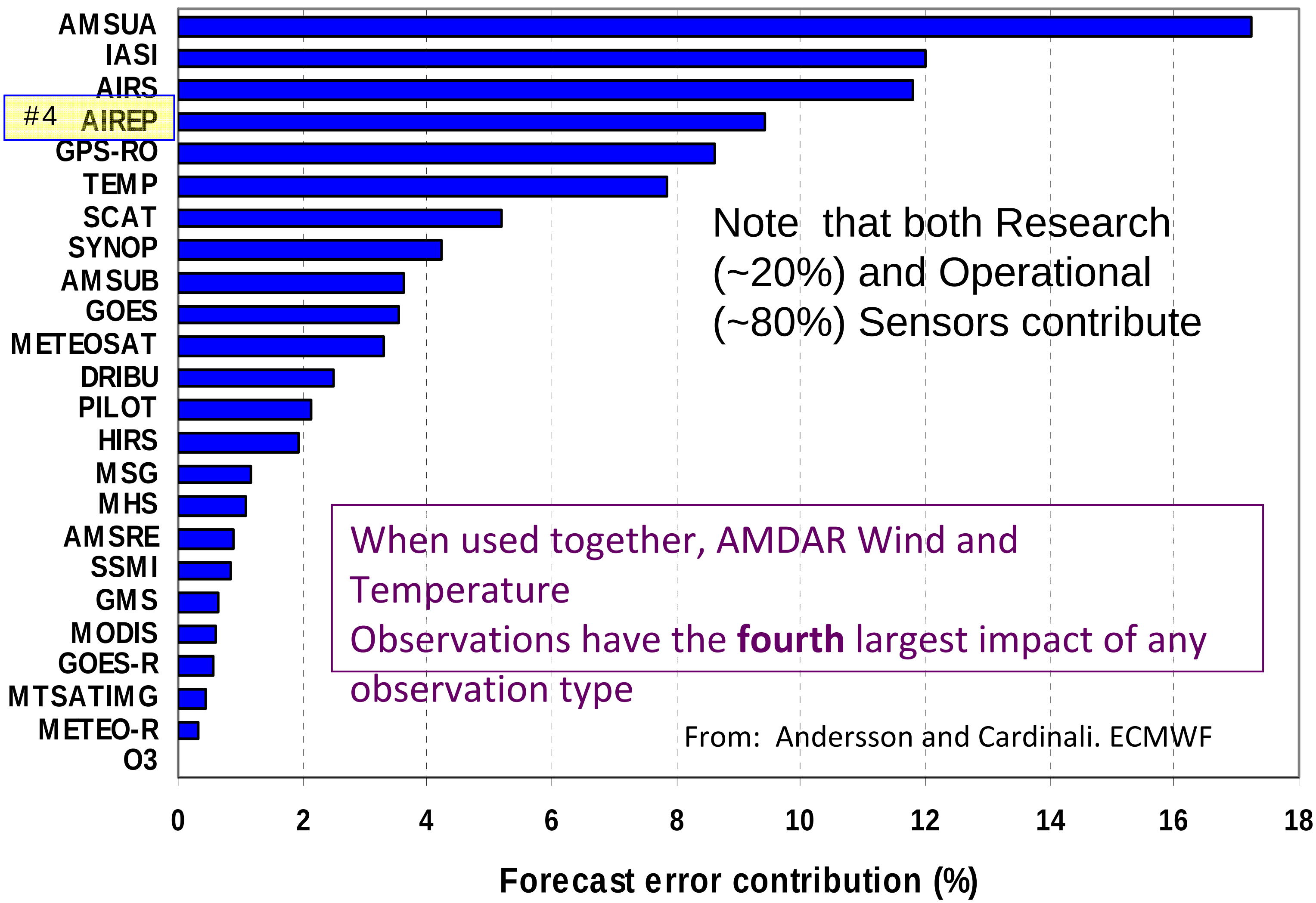


Points to remember about AMDAR Impacts

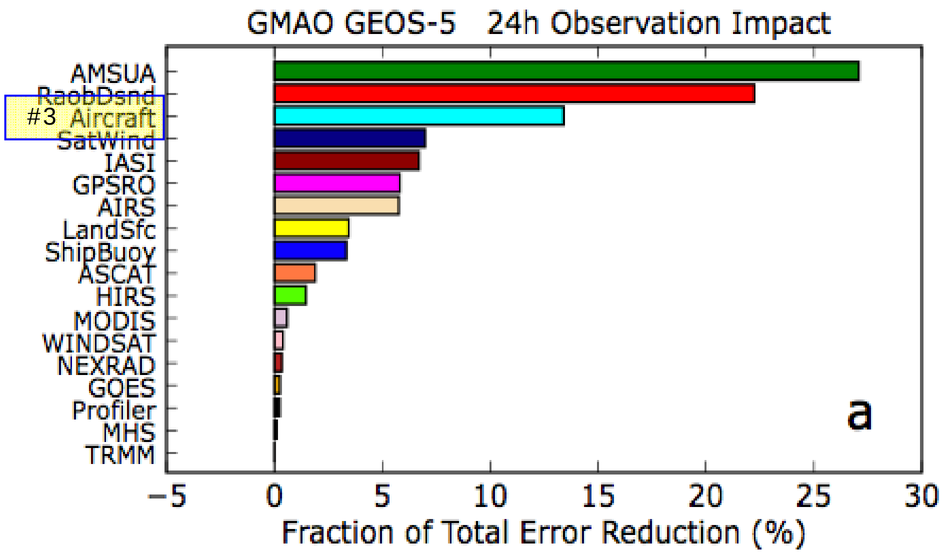
- AMDAR data continue to be among 4-5 most important data sources for global assimilation

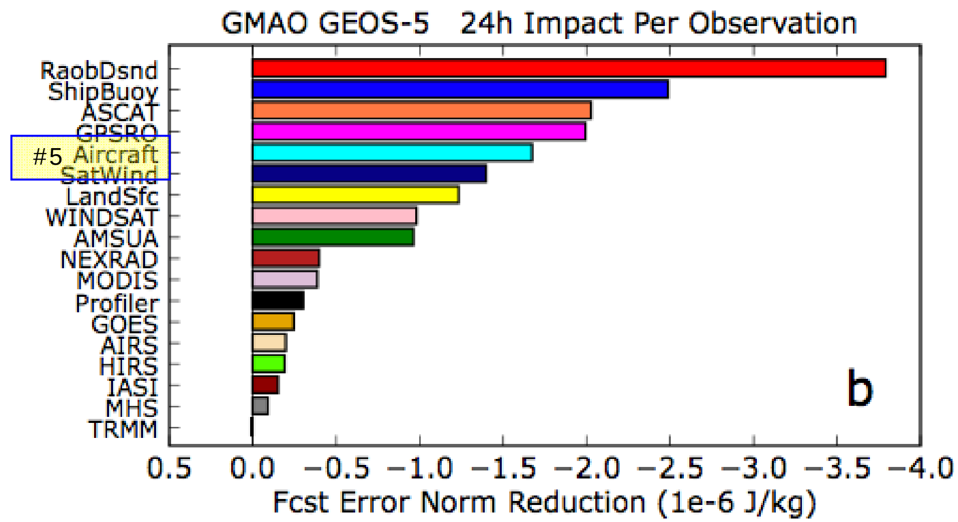
Adjoint-based Observation Impact Analysis from the European Center

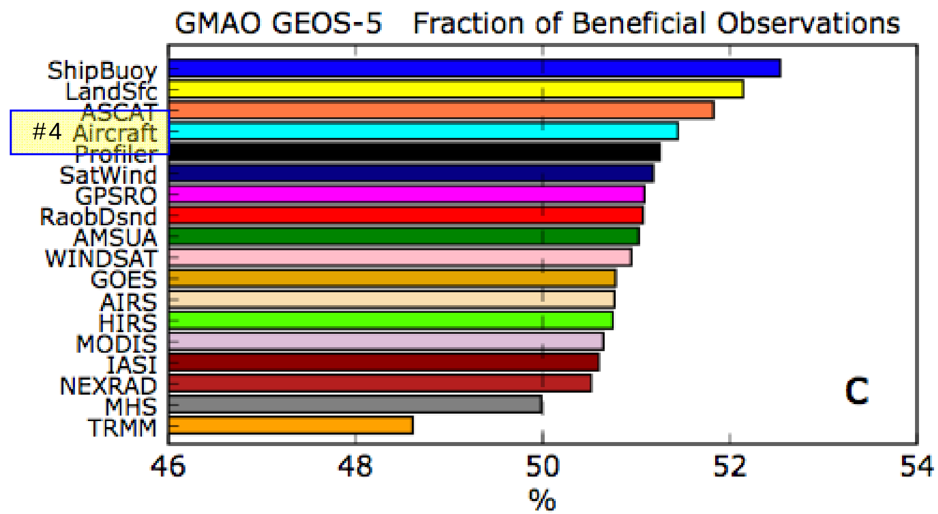


(Contribution (%) to Total Forecast Error Reduction)

Observation Impact Analysis from the JCSDA/GMAO







From:

JCSDA Quarterly

No. 35, June 2011

Joint Center for Satellite Data Assimilation • 5200 Auth Road • Camp Springs • MD • 20746 *Editor: George Ohring*

NOAA……………NASA…………US Navy…………US Air Force *Web-site: www.jcsda.noaa.gov*

Points to remember about AMDAR Impacts

- AMDAR data continue to be among 4-5 most important data sources for global assimilation
  - They are extremely cost effective
  - **ROUGH** estimates of daily costs per obs. system:
    2 LEOs ~ $3.75M/day
    Raobs ~ $0.3M/day
    AMDAR ~ $0.014M/day (possibly large)
    (< $300/workshop attendee/day)

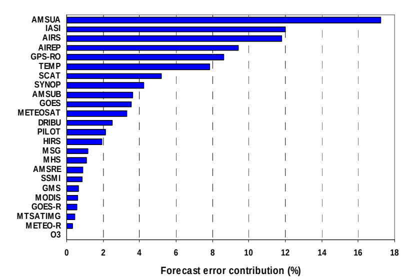
Costs must be considered in our "Age of Austerity," especially for 'conventional' observations that are not included in major new observation programs

Need funding strategies for 'baseline' observations.

Points to remember about AMDAR Impacts

- AMDAR data continue to be among 4-5 most important data sources for global assimilation
  - They are extremely cost effective
  - **ROUGH** estimates of daily costs per obs. system:
    - 2 LEOs ~ $4M/day
    - Raobs ~ $0.3M/day
    - AMDAR ~ $0.014M/day (possibly large)
  - *ROUGH Cost per unit impact (% impact taken from ECMWF ↓) :*
    - *AMSUA ~ $105K/day/% error reduction*
    - *IASI/AIRS(CRiS) ~ $80K/day/% (each)*
    - *Raobs ~ $35K/day/%*
    - *AMDAR ~ $1.5K/day/%*

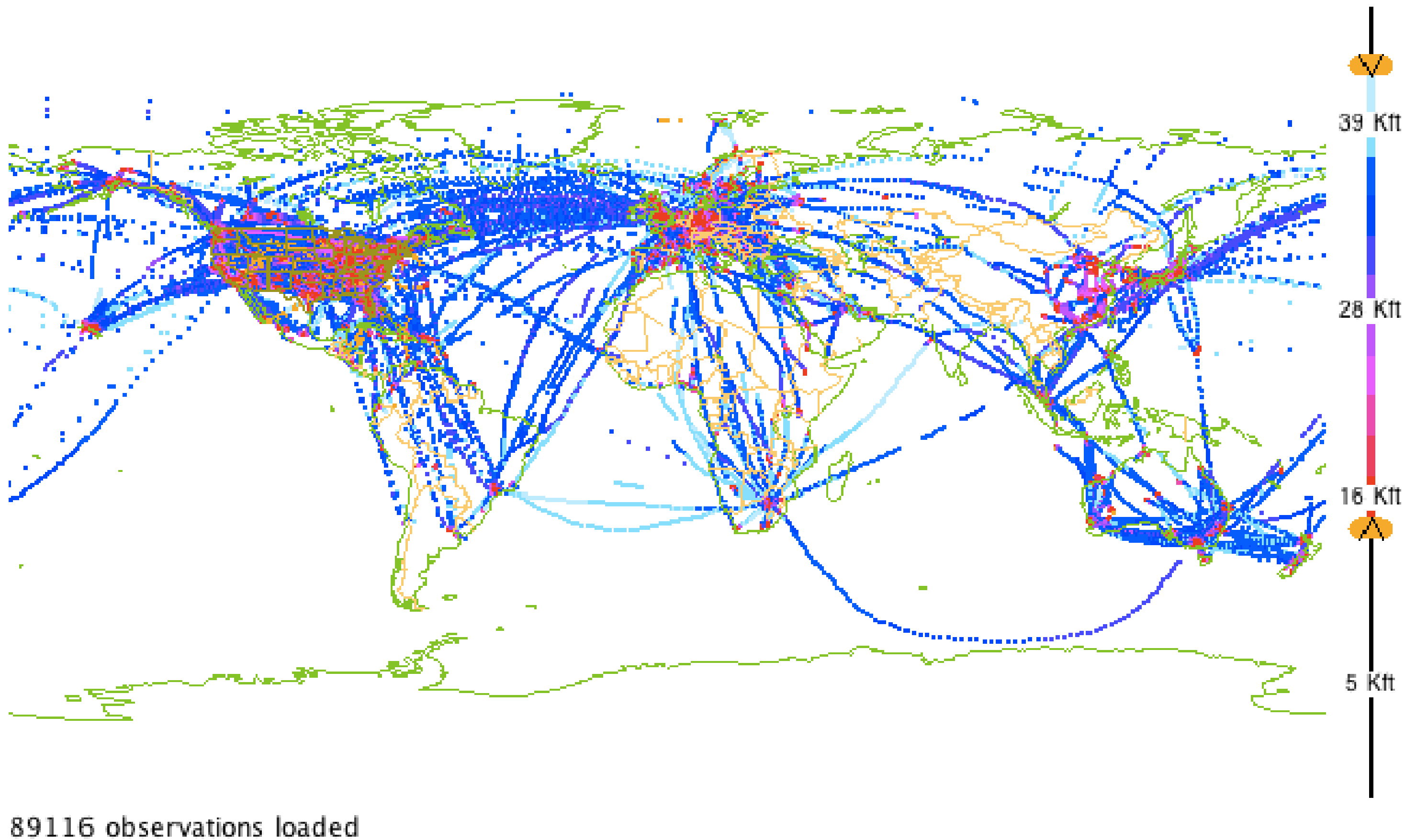
Adjoint-based Observation Impact Analysis from the European Center



Should AMDAR be viewed as a 'community supported safety net' option in countries where raobs are at

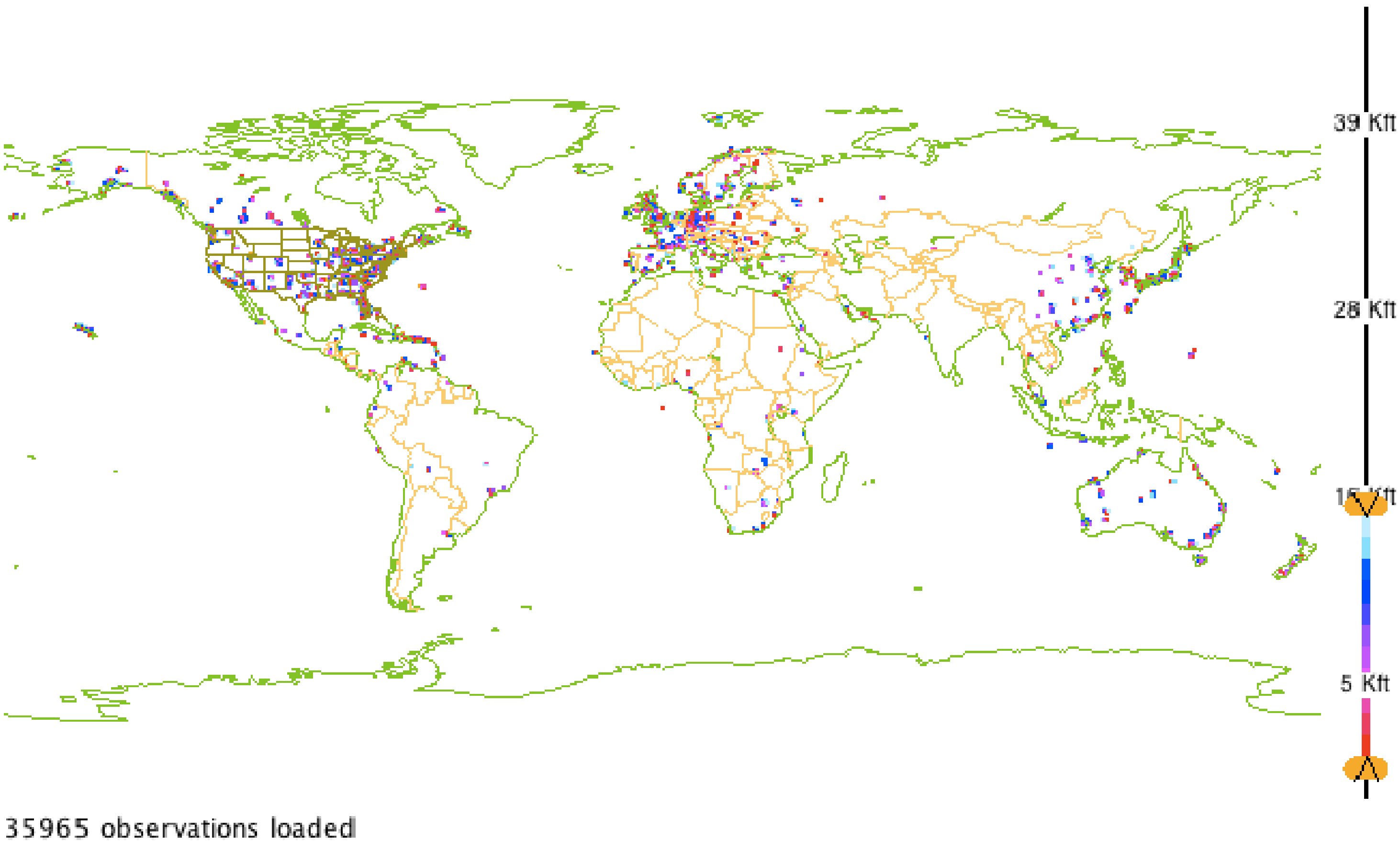
Typical Daily AMDAR Enroute Coverage

10 Met Services, 31 Airlines, 2800 Aircraft



Typical Daily AMDAR Profile Coverage

10 Met Services, 31 Airlines, 2800 Aircraft



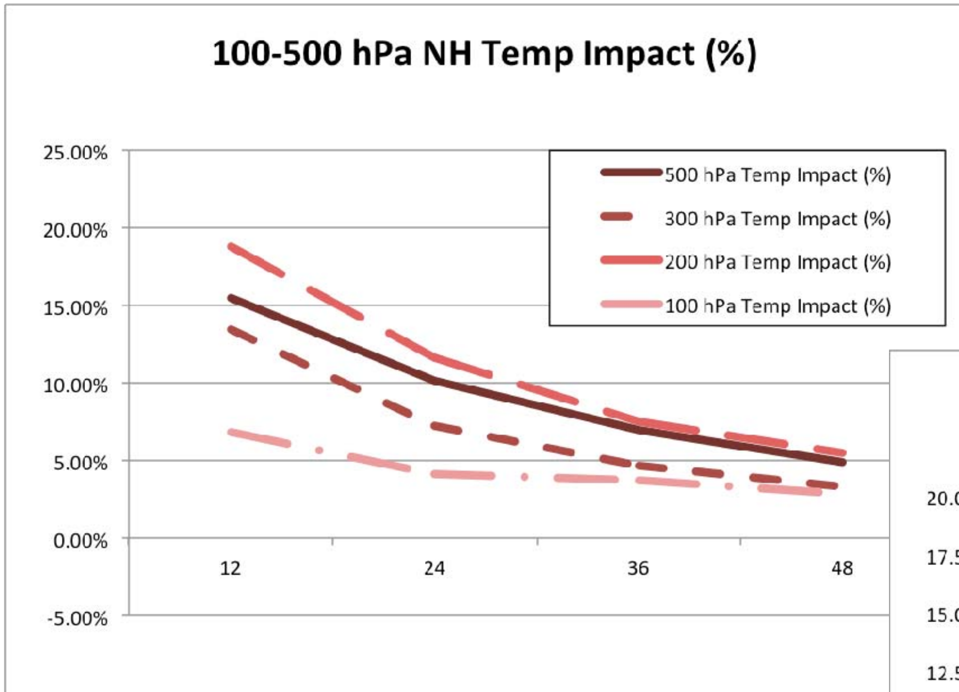
Points to remember about AMDAR Impacts

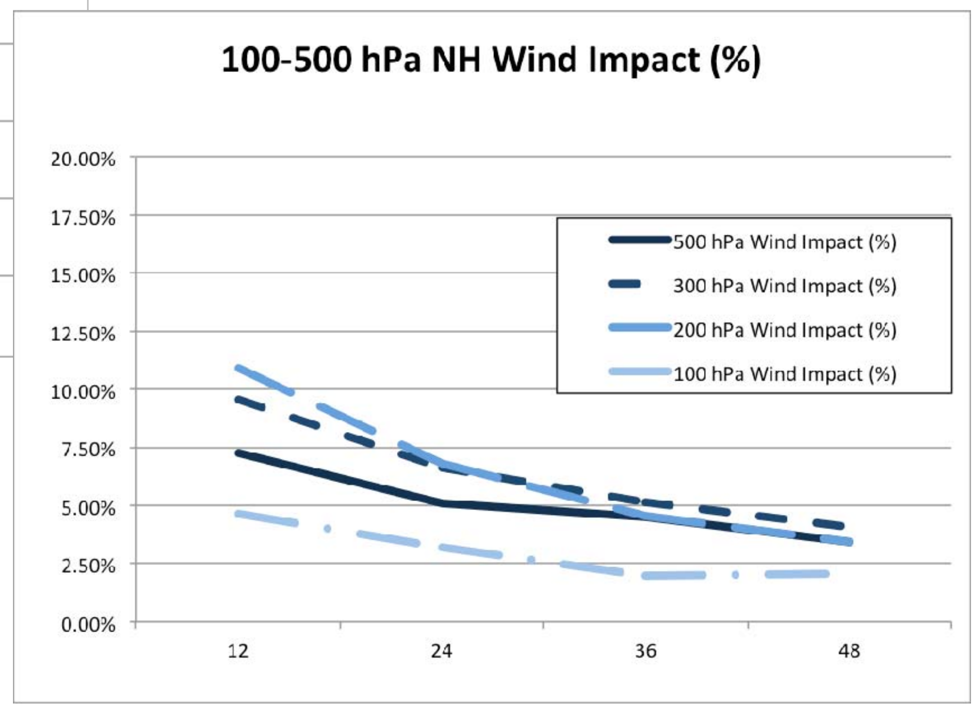
- AMDAR data continue to be among 4-5 most important data sources for global assimilation
  - Large “Bang for the Buck” but lack expansion funding
- Greater impact at shorter time ranges

–Observations also have value in

monitoring other global data sources

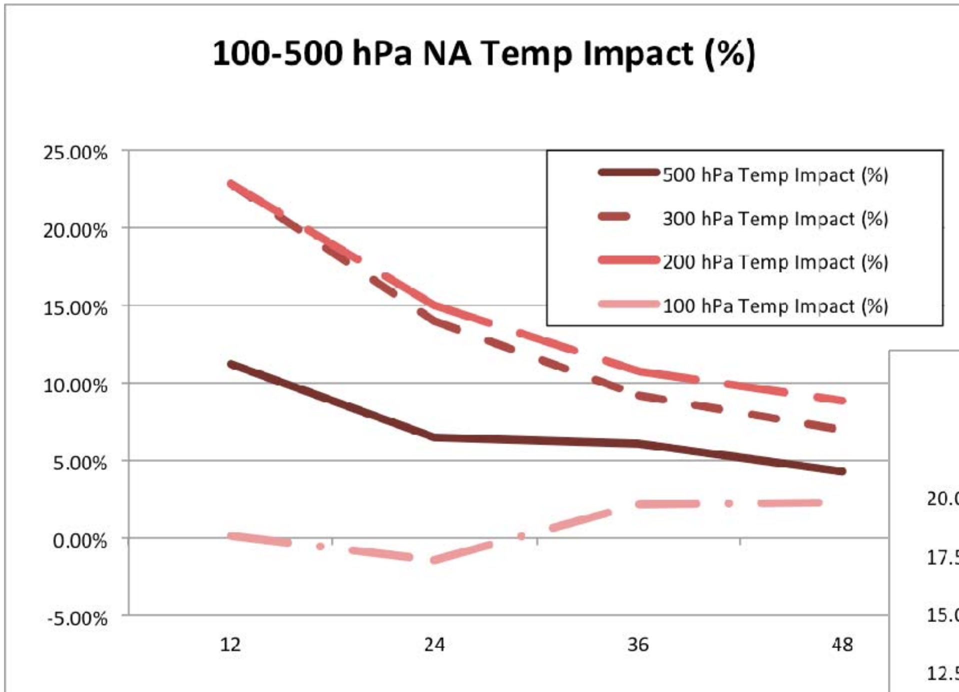
N. Hemi. AMDAR Error Reduction from ECMWF Data Denial Tests ~ 2003

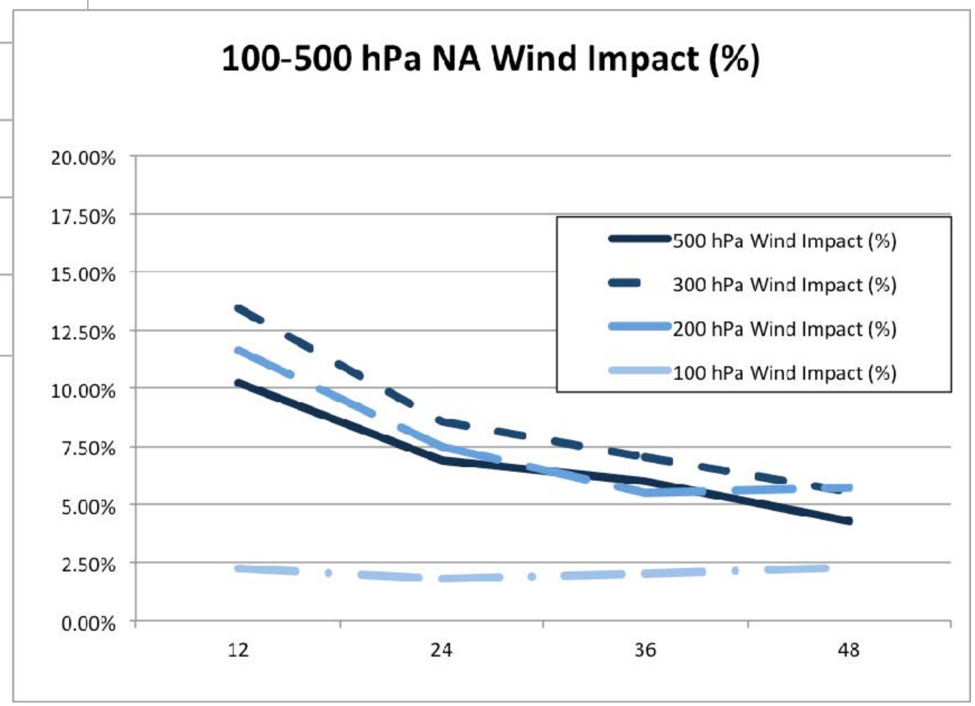




Impact of AMDAR data is greater:
-In days 1-2.
-In the NH .

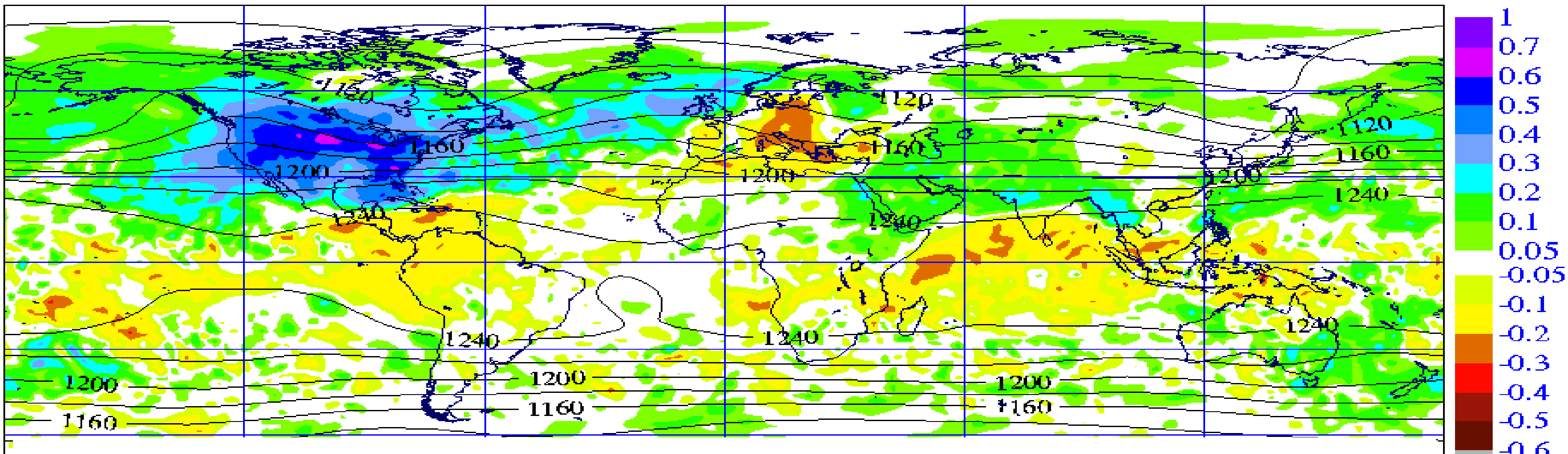
N. Am. AMDAR Error Reduction from ECMWF Data Denial Tests ~ 2003



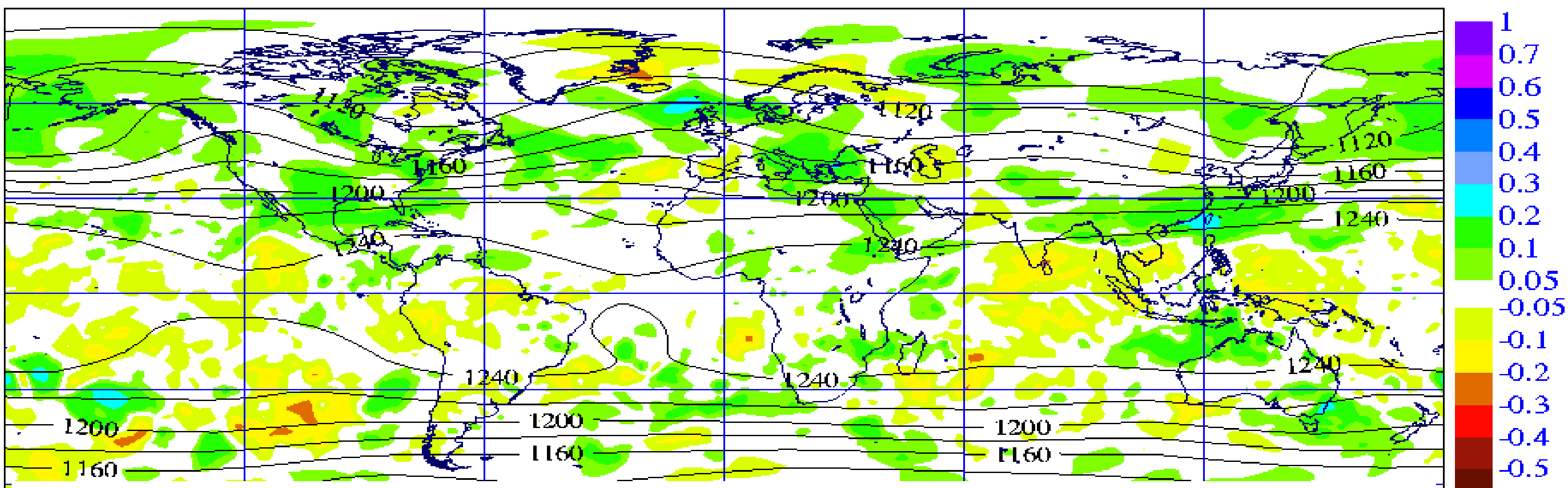


Impact of AMDAR data is greater: In data-rich areas

pos imp



NOAIREP <u>12hr</u> normalized error 200hPa height



NOAIREP <u>48hr</u> normalized error 200hPa height

From: Andersson and Cardinali. ECMWF

neg imp

Bias corrected AMDAR data in the troposphere and lower stratosphere compliment the strengths of GPSRO data above 12km

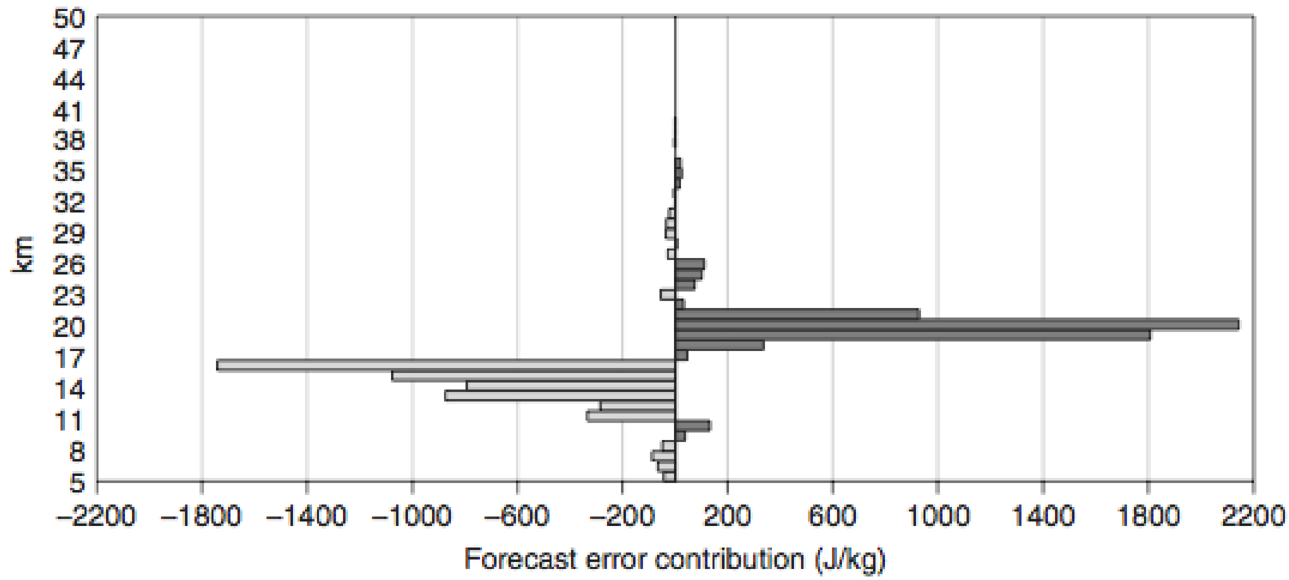


Figure 7. 24-hour forecast error contribution (J/kg) of GPS-RO at different vertical levels, from 5 km above the surface up to 50 km.

From: Cardinali. ECMWF

Even at longer ranges, AMDAR <u>Profiles</u> can influence forecasts in data-rich areas

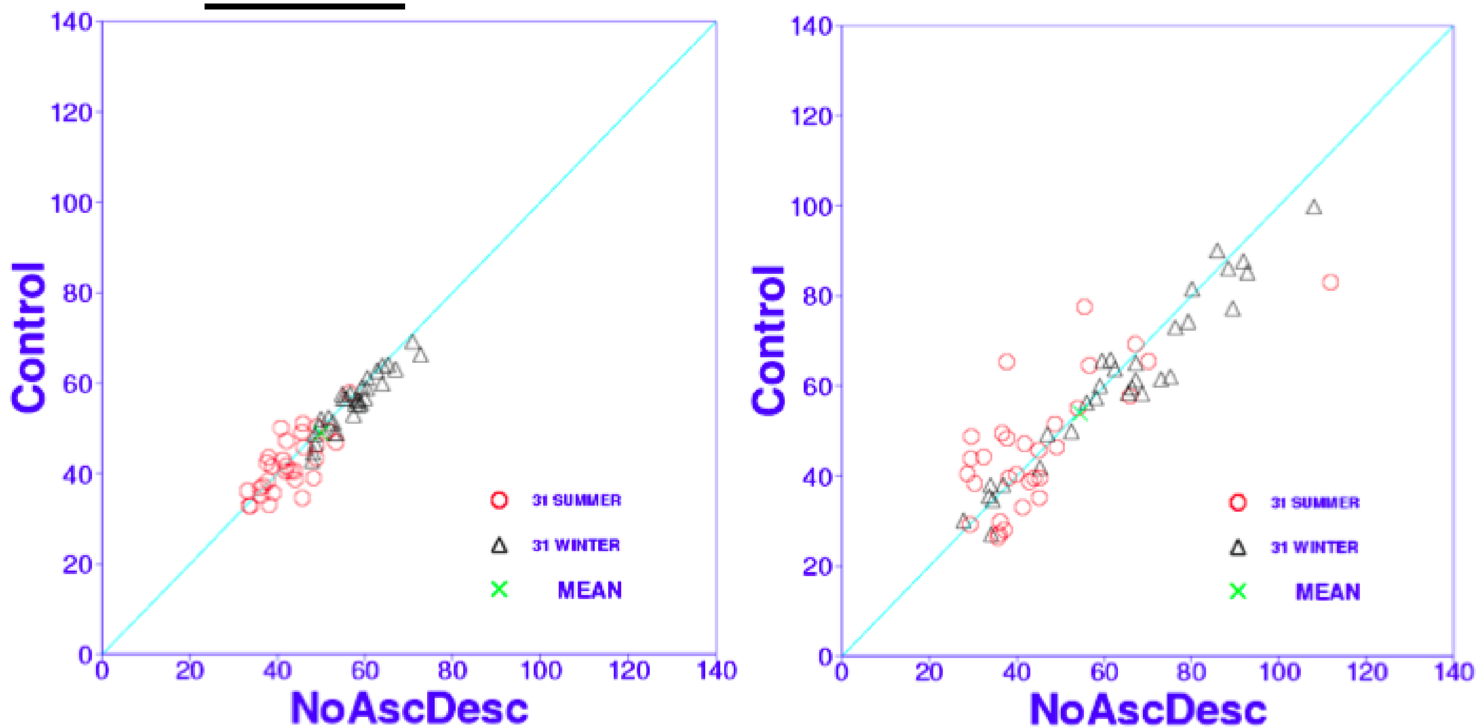
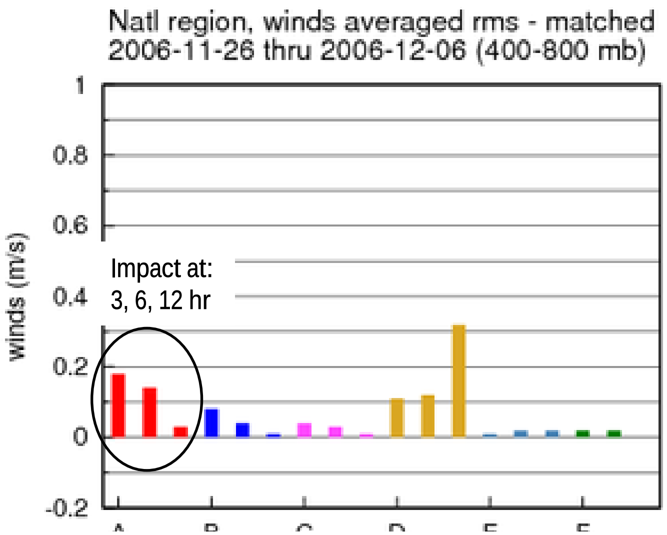
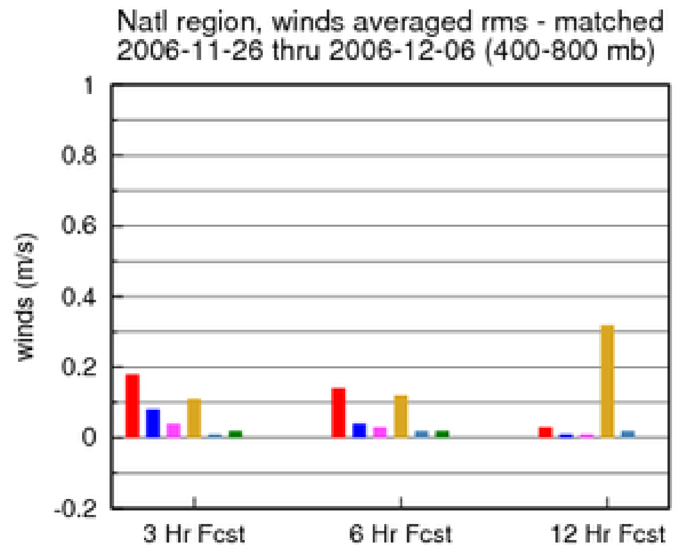


Figure 13 Scatter plot of the rms of 120-hour forecast error (m) for 500 hPa geopotential height. Each marker represents one day in the January period 2001 (black triangles) and July 2001 (red circles), for the Northern Hemisphere extra tropics (left) and Europe (right). The error in the forecast from the denial experiment is plotted along the x-axis and that of the control along the y-axis. The average forecast error is shown by the green x-marker. Markers plotted below the diagonal indicate larger error in the data denial experiment than in the control.

RUC

WINTER





- A - No-aircraft - control
- B - No-profiler - control
- C - No-VAD - control
- D - No-RAOB - control
- E - No-surface - control
- F - No-GPS-PW - control

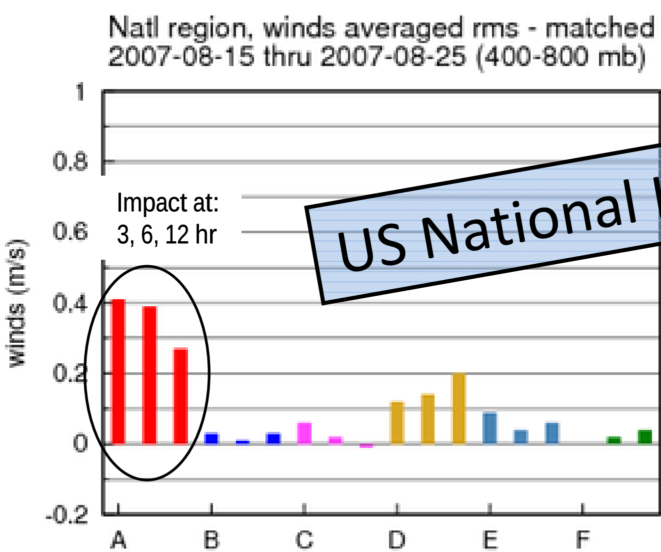
Wind - national - 800-400 hPa

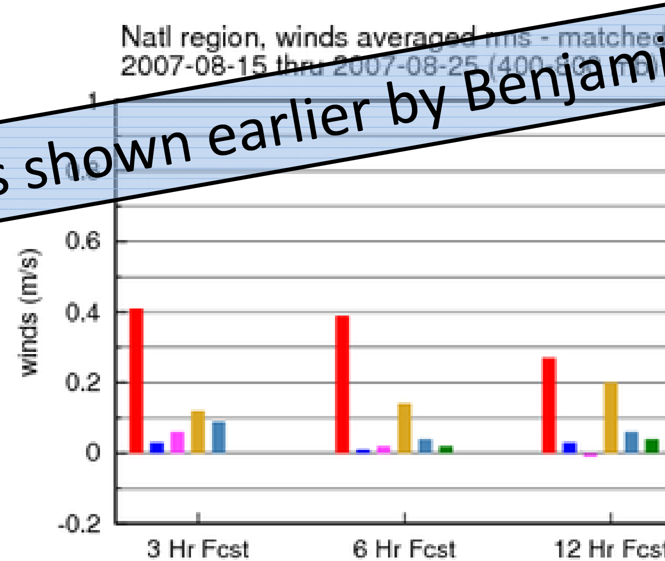
#1 overall - Aircraft

RAOBs - #1 winter @ 12h

US National Impacts shown earlier by Benjamin

SUMMER

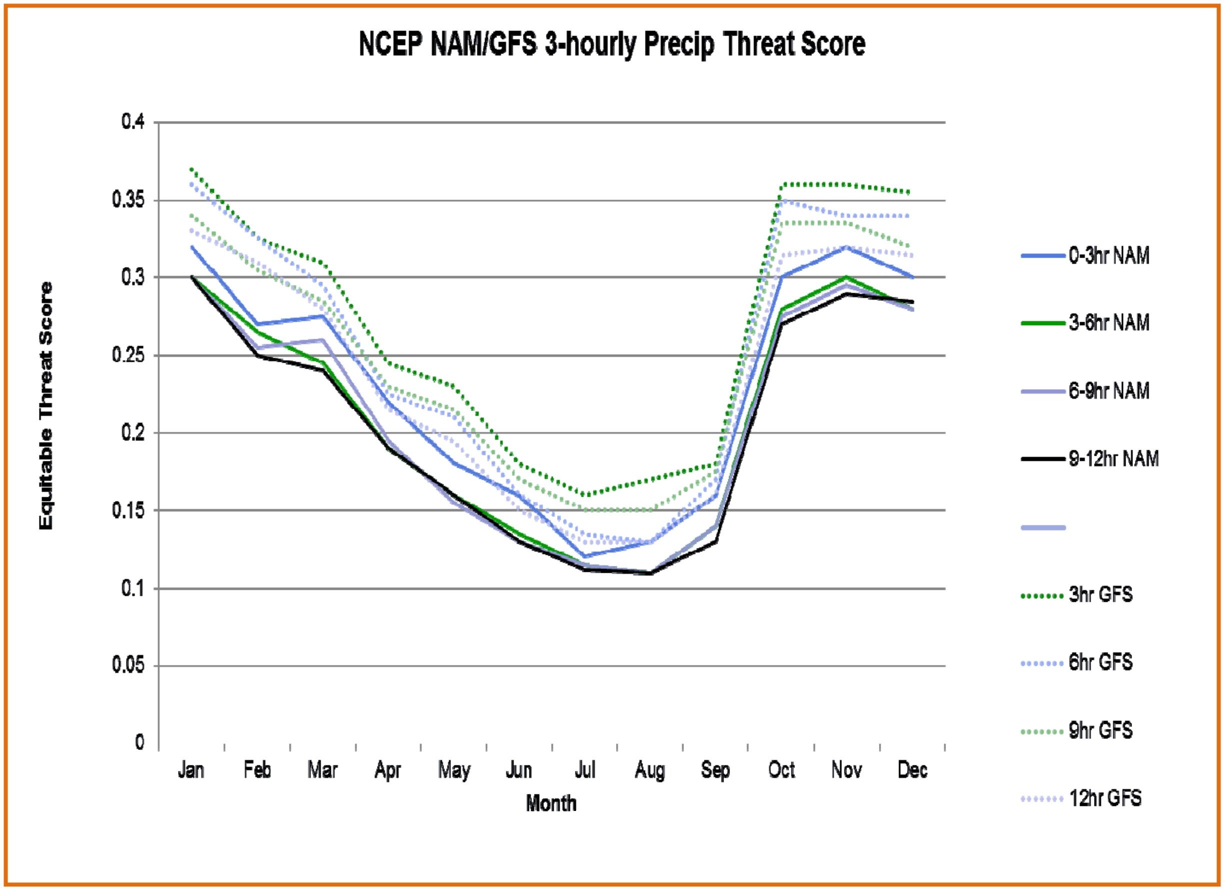




From:
Benjamin, ESRL

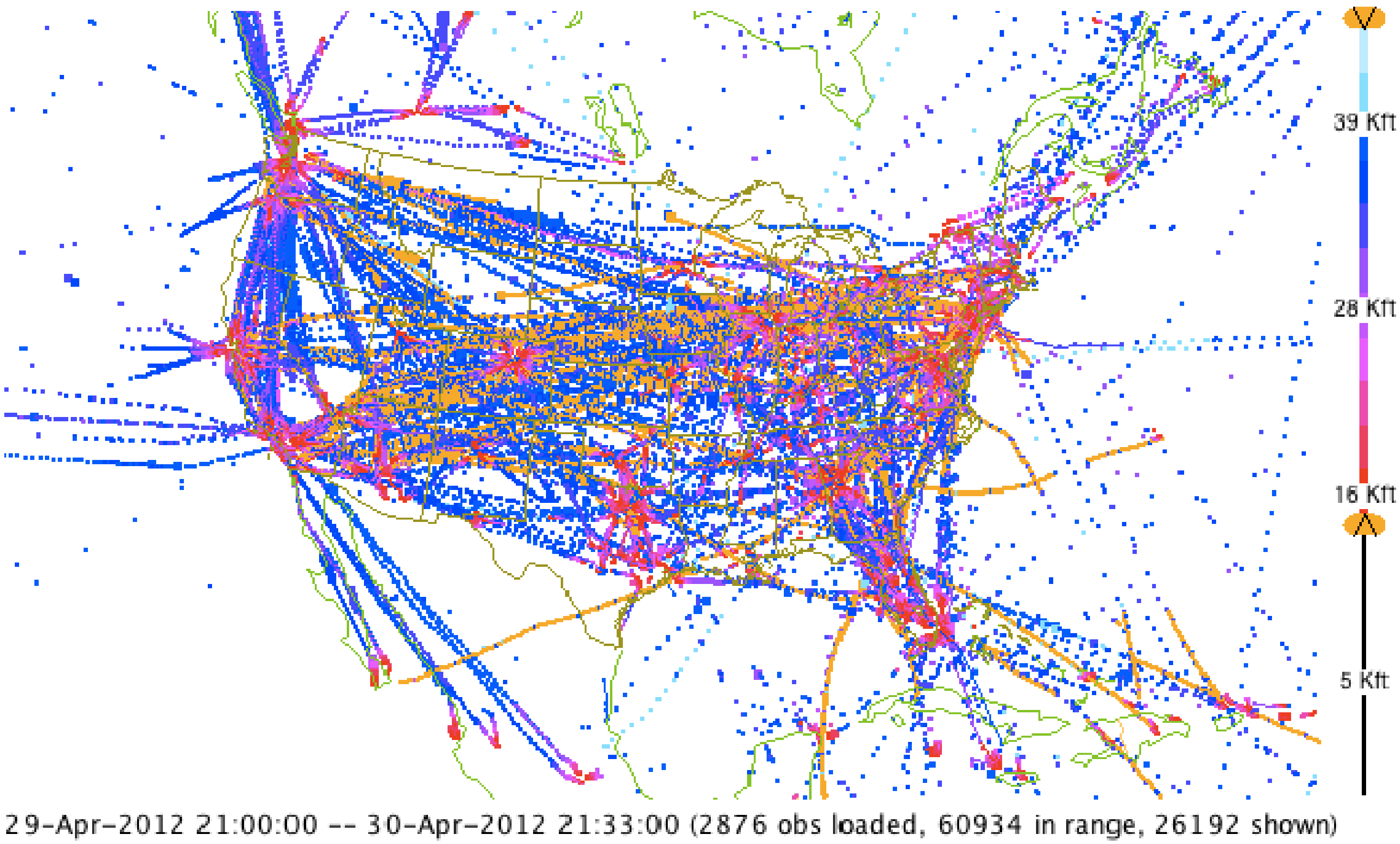
A fundamental short-range forecast problem in the US:

Current NWP systems do poorly in forecasting the timing and location of precipitation during the warm months

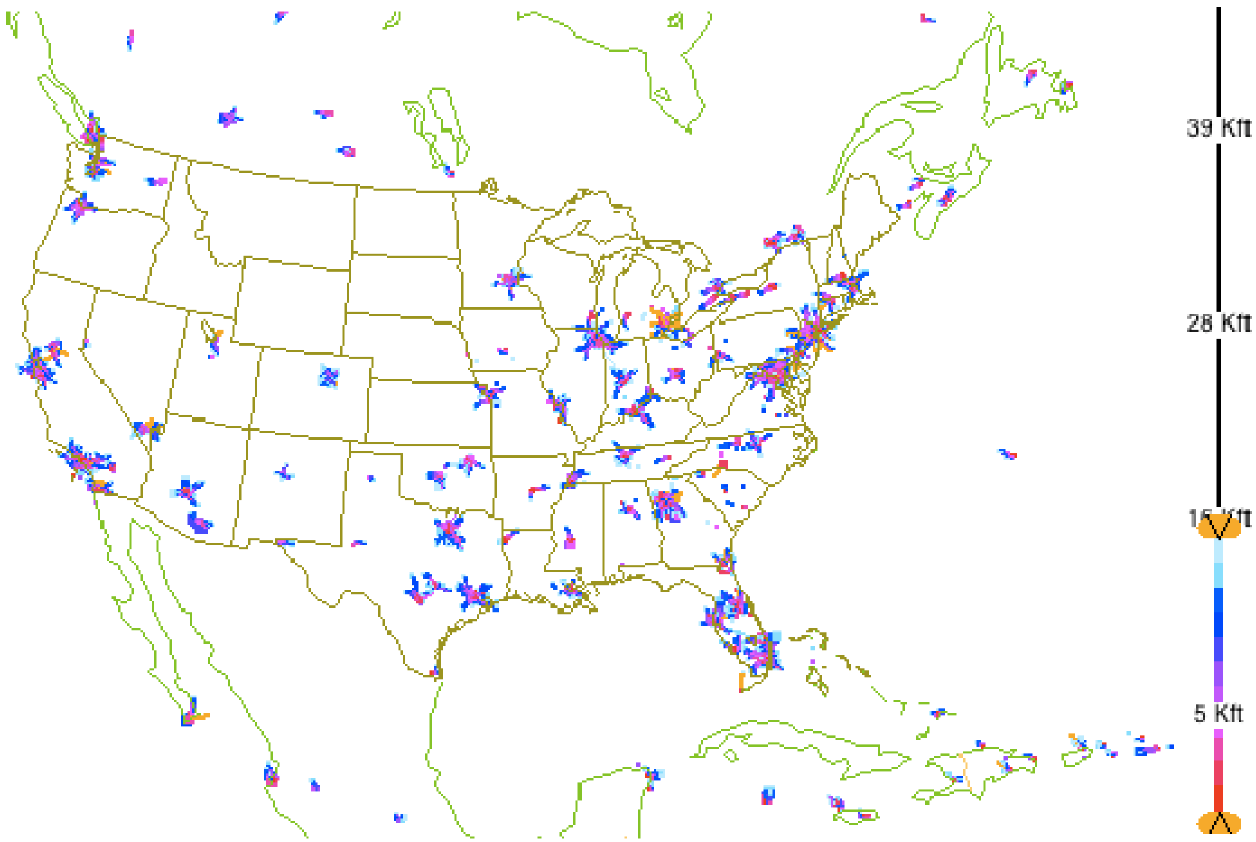


Need improved observations of Boundary Layer structure over land, including B/L depth and Moisture Flux

Typical Daily AMDAR Enroute Coverage



Typical Daily AMDAR Profile Coverage



29-Apr-2012 21:00:00 -- 30-Apr-2012 21:33:00 (2876 obs loaded, 37638 in range, 3409 shown)

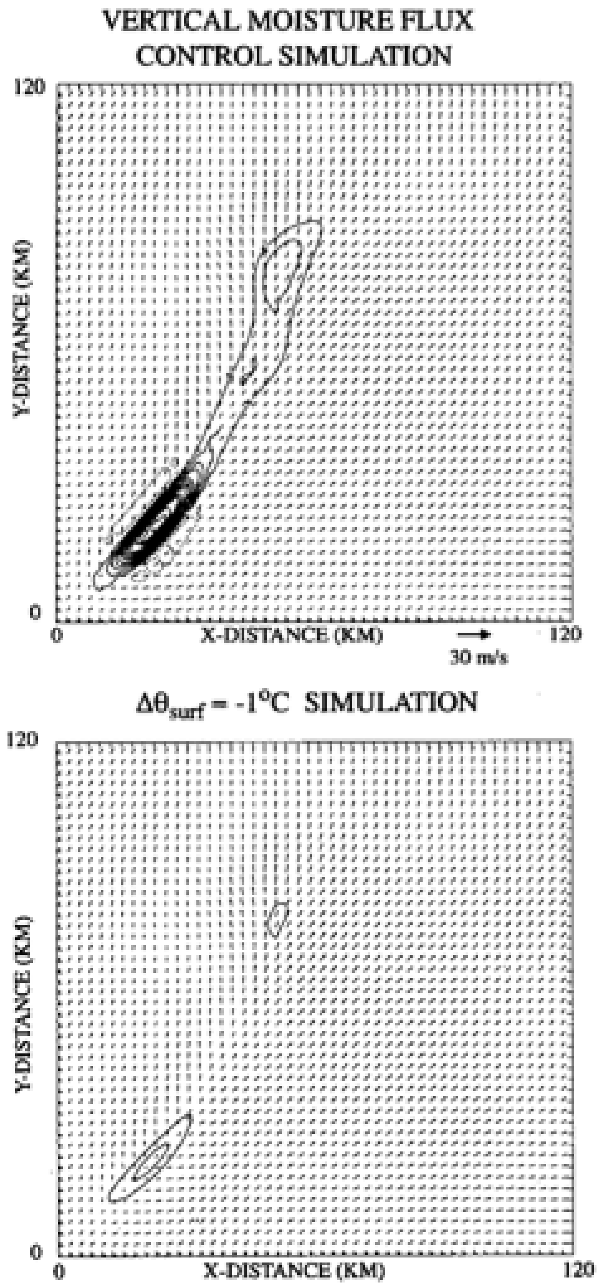


FIG. 18. Vertical moisture flux at the top of the boundary layer (z = 2.0 km, AGL) at the same time shown in Fig. 17 in (a) the control simulation and (b) simulation with ΔT_{surf} reduced by 1.0°C. Contour interval is 5 g kg^{-1} m s^{-1}.

Why are the profiles so important for future Mesoscale NWP?

Crook, and recently Ziegler, have shown the storm-scale models can only produce useful forecasts if the pre-storm and near-storm environments are captured correctly.

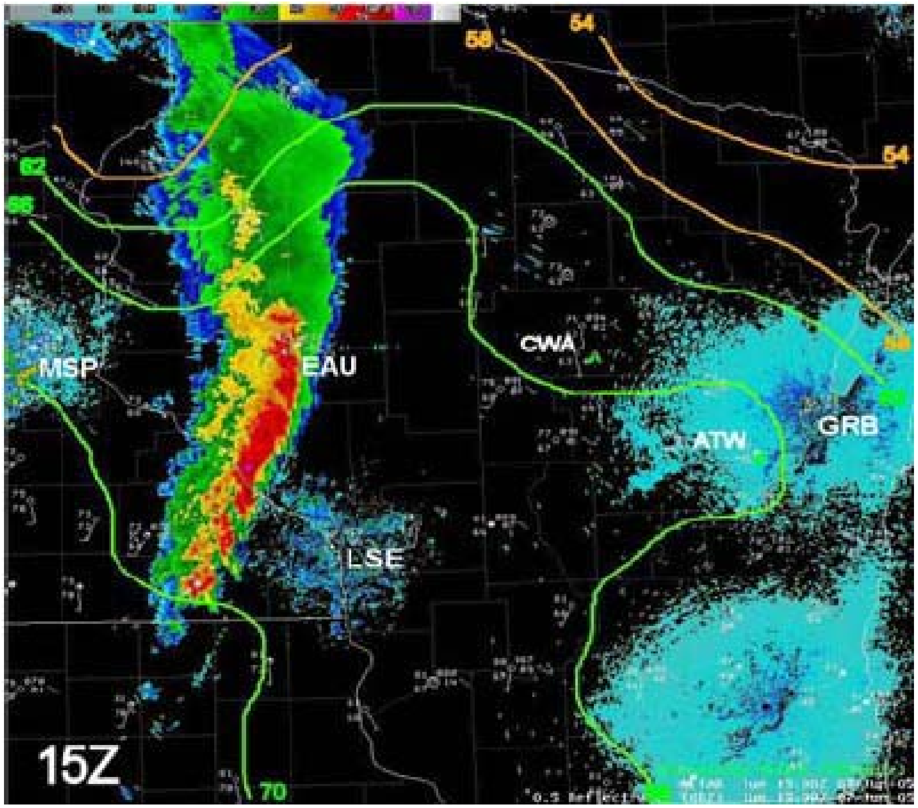
Even 1K temperature or small moisture errors can give very different results

- Not only an NWP question -

Forecasters using experimental TAMDAR data demonstrated the importance of filling this information gap

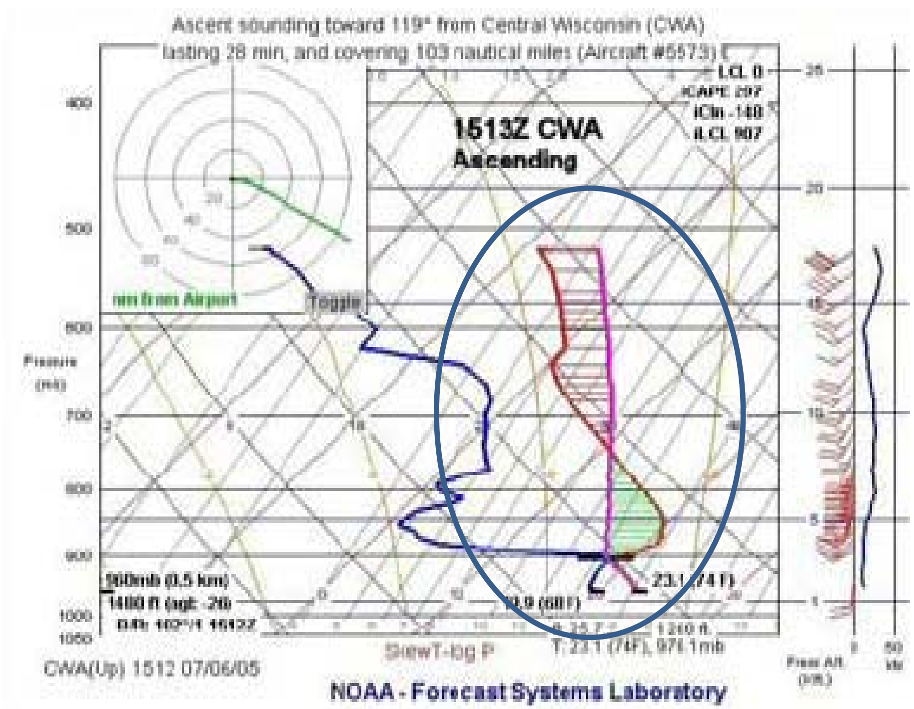
Using aircraft T/Q profiles in forecasting Convective Storms

- Central Wisconsin, 6 July 2005
  - Linear mesoscale convective system expected to persist into Wisconsin
  - Severe thunderstorm watch was issued at 1530 UTC for most of Central Wisconsin

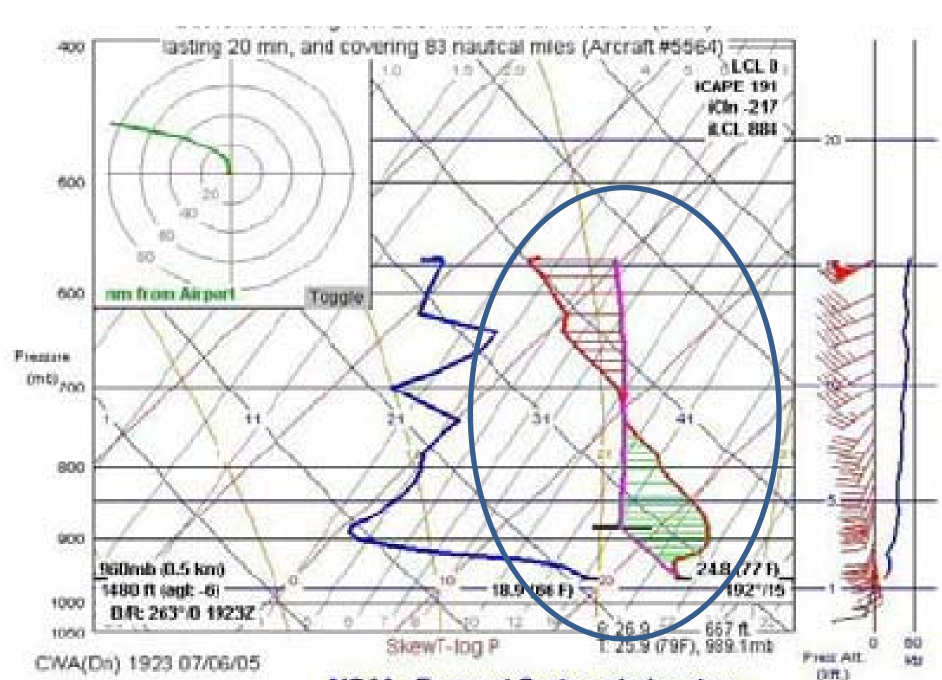


Using aircraft T/Q profiles in forecasting Convective Storms

- Aircraft soundings from watch area at watch issuance and later showed strong capping inversion unlikely to break
- Forecasters lowered the chance for storms and the severe thunderstorm watch was cancelled
- Storms dissipated before reaching central Wisconsin

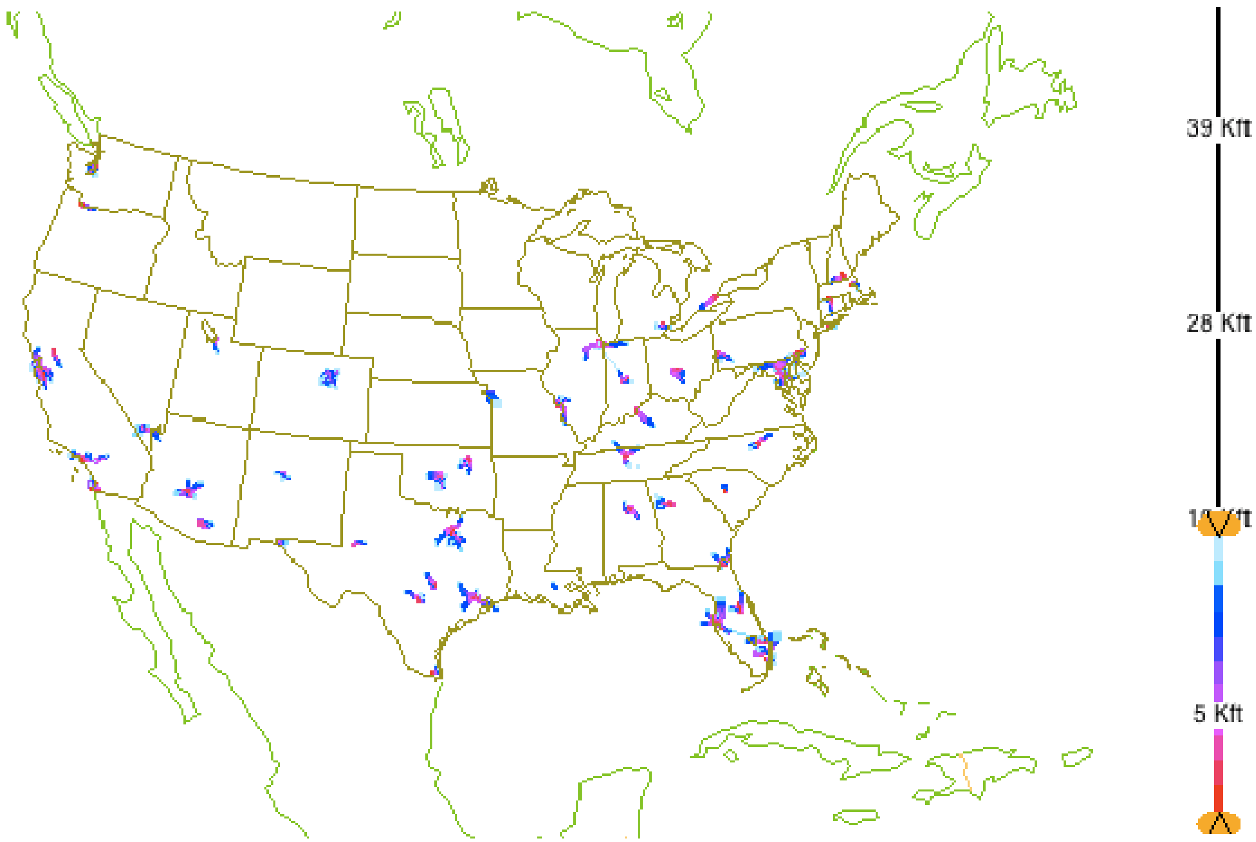


1513 UTC



1923 UTC

Typical Daily
AMDAR WVSS-II Humidity Profiles



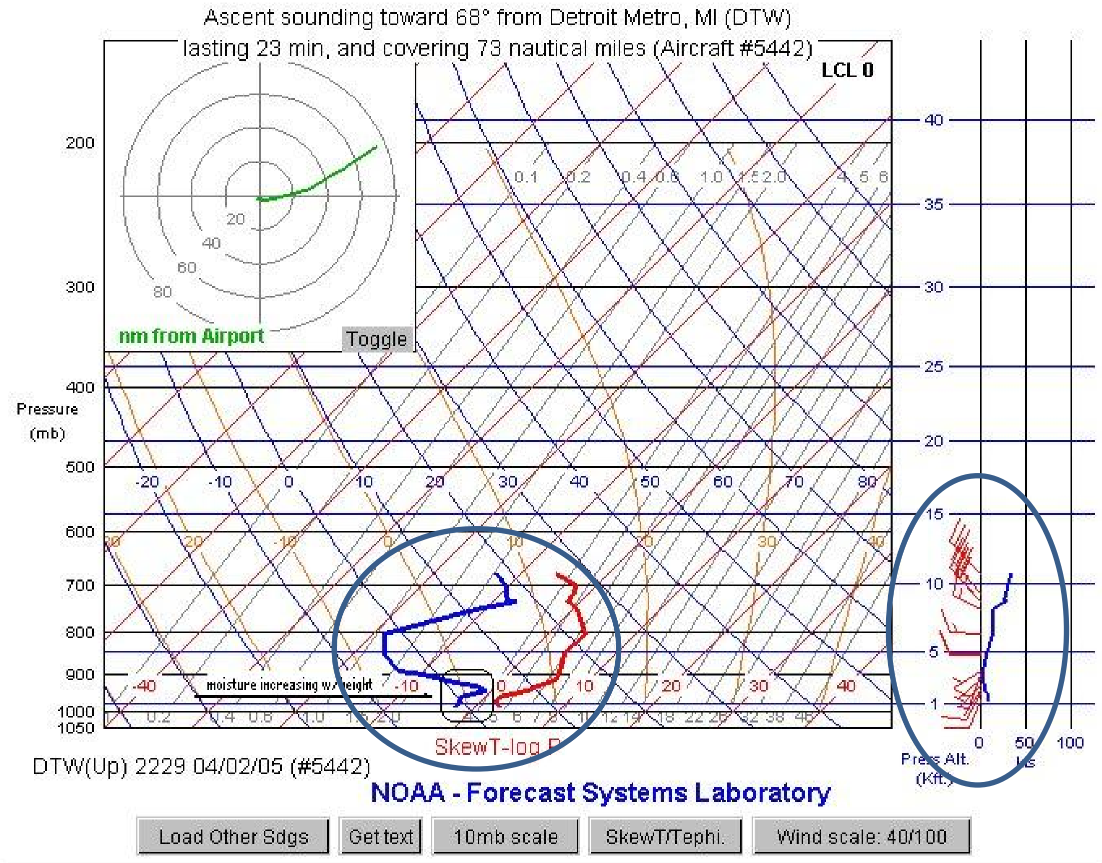
29-Apr-2012 21:00:00 -- 30-Apr-2012 21:33:00 (2876 obs loaded, 3934 in range, 919 shown)

Using aircraft T/Q profiles in forecasting Low Ceilings, Visibilities and Fog

- Detroit, Michigan, 4 February 2005
  - Soundings near 2230 UTC showed light boundary layer winds, near-surface moisture, dryness above
  - Commonly favorable conditions for fog development

- Based on the observations, the TAFs for 09 and 12 UTC were amended, reducing visibilities to ½ mile.
- METARS showed that visibilities did decrease

KDTW 0532z 00000kt **2sm br clr**
KDTW 0739z 17003kt **1 3/4sm br** r04/ 1000v3500
KDTW 0936z 17004kt **1/4sm fg** r04/ 0500v0600
KDTW 1154z 16004kt **1/4sm fg** r04/ 2800v0600



Points to remember about AMDAR Impacts

- AMDAR data continue to be among 4-5 most important data sources for global assimilation
  - Large "Bang for the Buck" but lack expansion funding
- Greater impact at shorter time ranges
- Useful for forecasting a variety of mesoscale events
  - Useful to forecasters as well as NWP

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- Water Vapor Measurements from aircraft can help fill a-synoptic data voids over land

Evaluations of AMDAR Observations using Co-Located Radiosonde and Inter-Aircraft Comparisons

An Important Compliment to Data Impact Tests

Ralph Petersen[1], Lee Cronce[1], Erik Olson[1], Wayne Feltz[1], David Helms[2] and Randy Baker[3]

[1] Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin – Madison

[2] NOAA, National Weather Service, Office of Science and Technology, Silver Spring, Maryland

[3] United Parcel Service, Louisville, Kentucky

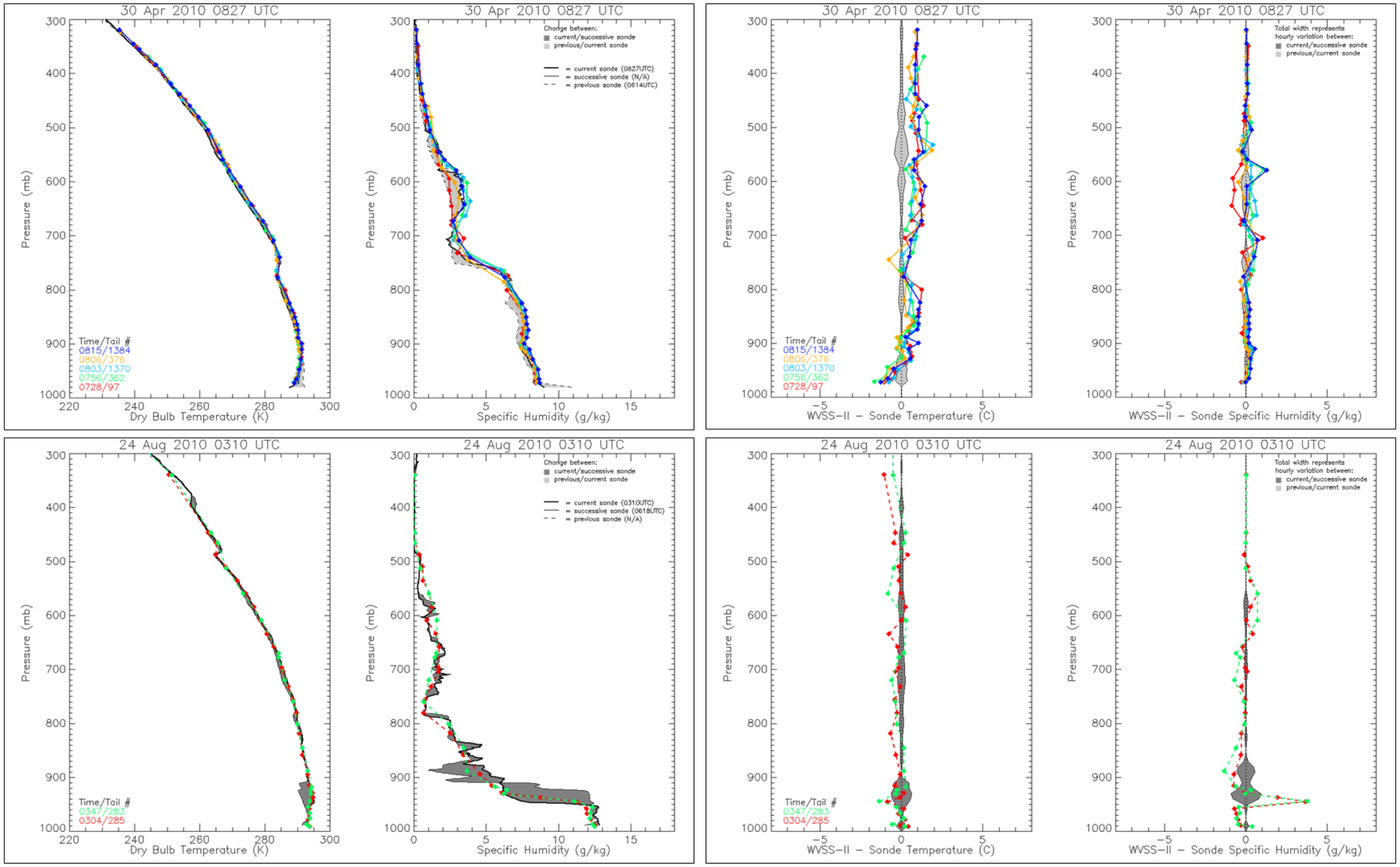
Measuring Moisture from Commercial Aircraft

- Newer system was developed
  - Second-generation Water Vapor Sensing System (*WVSS-II*) measures Mixing Ratio (specific humidity) directly
    - Uses a laser-diode system to measure number of water molecules passing sensor
    - Instruments Tested on UPS 757
      - Used by UPS for fog forecasting
      - Final tests in 2009-2010
      - Re-engineered electronics
      - Improved mechanics
    - Southwest Airlines added

Evaluations of AMDAR Observations using Co-Located Radiosonde and Inter-Aircraft Comparisons made within 50 km and ± 1 hour

2009-2010 Validation Results

Direct Sounding Inter-comparisons

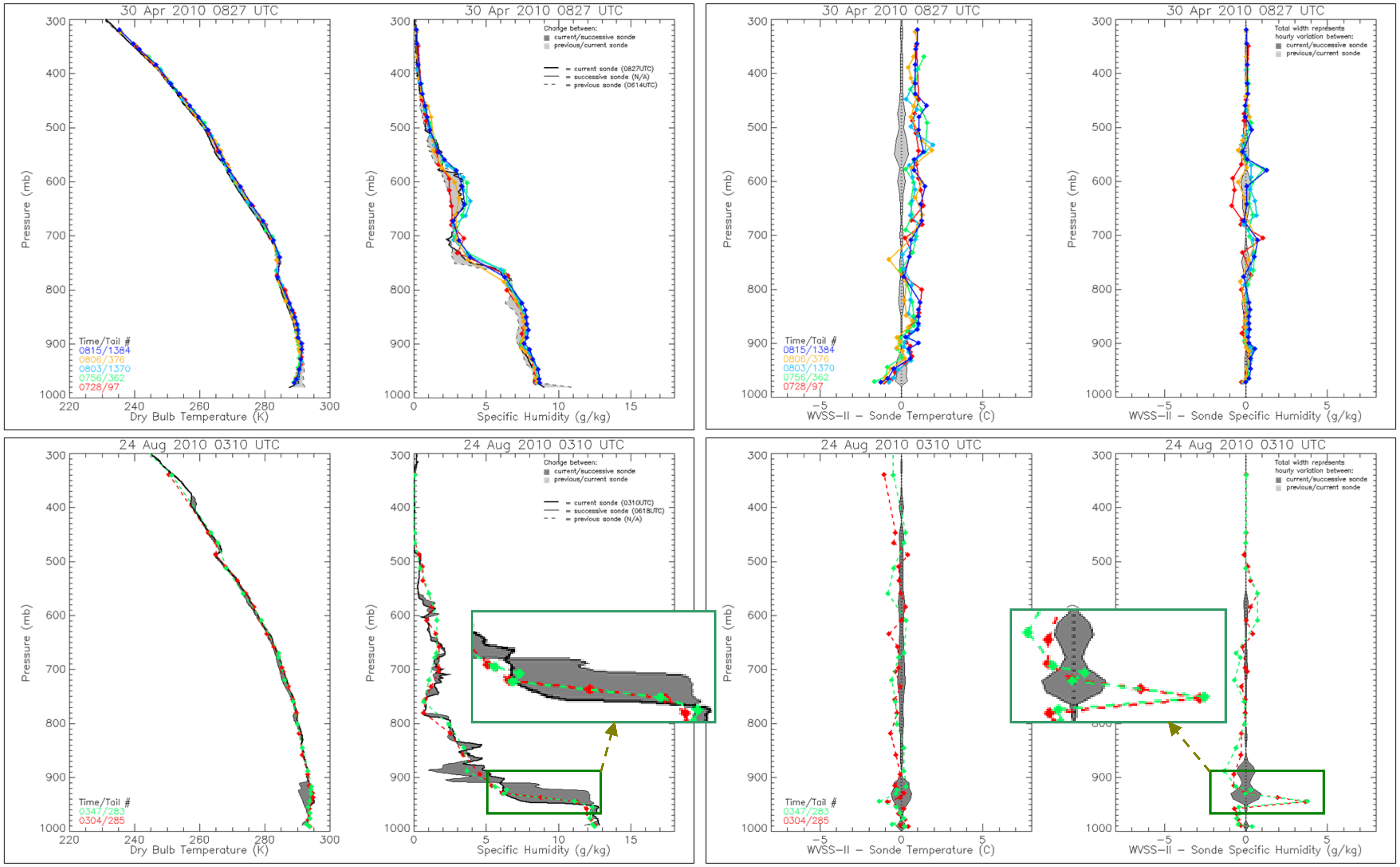


Direct Data Comparison:

Aircraft data generally fell between bounding radiosonde reports

2009-2010 Validation Results

Direct Sounding Inter-comparisons



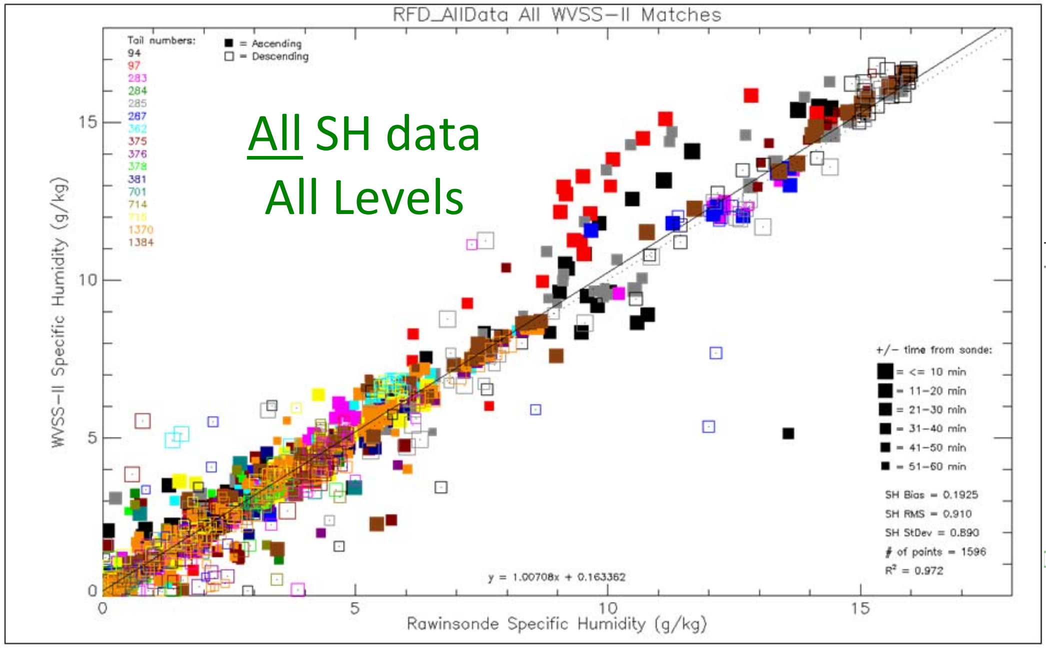
Direct Data Comparison:

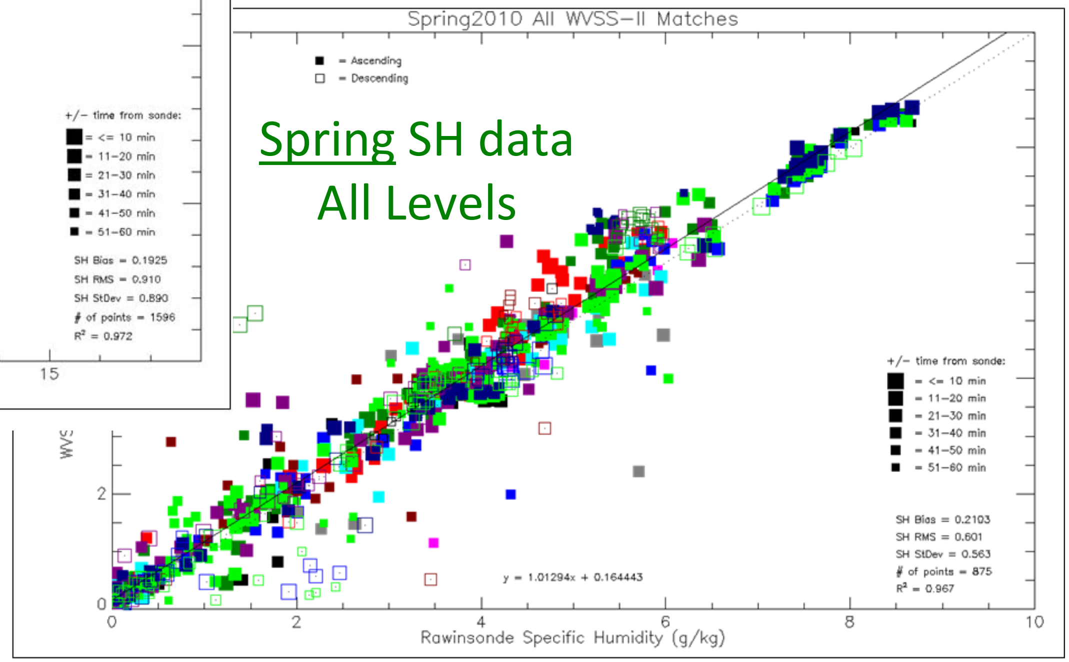
Aircraft data generally fell between bounding radiosonde reports

Large variability within moist regimes led to large specific humidity differences

2009-2010 Validation Results

Summary of Direct Specific Humidity Inter-comparisons





Differences showed:

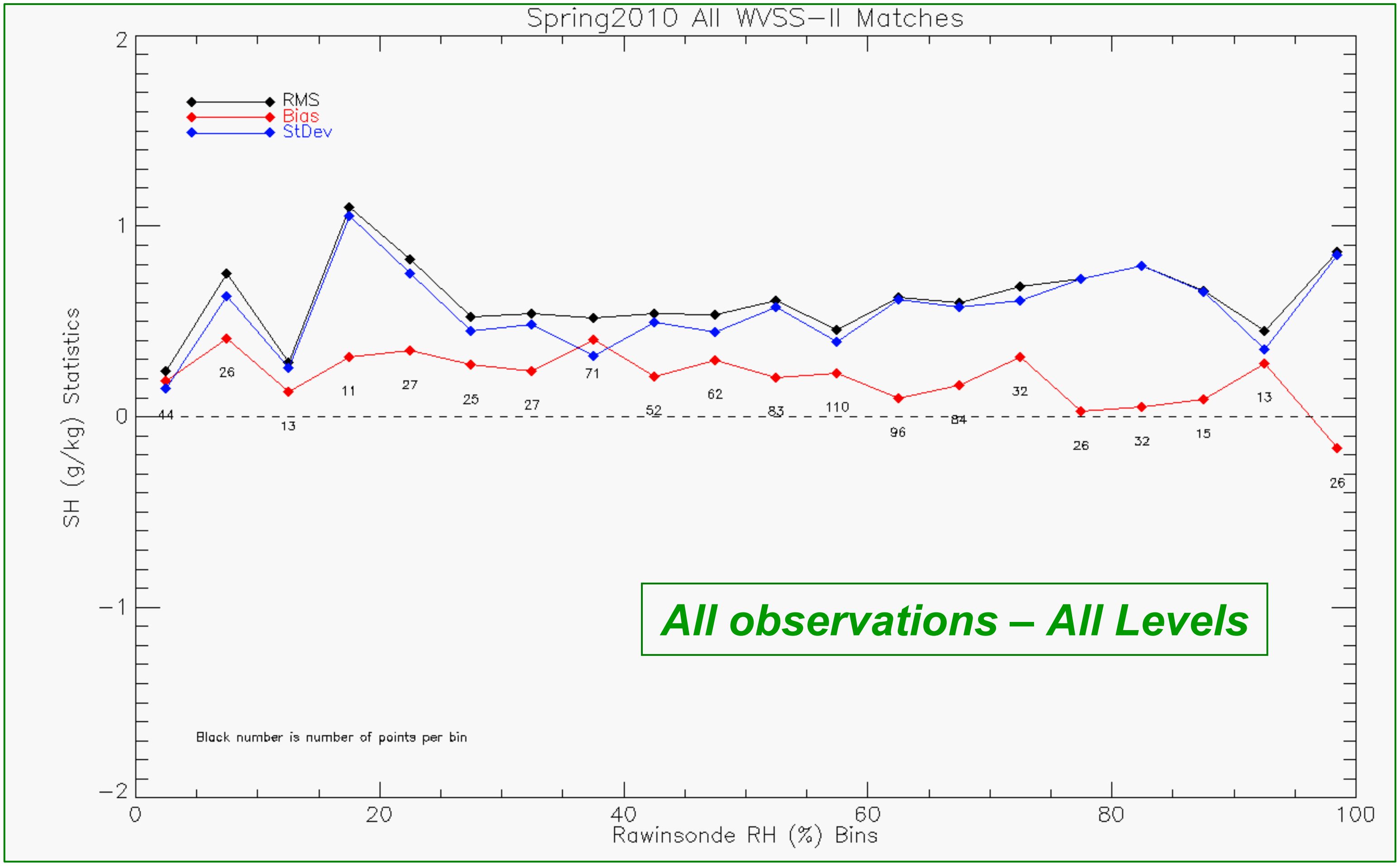
Aircraft data and radiosonde reports agreed quite well

Overall small positive WVSS-II bias

Few moist outliers from one case in 10-12 g/kg range – good for moister data

2009-2010 Validation Results

Direct Specific Humidity Inter-comparisons by Relative Humidity Bins



Differences showed:

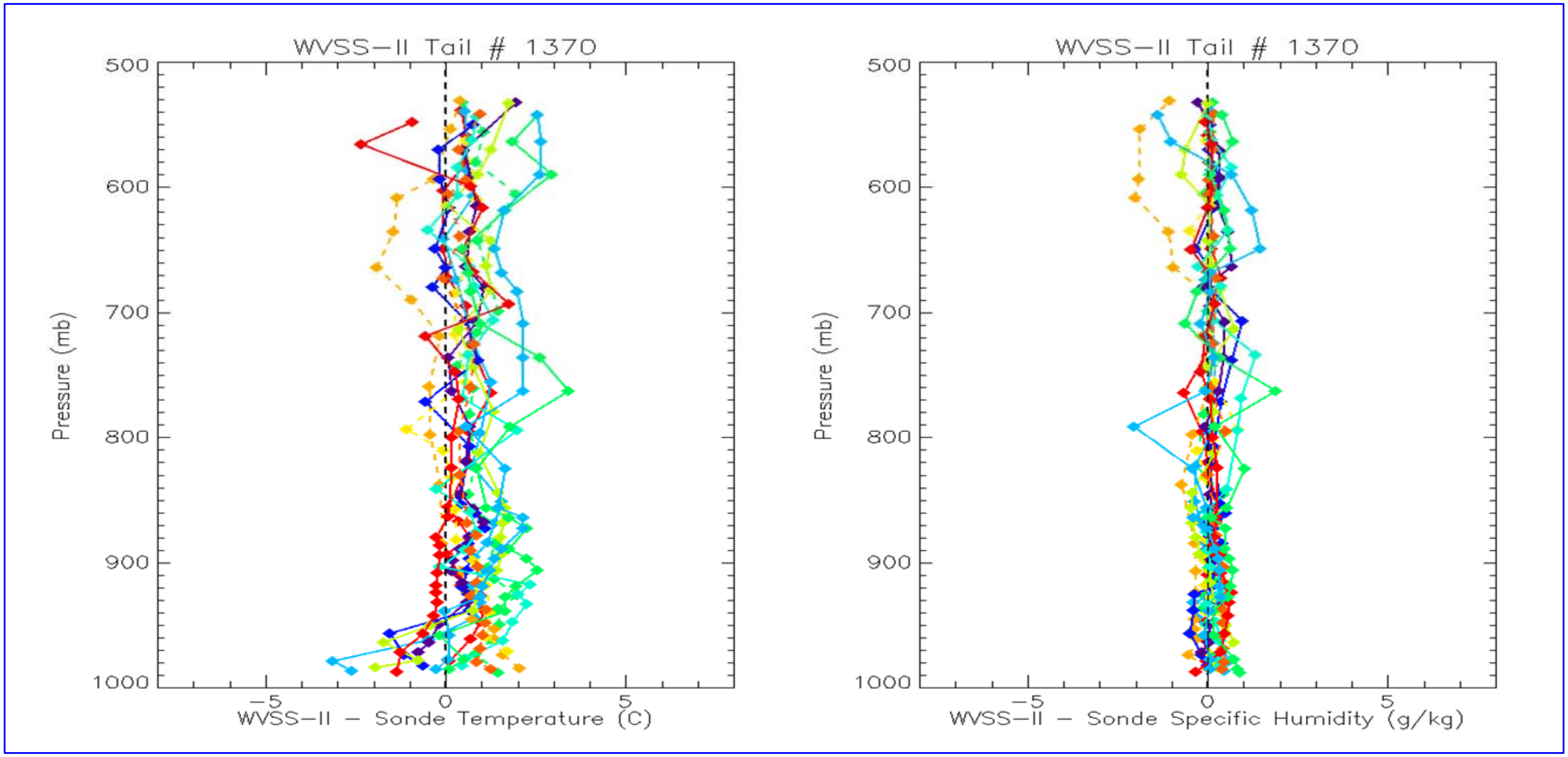
Small positive bias across all RH ranges

Random errors average ~0.5-0.7 g/kg

Higher random errors near 20-25% RH and approaching saturation

Spring 2010 Validation Results

Direct Temperature (left) and Specific Humidity (right) Inter-comparisons



Differences from radiosondes showed:

Warm temperature bias at all levels

Large temperature variability

Random SH differences average ~ ± 0.5 g/kg

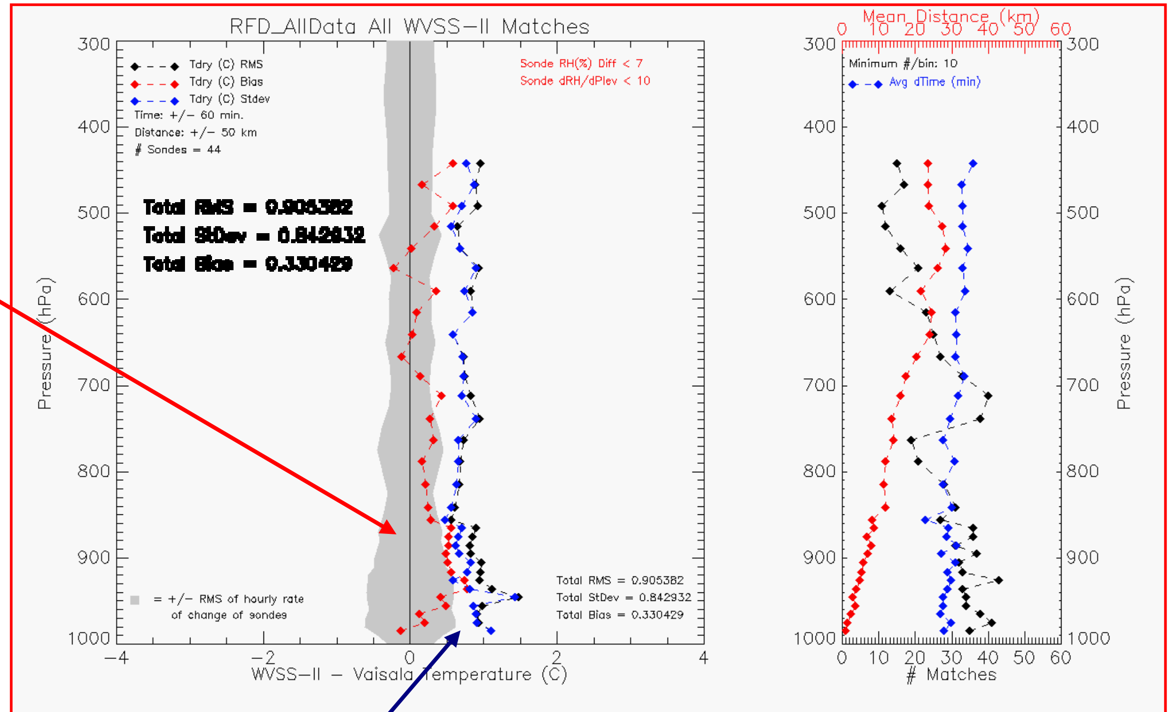
2009-2010 Validation Results

AMDAR Temperature

Systematic Differences:

Aircraft Temperature Biases at low levels of 0.2 to +0.7°C. from surface to 700 hPa.

Net neutral above that level



Random Differences *:*

Differences between aircraft data and radiosonde reports generally showed variability of 0.8 to +1.5°C from the surface to 850 hPa.

Above 850 hPa, SdtDev stabilizes to about 1.0°C

Differences larger than 1-hour variability between bounding radiosonde reports (gray shading).

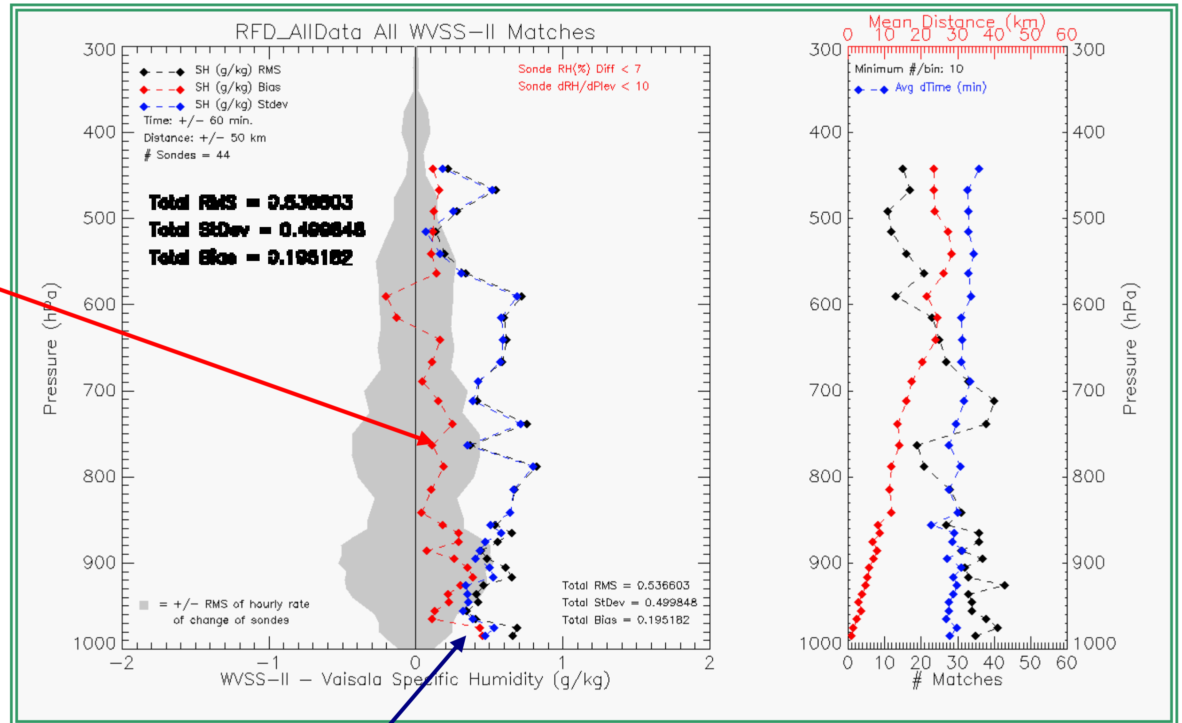
2009-2010 Validation Results

Specific Humidity

(Excludes cases with large time and vertical radiosonde differences)

Systematic Differences:

WVSS-II Biases at low levels of 0.1 to +0.4 g/kg from surface to 850 hPa. ±0.2 g/kg above



Random Differences *(Including Dry/Moist Environments):*

Differences between aircraft data and radiosonde reports generally showed variability of 0.3 to 0.7 g/kg from the surface to 600 hPa – decreases aloft.

StdDev slightly larger than 1-hour variability between bounding radiosonde reports (gray shading).

Note: Fewer inter-comparisons near 800 hPa and above 700 hPa. Greater time and space separation above 650 hPa.

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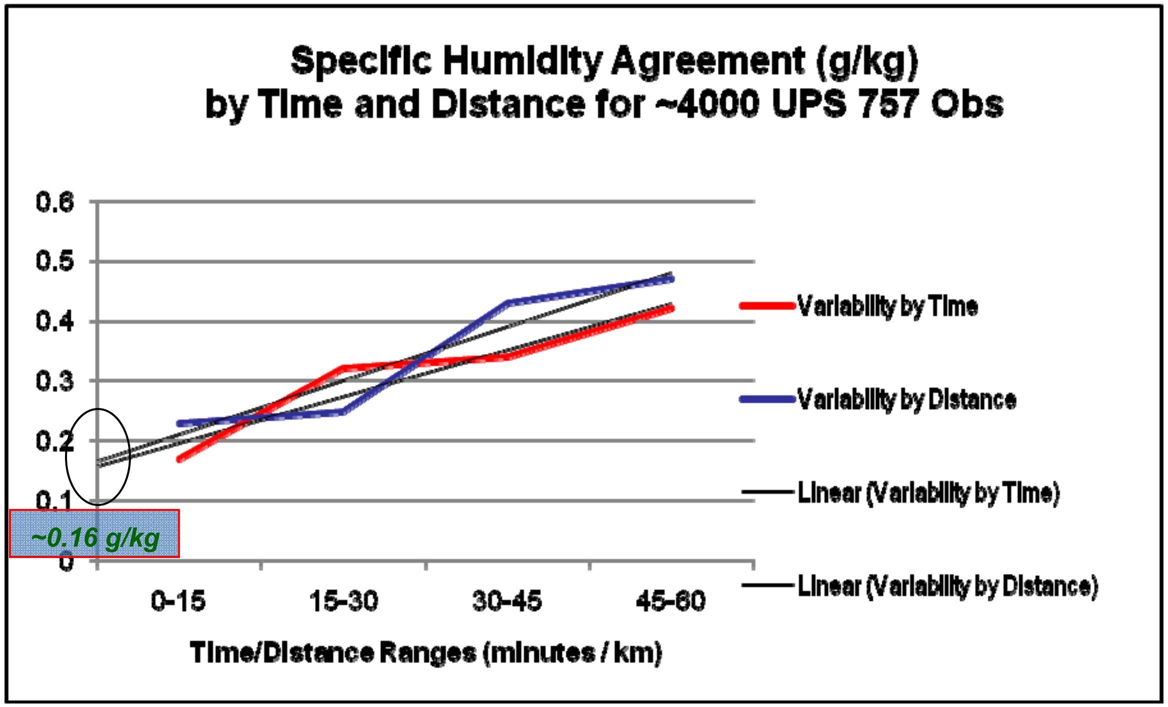
- AMDAR data continue to be among 4-5 most important data sources for global assimilation
  - Large “Bang for the Buck” but lack expansion funding
- Greater impact at shorter time ranges
- Useful for forecasting a variety of mesoscale events
  - Useful to forecasters as well as NWP
- Water Vapor Measurements from aircraft can help fill a-synoptic data voids over land
  - Data appear to be extremely good
  - Impact greatest in first 24 hours or less
  - Frequent ‘redundant’ observations may be useful for determining how best to use high-density data

AMDAR Inter-Aircraft Comparison

Approximating Representativeness Error using WVSS-II SH Observations

RMS calculated for:

Time (and distance) ranges of 0-15, 15-30, 30-45, and 45-60 minutes (km)



***RMS Differences show** (ALL reports, All Seasons):*

Moisture Variability more than doubles from 0-15 to 30-45 minute intervals

Because the Total Variability is made up of two parts:
1) Instrument Error and 2) Atmospheric Variability

If we project nearby results to exact co-locations ***(@ΔT~0 and ΔX~0) ,*** ***Δq~0.16 g/kg***

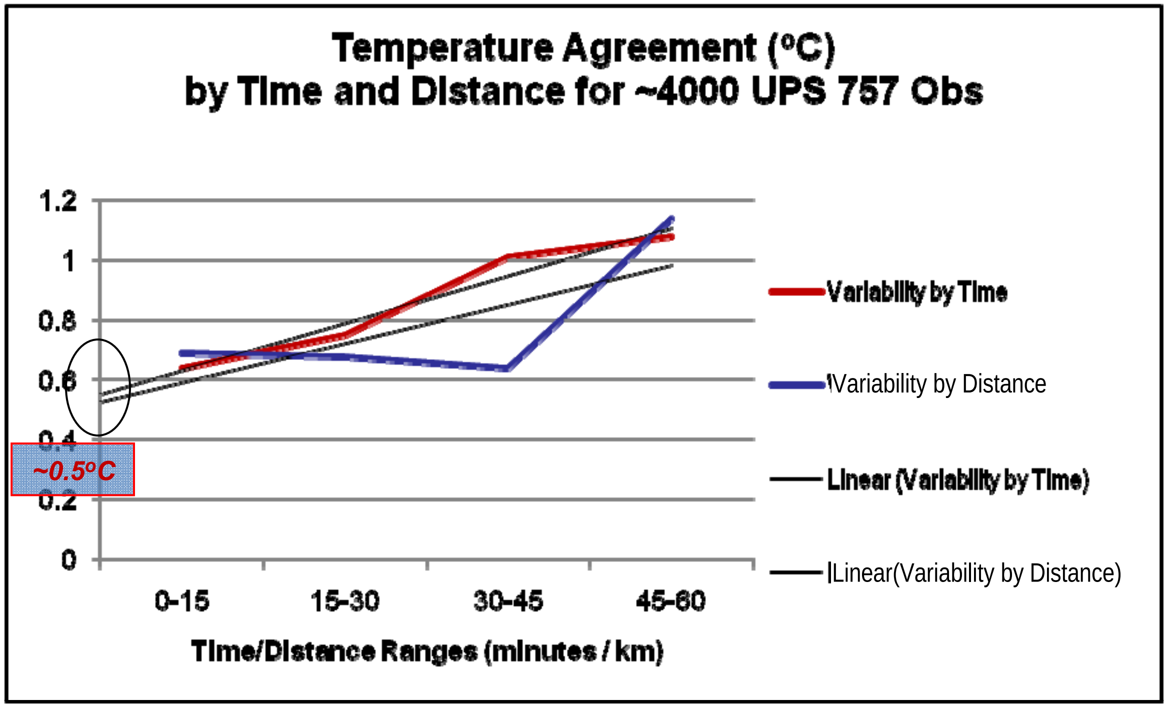
This is better than WVSS-II vs. Radiosonde Std. Dev.

AMDAR Inter-Aircraft Comparison

Approximating Representativeness Error using WVSS-II T Observations

RMS calculated for:

Time (and distance) ranges of 0-15, 15-30, 30-45, and 45-60 minutes (km)



RMS Differences show *(ALL reports, ALL Seasons):*

Variability can more than double over 60 minutes and 60 kms

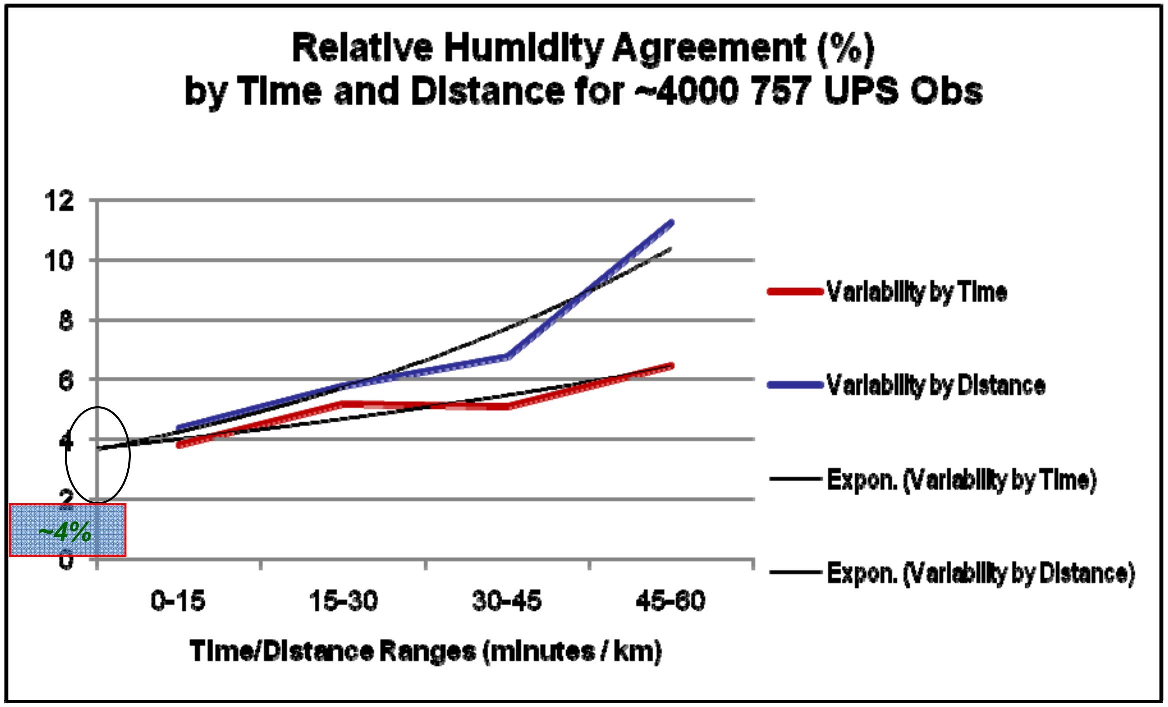
Variable	*Observed Variability @ 45-60 km and 45-60 minutes*	Derived Variability for perfect co-locations
Specific Humidity	***~0.45 g/kg (both)***	**:** ***~0.16 g/****kg (Better than Raob compari****sons)***
Temperature	***~1.0°C (both)***	**:** ***~0.5°C*** *(Similar to Roab comparisons)*

AMDAR Inter-Aircraft Comparison

Approximating Representativeness Error using WVSS-II SH/T Obs

RMS calculated for:

Time (and distance) ranges of 0-15, 15-30, 30-45, and 45-60 minutes (km)



RMS Differences show *(ALL reports, ALL Seasons):*

Variability can more than double from 0-15 to 30-45 minute intervals

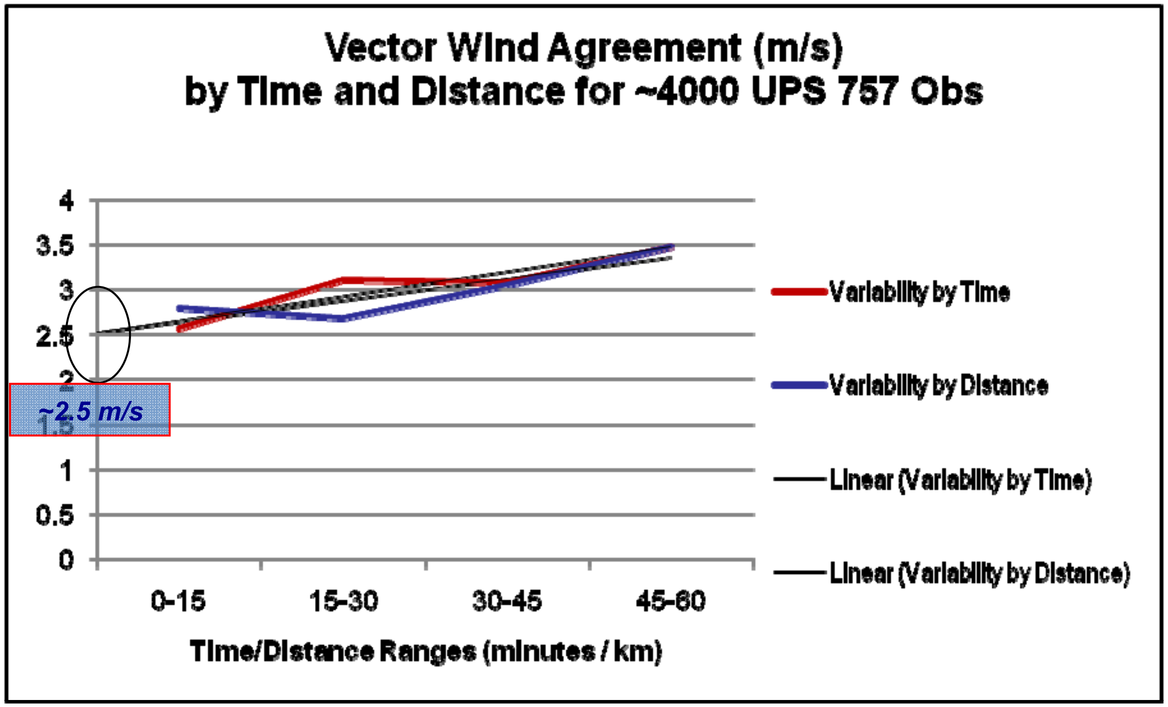
Variable	*Observed Variability @ 45-60 km and 45-60 minutes*		*Derived Variability for perfect co-locations*
Specific Humidity	*~0.45 g/kg (both)*	:	*~0.16 g/kg*
Temperature	*~1.0ºC (both)*	:	*~0.5ºC*
Derived Relative Humidity	*~11% and ~6% (respectively)*	:	*~4%*

AMDAR Inter-Aircraft Comparison

Approximating Representativeness Error using WVSS-II Wind Obs

RMS calculated for:

Time (and distance) ranges of 0-15, 15-30, 30-45, and 45-60 minutes (km)



***RMS Differences show** (ALL reports, All Seasons):*

Variability increases from 0-15 to 30-45 minute intervals

Variable	*Observed Variability @ 45-60 km and 45-60 minutes*		*Derived Variability for perfect co-locations*
Specific Humidity	*~0.45 g/kg (both)*	:	***~0.16 g/kg** (Better than Raob compari**sons)***
Temperature	*~1.0°C (both)*	:	***~0.5°C** (Similar to Roab comparisons)*
Derived Relative Humidity	*~11% and ~6% (respectively)*	:	*~4%*
Vector Wind RMS	*~3.5 m/s (both)*	:	***~2.5 m/s** (Similar to Raob comparisons)*

Points to remember about AMDAR Impacts

- AMDAR data continue to be among 4-5 most important data sources for global assimilation
  - Large "Bang for the Buck" but lack expansion funding
- Greater impact at shorter time ranges
- Useful for forecasting a variety of mesoscale events
  - Useful to forecasters as well as NWP
- Water Vapor Measurements from aircraft can help fill a-synoptic data voids over land
  - Data appear to be extremely good
  - Impact likely to be localized and 24 hours or less
  - Don't over-thin low-cost observations – 'Redundant' observations can be useful for determining how best to use mesoscale (point) observations data in NWP
  - Should we consider assimilating moisture flux on the mesoscale