Automated Aircraft Observations: Their Importance to Future Aviation Transportation Operations

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Just as Efficient use of Weather is key to optimizing the Future Air Transportation System, Availability of Good (and Adequately Distributed) Observations is key to Understanding Weather, Now and into the Future.

6 to 10 November 2017, Météo-France, Toulouse
**AMDAR Temperature and Wind** data are among 3-5 most important data sources for global analyses across multiple NWP centers

- **Extremely Cost Effective (Very Low Cost / High Impact)**
  - AMDAR profiles could backfill for lost rawinsondes if moisture is included

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![Composite of contributions to 24 hour forecast error reduction by data type from 6 global NWP centers](chart1.png)

Results from 2012 WMO Data Impact Workshop

![Comparison of Met Office 2013 Data Impacts by Observation Category Including Impact per Observing Category Cost](chart2.png)

[Based on Eyre and Reid (2014)]

Using the operational US Navy Global Model
Data from an 11-month period between Oct 2016 and September 2017

• The impact of AMDAR observations in the Navy Global Environmental Model (NAVGEM) was determined using Forecast Sensitivity Observation Impact (FSOI) methods (Hogan et al. 2014; Langland and Baker 2004).

• FSOI values were computed for each observation type included in the operational NAVGEM.
  • The relative importance of each instrument type and variable in reducing the 24-hr forecast error was measured by the total moist energy error norm.
  • In these tests, the Global and Regional Impact of Temperature and Wind observations were determined throughout the entire atmosphere.

• Note: The Navy Global Model is tuned to optimize oceanic forecasts and relies more heavily on Satellite Cloud Motion Winds observations than other Global Forecast Centers.
Global and Regional Impacts of AMDAR on NWP
Based on Influence of all Observation types on 24 hr. forecasts from US Navy Global Model


Benchmark Map of typical daily AMDAR Observation Distribution from October 2016 – Before the US began supporting enhanced data collection over South America

Assessing impact of augmenting AMDAR observations over South America
Global and Regional Impacts of AMDAR on NWP
Based on Influence of all Observation types on 24 hr. forecasts from US Navy Global Model

Updated Map of typical daily AMDAR Observation Distribution from September 2016 – After the US began supporting enhanced data collection over South America

The following slides will compare 2016 and 2017 observation impacts for 4 areas:

- **Globe**
- **Contiguous US**
- **Southern Africa** (south of Equator) + offshore areas
- **South American** (south of Equator) + offshore areas

Assessing impact of augmenting AMDAR observations over South America
Global and Regional Impacts of AMDAR on NWP
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Assessing impact of augmenting AMDAR observations over South America
Global and Regional Impacts of AMDAR on NWP
Influence of all Observation types on 24 hr. US Navy Global Model Forecasts – Oct 2016

In Oct. 2016, Aircraft Observations were the 6th most important data source Globally in the Navy Model.

Over less-AMDA-rich Southern Africa, Aircraft Observations had greater impact than Radiosondes.

Over data-dense US, Aircraft Observations were the most important data sources.

Oct. 2016 - Before increase in AMDAR observations over South America
Global and Regional Impacts of AMDAR on NWP
Influence of all Observation types on 24 hr. US Navy Global Model Forecasts – Sept 2017

Globally, Aircraft Observations remain in group of 6 major data sources, but increase impact

Over data-dense US, Aircraft Observations are again the most important data sources


Over South America, abundant new Aircraft Observations have become the most important data source

Sep. 2017 - After increase in AMDAR observations over South America
AMDAR Temperature/Wind Impacts

- **AMDAR Temperature and Wind** data continue to be among 4-5 most important data sources for global assimilation across multiple NWP centers

- Having sufficient AMDAR data density is essential to improving analyses and 0-48 hour forecasts
  - Requires only air-to-ground communications support
  - Major impacts on parameters important to flight planning
    - Temperature and Winds

Refs:

Measuring AMDAR Impacts

• **AMDAR Temperature and Wind** data continue to be among 4-5 most important data sources for global assimilation across multiple NWP centers
  - Extremely Cost Effective (Cost/Impact)
    – Profiles could backfill for lost rawinsondes if moisture is included
• **Large number of moisture profiles now available over US**
  - Greater impact expected at shorter time ranges and in local areas
    • *Useful for subjective Nowcasts as well as NWP*

**AMeDAR Water Vapor Sensing System (WVSS) measures Specific Humidity directly**

– Uses a laser-diode system to ‘count’ the number of water vapor molecules passing sensor
– Instruments Tested on UPS 757s
  • 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
Measuring AMDAR Impacts

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Typical Daily US AMDAR WVSS (Water Vapor Sensing System) Humidity Profiles

- Currently, 135 WVSS-equipped aircraft in US
  - 700+ Profiles/day
- ~10 WVSS aircraft in Europe (E-AMDAR)
**Forecaster Impacts:** Using real-time aircraft T/Q profiles in Nowcasting where Convective Storms will *and will not* develop

- **Central Wisconsin, 6 July 2005** (Example used TAMDAR Observations)
  - Linear mesoscale convective system expected to persist into Wisconsin
  - Severe thunderstorm watch was initially issued at 1530 UTC for most of Central Wisconsin
**Forecaster Impacts:** Using real-time aircraft T/Q profiles in Nowcasting where

**Convective Storms will and will not develop**

- Aircraft soundings from watch area showed a persistent strong capping inversion that appeared unlikely to break
- Forecasters lowered the chance for storms and the severe thunderstorm watch was cancelled
- Storms dissipated before reaching central Wisconsin
**Forecaster Impacts:** Using aircraft T/Q profiles in Nowcasting Low Ceilings, Visibilities and Fog

- Detroit, Michigan, 4 February 2005
  - Soundings near 2230 UTC showed light boundary layer winds, near-surface moisture, dryness above
  - Favorable conditions for fog development (Petterssen, 1940s)
  - Based on the observations, the TAFs for 09 and 12 UTC were amended, reducing visibilities to ½ mile.
  - METARS showed that visibilities remained below ¼ mile

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
Measuring AMDAR Moisture Impacts

- **AMDAR Temperature and Wind** data are among 4-5 most important data sources for global assimilation across multiple NWP centers
  - Extremely Cost Effective (Cost/Impact)
    - Profiles could backfill for lost rawinsondes if moisture is included
- **Large number of moisture profiles now available over US**
  - Greater impact expected at shorter time ranges and at mesoscale
    - Useful to forecasters (and NWP)

Refs:
Systematic Differences showed Small positive Bias across all RH ranges

Random Differences (Including Dry/Moist Environments):
Differences between aircraft data and rawinsonde reports generally showed variability of 0.3 to 0.8 g/kg from the surface to 600 hPa – decrease aloft. StDev less than 3-hour variability between bounding rawinsonde reports.

All observations – All Levels

Systematic Differences showed
Small positive Bias across all RH ranges
Recent WVSS-to-Operational-RAOB Comparisons
Summary of year-long Humidity Inter-comparisons - 2015

- All US Sites, Multiple airlines
- Operational NWS RAOBS
  - Two manufacturers
  - Same Matchup criteria
    - Within 30 minutes and 50 km
- Results validate special tests
- Two US RAOBs provide similar results

Upper atmospheric comparisons show moister results in region of suspect radiosonde accuracy.

- - Important for managing Contrails, . . . - -
Inter-Comparisons amongst co-located WVSS Aircraft

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

Projecting to exact co-locations (ΔT=0 and ΔX=0), Δq~0.16 g/kg

This is substantially better than WVSS-II vs. Rawinsonde Std. Dev. (top)
Inter-Comparisons amongst co-located WVSS Aircraft

Approaching Representativeness Error using WVSS-II SH Observations

WVSS Observations are likely to be the best available operationally moisture data source, now and into the future.

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

Projecting to exact co-locations ($\Delta T=0$ and $\Delta X=0$), $\Delta q \approx 0.16$ g/kg

This is substantially better than WVSS-II vs. Rawinsonde Std. Dev. (top)
Measuring AMDAR Moisture Impacts

- **AMDAR Temperature and Wind data** continue to be among 4-5 most important data sources for global assimilation across multiple NWP centers
  - Extremely Cost Effective (Cost/Impact)
    - Profiles could backfill for lost rawinsondes if moisture is included
- **Large number of moisture profiles now available over US**
  - Greater impact expected at shorter time ranges and at mesoscale
    - *Useful to forecasters (and NWP)*
- **Aircraft Water Vapor Measurements are high quality (Bias and Std. Dev. small)**
  - *Can fill a-synoptic data voids over land*

**Refs:**


The impact of WVSS observations in the Navy Global Environmental Model (NAVGEM) was determined using Forecast Sensitivity Observation Impact (FSOI) methods (Hogan et al. 2014; Langland and Baker 2004).

- FSOI values were computed for each observation as part of operational NAVGEM.
- All observations and variables were summed over a specified period to provide a measure of the relative importance of each instrument type in reducing the 24-hr forecast error, as measured by the total moist energy error norm.

- Global impact of WVSS observations concentrated in CONUS was relatively small
- Regional impacts over CONUS were large
  - Consistent across seasons
  - Important through entire troposphere
WVSS data dominate at all seasons and all levels except surface & 600-700hPa.

Ascent profiles have more impact than descent, but impact per ob. ~ equal
Further tests of WVSS Specific Humidity Impacts for multi-season experiments in NCEP’s Global Data Assimilation System

In coordination with the National Center for Environmental Prediction (NCEP), WVSS SH observations were added to the Global Data Assimilation System (GDAS) and Global Forecast System (GFS) - Hoover et al. (2017)

- Tests for both warm (April – May 2014) and cold seasons (Dec. 2014 – Jan. 2015)

- **WVSS Observations were used in Native Form (Specific Humidity)**
  - Avoided detrimental effects to variable AMDAR Temperature biases

- Negligible additional QC or analysis system changes were needed

Impacts of WVSS observations were based on a board set of diagnostics

**Impacts on Analyses:**

- Impacts larger in warm season with greater moisture variability
  - WVSS obs:
    1 - Improve ROAB fits
    2 - Fit analysis background better than RAOBs

**Impacts on Precipitation Forecasts:**

- Improvements at most threshold
  - Most impacts for large amounts
  - Few are statistically significant

- Note: Precipitation scores reflect integrated deficiencies full model precipitation process, not just moisture fields – *Use a more direct approach*
Compare forecasts to GPS/TPW Observations for Multi-Season Tests

- Blue – Control – no WVSS
- Red – Experiment with WVSS

5% and 95% confidence limits shaded.

Dots indicate statistically significant differences between the experiment and control

Random Error - Bias
Systematic Error - StDev

When used in combination with ROABS over CONUS, WVSS observations:
- Had larger impacts larger in warm season
- Increased known seasonally-variable GFS dry bias
- Reduced Random errors - out to 66hrs in warm season

A More Direct Approach
Error in forecasts relative to GPS/TPW Observations for Multi-Season Tests

Blue – Control – no WVSS

Red – Experiment with WVSS

5% and 95% confidence limits shaded.

Dots indicate statistically significant differences between the experiment and control

When used in combination with ROABS over CONUS, WVSS observations:

- Had larger impacts larger in warm season
- GFS Random Errors were reduced out to 66hrs (warm season)
- GFS integrated dry bias observed during tests persisted
WVSS Impact on Random Errors in GFS Analyses for Warm Season Period

WVSS impacts on GDAS random integrated moisture errors were positive across all moisture ranges. Largest impacts occurred:

- In areas with ‘mid-ranges’ of moisture – about 85% of cases
- At locations with large amounts of water vapor
- Smallest impact for least amounts of TPW
Throughout the 48 hour forecast period, impacts of the added WVSS observations:

- Decrease with forecast time
  - Few negative impacts
- Positive TPW impacts remain concentrated in 10-30 mm range
- Large, but less well organized positive impacts at high TPWs

What is the distribution of moisture changes over forecast time?

WVSS Impact on Random Errors in GFS Analyses for Warm Season Period

WVSS impacts on GFS random integrated moisture forecast errors were also positive and most apparent:

- At shortest forecast ranges
- >1% Reduction in Random Error out to 42 hours
- Majority of GPS sites showed improvements at ALL forecast lengths
Throughout the 48-hour forecast period, impacts of the added WVSS observations:

- Decrease with forecast time
- Few negative impacts
- Positive TPW impacts remain concentrated in 10-30 mm range
- Large, but less well organized positive impacts at high TPWs

Based on these results, WVSS moisture observations were included in the operational GDAS starting in May 2016.

A RAOB Data Denial test was also performed to determine how well AMDAR observations with WVSS could account for the loss of RAOB observations. For these tests, ALL RAOB data were denied at 10 locations that had the most co-located AMDAR/WVSS profiles available over the CONUS.
Tests removing 10 RAOBS - Error in forecast fit-to-GPS/TPW Observations

An Extreme Test
Blue – Control – no WVSS

Red – Experiment with WVSS

Green – Experiment with WVSS but withholding 10 RAOBS

5% and 95% confidence limits shaded.

Dots indicate statistically significant differences between the experiment and control

When used in combination with reduced set of RAOBS over CONUS in the warm season, WVSS observations:

- Forecast Errors out to 42hrs were essentially unchanged
- Seasonally-variable GFS dry bias still persists
- Degraded forecasts past 48 hr.
  - Possibly due to errors in moisture fields or lack of dynamical information in upper-trop/lower-strat
Now starting a Less Extreme Test – Removing only “Special Off-Time” RAOBs

Objective - Determine if savings from reduced supplemental RAOBS could save resources without jeopardizing forecast accuracy

Asynoptic launches by month 2015

Asynoptic launches by hour 2015

Cumulative total
• **AMDAAR Temperature and Wind data** are among 4-5 most important data sources for global assimilation across multiple NWP centers

  • Extremely Cost Effective (Cost/Impact) – *Easy to expand*

• **Large number of moisture profiles now available over US**
  • Greater impact expected at shorter time ranges and at mesoscale
    • *Useful to forecasters (and NWP)*

• **Aircraft Water Vapor Measurements are high quality**
  • *Can fill a-synoptic data voids over land*

• **AMDAAR WVSS observation have positive impacts in NWP**
  • *Forecast improvements extend beyond 48 hours*

**Similar improvements are expected in other areas of the globe as data coverage increases spatially and temporally**
AMDAR Temperature and Wind data are among 4-5 most important data sources for global assimilation across multiple NWP centers.

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- Forecast improvements extend beyond 48 hours
- Similar improvements are expected in other areas of the globe as data coverage increases spatially and temporally

Just as Efficient use of Weather is key to optimizing the Future Air Transportation System, Availability of Good (and Adequately Distributed) Observations is key to Understanding Weather, Now and into the Future.

Thank you Questions?

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