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National Weather Service
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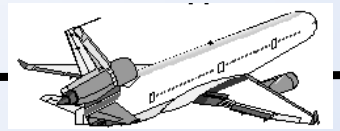
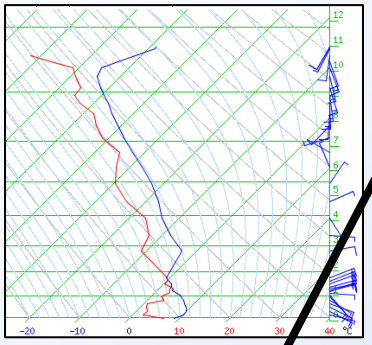
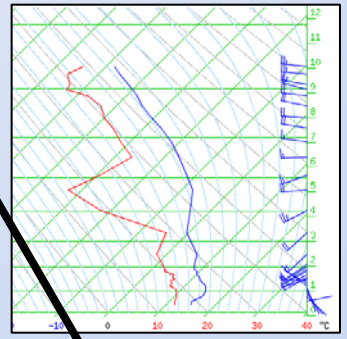
Advancements in the AMDAR Humidity Sensing

August 31, 2010







Aircraft **M**eteorological **Da**ta **R**elay

Pressure, Temperature, Wind
\+ Humidity

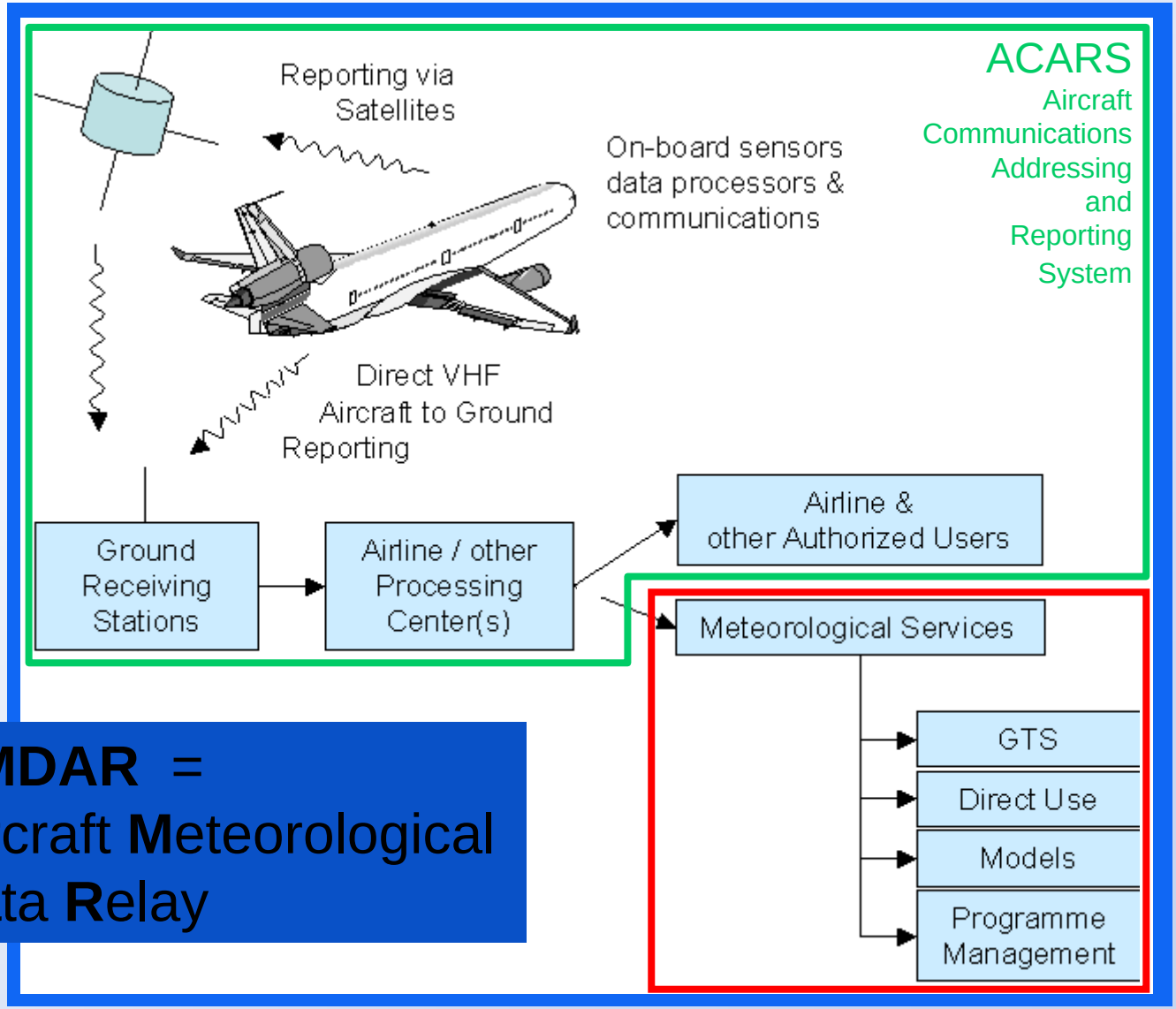
Axel Hoff

DWD
(Deutscher Wetterdienst /
German Meteorological Service)

- Background
- Engineering
- Assessments
- Deployments
- Future Activities
- Summary



Background



AMDAR = **A**ircraft **M**eteorological **D**ata **R**elay

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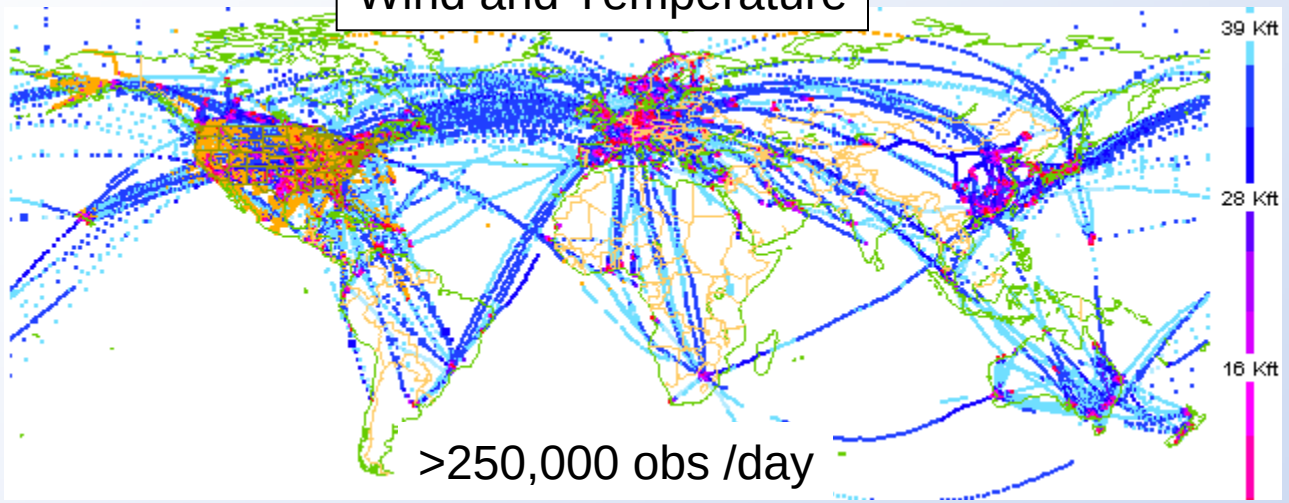
Background

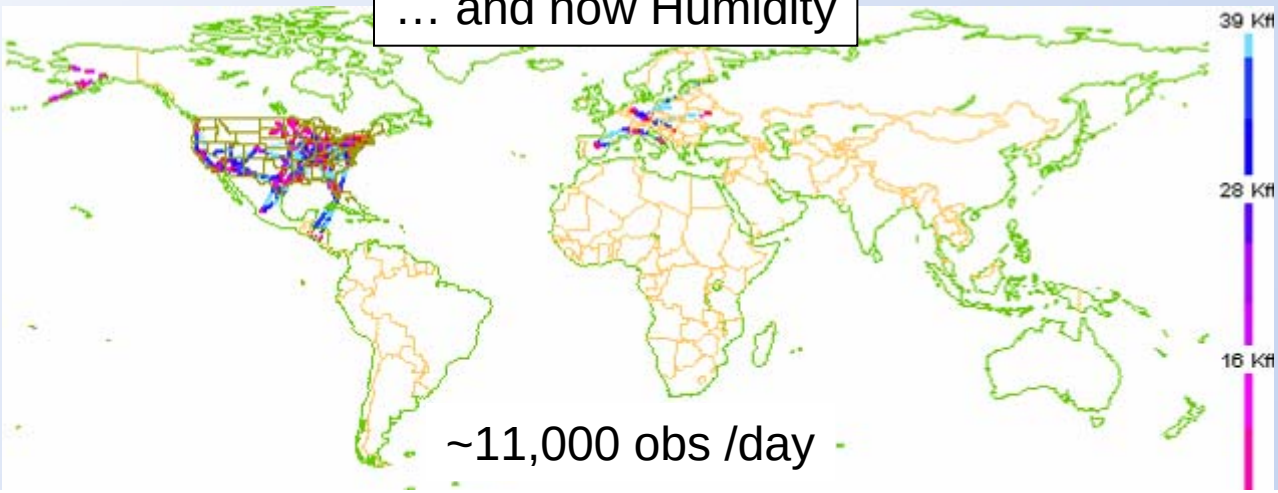
AMDAR Data Coverage

Wind and Temperature



>250,000 obs /day

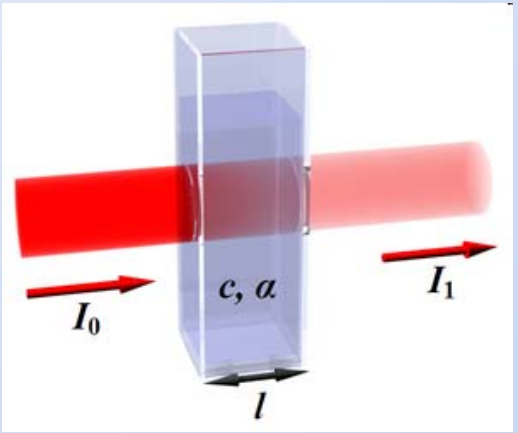
… and now Humidity



~11,000 obs /day

Background

- Aircraft Humidity Sensor Type: SpectraSensors, Inc. (SSI) WVSS-II
- Currently, SSI technology is used in 2,000 pipeline and refinery operational applications
- Sensor's principle is based on Beer's Law:
  Transmittance (T) is a function of absorption

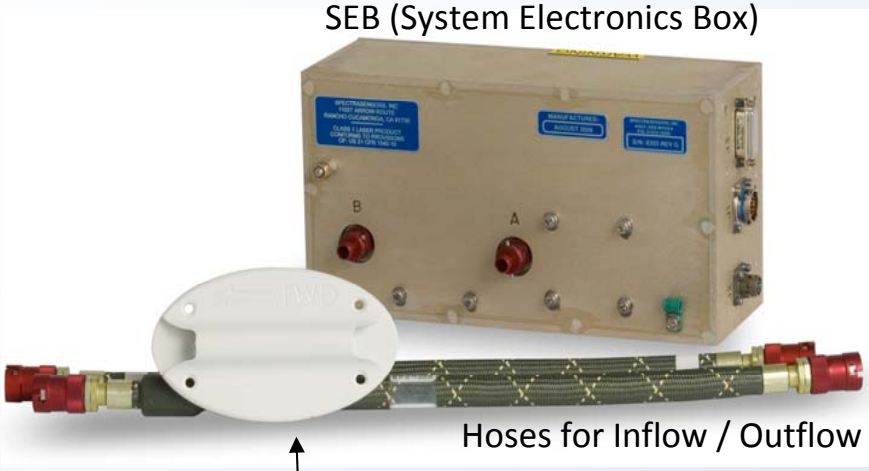


$$T = \frac{I}{I_0} = e^{-\alpha' l} = e^{-\sigma \ell N}$$

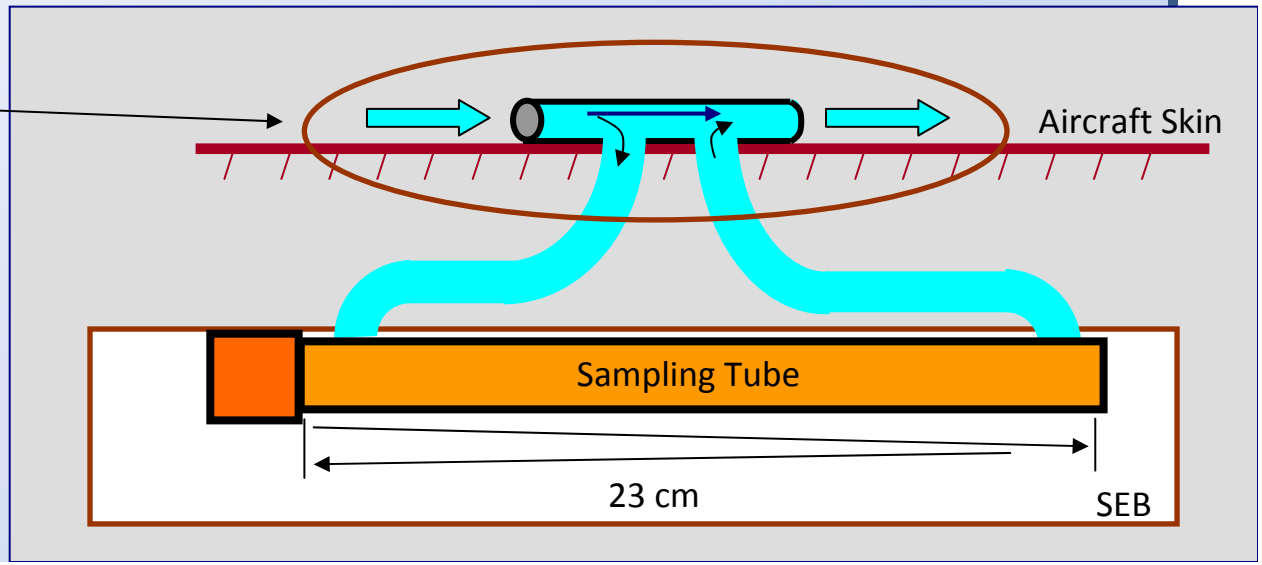
where I_0 and I are the intensity (or power) of the incident light and the transmitted light, respectively; σ is cross section of light absorption by a single particle and N is the density (number per unit volume) of absorbing particles.



Background

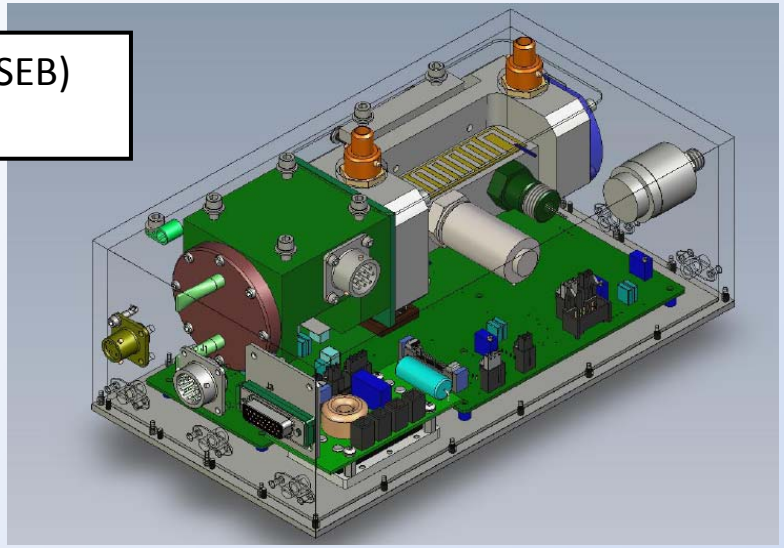


- Humidity sensor's name:
  WVSS-II
- Manufacturer:
  SpectraSensors Inc. (SSI), USA
  products: gas sensors
  for pipelines, rafineries, etc.
- Physical Principle:
  Infrared Absorption Spectroscopy
  "2f – Method" by use of
  Tunable Diode Laser (TDL)



Engineering

System Electronics Box (SEB)
3-D Schematic



- Infrared Tunable Diode Laser (TDL)
  scans a water vapor absorption band near 1.37 µm
- Path length: 23 cm
- Samples internally at 4 Hz
- Generates every 2 seconds a “product”:
  water vapor mass mixing ratio

Engineering

History of the WVSS-II

- Alpha Version 1: 2005
  - First deployment on commercial aircraft
  - Issues indicated by testing:
    - condensation during descent
    - Coding algorithms limitations
- Beta Version 2: 2006
  - Implemented heated hose
  - New coding algorithm to capture precision and dynamic range of mixing ratio (10 - 40,000 ppmv)
  - Issues:
    - Moisture intrusion into sample chamber
    - Thermal stability of chamber of limiting accuracy
- Production Version 3: 2008
  - Improved laser seal
  - Improved thermal stability
  - Improved factory testing, calibration procedures

"Cargo-Door" View WVSSII
WVSSII Located on Forward-Port Side of UPS B-757

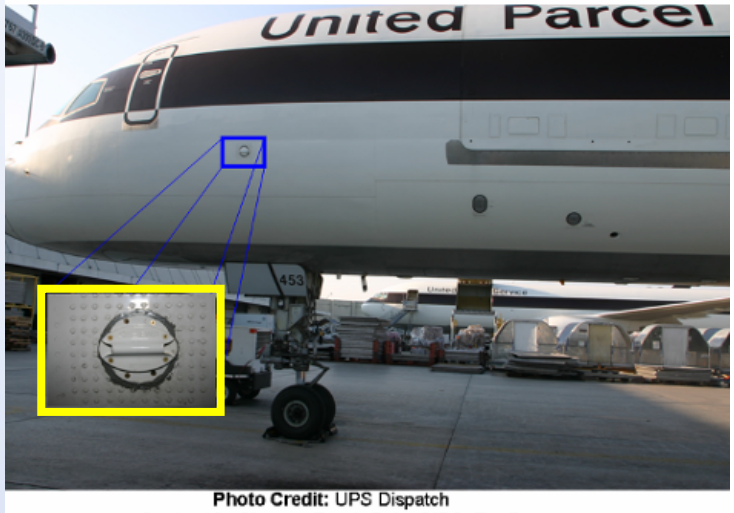


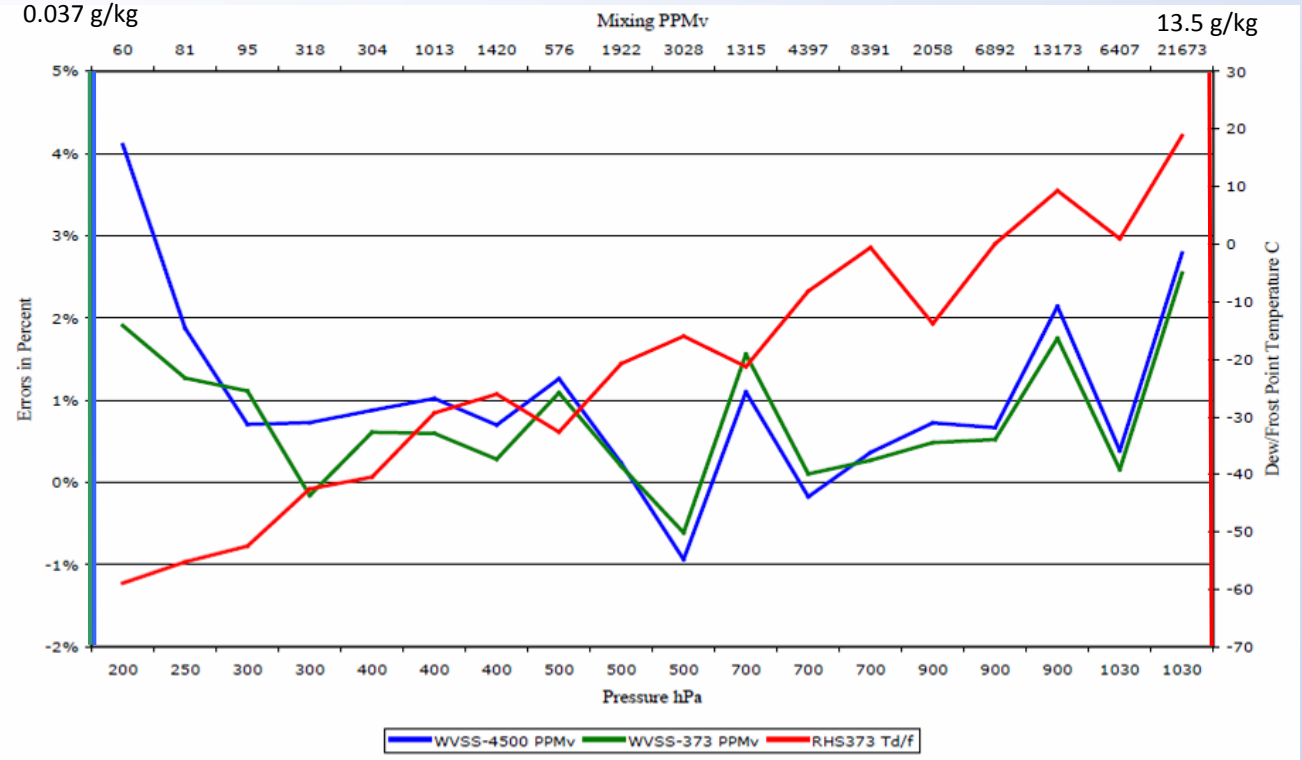
Photo Credit: UPS Dispatch
Contact for Usage: Randy Baker/UPS; Email: air1rtb@ups.com

Assessments

NOAA Chamber Results

Chamber Tests Against Reference Sensors (Chilled Mirror/RH373 and TS4500)

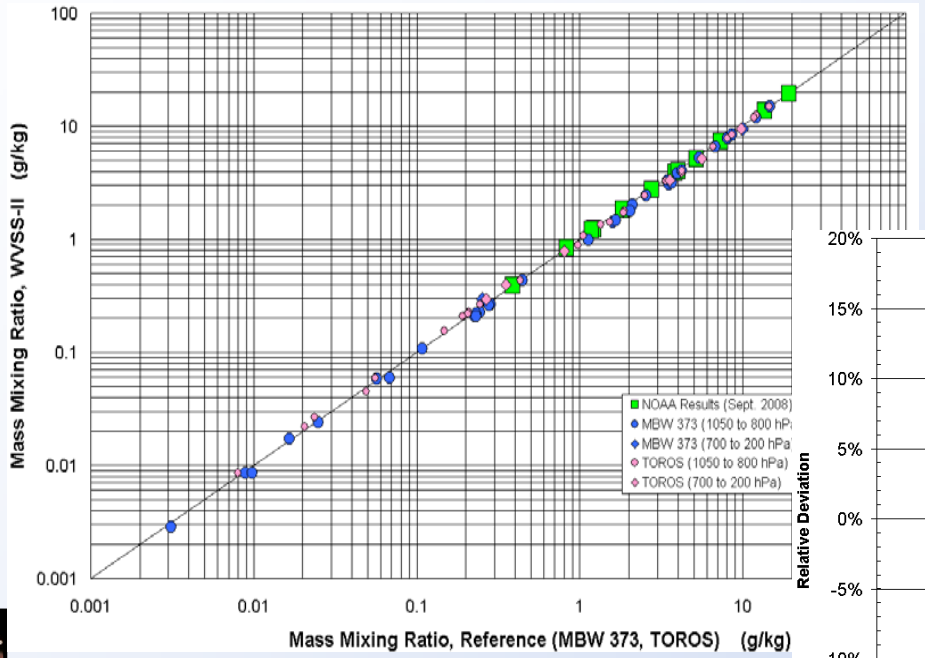
- Sterling Field Support Center, October 2009:
  "WVSS-II sensor performed well under most of the test conditions"



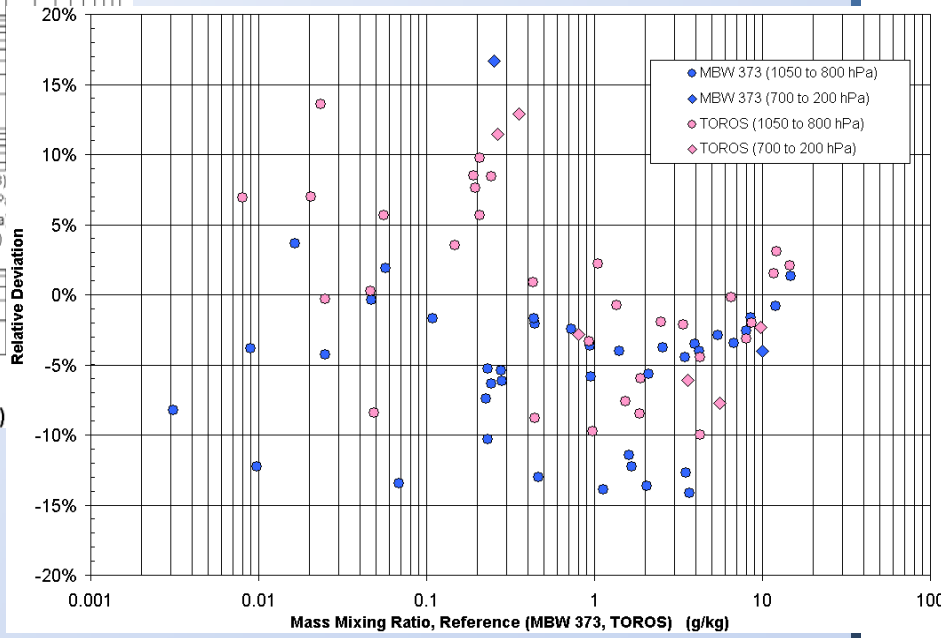
Chamber results, % difference in ppmv, between WVSS-II/TS4500 (**blue**), WVSS-II / RH373 (**green**) and dew / frost points (red)

Assessments

DWD Climate Chamber Results



Reference Sensors:
Chilled Mirrors
MBW 373 and Toros



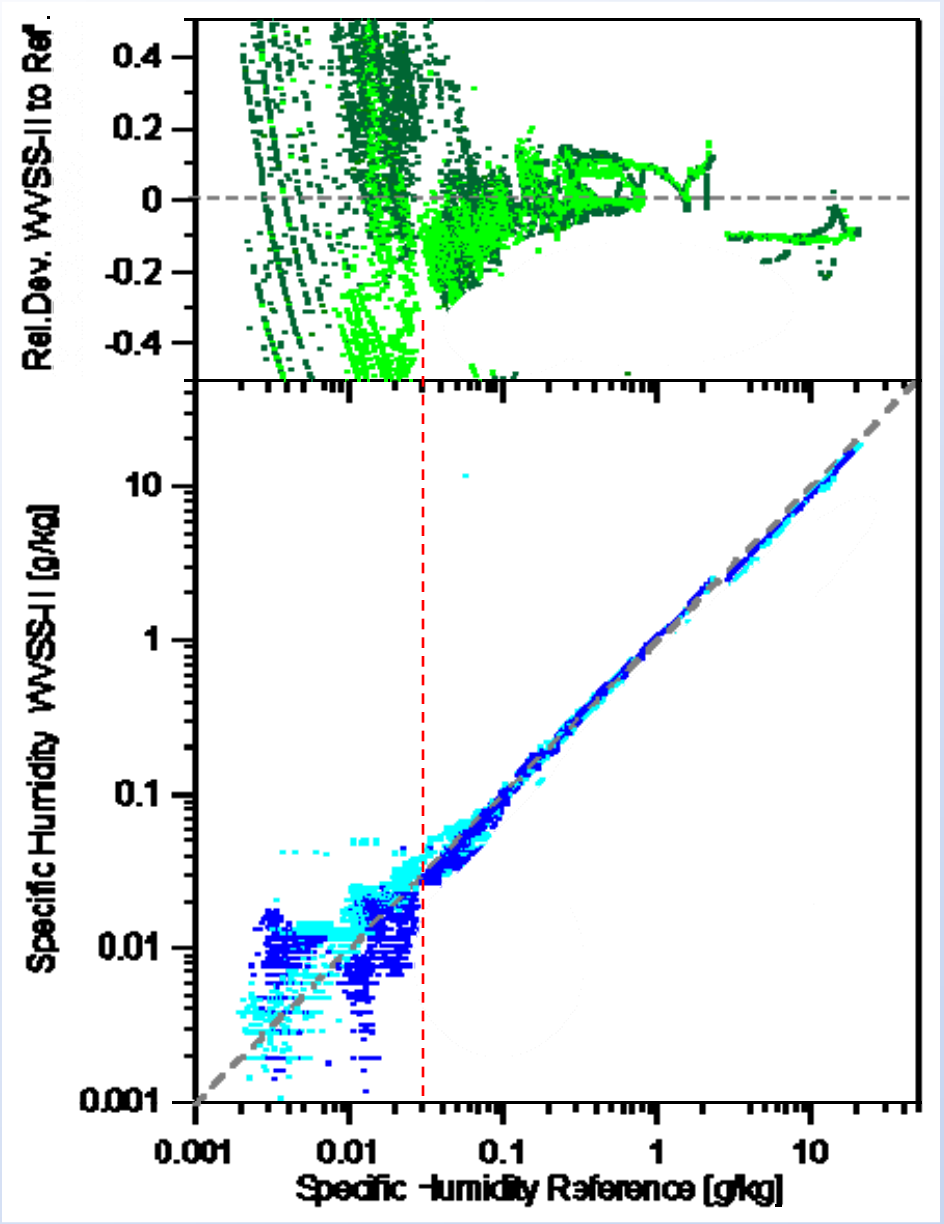
From DWD Report, Sept 2009

The sensitivity of the WVSS-II touches the upper Troposphere.

Assessments

Climate Chamber Results of Research Centre Jülich, Germany

Sensitivity limit
at 0.02 g/kg (30 ppmv)
Altitude: 200 hPa
Temperat.: – 60 °C



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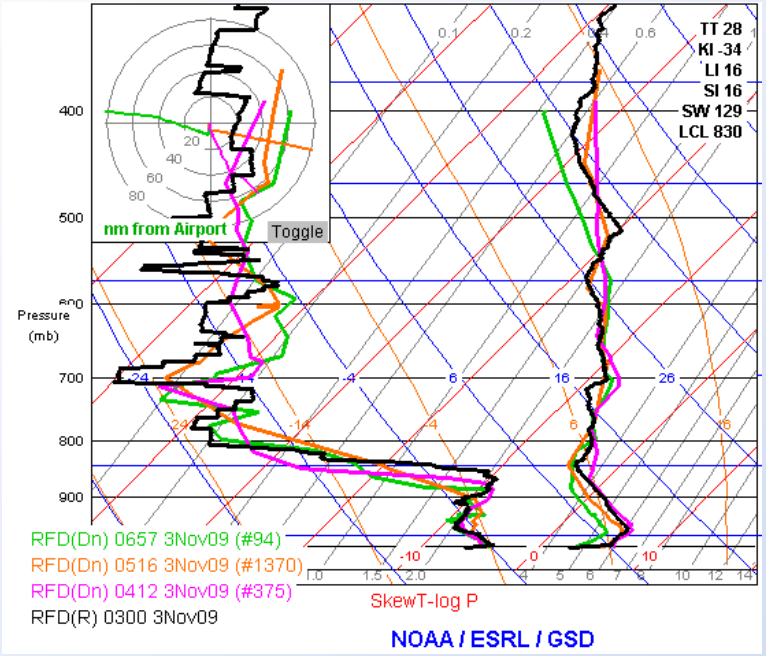
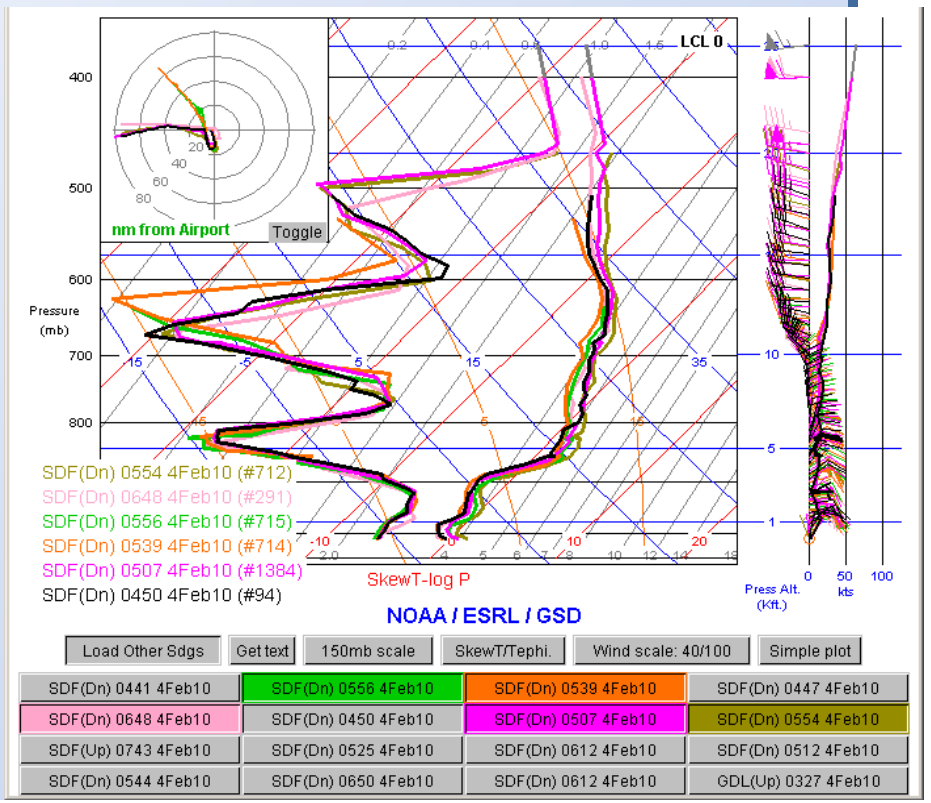
Assessments

Radiosonde Field Tests

Rockford, IL, (KRFD) Airport
University of Wisconsin AERIBAGO / RS92 Tests
November 2009, May 2010, and August 2010

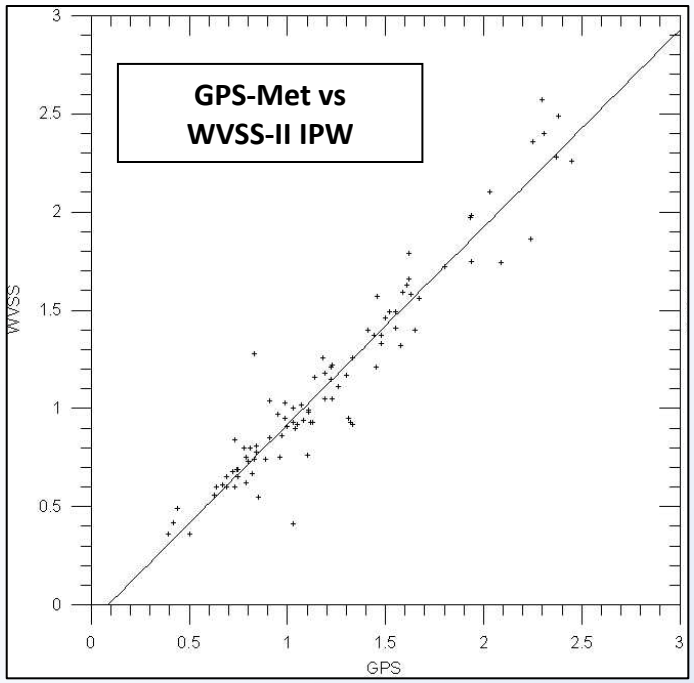




Inter-comparisons of WVSS-II sensors show high correlation

Assessments

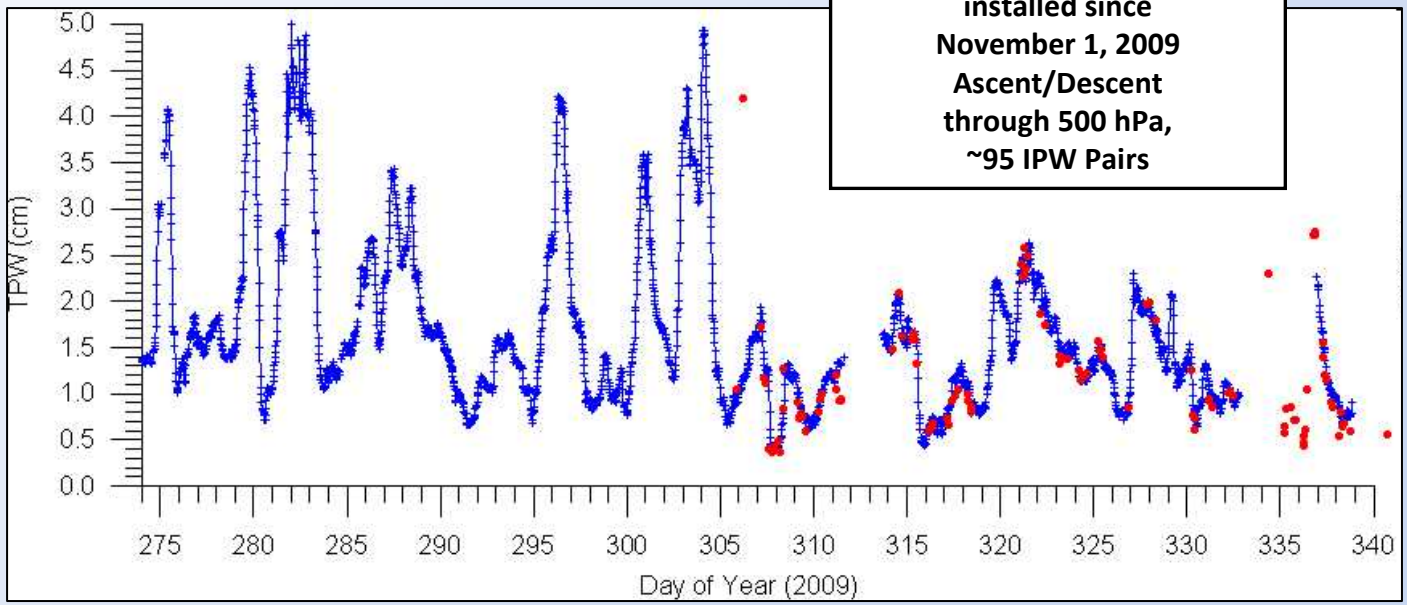
GPS-Met IPW Inter-Comparisons



Integrated Precipitatble Water (IPW) derived from GPS-Met and WVSS-II

"After removing outlier points, slope of fit linear line is 1.0, with a 3% negative bias for WVSS-II v3 as compared with GPS-Met IPW." (Seth Gutman)

8 Aircraft with WVSS-II v3 installed since November 1, 2009
Ascent/Descent through 500 hPa, ~95 IPW Pairs

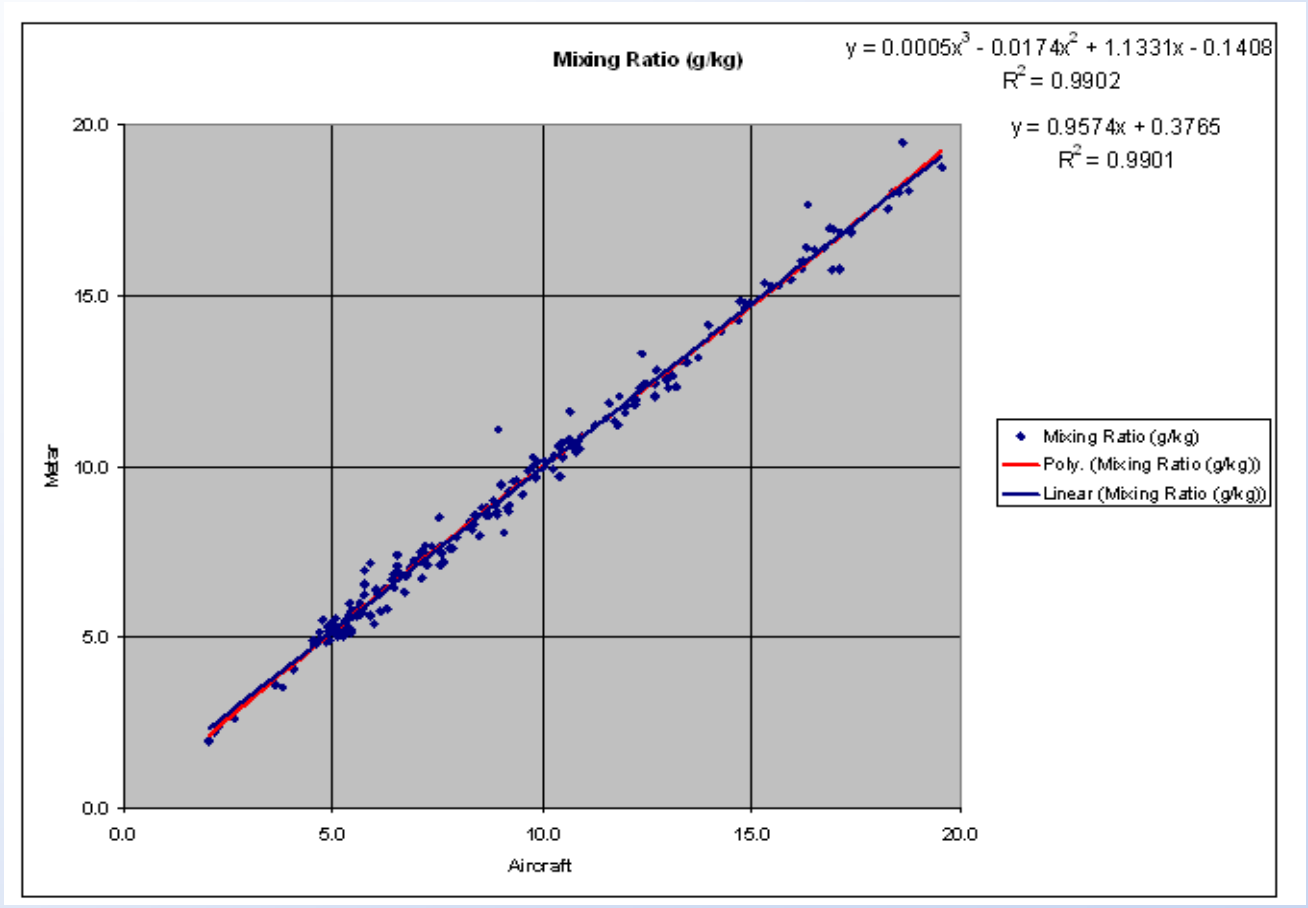


Assessments

ASOS Inter-Comparisons

Louisville (KSDF) ASOS / WVSSII Surface / Lowest Level Sounding

"When the temperature error components are removed,
the moisture errors account for an RH error of <4%" (Ralph Petersen)



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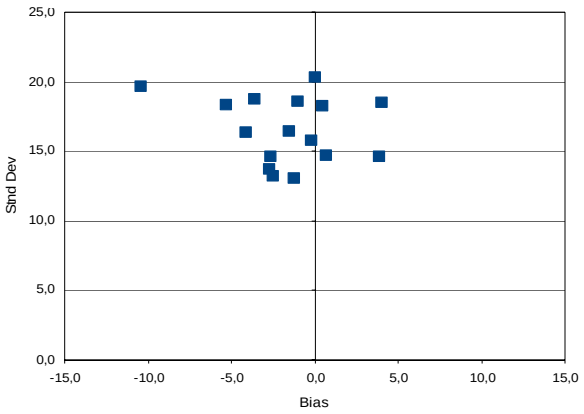
Assessments
Model Inter-comparisons

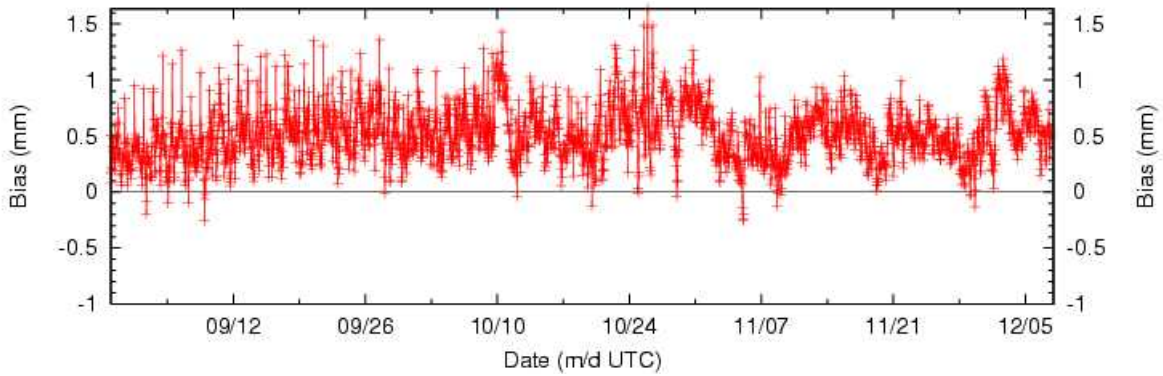
Bill Moninger:

- WVSSII data are now performing well enough to be accepted for assimilation into the GSD Rapid Refresh Development Model
- Model bias and RMSE were good through 300 hPa, but diverged from model guess at lower pressures; outlier units were diagnosed to be problems with blocked intake hoses (now corrected)
- Inter-comparing WVSSII with models is useful for identifying trends and outliers; however, models are not 'truth', with RUC/RR demonstrating a wet bias and limited assimilation of other in situ observations

WVSSII vs. RUC Model Analysis By Individual Tail #



GPS-Met/RUC Model IPW Time Series (Bias and RMSE)



RUC maintains a ~0.5 mm wet bias against the GPS-Met IPW

Deployments

Supplemental Type Certificates (STCs) issued by the FAA

Completed for WVSSII:

- August 26, 2009 for Boeing B757-200 (UPS fleet).
- December 9, 2009 for Boeing B737-300 (SWA fleet).

Planned:

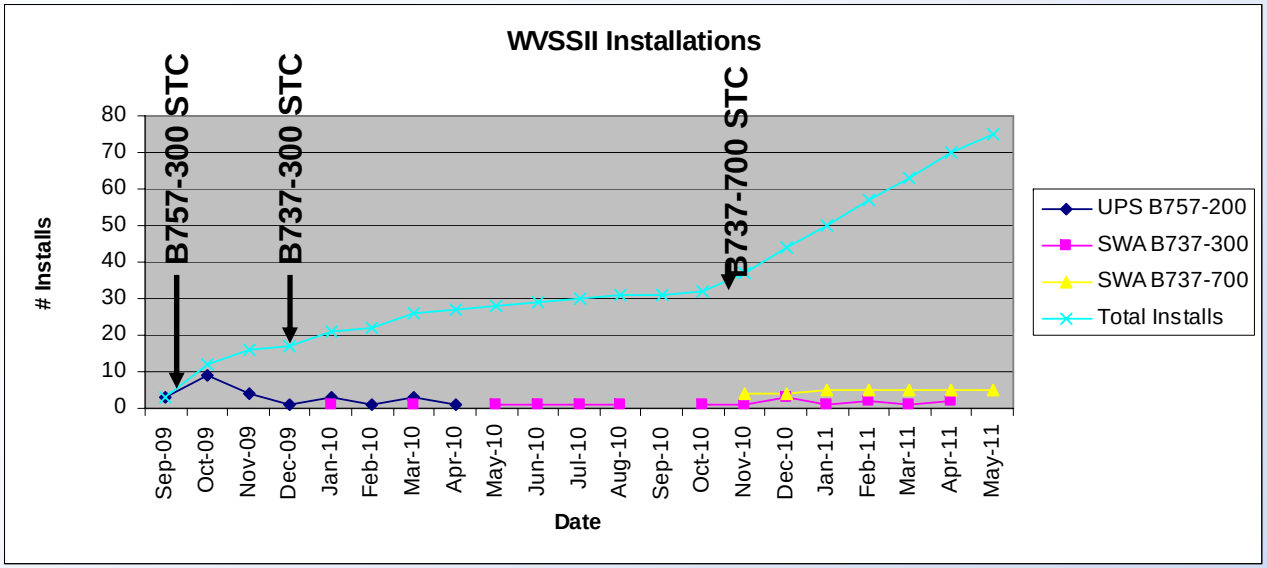
- STC for B737-700 is estimated to be awarded in December 2010.

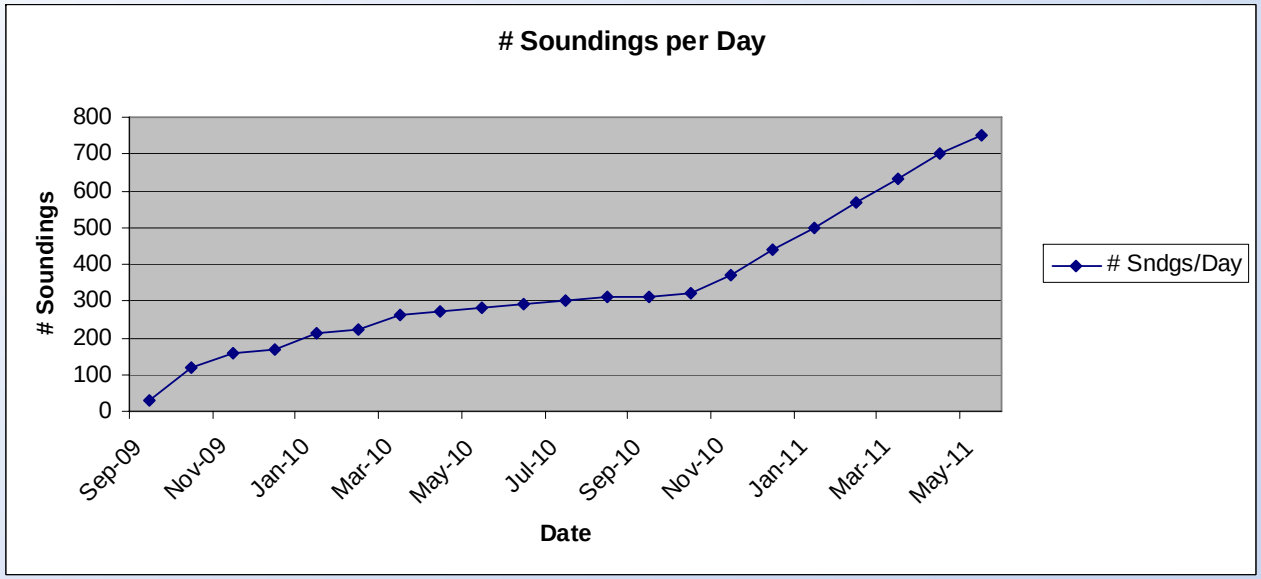


Current WVSS-II installations:

- 25 sensors on United Parcel Service (UPS) on B757-200 aircraft
- 5 sensors on Southwest Airlines (SWA) on B737-300 aircraft
- 3 sensors on Lufthansa on Airbus A319 aircraft

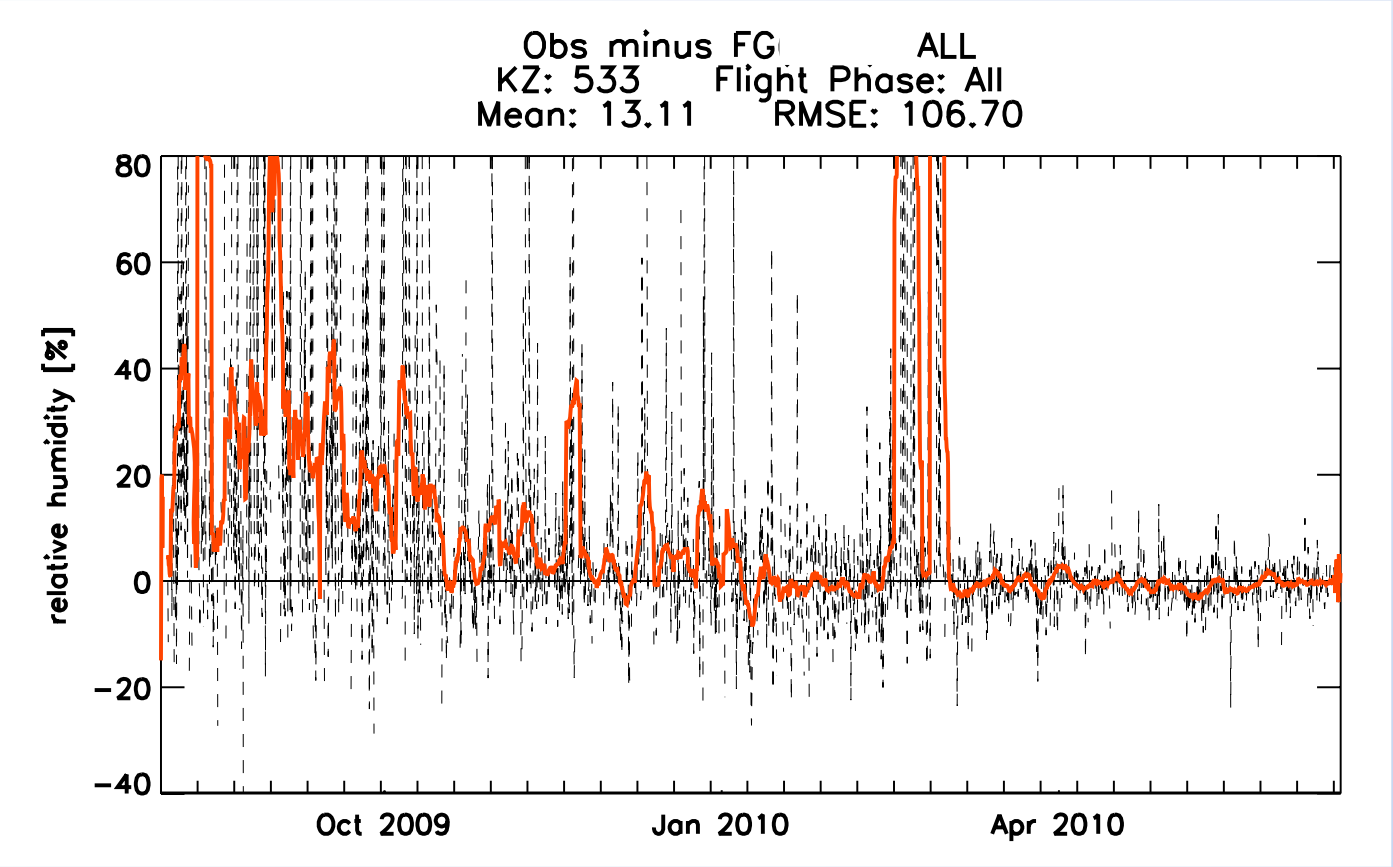
Deployments





Deployments

Mean Bias of all WVSS-II observations
against the First Guess of the DWD global model GME





Future Activities

- USA-NOAA plans 92 total installations, mostly on SWA B737-700 aircraft (2011)
- EUMETNET-AMDAR plans for Airbus A320 family
  - replacement of the 3 old units
  - 6 new deployments (2011 – 2012)
  - with potential for another 6 units (2012 +)
- Research Aircraft Inter-comparisons:
  - BAe146 (UK Met Office) (2010)
  - Piper Navaho (NOAA) (2011)
- Improved Coding and Metadata
- Enhanced Monitoring
- Extended Performance (to 1 ppmv, below 0.001 g/kg)



Summary

- WVSS-II meets or exceeds performance requirements from 50-40,000 ppmv.
- WVSS-II moisture observations are as good or better than existing in situ observations.
- WVSS-II has shown a degradation of performance at ppmv less than 50 (0.03 g/kg), which occurs ~1% of time at elevations above 30,000 ft AGL, in chamber tests, and in model inter-comparisons.
- Follow-on research and development is planned to use TDL to observe water vapor
  down to 1 ppmv (0.0006 g/kg),
  and other trace gases.



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Thank you for your attention!

Axel Hoff

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EUMETNET
The Network of European Meteorological Services

SMHI

Met Office

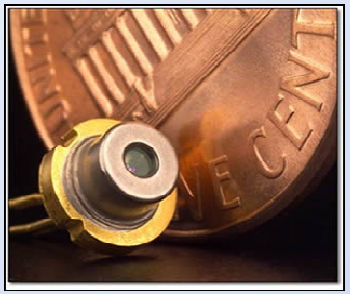
Lufthansa

UCAR
The University Corporation for Atmospheric Research
Operating NCAR and UOP in partnership with the universities

National Oceanic and Atmospheric Administration

Water Vapor Sensing System II (WVSSII)

Federal Aviation Administration
Moving America Safely



ARINC

SpectraSensors

ups

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- **AMDAR Technical Coordinator**
- **World Meteorological Organization**

WVSS-II

NOAA Contract Performance Criteria

	Requirement	Specification	WVSS-II Compliance
1	Accuracy	Threshold: 8.0% Objective 5.0%	1. Expected performance is ±50 ppmv or ± 5% of reading whichever is larger. 2. Spatial interval in level flight at 575 mph ground speed is ~ 0.06 Km. Measurement interval drops linearly with ground speed.
2	Dynamic Range (RH)	Threshold 0.0% - 100.0%	50 to 40,000 ppmv
3	Dynamic Range (Mixing Ratio, g/kg)	Minimum Threshold: 0.015 Objective: 0.005 Maximum Objective: 38.0	50 to 40,000 ppmv
4	Precision (RH)	Threshold: 0.1%	± 5% of the mixing ratio
5	Precision (Mixing Ratio, g/kg)	Threshold Sfc - 03 Km: 0.1 03 - 08 Km: 0.01 08 - 16 Km: 0.001	± 5% of the mixing ratio
6	Operating Range	Threshold: +40°C through -99°C	Comply on high termperature side and have no data on the low side. -65°C has been encountered in previous flight data without problems. Assumes that this relates to the sample air temperature range.



Terms

➢**WMO Aircraft Meteorological DAat and Reporting (AMDAR) Program:** *An international effort within the World Meteorological Organization (WMO) to coordinate the collection o f environmental observations from commercial aircraft. AMDAR largely leverages sensors (temperature and wind) and communication capabilities used to operate larger commercial aircraft for environmental applications.*

•**E-AMDAR:** *A EUMETNET-AMDAR (E-AMDAR) Programme serves EUCOS requirements for additional upper air measurements of wind and temperature and to maximize the efficiency/cost ratio of implementing AMDAR (Aircraft Meteorological Data Relay) systems for EUMETNET Participants by reducing duplication in the use of resources and seeking to meet requirements in the most cost-effective manner.*

•**U.S. AMDAR Program:** *A private/public partnership facilitating the collection of atmospheric measurements from commercial aircraft to improve aviation safety. This partnership includes seven air carriers, two federal agencies, and several private sector companies.*

Aircraft Communications Addressing and Reporting System (ACARS): *A digital datalink system, provided by ARINC and SITA, for transmission of short, relatively simple messages between aircraft and ground stations via radio or satellite. ACARS is also a message format transmitted to the ground using ARINC 620 protocol.*

Meteorological Data Collection and Reporting System (MDCRS): *The environmental component of the ACARS message. ARINC is under contract by the FAA and NWS to strip out the weather data from the ACARS messages and encoded these data into WMO compliant BUFR files using the ARINC "MDCRS" server in Annapolis, Maryland. The MDCRS BUFR file is NOAA's operational contribution to the WMO AMDAR Program, transmitted via GTS.*

Tropospheric Airborne Data DAta Reporting (TAMDAR): *NASA Langley developed the TAMDAR sensor suite and communications capability (Iridium) to augment regional aircraft which typically do not have air-to-ground communications or high-quality sensors. Through TAMDAR, the number of airports which sounding data are collected from can be increased by significantly. NASA transferred the TAMDAR Program to a company called AirDat which provides TAMDAR data through a contract to NOAA.*