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9.2 TAMDAR/AMDAR DATA ASSESSMENTS USING THE RUC AT NOAA'S GLOBAL SYSTEMS DIVISION

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1. INTRODUCTION

Commercial aircraft now provide more than 150,000 observations per day of winds and temperature aloft over the contiguous United States. The general term for these data is AMDAR (Aircraft Meteorological Data Reports). These data have been shown to improve both short-term and long-term weather forecasts (Moninger, et al., 2003).

One weakness of the current AMDAR data set is the absence of data below 25,000 ft between major airline hubs and the almost complete absence of water vapor data at any altitude. To address this weakness, a sensor called TAMDAR (Tropospheric AMDAR), developed by AirDat, LLC, under sponsorship of the NASA Aviation Safety and Security Program, has been deployed on approximately 60 regional turboprop aircraft operated by Mesaba airlines flying over the middle U. S. (Daniels, et al., 2006) Like the rest of the AMDAR fleet, TAMDAR measures winds and temperature. But unlike most of the rest of the fleet, TAMDAR measures humidity, turbulence, and icing. By mid-2007, AirDat expects to have more than 400 aircraft operating in the U.S.

GSD has built an extensive system for evaluating the quality of TAMDAR and AMDAR data, and has applied this system for the two years that TAMDAR has been in operation. Our evaluation system relies on the Rapid Update Cycle (RUC) numerical model and data assimilation system (Benjamin, et al., 2004a,b). The RUC provides a common background against which AMDAR and TAMDAR data are compared.

In particular, we look at differences between RUC background fields (one-hour forecasts from the previous hour) and aircraft data. Results suggest that TAMDAR data have error characteristics different from those of traditional AMDAR fleets, which consist of long-haul jet aircraft, and that it may be useful and important to treat TAMDAR differently than data from other fleets when assimilating the data into models.

This extends our presentation given at the AMS Annual Meeting last year (Moninger, et al., 2006): we now include results from 2006—a period during which TAMDAR data processing, data resolution, quality control, and assimilation into the RUC all changed.

This is a companion paper to one by Benjamin et al. (2007), in which the impact of TAMDAR on the RUC is assessed, and one by Szoke, et al. (2007), in which the statistical impact of individual events is examined.

We believe these studies are particularly important as the U.S. government considers paying a larger portion of the costs associated with aircraft-measured meteorological data. In this new era, the government will have to more carefully monitor the quality of data from a variety of aircraft fleets, and provide detailed data quality information to both data providers and data users.

2. GSD INFRASTRUCTURE

2.1 RUC-AMDAR Database

GSD maintains a database of AMDAR and TAMDAR observations, and 1-h forecasts interpolated to the AMDAR observation point from several versions of the RUC. This enables us to compute mean and RMS difference between RUC 1-h forecasts and aircraft-observed temperature, wind, and relative humidity. RUC cycles currently included in the database are:

- "dev" (or "development version 1") which assimilates all hourly non-TAMDAR observations (profiler, aircraft, surface, satellite, integrated precipitable water estimates from global positioning satellite systems (GPS-IPW), rawinsonds (RAOBs)).
- "dev2" which is the same as "dev", but includes TAMDAR aircraft observations.

Model data are interpolated vertically (in log-p) and horizontally to the location of the observation. No temporal interpolation is performed; observations are compared with the 1-h forecast valid at the nearest hour.

For each observation time and location we store observed and forecasted temperature, relative humidity, and wind direction and speed, and phase of flight (ascent, descent, or en-route). In addition, the RUC quality control disposition of each observation has been stored since 8 December 2005, as well as which variable(s) were actually used in the RUC analysis. Examples of recorded reject information include:

- The aircraft is on a reject list for T, RH, or Wind.
- A variable was flagged as bad by "front-end" (non model-based) QC checks (e.g., due to track checking or climatological consistency).

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- A wind observation was taken during descent by TAMDAR-equipped aircraft (these observations are of lower quality than other aircraft observations, as will be argued in Sec. 3).
- Data were taken by Canadian AMDAR aircraft (some of these data are currently of uncertain quality, Zaitseva, et al., 2006).
- The observation is a duplicate.
- The difference between the observation and the model background is unacceptably large to be considered reliable for use in the RUC data assimilation.
- The location of the observation is out of the RUC horizontal domain.
- The altitude of the observation is out of range.
- The observation time is not within the analysis time window.
- The dewpoint is greater than the temperature.
- The observation is taken by an aircraft that has had too many other errors in the analysis time window.
- The QC disposition is unknown. (This can happen if the analysis did not run.)

2.2 Web-based access to the AMDAR-RUC Database

Access to the AMDAR-RUC database is available at http://amdar.noaa.gov/ruc_acars/. Because access to real-time (i.e., less than 48 h old) AMDAR data is restricted to NOAA and selected other users, access to the real-time portions of this site is restricted. (See http://amdar.noaa.gov/FAQ.html.)

Database access is provided in the following forms:

- 3- and 7-day statistical summaries for each aircraft, sortable by a variety of values
- time-series data for any aircraft (restricted)
- plan views of aircraft data and corresponding model results (restricted)

Fig. 1 shows an example of the 7-day statistical summary. Data may be sorted by each column by clicking on the column heading. Statistical values which are outside of predetermined limits are shown in red. This portion of the data shows TAMDAR aircraft, for which we reject descent winds. Hence the column "pe_W" which is the percentage of RUC wind QC failures, is large in this case. However, note that the individual wind-related statistics (speed bias, RMS of the vector wind difference, standard deviation of the wind direction difference) are generally not out of range, suggesting that rejecting all TAMDAR winds taken on descent is too strict of a measure.

Aircraft data minus dev2 RUC 1-h forecast.

abs(bias_T) > 2°C shown in red
std_T > 2°C shown in red
abs(bias_S) > 2 m/s shown in red
std_S > 5 m/s shown in red
abs(bias_D) > 7° shown in red (when S > 10 m/s)
std_D > 30° shown in red (when S > 10 m/s)
rms_W > 7 m/s shown in red (vector wind difference, when heading is known)
abs(bias_RH) > 10% shown in red
std_RH > 20% shown in red
pe_T > 4% (percent RUC QC Failures) shown in red
pe_W > 4% (percent RUC QC Failures) shown in red
pe_R > 4% (percent RUC QC Failures) shown in red
rj_T > 0 (percent of obs taken when the aircraft was on the T reject list) shown in red
rj_W > 0 (percent of obs taken when 1) the aircraft was on the W reject list or 2) W was rejected as a TAMDAR descent) shown in red
rj_R > 0 (percent of obs taken when the aircraft was on the RH reject list) shown in red

detailed descriptions of summary statistics (in another window)

For the period 2006-07-31 00:00:00 to 2006-08-06 23:59:57
(Click on a column header to sort by that column)

FSL_ID	N_qc	pe_T	rj_T	N_T	avg_T	bias_T	std_T	pe_W	rj_W	N_S	avg_S	bias_S	std_S	bias_D	std_D	rms_W	pe_R	rj_R	N_RH	avg_RH	bias_RH	std_RH	model
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	V
5434	240	1	0	240	16.2	0.6	0.9	65	0	168	9.0	1.1	4.8	30	17	7.2	1	0	240	55.2	-7.9	13.0	SAAB-340
8683	2649	3	0	2649	15.8	0.0	0.9	59	0	1780	9.8	1.8	4.2	4	19	6.5	5	0	2649	57.8	0.8	12.6	SAAB-340
8696	3289	3	0	3288	14.3	-0.0	1.0	64	0	2114	11.3	1.6	4.2	-4	16	6.0	2	0	3261	58.6	1.6	12.2	SAAB-340
8711	2921	3	0	2921	14.4	0.2	0.9	57	0	1961	9.9	0.0	3.2	0	14	4.7	2	0	2918	55.9	-1.1	12.6	SAAB-340
5562	3019	1	0	3018	15.2	0.2	0.8	55	0	2039	10.5	0.8	2.7	3	13	4.0	1	0	3003	51.6	-2.0	12.4	SAAB-340
5594	3382	2	0	3381	15.6	-0.1	0.9	64	0	2208	11.1	1.2	3.9	3	18	5.7	1	0	3373	57.5	3.1	12.4	SAAB-340
8773	2531	3	0	2531	15.0	0.4	0.8	55	0	1715	11.1	0.9	3.6	-4	18	5.7	0	0	0	0.0	0.0	0.0	SAAB-340
5563	2339	0	0	2339	17.5	0.2	0.8	55	0	1579	6.5	1.6	3.0	-3	14	5.0	0	0	2337	59.0	2.8	15.1	SAAB-340
7103	3085	2	0	3081	15.2	0.2	0.9	63	0	1939	10.4	1.2	3.6	3	16	5.3	1	0	2986	57.9	1.8	12.5	SAAB-340
5568	2899	3	0	2898	15.9	0.5	0.8	64	0	1925	10.5	1.0	3.2	5	15	5.0	2	0	2889	57.6	1.0	12.4	SAAB-340
5573	3139	4	0	3133	16.1	-0.2	1.0	63	0	2100	10.4	1.4	4.4	7	21	6.7	0	0	0	0.0	0.0	0.0	SAAB-340
5575	3095	2	0	3090	16.3	-0.3	1.0	61	0	1946	11.4	1.1	3.8	2	17	5.5	2	0	3066	59.2	0.5	10.7	SAAB-340
8679	3521	3	0	3521	14.2	-0.2	1.0	61	0	2301	10.6	1.7	4.1	-1	18	6.0	2	0	3518	55.0	1.8	13.1	SAAB-340
8678	2788	3	0	2788	16.3	0.2	0.8	58	0	1938	5.7	1.2	2.7	-7	9	4.4	4	0	2786	62.3	2.5	13.8	SAAB-340
8671	2916	1	0	2915	15.2	0.0	0.9	57	0	1916	11.7	1.2	3.4	3	15	5.2	1	0	2907	56.2	1.7	12.2	SAAB-340
5511	3015	0	0	3015	16.0	-0.8	0.9	62	0	1994	11.6	0.3	3.1	-0	14	4.5	0	0	3005	59.6	1.3	12.2	SAAB-340
7184	2801	2	0	2801	16.3	0.1	1.0	61	0	1667	10.8	0.5	3.4	3	15	4.9	2	0	2792	52.8	-0.7	12.6	SAAB-340
5522	3216	1	0	3214	14.1	-0.8	1.0	100	44	2056	11.1	1.1	4.1	2	22	6.6	1	0	3087	54.4	-0.3	13.4	SAAB-340
7159	2870	3	0	2867	15.3	0.1	0.8	54	0	1966	9.8	-0.1	3.5	2	12	4.8	1	0	2865	53.7	-0.6	11.7	SAAB-340

Figure 1. Example of 7-day statistics from http://amdar.noaa.gov/ruc_acars/7day_stats.cgi.

Fig. 2 shows a typical time series; in this case for aircraft #8683 (GSD uses special identifiers for each aircraft at the airlines' request). The right-hand column indicates the RUC QC error disposition(s) of each observation. These data show that the RUC has rejected several wind measurements—in this case, for the simple reason that the winds were missing for those observations.

Time series for aircraft 8683 compared with FSL Dev2 RUC 1-h forecast

t = temperature
S = wind speed
RH = relative humidity
suffix f = from forecast
prefix d = observation minus forecast

abs(t-tf) > 2°C shown in red
std(t-tf) > 2°C shown in red
abs(S-Sf) > 2 m/s shown in red
std(S-Sf) > 5 m/s shown in red
abs(dir-dirf) > 7° shown in red (when S and Sf > 10 m/s)
std(dir-dirf) > 30° shown in red (when S and Sf > 10 m/s)
abs(RH-RHf) > 10% shown in red
std(RH-RHf) > 20% shown in red

used is a multi bit number:
bit 1 (= 1) is on if T was used in the RUC analysis,
bit 2 (= 2) is on if W was used in the RUC analysis,
bit 3 (= 4) is on if RH was used in the RUC analysis,
thus used = 3 means T and W were used, but RH was not
(used = 9 means we do not know whether this ob ws used)

date	time	used	p	t	tf	dt	S	Sf	dS	dir	dirf	ddir	RH	RHf	dRH	RH_un	TAS	up_dn		
--------	UTC -----		mb	-----	°C	------	------	m/s-----		-----	°	-----	----	%	-----		m/s	hdg		rjct
averages:			852	20.4	20.2	0.2	5.7	5.4	0.2			0	60	59	1					
std deviations:						0.4			1.5			0			10					
counts:			102	102			63			0			102							
2006-08-06	16:55:32	7	991	29.2	28.9	0.3	1.0	1.4	-0.4	144	193	-49	56	60	-4	3	74	226	1	
2006-08-06	16:55:41	7	980	28.2	28.0	0.2	1.0	1.7	-0.7	177	194	-17	58	62	-4	3	78	230	1	
2006-08-06	16:55:49	7	971	27.4	27.2	0.1	3.0	1.9	1.1	173	194	-21	58	63	-5	3	76	226	1	
2006-08-06	16:55:59	5	960	26.4	26.3	0.1	--	2.0	--	--	195	--	61	65	-4	3	78	0	1	Wind
2006-08-06	16:56:13	5	951	25.6	25.5	0.1	--	2.0	--	--	195	--	60	66	-6	4	82	0	1	Wind
2006-08-06	16:56:25	7	941	24.8	24.7	0.1	3.6	2.3	1.3	140	198	-58	62	66	-4	4	82	198	1	
2006-08-06	16:56:39	5	931	23.8	23.9	-0.1	--	2.6	--	--	201	--	65	66	-1	4	82	0	1	Wind
2006-08-06	16:56:54	7	921	22.8	23.1	-0.4	2.0	3.0	-1.0	129	203	-74	69	64	5	4	84	207	1	
2006-08-06	16:57:07	5	911	21.9	22.4	-0.6	--	3.3	--	--	205	--	70	62	8	4	84	0	1	Wind
2006-08-06	16:57:19	5	901	21.8	21.7	0.0	--	3.7	--	--	207	--	66	60	6	4	86	0	1	Wind
2006-08-06	16:57:36	5	891	20.8	21.1	-0.3	--	4.1	--	--	207	--	65	58	7	4	86	0	1	Wind
2006-08-06	16:57:49	7	880	20.4	20.4	-0.0	2.5	4.6	-2.1	175	207	-32	61	57	4	4	86	207	1	
2006-08-06	16:58:03	7	871	19.6	19.7	-0.1	3.6	5.0	-1.4	160	207	-47	63	57	6	4	88	201	1	
2006-08-06	16:58:17	7	860	18.9	18.9	-0.0	4.6	5.3	-0.8	170	206	-36	63	61	2	4	88	204	1	

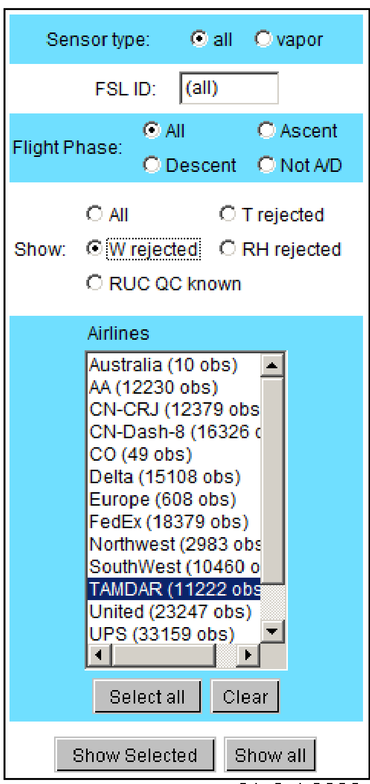
Figure 2. Time series for a particular aircraft, from http://amdar.noaa.gov/ruc_acars/interactive/

Fig. 3 shows an example plot from the AMDAR-RUC web display. In this figure we have selected to show TAMDAR observations that had their wind report rejected by the RUC dev2 cycle. And we have chosen to plot “A-R barbs”, which show the AMDAR observation minus RUC vector wind difference. Most of the observations have missing winds, indicated by the yellow x’s. The winds are missing because AirDat’s ground processing (Anderson, 2006) has already determined that these winds are likely erroneous.

However, some TAMDAR observations with non-missing winds also failed RUC QC such as the one shown at the cursor. Data values for that datum are shown around the cursor, and are (clockwise from upper left):

- Altitude (16 678 ft)
- Pressure (534 hPa)
- TAMDAR wind (79 kts from 274º)
- RUC wind, in blue (52 kts from 285º)
- Difference wind, in red (29 kts from 254º)
- RUC error codes (described at http://amdar.noaa.gov/ruc_acars/plan_view/reject.html)
- GSD aircraft ID (#5601)
- Flight origin and destination (CYQT to MSP)
- RUC T/T_d, in blue (-30.4ºC /–38.8ºC)
- TAMDAR T/T_d (-30.6ºC/-36.9ºC)
- Time and day of month (2103 UTC on 31Oct 2006.)

All of these tools are useful in evaluating the quality of TAMDAR and the rest of the AMDAR fleet. Moreover, users outside of GSD, such as AirDat, routinely and automatically download RUC-AMDAR comparison data from GSD as a complement to their own quality control work.



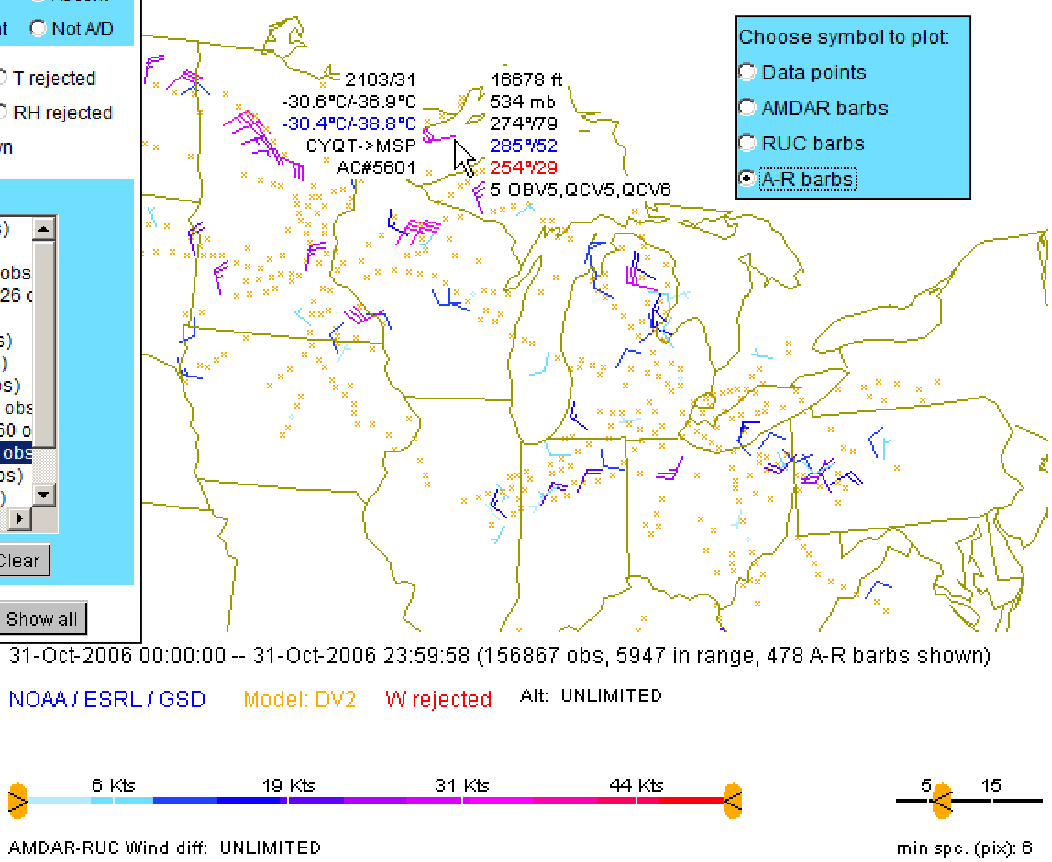


Figure 3. Plan view of AMDAR and RUC values from http://amdar.noaa.gov/ruc_acars/plan_view/, showing plan-view map and ‘select’ window. This plot shows vector difference between TAMDAR and dev2 winds.

3. ERROR CHARACTERISTICS OF THE TAMDAR/AMDAR FLEET

In this section we look at aircraft differences with respect to the dev2 cycle. We don't consider the RUC to be "truth"; rather we use it as a common benchmark with which to compare the error characteristics of various aircraft fleets.

In the results to be shown, we look at aircraft-RUC differences over what we shall call the "TAMDAR Great Lakes Region" (between 37ºN and 49ºN, 79ºW and 101ºW), which includes the upper Midwest region of the U.S., for "daylight" hours (12 UTC to 03 UTC) when TAMDAR-equipped aircraft generally fly. Moreover, data are stratified by phase of flight. Data taken during descent are shown in blue; data taken during ascent or en-route are shown in red. Most results are for 1-30 October 2006. All data points are the average of at least 100 observations; in most cases, especially lower in the atmosphere, each data point represents the average of more than 1000 observations.

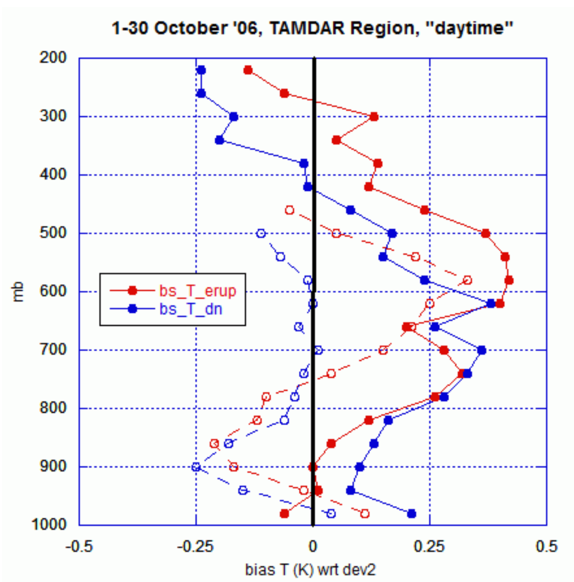


Figure 4. TAMDAR (open circles) and AMDAR (solid circles) temperature bias for Oct '06.

Fig 4. shows temperature bias relative to the dev2 1-h forecast for traditional AMDAR jets and TAMDAR turboprops. The jets show a small warm bias at most altitudes, and descents show a cool(er) bias than en-route/ascent data above 600 hPa. Below 800 hPa, descents show a slightly warmer bias than ascents for this time period.

TAMDAR show a slightly cooler bias than AMDAR at most levels.

In general, both AMDAR and TAMDAR temperature biases are small, being less than 0.25ºK in absolute magnitude.

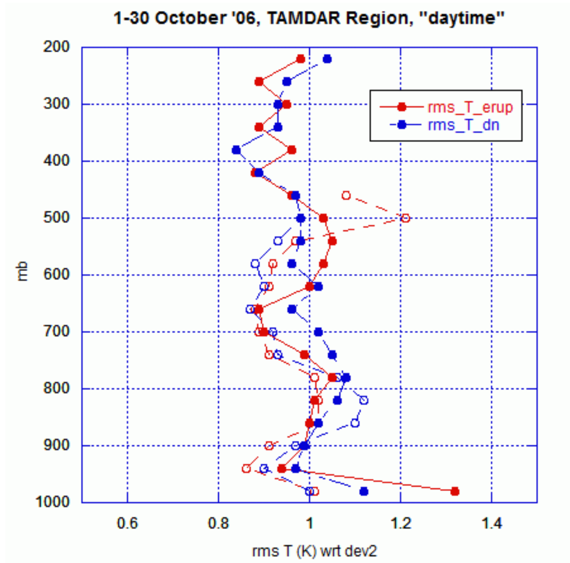


Figure 5. TAMDAR (open circles) and AMDAR (solid circles) temperature RMS for Oct '06.

Fig. 5 shows temperature RMS difference for TAMDAR and AMDAR. For both fleets, temperature RMS is small at most levels, with TAMDAR RMS being generally equivalent to that of AMDAR jets.

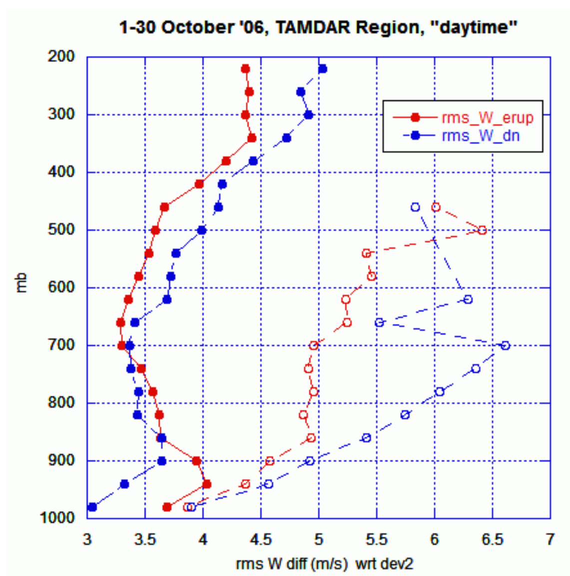


Fig 6. TAMDAR (open circles) and AMDAR (solid circles) vector wind difference RMS for October '06.

Figure 6 shows RMS of the vector wind difference between aircraft-measured winds and RUC 1-h forecast winds. In this case, TAMDAR departures from the RUC are considerably larger than those of AMDAR jets, and TAMDAR differences on descent are larger than those on ascent and en-route. This is not due to the TAMDAR sensor itself, but rather to the heading information provided to TAMDAR by the SAAB-340b avionics. The SAAB heading sensor is magnetic, and is known to be less accurate than the heading sensors commonly used on large jets.

Accurate heading information is needed to compute winds aloft from ground speed and air speed. The greater error on descent is due, we believe, to aircraft maneuvers, which occur more often on descent than on ascent.

TAMDAR descent wind errors above 700 hPa have improved in the last several months because, as of 8 March 2006, AirDat no longer reports winds measured while the aircraft is descending at altitudes above 10 000 ft, having determined that wind errors are largest under these conditions. Descent data above 700 hPa are therefore from level portions of the "descent" phase of flight.

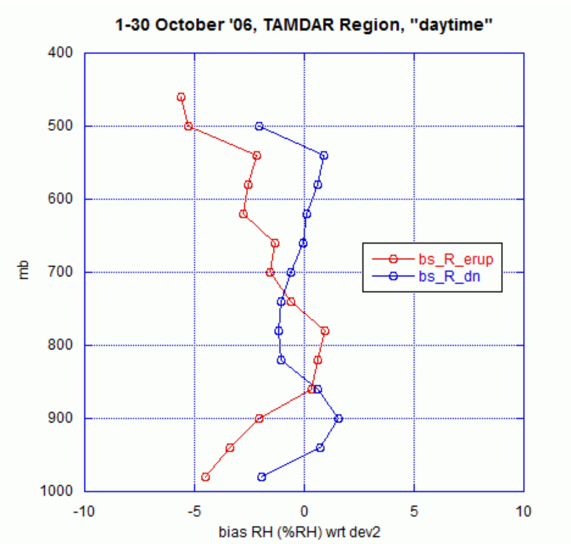


Figure 7. TAMDAR (open circles) relative humidity difference (observation minus dev2) for Oct '06.

Fig. 7 shows relative humidity bias relative to the dev2 for TAMDAR only, because most traditional AMDAR jets do not measure moisture. The humidity bias is generally below 5 %RH. This is a substantial improvement since January 2006, when RH biases for data taken during ascent were substantially higher. (In fact, the improvement in TAMDAR RH bias occurred by April 2006, and has remained good since that time.)

Fig. 8 shows relative humidity RMS difference for TAMDAR. The RMS difference is generally similar on ascent/en-route and descent, and increases from ~9 %RH near the surface to ~20%RH at 500 hPa. To put this statistic in perspective, the assumed RAOB RMS observational error used by the North American Mesoscale (NAM) model run operationally at the National Centers for Environmental Prediction (NCEP) in its assimilation cycle (Dennis Keyser, 2006, personal communication) is shown in black. This error varies from ~8 %RH near the surface to ~16% above 600 hPa. It is notable that assumed RH errors for RAOBS (often taken as a data standard) do not differ greatly from the RH errors shown by TAMDAR.

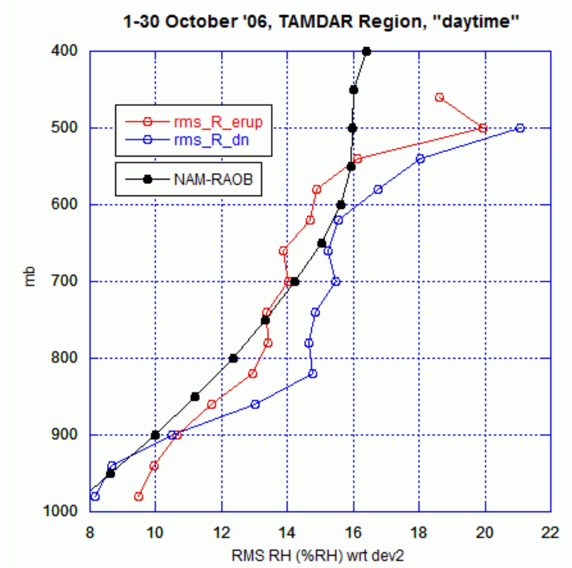


Figure 8. TAMDAR (open circles) relative humidity RMS for Oct '06. Solid black circles show the RAOB RH error assumed by the operational NAM model run at NCEP.

4. PLANS AND CONCLUSION

TAMDAR data availability to GSD and others after 15 November 2006 is uncertain at this time. If AirDat chooses to make their data available to GSD, we will continue these evaluations, particularly as TAMDAR coverage is expanded to additional fleets nationwide, although we may be unable to share TAMDAR data outside of GSD.

We will provide an update of this situation at the conference.

In any case, we will continue to refine our evaluation tools, make them available to others as appropriate, and use them to evaluate the error characteristics of AMDAR fleets.

Also, we plan to expand the number of models and the number of forecast projections (currently we only store 1-h forecasts) in the database. By doing this we can actually turn the evaluation process around and use (the best) AMDAR data as a standard against which to verify various RUC forecasts. This has the potential to provide verification where RAOB data are absent, such as between RAOB sites, and in upper-air high wind regions, where RAOBs are often blown out of receiver range.

Moreover, the techniques developed here are applicable to other *in-situ* data sources such as surface mesonetworks. As resources allow, we plan to expand our system to include data from these other sources along with the corresponding model values.

5. ACKNOWLEDGMENTS

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