ACARS Wind Measurements: An Intercomparison with Radiosonde, Cloud Motion and VAS Thermally Derived Winds

RAYMOND J. LORD, W. PAUL MENZEL¹ AND LORI E. PECHT²

Space Science and Engineering Center, University of Wisconsin, Madison, WI 53706

(Manuscript received 7 June 1983, in final form 22 March 1984)

ABSTRACT

Statistical comparisons between winds measured by ACARS and winds obtained from radiosondes, geostationary satellite image cloud motions, and VAS are presented. Observations from three separate comparisons reveal over 60% of wind vector magnitude differences are within 9 m s^{-1} , and 70% of the directional differences are within 15° . The comparisons indicate that the ACARS system provides an independent source of wind data that complements other sources of wind data for constructing composite wind field analyses.

1. Introduction

A study was conducted to explore the utility of meteorological data obtained from the ARINC (Aeronautical Radio, Inc.) Communications, Addressing and Reporting System (ACARS). Comparisons between ACARS and several other methods of determining wind values were made. One method of obtaining winds is to track the motion of clouds seen on time sequences of geostationary satellite images (Mosher, 1979). Another method involves the application of the gradient and thermal wind equations to geopotential fields derived from radiance measurements by the VISSR (Visible Infrared Spin Scan Radiometer) Atmospheric Sounder (VAS) (Montgomery, 1984). The third method included in this study is the conventional radiosonde balloon tracking.

All data processing was done on the Man-computer Interactive Data Access System (McIDAS) at the University of Wisconsin-Madison (Suomi *et al.*, 1983). Acquisition of ACARS data was from the National Meteorological Center (NMC) data base in Suitland.

2. ACARS description

ACARS provides meteorological reports from units installed aboard commercial aircraft. The units or MOATs (Meteorological Optional Auxiliary Terminal) are now operational on eleven American Airlines B-747's. Reports from these aircraft are sent to ground-based radio receiving stations from which they are transferred by telephone lines through ARINC to NMC.

Parameters measured by ACARS units include latitude, longitude, time, altitude, temperature, wind direction and wind speed. The wind measurements are obtained via the aircraft's Inertial Navigation System (INS) which measures aircraft acceleration, velocity, position and angles of altitude. Measurements taken by the aircraft pitot-static system and outside air temperature measurement systems are combined to determine a true airspeed vector. This vector is then fed to the INS computer where it is subtracted from the ground speed vector to obtain the wind velocity (Rhyne, 1980). This information is recorded every 7.5 min. Data originates from over the United States and the Caribbean, thus providing useful information for various forecasts and comparisons. ACARS is similar in many respects to the ASDAR (Aircraft to Satellite Data Relay) program (Sparkman and Giraytys, 1981). The major difference, however, is ASDAR data are transferred to earth via the GOES (Geostationary Operational Environmental Satellite) Data Collection System, while ACARS data transfer is directly to the ground.

3. Wind derivation techniques

a. Gradient-thermal winds

Gradient winds represent motion parallel to isobars subject to Coriolis and centripetal forces balanced against pressure gradient forces. The geopotential height fields derived from the VAS data are used to evaluate the gradient wind (Montgomery, 1984). In addition the vertical wind shear is calculated from the horizontal gradient of the geopotential thickness between two pressure levels. This is often referred to as the thermal wind. The combined gradient thermal wind (or VAS wind) is derived completely from the

¹ Present Affiliation: NOAA/NESDIS, Madison, WI 53706.

² Present Affiliation: Analytic Services, Inc., Arlington, VA 22210.

TABLE 1. Comparison of ACARS and radiosonde winds. Latitude and longitude are given in degrees and minutes (DDMM); direction as degrees from north.

Date of observation	Time (GMT)	Latitude (DDMM)	Longitude (DDMM)	ACARS pressure (mb)	Direction (deg)	Speed (m s ⁻¹)	Time (GMT)	Latitude (DDMM)	Longitude (DDMM)	RAOB pressure (mb)	Direction (deg)	Speed (m s ⁻¹)	Distance between RAOB and ACARS (km)
27 Aug 1982	1000	3826	8143	238	281	26	1200	3822	8233	238	268	25	72
27 Aug 1982	1008	3807	8250	238	270	23	1200	3822	8233	238	268	25	39
27 Aug 1982	1038	3629	8702	215	280	15	1200	3615	8634	215	285	18	49
27 Aug 1982	1225	3916	8956	208	257	38	1200	3839	8858	208	266	35	106
27 Aug 1982	1255	3654	9313	194	239	21	1200	3653	9354	194	231	13	60
7 Oct 1982	1050	3326	11723	218	285	19	1200	3249	11708	218	287	22	70
7 Oct 1982	1127	3407	11119	218	275	19	1200	3501	11044	218	262	22	111
7 Oct 1982	1157	3414	10603	218	233	20	1200	3503	10637	218	240	25	107
13 Oct 1982	1136	3909	7756	237	255	48	1200	3857	7727	237	259	46	44
13 Oct 1982	1214	3743	8243	237	247	56	1200	3822	8233	237	246	48	71
13 Oct 1982	1244	3628	8621	237	244	54	1200	3615	8634	237	237	56	34
13 Oct 1982	1323	3622	9358	195	233	42	1200	3653	9354	195	235	34	54
13 Oct 1982	1329	3445	9157	237	229	54	1200	3450	9215	237	236	48	33
14 Oct 1982	1012	3836	10804	195	066	29	1200	3907	10832	195	080	33	72
14 Oct 1982	1020	3202	10148	214	261	35	1200	3157	10211	214	257	30	35
14 Oct 1982	1032	3806	8248	237	261	60	1200	3822	8233	237	258	56	30
14 Oct 1982	1043	3225	9750	454	257	17	1200	3213	9811	454	257	21	41
14 Oct 1982	1102	3658	8633	237	257	54	1200	3615	8634	237	255	59	78
14 Oct 1982	1147	3458	9213	257	250	42	1200	3450	9215	257	250	41	16
15 Oct 1982	1001	4104	9025	261	309	29	1200	4040	8941	261	301	30	76
15 Oct 1982	1022	3801	8217	237	286	19	1200	3822	8233	237	279	22	50
15 Oct 1982	1045	3700	8619	237	276	7	1200	3615	8634	237	272	15	80
15 Oct 1982	1122	3504	9155	237	266	16	1200	3450	9215	237	256	21	39
15 Oct 1982	1333	4009	7503	431	269	48	1200	3927	7434	431	269	39	91
15 Oct 1982	1356	3957	7745	334	259	45	1200	3857	7727	334	275	33	111
Average 33.44													Average 32.68
Standard Deviation 15.76													Standard Deviation 13.33

TABLE 2. Comparison of ACARS and cloud-tracked winds. See Table 1.

Date of observation	Time (GMT)	Latitude (DDMM)	Longitude (DDMM)	ACAR			Time (GMT)	Latitude (DDMM)	Longitude (DDMM)	WINDCO			Distance between WINDCO and ACARS (km)
				Pressure (mb)	Direction (deg)	Speed (m s^{-1})				Pressure (mb)	Direction (deg)	Speed (m s^{-1})	
27 Aug 1982	902	3926	7944	217	278	33	1030-1100	3935	8011	243	264	29	37
27 Aug 1982	907	3902	8927	214	254	29	1000-1030	3853	8908	248	276	27	28
27 Aug 1982	914	3857	8800	214	252	25	1030-1100	3850	8834	257	277	27	48
27 Aug 1982	937	3936	8348	215	264	42	1000-1030	3937	8405	188	254	44	22
27 Aug 1982	952	3938	8042	215	278	37	1000-1030	3931	8047	234	262	29	23
27 Aug 1982	953	3843	8036	238	281	27	1000-1030	3831	8037	309	268	26	20
27 Aug 1982	959	3937	7913	214	282	32	1000-1030	4032	7958	221	269	38	106
27 Aug 1982	1000	3826	8143	238	281	26	1000-1030	3851	8153	206	262	27	43
27 Aug 1982	1008	3807	8250	238	270	23	1000-1030	3740	8140	232	267	19	111
27 Aug 1982	1015	3737	8349	238	282	22	1030-1100	3656	8335	172	283	23	77
27 Aug 1982	1023	3707	8449	238	294	18	1000-1030	3700	8401	172	282	22	69
27 Aug 1982	1053	3550	8910	237	323	10	1030-1100	3557	8928	244	315	15	39
27 Aug 1982	1100	3528	9019	237	325	12	1030-1100	3517	9031	296	320	10	28
7 Oct 1982	1228	4158	8319	262	238	49	1300-1330	4121	8310	231	244	41	66
7 Oct 1982	1235	4207	8148	237	240	51	1330-1400	4139	8223	238	238	43	72
7 Oct 1982	1250	4155	7845	237	271	29	1300-1330	4235	7836	296	276	23	78
7 Oct 1982	1258	4146	7716	237	282	32	1300-1330	4150	7649	257	278	17	42
7 Oct 1982	1305	4125	7554	294	266	15	1330-1400	4148	7625	252	281	18	58
7 Oct 1982	1356	4009	7733	299	269	18	1330-1400	3950	7736	290	271	14	31
7 Oct 1982	1411	4012	7957	239	264	33	1330-1400	3929	8021	289	248	22	85
7 Oct 1982	1418	4011	8106	240	259	38	1300-1330	3950	8103	278	251	25	37
7 Oct 1982	1433	4009	8322	240	238	39	1330-1400	4019	8309	269	234	38	29
7 Oct 1982	1441	4007	8430	239	244	45	1300-1330	4057	8442	260	235	46	91
												Average 27.09	
												Standard Deviation 10.19	

TABLE 3. Comparison of ACARS and VAS winds. See Table 1.

Date of observation	Time (GMT)	Latitude (DDMM)	Longitude (DDMM)	ACARS Pressure (mb)	Direction (deg)	Speed (m s ⁻¹)	Time (GMT)	Latitude (DDMM)	Longitude (DDMM)	VAS Pressure (mb)	Direction (deg)	Speed (m s ⁻¹)	Distance between VAS and ACARS (km)
13 Oct 1982	1251	3613	8718	237	242	54	1300	3635	8721	250	254	46	39
13 Oct 1982	1259	3556	8814	237	240	54	1300	3553	8826	250	256	44	17
13 Oct 1982	1306	3540	8909	237	235	53	1300	3531	8911	250	256	40	15
13 Oct 1982	1308	3737	9229	195	235	38	1300	3721	9149	200	249	49	68
13 Oct 1982	1314	3522	9004	237	232	51	1300	3517	8943	250	256	43	36
13 Oct 1982	1315	3659	9315	195	235	43	1300	3725	9320	200	249	50	45
13 Oct 1982	1321	3504	9101	237	231	53	1300	3520	9114	250	253	46	34
13 Oct 1982	1323	3622	9358	195	233	42	1300	3541	9337	200	250	52	85
13 Oct 1982	1329	3445	9157	237	229	54	1300	3449	9156	250	252	50	5
13 Oct 1982	1330	3541	9438	195	238	41	1300	3545	9507	200	251	50	46
13 Oct 1982	1336	3427	9254	237	232	53	1300	3437	9316	250	251	53	36
13 Oct 1982	1338	3457	9511	195	240	45	1300	3455	9542	200	252	56	47
13 Oct 1982	1344	3408	9350	237	233	52	1300	3353	9346	250	254	53	29
13 Oct 1982	1345	3413	9543	263	238	53	1300	3404	9605	250	253	64	37
13 Oct 1982	1359	3328	9551	433	243	36	1300	3259	9547	450	255	49	55
14 Oct 1982	1002	3908	7904	237	256	62	1200	3859	7845	250	267	51	33
14 Oct 1982	1004	3907	10646	195	074	29	1200	3937	10611	200	070	30	75
14 Oct 1982	1005	3143	10431	213	264	30	1200	3232	10421	200	275	32	94
14 Oct 1982	1009	3851	7959	237	255	63	1200	3832	7936	250	269	57	49
14 Oct 1982	1024	3822	8152	237	259	60	1200	3821	8144	250	262	48	9
14 Oct 1982	1028	3211	10028	214	264	31	1200	3222	10110	200	264	21	71
14 Oct 1982	1032	3806	8248	237	261	60	1200	3750	8254	250	267	45	31
14 Oct 1982	1039	3750	8345	237	261	59	1200	3730	8339	250	271	52	36
14 Oct 1982	1047	3733	8441	237	258	59	1200	3643	8416	250	271	52	102
14 Oct 1982	1054	3716	8551	238	260	59	1200	3645	8542	250	271	52	59
14 Oct 1982	1102	3659	8633	237	257	55	1200	3729	8636	250	270	46	54
14 Oct 1982	1109	3640	8729	237	255	55	1200	3648	8706	250	270	47	46
14 Oct 1982	1117	3622	8825	237	257	51	1200	3648	8834	250	270	44	51
14 Oct 1982	1124	3602	8922	237	254	49	1200	3602	8856	250	267	46	33
14 Oct 1982	1132	3541	9019	237	255	46	1200	3518	9013	250	262	48	44
14 Oct 1982	1139	3520	9117	237	253	44	1200	3521	9140	250	255	42	36
14 Oct 1982	1147	3459	9213	237	250	42	1200	3437	9211	250	255	43	43
14 Oct 1982	1154	3437	9310	237	248	40	1200	3422	9330	250	248	31	41
14 Oct 1982	1202	3414	9407	237	248	38	1200	3344	9408	250	250	28	55
14 Oct 1982	1209	3352	9501	294	257	32	1200	3426	9500	300	255	26	65
						Average 48.17							Average 45.31
						Standard Deviation 9.74							Standard Deviation 9.35

VAS determinations of geopotential thickness. These winds are determined from radiances emanating from a square area with 75 km on a side and thus represent an average wind, in contrast to the single point observations from the aircraft and radiosonde.

b. Radiosonde winds

The radiosonde winds are determined as functions of height by tracking the ascent curve of a balloon filled with buoyant gas. This conventional method of wind measurement is well documented in the literature (Reiter, 1967).

c. Cloud-tracked winds

Another method of establishing winds is to trace the motion of cloud elements viewed on time sequences of geostationary satellite images. This process is based on the assumption that the cloud elements follow the motion of the air in their vicinity. By tracking the movement of a cloud element through a sequence of navigated VISSR images, wind speed and direction are determined. These winds represent average motion over the satellite field of view size (1 km resolution for the visible images). Cloud heights are assigned by using the infrared data in conjunction with a nearby atmospheric sounding (Mosher, 1979).

4. Comparisons

Several comparisons were made between wind measurements obtained from ACARS data and those determined by the radiosonde, cloud tracking and VAS thermal wind calculations. Aircraft reports close in time, within 2 h, and horizontal distance, within 111 km, with respect to the radiosonde and satellite derived winds were found on several days. Radiosonde winds were interpolated from significant level data to correspond directly with the ACARS altitude; VAS derived winds within 20 mb of the ACARS altitude were accepted for comparison while cloud drift winds within 70 mb were included (the height assignment for the clouds is usually not known to better than 50 mb (Menzel *et al.*, 1983)).

The radiosonde comparisons from five different days are listed in Table 1. The agreement between the two methods of wind measurements is fairly good; in Table 4 radiosonde winds are offset by -0.76 m s^{-1} in the mean and have a relative root mean square deviation of 5.33 m s^{-1} with respect to ACARS winds. Wind directions compare typically within 8° . While some comparisons are made with measurements as much as 2 h apart, these are of upper level winds (around 250 mb) and are not expected to vary rapidly. These comparisons fall within the accuracy of upper level wind measurements by radiosondes; for 41 paired, simultaneous radiosonde flights for launch sites 16.25 km apart, Lenhard (1973) found

observed wind vector magnitude variability between 2 and 10 m s^{-1} within a height range of 5–10 km.

In order to find suitable comparisons of cloud tracked winds to ACARS winds, it was necessary to find an airplane flight path through trackable clouds. The aircraft flights near the jet and cirrus streaks were found to be most usable for the cloud track wind comparisons. The comparisons for two days are listed in Table 2. Again the results are fairly good; in Table 4 cloud tracked (denoted by WINDCO) less ACARS winds are offset by -2.70 m s^{-1} and have a relative root mean square deviation of 5.64 m s^{-1} . Wind directions compare typically within 12° . Cloud wind speeds were found to have rms differences of $6\text{--}10 \text{ m s}^{-1}$ during the First GARP Global Experiment when determined at the same location and time by different data producers (Mosher, 1981); thus the ACARS and cloud drift wind measurements intercompare within the accuracy of the cloud tracked wind measurements.

The comparisons with VAS derived gradient thermal winds were accomplished on two separate days, when the airplane flew through clear air at times when VAS sounding data were available. Table 3 shows these comparisons. The results in Table 4 show the VAS wind speeds to be offset by -2.86 m s^{-1} and to have a relative root mean square deviation of 7.83 m s^{-1} . Wind directions are within 8° . The VAS gradient-thermal wind calculation is based upon the assumption of steady state conditions in the atmosphere. Since a majority of ACARS observations are at relatively high altitudes (200 mb) with wind speeds approaching 50 m s^{-1} , obviously there is a departure from the gradient wind assumption. However, while the VAS/ACARS rms difference (7.83 s^{-1}), is greater than the RAOB/ACARS rms difference (5.33 m s^{-1}), it is clear that the VAS thermal winds at higher altitudes provide wind information that complements other observation methods. In addition, VAS winds are often available when and where other observations are not: cloud motion vectors are unavailable in clear areas; radiosondes are launched only at synoptic times at only selected sites; ACARS data is by definition only following a flight path.

Figure 1 shows the cumulative frequency of the

TABLE 4. Summary of ACARS comparisons.

Comparison	Magnitude		Direction	
	Average offset (m s^{-1})	Relative rms deviation (m s^{-1})	Average offset (deg)	Relative rms deviation (deg)
RAOB vs ACARS	-0.76	5.33	0.64	7.43
WINDCO vs ACARS	-2.70	5.64	-3.48	11.51
VAS vs ACARS	-2.86	7.83	11.37	7.12

FIG. 1. Cumulative frequency of wind vector magnitude differences for three separate ACARS comparisons.

vector magnitude differences for the comparisons discussed above; Fig. 2 shows the cumulative frequency of the vector direction differences. In Fig. 1, over 60% of all the comparisons have vector magnitude differences within 9 m s⁻¹. Over 70% of the radiosonde comparisons have differences within 5 m s⁻¹. In Fig. 2, the wind directions compare quite favorably with over 70% of all directional differences within 15°; 70% of the directions for the radiosonde comparisons are within 7°. The difference in observing techniques (spot versus average wind) and the atmospheric variability (due to unavoidable space-time differences in the observations) are responsible for some of the differences in these ACARS comparisons, so the true differences are somewhat less than reported

here. The different wind measuring methods have comparable accuracies and can be used to form composite wind field descriptions.

5. Conclusion

Comparisons presented here indicate that the ACARS data compares to other observing methods within the accuracy associated with those other observing methods. The ACARS system provides an independent data source that can complement other wind data for constructing wind field analyses.

The major difficulty of the ACARS system as it exists today lies in the poor availability of the data. Acquisition of the data for these comparisons was very cumbersome (by remote job entry interrogation

FIG. 2. Cumulative frequency of wind vector directional differences for three separate ACARS comparisons.

of the NESS/Suitland data base) and resulted in untimely data. Because of the apparent accuracy and usefulness of these data, we believe that they would be beneficial for improved weather analyses if they were made available to the general public in real time through the FAA (Federal Aviation Administration) wire service.

Acknowledgments. This research was supported by the National Aeronautics and Space Administration under Grant NAS5-21965. The authors benefitted from several discussions with Dr. William L. Smith, Director of the NOAA/NESDIS Development Laboratory. In addition, Dr. Christopher M. Hayden and Mr. Harold Woolf of NOAA/NESDIS Development Laboratory counselled on VAS system operations and assisted in ACARS software development. From the staff of the Space Science and Engineering Center, University of Wisconsin-Madison, Mr. Chris Velden analyzed the VAS retrievals and Mr. Dave Santek provided McIDAS programming support.

REFERENCES

- Lenhard, R. W., 1973: Variability of wind over a distance of 16.25 km. *J. Appl. Meteor.*, **12**, 1075-1078.
- Menzel, W. P., W. L. Smith and R. R. Stewart, 1983: Improved cloud motion wind vector and altitude assignment using VAS. *J. Climate Appl. Meteor.*, **22**, 377-384.
- Montgomery, H., 1984: VAS demonstration description, summary, and final report. NASA. Publication (in press).
- Mosher, F. R., 1979: Cloud drift winds from geostationary satellites. *Atmos. Tech.*, **10**, 53-60.
- , 1981: The compatibility of cloud tracked winds from the United States, European, and Japanese geostationary satellites. *Adv. Space Res.*, COSPAR, **1**, 139-146.
- Reiter, E. R., 1967: *Jet Streams*. Doubleday, 189 pp.
- Rhine, R. H., 1980: Accuracy of aircraft velocities obtained from inertial navigation systems for application to airborne wind measurements. *NASA Tech. Memo.*, 81826, 15 pp.
- Sparkman, J. K., and J. Giraytys, 1981: ASDAR: A FGGE real-time data collection system. *Bull. Amer. Meteor. Soc.*, **62**, 394-400.
- Suomi, V. E., R. Fox, S. S. Limaye, and W. L. Smith, 1983: McIDAS III: A modern interactive data access and analysis system. *J. Climate Appl. Meteor.*, **22**, 766-778.