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FIELD FORECASTER EVALUATION OF ACARS DATA- RESULTS OF THE NAOS ACARS ASSESSMENT

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1.0 INTRODUCTION

Meteorologists from twenty forecast centers of the National Weather Service (NWS), Meteorological Service of Canada, and United Airlines participated in an assessment of ACARS data from the fall of 1997 through the spring of 1999. The assessment was part of the North American Atmospheric Observing System (NAOS) program. NAOS is a joint effort of the meteorological services of Mexico, Canada and the United States, whose purpose is to define the best combination of observing systems and strategies to cost-effectively meet the requirements of meteorological observations over North America and the adjacent oceans. For a more detailed discussion of NAOS, see Decker, et al. 1999.

The meteorologists were asked to use ACARS sounding and en-route data, and to report on the utility of the data in forecasting different weather phenomena. ACARS data were supplied by several commercial air carriers (United, American, United Parcel Service, Northwest, Federal Express, and Delta) and was accessed in the forecast offices via an internet page hosted by the Forecast Systems Laboratory (FSL). They completed surveys at the completion of the assessment, and were asked to comment of the availability, use and accuracy of the data, and whether ACARS data could replace radiosonde soundings in certain locations.

2.0 DESIGN OF THE ASSESSMENT

The offices that were asked to participate in the assessment were chosen based on a number of factors, including climate, geography, forecaster resources, and availability of nearby ACARS data. The majority of the participants are in the United States, as ACARS data were not as abundant in Canada. The offices in the assessment include:

-United Airlines Meteorology office
-Meteorological Service of Canada Forecast offices in Kelowna and Vancouver, British Columbia
-NWS Forecast offices in Seattle, Los Angeles, Denver, New Orleans, Fort Worth, Chicago, Louisville, Columbia, Miami, New York, and Portland, Maine.
-NWS Center Weather Service Units in Chicago, Fort Worth, Seattle, and Houston.
-NWS Aviation Weather Center and Storm Prediction Center

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Two meteorologists from the NWS Office of Meteorology Upper Air program office, and a meteorologist from the NWS office in Chicago visited the participating offices and made short presentations describing the assessment, and offered examples of how the data might be used. The offices were asked to submit quarterly summaries and examples of how their staff used ACARS data, and their impressions on it's reliability, utility, and quality.

3.0 RESULTS

3.1 Forecast applications The Forecast Systems Laboratory compiled usage statistics which showed that the twenty participating offices accessed the ACARS site over 30,000 times during the assessment period. The assessment participants reported ACARS data to be extremely useful in areas where the data are plentiful, such as near medium and large cities, but less so in places where data are infrequent. The data were used in forecasting many different phenomena, including winter storms, convective systems, fire weather, and marine and aviation hazards. There were several instances where meteorologists were able to correctly forecast an event that would have been difficult, or impossible to forecast otherwise.

Forecaster acceptance and use of ACARS data varied greatly among the assessment participants. ACARS data is routinely used by United Airlines, the Center Weather Service Units (CWSUs), and the Chicago, Seattle, Los Angeles, San Diego, and Denver NWS offices, while it is accessed rather infrequently at others. There are many possible explanations for this disparity, some meteorological and some not. For example the Los Angeles area has frequent ACARS soundings, has many mesoscale weather features (marine stratus and fog, mountain gap winds, etc.) that require frequent soundings of the atmosphere, and is in a region with little upstream data.

This is the likely reason that forecasters there have found it so useful. The Columbia office has found lesser use of ACARS chiefly because of it's limited availability on certain days of the week (when the air freight company supplying ACARS has few flights). Despite this, they have put the limited amount of data to good use. The participating offices who utilize ACARS data most frequently seem to be those that: have data available at most times of the day, are near large bodies of water, and have mesoscale phenomena that ACARS data are

very useful in forecasting.

The ingenuity of meteorologists at the assessment offices has resulted in many applications of ACARS data. It is used for rather simple (but important) tasks such as updating wind and temperature forecasts at most offices, but sometimes finds more exotic uses such as: finding lighter headwinds for an Italian airliner low on fuel over the Caribbean, providing wind and temperature data to avalanche rescuers on Mount Rainier, and providing forecasts for helicopter flights to oil rigs in the Gulf of Mexico. Many applications of ACARS data to summer and winter forecast challenges were also refined or discovered.

The Miami NWS office now issues a waterspout forecast in the hazardous weather outlook, thanks largely to ACARS soundings. The Chicago NWS uses ACARS data to initialize a model to forecast the lake breeze on Lake Michigan (Labas, Arritt, and Anderson, 1999), and to forecast lake effect snow. The CWSUs at Miami, Chicago, Seattle, Fort Worth and New York can now give more accurate briefings of jet stream location and possible areas of icing and turbulence to controllers and flight dispatchers in the early morning hours before the 12UTC radiosonde data are available.

Many more applications of ACARS data were reported, including:

- Using ACARS data to issue High Wind Warnings
- Including low level wind shear (LLWS) in aviation forecasts.
- Precipitation type forecasts of winter storms
- Forecasting downslope wind events in the lee of the Rockies
- Verification of model forecasts
- Forecasting convection initiation
- Comparisons with other data sets

The forecasters completed surveys to determine how frequently ACARS data were used, for what purpose, and what it's advantages and disadvantages over other data sources are. State and Area Forecast discussions were also collected to gauge how ACARS data were being used. FSL also has usage statistics of the web page that supplied ACARS data to the participants. Their data support that idea that ACARS use is increasing not only among the offices in the assessment, but in other offices as well.

3.2 Application to Specific Program Areas

3.2.1 Aviation Weather

ACARS data are especially useful to aviation weather forecasters because the data are collected from aircraft flying through the area of interest. For example, the frequent ACARS data available at a large hub airport give the aviation forecaster a real-time assessment of the atmosphere in the vicinity of the airport, which allows the production of more accurate aviation forecasts (including Terminal Aerodrome Forecasts (TAFs), and Transcribed Weather Broadcasts (TWEB) route forecasts).

Meteorologists at the assessment offices found the data extremely valuable in forecasting ceiling heights and the dissipation of fog by being able to monitor the strength of low-level inversions. Martin (1999) showed how ACARS and the 10km ETA model was used to improve forecasts of coastal stratus and fog that affect the airports in southern California. The data are also very useful in revealing areas of low level wind shear, especially during the nighttime hours between the 00utc and 12utc radiosonde flights. Many offices were able to include the mention of LLWS in their TAF because of the availability of ACARS data. The data are also helpful in monitoring and forecasting wind shear and turbulence in the mid and upper levels of the atmosphere. The CWSU participants regularly use ACARS data to locate jet streams and jet streaks, and to use the information to brief FAA personnel about areas of turbulence.

---------- *Low-level wind shear* ----------

The NWS office at Chicago used ACARS data on June 25, 1998 to forecast LLWS in the TAFs for Rockford, Midway, O'Hare, and Du Page airports in northern Illinois. The TAFs issued at 0533 UTC for the airports had no mention of LLWS. The TAF valid at 06UTC for O'Hare was as follows:

TAF
KORD 250533Z 250606 18010KT P6SM SKC
FM1300 22013G23KT P6SM SCT300
FM1900 23015G25KT P6SM SCT050 BKN250
FM0100 21012KT P6SM SCT060 PROB30
0106 5SM TSRA OVC035CB=

ACARS soundings from O'Hare and Rockford between 0600 UTC and 0700 UTC, showed winds of only 13 knots (7 ms $^{-1}$)at 790' MSL (240m), but winds of nearly 50 knots (26 ms $^{-1}$) at 2150' MSL (777m). The TAFs for all four airports were updated at 0659 UTC to include mention of LLWS. The updated TAF for O'Hare:

TAF AMD
KORD 250659Z 250706 18010KT P6SM SKC
WS020/21045KT
FM1300 22013G23KT P6SM SCT300

FM1900 23015G25KT P6SM SCT050 BKN250
FM0100 21012KT P6SM SCT060 PROB30
0106 5SM TSRA OVC035CB=

The data were especially valuable because the Chicago WSR-88D VAD Wind Profile showed little or no wind information near the ground due to the lack of sufficient scatterers. Without the availability of ACARS data, the TAFs would probably not have been updated until the 1200 UTC radiosonde winds became available, or a report of LLWS was received.

---------- *Turbulence forecasting* ----------

The CWSU at Seattle found the data especially useful on January 17, 1998 as a strong polar jet stream was lifting slowly north across the Pacific Northwest. A Boeing 737

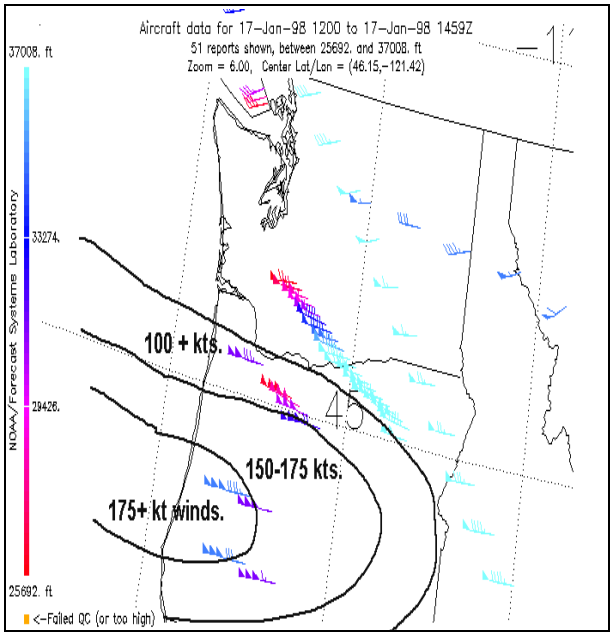

Figure 1. ACARS wind data between 25,692' and 37008' MSL for the period 1200 UTC to 1459 UTC January 17, 1998

reported moderate to severe turbulence while descending into Seattle that morning. Meteorologists at the CWSU were unable to exactly correlate the turbulence reports to upper air features as the radiosonde flights in the northwestern United States ended below the strongest part of the jet stream (the very strong winds carry the radiosonde sufficiently far away from the ground station and the radio signal is lost). ACARS data from the area (fig. 1) showed a 100 to 180 knot (51 to 93 ms $^{-1}$) jet over much of Oregon, explaining the turbulence reported north of the jet stream. An aircraft near the jet stream reported winds increasing by 51 knots (26 ms $^{-1}$) between 22,700' and 24,400' (6918m to 7437m) above Mean Sea Level (MSL) and 71 knots (37 ms $^{-1}$)between 21,500' and 24,920' (6553m and 7595m) above MSL. The fact that the jet stream was moving slowly north allowed them to advise FAA personnel about the location and severity of possible turbulence through the day.

---------- *ACARS used to help Air Traffic Control in Dallas-Fort Worth and Chicago*----------

The CWSU in Fort Worth utilizes ACARS to assist the FAA in "metering" aircraft into the Dallas-Fort Worth airport. When aircraft descend into the DFW area from the west when a strong west to east oriented jet stream is overhead, the aircraft ground speed is severely reduced. This causes aircraft to "bunch-up" resulting in reduced aircraft separation.

In order to maintain safe intervals between aircraft, ground stops or air delays are sometimes employed. The availability of ACARS wind data near the airport allows the CWSU meteorologists to give FAA personnel very accurate guidance concerning the amount of aircraft compression that is expected. The CWSU in Chicago uses ACARS data each day to help locate areas of icing and turbulence, and to brief controllers on the strength and location of the jetstream. The briefing occurs a couple of hours before the 1200 UTC radiosonde data are available, so ACARS wind data is the chief component of the briefing.

------- *ACARS helpful in data-sparse regions* ---------

The Miami CWSU finds ACARS wind information extremely useful in data sparse areas such as the Bahamas. At 12:00 noon on February 6, 1998 the ATC supervisor for the oceanic route over the Bahamas notified the CWSU that an Italian airliner had encountered sustained, strong headwinds over the Atlantic that were not taken into account when the plane was fueled in Italy. They were concerned that they might run out of fuel, so they requested that the CWSU advise them where a lighter headwind could be expected. Fortunately, the ACARS web page showed a flight track over the Bahamas less than one hour old with headwinds 40 knots (21 ms $^{-1}$) less than the winds that the Italian airliner was reporting. Controllers immediately assigned the airliner to that

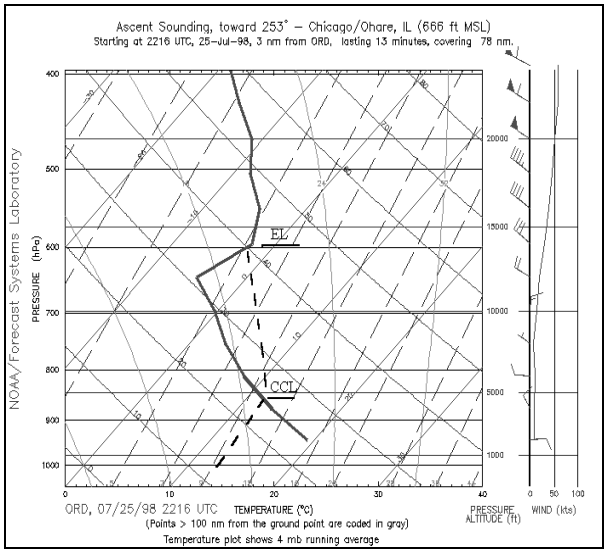

Figure 3. ACARS sounding from 2216 UTC near Chicago's O'Hare International airport on July 25, 1998.

altitude and flight path and the aircraft was able to complete the flight without incident. Figure 2 shows wind reports from three aircraft over the Bahamas for 1500-1659UTC.

3.2.2 Convective Weather

------ *Thunderstorms at O'Hare?* -----

The meteorologists at the United Airlines weather office used ACARS data during the late afternoon and evening of July 25, 1998 to determine if thunderstorms were likely near O'Hare International Airport. Thunderstorms in the vicinity of the airport often cause lengthy delays and sometimes cancellations, so it is very important for the meteorologists to forecast their occurrence so that dispatchers can decide whether adjustments to the flight schedule are warranted. Scattered thunderstorms began to develop over southern Wisconsin and southern Lower Michigan during the late afternoon, and the forecasters were concerned that they might form in the vicinity of O'Hare during the high-traffic period during the later afternoon and early evening. To determine the possibility of thunderstorms in the vicinity of O'Hare, they obtained ACARS soundings between 2100 and 2300 UTC. Figure 3 shows a sounding from 2216 UTC that with a surface dew point of 13C, suggests a convective condensation level (CCL) about 850mb (hPa), and an equilibrium level around 600mb (hPA). The soundings showed that while the atmosphere was conducive to convective clouds, there was a significant inversion in the mid levels that would hinder vertical development. Therefore, cloud tops were expected to be less than 20,000' (6096m) MSL and warm enough such that ice processes in the cloud tops would be insufficient to produce thunder and lightning. The sounding supported the formation of showers, however, which did occur in the area. The meteorologist was pleased that he could assure flight dispatchers that thunderstorms were very unlikely in the area. Without the availability of the ACARS data it would have been more difficult or impossible to monitor and forecast this event.

The fact that the upper air network is synoptic scale, and areas of convection are generally mesoscale or smaller, makes ACARS data quite useful in forecasting convection. If ACARS data are plentiful (such as in Chicago, Dallas, Denver, etc.) meteorologists can usually monitor atmospheric stability and wind shear on an hourly basis. ACARS can show the strengthening or weakening of a mid-level capping inversion, a wind field that is becoming more or less favorable for rotating thunderstorms, and mid-level temperatures that can be used to deduce hail potential. Prior to the beginning of the assessment period, meteorologists at the NWS office in Chicago used ACARS soundings to forecast a severe

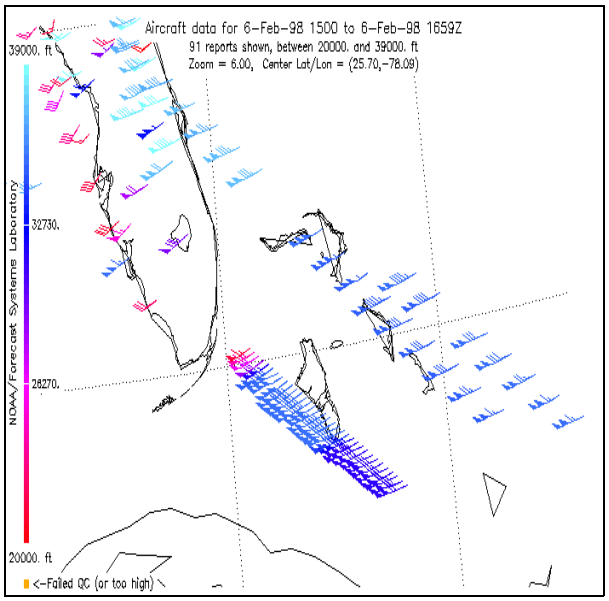

Figure 2. ACARS wind data between 22,000' and 39,000' MSL for the time period 1500 UTC to 1659 UTC.

weather event in northern Illinois. Details of the event are found in Mamrosh (1998).

____ Front range thunderstorms_____

The Denver NWS uses ACARS to monitor the mid level capping inversions that often form downwind of the front range of the Rockies. A good example of this was on May 27, 1998 when low level outflow boundaries east of Denver were producing areas of convergence. The forecaster thought convection was unlikely near the front range because dewpoints were very low. Better surface moisture was available further east, but a strong mid level cap evident on afternoon ACARS soundings also argued against convective development. Thus, the forecaster decided to keep dry weather in the nighttime forecast. This was noted in the State Forecast Discussion.

----- Storm Prediction Center uses ACARS ---------

The Storm Prediction Center mentioned ACARS data in a Mesoscale Convective Discussion on July 31, 1998 concerning heavy convective rainfall and possible flooding along the Idaho, Washington and Oregon border. Fig. 4 shows an excerpt from the discussion..

3.2.3 Winter Weather

Knowledge of the atmospheric temperature structure is crucial to an accurate forecast of precipitation type in a winter storm. The spatial and temporal resolution of the current radiosonde network often do not provide adequate information to make a confident prediction of precipitation type with many winter storms, and forecast "surprises" are fairly common. ACARS data, if available, can be extremely valuable in such situations, as it often supplies timely information of the temperature structure ahead of a winter storm. This is especially true at places far from radiosonde sites.

----- Christmas Eve Snow at O'Hare ----------

Forecasters at the United Airlines Meteorology office found ACARS to be useful for a moderate snowfall on Christmas Eve (December 24th) of 1997. An approaching upper level trough promised to bring precipitation to the Chicago area during the afternoon and evening hours. The 12/24/97 0000 UTC numerical models (AVN,NGM,ETA) and recent mild weather suggested that rain would be the most likely precipitation type with this system.

The NGM MOS guidance issued at 0340 UTC for ORD (below) shows that the precipitation type (PTYpE) is forecasted as rain from 1500 UTC on the 24th until 0300 UTC on the 25th. The snow amount (SNOW) only predicted a trace through 1200 UTC on Christmas Day

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ORD  EC   NGM MOS GUIDANCE    12/24/97 0000 UTC
DAY /DEC 24                /DEC 25

HOUR   06 09 12 15 18 21 00 03 06 09 12

MX/MN                    38          29
TEMP   32 32 32 34 35 35 36 35 33 33 31
DEWPT  28 29 29 30 33 34 35 34 32 30 28
CLDS   OV OV OV OV OV OV OV OV OV OV OV
WDIR   07 07 09 08 09 07 05 02 32 31 30
WSPD   05 07 09 15 20 13 13 12 10 11 11
POP06        0     45     94     62     25
POP12                    79            59
QPF        0/     2/     3/4    1/     0/1
TSV06     0/ 4   7/ 2   12/ 0   6/ 0   0/ 0
TSV12           3/ 4          14/ 0
PTYPE   S  Z  Z  R  R  R  R  S  R  S  S
POZP   27 33 32 15 17  0  5 11 14 13 12
POSN   36 31 33 27 28 22 11 40 37 47 51
SNOW       0/     0/     0/1    0/     0/1
CIG     4  4  4  4  4  3  3  2  3  3  4
VIS     4  4  4  3  3  3  3  3  3  3  4
OBVIS   F  F  F  H  H  F  F  F  F  F  F
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The meteorologist looked at several ACARS soundings between 04UTC and 09UTC before the 09UTC forecast issuance. From the soundings at 0406 and 0645 UTC (Figs. 5 and 6), he could see that there was considerable low level sub-freezing air, and that the depth of the mid level air above freezing was diminishing. In addition, the low level flow had an easterly component, which would serve to bring dry air from the anticyclone to east, and produce evaporative cooling.

The precipitation started at 1937UTC as freezing rain and changed quickly to snow. The snow continued, heavy at times, through the afternoon and early evening, before ending as drizzle during the late evening. About 2.5 inches (6.5 cm) of snow was recorded. This was an especially useful forecast as even modest snowfalls as this has significant impact on a busy airport such as O'Hare - especially the day before Christmas!

SPC MESOSCALE DISCUSSION #0836 FOR EXTREME SOUTHEAST WASHINGTON...EXTREME NORTHEAST OREGON AND CENTRAL IDAHO PANHANDLE...CONCERNING HEAVY RAINFALL.

THUNDERSTORMS WILL LIKELY PRODUCE RAINFALL RATES OF UP TO TWO INCHES PER HOUR THROUGH 01/00Z. THE MOST INTENSE RAINS ARE EXPECTED IN A 50 MILE WIDE CORRIDOR FROM JUST NORTHWEST OF KONO-KMLP. VISIBLE SATELLITE PICTURES DEPICT SCATTERED THUNDERSTORMS DEVELOPING RAPIDLY IN AN AREA WHERE SKIES HAVE BEEN GENERALLY CLEAR THIS AFTERNOON. **18Z ACARS DATA SHOWS THAT THE 500MB TEMPERATURES HAVE COOLED ABOUT 3 DEGREES SINCE 12Z...LEADING TO STEEP LAPSE RATES.**

Figure 4. Mesoscale discussion issued by the SPC on July 31, 1998

------- *Freezing Rain in New England* ----------

The Storm Prediction Center used ACARS data for a freezing rain event across eastern New York and southern New England on December 8, 1998. Their discussion issued in the early afternoon used ACARS soundings from the vicinity of Boston. These were especially useful due to the fact that the event occurred between the availability of 1200 UTC and 0000 UTC radiosonde data. The following is an excerpt from the discussion:

SPC MESOSCALE DISCUSSION #1100 FOR FREEZING RAIN...

AREAS OF FREEZING RAIN ARE LIKELY ACROSS PARTS OF EAST CENTRAL NEW YORK...SRN NH AND SRN VT. FREEZING RAIN IS EXPECTED TO ACCUMULATE ON EXPOSED SURFACES THROUGH 08/23Z.

LATEST SATELLITE PICTURES INDICATE CLOUD TOPS HAVE COOLED OVER ERN NY...SRN NH...AND SRN VT IN THE PAST HOUR. **ACARS SOUNDINGS FROM BOS SHOW 850MB TEMPERATURE OF 4C WHILE SURFACE TEMPERATURES REMAIN NEAR FREEZING...**

3.2.4 Wind Forecasts

Forecasters at the NWS in Denver use ACARS and wind profiler information frequently when attempting to forecast the sometimes dangerous downslope wind events along the foothills of the Rockies. ACARS soundings from the Denver and Colorado Springs vicinity are used to determine the presence and strength of mountain top temperature inversions that are often associated with these events. When mid level winds are perpendicular to the front range of the Rockies, and a temperature inversion is present, wind gusts of over 100 knots (51 ms $^{-1)}$ are sometimes reported at the surface. The forecast office used ACARS data November 21, 1998 in deciding to issue a High Wind Warning. An ACARS sounding from 1401 UTC showed a strong mountain top inversion and 50 knot winds around 600mb. The event produced wind gusts of up to 106 mph in the mountains and 70 to 80 mph along the foothills. Later soundings were useful in showing that the inversion had weakened during the afternoon, and the High Wind Warning was discontinued.

The Meteorological Service of Canada office finds ACARS wind and temperature data to be valuable for the Vancouver metropolitan area, as it is quite distant from radiosonde sites in Quillayute, Washington and Kelowna, British Columbia. The presence of the Pacific Ocean and the Rocky Mountains often produces winds at Quillayute and Kelowna that are significantly different from Vancouver. ACARS data on November 24, 1998 was used to determine that the wind fields available from the Quillayute radiosonde were not compatible with reports of strong low level winds and moderate turbulence reported in the Vancouver area. ACARS data are now used for the production of wind forecasts for the Vancouver area whenever available.

3.2.5 Miscellaneous Applications

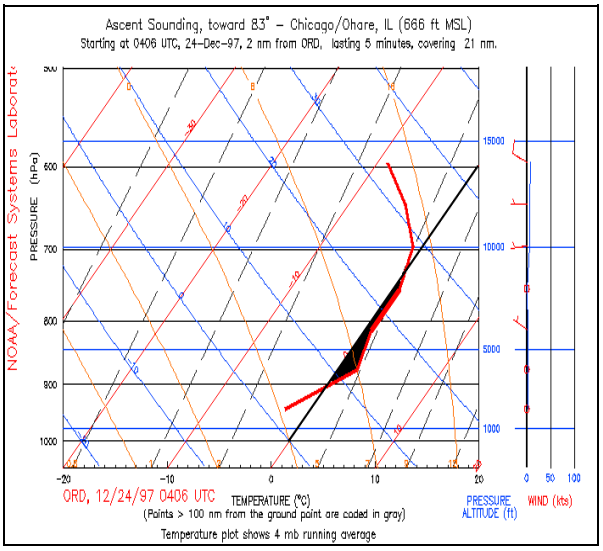

Figure 5. ACARS sounding from 0406 UTC shows above-freezing layer between 900 and 700mb on December 24, 1997.

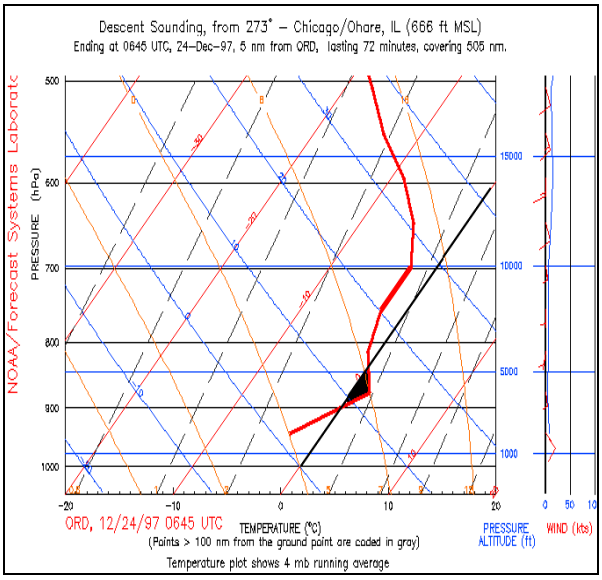

Figure 6. ACARS sounding from 0645 UTC on December 24, 1997 in the O'Hare vicinity shows that the above freezing layer had diminished since 0406 UTC..

------- *Comparison with other Data Sources* ----------

ACARS data have been used to verify wind data from the WSR-88D VAD Wind Profiles, and to a lesser extent, the Wind Profiler Network in the spring and fall when migrating birds often cause erroneous wind profiles. The migrating birds fly during the overnight hours, at altitudes to 10,000 feet, and are excellent reflectors to most meteorological radars and profilers. When migrating they produce an erroneous 10-20 knot meridional component to the real wind. This can seem to "strengthen" a wind when the birds are flying with the wind, or "reduce" the actual wind if the birds are flying into it. The birds will fly almost every night, barring precipitation or strong headwinds.

The New York NWS office used ACARS data to determine that WSR88D VWP winds from New York and Boston were both erroneous during the early morning hours of May 28, 1998. The VWP indicated southwest winds of 20 to 30 knots at 2000 and 3000 feet above the ground. ACARS data from New York and Providence showed that winds were from northeast at 5 to 10 mph!

------- *Comparison with Model Data* ----------

The NWS office in Seattle is collaborating in a project with the University of Washington to compare ACARS and other real-time data to the wind and temperature analyses of the numerical models, especially in the data sparse areas over the eastern Pacific.

3.3 Survey Results

The forecasters were asked to complete surveys one year after the assessment period ended to determine if they continued to use the data. The survey included questions regarding data availability, data utility, and resolution of the data. They were also asked to comment on the quality of the FSL ACARS web page, and to respond to a hypothetical question asking whether ACARS data could replace radiosonde soundings in certain locations.

Of the ninety-four surveys that were returned, approximately 75% stated that they still used ACARS data a year after the assessment ended. About two-thirds of the forecasters that used the data said it helped the make better forecasts. One third of the forecasters said that ACARS data contributed to greater accuracy of their forecasts and warnings on *over half of the shifts they work*.

When asked which forecast elements the data were most useful for, the respondents ranked them in the following order: low level winds and temperatures, cloud cover and ceilings, severe weather, upper level winds, maximum and minimum temperatures, and precipitation type. When asked which data sources contributed most to forecast accuracy, they ranked them in this order: satellite, radar, surface observations, radiosondes, ACARS, profiler, lightning, and other data.

The forecast offices were nearly unanimous in stating that the ascent-descent data (soundings) were the most useful ACARS displays, while the CWSUs and AWC found the upper level wind plots much more useful than the soundings.

Despite the considerable use of ACARS data by the assessment participants, and the many examples of forecast improvements made possible by ACARS, the meteorologists did not want to see ACARS data replace radiosondes at the present time. Many forecasters made comments that the present radiosonde network was the only data collection system that hasn't been altered significantly in recent years. Some had an almost nostalgic attachment to it, and said they would be reluctant to see it change. Though they want the present day radiosonde system to remain intact, they overwhelmingly supported the use and increased availability of ACARS data as a supplemental data source.

Acknowledgments

The authors would like to thank the airlines for allowing access to their data, Bill Moninger of the FSL for designing and maintaining the web page, the assessment participants, and Scott Stephens of the National Climatic Data Center for providing historical data.

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