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Complete Decoding and Reporting of Aviation Routine Weather Reports (METARs)

Max Lui
Intrinsyx Technologies Corporation
Ames Research Center, Moffett Field, California

October 2014

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Intrinsyx Technologies Corporation
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National Aeronautics and
Space Administration

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Moffett Field, CA 94035-1000

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Summary

Aviation Routine Weather Reports (METARs) provide surface weather information at and around observation stations, including airport terminals. These weather observations are used by pilots for flight planning and by air traffic service providers for managing departure and arrival flights. METARs are also an important source of weather data for Air Traffic Management (ATM) analysts and researchers at NASA and elsewhere. These researchers use METAR to correlate severe weather events with local or national air traffic actions that restrict air traffic, as one example. A METAR is made up of multiple groups of coded text, each with a specific standard coding format. These groups of coded text are located in two sections of a report: Body and Remarks. The coded text groups in a U.S. METAR are intended to follow the coding standards set by the National Oceanic and Atmospheric Administration (NOAA). However, manual data entry and edits made by a human report observer may result in coded text elements that do not follow the standards, especially in the Remarks section. And contrary to the standards, some significant weather observations are noted only in the Remarks section and not in the Body section of the reports. While human readers can infer the intended meaning of nonstandard coding of weather conditions, doing so with a computer program is far more challenging. However such programmatic preprocessing is necessary to enable efficient and faster database query when researchers need to perform any significant historical weather analysis. Therefore, to support such analysis, a computer algorithm was developed to identify groups of coded text anywhere in a report and to perform subsequent decoding in software. The algorithm considers common deviations from the standards and data entry mistakes made by observers.

The implemented software code was tested to decode 12 million reports that had been collected from 267 airports over 1,575 days. The decoding process was completed in about 20 minutes, which translates to a sustained rate of about 10,000 reports per second. Of the 12 million reports, the decoding process was able to completely interpret 99.93 percent of the reports. The remaining reports (0.07 percent) were partially interpreted and any un-decodable texts within each report were identified.

This document presents the deviations from the standards and the decoding algorithm. Storing all decoded data in a database allows users to quickly query a large amount of data and to perform data mining on the data. Users can specify complex query criteria not only on date or airport but also on weather condition. This document also describes the design of a database schema for storing the decoded data, and a Data Warehouse web application that allows users to perform reporting and analysis on the decoded data. Finally, this document presents a case study correlating dust storms reported in METARs from the Phoenix Sky Harbor International Airport with Ground Stops issued by the Air Traffic Control System Command Center (ATCSCC). Blowing widespread dust is one of the weather conditions when dust storm occurs. By querying the database, 294 METARs were found to report blowing widespread dust at the Phoenix airport and 41 percent of them reported such condition only in the Remarks section of the reports. When METAR is a data source for an ATM research, it is important to include weather conditions not only from the Body section but also from the Remarks section of METARs.

1 Introduction

Aviation Routine Weather Reports (METARs) contain surface weather information collected from a weather observation station. These reports are vital to pilots during flight planning, as well as to air traffic service providers who must determine the capacity of airspace or an airport in the presence of various weather phenomena. The reports are also of use to analysts seeking to study weather impacts on Air Traffic Management (ATM) decision making. Therefore they represent a valuable source of data to be mined if they can be interpreted by software.

A METAR reporting station can be either automated or manual. In general, a report is scheduled to be disseminated on an hourly basis. When there is a significant weather change, an unscheduled Aviation Selected Special Weather Report (SPECI) is disseminated. Each report has two sections: Body and Remarks. The text in the report follows standard coding formats as documented in the Federal Meteorological Handbook No. 1 (FMH1) [1] by NOAA. Contractions are also used throughout a METAR. In the Body section of a report, there are 11 basic measurements and present weather observations. Fifty-eight types of possible coded remarks such as detailed observations may be appended to a METAR. A blank space is used as the delimiter between each group of coded text. Each group of coded text may include free-form text that may also include blank spaces. The lack of using a distinct character to separate groups of coded text, and the deviations from the coding standards in each group, pose significant challenges to a software-based METAR decoding. Focusing on decoding the coded text only in the Body section risks the chance of missing important observations reported in the Remarks section. Thus, decoding all the coded text in a METAR is essential to getting a full picture of all the conditions at an observation station.

This document describes the results of analyzing deviations from standard coding formats identified in 12 million METARs collected from 267 airports over 1,575 days. From these 12 million reports, all significant deviations were identified and categorized. These deviations are also described here because they are critical to understanding reports that don't follow the standard coding formats. Of the 12 million reports, 99.93 percent of them can be completely interpreted after the deviations were taken into account. The remaining reports were partially interpreted and any un-decodable texts within each report were identified for future analysis.

This document presents an algorithm for identifying and decoding all groups within a METAR so that all of the report content may be used. The decoded METAR data are stored in the NASA Ames Aviation Systems Division ATM NextGen Data Warehouse to allow ad-hoc user query and data mining. The design of the database schema for storing the decoded METAR data is also presented in this document. This document describes the capability of the Data Warehouse web application for reporting and analyzing METAR data.

Finally this document presents a case study of correlating dust storms reported in METARs from the Phoenix Sky Harbor International Airport and Ground Stop advisories issued by the Air Traffic Control System Command Center (ATCSCC). The case study emphasizes the importance of including weather conditions not only from the Body section but also from the Remarks section of METARs when conducting ATM research involving METAR as a data source.

2 Current METAR Decoding Tools

There are many METAR decoding tools that are available to the public, and they are written in different programming languages. One of them is the "Python METAR parser" open-source project [2], and it is written in Python. This tool decodes about 20 out of 69 METAR observations and remarks. It can only decode well-formatted coded text. When mal-formatted coded text is encountered, the tool aborts immediately. As will be described later, the tool documented in this paper decodes all METAR observations and remarks, and mal-formatted coded text is identified and processed accordingly.

3 Collecting METAR Data

There are three main data sources that provide METARs:

1. NOAA's METAR files from the last 24 hours are stored at NOAA's file transfer protocol (FTP) site: ftp://tgftp.nws.noaa.gov/data/observations/metar/cycles/
2. Historical METARs are available from the Weather Underground web site: http://www.wunderground.com
3. NOAA's Aviation Digital Data Service (ADDS) provides a Web Services interface to get the last 141 hours of METARs: http://www.aviationweather.gov/adds/dataserver

ADDS provides decoded METAR but not all the groups in a METAR are decoded. Only 31 fields are available [3]. Many groups from the Remarks section such as Lightning and Thunderstorm Location are not decoded and made available. Furthermore, ADDS can only decode groups that conform to the standard coding format described in FMH1. ADDS also imposes a limit of 1,000 reports per Web Services call.

Because NOAA's FTP site imposes no such limit, it is chosen to be the primary data source. In case any files cannot be downloaded from the FTP site because of problems on the client side, the Weather Underground web site is used as the alternative source; it does not have any date range limit when compared to the last-141-hour limit imposed by ADDS.

METARs from the NOAA's FTP site contain reports from over 4,000 observation stations. Of these observation stations, only those corresponding to 267 airports are analyzed and decoded. The 267 airports are from a superset of 264 Federal Aviation Administration (FAA) staffed facilities [4], 35 FAA Operational Evolution Partnership (OEP) airports [5], and 77 FAA Aviation System Performance Metrics (ASPM) airports [6].

The daily archiving of the historical METARs commenced on October 15, 2009, and continues today. METARs up to February 4, 2014, are used in this document. There are 12,046,057 METARs collected from 267 airports over 1,575 days. This translates to an average of 28.65 reports per airport per day. Because METARs are disseminated on a regular hourly schedule, the extra 4.65 reports can be explained by the dissemination of unscheduled special METARs.

4 Coding Format Overview

In order to decode a METAR, one needs to first understand the METAR coding format. Weather observations and other information reported in a METAR are divided into "groups" of coded text. Each group has its own unique coding format. There are two sections in a METAR: Body and Remarks. The Body section contains 11 groups (e.g., Weather Station ID, Wind, and Visibility). The Remarks section contains groups that are further classified in two categories: 36 groups in the "Automated, Manual, and Plain Language" category, and 22 groups in the "Additive and Maintenance Data" category. See Appendix A for complete details. A sample decoded METAR is described later in section 0.

Often observations reported in the Body section may be described with further details in the Remarks section (e.g., start time, end time, frequency, intensity, and location and direction of thunderstorms). The Remarks section is the portion of the METAR where an observer can enter plain text to describe weather phenomena qualitatively. It should be noted that some observations are only reported in the Remarks section (e.g., lightning).

The coding format for each group in a METAR is described in NOAA's FMH1 [1] and in FAA Advisory Circulars 00-45G, Aviation Weather Services (AWS) [7]. FMH1 is the definitive source on the METAR coding format. AWS compliments the FMH1 by describing METAR information as well as other weather products but leaves out information that has no direct impact on the aviation community. It also includes photographs of significant clouds and examples of decoded METARs.

Contractions are referenced throughout in a METAR. Standard contractions are described in the Aviation Weather Contractions document [8].

4.1 Observations Described Only in Remarks Section

Of the 12 million METARs analyzed, 97.66 percent of reports have Remarks. One example of observations that are noted in both the Body and Remarks sections is thunderstorms. Of those METARs, there are 100,203 having thunderstorms referenced only in the Remarks section and not in the Body section. Normally, thunderstorm observations are first noted in the Body section and details are noted in the Remarks section. Details include the beginning and/or ending time of thunderstorms, and the location and moving direction. Among those 100,203 reports, 23,437 reports have locations and/or movement directions of the thunderstorms, and 2,010 of those (2 percent) have thunderstorms occurring within 5 statute miles of airports. In other words, a reader of those 2,010 reports can only be aware of thunderstorms at the airports by reading the Remarks section, because they are completely missing in the Body section. Figure 1 shows the number of those 23,437 reports broken down by airport (OEP 35 vs. non-OEP 35 airports) and thunderstorm locations.

Lightning at an airport can affect ramp operations due to safety concerns to the ground personnel and may cause or worsen departure and arrival delays. Of the 12 million METARs analyzed, 263,685 reports have lightning observations in the Remarks section. In FMH1, lightning is *not* described in the Body section at all. 89,590 reports (34 percent) have lightning occurring within 5 statute miles of airport. Figure 2 shows the number of those 263,685 reports broken down by airport (OEP 35 vs. non-OEP 35 airports) and lightning locations.

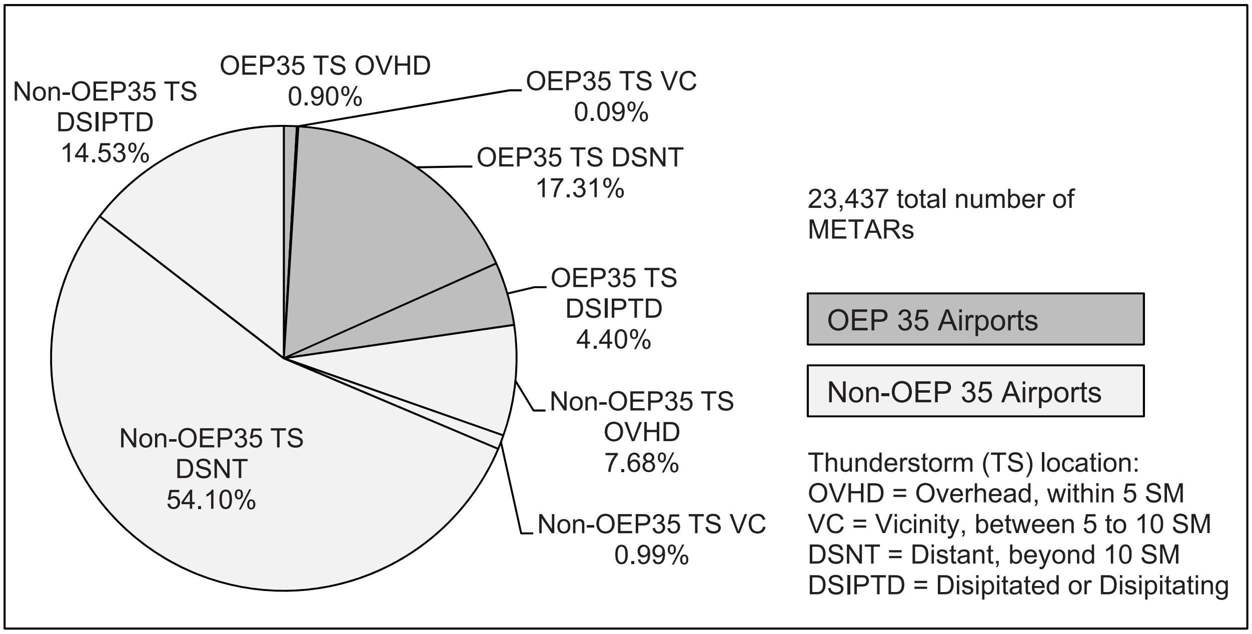


Figure 1. Number of METARs by airports: thunderstorms referenced in the Remarks section only.

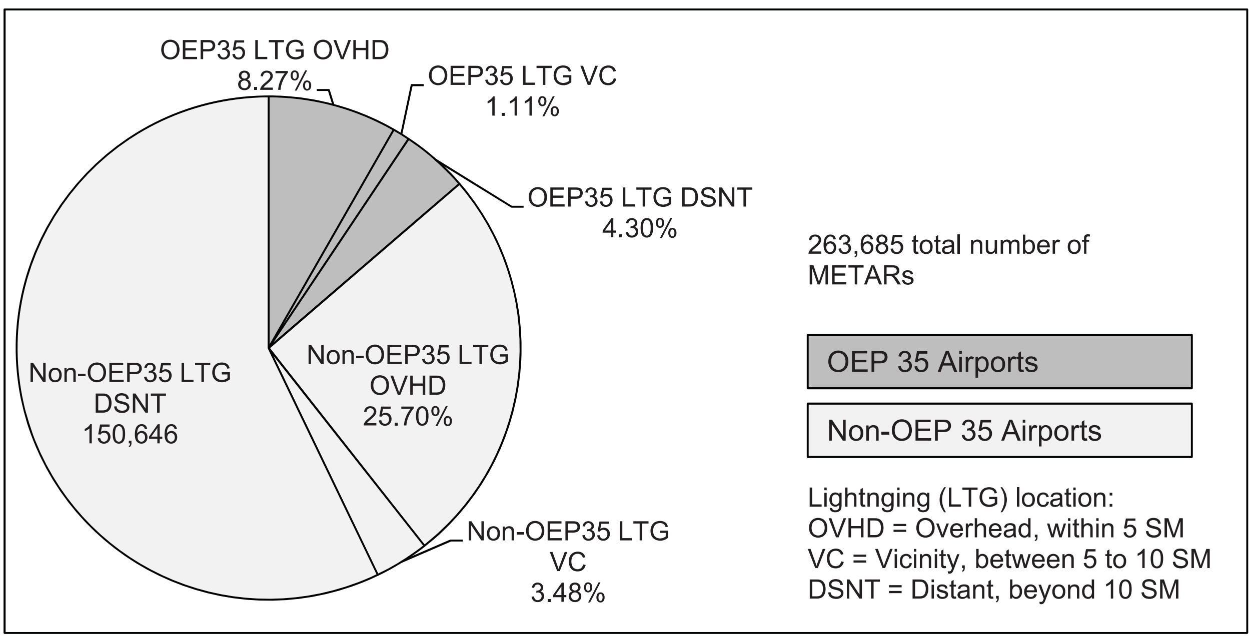


Figure 2. Number of METARs by airports: lightning referenced in the Remarks section only.

4.2 Blank Space as a Delimiter

In FMH1, each group has its own unique coding format that may include a blank space character. A blank space character is not only used as a delimiter between groups, it is also used as a delimiter within the text of a group. Therefore one cannot assume that any text between two blank spaces is automatically a group. Table 1 shows a sample METAR from AWS. The "Present Weather", "Sky Condition", "Peak Wind", and "Lightning" groups contain one or more blank spaces within the respective group, as indicated with the grey background.

Table 1. Groups containing blank space characters.

<table>
<tr><td colspan="3">SPECI KCOT 292020Z AUTO 13009KT 3SM TSRA BR SCT011 BKN028 OVC043 23/21 A2991 RMK AO2 PK WND 13029/2000 LTG DSNT ALQDS P0020</td></tr>
<tr><th>Group Name</th><th>Coded</th><th>Translation</th></tr>
<tr><td>Type of Report</td><td>SPECI</td><td>Aviation Selected Special Weather Report</td></tr>
<tr><td>Station Identifier</td><td>KCOT</td><td>United States Cotulla, Texas</td></tr>
<tr><td>Date and Time of Report</td><td>292020Z</td><td>29th day of the month, 2020 Coordinated Universal Time (UTC)</td></tr>
<tr><td>Report Modifier</td><td>AUTO</td><td>Automated observation with no human augmentation</td></tr>
<tr><td>Wind</td><td>13009KT</td><td>Wind from 130 degrees (the southeast) at 9 knots (10 mph, 4.7 m/s)</td></tr>
<tr><td>Visibility</td><td>3SM</td><td>Visibility 3 statute miles (5 kilometers)</td></tr>
<tr><td>Runway Visual Range</td><td>[omitted]</td><td></td></tr>
<tr><td>Present Weather</td><td>TSRA BR</td><td>Thunderstorm, moderate rain, mist</td></tr>
<tr><td>Sky Condition</td><td>SCT011 BKN028 OVC043</td><td>Scattered at 11,000 feet above ground level (AGL), Ceiling broken at 2,800 feet AGL, Overcast at 4,300 feet AGL</td></tr>
<tr><td>Temperature/ Dew Point</td><td>23/21</td><td>Temperature 23C (73F), dewpoint 21C (70F)</td></tr>
<tr><td>Altimeter</td><td>A2991</td><td>29.91 inches of mercury (1013.0 millibars, 1013.0 hectopascals)</td></tr>
<tr><td>Remarks</td><td>RMK</td><td>Remarks section designator</td></tr>
<tr><td rowspan="3">Automated, Manual, and Plain Language</td><td>AO2</td><td>Automated station with a precipitation discriminator</td></tr>
<tr><td>PK WND 13029/2000</td><td>Peak wind from 130 degrees (the southeast) at 29 knots (33 mph, 14.9 m/s) occurred at 2000 UTC</td></tr>
<tr><td>LTG DSNT ALQDS</td><td>Lightning distant all quadrants</td></tr>
<tr><td>Additive and Automated Maintenance Data</td><td>P0020</td><td>0.20 inches of precipitation fell in the past hour</td></tr>
</table>

4.3 Coding Missing Data

According to FMH1, Section 12.5, "When an element does not occur, or cannot be observed, the corresponding group and preceding space are omitted from that particular report." In other words, the number of groups in a report is not constant. When a group has no data to report in a METAR, it is simply skipped in the report. No special placeholder text such as "-NS-" is used.

5 Undocumented Groups

Both the FMH1 and AWS publications lack documentation on some groups found in the Remarks section of many historical METARs. After thorough analysis of historical METARs, these undocumented groups were identified. These groups and their respective coding formats are described below.

5.1 Depth of New Snow (931nnn)

Depth of new snow (snowfall) is reported every 6 hours at 0000, 0600, 1200, and 1800 UTC, when any amount of snow has fallen in the past 6 hours. **931** is the group indicator and **nnn** represents the depth of new snow in the past 6 hours reported in tens, units, and tenths of inches, using three digits. The new snow includes snow pellets, snow grains, ice pellets, ice crystals, and hail. For example, during the 6-hour period it snows two times. After the first snow there are 2.3 inches of new snow. Before the second snow, 0.5 inches of the new snow melts. The second snow adds another I.4 inches of new snow. The new snow depth is the sum of 2.3 and 1.4 inches, or 3.7 inches. The reported value of new snow does not include melted snow so the group "931nnn" would be coded "931037". Further details are described in the NOAA's Supplementary Climatological Data [9].

5.2 Ice Accretion (IHnnn)

Amount of ice accreting is measured on a flat surface (planar icing) as estimated by the data from a freezing rain sensor. **IH** is the group indicator where **H** can be 1, 3, or 6. When H is 1, the measurement is reported hourly for the past hour. When **H** is 3, the measurement is reported at 0300, 0900, 1500, and 2100 UTC for the past 3 hours. When **H** is 6, the measurement is reported at 0000, 0600, 1200, and 1800 UTC and covers the past 6 hours. **nnn** represents the thickness accumulated to the nearest one-hundredth of an inch. A trace amount is encoded as "000". For example, an ice accretion of 0.04 inch in the past hour and an ice accretion of 0.11 inch at 1500 UTC would be coded "I1004 I3011". Further details are described in the Automated Surface Observing System (ASOS) Release Note [10].

5.3 Significant Cloud Type Cumulus (CU_LOC)

Cumulus cloud is coded in the format **CU_LOC** where **CU** is the cloud type and **LOC** is the direction from the station. The cloud type and location entries are separated from each other with a space. For example, cumulus clouds beyond 10 but less than 30 nautical miles of the station in the direction of north through north-east through south-east would be coded "CU DSNT N-NE-SE".

5.4 Low-Level Wind Shear (LLWS) [Plain Language]

Low-level wind shear should be coded as **LLWS** followed by optional descriptive text. For example, “LLWS +/- 15KT".

5.5 Pilot Report (PIREP) [Plain Language]

Pilot report maybe coded as **PIREP** followed by observations from a pilot. For example, “PIREP 2118Z ON FINAL RWY 36L LGT RIME ICG AT 030MSL TEMP -4C BY E-135".

6 Deviations From Group Coding Format

Because blank spaces cannot be solely used to identify each group in a report, and because groups can be omitted from a report when there are no data to report, identifying all groups in a report is the first step in decoding a METAR. The text in a METAR needs to be divided into separate groups by matching up each group's coding format.

Twelve million historical METARs were analyzed to check if groups can be identified by their coding formats. The METARs from the analysis show that the reports contain groups that do not conform to the coding formats as specified in FMH1. Deviations from the coding format are likely due to manual data entry or editing by a human observer. Major deviations were identified in the following 16 subsections.

6.1 Groups Not Reported in Suggested Order

The order of the groups reported in a METAR is usually the same order as listed in Appendix A. However, this is not true in every report. Some reports have groups that do not follow the suggested order documented in FMH1, especially in the Remarks section. Hence, it is incorrect to assume that groups in a report are always in the suggested order. Table 2 shows some such examples in highlighted text with misplaced groups in bold.

Table 2. Groups not reported in standard order.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2011-04-05 08:54	KCRW	... SLP016 **PRESRR** ...	**PRESRR** SLP016 (Pressure Rapidly Rising group should precede Sea Level Pressure group)
2012-05-07 23:13	KCVG	... TSB13 **WSHFT 2310** ...	**WSHFT 2310** TSB13 (Wind Shift group should precede Beginning of Thunderstorms group)
2013-06-18 04:52	KABI	... SLP144 **FRQ LTGICCG DSNT NW** ...	**FRQ LTGICCG DSNT NW** SLP144 (Lightning group should precede Sea Level Pressure group)
2013-07-27 12:52	KATL	... SLP152 **SFC VIS 5** ...	**SFC VIS 5** SLP152 (Surface Visibility group should precede Sea Level Pressure group)
2013-12-21 14:15	KADS	... LTGICCG TSB15 **VIS1V2**	**VIS 1V2** LTGICCG TSB15 (Variable Prevailing Visibility group should precede Lightning group)

6.2 Standard Coding Format Not Followed

Some METARs do not follow the coding format of a group. The result from the analysis of the 12 million METARs shows that 31 of the 69 groups deviate from their respective standard coding formats. Without knowing what those deviations are, groups that do not conform to the standard coding formats will not be identified correctly in a report.

For example, the Peak Wind group has the coding format of **PK WND dddff(f)/(hh)mm** where **ddd** is the direction of the peak wind, **ff(f)** is the 2- or 3-digit peak wind speed in knots since the last METAR, and **(hh)mm** is the time of occurrence. A peak wind of 39 knots from 100 degrees that occurred at 0746Z would be coded "PK WND 10039/0746". Table 3 shows examples of deviations found in the Peak Wind group.

Temperature and Dew Point, and Altimeter groups are commonly reported in the METARs. Their coding formats are **$T'T'/T'_dT'_d$** and **$AP_HP_HP_HP_H$** respectively. **T'T'** is a two-digit number temperature in Celsius and **$T'_dT'_d$** is a two-digit number dew point in Celsius. **A** is the Altimeter group indicator and **$P_HP_HP_HP_H$** is a four-digit number indicating the altimeter setting of tens, units, tenths, and hundredths of inches of mercury. Table 4 shows some deviations from standard coding formats.

Table 3. Coded texts not following the standard coding format of the Peak Wind group.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2010-12-05 20:54	KSBN	... **PK WNO** 31026/2006 ...	**PK WND** 31026/2006
2011-08-28 05:51	KLGA	... **PKW**09036/0550 ...	**PK WND** 09036/0550
2011-08-28 08:01	KEWR	... **PKWIND** 10039/0746 ...	**PK WND** 10039/0746
2011-11-05 21:53	KDFW	... **PK WIND** 15026/2121 ...	**PK WND** 15026/2121
2013-07-14 22:53	KLBB	... **PEAK WIND** 08033/2253 ...	**PK WND** 08033/2253

Table 4. Coded texts not following the standard coding format of the Temperature and Dew Point group.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2010-02-09 07:53	KTUL	... -07/-13 ...	**M**07/**M**13 (sub-zero temperature and dew point should be prefixed with **M**)
2013-01-02 12:52	KCID	... -14/-17 30.09	**M**14/**M**17 **A**3009 (sub-zero temperature and dew point should be prefixed with **M**, and altimeter setting should be prefixed with **A** and without decimal point)
2013-08-09 21:42	KADW	... 32 21 ...	32**/**21 (temperature and dew point should be separated by "/")
2013-10-15 19:47	KADS	... 171/15 ...	17/15 (temperature and dew point should each be two-digits long; a value with higher precision should be reported as **T17101500** in the Remarks section)
2013-11-30 23:15	TIST	... A29 94 ...	A2994 (altimeter value should be a contiguous four-digit number)

Table 5 shows two more examples of groups that do not follow standard coding formats.

Table 5. Coded texts not following the standard coding formats of Pressure Rising Rapidly and Pressure Falling Rapidly groups.

Group Name	**Standard Coding Format**	**Variations**
Pressure Rising Rapidly	PRESRR	PRESSRR PRES RR PRESS RR PRESSURE RISING RAPIDLY
Pressure Falling Rapidly	PRESFR	PRESSFR PRES FR PRESS FR PRESRF PRESFF PRESSURE RAPIDLY FALLING PRESSURE FALLING RAPIDLY PRESSURE DROPPING RAPIDLY

6.3 Combining Multiple Groups Into One Group

Sometimes an observer may, for convenience, combine two separate or similar groups that share the same condition by using "/" and "AND". Table 6 shows some examples of combined groups in highlighted text.

Table 6. Coded texts combined from multiple groups into one group.

Observation Time (UTC)	**Observation Station**	**Report Text**
2010-12-17 22:56	KLAS	... CIG **AND** VIS LWR NW-N ...
2011-11-22 20:55	KRNO	... CCSL/ACSL DSNT N NE ...
2013-05-18 02:55	KRNO	... ACSL/CCSL ALQDS ...
2013-07-26 16:53	PAMR	... CEILING **AND** VIS LOW EAST ...
2013-08-24 15:57	PANC	... CIG **AND** VIS LWR NE-SE ...

6.4 Single Group is Split Into Multiple Groups

If a group has multiple observations, the observations should be reported adjacent to each other to form a single group. Some METARs have a group being split into multiple non-adjacent parts of the report. Table 7 shows some examples of these cases, with repeated groups in highlighted text.

Table 7. Coded texts split from one group into multiple groups.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2010-06-17 12:53	PANC	... RAB52 SLP171 RAE46 ...	RAE46 RAB52 SLP171 or RAE46B52 SLP171 (rain ended at 46 minutes past the hour and began at 52 minutes past the hour)
2011-09-05 20:52	KATL	... CB OHD OCNL LTGCG CB MOV N ...	CB OHD CB MOV N OCNL LTGCG ... or CB OHD MOV N OCNL LTGCG ... (cumulonimbus cloud overhead moving north)
2012-05-14 20:07	KAGS	... LTG DSNT NE TSB01 LTG S	LTG DSNT NE LTG S TSB01 (lightning in the distant north east and in the south)
2012-05-29 22:45	KSWF	... TS NW ONCL LGT TS MOVG SSE	TS NW TS MOVG SSE ONCL LGT or TS NW MOVG SSE ONCL LGT (thunderstorms in the northwest moving south-southeast)
2014-01-05 14:53	KDEN	... SNE43 SLP265 SNB44	SNE43 SNB44 SLP265 or SNE43B44 SLP265 (snow ended at 43 minutes past the hour and began at 44 minutes past the hour)

6.5 Missing Separator RMK

A proper METAR should have a "RMK" separator to separate the Body section from the Remarks section. Some reports miss the "RMK" separator. Table 8 shows some examples in highlighted text with the missing "RMK" in bold.

Table 8. Coded texts with missing Remarks (RMK) separator.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2009-12-19 14:54	KRIC	... A2957 TWR VIS 1 ...	A2957 **RMK** TWR VIS 1
2010-03-24 12:45	KMMU	... A2979 PRESRR	A2979 **RMK** PRESRR
2010-09-22 12:51	KFFZ	... A2966 CB N-S	A2966 **RMK** CB N-S
2011-07-19 20:50	KBJC	... A3004 LTG DSNT SW	A3004 **RMK** LTG DSNT SW
2011-08-14 10:53	KBGM	... A2993 CIG 004V009	A2993 **RMK** CIG 004V009

6.6 Wrong Order Within Group Coding Format

Some coding formats have a specific order of codes within a group. For example, the Lightning group has the format of **Frequency_LTG(type)_[LOC]**, where there is an optional frequency contraction, followed by a space, followed by **LTG** and a lightning type ("CG" (cloud-to-ground), "IC" (in cloud), "CC" (cloud-to-cloud), and "CA" (cloud-to-air)), and followed by an optional space and lightning location in plain text. Table 9 shows some examples where this format is not followed, with errors in highlighted text and misplaced codes in bold.

Table 9. Coded texts not following the order in the Lightning group.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2010-02-24 20:08	KFPR	... LTG **OCNL** CC ...	**OCNL** LTGCC (occasional lightning from cloud to cloud)
2010-03-10 16:32	KADS	... LTG **CONS** ...	**CONS** LTG (continuous lightning)
2010-09-08 16:44	KACK	... LTG **FREQ** CG ...	**FRQ** LTGCG (frequent lightning from cloud to ground)
2011-04-28 17:33	KTEB	... **VC** LTGICCCCG	LTGICCCCG **VC** (lightning within cloud, from one cloud to another, and from cloud to ground, in vicinity 5 to 10 nautical miles)
2012-06-07 13:25	KABI	... **CCCG**LGT ...	LGT**CCCG** (lightning from cloud to cloud and from cloud to ground)

6.7 Unexpected Descriptors in Groups

Some groups do not specify a descriptor (e.g., shape, intensity, frequency) as part of their coding formats, yet some reports show such descriptors. Table 10 shows some examples in highlighted text with the unexpected descriptors in bold.

Table 10. Coded texts with unexpected descriptors.

Observation Time (UTC)	Observation Station	Report Text
2010-05-28 22:52	KCLT	... **LINE** TS MOVD N ...
2010-10-19 21:53	KDAL	... **LRG** CB DSNT N MOV SE ...
2011-08-06 17:35	KCRW	... **OCNL** TS SW MOV E ...
2011-08-12 22:53	KDFW	... **LN** CB DSNT SW-W NW-N MOV NE ...
2012-04-21 12:53	KDEN	... **MULT** ACSL SW-W ...
2013-07-27 12:52	KDFW	... **OCNL** TCU DSNT SW-NW ...
2014-01-10 22:53	KDAL	... **LN** TCU DSNT NW ...

6.8 Use of FEW as Descriptor and Cloud Cover Layer

In a METAR, the contraction **FEW** can be used as an optional descriptor of weather phenomena (e.g., cloud or obscuration) and as a cloud cover type. When there is a contraction **FEW** in a report, it is necessary to examine the preceding and the following coded text to determine to which side **FEW** belongs. Table 11 shows some examples in highlighted text and the corresponding groups.

Table 11. Coded texts with FEW as descriptor and cloud cover layer.

Observation Time (UTC)	Observation Station	Report Text	Comments
2010-07-18 11:51	KALB	... RMK ... SCT V **FEW** 70053 ...	SCT V **FEW** (sky cover was varying between scattered and few clouds) is a Variable Sky Condition group.
2010-11-29 16:54	KBOS	... RMK ... SLP338 **FEW** CU DSNT NE ...	**FEW** CU DSNT NE (few cumulonimbus clouds in the distant north-east) is a Significant Cloud Type: Cumulonimbus group.
2011-02-27 22:53	KAMA	... RMK ... SLP968 **FEW** FU N ...	**FEW** FU N (few smoke in the north) is an Other Significant Information group because it does not meet the coding format of any groups.
2011-07-11 18:54	KRFD	...10SM **FEW** 038 SCT 150 ... RMK ...	**FEW**038 (extra space removed; few cloud cover layer at 3,800 feet) is a Sky Condition group.
2011-08-01 17:51	KALB	... RMK ... SCT035 V **FEW** CB DSNT S ...	SCT035 V **FEW** (sky cover at 3,500 feet was varying between scattered and few clouds) is a Variable Sky Condition group. **FEW** is not a descriptor to the following cumulonimbus cloud group.
2011-11-06 23:53	KSAT	... RMK ... SLP128 **FEW** SHRA VC ...	**FEW** SHRA VC (few rain showers in the vicinity) is an Other Significant Information group because it does not meet the coding format of any groups.
2012-10-10 21:53	KDAL	... RMK ... SLP182 **FEW** BRKS IN OVC ...	**FEW** BRKS IN OVC (few breaks in overcast; standard contraction of breaks in overcast is BINOVC) is an Other Significant Information group because it does not meet the coding format of any groups.
2013-06-23 09:53	KADW	... RMK ... BKN018 V **FEW** PNO ...	BKN018 V **FEW** (sky cover at 1,800 feet was varying between broken and few clouds) is a Variable Sky Condition group.
2014-01-18 18:53	KTLH	... RMK ... FU **FEW** 030 FU S-SW	FU **FEW**030 (extra space removed; a few sky cover layer at 3,000 feet composed of smoke) is an Obscurations group.

6.9 Using Nonstandard Contractions

In some METARs, some groups do not use standard contractions. Table 12 shows some examples from the Beginning and Ending of Precipitation group in highlighted text, and nonstandard contractions in bold.

Table 12. Coded texts with nonstandard contractions.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2010-02-02 13:22	KROA	... **S**B17PLB20 ...	**SN**B17PLB20 (SN = Snow)
2010-02-27 12:25	KBED	... **S**B08 ...	**SN**B08 (SN = Snow)
2011-05-20 21:47	KBJC	... **T**B47 ...	**TS**B47 (TS = Thunderstorm)
2012-12-26 12:46	KBWI	... **IP**B44 ...	**PL**B44 (PL = Ice Pellet)
2013-01-08 17:57	KADS	... **R**B57 ...	**RA**B57 (RA = Rain)

6.10 Use of NO in Remarks

Though occurring rarely and being nonstandard according to FMH1, a remark may negate an earlier remark within the same METAR. For example, instead of removing an erroneous remark, "SNB1455E1458" (snow began at 1455Z and ended at 1458Z), from a report, an observer may choose to insert a negating remark "NO SN" to correct the erroneous one in the same report. When a report user reads the coded text of such a METAR from the left to the right, the first encounter of "SN" can lead to the premature conclusion of the presence of snow only to find out that it is negated later on. After detailed analysis was performed on these rare reports, it is confirmed that these corrections are made only to the erroneous remarks within the same reports and not to the earlier transmitted reports. Table 13 shows some examples in highlighted text and negating remarks in bold.

Table 13. Coded text with NO to negate previous observations.

Observation Time (UTC)	Observation Station	Report Text	Comments
2010-04-26 20:53	KBPT	... RMK AO2 WSHFT 2032 RAB47E50 SLP081 **NO RAIN OBSERVED** ...	Rain from 2047Z to 2050Z was reported in error.
2010-10-25 11:53	KBNA	... RMK AO2 PK WND 33036/1139 SLP095 **PK WND INOPP NO GUST** ...	If peak wind sensor is inoperable PK WND 33036/1139 should have been removed entirely.
2010-12-16 17:24	KBNA	... RMK AO2 SFC VIS 2 RAB09FZRAB1655E1656 CIG 004V009 **NO FZRA** ...	Freezing rain from 1655Z to 1656Z was reported in error.
2012-07-06 22:17	KBNA	... RMK AO2 WSHFT 2140 TSE11 TS SW MOV SW TCU ALQDS **NO WSHFT**	Wind shift at 2140Z was reported in error.
2013-02-13 15:53	KBNA	... RMK AO2 SNB1455E1458 SLP114 **NO SN** ...	Snow from 1455Z to 1458Z was reported in error.

Table 13. Continued.

Observation Time (UTC)	Observation Station	Report Text	Comments
2013-07-11 00:00	KDFW	... 10SM FEW001 38/14 A2990 RMK AO2 T03780144 CNL SPECI ASOS REPORTED IN ERROR **NO FEW001**	FEW001 (few clouds at 100 feet) should have been removed because Automated Surface Observing System (ASOS) reported in error.
2013-11-04 15:56	KCAE	... RMK AO2 RAB05E35 SLP324 **NO RAIN ASOS MISREPRESENTATIVE** ...	Rain from 1505Z to 1535Z was reported in error.

In some other METARs, "NO" is used to describe the absence of an observation. When there is nothing to be reported, it should be omitted from the report in general. Otherwise, a METAR would be very long just to note the absence of everything possible. Table 14 shows some examples where groups are in highlighted text and the absence remarks are in bold.

Table 14. Coded texts with NO to describe the absence of observations.

Observation Time (UTC)	Observation Station	Report Text	Comments
2010-02-16 11:53	KPTK	... 2SM ... A02 **NO SFC VSBY** 4/004 ...	**NO SFC VSBY** should not be added if there is no surface visibility to be reported. But if there is low surface visibility of say one statute mile to be reported, the coded text of **SFC VIS 1** should be used.
2010-06-27 21:53	KBHM	... OCNL LTGCG OHD TS OHD **NO MOV** ...	**NO MOV** should not be added if there is no thunderstorm movement.
2011-07-07 19:53	KBNA	... CB S **NO MOV** ...	**NO MOV** should not be added if there is no cumulonimbus cloud movement.
2013-06-15 16:50	KOKC	... TSB26E27B50 **NO LTG OBS** TS DSNT S MOV N ...	**NO LTG OBS** should not be added if no lightning was observed.
2013-12-08 06:15	KAUS	... RMK AO2 SNB0559E15 **NO SN ACCUM** ...	There was snow but no snow was accumulated on the ground. If the coded text is **NO SN**, it would be treated as a negating remark.

In some rare METARs, "NO" is used to describe problems with transmitting the METARs, and they have remarks unrelated to weather observations. Table 15 shows some examples where groups are in highlighted text and the NO indicators are in bold.

Table 15. Coded text with NO to indicate problems with transmitting reports.

Observation Time (UTC)	Observation Station	Report Text	Comments
2010-11-17 17:54	KROA	... **NO** AUTO TRANSMISSION	This remark is seemingly an artifact from a phone modem transmission error, and it has nothing to do with weather observation.
2011-02-10 22:53	KFAR	... **NO** CARRIER RING +MCR	Same as above.
2011-07-17 10:51	KSAN	... **NO** CARRIER RING CONNECT 1200 PDXMTRREO ALL TTAA00	Same as above.

6.11 Typographical Errors in Use of 0 (Zero) and O ("Oh")

In some METARs, there are some mistaken uses of the letter O (capital letter "Oh") and 0 (digit zero). Table 16 shows some examples where groups are in highlighted text and typographical errors are in bold.

Table 16. Coded texts with misspelling of 0 (zero) and O ("Oh").

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2009-10-28 08:53	PAFA	... RVRN**0**	RVRN**O** ("Oh")
2010-03-23 14:39	KTPA	... 1**O**SM ...	1**0**SM (zero)
2010-12-10 02:47	KRHV	... FEW01**O** BKN080 ...	FEW01**0** BKN080 (zero)
2011-10-03 10:27	KBUF	... FEW001 **0**VC003 ...	FEW001 **O**VC003 ("Oh")
2013-05-27 09:24	KCVG	... **0**CNL LTGIC W ...	**O**CNL LTGIC W ("Oh")

6.12 Misspelling of Contractions

In some METARs, some contractions do not follow the standards. Table 17 shows some examples where groups are in highlighted text and misspellings are in bold.

Table 17. Coded texts with misspelling of contractions.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2010-01-28 15:52	KABI	... **OCCNL** LTGCG ...	**OCNL** LTGCG
2010-09-08 01:53	KAGC	... **FQNT** LTG CCCG ...	**FRQ** LTG CCCG
2011-04-22 00:52	KABI	... **FREQ** LTGCTG ...	**FRQ** LTGCTG
2011-12-15 21:55	KADS	... **LTNG** DSNT W-N ...	**LTG** DSNT W-N
2013-07-20 19:30	KABQ	... **ONCL** LTGICCG E ...	**OCNL** LTGICCG E

6.13 Inserting Extra Blank Spaces

In some METARs, extra blank spaces are inserted into the coded text. Table 18 shows some examples where groups are in highlighted text and extra blank spaces are underscored.

Table 18. Coded texts with extra blank space characters.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2010-08-07 01:22	KCHS	... FRO_PA ...	FROPA (contraction of frontal passage)
2011-06-15 20:53	KMEM	... SLP_NO ...	SLPNO (sea level pressure not available)
2012-02-09 03:45	KSWF	... 25006_KT 10_SM ...	25006KT 10SM (wind of 6 knots in the direction of 250° and visibility of 10 statute miles)
2012-11-20 07:51	KEWR	... SLP_230 ...	SLP230 (sea level pressure)
2013-06-21 19:04	KPIA	... LTG_CG DIST W ...	LTGCG DIST W (lightning from cloud to ground in distance west)
2013-09-17 16:09	TIST	... TS_NO ...	TSNO (sensor of lightning detection system is not operating)

6.14 Missing Blank Space

Many coding formats of groups have a blank space within the formats. Yet many METARs do not insert those required blank spaces. For example, when 1.5 statute miles of visibility is coded as "11/2SM" instead of "1 1/2SM", it would be interpreted as 5.5 statute miles. According to FMH1, all the expected fractions are from "1/16", ..., "1/2", ..., to "3/4". Each allowed fraction always has a numerator smaller than the denominator. Even though "11/2" is a legitimate fraction, an experienced reader would interpret it as "1 1/2" instead.

Blank space is also a delimiter between two groups, but many METARs miss these blank spaces or use different characters. Table 19 shows some examples where groups are in highlighted text and missing blank spaces are underscored.

Table 19. Coded texts with missing blank space characters.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2009-12-25 12:53	KTPA	... RMK/RB45 ...	RMK_R**A**B45 (rain began at 45 minutes past the hour; "/" is not a standard group separator)
2010-02-10 16:52	KCVG	... VIS S11/2 ...	VIS S**_**1**_**1/2 (sector visibility of 1.5 statute miles in the south; 11/2 is a typo because the smallest fraction is 3/4)
2010-02-26 19:47	KADS	... 11/2SM ...	1**_**1/2SM (visibility of 1.5 statute miles; 11/2 is a typo because the smallest fraction is 3/4)
2010-05-31 19:47	KGYY	... LTGVC ...	LTG**_**VC (lightning in the vicinity, i.e., between 5 and 10 statute miles from airport)
2011-04-24 19:53	KTPA	... VCSH/VIS LWR W ...	VCSH_VIS LWR W (showers in the vicinity and visibility lower to the west; "/" is not a standard group separator)
2013-05-16 12:17	KLBB	... RMKAO2 ...	RMK**_**AO2 (type of automation station is AO2)

6.15 Missing or Wrong Units of Measure

In the Body section, three groups require units of measure as part of the coding format: Wind group is in KT (knots), Visibility group is in SM (statute miles), and Runway Visual Range group is in FT (feet). All temperate-related groups do not require an explicit statement of the units because they are always reported in degrees Celsius implicitly.

Take the example of a five-digit number "11009". Without a unit of measure in the coded text, and without knowing the position of the coded text in the report, "11009" should technically be a 6-Hourly Maximum Temperature of –0.9°C because it matches the coding format of the 6-Hourly Maximum Temperature group. In the group format, the first digit "1" is the group indicator, the second digit "1" indicates a negative value ("0" means zero or positive temperature value), and the last three digits express temperature in tenths of degrees Celsius. But if "11009" is located within the Body section, it is more likely to be a Wind group despite the missing unit of measure "KT". In other words, "11009" should be decoded as a 6-hourly maximum temperature of –0.9°C instead of 11 knots wind from the direction of 9 degrees, but at times the Wind value is what is intended. When there is a "KT" suffix to the five-digit number, then there is no ambiguity. Such cases of missing units of measure exist in METARs. Table 20 shows some examples where groups are in highlighted text and missing units of measure are in bold.

Table 20. Coded texts with missing or wrong unit of measure.

Observation Time (UTC)	Observation Station	Report Text	Correct Code Should Be
2010-01-25 19:45	KADS	... 10 ...	10**SM** (visibility of 10 statute miles)
2010-08-10 09:53	KDTW	... 04R/1400V3000FTFT ...	R04R/1400V3000**FT** ("FTFT" is a typo and missing "R" for runway 04R)
2011-05-17 01:52	KDCA	... 11009 ...	11009**KT** (wind speed of 9 knots with a wind direction of 110°)
2011-06-14 04:53	KMEM	... 00000KT 10FT SKC ...	00000KT 10**SM** SKC (visibility is in statute miles and not in feet; METARs before and after 2011-06-14 04:53 reported 10 statute miles of visibility)
2012-03-20 16:53	KCMI	... 18020G33 ...	18020G33**KT** (wind speed of 20 knots with a wind direction of 180° and gusts at 33 knots)
2012-05-31 06:56	KISP	... R06/1600V4000 ...	R06/1600V4000**FT** (runway 06 has a visual range from1,600 to 4,000 feet)
2013-04-29 21:51	KMDW	... 18013G26 130V250 ...	18013G26**KT** 130V250 (wind speed of 13 knots with a wind direction of 180° and varying from 130° to 250° and gusts at 13 knots)

6.16 Missing Leading or Trailing Zeroes

Many groups require a fixed number of digits in their coding formats. Leading or trailing zeroes are often required to meet the coding formats and to avoid mistaking them for other groups. Without correct leading or trailing zeroes, a coded text requires an educated guess to interpret it.

For example, the Temperature and Dew Point group requires the format $\mathbf{T'T'/T'_dT'_d}$ where **T'T'** is a two-digit temperature in Celsius and $\mathbf{T'_dT'_d}$ is a two-digit dew point in Celsius. A value of "9/3" can be reasonably interpreted as temperature 9°C and dew point 3°C, instead of 90°C and 30°C respectively, but it does not meet the standard. Another example is the Sky Condition group. It has a coding format of **NNNhhh** where **NNN** is a contraction of sky layer and **hhh** is the layer's 3-digit height in hundreds of feet. When **hhh** is a two-digit number, there can be a missing leading zero or trailing zero. Because multiple sky layers can be in a Sky Condition group, and each sky layer can be followed by a higher sky layer, examination of adjacent layers can give a hint as to whether the missing digit is a leading zero or a trailing zero.

But some coded text cannot be decoded at all. For example, consider the Wind group. In the simplest format, it has a coding format of a three-digit wind direction in degrees followed by a two- or three-digit wind speed in knots. That is a total of five or six digits, depending on whether the wind speed is less than 100 or over 100 knots. A value of "2005KT" has a missing digit. Let us assume that the missing digit is a zero. But without knowing where the missing zero is, it is impossible to know whether it is 02005KT (20 degrees with 5 knots), or 20005KT (200 degrees with 5 knots). Table 21 shows some examples where decoding was possible based on other knowledge; groups are in highlighted text, and missing leading or trailing zeroes are in bold.

Table 21. Coded texts with missing leading or trailing zeroes.

Observation Time (UTC)	**Observation Station**	**Report Text**	**Correct Code Should Be**
2009-11-02 11:54	KBWI	... 9/3 ...	**0**9/**0**3 (temperature 9°C and dew point 3°C)
2010-06-19 16:47	KADS	... A30	A30**00** (altimeter setting of 3.00 inches of mercury)
2011-09-24 11:53	KMCI	... FEW80 SCT180 ...	FEW**0**80 SCT180 (FEW cloud layer has a height of 8,000 feet; it cannot be 80,000 feet because the next higher SCT (scattered) layer is 18,000 feet)
2011-09-26 10:45	KSWF	... R09/800FT...	R09/**0**800FT (runway R09 has a visibility of 800 feet; it cannot be 8,000 feet because visual range is only reported when it is less than 6,000 feet)
2011-09-27 09:45	KSWF	... R9/1600FT ...	R**0**9/1600FT (runway R09 has visibility of 1600 feet; there is no runway R90 at KSWF)
2013-10-29 08:00	TIST	... SCT038 BKN070 BKN09 ...	SCT038 BKN070 BKN09**0** (BKN (broken) cloud layer has a height of 9,000 feet; it cannot be 900 feet because the previously lower BKN layer is 7,000 feet)

7 Algorithm for Decoding Body and Remarks Sections

This section presents the algorithms developed to extract the maximum possible information from METARs in light of the format deviations presented in section 0. As illustrated in section 5, an algorithm relying solely on the standard coding formats from FMH1 to identify groups and group content would certainly fail in a significant number of cases where the formatting is not followed. This section describes the algorithm for identifying groups and decoding them. The algorithm was developed to address the following major issues found among the 12 million METARs:

- There is no unique separator character between each group. Even though there is supposed to be a blank space character, a blank space character is often also found within the text of a group, especially in groups containing plain text. And some groups are adjacent to each other without any separators. The missing separators are likely caused by manual edits of the reports prior to report submission.
- Groups are not always reported in the standard group order as described in FMH1. Manual edits of some reports may insert groups that do not follow the standard group order.
- Multiple contiguous texts of the same group type may be found in a correctly coded METAR. However cases were found where they are not adjacent as they should be. Manual edits may append additional observations to the end of the report instead of editing existing observations.

7.1 Using Regular Expressions for Text Pattern Matching

Central to the algorithm is the use of regular expression [11] processing to perform text pattern matching. There are two main reasons for using regular expressions. First, a regular expression can be used to find whether a piece of text in a report matches the coding format of a group. If a match is found, there is a "group-marker", and the piece of corresponding text in the report can be located. Second, regular expressions' "capturing group" feature can also be used to capture, within a group, one or more pieces of text that match additional patterns. This nested pattern capability is used to extract multiple pieces of data from within a group.

A regular expression is a text string that is made up of normal characters and special meta-characters. Table 22 shows a partial list of regular expression syntax.

For example, the Wind group in the Body part of a METAR has the standard coding format of $\mathbf{dddff(f)Gf_mf_m(f_m)KT\_d_nd_nd_nVd_xd_xd_x}$ where:

- **ddd** is wind direction expressed as a three-digit value in degrees, while the value is **VRB** when describing a variable wind direction with a wind speeds of six knots or less.
- **ff(f)** is wind speed expressed in two- or three-digit knots.
- $\mathbf{Gf_mf_m(f_m)}$ is the optional gust wind speed expressed with the letter **G** followed by two- or three-digit knots.
- **KT** is the wind speed unit of measure.
- $\mathbf{\_d_nd_nd_nVd_xd_xd_x}$ is the variable wind direction range with wind speeds greater than six knots. **_** is a blank space, $\mathbf{d_nd_nd_n}$ is the lower range three-digit degrees, **V** is an indicator of variable wind direction, and $\mathbf{d_xd_xd_x}$ is the upper range three-digit degrees.

Table 22. Partial list of regular expression syntax.

<table>
<tr><th>Syntax</th><th>Feature</th></tr>
<tr><td>\x</td><td>Matches any meta-character where x is one of the characters: [\^$.|?*+(){}</td></tr>
<tr><td>\d</td><td>Matches any digit-character.</td></tr>
<tr><td>.</td><td>Matches any character except the newline character.</td></tr>
<tr><td>|</td><td>An OR operator to match either side of the | meta-character. The evaluation order is from the left to the right.</td></tr>
<tr><td>(regex)</td><td>Specify a capturing group based on a regular expression regex.</td></tr>
<tr><td>(?:regex)</td><td>Specify a non-capturing group based on a regular expression regex.</td></tr>
<tr><td>{i}</td><td>Matches a preceding character or group exactly i times.</td></tr>
<tr><td>{i,j}</td><td>Matches a preceding character or group at least i times, but not more than j times.</td></tr>
<tr><td>?</td><td>Matches a preceding character or group zero or one times.</td></tr>
<tr><td>*</td><td>Matches a preceding character or group zero or more times.</td></tr>
<tr><td>+</td><td>Matches a preceding character or group one or more times.</td></tr>
</table>

There are five pieces of data that can be coded in a Wind group. If the coded text strictly follows the above standard coding formats, the regular expression to identify the Wind group and to capture the five pieces of data is:

```
(\d{3}|VRB)(\d{2,3})(?:G(\d{2,3}))?KT(?: (\d{3})V(\d{3}))?
```

When deviations from the standard coding format are taken into account (e.g., insertion of a backslash character "/" between wind direction and wind speed, and a blank space before the text string "KT"), the enhanced regular expression is:

```
(\d{3}|VRB)\/?(\d{2,3})(?:G(\d{2,3}))? ?KT(?: (\d{3})V(\d{3}))?
```

Table 23 shows the texts matching the enhanced regular expression and the corresponding capturing group in both standard and nonstandard formats. To identify all possible 68 groups found in a METAR, one regular expression needs to be defined for each group. For brevity, the rest of regular expressions are not included in this document.

Table 23. Decoded values in a Wind group.

Text	Capturing Group #1: Wind Direction	Capturing Group #2: Wind Speed	Capturing Group #3: Wind Gust Speed	Capturing Group #4: Variable Wind Direction, Lower Range	Capturing Group #5: Variable Wind Direction, Upper Range
27020G35KT	270	20	35	null	null
27020G35 KT	270	20	35	null	null
120/08G18KT	120	08	18	null	null
VRB03KT	VRB	03	null	null	null
21010KT 180V240	210	10	null	180	240
00000KT	000	00	null	null	null

7.2 Groups Containing Plain Text

About 30 Remarks groups may contain plain text to describe locations, moving directions, and/or general remarks about weather observations. Plain text does not have any recognizable text patterns in the content. Plain text may contain contractions, blank space characters (which are also used for separating groups), and even typos. However, with the exception of the Other Significant Information group, all these Remarks groups do have unique group-markers based on their unique text patterns. Only the Other Significant Information group is composed of plain text entirely, and it can be placed anywhere within a METAR. Any plain text that does not match any of the 58 Remarks groups is categorized as the Other Significant Information group.

The Thunderstorm Location group is a good example of a group containing plain text. Its coding format is **TS_LOC_(MOV_DIR)** where **TS** is the group indicator, **_** is a blank space, **LOC** is the location of the thunderstorm(s) from the observation station, **MOV_DIR** is the optional movement with direction, **MOV** is an indicator, and **DIR** is the direction. Both **LOC** and **DIR** are in plain text. In practice, **MOV_DIR** may actually is a coded text to describe no or little movement, e.g., "NO MOV", "LTL MOVT", "STATIONARY", or "STNRY". The following regular expression uses its capturing group feature to identify the location and the optional movement with direction:

```
TS (?:(.+) (MOV .+|LTL MOVT|NO MOV|STATIONARY|STNRY)|(.+))
```

Table 24 shows some examples of the Thunderstorm Location group, where highlighted text belongs to a Thunderstorm Location group, group indicators after the Thunderstorm Location groups are in bold italics, and corresponding capturing groups show locations and movement with directions.

Table 24. Coded text with plain text from the Thunderstorm Location group.

Observation Time (UTC)	Observation Station	Report Text	Capturing Group # 1: Location	Capturing Group # 2: Movement with Direction	Capturing Group # 3: Location Only
2009-11-02 11:54	KCHS	... **TS** ALL QDTS MOV SW ***P0002*** ...	ALL QDTS	MOV SW	
2010-11-22 20:54	KRFD	... **TS** S-SW AND_N MOV NE ***P0000*** ...	S-SW AND_N	MOV NE	
2011-07-28 20:41	KHOU	... **TS** SE LTL MOVT ***P0004***	SE	LTL MOVT	
2011-07-31 19:14	KGPT	... **TS** NW TO NE ***LTGCCGC*** ...			NW TO NE
2011-07-31 22:53	KSAV	... **TS** SW-NW STATIONARY ***TS*** OVH ...	SW-NW	STATIONARY	
2011-09-24 11:53	KCLT	... **TS** OHD E SIDE AIRPORT STNRY	OHD E SIDE AIRPORT	STNRY	

When one of these 30 Remarks groups is identified in a METAR and it has plain text, the group's plain text is always sandwiched between the group-marker and the next group-marker (or the end of the report). The text between two group-markers is called a "gap" piece of text. That "gap" piece of text usually contains plain text related to the group, but it may also contain information unrelated to the group. For example, consider the report text "... TS ALQDS MOV S MICRO BURST N ... ". "ALQDS MOV S MICRO BURST N" is a "gap" piece of text after the Thunderstorm Location group (indicated by the group-marker "TS"). "ALQDS MOV S" is a part of the Thunderstorm Location group because it follows the expected coding format of **LOC_(MOV_DIR)**. A human reader would be able to identify "MICRO BURST N" as a separate weather condition because it is unrelated to the movement of the thunderstorm direction. Furthermore, because it is not a part of any documented group, it should be categorized as the Other Significant Information group instead. For a software-based decoding solution, it would need to be programmed to identify text that describes direction so that unrelated text would not be included.

In some actual reports, instead of reporting a movement with direction alone in a Thunderstorm Location group, speed was added (e.g., speed in bold, "TS W-NW MOV **SLOLY S**", "TS VC NE-S MOV SE **SLO**"). Thus, in order to decode all plain-text-containing Remarks groups correctly, some analysis on the actual reports is required to determine if there is any "extended" coding format for each group.

One possible choice is to use a semantic-based text-recognition engine to determine which part of a "gap" piece of text is related to a group of a given coding format. This requires building a rich set of vocabulary for each type of description by reading historical reports. The vocabulary needs to include contractions as well as typos. For simplicity and performance reasons, this document applies a rule-based regular expression to determine which part of the "gap" piece of text is related to a group.

7.3 Metadata Structure to Identify Group

A METAR is American Standard Code for Information Interchange (ASCII) text that is made up of multiple groups separated (ideally) by a blank space character. To identify a group without referencing a semantic library of contractions and sound-alike text, the algorithm presented in this document relies on the use of regular expressions to perform text pattern matching and capturing. Each group in the Body and Remarks sections of a METAR has been assigned a corresponding token as part of the algorithm development. This group token, $\texttt{metarGroups}_i$, has the structure shown in Table 25.

To represent all the possible groups in a METAR, an array of the preceding structure is defined as `metarGroups`. The array includes a special group token to identify the Remarks indicator in a report. This is necessary because there are deviations in coding Remarks (**RMK**). Examples are **/RMK**, **RMK/**, **RMK:**, **RMKS**, **R_MK**, and **RM_K** where **_** is a blank space character.

A piece of coded text in a METAR may match multiple candidate groups. For each candidate group, the selection criteria for finding the correctly matched group are:

1. the position of the matched text in the report.
2. the matched index to the `metarGroups`.
3. the position of the matched text relative to a **RMK** indicator in the report.

Table 25. Metadata structure to identify a METAR group.

Element Name	Data Type	Description
`tokenName`	`String`	Regular expression name assigned to a group.
`tokenRegexpT`	`Regular Expression`	Text pattern to match a group and to extract subtext from within a group.
`tokenRegexpTGlobal`	`Boolean`	Indicates whether `tokenRegexpT` should be evaluated multiple times until none is found. Otherwise, `tokenRegexpT` should be evaluated just once.
`tokenRegexpE`	`Regular Expression`	Text pattern to match any text between the indicator of a plain-text-containing group and the indicator of a subsequent group (or end of a report). Optional.
`tokenRegexpD`	`Regular Expression`	Text pattern to extract subtext from within a plain-text-containing group. Optional.

For example, if **TS** (thunderstorm) is found in a METAR, it may be part of either the Present Weather group or the Thunderstorm Location group. If there is no **RMK** indicator in the report, it is part of the Present Weather group. If there is a **RMK** indicator in the report and **TS** is located to the left of **RMK**, it is part of the Present Weather group. Otherwise, it is part of the Thunderstorm Location group.

In some situations, there may be multiple candidate groups found at the same position in a report, and the arbitration rule is determined by the matched index to the `metarGroups`. The lower the matched index value, the higher the precedence order of the group. For example, if **FZFG BKN010** is found to be located to the right of **RMK** in a METAR, **FZFG BKN010** matches the Obscurations group and **FZFG** also matches the Other Significant Information group. When the Obscurations group is placed in a higher precedence order over the Other Significant Information group in `metarGroups`, the longer text string **FZFG BKN010** is matched to the Obscurations group.

7.4 Steps in Decoding METAR

The minimum desired results of decoding a METAR are a) to identify the groups, and b) to extract the measured values or observation text from each group. Additional derived data can be obtained from these outputs; for example, the ceiling height calculated from a set of sky cover layers and the presences of 43 different weather phenomena in the Body and Remarks section of a report. There are multiple steps in decoding the text of a METAR. Here are the major steps:

7.4.1 Identify All Candidate Tokens

For each $\texttt{metarGroups}_i$ in `metarGroups`, use regular expression `tokenRegexpT` to search in the original METAR text string and find any matched text. Store each of the matched text (the position in the original METAR text string and the length of the matched text), and the matched index to the `metarGroups`, `matchedMetarGroupsIndex`, into an array `candidateGroups`. The `candidateGroups` array stores all possible group-marker candidates that will be evaluated in subsequent processing steps. In addition, if the Remarks group is found, the position of the Remarks indicator is saved as `remarksFirstIndex`.

7.4.2 Body Groups Are Not Supposed to Be in the Remarks Section of a Report

To apply this rule, for each candidate token, `candidateGroups`$_i$, if the candidate group is one of the Body groups but the matched text is found to the right of Remarks indicator, special reassignment needs to be made. If the candidate token is one of the tokens that have `tokenRegexpTGlobal` set to be true (e.g., Sky Condition group) and the matched text contains " CB" or " TCU", it is reclassified as Other Significant Information group. Otherwise, the candidate token needs to be removed from the array `candidateGroups`.

7.4.3 Copy Qualified Tokens From `candidateGroups` *to* `qualifiedGroups`

To select only the qualified tokens from multiple tokens, first sort the array `candidateGroups` by the position in the original METAR text string and by `matchedMetarGroupsIndex`. For each of the sorted candidate tokens in `candidateGroups`, working from the left to the right of original METAR, a token is qualified if its matched text does not overlap with the previous qualified token. If it is qualified, it is copied to a new array `qualifiedGroups`. The `qualifiedGroups` array stores only the qualified group-markers.

7.4.4 Fill in Any Unmatched Text

At the end of the previous step, in the original METAR text string, there may be pieces of texts that do not get assigned to any of the tokens in `qualifiedGroups`. These "gap" pieces of text, sandwiched between two group-markers, may not match any of the groups or they may be part of the groups containing plain text. For the latter case, each of the group's `tokenRegexpE` is needed to identify the "extended" text that belongs to the part of the group as described in section 7.3. Depending on how `tokenRegexpE` is written, the "extended" text may accidentally contain coded text from groups that do not follow their coding formats or from undocumented groups (see section 7.2).

For each of the tokens in `qualifiedGroups`, if the token's `tokenRegexpE` is defined, the "gap" piece of text immediately after the group's matched text should be evaluated. Any successfully matched text is added to the existing group's matched text. And if the token's `tokenRegexpD` is defined, the extended matched text will be evaluated to extract any additional information. Any remaining "gap" pieces of text are assigned to the array `unknownBodyGroups` if they are located to the left of the Remarks indicator, or assigned to the array `unknownRemarksGroups` if they are located to the right of the Remarks indicator.

7.4.5 Copy Unique Tokens From `qualifiedGroups` *to* `uniqueGroups`

A group may have multiple pieces of matched text that are not contiguous in the original METAR text string (see section 6.4). In order to group all the matched text of a given group, the processing will first sort the array `qualifiedGroups` by `matchedMetarGroupsIndex` and by the position in the original METAR text string. For each of the sorted qualified tokens in `qualifiedGroups`, if two adjacent tokens share the same `matchedMetarGroupsIndex`, the matched text need to be concatenated and copied to a new array `uniqueGroups`.

7.4.6 Set Output Fields

At the end of the previous step, there are three arrays:

1. `uniqueGroups` is an array of unique groups (Body and Remarks) containing corresponding matched text and any extracted subtext from the matched text.
2. `unknownBodyGroups` is an array of "gap" pieces of text not matching any groups from the Body section of a report.
3. `unknownRemarksGroups` is an array of "gap" pieces of text not matching any groups from the Remarks section of a report.

In this step, any desirable output fields can be set by going through the appropriate arrays. Additional derived data can be computed. For example, a ceiling height can be computed by selecting the height of the lowest layer from the Sky Condition group. A Sky Condition group of "FEW 038 SCT 150" has a ceiling height of 3,800 feet.

8 Software Implementation

The previous section describes the metadata structure and algorithm for decoding a METAR. This section describes the implementation of the algorithm, which was performed by using Pentaho Data Integration (PDI), an open-source data extraction, transformation, and loading application tool. The core logic of the implementation is written in JavaScript. Within PDI, the JavaScript code is automatically compiled to byte-code by using an embedded Java-based JavaScript engine, Rhino, another open-source Mozilla project. The compilation of the JavaScript code to byte-code is set at the highest optimization of 9.

This implementation also calculates the local time of a report given its UTC time, the UTC time zone offset of the airport where the report is submitted, and whether daylight savings time is observed at the airport. For example, KDFW has a time zone offset of –7, and it observes daylight savings time. A METAR from KDFW at 2009-10-25 04:53 UTC has a local time of 2009-10-24 23:53.

Decoded METARs are saved into an Oracle database. This database is part of the ATM NextGen Data Warehouse at NASA Ames [12]. The schema of the database table for METARs is described in the section 9. Figure 3 shows the PDI implementation, which includes the step of saving the decoded data into an Oracle database.

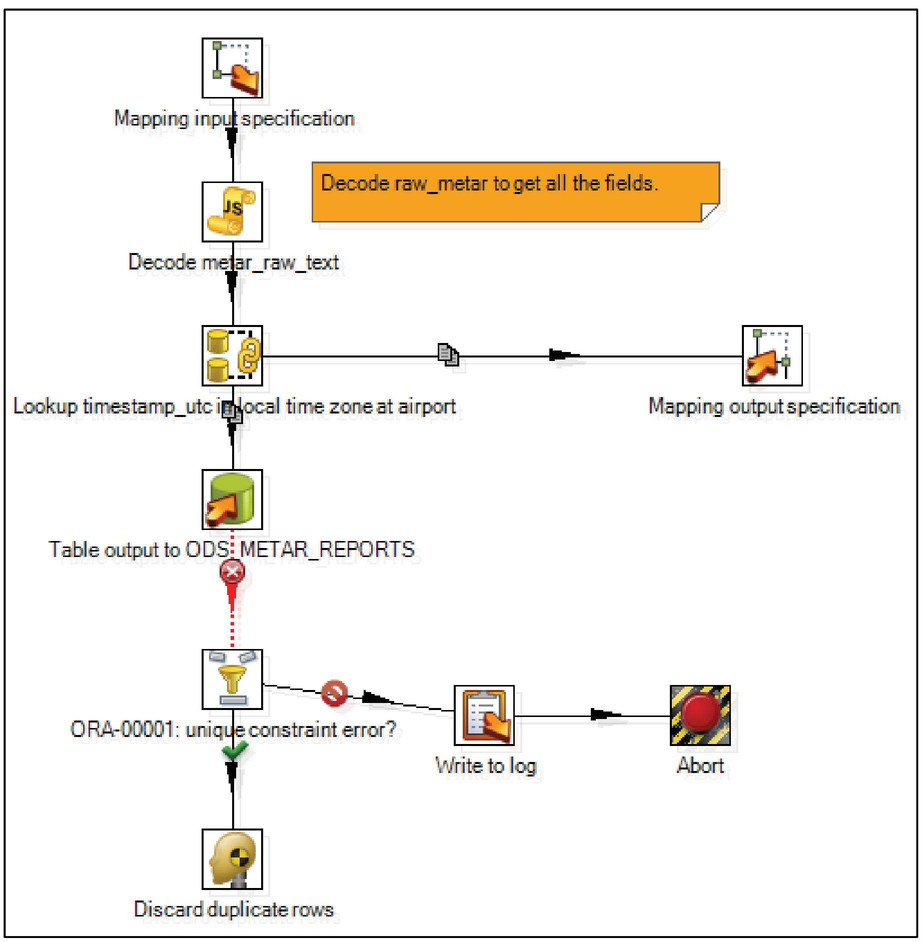


Figure 3. METAR decoding and subsequent storage into database implemented using Pentaho Data Integration.

A test was performed to see how well the decoding algorithm performs. The test was performed on a server with the following hardware specifications:

- Dual 12-core Xenon processors
- 94 GB memory; maximum memory allocation of 4 GB is set for PDI

To perform the test, 12 million METARs, from 267 airports over 1,575 days, were fed into this METAR decoding step without the saving-data-to-database step. The METAR decoding step was configured to run in 14 concurrent threads. The decoding of the entire 12 million reports finished in about 20 minutes, which translates to a sustained rate of about 10,000 reports per second. In other words, the 267 hourly METARs submitted from the 267 airports can be decoded in about 27 milliseconds.

9 Storing Decoded METARs Into a Relational Database

In a METAR, there are 69 groups. Some of the groups can be further normalized from a relational database modeling standpoint. For example, in the Body section, these groups can be normalized:

- Runway Visual Range group: for each runway, the visual range.
- Present Weather group: for each weather phenomenon, the respective intensity, proximity, and descriptor.
- Sky Condition group: for each layer, the sky cover and respective altitude.

In the Remarks section, the text of many groups can be normalized. In the current design, no normalization is made, and only the raw text of each group is saved to the database. When there are multiple observations coded in a group, only the first observation is further decoded. For example, the Lightning group may contain multiple lightning observations. The frequency, lightning type, and location of only the first lightning observation from the group are decoded and saved into the database. Future enhancements to the current design can include further normalizations.

Figure 4 illustrates the relational model of the METAR table (ODS_METAR_REPORTS) and the Airport table (ODS_AIRPORTS). ODS_AIRPORTS stores information about an airport per row and its primary key is AIRPORT_ID. ODS_METAR_REPORTS stores one METAR per row and its composite primary key is REPORT_DATE_TIME_UTC and STATION_ID. The column STATION_ID from ODS_METAR_REPORTS is a foreign key to ODS_AIRPORTS. The relationship between these two tables is "Each METAR must reference one and only airport."

To facilitate a faster search of data in the database, ODS_METAR_REPORTS also contains Boolean type of data indicating the presence of 43 weather phenomena in the Body section and in the Remarks section.

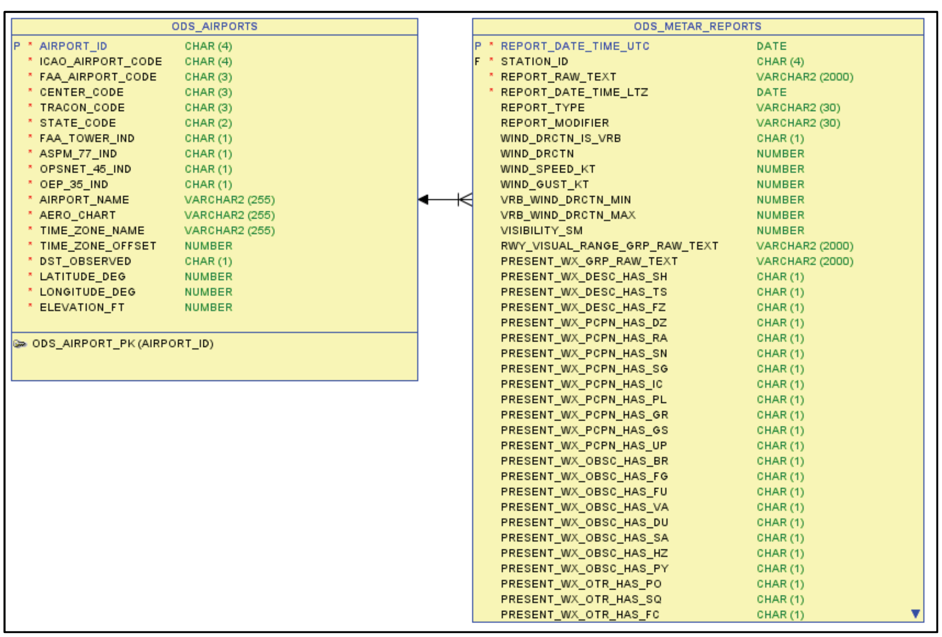


Figure 4. Relational database schema design to store METARs. Partial list of the 200+ METAR columns are shown.

10 Aggregating Daily Decoded METARs

Both weather and air traffic at an airport have a 24-hour cycle pattern. To facilitate search and reporting of weather aggregated to a daily level, METARs at each airport are aggregated from the respective local time instead of the UTC time of their reports. Star Schema Dimensional Modeling [13] is also used to model the daily aggregated observations. See Figure 5. All quantitative measurements from METARs are stored in the Fact table called F_METAR_REPORT_DAILY_AGG. The dimensional key LTZ_DATE_ID is the date (local time) reference to the Dimensional table D_Date; the dimensional key AIRPORT_ID is the airport reference to the Dimension table D_AIRPORT; and the dimensional key WX_PHENOMENA_ID is the aggregated weather reference to the Dimensional table D_WX_PHENOMENA. Each row in D_WX_PHENOMENA is a combination of weather phenomena reported in a 24-hour period.

A typical characteristic to Star Schema Dimensional Modeling is the large ratio of the number of rows in the Fact table to the number of rows from any of the related dimensional tables. This dimensional modeling approach is optimal for querying a large amount of data in the shortest amount of time. This simple model also allows a user to understand the relationships. There is one, and only one, simple join from a dimension to a fact table. By using any ad-hoc query tools, a user can specify any descriptive columns from any dimensional tables and any quantitative columns from a fact table to filter or to report in a query.

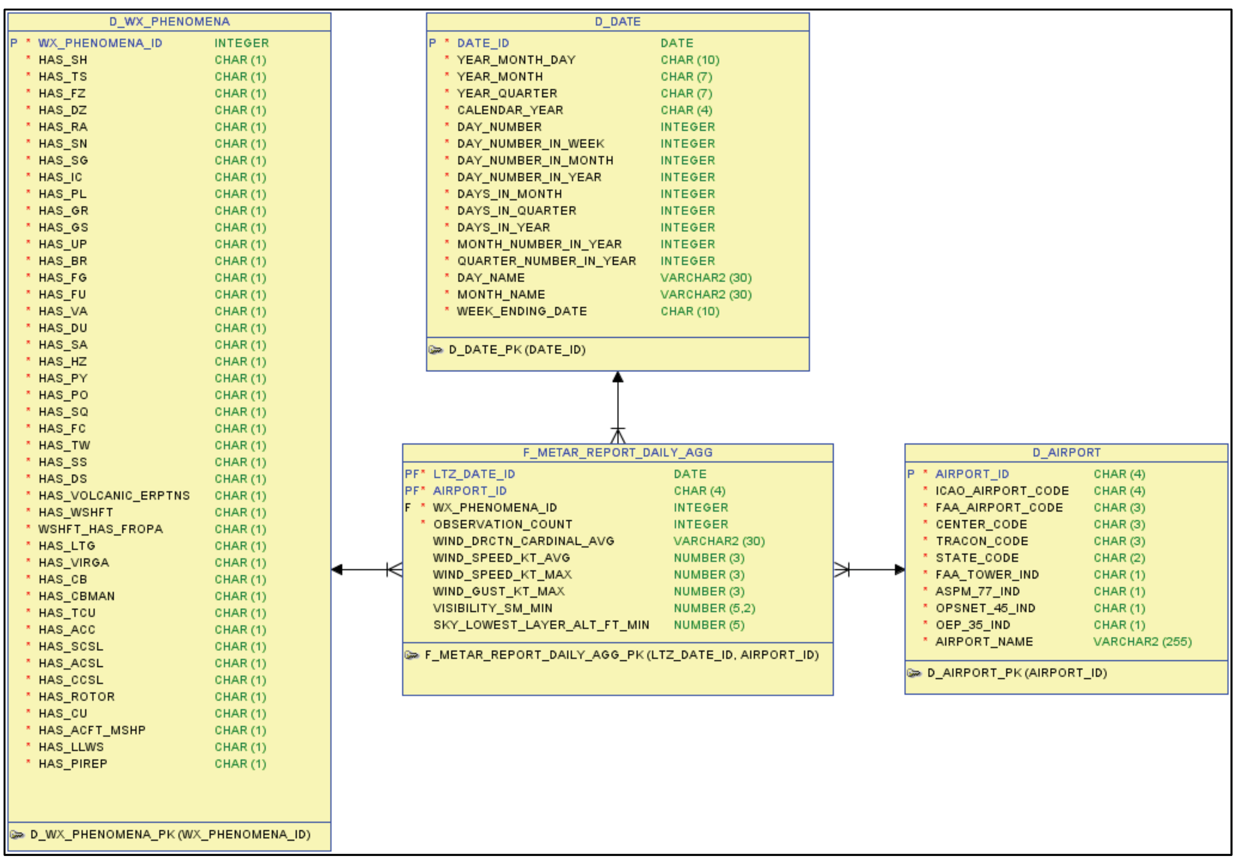


Figure 5. Star Schema dimensional model to store aggregated daily METARs.

11 Reporting on Decoded METARs

For the users of the ATM NextGen Data Warehouse at NASA Ames, a web-based reporting system was built to access the data in the Oracle database. The reporting system was built using the Oracle Application Express application. A user can specify basic search criteria to create a report. Built-in features of the Oracle Application Express allow a user to further filter, sort, and format data.

Figure 6 shows a sample of a METAR daily summary report. The search criteria are: a list of airports, a list of weather phenomena observed during the day, minimum wind gust, minimum wind speed, average wind speed, lowest ceiling height, lowest visibility, and date range or a set of dates. A user can click on a link to drill down to the detailed METARs on any given day at an airport. Figure 7 shows a sample of a METAR details report. The search criteria are a list of airports and a date range or a set of dates. A user can further filter, sort, and download the data by using built-in action menu options. Charts can also be created. Figure 8 shows charts of the number of days in which there were wind gusts and wind speeds exceeding 25 knots at selected airports.

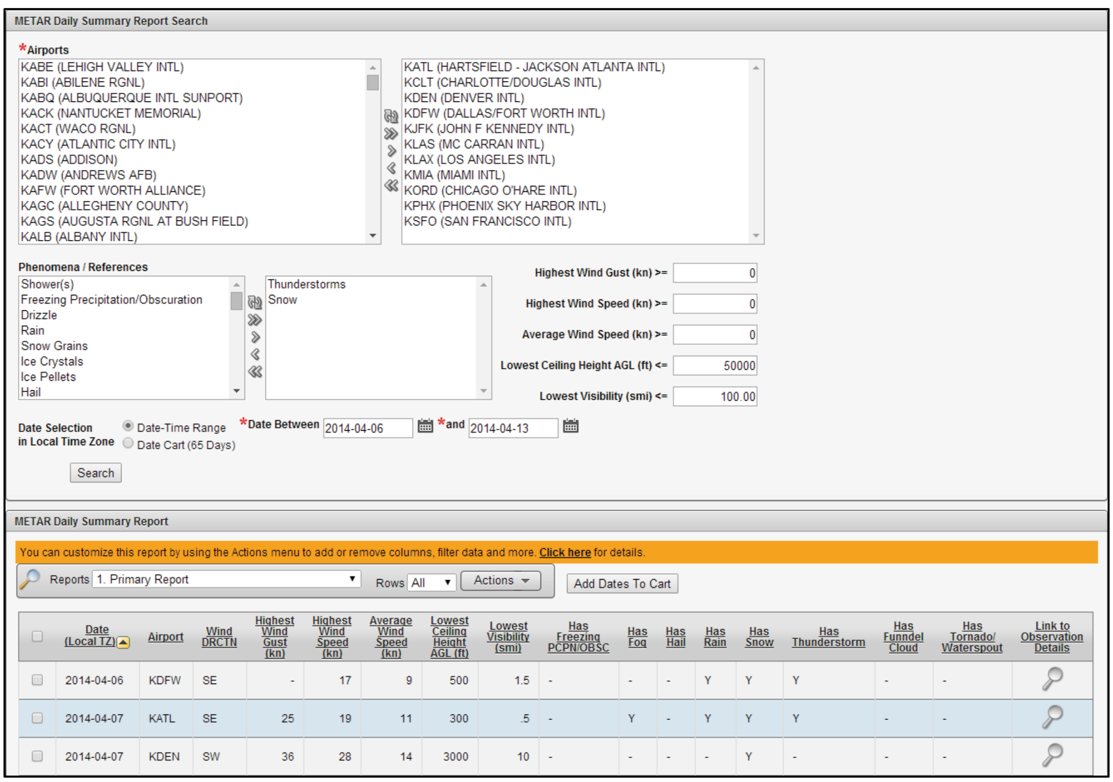
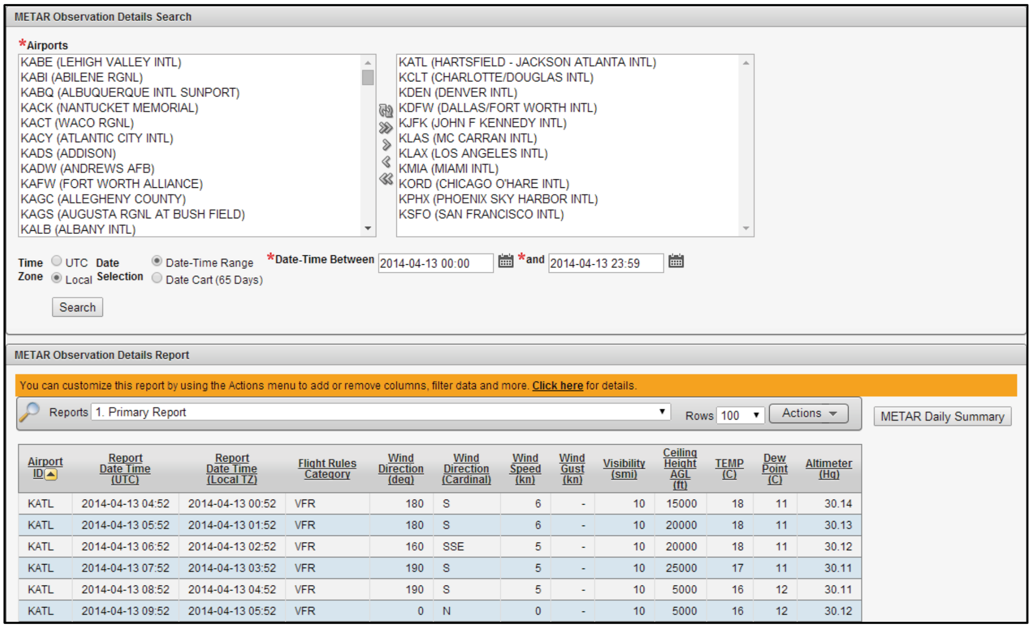


Figure 6. METAR daily summary report from ATM NextGen Data Warehouse.



Airport ID	Report Date Time (UTC)	Report Date Time (Local TZ)	Flight Rules Category	Wind Direction (deg)	Wind Direction (Cardinal)	Wind Speed (kn)	Wind Gust (kn)	Visibility (smi)	Ceiling Height AGL (ft)	TEMP (C)	Dew Point (C)	Altimeter (Hg)
KATL	2014-04-13 04:52	2014-04-13 00:52	VFR	180	S	6	-	10	15000	18	11	30.14
KATL	2014-04-13 05:52	2014-04-13 01:52	VFR	180	S	6	-	10	20000	18	11	30.13
KATL	2014-04-13 06:52	2014-04-13 02:52	VFR	160	SSE	5	-	10	20000	18	11	30.12
KATL	2014-04-13 07:52	2014-04-13 03:52	VFR	190	S	5	-	10	25000	17	11	30.11
KATL	2014-04-13 08:52	2014-04-13 04:52	VFR	190	S	5	-	10	5000	16	12	30.11
KATL	2014-04-13 09:52	2014-04-13 05:52	VFR	0	N	0	-	10	5000	16	12	30.12

Figure 7. METAR details report from ATM NextGen Data Warehouse.

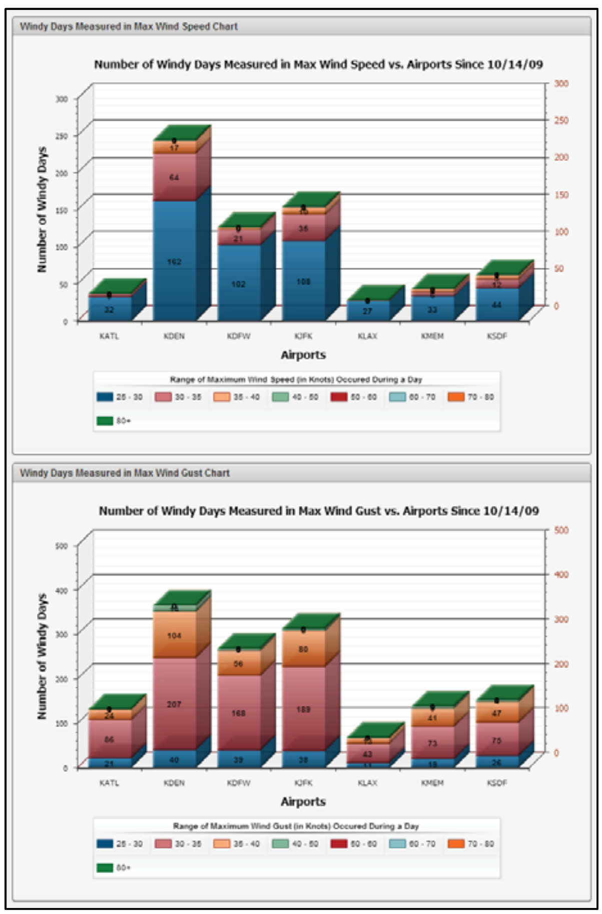


Figure 8. Sample charts displaying number of windy days measured by wind speed and wind gusts at selected airports.

12 Case Study of Dust Storm and Ground Stop at Phoenix Airport

A dust storm is a meteorological phenomenon common in arid and semi-arid regions. High winds and very low visibility caused by dust storms have significant impact on air traffic operations such as departures and arrivals. It is of interest to investigate how METARs can predict restrictions in air traffic operations, to perhaps develop predictive models of operational impacts. METARs between October 2009 and January 2014 show four dust storms at the Phoenix Sky Harbor International Airport in Arizona (KPHX). Each one of the reported dust storms had subsequent Ground Stop advisories issued by the ATCSCC. Departure flights from affected Centers to KPHX were halted as a result. Table 26 shows these Ground Stop advisories.

Table 26. Ground Stop advisories related to dust storms at KPHX.

Ground Stop (GS) Advisory						Ground Stop Cancellation (GSX)			
Advisory Date UTC	ADVZY #	GS Begin (UTC)	GS End (UTC)	Departure Facilities Included	GS Message Sent (UTC)	Advisory Date UTC	ADVZY #	GSX (UTC)	GSX Message Sent (UTC)
2011-07-06	4	2011-07-06 02:44	2011-07-06 04:00	ZAB ZLA	2011-07-06 02:57	2011-07-06	5	2011-07-06 03:47	2011-07-06 03:52
2011-08-19	17*	2011-08-19 00:47	2011-08-19 02:00	ZAB ZLA	2011-08-19 01:05	Ground Stop advisory # 17 was extended by the subsequent advisory # 30			
2011-08-19	30*	2011-08-19 00:47	2011-08-19 03:00	ZAB ZLA ZDV	2011-08-19 01:45	2011-08-19	31	2011-08-19 01:50	2011-08-19 01:52
2012-05-09	74	2012-05-09 23:37	2012-05-10 00:45	ZAB ZLA	2012-05-09 23:38	2012-05-10	2	2012-05-10 00:29	2012-05-10 00:31
2013-08-27	4	2013-08-27 01:39	2013-08-27 02:45	ZAB ZLA ZOA	2013-08-27 01:56	2013-08-27	5	2013-08-27 02:22	2013-08-27 02:24

Note that Ground Stop advisory # 30 on August 19, 2011, was an extension to advisory # 17. Even though there were two physical advisories issued, they were related, so they were counted as one logical Ground Stop advisory. METARs submitted around the same time as these advisories were issued are described in this section. These METARs contain contractions and corresponding descriptions as follows:

Contraction	Description
ALQDS	All Quadrants
DS	Dust Storm
BLDU	Blowing Widespread Dust
HZ	Haze
RA	Rain
TS	Thunderstorm
VC	Vicinity (5 to 10 statute miles)
+	Heavy
-	Light

12.1 Ground Stop Advisory # 4 on July 6, 2011, UTC

Table 27 shows the detailed observations made at the Phoenix airport relative to when the Ground Stop advisory began and when the Ground Stop message was sent.

Table 27. METARs submitted around when Ground Stop advisory # 4 was issued on July 6, 2011, UTC at KPHX.

METAR Report Date (UTC)	Flight Rules Category	Wind Direction	Wind Speed (kn)	Wind Gust (kn)	Visibility (smi)	Ceiling Height AGL (ft)	Body Present Weather Group	Remarks Other Significant Information
2011-07-06 01:51	VFR	WSW	7		10	8000		
Ground Stop advisory # 4 affecting departures from ZAB and ZLA began at 02:44Z.								
2011-07-06 02:51	Marginal VFR	S	17	21	3	8000	HZ	**DS VC NE-SW**
2011-07-06 02:53	Low IFR	S	17	24	0.75	8000	BLDU	**DS VC NE-SW**
2011-07-06 02:55	Low IFR	S	27	38	0.25	200	**+DS**	**DS ALQDS**
Ground Stop advisory # 4 message was sent from ATCSCC at 02:57Z.								
2011-07-06 03:05	Low IFR	SSW	19	46	0.125	300	-RA **+DS**	**DS ALQDS**
2011-07-06 03:12	Low IFR	S	16	33	0.125	100	-RA **+DS**	**DS ALQDS**
2011-07-06 03:16	Low IFR	S	17	27	0.25	200	-RA **+DS**	**DS ALQDS**

Note that at 02:51Z and 0253Z, dust storms at vicinity were already observed and were reported in the Remarks section.

12.2 Ground Stop Advisory # 17 on August 19, 2011, UTC

Table 28 shows the detailed observations made at the Phoenix airport relative to when the Ground Stop advisory began and when the Ground Stop message was sent.

Table 28. METARs submitted around when Ground Stop advisory # 17 was issued on August 19, 2011, UTC at KPHX.

METAR Report Date (UTC)	Flight Rules Category	Wind Direction	Wind Speed (kn)	Wind Gust (kn)	Visibility (smi)	Ceiling Height AGL (ft)	Body Present Weather Group	Remarks Other Significant Information
2011-08-18 23:51	VFR	W	8	16	10	9000		
Ground Stop advisory # 17 affecting departures from ZAB and ZLA began at 00:47Z.								
2011-08-19 00:51	VFR	W	7		10	9000		**DS VC E-S**
2011-08-19 01:00	IFR	SSE	19	29	1.25	9000	BLDU	**DS VC E-S**
2011-08-19 01:04	Low IFR	SSE	21	30	0.5	600	BLDU	**DS VC E-S**
Ground Stop advisory # 17 message was sent from ATCSCC at 01:05Z.								
2011-08-19 01:12	Low IFR	S	20	28	0.5	600	**DS**	
2011-08-19 01:35	IFR	SE	24	34	1	1000	BLDU	
2011-08-19 01:40	IFR	SE	18	33	2	1000	BLDU	
2011-08-19 01:48	IFR	SE	22	33	2	2000	BLDU	
2011-08-19 01:51	Marginal VFR	SE	19	33	4	2000	BLDU	

12.3 Ground Stop Advisory # 74 on May 9, 2012, UTC

Table 29 shows the detailed observations made at the Phoenix airport relative to when the Ground Stop advisory began and when the Ground Stop message was sent.

Table 29. METARs submitted around when Ground Stop advisory # 74 was issued on May 9, 2012, UTC at KPHX.

METAR Report Date (UTC)	Flight Rules Category	Wind Direction	Wind Speed (kn)	Wind Gust (kn)	Visibility (smi)	Ceiling Height AGL (ft)	Body Present Weather Group	Remarks Other Significant Information
2012-05-09 22:51	VFR	S	14	17	10	8000		
2012-05-09 23:33	IFR	E	35	41	1.75	8000	BLDU	
Ground Stop advisory # 74 affecting departures from ZAB and ZLA began at 23:37Z.								
Ground Stop advisory # 74 message was sent from ATCSCC at 23:38Z.								
2012-05-09 23:41	Low IFR	ENE	33	47	0.5	8000	TS **DS**	
2012-05-09 23:46	IFR	ENE	27	40	1.75	800	-TSRA BLDU	
2012-05-09 23:51	IFR	ENE	29	38	5	800	-TSRA BLDU	
2012-05-10 00:33	VFR	N	4		6	7000	+TSRA	
2012-05-10 00:51	Marginal VFR	SSE	22	32	5	8000	-TSRA	

12.4 Ground Stop Advisory # 4 on August 27, 2013, UTC

Table 30 shows the detailed observations made at the Phoenix airport relative to when the Ground Stop advisory began and when the Ground Stop message was sent.

Table 30. METARs submitted around when Ground Stop advisory # 4 was issued on August 27, 2013, UTC at KPHX.

METAR Report Date (UTC)	Flight Rules Category	Wind Direction	Wind Speed (kn)	Wind Gust (kn)	Visibility (smi)	Ceiling Height AGL (ft)	Body Present Weather Group	Remarks Obscuration Group
2013-08-27 00:51	VFR	N	0		10	8000		
2013-08-27 01:22	IFR	N	0		7	900		BLDU FEW009
2013-08-27 01:34	IFR	SSE	29	44	2	900	BLDU	BLDU SCT009
2013-08-27 01:37	IFR	S	23	44	1.25	900	BLDU	BLDU SCT009
2013-08-27 01:38	IFR	S	25	44	1.25	900	BLDU	BLDU BKN009
Ground Stop advisory # 4 affecting departures from ZAB and ZLA and ZOA began at 01:39Z.								
2013-08-27 01:40	Low IFR	S	28	44	.75	900	BLDU	BLDU BKN009
2013-08-27 01:42	Low IFR	S	21	44	.5	900	BLDU	BLDU BKN009
2013-08-27 01:48	Low IFR	S	28	41	.5	900	-TSRA BLDU	BLDU BKN009
2013-08-27 01:51	Low IFR	S	40	48	.5	900	-TSRA BLDU	BLDU BKN009
2013-08-27 01:56	Low IFR	SSW	20	48	.25	900	TSRA **DS**	DU BKN009
Ground Stop advisory # 4 message was sent from ATCSCC at 01:56Z.								

Table 30. Continued.

METAR Report Date (UTC)	Flight Rules Category	Wind Direction	Wind Speed (kn)	Wind Gust (kn)	Visibility (smi)	Ceiling Height AGL (ft)	Body Present Weather Group	Remarks Obscuration Group
2013-08-27 01:58	IFR	S	16	48	1.5	900	TSRA BLDU	DU BKN009
2013-08-27 02:01	IFR	SSE	16	48	2	2000	TSRA BLDU	
2013-08-27 02:10	Marginal VFR	WSW	4		5	2000	+TSRA	
2013-08-27 02:16	Marginal VFR	W	4		5	3200	-TSRA	
2013-08-27 00:51	VFR	N	0		10	8000		
2013-08-27 01:22	IFR	N	0		7	900	-	BLDU FEW009

Note that for Ground Stop advisories # 4 on July 6, 2011, UTC and # 17 on August 19, 2011, UTC, dust storms between 5 to 10 statute miles from KPHX were first described in the Remarks section of METARs. For Ground Stop advisory # 4 on August 27, 2013, UTC, blowing widespread dust was first described in the Remarks section of METARs.

12.5 Significance of Blowing Widespread Dust Referenced in the Remarks Section

From these four sets of METARs, one can notice that a dust storm at the airport may be preceded by a dust storm between 5 to 10 statute miles from KPHX, blowing widespread dust (BLDU), and/or a wind speed of 20 or more knots. There are other observations such as temperature and humidity in the reports that are not listed in the preceding tables. To develop a predictive model of whether a Ground Stop advisory (or Ground Delay Program) will be issued, all candidate input parameters should be fed into the model. If the model is reliable, it can prune the parameters and identify the influential ones. The input parameters in this case should include information from the METARs, Terminal Area Forecast (TAF) reports, and air traffic operational data. The construction of this predictive model is a separate research project and it is not covered in this document. But if the predictive model should ever be constructed, information from the METARs should obviously include BLDU.

There are three possible groups in which BLDU can be reported in a METAR, and BLDU may be reported in multiple groups within a METAR:

- Present Weather group in the Body section, e.g., "BLDU".
- Obscuration group in the Remarks section, an obscuration code followed by a sky cover amount, e.g., "BLDU FEW023".
- Other Significant Information group in the Remarks section, an obscuration code not followed by a sky cover amount, e.g., "BLDU ALQDS".

METARs that had BLDU reported between October 2009 and January 2014 at the Phoenix airport were analyzed. Figure 9 describes, via a Venn diagram, the number of METARs categorized by the three groups that had BLDU reported. There are 294 reports referencing BLDU in total. Among them, 174 reports (59 percent) have BLDU referenced in the Body section only and in both Body and Remarks sections; 120 reports (41percent) have BLDU referenced in the Remarks section only. Figure 10 shows these two sets of reports broken down by years. The annual percentage of reports that have BLDU referenced in the Remarks section only ranges from 29 percent in 2012 to 58 percent in 2013. This shows that reporting BLDU in the Remarks section only is not an isolated case in some distant past.

These two figures show that the Remarks section of a METAR is a significant source of weather conditions. In addition to BLDU, there are other qualitative and quantitative observations that can be extracted from the Remarks section. In conclusion, ignoring any of these observations located in the Remarks section can result in an incomplete or inaccurate model.

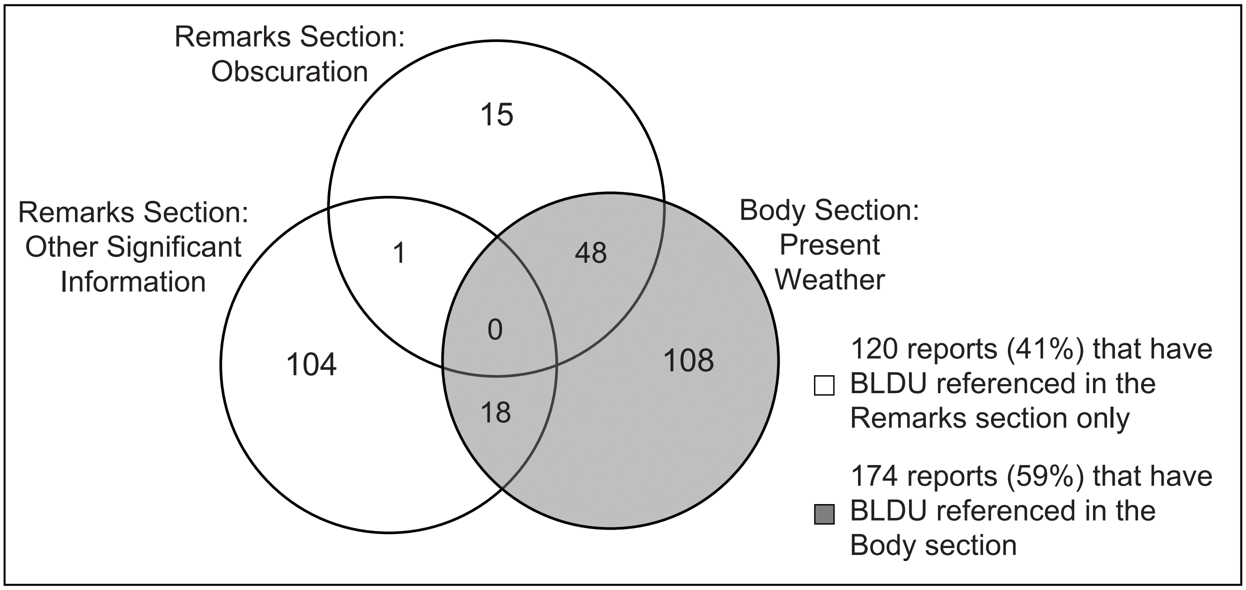


Figure 9. Number of METARs that reported blowing widespread dust.

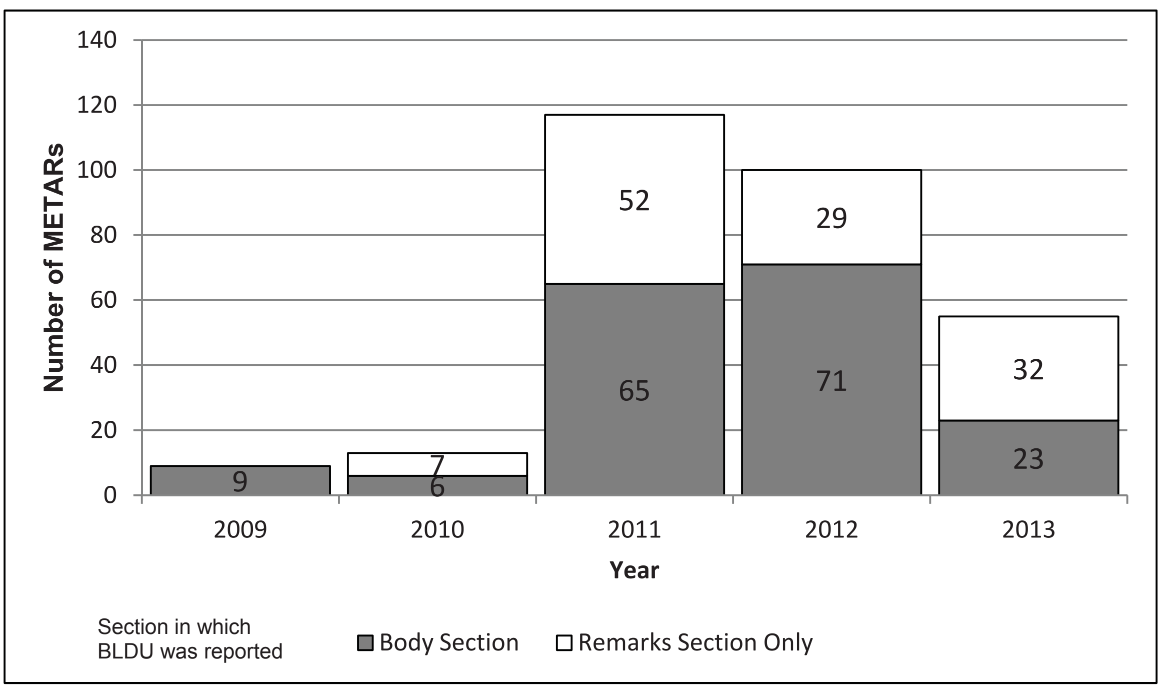


Figure 10. Number of METARs that reported blowing widespread dust by year.

13 Further Potential Works

The completely decoded METARs in the ATM NextGen Data Warehouse are valuable to ATM research. Weather conditions that are described in the Body as well as the Remarks sections are now accessible to researchers. The study of adverse weather conditions at airports, weather forecasts, air traffic operation data, and the probability of subsequent Air Traffic Management Initiatives being issued by ATCSCC is a potential project. Results from the study may help to prove the significance of adverse weather conditions found only in the Remarks section.

Because many of the deviations from the standard coding formats are likely to be caused by a human observer, a software tool should be developed to assist the observer before a METAR is disseminated. Mistakes such as a missing blank space character in a fraction could have been avoided if such a tool exists. As a minimum, the tool should validate a METAR so that any deviations are immediately identified to the observer prior to dissemination of the METAR.

14 Conclusions

Both the Body and Remarks sections of a METAR contain important surface weather observations at an airport. Some observations such as lightning are only available in the Remarks section of a report. Due to manual editing, an observer may enter some important observations in the Remarks section instead of the Body section of a METAR. Any analysis involving surface weather observations from the METARs should not rely solely on the information from the Body section of the reports; ignoring information from the Remarks section may lead to incomplete or inaccurate results.

This document identifies major deviations from the group coding formats found in 12 million METARs. The algorithm for decoding 11 groups from the Body section and 58 groups from the Remarks section accounts for these deviations. The algorithm uses regular expressions to perform text pattern matching to identify all the groups in a METAR.

Because there is no unique character separating groups in a METAR, the algorithm for decoding METARs is by no means perfect. Because no semantic analysis is used in the algorithm, when decoding groups that can contain plain text, in special circumstances, the algorithm can treat some unknown coded text as plain text of an identified group instead. Only a sophisticated semantic analysis of plain text can decipher and determine which part of the plain text describes an observation (e.g., detailed description, location, and moving direction of a weather phenomenon).

When the implemented software was used to decode 12 million METARs, a sustained rate of about 10,000 reports per second was achieved. Thus, any real-time system can also use this algorithm to decode a METAR and to extract the specific information it needs. Daily METARs are decoded and stored in the ATM NextGen Data Warehouse database at NASA Ames. A web-based report system allows users of the Data Warehouse to search, report, and analyze all METAR data from October 2009 to present. This enables users to perform fast ad-hoc data queries and to perform data mining over large amounts of data directly in the database.

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Appendix A: Groups in METAR

Observations and other information in a METAR are categorized in groups. The following list is a combination of groups documented in FMH1; groups that are not documented in FHMH1 are marked in bold.

Groups in the Body section:

1. Type of Report
2. Station Identifier
3. Date and Time of Report
4. Report Modifier
5. Wind
6. Visibility
7. Runway Visual Range
8. Present Weather
9. Sky Condition
10. Temperature and Dew Point
11. Altimeter

Groups in the Remarks section "Automated, Manual, and Plain Language" category:

1. Volcanic Eruptions
2. Funnel Cloud
3. Type of Automated Station
4. Peak Wind
5. Wind Shift
6. Tower or Surface Visibility
7. Variable Prevailing Visibility
8. Sector Visibility
9. Visibility at Second Location
10. Lightning
11. Beginning and Ending of Precipitation
12. Beginning and Ending of Thunderstorms
13. Thunderstorm Location
14. Hailstone Size
15. Virga
16. Variable Ceiling Height
17. Obscuration
18. Variable Sky Condition
19. Significant Cloud Type: Cumulonimbus
20. Significant Cloud Type: Cumulonimbus Mammatus
21. Significant Cloud Type: Towering Cumulus
22. Significant Cloud Type: Altocumulus Castellanus
23. Significant Cloud Type: Stratocumulus
24. Significant Cloud Type: Altocumulus
25. Significant Cloud Type: Cirrocumulus
26. Significant Cloud Type: Rotor Cloud
27. **Significant Cloud Type: Cumulus**

28. Ceiling Height at Second Location
29. Pressure Rising or Falling Rapidly
30. Sea Level Pressure
31. Aircraft Mishap
32. No SPECI Reports Taken
33. Snow Increasing Rapidly
34. Other Significant Information
35. **Low-Level Wind Shear**
36. **Pilot Report**

Groups in the Remarks section "Additive and Automated Maintenance Data" category:

1. Hourly Precipitation Amount
2. 3- and 6-Hour Precipitation Amount
3. 24-Hour Precipitation Amount
4. Snow Depth on Ground
5. Water Equivalent of Snow on Ground
6. **Depth of New Snow**
7. Cloud Types
8. Duration of Sunshine
9. Hourly Temperature and Dew Point
10. 6-Hourly Maximum Temperature
11. 6-Hourly Minimum Temperature
12. 24-Hour Maximum and Minimum Temperature
13. 3-Hourly Pressure Tendency
14. **Hourly, 3- and 6-Hourly Ice Accretion**
15. Sensor Status Indicator: Runway Visual Range Not Reporting
16. Sensor Status Indicator: Present Weather Sensor Not Operating
17. Sensor Status Indicator: Tipping Bucket Rain Gauge Sensor Not Operating
18. Sensor Status Indicator: Freezing Rain Sensor Not Operating
19. Sensor Status Indicator: Lightning Detection System Sensor Not Operating
20. Sensor Status Indicator: Second Visibility Sensor Not Operating
21. Sensor Status Indicator: Second Ceiling Height Sensor Not Operating
22. Automated System Maintenance Needed Indicator

Appendix B: Database Schema Storing Decoded METARs

In the ATM NextGen Data Warehouse, decoded METARs are stored in the table ODS_METAR_REPORTS. Primary key: DATE_TIME_UTC and STATION_ID. Here is the column structure of that table:

Column Name	Data Type	Nullable?	Description
REPORT_DATE_TIME_UTC	DATE	N	FMH1 12.6.3: Date and time in UTC when the METAR was reported.
STATION_ID	CHAR (4)	N	FMH1 12.6.2: Station ID where the METAR observation was made. For example, the ICAO Airport ID, "KJFK".
REPORT_RAW_TEXT	VARCHAR (2000)	N	METAR raw text.
REPORT_DATE_TIME_LTZ	DATE	N	FMH1 12.6.3: Date and time in Local Time Zone when the METAR was reported at the station. For example, "2010-09-15 22:00Z" at KJFK is "2010-09-15 17:00" at US/Eastern time zone.
REPORT_TYPE	VARCHAR (30)	Y	FMH1 12.6.1: METAR type. Either a) METAR: aviation routine weather report format or b) SPECI: aviation selected special weather report format. It is not provided in NOAA's raw METAR.txt.
REPORT_MODIFIER	VARCHAR (30)	Y	FMH1 12.6.4: Report modifier, AUTO, identifies the METAR/SPECI as a fully automated report with no human intervention or oversight. In the event of a corrected METAR or SPECI, the report modifier, COR, shall be substituted in place of AUTO.
WIND_DRCTN_IS_VRB	CHAR (1)	Y	FMH1 12.6.5.b: Wind direction is variable and speed is 6 knots or less. For example, if the wind is variable at 3 knots, it would be coded "VRB03KT".
WIND_DRCTN	NUMBER	Y	FMH1 12.6.5: Wind direction in degrees. For example, a wind direction of 90° at 8 knots shall be coded "09008KT"; a wind speed of 112 knots shall be coded "090112KT".
WIND_SPEED_KT	NUMBER	Y	FMH1 12.6.5: Wind speed in knots. For example, a wind direction of 90° at 8 knots shall be coded "09008KT"; a wind speed of 112 knots shall be coded "090112KT".
WIND_GUST_KT	NUMBER	Y	FMH1 12.6.5.a: Wind gust in knots. For example, a wind from due west at 20 knots with gusts to 35 knots would be coded "27020G35KT".

Column Name	Data Type	Nullable?	Description
VRB_WIND_DRCTN_MIN	NUMBER	Y	FMH1 12.6.5.c: The lower range of variable wind direction in degrees when speed is greater than 6 knots. For example, if the wind is variable from 180° to 240° at 10 knots, it would be coded "21010KT 180V240".
VRB_WIND_DRCTN_MAX	NUMBER	Y	FMH1 12.6.5.c: The upper range of variable wind direction in degrees when speed is greater than 6 knots. For example, if the wind is variable from 180° to 240° at 10 knots, it would be coded "21010KT 180V240".
VISIBILITY_SM	NUMBER	Y	FMH1 12.6.6: Visibility in statute miles. For example, a visibility of 1-1/2 statute miles would be coded "1 1/2SM"; "M1/4SM" means a visibility of less than 1/4 statute mile.
RWY_VISUAL_RANGE_GRP_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.6.7: Runway visual range group in raw text. The standards for observing and reporting Runway Visual Range (RVR) are described in FMH1 Chapter 7. For example, an RVR value for runway 01L of 800 feet would be coded "R01L/0800FT".
PRESENT_WX_GRP_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.6.8: Present weather group in raw text. The standards for observing and reporting present weather are described in FMH1 Chapter 8. For example, heavy rain shower(s) is coded as +SHRA.
PRESENT_WX_DESC_HAS_SH	CHAR (1)	Y	FMH1 12.6.8: Present weather group descriptor has shower(s).
PRESENT_WX_DESC_HAS_TS	CHAR (1)	Y	FMH1 12.6.8: Present weather group descriptor has thunderstorm.
PRESENT_WX_DESC_HAS_FZ	CHAR (1)	Y	FMH1 12.6.8: Present weather group descriptor has freezing precipitation (drizzle or rain) or obscuration (fog).
PRESENT_WX_PCPN_HAS_DZ	CHAR (1)	Y	FMH1 12.6.8: Present weather group precipitation has drizzle.
PRESENT_WX_PCPN_HAS_RA	CHAR (1)	Y	FMH1 12.6.8: Present weather group precipitation has rain.
PRESENT_WX_PCPN_HAS_SN	CHAR (1)	Y	FMH1 12.6.8: Present weather group precipitation has snow.
PRESENT_WX_PCPN_HAS_SG	CHAR (1)	Y	FMH1 12.6.8: Present weather group precipitation has snow grains.
PRESENT_WX_PCPN_HAS_IC	CHAR (1)	Y	FMH1 12.6.8: Present weather group precipitation has ice crystals.
PRESENT_WX_PCPN_HAS_PL	CHAR (1)	Y	FMH1 12.6.8: Present weather group precipitation has ice pellets.
PRESENT_WX_PCPN_HAS_GR	CHAR (1)	Y	FMH1 12.6.8: Present weather group precipitation has hail.

Column Name	Data Type	Nullable?	Description
PRESENT_WX_PCPN_HAS_GS	CHAR (1)	Y	FMH1 12.6.8: Present weather group precipitation has small hail and/or snow pellets.
PRESENT_WX_PCPN_HAS_UP	CHAR (1)	Y	FMH1 12.6.8: Present weather group precipitation has unknown precipitation.
PRESENT_WX_OBSC_HAS_BR	CHAR (1)	Y	FMH1 12.6.8: Present weather group obscuration has mist.
PRESENT_WX_OBSC_HAS_FG	CHAR (1)	Y	FMH1 12.6.8: Present weather group obscuration has fog.
PRESENT_WX_OBSC_HAS_FU	CHAR (1)	Y	FMH1 12.6.8: Present weather group obscuration has smoke.
PRESENT_WX_OBSC_HAS_VA	CHAR (1)	Y	FMH1 12.6.8: Present weather group obscuration has volcanic ash.
PRESENT_WX_OBSC_HAS_DU	CHAR (1)	Y	FMH1 12.6.8: Present weather group obscuration has widespread dust.
PRESENT_WX_OBSC_HAS_SA	CHAR (1)	Y	FMH1 12.6.8: Present weather group obscuration has sand.
PRESENT_WX_OBSC_HAS_HZ	CHAR (1)	Y	FMH1 12.6.8: Present weather group obscuration has haze.
PRESENT_WX_OBSC_HAS_PY	CHAR (1)	Y	FMH1 12.6.8: Present weather group obscuration has spray.
PRESENT_WX_OTR_HAS_PO	CHAR (1)	Y	FMH1 12.6.8: Present weather group other has well-developed dust/sand whirls.
PRESENT_WX_OTR_HAS_SQ	CHAR (1)	Y	FMH1 12.6.8: Present weather group other has squalls.
PRESENT_WX_OTR_HAS_FC	CHAR (1)	Y	FMH1 12.6.8: Present weather group other has funnel cloud.
PRESENT_WX_OTR_HAS_TW	CHAR (1)	Y	FMH1 12.6.8: Present weather group other has tornado or waterspout.
PRESENT_WX_OTR_HAS_SS	CHAR (1)	Y	FMH1 12.6.8: Present weather group other has sandstorm.
PRESENT_WX_OTR_HAS_DS	CHAR (1)	Y	FMH1 12.6.8: Present weather group other has dust storm.
SKY_CONDITION_GRP_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.6.9: Sky condition group in raw text. For example, a scattered layer of towering cumulus at 1,500 feet would be coded "SCT015TCU" and would be followed by a space if there were additional higher layers to code.
SKY_CONDITION_GRP_HAS_CB	CHAR (1)	Y	FMH1 12.6.9: Sky condition group has cumulonimbus (CB) reference(s).
SKY_CONDITION_GRP_HAS_TCU	CHAR (1)	Y	FMH1 12.6.9: Sky condition group has towering cumulus (TCU) reference(s).
SKY_LOWEST_LAYER_ALT_FT	NUMBER	Y	FMH1 12.6.9: The lowest layer altitude in feet within the sky condition group. For example, the ceiling is 1,200 feet if the reported sky condition is "BKN012 BKN018 OVC024".

Column Name	Data Type	Nullable?	Description
TEMPERATURE_C	NUMBER	Y	FMH1 12.6.10: Temperature in °C.
DEW_POINT_C	NUMBER	Y	FMH1 12.6.10: Dew point in °C.
ALTIMETER_HG	NUMBER	Y	FMH1 12.6.10: Altimeter in inches of mercury.
UNKNOWN_TOKENS_RAW_TEXT	VARCHAR (2000)	Y	Any undecodable text from the Body section of the METAR.
RMK_VOLCANIC_ERPTNS_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.a (remarks section): Volcanic eruptions in raw text. For example, "VA MOV NW", "VOLCANO 70 MILES SW ERUPTED 231505 LARGE ASH CLOUD EXTENDING TO APRX 30000 FEET MOVING NE".
RMK_HAS_VOLCANIC_ERPTNS	CHAR (1)	Y	FMH1 12.7.1.a (remarks section): Remarks has volcanic eruptions raw text.
RMK_FUNNEL_CLD_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.b (remarks section): Funnel cloud in raw text. For example, "TORNADO B13 6 NE" would indicate that a tornado, which began at 13 minutes past the hour, was 6 statute miles northeast of the station.
RMK_TYPE_OF_AUTOMATED_STATION	VARCHAR (30)	Y	FMH1 12.7.1.c (remarks section): Type of automated station. Only the first code is decoded. For example, automated stations without a precipitation discriminator shall be identified as AO1; automated station with one shall be identified as AO2.
RMK_PK_WND_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.d (remarks section): Remarks has peak wind raw text. For example, a peak wind of 45 knots from 280 degrees that occurred at 15 minutes past the hour would be coded "PK WND 28045/15".
RMK_PK_WND_DRCTN	NUMBER	Y	FMH1 12.7.1.d (remarks section): Peak wind direction in degrees.
RMK_PK_WND_SPEED_KT	NUMBER	Y	FMH1 12.7.1.d (remarks section): Peak wind speed in knots.
RMK_PK_WND_DATE_TIME_UTC	DATE	Y	FMH1 12.7.1.d (remarks section): Peak wind date and time in UTC.
RMK_WSHFT_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.e (remarks section): Wind shift raw text. For example, a remark reporting a wind shift accompanied by a frontal passage that began at 30 minutes after the hour would be coded as "WSHFT 30 FROPA".
RMK_WSHFT_DATE_TIME_UTC	DATE	Y	FMH1 12.7.1.e (remarks section): Wind shift date and time in UTC.
RMK_HAS_WSHFT	CHAR (1)	Y	FMH1 12.7.1.e (remarks section): Remarks has wind shift references.
RMK_WSHFT_HAS_FROPA	CHAR (1)	Y	FMH1 12.7.1.e (remarks section): Has frontal passage reference(s) that are usually associated with wind shift.

Column Name	Data Type	Nullable?	Description
RMK_TWR_VIS_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.f (remarks section): Tower visibility raw text. For example, the control tower visibility of 1-1/2 statute miles would be coded "TWR VIS 1 1/2".
RMK_TWR_VIS_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.f (remarks section): Tower visibility in statute miles (in most cases). The distance may contain fractions and other text. For example, "2", "2 1/2", "GTR THAN FOUR", etc.
RMK_SFC_VIS_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.f (remarks section): Surface visibility raw text.
RMK_SFC_VIS_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.f (remarks section): Surface visibility expressed in statute miles (in most cases). The distance may contain fractions and other text.
RMK_VRB_PRVL_VIS_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.g (remarks section): Variable prevailing visibility raw text. For example, a visibility that was varying between 1/2 and 2 statute miles would be coded "VIS 1/2V2".
RMK_VRB_PRVL_VIS_LOWEST_SM	NUMBER	Y	FMH1 12.7.1.g (remarks section): Lowest prevailing visibility in statute miles.
RMK_VRB_PRVL_VIS_HIGHEST_SM	NUMBER	Y	FMH1 12.7.1.g (remarks section): Highest prevailing visibility in statute miles.
RMK_SCTR_VIS_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.h (remarks section): Sector visibility raw text. For example, a visibility of 2-1/2 statute miles in the northeastern octant would be coded "VIS NE 2 1/2".
RMK_SCTR_VIS_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.h (remarks section): Sector visibility direction and distance in statute miles (in most cases). For example, "W 2", "LWR W", "LWR SE MTNS PRTLY OBSCD ALQDS", etc.
RMK_VIS_SCND_LCTN_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.i (remarks section): Visibility at second location raw text. For example, a visibility of 2-1/2 statute miles measured by a second sensor located at runway 11 would be coded "VIS 2 1/2 RWY11".
RMK_VIS_SCND_LCTN_SM	NUMBER	Y	FMH1 12.7.1.i (remarks section): Visibility at second location in statute miles.
RMK_VIS_SCND_LCTN_LOC	VARCHAR (2000)	Y	FMH1 12.7.1.i (remarks section): Location of the observed visibility at second location.
RMK_LTG_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.j (remarks section): Lightning raw text. For example, "OCNL LTGICCG OHD", “FRQ LTG VC", or "LTG DSNT W".
RMK_HAS_LTG	CHAR (1)	Y	FMH1 12.7.1.j (remarks section): Remarks has lightning references.
RMK_LTG_FREQUENCY	VARCHAR (30)	Y	FMH1 12.7.1.j (remarks section): Lightning frequency.

Column Name	Data Type	Nullable?	Description
RMK_LTG_TYPE	VARCHAR (30)	Y	FMH1 12.7.1.j (remarks section): Lightning type.
RMK_LTG_LOC	VARCHAR (2000)	Y	FMH1 12.7.1.j (remarks section): Lightning location.
RMK_BE_PCPN_OR_TS_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.k (remarks section): Beginning and ending of precipitation or thunderstorms raw text. For example, if rain began at 0005, ended at 0030, and snow began at 0020, and ended at 0055, the remarks would be coded "RAB05E30SNB20E55".
RMK_BGN_TS_DATE_TIME_UTC	DATE	Y	FMH1 12.7.1.l (remarks section): Beginning of thunderstorm date and time in UTC.
RMK_END_TS_DATE_TIME_UTC	DATE	Y	FMH1 12.7.1.l (remarks section): Ending of thunderstorm date and time in UTC.
RMK_TS_LCTN_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.m (remarks section): Thunderstorm location raw text. For example, a thunderstorm southeast of the station and moving toward the northeast would be coded "TS SE MOV NE".
RMK_TS_LCTN_LOC	VARCHAR (2000)	Y	FMH1 12.7.1.m (remarks section): Location of thunderstorm.
RMK_TS_LCTN_MVNG_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.m (remarks section): Thunderstorm moving direction.
RMK_GR_SIZE_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.n (remarks section): Hailstone size in raw text. For example, "GR 1 3/4" would indicate that the largest hailstones were 1-3/4 inches in diameter.
RMK_GR_SIZE_IN	NUMBER	Y	FMH1 12.7.1.n (remarks section): Hailstone size in inches.
RMK_VIRGA_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.o (remarks section): Virga raw text. For example, "VIRGA SW".
RMK_HAS_VIRGA	CHAR (1)	Y	FMH1 12.7.1.o (remarks section): Remarks has virga references.
RMK_VIRGA_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.o (remarks section): Virga direction from the station.
RMK_VRB_CIG_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.p (remarks section): Variable ceiling height raw text. For example, "CIG 005V010" would indicate a ceiling that was varying between 500 and 1,000 feet.
RMK_VRB_CIG_LOWEST_FT	NUMBER	Y	FMH1 12.7.1.p (remarks section): Lowest ceiling height in feet.
RMK_VRB_CIG_HIGHEST_FT	NUMBER	Y	FMH1 12.7.1.p (remarks section): Highest ceiling height in feet.

Column Name	Data Type	Nullable?	Description
RMK_OBSC_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.q (remarks section): Obscurations raw text. For example, fog hiding 3-4 oktas of the sky would be coded "FG SCT000"; a broken layer at 2,000 feet composed of smoke would be coded "FU BKN020".
RMK_OBSC_CAUSING_WX	VARCHAR (30)	Y	FMH1 12.7.1.q (remarks section): Obscuration causing weather.
RMK_OBSC_SKY_COVER	VARCHAR (30)	Y	FMH1 12.7.1.q (remarks section): Obscuration sky cover.
RMK_OBSC_HGT_FT	NUMBER	Y	FMH1 12.7.1.q (remarks section): Obscuration height in feet.
RMK_VRB_SKY_COND_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.r (remarks section): Variable sky condition raw text. For example, a cloud layer at 1,400 feet that is varying between broken and overcast would be coded "BKN014 V OVC".
RMK_VRB_SKY_COND1	VARCHAR (30)	Y	FMH1 12.7.1.r (remarks section): First of two operationally significant sky conditions.
RMK_VRB_SKY_COND1_LYR_HGT_FT	NUMBER	Y	FMH1 12.7.1.r (remarks section): First sky condition layer height in feet.
RMK_VRB_SKY_COND2	VARCHAR (30)	Y	FMH1 12.7.1.r (remarks section): The second condition of two operationally significant sky conditions.
RMK_SGFNT_CLD_CB_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Significant cloud type cumulonimbus raw text.
RMK_SGFNT_CLD_HAS_CB	CHAR (1)	Y	FMH1 12.7.1.s (remarks section): Remarks has cumulonimbus cloud.
RMK_SGFNT_CLD_CB_LOC	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Location of cumulonimbus cloud.
RMK_SGFNT_CLD_CB_MVNG_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Moving direction of cumulonimbus cloud.
RMK_SGFNT_CLD_CBMAM_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Significant cloud type cumulonimbus mammatus raw text.
RMK_SGFNT_CLD_HAS_CBMAM	CHAR (1)	Y	FMH1 12.7.1.s (remarks section): Remarks has cumulonimbus mammatus cloud.
RMK_SGFNT_CLD_CBMAM_LOC	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Location of cumulonimbus mammatus cloud.
RMK_SGFNT_CLD_CBMAM_MVNG_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Moving direction of cumulonimbus mammatus cloud.
RMK_SGFNT_CLD_TCU_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Significant cloud type towering cumulus raw text.
RMK_SGFNT_CLD_HAS_TCU	CHAR (1)	Y	FMH1 12.7.1.s (remarks section): Remarks has towering cumulus cloud.
RMK_SGFNT_CLD_TCU_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Direction of towering cumulus cloud.

Column Name	Data Type	Nullable?	Description
RMK_SGFNT_CLD_ACC_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Significant cloud type altocumulus castellanus raw text.
RMK_SGFNT_CLD_HAS_ACC	CHAR (1)	Y	FMH1 12.7.1.s (remarks section): Remarks has altocumulus castellanus cloud.
RMK_SGFNT_CLD_ACC_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Direction of altocumulus castellanus cloud.
RMK_SGFNT_CLD_SCSL_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Significant cloud type stratocumulus raw text.
RMK_SGFNT_CLD_HAS_SCSL	CHAR (1)	Y	FMH1 12.7.1.s (remarks section): Remarks has stratocumulus cloud.
RMK_SGFNT_CLD_SCSL_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Direction of stratocumulus cloud.
RMK_SGFNT_CLD_ACSL_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Significant cloud type altocumulus raw text.
RMK_SGFNT_CLD_HAS_ACSL	CHAR (1)	Y	FMH1 12.7.1.s (remarks section): Remarks has altocumulus cloud.
RMK_SGFNT_CLD_ACSL_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Direction of altocumulus cloud.
RMK_SGFNT_CLD_CCSL_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Significant cloud type cirrocumulus raw text.
RMK_SGFNT_CLD_HAS_CCSL	CHAR (1)	Y	FMH1 12.7.1.s (remarks section): Remarks has cirrocumulus cloud.
RMK_SGFNT_CLD_CCSL_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Direction of cirrocumulus cloud.
RMK_SGFNT_CLD_ROTOR_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Significant cloud type rotor clouds raw text.
RMK_SGFNT_CLD_HAS_ROTOR	CHAR (1)	Y	FMH1 12.7.1.s (remarks section): Remarks has rotor clouds.
RMK_SGFNT_CLD_ROTOR_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Direction of rotor clouds.
RMK_SGFNT_CLD_CU_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Significant cloud type cumulus raw text.
RMK_SGFNT_CLD_HAS_CU	CHAR (1)	Y	FMH1 12.7.1.s (remarks section): Remarks has cumulus cloud.
RMK_SGFNT_CLD_CU_LOC	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Location of cumulus cloud.
RMK_SGFNT_CLD_CU_MVNG_DRCTN	VARCHAR (2000)	Y	FMH1 12.7.1.s (remarks section): Moving direction of cumulus cloud.
RMK_CIG_SCND_LCTN_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.t (remarks section): Ceiling height at second location raw text. For example, if the ceiling measured by a second sensor located at runway 11 is broken at 200 feet, the remark would be "CIG 002 RWY11".

Column Name	Data Type	Nullable?	Description
RMK_CIG_SCND_LCTN_FT	NUMBER	Y	FMH1 12.7.1.t (remarks section): Ceiling height at second location in feet.
RMK_CIG_SCND_LCTN_LOC	VARCHAR (2000)	Y	FMH1 12.7.1.t (remarks section): The second location of ceiling height.
RMK_PRESRR	CHAR (1)	Y	FMH1 12.7.1.u (remarks section): Pressure was rising rapidly at the time of observation.
RMK_PRESFR	CHAR (1)	Y	FMH1 12.7.1.u (remarks section): Pressure was falling rapidly at the time of observation.
RMK_SLP_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.v (remarks section): Sea level pressure raw text. For example, a sea level pressure of 998.2 hectopascals would be coded as "SLP982". For a METAR, if sea level pressure is not available, it is coded as "SLPNO".
RMK_SLP_MB	NUMBER	Y	FMH1 12.7.1.v (remarks section): Sea level pressure in millibar or hectopascals.
RMK_ACFT_MSHP_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.w (remarks section): Aircraft mishap raw text.
RMK_HAS_ACFT_MSHP	CHAR (1)	Y	FMH1 12.7.1.w (remarks section): Remarks has aircraft mishap references.
RMK_NOSPECI_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.x (remarks section): No SPECI reports taken raw text. At manual stations where SPECIs are not taken, the remark NOSPECI shall be coded to indicate that no changes in weather conditions will be reported until the next METAR.
RMK_NOSPECI	CHAR (1)	Y	FMH1 12.7.1.x (remarks section): Remarks has no SPECI reports taken references.
RMK_SNINCR_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.y (remarks section): Snow was increasing rapidly raw text. For example, a snow depth increase of 2 inches in the past hour with a total depth on the ground of 10 inches would be coded "SNINCR 2/10".
RMK_SNINCR_INHR	NUMBER	Y	FMH1 12.7.1.y (remarks section): The snow depth increase in the past hour.
RMK_SNINCR_ON_GROUND_IN	NUMBER	Y	FMH1 12.7.1.y (remarks section): The total snow depth in inches on the ground at the time of the report.
RMK_OTHR_SGFNT_INFO_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.1.z (remarks section): Other significant information raw text. Agencies may add to a report other information significant to their operations, such as information on fog dispersal operations, runway conditions, "FIRST" or "LAST" report from station, etc. It may also contain any undecodable text from the Remarks section of the METAR.
RMK_HOURLY_PCPN_AMT_IN	NUMBER	Y	FMH1 12.7.2.a.3.a (remarks section): Hourly precipitation amount in inches.

Column Name	Data Type	Nullable?	Description
RMK_3HOURLY_PCPN_AMT_IN	NUMBER	Y	FMH1 12.7.2.a.3.b (remarks section): The amount of precipitation in inches (water equivalent) accumulated in the past 3 hours shall be reported in a 3-hourly report when the observation hour is either 02, 03, 08, 09, 14, 15, 20, or 21.
RMK_6HOURLY_PCPN_AMT_IN	NUMBER	Y	FMH1 12.7.2.a.3.b (remarks section): The amount of precipitation in inches (water equivalent) accumulated in the past 6 hours shall be reported in a 6-hourly report when the observation hour is either 00, 05, 06, 11, 12, 17, 18, or 23.
RMK_24HOUR_PCPN_AMT_IN	NUMBER	Y	FMH1 12.7.2.a.3.c (remarks section): The amount of precipitation in inches in the past 24 hours.
RMK_SN_DPTH_ON_GRD_IN	NUMBER	Y	FMH1 12.7.2.a.3.d (remarks section): The total snow depth on the ground in inches reported in the 0000, 0600, 1200, and 1800 UTC observations.
RMK_WTR_EQVT_OF_SN_ON_GND_IN	NUMBER	Y	FMH1 12.7.2.a.3.e (remarks section): At designated stations, the water equivalent of snow on the ground in inches shall be coded each day, in the 1800 UTC report, if the average snow depth is 2 inches or more.
RMK_DPTH_OF_NEW_SN_IN	NUMBER	Y	FMH1 12.7.2.a.3 (remarks section): Depth of new snow (snowfall) in inches in the last 6 hours. It includes all fallen snow even if some (or all) of it melted. This is not described in the Federal Meteorological Handbook. See http://www.ncdc.noaa.gov/gw/scddoc.html.
RMK_PDMT_CLD_TYPES_RAW_TEXT	VARCHAR (2000)	Y	FMH1 12.7.2.b (remarks section): Predominant cloud types raw text. For example, a report of "8/6//" would indicate an overcast layer of stratus clouds; a report of "8/903" would indicate cumulonimbus type low clouds, no middle clouds, and dense cirrus high clouds.
RMK_PDMT_LOW_CLD_CODE	CHAR (1)	Y	FMH1 12.7.2.b (remarks section): Predominant low cloud code. See WMO International Cloud Atlas, Volumes I and II, or the WMO Abridged International Cloud Atlas or agency observing aids for cloud identification.
RMK_PDMT_MED_CLD_CODE	CHAR (1)	Y	FMH1 12.7.2.b (remarks section): Predominant middle cloud code. See WMO International Cloud Atlas, Volumes I and II, or the WMO Abridged International Cloud Atlas or agency observing aids for cloud identification.

Column Name	Data Type	Nullable?	Description
RMK_PDMT_HGH_CLD_CODE	CHAR (1)	Y	FMH1 12.7.2.b (remarks section): Predominant high cloud code. See WMO International Cloud Atlas, Volumes I and II, or the WMO Abridged International Cloud Atlas or agency observing aids for cloud identification.
RMK_DURN_OF_SUNSHINE_MIN	NUMBER	Y	FMH1 12.7.2.c (remarks section): The duration of sunshine in minutes that occurred the previous calendar day shall be coded in the 0800 UTC report.
RMK_HOURLY_TEMPERATURE_C	NUMBER	Y	FMH1 12.7.2.d (remarks section): Hourly temperature in °C.
RMK_HOURLY_DEW_POINT_C	NUMBER	Y	FMH1 12.7.2.d (remarks section): Hourly dew point in °C.
RMK_6HOURLY_MAX_TEMP_C	NUMBER	Y	FMH1 12.7.2.e (remarks section): 6-hourly maximum temperature in °C.
RMK_6HOURLY_MIN_TEMP_C	NUMBER	Y	FMH1 12.7.2.f (remarks section): 6-hourly minimum temperature in °C.
RMK_24HOUR_MAX_TEMP_C	NUMBER	Y	FMH1 12.7.2.g (remarks section): 24-hour maximum temperature in °C.
RMK_24HOUR_MIN_TEMP_C	NUMBER	Y	FMH1 12.7.2.g (remarks section): 24-hour minimum temperature in °C.
RMK_3HOURLY_PRES_TENDENCY_CODE	CHAR (1)	Y	FMH1 12.7.2.h (remarks section): 3-hourly pressure tendency code. See Table 12-7 of FMH1 for the list of codes.
RMK_3HOURLY_PRES_TENDENCY_MB	NUMBER	Y	FMH1 12.7.2.h (remarks section): 3-hourly pressure tendency, the amount of barometric change, in millibar or hectopascals.
RMK_HOURLY_ICE_ACC_AMT_IN	NUMBER	Y	Hourly ice accretion amount in inches. This is not described in the Federal Meteorological Handbook but in Automated Surface Observing System (ASOS) Release Note Software Version 3.7 or later, http://www.nws.noaa.gov/ops2/Surface/documents/release_notes_307_draft.pdf.
RMK_3HOURLY_ICE_ACC_AMT_IN	NUMBER	Y	Ice accretion amount in inches in the past 3 hours shall be reported in a 3-hourly report when the observation hour is either 02, 03, 08, 09, 14, 15, 20, or 21. This is not described in the Federal Meteorological Handbook but in Automated Surface Observing System (ASOS) Release Note Software Version 3.7 or later, http://www.nws.noaa.gov/ops2/Surface/documents/release_notes_307_draft.pdf.

Column Name	Data Type	Nullable?	Description
RMK_6HOURLY_ICE_ACC_AMT_IN	NUMBER	Y	Ice accretion amount in inches in the past 6 hours shall be reported in a 6-hourly report when the observation hour is either 00, 05, 06, 11, 12, 17, 18, or 23. This is not described in the Federal Meteorological Handbook but in Automated Surface Observing System (ASOS) Release Note Software Version 3.7 or later, http://www.nws.noaa.gov/ops2/Surface/documents/release_notes_307_draft.pdf.
RMK_SENSOR_STATUS_RVRNO	CHAR (1)	Y	FMH1 12.7.2.i.1 (remarks section): Sensor status of runway visual range should be reported but is missing.
RMK_SENSOR_STATUS_PWINO	CHAR (1)	Y	FMH1 12.7.2.i.2 (remarks section): Sensor status of present weather sensor is not operating.
RMK_SENSOR_STATUS_PNO	CHAR (1)	Y	FMH1 12.7.2.i.3 (remarks section): Sensor status of tipping bucket rain gauge is not operating.
RMK_SENSOR_STATUS_FZRANO	CHAR (1)	Y	FMH1 12.7.2.i.4 (remarks section): Sensor status of freezing rain sensor is not operating.
RMK_SENSOR_STATUS_TSNO	CHAR (1)	Y	FMH1 12.7.2.i.5 (remarks section): Sensor status of lightning detection sensor is not operating.
RMK_SENSOR_STATUS_VISNO_LOC	VARCHAR (30)	Y	FMH1 12.7.2.i.6 (remarks section): Sensor status of secondary visibility sensor is not operating.
RMK_SENSOR_STATUS_CHINO_LOC	VARCHAR (30)	Y	FMH1 12.7.2.i.7 (remarks section): Sensor status of secondary ceiling height sensor is not operating.
RMK_SENSOR_STATUS_MAINT_NEEDED	CHAR (1)	Y	FMH1 12.7.2.j (remarks section): Automated system detects that maintenance is needed on the system.
RMK_HAS_SH	CHAR (1)	Y	Remarks section has shower(s) reference(s).
RMK_HAS_TS	CHAR (1)	Y	Remarks section has thunderstorm reference(s).
RMK_HAS_FZ	CHAR (1)	Y	Remarks section has freezing reference(s) of precipitation (drizzle or rain) or obscuration (fog).
RMK_HAS_DZ	CHAR (1)	Y	Remarks section has drizzle reference(s).
RMK_HAS_RA	CHAR (1)	Y	Remarks section has rain reference(s).
RMK_HAS_SN	CHAR (1)	Y	Remarks section has snow reference(s).
RMK_HAS_SG	CHAR (1)	Y	Remarks section has snow grains reference(s).
RMK_HAS_IC	CHAR (1)	Y	Remarks section has ice crystals reference(s).
RMK_HAS_PL	CHAR (1)	Y	Remarks section has ice pellets reference(s).
RMK_HAS_GR	CHAR (1)	Y	Remarks section has hail reference(s).
RMK_HAS_GS	CHAR (1)	Y	Remarks section has small hail and/or snow pellets reference(s).
RMK_HAS_UP	CHAR (1)	Y	Remarks section has unknown precipitation reference(s).
RMK_HAS_BR	CHAR (1)	Y	Remarks section has mist reference(s).

Column Name	Data Type	Nullable?	Description
RMK_HAS_FG	CHAR (1)	Y	Remarks section has fog reference(s).
RMK_HAS_FU	CHAR (1)	Y	Remarks section has smoke reference(s).
RMK_HAS_VA	CHAR (1)	Y	Remarks section has volcanic ash reference(s).
RMK_HAS_DU	CHAR (1)	Y	Remarks section has widespread dust reference(s).
RMK_HAS_SA	CHAR (1)	Y	Remarks section has sand reference(s).
RMK_HAS_HZ	CHAR (1)	Y	Remarks section has haze reference(s).
RMK_HAS_PY	CHAR (1)	Y	Remarks section has spray reference(s).
RMK_HAS_PO	CHAR (1)	Y	Remarks section has well-developed dust/sand whirls reference(s).
RMK_HAS_SQ	CHAR (1)	Y	Remarks section has squalls reference(s).
RMK_HAS_FC	CHAR (1)	Y	Remarks section has funnel cloud reference(s).
RMK_HAS_TW	CHAR (1)	Y	Remarks section has tornado or waterspout reference(s).
RMK_HAS_SS	CHAR (1)	Y	Remarks section has sandstorm reference(s).
RMK_HAS_DS	CHAR (1)	Y	Remarks section has dust storm reference(s).
RMK_LLWS_RAW_TEXT	VARCHAR (2000)	Y	Low-level wind shear raw text. This is not described in the Federal Meteorological Handbook.
RMK_HAS_LLWS	CHAR (1)	Y	Remarks has low-level wind shear references.
RMK_PIREP_RAW_TEXT	VARCHAR (2000)	Y	Pilot report raw text. This is not described in the Federal Meteorological Handbook.
RMK_HAS_PIREP	CHAR (1)	Y	Remarks has pilot report reference(s).