Six Years of the Solar Radiation Data Archive
Citizen Weather Observer Program

February 2009 – February 2015

February 17, 2015
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FOREWORD

In the State of the Union address of February 9, 2009, President Barack Obama highlighted a vision that solar energy assume a greater role America's future mix of energy sources. The Citizen Weather Observer Program (CWOP) was collecting weather data from interested citizens but not saving solar radiation data. If the solar radiation data being sent to CWOP were archived permanently and made available, it would over time comprise a useful observational basis for research and planning of solar energy generation.

So, automatic collection of most CWOP reports of solar radiation was programmed. On February 18, 2009, the new archive began to collect data.

This data report marks the sixth anniversary of that archive. As of January 20, 2015, the archive had collected about 240 million reports. This report aims to present the dimensions of the data archive as it is now – February 18, 2009 through January 20, 2015 (and growing daily) – and to publicize means of universal access.

BACKGROUND

The CWOP solar radiation data archive is a subset of the Citizen Weather Observer Program, in turn a part of the APRS (Automatic Position Reporting System or Automatic Packet Reporting System) data sharing infrastructure, a digital communications system that grew out of amateur radio over the past two decades. For the origin of APRS, see http://aprs.org/. In 2000, the Citizen Weather Observer Program came into being using APRS as a platform for the sharing of weather station reports, initially from hams to NOAA and shortly from other citizens to NOAA. See http://wxqa.com. CWOP used the existing APRS protocols for sharing of such data. The service proved popular and it grew rapidly and today has over 10,000 regularly contributing stations. CWOP today provides standards, technical support and a community to interested weather observers making observations and willing to share them with NOAA and other users.

There are several web-based pages that CWOP members can use to view their and other CWOP station data and relevant information. The findu.com site shows station location

http://www.findu.com/cgi-bin/find.cgi?call=K4HG-2&radar=***

and the links on the left side of the page show graphs and displays relating to the weather data. The gladstonefamily.com site gives information, including quality checking, relating to any specific site

http://weather.gladstonefamily.net/site/C0003

and other services relating to data quality as listed here http://wxqa.com/aprswxnetqc.html

including an e-mail reflector by which volunteer experts provide support to new observers.

The wxqa.com site has a search tool that does searches for results and other information relating to any of the CWOP stations,

http://wxqa.com/search.htm

There is also a search tool relating specifically to those stations that include solar radiation data with the weather data they send in,

http://wxqa.com/lum_search.htm

CWOP collects and shares a torrent of weather data, but at the outset did not undertake to archive all of it. In this context, the role of the solar radiation data archive has been to secure most CWOP measurements of solar radiation, since February 18, 2009. This report aims to describe those data holdings.

THE SOLAR RADIATION DATA ARCHIVE

About 240 million reports are now in the archive. Their accession to the archive over time is as shown in Figure 1, which indicates seasonal variation because the network is denser in the Northern Hemisphere. Thus the number of weather packets reporting non-zero solar radiation is greater during Northern Hemisphere summer when daylight is longer.

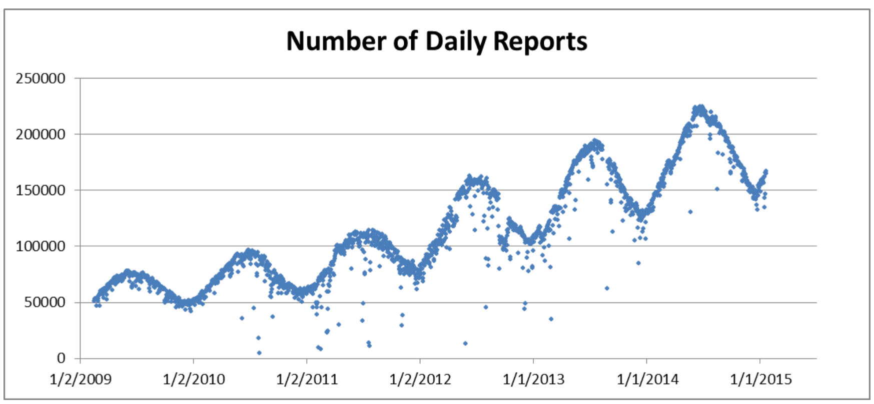


Fig. 1 Number of daily reports in the CWOP Solar Radiation Archive.

Of the 2163 days from February 18, 2009 to January 20, 2015 inclusive, the archive has captured data from 2130 days. A few percent of data were lost while server operational procedures were being stabilized: altogether 33 days (see Annex A).

The number of stations reporting solar radiation has risen steadily. Figure 2 presents the number of stations reporting each day over the six year period.

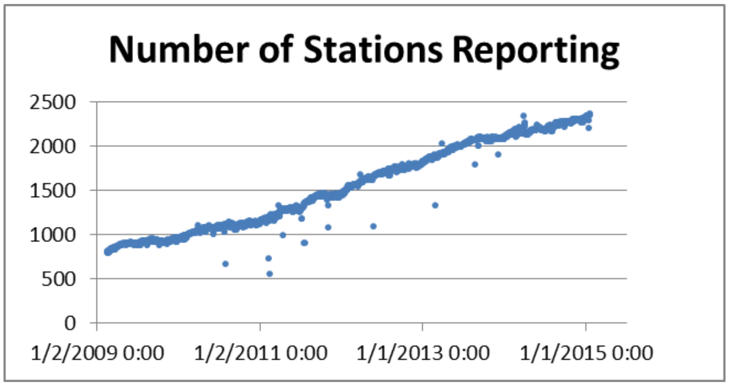


Fig. 2 Number of stations reporting each day.

Altogether, more than 4100 stations have reported to the archive ten times or more during the six year period, with a distribution of time series length as shown in Figure 3.

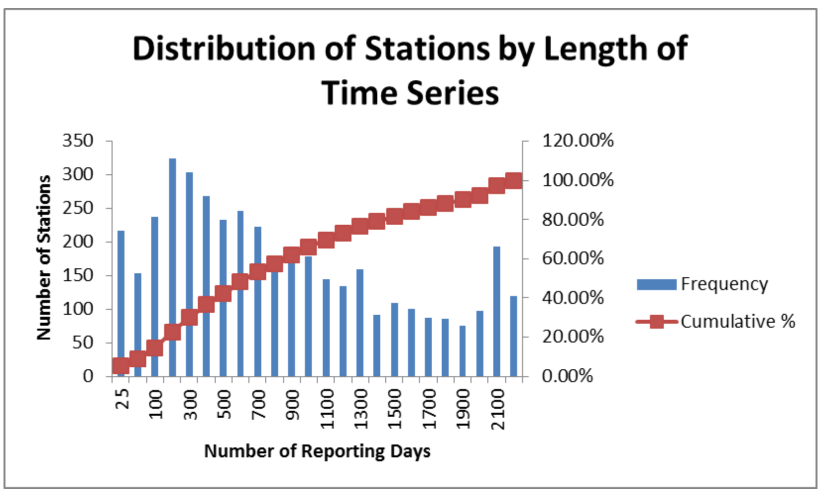


Fig. 3 Histogram showing number of stations vs. number of days.

The typical frequency of station reports can be estimated by a count of the number of reports from each station on a day when all are equally illuminated. The selection of September 21, for example, sets the average illumination of all stations to twelve hours (apart from weather, astronomical phenomena and so on). On this day of year (or on March 21) the number of reports at any station provides an indication of the station's usual reporting interval: 48 reports would be average for a 15 minute interval, 72 for a ten-minute interval, 144 for a five-minute interval, and 720 for a once/minute interval. Figure 4, a histogram of the number of reports per station on September 21, 2014, therefore indicates the typical reporting intervals.

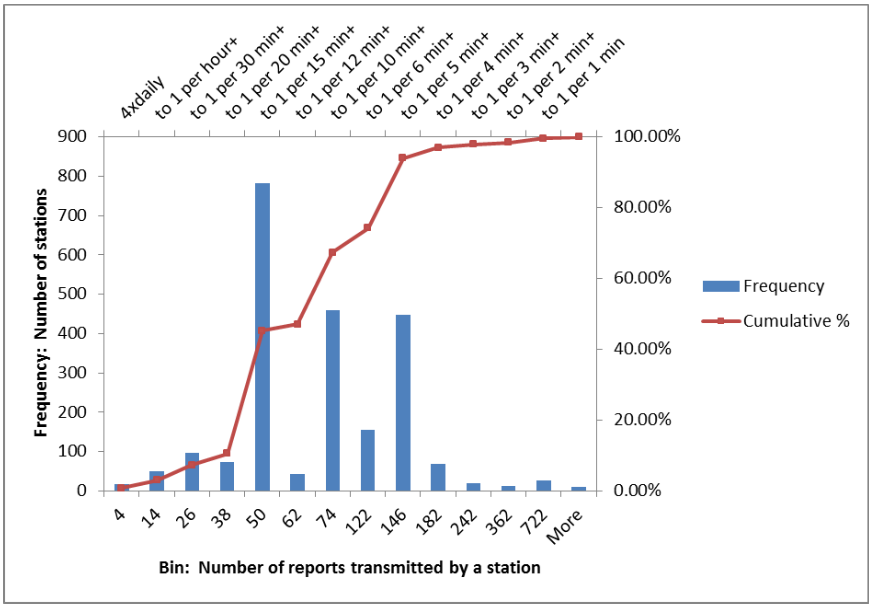


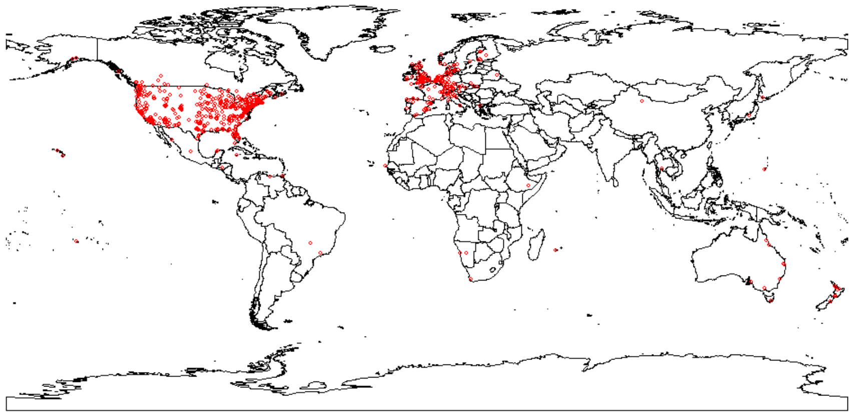
Fig. 4 Histogram of the number of reports on Sept 21, 2014, vs. reporting interval.

Table 1 presents the distribution of number of reports obtained on September 21 year by year, 2009 to 2014, as above taken to represent the distribution of reporting intervals.

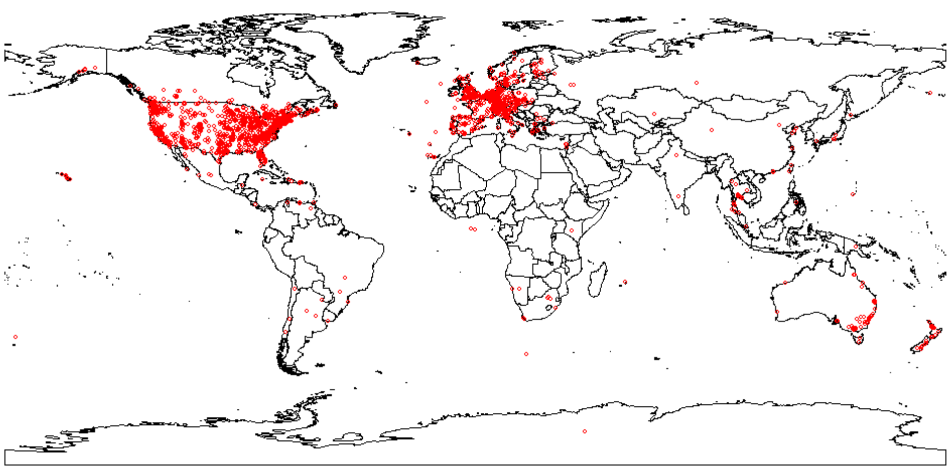
Table 1. Frequency distribution of the number of packets sent by stations for September 21 of the years 2009 to 2014.

Estimated Reporting Interval	2014	2013	2012	2011	2010	2009
to 4x daily	0.8%	1.2%	1.4%	1.8%	0.7%	1.4%
to 1 per hour+	2.2%	2.6%	3.9%	4.0%	3.8%	4.1%
to 1 per 30 min+	4.2%	4.8%	8.6%	5.8%	5.8%	7.2%
to 1 per 20 min+	3.3%	4.6%	12.7%	6.3%	3.0%	3.1%
to 1 per 15 min+	34.6%	35.8%	41.2%	38.1%	30.4%	28.0%
to 1 per 12 min+	1.9%	2.9%	4.4%	9.3%	6.2%	7.0%
to 1 per 10 min+	20.3%	20.8%	7.4%	15.0%	29.6%	29.1%
to 1 per 6 min+	6.9%	5.6%	7.7%	6.3%	5.5%	6.6%
to 1 per 5 min+	19.8%	15.8%	8.9%	8.8%	13.0%	10.7%
to 1 per 4 min+	3.0%	2.3%	1.2%	1.9%	0.7%	1.9%
to 1 per 3 min+	0.8%	1.0%	1.0%	0.8%	0.5%	0.5%
to 1 per 2 min+	0.5%	1.2%	0.9%	1.2%	0.1%	0.1%
to 1 per 1 min	1.2%	0.9%	0.6%	0.6%	0.3%	0.3%
More	0.4%	0.3%	0.1%	0.0%	0.3%	0.0%

Geographically, the distribution of data is skewed toward the Northern Hemisphere although coverage where sparse is expanding. See Maps 1 and 2 for the nominal positions of stations on the first and last day of the period under review.



Map 1. Stations reporting February 18, 2009.



Map 2. Stations reporting January 20, 2015.

Some stations have come and gone within the span of the archive operations. The time span of operations offers some insight as to persistence of station operators, although the data should not be over interpreted considering that many stations still reporting were already in place when the archive opened. With that caution, Figure 5 presents the number of reporting days for all stations that opened after February 18, 2009, closed before January 20, 2015, and transmitted for ten or more days.

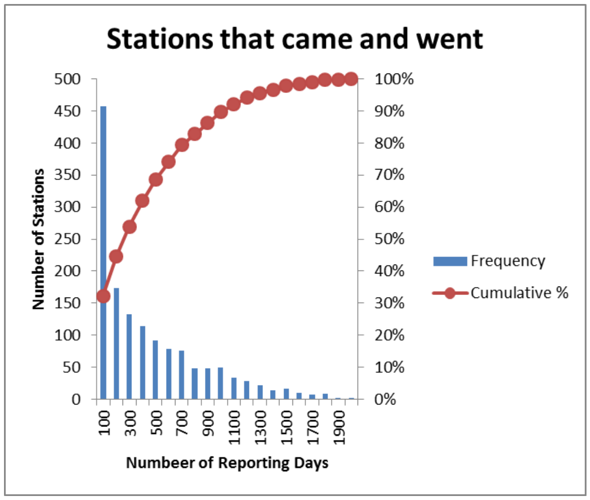


Figure 5. Histogram of the number of reporting days for all station histories excluding those of fewer than ten days, stations that reported on 2/18/2009, and stations that reported on 1/20/2015.

Most solar radiation stations are also met stations. See Table 2.

Table 2. Number of stations reporting met observations on 20150120

Total N Stations	Wind direction	Wind speed	Wind gust	Temp	Rainfall in hour	Rainfall today	Rainfall in 24 h	RH	Pressure
2362	2354	2354	2104	2361	2083	2278	2074	2352	2350
	99.7%	99.7%	89%	<100%	88%	96%	88%	<100%	99%

STATION HARDWARE AND SOFTWARE

In the final field of each packet, CWOP stations report on station hardware and software. This is valuable for example because where the manufacturer is known, the sensor accuracy and precision and stability are characterized by manufacturer testing. In practice that segment of the station report is idiosyncratic. For example, Table 3 below presents a breakout of the most frequent annotations, altogether representing 90 percent of the data reported on January 20, 2015. Evidently, some mention only hardware (usually in these cases the Davis Vantage Pro), others mention only software (Davis Weather IP, eCumulus, Weather View, Weather Cat, and weewx). The subset of annotations that includes "eMB24" and the others of similar format is popular but the authors do not know what hardware or software it represents. (We would be grateful to know.)

A breakout of sensor manufacturers is clearly not possible from this data. By inspection, well more than half of data from January 20, 2015 came from Davis stations, but Campbell Scientific and Ambient are also named.

Table 3. Hardware/software descriptions.

This list presents the most popular fields, together comprising 90 percent of reports from January 20, 2015.

Hardware/software description	Number of times used	Percentage of all this day's data
".DsVP"	42053	25%
".DsIP-VP"	26373	16%
".WD 31"	18834	11%
"eCumulusDsVP"	17645	11%
"eMB24"	9024	5%
"eMH49"	6209	4%
"eCumulusFOs"	5576	3%
"eMH50"	4134	2%
".wview_5_21_7"	3293	2%
".wview_5_20_2"	2274	1%
"eMB25"	2195	1%
".weewx-3.0.1-Vantage"	1765	1%
"ws31"	1497	1%
"WeatherCatV124B11H31"	1367	1%
"WeatherCatV202B30H31"	1336	1%
"eWUHU216DAVISVP2."	1225	1%
".weewx-2.6.2-Raspberry_pi"	1126	1%
"eMB23"	948	1%
"WeatherCatV122B15H31"	759	0%
".weewx-2.6.4-Vantage"	713	0%
"eX320M-V1.02"	690	0%
".weewx-2.7.0-Vantage"	684	0%

UNIVERSAL ACCESS TO THE SOLAR RADIATION DATA ARCHIVE

The data in the CWOP solar radiation archive is available to anyone. This access is by several means.

All CWOP reports containing a non-zero value for solar radiation are collected each day, gzipped, and made available on Google Docs via the clicks provided (by year) at http://wxqa.com/lum_search.htm.

Users may choose to download and parse individual datasets. In case useful, a parsing routine written in R is presented in Annex B.

The parsing routine has been undertaken for all datasets from February 18, 2009 through February15, 2015, and the results uploaded to a Redshift database (at aws.amazon.com). From those files, all duplicates have been deleted, header lines removed, and "NA" set to NULL. Errors due to use of old L protocols have been corrected on the Redshift database. Anyone who wishes may initialize a snapshot of that dataset so creating a stand-alone database under their own control. Contact lohancock@aol.com.

CONCLUSION

Happy Anniversary to the CWOP Solar Radiation Data Archive

The solar radiation data archive is becoming ever more dense and useful. Its geographic distribution is uneven but the network is growing even in under-represented regions. The time series available are now up to six years in length and continuing to grow.

Practical use of the archived data will depend on calibration of quality control approaches. These should be applicable to all datasets and should draw on the data itself and on metadata that is routinely available. A few words on the subject are here as Annex D.

Question for the Community:
Should Hi Solar Rad be added to APRS reports?

We ask whether the community of observers would be interested in an effort to add to APRS protocol for weather reports the quantity "High Solar Radiation" – which ,e.g., Davis reports to users: that is, Davis reports to users both the reporting interval's average L and its high L. But only the average L has a place in an APRS report. It seems more than likely that high L carries meteorological information otherwise unavailable. Some think that solar radiation glints may be caused by ice in the upper atmosphere, and if so, high L may be of interest as a flag of such conditions. It is impossible to know what use this information might be, until more of it is available.

Should this community request an APRS delimiter for Hi Solar Rad and ask manufacturers to update software to enable upload of Hi Solar Rad to CWOP?

Annex A: Missing Days Table

2009 – None missing.
2010 - 03/31, 05/25, 05/26, 8/1, 8/2, 8/3 (6 days)
2011 - 7/23, 7/28, 7/29, 7/30, 11/6 (5 days)
2012 - 1/7, 7/25 (2 days)

2013 - 2/26, 8/13 to 8/25, 8/31 (15 days)
2014 - 5/23, 5/24, 5/25, 5/26, 5/27 (5 days)
2015 – None missing

Annex B – Sample R code for parsing data from the main archive.

The routine below is offered in case useful as a means to parse data from the main archive. It extracts from a one-day zipped archive a text file listing each field in a tab-separated format and adding some error-checking fields. The code is verbose and a bit idiosyncratic: it was written to enable ongoing examination of intermediate outputs. It does not fix the issue of data that reports solar radiation using lxxxx (that is, small l followed by four digits). There are very few such datapoints and for now they are fixed by a patch in the Redshift database rather than here. Still, users are invited to shorten and/or tailor it. For example, to parse L20150101.txt.gz:

- Place the gzipped input data downloaded from the main archive into a folder d:/solar data/2014 solar data/ .
- Have ready a folder d:/solar data parsed/
- Save the function below in a directory where R will find it, calling it parsecwoptxt.R
- Issue these commands in R:
    - **filedate<-'20150101'**
    - **parsecwoptxt(filedate)**

If the routine informs you as it works that some NAs were introduced by coercion, this is a signal that it processed some out-of-format reports such as latitude and longitude. It is valuable information but the parser will continue to work. When the routine has finished, you would in this case find a file called LP20150101P.txt saved in the output directory “solar data parsed”

```
parsecwoptxt <- function(filedate) {

  thisyear<-substr(filedate,1,4)
  thismonth<-substr(filedate,5,6)
  thisday<-substr(filedate,7,8)
  thisdate<-paste(thisyear,thismonth,thisday,sep="-")
  thisdateasdate<-as.Date(thisdate)

  yesterdayasdate<-thisdateasdate-1
  yesterdayyear<-substr(as.character(yesterdayasdate),1,4)
  yesterdaymonth<-substr(as.character(yesterdayasdate),6,7)
  yesterdayday<-substr(as.character(yesterdayasdate),9,10)
  yesterdaydate<-paste(yesterdayyear,yesterdaymonth,yesterdayday,sep="-")

  filename<-paste("d:/a solar data/2014 solar data/L",filedate,".txt.gz",sep="")
  mydataout <- paste("d:/solar data parsed/LP",filedate,"P.txt",sep="")

  unlista<-readLines(filename)
  report<-unlista

  stationpat<-"([a-zA-Z0-9-]{1,})(>)"
  statns<- str_match(unlista,stationpat)
```

```
  stationname<- statns[,2]

  timepat<-"(>)([0-9]{1,6})([a-z])"
  dtimes<- str_match(unlista,timepat)

  datatimes<-dtimes [,3]

  recordday<-substr(datatimes,1,2)
  rightday<-recordday==thisday
  rightyesterday<-recordday==yesterdayday
  wrongday<-!(recordday==thisday|recordday==yesterdayday)

  dateflag<-integer()
  dateflag[rightday]<-1
  dateflag[rightyesterday]<-2
  dateflag[wrongday]<-3


  recordhour<-substr(datatimes,3,4)
  recordmin<-substr(datatimes,5,6)
  recordtime<-paste(recordhour,recordmin,sep=":")
  recordstamp<-paste(thisdate,recordtime,sep=" ")

  z <- strptime(recordstamp, "%Y-%m-%d %H:%M",tz='UTC')
  z[dateflag!=1]<-NA

# Next latitude and longitude.

  latpat<-"([a-z -]{1,})([0-9]{1,4}.[0-9]{1,2})([N n S s]{1,1})"
  latparts<-str_match(unlista,latpat)
  lat<-latparts[,3]
  latd<-as.numeric(substr(lat,1,2))
  latmin<-as.numeric(substr(lat,3,7))
  latitude<-(latd+(latmin/60))
  latsign<-latparts[,4]

  lonpat<-"(/)([0-9]{1,5}.[0-9]{1,6})([E e W w]{1,1})"
  lonparts<-str_match(unlista,lonpat)
  lon<-lonparts[,3]
  lond<-as.numeric(substr(lon,1,3))
  lonmin<-as.numeric(substr(lon,4,8))
  lonsign<-lonparts[,4]
  longitude<-(lond+(lonmin/60))

# Next the data.

  windpat<-"(_)([0-9]{1,3})/([0-9]{1,3})"
  windparts<-str_match(unlista,windpat)
  winddir<-windparts[,3]
  windknots<-windparts[,4]

  gustpat<-"(g)([0-9]{1,3})([a-z]){1,1}"
  gparts<-str_match(unlista,gustpat)
  gust<-gparts[,3]

  tpat<-"(t)([- 0-9]{1,3})([a-z A-Z]){1,1}"
  tparts<-str_match(unlista,tpat)
```

```
  temp<-tparts[,3]

  rpat<-"(r)([0-9]{1,3})([a-z A-Z]){1,1}"
  rparts<-str_match(unlista,rpat)
  rainfallhour<-rparts[,3]

  ppat<-"(p)([0-9]{1,3})([a-z A-Z]){1,1}"
  pparts<-str_match(unlista,ppat)
  rainfall24h<-pparts[,3]

  bigppat<-"(P)([0-9]{1,3})"
  bigpparts<-str_match(unlista,bigppat)
  rainfalltoday<-bigpparts[,3]

  hpat<-"(h)([0-9]{1,2})"
  hparts<-str_match(unlista,hpat)
  relativehumidity<-hparts[,3]

  bpat<-"(b)([0-9]{1,5})"
  bparts<-str_match(unlista,bpat)
  baropressure<-bparts[,3]


  lpat<-"([L l])([0-9]{3,4})"
  lparts<-str_match(unlista,lpat)
  lrec<-lparts[,1]
  lcharerr<-nchar(lparts[,1])>4
  lrecord<-as.integer(lparts[,3])
  lstyle<-(lparts[,2]=="l")
  laddend<-lstyle*1000
  lfin<-lrecord+laddend

  techbreak<-str_locate(unlista,lpat)
  totalchar<-nchar(unlista)
  tsuffix<-totalchar-techbreak[,2]
  tech<-substrRight(unlista,tsuffix)

  outtable<-data.frame(report,stationname,thisdate,
datatimes,dateflag,z,latitude,latsign,longitude,
lonsign,winddir,windknots,gust,temp, rainfallhour,
rainfall24h,rainfalltoday,relativehumidity,baropressure,
lrec,lfin,lcharerr,tech)

  write.table(outtable,mydataout,sep="\t",row.names=FALSE)

}
```

The output variables are as follows:

```
#  report = the packet received at CWOP
#  stationname = reported station name
#  thisdate = the date of the data archive, expressed as a date
#  datatimes = the timestamp within the packet
#  z = the imputed time of the data expressed as a date
#  latitude = absolute value of latitude
#  latsign = N or S
```

```
#  longitude = absolute value of the longitude
#  lonsing = E or W
#  windknots = wind in knots
#  winddir = wind direction in degrees clockwise from north.
#  gust = peak wind speed in mph in the last 5 minutes.
#  temp = temperature (in degrees Fahrenheit (below zero as -01 to -99)
#  rainfallhour = rainfall (in hundredths of an inch) in the last hour.
#  rainfall24h = rainfall (in hundredths of an inch) in the last 24 hours.
#  rainfalltoday = rainfall (in hundredths of an inch) since midnight.
#  relativelhumidity = humidity (in %. 00 = 100%)
#  baropressure = p in tenths of millibars/tenths of hPascal
#  lrec = the luminosity record pre-parsing
#  lfin = calculation of luminosity from that record
#  lcharerr = a flag that is TRUE for protocols Lxxxx or lxxxx
#  tech = the suffix that is supposed to describe tecnology.
```

Note that the APRS protocol is Lxxx or lxxx: L = luminosity (in watts per square meter) 999 and below. while l, that is lower-case letter "L" = luminosity (in watts per square meter) 1000 and above.

Annex C. Processing Notes

Errors in data transmission can, at times, corrupt packets, introducing stray characters to varying effect. This often results in a packet that is out of format and is headed by a nonexistent station name. At the archive ingest, therefore, all packets headed by station names that occur only once in a day are deleted .

Some data slips through that net; at the next stage, the R parsing routine tries to preserve data as it was received, but in parsing to dates and numbers, sets fields to NA if their contents do not correspond to APRS standard for the respective field.

The Redshift database comprising the R-parsed data replaces non-UTF-8 characters with “^”.

Where a copy of data to the Redshift database could not be undertaken due to data errors, individual packets are deleted or when necessary a few station-day reports. This final step has been undertaken for fewer than ten station-days thus far, of the several million station-days in the archive.

Annex D – Some remarks on data quality

Latitude and longitude

Stations report latitude and longitude in LORAN format in each packet. Also, most station operators hare informed CWOP of their precise location and that information is contained in http://www.wxqa.com/APRSWXNETStation.txt . Sometimes there can be errors in location, as when a station is relocated (owner moves) and the operator does not inform CWOP of the new location. This can often be diagnosed by comparing the time of apparent solar noon with nearby stations. Most of the stations have good location data, especially those that have reported for a long time, like those listed in Appendix D.

Time stamps

Stations self-report the timing of each measurement. APRS standard permits timestamp formats as ddhhmm or hhmmss. Almost all stations in the archive use ddhhmm. Time stamps might be expected to be trustworthy on the consideration that typical station setups draw the timestamp from the computer clock, and in turn typical computer clocks check themselves continuously against global standards. This reasonableness of this expectation can be checked on the consideration that each daily data file comprises data collected within a 24-hour period (ending at 11 PM UTC daily). There appear to be time errors in about 1% of the reporting stations.

A more complex but universally applicable test of reported time can also be defined via comparison between station data and modeled solar radiation. However, that outcome is beyond the scope of this note.

Meteorological data

Most, but not all, stations report meteorological data. Thus the following remarks are relevant to most station reports.

- Variations of barometric pressure over time are perhaps the measurements most robust against error. Even so, absolute values of barometric pressure are subject to error where the elevation of a station is uncertain.
- Temperature and relative humidity are reasonably robust although nearby activity can be a contaminant to temperature, affecting relative humidity in turn, and microclimate values of temperature in the best case respond differently to diurnal variation.
- Rainfall at unknown stations should not be trusted without a positive reason to do so: tipping buckets are sometimes uncertain, and when stuck or clogged they may even stop reporting.
- Wind speed depends on siting of the station away from objects that disturb the air flow; wind direction depends on accurate calibration of station orientation.

Users need not be discouraged by these issues. The system comprises very many excellently operated and maintained stations. To highlight these, many though not all CWOP members submit daily data to a systematic quality check, updated daily. For a link to an example, and in turn to explanations, see, e.g., http://weather.gladstonefamily.net/site/C0003?tile=10;days=28 and the links therein.

Solar Radiation Data

Solar radiation data are not comprised within the existing quality checks; but they are intrinsically robust to circumstances that cause error in other variables. Significant variations of solar radiation do not occur over small variations in elevation, as variations of barometric pressure do. Solar sensors are not subject to the vagaries of moving parts such as the tipping bucket or the wind vane. Solar sensors are usually factory calibrated and need not be calibrated *in situ.* Nearby airflow does not matter to a solar transducer. Nearby human activity can mimic variations in most met variables, but no ordinary human activity can mimic or significantly alter the measure of noonday solar radiation. That is, a station manager may dump water in the rain gauge, blow on the wind vane, or park a running car next to a temperature and humidity station. But short of lightning or ordnance, there is little one can do to amplify measures of solar radiation in daytime. Accidental shading can significantly affect a single station, but not on a regional basis.

Finally, should a sensor be installed incorrectly or fall into shade, expected solar radiation is straight forward to compute and error-prone installations may be identifiable on the basis of quality checks undertaken at a distance on the basis of the data supplied.

The protocol by which L is reported in APRS has evolved and stabilized over the archive's life, 2009-2015. In its final form, the protocol has it that a report is formatted Lxxx for a value of L below 1000 (thus, L750 means L=750); it is formatted lxxx is used for a value above 1000 (thus, l020 means L=1020). Because this protocol has recently evolved, it is unsurprising that the archive includes records that use the protocol according to an old usage. 1211 stations, about a quarter of the ensemble, have used the format *Lxxxx* or *lxxxx* at some time. However the mix of reporting protocols can be parsed (Annex B provides an example).

Annex E. The Longest Time Series

The cutoff point for this list of longest time series is admittedly arbitrary; moreover, this annex would certainly be more useful if it also included QC analyses for each station, following which, reliable values for latitude, longitude, and number of points per day. Such a catalog is envisioned but in the meantime this may be useful for some applications. For context, the maximum number of days possible is 2130 and stations with this number have reported every day the archive file was made. But the others may have as well: due to server issues, some stations that have reported continuously do not have full time series in the archive. Thus, all stations on this list may be taken to have reported approximately continuously from the first day of the Solar Radiation Archive to the last.

Station Name	Number of Days Reporting
"CW3318"	2130
"CW4778"	2130
"DW2282"	2130
"CW7137"	2130
"CW9688"	2130
"CW0343"	2130
"CW3882"	2129
"CW3806"	2128
"CW8027"	2127
"DW1774"	2126
"CW9086"	2126
"DW1879"	2125
"CW4113"	2125
"KC9DNQ-3"	2125
"CW5772"	2125
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