Universal Data Structures for Air Quality Data

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

South Coast AQMD

MAZAMA SCIENCE
SEE YOUR DATA

DRI
Desert Research Institute

Target Audience

- Sensor manufacturers
- Data aggregators
- Local AQ agencies
- National AQ agencies
- NGOs
- Software companies

- Data analysts
- Air quality advisors
- Post docs
- Grad students
- IT teams
- Software developers

Basically, anyone working with AQ data.

Why trust me?

- Grad school experience building instruments
- 30 years doing data visualization
- 12 years running a business writing operational software
- 10 years working with air quality data
- 4 years working with sensor data
- I maintain the **PWFSLSmoke** and **AirSensor** R packages

Data Producers & Data Consumers

Producers

Hardware & Software Engineers

Concerns

- Electronics (amps, ADCs, wifi chips)
- Firmware
- Data transfer protocols
- Real-time data storage and retrieval
- Cost / size / reliability
- **Single device type**

Consumers

Scientists, Analysts & Statisticians

Concerns

- Data access
- Data usability
- Quality Control
- Statistics
- Data visualization
- **Multiple device types**

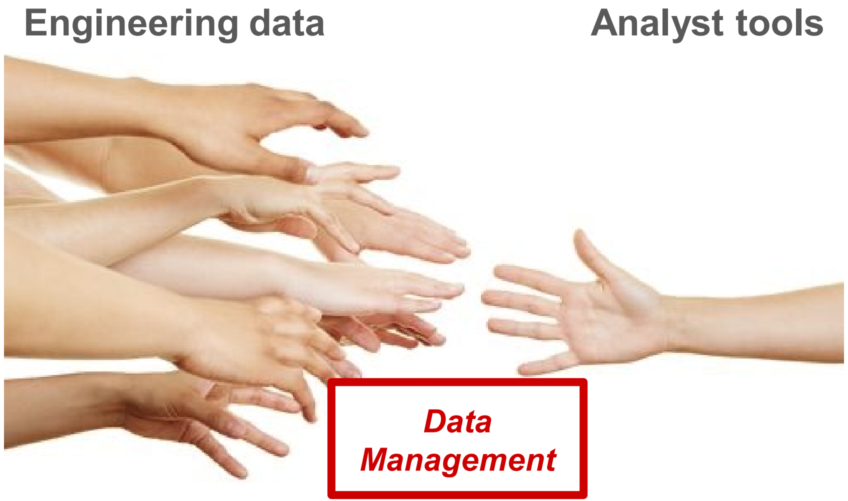
Scientific Data Management

Goal

- Meet needs of engineers and analysts

Concerns

- Engineering variables, units and formats
- Instrument specific concerns
- Analyst general questions
- Raw data ingest
- Data harmonization
- QC algorithms
- Data aggregation
- Data access



Engineering data

Analyst tools

Data Management

Scientific Data Management

1. Standardize/harmonize/correct low level data
    a. Download
    b. Parse
    c. Harmonize
    d. Add metadata
    e. Quality Control

2. **Combine low level data into useful summaries**
    a. Aggregate to hourly
    b. Combine multiple time series
    c. Use a common data format

3. Make data easily accessible

Google Maps -- low level data

Pasadena Convention Center
©2021 Google
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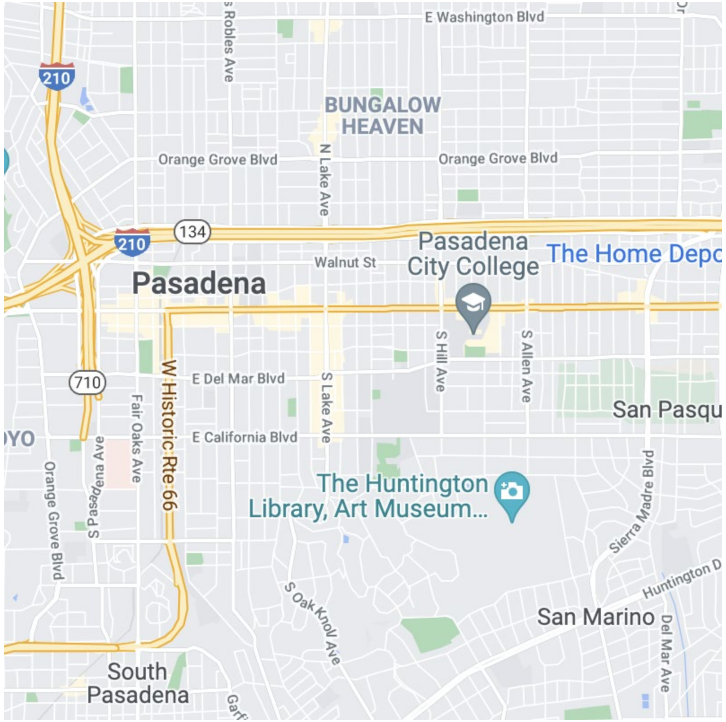
Lowest level has lots of details

Each pixel represents ~15 cm

Zoom level 21 has **~25,000 Terabytes** of data

Great for diving into the details.

Google Maps -- useful summary 1



Higher level summary

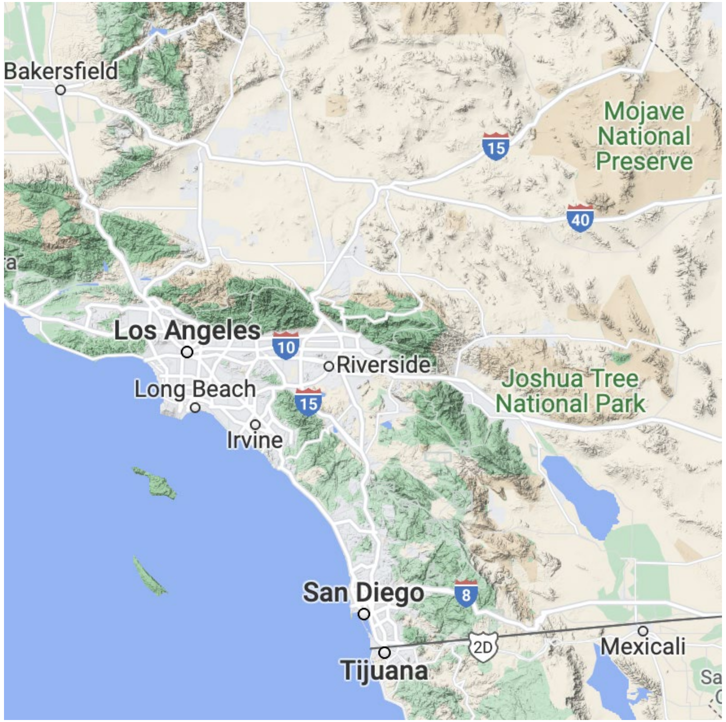
Each pixel represents ~15 m

Zoom level 13 has **~4.4 Terabytes** of data

Enhanced with spatial metadata

Great for driving.

Google Maps -- useful summary 2



Even higher level summary

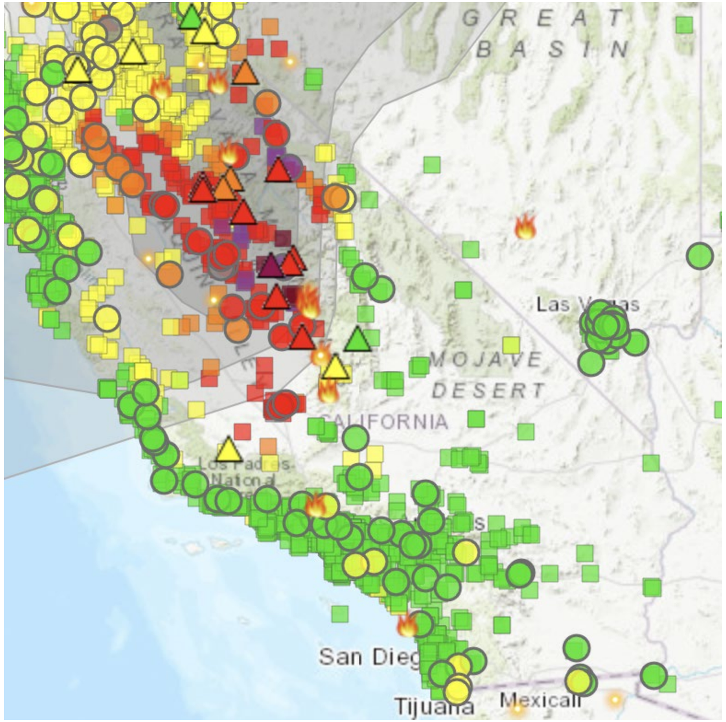
Each pixel represents ~1.0 klm

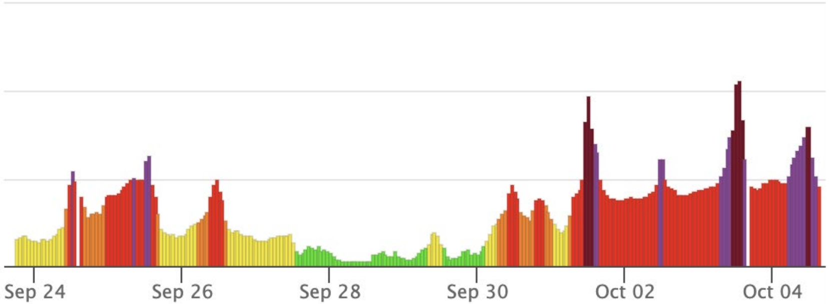
Zoom level 7 has **~1.1 Gigabytes** of data

Enhanced with elevation data

Great for regional planning.

For Air Quality data, people want maps and time series





Air Quality Data -- low level data

```
2021-10-07T07:01:00Z,27.09,27.82,71,53,973.3,18.6,27.09,29.58,18.25,27.82,31.07,6040,-65,18120,0.03,NA,2021-10-07T07:01:49Z,2021-10-07T07:01:52Z
2021-10-07T07:03:00Z,26.95,28.04,71,53,973.28,18.22,26.95,30.05,18.26,28.04,30.93,6042,-63,18120,0.03,NA,2021-10-07T07:03:49Z,2021-10-07T07:03:52Z
2021-10-07T07:05:00Z,26.03,29.18,71,53,973.28,17.78,26.03,27.13,19.24,29.18,33.6,6044,-63,18120,0.03,NA,2021-10-07T07:05:49Z,2021-10-07T07:05:52Z
2021-10-07T07:07:00Z,26.37,29.52,70,54,973.28,17.87,26.37,28.52,19.5,29.52,33.04,6046,-64,18120,0.03,NA,2021-10-07T07:07:49Z,2021-10-07T07:07:52Z
2021-10-07T07:09:00Z,27,29.75,70,54,973.3,18.78,27,28.91,19.21,29.75,34.82,6048,-65,18120,0.03,NA,2021-10-07T07:09:49Z,2021-10-07T07:09:52Z
2021-10-07T07:11:00Z,28.11,31.84,70,54,973.34,19.3,28.11,31.58,20.14,31.84,36.42,6050,-61,18120,0.03,NA,2021-10-07T07:11:49Z,2021-10-07T07:11:52Z
2021-10-07T07:13:00Z,27.66,29.53,70,54,973.24,18.53,27.66,30.16,18.51,29.53,33.58,6052,-65,18120,0.03,NA,2021-10-07T07:13:49Z,2021-10-07T07:13:52Z
2021-10-07T07:15:00Z,27.3,30.69,70,54,973.22,18.67,27.3,30.13,19.67,30.69,35.55,6054,-66,18120,0.03,NA,2021-10-07T07:15:49Z,2021-10-07T07:15:52Z
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2021-10-07T07:19:00Z,28.07,29.89,70,54,973.26,18.79,28.07,31.55,20.02,29.89,34.12,6058,-62,18120,0.03,NA,2021-10-07T07:19:49Z,2021-10-07T07:19:52Z
2021-10-07T07:21:00Z,28.83,30.74,70,54,973.26,18.78,28.83,32.32,20.26,30.74,34.21,6060,-65,18120,0.03,NA,2021-10-07T07:21:50Z,2021-10-07T07:21:52Z
2021-10-07T07:23:00Z,27.97,30.32,70,55,973.26,18.27,27.97,31.73,19.66,30.32,33.84,6062,-63,18120,0.03,NA,2021-10-07T07:23:49Z,2021-10-07T07:23:52Z
2021-10-07T07:25:00Z,28.89,31.37,69,55,973.34,19.46,28.89,32.41,19.91,31.37,35.46,6064,-66,18120,0.03,NA,2021-10-07T07:25:49Z,2021-10-07T07:25:52Z
2021-10-07T07:27:00Z,29.2,30.43,69,56,973.35,19.66,29.2,32.25,19.45,30.43,33.46,6066,-66,18120,0.03,NA,2021-10-07T07:27:49Z,2021-10-07T07:27:52Z
2021-10-07T07:29:00Z,29.03,32.74,69,56,973.38,19.64,29.03,31.95,20.35,32.74,38.35,6068,-63,18120,0.03,NA,2021-10-07T07:29:49Z,2021-10-07T07:29:52Z
2021-10-07T07:31:00Z,29.65,32.33,69,56,973.41,19.13,29.65,32.77,19.98,32.33,35.98,6070,-61,18120,0.03,NA,2021-10-07T07:31:49Z,2021-10-07T07:31:52Z
2021-10-07T07:33:00Z,28.84,31.93,70,56,973.4,19.1,28.84,32.08,19.76,31.93,35.84,6072,-60,18120,0.03,NA,2021-10-07T07:33:49Z,2021-10-07T07:33:52Z
2021-10-07T07:35:00Z,28.51,32.33,70,56,973.43,19.25,28.51,31.81,19.93,32.33,36.84,6074,-61,18120,0.03,NA,2021-10-07T07:35:49Z,2021-10-07T07:35:52Z
2021-10-07T07:37:00Z,28,30.07,68,56,973.49,18.73,28,31.81,19.19,30.07,33.49,6076,-67,18120,0.03,NA,2021-10-07T07:37:49Z,2021-10-07T07:37:52Z
2021-10-07T07:39:00Z,28.07,31.05,70,56,973.48,18.82,28.07,30.13,19.68,31.05,35.23,6078,-61,17952,0.03,NA,2021-10-07T07:39:50Z,2021-10-07T07:39:52Z
…
```

Plus 822 more lines

All Parameters, 1 Day, 1 Sensor (112 Kilobytes)

Great for diving into details.

Air Quality Data -- summary 1

```
2021-10-07T07:00:00Z, 29
2021-10-07T08:00:00Z, 34
2021-10-07T09:00:00Z, 38
2021-10-07T10:00:00Z, 39
2021-10-07T11:00:00Z, 38
2021-10-07T12:00:00Z, 40
2021-10-07T13:00:00Z, 39
2021-10-07T14:00:00Z, 40
2021-10-07T15:00:00Z, 42
2021-10-07T16:00:00Z, 40
2021-10-07T17:00:00Z, 32
2021-10-07T18:00:00Z, 22
2021-10-07T19:00:00Z, 25
2021-10-07T20:00:00Z, 22
2021-10-07T21:00:00Z, 18
2021-10-07T22:00:00Z, 14
2021-10-07T23:00:00Z, 14
2021-10-08T00:00:00Z, 13
2021-10-08T01:00:00Z,  9
2021-10-08T02:00:00Z, 10
2021-10-08T03:00:00Z, 11
2021-10-08T04:00:00Z, 12
2021-10-08T05:00:00Z, 13
2021-10-08T06:00:00Z, 16
```

1 Parameter, 1 Day, 1 Sensor

Raw = 112 Kilobytes
Summarized = 606 bytes

Great for plotting time series.

Air Quality Data -- summary 2

```
2021-10-07T07:00:00Z, 28, 28, 26, 29, 28, 26, 26, 27, 24, 20, 17, 19
2021-10-07T08:00:00Z, 31, 31, 28, 34, 33, 28, 27, 28, 27, 24, 20, 23
2021-10-07T09:00:00Z, 32, 31, 31, 38, 36, 30, 29, 29, 31, 31, 24, 24
2021-10-07T10:00:00Z, 36, 31, 36, 39, 37, 35, 31, 33, 35, 36, 28, 24
2021-10-07T11:00:00Z, 37, 33, 35, 38, 37, 34, 33, 34, 34, 35, 25, 28
2021-10-07T12:00:00Z, 36, 28, 36, 40, 38, 36, 32, 33, 36, 34, 27, 23
2021-10-07T13:00:00Z, 38, 32, 37, 39, 39, 36, 34, 35, 35, 34, 25, 28
2021-10-07T14:00:00Z, 38, 36, 39, 40, 38, 38, 34, 36, 39, 39, 29, 32
2021-10-07T15:00:00Z, 37, 36, 39, 42, 38, 38, 32, 34, 39, 40, 30, 31
2021-10-07T16:00:00Z, 35, 34, 35, 40, 38, 35, 31, 33, 36, 37, 28, 32
2021-10-07T17:00:00Z, 15, 32, 31, 32, 31, 31, 16, 16, 31, 31, 21, 30
2021-10-07T18:00:00Z,  8, 27, 24, 22, 15, 23,  7,  7, 24, 27, 17, 25
2021-10-07T19:00:00Z,  7, 20, 22, 25, 21, 22,  8,  8, 22, 21, NA, 21
2021-10-07T20:00:00Z, 23, 12, 15, 22, 21, 16, 21, 22, 15, 13, NA, 11
2021-10-07T21:00:00Z, 17, 11, 13, 18, 16, 13, 16, 17, 13, 12, 10,  9
2021-10-07T22:00:00Z, 15, 12, 12, 14, 13, 12, 14, 15, 11, 11, NA, 10
2021-10-07T23:00:00Z, 14, 12, 11, 14, 12, 11, 13, 13, 11, 11,  8,  9
2021-10-08T00:00:00Z, 12,  9, 11, 13, 11, 11, 11, 12, 10,  9,  7,  9
2021-10-08T01:00:00Z,  9,  7,  9,  9,  7,  8,  8,  9,  8,  7,  6,  5
2021-10-08T02:00:00Z,  9,  8,  9, 10,  9,  8,  8,  8,  8,  8,  7,  7
2021-10-08T03:00:00Z,  8,  9,  9, 11,  9,  9,  8,  8,  9, 11,  6,  7
2021-10-08T04:00:00Z,  6, 12, 11, 12, 11, 10,  7,  7, 10, 11,  7,  8
2021-10-08T05:00:00Z,  7, 13, 12, 13, 12, 12,  7,  7, 12, 12,  8,  8
2021-10-08T06:00:00Z, 11, 14, 15, 16, 16, 15, 11, 11, 15, 15,  9, 11
```

1 Parameter, 1 Day, 12 Sensors

Raw = 1.34 Megabytes
Summarized = 1.58 Kilobytes

Great for maps AND time series.

Air Quality Data – high level summary (*compact!!*)

```
2021-10-07T07:00:00Z, 28, 28, 26, 29, 28, 26, 26, 27, 24, 20, 17, 19
2021-10-07T08:00:00Z, 31, 31, 28, 34, 33, 28, 27, 28, 27, 24, 20, 23
2021-10-07T09:00:00Z, 32, 31, 31, 38, 36, 30, 29, 29, 31, 31, 24, 24
2021-10-07T10:00:00Z, 36, 31, 36, 39, 37, 35, 31, 33, 35, 36, 28, 24
2021-10-07T11:00:00Z, 37, 33, 35, 38, 37, 34, 33, 34, 34, 35, 25, 28
2021-10-07T12:00:00Z, 36, 28, 36, 40, 38, 36, 32, 33, 36, 34, 27, 23
2021-10-07T13:00:00Z, 38, 32, 37, 39, 39, 36, 34, 35, 35, 34, 25, 28
2021-10-07T14:00:00Z, 38, 36, 39, 40, 38, 38, 34, 36, 39, 39, 29, 32
2021-10-07T15:00:00Z, 37, 36, 39, 42, 38, 38, 32, 34, 39, 40, 30, 31
2021-10-07T16:00:00Z, 35, 34, 35, 40, 38, 35, 31, 33, 36, 37, 28, 32
2021-10-07T17:00:00Z, 15, 32, 31, 32, 31, 31, 16, 16, 31, 31, 21, 30
2021-10-07T18:00:00Z,  8, 27, 24, 22, 15, 23,  7,  7, 24, 27, 17, 25
2021-10-07T19:00:00Z,  7, 20, 22, 25, 21, 22,  8,  8, 22, 21, NA, 21
2021-10-07T20:00:00Z, 23, 12, 15, 22, 21, 16, 21, 22, 15, 13, NA, 11
2021-10-07T21:00:00Z, 17, 11, 13, 18, 16, 13, 16, 17, 13, 12, 10,  9
2021-10-07T22:00:00Z, 15, 12, 12, 14, 13, 12, 14, 15, 11, 11, NA, 10
2021-10-07T23:00:00Z, 14, 12, 11, 14, 12, 11, 13, 13, 11, 11,  8,  9
2021-10-08T00:00:00Z, 12,  9, 11, 13, 11, 11, 11, 12, 10,  9,  7,  9
2021-10-08T01:00:00Z,  9,  7,  9,  9,  7,  8,  8,  9,  8,  7,  6,  5
2021-10-08T02:00:00Z,  9,  8,  9, 10,  9,  8,  8,  8,  8,  8,  7,  7
2021-10-08T03:00:00Z,  8,  9,  9, 11,  9,  9,  8,  8,  9, 11,  6,  7
2021-10-08T04:00:00Z,  6, 12, 11, 12, 11, 10,  7,  7, 10, 11,  7,  8
2021-10-08T05:00:00Z,  7, 13, 12, 13, 12, 12,  7,  7, 12, 12,  8,  8
2021-10-08T06:00:00Z, 11, 14, 15, 16, 16, 15, 11, 11, 15, 15,  9, 11
```

Map

Time Series

A Maximally Compact “Universal” Data Model

For “stationary” time series only

All time dependent measurements go into a **‘data’** table

All static, spatial/instrument metadata goes into a **‘meta’** table

A unique **‘deviceDeploymentID’** connects the tables

Air Quality Metadata – high level summary

deviceDeploymentID	**deviceID**	deviceType
deviceDescription	deviceExtra	pollutant
units	dataIngestSource	dataIngestURL
dataIngestUnitID	dataIngestExtra	dataIngestDescription
locationID	locationName	longitude
latitude	elevation	countryCode
stateCode	countyName	timezone
houseNumber	street	city
zip	AQSID	airnow_parameterName
airnow_siteCode	airnow_status	airnow_agencyID
airnow_agencyName	airnow_EPARegion	airnow_GMTOffsetHours
airnow_FIPSMSACode	airnow_MSAName	address
wrcc_type	wrcc_serialNumber	wrcc_monitorName
wrcc_monitorType		

Only 1 entry per “device-deployment”.

Compact ‘meta’ table – *‘ID’ is the primary key*

ID	locationName	longitude	latitude	elevation	countryCode	stateCode	county	timezone
1	Fairhope, Alabama	-87.9	30.5	37.2	US	AL	Baldwin	America/Chicago
2	Ashland	-85.8	33.3	344.	US	AL	Clay	America/Chicago
3	Muscle Shoals	-87.6	34.8	122	US	AL	Colbert	America/Chicago
4	Muscle Shoals	-87.6	34.8	122	US	AL	Colbert	America/Chicago
5	Crossville	-86.0	34.3	500	US	AL	DeKalb	America/Chicago
6	Brewton (Closed 12/30/07)	-87.1	31.1	50	US	AL	Escambia	America/Chicago
7	Gadsden C. College	-86.0	34.0	50	US	AL	Etowah	America/Chicago
8	Dothan	-85.4	31.2	102	US	AL	Houston	America/Chicago
9	Dothan (Civic Center)	-85.4	31.2	264	US	AL	Houston	America/Chicago

…

Compact ‘data’ table

```
           datetime  1   2   3   4  5  6  7   8   9 10 11   12    13  14 15  16  17 18  19
2020-01-01 05:00:00 NA 5.1 1.5 4.4 NA NA NA 4.5 8.8 NA NA   NA    NA  NA NA 2.9 4.6 NA  NA
2020-01-01 06:00:00 NA 4.2 0.5 5.7 NA NA NA 4.3 7.6 NA NA 11.0    NA  NA  7 2.7 6.6 NA 3.3
2020-01-01 07:00:00 NA 3.0 0.3 5.5 -2 NA NA 4.3 5.2 NA NA  4.3 349.0  NA  5 2.2 4.8 NA 4.8
2020-01-01 08:00:00  2 3.3 0.7 5.8 -1 26 17 4.5 6.5 11 NA  4.8 462.9 105  4 1.9 3.0 16 4.2
2020-01-01 09:00:00  3 3.0 1.0 5.8  1 27 42 5.4 7.2  7 NA  6.4 549.8 118  4 1.9 2.4 14 4.5
2020-01-01 10:00:00  4 3.8 0.8 5.8  1 27 22 5.6 8.4  9 NA  7.4 550.0  70  1 1.8 3.3  9 6.5
2020-01-01 11:00:00  3 3.8 1.6 6.1 -1  7 24 5.7 9.2  6 NA  5.3 498.6  66  7 1.7 3.5  8 7.5
2020-01-01 12:00:00  3 3.5 2.7 6.1  0 16 19 5.9 5.7  2 NA  7.3 342.1  76  3 2.0 4.0  5 7.2
2020-01-01 13:00:00  4 3.2 2.6 6.4  1 11 15 4.1 6.7  5 NA  5.8 195.1  70  3 2.5 3.8  5 7.9
2020-01-01 14:00:00  2 2.6 1.5 5.5  0 13 23 2.6 8.1  5 NA  5.2 142.9  55  8 2.3 3.3  6 8.0
2020-01-01 15:00:00  1 2.0 0.5 5.6  0  9 13 2.6 5.5  1 NA  2.8 134.9  54  4 2.5 3.3  7 3.9
```

Advantages of Meta/Data “Universal” Structure

Simple & Understandable

Maximally Compact

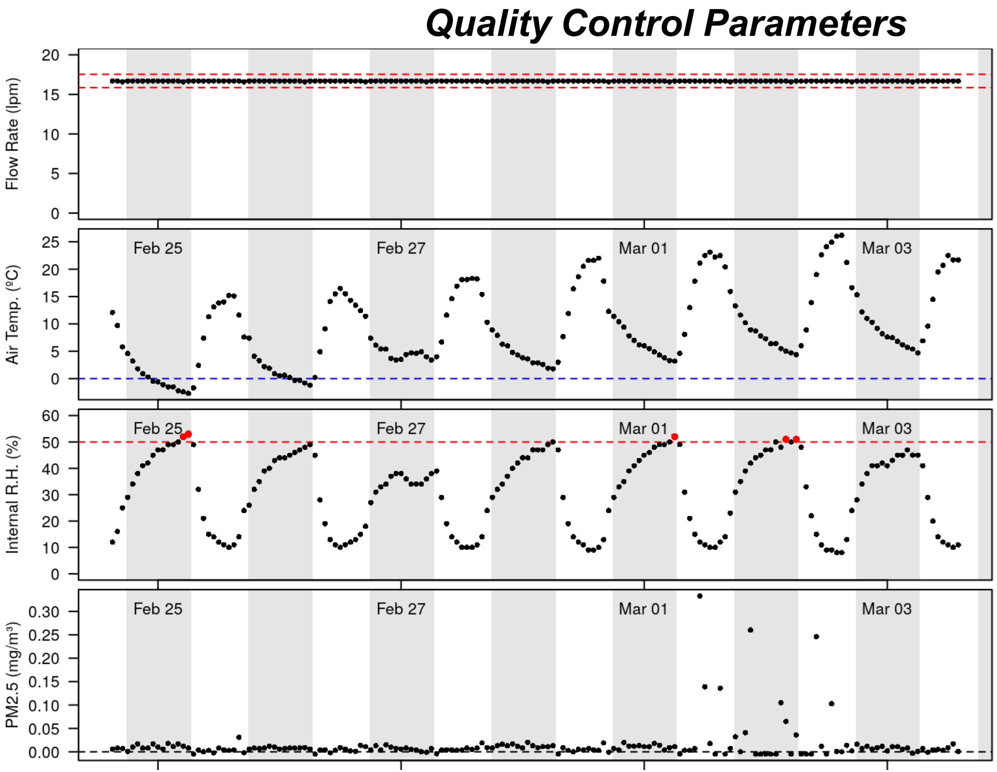
Multiple monitors in a single file

Sufficient for both Maps and Time Series

CSV file format is well understood

Simple web server can serve static files

What about low-level, engineering data?



Data model for low-level, engineering data

Assume interest in a single monitor

‘Meta’ table is the same (but only has one row)

‘Data’ table has one column per engineering parameter

Similar advantages:

- Simple, understandable data structure
- Maximally Compact
- CSV file format is well understood
- Simple web server can serve static files

Data Access

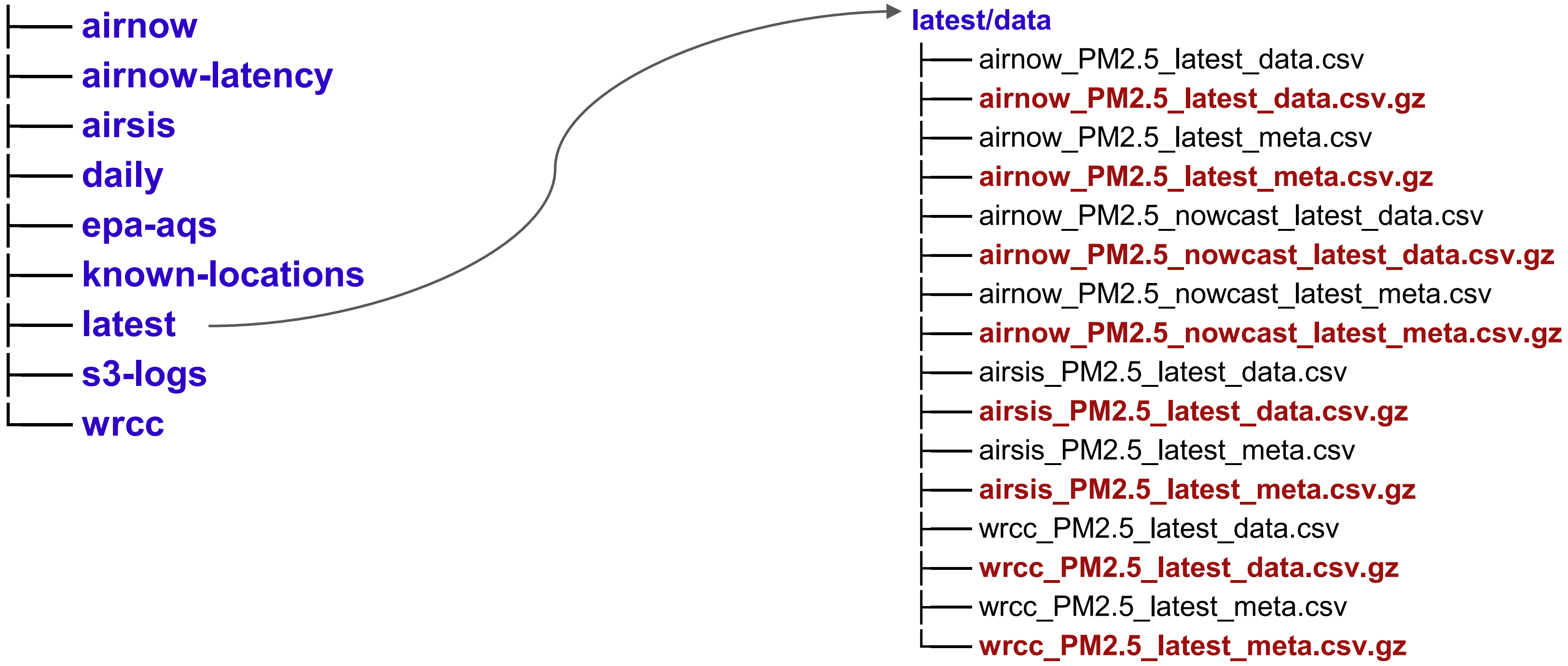
Jon’s favorite data access – download static files

- Easy
- Fast
- All the data at once
- No programming required
- No authentication required

Jon’s favorite time series format – CSV

- XML 😞
- JSON 😐
- CSV 🥳 🎉 🎊

http://data-monitoring_v2-c1.airfire.org/monitoring-v2/



```
├── airnow
├── airnow-latency
├── airsis
├── daily
├── epa-aqs
├── known-locations
├── latest
├── s3-logs
└── wrcc
```

```
latest/data
├── airnow_PM2.5_latest_data.csv
├── airnow_PM2.5_latest_data.csv.gz
├── airnow_PM2.5_latest_meta.csv
├── airnow_PM2.5_latest_meta.csv.gz
├── airnow_PM2.5_nowcast_latest_data.csv
├── airnow_PM2.5_nowcast_latest_data.csv.gz
├── airnow_PM2.5_nowcast_latest_meta.csv
├── airnow_PM2.5_nowcast_latest_meta.csv.gz
├── airsis_PM2.5_latest_data.csv
├── airsis_PM2.5_latest_data.csv.gz
├── airsis_PM2.5_latest_meta.csv
├── airsis_PM2.5_latest_meta.csv.gz
├── wrcc_PM2.5_latest_data.csv
├── wrcc_PM2.5_latest_data.csv.gz
├── wrcc_PM2.5_latest_meta.csv
└── wrcc_PM2.5_latest_meta.csv.gz
```

Reading in ‘csv.gz’ data

R

```
meta <- readr::read_csv("meta.csv.gz")
data <- readr::read_csv("data.csv.gz")
```

Python

```
meta = pandas.read_csv("meta.csv.gz")
data = pandas.read_csv("data.csv.gz")
```

Thanks for listening!

MAZAMA SCIENCE
SEE YOUR DATA