WEATHER DATA FOR BUILDING ENERGY SIMULATIONS

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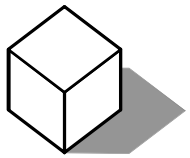


Acknowledgements

- **Lukas Lundström,** Mälardalen University, Sweden for information on sources of satellite-derived solar in Europe
- **Lachlan Strong**, Australian Bureau of Meteorology for information on satellite-derived solar from the Japanese Himawari-8 satellite
- **Aron Habte** and **Anthony Lopez**, US National Renewable Energy Laboratory for information on the NSRDB (National Solar Radiation Data Base)

Self-intro

- Formal training in physics and architecture
- Staff scientist at LBL 1981-2007, working in building energy simulations, and using simulations to evaluate new technologies and guide building energy policy.
- Interest in weather data stemmed from need on international projects, which expanded as data availability increased over time.
- Left LBNL 2007, and started a small consultant company called White Box Technologies.
- Developed weather sets for ASHRAE, Calif. Energy Comm., ISHRAE.
- Launched in 2012 http://weather.whiteboxtechnologies.com to provide weather products and services over the Web to the building simulation community.
- Former chair of ASHRAE TC 4.2 Climatic Information and TC 4.7 Energy Calculations.

Weather data needs for building energy simulations

- Hourly observations of temperature, humidity, pressure, wind speed and direction, and solar radiation.
- Virtually all digital weather stations today record all of the preceding elements, except for solar radiation.
- Simulations require two forms of solar radiation: Global Horizontal (GHI) and Direct Normal or beam (DNI). As rare as stations that measure GHI, those that measure DNI are even more rare and practically nonexistent.
- Solar radiation values found on weather files are almost always derived from models, although recently satellite-derived are now becoming more available.

Formats, Formats

Raw data formats

- **ISH DSI-3505 *(previously DATSAV, TD-9685, TD-1440)***
- **METAR *(originally developed by the US FAA for aviation, since adopted by WMO and used by many organizations)***
- **Others *(expect the unexpected!)***

Processed data formats

- **TMY2/IWEC (142 column fixed field format)**
- **TMY3/IWEC2 (CSV format with 68 fields)**

Simulation program formats

- ***.epw (for *EnergyPlus*, contents identical to TMY2/TMY3)**
- ***.bin/*.binm (for *DOE-2*, binary file in integer IP units, 15 fields "packed" into 4 integer numbers)**
- ***.fmt/.fmtm (ASCII equivalent of above; originally created for transfering *.bin files across different OS)**

Types of weather data used in simulations

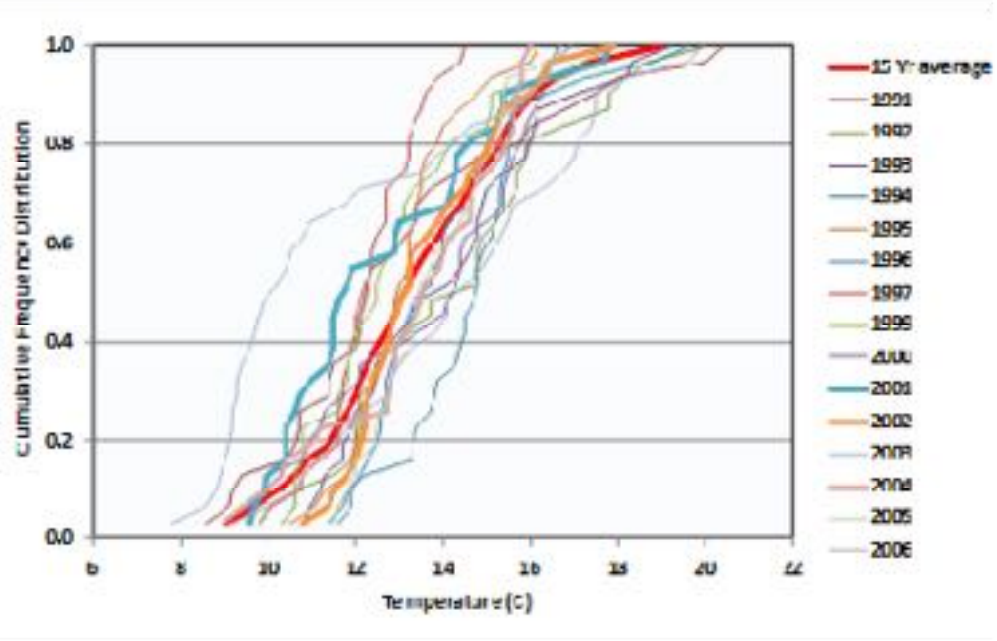
- Typical year vs actual year
- Observed data vs synthetic data
- Hourly data vs summary data, e.g., daily max-min data

What goes into a “typical year” weather file?

- Basically an exercise in selection, not in creation.
- 95% of the effort is in producing the historical weather data!
- Different methods have been proposed in the past (TRY, DRY, etc.), but the consensus has developed in favor of the TMY Method developed by NREL in the early 1980s.
- The TMY Method is a compilation of 12 actual months from the selected period of record, each of which has been chosen as the most representative using the Finkelstein-Schafer Statistic (FS).

Brief explanation of the TMY Method

- The Finkelstein-Shafer (FS) statistic is the absolute area enclosed between the Cumulative Frequency Distribution (CFD) of a climate parameter for each month and the long-term CFD for the same month over all years.
- The weighted sum of the FS statistic for all the parameter considered is the Cumulative FS (CFS) for that month.
- The month with the smallest CFS is picked as the "typical month" for that month.



How sensitive are the "typical year" files to the weighting used?

Climate Parameters and Weights used in different projects

Climate Variable	TMY	TMY2, TMY3	IWEC	IWEC2
Maximum Daily Dry-Bulb Temperature	1/24	1/20	1/20	1/20
Average Daily Dry-Bulb Temperature	1/24	2/20	6/20	2/20
Minimum Daily Dry-Bulb Temperature	1/24	1/20	1/20	1/20
Maximum Daily Dewpoint Temperature	1/24	1/20	0.5/20	1/20
Average Daily Dewpoint Temperature	1/24	2/20	1/20	2/20
Minimum Daily Dewpoint Temperature	1/24	1/20	0.5/20	1/20
Average Daily Wind Speed	2/24	1/20	1/20	1/20
Maximum Daily Wind Speed	2/24	1/20	1/20	1/20
Daily Global Horizontal Solar Radiation	12/24	5/20	8/20	5/20
Daily Direct Normal Solar Radiation	not used	5/20	not used	5/20

Answer: not so much (see Su, Huang, Xu, and Zhang 2009)

"Typical year" weather data sets

- TMY2 (NREL 1993, 239 US, free)
- TMY3 (NREL 2005, 1020 US, free)*
- TMYX (NREL 2015, > 1 million grid points for Western Hemisphere from 60N to 20S latitude, free)
- CWEC2 (EnvCanada 1990, 47 Canada, free)*
- CZ2010 (CEC 2011, 88 California, free)*
- IWEC2 (ASHRAE 2011, 3012 international, cost)*
- ISHRAE (2015, 61 India, free)*
- CN2014 (WBT 2015, 224 Canada, cost)*
- MX2015 (WBT 2016, 119 Mexico, cost)*
- *see EnergyPlus* web site for other international weather data

** available at http://weather.whiteboxtechnologies.com*

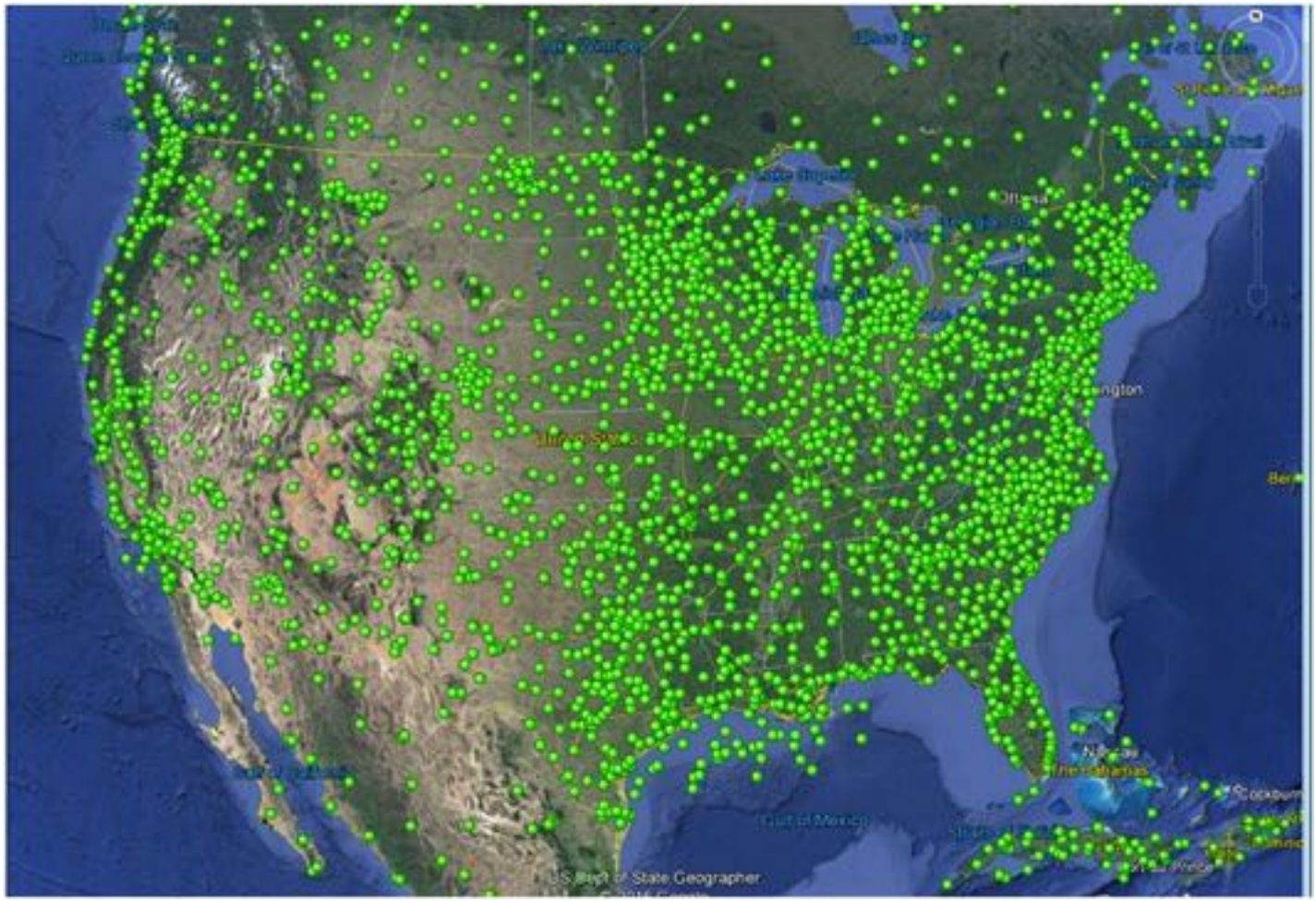
Actual year weather data sets

Integrated Surface Database

National Center for Environmental Information (NCEI), formerly the Nat'l Climatic Data Center (NCDC) (*www.ncdc.noaa.gov/isd*)

22747 stations, of which approx. 10,000 are active. For 2016, there are 8,140 stations with sufficient data to create usable hourly weather files (2110 US, 275 Canadian, 5775 rest of the world)

ISD 2015 stations in the US



ISD 2015 stations in Europe

Going from DSI-3505 to *.DAT to *.FIN4

DSI-3505

```
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11999GE19MSL   +99999+99999GF199999021999005791999999MA1098401999999REMMET081METAR COR EGLL
031450Z AUTO 20011KT 170V250 9999 FEW019 BKN043 09/08 Q0984 NOSIG=
023503772099999201601031500 4+51483-000450FM-
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3772 47681 /1910 10096 20085 39817 49847 55042 723// 333 55300 20061 81/33 87/45 90710
91128=
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*.DAT

```
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037720 201601010300 +0020 +0012 10223 0015 170 99 99 99 008000 99999 9999 999 0
037720 201601
037720 201601
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037720 201601
037720 201601
037720 201601
```

*.FIN4

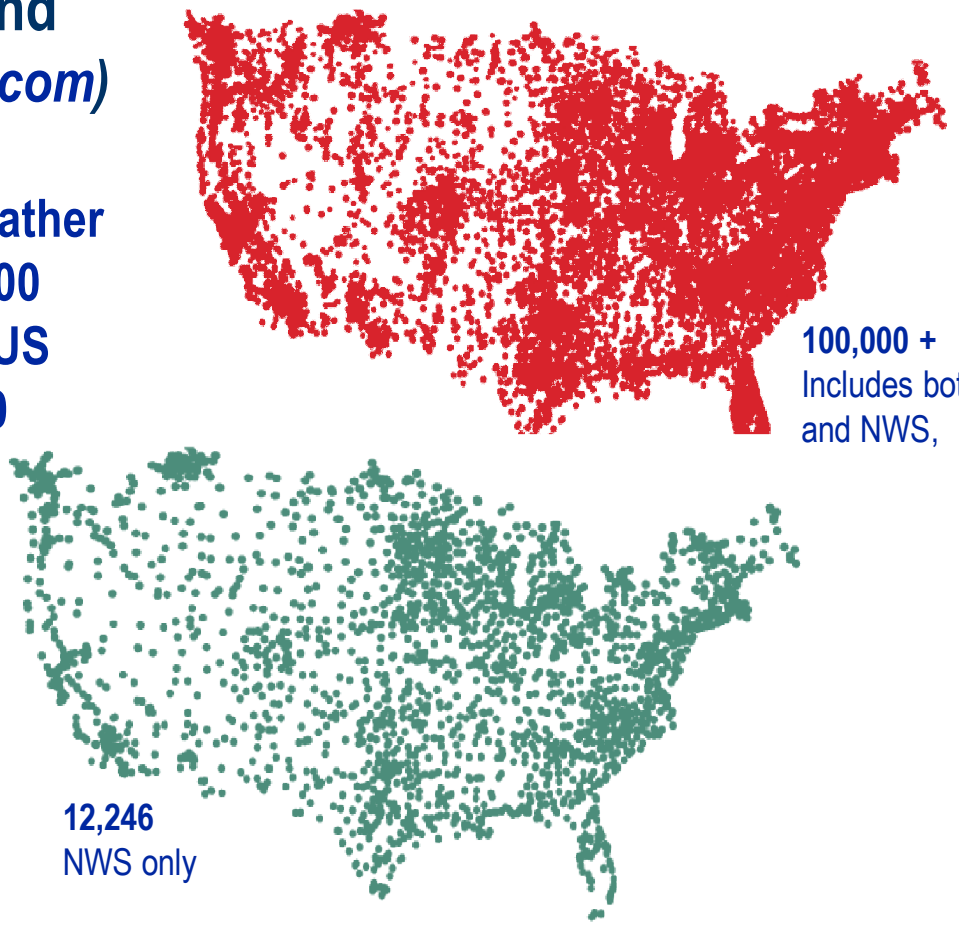
```
GBR_LONDON-HEATHROW-AP         037720  51.478   -0.461   25 6   0.0 GMT Cfb
                        DBT     DPT     Press  Altim  Sky Opq WSpd  Wnd  TotSol DirNorm Pres
Year Mo Dy Hr    (C)     (C)     (mb)   (inHg) Cov Cov (m/s) Dir  (W/m2)  (W/m2)   Wth  Rain  Visib    Ceil   SolarZ
2016  1  1  1   3.7     2.4   1018.5          0  99R  2.6  230     0.0     0.0   40R    0F  14000   22000  0.0000
2016  1  1  2   2.6     1.9   1018.7          0  99R  0.0  150     0.0     0.0   40R    0F   7000   22000  0.0000
2016  1  1  3   2.0     1.2   1019.1          0  99R  1.5  170     0.0     0.0   40R    0F   8000   22000  0.0000
2016  1  1  4   2.3     1.8   1019.5          0  99R  1.5  110     0.0     0.0   40R    0F   7000   22000  0.0000
2016  1  1  5   2.4     2.0   1019.8          0  99R  1.0  100     0.0     0.0   40R    0F   8000   22000  0.0000
2016  1  1  6   2.3     1.8   1019.8          0  99R  1.5   90     0.0     0.0   40R    0R  11000   22000  0.0000
2016  1  1  7   2.6     1.9   1019.3          0  99R  1.0   80     0.0     0.0   40R    0R  12000    5100  0.0000
2016  1  1  8   2.2     1.5   1019.1          0  99R  1.0   60     0.0     0.0   40R    0R   9000    5400  0.0000
2016  1  1  9   2.2     1.2   1018.8          0  99R  2.6  100    26.2   143.2   40R    0R  11000    4200  0.0421
2016  1  1 10   4.0     1.8   1017.8          0  99R  4.1   90    89.8   286.5   40R    0R  25000    3900  0.1388
2016  1  1 11   5.4     1.9   1017.3          0  99R  3.6  120   156.4   373.4   40R    0R  29000    3600  0.2151
2016  1  1 12   7.0     4.4   1016.0          0  99R  5.1  120   195.8   414.8   40R    0F  21000    3300  0.2566
2016  1  1 13   7.2     4.4   1014.5          0  99R  5.7  110   199.1   418.0   40R    0F  21000    3000  0.2600
2016  1  1 14   7.4     4.5   1013.1         0L  99R  5.1  100   165.8   383.8   40R    0F  19000    3000  0.2252
2016  1  1 15   7.5     5.6   1011.8         0L  99R  7.2  100   103.0   305.7   40R    0F  15000     450  0.1548
2016  1  1 16   7.6     6.7   1010.7         0L  99R  5.7  110    34.0   241.4   40R    0F  13000     330  0.0577
2016  1  1 17   8.0     7.1   1009.4         0L  99R  6.7  120     0.0     0.0   40R    0F  21000     270  0.0001
2016  1  1 18   8.1     6.5   1007.9         0L  99R  7.7  130     0.0     0.0   40R    2R  21000    2700  0.0000
2016  1  1 19   8.1     6.3   1007.1         0L  99R  8.8  120     0.0     0.0   40R    2R  17000    2700  0.0000
```

Actual year weather data sets

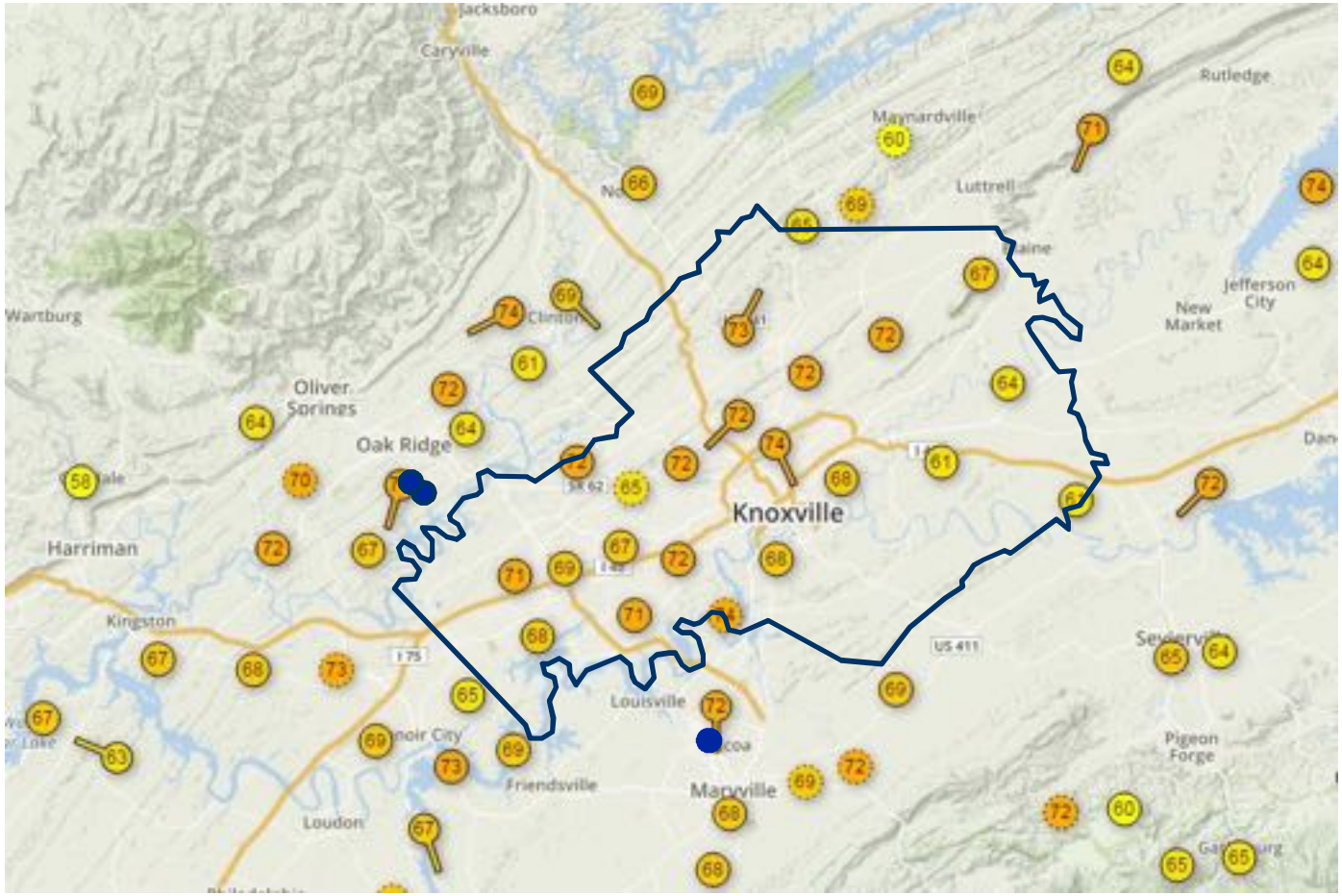
Web-based sources of weather data

Weather Underground
(www.wunderground.com)

Commercial Internet weather service, with over 100,000 weather stations in the US Including links to 34,000 to government weather stations (26,000 US, 6000 international (WU 2013, 2015).



Comparison of ISD and WU stations around Knox County, Tennessee



ISD Stations 68 WU stations

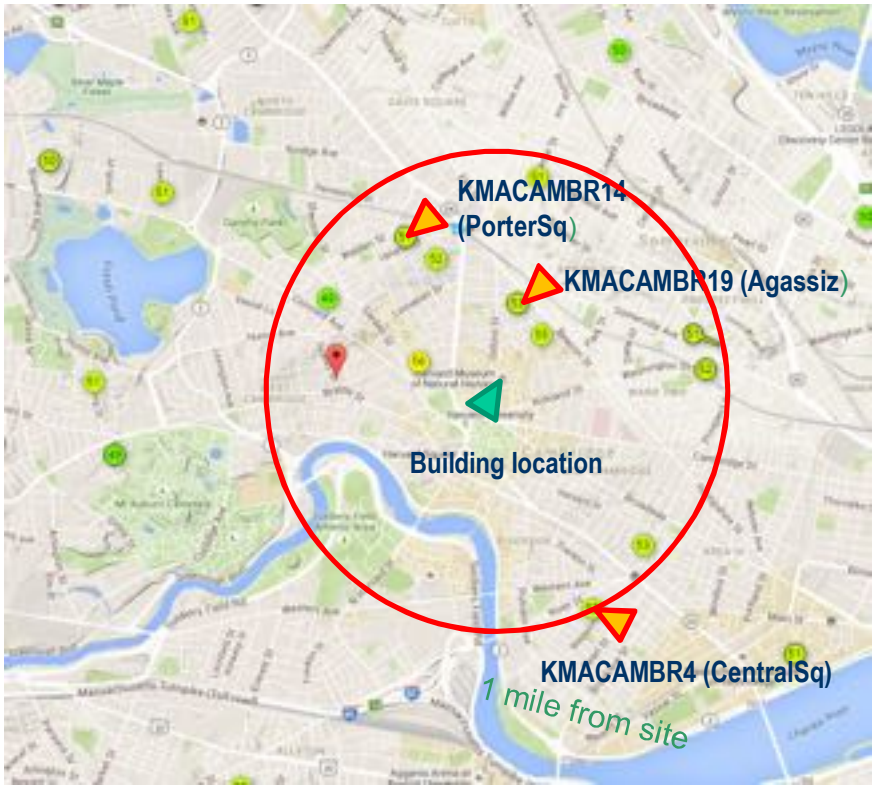
Two PWS in my home town Moraga CA

KCAMORAG2 at St. Mary's College
(operational through May 6, 2014)
Frequency: every 5 minutes
Parameters: Dry-bulb and Dewpoint Temperatures, Pressure, Wind Speed, Wind Direction, Wind Speed Gusts, Relative Humidity, Liquid Precipitation, and Global Solar Radiation

KCAMORAG13 at Campolindo High School
(online since March 2015)
Frequency: every 5 minutes
Parameters: Dry-bulb and Dewpoint Temperatures, Pressure, Wind Speed, Wind Direction, Wind Speed Gusts, Relative Humidity

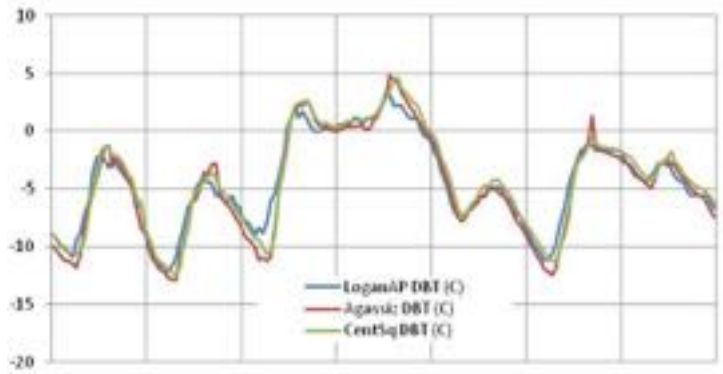
Example use of Web weather data in Cambridge (1)

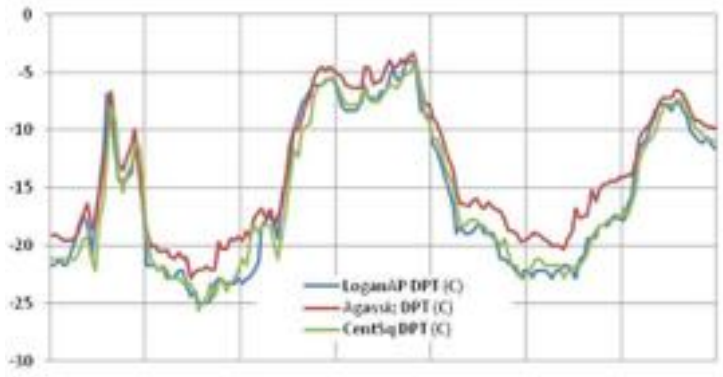
- Client with M&V project in Harvard needed onsite weather data for 2014.
- Nearest ISD station is Logan Airport 5.2 miles due east
- WU showed there were 11 PWS within a mile of the building site. Data was downloaded for three of the closest PWS (Agassiz, Porter Square, Central Square).
- Agassiz was chosen as the primary station because it's the closest and has high quality 15-minute data.
- Logan AP weather data was used as a baseline station.



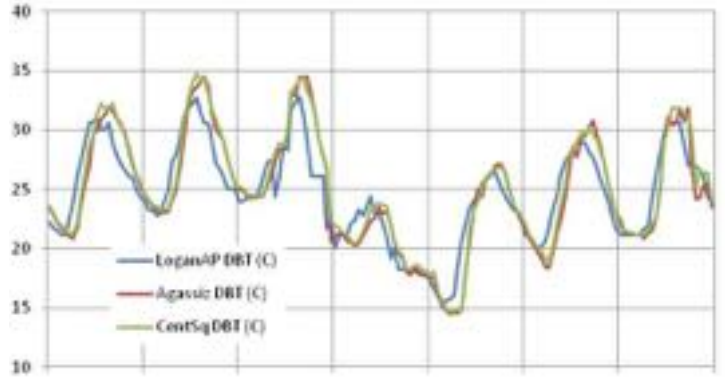
Example use of Web weather data in Cambridge (2)
Temperature comparison

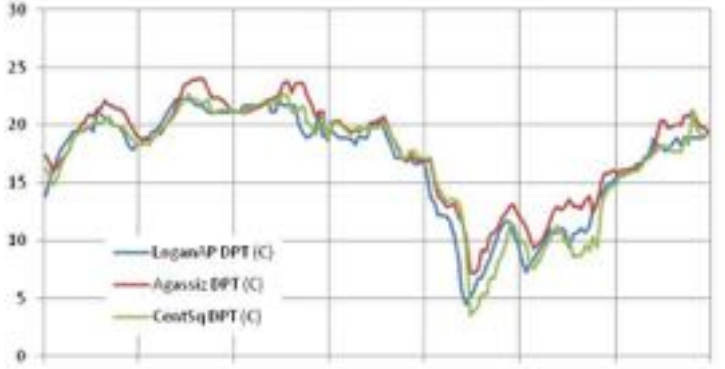
Winter week (Jan 1 – 7, 2014)





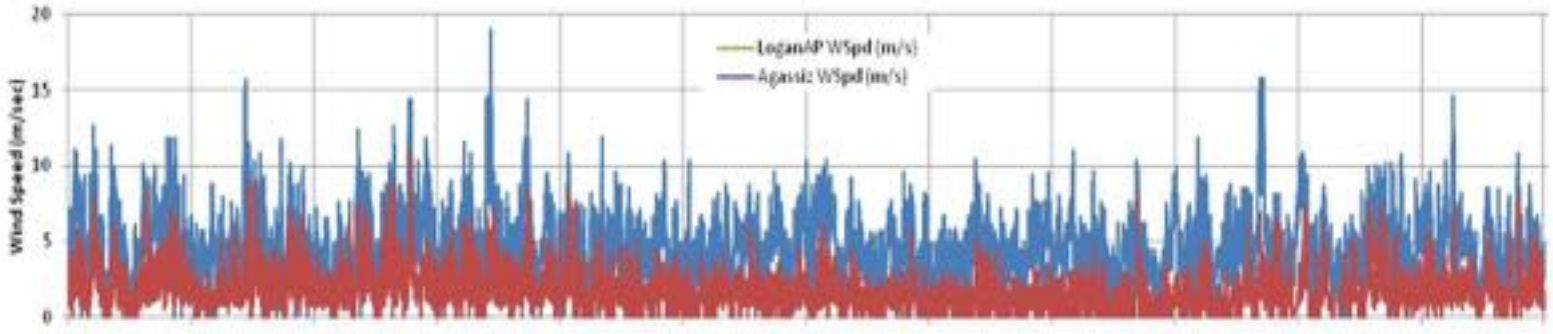
Summer week (Aug. 1 – 7, 2014)



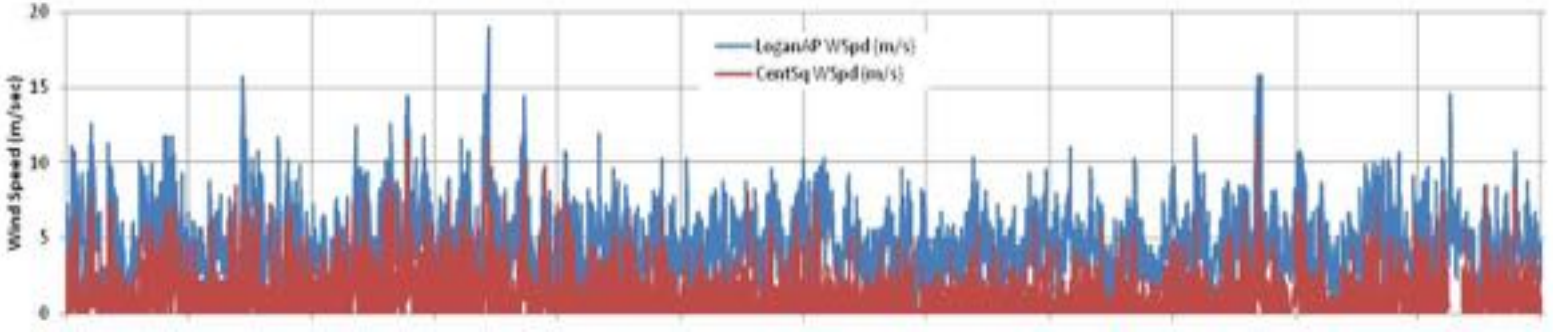


Example use of Web weather data in Cambridge (3)
Wind speed comparison

Logan AP vs Agassiz



Logan AP vs Central Square



Recent Developments in Weather Data: Satellite-derived solar radiation

pros: 1. universal coverage on a grid scale (continental US 1998-2009 available from Clean Power Research (*www.solaranywhere.com*) entire world will be made available by NOAA); North America 20°S - 60° N 1998-2015 available from NREL as the NSRDB along surface conditions taken from MERRA)

2. accuracy significantly better than modeled solar; effort driven primarily by the needs of the PV industry.

cons: 1. data outside the released domains or time periods available only from commercial vendors and are prohibitively expensive.

Derivation of global horizontal solar radiation

- Used Zhang-Huang Model correlating global horizontal radiation to cloud cover, change in dry-bulb temperature over the past 3 hours, relative humidity, and wind speed

$$I = Io \bullet \sin h \bullet \{C_0 + C_1(CC) + C_2(CC)^2 + C_3(T_n - T_{n-3}) + C_4 \varphi + C_5 V_w\} + D$$

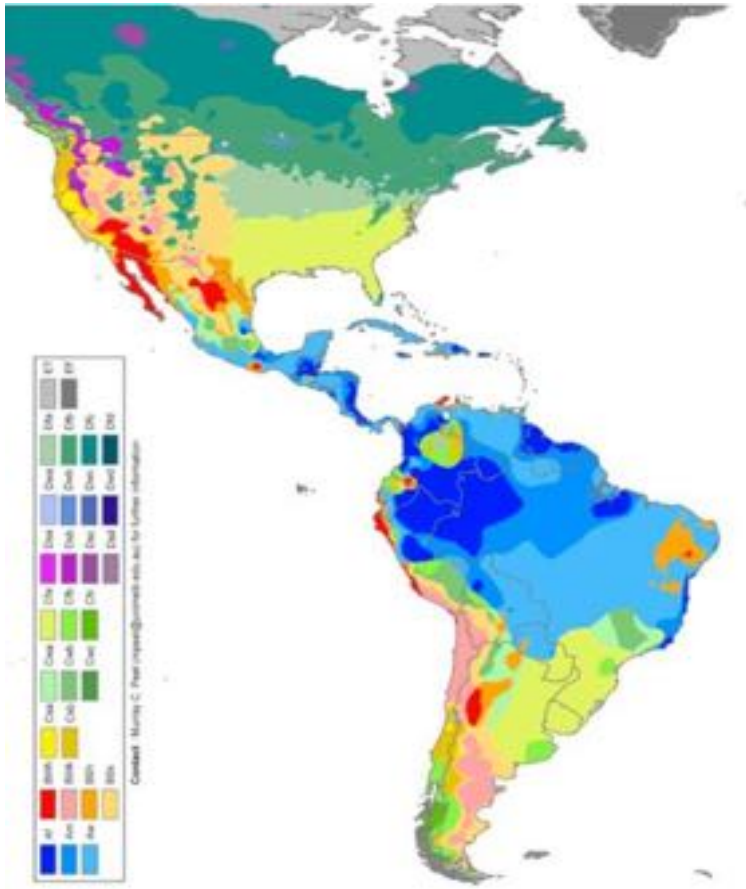
when $ET^*0.10 > I > ET^*0.90$

$= ET^*0.90$ when $I > ET^*0.90$

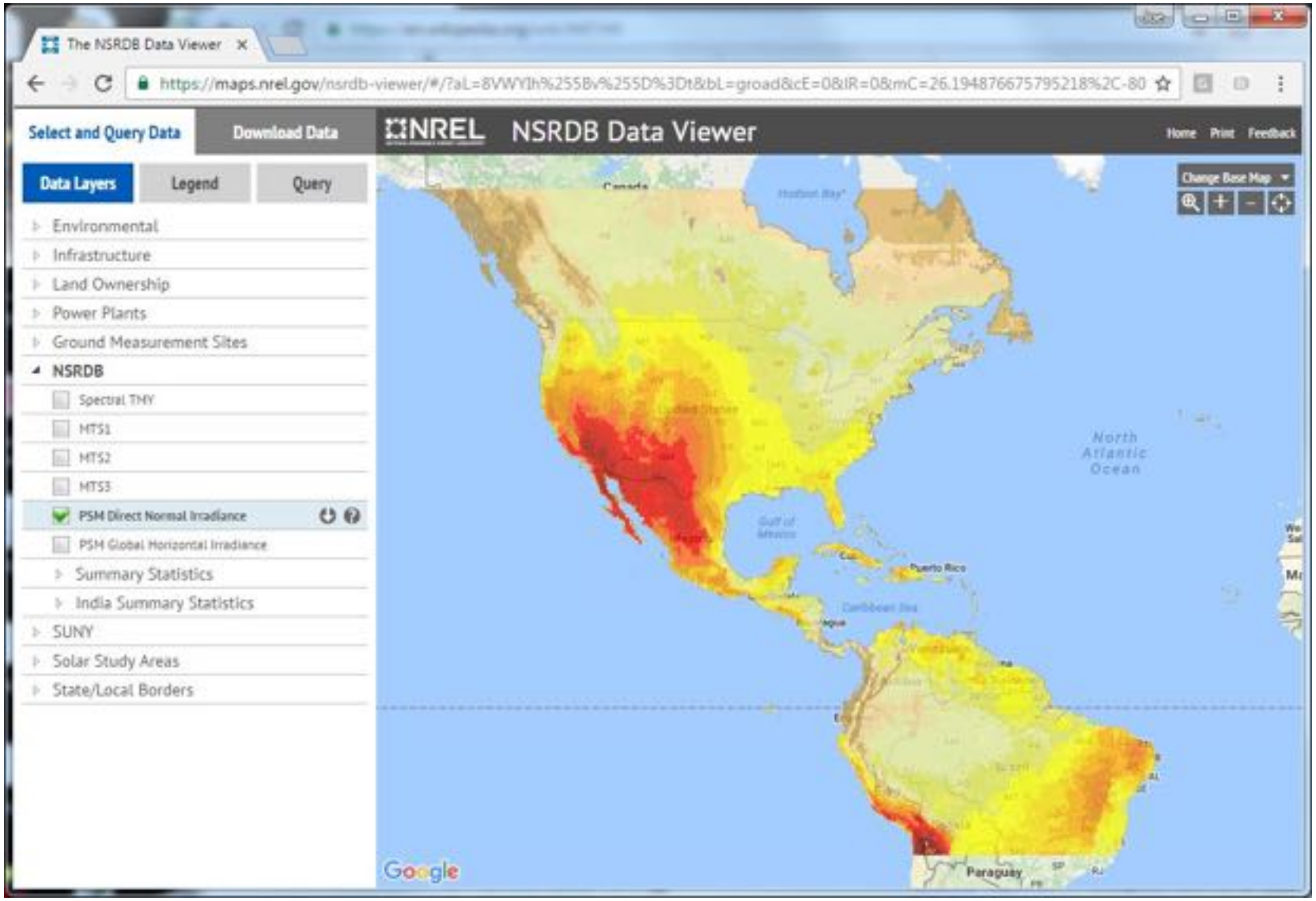
$= ET^*0.10$ when $I < ET^*0.10$

- Coefficients C_0 , C_1 , C_2 , C_3, C_4 , C_5 , D taken from RP-1477 by Köppen Class:

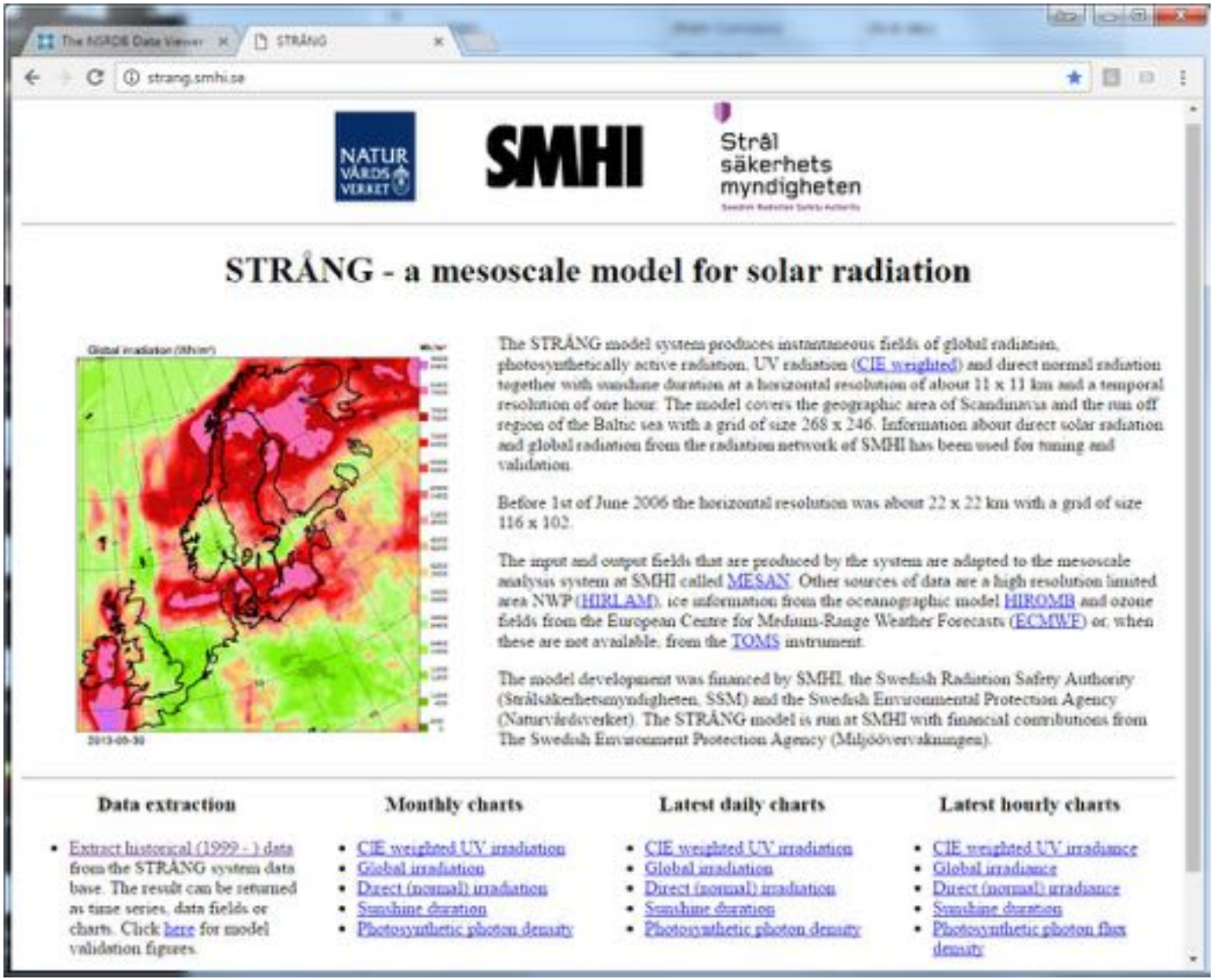
Am = Miami	BWh = Kuwait
Aw = Honolulu	Cfa=Nashville
BSh = Phoenix	ETh=Davos



https://maps.nrel.gov/nsrdb-viewer

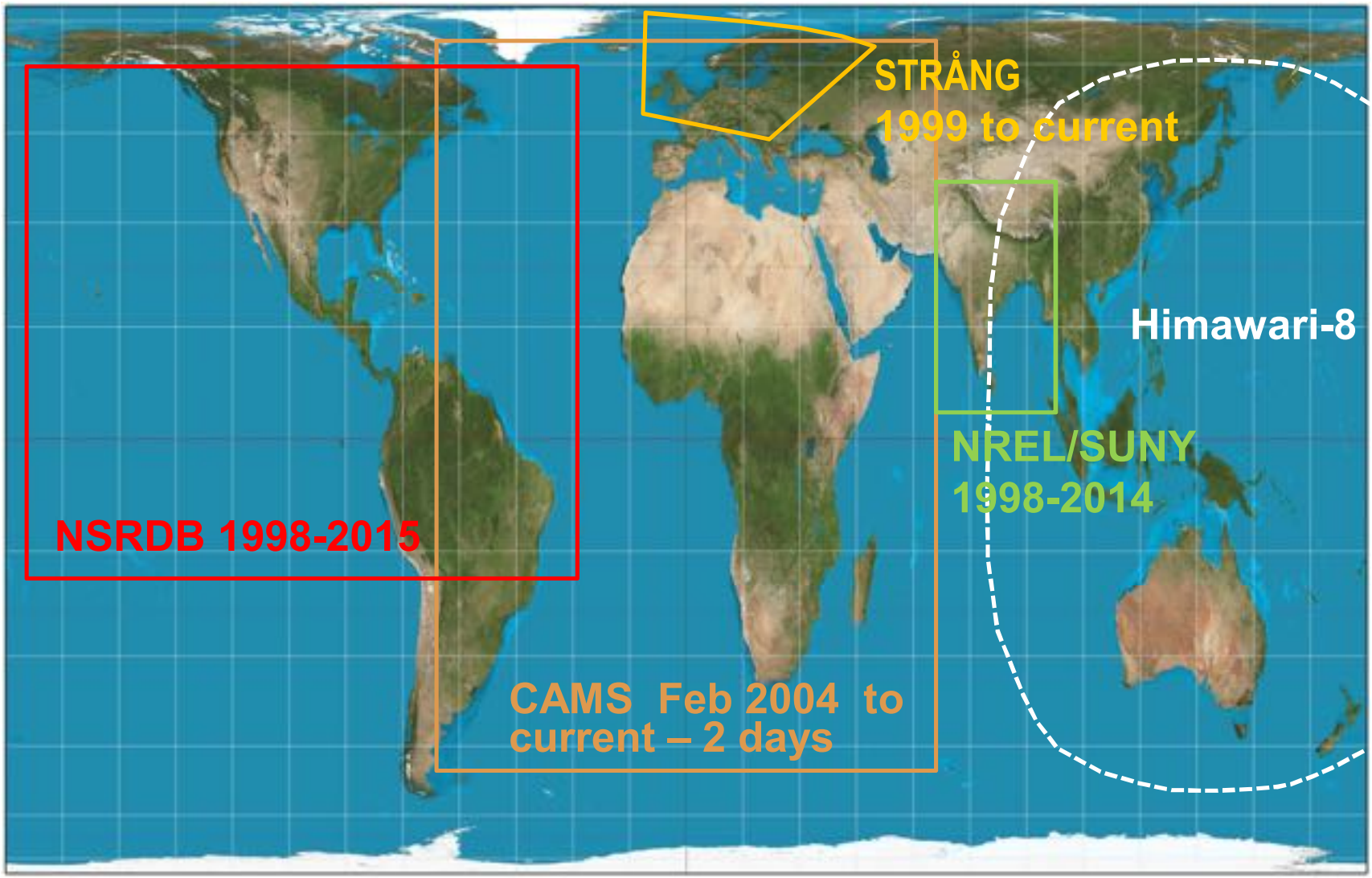


https://www.strang.smhi.se

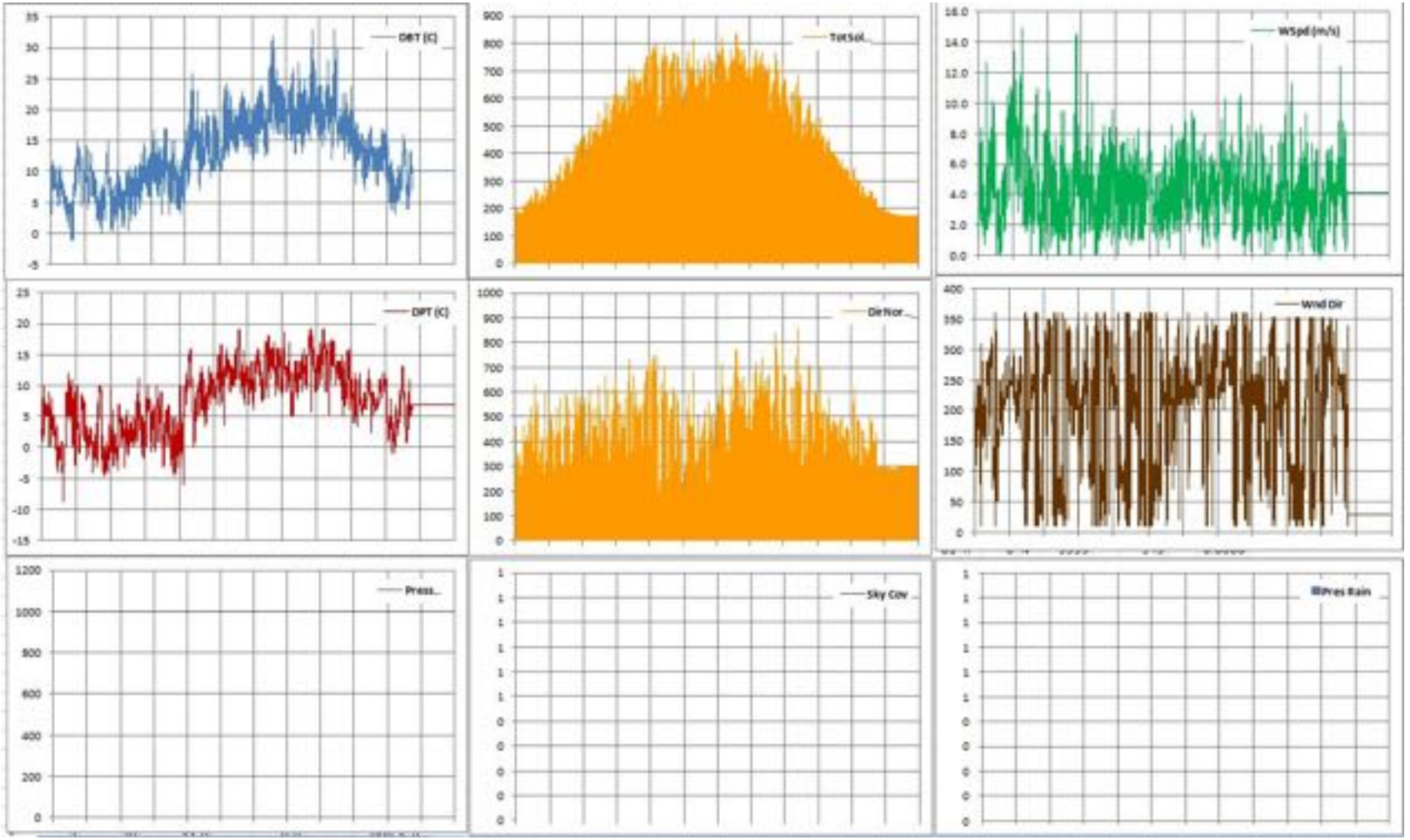


http://www.soda-pro.com/web-services/radiation/cams-radiation-service

Coverage of satellite-derived solar radiation in the public domain (2016)

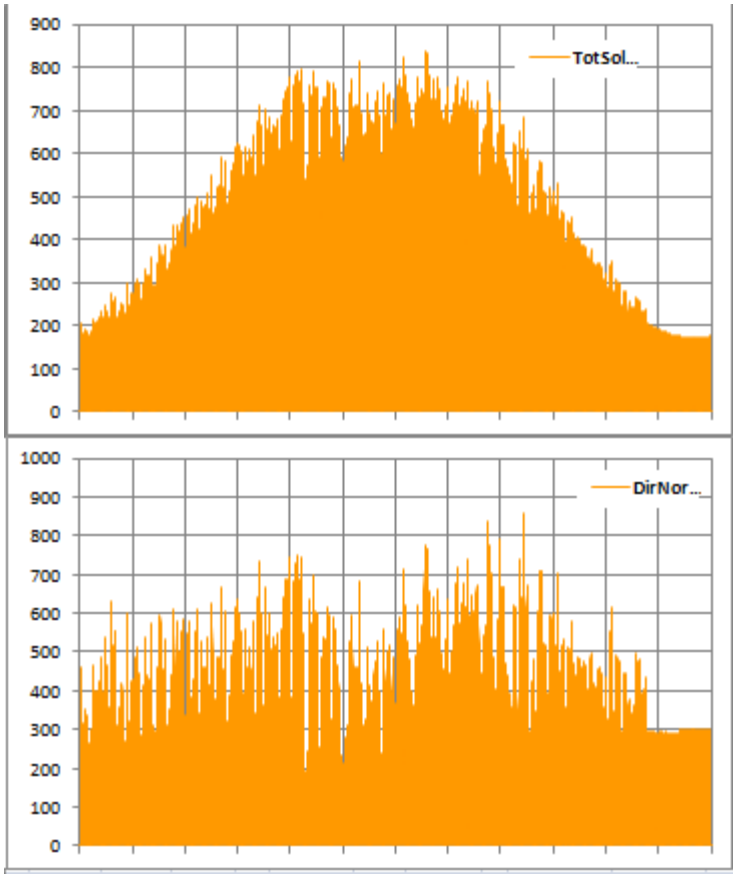


Weather data for GBR_London-City_37683_16

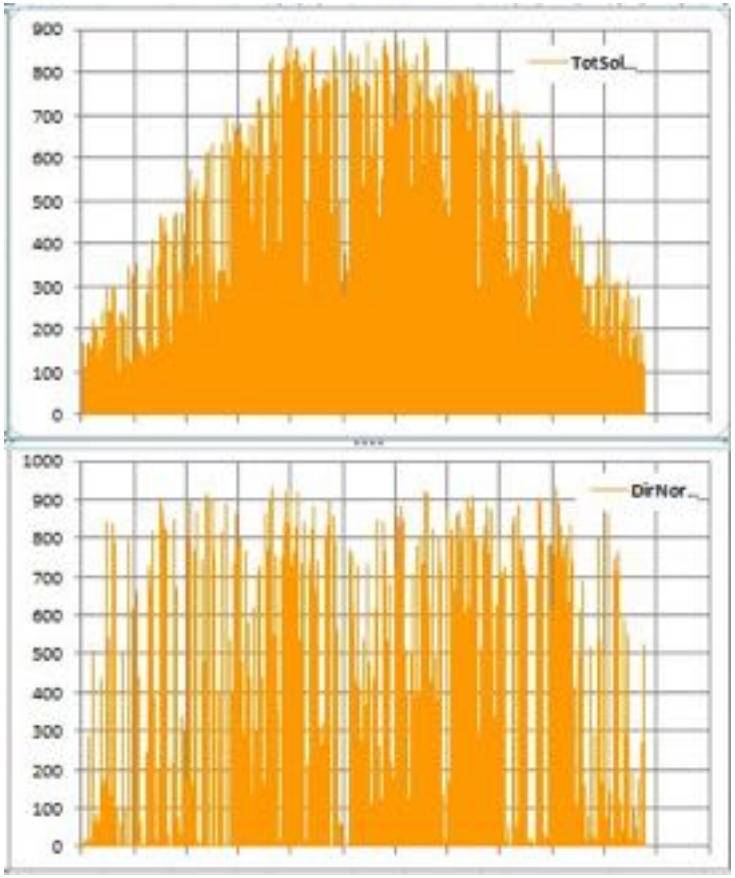


Weather data for GBR_London-City_37683S_16

ISD (Cloud Cover always 0)



CAMS satellite-derived



Synthetic or modeled weather data sets

- MeteoNorm – uses statistical models to generate "typical year" weather data for any location in the world
- Autodesk Green Building Studio Weather – combines NOAA's Rapid Update Cycle (RUC) forecasting model that predicts weather conditions anywhere in the US on a 20-km grid with the Mesoscale Meteorological Model Version 5 (MM5) to fill data gaps.
- Reanalysis data – Climate Forecast System Reanalysis (CFSR), Modern Era Retrospective-Analysis (MERRA) from NOAA.

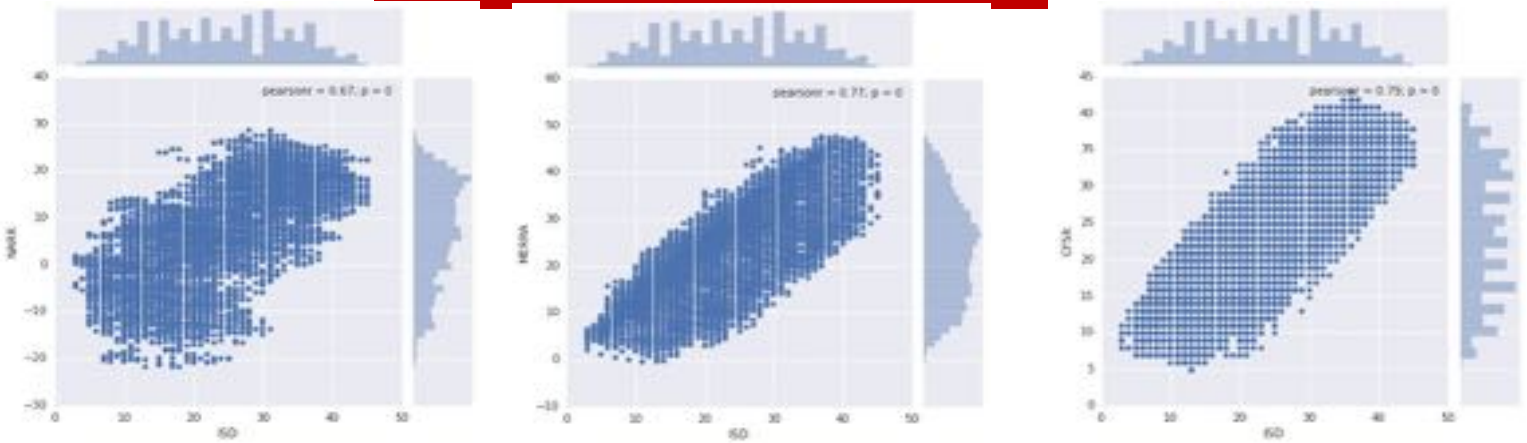
Synthetic or modeled weather data sets

- Great promise, but results so far are still uneven, possibly due to “teething” errors.
- Benefit to building energy simulation needs to be evaluated
  - Buildings are predominantly located in large urban areas, often with multiple weather stations
  - Is there a “Catch 22” situation here? Climate forecasting is most accurate with ground observations to “seed” the model; however, if there are observed data, forecasting results would not be needed.

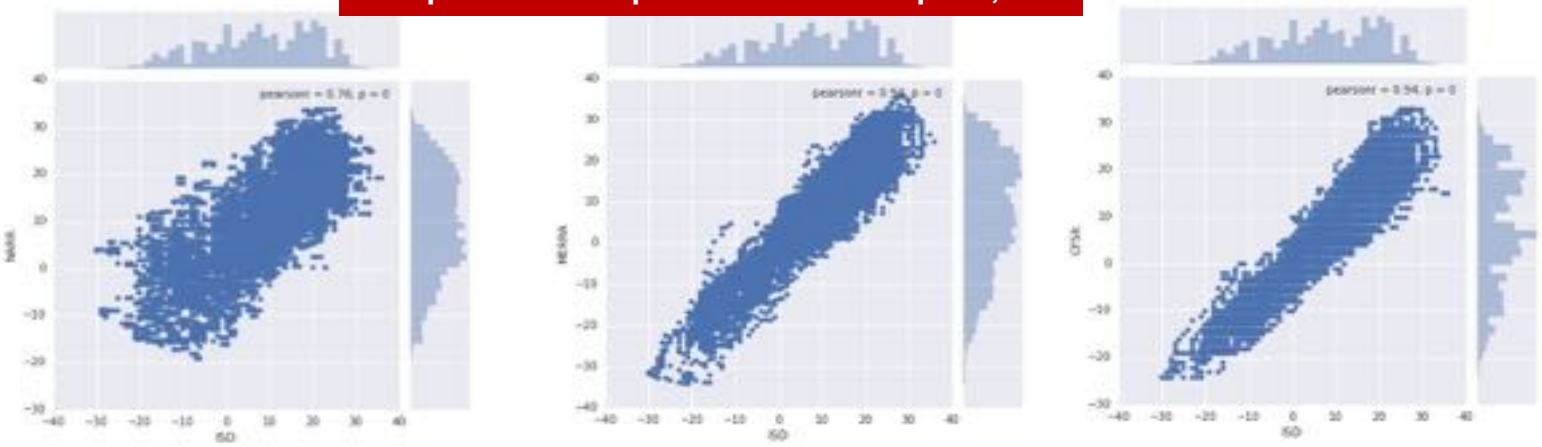
Comparison of MERRA to observed dry-bulb temperatures for 3 reanalysis programs in two US cities

NARR **CSFR** **MERRA**

Temperature Comparison for Phoenix, AZ

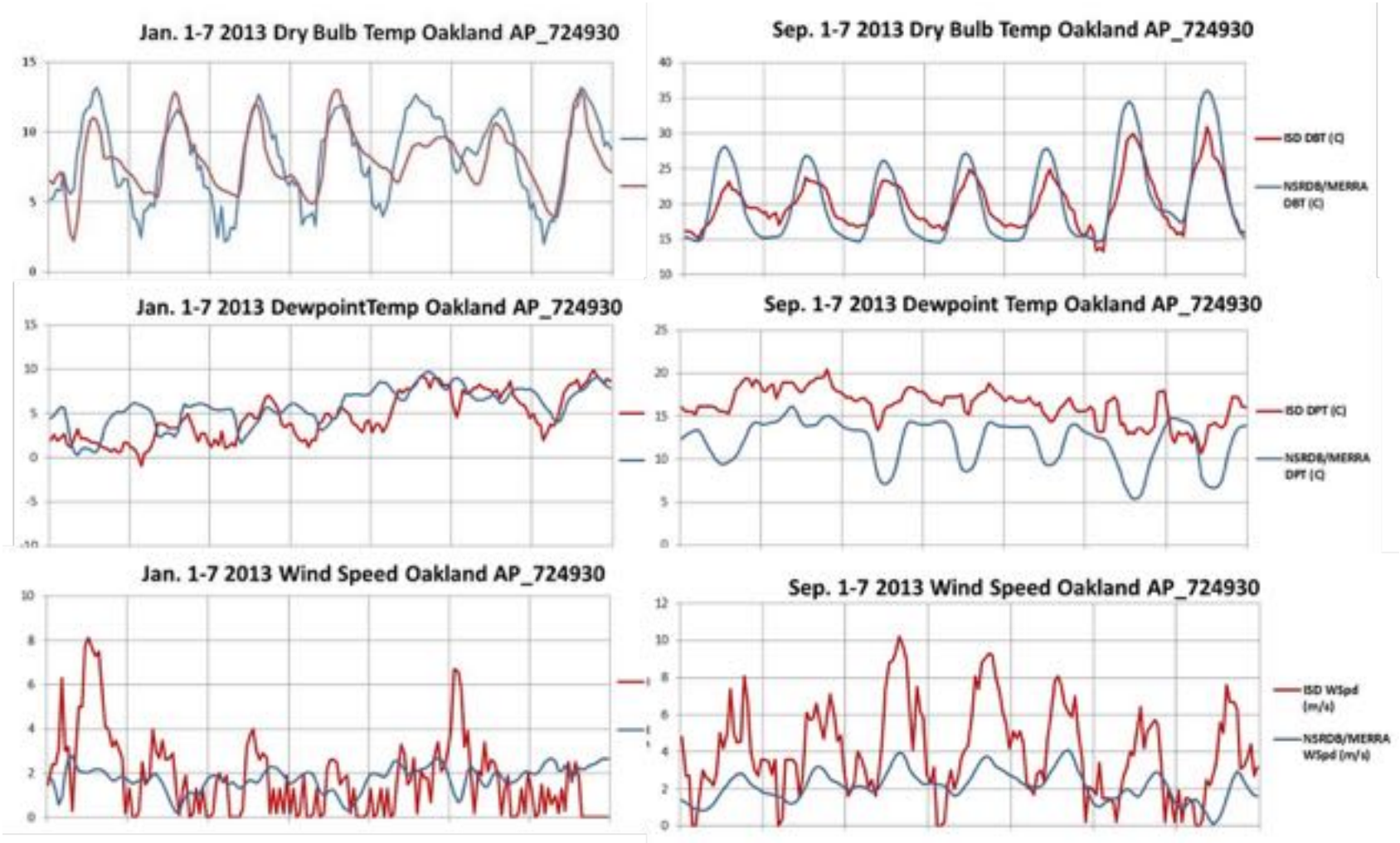


Temperature Comparison for Minneapolis, MN

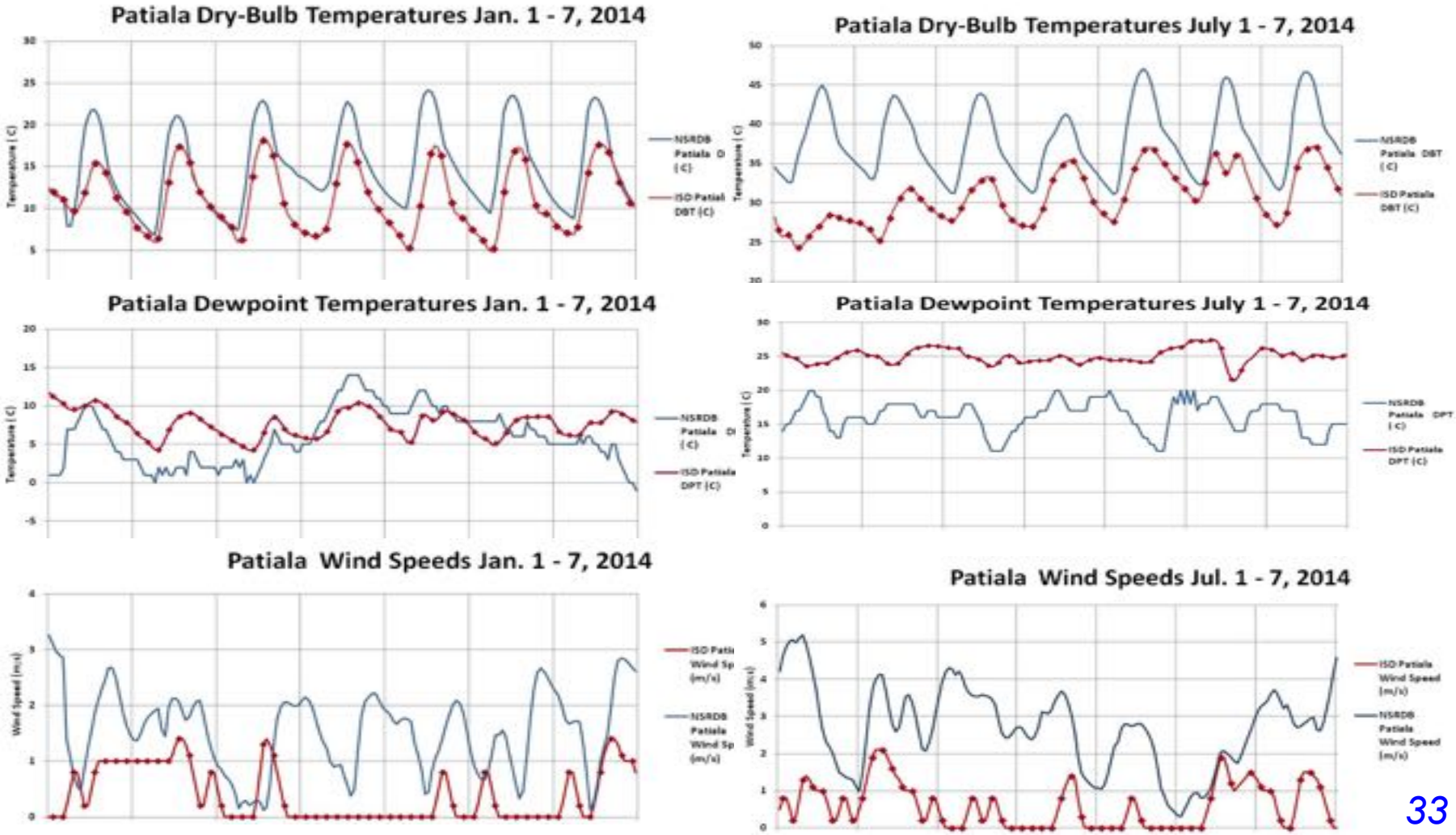


Source: Anthony Lopez NREL 2016

Comparison of NSRDB/MERRA to observed data for Oakland 2013



Comparison of NSRDB/MERRA to observed data for Patiala, India 2014

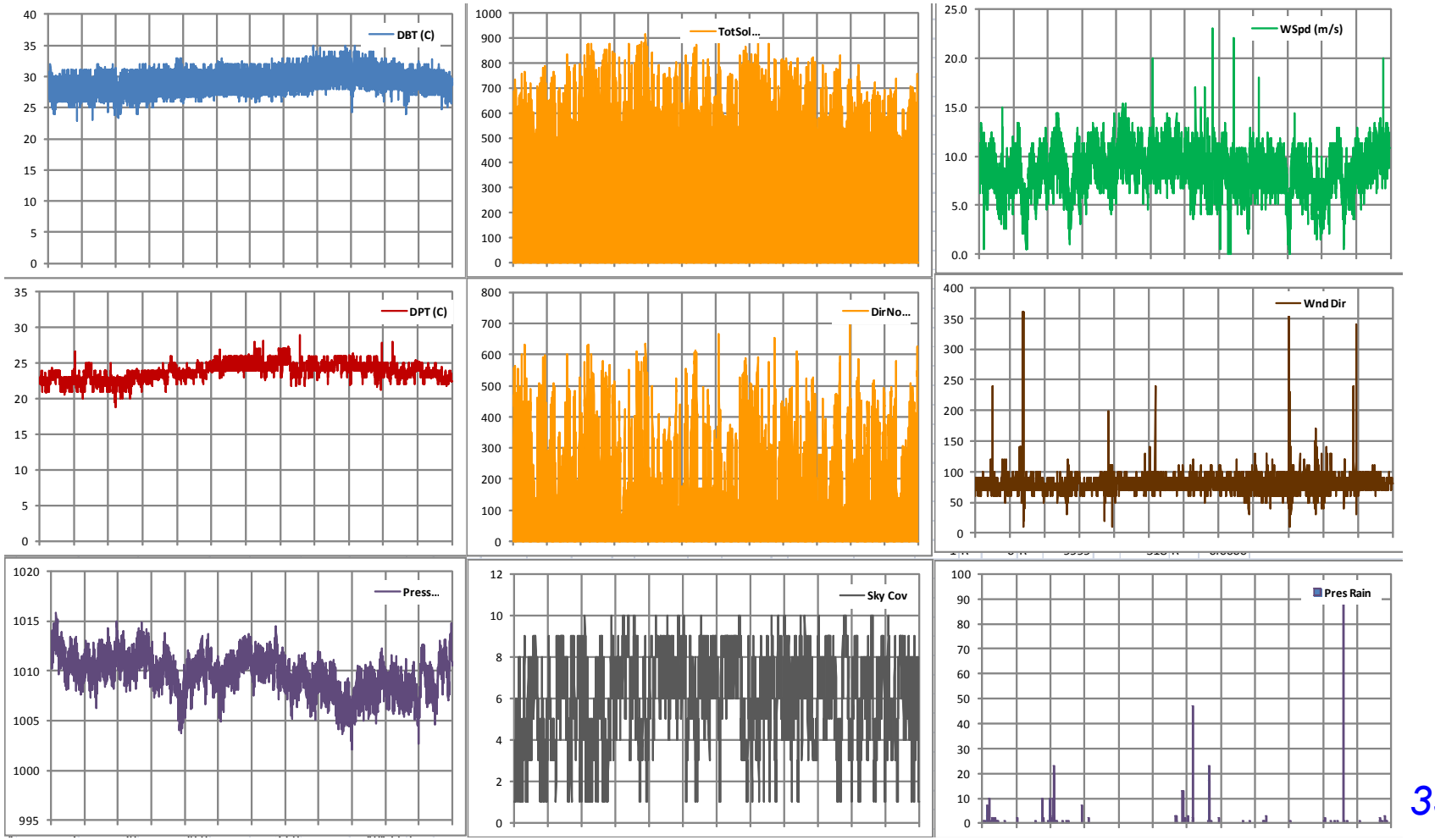


Things to watch out for when working with weather data

- What is the time stamp? (time is always in GMT for the ISD)
- How is pressure reported ? (pressures are all adjusted to sea level in the ISD)
- Does the station only report data during daytime hours? (roughly 5% of stations in ISD)
- Is the solar radiation the aggregate over the past timestep (North American convention), or the average rate at the time step (European convention)?

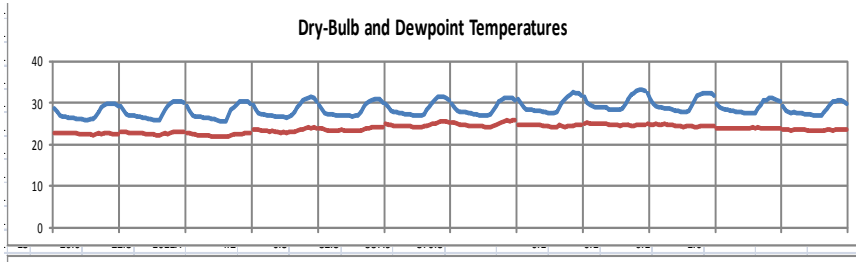
Evaluating the data quality of a weather file (1)

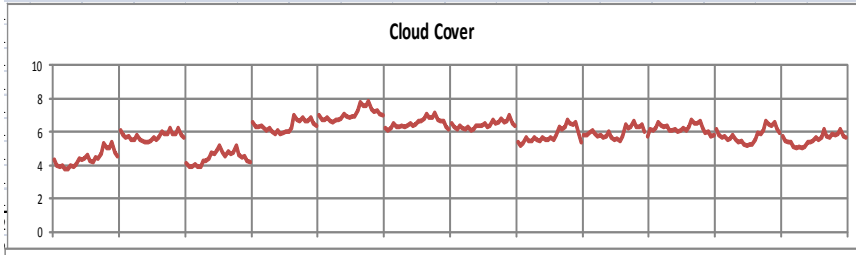
Display the time series for important weather parameters

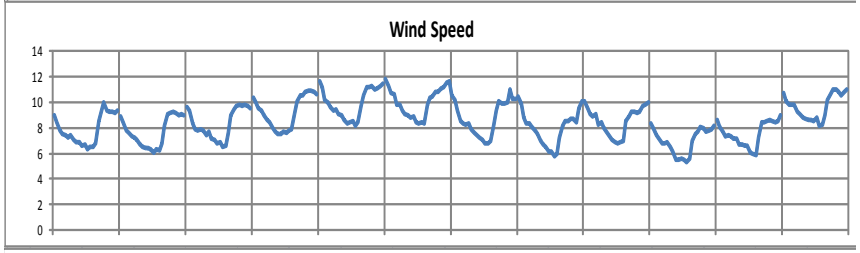


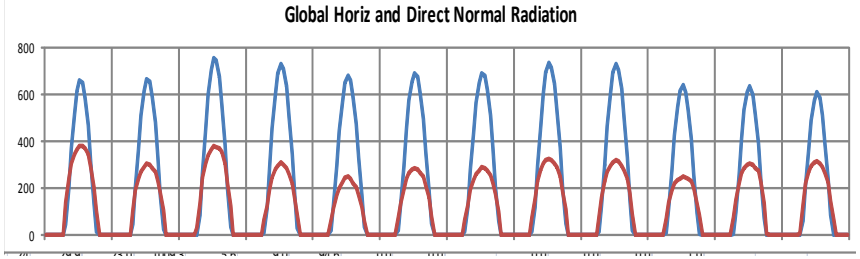
Evaluating the data quality of a weather file (2)

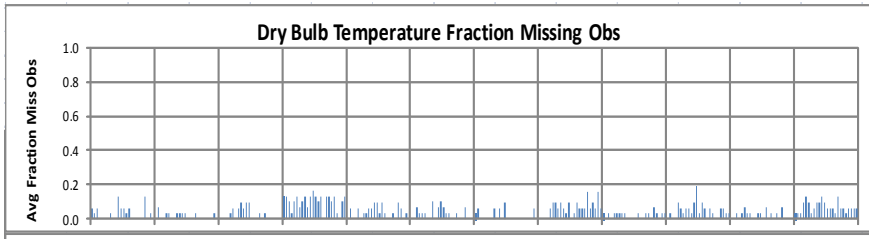
Look at average days per month and the number of observations by hour of day for possible problem areas

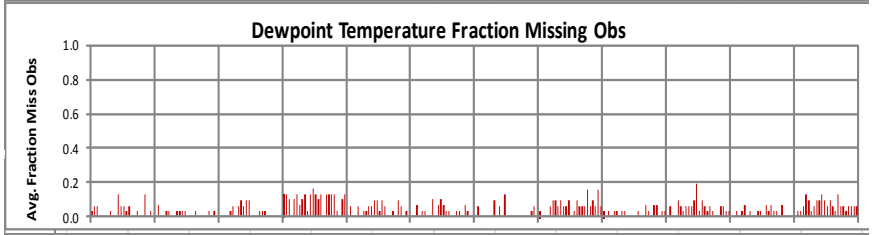


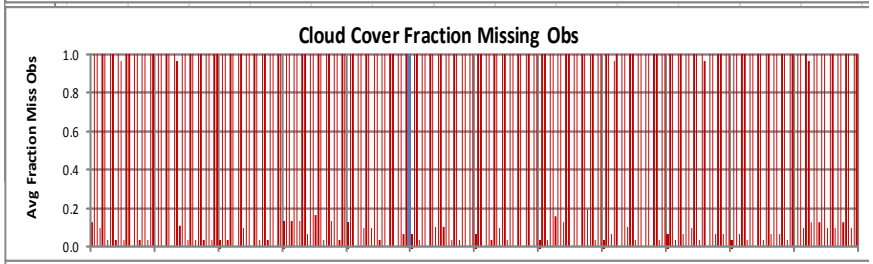


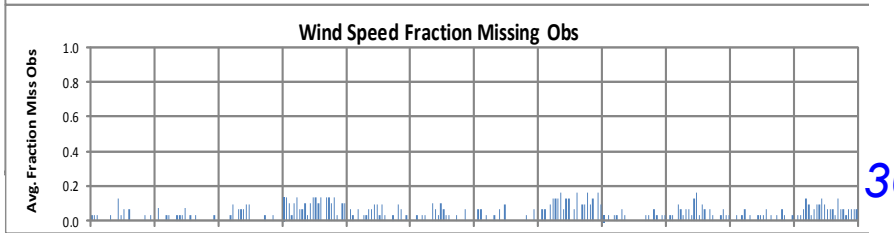












Conclusions

- "typical year" files provide just a snapshot view of the weather.
- Use historical year files any time you're evaluating measured data.
- The availability of both raw and processed weather data has greatly expanded over the past decade.
- Satellite-derived solar radiation can transform what had been the most problematic to the most easily accessible climate parameter.
- Climate reanalysis shows promise for providing data for any place and time, but still some time away.
- More attention needs to be paid to temporal variations in climate and microclimate variations in urban areas.
- Use average days by month and number of observations by hour of day to detect data quality issues.

Thank you for your attention!

Please let me know if you have any questions

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