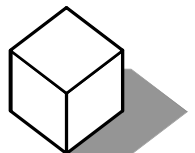


WEATHER DATA FOR BUILDING ENERGY SIMULATIONS

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Moraga CA**

**CIBSE-ASHRAE Webinar
December 14, 2016**



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 transferring *.bin files across different OS)

Types of weather data used in simulations

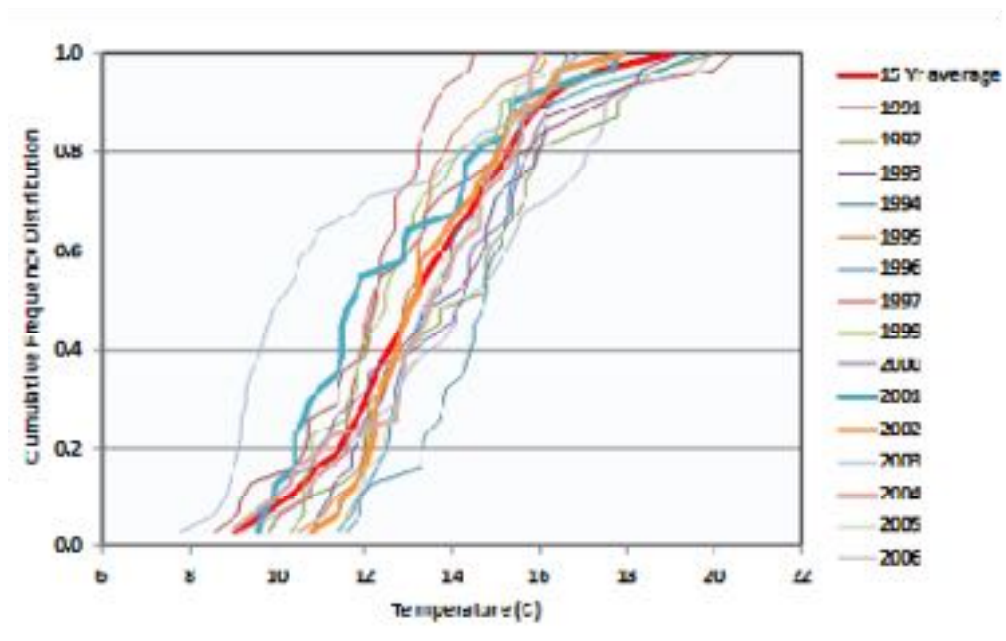
- Typical year vs actual year
- Observed data vs synthetic data
- Hourly data vs summary data, e.g., daily max-min data

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
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 Cana-
dian, 5775 rest of the world)**

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)

National Climatic
Data Center
U.S. Department of Commerce

Integrated Surface Database

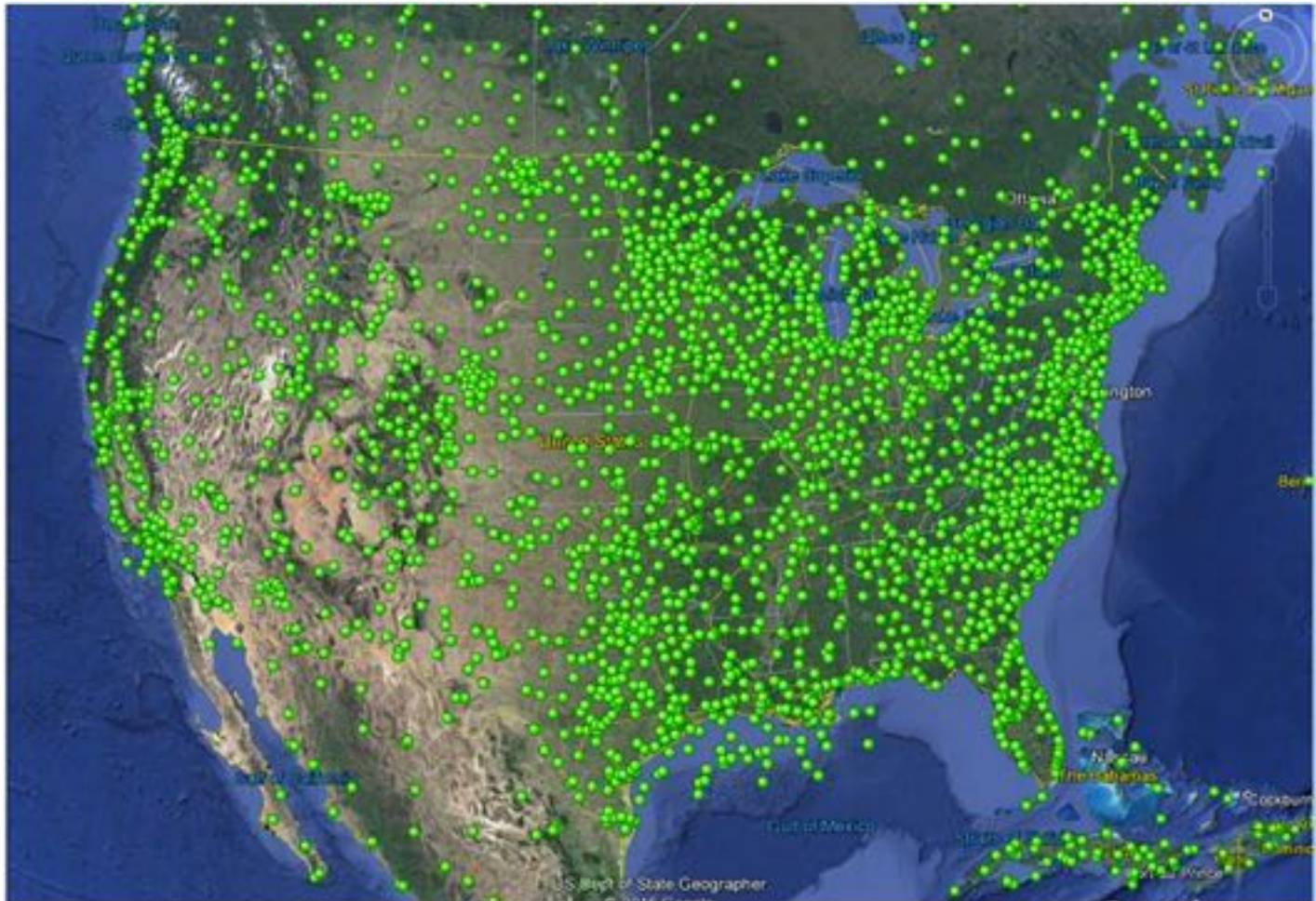
The Integrated Surface Database (ISD) consists of global hourly and synoptic observations compiled from numerous sources, into a single common ASCII format and common data model. ISD was developed as a joint activity within Asheville's Federal Climate Complex. The National Climatic Data Center, with U.S. Air Force and Navy partners, began the effort in 1998 with the assistance of external funding from several sources. ISD integrates data from over 100 original data sources, including numerous data formats which were key-entered from paper forms during the 1950's-1970's timeframe. ISD Version 1 was released in 2001, with Version 2 (additional quality control applied) in 2003. Since 2003, there have been continued incremental improvements in automated quality control software.

The database comprises over 20,000 stations worldwide, with some having data as far back as 1901, though the data show a substantial increase in volume in the 1940's and again in the early 1970's. Currently there are over 11,000 stations "active" and updated daily in the database. Total data volume



Photo courtesy Grant Goodge/NCDC

ISD 2015 stations in the US



ISD 2015 stations in Europe



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

DSI-3505

```
0188037720999992016010314504+51478-000461FM-
15+002599999V0202001V005710131119N009999199+00901+00801999999ADDGA1021+005791999GA2071+0131
11999GE19MSL +99999+99999GF199999021999005791999999MA1098401999999REMMET081METAR COR EGLL
031450Z AUTO 20011KT 170V250 9999 FEW019 BKN043 09/08 Q0984 NOSIG=
0235037720999992016010315004+51483-000450FM-
12+002599999V0201901N00511013501CN035000199+00961+00851098471ADDAW1231GA1011+009901999GA207
1+013501999GE19MSL
+99999+99999GF199999011999009901999999MA1999999098171MD1510421+9999OD139901441999REMSYN0940
3772 47681 /1910 10096 20085 39817 49847 55042 723// 333 55300 20061 81/33 87/45 90710
91128=
0186037720999992016010315204+51478-000461FM-
15+002599999V0201901V004110091419N009999199+00901+00801999999ADDGA1071+009141999GE19MSL
```

*.DAT

```
+99999+99999GF199
031520Z AUTO 1900
01780377209999920
15+002599999V0201
01999GE19MSL
037720 201512302120 +0100 +0090 99999 0057 180 99 99 07 007000 00335 9999 999 0
037720 201601010000 +0038 +0024 10209 0031 240 99 99 99 020000 99999 9999 999 1 06000091
037720 201601010020 +0050 +0020 99999 0021 230 00 99 99 009999 22000 9999 999 0
037720 201601010050 +0040 +0020 99999 0021 200 00 99 99 009999 22000 9999 999 0
037720 201601010100 +0037 +0024 10216 0026 230 99 99 99 014000 99999 9999 999 0
037720 201601010120 +0030 +0020 99999 0015 170 00 99 99 008000 22000 9999 999 0
037720 201601010150 +0020 +0000 99999 0010 150 00 99 99 003500 22000 9999 999 0
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```

*.FIN4

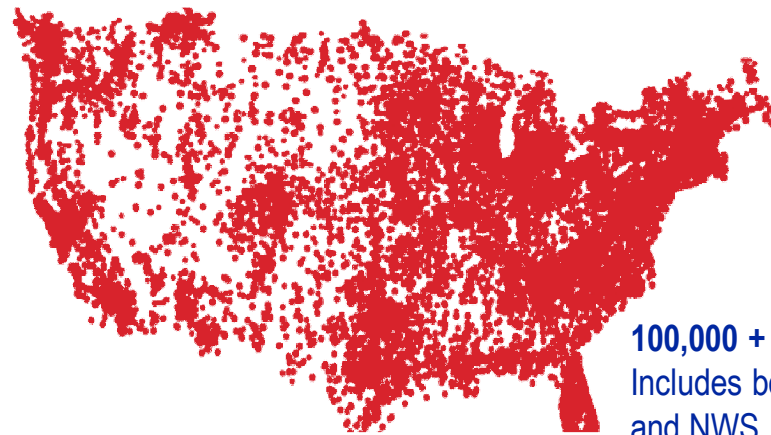
GBR_LONDON-HEATHROW-AP													037720 51.478 -0.461 25 6 0.0 GMT Cfb												
Year	Mo	Dy	Hr	DBT	DPT	Press	Altim	Sky	Opq	WSpd	Wnd	TotSol	DirNorm	Pres	Wth	Rain	Visib	Ceil	SolarZ						
				(C)	(C)	(mb)	(inHg)	Cov	Cov	(m/s)	Dir	(W/m2)	(W/m2)												
2016	1	1	1	3.7	2.4	1018.5		0	99R	2.6	230	0.0	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

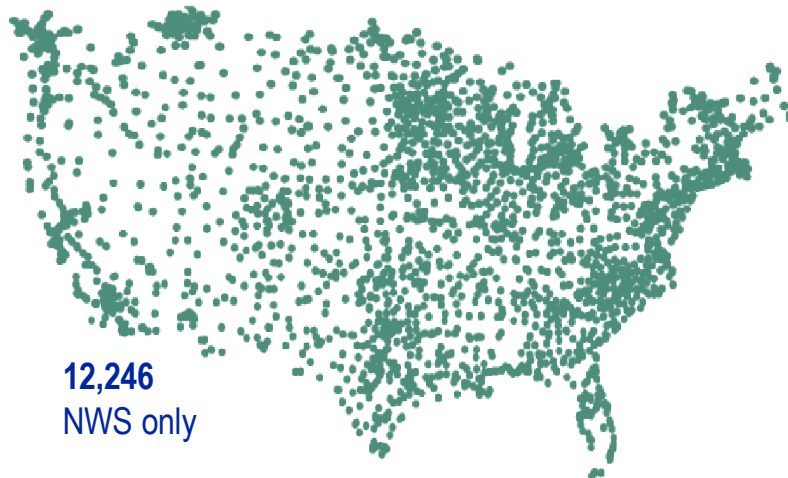
Web-based sources of weather data

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).

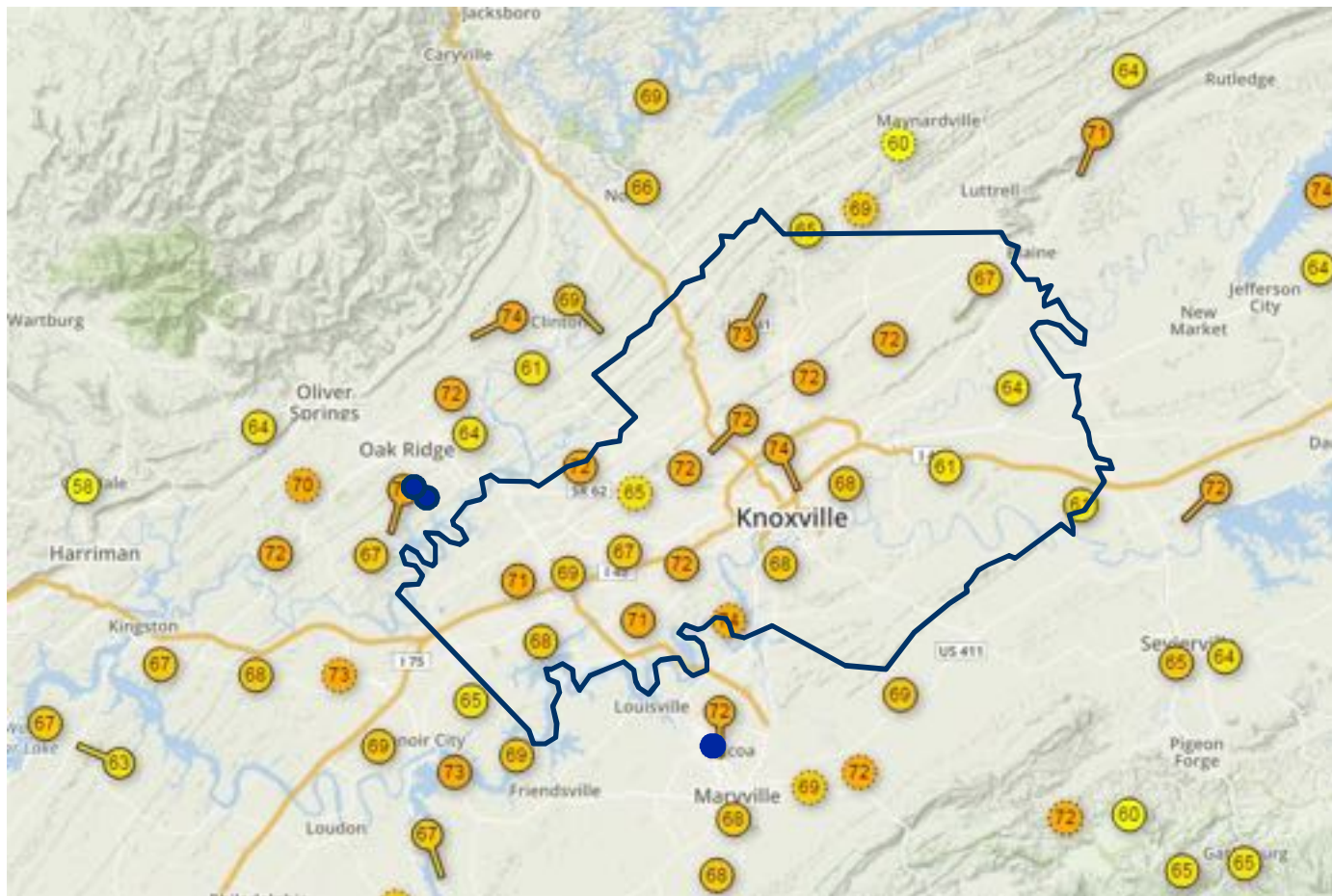


100,000 +
Includes both PWS
and NWS,



12,246
NWS only

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

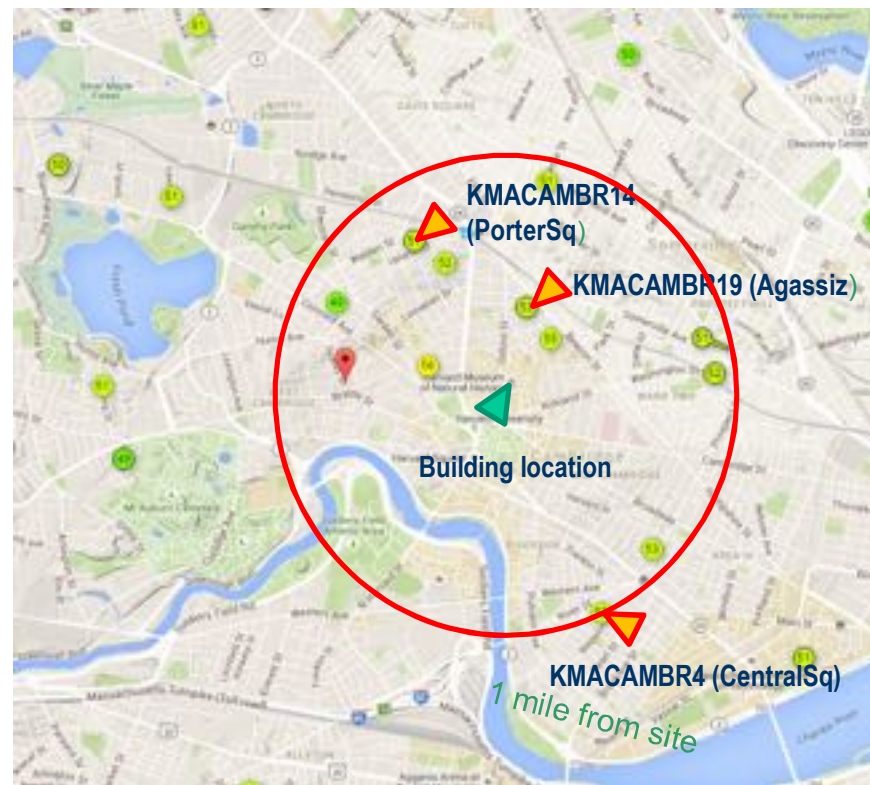
(online since March 2015)

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)

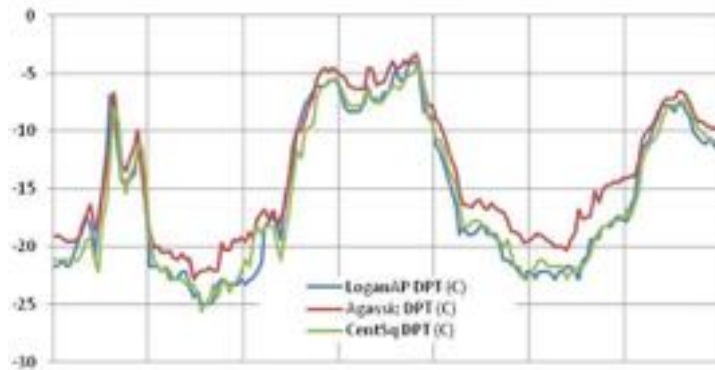
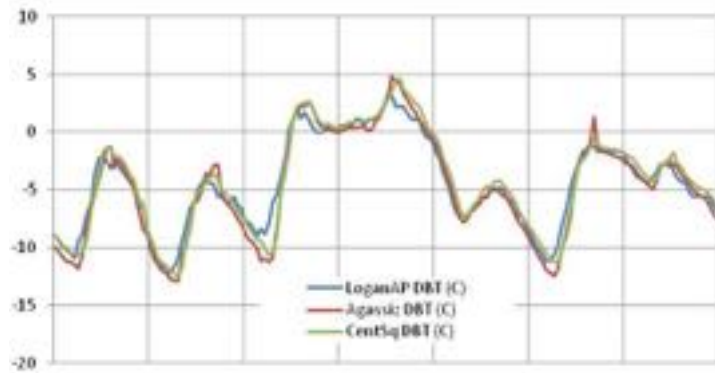
- Client with M&V project in Harvard needed onsite weather data for 2014.
- Nearest ISD station is Logan Airport 5.2 miles due east
- WU showed there were 11 PWS within a mile of the building site. Data was downloaded for three of the closest PWS (Agassiz, Porter Square, Central Square).
- Agassiz was 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.



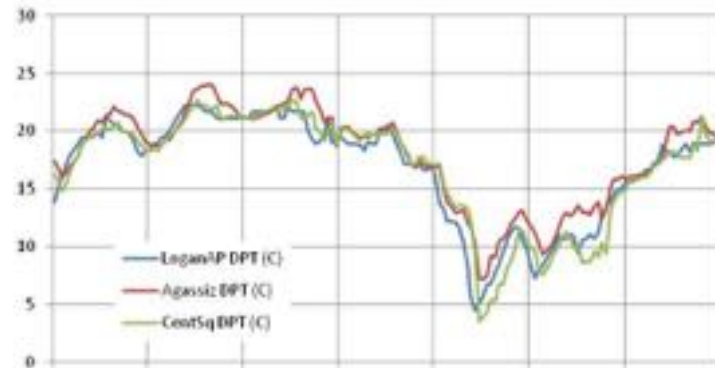
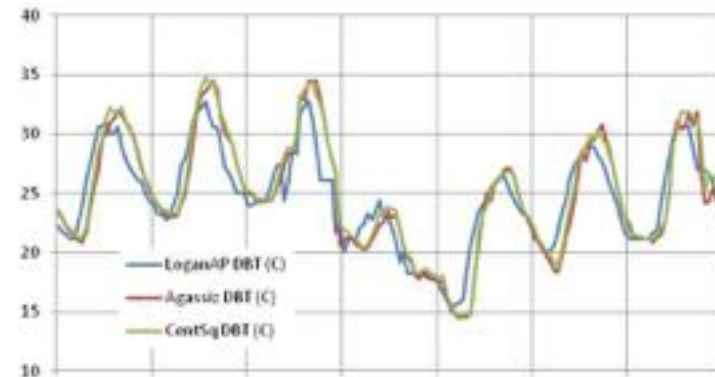
Example use of Web weather data in Cambridge (2)

Temperature comparison

Winter week (Jan 1 – 7, 2014)



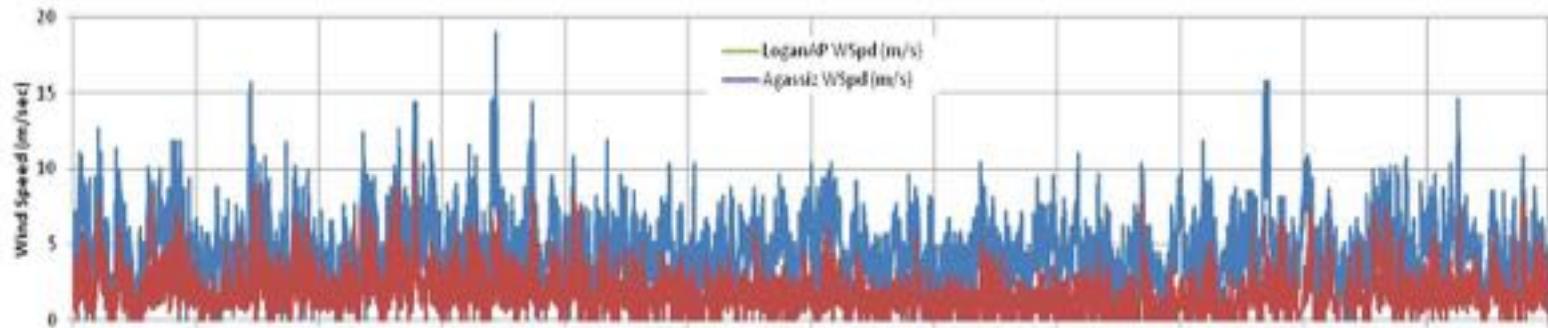
Summer week (Aug. 1 – 7, 2014)



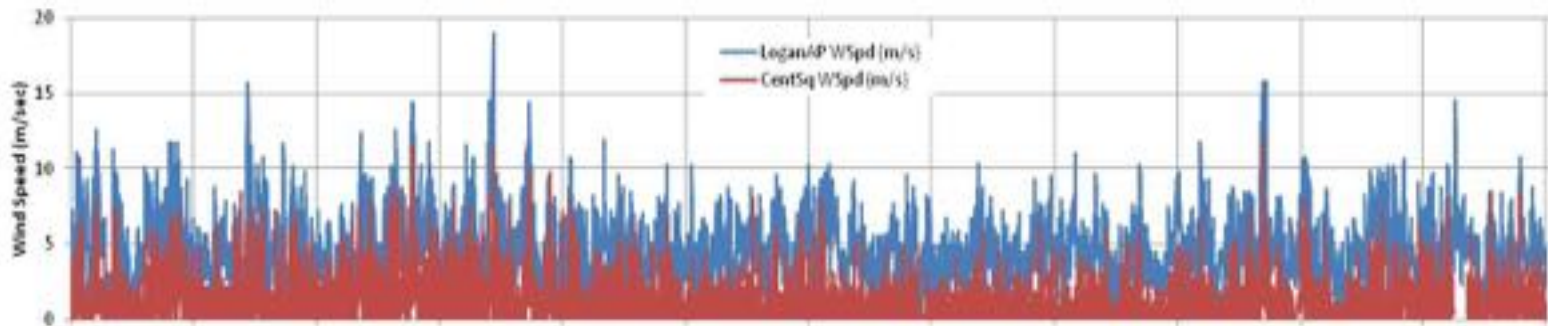
Example use of Web weather data in Cambridge (3)

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

$$I = I_0 \cdot \sin h \cdot \{C_0 + C_1(CC) + C_2(CC)^2 + C_3(T_n - T_{n-3}) + C_4 \varphi + C_5 V_w\} + D$$

when $ET \cdot 0.10 > I > ET \cdot 0.90$

$$= ET \cdot 0.90 \quad \text{when } I > ET \cdot 0.90$$

$$= ET \cdot 0.10 \quad \text{when } I < ET \cdot 0.10$$

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

Am = Miami

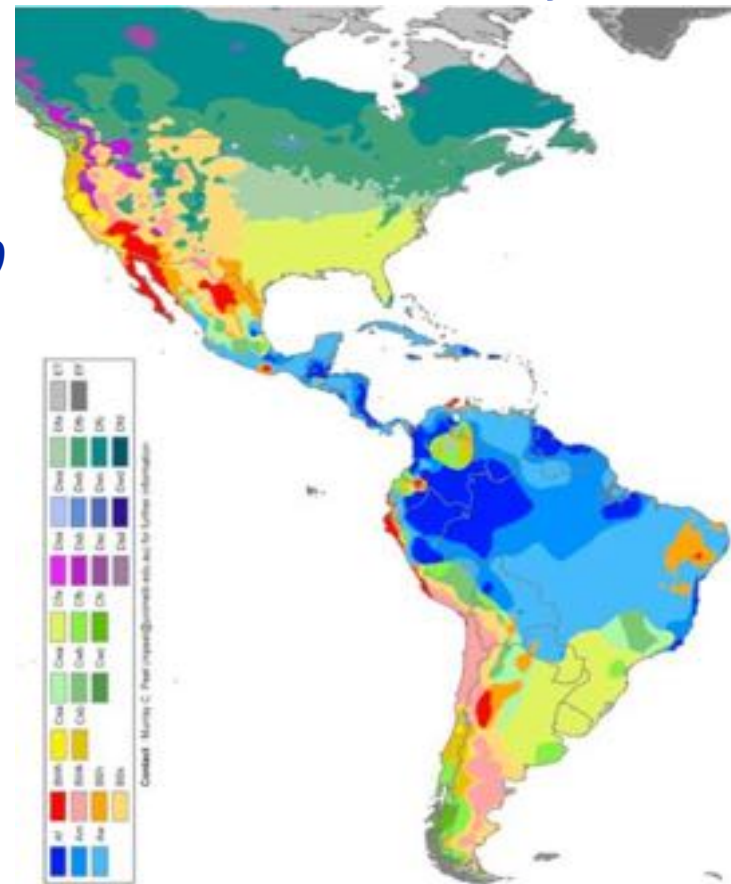
Aw = Honolulu

BSh = Phoenix

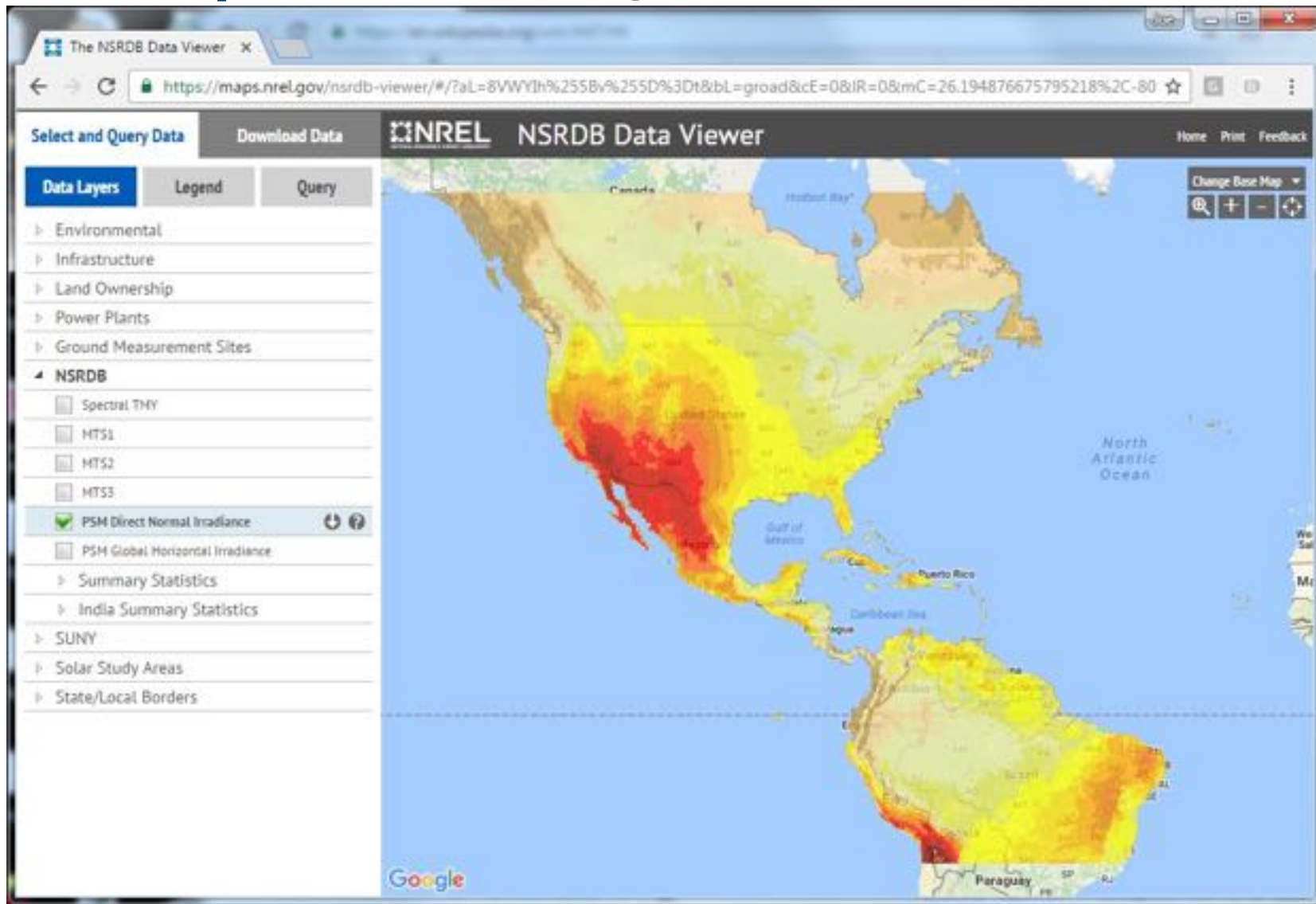
BWh = Kuwait

Cfa = Nashville

ETh = Davos



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



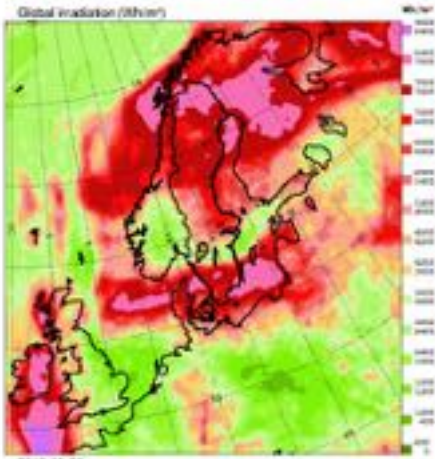
<https://www.strang.smhi.se>

The AGRIE Data Viewer x STRANG x

← → ↻ ⓘ strang.smhi.se

NATUR VÄRDS VERKET **SMHI** Strål säkerhets myndigheten
Swedish Radiation Safety Authority

STRÅNG - a mesoscale model for solar radiation



Global irradiation (kWh/m²)

2013-06-30

The STRÅNG model system produces instantaneous fields of global radiation, photosynthetically active radiation, UV radiation ([CIE weighted](#)) and direct normal radiation together with sunshine duration at a horizontal resolution of about 11 x 11 km and a temporal resolution of one hour. The model covers the geographic area of Scandinavia and the run off region of the Baltic sea with a grid of size 268 x 246. Information about direct solar radiation and global radiation from the radiation network of SMHI has been used for tuning and validation.

Before 1st of June 2006 the horizontal resolution was about 22 x 22 km with a grid of size 116 x 102.

The input and output fields that are produced by the system are adapted to the mesoscale analysis system at SMHI called [MESAN](#). Other sources of data are a high resolution limited area NWP ([HIRLAM](#)), ice information from the oceanographic model [HIROMB](#) and ozone fields from the European Centre for Medium-Range Weather Forecasts ([ECMWF](#)) or, when these are not available, from the [TOMS](#) instrument.

The model development was financed by SMHI, the Swedish Radiation Safety Authority (Strålsäkerhetsmyndigheten, SSM) and the Swedish Environmental Protection Agency (Naturvårdsverket). The STRÅNG model is run at SMHI with financial contributions from The Swedish Environment Protection Agency (Miljöövervakningen).

Data extraction	Monthly charts	Latest daily charts	Latest hourly charts
<ul style="list-style-type: none">Extract historical (1999 -) data from the STRÅNG system data base. The result can be returned as time series, data fields or charts. Click here for model validation figures.	<ul style="list-style-type: none">CIE weighted UV irradiationGlobal irradiationDirect (normal) irradiationSunshine durationPhotosynthetic photon density	<ul style="list-style-type: none">CIE weighted UV irradiationGlobal irradiationDirect (normal) irradiationSunshine durationPhotosynthetic photon density	<ul style="list-style-type: none">CIE weighted UV irradianceGlobal irradianceDirect (normal) irradianceSunshine durationPhotosynthetic photon flux density

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

TIME SERIES OF SOLAR RADIATION DATA FROM THE CAMS RADIATION SERVICE

The CAMS radiation service provides time series of Global, Direct, and Diffuse Irradiations on horizontal surface, and Direct Irradiation on normal plane (DNI) for the actual weather conditions as well as for clear-sky conditions. The geographical coverage is the field-of-view of the Meteosat satellite, roughly speaking Europe, Africa, Atlantic Ocean, Middle East (-66° to 66° in both latitudes and longitudes). The time coverage of data is from 2004-02-01 up to 2 days ago. Data are available with a time step ranging from 1 min to 1 month. The number of requests (via the WPS or via this website) is currently limited to 15 per day. This limit may evolve. The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 218793 (MACC project, 2009-2011), no. 283576 (MACC-II project, 2011-2014) and from the European Union's H2020 Programme (FP7/2007-2013) under grant agreement no. 633980 (MACC-III project, 2014-2015). The service is part of the Copernicus Atmosphere Monitoring Service (CAMS).

[The Copernicus Atmosphere Monitoring Service \(CAMS\) Radiation Service in a nutshell](#)

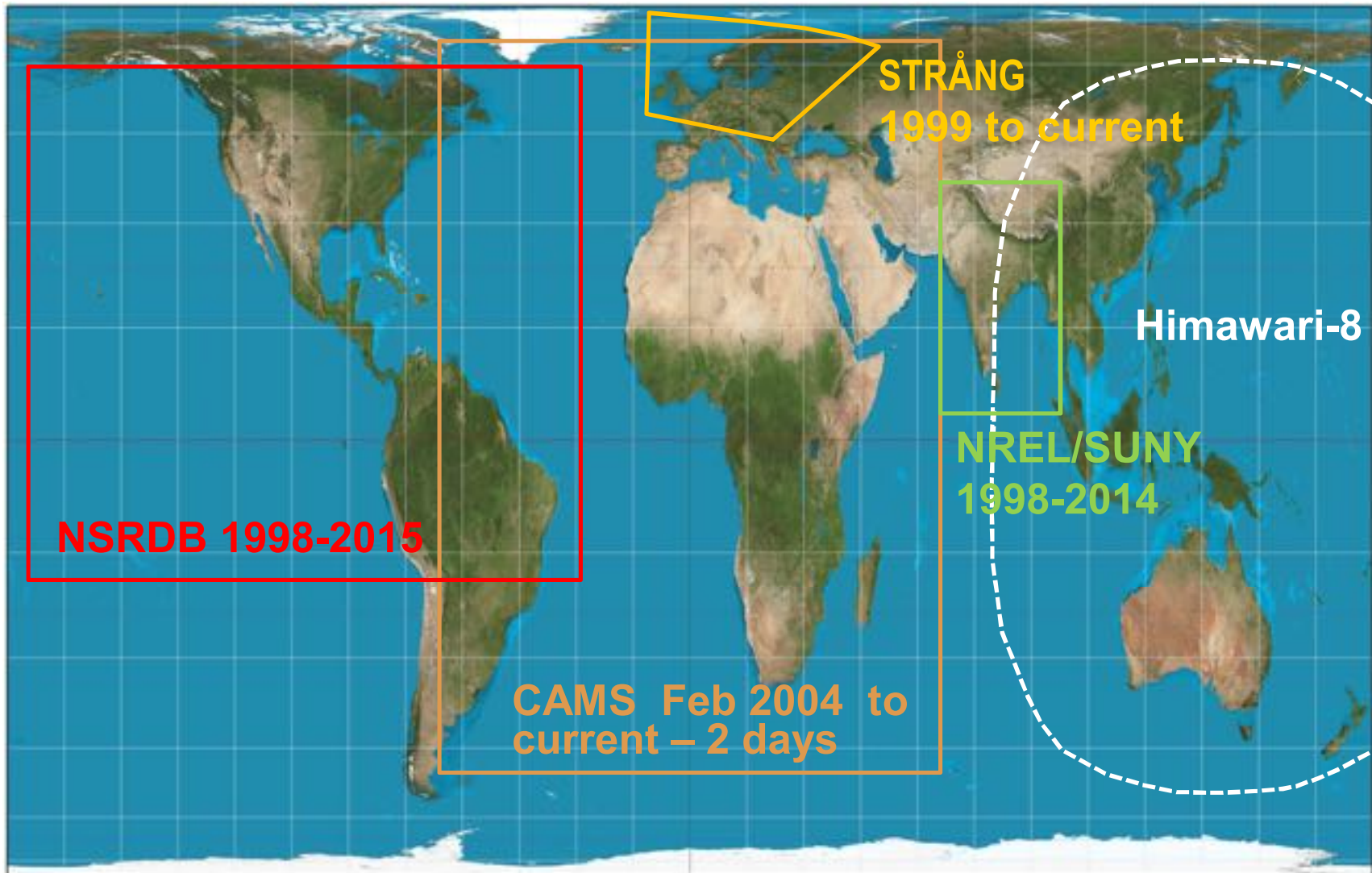
[More information >>](#)
[Licence terms](#)

NEW! you may now request time series from 2004 to two days ago!

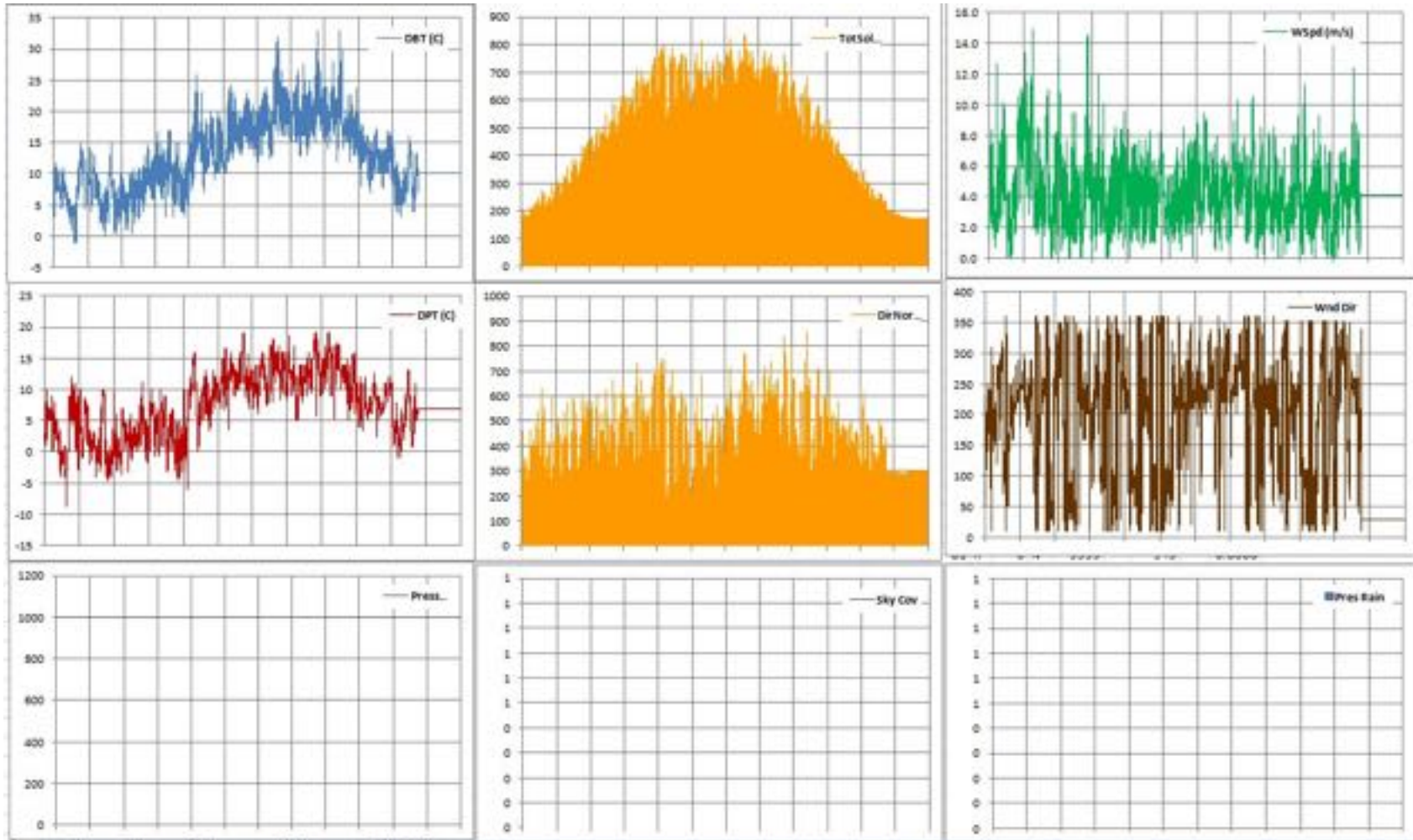
CAMS Radiation Service

Max Extent | Back | Search Address:

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

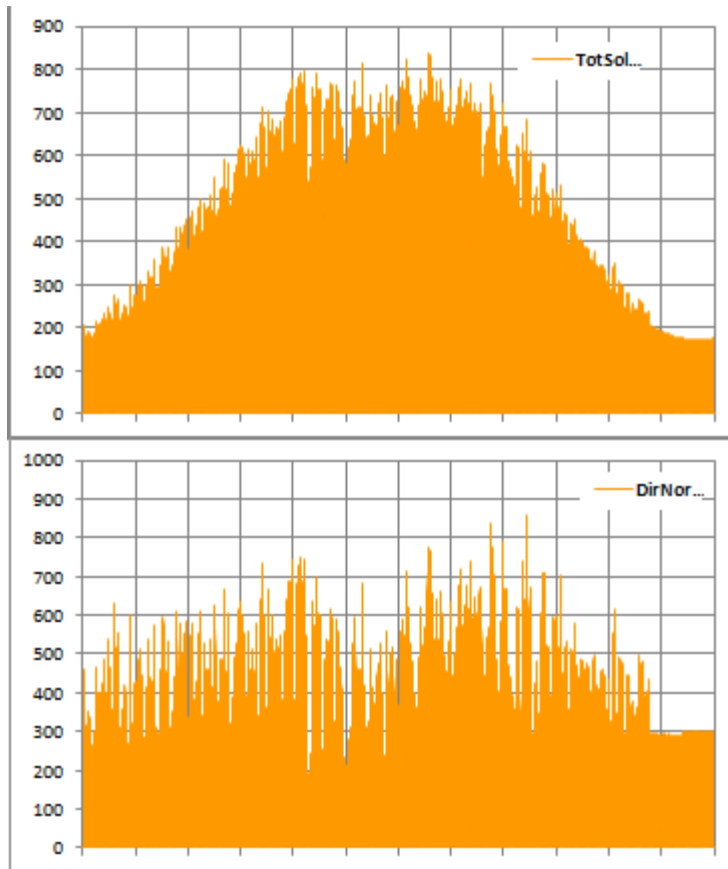


Weather data for GBR_London-City_37683_16

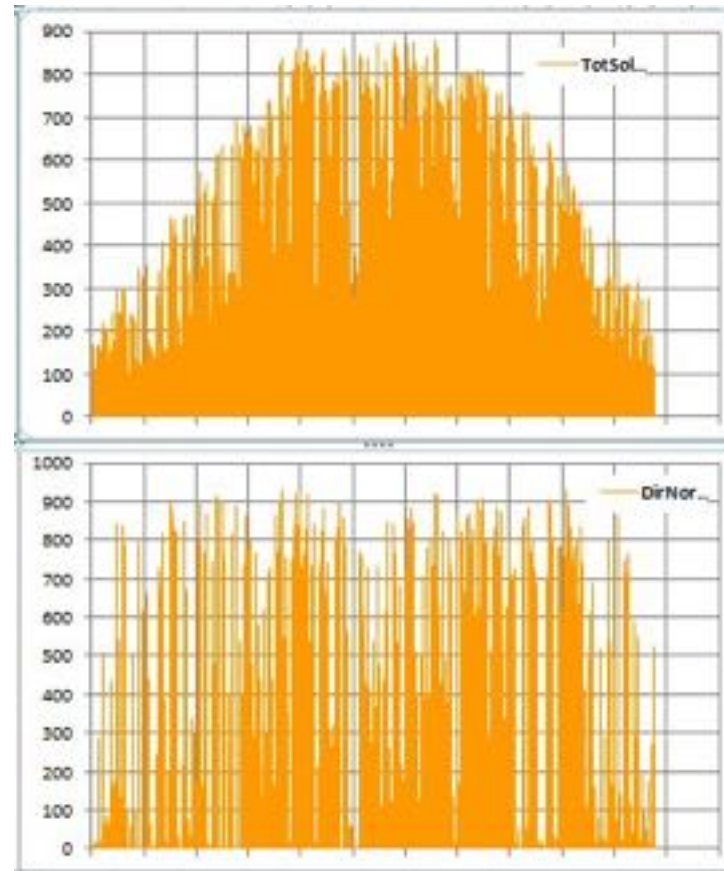


Weather data for GBR_London-City_37683S_16

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.**

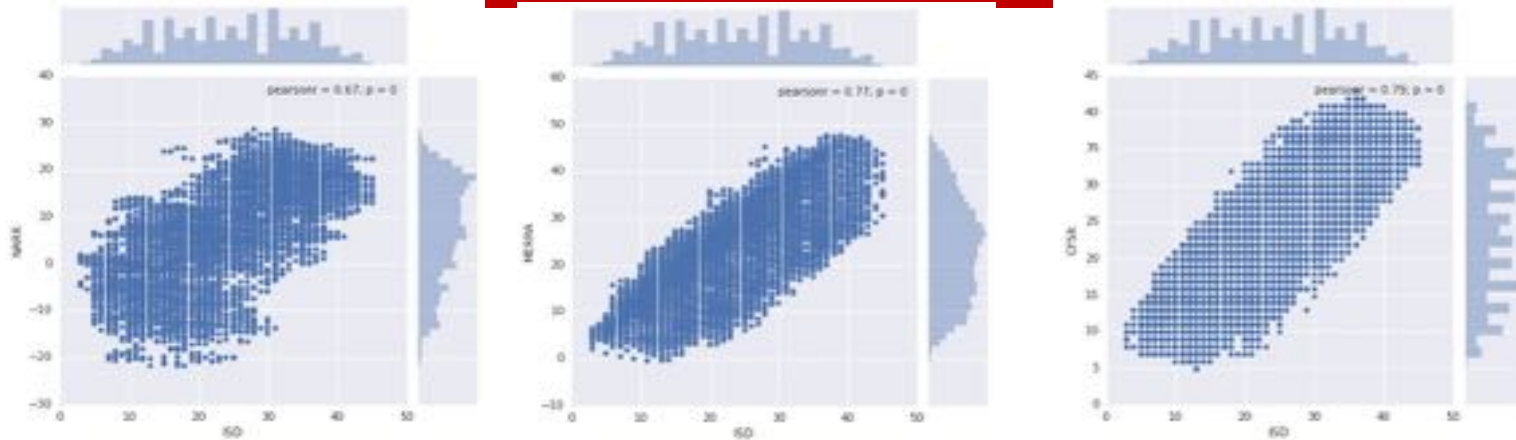
Comparison of MERRA to observed dry-bulb temperatures for 3 reanalysis programs in two US cities

NARR

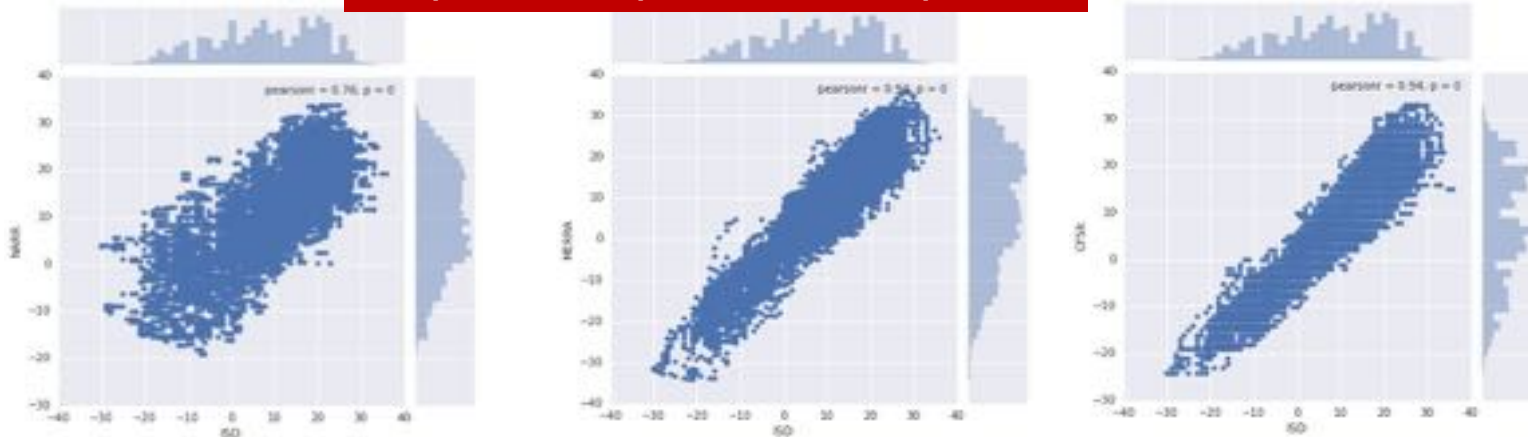
CSFR

MERRA

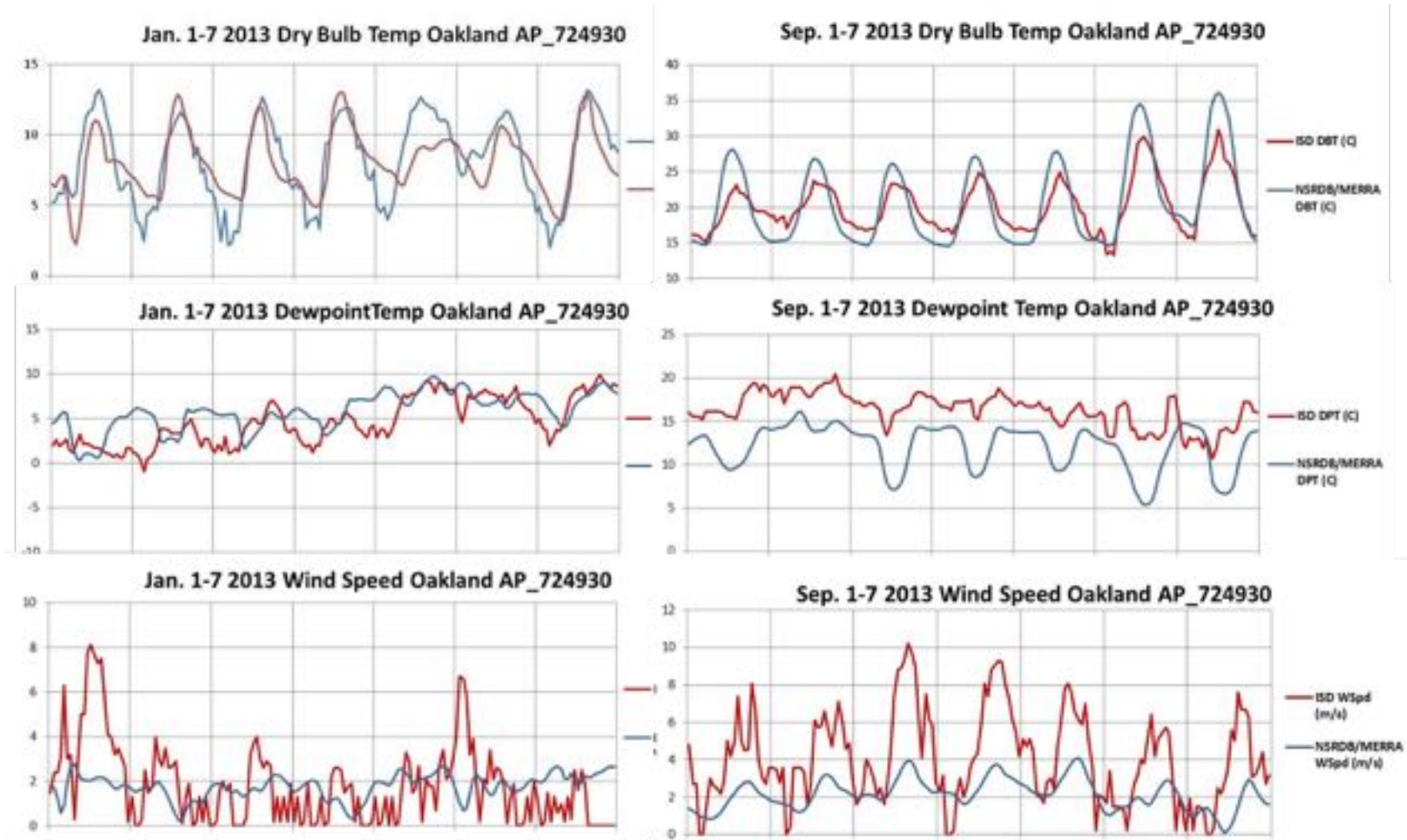
Temperature Comparison for Phoenix, AZ



Temperature Comparison for Minneapolis, MN

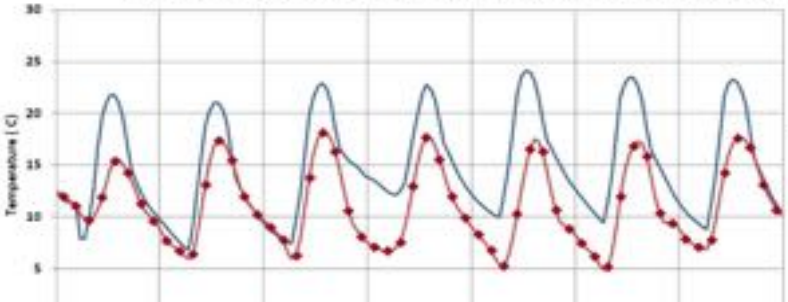


Comparison of NSRDB/MERRA to observed data for Oakland 2013

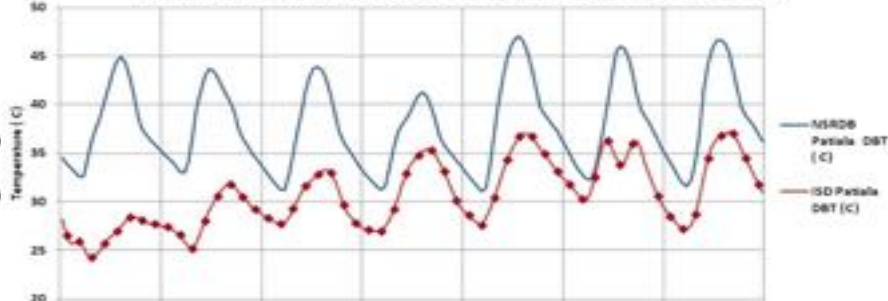


Comparison of NSRDB/MERRA to observed data for Patiala, India 2014

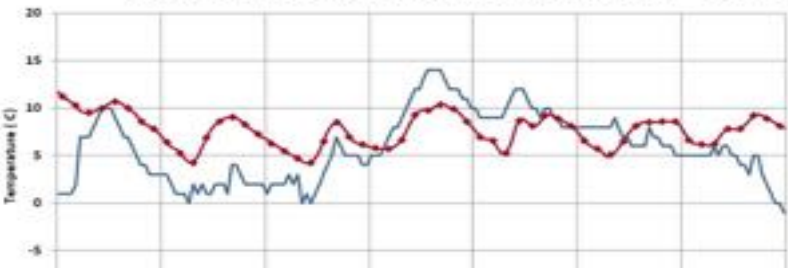
Patiala Dry-Bulb Temperatures Jan. 1 - 7, 2014



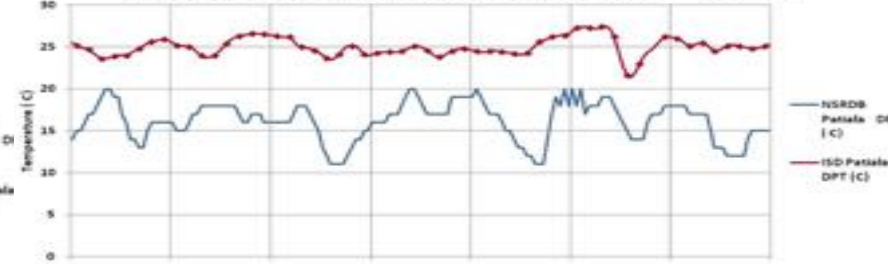
Patiala Dry-Bulb Temperatures July 1 - 7, 2014



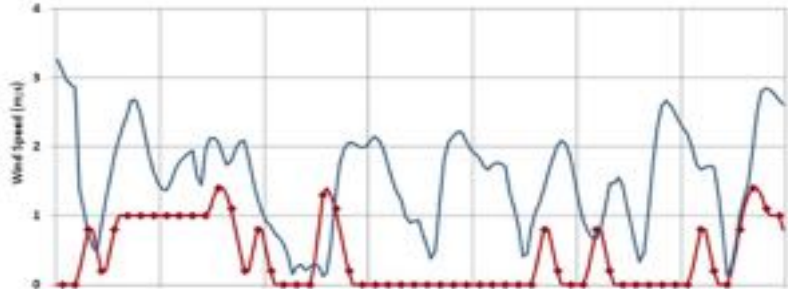
Patiala Dewpoint Temperatures Jan. 1 - 7, 2014



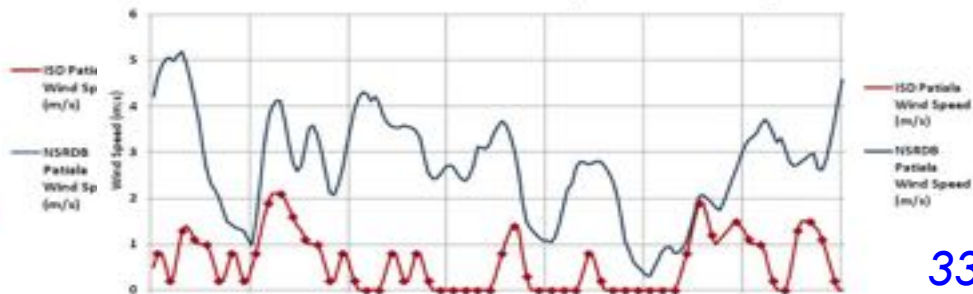
Patiala Dewpoint Temperatures July 1 - 7, 2014



Patiala Wind Speeds Jan. 1 - 7, 2014



Patiala Wind Speeds Jul. 1 - 7, 2014

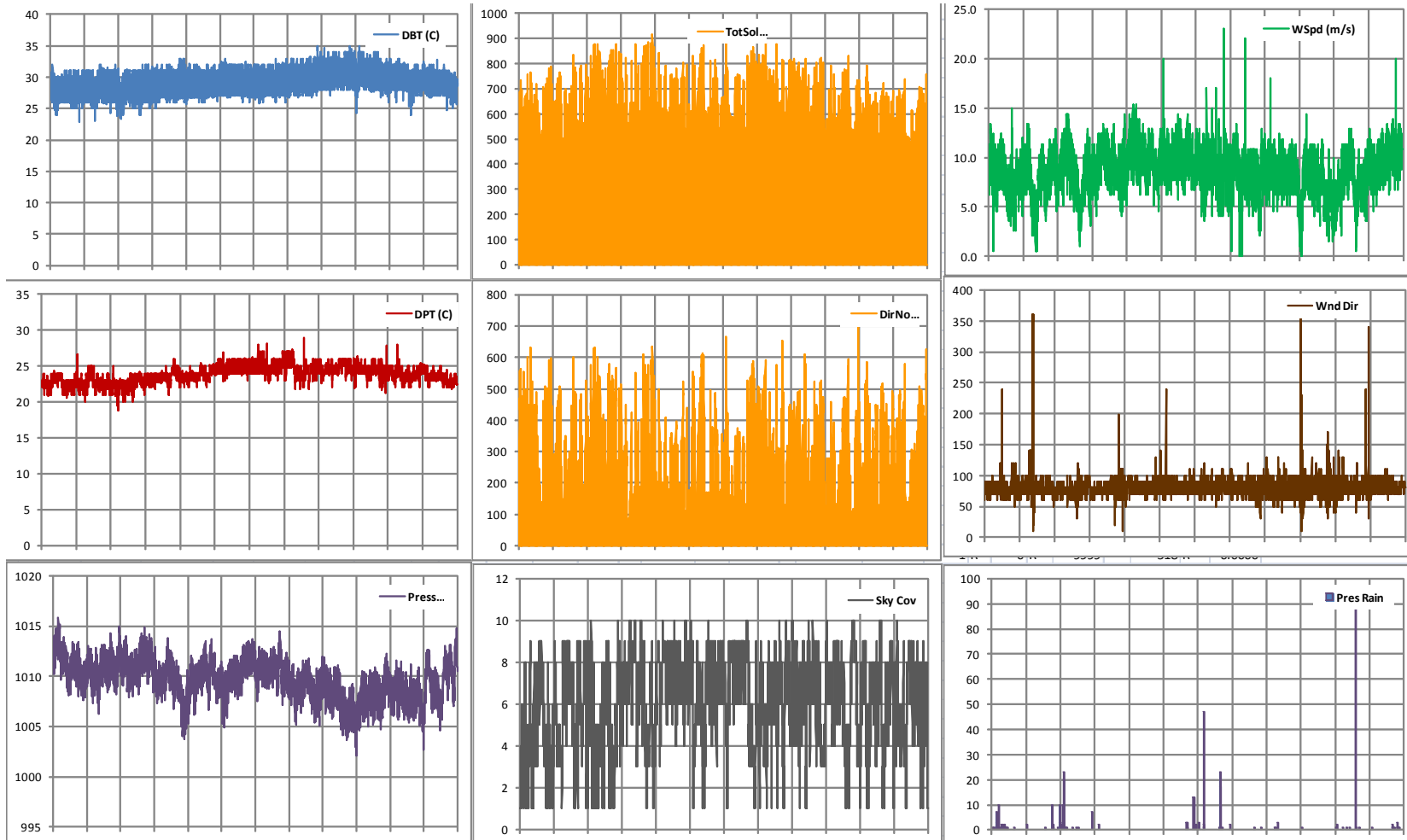


Things to watch out for when working with weather data

- **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)?**

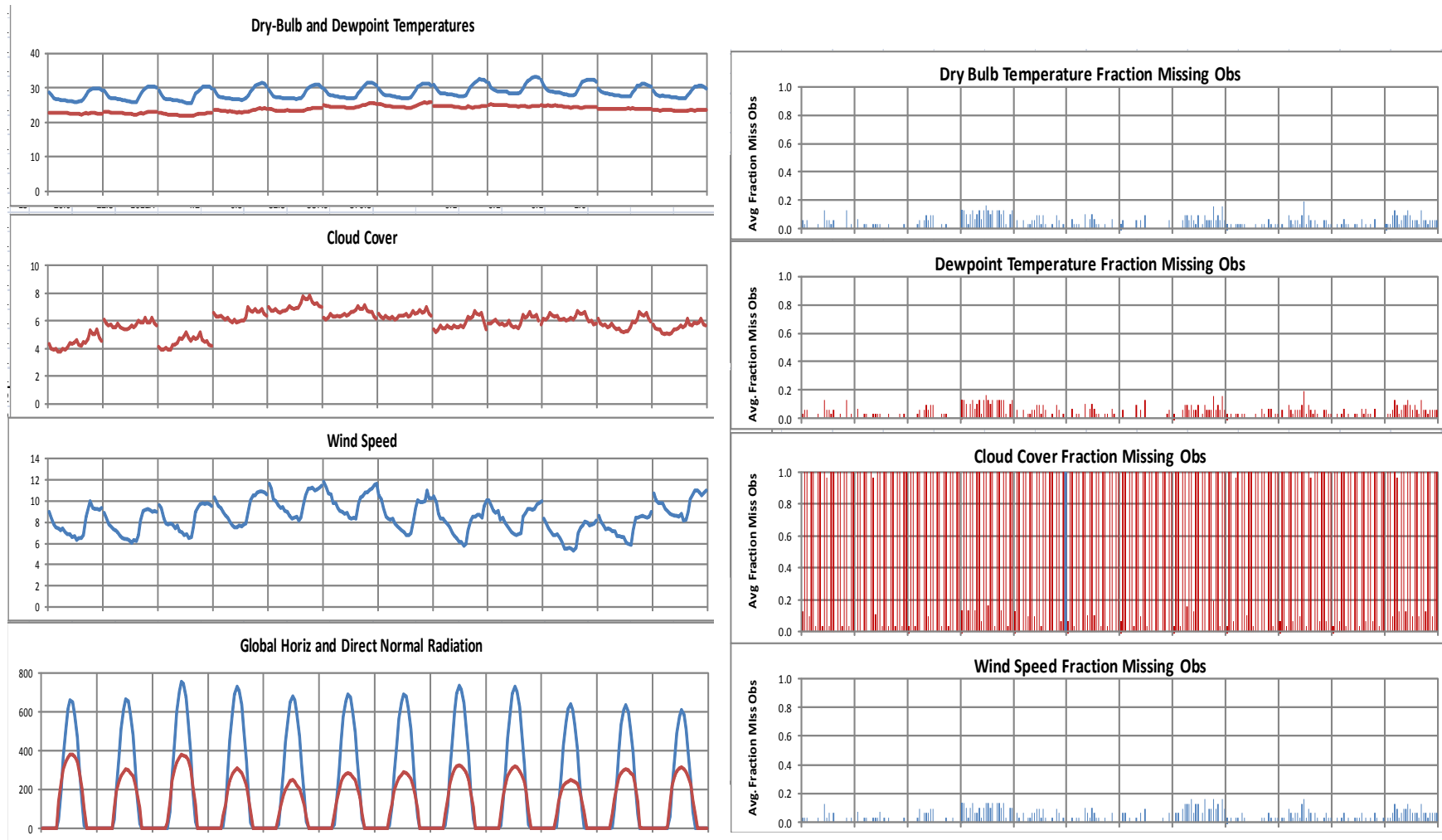
Evaluating the data quality of a weather file (1)

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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