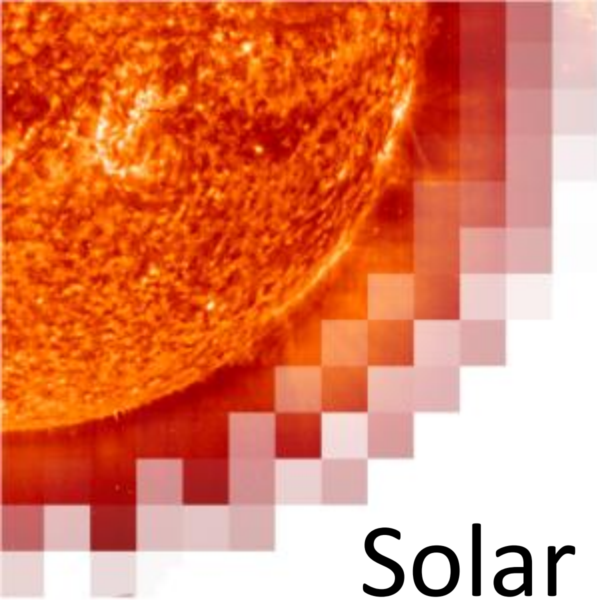

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Solar Resource Assessment: A Practical Overview

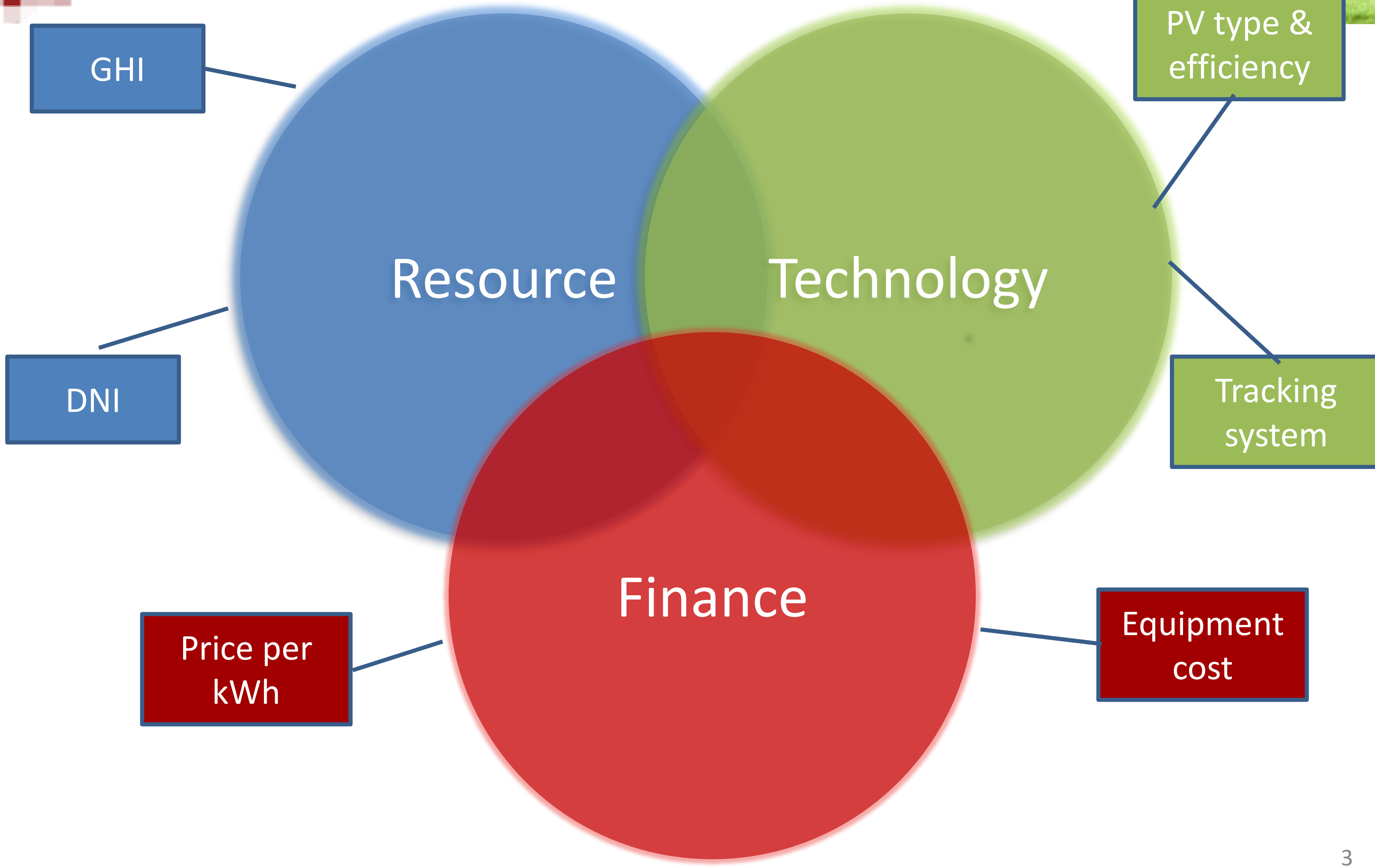
Dr. Ozgur Gurtuna
gurtuna@turquoisetech.com

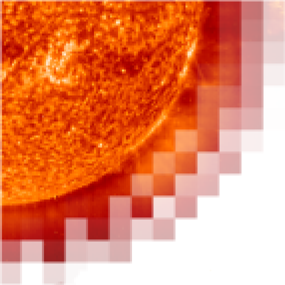
May 17, 2012
First Canadian Photovoltaics Graduate School
Ottawa

Agenda

- Motivation and definitions
- Comparative overview of SRA methods
- Data availability in Canada
- Case study

Valuation of a PV Project





Definitions and Units

- Insolation
  - Generic term representing the solar energy received on a horizontal surface regardless of the time interval
- Irradiance (W/m2) -> Power
  - Radiation incident onto a surface
  - Instantaneous insolation
- Irradiation (J/m2 or Wh/m2) -> Energy
  - Total irradiance over a specific time period
  - Usually one hour, one day

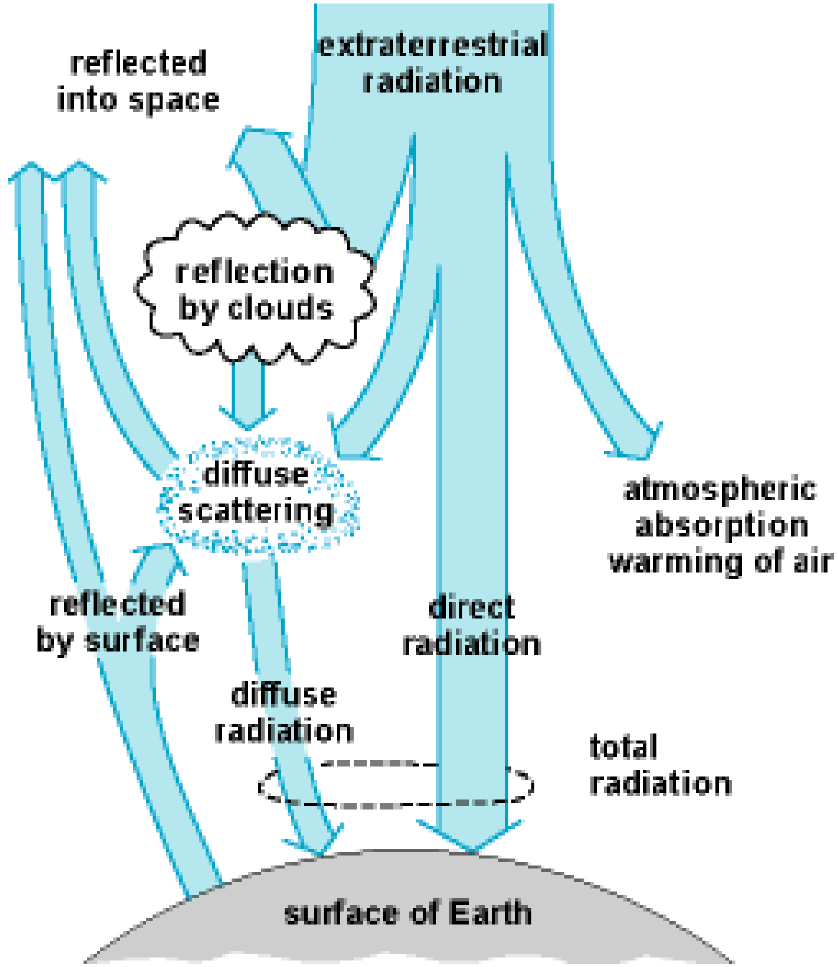
What Are We Trying to Estimate?

- Solar radiation at the surface of Earth
  - Composed of:
    - Direct radiation
    - Diffuse radiation
  - Global Horizontal Irradiance (GHI)
    - “Fuel” of solar PV projects
  - Direct Normal Irradiance (DNI)
    - “Fuel” of concentrating solar and solar thermal applications

Components of Solar Radiation

- As the solar radiation passes through the atmosphere, some of it is absorbed or scattered by air molecules, water vapor, aerosols, and clouds.
- Direct solar radiation
  - Radiation that passes through directly to the Earth's surface.
- Diffuse solar radiation
  - Radiation that has been scattered out of the direct beam.
- Global solar radiation
  - The direct component of sunlight plus the diffuse component of skylight falling together on a horizontal surface.

Atmospheric Effects

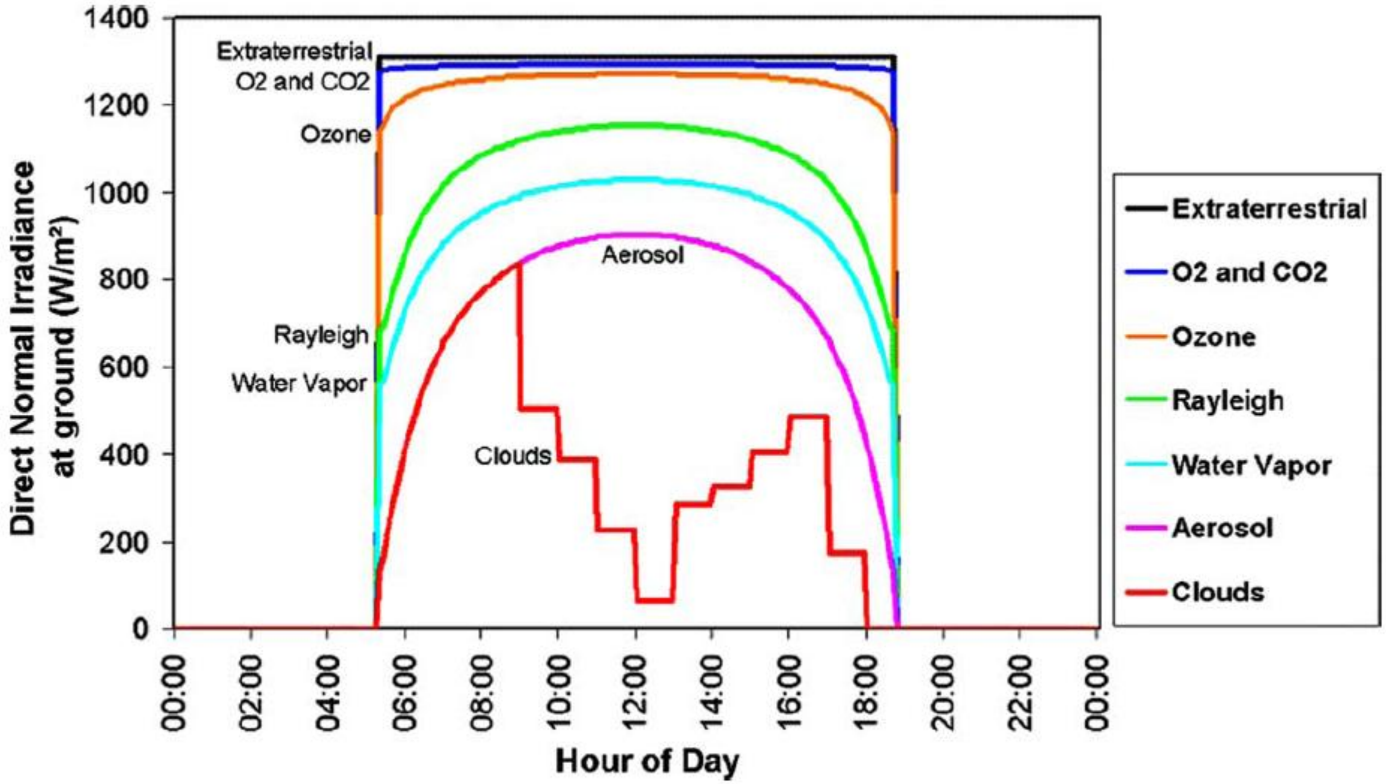


W. C. Dickinson and P. N. Cheremisinoff (1980)

Three Main Determinants of Solar Irradiance

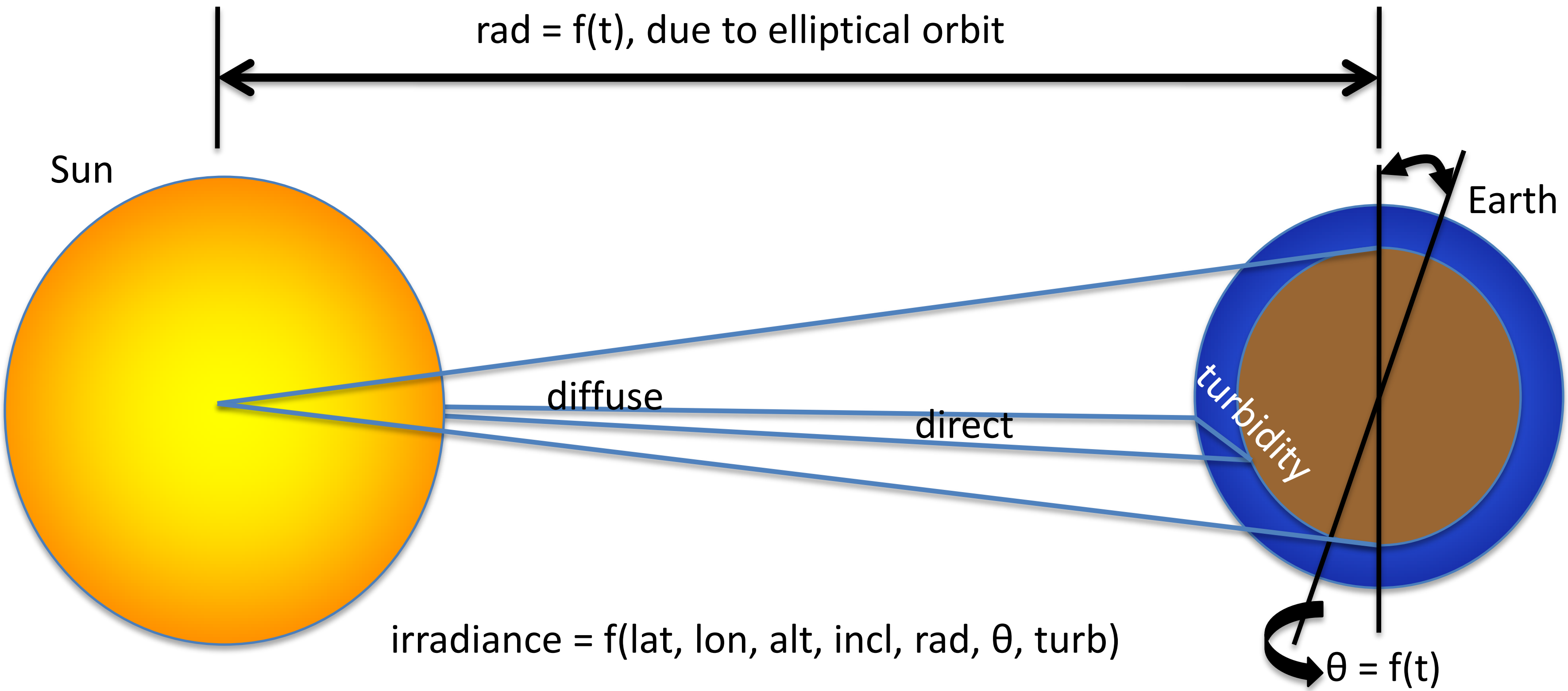
- Earth's orbital position
  - extraterrestrial solar radiant flux
  - Near constant value for our time scale of interest (decades)
  - Very simple to model (adjustment based on Sun-Earth distance)
- Solar geometry
  - Latitude (energy density)
  - Seasonal and diurnal variation
  - Deterministic and relatively easy to model
- Atmospheric effects
  - Atmospheric turbidity: absorption and scattering by air molecules, water vapour and aerosols
  - Reflection by clouds
  - Hardest to model; not deterministic
  - Largely determines the available radiation at the surface (direct, diffuse)

Daily Variation of Irradiance



Source: Schillings et al., 2004

Clear Sky Model



Sources of Data

	Type	Advantages	Disadvantages
On-site measurements	Measured	•Very accurate	•Location specific •Costly •No “memory”
Reanalysis data	Modeled	•Global coverage •Decades of available data	•Low spatial resolution •Medium-high accuracy
Satellite-to-irradiance models	Modeled	•Global coverage •Relatively high spatial resolution •Decades of available data	•Medium-high accuracy •Gaps in satellite data availability •Snow cover difficult to handle

Measure-Correlate-Predict

- Fine tuning the satellite-to-irradiance models by adjusting model parameters based on measured data
- Best of both worlds
  - Location specific accuracy of measured data
  - "Time machine" advantage of satellite data

Ground-based Data Availability in Canada

- Limited availability of historical solar radiation data
- Obtaining recent data (<5 years) is especially problematic.

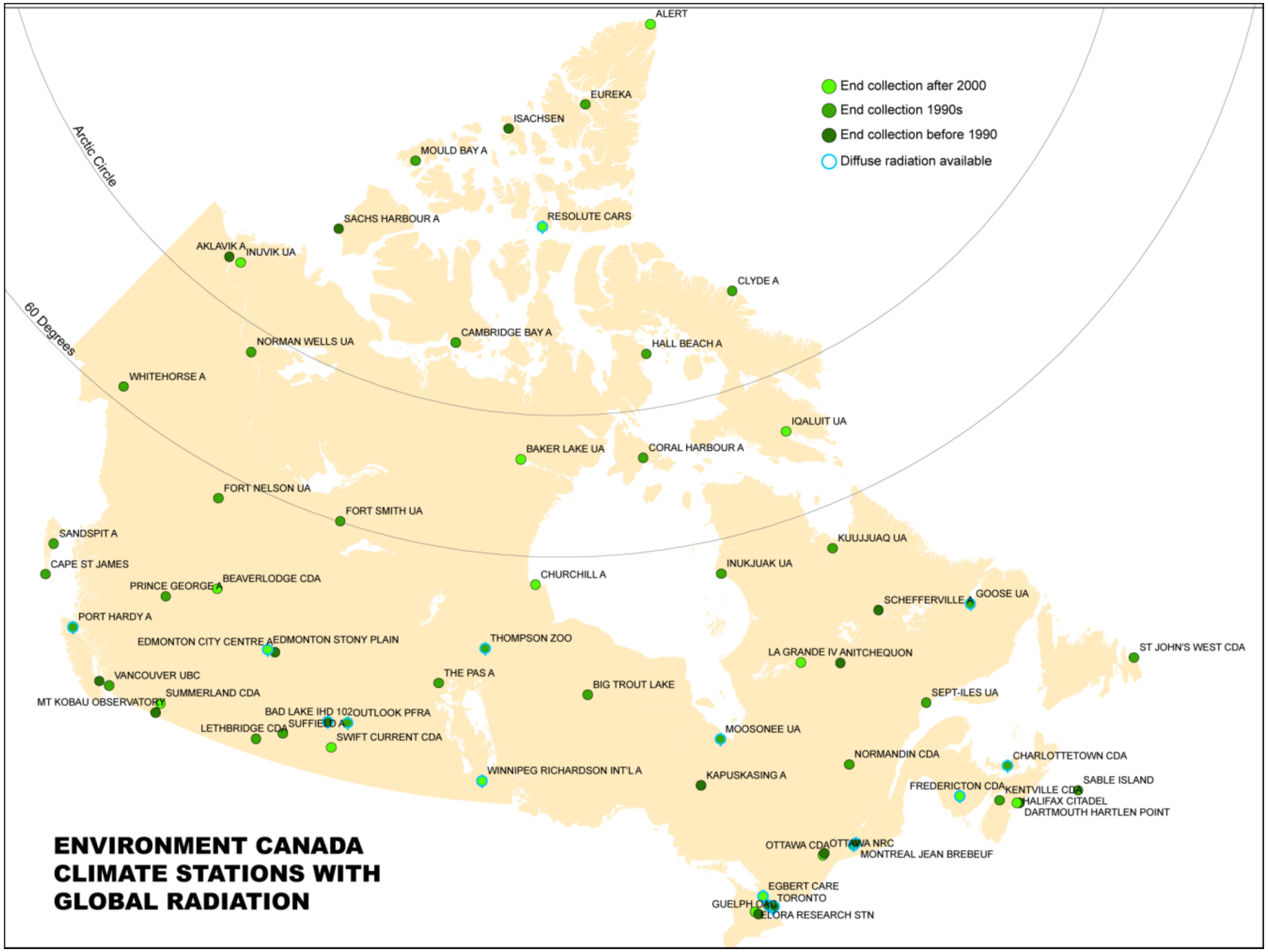


Image credit: Rory Tooke, UBC

Ground Station for On-site Measurements

- Pyranometer, pyrheliometer and a shadow pyranometer on a tracking system.
- Cost: approximately $28,500
- Source: meteorologyshop.eu Kippzonen.com

Ground-based Data Availability in the US

- Data coverage from mid 1990s to yesterday
- By-minute data sets
- Publicly accessible

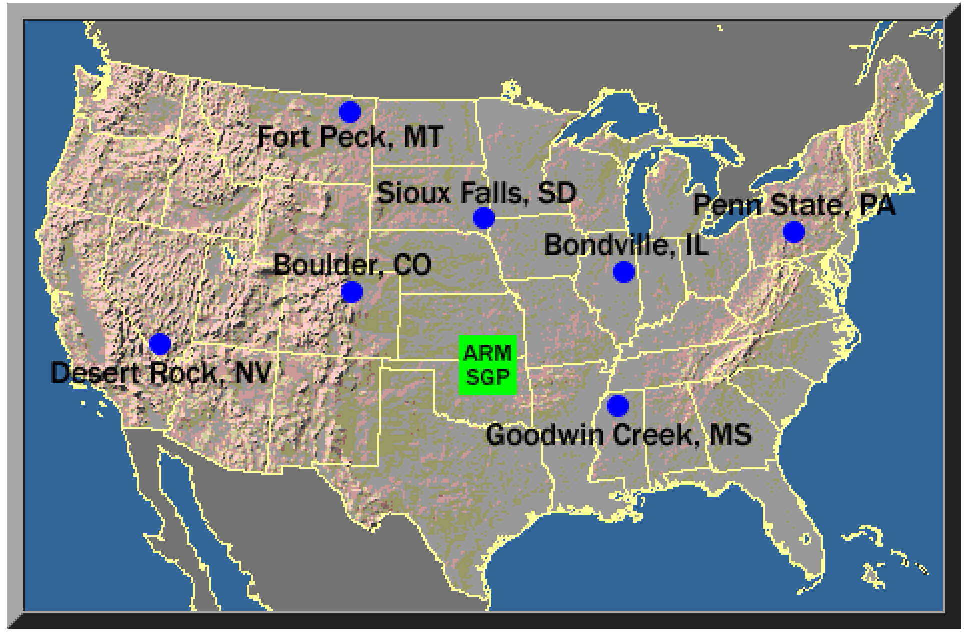


Image credit: NOAA

http://www.srrb.noaa.gov/surfrad/

Satellite-based Data Availability in Canada

- Hourly dataset covering [2000-2011]
- 1-2 km/pixel spatial resolution
- Very recent data available

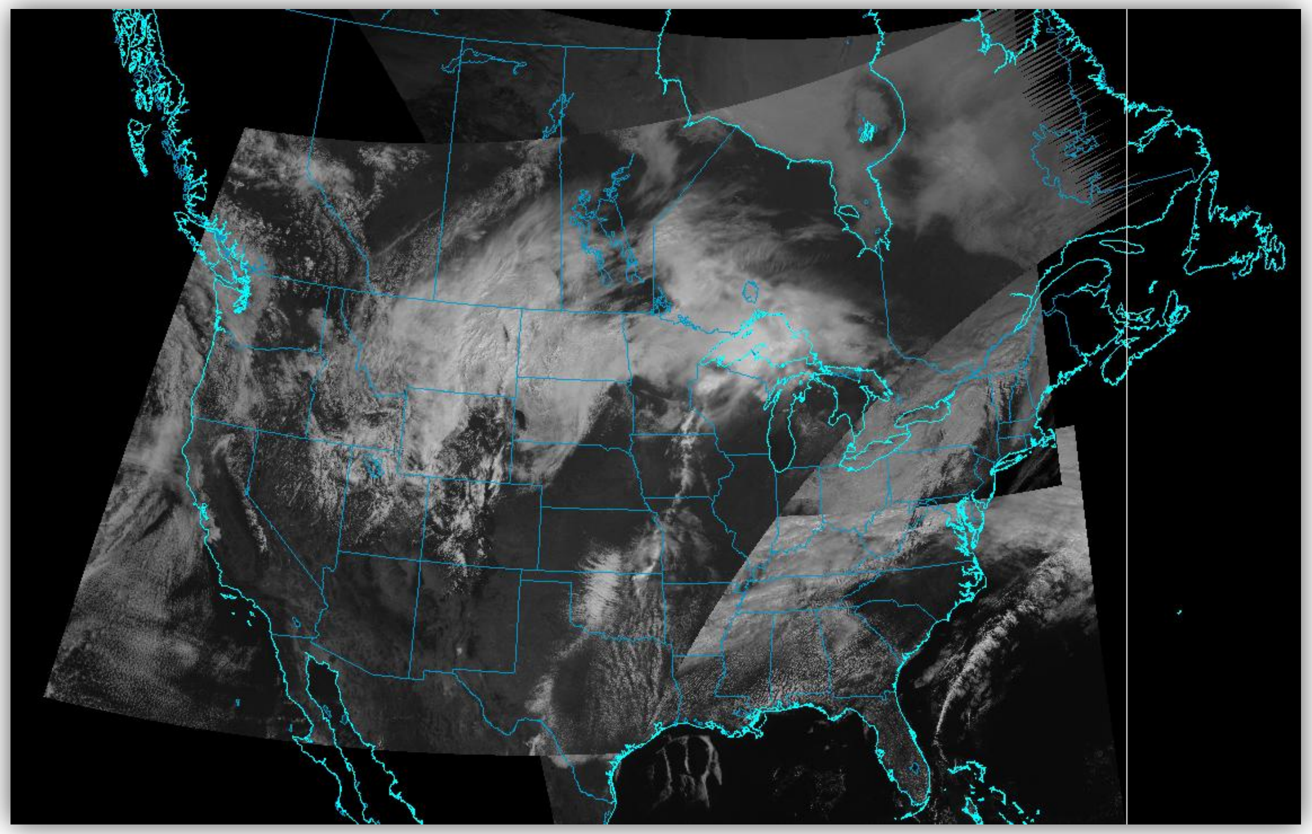
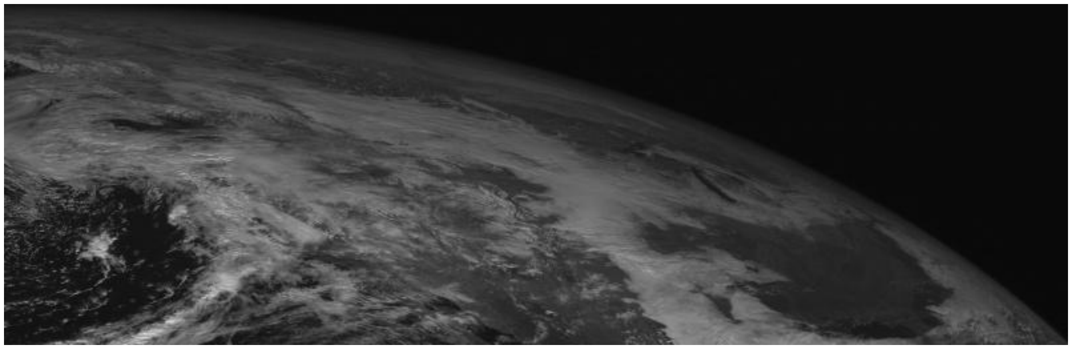


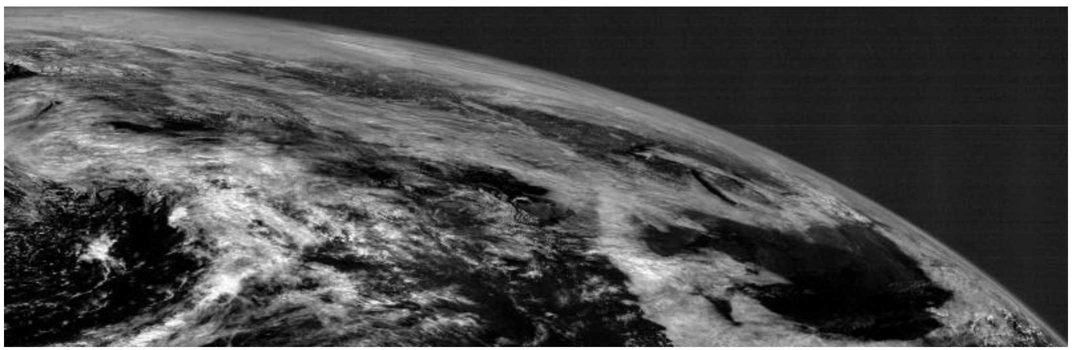
Image credit: Turquoise

Implementation Example

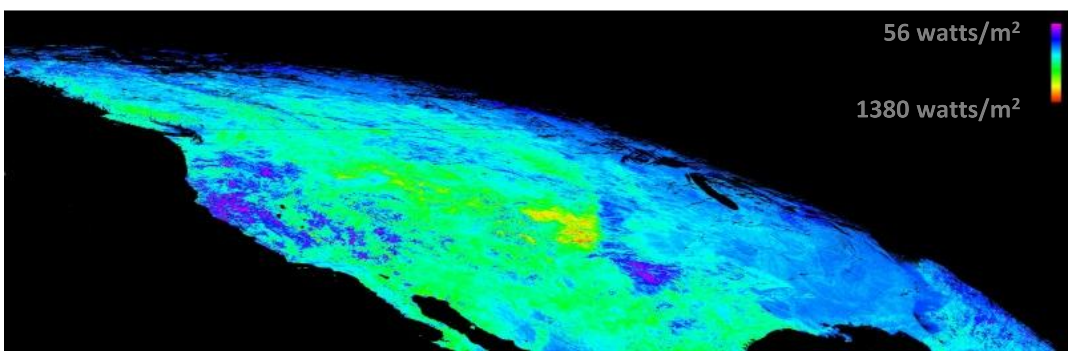


GOES 11 Image

Feb 10, 2007 9pm GMT



Cloud Index



Irradiance map

Satellite Data Availability (Global)

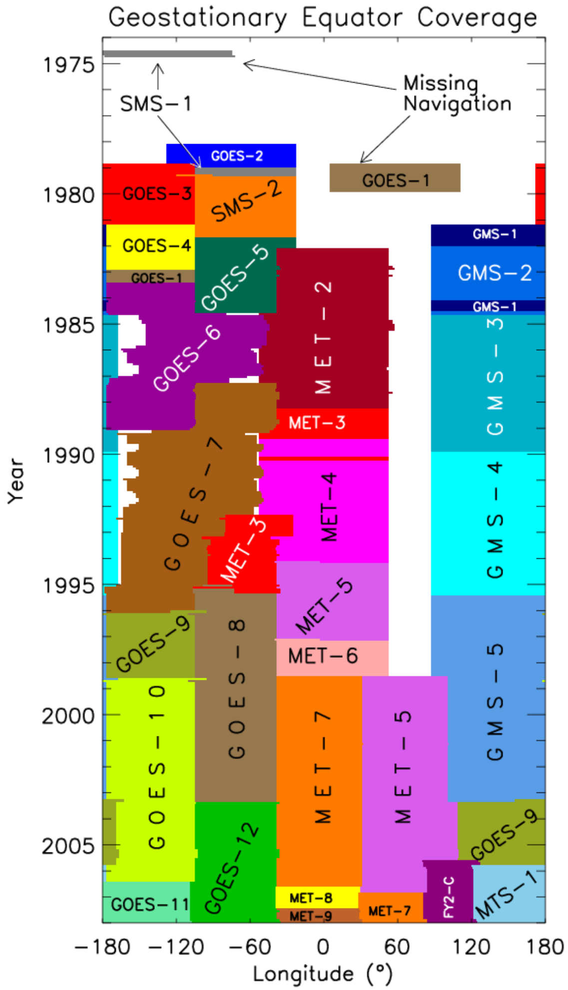


Image credit: NOAA

- Satellite systems providing imagery
  - GOES (Americas)
  - Meteosat (Europe, Africa, Middle East)
  - MTSAT, FY (Asia, Australia)
- Data availability
  - Going back multiple decades
- Image refresh rate
  - Depends on the type of satellite (every 15 minutes for latest generation of Meteosat images)

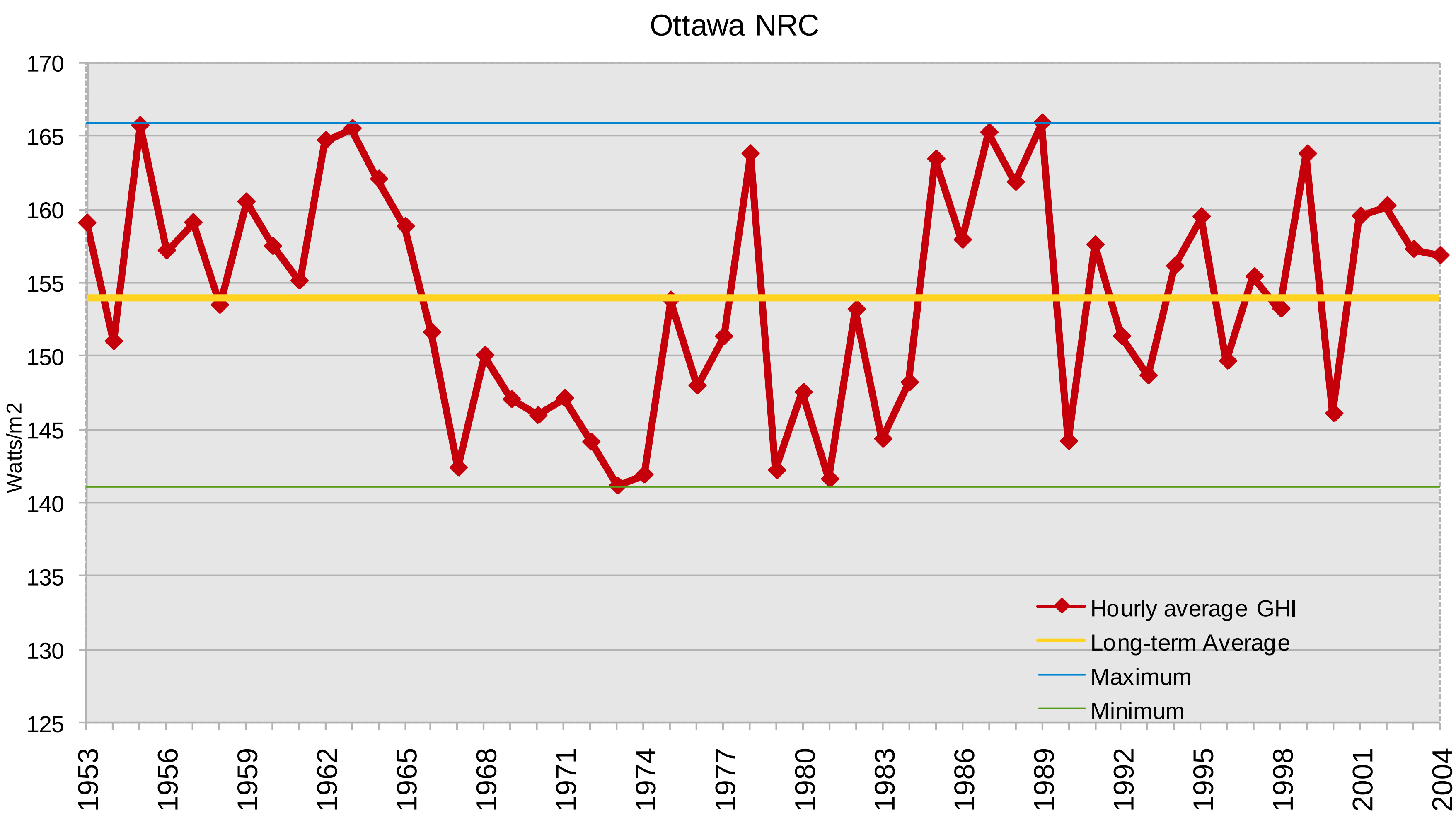
Statistical Characterization of the Resource

- Time series data
- Histograms
- Heatmaps
- P95
- Typical Meteorological Year

Common Metrics

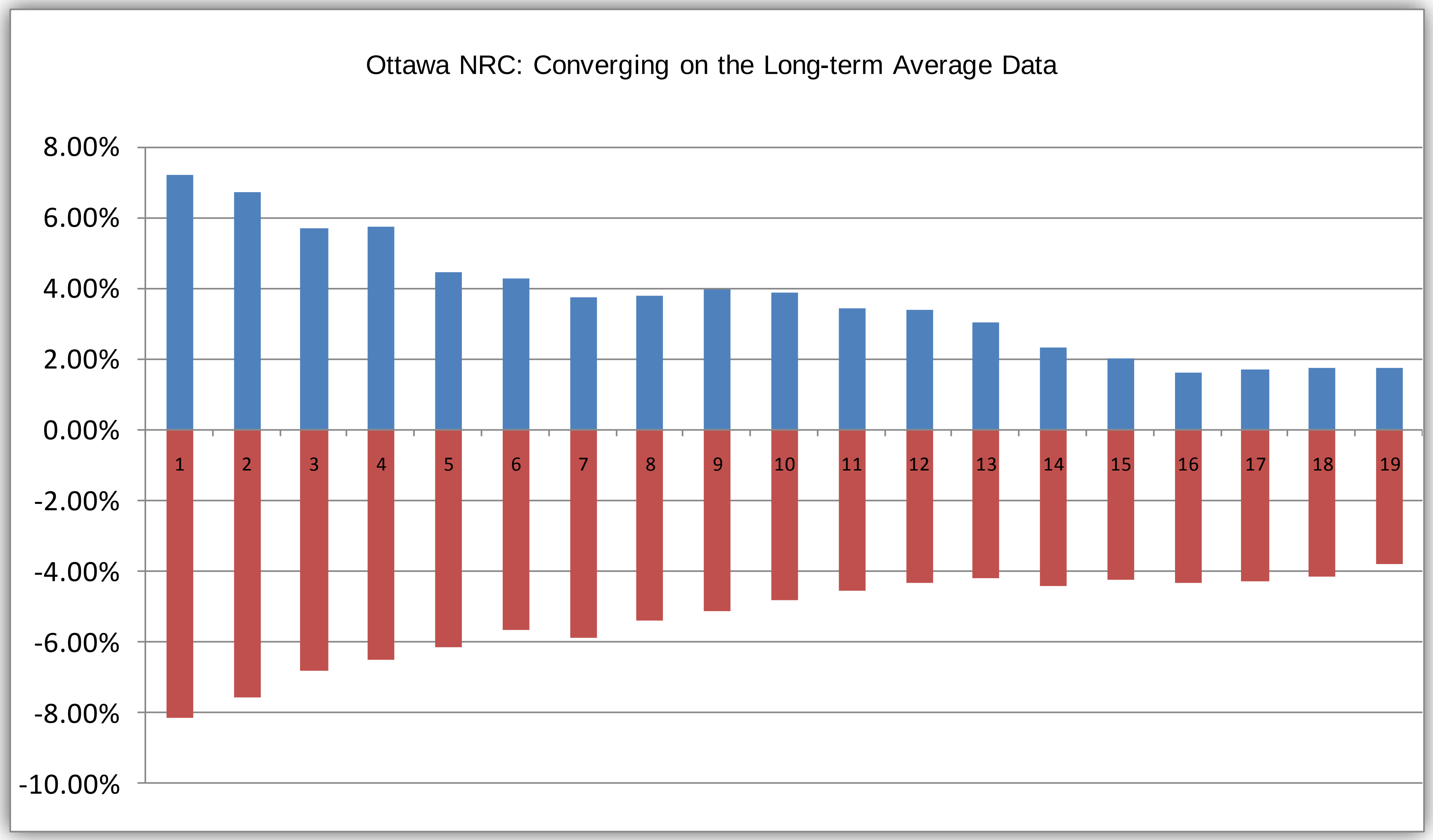
- Hourly GHI
  - Easiest way to deal with missing data points
  - Can be easily converted to daily and annual averages
  - 150-160 watts/m2 for Ottawa-Toronto area
- kWh/kW
  - Annual output of installed capacity
  - 1200 kWh/kW for Ottawa-Toronto area
- Full sun hours
  - Number of hours per day at 1000 watts/m2

Historical Data for Ottawa

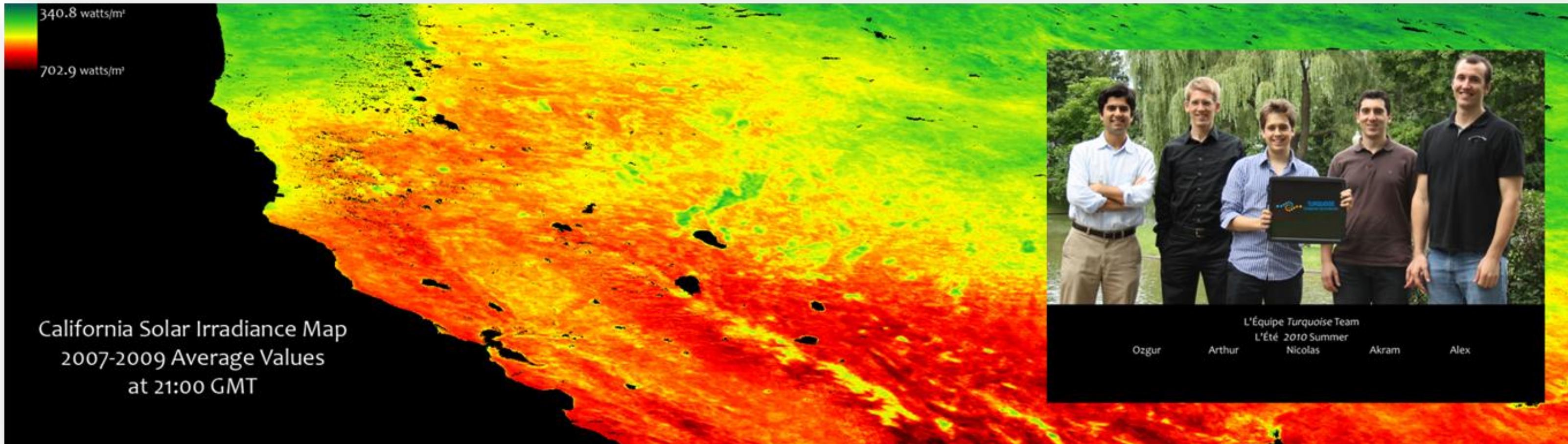


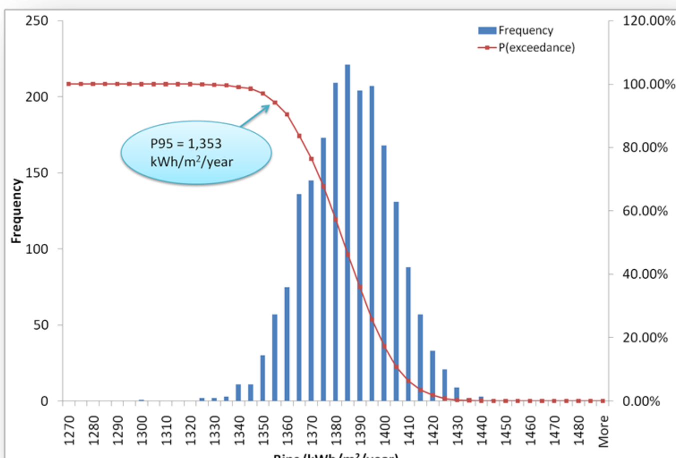
Data source: Environment Canada

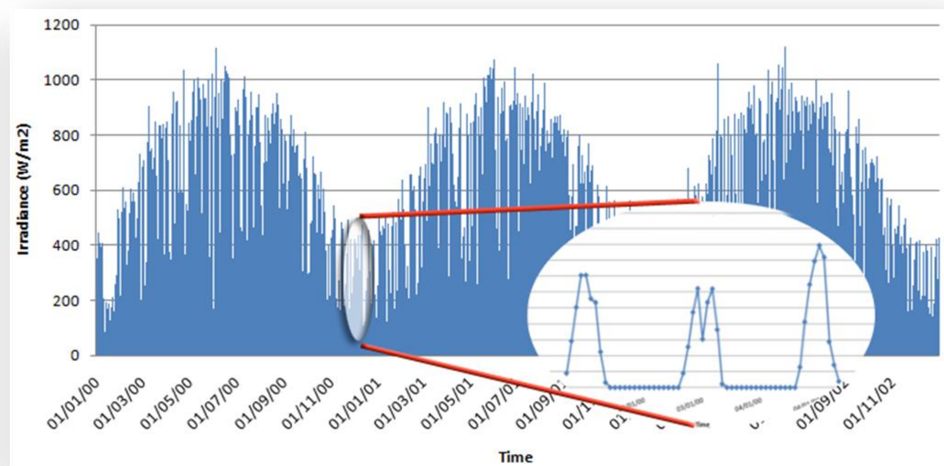
The Need for Historical Data



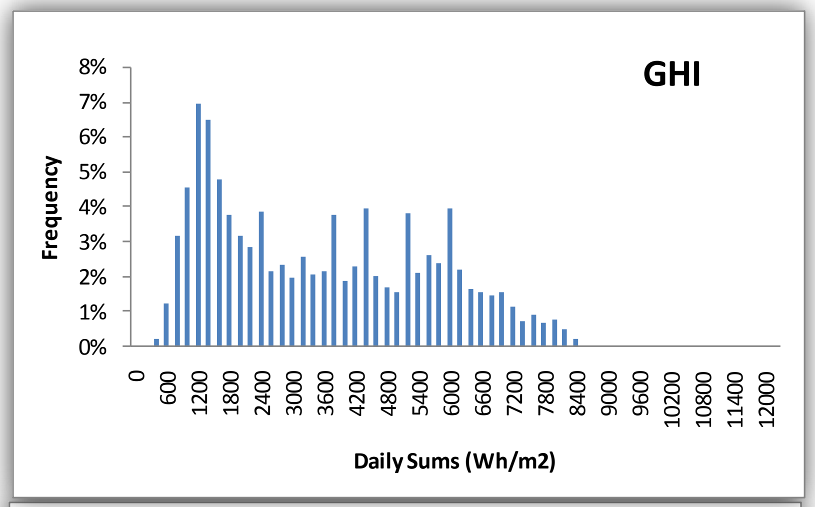
Maps, P95 and Time Series

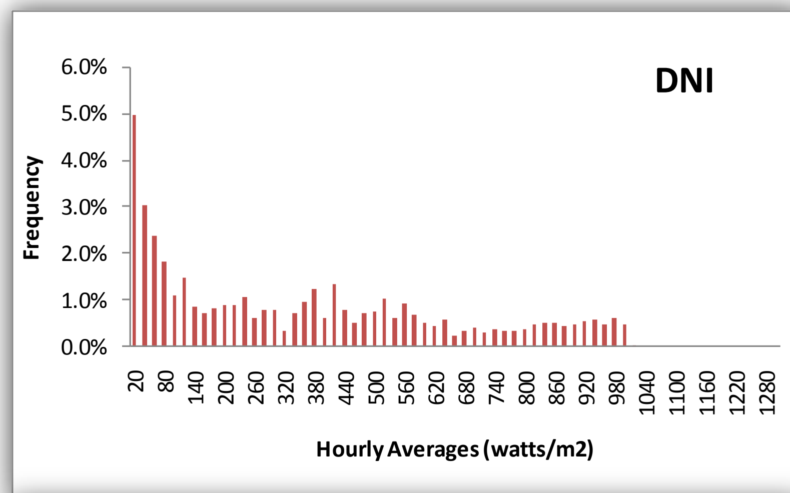


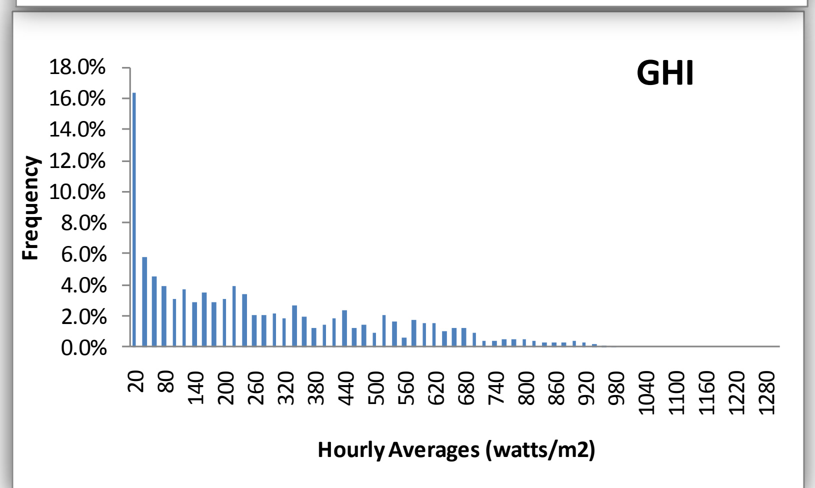


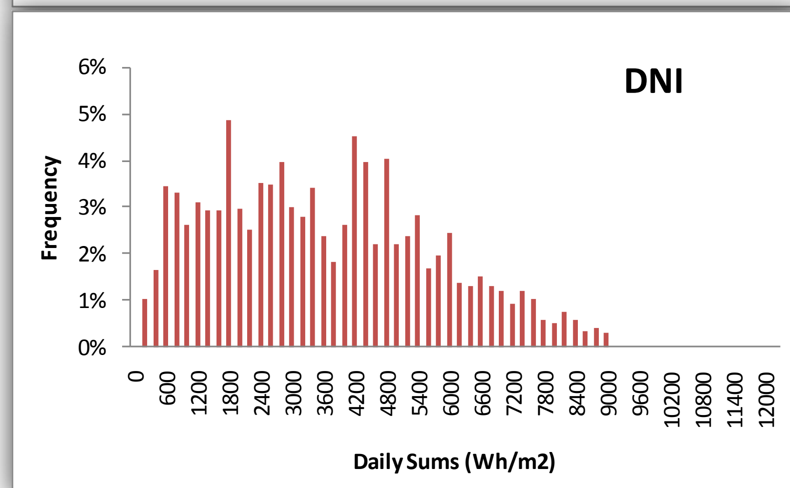


Histograms


GHI
Frequency
8%
7%
6%
5%
4%
3%
2%
1%
0%
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200 7800 8400 9000 9600 10200 10800 11400 12000
Daily Sums (Wh/m2)


DNI
Frequency
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
20 80 140 200 260 320 380 440 500 560 620 680 740 800 860 920 980 1040 1100 1160 1220 1280
Hourly Averages (watts/m2)


GHI
Frequency
18.0%
16.0%
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
20 80 140 200 260 320 380 440 500 560 620 680 740 800 860 920 980 1040 1100 1160 1220 1280
Hourly Averages (watts/m2)


DNI
Frequency
6%
5%
4%
3%
2%
1%
0%
0 600 1200 1800 2400 3000 3600 4200 4800 5400 6000 6600 7200 7800 8400 9000 9600 10200 10800 11400 12000
Daily Sums (Wh/m2)

Heatmap Example

Average hourly irradiance (watts/m2)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4:00	0	0	0	0	0	0	0	0	0	0	0	0
5:00	0	0	0	0	7	18	12	0	0	0	0	0
6:00	0	0	0	20	67	91	81	34	2	0	0	0
7:00	1	15	78	117	188	207	234	176	51	8	0	0
8:00	2	31	110	212	281	318	322	262	146	56	7	0
9:00	51	119	224	327	400	434	453	388	263	151	59	29
10:00	142	215	332	436	515	567	599	519	402	248	145	119
11:00	174	262	372	489	594	621	660	587	458	303	190	153
12:00	209	312	424	529	653	640	688	604	508	343	222	192
13:00	213	303	408	527	668	685	677	617	511	347	228	221
14:00	192	280	378	507	611	640	638	580	460	316	191	168
15:00	135	221	322	460	560	575	568	529	413	263	154	119
16:00	49	118	225	331	433	439	423	396	286	149	66	35
17:00	8	50	139	244	335	351	331	290	195	84	16	3
18:00	0	2	41	129	202	217	213	159	71	12	0	0
19:00	0	0	0	6	0	6	0	0	0	0	0	0
20:00	0	0	0	1	18	23	24	4	0	0	0	0
21:00	0	0	0	0	0	0	0	0	0	0	0	0

Typical Meteorological Year

- Data sets of hourly values of solar radiation and meteorological elements for a 1-year period.
- Used for numerical simulation of solar energy conversion systems and building systems to analyze different system types, configurations, and locations.
- They represent typical rather than extreme conditions.

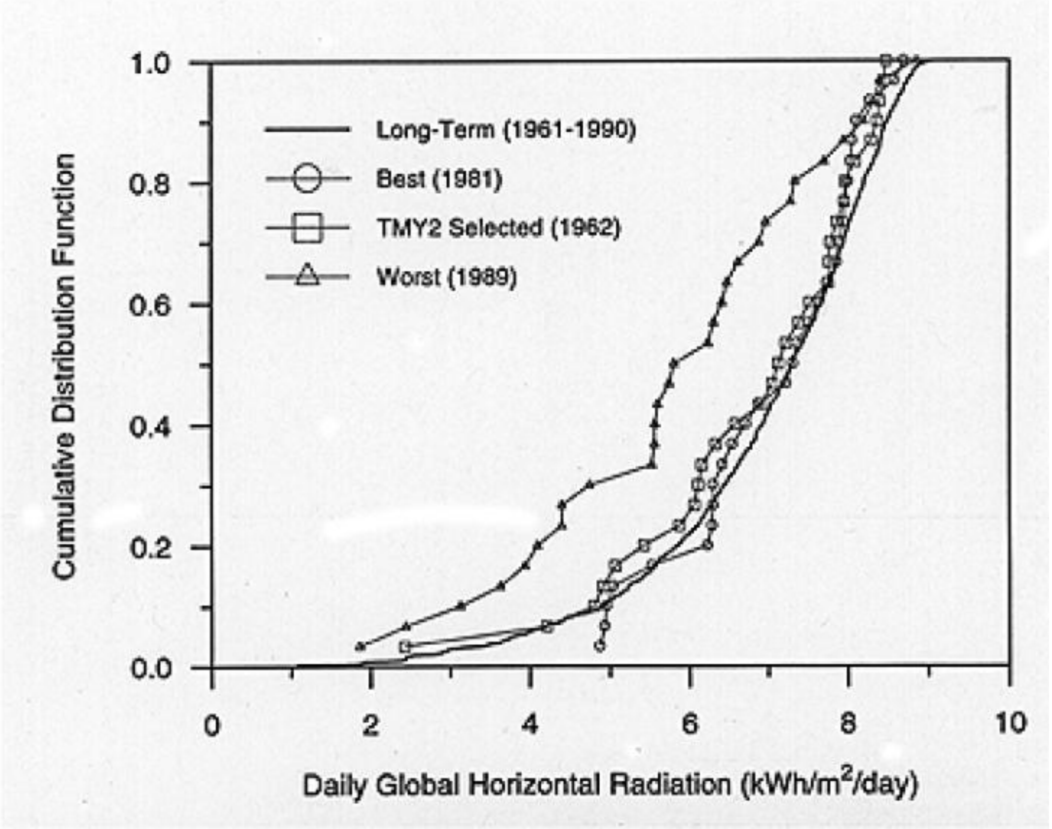


Image source: NREL

Common Software Tools

- RETScreen (http://www.retscreen.net/)
- PVSyst (http://www.pvsyst.com)
- PVSol (http://www.valentin.de/)
- Homer (https://analysis.nrel.gov/homer/)
- SAM (https://sam.nrel.gov/)

Case Study – Thunder Bay

Category	Inputs
Price per kWh (in cents): The rate at which the generated electricity will be sold to the grid.	54.9
Slope (in degrees): The angle between the panels and the horizontal.	20
Azimuth (in degrees): The preferred orientation of the panels.	0
Power Capacity (in kW): Total power capacity of the system (i.e., capacity of each panel x the number of panels)	14.4 kWp
Efficiency (%): The nominal efficiency (%) of the PV modules used in the project	15.2%
Miscellaneous losses (%): Various system losses (e.g., due to the presence of dirt or snow on the panels, wiring, etc.). Typical values range from zero to a few percent.	5%
Inverter – Efficiency (%): Efficiency of the inverter used to transform the DC output to AC. Typical values are between 90 to 95%.	94.5%
Inverter – Capacity (kW): The nominal output of the inverter (AC).	10 kW
Cost of installation (per kW)	$4500

RETScreen Energy Model

Proposed case power system Inc

Technology		Photovoltaic
Analysis type		○ Method 1 ⦿ Method 2
Resource assessment		
Solar tracking mode		Fixed
Slope	°	20.0
Azimuth	°	

☑ Show data

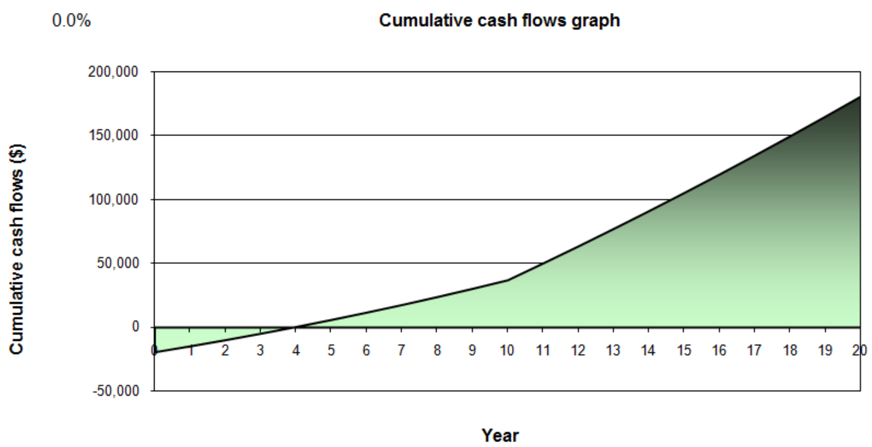
Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	1.25	1.96	549.0	0.872
February	1.97	2.72	549.0	1.076
March	3.21	3.91	549.0	1.649
April	4.56	4.99	549.0	1.957
May	5.74	5.91	549.0	2.326
June	5.98	5.98	549.0	2.236
July	6.10	6.18	549.0	2.342
August	5.34	5.70	549.0	2.172
September	3.87	4.50	549.0	1.709
October	2.34	3.06	549.0	1.245
November	1.38	2.05	549.0	0.840
December	1.10	1.86	549.0	0.816
Annual	**3.58**	**4.08**	**549.00**	**19.241**

Annual solar radiation - horizontal	MWh/m²	1.31
Annual solar radiation - tilted	MWh/m²	1.49
Photovoltaic		
Type		mono-Si
Power capacity	kW	14.40
Manufacturer		
Model		
Efficiency	%	15.2%
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.40%
Solar collector area	m²	95
Miscellaneous losses	%	5.0%
Inverter		
Efficiency	%	94.5%
Capacity	kW	10.0
Miscellaneous losses	%	0.0%
Summary		
Capacity factor	%	15.3%
Electricity exported to grid	MWh	19.241

RETScreen Financial Model

Financial Analysis

Financial parameters			
Inflation rate	%	2.0%	
Project life	yr	20	
Debt ratio	%	70%	
Debt interest rate	%	6.00%	
Debt term	yr	10	
Initial costs			
Power system	$	64,800	100.0%
Other	$		0.0%
Total initial costs	$	64,800	100.0%
Incentives and grants	$		0.0%
Annual costs and debt payments			
O&M (savings) costs	$		
Fuel cost - proposed case	$	0	
Debt payments - 10 yrs	$	6,163	
	$		
Total annual costs	$	6,163	
Annual savings and income			
Fuel cost - base case	$	0	
Electricity export income	$	10,563	
	$		
Total annual savings and income	$	10,563	
Financial viability			
Pre-tax IRR - equity	%	29.6%	
Pre-tax IRR - assets	%	10.4%	
Simple payback	yr	6.1	
Equity payback	yr	3.9	



Conclusion

- Solar resource assessment is a key part of feasibility analyses for solar energy investments.
- Data availability is quite limited in Canada, especially for recent years.
- Satellite-based technologies are rapidly maturing and becoming a viable alternative for supplementing ground-based measurements.