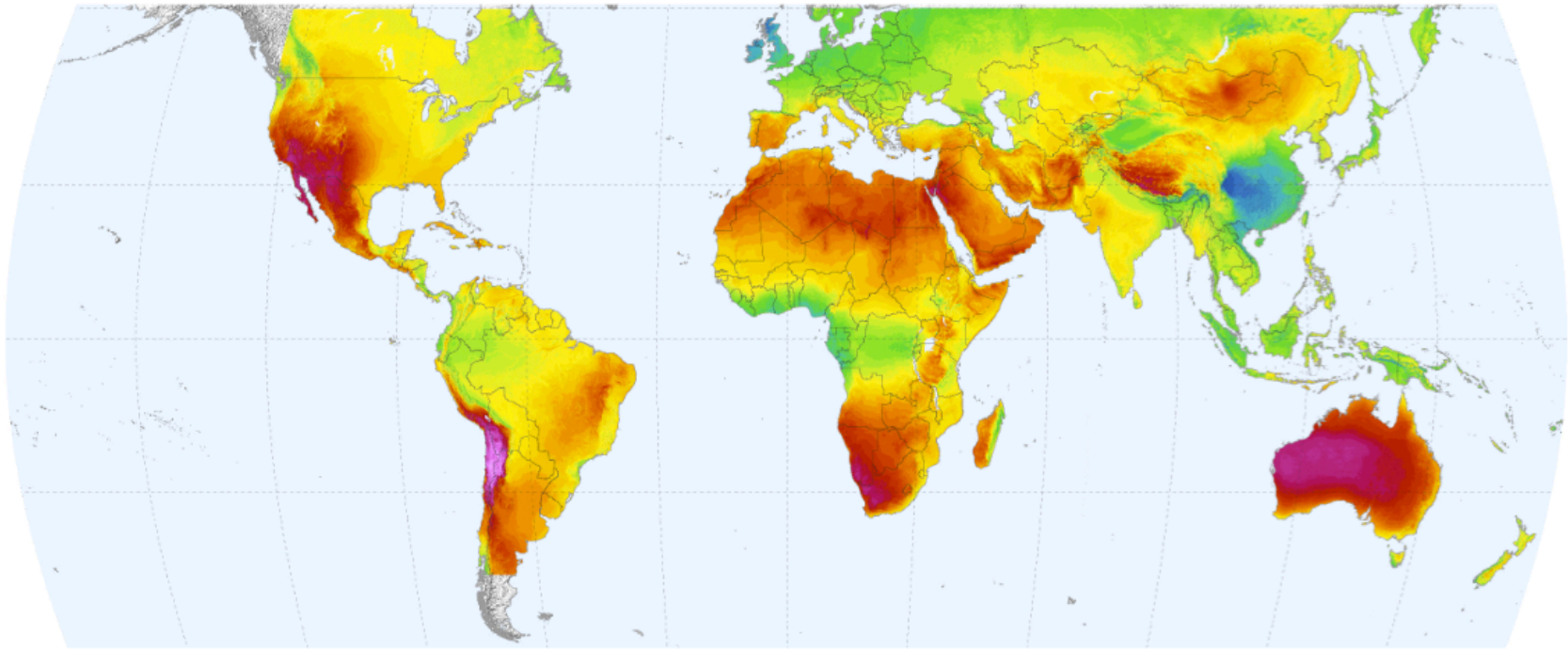


Improved method for generating Typical Meteorological Year data for solar energy simulations

Tomas Cebecauer and Marcel Suri
GeoModel Solar, Slovakia
geomodelsolar.eu

SolarPACES Conference, 16-19 September 2014, Beijing, China

GeoModel SOLAR

About GeoModel Solar

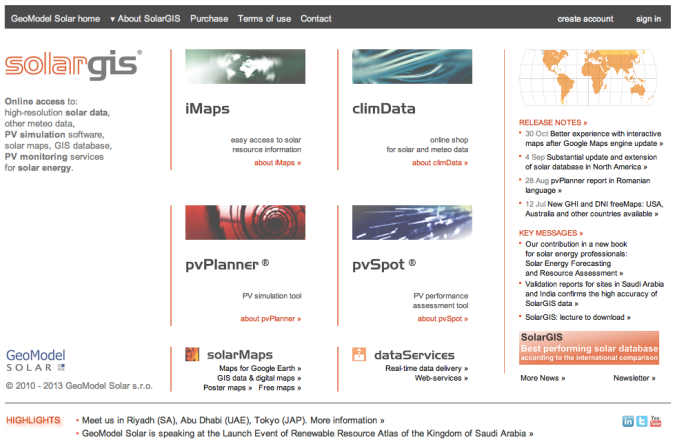
Development and operation of SolarGIS online system

- Solar resource and meteo database
- PV simulation software
- Data services for solar energy and PV:
  - Planning
  - Monitoring
  - Forecasting

Consultancy and expert services

- Solar resource assessment
- PV yield and performance assessment
- Country studies

http://solargis.info



Topics

1. Principle of TMY construction
2. Criteria
3. Overview of methods
4. SolarGIS method
5. TMY for P90, P75, …

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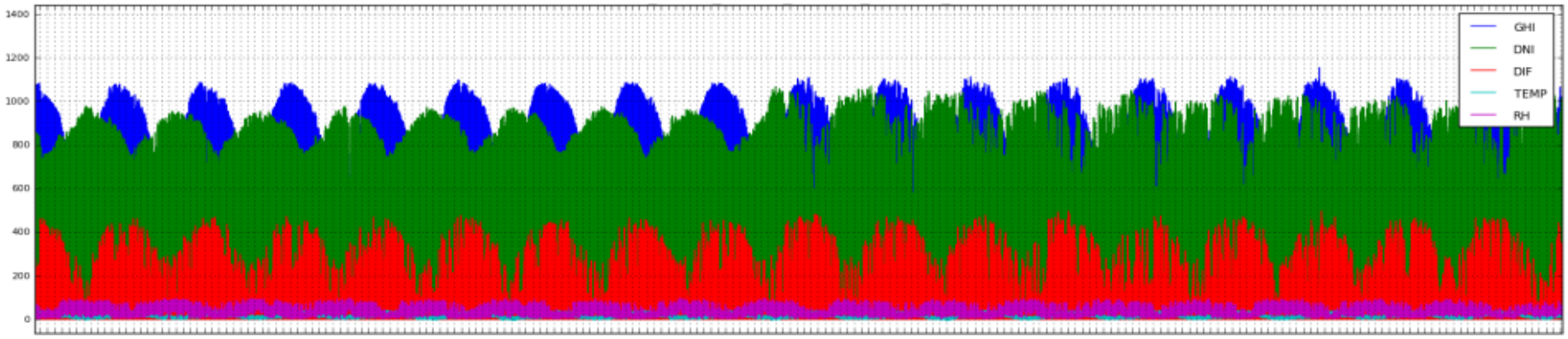
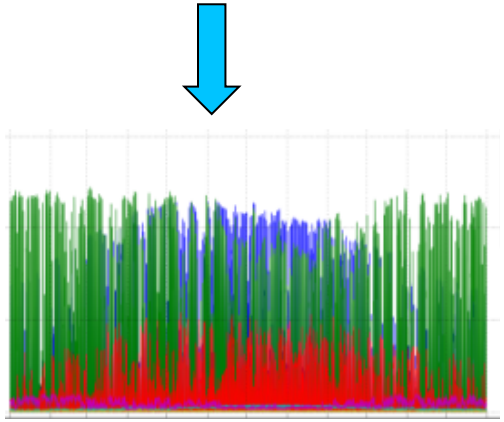
Principle



Reduction of multiyear time series to one year
(set of 8760 hourly parameters, sub-hourly possible)

- Speeding up simulations
- Most simulation packages – TMY is only supported
- Data compression leads to the loss of information



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History

- 1970's Sandia , 30-years of data – only at meteostations
- TMY2, TMY3 - 15 years allows the use of satellite data
- NREL's National Solar Radiation Data Base (NSRDB)
    - TMY2 at 239 stations in US
    - TMY3 at 1020 stations in US
- Recent developments – focus to TMY's that better fulfill needs of specific application
- Development by many groups: Stofel at al, Kalogirou, Fainman at al, Way at al, Hoyer-Click at al,….

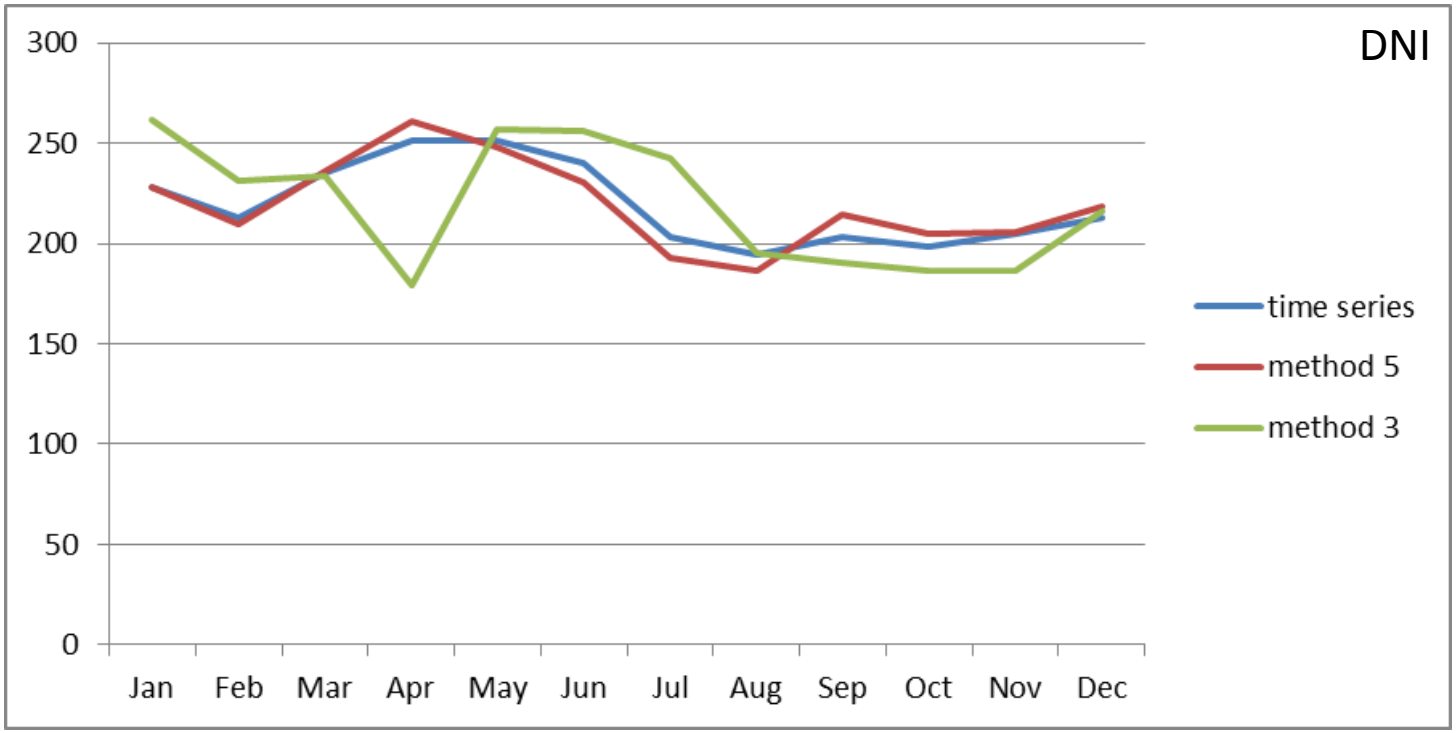
Criteria

- **Minimum difference** between statistical characteristics (annual average, monthly averages, medians)
- **Maximum similarity** of monthly Cumulative Distribution Functions between TMY and multiyear time series
- **Persistence of specific temporal patterns** such as sequence of days with certain type of weather
- **Consistency** of GHI and DNI and other meteorological parameters

Criteria

- Which criteria are important for CSP?
- How to apply them? One parameter, many parameters simultaneously?

- Some criteria may be contradictory



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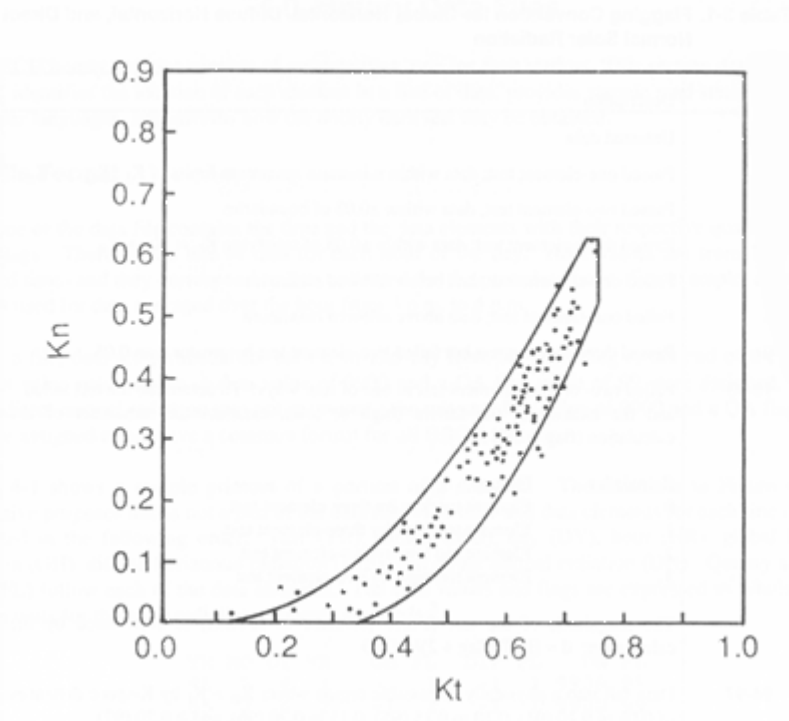
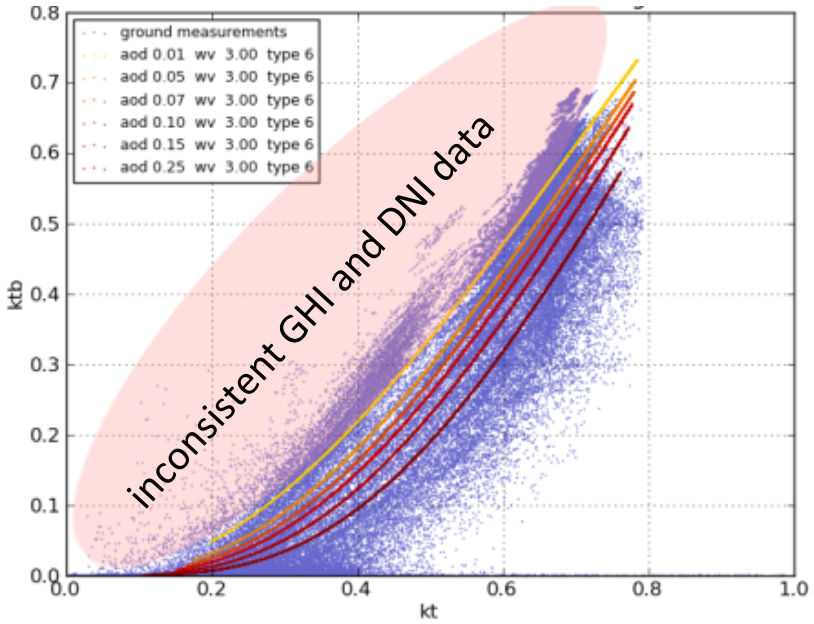
Criteria - consistency of GHI and DNI



Principle of component test
Seri QC assessment (NREL)



Independent processing of GHI and DNI
may result in data inconsistency

Some methods 'neglect' this criterion

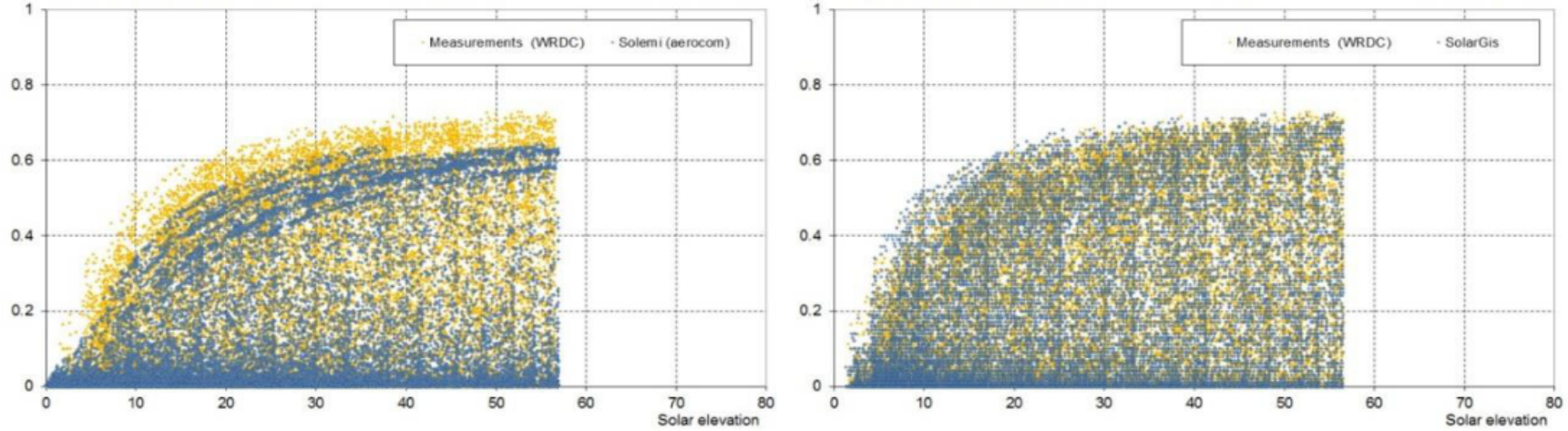
Factors to be considered

- **Time representativeness** (optimum 15+ years)
- Time-series **data origin**
  - Ground-measured
  - From raw models (satellite and meteorological)
  - Site-adapted modeled data
- **Temporal resolution** (hourly, sub-hourly)
- **Weight of parameters** (GHI, DNI, DIF, TEMP, …)
- **Statistical indicators** (mean, median, CDF , persistence)

- **TMY representation**
  - Typical (average) weather (P50)
  - Conservative year with low solar resource (P90, P75, P95, P99)

Factors to be considered

- **Time representativeness** (optimum 15+ years):
  - data must be from project site
  - less than 10 years may result in higher uncertainty
  - solar and meteo parameters must be from the same period
- Time-series **data origin**
  - Ground-measured (not available, short period)
  - From raw models (satellite and meteorological)
  - Site-adapted modeled data



Source: Ineichen, 2013

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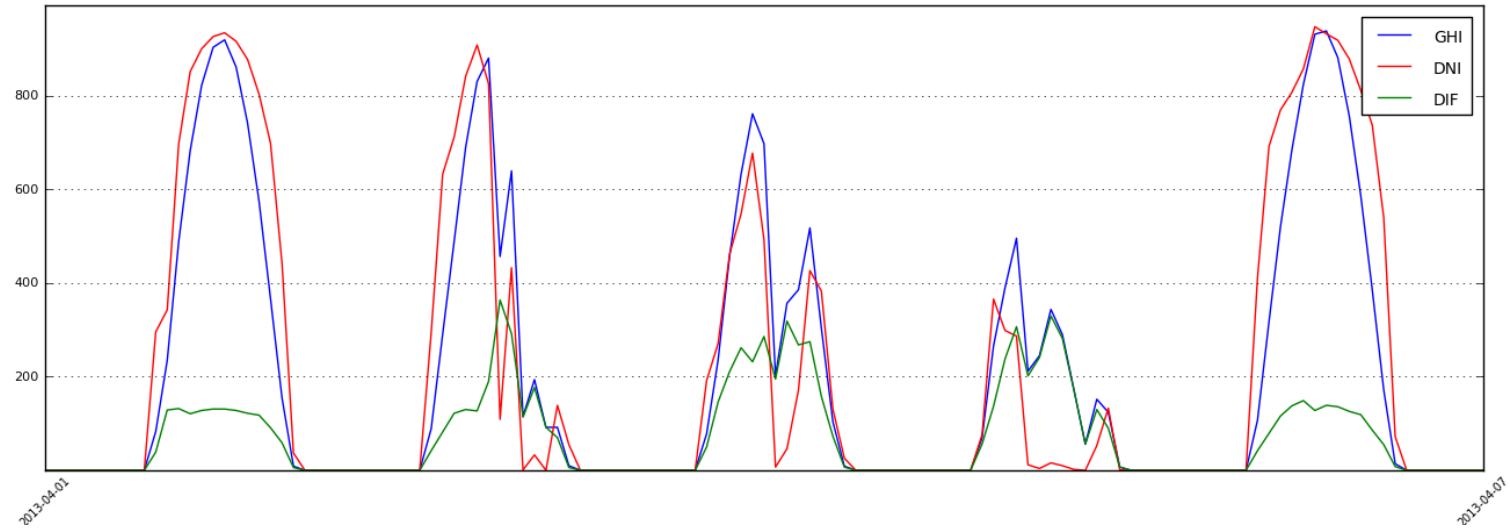
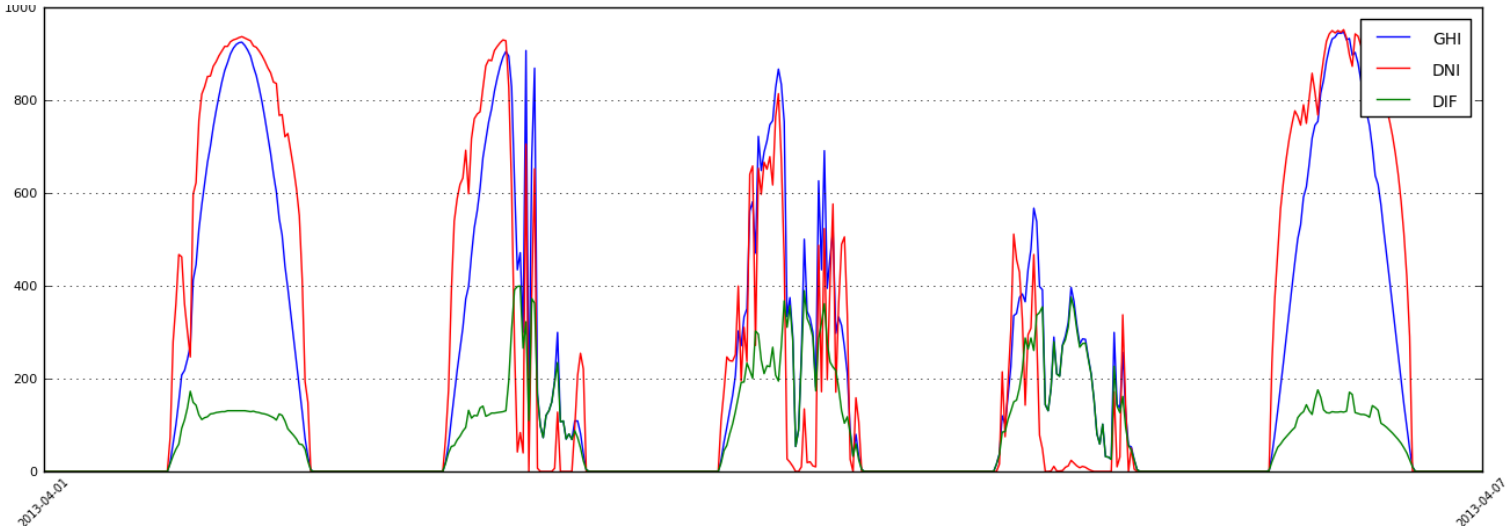
Factors to be considered

- **Temporal resolution**



hourly



15min

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Factors to be considered

- **Temporal resolution**
  - Native satellite data resolution 15 to 30 minute
  - Methods for improving resolution (1, 5, 10 minutes):
    - Fusion of local measurements with satellite data
    - Statistical post-processing
    - Time interpolation of cloud index
    - Cloud motion vectors

Factors to be considered

- **Weight of parameters** (GHI, DNI, DIF, TEMP, …)

- custom-tailored TMY data products for solar energy
- strong focus on GHI and DNI

Weather variable	Sandia (TMY2)	NREL (TMY3)	Kalogirou (Cyprus)	Meyer (CSP)	SolarGIS (PV)	SolarGIS (CSP/CPV)
Max. temperature of the dry bulb	1/24	1/20	1/32	1	—	—
Min. temperature of the dry bulb	1/24	1/20	1/32	2	—	—
Average temperature of the dry bulb	2/24	2/20	2/32	1	0.05*	0.04*
Temp. deviation of the dry bulb	—	—	1/32	—	—	—
Max. temperature of Dew point	1/24	1/20	—	2	—	—
Min. temperature of Dew point	1/24	1/20	—	—	—	—
Average temperature of Dew point	2/24	2/20	—	1	—	—
Max. relative humidity	—	—	1/32	—	—	—
Min. relative humidity	—	—	1/32	—	—	—
Average relative humidity	—	—	2/32	—	—	—
Deviation of relative humidity	—	—	1/32	—	—	—
Wind speed max.	2/24	1/20	1/32	4	—	—
Average wind speed	2/24	1/20	2/32	2	—	—
Deviation of wind speed	—	—	1/32	—	—	—
Average wind direction	—	—	1/32	1	—	—
Global irradiance	12/24	5/20	8/32	—	0.75*	0.23*
Direct irradiance	—	5/20	8/32	85	—	0.70*
Diffuse irradiance	—	—	—	—	0.20*	0.03*

** Weights are indicative and may be adapted to improve results*

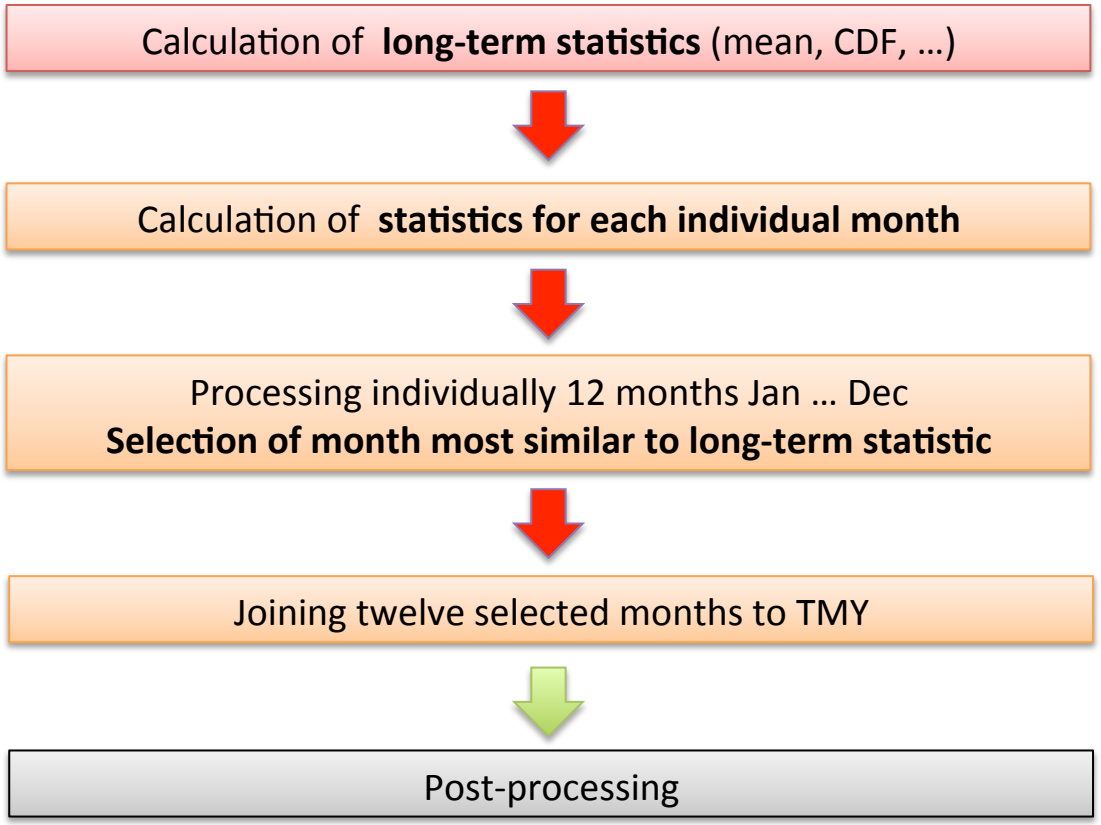
GeoModel SOLAR

Factors to be considered

- **TMY representation**
  - Typical (average) weather (P50)
  - Conservative year with low solar resource (P90, P75, P95, P99)

General methodology

Used by majority of methods: selection of the most similar month



Resulting TMY:

Jan 1999	Feb 2004	Mar 1994	Apr 2012	May 2004	Jun 2006	Jul 2000	Aug 1996	Sep 1997	Oct 2003	Nov 1995	Dec 2010

GeoModel SOLAR

General methodology

GHI

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	127	136	194	221	245	248	234	219	194	160	128	114
1995	134	145	184	210	249	248	243	214	186	157	120	113
1996	112	137	181	226	229	232	245	227	187	167	127	111
1997	121	142	195	209	250	249	249	220	187	159	130	117
1998	121	130	179	224	244	238	236	221	199	170	127	111
1999	124	147	196	234	246	237	238	218	194	148	130	113
2000	124	146	193	220	243	231	237	217	200	173	126	112
2001	131	146	198	229	257	252	234	216	190	159	111	100
2002	116	145	191	212	252	249	238	214	186	161	124	104
2003	129	142	193	217	250	241	221	210	184	145	132	114
2004	128	142	195	216	247	242	234	217	175	150	119	121
2005	133	128	192	227	239	231	250	216	188	150	129	111
2006	116	130	209	214	246	252	219	226	190	156	119	120
2007	122	148	205	234	266	257	224	216	199	159	132	121
2008	134	131	197	214	260	254	233	211	170	160	130	114
2009	132	137	187	232	257	222	240	212	192	169	133	114
2010	134	128	189	214	248	260	233	210	169	164	128	112
2011	131	151	195	216	202	235	235	205	198	152	130	121
2012	131	157	191	220	243	237	226	208	193	158	130	126
2013	138	150	198	224	261	253	224	212	183	166	131	108
SUM	127	141	193	221	247	243	235	215	188	159	127	114
	1994	2004	2000	1994	2004	2004	2011	2001	2005	1997	1998	2009
TMY	127	142	193	221	247	242	235	216	188	159	127	214

DNI

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	191	160	217	231	245	229	183	177	187	176	172	175
1995	216	187	196	204	249	233	201	174	171	170	148	173
1996	156	167	186	238	220	209	203	196	179	189	173	166
1997	173	181	216	211	251	237	212	182	170	174	178	188
1998	171	154	195	233	237	219	185	183	199	193	175	165
1999	191	195	219	258	244	217	190	172	182	159	179	176
2000	187	185	203	224	239	197	187	175	201	206	172	168
2001	204	190	218	240	266	238	179	174	178	168	134	133
2002	165	187	214	212	250	236	188	176	169	178	163	153
2003	212	193	211	226	251	219	156	170	158	158	198	181
2004	202	183	221	226	258	220	195	195	146	158	154	203
2005	211	158	210	244	215	197	237	178	187	159	180	178
2006	179	174	269	209	226	257	152	211	187	158	147	189
2007	174	211	240	271	306	294	165	193	221	179	189	199
2008	219	142	219	203	286	255	177	156	165	182	188	187
2009	215	166	192	253	263	205	201	183	197	203	185	177
2010	218	147	188	209	258	286	179	165	140	204	190	167
2011	204	219	223	209	167	202	190	141	202	160	180	186
2012	202	225	197	247	234	224	171	147	206	181	189	217
2013	244	214	236	238	286	254	156	168	195	200	195	154
SUM	197	182	214	229	248	231	185	176	182	178	174	177
	1994	2004	2000	1994	2004	2004	2011	2001	2005	1997	1998	2009
TMY	191	183	203	231	258	220	190	174	187	174	175	177

DIF
TEMP
RH
WS
WD
.
.
.

- for each month one representative month from time-series is used
- all parameters (GHI, DNI, DIF, TEMP, …) are taken from same month

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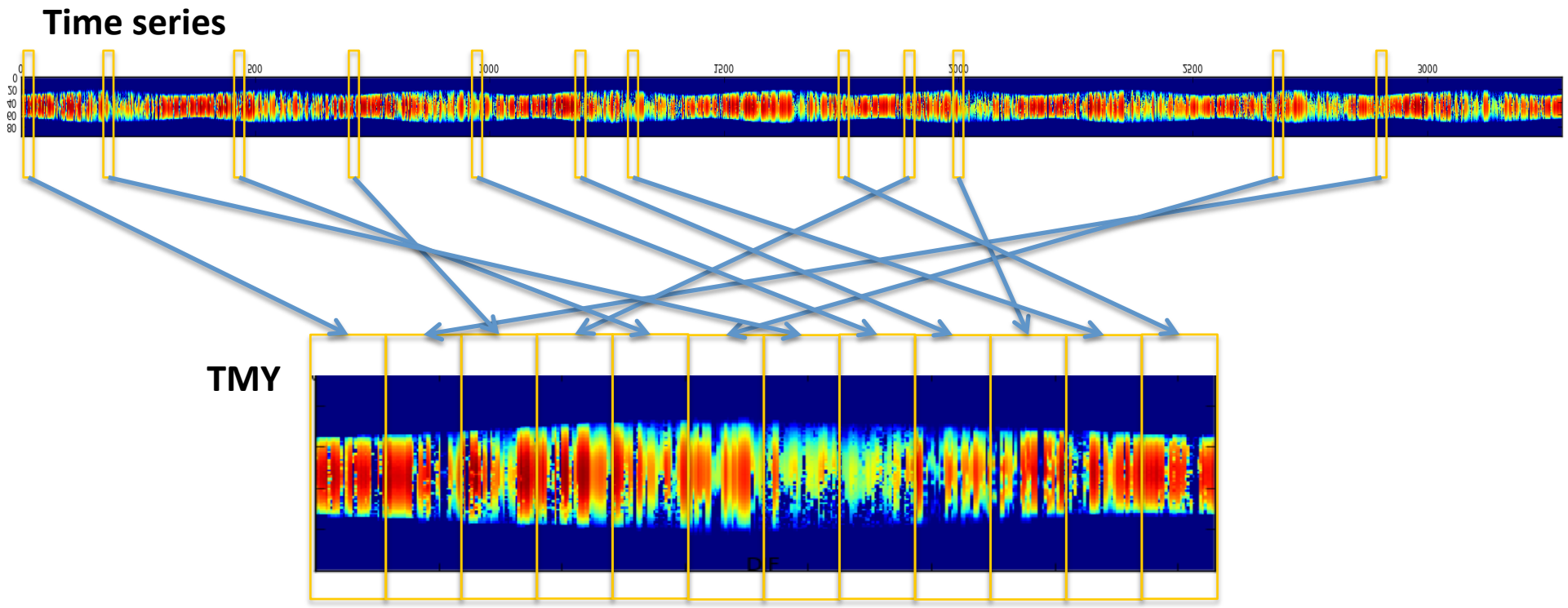
General methodology



TMY is assembled from hourly, 15-min or 10-min data

GeoModel SOLAR

Data structure

Data sources

Solar radiation (GHI, DNI, DIF)

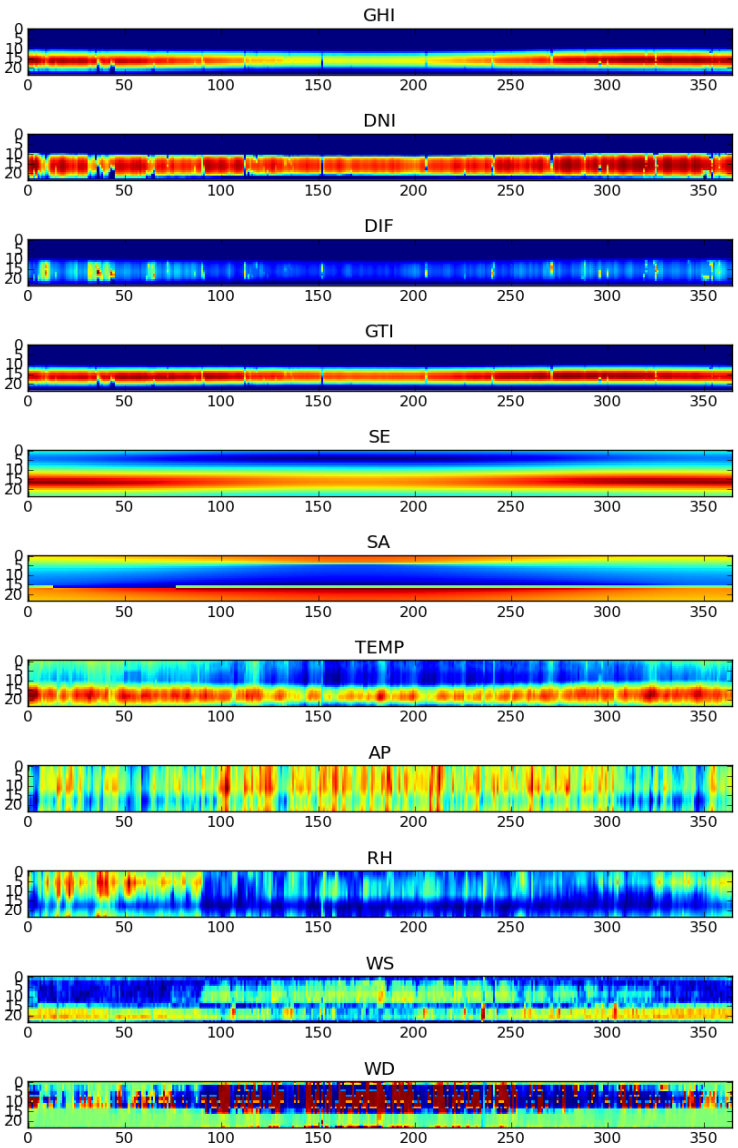
- satellite model (& ground measurements)

Meteo data (temperature, humidity, wind, …)

- meteorological model
  (& ground measurements)

Output TMY

- One year (365 days)
- Hourly, 15 min, 10 min step



Methods

1.	Minimalization of deviation of DNI monthly average	(Wey 2012)
2.	Stepwise exclusion of the individual months	(Sandia, NREL, …)
3.	SolarGIS method - similarity index of averages and CDFs	(GeoModel Solar)
4.	Moving window over the time series	(Hoyer-Click)
5.	Adapted moving window	(GeoModel Solar)
6.	Manual replacing the individual days	(Hoyer-Click)
7.	Normalized residuals of parameters	

Methods

Method 1: Minimization of deviation of DNI monthly average (**Wey 2012**)

- For each month in TMY - use of month from year having smallest difference to long-term average
- *Does not consider CDF*
- *Only one parameter is considered, other parameters ignored*

Method 2: Stepwise exclusion of the individual months (**Sandia, NREL**, …)

- Exclusion months with very different CDF – remains 5 candidates for each month
- Exclusion of months by persistence criteria – 1 candidate
- TMY3 – includes also criterion of closest average
- *30 years of ground measured data in original method –> lot of modeled data*
- *TMY3 version: 15 years of data, use of satellite data, new weights*
- *Weights aim for general use, not for PV or CSP*

Methods

Method 3: SolarGIS method - similarity index of averages and CDFs

- Calculation of monthly averages and CDFs
- Combined index (weight CDF/mean; weight of parameters: GHI,DNI, DIF, TEMP)
- Selection of month using best index score
- Post-processing - ratio (rescaling) to fit GHI and DNI to longterm average
- *Generated from hourly (or sub-hourly) time series*
- *Flexible weights, predefined – for PV and CSP TMYs*
- *Geographically variable weighting for optimum TMY (expert evaluation of results)*

Method 4: moving window over the time series (Hoyer-Click)

- 365 days long window screening for annual average close to long term average of DNI
- Selected candidates evaluated by other criteria (e.g. CDF fit , average of other parameter)
- *Good fit of annual value of only one parameter (DNI)*
- *No fit of monthly values*

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Methods

Method 5: manual replacing the individual days (Hoyer-Click)

- Iterative replacement of days in TMY from TS to get statistical similarity
- *Subjective method done by operator, non-repetable*
- *Very time demanding*

Method 6: normalized residuals of parameters

- Similar to advanced multi-criterial methods (stepwise or similarity index)
- *Reported big deviations in specific conditions*

Methods

1.	Minimalization of deviation of DNI monthly average	(Wey 2012)
2.	Stepwise exclusion of the individual months	(Sandia, NREL, …)
3.	SolarGIS method - similarity index of averages and CDFs	(GeoModel Solar)
4.	Moving window over the time series	(Hoyer-Click)
5.	Manual replacing the individual days	(Hoyer-Click)
6.	Normalized residuals of parameters	

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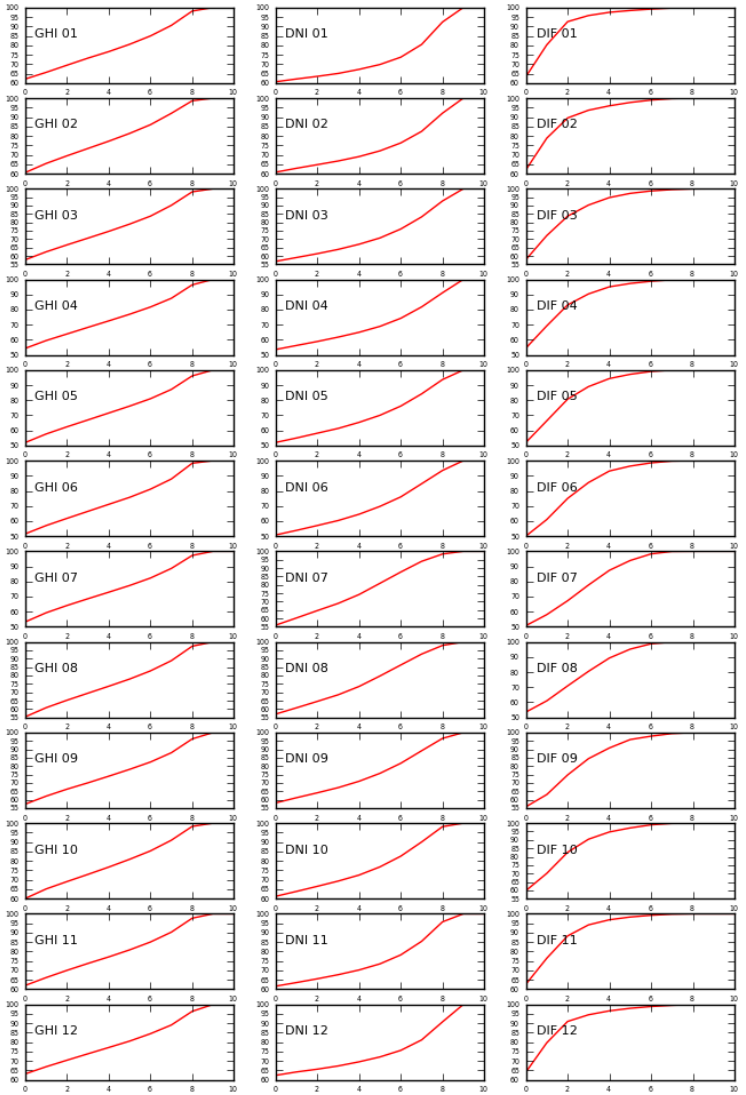
TMY - SolarGIS method (Step 1)

Full time series long-term monthly statistics

- each parameter (GHI,DNI, DIF, TEMP, …)
- monthly mean and CDF

- used as P50 reference

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GHI	97	116	166	191	217	227	228	206	170	136	99	87
DNI	171	168	193	198	204	213	200	191	177	164	154	158
DIF	25	31	49	56	68	68	76	68	55	45	29	24
TEMP	6.5	7.9	11.4	13.6	18.2	23.6	27.3	26.8	21.4	16.9	10.8	7.3



TMY - SolarGIS method (Step 2)

Monthly statistics of individual years

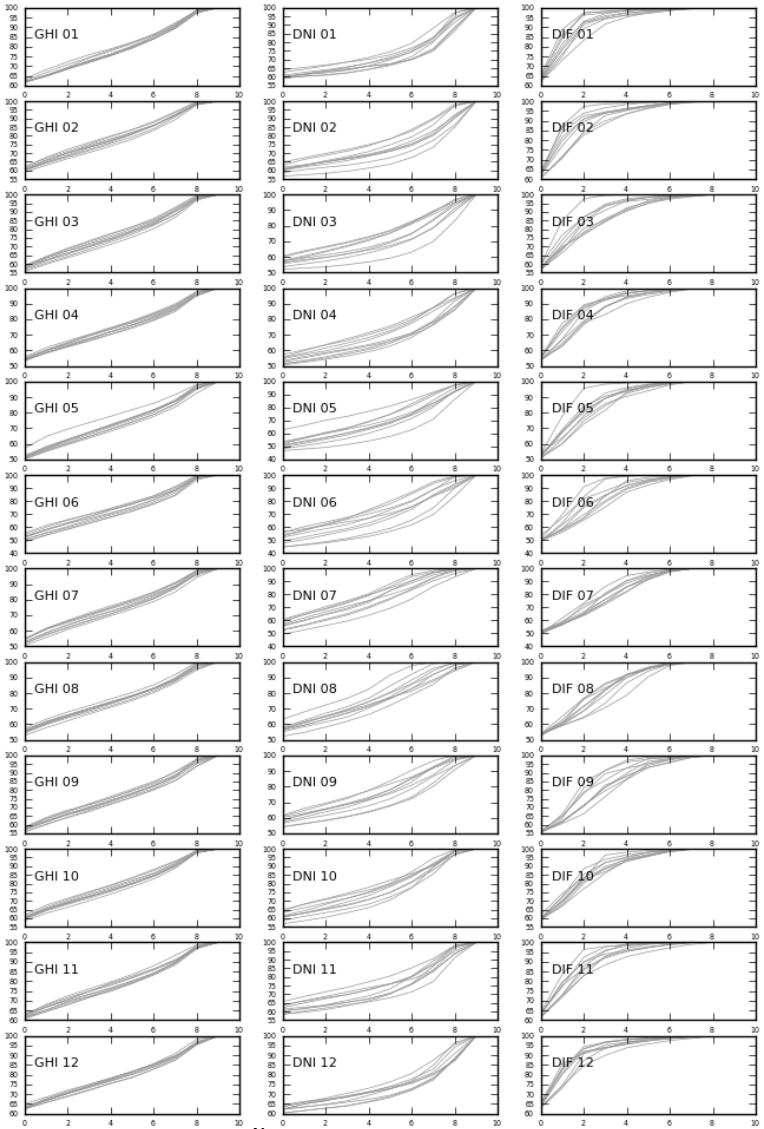
- each parameter (GHI,DNI, DIF, TEMP, …)
- monthly mean and CDF

- used to select TMY months

GHI	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	95	109	166	204	224	225	218	202	174	122	109	99
1995	108	122										
1996	83	103										
1997	85	131										
1998	99	116										
1999	100	113										
2000	109	141										
2001	100	126										
2002	104	125										
2003	88	102										
2004	101	120										
2005	105	112										
2006	84	102										
2007	103	112										
2008	102	114										
2009	81	116										
2010	90	95										
2011	99	126										
2012	108	119										

DNI	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	168	149	190	221	213	207	182	178	183	126	184	203
1995	208	190										
1996	119	131										
1997	131	205										
1998	177	164										
1999	180	165										
2000	212	230										
2001	175	189										
2002	184	191										
2003	159	137										
2004	186	173										
2005	212	178										
2006	132	124										
2007	192	154										
2008	193	152										
2009	115	165										
2010	137	107										
2011	165	207										
2012	214	186										

TEMP	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	5.9	7.3	11.6	12.2	19.1	23.8	29.1	28.1	20.4	15.8	11.8	7.3
1995	5.8	9.3	10	12.3	19.5	21	25.4	25.7	18.5	16.7	12.8	9
1996	8.3	6.1	10.2	13.5	16.6	22.1	25.3	24.6	18.7	14.9	11	8.3
1997	8	10.3	12	13.8	17.7	21.8	24	25.1	21.4	17.4	11.2	7.5
1998	7.6	9.4	12.2	12.9	15.5	23.8	27.7	27.1	22.3	15.2	10.7	6.3
1999	6.1	5.1	10.3	14.6	20.4	23.4	26.8	27	21.3	18.4	9.1	5.8
2000	4.5	9.6	12.3	13.3	18.3	24.3	27.4	27.4	21.5	13.7	10.1	8.7
2001	6.8	8.1	14	14.2	16.6	25.2	26.9	27.1	21.9	19.8	9.7	8.1
2002	7.8	9.4	11.4	12.7	17.5	25.3	24.9	24.4	21.1	17	10.7	8.3
2003	5.1	6.4	12.4	13.7	18.4	26.1	28.9	26.9	22	16.7	10.3	6.8
2004	6.8	9.6	10.2	13	14.2	23.5	26.7	26.9	22.8	18.3	9.3	6
2005	4.4	4.4	11.6	14.8	20.9	23.9	27.3	26.4	20.8	17.9	9.9	5.9
2006	4.7	6.3	11.9	16.1	20.8	23.4	28.2	25.8	21.3	18.8	12.5	6.1
2007	7.4	9.3	9.3	11.4	17.3	21.5	27.4	26.5	21.8	15.6	10.2	5.9
2008	6.9	9.5	10.9	15	16.1	22.7	27.2	27.2	21	14.8	7.5	5
2009	5.1	7.1	11.7	11.6	19.4	24.5	28.6	26.5	19.4	17.8	12.8	9
2010	7.9	10.2	11.9	15.1	16.7	21.4	28.7	27.6	22.3	15.4	10.1	8.7
2011	7.3	6.7	10.1	16.4	19.6	24.6	28.2	29.4	23.9	17.6	11.6	7.8
2012	6.8	5.1	11.8	12.9	21.4	26.8	29.2	30.5	23.9	19.2	13	8.5



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TMY - SolarGIS method (Step 3)

Differences between individual years and long- term monthly (LT)

- difference in monthly average for each year- month

$$\text{diff\_AVG}_{year,month} = \text{abs}(\text{AVG}_{year,month} - \text{AVG}_{LT\_month}) / \text{AVG}_{LT\_month}$$

- difference in CDF

$$\text{diff\_CDF}_{year,month} = \sum \text{abs}(\text{CDF}_{year,month} - \text{CDF}_{LT\_month}) / \sum (\text{CDF}_{LT\_month})$$

- calculated for each parameter

- calculated for each year, month combination

TMY - SolarGIS method (Step 3)

Differences between individual years and full time series (TS)

GHI example

Long term monthly average

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TS	97	116	166	191	217	227	228	206	170	136	99	87

time series monthly

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	95	109	166	204	224	225	218	202	174	122	109	99
1995	108	122	158	181	231	218	239	198	171	135	101	82
1996	83	103	146	173	217	210	237	213	168	150	111	78
1997	85	131	188	166	207	234	234	193	164	144	97	87
1998	99	116	169	204	207	230	233	202	169	148	107	96
1999	100	113	157	216	216	224	232	199	171	127	97	83
2000	109	141	174	201	215	222	227	209	179	134	97	84
2001	100	126	174	208	225	232	224	205	171	135	87	76
2002	104	125	166	189	218	227	241	206	175	136	99	84
2003	88	102	148	185	233	221	218	198	181	116	95	85
2004	101	120	163	197	205	233	230	204	168	135	96	84
2005	105	112	158	204	225	231	233	218	168	137	97	86
2006	84	102	182	190	204	219	223	224	174	141	99	88
2007	103	112	179	165	233	245	232	209	168	134	107	90
2008	102	114	179	207	198	236	227	215	159	120	94	87
2009	81	116	166	195	227	219	228	210	153	151	106	89
2010	90	95	152	181	221	235	205	209	170	135	106	86
2011	99	126	163	179	200	227	231	200	179	141	98	95
2012	108	119	168	189	225	219	226	209	173	138	79	92

diff = abs(94.7-97.1)/97.1 = 0.025

difference

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	0.025	0.056	0.002	0.065	0.029	0.009	0.045	0.020	0.024	0.102	0.100	0.135
1995	0.115	0.055	0.049	0.055	0.064	0.041	0.046	0.038	0.006	0.005	0.019	0.055
1996	0.150	0.108	0.123	0.097	0.002	0.073	0.037	0.032	0.014	0.105	0.120	0.104
1997	0.130	0.127	0.130	0.132	0.046	0.030	0.026	0.065	0.040	0.062	0.021	0.006
1998	0.024	0.002	0.018	0.069	0.047	0.016	0.021	0.023	0.005	0.088	0.080	0.103
1999	0.034	0.028	0.054	0.132	0.006	0.011	0.018	0.038	0.004	0.068	0.016	0.043
2000	0.125	0.215	0.049	0.050	0.009	0.021	0.007	0.011	0.050	0.013	0.020	0.032
2001	0.033	0.085	0.047	0.087	0.034	0.022	0.021	0.005	0.006	0.004	0.124	0.127
2002	0.068	0.082	0.001	0.012	0.001	0.002	0.056	0.003	0.029	0.003	0.000	0.028
2003	0.090	0.123	0.110	0.033	0.071	0.025	0.045	0.038	0.063	0.147	0.037	0.026
2004	0.043	0.032	0.017	0.031	0.058	0.028	0.008	0.012	0.011	0.008	0.034	0.033
2005	0.083	0.030	0.048	0.069	0.035	0.021	0.021	0.054	0.016	0.012	0.022	0.007
2006	0.140	0.117	0.096	0.007	0.062	0.034	0.025	0.083	0.022	0.039	0.002	0.008
2007	0.062	0.035	0.077	0.140	0.070	0.079	0.018	0.011	0.012	0.010	0.080	0.031
2008	0.046	0.014	0.077	0.082	0.090	0.041	0.006	0.040	0.065	0.113	0.046	0.002
2009	0.163	0.001	0.001	0.021	0.046	0.033	0.003	0.016	0.100	0.115	0.067	0.030
2010	0.074	0.182	0.084	0.053	0.015	0.037	0.101	0.013	0.004	0.004	0.071	0.014
2011	0.018	0.084	0.017	0.063	0.080	0.003	0.010	0.029	0.049	0.035	0.011	0.099
2012	0.116	0.029	0.014	0.012	0.036	0.034	0.011	0.014	0.018	0.016	0.197	0.065

TMY - SolarGIS method (Step 4)

Integrated similarity index

integrate differences of AVG and CDF – use weights
- for each parameter individually

$$score_{year,month,param} = diff\_AVG_{year,month,param} * weight\_AVG + diff\_CDF_{year,month,param} * weight\_CDF$$

weight_AVG ≈ 0.8 weight_CDF ≈ 0.2

integrate all parameters – use parameter weights

$$total\_score_{month,param} = \sum score_{year,month,param}$$

Indicative weights of parameters

	PV	CSP
DNI	-	0.70
GHI	0.70	0.23
DIF	0.25	0.03
TEMP	0.05	0.04

GeoModel SOLAR

TMY - SolarGIS method (Step 4)

Integrated similarity index

partial diff_AVG, diff_CDF

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	0.025	0.056	0.002	0.065	0.029	0.009	0.045	0.020	0.024	0.102	0.100	0.135
1995	0.115	0.055	0.049	0.055	0.064	0.041	0.046	0.038	0.006	0.005	0.019	0.055
1996	0.150	0.108	0.123	0.097	0.002	0.073	0.037	0.032	0.014	0.105	0.120	0.104
1997	0.130	0.127	0.130	0.132	0.046	0.030	0.026	0.065	0.040	0.062	0.021	0.006
1998	0.024	0.002	0.018	0.069	0.047	0.016	0.021	0.023	0.005	0.088	0.080	0.103
1999	0.034	0.028	0.054	0.132	0.006	0.011	0.018	0.038	0.004	0.068	0.016	0.043
2000	0.125	0.215	0.049	0.050	0.009	0.021	0.007	0.011	0.050	0.013	0.020	0.032
2001	0.033	0.085	0.047	0.087	0.034	0.022	0.021	0.005	0.006	0.004	0.124	0.127
2002	0.068	0.082	0.001	0.012	0.001	0.002	0.056	0.003	0.029	0.003	0.000	0.028
2003	0.090	0.123	0.110	0.033	0.071	0.025	0.045	0.038	0.063	0.147	0.037	0.026
2004	0.043	0.032	0.017	0.031	0.058	0.028	0.008	0.012	0.011	0.008	0.034	0.033
2005	0.083	0.030	0.048	0.069	0.035	0.021	0.021	0.054	0.016	0.012	0.022	0.007
2006	0.140	0.117	0.096	0.007	0.062	0.034	0.025	0.083	0.022	0.039	0.002	0.008
2007	0.062	0.035	0.077	0.140	0.070	0.079	0.018	0.011	0.012	0.010	0.080	0.031
2008	0.046	0.014	0.077	0.082	0.090	0.041	0.006	0.040	0.065	0.113	0.046	0.002
2009	0.163	0.001	0.001	0.021	0.046	0.033	0.003	0.016	0.100	0.115	0.067	0.030
2010	0.074	0.182	0.084	0.053	0.015	0.037	0.101	0.013	0.004	0.004	0.071	0.014
2011	0.018	0.084	0.017	0.063	0.080	0.003	0.010	0.029	0.049	0.035	0.011	0.099
2012	0.116	0.029	0.014	0.012	0.036	0.034	0.011	0.014	0.018	0.016	0.197	0.065

Integrated similarity (difference) index

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	0.024	0.074	0.006	0.080	0.033	0.015	0.059	0.035	0.026	0.141	0.129	0.180
1995	0.145	0.078	0.058	0.072	0.073	0.057	0.059	0.051	0.006	0.015	0.024	0.081
1996	0.197	0.141	0.158	0.116	0.014	0.094	0.045	0.033	0.014	0.133	0.152	0.127
1997	0.161	0.154	0.174	0.166	0.047	0.039	0.033	0.077	0.050	0.073	0.046	0.008
1998	0.026	0.009	0.038	0.087	0.067	0.017	0.030	0.030	0.025	0.115	0.102	0.129
1999	0.038	0.025	0.072	0.167	0.004	0.019	0.021	0.062	0.006	0.097	0.020	0.047
2000	0.158	0.262	0.057	0.049	0.016	0.030	0.009	0.012	0.057	0.014	0.034	0.043
2001	0.029	0.096	0.050	0.112	0.046	0.024	0.028	0.007	0.014	0.013	0.147	0.151
2002	0.069	0.098	0.006	0.020	0.002	0.013	0.074	0.007	0.027	0.004	0.007	0.046
2003	0.084	0.141	0.134	0.029	0.117	0.049	0.064	0.033	0.084	0.189	0.035	0.022
2004	0.056	0.031	0.029	0.058	0.076	0.049	0.018	0.012	0.019	0.027	0.041	0.042
2005	0.129	0.039	0.086	0.082	0.028	0.039	0.031	0.082	0.020	0.012	0.023	0.013
2006	0.167	0.161	0.154	0.031	0.093	0.060	0.035	0.126	0.037	0.041	0.012	0.010
2007	0.079	0.050	0.127	0.172	0.124	0.135	0.039	0.014	0.022	0.028	0.085	0.047
2008	0.070	0.039	0.122	0.118	0.120	0.055	0.020	0.053	0.075	0.155	0.049	0.009
2009	0.213	0.006	0.017	0.039	0.049	0.032	0.011	0.023	0.133	0.195	0.092	0.034
2010	0.112	0.237	0.132	0.098	0.026	0.057	0.126	0.012	0.008	0.023	0.103	0.045
2011	0.024	0.128	0.031	0.087	0.107	0.013	0.015	0.061	0.062	0.057	0.015	0.124
2012	0.156	0.052	0.010	0.018	0.049	0.066	0.031	0.013	0.037	0.030	0.234	0.101

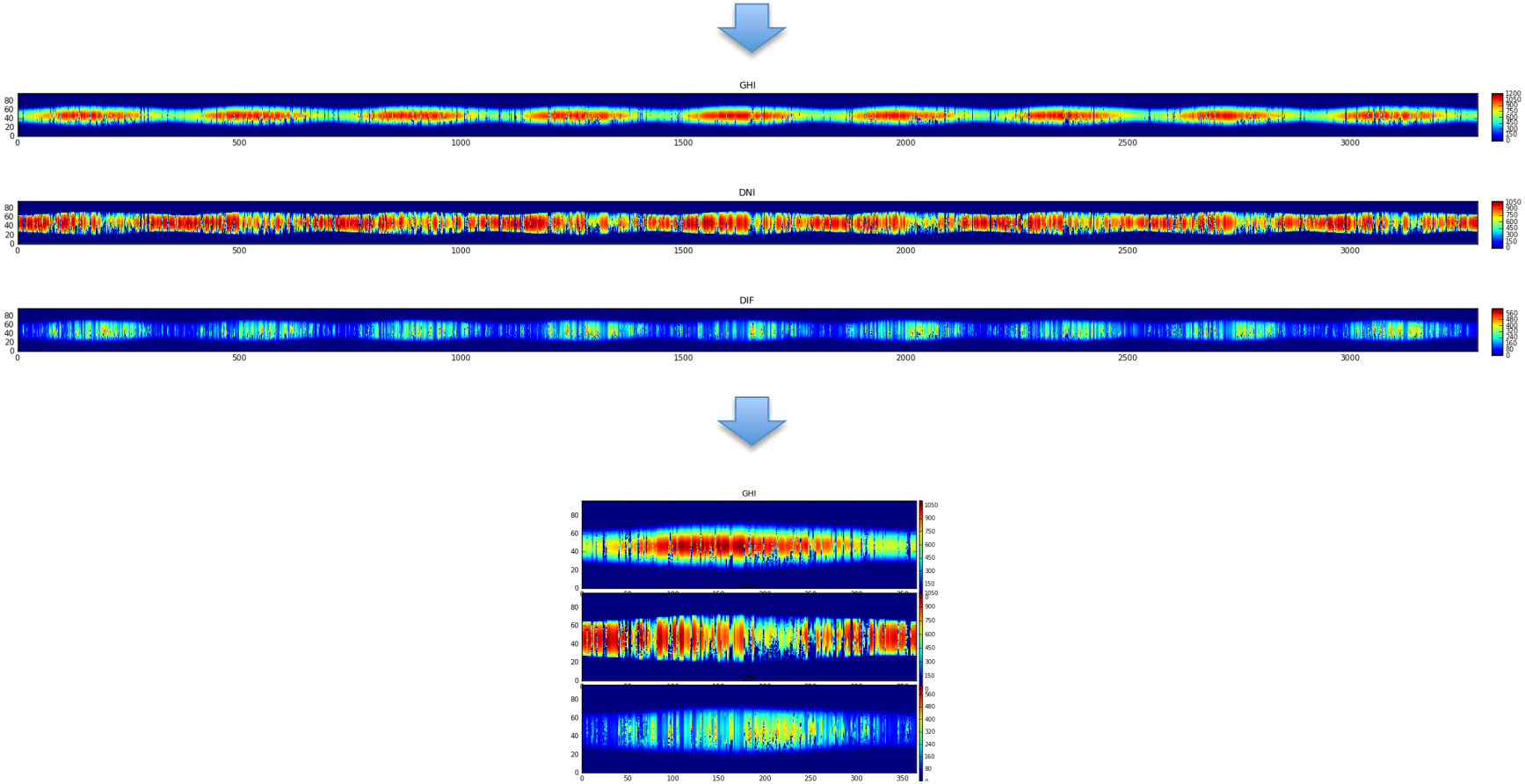
- output one matrix with one index calculated for each month, year
- Selection of months with minimum index

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMY	2011	2009	2002	2012	2002	2011	2000	2001	1999	2002	2006	2008

TMY - SolarGIS method (Step 5)

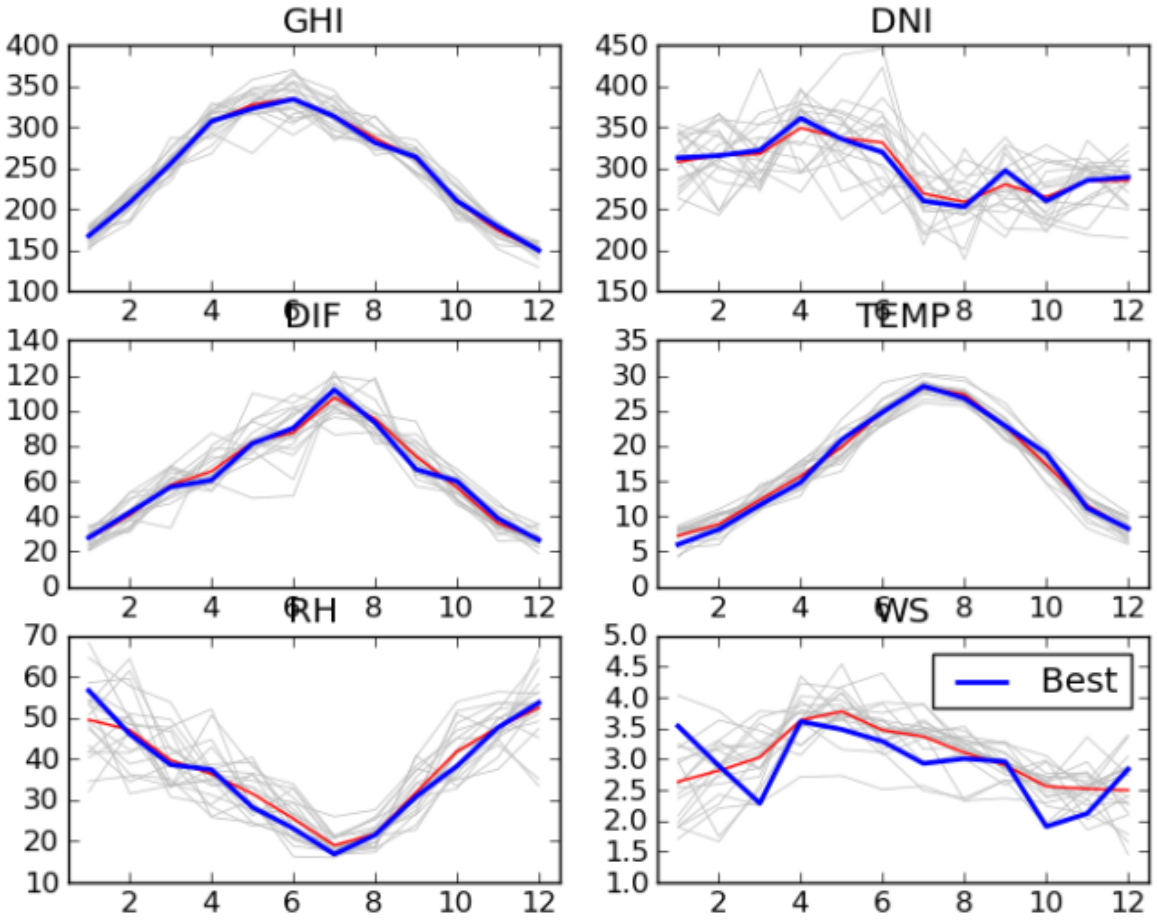
AssembleTMY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMY	2011	2009	2002	2012	2002	2011	2000	2001	1999	2002	2006	2008



GeoModel SOLAR

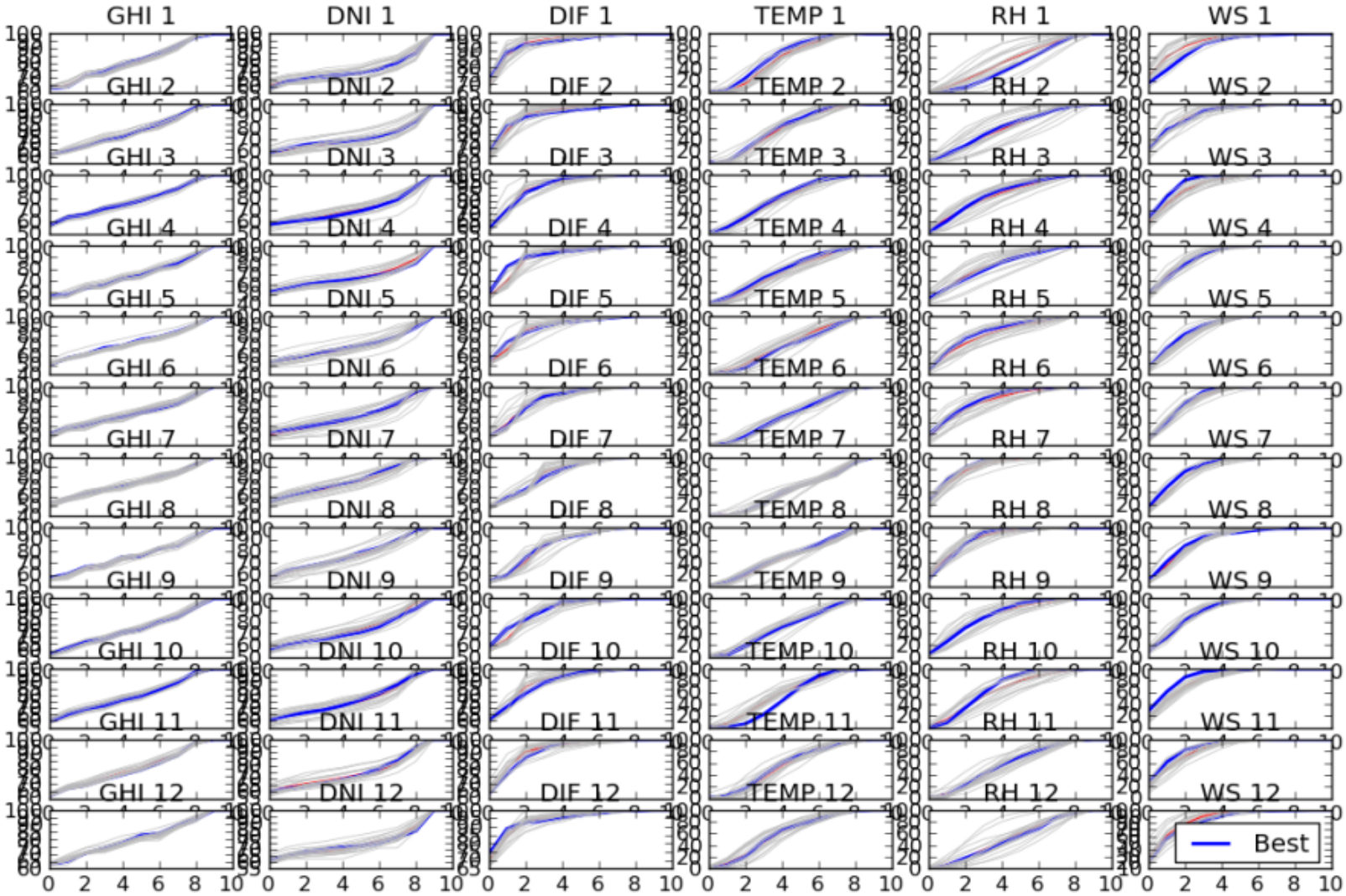
TMY: comparison of monthly means



long-term monthly
TMY monthly

GeoModel SOLAR

TMY – comparison of cumulative distribution of values



long-term monthly

TMY monthly

GeoModel SOLAR

Bankable TMY

Financial institutions require a risk assessment described by the probability exceedance at 90% confidentiality (P90) - **uncertainty**:

1. Uncertainty of the **estimate**
    - Uncertainty of the satellite-based solar model
    - *Uncertainty of the ground instruments (if site adaptation applied)*

2. Uncertainty from **interannual variability**
    - Considering any single year

GHI 1 year	Uncertainty [%]	Cumulative uncertainty [%]	Annual GHI [kWh/m^2]
Annual average, P50			**1941**
Minimum annual GHI at P90, assuming uncertainty of the estimate	±3.0	±3.0	**1883**
Minimum annual GHI at P90, assuming uncertainty of the interannual variability for one year	±2.2	±3.7	**1869**

GeoModel SOLAR

Bankable TMY

- **P50 TMY** data set represents, for each month, the average climate conditions and the most representative cumulative distribution function; extreme weather situations are missing.
- **P90 TMY** data set represents a year with the "low or conservative" solar resource – annual DNI and GHI after summarization results in the value close to P(90).

TMY - SolarGIS method P90

Step 1: Derive P90 GHI and DNI values

Both components of uncertainty are calculated considering 90% probability of exceedance, P90:

- **Uncertainty of the estimate** is asessed from typical accuracy statistics (bias) of SolarGIS, which is given by underlying input data and numerical models and their performance in the particular climate and geography.
- **Uncertainty from interannual variability** is caluclated from standard deviation of X years:

$$\mathrm{var}_n = \frac{stdev}{\sqrt{n}}$$

$$Uncert = 1.28155 * var_n$$

GeoModel SOLAR

TMY - SolarGIS method P90

Step2: TMY construction

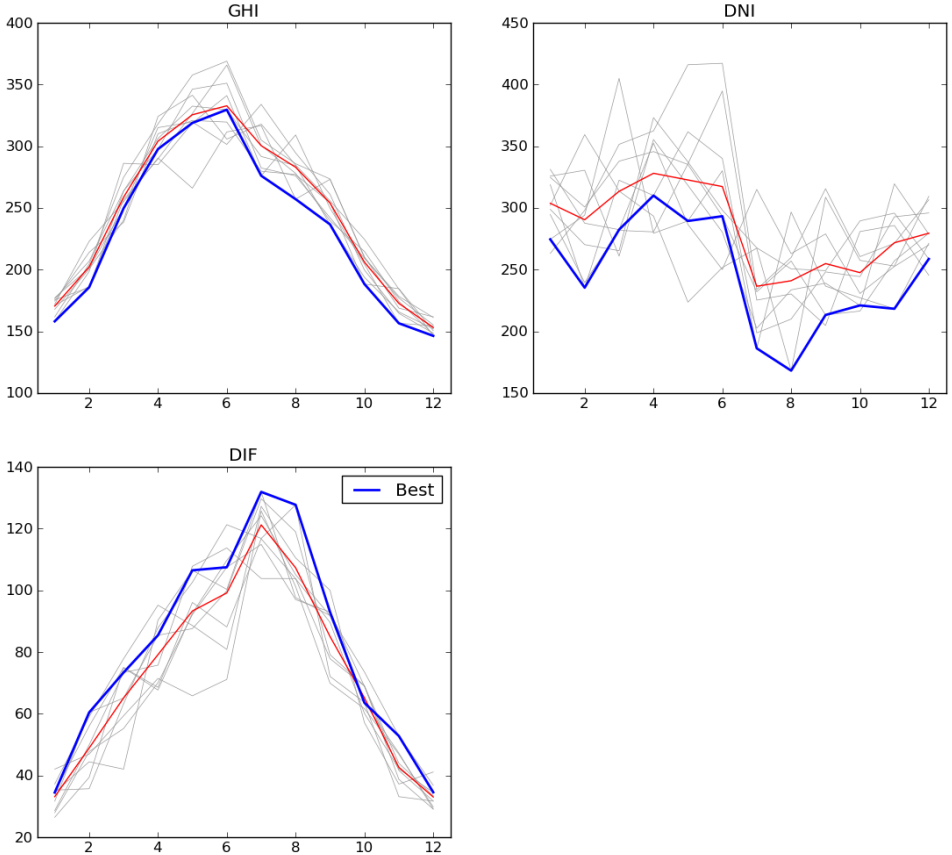
Searching data for combination of 12 months for TMY P90:

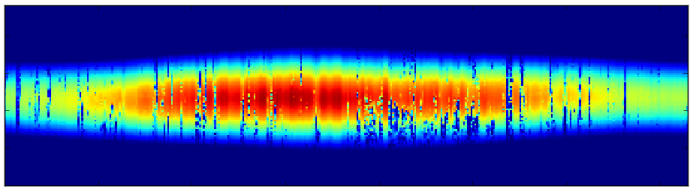
- Initial TMY – concatenate lowest monthly values
- Iterate through data to find months to minimize TMY annual average and P90 value

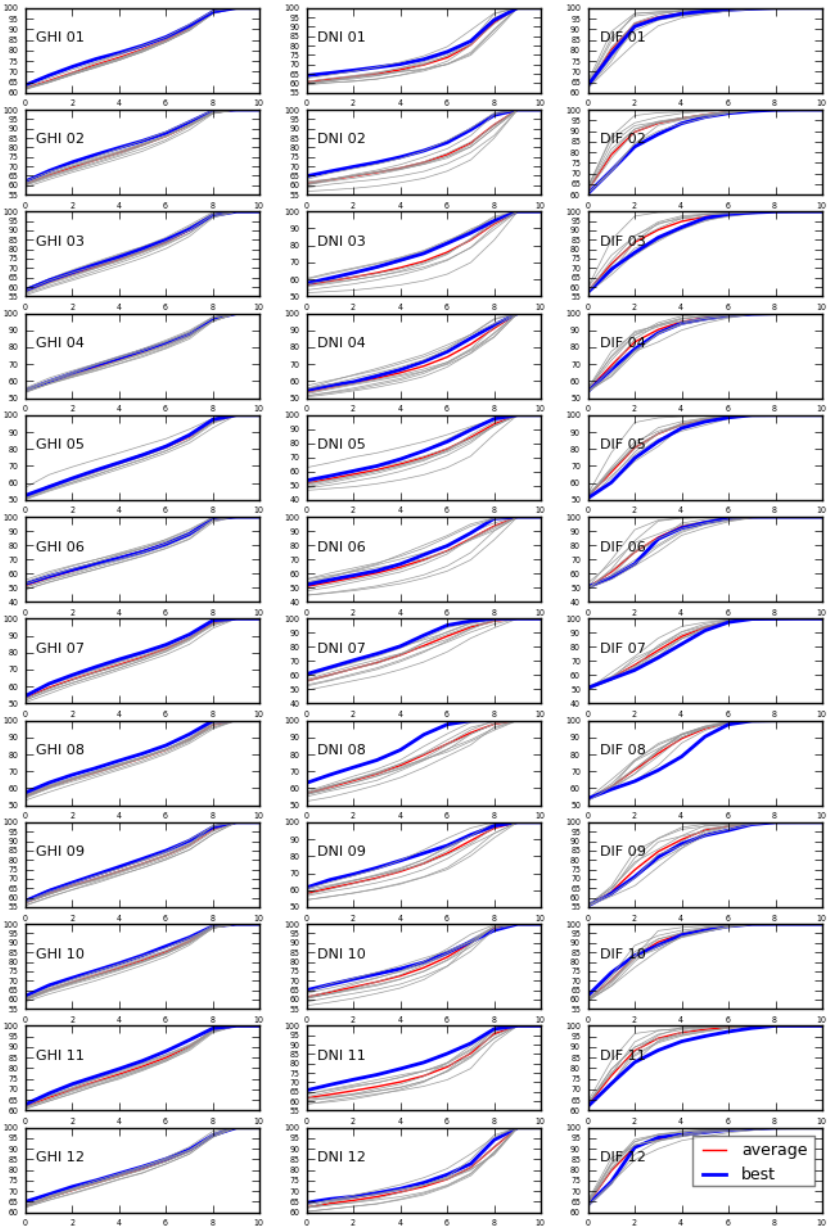
GeoModel SOLAR

TMY - SolarGIS method P90

Assemble TMY P90







GeoModel SOLAR

Conclusions

Good TMY:

- must reflect needs of application
- based on high quality time series data
- preserve monthly averages and distribution of values
- maintain consistency of all parameters
- expert controlled – to adapt controlling parameters to specific local conditions

TMY:

- **always reduces original information content of full time series**
- **simulation will only reflect situations which were extracted during TMY construction**

Typical Meteorological Year (TMY)

http://geomodelsolar.eu/data/typical-meteorological-year

TomasCebecauer

Marcel Suri

GeoModel Solar

GeoModel SOLAR