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Energy & Extractives

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ARMENIA RENEWABLE RESOURCES AND ENERGY EFFICIENCY FUND

Final Meeting

Yerevan. June 2017

Task 4: Production of Validated Solar Atlas

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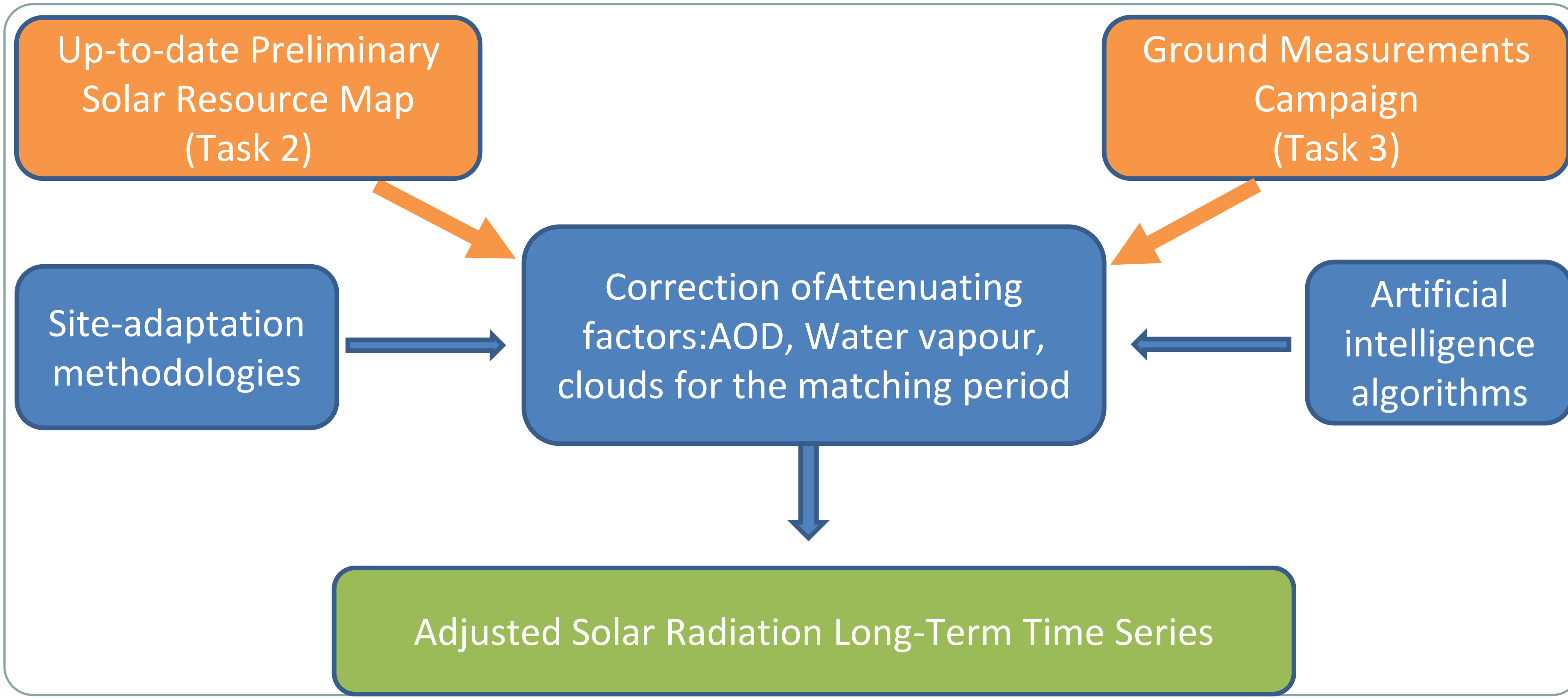
1 Data correction

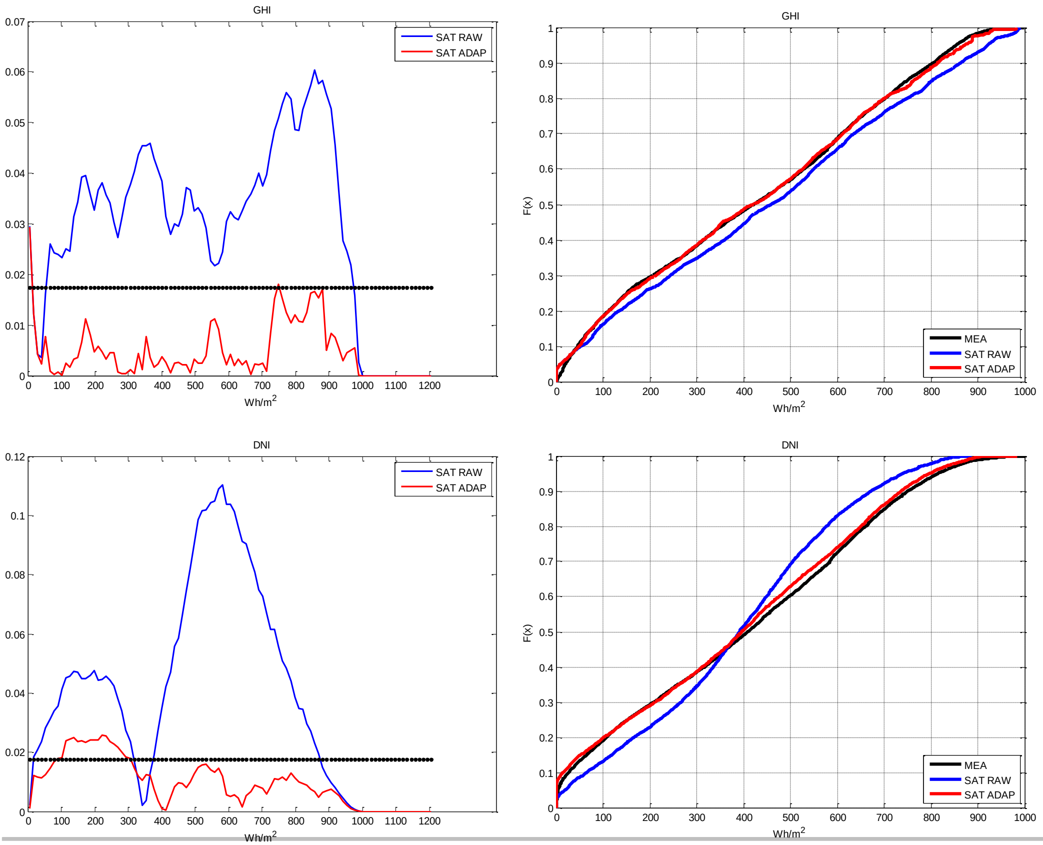
1. Data correction

Solar Map correction



2. The Project. Task 4: Validated Solar Atlas

Solar Map adjustment



Results of the adjustment

- Removal of systematic differences between satellite estimations and ground measurements for different atmospheric, seasonal, illumination conditions for:
  - **Absolute values**
  - **Frequency distribution**

Two main issues for satellites, characteristic of Armenia:

- Aerosols
- Snow

1. Data correction

Solar Map correction: characteristics

- **Site adaptation for an extended region**
- **Statistical climatology is reproduced by long-term satellite estimations and model reanalysis**
- **Annual measurement of select locations allows for fine tunning of the long-term information, essentially by reducing the systematic errors (bias)**
- **Annual measurement are only a sample of the long-term**
- **Long-term tendences and fine adjustment should be spatialy propagated in a proper way**

1. Data correction

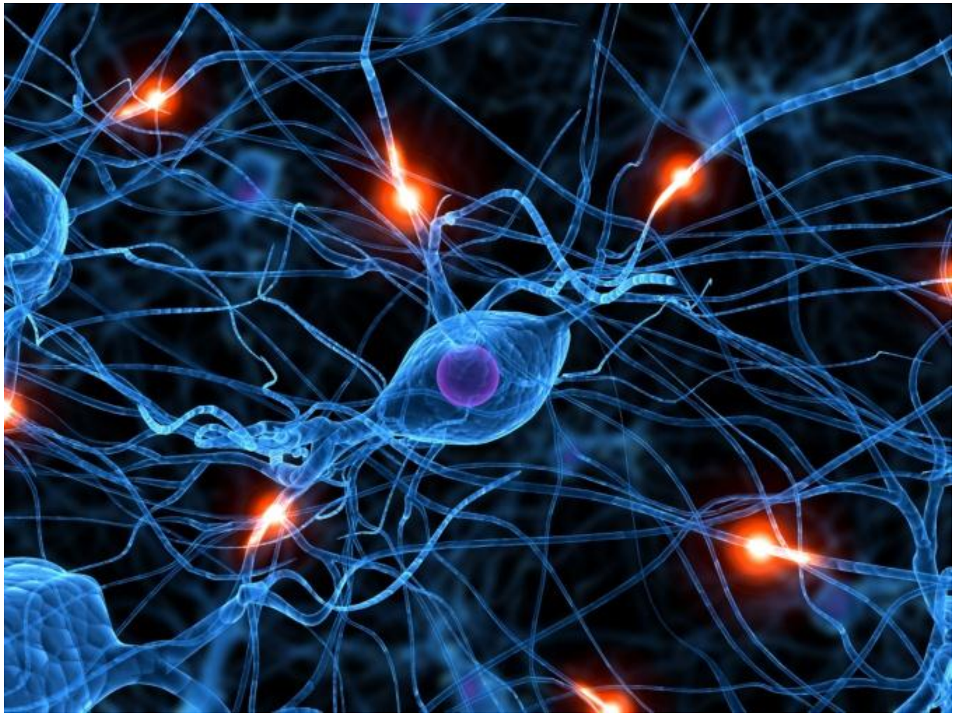
Representative sites

Initial study for optimizing station locations:

- D7. Candidate site identification report (clustering)
- D11. Advice on site selection report

1. Data correction

Methodology

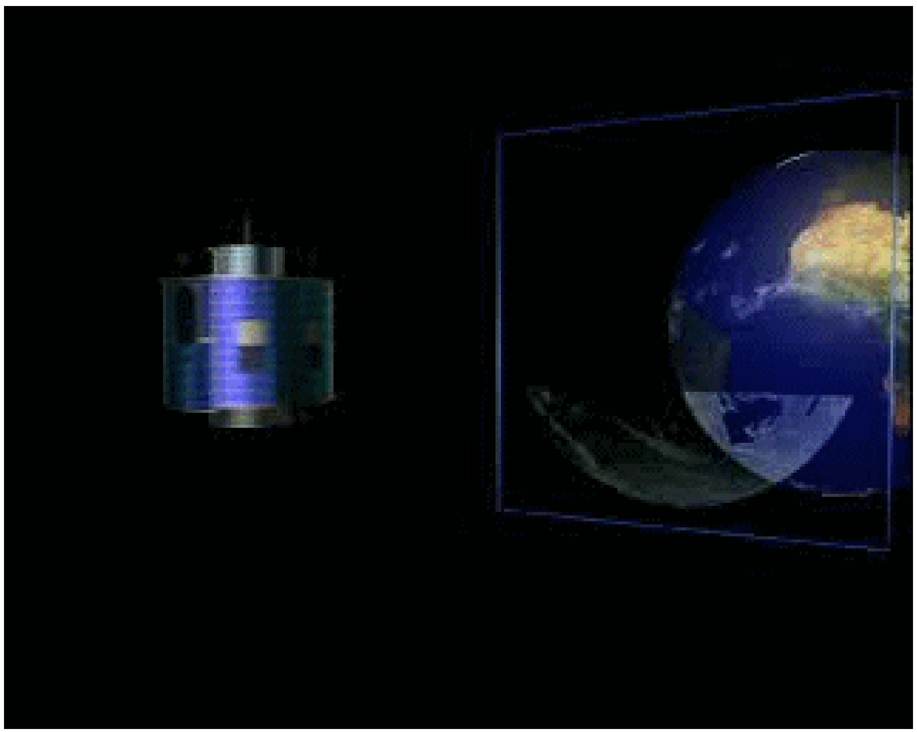


Method based on artificial intelligence technics

- Gradient boosting regressor
- Neural networks
- Genetic algorithms

1. Data correction

Methodology

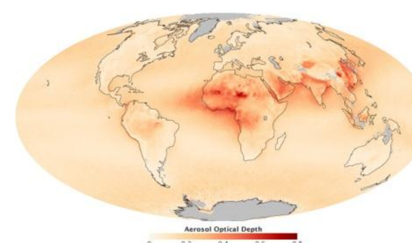


Allows for coherent integration of different sources of information: satellite irradiances, aersols, meteo variables, topographic characteristics, etc.

ECMWF

NASA

macc
Monitoring atmospheric composition & climate – II



1. Data correction

Model validation

- **Model has been evaluateded against the 5 radiometric stations along the complete year period**
- **The comparison has been made in different time ranges: from 1h to yearly-basis**
- **The data before and after the correction are also compared**
- **Additionally, external sources of information has been used as reference values for comparison purposes**
- **The period is extended to 11 years for benchmarking with other sources (due to data availability)**
- **Results differe from GHI and DNI.**

1. Data correction

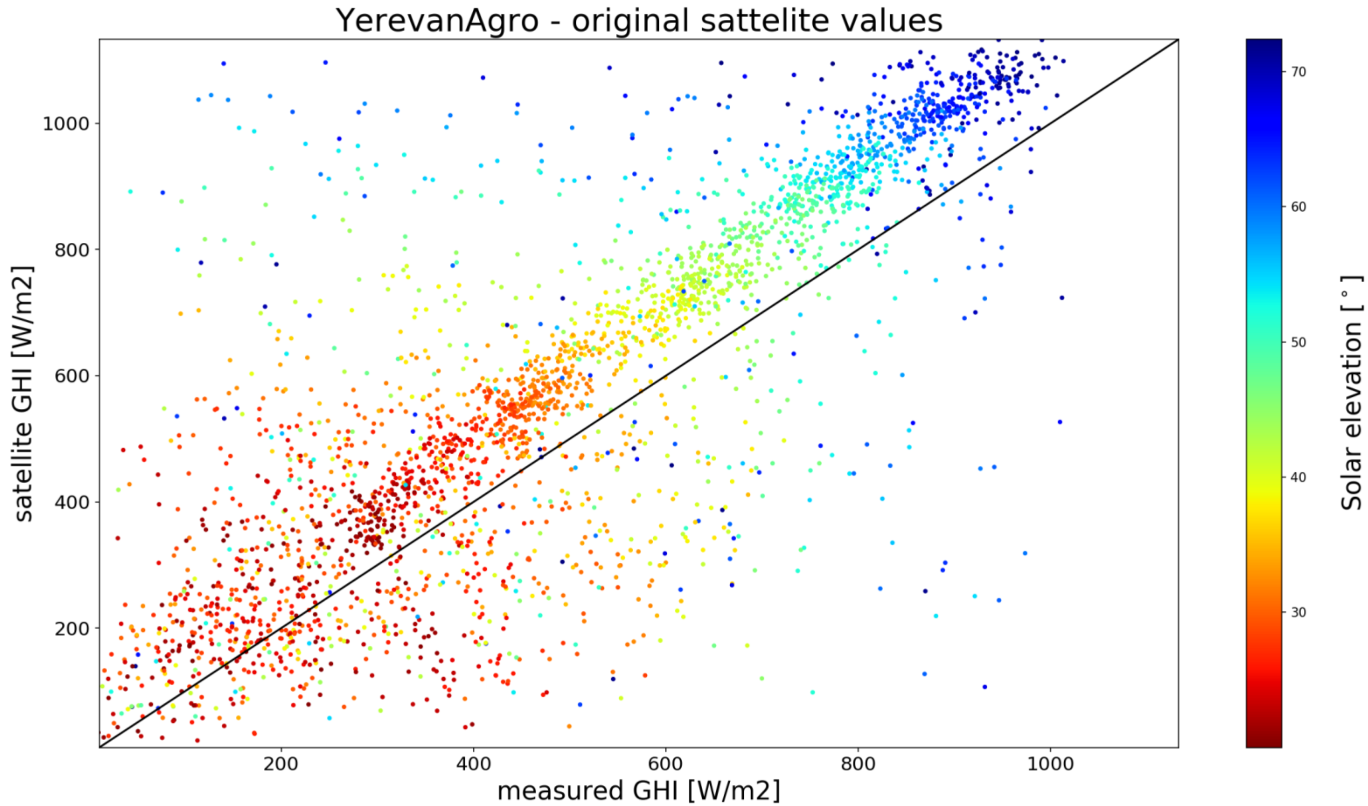
Model validation

Main results:

- Armenia presents a challenge for satellites to estimate reliably solar irradiance. This could be partially explained by aerosols and snow
- DNI is estimated worst, with extremelly high error values for all the sources analyzed
- GHI is estimated reasonably well, after correction
- Methodology correction improves significantly the initial results
- Long-term and average monthly and yearly values are estimated with reasonable accuracy

1. Data correction

Model validation



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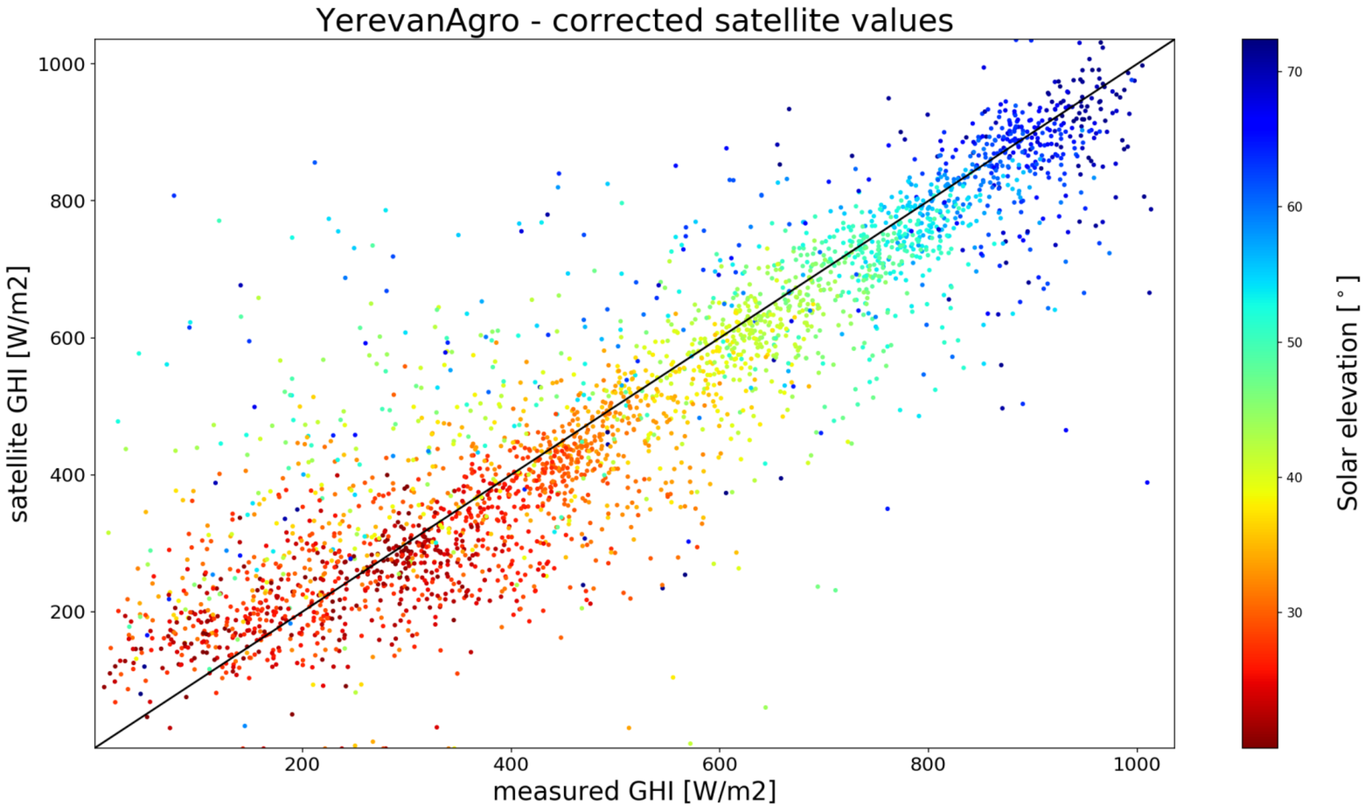
Model validation



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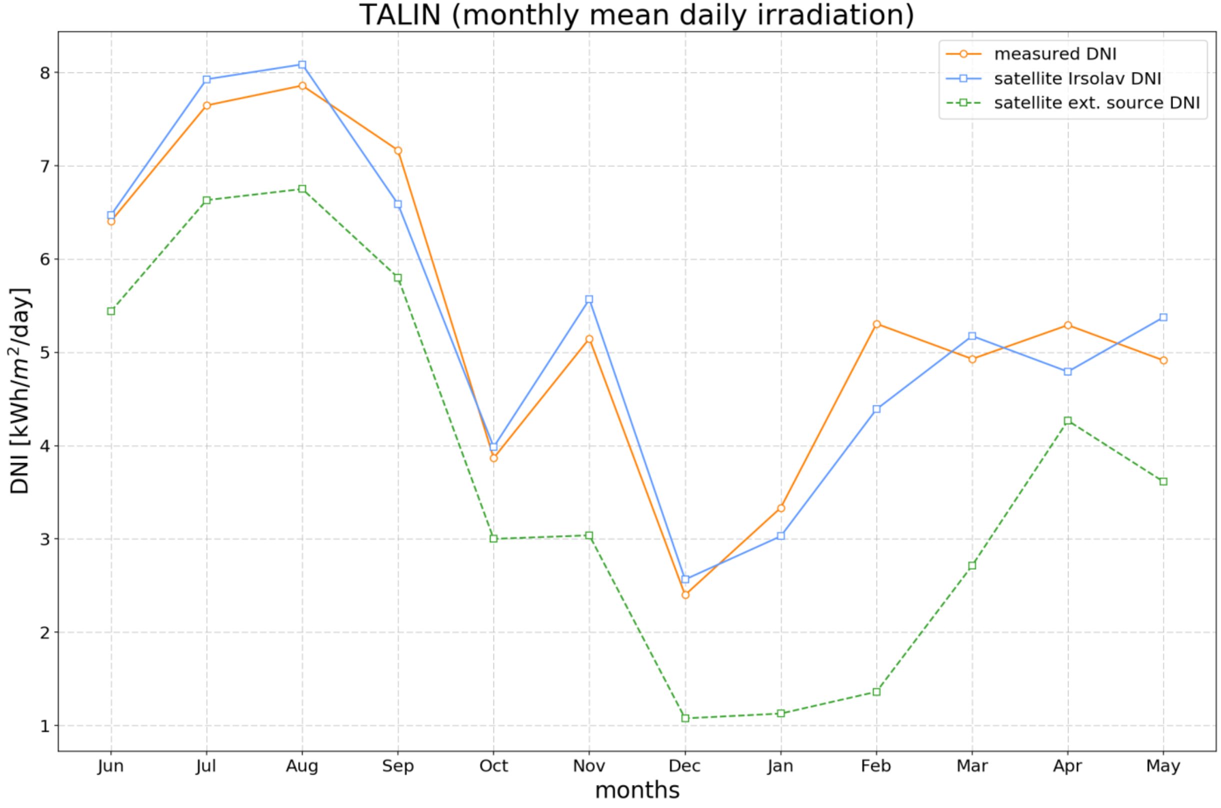

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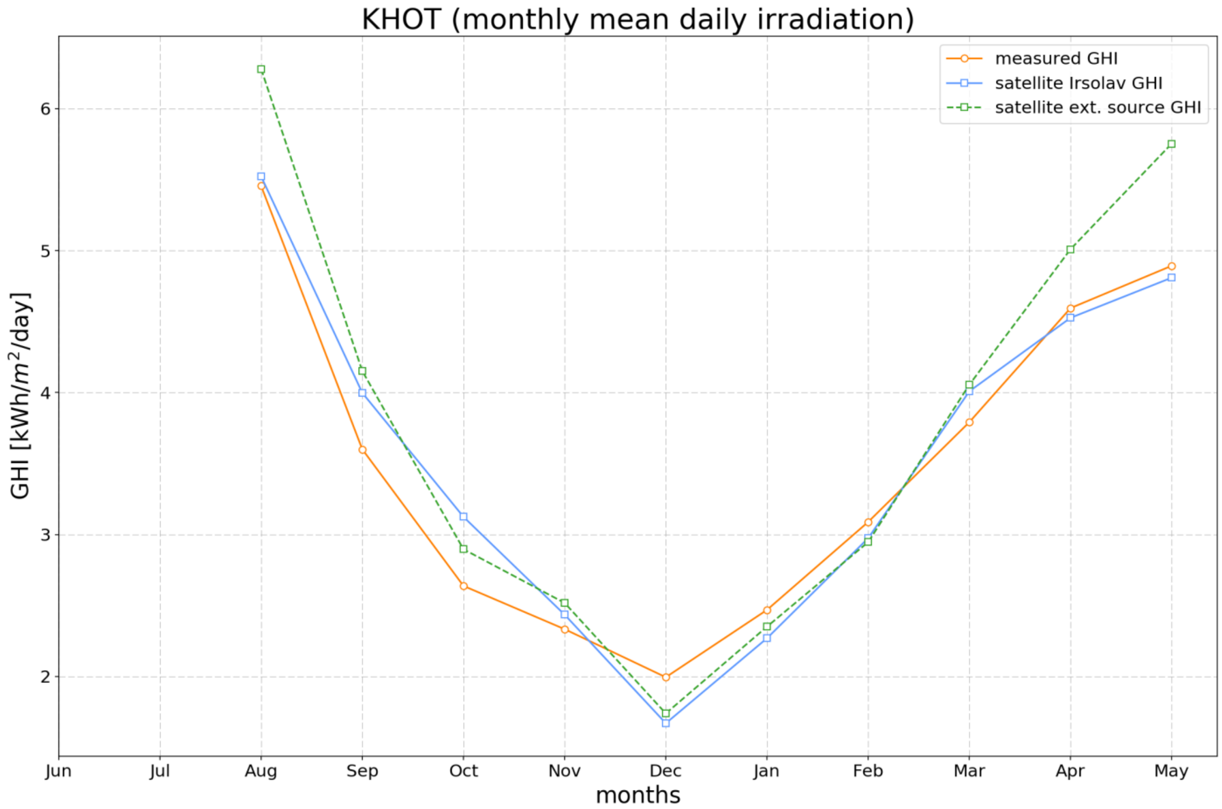
1. Data correction

Model validation



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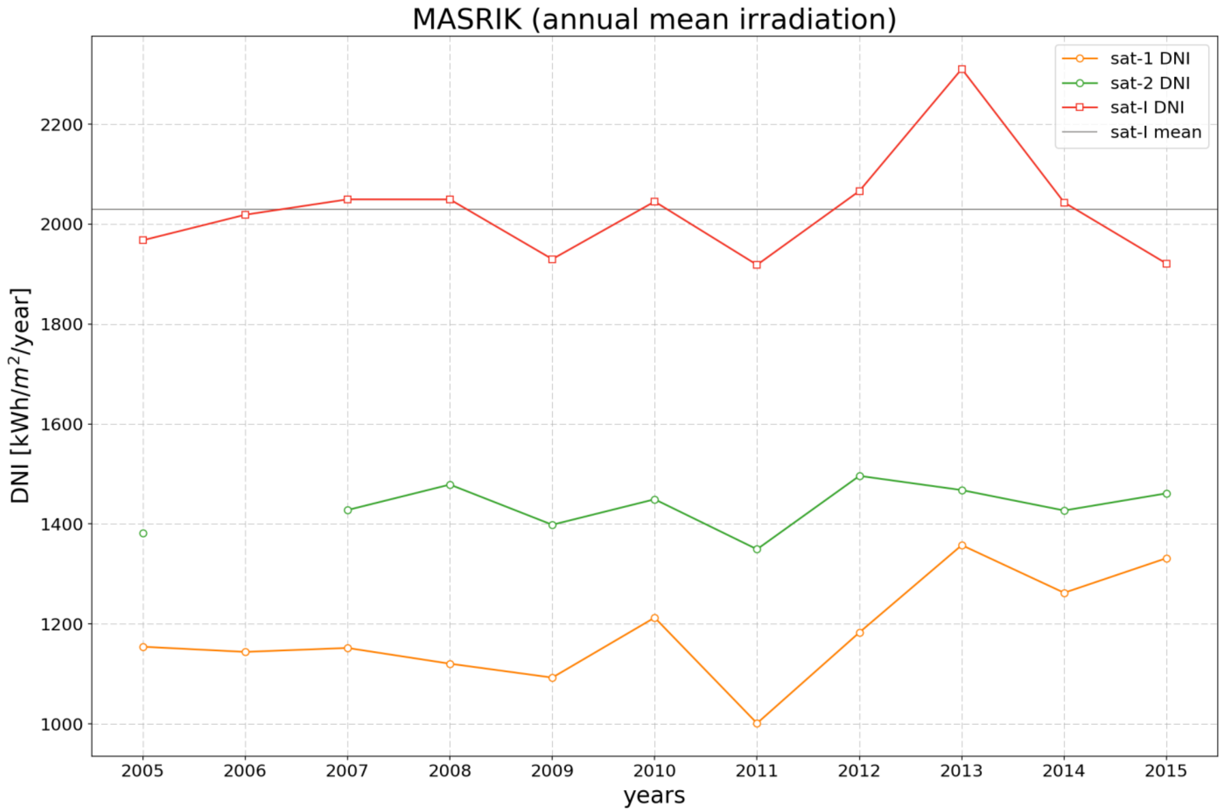
1. Data correction

Model validation



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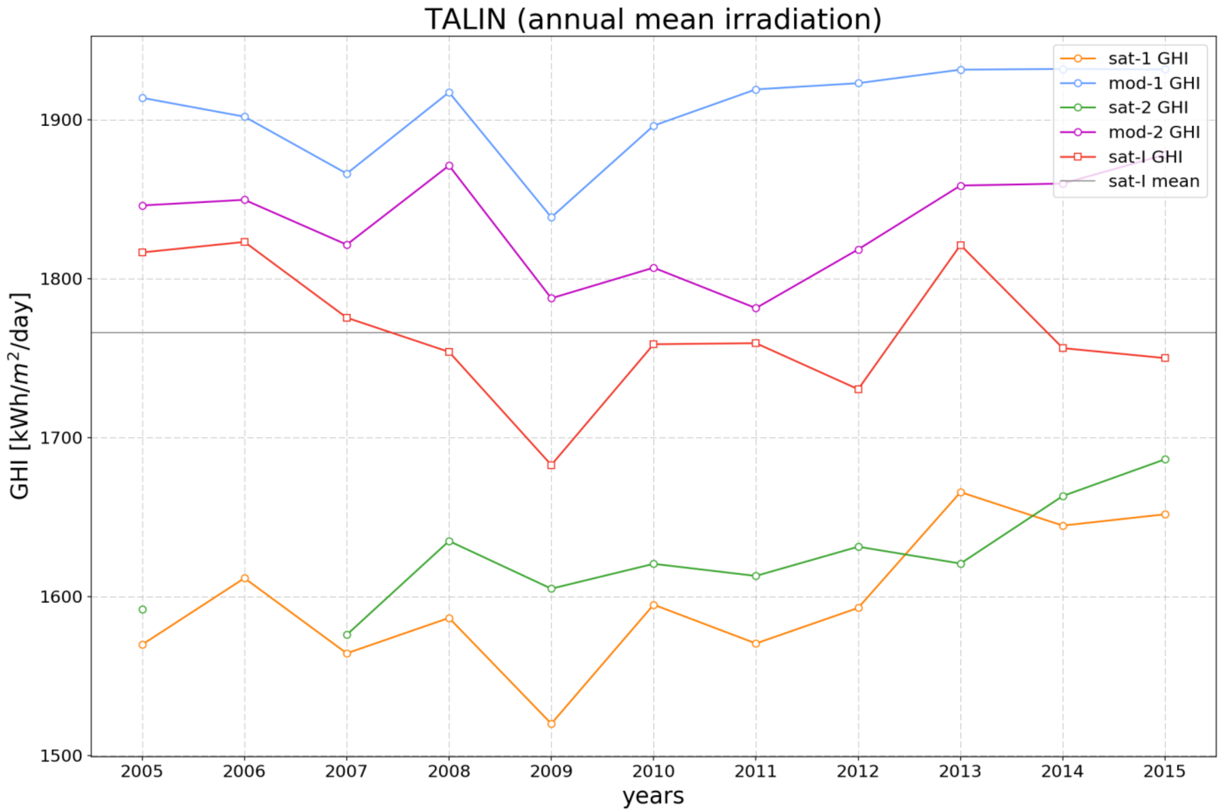

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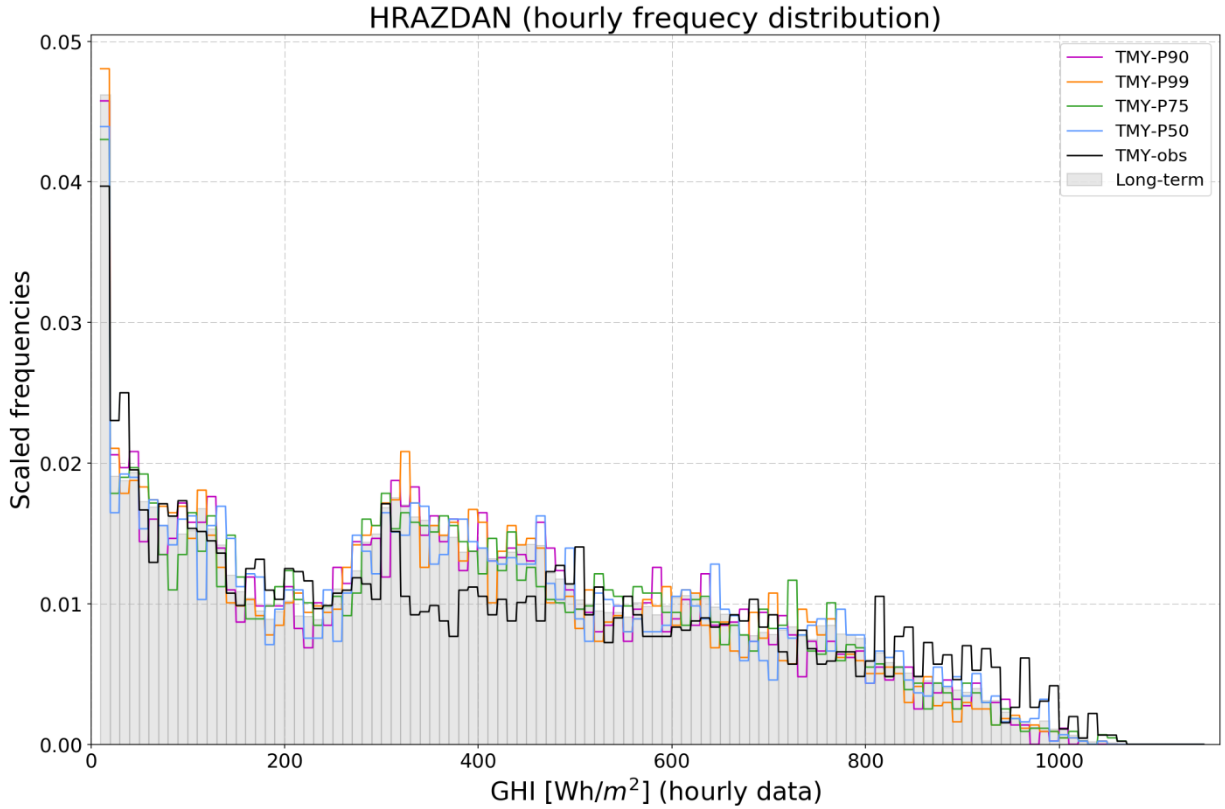

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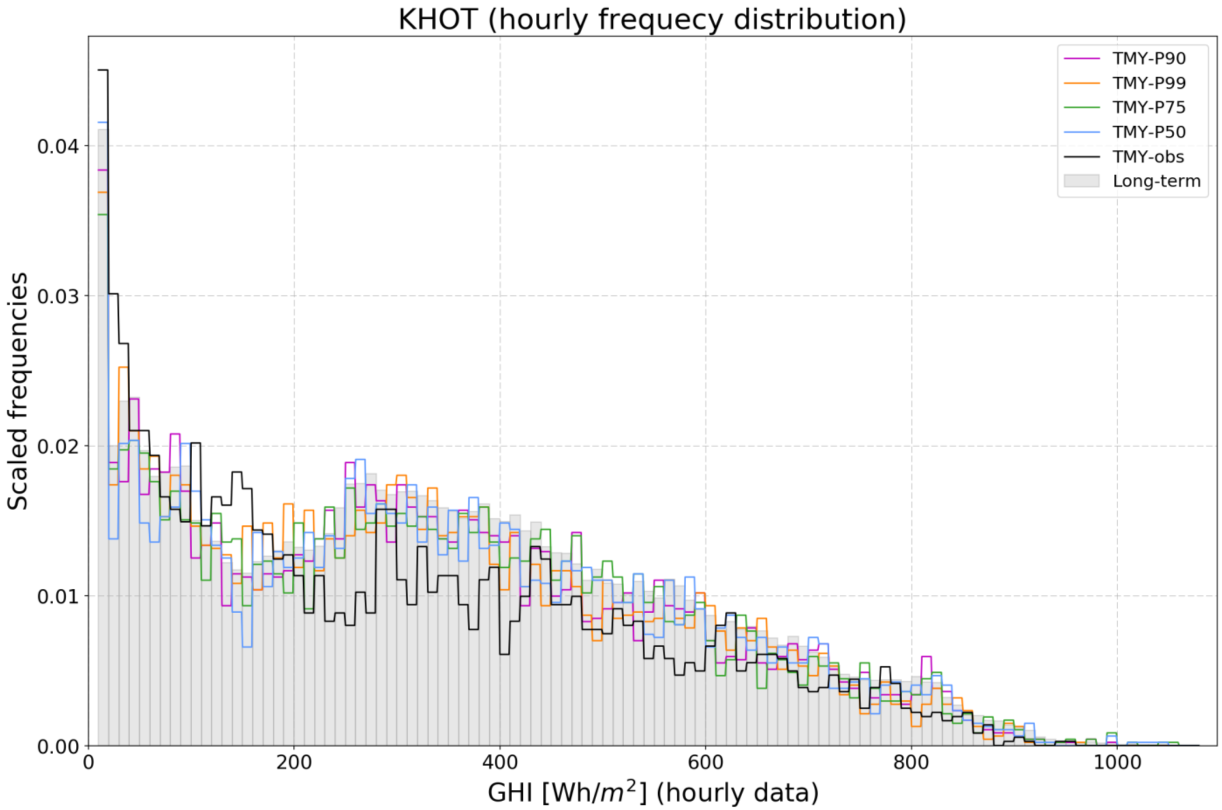
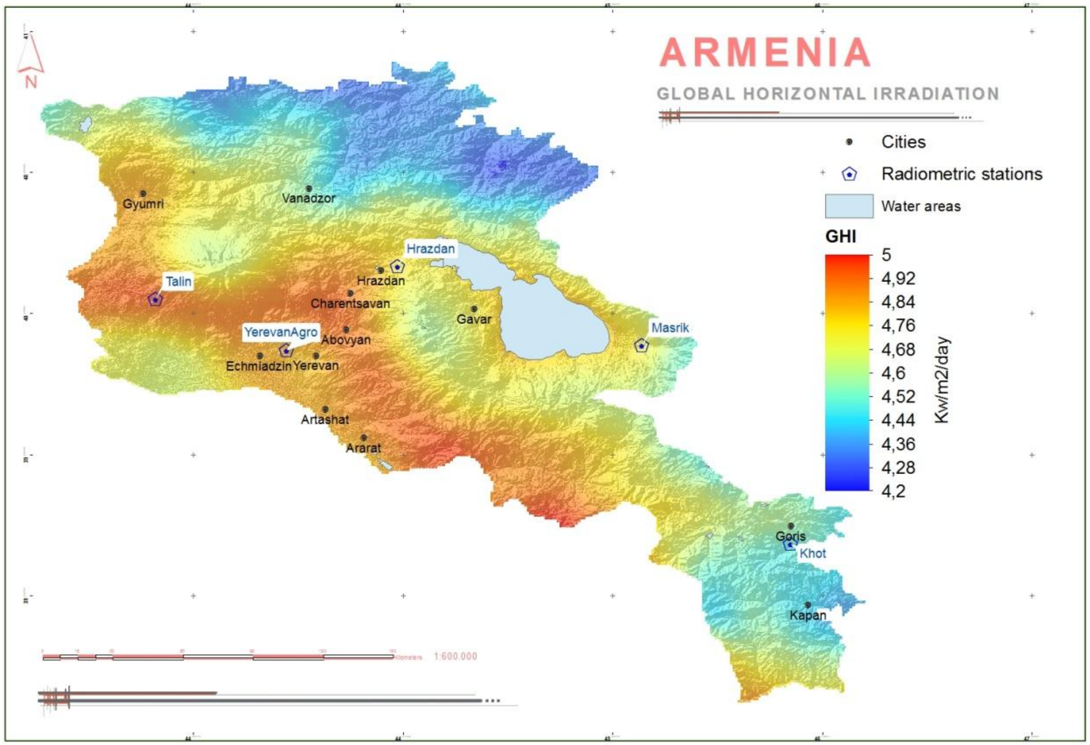
Model validation



2 Solar Atlas

2. Solar Atlas

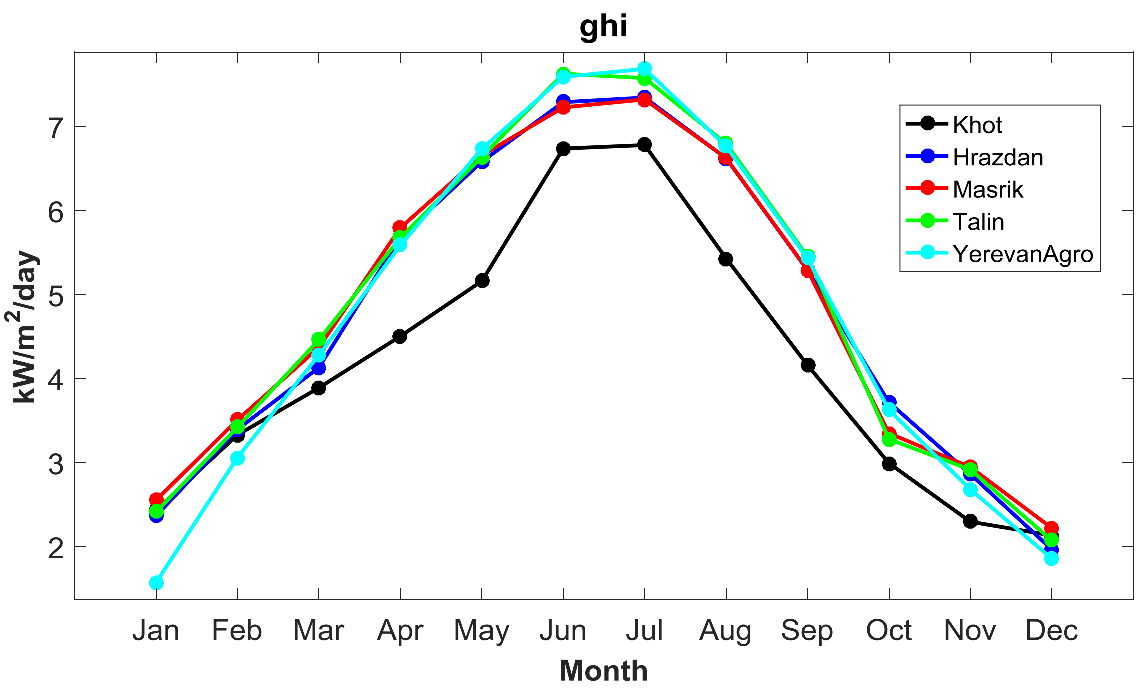
GHI



- Mean Yearly Values
  - 2000-2016 period.
- Highest:
  - 5 kW/m²/day
  - 1800kW/m²/year
- Belt rounding south face of Aragats mount
- Between provinces of Aragats and Kotayk
- the Ararat valley
- Vayots Dzor
- Lake Sevan

2. Solar Atlas

GHI: representative sites

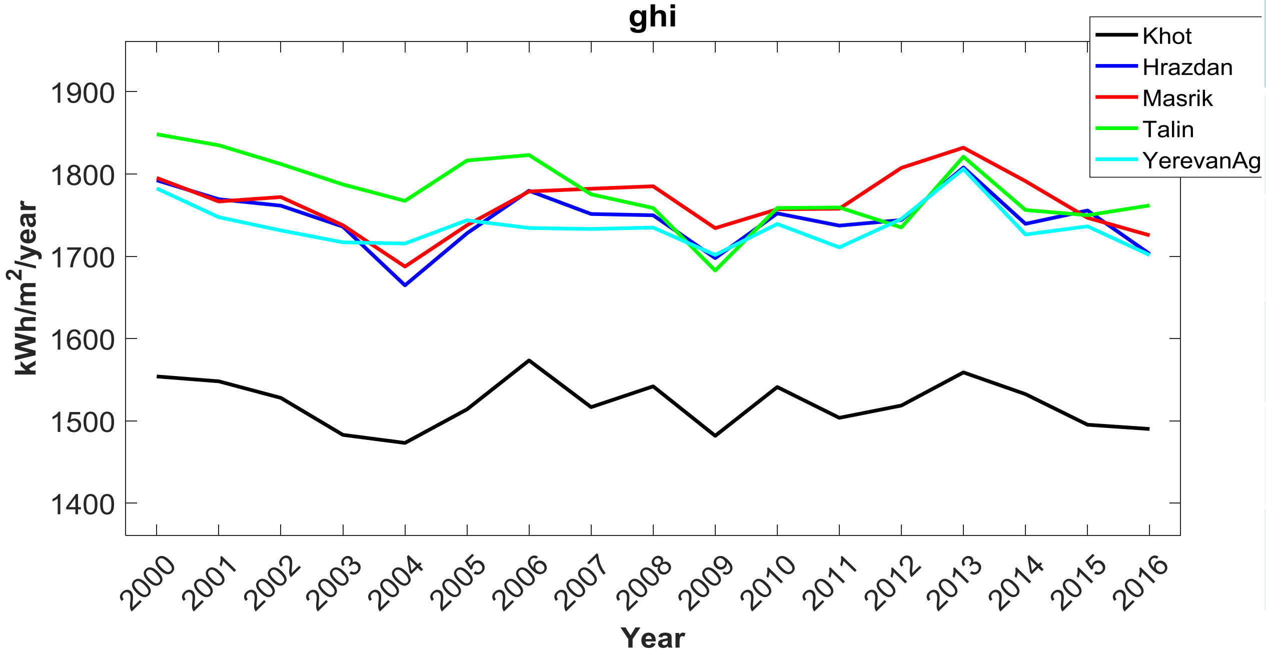


- Monthly averages
  - 2000-2016 period.
- Highest:
  >7 kW/m^2/day in Summer

2. Solar Atlas

GHI: representative sites

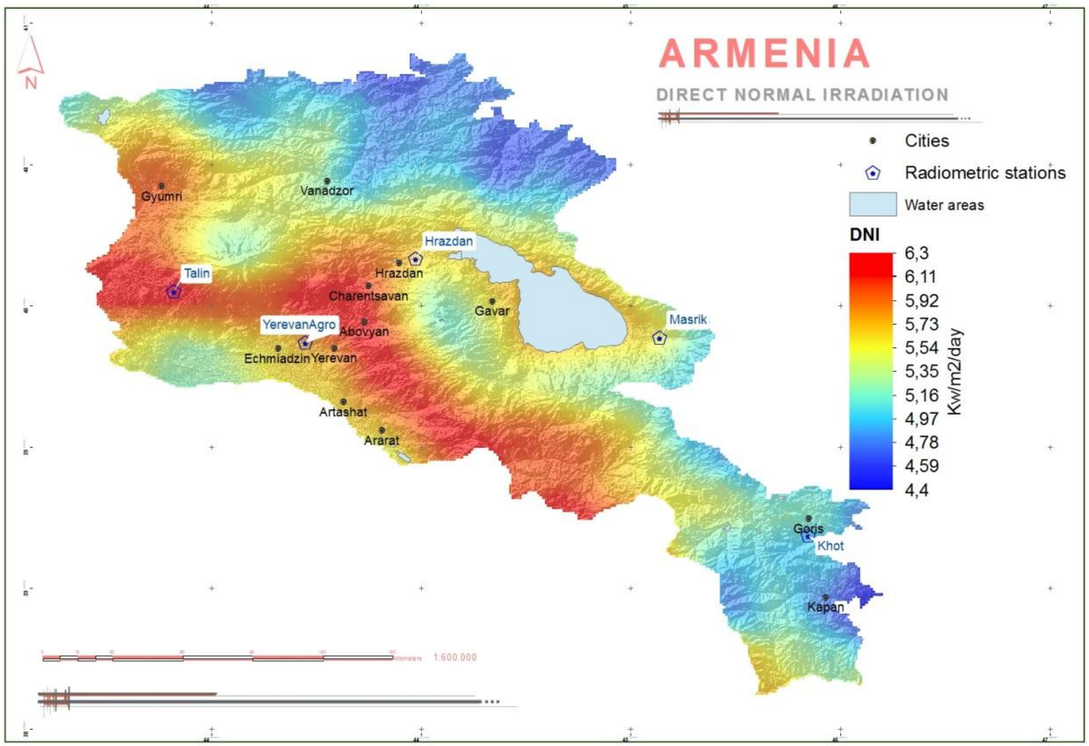
Yearly sums: 2000-2016



Site	Average Yearly sum (kW/m2/year)
Khot	1520
Hrazdan	1750
Masrik	1765
Talin	1780
Yerevan-Agro	1740

2. Solar Atlas

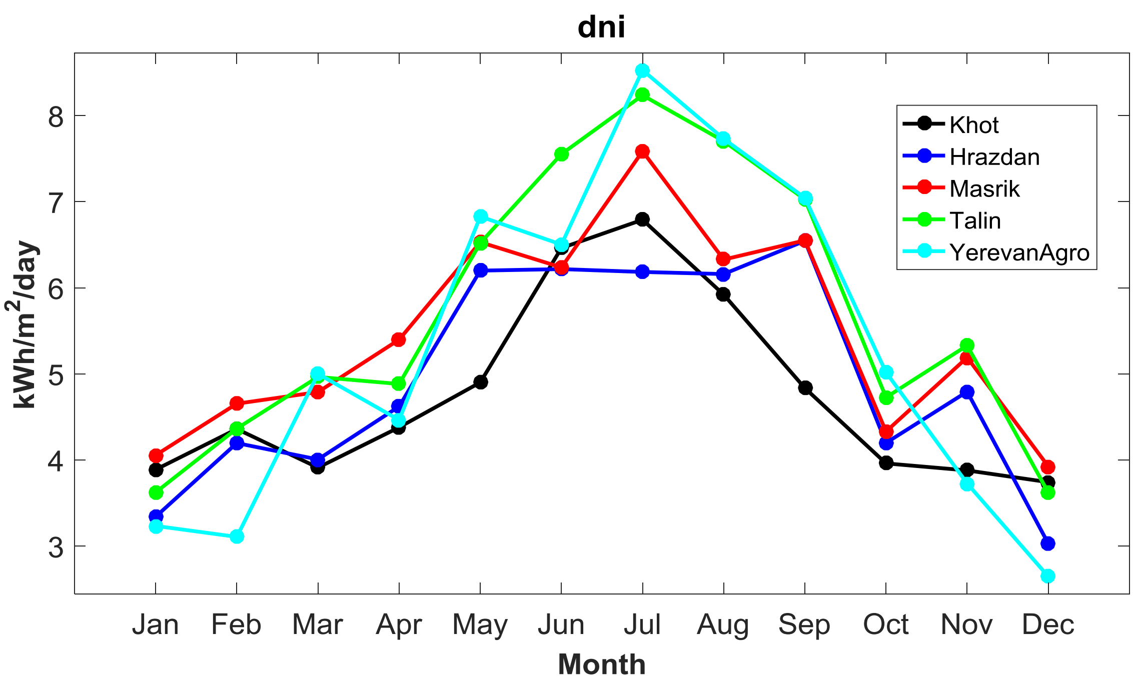
DNI



- Mean Yearly Values
  - 2000-2016 period.
- Highest:
  - 6.3 kW/m^2/day
  - 2300kW/m^2/year
- Belt rounding south face of Aragats mount
- Between provinces of Aragats and Kotayk
- the Ararat valley
- Vayots Dzor
- Lake Sevan

2. Solar Atlas

DNI



- Monthly averages
  - 2000-2016 period.
- Large variability
- Highest
  6 to 8 kW/m²/day in Summer

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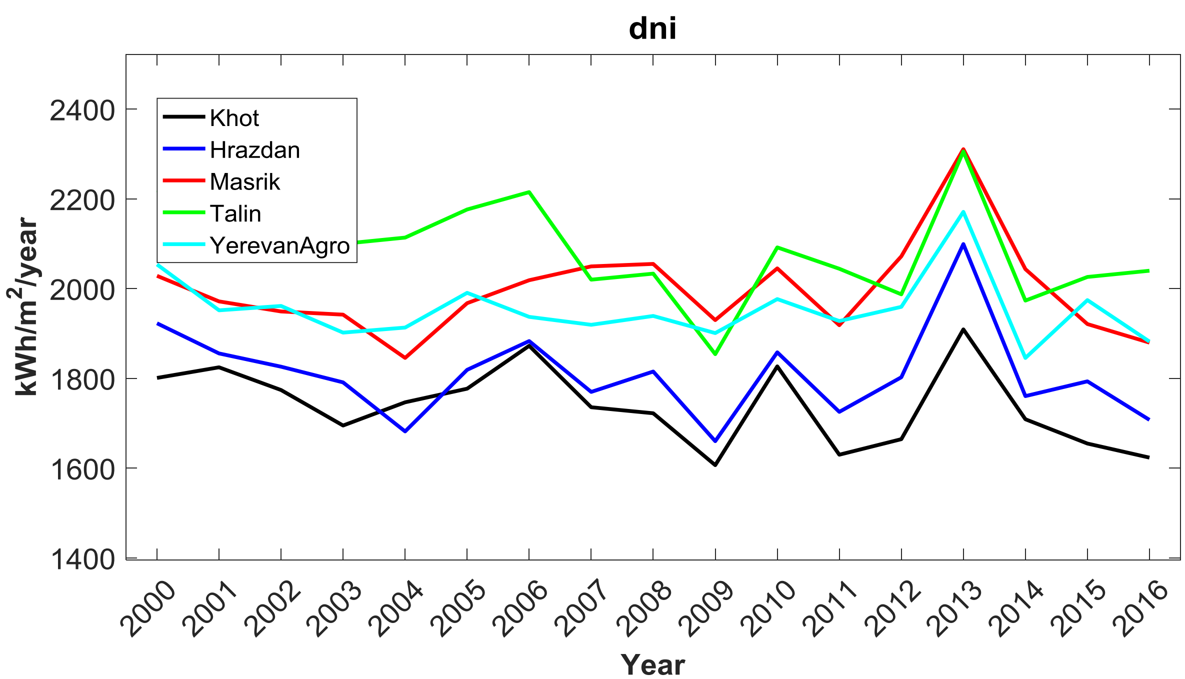
2. Solar Atlas

DNI

Yearly sums: 2000-2016



Site	Average Yearly sum (kW/m2/year)
Khot	1740
Hrazdan	1810
Masrik	2000
Talin	2100
Yerevan-Agro	1950

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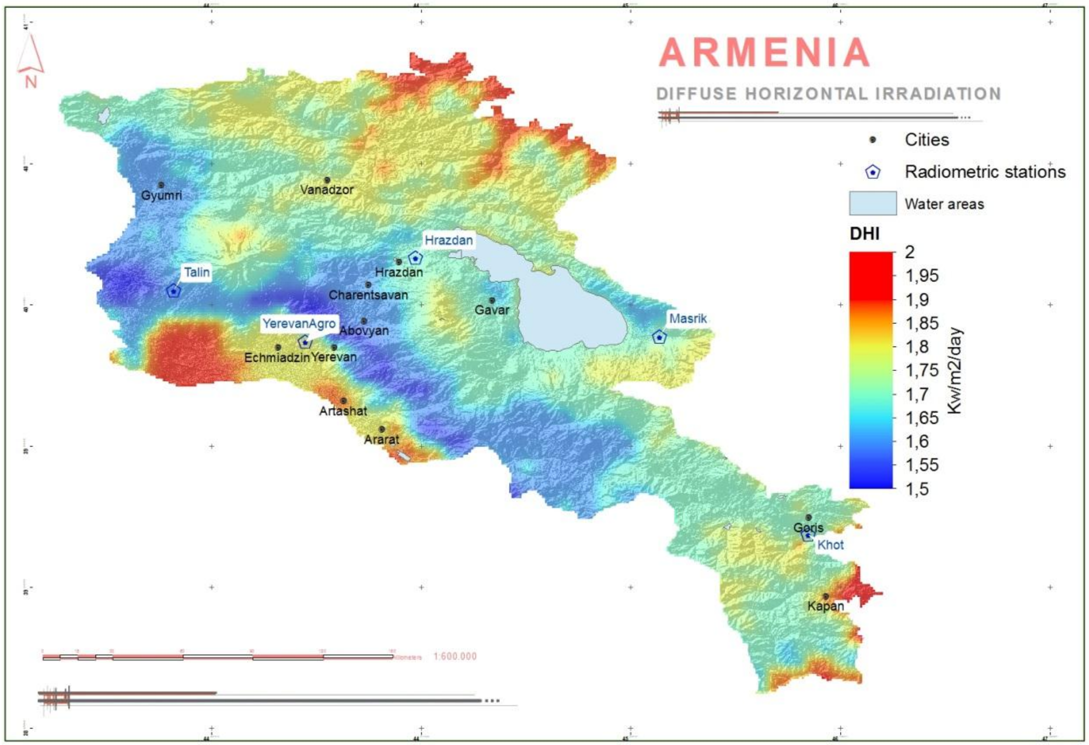
2. Solar Atlas

DHI

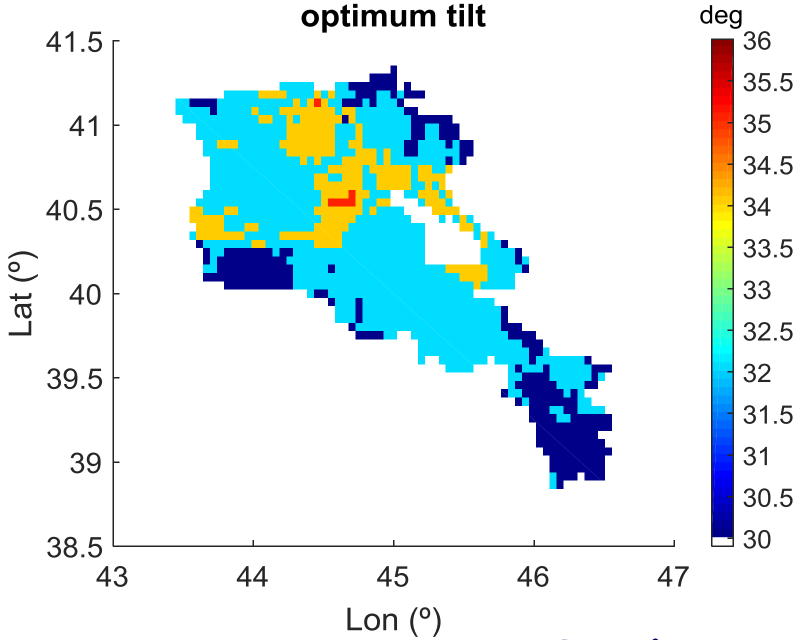


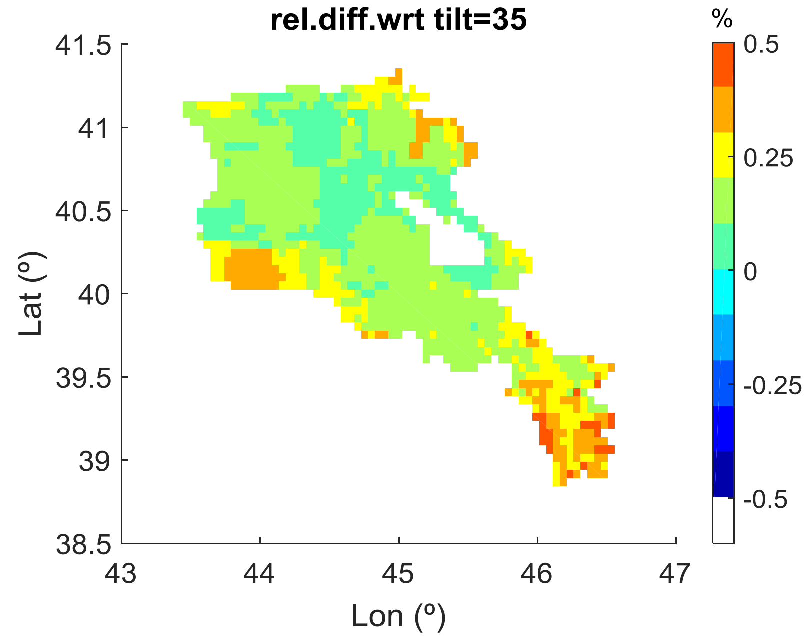
- Mean Yearly Values
  - 2000-2016 period.
- Lowest:
  - 1.5 kW/m^2/day
  - 550 kW/m^2/year
- Belt rounding south face of Aragats mount
- Between provinces of Aragats and Kotayk
- the Ararat valley
- Vayots Dzor
- Lake Sevan

2. Solar Atlas

Optimum Tilt

Study over a tilt range : [30, 42]

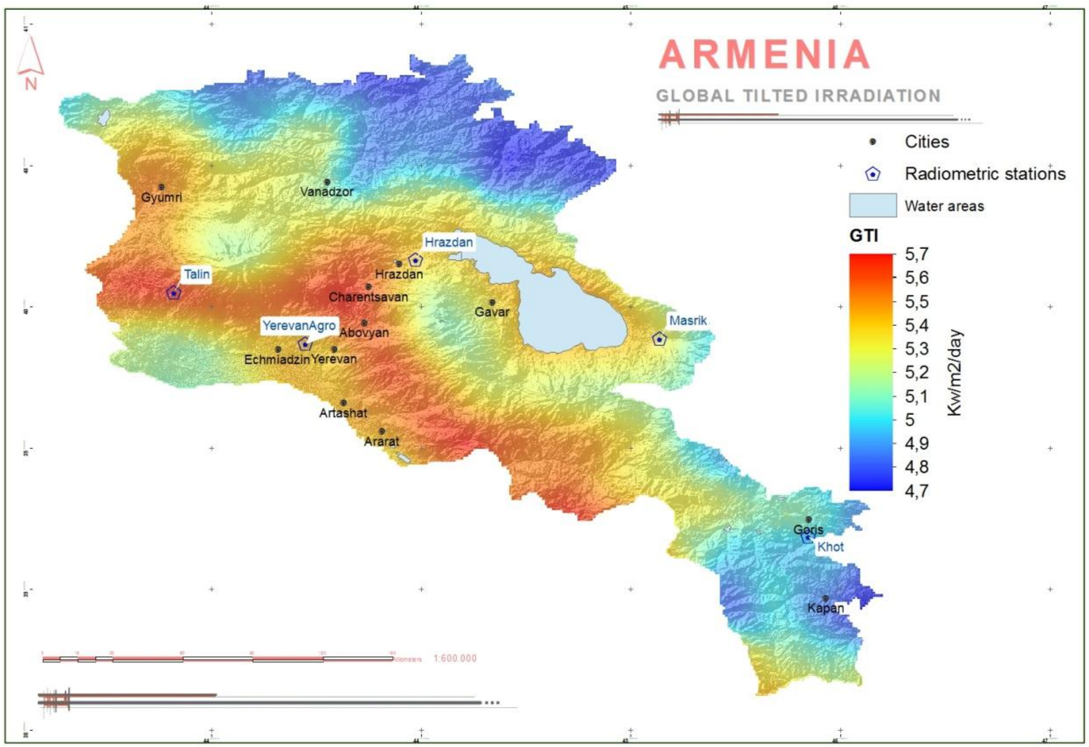




Optimum tilt = 35º is good assumption

2. Solar Atlas

GTI at Tilt 35º



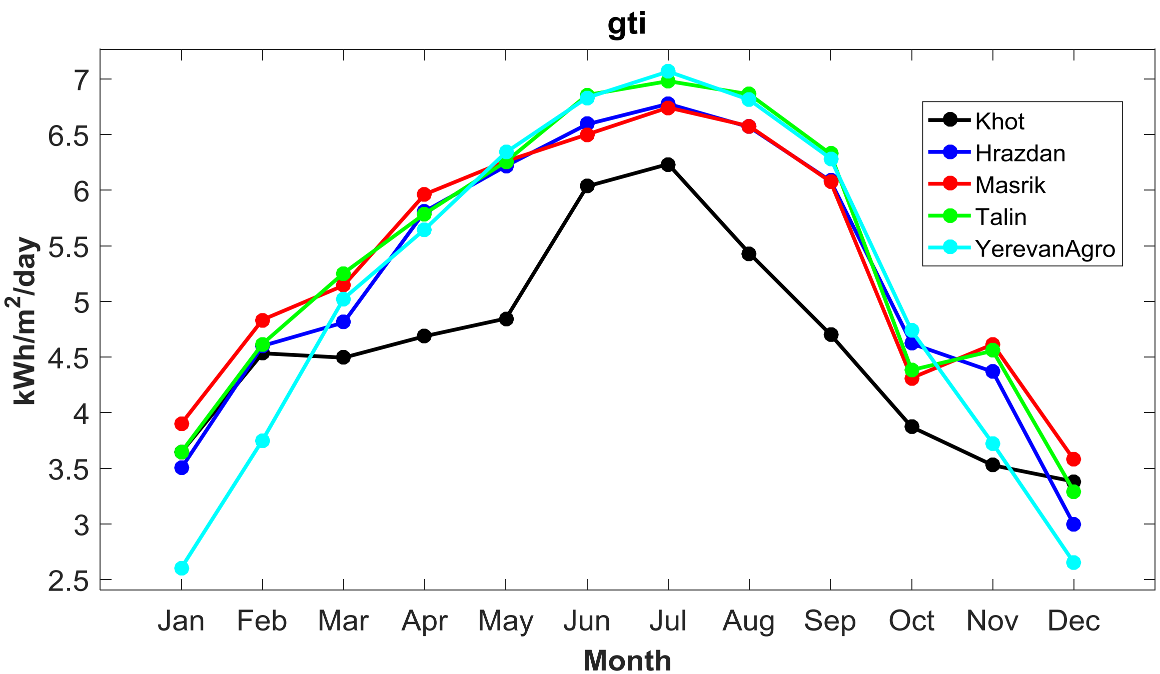
- Mean Yearly Values
  - 2000-2016 period.

- Highest:
  5,7 kW/m^2/day
  2100kW/m^2/year

- Belt rounding south face of Aragats mount
- Between provinces of Aragats and Kotayk
- the Ararat valley
- Vayots Dzor
- Lake Sevan

2. Solar Atlas

GTI at Tilt 35º

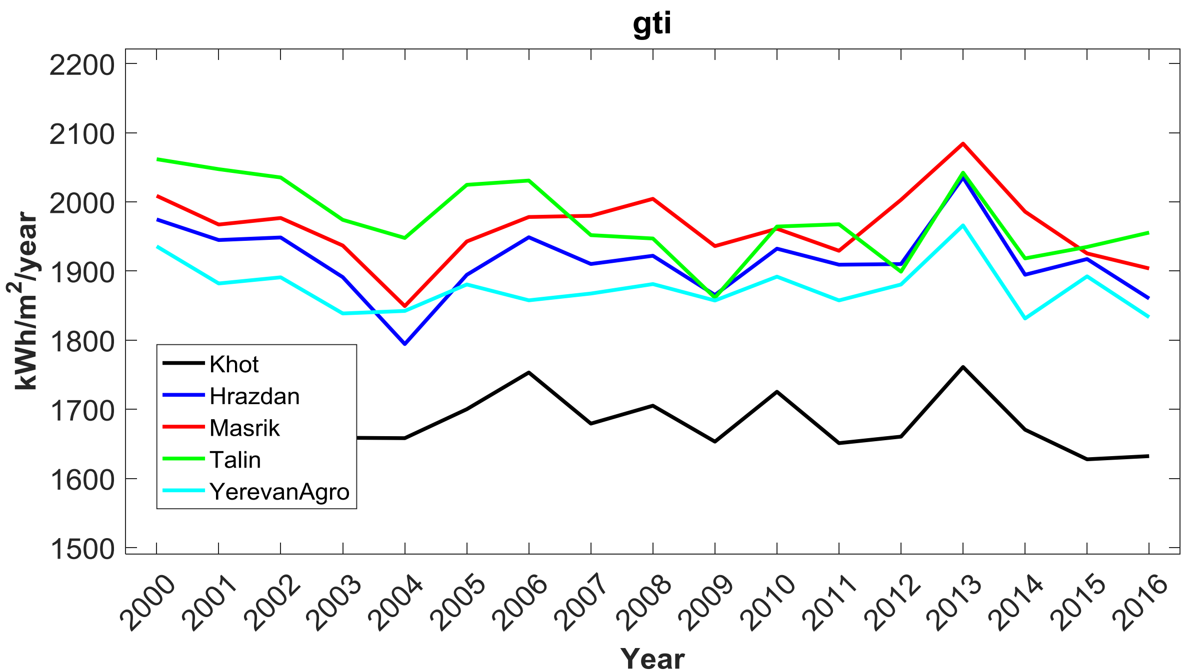


- Monthly averages
  - 2000-2016 period.
- Highest
  6 to 7 kW/m²/day in Summer

2. Solar Atlas

GTI at Tilt 35º

Yearly sums: 2000-2016

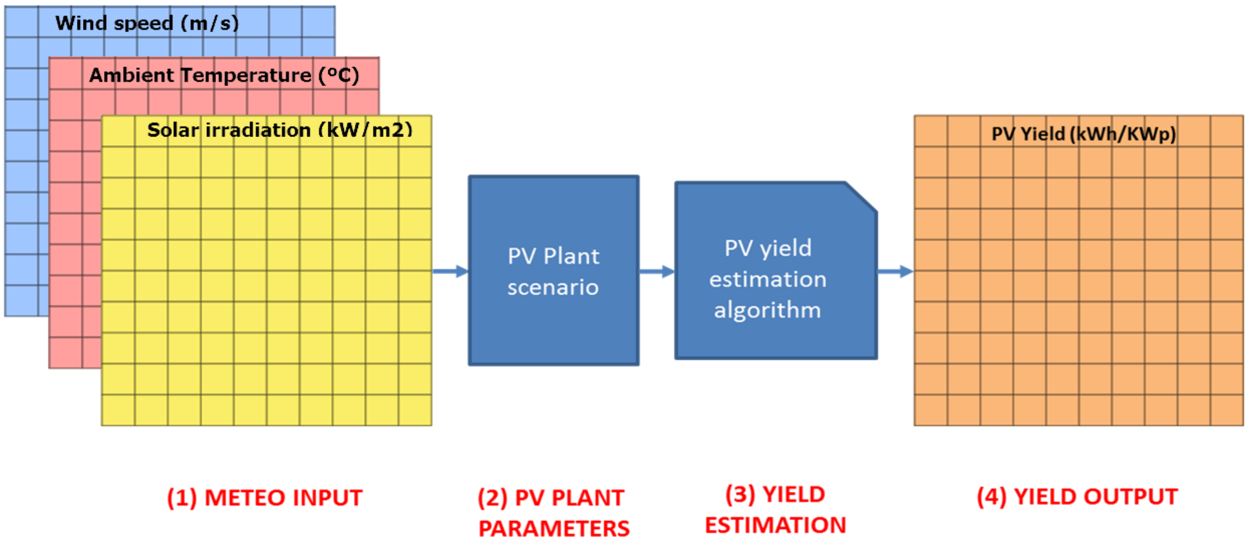


Site	Average Yearly sum (kW/m2/year)
Khot	1690
Hrazdan	1915
Masrik	1960
Talin	1975
Yerevan-Agro	1875

2. Solar Atlas

Methodology for PV potential

PV Yield is the specific energy that a PV system produce per kWp installed.



2. Solar Atlas

Methodology for PV potential

1. **METEO INPUT**

   Averaged meteorological year: 8760 hourly values for each cell of the map grid (0.05º).
   - GTI, Temperature, Wind

2. **PV PLANT PARAMETERS**
   - PV Generator: PV Si-c modules (REC Peak Energy 72, 310Wp)
   - Mounting: static tilt angle 35º
   - Inverter vs PV Peak Power Ratio: 1.2
   - PV Inverter: 1MW SMA Sunny Central MPVS-100 (94.4% European Efficiency)
   - LV/MV Transformer: Commercial 1.2 MW capacity (SMA SC1000-CPXT)
   - Losses:
     - Dust: 2%, Maximum Peak Power Tracking: 2%, Electrical (due to cables, fuses, and other electrical components): 2%, Shadows: 1%.
     - Total losses factor: 7%

2. Solar Atlas

Methodology for PV potential

3. PV YIELD ESTIMATION

$$E_{annual} = \int P_{AC}(G,T)\,dt = \int P_{DC}(G,T) \cdot \eta_{Inv} \cdot \eta_T\,dt$$

- Output power of the PV Generator:

$$P_{DC} = P^* \frac{G}{G^*} \cdot \frac{\eta}{\eta^*}$$

- Power efficiency of the inverter:

$$\eta_{Inv} = \frac{P_{AC}}{P_{DC}} = \frac{p_{DC} - (k_0 + k_1 \cdot p_{DC} + k_2 \cdot p_{DC}^2)}{p_{DC}}$$

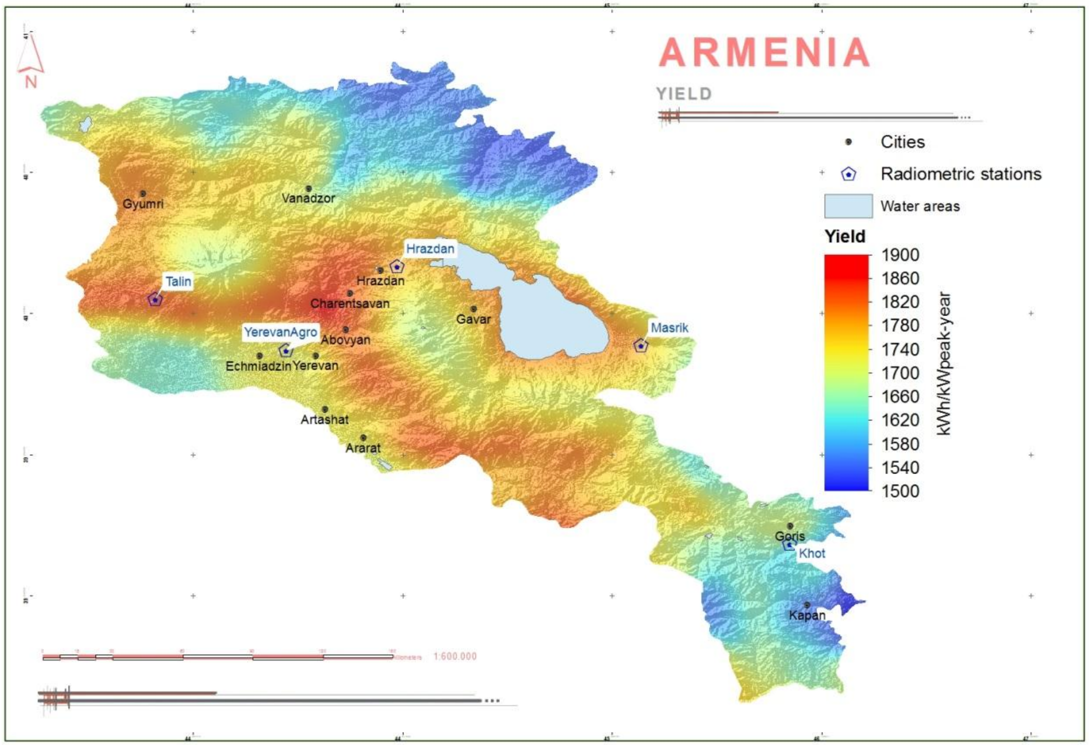
- Power efficiency of the LV/MV transformer:

$$\eta_T = \frac{P_{out}}{P_{AC}} = \frac{P_{out}}{P_{out} + P_{Core} + P_{Cu}}$$

- Further details found in Deliverable 5 of the Project.: D5. Interim Solar Modeling Report.

2. Solar Atlas

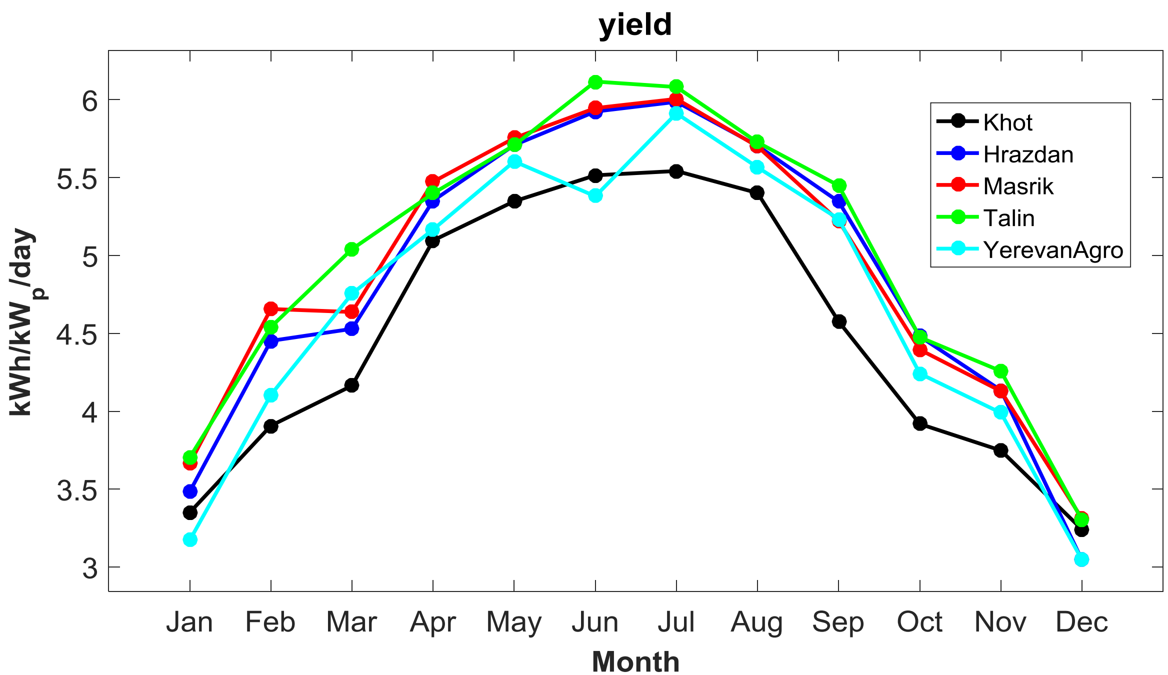
PV Yield



- TMY
- Highest: 1900kWh/kWp
- Belt rounding south face of Aragats mount
- Between provinces of Aragats and Kotayk
- the Ararat valley
- Vayots Dzor
- Lake Sevan

2. Solar Atlas

PV Yield



- Monthly averages
  - 2000-2016 period.
- Highest
  5 to 6 kW/kWp/day
  in Summer

Site	Average Yearly sum (kW/kWp/year)
Khot	1640
Hrazdan	1770
Masrik	1790
Talin	1820
Yerevan-Agro	1710

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