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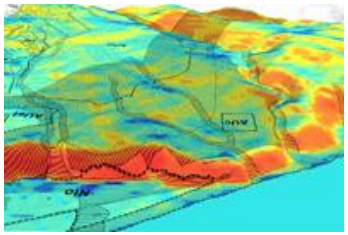


Using cloud fraction derived from all-sky camera to improve beam solar irradiance forecasting by time-series modelling

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ADEME Agence de l'Environnement et de la Maîtrise de l'Energie

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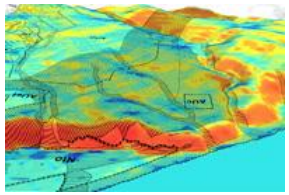
Reuniwatt SAS

- Young company based in Reunion Island (Indian Ocean) with a Parisian office
- Coupling renewables and IT

Soleka

Solar Energy Forecasting tool



Climatic information System

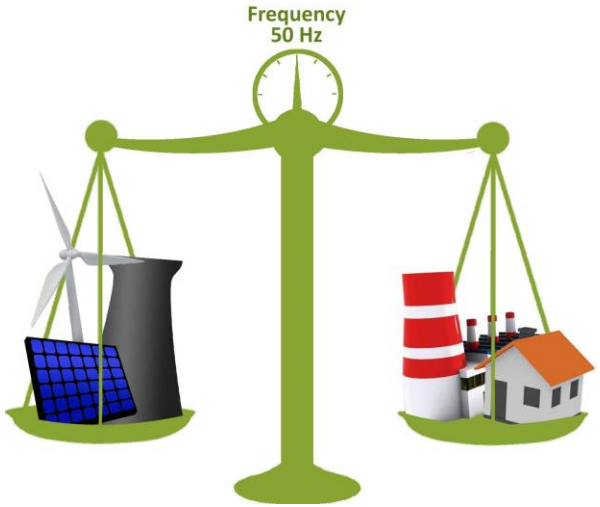
Energy Mix Expertise

Solar energy and derived forecasting issues

High variability of the solar resource must be monitored to increase its use.

Challenges of solar energy forecasting:

- Converting an intermittent solar energy production into a guaranteed energy
- Massive and safe penetration of PV into the energy mix



Short-term solar energy forecasting applications:

- Smart-grids (network security)
- Storage management
- Trading

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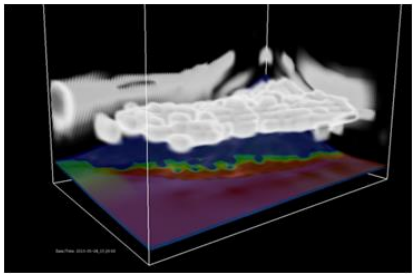
Outline

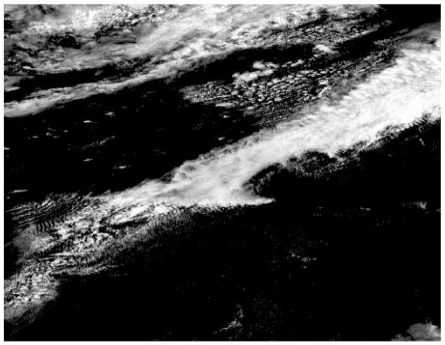
1) Forecasting methods
2) Objective & approach
3) Data used
4) Modelling
5) Simulations & Results
6) Conclusion & Perspectives

Forecasting methods

Different forecasting methods are used for specific forecasting time-horizons

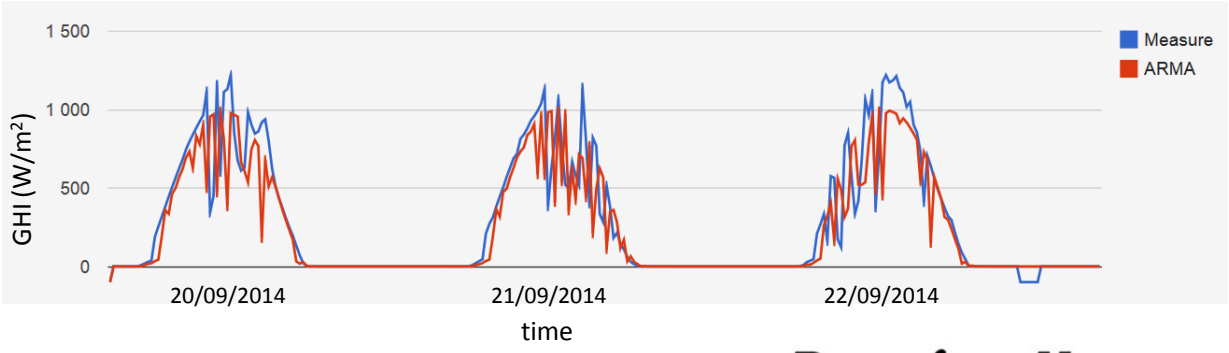


NWP (Numerical Weather Prediction)
Day-ahead forecasts
Res: ~10 km^2



Satellite images
Hour-ahead forecasts
Res: ~1 km^2

Time-series modelling (ARMA, ANN…)
Intra-hour forecasts
→ Adapted for local forecasting



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Forecasting methods (2)

- Since 2011:

  Total sky imagers are more and more used for nowcasting and deterministic shortcasting (up to 30 min ahead forecasts)

  (Gauchet *et al.*, 2012; Chow *et al.*, 2013; Coimbra and Marquez 2013)

  → *Provide pertinent sky information over a single site*

- Our work:

  Preliminary study that uses **sky observations** as **an additional information** to a standard **statistical model** for direct solar irradiance shortcasting (t+10 min, t+20min, t+30 min)

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Objective

Show within a simplified framework:

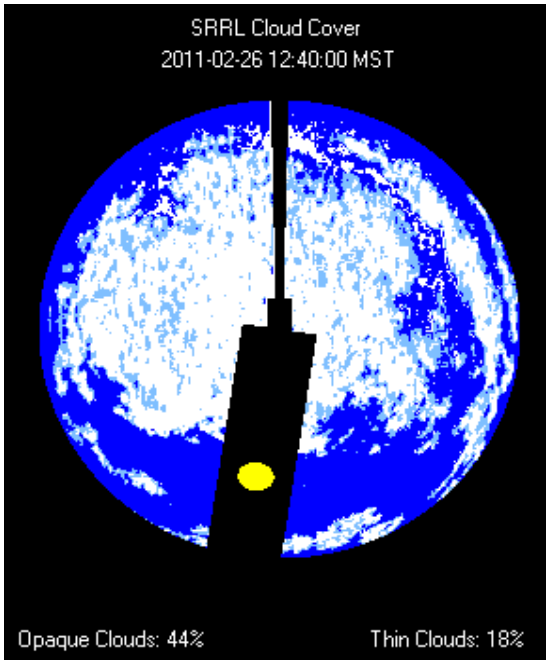
- An example of methodology to **integrate sky observations** into a statistical model
- **Improvements made** by the use of these observations for direct solar irradiance shortcasting

Approach

- Extract cloud cover from a Total Sky Imager

TSI

Sky image



Processed Sky Image (TSI software)

- Use this information as an external input of an **ARMAX** (*Auto-Regressive Moving Average with eXternal Input*) model.

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Data Used

3 types of data:

1) Processed total sky images taken every 10 min from a TSI (*Total Sky Imager*)
2) DNI (*Direct Normal Irradiance*) measurements synchronized with images
3) Modelled DNI under McClear clear sky model (Lefevre *et al.* 2013) for direct irradiance normalization

Data extracted from the NREL (*National Renewable Energy Laboratory*) database

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Data period: from 01/01/2011 to 30/12/2011
→ **10 819** observations used after filtering (night data, missing consecutive values or images…)

Public data → reproducible results

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Modelling (1) : ARMAX model

- ARMA(X) Model (Auto-Regressive Moving Average with eXternal Input)

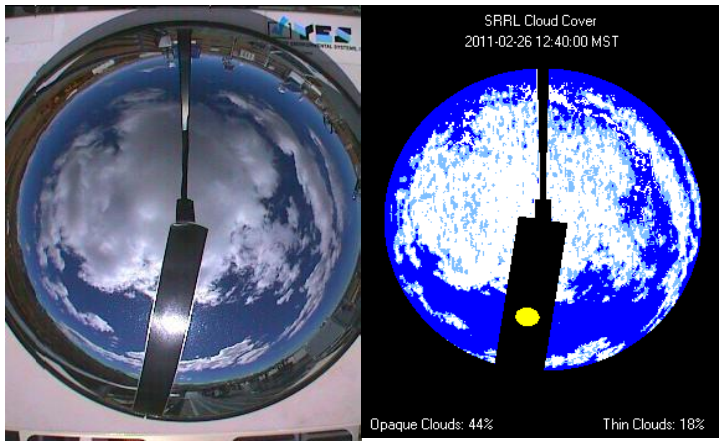
$$Y_t = \theta_0 + \sum_{i=1}^{p} \theta_i Y_{t-i} + \sum_{j=1}^{q} \varphi_j \varepsilon_{t-j} + \sum_{k=1}^{r} \beta_k X_{t-k} + \varepsilon_t$$

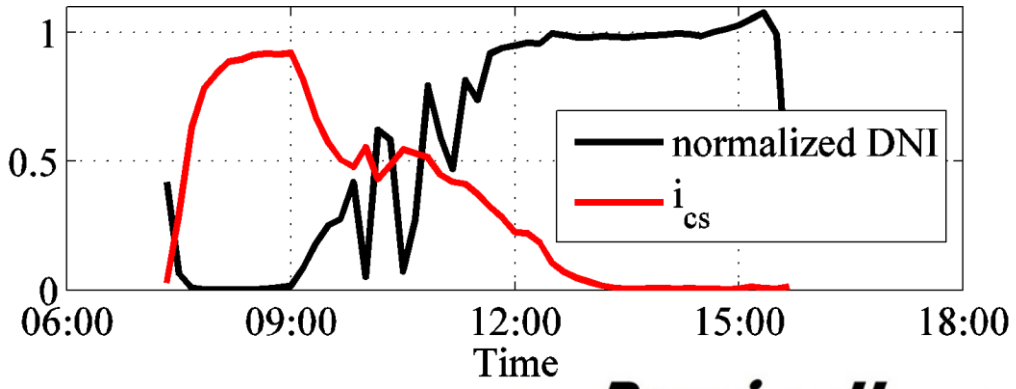
Where $\{\varepsilon_t\}$ is a series of independent and identically distributed error terms.

→ Simple but efficient model

- External Input = cloud cover index:

$$X = i_{cs} = \frac{number\ of\ pixels\ corresponding\ to\ a\ cloud}{number\ of\ pixels\ of\ the\ sky\ part}$$





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Modelling (2) : Parameter Estimation

Parameter Estimation

- Parameters to be estimated:

$$\boldsymbol{\Theta} = (\theta_0, \dots, \theta_p, \varphi_1, \dots, \varphi_q, \beta_1, \dots, \beta_r)$$

- Estimation by **RLS** (*Recursive Least Squares*) method:
  - Parameters updated after each new observation $\boldsymbol{\Theta} \rightarrow \boldsymbol{\Theta_t}$
  - Same weight for each passed observation
  - Algorithm well adapted for operational forecasting (low complexity)
- Parameters $\boldsymbol{\Theta_t}$ calibrated with half the data. Second half used for testing.

Choice of the model

- Order p, q, r of ARMA and ARMAX models chosen by grid-search
- One model per forecasting horizon (t+10min, t+20min, t+30min)

Simulations & Results

- All simulations made on DNI normalized by McClear Direct Irradiance.
- ARMA and ARMAX models are compared with persistence model.
- Criterion of comparison (on non-normalized DNI):

$$\mathrm{RMSE}(h) = \sqrt{\frac{1}{T}\sum_{t=1}^{T}(y_{t+h} - \hat{y}_{t+h|t})^2},$$

with y = normalized DNI and $h = 10, 20, 30\ min$

RMSE Table (in W/m2)

	t+10 min	t+20 min	t+30 min
Persistence	160,73	204,40	232,14
ARMA	155,67 (+3,1%)	191,68 (+6,2%)	214,10(+7,8%)
ARMAX	**148,62 (+7,5%)**	**181,61 (+11,11%)**	**202,76 (+12,7%)**

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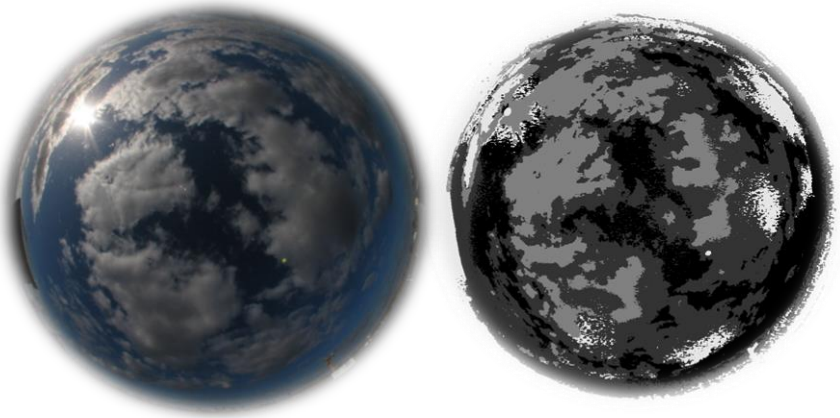
Conclusion & Perspectives

- Total Sky Images help time-series modelling provide **better solar direct irradiance forecasts.**
- Proposed framework can be a starting point to numerous lines of research:

  - **Extension of ARMA models:** Regime-switching model (TAR) driven by image information.



  - **ARMAX extension:** use more than 1 external input (e.g. proportion of thin/thick cloud, kind of cloud, cloud motion…)

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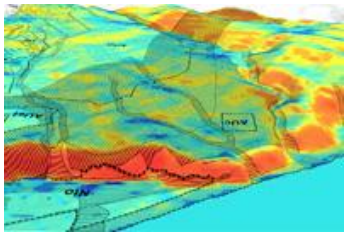

Thank you!

Any questions?

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