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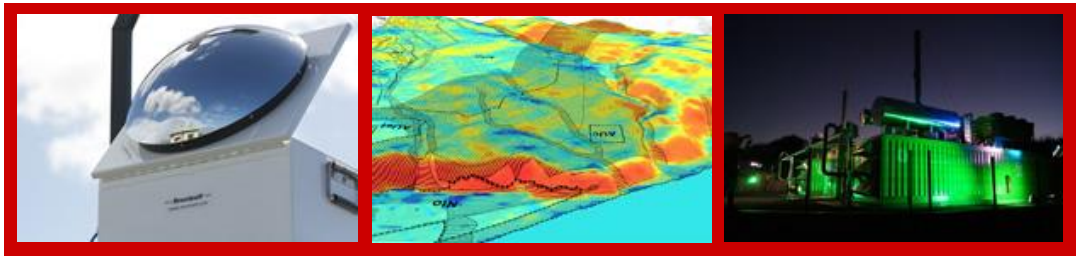

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Laboratoire d'Energétique, d'Electronique et Procédés

Satellite-based solar irradiance assessment and forecasting in tropical insular areas

Sylvain Cros, Maxime De Roubaix, Mathieu Turpin, Patrick Jeanty

16th EMS Annual Meeting & 11th European Conference on Applied Climatology (ECAC) | 12–16 September 2016 | Trieste, Italy

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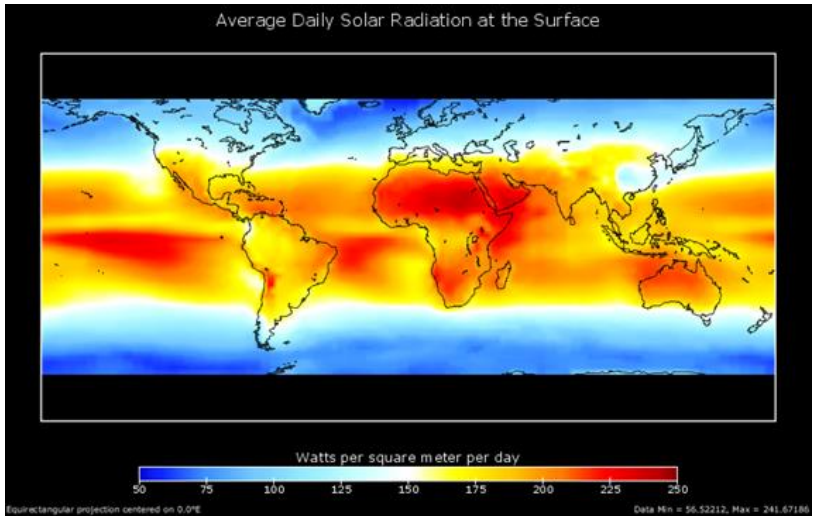
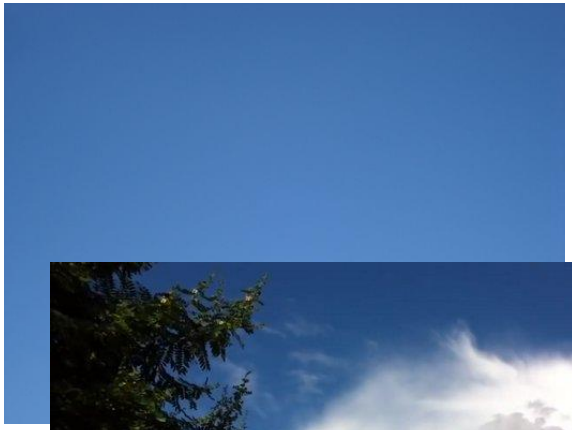
Solar energy in tropical islands – Opportunities

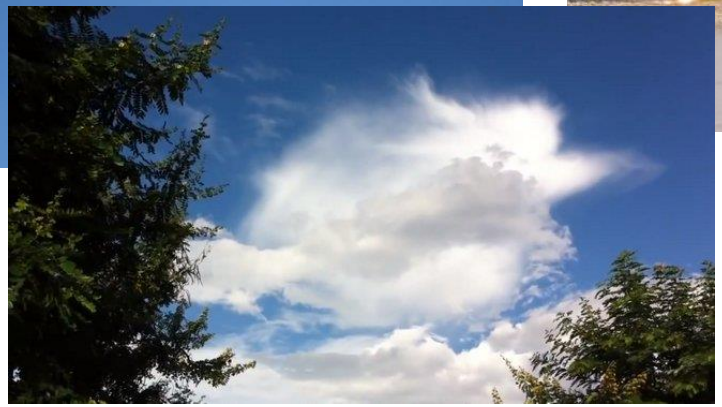
- Production of an affordable, low-carbon and locally produced energy
- Contribution to a low-carbon development in very populated territories
- High solar yield

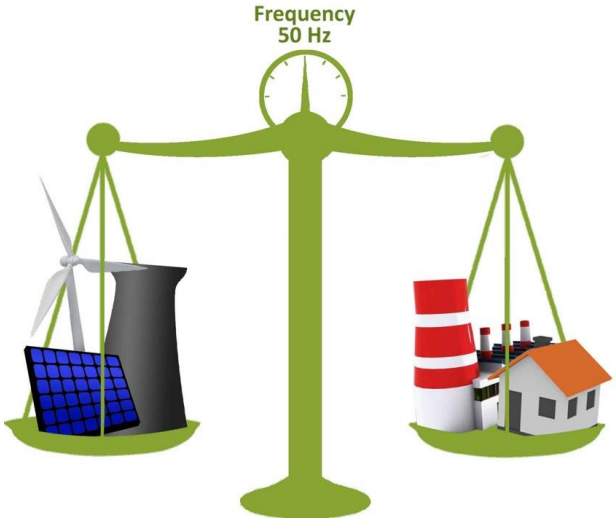


Solar energy in tropical islands – Some issues

- Solar energy is variable
- Insular tropical weather shows high solar irradiance variability and amplitude
- Islands are non-interconnected areas. Electricity compensation must be locally produced

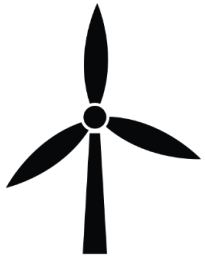
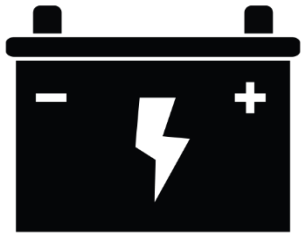






Managing variable power in Non-Interconnected Territories

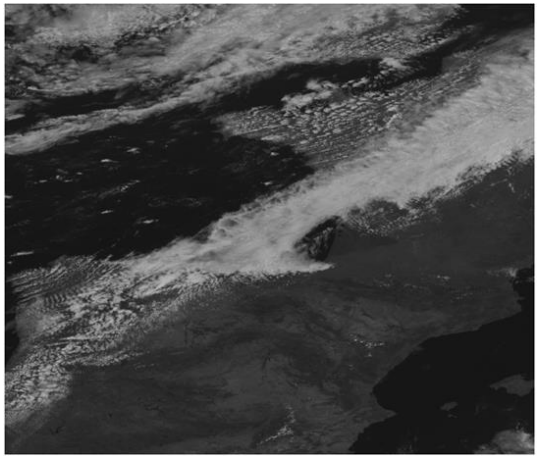
- Forecasting variable energy is helps to schedule compensation needs (conventional electricity, storage …)

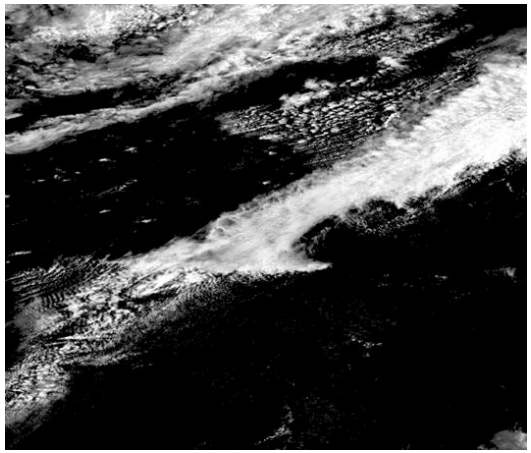




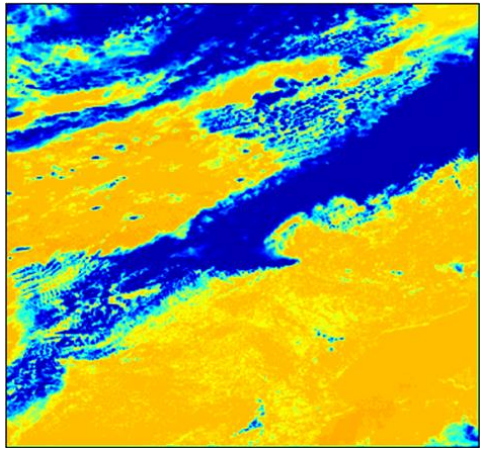
- Intraday forecast of PV production is a necessity

Satellite-based forecasts – Cloud index and irradiance mapping

- For intraday forecast (up to 6 hours), satellite image processing provides more accurate results than NWP







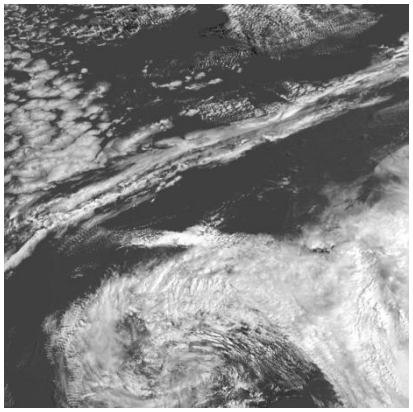
Meteosat-9 raw image (June 6th 2012, 1200 UTC)

Cloud index: comparison between actual and clear sky reflectance for a given pixel

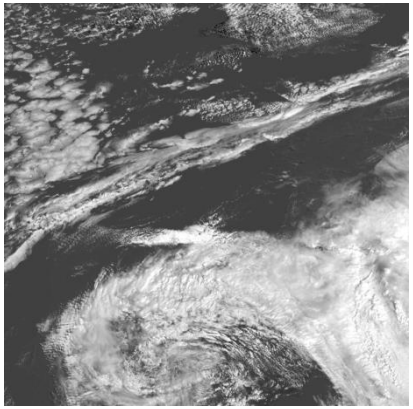
GHI: global horizontal irradiation at ground level

Based on Heliosat-2 method. Rigollier et al., (2004); Cros (2004)

Satellite-based forecasts – Motion analysis & extrapolation



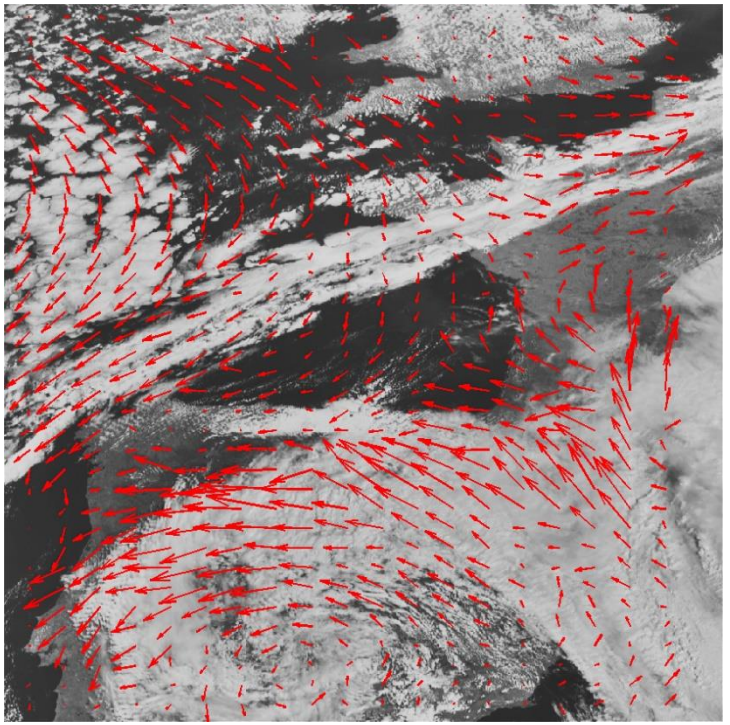
T0 – 15 min. Cloud index map



T0 Cloud index map

Optical flow analysis by Lucas-Kanade method

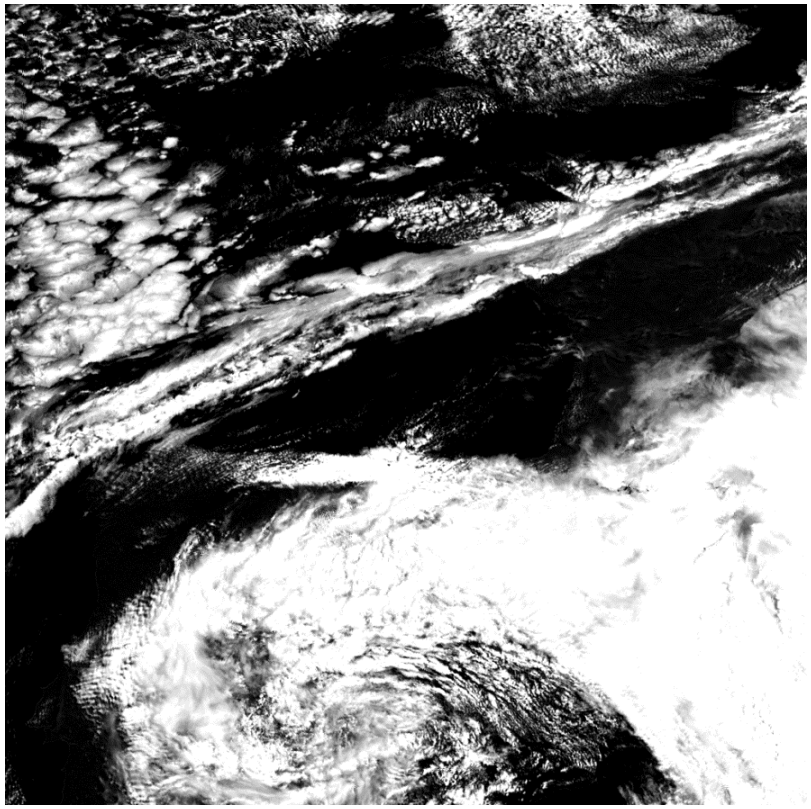
Cloud motion vector extraction



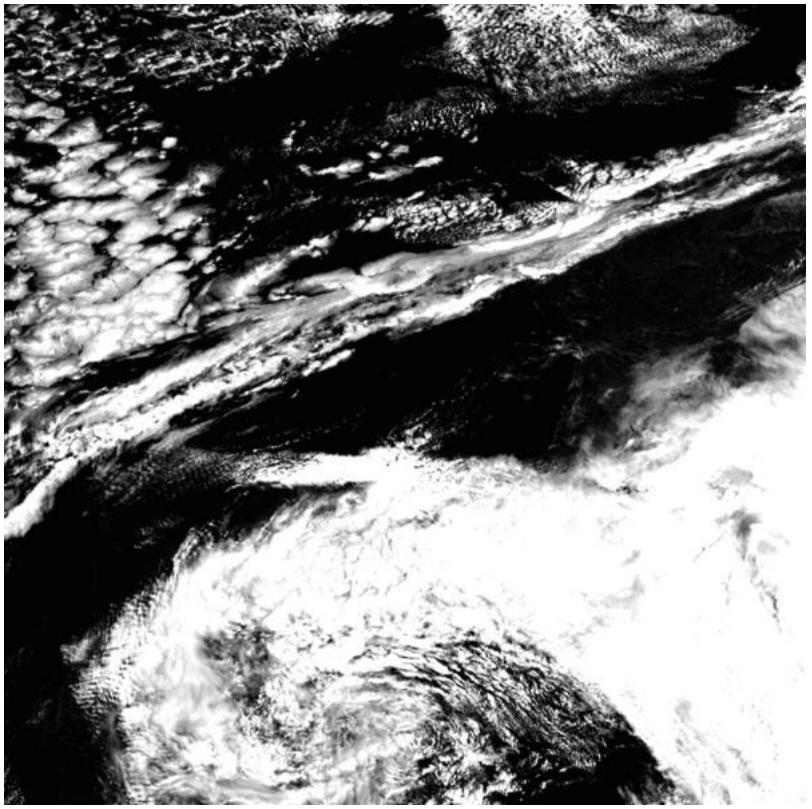
Cloud motion vector field on T0 HRV map

Lucas and Kanade (1981)
Cros *et al.* (2014)

Satellite-based forecasts – Motion analysis & extrapolation



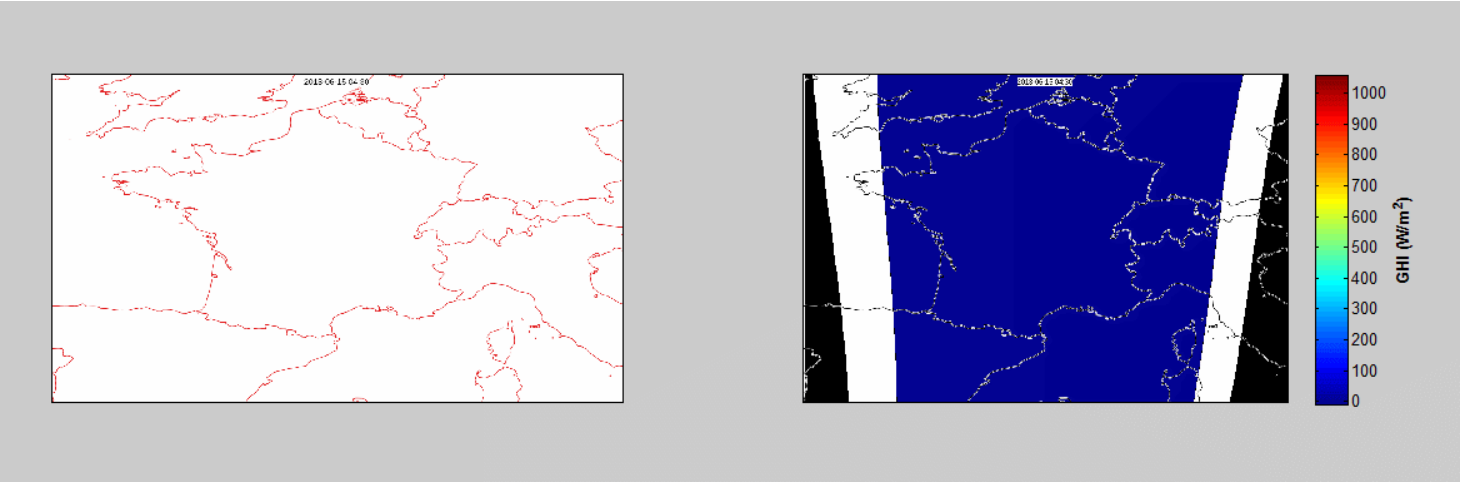
Original T0 Cloud Index map



Forecasted Cloud index maps – Up to 6 hours (step 15 min)

Satellite-based forecasts – Motion analysis & extrapolation

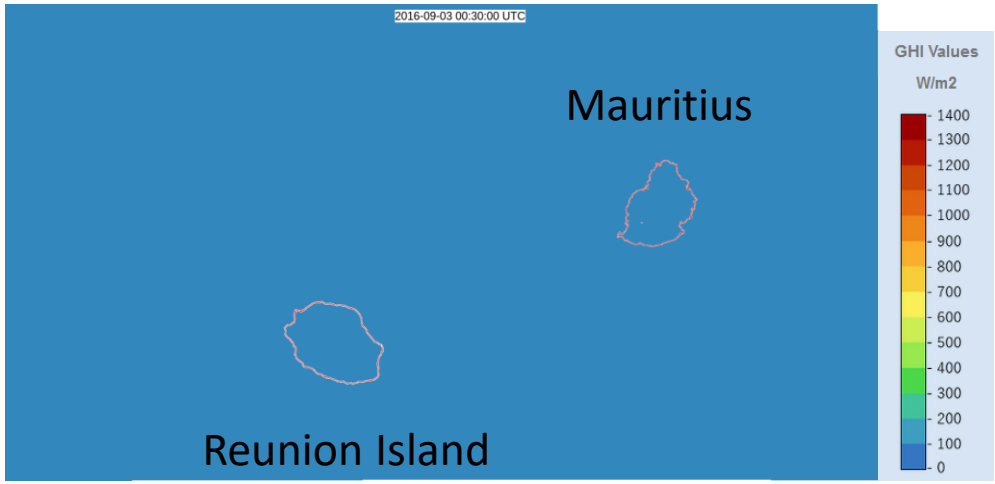
- Proven quality forecast over Europe
- But this method assumes :
  - Cloud are single layered
  - Cloud motion is only due to horizontal advection (forming and dissolving clouds are ignored)



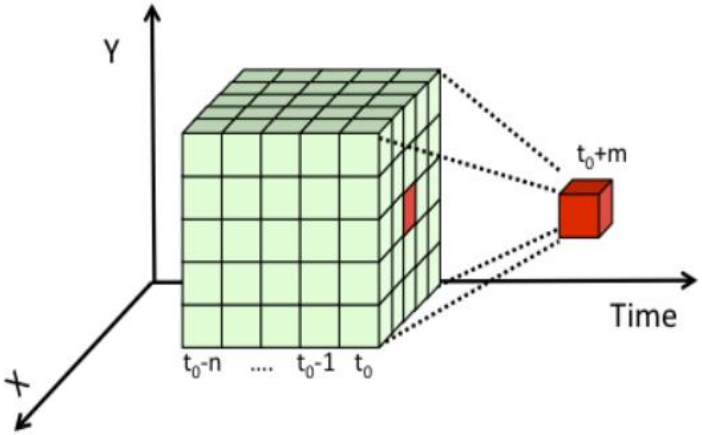
Derived from Meteosat-10 images (EUMETSAT)

Satellite-based forecasts – Autoregression of cloud index patterns

- Assumption of cloud advection for tropical islands is not obvious:
  - Coastal and mountainous areas are zones of frequent cloud formation and dissipation
  - Tropical atmospheric profiles lead to frequent convection situations
  - Advection concerns mostly larger scales than cloud cover evolution over the island



Derived from Meteosat-7 images (EUMETSAT)

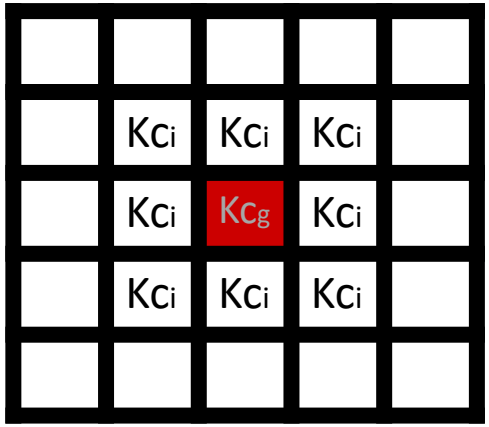


- An alternative is the time-series modeling applied on 2D cloud index maps
  - Statistical information on diurnal cycle
  - Quality less dependent on weather situation, robustness
  - Good candidate to complete a motion analysis scheme

ARX implementation

- Autoregressive model with exogenous data (ARX) Dambreville *et al.*, 2014
  - Considering 1-D time series of pyranometer measurements, converted into clear sky index $Kc_g(t)$. Normalized values => stationary time-series.
  - Kc_i : exogenous variables computed from satellite-based cloud indices (the X of ARX)

Does all the Kci are equally important for ARX ?



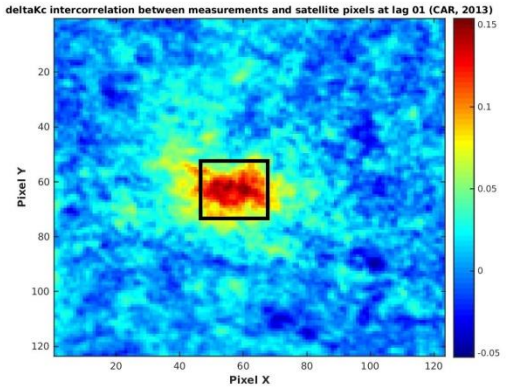
A spatial analysis can identify the locations of the most relevant surrounding pixels
ΔKc spatial intercorrelation with given site between T0 and various lag

Spatial analysis in Carpentras

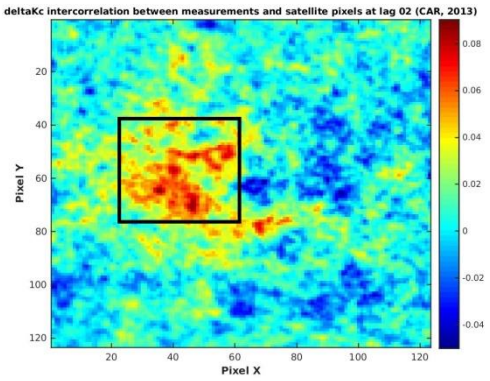
Carpentras, south of France
(44.08° ; 5.04°)
Year 2013
BSRN pyranometer

Kc computed using
McClear Clear sky model

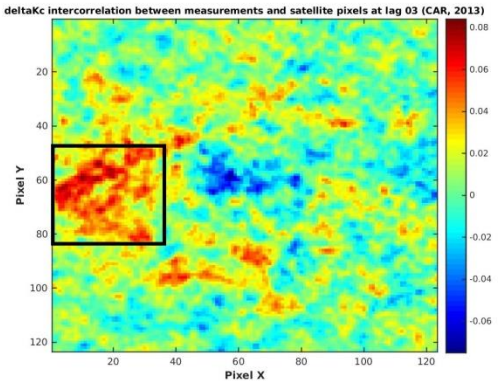
T0



T0+15 min.



T0+30 min.



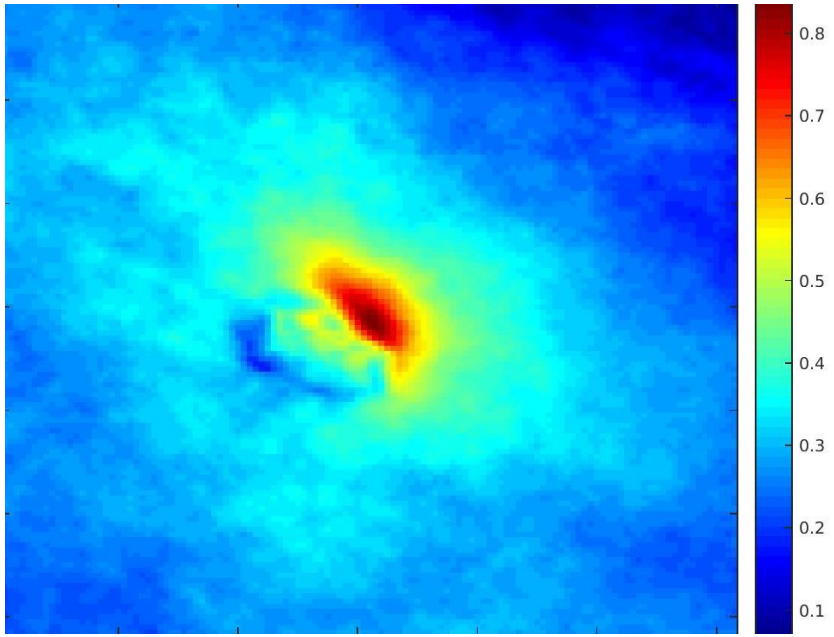
Sky state changes are coming from the west, consistent with averaged wind direction

Spatial analysis in Reunion Island

Saint-Benoît
(-21.05° ; 55.70°)
Year 2013
GHI data from Reuniwatt sensor

Kc computed using
McClear Clear sky model

Intercorrelation map between T0 and T0+30

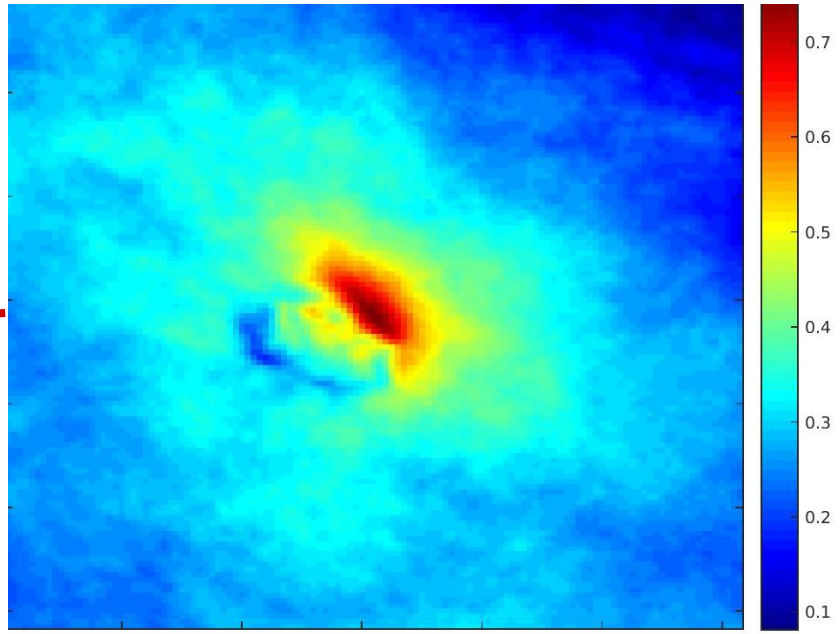


Spatial analysis in Reunion Island

Saint-Benoît
(-21.05° ; 55.70°)
Year 2013
GHI data from Reuniwatt sensor

Kc computed using
McClear Clear sky model

Intercorrelation map between
T0 and T0+60 min

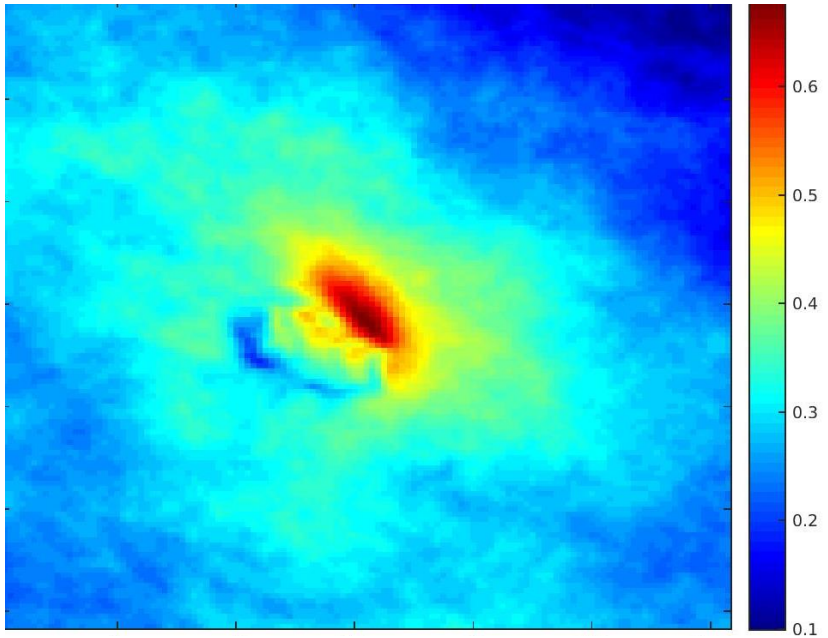


Spatial analysis in Reunion Island

Saint-Benoît
(-21.05° ; 55.70°)
Year 2013
GHI data from Reuniwatt sensor

Kc computed using
McClear Clear sky model

Intercorrelation map between
T0 and T0+90 min

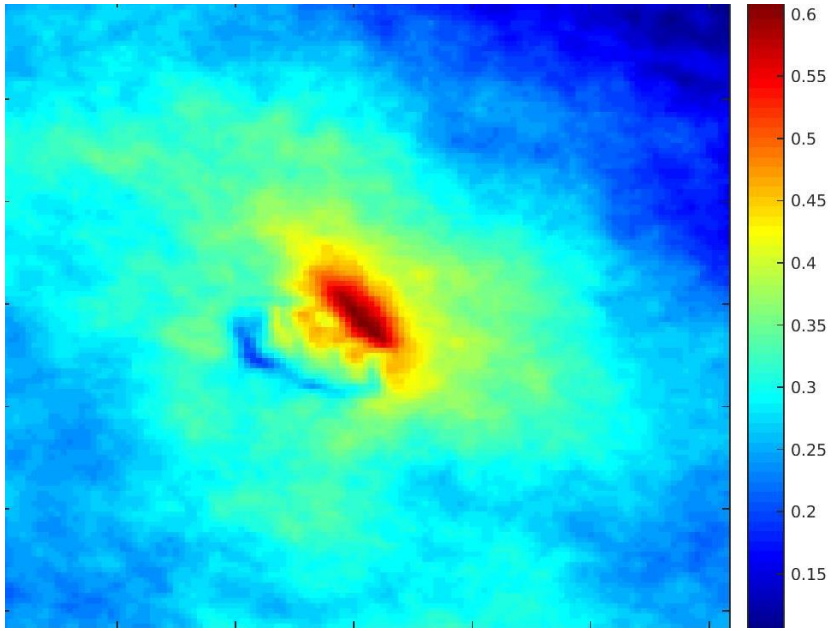


Spatial analysis in Reunion Island

Saint-Benoît
(-21.05° ; 55.70°)
Year 2013
GHI data from Reuniwatt sensor

Kc computed using
McClear Clear sky model

Intercorrelation map between
T0 and T0+120 min

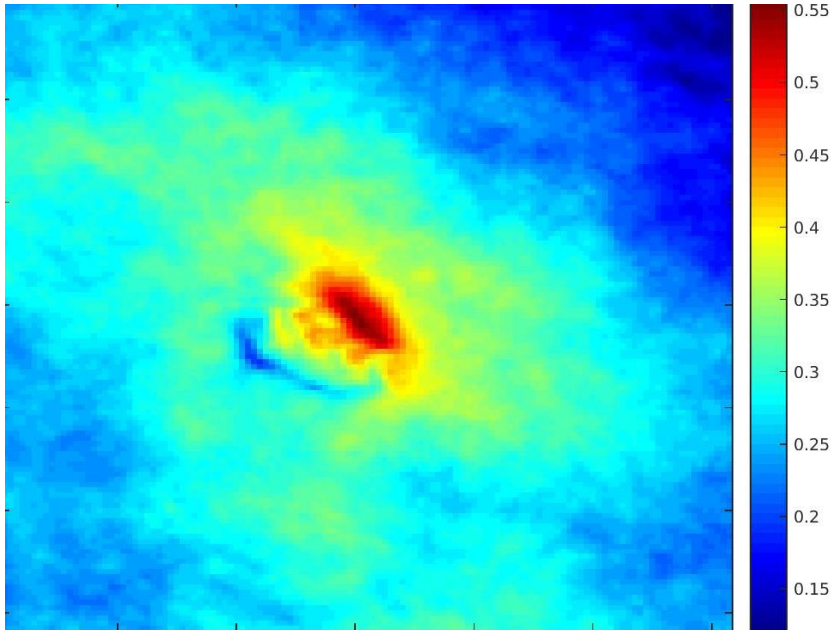


Spatial analysis in Reunion Island

Saint-Benoît
(-21.05° ; 55.70°)
Year 2013
GHI data from Reuniwatt sensor

Kc computed using
McClear Clear sky model

Intercorrelation map between
T0 and T0+150 min

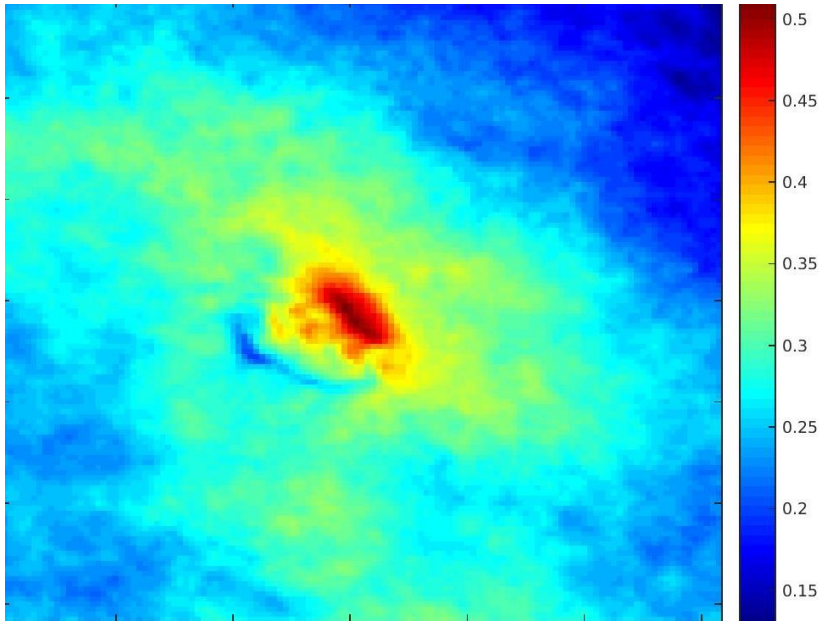


Spatial analysis in Reunion Island

Saint-Benoît
(-21.05° ; 55.70°)
Year 2013
GHI data from Reuniwatt sensor

Kc computed using
McClear Clear sky model

Intercorrelation map between
T0 and T0+180 min

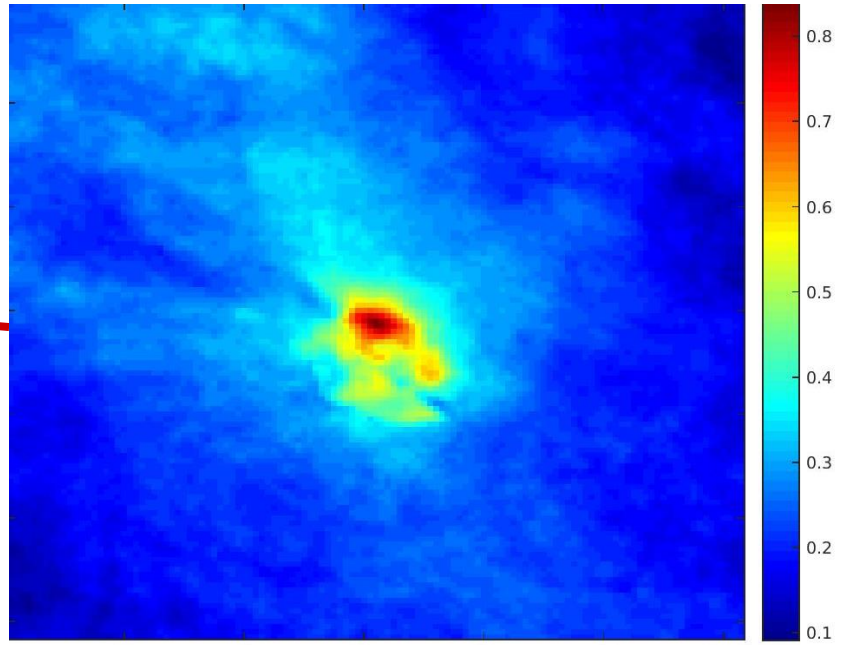


Spatial analysis in Reunion Island

Moufia – Saint-Denis
(-20.91° ; 55.48°)
Year 2013
GHI data from pyranometer
LE2P, université de La Réunion

Kc computed using
McClear Clear sky model

Intercorrelation map between
T0 and T0+30 min



Spatial analysis in Reunion Island

Moufia – Saint-Denis
(-20.91° ; 55.48°)
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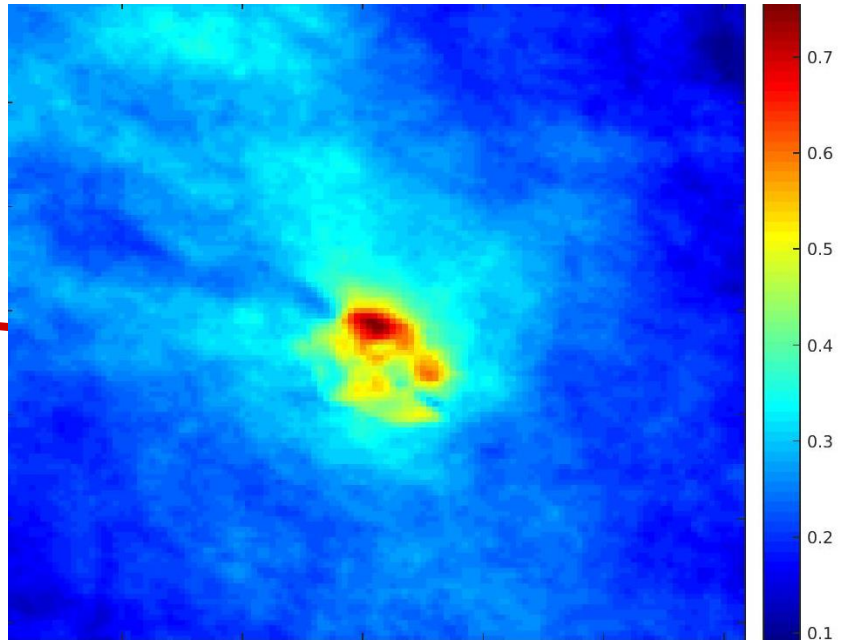
GHI data from pyranometer
LE2P, université de La Réunion

Kc computed using
McClear Clear sky model

Intercorrelation map between
T0 and T0+60 min



Spatial analysis in Reunion Island

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Intercorrelation map between
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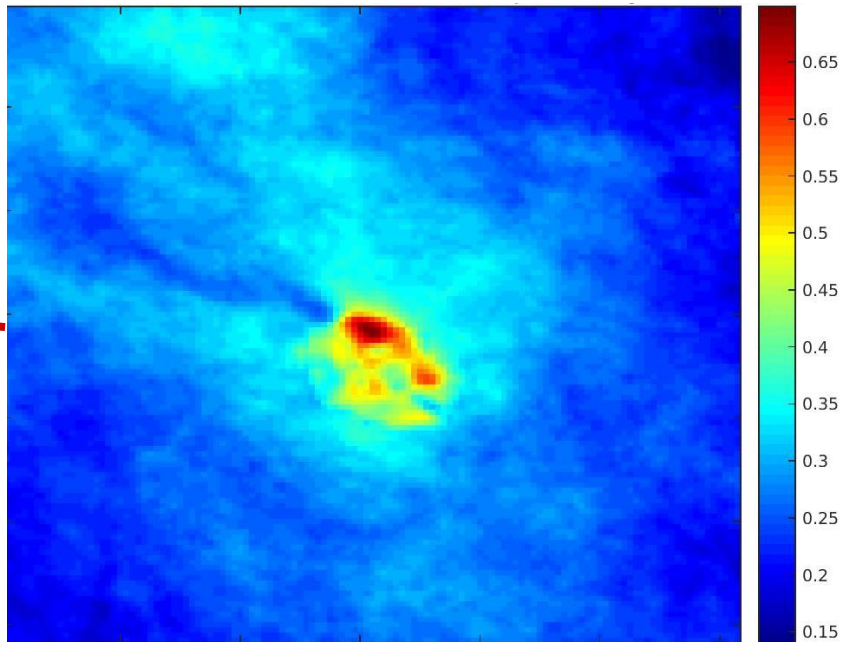

Spatial analysis in Reunion Island

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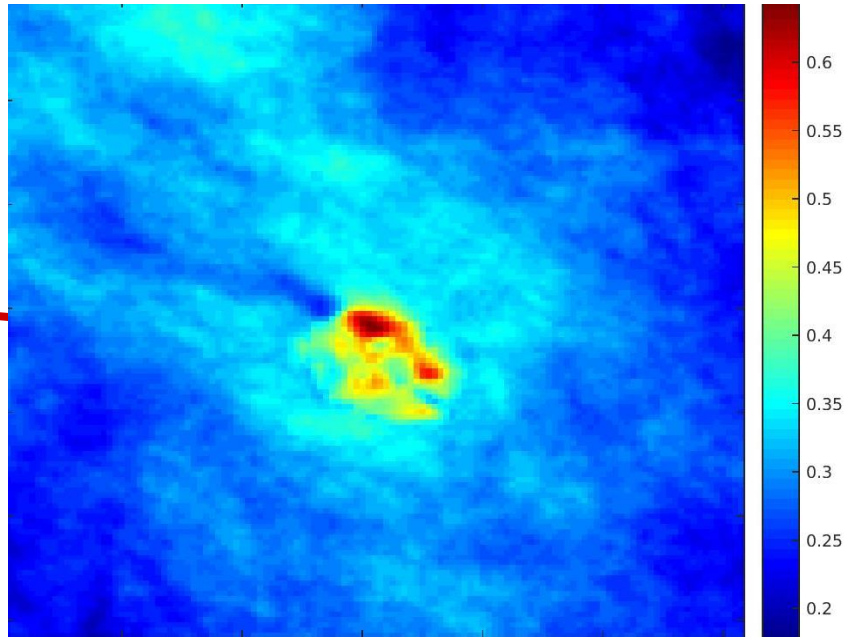
(-20.91° ; 55.48°)
Year 2013
GHI data from pyranometer
LE2P, université de La Réunion

Kc computed using
McClear Clear sky model

Intercorrelation map between
T0 and T0+120 min

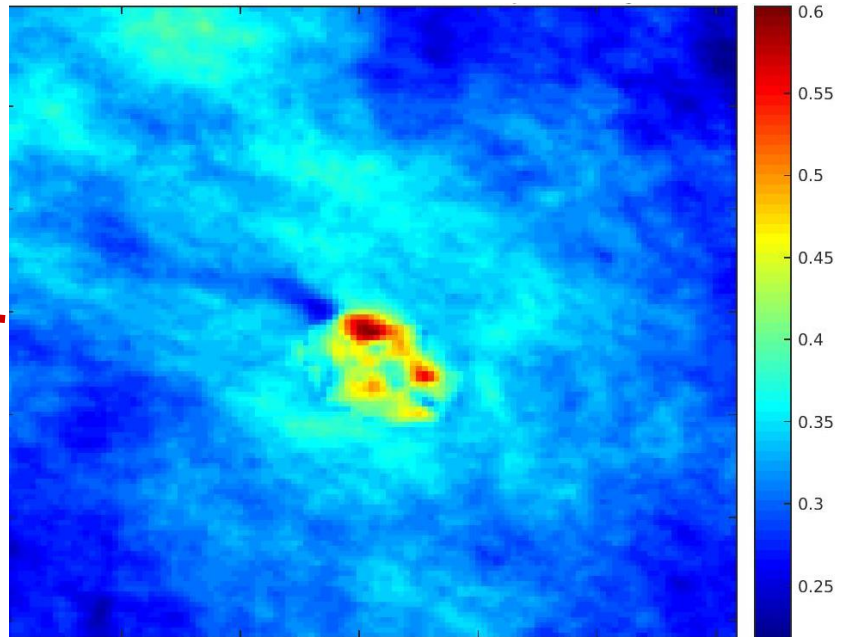


Spatial analysis in Reunion Island

Moufia – Saint-Denis
(-20.91° ; 55.48°)
Year 2013
GHI data from pyranometer
LE2P, université de La Réunion

Kc computed using
McClear Clear sky model

Intercorrelation map between
T0 and T0+150 min

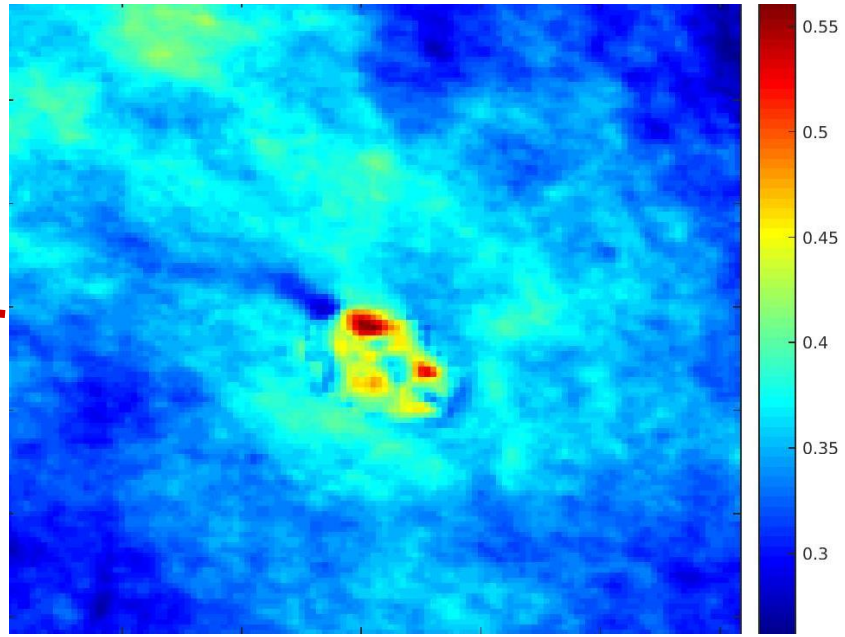


Spatial analysis in Reunion Island

Moufia – Saint-Denis
(-20.91° ; 55.48°)
Year 2013
GHI data from pyranometer
LE2P, université de La Réunion

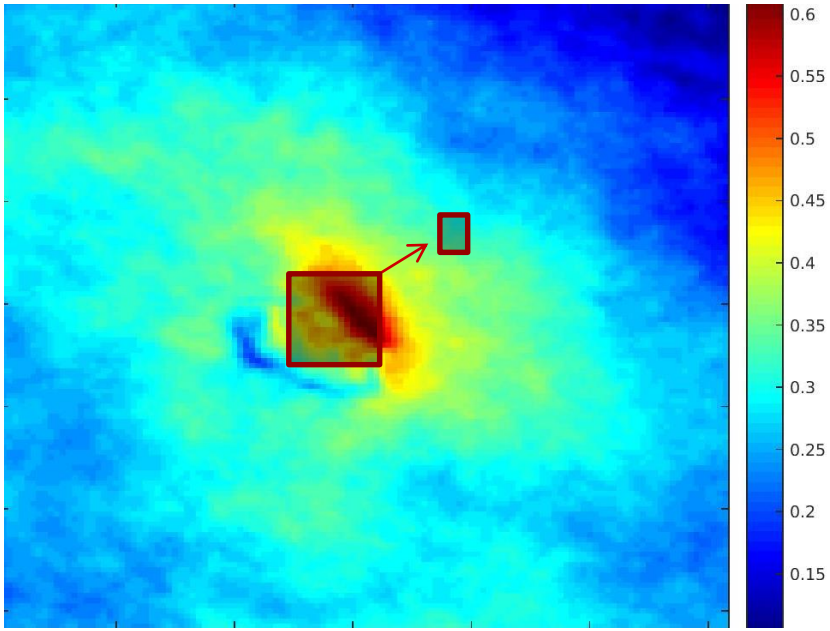
Kc computed using
McClear Clear sky model

Intercorrelation map between
T0 and T0+180min



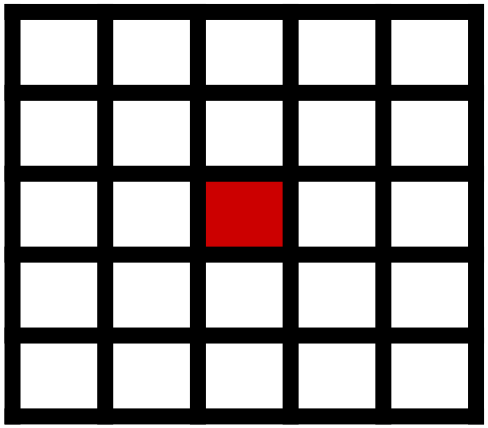
Combining auto-regression and motion analysis

- Location of priority exogenous data is not so obvious than in mainland
- We choose to use the CMV model to deduce priority pixels at each time step, instead of spatial analysis over one year



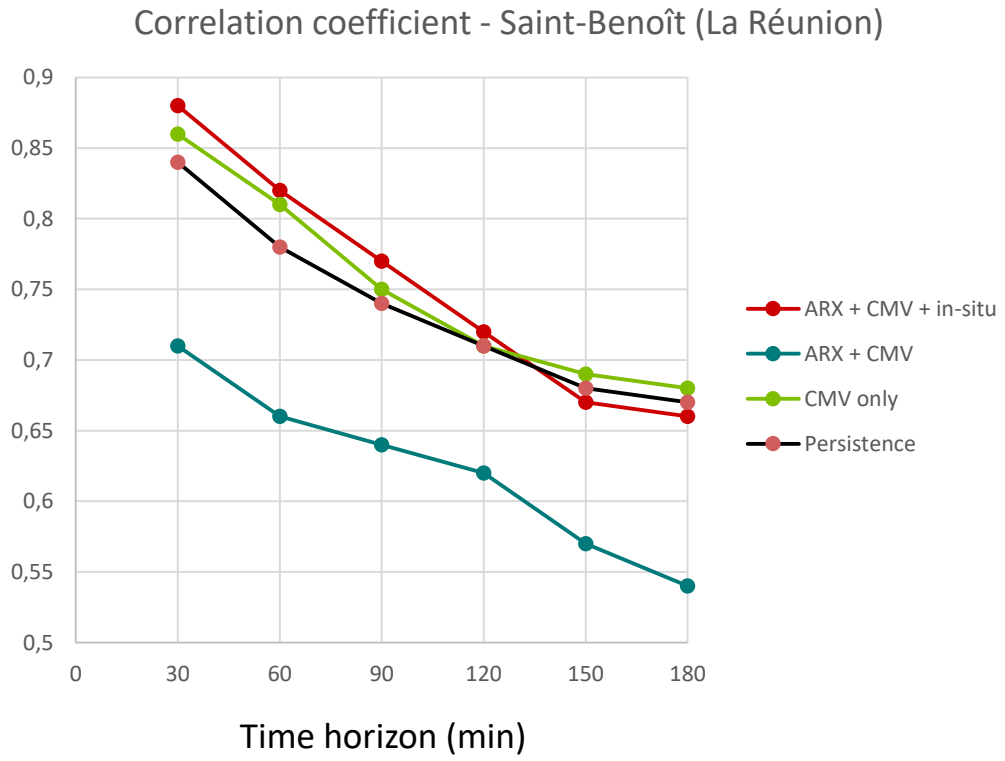
Implementation in Reunion Island

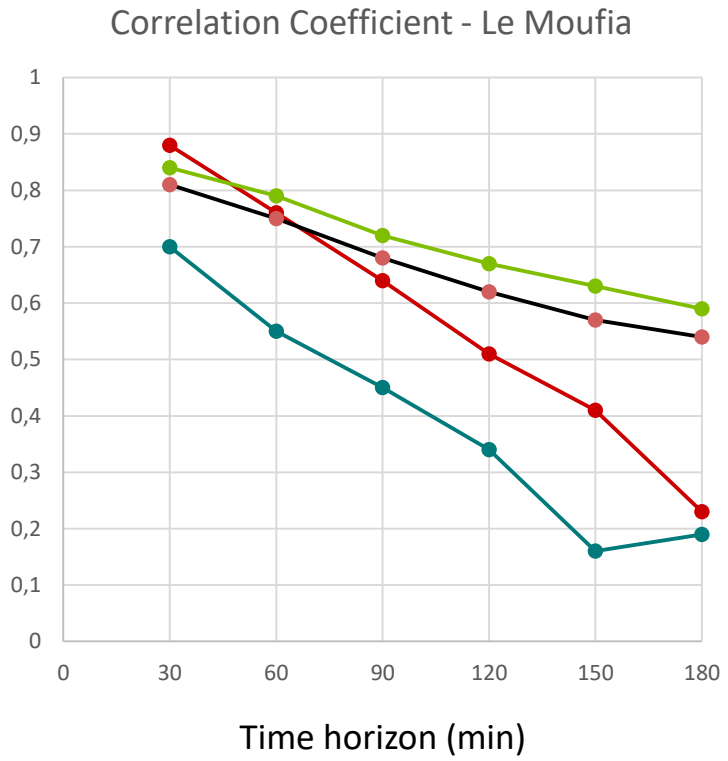
- ARX model trained on 2013 Kc data for both sites Le Moufia and Saint-Benoît
- Training on a half of 2013 values (randomly selected)
- Model assessed on the other half of the values
- Two options:
  1. Kc on the site is computed from in-situ data
  2. Kc on the site is computed from satellite assessment (if customer does not have historical measurement)



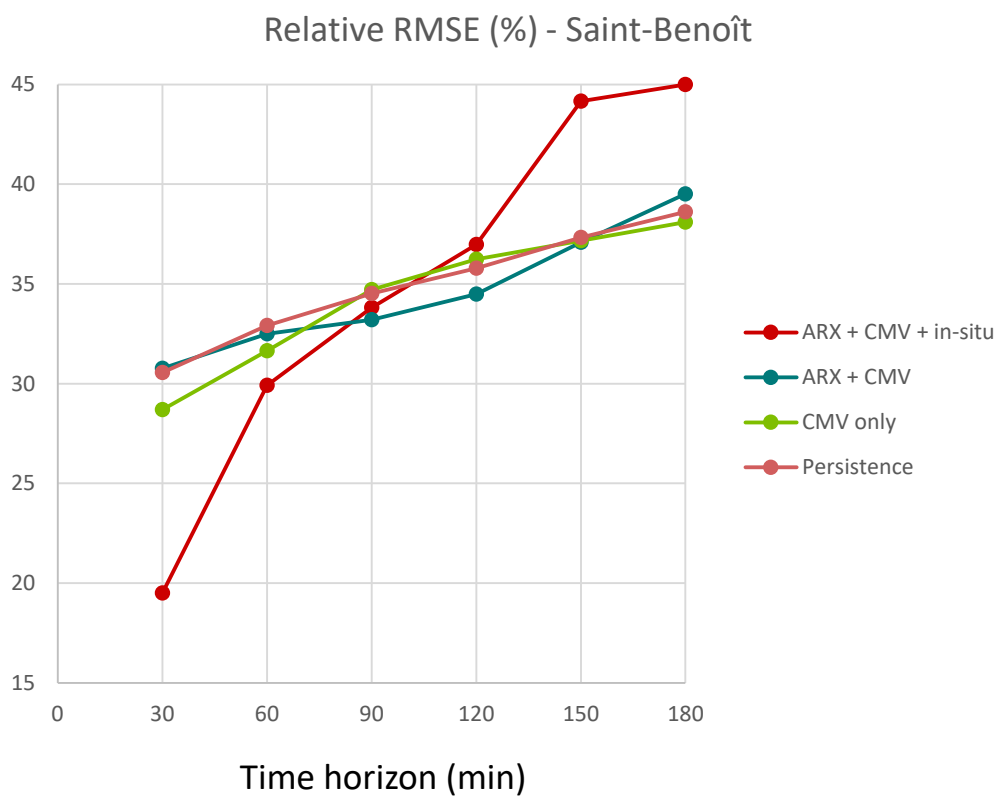
Meteosat-7 pixels

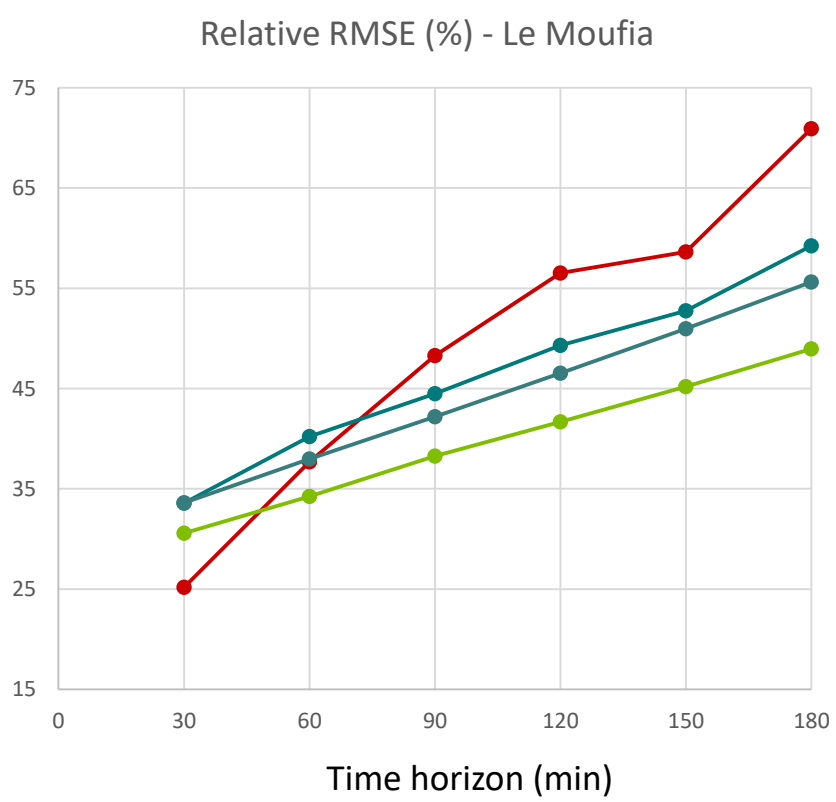
Results - Correlation



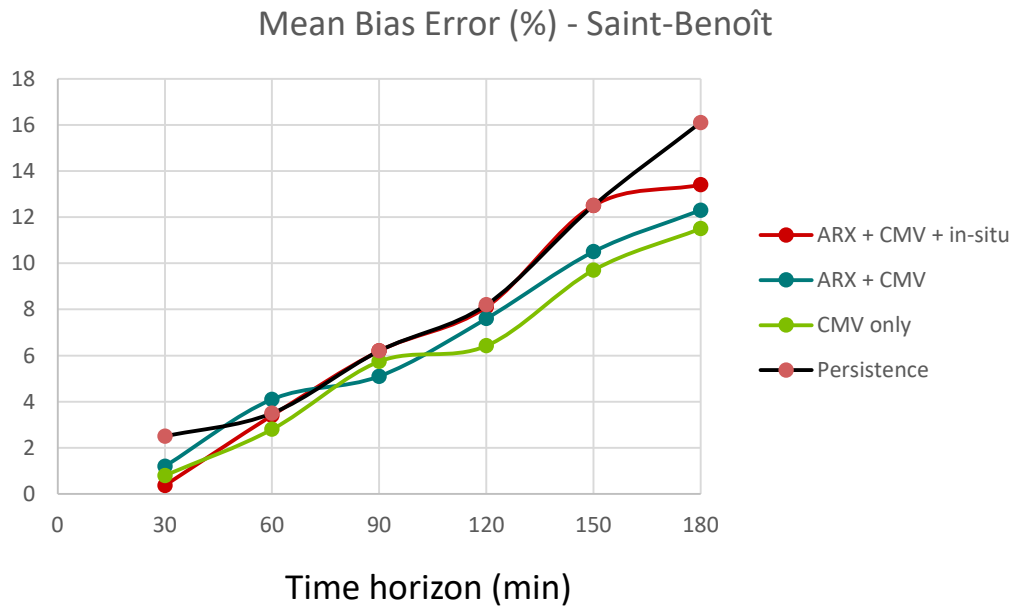


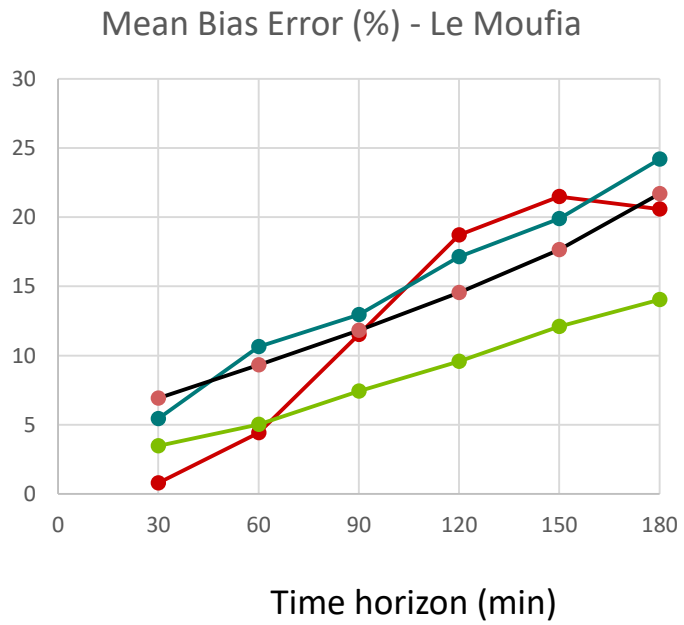
Results – RMSE





Results – Bias





Conclusion

- Autoregressive and motion analysis forecast models using satellite images have been evaluated on tropical insular areas in 2 sites of Reunion Island
- This work demonstrate that ARX model is a valuable complement for cloud motion-based model, especially for very short-term forecast (up to 60-90 min.)
- ARX model without in-situ measurements is much less accurate - historical measurements on-site are necessary
- Meteosat-7 has a time resolution of 30 min. Improvements are expected when MSG-1 will operate at longitude 40.5° (higher spatial resolution, 1 image every 15 min.)
- Local specific studies can be undertaken for further improvements (evolution of other parameters, e.g. temperature, humidity)

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