Creation of a 30 years-long high resolution homogenized solar radiation data set over the Benelux

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Context

- RMI faced with increasing demands for reliable solar resource data
  - Design, planning and operation of solar energy systems
  - Architectural design, e.g., passive solar building design
  - Agrometeorology, e.g., crop grow models
  - Evapotranspiration models, ecosystem models

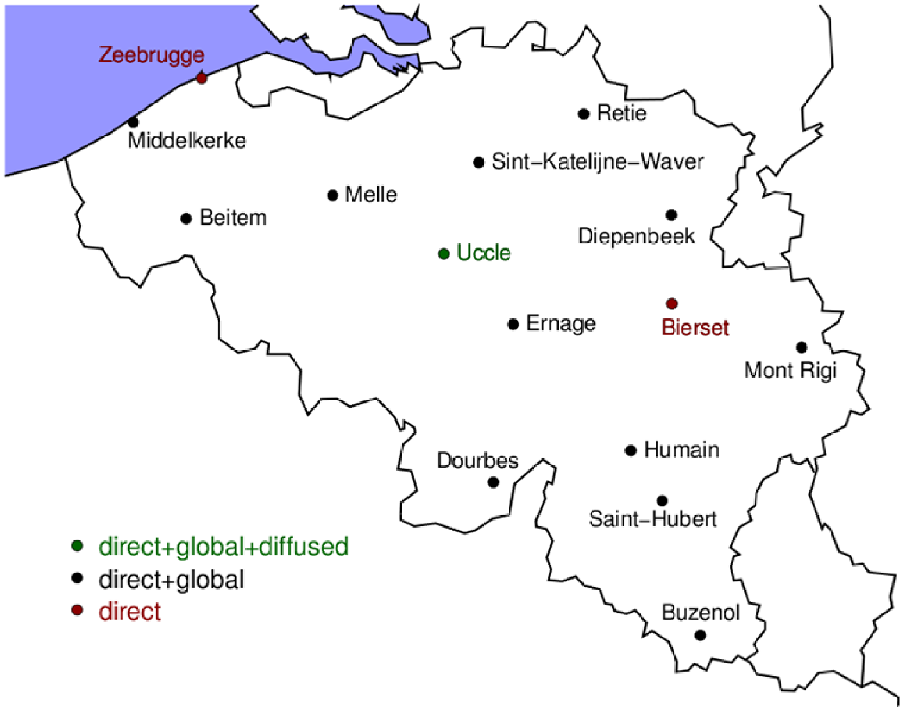
- Solar radiation observed by means of networks of meteorological stations

  → Costs for installation and maintenance: very high

  → National networks comprise only few stations

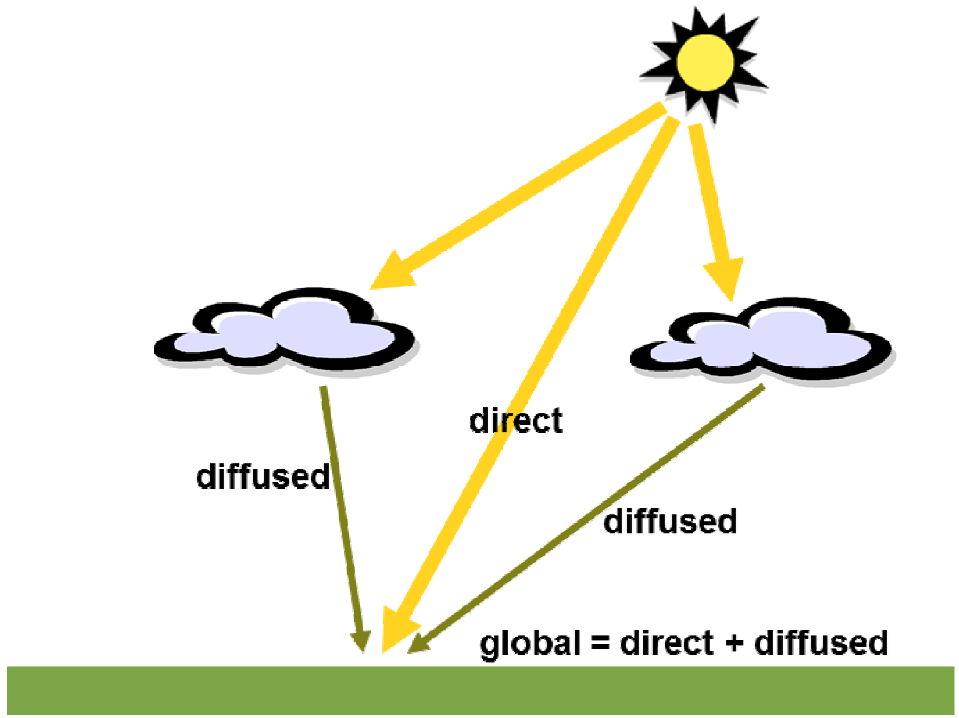
  → Inadequate for many applications

Context: RMI's radiometric network



15 automatic weather stations
(global solar radiation: 13 stations)

temporal resolution: 10 min. average



Semi-automated data QC

Journée and Bertrand , 2011. Solar Energy 85:72-86

Raw 10-min data

Every day — Automatic QC procedures

10-min data (free of gross errors)

As soon as possible — Human QC

Controlled 10-min data

Hourly and daily totals

Automatic QC

- physical threshold tests
- step tests (snow, shadow, bird dejection, …)
- persistence tests (standard deviation within acceptable limits)
- QC envelope tests
- proposal of model estimates

Automatic QC

- Spatial consistency

Context: development of solar-based renewable energy technologies (SES)

7% of the Belgian households equipped with PV systems

- Site specific information: essential

  → Design details and economic feasibility of SES :
  direct function of local solar resource (magnitude & quantity)

- Full climate characterization: several decades of measurement

  → Only a subset of stations have been operating for a long period (inter-annual variability & long-term trend)

  → Mapping by interpolation/extrapolation of measurements:
  - possible but large errors
  - smooth out local specificities

- Satellite-based retrieval of solar radiation: highly valuable

  → Long-term time series of data without the expense and wait !

The Heliosat method

→ **<u>PRINCIPLE</u>**: a difference in global radiation perceived by the sensor is only due to a change in the apparent albedo, which is itself due to an increase of the radiation emitted by the atmosphere towards the sensor

<u>reflectance</u> : ratio of the total amount of radiation reflected by a surface to the total amount of radiation incident on the surface

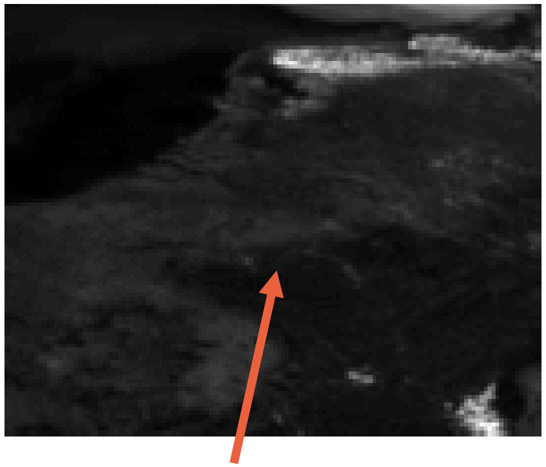
$$n = \frac{\rho - \rho_{cs}}{\rho_{\max} - \rho_{cs}}$$

n = cloud index

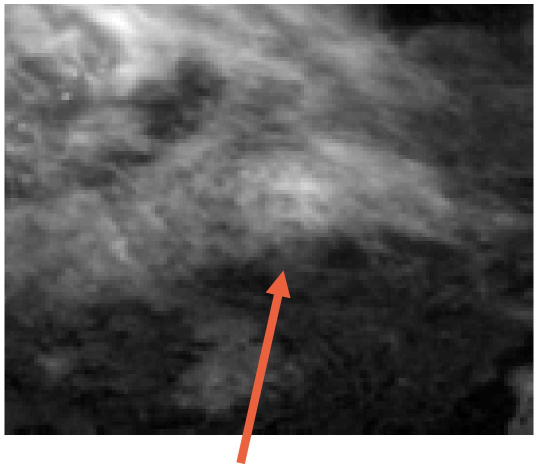
ρ = reflectance or apparent albedo

ρ_{max} = apparent albedo of the brightest cloud

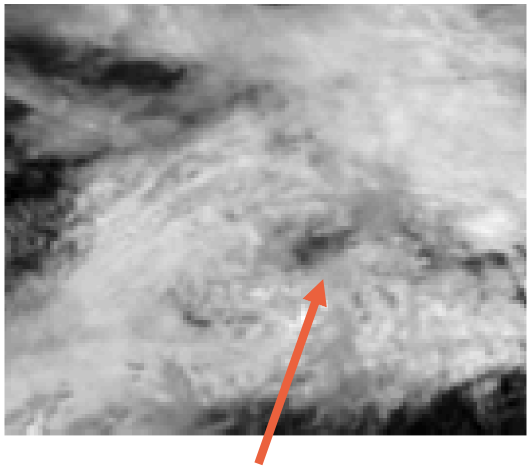
ρ_{cs} = apparent ground albedo under clear-sky condition



clear sky: n=0



partly cloudy n=0.5



Cloudy: n=1

The Heliosat method

- The cloud index, n, is related to the clear-sky index, k:

$$k = 1 - n$$

- *The* clear-sky index, k, is the ratio between the all-sky surface irradiance, G, and the clear-sky surface irradiance, G_{clear}:

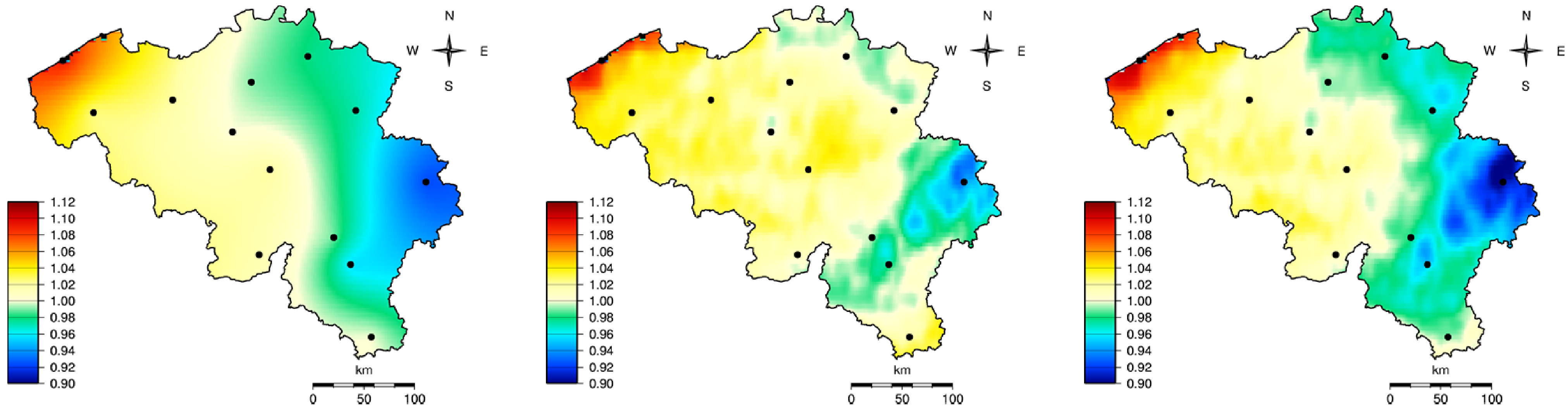
$$G = k * G_{clear}$$

- G_{clear} can be calculated by radiation transfer calculations using the fast and accurate clear-sky model ***gnu-MAGIC*** *(Mesoscale Atmospheric Global Irradiance Code, Mueller et al., 2009,* http://sourceforge.net/projects/gnu-magic/)

Meteosat & stations data – merging

Spatial distribution of surface solar radiation in Belgium

Interpolation **Satellite derived** **Merged data**



Relative distribution for 2009 with respect to Uccle (100% = 1083 kWh/m²)

KRIGING WITH EXTERNAL DRIFT (interpolate a non-stationary random field from observation at selected stations and the knowledge of a densely sampled auxiliary variable):

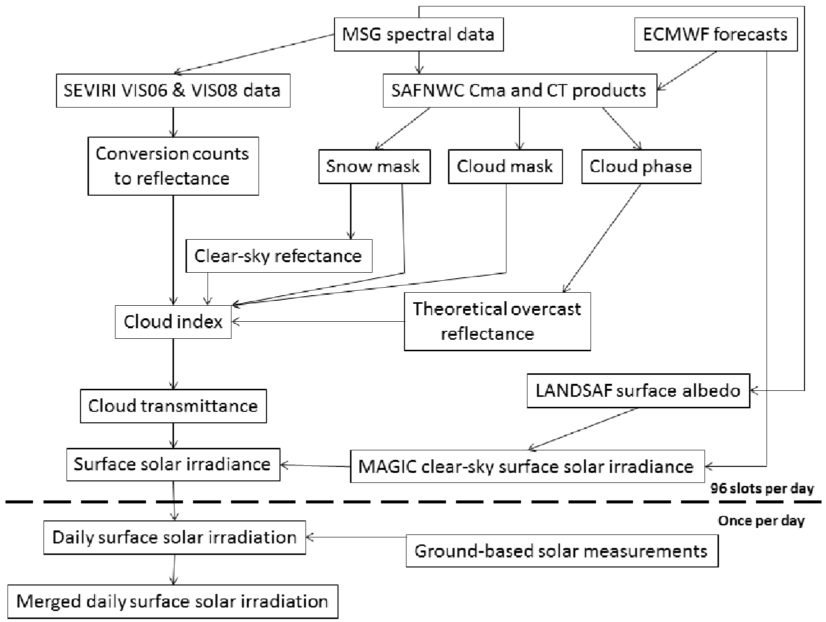
→ takes advantage of the **accuracy of ground measurement**
global coverage of satellite data

→ always improves the result (**leave-one-out cross validation**: the value at one measuring station s was successively omitted . Then the value of the omitted site was calculated from the measurements of the other sites either by interpolation or by merging with the satellite data)

Journée & Bertrand (2010). Remote Sensing of Environment 114:2692-2704
Journée et al. (2012). Solar Energy 86:3561-3574

Climatology:
METEOSAT images + ground measurements

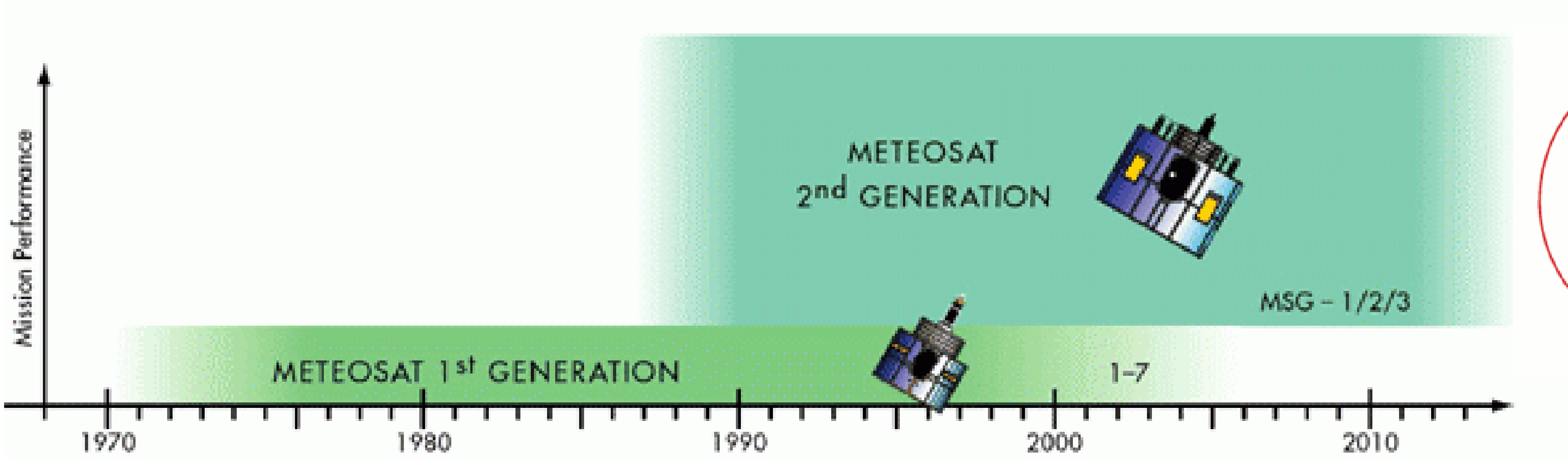
- **Meteosat First Generation (MFG)** MAGIC/Heliosat-2 surface irradiance (global radiation) dataset: 1983-2005 (CM-SAF). Daily cumul regridded to a 0.03°x0.03° lat-lon grid
- RMI's MAGIC/Heliosat-2' algorithm applied to **Meteosat Second Generation (MSG)** Satellite images: 2005-present. 6 km x 3.3 km SEVIRI resolution regridded to a 0.03°x0.03° lat-lon grid



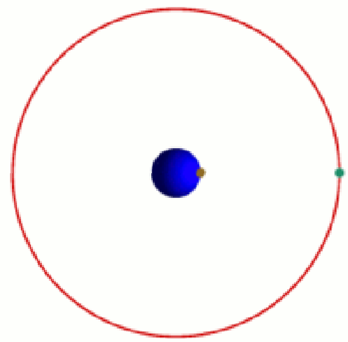
Demain et al. (2013). Adv. Sci. Res 10:7-13

- **46 ground stations** (13 RMI + 33 KNMI).

Meteosat geostationary satellites



(Crédits: Alcatel Aleonia Space)



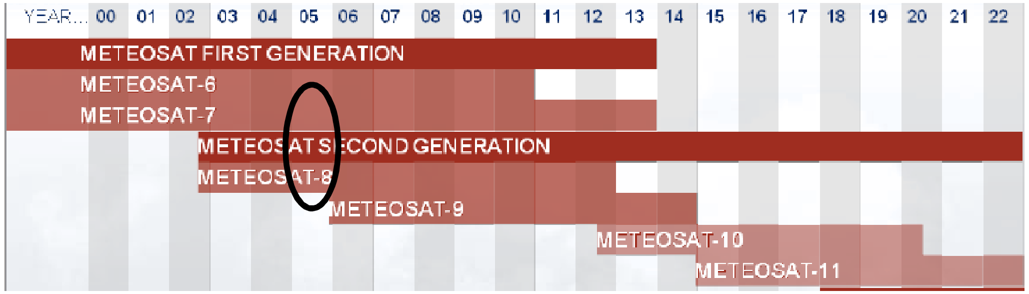
METEOSAT FOV

MFG, 1983-2005: 6 satellites (2 to 7)
MSG, 2006-2012: 3 satellites (1 to 2)

Parameter / Satellite-Instrument	**MVIRI (Meteosat First Generation)**	**SEVIRI (Meteosat Second Generation)**
Imaging cycle	30 minutes	15 minutes
Visible channels	1 (0.5 - 0.9 µm)	4 (0.4-1.6 µm) inclusive HRV
Infrared channels	2 (6.4 µm & 11.5 µm)	8 (3.9-13.4 µm)
Resolution of visible channels	2.25 km	1 km HRV
Resolution of infrared channels	5 km	3 km
Detectors	4	42

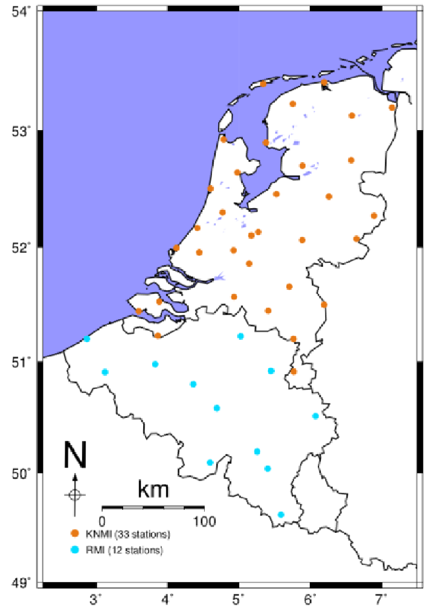
Overlap correction approach

- 10 months of overlap period between Meteosat 7 and 8 in 2005



→ Evaluate the agreement between the MFG/MSG based solar radiation and ground stations data

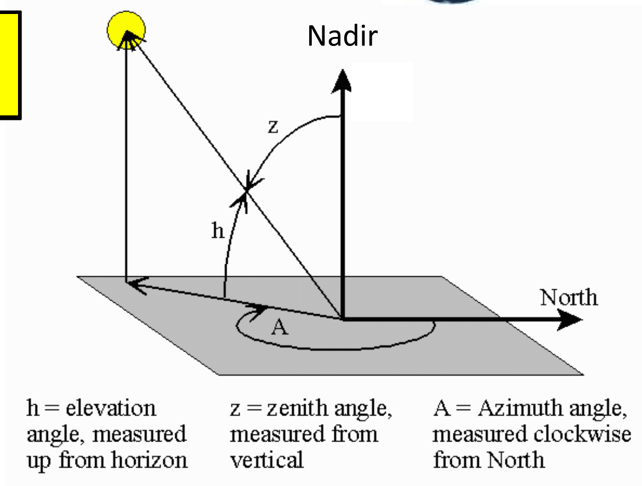
03/05 to 12/05 comparison (daily basis)				
	Satellite mean ($Wh.m^{-2}$)	Stations mean (Whm^{-2})	MAE (Whm^{-2})	MBE (Whm^{-2})
MFG - RMI	3384.76	3250.83	281.18 (8.65 %)	133.93 (4.12 %)
MSG - RMI	3281.24	3250.83	245.40 (7.55 %)	30.41 (0.93 %)
MFG - KNMI	3308.79	3174.77	288.75 (9.09 %)	134.02 (4.22 %)
MFG - KNMI	3193.85	3174.77	228.02 (7.18 %)	19.09 (0.60 %)



→ Develop transfer functions correction

Overlap correction approach

$$G_{MFG\ COR}(x,y,t) = G_{MFG}(x,y,t) * \tilde{A}(x,y,z)$$

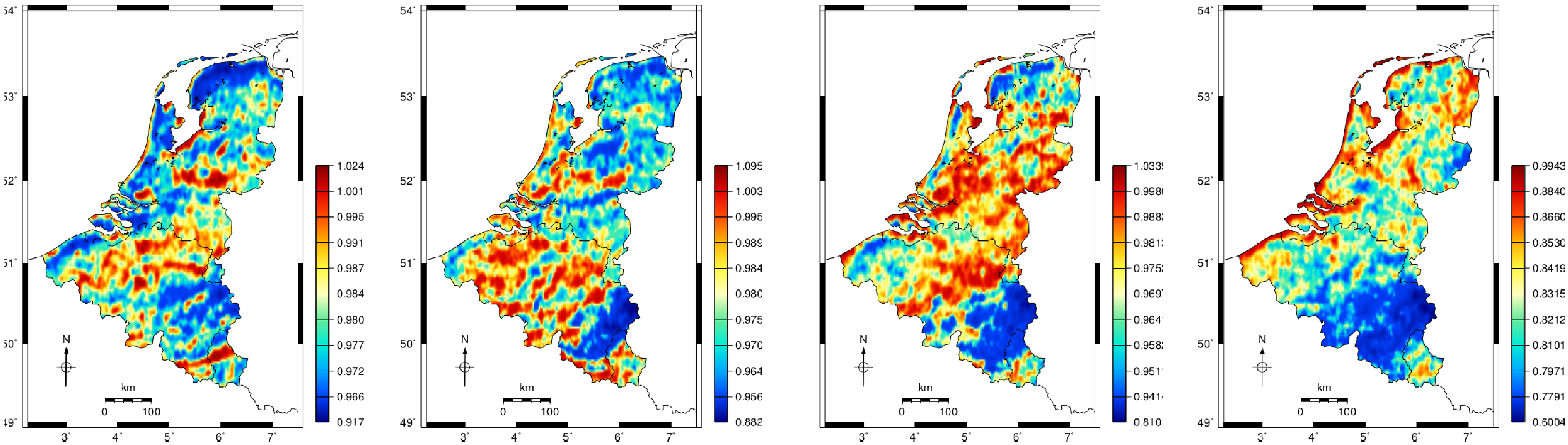


➡ $\tilde{A}(x,y,z)$ = median of $G_{MSG,\ OVERLAP}(x,y,z)/G_{MFG,OVERLAP}(x,y,z)$

→ mid-day z value

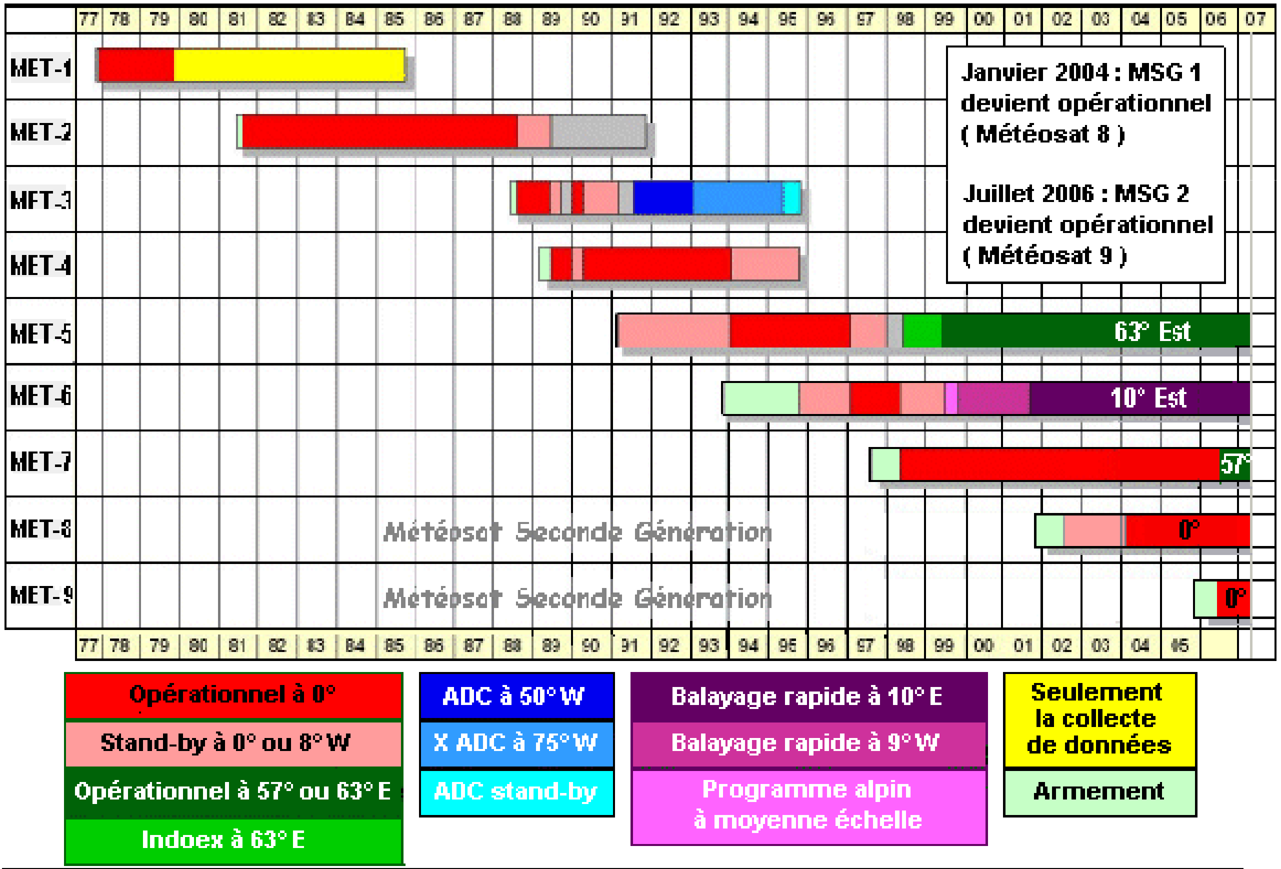
→ 4 bins:]0.40, 0.65[,]0.65, 0.90],]0.90, 1.15],]1.15, 1.40]

$\tilde{A}(x,y,z_1)$ $\tilde{A}(x,y,z_2)$ $\tilde{A}(x,y,z_3)$ $\tilde{A}(x,y,z_4)$



→ Assume that all instruments before 2005 have similar spectral sensitivities and thus the pattern of differences between MSG and MFG instruments are kept the same !

History of Meteosat satellites used to derived the dataset



Satellite	Start	End
MET-2*	16/08/81	11/08/88
MET-3	11/08/88	19/06/89
MET-4	19/06/89	24/01/90
MET-3	24/01/90	19/04/90
MET-4	19/04/90	04/02/94
MET-5	04/02/94	13/02/97
MET-6	13/02/97	03/06/98
MET-7	03/06/98	31/12/05
MET-8	31/12/05	11/04/07
MET-9	11/04/07	21/01/13

* Gain shift May 1987

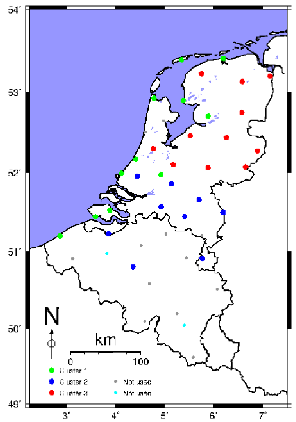
→ Switches between instruments within a given generation of satellite might have introduced additional inhomogeneities

Homogenization software approach

HOMER 2.6

I. Homogenization of ground stations measurements (monthly data)

Detected break(s)	Nbr Station(s)
0	1 (0, 1, 0)
1	4 (2, 1, 1)
2	14 (4, 3, 7)
3	9 (4, 2, 3)
4	3 (1, 2, 0)

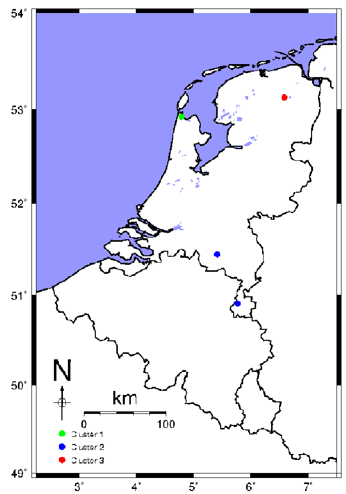


→ Minimum requirement: 15 years of continuous data over the time period 1983-2012

→ 31 stations (3 clusters)

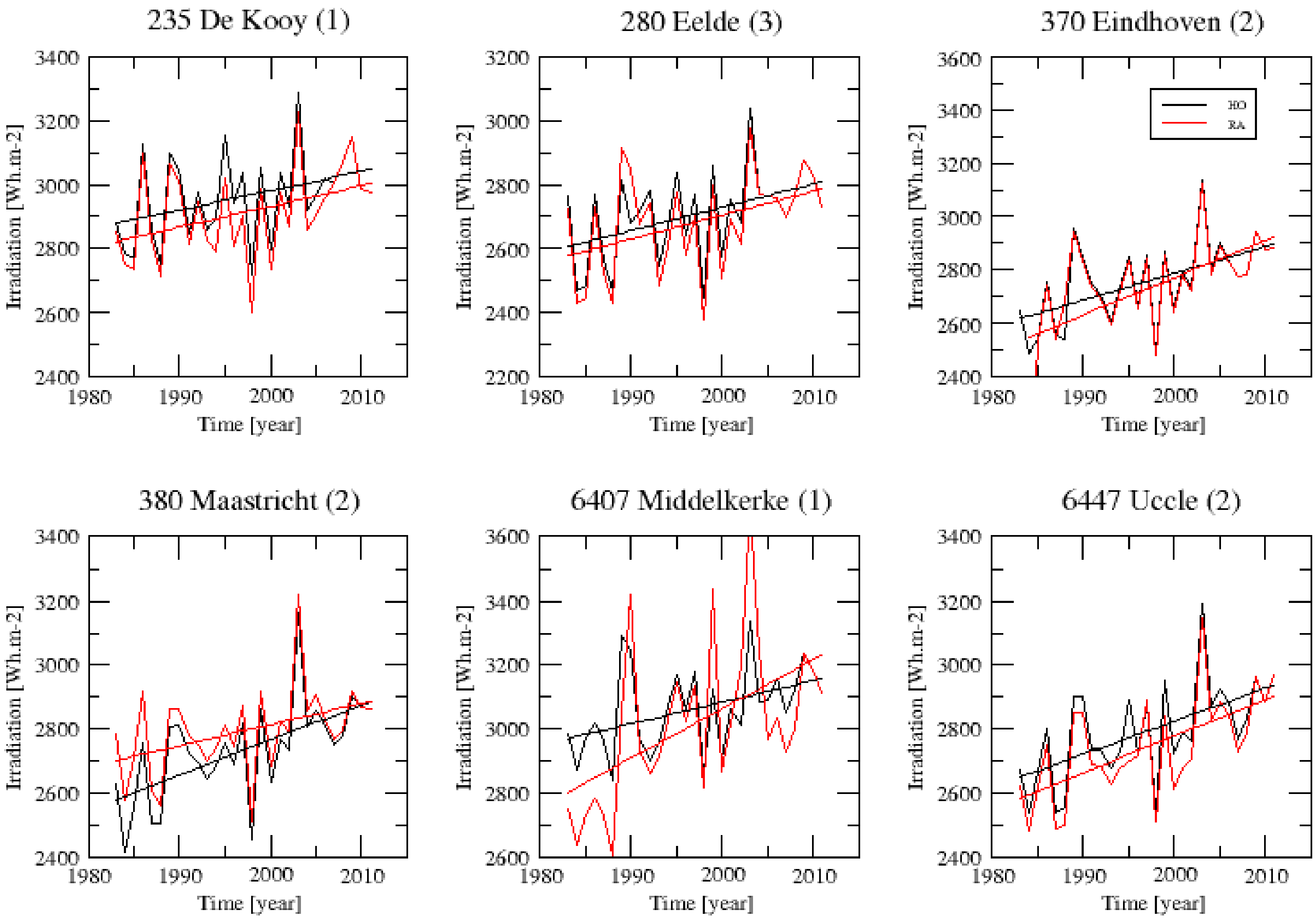
II. Breaks detection in the satellites derived values using the homogenized stations time series

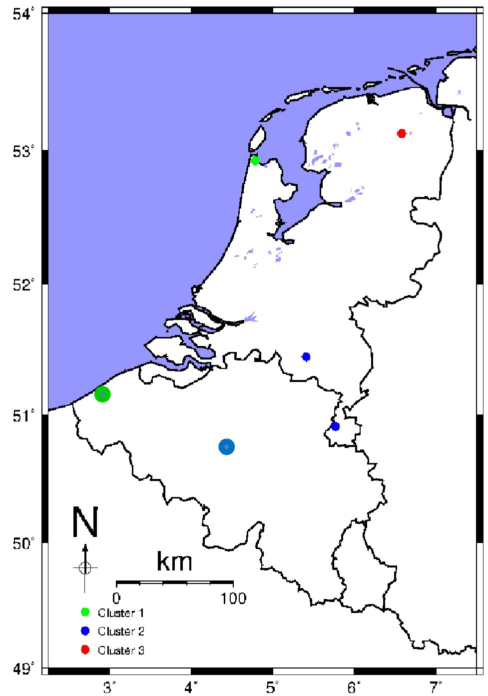
Reference Stations	Years of detected breaks							
De Kooy	1986	1989	1992	1997	2000	2003	2005	2009
Maastricht	1986	1988	1993	1995	1999	2002	2005	2008
Eindhoven	1986	1988	1993	1996	2000	2003	2005	2008
Eelde	1986	1988	1993	1997	2001	2003	2005	2008
Dates of Breaks	**09/86**	**10/88**	**07/94**	**08/96**	**04/01**	**10/03**	**02/06**	**04/09**



III. Use the detected breaks to homogenize the satellites derived time series over the full domain

Stations homogenisation





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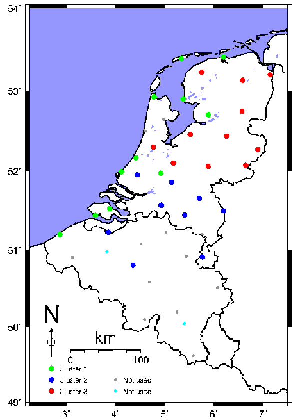

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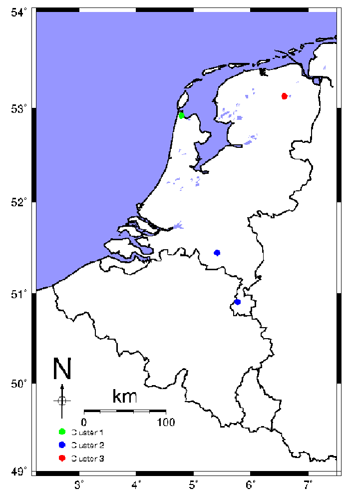
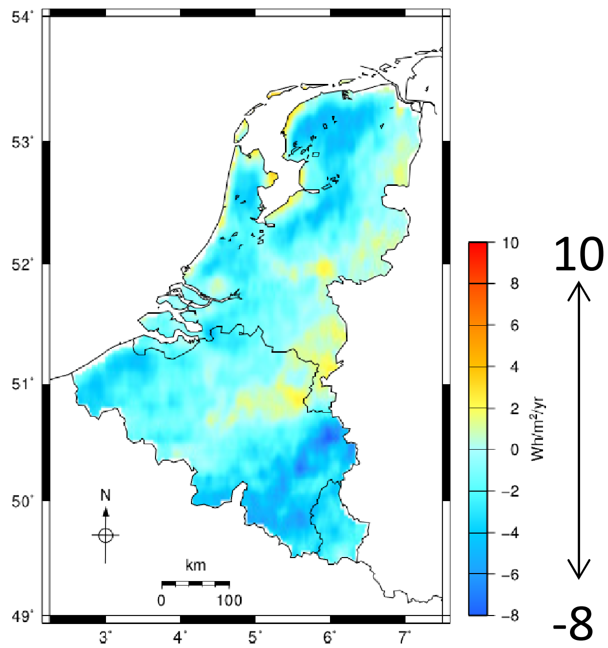


III. Use the detected breaks to homogenize the satellites derived time series over the full domain

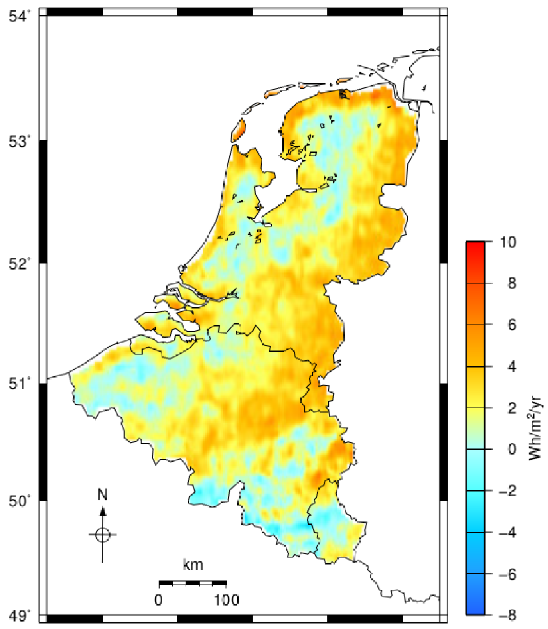
Trends – Meteostat derived dataset

$Y = A * X + B$

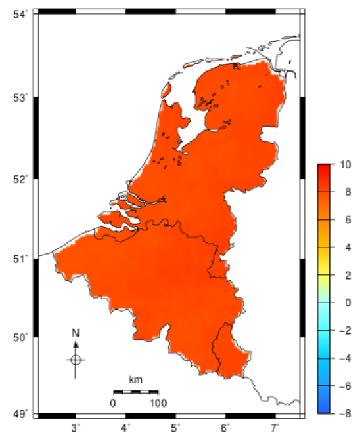
Raw data (RA)

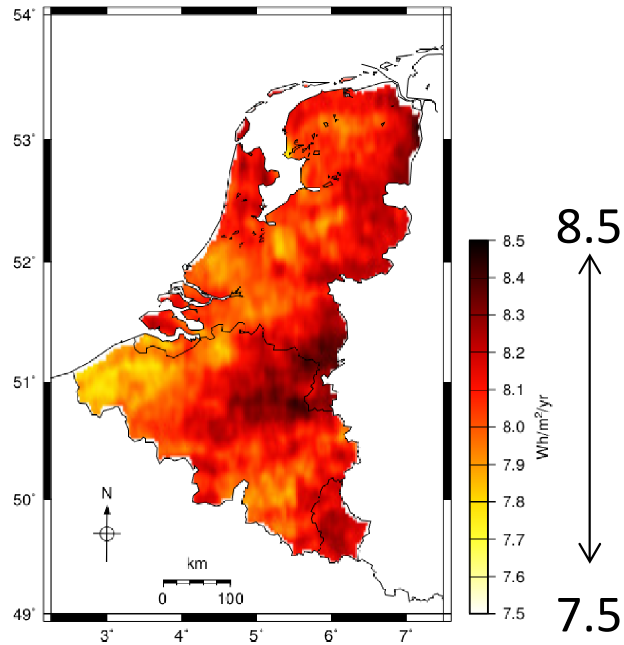


Corrected data (COR)



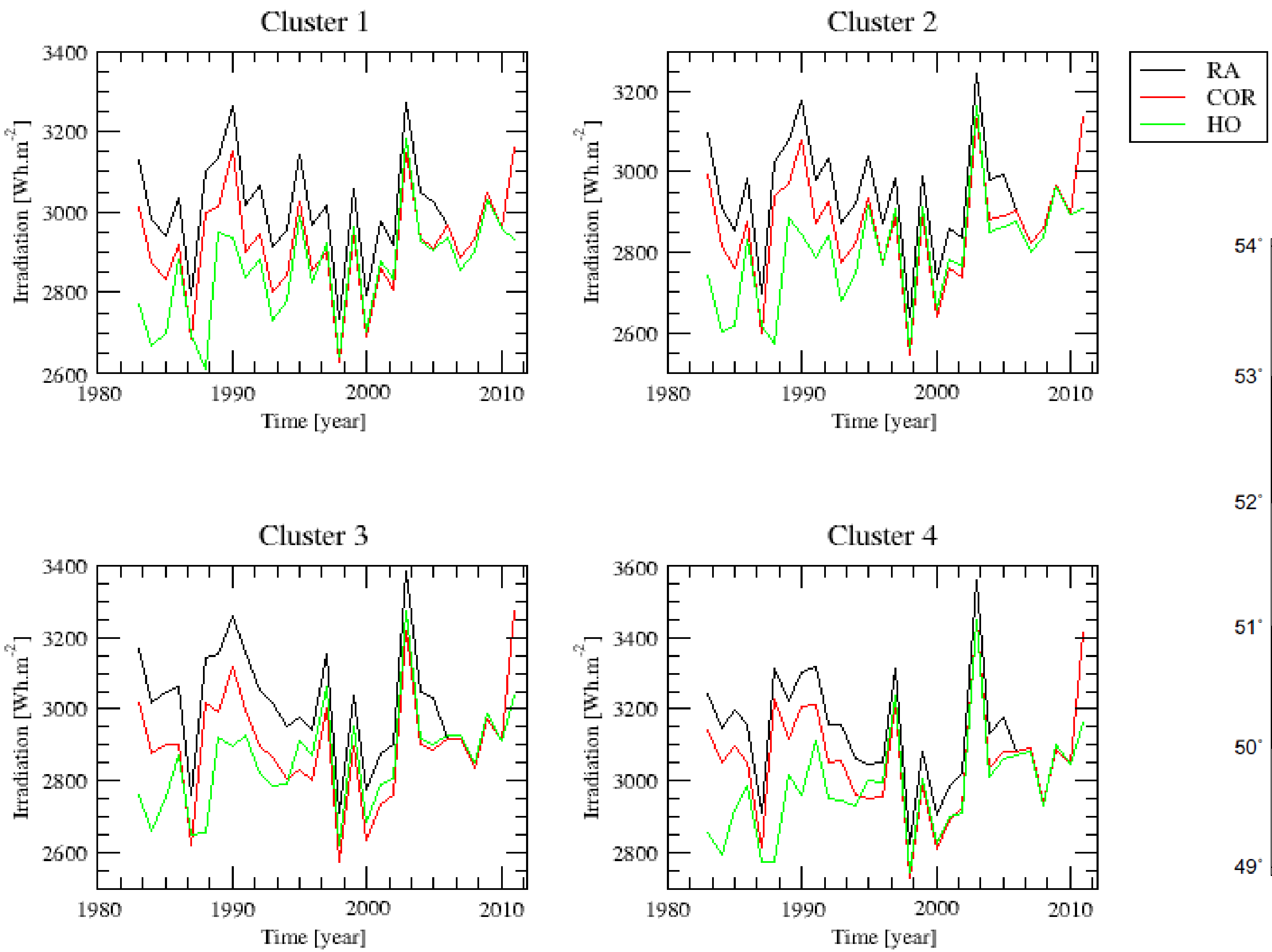
Homogenized data (HO)

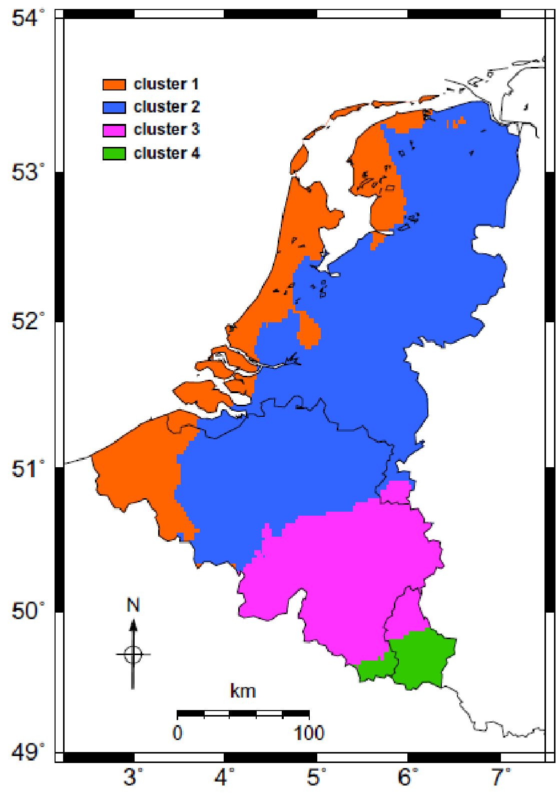




Cloud cover change
→ Climatological aerosol database used in the retrieval process

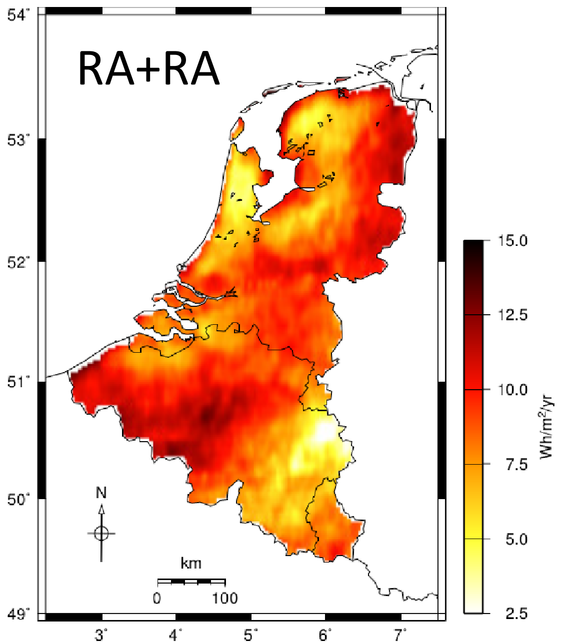
Meteosat derived dataset

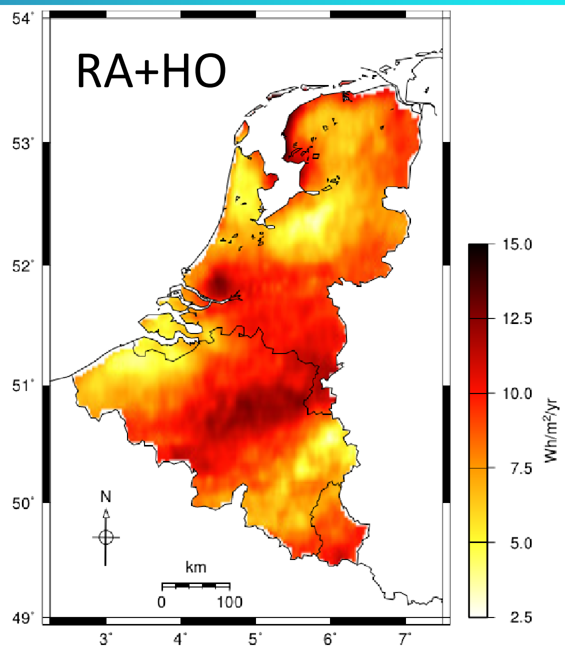


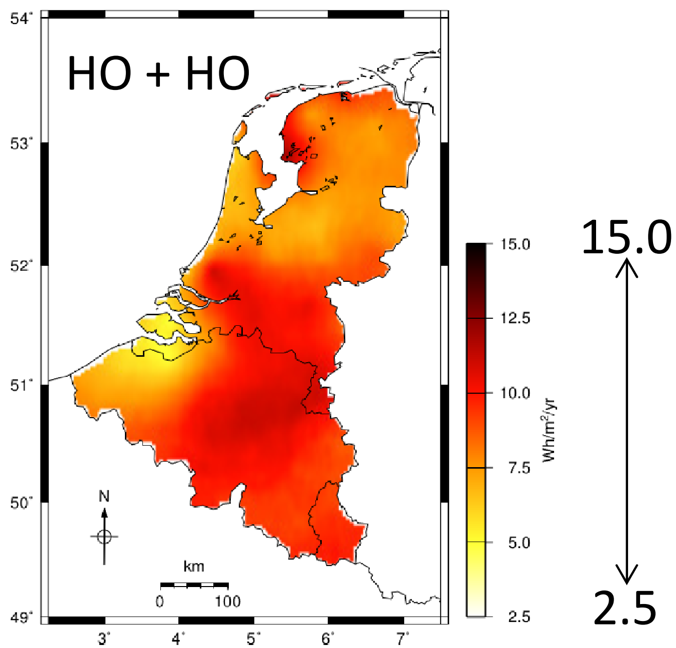


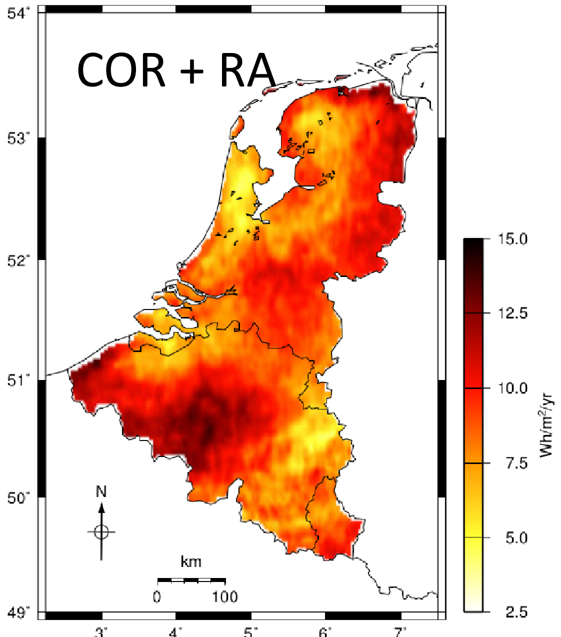
Trends –merged data

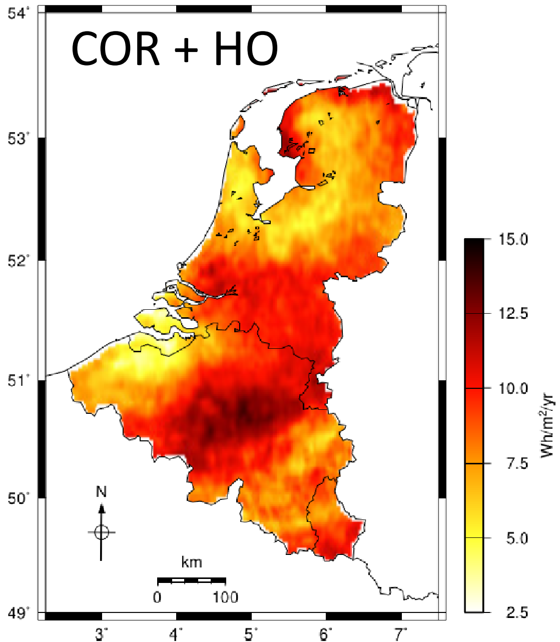
$\boxed{Y = A * X + B}$





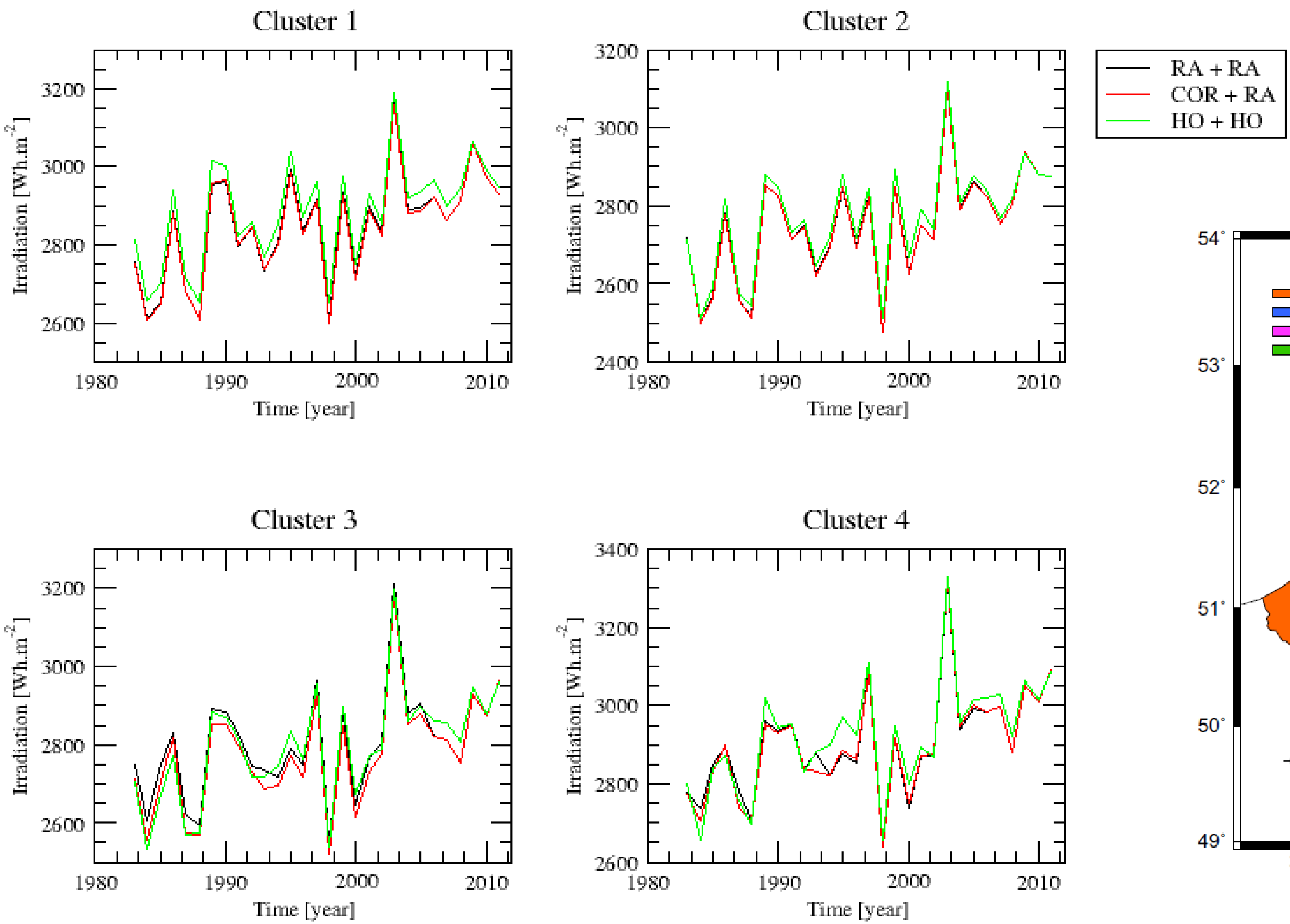


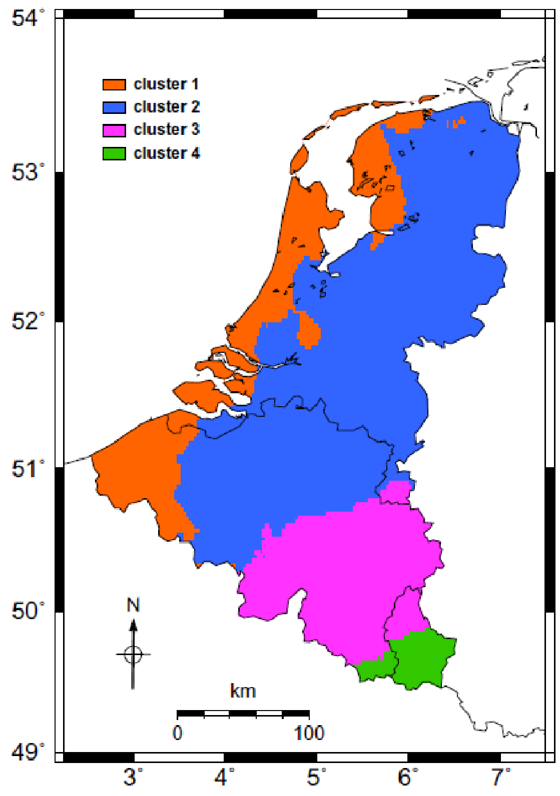




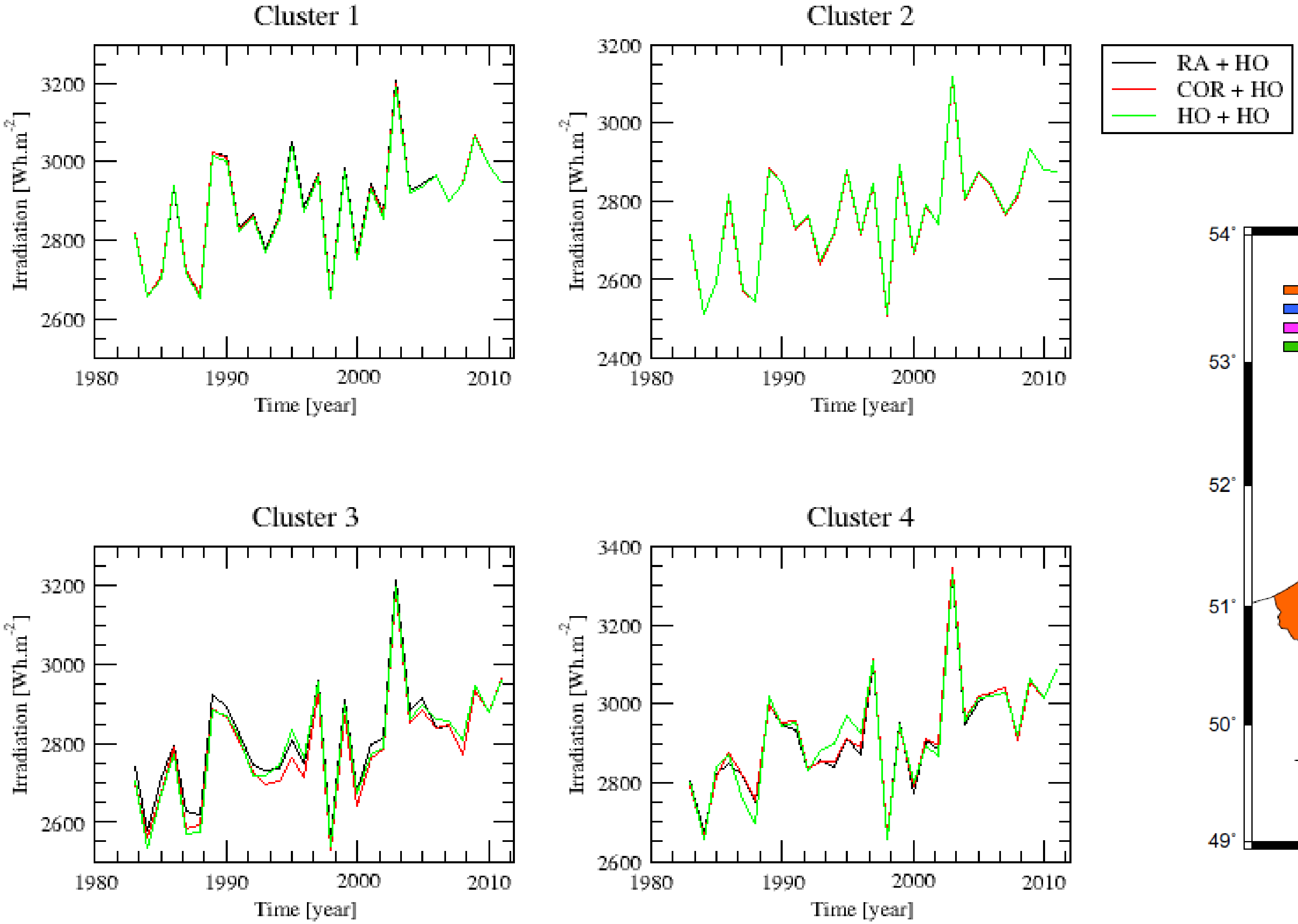
Cloud cover + aerosols direct effect

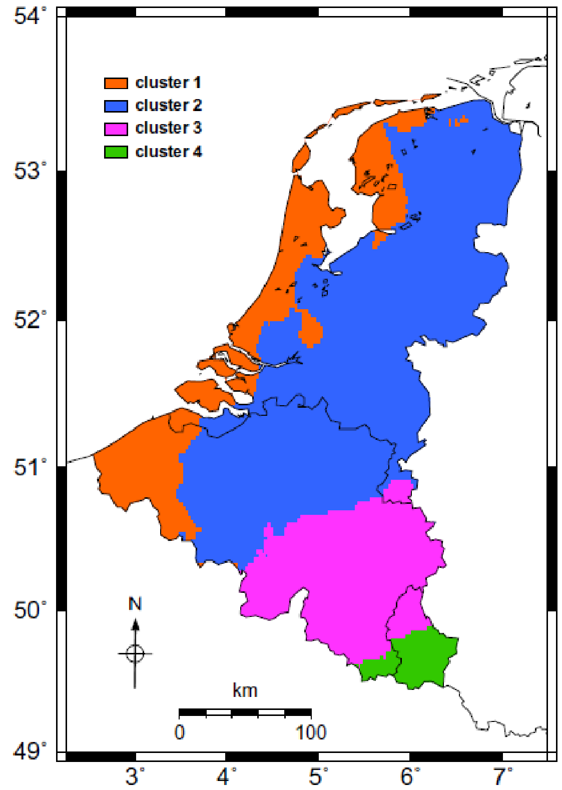
Merged dataset (RA stations)





Merged dataset (HO stations)





Clusters 3 & 4: no ground stations

→ larger dependency on the auxiliary variable during the merging process !

Conclusions

- Two different approaches have been considered to generate a 30-years long solar radiation database over the Benelux from Meteosat satellites images

  → Only the "homogenization software approach" allows to adjust for both intra- and inter- satellites generations induced inhomogeneities

- Because of our merging strategy homogenization of the ground measurements measurements appears to be of the prime importance

  → Impact of the inhomogeneities in the auxiliary variable is limited in the merged product

QC envelope tests

→ Operate in a dimensionless space within which expectancy envelopes or quality envelopes are defined

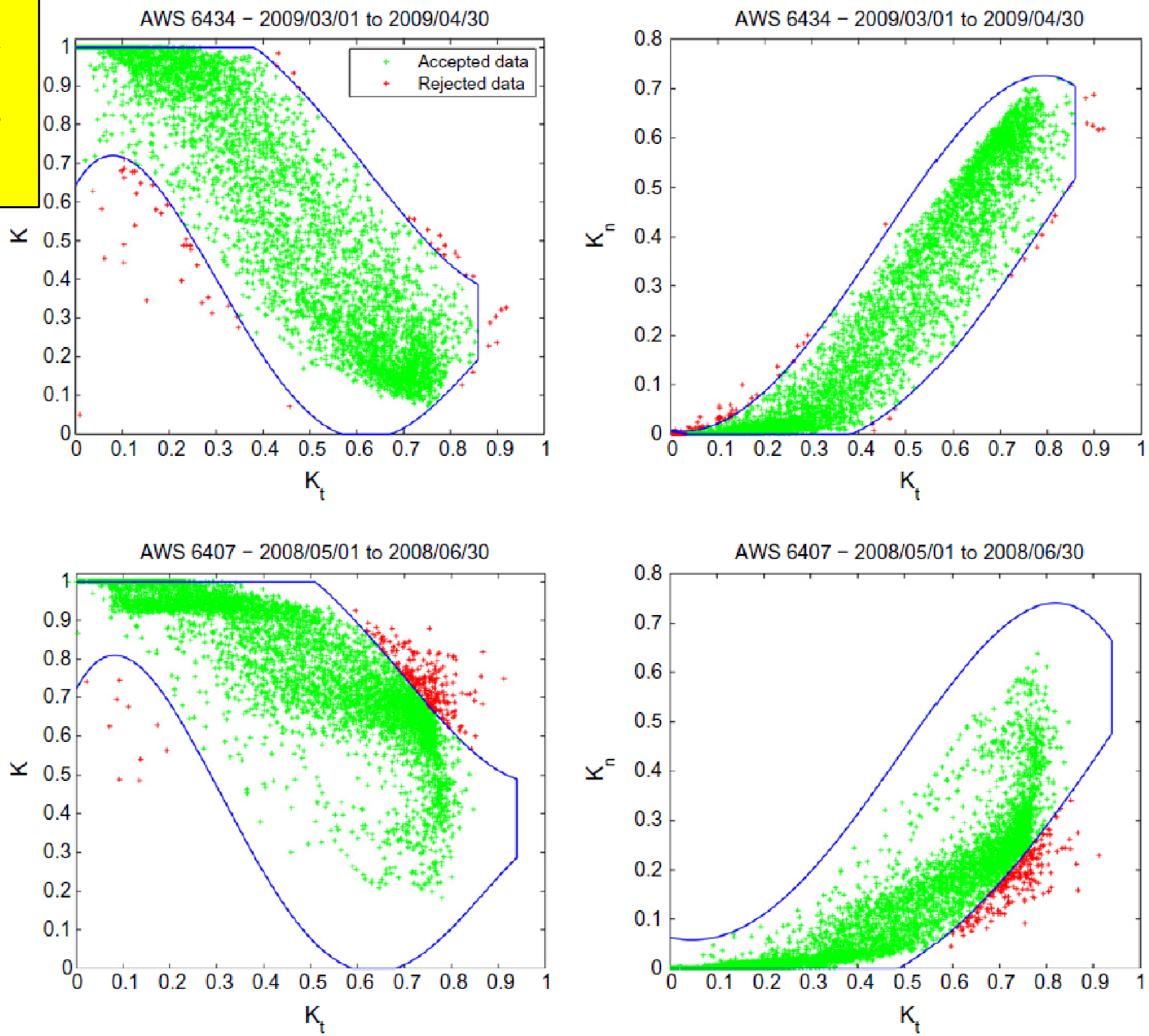
Variable that form the abscissa and ordinate are:

K_t = G/E   Clearness index

K_n = B/E   Beam transmittance

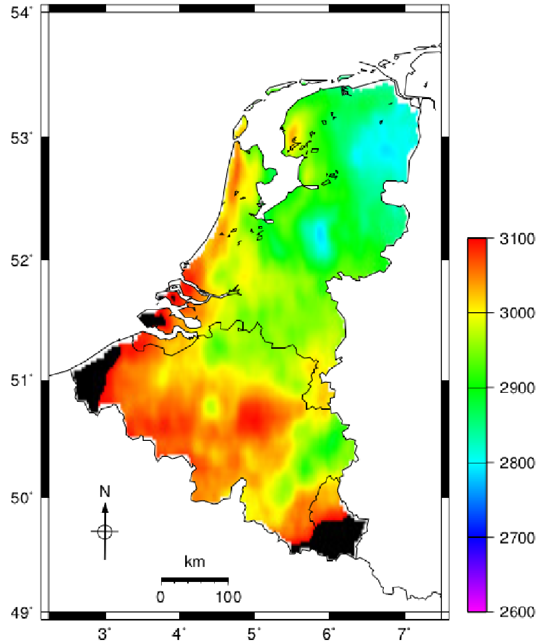
K   = D/G Diffuse ratio

K_t – K space   **K_t – K_n space**



Mean – Meteosat derived dataset

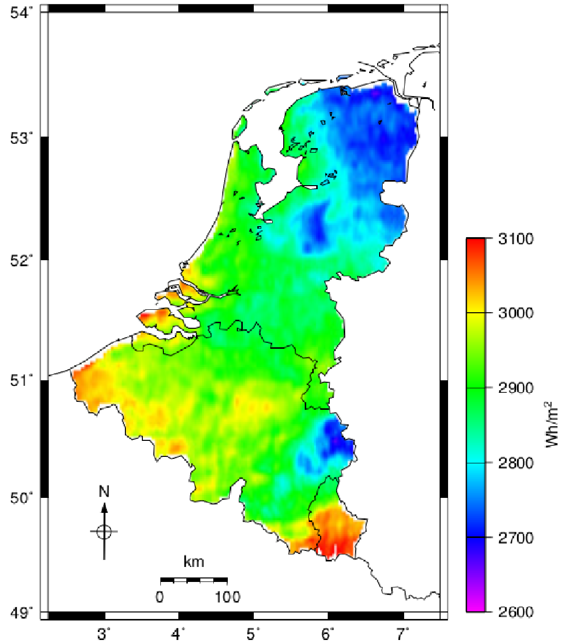
Raw data (RA)



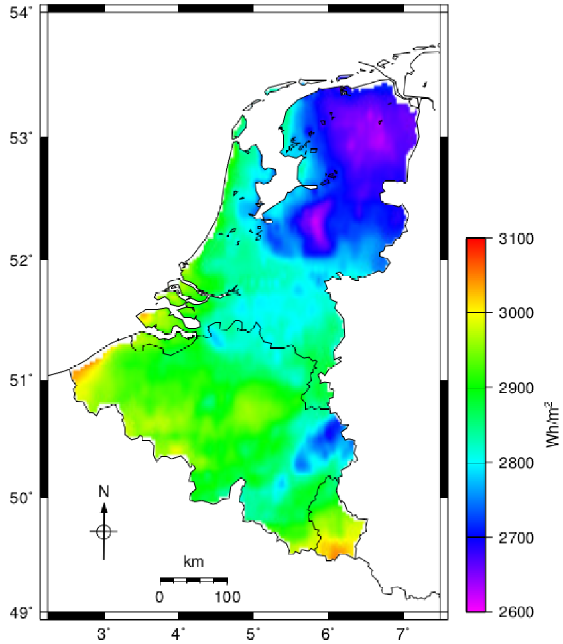
3100

2600

Corrected data (COR)



Homogenized data (HO)



Mean – Merged dataset