Accuracy improvement of irradiation data by combining ground and satellite measurements

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Introduction:

- Planning, monitoring and operation of PV systems require accurate irradiation data
- Knowledge of the accuracy improves the value of the irradiation data
- Options to obtain site-specific irradiance data:
  1) Local measurements with pyranometer are very accurate, but also very expensive
  2) Measurements from nearby meteorological station are only accurate when close to the station
  3) Data derived from satellite images using Heliosat is are accurate than local measurement, but available in a fine grid (~2km x 3km)
  4) Combining satellite and ground data with Kriging of Differences gives a high accuracy, on a fine grid, and an estimate of the error
- Questions:
  - How much accuracy can we gain by using Kriging of Differences?
  - How well does the error prediction work?
  - On which factors does the accuracy improvement depend?

Kriging

- Interpolation is taking a weighted average: $H_{int}^{PV}=\Sigma\ \beta_i\ H_i^{meteo}$
- Kriging determines optimal weights β_i by minimising the estimated error of the interpolated value H_{int}^{PV}: $\delta^2=\Sigma\ \beta_i\beta_j\ \Upsilon_{ij}+\Sigma\ 2\beta_i\Upsilon_{io}$
- The semivariogram Υ_{ij} is a measure for the spatial variability of the irradiation: $2\Upsilon_{ij} = (H_i^{meteo}-H_j^{meteo})^2$

Kriging of Differences

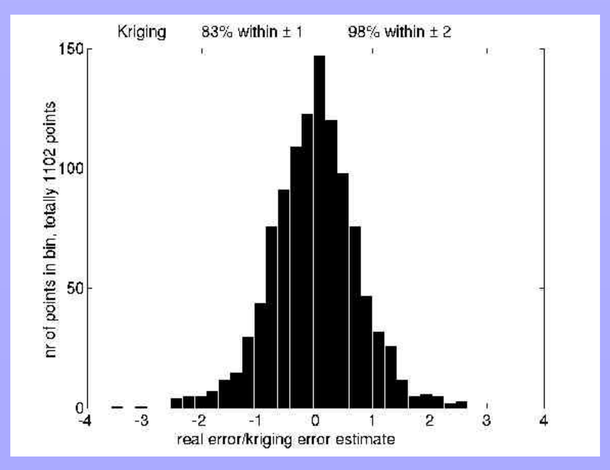
- Interpolation of the difference between meteostation and Heliosat values gives a correction on Heliosat values: $H^{PV}=H^{sat} + \Sigma\ \beta_i\ (H_i^{meteo}-H_i^{meteo})$

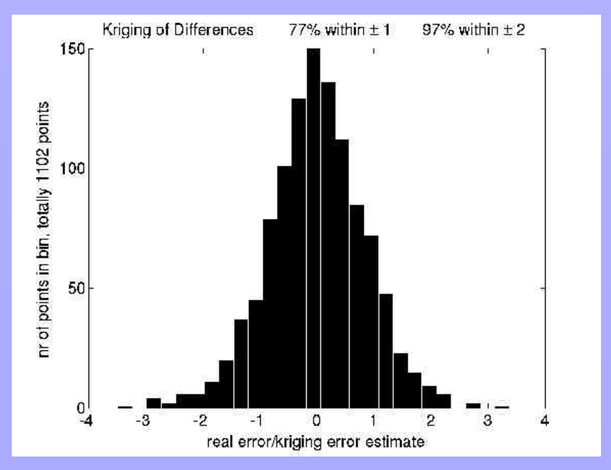
Cross validation on two sets of pyranometer data

Dataset	Netherlands	Eastern Germany
Time step	Month	Day, Hour
Period	1996 to 1998	30 May 2003 to 23 March 2004
Data availability	100%	91.5%
Number of stations	32	34
Average distance between neighbouring stations	28 km	59 km
Average daily irradiation	2697 Wh/m2	2761 Wh/m2
Source	KNMI	Meteocontrol

Overall results

	(%)	Heliosat	Kriging	Kriging of Differences
Monthly	RMSE	5.2	3.6	2.8
	Predicted RMSE	-	4.5	3.1
Daily	RMSE	14.5	16.7	12.4
	Predicted RMSE	-	18.8	12.2
Hourly	RMSE	26.3	32.1	24.3
	Predicted RMSE	-	31.7	24.5



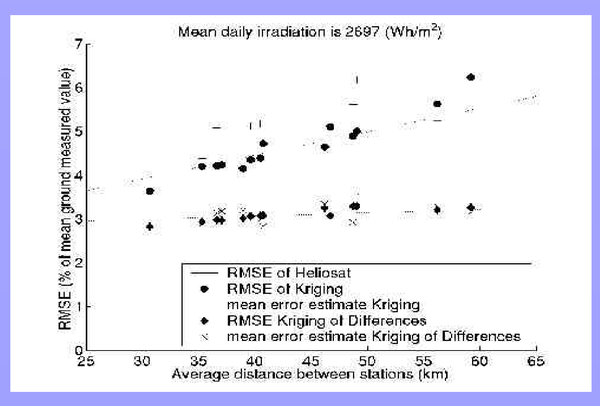


How well does the error prediction work

- The result table shows that the average predicted error agrees well with the average actual error. But is it right for individual cases?
- The figures show the histogram of predicted divided by actual error
- The distribution has a proper Gaussian-like shape
- Error prediction is slightly to conservative
- Similar results are achieved for other time scales

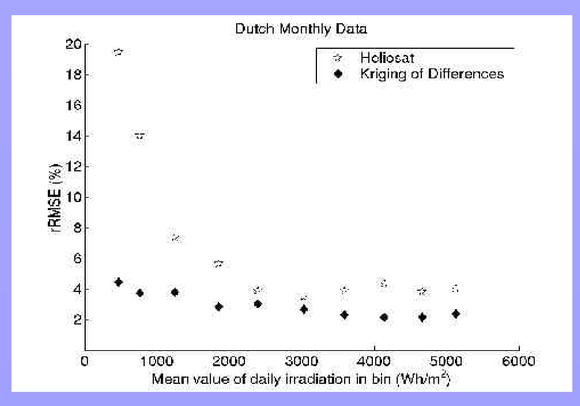
Accuracy as function of distance between meteorological stations

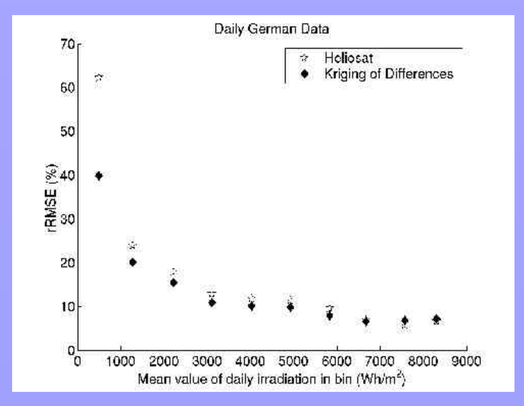
- RMSE of Kriging increases when station lie further apart
- RMSE of Kriging of differences increases only slightly if meteorological stations lie further apart



Accuracy as function of irradiation

- Heliosat has largest errors at low irradiation levels
- Largest improvement is obtained for low irradiation





Conclusion: Kriging of Differences gives...

- a significant improvement to the accuracy of irradiation data
- this improvement even when meteostations lie far apart
- a slightly conservative estimate of it's own accuracy
- the largest improvement at low irradiance values
- the largest improvement at long time scales

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