PREDICTION OF NET RADIATION ON THE ROAD SURFACE FROM CLOUDINESS

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Abstract

The present paper describes a model for prediction of all wave net radiation flux density at the road surface. It was specifically developed for short range forecasts of radiation processes in road surface temperature prediction models. It is based on statistical data for the actual site and on external input given from cloud cover predictions (cloud amount and cloud type). The radiation model includes a feedback algorism using radiation data recorded by field stations at the road site to reduce prediction errors.

Introduction

In Austria road winter warning systems have been operated for many years. They are based on a network of automatic road weather stations, and provide continuous records of data including the actual values of road and atmospheric parameters like surface temperature, air temperature as well as solar radiation, humidity, wind etc. These parameters are used as input for short range forecat models of road surface temperature.

The models are usually based on the evaluation of energy fluxes at the road surface. *As the net radiation flux density is the driving force for changes in road surface temperature, its prediction is an important part of road surface temperature modelling.*

Referring to the fact, that road condition forecasting has to be operational, external input like weather or cloud cover predictions should be limited to data provided by the national weather service. For that reason an empirical and site dependent model was developed for a specific highway section near Vienna.

The background information, which forms the basis of the calculations, was derived from radiation recordings and cloud observations at a specific site. Using this statistical information the required external input data can be reduced to only cloud cover predictions (cloud amount and cloud type).

For an application of the radiation model to other road stretches some model parameters have to be validated for the new area.

Depending on available data the model can be run with or without a feedback algorism using radiation data recorded by road weather stations. This is a method for improving the operational performance of the model. It was developed referring to the fact, that solar radiation is very difficult to model due to a lot of different reasons.

Some of the most important are:

- *Radiation properties of a given cloud type can vary in a wide range. The radiation model can only work with empirical mean parameters.*
- *Some error in the forecast of cloud cover and cloud type is usually unavoidable. Referring to the fact, that cloud amount and cloud type are key factors governing the variation of net radiation, forecast errors of these parameters are one of the mayor sources of model prediction error.*
- *Shadowing effects of broken cloud fields are in general impossible to be predict for a given site, but they can be important for the radiation amount reaching the road surface.*

To reduce radiation forecast errors mainly caused by these facts the feetback algorism (outlined in "Model Physics") is used.

Physics of the model

Parameterization of clear-sky radiation

The radiation model is developed to give a short range forecast (up to 3 hours) for the all wave net radiation flux density.It starts with the prediction of the two components of the global irradiance (G) reaching the ground, the direkt solar radiation (Is) and the diffuse sky irradiance (Id). In a first step clear sky values were predicted.

The extraterrestrial radiation (Io) is derived from equation (1):

$$Io = S * Eo \qquad (1)$$

Where S is the solar constant and Eo an eccentricity correction factor to account for deviation in mean earth-sun distance. This correction factor is computed from the astronomical equation (Spencer,1971):

$$Eo = 1.0001100 + 0.034221 * \cos T + 0.001280 * \sin T + 0.000719 * \cos 2T + 0.000077 * \sin 2T \qquad (2)$$

Where T is the day time angle equal to 2π(dn - 1)/365 with dn the Julian day. In the following step, absorption and scattering of solar radiation in the atmosphere is considered. This is carried out with empirical monthly mean extinction coefficients (Ext) developed from long time radiation recordings of the given area. With this information on a climatological basis and equation (3) the direct solar radiation on a horizontal plane (Is) is modeled.

$$Is = (Io * \cos\theta z) * \exp(-Ext * mr) \qquad (3)$$

Where the zenit angle (θz) and the relative optical air mass (mr) are computed from astronomical equations.

A simple treatment for the diffuse sky irradiance (Id) is based on results of solar radiation recordings (Peterson and Dirmhirn, 1981). The diffuse sky irradiance is parameterized as a fraction of direkt solar radiation on a plane perpendicular to direct solar radiation propagation. The climatological value of this fraction (monthly mean values) for the given site was determined by long time radiation recordings in Austria.

The diffuse sky irradiance and the direkt solar radiation can finally be added in equation (4) to the global radiation reaching the road surface:

$$G = Is + Id \qquad (4)$$

The all wave net irradiance flux density (Rn) is modeled from the global irradiance in a final step by a linear regression equation (5):

$$Rn = A + B * G \qquad (5)$$

with the global radiation G and the regression coefficients A and B, which depend on season and site. For a specific road section they have to be developed from radiation recordings.

Parameterization of cloudy-sky radiation

Clouds affect both components of the global radiation. In general the direkt part is reduced, the diffuse sky irradiaance enhanced. The processes depend on cloud amount and cloud type. The model works with cloud type clusters shown in table 1.

Table 1 Cloud type clusters used in the model (usd cloud code: WMO, 1982)

CLOUD TYPE CLUSTER	INCLUDED CLOUD TYPES
high clouds (7km to tropopause)	
C1a	CH = 1, CH = 2a, CH = 2b, CH = 2c, CH = 3, CH = 4
C1b	CH = 5, CH = 6, CH = 7, CH = 8, CH = 9
middle clouds (2 to 7km)	
C2a	CM = 1, CM = 3, CM = 4, CM = 5
C2b	CM = 2, CM = 6, CM = 7a, CM = 7b, CM = 7c, CM = 8, CM = 9
low clouds (surface to 2km)	
C3a	CL = 1, CL = 2, CL = 4, CL = 5, CL = 8
C3b	CL = 3, CL = 7, CL = 9,
C3c	CL = 6, fog

For the cloud clusters modification parameters for clear-sky values of direkt solar radiation and diffuse sky irradiance were developed from radiation recordings and cloud observations at the given site (table 2). Clouds also control the regression parameters A and B in equation (5). An example is shown in figure 1 for clear-sky conditions and in figure 2 for a cloudy sky (8/8 St).

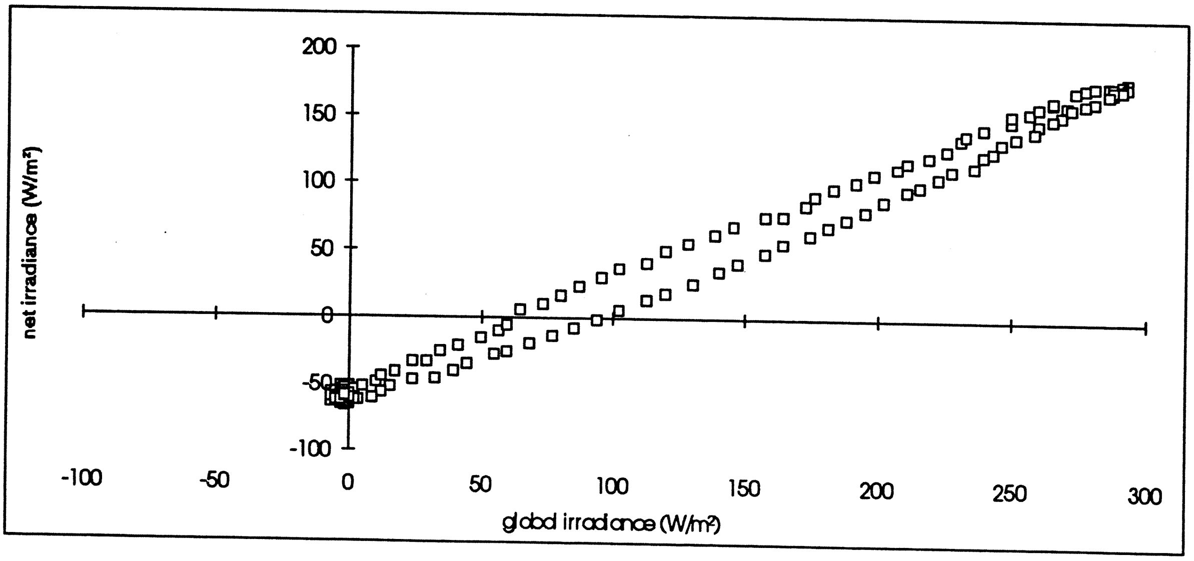

Figure 1: relation between global irradiance and net irradiance at the road surface for a cloudless day (A = -57.9, B = 0.79, $r^2 = 0.99$)

By comparing the regression parameters A and B for these two cases it is clearly shown, that clouds influence primarily the parameter A. In general Its value is negative for cloudless condition and is shifted towards zero for cloudy skies. The order of this shifting effect depends on cloud type and cloud amount. For simplicity only the cloud dependent variations of parameter A were considered in the model. Mean values of this parameter for the used cloud type clusters are shown in table 2.

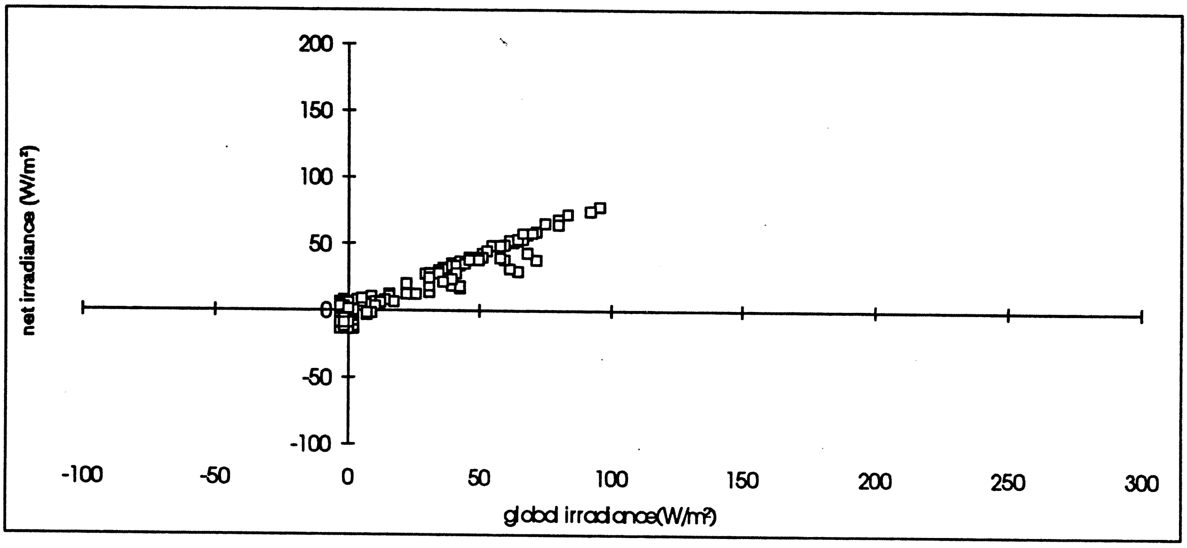

Figure 2: relation between global irradiance and net irradiance for a cloudy day (8/8 St for the whole day, A = 0.27, B = 0.76, $r^2 = 0.92$)

Table 2 Modification parameters for the clear-sky values of the direkt solar irradiance (Is),the diffuse sky irradiance (Id) and the regression parameter (A) in per cent.

CLOUD COVER	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8
cloud type cluster C1a								
Is	99	98	97	96	95	94	93	92
Id	112	123	132	140	246	152	155	156
A	98	96	94	92	90	88	86	84
cloud type cluster C1b								
Is	97	95	93	91	89	87	85	83
Id	125	145	165	185	200	210	215	220
A	98	96	94	92	90	88	86	84
cloud type cluster C2a								
Is	94	88	80	71	61	48	33	15
Id	129	155	180	200	214	216	210	200
A	90	80	70	60	50	40	30	20
cloud type cluster C2b								
Is	91	83	74	64	52	38	22	5
Id	120	138	153	170	182	183	165	130
A	90	80	70	60	50	40	30	20

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continued from table 2

cloud type cluster C3a								
Is	96	92	86	78	69	57	42	20
Id	120	138	153	170	182	183	165	130
A	88	75	63	50	38	25	13	0
cloud type cluster C3b								
Is	87	74	62	49	37	24	12	0
Id	104	109	114	117	119	118	112	100
A	88	75	63	50	38	25	13	0
cloud type cluster C3c								
Is								60
Id								200
A								0

Feedback algorism

The feedback algorism uses the actual pyranometer (short wave global irradiance) and pyrradiometer (all wave net irradiance) recordings of the road weather stations. To reduce prediction errors for the next 3 hours, two different ways are tested for short wave global irradiance (G) and net irradiance (Rn).

For the short wave global irradiance hourly integrated data (recorded (Qre) and forecasted (Qcal) radiation values for the last prediction period) are used in the equations (6) and (7) to correct the radiation estimates (qi) for the following three hours.

$$(Qcal - Qre) / (Qcal/100)) * 0.5 = f' \qquad (6)$$

Equation (6) defines a correction factor (f'), which is introduced to equation (7) to derive at the corrected solar irradiance values (qi').

$$qi - (qi/100) * f' = qi' \qquad (7)$$

with qi' = corrected global irradiance

The feedback algorism in the calculation part of net radiation modifies the primary cloud parameter A for the following prediction perod. The parameter is adapted in that way, that the mean error of the predicted hourly integrated net radiation is reduced to lowest amount for the previous forecast hour.

Results

In order to test the radiation model, it was run under perfect prognoses. That means, that cloud observations were used as external input data instead of cloud forecasts. In that way prediction errors due to external forecast errors could be excluded. A standard set of statistical parameters using:

- mean error (BIAS),
- maximum error (RMSE),
- root-mean-square error (rms) and
- standard deviation (SD)

was applyed to net radiation forecasts and recordings for the road weather station Göttlesbrunn near Vienna. Three days were used to give an example for the model calculations in characteristic cloud cover situations (figure 3, 4, 5 and 6). Figure 3

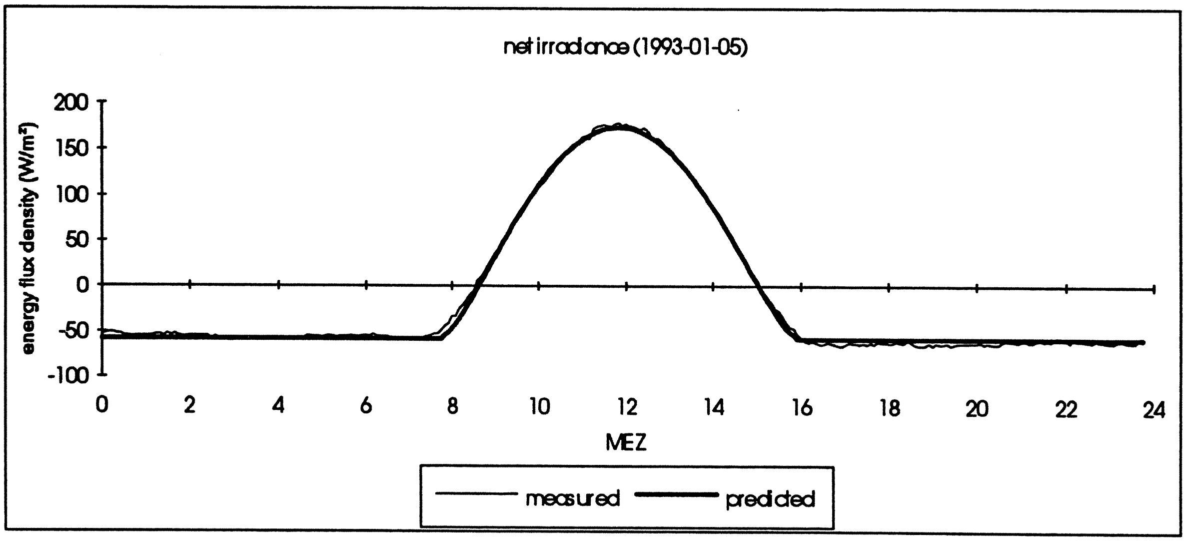

Figure 3: recorded and predicted net irradiance for a clear day (BIAS = -0.3W/m², RMSE = 7.7 W/m², rms = 3.8 W/m²)

compares model predictions and net radiation recordings for a clear day (05.01.1993, road weather station Göttlesbrunn). *The model computations are in good agreement with the recorded data, shown by a mean error of -0.3 W/m² and a maximum error of only 7.7W/m².*

A second typical forecast situation is represented in figure 4. At that day the sky

remained completely overcast (8/8 St.) for the whole day. *Similar to the model results for clear-sky conditions the net radiation forecast error was not significant.*

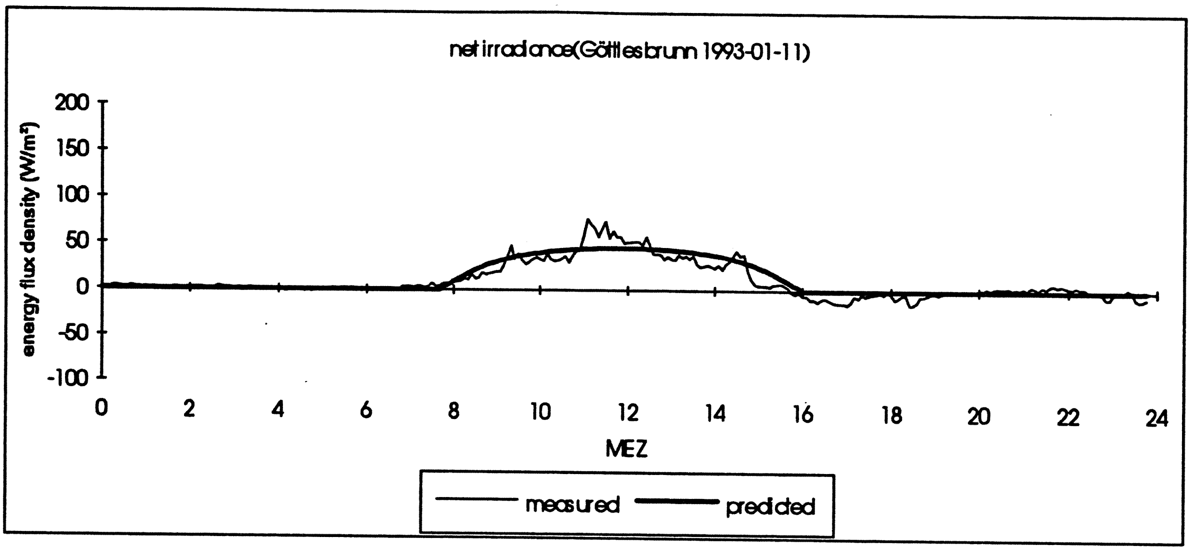

Figure 4: recorded and predicted net irradiance for a completely overcast day (11.01.1993, road weather station Göslltesbrunn, 8/8 St) , BIAS = 1.5W/m², RMSE = 17.6W/m², rms = 6.5W/m²

The derived forecast accuracy can by seen as an example for all model predictions at overcast days, independent of the cloud type.

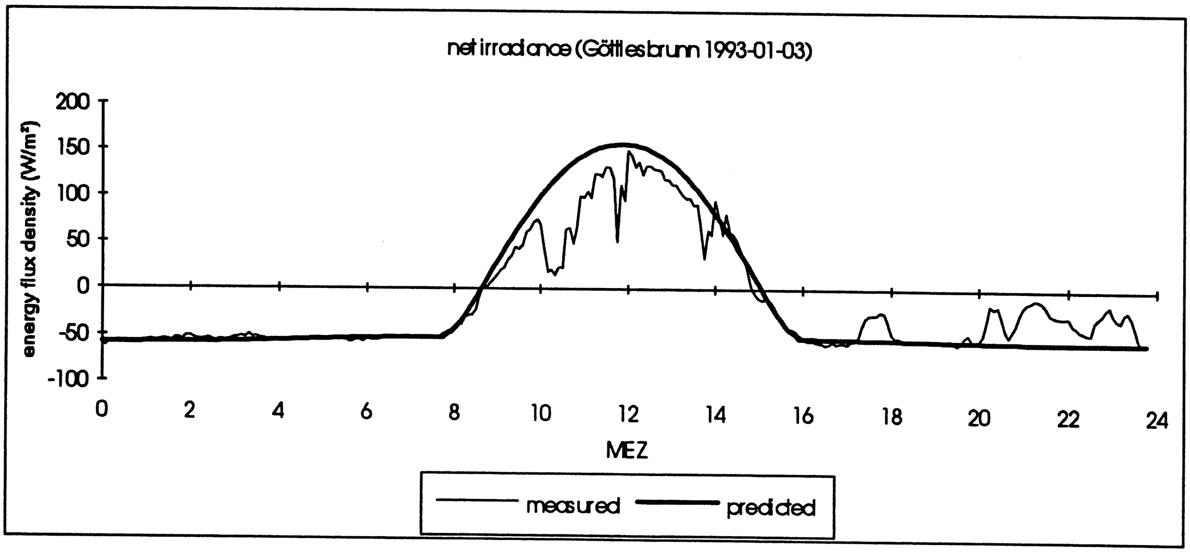

Figure 5: recorded and predicted net irradiance for a broken cloud field (1/8 - 5/8 Ac and 1/8 - 4/8 Ci) BIAS = 3.0, RMSE = 76.9, rms = 22.9

Larger differences between forecasted and measured radiation data appear in computations for broken cloud fields (figure 5). That is mainly due to the fact, that cloud distributions an combined shadowing effects are in general unpredictable. *In such forecast situations the feedback algorism using recorded data reduces the radiation forecast error very effectively.* Figure 6 shows these model computations when including the feedback algorism. An other advantage of this algorism is shown in

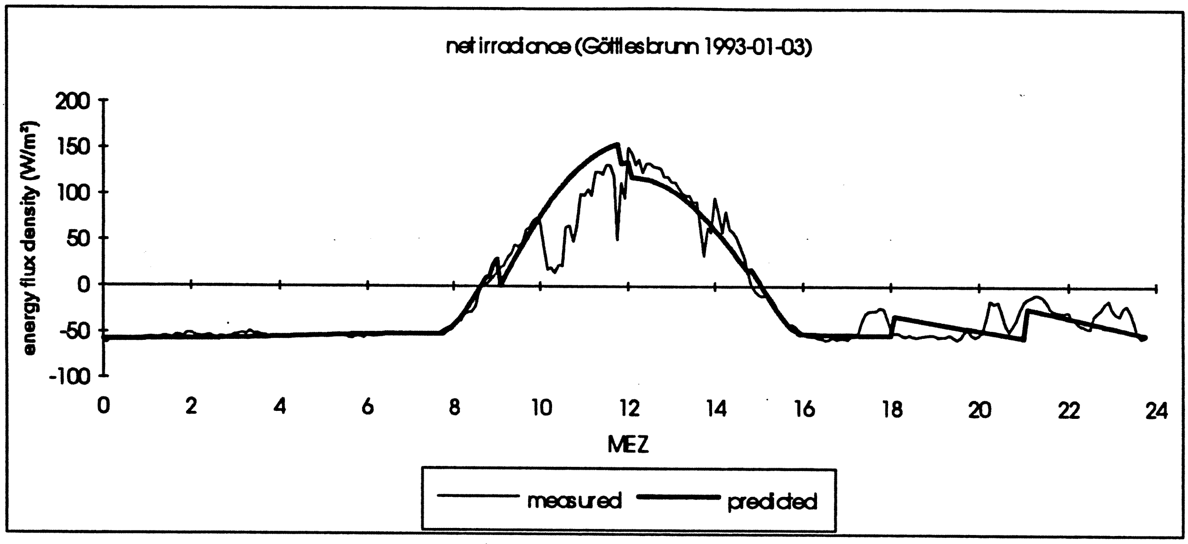

Figure 7: recorded and predicted net irradiance for the road weather station Göttlesbrunn including the feedbackalgorism in the model run (BIAS = 0.96W/m², RMSE = 58.8W/m², rms = 16.5W/m²)

the figures 5 and 6. By running the model fot the 03.01.1993 the occurrence of fog at night remained unconsidered in the cloud input data. By comparing the model predictiones for this period it can be seen, that the feedback to recorded data represents a useful tool for improving the model results.

To test the radiation model for operational use, a period of 7 days was chosen (01.01.1993 - 07.01.1993). To get representative results this test period includes al three previosly discussed typical cloud cover situations (broken cloud fields occur at 5 days). The model was run including the feedback algorism. An computation of hourly integrated net radiation data predicted by the model and recorded at the road weather station Göttlesbrunn is presented in figure 7.

Conclusions

For perfect cloud predictions the model permits the prediction of the net irradiance to a high accuracy.

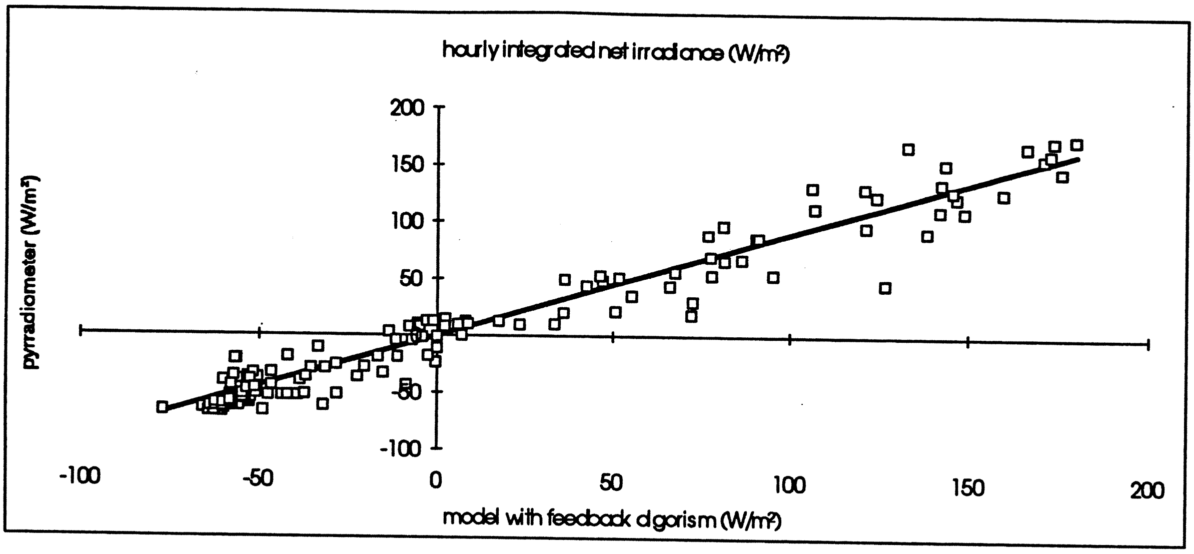

Figure 7: hourly integrated net irradiance data modeled and recorded for the road weather station Göttlesbrunn using the feedback algorism (N = 168, BIAS = 2.9W/m², RMSE = 80.3W/m², rms = 15.9W/m², SD = 14.5)

With erroneous cloud prediction es, the presented algorism can considerably improve net irradiance predictions.

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