FORECASTING SOLAR RADIATION
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PRELIMINARY EVALUATION OF AN APPROACH BASED UPON THE NATIONAL FORECAST DATA BASE

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ABSTRACT

Our objective is to develop, and undertake a preliminary evaluation of, a simple solar radiation forecast model using sky cover predictions from the National Digital Forecast Database as an input. This report describes the model and presents a limited evaluation of its performance against ground-measured and satellite-derived irradiances in Albany, New York.

1. METHODS

Forecasts: The National Digital Forecast Database [NDFD, 2004] is a new experimental product from the United States National Weather Service (NWS) providing gridded forecasted parameters for the entire country. The NDFD is assembled from the forecasting work of local and regional NWS offices in collaboration with the National Centers for Environmental Prediction (NCEP). Local forecasts are generated as a byproduct of national model outputs, mesoscale model runs and human input [Snyder, 2004]. These local forecasts are then merged and assembled on a national grid.

At present, forecast products include ambient temperature, dew point temperature, probability of precipitation, weather type, sky cover, wind speed and direction, significant wave height, quantitative precipitation forecasts, and snow amount. For most of these parameters, three-hour forecasts are provided out to 72 hours and six-hour forecasts are provided out to 168 hours. Forecasts are updated hourly. The nominal ground resolution of the gridded forecasts is 0.05^{o} in latitude and longitude.

Solar Radiation model: The model presented in this paper derives surface global irradiance from one of the NDFD products: sky cover. The sky cover-to-irradiance model retains the approach of the visible satellite pixel-to-irradiance model previously developed by the authors [Perez et al., 2002] that is, modulating a simple clear sky transfer model using a function of forecasted sky cover in lieu of satellite-sensed cloud indices. Recalling the governing equation of the satellite model:

$$GHI / GHI_{clear} = f(CI) \qquad (1)$$

where GHI is the hourly global irradiance, GHI_{clear} is the clear sky hourly global irradiance, itself a function of turbidity and ground elevation (e.g., [Perez et al., 2002], [Ineichen, 2004]) and f(CI) is a function of the satellite image pixel-derived cloud index, CI [Perez et al., 2002].

For the present model, we propose to replace the function f(CI) by a function g(SK) of the forecasted sky cover, SK.

Experimental Data: From April to September 2004, we acquired sky cover forecasts assembled each day at 13:00

GMT, and extending out to 76 hours, for the grid point closest to Albany, NY

Validation measurements: For the same period and for the times corresponding to the forecasts, we acquired GHI measurement performed at our research center in Albany [ASRC, 2004], as well as satellite-derived GHI estimates for the closest Albany image pixel. Ground measurement accuracy is better than ± 5%.

2. RESULTS

Model Formulation: Our first task was to analyze the nature of the relationship between the forecasted sky cover parameter SK and the global index, GHI/GHI_{clear} . Figure 1 is a plot of forecasted SK against measured global index for all forecasts ranging from 4 to 8 hours. Unlike the quasi-linear relationship observed for the satellite-derived cloud cover CI (see Fig. 2). The relationship between the GHI index and SK is markedly non- linear and is reminiscent of the relationships observed between the global index and ground-observed cloud cover. Kasten and Czeplak [1979] had proposed the following expression to model this relationship:

$$GHI / GHI_{clear} = (1 - 0.75\ (N/8)^{3.4}) \qquad (2)$$

where N is the ground-observed cloud cover in octas.

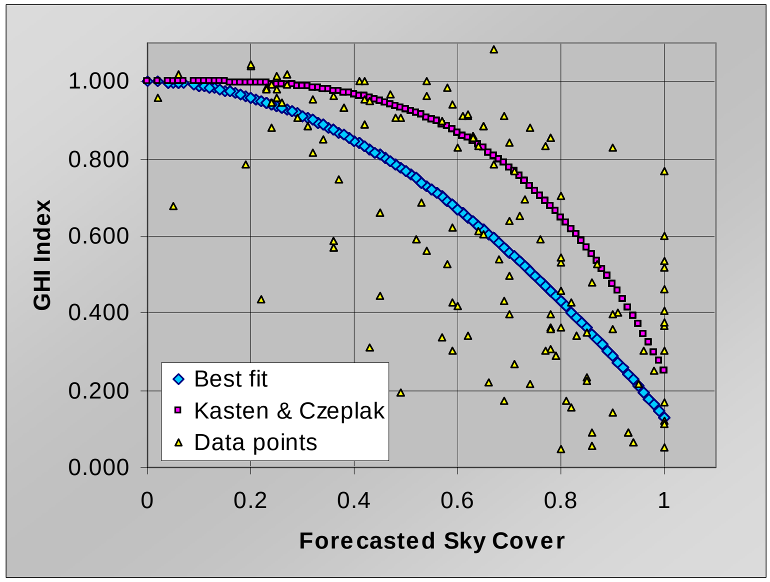

Fig. 1: Relationship between 4-8 hours SK forecasts and observed global irradiance index

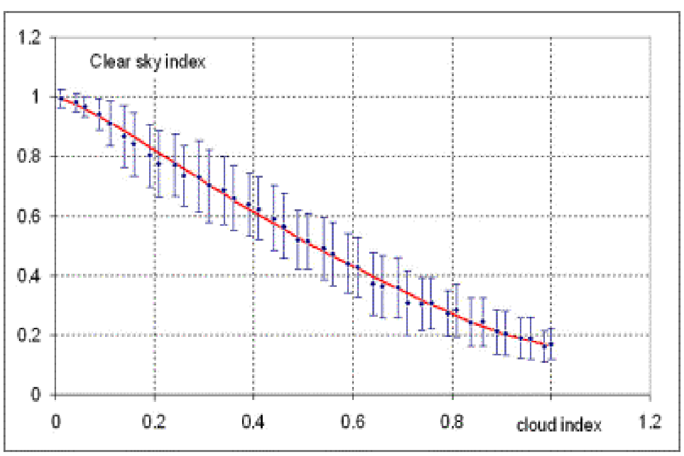

Fig. 2: Relationship between satellite-derived cloud index CI and observed global irradiance index

An empirical fit between our forecasted sky cover data and the global index suggested that, while the general shape of the Kasten and Czeplak formulation could be retained, its coefficients had to be substantially modified, leading to the formulation in equation (3)

$$GHI/GHI_{clear} = (1 - 0.87\ SK^{1.9}) \qquad (3)$$

with SK given in fractional units

Preliminary Validation: Forecasts were grouped into four time frames which we separately validated.

1. Less than 4 hours,
2. 4 to 8 hours,
3. 8 to 26 hours, and
4. 26 to 76 hours.

Figure 3 includes scatter plots of forecasted vs. measured GHI for each forecast time frame. For reference, the plots also include forecasted GHI while modulating GHIclear linearly with SK per equation (1). Figure 4 is analogous to figure 3 but the ground-measured ground truth is replaced by satellite-derived irradiance for the closest image pixel.

Table I summarizes the performance of the proposed irradiance forecast model against both ground measurements and satellite benchmarks, as quantified by their relative root mean square and mean bias errors (RMSE and MBE).

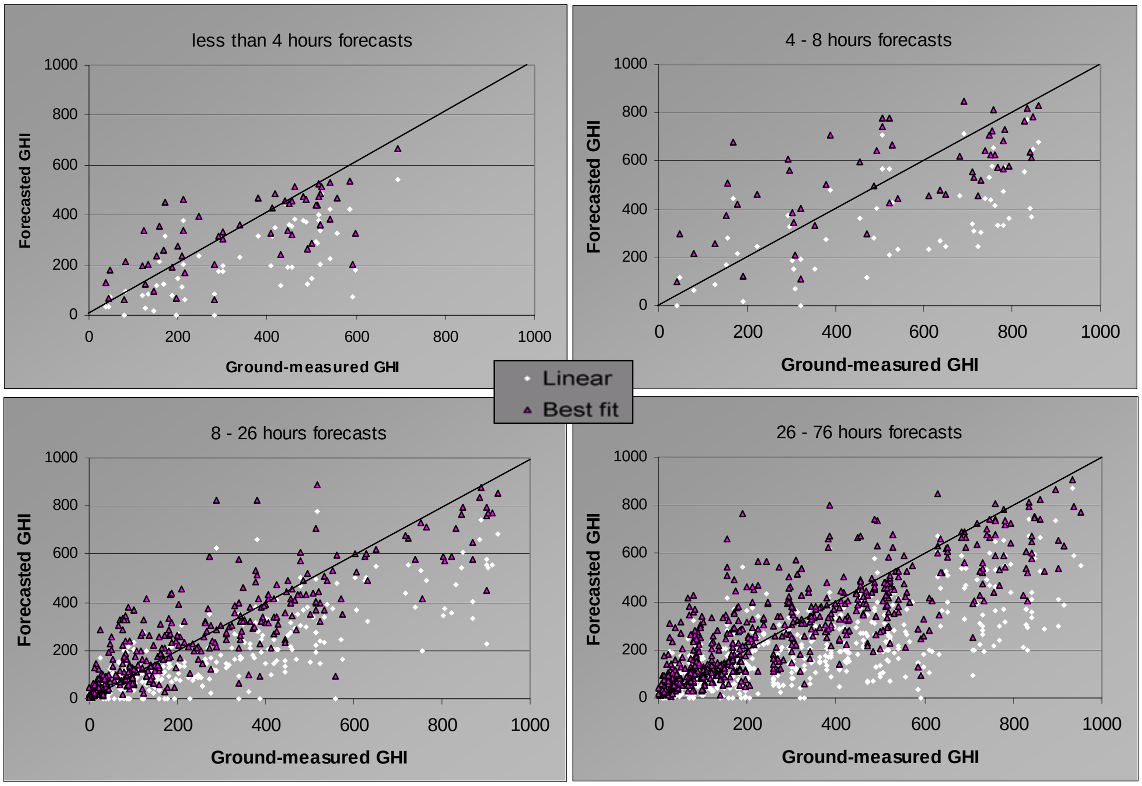

Fig. 3: Forecasted vs. ground-measured irradiance for the best fit and linear models (respectively equations 3 and 1).

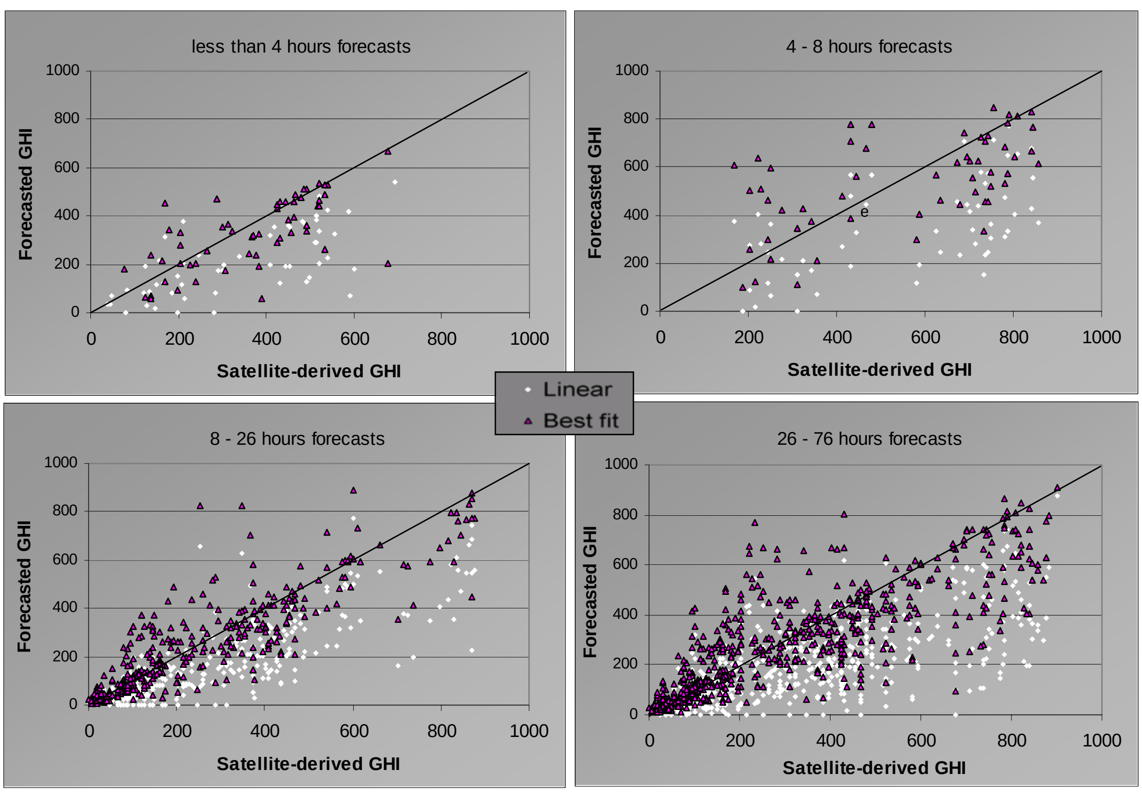

Fig. 4: Forecasted vs. satellite-derived irradiance for the best fit and linear models (respectively equations 3 and 1).

TABLE I
Compared Performance of Linear, Kasten & Czeplak, and Best Fit Models

	FORECAST RANGE	Relative Mean Bias Error			Relative Root Mean Square Error		
		A	B	C	A	B	C
Satellite reference	< 4 hours	-36%	22%	-2%	51%	42%	35%
	4 - 8 hours	-33%	30%	4%	49%	46%	34%
	8 - 26 hours	-35%	35%	5%	57%	59%	46%
	26 - 76 hours	-35%	32%	4%	59%	58%	48%
Ground reference	< 4 hours	-41%	12%	-10%	52%	32%	32%
	4 - 8 hours	-38%	21%	-3%	52%	40%	34%
	8 - 26 hours	-39%	27%	-1%	54%	47%	38%
	26 - 76 hours	-40%	22%	-4%	56%	44%	40%

A: Linear fit to Sky Cover (equation 1)
B: Original Kasten & Czeplak formula (equation 2)
C: Best fit formula (equation 3)

3. DISCUSSION

Results show that NFDB-derived irradiance forecast are well correlated with ground and satellite observations and thus could provide invaluable operational information as solar technologies begin to penetrate the energy distribution networks.

The use of equation 3 – best fit formula – provides much better results than other cloud-to-irradiance functions. This is an indication that forecasted sky cover is an inherently different parameter than both observed sky cover – equation 2 – and sky cover seen from above by satellites – equation 1.

Forecast accuracy decreases with forecast lead time as expected and results are consistent with preliminary analysis of Multiple Output Statistics (MOS) and mesoscale forecast models elsewhere [e.g., Heinemann, 2004]. The data sample is too small and site-specific to draw definitive conclusions, but the results are promising. This potential is highlighted by the fact that the forecast RMSE is only slightly worse that the satellite model error over the same period. The relatively mediocre satellite performance over the period maybe attributable to the large number of low sun points (almost 50%) used for the analysis, due to our arbitrary daily forecast acquisition procedure.

The next logical step is to build up on these initial positive results by (1) extending the initial data sample in Albany; (2) extending the analysis to other climatic environments; and (3) performing regional – as opposed to site-specific – assessments.

4. ACKNOWLEDGEMENT

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5. REFERENCE

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