Bias correction of global irradiance modelled with the Weather Research and Forecasting model over Paraguay

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Topics outline

International
Solar Energy Society

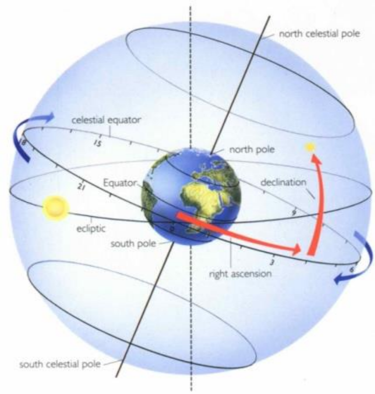
- INTRODUCTION
- METHODOLOGY
- RESULTS
- SUMMARY & CONCLUSIONS

Introduction: Solar Energy and Numerical Weather Prediction (NWP)

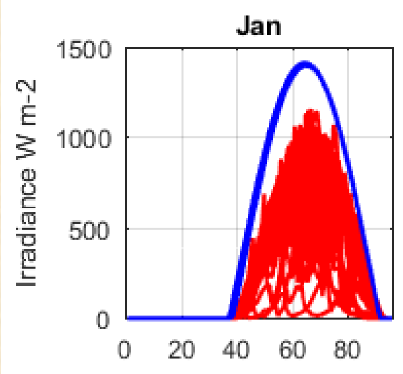
- Increased contribution of solar energy to power generation sources.

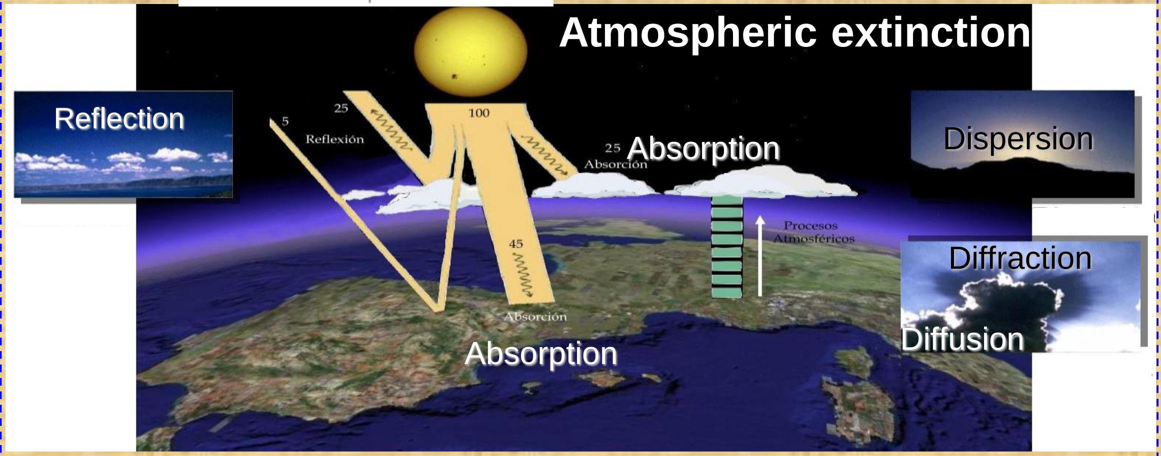
Geographical, temporal & meteorological variability

Solar position



Temporal Cycles

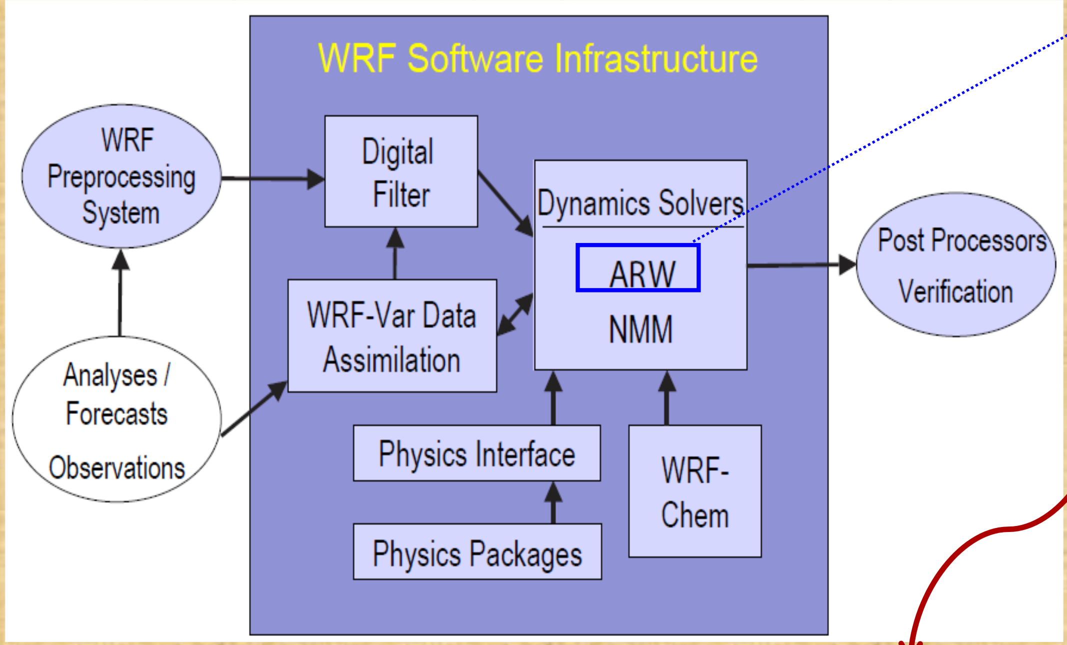




Increase the reliability of available solar energy in the global energy participation.

NWP models simulate the earth-atmosphere system by solving fluid mechanics and thermodynamic equations in a nonlinear computing environment

Introduction: Model simulations of global solar irradiance (GHI)



Use of WRF-ARW mesoscale model (*Skamarock et al., 2008*).

Parameterizations:

- **Microphysics:** *Single-Moment 3-class (WSM3-class*)
- **Longwave Radiation:** RRTM scheme
- **Shortwave Radiation: Dudhia scheme**
- **Surface Layer:** MM5 scheme
- **Land Surface:** Unified Noah land-surface model
- **PBL** de *Yonsei University*
- **Cumulus:** *Kain-Fritsch*

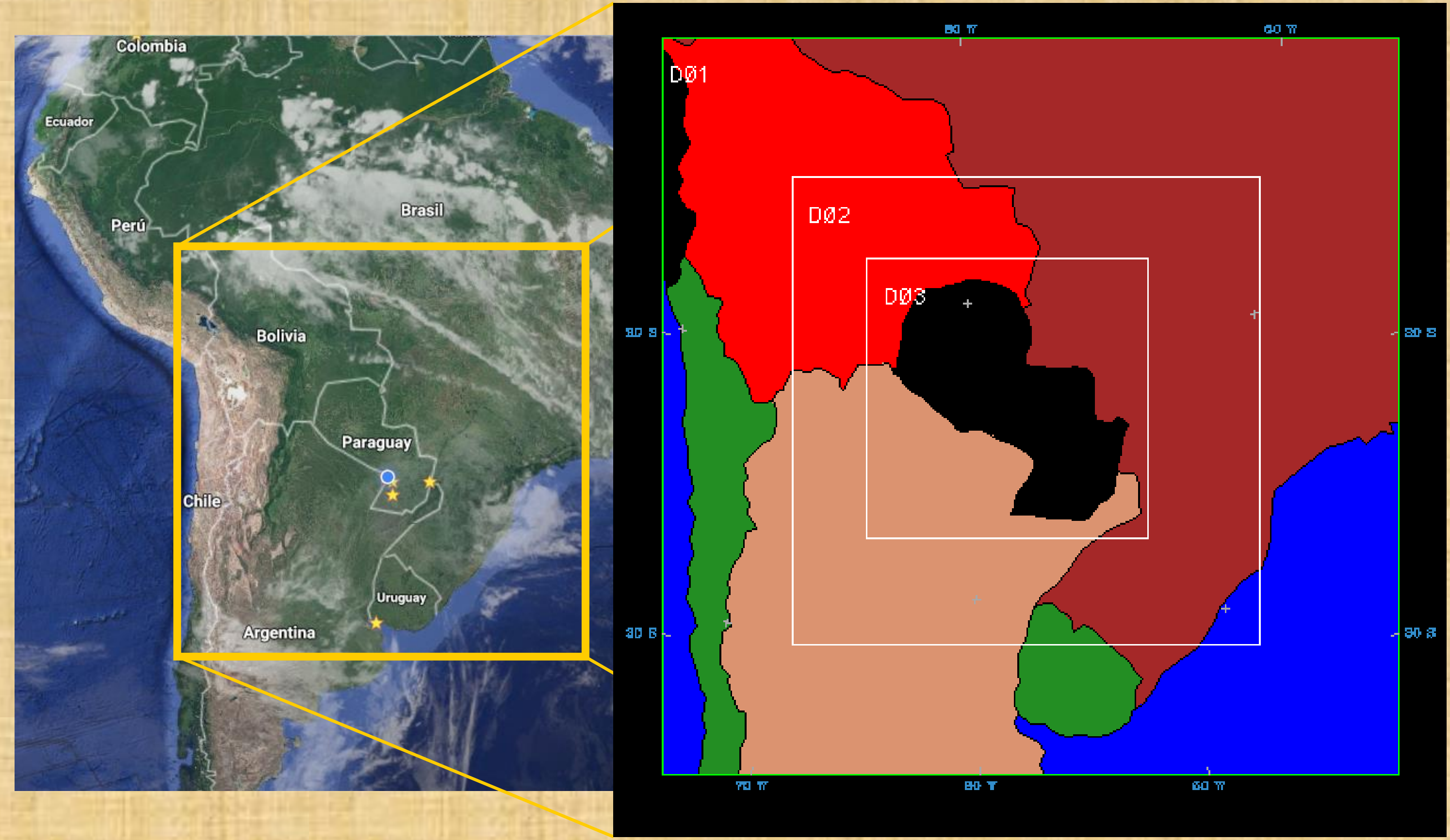
Systematic errors for simulations of radiative transfer schemes

1. **Miscalculation of location of the clouds and total cloud water content in the atmosphere;**
2. **Incorrect specification of the optical thickness of aerosols;**
3. **Decrease of atmospheric water vapor absorption for clear skies conditions.**

- **NWP models combined with statistical post-processing to reduce the systematic errors and satisfy the requirements of solar irradiance forecasting (Heinemann, 2006).**

Methodology: Annual simulation of WRF-ARW meteorological model (v3.7.1/2015)

- **WRF-ARW model is run in hindcast mode over South American continent**



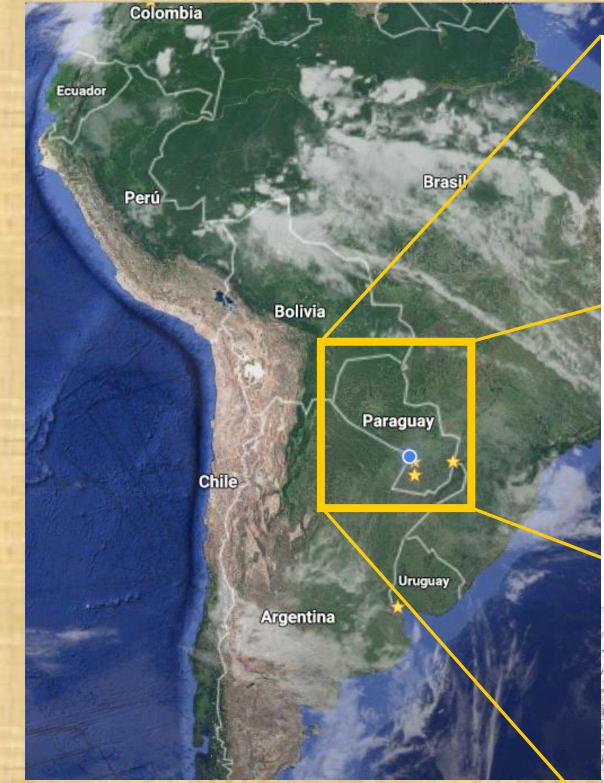
- **Horizontal grid resolution over Paraguay:**
  - D01: 36 km
  - *D02: 12 km*
  - *D03: 4 km*
- **Hourly temporal resolution**
- **30 vertical layers**

- **Initialization and boundary conditions are provided by Reanalysis DS090.0** (NCEP/NCAR, 1994).

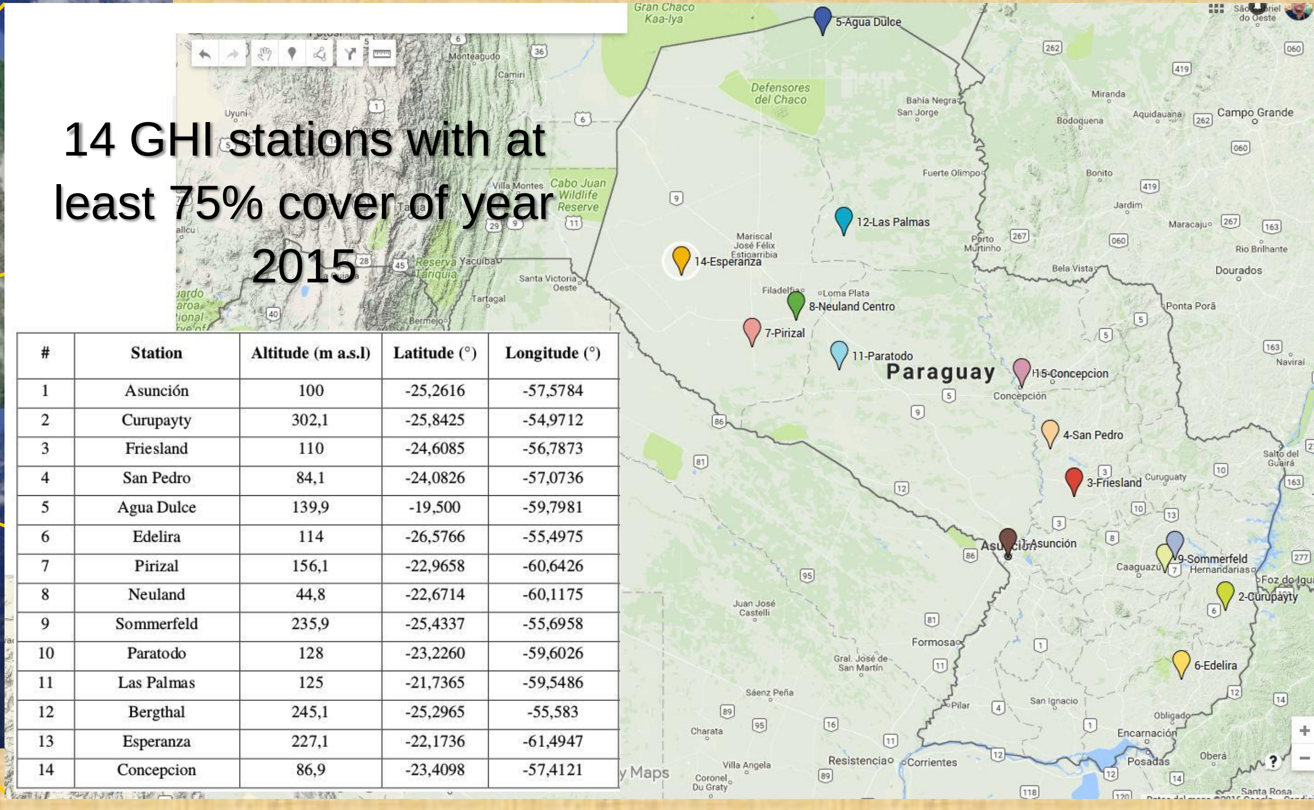
The GHI hourly simulations consist of 365 daily runs to simulate the entire year 2015.

Methodology: Radiometric ground stations of PARAGUAY

- **South American continent**



- **Paraguay**



14 GHI stations with at least 75% cover of year 2015

#	Station	Altitude (m a.s.l)	Latitude (°)	Longitude (°)
1	Asunción	100	-25,2616	-57,5784
2	Curupayty	302,1	-25,8425	-54,9712
3	Friesland	110	-24,6085	-56,7873
4	San Pedro	84,1	-24,0826	-57,0736
5	Agua Dulce	139,9	-19,500	-59,7981
6	Edelira	114	-26,5766	-55,4975
7	Pirizal	156,1	-22,9658	-60,6426
8	Neuland	44,8	-22,6714	-60,1175
9	Sommerfeld	235,9	-25,4337	-55,6958
10	Paratodo	128	-23,2260	-59,6026
11	Las Palmas	125	-21,7365	-59,5486
12	Bergthal	245,1	-25,2965	-55,583
13	Esperanza	227,1	-22,1736	-61,4947
14	Concepcion	86,9	-23,4098	-57,4121

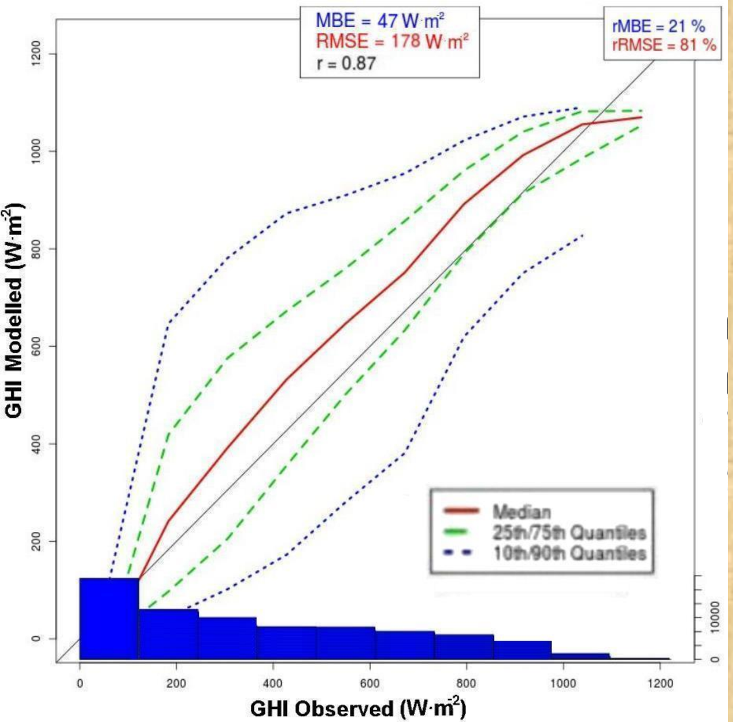
FECOPROD agroclimatic network

Application of Quality control of the dataset *(Roesch et al., 2011)*:

1. *"Physically possible": detecting extremely large errors*
2. *"Extremely rare": error data in short time periods under very rare conditions.*

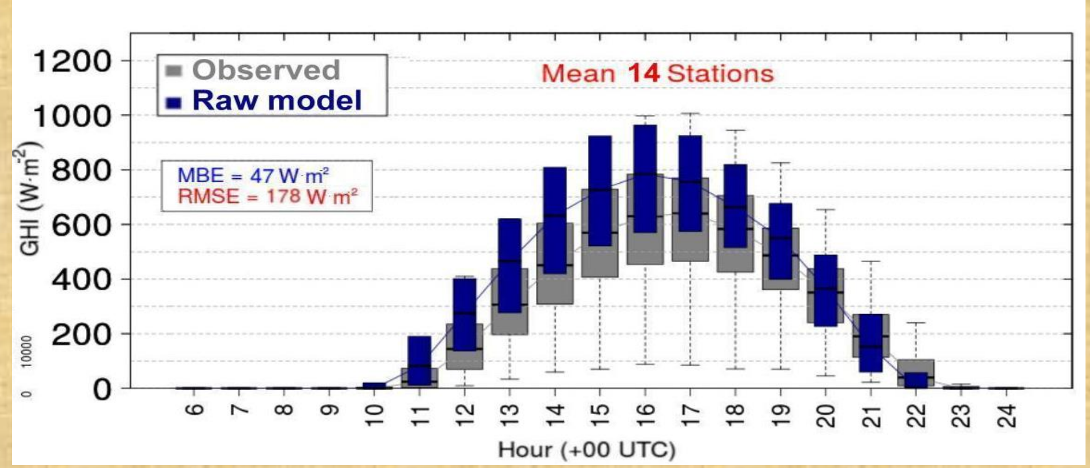
Methodology: Solar irradiance evaluation of WRF-ARW model – 2015

GHI (W m^{-2})



Overestimation between 200 and 1000 W m^{-2} for the whole year.

Hourly distribution: Interquartile range



Systematic overestimation for the whole daily cycle (12:00-19:00h UTC).

Annual systematic errors of Dudhia Scheme

MBE = 47 W·m²
rMBE = 21 %
RMSE = 178 W·m²
rRMSE = 81 %

Similar systematic errors in other work:

- Mathiesen and Kleissl (2011)
- Lara-Fanego et al. (2011)
- Ruiz-Arias et al. (2008)
- Zamora et al. (2005)

MBE > 50 W m^{-2}
(rMBE = 12-15 %)
RMSE > 130 W m^{-2}
(rRMSE = 32-33 %)

Methodology: Post-processing methods / Model Output Statistics (MOS)

MOS (Glahn & Lowry, 1972) is a technique that has the ability to predict the systematic error through polynomial regression and is applied to improve correlations between simulations and observations.

Fourth order polynomial regression

$$Bias_C = \varepsilon + \alpha_1 \cdot k_t^* + \alpha_2 \cdot \cos(SZA) + \alpha_3 \cdot (k_t^*)^2 + \alpha_4 \cdot k_t^* \cdot \cos(SZA) + \alpha_5 \cdot (\cos(SZA))^2 + \alpha_6 \cdot (k_t^*)^3 + \alpha_7 \cdot (k_t^*)^2 \cdot \cos(SZA) + \alpha_8 \cdot k_t^* \cdot (\cos(SZA))^2 + \alpha_9 \cdot (\cos(SZA))^3 + \alpha_{10} \cdot (k_t^*)^4 + \alpha_{11} \cdot (k_t^*)^3 \cdot \cos(SZA) + \alpha_{12} \cdot (k_t^*)^2 \cdot (\cos(SZA))^2 + \alpha_{13} \cdot k_t^* \cdot (\cos(SZA))^3 + \alpha_{14} \cdot (\cos(SZA))^4 \qquad \text{(eq. 1)}$$

Where,

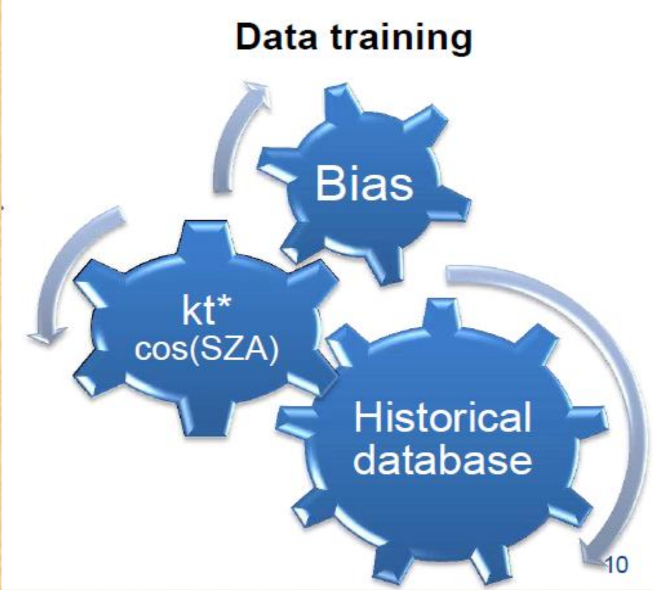
$Bias_C$ is Bias estimation

k_t^* Clear sky index

$\cos(SZA)$ cosine of solar zenith,

ε constant of regression and

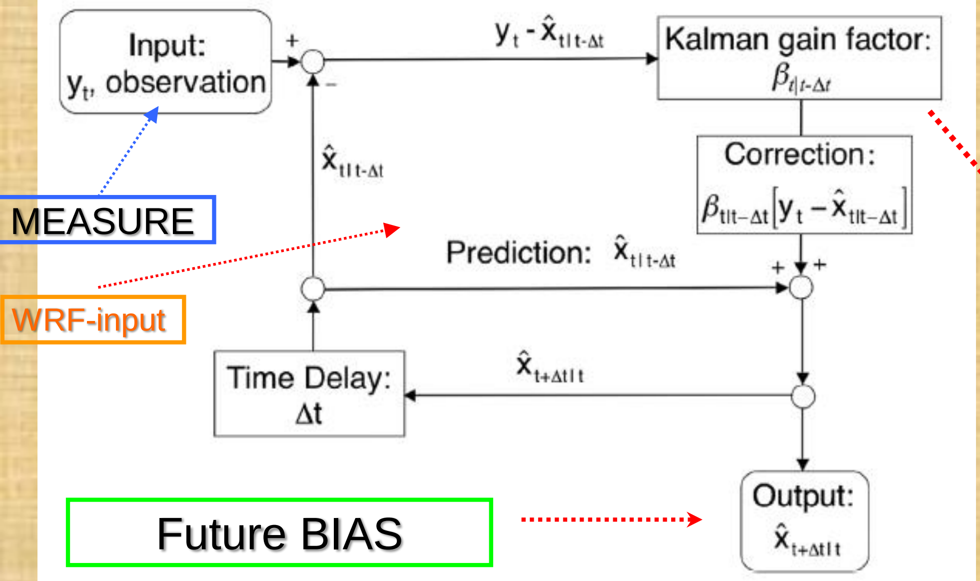
α regression coefficients.



- **60 days of training for dataset.**

Methodology: Post-processing methods / Kalman Filter

Kalman Filter* (Kalman, 1960) establishes a dynamic linear relationship by estimating the previous error and a correction factor proportional to the forecast error.



PERFORMANCE OF THE KALMAN:

$$\text{ratio} = \frac{\sigma_\eta^2}{\sigma_\varepsilon^2}$$

Previous error variance

Forecast error variance

Optimal error ratio calculated for all seasons of year 2015

- Kalman only needs a short training period (15 days for this work).

- Kalman is not likely to predict sudden changes in the forecast error caused by rapid transitions from one weather regime to another (Monache et al., 2011).

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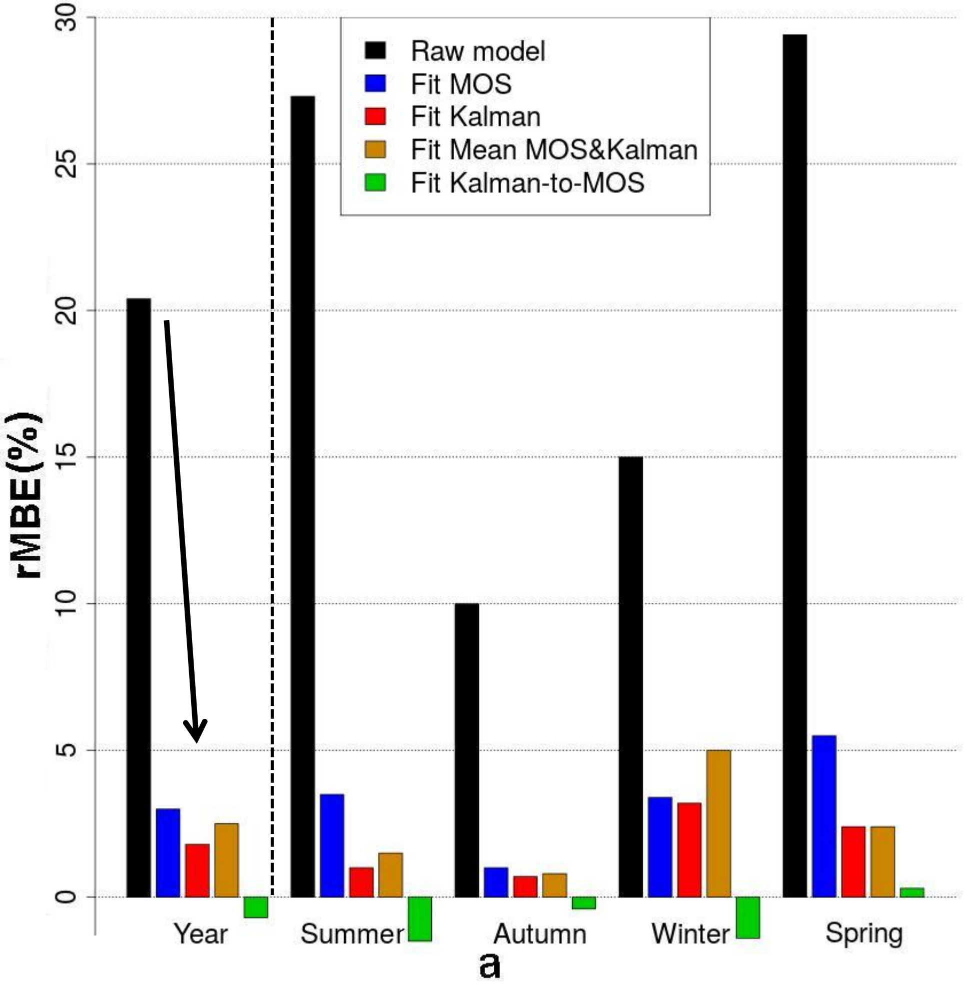
* Code provided by Dr. Luca Delle Monache [lucadm@ucar.edu; NCAR, USA]

Results: Post-process application

Four combinations of post-process adjustments



1) Only fit of MOS regression

2) Only fit of Kalman algorithm

3) Fit of mean between MOS and Kalman corrections

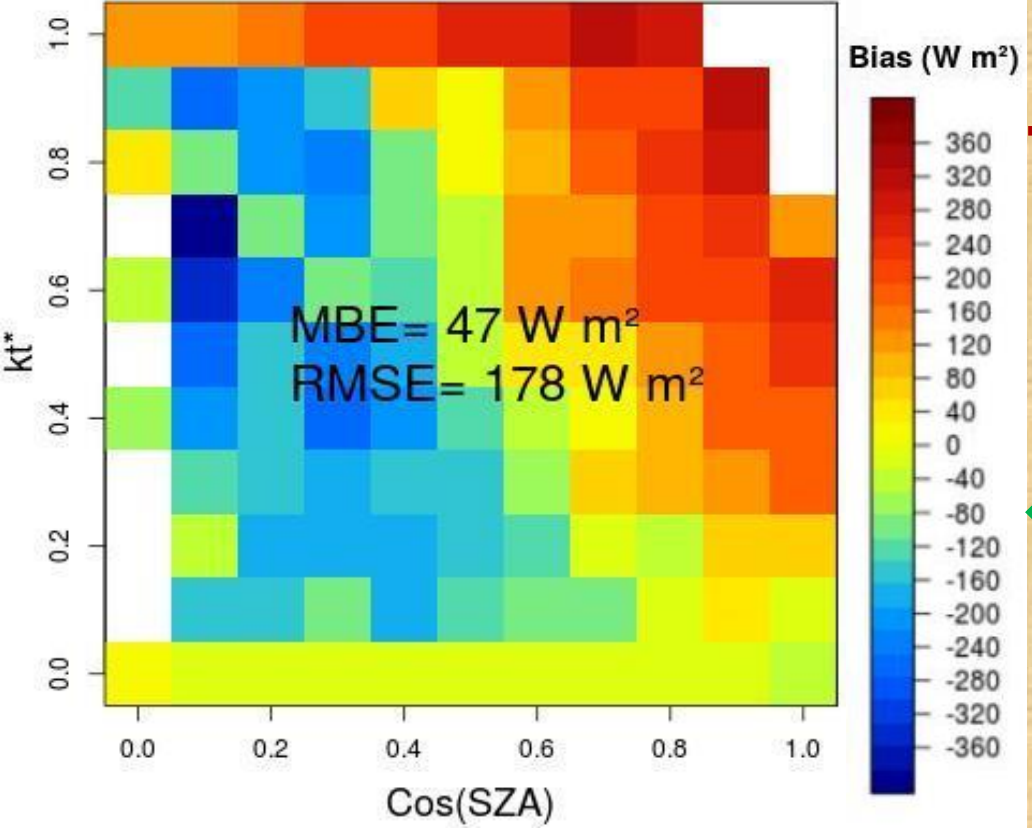
4) Fit of Kalman for corrections produced by MOS

- Significant relative bias-removal for fit of Kalman-to-MOS (combination 4).
- Same combination shows the best bias-removal for summer and spring.

Results: Post-process application

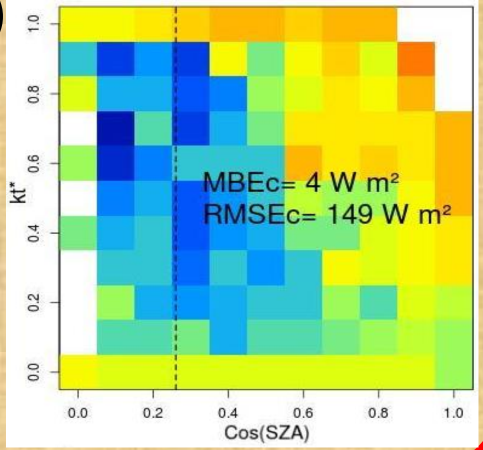
Post-process errors function of index kt* and cos(SZA)

Raw model



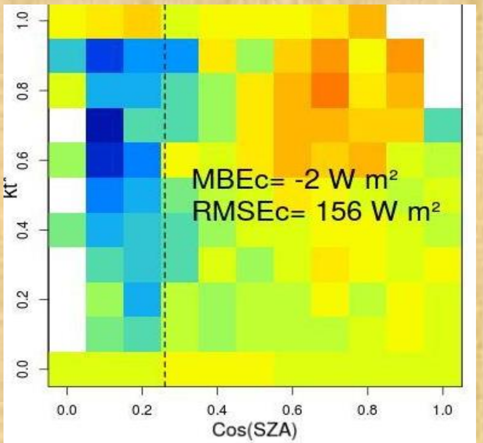
MBE= 47 W m^2
RMSE= 178 W m^2

KALMAN correction



MBEc= 4 W m^2
RMSEc= 149 W m^2

Kalman-to-MOS correction

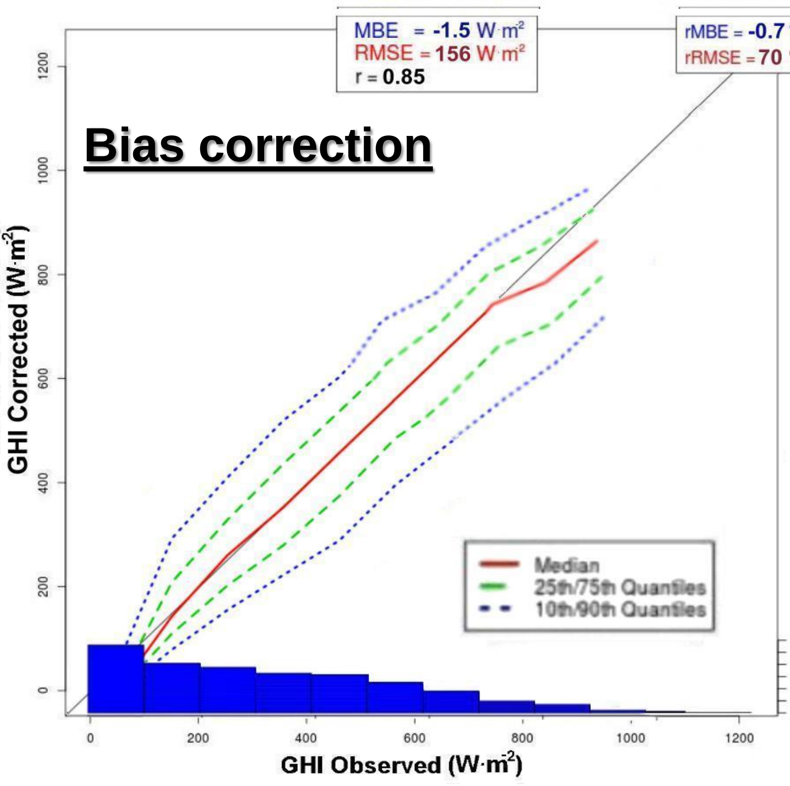


MBEc= -2 W m^2
RMSEc= 156 W m^2

Best results with fit Kalman-to-MOS for cloudy and clear-sky conditions for zenith angles between 60º to 75º.

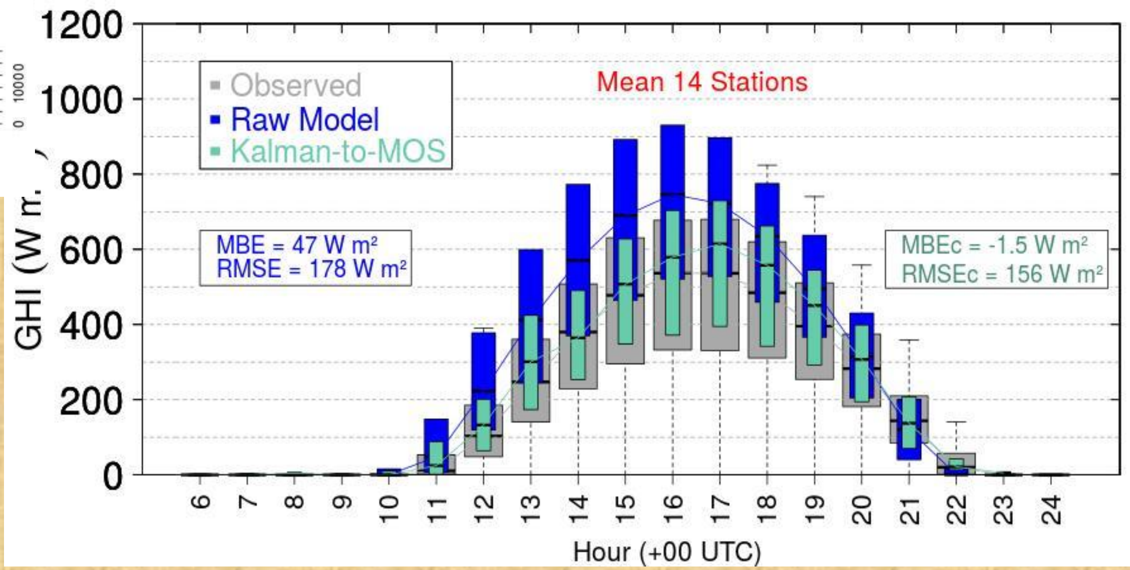
Results: Kalman-to-MOS bias correction

Improvement of GHI (W m^{-2})



- **Significant removal of overestimation between 0 - 1000 W m^{-2} of the raw model.**

Improvement of inter-quartile range



- **Low variability of hourly distribution with a difference of less than 50 W m^{-2} (10 to 20h UTC).**

Results: Kalman-to-MOS bias correction

Comparison of results between raw model and Kalman-to-MOS

Season	Bias		RMSE	
	WRF	Kalman-to-MOS	WRF	Kalman-to-MOS
SUMMER	**68 W m^{-2} (27%)**	**-1.1 W m^{-2} (-1.5%)**	**207 W m^{-2} (71%)**	**169 W m^{-2} (61%)**
SPRING	**60 W m^{-2} (29%)**	**0.8 W m^{-2} (0.3%)**	**198 W m^{-2} (75%)**	**175 W m^{-2} (68%)**
AUTUMN	12 W m^{-2} (6%)	-0.8 W m^{-2} (-0.4%)	150 W m^{-2} (83%)	147 W m^{-2} (81%)
WINTER	21 W m^{-2} (11%)	-1.8 W m^{-2} (-1.4%)	132 W m^{-2} (67%)	126 W m^{-2} (64%)
YEAR	**47 W m^{-2} (21%)**	**-1.5 W m^{-2} (-0.7%)**	**178 W m^{-2} (81%)**	**156 W m^{-2} (70%)**

- **Significant improvement of the mean error with the fit Kalman-to-MOS, especially for spring and summer.**

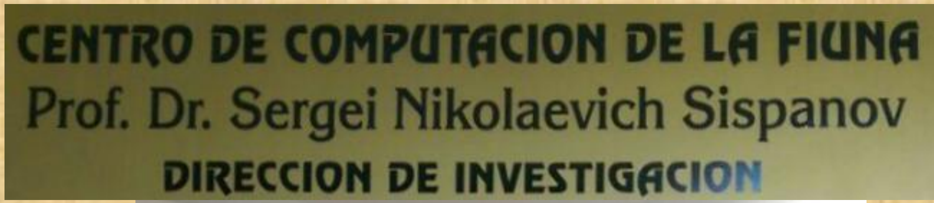
SUMMARY & CONCLUSIONS

- **Systematic WRF model overestimation errors of GHI presented in wide angle zenith ranges to cloudy and clear skies for spring and summer (incorrect location of clouds and total cloud water).**

- **Improvement of GHI WRF simulation using post-processing techniques (MOS & Kalman) year 2015 - Paraguay domain.**

- **The fit of Kalman-to-MOS provides better results reducing the errors of the raw model up to 97% of bias.**

- **Future application in the estimation of energy production of solar devices in Paraguay.**



Thanks for your attention

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- Project 14-INV-289 of **CONACYT**.
- The simulations were performed in the **supercomputer cluster** hosted by the **Department of Engineering at the National University of Asuncion (FIUNA), Paraguay.**
- **FECOPROD** agroclimatic network has provided the observations for this study.