Improvement of the WRF Model for Solar Resource Assessment and Forecast Under Clear Skies

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MOTIVATIONS – The Scope

Solar energy applications are demanding an **increased reliability** in the current methods for **GHI and DNI**...

... **assessment** (bankability) from, at least, 10 years but, ideally, up to 20 or 30 years.

lenders need to assess risks due to "bad" years and long-term variability

...and **short-term forecasting** (minutes to few days ahead)

for improved solar power plants operation, grid stability and higher penetration. Very important for CSP plants (thermal storage management)

GHI: Global Horizontal Irradiance
(Fuel for PV – H&C Building)

DNI: Direct Normal Irradiance
(Fuel for CSP – CPV)

SURFACE SOLAR RADIATION

MOTIVATIONS – What Is This About?

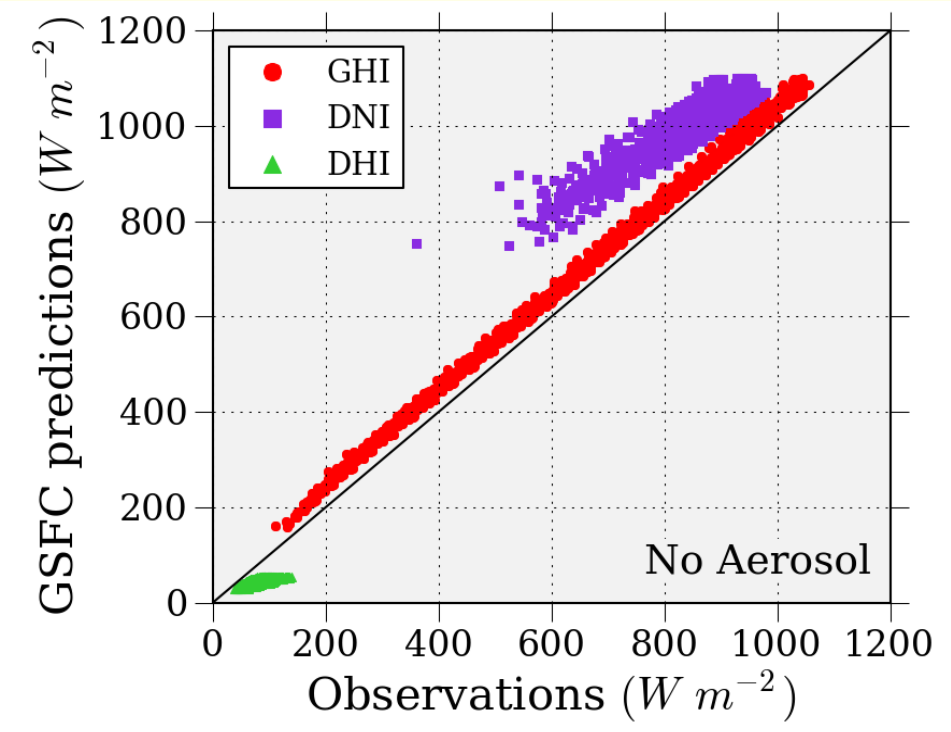
Surface shortwave **solar radiation components** (DNI[1] and DIF[2]) are **not among the regular outputs** of WRF. But some SW schemes calculate them internally

For instance, the **Goddard Space Flight Center (GSFC)** shortwave radiation scheme

Bias caused by lack of aerosols

Major impact is on DNI and DIF irradiances

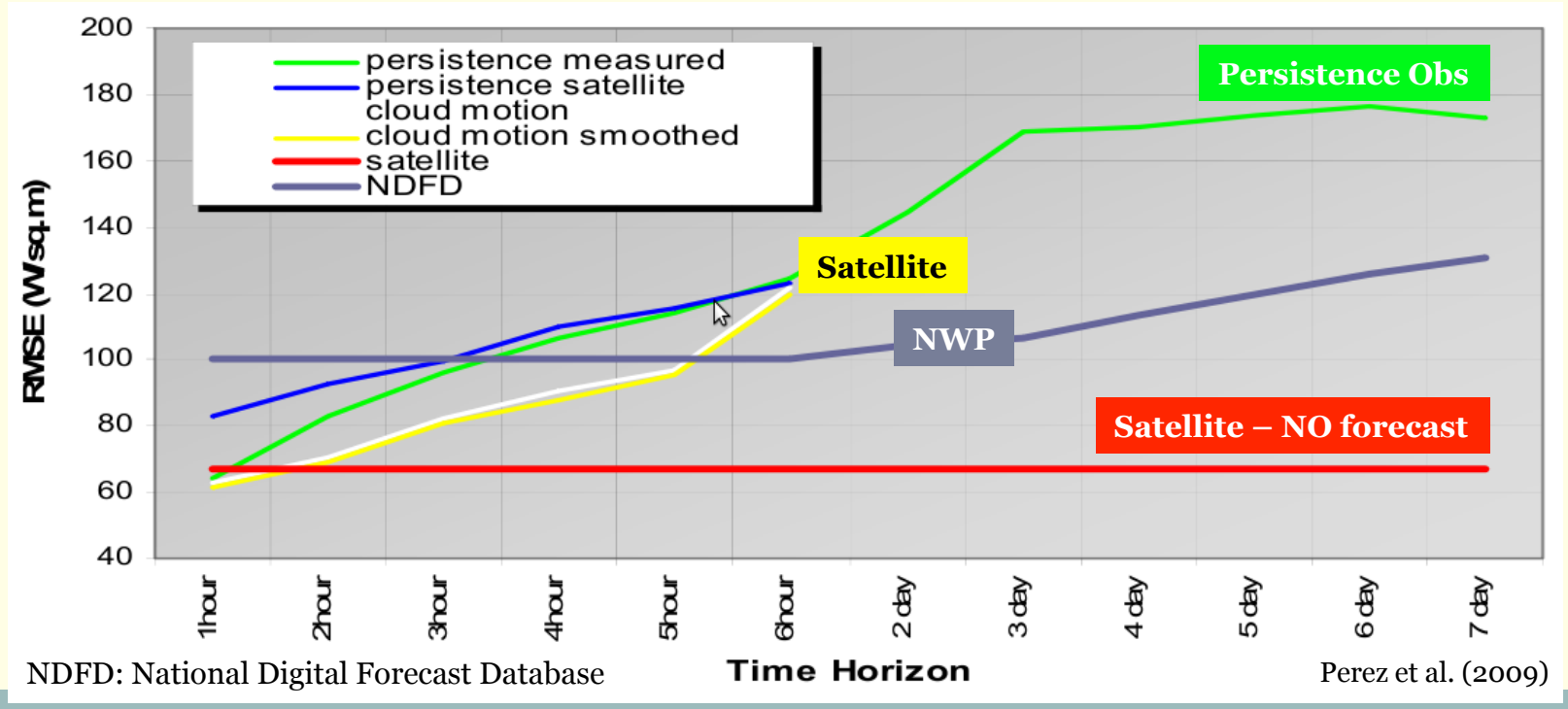
Here, we present a **new aerosol parameterization and early tests using the GSFC SW scheme**



[1]: Direct Normal Irradiance
[2]: Diffuse Irradiance

MOTIVATIONS – Current Gaps

- Currently, satellite-based methods dominate in the solar industry. But they suffer of two main shortcomings:
  1. satellite records for solar assessment are heterogeneous and limited both in time and space. **Series longer than 10-15 years are desirable!!**
  2. The **performance** of the satellite-based forecasts drastically **disminishes beyond 4-6 hours!!**



NDFD: National Digital Forecast Database

Perez et al. (2009)

OBJECTIVES – Solar Industry Requirements

1. To provide **GHI and DNI**
2. To assess surface solar resource from, at least 10 years. Ideally**, 20 or even 30 years**
3. To forecasts **2-3 days ahead** at sub-hourly scale

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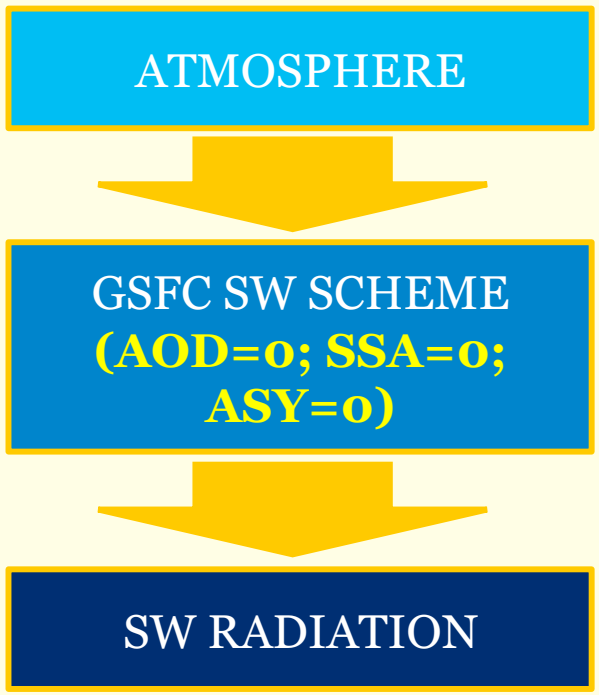
What do we need to improve in WRF?

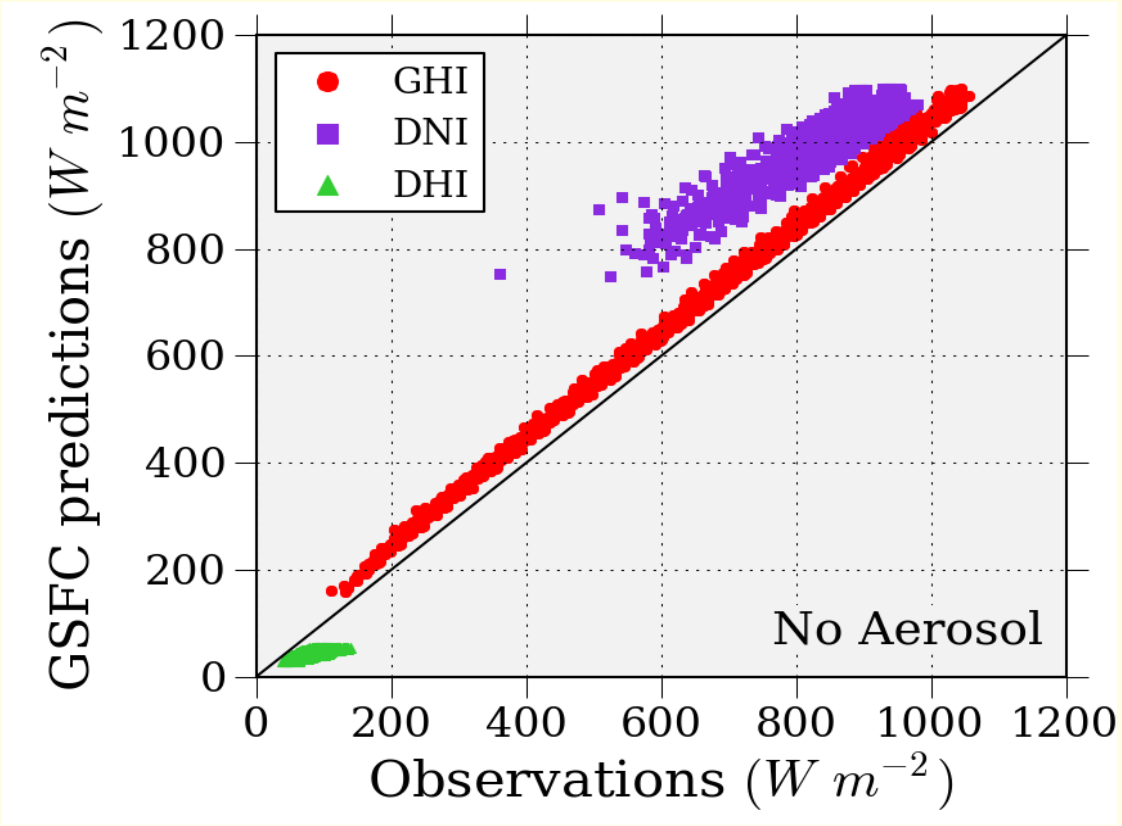
1. **To include DNI in the output dataset**

1.) DNI CALCULATION

GSFC SW scheme **already calculates** internally the **direct and diffuse** components at each spectral band

However, **aerosol optical properties are turned down!!**





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What do we need to improve in WRF?

1. To include DNI in the output dataset
2. To include the direct effect of aerosols in the SW radiative transfer
   - **An aerosol parameterization is required**

2.) AEROSOL PARAMETERIZATION

The inclusion of aerosols in the model should be…

…**as simple as possible** to make it easy to the people of the solar industry,

…**versatile** to allow rapid updating of aerosols from multiple (heterogeneous) sources

…and sufficiently **precise and accurate** for, specially, DNI assessment and short-term forecast.

In turn, current **atmospheric chemistry models**, still under strong development,…

…are still **computationally expensive** –not desirable for operational forecasting.

…require a **complex and somehow rigid initialization** of aerosols – not suitable for very short-term applications

…**a thorough description** of aerosols as in these models **might not be required** for surface solar radiation assessment

2.) AEROSOL PARAMETERIZATION

To account for aerosols, we need to parameterize…

… **aerosol optical depth (AOD)**

… **aerosol single-scattering albedo (SSA)**, and

… **aerosol asymmetry factor (ASY)**

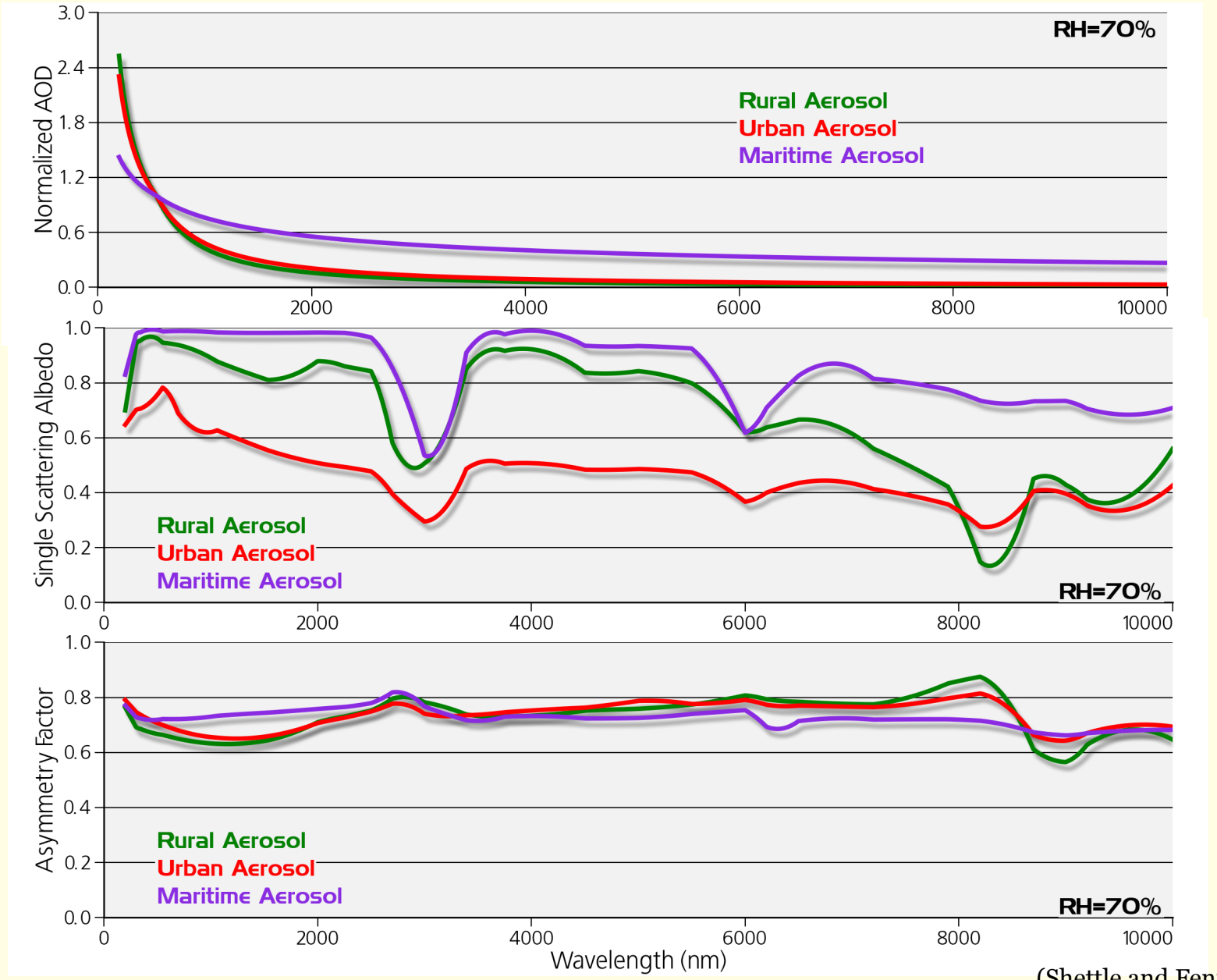
at each spectral band (11) and every grid-cell of the domain, including each model vertical layer (we assume an exponential profile)

The proposed parameterization only requires…

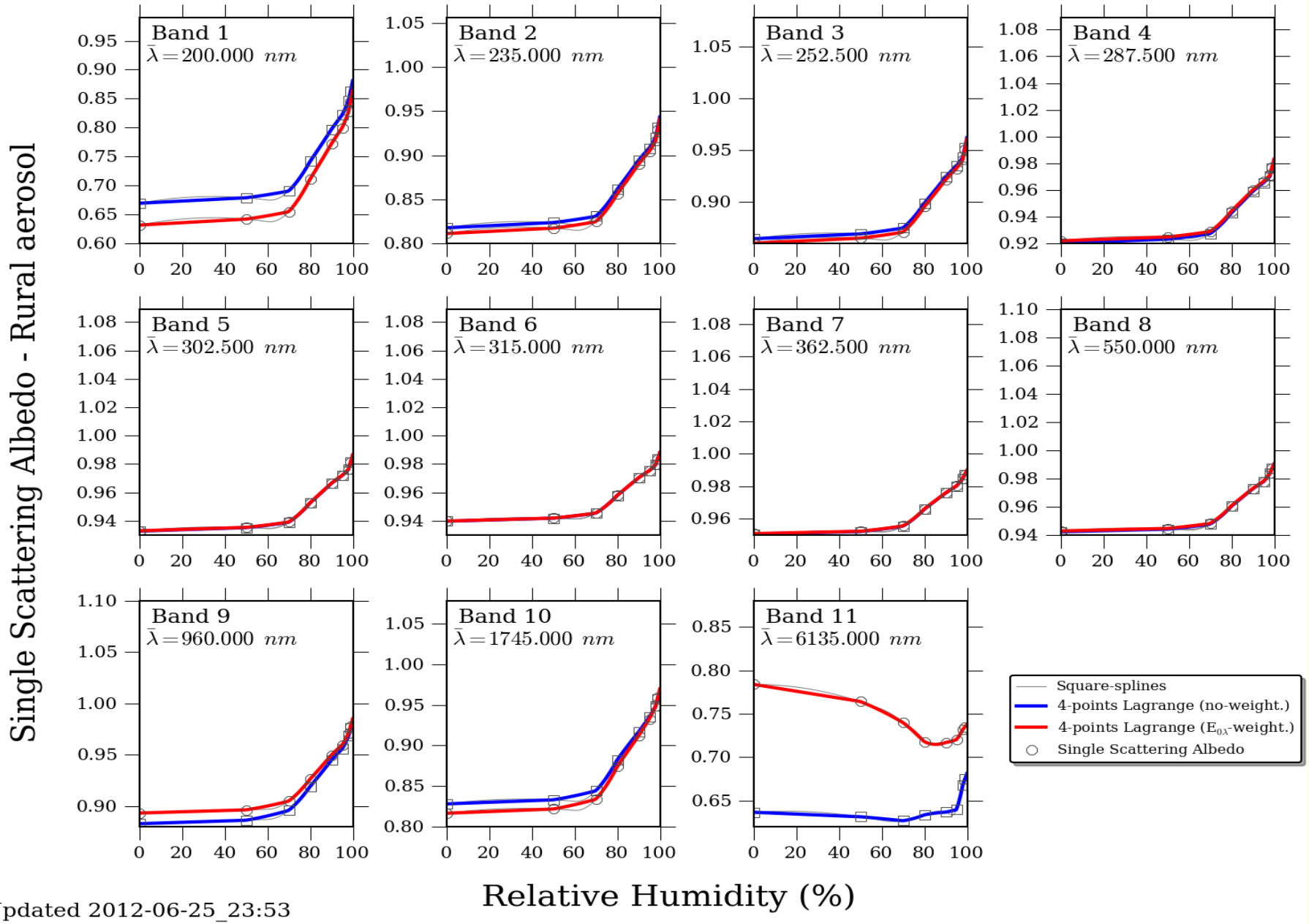
… the **total aerosol optical depth at 550 nm**,

… the predominant **type of aerosol**, and

… the **relative humidity**.



(Shettle and Fenn, 1979)



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CASE STUDY – Experiment Design

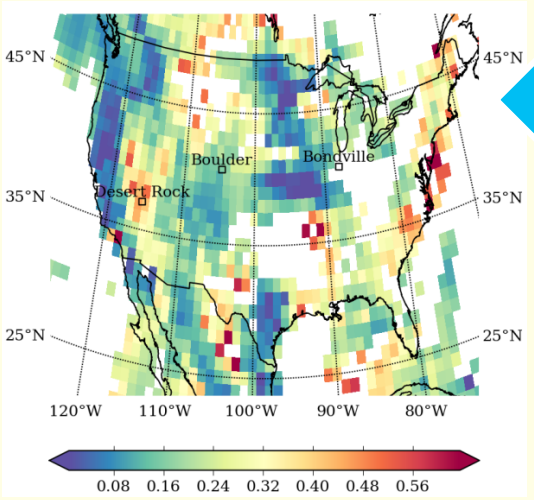
- CONUS, June – August 2009, ERA-Interim, 27 km, data every 10 minutes
- **Daily gridded AOD** at 550 nm from **Level-3 MODIS dataset (1^{o}x1^{o})**
- **3 runs: no-aerosols, rural aerosol, urban aerosol**

Three radiometric stations from NOAA's SURFRAD network:

- Bondville (IL), Boulder (CO) and Desert Rock (NV)
- **1-minute measurements** of GHI, DNI and DIF
- **Concurrent measurements of spectral AOD**
- **Validation under cloudless conditions only** both in WRF and observations (cloud-screening algorithm)

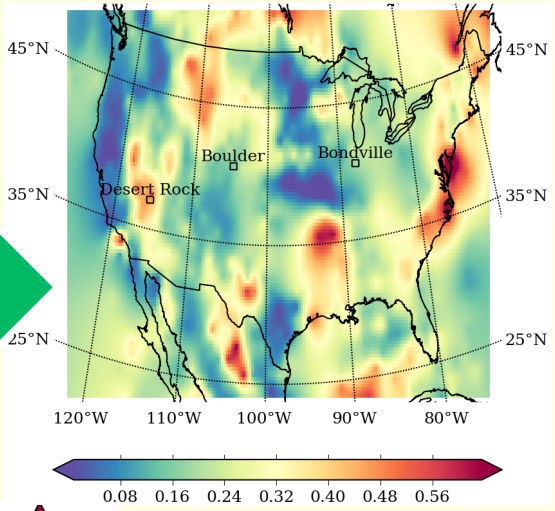



CASE STUDY – Gridded AOD Source

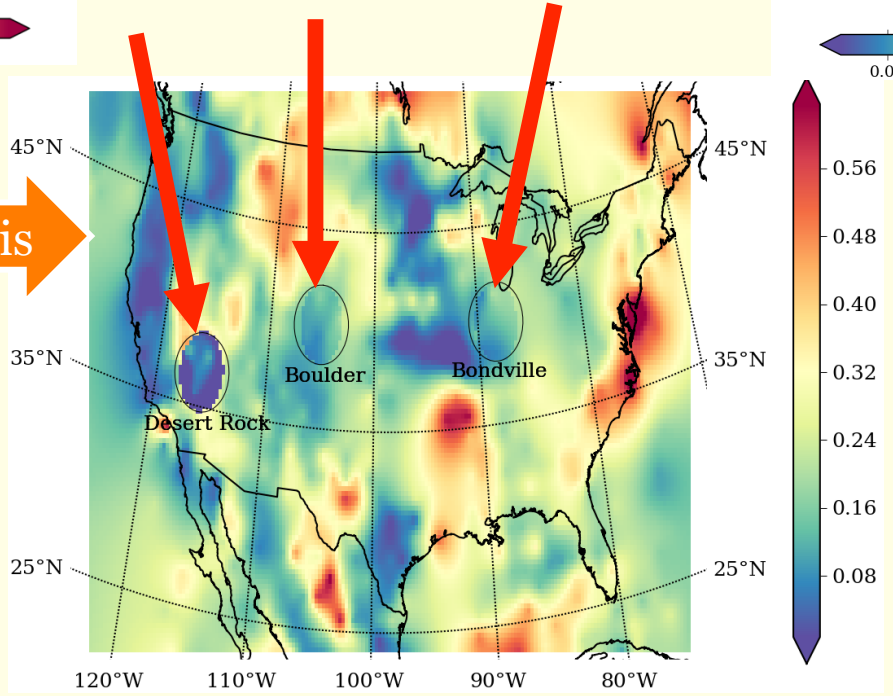


1.) Initial L3 MODIS AOD

2.) Interpolated with Kriging



3.) Cressman Analysis



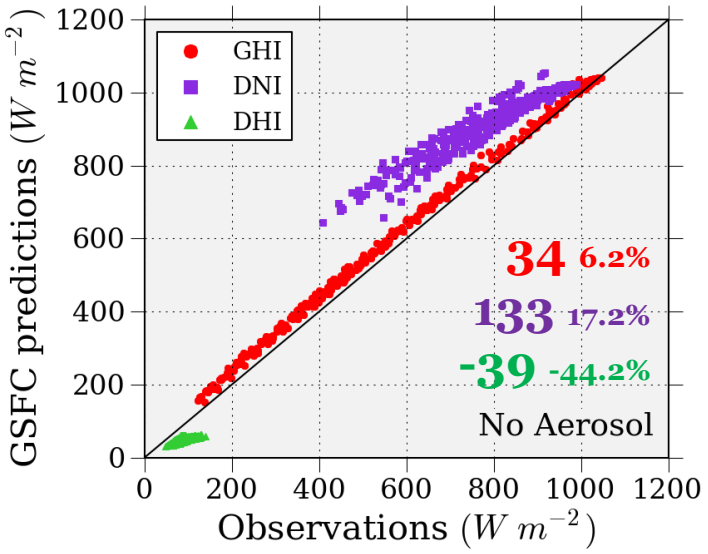
This procedure was repeated every day of the study period

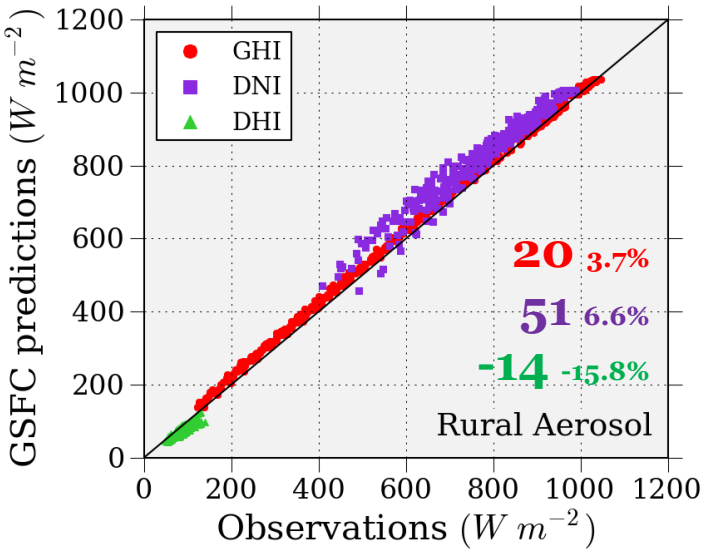
RESULTS – Bondville (IL)

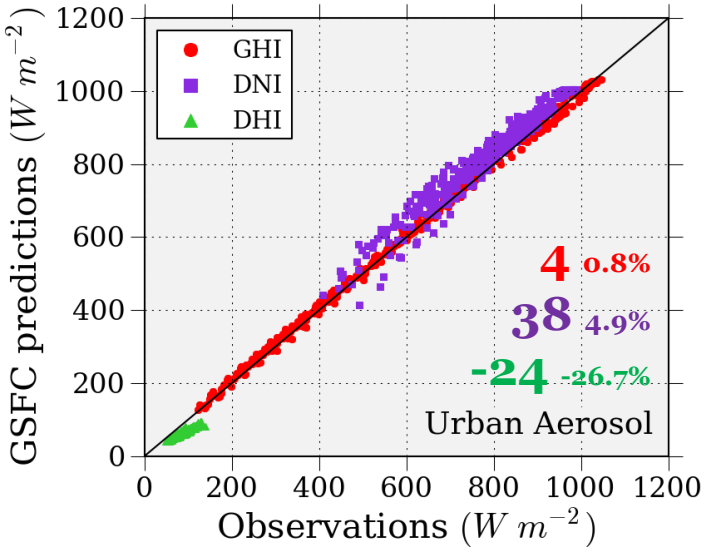
Non-screened Obs:
2.6%

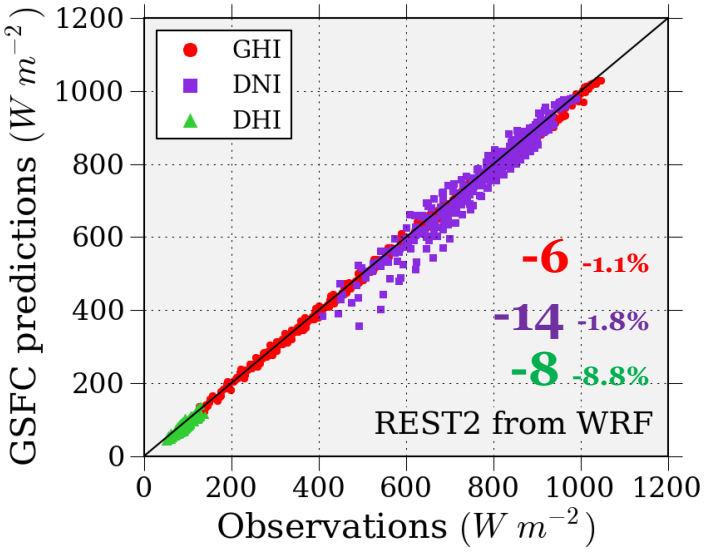
Mean AOD:
0.17

Mean Precip. Water:
2.74 cm







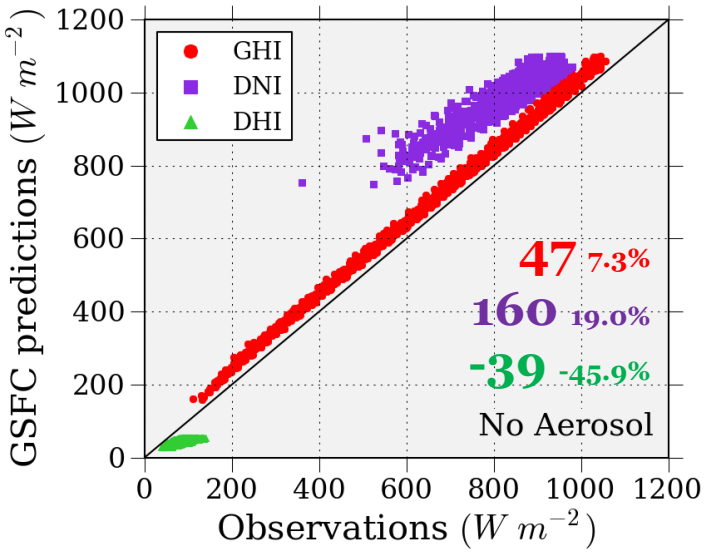


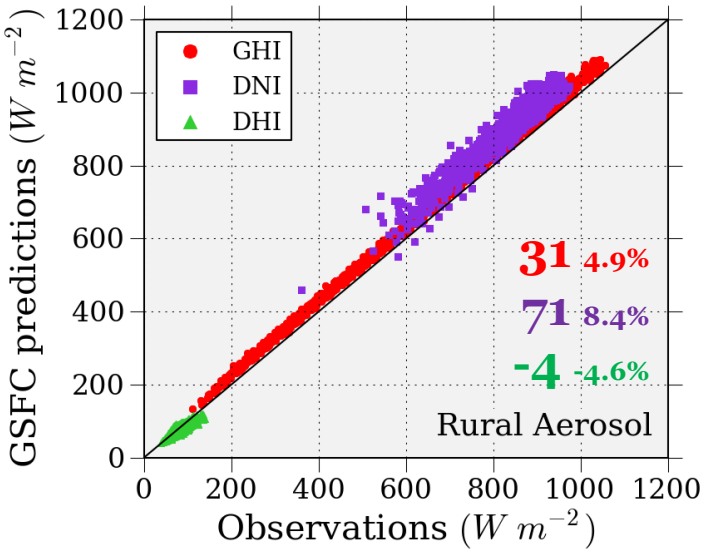
RESULTS – Boulder (CO)

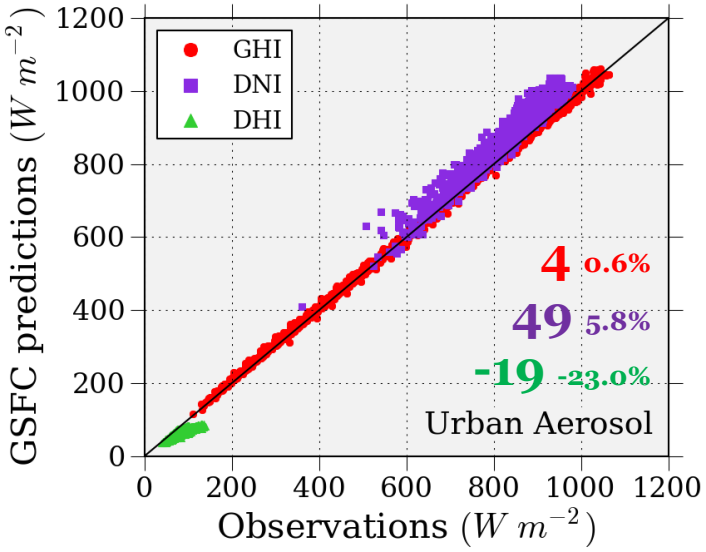
Non-screened Obs:
9.2%

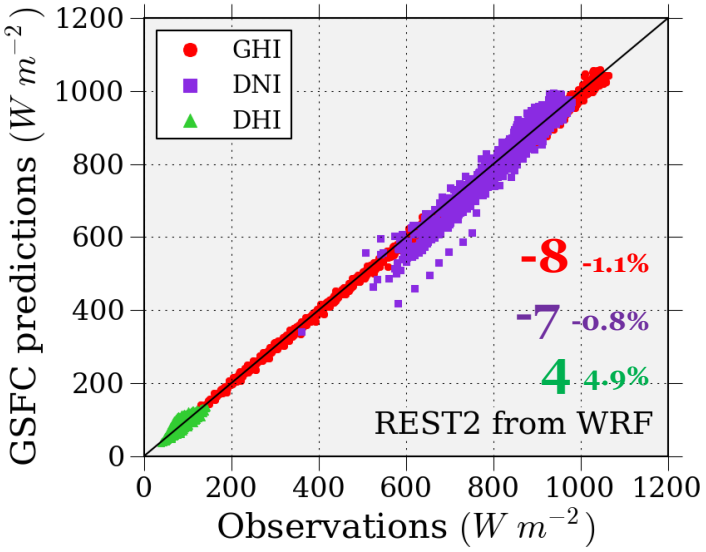
Mean AOD:
0.13

Mean Precip. Water:
1.13 cm









RESULTS – Desert Rock (NV)

Non-screened Obs:

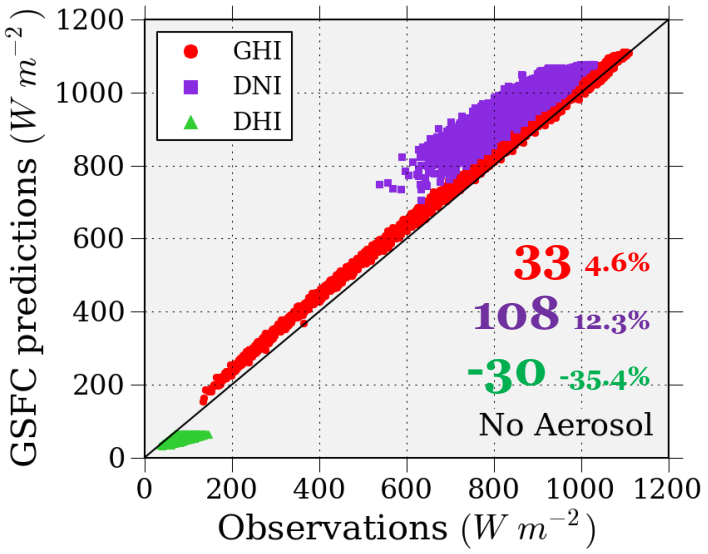
21.3%

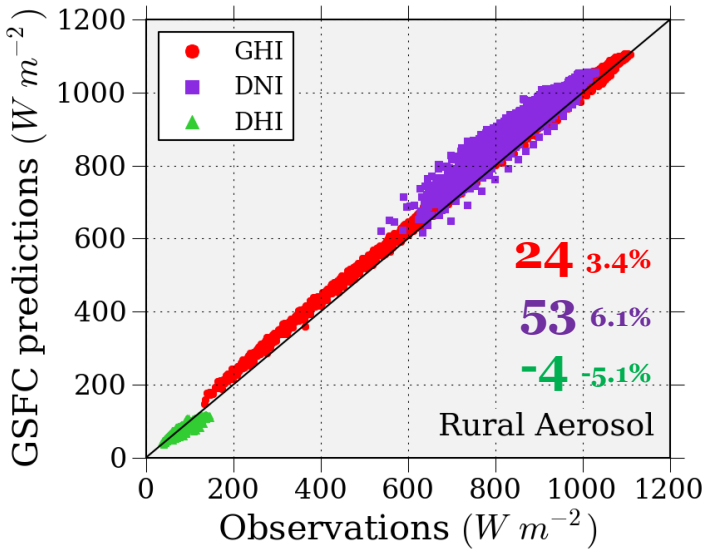
Mean AOD:

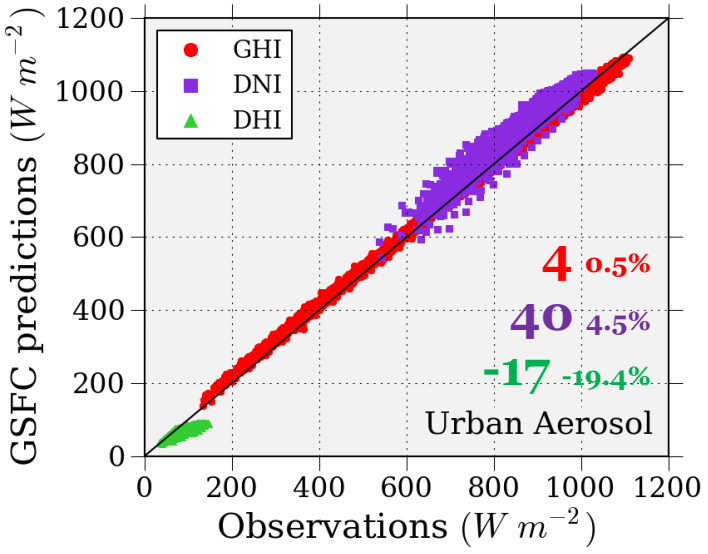
0.09

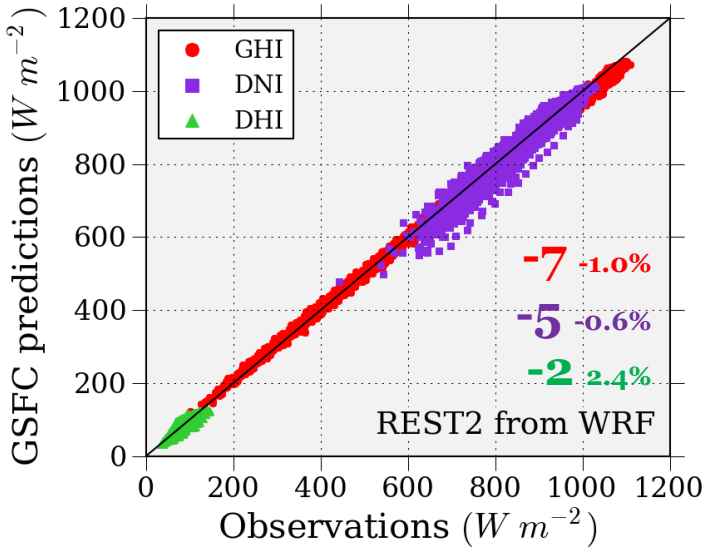
Mean Precip. Water:

1.54 cm

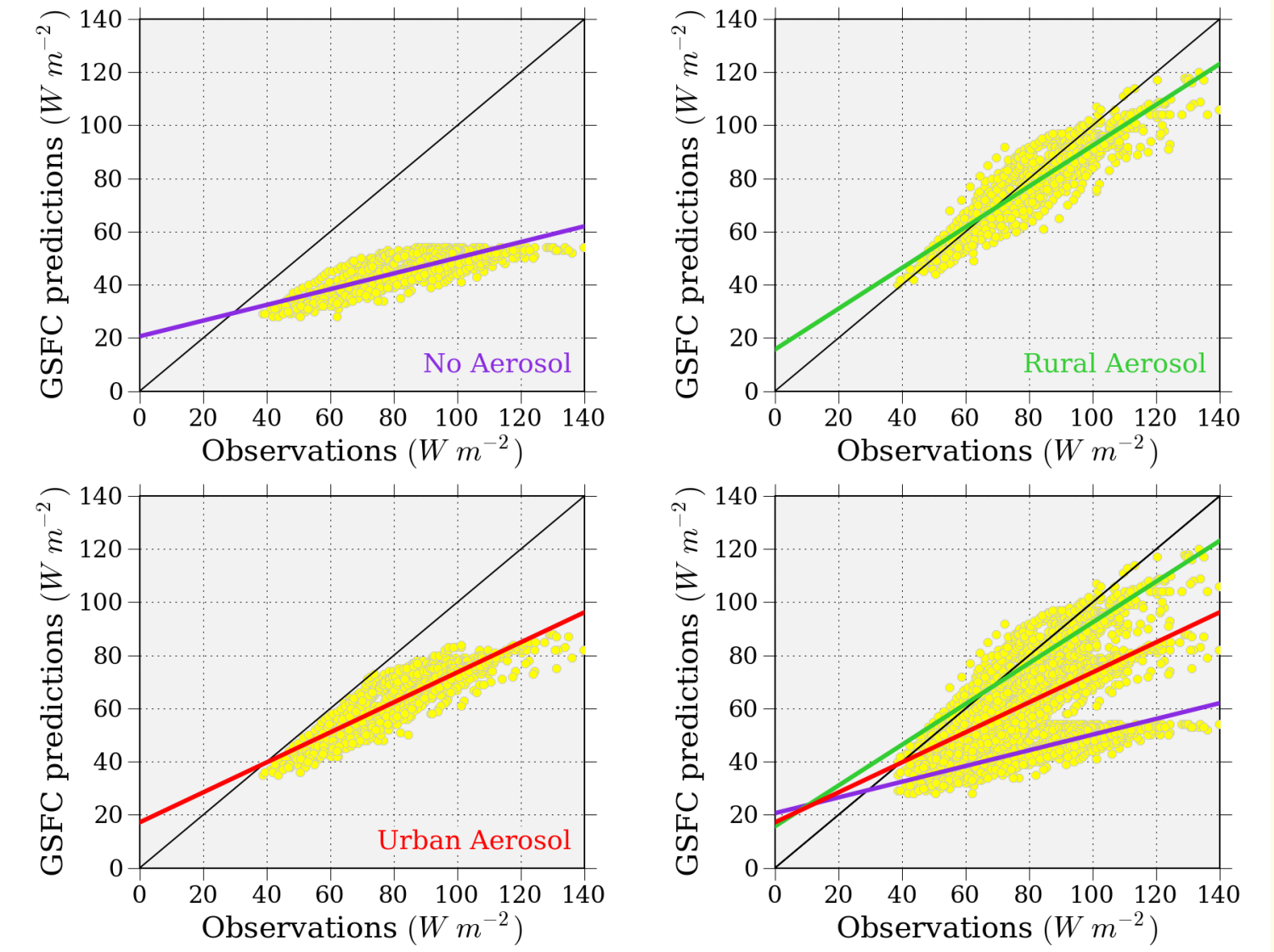




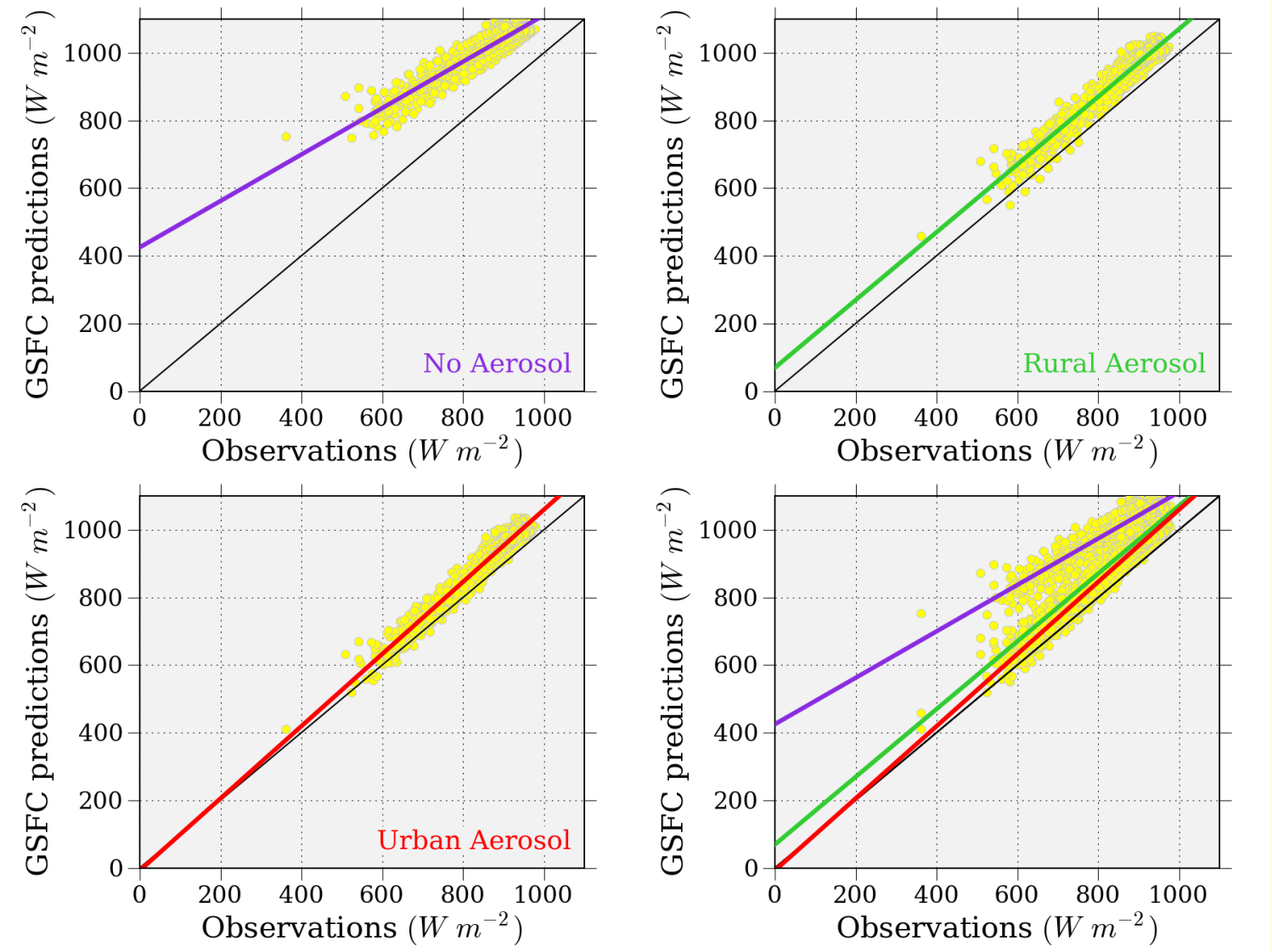




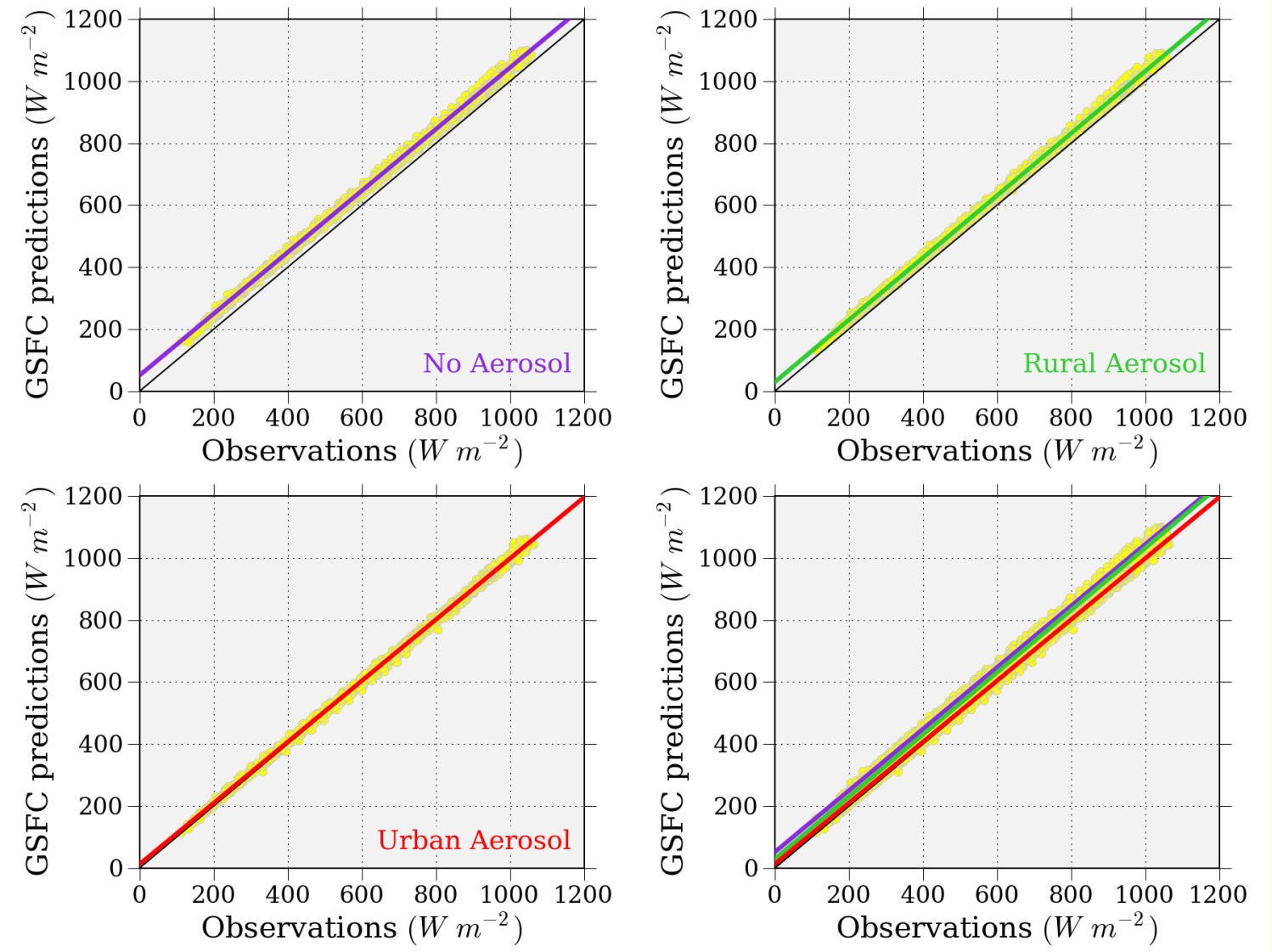
RESULTS – Boulder (DIF)



RESULTS – Boulder (DNI)

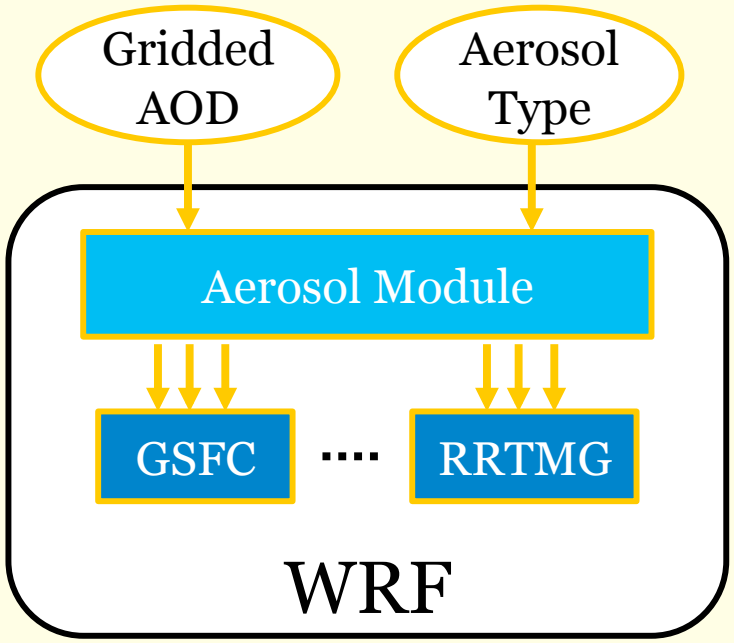


RESULTS – Boulder (GHI)



NEXT STEPS

We want to make also available the parameterization to other SW schemes, as the RRTMG. **New implementation**:



The extended validation to other SW schemes **will increase our knowledge on the parameterization** and may lead to further improvements

The **Angstrom exponent** could be used to infer the type of aerosol and spectral AOD. But so far there is no a reliable data source.

The parameterization could ingest AOD from the **IFS/ECMWF**

Are **more aerosol types** required?

CONCLUSIONS

1. **The bias caused in DNI and DIF by the lack of aerosols is much larger than in GHI**

2. When the right AOD is provided, **the aerosol parameterization corrects the bias in GHI and most of it in DNI and DIF irradiances**

3. The **vertical profile** of aerosols seems to be a **second order effect**

4. Finally, the parameterization would benefit from a **thorough validation of the currently available AOD satellite datasets and development of bias reduction methods for them.**

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