GOAC-INSMET, Cuba in cooperation with GOA, UVA Spain will contribute to TEMPO:

After TEMPO launch:
- TEMPO AOD validation with sun photometer AOD and phyrheliometer BAOD.
- TEMPO Integrated Water Vapor (IWV) with sun photometer IWV and GPS IWV.
- Develop local services w/ hourly TEMPO AOD & IWV to be scaled later to country.

Diagnostic Service of Solar Radiation for Cuba:

2012: Three actinometrical stations in the country joined, becoming the “Diagnostic Service of the Solar Radiation for Cuba”. Guarantees the update of the stations observation’s digital records up to the present.

The direct irradiance measurements used to derive the Broadband AOD (BAOD) at all the 4 sites.

http://www.goac.cu/actino
Comparing sun photometer AOD & pyrheliometer BAOD:

Temporal coincident sun photometer AOD (440, 500, 675 nm) & BAOD at Camagüey, Cuba.

Better results in bold.

<table>
<thead>
<tr>
<th>BAOD vs. AOD$_{SP}$(λ)</th>
<th>675 nm</th>
<th>500 nm</th>
<th>440 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>0.048</td>
<td>0.044</td>
<td>0.056</td>
</tr>
<tr>
<td>MAE</td>
<td>0.037</td>
<td>0.030</td>
<td>0.040</td>
</tr>
<tr>
<td>BIAS</td>
<td>0.032</td>
<td>-0.002</td>
<td>-0.022</td>
</tr>
</tbody>
</table>


Clear Sky Global Irradiance increasing trend 2.2 W m$^{-2}$ year$^{-1}$ (BRIGHTENING) for 1981-2010.

BAOD had a decreasing trend of -2.8 x 10$^{-3}$ year$^{-1}$
Validation of MODIS AOD (Terra & Aqua) w/ sun photometer AOD & BAOD:

**BAOD at the 4 solar radiation stations:**

<table>
<thead>
<tr>
<th>Camagüey, La Fe, Topes de Collantes &amp; Jovellanos</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAOD vs. AOD(_t)</td>
</tr>
<tr>
<td>DB</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>RMSE</td>
</tr>
<tr>
<td>MAE</td>
</tr>
<tr>
<td>BIAS</td>
</tr>
<tr>
<td>R</td>
</tr>
<tr>
<td>Cases</td>
</tr>
</tbody>
</table>

**Tables Legend:**

AOD\(_t\): AOD Terra  AOD\(_a\): AOD Aqua  AOD\(_{ta}\): Terra & Aqua  
AOD\(_{SP}\): AOD Sun photometer  DB: Deep Blue  DT: Dark Target  
f: MODIS/AERONET AOD retrievals in %  

BAOD-MODIS comparison showed higher uncertainties than for MODIS-sun photometer, **but at the same order of magnitude.**

- BAOD\(_{SP}\) shows, in general, a better performance for the DT than for the DB algorithm.  
- Small differences between AOD\(_t\) and AOD\(_a\), justifying combining these observations in a single data set for climatological studies. DT & DB algorithms are better than expected (f ~ 80 %) from November to January, but in other months f = 68 %, ~ one standard deviation for DT and significantly lower for DB.

---

GPS operative at GOAC: May 22nd 2014 to the present.


Preliminary validation of IWV from ERA-I w/ sun photometer & GPS Measured at Camagüey by GOAC

### Instrument RMSE MAE BIAS R N

<table>
<thead>
<tr>
<th>Instrument</th>
<th>RMSE</th>
<th>MAE</th>
<th>BIAS</th>
<th>R</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP/GPS</td>
<td>0.406</td>
<td>0.335</td>
<td>-0.240</td>
<td>0.935</td>
<td>146</td>
</tr>
<tr>
<td>SP/ERA-I</td>
<td>0.806</td>
<td>0.623</td>
<td>-0.123</td>
<td>0.683</td>
<td>1638</td>
</tr>
<tr>
<td>GPS/ERA-I</td>
<td>0.885</td>
<td>0.682</td>
<td>-0.108</td>
<td>0.548</td>
<td>911</td>
</tr>
</tbody>
</table>
SUMMARY: GOAC measurements capabilities:

Radiation, Aerosols, Clouds and IWV(GPS)

GOA - Univ. Of Valladolid, Spain (GOA-UVA)

GPS (IWV)
UNAVCO
NCAR, US

Pyranometer
Prof. Alan Robock,
Rutgers Univ., US

PAR Sensor

Sun-photometer
Built & operated
in cooperation with
GOA-UVA
Operative from 2018

Cloud Sky Camera
Contributing to
AERONET

Supported by Cooperation Agreement
GOA-UVA & INSMET (2007-present)
http://www.goac.cu/uva/
Main Contributors to the GOAC Observational Facilities:


More than 10 years of sustained cooperation.
- Sun photometer & its calibration (2008-2021)
- PM impactor.
- Photosynthetic Active Radiation sensor
- Calibration bench for radiation sensors.
- Computing & hardware resources
- PhD fellowship: Cloud Camera photometry.
- Broad know-how transfer & multiple trainings.
- Support for GOAC & LALINET publications

Prof. Ángel de Frutos, Prof. Victoria Cachorro, & GOA-UVA team, Univ. Valladolid, Spain.

Promoting and facilitating GOAC International Cooperation:
- PhD fellowship: Pinatubo lidar & satellite validation.
- Earlier contacts and exchanges with AERONET.
- Contributor to design, promote, support and setup LALINET.
- Key role in US-Cuba contacts for GPS setup at GOAC.
- Promoted GOAC invitation to Norway funded XCUBE project.
- Earlier contacts with TEMPO Science Team.
- Pyranometer CM-21 & Data logger LOGBOX SD (Kip & Zonen).

Prof. Alan Robock, Rutgers University, USA

Data Rescue know-how transfer and promotion of cooperation:
- PhD fellowship: for Pinatubo lidar & satellite validation.

Prof. Ricardo García Herrera, Complutense Univ. Madrid, Spain

Relevant contributors for GPS setup at GOAC.
Prof. Rick Anthes, UCAR, Dr. John Braun, NCAR, Prof. Oswaldo Garcia, San Francisco State University, CA, US