Projet / Project:

Développement de l'énergie solaire en Afrique subsaharienne /

Solar Development in Sub-Saharan Africa

CAMPAGNE DE MESURES SOLAIRES EN AFRIQUE DE L'OUEST /

SOLAR RESOURCE MEASUREMENT CAMPAIGN IN WEST AFRICA

Rapport d' Installation Station Météorologique Automatique /

Automatic weather station installation report

Bauchi - Nigéria / Bauchi - Nigeria

Septembre 2021 / September 2021

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Résumé d'installation et du site / Site and installation summary	
Client / Client:	*Système d'Échanges d'Énergie Électrique Ouest* Africain (EEEOA) / West African Power Pool (WAPP)
Site / Site:	*Sous-station de TCN, Bauchi, Nigéria* / TCN substation, Bauchi, Nigeria
Coordonnées / Coordinates :	10.28526°N, 9.85059°E, altitude: 597 m
Type de station / Station type :	*Tier1 station météorologique automatique* / Tier1 automatic weather station
Date de mise en service / Date of commissioning :	2021-09-19
Démarrage de la campagne de mesure / Start of measurement campaign	2021-09-20
***Mise en service* / Commissioning**	
Installation et mise en service effectuées par Installation and commissioning performed by *Date : 19 Septembre 2021* / Date: 19 September 2021	*Installation sur place* / Installation on site : Daniel Okoho *Mise en service à distance* / Remote commissioning : Roman Affolter, CSP Services

1 *Resumé* / Summary

Dans le cadre du projet "Développement de l'énergie solaire en Afrique subsaharienne, campagne de mesure solaires en Afrique de l'Ouest", une station météorologique automatique (SMA) a été installée au Nigéria pour la mesure de l'irradiance solaire et d'autres paramètres pertinents pour le développement de projets de centrales solaires. La station a été installée dans la sous-station de la TCN à Bauchi.

Le but de cette installation est de collecter deux ans de données de mesure au sol pour la centrale photovoltaïque (PV) à l'échelle du service public prévue à l'endroit décrit. Les paramètres de mesure sont principalement l'irradiation horizontale globale (GHI), l'irradiation normale directe (DNI) et l'irradiation horizontale diffuse (DHI). En outre, sont mesurés la température et l'humidité relative, la pression barométrique, la pluie, la vitesse et la direction du vent, ainsi que le taux d'encrassement des modules PV et le taux de corrosion de différents échantillons métalliques.

Les données de mesure de la station sont transférées à CSPS à intervalles réguliers pour le suivi et le contrôle de la qualité des données. De plus, les données sont disponibles sur un serveur web protégé pour une surveillance et un téléchargement des données en temps réel.

CSPS appliquera des tests quotidiens de qualité des données et enverront les données de mesure finales contrôlées par la qualité à intervalles mensuels aux destinataires définis par le client.

Du personnel sous-traité localement est chargé de l'entretien et du nettoyage des capteurs. La personne responsable était présente le dernier jour de l'installation et a été informée des procédures de maintenance et de nettoyage

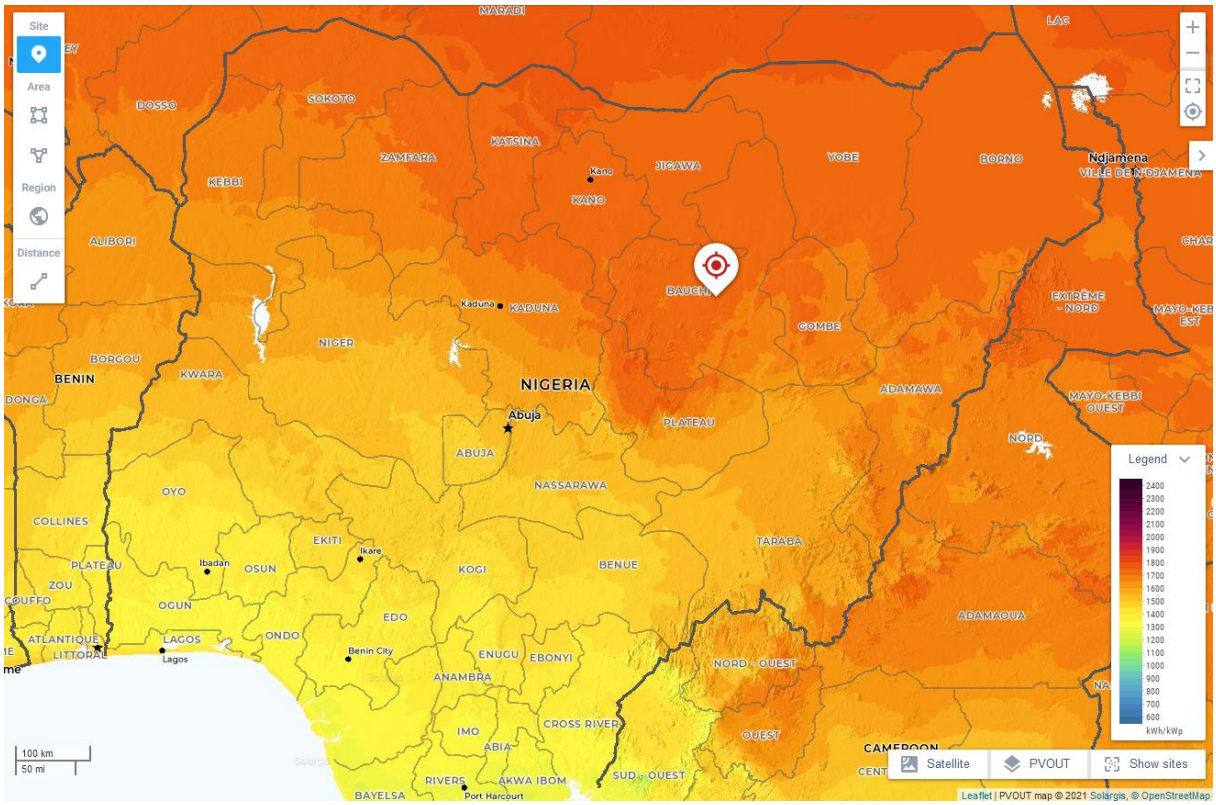

Figure 1: Site de Bauchi au Nigéria (source : globalsolaratlas.info) / Bauchi site in Nigeria.

In the framework of the project "Solar Development in Sub-Saharan Africa, Solar resource measurement campaign in West Africa", an automatic weather station (AWS) was installed in Nigeria for the measurement of the solar irradiance and other parameters relevant for the development of solar energy power plant projects. The station was installed at the TCN substation in Bauchi.

The purpose of this installation is to collect two years of ground measurement data for the planned utility scale photovoltaic (PV) power plant at the described location. Measurement parameters are primarily global horizontal irradiance (GHI), direct normal irradiance (DNI) and diffuse horizontal

irradiance (DHI). Further, temperature and relative humidity, barometric pressure, rain, wind speed and direction as well as the soiling rate on PV modules and the corrosion rate on different metal samples is measured.

Measurement data from the station are transferred to CSPS in regular intervals for data quality monitoring and control. Additionally, the are available on a protected web server for real time data monitoring and download.

CSP Services will apply daily data quality tests and send quality-controlled final measurement data in monthly intervals to the client-defined recipients.

Local subcontracted staff is in charge of the maintenance and sensor cleaning. The responsible person was present on the last day of the installation and was briefed on the maintenance and cleaning procedures

2 *Description du site* / Site description

2.1 *Emplacement* / Location

Site / Site :	Bauchi
Cordonnées / Coordinates :	10.28526°N, 9.85059°E, altitude: 597 m
Climat / Climate :	*Climat tropical de savane* / Tropical savanna climate (Köppen-Geiger Aw, (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006))

Table 1: Informations de l'emplacement / Location information.

Figure 2: Emplacement dans la sous-station de la TCN à Bauchi / Location at the TCN substation in Bauchi.

2.2 *Environnement et ombrage* / Surroundings and shading profile

Les environs immédiats sont plats, avec quelques installations et structures à l'ouest et au sud. Après l'installation de la station météorologique automatique, des photos de l'horizon dans toutes les directions ont été prises à partir de l'emplacement des capteurs d'irradiance et une vue panoramique a été générée à partir de ces photos.

La Figure 3 montre l'image panoramique avec la ligne d'horizon et la course du soleil tout au long de l'année.

The immediate surroundings are flat with some facilities and structures to the west and south. After the installation of the automatic weather station, pictures of the horizon in all directions were taken from the location of the irradiance sensors and a panoramic view was generated from these pictures.

Figure 3 shows the panoramic picture with the horizon line and the sun path throughout the year.

Figure 3: Ligne d'horizon du point de vue du pyranomètre et course du soleil tout au long de l'année / Horizon line from the perspective of the pyranometer and sun path throughout the year.

La Figure 4 montre l'analyse de la ligne d'horizon et les occurrences d'ombrage attendues sur les mesures de données d'irradiation. L'analyse montre que le champ de vision des capteurs est presque libre et qu'il y a peu d'obstruction relevant au-dessus de l'horizon, en particulier dans les directions est et ouest où le soleil est proche de l'horizon au lever et au coucher du soleil. En général, on prévoit qu'il n'y aura peu d'ombrage sur le site.

Figure 4 shows the analysis of the horizon line and the expected shading occurrences on the irradiance data measurements. The analysis shows an almost free field of view for the sensors, only little relevant obstructions above horizon exist, especially in east and west direction where the sun is near the horizon on sunrise and sunset. In general, only little shading is expected at the site.

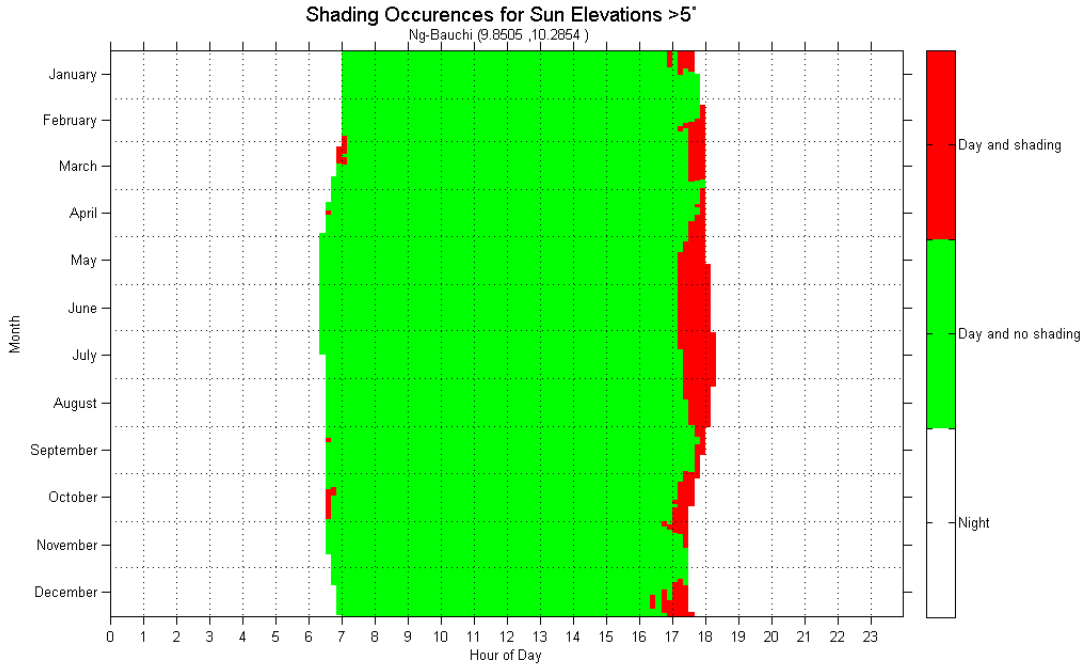

Figure 4: Ombrage pour l'élévation du soleil > 5° / Shading occurrences for sun elevations >5°.

3 *Configuration et disposition de la station météorologique automatique* / Automatic weather station configuration and layout

Cette section donne une vue d'ensemble de l'équipement installé et des capteurs avec leurs numéros de série respectifs. En outre, un plan de la station météorologique telle qu'elle a été construite est présenté.

This section gives an overview of the installed equipment and sensors with respective serial numbers. Further, a layout drawing of the weather station as built is shown.

3.1 *Équipement de mesure* / Measurement equipment

Équipement et numéros de série / **Equipment and serial numbers**		
Station météorologique automatique Automatic weather station	*CSP Services Tier1* / CSP Services Tier1	CSPS.MT.21.222
Boitier de contrôle / Main control box	*CSP Services Tier1* / CSP Services Tier1	CA.21.222.0001
Enregistreur de données / Datalogger	Campbell CR1000X	22461
Modem / Modem	Teltonika RUT240 LTE Router	111017674
Alimentation électrique / Power supply	*Alimentation électrique autonome avec panneaux PV et batterie* / Autonomous power supply with PV panels and battery	-
Tracker solaire / Solar tracker	Kipp&Zonen SOLYS2 Tracker	210675

Paramètre mesuré / **Measured parameter**	***Unité*** / **Unit**	***Type de capteur*** / **Sensor type**	***Numéro de série*** / **Serial Number**
GHI, DHI	W/m²	*Pyranomètre Kipp&Zonen CMP10 (installé à 2m du sol)* / Kipp&Zonen CMP10 pyranometer (installed 2m above ground)	GHI: 210853 DHI: 210854
DNI	W/m²	*Pyrhéliomètre Kipp&Zonen CHP1 (installé à 2m du sol)* / Kipp&Zonen CHP1 pyrheliometer (installed 2m above ground)	210874
Température / Temperature (T)	°C	*Capteur de température et d'humidité Hygrovue5 avec écran anti-rayonnement RAD06 (installé à 1,5 m du sol)* / Hygrovue5 T/RH sensor with RAD06 radiation shield (installed 1.5m above ground)	E2854
Humidité / Humidity (RH)	%		
Pression barométrique / Barometric pressure (BP)	hPa	*Capteur de présion Vaisala PTB110 (CS106)* / Vaisala PTB110 (CS106) pressure sensor	S4950663
Précipitations (pluie) / Precipitation (Rain)	mm	*Campbell Scientific 52203 (installé à 2m du sol)* / Campbell Scientific 52203 (installed 2m above ground)	TB 16362
Vitesse du vent / Wind speed (WS)	m/s	*Anémomètre NRG #40C Classe 1 (installé à 10m du sol)* / NRG #40C Class 1 anemometer (installed 10m above ground)	179500332897
Direction de vent / Wind direction (WD)	°N	*Girouette NRG #200M (installée à 10m du sol)* / NRG #200M wind vane (installed 10m above ground)	1007000008937

***Paramètre mesuré* / Measured parameter**	***Unité* / Unit**	***Type de capteur* / Sensor type**	***Numéro de série* / Serial Number**
Taux d'encrassement / Soiling rate	%	*CSP Services système de mesure de l'encrassement des services PV* / CSP Services PV soiling measurement system	MS.21.201.0022
Taux de corrosion / Corrosion rate	%	Échantillonneur de corrosion Fraunhofer avec 12 échantillons métalliques normalisés d'aluminium, d'acier au carbone, de zinc et de cuivre (trois échantillons de chaque métal) / Fraunhofer corrosion sampler with 12 standardized metal samples of aluminum, carbon steel, zinc and copper (three samples from each metal)	MT.21.222

Informations sur les capteurs et systèmes de mesure sont décrites dans la documentation de spécifications de la station Tier1. Pour les certificats d'étalonnage des capteurs, voir le chapitre 9.

Further information on the listed sensors and measurement systems can be found in the station specification documentation. For calibration certificates of sensors see chapter 9.

3.2 *Disposition de la station* / Station layout

La disposition la station Tier 1 est illustrée dans les figures ci-dessous. Les principaux composants sont la structure de montage avec les capteurs d'irradiance et le mât de mesure du vent avec des capteurs supplémentaires.

The layout of the Tier1 AWS is shown in the figures below. The main components are the mounting structure with the irradiance sensors and the wind mast with additional sensors.

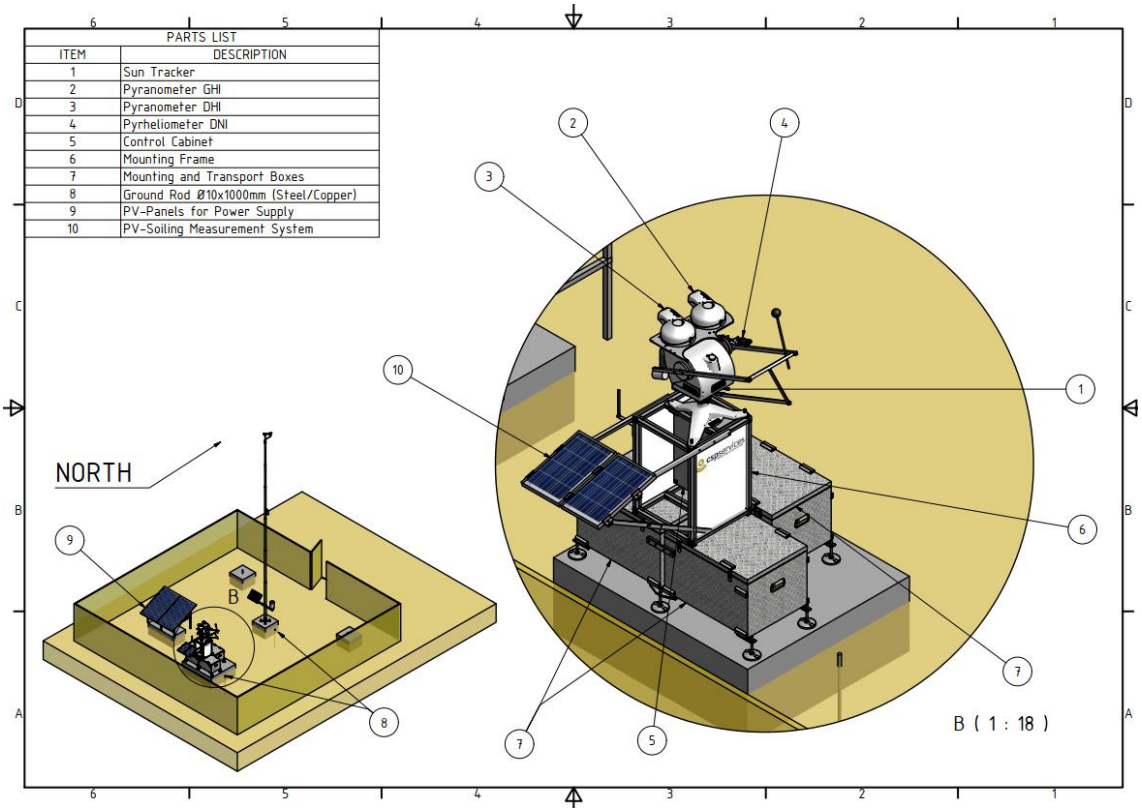

Figure 5: Disposition de la station météorologique automatique Tier1 : Capteurs d'irradiance, système de mesure du taux de salissure PV, panneaux PV pour l'alimentation électrique / Tier1 automatic weather station layout: Irradiance sensors, PV soiling rate measurement system, PV panels for power supply.

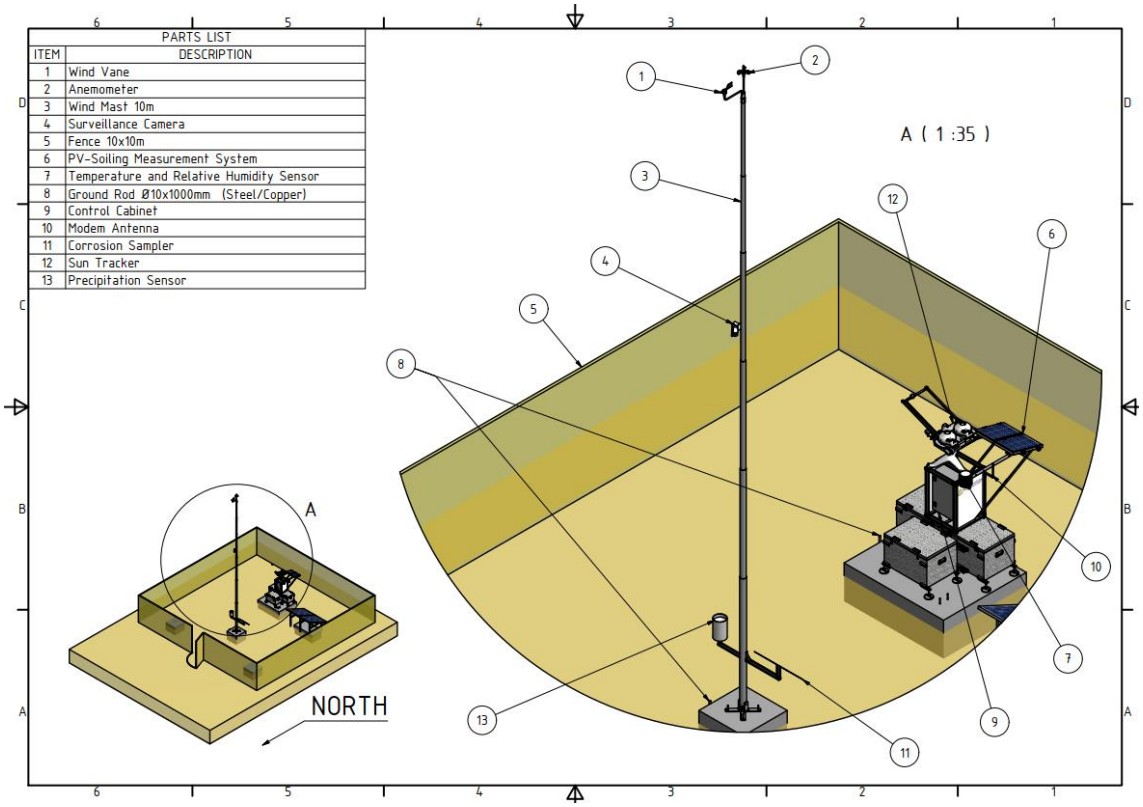

Figure 6: Disposition de la station météorologique automatique Tier1 : détails du mât éolien de mesure et des capteurs de vent / Tier1 automatic weather station layout: wind mast and wind sensors details.

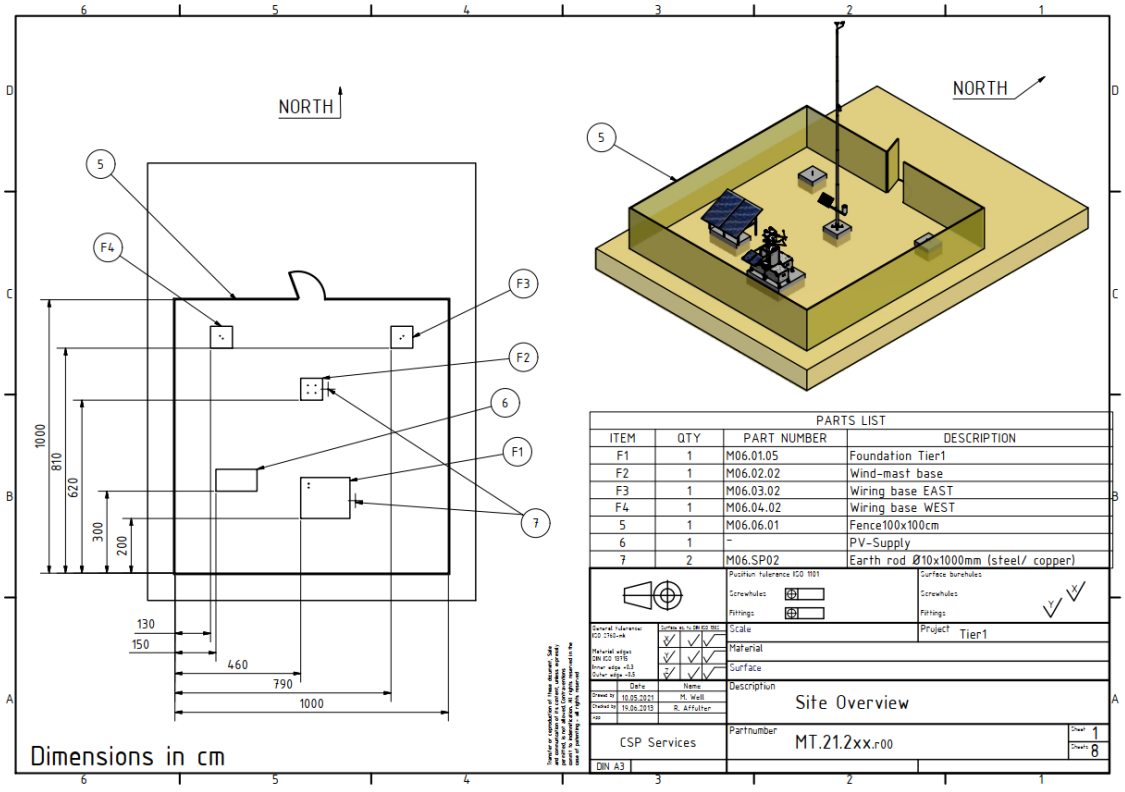

Figure 7: Disposition de la station météorologique automatique Tier1 : détails des fondations / Tier1 automatic weather station layout: foundation detail.

Le mât de mesure du vent est ancré aux fondations de la base de mat et aux fondations des câbles d'haubanage. La station elle-même est fixée à la fondation principale.

Les dimensions et les distances sont indiquées dans les dessins de fondation dans la Figure 7 ci-dessus. La hauteur de la clôture est de 2m. La distance entre le système PV-Soiling et la clôture est d'environ 1.8m.

The wind mast is anchored to the wind mast foundations and guying rope foundations. The station itself is fixed to the main foundation.

The dimensions and distances are shown in the foundation drawings in Figure 7. The height of the fence is 2m. The distance of the PV-Soiling system to the fence is approximately 1.8m.

3.3 *Mesures, transmission et analyse des données* / Data measurement, transmission and analysis

Les signaux des capteurs sont mesurés à une fréquence de 1 Hz et stockés dans des tables de données moyennes sur 1 minute et 10 minutes dans la mémoire interne de l'enregistreur de données, incluant les valeurs max, min et dév. std.

Les données de mesure sont envoyées aux serveurs de CSPS en temps réel via un routeur 4G LTE avec une carte SIM d'un opérateur local.

Les données de mesure sont envoyées en parallèle au serveur de traitement des données CSPS et au serveur web pour l'accès par le client permettant le téléchargement des données (voir section 7). Elles sont stockées dans la mémoire interne de l'enregistreur de données pendant plus de 3 mois. En cas de problèmes de réseau prolongés, les données peuvent être récupérées après que ceux-ci aient été résolus ou manuellement sur site via un accès USB direct à l'enregistreur de données si nécessaire.

En parallèle avec les données de mesure, les images de la caméra de surveillance sont transmises au serveur CSPS à intervalles réguliers.

L'état de communication du routeur LTE et les paramètres de la configuration mobile (Auto APN) sont illustrés à la Figure 8. L'utilisation des données dépend principalement de la quantité d'images et de vidéos transmises par la caméra et devrait être inférieure à 1 GB/mois en fonctionnement normal.

The sensor signals are scanned with a frequency of 1 Hz and stored in 1-minute and 10-minute average data tables in the datalogger's internal memory together with the max, min and StDev values.

The measurement data is sent to the CSPS servers in real time through a 4G LTE router with a SIM card from a local operator.

The measurement data is sent in parallel to the CSPS data processing server and the web server for client access for data monitoring and download (see section 7). It is stored in the internal memory of the datalogger for more than 3 months. In case of prolonged network issues, the data can be retrieved after the network issues have been resolved or manually on site via direct USB access to the datalogger if necessary.

Together with the measurement data, pictures from the surveillance camera are transmitted to the CSPS server in regular intervals.

The communication status of the LTE router and the settings of the mobile configuration (Auto APN) is shown in Figure 8. The data usage depends mainly on the amount of transmitted pictures and videos from the camera and is expected to be less than 1 GB/months during normal operation.

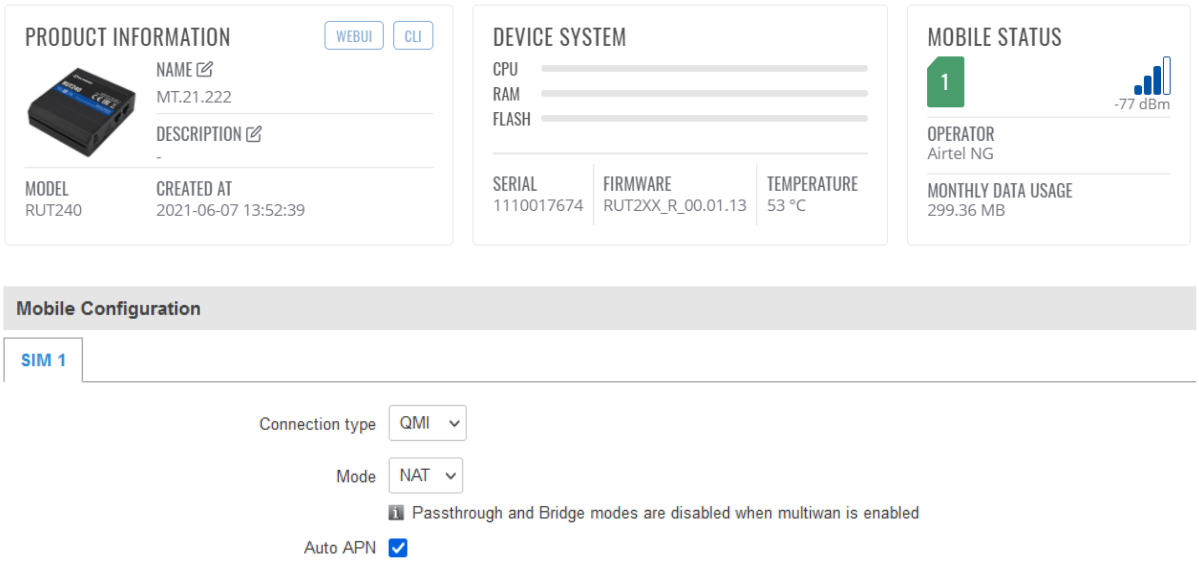

Figure 8: État de communication du routeur LTE pour la transmission de données / Communication status of LTE router for data transmission

Pour les procédures de contrôle de la qualité des données, CSPS effectue les tâches suivantes pour assurance de la qualité / contrôle de la qualité (AQ/CQ) des données :

- *Téléchargement régulier de données via le réseau de téléphonie mobile (normalement en temps réel).*
- *Vérification du bon fonctionnement de l'équipement, coordination du personnel de maintenance local.*
- *Analyse des données, y compris le contrôle de la qualité des données et l'établissement de rapports conformément aux normes internationales.*
- *Correction des valeurs apparemment erronées et comblement des lacunes (lorsque cela est possible et raisonnable).*
- *Supervision de la fréquence de maintenance, nettoyage correct du capteur, analyse de l'encrassement du capteur.*

For the data quality control procedures, CSPS performs the following tasks for data quality assurance and control (QA/QC):

- Regular data retrieval via mobile phone network (usually in real time).
- Check of correct operation of the equipment, coordination of local maintenance staff.
- Data analysis including data quality screening and reporting according to international standards.
- Correction of apparently erroneous values and gap filling (where possible and reasonable).
- Supervision of maintenance frequency, correct sensor cleaning, analysis of sensor soiling.

4 *Installation et mise en service de la station* / Station installation and commissioning

L'installation et la mise en service de la station ont été terminés le 19 Septembre 2021. Avant l'installation de la station, le site a été préparé avec une clôture et des fondations pour l'installation stable et sécurisée de la station météorologique automatique pour la période de la campagne de mesure.

Ce chapitre décrit le calendrier d'installation et les tâches accomplies jusqu'à la mise en service, ainsi qu'une liste de contrôle pour l'achèvement de l'installation et la fonctionnalité de celui-ci.

Une documentation photographique complète du processus d'installation est présentée au chapitre 6.

The station installation and commissioning were completed on 19 September 2021. Before the installation of the station, the site was prepared with a fence and foundations for the stable and secure installation of the automatic weather station over the entire measurement period.

This chapter describes the installation timeline and the accomplished tasks up to the commissioning as well as a checklist for the installation completion of the installation and functionality tests of the equipment.

A complete photographic documentation of the installation process is given in chapter 6

4.1 Tâches accomplies et calendrier d'installation / Completed tasks and installation timeline

Les préparatifs du site et l'installation de la station ont eu lieu en Septembre 2021. Le tableau ci-dessous détaille chaque tâche réalisée et son délai d'exécution.

The site preparations and the station installation took place in September 2021. The table below details each completed task and its completion time.

Date d'achèvement **Completion date**	**Tâche / Task**	**Photo / Picture**
2021-09-04	*Détermination de l'emplacement de la station et de la direction du nord. Marquage du périmètre et vérification de l'emplacement et de l'orientation corrects.* Determination of the station location and the north direction. Perimeter marked and correct location and orientation verified.	
2021-09-04	*Préparation du terrain, des fondations et de la clôture.* Preparation of the ground, the foundations and the fence.	

Date d'achèvement **Completion date**	**Tâche / Task**	**Photo / Picture**
2021-09-04	*Mise en place des blocs de ciment et coulage des fondations.* Positioning of the cement blocks and casting of the foundations.	
2021-09-05	*Installation de la structure de montage et du boîtier de contrôle des mesures.* Installation of the mounting structure and measurement control box.	
	Installation du système de mesure de l'encrassement des modules PV (PV-S) : • *Structure de montage du panneau PV installée* • *Panneaux PV à couche mince montés sur la structure, orientation vers le sud* • *Capteurs de température des panneaux PV installés à l'arrière des panneaux* Installation of the PV module soiling measurement system (PV-S): • PV panel mounting structure installed • PV thin-film panels mounted on structure, orientation towards south • PV panel temperature sensors installed on panel backsides	
2021-09-05	*Installation de la structure de montage et du boîtier de contrôle des mesures.* Installation and connection of the irradiance and other meteorological sensors.	
2021-09-07	*Vérification du nivellement et de l'inclinaison de la structure des panneaux PV. Connexion du système de mesure de l'encrassement PV-S et des panneaux d'alimentation.* Verification of the PV panel structure levelling and inclination. Connection of the PV-S soiling measurement system and the power supply panels.	

Date d'achèvement **Completion date**	**Tâche / Task**	**Photo / Picture**
2021-09-07	*Installation du mât de 10m avec des capteurs de vitesse et de direction du vent, le capteur de direction du vent étant orienté vers le nord* *Formation des opérateurs de l'équipe de maintenance sur site (EMS)* Installation of 10m wind mast with wind speed and wind direction sensors, wind direction sensor oriented towards north Operator training for on-site maintenance team (OMT)	
2021-09-19	• *Contrôles de fonctionnalité (ingénieurs locaux avec support à distance du personnel de CSPS)* • *Mise en service de la station (à distance par le personnel de CSPS)* • Functionality checks (local engineers with remote support from CSPS staff) • Commissioning of the station (remotely by CSPS staff)	

5 *Liste de contrôle de l'installation* / Installation checklist

Composant Component	*Point de contrôles* Work item	*Vérifié* Checked		*Commentaires* Comments
		yes	no	
Fondations, clôture **Foundations, fence**	*Fondations correctement préparées* Foundations correctly prepared	X		
	Boulons filetés correctement préparés Threaded bolts correctly prepared	X		
	Clôture correctement préparée Fence correctly prepared	X		
	Panneaux de projet attachés Project signs attached	X		
Structure de support avec boîte de contrôle **Support structure with Control box**	Supports de montage PV ajustés PV mounting supports adjusted	X		
	Nivellement horizontal Horizontally leveled	X		
Câblage, câbles **Wiring, cables**	*Examen visuel* Visual examination	X		
	Fusibles ok Fuses ok	X		
	Tous les capteurs sont connectés All sensors connected	X		
	Tous les câbles sont fixés de manière ordonnée All cables orderly fixed	X		
Tracker solaire **Solar tracker**	*Dispositif d'ombrage installé* Shading assembly installed	X		
	Mise à niveau horizontal Horizontal leveling	X		
	Alignement est-ouest East/West alignment completed	X		
Pyranomètres **Pyranometers**	*Pyranomètre installé* Sensors installed	X		
	Opérabilité des capteurs Operability of sensor	X		
	Nivellement horizontal Horizontal leveling	X		

Composant Component	*Point de contrôles* Work item	*Vérifié* Checked		*Commentaires* Comments
		yes	no	
Capteur de pression barométrique **Barometric Pressure Sensor**	*Capteur installé* Sensor installed	X		
	Échangeur de pression Pressure exchange vent	X		*Installé à l'intérieur du boitier de contrôle* Installed inside main control cabinet
Capteur de précipitations **Precipitation Sensor**	*Capteur installé et mis à niveau* Sensor installed and leveled	X		
	Opérabilité des capteurs Operability of sensor	X		
Capteur de temperature et humidité **Temperature and humidity sensor**	*Capteur fixé au cadre* Sensor fixed to frame	X		
Mât éolien, capteurs de vitesse et de direction du vent **Wind tower, wind speed and direction sensors**	*Déploiement mât télescopique* Mast extended	X		*Extension à une longueur de 10 m* Extended to length of 10 m
	Les haubans sont fixés et tendus en toute sécurité Guy wires safely attached and tense	X		
	Câble de mise à la terre connecté Grounding cable connected	X		*Pour une tige métallique enfoncée dans le sol* To metal rod driven into ground
	Installation de capteurs de vent Wind sensors installed	X		
	Orientation nord du capteur WD North Orientation of WD sensor	X		
	Câble fixé aux capteurs, à la tour et au boîtier Cable fixed to sensors, tower and box	X		
	Opérabilité des capteurs Operability of sensors	X		

Composant Component	*Point de contrôles* Work item	*Vérifié* Checked		*Commentaires* Comments
		yes	no	
Système de mesure de la salissure des PV **PV soiling measurement system**	*Structure de montage nivelée et alignée au sud* Mounting structure leveled and aligned to south	X		
	Panneaux PV installés PV panels installed	X		
	Réglage de l'angle d'inclinaison Inclination angle adjusted	X		*15 degrés par rapport à l'horizontale* 15 degrees from horizontal
	Capteurs de température du module installés Module temp. sensors installed	X		
	Exploitabilité du système Operability of system	X		
	Panneaux nettoyés Panels cleaned	X		
LTE router	*Carte SIM insérée* SIM card inserted	X		*Connexion de données au serveur établie* Data connection to server established
	Connexion au serveur Server connection	X		*Connexion au serveur confirmée* Connection to server confirmed
Enregistreur de données **Datalogger**	*Système d'exploitation installé* Operation system installed	X		Version: CR1000X Std.05.00
	Corriger les constantes du capteur dans le programme Correct sensor constants in program	X		*Comparaison avec les photos des capteurs installés* Compared against photographs of installed sensors
	Coordonnées correctes dans le programme Correct coordinates in program	X		*Obtenu à partir du GPS* Obtained from GPS
	Programme de l'enregistreur de données installé Datalogger program installed	X		Program name: Ng-Bauc_2021-09-07_str.CR1X Subroutines: Subroutines-Tier1_2021-02-21.CR1X
	Horloge de l'enregistreur de données correcte Datalogger clock correct	X		*Heure locale standard, pas d'heure d'été l'heure : UTC +1* Local standard time, no daylight saving time: UTC +1

6 *Documentation photographique* / Photographic documentation

Figure 9: Clôture et fondation / Fence and foundation

Figure 10 : Fondations de la station et du mât du vent / Station and wind mast foundations

Figure 11: Préparatifs du mât du vent / Wind mast preparations

Figure 12 : Fondations du mât du vent, câble de terre fixé au boulon de terre, tube de protection pour les câbles du mât du vent / Wind mast foundations, ground cable fixed to ground bolt, protective tube for wind mast cables

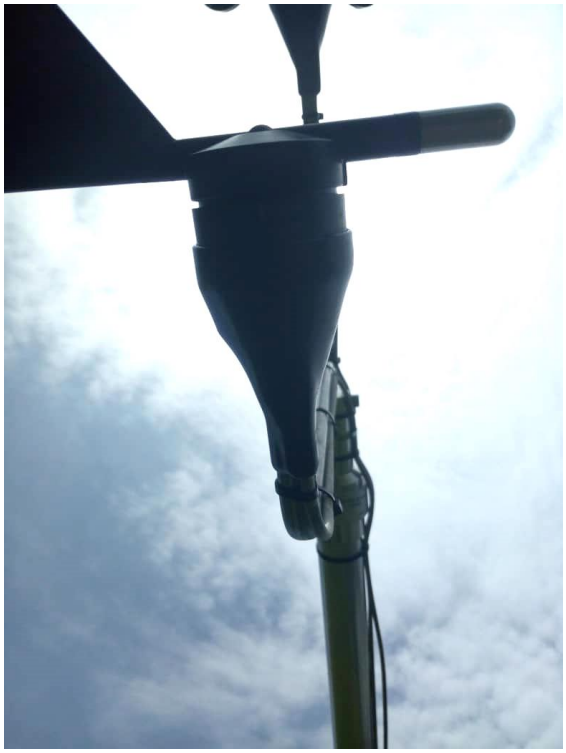

Figure 13: Marque nord du capteur de direction du vent alignée avec le cantilever de montage et la direction du nord. / Wind direction sensor north mark aligned with mounting cantilever and north direction

Figure 14: Capteurs de vent installés sur le mât du vent / Wind sensors installed on wind mast

Figure 15: Mât du vent installé capteur de direction du vent orienté vers le nord / Wind mast erected; wind direction sensor orientated to North

Figure 16: Numéro de série du pyranomètre CMP10 (GHI) / CMP10 pyranometer serial number (GHI)

Figure 17: Numéro de série du pyranomètre CMP10 (DHI) / CMP10 pyranometer serial number (DHI)

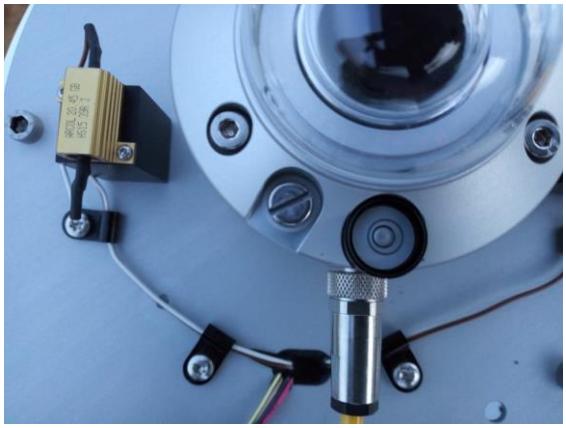

Figure 18: Mise à niveau du pyranomètre CMP10 (GHI) / CMP10 pyranometer leveling (GHI)

Figure 19: Mise à niveau du pyranomètre CMP10 (DHI) / CMP10 pyranometer leveling (DHI)

Figure 20: Mise à niveau du tracker / Tracker leveling

Figure 21 : Numéro de série du tracker / Serial number of tracker

Figure 22 : Tracker installé / Installed tracker

Figure 23 : Número de serie du sun sensor / Sun Sensor serial number

Figure 24: Capteur de pluie et échantillonneur de corrosion / Rain sensor and corrosion sampler

Figure 25 : Numéro de série du pyrhelimètre / Pyrheliometer serial number

Figure 26: Numéro de série du capteur de pluie / Rain sensor serial number

Figure 27: Mise à niveau du dispositif d'ombrage / Shading assembly alignment

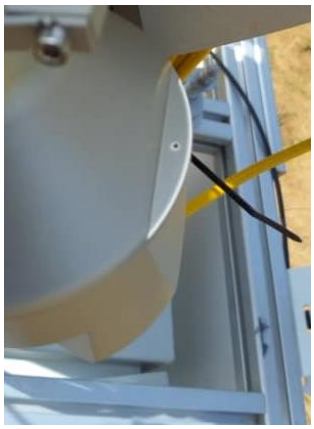

Figure 28 : Alignement du pyrhéliomètre / Pyrheliometer alignment

Figure 29: Capteur T/RH et antenne du modem / T/RH sensor and modem antenna

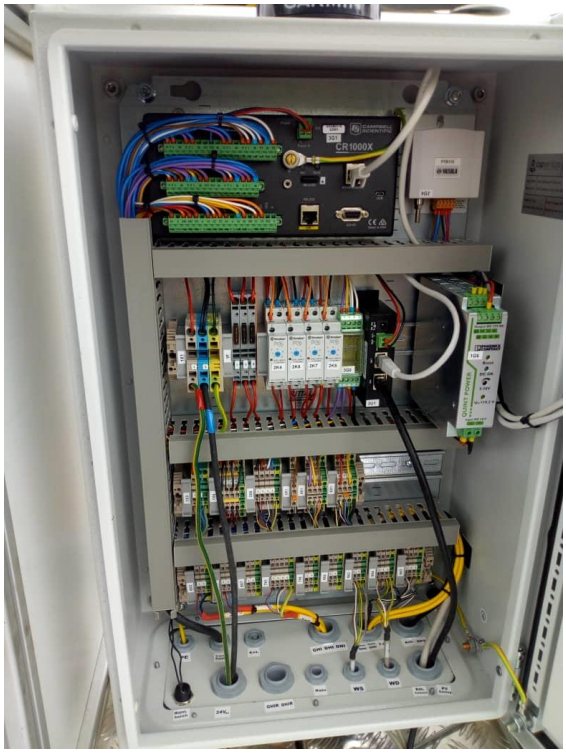

Figure 30: Intérieur du boîtier de contrôl / Control box interior.

Figure 31: Ruteur LTE 7 LTE router

Figure 32: Assemblage de la structure PV-S + modules / Assembly of PV-S structure + modules.

Figure 33: Structure de support PV-S avec un angle d'inclinaison de 15° vers le sud / PV-S support structure with 15° tilt angle towards South.

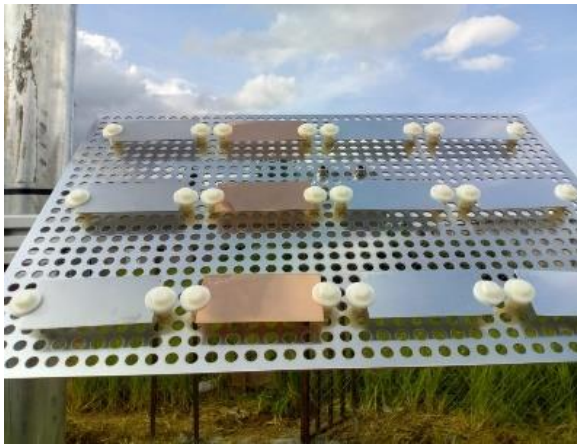

Figure 34: Echantillonneur de corrosion / Corrosion sampler.

Figure 35 : Système d'alimentation / Power supply PV system

Figure 36 : Tracker solaire, capteurs et panneaux PV du système de mesure de salissure (PV-S) / Solar tracker, sensors and PV panels of soiling measurement system (PV-S).

Figure 37 : Structure de montage, suiveur solaire, capteurs et boîtier de contrôle / Mounting structure, solar tracker, sensors and control box.

Figure 38: Base de mât de mesure du vent, capteur de pluie et échantillonneur de corrosion / Wind mast foot, rain sensor and corrosion sampler.

Figure 39 : Installation finale de la station vue du sud / Final station installation as seen from south

Figure 40 : Installation finale de la station vue du sud-ouest / Final station installation as seen from south-west

7 *Procédures de maintenance* / Station Maintenance procedures

La maintenance régulière sur site et le nettoyage des capteurs sont effectués par une équipe de maintenance sur site (EMS) sous contrat local. Les procédures de maintenance et de nettoyage des capteurs ont été définies avant l'installation de la station et un manuel contenant les procédures définies a été fourni à l'EMS. De plus, une formation des opérateurs a été organisée pendant la phase de mise en service de la station. Les capteurs d'irradiation et les panneaux PV du système de mesure de l'encrassement PV-S seront nettoyés conformément au tableau ci-dessous.

(La mesure du taux de salissure avec le système de mesure de la salissure PV-S est basée sur la comparaison entre un module de référence propre (module A) et un module de mesure (module B) qui peut accumuler de la salissure sur sa surface. Le module A est donc nettoyé à chaque visite de l'EMS et le module B est nettoyé une fois par mois pour relancer le cycle de mesure des salissures).

Regular on-site maintenance and sensor cleaning is performed by a locally contracted on-site maintenance team (OMT). The maintenance and sensor cleaning procedures were defined prior to the installation of the station and a manual with the defined procedures was provided to the OMT. Additionally, an operator training was held during the commissioning phase of the station. The irradiance sensors and the PV panels for the PV-S soiling measurement system will be cleaned according to the table below.

(The measurement of the soiling rate with the PV-S soiling measurement system is based on the comparison of a clean reference module (Module A) to a measurement module (Module B) which is allowed to accumulate soiling on its surface. Module A is therefore cleaned upon each visit by the OMT and Module B is cleaned once per month to restart the soiling measurement cycle.)

Capteurs **Sensors**	***Nettoyage*** **Cleaning**		***Commentaires*** **Comments**
	1 x par jour **1 x per day**	***1 x par mois*** **1 x per month**	
Pyranomètre GHI et DHI GHI and DHI pyranometer	x		
Pyrhéliomètre DNI DNI pyrheliometer	x		
Module PV propre (modA) Clean module (Module A)	x		
Module PV sale (modB) Dirty module (Module B)		x	*Premier jour de chaque mois* First day of the month

Les visites d'entretien programmées pour la maintenance étendue du système sont prévues tous les six mois pendant la durée de la campagne de mesure.

Scheduled maintenance visits for extended system maintenance are planned to be performed every six months for the duration of the measurement campaign.

8 *Données de mesure* / Measurement data

Les données de mesure sont accessibles sur un serveur web protégé pour un contrôle et un téléchargement des données en temps réel. De plus, CSPS fournira des rapports de données mensuels avec les données de mesure finales de qualité contrôlée. Les graphiques ci-dessous montrent des données exemplaires peu après l'installation.

The measurement data can be accessed on a protected web server for real time data monitoring and download. Additionally, CSPS will provide monthly data reports with the final quality-controlled measurement data. The graphs below show exemplary data shortly after the installation.

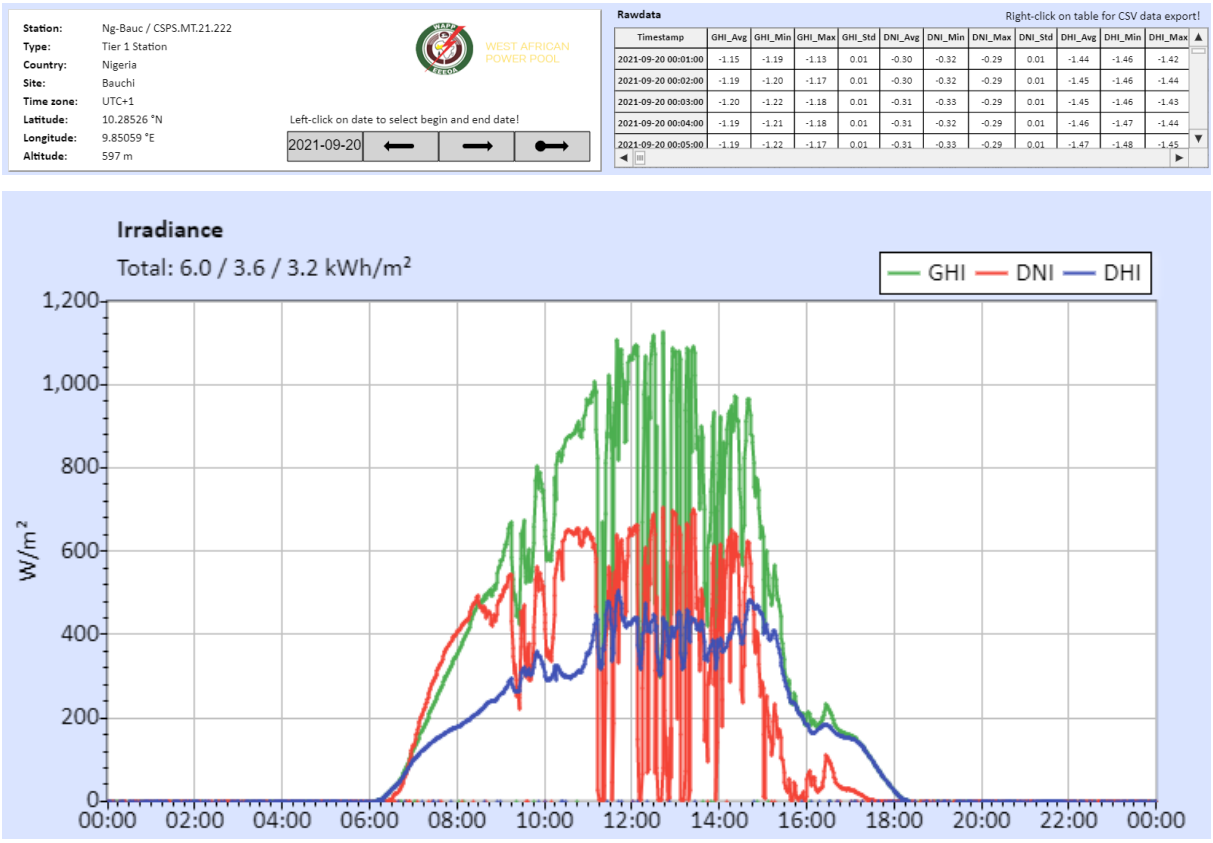

Figure 41 : Irradiance measurement. GHI, DNI and DHI.

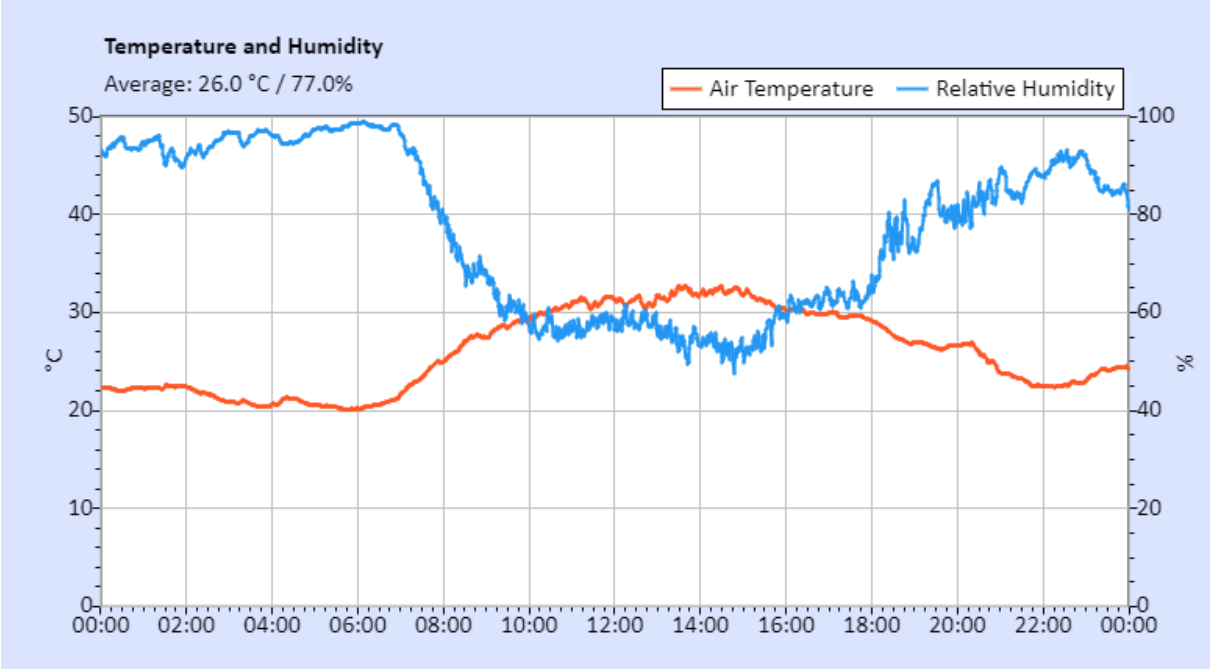

Figure 42 : Temperature and Humidity measurements.

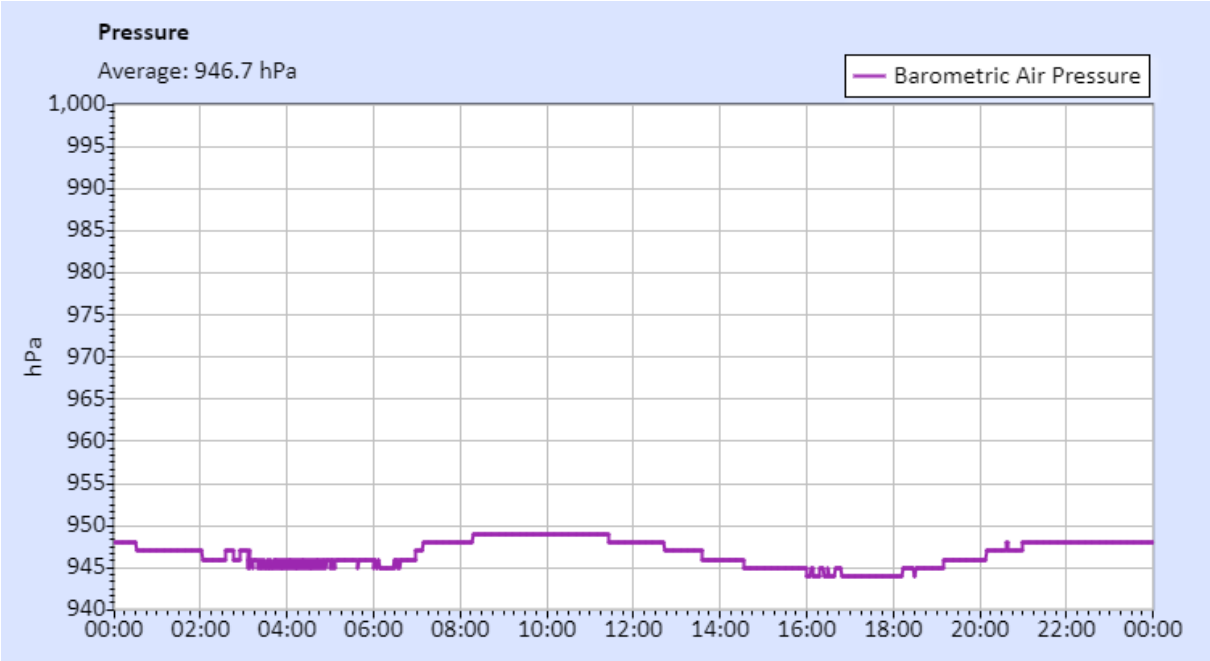

Figure 43 : Barometric air pressure measurement.

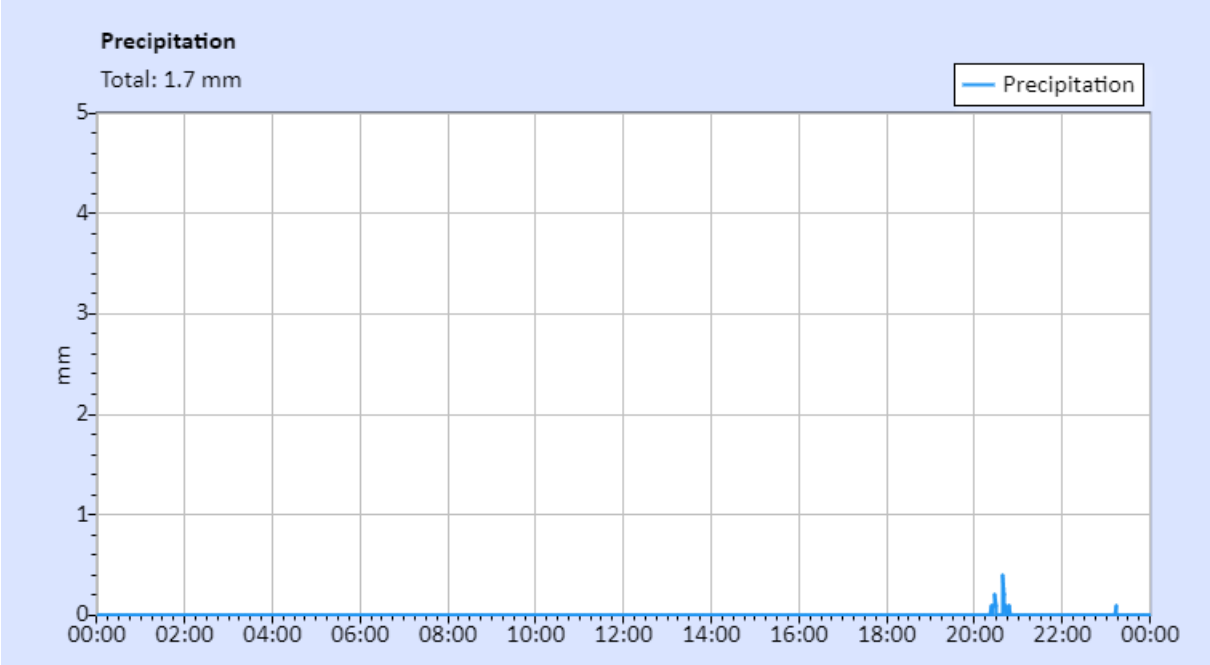

Figure 44 : Precipitation measurement.

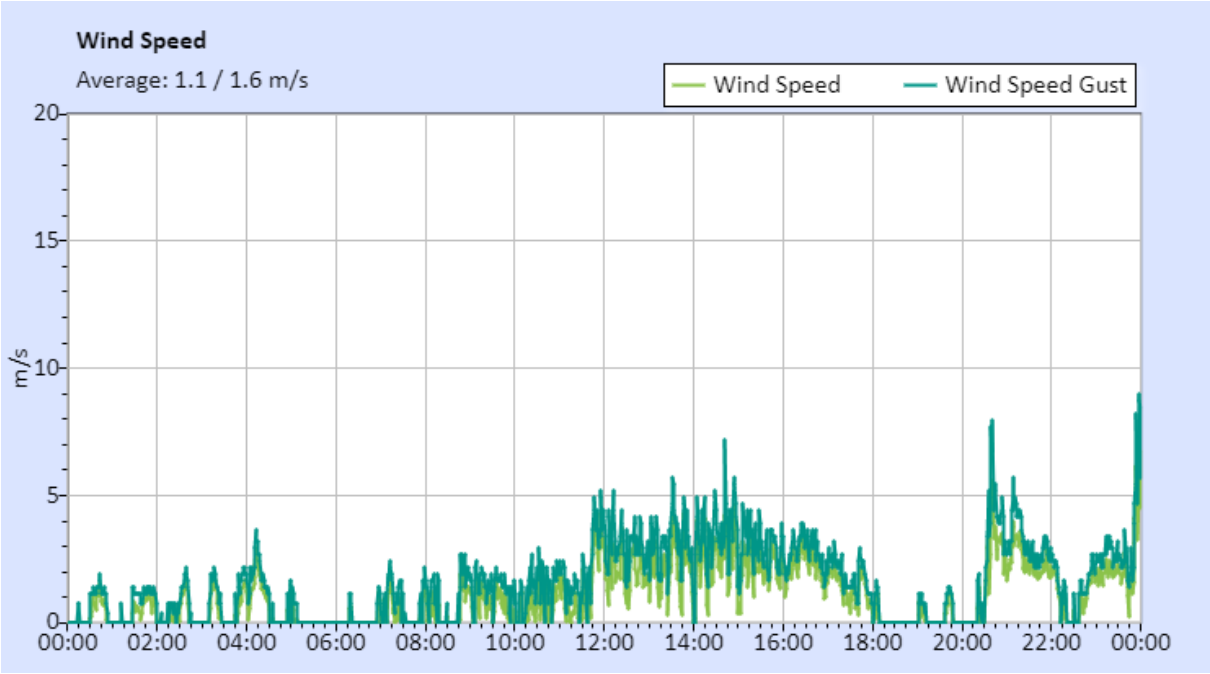

Figure 45 : Wind speed measurement.

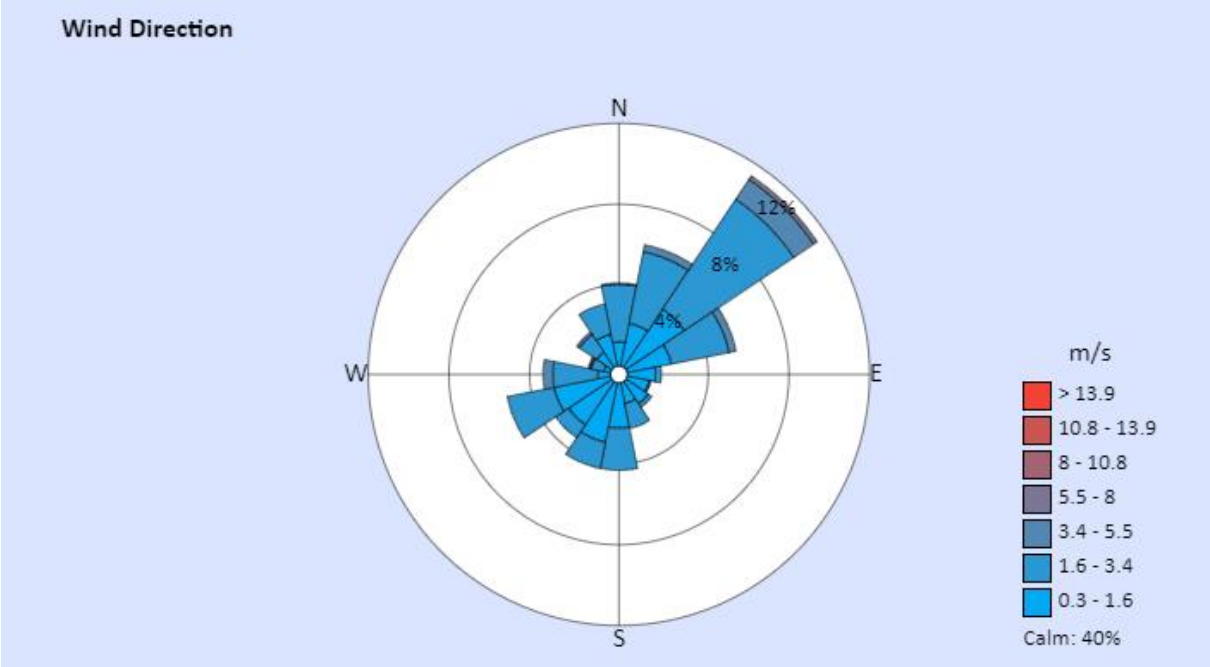

Figure 46 : Wind direction measurement.

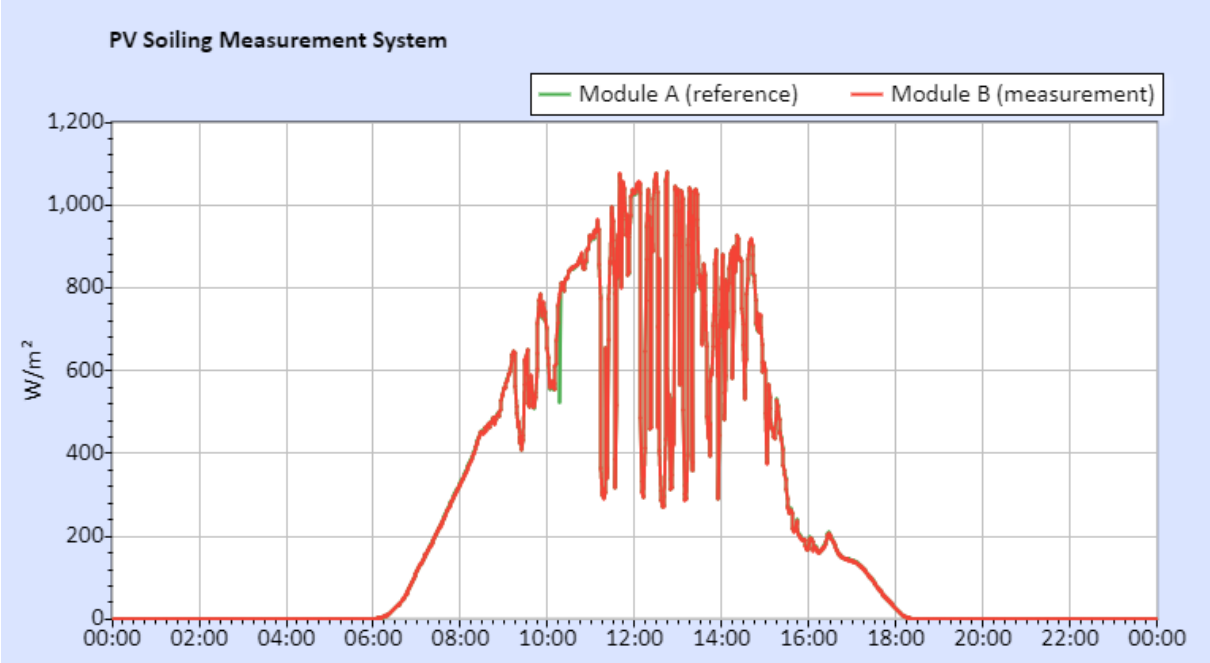

Figure 47 : PV soiling measurements.

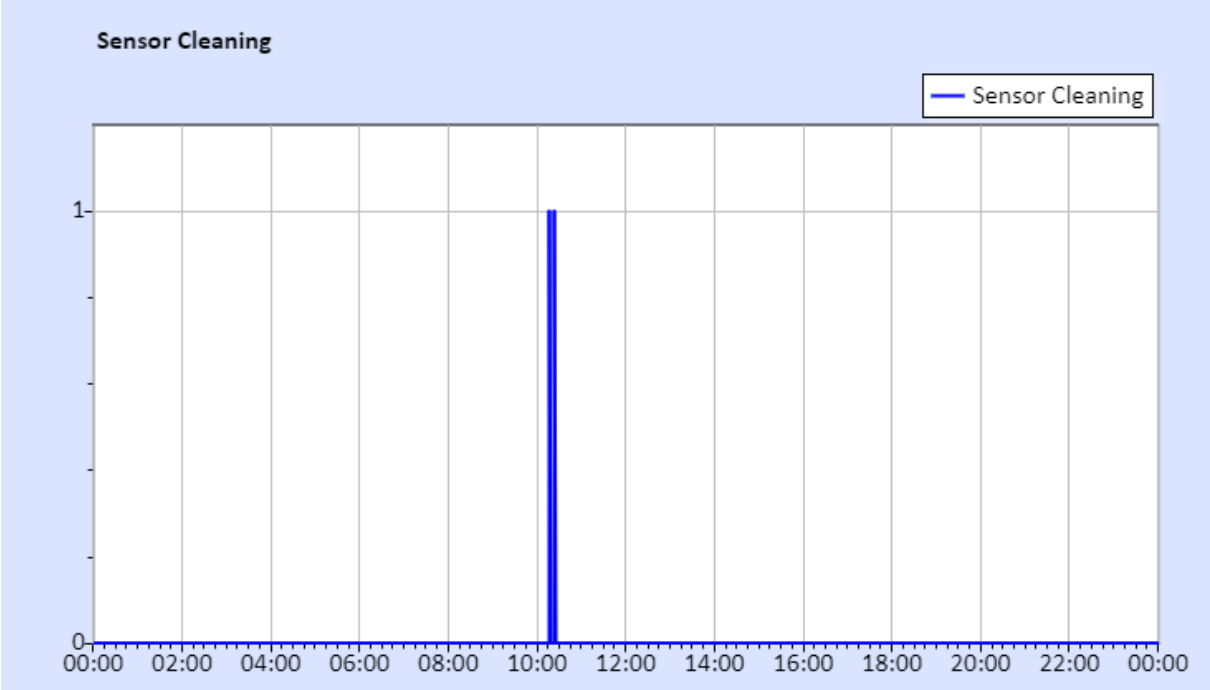

Figure 48 : Sensor cleaning recordings.

9 *Certificats d'étalonnage* / Calibration certificates

Cette section fournit les certificats d'étalonnage pour chaque capteur. Tous les équipements de mesure sont neufs, non utilisés et incluent les étalonnages d'usine.

À la fin de la première année de mesures, un étalonnage sur le terrain à l'aide d'un pyranomètre de référence (référencé à la référence radiométrique mondiale établie à Davos, en Suisse) sera effectué à la station de mesure solaire.

This section provides the calibration certificates for each sensor. All measurement equipment is new, unused and includes factory calibrations.

At the end of the first year of measurements, a field calibration using a reference pyranometer (referenced to the World Radiometric Reference established in Davos, Switzerland) will be conducted at the solar measurement station.

Paramètre mesuré **Measured parameter**	***Type de capteur*** **Sensor type**	***Numéro de série*** **Serial number**	**Date d'étalonnage** **Calibration date**	**Date d'installation** **Installation date**
DHI	Kipp&Zonen CMP10	210854	2021-02-12	2021-09-07
GHI	Kipp&Zonen CMP10	210853	2021-02-12	2021-09-07
DNI	Kipp&Zonen CHP1	210874	2021-01-29	2021-09-07
Wind speed (WS)	NRG40C anemometer	179500332897	2020-10-26	2021-09-07
Wind direction (WD)	NRG #200M wind vane	1007000008937	2020-09-12	2021-09-07
Barometric pressure (BP)	Vaisala PTB110 (CS106)	S4950663	2020-12-07	2021-09-07

9.1 CMP10 pyranometer (DHI)

OTT HydroMet

KIPP & ZONEN
Meteorology Division of OTT HydroMet

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ISO/IEC 17025 CALIBRATION CERTIFICATE

CERTIFICATE NUMBER	022874210854
PYRANOMETER MODEL	CMP 10
SERIAL NUMBER	210854
CALIBRATION DATE	16 February 2021
INSTRUMENT CLASS	ISO 9060, Class A (Sec. Standard)*
CALIBRATION PROCEDURE	ISO 9847 par5.3.2, A3
REFERENCE PYRANOMETER	Kipp & Zonen CMP 21 sn 070114 active from 01 January 2021
REFERENCE PYRANOMETER CALIBRATION PROCEDURE	ISO 9846 par5
CALIBRATION LOCATION	Delft The Netherlands
CUSTOMER	
REMARKS	

Delft, The Netherlands, 16 February 2021

J. Mes
(in charge of calibration facility)

F. de Wit
(in charge of test)

Page: 1 of 2

OTT HydroMet | ilac-MRA | RvA CALIBRATION RvA K 180 | KIPP & ZONEN Meteorology Division of OTT HydroMet

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ISO/IEC 17025 CALIBRATION CERTIFICATE

CERTIFICATE NUMBER 022874210854

Calibration procedure

The indoor calibration procedure is based on a side-by-side comparison with a reference pyranometer under an artificial sun fed by an AC voltage stabiliser. It embodies a 150 W Metal-Halide high-pressure gas discharge lamp and a reflector with a diameter of 16.2 cm. The lamp is positioned 1 m above the pyranometers producing a vertical beam. The reference- and test pyranometer are mounted horizontally on a table, which can rotate. The irradiance at the pyranometers is approximately 500 W/m². During the calibration procedure the reference and test pyranometer are interchanged to correct for any non-homogeneity of the beam. Temperature during calibration: 22 °C ± 2 °C.

Hierarchy of traceability

The measurements have been executed using standards for which the traceability to international standards has been demonstrated towards the RvA.

The reference pyranometer was compared with the sun and sky radiation as source under clear sky conditions using the "alternating sun-and-shade method" ISO 9846 paragraph 5. The measurements were performed in Delft, The Netherlands (latitude: 51.9969˚, longitude: 4.3863˚, altitude: 10m above sea level). Dates of measurements: 22-24 June 2020.
The receiver surface was pointed directly at the sun using a solar tracker. During the comparisons, the instrument received tilted global radiation intensities from 834 W/m² to 1124 W/m² with a mean of 992 W/m² and tilted diffuse radiation intensities from 83 W/m² to 250 W/m² with a mean of 148 W/m². The ambient temperature ranged from +19.0 °C to +29.9 °C with a mean of +23.9 °C.
The direct radiation on the reference pyranometer as obtained with the alternating-sun-shade method was compared to the DNI measured by the absolute cavity pyrheliometer PMO6 SN 103. The PMO6 is calibrated against the World Standard Group (WSG), maintained at the WRC Davos every International Pyrheliometer Comparison (IPC). WRR factor of PMO6: 0.99787 (from the last IPC-2015).

This calibration proved that the reference pyranometer has been stable and that the original sensitivity 8.37 µV/(W/m²) ± 0.11 µV/(W/m²) is valid and will be applied (see PMOD calibration details). Observed sensitivity differences between the consecutive years are well within the calibration uncertainty.

PMOD calibration details: The reference pyranometer was compared with the sun and sky radiation as source under mainly clear sky conditions using the "continuous sun-and-shade method". The pyranometer was installed horizontally. During the comparisons, the global radiation ranged from 638 W/m² to 1195 W/m² with a mean of 874 W/m². The solar zenith angle varied from 23.5° to 49.8° with a mean of 32.9°. The ambient temperature ranged from +12.6 °C to +26.2 °C with a mean of +23.7 °C. The sensitivity calculation is based on 435 individual measurements. The readings of the WSG are referred to the World Radiometric Reference (WRR). The estimated uncertainty of the WRR relative to SI is ±0.3%. The obtained sensitivity value and its expanded uncertainty (95% level of confidence) are valid for similar conditions and are:8.37 ± 0.11 µV/W/m². The measurements were performed in Davos (latitude: 46.8143˚, longitude: -9.8458˚, altitude: 1558 m above sea level). Dates of measurements: 24, 30 June 1, 2 July 2015. Global radiation data were calculated from the direct solar radiation as measured with the absolute cavity pyrheliometer PMO2 (member of the WSG, WRR- factor: 0.998623 from the last international Pyrheliometer Comparison, IPC-2015) and from the diffuse radiation as measured with a continuous disk shaded pyranometer Kipp & Zonen CM22 SN 020059 (ventilated with heated air).

SENSITIVITY	10.16 µV/(W/m²) at normal incidence on horizontal pyranometer
UNCERTAINTY	0.15 µV/(W/m²) = 1.44 %
IMPEDANCE	23 ± 1.5 Ω

Justification of total instrument calibration uncertainty

The combined uncertainty of the result of the calibration is the positive "root sum square" of the following components.
1. The expanded uncertainty due to random effects and instrumental errors during the calibration of the reference CMP 21 is ±0.11/8.37 = ±1.31% (k=2). See traceability text.
2. The expanded uncertainty of the transfer procedure (calibration by comparison) is estimated to be ±0.5% (k=2).
3. The estimated uncertainty of the WRR relative to SI: ±0.3% (k=2).
The expanded uncertainty is: $\sqrt{(1.31\%^2 + 0.5\%^2 + 0.3\%^2)} = \pm 1.44\%$ (k=2).

The resistance measurement uncertainties are due to the PXI 4065 uncertainty in the 100 Ω range: 150ppm of range (=15mΩ) the cable resistance (estimated 0.1 Ω) and due to the electrothermal effect the measurement current in the thermal detector of the pyranometer. This was found to be a resistance error of 1.5 Ω, which results in a total resistance uncertainty of $\sqrt{(0.015^2+0.1^2+ 1.5^2)} = 1.5$ Ω or 5%.

The PXI 4065 is calibrated by National Instruments Hungary, on 7 november 2018 at a temperature of 22.7 °C, under ISO 17025:2005 accreditation. This calibration is traceable to NIST and/or other National Measurement Institutes (NMI's).

The reported expanded uncertainty is based on the standard uncertainty of the measurement multiplied by a coverage factor k, such that the coverage probability corresponds to approximately 95%. The standard uncertainty has been determined in accordance with EA 04/2.

Notice

The calibration certificate supplied with the instrument is valid at the date of first use. Even though the calibration certificate is dated relative to manufacture, or recalibration, the instrument does not undergo any sensitivity changes when kept in the original packing.

* from October 2018 the classification conforms to ISO 9060:2018. Instruments issued before that date conform to ISO 9060:1990.

RvA is member of the European Co-operation for Accreditation (EA) and is one of the signatories to the EA Multilateral Agreement (MLA) and to the ILAC Mutual Recognition Arrangement (MRA) for the mutual recognition of calibration certificates.

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BIC: DEUTDEBB101

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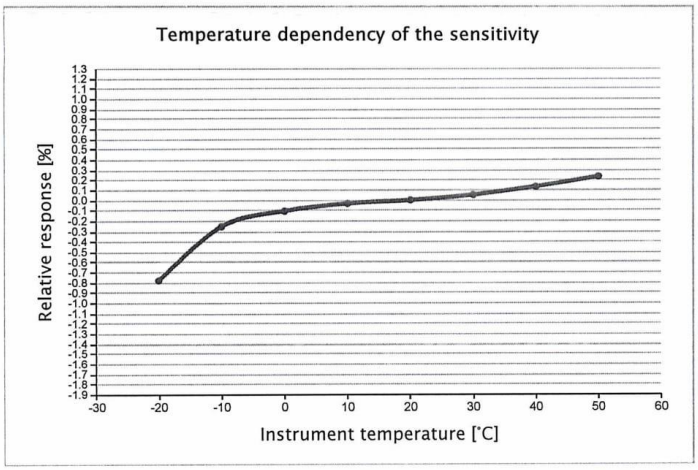
MEASUREMENT REPORT
PYRANOMETER

Routine measurement of temperature dependency during final inspection

PYRANOMETER TYPE	CMP 10
SERIAL NUMBER	210854
DATE OF MEASUREMENT	21 December 2020
PERFORMED BY	F. de Wit
PROCEDURE	The pyranometer is mounted inside the climate chamber and illuminated with a white light source under normal incidence. A CMP22 pyranometer outside the chamber is used to monitor the lamp stability.
	The pyranometer is tested over a temperature range from 50 °C down to -20 °C in steps of 10 °C. The relative temperature dependency is plotted below.
	The measurement uncertainty of this characterisation is ±0.1% (k=2).



Instrument temperature [°C]	Relative response [%]
-20	-0.77
-10	-0.25
0	-0.10
10	-0.03
20	0.00
30	0.05
40	0.13
50	0.23

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MEASUREMENT REPORT
PYRANOMETER

Routine measurement of directional error during final inspection

Mean cosine error of each new pyranometer type CMP 10 is measured by a simple routine.

Routine:

The pyranometerbase is placed against the vertical turntable of a goniometer in the parallel (0,5°) beam of a sunsimulator.
Voltage output U(z) is measured for beam incidence (zenith) angles of 0°,40°, 60°, 70° and 80° coming in over azimuth south (cable pointing to North).
Next the pyranometer output U(-z) is measured for incidence angles of -80°, -70°, -60°, -40° and 0° consequently for azimuth south. The dark signal is measured at the beginning of the routine in the middle and at the end. For each beam incident angle the dark signal is interpolated.

During the CMP 10 measurement cycle, a check is done on the azimuth error at 40° and 70° by measuring voltages for azimuth-directions S, E, N and W . Also at -70° and -40° this azimuth error is measured and the mean of both azimuth measurements cancels out the eventual error in the 0° position.

With the extended procedure at both 40° and -40° and 70° and -70° the specific cosine error for 8 azimuth directions (40° S, W, N and E and 70° E, N, W, S) can be calculated according to formula 1 and verified whether it is within ± 10 W/m².

The applied formula for the relative cosine error is:

U(0°) Pyranometer output voltage for normal incidence
U(z) Pyranometer output voltage for angles (z)
Zero(z) Dark signal for angles

$$\frac{\frac{(U(z)+U(-z))}{2} - \text{zero}(z)}{\left(\frac{U(0°)+U(0°)}{2} - \text{zero}(z)\right)\cdot\cos(z)} \cdot 100\%$$

Formula 1.

Relative cosine error at zenith angle in %

Zenith angle	South	East	North	West
40	-0.23	-0.42	0.21	0.44
60	-0.33			
70	-0.29	-0.62	0.25	0.35
80	-1.03			

Absolute cosine error for 1000 W/m² beam radiation in W/m²

Zenith angle	South	East	North	West
40	-1.75	-3.22	1.58	3.35
60	-1.67			
70	-1.00	-2.13	0.84	1.19
80	-1.78			

PYRANOMETER MODEL: CMP 10 SERIAL NUMBER: 210854

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BIC: DEUTDEBB101

9.2 CMP10 pyranometer (GHI)

OTT HydroMet

CALIBRATION RvA K 180

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Meteorology Division of OTT HydroMet

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ISO/IEC 17025 CALIBRATION CERTIFICATE

CERTIFICATE NUMBER	022874210853
PYRANOMETER MODEL	CMP 10
SERIAL NUMBER	210853
CALIBRATION DATE	12 February 2021
INSTRUMENT CLASS	ISO 9060, Class A (Sec. Standard)*
CALIBRATION PROCEDURE	ISO 9847 par5.3.2, A3
REFERENCE PYRANOMETER	Kipp & Zonen CMP 21 sn 070114 active from 01 January 2021
REFERENCE PYRANOMETER CALIBRATION PROCEDURE	ISO 9846 par5
CALIBRATION LOCATION	Delft The Netherlands
CUSTOMER	

REMARKS

Delft, The Netherlands, 12 February 2021

Joop Mes

J. Mes
(in charge of calibration facility)

F. de Wit

F. de Wit
(in charge of test)

Page: 1 of 2

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ISO/IEC 17025 CALIBRATION CERTIFICATE

CERTIFICATE NUMBER 022874210853

Calibration procedure

The indoor calibration procedure is based on a side-by-side comparison with a reference pyranometer under an artificial sun fed by an AC voltage stabiliser. It embodies a 150 W Metal-Halide high-pressure gas discharge lamp and a reflector with a diameter of 16.2 cm. The lamp is positioned 1 m above the pyranometers producing a vertical beam. The reference- and test pyranometer are mounted horizontally on a table, which can rotate. The irradiance at the pyranometers is approximately 500 W/m². During the calibration procedure the reference and test pyranometer are interchanged to correct for any non-homogeneity of the beam. Temperature during calibration: 22 °C ± 2 °C.

Hierarchy of traceability

The measurements have been executed using standards for which the traceability to international standards has been demonstrated towards the RvA.

The reference pyranometer was compared with the sun and sky radiation as source under clear sky conditions using the "alternating sun-and-shade method" ISO 9846 paragraph 5. The measurements were performed in Delft, The Netherlands (latitude: 51.9969˚, longitude: 4.3863˚, altitude: 10m above sea level). Dates of measurements: 22-24 June 2020.
The receiver surface was pointed directly at the sun using a solar tracker. During the comparisons, the instrument received tilted global radiation intensities from 834 W/m² to 1124 W/m² with a mean of 992 W/m² and tilted diffuse radiation intensities from 83 W/m² to 250 W/m² with a mean of 148 W/m². The ambient temperature ranged from +19.0 °C to +29.9 °C with a mean of +23.9 °C.
The direct radiation on the reference pyranometer as obtained with the alternating-sun-shade method was compared to the DNI measured by the absolute cavity pyrheliometer PMO6 SN 103. The PMO6 is calibrated against the World Standard Group (WSG), maintained at the WRC Davos every International Pyrheliometer Comparison (IPC). WRR factor of PMO6: 0.99787 (from the last IPC-2015).

This calibration proved that the reference pyranometer has been stable and that the original sensitivity 8.37 µV/(W/m²) ± 0.11 µV/(W/m²) is valid and will be applied (see PMOD calibration details). Observed sensitivity differences between the consecutive years are well within the calibration uncertainty.

PMOD calibration details: The reference pyranometer was compared with the sun and sky radiation as source under mainly clear sky conditions using the "continuous sun-and-shade method". The pyranometer was installed horizontally. During the comparisons, the global radiation ranged from 638 W/m² to 1195 W/m² with a mean of 874 W/m². The solar zenith angle varied from 23.5° to 49.8° with a mean of 32.9°. The ambient temperature ranged from +12.6 °C to +26.2 °C with a mean of +23.7 °C. The sensitivity calculation is based on 435 individual measurements. The readings of the WSG are referred to the World Radiometric Reference (WRR). The estimated uncertainty of the WRR relative to SI is ±0.3%. The obtained sensitivity value and its expanded uncertainty (95% level of confidence) are valid for similar conditions and are:8.37 ± 0.11 µV/W/m². The measurements were performed in Davos (latitude: 46.8143˚, longitude: -9.8458˚, altitude: 1558 m above sea level). Dates of measurements: 24, 30 June 1, 2 July 2015. Global radiation data were calculated from the direct solar radiation as measured with the absolute cavity pyrheliometer PMO2 (member of the WSG, WRR- factor: 0.998623 from the last international Pyrheliometer Comparison, IPC-2015) and from the diffuse radiation as measured with a continuous disk shaded pyranometer Kipp & Zonen CM22 SN 020059 (ventilated with heated air).

SENSITIVITY	10.26 µV/(W/m²) at normal incidence on horizontal pyranometer
UNCERTAINTY	0.15 µV/(W/m²) = 1.44 %
IMPEDANCE	24 ± 1.5 Ω

Justification of total instrument calibration uncertainty

The combined uncertainty of the result of the calibration is the positive "root sum square" of the following components.
1. The expanded uncertainty due to random effects and instrumental errors during the calibration of the reference CMP 21 is ±0.11/8.37 = ±1.31% (k=2). See traceability text.
2. The expanded uncertainty of the transfer procedure (calibration by comparison) is estimated to be ±0.5% (k=2).
3. The estimated uncertainty of the WRR relative to SI: ±0.3% (k=2).
The expanded uncertainty is: $\sqrt{(1.31\%^2 + 0.5\%^2 + 0.3\%^2)} = \pm 1.44\%$ (k=2).

The resistance measurement uncertainties are due to the PXI 4065 uncertainty in the 100 Ω range: 150ppm of range (=15mΩ) the cable resistance (estimated 0.1 Ω) and due to the electrothermal effect the measurement current in the thermal detector of the pyranometer. This was found to be a resistance error of 1.5 Ω, which results in a total resistance uncertainty of $\sqrt{(0.015^2+0.1^2+ 1.5^2)} = 1.5$ Ω or 5%.

The PXI 4065 is calibrated by National Instruments Hungary, on 7 november 2018 at a temperature of 22.7 °C, under ISO 17025:2005 accreditation. This calibration is traceable to NIST and/or other National Measurement Institutes (NMI's).

The reported expanded uncertainty is based on the standard uncertainty of the measurement multiplied by a coverage factor k, such that the coverage probability corresponds to approximately 95%. The standard uncertainty has been determined in accordance with EA 04/2.

Notice

The calibration certificate supplied with the instrument is valid at the date of first use. Even though the calibration certificate is dated relative to manufacture, or recalibration, the instrument does not undergo any sensitivity changes when kept in the original packing.

* from October 2018 the classification conforms to ISO 9060:2018. Instruments issued before that date conform to ISO 9060:1990.

RvA is member of the European Co-operation for Accreditation (EA) and is one of the signatories to the EA Multilateral Agreement (MLA) and to the ILAC Mutual Recognition Arrangement (MRA) for the mutual recognition of calibration certificates.

Kipp & Zonen B.V.
Trade name: OTT HydroMet
Company registered in Delft

Trade register no.: 27239004
VAT no.: NL0055.74.857.B.01
Member of HMEI

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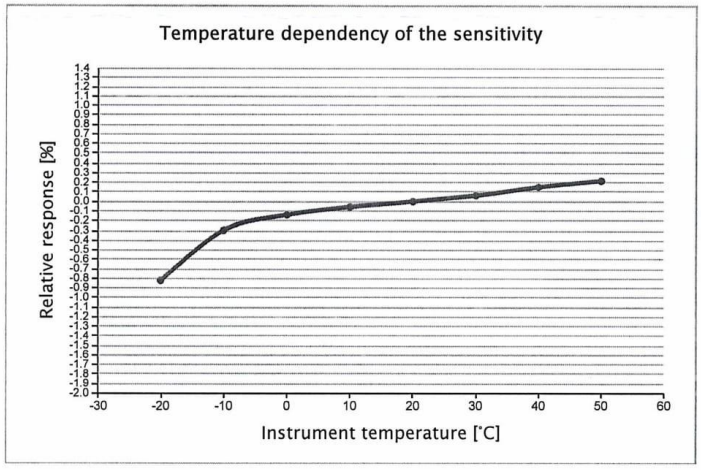
MEASUREMENT REPORT PYRANOMETER

Routine measurement of temperature dependency during final inspection

PYRANOMETER TYPE	CMP 10
SERIAL NUMBER	210853
DATE OF MEASUREMENT	21 December 2020
PERFORMED BY	F. de Wit
PROCEDURE	The pyranometer is mounted inside the climate chamber and illuminated with a white light source under normal incidence. A CMP22 pyranometer outside the chamber is used to monitor the lamp stability.
	The pyranometer is tested over a temperature range from 50 °C down to -20 °C in steps of 10 °C. The relative temperature dependency is plotted below.
	The measurement uncertainty of this characterisation is ±0.1% (k=2).



Instrument temperature [°C]	Relative response [%]
-20	-0.82
-10	-0.30
0	-0.14
10	-0.06
20	0.00
30	0.06
40	0.15
50	0.22

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MEASUREMENT REPORT
PYRANOMETER

Routine measurement of directional error during final inspection

Mean cosine error of each new pyranometer type CMP 10 is measured by a simple routine.

Routine:

The pyranometerbase is placed against the vertical turntable of a goniometer in the parallel (0,5°) beam of a sunsimulator.
Voltage output U(z) is measured for beam incidence (zenith) angles of 0°,40°, 60°, 70° and 80° coming in over azimuth south (cable pointing to North).
Next the pyranometer output U(-z) is measured for incidence angles of -80°, -70°, -60°, -40° and 0° consequently for azimuth south. The dark signal is measured at the beginning of the routine in the middle and at the end. For each beam incident angle the dark signal is interpolated.

During the CMP 10 measurement cycle, a check is done on the azimuth error at 40° and 70° by measuring voltages for azimuth-directions S, E, N and W . Also at -70° and -40° this azimuth error is measured and the mean of both azimuth measurements cancels out the eventual error in the 0° position.

With the extended procedure at both 40° and -40° and 70° and -70° the specific cosine error for 8 azimuth directions (40° S, W, N and E and 70° E, N, W, S) can be calculated according to formula 1 and verified whether it is within ± 10 W/m².

The applied formula for the relative cosine error is:

U(0°) Pyranometer output voltage for normal incidence
U(z) Pyranometer output voltage for angles (z)
Zero(z) Dark signal for angles

$$\frac{\frac{(U(z)+U(-z))}{2} - \text{zero}(z)}{\left(\frac{U(0°)+U(0°)}{2} - \text{zero}(z)\right)\cdot\cos(z)} \cdot 100\%$$

Formula 1.

Relative cosine error at zenith angle in %

Zenith angle	South	East	North	West
40	-1.05	-0.33	-0.34	-1.11
60	-1.43			
70	-1.78	-0.96	-0.98	-2.02
80	-1.86			

Absolute cosine error for 1000 W/m² beam radiation in W/m²

Zenith angle	South	East	North	West
40	-8.07	-2.52	-2.59	-8.51
60	-7.13			
70	-6.09	-3.27	-3.33	-6.87
80	-3.21			

PYRANOMETER MODEL: CMP 10 SERIAL NUMBER: 210853

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9.3 CHP1 pyrheliometer

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ISO/IEC 17025 CALIBRATION CERTIFICATE

CERTIFICATE NUMBER	022761210874
PYRHELIOMETER MODEL	CHP 1
SERIAL NUMBER	210874
CALIBRATION DATE	29 January 2021
INSTRUMENT CLASS	ISO 9060, Class A*
CALIBRATION PROCEDURE	Validated indoor procedure as described on page 2
REFERENCE PYRHELIOMETER	Kipp & Zonen CHP 1 sn REF1 active from 01 January 2021
REFERENCE PYRHELIOMETER CALIBRATION PROCEDURE	ISO 9059
CALIBRATION LOCATION	Delft The Netherlands
CUSTOMER	

REMARKS	Instrument condition: The calibration item was received fully functional and did not show any erratic behavior or irregularities during calibration. Instrument changes after last calibration:

Delft, The Netherlands, 29 January 2021

J. Mes
(Calibration Manager)

F. de Wit
(Calibration Technician)

Page: 1 of 2

Meteorology Division of OTT HydroMet

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ISO/IEC 17025 CALIBRATION CERTIFICATE

CERTIFICATE NUMBER 022761210874

Calibration procedure

The indoor transfer calibration is performed in analogy to the ISO 9847 pyranometer calibration; the reference and test instrument are of the same type. In the first step the reference pyrheliometer is placed in the collimated beam of a Xenon lamp. After a stabilization period the irradiance is measured and a dark measurement is performed. Then the reference instrument is replaced by the test instrument, after stabilization its output signal is measured. As a last step the reference instrument is again placed in the beam to validate the beam irradiance has not drifted. The sensitivity is calculated from the irradiance as measured by the reference pyrheliometer and the voltage output of the test instrument. The minimum beam intensity is 650 W/m², room temperature is 22 °C ±2 °C

Hierarchy of traceability

The measurements have been executed using standards for which the traceability to international standards has been demonstrated towards the RvA.

This reference pyrheliometer was compared against the absolute cavity pyrheliometer PMO6 SN 103 using the sun as source according to ISO 9059 "Calibration of field pyrheliometers by comparison to a reference pyrheliometer". The comparison was performed in Delft, The Netherlands (latitude: 51.9969°, longitude: 4.3863°, altitude: 10 m above sea level). During the comparisons the reference pyrheliometer received direct solar radiation with intensities ranging from 992 W/m² to 1006 W/m², with a mean of 1000 W/m². The ambient air temperature ranged from +19.0°C to +29.9°C with a mean of +23.9°C. The sensitivity calculation is based on 101 individual measurements. The sensitivity and its expanded uncertainty (95% level of confidence) with respect to the WRR are valid for similar environmental conditions and amount to:
7.95 µV/(W/m²) ± 0.02 µV/(W/m²). Date of measurements: 22-24 June 2020

The absolute cavity pyrheliometer PMO6 SN 103 is calibrated against the World Standard Group (WSG), at the WRC Davos, Switzerland (latitude: 46.8143°, longitude: -9.8458°, altitude: 1558 m above sea level). This is done every 5 years at the International Pyrheliometer Comparison (IPC). The readings of the WSG are referred to as the World Radiometric Reference (WRR) as stated in the WMO Technical Regulations.

WRR- factor of PMO6 SN 103: 0.99787 (from the last international Pyrheliometer Comparison, IPC-2015). The estimated uncertainty of the WRR relative to SI is ±0.3%. During the yearly NPC hosted by NREL in Golden, Colorado (latitude: 39.742°, longitude: 105.18°, altitude: 1829 m above sea level) the WRR factor of the reference PMO6 SN 103 is verified.

SENSITIVITY	8.09 µV/(W/m²) at normal incidence
UNCERTAINTY	0.09 µV/(W/m²) = 1.07 %
IMPEDANCE	27 Ω ± 2Ω

Justification of total instrument calibration uncertainty

The combined uncertainty of the result of the calibration is the positive "root sum square" of the following components:
1. The expanded uncertainty due to random effects and instrumental errors during the calibration of the reference CHP 1:
0.02 µV/(W/m²) / 7.95 µV/(W/m²) = ±0.25% with respect to the WRR (See traceability text).
2. The estimated uncertainty of the WRR relative to SI: ±0.3% (k=2).
3. The expanded uncertainty of the transfer procedure (calibration by non-simultaneous comparison) is estimated to be ±1% (k=2).

The expanded uncertainty is: $\sqrt{(0.25\%^2 + 0.3\%^2 + 1\%^2)} = \pm 1.07\%$ (k=2).

The reported expanded uncertainty is based on the standard uncertainty of the measurement multiplied by a coverage factor k, such that the coverage probability corresponds to approximately 95%. The standard uncertainty has been determined in accordance with EA 04/2.

Notice

The calibration certificate supplied with the instrument is valid at the date of first use. Even though the calibration certificate is dated relative to manufacture, or recalibration, the instrument does not undergo any sensitivity changes when kept in the original packing.

* from October 2018 the classification conforms to ISO 9060:2018. Instruments issued before that date conform to ISO 9060:1990.

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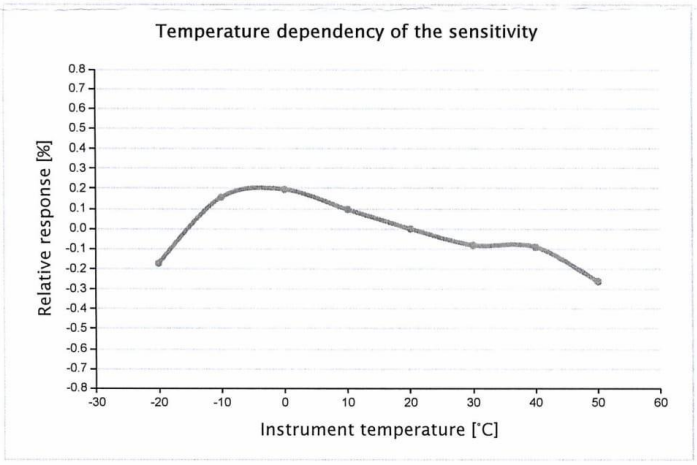
MEASUREMENT REPORT
PYRHELIOMETER

Routine measurement of temperature dependency during final inspection

PYRHELIOMETER TYPE	CHP 1
SERIAL NUMBER	210874
DATE OF MEASUREMENT	21 January 2021
PERFORMED BY	J.P. Vink
PROCEDURE	The pyrheliometer is mounted inside the climate chamber and illuminated with a white light source under normal incidence. A CMP22 pyranometer outside the chamber is used to monitor the lamp stability. The pyrheliometer is tested over a temperature range from 50 °C down to -20 °C in steps of 10 °C. The relative temperature dependency is plotted below. The measurement uncertainty of this characterisation is ±0.1% (k=2).



Instrument temperature [°C]	Relative response [%]
-20	-0.17
-10	0.16
0	0.20
10	0.10
20	0.00
30	-0.08
40	-0.09
50	-0.26

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9.4 #40C anemometer

SOH Wind Engineering LLC

141 Leroy Road · Williston, VT 05495 · USA

Tel 802.316.4368 · Fax 802.735.9106 · www.sohwind.com

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 20.US1.00736 **Date of issue:** October 26, 2020

Type: NRG 40C Anemometer **Serial number:** 179500332897

Manufacturer: NRG Systems Inc, 110 Riggs Road, Hinesburg, VT 05461, USA

Client: NRG Systems Inc, 110 Riggs Road, Hinesburg, VT 05461, USA

Anemometer received: October 20, 2020 **Anemometer calibrated:** October 24, 2020

Calibrated by: MEJ **Procedure:** MEASNET, IEC 61400-12-1:2017 Annex F

Certificate prepared by: EJF **Approved by:** Calibration engineer, EJF

Calibration equation obtained: v [m/s] = 0.75808 · f [Hz] + 0.39263

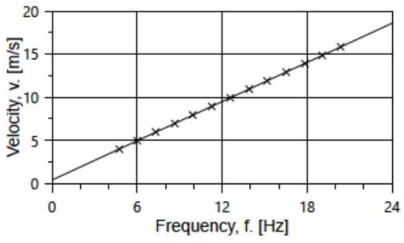
Standard uncertainty, slope: 0.00133 **Standard uncertainty, offset:** 0.03472

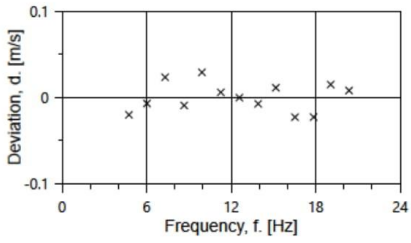
Covariance: -0.0000128 (m/s)²/Hz **Coefficient of correlation:** ρ = 0.999990

Absolute maximum deviation: 0.029 m/s at 7.949 m/s

Barometric pressure: 1002.8 hPa **Relative humidity:** 46.3%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in d.p. box [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
1-first	9.27	23.0	27.0	3.973	4.7494	-0.020	0.023
13-last	14.41	23.0	27.0	4.953	6.0255	-0.007	0.026
2	20.87	22.9	27.0	5.962	7.3157	0.023	0.030
12	28.37	23.1	27.0	6.952	8.6650	-0.010	0.034
3	37.11	22.9	27.0	7.949	9.9297	0.029	0.038
11	46.93	23.1	27.0	8.942	11.2704	0.006	0.042
4	57.93	22.9	27.0	9.932	12.5839	-0.001	0.046
10	70.19	23.1	27.0	10.937	13.9195	-0.008	0.050
5	83.26	22.9	27.0	11.908	15.1750	0.011	0.055
9	97.66	23.1	27.0	12.902	16.5322	-0.023	0.059
6	113.51	22.9	27.0	13.906	17.8557	-0.023	0.063
8	129.55	23.1	27.0	14.861	19.0656	0.015	0.067
7	147.25	23.0	27.0	15.841	20.3685	0.008	0.071





AC-1746

Page 1 of 2

EQUIPMENT USED

Serial Number	Description
Njord1	Wind tunnel, blockage factor = 1.0017
2254	Control cup anemometer
-	Mounting tube, D = 12.7 mm
TT003	Summit Electronics, 1XPT100, 0-10V Output, wind tunnel temp.
TT001	Summit Electronics, 1XPT100, 0-10V Output, differential pressure box temp.
DP005	Setra Model 239, 0-1inWC, differential pressure transducer
HY002	Dwyer RHP-2D20, 0-10V Output, humidity transmitter
BP001	Setra Model 278, barometer
PL8	Pitot tube
XB002	Computer Board. 16 bit A/D data acquisition board
Njord1-PC	PC dedicated to data acquisition

The accuracies of all measurements were traceable to the SI through NIST or CIPM recognized NMI's. A real-time analysis module within the data acquisition software detects pulse frequency.

Photo of the wind tunnel setup. The cross-sectional area is 2.5m x 2.5m.

UNCERTAINTIES

The documented uncertainty is the total combined uncertainty at 95% confidence level (k=2) in accordance with EA-4/02. The uncertainty at 10 m/s comply with the requirements in the IEC 61400-12-1:2005 procedure. See Document US.12.01.004 for further details.

COMMENTS

(none)

Certificate number: 20.US1.00736

The results on this certificate relate only to the serial number listed.
All calibrations are done in the "As Found" condition unless otherwise noted.
This certificate must not be reproduced, except in full, without the approval of SOH Wind Engineering LLC Page 2 of 2

9.5 #200M Wind vane

NRG Systems

Factory Calibration

NRG Systems 200M Wind Direction Vane

Serial No. 10070 00008937

Product Description:

Manufacturer	Description	Cal. Date
NRG Systems	200M Wind Direction Vane	12/9/2020

NRG Systems, hereby certifies that the above instrumentation has been calibrated and tested to **meet or exceed** the published specifications. This calibration and testing was performed using instrumentation and standards that are traceable to the **National Institute for Standards and Technology (NIST).**

Standard Uncertainty of Degree Measurement = ±0.31°

The output (in Deg.) for this 200M sensor is defined by: $\Theta = V * Scale\ Factor + Offset$

Criteria	Value	Units
200M Scale Factor	147.5848	Deg./Volt
200M Offset	-1.3556	Deg.

Linearity Results (R^2): 0.99999

Slope (Scale Factor) and Offset Conversion Chart for NRG Systems' Data Loggers.

To Scale to...	SymphoniePLUS3 and Older *[Symphonie Data Retriever (SDR) software]*		SymphoniePRO Data Logger *[SymphoniePRO Desktop Application]*	
	enter Scale Factor	and enter Offset	enter Scale Factor	and enter Offset
°	0.368	-5.3	147.5848	-1.3556

Procedure: WI-ELE-489

Calibration performed by: sms **Date:** 12/9/2020

NRG Systems' management system has been certified to ISO 9001: 2015.

110 Riggs Road • Hinesburg, Vermont 05461 | o: +1 802.482.2255 f: +1 802.482.2272 | nrgsystems.com

9.6 CS106 (PTB110) barometer

VAISALA

1 (1)
Certificate report no. H47-20500005

CALIBRATION CERTIFICATE

Instrument	PTB110 Barometer
Serial number	S4950663
Manufacturer	Vaisala Oyj, Finland
Calibration date	7th December 2020

This instrument has been calibrated against a Vaisala PTB220 factory working standard. The Vaisala PTB220 is traceable to the National Institute of Standards and Technology (NIST, USA) via Vaisala Measurement Standards Laboratory (MSL). Vaisala MSL has been accredited by FINAS according to ISO/IEC 17025 standard.

At the time of shipment, the instrument described above was within its operating specifications.

Calibration results

Reference pressure hPa	Calculated pressure hPa	Observed voltage Vdc	Correction* hPa	Uncertainty** hPa
510.2	510.2	0.043	0.0	± 0.15
610.0	610.0	0.458	0.0	± 0.15
700.1	700.2	0.834	-0.1	± 0.15
810.1	810.1	1.292	0.0	± 0.15
900.2	900.2	1.668	0.0	± 0.15
1000.0	1000.0	2.083	0.0	± 0.15
1059.8	1059.8	2.333	0.0	± 0.15
1100.0	1100.0	2.500	0.0	± 0.15

*To obtain the true pressure, add the correction to the barometer reading. Interpolated corrections may be used at intermediate readings of the scale of the barometer.
**The calibration uncertainty given at 95 % confidence level, k = 2

Equipment used in calibration

Type	Serial number	Calibration date	Certificate number
HP34970A	EM 12997	2020-03-10	11-9485435-009
PTB220	PA 14018	2020-06-11	K008-D02088

Ambient conditions
Humidity: 34 ± 5 %RH
Temperature: 22 ± 2 °C
Pressure: 1012 ± 20 hPa

Technician

Doc214685-B

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Email firstname.lastname@vaisala.com | www.vaisala.com
Domicile Vantaa, Finland | VAT FI01244162 | Business ID 0124416-2