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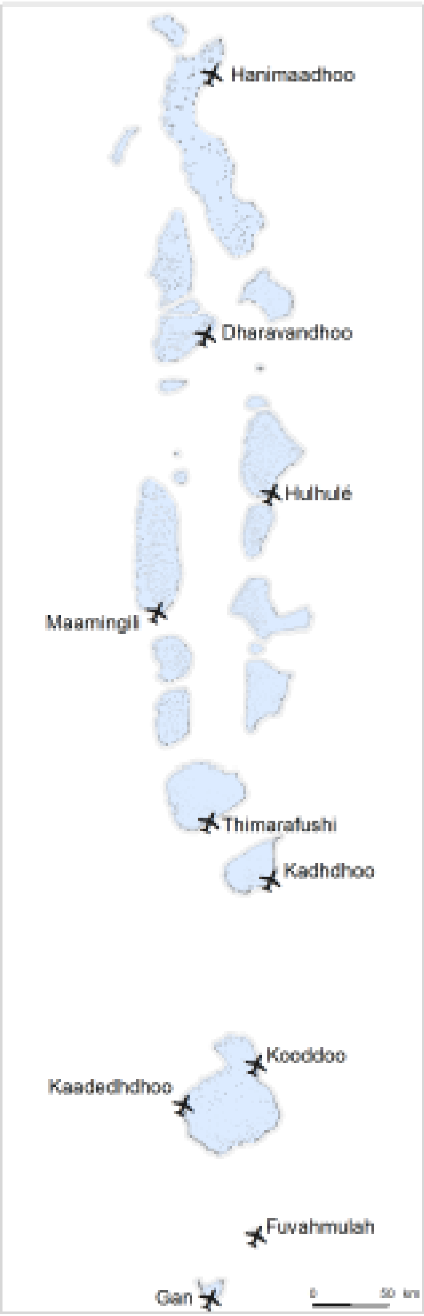
# Solar Resource Mapping in the Maldives

# SITE SELECTION REPORT

FEBRUARY 2015




This report was prepared by GeoModel Solar, under contract to The World Bank.

It is one of several outputs from the solar resource mapping component of the activity "Renewable Energy Resource Mapping and Geospatial Planning – Maldives" [Project ID: P146018]. This activity is funded and supported by the Energy Sector Management Assistance Program (ESMAP), a multi-donor trust fund administered by The World Bank, under a global initiative on Renewable Energy Resource Mapping. Further details on the initiative can be obtained from the ESMAP website.

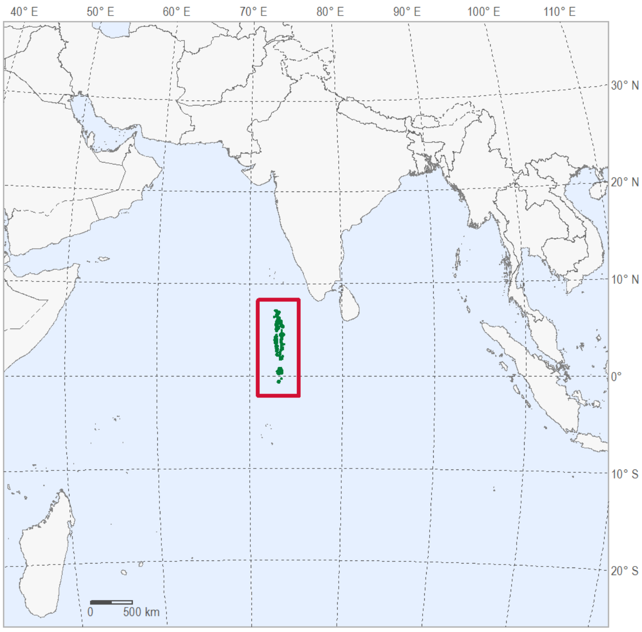
This document is an **interim output** from the above-mentioned project. Users are strongly advised to exercise caution when utilizing the information and data contained, as this has not been subject to full peer review. The final, validated, peer reviewed output from this project will be the Maldives Solar Atlas, which will be published once the project is completed.

GeoModel SOLAR

World Bank Group, Global ESMAP Initiative: Renewable Energy Resource Mapping: Solar − Maldives
Project ID: P146018

**Site Selection Report**

February 2015




Reference No. (GeoModel Solar): 129-03/2015

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# 1 SUMMARY

**Background**

This report is prepared within Phase 1 of the project *Renewable Energy Resource Mapping for the Republic of the Maldives*. This part of the project focuses on solar resource mapping and measurement services as part of a technical assistance in the renewable energy development implemented by the World Bank in Maldives. It is being undertaken in close coordination with the Ministry of Environment and Energy (MEE) of Maldives, the World Bank's primary country counterpart for this project.

This project is funded by the *Energy Sector Management Assistance Program* (ESMAP) and *Asia Sustainable and Alternative Energy Program* (ASTAE), both administered by the World Bank and supported by bilateral donors.

**Objective**

Important part of the project is to deliver high quality solar resource measured data that are to be used for validation of solar resource and meteorological models. Central in this effort is a focus on reducing uncertainty of the models and thus reducing financial and technical risk during implementation of solar energy technologies in Maldives. Objectives of the project are as follows:

- To improve the quality of available information on RE resources in the Maldives by developing resource maps for priority renewables.
- These resource maps will
    - Provide a detailed assessment and planning framework for RE resources in Maldives,
    - Increase the awareness and knowledge of the government and other energy sector players on renewable energy potential
    - Encourage new public and private sector investments in RE projects.

This report identifies a long and short lists of potential solar measuring sites in Maldives and proposes set of instruments to be deployed and operated at the agreed meteorological sites. This report also ranks the sites, according to our findings, to contribute to the information-based decision-making on the final site selection.

**Data and methods**

Selection of candidate sites is the outcome of the methodology, which is based on the following steps:

- Identification of representative climate zones in Maldives to understand geographical differences
- Identification of areas not suitable for deployment of solar measuring stations
- Description of localisation criteria for identification of preferred sites
- Compilation of a long list of sites based on localisation criteria. Categorization of each site into Tier 1 and 2 category, description of instruments and equipment to be deployed for each category
- Preliminary proposal of short-listed sites. The long list and preliminary short-list will serve to decision makers for negotiation and taking final decision about the set-up of the solar measuring network.

The report is accompanied by analytical maps and criteria-supported arguments resulting in synthetic indicators and identification of long list and preliminary proposal for a short-list of candidate sites.

Geographical differences of the country are discussed in Chapter 2.

Quality and reliability of measuring campaign is one of the most important criteria taken into account. Chapter 3 describes the sites identified on the long list.

From the **local perspective**, there are several localisation criteria for identification of the most suitable sites, such as accessibility, availability of personnel for maintenance and cleaning, security, sustainability of running the measurement campaign in a long term, acceptance/interest of the present land owner, and other economical and logistical criteria.

In the report we rank long list of sites according to the above-mentioned criteria. Ranking from 1 to 5 (1 = not suitable and 5 = excellent) was attributed to each site, based on its suitability to host the station. This ranking ignored proximity to adjacent sites, i.e. two sites close to each other could both get a 5. Next, the sites were selected based on their geographic distribution and ranking. Based on the site ranking, we propose four out of long-listed sites as good candidates for deployment of solar measuring stations.

At this point we should underline, that correct measurement routine during two years campaign is as important as selection of suitable location based on regional and local criteria. As the project objective is to provide high accuracy solar resource data and to attract the investors in solar energy, we consider as appropriate to locate at least one measurement station close to Malé and to highest electrical demand.

These aspects of project deployment and implications for Phase 2 are discussed in Chapter 4.

**Results**

Based on the selection procedure we have identified a *long list* of 10 potential sites that are suitable for installation of Tier 1 and Tier 2 solar resource measuring instruments. In the report we describe 4 of them in a more detail. At this subset of sites managed by Maldives Meteorological Service (MMS), there is located a meteorological station with some instrumentation and personnel. The long-listed sites represent fully the climate of Maldives. We also propose a *short list* of preselected sites to facilitate the final decisions.

To ensure viability of the project, regular maintenance and cleaning is inevitable precondition to achieve reliable validation data sets. From this perspective, hosts who are interested to acquire measurements for their professional purposes (during and after measurement campaign) create the priority group of potential hosts.

# 2 SITE SELECTION CRITERIA

## 2.1 Climate zones and geographical differences

As demonstrated in the *Solar Modelling report 129-01/2015,* climate and geographical differences across the Maldives are very small. The archipelago is spread in equatorial zone, where air temperature and solar radiation varies very little. All islands are located in very low altitude (maximum altitude is less than 2.5 m), thus altitude has no influence on the climate zonation.

Figures 2.1 to 2.3 show differences of GHI, DNI and temperature between four sites (proposed as candidates for a shortlist) located in central, position as well as in North (Hanimaadhoo) and South (Gan) of the country. Flat curves of the graphs demonstrate stable radiation characteristics during the whole year.

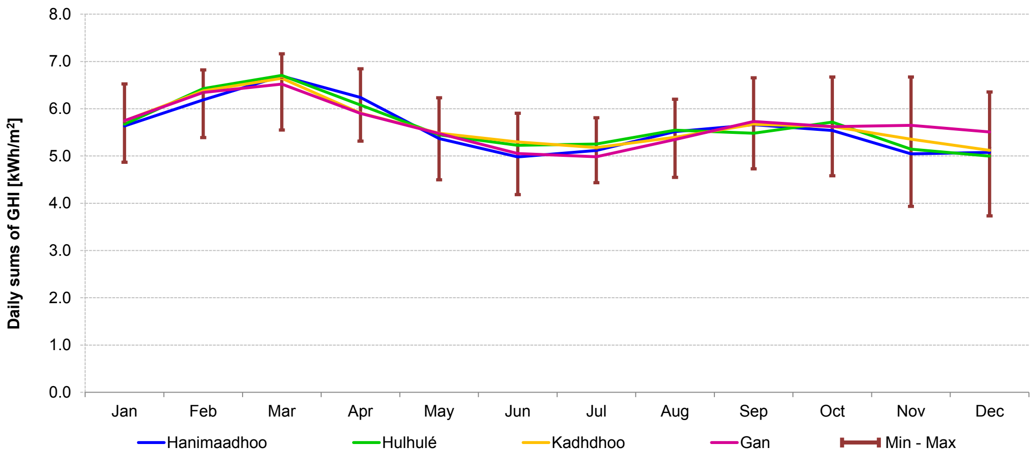


Figure 2.1: Global Horizontal Irradiation − long-term monthly averages, minima and maxima.

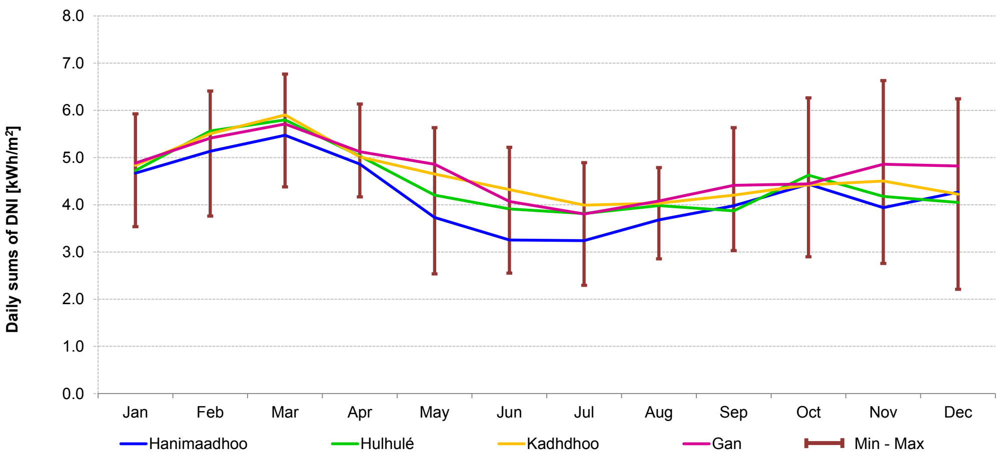


Figure 2.2: Daily averages of Direct Normal Irradiation at selected sites.

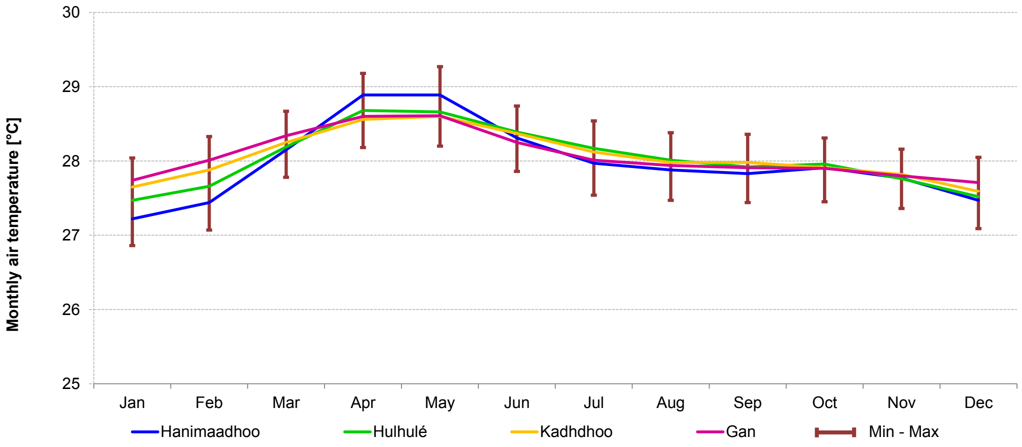


Figure 2.3: Monthly averages, minima and maxima of air-temperature at 2 m for selected sites.

In the north of Maldives, which is also visible on the Hanimaadhoo site, there is slightly higher seasonality, driven possibly also by proximity to the flow of aerosols (Figure 2.4) with peak concentrations in July. Most of the archipelago, however, shows very little aerosol load during the year (Figure 2.5).

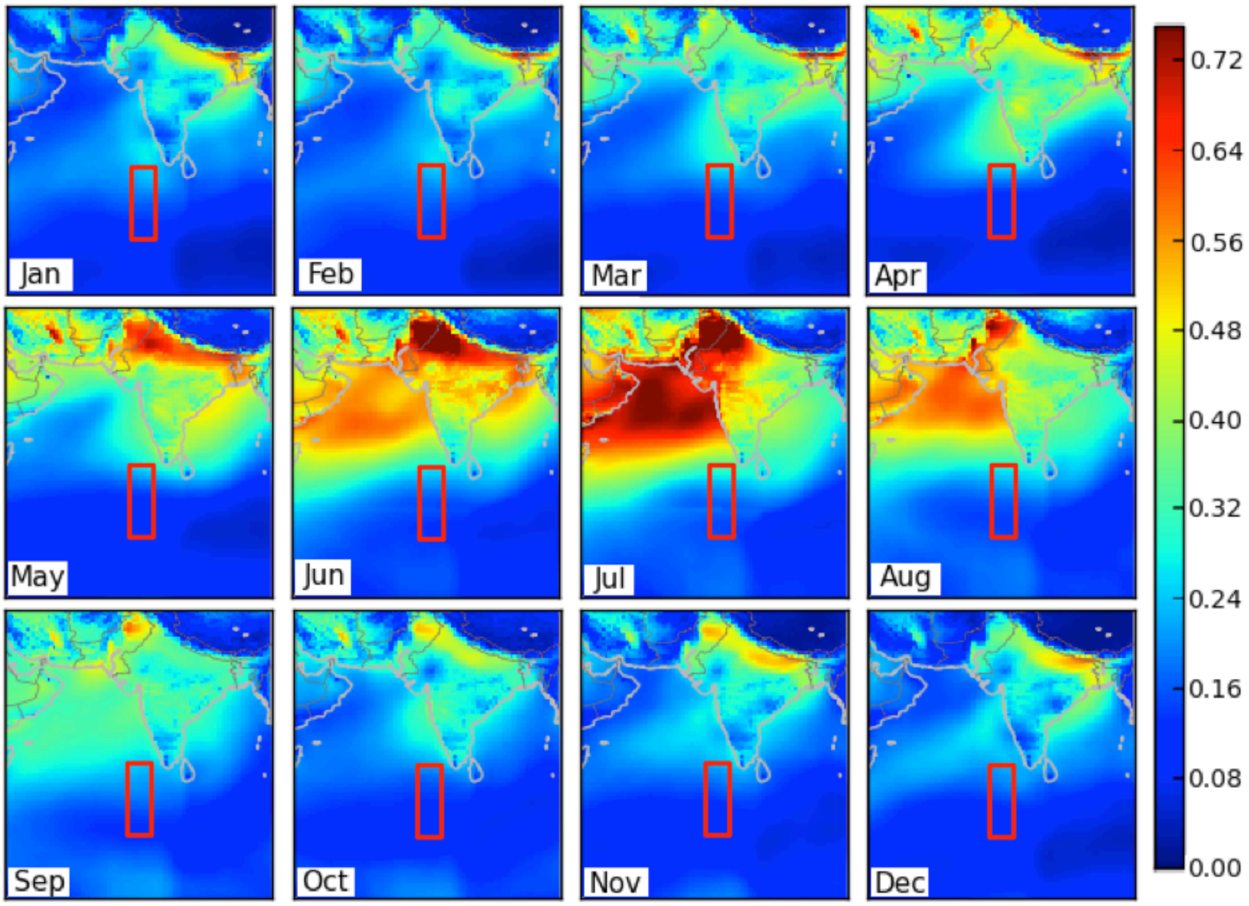


Figure 2.4: Monthly-averaged aerosol maps (AOD 670) derived from the MACC-II database and adapted for the SolarGIS model. Period 2003 to 2013

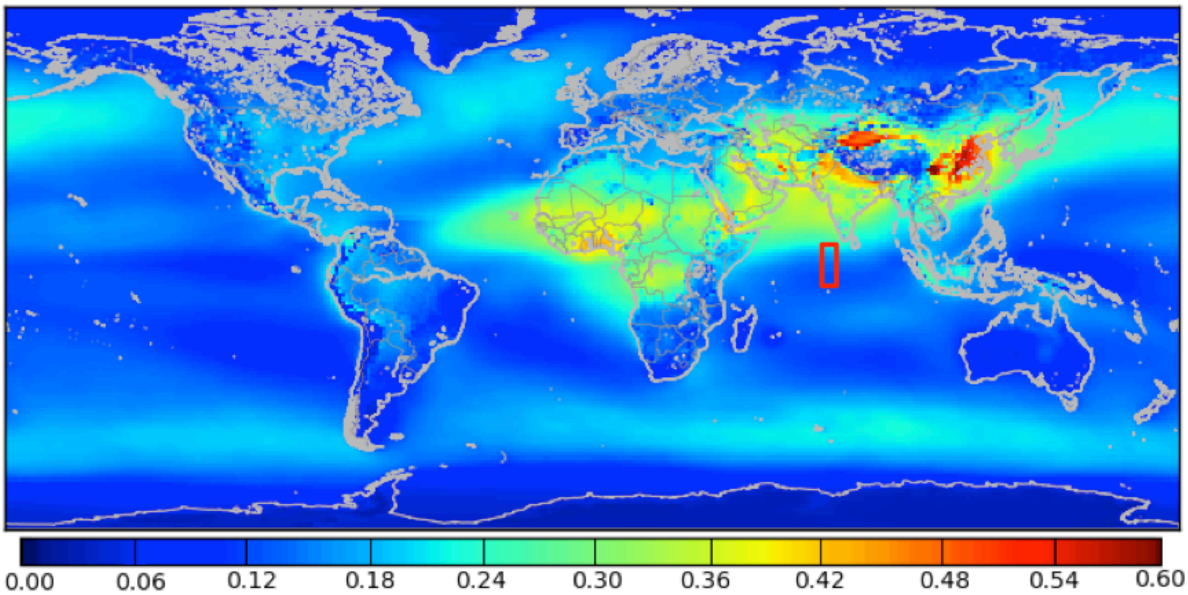


Figure 2.5: Average annual aerosols − Maldives in the global context
AOD 670 nm is computed by the MACC-II model and adapted for SolarGIS.
Period 2003 to 2012. Values are dimensionless.

The solar radiation increases only marginally from the North to South and no distinctive climate zones can be delineated. Distribution of proposed short listed measurement stations (Chapter 4.1) ensures geographical representativeness of data measured in future.

## 2.2 Deployment of measurement stations – regional optimisation

One of the requirements of two years measurement campaign is to receive high quality, continuous data sets that can be used for *satellite data validation* and *regional adaptation of the solar model*. Solar measuring stations should preferably not be installed in areas that are difficult to access, lacking transport infrastructure, in environmentally sensitive areas, and where adequate security cannot be achieved.

On Maldives all islands where there is no regular air transport were excluded (Figure 2.6). We consider accessibility of places as the most important characteristic. Airports with their infrastructure, dedicated spaces for installed meteorological measurements and operational personnel are considered as the best candidates for deployment of solar measurement stations.

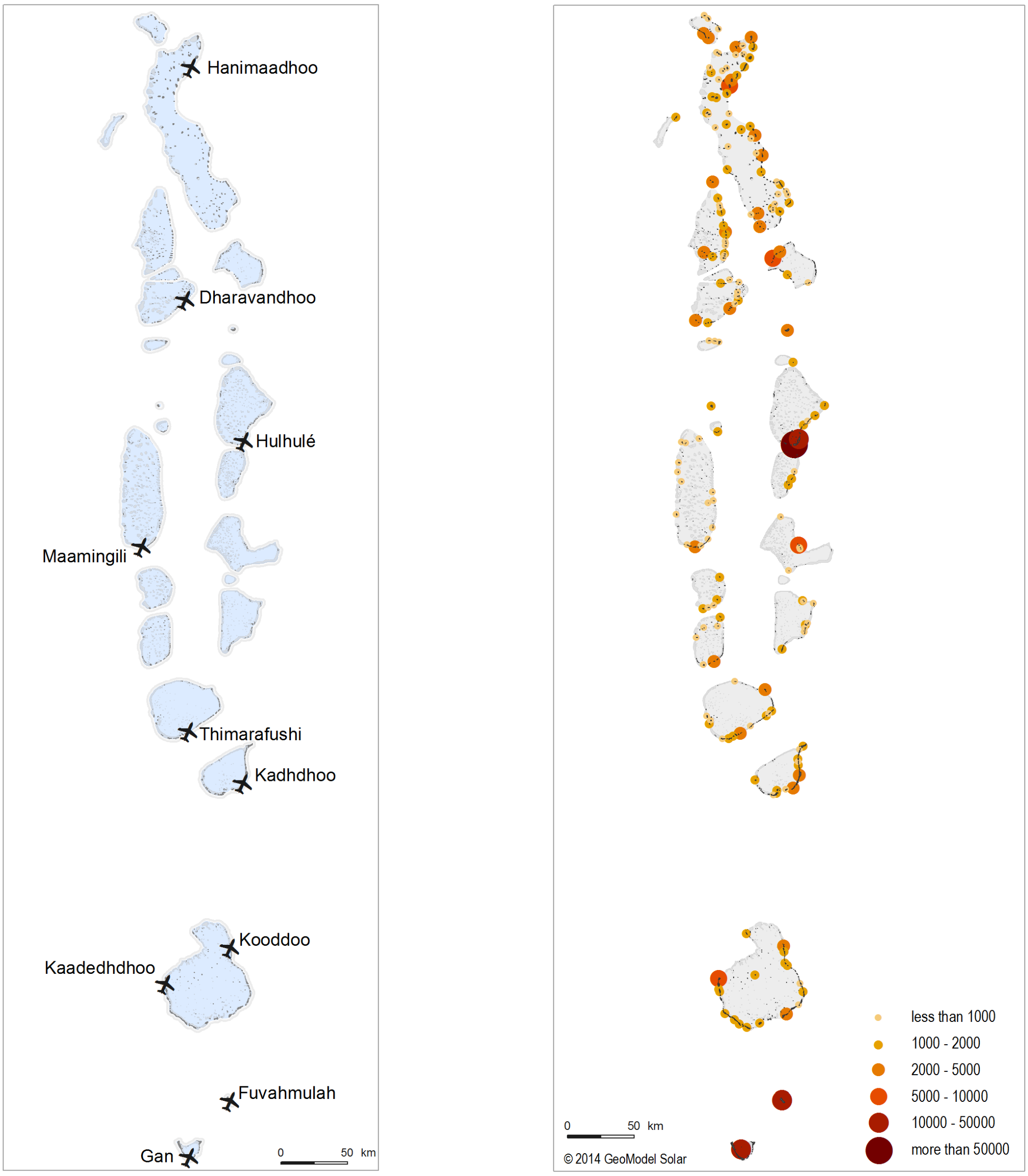


Figure 2.6: Localisation of airports (left) and population centres with number of inhabitants (right)

# 3 CANDIDATE SITES

## 3.1 Long list of sites

Rationale for selecting the sites

The main objective of Phase 2 of this project is to collect 'high quality, credible and reliable' ground-based measurements that can be used for improving the solar atlas of Maldives. The most important task to achieve this objective is the ability to operate and maintain stations as per the specific requirements. Maldives being a garland of 192 islands, regional variation can be diverse and availability of skilled manpower can be a problem. Discussions were held with various local institutions and various factors were considered. Hence, to make sure that most of the regions of Maldives are covered and manpower is available, we have chosen airports as the primary sites for installation of the solar radiation stations after consultation with the local institutions. Most of the sites proposed for the long-list of sites are located at the airports operated by the Maldivian government. These sites also fulfil other criteria for the selection, operation and maintenance of the solar radiation measurement stations such as:

- Availability of free horizon,
- Availability of GSM networks,
- Availability of local work force for maintenance,
- Easy to access and high level of security.

Airfields generally have the advantage of relatively flat terrain and thus provide good solar observation conditions with few obstacles on the horizon. Further, airports with regular airline traffic are usually situated on or near islands with a substantial amount of inhabitants and thus are at solar energy relevant sites. At airports skilled and reliable work force is easy to find. Most of the national and international airports are already equipped with a meteo station of the Maldives Meteorological Service, where well-trained weather experts familiar with meteorological equipment are already available. In some cases parts of airports may be even suitable for PV systems installation, which would be a great advantage as there is not much land available for PV plants on the Maldives and would bring close generation and load centres. Therefore, our search was concentrated on islands with airports (see Figure 2.6).

Based on the above, an overview of long-listed sites is shown in Figure 3.1, Tables 3.1 and 3.2. The sites are positioned at each of the airports under the assumption that area required for the installation of solar radiation measurement stations would be available. The final position at the airports would be determined after discussions with the corresponding authorities.

It is assumed that for security of the stations proper fencing would be installed. At some of the sites proposed above, solar radiation measurement stations already exist. These stations have an added advantage that historical solar radiation data is available and can be used for the project.

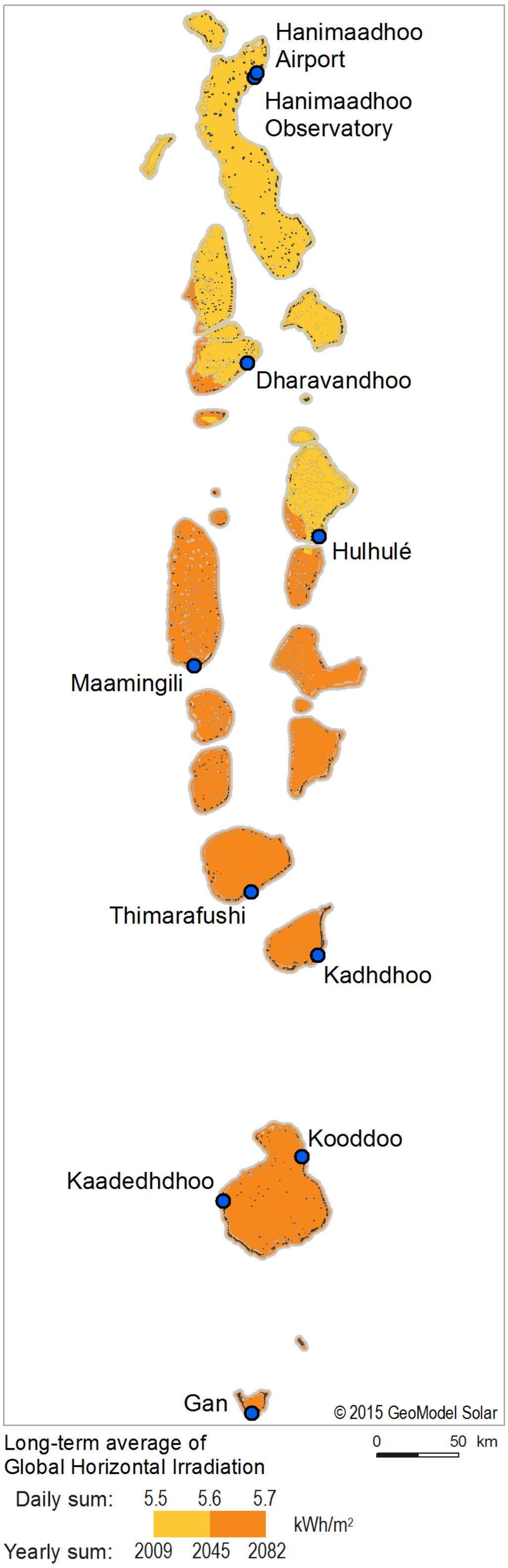


Figure 3.1: Map of the long-listed candidate sites for solar radiation measurement stations

Table 3.1: Long list of sites – position ordered from North to South.

| ID | Site name | Land /site Owner | Island | Atoll | Latitude [°] | Longitude [°] | Elevation [m] |
|---|---|---|---|---|---|---|---|
| MVHAO | Hanimaadhoo Observatory | MCOH | Hanimaadhoo | Haa Dhaalu | 6.776 | 73.183 | 3 |
| MVHAQ | Hanimaadhoo Airport | Hanimaadhoo International Airport | Hanimaadhoo | Haa Dhaalu | 6.744 | 73.170 | 2 |
| MVDRV | Dharavandhoo | Dharavandhoo Airport | Dharavandhoo | Baa | 5.156 | 73.133 | 3 |
| MVMLE | Hulhulé | Ibrahim Nasir International Airport | Hulhulé | North Malé (Kaafu) | 4.192 | 73.529 | 2 |
| MVVAM | Maamingili | Villa International Airport | Maamingili | Alifu Dhaalu | 3.471 | 72.836 | 2 |
| MVTMF | Thimarafushi | Thimarafushi Airport | Thimarafushi | Thaa | 2.210 | 73.151 | 1 |
| MVKDO | Kadhdhoo | Kadhdhoo Airport | Kadhdhoo | Laamu | 1.859 | 73.522 | 2 |
| MVGKK | Kooddoo | Kooddoo Airport | Kooddoo | Gaafu Alifu | 0.734 | 73.433 | 0 |
| MVKDM | Kaadedhdhoo | Kaadedhdhoo Airport | Kaadedhdhoo | Gaafu Dhaalu | 0.488 | 72.997 | 0 |
| MVGAN | Gan | International Airport | Gan | Addu (Seenu) | -0.693 | 73.156 | 2 |

Sites are evaluated based on the following criteria:

Space availability

- Obstruction by the objects in vicinity
- Sources of air pollution
- Available GSM network
- Security measures at the site
- Accessibility (airport, roads)
- Electricity available
- Land use permit
- Operational permit

In the site identification we tried to find a synergy with already on-going similar activities.

The proposed long-list of sites is characterized below.

Regional coverage:

- The sites Hanimaadhoo Airport, Hanimaadhoo Observatory, Dharavandhoo Airport, Hulhule Airport, Maamingili Airport are located in the **North Maldives**.
- The sites Thimarafushi Airport, Kadhdhoo Airport, Kooddoo Airport, Kaadedhdhoo Airport and Gan Airports are located in the **South Maldives**.
- The sites Kadhdhoo, Kooddoo and Hulhule Airport are located in **East Maldives**.
- Kaadedhdhoo Airport, Thimarafushi Airport and Villa International Airport at Maamingili are located in **West Maldives**.

Climate zone:

- Maldives being a country with tropical climate and a chain of islands, the weather across most of its islands remains the same. No major variation with respect to the climate is observed within Maldives.

Proximity to electricity load:

- The most populated cities in Maldives are Male, Addu City, Fuvahmulah, Gan, Dhuvaaafaru, Dhidhdhoo etc. Many of these have been selected on the long-list of sites. At the same time, these selected sites with higher population also represent areas with high potential for solar power plant development.

Existing solar radiation measurement stations

- At Hulhule Airport, Hanimaadhoo Airport and Hanimaadhoo Observatory solar radiation measurement stations already exist. These are probably the only sites in Maldives with existing solar radiation measurements.

Long listed sites are ranked based on the following principles:

- Sites should be accessible in a reasonable time (by boat or plane)
- Sites should provide area on land/rooftop available on a long-term basis
- Site should have a free horizon i.e. no shadows from obstructions such as trees or buildings in the vicinity. Site should be at least 20 m away from any permanent structure of more than 8 m height.
- Site should be free from electromagnetic interference. Site should be away from any overhead high tension lines, high voltage transformers and underground high voltage electric cables
- Sites should be in a safe distance away from sources of dust and dirt.
- Sites should be located in a secure environment with the presence of trained personnel, so that non-interrupted and high quality data can be obtained (cleaned instruments, broken parts replaced in a short period of time)
- Site should be located at places with higher potential for implementation of solar power plants or in their immediate vicinity
- Site should be located at places with good GSM network availability for effective transmission of data measured by the stations to the central collecting point

The ranking of the sites is shown in Table 3.2

Table 3.2: Long list of sites – characteristics and ranking from 1 to 5 (1 is the best rating).

| ID | Site name | Existing meteo station | Personnel on site | Individual rank |
|---|---|---|---|---|
| MVHAO | Hanimaadhoo Observatory | Yes | Yes | 2 |
| MVHAQ | Hanimaadhoo Airport | Yes | Yes | 1 |
| MVDRV | Dharavandhoo | Yes automatic | No | 3 |
| MVMLE | Hulhulé | Yes | Yes | 1 |
| MVVAM | Maamingili | No | No | 4 |
| MVTMF | Thimarafushi | No | No | 4 |
| MVKDO | Kadhdhoo | Yes | Yes | 1 |
| MVGKK | Kooddoo | No | No | 3 |
| MVKDM | Kaadedhdhoo | Yes | Yes | 2 |
| MVGAN | Gan | Yes | Yes | 1 |

## 3.2 Tier 1 and Tier 2 stations and instrumentation

The list of instruments to be included in the Tier 1 and Tier 2 stations and the parameters measured by them are shown in Table 3.3.

Table 3.3: Equipment to be installed on the solar radiation measurement stations

| Instrument | Parameter | Meteo station | |
|---|---|---|---|
| | | Tier 1 | Tier 2 |
| Thermopile Pyranometer - Secondary Standard according to ISO 9060 | Global Horizontal Irradiance | Yes | Yes |
| Thermopile Pyranometer - Secondary Standard according to ISO 9060 | Diffuse Horizontal Irradiance | Yes | |
| Thermopile Pyrheliometer - First Class according to ISO 9060 | Direct Normal Irradiance | Yes | |
| 2-axis Solar Tracker with Sun Sensor | Accessory | Yes | |
| Calibrated Rotating Shadowband Radiometer | Direct Normal Irradiance | | Yes |
| Calibrated Rotating Shadowband Radiometer | Diffuse Horizontal Irradiance | | Yes |
| Calibrated Rotating Shadowband Radiometer | Global Horizontal Irradiance | | Yes |
| Ambient Temperature encased in radiation shield | Ambient Temperature | Yes | Yes |
| Relative Humidity Sensor encased in radiation shield | Relative Humidity | Yes | Yes |
| Barometric Pressure Sensor | Barometric Pressure | Yes | Yes |
| Anemometer | Wind Speed | Yes | Yes |
| Data logger with 2 GB memory storage for storing up to 3 months data | Data logger | Yes | Yes |
| GPRS Modem | Communication | Yes | Yes |
| PV panel, battery | Power Supply | Yes | Yes |
| Weather proof control cabinet | Accessory | Yes | Yes |
| Grounding and lightning protection kit | Accessory | Yes | Yes |
| Mounting material, casing, cabling and other accessories required | Accessory | Yes | Yes |
| Wind Vane | Wind Direction | Yes | Yes |

Table 3.4: Technical parameters of instruments considered for Tier 1 solar measuring station according to ToR specifications.

| Instrument | Parameter | Technical specifications for Tier 1 meteo station | | | | |
|---|---|---|---|---|---|---|
| | | Range | Resolution | Accuracy | Response Time | Calibration |
| Thermopile Pyranometer (ISO 9060 Sec. Std.with heating) | Global Horizontal Irradiance (GHI) | 0.3 - 2.8 μm, -40 to + 80°C | 7 to 15 $\mu V/W/m^2$ | <2% daily uncertainty | ≤ 5 s | Yes |
| Thermopile Pyranometer - Secondary Standard according to ISO 9060 | Diffuse Horizontal Irradiance | 0.3 μm to 2.8 μm, -40 to + 80°C | 7 to 15 μV/W/m2 | <2% daily uncertainty | ≤ 5s | Yes |
| Thermopile Pyrheliometer - First Class according to ISO 9060 | Direct Normal Irradiance | 200 to 4000 nm, -40 to + 80°C | 7 to 15 μV/W/m2 | 1% daily uncertainty | ≤ 5s | Yes |
| 2-axis Solar Tracker with Sun Sensor | Accessory | -20 to + 50°C | GPS controlled with sun sensor | 0.02° | - | N.A. |
| Ambient Temperature and Relative Humidity Sensor encased in radiation shield | Air Temperature | -40 to + 70°C | 0.01°C | ±0.5°C | <120s | Yes |
| | Relative Humidity | 0 to 100% RH | 0.05% | ±3%: 10% to 90% RH | <10s | Yes |
| Pressure Sensor | Barometric Pressure | 400 to 1100 hPa | - | ±1.5 hPa | 15ms | Yes |
| Anemometer | Wind Speed | 1 to 96 m/s | 0.25 m | ± 0.3 m/s < 10 m/s | - | Yes |
| Datalogger with memory for storing up to 3 months data | Datalogger | - | - | - | - | Yes |
| GPRS Modem | Communication | - | - | - | - | N.A. |
| PV panel | Power Supply | ≥ 60 Wp | - | - | - | N.A. |
| 2 redundant batteries | Power Supply | each ≥15 Ah | - | - | - | N.A. |
| Weather proof control cabinet | Accessory | - | - | - | - | N.A. |
| Lightning protection kit | Accessory | - | - | - | - | N.A. |
| Mounting material, tripod, 3 m wind mast, casing, cabling & other accessories | Accessory | - | - | - | - | N.A. |

Table 3.5: Technical parameters of instruments considered for Tier 2 solar measuring station

| Instrument | Parameter | Technical specifications for Tier 2 meteo station | | | | |
|---|---|---|---|---|---|---|
| | | Range | Resolution | Accuracy | Response Time | Calibration |
| Thermopile Pyranometer (ISO 9060 Sec. Std. with heating) | Global Horizontal Irradiance (GHI) | 0.3 - 2.8 µm, -40 to + 80°C | 7 to 15 $\mu V/W/m^2$ | <2% daily uncertainty | ≤ 5 s | Yes |
| Rotating Shadowband Radiometer | GHI, DHI, DNI | 0.3 - 1.1 µm, -40 to + 80°C | | DNI <2% for annual values with long-term outdoor calibration | | Yes |
| Ambient Temperature and Relative Humidity Sensor encased in radiation shield | Air Temperature | -40 to + 70°C | 0.01°C | ±0.5°C | <120s | Yes |
| Pressure Sensor | Relative Humidity | 0 to 100% RH | 0.05% | ±3%: 10% to 90% RH | <10s | Yes |
| | Barometric Pressure | 400 to 1100 hPa | - | ±1.5 hPa | 15ms | Yes |
| Anemometer | Wind Speed | 1 to 96 m/s | 0.25 m | ± 0.3 m/s < 10 m/s | - | Yes |
| Datalogger with memory for storing up to 3 months data | Datalogger | - | - | - | - | Yes |
| GPRS Modem | Communication | - | - | - | - | N.A. |
| PV panel | Power Supply | ≥ 60 Wp | - | - | - | N.A. |
| 2 redundant batteries | Power Supply | each ≥15 Ah | - | - | - | N.A. |
| Weather proof control cabinet | Accessory | - | - | - | - | N.A. |
| Lightning protection kit | Accessory | - | - | - | - | N.A. |
| Mounting material, tripod, 3 m wind mast, casing, cabling & other accessories | Accessory | - | - | - | - | N.A. |

# 4 IMPLEMENTATION OF PHASE 2

Based on the information presented in Chapter 3 and after having multiple discussions with the partners and the project team, a short list of four (4) sites is proposed. These sites are essentially the sites with the highest ranking. Final decision on the actual position of each site will be made at the start of Phase 2.

In the ESMAP ToR, it is suggested to install 4 Tier 2 (RSR) stations at 4 sites in Maldives. However, having learned from the analysis of existing solar measurements in a broader region (see *Model Validation report 129-02/2015*), we **recommend installing one Tier 1 station on Maldives**. Therefore, in this report, **we propose that the choice is made as follows**, preferably installed at the existing meteo sites operated by Maldivian Meteorological Service:

- 1x Tier 1 meteo station, installed at the Hulhulé airport
- 3x Tier 2 meteo stations, installed at the Hanimaadhoo, Kadhdhoo and Gan airports

At present accurate long term solar measurements are not available for Maldives, except for data from a very short measuring campaign run at the ARM meteo station at the Gan Island. There is another possibility of having access to solar radiation data measured at the Atmospheric Observatory in Hanimaadhoo Island, if successfully negotiated. However there is little known about quality of these measurements.

**This project provides a unique opportunity to set-up systematic high-precision solar measurements from a well-maintained Tier 1 station, which is missing in the broader region.**

Based on these findings, and on validation of ground-measured data available in similar tropical conditions, the following has to be considered for a successful Phase 2 measuring campaign:

- Model validation data must come from high accuracy instruments; technical description of instruments and information on their calibration status must be available.
- The equipment must be diligently maintained, and regular cleaning of sensors must be applied. Data cleaning should be systematic and logged.
- Redundant sensors have to be used for rigorous quality control: for example diffuse (DIF) measurements in addition to GHI and DNI) or two sensors measuring GHI.
- Data should be quality checked on a continuous basis and erroneous values should be flagged to avoid use of data, not passing through QC, in validation and/or calibration of models.
- Regular scheduled visits on the station every few months could prevent common issues such a tracker misalignment, sensor levelling, PV power supply or battery.

## 4.1 Short list of solar measuring stations

Figure 3.1 shows distribution of the long-listed sites. For a good representation of the climate of Maldives, the first goal is that the planned sites are to be geographically well distributed across the country. The airport premises seem to be the best option:

- Gan airport is a natural choice to represent the very South.
- Hanimaadhoo is the natural choice for the northern site. Figure 2.5 shows that North is slightly affected by aerosols, and thus having a meteo station there is especially useful. In Hanimaadhoo, the choice has to be made between the airport and the observatory site. As all other sites are going to be located at the premises of MMS at the airports, it can be considered to have also the Hanimaadhoo meteo station operated the MMS at the airport. In such a case the position of the instruments would be compatible – at the same type of mast at standard height above ground (while at MCAO it would have to be erected at the top of approximately 12-m high tower). However there is a unique opportunity, for the same budget, to upgrade the instrumentation of the Observatory to re-start operation at the level of Tier 1 station.
- The proposed location for other two sites is Hulhulé and Kadhdhoo airports in the central part of the archipelago. Hulhulé site is propose to be equipped by Tier 1 equipment.

To best fit the goals of the project the short-listed sites are proposed in Table 4.1 and Figure 4.1. Besides the good geographic distribution, this choice also fits very well to the population centres, where larger solar installations will be deployed. Having a solar measurement station there will be beneficial for financing the power plants nearby.

For more details about proposed upgrades, read Chapter 4.3.

Table 4.1: Proposed short list of solar measuring stations

| ID | Site name | Existing meteo station | Personnel on site | Individual rank |
|---|---|---|---|---|
| MVHAQ | Hanimaadhoo airport | Yes | Yes | 1 |
| MVMLE | Hulhulé airport | Yes | Yes | 1 |
| MVKDO | Kadhdhoo airport | Yes | Yes | 1 |
| MVGAN | Gan airport | Yes | Yes | 1 |
| MVHAO | Hanimaadhoo Observatory | Yes | Yes | 2 |
| MVKDM | Kaadedhdhoo | Yes | Yes | 2 |
| MVGKK | Kooddoo | No | No | 3 |
| MVDRV | Dharavandhoo | Yes automatic | No | 3 |
| MVVAM | Maamingili | No | No | 4 |
| MVTMF | Thimarafushi | No | No | 4 |

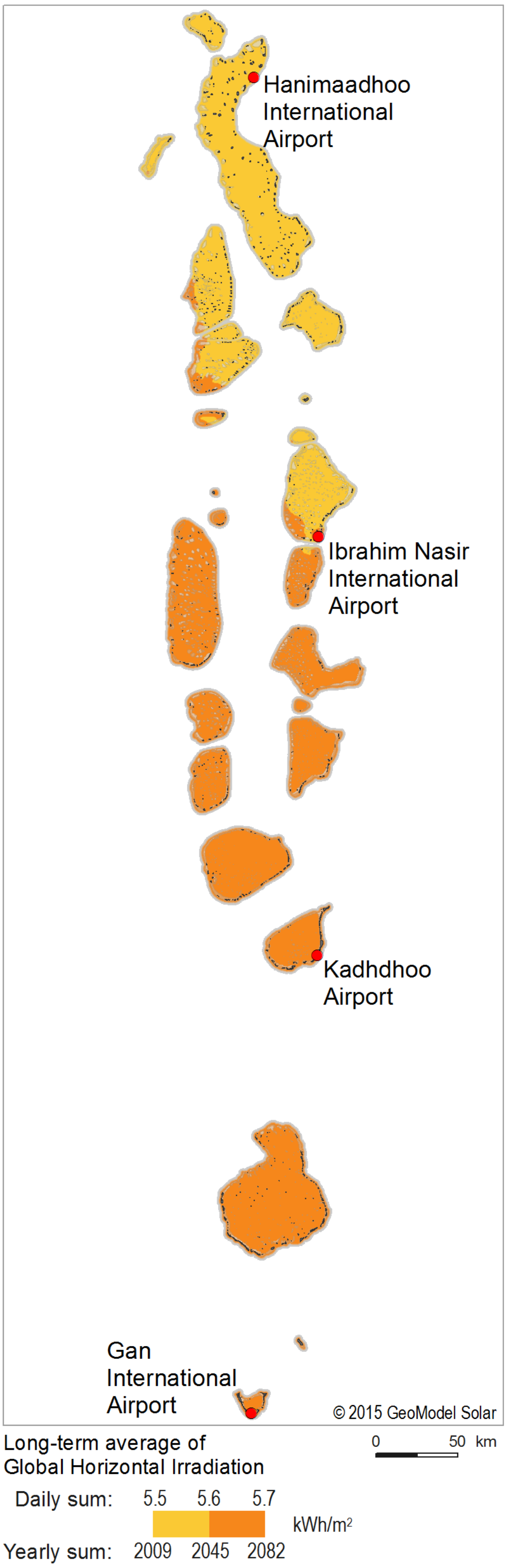


Figure 4.1: Position of proposed short-listed candidate sites

## 4.2 Description of proposed short-listed sites

The selected sites, proposed for the installation of solar radiation measurement stations, are briefly described below.

### 4.2.1 Site 1: Hanimaadhoo airport (MVHAQ)

**Site location**: Airport at Hanimaadhoo Island, Haa Dhaalu Atoll.

**Owner of the MVHAQ site**: Maldives Meteorological Service

**Proposed type of meteo station**: Tier 2 (please see the proposed option)

| Site | Latitude | Longitude | Elevation |
|---|---|---|---|
| Hanimaadhoo | 6.7482° | 73.1696° | 2 m |

**Description**: This site is located in the North of Maldives and the proposed location would be a meteo site at the airport (standard option). It already has a meteo station operated by MMS. An advantage of using data from this station is that there is already some historical data available. The presence of manpower at the airport to operate and maintain the station is also beneficial for the operation of the station.

However, **we propose to consider an enhanced option.** As explained in Chapter 4.3, we propose an option of refurbishing equipment managed by the local Observatory, which would make it possible to re-start operation of the Tier 1 grade equipment at comparable costs as is an installation of a Tier 2 station.

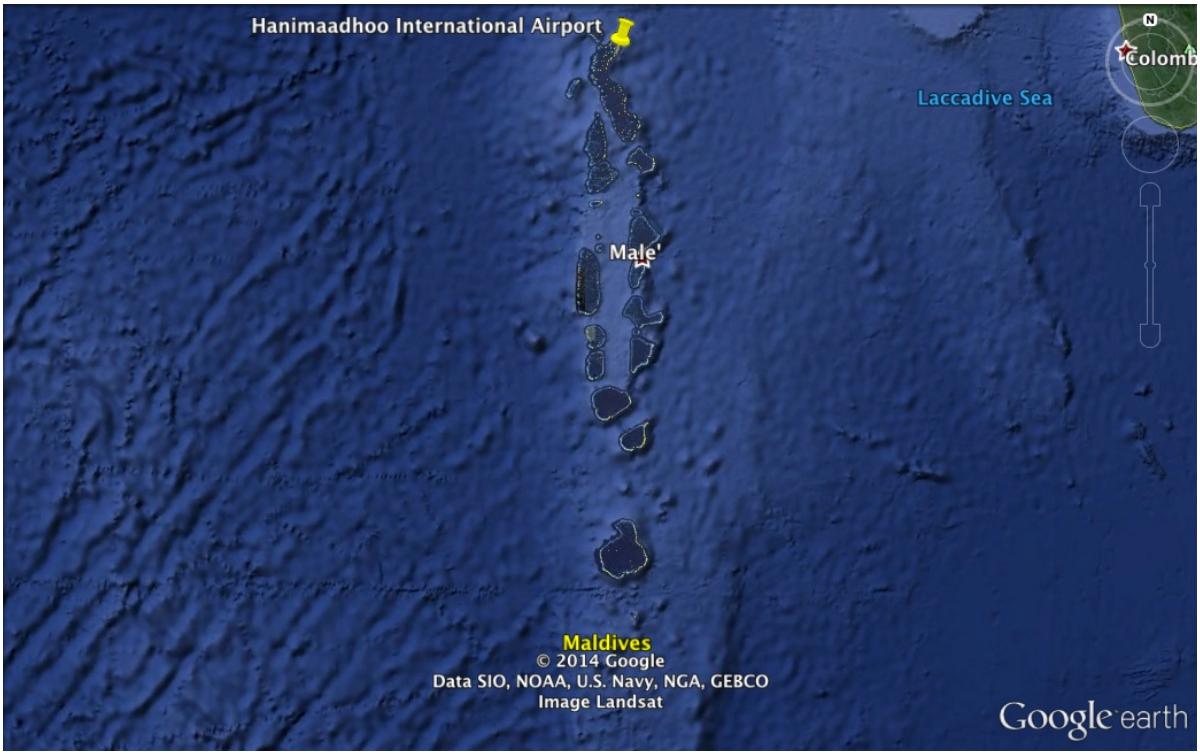


Figure 4.2: Location of site MVHAQ within Maldives (Google satellite map)


Figure 4.3: Location of site MVHAQ on the selected island (Google satellite map)

### 4.2.2 Site 2: Hulhulé (MVMLE)

**Site location**: Ibrahim Nasir international airport at Hulhulé Island, North Malé (Kaafu) Atoll

**Owner of the MVMLE site**: Maldives Meteorological Service

**Proposed type of meteo station**: Tier 1

| Site | Latitude | Longitude | Elevation |
|---|---|---|---|
| Hulhulé | 4.1927° | 73.5281° | 2 m |

**Description**: This site is located at the international airport, serving Malé, which is the most populated city in Maldives. The site is located in the mid-Maldives eastern islands. The position is proposed at the site of existing meteorological station, which is operated by the Maldives Meteorological Service. The presence of manpower at the airport to maintain the equipment is also beneficial for the operation of the station. In the islands around, there is a high potential for the development of larger solar power plants.

We suggest installation of Tier 1 station in this site.

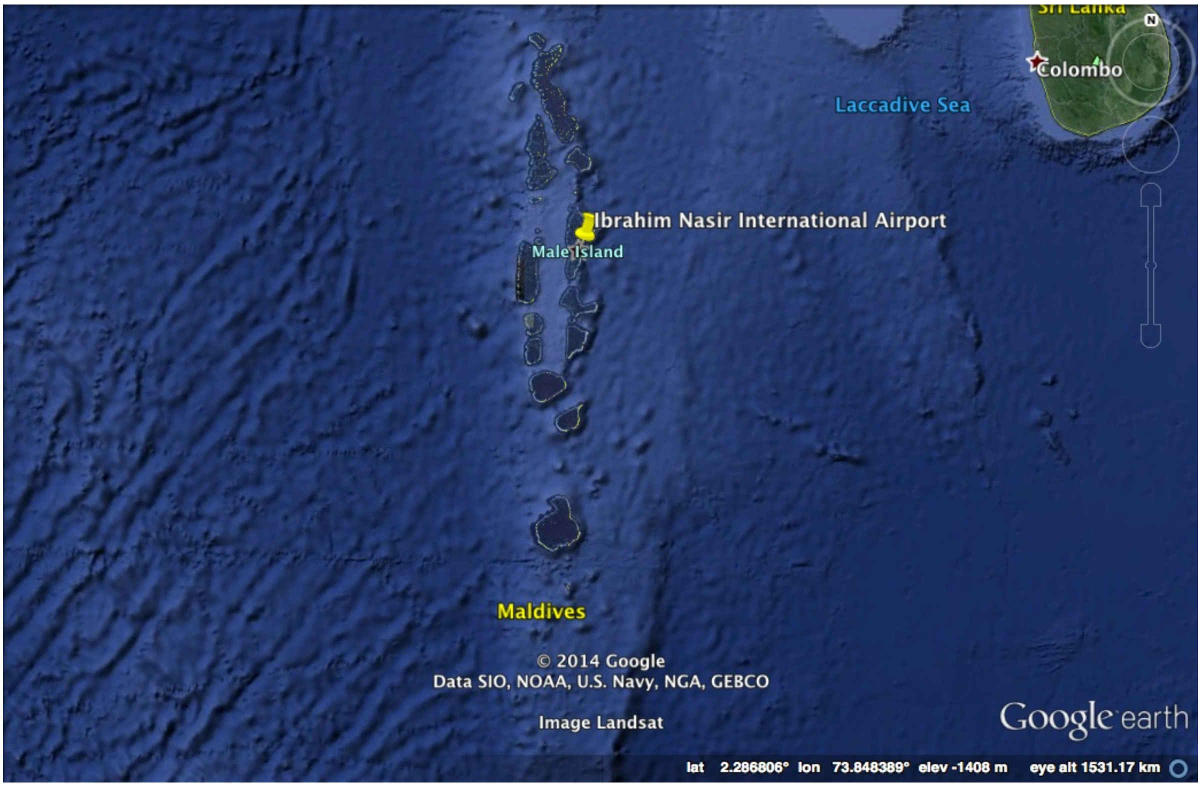


Figure 4.4: Location of site MVMLE within Maldives (Google satellite map)


Figure 4.5: Location of site MVMLE on the selected island (Google satellite map)

### 4.2.3 Site 3: Kadhdhoo airport (MVKDO)

**Site location**: Airport at Kadhdhoo Island, Laamu Atoll.

**Owner of the MVKDO site:** Maldives Meteorological Service

**Proposed type of meteo station**: Tier 2

| Site | Latitude | Longitude | Elevation |
|---|---|---|---|
| Kadhdhoo | 1.8599° | 73.5203° | 2 m |

**Description**: This site is located in the south eastern atoll chain at island Kadhdhoo. This site is also proposed to be located at the premises of MMS at the airport. The presence of manpower at the airport to operate and maintain the station is also beneficial for the operation of the station.

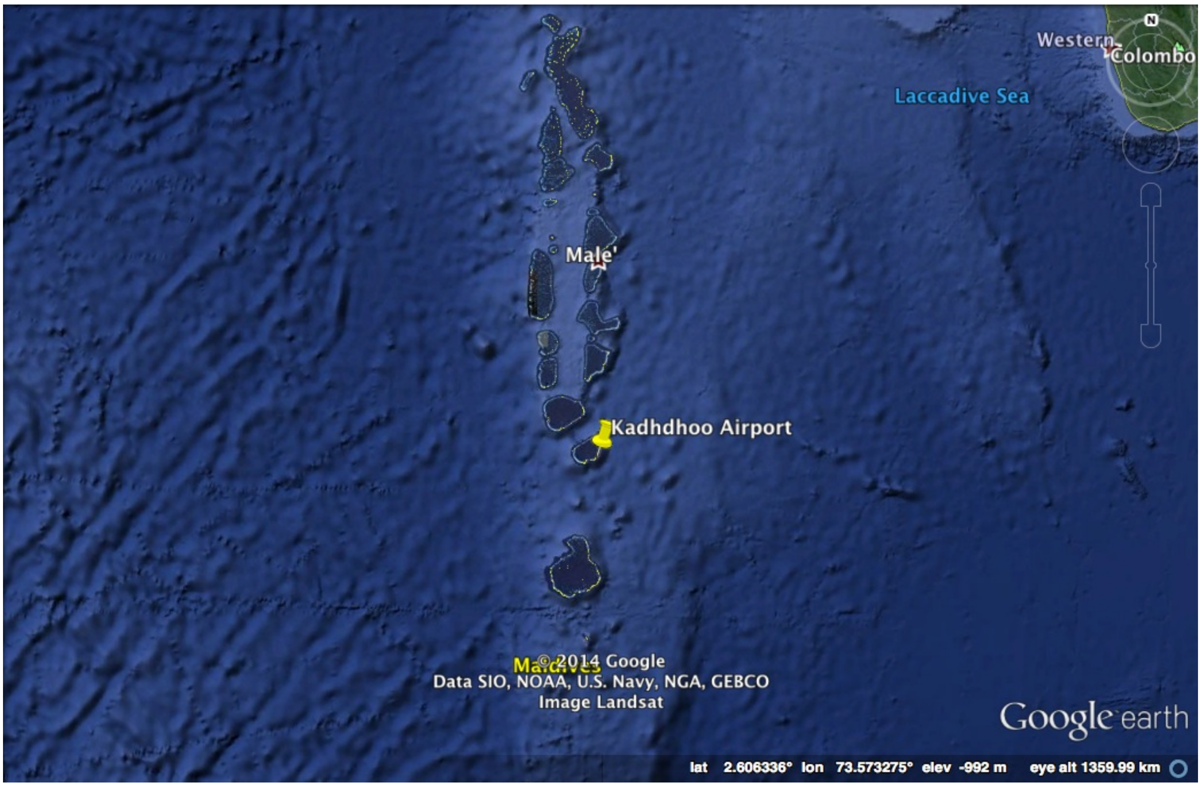


Figure 4.6: Location of site MVKDO within Maldives (Google satellite map)


Figure 4.7: Location of site MVKDO on the selected island (Google satellite map)

### 4.2.4 Site 4: Gan International airport (MVGAN)

**Site location**: Airport at Gan Island, Addu (Seenu) Atoll

**Owner of the MVGAN site**: Maldives Meteorological Service

**Proposed type of meteo station**: Tier 2

| Site | Latitude | Longitude | Elevation |
|---|---|---|---|
| Gan | -0.6906° | 73.1599° | 2 m |

**Description**: This airport is the only airport South of equator in the Maldives. Moreover, this airport is easily accessible with frequent flights to and from Malé. Gan is also one of the most populated cities in Maldives. Hence, there is also good potential for the development of solar power plants at or near this island. The presence of manpower at the airport to operate and maintain the station is also beneficial for the operation of the station.

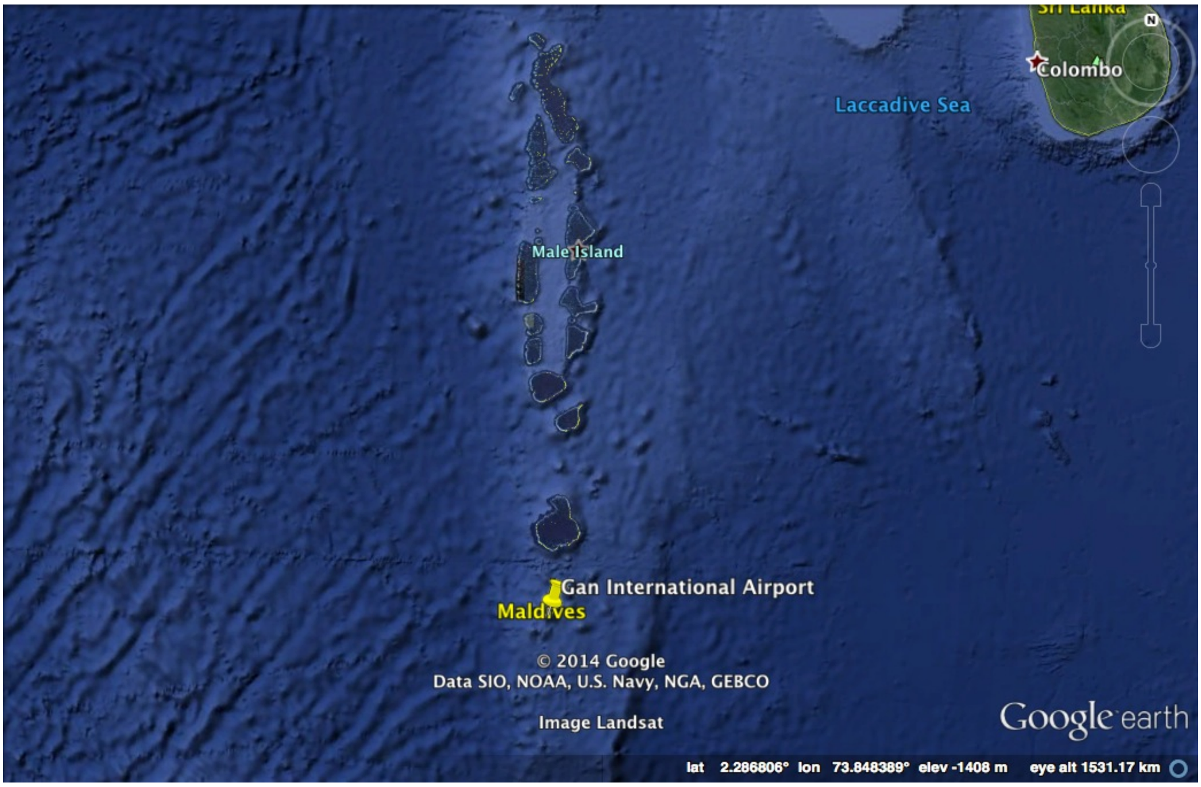


Figure 4.8: Location of site MVGAN within Maldives (Google satellite map)


Figure 4.9: Location of site MVGAN on the selected island (Google satellite map)

## 4.3 Options for the layout of the solar radiation stations

The original plan for this project foresaw only stations of Tier 2 type. This is a good choice of robust instruments, which are expected to provide reliable results for GHI, DIF and DNI. However, Tier 2 stations are missing an ISO9060 First Class pyrheliometer, which is the key instrument to allow for local re-calibration of all other applied solar radiation instruments. Such an instrument together with a solar tracker is only available at Tier 1 stations.

First, precise instruments at Tier 1 would allow to more adapt the solar models more accurately and with higher reliability. Second, the Tier 1 instruments would allow for regional re-calibration of other instruments.

Pyrheliometers are the commercial solar radiation measurement instruments, which show highest absolute accuracy. The procedure for highly precise calibration recommended by WMO is to calibrate pyranometers using a pyrheliometer as described in ISO 9846[1]. Such outdoor calibrations are even better than most factory calibrations as applied today by instrument suppliers. Having freshly calibrated pyranometers on the Tier 1 stations with a shaded and un-shaded pyranometer together with the pyrheliometer would allow local recalibration of the RSI-type instruments of the Tier 2 stations.

As such re-calibration is required at least every second year and shipping all instruments to foreign calibration sites might be too expensive and time consuming, it is highly recommended that one station on the Maldives is upgraded to a Tier 1 station. The station operators should receive sufficient training to execute the recalibrations in the future.

To reach this goal either Option 1 or Option 2, as described in the following, section should be realized.

Option 3 of adding an Absolute Cavity Radiometer (ACR) would give the Tier 1 station even greater credibility. Option 4 of upgrading the wind masts from only 3 m height to 10 m would allow more representative wind measurements.

### 4.3.1 Option 1: Upgrade of MVMLE station at Hulhulé Airport to Tier 1 accuracy

According to the original plans, given in the ESMAP ToR, the proposed meteo site in Hulhulé airport (MVMLE) would be only equipped by Tier 2 station. Here we propose to consider installing Tier 1 station with-higher accuracy instruments.

Upgrade from Tier 2 to Tier 1 would help receiving data at highest possible quality, which are needed for calibration of satellite-based solar models. At the MVMLE site, which is directly located at the Head Office of the Maldives Met Service we expect that the staff if highly motivated to do the required daily cleaning. Also the staff employed there should be capable of performing calibration, which Suntrace will train them to do, so that the project can be sustained on a high quality level even beyond the first 2 years.

### 4.3.2 Option 2: Refurbishing MCOH observatory solar radiation equipment

In case there are budget constraints, an alternative to upgrading the MVMLE at Malé airport from a Tier 2 to Tier 1 station, there is the option to support the Maldives Climate Observatory Hanimaadhoo (MCOH) in re-furbishing the already existing solar radiation equipment. The existing instrumentation is of the same or better accuracy than the proposed Tier 1 station. But the solar tracker needs repair, the data logger needs to be replaced, and at least one pyrheliometer needs to be freshly calibrated to re-calibrate the remaining instruments following the ISO codes.

The hardware costs for this refurbishment are estimated to be in the range of USD 10,000 to 25,000 and thus expected to be cheaper than upgrading the station at Hulhulé from Tier 2 to Tier 1.

The high-precision station at Hanimaadhoo is being operated by a team of scientists. MCOH is permanently staffed by a local Maldivian technician and by a resident scientist. The costs for the resident scientist and the operational (utilities and much of upkeep) is covered by MCOH-active scientists.

[1] ISO 9846 (1993), Solar energy -- Calibration of a pyranometer using a pyrheliometer. Standard of the International Organization for Standardization (ISO),

MCOH is well equipped for aerosol physics and chemistry studies and also has the equipment for measurement of solar radiation. The solar radiation instruments available at this station are of the highest quality. The solar radiation data (global horizontal, direct normal and diffuse horizontal irradiance) shall be available for the entire period from Oct 2004 to Dec 2012.

The site and the instruments at Hanimaadhoo Observatory can be used for this project as there is an in-principle approval from the director of the Hanimaadhoo Observatory.

The advantage of upgrading this station to the Tier 1 is the observatory already has the historical data, which would better help understanding the characteristics of solar radiation and the parameters influencing it. The presence of highly qualified scientists at the Observatory would ensure proper operation and maintenance of the stations. The scientists at MCOH have offered to maintain the station on a daily basis. Moreover, this high precision Tier 1 station can be used for local recalibration of solar radiation sensors from other stations.

**In return, the scientists at MCOH would like to have an access the measured data at the Hanimaadhoo Observatory.**

Details regarding the ownership of the sensors, site and the data need to be discussed further together with WB and Hanimaadhoo Observatory. Refurbishing the MCOH station to a Tier 1 station would involve marginally higher costs than installing a Tier 2 station. Hence, we recommend refurbishing the station at MCOH to a Tier 1 station instead of installing a Tier 2 station at Hanimaadhoo airport.

### 4.3.3 Option 3: Adding an absolute cavity radiometer to the Tier 1 station

The “gold meter” of solar radiation instrumentation are special sorts of pyrheliometers called Absolute Cavity Radiometers (ACR). These highly stable instruments are capable of measuring DNI with 0.1 % absolute accuracy. Therefore, ACR instruments are mandatory for BSRN solar radiation stations to allow direct inter-calibration to the world radiation reference situated at the World Radiation Center (WRC) at Davos, Switzerland. By having at least one of such instruments the calibration station would only require that the ACR is participating at an international pyrheliometer Inter-comparison campaign every 5$^{th}$ year. Otherwise one of the two usual pyrheliometers must be recalibrated at least every second year abroad.

### 4.3.4 Option 4: Upgrading wind masts from 3 m to 10 m height

The original proposal asked for wind measurements at only 3-meters height. This height is well representative for many solar panel installations. However, measuring wind at 3 m height is usually not recommended because the wind field at this height is strongly influenced by turbulences and slowed down by nearby obstacles. Therefore, WMO recommends representative near-surface wind measurements at a height of 10 m. The station supplier of the solar radiation measurement stations is also highly experienced in wind measurements and could supply a 10 m mast instead of a 3 m mast for a small additional amount. Best solution and still economic with partial redundancy for wind speed checks would be to have anemometer and wind vane at 10 m and a second anemometer installed at 3 m height. This would also enable to inter-connect readings at 10 m and at 3 m and give some hints on the local wind shear.

## 4.4 Reasons for realizing the Phase 2 of the project

Economically and technically effective solar electricity projects require representative and accurate DNI and GHI time series. Satellite-derived databases are used to describe long-term solar resource for a specific site. However, their problem when compared to the ground measurements may be a higher bias (systematic deviation) and partial disagreement of frequency distribution functions (which limits their potential to record the occurrence of extreme situations, e.g. very low atmospheric turbidity resulting in a high DNI).

At present, there are no active measurements of solar radiation in Maldives. Installation of solar meteorological stations has several benefits:

- Improved knowledge of solar radiation, in terms of absolute values and also the patterns of geographical and temporal variability,

- More accurate estimate help to reduce costs in the planning (technical design) and financing of solar power generation capacities.

From the perspective of the regional adaptation of the solar model, ground measurements are correlated with satellite-derived data to improve the accuracy of the time series computed by the solar model. For achieving robust results, ground-based measurements from several locations in the regions are needed.

The correlation of satellite-derived data with ground measurement data will lead to (i) reduction of bias of the model, and (ii) improved fit of the frequency distribution function high-frequency values. For model adaptation, ground measurements should be available for a period of at least one year, optimally two years.

We propose to invest into installing of at least one Tier 1 measuring station (with high-accuracy instrumentation), out of originally planed four Tier 2 measuring stations:

- Tier 1 station make it possible to re-calibrate the SolarGIS satellite-based solar model with higher accuracy
- Robustness of the SolarGIS model calibration is higher for Tier 1 measurements as there is better redundancy of measurements needed for quality control
- Tier 1 instruments (pyrheliometer) can help in regular re-calibration of Tier 2 instruments located at other measuring stations.

Table 4.2: Expected SolarGIS model uncertainty for annual DNI and GHI estimates
Comparison of original SolarGIS uncertainty to theoretical (laboratory) uncertainty of the instruments, and achievable uncertainty of the SolarGIS model after first and second years of measurements.

| | | Instruments | SolarGIS | SolarGIS adapted [%] | |
|---|---|---|---|---|---|
| | | (theoretical) | original | at year 1 | at year 2 |
| DNI | First class pyrheliometer | 1.0% | 12.0% | 5.0 – 6.0 | 4.0 – 5.0 |
| GHI | Secondary standard pyranometer | 2.0% | 6.0% | 3.0 – 4.0 | 2.5 – 3.5 |
| DNI | RSR | 4.0% | 12.0% | 6.5 – 8.0 | 5.0 – 6.0 |
| GHI | RSR | 3.5% | 6.0% | 4.0 – 4.5 | 3.5 – 4.0 |

## 4.5 Proposal for implementation of Phase 2

Our proposal for implementation of Phase 2 follows our methodology described in the offer. We primarily foresee the following tasks to be carried out in a sequential order. The main tasks:

- Task 2.1: Final site selection and Phase 2 Implementation Plan
- Task 2.2: Procurement and installation of solar radiation met stations and site installation reports
- Task 2.3: Operation and maintenance
- Task 2.4: Data quality control and delivery
- Task 2.5: Training and capacity building
- Task 2.6: Annual Site Resource Report after 12 months
- Task 2.7: Annual Site Resource Report after 24 ,months

Assuming that the Phase 2 would commence in March 2015, the site selection and Phase 2 Implementation Plan would be finished in April 2015.

The procurement of the solar radiation measurement stations shall start in March 2015, and we expect to complete the installation and commission all the 4 stations latest by July 2015.

The first annual site resource report shall be delivered by July 2016, whereas the second annual site resource report would be delivered by July 2017.

## 4.6 Recommendations for site layout

For proper installation, operation and maintenance of the stations over a longer period it is necessary to have proper foundation on which the station would be installed. It is also to be considered to cordon the area where the station would be installed with fencing to prevent disturbing/damaging the station. For the installation of Tier 2 stations with wind speed measurement, we recommend to prepare a foundation that is ca. 6 m x 10 m in size. An example of one such foundation is shown in Figure 4.10.

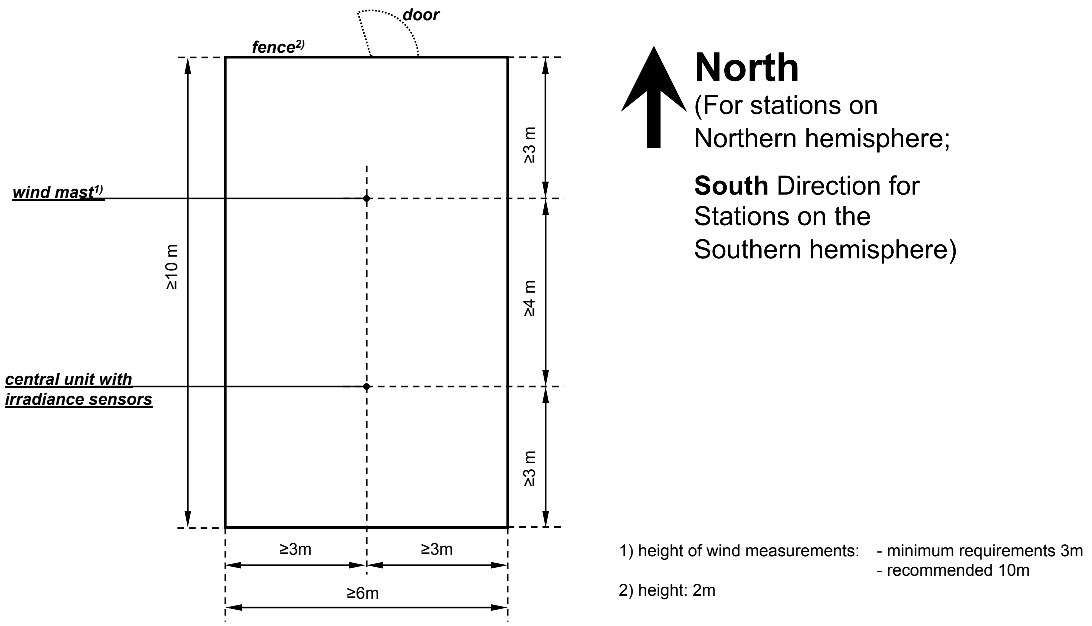


Figure 4.10: Recommendation for fencing of Tier 2 meteorological stations with wind measurements

For the installation of Tier 2 stations without wind speed measurements, an area of ca. 7 m x 6 m is required as can be seen in Figure 4.11. Implementation plan will consider the actual situation of the existing met station and fit in where the main requirement of a free horizon fits best.

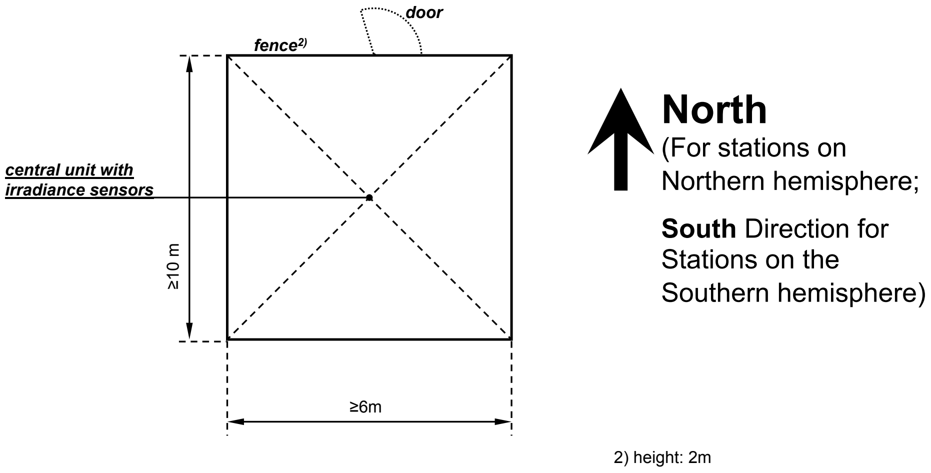


Figure 4.11: Recommendation for fencing of Tier 2 meteorological measurement station without wind measurements.

It is to be noted that for upgrading from a Tier 2 station to a Tier 1 station, the area required would not be more than 10 m x 10 m. Due to the compact design of our Tier 1 stations, the actual area required are less than 10 m x 10 m. Implementation plan will consider the actual situation of the existing met station and fit in where the main requirement of a free horizon fits best.

## 4.7 Next steps

We recommend that in time of workshop presenting the Phase 1 results, we hold discussions with all stakeholders (World Bank. Ministry of Energy and Environment, Maldives Meteorological Service, etc.) for the implementation of Phase 2. We will update our financial and technical proposals for the implementation of Phase 2 based on the discussions above.

The Contractor along with its sub-contractor and the local partner shall present their approach, methodology and a tentative time schedule to the World Bank at the workshop. Other topics to be discussed at the workshop include the ownership of the stations, their insurance during the operation and maintenance period of 2 years, calibration after a period of 2 years and final transfer to a local institute.

# 5 LIST OF FIGURES

# 6 LIST OF TABLES

# 7 CONSULTANTS

## 7.1 Lead contractor: GeoModel Solar

Primary business of GeoModel Solar is in providing support to the site qualification, planning, financing and operation of solar energy systems. We are committed to increase efficiency and reliability of solar technology by expert consultancy and access to our databases and customer-oriented services.

The Company builds on more than 25 years of expertise in geoinformatics and environmental modelling, and more than 15 years in solar energy and photovoltaics. We strive for development and operation of new generation high-resolution quality-assessed global databases with focus on solar resource and energy-related weather parameters. We are developing simulation, management and control tools, map products, and services for fast access to high quality information needed for system planning, performance assessment, forecasting and management of distributed power generation.

Members of the team have long-term experience in R&D and are active in the activities of International Energy Agency, Solar Heating and Cooling Program, Task 46 Solar Resource Assessment and Forecasting.

GeoModel Solar operates a set of online services, integrated within SolarGIS® information system, which includes data, maps, software, and geoinformation services for solar energy.

See more at http://geomodelsolar.eu and http://solargis.info

ISO 9001
LL-C (Certification)

GeoModel Solar is ISO 9001:2008 certified company for quality management since 2011.

## 7.2 Subcontractor: Suntrace

Suntrace was established in 2009 in Hamburg, Germany, as a company specialized on larg scale solar power plants. It gives expert advice for the growing solar energy activities in emerging solar markets from the Middle East, African countries to Latin America, but also in Asia, especially India.

Our advisory mandates cover measurement of solar radiation, solar resource assessments of project sites, technical concepts, performance analysis, lenders engineering, owners engineering, feasibility studies, financial advisory for project finance of large solar plants, etc. Our services also include strategic market intelligence, knowledge regarding main equipment manufacturers and local capacity building. Suntrace' success in providing its expertise and services in many countries of the world is achieved by associating with local companies, who have the local market experience and knowledge and Suntrace brings its international experience and domain-specific expertise.

For design, manufacturing and distribution of solar energy specific meteorological measurement stations Suntrace has established a collaboration with the Hamburg based company Wilmers Messtechnik GmbH. Since 1991 Wilmers develops and produces data loggers, and turnkey measurement systems for wind site assessment, climate research and meteorological observations. Under the brand HelioScale Wilmers and Suntrace market their solar radiation measurement stations.

See more at http://www.suntrace.de and http://www.helioscale.com

## 7.3 Local partner: Renewable Energy Maldives

Renewable Energy Maldives (REM) was formed in 2007 with the mission of reducing Maldives' over reliance on fossil fuel for its energy needs. REM is a company engaged in the development of renewable energy and energy efficiency projects in the Republic of Maldives.

The focus of REM is on renewable energy, energy efficient equipment particularly cooling technology, designing and building energy efficient electric boats and energy management programs tailored to a client's needs.

REM formed a joint venture company, Wirsol RE Maldives (WREM), with WIRSOL APAC GmbH, Germany, which is a 100% subsidiary of WIRSOL Solar AG, Germany, to strengthen the company's' capacity to deliver viable Solar PV projects. Under this joint venture REM has installed more than 700 kW solar PV projects until 2013. REM continues to undertake small solar PV projects for private and government as well as donor funded projects in the Maldives.

See more at http://www.renewableenergymaldives.com.mv