Solargis Technical Report

Solar resource raster GIS data
New Zealand

Reference No.: **990-26/2019**
Date: **3 July 2019**

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ACRONYMS

CFSR	Climate Forecast System Reanalysis. The meteorological model operated by the US service NOAA (National Oceanic and Atmospheric Administration)
CFSv2	Climate Forecast System Version 2. CFSv2 model is the operational extension of the CFSR (NOAA)
ERA5	Climate reanalysis dataset produced by European Centre for Medium Range Weather Forecasts (ECMWF), providing atmospheric, land-surface and sea-state parameters with estimates of uncertainty.
DIF	Diffuse horizontal irradiation, if integrated solar energy is assumed. Diffuse horizontal irradiance, if solar power values are discussed
DNI	Direct normal irradiation, if integrated solar energy is assumed. Direct normal irradiance, if solar power values are discussed.
GFS	Global Forecast System. Meteorological model operated by the US service NOAA
GHI	Global Horizontal Irradiation, if integrated solar energy is assumed. Global Horizontal Irradiance, if solar power values are discussed.
GTI	Global Tilted Irradiation impinging to the plane of photovoltaic modules defined by the tilt and azimuth.
Himawari 8	Geostationary weather satellite operated by the Cambodia Meteorological Agency (JMA), operational since the year 2017
MACC	Monitoring Atmospheric Composition and Climate. Meteorological model operated by the European service ECMWF (European Centre for Medium-Range Weather Forecasts)
MTSAT 2	Multifunctional Transport Satellite operated by Japan Meteorological Agency (JMA), also known as Himawari 7, positioned at 145° East
PVOUT	Photovoltaic electricity output calculated from solar resource and air temperature time series
TEMP	Air temperature at 2 metres

1 DESCRIPTION OF DATA DELIVERY

This technical report has been elaborated as a part of GIS data delivery of solar resource, photovoltaic power potential and air temperature data for New Zealand (Tab 1.1).

Provided GIS data include raster data layers of:

- PVOUT: Photovoltaic Electricity Output [kWh/kWp]
- GHI: Global horizontal irradiation [kWh/m^2]
- DNI: Direct Normal Irradiation [kWh/m^2]
- GTI: Global Tilted Irradiation at optimum angle [kWh/m^2]
- DIF: Diffuse horizontal irradiation [kWh/m^2]
- OPTA: Optimum angle for GTI [º]
- TEMP: Temperature at 2 meters [ºC]

presented as

- Long-term average of yearly totals
- Long-term average of monthly totals

Solar and PVOUT parameters are available for a period of recent 12 years (2007-2018), air temperature data for the recent 25 years (1994-2018). Data covers the land area of New Zealand, including approx. 20 km buffer zone along the coastline. Altogether 79 raster data layers are provided in the GeoTIFF format that is suitable for use in Geographical Information Systems (GIS), such as:

- Processing, analysing and querying in the region
- Spatial analysis and expertise with other data sources
- Creating custom maps or applications.

Metadata is delivered with the data files in two formats, according to ISO 19115:2003/19139 standards:

- PDF - human readable
- XML - for machine-to-machine communication

The solar radiation data are created by Solargis algorithms from original 10-minute and 30-minute time series of satellite images and auxiliary atmospheric datasets. Air temperature data are created by Solargis algorithms from original 60-minute meteorological model data. Data layers are projected to Geographical coordinate system (EPSG:4326).

Snapshots of the annual data layers are presented on the Fig. 4.1 to 4.7.

Tab. 1.1: Description of delivered data layer

Acronym	Description	Unit	No. of layers
GHI	Long-term average of yearly totals of global horizontal irradiation	kWh/m^2	1
DNI	Long-term average of yearly totals of direct normal irradiation	kWh/m^2	1
DIF	Long-term average of yearly totals of diffuse horizontal irradiation	kWh/m^2	1
GTI	Long-term average of yearly totals of global irradiation for optimally tilted surface	kWh/m^2	1
OPTA	Optimum tilt of PV modules to maximize the yearly yield	º	1
PVOUT	Photovoltaic power potential of a typical PV power plant with c-Si, ground mounted modules, optimally tilted towards the Equator	kWh/kWp	1
TEMP	Long-term average of air temperature at 2 m height above ground	ºC	1
GHI_MM	Long-term average of monthly totals of global horizontal irradiation	kWh/m^2	12
DNI_MM	Long-term average of monthly totals of direct normal irradiation	kWh/m^2	12
DIF_MM	Long-term average of monthly totals of diffuse horizontal irradiation	kWh/m^2	12
GTI_MM	Long-term average of monthly totals for global irradiation on optimally tilted surface	kWh/m^2	12
PVOUT_MM	Long-term average of monthly totals of photovoltaic power potential	kWh/kWp	12
TEMP_MM	Long-term monthly averages of air-temperature	ºC	12
	Total no. of layers		79

Notes: *MM* – Month of the year, presented as 2 digits (e.g. *01* = January, *02* = February … *12* = December)

Filename convention of data layers

Data layer filename is based on acronym (see Tab. 1.1).

Examples of data layer filenames:

- *GHI.tif* - GeoTIFF data layer with GHI long-term average of yearly sum values
- *GHI_01.tif* - GeoTIFF data layer with GHI long-term average of monthly sum values

Examples of metadata filenames:

- *GHI_01.tif.xml* – metadata for provided GeoTIFF data layer in XML format
- *GHI_01.tif.pdf* – human readable metadata for GeoTIFF data layer in PDF format

To avoid the excessive files' size, data is provided separately for the land on Eastern hemisphere and Western hemisphere. Data layers for each hemisphere are available in the subfolders:

- *east-hemisphere* – include data for New Zealand mainlands, Auckland Island, Cambell Island, Antipodes Islands
- *west-hemisphere* – include data for Chatham Island, Pitt Island and Kermadec Islands

Geographical coverage of the data

- Land territory New Zealand, including approx. 20 km buffer zone along the coastline towards the ocean
- Total area approx. 450 000 km^2

File format of the delivered data:

- GeoTIFF

Data layers coordinate system:

- EPSG:4326 (also known as GCS_WGS84, Geographical latitude/longitude map projection)

Spatial resolution of solar resource data (pixel size)

- Solar resource and PVOUT data: 9 arc-sec (0.0025°, nominally 250 m, approx. 275x280 m)
- TEMP: 30 arc-sec (0.0083333333°, nominally 1 km, approx. 925x930 m)
- OPTA: 2 arcmin (0.0333333333°, nominally 4 km, approx. 3700x3720 m)

Data value type

- Solar resource and PVOUT data: Float
- TEMP: Float
- OPTA: Integer

Temporal coverage of the data

- Solar resource and PVOUT: From 1 January 2007 to 31 December 2018 (12 years)
- Air temperature: From 1 January 1994 to 31 December 2018 (25 years)

Copyright notice

The delivered data are copyrighted by Solargis s.r.o. The copyright notice must be attached to data or derived products (like maps or analysis) and displayed in a suitable position.

Solar resource data © 2019 Solargis

2 SOLARGIS DATABASE

2.1 Satellite-derived solar radiation

Solargis is high-resolution global database of solar resource and meteorological parameters, operated by the company of the same name. Its geographical extent covers most of the land surface between latitudes 60º North and 55º South.

Solar radiation is calculated by numerical models, which are parameterized by a set of inputs characterizing the cloud transmittance, state of the atmosphere and terrain conditions. A comprehensive **overview of the Solargis model** is made available in the book publication [1]. The methodology is also described in [2, 3]. The related uncertainty and requirements for bankable data sets are discussed in [4, 5].

In Solargis approach, the **clear-sky irradiance** is calculated by the simplified SOLIS model [6]. This model allows fast calculation of clear-sky irradiance from the set of input parameters. Sun position is deterministic parameter, and it is described by the algorithms with satisfactory accuracy. Stochastic variability of clear-sky atmospheric conditions is determined by changing concentrations of atmospheric constituents, namely aerosols, water vapour and ozone. Global atmospheric data, representing these constituents, are routinely calculated by world atmospheric data centres:

- In Solargis, the new generation **aerosol data set** representing Atmospheric Optical Depth (AOD) is used. The core database is developed and regularly updated by MACC-II/CAMS project (ECMWF) [7, 8]), and delivered at a spatial resolution of approx. 75 km and 125 km. Important feature of the implemented database is that it captures daily variability of aerosols and allows simulating more precisely the events with extreme atmospheric load by aerosol particles. Thus, it reduces uncertainty of instantaneous estimates of GHI and especially DNI, and it improves the statistical distribution of solar irradiance values [9, 10]. For a period from 2007 to 2012 the reanalysis data set is used. The data representing years 2013-present is derived from the near-real time operational model. The Solargis calculation accuracy of the clear-sky irradiance is especially sensitive to the information on aerosols.
- **Water vapour** is also highly variable in space and time, but it has lower impact on the values of solar radiation, compared to aerosols. The GFS and CFSR values (© NOAA NCEP) are used in Solargis, representing the daily variability from 2007 to the present [11, 12, 13].
- **Ozone** absorbs solar radiation at wavelengths shorter than 0.3 µm, thus having negligible influence on the broadband solar radiation.

The **clouds** are the most influencing factor, modulating clear-sky irradiance. Effect of clouds is calculated from the satellite data in the form of cloud index (cloud transmittance). The cloud index is derived by relating irradiance recorded by the satellite in four spectral channels and surface albedo to the cloud optical properties. On the project site the Solargis is based on the MTSAT and HIMAWARI satellite data [14]. In Solargis, the modified calculation scheme by Cano has been adopted to retrieve cloud optical properties from the satellite data [15]. A number of improvements have been introduced to better cope with specific situations such as snow, ice, or high albedo areas (arid zones and deserts), and with complex terrain.

To calculate **all-sky irradiance** in each time step, the clear-sky global horizontal irradiance is coupled with cloud index.

Direct Normal Irradiance (DNI) is calculated from Global Horizontal Irradiance (GHI) using modified Dirindex model [16]. Diffuse irradiance for tilted surfaces, which is calculated by Perez model [17]. The calculation procedure also included terrain disaggregation model for enhancing spatial representation – from the satellite resolution to the resolution of digital terrain model (250 meters) [18].

Solargis model version 2.1 has been used for computing the data. Tab. 2.1 summarizes technical parameters of the model inputs and of the primary outputs.

Tab. 2.1: Input data used in Solargis solar radiation model and related GHI and DNI outputs

Inputs into the Solargis model	Source of input data	Time representation	Original time step	Approx. grid resolution
Cloud index	MTSAT 2 satellite Himawari 8 satellite (both JMA)	07/2006 to 2015 2016 to date	30 minutes 10 minutes	4.6 x 7.1 km 2.3 x 3.6 km
Atmospheric optical depth (aerosols)*	MACC-II/CAMS* (ECMWF)	2007 to date	3 hours (aggregated to daily)	75 km and 125 km
Water vapour	CFSR/GFS (NOAA)	01/2006 to date	1 hour (aggregated to daily)	35 and 55 km
Elevation and horizon	SRTM-3 (SRTM)	-	-	250 m
Solargis primary data outputs (GHI and DNI)	-	2006 to date	30 minutes	250 m

** Aerosol data for 2007-2012 come from the reanalysis database; the data representing years 2013-present are derived from near-real time (NRT) operational model*

Validation of solar data

Accuracy of Solargis data has been compared with high-quality solar measurements at 250+ public meteorological stations, distributed worldwide. Fig. 2.1 shows selected validation sites in the region. Tabs. 2.2 to 2.4 show the model quality indicators for DNI and GHI.

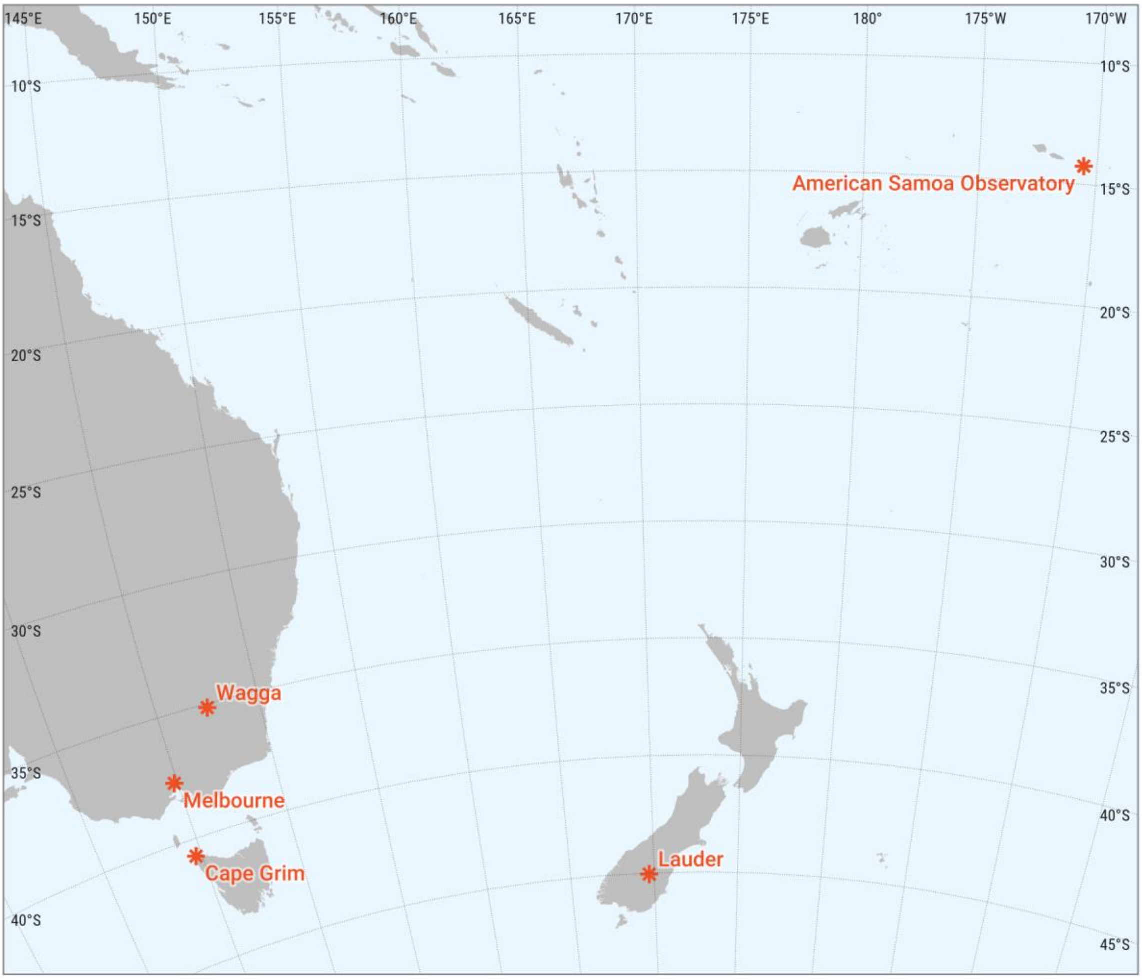

Fig. 2.1: Geographical position of the selected solar radiation validation sites

Tab. 2.2: Selected validation sites in the region

Name	Source	Latitude [°]	Longitude [°]	Elevation [m a.s.l.]
Lauder, New Zealand	BSRN	-45.045	169.689	350
Wagga, Australia	BOM	-35.1583	147.4573	212
Melbourne, Australia	BOM	-37.6655	144.8321	113
Cape Grim, Australia	BOM	-40.6817	144.6892	95
American Samoa Observatory	NOAA ESRL	-14.2474	-170.5644	42

Tab. 2.3: Direct Normal Irradiance – quality indicators

Direct Normal Irradiance, DNI	Bias		Root Mean Square Deviation, RMSD		
	[W/m^2]	[%]	Hourly [%]	Daily [%]	Monthly [%]
Lauder	23	5.8	51.5	27.0	7.0
Wagga	11	2.1	29.4	16.2	4.5
Melbourne	18	5.0	41.4	21.3	5.8
Cape Grim	2	0.5	45.8	24.1	3.6
American Samoa Observatory	-17	-4.1	42.2	19.9	4.8

Tab. 2.4: Global Horizontal Irradiance – quality indicators

Global Horizontal Irradiance, GHI	Bias		Root Mean Square Deviation, RMSD		
	[W/m^2]	[%]	Hourly [%]	Daily [%]	Monthly [%]
Lauder	-14	-4.0	29.6	15.7	5.3
Wagga	-8	-1.7	16.6	8.8	2.7
Melbourne	-11	-2.8	21.5	10.8	3.7
Cape Grim	-18	-4.8	20.2	10.9	5.4
American Samoa Observatory	-3	-0.6	21.2	9.0	0.9

Comparison of validation statistics computed for the solar meteorological sites in the region shows stability of the Solargis model and underlying input data and provides confidence about the uncertainty of calculated irradiation values.

The independent validation shows that Solargis is the most reliable solar resource database [19, 20, 21 and 22].

Uncertainty of solar resource estimate

The **accuracy of satellite-based solar and meteorological parameters** depends on the applied numerical models and on the data used as inputs to these models, more specifically, on:

1. Parameterization and adaptation of **numerical models integrated in Solargis** for the given data inputs and their ability to generate accurate results for various geographical and time-variable conditions:
- Clear-sky model and its capability to properly characterize various states of the atmosphere
- Simulation accuracy of the satellite model and cloud transmittance algorithms, being able to properly distinguish different types of desert surface, clouds, fog, but also snow and ice.
- Diffuse and direct decomposition models

2. Accuracy, temporal and spatial resolution of **data inputs for the Solargis model**:
- Satellite data: their availability, geometric and radiometric corrections, occurrence of artefacts and their mitigation,
- Parameters describing actual state of the atmosphere, such as aerosols and water vapour,
- Spatial resolution and accuracy of the Digital Terrain Model (DTM).

Statistics, such as bias and RMSD (Tabs. 2.3 and 2.4) characterize accuracy of Solargis model in the given validation points, relative to the ground measurements. The validation statistics is affected by local geography and by quality and reliability of the ground-measured data. Therefore, this statistics only indicates performance of the model in the region.

Solargis model uncertainty is compared to the high-quality data measured by the meteorological instruments. Representativeness of such data comparison (satellite and ground-measured) is determined by the precision of the measuring instruments, the maintenance and operational practices, and by quality control of the measured data – in other words, by the measurement accuracy achieved at each measurement station.

From the user's perspective, the information about the model's uncertainty has probabilistic nature. It generalizes the validation accuracy and it has to be considered at different confidence levels. The expert estimate of the calculation uncertainty in this report (Tab. 2.5) assumes 80% probability of occurrence of values.

Tab. 2.5: Estimate of typical model uncertainty of selected parameters in New Zealand

Parameter	Model uncertainty for yearly values territory of New Zealand
Global Horizontal Irradiation (GHI)	from ±4.0 to ±5.5%
Direct Normal Irradiation (DNI)	from ±9.0 to ±13.0%
Global Tilted Irradiation (GTI)	from ±5.0 to ±6.5%*

** Locally, in specific conditions (e.g. high mountains), the uncertainty may be higher.*

2.2 Meteorological data

Role of meteorological data

The requirements for the meteorological data for solar energy projects are:

- Long and continuous record of data, preferably covering the same time period as satellite-based solar resource data,
- Should reliably representative the local climate,
- Data should be accurate, quality-controlled and without gaps.

The best option would be to have continuous measurements from high-accuracy sensors installed on the site in a **meteorological station**. However, except for sites where long-term meteorological observations are operated as part of national meteorological service or some other observation network, this option is typically not available. Even if some measurements are available, often the time series are incomplete or not reliable.

In Solargis database, the historical meteorological data are derived from **meteorological models**. Several models are available, a good option is to use ERA5 European atmospheric reanalysis (source ECMWF) and Climate Forecast System Reanalysis (CFSR) and its operational extension the Climate Forecast System Version 2 (CFSv2) models (source NOAA, NCEP, USA) covering long period of time with continuous data[12, 13, 14, 23]. The results of these models are implemented in Solargis.

Air temperature data in New Zealand - data inputs and method

The air temperature (TEMP) data, stored in Solargis database for the region, is derived from the data source ERA5 (ECMWF), which original characteristics are specified in Tab. 2.6.

Tab. 2.6: Original source of Solargis air temperature data in the region: model ERA5

	ERA5 European reanalysis
Period	1994 to the present time
Original spatial resolution	25 x 25 km
Original time resolution	1 hour

The original spatial resolution of the model is enhanced to 1 km by spatial disaggregation and use of the Digital Elevation Model SRTM-3.

Important note: air temperature is derived from the numerical weather model outputs and they have lower spatial and temporal resolution. They do not represent the same accuracy as the solar resource data. **Thus, local microclimate of some sites may deviate from the values derived from the Solargis global database**.

Validation of air temperature data

The validation procedure was carried out to compare the modelled data with ground-measurements, from the meteorological stations, available through NOAA ISD network (Fig. 2.2 and Tab. 2.7).

Compared to the meteorological station, the data from the models represent larger area, and they are not capable to represent accurately the local microclimate, especially in the mountainous and coastal regions.

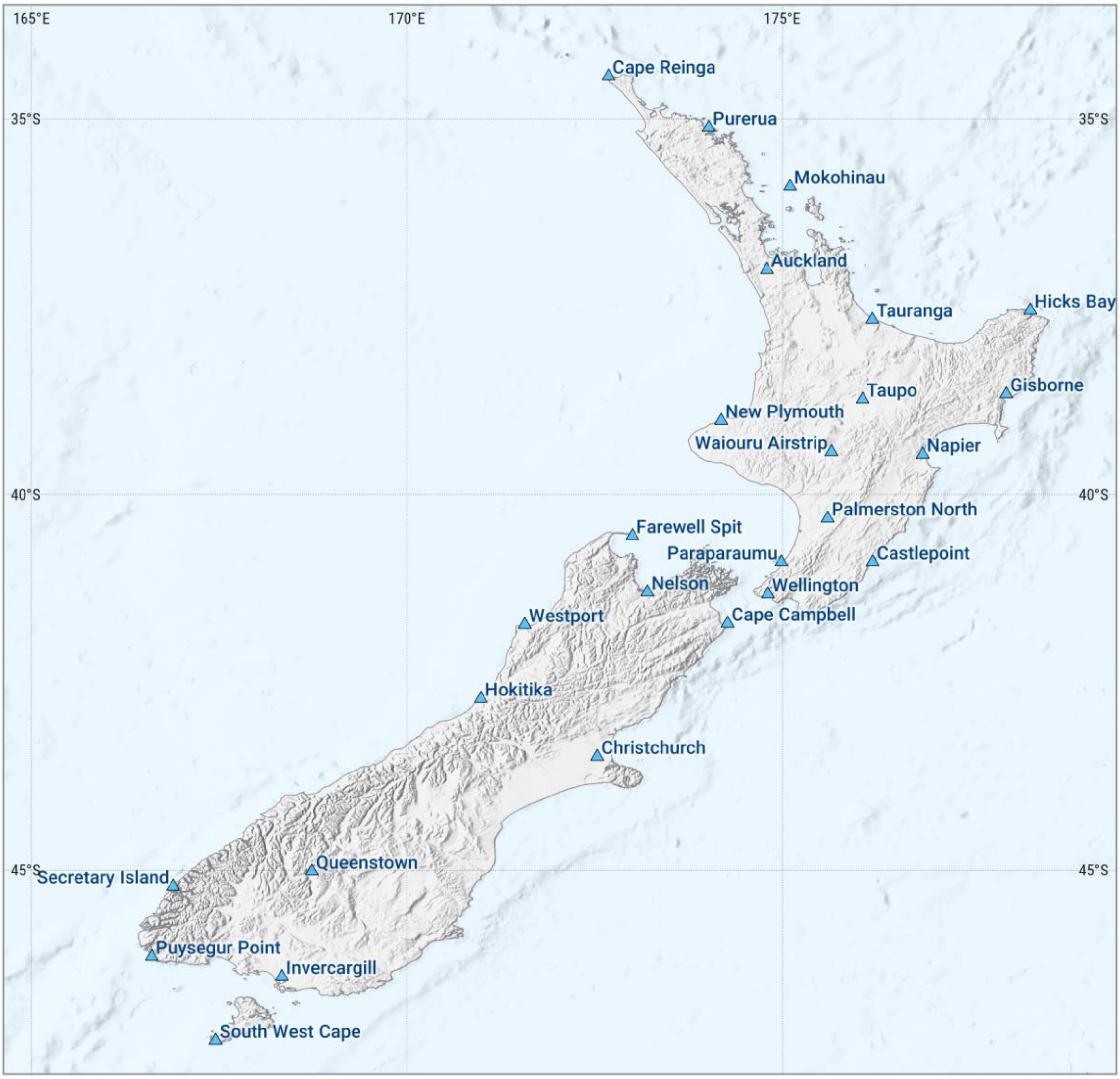

Fig. 2.2: Geographical position of meteorological stations considered in the TEMP validation

Air temperature is derived from the outputs of ERA5 meteorological model and recalculated at the spatial resolution of 1 km (Tab. 2.8). Considering spatial and time interpolation, the deviation of the modelled values to the ground observations for hourly values can occasionally reach several degrees of Celsius.

In general, the model matches the ground measurements quite well, in terms of annual and monthly averages, but due to coarse resolution of the models daily amplitude of air temperature maybe under or overestimated especially for the coastal zones.

Tab. 2.7: Meteorological stations and data time extent considered in the air temperature model validation

Meteorological station	Data source	Validation period	Latitude [º]	Longitude [º]	Elevation [m a.s.l.]
Auckland	NOAA ISD	01/2007 – 12/2018	-37.008	174.792	7
Cape Campbell	NOAA ISD	01/2007 – 12/2018	-41.717	174.267	32
Cape Reinga	NOAA ISD	01/2007 – 12/2018	-34.433	172.683	216
Castlepoint	NOAA ISD	01/2007 – 12/2018	-40.900	176.200	120
Christchurch	NOAA ISD	01/2007 – 12/2018	-43.489	172.532	38
Farewell Spit	NOAA ISD	01/2007 – 12/2018	-40.550	173.000	3
Gisborne	NOAA ISD	01/2007 – 12/2018	-38.663	177.978	5
Hicks Bay	NOAA ISD	01/2007 – 12/2018	-37.550	178.300	46
Hokitika	NOAA ISD	01/2007 – 12/2018	-42.717	170.983	44
Invercargill	NOAA ISD	01/2007 – 12/2018	-46.417	168.333	2
Mokohinau	NOAA ISD	01/2007 – 12/2018	-35.900	175.100	60
Napier	NOAA ISD	01/2007 – 12/2018	-39.467	176.867	3
Nelson	NOAA ISD	01/2007 – 12/2018	-41.300	173.200	6
New Plymouth	NOAA ISD	01/2007 – 12/2018	-39.017	174.183	32
Palmerston North	NOAA ISD	01/2007 – 12/2018	-40.317	175.600	39
Paraparaumu	NOAA ISD	01/2007 – 12/2018	-40.900	174.983	7
Purerua	NOAA ISD	01/2007 – 12/2018	-35.117	174.017	84
Puysegur Point	NOAA ISD	01/2007 – 12/2018	-46.150	166.600	44
Queenstown	NOAA ISD	01/2007 – 12/2018	-45.017	168.733	358
Secretary Island	NOAA ISD	01/2007 – 12/2018	-45.217	166.883	19
South West Cape	NOAA ISD	01/2007 – 12/2018	-47.267	167.450	102
Taupo	NOAA ISD	01/2007 – 12/2018	-38.733	176.067	401
Tauranga	NOAA ISD	01/2007 – 12/2018	-37.672	176.196	4
Waiouru Airstrip	NOAA ISD	01/2007 – 12/2018	-39.433	175.650	819
Wellington	NOAA ISD	01/2007 – 12/2018	-41.327	174.805	13
Westport	NOAA ISD	01/2007 – 12/2018	-41.733	171.567	5

Tab. 2.8: Air temperature at 2 m: accuracy indicators of the model output [ºC].

Meteorological station	ERA5 model							
	Bias mean	Bias min	Bias mean	Bias nigh-time	Bias mean	RMSD hourly	Bias mean	RMSD monthly
Auckland	0.4	1.2	-0.5	0.7	0.2	1.3	0.8	0.5
Cape Campbell	0.3	-0.2	1.0	-0.3	0.8	1.5	1.0	0.7
Cape Reinga	0.1	1.1	-1.6	1.0	-0.7	1.6	0.7	0.2
Castlepoint	-0.2	-0.6	0.2	-0.5	0.2	1.5	1.0	0.5
Christchurch	-0.4	-0.2	0.1	-1.1	0.3	2.3	1.2	0.4
Farewell Spit	0.8	2.2	-1.3	1.9	-0.4	2.1	1.2	0.9
Gisborne	0.2	0.7	-0.2	0.1	0.1	1.9	1.1	0.3
Hicks Bay	1.2	2.5	-0.5	2.1	0.3	2.1	1.5	1.2
Hokitika	0.4	1.5	-0.6	0.9	-0.2	1.9	1.2	0.5
Invercargill	0.0	0.6	-0.4	0.0	0.0	1.8	1.0	0.2
Mokohinau	0.2	0.7	-0.6	0.7	-0.2	1.1	0.6	0.3
Napier	0.8	1.8	0.2	0.9	0.6	2.2	1.5	0.8
Nelson	-0.6	-0.5	-0.5	-1.2	-0.2	2.1	1.4	0.7
New Plymouth	0.4	1.4	-0.3	0.7	0.1	1.6	1.0	0.4
Palmerston North	-1.0	-1.1	-0.6	-1.4	-0.6	2.1	1.3	1.0
Paraparaumu	0.3	1.7	-0.9	0.8	-0.4	2.0	1.2	0.5
Purerua	0.4	0.9	-0.1	0.5	0.3	1.4	0.8	0.4
Puysegur Point	0.0	0.6	-0.7	0.2	-0.3	1.3	0.8	0.1
Queenstown	-1.4	-1.1	-1.6	-2.0	-0.9	3.1	2.3	1.5
Secretary Island	-1.0	-0.5	-2.1	-0.6	-1.5	1.8	1.4	1.0
South West Cape	0.5	1.3	-0.6	1.1	0.1	1.5	1.0	0.5
Taupo	-0.7	-0.9	0.0	-1.4	-0.1	2.2	1.3	0.7
Tauranga	0.2	1.1	-0.8	0.6	-0.3	1.6	0.9	0.5
Waiouru Airstrip	-0.8	-0.6	-0.7	-1.0	-0.7	2.0	1.2	0.8
Wellington	0.0	0.8	-0.9	0.2	-0.2	1.3	0.8	0.2
Westport	0.6	2.0	-1.0	1.5	-0.4	2.0	1.2	0.7

Summary and uncertainty

Air temperature is derived from ERA5 numerical meteorological model, covering period from 1994 to 2018. Taking into account the data comparison, the uncertainty of the estimate for the air temperature is summarised in Tab. 2.9.

Tab. 2.9: Expected uncertainty of modelled air temperature for New Zealand.

	Unit	Annual	Monthly	Hourly
Air temperature at 2 m	°C	±1.0	±1.5	±2.5

3 SOLARGIS SIMULATION OF SOLAR PHOTOVOLTAIC POTENTIAL

3.1 Principles of PV electricity simulation

Results of photovoltaic (PV) electricity simulation, presented in this study, are based on software developed by Solargis. This Chapter summarizes key elements of the simulation chain.

The PV software implemented by Solargis has scientifically proven methods [24 to 29] and uses full historical time series of solar radiation and air temperature data on the input (Tab. 2.1 and Tab. 2.6). Data and model quality are checked using field tests and ground measurements.

In PV energy simulation procedure, there are several energy losses that occur in the individual steps of energy conversion:

1. **Losses due to terrain shading** caused by far horizon**.** On the other hand, shading of local features such as nearby building, structures or vegetation is not considered in the calculation,
2. Energy conversion in PV modules is reduced by **losses due to angular reflectivity**, which depends on the relative position of the sun and plane of the module and **temperature losses,** caused by the performance of PV modules working outside of STC conditions defined in datasheets,
3. DC output of PV array is further reduced by **losses due to dirt or soiling** depending mainly on the environmental factors and module cleaning**, losses by inter-row shading** caused by preceding rows of modules, **mismatch** and **DC cabling losses**, which are caused by slight differences between the nominal power of each module and small losses on cable connections,
4. DC to AC energy conversion is performed by an inverter. The efficiency of this conversion step is reduced by **inverter losses**, given by the inverter efficiency function. Further factors reducing AC energy output are **losses in AC cabling** and **transformer losses** (applies only to large-scale open space systems),
5. **Availability.** This empirical parameter quantifies electricity losses incurred by the shutdown of a PV power plant due to maintenance or failures, including issues in the power grid. Availability of well operated PV systems is approximately 99%.

According to experience in many countries, the crystalline silicon PV modules show a relatively low performance reduction over time. The rate of the performance degradation is higher at the beginning of exposure, and then stabilizes at a lower level. Initial degradation may be close to the value of 0.8% for the first year and 0.5% or less for subsequent years [29]. The performance ageing of PV modules is not considered in this study. The calculation results of PV power potential for New Zealand are shown in Chapter 4.

3.2 Technical configuration of a reference PV system

Theoretical photovoltaic power production in New Zealand has been calculated using numerical models developed and implemented in-house by Solargis. 10-minute and 30-minute **time series of solar radiation and air temperature**, reduced to aggregated statistics, representing last 12 years, are used as an input to the simulation. The models are developed based on the advanced algorithms, expert knowledge and recommendations given in [30] and tested using monitoring results from existing PV power plants. Tab. 3.2 summarizes losses and related uncertainty throughout the PV computing chain.

In this study, the reference configuration for the PV potential calculation is a PV system with crystalline-silicon (c-Si) modules mounted in a fixed position on a table facing towards the Equator (north) and inclined at an angle close to optimum, i.e. at the angle at which the yearly sum of global tilted irradiation received by PV modules is maximized. The fixed-mounting of PV modules is very common and provides a robust solution with minimal maintenance effort.

Fig. 4.6 shows theoretical potential power production of a PV system installed with a typical technology configuration for open space PV power plants optimally tilted towards the Equator. The technical parameters are described in Tab. 3.1.

Tab. 3.1: Reference configuration - photovoltaic power plant with fixed-mounted PV modules

Feature	Description
Nominal capacity	Configuration represents a typical PV power plant of 1 MWp or higher. All calculations are scaled to 1 kWp, so that they can be easily multiplied for any installed capacity.
Modules	Crystalline silicon modules with positive power tolerance. Nominal Operating Cell Temperature (NOCT) 45ºC and temperature coefficient of the Pmax -0.45 %/K
Inverters	Central inverter with declared datasheet efficiency (Euro efficiency) 97.5%
Mounting of PV modules	Fixed mounting structures facing towards the Equator with optimum tilt (the range from 23º to 44º), Fig. 4.5. Relative row spacing 2.5 (ratio of absolute spacing and table width)
Transformer	Standard transformer with 1% losses

Tab. 3.2: Yearly energy losses and related uncertainty in PV power simulation

	Simulation step	Losses [%]	Uncertainty [± %]	Notes
1	Global Tilted Irradiation (model estimate with terrain shading)	N/A	6.5	Annual Global Irradiation falling on the surface of PV modules
2	Module surface angular reflectivity (numerical model)	-2.6 to -3.2	1.0	Slightly polluted surface is assumed in the calculation of the module surface reflectivity
	Conversion in modules relative to STC (numerical model)	-0.5 to -7.8	3.5	Depends on the temperature and irradiance. NOCT of 45ºC is considered
3	Polluted surface of modules (empirical estimate)	-2.5	1.5	Losses due to dirt, dust, soiling, and bird droppings
	Power tolerance (value from the data sheet)	0.0	0.0	Value given in the module technical data sheet (we calculate with modules having positive power tolerance)
	Module inter-row shading (model estimate)	-1.0	1.0	Partial shading of strings by modules from adjacent rows
	Mismatch between modules (empirical estimate)	-0.5	0.5	Well-sorted modules and lower mismatch are considered.
	DC cable losses (empirical estimate)	-1.5	1.0	This value can be calculated from the electrical design
4	Conversion in the inverter (value from the technical data sheet)	-2.5	0.5	Given by the Euro efficiency of the inverter, which is considered at 97.5% in this case (value given in module technical data sheet)
	AC cable losses (empirical estimate)	-0.5	0.5	Standard AC connection is assumed
	Transformer losses (empirical estimate)	-1.0	0.5	Standard transformer is assumed
5	Availability	0.0	1.5	100% technical availability is considered; the uncertainty assumes a well-integrated system; the real value strongly depends on the efficiency of PV integration into the existing grid.
	Range of cumulative losses and indicative uncertainty	-11.9 to -18.9	7.9	These values are indicative only and do not consider project specific features and performance degradation of a PV system over its lifetime

4 DATA SNAPSHOTS

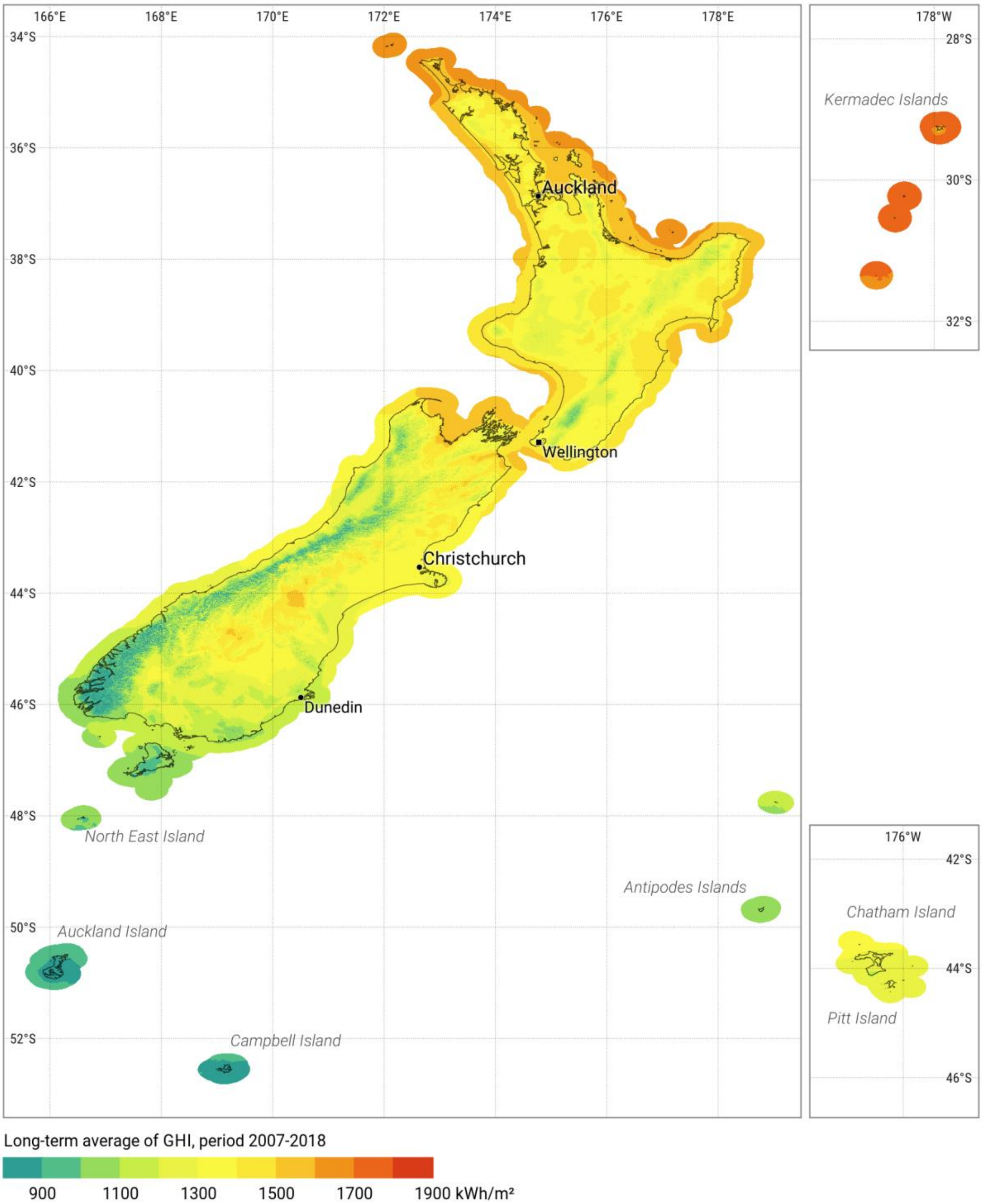

Fig. 4.1: Long-term average of annual sum of global horizontal irradiation (GHI), period 2007-2018 [kWh/m^2].

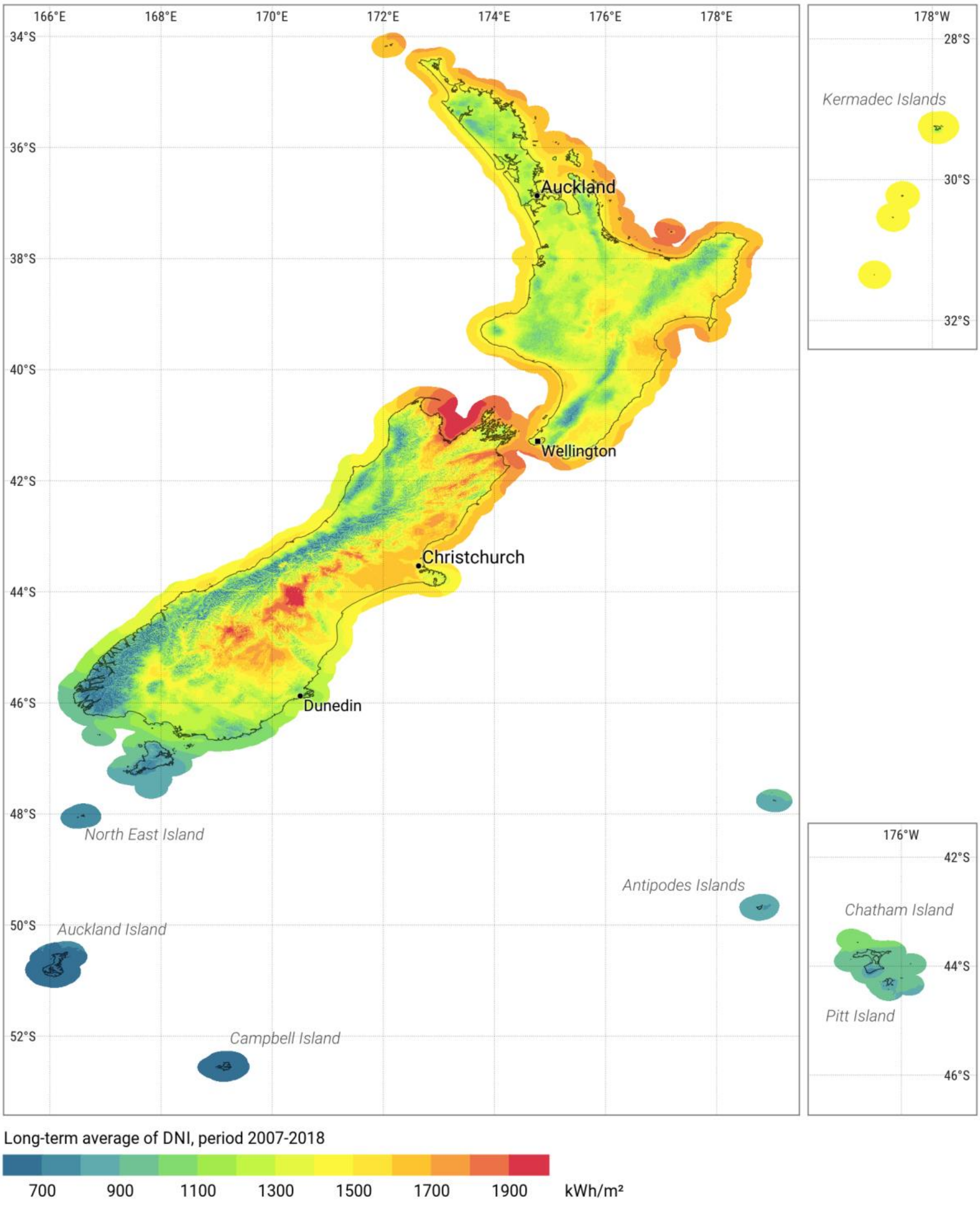

Fig. 4.2: Long-term average of annual sum of direct normal irradiation (DNI), period 2007-2018 [kWh/m^2].

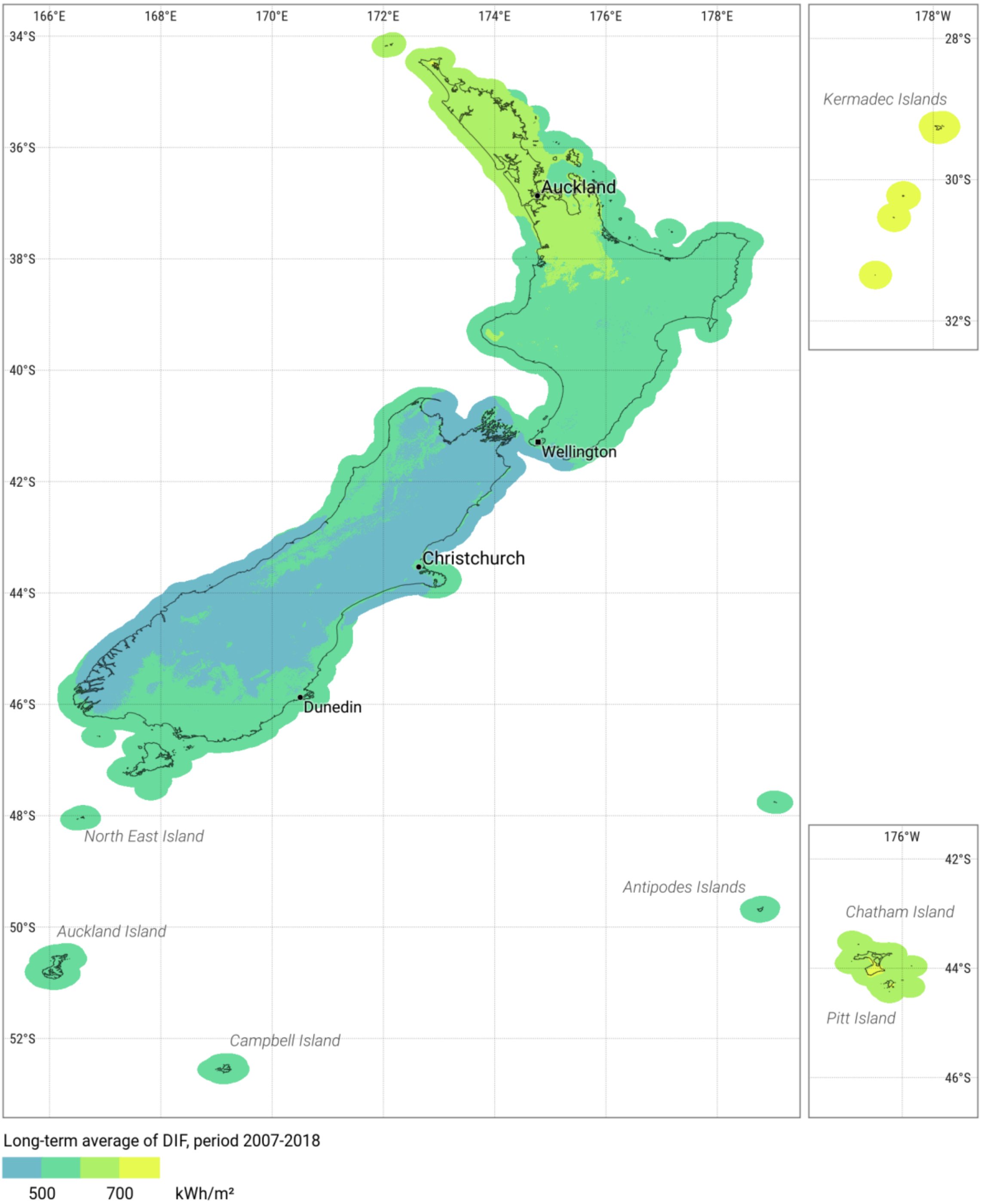

Fig. 4.3: Long-term average of annual sum of diffuse horizontal irradiation (DIF), period 2007-2018 [kWh/m^2].

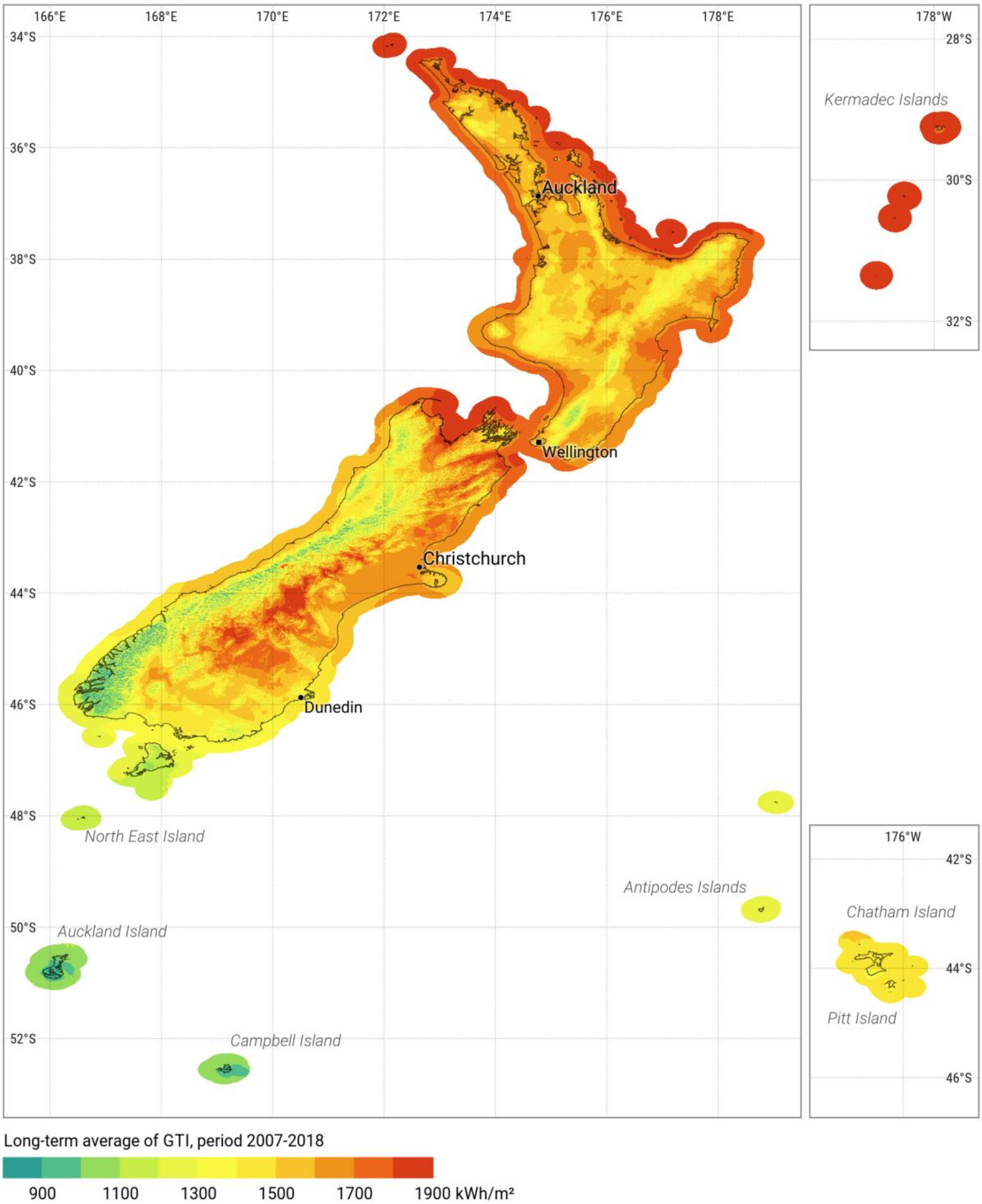

Fig. 4.4: Long-term average of annual sum of global tilted irradiation (GTI), period 2007-2018 [kWh/m^2].

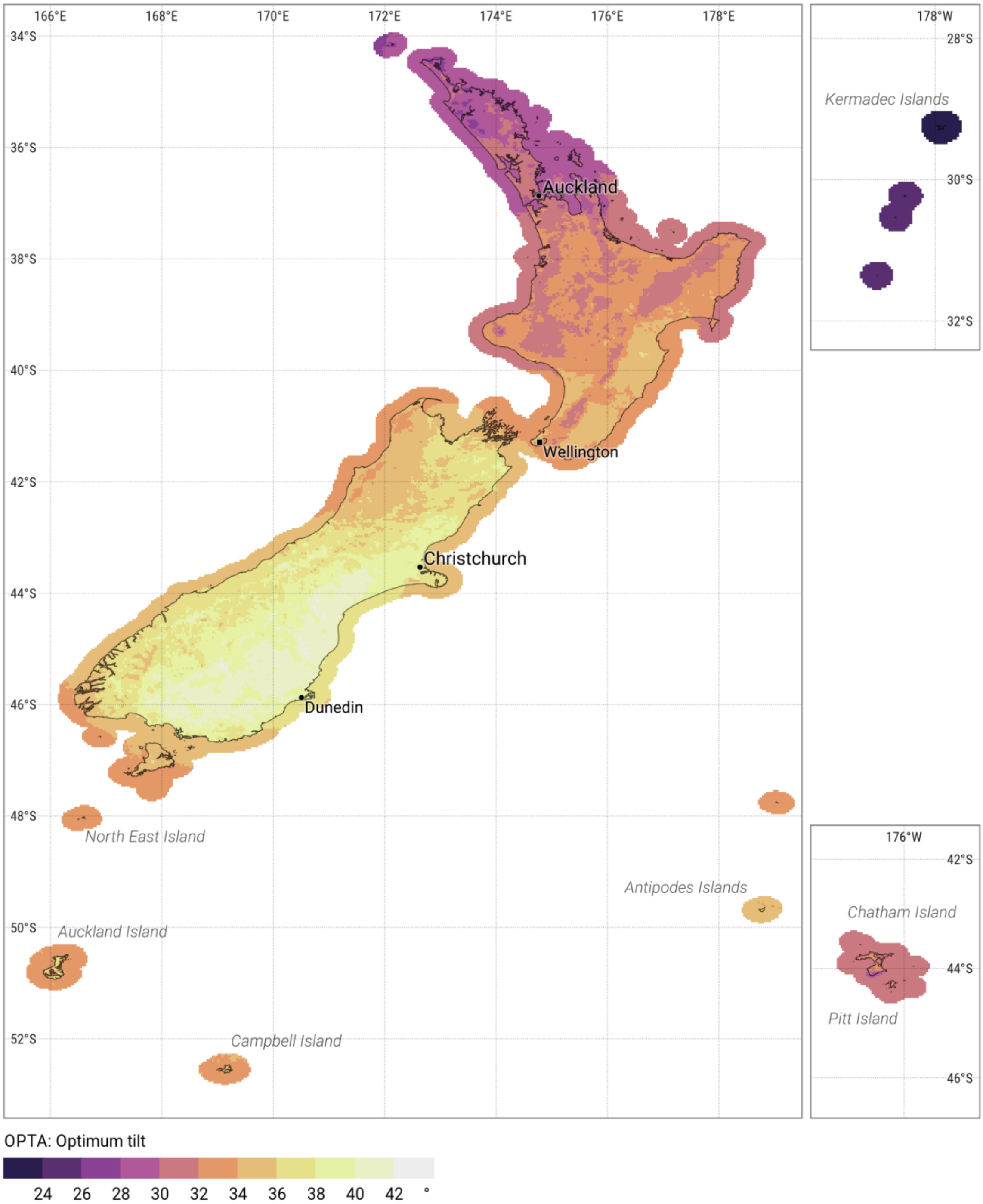

Fig. 4.5: Optimum inclination of the PV modules (OPTA) [°].

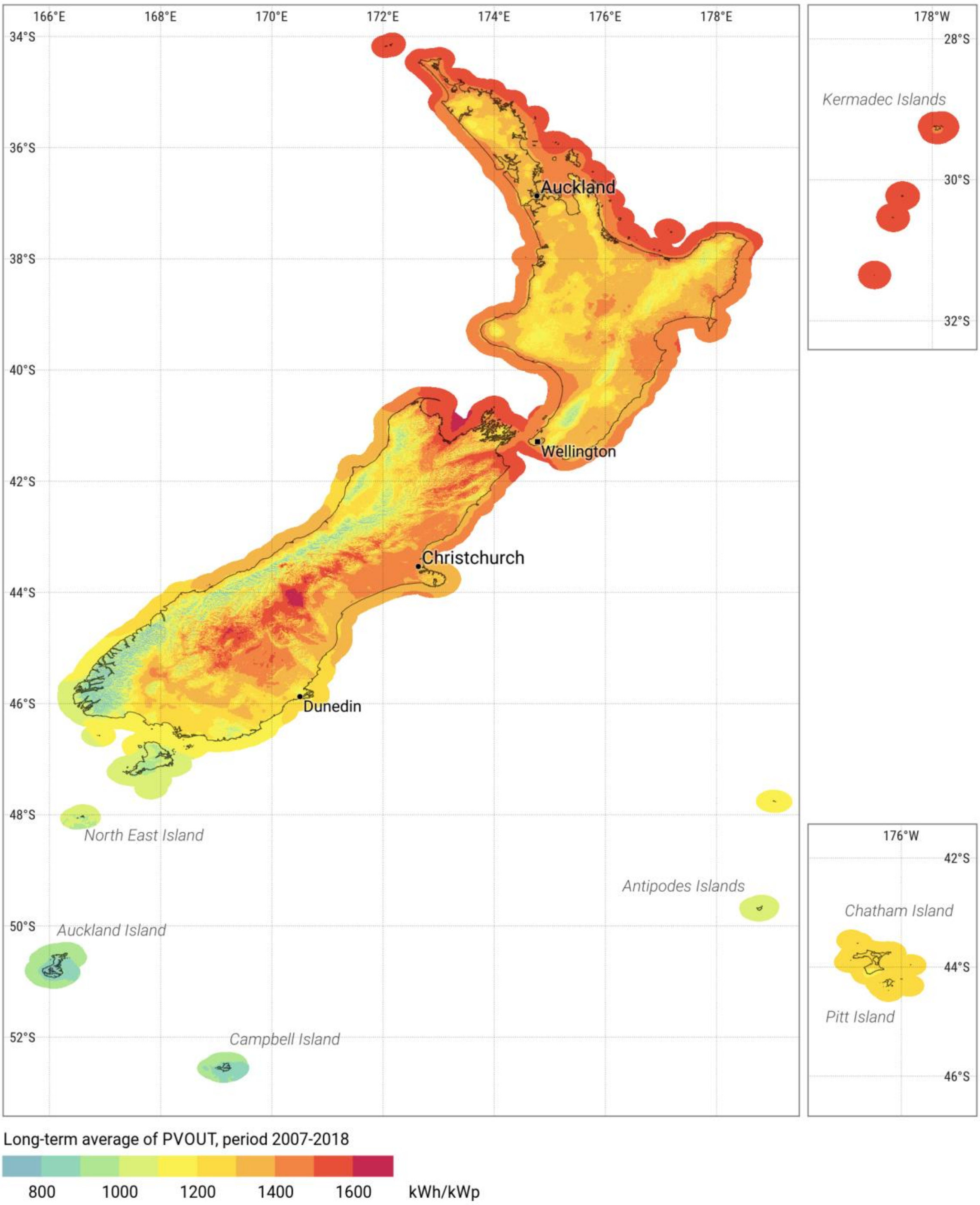

Fig. 4.6: Long-term average of annual sum of PV Electricity Output (PVOUT), period 2007-2018 [kWh/kWp].

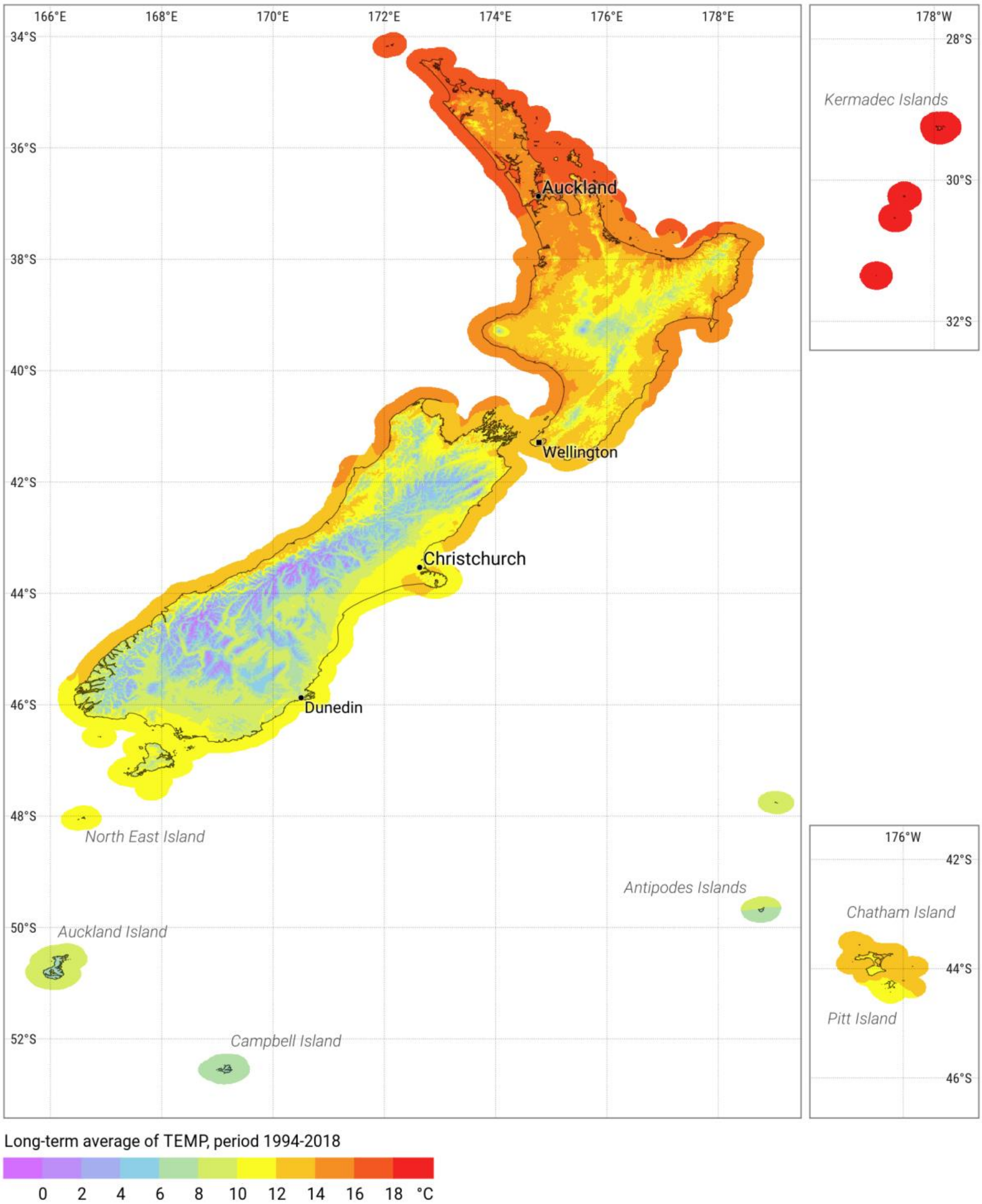

Fig. 4.7: Long-term average of air temperature at 2 m height (TEMP), period 1994-2018 [°C].

5 LIST OF FIGURES

6 LIST OF TABLES

7 REFERENCES

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