ESMAP - Renewable Energy Resource Mapping Initiative

- Solar Resource Mapping for Pakistan -

WB Selection #11260861

Solar Modeling Report Pakistan #1

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Contents

1. Introduction

This solar modeling report gives an overview on the results achieved by modeling the solar radiation based on satellite data in Phase 1 of the Solar Resource Mapping Project for Pakistan (WB Selection #11260861). The project consists of three Phases where within Phase 1 capacity building is conducted, a site selection process for setting up measurement sites is undertaken, workshops are held and an unvalidated solar atlas based on satellite data for Pakistan is processed. The interim result of the solar atlas is presented in this report. Within Phase 2, which will follow directly upon the Phase 1 workshop held in Pakistan in October 2014, a measurement campaign at nine selected sites begins for a two-year period. In Phase 3, the interim results of Phase 1 will be validated against the measurement data of Phase 2, allowing the DLR to adapt the satellite estimates if necessary.

Within this report, satellite specifications and a short approach of methodology will be given in chapter 2. Within chapter 3, a short overview over the climate of Pakistan and an introduction to solar radiation and the radiation budget is presented followed by interim results of Phase 1 modelling. Chapter 3 and 4 give an overview over the regional and seasonal dust outbreaks in western Pakistan and focus on the winter-fog regions in the northeast.

The solar radiation assessment using satellite data is based on the well-proven Heliosat-2 Method, which will be screened in more detail within this report. Most of the radiation maps displayed in this report will be delivered in a GIS-conform format to WBG for further processing. Within this report, the main focus is set on the multi-year annual sum and the monthly sums of the parameters Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI) in kWh/m². The first two parameters will be evaluated thoroughly in terms of spatial and temporal variation, while DHI will be screened more generally.

For a more detailed regional look, the provinces of Sindh, Balochistan, Islamabad, Azad Jammu/Kashmir + Gilgit Baltistan, Khyber Pakhtunkhwa (former NWFP) and Federally Administered Tribal Areas (FATA) have been screened separately. Azad Jammu/Kashmir and Gilgit Baltistan are summarized to “Northern Regions” for the analysis as the irradiance values estimated for high mountain areas have to be handled with extreme caution. The names of the different Administrative units of Pakistan are summarized to “provinces” for simplicity. If not indicated specifically, all data and numbers are based on hourly satellite estimates with approx. 5 km x 5 km nominal spatial resolution (Meteosat-5 and Meteosat-7 data) produced for this study. The timespan considered in this analysis are the years 2000-2012. It must be pointed out that the modeled solar radiation data is not yet validated against ground measurement and therefore an unknown deviation between the real solar radiation in Pakistan and the modeled data exist. The reliable solar radiation data set with well-known accuracy will be provided after the measurement and validation campaign in 2016/2017.

2. Satellite resource assessment specifications

Pakistan is fully covered by the Meteosat-7 (Met-7) geostationary satellite, which is positioned 57.5°E (Indian Ocean Data Coverage). Met-7 is operational since November 2006 and was preceded by Meteosat-5 (Met-5), positioned 63°E. Both satellites are nearly identical, so homogeneity of the data is ensured. Meteosat-5 data is available from the end of 1999, so DLR proposes to use a dataset beginning in the year 2000, as only full years lead to satisfying results so a 13-year dataset (2000-2012) for Pakistan is available. Both satellites are *Meteosat East*. *Meteosat Prime* is **not** used within the project as the satellite elevation angle is too low in the region.

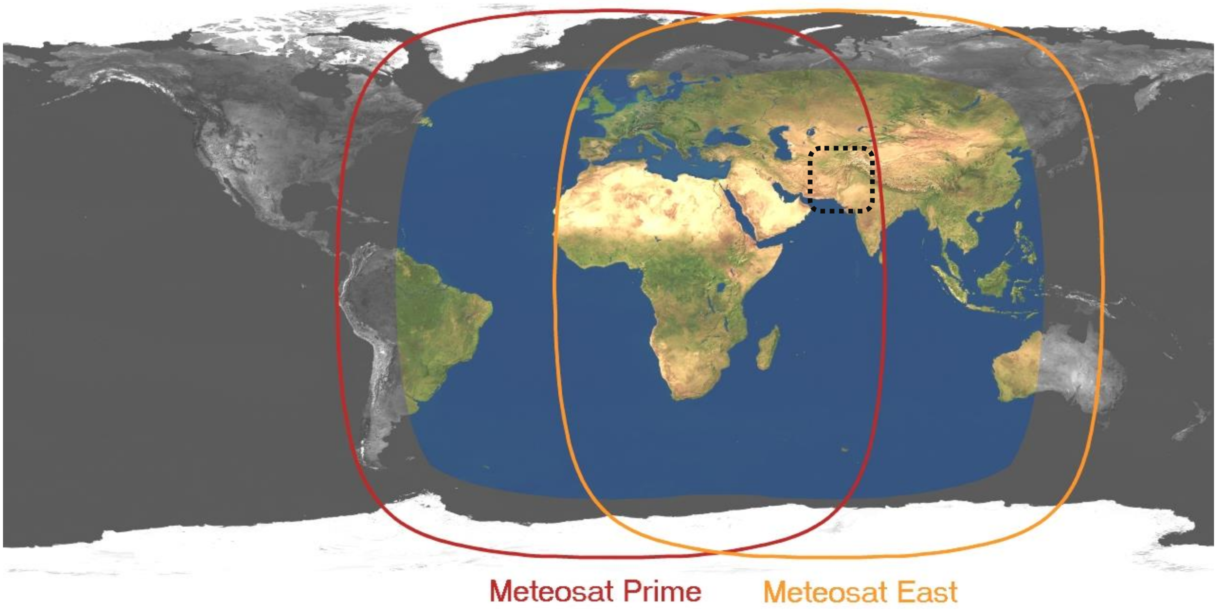


Figure 1: Satellite's field of view. Dotted square indicates location of Pakistan relative to satellite's field of view

The computational method to process the downward solar irradiance in use is an enhanced Heliosat-2-Method (see also Cano et al., 1986, Hammer et al., 2003, Rigollier et al., 2004, Schillings et al., 2004)

Several computational methods have been developed in the past two decades for estimating the downward solar irradiance from satellite observations (Renne et al., 1999). Among them is the HELIOSAT method. It has proven to be a reliable method in several European research projects. The general idea of the HELIOSAT method for the estimation of surface solar irradiance from satellite images is to deal with atmospheric and cloud extinction separately. In a first step the clear sky irradiance for a given location and time is calculated. In a second step a cloud index is derived from Meteosat imagery. This step uses the fact that the reflectivity measured by the satellite is approximately proportional to the amount of cloudiness characterized by the cloud index. This value then is correlated to the cloud transmission. Finally, the clear sky irradiance is diminished by the cloud transmission to infer the surface irradiance.

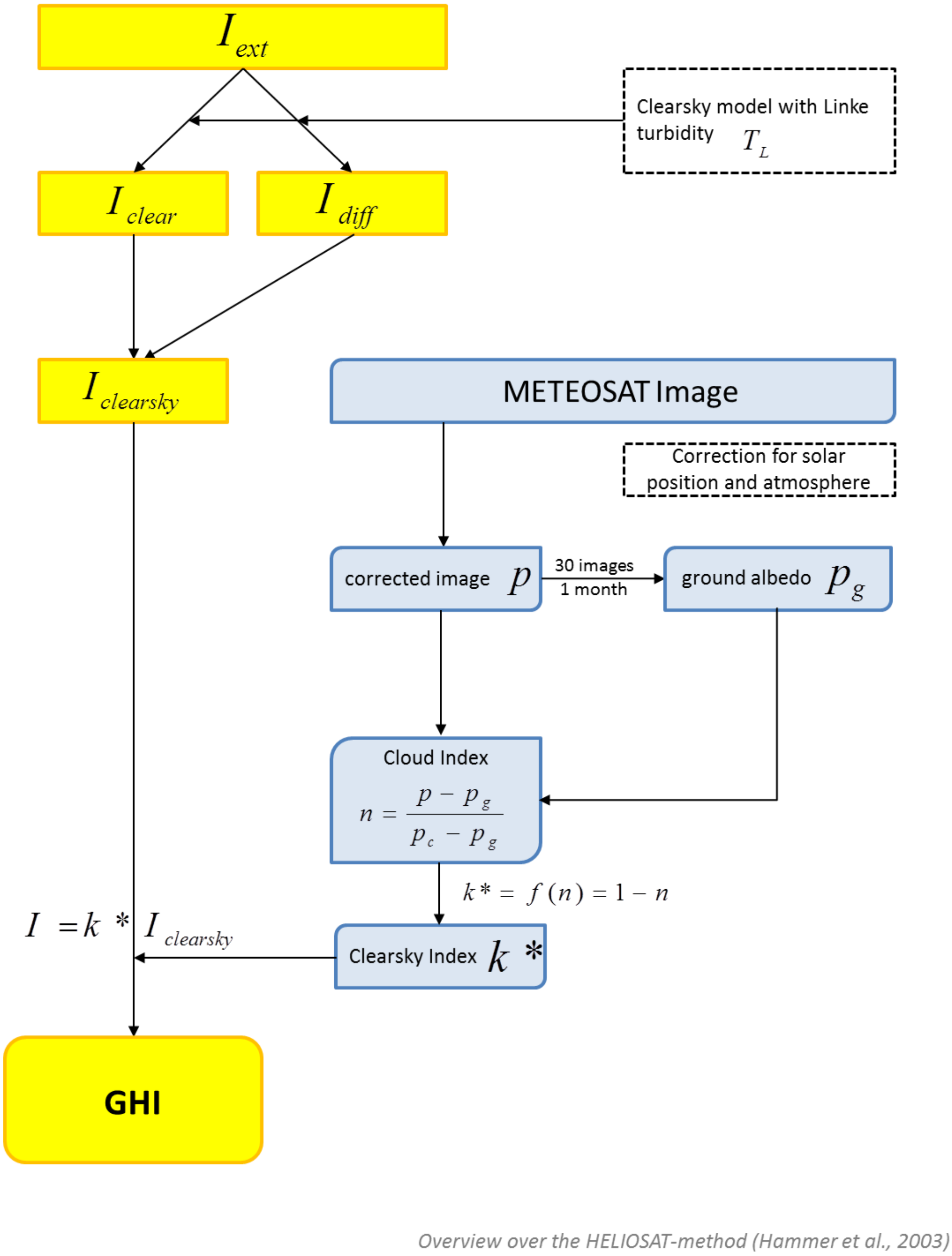


Figure 2: Schematic overview on Heliosat-2 methodology

The resulting irradiance data of Direct Normal Irradiance (DNI), Global Horizontal Irradiance (GHI) and Diffuse Iradiance (DIF) is based on global atmospheric data sets (aerosol, water vapor, ozone) from different earth observation sources and climate models as well as cloud data from Meteosat.

Daily climatology for the Aerosol Optical Depth (AOD) is used from the NASA/DLR Model of Atmospheric Transport and Chemistry (MATCH). Alternatively the ECMWF Monitoring Atmospheric Composition and Climate (MACC) model can be applied, which would be applied in the final product if there is a lower bias to the measured data. The MATCH-dataset has an original spatial resolution of 1.9° x 1.9°, increased to 0.5° x 0.5° by bilinear interpolation. The MACC dataset is available in its 1.25°x1.25° original resolution and has a disadvantage compared to MATCH, as it is only available from the year 2003 onwards. During phase 3 validation, DLR will select the best suitable datasets for the site comparing both model data with adjacent measurements of sites used by the Aerosol Robotic Network (AERONET) and by comparing single time-series with measured data, if available.

Water vapour data derived from the NCEP/NCAR-Reanalysis of the Climate Diagnostic Center (CDC-NOAA) is used with a monthly temporal resolution and a 2.5° x 2.5° spatial resolution. Ozone data input is derived from the Total Ozone Mapping Spectrometer (TOMS) and is available in monthly values and a 1° x 1.25° spatial resolution. All of the climatological parameters are described in detail in the processing documentation.

Model validation has been conducted within the project "Management and Exploitation of Solar Resource Knowledge Project" (MESOR). To validate the satellite data with data of surface measurements or other model-data sources, the mean bias and the root mean square error for single point locations and difference-maps will be produced.

Satellite data (as well as MATCH aerosol data) has to be thoroughly processed and checked at the German Remote Sensing Center (DFD) and the Institute of Atmospheric Physics (IPA) before it can be imported to the irradiance-processor. This results in a standby-time of about 3 months when also applying the transferring time before the latest data can be ingested to the processing system. December-data will be applicable in the following March/April, for example.

Deliverables of this work package are digital maps suitable for GIS use in GeoTiff format. One map of the annual average and 12 maps of monthly averages (January to December). The maps can be used with ArcGIS-software (e.g. Shapefile or Geodatabase). All sites/pixels within the map are identified by their DNI/GHI-values and geographic coordinates. Maps of the global tilt irradiance and of PV output will be produced using the optimal tilt angle of the collectors and a simple PV model. Global Irradiation on an inclined plane has been described by many authors and is used in DLRs Remix model. A common approach used in many applications is well described by Iqbal 2003.

3. The climate of Pakistan and its influence on solar irradiance

Pakistan's climate is influenced by monsoon seasons and from westerly disturbances. The effects of this mixture of seasonal and diurnal climate on solar irradiance are versatile and have to be considered in many aspects of solar irradiance modeling. The geographic location of the country allows a good solar elevation angle for PV or even CSP applications throughout the year but certain regions with high aerosol content or cloud cover cannot make use of the full potential of this natural source of energy. Pakistan is also affected by the global climate change and effects of this change influence the solar irradiance directly, though, it is not contributing much to greenhouse gas emissions (Chaudhari et al., 2009).

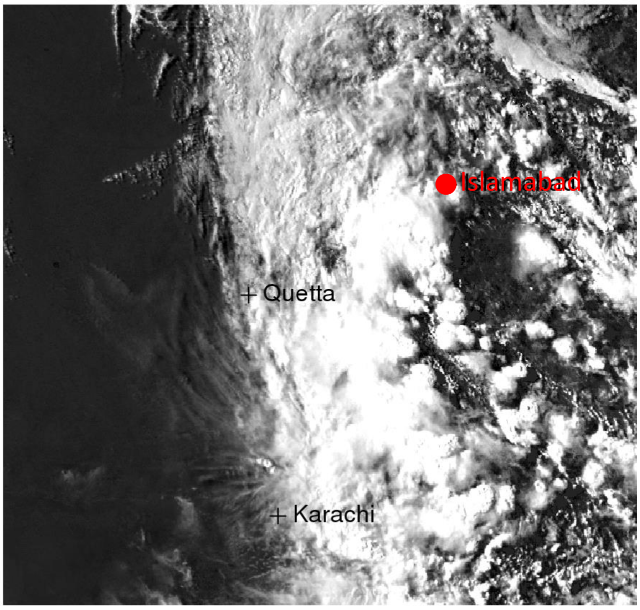


Figure 3: Thunderstorms during wet monsoon in August 2008 over Indus plains.

Figure 3 shows different types of clouds over vast areas of Pakistan. Optical thick storm clouds cover the plains along the Indus and reduce solar irradiance on the ground remarkably. These types of clouds often are a consequence of daylight heating in a moist environment and, thus start to grow mainly in the afternoon hours. The western and southern parts of Balochistan are cloud-free and receive the full amount of irradiance that particular day. Besides clouds, the aerosol content in the atmosphere plays an important part in the spatial and temporal variability of irradiance in Pakistan. Within this report, two chapters focus on the aerosol content and variability in Pakistan. In the past, there were severe droughts and flooding, heat waves and storms and all of these extremes not only have impact on the people but also on the solar irradiance reaching the ground. These effects can be of positive or negative nature and have to be evaluated for a prediction of Pakistan's solar resources in the future.

3.1 The radiation budget and types of solar irradiance

Irradiance is the transport of Energy by electromagnetic waves and is generally measured in Watts per squaremeter (W/m²). A certain amount of energy is reaching the top of the earth's atmosphere. The mean value of this extraterrestrical irradiance is 1365 W/m² in the global mean. This amount of energy does not reach the earth's surface as the irradiance is absorbed, scattered and reflected by clouds, aerosols, water vapour, ozone and other trace gases. Summing up all of these processes leads to the earth's radiation budget which explains how much of the original irradiance received on the top of the atmosphere reaches the surface and how much is absorbed and how much is scattered by particles.

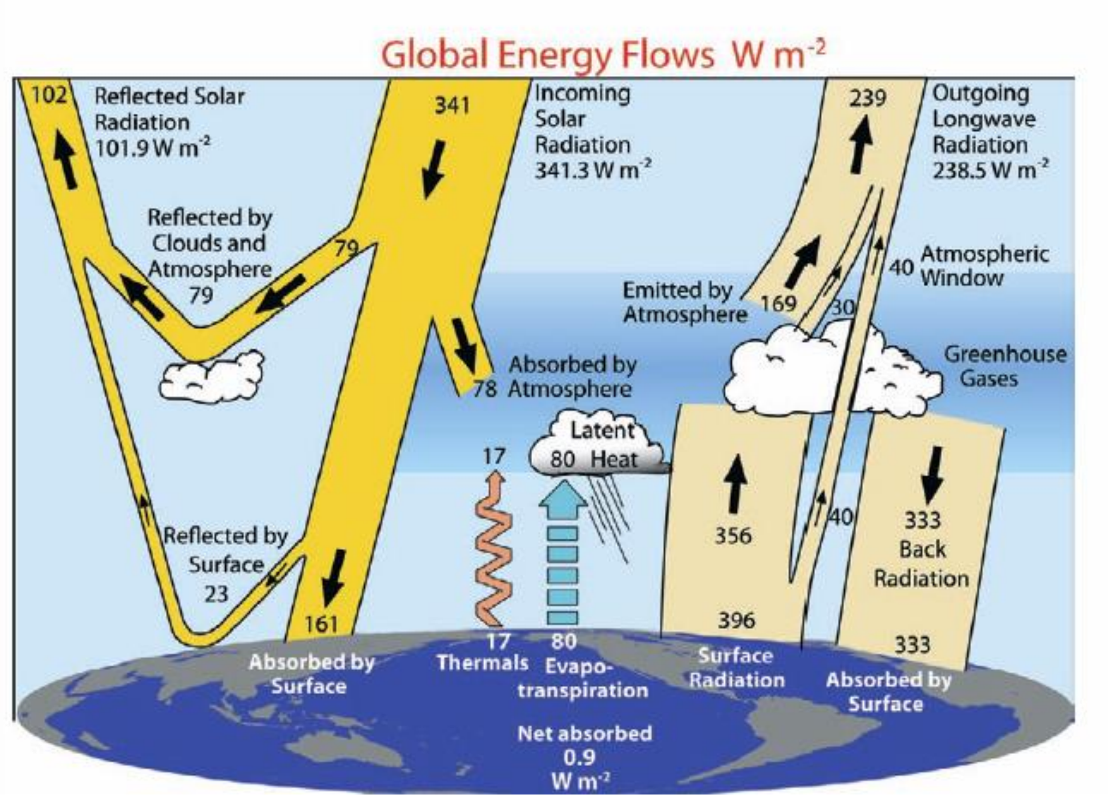


Figure 4: The global annual mean oft the earth's radiation budget for the period march 2000 to may 2004, taken from Trenberth et al., 2009.

The size and shape of atmospheric particles have a strong influence on the nature of scattering (ie. Mie- or Raleygh scattering) and the intensity of attenuation of solar irradiance before it reaches the ground. The values of the earth's radiation budget vary considerably in space and time and the values shown in Figure 4 are global mean values and may not representative for a certain location in Pakistan.

For solar energy needs we mainly differ between Global Horizontal Irradiance, which consist of Direct Irradiance of the sun and the scattered Irradiance (see Figure 5) and Direct Normal Irradiance (DNI), which is the Direct Irradiance reaching a surface that is always perpendicular to the sun. GHI is from importance for photovoltaics, while DNI is of special importance for solar thermal applications.

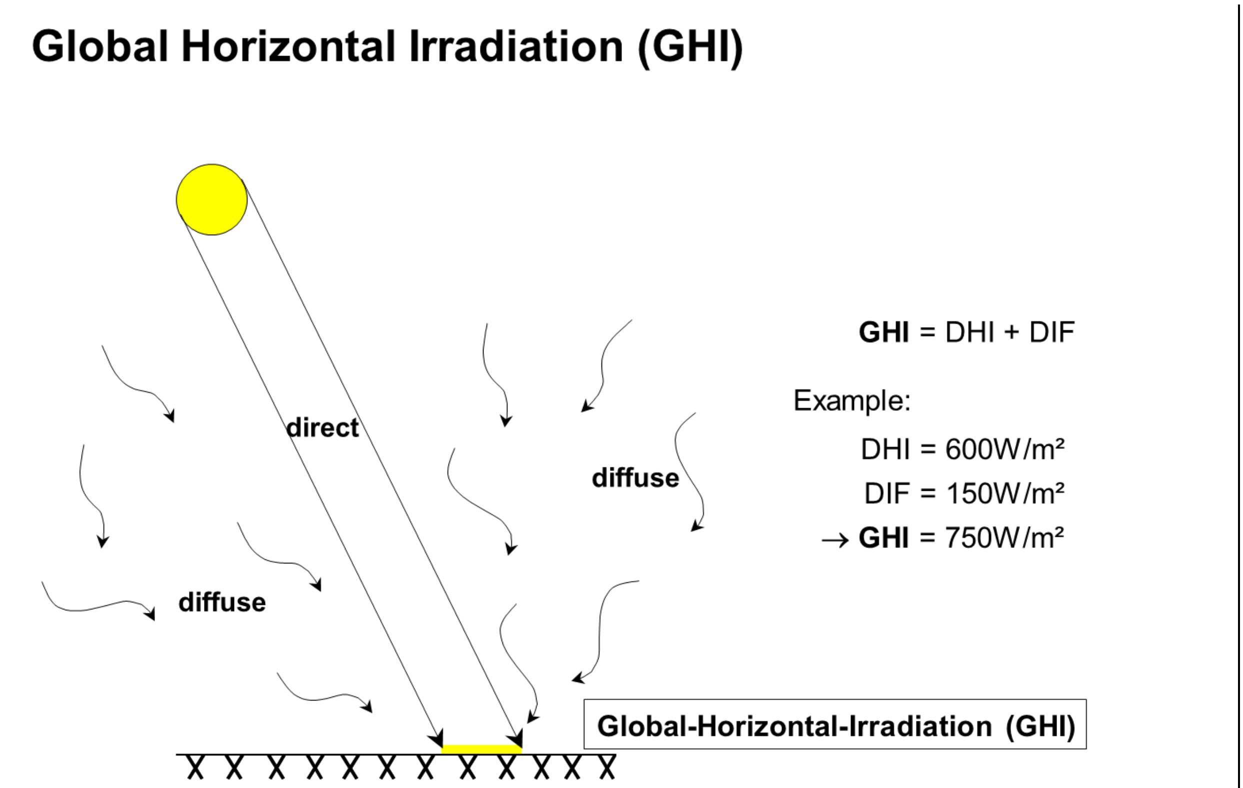


Figure 5: Schematic illustration of Global Horizontal Irradiance (GHI).

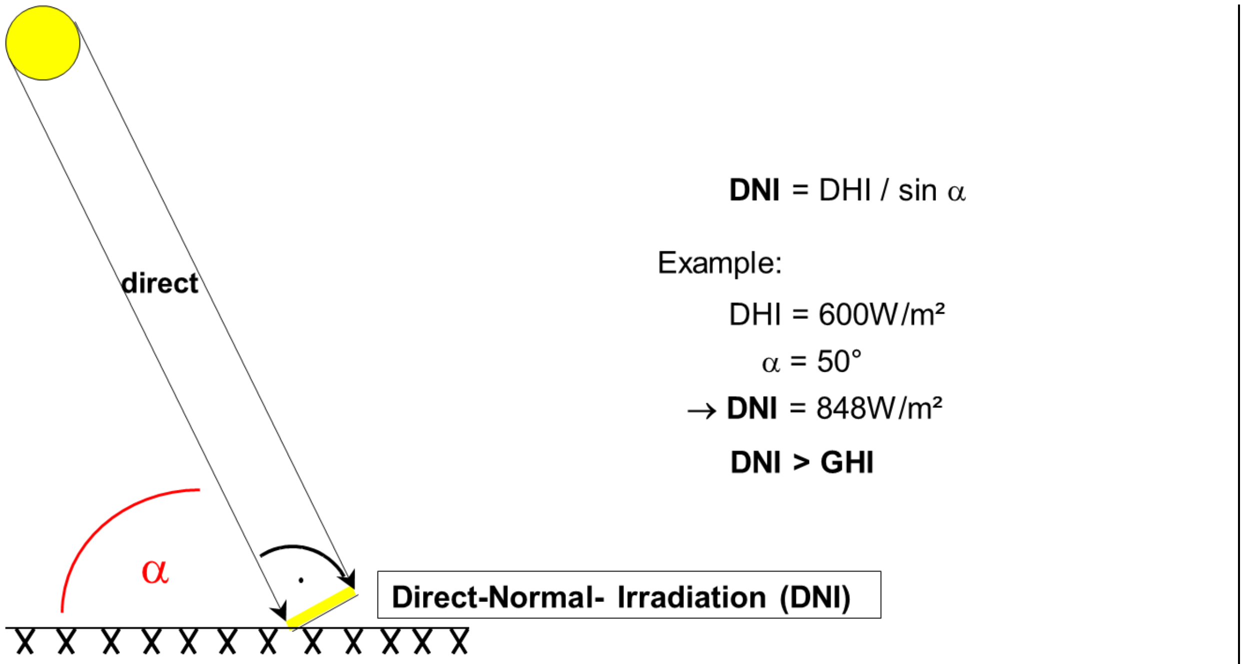


Figure 6: Schematic illustration of Direct Normal Irradiance (DNI).

The preliminary solar radiation data displayed in the following chapters is not suitable for solar project developing and planning or tariff assessments!

3.2 Global Horizontal Irradiance

Global Horizontal Irradiance (GHI) shows highest values in southwest Pakistan, gradually decreasing to the north and northeast of the country with minimums in the Himalayan Mountains. Maximum values of just over 2300 kWh/m² are reached in the southwestern region of Balochistan. The estimated values only decrease gradually towards the northeast of the country and still in more than 90% of the land area values over 1500 kWh/m² are reached.

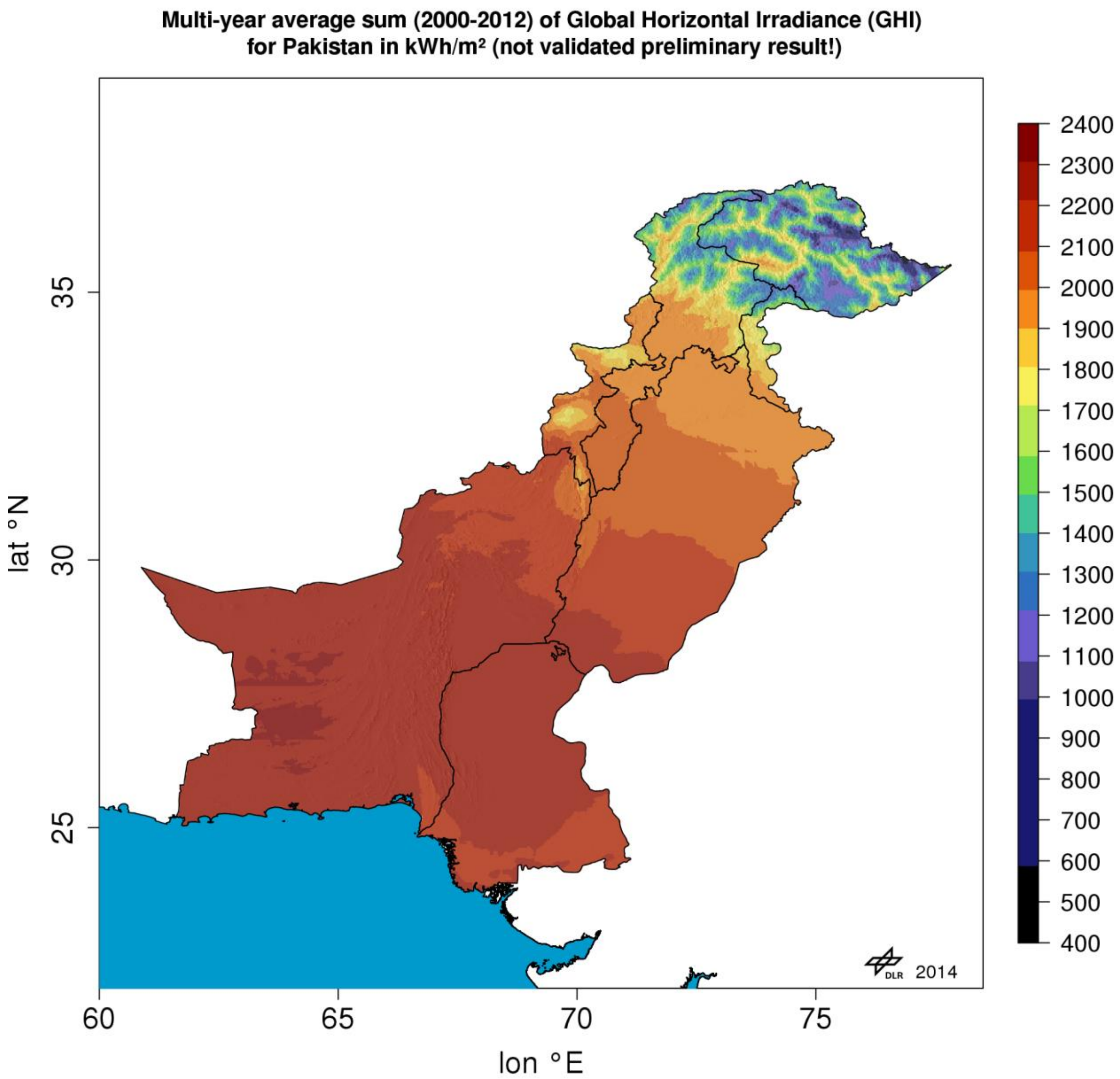
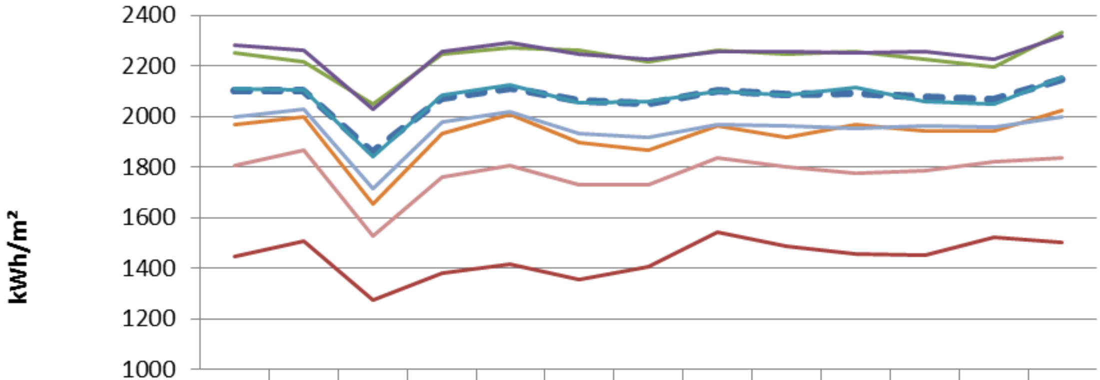


Figure 7: Multi-year mean (2000-2012) of annual Global Horizontal Irradiance (GHI) for Pakistan in kWh/m²

The annual mean value of GHI for whole Pakistan is 2071 kWh/m². The mean values for the single provinces are listed in Figure 8. Highest values of GHI can be found in the provinces Sindh, Balochistan and Punjab, while lowest sums have been estimated for the Northern Regions (including Azad Kashmir) and Khyber Pakhtunkhwa.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Pakistan	2104	2100	1859	2073	2111	2059	2050	2103	2088	2090	2075	2066	2149
Northern Regions	1447	1506	1273	1382	1415	1355	1404	1545	1487	1455	1454	1523	1504
Sind	2254	2215	2049	2245	2273	2259	2215	2260	2244	2256	2225	2194	2333
Balochistan	2284	2260	2030	2254	2293	2247	2227	2254	2256	2252	2256	2227	2319
Punjab	2112	2104	1843	2084	2123	2055	2061	2099	2086	2113	2061	2049	2156
Islamabad	1966	1997	1654	1931	2006	1897	1866	1964	1920	1966	1942	1944	2025
Fata	1996	2026	1713	1980	2020	1931	1918	1970	1961	1954	1965	1960	1997
Nwfp	1807	1869	1530	1758	1804	1728	1728	1837	1801	1778	1784	1819	1836

Figure 8: Annual sums of GHI (2000-2012) for Pakistan and Provinces based on satellite estimates.

The general trend of the annual sums is for the 13-year period is nearly constant, with a significant decline of values in the year 2002, where the annual sum of 1859 kWh/m² for Pakistan is 11% below the average compared to the other years considered in this report. The year 2002 marked the end of drought period which began in 1998 and was a so-called bad monsoon year (Sarfaraz, 2007). It has to be evaluated in the Phase 3 validation process what causes this decrease of annual sum for the GHI. One option might be an increased number of dust-storms caused by the drought which led to a seasonal dimming of sunlight.

A similar dip as for GHI in 2002 is not seen for the DNI pattern in Figure 12, as would be expected under anomalously high dust conditions, so other explanations for this dip will also be explored during Phase 3.

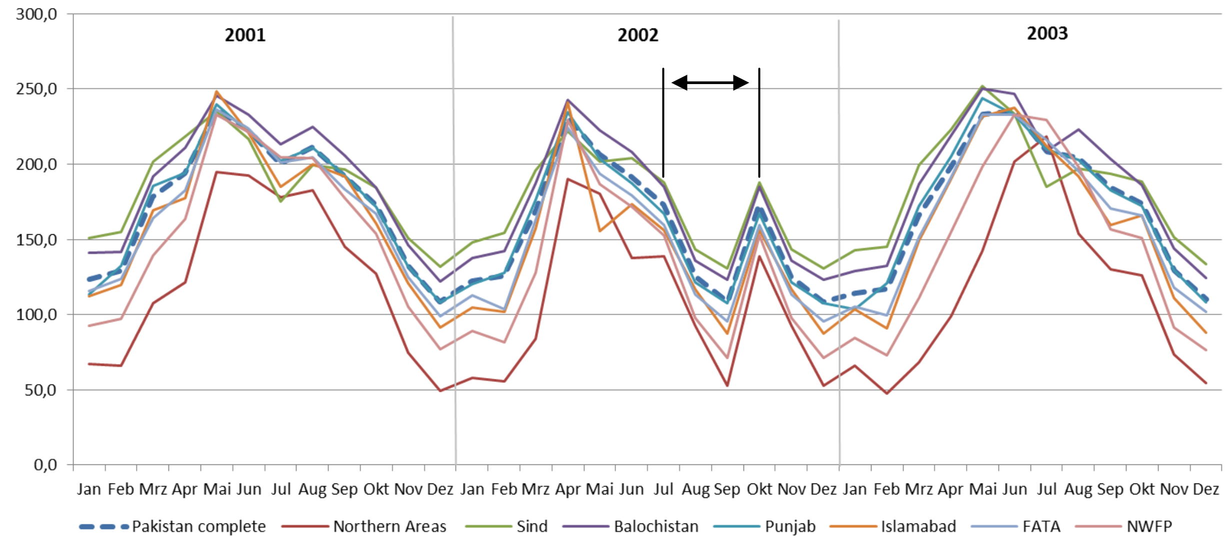


Figure 9: Monthly sums of GHI 2001-2003 for Pakistan and Provinces in kWh/m² based on satellite estimates.

Figure 10 reveals the annual average sum of GHI distributed in Pakistan. The black lines indicates the frequencies for the whole country, while the colored lines indicate the frequencies for four different elevation levels (see legend in Figure 10 and ANNEX D). This approach considers the fact that Pakistan is characterized by its distinctive topography. Satellite estimations show that 75% of the land area of Pakistan has annual average GHI sums above 2000 kWh/m² and 92,6% are above 1500 kWh/m².

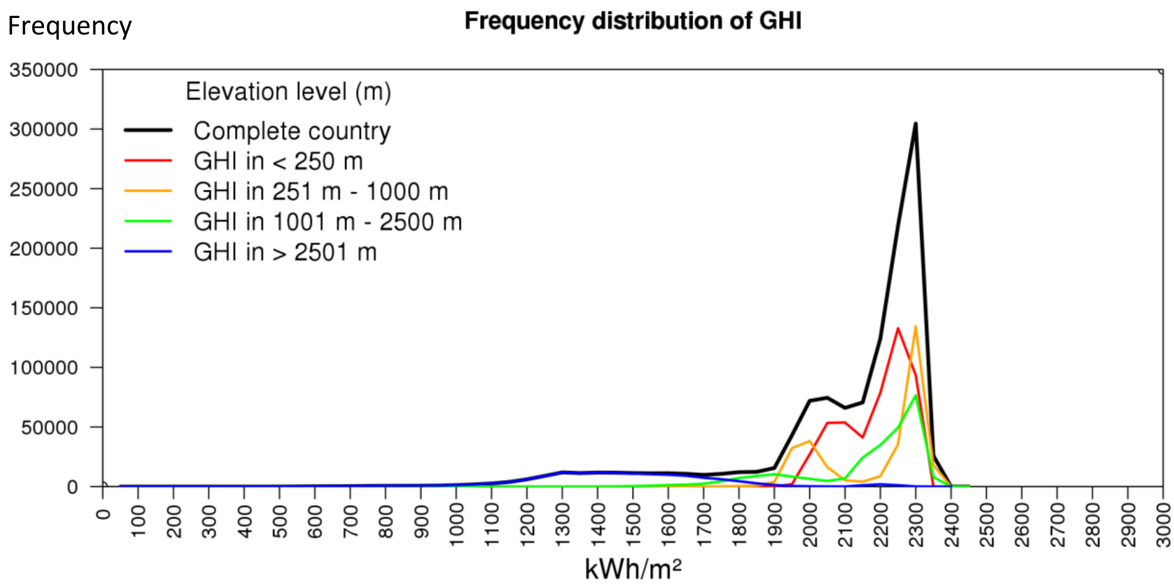


Figure 10: Frequency distribution of GHI (2000-2012 annual average sum) for complete Pakistan and elevation levels based on satellite estimates

3.3 Direct Normal Irradiance

The Direct Normal Irradiance (DNI) reaches highest values on dry plateaus or rock desserts when there is little or no dust advection from surrounding regions. Generally, high sums of DNI are available all over Pakistan, with the exception of the Himalayan Mountains. Estimated peak values, exceeding 2700 kWh/m², can be found in northwestern Balochistan, while 83% of the land area still exceeds the threshold of 2000 kWh/m². These maximum values are comparable with the maximum values surrounding the Sinai Peninsula, which represents one of the top locations for irradiance in the MENA region. As already stated in the solar regimes report, it is important to consider the inter-annual as well as the intra-annual availability of irradiance beyond the annual sums.

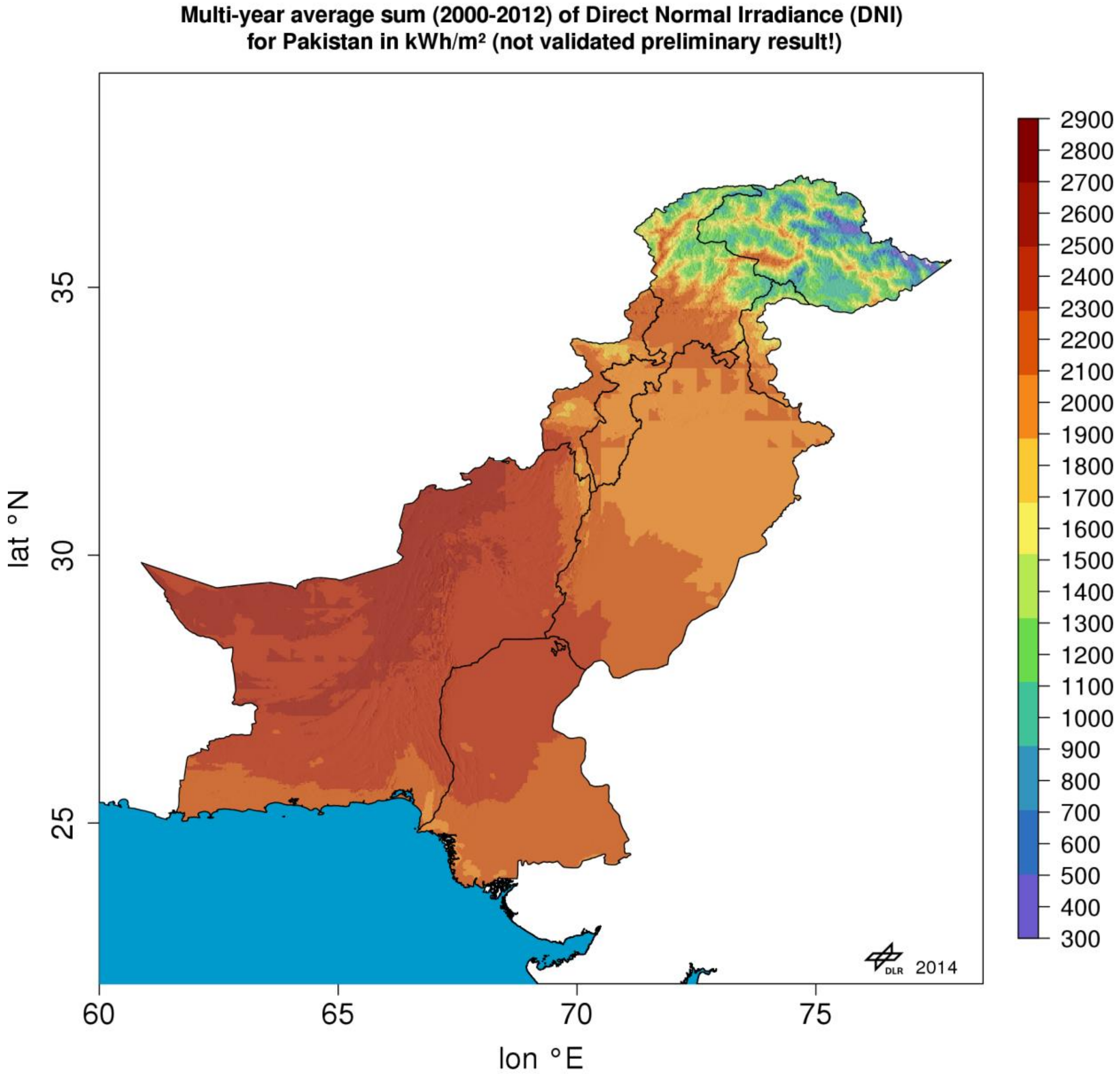
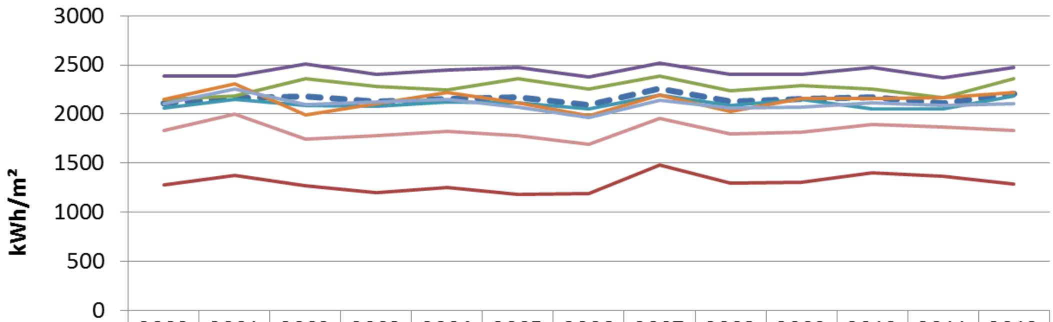


Figure 11: Multi-year mean (2000-2012) of annual Direct Normal Irradiance (DNI) for Pakistan in kWh/m²

The characteristics of the fluctuation of the annual sums of DNI for Pakistan is, like the sums for GHI, only small. With exception of Kyber Pakhtunkhwa and the Northern Regions, the average of the yearly sums for most years is around 2100 kWh/m² for most regions. Highest values are estimated for the provinces of Sindh and Balochistan, where annual sums can exceed 2400 kWh/m² on average in some years (see Figure 12). Highest annual sums are estimated for the years 2007 and 2012.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Pakistan	2105	2163	2182	2123	2156	2169	2090	2258	2129	2154	2172	2111	2202
Northern Reg.	1280	1377	1273	1195	1248	1180	1191	1479	1292	1303	1399	1365	1288
Sindh	2149	2186	2357	2281	2248	2362	2255	2389	2237	2286	2251	2169	2360
Balochistan	2384	2390	2510	2399	2446	2474	2379	2518	2407	2400	2476	2367	2477
Punjab	2065	2151	2085	2082	2123	2110	2048	2196	2084	2152	2056	2054	2181
Islamabad	2147	2303	1988	2109	2219	2115	1979	2191	2028	2158	2159	2162	2217
Fata	2108	2251	2093	2123	2149	2072	1960	2144	2060	2070	2113	2090	2101
Khyber P.	1829	1998	1747	1778	1824	1782	1692	1955	1794	1819	1890	1870	1828

Figure 12: Annual sums of DNI (2000-2012) for Pakistan and Provinces based on satellite estimates.

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2600 kWh/m² (Figure 13). 83,5% of all values are above 2000 kWh/m² and 12,1% of values are above 2500 kWh/m². Highest values are reached in elevation levels above 251 m and in particular above 1000 m. Lowest values are found in the Himalayan mountains to the north of the area investigated.

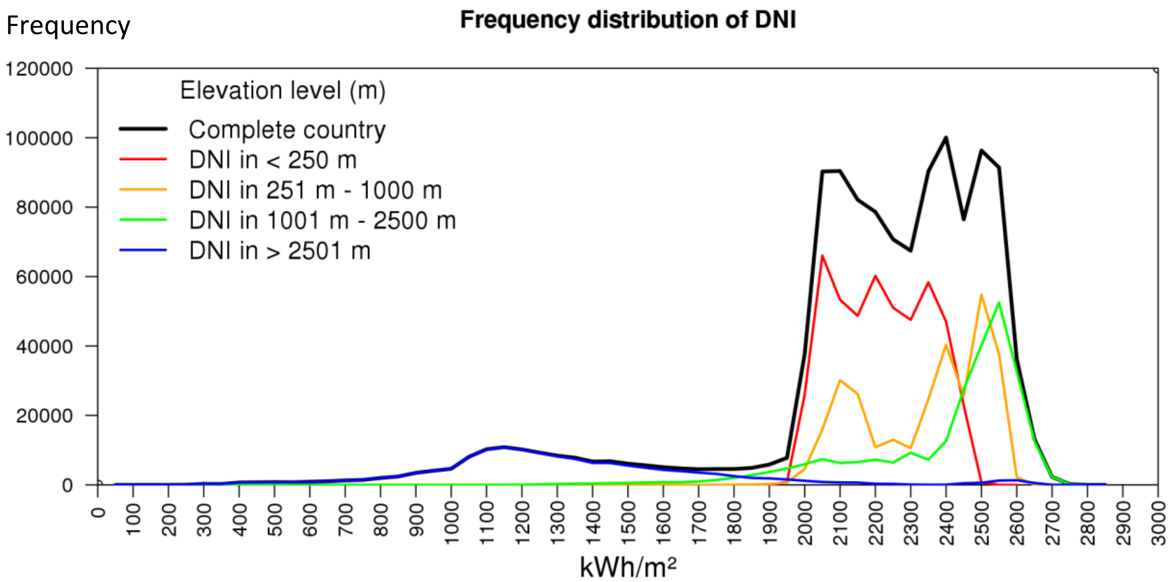


Figure 13: Frequency distribution of GHI (2000-2012 annual average sum) for complete Pakistan and elevation levels based on satellite estimates

3.4 Diffuse Horizontal Irradiance

Diffuse Horizontal Irradiance (DHI) has highest values along the Pakistan south coast and within Punjab. Diffuse Irradiance is an indicator for the intensity of scattering of solar irradiance and is influenced by particles, like dust and aerosols or water vapor in the atmosphere. The more hazy or cloudy the sky is, the higher is the diffuse component of irradiance. Relatively cloud-free areas like the region west of Quetta receive a higher share of direct irradiance since the diffuse portion of irradiance is small here. We can find the reversed situation in the coastal area south of Karachi, which is affected by persistent cloud cover throughout the year. In some places, the thresholds of values seem to have a "squared look" with sharp geometrical borders on the map of Figure 14. This is the consequence of using an aerosol model with a spatial resolution of 0.5° x 0.5°. No smoothing has been conducted to achieve scientifically valid and transparent results.

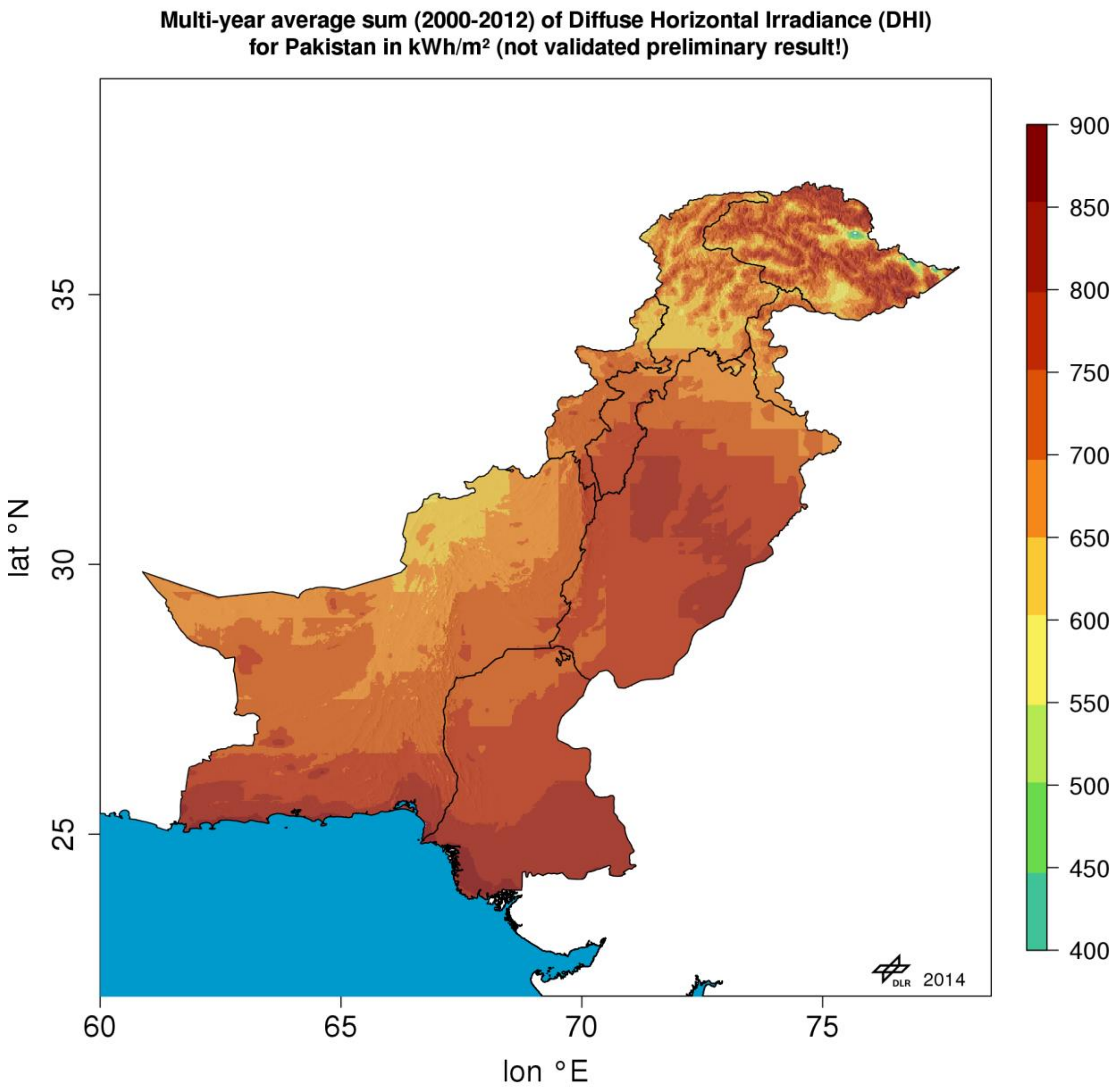


Figure 14: Multi-year mean (2000-2012) of annual Diffuse Horizontal Irradiance (DHI) for Pakistan in kWh/m²

These artefacts are also visible in the DNI map of the following chapter. The surface measurements of Phase 2 will help to reduce this effect and to optimize the aerosol models for the irradiance transfer processing.

Frequencies of DHI (Figure 15) show the distribution of the diffuse fraction of irradiance. Most pixel cells show annual average sums between 650 kWh/m² and 850 kWh/m², strongly depending on the location of each pixel. The lowlands in eastern Pakistan (below 250 m) have a high share of diffuse irradiance, while the high plateaus to the west and particulary the mountains to the north have a significantly lower portion of diffuse irradiance.

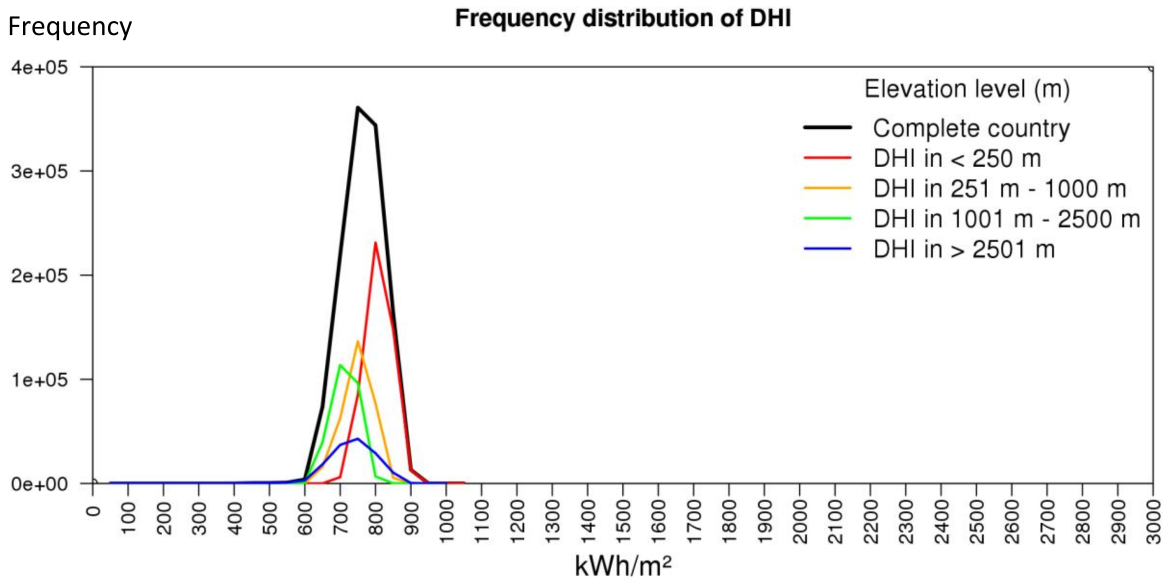


Figure 15: Frequency distribution of DHI (2000-2012 annual average sum) for complete Pakistan and elevation levels based on satellite estimates

4. “A 120 days of wind” – dust events with distant origin affect Pakistan

Satellite imagery of the South-Asia region reveals frequent outbreaks of dust, which have a large impact on Pakistan’s climate and solar irradiance in the summer months. In South Asia, the highest values of mean mineral dust concentration - estimations based on visibility - are found in Pakistan (Rezazadeh et al., 2013). The main source of dust and sand in the atmosphere can be traced back to the Sistan/Helmand river basin in western Afghanistan and Iran.

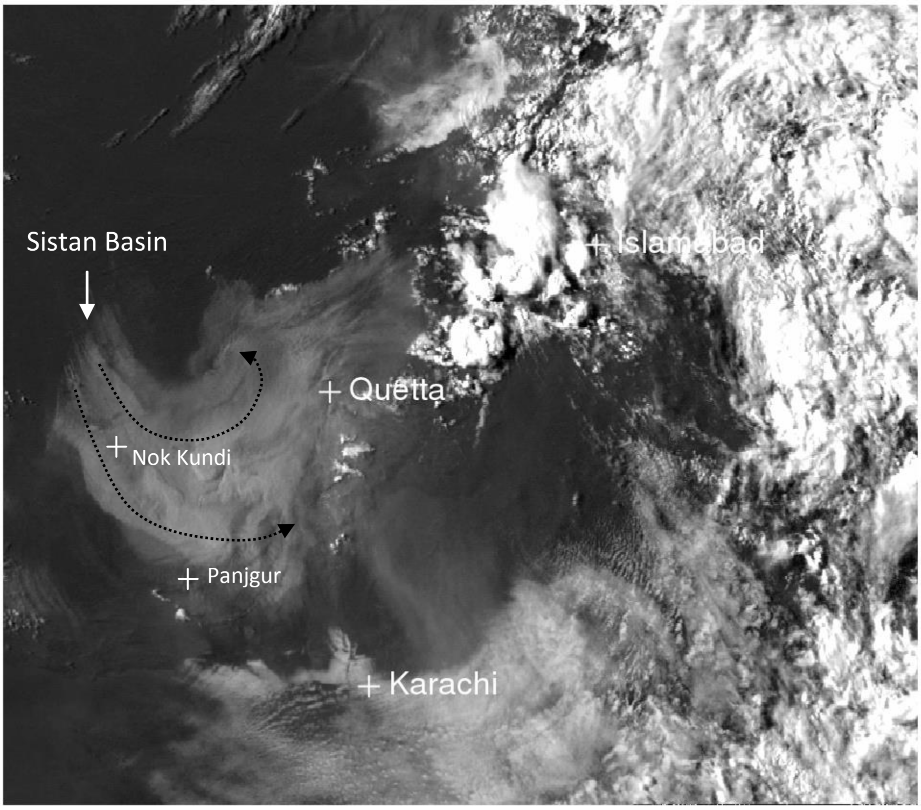


Figure 16: Met-5 imagery of dust outbreak in August 2002. Dotted lines indicate propagation of dust.

The Sistan Basin receives about 50 mm of precipitation annually in “normal” years but is mainly nourished by snowmelt-water of the Hindu Kush. A severe drought, beginning in 1998, has caused the Sistan basin to dry out (UNEP, 2006). Besides the negative impacts on the region’s agriculture, a further consequence for even distant places can be seen in Figure 16. Atmospheric dust transport obscures the skies east and south of the basin, in this case affecting Balochistan and even Sindh. These, sometimes regional events, can only hardly be captured by global chemical transport models, which have a nominal spatial resolution of at least 0.5° x 0.5° (approx. 50 km x 50 km) or less. Strong dust cases like the example displayed in Figure 16, can be detected by the cloud-detection algorithm of the Meteosat Satellites. In this specific case, a massive dust plume was triggered by a nortwesterly flow and has been advected as far as Karachi and eastern Punjab, while the highest atmospheric dust load could be examined over Balochistan and southern Afghanistan.

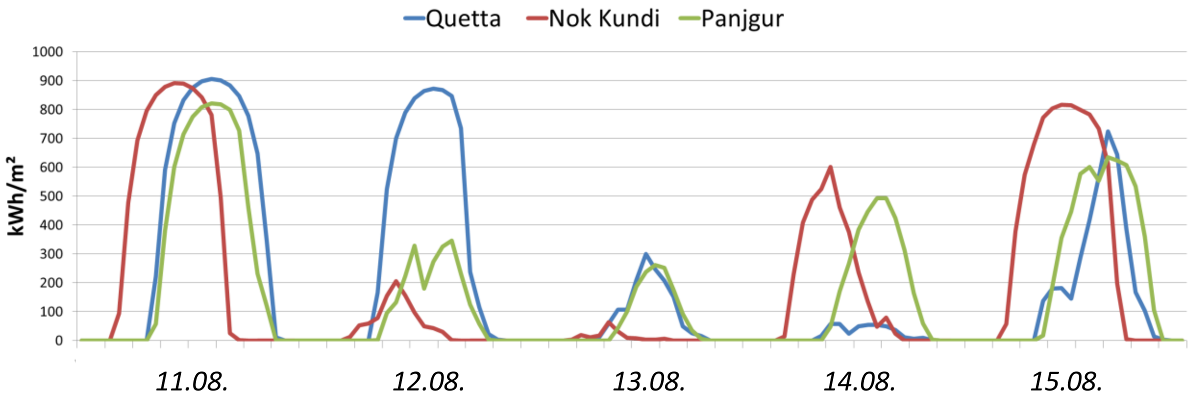


Figure 17: Hourly DNI values for three locations in Balochistan during 11.-15. August 2002 dust case. Data from MET-7 in hourly temporal resolution and ~5 km by 5 km spatial resolution.

Figure 17 reveals the impact of the aerosol load on the DNI estimate in Balochistan for Nok Kundi, Quetta and Panjgur in a certain example. August 11th 2002 was a clearsky day for all of the three locations and satellite imagery (not included) shows that the dust plume was triggered in the early afternoon over the Sistan basin, but has not reached Pakistan yet. During the following night hours, the dust plume reached southern Balochistan and obscured the sky over Nok Kundi. As Panjgur is located at the southern edge of the plume, DNI values did not drop as low as it did in Nok Kundi. Quetta still experienced a clear sky until the late afternoon that day. August 13th shows the highest atmospheric dust-load for all of the three locations, mirrored by the very low DNI values (see also Figure 16). It is remarkable that DNI estimates did not even reach 75 kWh/m² in Nok Kundi at this date. August 14th brought more clear skies to the south of Balochistan (Nok Kundi and Panjgur), while Quetta experienced the peak of its dust load on that day with very low values of DNI. On August 15th the skies began to clear up steadily and hourly DNI sums increased. This dust plume was (along with the other major dust outbreaks) detected by the cloud-index algorithm. From Figure 16 it is easy to see that dust clouds reveal a similar reflectance as low. Stratiform clouds or fog.

This strong dust transport is triggered by a frequently recurring system called “the wind of the 120 days”, which appears every year in the summertime. Between a heat low over the Iranian dessert and a high pressure system over the Hindu Kush, a persistent (mainly nocturnal) low level jet is generated, resulting in a large scale dust emission that originates in the Sistan Basin (Alizadeh-Choobari et al., 2014). The retention time of the dust aerosol content can be relatively long and lead to regional dimming of irradiance, even days after the actual outbreak. At a measurement site in Quetta, dozens of dust cases have been observed in the period between 1998 and 2003 (Rezazadeh et al., 2013). Along the leading edge of a moving dust plume a further effect of increased aerosol content becomes apparent on satellite imagery - a change of aerosol content influences cloud development and –lifetime (Charlson et al., 1992). These regional effects have to be monitored closely in solar resource assessments and play an important role in the irradiation budget of a country.

5. Winter fog areas in Punjab and Sindh

From fall to winter, frequently recurring dense fog affects northeastern Pakistan and decreases solar irradiance drastically. A study revealed that especially persistent high-pressure systems favor the accumulation of anthropogenic pollutants (aerosols) in industrialized areas like Lahore, which lead to widespread development of fog over large areas (Hameed et al., 2000).

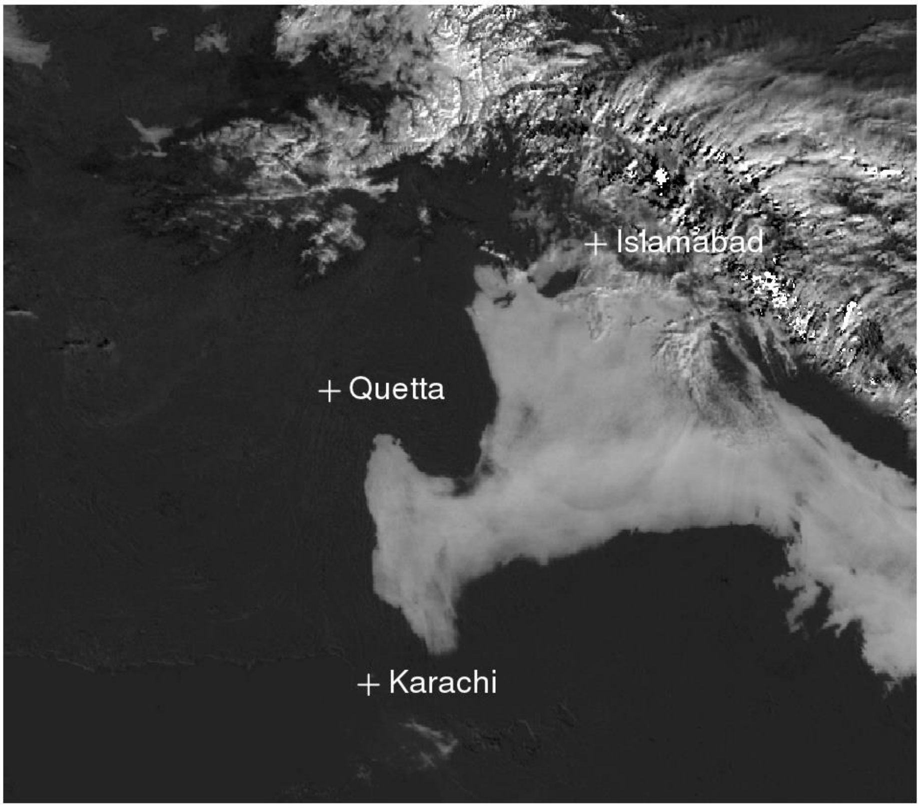


Figure 18: Met-7 imagery of winter fog in Punjab and Sindh in January 2011.

Figure 18 shows a satellite image of Meteosat-7 with a typical winter-fog situation in northern and eastern Pakistan. Cloud free skies elsewhere indicate the presence of a strong high pressure system over Pakistan and surrounding areas, leading to a nocturnal formation of fog cover over the Indus plains. This layer of fog generally has its maximum extension in the early morning hours and shrinks during the day with increasing strength of the sun. Some areas only are covered by fog for a short time after sunrise and some other areas are fogged in for the whole day. This situation can last for several days in a row, with increasing fog cover every morning, until a disturbance clears the inversion and fresh air brings relief to the affected areas. As emissions are likely to increase in the future, fog episodes may increase in the region (Hameed et al., 2000).

Irradiance is strongly affected and dimmed by thick layers of fog and only a few kilometers between locations can make the difference between a dull day and a sunny day with a lot of solar potential. The sharp borders of the fog cloud on the satellite image in Figure 18 are mainly caused by abrupt changes in topography. For project planners it can be of high importance to analyze if it makes sense to prioritize locations for solar plants in areas that are not as much affected by such local effects, even though this means a greater distance from the source to the end-consumer. Figure 19 shows an irradiance time series of two towns for five days in January 2010. The locations were chosen arbitrarily but it is a good example for two nearby cities (~18 km apart) with significantly different solar irradiance regimes during winter fog days. Tatral is located on a plateau northwest of a mountain ridge at an elevation of 700 m. Pind Dadan Khan is situated on the banks of River Jhelum at an elevation of 200 m.

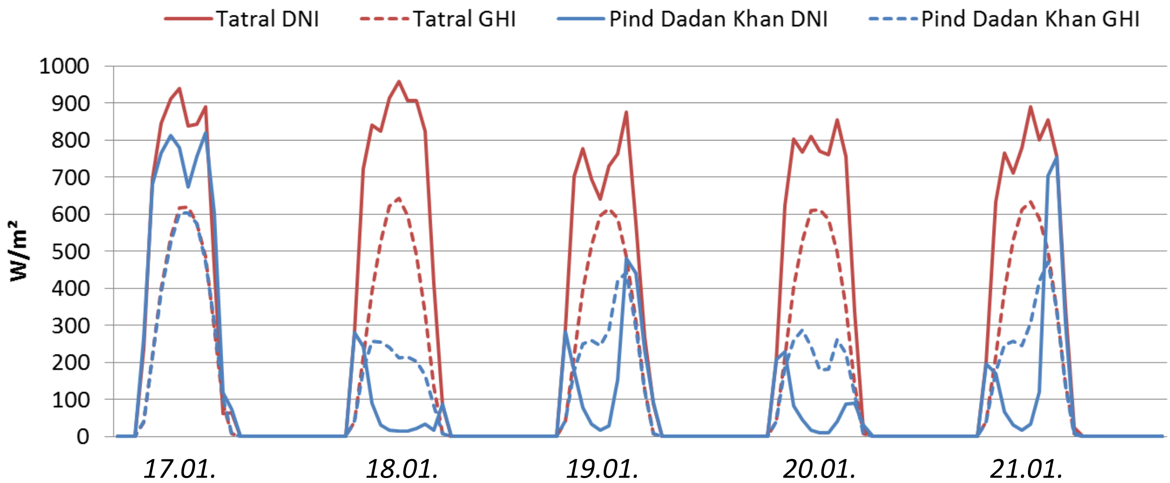
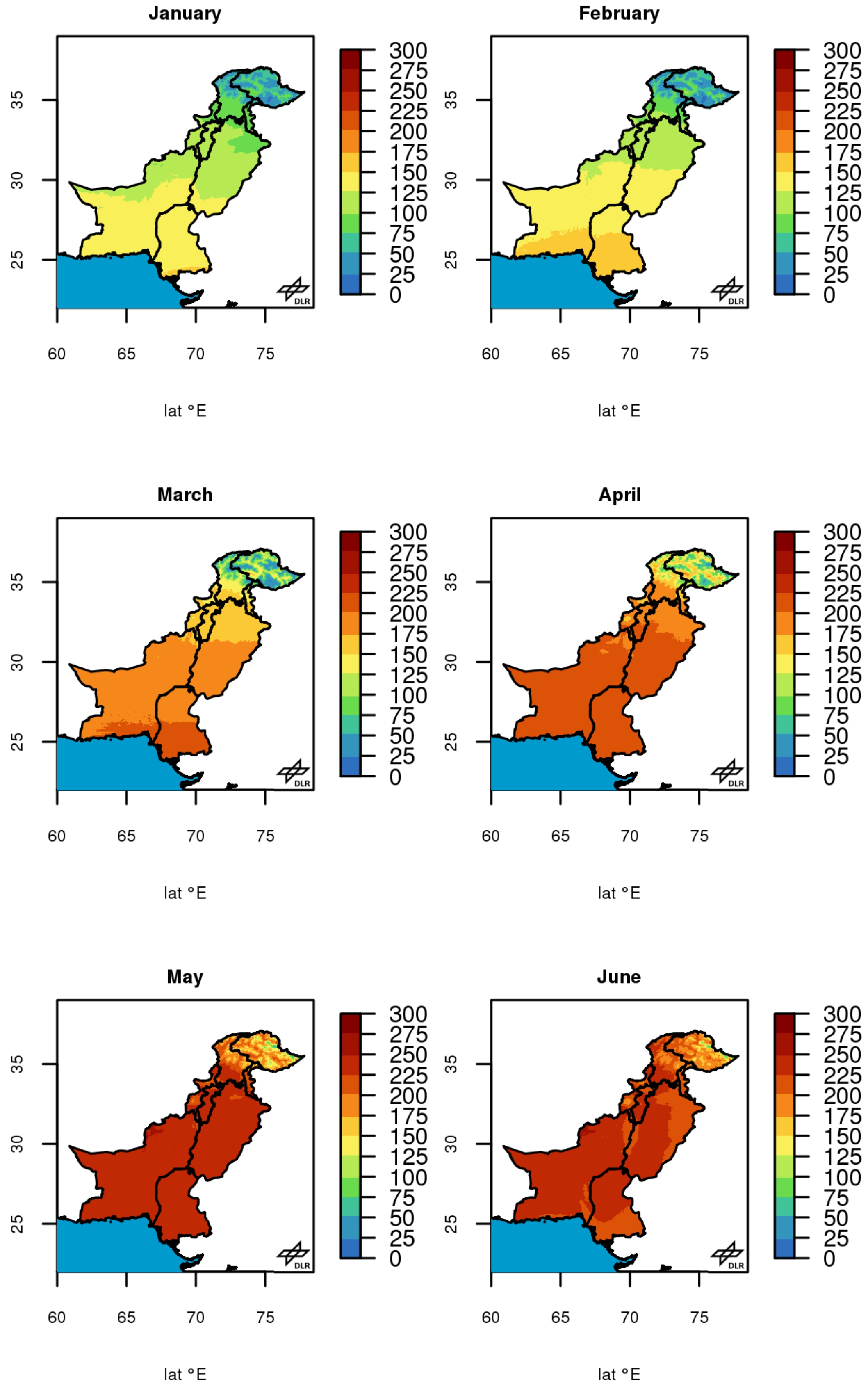


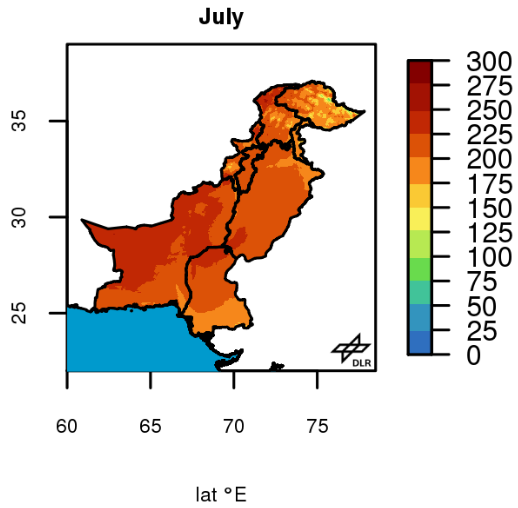
Figure 19: Time series DNI and GHI for two adjacent cities in northern Punjab (January 2010).

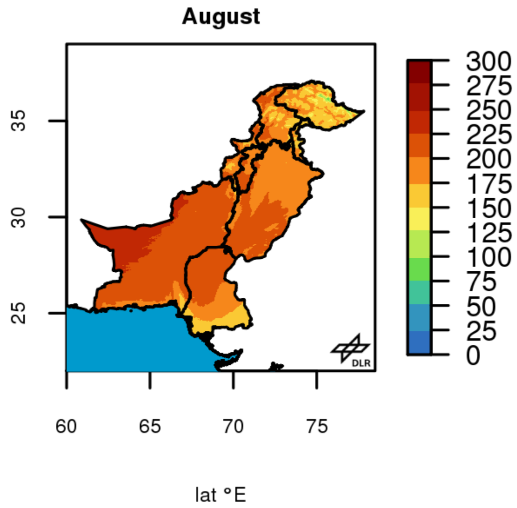
As shown in the Figure above, Tatral received much higher values of irradiance than Pind Dadan Khan. This is caused by the big difference in elevation (Tatral is located above the nocturnal inversion) and the shelter of the mountain ridge between the high plateau and the river valley below. January 17th shows nearly clearsky conditions for both locations, revealing only a small “dent” in for DNI in the afternoon due to temporal high cirrus cloud cover. The following days show big differences in DNI and GHI between the locations due to the influence of the high atmospheric pressure and the presence of fog in Pind Dadan Khan. Nevertheless, January 19th and January 21st show an increase of irradiance in the late afternoon hours, as the fog was heated away by the suns influence. Tatral neither received the full amount of sunlight, as it was affected by thin cirrus clouds, but still the differences in hourly/daily sums are significant between both locations. Low fog or stratus can be detected by the satellite very well on visible and ir-channels.

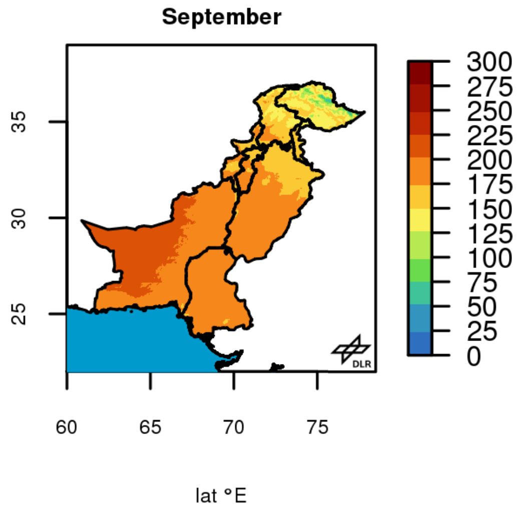
ANNEX A – Multi-year monthly-means of GHI in kWh/m² (part 1)

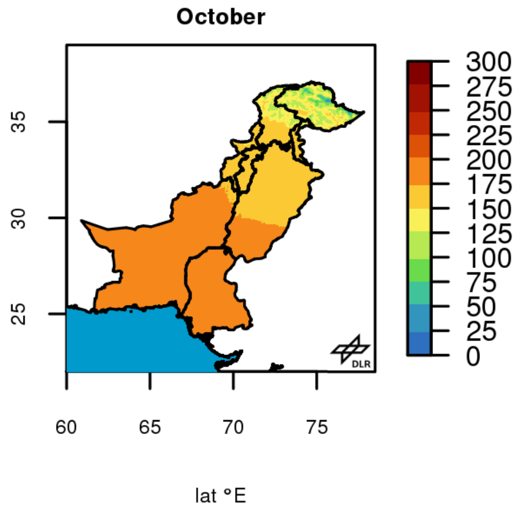


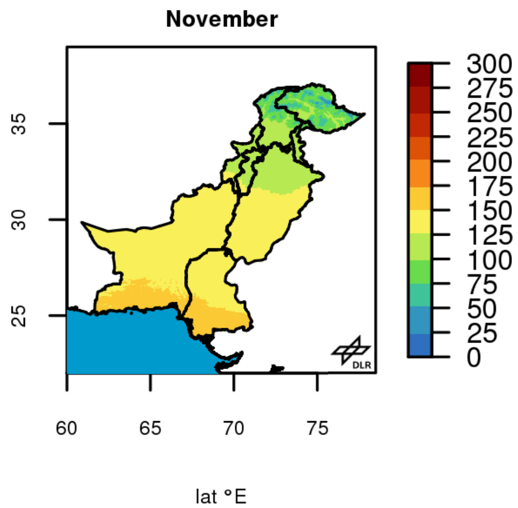
ANNEX A – Multi-year monthly-means of GHI in kWh/m² (part 2)

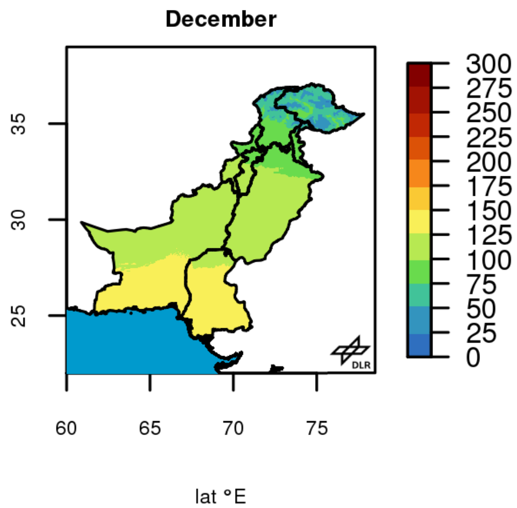




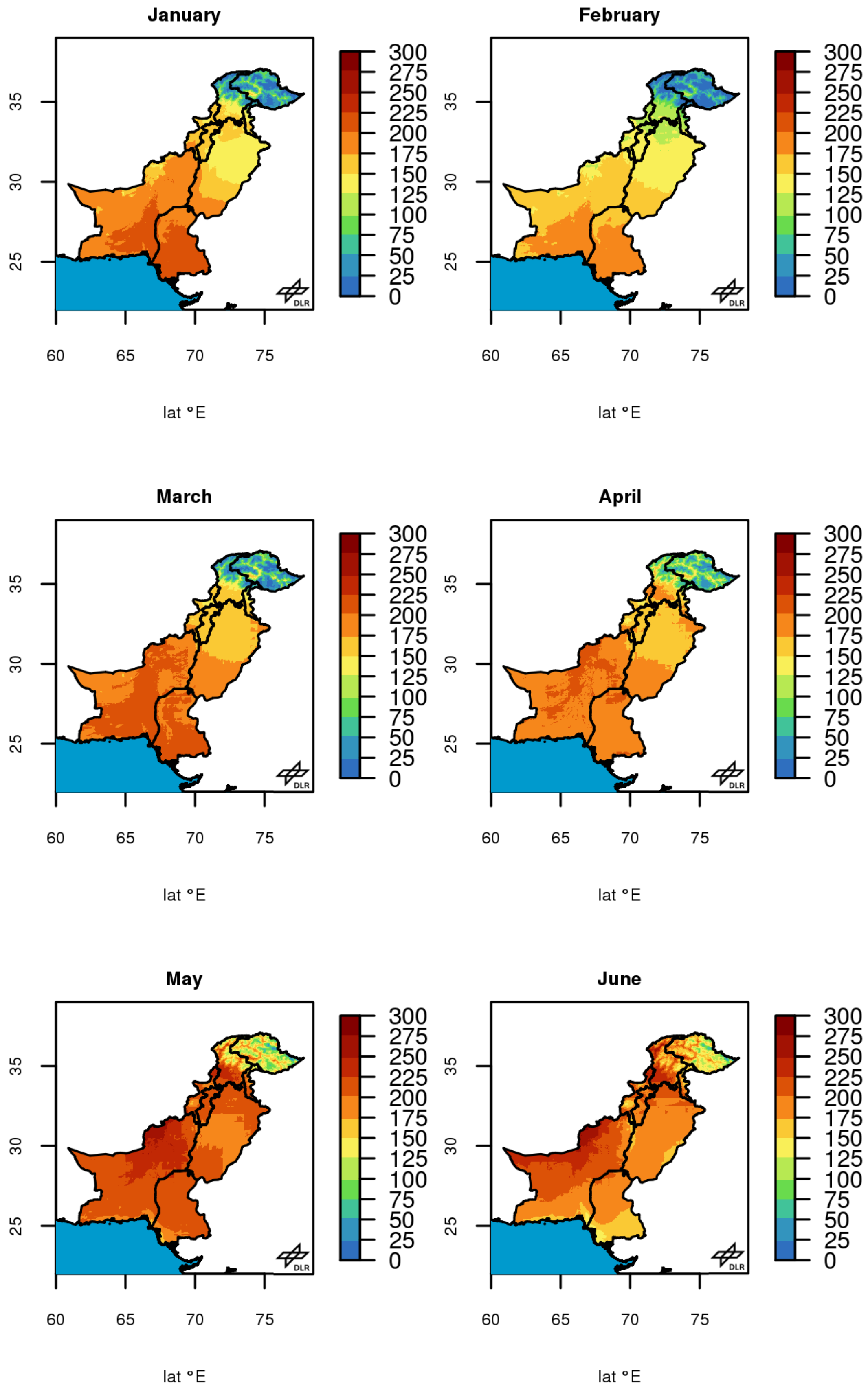




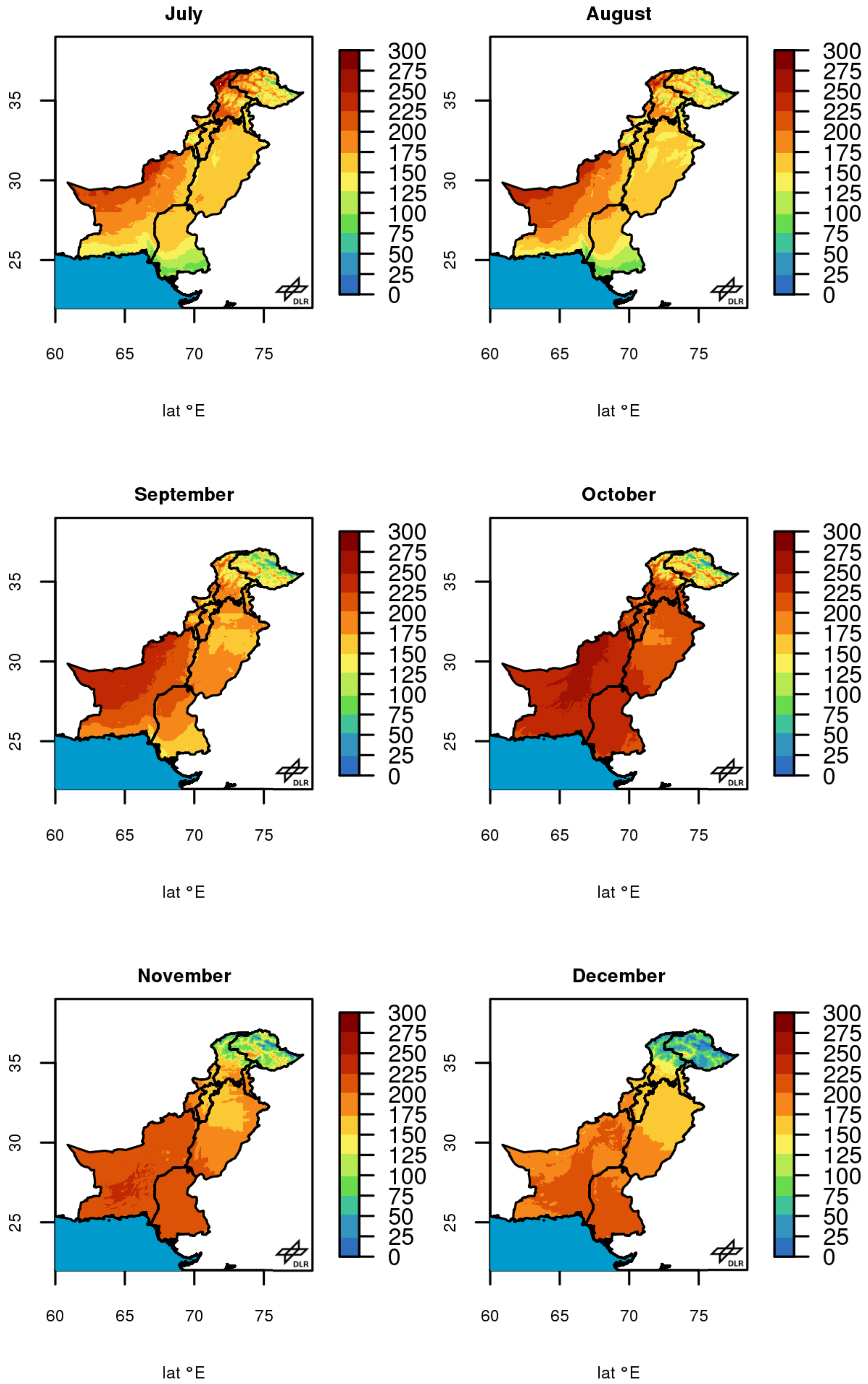




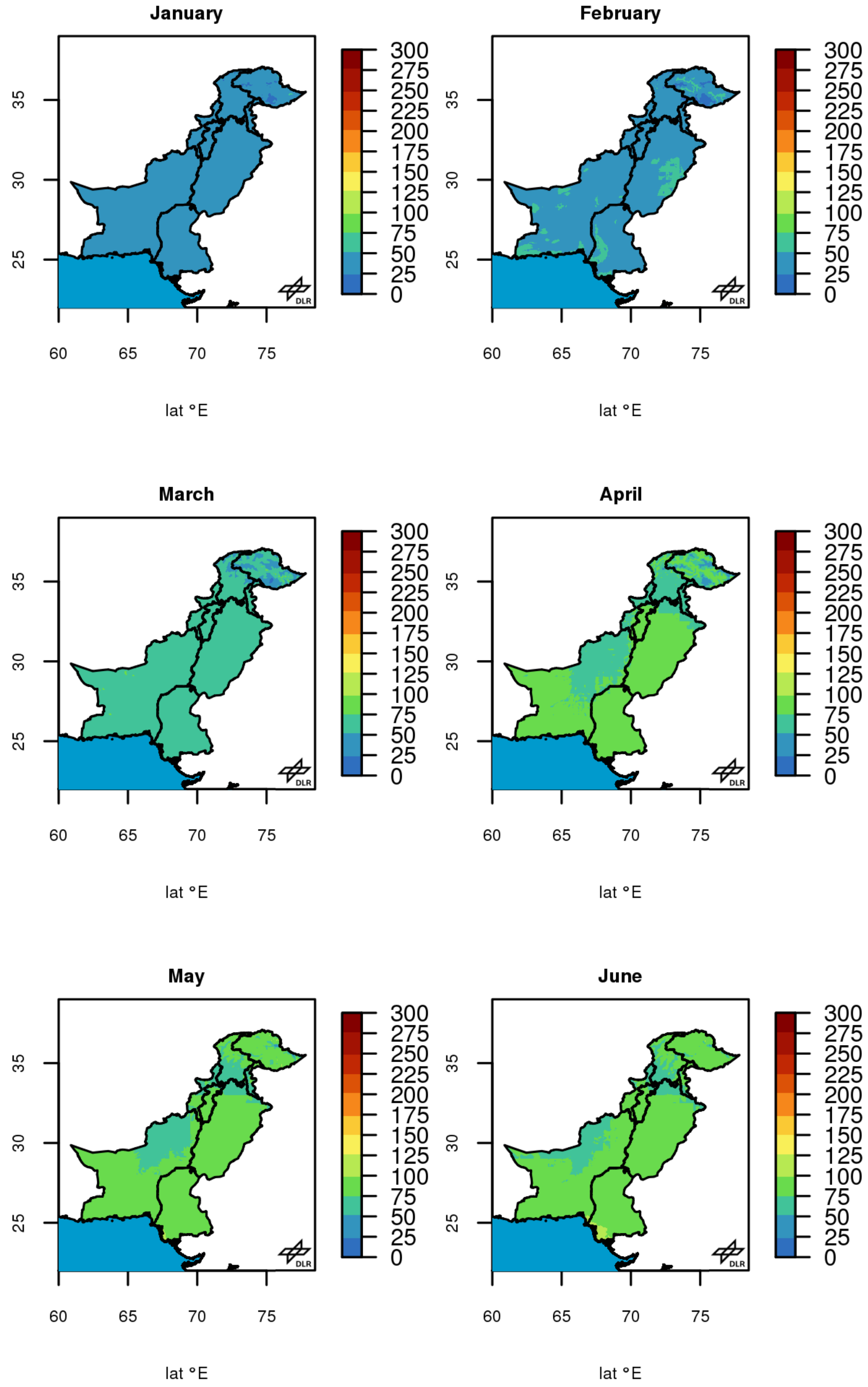
ANNEX B – Multi-year monthly-means of DNI in kWh/m² (part 1)



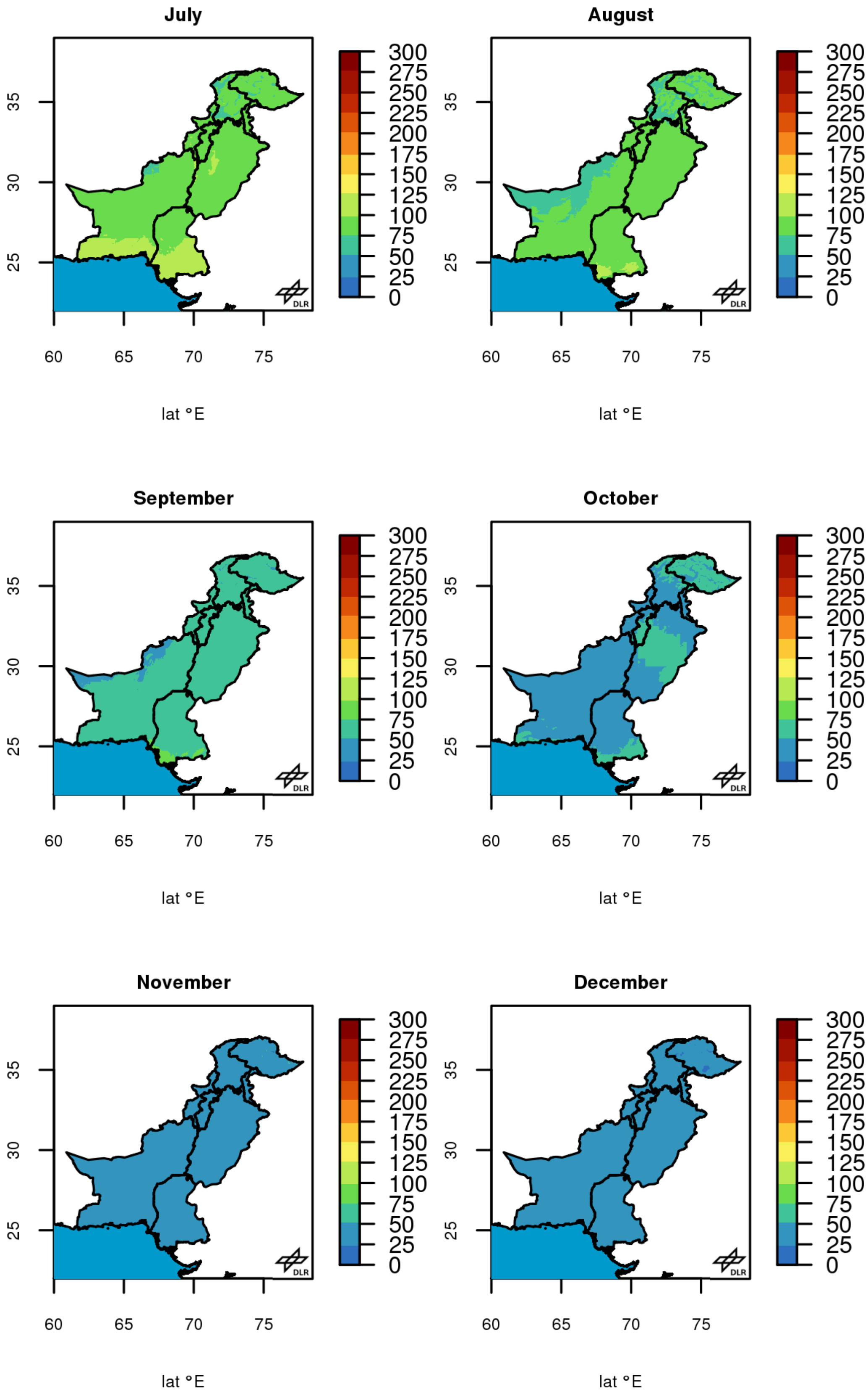
ANNEX B - Multi-year monthly-means of DNI in kWh/m² (part 2)



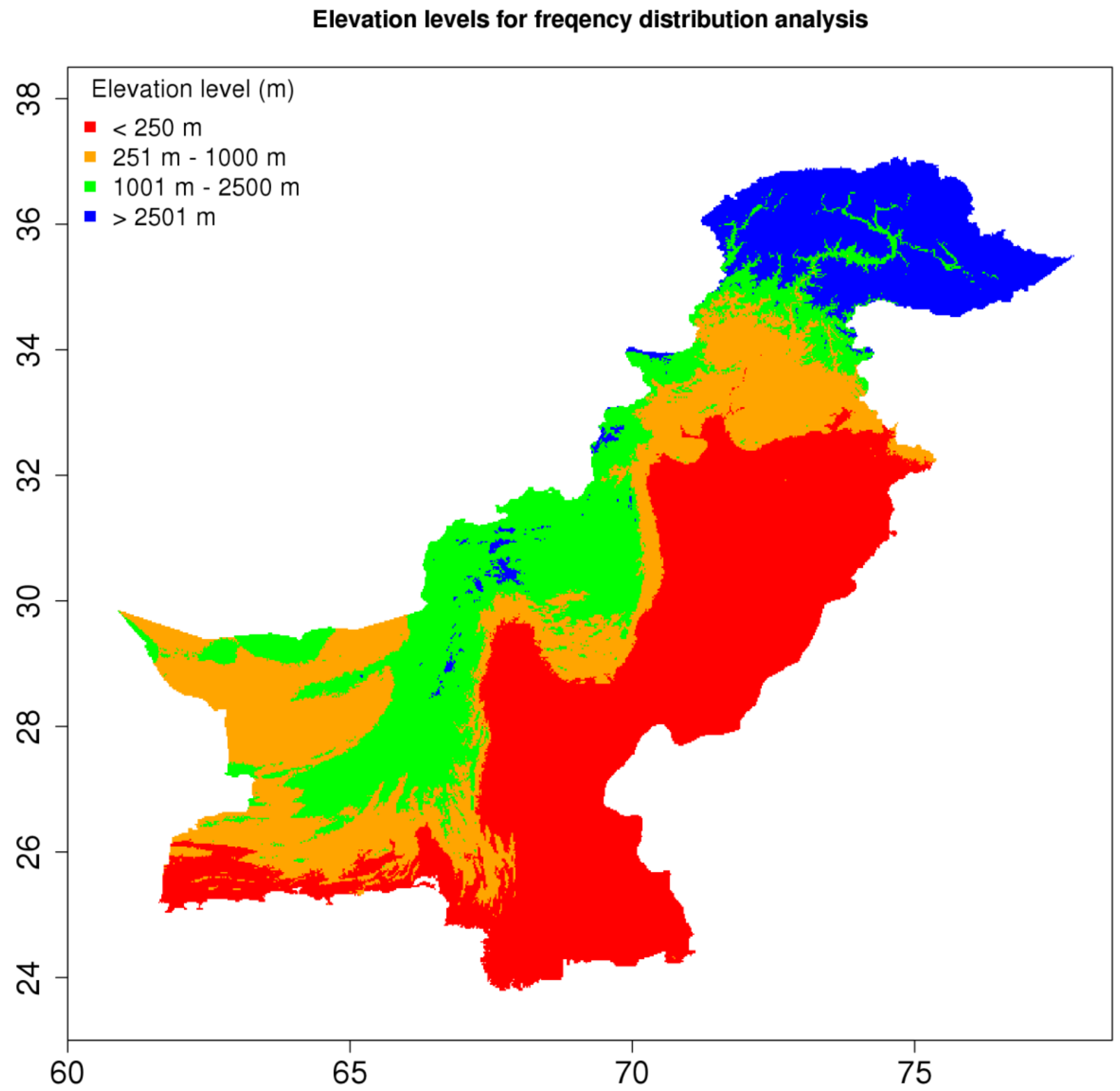
ANNEX C – Multi-year monthly-means of DHI in kWh/m² (part 1)



ANNEX C – Multi-year monthly-means of DHI in kWh/m² (part 2)



ANNEX D – Map of elevation levels



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