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Solar energy resource assessment in Chile: Satellite estimation and ground station measurements

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ABSTRACT

The progress from the last four years in solar energy resource assessment for Chile is reported, including measurements from a ground station network spanning from two to three years of data, and satellite estimations from the recently developed Chile-SR model including two full years of data. The model introduces different procedures for the meteorological variables and the effective cloud cover computations that allow estimation of the global horizontal and diffuse irradiation on an hourly basis. Direct normal irradiation is computed by applying proper solar geometry corrections to the direct horizontal irradiation. The satellite estimation model was developed as an adaptation from Brazil-SR model, with an improved formulation for altitude-corrected atmospheric parameters, and a novel formulation for calculating effective cloud covers while at the same time detecting and differentiating it from snow covers and salt lakes. The model is validated by comparison with ground station data. The results indicate that there are high radiation levels throughout the country. In particular, northern Chile is endowed with one of the highest solar resources in the world.

1. The need for solar energy data in Chile

Recently, Chile has renovated his law of Renewable Energy promotion. The new regulation sets a quota for energy coming from renewable sources of 20% of the total electricity production to be achieved in 2025 [1]. This plan increases the quota previously established by the former governments (10% of electrical energy generated by 2024 [2]) and encourages power generating companies to incorporate renewable energy systems to the country's electricity system. Solar energy is currently at the initial stages of market penetration, with several projects being announced including photovoltaics (PV), concentrated solar power (CSP), and industrial process heat supply plants. However, strong barriers still exists due to the absence of a valid solar energy database, adequate for energy system simulation and planning activities. In fact, the current state of Solar Energy utilization in Chile is rather unsatisfactory. Even as the country is being endowed with an exceptional solar potential, the contribution of solar energy to the energy mix in Chile is negligible. Only 6.7 MW of PV are currently in operation and 126 MW are being built [3]. Although there have been several announcements for commercial and demonstration plants, no additional projects are currently in execution – either PV or CSP. Worth mentioning that there are two projects to deliver process heat: a parabolic trough collector's plan was built at Minera El Tesoro in Northern Chile [4]; and a flat-plate collector plant for Codelco, located in Division Gabriela Mistral, is at construction stage [5]. As of November 2013, the Environmental Impact Assessment System (SEIA) listed a total of 5167 MW of solar plants approved that have not yet initiated construction. Also several projects have applied for environmental evaluation, totalizing 2695 MW; of which 360 MW correspond to a single CSP project (4×90 MW), 400 MW belong to a solar power tower project and the rest are PV plants. However, according to the Chilean Government Renewable Energy Center (CER) [6], none of the projects has already secured funding and are facing serious financial difficulties. Regarding solar heating and cooling systems, statistics from the "Solar Program" at the Energy Ministry indicate that as of 2011 there are 58,000 m^2 of installed solar thermal collectors for both the residential and commercial sectors, projected to reach 190,000 m^2 by 2015 [7]. There are

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currently no solar desalination projects in Chile. One of the several reasons that explain this difficulty in financing solar projects lies in the lack of adequate resource assessment activities that could allow reducing the risk associated to the real energy yield of the solar plants to be deployed in Chile. The efforts of our research team aim to produce and make available to the public and industry a proper set of solar radiation data able to allow project development with lower resource-related uncertainty.

Previous reports by the authors identified several databases of solar radiation which are available for Chile and discussed their merits and shortcomings. It has been found that significant deviation exists between sources, and that all ground station measurements display unknown uncertainty levels, thus highlighting the need for a proper, country-wide long-term resource assessment initiative. However, the solar energy levels throughout the country can be considered as high, and it is thought that they are adequate for energy planning activities – although not yet for proper power plant design and dimensioning. As a general conclusion, the previous work by the authors demonstrated that although for Chile there are several databases of ground measurements, a weather simulation model, and satellite-derived data, none of these data sources are completely valid and therefore a nationwide effort of resource assessment was needed [8–10].

As context, it is possible to mention that solar radiation data for large spatial regions can be obtained from ground station networks that provide discrete data points from which a continuous map can be obtained by means of a proper interpolation scheme. In addition, surface radiation can be estimated by satellite data processing. The latest Brazilian Solar Atlas [11], for example, combines both measurement techniques in order to obtain data with low uncertainty levels. Pyranometer-based measurements from ground stations typically have lower uncertainty levels that satellite-derived data obtained by radiative transfer models, although this cannot be guaranteed for locations in between stations for data that has been computed by means of interpolation schemes. However, it has been shown that uncertainty levels for ground stations data are higher than satellite-derived measurements whenever the distance between stations is larger than 35 km [12,13], and thus, a sensible resource assessment campaign will try to use satellite-derived irradiance for ample terrain coverage, at the same time as the use of ground stations for monitoring and validation purposes. As reference regarding proper time periods for measurement campaigns, the temporal variability of solar irradiance indicates that 5-year data sets can help determine the long-term average solar radiation with a fair degree of accuracy (estimated to be slightly larger than 5%), but do not contain enough information to accurately represent year-to-year variability. A 15-year data set can show inter annual patterns and trends, although statistically these variations are complex and do not follow a simple bell shaped curve of a random distribution. However, as mentioned by [14] a long term accurate average can be obtained by this data. The characteristics of solar irradiance can be described with a high degree of

Table 1
Ground station network.

Station name	Type	Start date of operation
1. Arica	RSBR	01/08/2011
2. Pozo Almonte	RSBR	04/04/2012
3. Patache	RSBR	16/01/2013
4. Sur Viejo	RSBR	07/07/2011
5. Crucero	RSBR	16/01/2012
6. Coya Sur	RSBR	05/07/2011
7. San Pedro	Sun Tracker	03/12/2010[a]
8. El Tesoro	RSBR	01/01/2009
9. Diego de Almagro	RSBR	02/08/2011
10. Santiago	Sun Tracker	22/12/2010
11. Curicó	Sun Tracker	01/06/2012
12. Talca	Sun Tracker	09/08/2012
13. Marimaura	RSBR	12/07/2012

[a] Operation finished 04/07/2011.

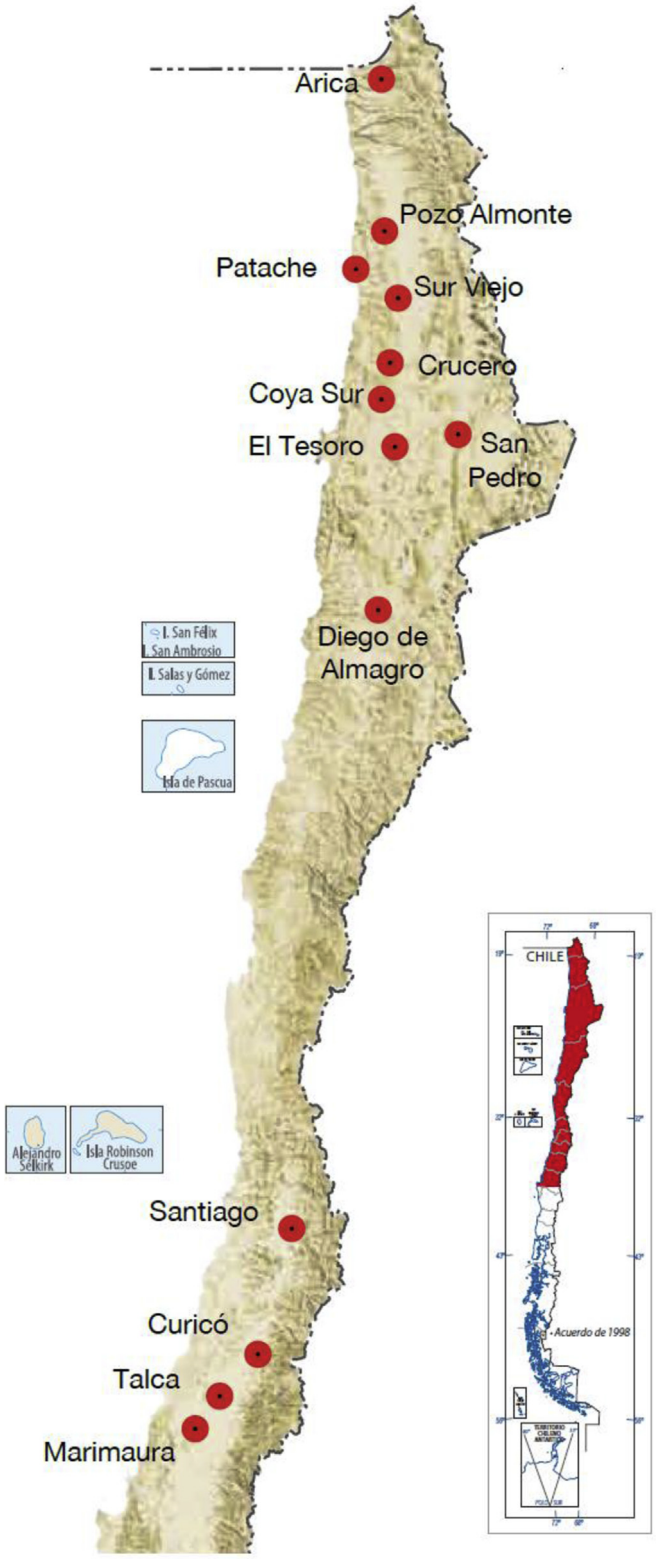

Fig. 1. Northern and Central Chile, and the approximate locations of the ground stations of the UC-FONDEF network.