

# A SATELLITE ESTIMATION MODEL FOR SOLAR ENERGY RESOURCE ASSESSMENT IN CHILE

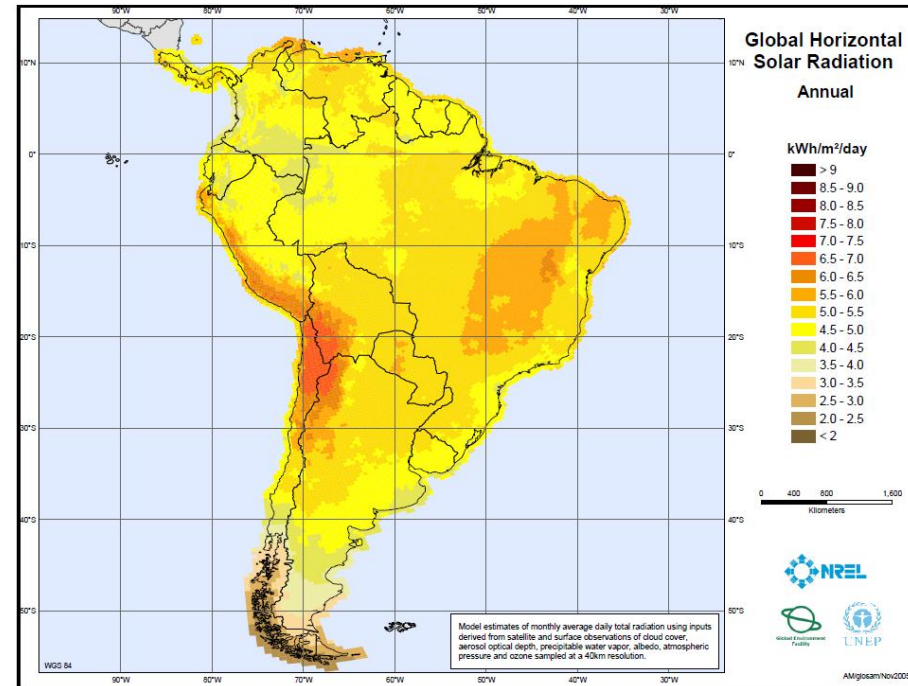
## Model CHILE-SR

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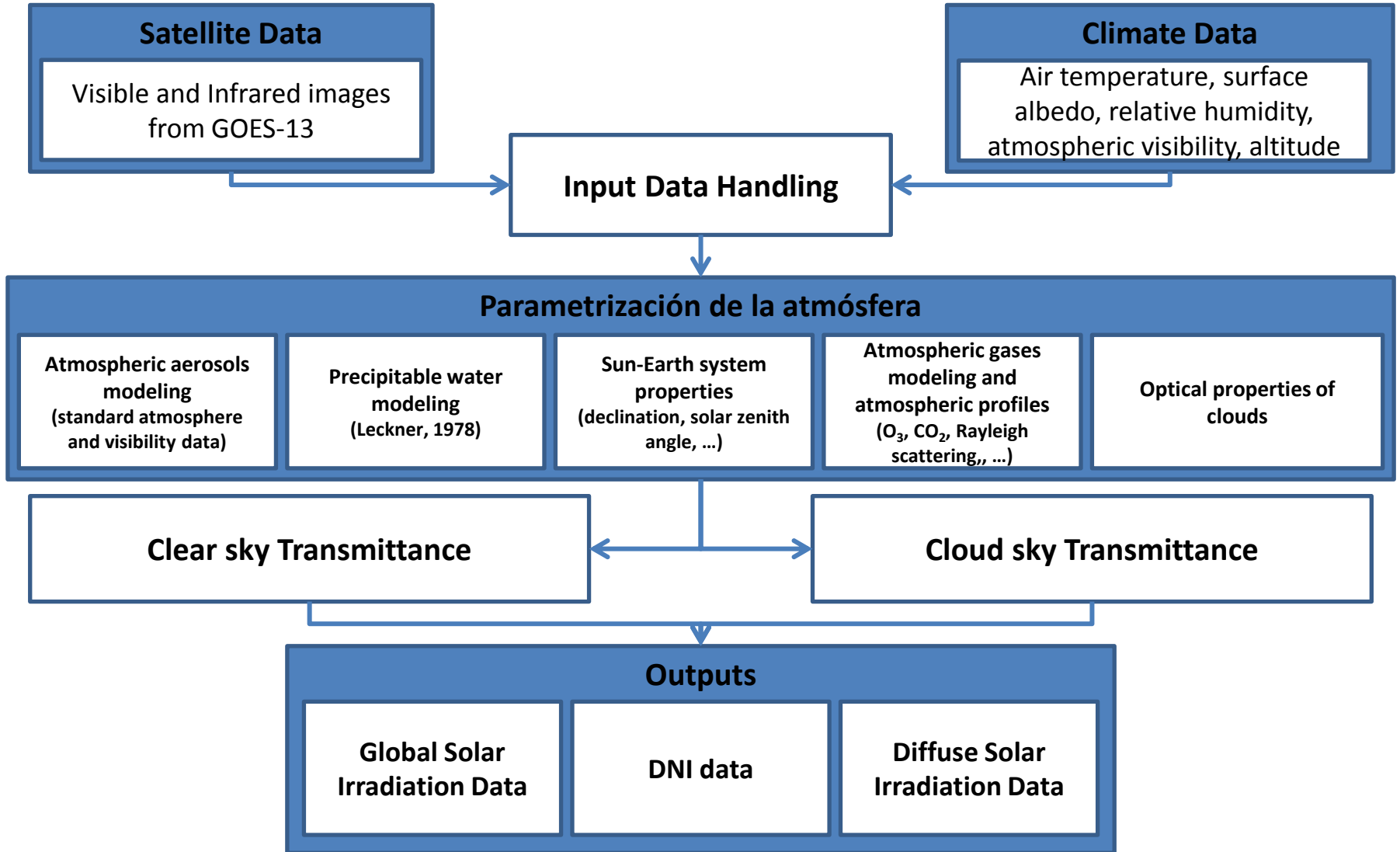
# Motivación



# Major Goals

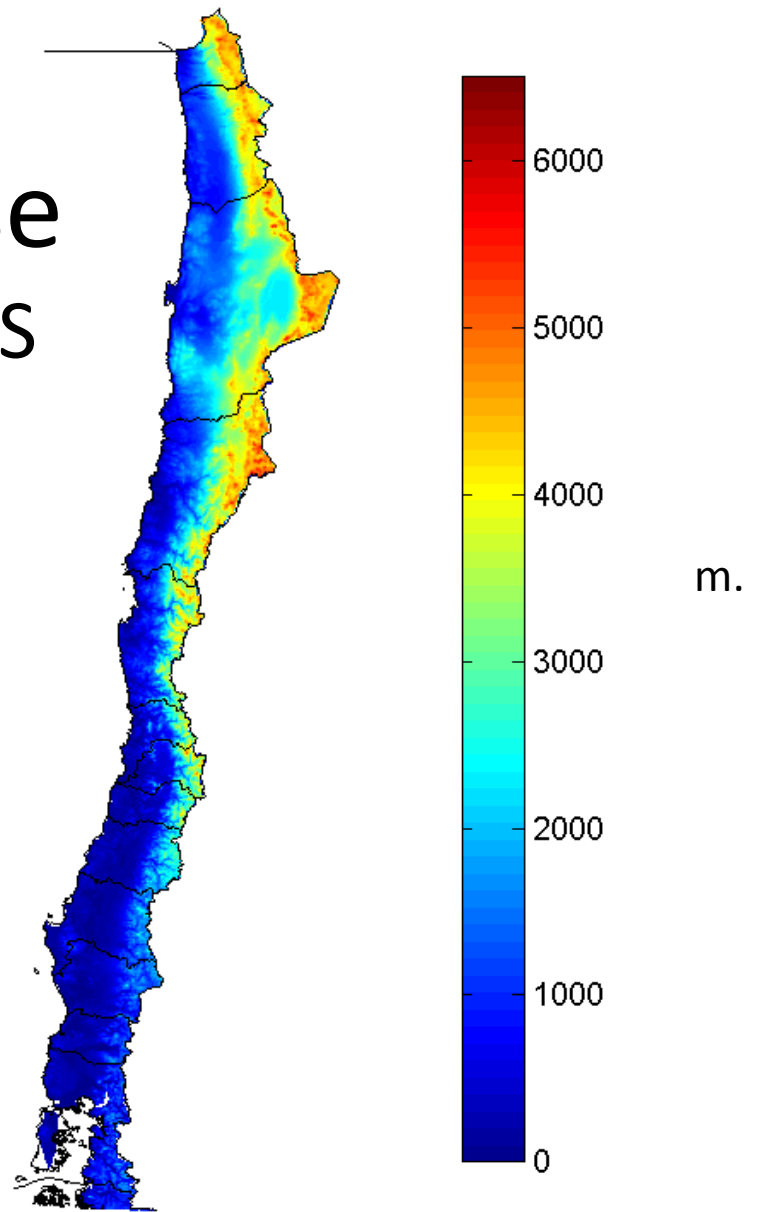
- Solar energy resource assessment for Chilean territory
- Develop suitable methodology for the climatic and environmental characteristics of the Chilean territory

# Model Chile-SR



# Topography database

## DEM files provided by USGS

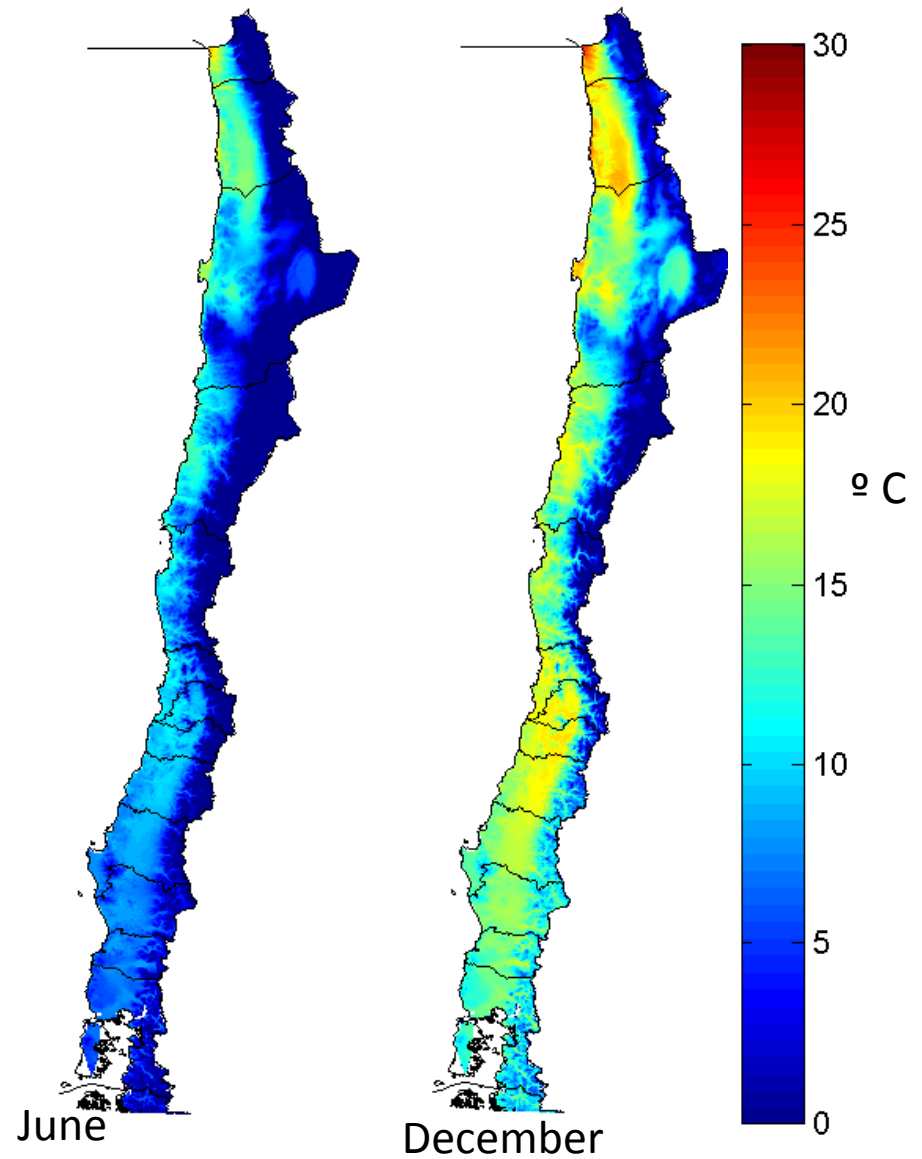


# Input Data

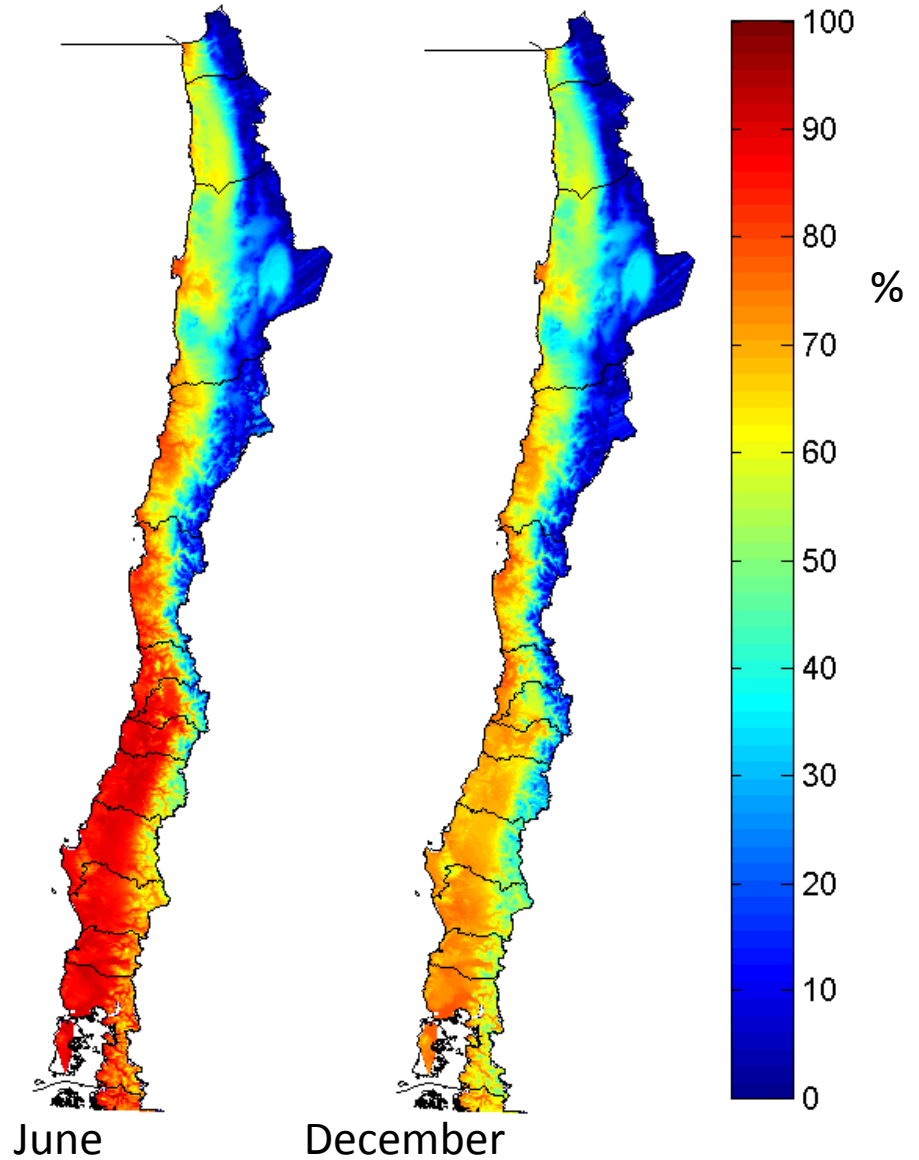
## Climate data

- Maps for the following climate variables were prepared at the same spatial resolution of satellite images:
  - Air Temperature
  - Surface Albedo
  - Relative Humidity
  - Atmospheric Visibility
- Methodology used for Air temperature and RH:
  - temporal series acquired at ground site managed by DMC
  - determination of monthly mean values for each ground site
  - Geostatistical interpolación (Kriging)

# Air Temperature



# Relative Humidity



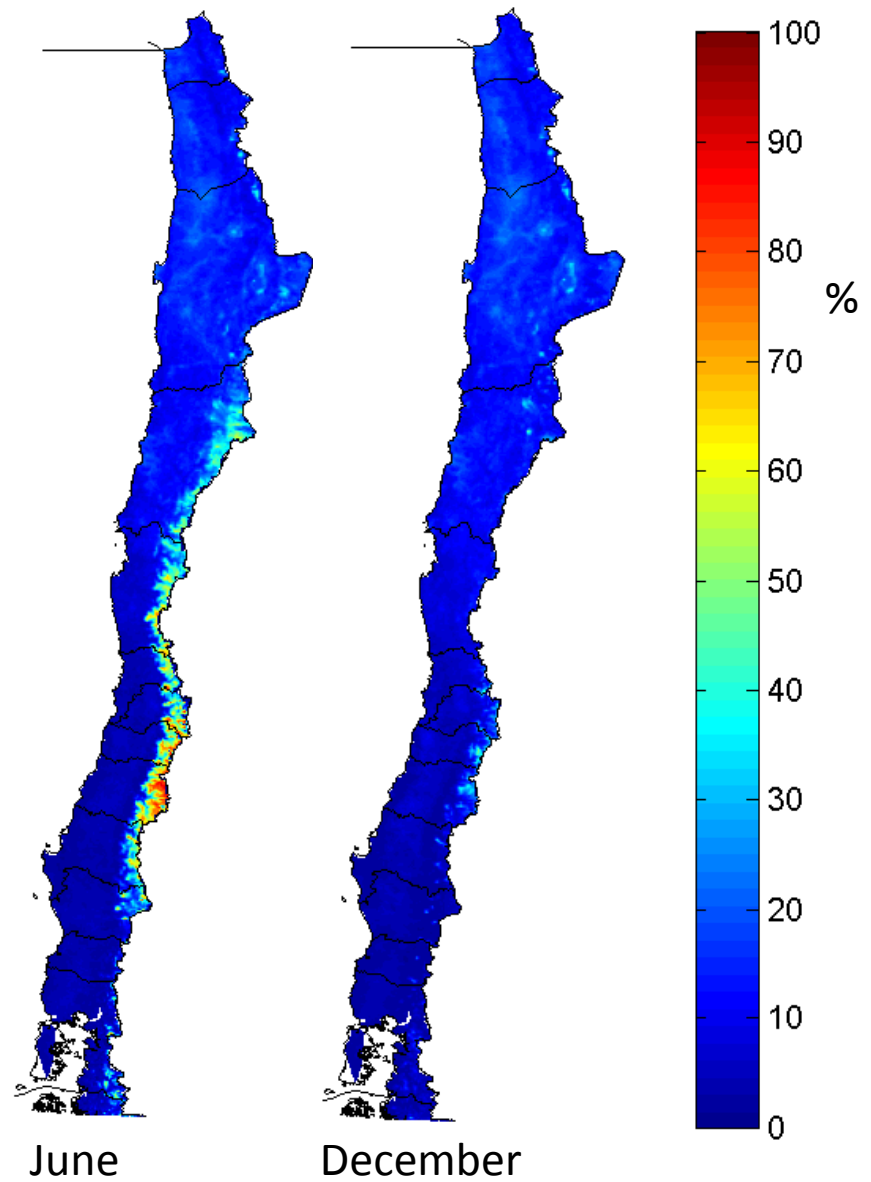


# Input Data

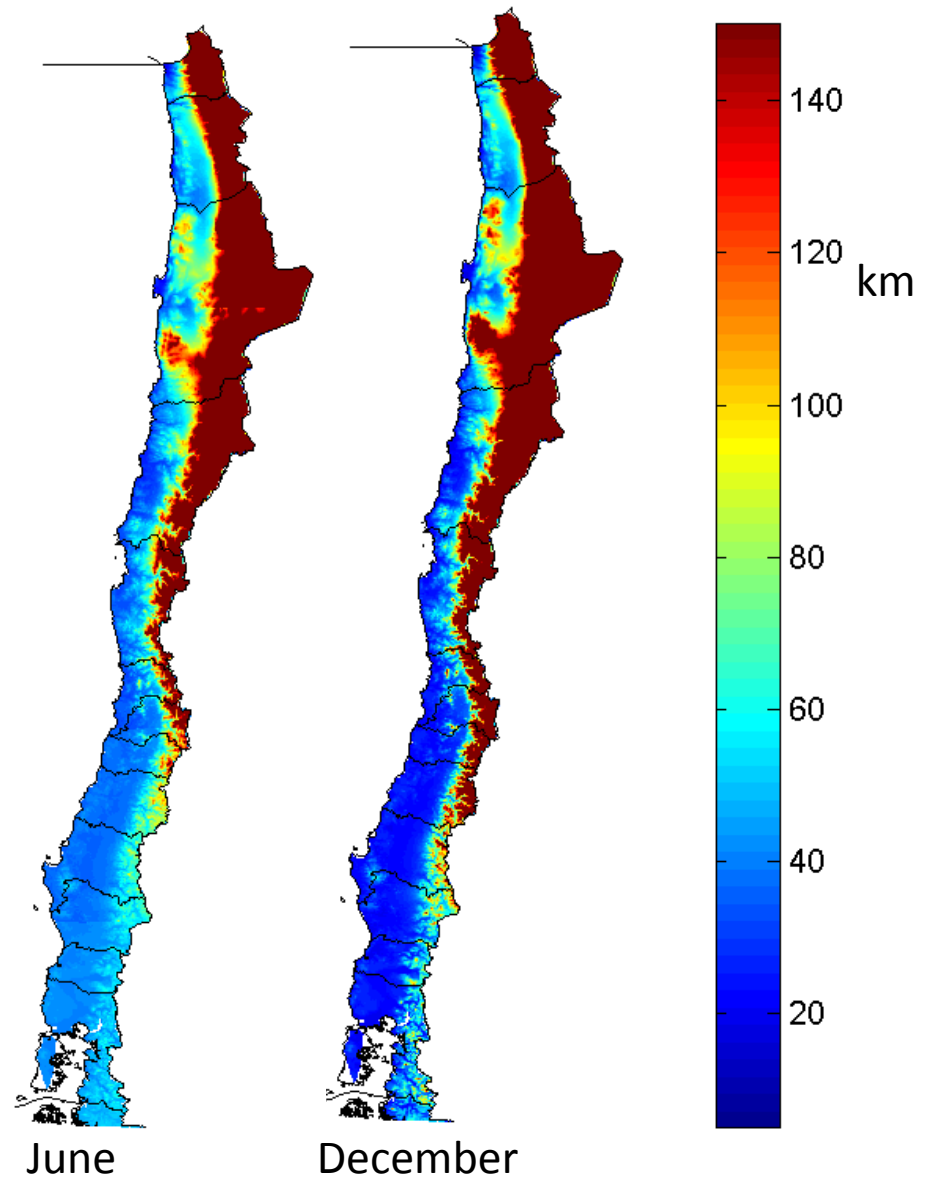
## Climate data

- Surface Albedo:
  - obtained from MCD43C3 MODIS product provided by NASA
- Atmospheric Visibility:
  - due to the scarcity of ground observations for Chile, global database were used: values between 5 and 50 km were corrected by altitude, using the empirical formulation

# Surface Albedo



# Visibility



June

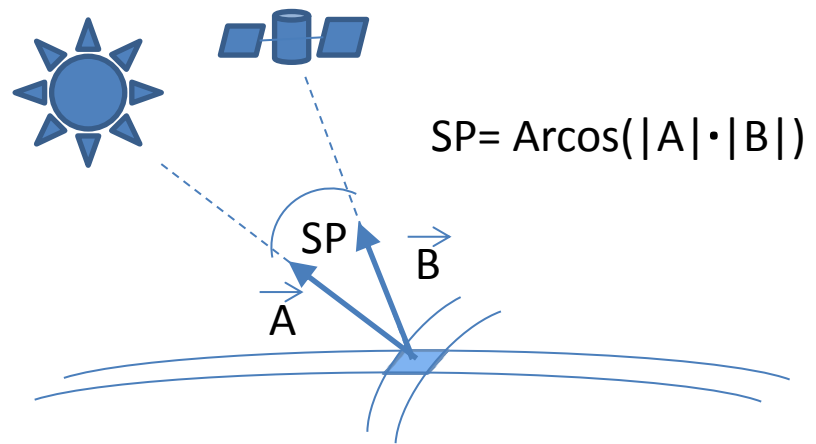
December

# Input Data

## Cloud cover index from satellite images

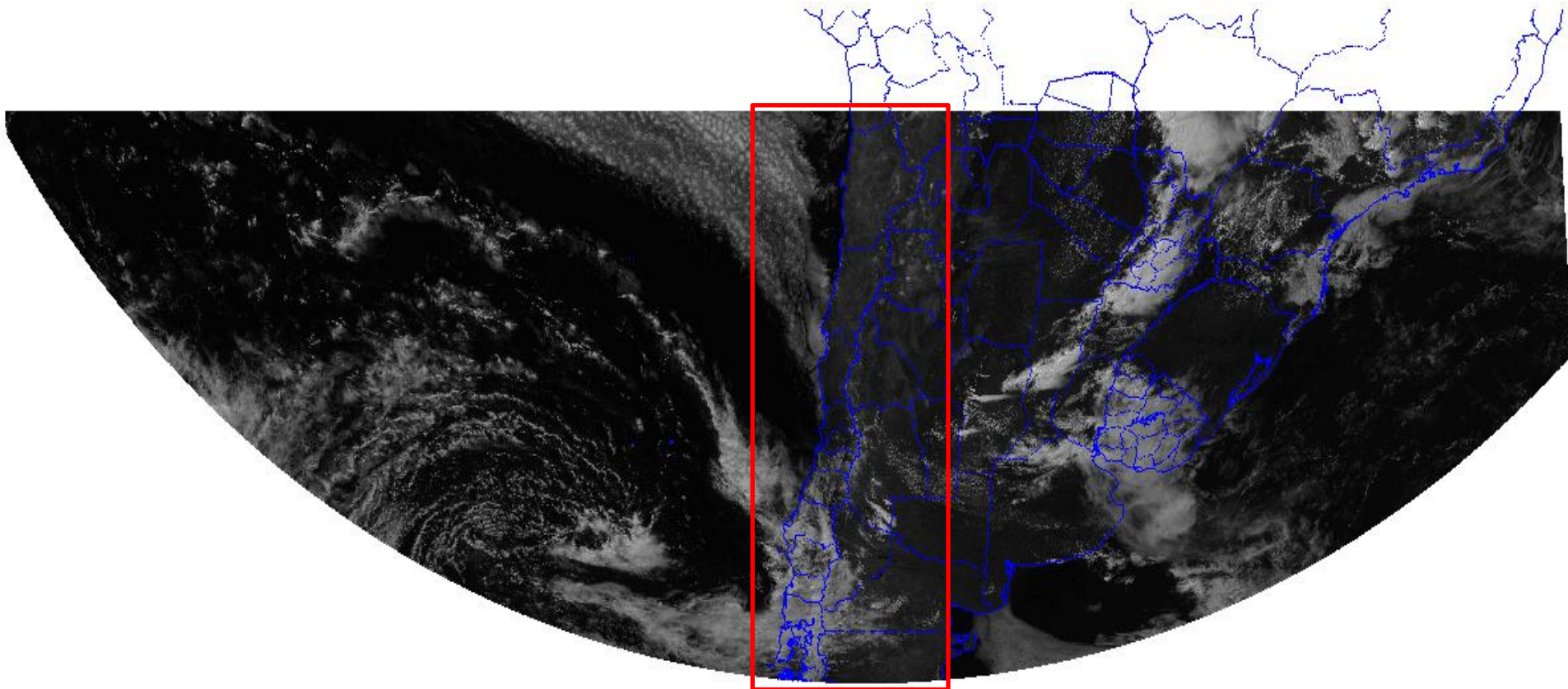
- Satellite: GOES 13
- Each data file provides information on:
  - Visible Radiance
  - Infrared Radiance
  - Latitud
  - Longitud
  - Scatter phase

	Visible data	Infrared data
Spatial resolution	1 km	4 km
Spectral Range	0,5 $\mu\text{m}$ – 0,7 $\mu\text{m}$	10,2 $\mu\text{m}$ – 11,2 $\mu\text{m}$



# Input Data

Cloud cover index from satellite images



19/10/2012 14:40 horas

# Input Data

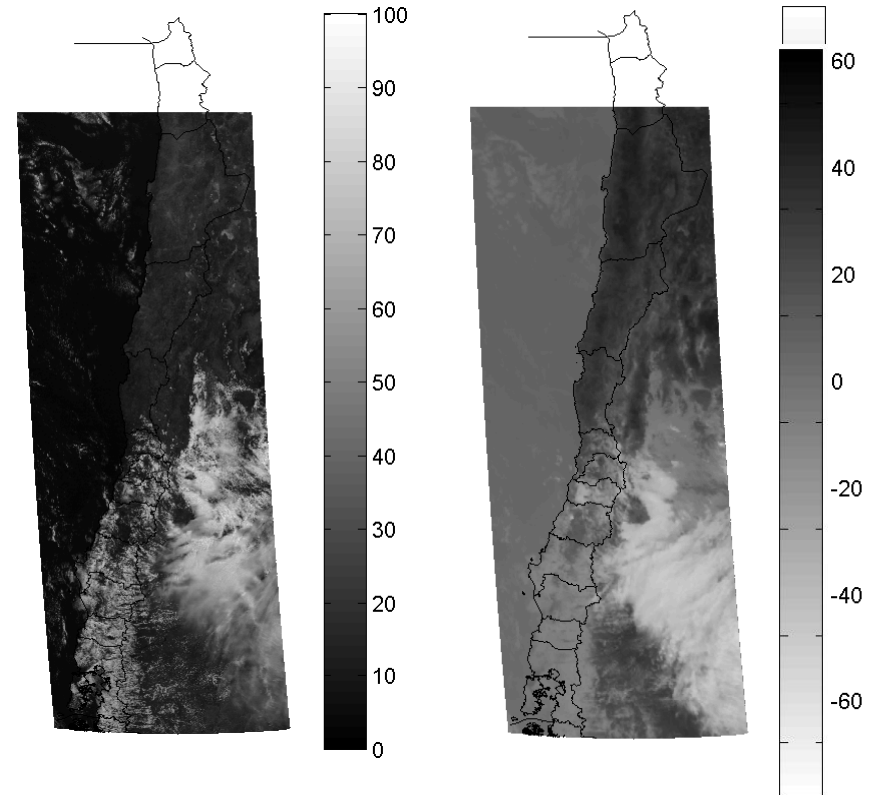
## Cloud cover index from satellite images

- Three steps
  - Supervised training
  - Pattern recognition
  - $CCI_{eff}$  determination

# Supervised Training

- Expert knowledge to identify classes manually

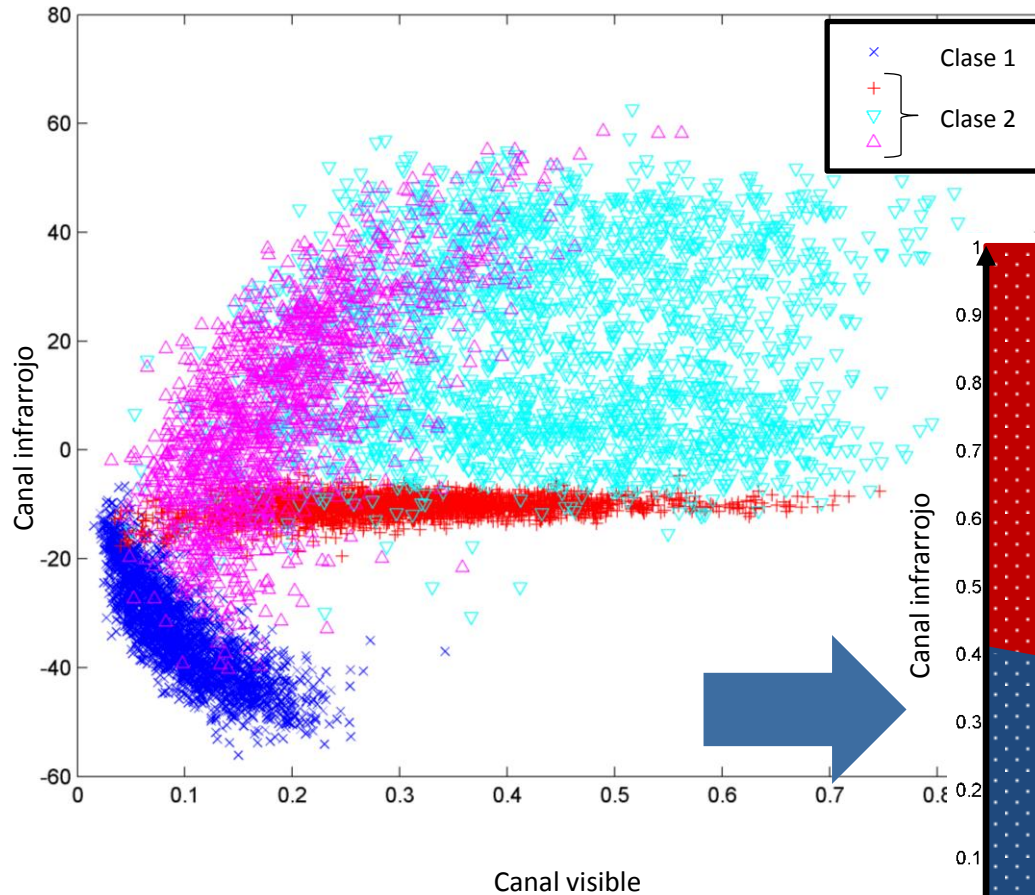
Sky condition	Visible channel	IR channel
Clear Sky	Opaque	Opaque
Cloudy sky	Half-bright	Half-opaque
	-	-
	Bright	Bright
	-	-
	Opaque	Bright



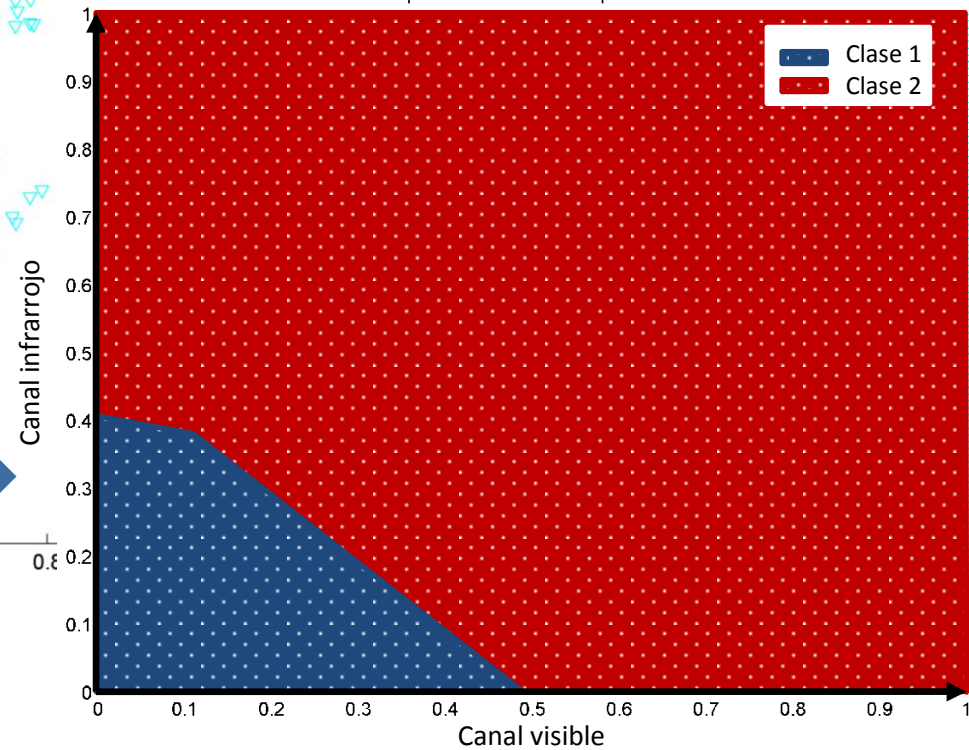
Canal 1



# Pattern Recognition



LDA classifier is used to identify areas



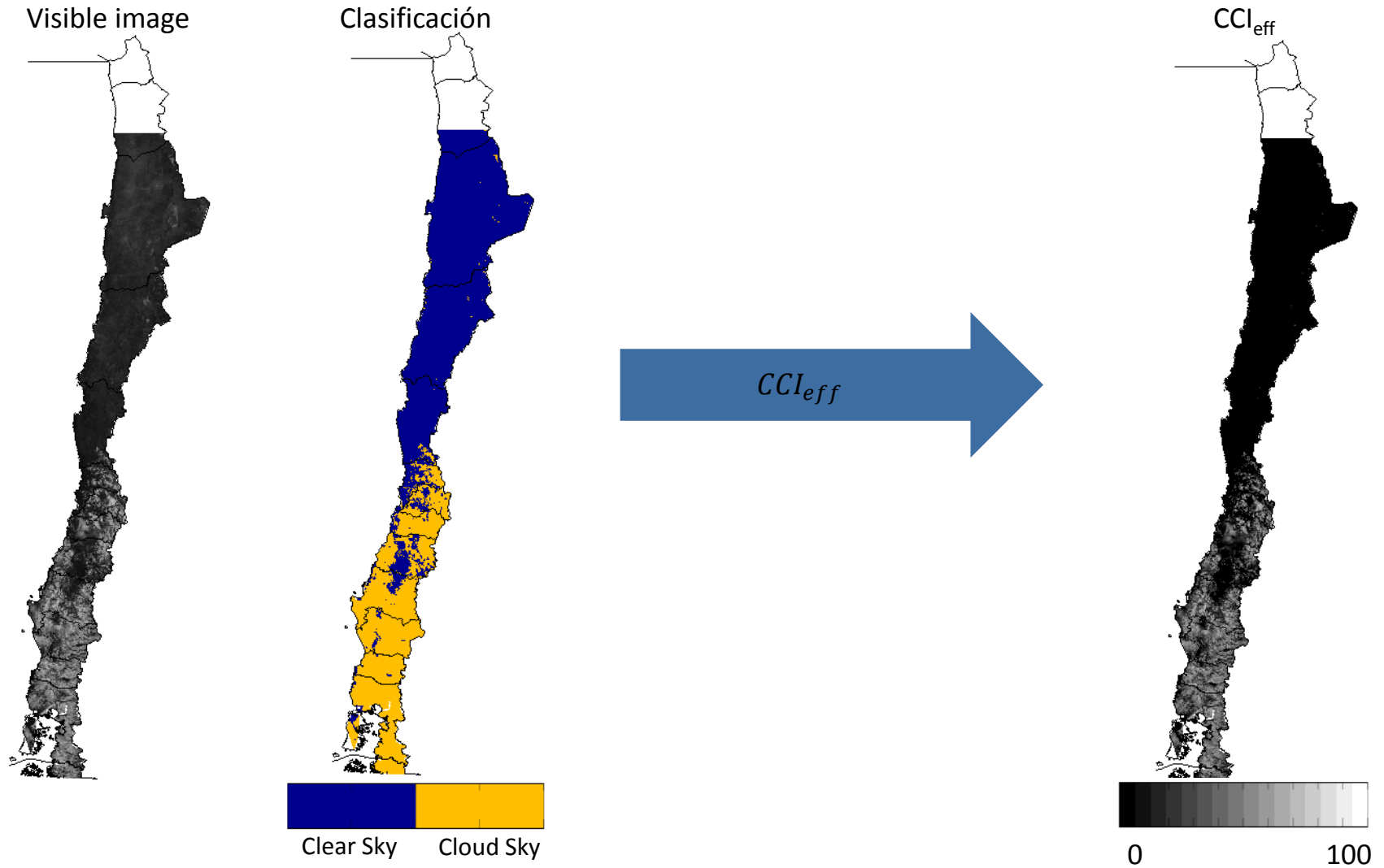


# CCI<sub>eff</sub> determination

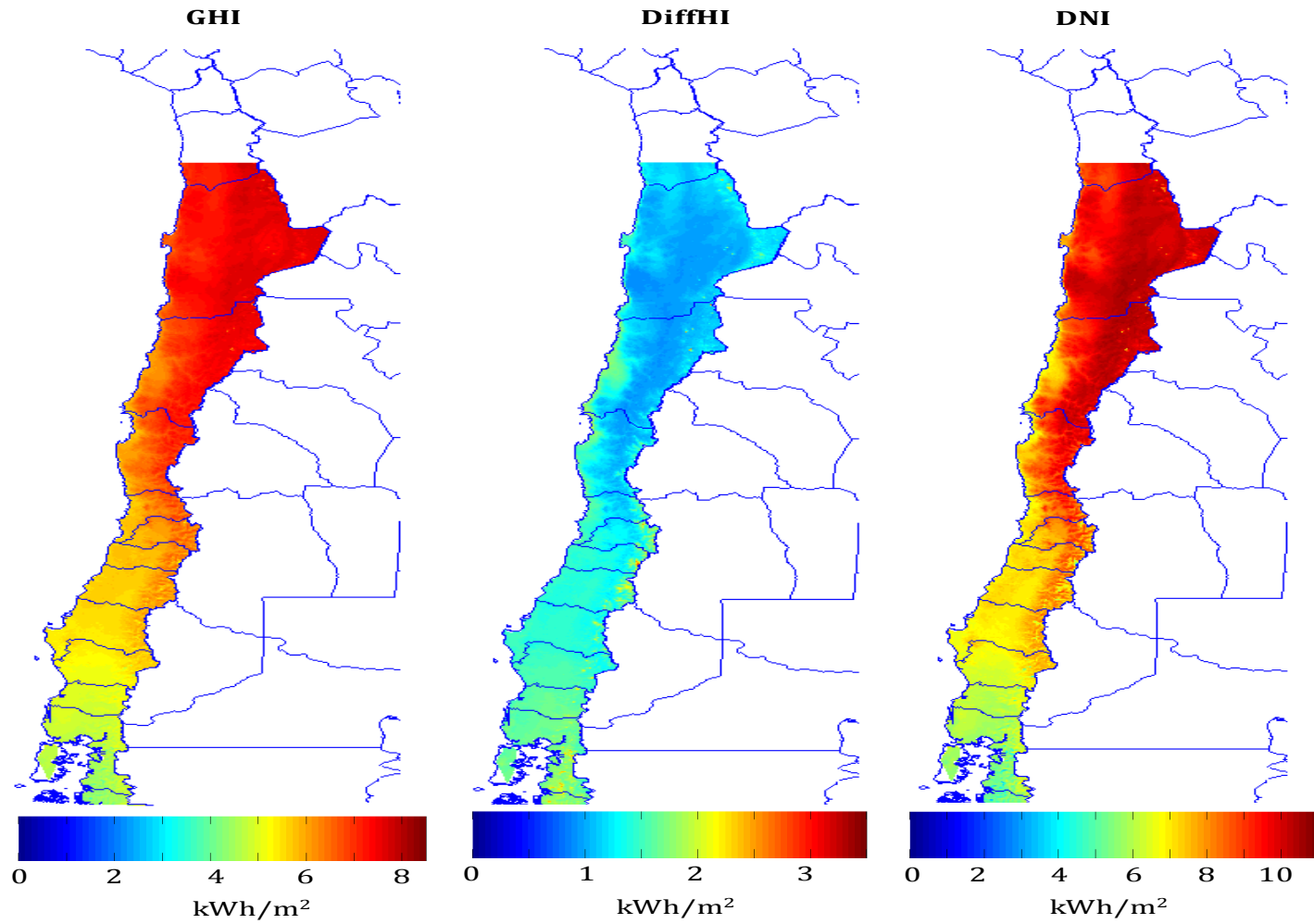
- $L_{clear}$  : the visible radiance related to clear sky condition for each pixel
- $L_{cloud}$ : the visible radiance for cloud sky related to Satellite/Pixel/Sun geometry (SP angle)

$$CCI_{eff} = \frac{L - L_{clear}}{L_{cloud} - L_{clear}}$$

# CCI<sub>eff</sub> determination



# Results



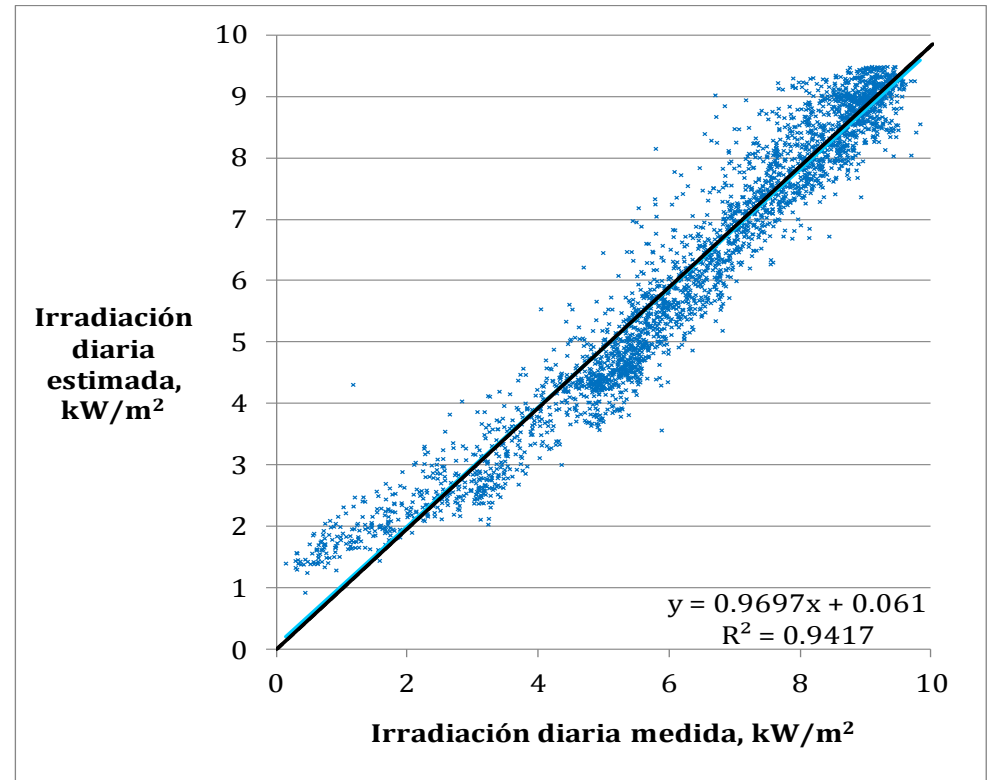
# Ground Data Network

Nombre	Localización	Altitud	Región	Tipo de estación	Período de operación	
Arica	Lat: 18,48° S Lon: 69,92° W	1.792 m.s.n.m.	XV región de Arica y Parinacota	RSBR	01/08/2011 - a la fecha	
Pozo Almonte	Lat: 20,26° S Lon: 69,77° W	1030 m.s.n.m.	I región de Tarapacá	RSBR	04/04/2012 - a la fecha	
Patache	Lat: 20,83° S Lon: 70,16° W	760 m.s.n.m.	I región de Tarapacá	RSBR	16/01/2013 - a la fecha	
Sur Viejo	Lat: 20,94° S Lon: 69,54° W	930 m.s.n.m.	I región de Tarapacá	RSBR	07/07/2011 - a la fecha	
Crucero	Lat: 22,24° S Lon: 69,51° W	1.146 m.s.n.m.	II región de Antofagasta	RSBR	16/01/2012 - a la fecha	
Coya Sur	Lat: 22,40° S Lon: 69,63° W	1.320 m.s.n.m.	II región de Antofagasta	RSBR	05/07/2011 - a la fecha	
San Pedro de Atacama	Lat: 22,91° S Lon: 68,20° W	2.450 m.s.n.m.	II región de Antofagasta	Estación completa	03/12/2010 - 04/07/2011	
El Tesoro	Lat: 22,93° S Lon: 69,10° W	2.130 m.s.n.m.	II región de Antofagasta	RSBR	01/01/2009 - 30/06/2011	
Diego de Almagro	Lat: 26,44° S Lon: 69,66° W	1.070 m.s.n.m.	III región de Atacama	RSBR	02/08/2011 - a la fecha	
Santiago	Lat: 33,50° S Lon: 70,61° W	579 m.s.n.m.	Región Metropolitana	Estación completa	22/12/2010 - a la fecha	
Curicó	Lat: 35,00° S Lon: 71,23° W	215 m.s.n.m.	VII región del Maule	Estación completa	01/06/2012 - a la fecha	
Talca	Lat: 35,40° S Lon: 71,63° W	110 m.s.n.m.	VII región del Maule	Estación completa	09/08/2012 - a la fecha	
Marimaura	Lat: 35,80° S Lon: 71,82° W	130 m.s.n.m.	VII región del Maule	RSBR	12/07/2012 - a la fecha	



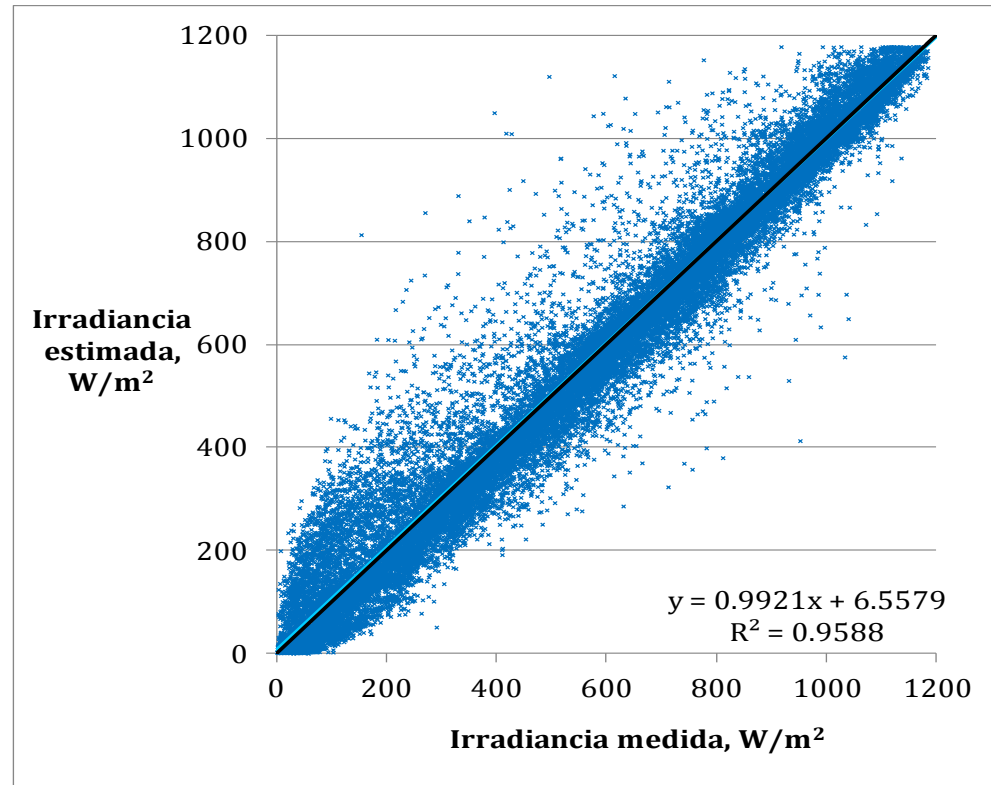
# Solar Estimates Validation

	MBE, kWh/m <sup>2</sup>	rMBE, %	RMSE, kWh/m <sup>2</sup>	rRMSE, %	R <sup>2</sup>
Pozo Almonte	0,15	2,3	0,60	9,4	0,94
Sur Viejo	-0,20	-2,9	0,57	8,1	0,91
Crucero	-0,19	-2,7	0,55	7,9	0,93
Coya Sur	-0,09	-1,2	0,54	7,5	0,93
Diego de Almagro	-0,36	-4,5	0,56	7,1	0,93
Santiago	-0,01	-0,2	0,51	10,2	0,96
Curicó	-0,12	-2,7	0,65	14,6	0,97
Talca	-0,27	-4,8	0,64	11,2	0,95
Marimaura	-0,23	-0,1	0,79	19,8	0,92
<b>Total</b>	-0,13	-2,1	0,57	8,9	0,94



# Solar Estimates Validation

	MBE, W/m <sup>2</sup>	rMBE, %	RMSE, W/m <sup>2</sup>	rRMSE, %	R <sup>2</sup>
Pozo Almonte	14,3	2,6	69,0	12,4	0,96
Sur Viejo	-16,1	-2,7	69,7	11,6	0,96
Crucero	6,1	1,0	62,9	10,4	0,97
Coya Sur	14,0	2,3	63,4	10,3	0,97
Diego de Almagro	-6,5	-1,0	53,8	8,3	0,98
Santiago	-0,3	-0,1	73,0	16,5	0,95
Curicó	22,1	5,7	92,8	24,0	0,92
Talca	6,1	1,3	87,4	18,9	0,93
Marimaura	4,8	1,4	86,0	24,0	0,90
<b>Total</b>	<b>2,4</b>	<b>0,4</b>	<b>70,0</b>	<b>12,8</b>	<b>0,96</b>



# Conclusions

- The model CHILE-SR was able to simulate the typical atmospheric radiative processes for Chilean territory
  - good agreement between observations and estimates
  - Bias lower than 2%
  - RMSE around 9% for daily total data and 13% for hourly data
- The larger solar energy resource is available in the Northern region at the Atacama Desert where the energy demand is large due to mining industry

# Thank for your attention

You can get more detailed information or send comments and suggestions to:

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