

### Description of raster data provided as supplements

Sixty supplementary georeferenced geotiff files are provided. These are zero-curtain duration and zero-curtain starting dates (two variables) that are annually calculated between 2003 and 2017 (15 raster data for each variable) for two seasons (freezing and thawing) of each year. The zero-curtain duration is the number of days within a season of the year that the daily MODIS LSTs satisfy the requirements in the “threshold window” algorithm. The zero-curtain starting date for a given season is the day of the year when the MODIS LST with zero curtain first occurs. The raster data were generated from MATLAB using the same gridding system as MODIS LST (MYD11A1) data reprojected into the geographic coordinate system. The details of the raster data are provided in Table S1.

**Table S1.** Details of raster data provided as supplementary.

Characteristic	Description
Exemplary name 1	zerocurtain_length_freezing_season_2003.tif
Exemplary name 2	zerocurtain_startdate_freezing_season_2003.tif
File size	20 kb
Temporal resolution	Annual
Temporal extent	2003–2017
Spatial extent	Longitude: 68.3872–69.1325 °W Latitude: 26.8225–27.1566 °S
Coordinate system	Geographic
Datum	WGS 84
File format	Geotiff
Columns/rows	87 × 39
Pixel size	1 km (0.0086°)
No data value	NaN (Not a Number)

**Table S2.** Annual land-cover classification estimated from MODIS (MCD12Q1v006: cover type 1) over the study region (extent: from 67°54'15" W to 69°48'15" W and from 25°56'30" S to 27°25'15" S).

Year	Percentage of total area				
	Shrublands	Grassland	Glaciers	Water	Barren
2003	0.6%	0.2%	0.3%	0.1%	98.8%
2004	0.6%	0.2%	0.1%	0.1%	98.9%
2005	0.6%	0.2%	0.1%	0.1%	99.0%
2006	0.6%	0.2%	0.1%	0.1%	99.0%
2007	0.6%	0.3%	0.1%	0.1%	98.9%
2008	0.7%	0.3%	0.1%	0.1%	98.9%
2009	0.7%	0.3%	0.0%	0.1%	98.9%
2010	0.7%	0.3%	0.0%	0.1%	98.9%
2011	0.7%	0.3%	0.1%	0.1%	98.9%
2012	0.7%	0.3%	0.1%	0.1%	98.8%
2013	0.7%	0.3%	0.1%	0.1%	98.9%
2014	0.7%	0.3%	0.0%	0.0%	98.9%
2015	0.7%	0.3%	0.1%	0.0%	98.9%
2016	0.7%	0.3%	0.1%	0.0%	98.8%
2017	0.7%	0.3%	0.1%	0.1%	98.8%
2018	0.7%	0.3%	0.1%	0.1%	98.9%

**Table S3.** Soil descriptions at Site #1 (27°02'54" S, 69°04'52" W, 3815 m asl).

Soil horizon	Depth, cm	Description
A <sub>0</sub>		Moderately developed desert pavement, gravel 2–3 cm and 0.5–1 cm, not anchored to the surface.
A <sub>v</sub>	0–2	Silty sandy vesicular horizon; clear lower boundary.
A <sub>p</sub>	2–5	Silty sandy, gravel-free, polygon structure, platy structure.
B <sub>k</sub>	5–20	Gravelly loam, some gypsum veins. No soluble salts, gradual lower boundary.
B <sub>2</sub>	20–30	Loamy very fine sand, stratified alluvial horizon, sand and gravel.
B <sub>3</sub>	30–40+	Slightly moist, gravelly loamy sand, original stratification

**Table S4.** Soil descriptions at Site #2 (26°57'31" S, 68°49'09" W, 4415 m asl) <sup>1</sup>.

Soil Horizon	Depth, cm	Description (Sample ID RS2/1)
A <sub>0</sub>		Moderately developed desert pavement, gravel 2–3 cm and 0.5–1 cm, not anchored to the surface.
A <sub>v</sub>	0–10	Silty sandy vesicular horizon; clear lower boundary.
B <sub>1</sub>	11–12	Silty sandy, gravel-free, polygon structure. The polygons have platy structure separating them into subunits (1–6, 6–9, 9–12 cm depth). Fine sand fills the cracks between the polygons. Gypsum spots. Clear lower boundary.
B <sub>2k</sub>	12–20	Coarse sand and very fine gravel (granules), matrix composed of a mixture of coarse and fine sand and gravel slightly cemented by calcium carbonate. No soluble salts, gradual lower boundary.
B <sub>3ky</sub>	20–40	Gravelly horizon, coarser than previous, (2 cm max.) mixture of gypsum and some carbonate, gypsum crystals adhere to the gravel, matrix is coarse sand and granules, gradual lower boundary.
B <sub>4zy</sub>	40–50	A mixture of coarse sand with fine gravel, spots of salts (may be gypsum), clear lower boundary.
	50–55+	Well-stratified alluvial sediment. Sandy unit with no gravel.

<sup>1</sup> In this soil profile the calcic horizon was formed, followed by deposition of small amount of gypsum which does not increase downward. The vesicular structure of the A<sub>v</sub> and the platy structure of the polygons indicate seasonal frost activity. The leaching process is limited.

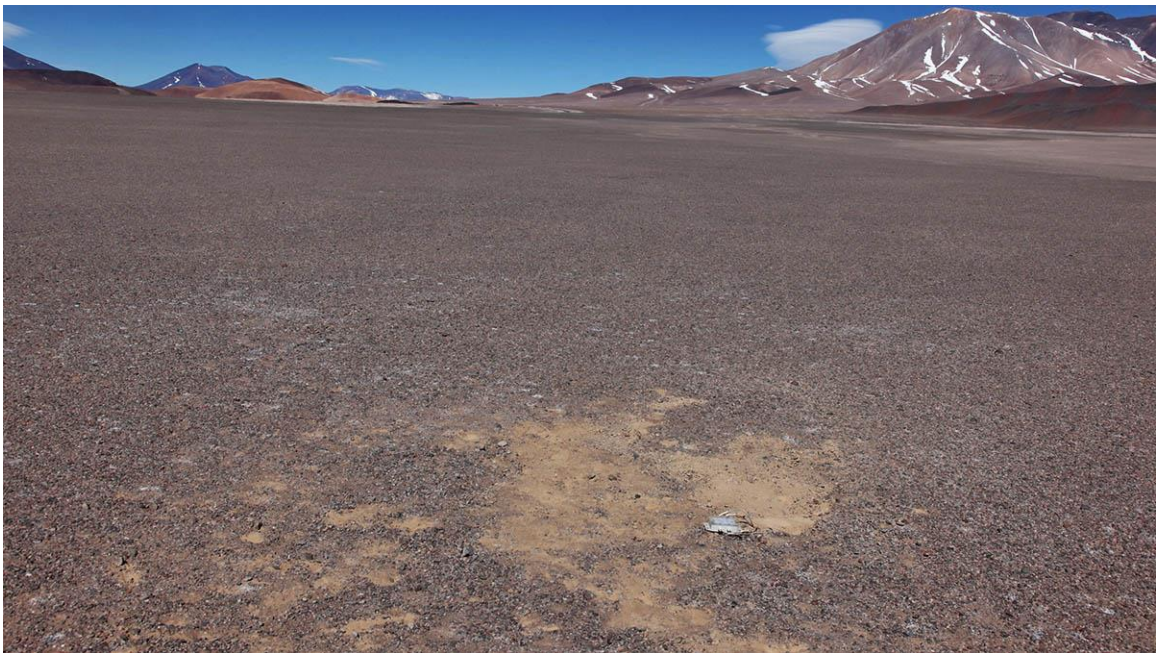
**Table S5.** Soil descriptions at Site #3 (27°00'09" S, 68°42'55" W, 4910 m asl) <sup>1</sup>.

Soil Horizon	Depth, cm	Description (Sample ID HLS1-1)
A <sub>0</sub>	0–2	Well-developed desert pavement, flat gravel, 4 cm average, gravels are not anchored, no reddening at the bottom, patches of salts on the surface. Overland flow formed rills in which large gravel are concentrated while the fines were washed downward. Very large smooth and relatively flat boulders are scattered on the surface polished probably by wind.
A <sub>1</sub>	0–2	Fine sand and silt, friable, no structure.
B <sub>1ky</sub>	2–10	Mixture of coarse sand and gravel (max 0.5 cm), sandy matrix, some calcic or salt coatings. Clear lower boundary.
B <sub>2k</sub>	10–20	Gravelly, coarse sand, some salt efflorescence and some carbonate coatings. Gradual boundary.
B <sub>3</sub>	20–40	Coarse gravel, coarse sand matrix, clay cutans, very moist. Gradual boundary.

<sup>1</sup> The surface has topography of small terracettes, and the surface is dissected by shallow rills. The sediment is coarse and too friable to maintain any structure. However, the platy structures in the upper 2 cm indicate frost activity.



**Figure S1.** Surface features of the alluvial fan surface at Site #1. The shovel in the foreground is ~1 m long.



**Figure S2.** Surface features of the alluvial fan surface at Site #2. The datalogger on the ground is ~30 cm long.





**Figure S3.** The platy structure and the patterned ground are revealed under the pavement of pebbles at Site #2. These features indicate the heaving due to seasonal freezing and thawing of moisture in the soil. The metal ruler is 15 cm long.





**Figure S4.** Photo showing the frost cracks and platy structure in the upper 2 cm of the soil profile at Site #2. The horizontal platy structure and the vertical cracks indicate the heaving due to seasonal freezing and thawing of moisture in the soil. The red ticks on the measuring tape are in cm.



**Figure S5.** Surface features of the alluvial fan surface at Site #3. The stretched measuring tape is ~30 cm long.

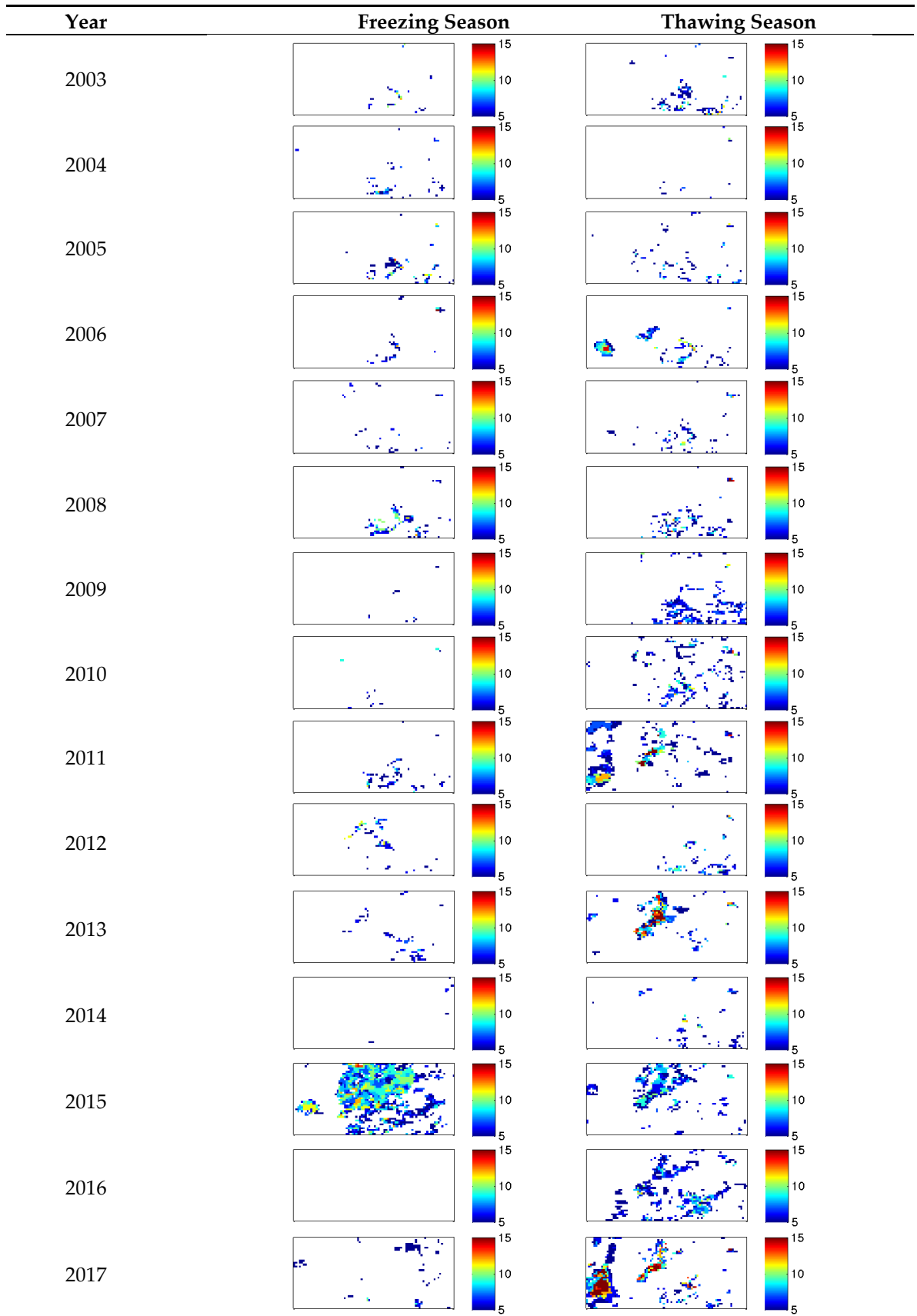




**Figure S6.** The 'nieves penitentes' near the Site #3 in Barrancas Blancas. These long spires of remnant snow in the Atacama are formed due to sublimation, an indication of cold and dry condition.

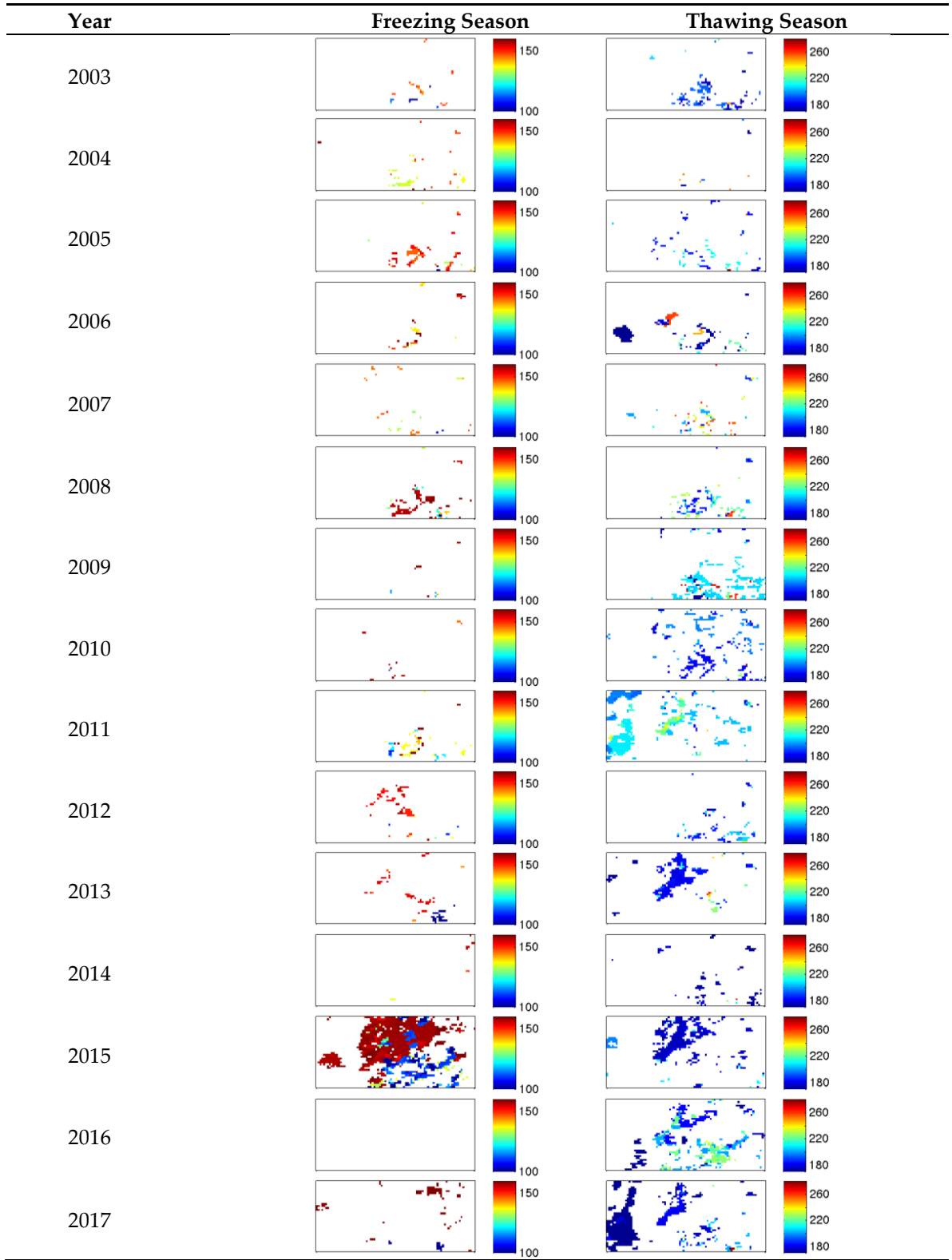


**Figure S7.** The nieves penitents near Laguna Verde ( $26.8902^{\circ}$  S and  $68.4881^{\circ}$  W, 4360 m asl).



**Figure S8.** Maps of zero-curtain duration from 2003 to 2017. The spatial extents of the maps are the same as in Figure 3 in the main text. The scale of the color bar shows the zero-curtain duration and is set at 5–15 days for all maps.

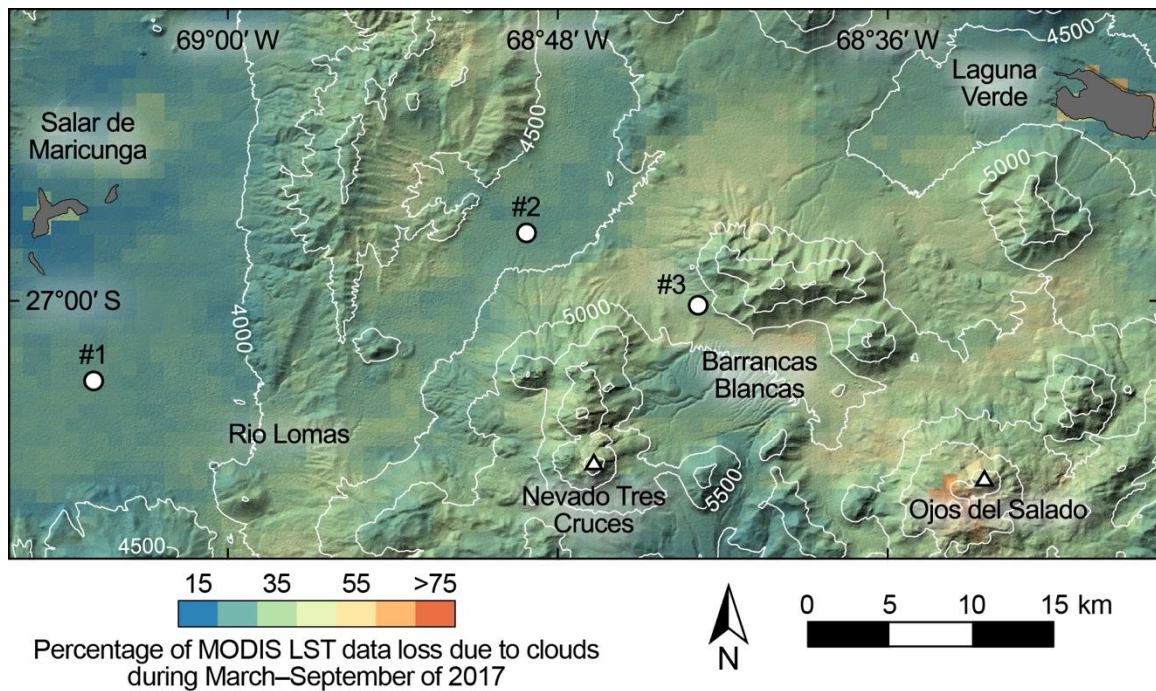




**Figure S9.** Maps of zero-curtain starting day from 2003 to 2017. The spatial extents of the maps are the same as in Figure 3 in the main text. The scale of the color bar shows the day of the year and is set to 100–150 for freezing seasons and 170–280 for thawing seasons.

**Table S6.** Percentage of MODIS LST data loss due to clouds during March–September from 2003 to 2017.

Year	Data loss due to clouds during March–September, %		
	Site #1	Site #2	Site #3
2003	22	39	31
2004	20	29	28
2005	30	43	56
2006	27	44	38
2007	42	56	45
2008	17	30	28
2009	22	40	36
2010	16	48	33
2011	28	38	39
2012	22	29	30
2013	29	31	42
2014	22	27	32
2015	32	30	39
2016	34	45	52
2017	27	28	37
Minimum	16	27	28
Maximum	42	56	56
Mean	26	37	38
1 $\sigma$ st. dev	6.9	8.8	8.3



**Figure S10.** MODIS LST data loss due to clouds during March–September of 2017. The numbered circles indicate the locations of validation sites where we measured subsurface ground temperatures. The background hillshade image and the contour lines were constructed from 1 arcsec SRTM DEM (product SRTMGL1).