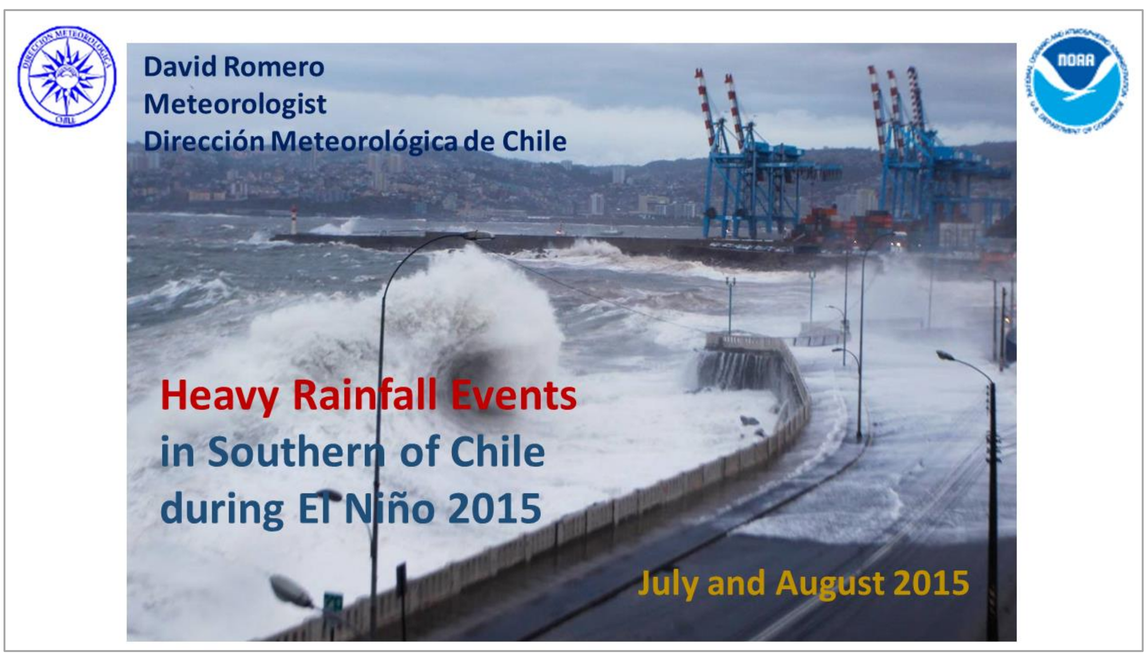
WPC South American Desk Presentation

Heavy Rainfall Events in Southern Chile during El Niño 2015

David Romero

Dirección Meteorológica de Chile

11 September 2015

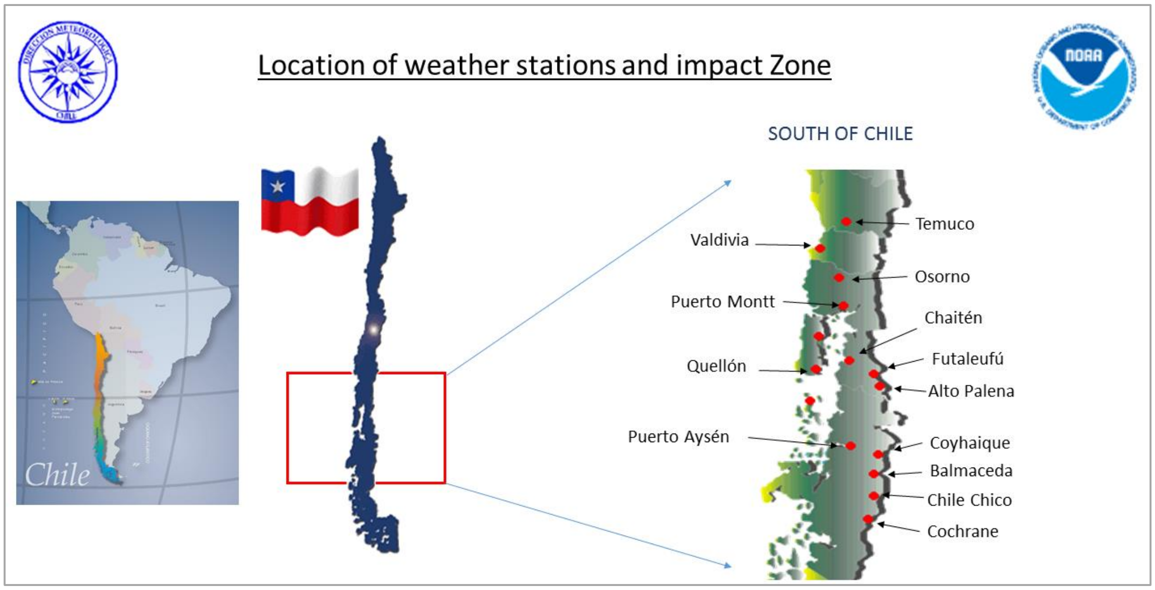


CASE STUDY: HEAVY RAINFALL EVENTS IN SOUTHERN CHILE IN JULY AND AUGUST 2015

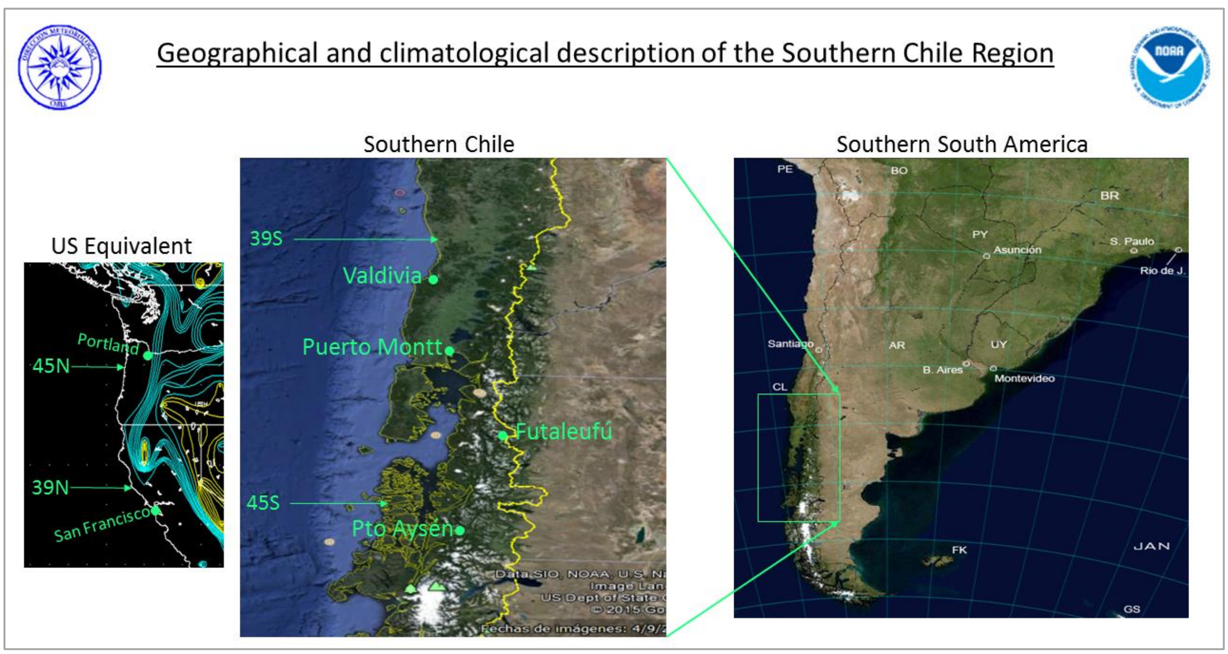
- **Objective**: Identify recurring meteorological patterns and predictors that lead to heavy rainfall events to improve forecast confidence and accuracy.

Several heavy rainfall events occurred in Southern Chile during July and August of 2015. These events were enhanced by a strong El Niño, which is usually associated with stronger upper jets and with robust and frequent subtropical moisture connections/atmospheric rivers. These rivers often originate on the Central Equatorial Pacific and transport columns of enhanced precipitable water (>20mm) into Southern Chile.

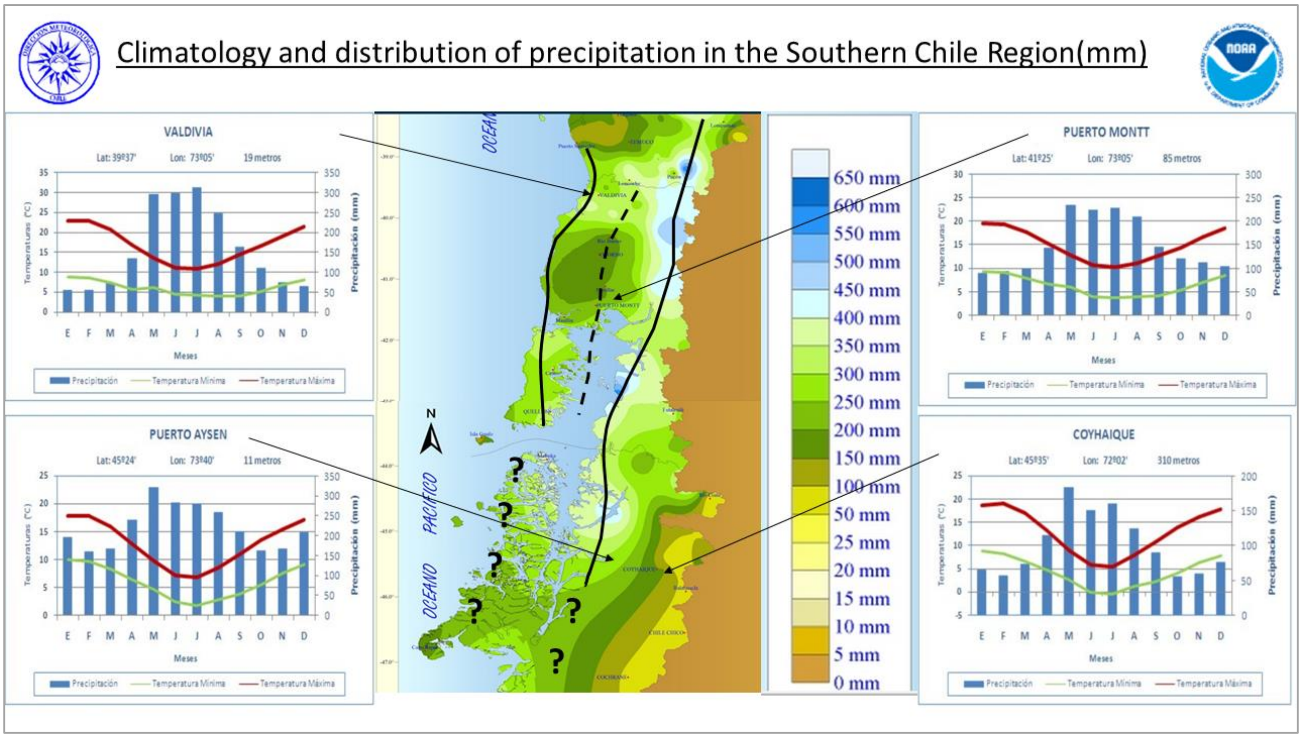
The rain events required the emission of Weather Advisories (Alertas) for heavy rains and strong winds. This motivated interest in studying the specific characteristics of the weather events that led to the emission of advisories. The present study analizes and compares 5 heavy rainfall events that occurred in Southern Chile during July and August of 2015.



The stations affected by the rains that were used in this study are here presented, and extend from Temuco to the north to Cochrane to the south. They comprise several regions of Southern Chile.

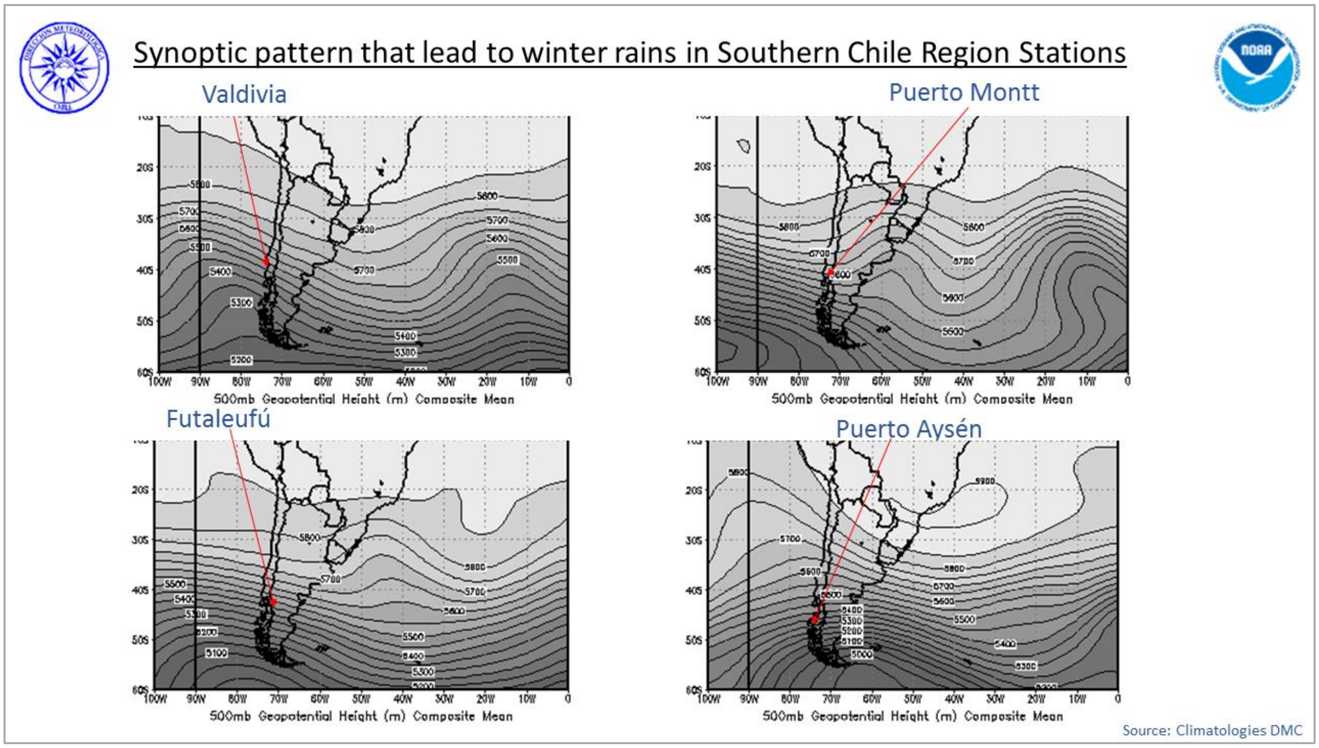


The region of study lies in Southern Chile between the latitudes of 39°S and 45°S. It is located in southwestern South America in the windward side of the Andes. The latitudes and climate correspond approximately to those of Northern California and Oregon in the United States.

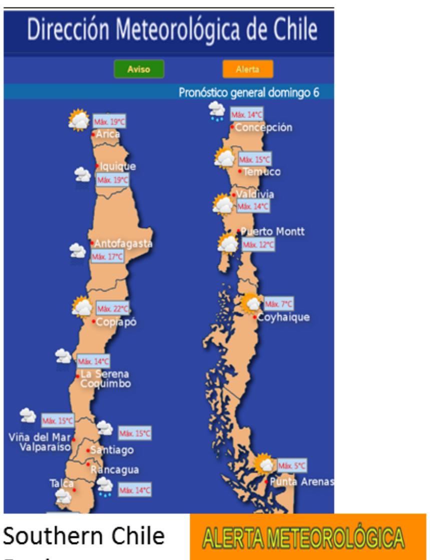


Annual rainfall in Southern Chile is high. It approaches 2000-3000 mm/yr. Most of it occurs during winter, when months with totals exceeding 300mm are not uncommon. One limitation to accurately determine the distribution of rainfall is the limited number of stations. This is in part due to the low population density of sectors of the region. Yet, two rainfall maxima can be identified. One lies along and west of the coastal mountain range, and another lies along the western slopes of the Andes and into the cordillera. These are associated with enhanced moisture convergence on the windward side of the ranges. This leads to a relative minimum along the central valley where populated areas such as Puerto Montt and Valdivia lie.

The next slide shows the distribution of 500 hPa during previous heavy rainfall events for different parts of Southern Chile. This shows the structure of the upper troughs and flow associated with heavy rains in different locations (Source: Climatologies, Dirección Nacional de Meteorología de Chile). It can be seen that northernmost stations are more sensitive to a northwesterly component than the southern locations. This partly associated with the arrival of subtropical moisture connections/atmospheric rivers from the northwest. Further south, however, heavier precipitation is stimulated during periods of west-southwesterly flow. This stimulates the inland advection of shallow showers that originate in shallow unstable layers. The latter form when cool southwesterly flow blows over a relatively warm ocean.



Thresholds to emit an ADVISORY (ALERTA) for precipitation events



Southern Chile Region
PP > 35mm

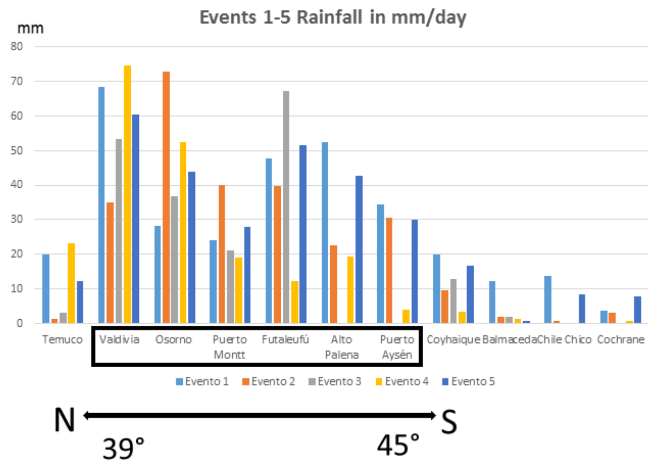
CHILE		OUTLOOK (AVISO)	ADVISORY (ALERTA)		WARNING (ALARMA)
	REGION	NORMAL	MODERATE	STRONG	INTENSE
NORTHERN ZONE	Arica - Parinacota (costa)	0,5 – 0,8	0,8 – 5	5 - 10	>10
	Tarapacá (costa)	0,5 – 1	1 – 5	5 – 10	>10
	Antofagasta (costa)	1 – 2	2 – 8	8 – 15	>15
	Atacama (costa y valles)	5 - 9	9 - 15	15 - 25	>25
	Altiplano y Precordillera Z.Norte	8 - 13	13 - 25	25 - 50	>50
	Coquimbo	5 - 15	15 - 20	20 - 40	>40
CENTRAL ZONE	Valparaíso	10 - 20	20 - 40	40 - 60	>60
	Isla de Pascua e Isla Juan Fernández	15 – 25	25 – 40	40 – 70	>70
	Metropolitana	10 - 20	20 - 40	40 - 60	>60
	O'Higgins	10 - 20	20 - 40	40 - 60	>60
	Maule	15 - 30	30 - 50	50 - 80	>80
	Biobío	15 - 30	30 - 50	50 - 80	>80
SOUTHERN ZONE	Araucanía	20 - 35	35 - 60	60 – 80	>80
	Los Ríos	25 - 40	40 - 65	65 – 85	>85
	Los Lagos	25 - 40	40 - 65	65 – 80	>80
	Aysén (costa)	35 - 50	50 - 70	70 – 90	>90
	Aysén (interior)	25 - 35	35 - 55	55 - 70	>70
Austral Zone	Magallanes	10 - 20	20 - 35	35 - 50	>50

Table 1. Rainfall categories (mm/day)

This slide shows precipitation ranges that require the issuance of an advisory (alerta). Given that heavier rains fall in Southern Chile in comparison to other parts of the country (e.g. the Northern Zone), the threshold to issue an advisory is higher. It requires rainfall above 35mm/day. Accordingly, the study emphasizes on characterizing the events that produced precipitations exceeding these threshold during July and August of 2015.

Heavy precipitation events in the Southern Chile Region during 2015

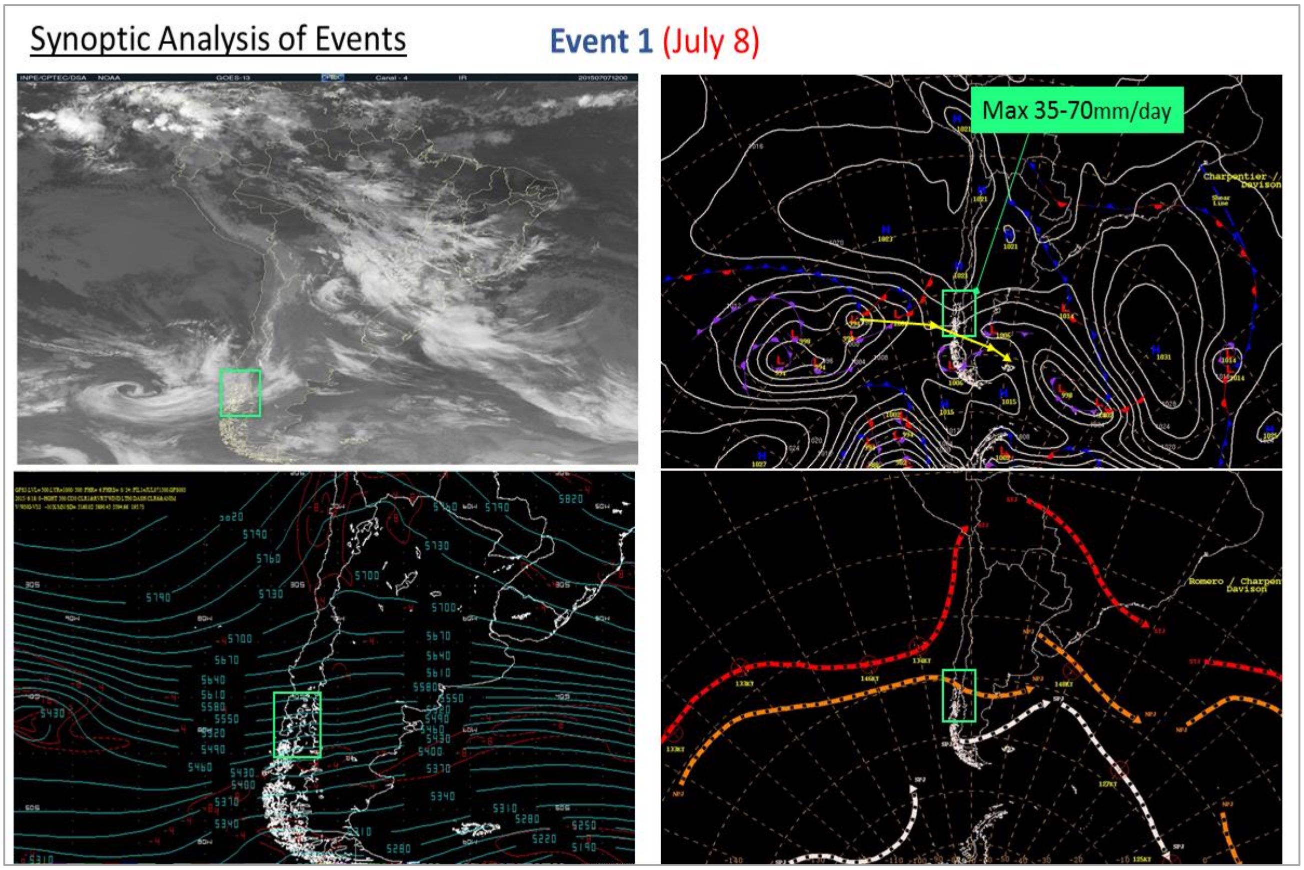
2015	July			August	
CHILE	Event 1	Event 2	Event 3	Event 4	Event 5
Cities	Wed 8	Fri 17	Sun 26	Tue 25	Fri 28
Temuco	19,9	1,4	3	23,3	12,2
Valdivia	68,5	35	53,3	74,5	60,5
Osorno	28,2	72,8	36,7	52,5	43,8
Puerto Montt	24,2	40	21	19	27,8
Futaleufú	47,8	39,6	67,2	12,4	51,6
Alto Palena	52,5	22,6	0	19,5	42,6
Puerto Aysén	34,4	30,5	0	4	30
Coyhaique	19,9	9,6	12,8	3,5	16,6
Balmaceda	12,2	2	1,8	1,4	0,8
Chile Chico	13,8	0,8	0	0	8,4
Cochrane	3,8	3,2	0	0,8	7,8



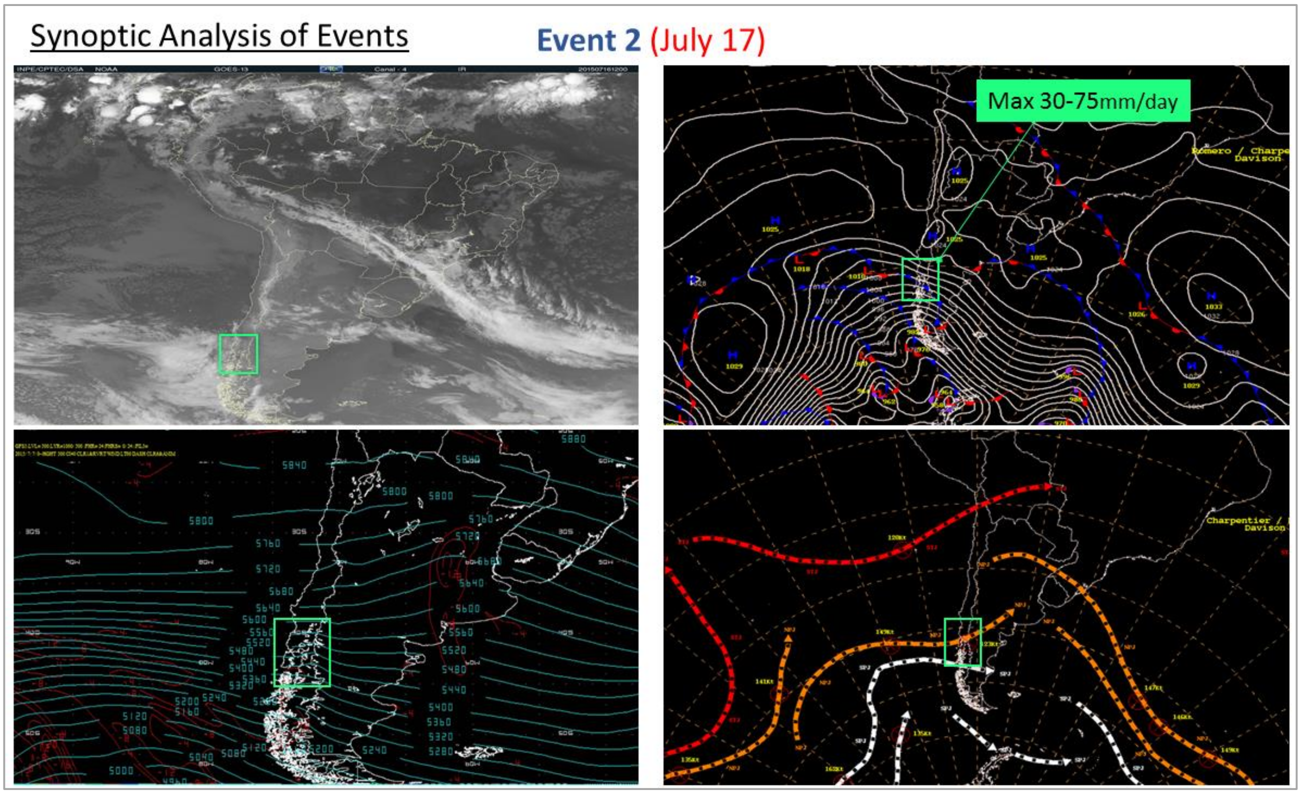
The table shows the 24-hr rainfall collected during the peak fay of the five rainfall events studied. Stations are organized from north to south. It shows that the largest rainfall amounts – that lie over the advisory threshold of 35mm – occurred between Valdivia and Futaleufú, sometimes extending into adjacent southern locations. The figure shows a graph with the rainfall totals, where stations are organized from north (left) to south (right). Each color corresponds to a different event.

Data, Information Sources and Tools

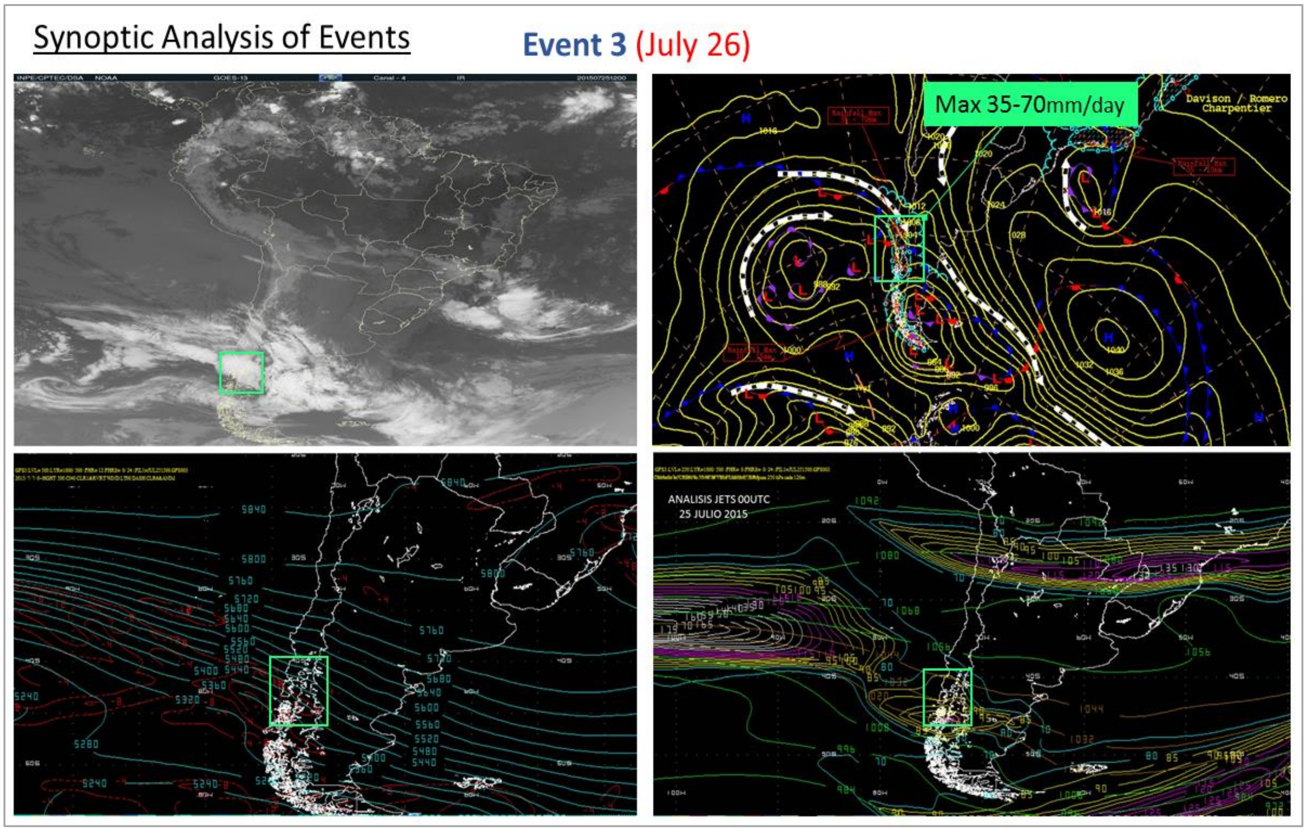
- Satellite Images
- Meteorological observations (METARs)
- Southern Chile Region Climate data
- 1° GFS Model Data (00UTC)
- South American Desk Jets Stream and Surface Analyses (00z)
- South American Desk Daily forecast charts
- PWAT Analyses.
- TOOLS: WINGRIDDS, NAWIPS System



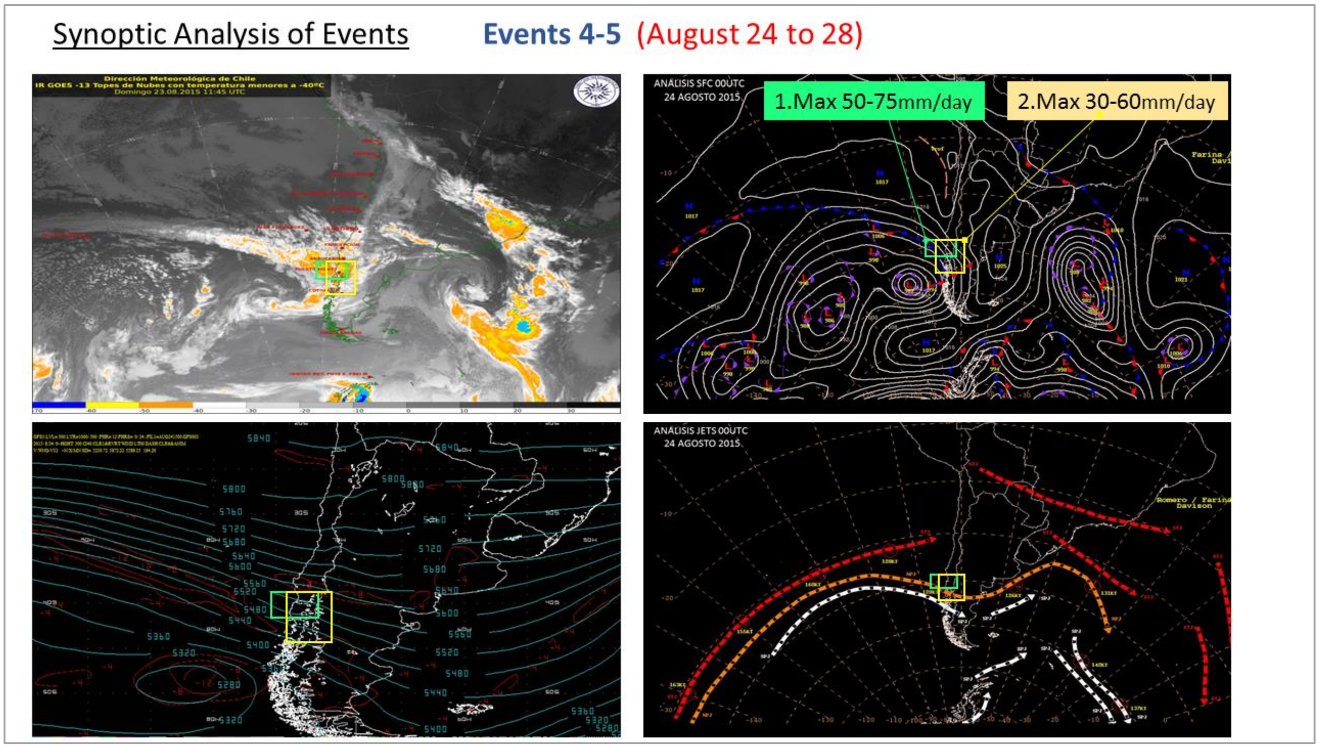
The slide above has animations that are not available in the PDF. Event #1 shows the passage of a cold front accompanied by several occluded lows. The triple point passed just to the south of the region of heavy rains that ranged 35-70mm/day. The event was also accompanied by the northern polar upper jet. A band of the southern polar jet formed during the event. This suggests cooling of the troposphere over the Southeastern Pacific. A short wave upper trough was also present, and the period with cyclonic vorticity advection coincided with the period of heavier precipitation (Jul 8 00Z-06Z).



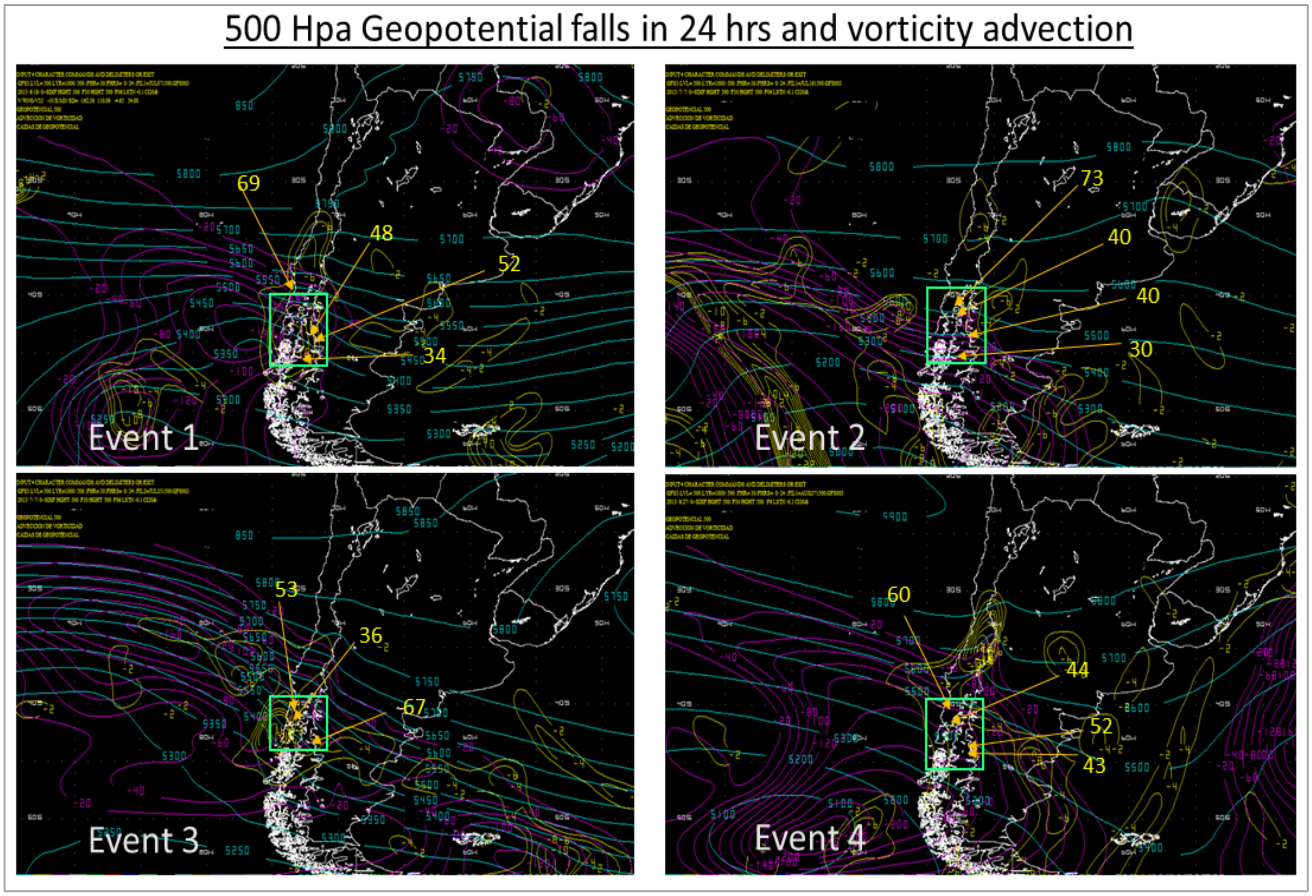
The slide above has animations that are not available in the PDF. Event #2 shows the passage of a cold front. Occluded lows were not present. The wind component was more zonal compared to event #1. The trough moved in from the west-southwest instead of from the west as it did on event #1. The jets present were the Southern Polar and the Northern Polar Jet. The region of heaviest rainfall did not necessarily fall under the divergent quadrants of the jets. This event produced 30-75mm/day in the region. Heavy rainfall was not only observed along the mountain ranges but in valley stations. Puerto Montt received 40mm/day and Osorno 72.8mm/day.



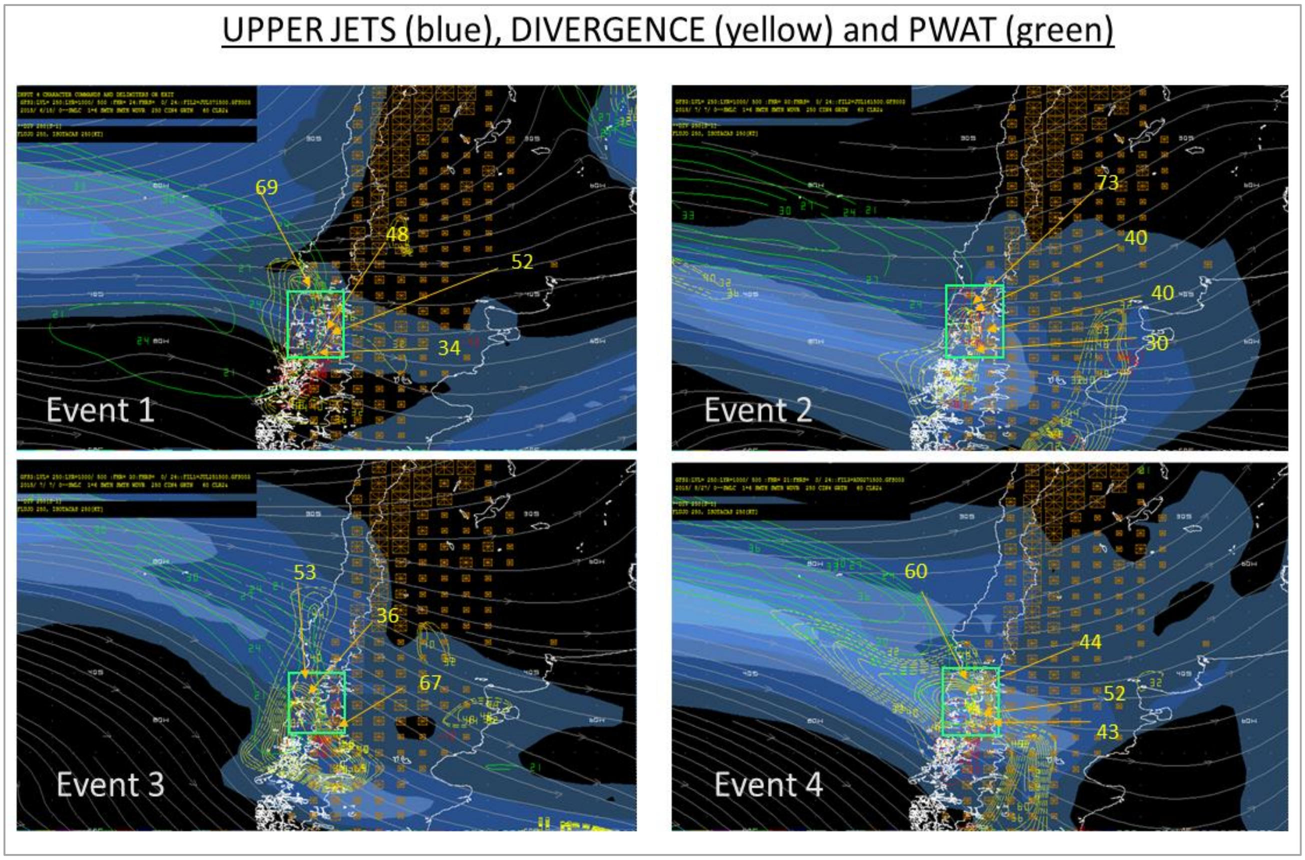
The slide above has animations that are not available in the PDF. Event #3 was characterized by the passage of a surface fronts and trailing occluded lows. The low-level flow was from the northwest during the period of heavy rains. The system was accompanied by a negatively tilted 500 hPa trough. Coupled jets were present at upper levels. The divergent exit of the northern jet entered in phase with the divergent entrance of a southern jet when they were crossing Southern Chile. This event produced rainfall amounts of 35-70mm/day in the region. Amount peaks were observed along the mountain ranges with lesser amounts in the valleys.



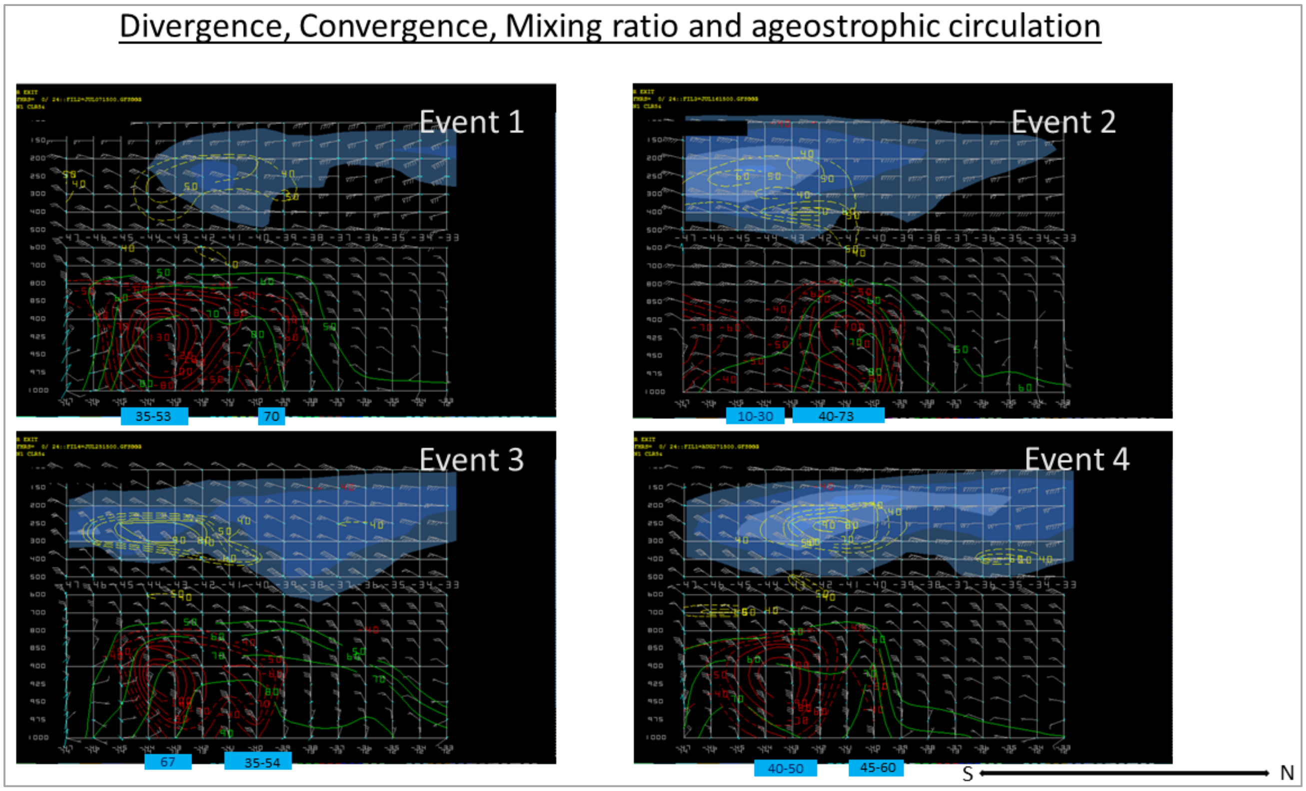
The slide above has animations that are not available in the PDF. Events #4 and #5 were characterized by the passage of a surface fronts and trailing occluded lows. The low-level flow was from the northwest during the period of heavy rains. Upper troughs arrived from the west instead of the south west as seen in event #2. The systems were accompanied by the Northern Polar and Southern Polar jets. The divergent exit of the jets was present during the rainfall events.



The slide above shows 500 hPa geopotential heights (light blue), cyclonic vorticity advection (yellow) and geopotential heights during the peak of each event. Rainfall amounts are indicated in mm/day. The region with the heaviest rains is indicated with a green box for reference.



The slide above shows data near the peak of each rainfall event. 250 hPa isotachs > 70kt are plotted every 20kt (blue shades). 250 hPa streamlines are also included. The slide also shows precipitable water totals in mm (green contours); 250 hPa divergence in 10^{-6} s^{-1} (yellow dashed lines) and convergence at 850 hPa in 10^{-6} s^{-1} (red contours). Orography is shown in brown boxes. Most of the events were accompanied by the divergent exit of an upper jet in phase with a subtropical moisture connection/atmospheric river. The latter is characterized by a band of precipitable water exceeding 20 g kg^{-1}. A band of enhanced upper divergence is evident along the windward side of the Andes in association with interactions between the jet and the mountains. The heaviest rains occurred in the region where all these factors intercepted. The event #2 was the outlier in terms of upper jet dynamics, as the highest rainfall totals were observed under the convergent exit of the jet. A common feature was the maximum rainfall amounts downwind and just to the south of the precipitable water maxima.



The slide above shows south-north cross sections constructed along the Chilean coast during the peak of each event. The fields plotted are similar to those plotted in the former panel. The figures show that heaviest rains (indicated on each panel in light blue boxes) occurred in the regions where the different variables plotted intercepted. Heavy rainfall seems to me more sensitive to moisture than the other predictors. This is consistent with the findings of Falvey and Garreaud (2006), who described that the moisture flux was the strongest of the predictors for rainfall amounts in Central Chile. An exception is the event #3, where the powerful dynamics produced larger totals to the south. Note that moisture content was larger to the north.

Meteorological Predictors

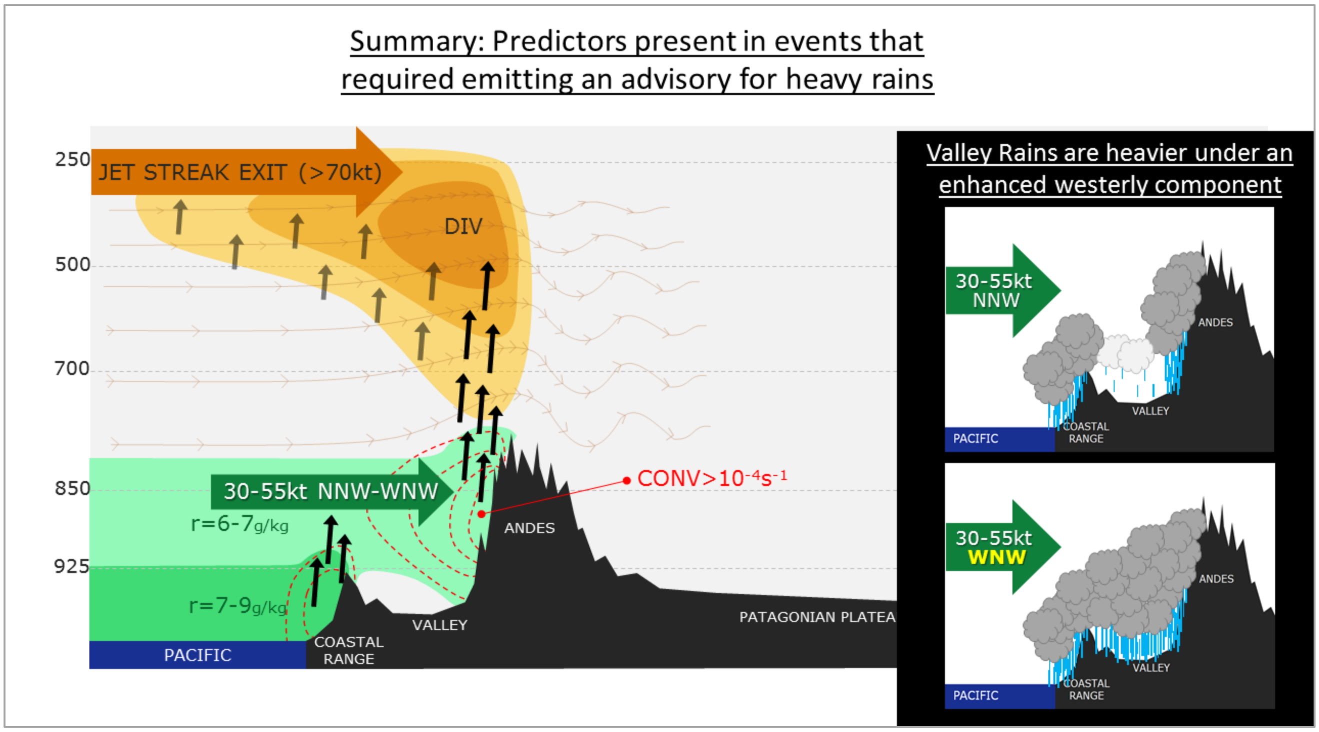
TABLE 1. Predictors Events of Precipitation												
EVENTS		CONVERGENCE			DIVERGENCE			MIXING RATIO g/kg	LAYER		
	DATE/HOUR	VALUES (-)	LAYER	AREA LAT.	VALUES (+)	LAYER	AREA LAT.		M.RATIO	WINDS KT	AREA LAT
EVENT 1	July 8 00z	110/130	975/850	43-45 SCFT-SCBA	40/50	200/400	39-44 SCVD-SCAS	7-8	900/SFC	Norte 30-40	40-42
	July 8 06z	90/110	850/950	39-41 SCVD SCTE	40/50	200/400	39-42 SCVD-SCAC	7-8	950/SFC	NW/N 15 N 20-25	39-41 41-42
	July 8 12z	80/90	900/950	39-44 SCVD-SCAP	40/50	200/400	41-43 SCTE-SCAP	7-8	950/SFC	NW 15-35	
EVENT 2	July 17 00z	100/130	900/975	42-45 SCAC- SCBA	50/80	600	41-46 SCTE-SCCC	6	950/SFC	N 50-30	42-44
	July 17 06z	60/90	850/950	40-43 SCJO- SCAP	40/80	300/400	41-43 SCTE-SCAP	6-7	925/SFC	N/NW 15-20	41-43
	July 17 12z	90/110	850/950	40-41 SCJO-SCTE	40/60	300/600		60-70	925/SFC	N 10/15	39-40
EVENT 3	July 26, 06z	70	975/900	40-42 SCJO SCAC	50/90	250/400	40-45 SCJO-SCBA	80/90	925/SFC	N 30	40-43
		70/100	975/850	42-44 SCAC SCLI	50/90	250/400	40-45 SCJO-SCBA	90	975/SFC	NE 30/15	42-45
EVENT 4	August 25, 06z	40/60	975/850	38-39 SCTC SCVD	40/60	300	38/41 SCTC-SCTE	80	950/SFC	NNE 10/25	40-43
EVENT 5	August 27, 21z	60/90	975/850	42-45 SCAC-SCVD	40/90	200/350	40/43 SCJO-SCAP	70	950/SFC	N 40 costa 25/30 valle	40-44
Predictors		Undefined	975-850	39-45	40-90	200-400	39-41	70-90	950-SFC	20-40 KT	40-44

A list of values for the predictors plotted on the previous cross sections is summarized in Table 1.

Meteorological Predictors

TABLE 2	PWAT	CONV(-) 850	DIV (+) 250	500 Geop. (-) Falls	Sector	Advection Vorticity (-)	Amounts RR (mm/day)
Event 1	21-27	40/100	32/56	120/140	LOS LAGOS	6 a 10	35-70
Event 2	21-24	40/80	32/56	60/80	SCON-SCAS	2	30-75
				80/140	SCAS-TAITAO	2	
Event 3	21-27	40/100	32/84	60/80	SCTC - SCMK	2 a 12	35-70
Event 4	21-25	40/60	32/48	60/80	SCTE-SCTC	2 a 6	50-75
Event 5	21-27	40/80	32/84	80/130	SCVD-SCTE	2 a 6	30-60
				130/160	SCTE-TAITAO		
	20-27	40/80	32/84	Undefined		Undefined	

A list of values for the predictors plotted on a planar analysis is shown in Table 2.



These figures summarize the findings. The figure on the left shows a west-east section across the Andes. It shows the air masses arriving from the west accompanied by 30-55kt winds at 850 hPa and a jet streak at 250 hPa. Mixing rations during the heavy rains were 7-9g/kg below 925 hPa and 6-7 g/kg between 925 hPa and 800 hPa. Upper divergence in the windward side of the Andes was stimulated generally by the presence of the right (divergent) exit of an upper jet streak, but also by the Bernoulli effect that causes winds to speed up over mountain ranges. A summary follows.

Summary

- "El Niño" winter 2015 led to frequent intense precipitation events in southern Chile.
- The associated atmospheric patterns were relatively similar between events.
- Through this work, ingredients / relevant predictors were identified:

✓ Robust connections subtropical moisture (> 20mm, SFC-800hPa)
✓ Strong low level winds (WNW-NNW 30-55kt at 850 hPa)
✓ Enhanced westerly component increases significantly rainfall totals in the valley.
✓ Upper Jet Support (right exit, coupled jets, divergence from Bernoulli effect by mountains)
✓ Mid-level troughs (height falls>100kt, Cyclonic Vorticity Advection)
✓ Short wave troughs play an important role.

- Troughs and jets high are present every year. The remarkable feature was the magnitude and frequency of the subtropical connections / low-level atmospheric rivers that generated massive moisture convergence.

References

Falvey M., and R. Garreaud, 2006: Wintertime Precipitation Episodes in Central Chile: Associated Meteorological Conditions and Orographic Influences. *Journal of Hydrometeorology, 8,* 171-193.

Garreaud, R., 2013: Warm winter storms in Central Chile. *Journal of Hydrometeorology,* 14, 1515–1534.

R. Garreaud, P. Lopez, M. Minvielle and M. Rojas, 2013: Large-Scale Control on the Patagonian Climate. *Journal of Climate, 8,* 215-230.

APPENDIX

WINGRIDDS macros/scripts were generated to enhance the visualization of the features involved in the generation of the heavy rainfall events in Southern Chile.