The complex cocktail of mountain meteorology and atmospheric chemistry in central Chile

Rémy Lapere, Laurent Menut, Sylvain Mailler, Nicolás Huneeus

Séminaire LMD – 26 Novembre 2020

LMD

ÉCOLE POLYTECHNIQUE

INSTITUT POLYTECHNIQUE DE PARIS

©Thinkstock

Before we begin...

Fine particles - PM2.5

- Aerosols (solid or liquid particles) of diameter <2.5µm
- Decreased visibility
- Cardiovascular and lungs diseases, asthma
- Direct and indirect radiative effects

Tropospheric Ozone

- Secondary pollutant & greenhouse gas (“bad” ozone)
- Non-linear chemistry (NOx+VOC+sunlight)
- Cardiovascular diseases, asthma
- Affects vegetation



Photochemical smog over Paris (source 20minutes.fr)

Chimere

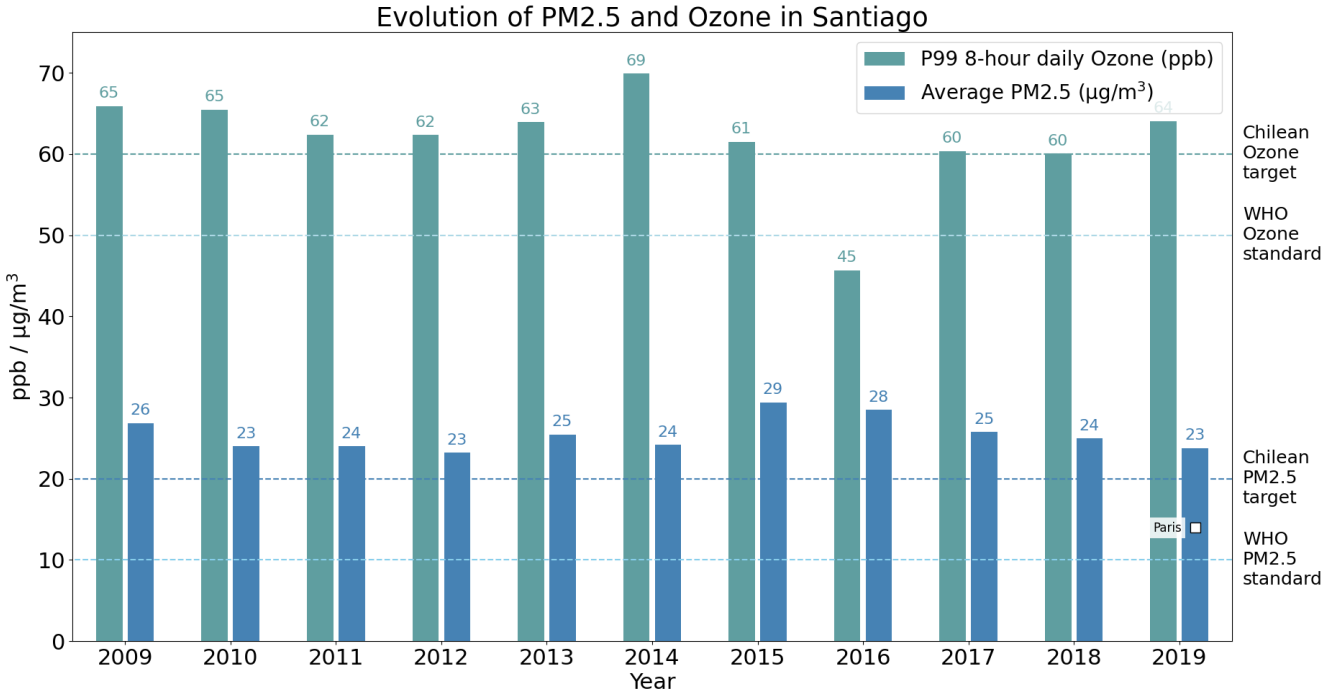
LMD+INERIS+LISA

“A multi-scale chemistry-transport model for atmospheric composition analysis and forecast”

All along the presentation meteorological forcings are simulated with WRF

Why air pollution in Chile matters

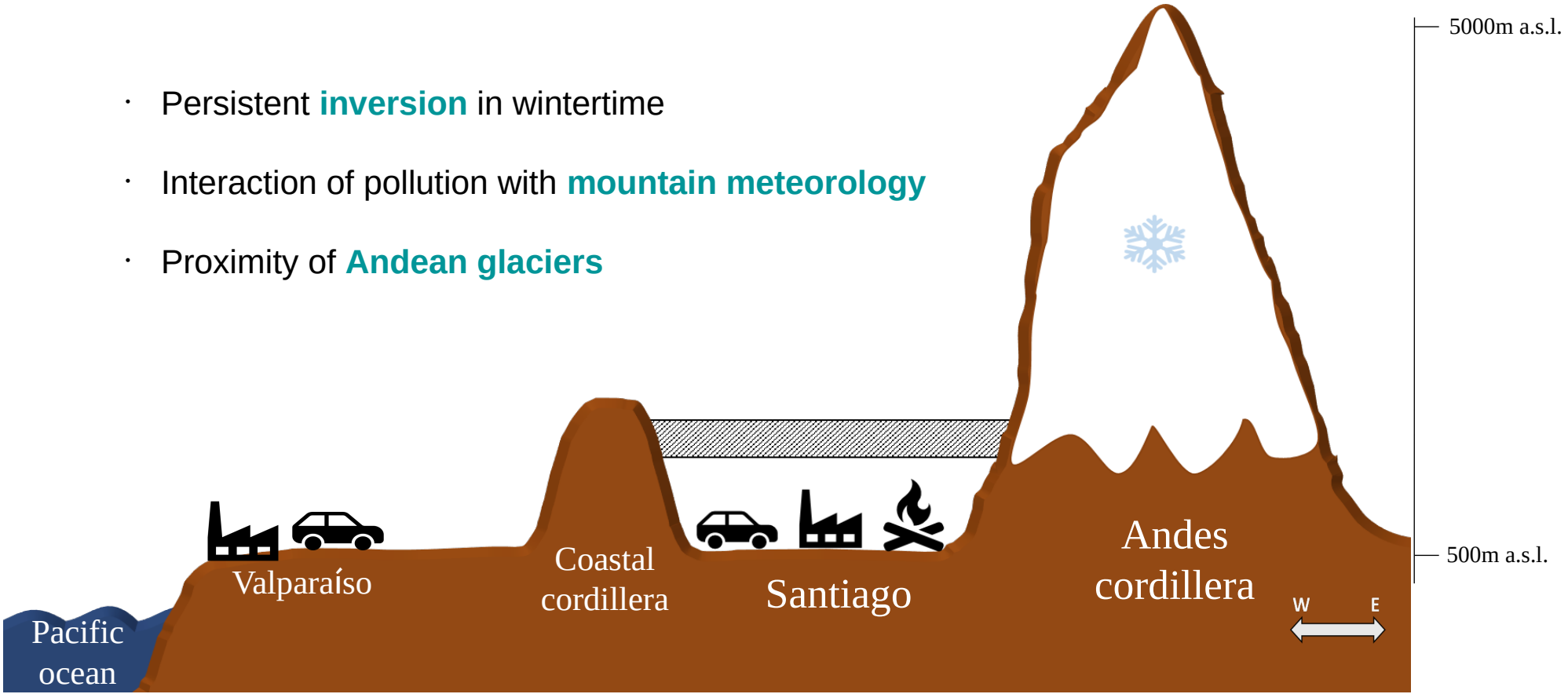
Air pollution in Santiago: key figures



Santiago area population	Lifetime reduction per capita	Estimated economic cost of non-compliance
7 million	**1.4 year**	**>200M$ / year**

A confined basin

- Persistent **inversion** in wintertime
- Interaction of pollution with **mountain meteorology**
- Proximity of **Andean glaciers**



Agenda

1) Wintertime PM2.5 extreme events

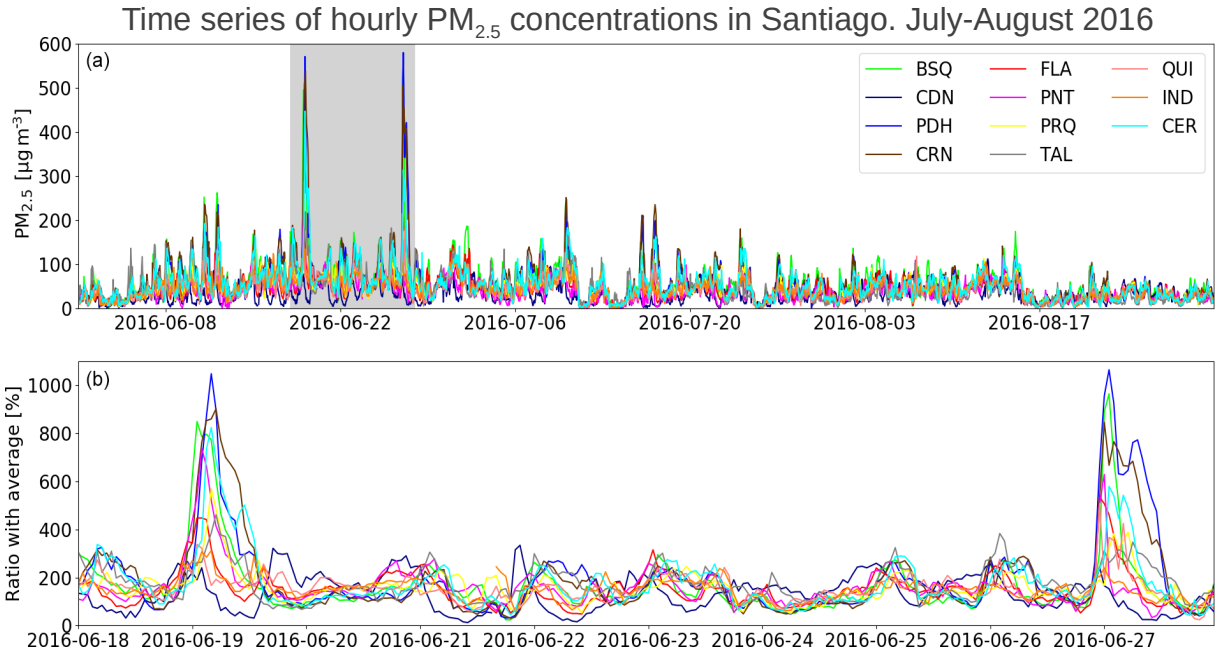
2) Pathways of Black Carbon towards the Andes

3) Regional influence of emissions from Santiago

1 – Wintertime PM2.5 extreme events

Based on Lapere, R., Menut, L., Mailler, S., and Huneeus, N.: Soccer games and record-breaking PM2.5 pollution events in Santiago, Chile, *Atmos. Chem. Phys.*, 20, 4681–4694, https://doi.org/10.5194/acp-20-4681-2020, 2020.

Context

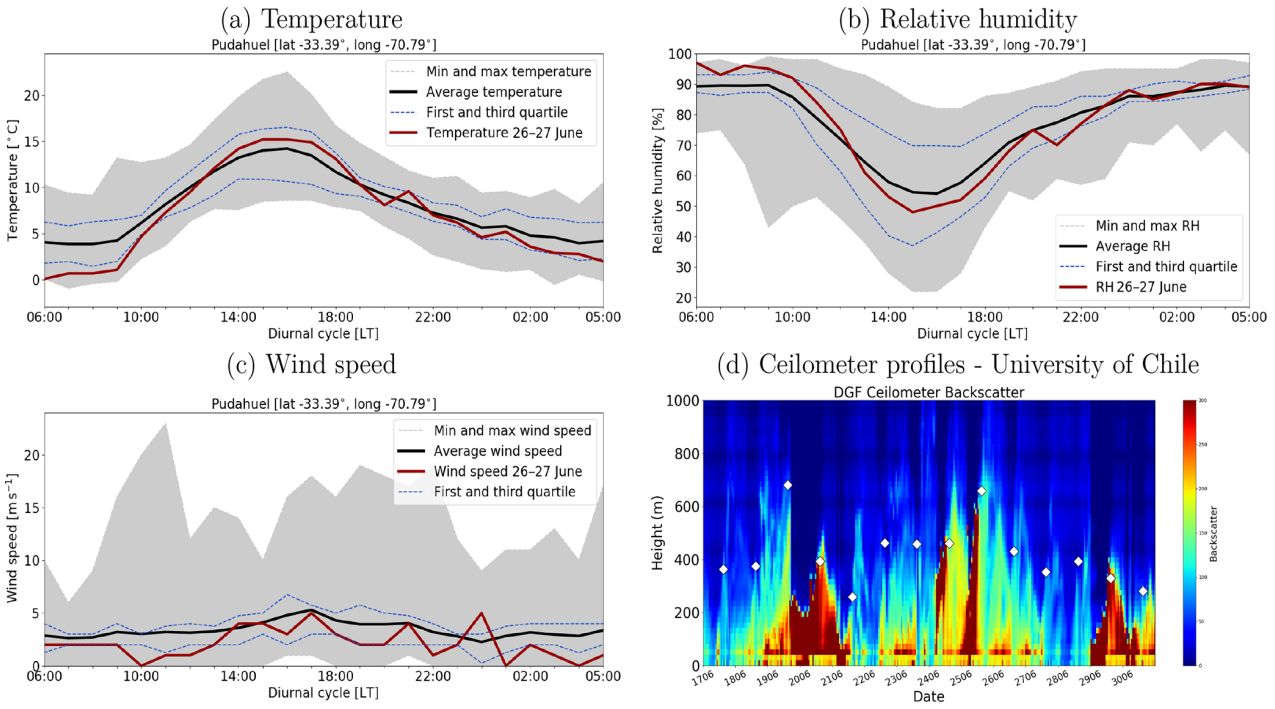


All-time record-breaking peaks of $PM_{2.5}$ in June 2016:

- Hourly concentrations up to **600µg/m³**
- **10 times higher** than the monthly average
- **2 short-lived spikes** generalized throughout the city

Question: what is the origin of these peaks?

Extreme weather?



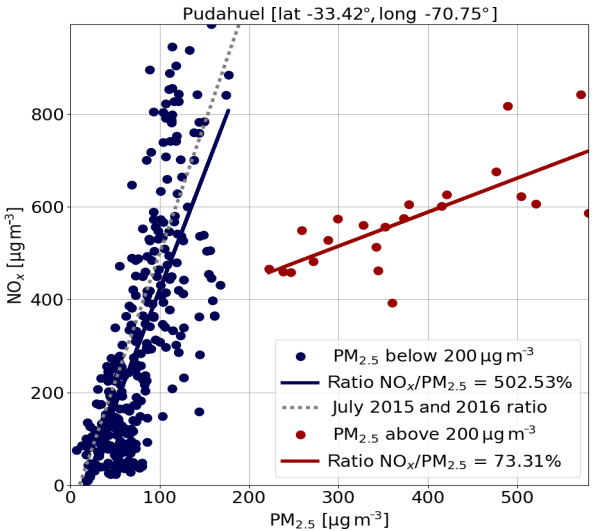
Temperature, Relative humidity and wind speed within 1st and 3rd quartiles for the month

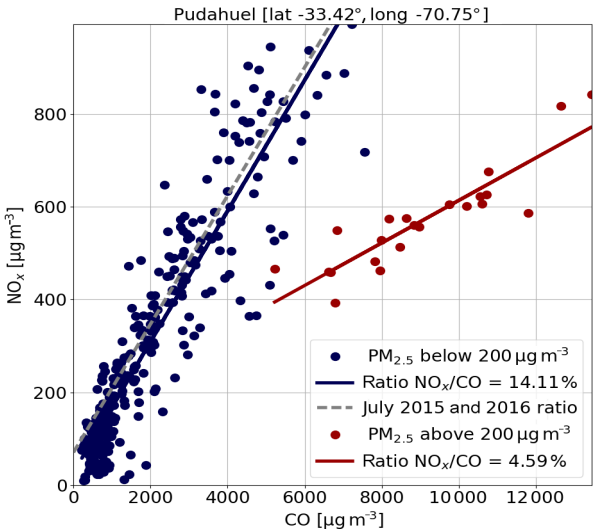
Boundary layer not shallower than on other days without peaks

A meteorological origin can be ruled out => exceptional emissions

Chemical footprint

Observed NOx/$PM_{2.5}$ and NOx/CO concentration ratios. Station Pudahuel JJ 2016





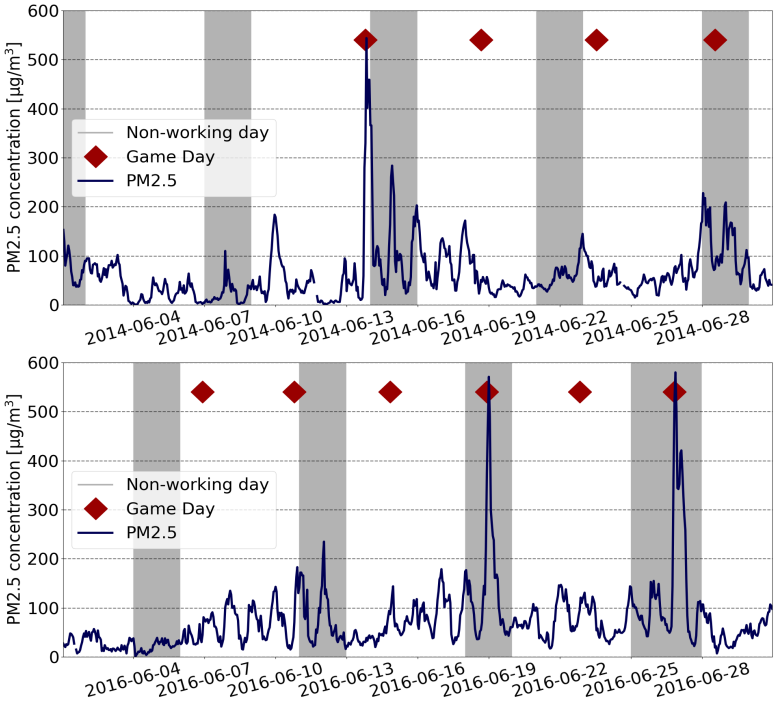
Concentration **ratios of pollutants** greatly differ between usual and peak conditions

The **usual mix** of sources **cannot account** for the observed chemical footprint

	NOx/$PM_{2.5}$	NOx/CO
Traffic	1750%	7.5%
Residential	200%	19%
Industry	186%	20%
Observed	**73%**	**4.6%**

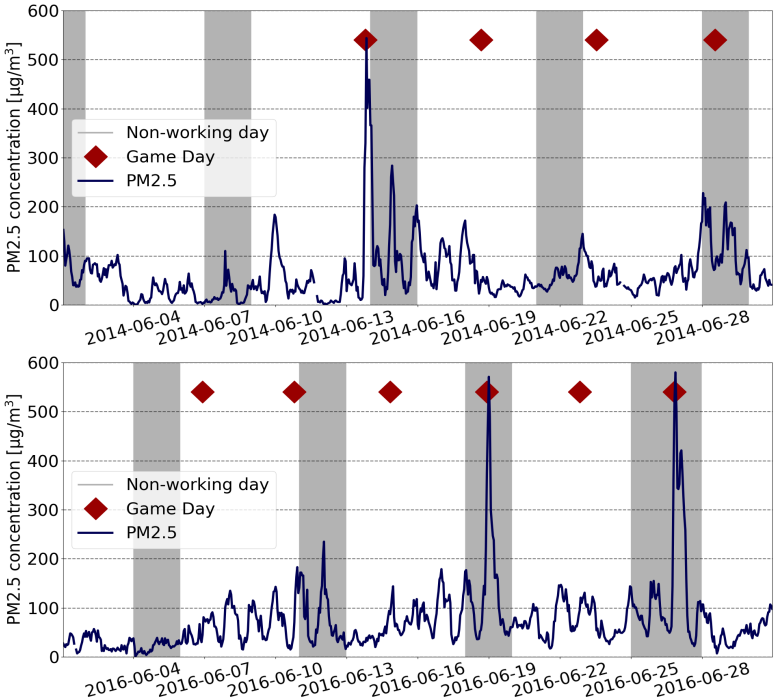
An unusual source, strongly emitting, is at play, but what?

A correlation with soccer games of *La Roja*





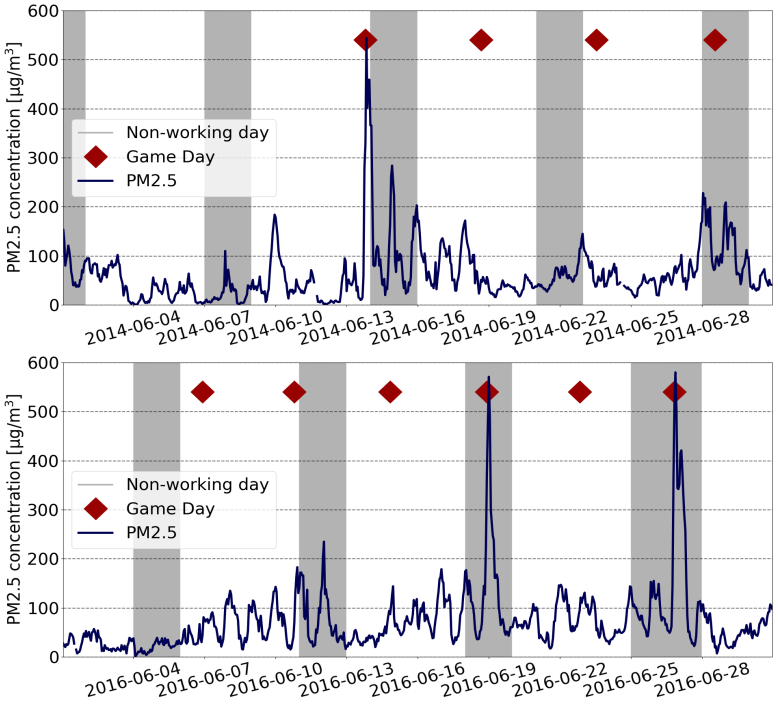
A correlation with soccer games of *La Roja*







A correlation with soccer games of *La Roja*

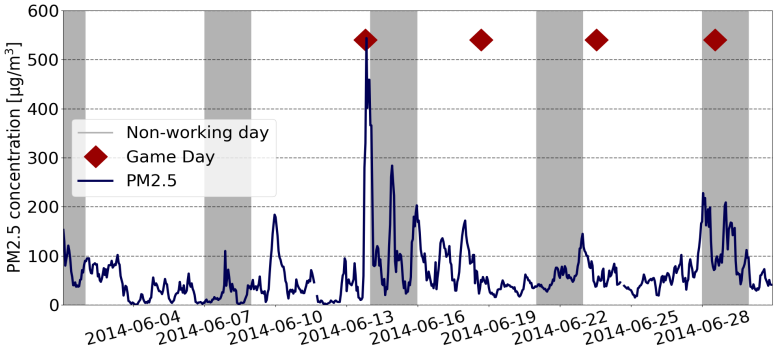


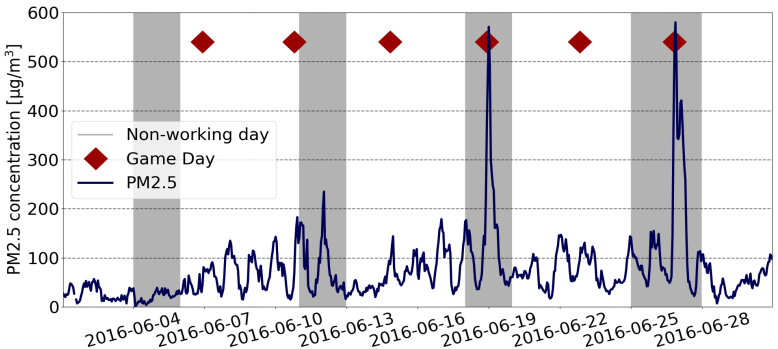






A correlation with soccer games of *La Roja*











Barbecues?
Seriously?

1st piece of evidence

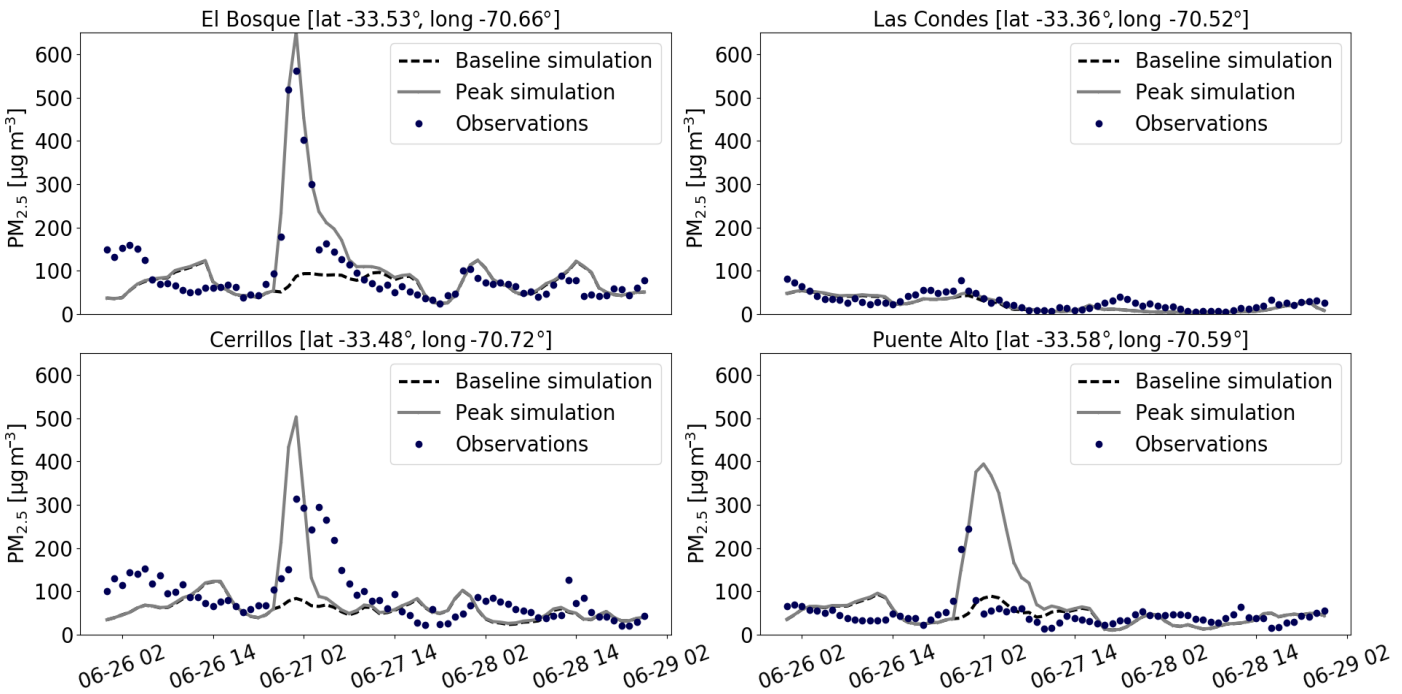
	$NOx/PM_{2.5}$	NOx/CO
Traffic	1750%	7.5%
Residential	200%	19%
Industry	186%	20%
Barbecue	**41-62%**	**1.4-2.4%**
Observed	**73%**	**4.6%**

Barbecues, seriously

2nd piece of evidence

2016 poll: 29% of Santiaguinos would cook a barbecue for the final game
=> around **100,000 fires**
i.e. **+2ton/h of PM2.5**

Let's plug it into **WRF-CHIMERE**



Conclusion



- A **simple, transposable methodology** was built to trace back the cause of 2016 peak events in Santiago
- It showed that **barbecue emissions** played a major role
- Policy design needs also consider **sporadic acute events** induced by specific sources
- The raised awareness led to the **absence of peak during the 2019 Copa America**



EL MERCURIO
JUEVES 6 DE JUNIO DE 2019

NACIONAL C 7

Investigador francés Rémy Lapere advierte sobre posibles episodios críticos luego de los partidos de la Roja en Brasil

"Efecto asado" enciende antesala de la Copa América: alertan por impacto en la contaminación



MKT [redacted]

¡INSÓLITO!

Chile prohibió los asados en Santiago por la concentración de partículas nocivas en la atmósfera

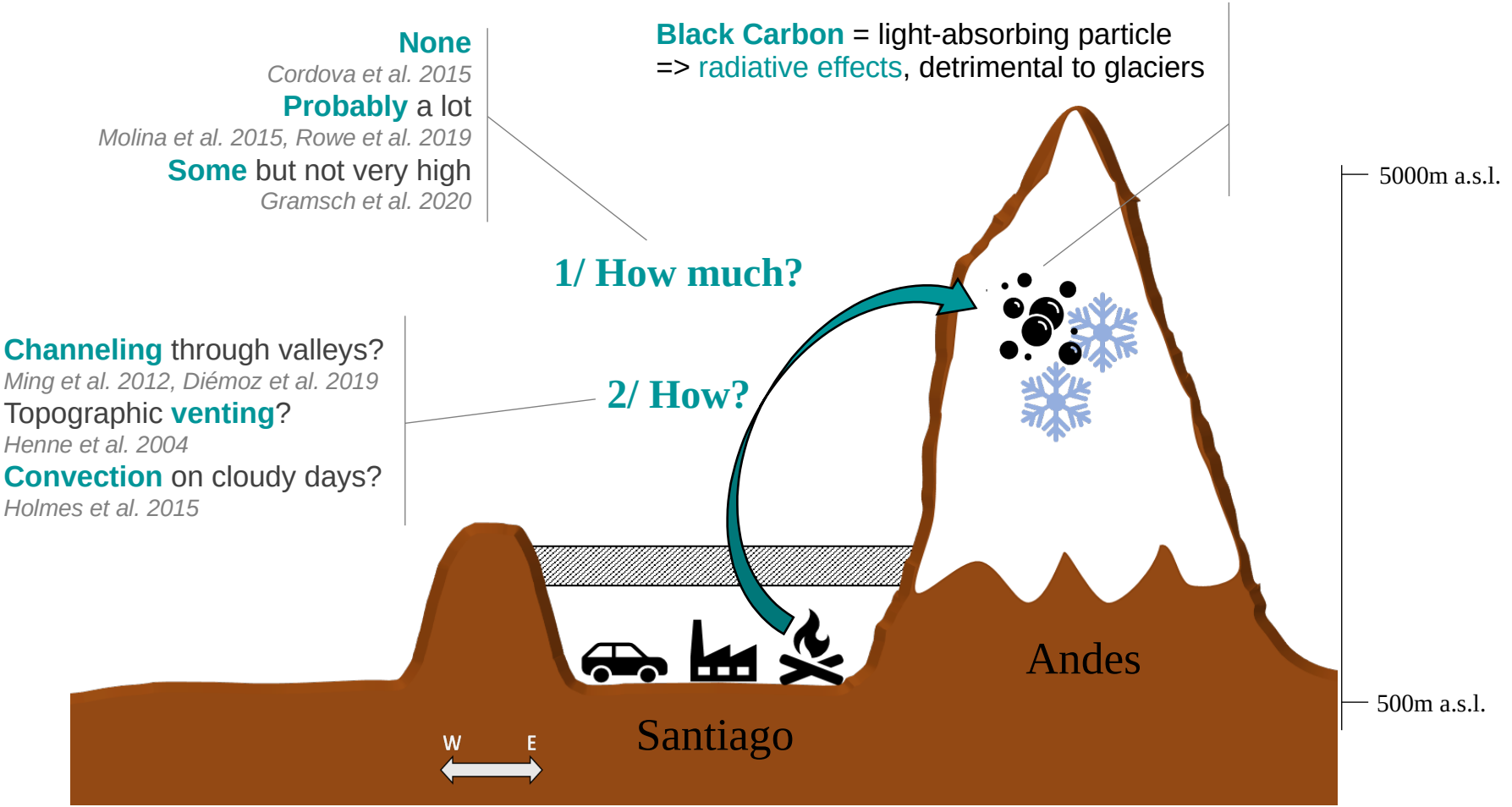
El llamado "efecto asado" existe, afirmó Diego Riveaux, secretario regional del Ministerio del Medio Ambiente#MktR

13 22:42 - 21 jun. 2019

2 – Pathways of Black Carbon towards the Andes

Based on Lapere, R., Mailler, S., Menut L., and Huneeus, N.: Pathways for wintertime deposition of anthropogenic light-absorbing particles on the Central Andes cryosphere, *Env. Poll.*, In press, https://doi.org/10.1016/j.envpol.2020.115901, 2020.

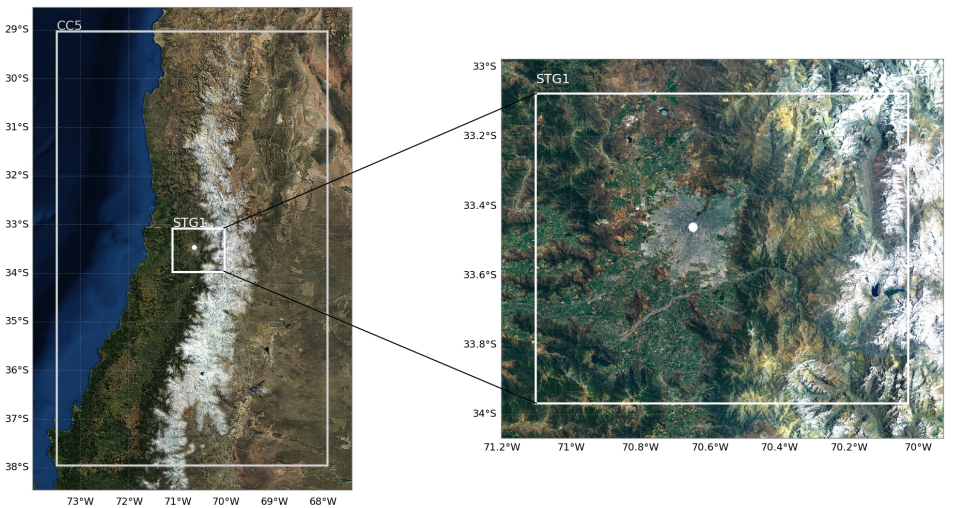
Context

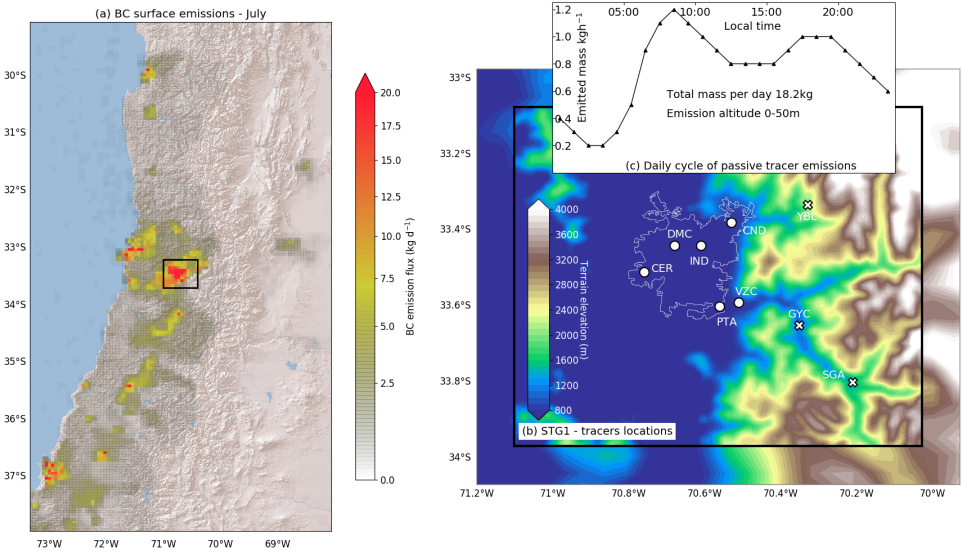

None
Cordova et al. 2015
Probably a lot
Molina et al. 2015, Rowe et al. 2019
Some but not very high
Gramsch et al. 2020
Black Carbon = light-absorbing particle
=> radiative effects, detrimental to glaciers
1/ How much?
Channeling through valleys?
Ming et al. 2012, Diémoz et al. 2019
Topographic **venting**?
Henne et al. 2004
Convection on cloudy days?
Holmes et al. 2015
2/ How?
5000m a.s.l.
500m a.s.l.
Andes
Santiago
W
E

Simulation design

Domain	Horizontal resolution	Purpose	Key output
CC5	5km (100x200 grid points)	Scenario on BC urban emissions	Contribution of BC from Santiago to deposition on glaciers
STG1	1km (100x100 grid points)	High resolution transport of tracers without chemistry	Pathways of aerosols from Santiago to the glaciers

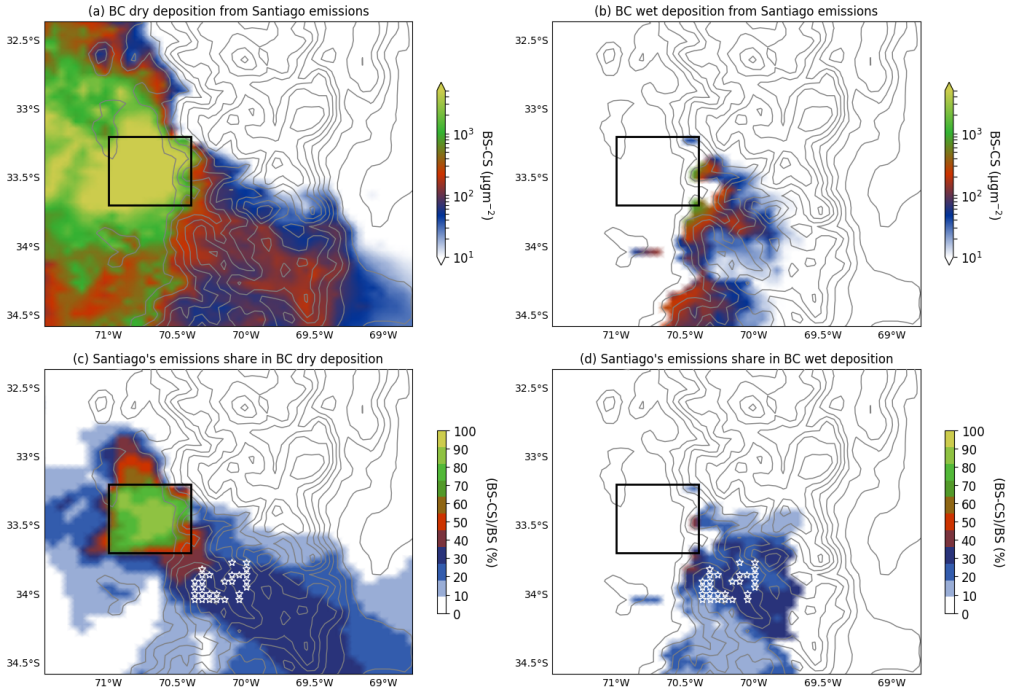
2 domains / 2 objectives



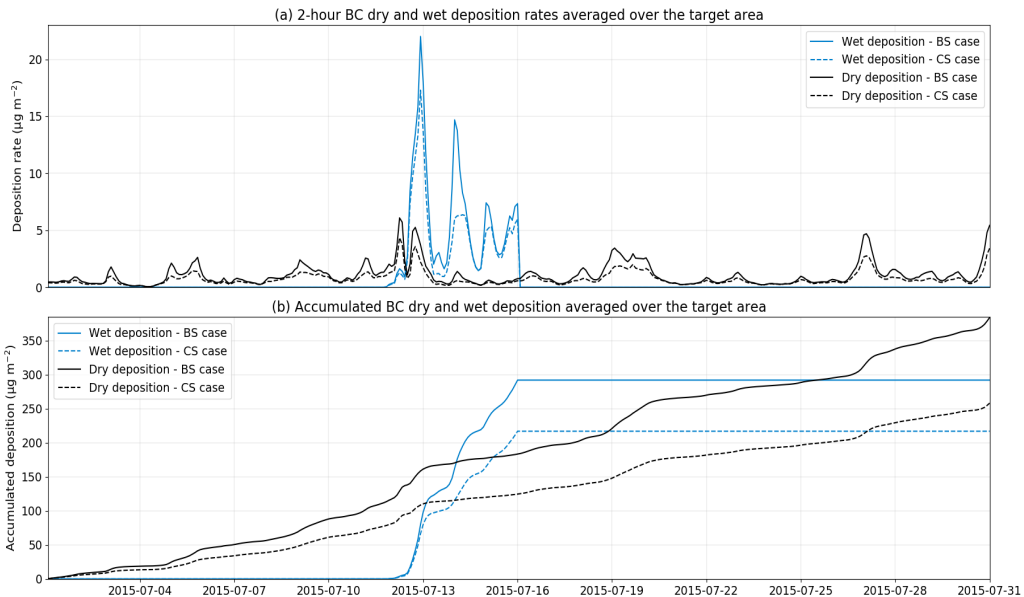


How much?

~30% on average in July 2015...

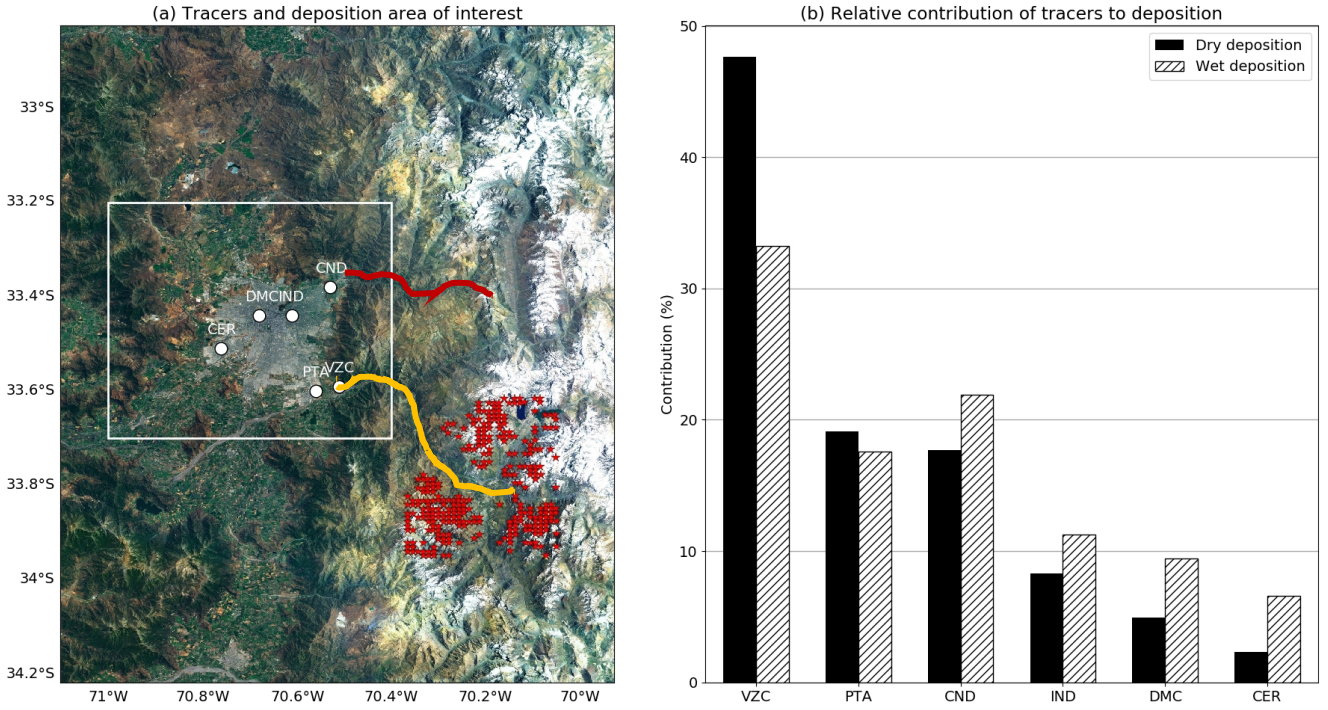


… corresponding to **200µg/m²**



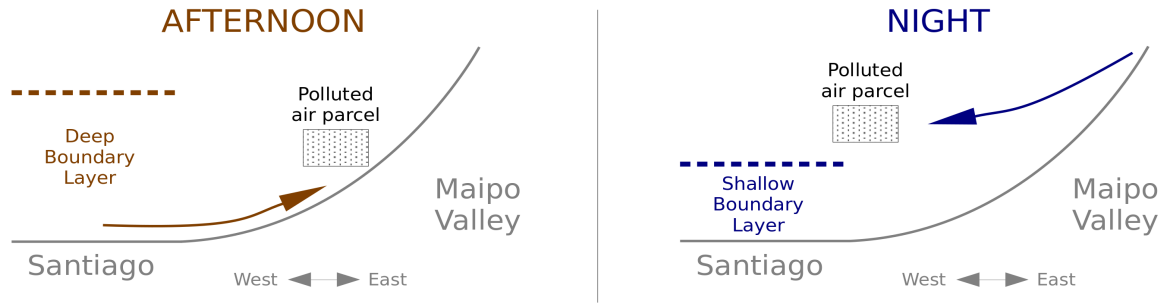
How?

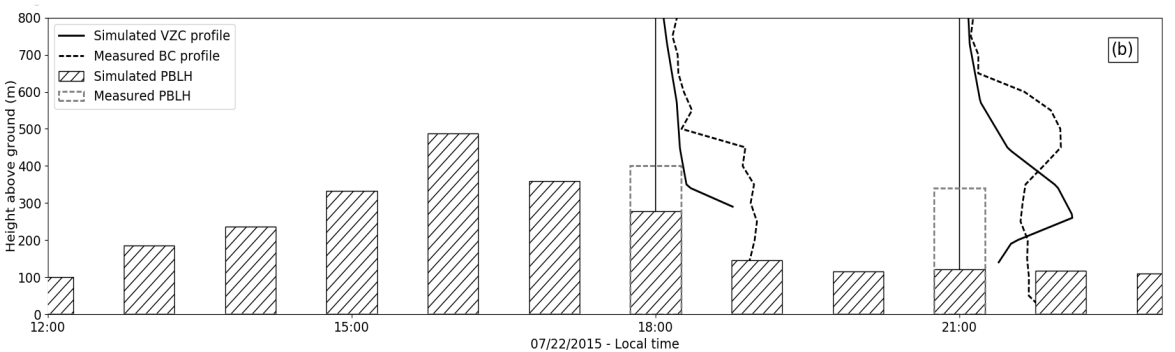
Contribution is greater for **sources close to the foothills**



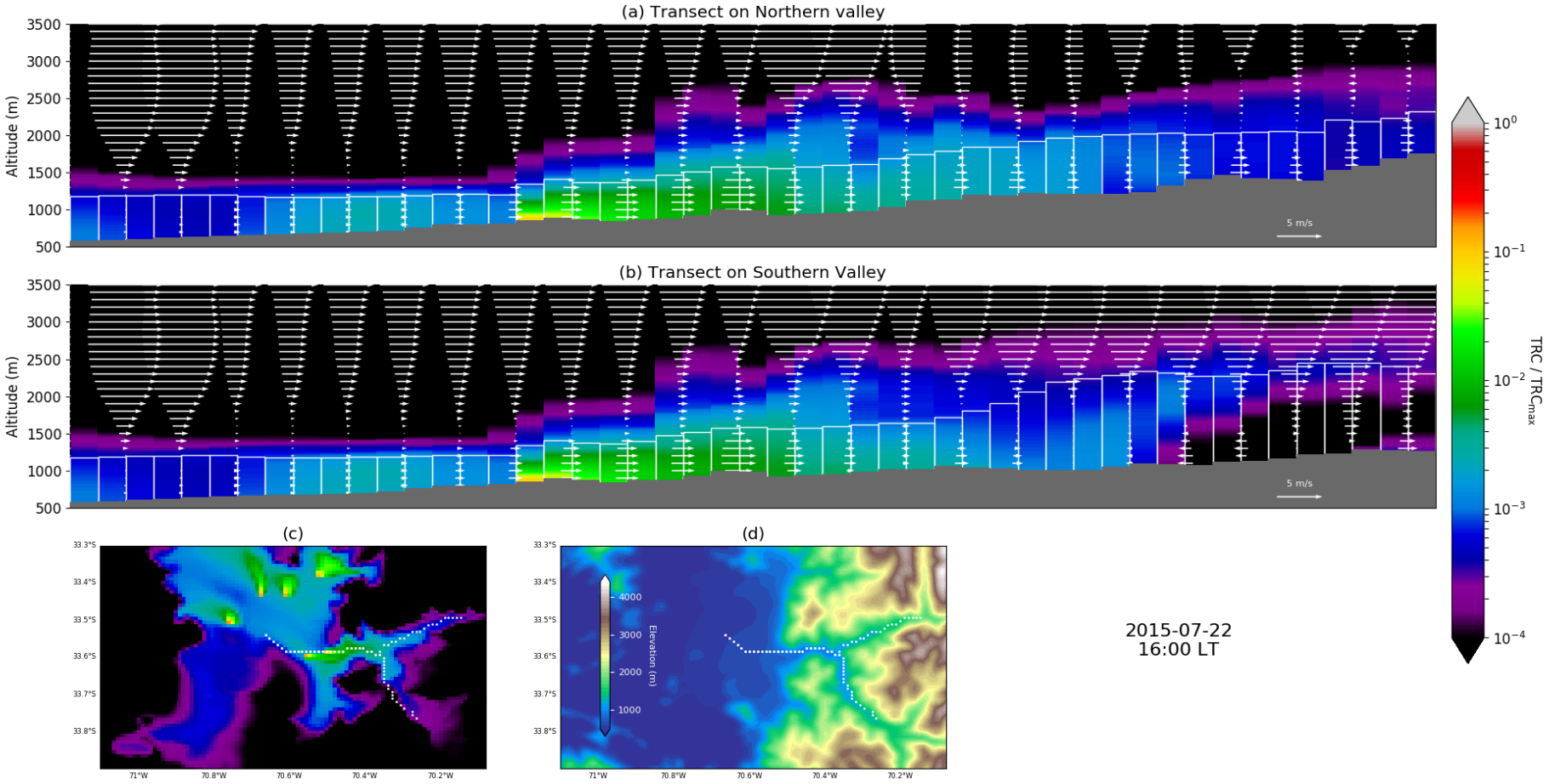
How?

Venting mechanism? **YES, but NO**

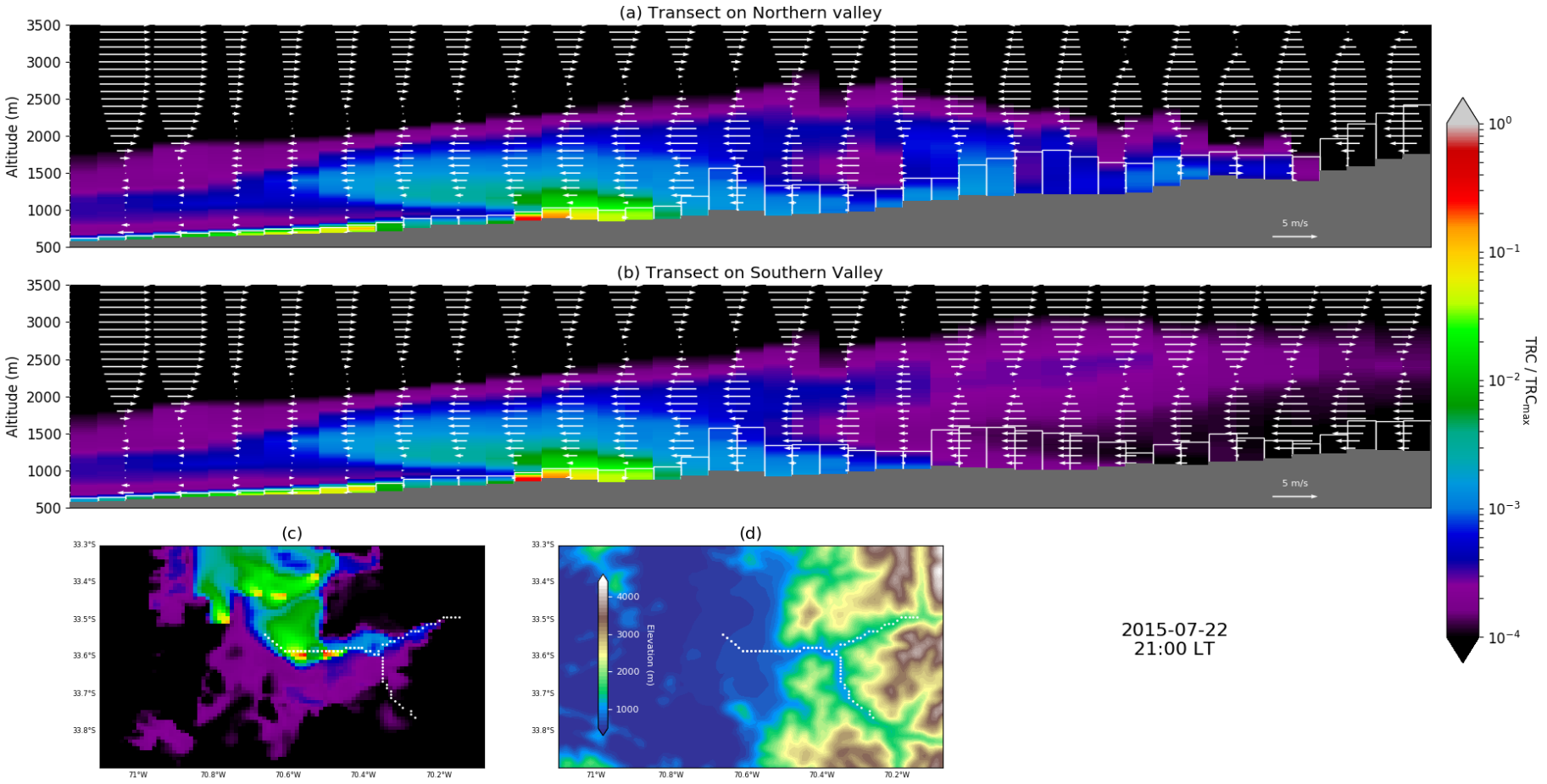




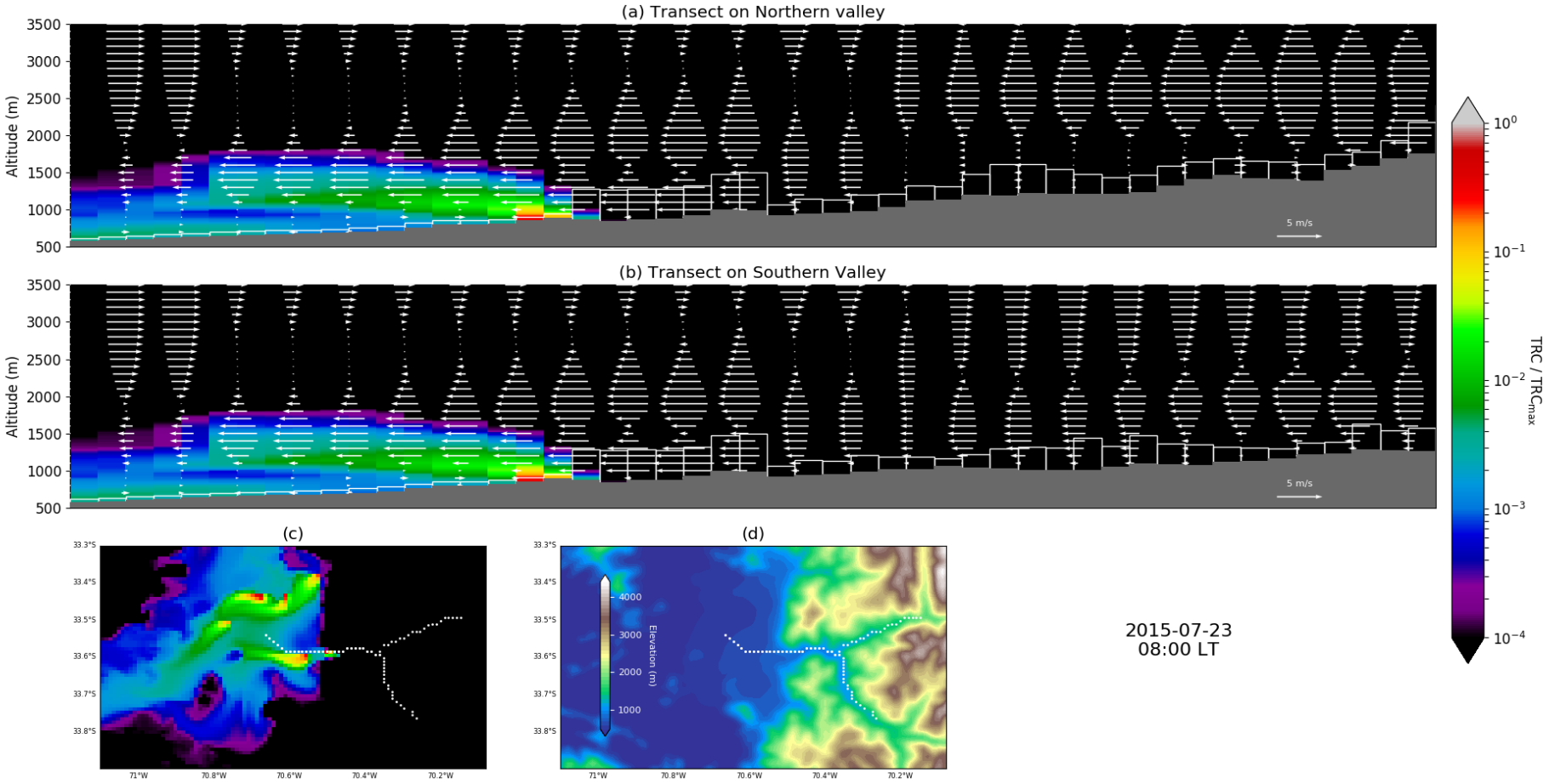
How?


(a) Transect on Northern valley
(b) Transect on Southern Valley
Altitude (m)
3500
3000
2500
2000
1500
1000
500
5 m/s
(c)
(d)
33.3°S
33.4°S
33.5°S
33.6°S
33.7°S
33.8°S
71°W
70.8°W
70.6°W
70.4°W
70.2°W
4000
3000
2000
1000
Elevation (m)
2015-07-22
16:00 LT
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
TRC / TRC$_{max}$

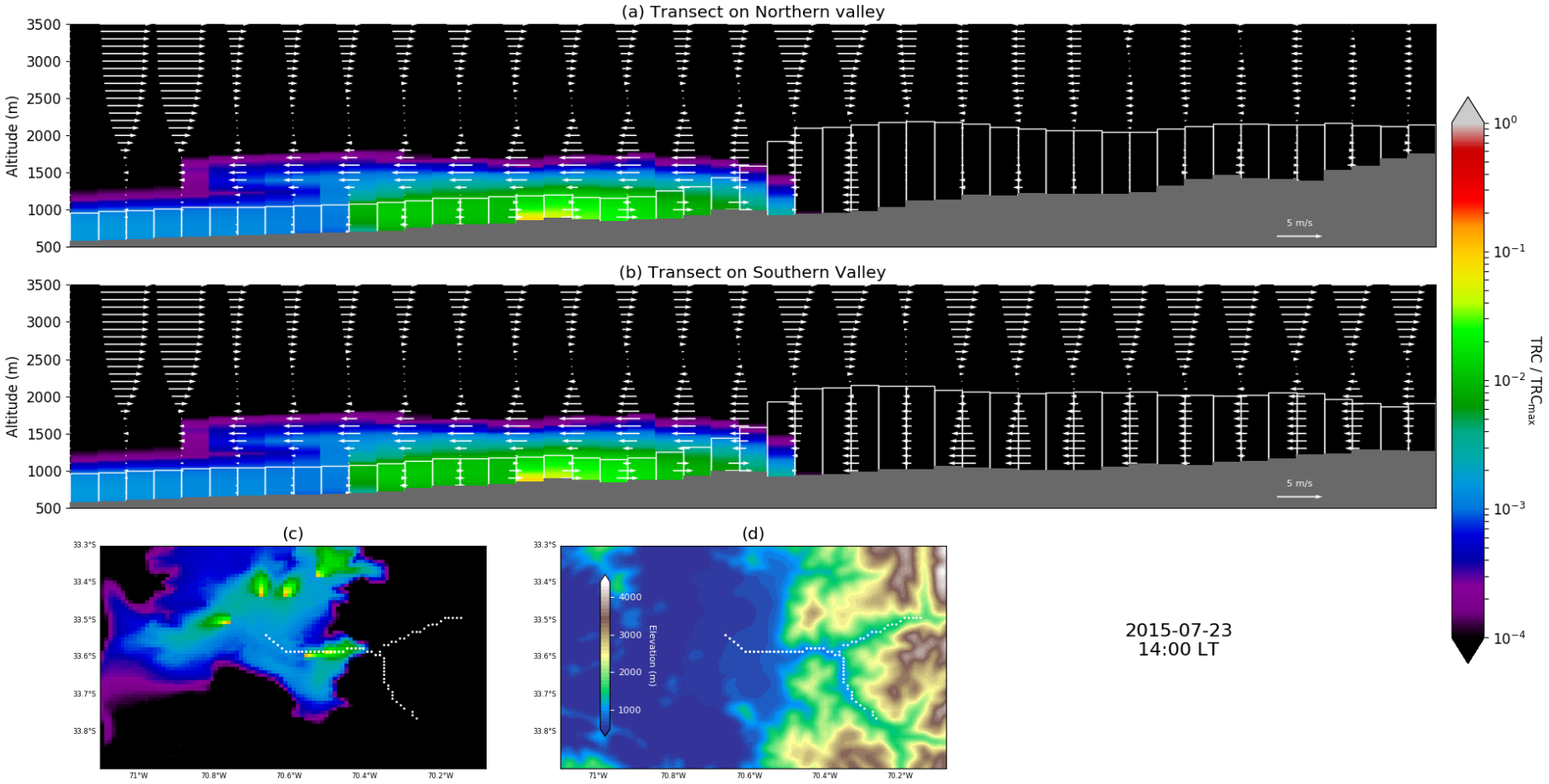
How?


(a) Transect on Northern valley
Altitude (m)
3500
3000
2500
2000
1500
1000
500
5 m/s
(b) Transect on Southern Valley
Altitude (m)
3500
3000
2500
2000
1500
1000
500
5 m/s
(c)
33.3°S
33.4°S
33.5°S
33.6°S
33.7°S
33.8°S
71°W
70.8°W
70.6°W
70.4°W
70.2°W
(d)
33.3°S
33.4°S
33.5°S
33.6°S
33.7°S
33.8°S
4000
3000
2000
1000
Elevation (m)
71°W
70.8°W
70.6°W
70.4°W
70.2°W
2015-07-22
21:00 LT
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
TRC / TRC_{max}

How?

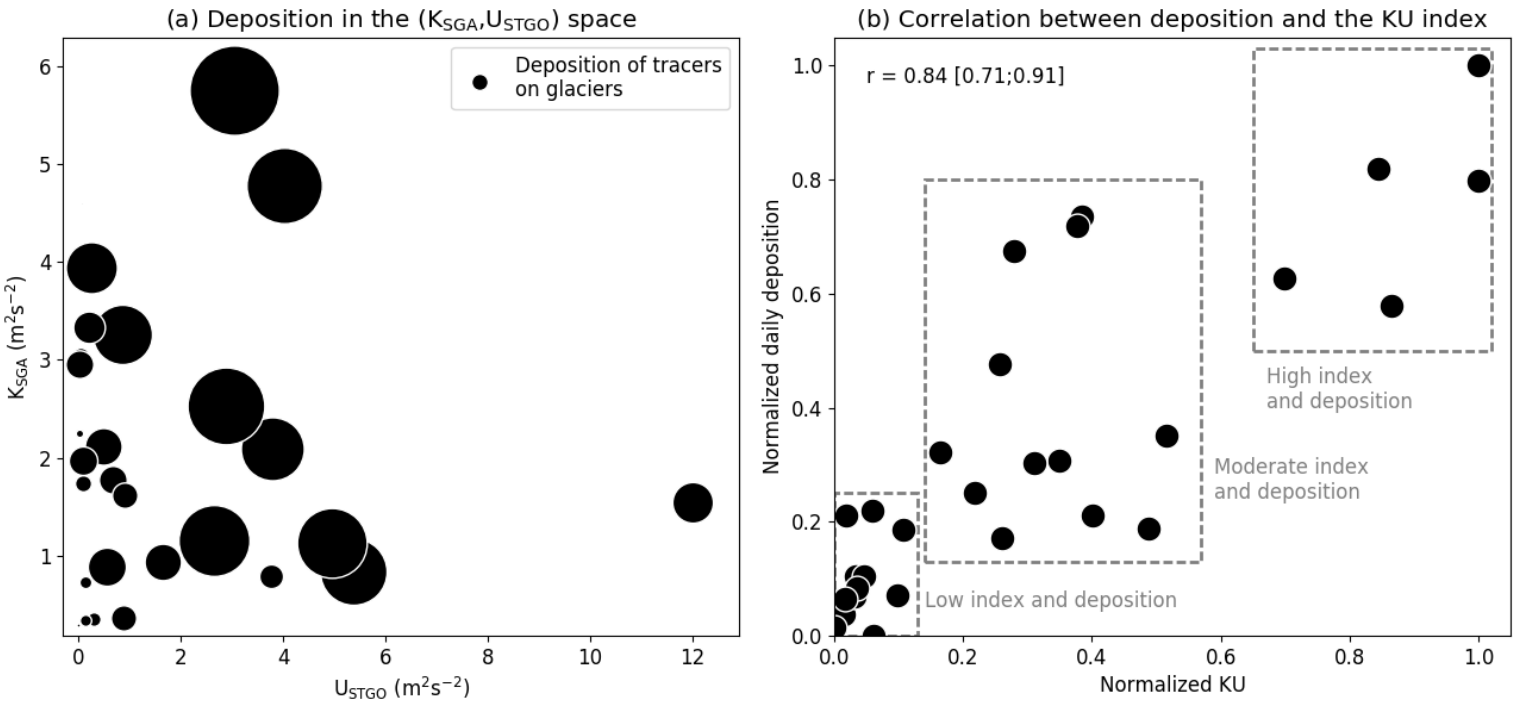

(a) Transect on Northern valley
Altitude (m)
3500
3000
2500
2000
1500
1000
500
5 m/s
(b) Transect on Southern Valley
Altitude (m)
3500
3000
2500
2000
1500
1000
500
5 m/s
(c)
33.3°S
33.4°S
33.5°S
33.6°S
33.7°S
33.8°S
71°W
70.8°W
70.6°W
70.4°W
70.2°W
(d)
33.3°S
33.4°S
33.5°S
33.6°S
33.7°S
33.8°S
4000
3000
2000
1000
Elevation (m)
71°W
70.8°W
70.6°W
70.4°W
70.2°W
2015-07-23
08:00 LT
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
TRC / TRC_{max}

How?


(a) Transect on Northern valley
Altitude (m)
3500
3000
2500
2000
1500
1000
500
5 m/s
(b) Transect on Southern Valley
Altitude (m)
3500
3000
2500
2000
1500
1000
500
5 m/s
(c)
33.3°S
33.4°S
33.5°S
33.6°S
33.7°S
33.8°S
71°W
70.8°W
70.6°W
70.4°W
70.2°W
(d)
33.3°S
33.4°S
33.5°S
33.6°S
33.7°S
33.8°S
4000
3000
2000
1000
Elevation (m)
71°W
70.8°W
70.6°W
70.4°W
70.2°W
2015-07-23
14:00 LT
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
TRC / TRC_{max}

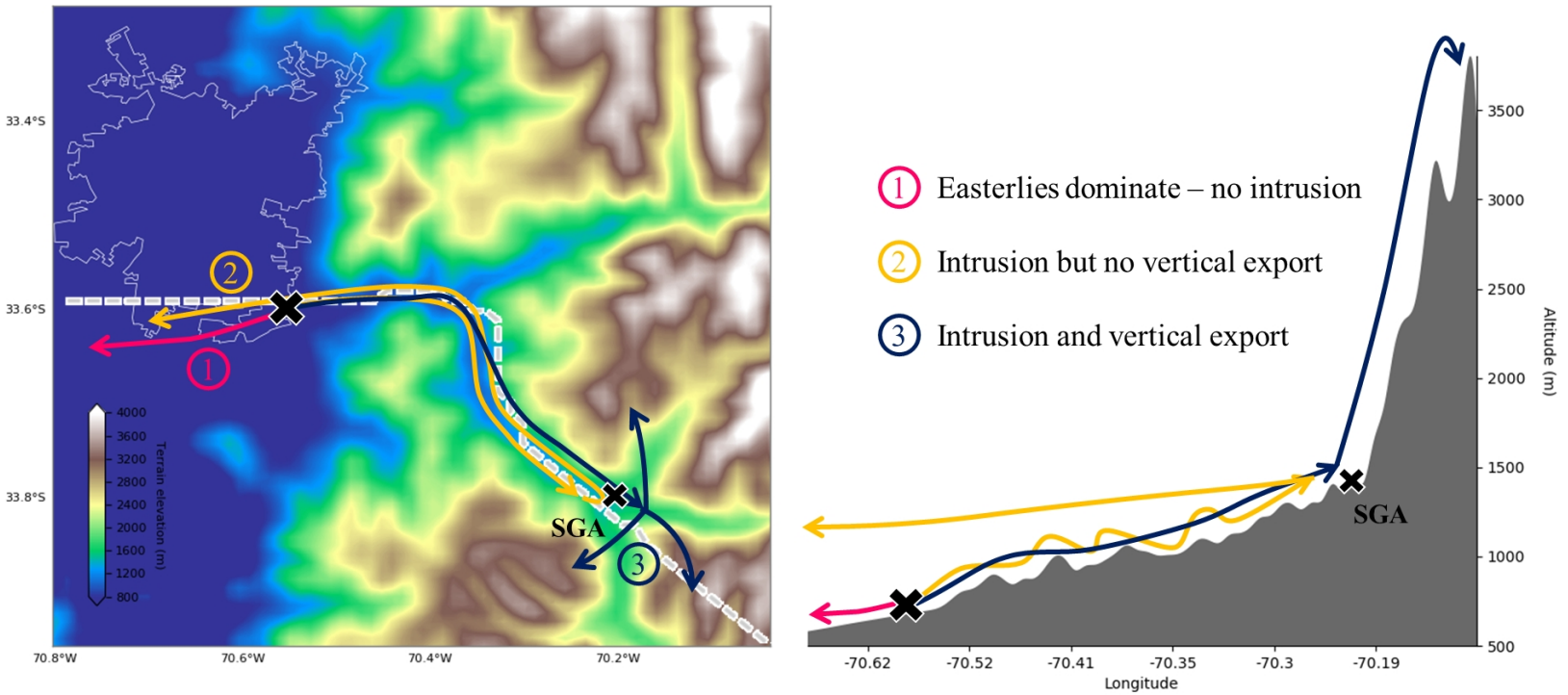
How?

Intrusion into the canyons followed by **vertical export**
accounts for most of the variance in deposition



How – in summary

In summary, **1 of 3 situations** occur



Conclusion

How much

- First ever estimate of **BC deposition** on the Andes attributable to Santiago emissions: **200µg/m²** (~30%) for July 2015, based on chemistry-transport modeling
- The **probability** of an emitted particle reaching the Andes is **heterogeneous** across locations within Santiago

How

- Interaction of urban air masses with canyons: gentle **up-slope terrain following**, then **vertical export** deep in the valley
- A meteorological index combining **urban zonal wind** and **valley vertical diffusion** accounts for most of the variance in deposition
- **Coastal low** and ***Raco*** phenomena prevent export, hence deposition

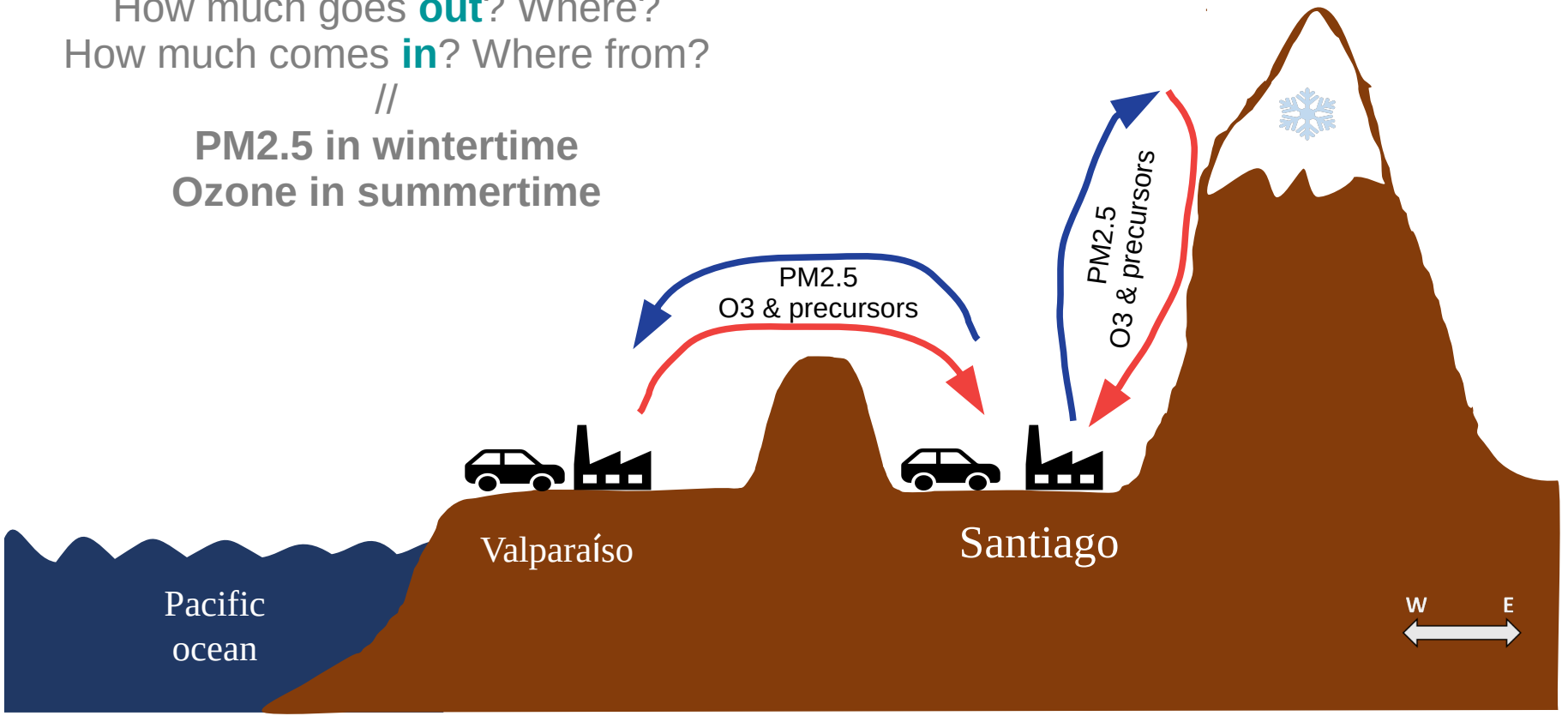
Corollary

- Urban PM **pollution** and **deposition** on Andean glaciers are **anti-correlated phenomena**

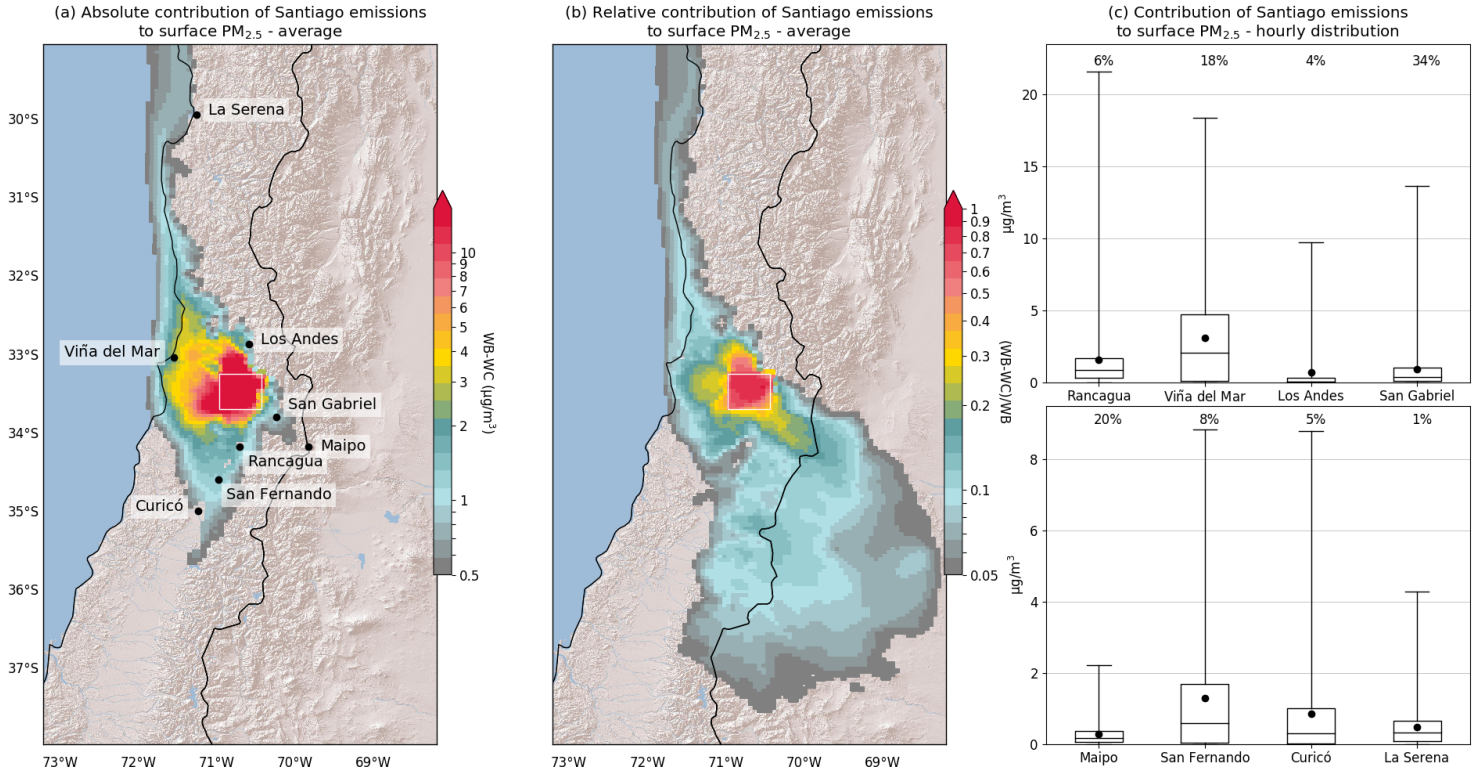
3 – Regional influence of emissions from Santiago

Context

How much goes **out**? Where?
How much comes **in**? Where from?
//
PM2.5 in wintertime
Ozone in summertime



PM2.5 export in wintertime

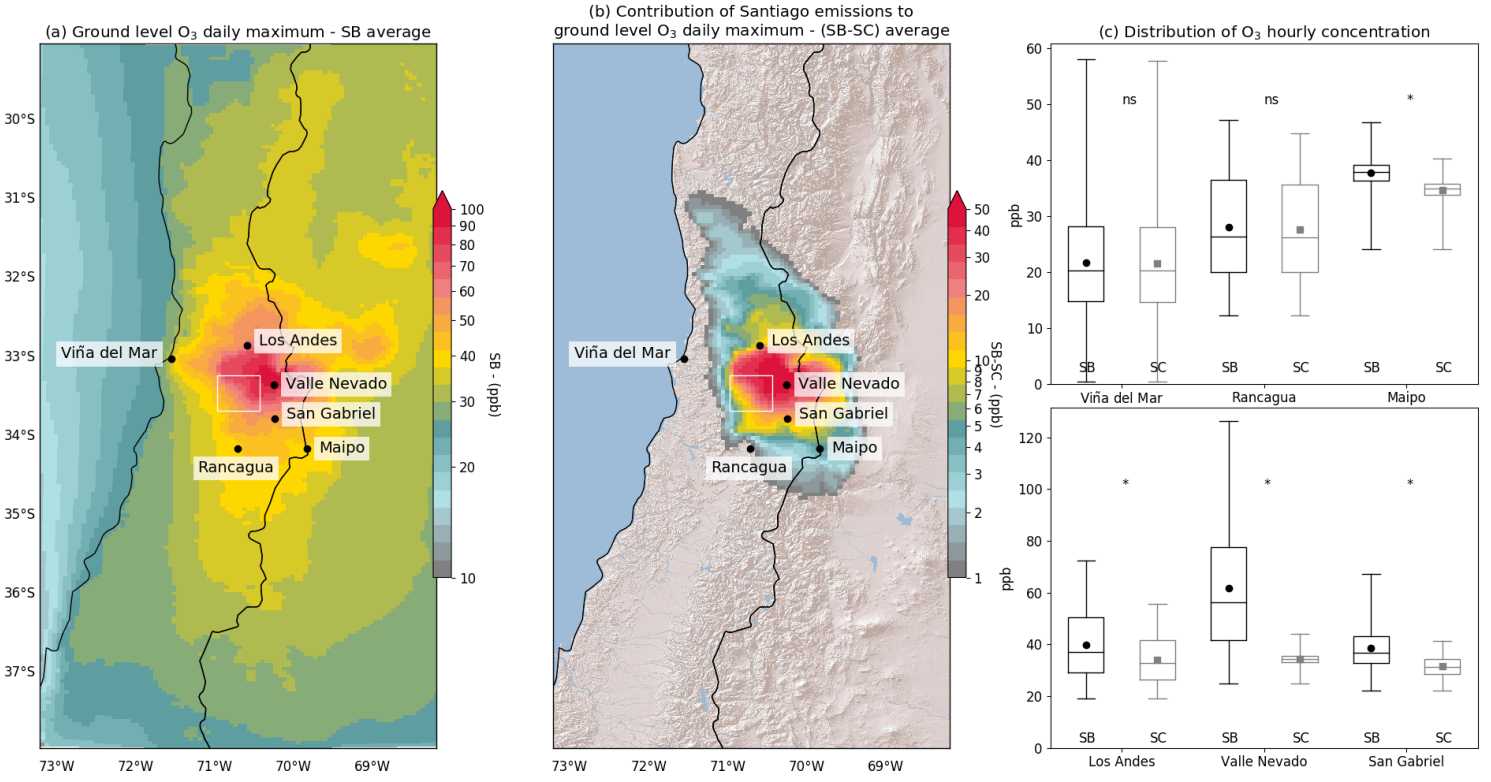


A significant plume **as far North as 4°**

Air quality in coastal urban areas is affected by a few µg/m^3 on average with **18% at Viña**

Places as remote as an **Andean volcano** summit are under the influence of Santiago air masses

Ozone and precursors export in summertime

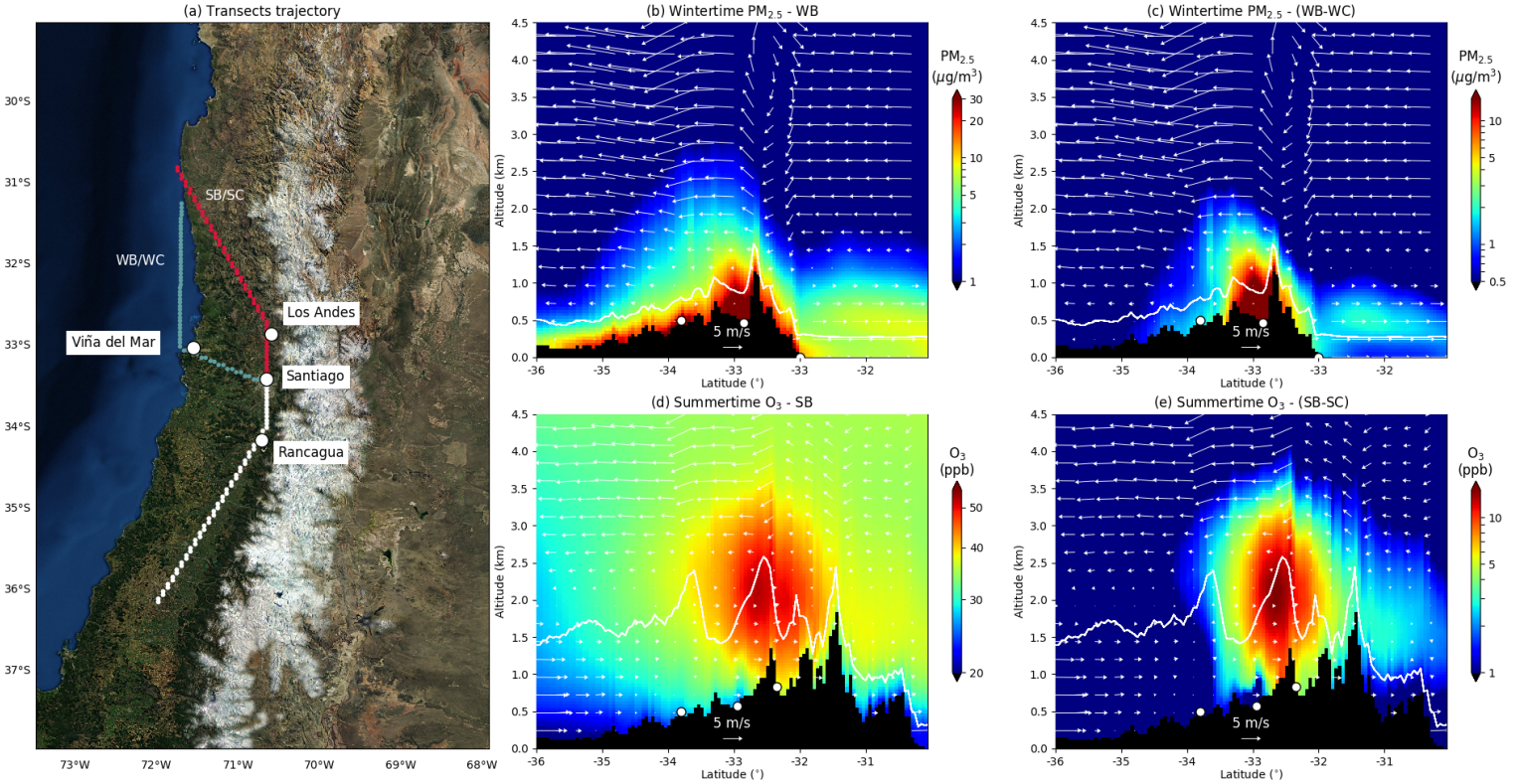


More limited area of influence (lifetime)

Large contribution to daily peaks mostly **East** of Santiago

Non-significant export towards large urban areas but **close to 100% of the signal for more remote locations**

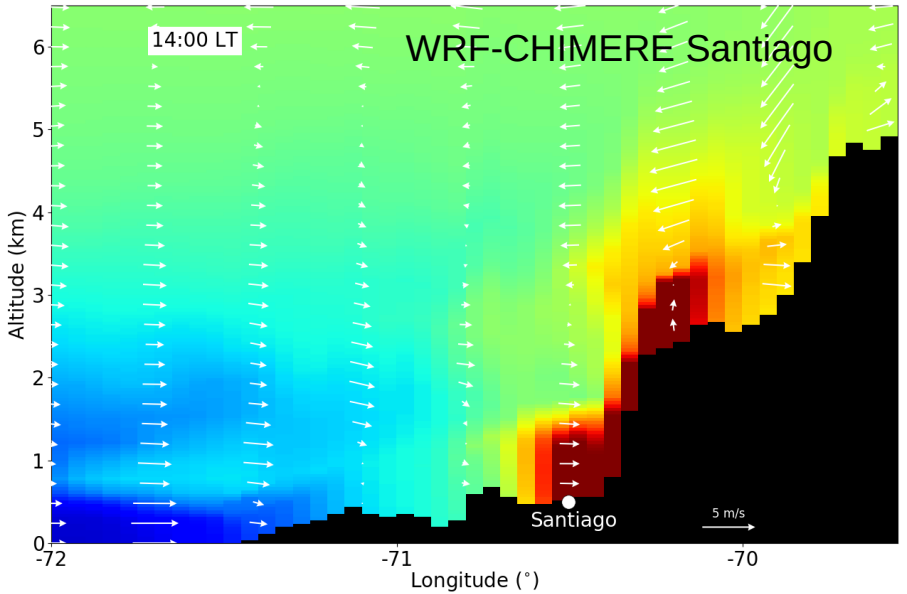
Average transport

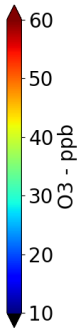


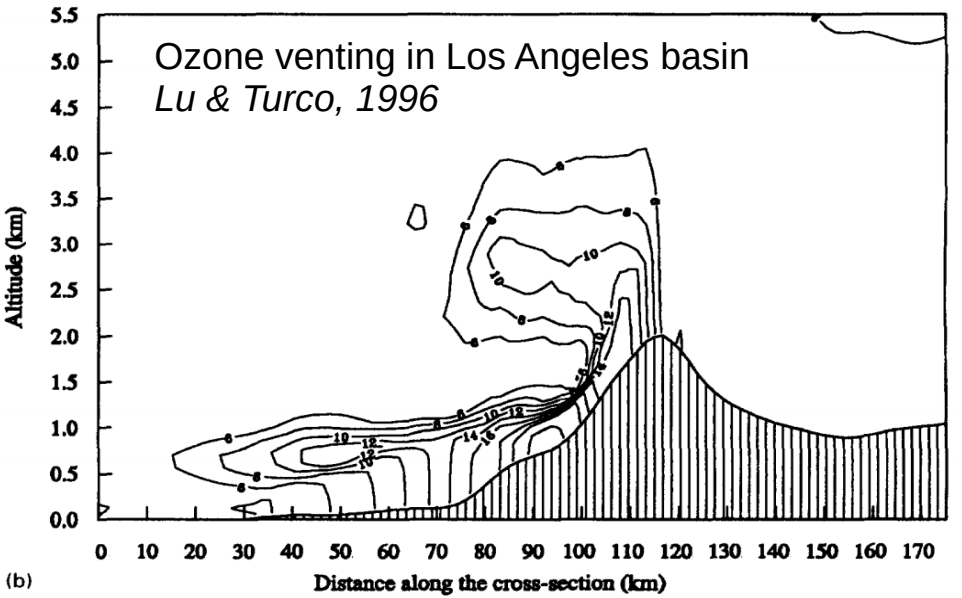
Wintertime **PM2.5** transport **within the boundary layer** except above the ocean

Summertime **Ozone** venting creates a **permanent bubble**, mostly from Santiago emissions, high above ground

After the Ozone layer, the “Ozone bubble”



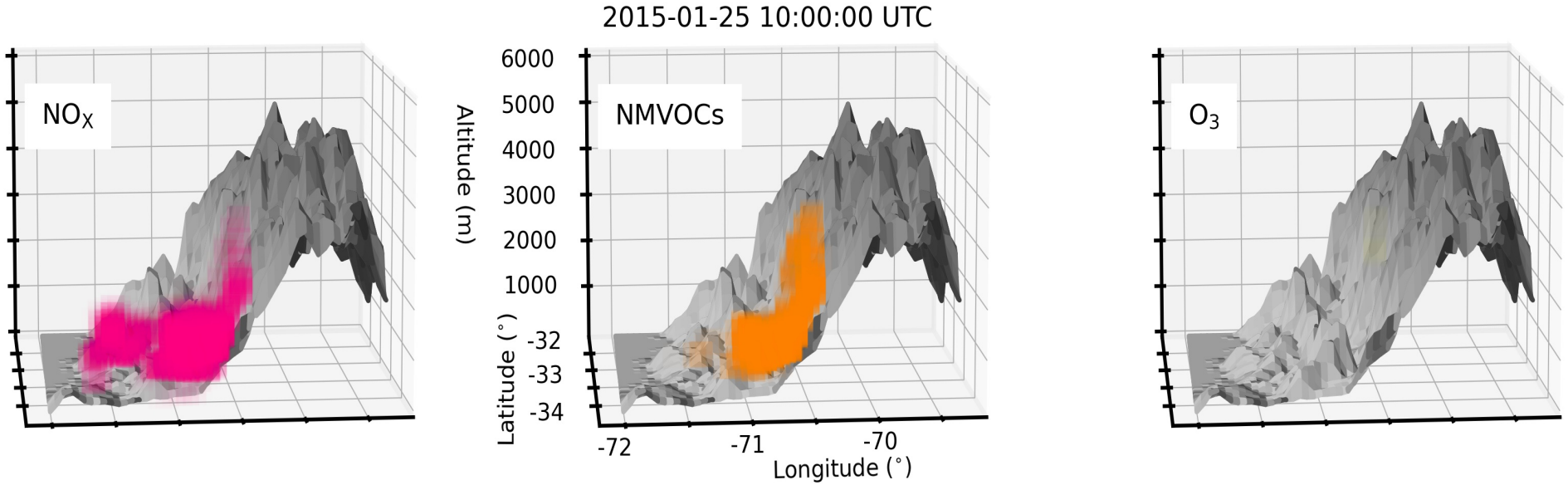




Similar summertime mid-day **Ozone venting** as observed in the **Los Angeles** basin…
but **what happens during a whole daily cycle?**

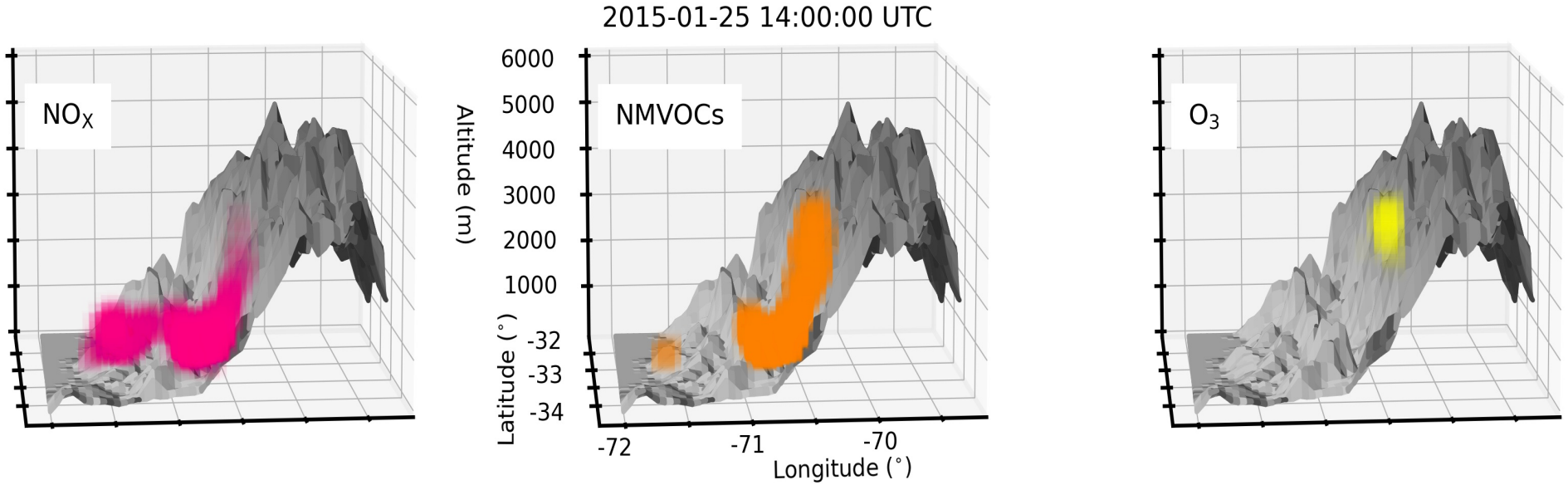
After the Ozone layer, the “Ozone bubble”

How does it form?



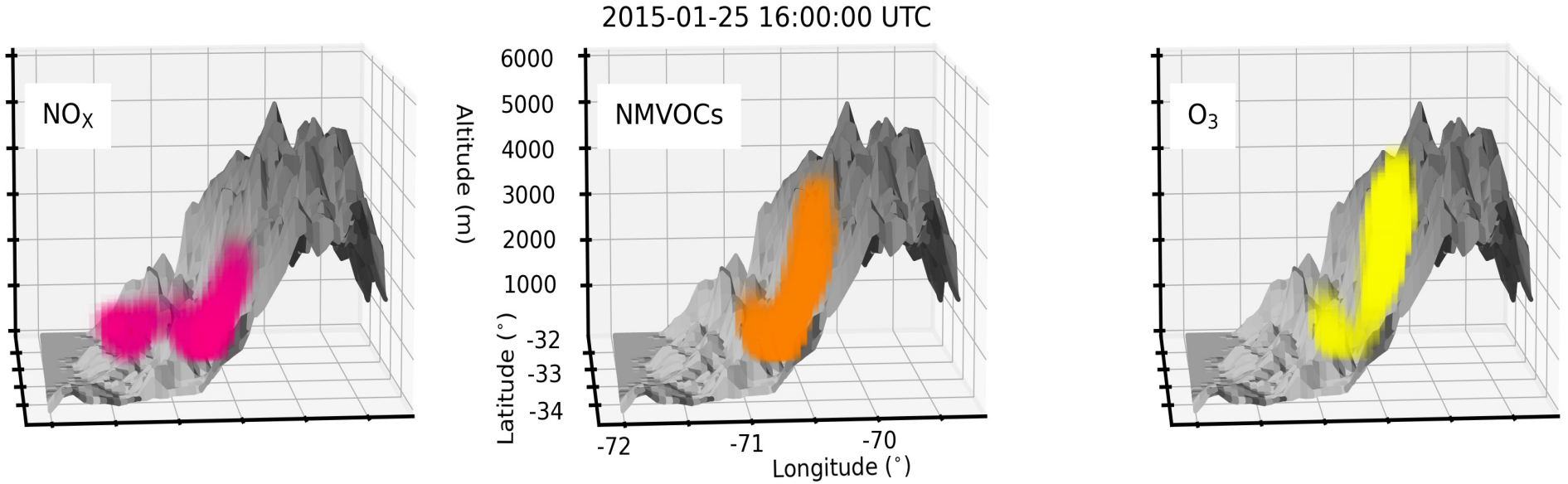
After the Ozone layer, the “Ozone bubble”

How does it form?



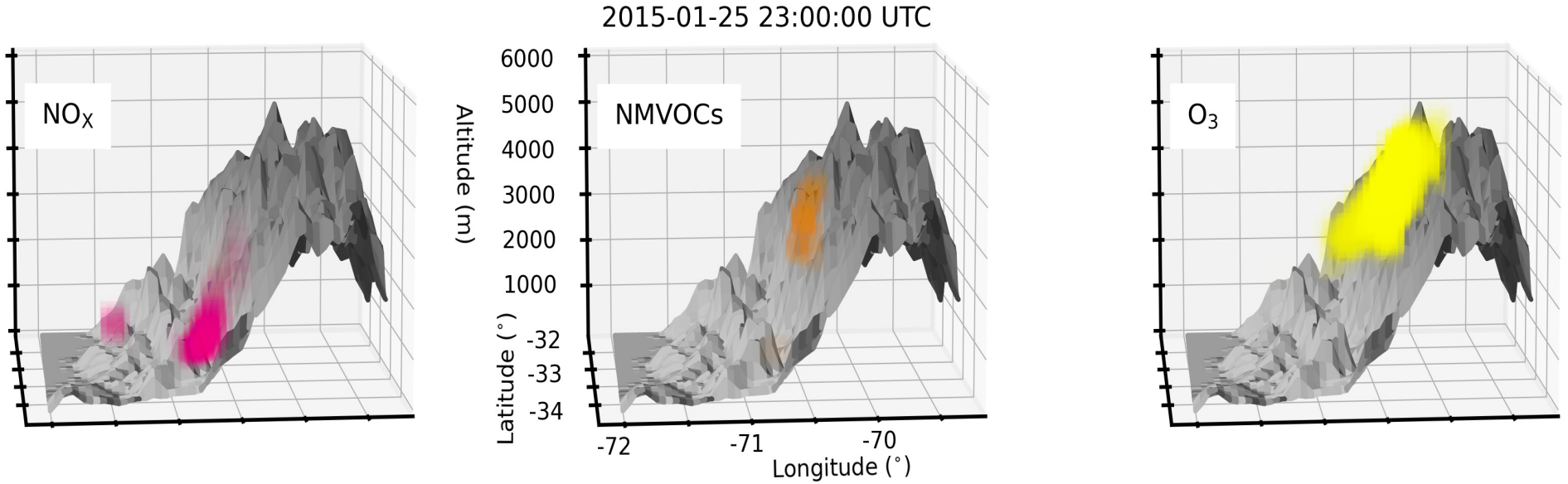
After the Ozone layer, the “Ozone bubble”

How does it form?



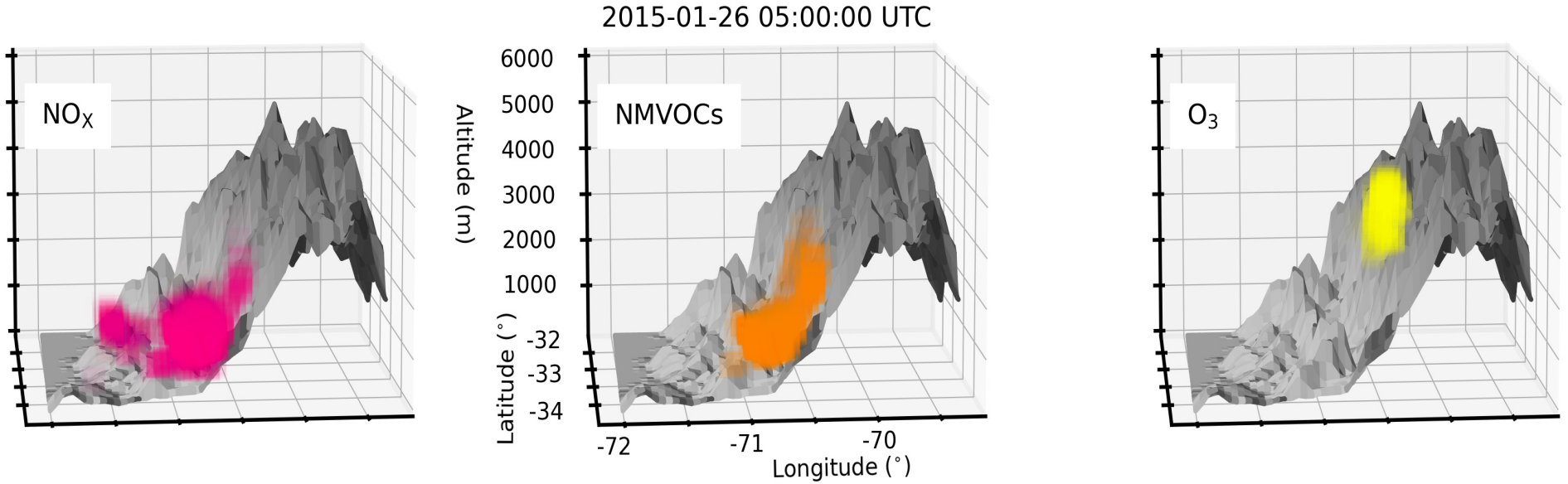
After the Ozone layer, the “Ozone bubble”

How does it form?



After the Ozone layer, the “Ozone bubble”

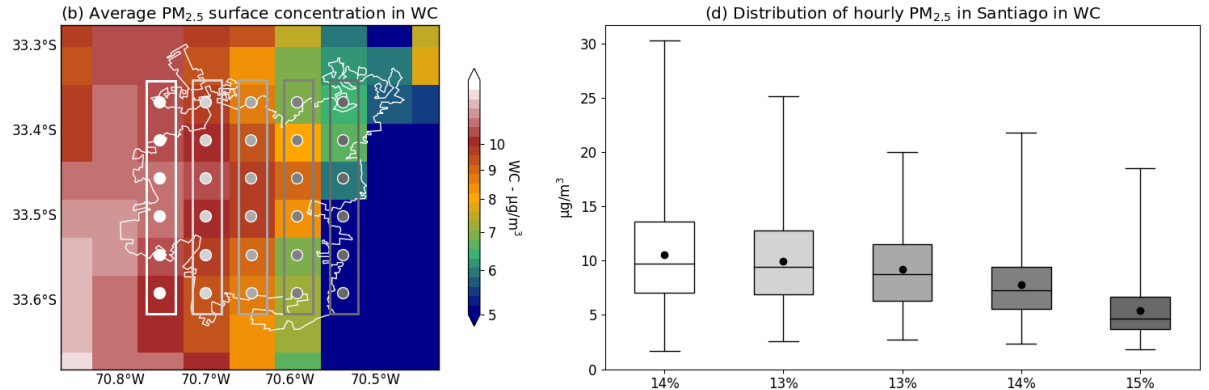
How does it form?

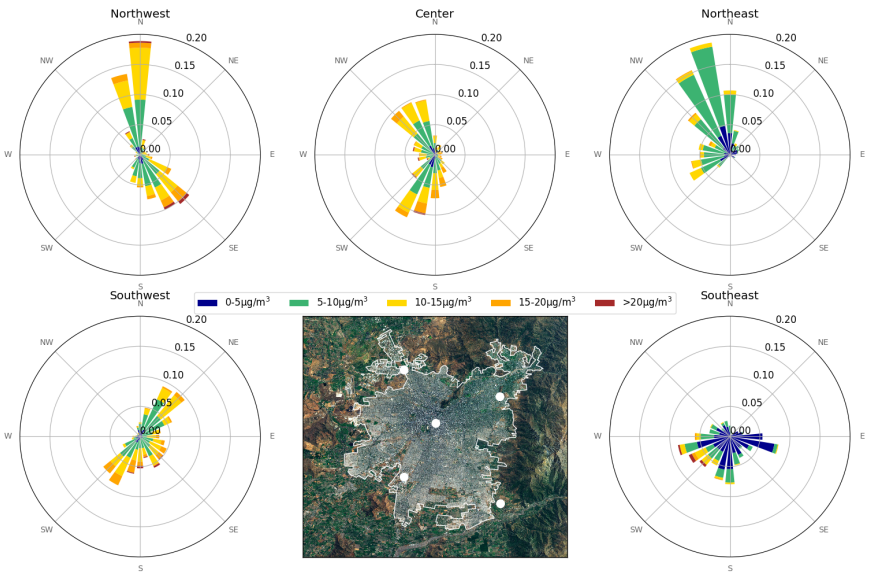


No **observational data** fit for comparison => dedicated campaign?

Radiative effects to be investigated (0.2-0.6W/m^2 globally for tropospheric Ozone)

PM2.5 import in wintertime

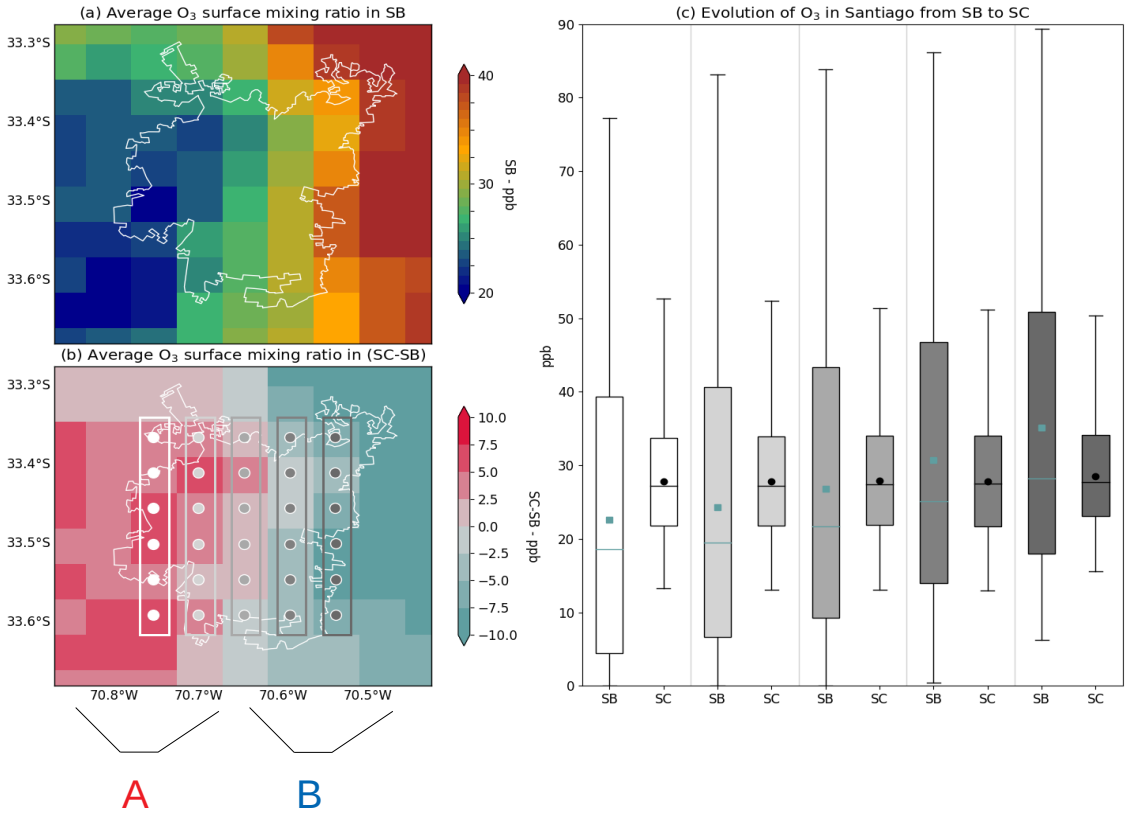




On average in wintertime, **14%** of **PM2.5** concentration in Santiago come from long-range transport. (22% in summertime)
NB: exceedance of Chilean standards in 2019: **18%**

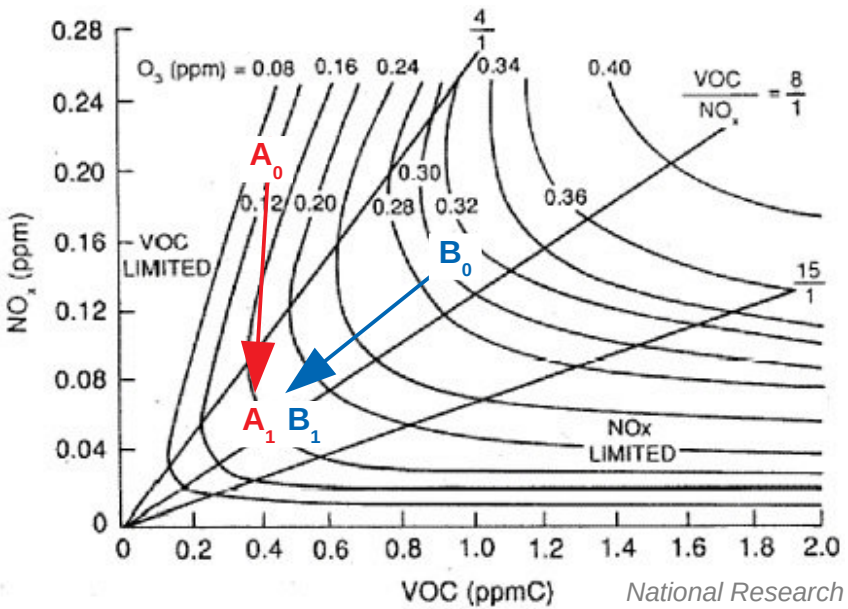
Logically, most imports comes either from the Southern or coastal urban areas

Ozone import in wintertime



No import of Ozone nor precursors, but heterogeneous sensitivity

Different **chemical regimes** in the baseline case, due to excess emissions of NOx in the Western area



National Research Council, 1991

Conclusion

In winter

- Despite stability, **significant exchanges of PM2.5** in winter in central Chile
- **14% import** on average in Santiago versus significant **contribution up to 4° North**
- Transport mostly close to the ground, except over the ocean

In summer

- Significant **contribution of Santiago** emissions to **Ozone daily peaks** in the vicinity
- Mountain-valley circulation generates the formation of a **persistent Ozone bubble**
- In Santiago, the **response to cutting emissions** of precursors is **heterogeneous**

Overall conclusions

Overall conclusions

- **Causes and consequences** of air pollution in Chile still bear many **uncertainties**
- Regional chemistry-transport **modeling** at high-resolution can help provide **answers**…

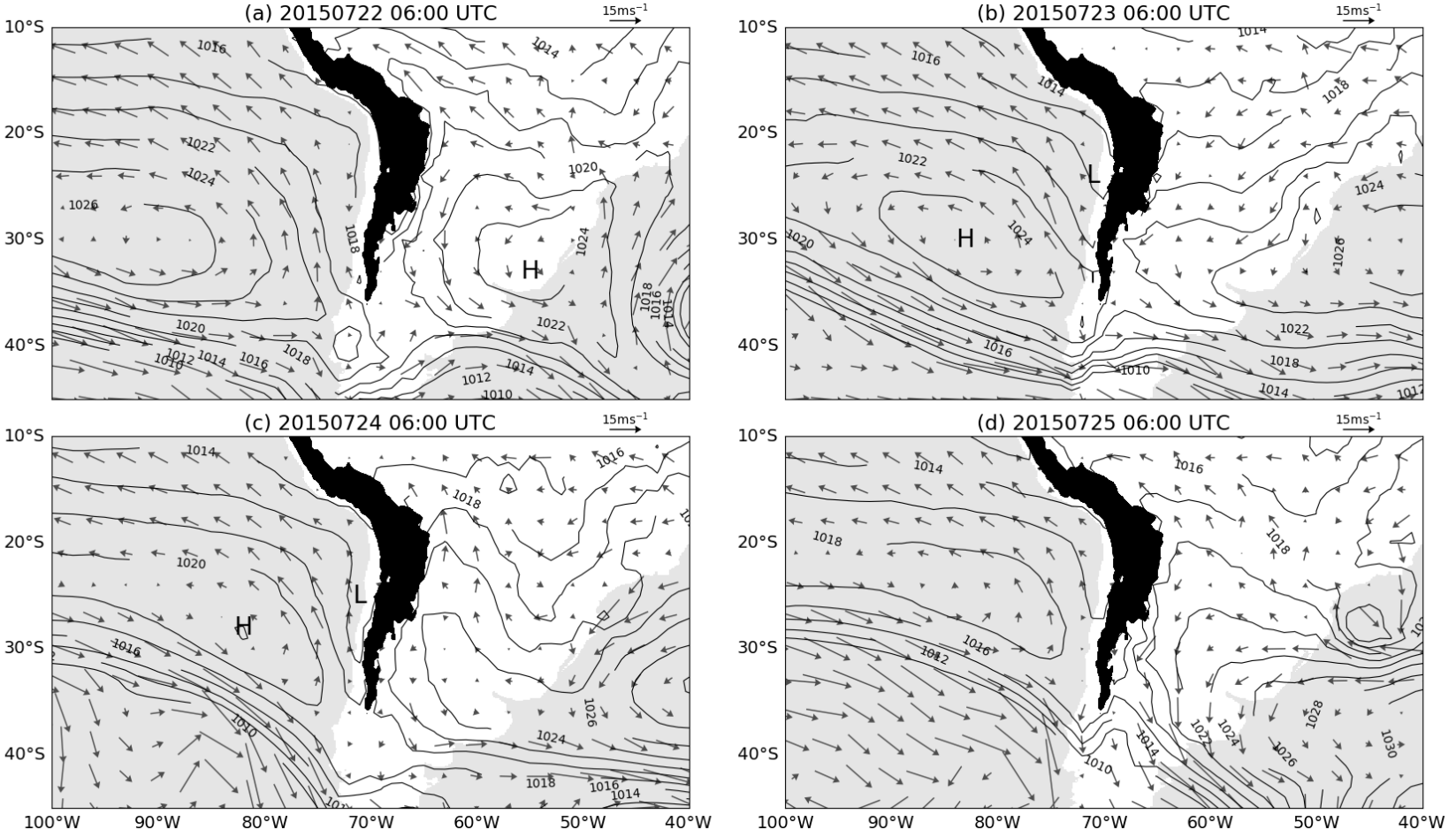
  … and suggest **new phenomena**
- Chile is **politically active** on the topic, with “decontamination plans” every 5 years…

  … but mostly to cope with **health and economy issues**

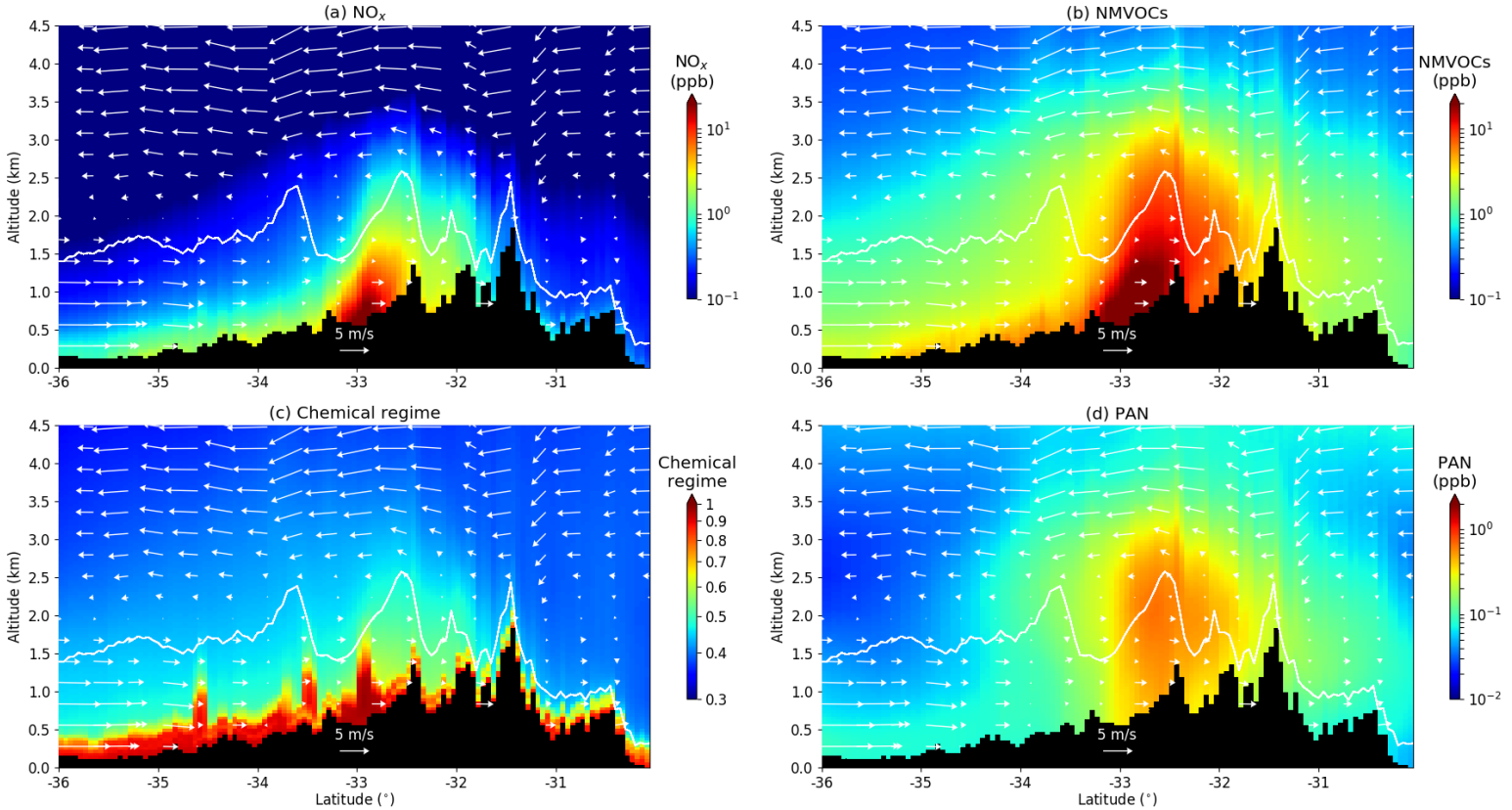
Thank you!
Questions?

Appendix

Appendix


(a) 20150722 06:00 UTC
(b) 20150723 06:00 UTC
(c) 20150724 06:00 UTC
(d) 20150725 06:00 UTC
15ms⁻¹
10°S
20°S
30°S
40°S
100°W
90°W
80°W
70°W
60°W
50°W
40°W
H
L

Appendix


(a) NO_x
(b) NMVOCs
(c) Chemical regime
(d) PAN
Altitude (km)
Latitude (°)
NO_x (ppb)
NMVOCs (ppb)
Chemical regime
PAN (ppb)
5 m/s