Simulating aerosols, radiative forcing, and impacts on marine stratocumulus during VOCALS REx

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CGRER

VOCALS
VAMOS Ocean-Cloud-Atmosphere-Land Study
WCRP / CLIVAR / VAMOS / GEWEX Program

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Motivations: Policy Relevance

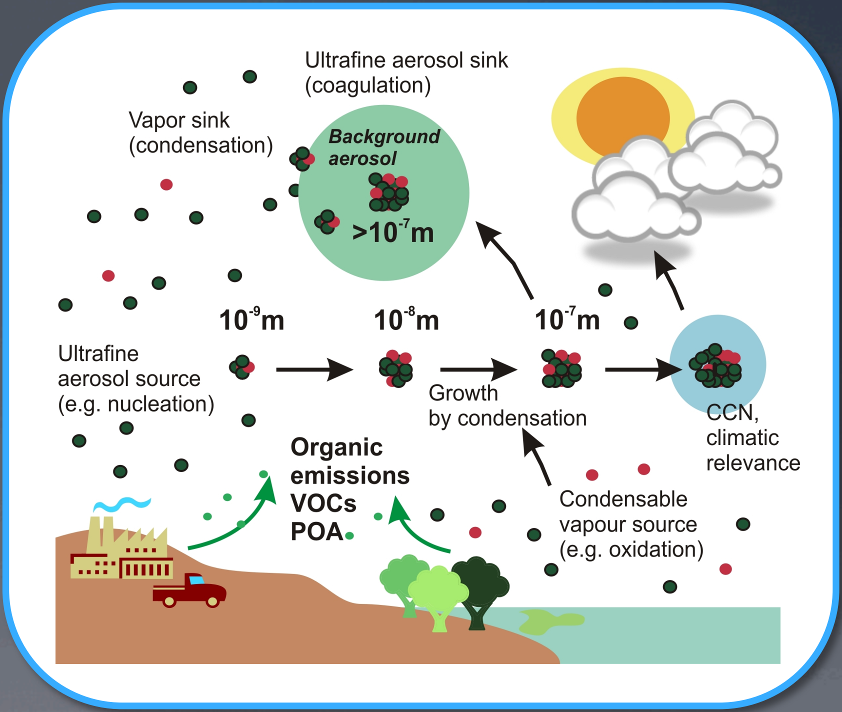
- How have anthropogenic emissions altered SEP Sc? Which sources matter most? How are they expected to change?
- Unintended regional/global climate consequences of Santiago’s urban development?
- What about geo-engineering proposals?
- The SEP, beyond clouds and climate
  - traditional criteria air pollution questions for human health
  - direct radiative forcing and BC:S strategies
  - acid deposition to the southern oceans

Motivation → Approach

Simulate & evaluate basic properties of chemical transport during REx

then aerosol effects on cloud microphysics & climate

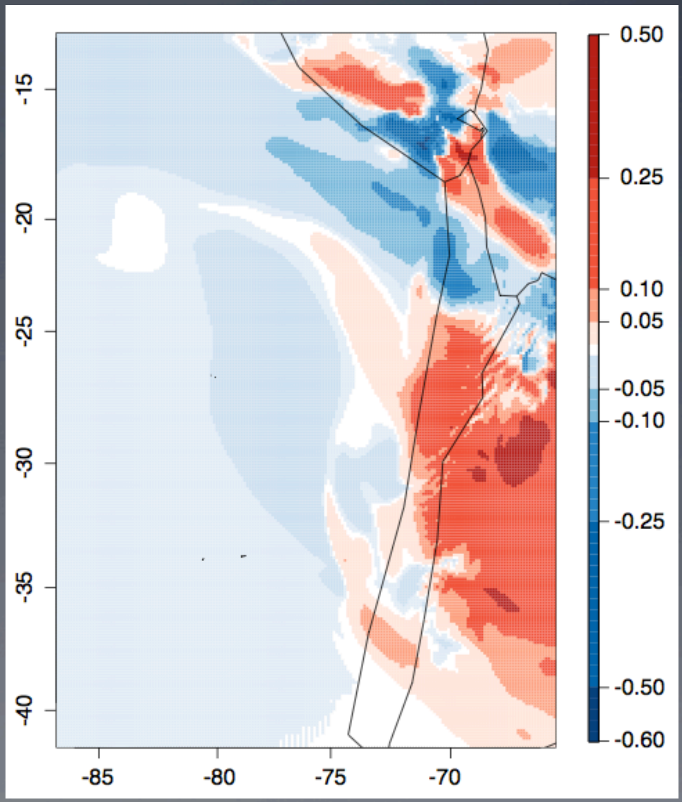
then response to changes in human activities



Building on ... tracer modeling

- Daily variability in SO_4 driven by synoptic condition: SEP Subtropical High location & strength
- DMS importance by omission: anthropogenic emissions can't account for observed offshore SO_4 & SO_2 concentrations
- Coastal and Altiplano emissions entrained from FT to clouds in WRF-STEM

Δ Cloud-level LPS SO_4 (μg/m³)
RF03-RF06 & RF10 – other flights



S.N. Spak, M.A. Mena-Carrasco, G.R. Carmichael (2010). Atmospheric transport of anthropogenic oxidized sulfur over the Southeast Pacific during VOCALS REx, *CLIVAR Exchanges*, **53**, 20-21.

Model Configuration

WRF-Chem v3.1.1 @ 12 km, 27 layers

- CBM-Z + MOSAIC (8 bins), Lin microphysics, Grell cumulus
- No DMS yet!
- MYNN v2.5 PBL
- Direct, 1st & 2nd indirect, semi-direct aerosol radiative forcing
- Restarted every 5 days with 1 day spin-up for continuity
- MOZART 4 boundary conditions
- **Emissions**

  daily 1 km FINN fires (Wiedinmeyer *et al.*, GMDD, 2010)

  + MEGAN biogenics

  + VOCA anthropogenic emissions **ON/OFF** through 10/27

Campaign chemical transport evaluation

No DMS, too much OC (FINN + MOZART)

	Observed	Mean Bias	RMSE	FB*	FE*
O_3 (ppb)	37.25	-3.53	10.47	***-0.12***	0.26
CO (ppb)	65.68	2.60	20.40	***0.06***	***0.13***
SO_2 (ppt)	52.71	-32.00	152.04	-1.25	1.49
SO_4 (µg/m^3)	0.43	-0.01	0.73	***0.34***	1.09
NO_3 (µg/m^3)	0.011	0.002	0.035	NA	NA
NH_4 (µg/m^3)	0.08	-0.01	0.11	***0.35***	1.31
OC (µg/m^3)	0.13	0.37	0.52	1.58	1.81

*Fractional bias = (2 x bias)/(observed + modeled)

Bolded values meet US EPA/community performance standards

Italicized values exceed targets

20° S chemical transport evaluation

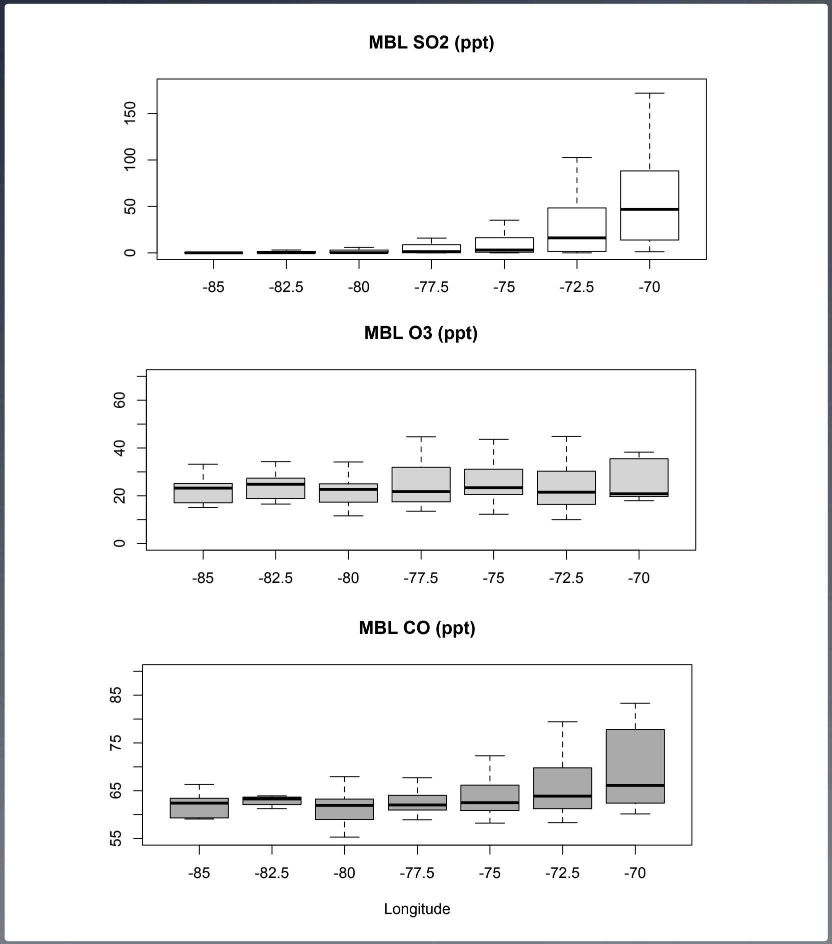
all C-130 flights @ 1 minute average, processed per Allen *et al.* (ACPD)

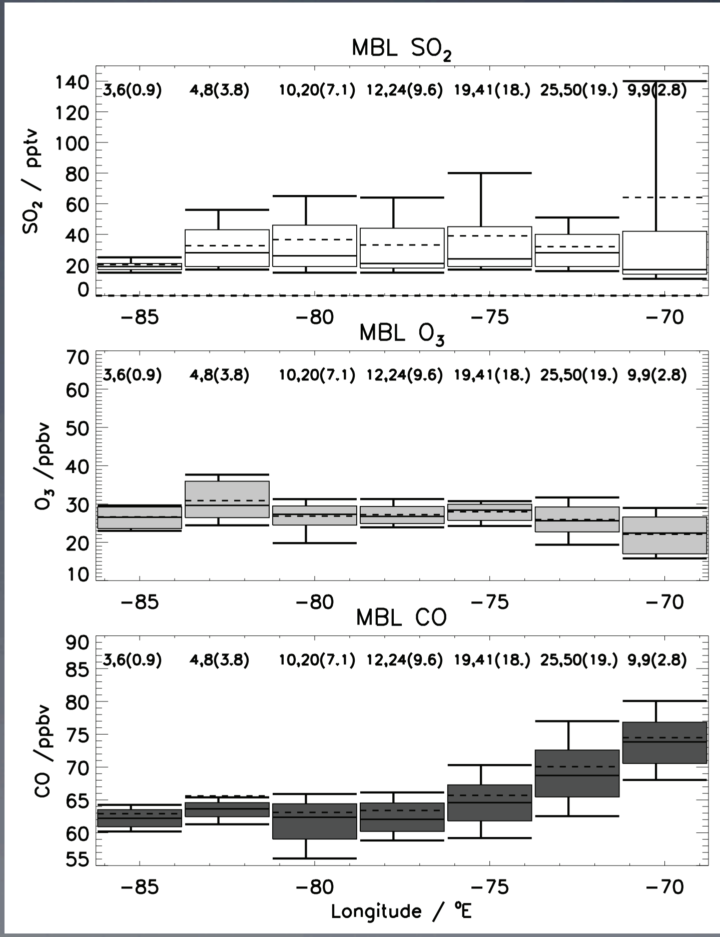
	Observed	Mean Bias	RMSE	FB*	FE*
O_3 (ppb)	34.84	-5.71	10.83	**-0.22**	0.30
CO (ppb)	65.89	0.83	16.37	***0.03***	***0.11***
SO_2 (ppt)	34.31	-16.06	61.75	-1.21	1.52
SO_4 (µg/m^3)	0.47	-0.07	0.63	***0.06***	1.13
NO_3 (µg/m^3)	0.011	0.001	0.021	NA	NA
NH_4 (µg/m^3)	0.08	-0.02	0.10	***-0.03***	1.36
OC (µg/m^3)	0.12	0.33	0.47	1.44	1.81

Bolded values meet US EPA/community performance standards

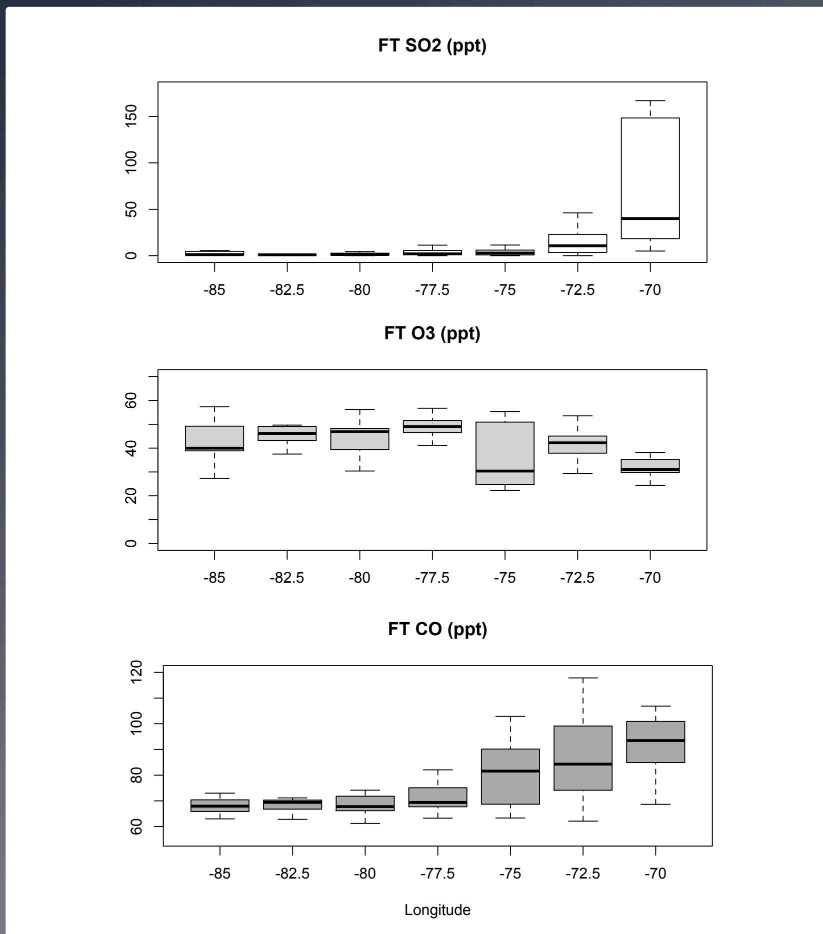
Italicized values exceed targets

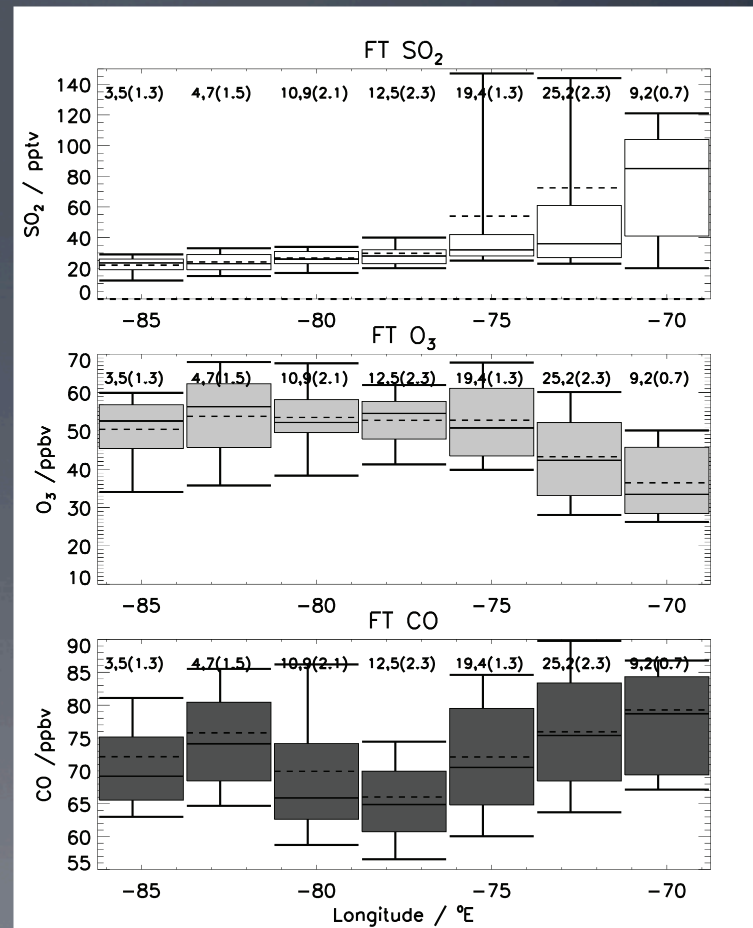
WRF-Chem MBL Gases @ 20°S vs. Allen *et al.* (2011)



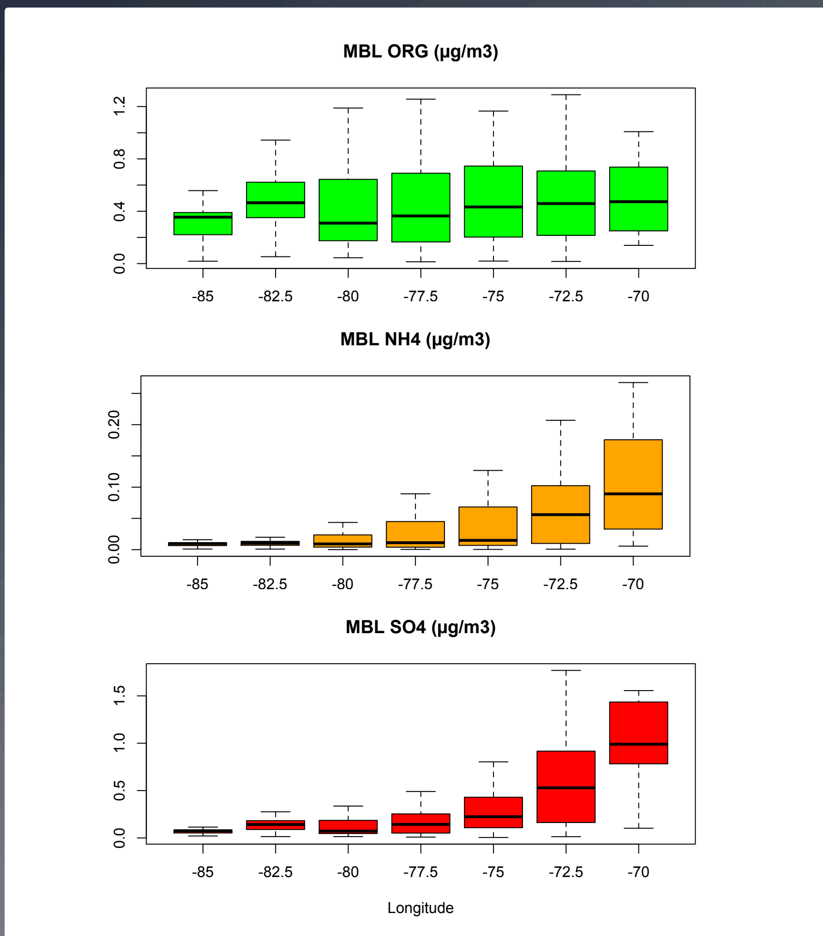


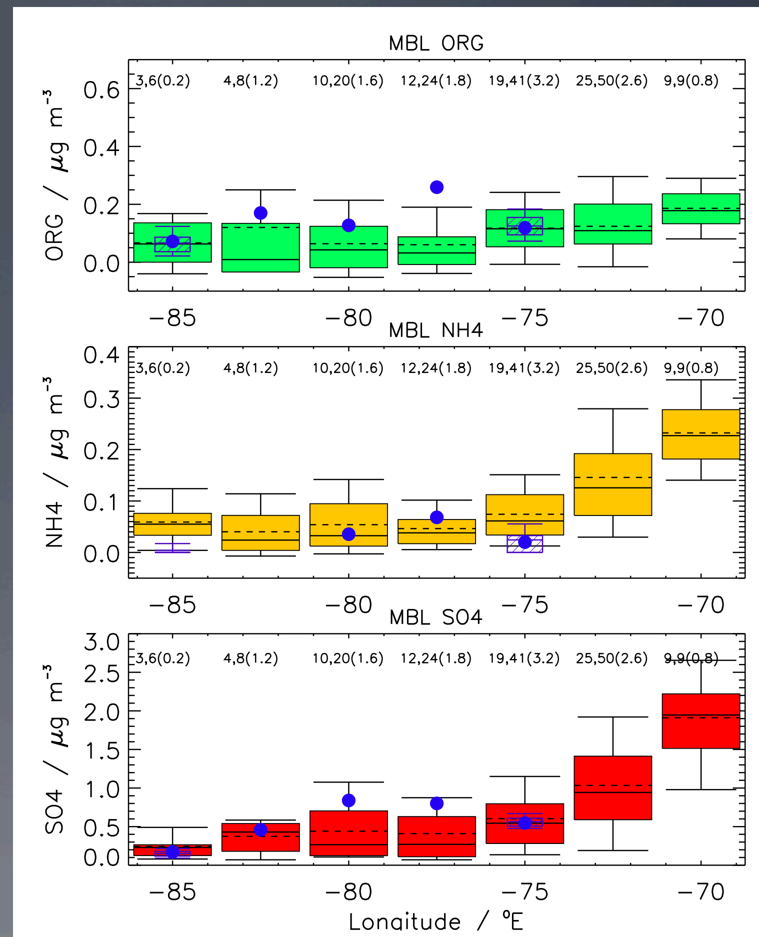
FT Gases: whiskers better than boxes



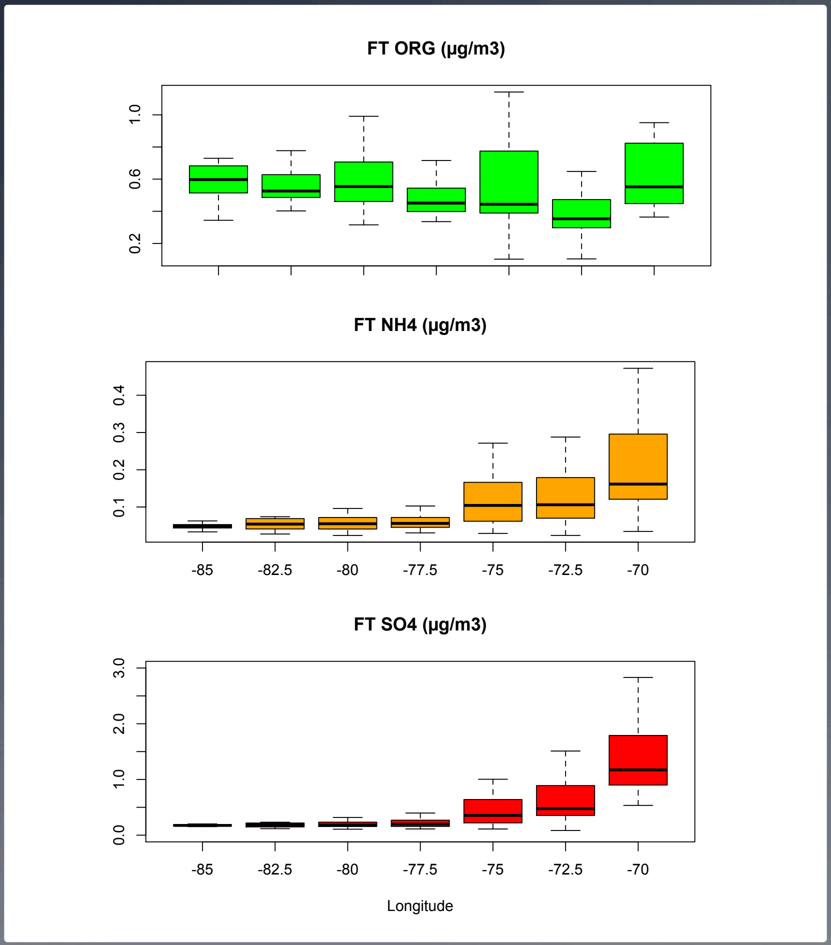


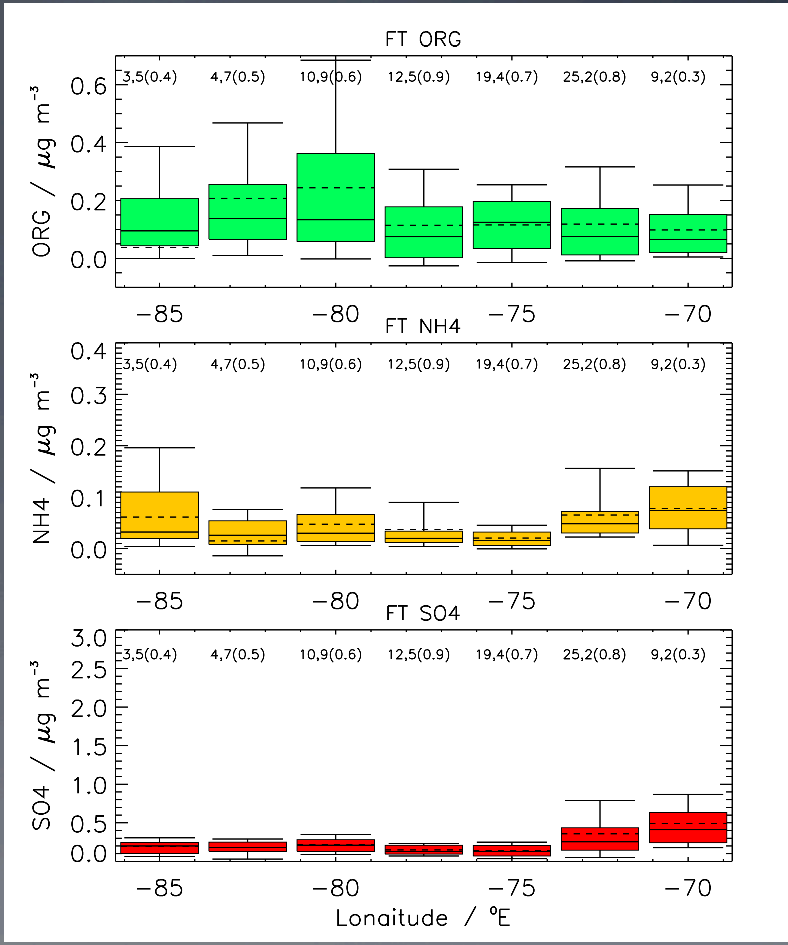
MBL aerosol composition



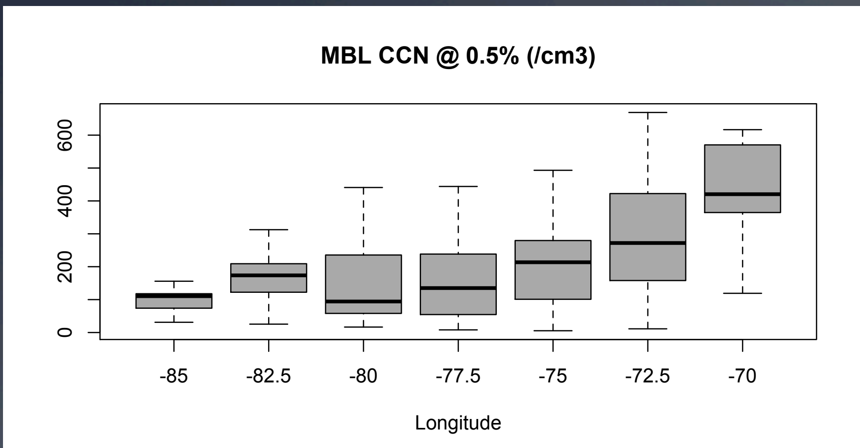


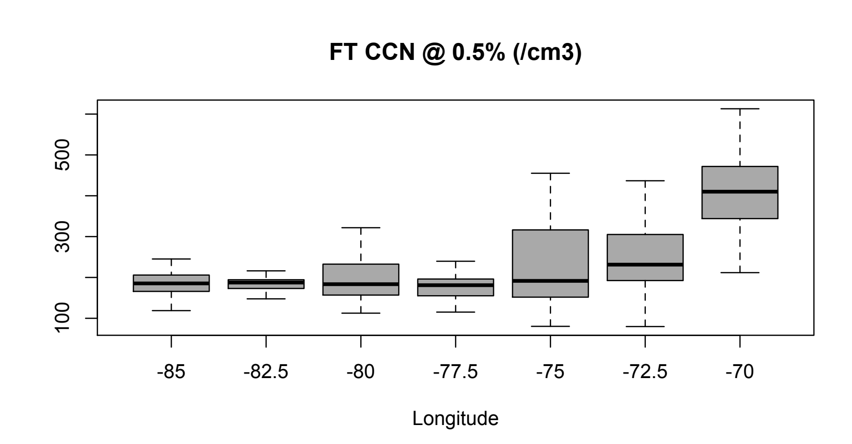
FT aerosol composition

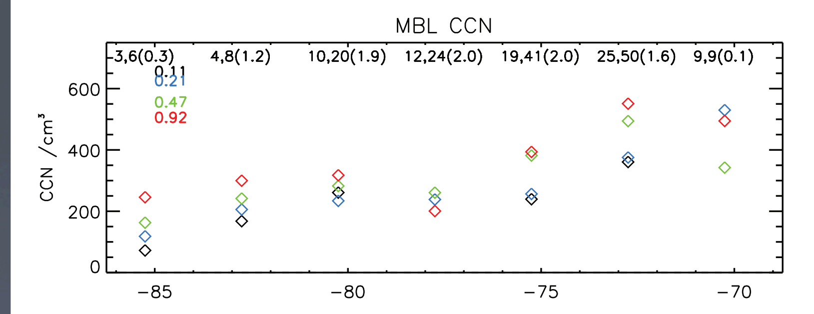


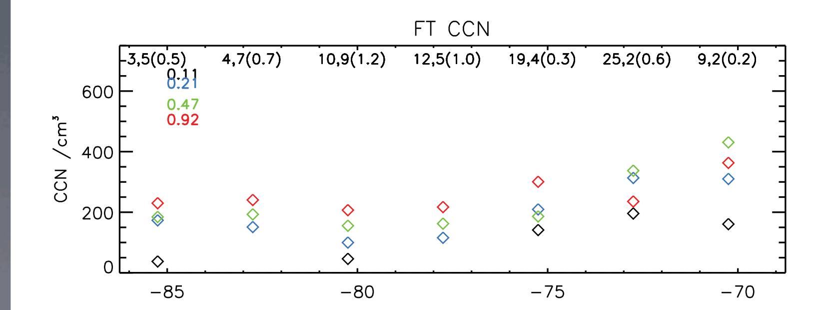


Cloud Condensation Nuclei





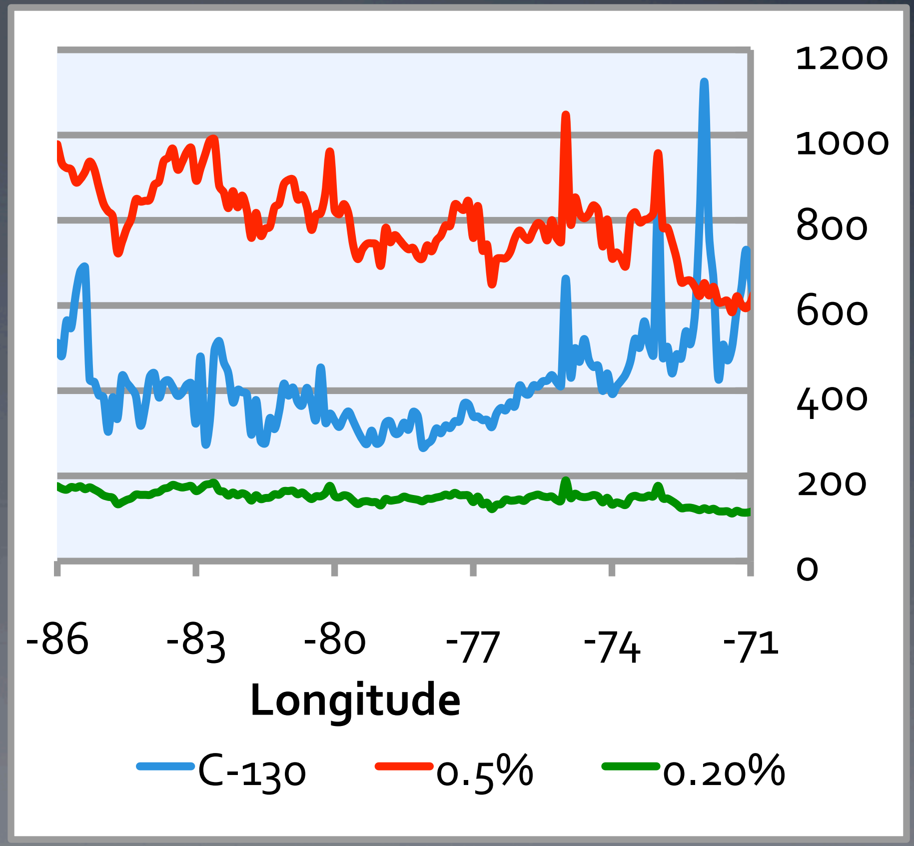




A word about CCN in WRF-Chem…

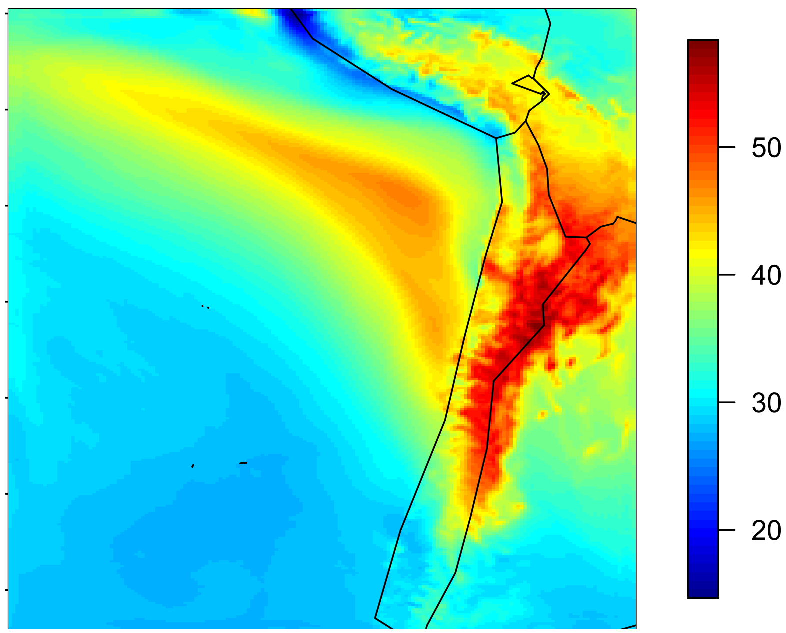
- WRF-Chem assumes 0.2% supersaturation for aerosol coupling
- CCN not well simulated by any WRF supersaturation level: observed @ 0.55 – 0.75% < modeled CCN @ 0.5%
- Variability along flight paths encouraging

C-130 CCN (#/cm³), all flights

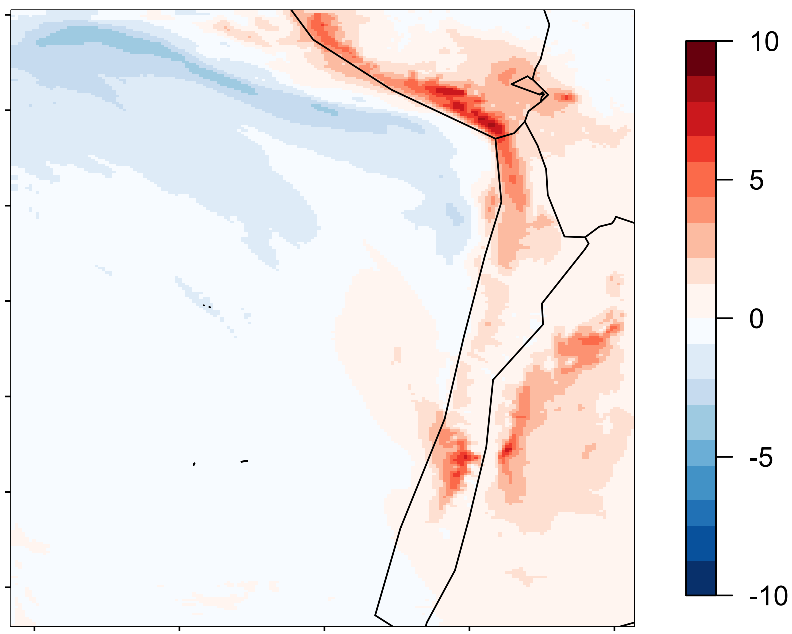


Average 10/15 – 10/27 ozone (ppb), cloud level

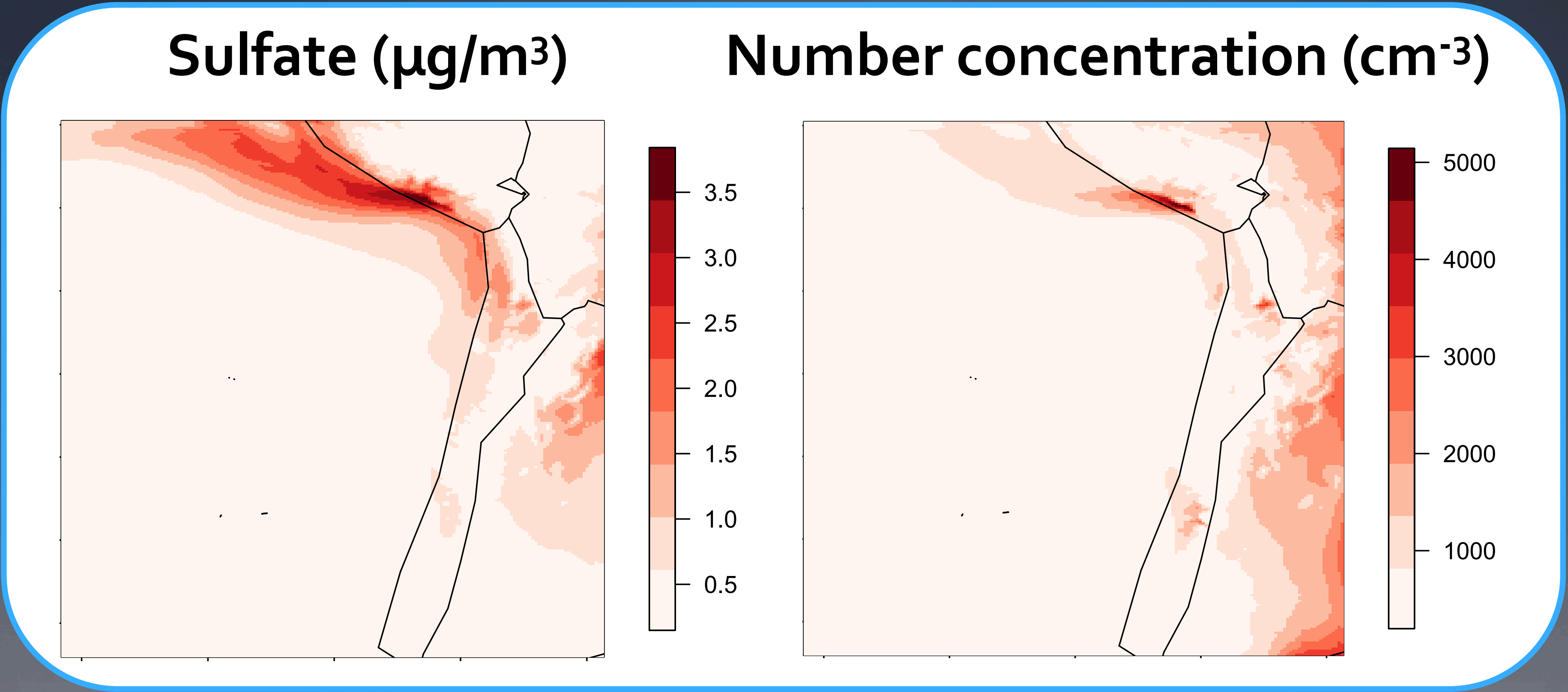
Base case



Anthropogenic impact

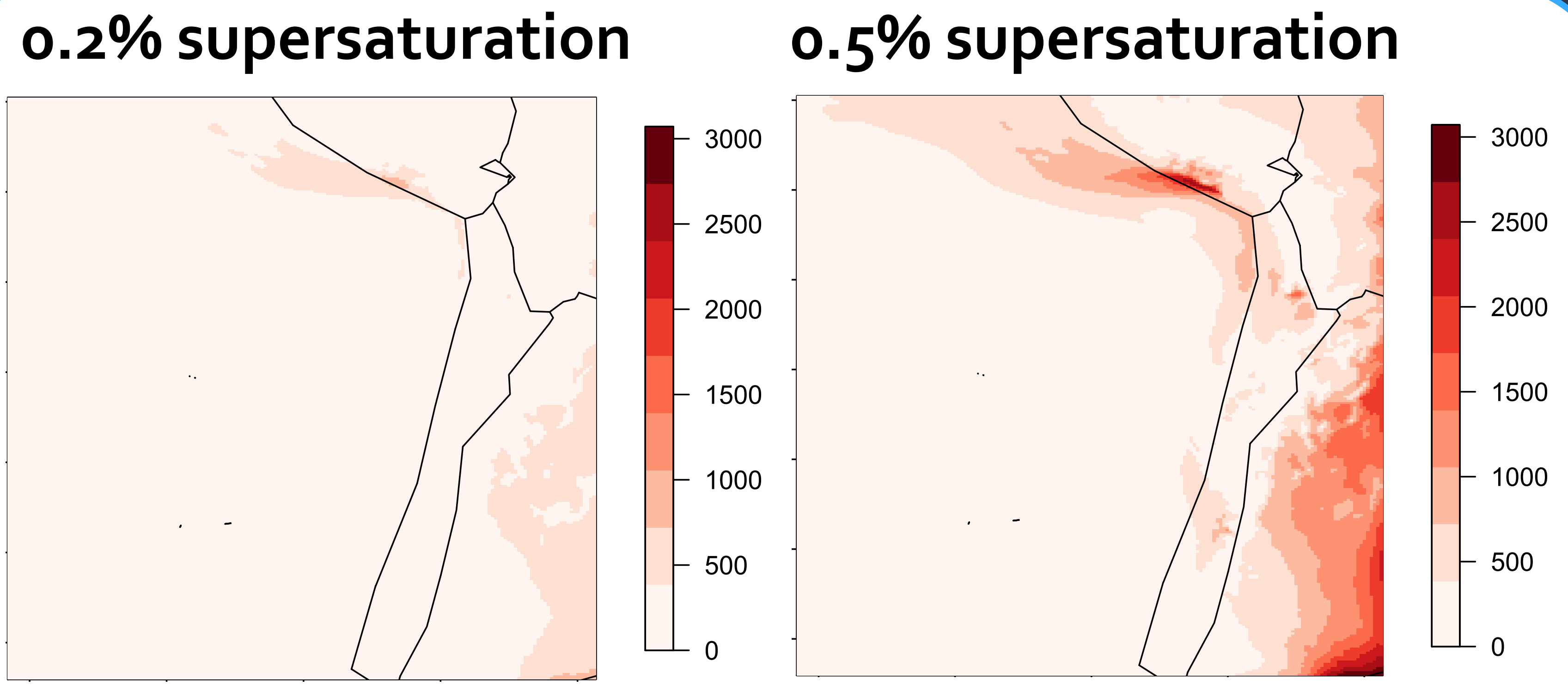


Anthropogenic impact: cloud-level aerosol properties



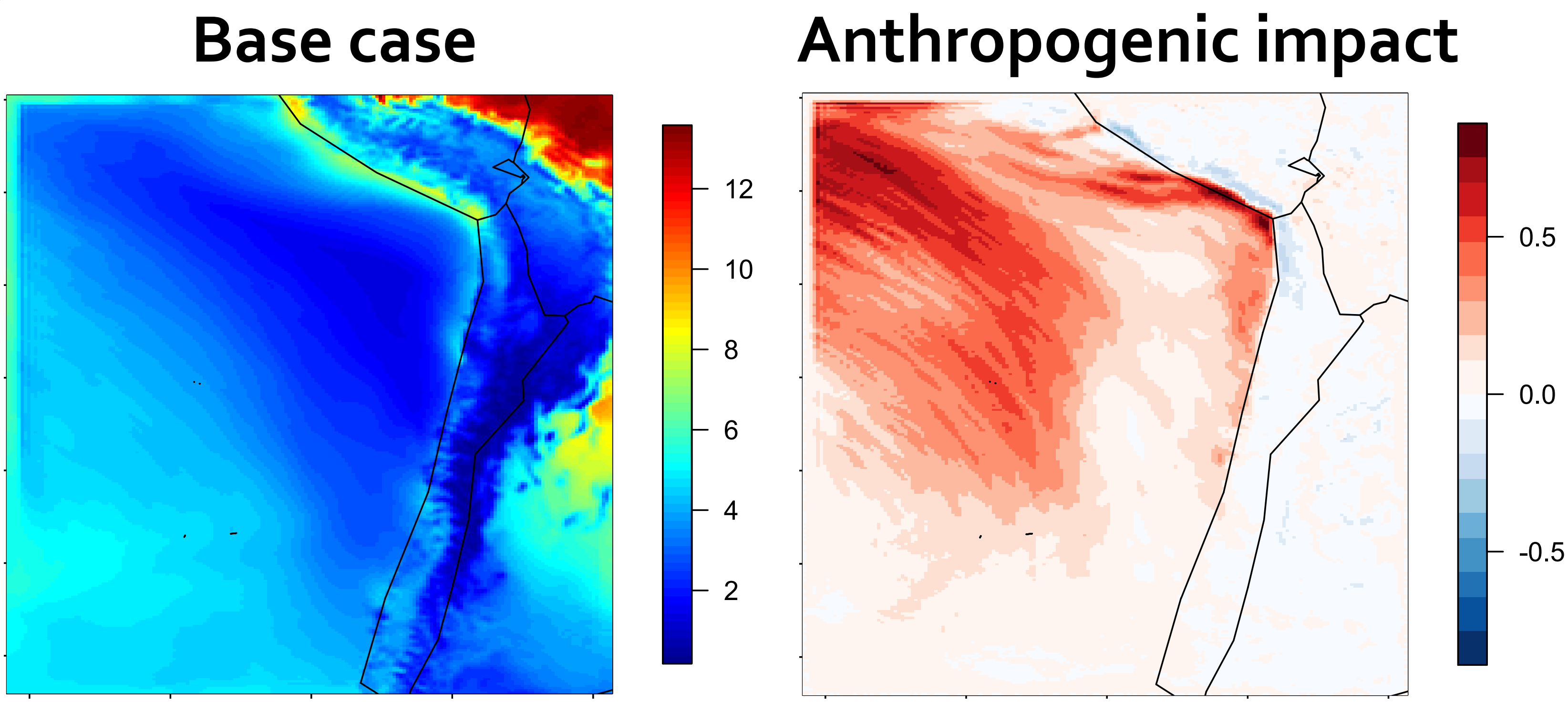
Number concentration enhancement by LPS >> central Chile

Anthropogenic impact: cloud-level CCN (cm^{-3})



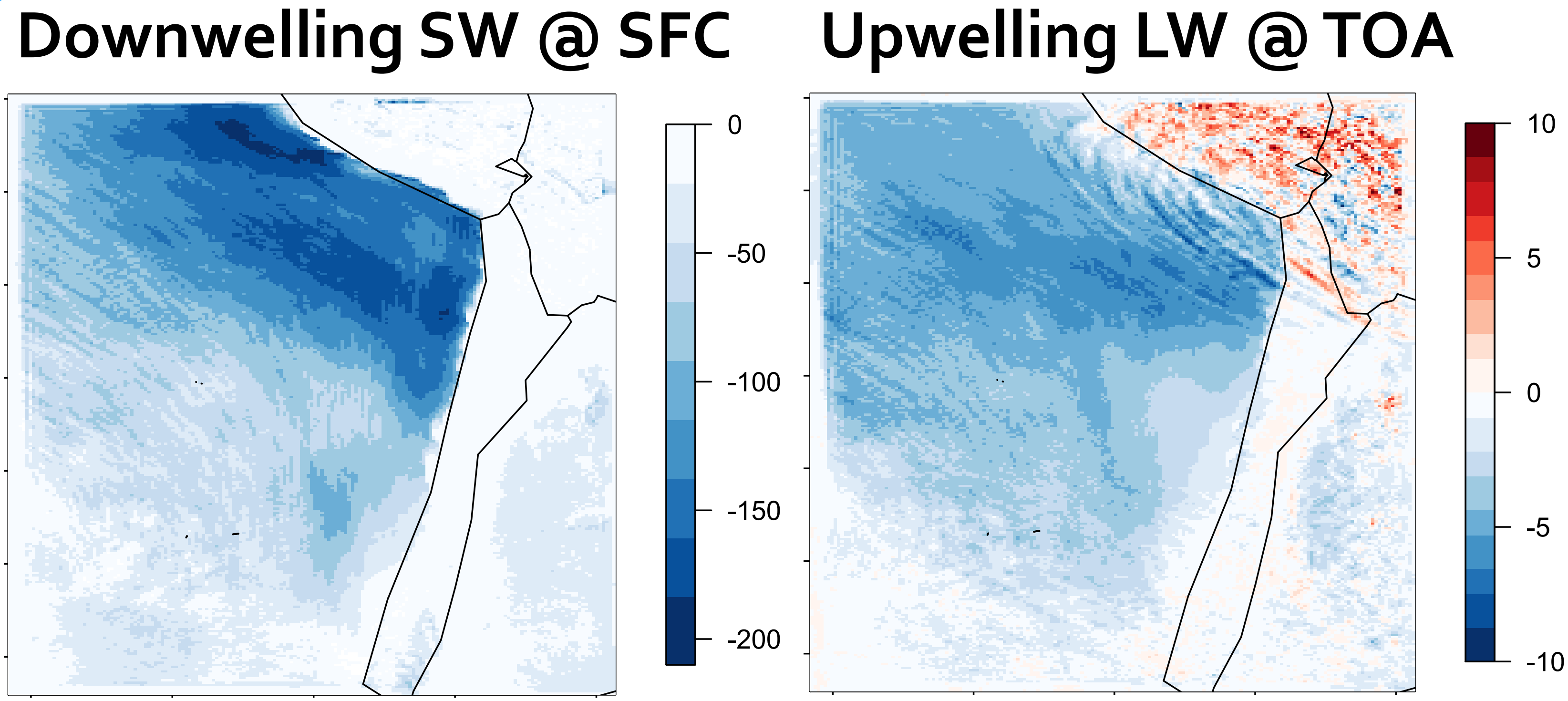
Order of magnitude underestimate in local coastal effect in WRF-Chem

Water vapor (g/kg), cloud level

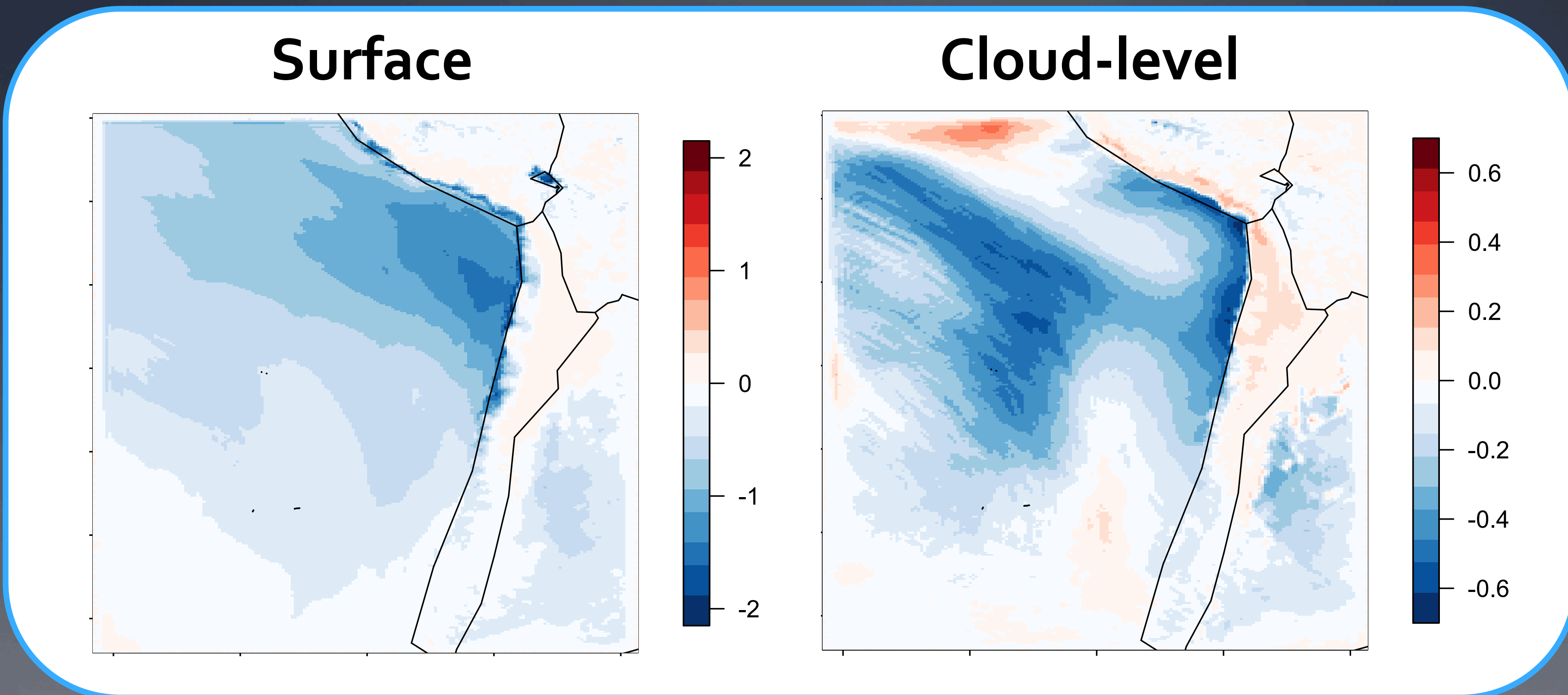


20° S changes due to LPS (coastal) and central Chile (offshore)

Radiative forcing (W/m²)



Anthropogenic impact on Temperature (K)



Coastal surface cooling by brighter clouds,
offshore cloud-level cooling by longer cloud lifetime

Conclusions

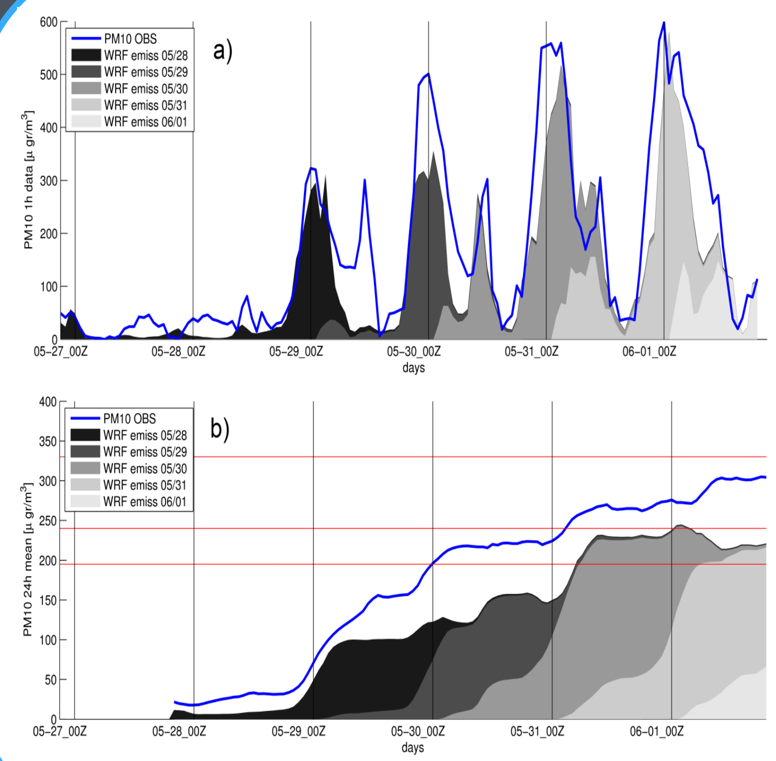
- **Emissions & chemical transport: <u>cautious but confident</u>**
  - ✓ Most species of interest simulated as well or better than regulatory modeling standards, prior airborne field campaigns
  - ✓ aerosols offshore @ 20S: central Chile + northern large point sources
  - ✓ natural emissions are key to improvement: DMS & biomass burning essential, sea salt algorithms and OC too high
- **Modeling anthropogenic aerosol influence on clouds & climate: <u>large but uncertain</u>**
  - ✓ Very strong anthropogenic indirect radiative forcing
  - ✓ *Average* >0.5 °C surface & in-cloud cooling
  - ✓ CCN diverges from observations, insensitive to anthropogenic emissions

Ongoing extensions

- Santiago daily operational WRF-Chem $PM_{10}/PM_{2.5}$ forecast
- Adjoint WRF-Chem aerosol direct/indirect/semi-direct effects
- Effects of Santiago's development on regional climate and SEP Sc

  - land use/density/transportation

  - vehicle/energy technology



P. Saide *et al.* (2011). Forecasting urban PM10 and PM2.5 pollution episodes in very stable nocturnal conditions and complex terrain using WRF-Chem CO tracer model, *Atmospheric Environment*, in press, doi:10.1016/j.atmosenv.2011.02.001.

Next steps

- 1 km simulations on new UI supercomputer to resolve clouds & changes in Santiago's urban form
- Ocean-atmosphere-aerosol coupling WRF-Chem with ROMS
  - effects of aerosols on SEP SSTs, ENSO
  - aerosol vs. ocean contributions to Sc variability
- Adjoint applications
  - **emissions sectors & aerosol composition** impacting 20° s clouds
  - SO_2 emissions **inversion**: an initial test for 4DVAR
  - constraining box/column simulations with REx observations to **isolate process errors** in aerosol-microphysics interactions

Larger Questions

- How much skill must >LES models demonstrate to be useful?
  - primary: aerosols (concentrations, AOD, CCN, CDN, CN)
  - secondary: clouds (LWP, drizzle/rain rate, τ_{CLOUD}, brightness temperature)
  - tertiary: climate (SST, ocean/atmosphere energy balance, radiative forcing)
- Beyond "lots of CCN" geoengineering, other scenarios of interest?
- VOCALS "summary for policymakers" on atmosphere-ocean-cloud interactions
  - confidence in processes, answers to hypotheses
  - community metrics for model performance: criteria & target
  - specific process improvements needed
  - REx findings, long-term reanalyses, projections

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  - L. Emmons, NCAR
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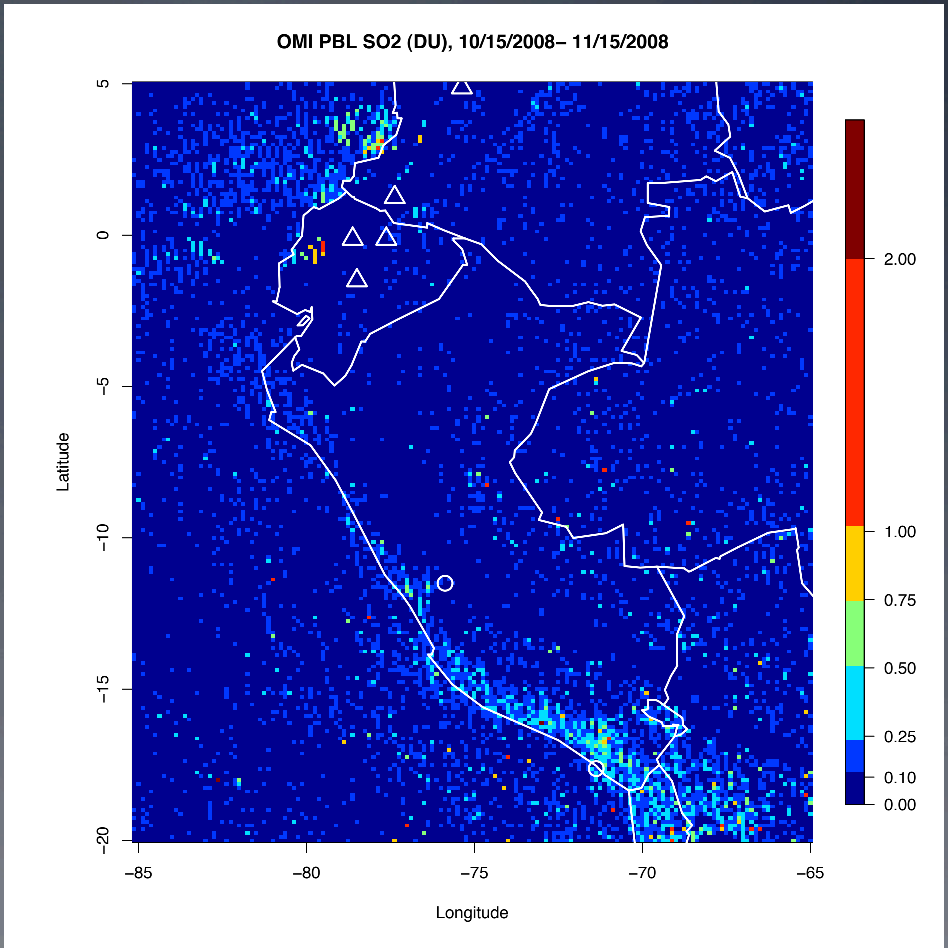
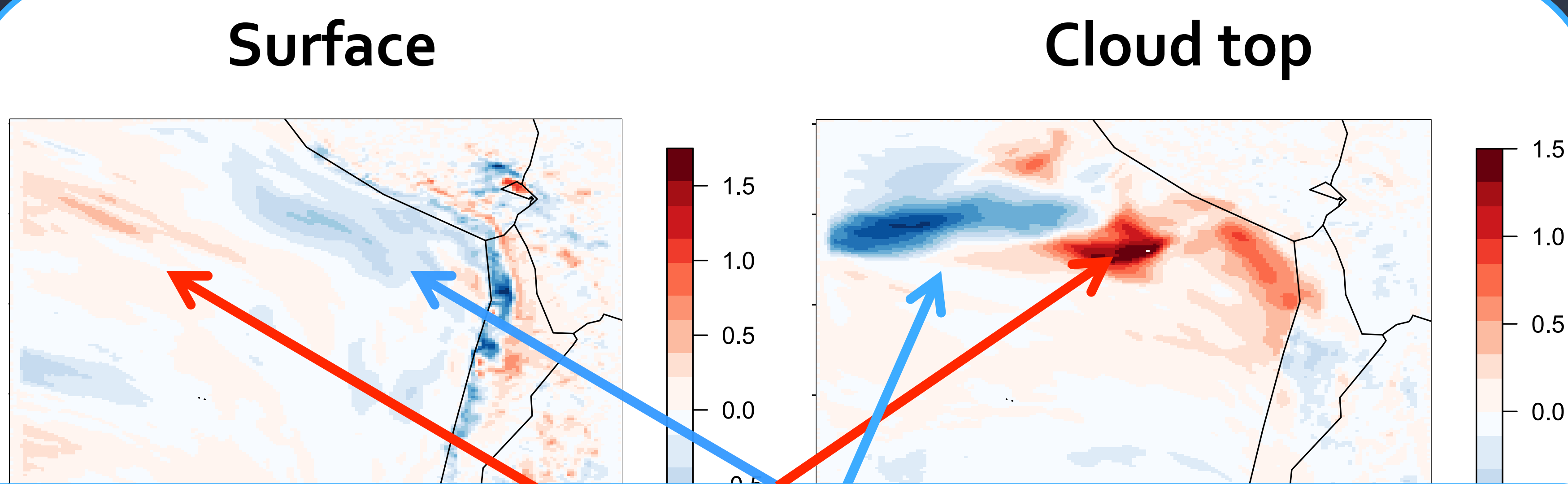
Building on…
VOCA Emissions Inventory

- Anthropogenic
  - EDGAR 3.2 FastTrack 2000 + Bond *et al.* (2004) BC/OC @ LandScan
  - CONAMA/CODELCO 2008 for Chile
    - 1,400+ point sources
    - Municipal-level residential, industrial, mobile area sources
- Volcanoes & Peruvian smelters from OMI SO2 during VOCALS REx inverted as in Cairn *et al.* (2007)



Episodic temperature (K): 10/15/08 only



Point source sulfate -> brighter coastal clouds, surface cooling

Less drizzle, inhibited convection -> offshore surface warming