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An aircraft-based investigation of the first aerosol indirect effect during VOCALS-REx

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- 1B “The small effective radii measured from space over SEP are primarily controlled by anthropogenic rather than natural, aerosol production, and entrainment of polluted air from the lower free-troposphere is an important source of cloud condensation nuclei”

- ↑**Aerosols** ⟶ ↑**# of droplets** ⟶ ↑**albedo**
  - **One of the largest source of uncertainty**
  - **Quantification of the aerosol indirect effect**

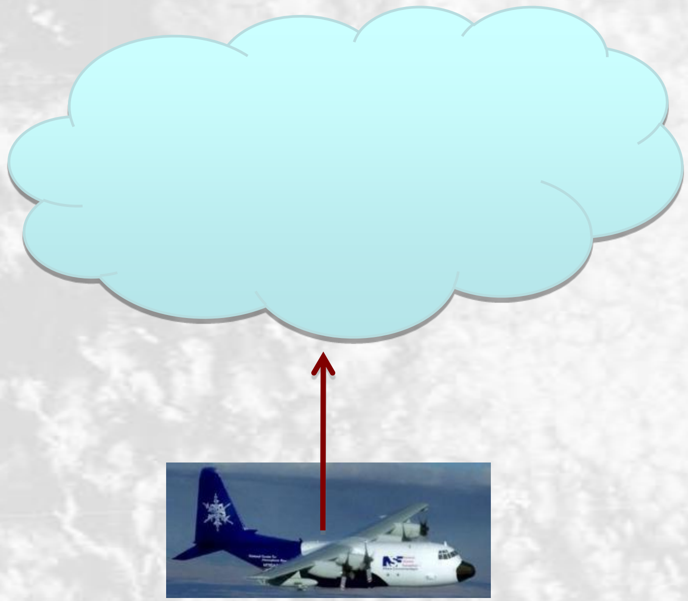
Cloud-aerosol interactions

- Requirements:
  - Measurements of microphysics (r_e and/or N_d)
  - Measurements of aerosols (CCN, accumulation mode)

  - Isolate the aerosol effect from effects associated with:
    - Precipitation
    - Cloud dynamics (LWP)

Studying cloud-aerosol interactions

- In-situ measurements: C-130 aircraft
  - Subcloud observations: larger dataset



Aerosol ✔
LWP, τ ✔
N_d ✖

- **N_d can be parameterized as a function $f(LWP,\tau)$**

Retrievals

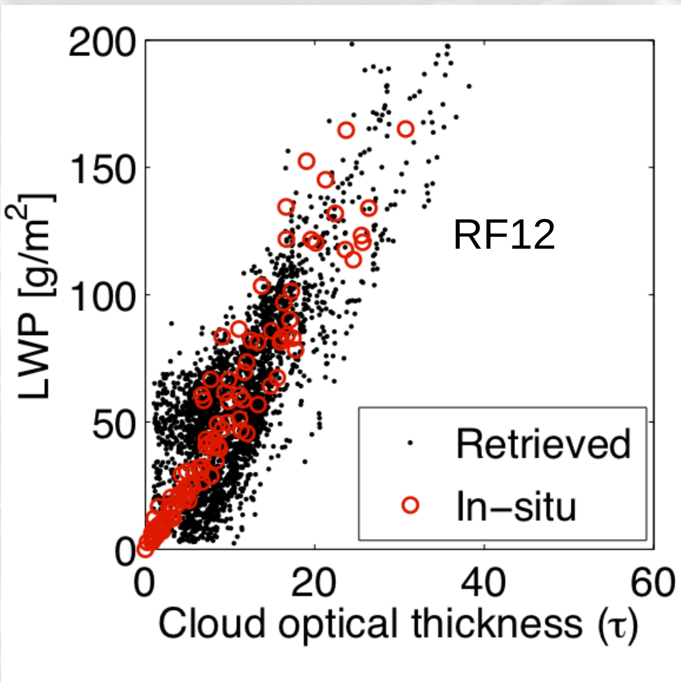
- Iterative algorithm based on radiative transfer simulations.

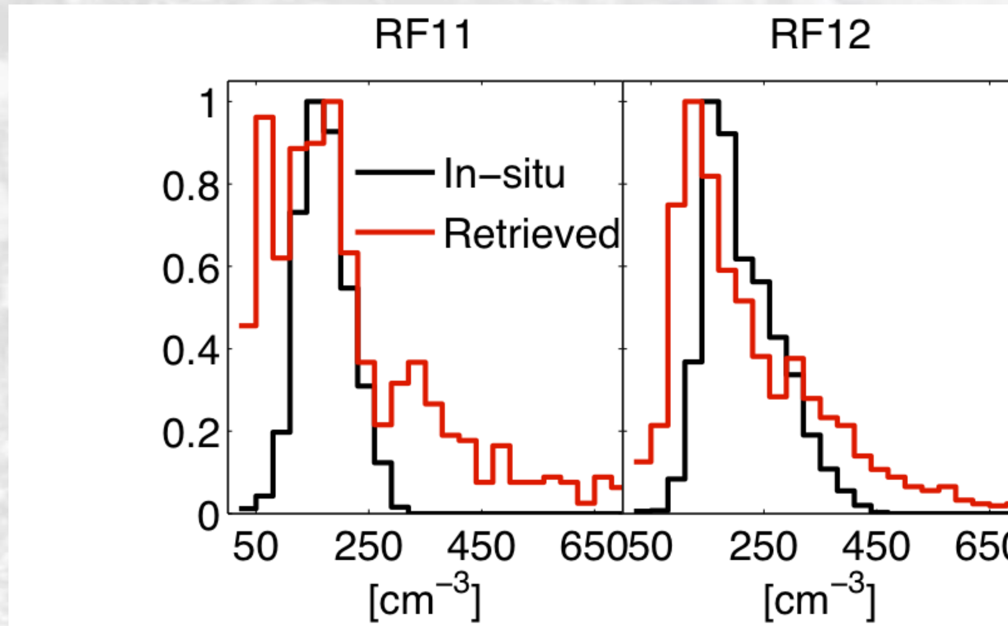
- LWP: GVR microwave radiometer

 τ: pyranometer

τ vs LWP and N_d

- Good correlation between τ and LWP: retrievals are physically consistent





$$N_d = A \times \frac{G}{k} \frac{t^3}{LWP^{5/2}}$$

Retrieved N_d tends to present wider distributions.

Quantifying cloud aerosol interactions

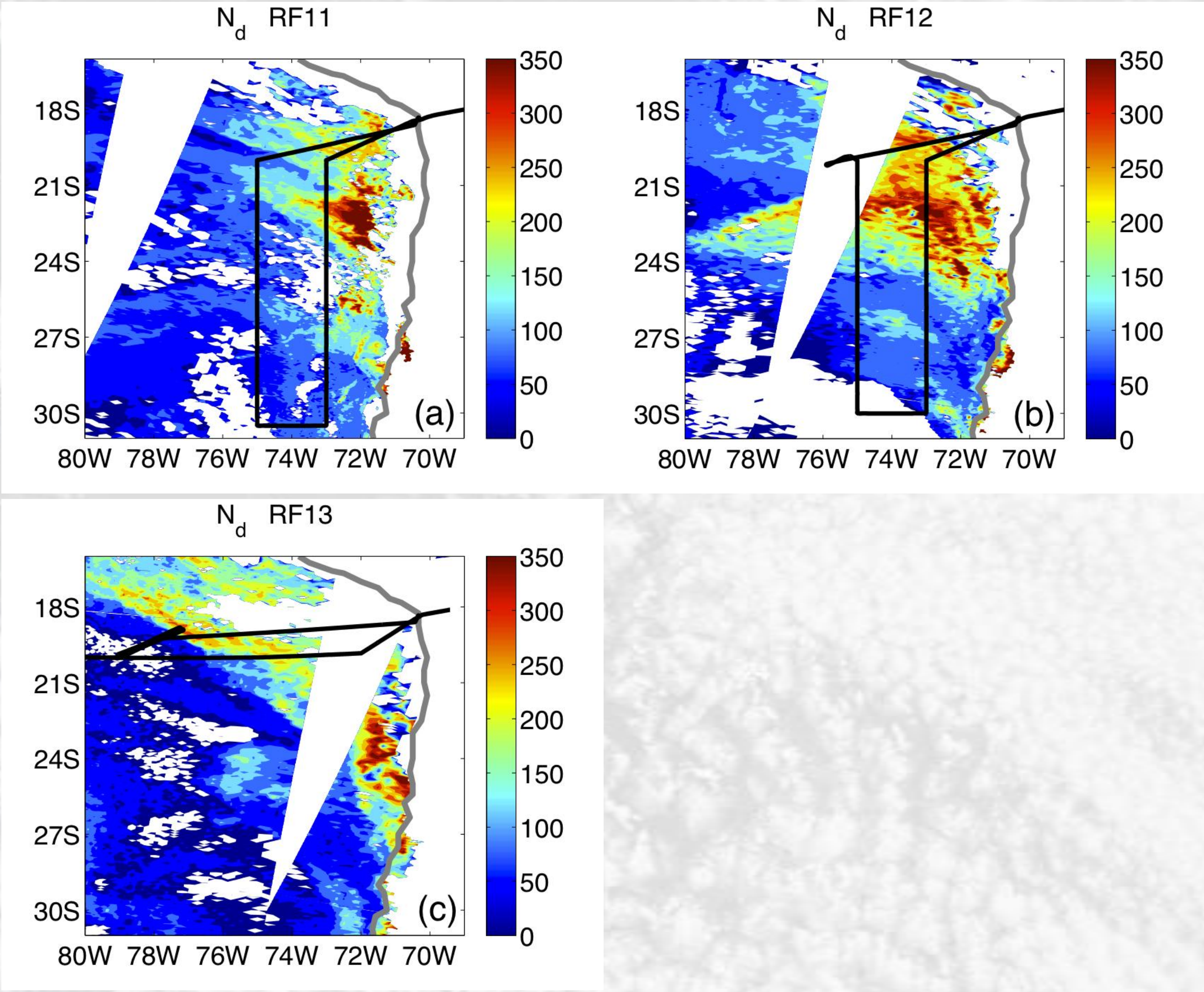
- 1st aerosol indirect effect: Increase in aerosol concentration (N_a) leads to an increase in cloud droplet number concentration (N_d)

$$N_d \propto \tau^3$$

$$ACI_N = \left.\frac{\partial \log N_d}{\partial \log N_a}\right|_{LWP} \approx 3ACI_\tau = 3 \times \left.\frac{\partial \log \tau}{\partial \log N_a}\right|_{LWP}$$

- Theory imposes constraint in ACI_N:
  - $0 < ACI_N < 1$
  - It is necessary to control for the cloud dynamics (LWP) because:
  - Changes in N_d are controlled by both: LWP and N_a
  - We are interested in isolating the aerosol effect

Regional perspective: MODIS N_d

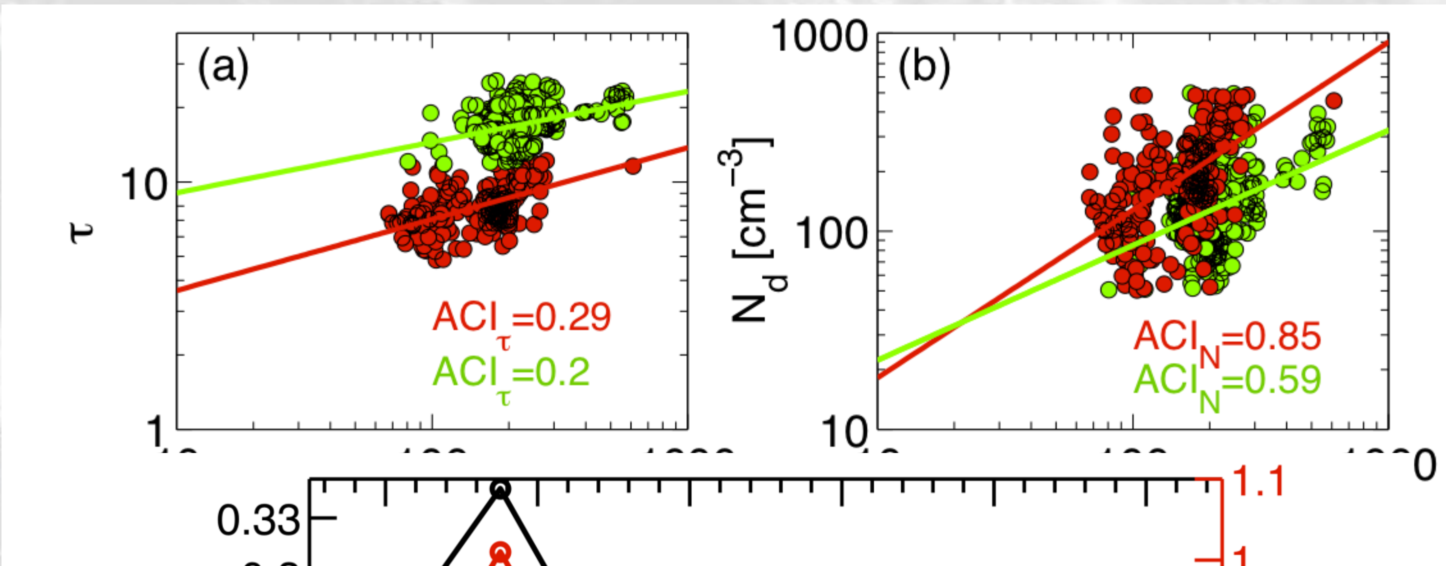


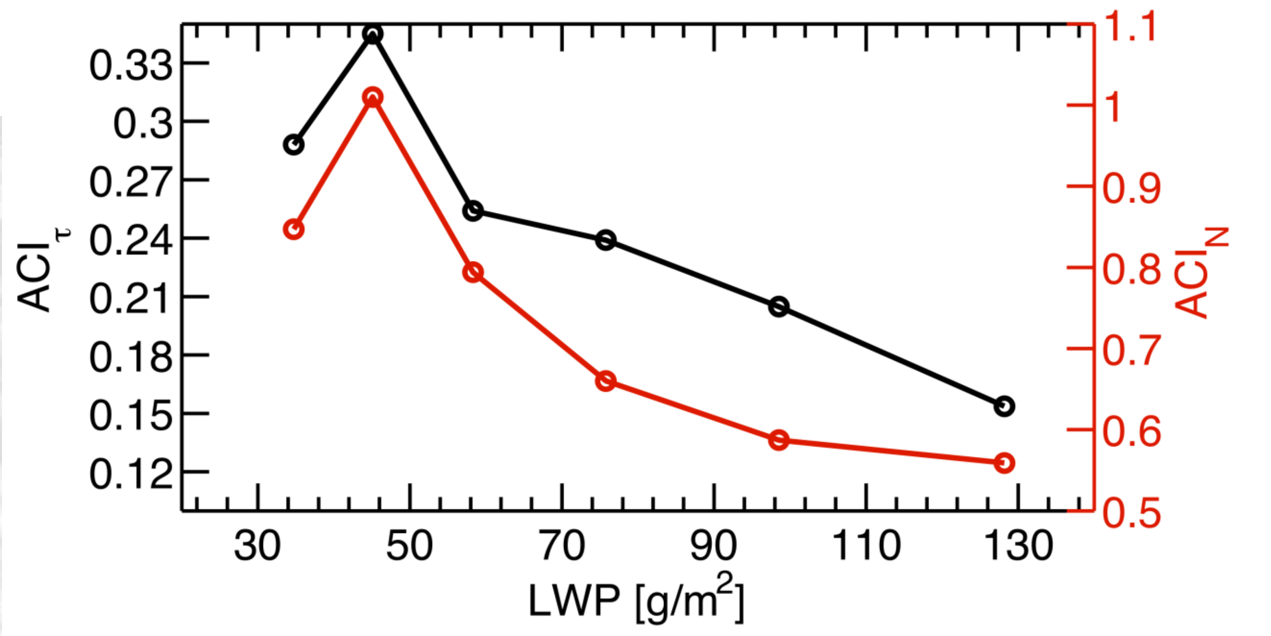
N_a-N_d correlation

- Strategy:
  - Stratify observation based on LWP:
    - **$LWP_{i+1}=1.3 \cdot LWP_i$**
- Statistically significant correlations

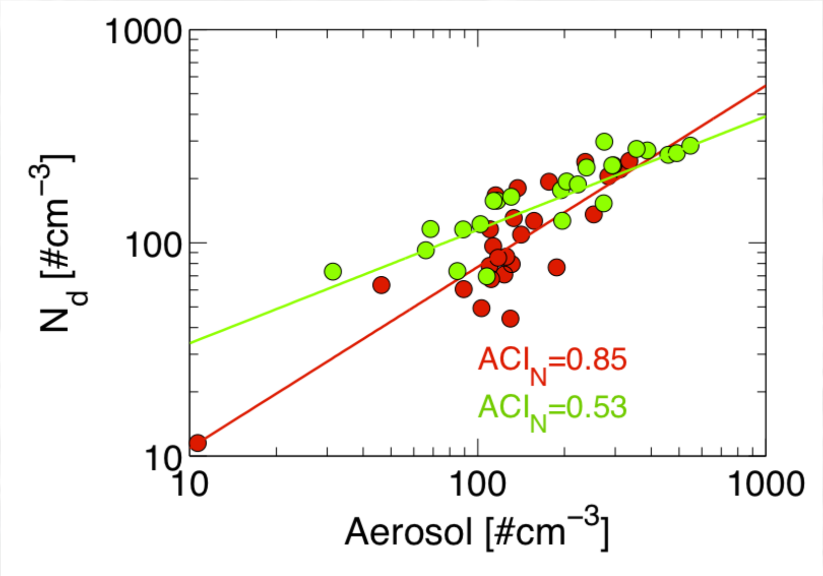
LWP bins [g/m^2]	Nº of samples	r
30-39.7	207	0.55
39.5-50.7	315	0.58
50.7-65.9	355	0.5
65.9-85.7	362	0.52
85.7-111.4	312	0.4
111.4-145	133	0.27

$$ACI_N = \left. \frac{\partial \log N_d}{\partial \log N_a} \right|_{LWP}$$





ACI_N from cloud probes

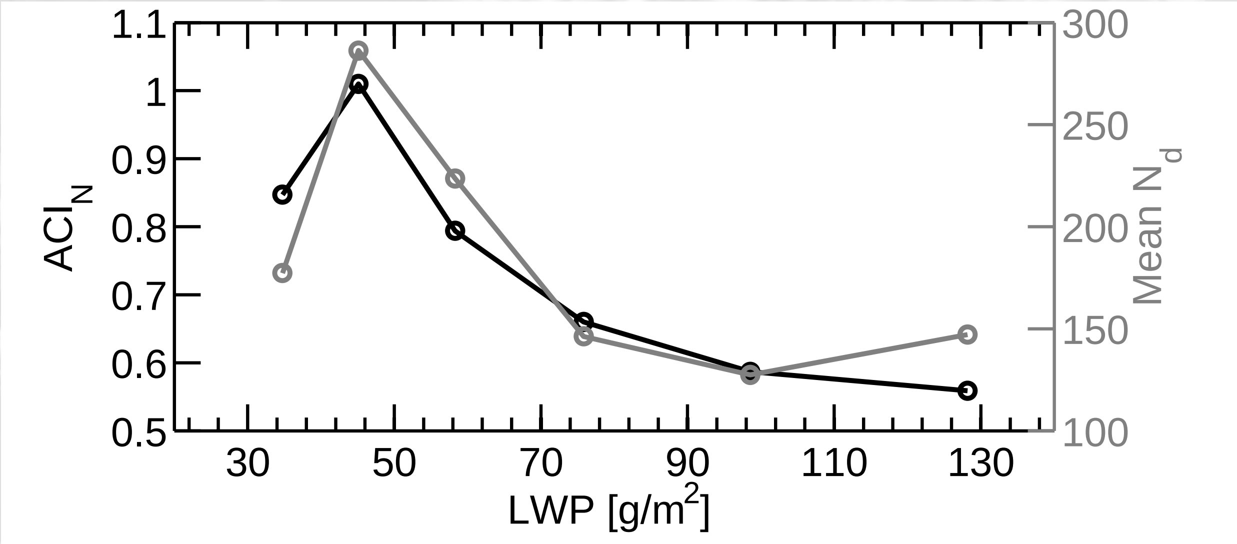


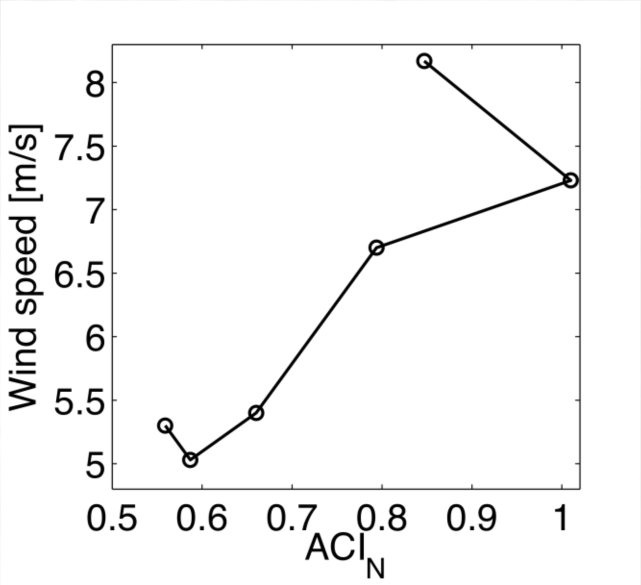
- ACI_N estimates for aricraft ascent/descent only:
  - N_a right before/after ascents/descents
  - Mean N_d of the cloudy column.

LWP<40 **LWP>50**

- A dependence of ACI on LWP is confirmed
- High values consistent with some other aircraft studies (e.g Twohy et al., 2005) and satellite retrievals (Painemal and Zuidema, 2010).
- Higher values than ARM site-based investigations (ACI< 0.5).
  - Temporal resolution?
  - Chile-Peru Sc higher sensitivity?

Controlling factors





- ACI decreases with N_d
- ACI increases with wind speed

- Implications for the overall cloud radiative response?

Radiative implications

- Q = 800 W/m^2

LWP	% Na	% Nd	% A	ΔQ [W/m^2]
30-39.7	10 %	8.5	2.2	-17.6
39.5-50.7	10 %	10	2.45	-19.6
50.7-65.9	10 %	7.9	1.66	-13.28
65.9-85.7	10 %	6.6	1.14	- 11.2
85.7-11.4	10 %	5.8	0.93	- 7.44
11.4-145	10 %	5.6	0.68	-5.44

- e.g. IPCC estimates < \|-3 W/m^2\|

Conclusions

- Combination of remote sensing allow estimate the cloud aerosol first indirect effect.
- Quantitative assessment of the first indirect effect
  - High temporal resolution(1s)
  - Relatively high N_a-N_d correlations
- Results consistent with cloud probes-based estimates.
  - Chile-Peru Sc present high sensitivities to aerosol variability.
- High radiative forcing, magnitudes 5-10 times larger than GCM and satellite estimates

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