A Study of Impact of Aerosols on Marine Stratocumulus Clouds during the Second Aerosol Characterization Experiment (ACE-2)

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Outline

- **Motivation**
- **ACE-2 base cases:** clean & polluted
- **Sensitivity tests:** swapping aerosols and meteorological background between clean and polluted cases.
- **Conclusions**

ACE-2: Second Aerosol Characterization Experiment

Motivation

Does cloud fraction & liquid water path increase with aerosols?

(1) Satellite and analysis of cloud fraction using AERONET observations show that cloud fraction increases with aerosols; but global climate model results do not show this[2].

(2) Liquid water path is expected to increase with aerosols (2nd aerosol indirect effect)[3]; but observations do not always support this[4].

1. Kaufman et al., *PNAS*, 2005;
2. Lohmann et al., *GRL*, 2006;
3. Albrecht, *Science*, 1989;
4. Ackerman et al., *JAS*, 2000.

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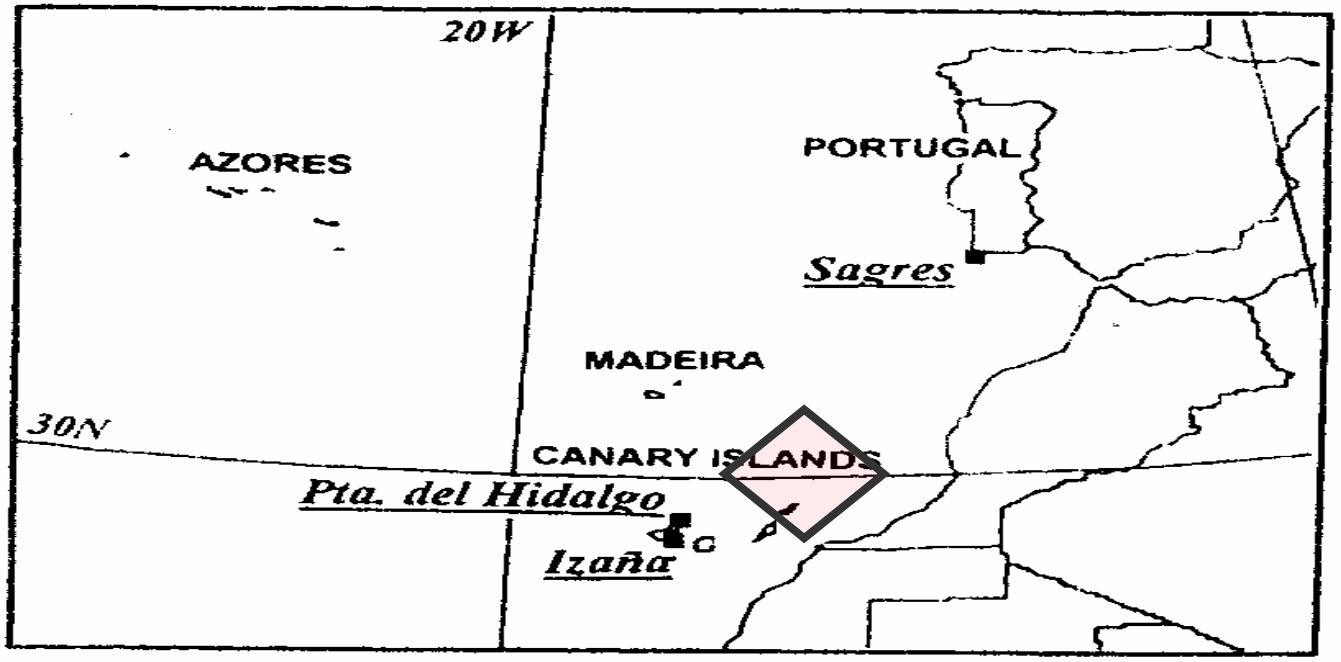
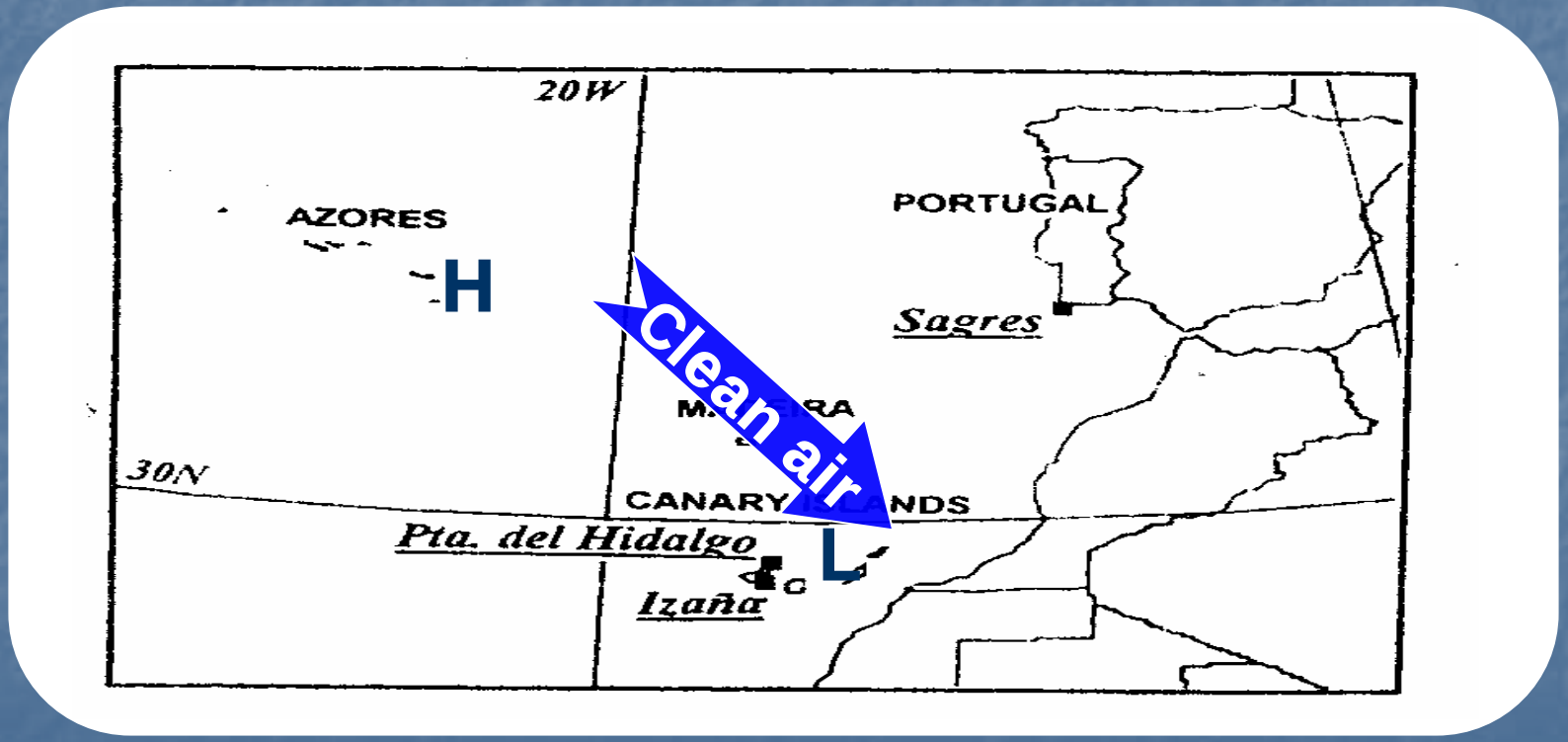
ACE-2: Second Aerosol Characterization Experiment

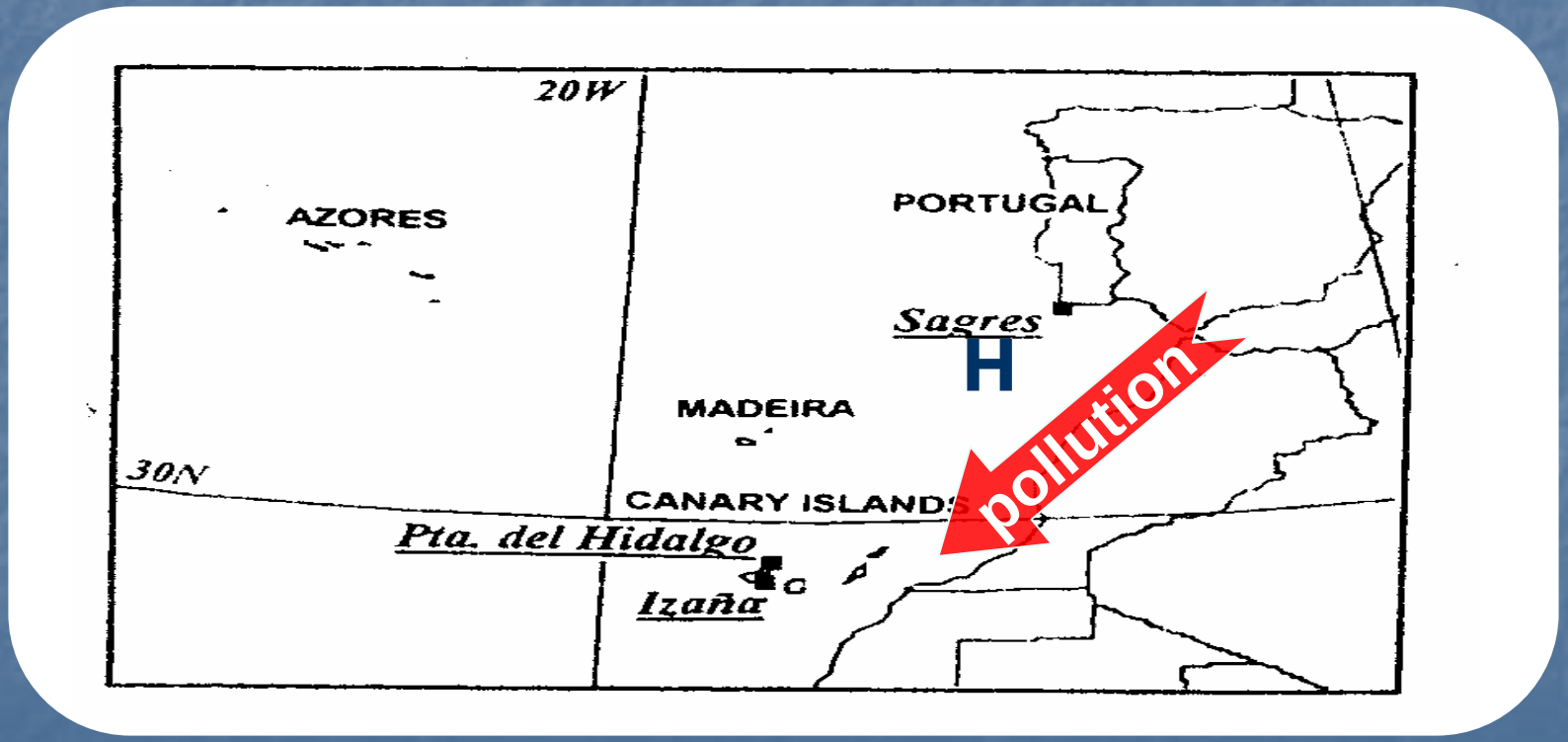
The ACE-2 took place from 16 June to 24 July, 1997, over the sub-tropical northeast Atlantic (29.4N, 16.7W).



Clean case: on June 26, ACE-2 area was under the control of a cyclone.



Polluted case: on July 9, ACE-2 area was under the influence of the Azores High.



ACE-2

Two cases: Clean VS. Polluted

		Clean (June 26)	Polluted (July 9)
	air	maritime	continental
Aerosols	$N_a(cm^{-3})$	218	636
	Sulfate(ug/m^3)	0.2	2.8
Meteorology	system	cyclone	Azores High
	subsidence	weak	strong
	W (cm/s)	-0.08	-0.43

Ref. Verver et al. 2000; Brenguier et al. 2000; Guibert et al. 2003; …

ACE-2, base case

Model & simulation set-up

(1) A cloud resolving model, ATHAM, was used.

(2) ECMWF reanalysis data was used to initialize and drive ATHAM.

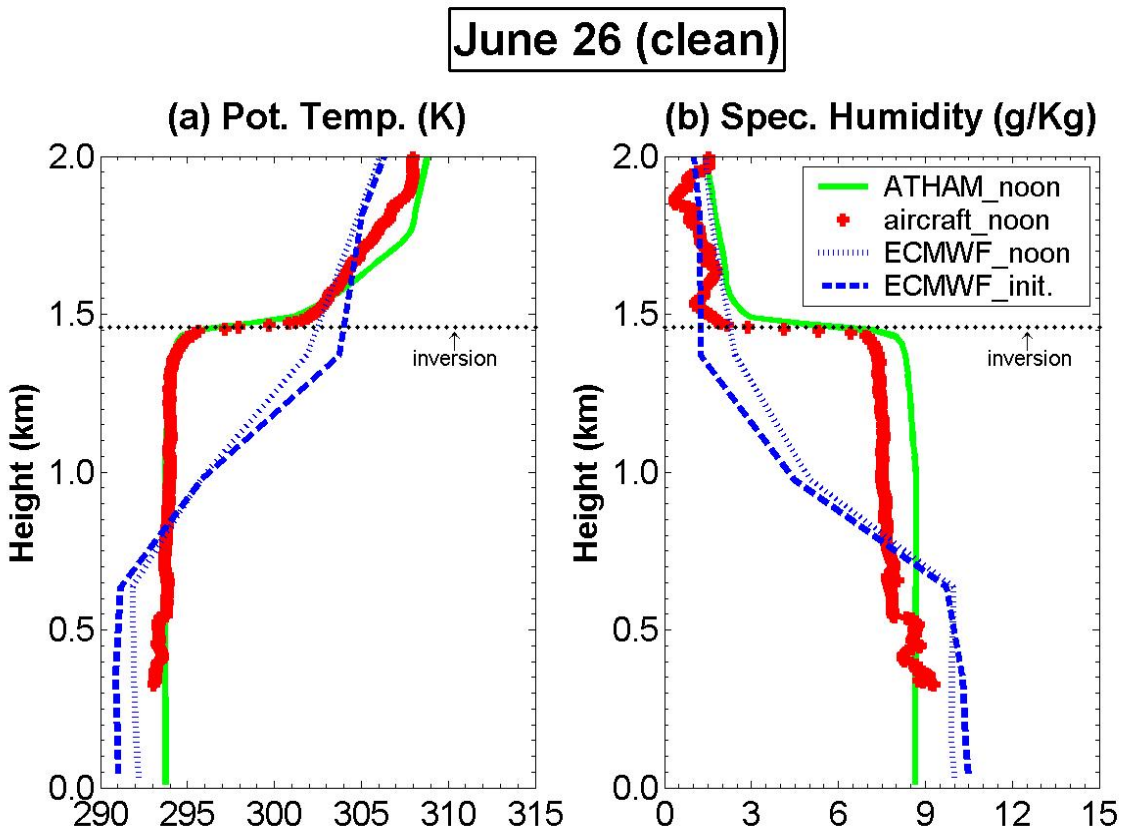
(3) 48-hr simulations have been conducted, only the last 24 hrs results were analyzed.

ATHAM: Active Tracer High resolution Atmospheric Model;

ECMWF: European Centre for Medium-Range Weather Forecasts.

Base case: clean

Thermo-dynamic profile of clean case at 12 LST



Inversion Layer Z_i ~ 1.5 km;

Well-mixed boundary layer.

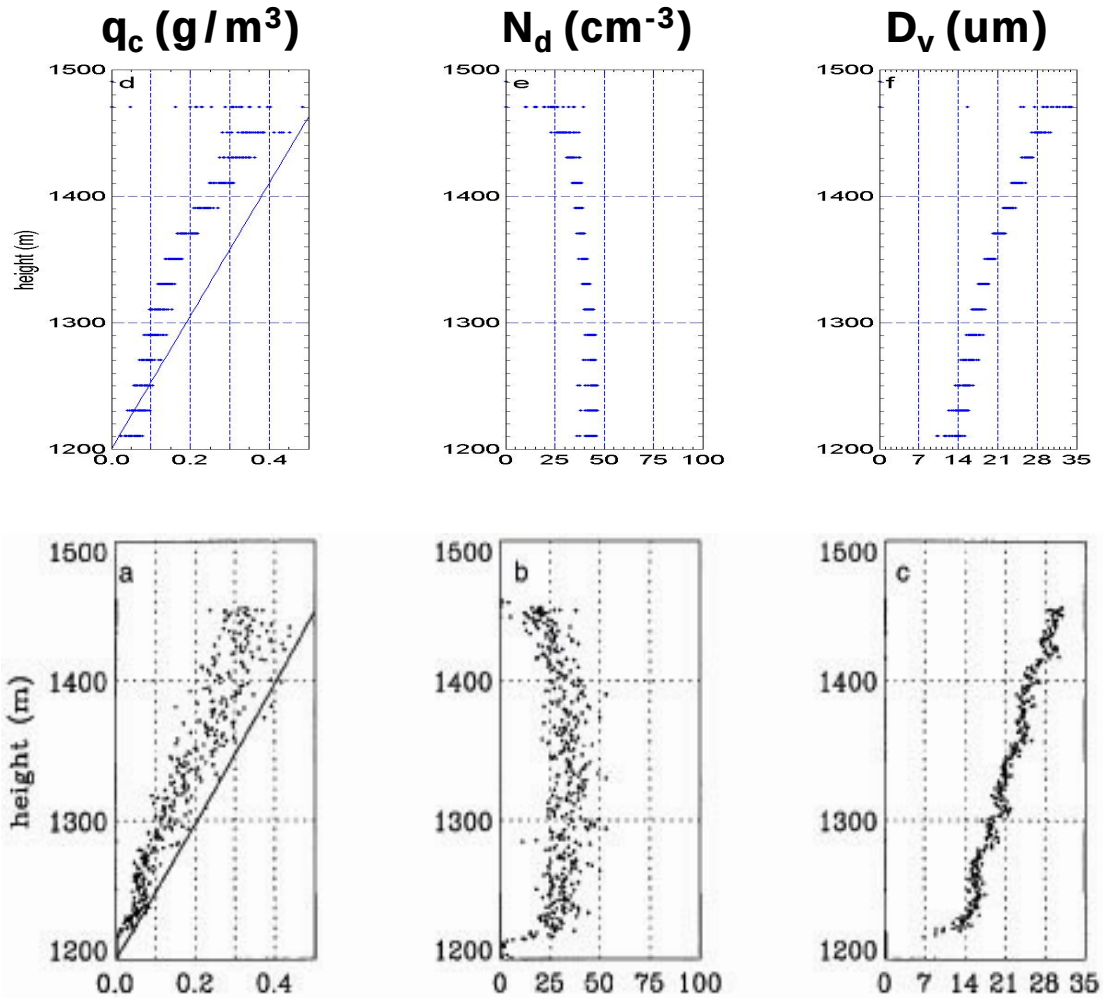
Base case: clean

Cloud profile of clean case from 13 LST - 15 LST

Model outputs

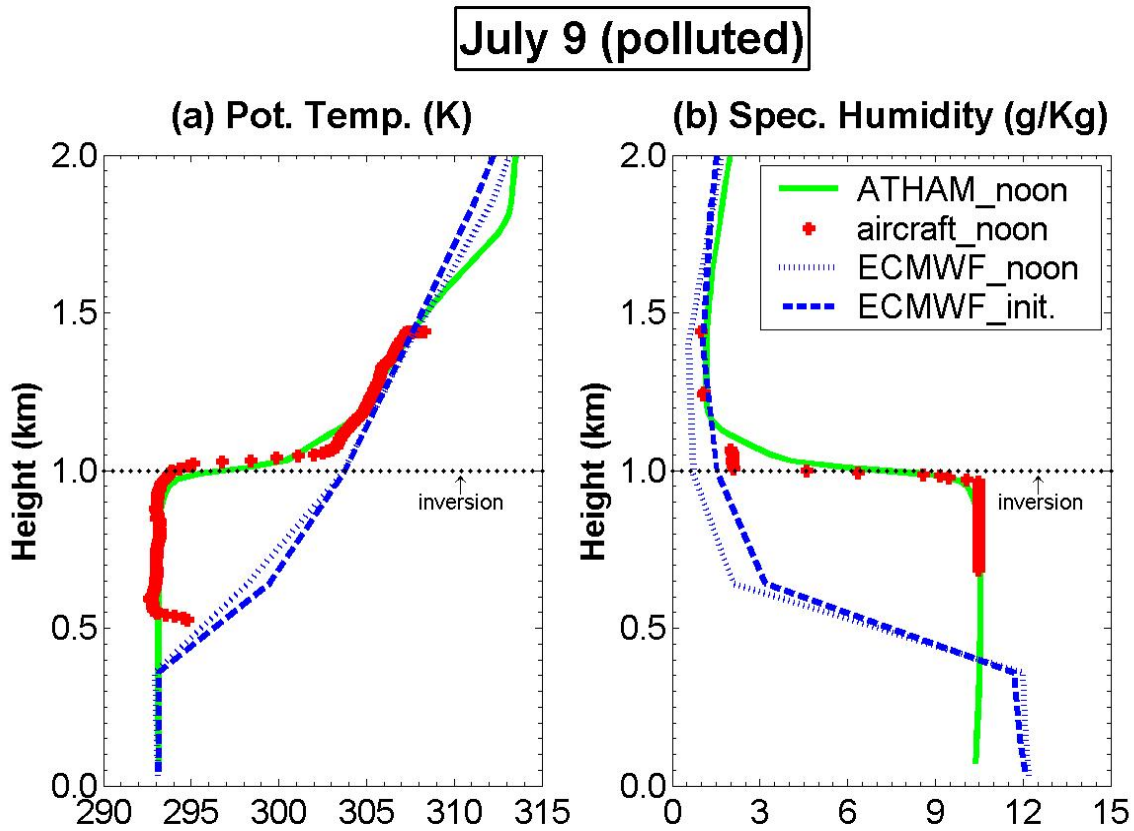
Airborne measurement

(Brenguier, et al., *JAS*, 2000)



Base case: polluted

Thermo-dynamic profile of polluted case at 12 LST



Inversion Layer Z_i ~ 1.0 km;

Well-mixed boundary layer.

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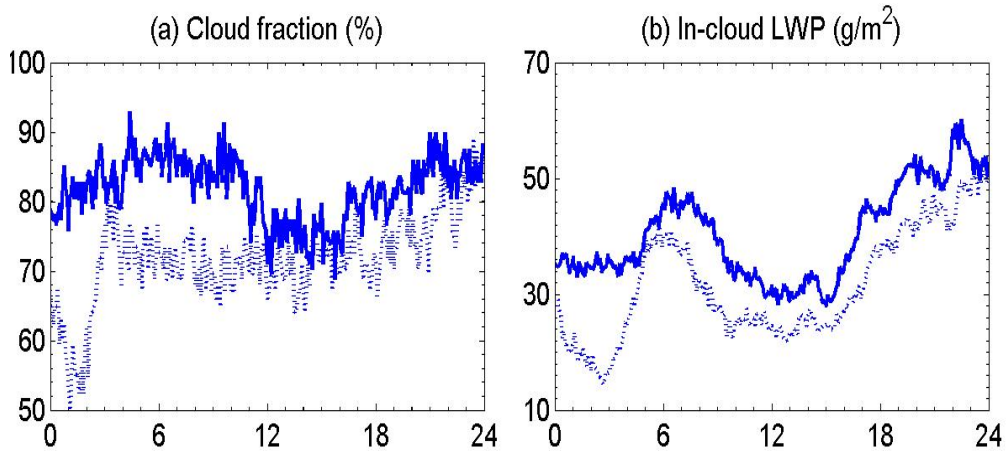
ACE-2: 2nd aerosol characterization experiment

Sensitivity tests

Clean Met:

__ clean aerosol

..... polluted aerosol

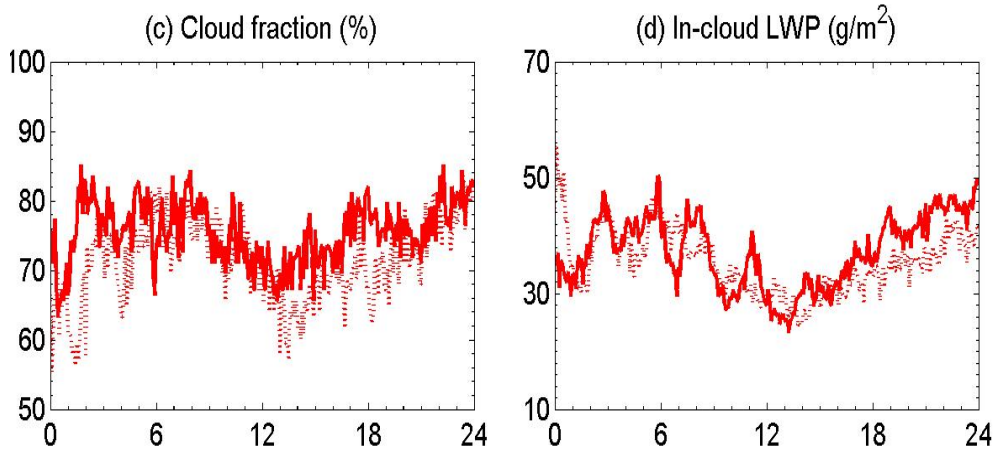


$$\begin{cases} \dfrac{\partial CF}{\partial N_a} < 0 \\ \dfrac{\partial LWP}{\partial N_a} < 0 \end{cases}$$

Polluted Met:

__ clean aerosol

..... polluted aerosol



$$\begin{cases} \dfrac{\partial CF}{\partial N_a} \approx 0 \\ \dfrac{\partial LWP}{\partial N_a} \approx 0 \end{cases}$$

Cloud top entrainment

Clean Met:

..... polluted aerosol

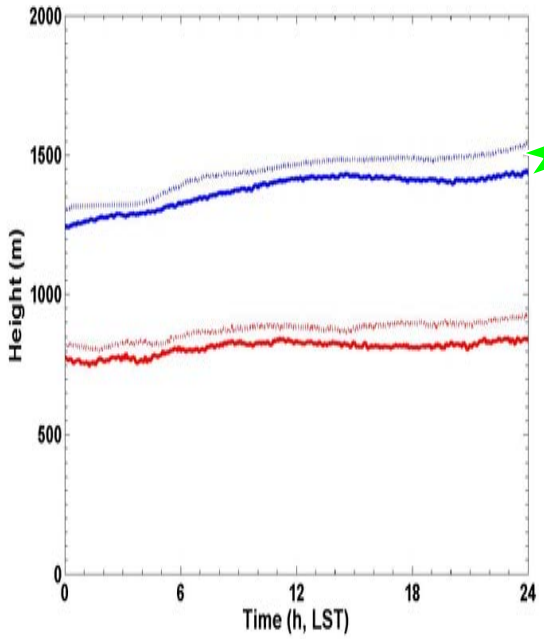
__ clean aerosol

Polluted Met:

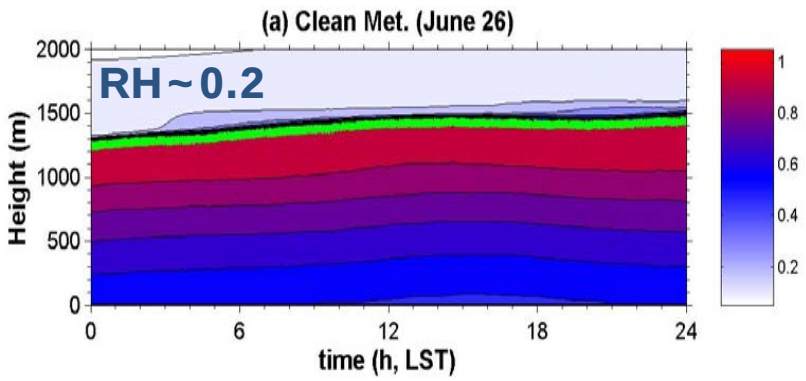
..... polluted aerosol

__ clean aerosol

Cloud top height



Relative humidity (RH)



Under the 'Clean Met.', higher entrainment of dry air with the 'polluted aerosol' helps remove cloud water; and leads to lower CF & LWP (Ackerman et al., *Nature*, 2004).

Cloud top entrainment

Clean Met:

..... polluted aerosol

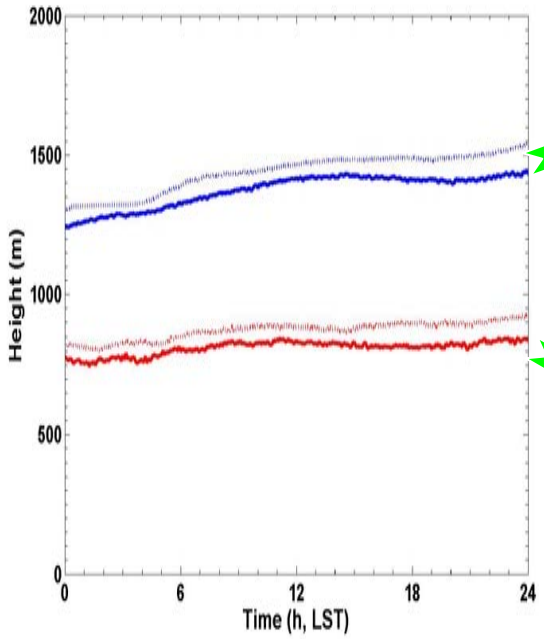
__ clean aerosol

Polluted Met:

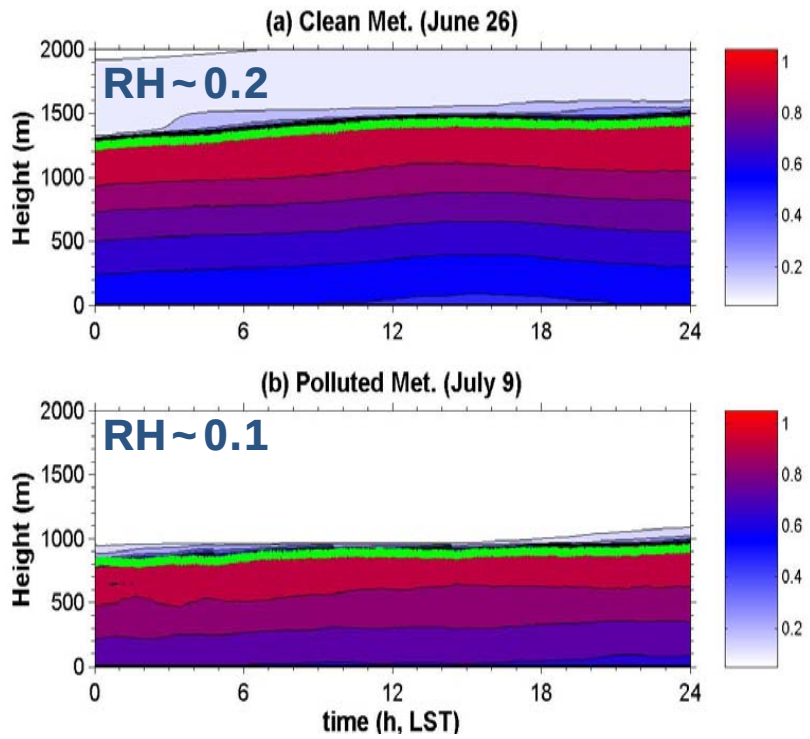
..... polluted aerosol

__ clean aerosol

Cloud top height



Relative humidity (RH)



Sensitivity tests

Cloud top entrainment & large-scale subsidence (*W*)

Cloud top height

Clean Met:

(*W*=-0.08 cm/s)

..... polluted aerosol

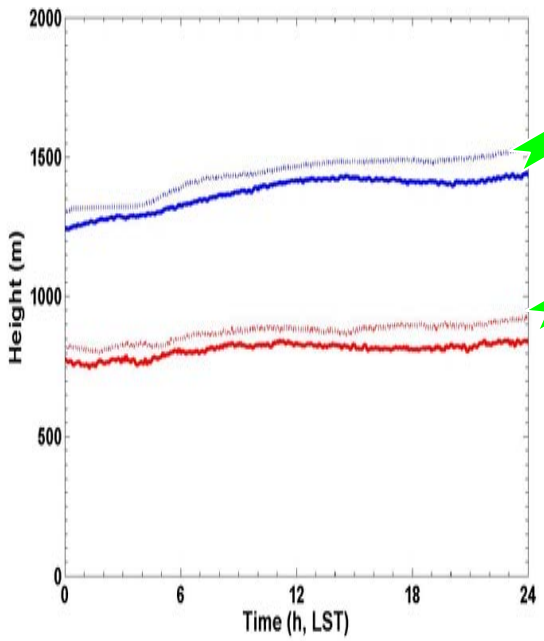
__ clean aerosol

Polluted Met:

(*W*=-0.43 cm/s)

..... polluted aerosol

__ clean aerosol



Cloud top growth rate

$D(Z_{cld\_top})/Dt$ (cm/s)

Clean Met.	polluted aerosol	0.28
	clean aerosol	0.23
Polluted Met.	polluted aerosol	0.13
	clean aerosol	0.12

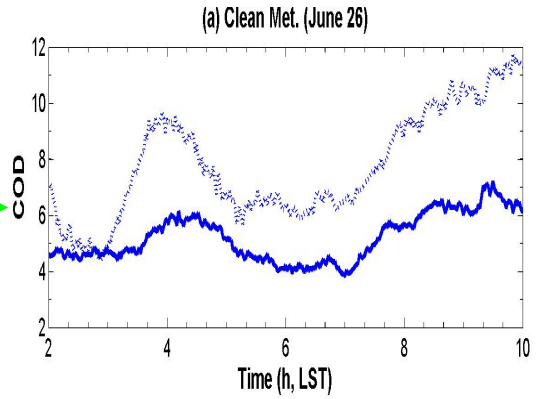
Under the 'Polluted Met.', strong subsidence masks the difference of *D*(Zcld_top)/*D*t between clean and polluted aerosols; and leads to similar CF & LWP for clean and polluted cases.

Sensitivity tests

Radiative forcing (TOA, W/m^2)

	dF_1	dF_2	dF_t
Clean Met.	-24.8	14.6	-10.2
Polluted Met.	-17.8	-0.5	-18.3

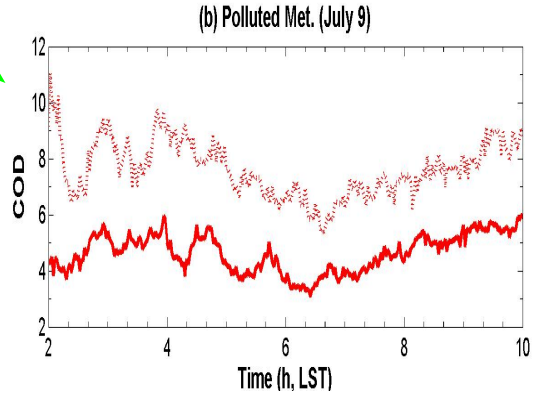
Cloud optical depth



Clean Met:

..... polluted aerosol

__ clean aerosol



Polluted Met:

..... polluted aerosol

__ clean aerosol

Conclusions

1) The strength of the large-scale subsidence, as well as RH above clouds, plays an important role in the response of CF & LWP to an increase in aerosols. Weak subsidence can lead to a decrease in CF and LWP and a positive second indirect effect.

2) Nevertheless, a **p**ositive second AIE does not overwhelm the negative first AIE. It can decrease the magnitude of total AIE, but is unlikely to change the sign of the total AIE.

CF: Cloud Fraction; LWP: Liquid Water Path;

RH: Relative Humidity; AIE: Aerosols Indirect Effect.

Future work

- Use cloud resolving model to examine other cases sampled by ARM studies.
- Examine the frequency of meteorological conditions that might lead to positive and negative 2nd AIE.

Thank you !