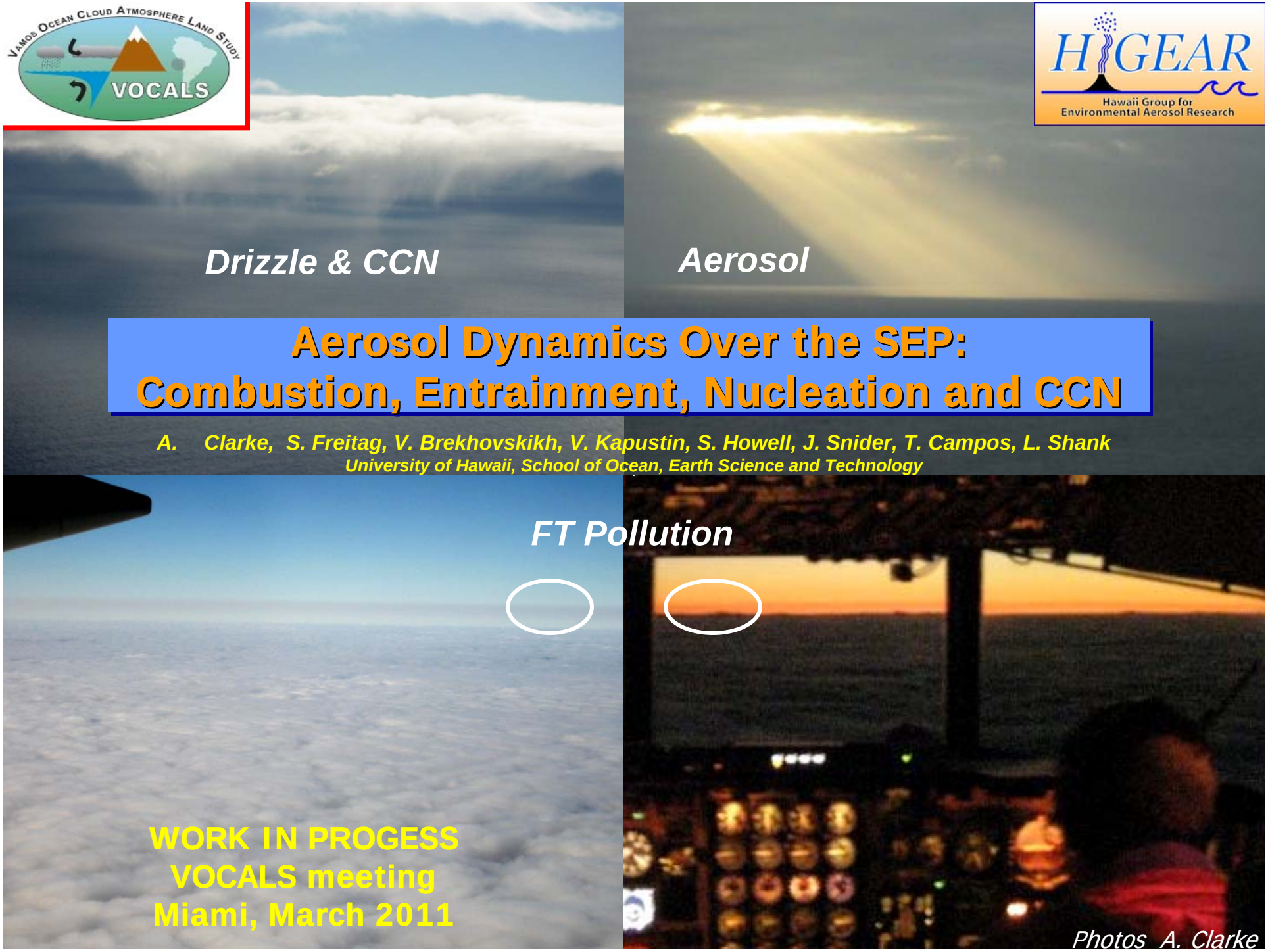


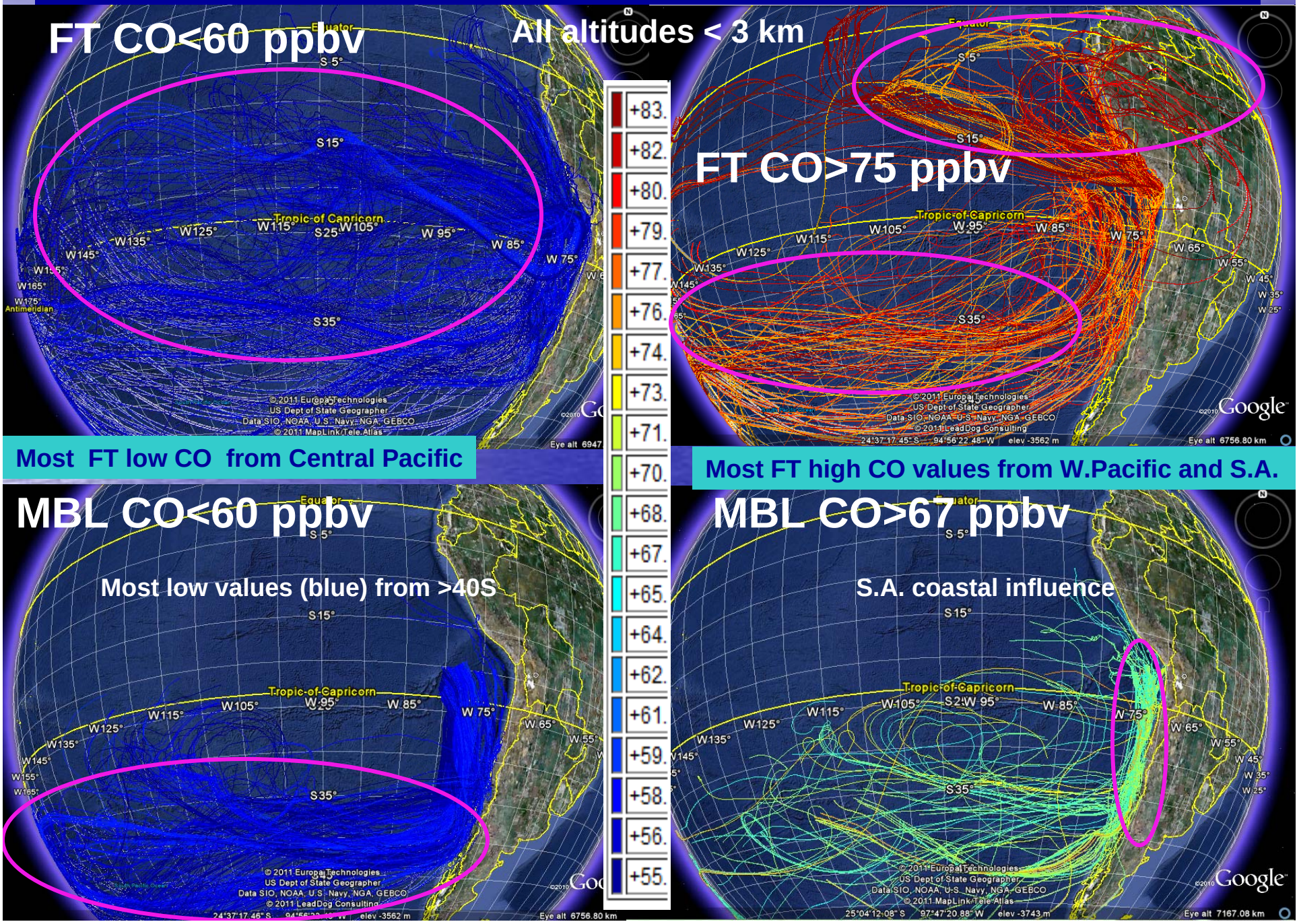
Aerosol Dynamics Over the SEP: Combustion, Entrainment, Nucleation and CCN

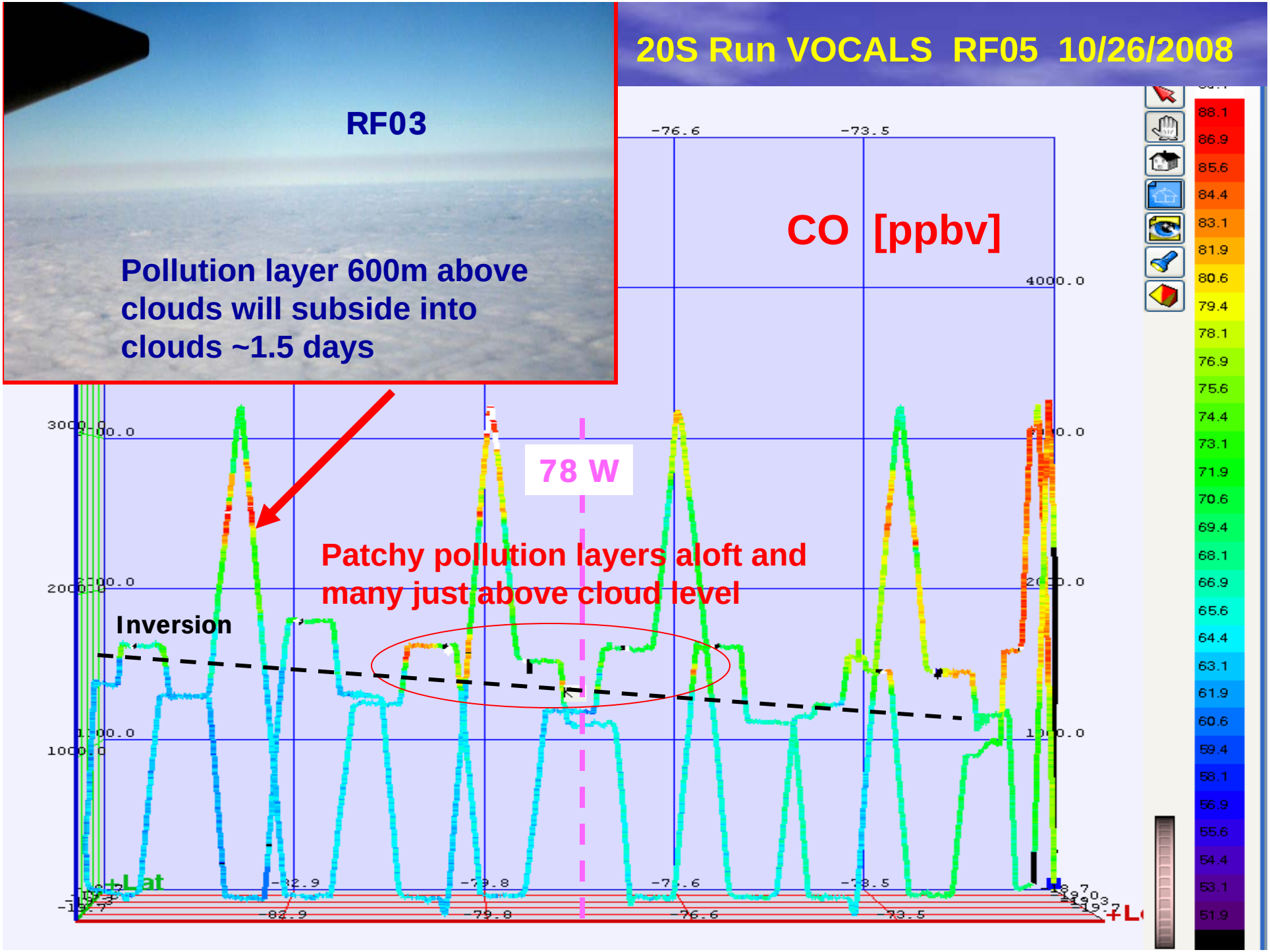
A. Clarke, S. Freitag, V. Brekhovskikh, V. Kapustin, S. Howell, J. Snider, T. Campos, L. Shank
University of Hawaii, School of Ocean, Earth Science and Technology

OUTLINE

- **Where, what is clean unperturbed South Pacific aerosol?**
- **What are typical SEP aerosol fields in Marine Boudary Layer (MBL) and Free Troposphere (FT)?**
- **Relation between Transport, Entrainment & MBL CCN?**
- **Implications for Clouds and POC's over the SEP?**

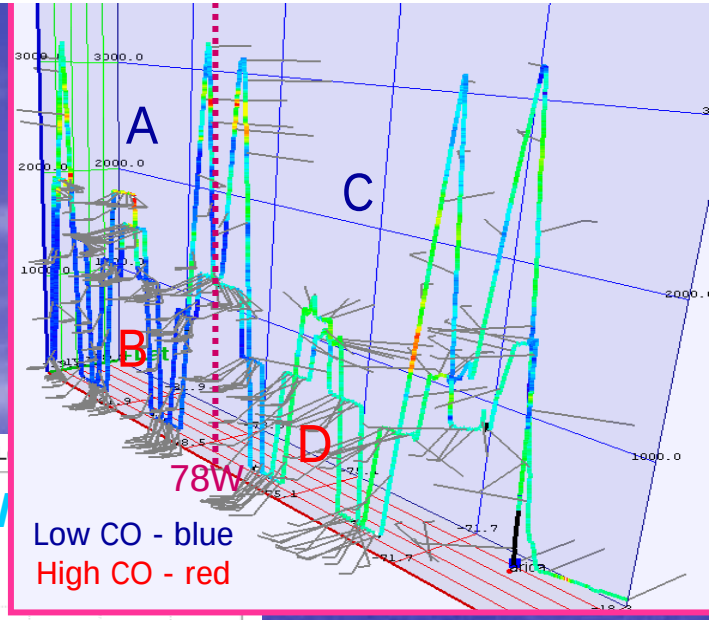
Characteristic Trajectories for low and high CO in the FT and MBLfor VOCALS

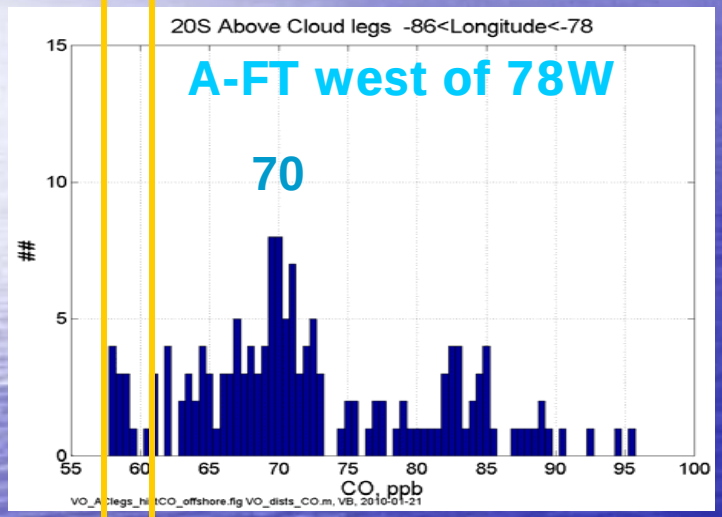


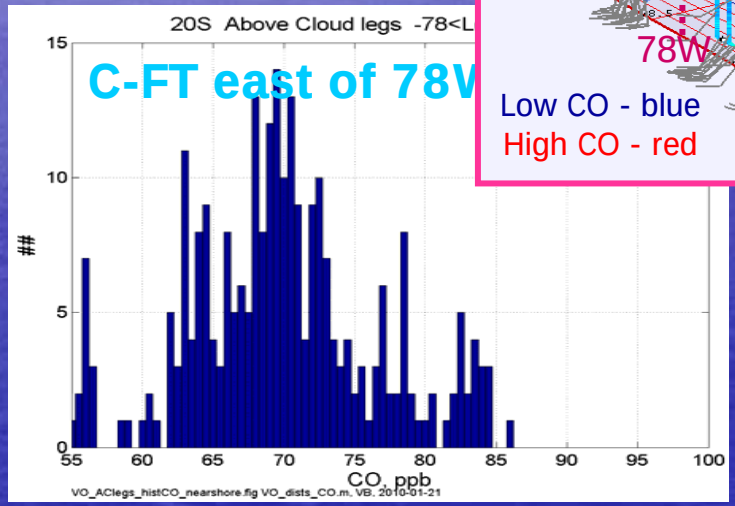

20S Run VOCALS RF05 10/26/2008
RF03
Pollution layer 600m above clouds will subside into clouds ~1.5 days
CO [ppbv]
78 W
Patchy pollution layers aloft and many just above cloud level
Inversion
88.1
86.9
85.6
84.4
83.1
81.9
80.6
79.4
78.1
76.9
75.6
74.4
73.1
71.9
70.6
69.4
68.1
66.9
65.6
64.4
63.1
61.9
60.6
59.4
58.1
56.9
55.6
54.4
53.1
51.9

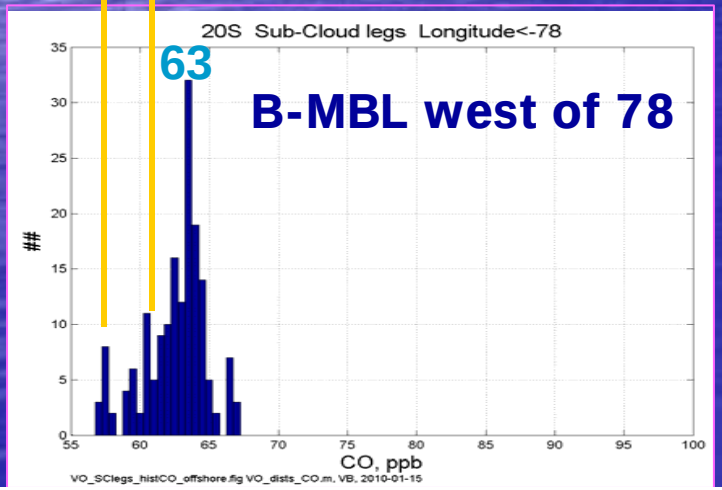
Histograms of CO for 20S Missions

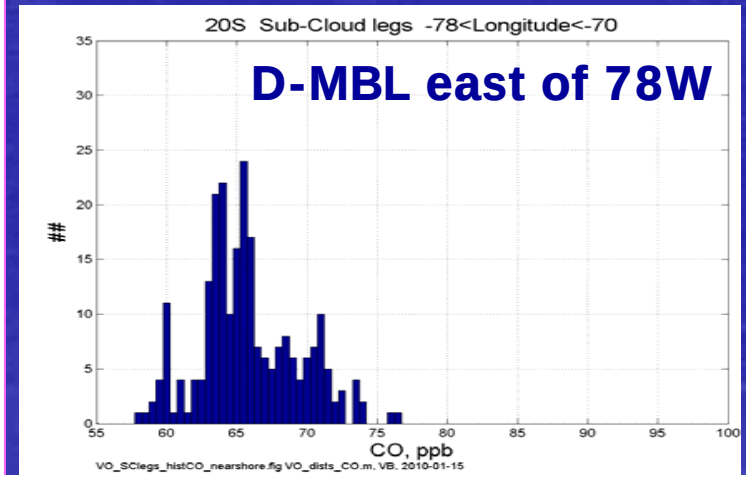
Clean MBL and FT air from S. Pacific have the two lowest clusters of low CO <60ppbv.
Higher values in cloudy air – lower values in POC's



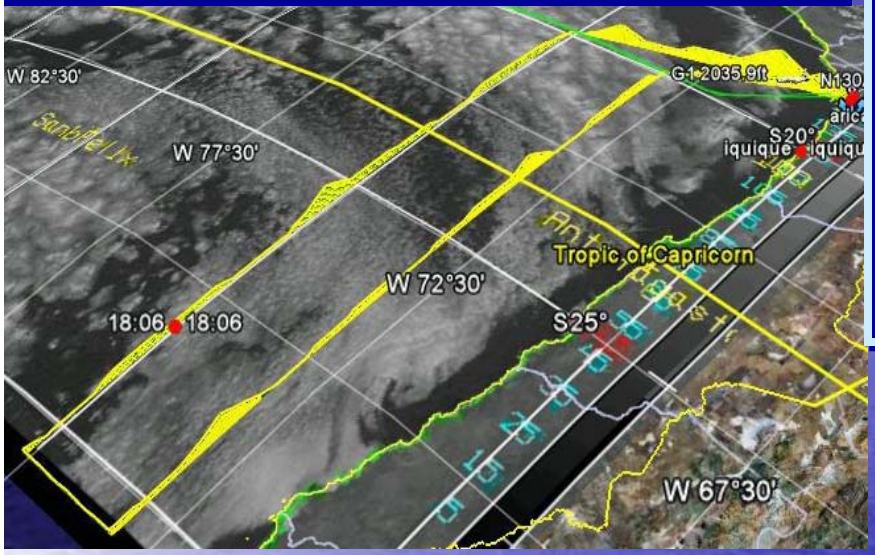


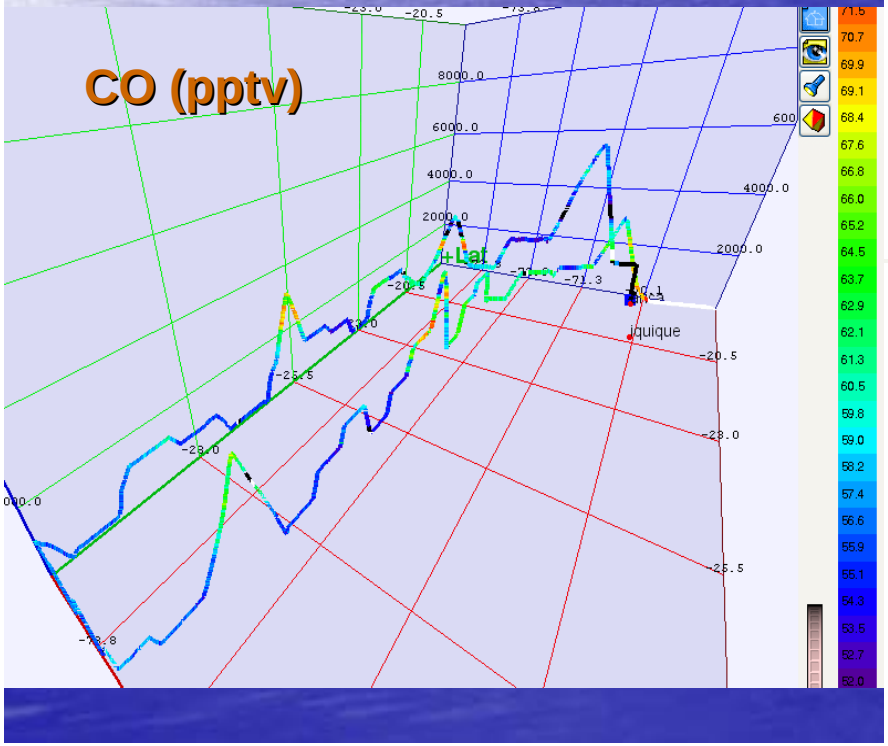






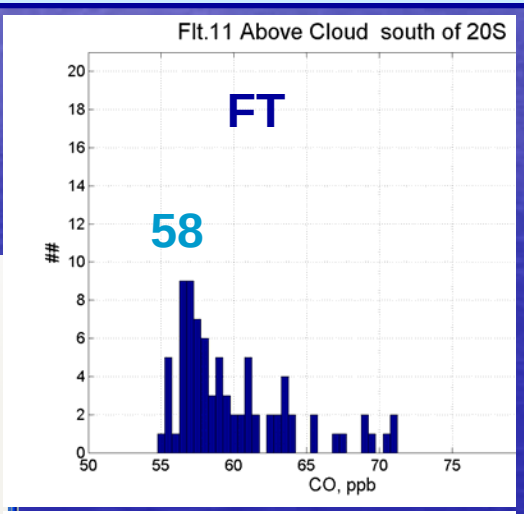
VOCALS RF11 11/9/2008

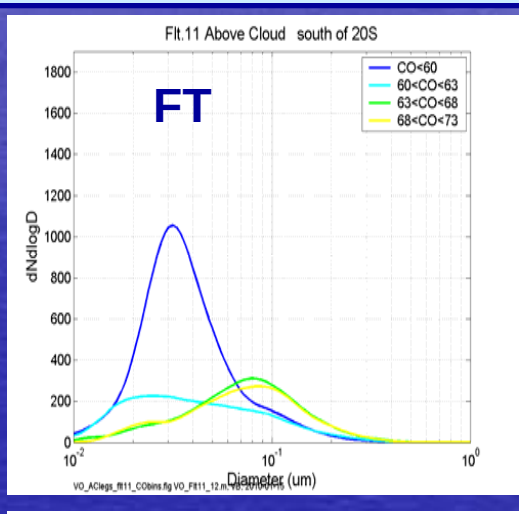


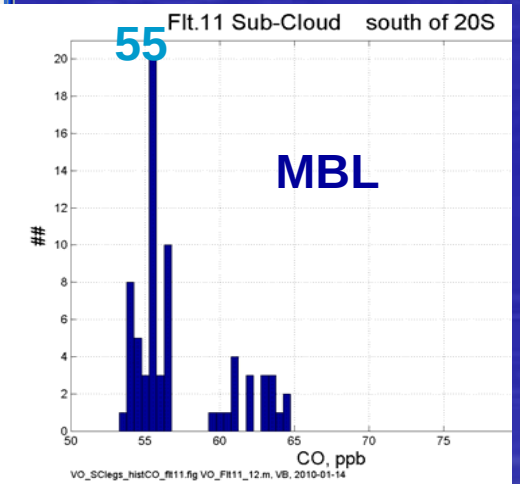


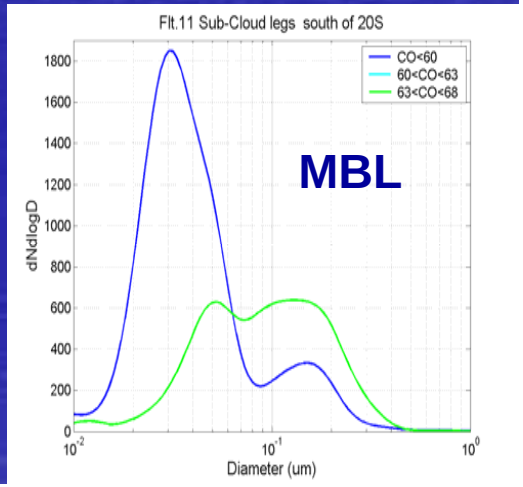
RF 11 Clean Airmass South of 20.5 S
Clean FT CO=58 ppbv
Clean MBL CO=56 ppbv

Lower MBL value is consistent with 2-3 days destruction after entrainment from FT

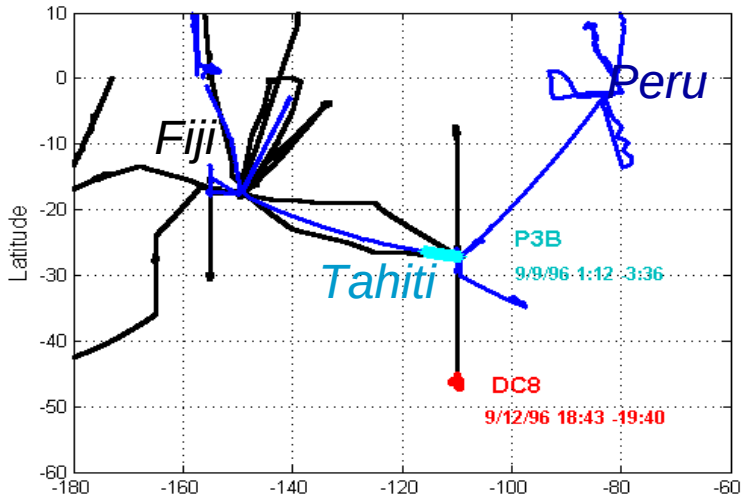


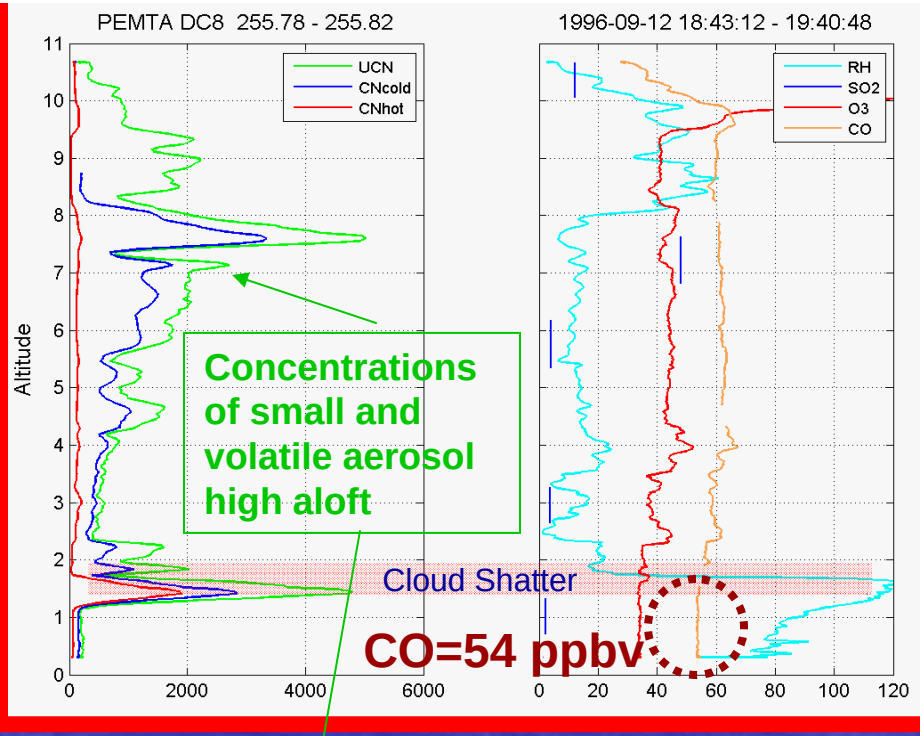




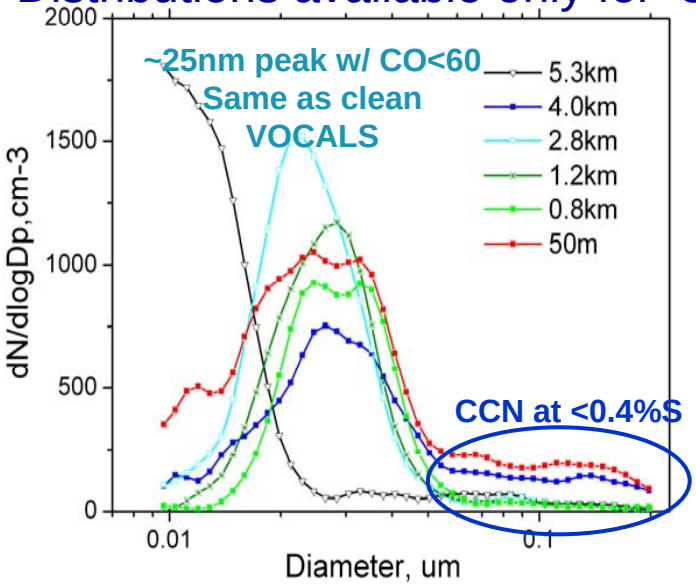


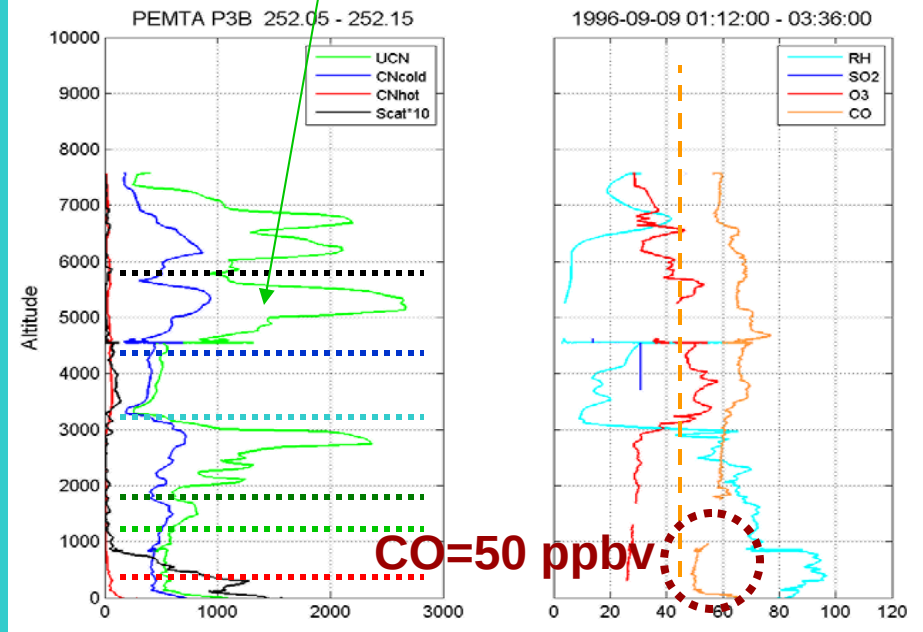
What CO and aerosol reach SEP from S. Pacific MBL?
--30S and 50S data from NASA PEMT 1996



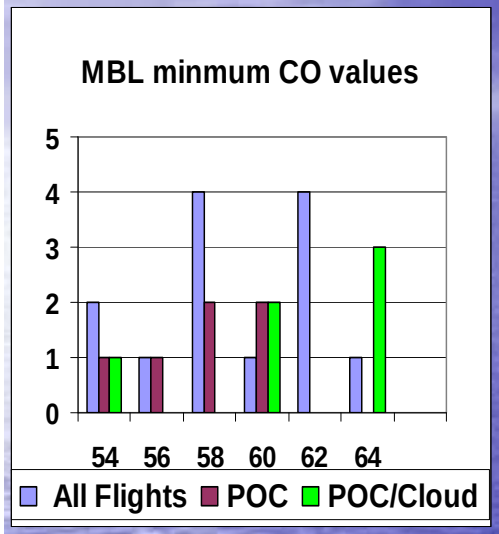


Distributions available only for 30S



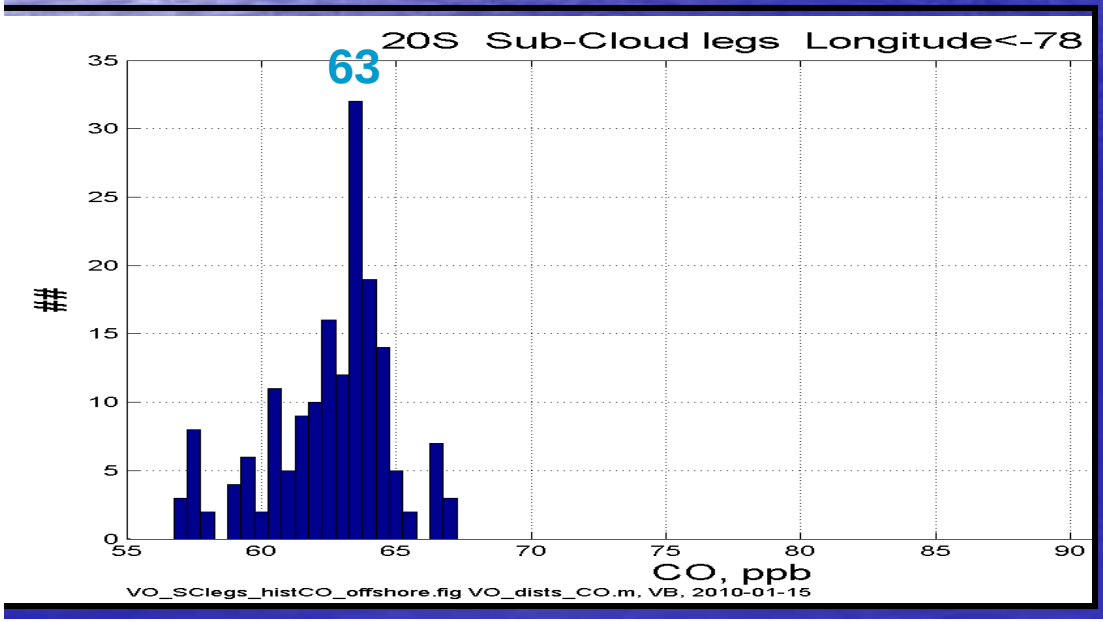


MBL CO west of 78W much higher than in clean SP air but lower than FT above (about 70 ppbv)
POC CO is lower than adjacent cloudy regions.



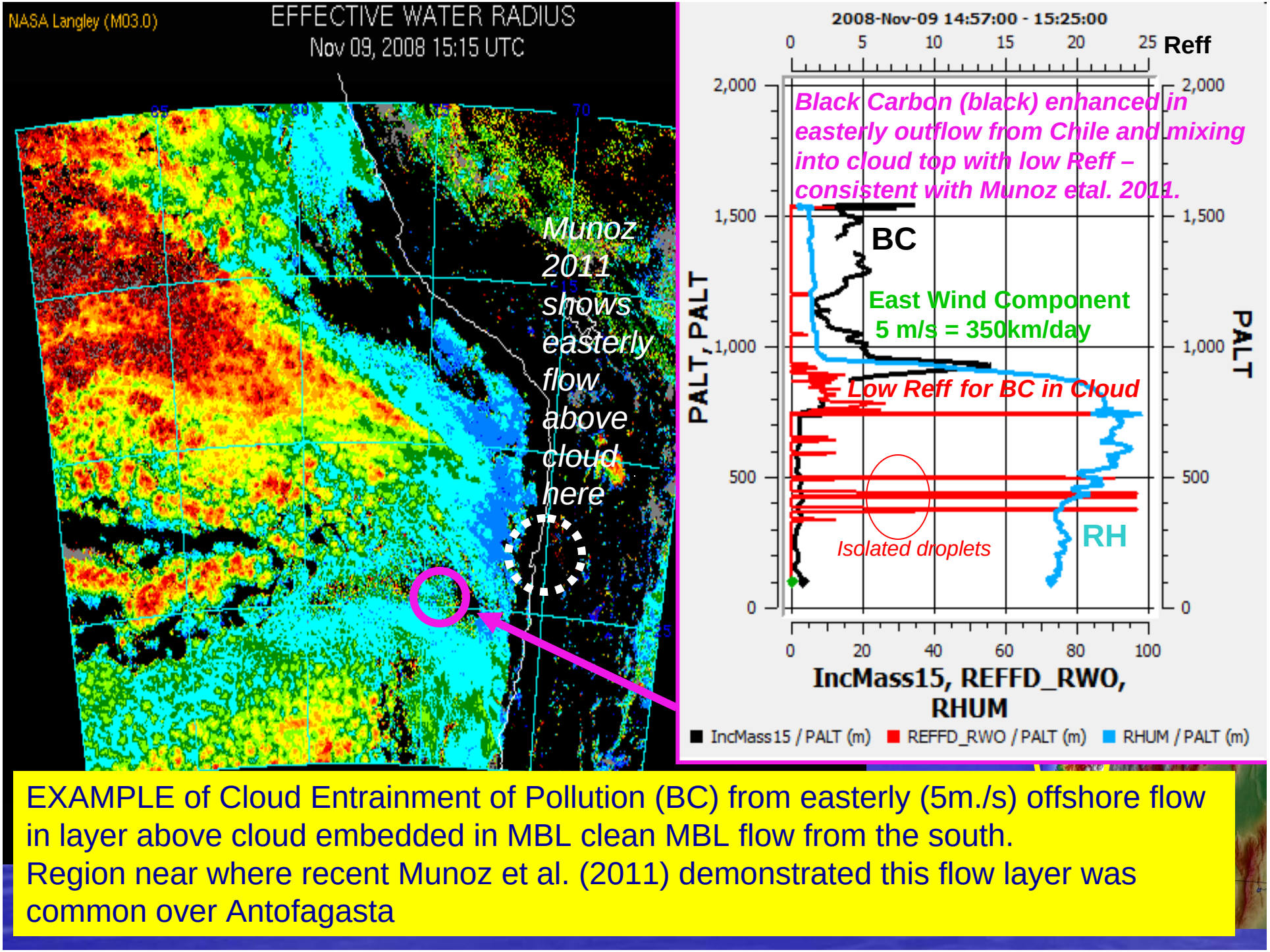
Low CO measured in POC's about 56 ppbv (Clean SP)
Low CO measured in clouds next to POC's about 62 ppbv

Suppose we entrain mean FT CO at 70 ppbv into MBL at 56 ppbv for 2 days at 4mm/s (700m) into a 700m thick MBL to get a 50:50 mix



50% 56 ppbv
+ 50% 70 ppbv

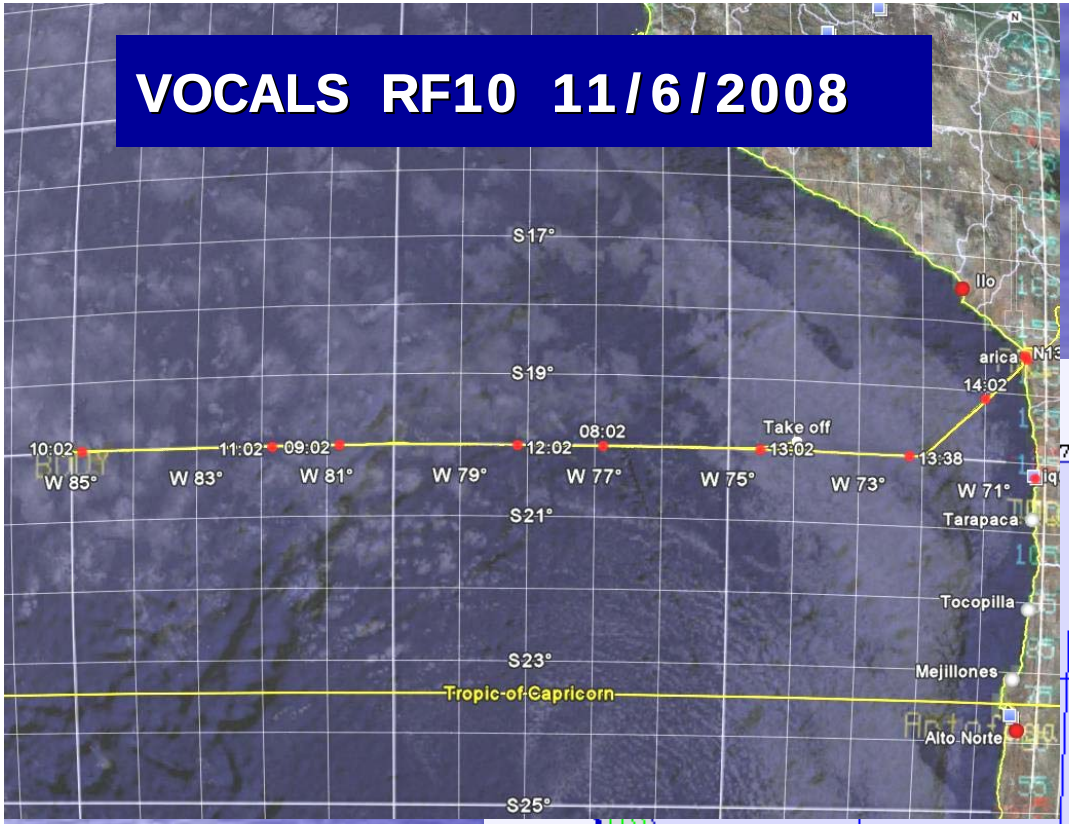
= 62 ppbv



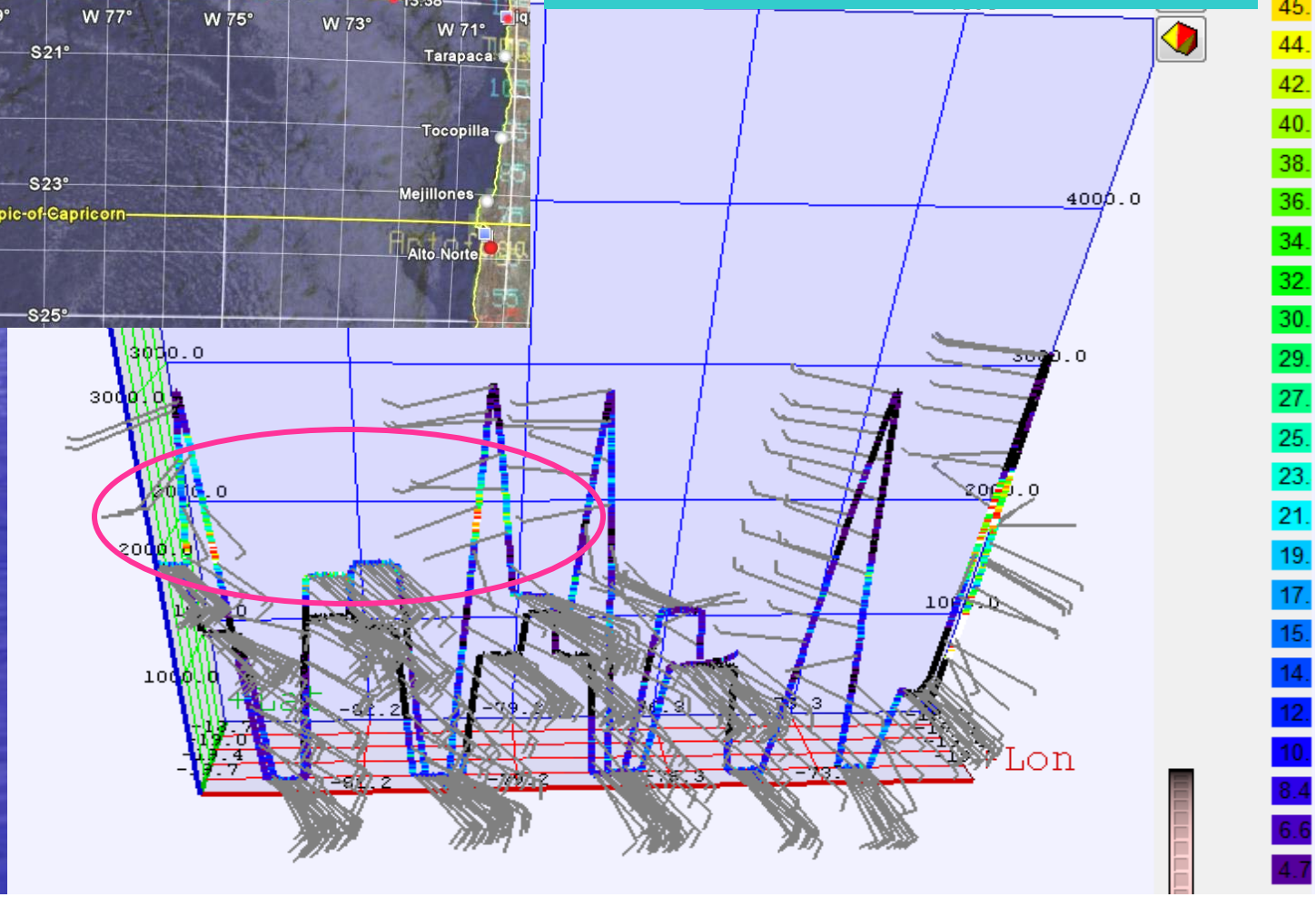
EXAMPLE of Cloud Entrainment of Pollution (BC) from easterly (5m./s) offshore flow in layer above cloud embedded in MBL clean MBL flow from the south.
Region near where recent Munoz et al. (2011) demonstrated this flow layer was common over Antofagasta

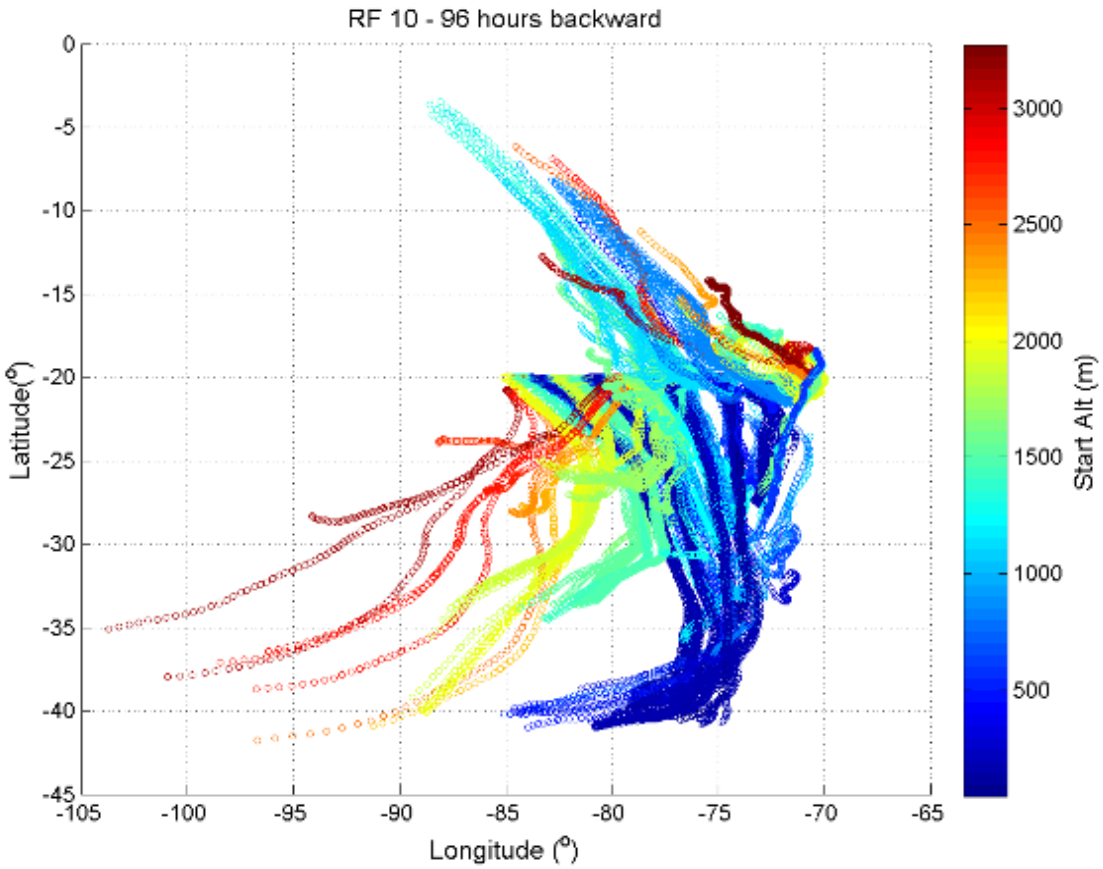
VOCALS RF10 11/6/2008

Long range transport from S. Pacific in pollution in FT to west

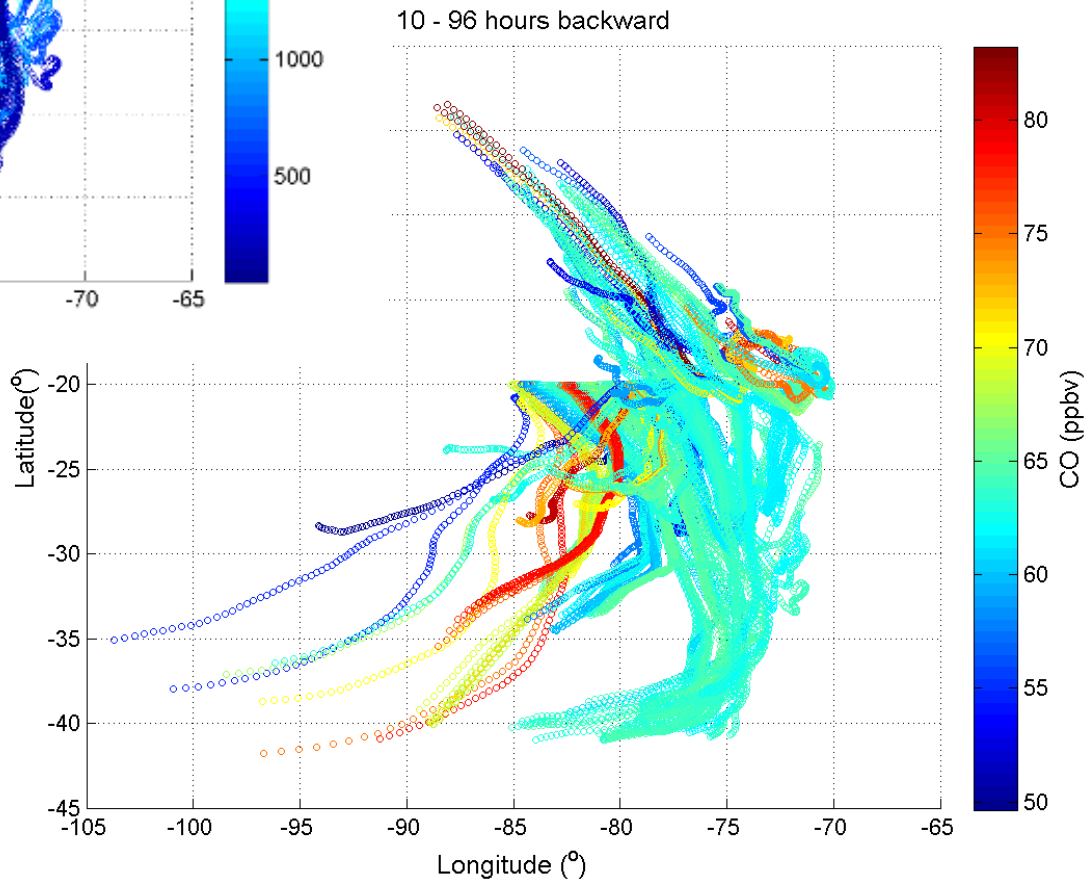


BC [ng/m3] and Winds

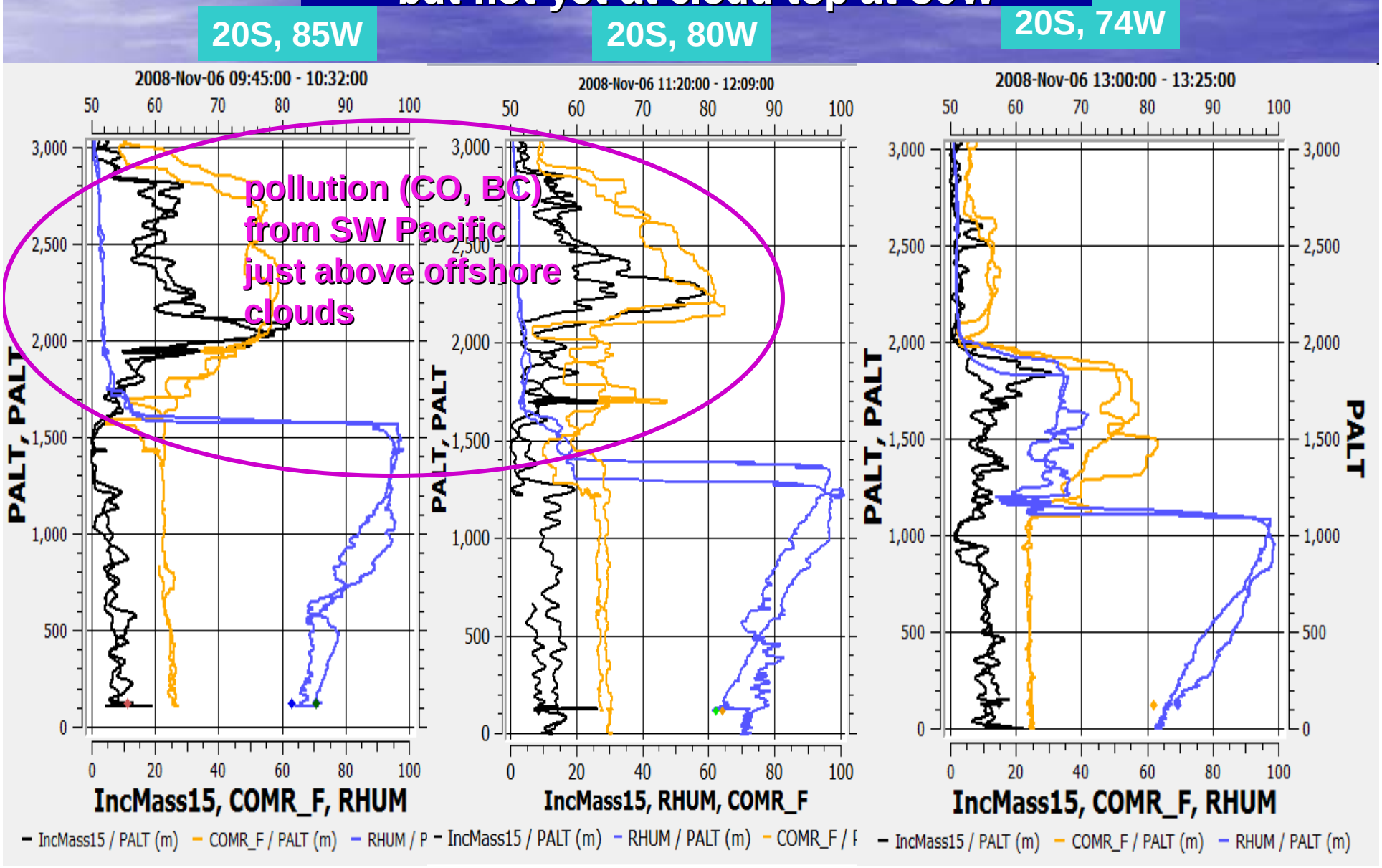




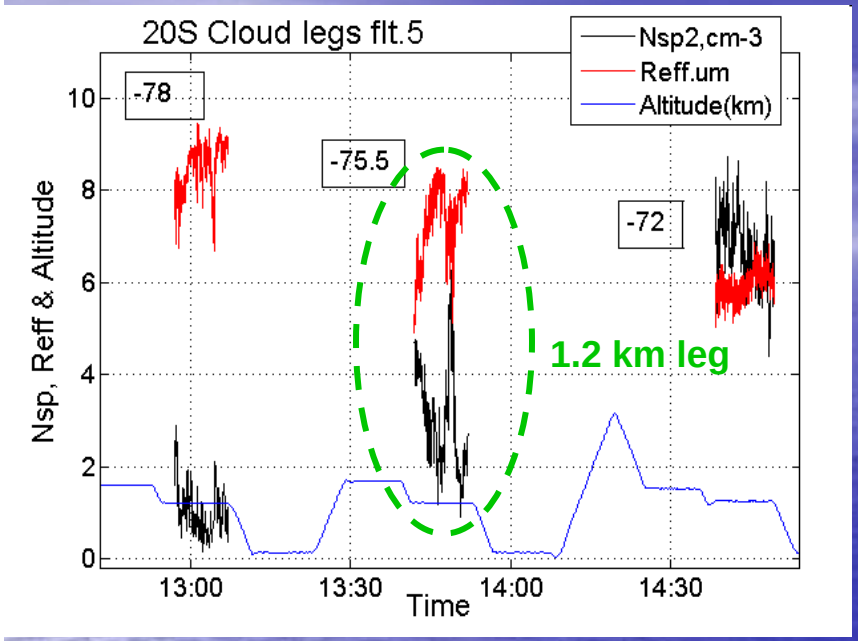
RF10 Trajectories showing Long Range Transport of high CO (below) across S. Pacific encountered near 2km (left)

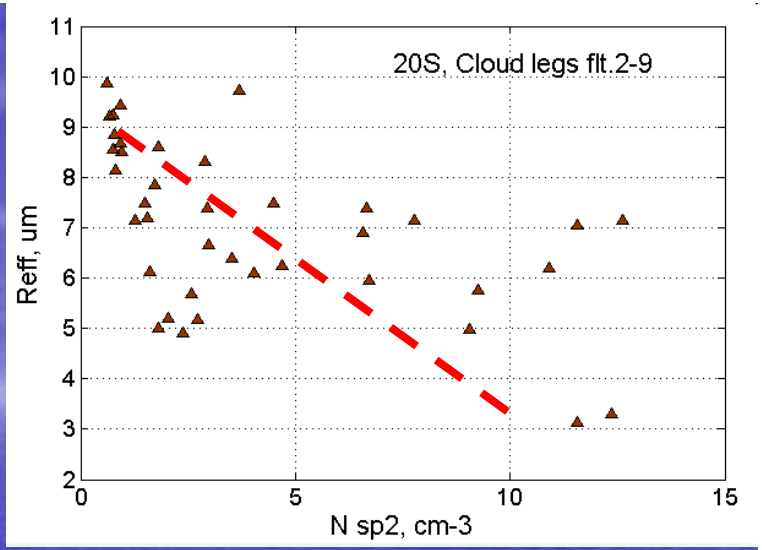


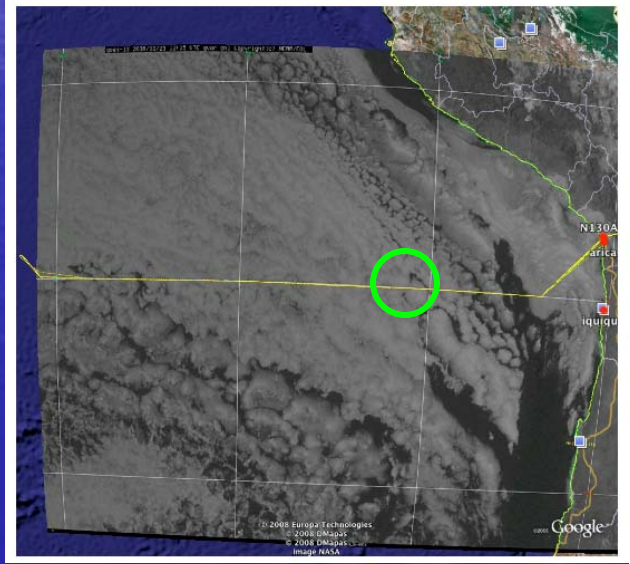
VOCALS RF10 11/6/2008
BC[ng/m3], CO [ppbv], RH%
Pollution at 85W is just above clouds but not yet at cloud top at 80W

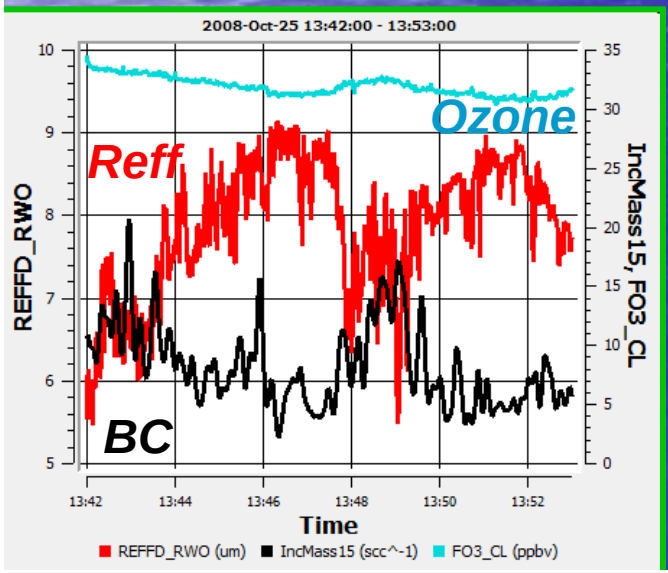


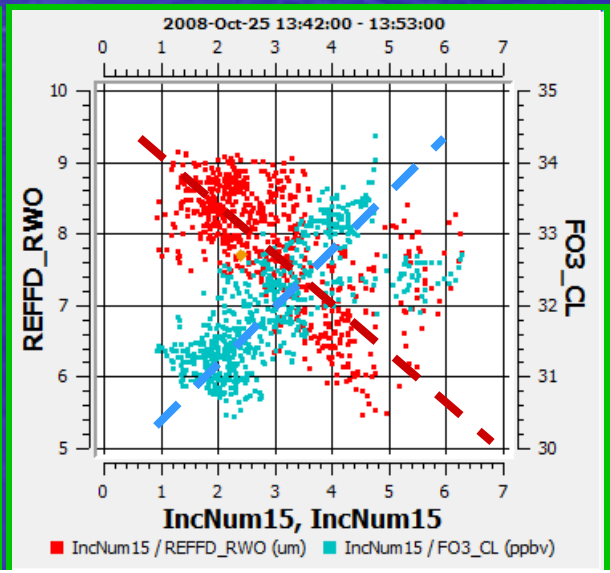
EFFECTIVE RADIUS and BC, OZONE







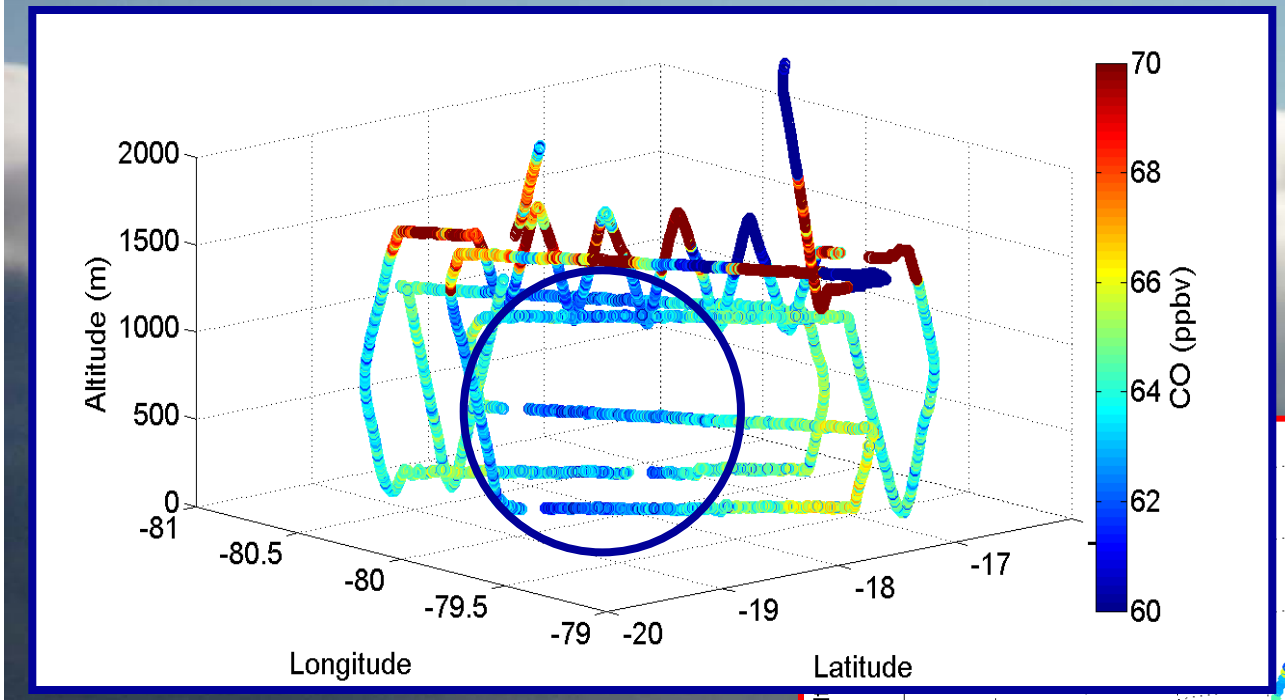


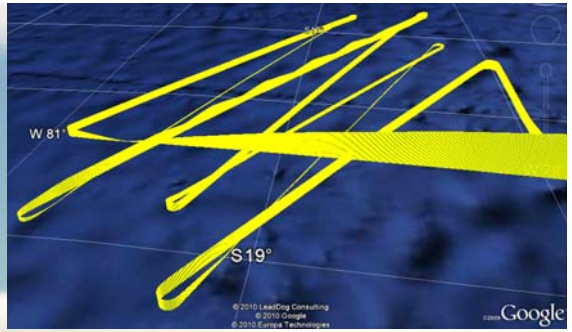


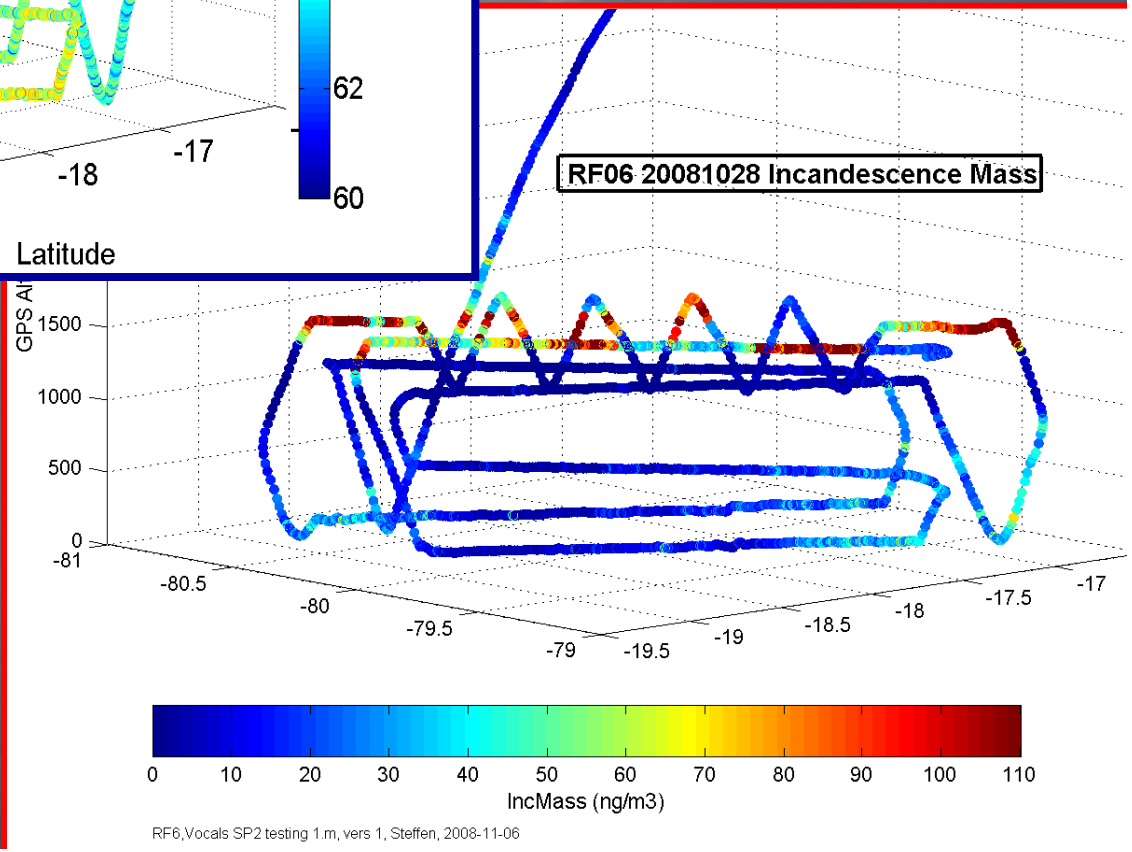
Ozone and BC trend as pollution indicators

Reff decreases with increased pollution aerosol

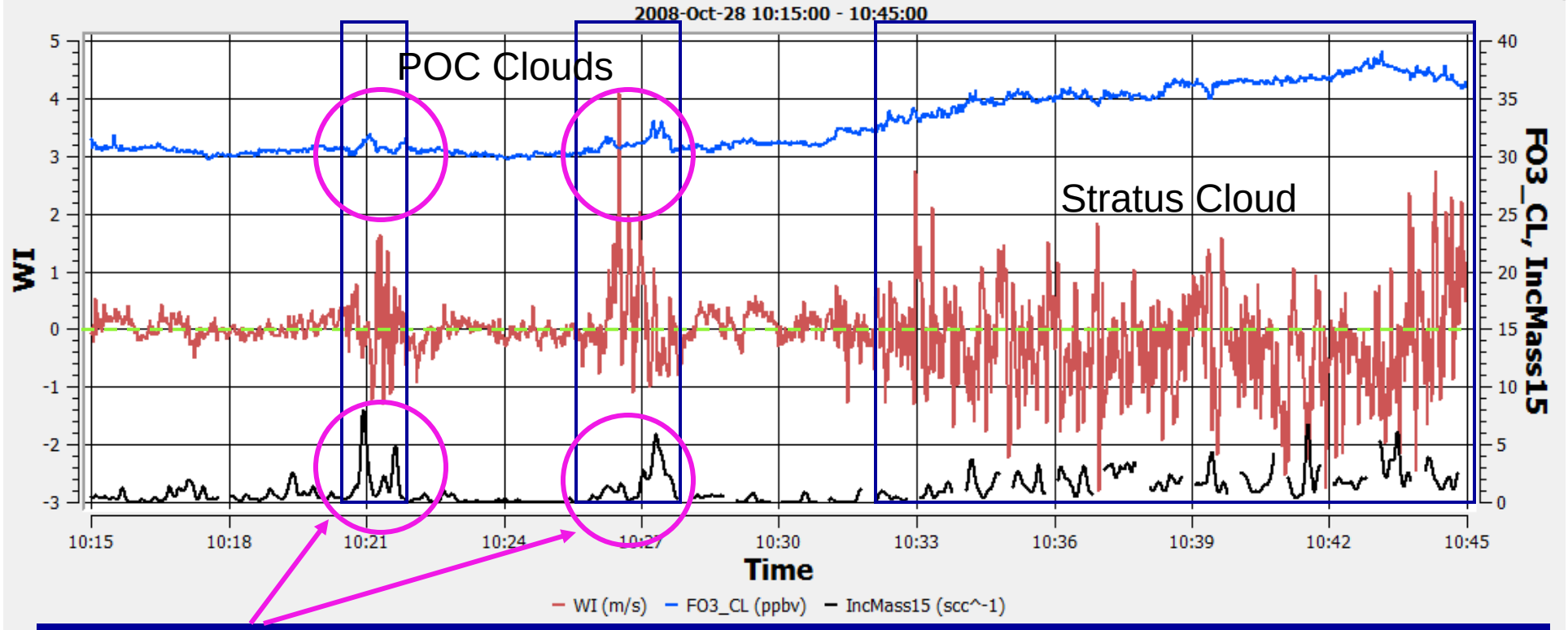
POC survey - VOCALS RF06 - 10/28/2008
Black Carbon (Incand. Mass) and CO above clean POC



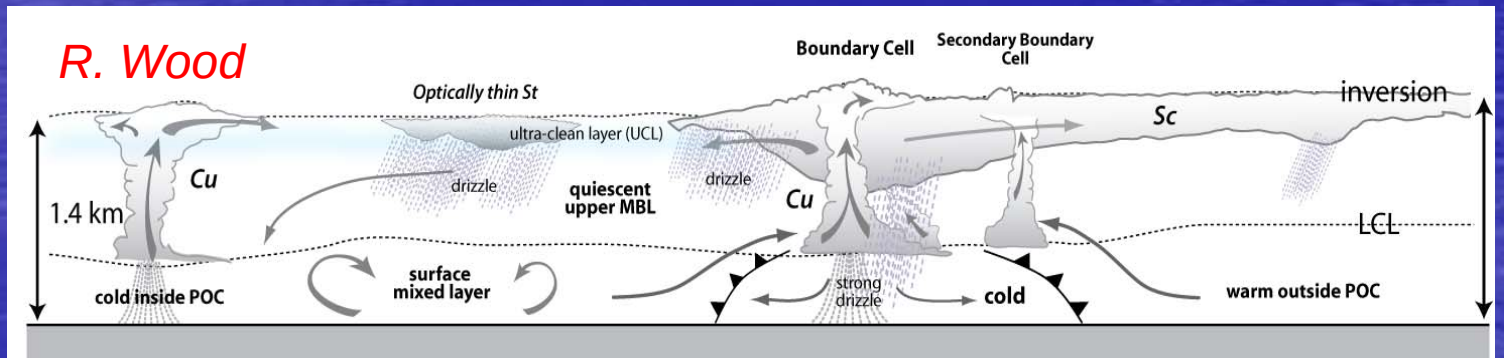




30 min cloud run across POC-cloud boundary on RF06 shows O3 and BC mixing into POC from FT at cloud regions with higher negative vertical gusts



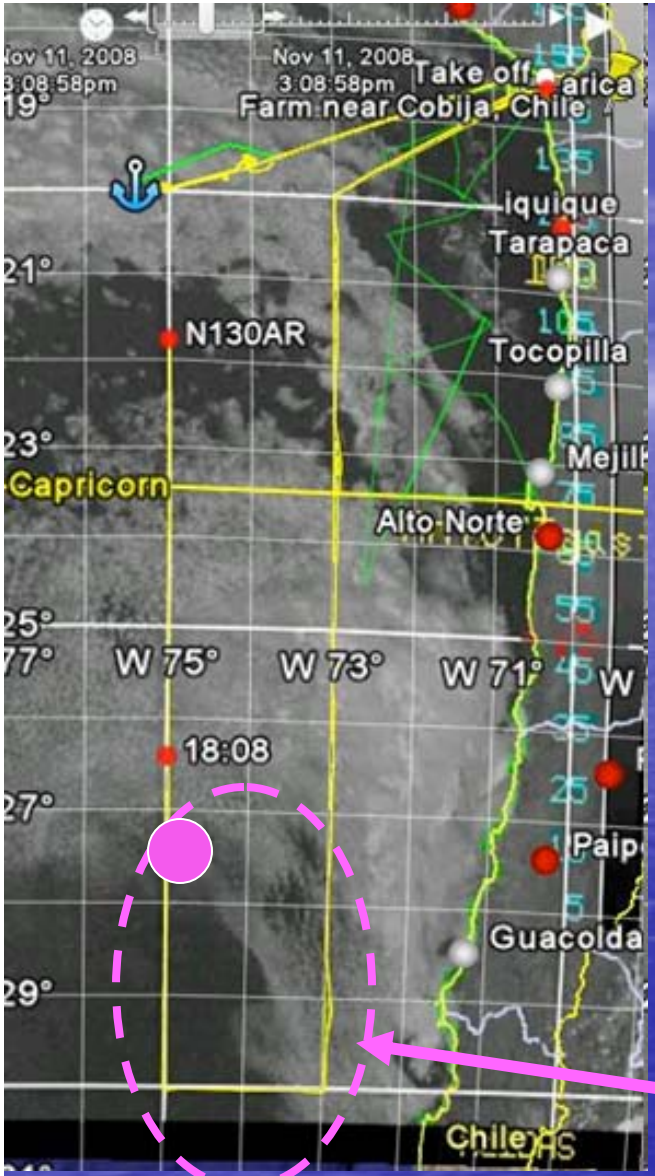
BC & O3 entrained from polluted FT into clean POC near isolated clouds with high vertical velocity (WI)

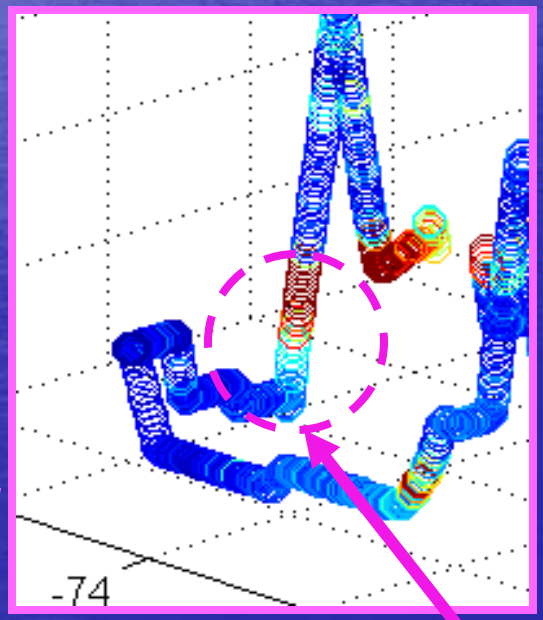


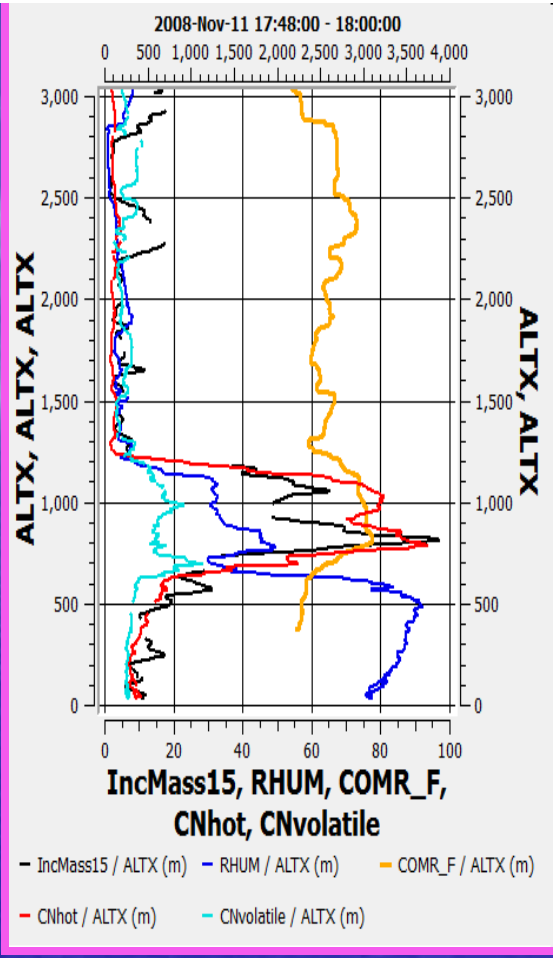
VOCALS RF12 11/11/2008

Nearshore Entrainment Example

Here again pollution eit BC(Black line) present above cloud in low RH continental air is entraining into MBL from above cloud level.





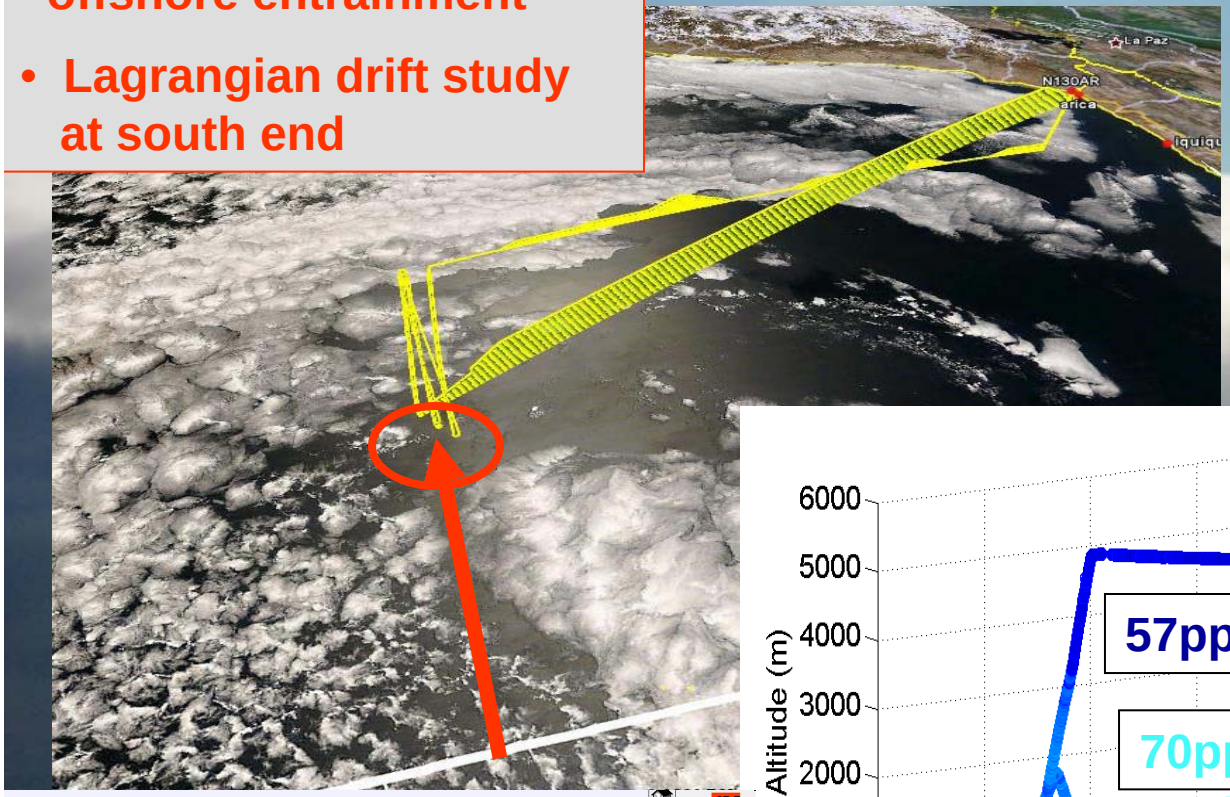


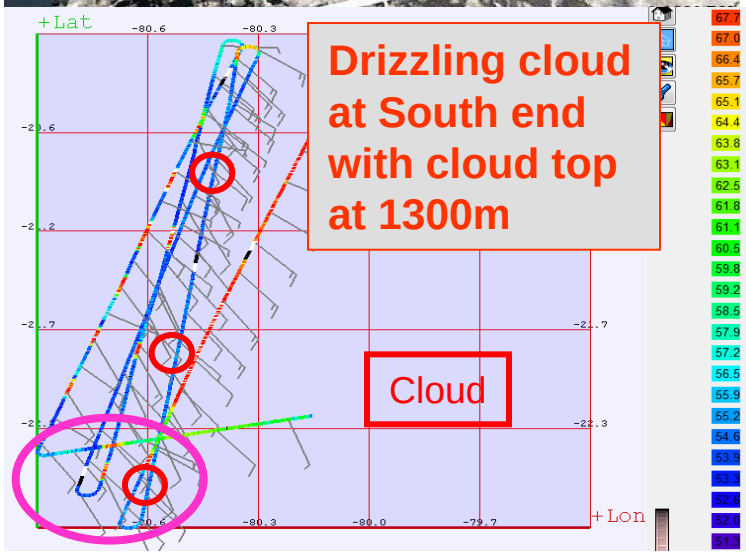
Profile shows dry FT air above 1700m Polluted low RH continental air above cloud level (500m) with high BC (IncMass) volatile CN and CO
Gradient in BC from above cloud level toward surface.

Clean (low CO) MBL flow from South with polluted (high CO) flow in FT from SE. Entrainment revealed in offshore CO gradient toward surface.

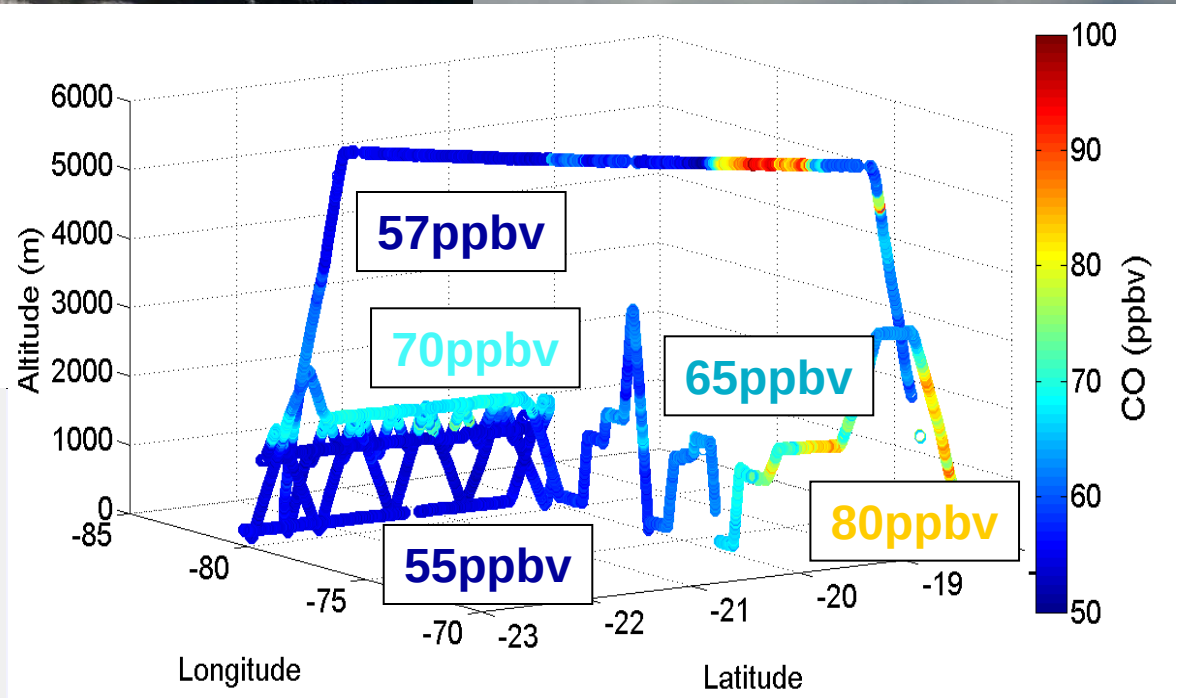
POC survey - VOCALS RF14 - 11/15/2008

- **Broken closed cells with offshore entrainment**
- **Lagrangian drift study at south end**



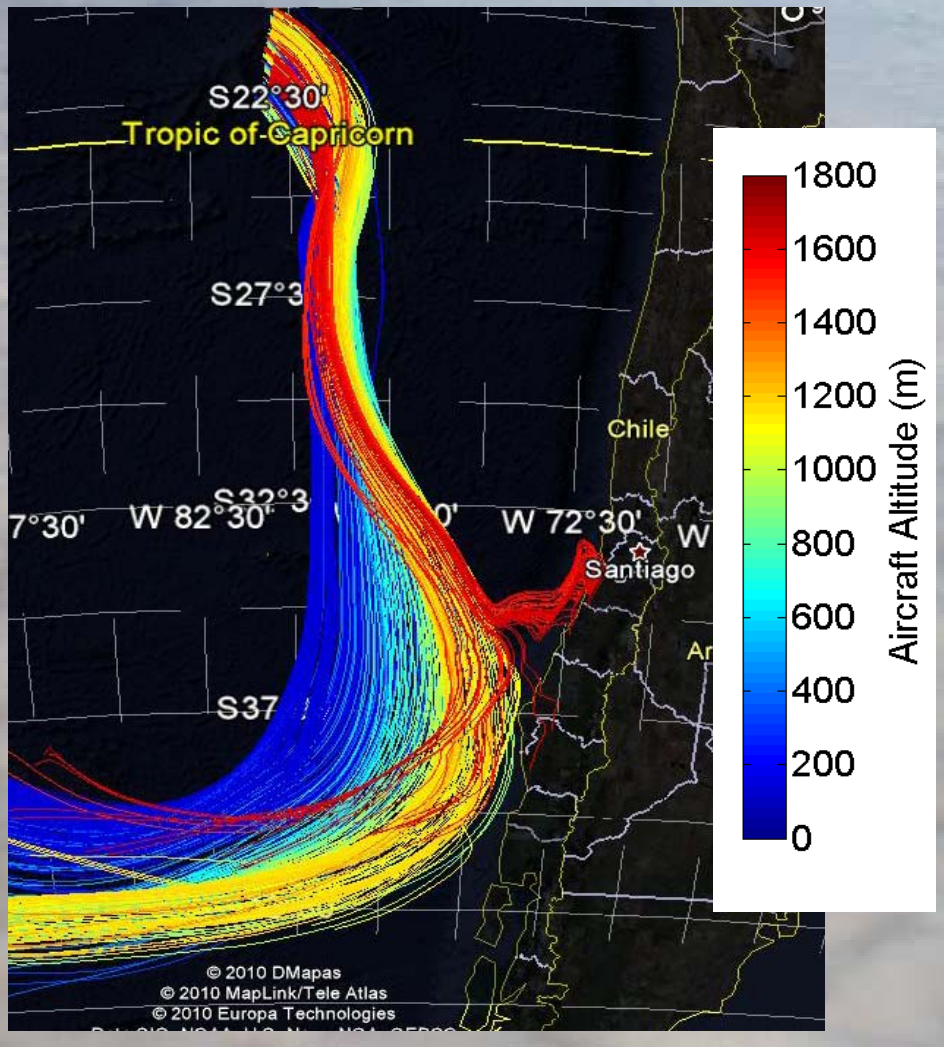


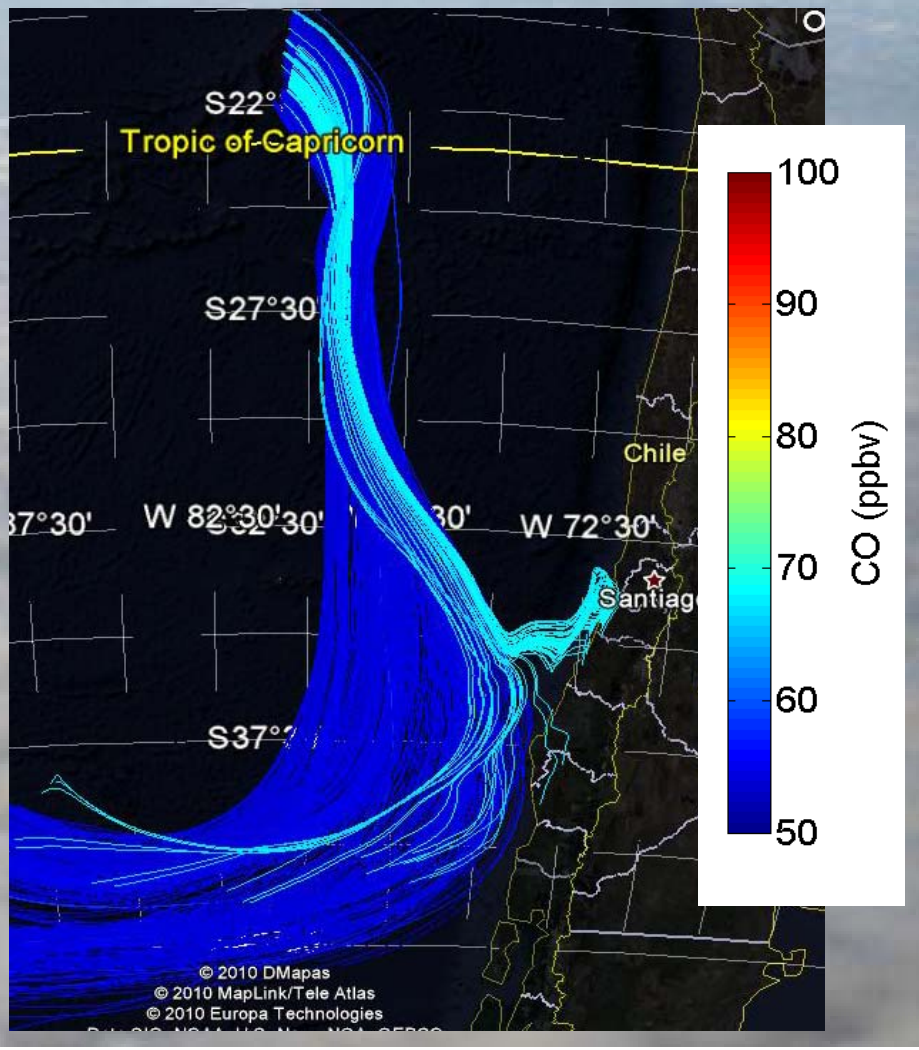
Drizzling cloud at South end with cloud top at 1300m



Entrainment Pseudo POC - VOCALS RF14 - 11/15/2008

- **96h HYSPLIT back trajectory analysis**
- **Trajectories above cloud at 1500m (left) have the high CO (right) originating from Santiago region overly low CO in MBL air coming from South.**



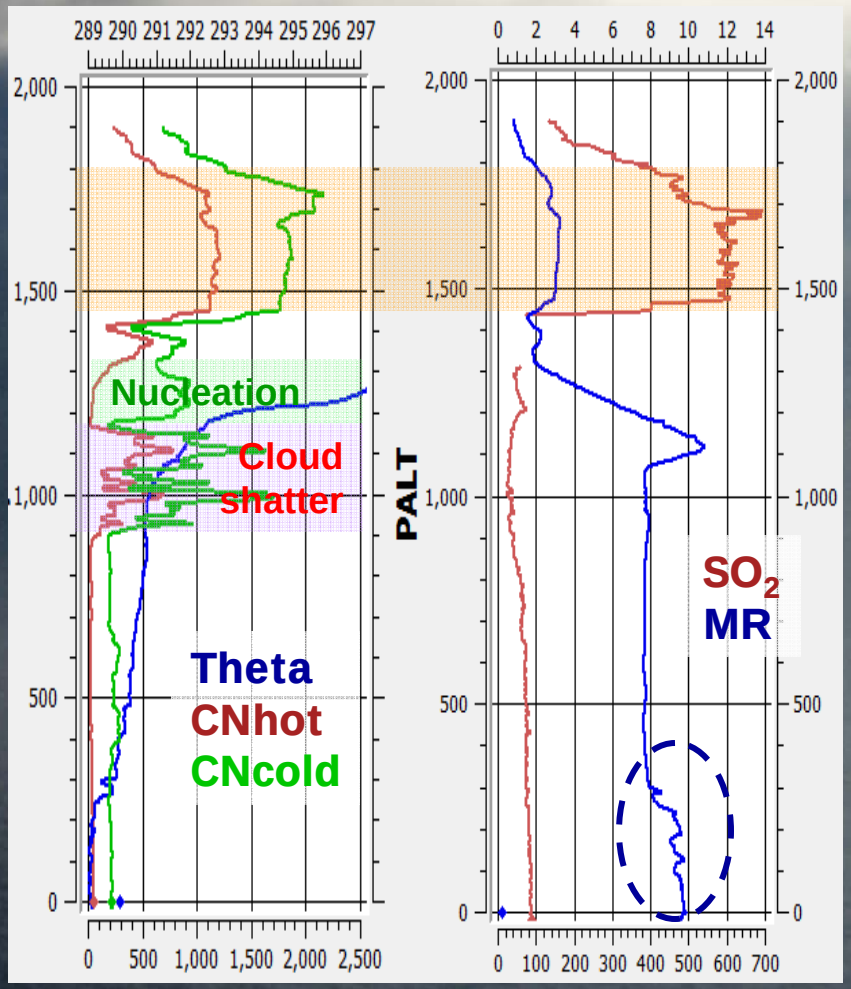


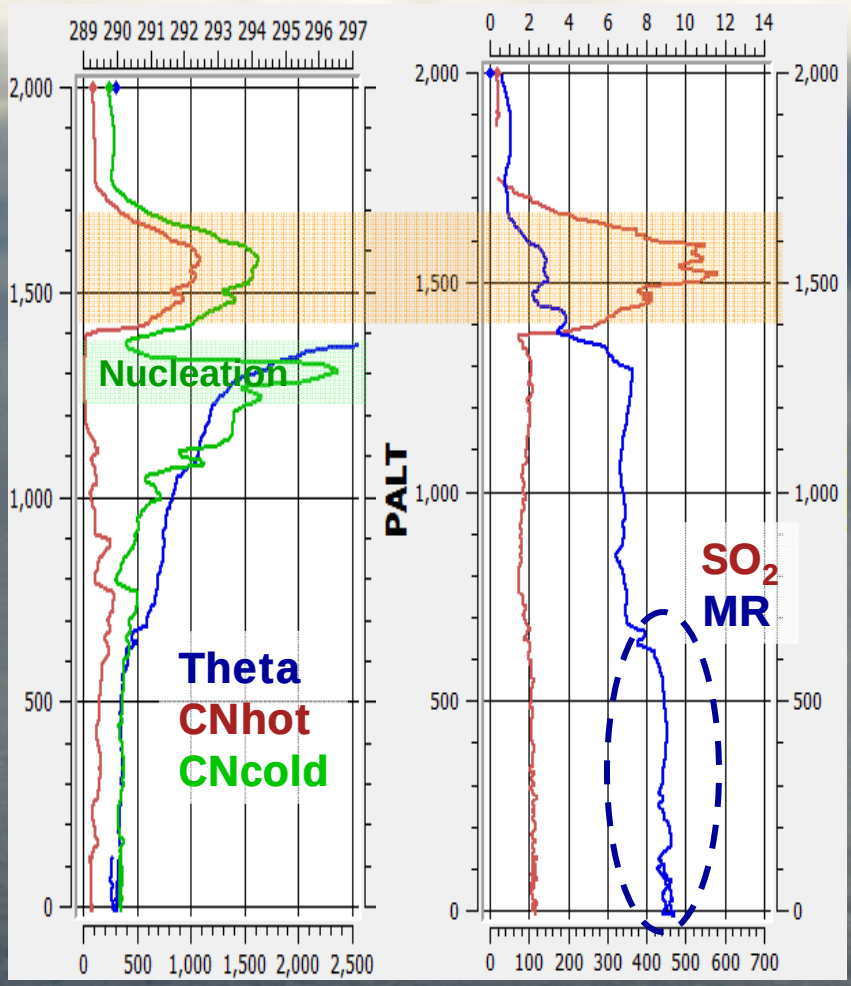
3 hr Pseudo-Lagrangian evolution at south end of RF14 legs advected with wind
FT Pollution (CNhot, SO2 etc.) entrained into MBL during 3hr between profiles

INITIAL DESCENT 16:23

FINAL ASCENT 19:41

~120m in 3hr =
We ~ 1.2 cm/s local

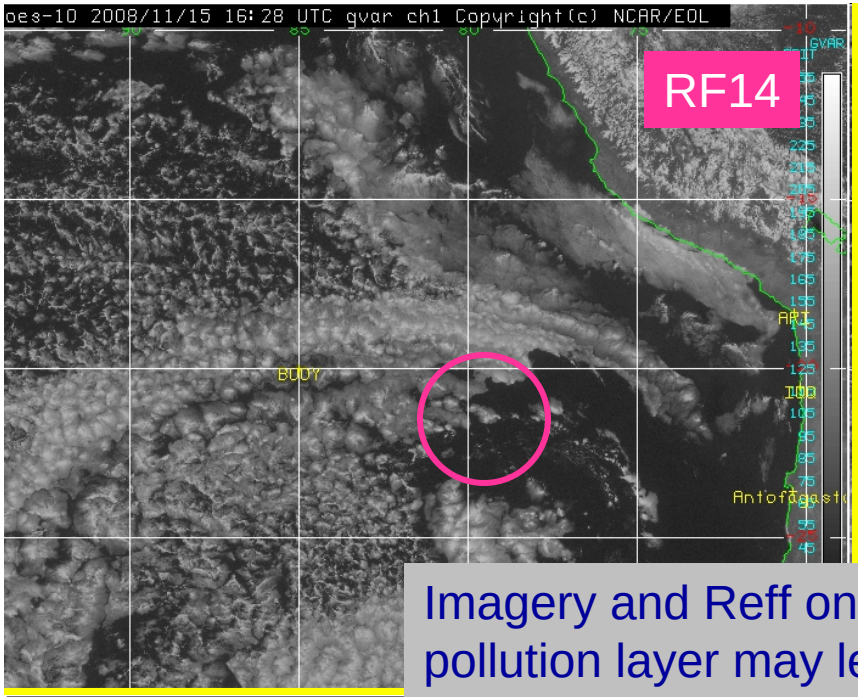


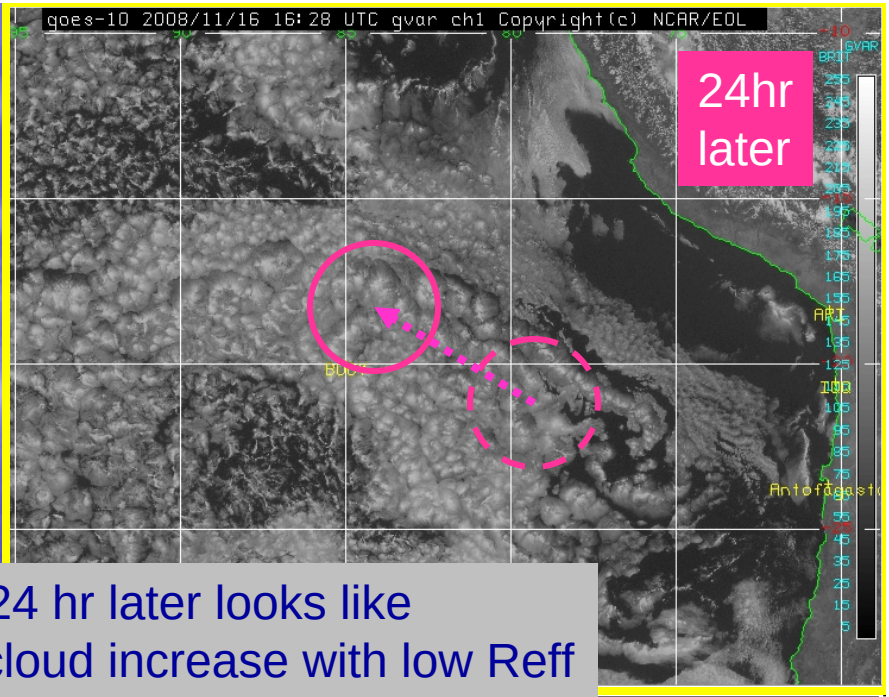


South end - 3 hr Lagrangian evolution: FT Pollution entrained into MBL near Cloud

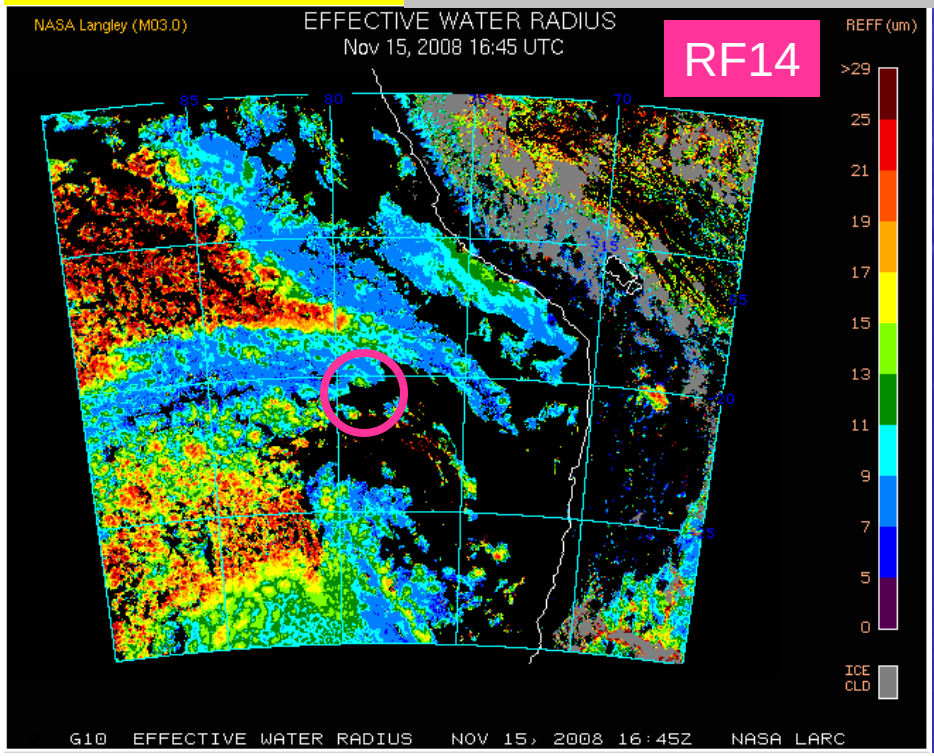
% Change in Aerosol above and Below Inversion Before and After Entrainment

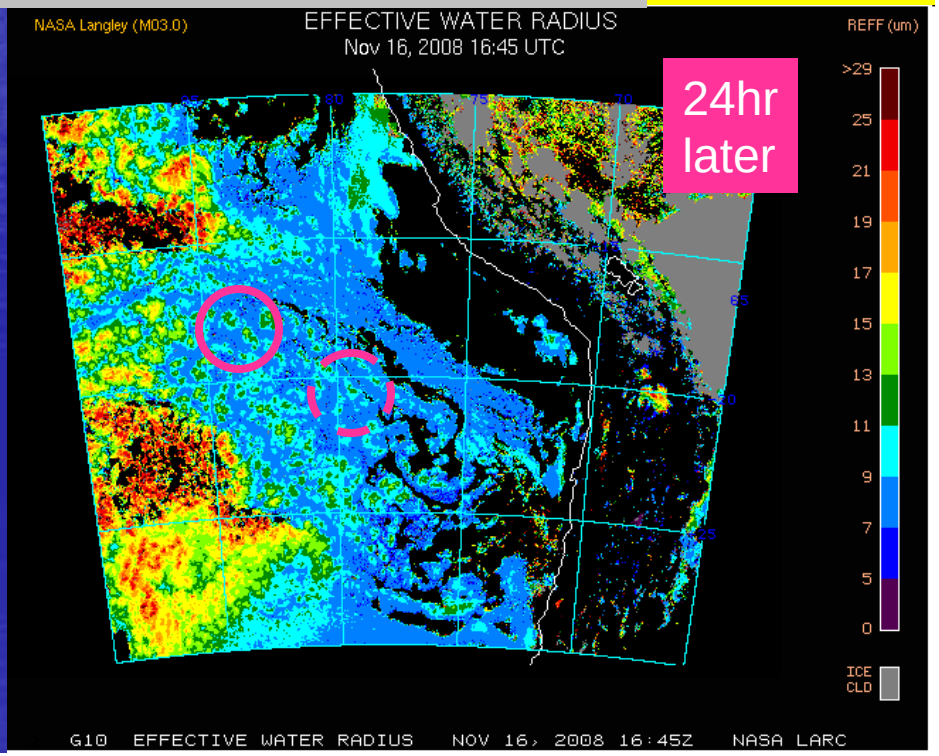
% of Column:	Initial Profile		Final Profile		%Col Entrained
Component	Below Inv.	Above Inv.	Below Inv.	Above Inv.	
SO_2	25%	75%	49%	49%	25%
CO - 54ppb	5%	95%	28%	72%	23%
Heated CN	5%	95%	34%	66%	29%
SP2	6%	94%	48%	52%	42%



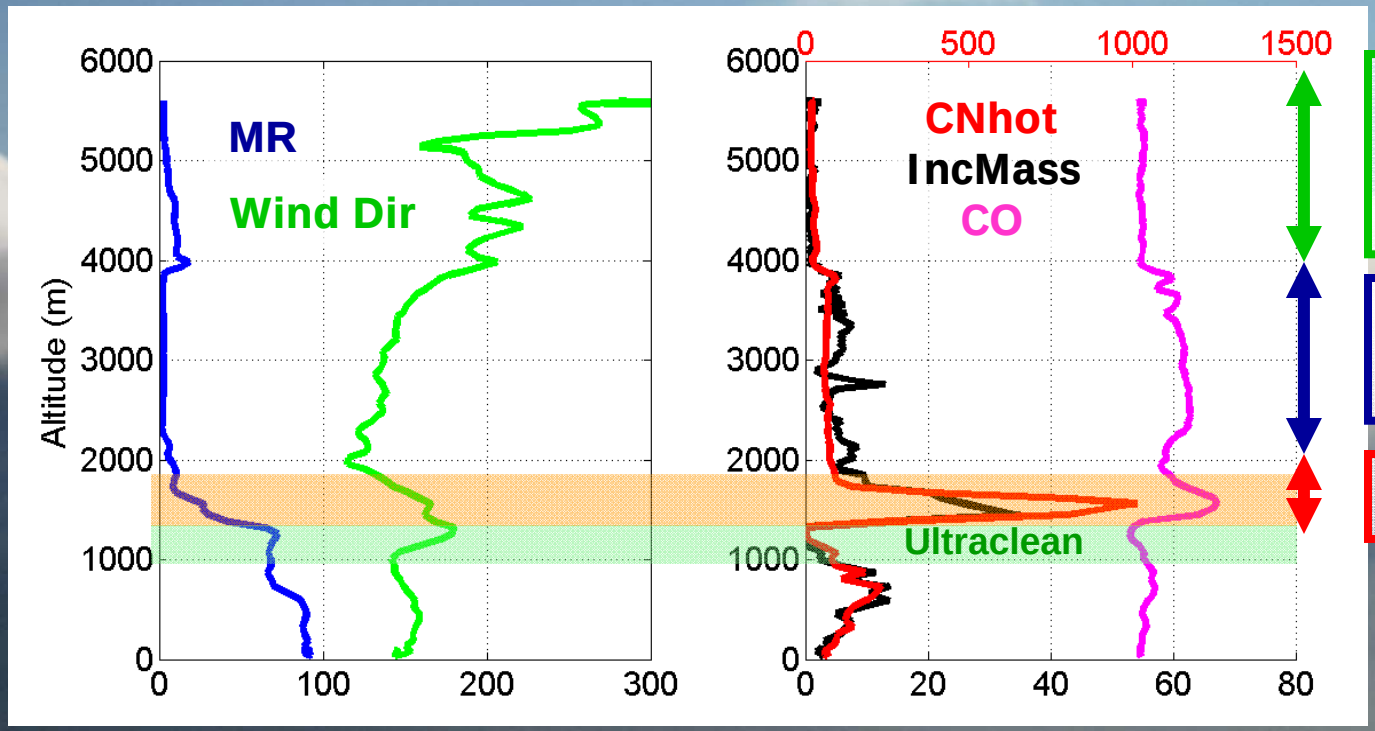


Imagery and Reff on clouds 24 hr later looks like pollution layer may leads to cloud increase with low Reff





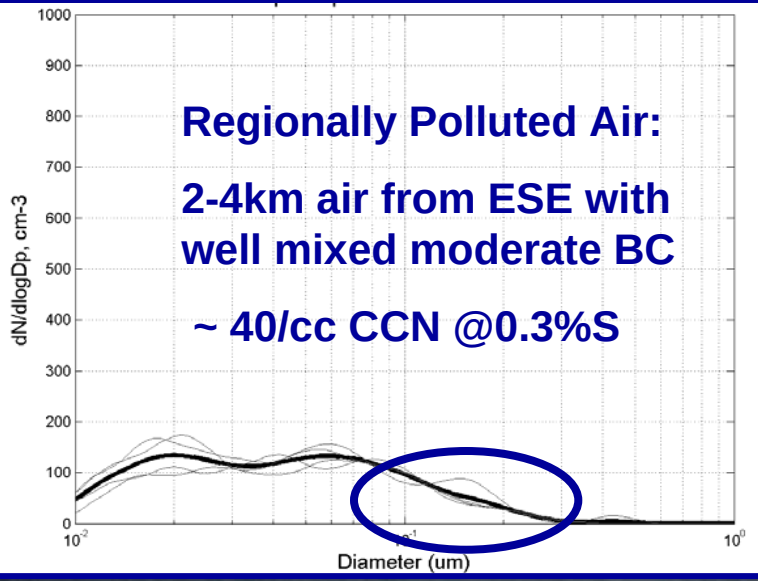
At higher altitudes above RF14 pollution we see Regional Pollution and Clean Air

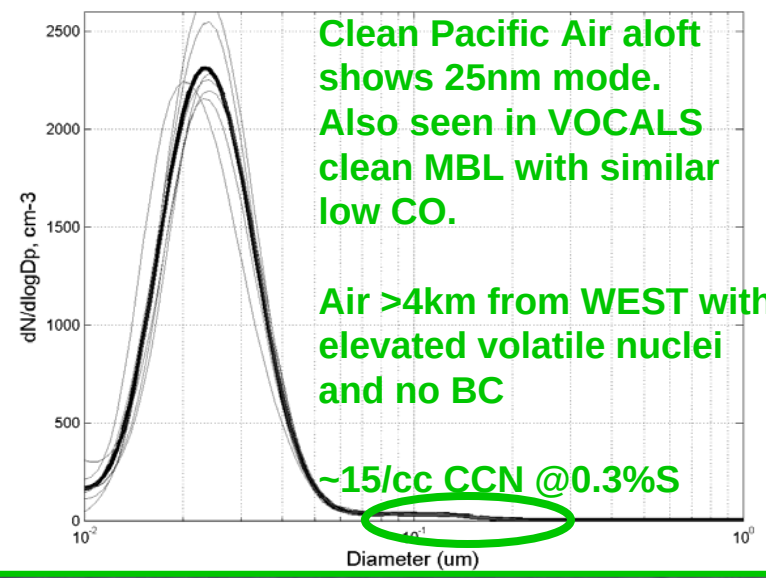


Clean nucleated aerosol above 4km from ITCZ

Regional pollution from SE above 2km

Santiago Pollution





OBSERVATIONS

- "Clean" MBL w/ low CO indicate aerosol sources influenced by subsidence around SP high – low values characteristic of POC's indicate little or no pollution aerosol entrained into POC's.
- Concentrations at CCN sizes (%S<0.3) in FT are significant fraction of MBL CCN and smaller "natural" sizes <30nm in MBL are not activated at these %S.
- MBL CCN sizes >50nm are activated and can be depleted by drizzle, precip leading to low CCN and weaker cloud formation (eg. POC's).
- Lofting and long range transport of continental combustion aerosol (biomass and pollution) in the free troposphere is a common but patchy feature above cloud.
- Entrainment into cloud top observed for clouds with clean MBL below them.
- Higher CO (and CCN) in cloudy regions offshore appears related to entrainment from above both from S. A. and long range transport across S. Pacific south of 35S.
- Nucleation generally not effective source of new CCN>50nm. Sea-salt weak source and often decoupled

Under Investigation

- Aerosol and CCN depleted through drizzle may be replenished by entrainment of aerosol/CCN from layers aloft (if present), leading to St stabilization.
- Enhanced cloud fraction, lifetime and albedo coupled to stabilizing effect of entrained pollution aerosol

** LEADS TO FOLLOWING HYPOTHESES **

"POC's are the Natural State" Hypothesis - Flow Chart for SEP

Clean marine aerosol advected into south of SEP is in quasi equilibrium with entrained FT air (low CO and small 30 nm mode) where some activated in MBL grow larger via DMS in non-precip cloud cycles

Warmer surface waters heat and raise MR as air advects North under stronger subsidence inversion leads to clean turbulent St deck and increased entrainment

"Clean layer" develops under stronger inversion near cloud top via sedimentation of larger droplets, and latent heat release leading to stabilization. Clean layer suppresses entrainment but may be eroded by more active night-time convection. Meanwhile drizzle gradually reduces CCN throughout MBL.

If Clean FT aerosol is above cloud CCN<15/cc @ %S-0.3

Entrained CCN insufficient to compensate for drizzle, drizzle is enhanced by lower CCN, Reff larger and transition to POC occurs. Clean layer no longer eroded by clouds and entrainment suppressed except near active clouds.

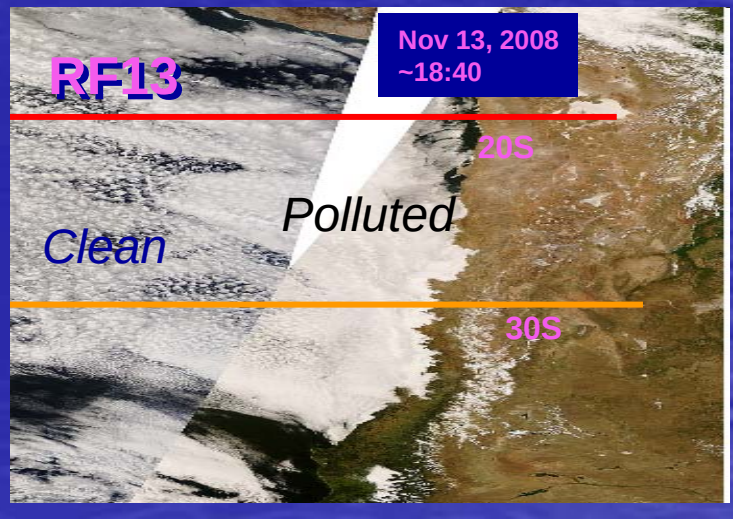
If Polluted aerosol is above cloud CCN>40/cc @ %s=0.3

Entrained CCN sufficient to partially or fully compensate for drizzle loss and transition to POC is delayed or suppressed, St clouds persist, Reff smaller - depending on pollution concentration aloft when St clouds entraining.

Persistent above cloud aerosol flow probably coupled to upslope-downslope flow from SA. Aerosol will spread out with easterly flow (200-500km/day?) above clouds embedded in a southerly boundary layer flow. Clouds responding to entrainment from this upper aerosol layer (more easterly component above cloud) can take on archlike shape anchored to the land sources. Long range FT transport can also add aerosol to the clouds elsewhere.

>> WITHOUT COMBUSTION SOURCE OF CCN FROM FT– ARE POCS THE NORMAL DEMISE OF THE SEP St CLOUDS?

>> IF SO, HOW LONG HAS IT BEEN GOING ON – CLIMATE?



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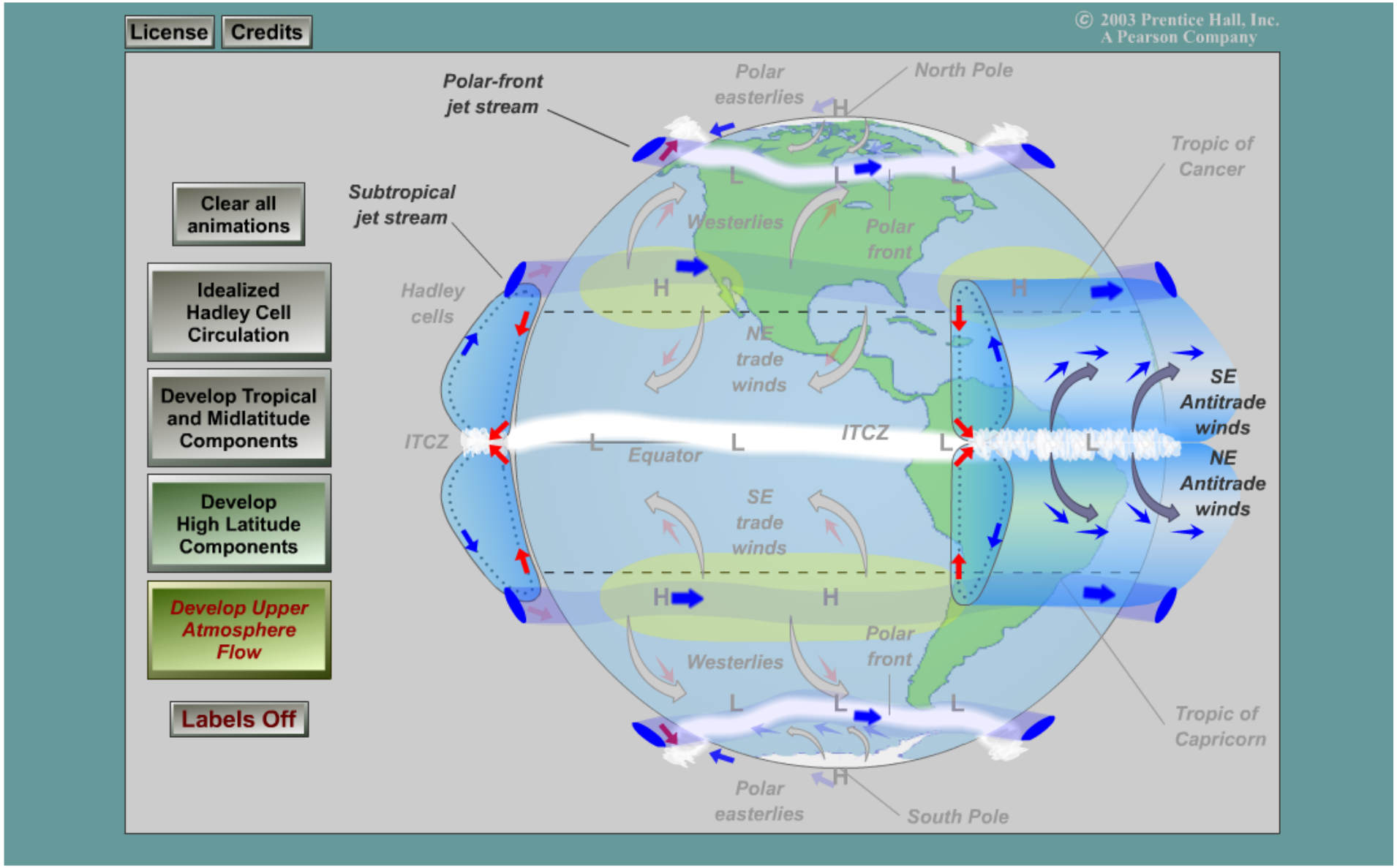

Title: Global Atmospheric Circulation Model