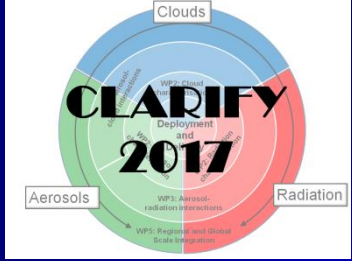


MANCHESTER 1824
The University of Manchester

Cloud Microphysics and Cloud-Aerosol Interactions over the South-East Atlantic Ocean

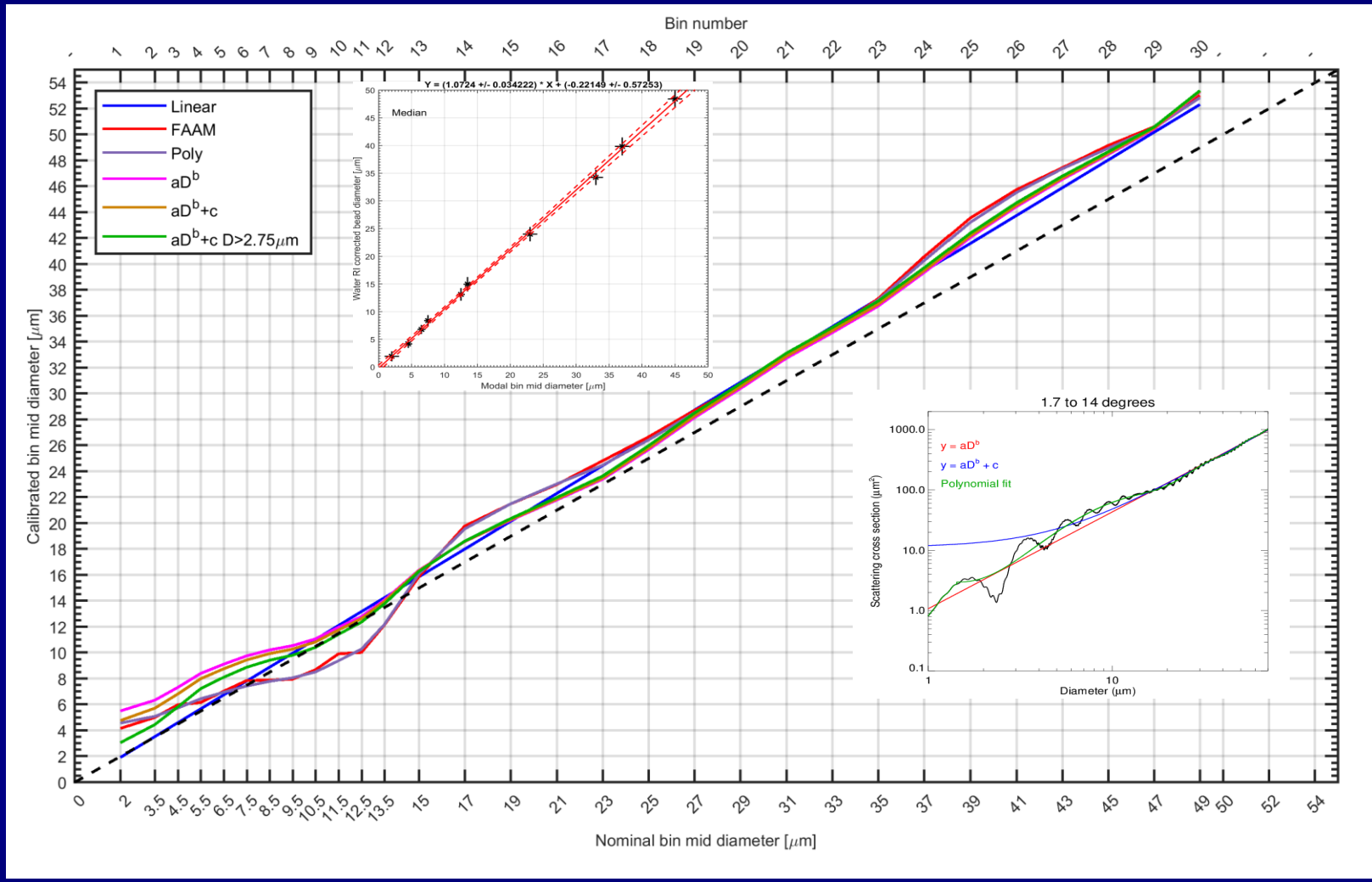
… during CLARIFY 2017 (or in full, during the ….)

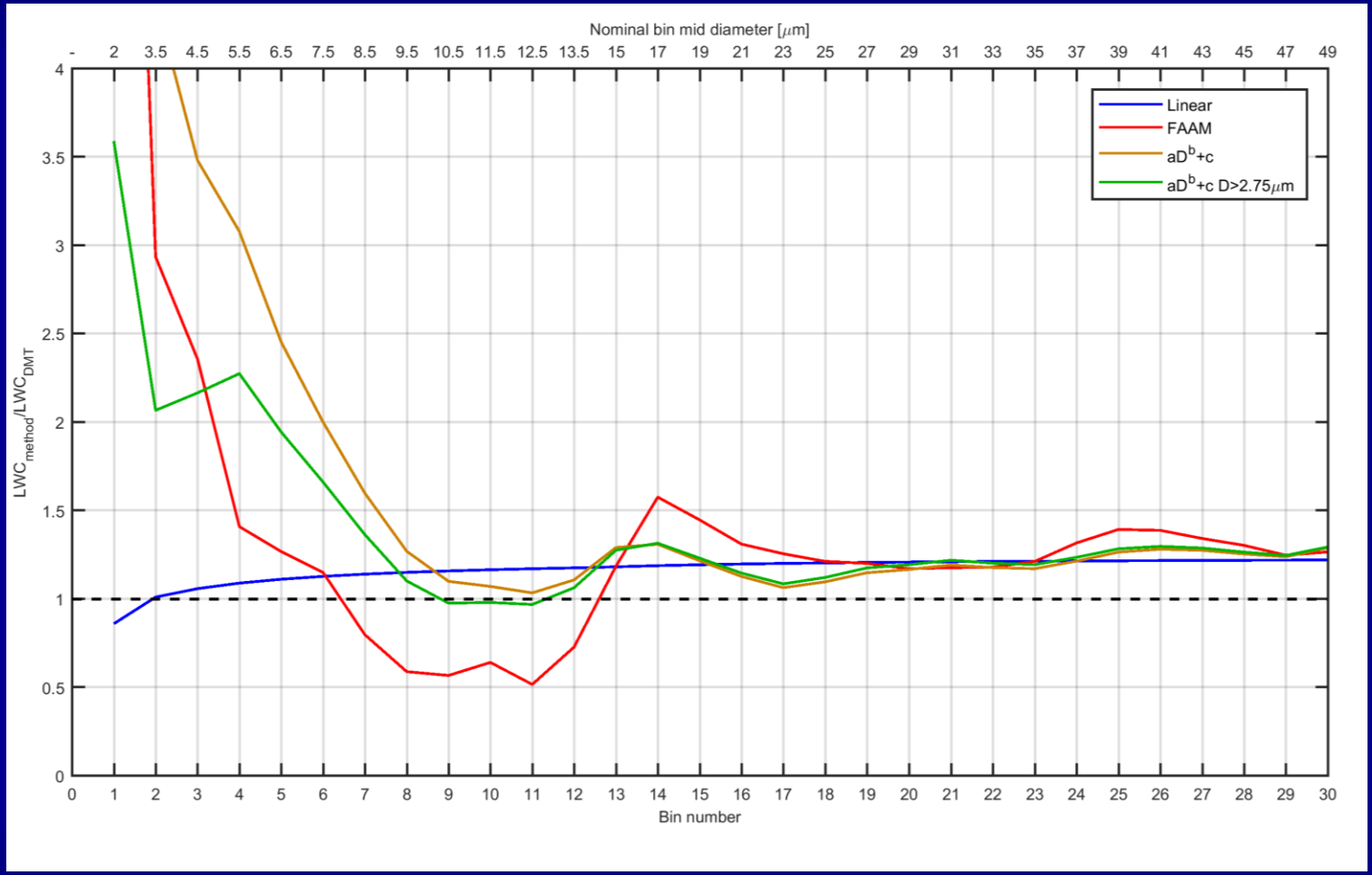
CLoud-Aerosol-Radiation Interactions and Forcing: Year 2017 Experiment

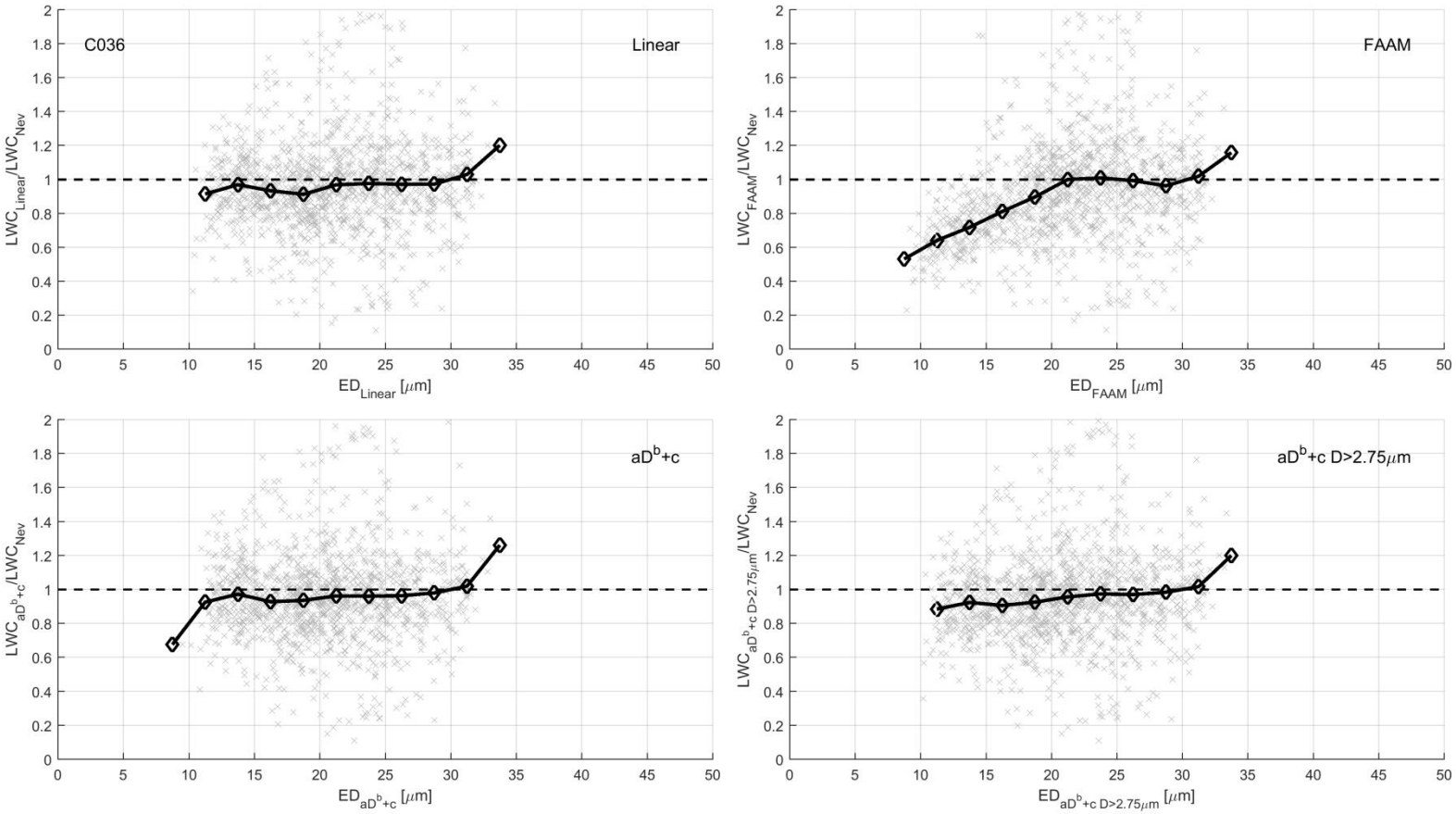
Ian Crawford[1], Keith N. Bower[1], *et al.,* . … and the CLARIFY team (Universities: Manchester, Exeter, Leeds, Oxford, Reading & Met Office),

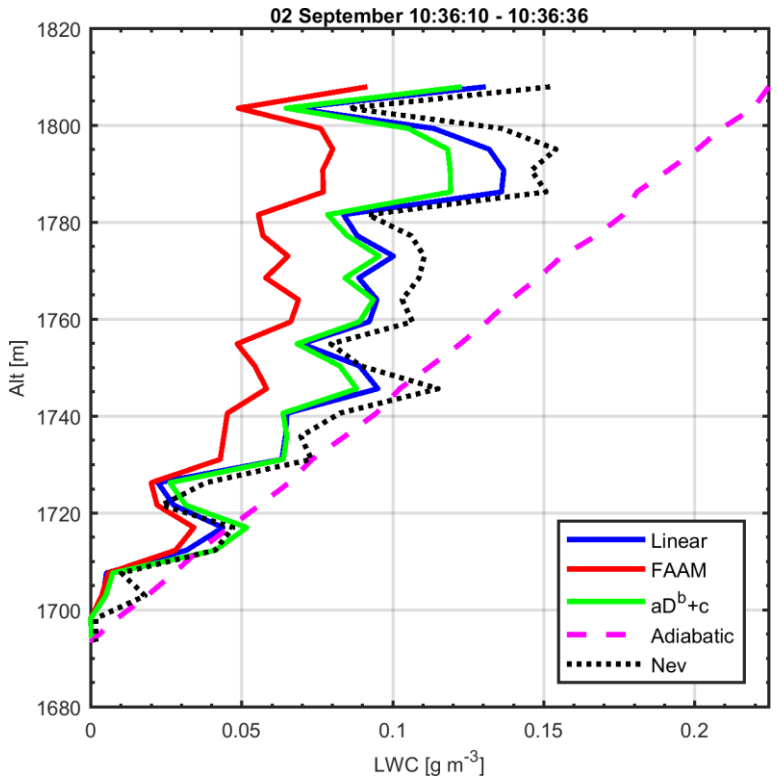
1. CDP calibration … and derived cloud droplet size distribution, liquid water content, effective diameter etc.

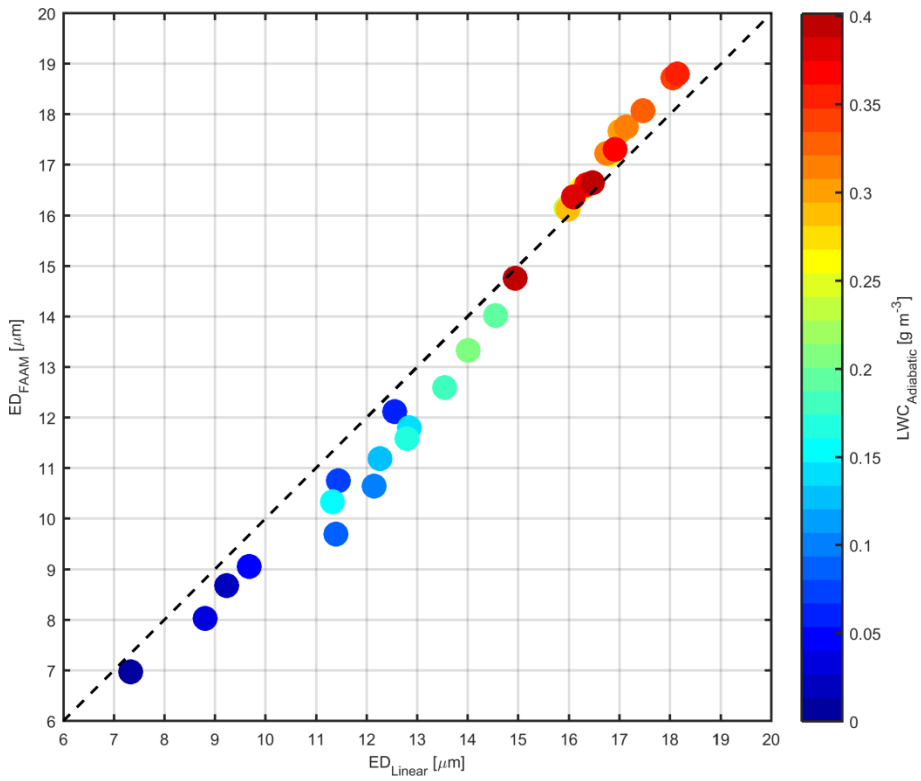
… see recently circulated report from Ian Crawford for the details of this (if you are interested) – just basic issues summarised here


Bin number
Linear
FAAM
Poly
aD^b
aD^b+c
aD^b+c D>2.75μm
Y = (1.0724 +/- 0.034222) * X + (-0.22149 +/- 0.57253)
Median
Water RI corrected bead diameter [μm]
Modal bin mid diameter [μm]
1.7 to 14 degrees
y = aD^b
y = aD^b + c
Polynomial fit
Scattering cross section (μm²)
Diameter (μm)
Calibrated bin mid diameter [μm]
Nominal bin mid diameter [μm]

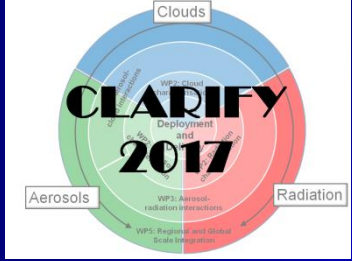

Nominal bin mid diameter [μm]
- 2 3.5 4.5 5.5 6.5 7.5 8.5 9.5 10.5 11.5 12.5 13.5 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49
Linear
FAAM
aD^b+c
aD^b+c D>2.75μm
LWC_method/LWC_DMT
0 0.5 1 1.5 2 2.5 3 3.5 4
Bin number
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30


C036
Linear
FAAM
aD^b+c
aD^b+c D>2.75μm
LWC_Linear/LWC_Nev
LWC_FAAM/LWC_Nev
LWC_aD^b+c/LWC_Nev
LWC_aD^b+c D>2.75μm/LWC_Nev
ED_Linear [μm]
ED_FAAM [μm]
ED_aD^b+c [μm]
ED_aD^b+c D>2.75μm [μm]


02 September 10:36:10 - 10:36:36
Alt [m]
LWC [g m-3]
Linear
FAAM
aDb+c
Adiabatic
Nev


EDFAAM [μm]
EDLinear [μm]
LWCAdiabatic [g m-3]

2. Cloud Microphysics and Cloud-Aerosol Interactions over the South-East Atlantic Ocean during CLARIFY…



Observations of Cloud-Aerosol Interactions over the South-East Atlantic Ocean

… during CLARIFY 2017 (or in full, during the ….)

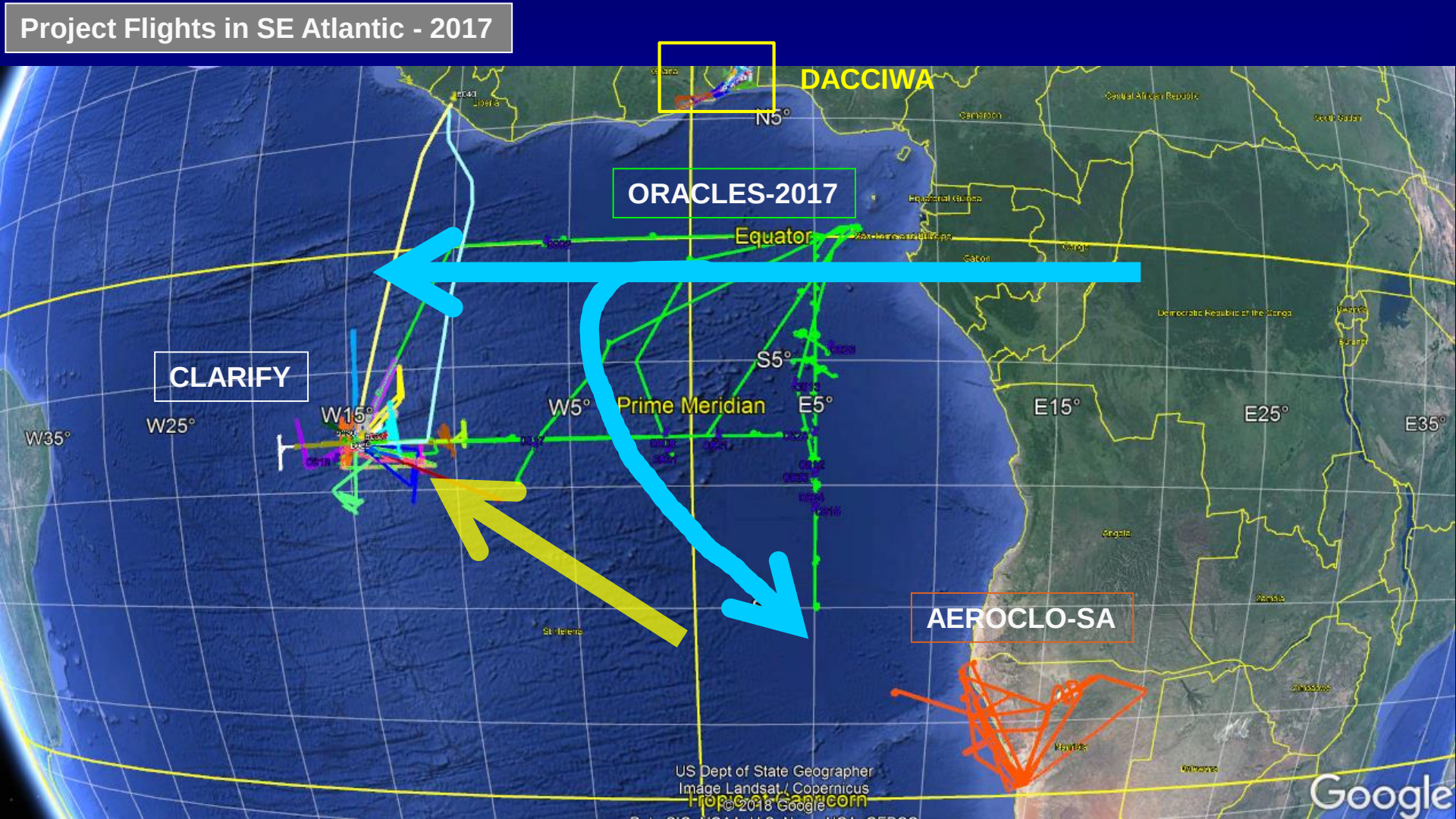
CLoud-Aerosol-Radiation Interactions and Forcing: Year 2017 Experiment

Ian Crawford[1], Keith N. Bower[1], H. Coe[1], J. Taylor[1], T. W. Choularton[1], J. R. Dorsey[1], M. J. Flynn[1], P. I. Williams[1], J. Crosier[1], P. J. Connolly[1], S. Abel[2], P. Barrett[2]
… and the CLARIFY team (Universities: Exeter, Leeds, Oxford, Reading & Met Office),

[1] University of Manchester, Manchester, United Kingdom; [2] Met Office, Exeter UK

Summary of observations:

- days when MBL clear of effects of BB smoke (low CO, no BC (SP2) aerosols) – low N_{PCASP} N_{CDP} .....
- Back Trajectories* generally show air not from BB area of Africa – more from southern Africa/ SE over sea
- MBL generally decoupled to varying degrees (various definitions of this this week (e.g. In Barratt et al.) and drizzle probably enhances this.
- Influence of BBA above in FT v limited on timescales of observations of cloud flights, but ...
- Regime with BB smoke in MBL: see much higher N_{CDP}, N_{PCASP} & BC aerosol, (elevated CO) (but mixing of BB air into MBL probably occurs upwind of ASI & advected to ASI in SE tradewinds c.f. mixing from above)
- significant effect on Ndrop etc. (polluted MBL should inhibit drizzle - but still present (Q. Deeper clouds?))
- evolution of polluted to less polluted MBL (by washout out of aerosols? – effect on transition closed to open cellular cloud structure? - potentially to formation of pockets of open cells (Abel et al. poster) (but no BC aerosols, low CO here too)


Project Flights in SE Atlantic - 2017
DACCIWA
N5°
ORACLES-2017
Equator
CLARIFY
S5°
W35°
W25°
W15°
W5°
Prime Meridian
E5°
E15°
E25°
E35°
AEROCLO-SA
US Dept of State Geographer
Image Landsat / Copernicus
© 2018 Google
Tropic of Capricorn
Google

CLARIFY Flight Summary:

Flying Period: 16th August to 9th September (18/25 flying days inc ferry flight to/from Monrovia)

Science Flights: 28 flights on 18 flying days (8x single &10x double (inc ferry) flight days)

Flight number	Flight Date	Take off time	Aeronet AOD	MBL:FT Aerosol(cm-3) Regime	BBA?	CDNC (cm-3)	Clouds?	Drizz drop /precip?	Location	Comments
C028	16-Aug	09:00	0.19	Pol MBL 800/cc : Clean aloft	yes	High 300-400	No	No	E, ASI	Installation flight East and around ASI
C029	17-Aug	09:00	0.18	Pol MBL 600/cc : Clean aloft	yes	High 250-300	yes	*drops/no P*	W	
C030	17-Aug	14:00	0.18	Pol MBL 700/cc : Clean aloft	yes	High 250-300	poss	No	E, SE, ASI	
C031	18-Aug	12:00	0.16	Pol MBL 400/cc : Clean aloft	yes	High 200-300	poss	No	E, SE, ASI	
C032	19-Aug	10:00	0.24	Pol MBL 600/cc : Clean aloft	yes	High 200-350	yes	**YES**	S	
C033	22-Aug	09:00	0.27	MBL Clean 50 : Pol aloft 200-600	NO	Low 30-50c	yes	YES	ESE, ASI	POC like. Low CO& no BBA. Inversion unusually weak. Aerosol unusually large ~ 1µm Little ORG in BL
C034	23-Aug	09:00	0.30	MBL Clean 50 : Pol aloft 800-1600	*Slight*	Low 30-50	No	**YES**	N	Little cloud work - CB near LCL? Aerosol unusually large ~ 1µm. Little ORG in BL
C035	23-Aug	14:00	0.30	MBL Clean 50 : Pol aloft 800-1600	*slight*	Low 50-70	No	No	NE	
C036	24-Aug	09:00	0.22	MBL Clean 75-100 : Pol aloft 600-900	*slight*	Low 50-100	Yes	*Tenuous*	ASI	
C037	24-Aug	13:45	0.22	MBL Clean 75 : Pol aloft 700-850	slight	Low 30-40	poss	*drops/no P*	W	
C038	25-Aug	09:00	0.19	Pol (messy) 300-400 : Pol aloft 1500	yes	Mod 150	yes	*drops/no P*	E	
C039	25-Aug	14:00	0.19	Clean 40 : Pol aloft 1100-800	slight	Low <20	yes	*Tenuous*	ASI	No sonde. POC like. Drops - very large (upper end of CDP range)
C040/41	26-Aug	transit	0.43				Yes		N	
C042	28-Aug	09:00	0.54	Pol MBL 600-700 : Pol aloft 1500	yes	High 350-400	Yes	No	near ESE	High ORG. Aerosol large (up to 1µm over all profiles - smaller on most P: 0.5-0.75µm) Drizzle evap in dry layer.
C043	28-Aug	13:45	0.54	Pol MBL 500-600 : Pol aloft 1250	yes	High 250	No	No	near ,E	Little cloud work. High ORG. Aerosol unusually large (up to 1µm overall profile)
C044	29-Aug	09:00	-	Pol MBL - 550-700 : Pol aloft 1250	yes	250-300 (150 in driz)	Yes	**YES**	ESE, ASI	
C045	29-Aug	14:00	-	Pol MBL 600-700 : Pol aloft 900	yes	Low/Mod 100-200	Yes	**YES**	ASI	
C046	30-Aug	08:45	0.32	Pol MBL 550 : Pol aloft 1000	yes	High 250-350	Yes	No	W	
C047	01-Sep	09:00	0.37	Mod pol MBL 320 : Pol Aloft 900	yes	High 200	Yes	No	NW	
C048	01-Sep	13:00	0.37	Mod pol MBL 260 : Pol aloft 680	**No**	Moderate 180	Yes	**YES**	E	
C049	02-Sep	09:00	0.32	Mod pol MBL 260-280 : Pol aloft 1500	**No**	Mod 150	Yes	*drops/no P*	NNE	
C050	04-Sep	14:00	0.58	Pol MBL 360 : Pol aloft 1500+	yes	Low 60	Yes	*drops/no P*	nearE, ASI	
C051	05-Sep	09:00	0.34	Pol MBL 420 : Pol aloft 1500	**No**	High 250	Yes	No	ASI	High ORG
C052	05-Sep	14:00	0.34	MBL clean in POC 50 : Pol layer aloft	**No**	Low <20	Yes	YES	far ESE	
C053	06-Sep	09:00	-	MBL clean 100/50 in POC : 2000 aloft	**No**	Low 20-60	Yes	YES	near W	
C054	06-Sep	14:30	-	MBL clean 100/50 in POC : 2000 aloft	**No**	20 in POC, 80 in SCu	YES		near W	
C055	07-Sep	13:45	0.20	MBL Clean 100 : Pol aloft 1000			few			

Polluted MBL/Clean aloft

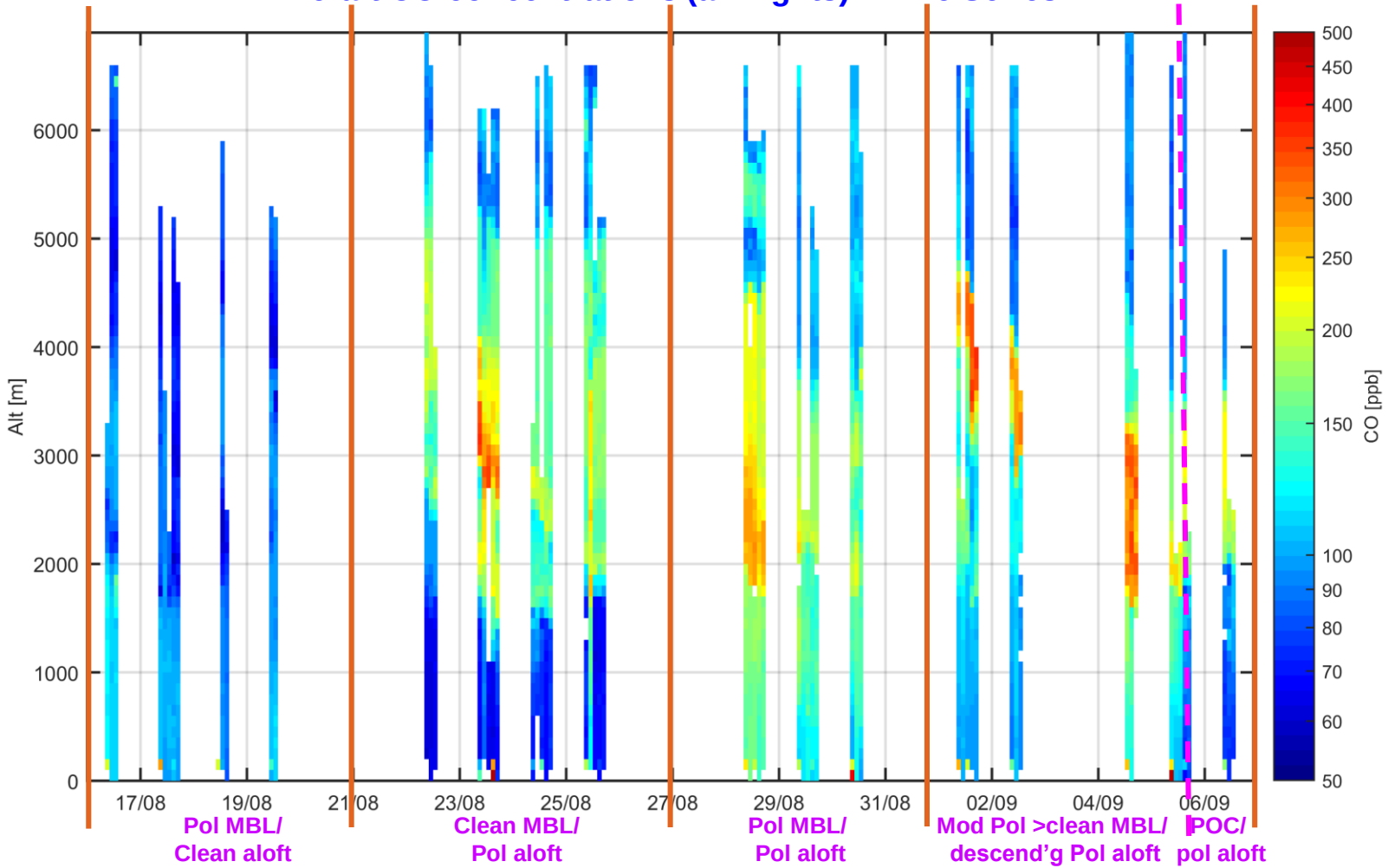
Clean MBL/ Polluted aloft

Polluted MBL/Polluted aloft

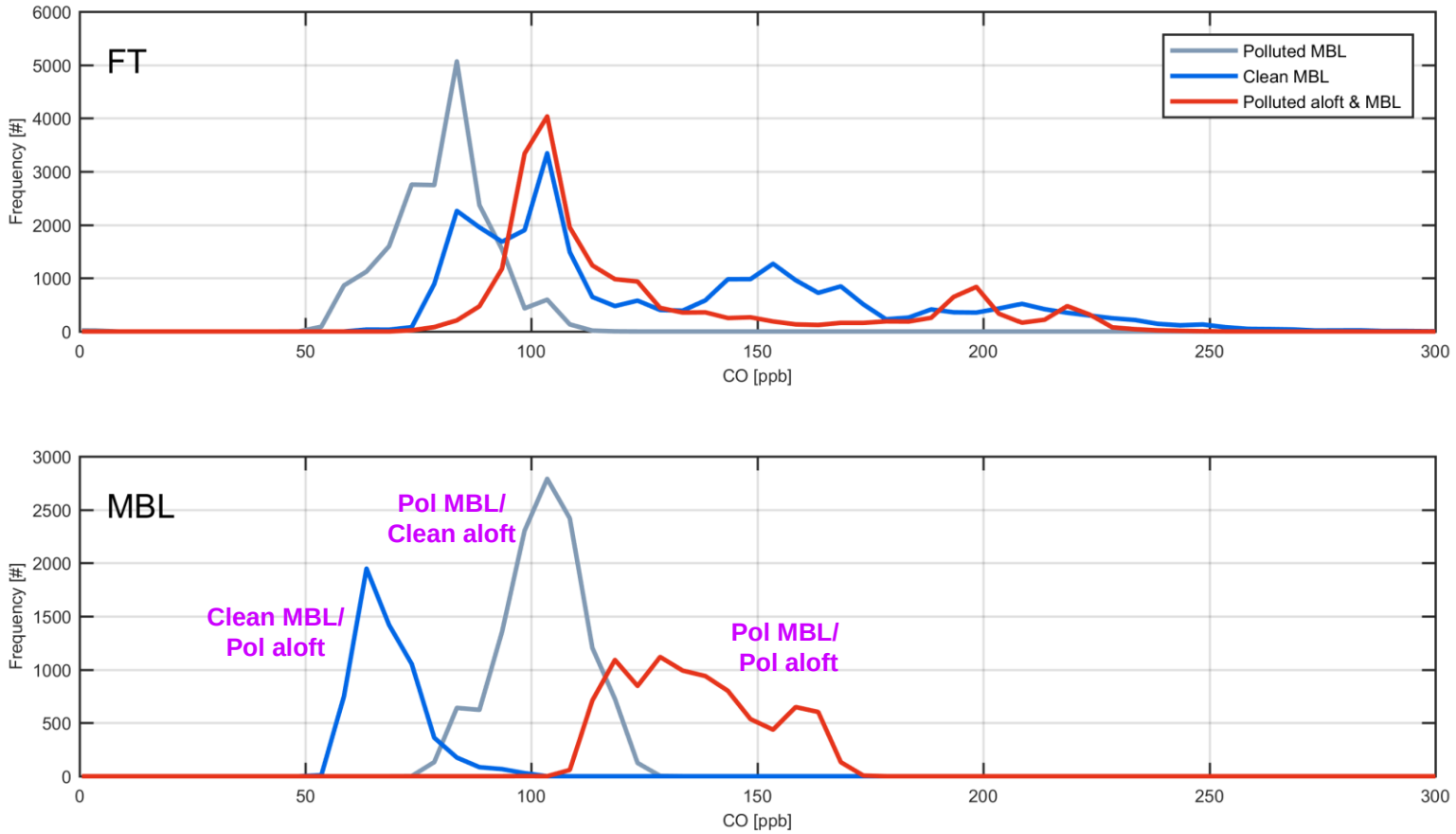
Mod poll MBL/Polluted aloft

POC (Clean MBL) Polluted aloft

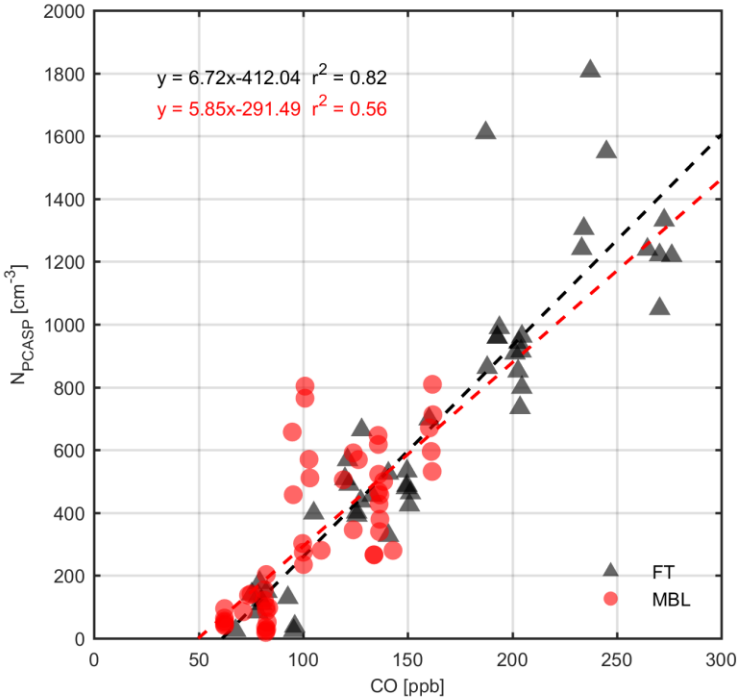
Aircraft CO concentrations (all flights) - Time Series

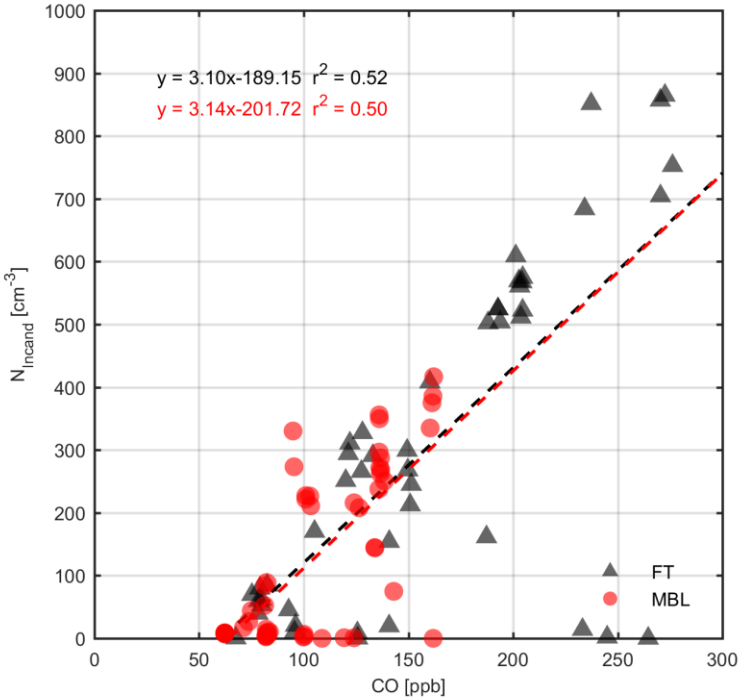


CO concentration PDFs - CLARIFY-2017 regimes

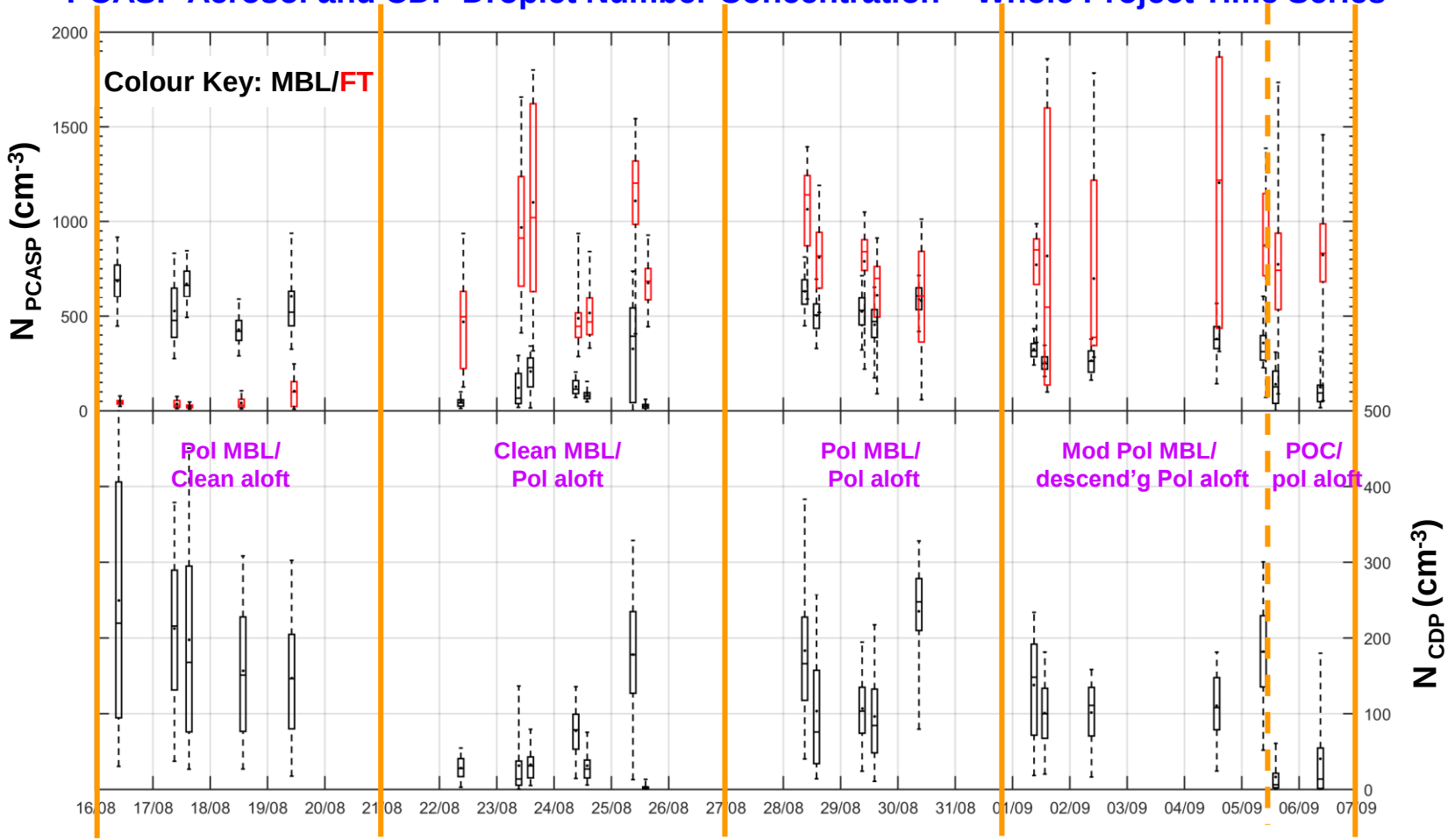


Aerosol Concentrations (PCASP, $SP2_{incand}$) (cm^{-3}) vs CO concentrations (ppb) (all flights)



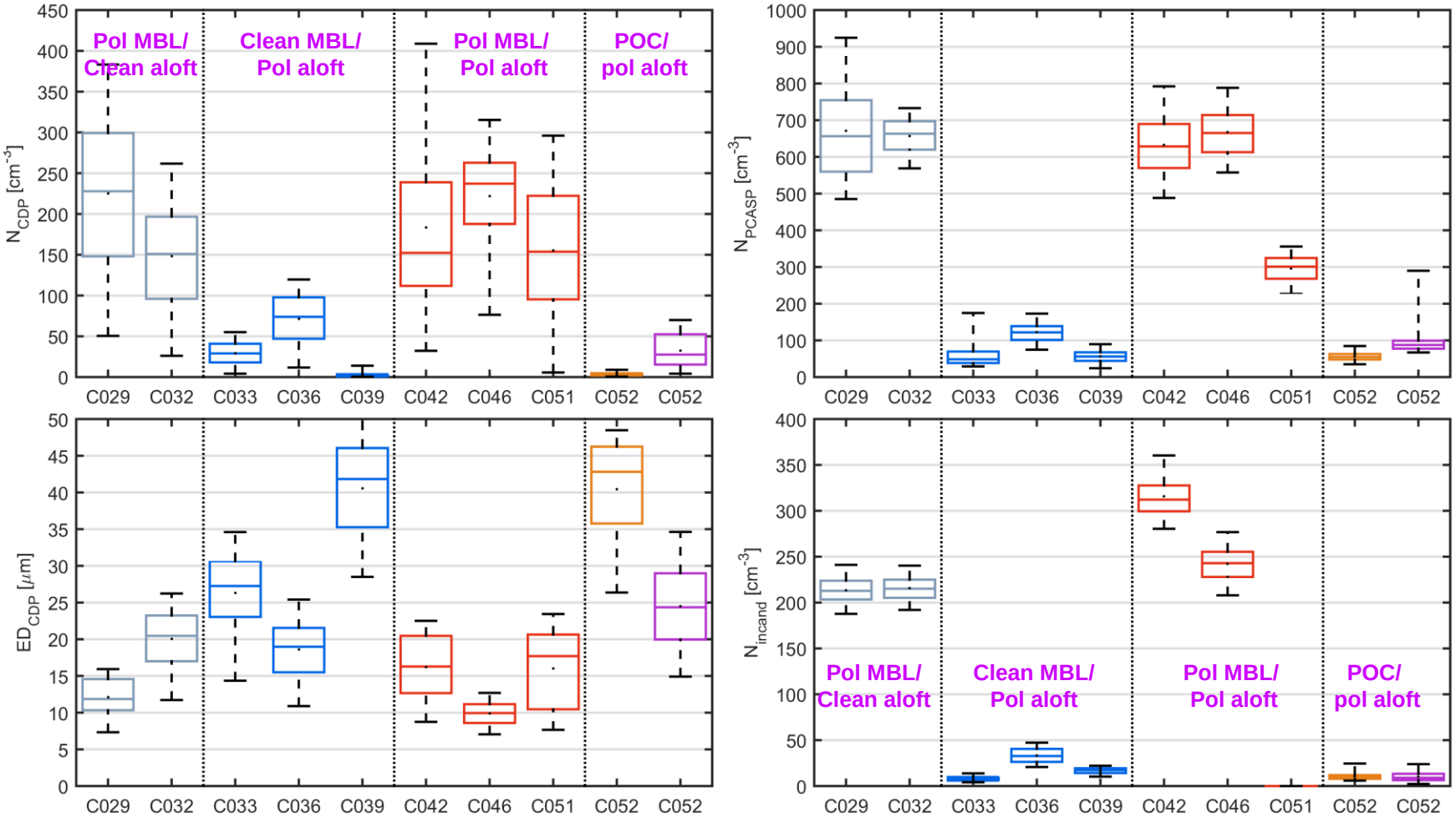


PCASP Aerosol and CDP Droplet Number Concentration – Whole Project Time Series

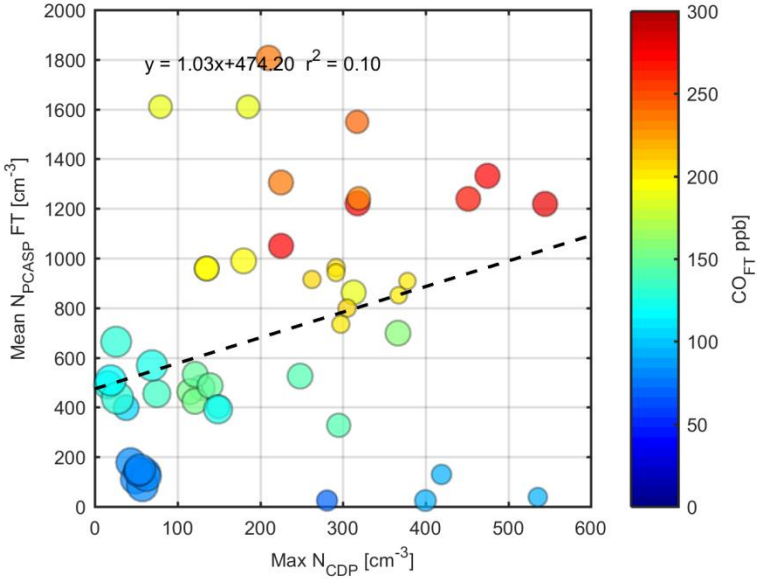


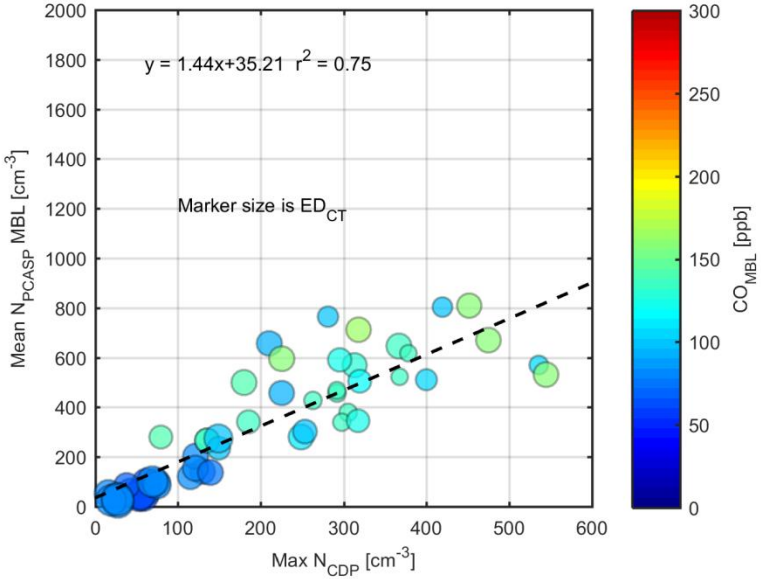
(red is 2000-4000m; black is 0-1500m)

Example case studies from each of the different regimes .....

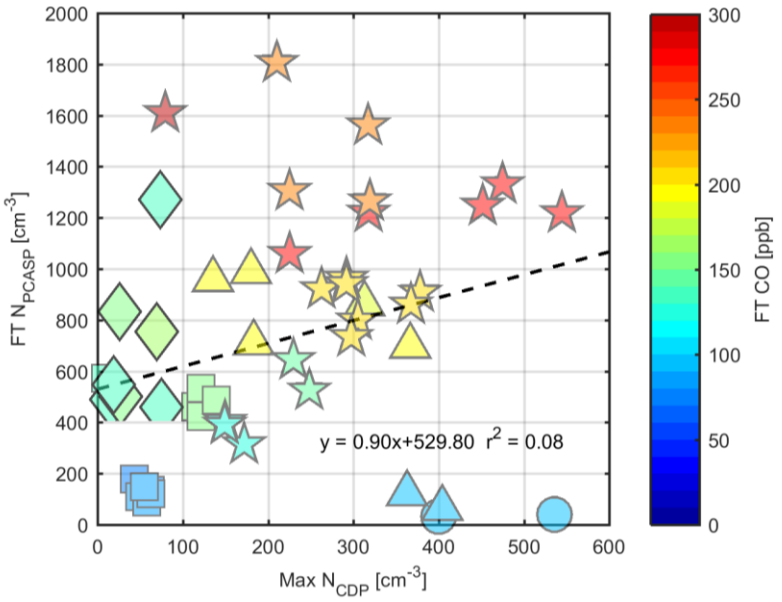


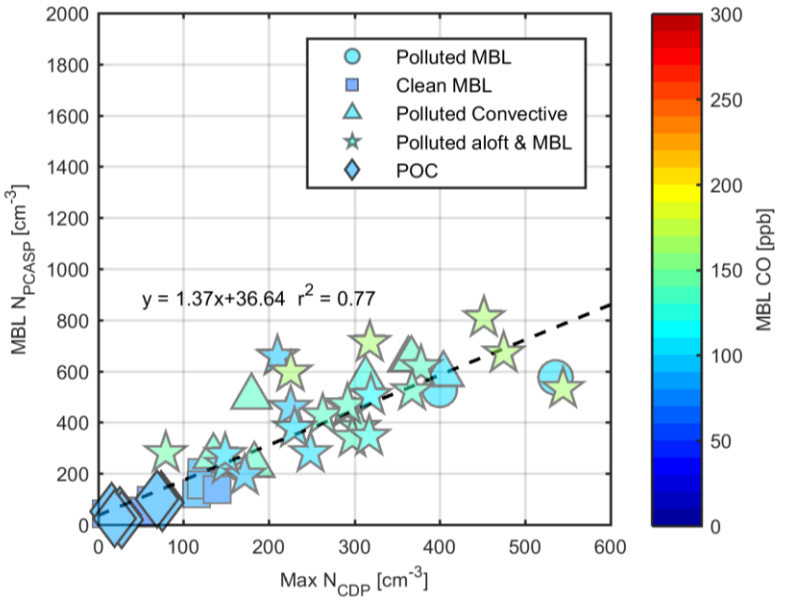
Aerosol Concentrations (mean PCASP) vs max droplet concentration (from all profiles*)



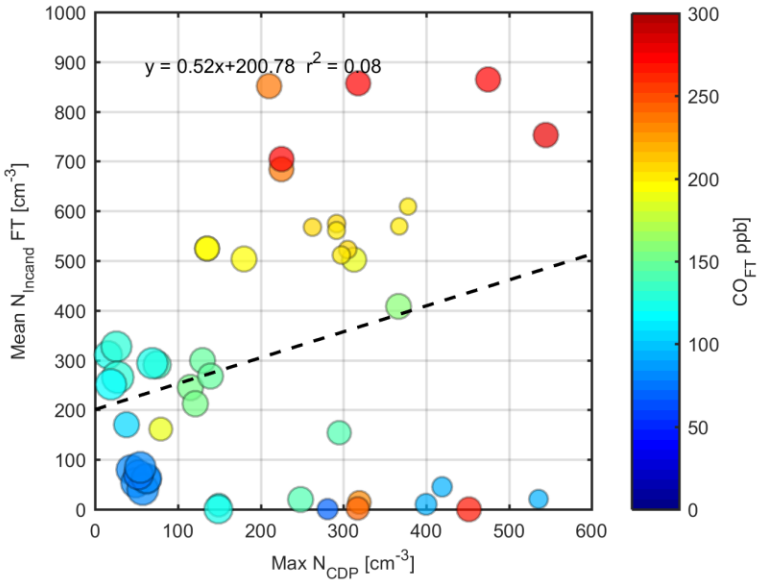


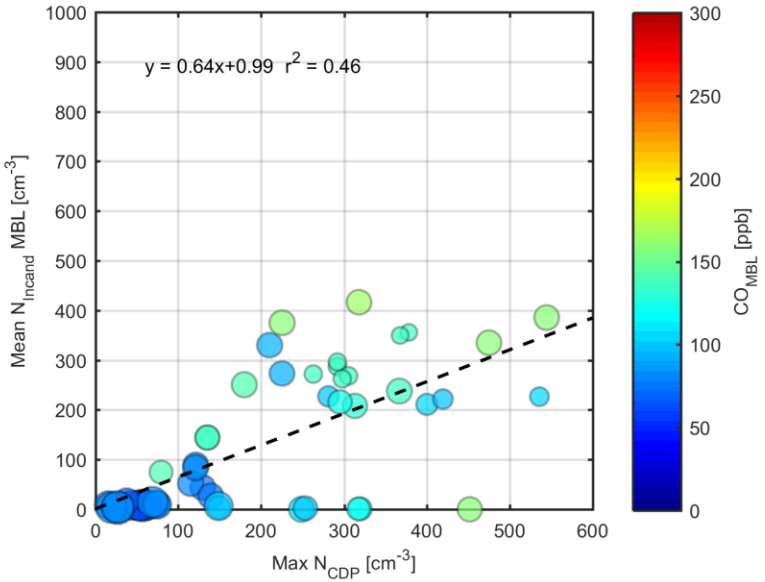
Aerosol Concentrations (mean PCASP) vs max droplet concentration (from all profiles)



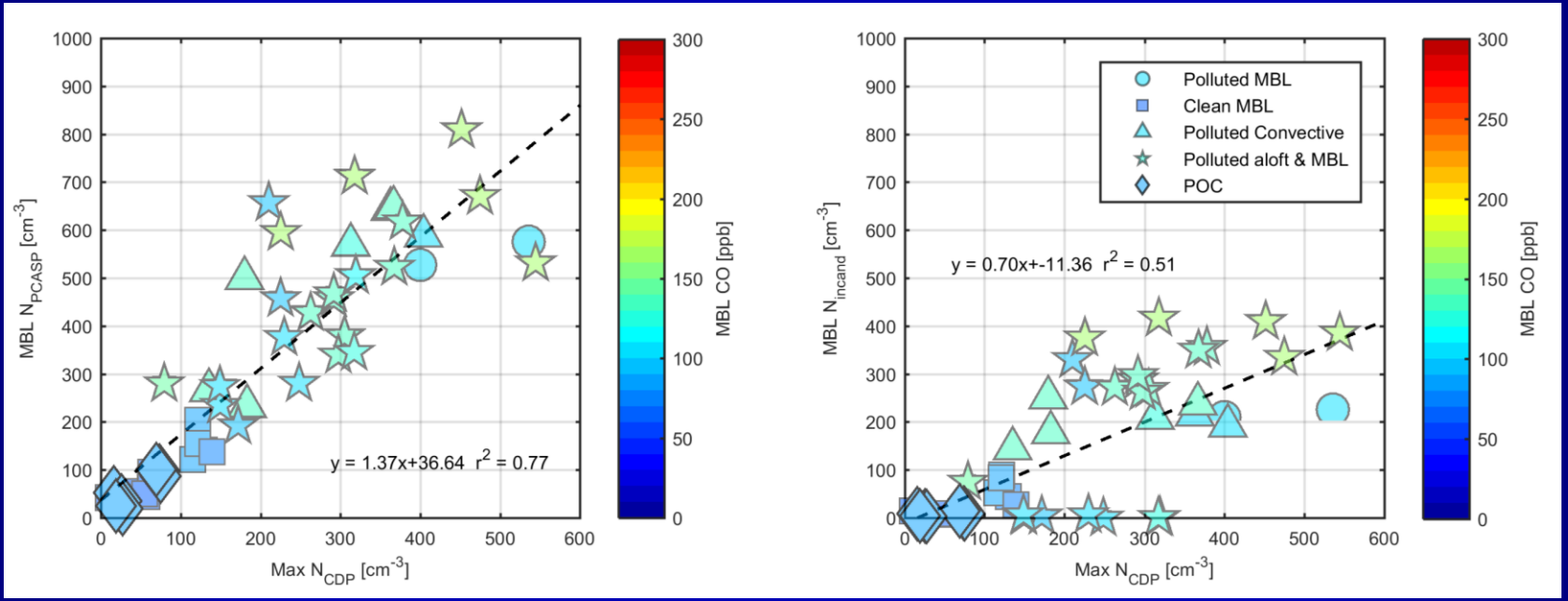


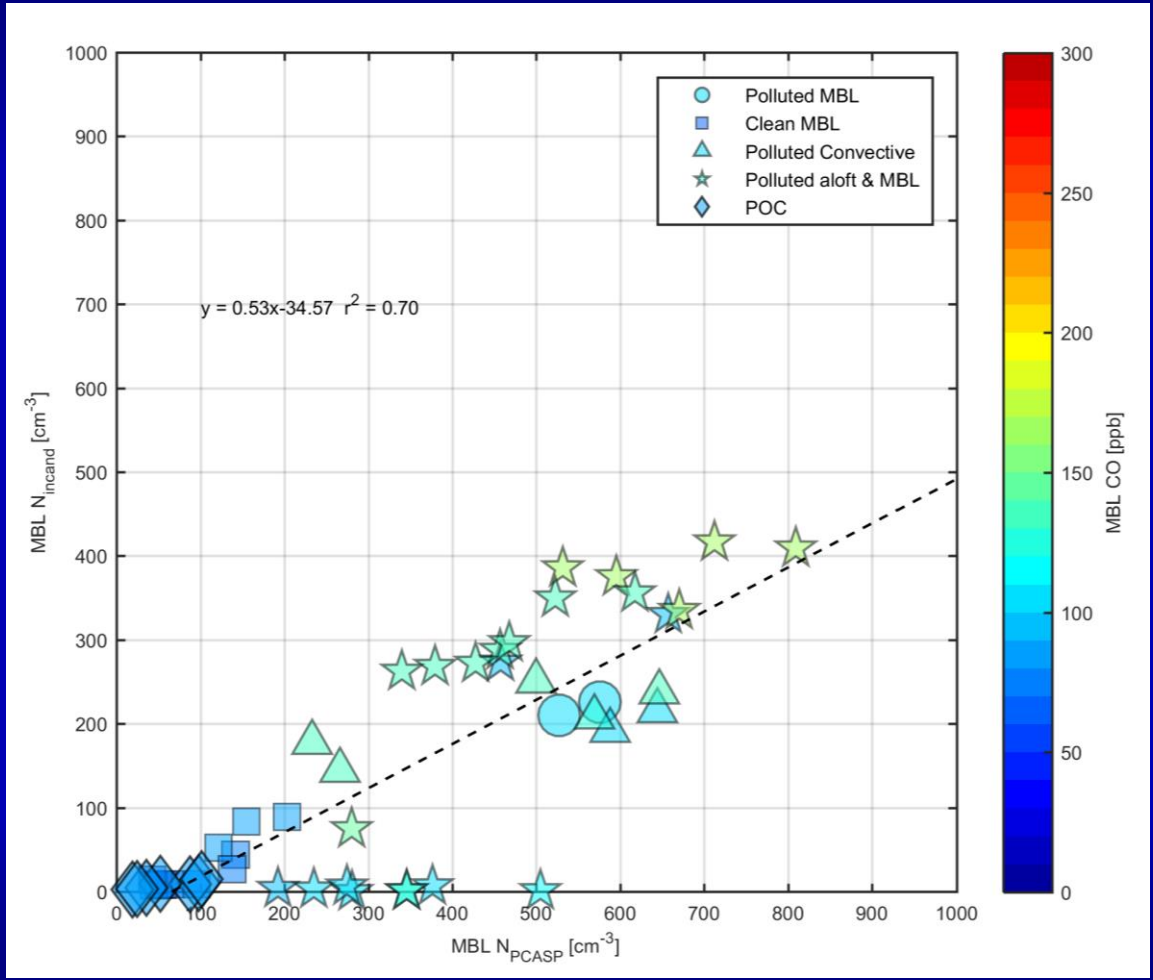
Aerosol Concentrations (mean $SP2_{incand}$) vs max droplet concentration (from all profiles)



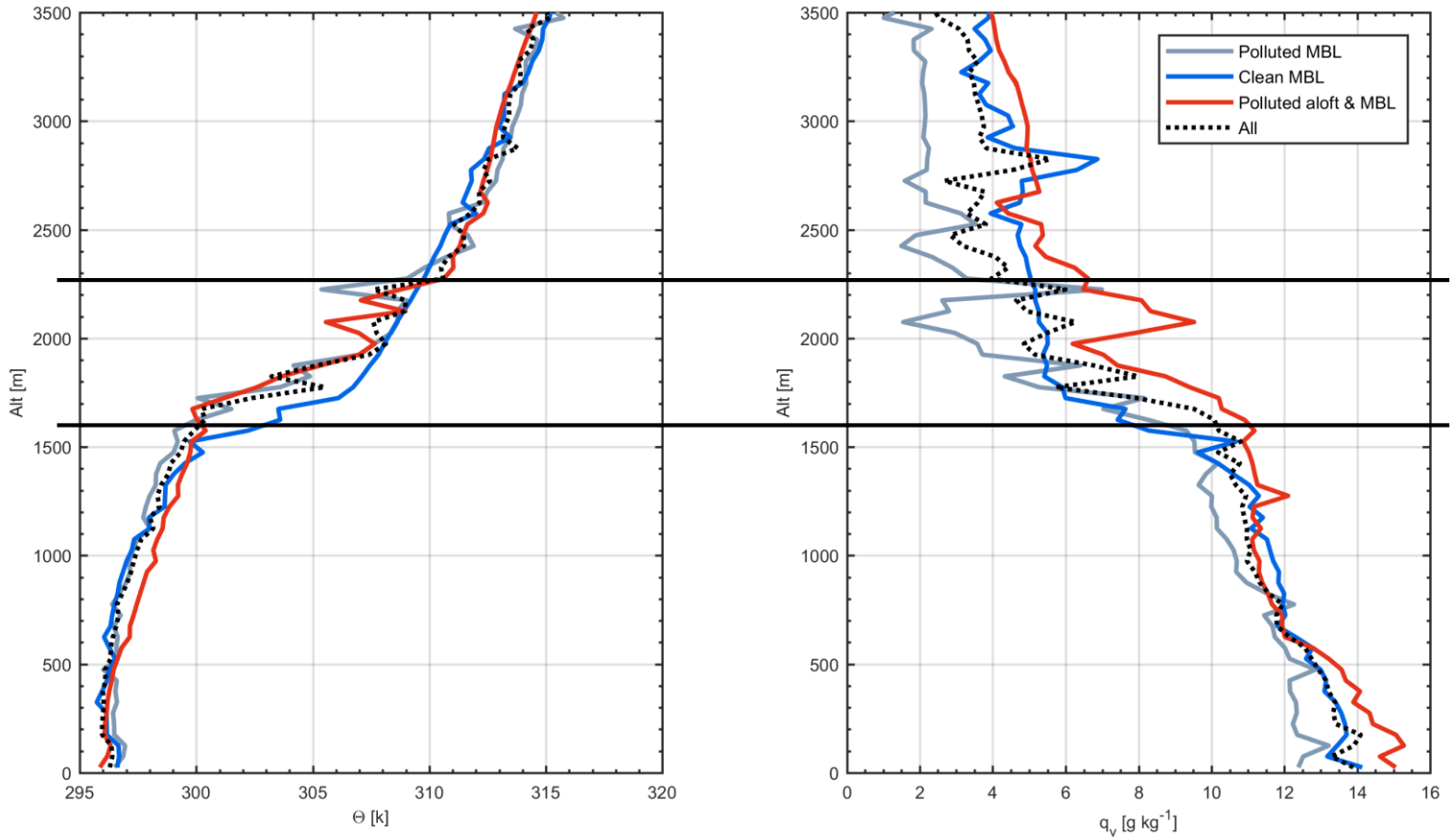


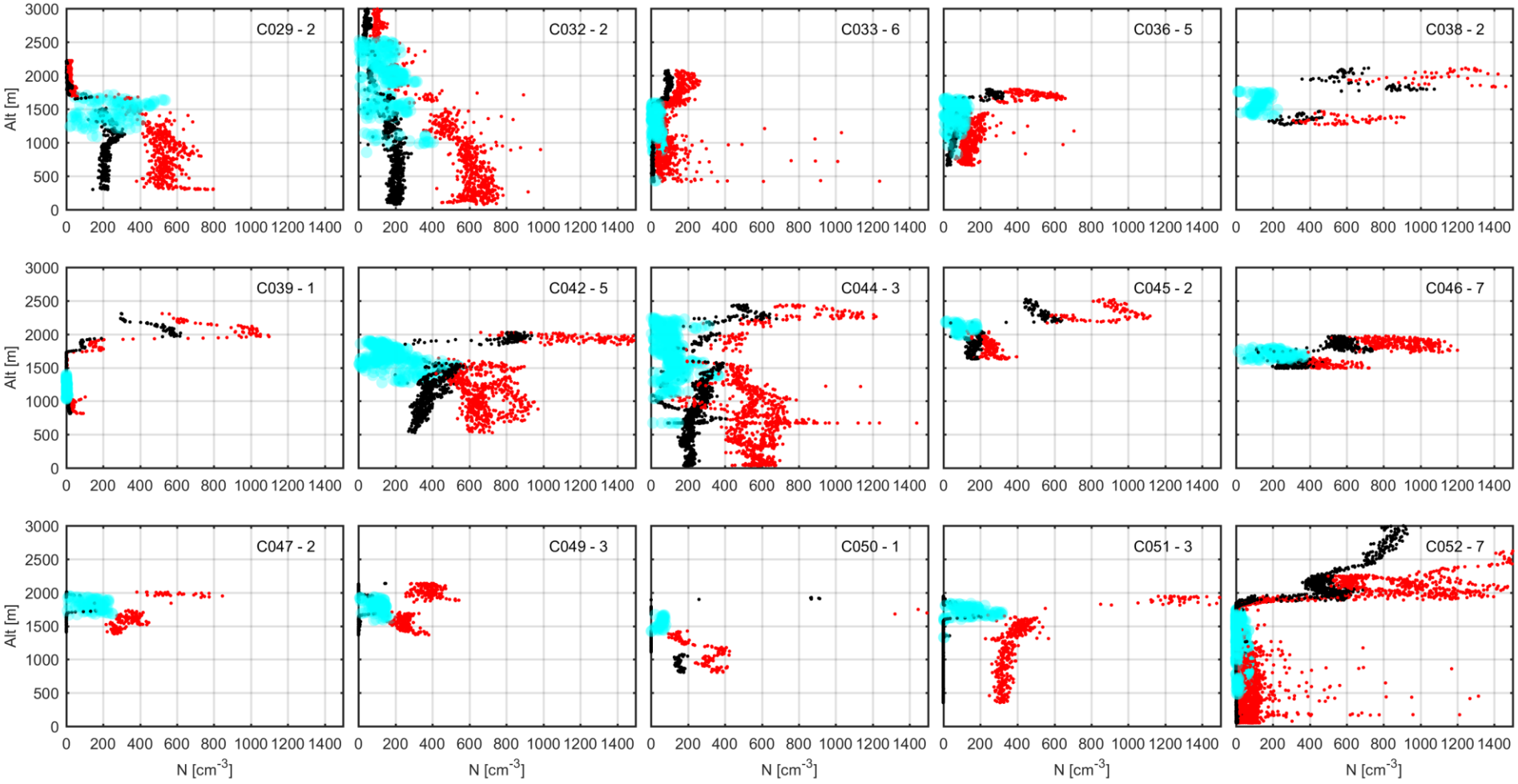
Aerosol Concentrations (mbl PCASP & SP2inc) vs max droplet concentration (from 51profiles)

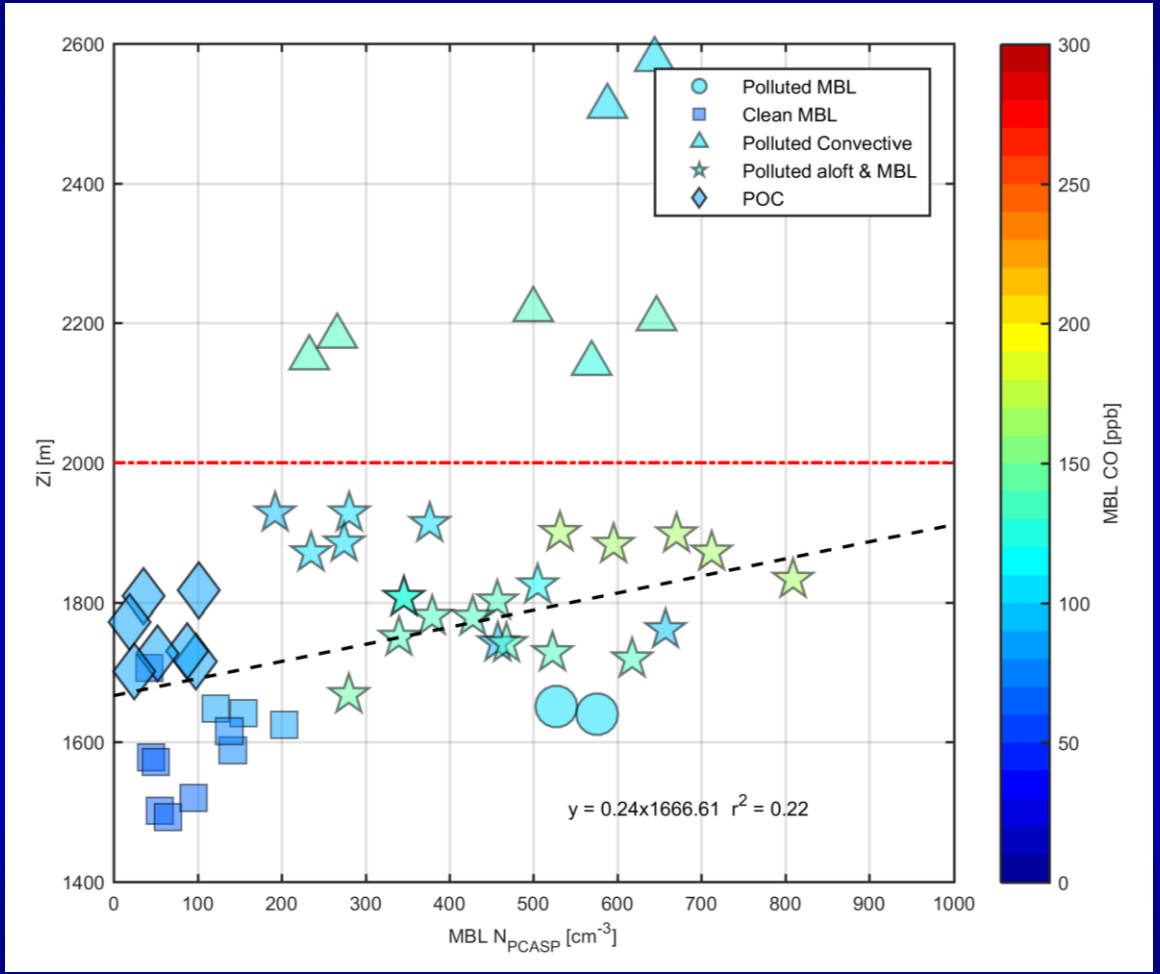


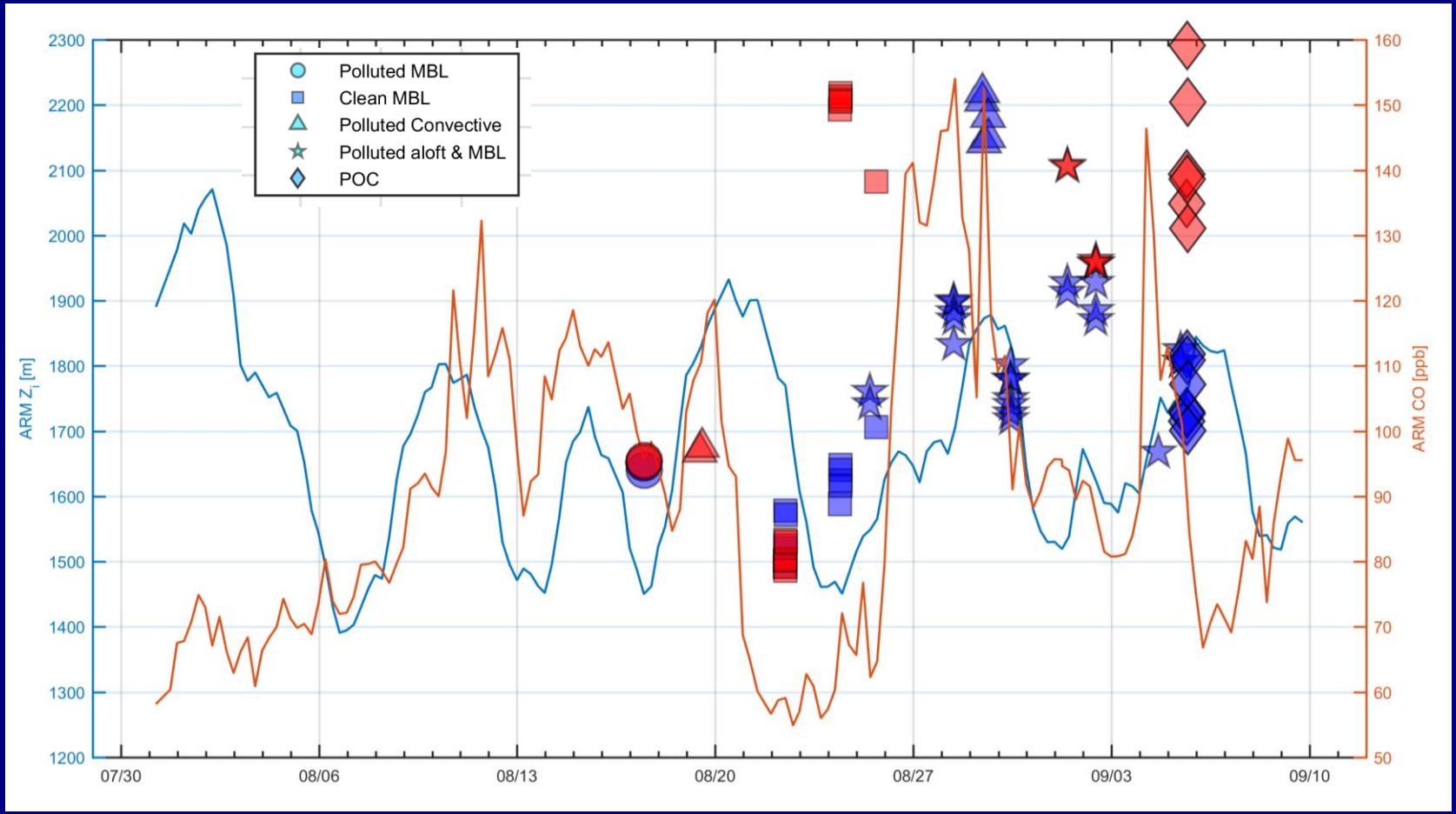

Polluted MBL
Clean MBL
Polluted Convective
Polluted aloft & MBL
POC
y = 0.53x-34.57 r2 = 0.70
MBL Nincand [cm-3]
MBL NPCASP [cm-3]
MBL CO [ppb]
0
100
200
300
400
500
600
700
800
900
1000
0
50
100
150
200
250
300

Potential Temperature, Water Vapour (mixing ratio) profiles - CLARIFY-2017 regimes



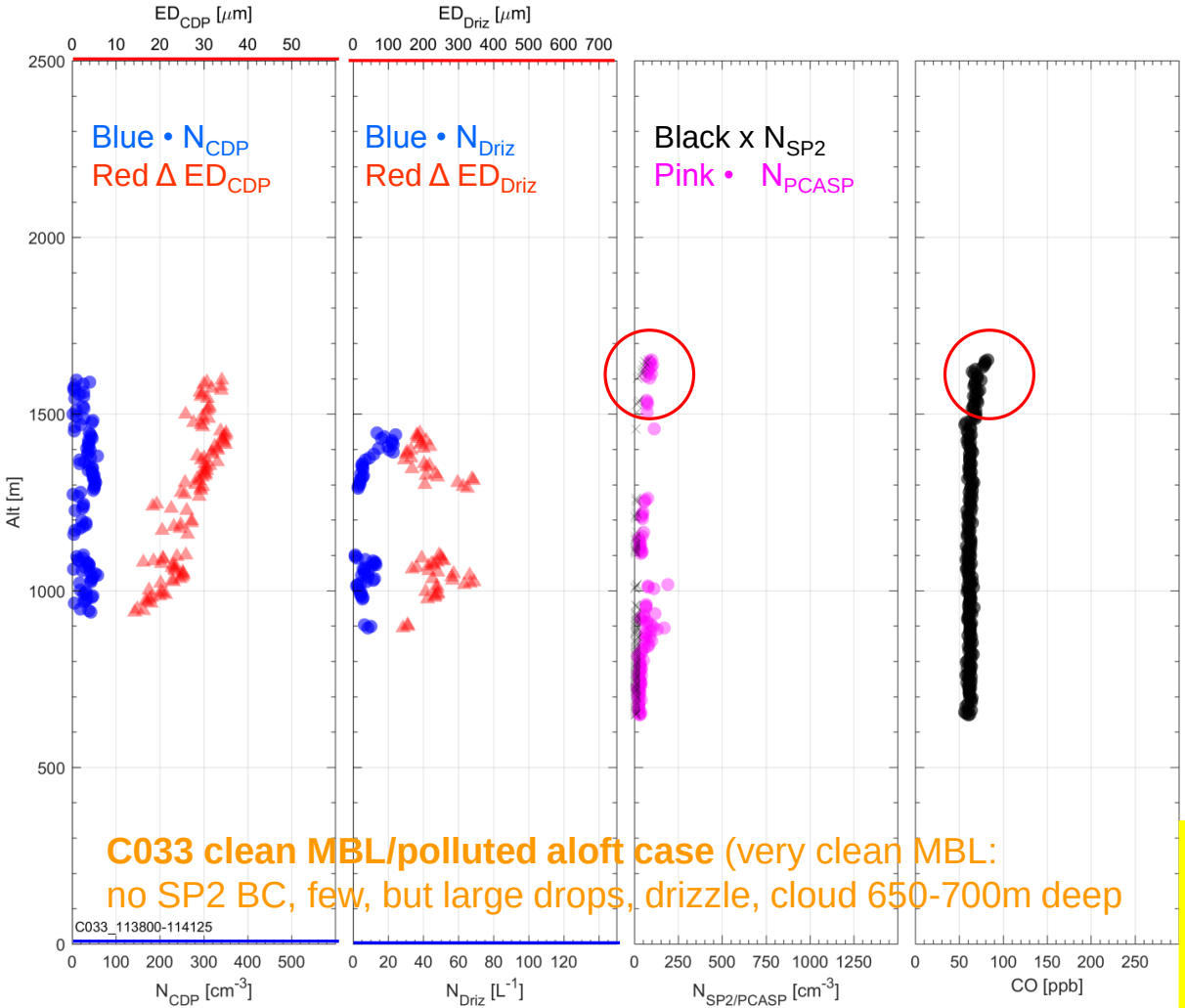

C029 - 2
C032 - 2
C033 - 6
C036 - 5
C038 - 2
C039 - 1
C042 - 5
C044 - 3
C045 - 2
C046 - 7
C047 - 2
C049 - 3
C050 - 1
C051 - 3
C052 - 7
Alt [m]
N [cm^{-3}]
0 200 400 600 800 1000 1200 1400
0 500 1000 1500 2000 2500 3000

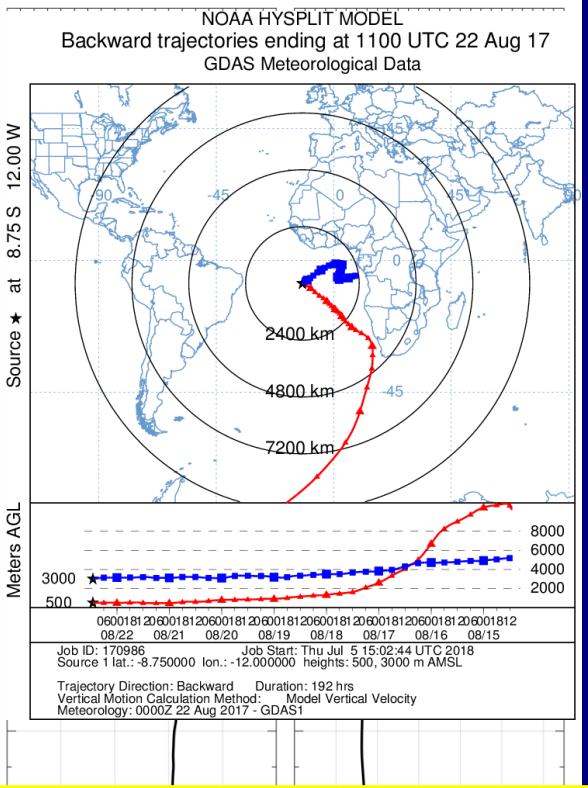

Polluted MBL
Clean MBL
Polluted Convective
Polluted aloft & MBL
POC
y = 0.24x1666.61 r2 = 0.22
Zi [m]
MBL NPCASP [cm-3]
MBL CO [ppb]
2600
2400
2200
2000
1800
1600
1400
0
100
200
300
400
500
600
700
800
900
1000
300
250
200
150
100
50
0


Polluted MBL
Clean MBL
Polluted Convective
Polluted aloft & MBL
POC
ARM Z_i [m]
ARM CO [ppb]
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
160
150
140
130
120
110
100
90
80
70
60
50
07/30
08/06
08/13
08/20
08/27
09/03
09/10

Results from individual case studies in different CLARIFY-2017 regimes

,,,, to be skipped if time does not permit !!!



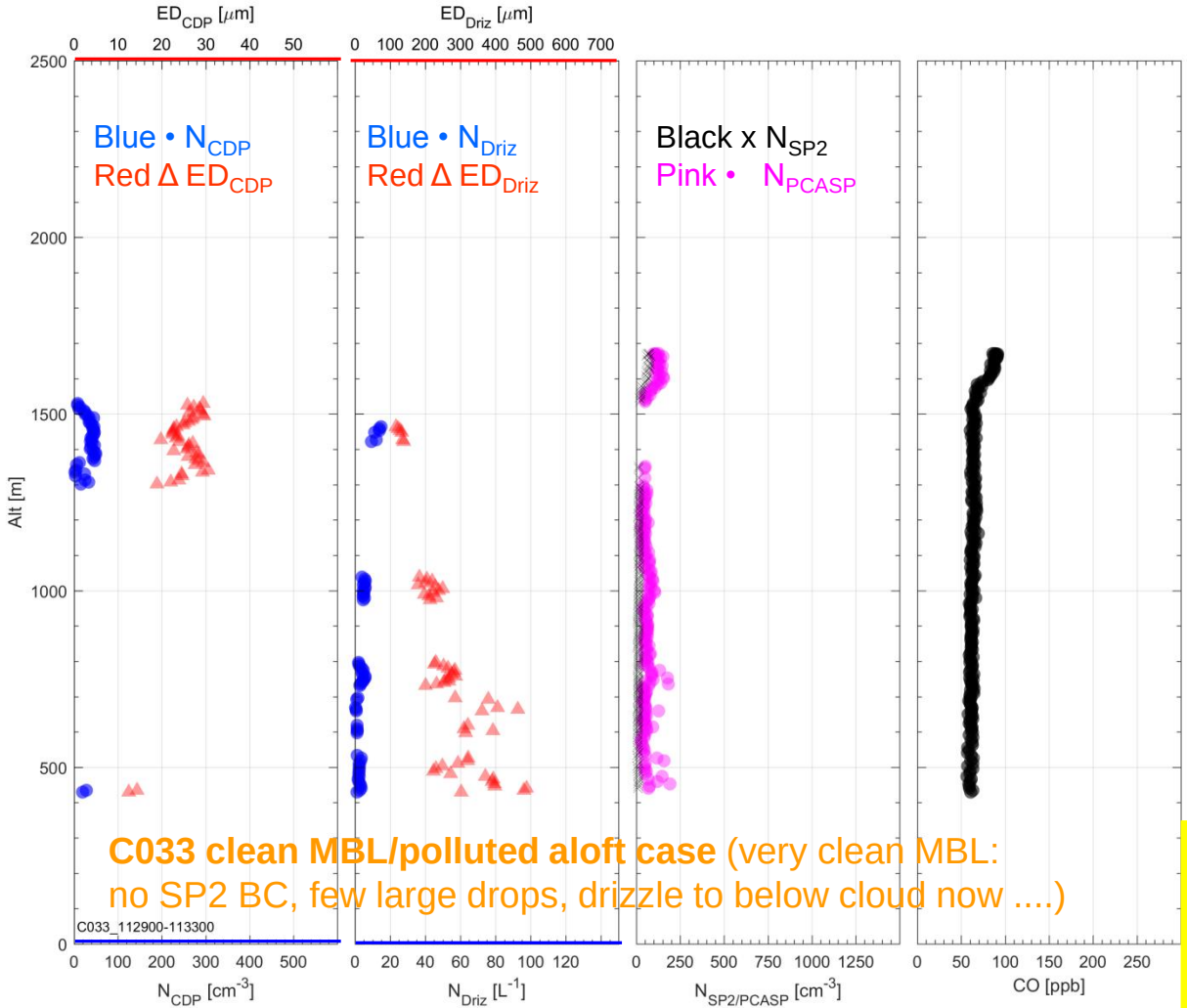


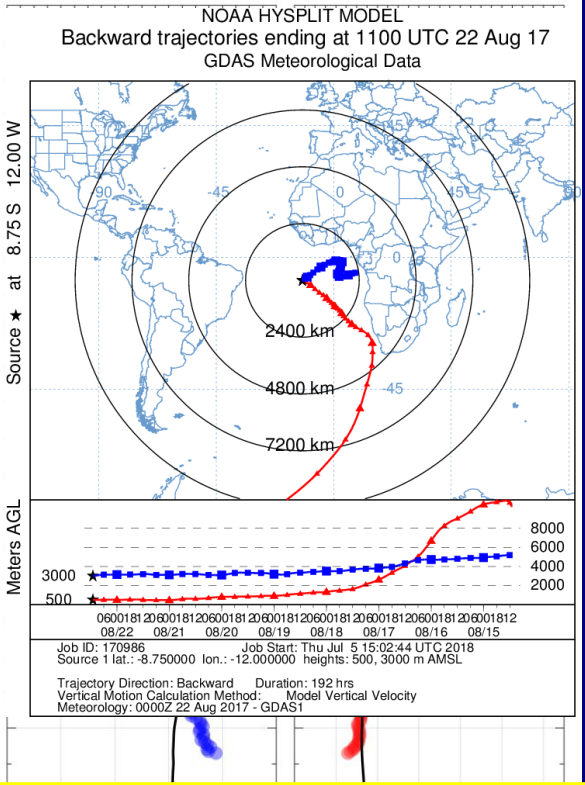
C033 clean MBL/polluted aloft case (very clean MBL: no SP2 BC, few, but large drops, drizzle, cloud 650-700m deep

Hysplit 7-day Back Trajectories

C033 clean MBL/polluted aloft

.... 500m (red) and 3000m (blue)



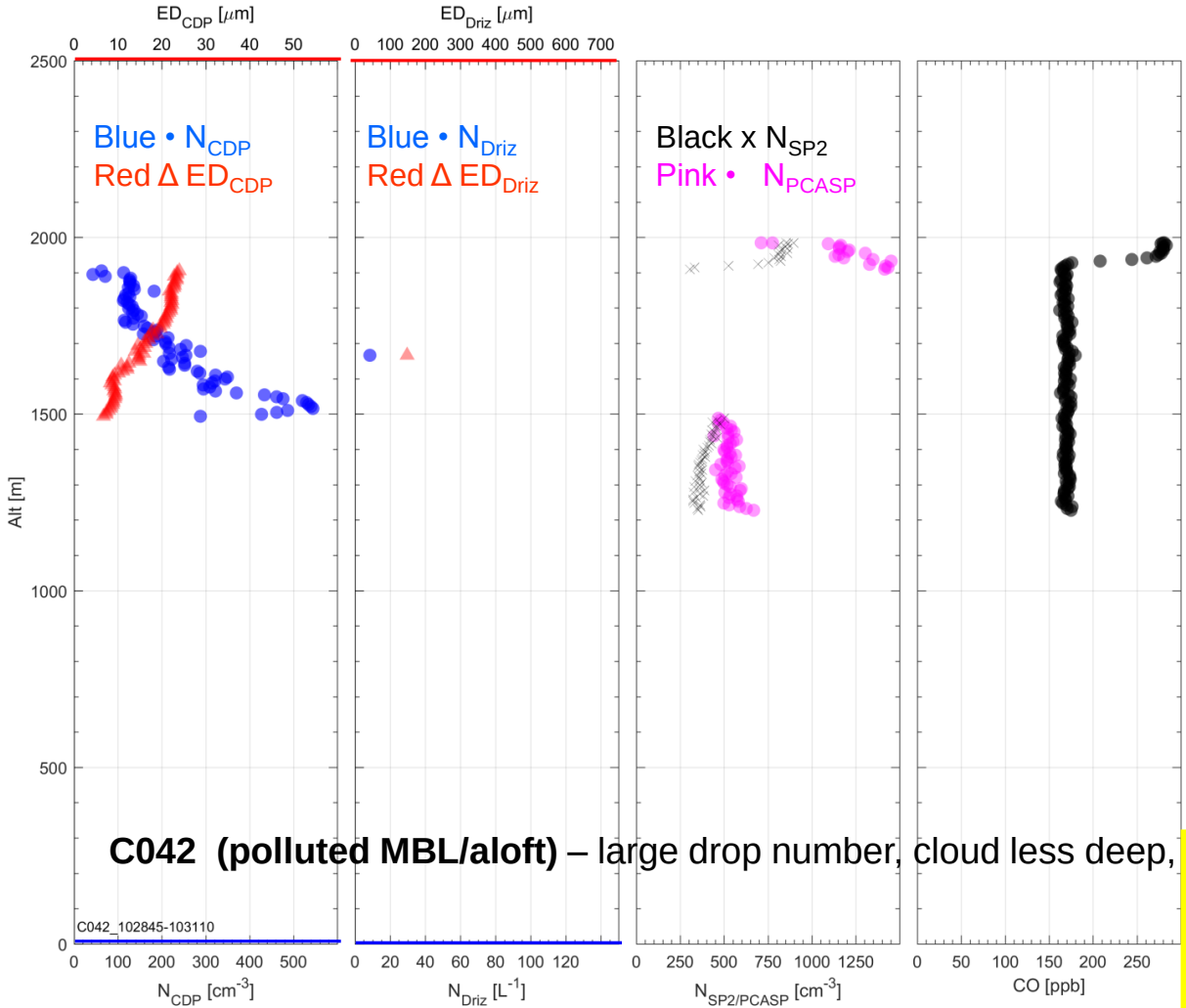


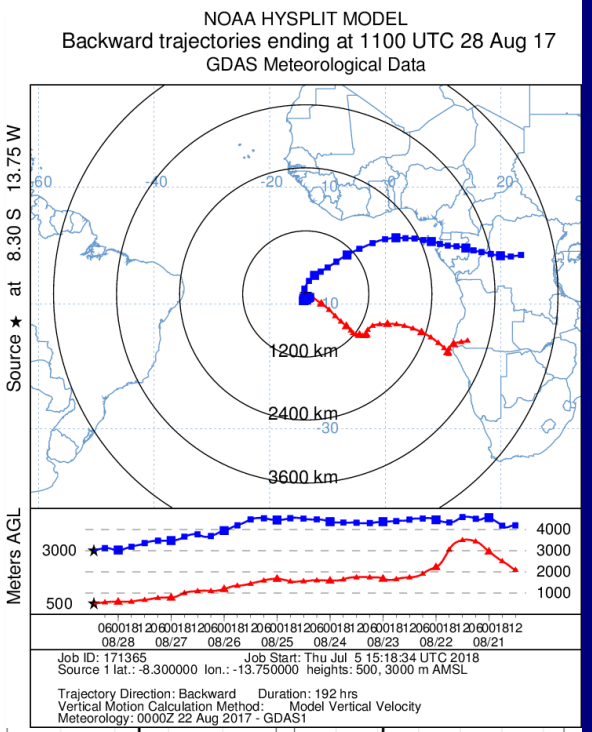
C033 clean MBL/polluted aloft case (very clean MBL: no SP2 BC, few large drops, drizzle to below cloud now ....)

Hysplit 7-day Back Trajectories

C033 clean MBL/polluted aloft

.... 500m (red) and 3000m (blue)



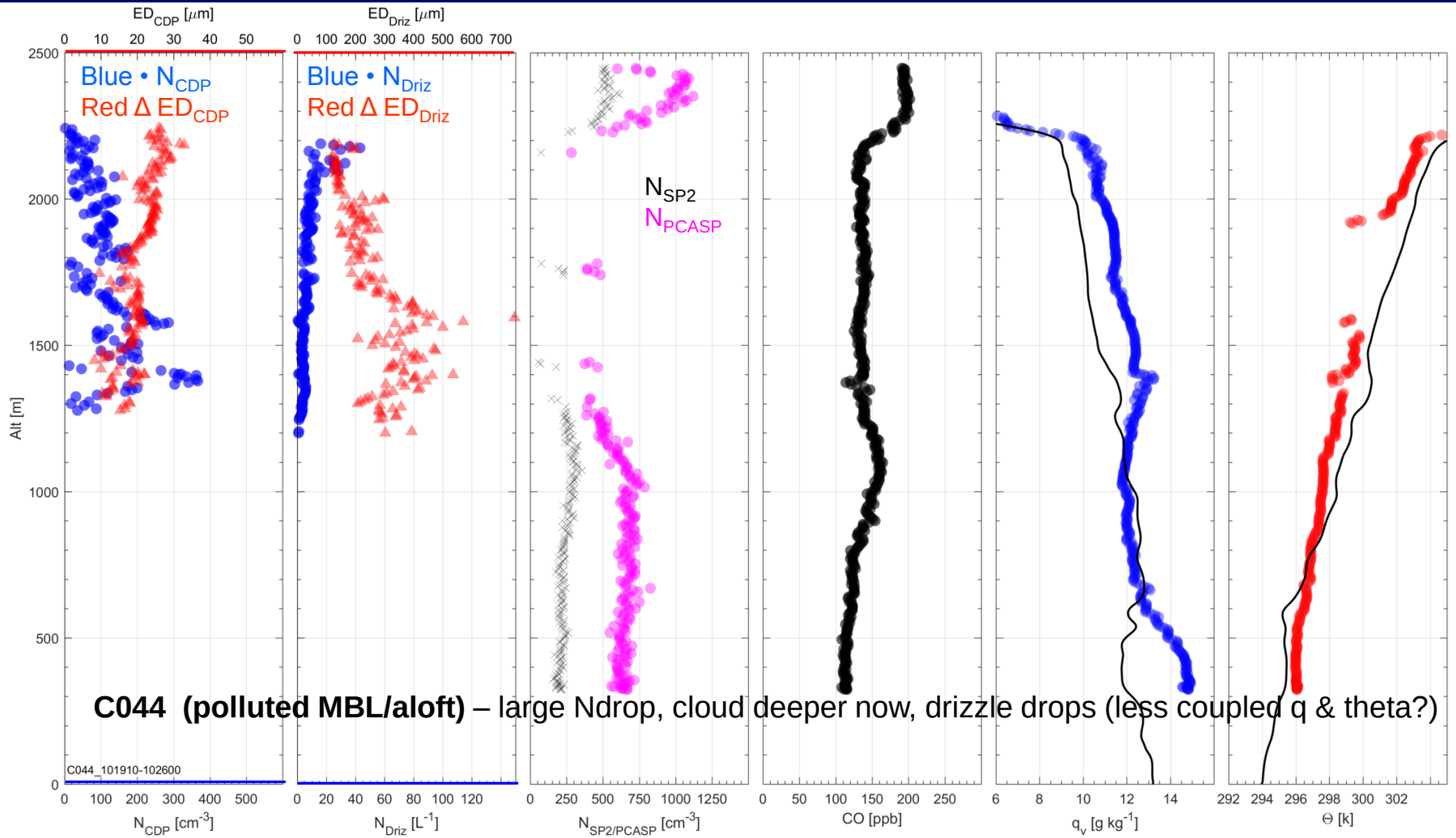


C042 (polluted MBL/aloft) – large drop number, cloud less deep,

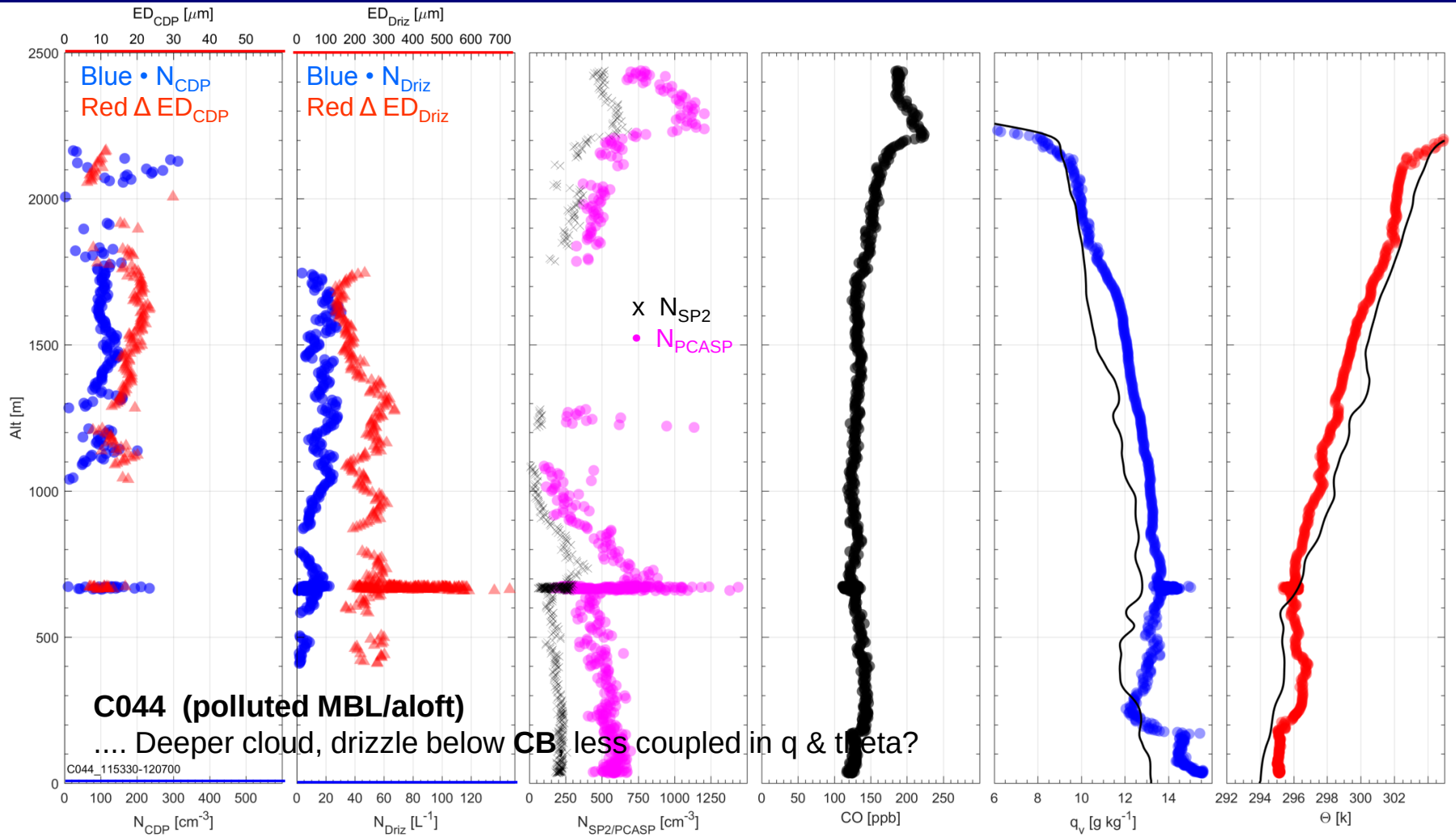
Hysplit 7-day Back Trajectories

C042 polluted MBL & aloft

.... 500m (red) and 3000m (blue)



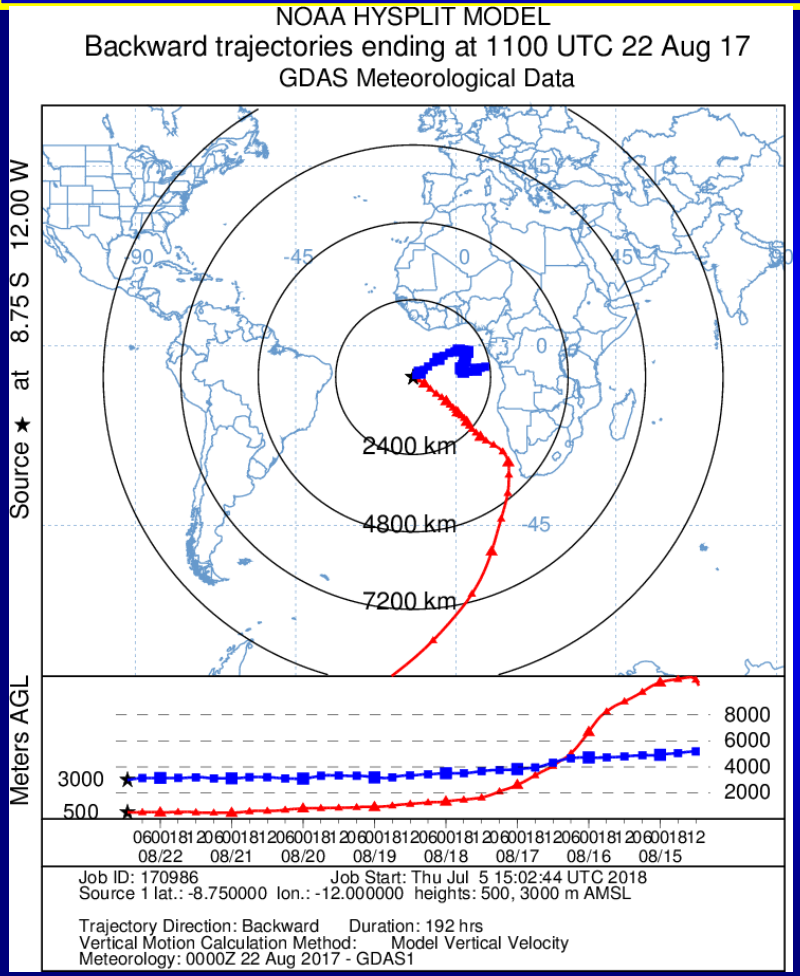
C044 (polluted MBL/aloft) – large Ndrop, cloud deeper now, drizzle drops (less coupled q & theta?)

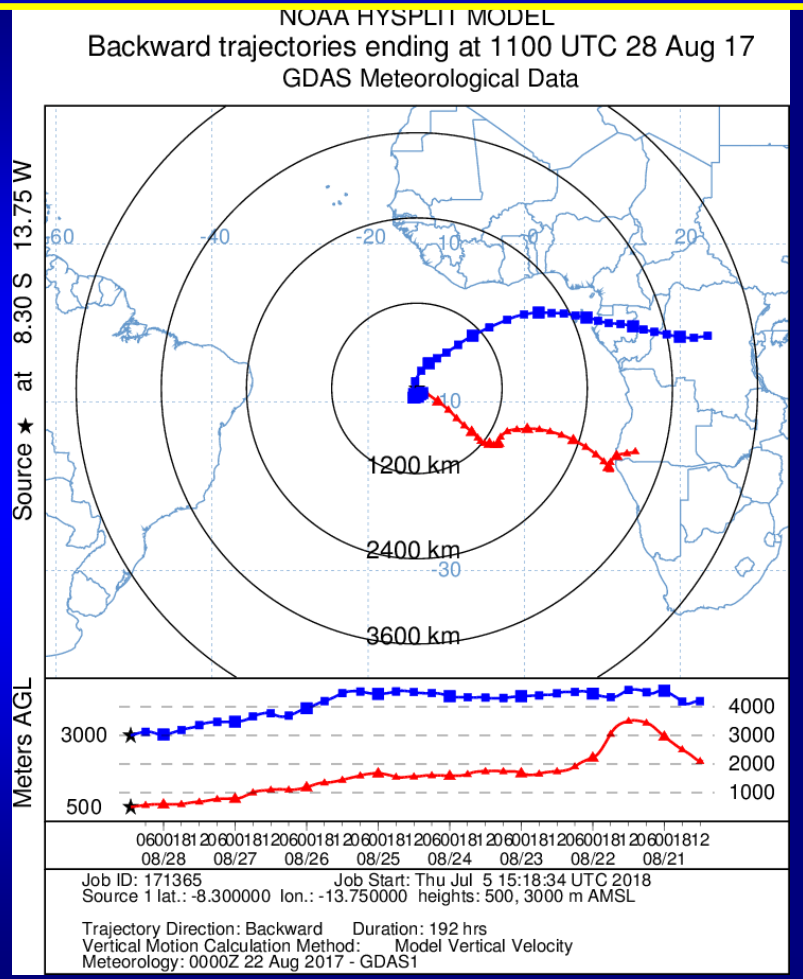


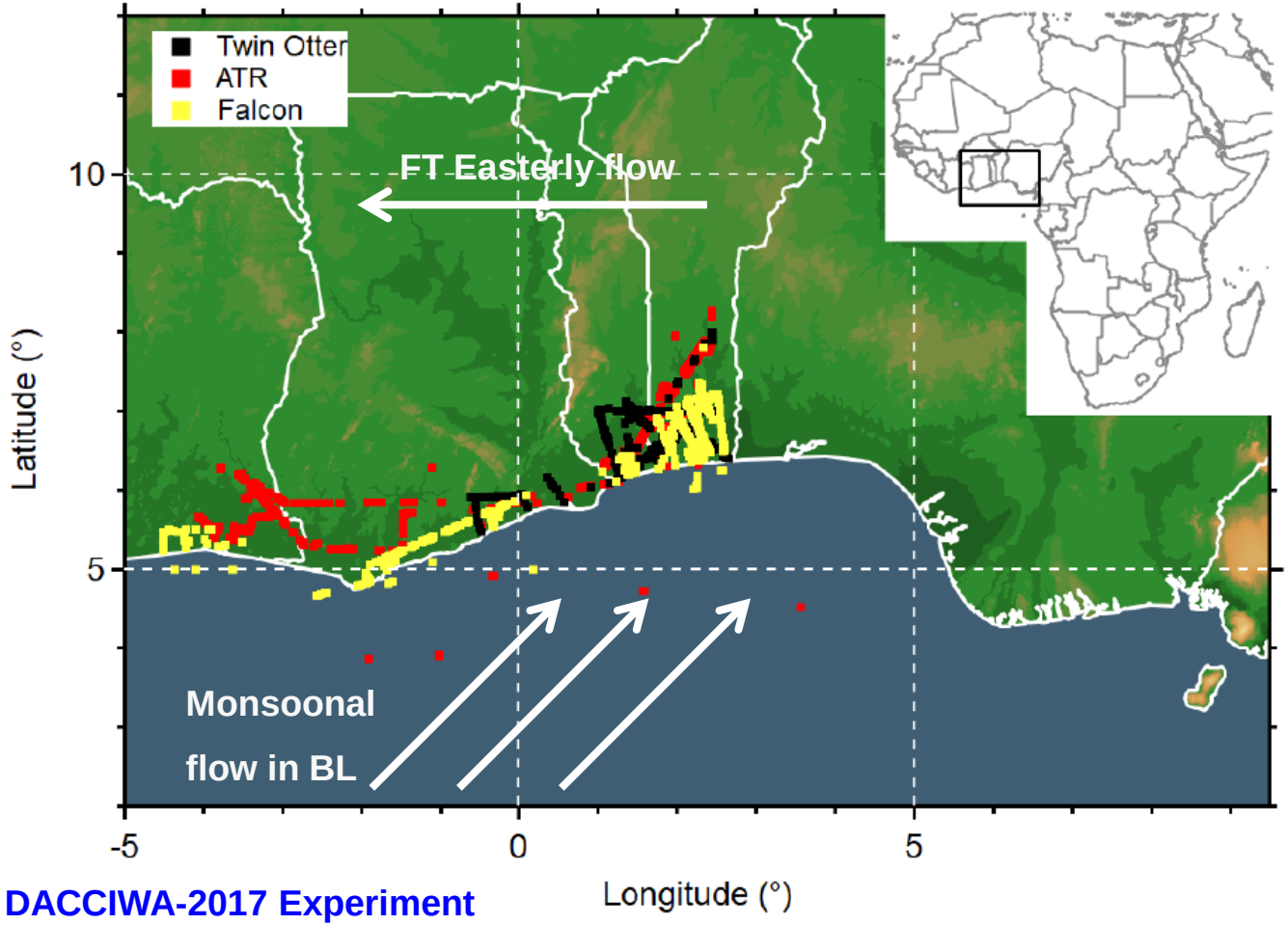
C044 (polluted MBL/aloft)

.... Deeper cloud, drizzle below **CB**, less coupled in q & theta?

Hysplit Back Trajectories: C033 clean MBL/polluted aloft (left); C042 polluted MBL & aloft





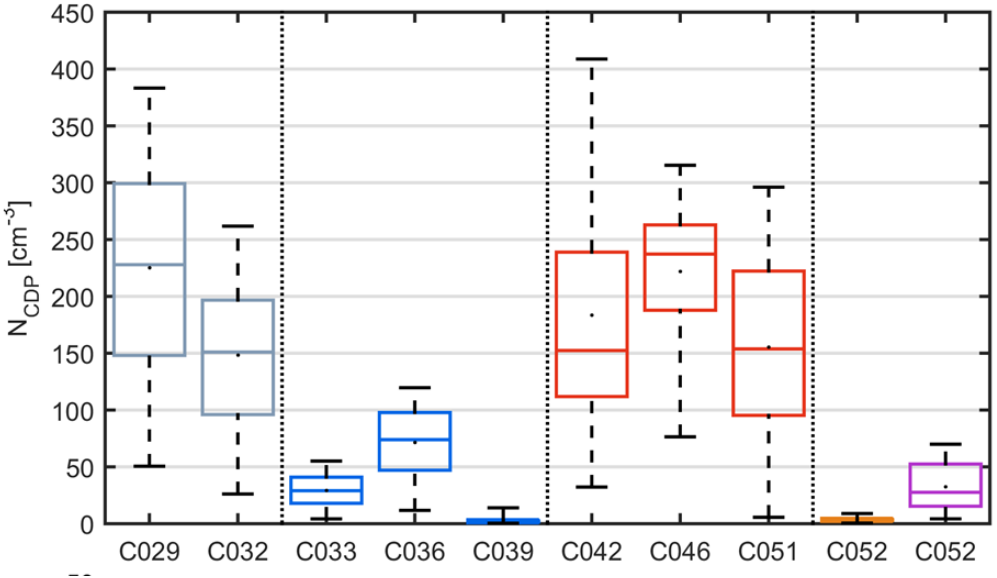


DACCIWA-2017 Experiment

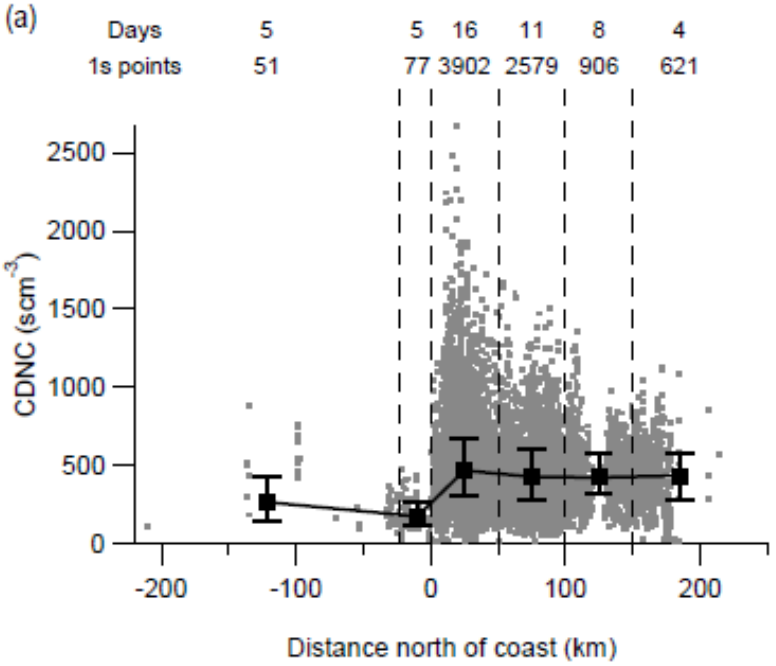
Dynamics-Aerosol-Chemistry-Clouds Interactions in West Africa "DACCIWA" Experiment

Comprehensive overview of cloud-aerosol-precipitation interactions in the region, inc effects of anthropogenic inputs from local sources

Observations of cloud microphysics and low-level cloud fraction measured over southern West Africa (SWA) during June-July 2016



CLARIFY regime summary: Cloud Droplet Number Concentration



DACCIWA (West Africa) zonal summary: Cloud Droplet Number Concentration

The polluted background droplet number concentrations over the sea are quite comparable, but the additional local pollution/continental inputs over the African continent creates significant additional enhancements over the mixing in of BB aerosol to the MBL (during West African summer Monsoon)

Summary of observations so far:

- days when MBL clear of effects of BB smoke (low CO, no BC (SP2) aerosols) – low N_{PCASP} N_{CDP} .....
- Back Trajectories generally show air not from BB area of Africa – more from southern Africa/ SE over sea
- MBL generally decoupled to varying degrees (various definitions of this this week (e.g. In Barratt et al.) and drizzle probably enhances this.
- Influence of BBA above in FT v limited on timescales of observations of cloud flights, but ...
- Regime with BB smoke in MBL: see much higher N_{CDP}, N_{PCASP} & BC aerosol, (elevated CO) (but mixing of BB air into MBL probably occurs upwind of ASI & advected to ASI in SE tradewinds c.f. mixing from above)
- significant effect on Ndrop etc. (polluted MBL should inhibit drizzle - but still present (Q. Deeper clouds?))
- evolution of polluted to less polluted MBL (by washout out of aerosols? – effect on transition closed to open cellular cloud structure? - potentially to formation of pockets of open cells (Abel et al. poster)

Future work:

- look at thermodynamics of profiles, drizzle production, decoupling of MBL - didn't work!
- degree and effects of entrainment at CT and mixing of BB air into MBL (secondary?) – to do (more than a/c data? Q) - remote sensing obs - LASIC?
- model example case studies .....

Acknowledgements: CLARIFY was funded by the UK Natural Environment Research Council (NERC)

Crawford et al (Bower) presentation back-up slides.....

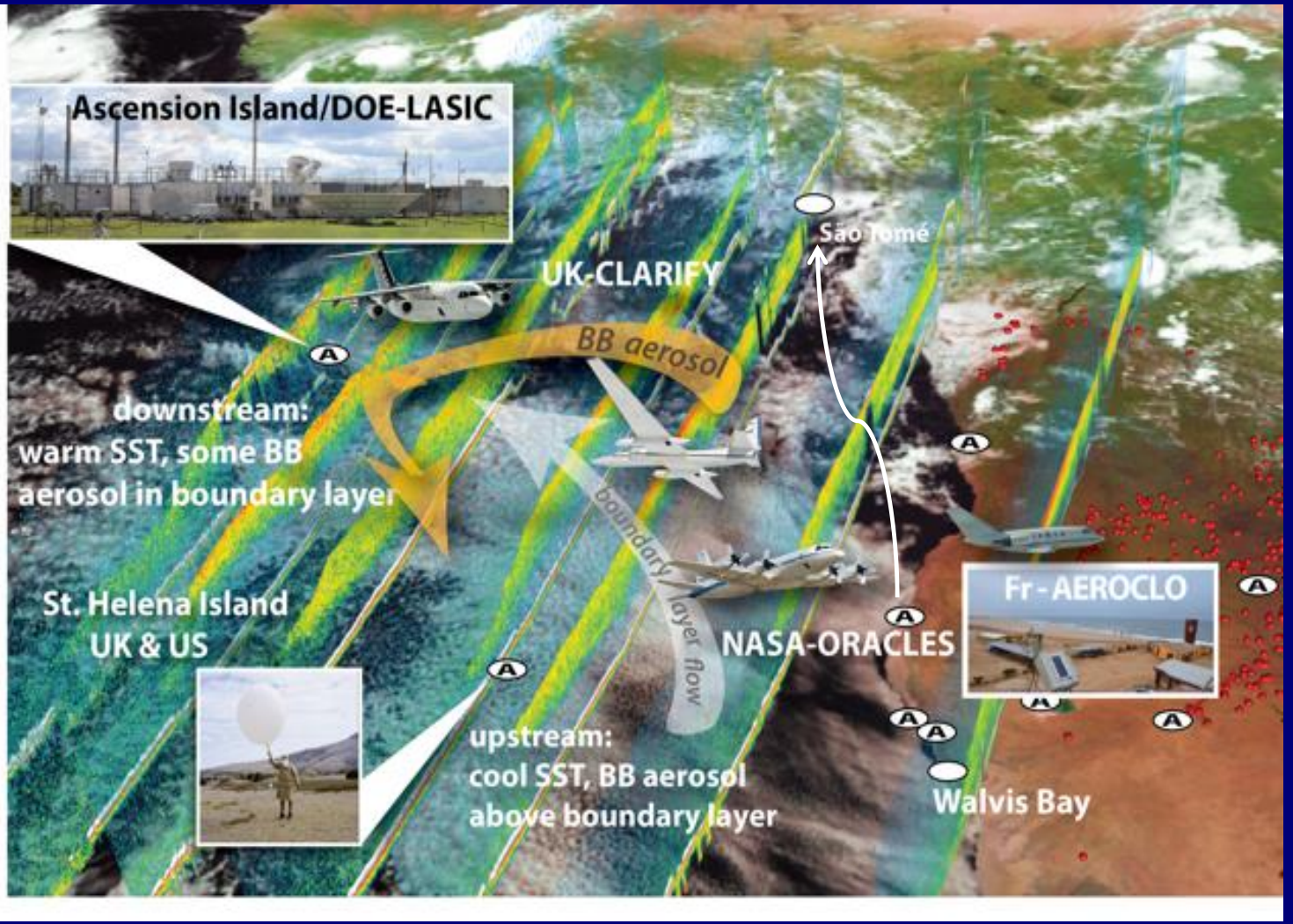
CLARIFY-2017

… part of a larger set of studies of the SE Atlantic region inc.....

NASA-ORACLES

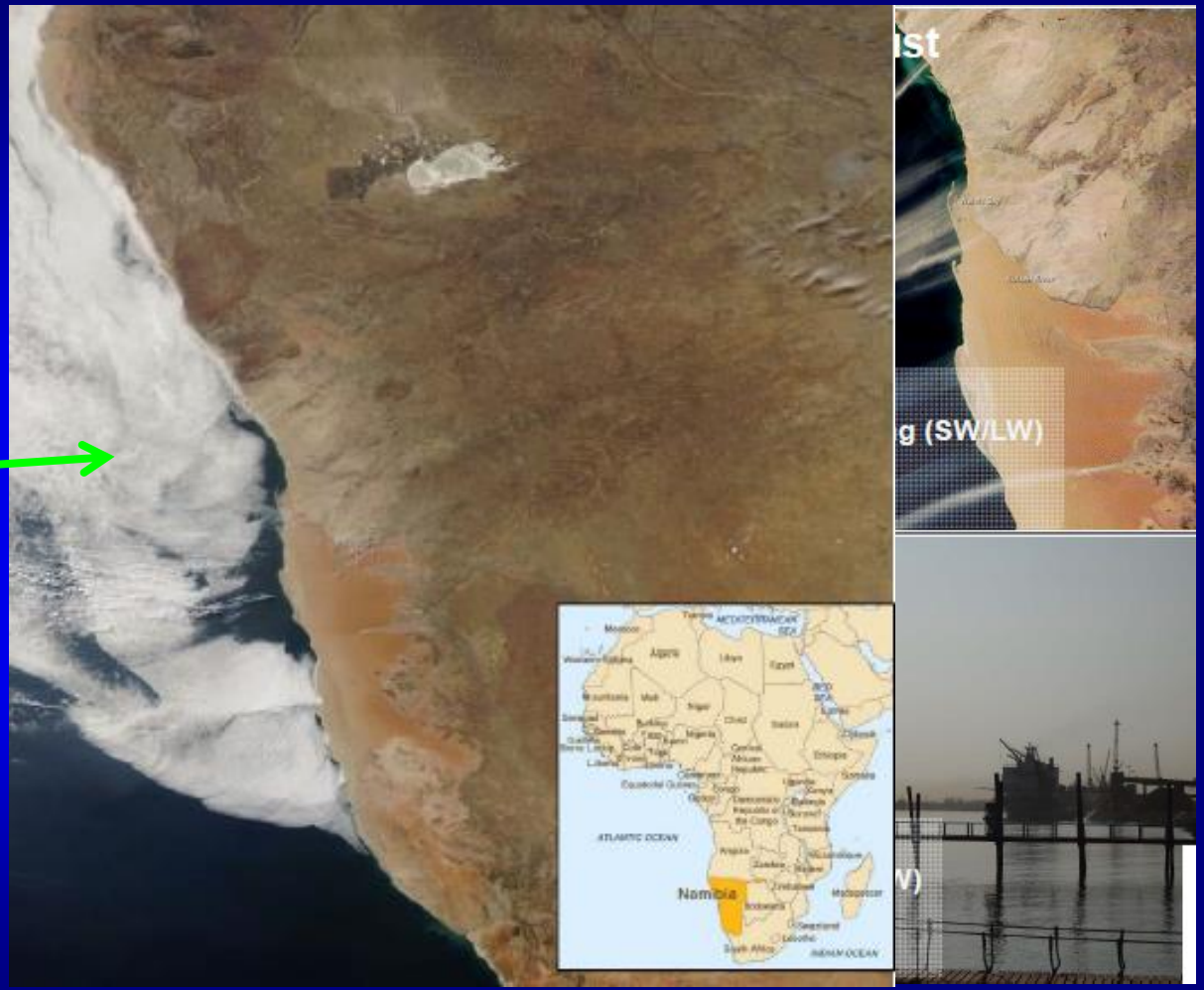
Fr-AEROCLO-SA

DOE-AMF LASIC (on ASI) extended

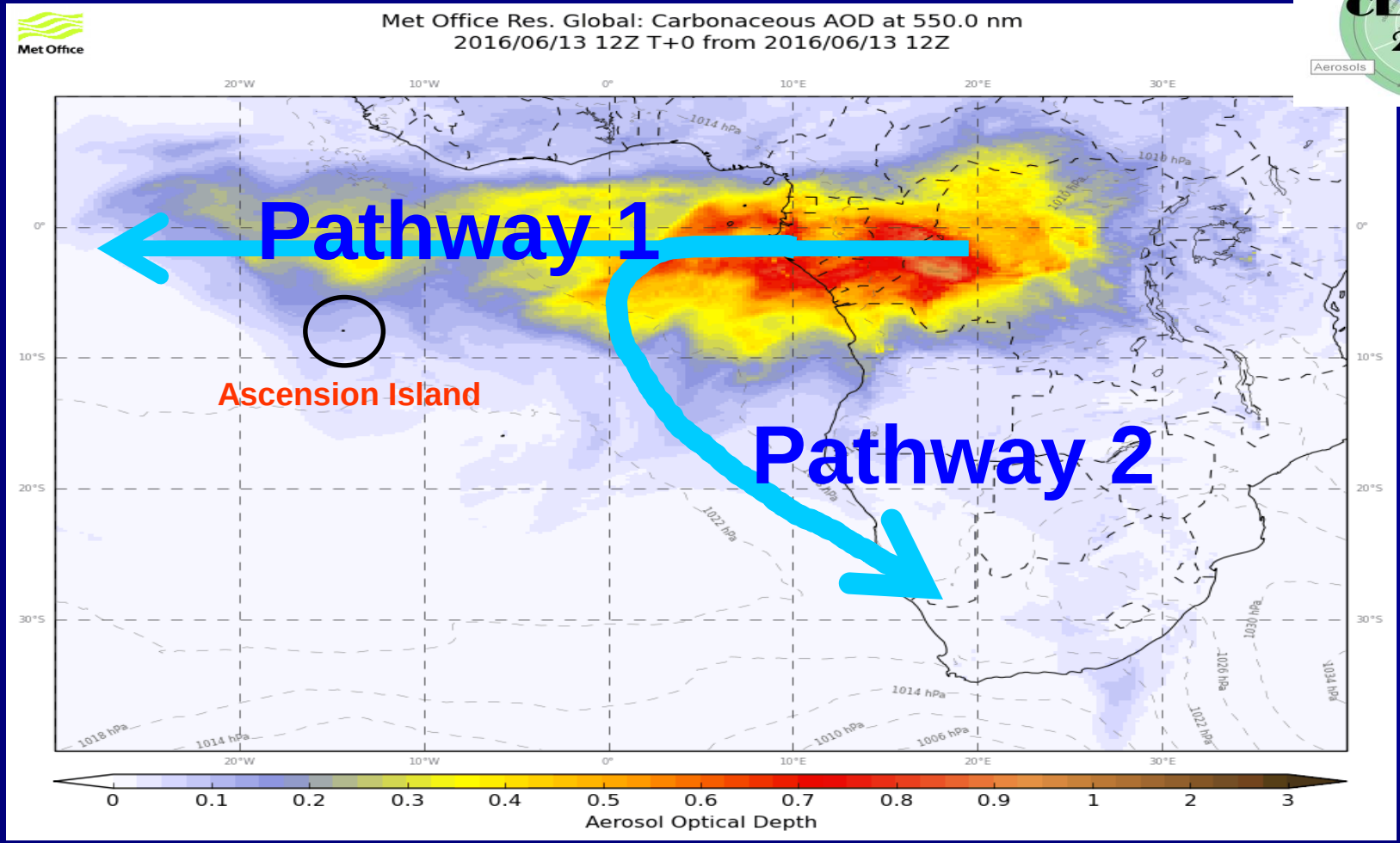


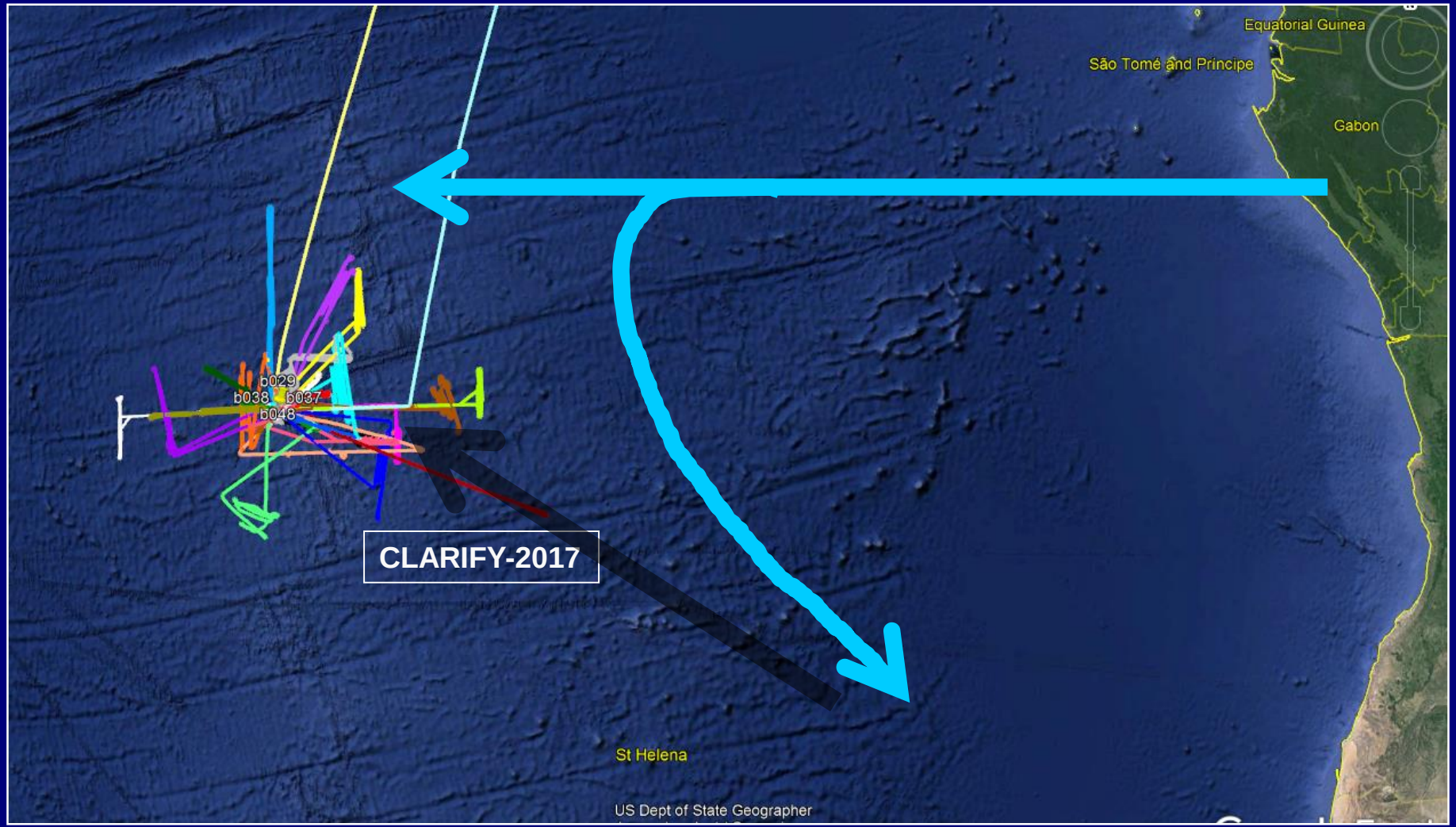
Interaction of BBA (and Dust, Marine, Urban) Aerosols with .....

Extensive semi-permanent layer of Marine Strato-cumulus cloud forming over the cool (low SST) SE Atlantic (climaticaly important)

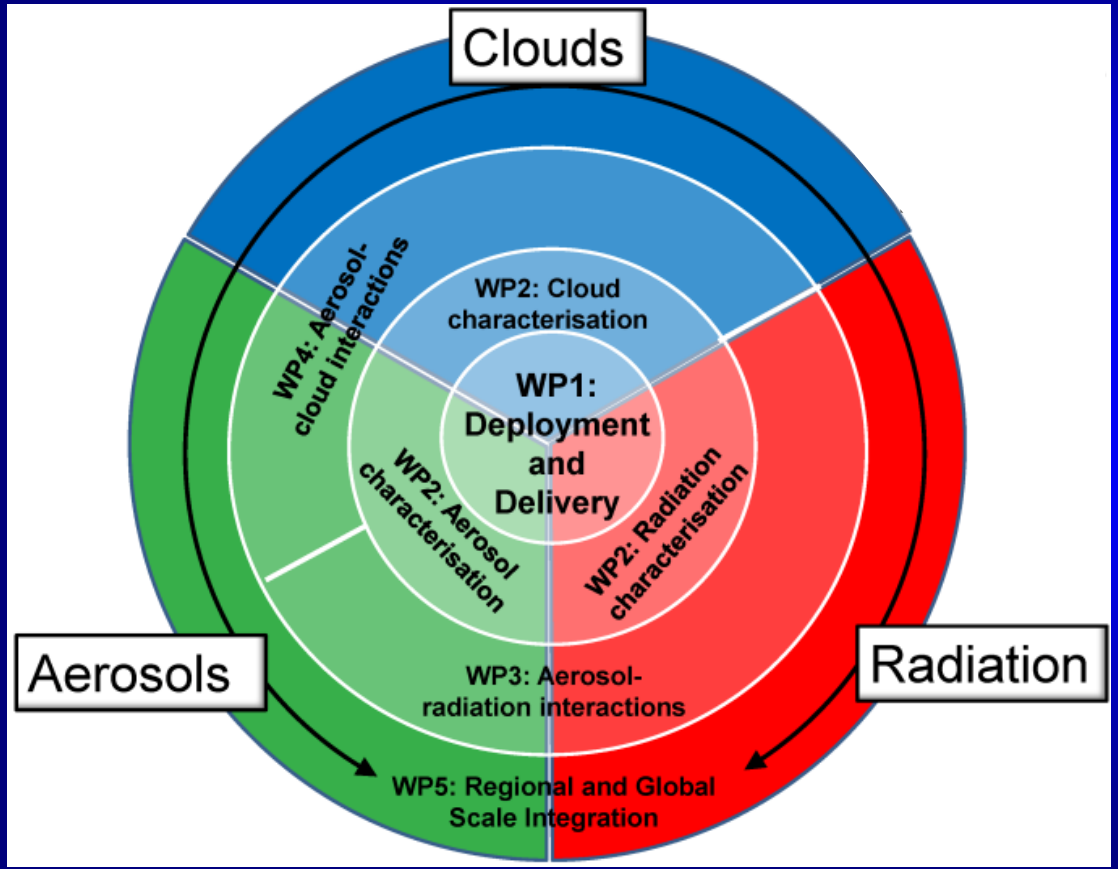


(figures From AEROCLO pre-campaign meeting Jan 2016)


Met Office
Met Office Res. Global: Carbonaceous AOD at 550.0 nm
2016/06/13 12Z T+0 from 2016/06/13 12Z
Pathway 1
Ascension Island
Pathway 2
Aerosol Optical Depth
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3


Equatorial Guinea
São Tomé and Príncipe
Gabon
b029
b038
b037
b048
CLARIFY-2017
St Helena
US Dept of State Geographer

The CLARIFY-2016/7 : Approach ……



Objectives / Work-Package Structure:

WP1: Deployment and delivery:
UoM (Coe, PI), UoE, UoO, UoL, Met Office, FAAM

WP2: Cloud, aerosol and radiation characterisation:
UoL (Blyth, PI), UoM, UoE, UoO, Met Office

WP3: Aerosol-radiation interactions:
UoE (Haywood, PI), Met Office, UoR, proj partners

WP4: Aerosol-cloud interactions:
UoO (Stier, PI), UoL, UoM

WP5: Regional and global scale integration:
UoR (Bellouin, PI), UoL, UoM, UoO, UoE, Met Office

FAAM BAe146 Instrument Fit during CLARIFY -2017:

- **Microphysics (external - wing mounted):**

PCASP	Aerosol Size	0.1 – 3.0 μm
CAS**	Cloud &aerosol size	0.6 – 50 μm
CDP	Droplet Size	2 – 50 μm
F-FSSP*	Droplet Size	2 – 50 μm
2D-S	Shadow imaging	10 – 1280 μm
CIP-15G**	Shadow imaging	15 – 960 μm
CIP-100G	Shadow imaging	100 – 6400 μm

- **Aerosol (internal - rack mounted):**
  cToF_AMS, SMPS(30-300nm), CCN, CN, Filters, SP2, UHSAS*, CPC*, APS*, Nephelometer , PSAP, EXSCALABAR#

  (off new **CVI** inlet;* **part of **CAPS**; # multi-channel, multi-wavelength: photoacoustic spectrometer & cavity ringdown spectrometer; OPC)*

- **Hygrometers:**
  SEA-wcm2000, Nevzorov (LWC, TCW), WVSS2 (TDL**), General Eastern, Buck CR2** (chilled mirrors)**, TWC** (Ly α) **….**

- **Others:**
  Gases (O_3, SO_2 CO, FGGA); Met (T, p, wind, turb), AIMMS-20, Drop Sondes, Radiometers (BBR Pyr/Purg)**, MARRS, SWS, SHIMS, Aerosol Lidar …etc**

FAAM (Facility for Airborne Atmospheric Measurements) BAe146

Flying Period

16th August to 9th September (25 days)

Science Flights:

28 flights on 18 flying days (~100 hours)

8x singles and
10x doubles

(flying days inc: 1x double: ferry flight to/from Monrovia)

FAAM aircraft on the apron on Ascension Island – cloud in background

Intercomparison Flight

FAAM BAe146 and NASA P3 (Oracles)

18th August (C031)

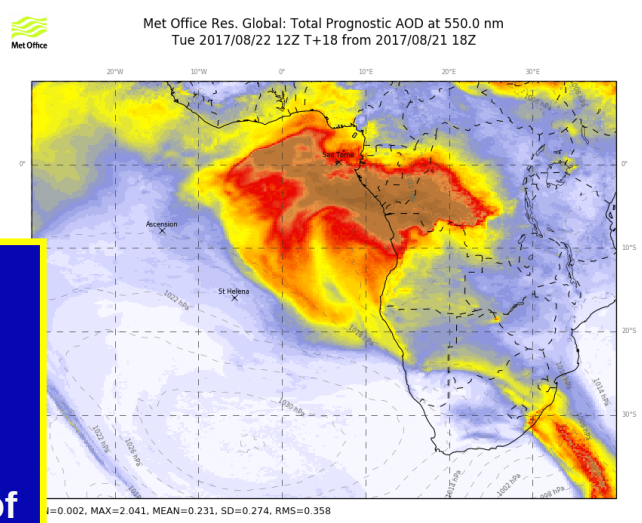
Offset and wing tip to wing tip out of cloud SLRs at various altitudes

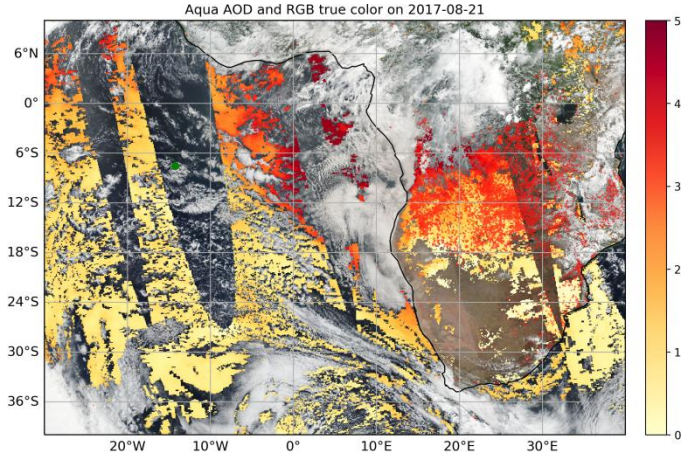
trailing legs in-cloud

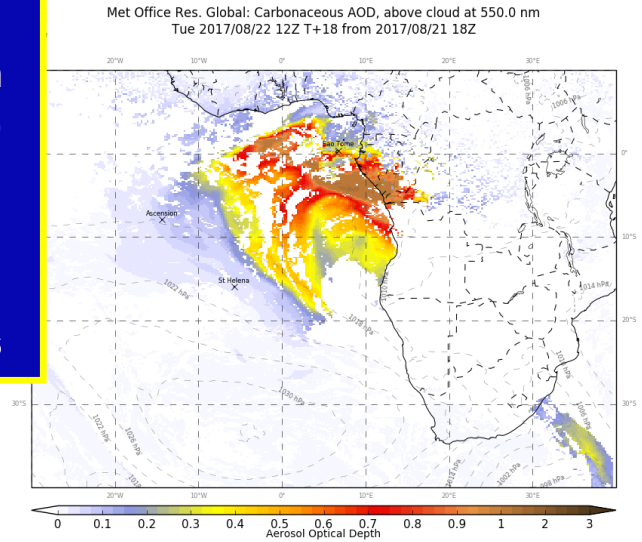
Flight planning:

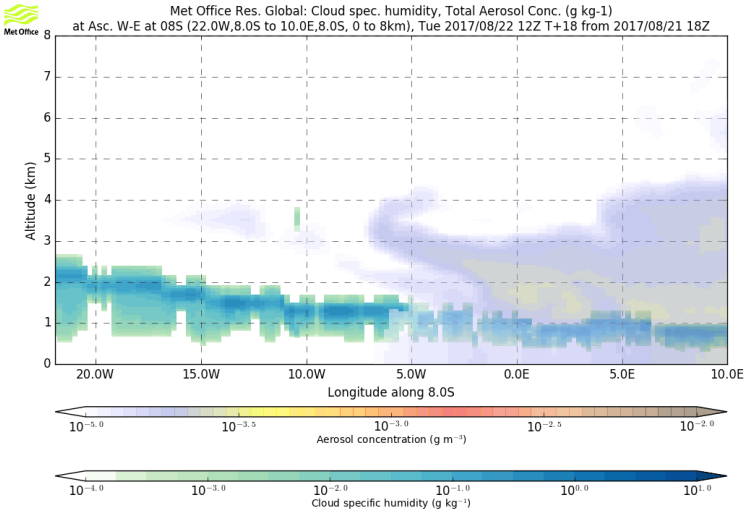
Use various model products to predict presence/position of BBA plumes day to day, and interaction with MBL cloud etc.

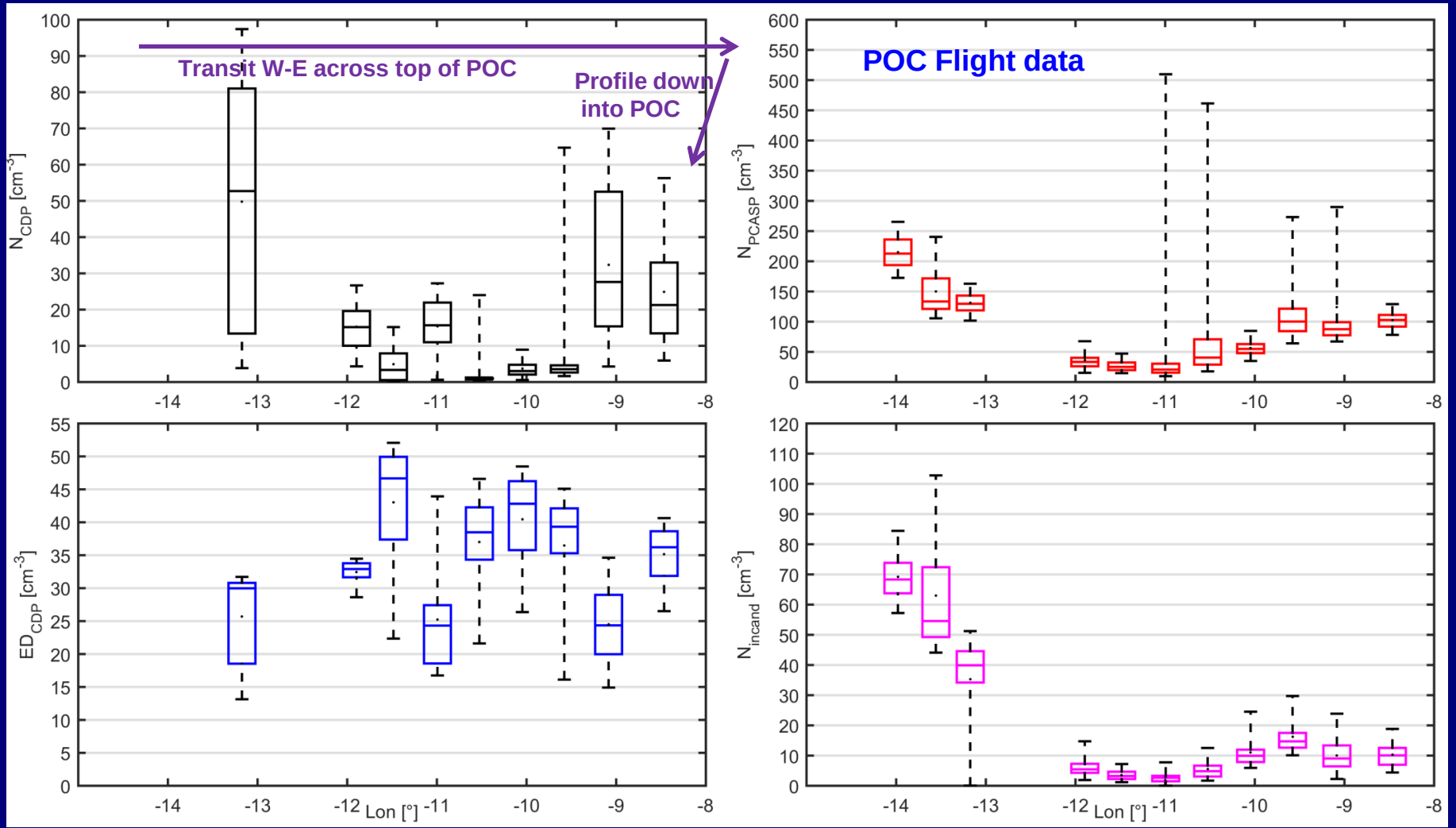
.... to determine the objectives and detailed flight plans

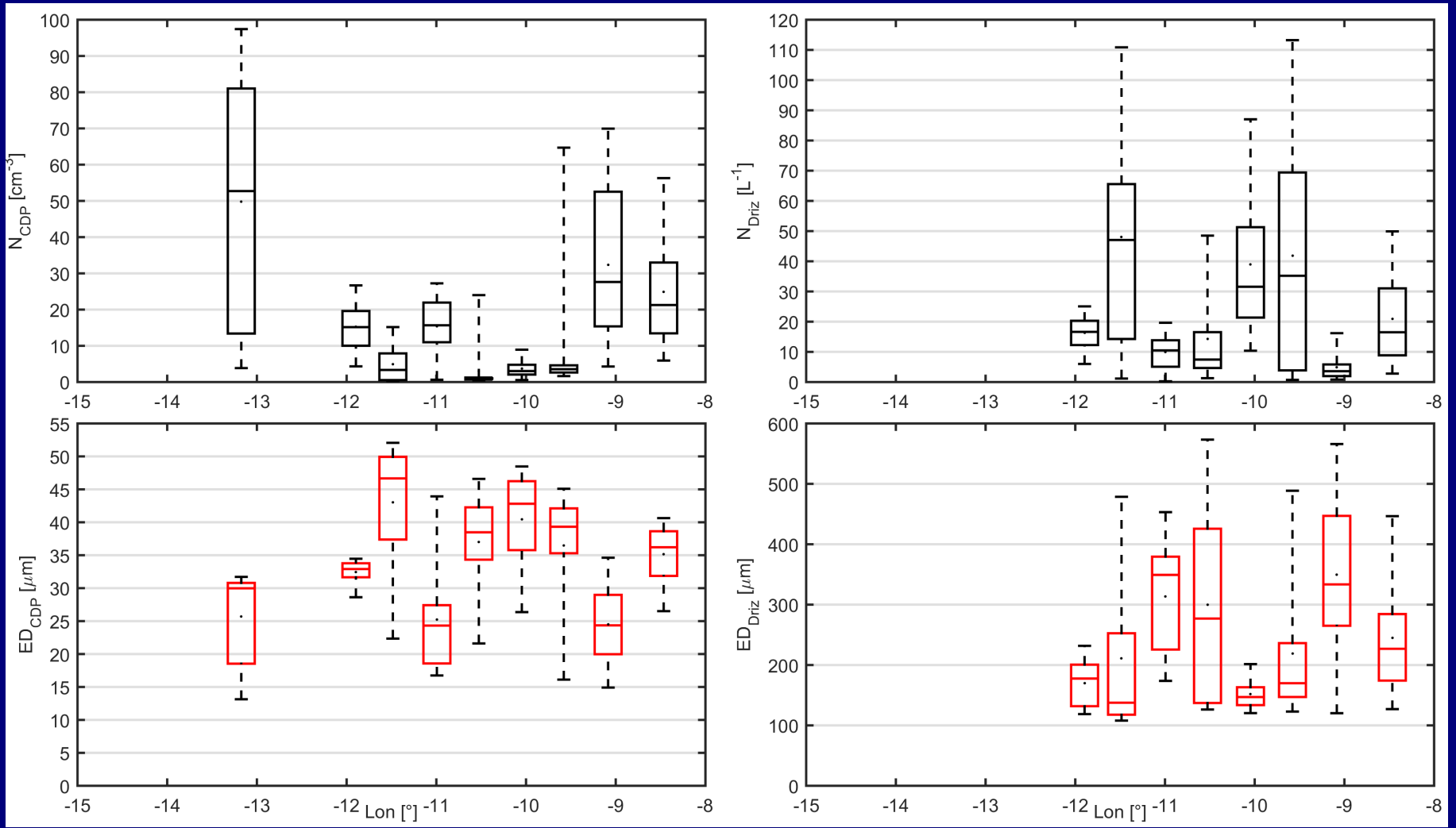


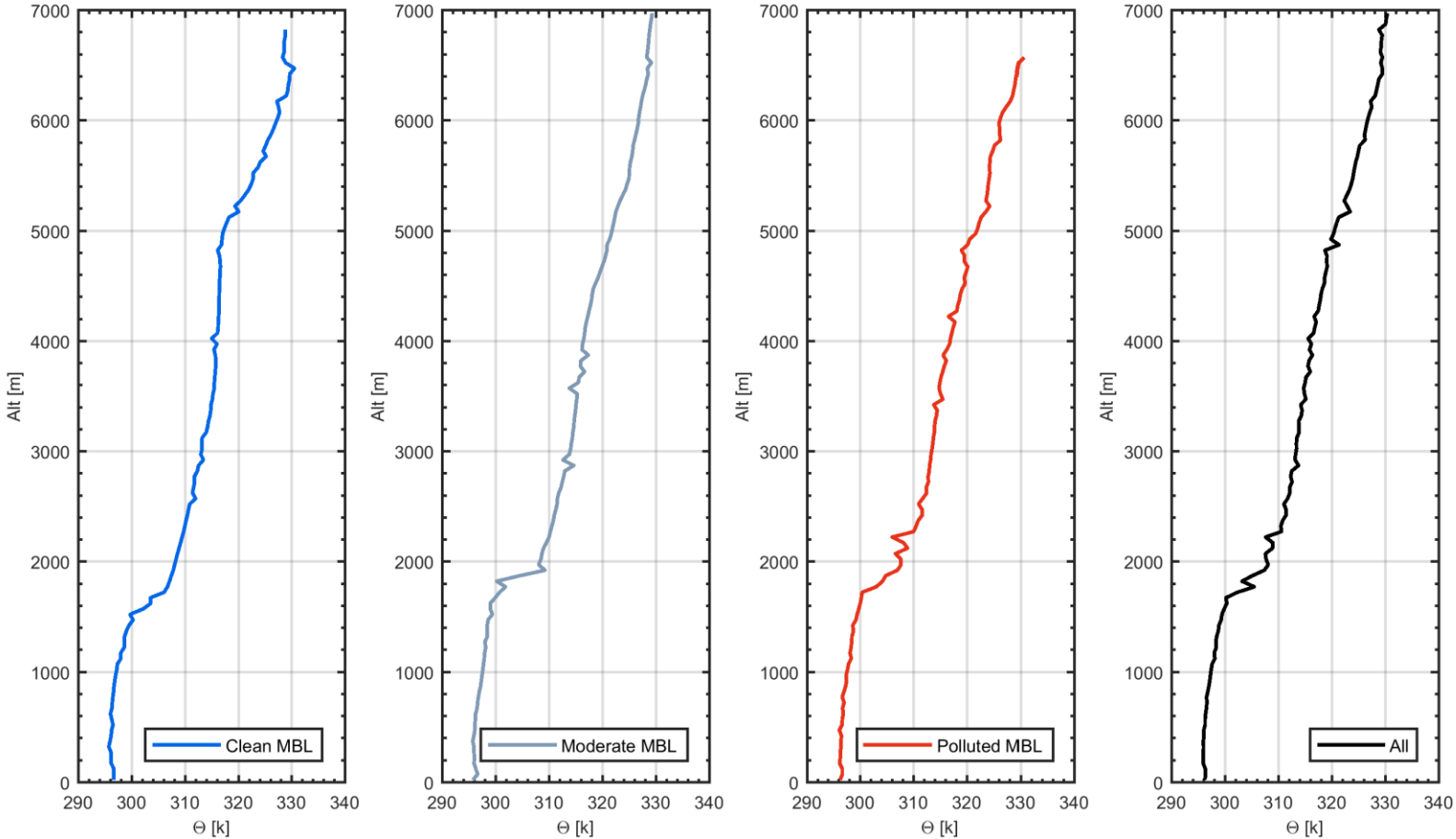


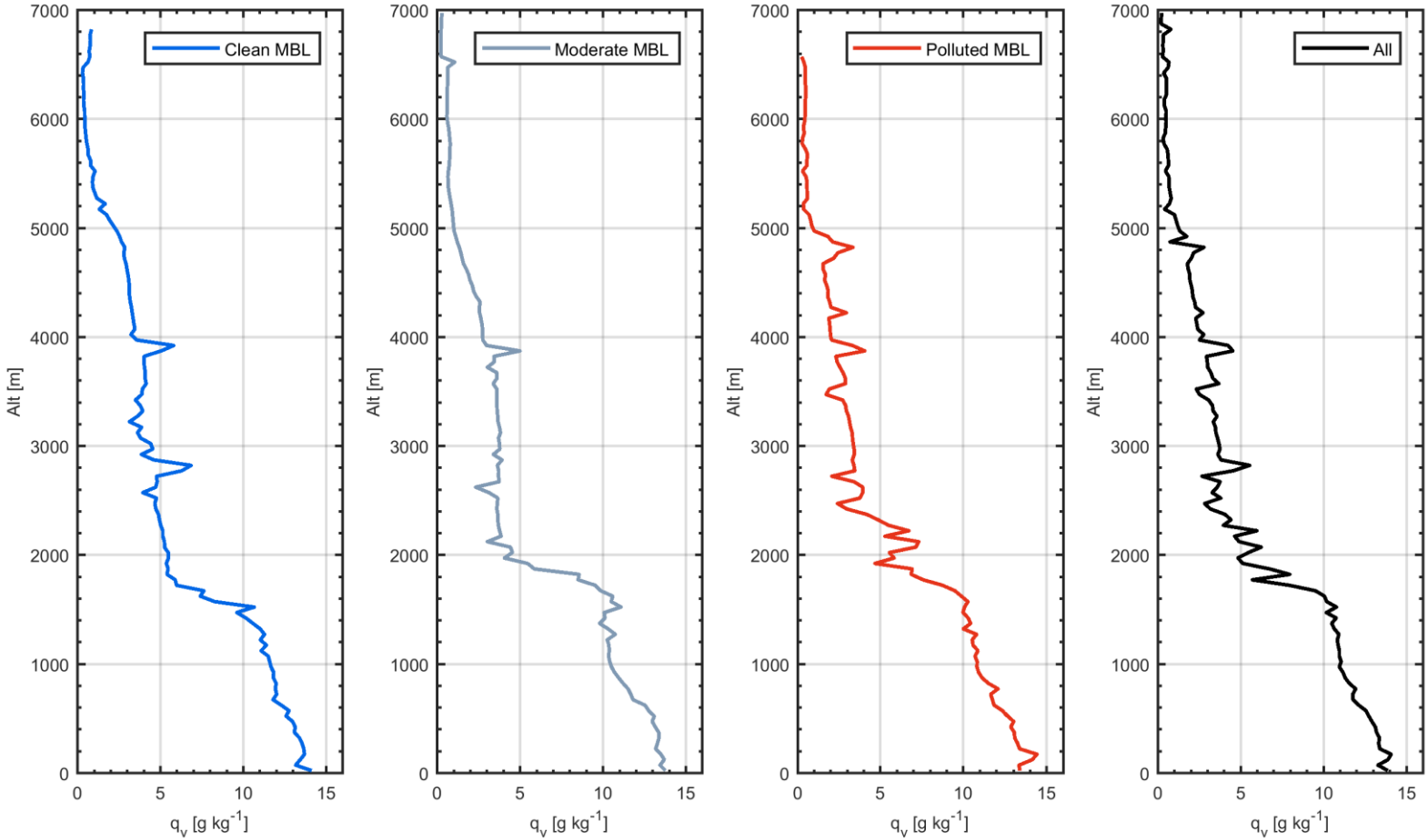





Transit W-E across top of POC
Profile down into POC
POC Flight data
N_{CDP} [cm^{-3}]
N_{PCASP} [cm^{-3}]
ED_{CDP} [cm^{-3}]
N_{incand} [cm^{-3}]
Lon [°]
Lon [°]

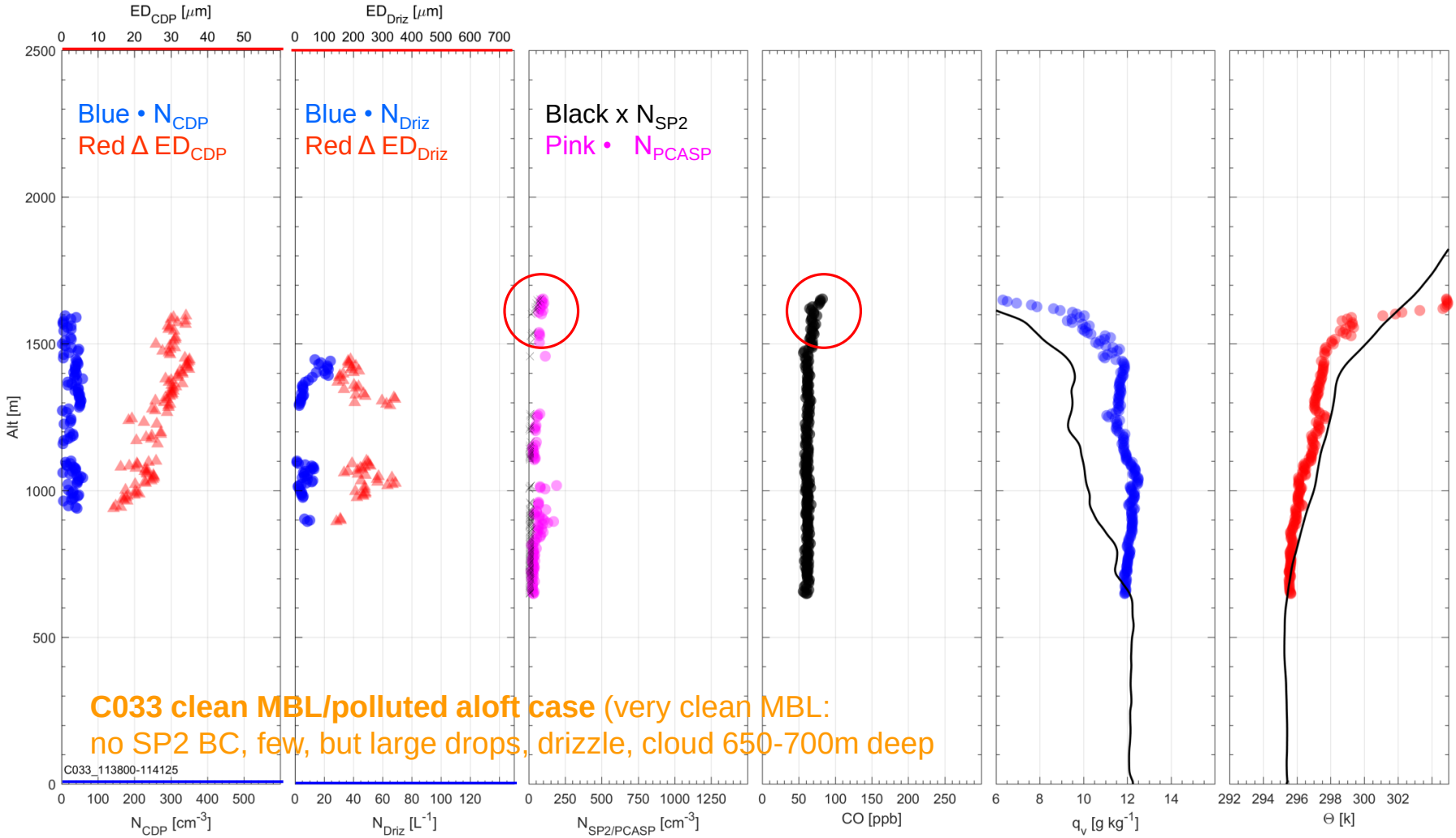

N_CDP [cm^-3]
N_Driz [L^-1]
ED_CDP [μm]
ED_Driz [μm]
Lon [°]
Lon [°]


Alt [m]
Θ [k]
Clean MBL
Moderate MBL
Polluted MBL
All

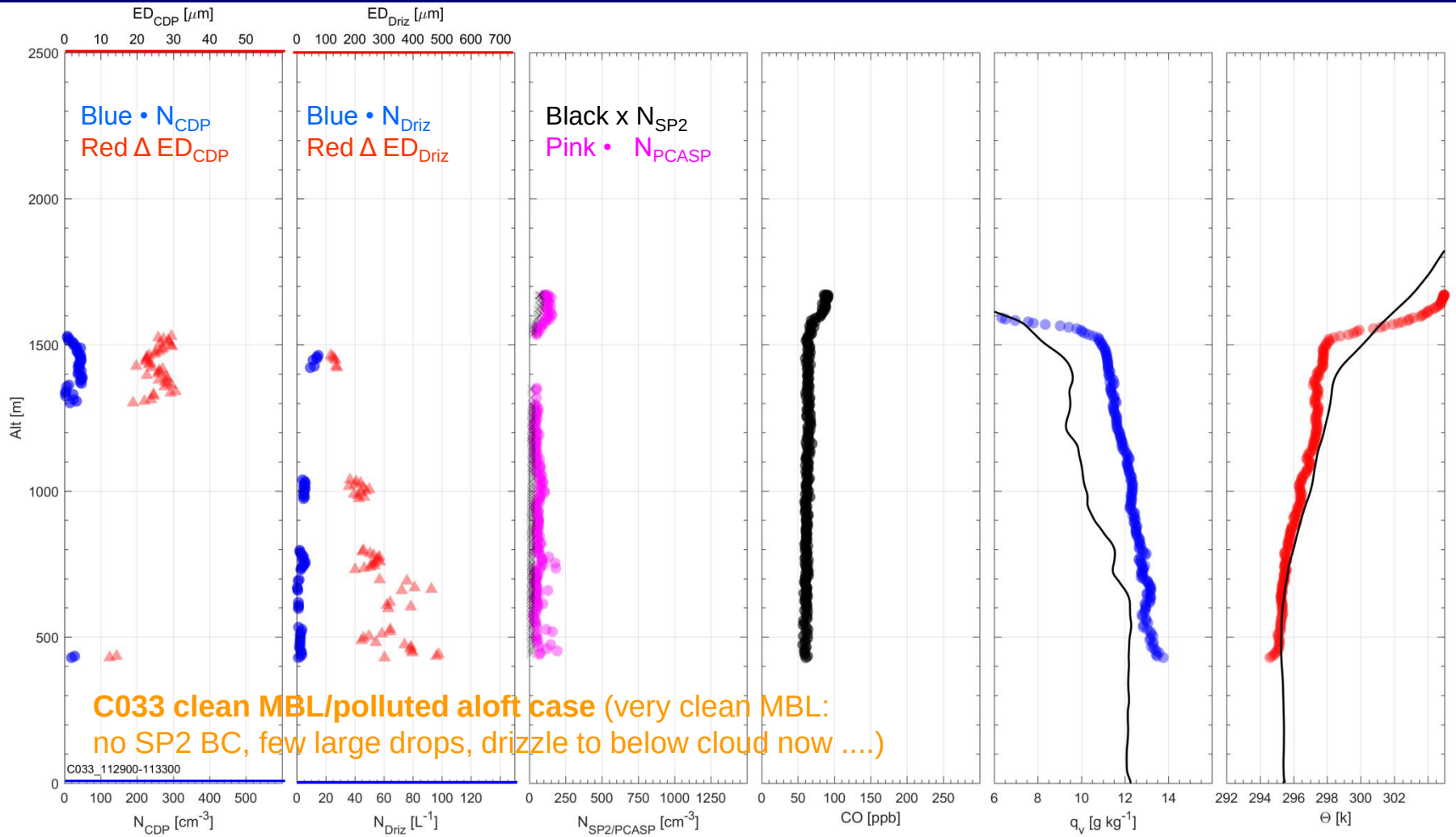

Clean MBL
Moderate MBL
Polluted MBL
All
Alt [m]
q_v [g kg^{-1}]
0
1000
2000
3000
4000
5000
6000
7000
0
5
10
15

If time permits: some individual case study profiles and relevant back trajectories showing diff origins of air (500m /3km altitudes)

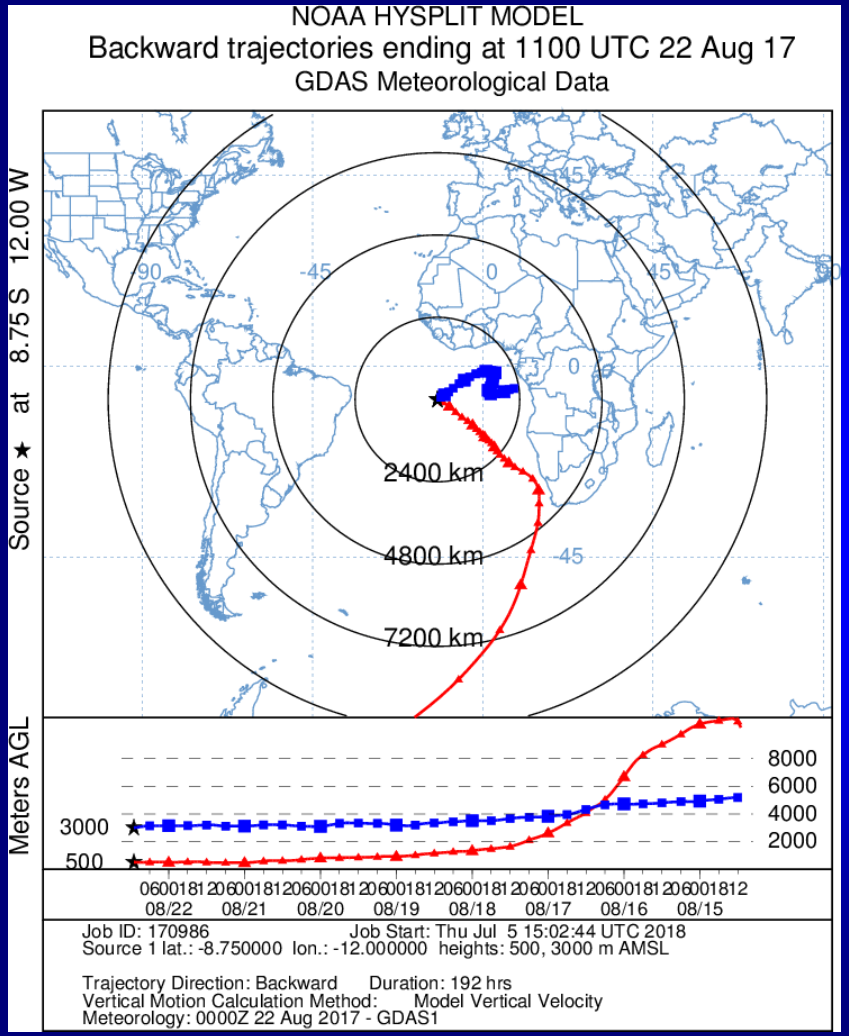
Or skip these and go to compare CLAIRIFY with DACCIWA-2016 results .....



C033 clean MBL/polluted aloft case (very clean MBL:
no SP2 BC, few, but large drops, drizzle, cloud 650-700m deep



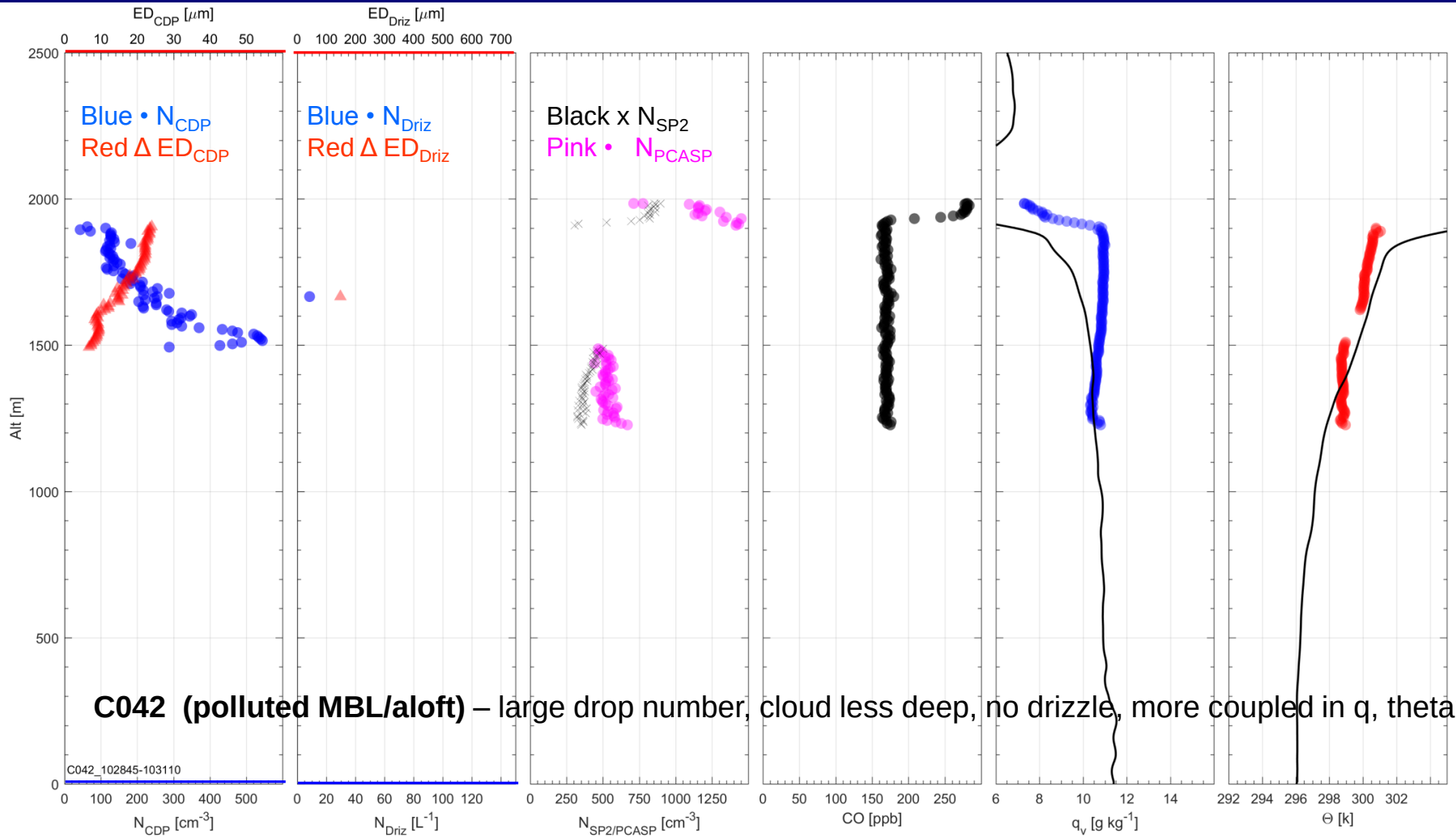
C033 clean MBL/polluted aloft case (very clean MBL:
no SP2 BC, few large drops, drizzle to below cloud now ....)



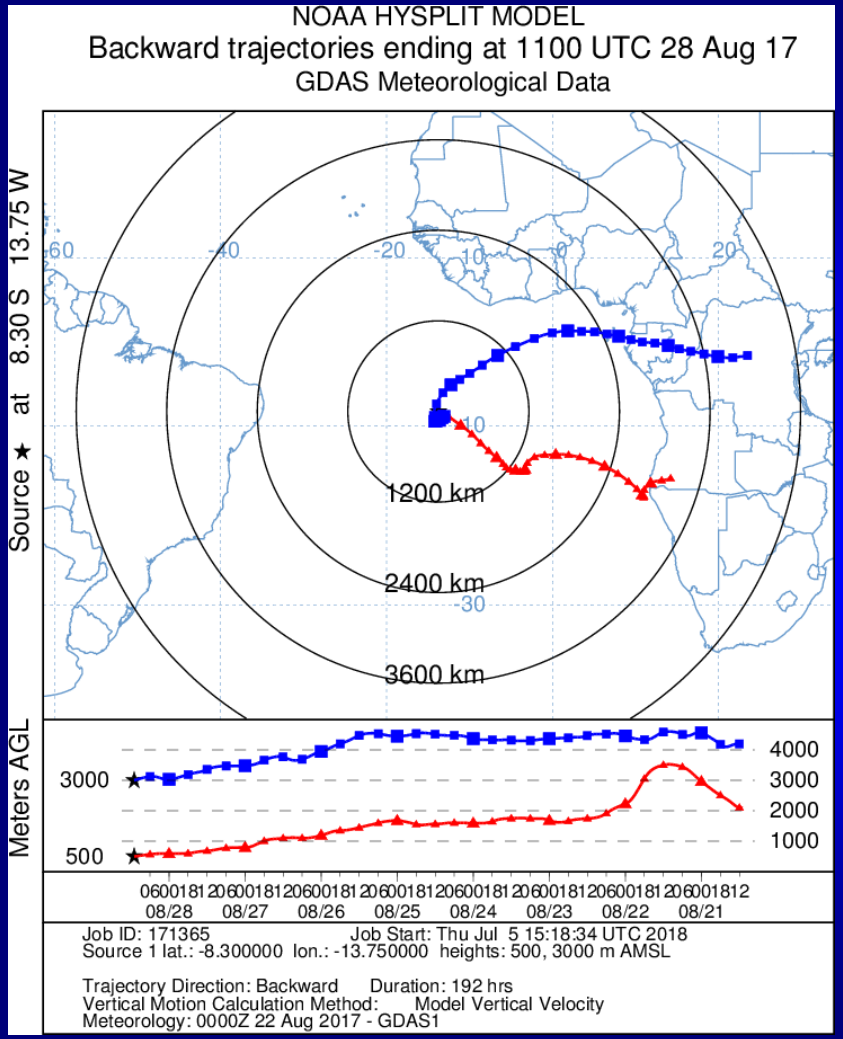
Hysplit 7-day Back Trajectories

C033 clean MBL/polluted aloft

.... 500m (red) and 3000m (blue)



C042 (polluted MBL/aloft) – large drop number, cloud less deep, no drizzle, more coupled in q, theta?



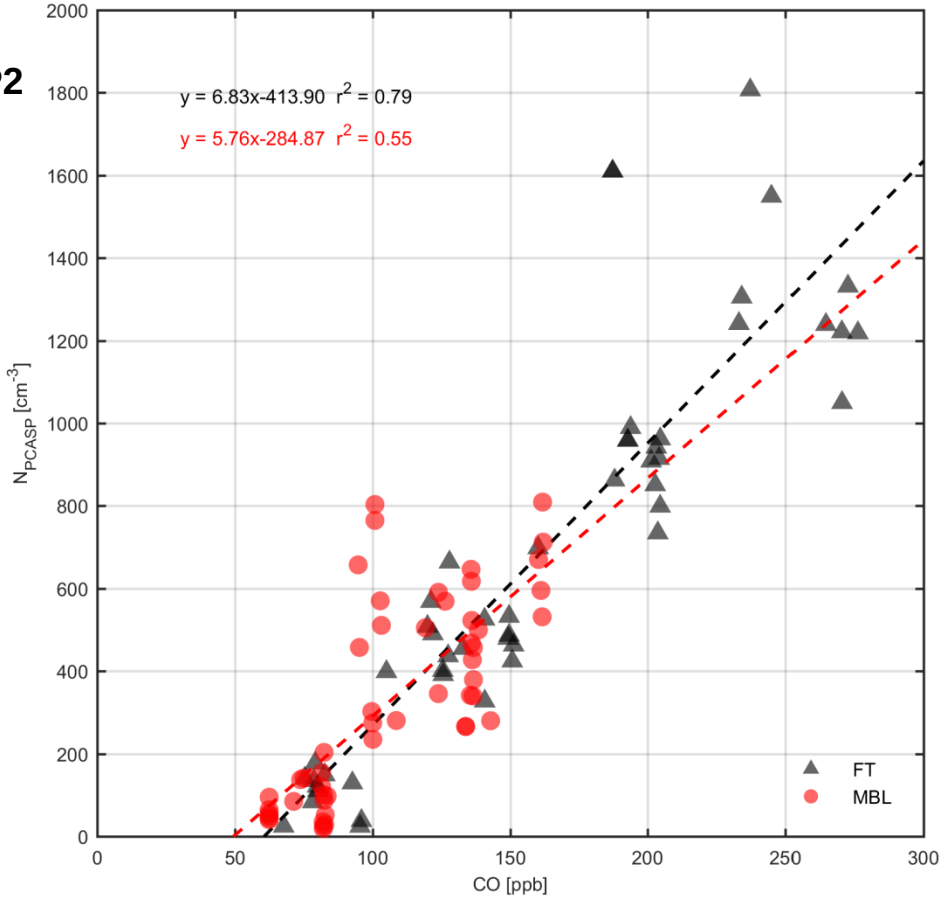
Hysplit 7-day Back Trajectories

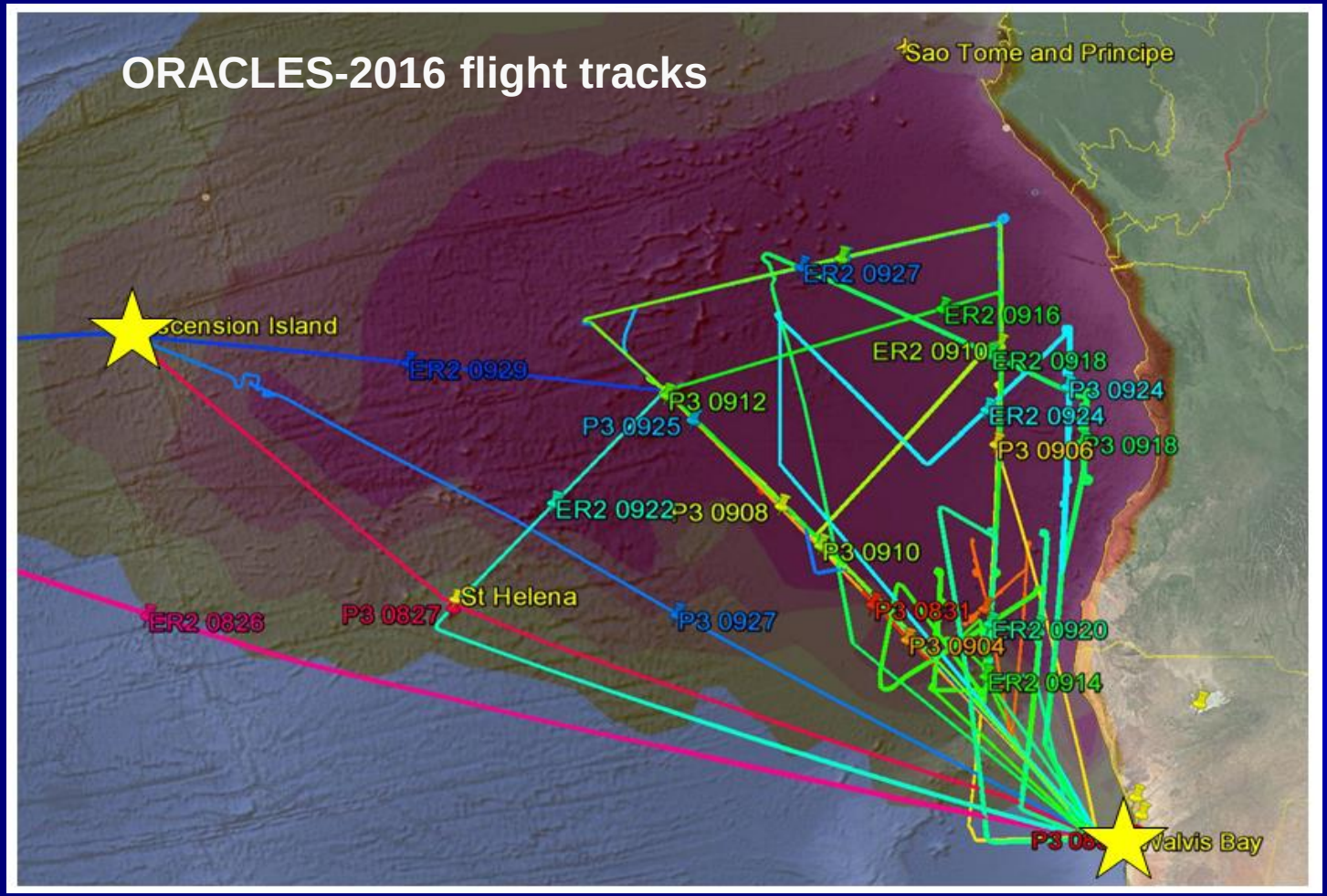
C042 polluted MBL & aloft

.... 500m (red) and 3000m (blue)

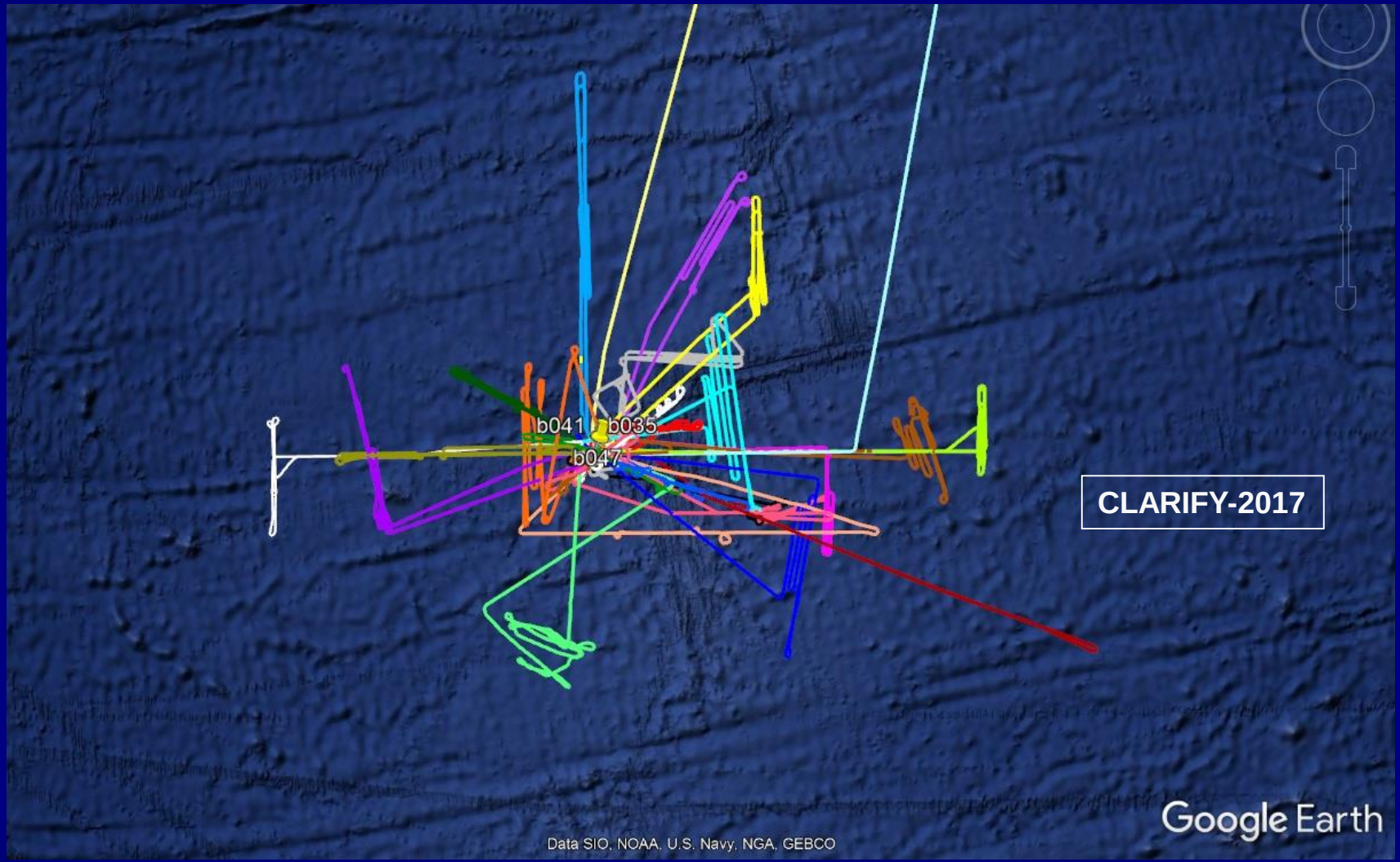
Have double plot with SP2

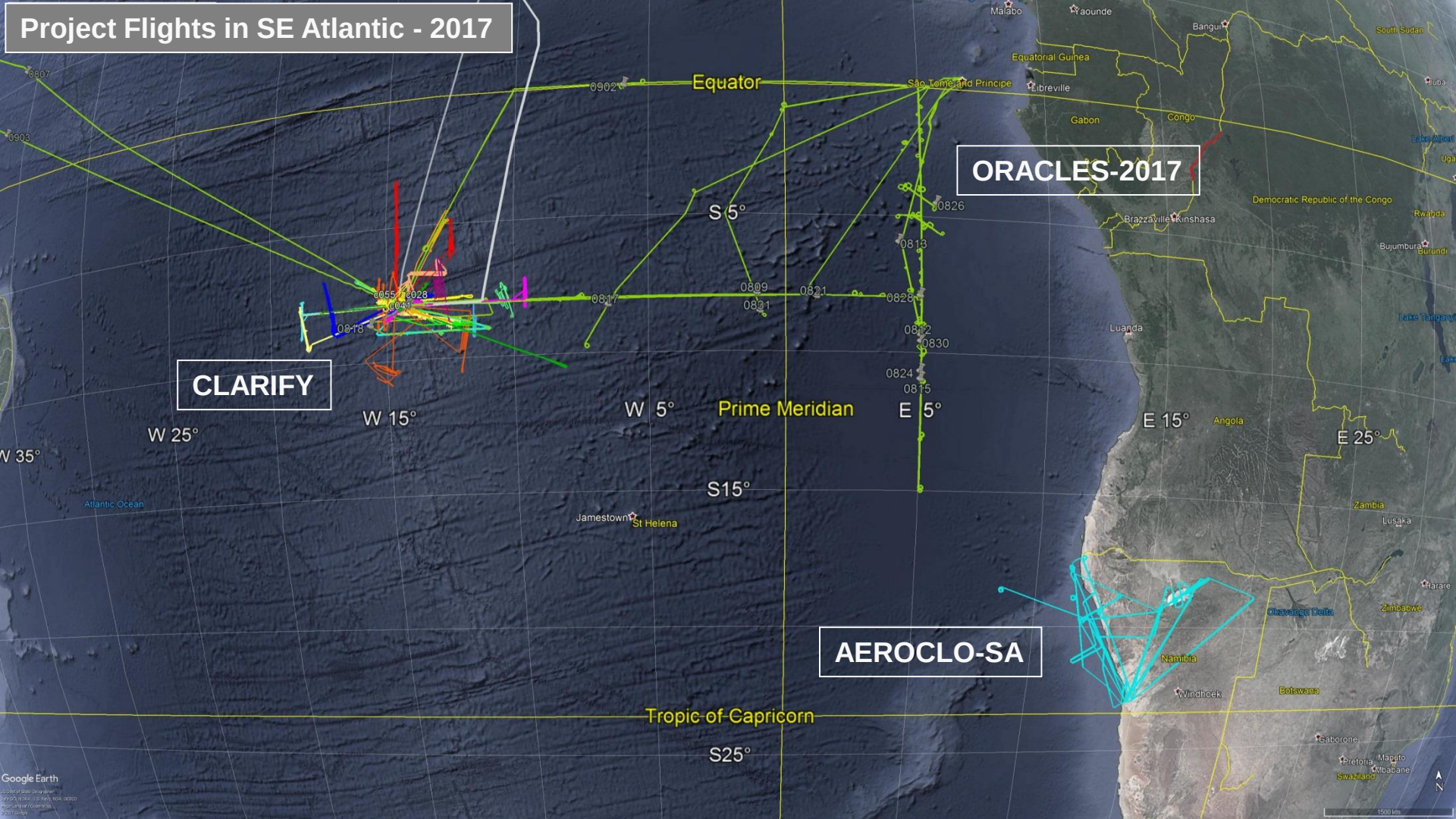
To be updated

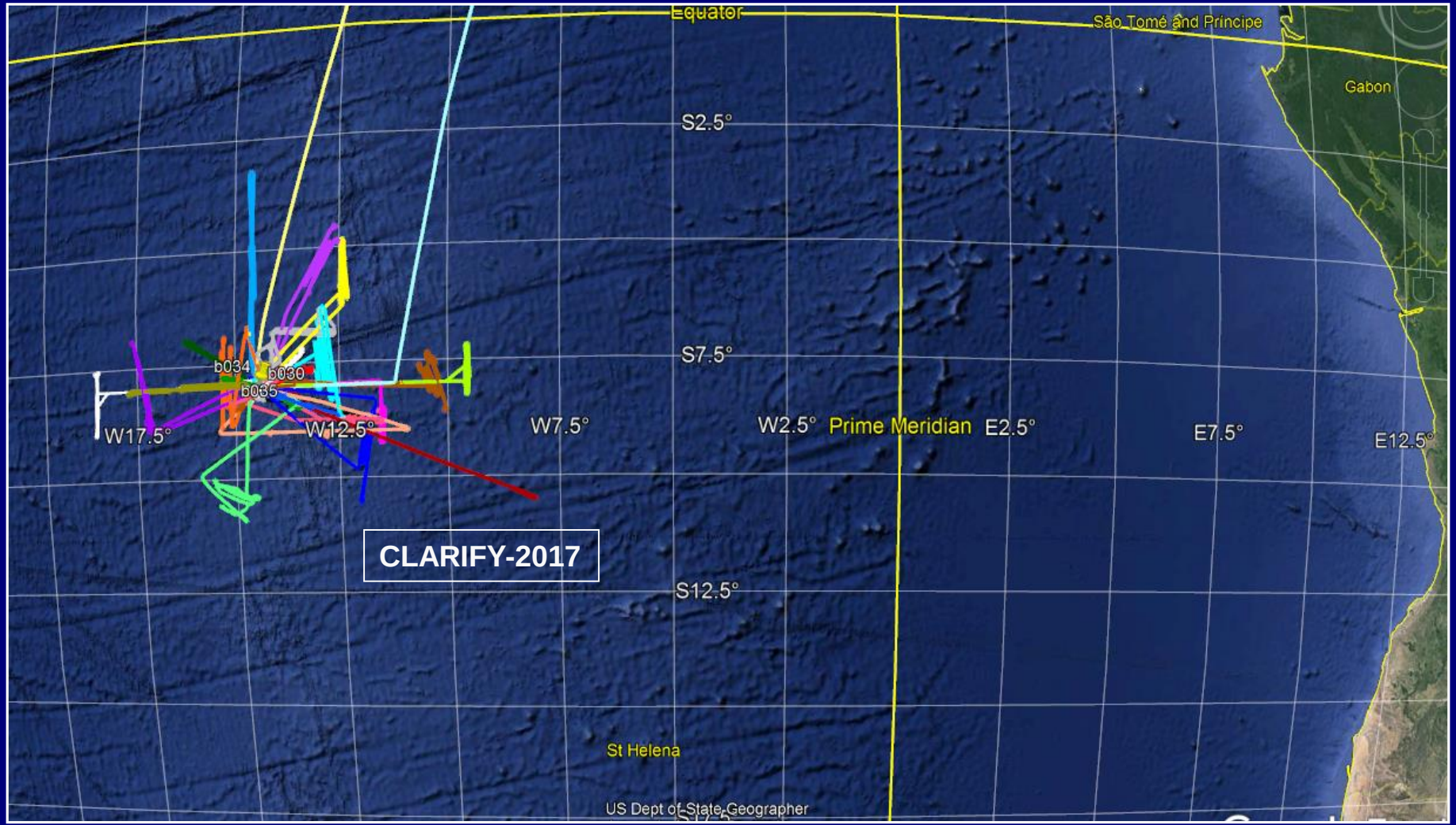




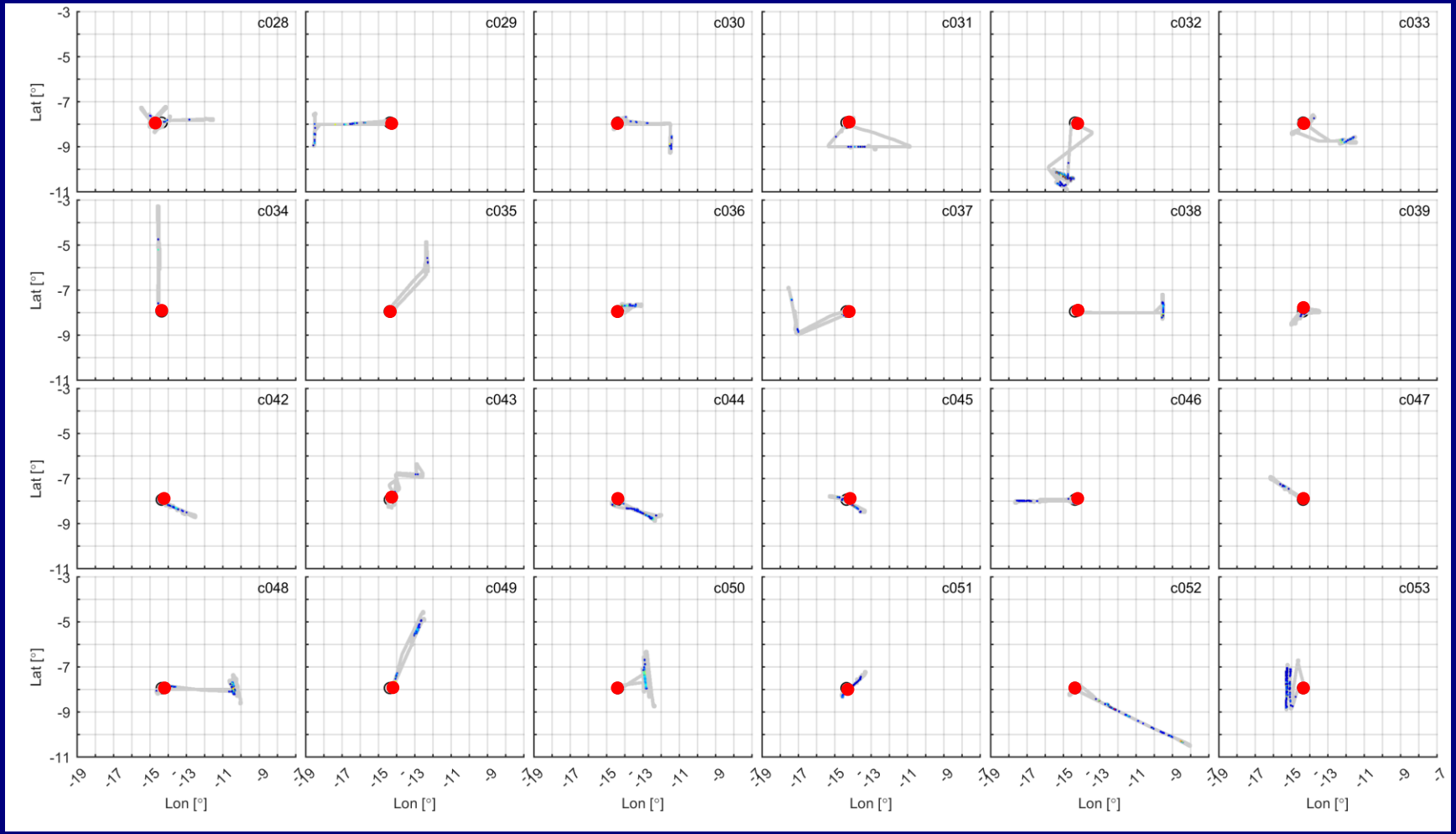
The successful deployment of the ORACLES campaign in 2016 ..... which focussed on a different meteorological regime


b041
b035
b047
CLARIFY-2017
Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

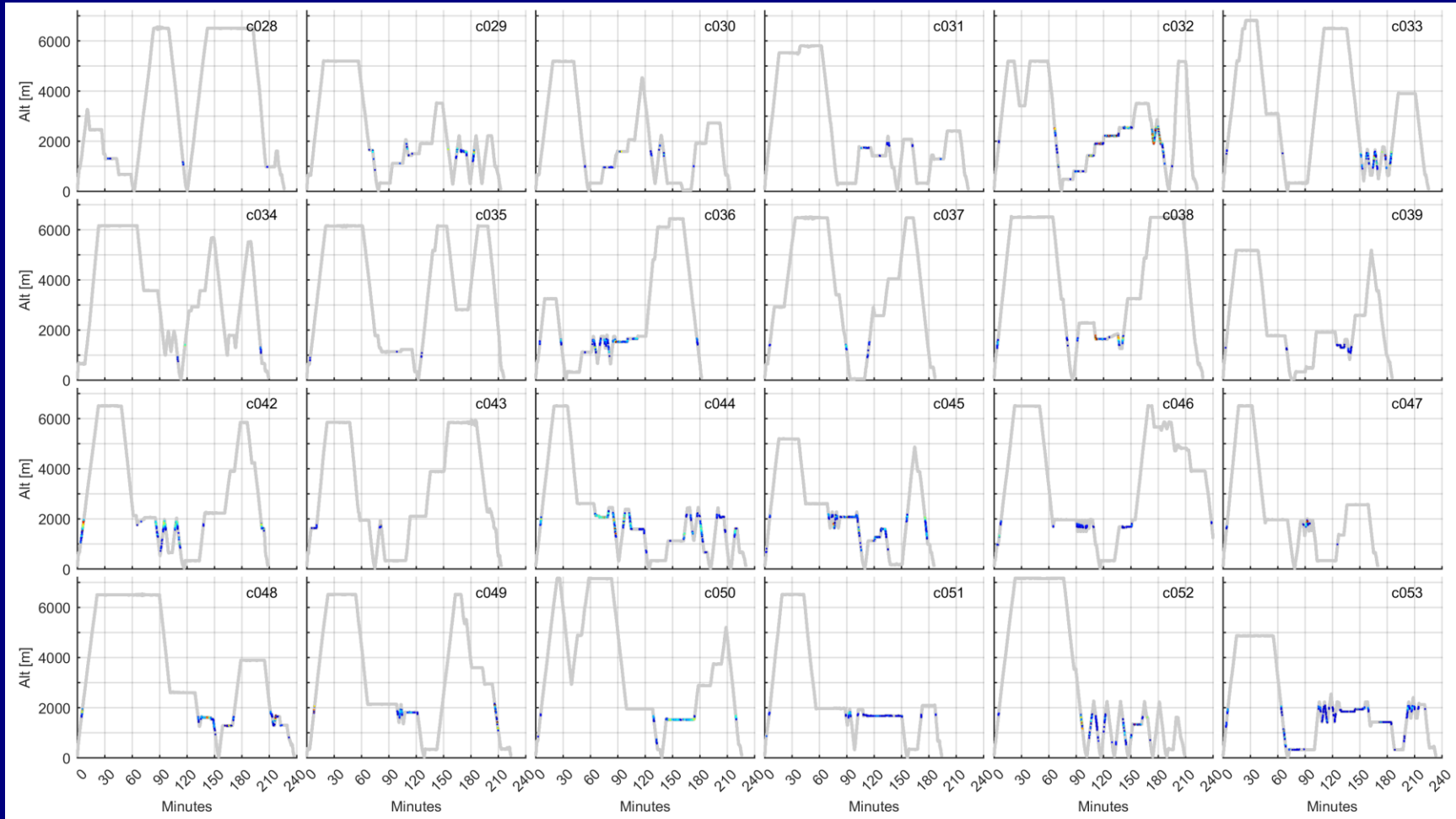

Project Flights in SE Atlantic - 2017
ORACLES-2017
CLARIFY
AEROCLO-SA
Equator
Prime Meridian
Tropic of Capricorn
S 5°
S15°
S25°
W 25°
W 15°
W 5°
E 5°
E 15°
E 25°
W 35°
0807
0902
0903
0826
0813
0809
0821
0817
0831
0828
0818
0812
0830
0824
0815
c055
c028
c041
São Tomé and Principe
Malabo
Yaounde
Bangui
South Sudan
Equatorial Guinea
Libreville
Gabon
Congo
Democratic Republic of the Congo
Brazzaville
Kinshasa
Bujumbura
Burundi
Rwanda
Luanda
Angola
Zambia
Lusaka
Zimbabwe
Harare
Okavango Delta
Namibia
Windhoek
Botswana
Gaborone
Pretoria
Maputo
Mbabane
Swaziland
Atlantic Ocean
Jamestown
St Helena
Google Earth

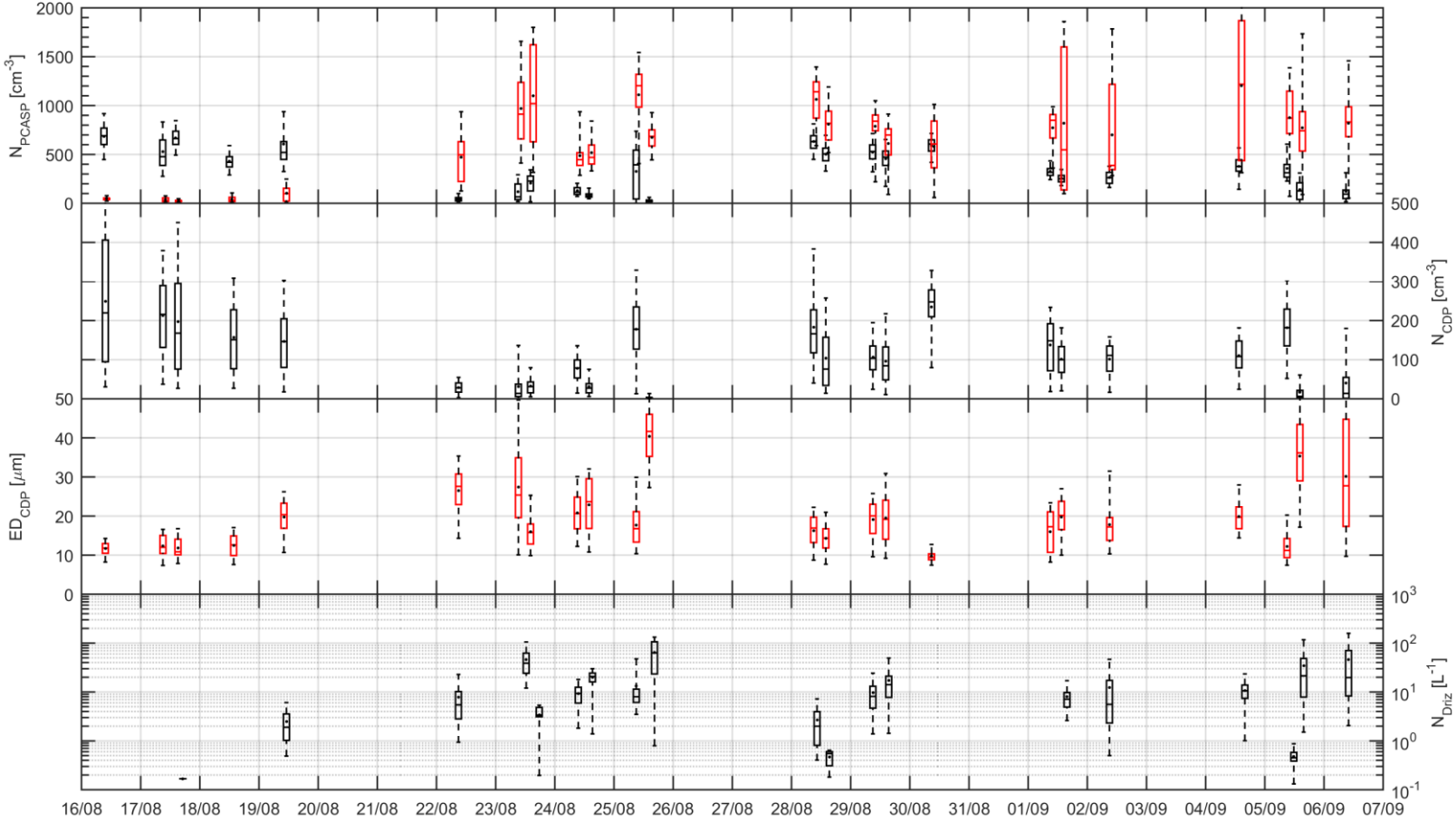

Equator
São Tomé and Príncipe
Gabon
S2.5°
S7.5°
S12.5°
W17.5°
W12.5°
W7.5°
W2.5°
Prime Meridian
E2.5°
E7.5°
E12.5°
b034
b030
b035
CLARIFY-2017
St Helena
US Dept of State Geographer

Flight track summary – CLARIFY-2017



Flight profile summary – CLARIFY-2017




N_PCASP [cm^-3]
2000
1500
1000
500
0
N_CDP [cm^-3]
500
400
300
200
100
0
50
ED_CDP [μm]
40
30
20
10
0
N_Driz [L^-1]
10^3
10^2
10^1
10^0
10^-1
16/08
17/08
18/08
19/08
20/08
21/08
22/08
23/08
24/08
25/08
26/08
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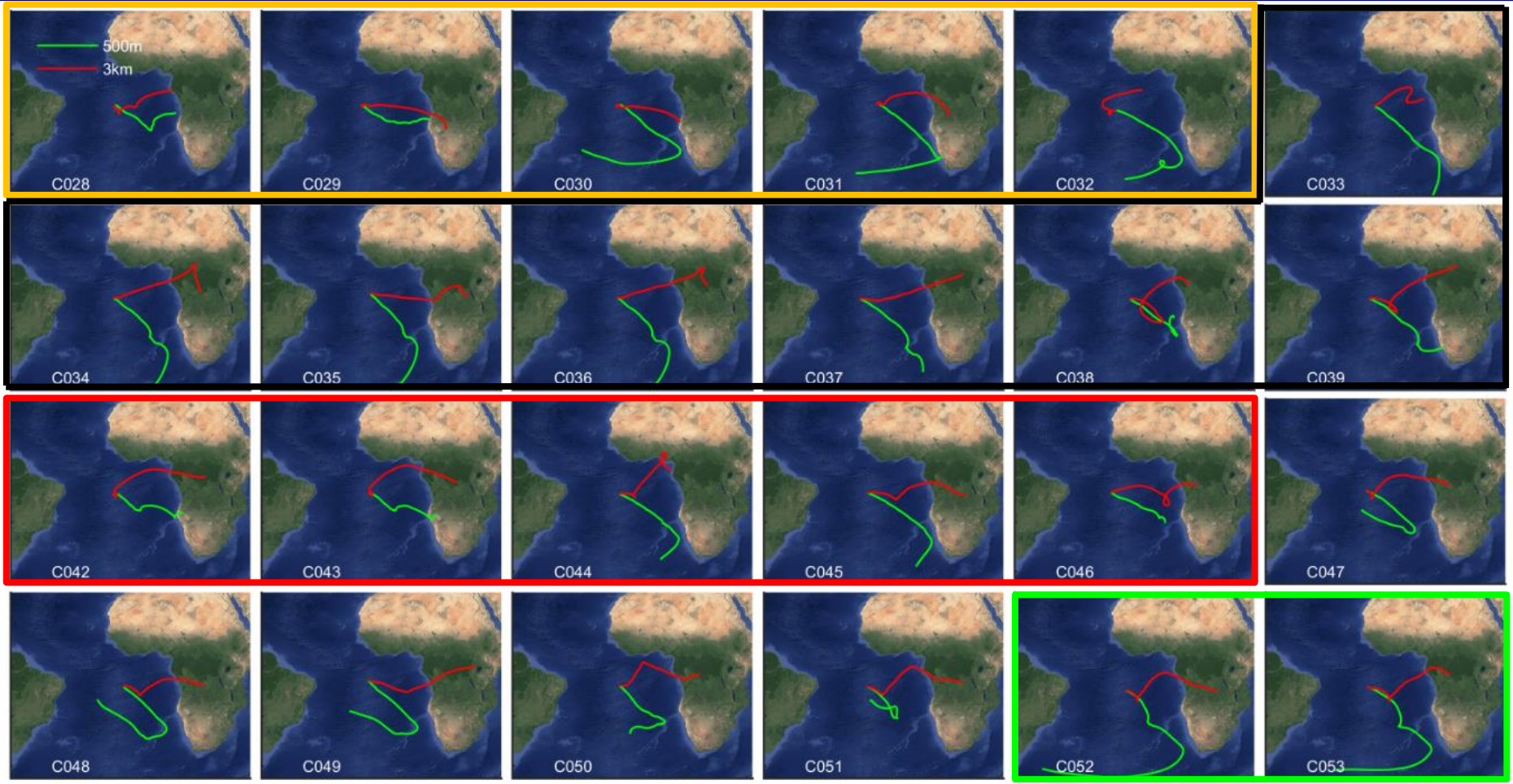
05/09
06/09
07/09

7day Back Trajectory summary – CLARIFY-2017