An aerosol-aware Lagrangian case study ensemble for LES and SCM based on the Cold-Air Outbreaks in the Marine Boundary Layer Experiment (COMBLE)

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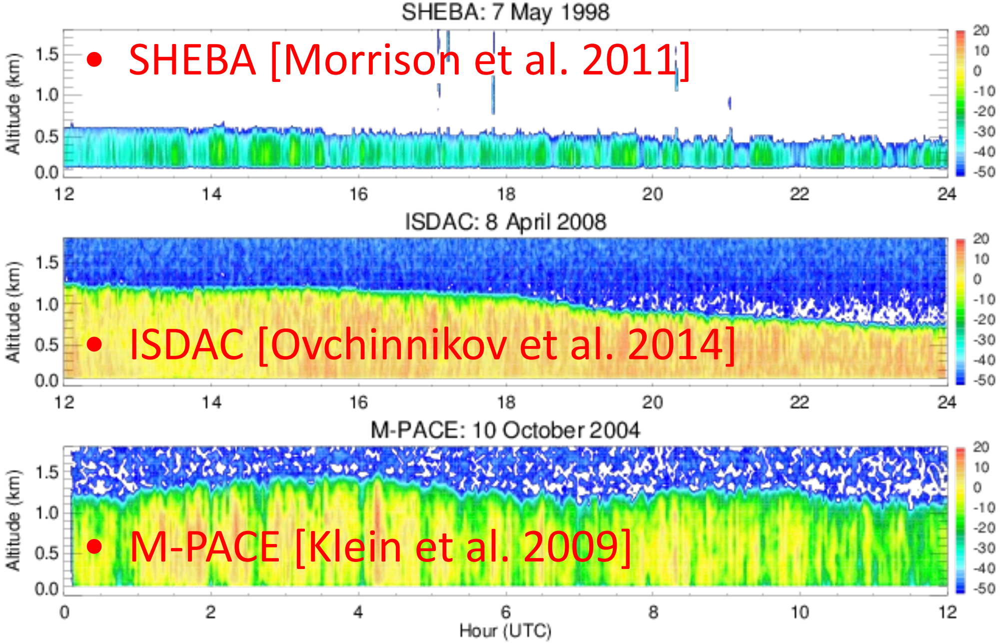
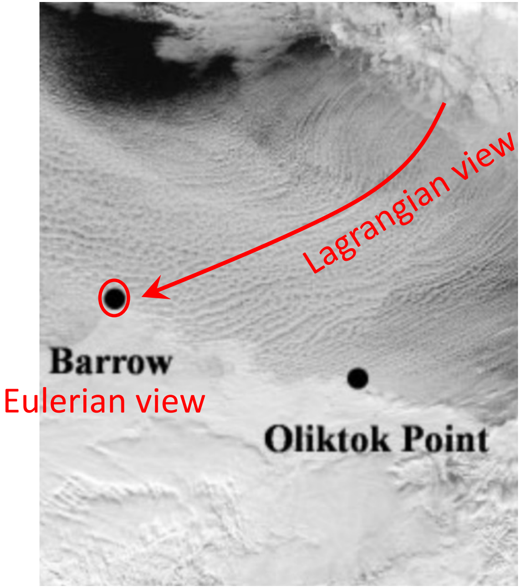
Bart Geerts / University of Wyoming
thanks also to Christian Lackner and Mikhail Ovchinnikov

Vertically pointing mm-wavelength radar

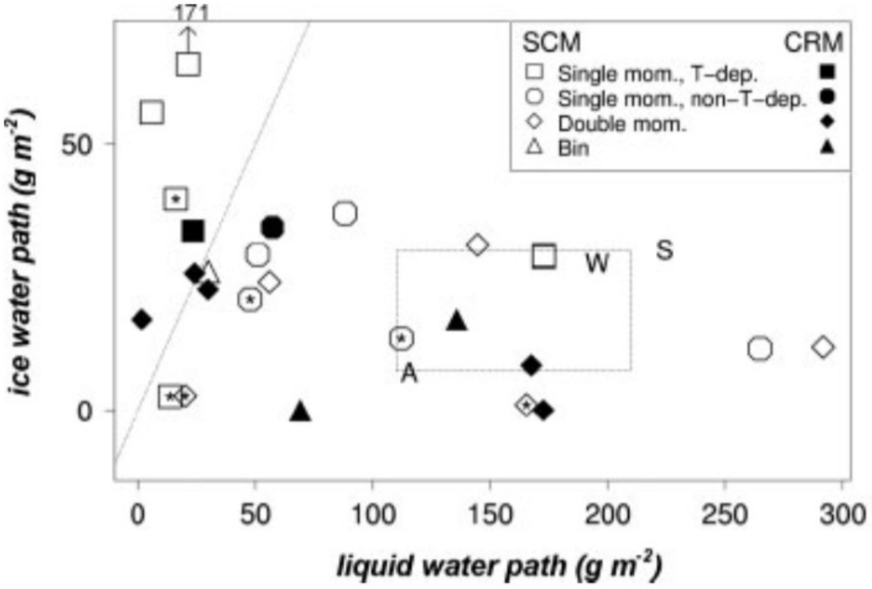


M-PACE [Klein et al. 2009]



Fridlind and Ackerman [Ch. 7 in *Mixed-Phase Clouds: Observations and Modeling*, Ed. C. Andronache, 2018]

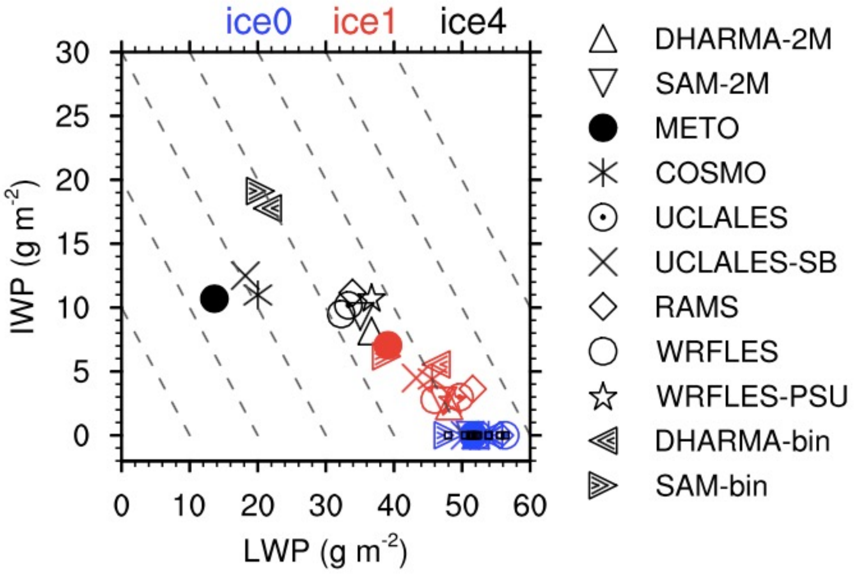
Case study setup specifications	M-PACE
nudged horizontal wind profile	Y
subsidence profile	Y
horizontal advective tendency profiles	Y
sensible and latent heat fluxes	Y
hygroscopic aerosol size distribution	Y
ice nucleating aerosol (somehow)	Y
setup for LES and SCM	Y



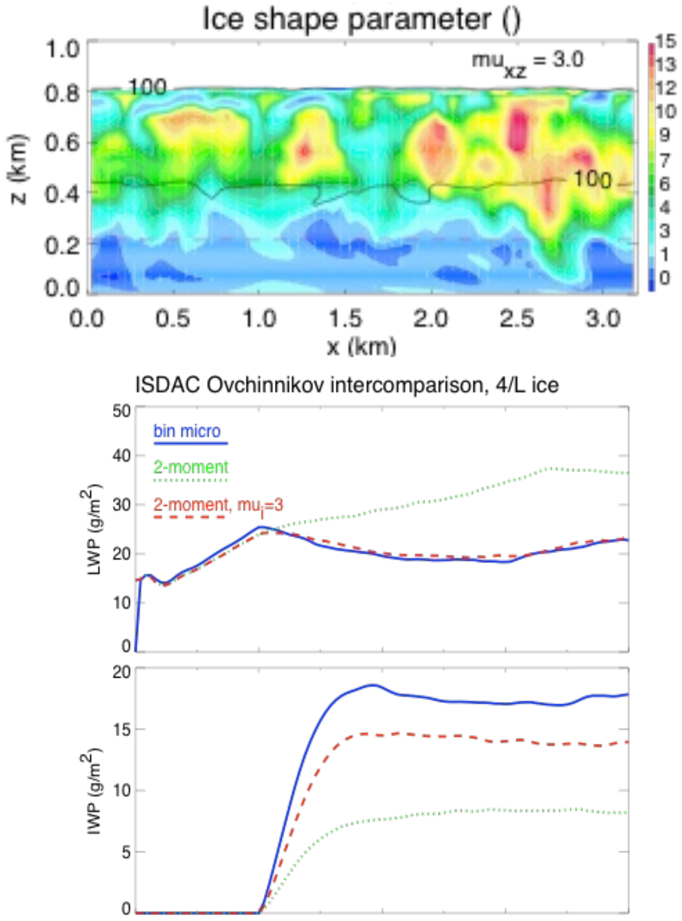
Klein et al. (2009)

Case study setup specifications	M-PACE	SHEBA	ISDAC
nudged horizontal wind profile	Y	Y	Y
subsidence profile	Y	Y	Y
horizontal advective tendency profiles	Y		
sensible and latent heat fluxes	Y	Y	Y
hygroscopic aerosol size distribution	Y	Y	Y
ice nucleating aerosol (somehow)	Y		
set-up for SCM and LES	Y		
in-cloud ice number concentration		Y	Y
ice properties (shape, capacitance, fall speed)			Y
nudged temperature and water vapor			Y
parameterized longwave radiative cooling			Y
collision-coalescence turned off			Y

M-PACE to ISDAC progress



Ovchinnikov et al. (2009)



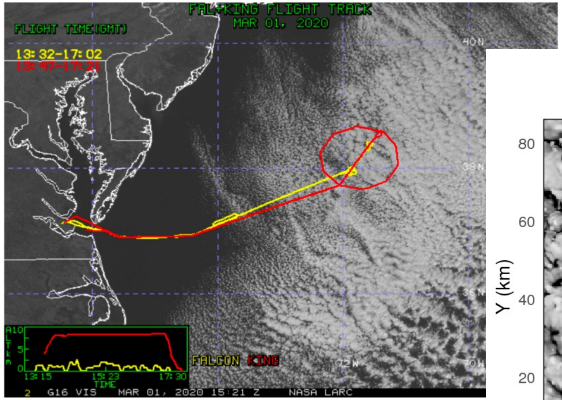
courtesy Andy Ackerman

Case study setup specifications	M-PACE	SHEBA	ISDAC	COMBLE	CONSTRAIN*
nudged horizontal wind profile	Y	Y	Y	?	geostrophic
subsidence profile	Y	Y	Y	Y	Y
horizontal advective tendency profiles	Y				
sensible and latent heat fluxes	Y	Y	Y		
hygroscopic aerosol size distribution	Y	Y	Y	Y	fixed Nd
ice nucleating aerosol (somehow)	Y			Y	—
setup for SCM and LES	Y			Y	
in-cloud ice number concentration		Y	Y		
ice properties (shape, capacitance, fall speed)			Y		
nudged temperature and water vapor			Y		
parameterized longwave radiative cooling			Y		
collision-coalescence turned off			Y		
Lagrangian following PBL trajectory				Y	Y

*de Roode et al. [JAMES 2019] following Field et al. [2014] cold-air outbreak case

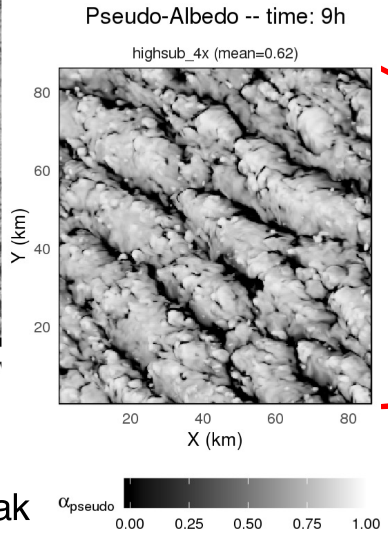
ModelE3 development approach

Field campaigns → LES → SCM



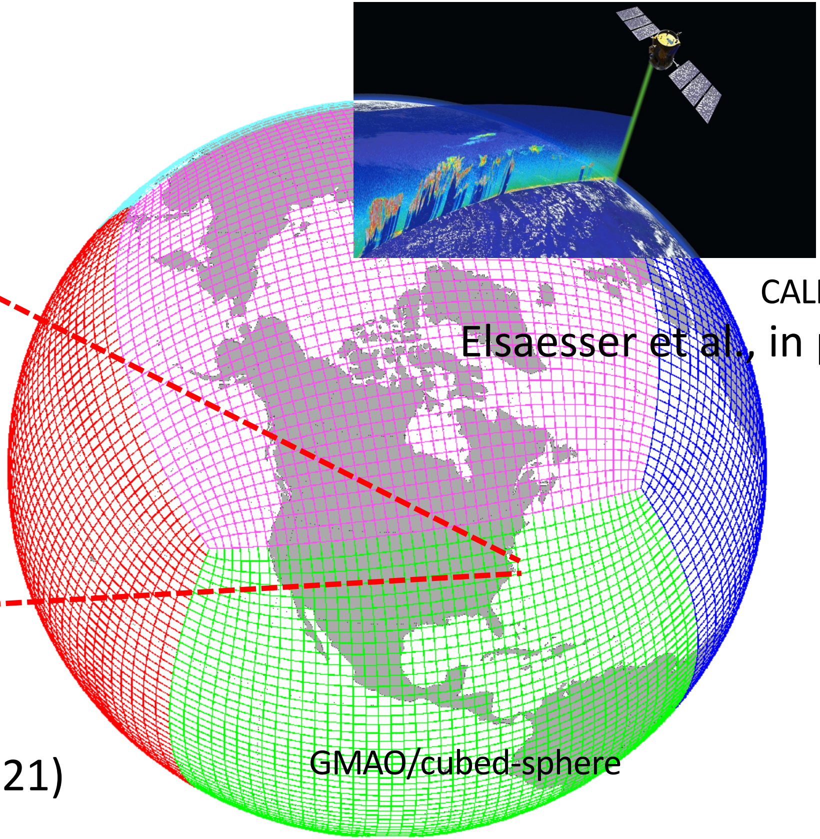
From https://satcorps.larc.nasa.gov

ACTIVATE Flight RF13
1 March 2020
mixed-phase cold-air outbreak



Tornow et al. (ACP 2021)

Global data → ESM tuning



Field campaigns —> LES —> Single-column model (SCM)

Conditions	Case study	Aerosol aware?
dry convective boundary layer	idealized [Bretherton and Park 2009]	—
dry stable boundary layer	GABLS1 [Cuxart et al. 2006]	—
marine stratocumulus	DYCOMS-II RF02 [Ackerman et al. 2009]	observed (2 modes)
marine trade cumulus (shallow)	BOMEX [Siebesma et al. 2003]	no
marine trade cumulus (deep, raining)	RICO [van Zanten et al. 2011]	no
marine stratocumulus-to-cumulus *	SCT [Sandu and Stevens 2011]	no
continental cumulus ^	RACORO [Vogelmann et al. 2015]	observed profile (3 modes)
Arctic mixed-phase stratus	M-PACE [Klein et al. 2009]	observed (2 modes)
Antarctic mixed-phase stratus *	AWARE [Silber et al. 2019, 2021, 2022]	estimated (1 mode)
tropical deep convection	TWP-ICE [Fridlind et al. 2012]	observed profile (3 modes)
mid-latitude synoptic cirrus *	SPARTICUS [cf. Mühlbauer et al. 2014]	no
mid-latitude cold-air outbreak *^	ACTIVATE [Tornow et al., 2021, 2022, in prep.]	observed profile (3 modes)
high-latitude cold-air outbreak *^	COMBLE [Tornow et al., in prep.]	observed/estimated profiles (3 modes w/INP)
marine cumulus and congestus *^	CAMP2Ex [Stanford et al., in prep.]	observed profiles (3 modes)
subtropical marine deep convection *^	SEAC4RS [Stanford et al., in prep.]	observed profiles (TBD)
continental sea breeze convection *^	TRACER [Matsui et al., in prep.]	observed profiles (TBD)

*Lagrangian (cf. Neggers JAMES 2015, Pithan et al. NatGeo 2019)
^ensemble (cf. Neggers et al. JAMES 2019)

SHEBA

Rangno and Hobbs [JGR 2001]

see McKenna Stanford's poster

(b) Moderately Supercooled Stratiform Clouds (Tops –10° to –20°C)

TYPE IV

Small droplets at cloud top, possible ice, little or no precipitation

- Droplet concentrations $> 100\ cm^{-3}$
- Maximum effective droplet radius $< 10\ \mu m$
- Maximum threshold droplet diameter $< 20\ \mu m$
- Ice concentrations nil or a few per liter

SHEBA
ISDAC
AWARE

TYPE V

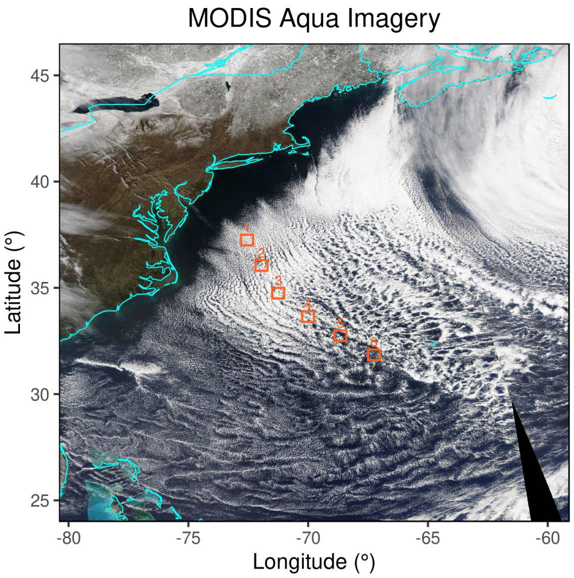
Large droplets at cloud top, ice, precipitation

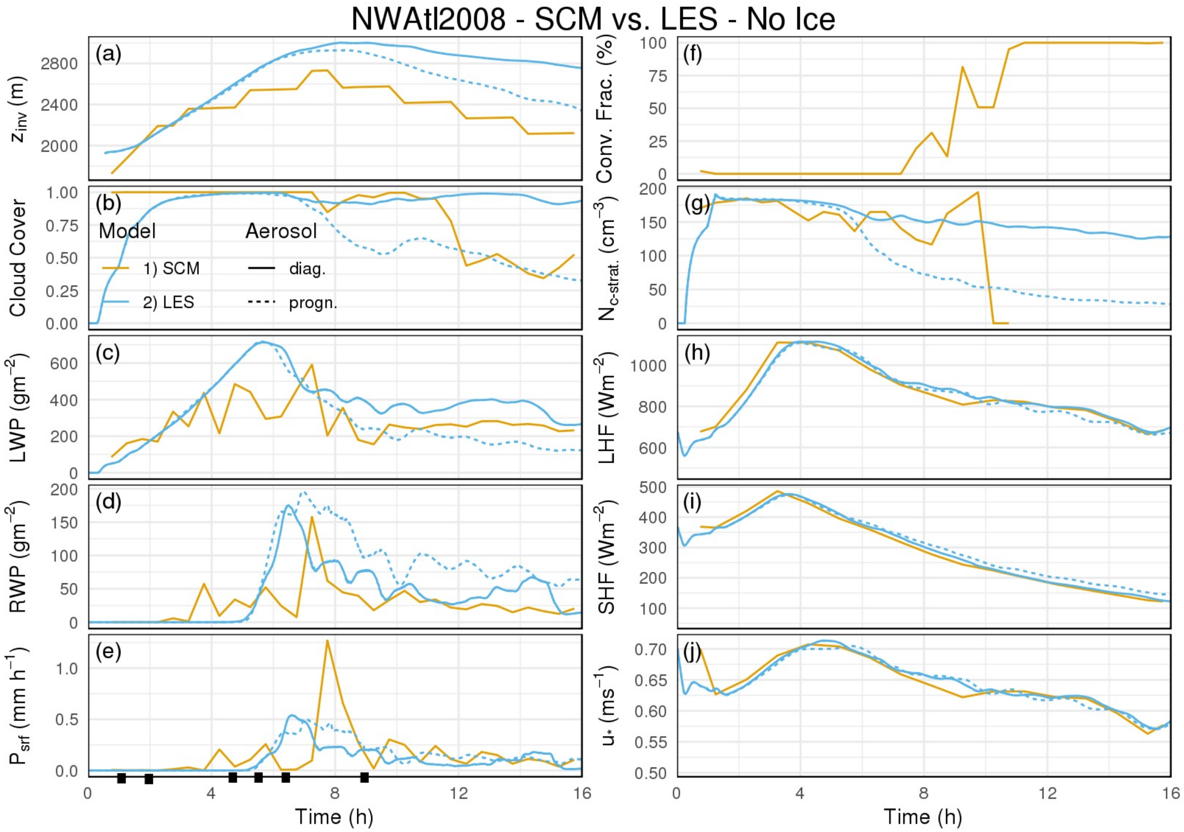
- Droplet concentrations typically $< 100\ cm^{-3}$
- maximum effective radius $> 10\ \mu m$
- Maximum threshold droplet diameter $> 20\ \mu m$
- Ice concentrations 10-100 per liter

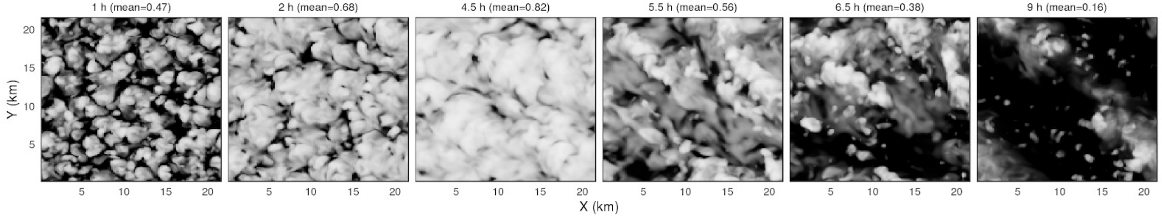
M-PACE
CONSTRAIN
COMBLE

ACTIVATE

see Florian Tornow's poster



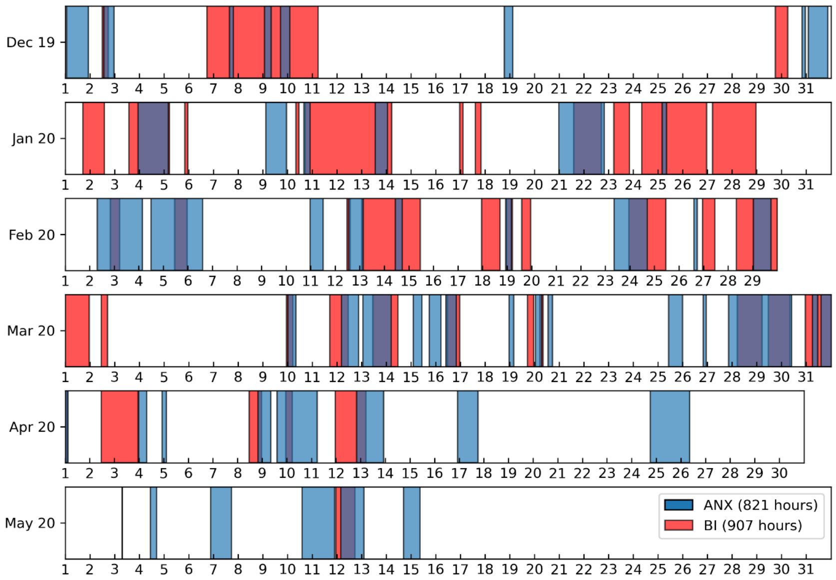




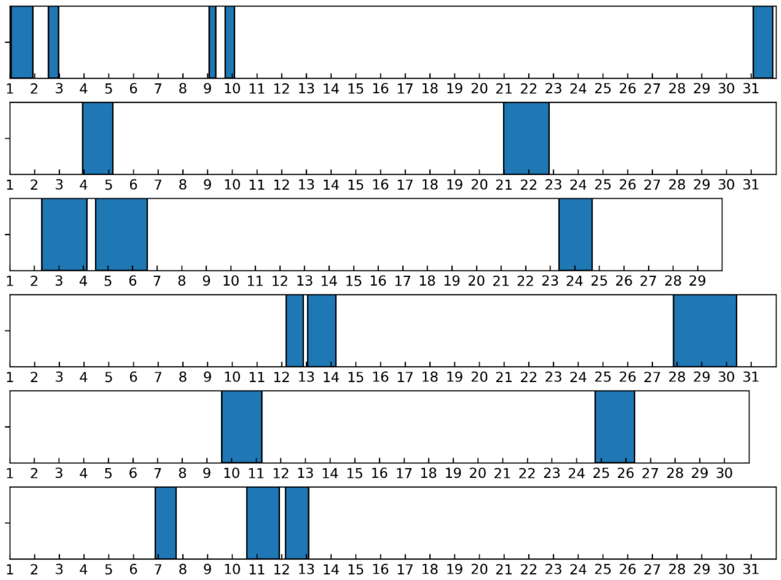
see Tornow et al. [ACP 2021, GRL 2022]

COMBLE case selection

CAO conditions based on *instability* (MCAO-index), and *wind speed* and *direction*



Reduction to most "interesting" cases based on duration, intensity, vertical transects, and satellite imagery

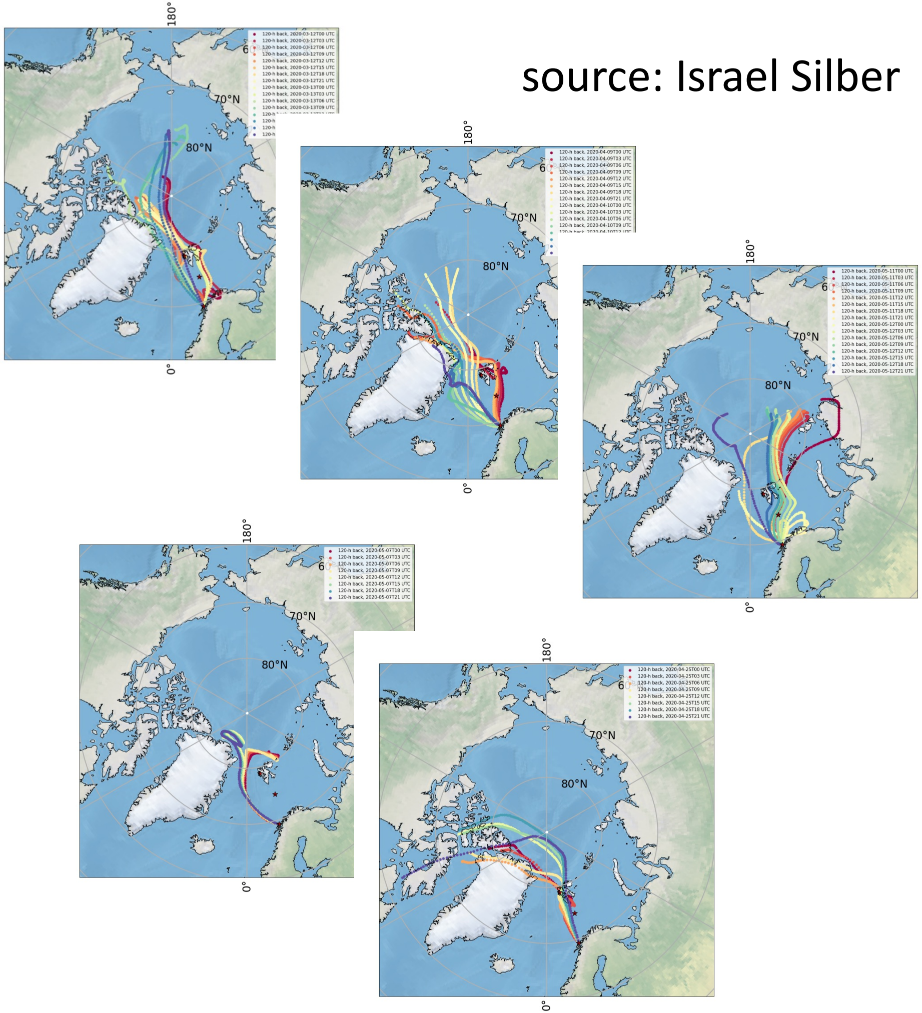


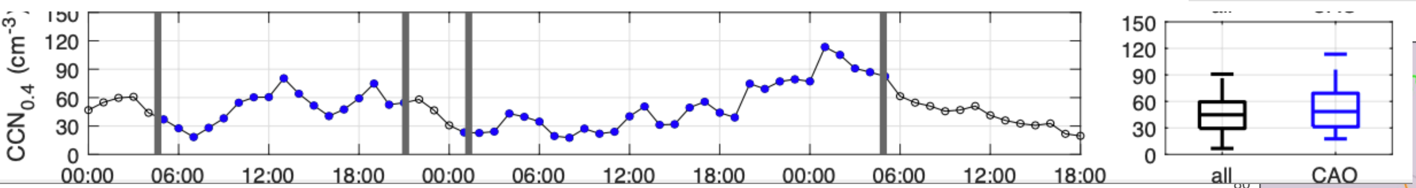
source: Christian Lackner and Bart Geerts

Ranking	Intensity	Data Availability
1st	Mar 12-13	May 7
2nd	Mar 28-29	Apr 25
3rd	Feb 2-6	May 11-12
4th	Jan 4	Apr 9-10
5th	Dec 1-2	Mar 12-13
6th	Apr 9-10	Feb 2-6
7th	Feb 23-24	Dec 1-2
8th	Dec 31	Feb 23-24
9th	Jan 21-22	Dec 31
10th	Dec 9	Mar 28-29
11th	May 11-12	Dec 9
12th	May 7	Jan 4
13th	Apr 25	Jan 21-22

source: Christian Lackner and Bart Geerts

source: Israel Silber

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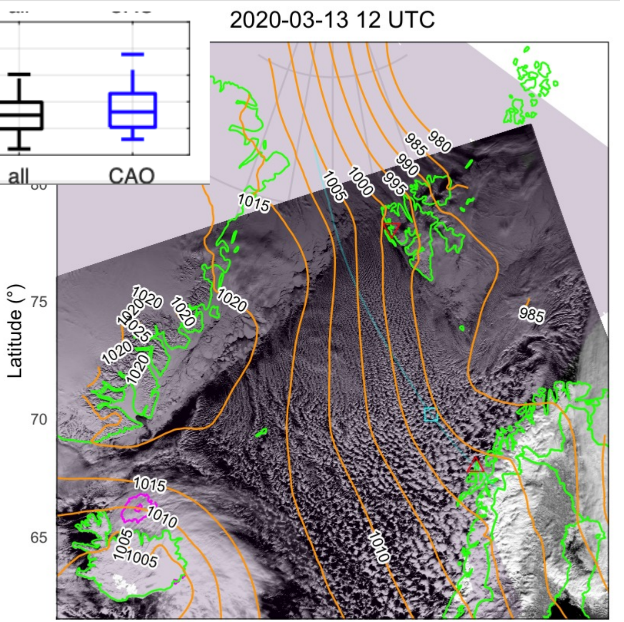
120
90
60
30
0
00:00
06:00
12:00
18:00
all
CAO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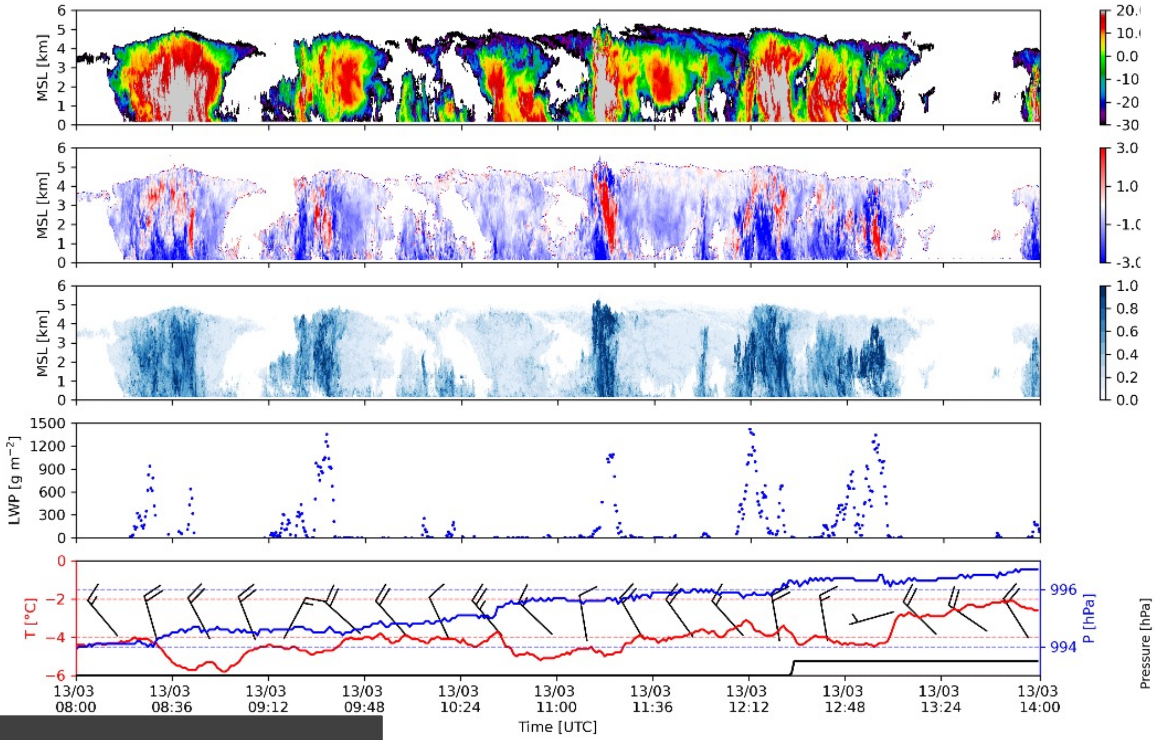
1020
1015
1010
1005
1000
995
990
985
980


MSL [km]
LWP [g m^{-2}]
T [°C]
P [hPa]
996
994
13/03 08:00
13/03 08:36
13/03 09:12
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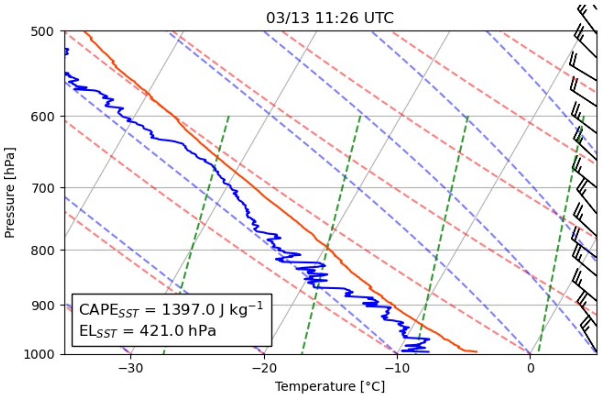
13/03 14:00
Time [UTC]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Pressure [hPa]
Temperature [°C]
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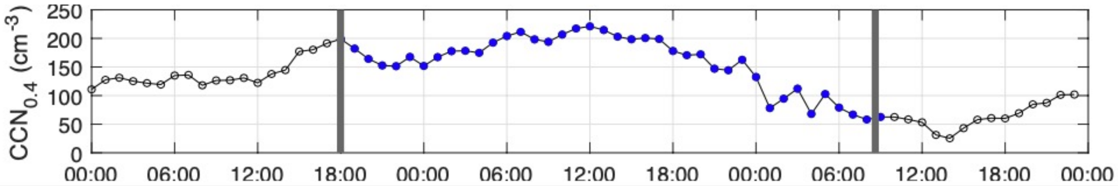
EL$_{SST}$ = 421.0 hPa

Mar 12-13


CCN$_{0.4}$ (cm^{-3})
250
200
150
100
50
0
00:00
06:00
12:00
18:00
00:00
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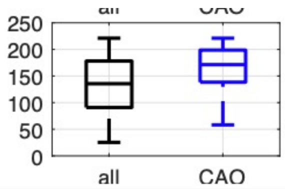
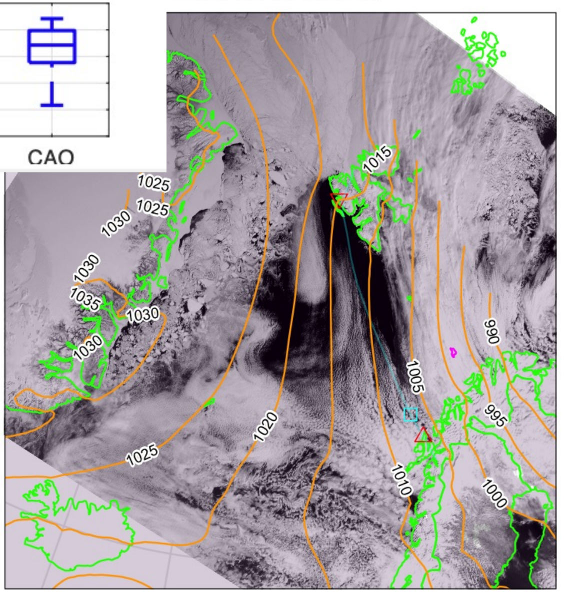
12:00
18:00
00:00


250
200
150
100
50
0
all
CAO


2020-04-25 09 UTC
Latitude (°)
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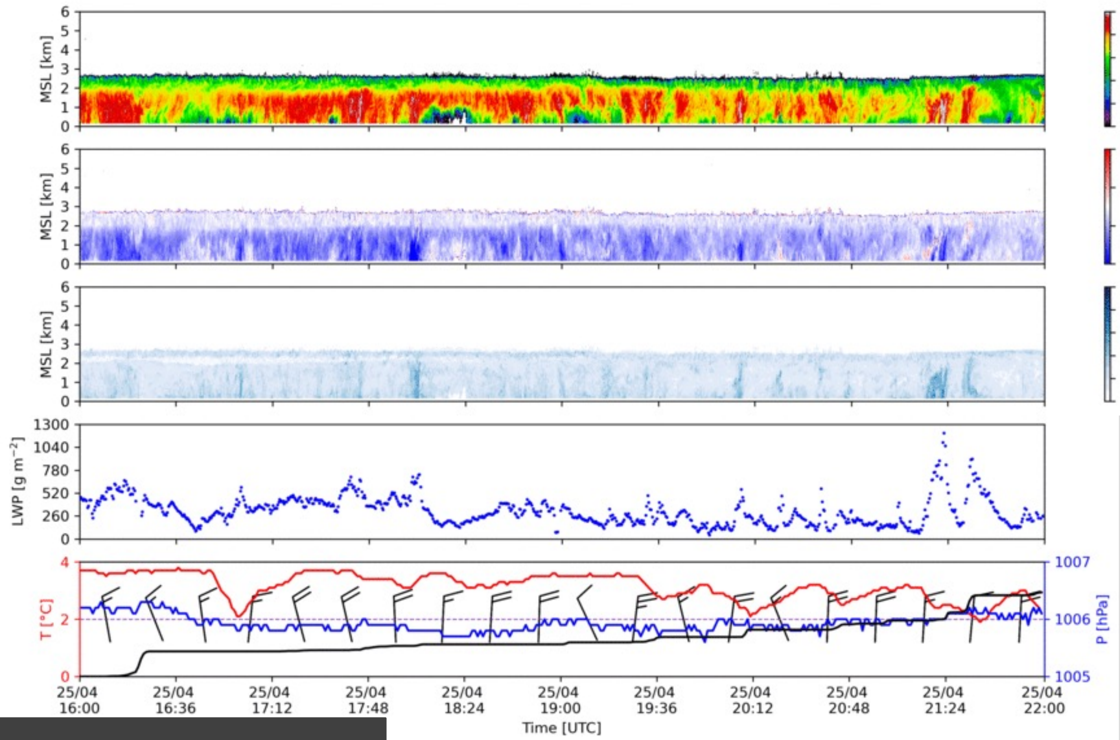
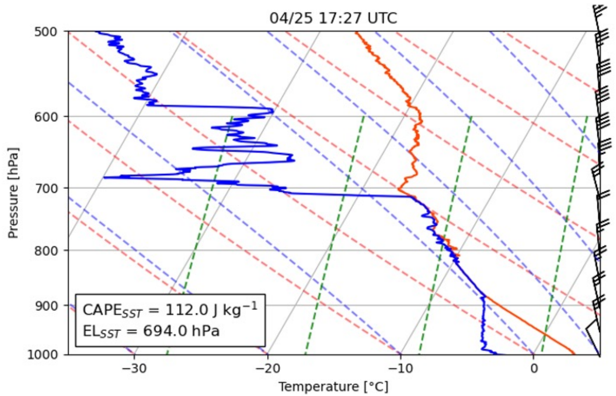
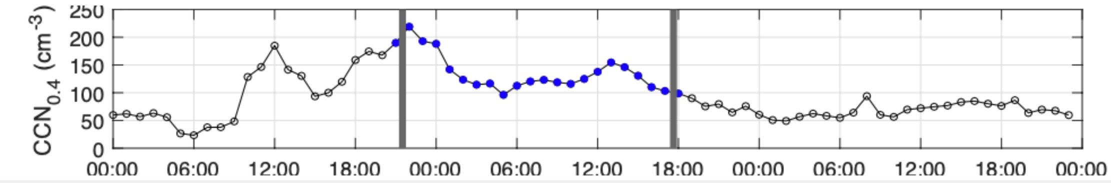
1015
1025
1025
1030
1030
1035
1030
1030
1020
1025
1005
1010
990
995
1000


MSL [km]
MSL [km]
MSL [km]
LWP [g m^{-2}]
1300
1040
780
520
260
0
T [°C]
P [hPa]
1007
1006
1005
25/04 16:00
25/04 16:36
25/04 17:12
25/04 17:48
25/04 18:24
25/04 19:00
25/04 19:36
25/04 20:12
25/04 20:48
25/04 21:24
25/04 22:00
Time [UTC]


04/25 17:27 UTC
Pressure [hPa]
500
600
700
800
900
1000
Temperature [°C]
−30
−20
−10
0
CAPE$_{SST}$ = 112.0 J kg^{-1}
EL$_{SST}$ = 694.0 hPa

Apr 25



$CCN_{0.4}$ (cm^{-3})
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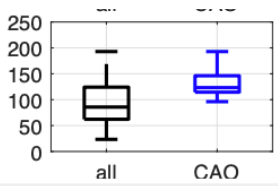
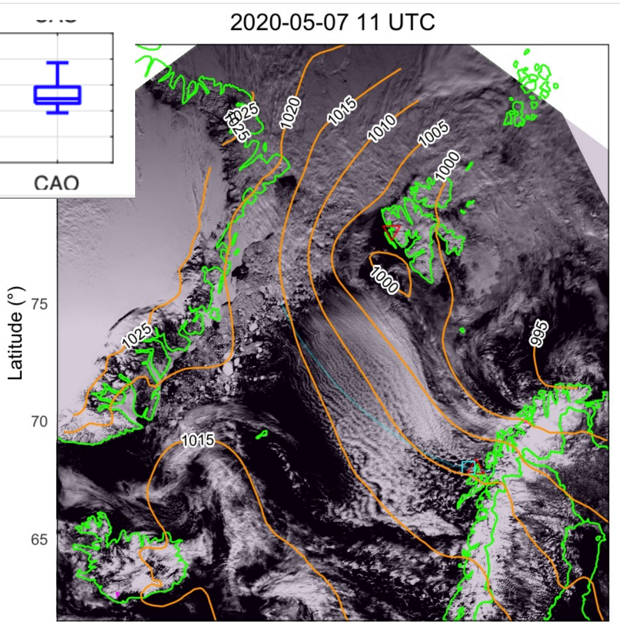


all
CAO



2020-05-07 11 UTC
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1020
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1010
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1000
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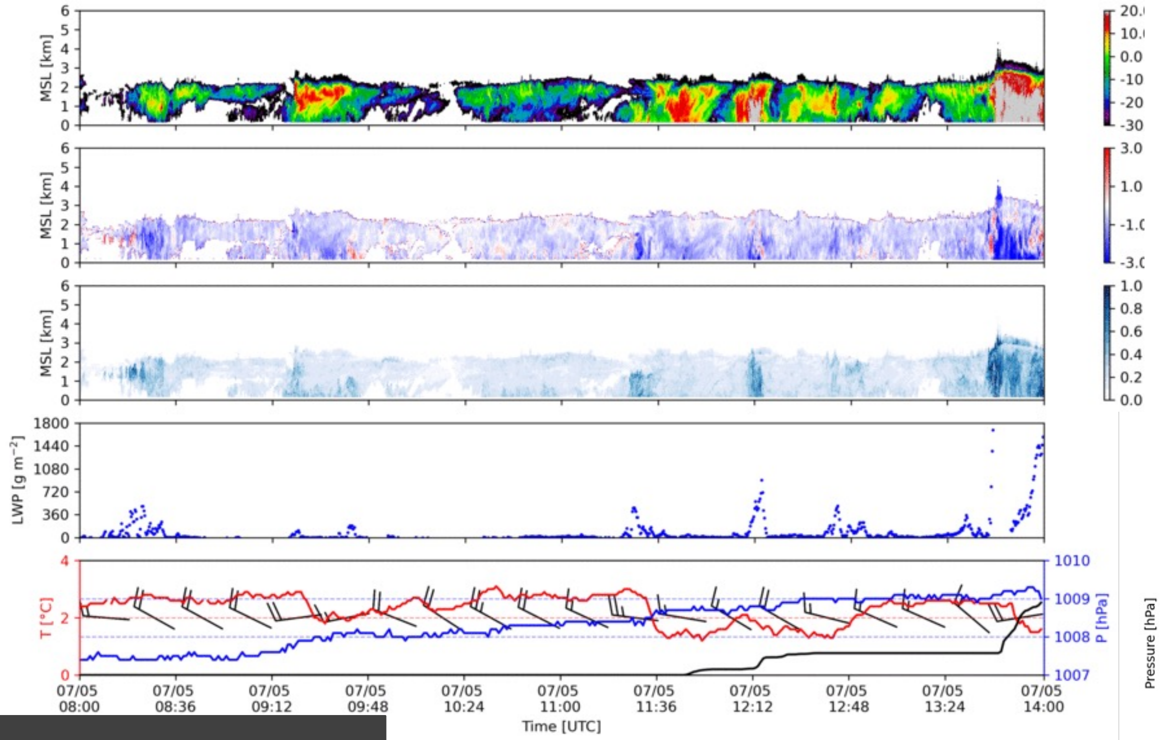

MSL [km]
LWP [g m^{-2}]
T [°C]
P [hPa]
Time [UTC]
07/05 08:00
07/05 08:36
07/05 09:12
07/05 09:48
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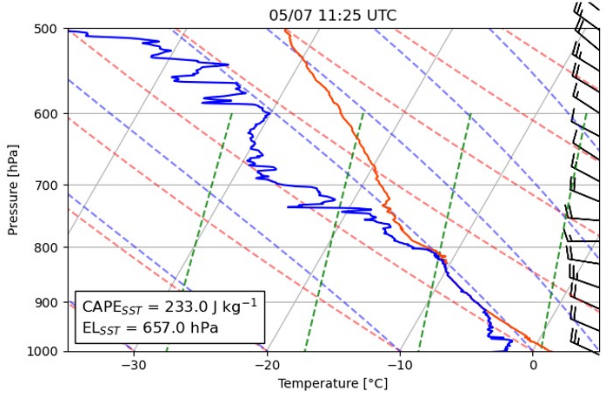
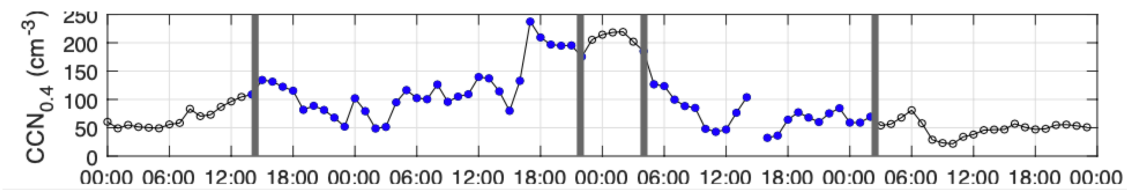
07/05 13:24
07/05 14:00



05/07 11:25 UTC
Pressure [hPa]
Temperature [°C]
$CAPE_{SST}$ = 233.0 J kg^{-1}
EL_{SST} = 657.0 hPa

May 7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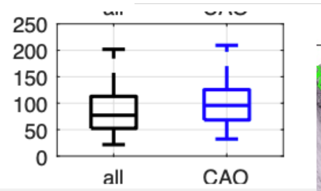
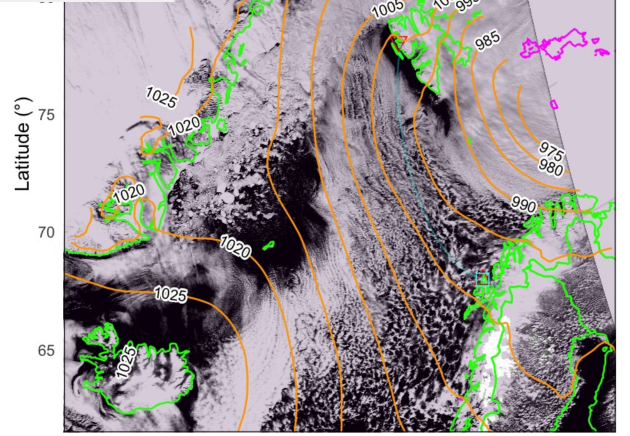

all
CAO


2020-05-12 12 UTC
Latitude (°)
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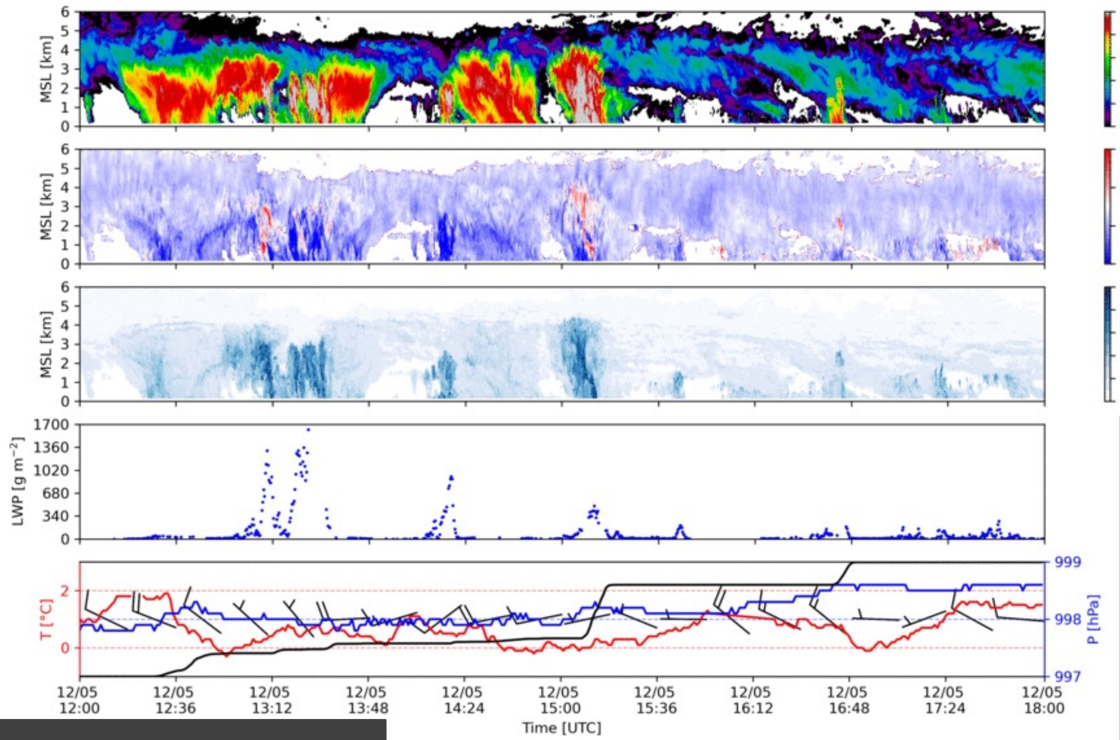
1015
1010
1005
1000
995
990
985
980
975


MSL [km]
LWP [g m−2]
T [°C]
P [hPa]
Time [UTC]
12/05 12:00
12/05 12:36
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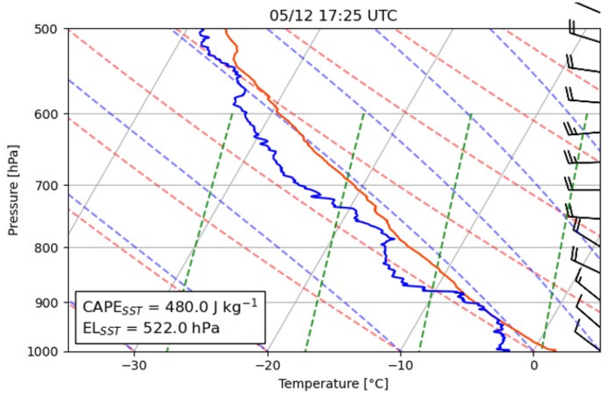
12/05 17:24
12/05 18:00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Pressure [hPa]
Temperature [°C]
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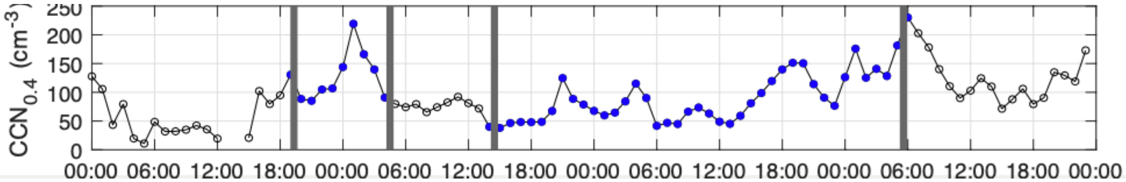
ELSST = 522.0 hPa

May 11-12


CCN$_{0.4}$ (cm^{-3})
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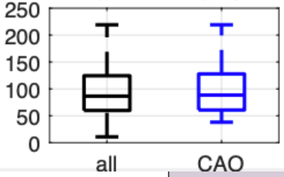
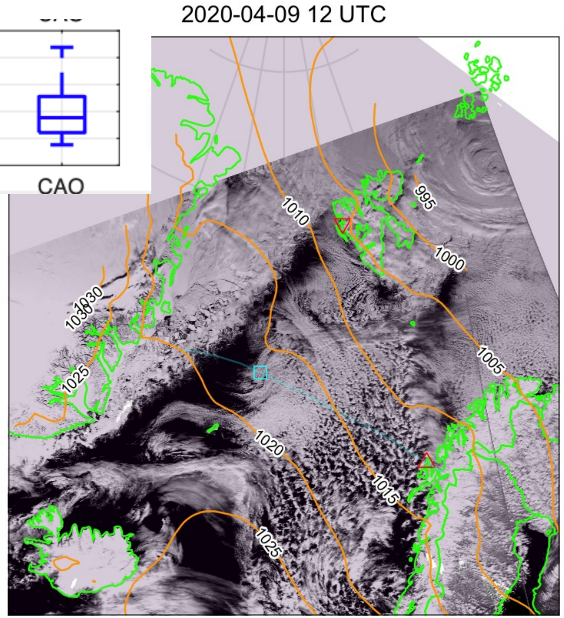

all
CAO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Latitude (°)
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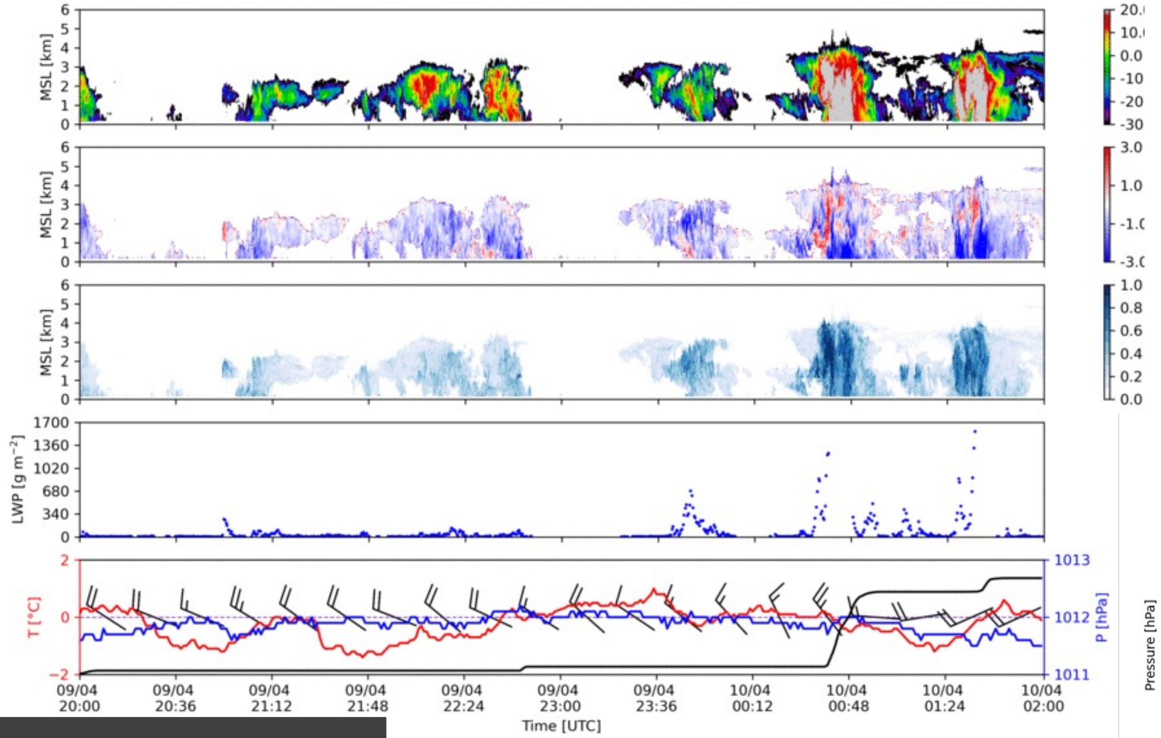
1015


MSL [km]
LWP [g m^{-2}]
T [°C]
P [hPa]
09/04 20:00
09/04 20:36
09/04 21:12
09/04 21:48
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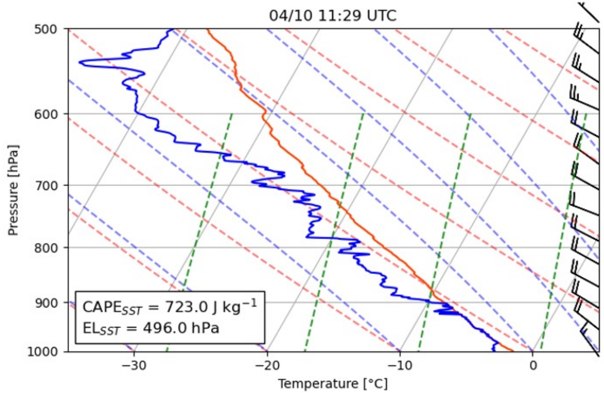
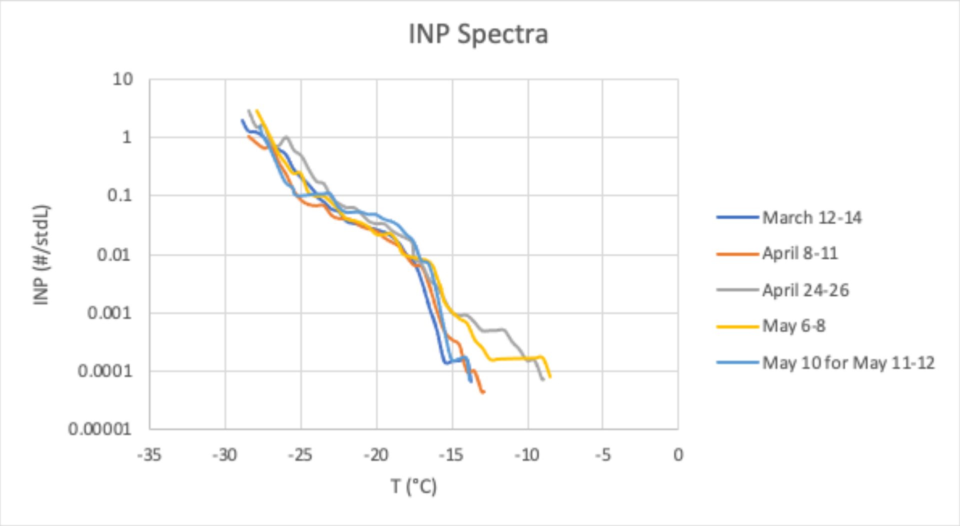
10/04 02:00
Time [UTC]

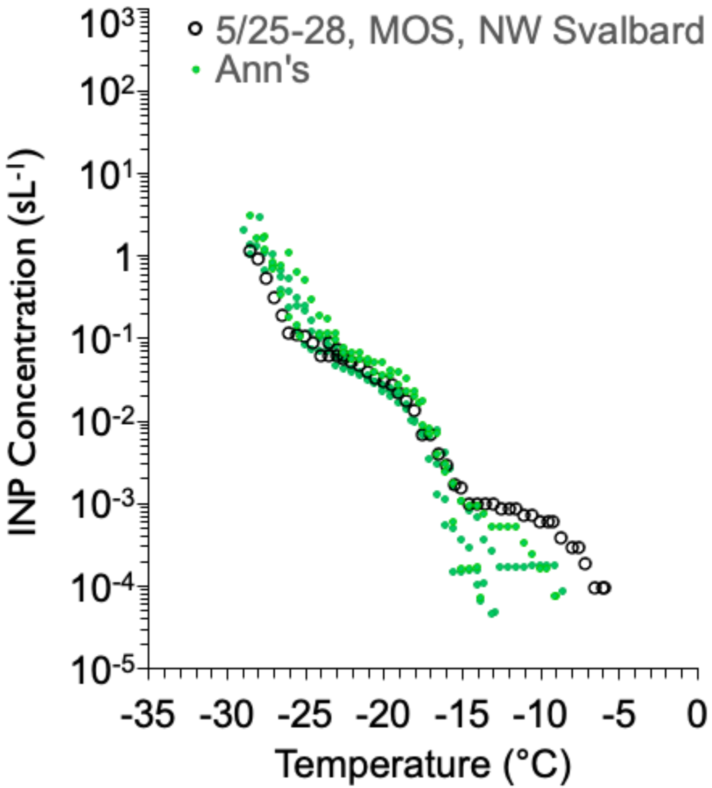

04/10 11:29 UTC
Pressure [hPa]
Temperature [°C]
CAPE$_{SST}$ = 723.0 J kg^{-1}
EL$_{SST}$ = 496.0 hPa

Apr 9-10

COMBLE INP measurements (marine origin?)

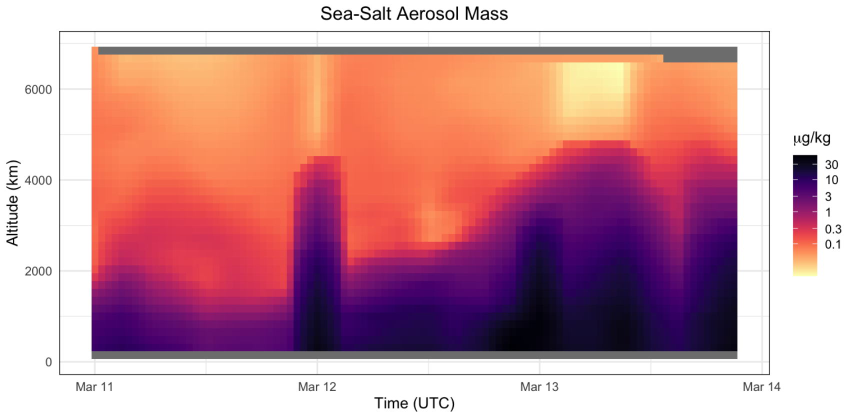
source: Paul DeMott et al.

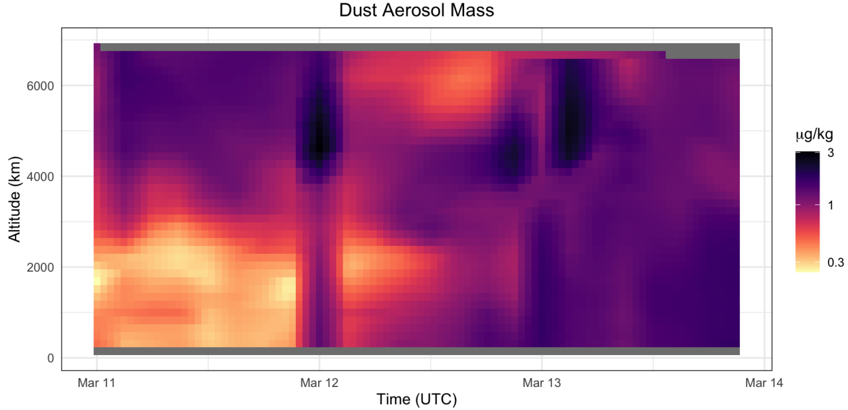




COMBLE aerosol specification

- initial aerosol profile + sea spray flux
- fixed modal parameters (D, sigma)
- modal N varies with height
- each mode of specified composition
  - kappa
  - aerosol type
- only for CCN
  - 1-2 submicron modes of mixed sulfate
- also for INP
  - initial and emitted sea spray
- sensitivity tests
  - add dust profile
  - add biomass burning aerosol





Summary

- derivation of COMBLE aerosol-aware LES+SCM case study ensemble for model development, tuning ESM parameters (e.g., Williamson et al. 2013)
- observation-derived cases highlight fundamental knowledge gaps at LES level (e.g., ice multiplication, mesoscale structure, CCN and INP budgets)
- are improvements borne out in free-running ESM? must be paired with additional evaluation (aerosol, thermodynamics, etc.)
- lack of in situ cloud data will be a limitation but long-term aerosol, met, remote sensing data is a strength (many cases)
- specifications and results will be archived in community DEPHY formats (e.g., AWARE Antarctic stratus LES+SCM in Silber et al. GMD 2022)