An LES Survey of Cold-Air Outbreaks Spanning ACTIVATE and COMBLE

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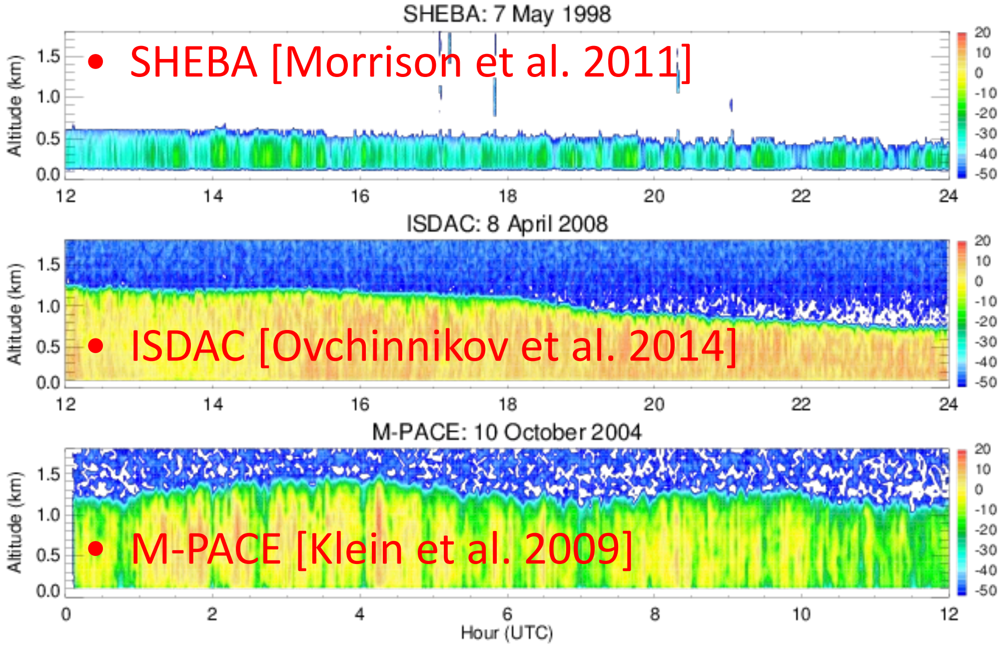
Field campaigns —> LES —> Single-column model (SCM)

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]	—
marine trade cumulus (deep, raining)	RICO [van Zanten et al. 2011]	—
marine stratocumulus-to-cumulus *	SCT [Sandu and Stevens 2011]	—
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]	—
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, 1 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)

Moving into the Lagrangian reference frame

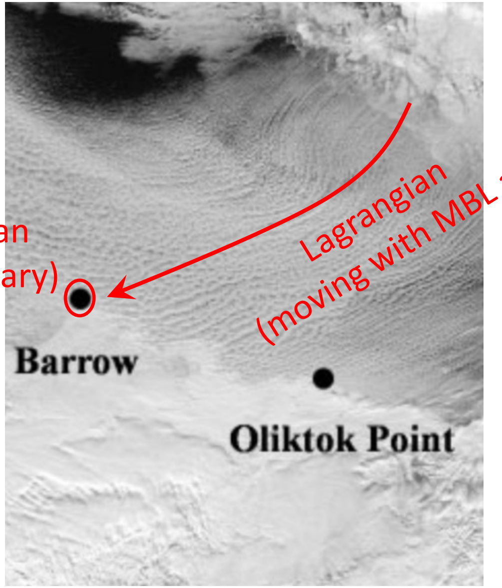
- Lagrangian and aerosol-aware go hand-in-hand



- SHEBA [Morrison et al. 2011]
- ISDAC [Ovchinnikov et al. 2014]
- M-PACE [Klein et al. 2009]

Vertically pointing mm-wavelength radar

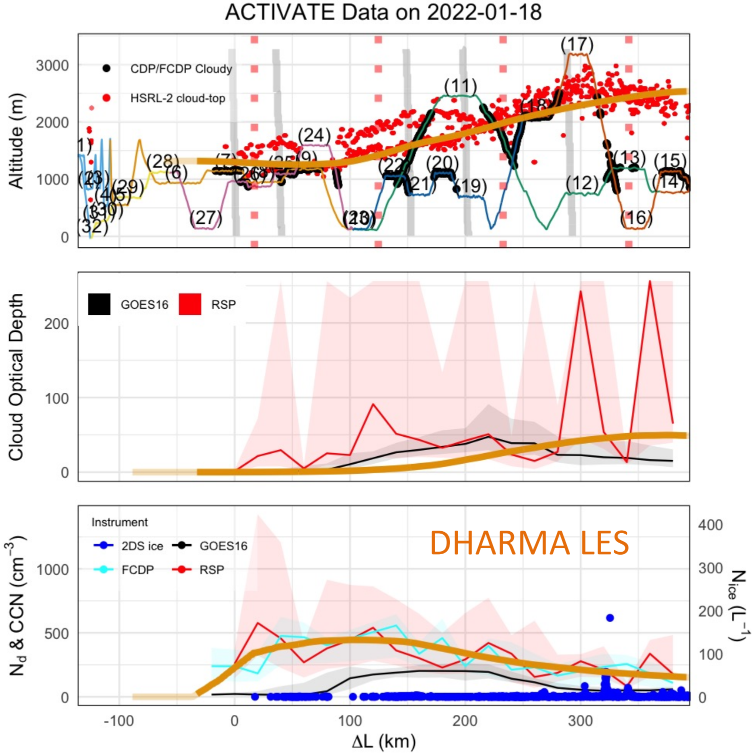
M-PACE [Klein et al. 2009]

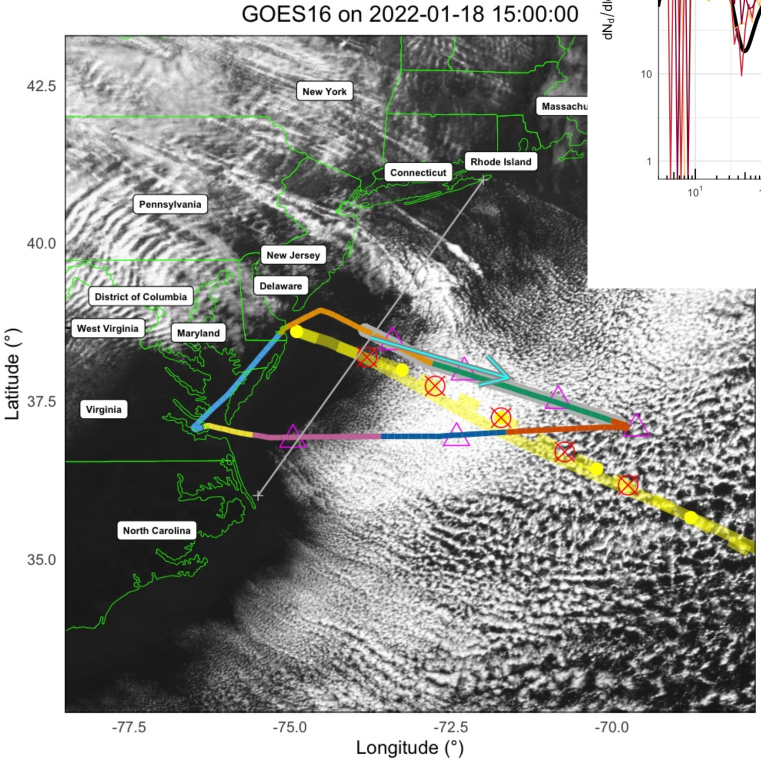


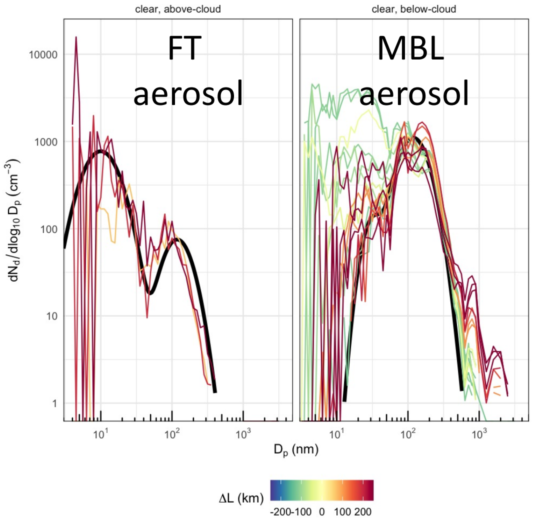
Fridlind and Ackerman [Ch. 7 in *Mixed-Phase Clouds*, Ed. C. Andronache, 2018]

ACTIVATE LES case study selection

- choose 2020-2022 flights with greatest fetch offshore







Tornow et al. (in prep.)

ACTIVATE aerosol budgets

- entrainment of FT air usually dilutes MBL CCN (and CN)
- leading cause of observed CCN and N_d reduction with fetch prior to substantial rain formation

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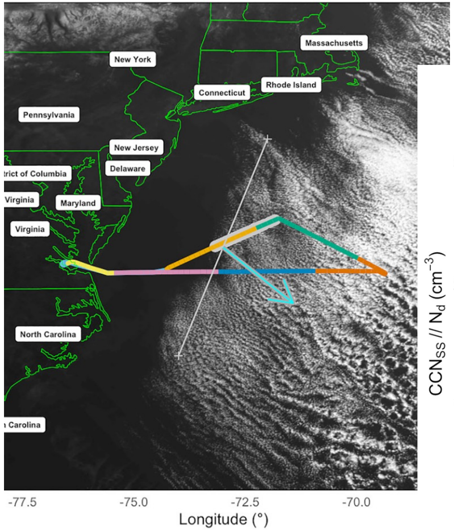
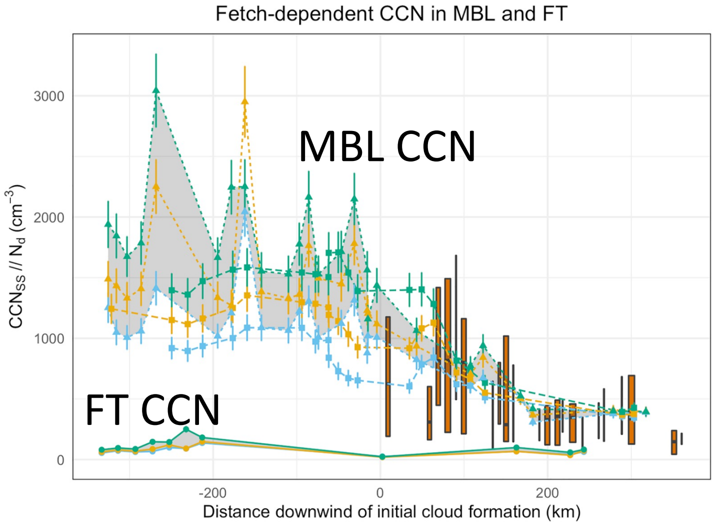
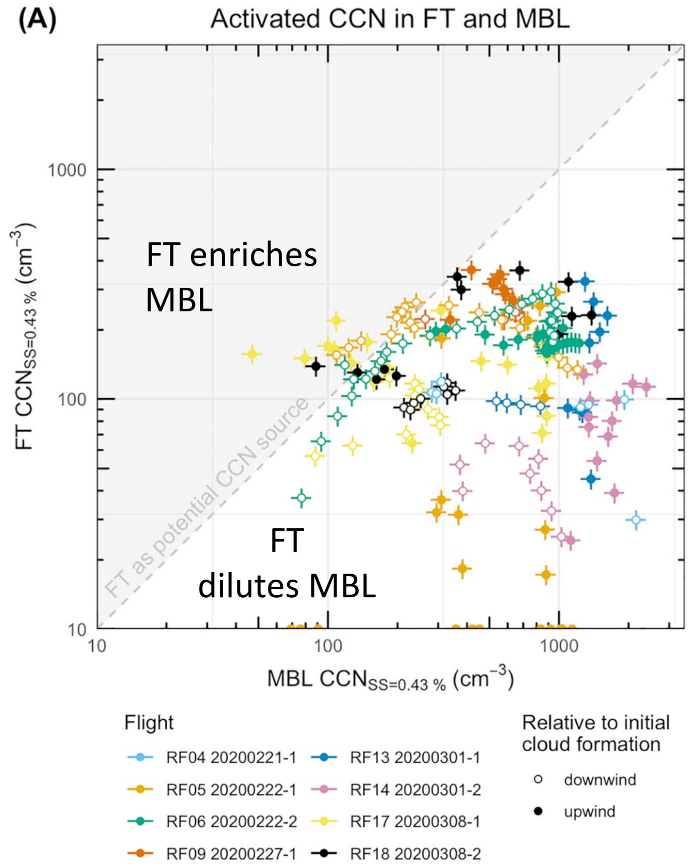


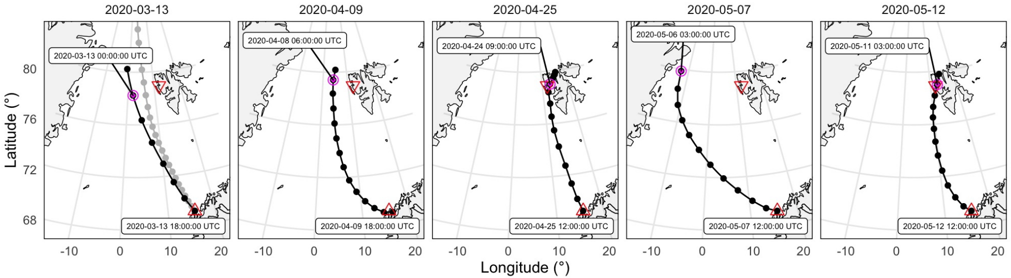


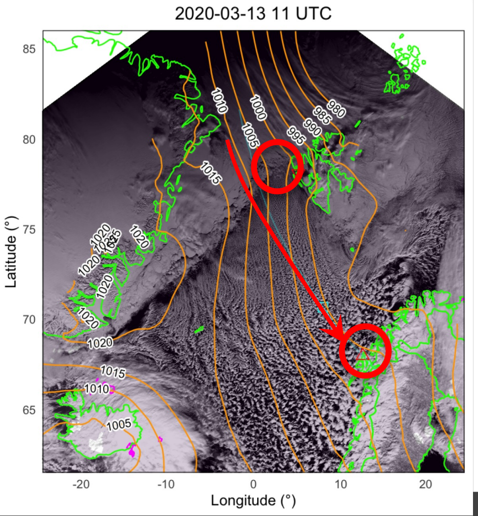


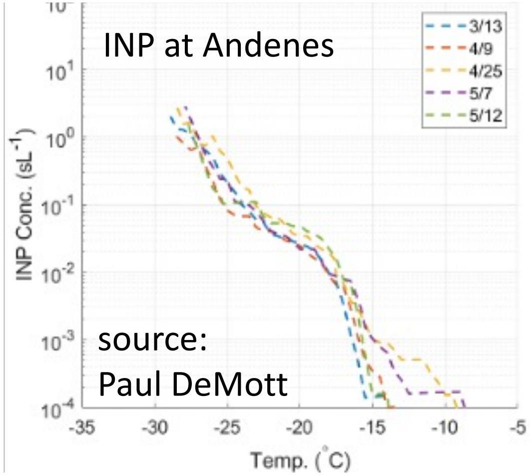
Tornow et al. (GRL 2022)

COMBLE LES case study selection

- choose CAO back trajectories passing near Zeppelin







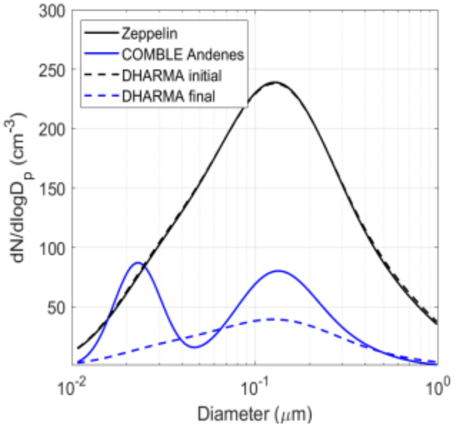
Tornow et al. (in prep.; see AMS 12B.5)

source: Christian Lackner

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

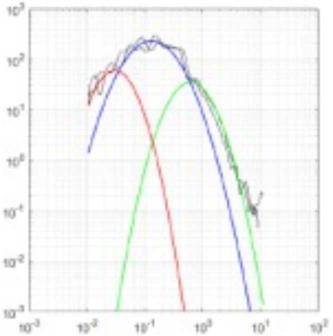
COMBLE aerosol budgets

Williams et al. (in prep.; see AMS 8B.4)

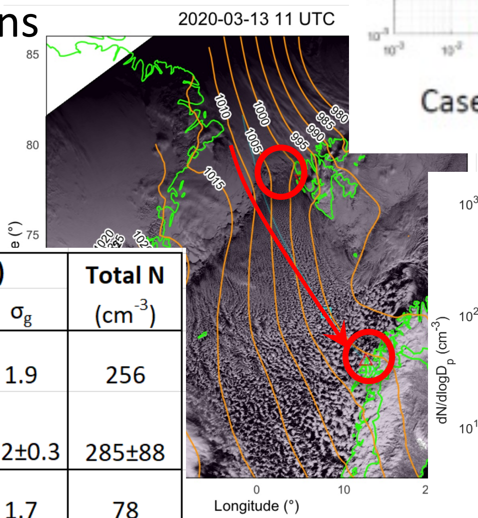


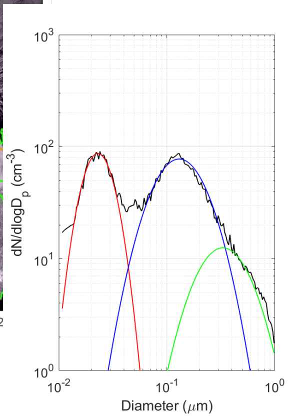
- trimodal aerosol with CCN reduction
- entrainment + wet scavenging + sea spray

- preliminary DHARMA simulations show excessive CCN reduction (and excessive LWP)



Case 1: March 13

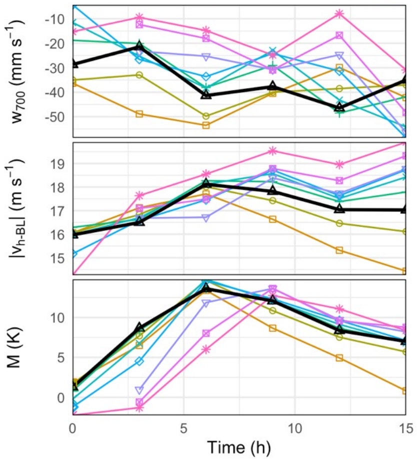




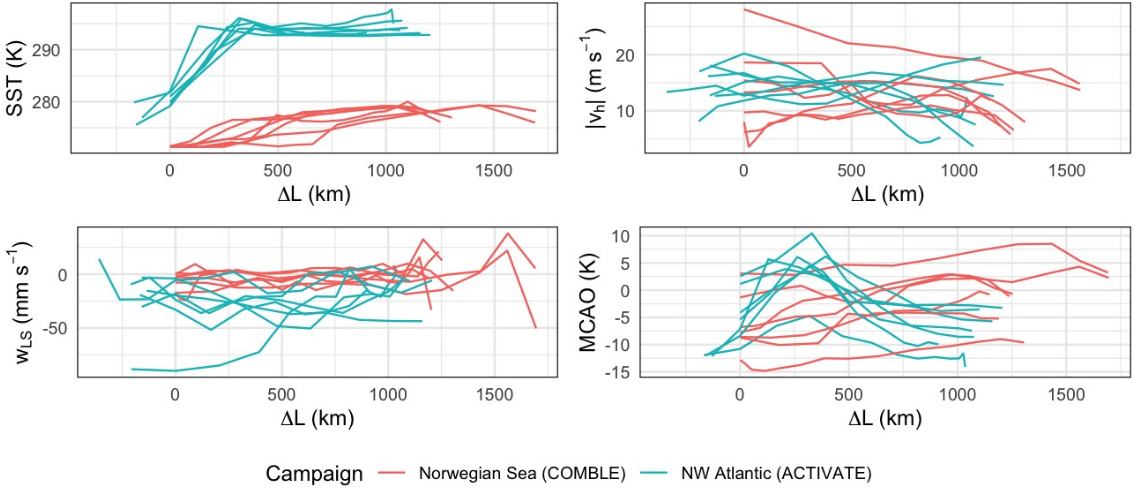
Location	Case	Mode 1 (Aitken)			Mode 2 (Accumulation)			Mode 3 (Coarse)			Total N
		N (cm^{-3})	D (µm)	σ_g	N (cm^{-3})	D (µm)	σ_g	N (cm^{-3})	D (µm)	σ_g	(cm^{-3})
Zeppelin	13-Mar	38	0.03	1.8	194	0.13	2.2	24	0.61	1.9	256
	5 Case Avg	125±114	0.04±0.01	1.6±0.1	154±36	0.15±0.02	1.7±0.3	9±9	0.4±0.1	2.2±0.3	285±88
Andenes (COMBLE)	13-Mar	28	0.02	1.4	43	0.13	1.7	7	0.33	1.7	78
	5 Case Avg	21±0.001*	0.02±0.001*	1.6±0.4*	94±73	0.13±0.01	1.6±0.1	6±3	0.40±0.07	1.7±0.2	99±60

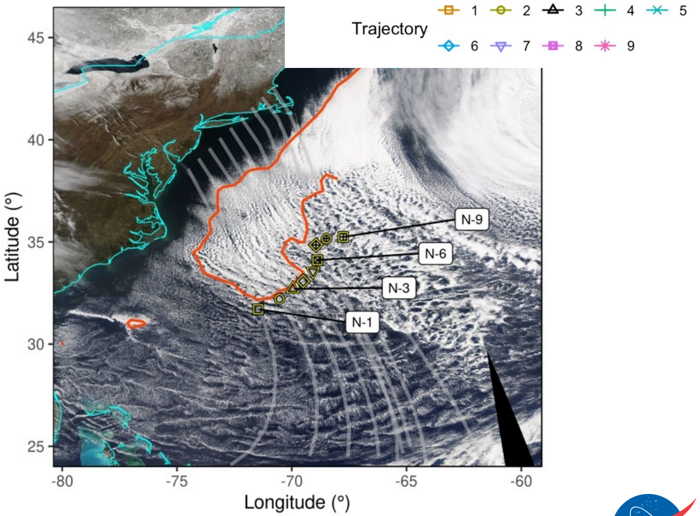
Contrasting subsidence

Tornow et al. (in prep.)



- powerful subsidence in some ACTIVATE cases!
- systematically weaker subsidence in COMBLE cases, can have negligible impact (cf. Chlond BLM 1992)
- corresponding contrast in inversion strengths

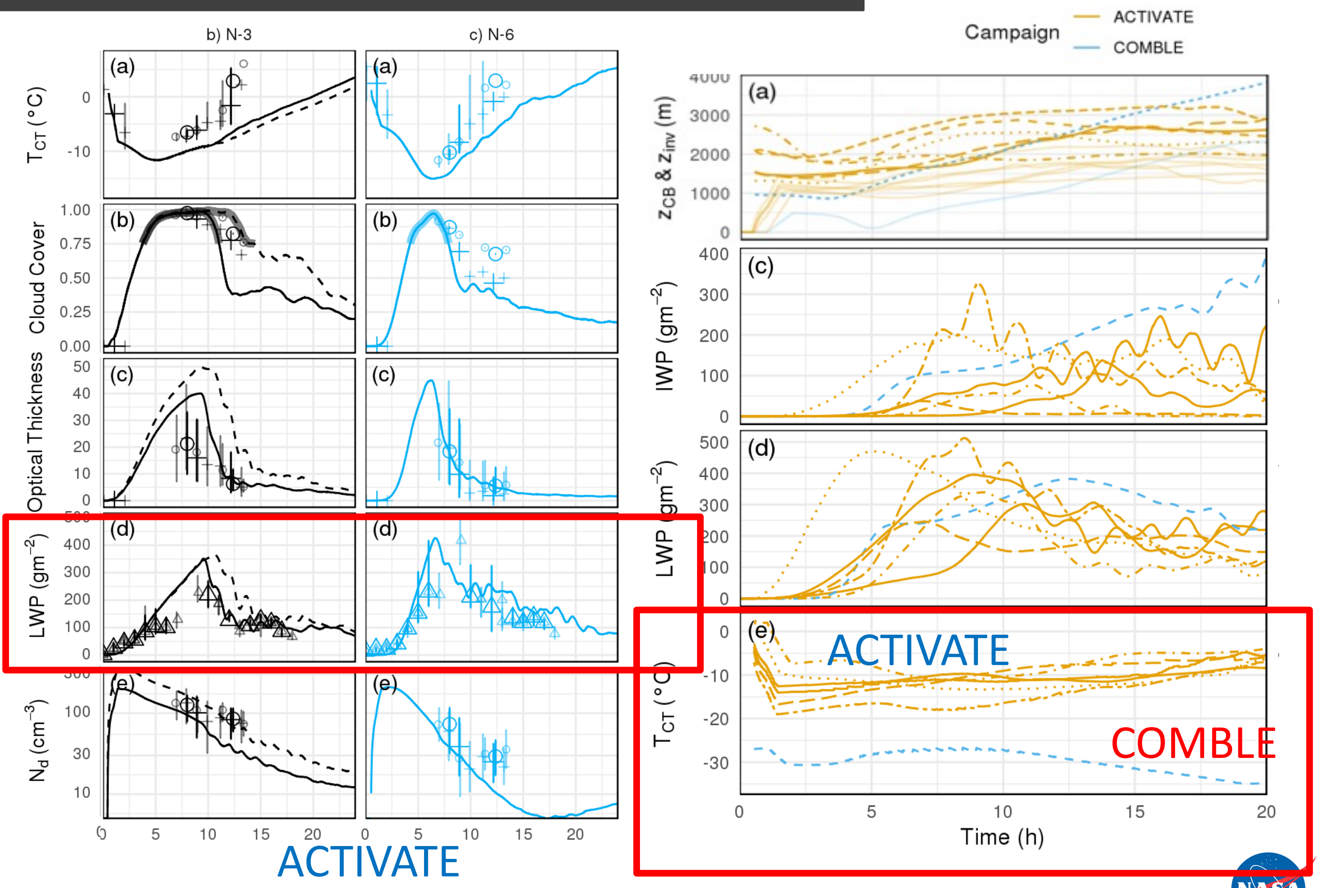




Contrasting CTT and LWP (CWP+RWP)

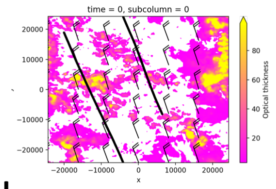
Tornow et al. (in prep.)

- ACTIVATE CTT reaches an early minimum with CTH < 2X increase
- COMBLE CTT may decrease, CTH > 3X in this case
- ACTIVATE LWP tends to exhibit rapid rise to a peak, followed by rain-modulated decline (MAC-LWP; Elsaesser et al. 2017)

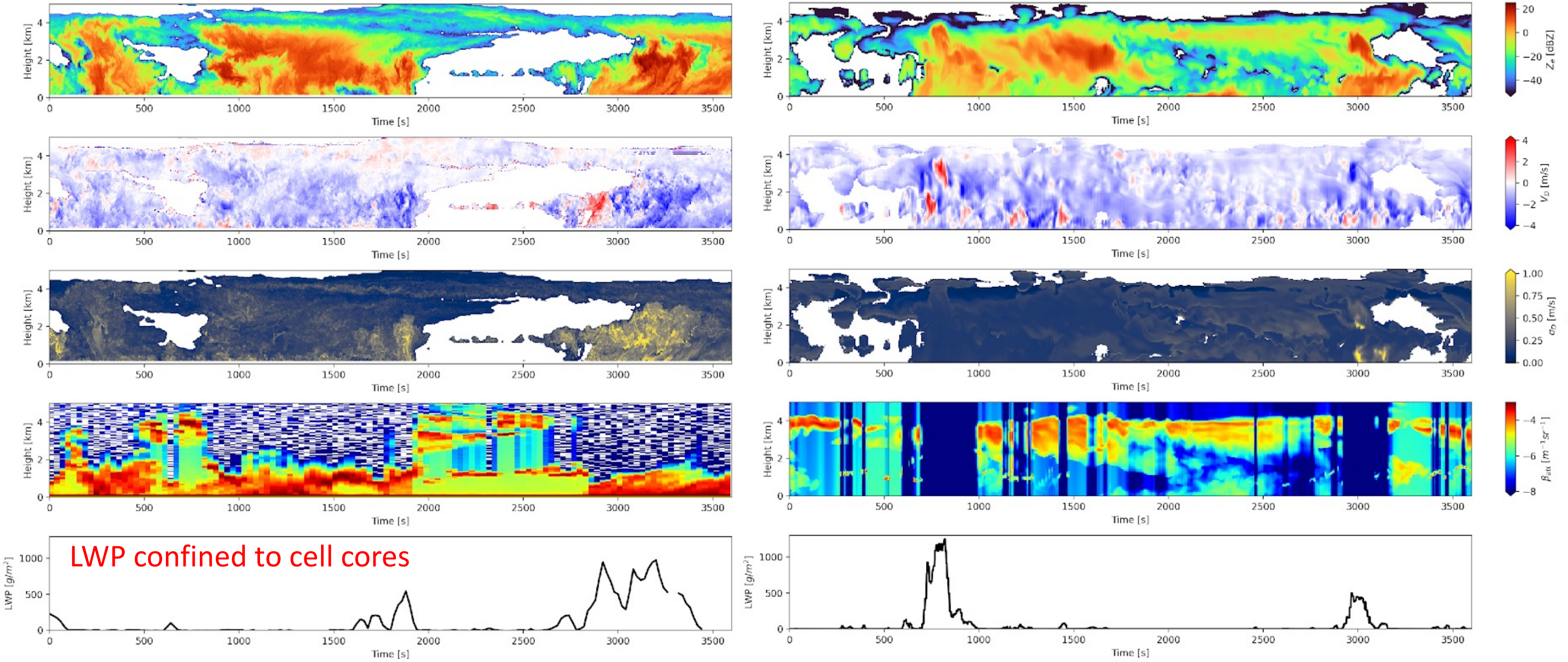


COMBLE observational constraint

Silber et al.
(in prep.)



- use EMC² (Silber et al. GMD 2022) to evaluate LES vs ground-based radar + lidar



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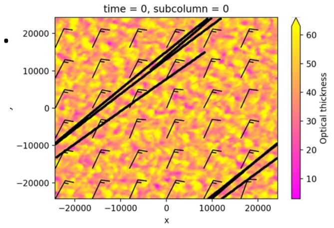
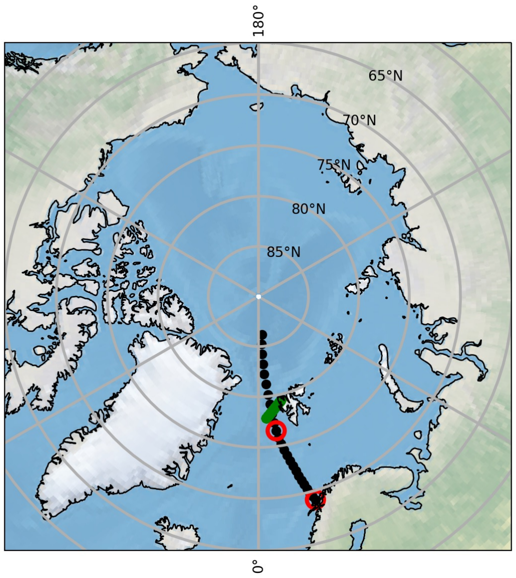
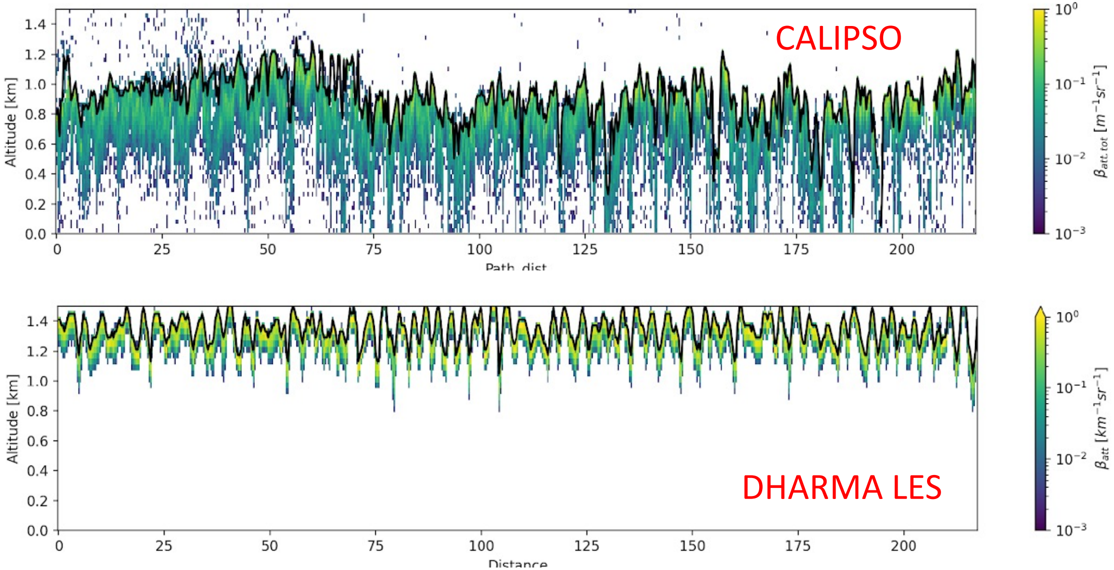


- use EMC[2] (Silber et al. GMD 2022) to evaluate LES vs CALIPSO satellite
- LES clouds too deep + dense





Progress report takeaways

- Aerosol-aware Lagrangian ensembles of case studies for LES + SCM
  - ACTIVATE's polluted MBL aerosol diluted by FT vs much cleaner Arctic
  - COMBLE's consistently weak subsidence
  - ACTIVATE's weaker supercooling vs COMBLE reaching homogeneous freezing
- Community exercises for LES and SCM (just getting started)
  - GEWEX Atmospheric System Study (GASS) COMBLE project (tjuliano@ucar.edu)
  - coordination of COMBLE and ACTIVATE cases in a GASS-CFMIP project?
- Remaining challenges
  - early high biases in LWP and CTH in COMBLE (ERA5 PBL biased over ice?)
  - weak cloud street formation in COMBLE case (cf. de Roode et al. JAMES 2019)
  - uncertainty in ice formation mechanisms (esp. COMBLE) and IWP constraints