Droplet Closure Analysis of Arctic Stratocumulus Clouds During ISDAC

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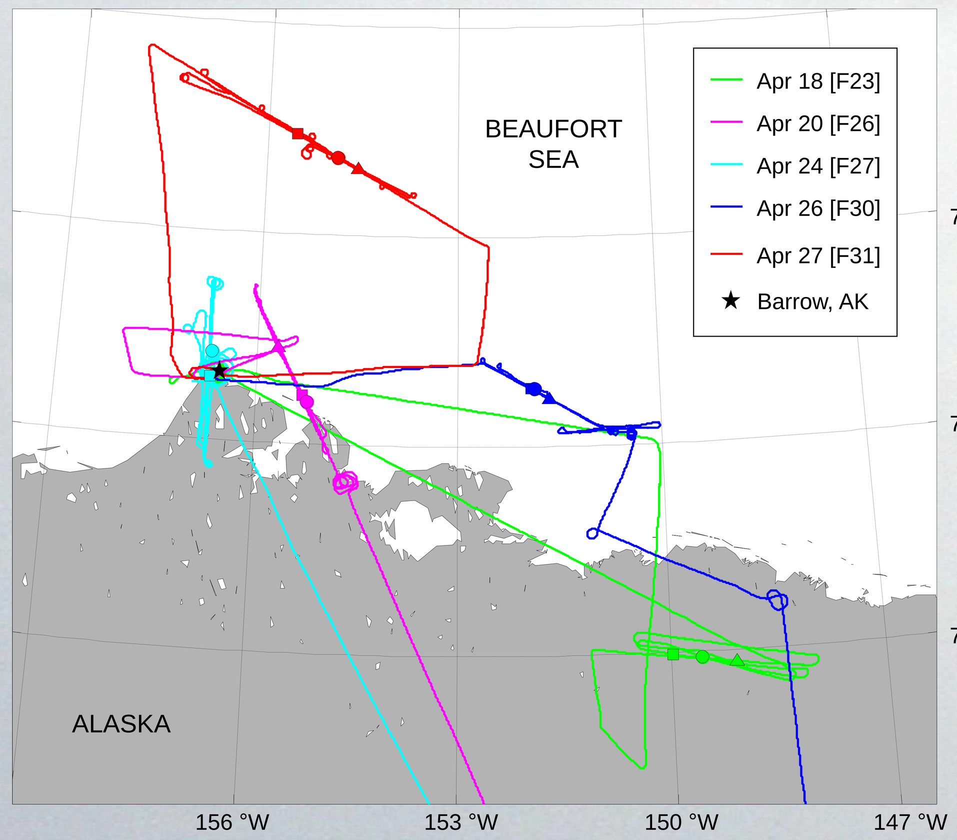
Overview

- Aerosol influences cloud droplet size, lifetime, and radiative properties via indirect effects
- Uncertainty in model descriptions of droplet activation; representation of vertical (updraft) velcocity a key issue
- Indirect and Semi-Direct Aerosol Campaign (ISDAC) – Barrow, Alaska, April 2008

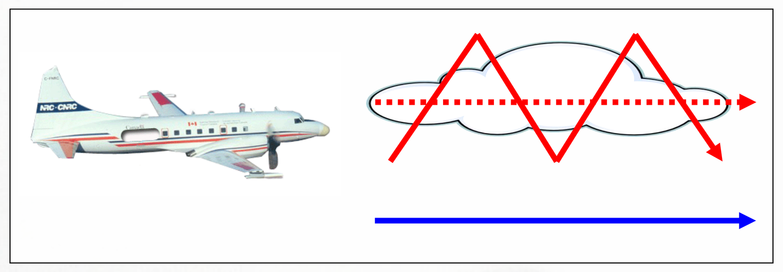
National Research Council of Canada (NRC) Convair-580, instrumented with probes for cloud (CDP, King LWC Probe), aerosol (PCASP-100X, SPLAT II single particle mass spectrometer), and atmospheric state measurements.

Approach



Flight tracks and locations of vertical profiles through cloud (circles) and constant-altitude flight legs in-cloud (squares), and below cloud base (triangles) for all cases considered in analysis.

- Five stratocumulus cloud cases:
  - April 26, 27: clean aerosol conditions
  - April 18, 20, 24: polluted aerosol conditions; biomass burning episode



Cloud: Droplet concentration from vertical profiles (solid line) and vertical gust velocity from constant-altitude legs (dotted line)

Aerosol: Particle size distribution and composition from constant-altitude legs below cloud base; define cloud nucleating ability of particles

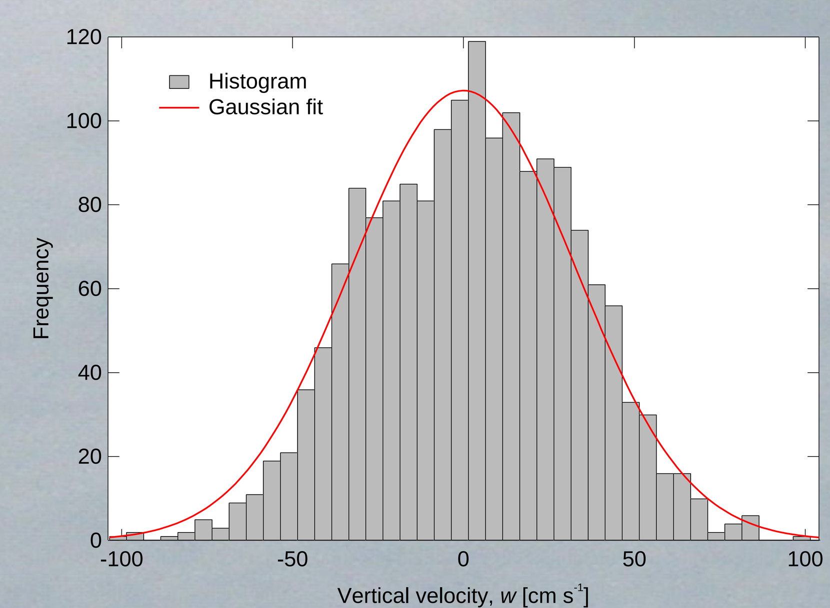
Observations

- Define cloud and aerosol properties, dynamics, for droplet closure analysis using an adiabatic cloud parcel model

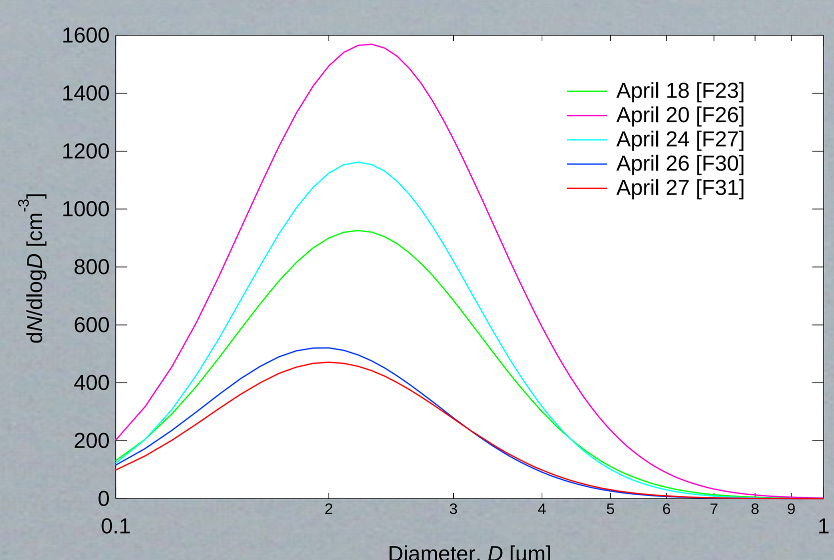
Flight	CDNC [cm^{-3}]	σ_w [cm s^{-1}]	N_a [cm^{-3}]
Apr. 18	270	32.8	402
Apr. 20	498	40.4	693
Apr. 24	301	25.6	470
Apr. 26	186	46.5	219
Apr. 27	189	35.0	201

Cloud droplet number concentration (CDNC) from CDP, standard deviation of Gaussian vertical velocity PDFs (σ_w), and average aerosol particle concentration below cloud base (N_a) from fits to PCASP-100X size distributions (right).

- Consider maximum droplet concentration from cloud profiles (95[th] percentile) for comparison with adiabatic model output



Histogram of measured vertical velocity values and Gaussian fit for the horizontal flight leg through cloud on April 18 (ISDAC flight 23).



Lognormal fits to average aerosol particle size distributions below cloud base for all cases.

Cloud Simulations

- Calculate 3-D cloud field using Large Eddy Simulation (LES) cloud model

In-cloud PDF: compiled from *w* values at level of in-cloud aircraft observations in 3-D model output

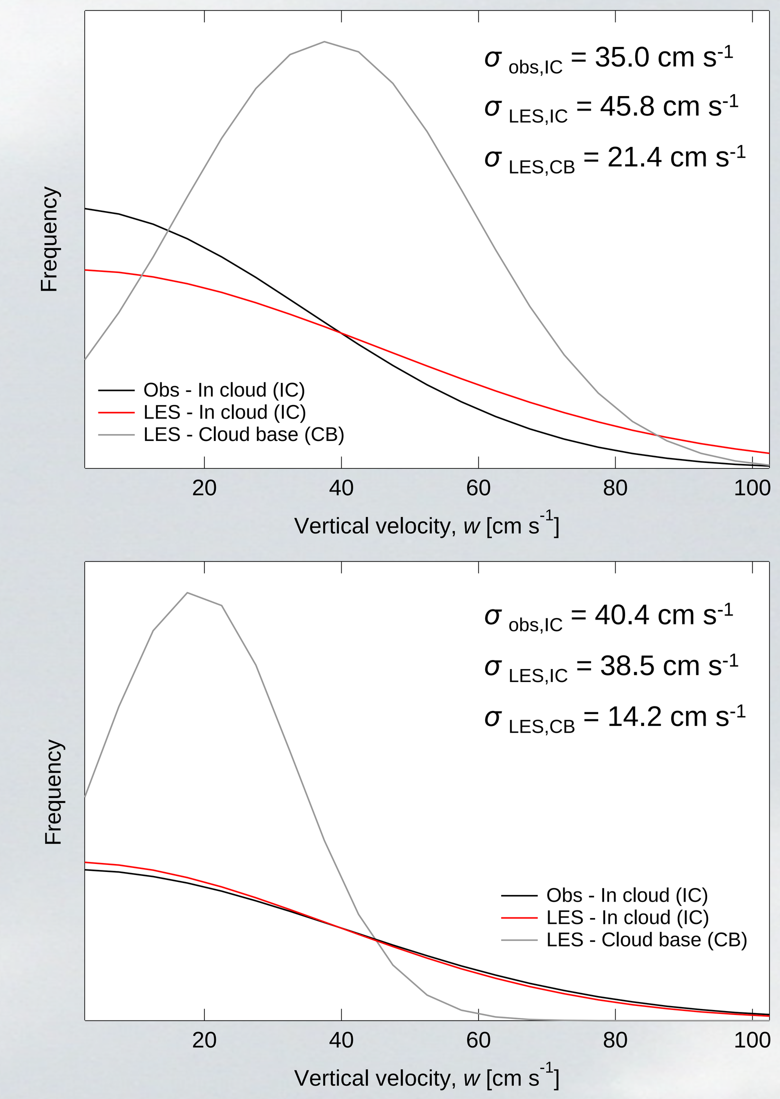
Cloud-base PDF: compiled from *w* values at cloud base from model trajectories specifically involved in activation (pass from below- to in-cloud level)

- Use LES analysis to determine characteristic velocity, w_{act}, representative of updrafts at cloud base

$$w_{act} = X_{LES}\sigma_{obs,IC}$$

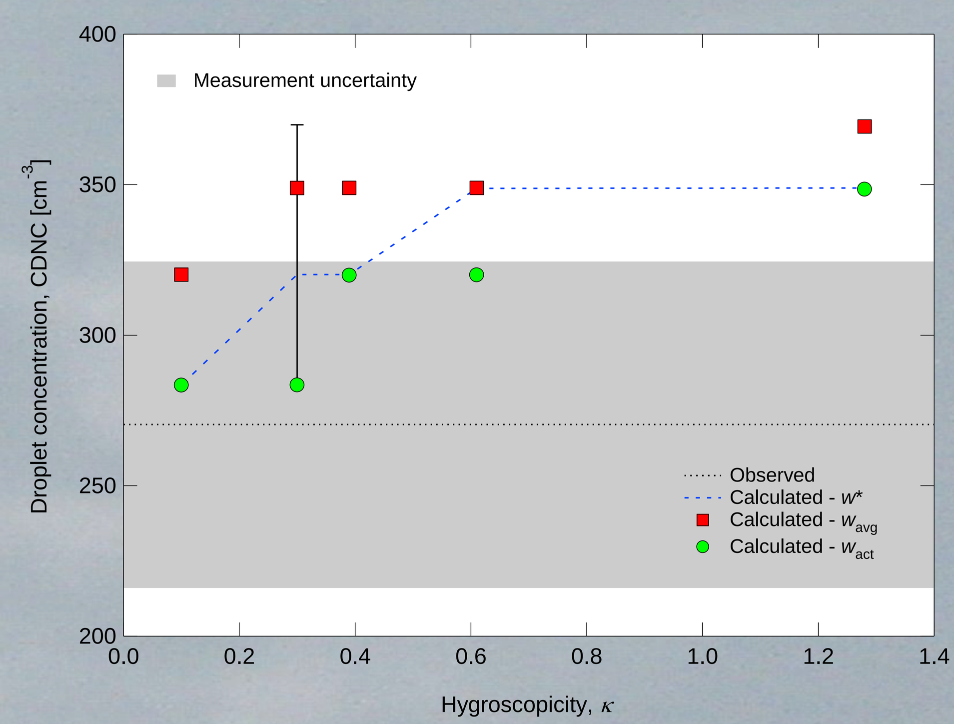
$$X_{LES} = \frac{w_{avg,CB}}{\sigma_{LES,IC}}$$

- Where $w_{avg,CB}$ is mean velocity from the cloud base PDF
- X_{LES} ~ 0.89 in clean and ~ 0.55 in more polluted aerosol conditions



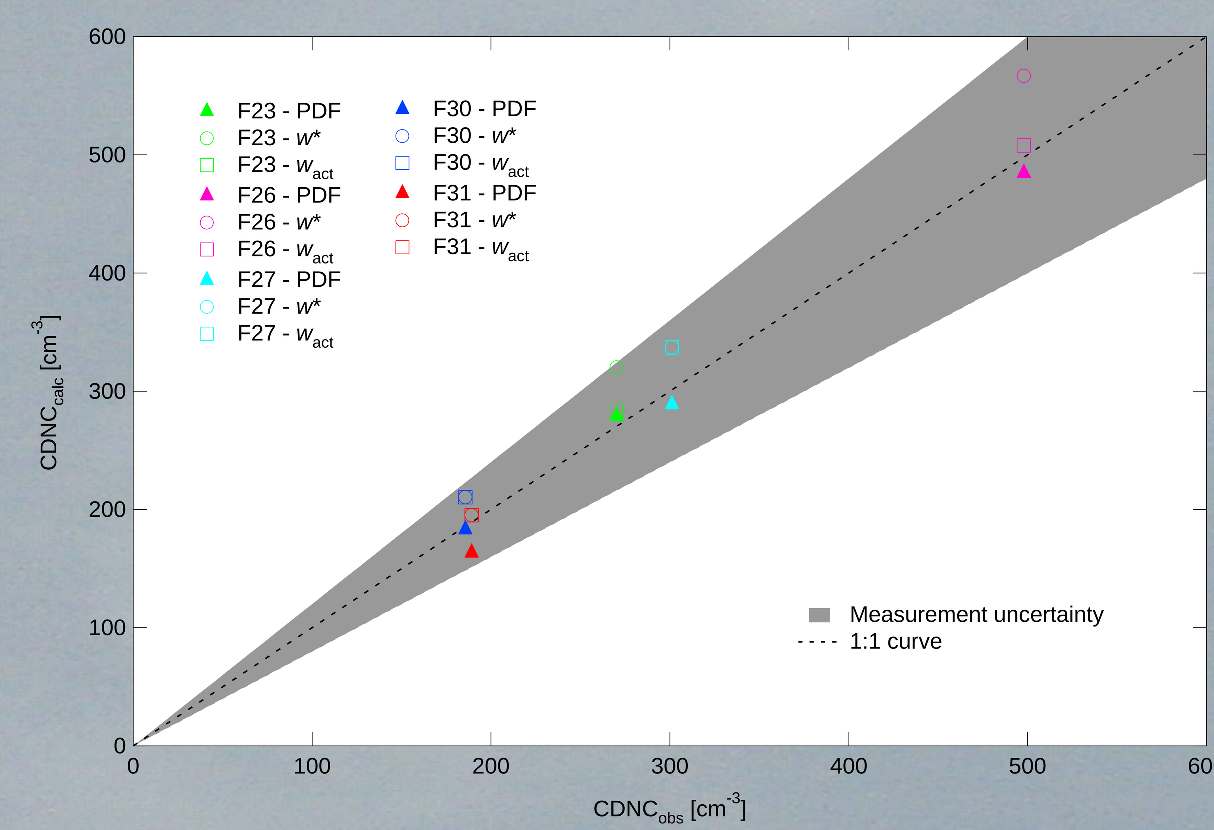
Updraft velocity PDFs from observations and LES model for clean case on April 27 (top) and polluted case on April 20 (bottom).

Results



Model sensitivity analysis for April 18 case (ISDAC flight 23). All values are calculated for condensation coefficient α_c = 1. The error bar shows the variation in results when α_c = 0.06.

- Conducted model sensitivity analysis for aerosol particle hygroscopicity, *κ*, and condensation coefficient, α_c
- Cases in present study represented well by *κ* = 0.3 and α_c = 1
- Test different representations of updraft velocity in adiabatic cloud parcel model simulations
  - Integrate results over *w* PDFs (longer computation)
  - Characteristic values: w_{act}, w_{avg} (PDF mean), and w^* (representative value derived from CCN spectrum; *Morales and Nenes*, 2010)



Adiabatic parcel model results for different representations of the updraft velocity, compiled for all ISDAC cases. All simulations assume *κ* = 0.3 and α_c = 1.

Summary of Key Findings

- Activation for ISDAC cases in clean aerosol conditions relatively insensitive to *w* representation
- Higher sensitivity in more polluted aerosol conditions; w_{avg} (~ 0.79 $\sigma_{obs,IC}$) and w^* (~ 0.70 $\sigma_{obs,IC}$) can overestimate CDNC in simulations relative to w_{act} (~ 0.55 $\sigma_{obs,IC}$)
- LES analysis can guide representation of updraft velocity for model descriptions of activation

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