Aircraft-based observations of turbulence fluxes over the Arctic marginal ice zone: Early results from ACCACIA

Andrew Elvidge, Alex Weiss, Ian Renfrew, Ian Brooks, Tom Lachlan-Cope
Aerosol-Cloud Coupling And Climate Interactions in the Arctic

Talk outline

• Introduction to ACCACIA
• Outline of field campaigns
• Analysis plans
• Preliminary results on air-sea-ice fluxes
• Provisional conclusions
Aerosol-Cloud Coupling And Climate Interactions in the Arctic

ACCACIA Objectives

1. Understand the microphysical properties of Arctic clouds and their dependence on aerosol properties
2. Determine the natural and anthropogenic sources of aerosol within the Arctic boundary layer
3. Determine boundary layer structure and turbulent mixing properties
4. Quantify the feedbacks between clouds, aerosol, sea ice and the wider climate system

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• Introduction to ACCACIA
• Outline of field campaigns
• Analysis plans
• Preliminary results on air-sea-ice fluxes
• Provisional conclusions
• FAAM aircraft focus is on:
  – Cloud microphysics
  – Aerosol properties above/in/below cloud
  – Turbulence structure of BL
  – Spring 2013 campaign

• BAS MASIN aircraft focus on
  – Greater emphasis on near surface aerosol & fluxes
  – Spring & Summer 2013

• Surface measurements from icebreaker RV Lance
  – Spring & Summer 2013
Nominal ship track
<table>
<thead>
<tr>
<th>date</th>
<th>FAAM</th>
<th>MS1</th>
<th>MASIN</th>
<th>Description</th>
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<tbody>
<tr>
<td>20 March</td>
<td>B759</td>
<td>Ian B</td>
<td></td>
<td>Over MIZ S. Svalbard, cloudy BL (mixed-phase)</td>
</tr>
<tr>
<td>21 March</td>
<td>B760</td>
<td>Ian R</td>
<td></td>
<td>Lance; Transition Ice (SBL)-MIZ-Water, no cloud, poor FC, fluxes</td>
</tr>
<tr>
<td>22 March</td>
<td>B761</td>
<td>Keith</td>
<td>180</td>
<td>Transition Ice-MIZ-Water, cloud, well-mixed &lt;1500m, fluxes Test flight</td>
</tr>
<tr>
<td>23 March</td>
<td>B762</td>
<td>Ian R</td>
<td>181</td>
<td>DS leg; Transition Ice (SBL)-MIZ-Water, w’ transition, cloud BL turbulence south of Svalbard</td>
</tr>
<tr>
<td>25 March</td>
<td>-</td>
<td>-</td>
<td>182</td>
<td>Cold-air outbreak north of Svalbard</td>
</tr>
<tr>
<td>26 March</td>
<td>B763</td>
<td>Ian R</td>
<td>183</td>
<td>Polar low on strong shear line Cold-air outbreak north of Svalbard</td>
</tr>
<tr>
<td>28 March</td>
<td>-</td>
<td>-</td>
<td>184</td>
<td>BL and aerosol north of Svalbard</td>
</tr>
<tr>
<td>29 March</td>
<td>B764</td>
<td>Ian B</td>
<td>185</td>
<td>Aerosols continental air mass, MIZ-Water, cloud-focus Aerosols &amp; BL, east of Svalbard</td>
</tr>
<tr>
<td>30 March</td>
<td>B765</td>
<td>Paul</td>
<td></td>
<td>Continental air, Ice-Water, BL jet &amp; inversion, unstable SL, fluxes</td>
</tr>
<tr>
<td>31 March</td>
<td>B766</td>
<td>Keith</td>
<td></td>
<td>East of Svalbard (aborted, anti-icing problem)</td>
</tr>
<tr>
<td>2 April</td>
<td>B767</td>
<td>Ian R</td>
<td>186</td>
<td>North of Svalbard (bird strike) North of Svalbard, clean air mass, cold-air outbreak</td>
</tr>
<tr>
<td>3 April</td>
<td>B768</td>
<td>Ian B</td>
<td>187</td>
<td>N. Svalbard, Transition ice-MIZ-water, stratus over ice SBL and aerosols north of Svalbard</td>
</tr>
</tbody>
</table>
Analysis plans I

• Surface fluxes (FAAM and MASIN)
  – B760, B761, B765
  – M181, 182, 184, 185
  – Surface exchange of momentum & heat over sea-ice and MIZ
  – Parameterization testing
  – Forecast model validation
Analysis plans II

• Arctic ABL thermal and turbulent structure; relationship to macrophysical cloud structure
  – focus on ABL transitions
  – sea-ice -> marginal ice zone -> open water
  – B760, 761, 762+M181, B765, M185, B768
  – [B759, M182, B764, M186]
  – UEA/Leeds/BAS/Manchester
  – Forecast model validation and testing

• NWP simulations of selected cases
Cloud Microphysical & Aerosol Properties - Deep Stratus Flight Profile

Above cloud turbulent entrainment velocities & Aerosol Properties inc. IN concentration

Super-cooled Layers, Primary Ice Generation

T °C
-11
-5
-3

H-M Zone 2-DS

Super Cooled Water Layers

Mixed Phase/Heterogeneity

Turbulent Entrainment

Above cloud fluxes

H-M Temperature Zone

Refractory Black Carbon Mass

Aerodynamic Diameter (nm)

Organic Aerosol Mass HOA, OOA Mo(D_p)
Inorganic Mass, NO_3, SO_4, NH_4, Cl IM(D_p)
Refractory black carbon mass & number rBC, N_BC(D_p)
Aerosol absorption coefficient k_e
Scattering/Absorbing M, N_{scat/absorb} (D_p)
CCN, Volatility
Ice Nucleus Concentration IN - (MO)

Turbulence – Latent/Sensible Heat

Below cloud aerosol profile & composition

Sea salt

Particle Shape, Roughness, Scattering Coefficient (UH)

Airborne Eddy Covariance Surface Fluxes

Sea

Liquid & Ice Water Profiles & Path

Turbulent Entrainment

Liquid/Mixed Phase Fraction

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Sea
B760 Overview
21 March 2013

R/V Lance overpass and
SBL over sea ice & MIZ south of
Svalbard
Whole Flight Overview Plots
Drag forces over sea ice

1) Skin drag: surface friction. Dependant on surface type – open sea, ice, snow etc.

2) Form drag: Sea ice, ice ridges, open water in melt ponds and leads – provide vertical faces that the wind pushes against. More pronounced in the summer and at the MIZ. (Andreas et al, 2010)
Andreas et al., 2010: both drag forces can be parameterized via ice concentration.

From Andreas et al. 2010, QJRMS
Legs under 100 m

- **B760 legs 1-2**: ship overpass: ~80 m
- **B760 leg 3**: From ice to sea: ~80 m
- **B761 leg 1**: Over ice: ~40 m
- **B765 leg 1**: From ice to sea: ~40 m
B760 Leg 3, ~80 m
B760 Leg 3, ~80 m

**CHN** = 10-m neutral heat exchange coefficient
B760 Leg 3, ~80 m
B760 Leg 3, ~80 m

From Andreas et al. 2010, QJRMS
**Sector 1**
- Lance overpass at 250 ft

**Sector 2**
- Profile descent to point D
- Straight and level legs from D to E, or midpoint, at various heights
- Note: no cloud encountered during low-level legs – in contrast to FC
Results – all runs from B760 legs 3-7
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• ABL over the sea ice was stable, and as we crossed the marginal ice zone to open water little in the way of BL transition, although pick up in turbulence.
• The winds were low so surface heat fluxes restricted, despite large sea-air temperature difference, meaning the BL was remaining stable even over open water?
• The profile ascent at the end showed SBL – just off the ice edge. And convective clouds did not start till considerably further downstream than forecast in the MO 4 km model.
Future work

• **FAAM flights: 7 in spring**
  – 3 good surface flux flights
  – 7 good ABL flights: Sea-ice -> MIZ -> open water
  – 1 polar low flight

• **MASIN flights: 7 in spring and 8 in summer**
  – 4 + 3 good for fluxes
  – 5 + 4 good for ABL studies.

• SST data – High frequency Heimann data adjusted using higher quality but low frequency ARIES data. OSTIA of no use over sea ice.

• **FAAM flux calculations** seem believable and have reasonable number of useable runs. But isn’t a great deal of data! MASIN and ASCOS to also be included.

• Next: parameterization testing and model validation.