The Arctic boundary layer
Interactions with the surface, and clouds, as learned from observations (and some modeling)

Michael Tjernström
Department of Meteorology & the Bert Bolin Center for Climate Research, Stockholm University

*With the help of many: Ola Persson, Chris Fairall, Ian Brooks, Matthew Shupe, Thorsten Mauritsen, Joseph Sedlar, Cathryn Birch and many, many others*
Context

• A few words about observations, or the lack thereof
• Boundary-layer structure
• Interaction with the surface: the seasonal story and what’s below
• Interactions with clouds
• Some modeling – here and there
A few words about observations

- Surface obs
- Soundings
- Aircraft obs
- Buoys & ships

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ASCOS 2008
Arctic troposphere vertical structure

From SHEBA soundings

Winter

Altitude (km)

\(\frac{d\theta}{dz} \text{ (K m}^{-1}\text{)}\)

Probability (%)
Arctic troposphere vertical structure
From SHEBA soundings

Winter

Altitude (km)

\( \frac{\partial \theta}{\partial z} \) (K m\(^{-1}\))

Probability (%)

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Arctic troposphere vertical structure
From SHEBA soundings

All seasons: Stable layer 200 m to ~2 km, near neutral 5-8 km & often near neutral PBL.

Winter: Additionally strong surface inversions ~ 50% of the time

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"Boundary layer"
Inversion base height

Inversion strength

Inversion thickness

Altitude (m)

Temperature (K)

1 Oct 1 Dec 1 Feb 1 Apr 1 Jun 1 Aug 1 Oct

1 Oct 1 Dec 1 Feb 1 Apr 1 Jun 1 Aug 1 Oct
Near-surface stability

Relative probability (%)

Vertical temperature gradient (°C m⁻¹)

-0.2  -0.1  0    0.1  0.2  0.3  0.4  0.5

SHEBA Summer
SHEBA Winter
ASCOS
AOE-2001
Vertical thermal structure

ASCOS Eq. potential temp. probability (%)

AOE Eq. potential temp. probability (%)

SHEBA Eq. potential temp. probability (%)

AOE-96 Eq. potential temp. probability (%)

~400 m

~300 m

~300 m

~300 - 600 m
Vertical moisture structure
Winter

Spring

Summer
SHEBA Relative humidity

Relative humidity (RH$_w$, %)

Days relative to 1 January 1998
SHEBA Relative humidity

Relative humidity ($R_{w}$, %)

Days relative to 1 January 1998

Relative humidity ($R_{h}$, %)

Days relative to 1 January 1998

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Winter

Spring

Summer
Winter

SHEBA stability

Spring

Summer
SHEBA sensible heat flux

Winter

Spring

Summer
SHEBA latent heat flux

Winter

Latent heat flux (W m$^{-2}$)

Number of observations

Spring

Latent heat flux (W m$^{-2}$)

Number of observations

Summer

Latent heat flux (W m$^{-2}$)

Number of observations
Non-melt season: Variable $T_s < 0^\circ C$

Non-melt season relationship
Exclude May 29- Aug. 23
Non-melt season: Variable $T_s < 0° C$

Melt season: Fixed $T_s \approx 0° C$
SHEBA
Polar
Night

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Momentum transfer to the surface

Bias:
- ArcSym = 0.08
- COAMPS = 0.04
- HIRHAM = 0.04
- Polar MM5 = 0
- RCA = 0.11
- Remo = 0.06
- COAMPS ice = 0.03

\( \sigma_0 = 0.12 \)
Surface sensible heat flux

$F_{shf\ annual\ (W\ m^{-2})}$

Bias:
- ArcSym = -0.96
- COAMPS = -2.01
- HIRHAM = -2.81
- Polar MM5 = -2.65
- RCA = -4.07
- Remo = 1.32
- COAMPS ice = -0.75

$\sigma_0 = 8.86$

Winter

Summer

Sensible heat flux (W m$^{-2}$)
Surface latent heat flux

$F_{lhf} \text{ annual (W m}^{-2}\text{)}$

Bias:
- ArcSym = 6.14
- COAMPS = 3.49
- HIRHAM = 1.66
- Polar MM5 = 0.28
- RCA = 4.69
- Remo = 1.59
- COAMPS ice = 4.79

Winter

Summer

Latent heat flux (w m$^{-2}$)
Clouds in global models
Clouds in global models
Clouds in regional models

CWP_{obs} > 0 (kg m^{-2})

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Surface energy balance

Energy flux (W m$^{-2}$)

- SW net radiation
- LW net radiation
- Sensible heat
- Latent heat
- Ocean heat flux
- Residual

Dates:
13-16/8, 17-19/8, 21-22/8, 24-29/8, 31/8-1/9
What is a cloud?

Cloud base (lidar)

Cloud top (radar)
Some reflections...

• What we think we know about small scale features such as low-troposphere vertical structure, clouds and surface fluxes rests on very “thin ice”. As a consequence modeling without observational constraints is problematic; even reanalysis is difficult.

• Some things stand out:
  – The overall boundary-layer structure is dominated by near-neutral conditions, but strong lasting surface inversions do occur in winter.
  – Three surface coupling regimes: melt (summer, fixed $T_s$), non-melt (spring, responsive $T_s$) and polar night (winter, no sun).
  – Near-surface moisture remains close to saturation – almost always!
  – In winter, conduction through ice & snow is as important as sensible heat flux and snow thickness is critical.
  – Low clouds dominate, but clouds are sometimes optically thin. In summer this is because of sometimes very low aerosol concentrations while cloud-water phase is also important, especially in winter.
  – Surface energy balance is dominated by (LW) radiation while turbulent heat fluxes are small ⇒ focus more on the momentum flux?