Humidity inversions above Arctic SC clouds: Small scale boundary layer processes observed with BELUGA

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1. Arctic humidity inversions - introduction
2. BELUGA measurements during PASCAL
3. Case study: BL processes on 6 June 2017
4. Summary & outlook
• Generally specific humidity $q$ is thought to decrease with height
• Arctic: frequently $q$ inversions in different altitude levels
• $q$ inversions may influence cloud lifetime

*Solomon, 2014*
Brief literature review

Arctic Humidity Inversions: Climatology and Processes
Tuomas Naakka, Tiina Nygård, and Timo Vihma
Finnish Meteorological Institute, Helsinki, Finland

(Manuscript received 25 July 2017, in final form 16 February 2018)

A brief review of the literature on Arctic humidity inversions.

→ based on radiosoundings and reanalysis

→ based on reanalysis

→ based on LES and radiosounding

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Moisture and dynamical interactions maintaining decoupled Arctic mixed-phase stratocumulus in the presence of a humidity inversion
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A brief review of the literature on moisture and dynamical interactions in the Arctic.
To better understand the Arctic climate system, further studies on the interactions between SHIs and the vertical distributions of clouds and moisture transport to the Arctic, as well as the associated radiative and turbulent processes, are needed. (Naakka et al., 2018)
BELUGA tethered balloon system

BELUGA: Balloon-born E moduLar Utility for profilinG the lower A tmosphere

Egerer et al., AMTD, 2019
BELUGA tethered balloon system

Ultrasonic Transducers → u,v,w, Tᵥ (50Hz)

Inertial measurement unit → attitude & motion

Temperature sensors → T, RH

Battery and data acquisition

Egerer et al., AMTD, 2019
BELUGA tethered balloon system

Deriving vertical profiles

GPS altitude (m)

Time (UTC)

Egerer et al., AMTD, 2019
BELUGA measurements during PASCAL

Ice floe camp at 81.5°N
4-16 June 2017
9 measurement days
16 balloon flights
BELUGA measurements during PASCAL

Photo: S. Helen
Measured humidity layers during PASCAL

7 June 2017
Is this an instrument artefact?

- Compare ascent and descent
- Use different sensor
- Compare to other measurements:
  - Radiosonde
  - Polar 6
  - Dropsondes

The measured humidity layers are real.

Plots by D. Chechin, AWI
Measured humidity layers during PASCAL

Persistent humidity layer 5 to 7 June 2017: radiosondes

Balloon flights

Radiosoundings: Schmithüsen 2017, Cloud extent: Griesche 2019
Measured humidity layers during PASCAL

Similar vertical structure 5 to 7 June 2017: balloon measurements
Knudsen et al., 2018: Climatologically warm period 30 May – 12 June 2017 with warm and moist maritime air from the south and east
Case study: PASCAL - June 6, 2017

- RH (%)
- Altitude (m)
- θ (°C)
- q (g kg⁻¹)
- $\partial T / \partial t$ (K h⁻¹)
- $U$, $w$ (m/s)
- $\varepsilon_\tau$ (m² s⁻³)

Humid layer
Cloud mixed layer
Case study: turbulent fluxes

Buoyancy flux: \[ H = \rho \ c_p \ \overline{w'\theta_v} \]

- **RH (%)**
  - 50
  - 100

- **Altitude (m)**
  - 150
  - 200
  - 250
  - 300
  - 350
  - 400
  - 450

- **\( \theta (\degree C) \)**
  - 0
  - 10

- **q (g kg\(^{-1}\))**
  - 2
  - 3

- **H (W m\(^{-2}\))**
  - -20
  - -10
  - 0
  - 10

Negative flux → entrainment of moist air into cloud

BUT: how trustworthy is measuring inside the inversion?

2017-06-06
Case study: turbulent fluxes

Flux estimation inside inversion layer

Strong temperature variations

High-pass filter (30s)

\( \theta_v (K) \)
\( w (m/s) \)

2017-06-06
Case study: turbulent fluxes

Filter decreases fluctuations and flux magnitude, but vertical structure remains.

2017-06-06
• Humidity layer probably formed by advection
• Humidity layer and cloud layer are not completely decoupled
• Indication for entrainment of moist air from above into cloud on 6 June
• Humidity layer feeds the cloud - one possible mechanism for persistent Arctic Sc layers
• Measuring turbulent fluxes on a moving platform is challenging, but important to understand vertical transport.
• Processes are further studied in collaboration with University Cologne by large eddy simulations (Neggers et al., 2019)
• Measurement instrumentation
References


- Schmithüsen, Holger (2017): Upper air soundings during POLARSTERN cruise PS106.1 (ARK-XXXI/1.1). Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, PANGAEA, https://doi.org/10.1594/PANGAEA.882736


Additional slides
Humidity layers during other campaigns

RV Oden close to north pole 2018-09-11

PAMARCMiP, Station Nord 2018-03-28

Patchy clouds

Cloud-free
Specific humidity inversions (SHI) below 800hPa:

Occurrence

Formation processes

- Upward increasing horizontal moisture advection
- Unsaturated conditions
- Saturated conditions
- SHI+RHI
- SHI+RHI+TI
- SHI+TI
- TI
- Condensation
- Surface cooling in winter
  Cold surface in summer

Naakka et al. (2018)

Occurrence

- ERA-Interim summer
- soundings
Wind speeds at balloon and mast

Vertical wind

![Graph showing vertical wind with frequency f (Hz) on the x-axis and power spectral density (σ²Hz⁻¹) on the y-axis. The graph includes lines for balloon uncorrected, balloon, and mast with a black line for f⁻⁵/³.](image-url)
Cloudnet: Humidity layer is above mixed-phase cloud layer

H. Griesche