Investigation of Aerosol Optical Properties in the European Arctic using Lidar remote sensing technique

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Motivation-Research Questions

- **Persistent lofted layers** over Ny-Ålesund and Fram Strait
- **Optical properties** in different transport events?
- **Radiative impact** of different transport events?
- **Contribution** to **Arctic Amplification (AA)**? [1]

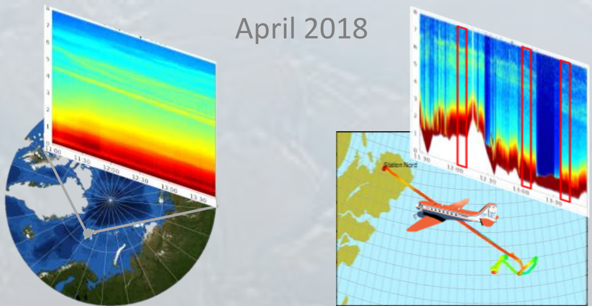

Fig 1: Lidar range-corrected signal at 532 nm (arbitrary units) measured over Ny-Ålesund (left) and Fram Strait (right).

Instrumentation

Ground-based system KARL [2]
- Raman aerosol Lidar
- "3β+2α+2δ+2wv" system
- Nd: YAG laser (1064, 532, 355 nm)

Air-borne system AMALi [3]
- Elastic aerosol Lidar
- "2β+1δ" system
- Nd: YAG laser (532, 355 nm)

Baseline Surface Radiation Network [4]
- Pyranometer→ SW diffuse, global, reflected (0.2-3.6 μm)
- Pyrheliometer→ SW direct (0.2-4 μm)
- Pyrgeometer→ LW fluxes (3.5-50 μm)

Fig 2: Emitting unit, comprising laser head, optical components and beam widening telescope (left), and hatch of KARL system (middle). The Baseline Surface Radiation Network (BSRN) station, which is located in Ny-Ålesund (right).

Elevated Layers over Ny-Ålesund in the past decade

Ground-based Lidar Observations

April 2009 March 2003

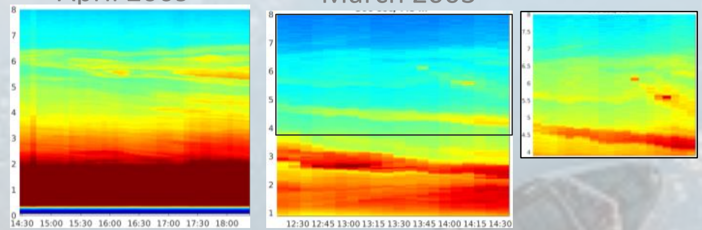

Fig 3: Lidar range-corrected signal at 532 nm (arbitrary units) over Ny-Ålesund on 1st April 2009 (left) and 14th March 2003.

Inversion of Aerosol Optical Properties

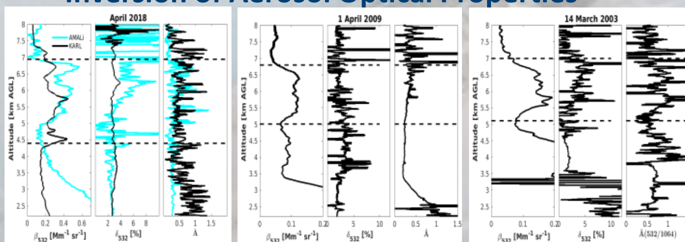

Fig 4: Aerosol optical properties on 5th April 2018 (left),1st April 2009 (middle) and 14th March 2003 (right).

$$\delta^{aer}(\lambda) = \frac{\beta_{\perp}^{aer}(\lambda)}{\beta_{\parallel}^{aer}(\lambda)}$$

$$\text{Å}(\lambda_1,\lambda_2) = -\frac{\log\frac{\lambda_1}{\lambda_2}}{\log\frac{\beta_{\lambda 1}}{\beta_{\lambda 2}}}, \lambda_1 < \lambda_2$$

Radiative Impact of Aerosol

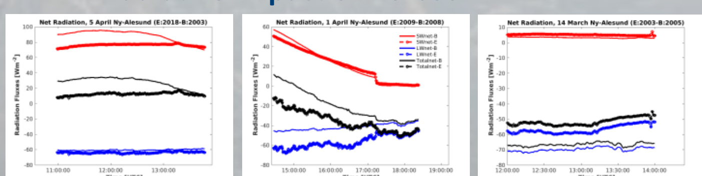

Fig 5: Radiative fluxes on ground level at Ny-Ålesund in April 2018/2003 (left), in April 2009/2008 (middle) and in March 2003/2005 (right).

$$F_{net}^{TOTAL} = (F_{in}^{SW} - F_{out}^{SW}) + (F_{in}^{LW} - F_{out}^{LW})$$

$$AF_{net}^{TOTAL} = F_{netE}^{TOTAL} - F_{netB}^{TOTAL} = (F_{netE}^{SW} - F_{netB}^{SW}) + (F_{netE}^{LW} - F_{netB}^{LW})$$

Findings

- Elevated **aerosol layers** (Fig. 1; Fig. 3) observed in the **Arctic** over the past decade (2003-2018) on an **infrequent basis**
- Inversion of optical properties [5], [6] in **2018** yielded **higher aerosol backscatter coefficient over Fram Strait** ($\beta_{532}^{AMALi} = 0.42 \pm 0.15$ Mm^{-1}sr^{-1}; $\beta_{532}^{KARL} = 0.34 \pm 0.08$ Mm^{-1}sr^{-1})
- In **2009** and **2003**, **lower β** ($\beta_{532}^{KARL} = 0.3 \pm 0.09$ Mm^{-1}sr^{-1}; $\beta_{532}^{KARL} = 0.2 \pm 0.09$ Mm^{-1}sr^{-1})
- Nearly **spherical particles** (low depolarization)
- Aerosol size parameter indicates **low spectral dependency** (Ångstrom exponent≈1)
- Lidar ratio (LR_{355nm}^{2018}=40 sr; LR_{355nm}^{2009}= 38 sr) suggesting **mixture of smoke and polluted continental particles** [7], [8], [9], similar to iAREA campaign in spring 2014 [10]
- In **2018**, moderate total net warming of 12 Wm^{-2} at ground level (Fig. 5) along with negative total aerosol forcing (AF=-15.3 Wm^{-2})
- In **2009**, total net ground cooling of -36 Wm^{-2} (Fig. 5) and negative total AF (-15.4 Wm^{-2})
- In **2003**, significant total net cooling of -48 Wm^{-2} at the surface, mainly due to LW (Fig. 5), while positive total AF (15 Wm^{-2})

Conclusions

- ✓ **Rare occurrence** of **elevated layers** in the Arctic but **impact on radiation** budget
- ✓ Similar optical properties indicating **smoke-polluted continental aerosol type**
- ✓ Similar AF in layers occurring in April, although total net radiation balance different
- ✓ Layers with **similar optical properties** potentially have **different impact on radiation** balance. The role of **insolation is potentially critical**

Future Work

- **Contribution to Arctic Amplification** needs further **investigation**
- Aerosol radiative impact at different atmospheric levels by means of **SCIATRAN RTM simulations** [8]
- **Inversion** of aerosol **microphysical** properties and **closure with in-situ** measurements [9], [10]

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