Radiative transfer simulations and observations of airborne infrared emission spectra in the presence of PSCs: Detection of clouds and discrimination of cloud types

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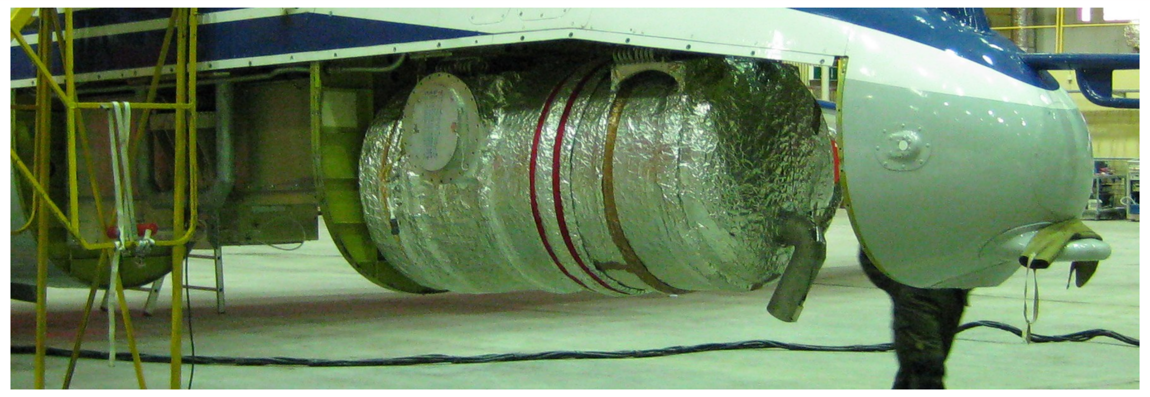
Introduction and motivation:

- **Polar stratospheric clouds** (PSC) form inside the cold polar vortex and consist of three particle types: **NAT** (nitric acid trihydrade), **STS** (super-cooled ternary solution), and **ice** [1]
- PSC play an **important role for** the spatial and temporal evolution of **trace gases** inside the vortex e.g. due to **chlorine activation** and **denitri-fication** of air masses [2,3]
- **infrared limb sounder** are well suited for the **detection** of PSCs and the **discrimination of particle types** [4]
- they partly deliver **complementary information** compared to other obser-vations such as in-situ measurements or lidar observations



CRISTA-NF instrument on Geophysica:[5,6]

measurement technique	limb sounding
altitude range	flight altitude (18-19 km) – 5km
vertical sampling	100 – 250 m
spectral resolving power	536 at 12.5 µm
spectral sampling	0.0065 µm
field of view (vertical x horizontal)	3 arcmin x 30 arcmin

Simulations and setup:

- simulations were performed with the radiative transfer code **JURASSIC** including **scattering** and **absorption / emission** by spherical particles (Mie theory) for two spectral ranges [7]
- **background atmosphere** partly set to **2010 (RECONCILE)** values (e.g. temperature, long lived species) and partly taken from **climatology** (e.g. ozone, $ClONO_2$)
- different scenarios by **varying microphysical properties** and **cloud dimensions**
- **PSDs** are represented by **log-normal distributions** (σ=1.35)

cloud dimensions:

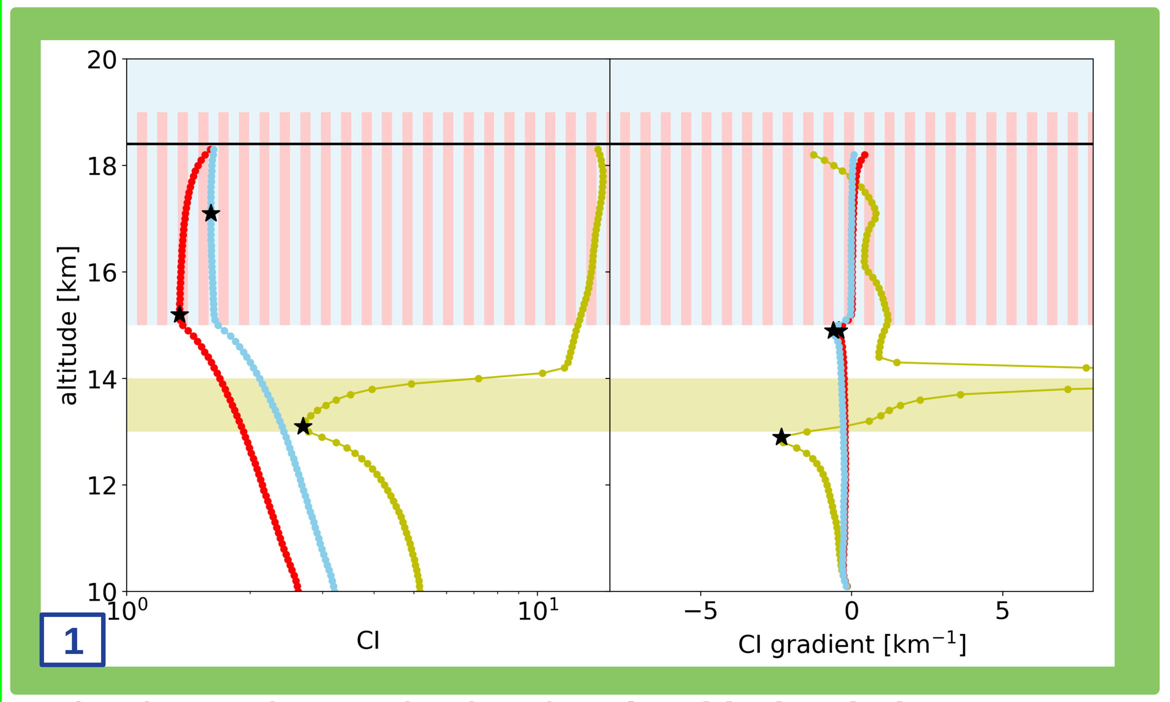
PSC position	13.0 – 30.0 km
PSC thickness	0.5, 1.0, 2.0, 4.0, 8.0 km

spectral range	considered constituents
785 – 840 cm^{-1}	temperature, pressure, CO_2, HNO_3, O_3, $ClONO_2$, H_2O, CCl_4, HNO_4, CFC-11, HCFC-22, CFC-113, PAN, ClO, NO_2
940 – 965 cm^{-1}	temperature, pressure, CO_2, HNO_3, O_3, H_2O, CFC-11, PAN, SF_6, NH_3, COF_2

microphysical properties:

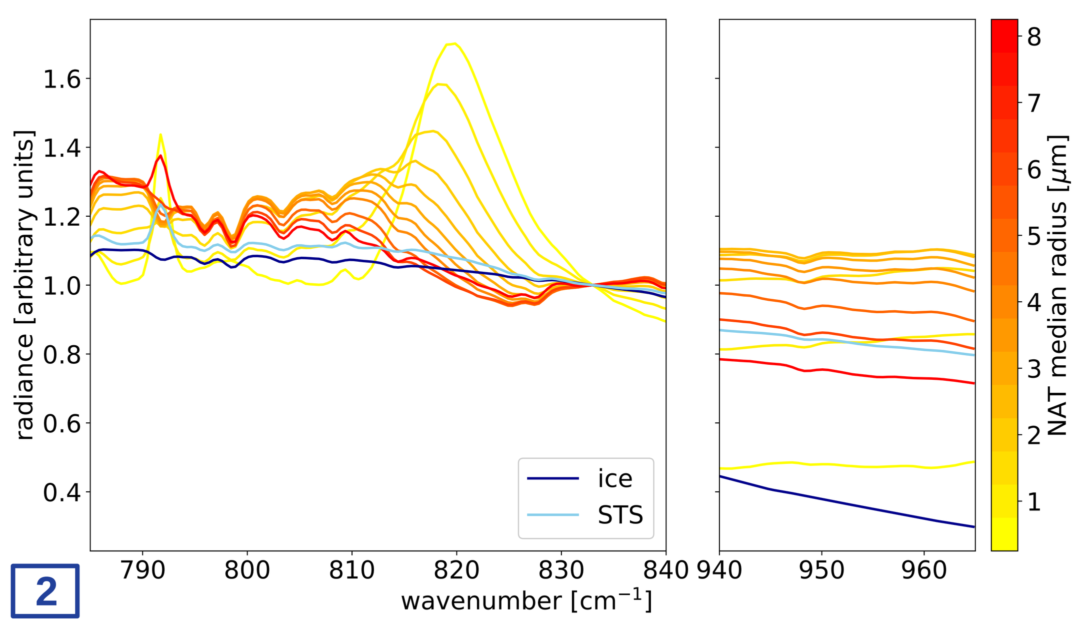
PSC type	HNO_3 VMR / volume density	median radius [µm]
NAT	1 – 15 ppbv	0.5 – 8.0
STS	0.1 – 10.0 µm³/cm³	0.1 – 1.0
ice	0.1 – 100.0 µm³/cm³	1.0 – 10.0

Cloud detection:



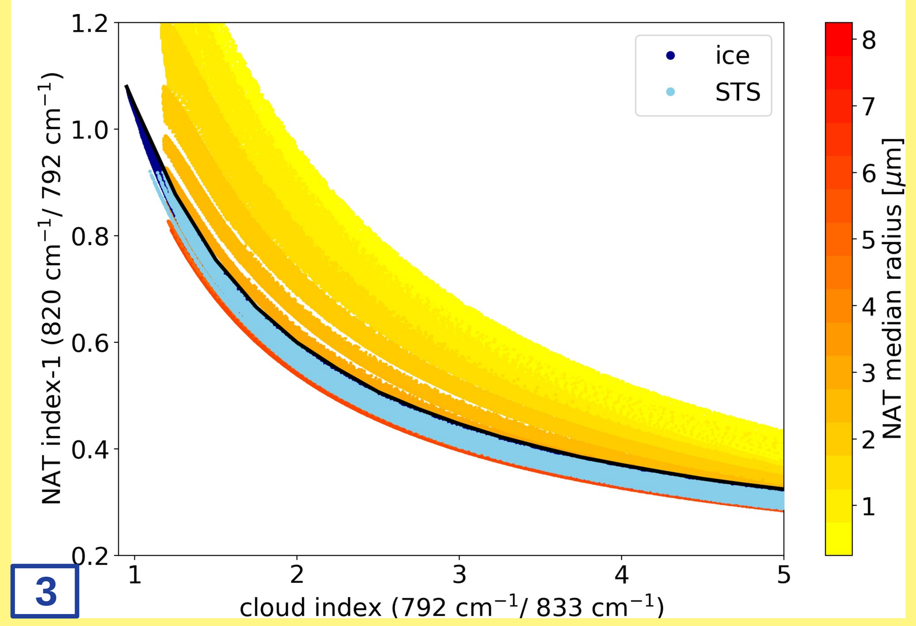
- clouds are detected using the **cloud index (CI)**: radiance ratio: **792 cm^{-1}** (CO_2-Peak) / **833 cm^{-1}** (aerosol) [8]
- **low values show clouds** and the **minimum CI** is located **inside the cloud** (typically close to bottom altitude)
- **minimum of the CI gradient** is located slightly below the **cloud bottom altitude** (cloud spectra: 1.2 < CI < 5.0)

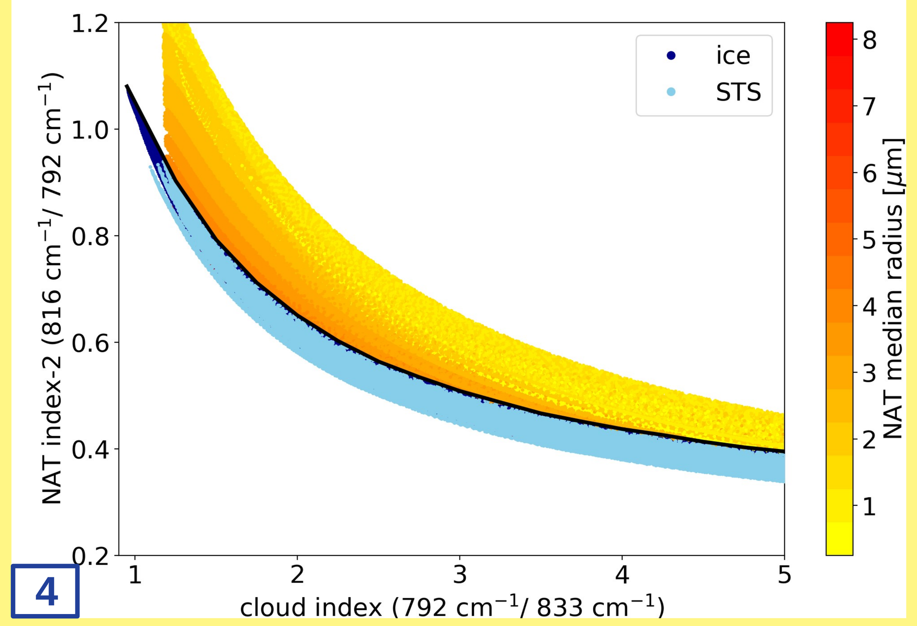
NAT feature:

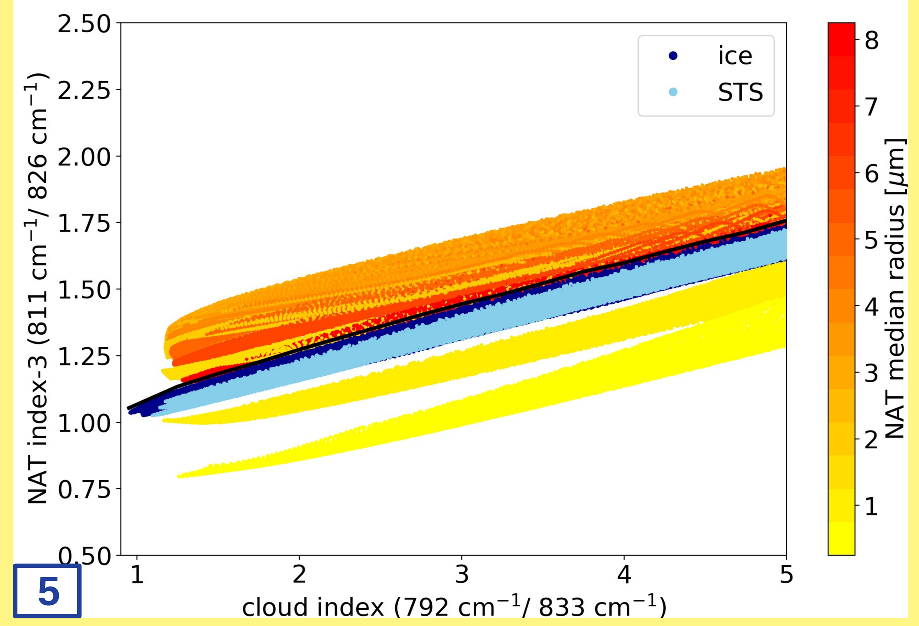


- **appearance** of the NAT feature changes with particle size
- it depends on the **proportion between scattering (large particles) and absorption (small particles)** contributions to the radiance signal
- real part (**scattering**) shows a **step-like** signature and imaginary part (**absorption**) shows a **peak at 820 cm^{-1}**

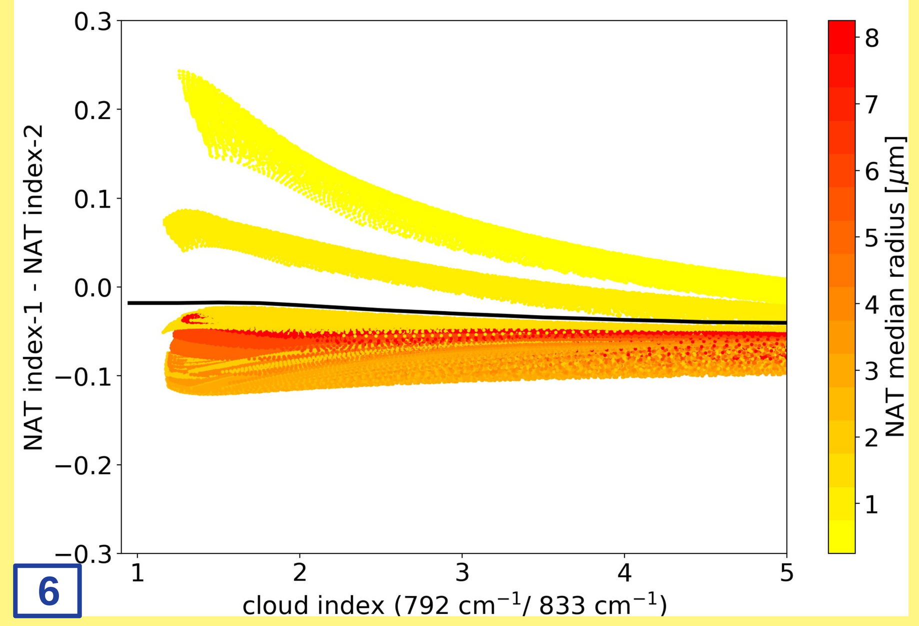
Detection of NAT:





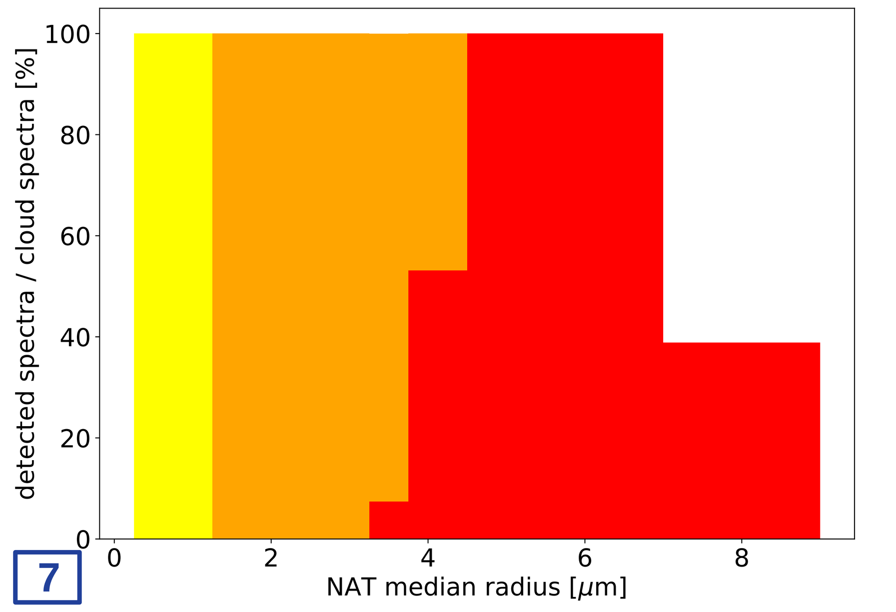


- **detection** of NAT is based on **three different NAT indices**:
  - NAT index-1: **820 cm^{-1} / 792 cm^{-1}**
  - NAT index-2: **816 cm^{-1} / 792 cm^{-1}**
  - NAT index-3: **811 cm^{-1} / 826 cm^{-1}**
- all indices have **different sensitvities** to NAT with **different median radii**
- difference of **NAT index-1 – NAT index-2** is used for the **size discrimination**

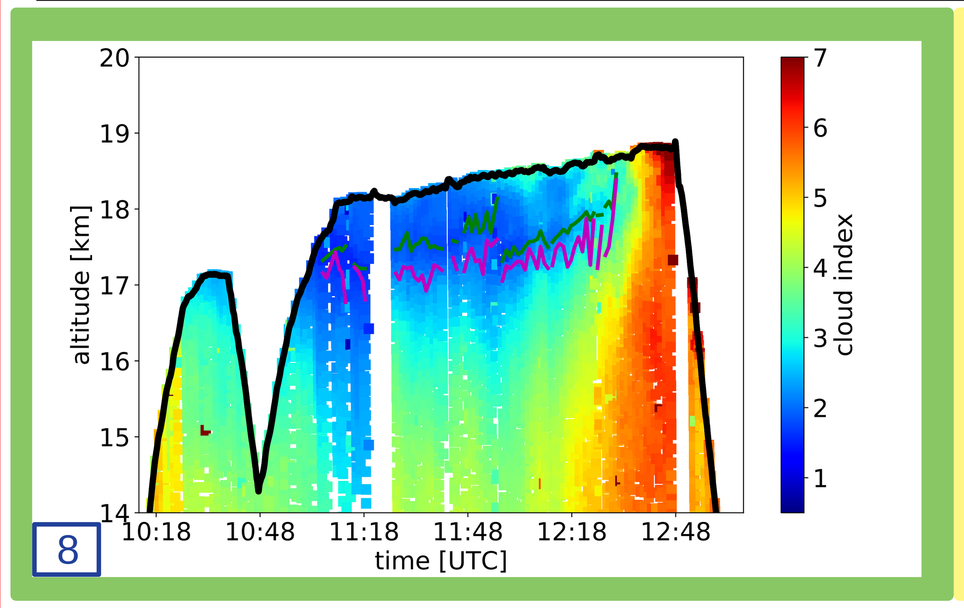


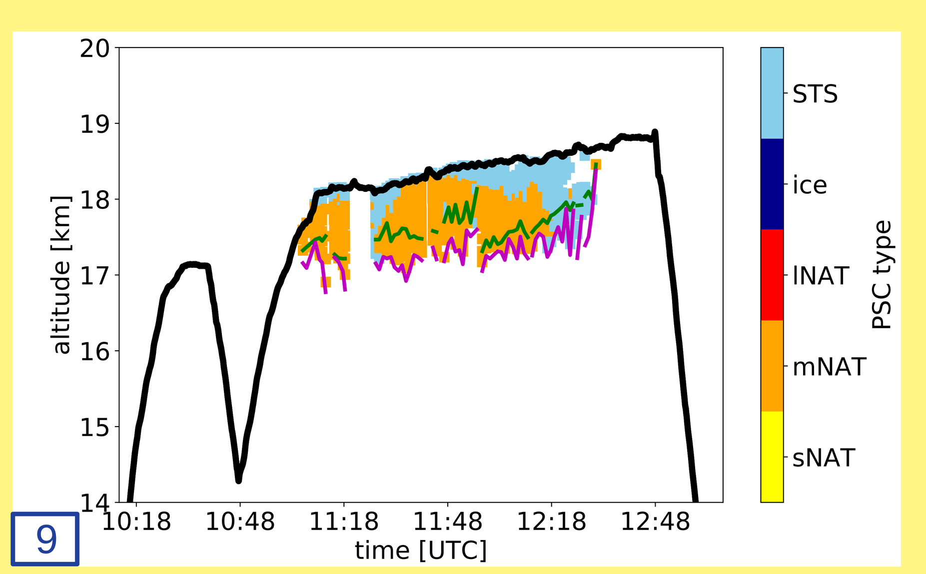
- **three different NAT cases**
  - **small NAT (sNAT) (≤ 1.0 µm):**
    - NAT index-1 positive (above separation line)
    - NAT index-1 – index-2 positive
  - **medium NAT (mNAT) (> 1.0 and ≤ 4 µm):**
    - NAT index-2 positive
    - NAT index-1 – index-2 negative (below separation line)
  - **large NAT (lNAT) (≥ 3.5 µm):**
    - NAT index-1 and index-2 negative
    - NAT index-3 positive

- **good separation** of different **particle sizes** for simulated spectra (CI < 3.0)
- size **discrimination works** also for mixed **NAT/STS clouds** and bimodal **NAT clouds**



CRISTA-NF observations during RECONCILE:





- the flight took place northward of **Kiruna (Sweden) at 22 January 2010**
- the **bottom altitude** of the cloud is located between the **CI minimum** (green line) and the **CI gradient minimum** (magenta line) at about **17 – 17.5 km**
- during the flight mainly **mNAT (1.5 – 4 µm)** was detected and, additionally, **STS**

Summary:

- new **detection method** enables the **discrimination** of PSC types **NAT, STS, and ice** with CRISTA-NF
- **first time discrimination of size ranges** of NAT particles: sNAT (≤ 1.0 µm), mNAT (> 1.0 and ≤ 4 µm), lNAT (≥ 3.5 µm)
- new **method to detect bottom altitude** of the PSC
- observation of **PSC** during RECONCILE flight **down to ~17 km**
- detected PSC types: **mainly mNAT** and **some STS**

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