Identification of aerosol sources in Siberia and study of aerosol transport at regional scale by airborne ans space-borne LIDAR measurement

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Abstract : Airborne lidar measurements were carried out over Siberia in July 2013 and June 2017. Aerosol types and optical properties are derived using the Lagrangian FLEXible PARTicle dispersion model (FLEXPART) simulations, Moderate Resolution Imaging Spectrometer (MODIS) Aerosol Optical Depth (AOD) and fire observations and maps of the Infrared Atmospheric Sounding Interferometer (IASI) CO total column. Six aerosol plumes have been studied and lidar ratio (LR) are compared with existing LR/aerosol type analysis made in North America using High Resolution Spectral Lidar (HSRL) airborne lidar data (Burton et al. 2015). Comparison with Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) aerosol products are discussed to assess the aerosol type identification in CALIOP version 4.20 algorithm above Siberia.

Context & Scientific objectives

- **Context :**
  - Lack of knowledge on the aerosol distribution and their optical properties = source of uncertainty in the evolution of the climate in Siberia.
  - Role of forest fires on aerosol distributions in Siberia well identified → what is the contribution of anthropogenic sources (urban pollution, exploitation of Siberian gas and oil) ?
  - What is the impact of remote sources (Central Asian desert, northern China pollution) on the optical properties of aerosols at higher latitudes ?
- **Scientific objectives :**
  - Identification and characterization of aerosol key sources in Siberia
  - Role of aging and transport on aerosol optical properties
  - Validation of the CALIOP aerosol type identification above Siberia

Methodology

- Exploitation of airborne lidar measurements from campaigns conducted in 2013 and 2017 in Siberia
  - **Step 1 :** Aerosol layers optical properties computation from airborne lidar data → backscatter ratio + integrated LR
  - **Step 2 :** Aerosol type identification
- CALIOP vs airborne lidar data
  - **Step 3 :** Comparison aerosol type and LR

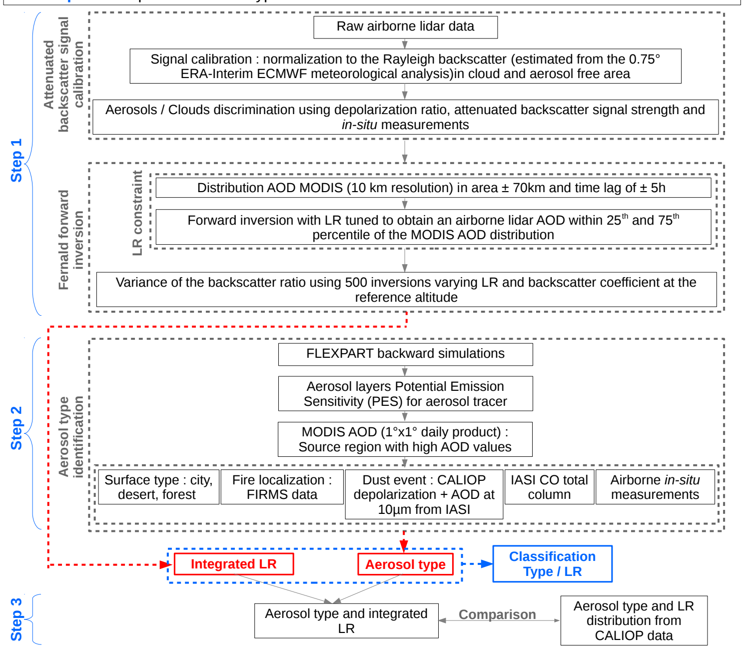

Fig. 1 : Fflow chart of airborne lidar data processing, optical properties retrieval and aerosol type identification complete methodology

Aircraft campaigns

- **Campaigns description :**
  - Two aircraft campaigns : July 2013 and June 2017 (total of 8 flights)
  - The aircraft flew over :(i) The major Siberian cities (Novossibirsk, Tomsk, Krasnoyarsk, Yakutsk) (ii) Gas flaring fields of the Ob valley (iii) The industrial city of Norilsk (iv) The Siberian taiga near forest fires
- **Airborne lidar system :**
  - Transmitter : Solid state Nd-YAG laser emitting 8 ns laser pulse at 532 nm
  - Receiver : 2 reception channels (co and cross-polarization)
  - Vertical sampling : less than 6m

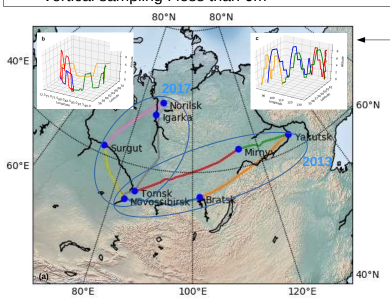

Fig. 3 : Map of the 8 aircraft flight tracks carried out in july 2013 (eastern loop) and in June 2017 (northern loop). The aircraft altitude ranges are also shown for the 2017 (b) and 2013 (c) flights.

- Aerosol type and LR distribution are assigned (flow chart fig. 1) to each aerosol layer detected during the airborne lidar campaigns.
- This classification is compared to [Burton et al., 2013] classification.

→ Good agreement for airborne and Burton classification

→ Bad agreement for « Urban » type
→ No classification for long range pollution

Table 2 : Results summary table of the comparisons airborne vs [Burton et al., 2013] classification

Aerosol type	Dusty aerosol mixture	Fresh smoke	Aged smoke	Ob valley industrial emissions	Urban pollution in Southern Siberia	Long range transport
Aircraft LR (sr)	26 - 40	39 - 41	64 - 86	43 - 60	71 - 90	37 - 45
Burton LR (5th-95th percentile)	29-49 (14-63)	33-46 (24-52)	55-73 (46-87)	53-70 (43-81)	53-70 (43-81)	36-45 (27-50)
Burton type	Dusty mix	Fresh smoke	Smoke	Urban	Urban	Polluted marine

Airborne Lidar observations – Example

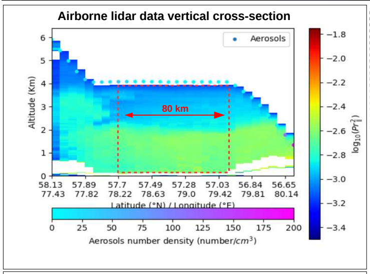

Fig. 4 : Vertical cross-section of aircraft $log_{10}(PR2)$ on June, 18 2017. Calibration constant is 83014 ± 5%. Grimm aerosol concentrations in particle.cm-3 are shown at the aircraft altitude.

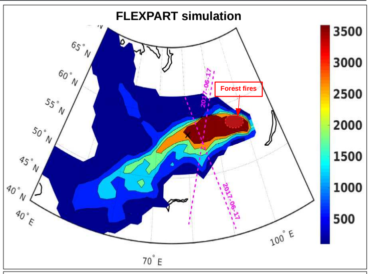

Fig. 5 : Map of the PES distribution for FLEXPART backward simulation for the aerosol layer between 0-2 km at 57.49°N. The red dotted area is FIRMS forest fire area and the pink dotted lines are the selected CALIOP overpasses in the source area.

- **Aerosol layer :**
  - Vertical extent : 0-2km
  - Horizontal extent : 100 km
- **Layer sensibility area (FLEXPART) :**
  - Novosibirsk and North of Irkutsk region
- **Aerosol type identification :**
  - High values of AOD locally and in Irkutsk region
  - FIRMS → forest fires in Irkutsk region
  - High ΔCO value (60 ppbv)
  - CCN to Aitken ratio = 0.6

→ Forest fire plumes from central Siberia
→ Inversion : 64 < LR < 86 sr

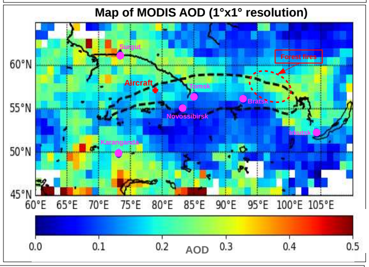

Fig. 6 : MODIS AOD 1°x1° averaged over the 4 days before the flight (June 15 to 18 2017). The black dotted lines are the high PES area (PES ≥ 2000 s) according to the FLEXPART simulation Fig. 15. The red cross is the presented aerosol layer position (red box Fig.14) and the red dotted squares define the area where the MODIS high resolution AOD distribution is calculated.

Comparison CALIOP vs airborne lidar data

- Mean backscatter ratio vertical profile : same vertical extent
- Aerosol type and LR :
  - Airborne lidar : Aged forest fire → LR : 64 – 86 sr
  - CALIOP : 66% « Polluted continental » (LR 70 ± 25 sr) → good agreement with airborne data
    34% « Polluted dust » (LR 55 ± 22 sr) → misclassification

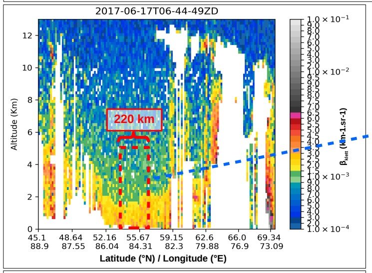

Fig. 7 : Vertical cross-section of CALIOP 532 backscatter coefficient on June 16 in the Novosibirsk region.

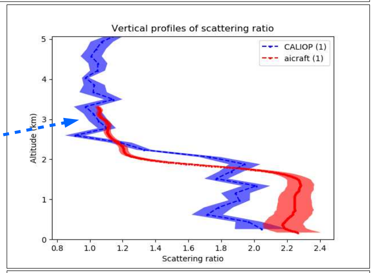

Fig. 8 : 80 km average of the backscatter ratio vertical profile from the airborne lidar on June 18th (green), 220 km average of CALIOP backscatter ratio vertical profile on June 17th (blue).

Aerosol type	Dusty aerosol mixture	Fresh smoke	Aged smoke	Ob valley industrial emissions	Urban pollution in Southern Siberia	Long range transport
Aircraft LR (sr)	26 - 40	39 - 41	64 - 86	43 - 60	71 - 90	37 - 45
CALIOP type	84 % Polluted dust (LR : 55 ± 22) 16 % Polluted Continental / Smoke (LR : 70 ± 25)	87 % Elevated smoke (LR : 70 ± 16) 9 % Polluted continental / smoke (LR : 70±25) 4 % Polluted dust (LR : 55±22)	66 % Polluted continental / smoke (LR : 70±25) 34 % Polluted dust (LR : 55±22)	65 % Polluted dust (LR : 55±22) 32 % Polluted continental / smoke (LR : 70±25) 3% Dust (LR : 44±9)	90 % Elevated smoke (LR : 70 ± 16) 10 % Polluted dust (LR : 55±22)	70 % Polluted continental / smoke (LR : 70±25) 30 % Elevated smoke (LR : 70 ± 16)
Airborne lidar vs CALIOP	LR_{CAL}>LR_{air} Good CALIOP classification Aersol aging	LR_{CAL} > LR_{air} No « Fresh smoke » included in CALIOP type	Same LR range	Same LR range but CALIOP « Polluted dust » type too high and LR_{CAL} « Polluted continental » too high	Same LR range but CALIOP type « Elevated smoke » misclassified	LR_{CAL} > LR_{air}

Table 2 : Results summary table of the comparisons CALIOP vs airborne lidar data

- **Aerosol aging and transport :**
  - Dusty aerosol mixture : LR_{CALIOP} « Polluted dust » too high
  - Polluted air masses from China or Ob valley : LR_{CALIOP} « Polluted continental » generally too high
- **Misclassification :**
  - No « Fresh smoke » type in CALIOP classification ($LR_{fresh\ smoke}$ < Lr_{smoke})
  - « Polluted dust » or « Elevated smoke » instead of « Polluted continental »

- **Conclusions :**
  - Lidar data inversion with lidar ratio (LR) constrained using the synergy between airborne and spaceborne data (MODIS AOD).
  - Identification of aerosol layers type using FLEXPART, MODIS, IASI and in-situ aircraft observations.
  - CALIOP aerosol type misclassification: fresh versus aged smoke, continental pollution versus elevated smoke.
  - No consideration of aerosol aging in polluted dust or continental pollution CALIOP type.
  - Paper in progress with submission before the end of the year !
- **Perspectives :**
  - Use AOD from the CALIOP lidar surface peak to constrain the integrated CALIOP lidar ratio.
  - Check the improved CALIOP aerosol retrieval using the aircraft case studies.
  - Check the summer lidar ratio statistical comparison with MODIS over land with a similar comparison using Synergized Optical Depth Aerosol (SODA) CALIOP data products over the ocean.