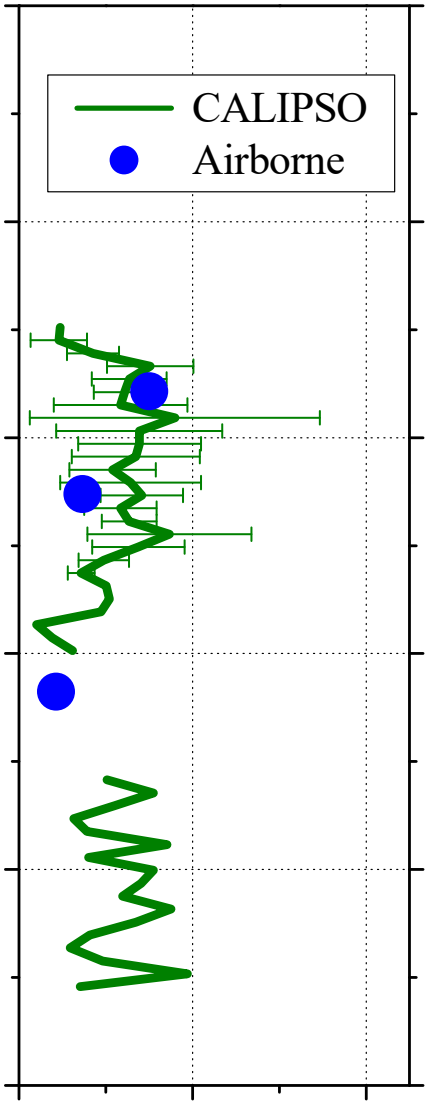
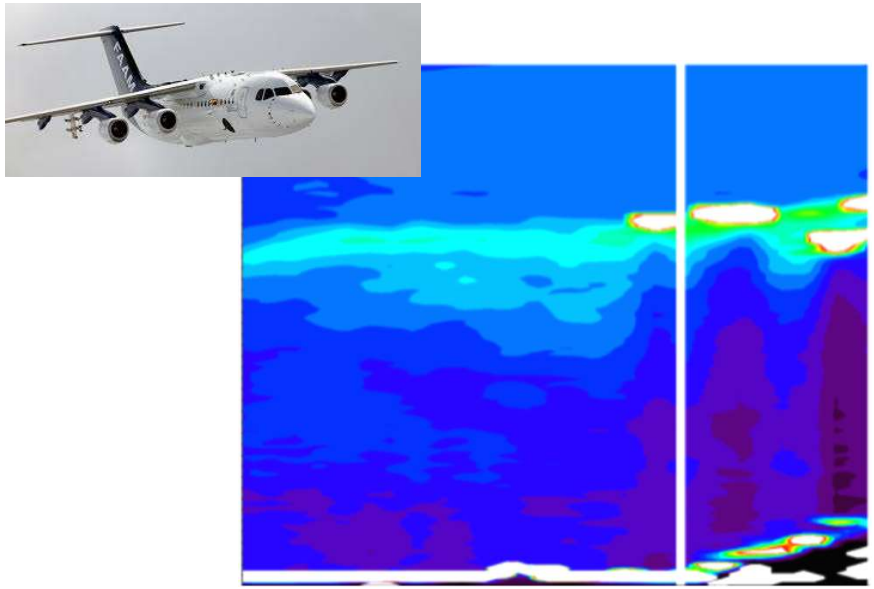
CALIPSO validation with airborne in-situ and lidar measurements: Tackling the problem of hygroscopic growth

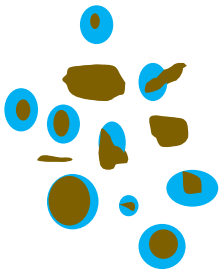


Overview

- CALIPSO validation with aircraft data: in-situ and lidar
- Discussion on challenges combining the different techniques
- Focus on humid ambient conditions and particle hydration

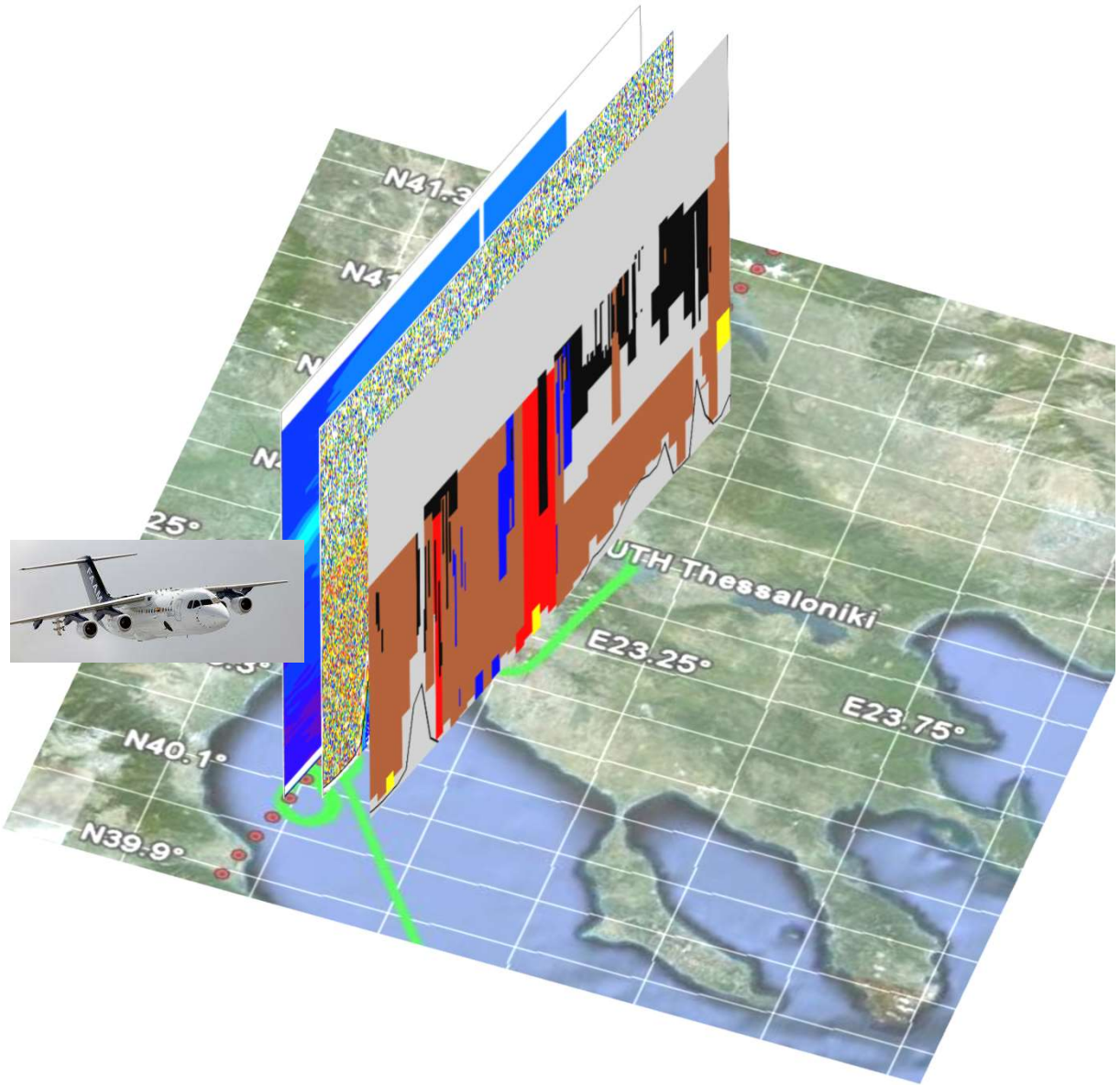


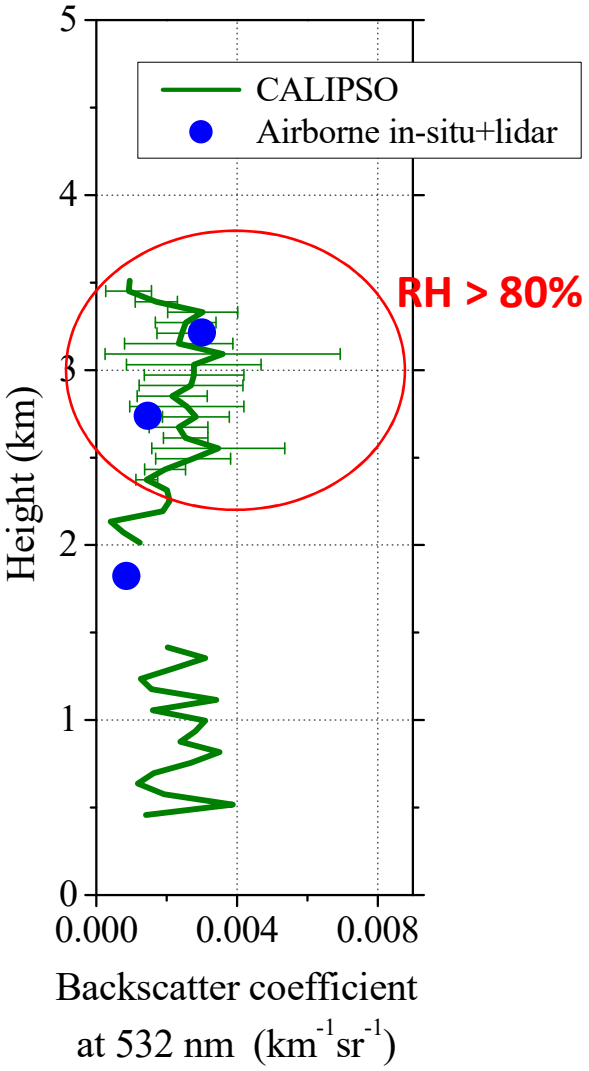
Particle hydration



- Water is on average 2–3 times the total aerosol dry mass on a global average
- Both organic and inorganic compounds contained within aerosol can drive the formation of a liquid aerosol phase
- Aerosol hydration changes the particle size and refractive index
- A relative humidity (RH) of 90 %, the scattering cross section can increase by a factor of 5 compared to that of the dry particle

Validate CALIPSO products

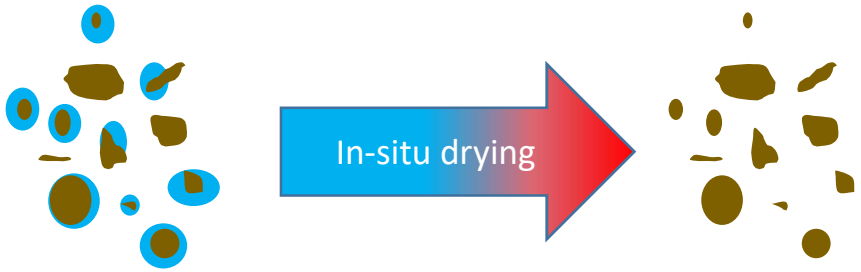


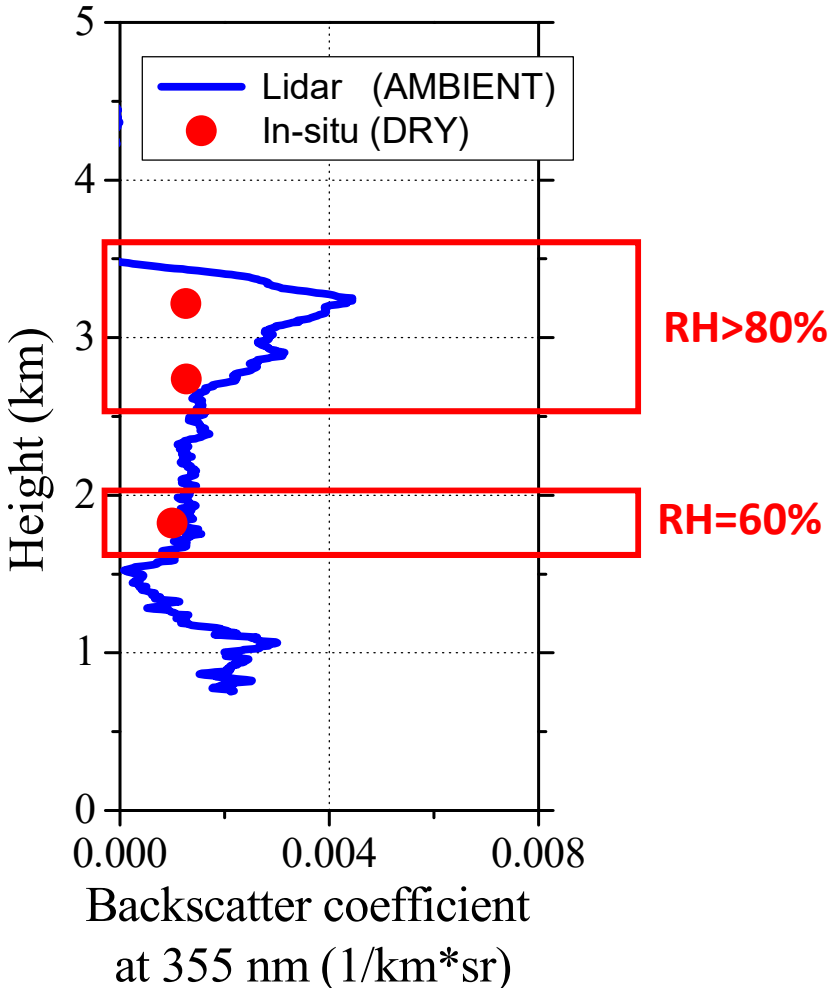


Tackling particle hydration

Problem when combining in-situ with remote sensing

- In-situ instruments dry particles (except open-path instruments)
- Remote sensing measures ambient particles

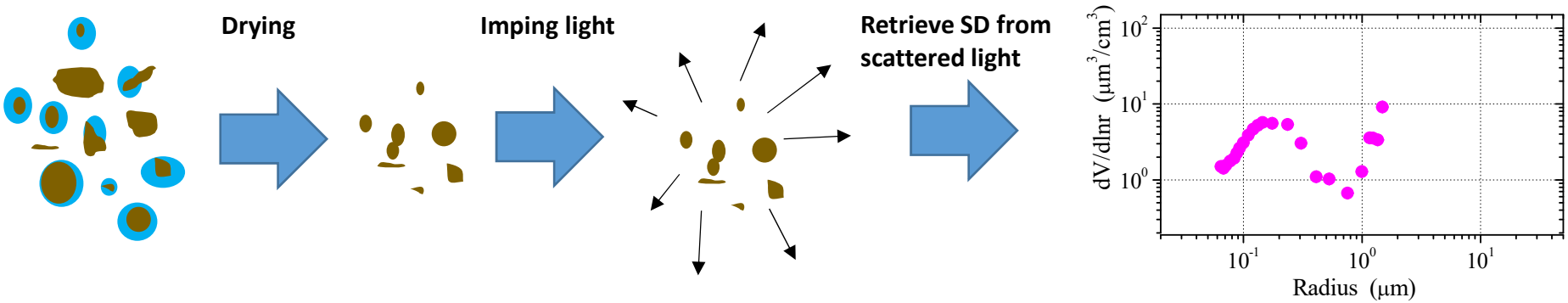




In-situ are NOT necessarily a direct measurement!

In-situ size distribution and refractive index are retrieved

- Optical methods are used to derive the particle size distribution with Optical Particle Counters (OPCs)

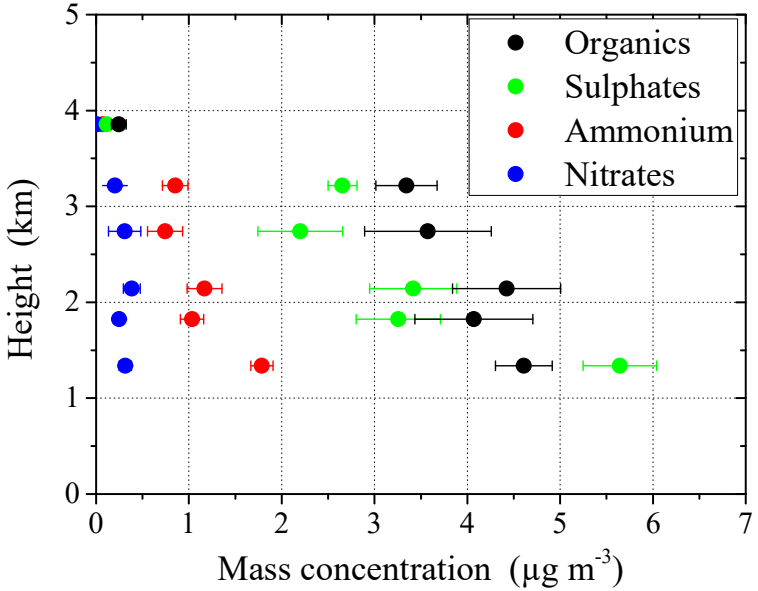


- The size distribution is retrieved from the sample scattered light, using assumptions:
  - Particle refractive index
  - Particle shape

In-situ are NOT necessarily a direct measurement!

- The refractive index can be calculated from measured chemical composition using assumptions (e.g. the effective refractive index of the chemical group)

Chemical composition



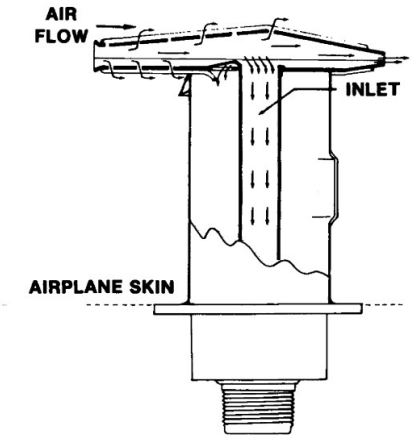
Effective RI for each chemical group

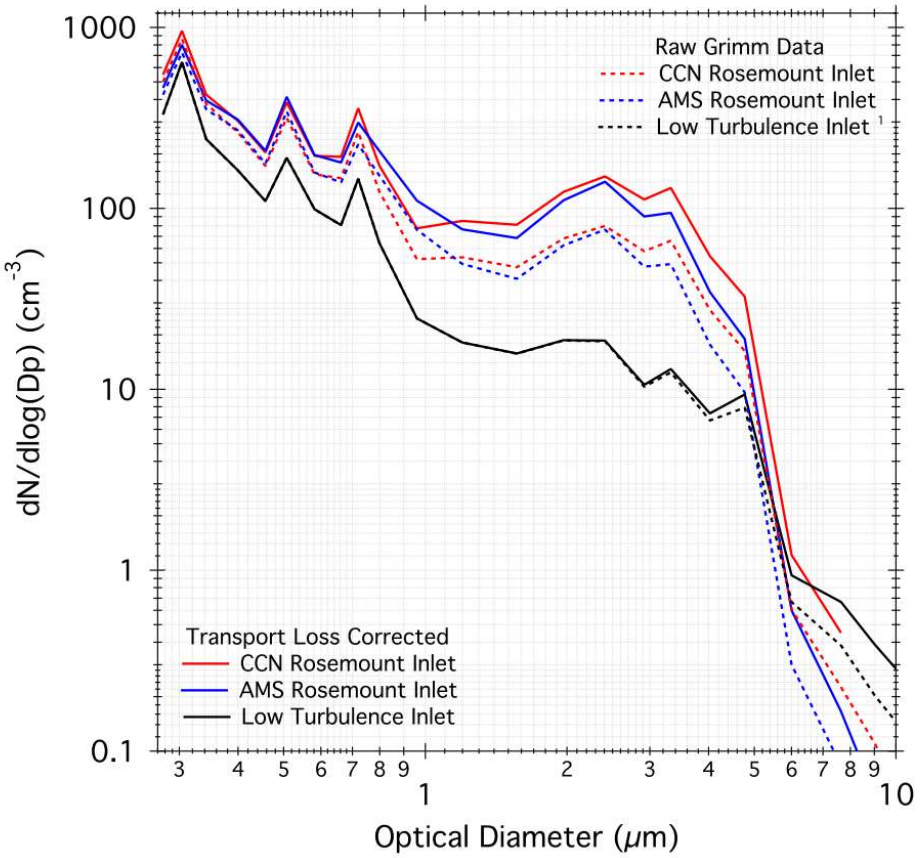
Chemical species	Refractive index at 550 nm	Density ($g\,cm^{-3}$)	References
Ammonium sulfate $(NH_4)_2SO_4$	$1.53 - 0i$	1.77	Toon (1976)
Ammonium nitrate NH_4NO_3	$1.611 - 0i$	1.8	Weast (1985)
Organic carbon of the Suwannee River fulvic acid	$1.538 - 0.02i$	1.5	Dinar et al. (2006, 2008)

Inlet effects

Inlet can cause particle enhancement/loses

- The effects are generally stronger for larger particles

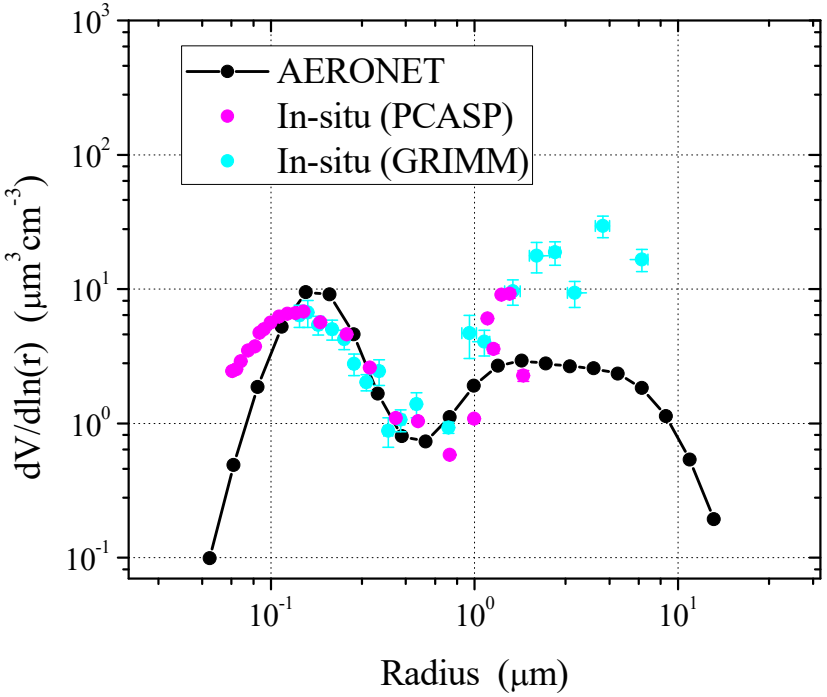




(Source: Trembath et al., 2012)

Different particle size ranges

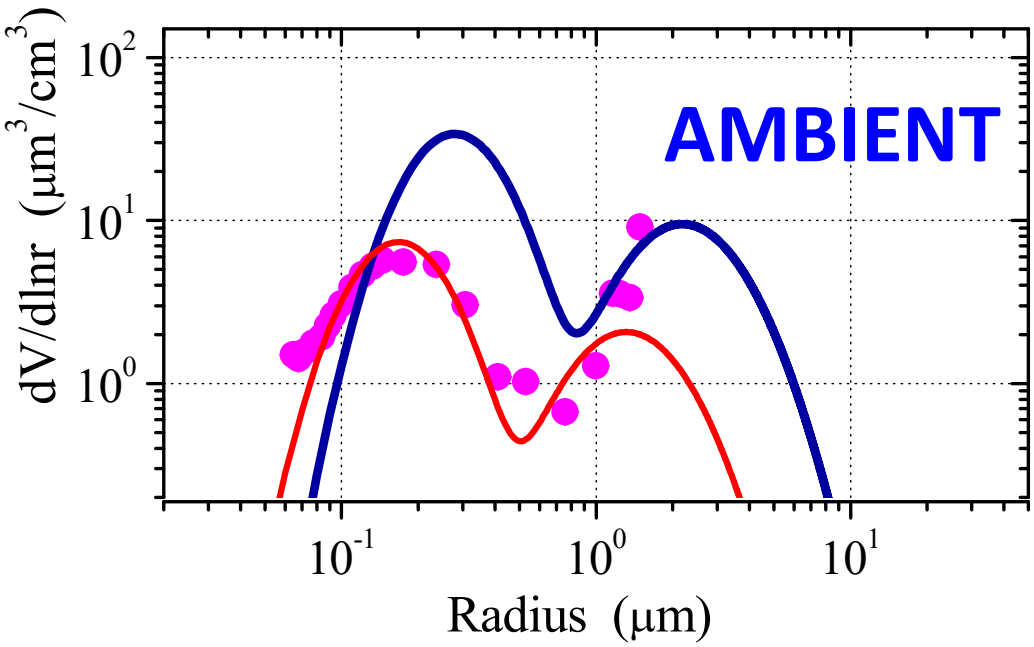
Need to combine measurements from instruments that cover different particle ranges



Particle hygroscopicity: the connection btn dry in-situ and ambient remote sensing

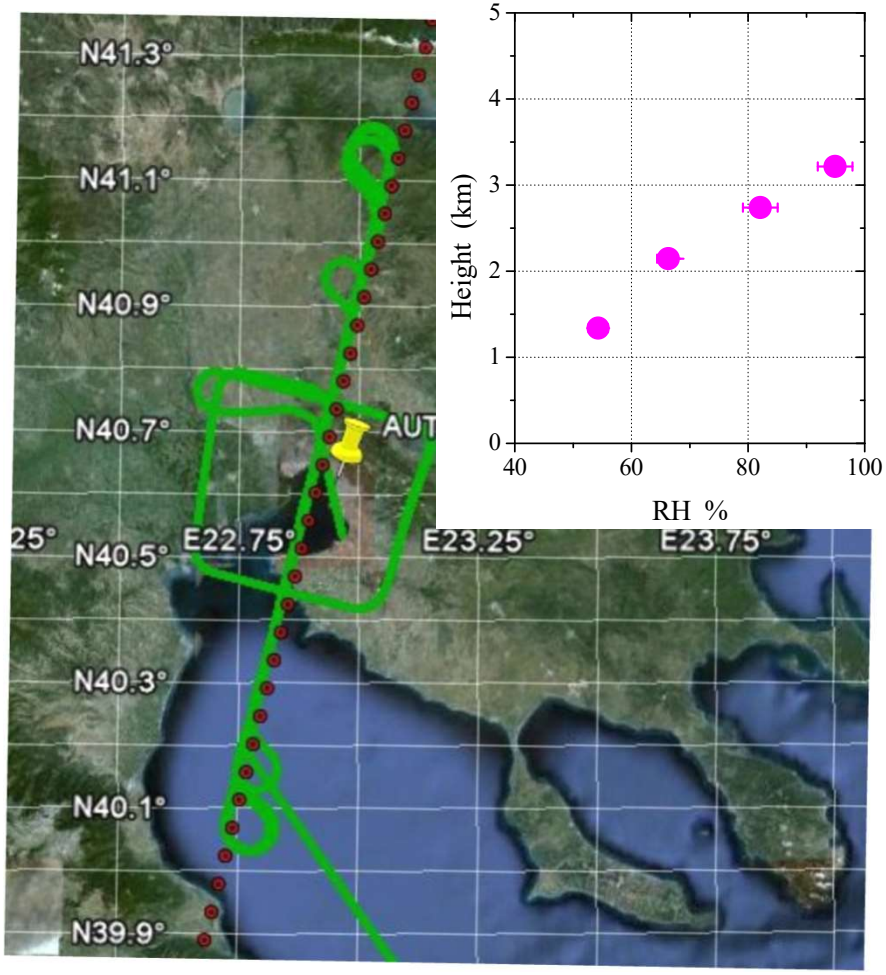
ISORROPIA II (Fountoukis and Nenes, 2007) models particle hygroscopicity

- Dry in-situ size distribution
- ISSOROPIA II input:
  - Dry size distribution fit
  - Chemical composition
  - RH,T,P
- ISORROPIA II calculates the hygroscopic growth and water content

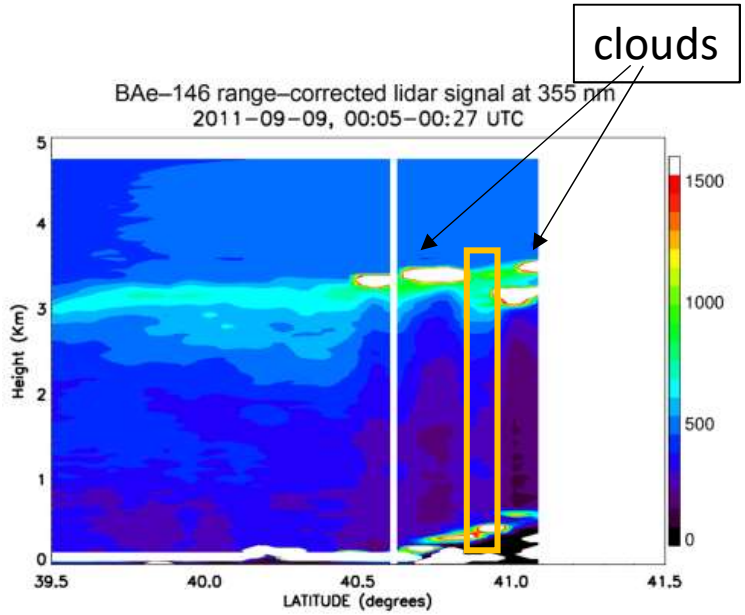


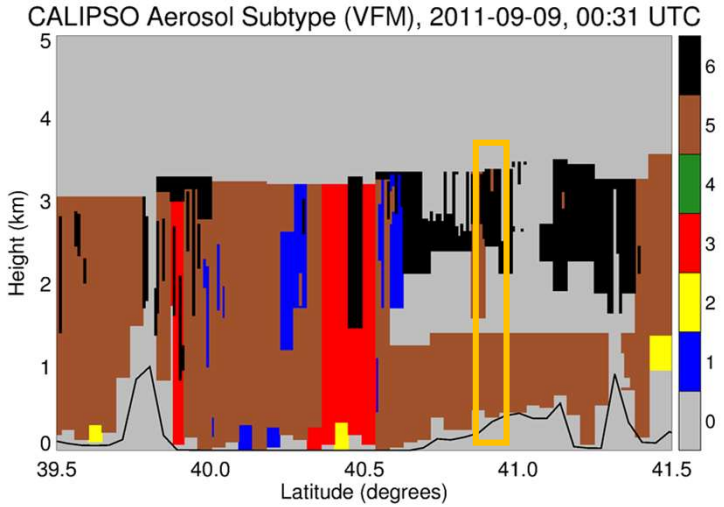
- Refractive index of ambient particles is calculated from their water content

Test case

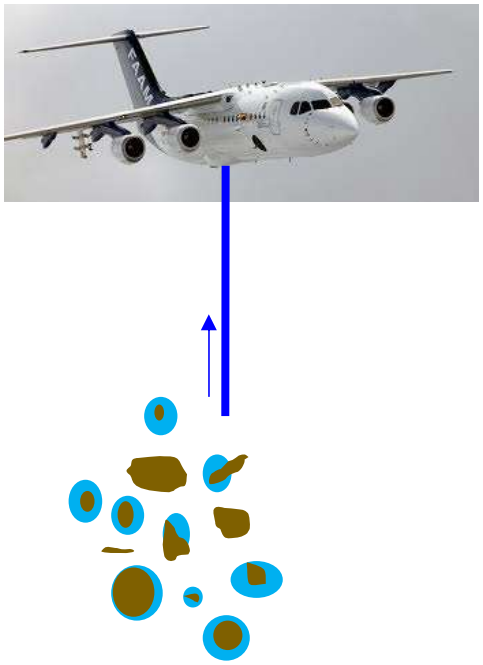

N41.3°
N41.1°
N40.9°
N40.7°
N40.5°
N40.3°
N40.1°
N39.9°
E22.75°
E23.25°
E23.75°

Height (km)
RH %
0
1
2
3
4
5
40
60
80
100

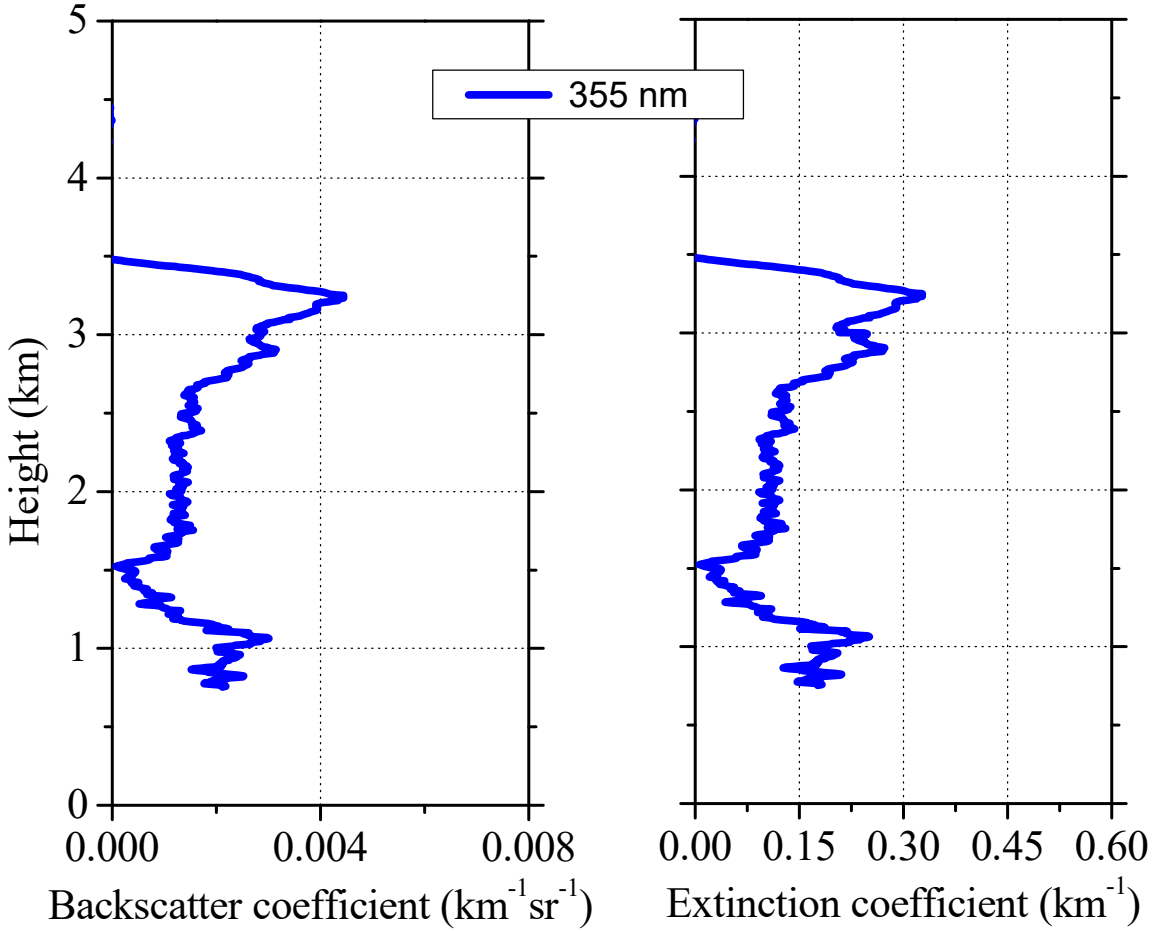

clouds
BAe–146 range–corrected lidar signal at 355 nm
2011–09–09, 00:05–00:27 UTC
Height (Km)
LATITUDE (degrees)
39.5
40.0
40.5
41.0
41.5
1500
1000
500
0


CALIPSO Aerosol Subtype (VFM), 2011-09-09, 00:31 UTC
Height (km)
Latitude (degrees)
39.5
40.0
40.5
41.0
41.5
6
5
4
3
2
1
0

Airborne lidar measurements

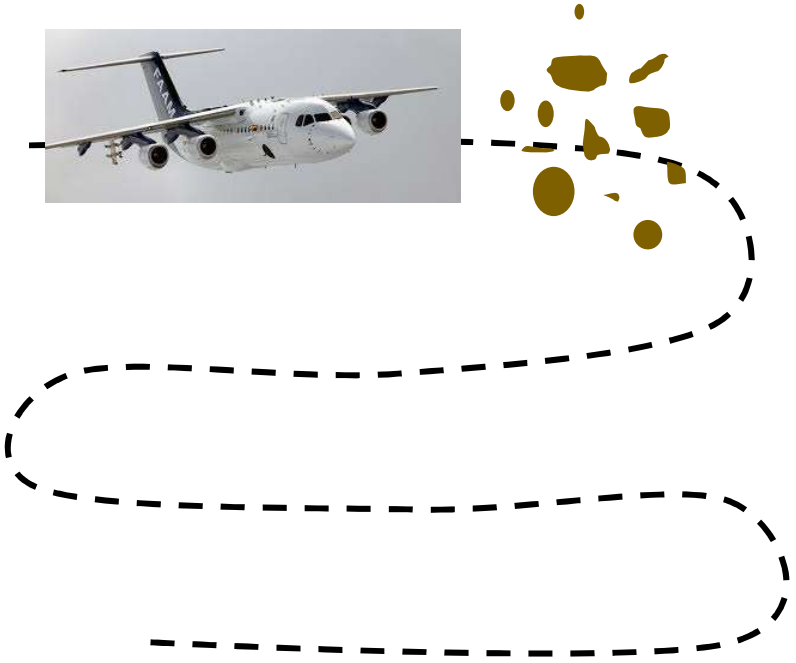


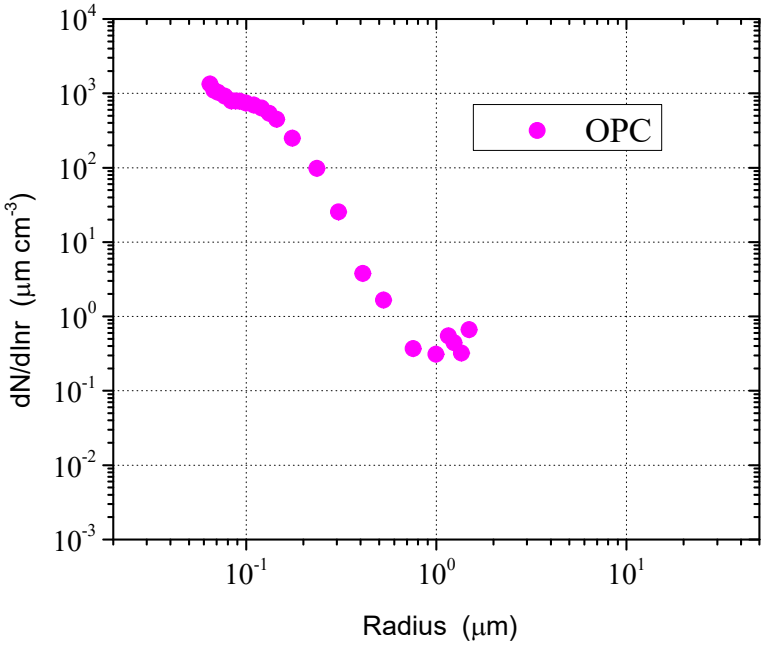
Backscatter and extinction coefficient profiles at 355 nm



Airborne in-situ dry size distribution

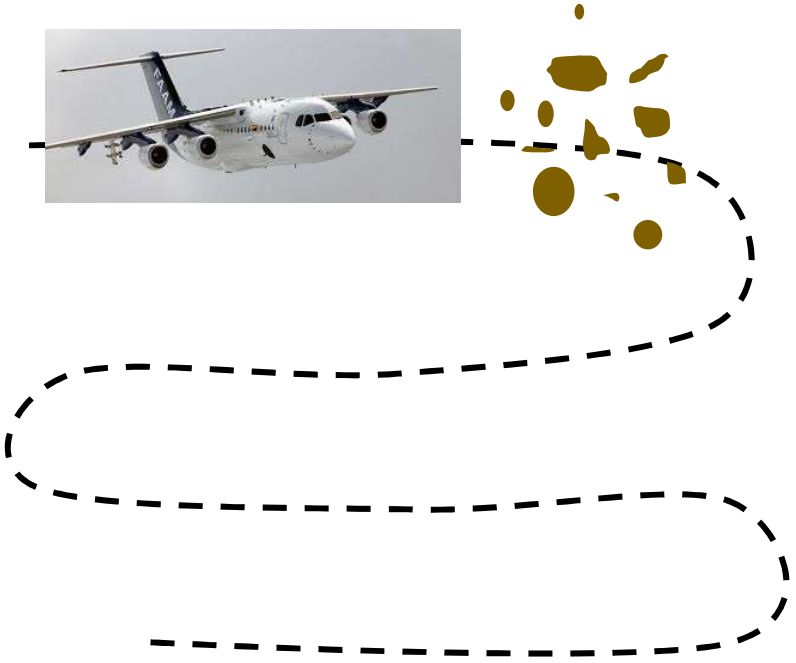
Number size distribution (measured with PCASP, GRIMM OPCs)

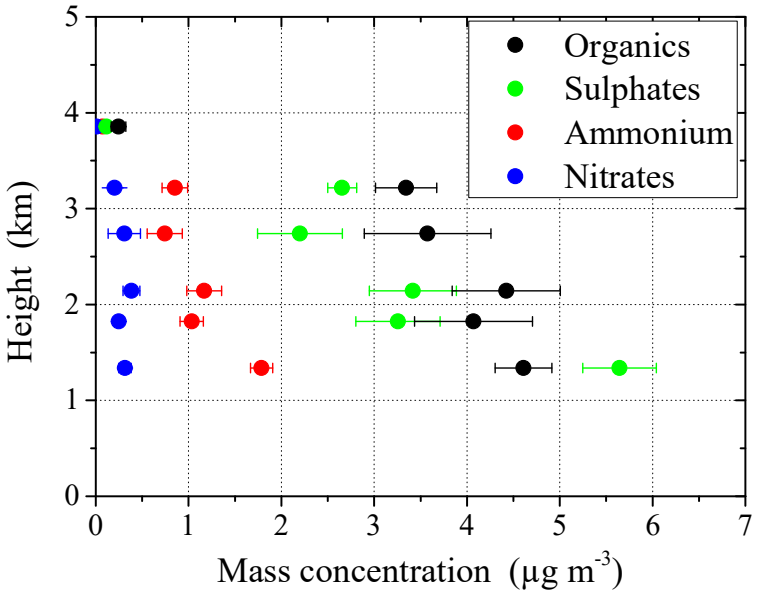




Airborne in-situ dry chemical composition

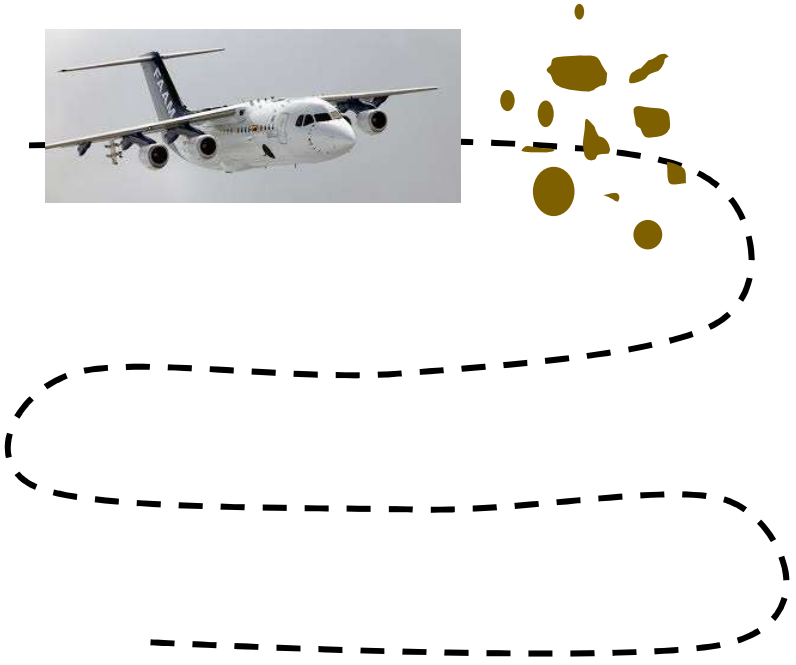
Chemical composition measured with AMS

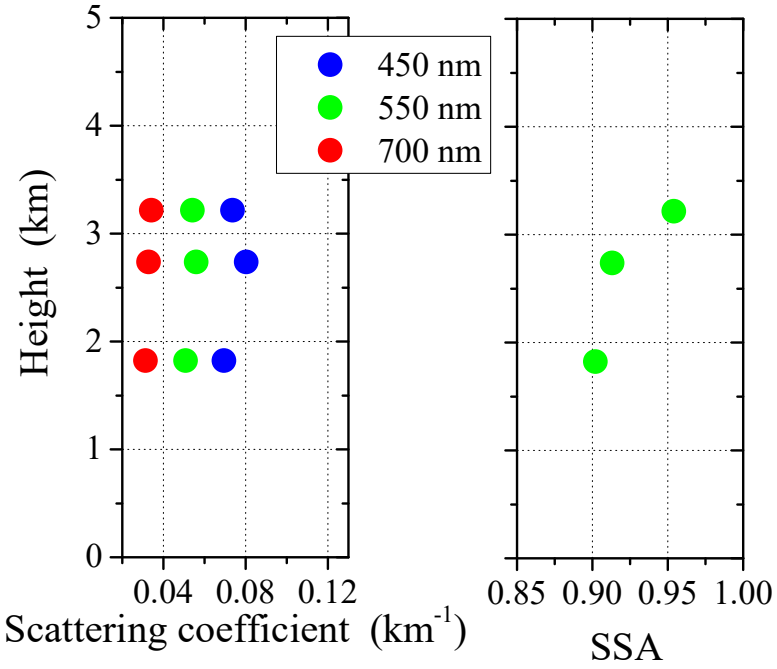




Airborne in-situ dry optical properties

Scattering coefficients at 450, 550, 700 nm from Nephelometer
Absorption coefficient at 567 nm from PSAP



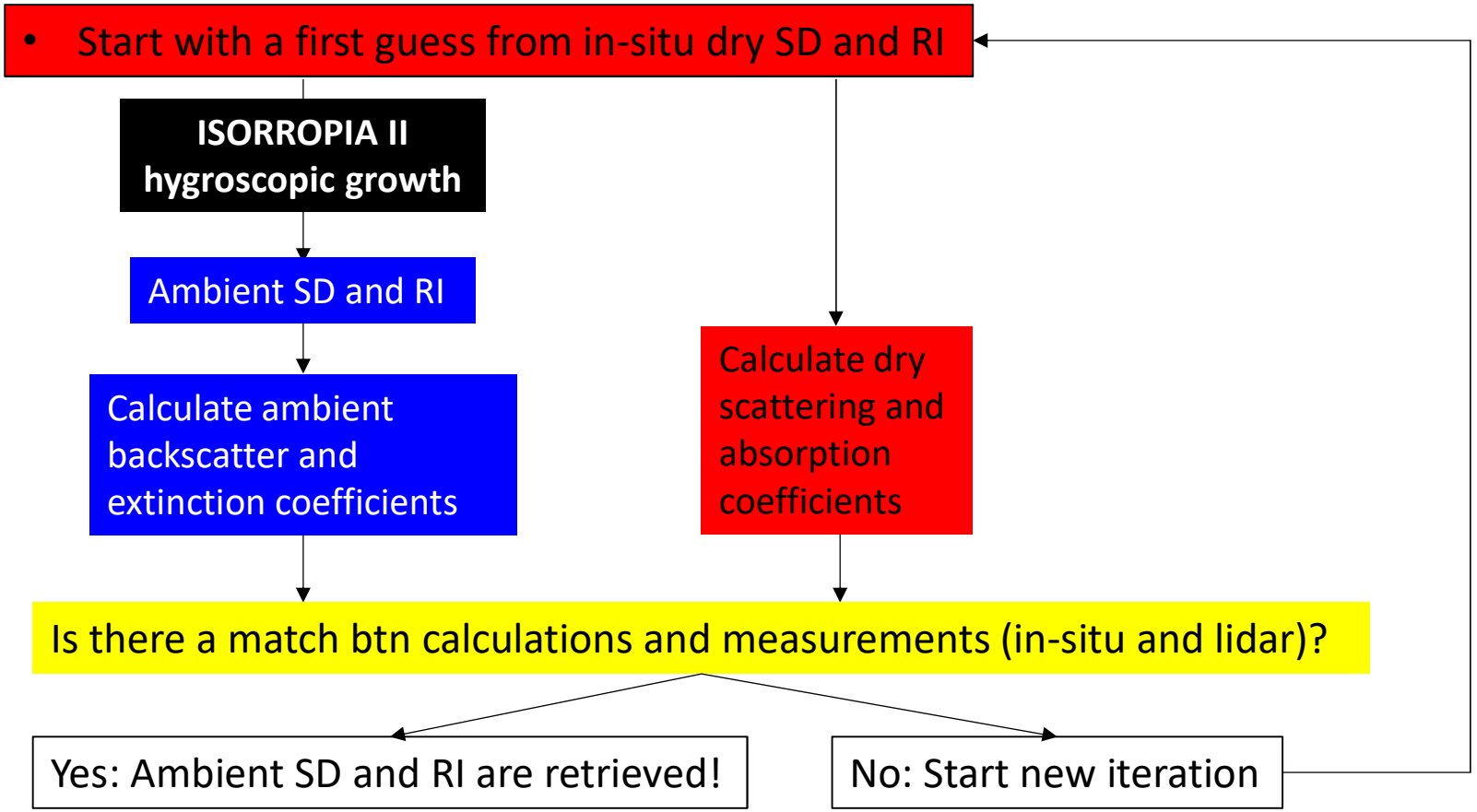


Challenges in retrieval

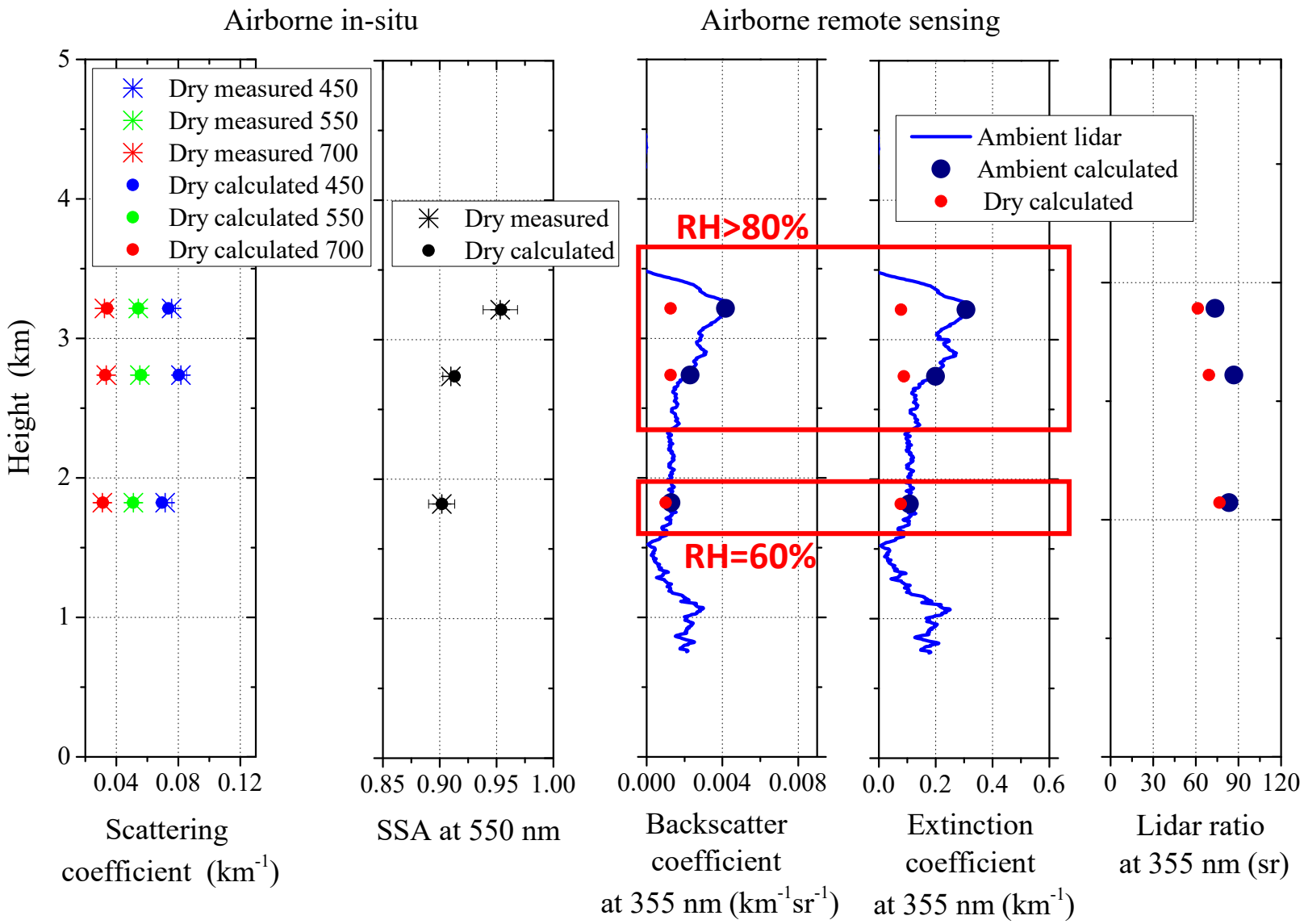
- Particle hydration
- Refractive index definition
- Limited wavelength dependence information from lidar (only 1 wvl)
- Limited information for the larger particles:
  - Lidar at 355 nm
  - Inlet sampling cut-off not only for SD, but also for optical and chemical composition measurements

In situ/Remote sensing aerosol Retrieval Algorithm (IRRA)

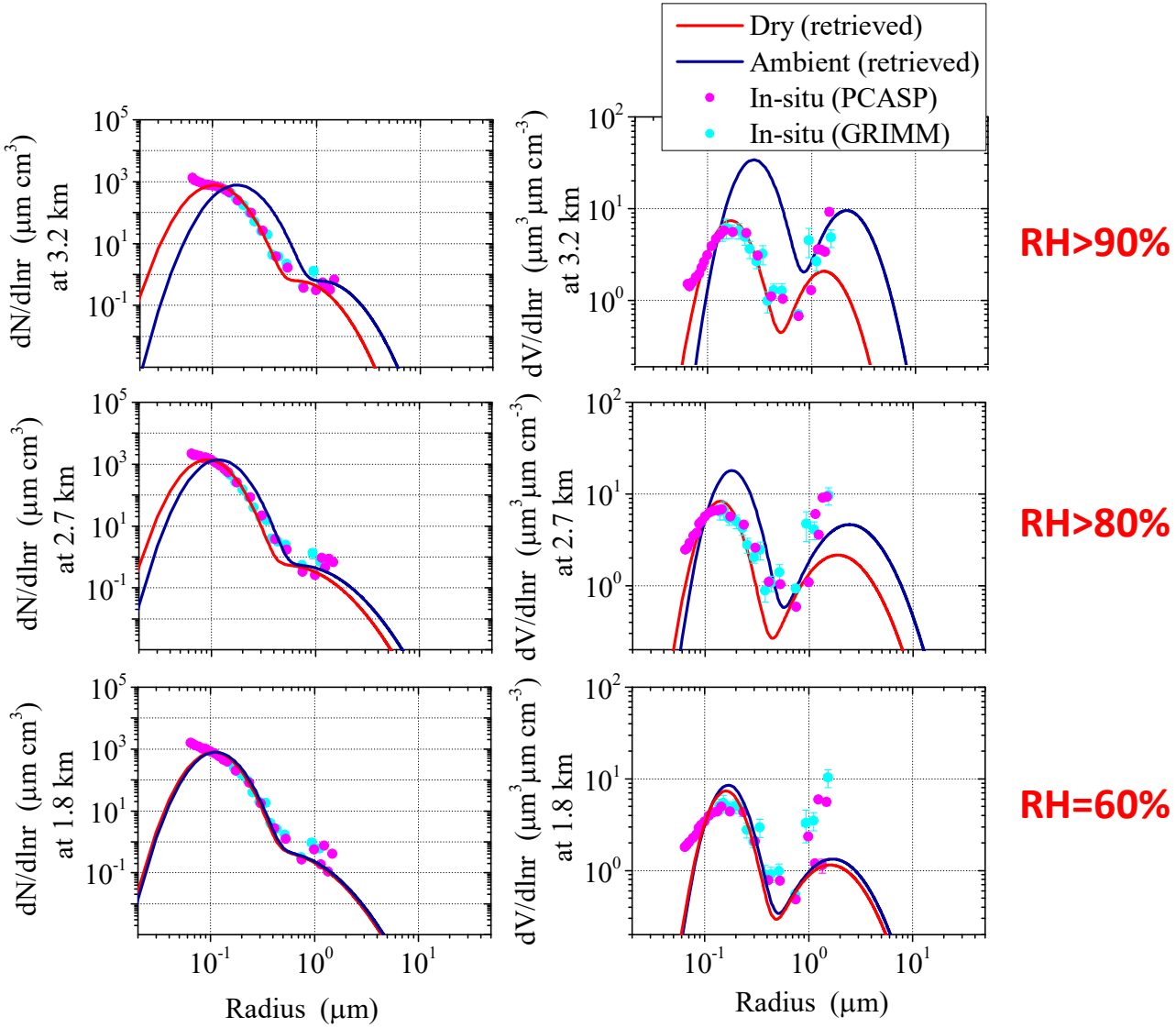
IRRA combines ambient remote sensing and dry in-situ measurements and derives the ambient SD and RI, using an optimization scheme:



IRRA measurement fits for test case

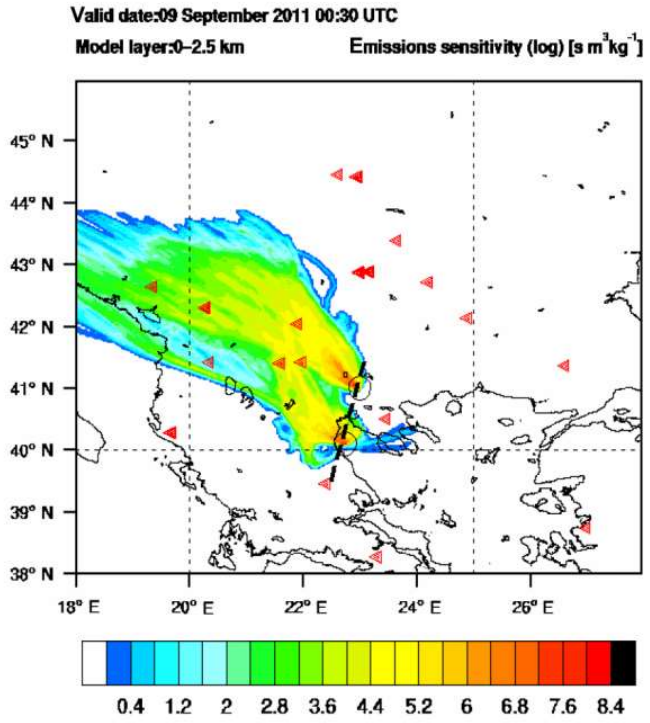


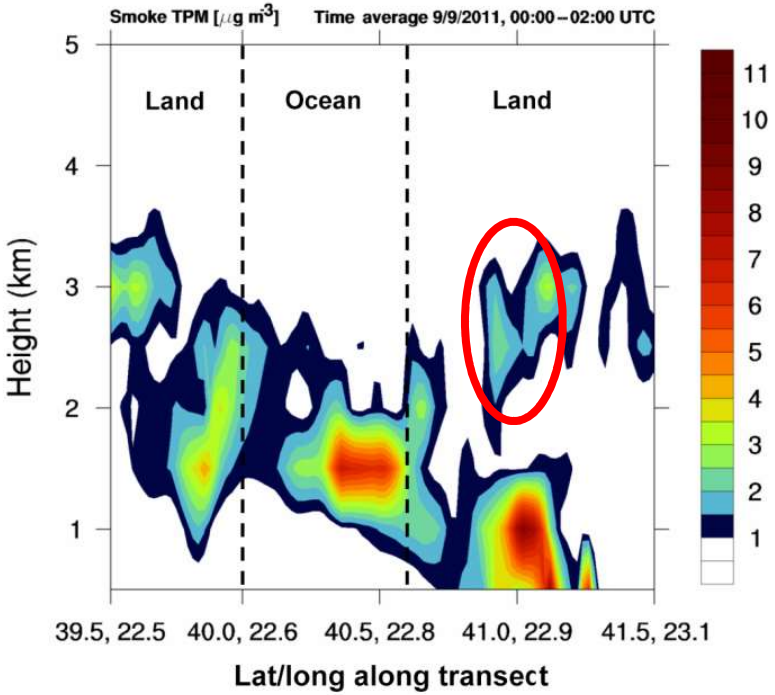
Ambient and dry particle retrieved SD



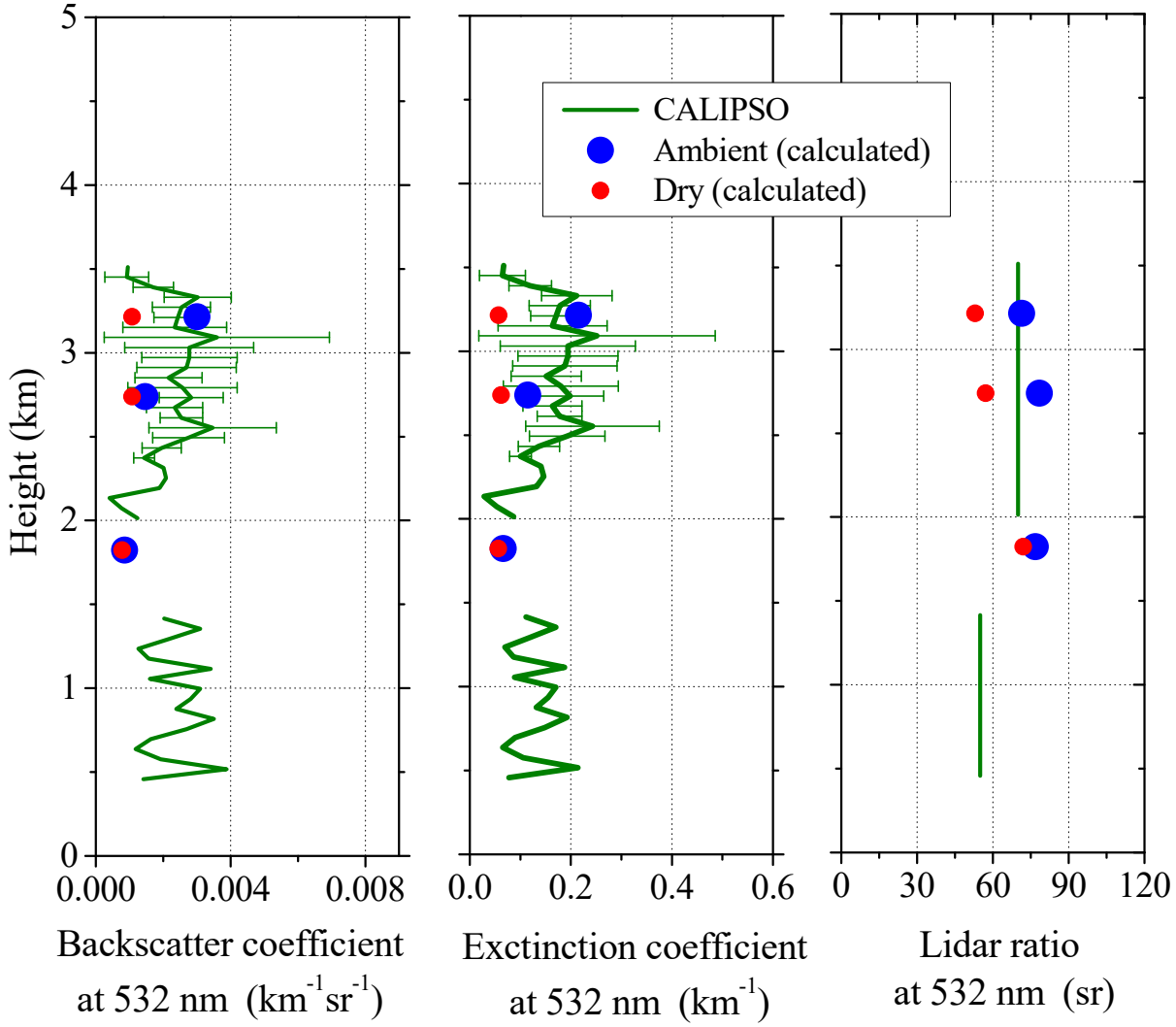
Validating the retrieved properties

IRRA retrieval indicates smoke particles
Verified by FLEXPART-WRF model





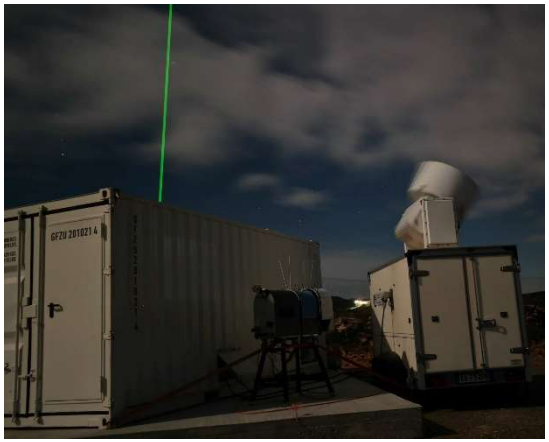
CALIPSO validation



IRRA alternative applications

- Aircraft measurements are costly and rare
- Use UAV (sondes?) in-situ
- Combine with ground-based lidar (multi-wavelength)

- IDEAS for PRE-TECT campaign:
  - A-LIFE experiment provides airborne in-situ and lidar measurements above Cyprus and Crete
  - Combine airborne data with ground-based lidar (multi-wavelength) and surface in-situ
  - Combine with sonde-OPC SD data (open-path measurements!)



Take-home message

- In-situ/remote sensing complement each other
- The combination should be done carefully
- Get familiarized with the in-situ methodologies before using the measurements!
- Apply all the necessary corrections
- In humid conditions we need to take care of the hygroscopic growth