Met Office

Airborne lidar for satellite cal/val (aerosols and clouds)

F. Marenco

Satellite Applications, Met Office, Exeter, United Kingdom

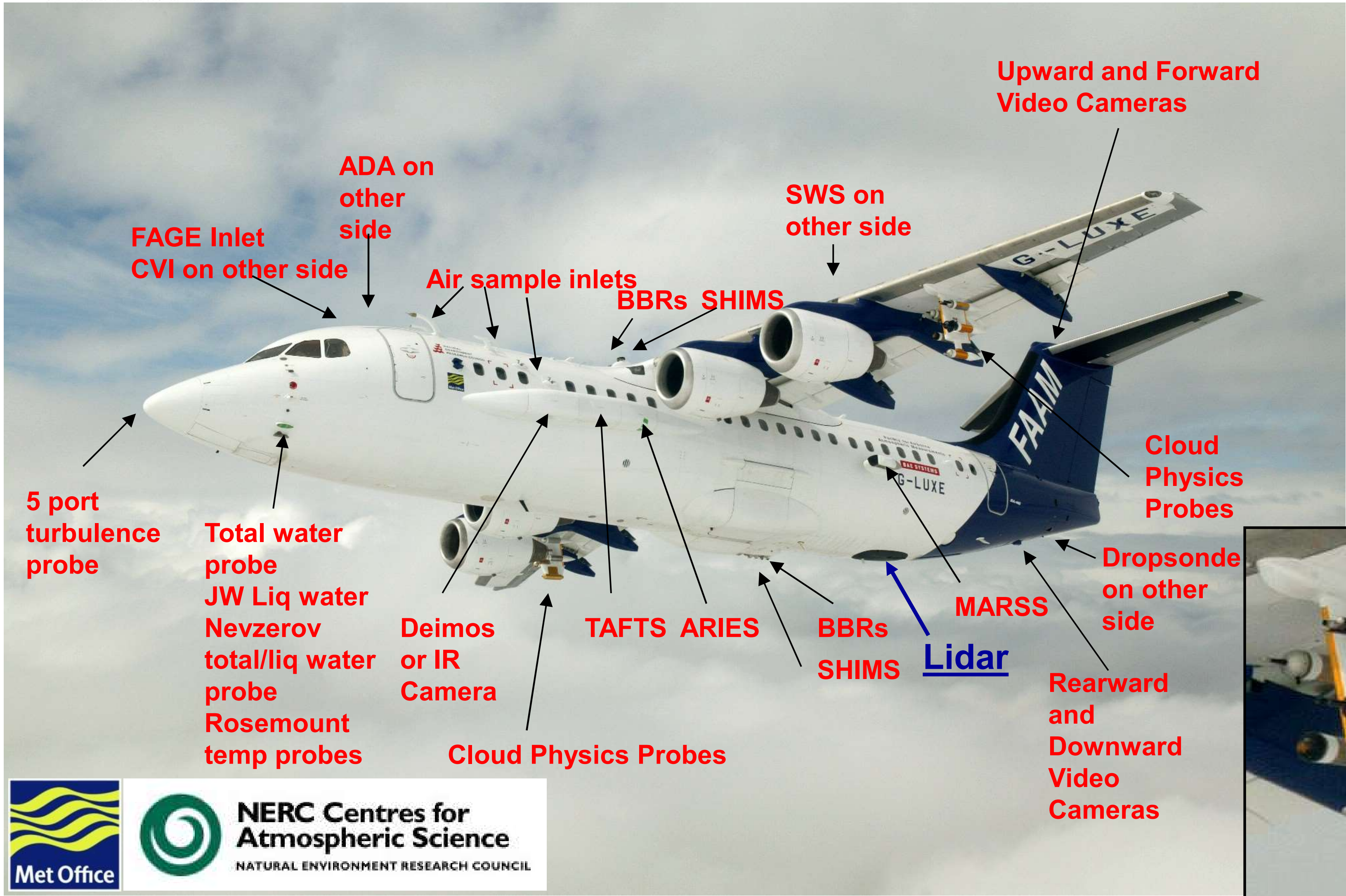
Airborne lidar for satellite cal/val

1. The FAAM aircraft
2. The Leosphere lidar
3. Volcanic ash in the UK
4. Smoke in the Amazon
5. Saharan dust in the Atlantic
6. Cirrus and stratocumulus
7. Clouds in the Sahara

The FAAM Bae-146
Atmospheric Research Aircraft

FAAM BAe–146–301

Atmospheric Research Aircraft



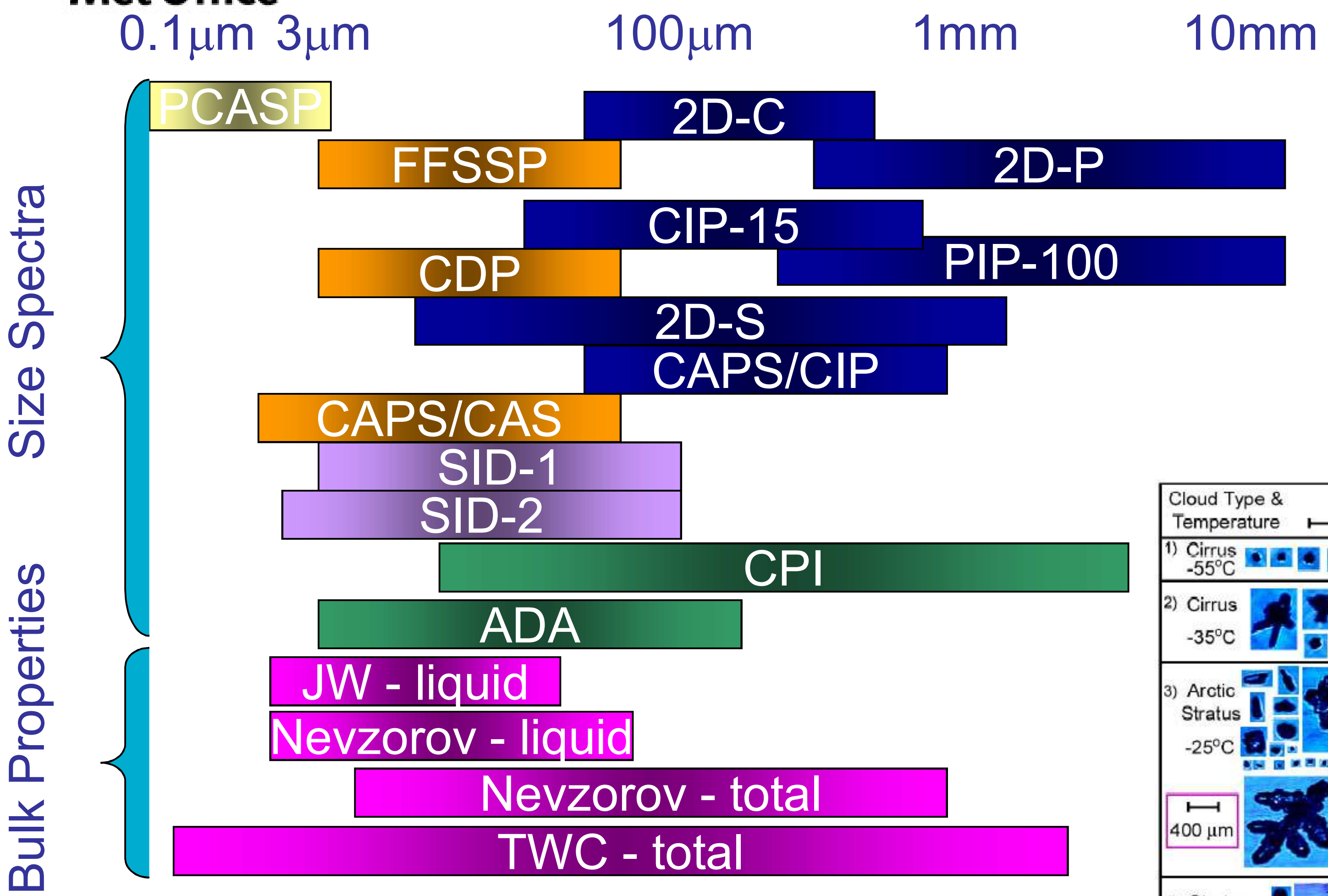
NERC Centres for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

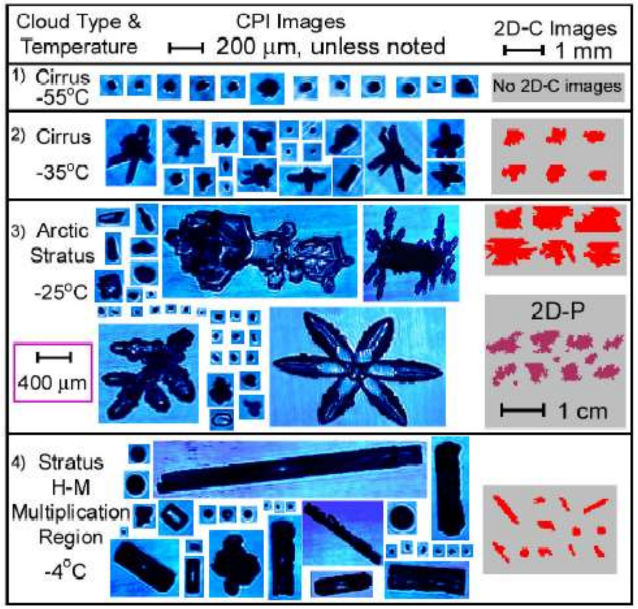
FAAM BAe–146–301

Atmospheric Research Aircraft

Crew	2 pilots (1 cabin crew)
Scientists	18 maximum
Length	31m
Wingspan	26m
Height	8.4m (to top of tail), 4.4m (top of fuselage)
Engines	4 Honeywell LF507-1H turbofans
Max altitude	35,000 ft
Min altitude	50ft (over sea)
Range	3,700 km
Cruise Altitude	27,000 ft
Typical endurance	5.5 hours
Min manoeuvring speed	90 - 115 ms^{-1} (depending on payload)
Payload	4,000 kg instrumentation

Cloud physics instruments





Radiometers

- BBR – irradiance measurements: 0.3–3.0μm; 0.7–3.0μm; 4–50μm
- Heimann – broadband infrared radiometer (8–12μm)
- SWS – Short Wave Spectrometer: 0.3–1.7μm (pixel resolution 3.2 nm up to 0.95μm, 6.3 nm thereafter)
- SHIMS – Spectral Hemispheric Irradiance Measurement: 0.3–1.7μm (pixel resolution 3.2 nm up to 0.95μm, 6.3 nm thereafter)
- ARIES – infrared interferometer: 3.3–16μm; max OPD = 1.037cm (~ 0.5cm^{-1}) – 4800 channels
- TAFTS – far infrared interferometer 10–125μm (Imperial College)
- ISMAR – submillimeter radiometer 118–874 GHz (7 channels)
- MARSS, Deimos – microwave radiometers 24–183 GHz (5 channels)

70 y meteorological research flight

Courtesy of K. McBeath


Canberra


Mosquito


MOCCA (Cessna)


Snoopy (C-130)

Met Office

FAAM BAe–146–301

Atmospheric Research Aircraft

FAAM BAe–146–301

Atmospheric Research Aircraft

- Major asset to the Met Office and the UK academic community
- Is part of a long history (70 y) of Meteorological Research Flight
- Provides independent observations of atmospheric fields
- Permits to complement observations from several instruments

- Model + parametrisations (UM, NAME)
- Verification/validation of satellite products

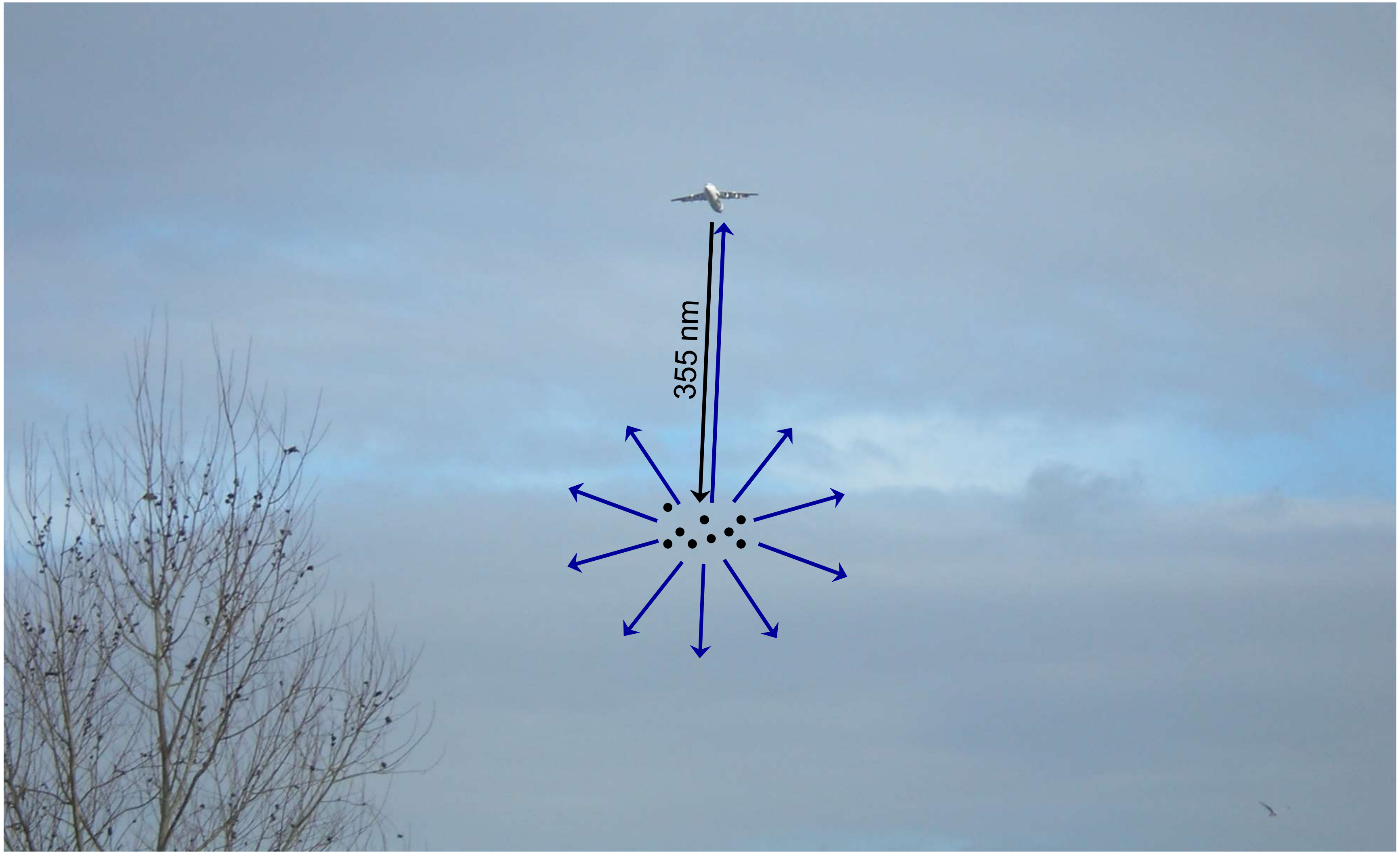
- Operational / Civil contingencies (e.g. volcano)

The Leosphere lidar

Leosphere lidar

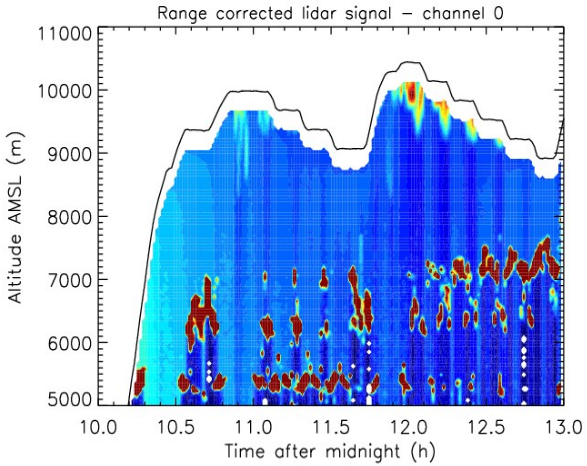
wavelength:	355 nm
laser source:	12 mJ @ 20 Hz
receiver aperture:	15 cm
receiver bandwidth:	0.36 nm
overlap range:	300 m
vertical resolution:	1.5 m (45 m)
integration time:	2-60s
footprint:	0.3–10 km
view:	nadir

Principle of lidar



Lidar time scales

Time to range conversion: $R = \frac{ct}{2}$



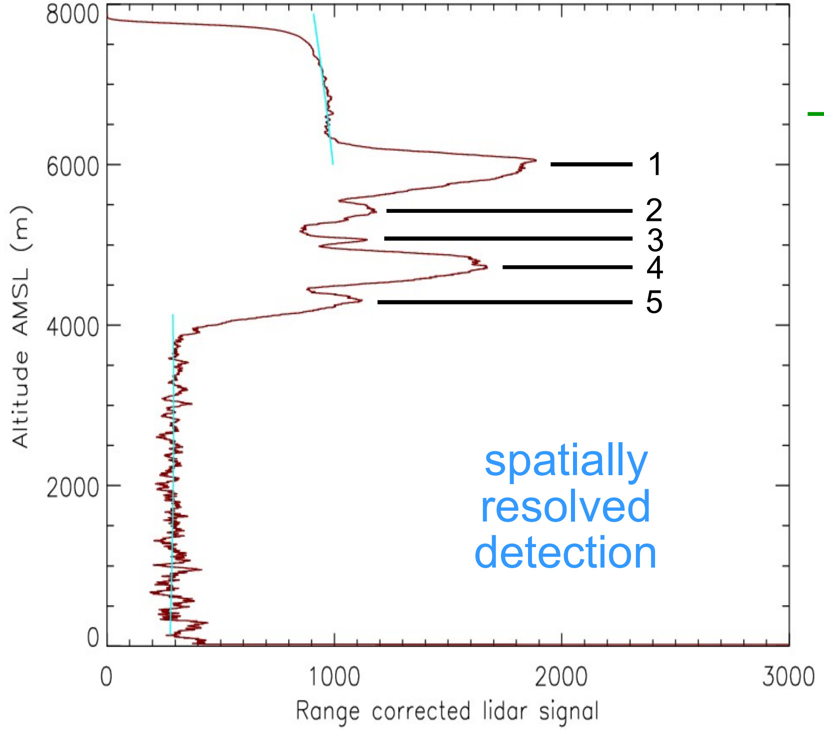
Range	4 ns	Laser pulse duration	→ Best “ideal” resolution 0.6 m
	10 ns	Signal sampling	→ Range sampling resolution 1.5 m
	300 ns	30-pt signal smoothing	→ Processing resolution 45 m
	50 µs	Atmospheric signal decay	→ Scale height 8 km
	50 ms	Pulse repetition	→ Frequency 20 Hz
	1s–10min	Integration time	→ User defined
Time	1s–hours	Atmospheric time scale	→ Depending on what you are studying

→ On aircraft: Time translates into horizontal along-track distance

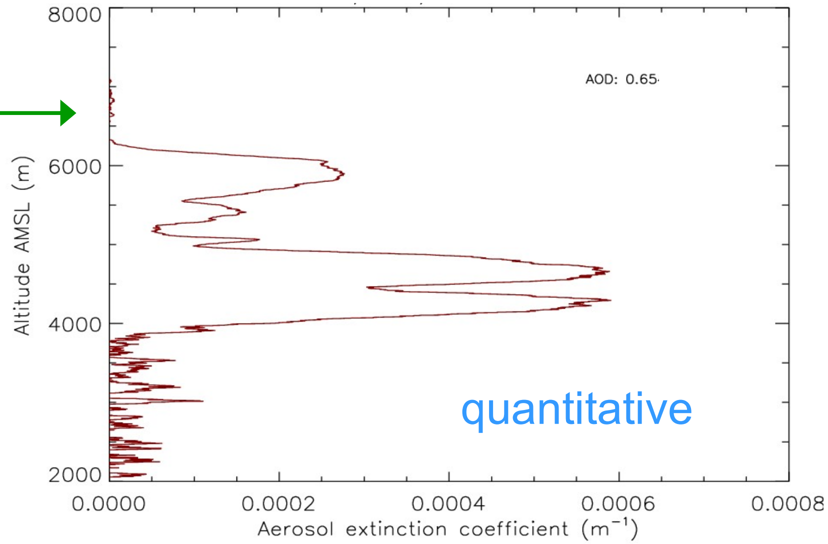
Inversion of lidar signals

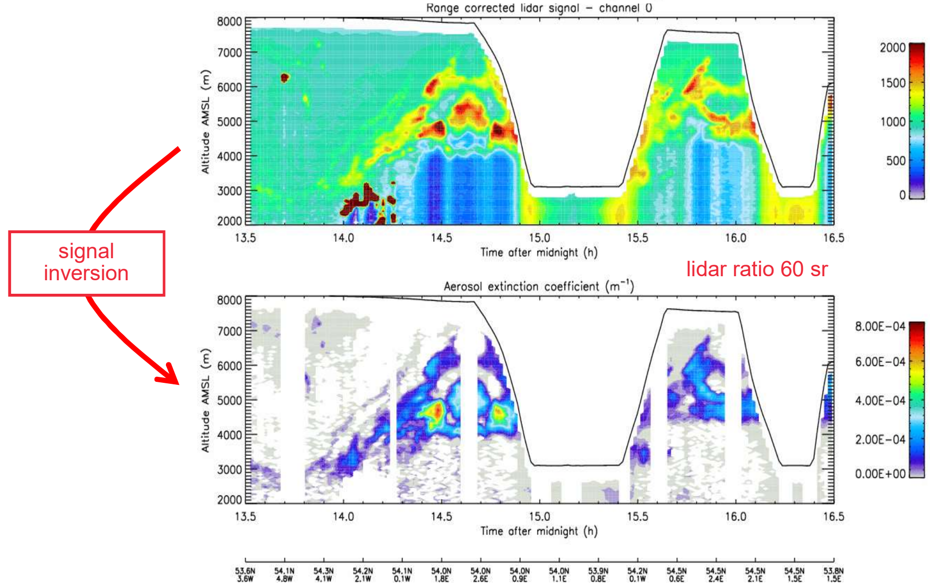
Met Office

Range corrected signal



Aerosol extinction coefficient





$$PR^2 = K\beta e^{-2\int_0^R \alpha\, dR}$$

extinction

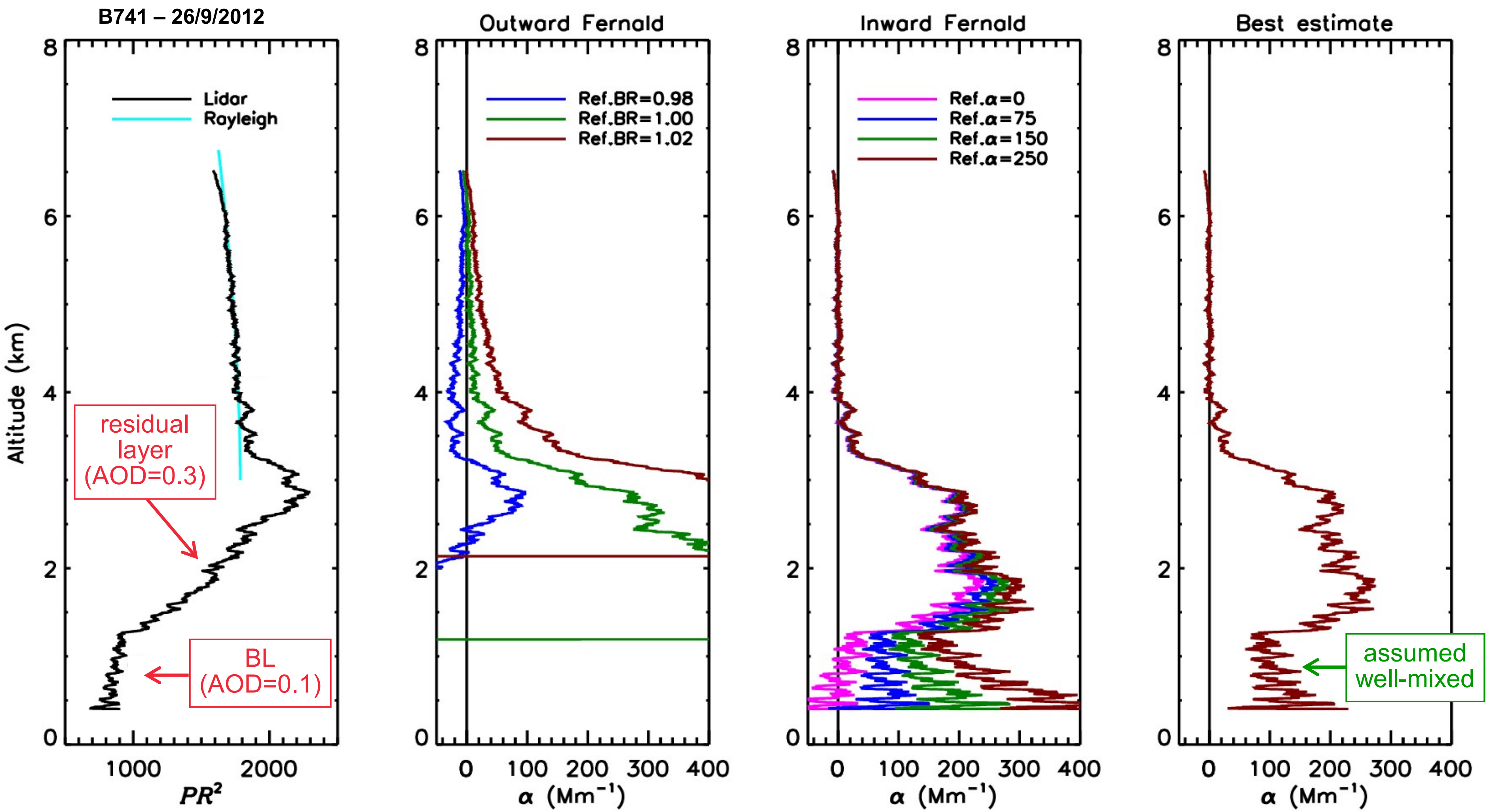
backscatter

$$S = \frac{\alpha}{\beta}$$

LIDAR RATIO

Intrinsic difficulties in retrievals and novel solutions

F. Marenco, Nadir airborne lidar observations of deep aerosol layers, *Atmos. Meas. Tech.* **6**, 2055-2064, 2013



Volcanic ash (2010)

The eruption of Eyjafjallajökull

Met Office

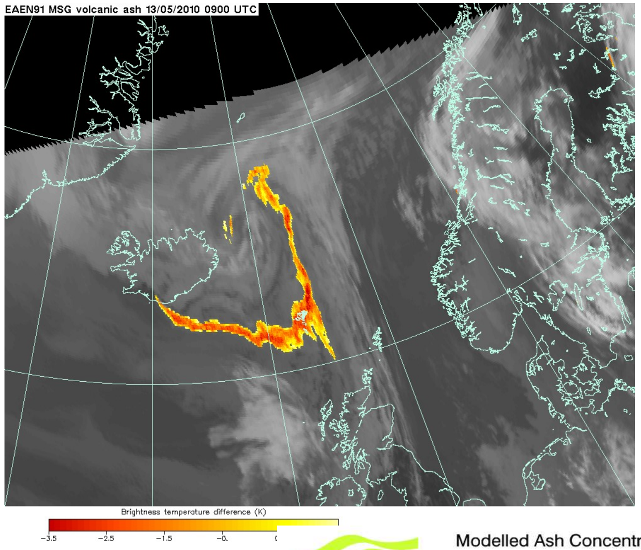
75% of European airspace closed during April 14 – 20th, 2010.

- Further closures in May.
- 100,000 flights cancelled
- 10 million passenger journeys affected
- Airline loses £200M/day
- Global economy ~$5B

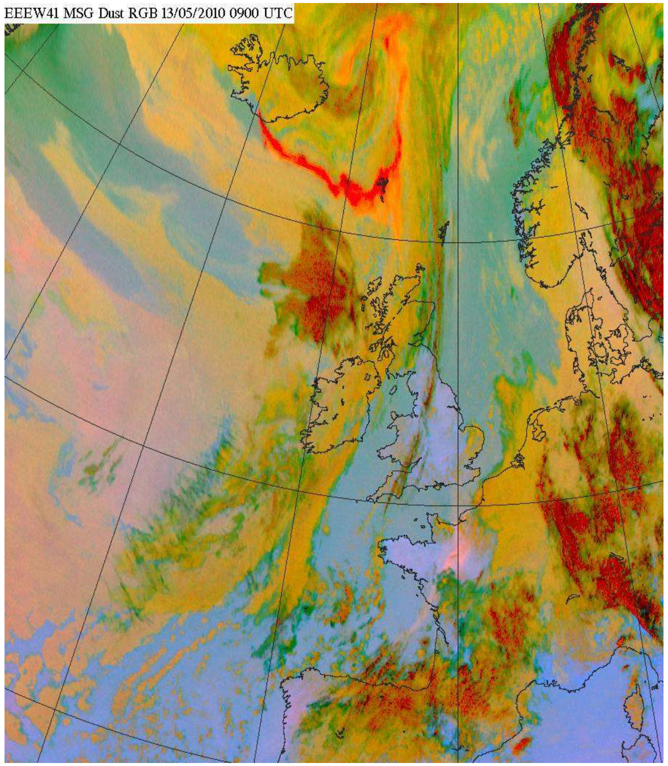
- Explosive eruption began 14th April 2010, continued until ~ 23rd May
- 0.25 km^3 of tephra ejected > 4 on volcanic explosivity index (0 – 7)
- NW atmospheric flow for much of April-May 2010 → Ash over Europe!

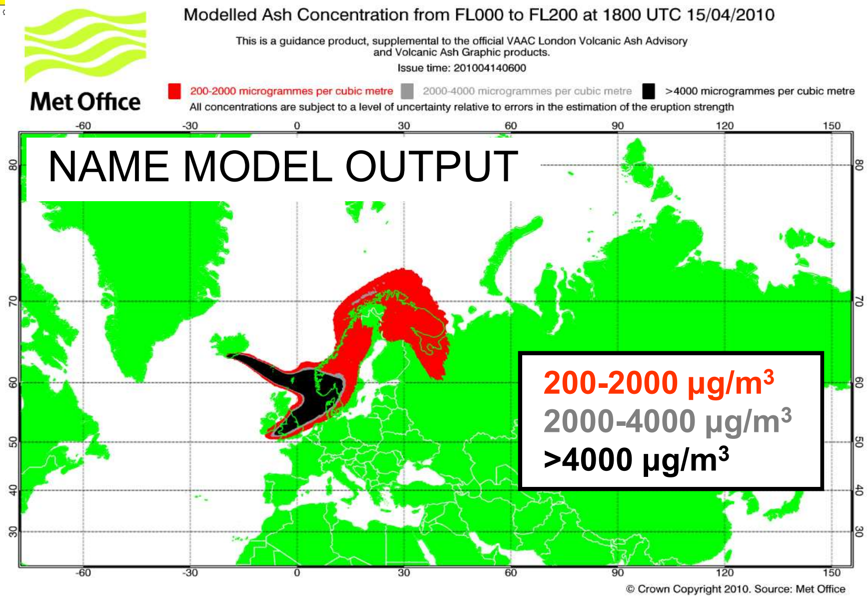
Volcanic ash: Satellite and modelling products

Improved ash detection algorithm



Dust RGB: useful qualitative product



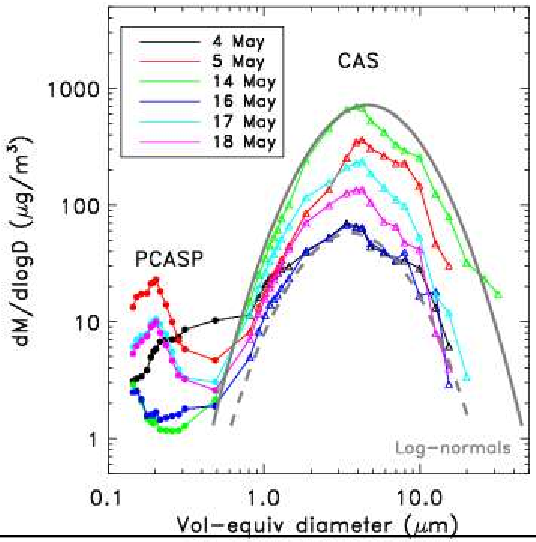


Lidar concentration estimates

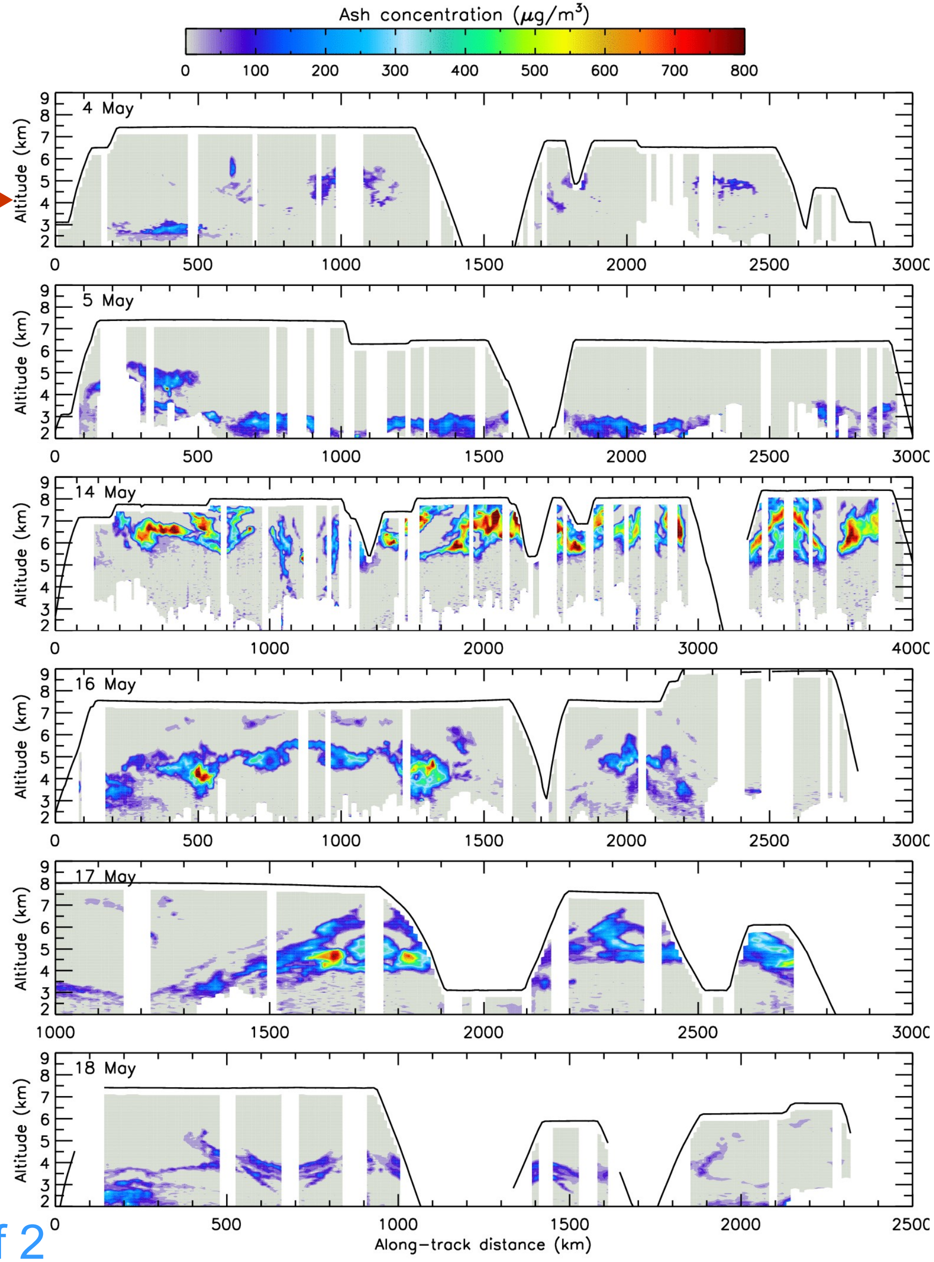
Met Office

$$M = \frac{f_c\, \alpha}{K_{ext}}$$

Date	f_c	K_{ext} (m^2/g)
4 May	0.52	0.92
5 May	0.72	0.65
14 May	0.97	0.62
16 May	0.78	0.82
17 May	0.82	0.72
18 May	0.75	0.74



courtesy of B. Johnson (MO), and J. Dorsey + M. Gallagher (University of Manchester)

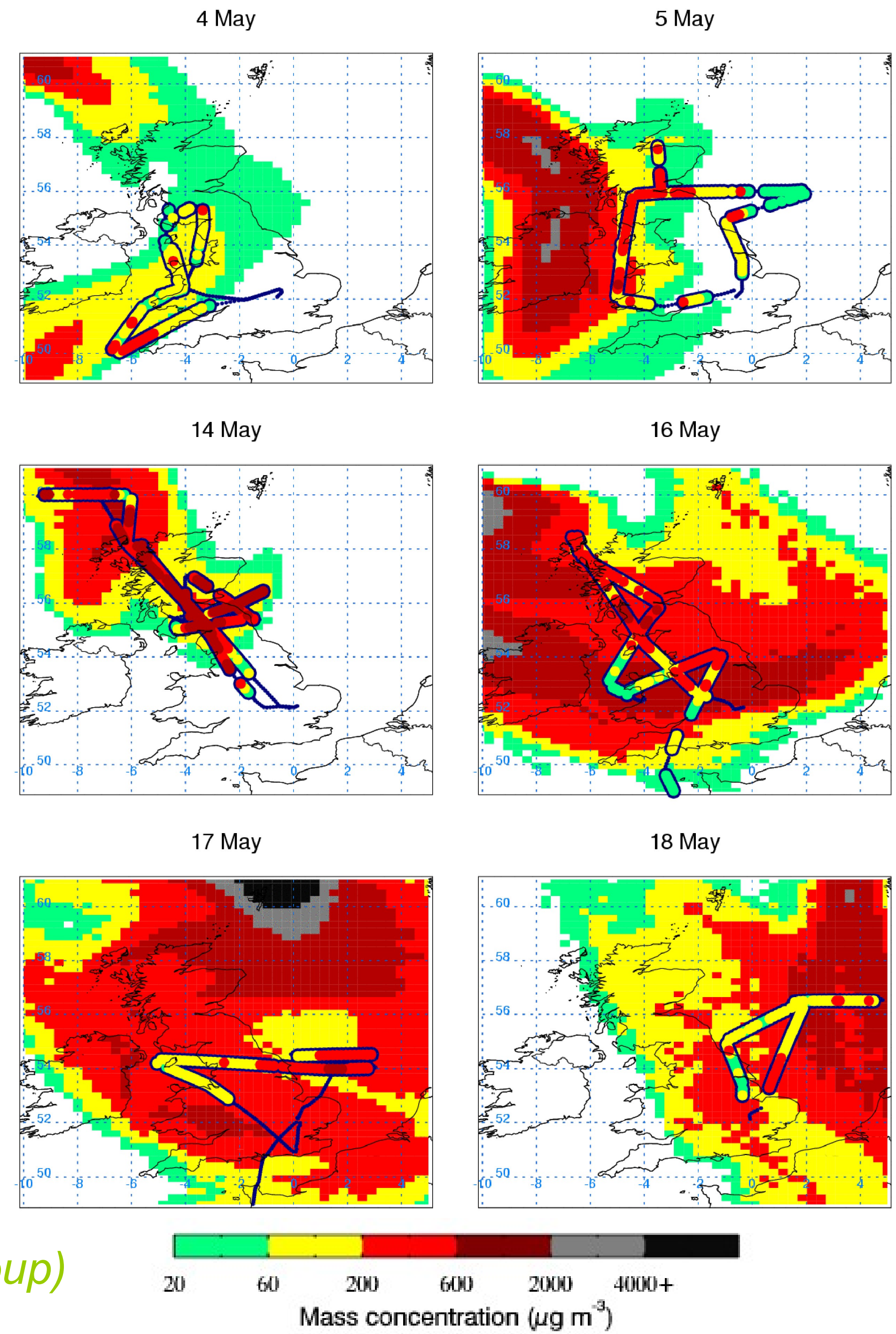


Marenco et al, Airborne lidar observations of the 2010 Eyjafjallajökull volcanic ash plume, *J. Geophys. Res.* **116**, D00U05, doi: 10.1029/2011JD016396 (2011).

Uncertainty: ~ factor of 2

Airborne lidar vs. NAME

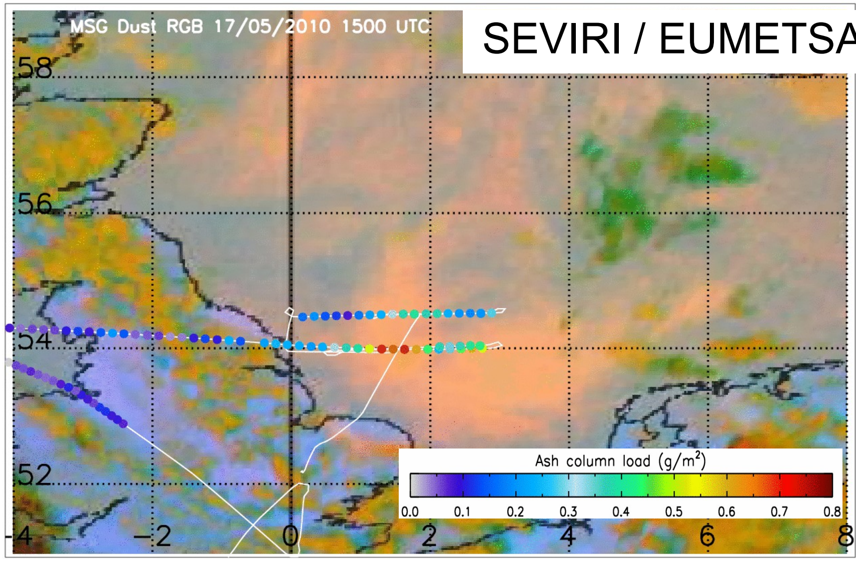
- reasonable overall magnitude
- positional errors sometimes
- model uncertainties: source term, meteorology, sub-scale processes



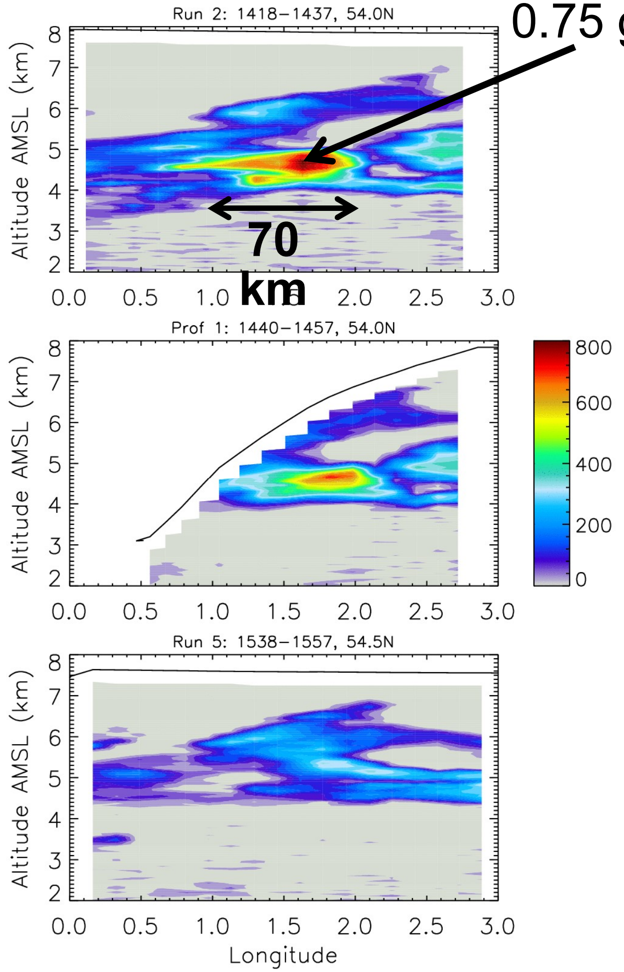
Marenco et al, Airborne lidar observations of the 2010 Eyjafjallajökull volcanic ash plume, *J. Geophys. Res.* **116**, D00U05, doi: 10.1029/2011JD016396 (2011).

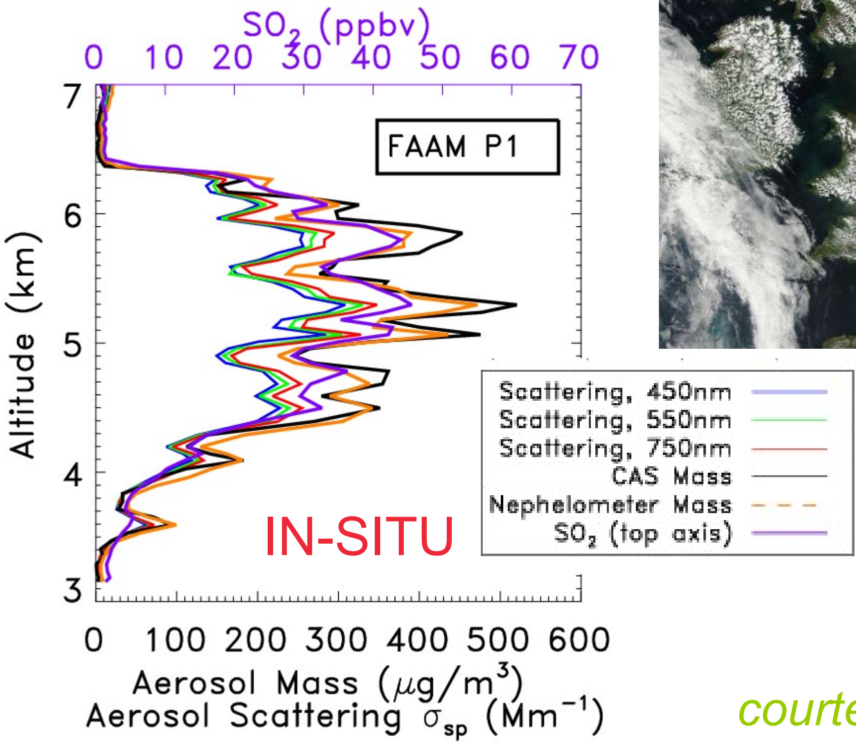
courtesy of H. Webster (Atmospheric Dispersion Group)

Case study
North Sea event
17 May 2010

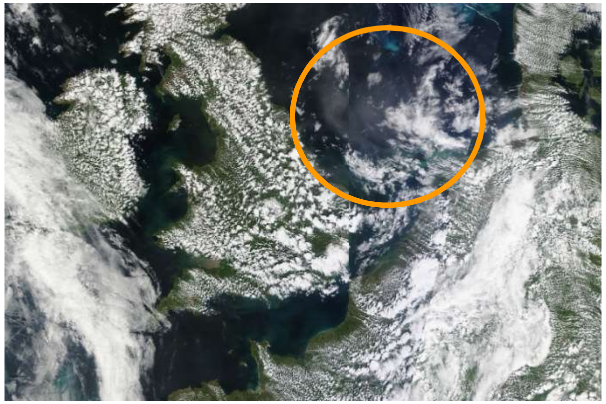


800 μg/m³
0.75 g/m²





IN-SITU



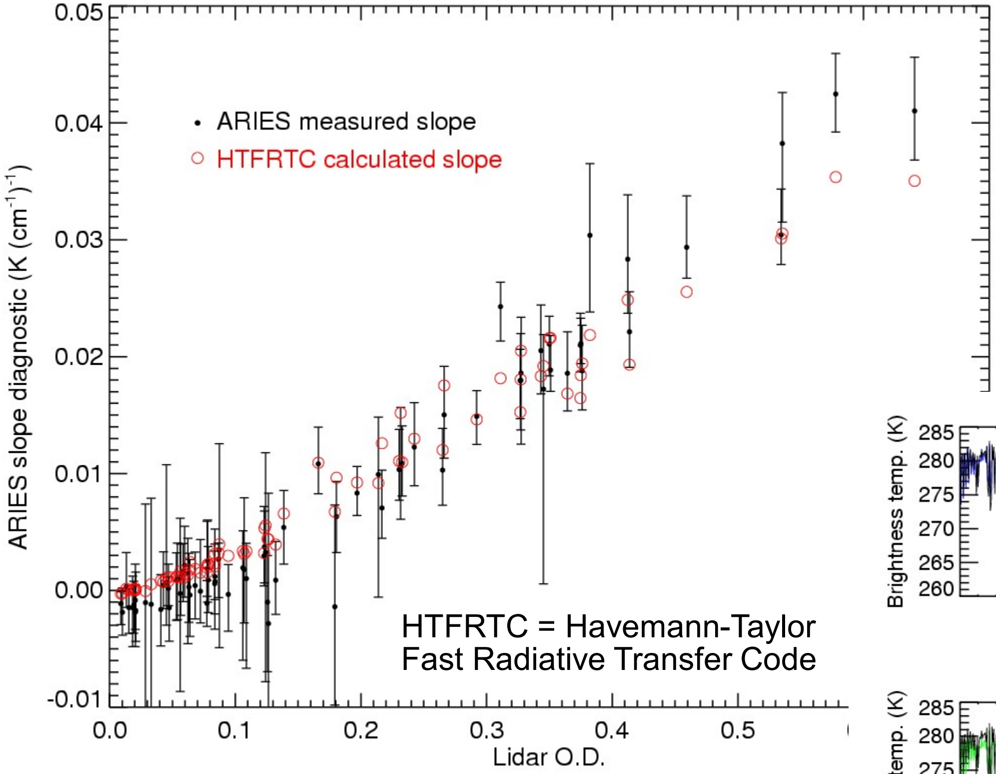
Turnbull et al, A case study of observations of volcanic ash from the Eyjafjallajökull eruption: 1. In situ airborne observations, *J. Geophys. Res.* **117**, D00U12, doi: 10.1029/2011JD016688 (2012).

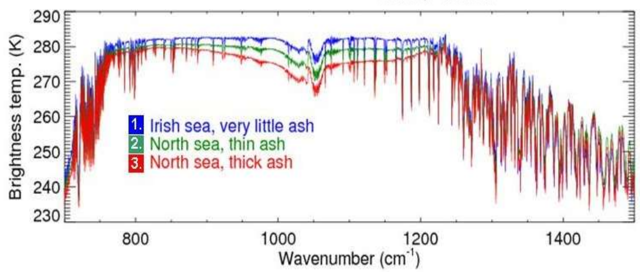
courtesy of K. Turnbull

courtesy of S. Newman

17 May

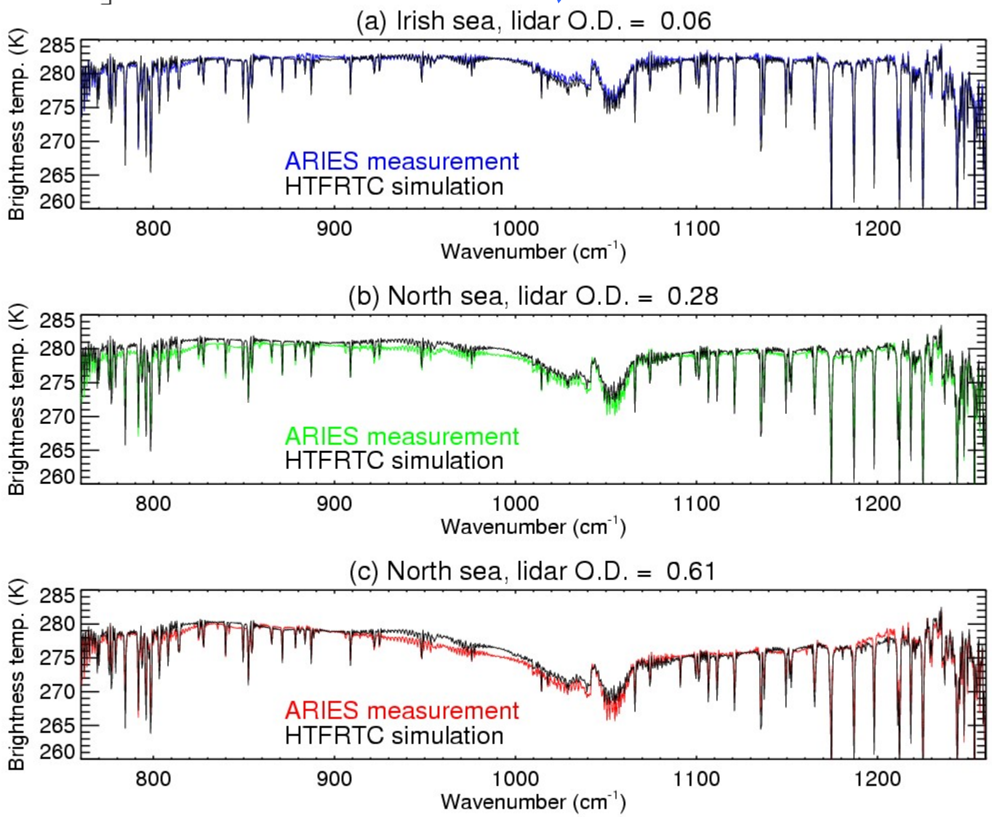
ARIES Infrared Spectrometer
on board the BAe-146 aircraft





Newman et al, A case study of observations of volcanic ash from the Eyjafjallajökull eruption: 2. Airborne and satellite radiative measurements, *J. Geophys. Res.* **117**, D00U13, doi: 10.1029/2011JD016780 (2012).

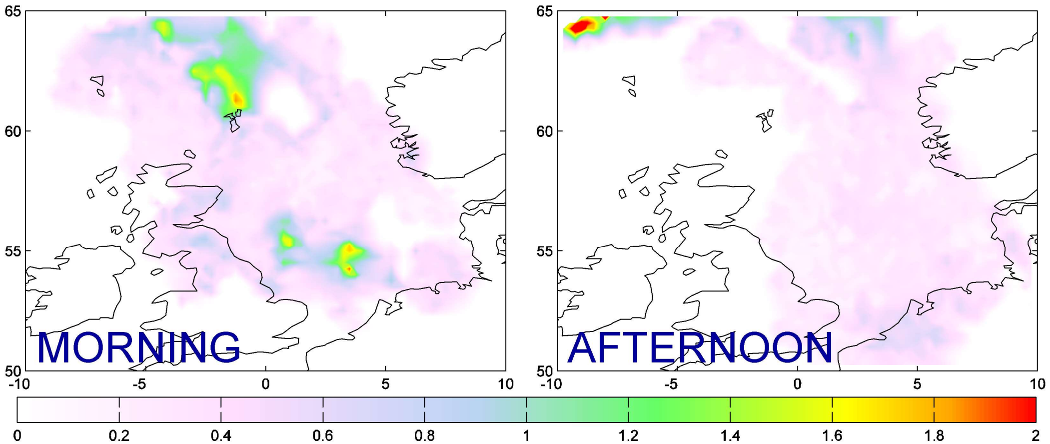
Simulation uses aerosol extinction profiles from the LIDAR; single-scattering albedo, asymmetry parameter and spectral dependence of aerosol extinction from the *in-situ* size-distributions; temperature and humidity from dropsondes; O_3 from *in-situ* observations; and climatological profiles for other trace gases.



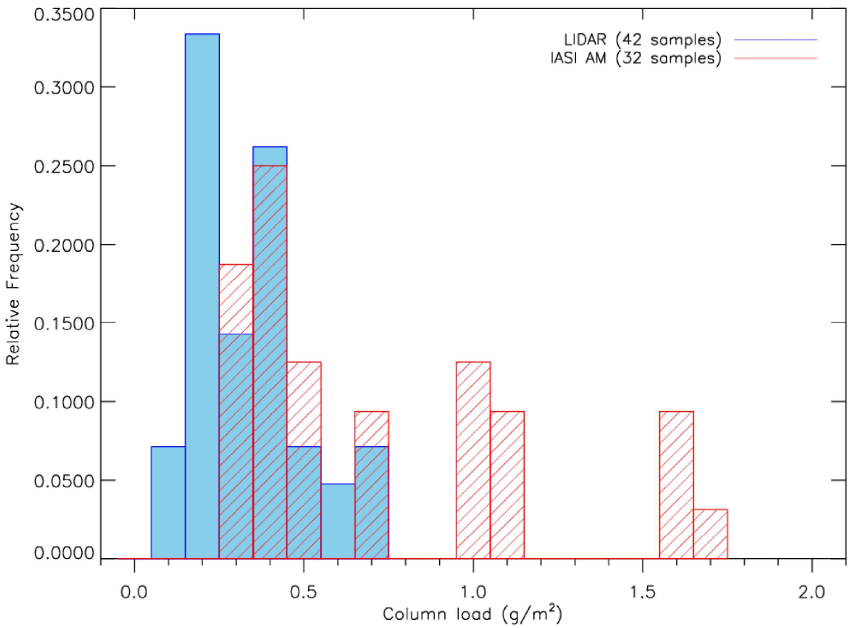
17 May

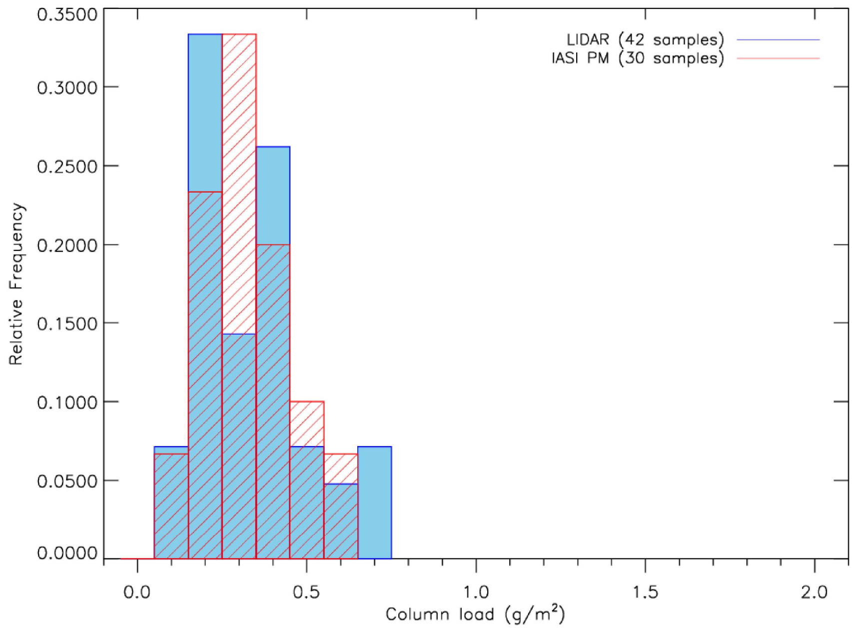
IASI Infrared Spectrometer on board the METOP-A satellite

Newman et al, A case study of observations of volcanic ash from the Eyjafjallajökull eruption: 2. Airborne and satellite radiative measurements, *J. Geophys. Res.* **117**, D00U13, doi: 10.1029/2011JD016780 (2012).



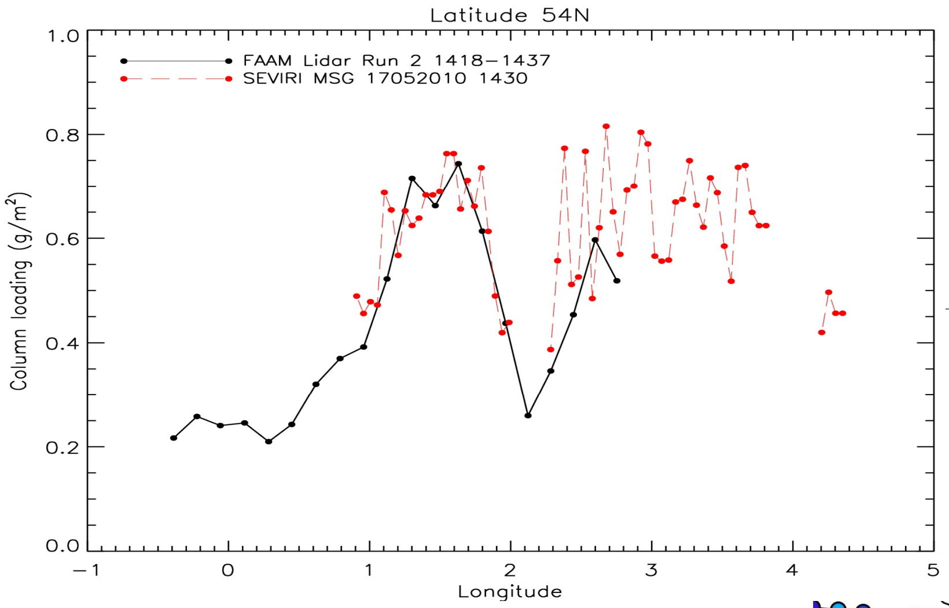
courtesy of L. Clarisse (ULB, Belgium)



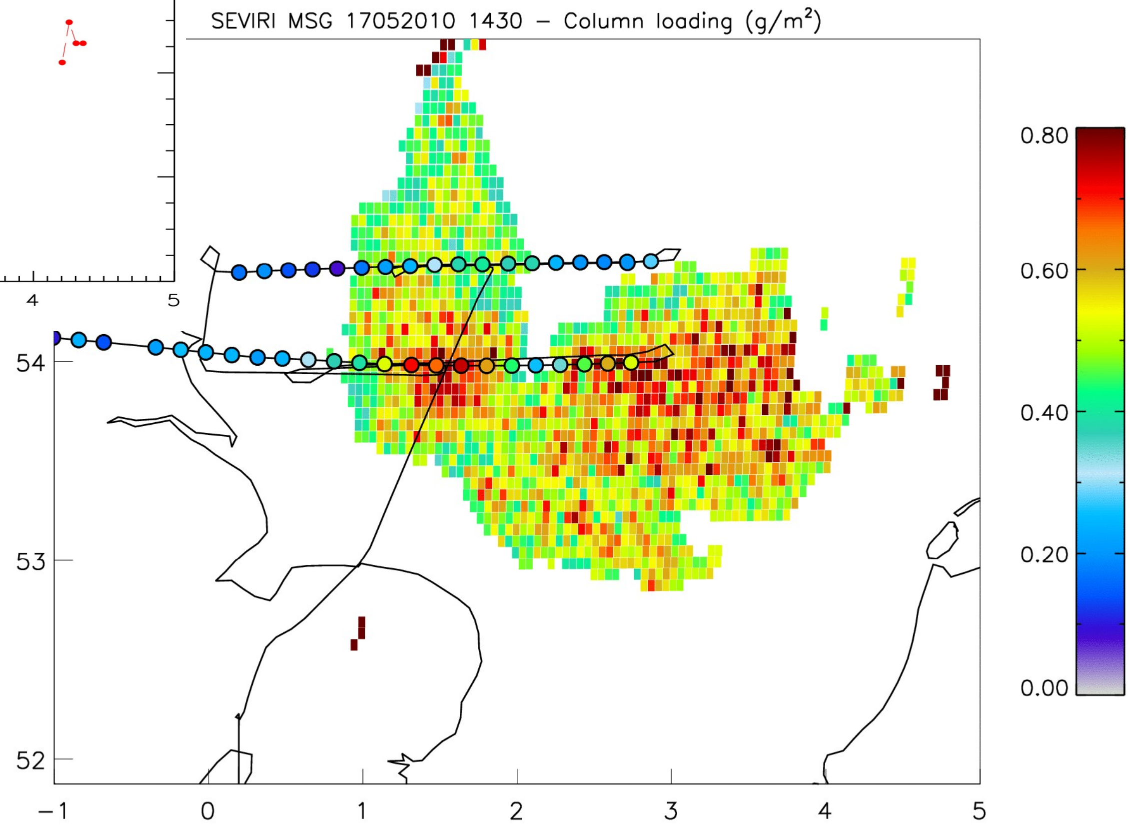


17 May

SEVIRI multichannel imager
on board METEOSAT



courtesy of P. Francis and M. Cooke

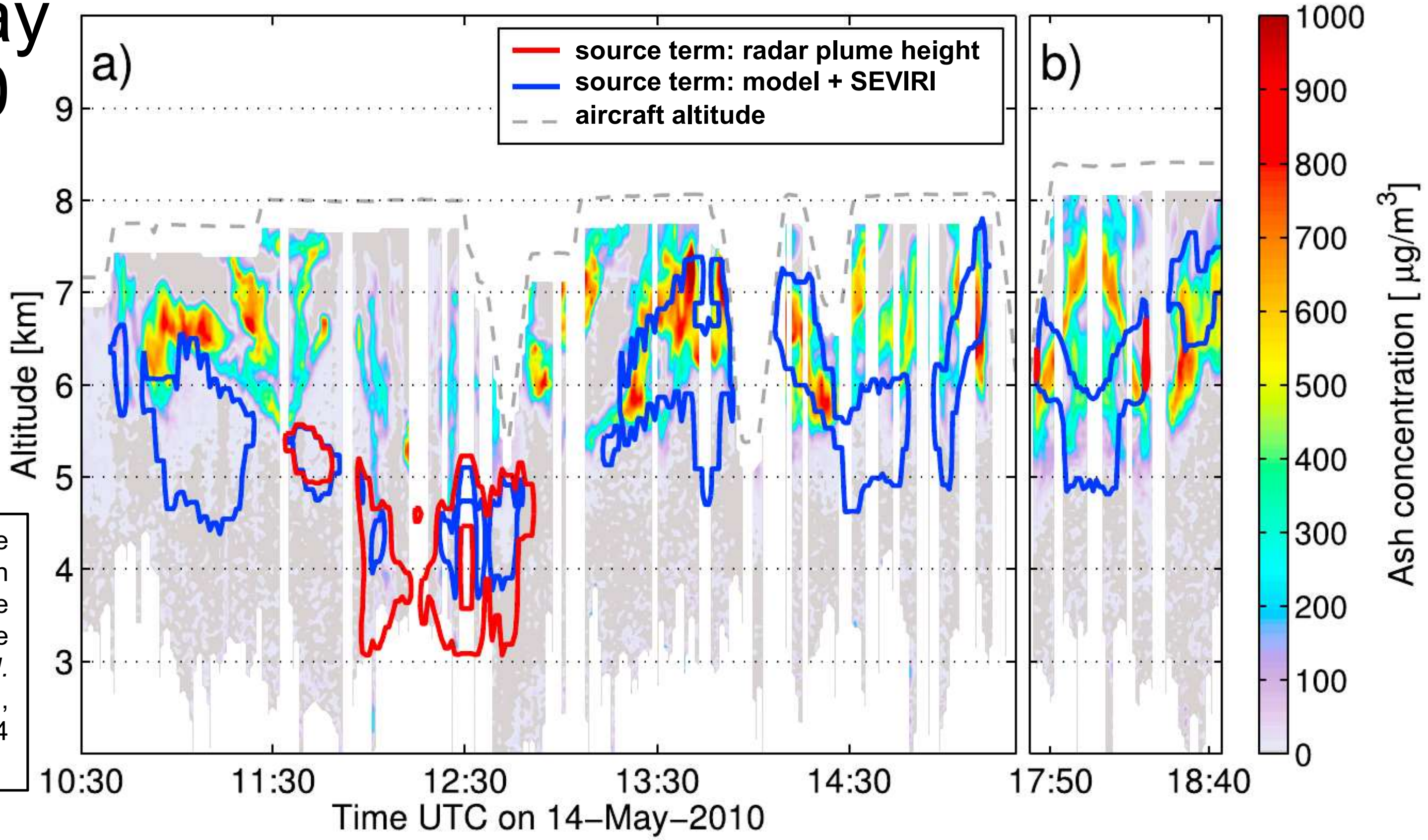


17 May 2010

Francis et al, Retrieval of physical properties of volcanic ash using Meteosat: A case study from the 2010 Eyjafjallajökull eruption, *J. Geophys. Res.* **117**, D00U09, doi:10.1029/2011JD016788. (2012).

Lidar data validate model improvements using Meteosat

14 May 2010

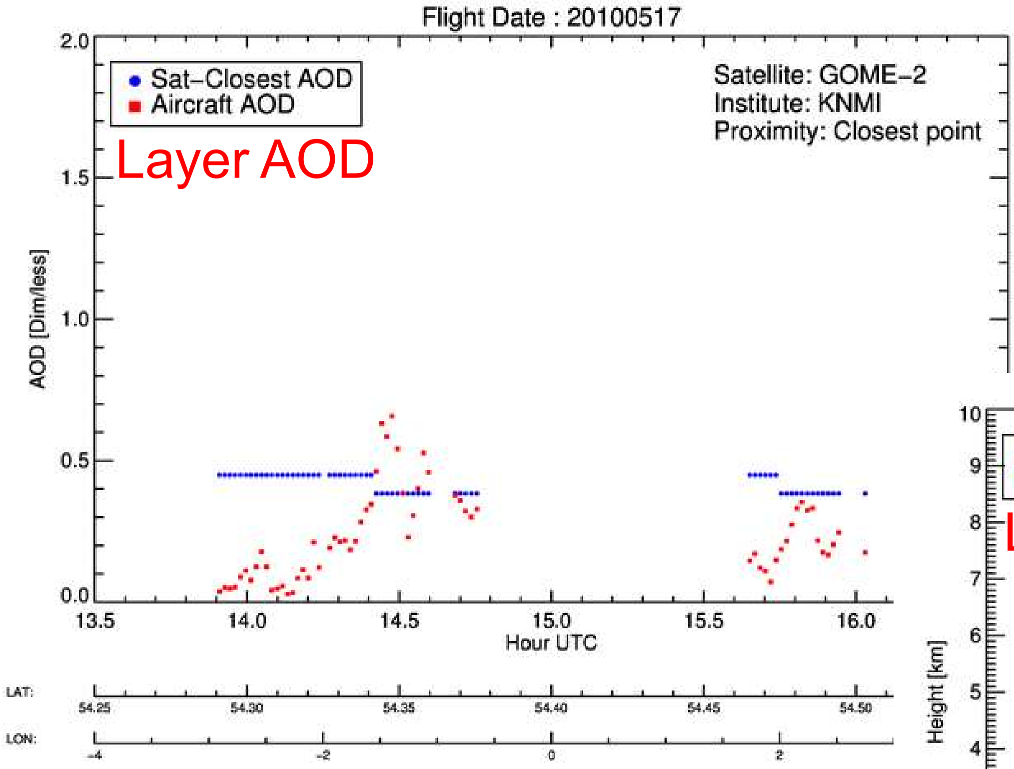


Kristiansen et al, Performance assessment of a volcanic ash transport model mini-ensemble used for inverse modeling of the 2010 Eyjafjallajökull eruption, *J. Geophys. Res.* **117**, D00U11, doi: 10.1029/2011JD016844 (2012).

: 500 mg/m^3 isolines of modeled ash mass concentrations (mean of FLEXPART-ECMWF, FLEXPART-GFS and NAME-MetUM)

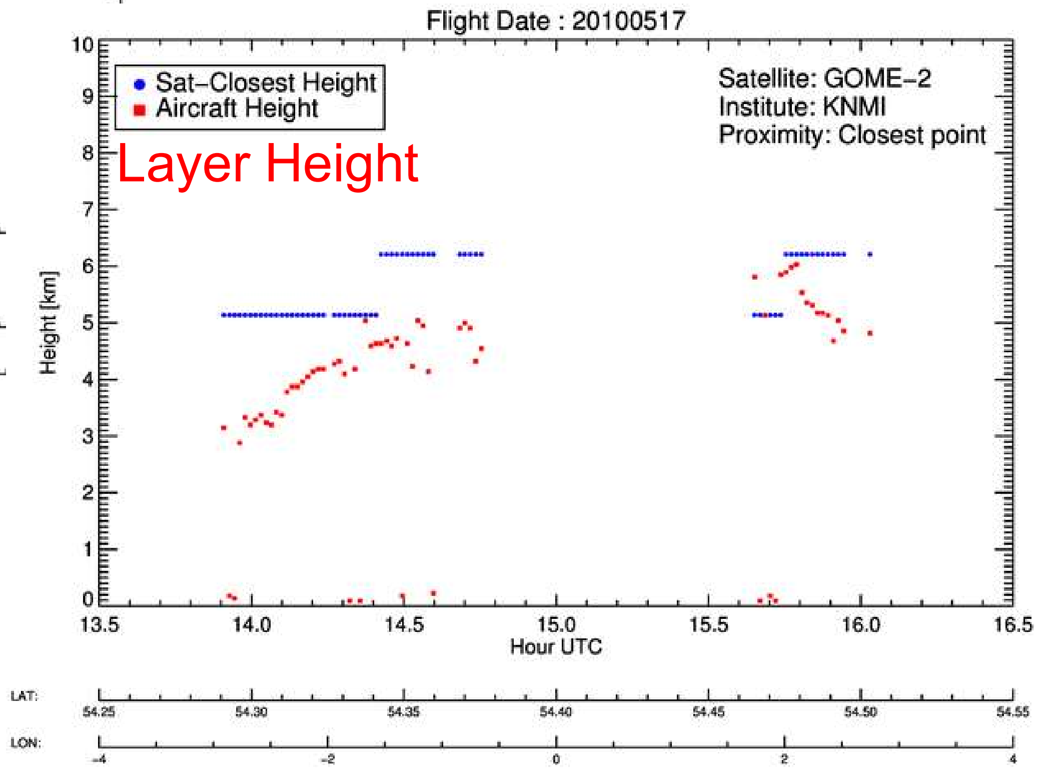
courtesy of N. Kristiansen (NILU, Norway)

ESA study on ash retrievals (SACS-2/SMASH)



KNMI GOME2 Ash product

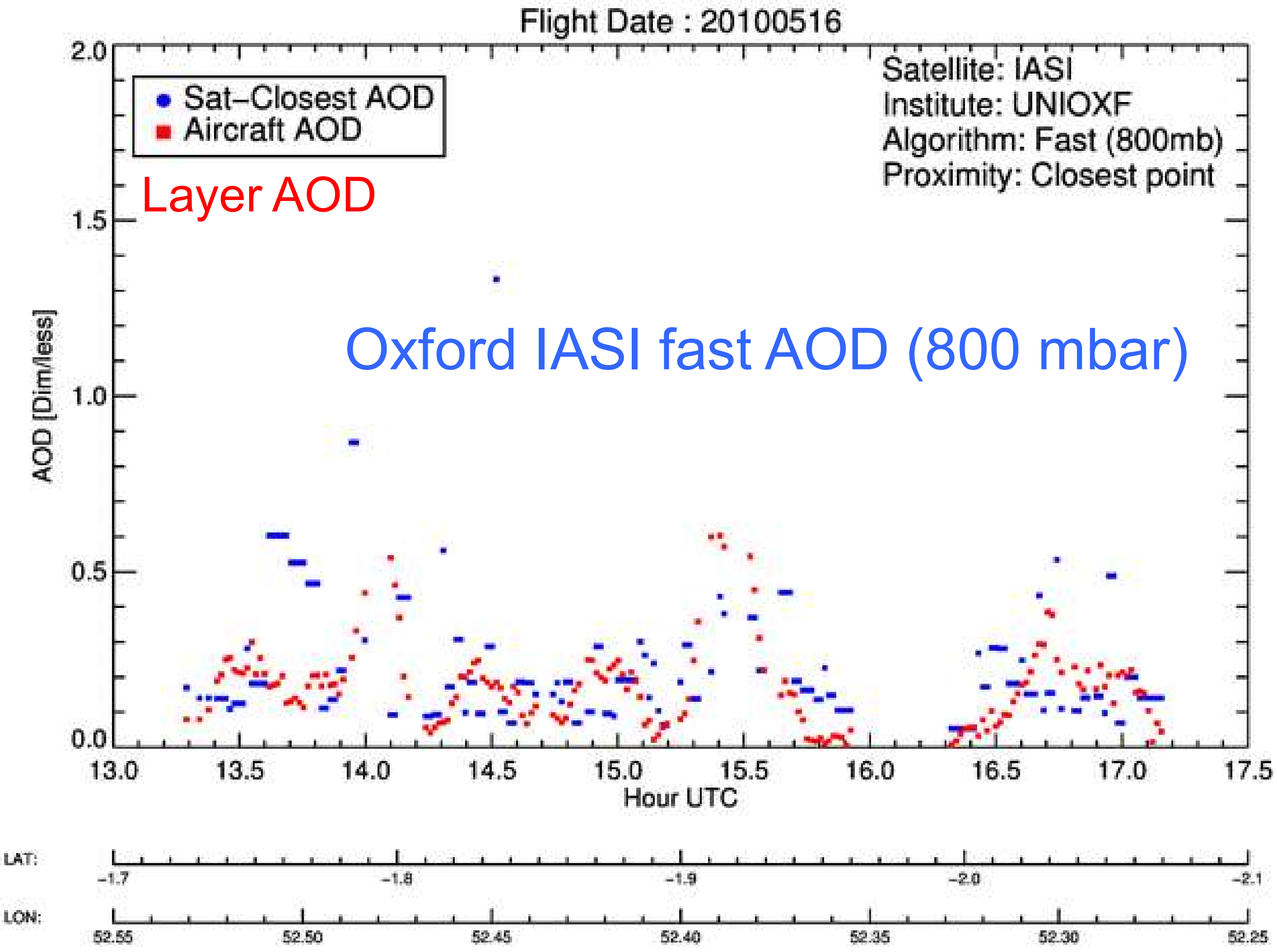
Balis et al, Validation of ash optical depth and layer height retrieved from passive satellite sensors using EARLINET and airborne lidar data: The case of the Eyjafjallajökull eruption, *Atmos. Chem. Phys.* **16**, 5705-5720, (2016).



courtesy of M. Koukouli (University of Thessaloniki)

ESA study on ash retrievals (SACS-2/SMASH)

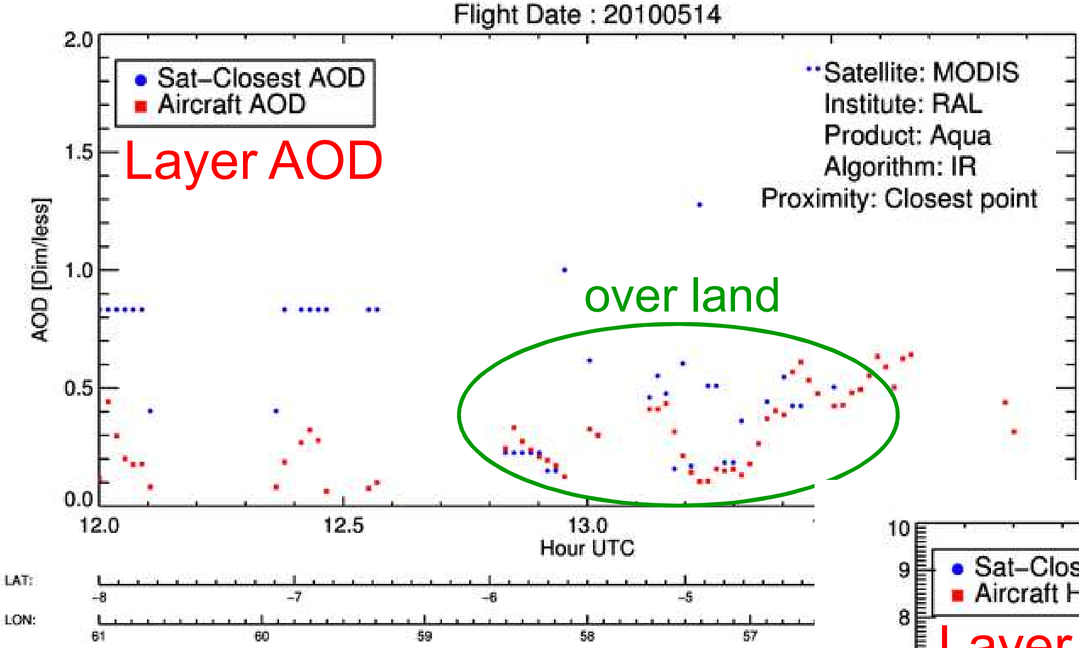
Balis et al, Validation of ash optical depth and layer height retrieved from passive satellite sensors using EARLINET and airborne lidar data: The case of the Eyjafjallajökull eruption, *Atmos. Chem. Phys.* **16**, 5705-5720, (2016).



courtesy of M. Koukouli (University of Thessaloniki)

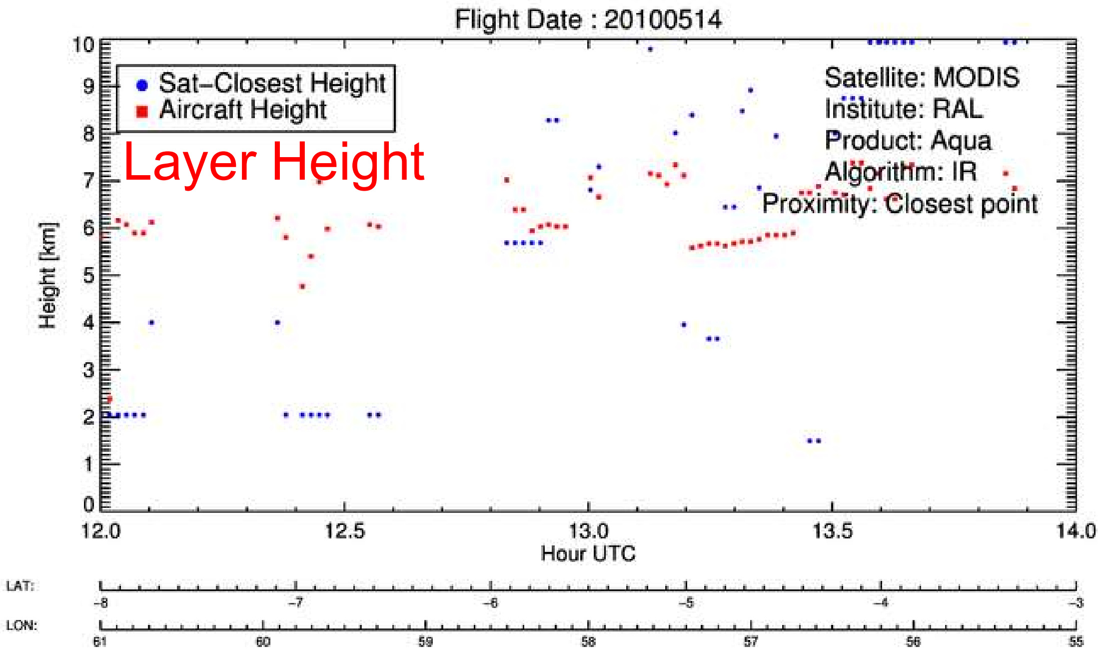
ESA study on ash retrievals (SACS-2/SMASH)

Met Office



RAL MODIS/Aqua IR

Balis et al, Validation of ash optical depth and layer height retrieved from passive satellite sensors using EARLINET and airborne lidar data: The case of the Eyjafjallajökull eruption, *Atmos. Chem. Phys.* **16**, 5705-5720, (2016).



courtesy of M. Koukouli (University of Thessaloniki)

First WMO Intercomparison of Satellite-based Volcanic Ash Retrieval Algorithms Workshop

Met Office

WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR BASIC SYSTEMS

OPEN PROGRAMME AREA GROUP ON INTEGRATED OBSERVING SYSTEMS

INTER-PROGRAMME EXPERT TEAM ON SATELLITE UTILIZATION AND PRODUCTS

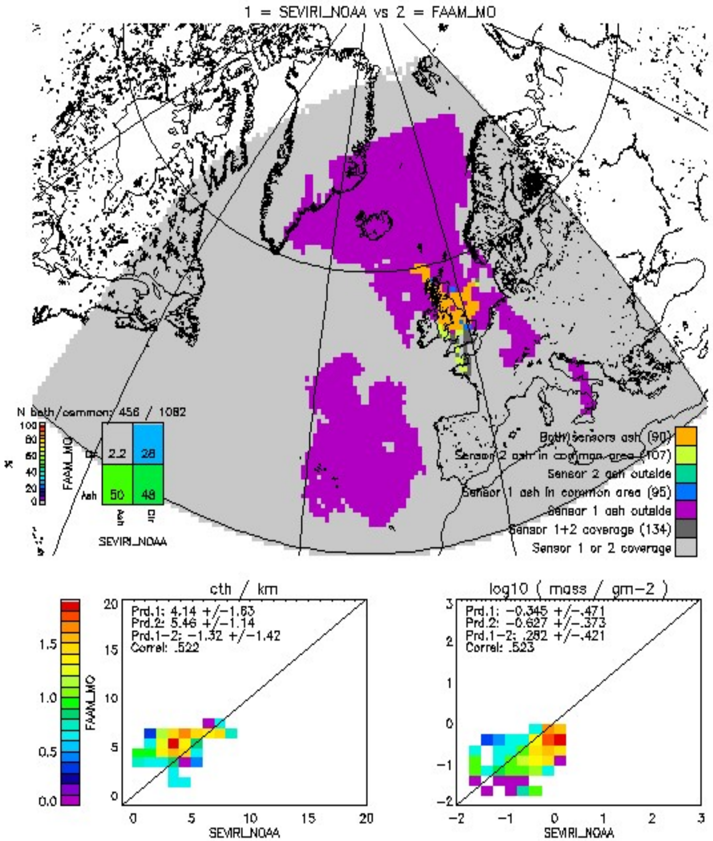
SCOPE-Nowcasting Pilot Project 2 : Globally consistent Volcanic Ash Products

Meeting on the Intercomparison of Satellite-based Volcanic Ash Retrieval Algorithms

Madison WI, USA

29 June – 2 July 2015

FINAL REPORT



"22 algorithms from institutions and groups all over the world using passive satellite imagery were considered in the intercomparison; reference data were used from the CALIPSO CALIOP space-borne lidar instrument, **the United Kingdom FAAM research aircraft**, and EARLINET ground-based lidar data."

Recomendation 10: "**Provision of airborne ash measurements during future eruptions, plus resources for associated scientific analysis**."

Volcanic ash: Summary

- A high quality dataset established (*not achieved with other means*)
- Ash is in *patches*: alt. 2–8 km; depth 1–2 km; extent 80–500 km
- Extinction 0–1.2 km-1; AOD 0–0.85
- Concentration 0–1900 $\mu g/m^3$; Column loading 0–1.3 g/m^2
- Validation of remote sensing: ARIES, IASI, SEVIRI, GOME2, MODIS
- Evaluation / validation of dispersion model + improvements

SAMBBA (2012)
South American Biomass Burning Analysis

Met Office

South American Biomass Burning Analysis (SAMBBA)

[Brazil, Sept /Oct 2012]

Met Office

NATURAL ENVIRONMENT RESEARCH COUNCIL

INPE

UNIVERSIDADE DE SÃO PAULO

SCIENTIA VINCES

- 20 Flights over Brazil looking at smoke from forest, savannah and cropland fires
- Ground-based measurements
- Atmospheric modelling studies
- Satellite remote sensing of fire and smoke plumes

SAMBBA Broad science drivers

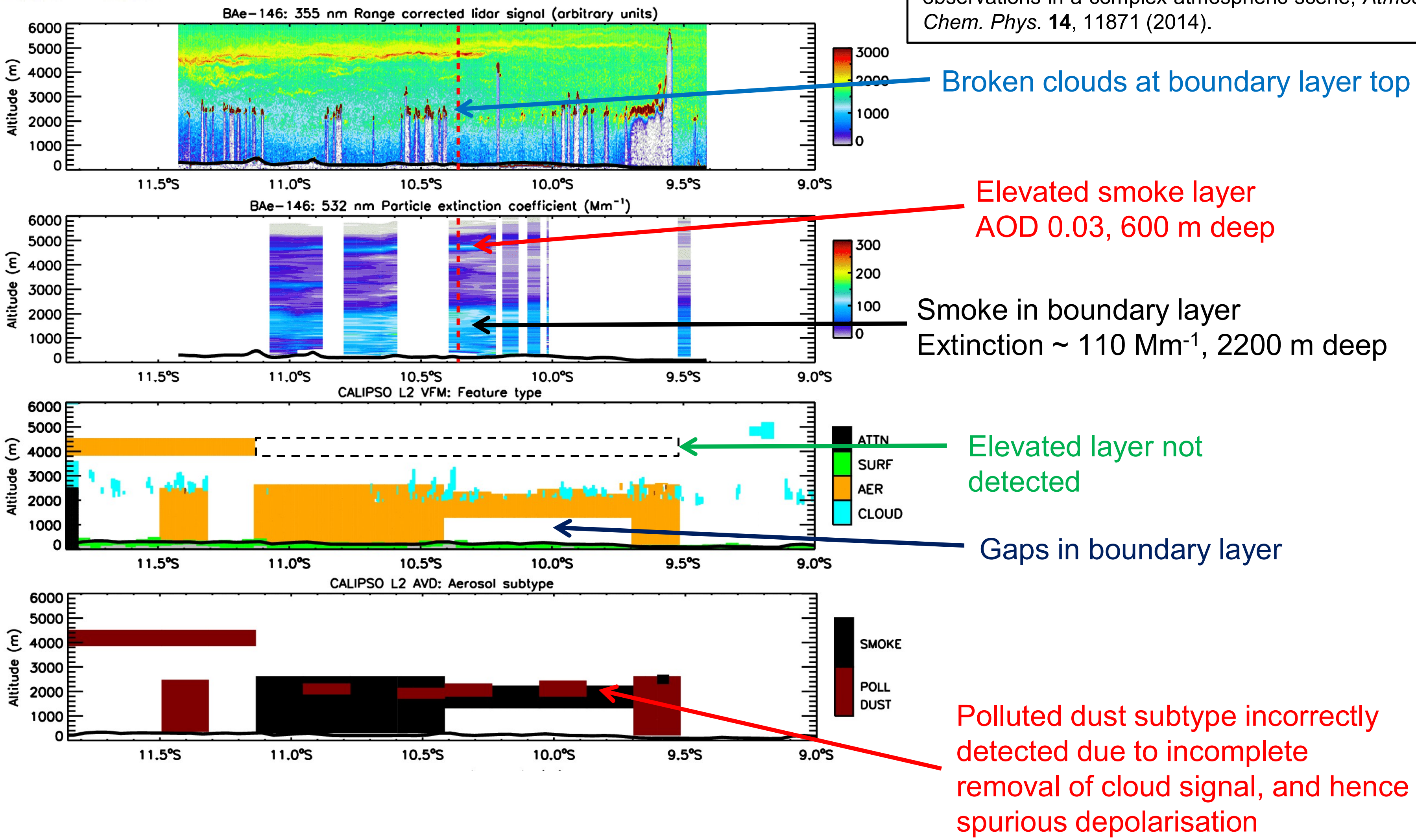
- Quantify emissions of trace gases and aerosols from biomass burning over S. America
- Changes to atmospheric composition
- Impacts on climate, weather and air quality
- Influence on biosphere
- Evaluation of earth-system models
- Validate satellite remote sensing of fires and smoke plumes

Papers in Atmos. Chem. Phys. (Special Issue)

http://www.atmos-chem-phys.net/special_issue354.html

CALIPSO underpass

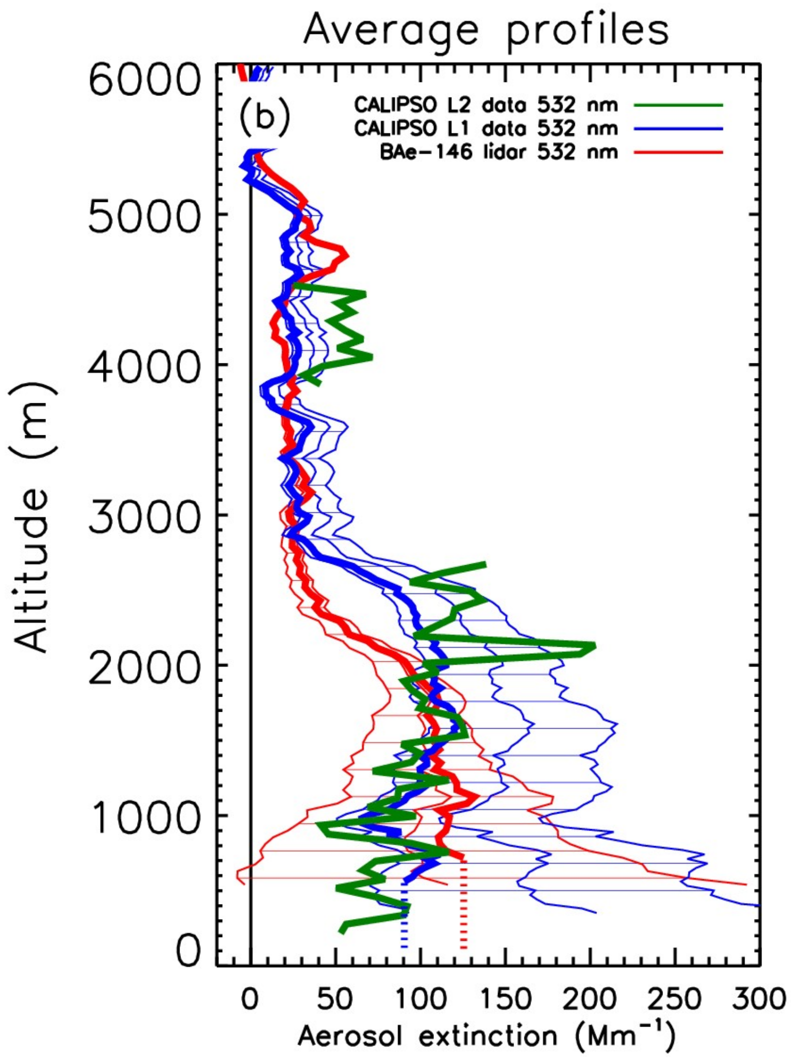
Marenco *et al*, Airborne verification of CALIPSO products over the Amazon: a case study of daytime observations in a complex atmospheric scene, *Atmos. Chem. Phys.* **14**, 11871 (2014).



 Note: low level clouds cause high albedo and hence large solar background.

CALIPSO underpass

Marenco *et al*, Airborne verification of CALIPSO products over the Amazon: a case study of daytime observations in a complex atmospheric scene, *Atmos. Chem. Phys.* **14**, 11871 (2014).



Good mean profile, but with some weaknesses highlighted in the detailed representation

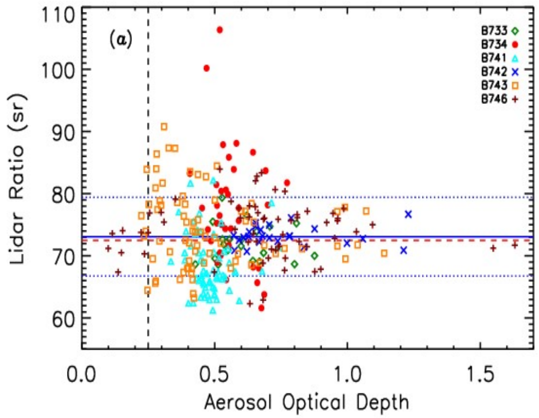
- Thin elevated layer missed
- Gaps in the BL aerosol (~ 30%)
- Oscillating aerosol subtype (Smoke / Polluted Dust)
- Incorrect removal of cloud signal → Polluted Dust
- Similar "mean" profile

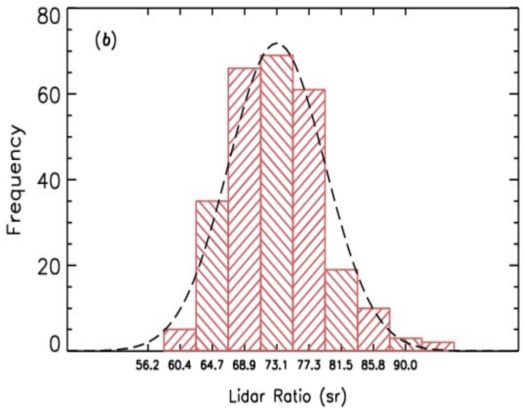
Difficult conditions for CALIPSO: daytime and broken clouds

Estimating the lidar ratio

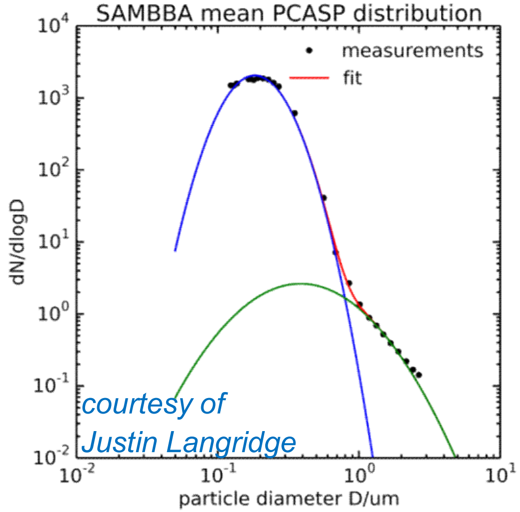
$$LR = \frac{\text{extinction}}{\text{backscattering}}$$

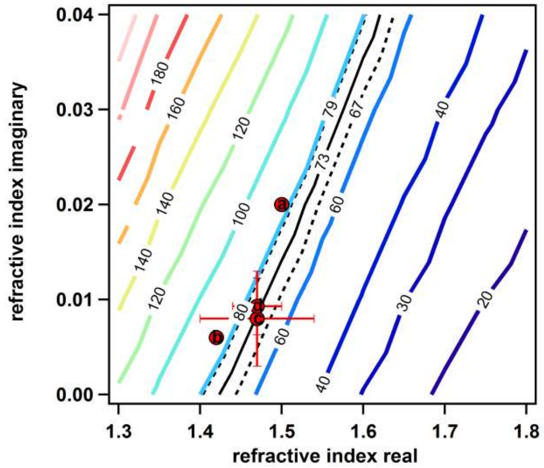
1) Iterate the deep layer method until Rayleigh scattering is matched above the aerosol layer





2) Estimate from measured size distribution



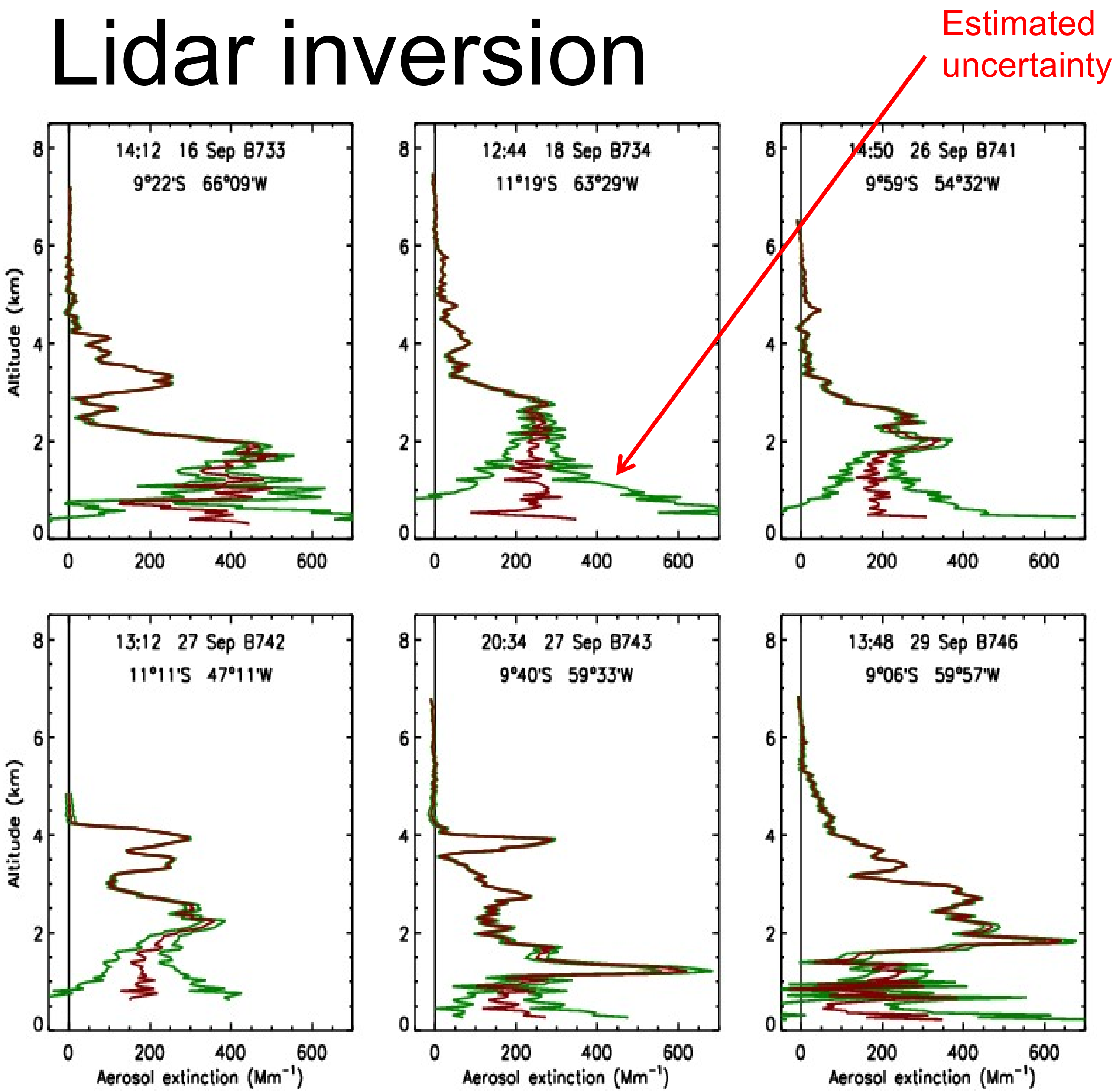


3) BB lidar ratio in the literature: 70-75 sr

73 ± 6 sr

a	Reid and Hobbs, JGR, 103, 32013, 1998	1.5 – 0.02i
b	Guyon P et al. , ACP, 3, 951, 2003.	1.42 – 0.006i
c	Rizzo et al., ACP, 13, 2391, 2013.	(1.47 ± 0.07) – (0.008 ± 0.005)i
d	Dubovik et al., J. Atmos. Sci., 59, 590, 2002.	(1.47 ± 0.03) – (0.0093 ± 0.003)i

Lidar inversion

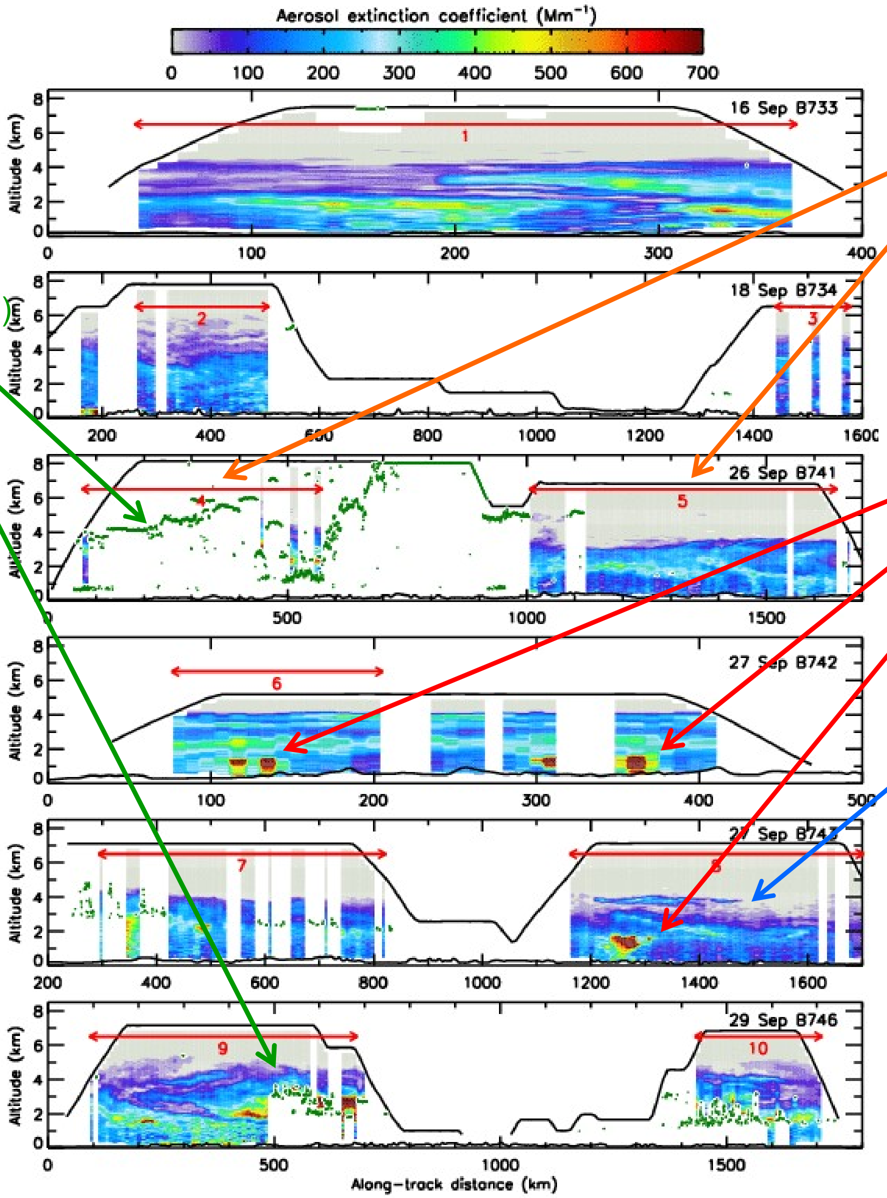


334 profiles inverted

The haze of the Amazon basin

Marenco *et al*, On the vertical distribution of smoke in the Amazonian atmosphere during the dry season, *Atmos. Chem. Phys.* **16**, 2155 (2016).

Clouds
Large extinction above
(~ 1000 Mm^{-1})

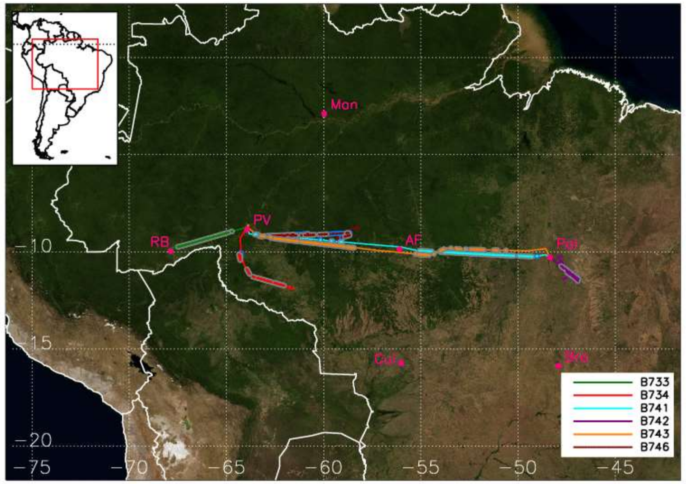


Horizontal sections for statistical analysis

- 6 flights
- Sampling period: 14 days
- Large distance (~ 2200 km)
- Mainly East-West (centred on 10S)

Single fire plumes (~ 1000 Mm^{-1})

Elevated layer, AOD 0.09
200-400 m deep
Horizontal extent 270 km



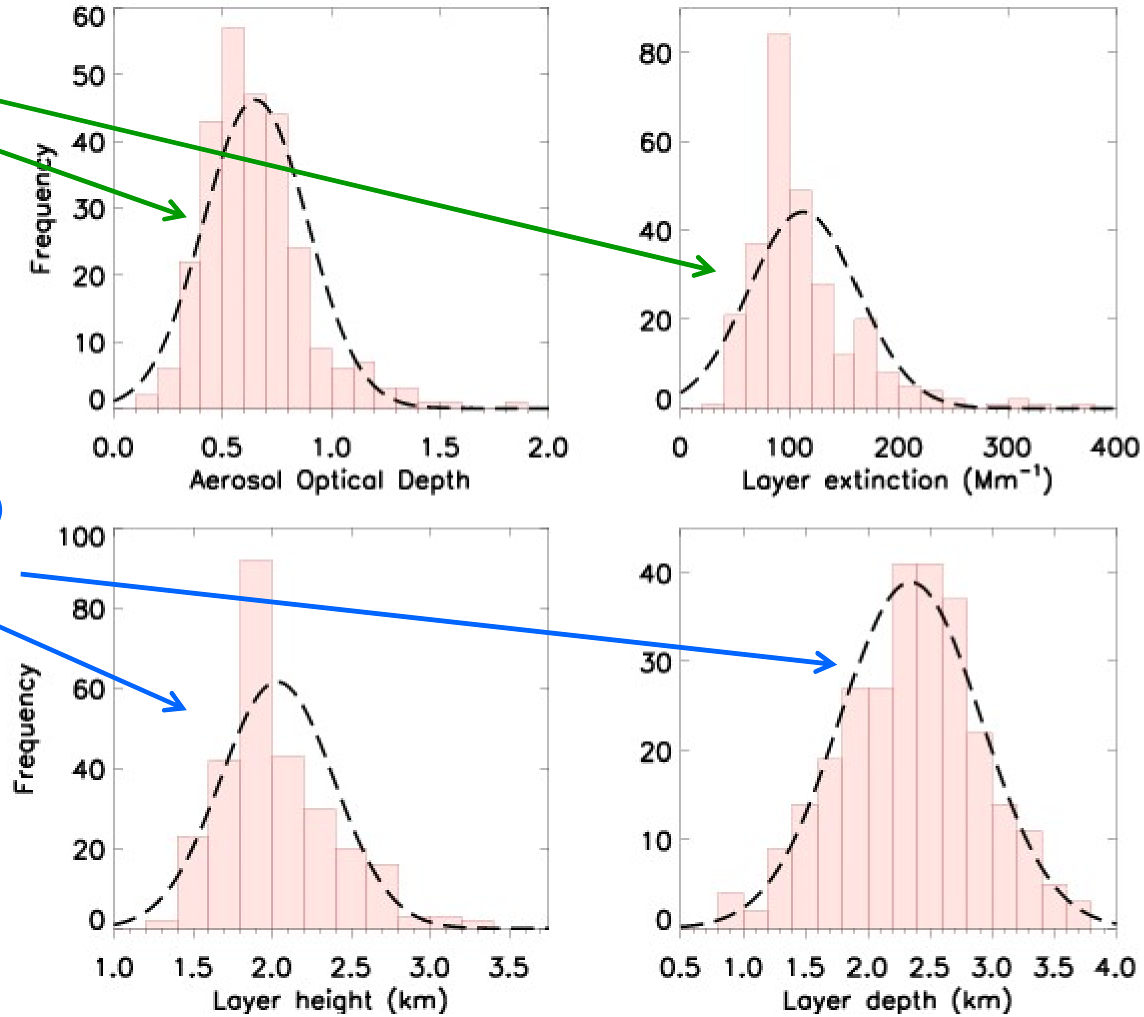
Statistical analysis

Met Office

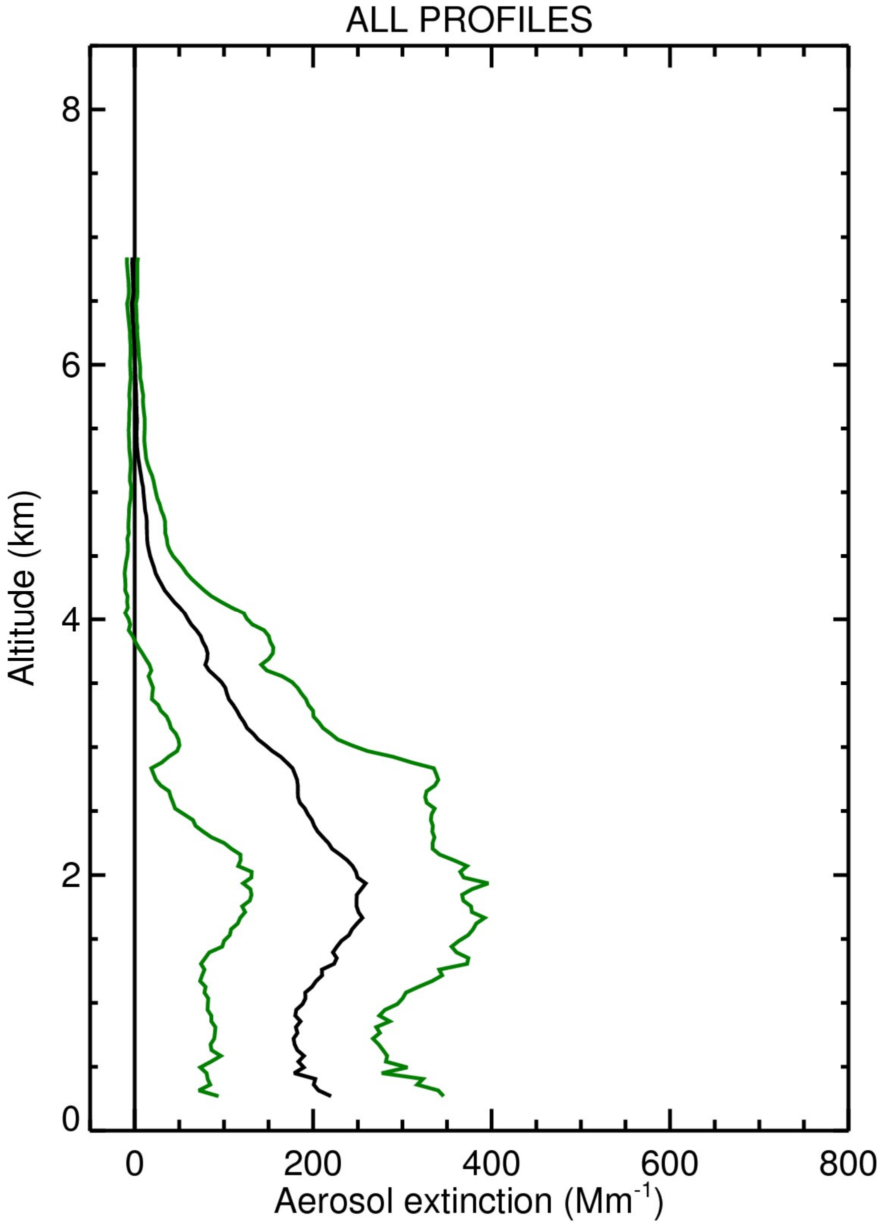
Marenco *et al*, On the vertical distribution of smoke in the Amazonian atmosphere during the dry season, *Atmos. Chem. Phys.* **16**, 2155 (2016).

Quantitative properties:
Variability ~40%

Geometrical properties:
Limited variability (~20%)
over ~ 2200 km and 14 d



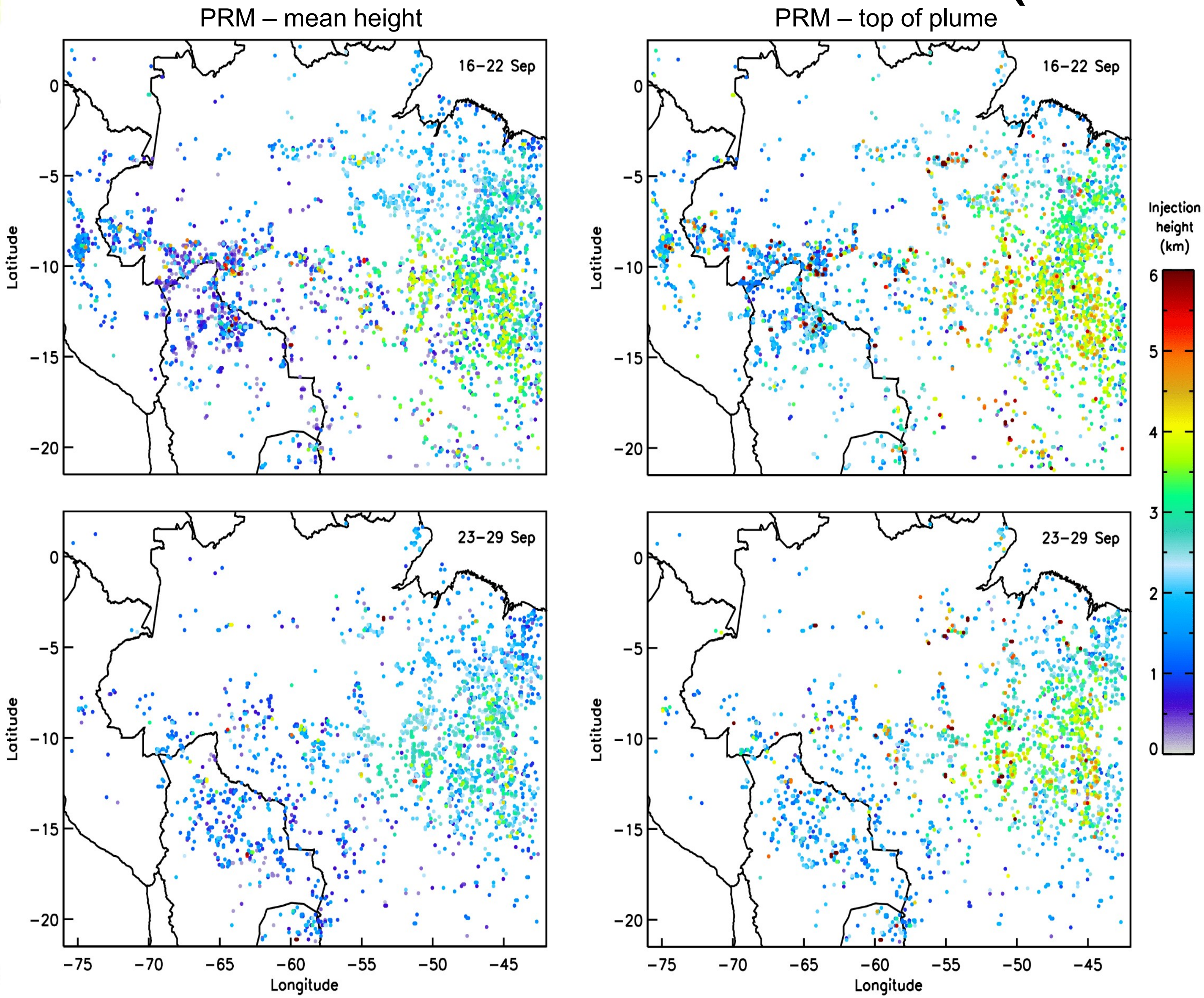
Campaign average vertical profile



Marenco *et al*, On the vertical distribution of smoke in the Amazonian atmosphere during the dry season, *Atmos. Chem. Phys.* **16**, 2155 (2016).

GFAS Plume Rise Model (PRM)

courtesy of Samuel Remy



Models used in comparison

MetUM:

- LAM configuration (Amazonia domain – set up for flight planning)
- 12 km resolution
- 70 levels
- Lateral boundary conditions from UM Global Model
- CLASSIC aerosols scheme – first attempt at using this in NWP
- Direct aerosol effects included (scattering+absorption)
- Emissions: GFAS X 1.7
- Injection height: 0-3 km (prescribed)

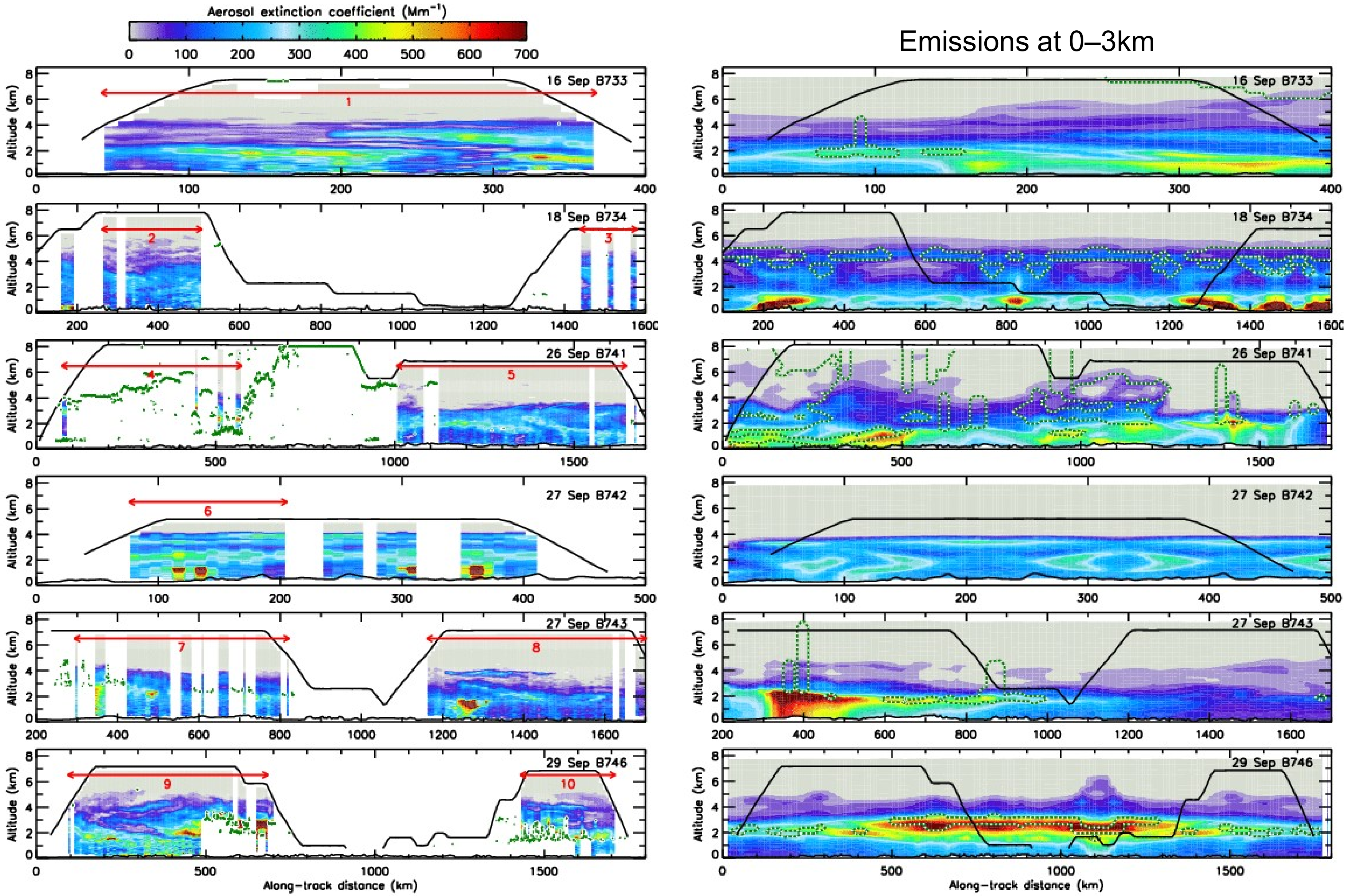
ECMWF-MACC:

- Operational global composition model
- ~ 80 km resolution (T255)
- 60 levels
- 5 aerosols species
- MODIS AOD assimilated in 4D-VAR
- Emissions: GFAS X 3.4
- Injection height: Surface, GFAS PRM (experimental)

Rémy *et al*, Two global data sets of daily fire emission injection heights since 2003, *Atmos. Chem. Phys.* **17**, 2921-2942 (2017).

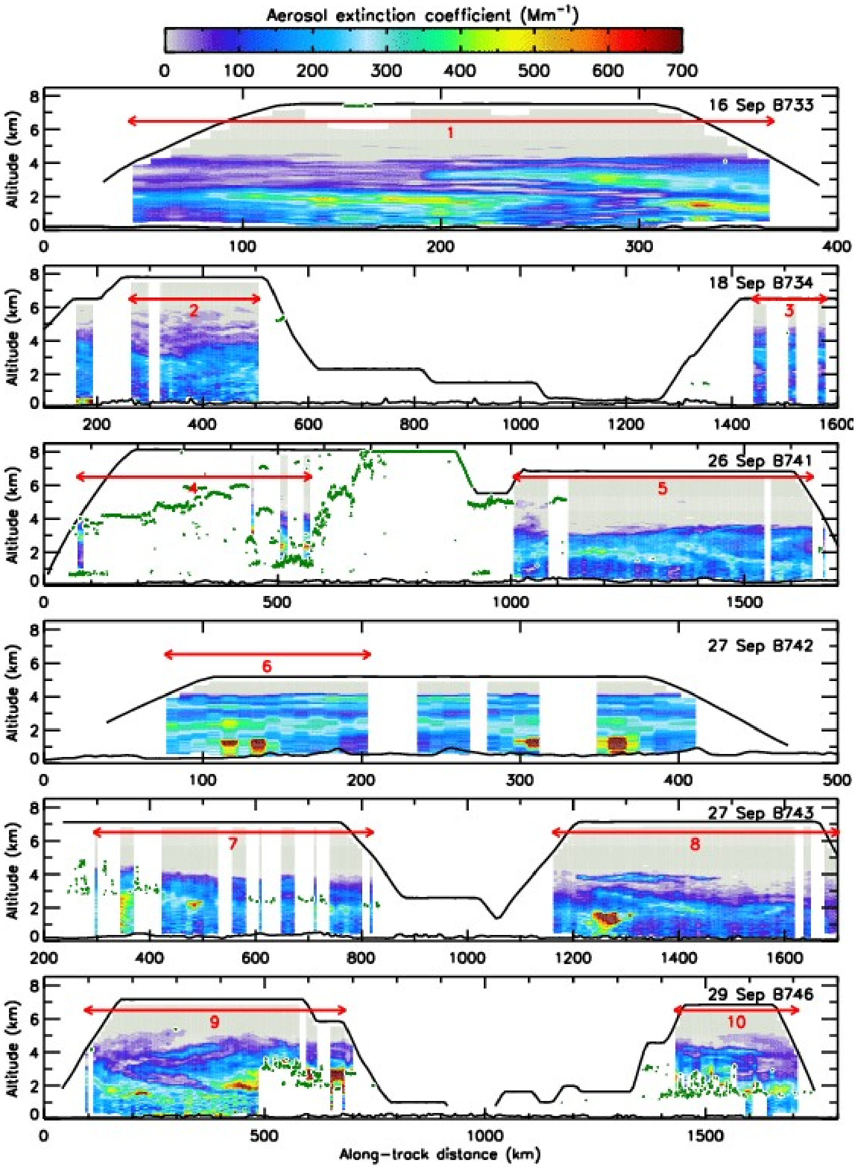
Marenco *et al*, On the vertical distribution of smoke in the Amazonian atmosphere during the dry season, *Atmos. Chem. Phys.* **16**, 2155 (2016).

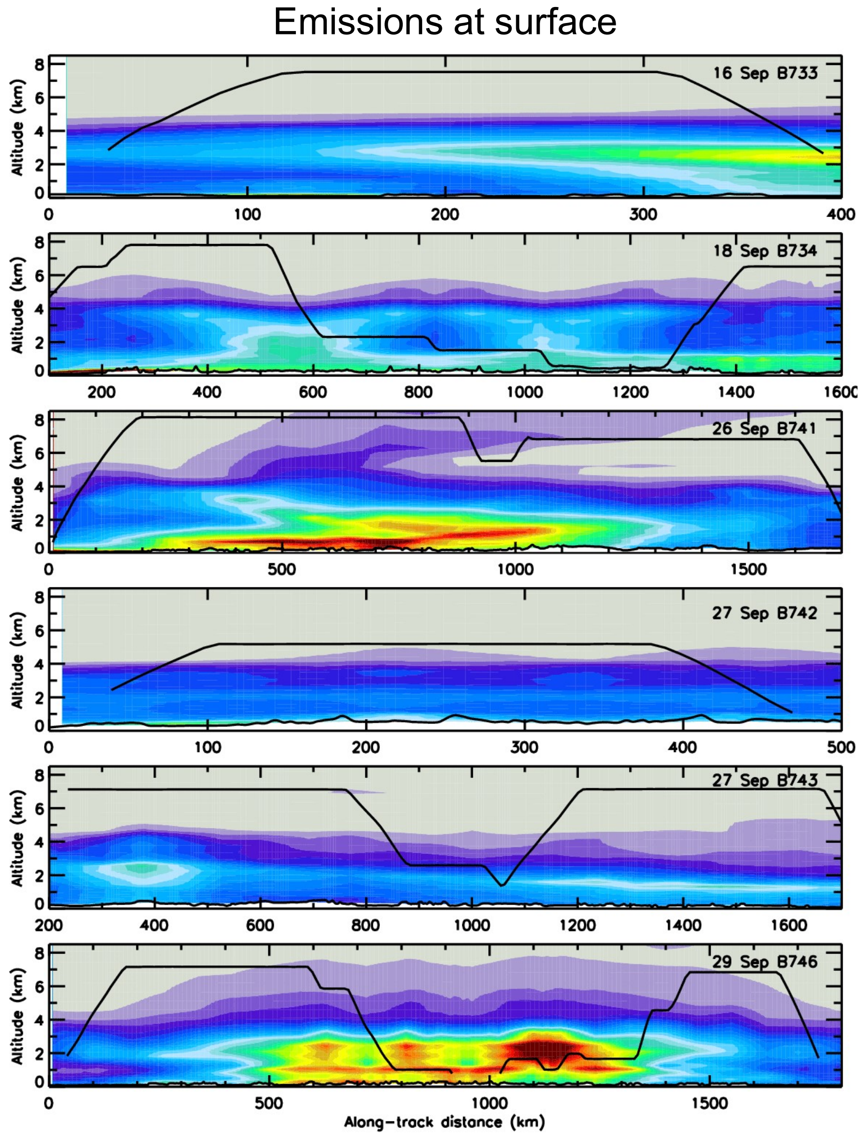
Comparison to MetUM (LAM)



courtesy of Jane Mulcahy and Ben Johnson

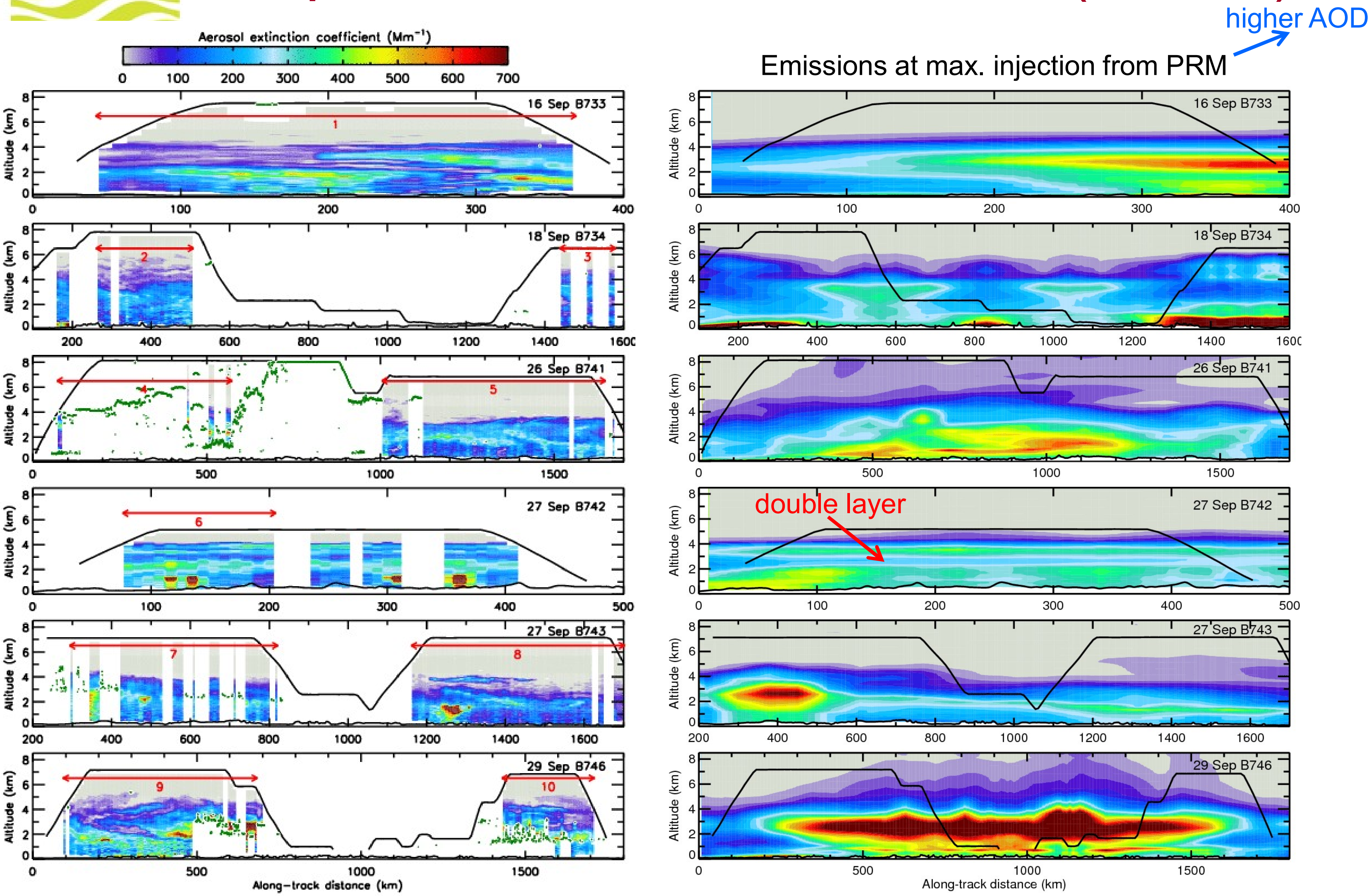
Comparison to ECMWF-MACC (Global)





courtesy of Samuel Remy, Angela Benedetti, and Luke Jones

Comparison to ECMWF-MACC (Global)



courtesy of Samuel Remy, Angela Benedetti, and Luke Jones

SAMBBA: Summary

Met Office

- AOD 0.65 ± 0.24
- Structure relatively consistent over 2200 km/14 d
- Consistency with Baars et al. (2012), Huang et al. (2015), and Bourgeois et al. (2015)

- CALIPSO: strengths and weaknesses highlighted

- Model representation is realistic (except single plumes)
- ECMWF-MACC: slight overestimation of the AOD
- MetUM CLASSIC: has skill for BB aerosol prediction
- ECMWF-MACC: PRM injection heights assessed vs. surface emissions

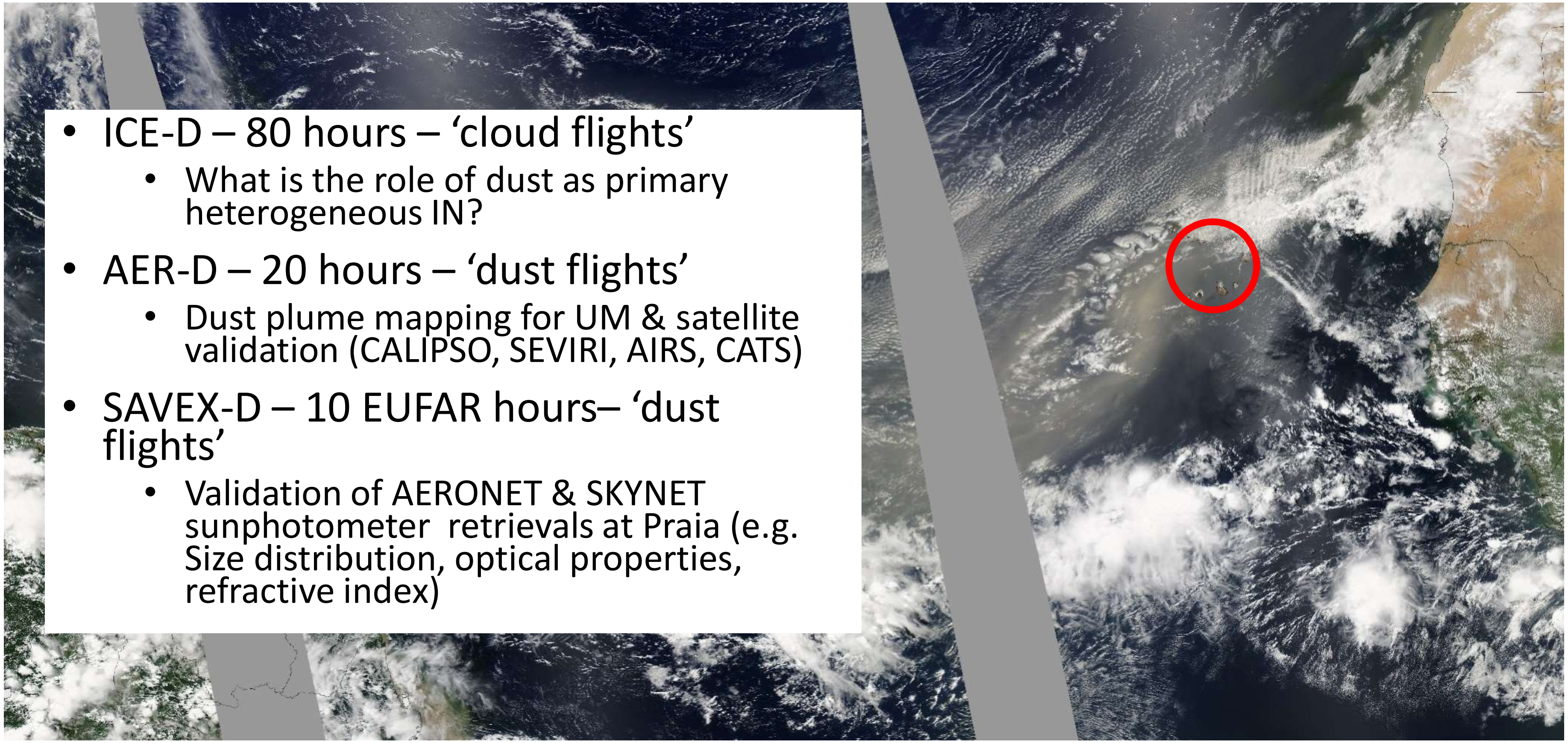
Baars et al, *J. Geophys. Res.* **117**, D21201,doi:10.1029/2012JD018338, 2012.
Bourgeois et al, *J. Geophys. Res.* **120**, 8411–8425, 2015.
Huang et al, *J. Geophys. Res.* **120**, 5085–5100, 2015.

ICE-D / AER-D / SAVEX-D

Cape Verde, August 2015

Met Office

ICE-D



- ICE-D – 80 hours – ‘cloud flights’
  - What is the role of dust as primary heterogeneous IN?
- AER-D – 20 hours – ‘dust flights’
  - Dust plume mapping for UM & satellite validation (CALIPSO, SEVIRI, AIRS, CATS)
- SAVEX-D – 10 EUFAR hours– ‘dust flights’
  - Validation of AERONET & SKYNET sunphotometer retrievals at Praia (e.g. Size distribution, optical properties, refractive index)

ICE-D / AER-D / SAVEX-D

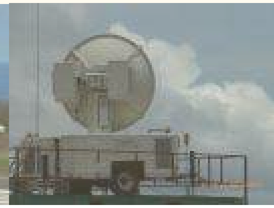
- ICE-D: dust-cloud interactions and subsequent evolution of towering cumulus clouds (role of dust as IN) – 10 successful flights
- AER-D mapping: validate 1D-VAR dust retrievals from MSG SEVIRI (for future use in data assimilation) + potential modelling studies – 3 successful flights
- AER-D space lidar: validate the retrievals of the space lidar CATS on the ISS – 1 successful flight (Note: 2nd flight, CATS was not working)
- SAVEX-D: validation of AERONET/SKYNET sunphotometer measurements of dust properties (size distribution, optical properties) – 2 successful flights
- Additional objective: validation of U. Hertsfordshire's dust sondes – 5 sondes (2 sondes coincident with a/c)

Ice in Clouds Experiment – Dust (ICE-D)

Met Office

National Centre for Atmospheric Science

NATURAL ENVIRONMENT RESEARCH COUNCIL



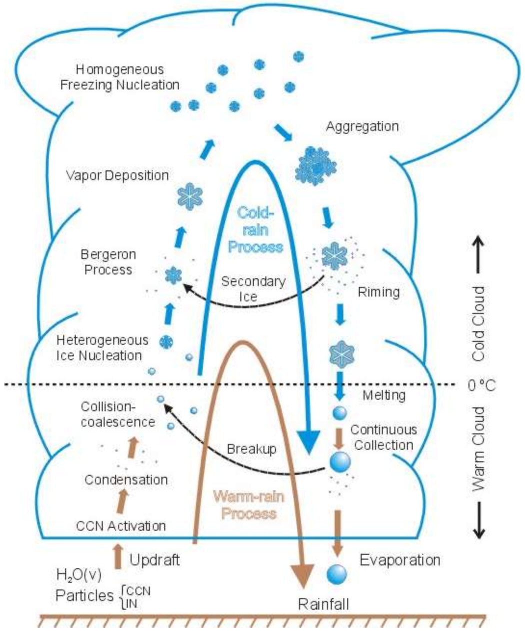
Ice in Clouds Experiment (ICE) focuses on the role of ice formation in ice cloud evolution.

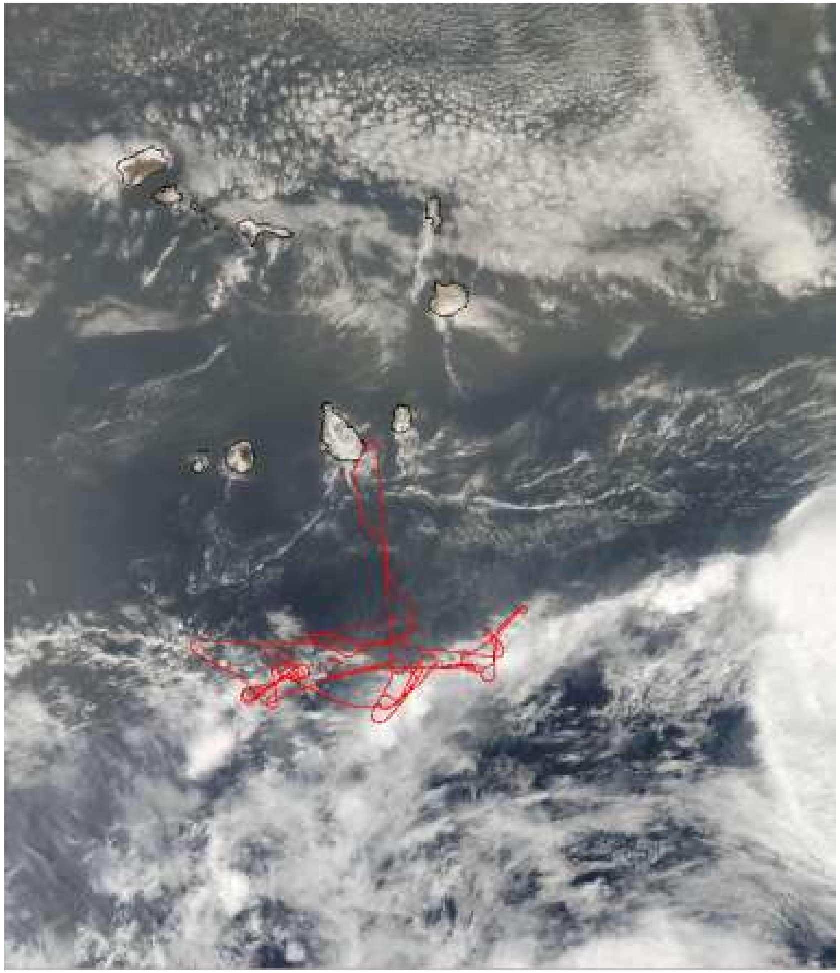
ICE-L: *Can direct Ice Nuclei measurements be used to predict the ice particle concentration in layer clouds (lenticular wave clouds). USA,2007 using NSF/NCAR C-130, A. Heymsfield, J. Stith, D. Rogers.*

ICE-T: *Both primary Ice Nucleation and secondary ice multiplication processes in tropical convective clouds. USA Virgin Islands, 2011 using NSF/NCAR C-130 and SPEC Learjet. A. Heymsfield, D. Rogers.*

ICE-D: *Role of mineral dust. Cape Verde 2015 using FAAM BAe-146. A. Blyth, T. Choularton, R. Cotton.*

Ice in Cloud Experiment – Dust (10 flights)





- <u>Met Office</u>: Research aircraft
- <u>U. Leeds</u>: NCAS X-band radar; filter samples on a/c
- <u>U. Manchester</u>: Ground-based aerosol measurements; cloud-aerosol instruments on a/c
- <u>U. Mainz</u>: HaloHolo instrument

Ground Obs

University of Leeds/NCAS

- Dual-polarisation X-band radar

University of Manchester

- Aerosol container

U.Valencia/Met Office

- Sunphotometers
    - AERONET Cimel
    - SKYNET Prede

University of Hertfordshire

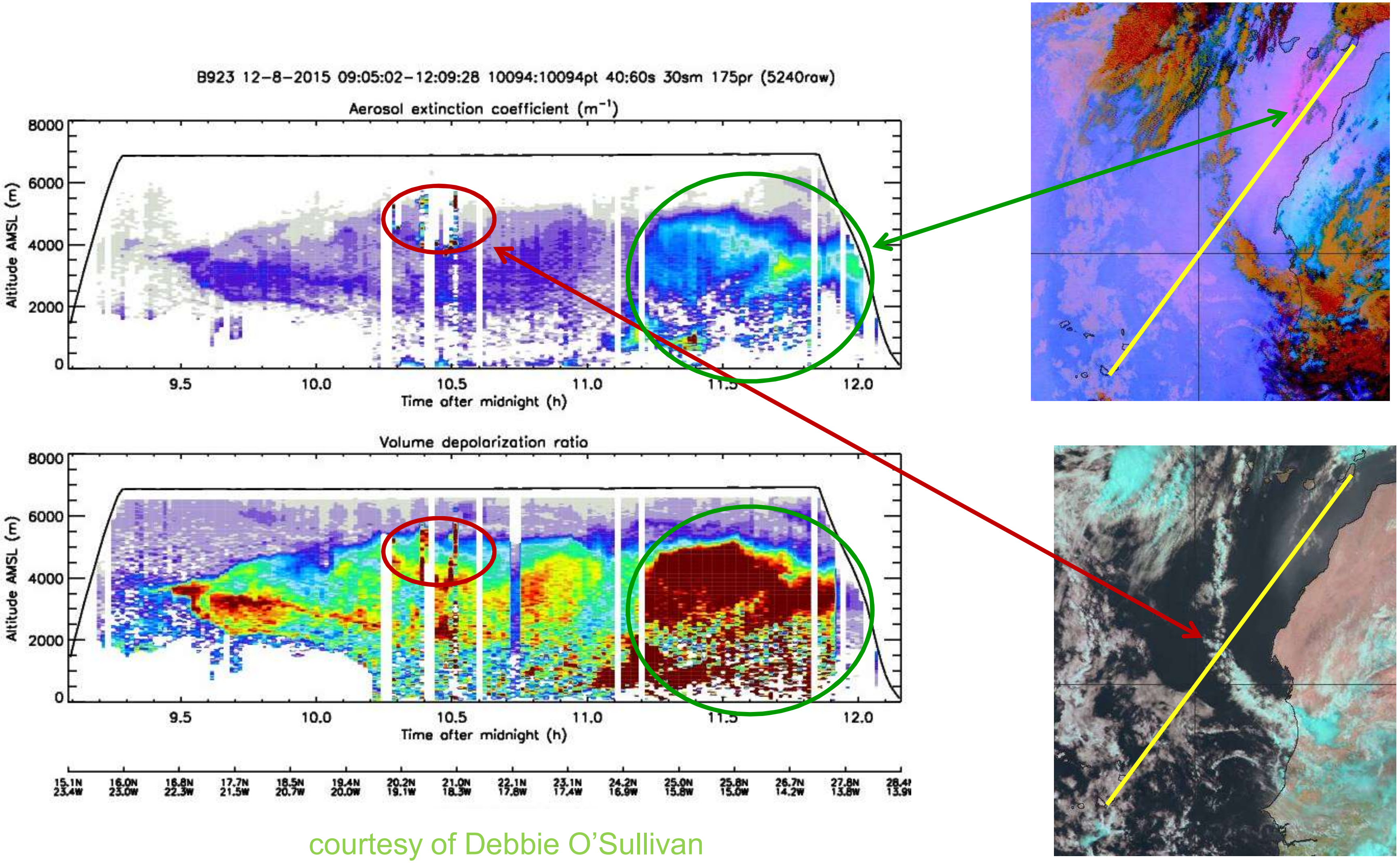
- Dustsondes

AER-D: Aerosol Science component (6 flights)

- Dust mapping for the validation of SEVIRI 1D-VAR retrievals and UM dust forecasts – 3 flights
- SAVEX-D: Sunphotometer validation experiment in dust (SAVEX-D, *EUFAR funded*) – 2 flights
- ACCURATE: GARRLiC validation in dust using PollyXT (*did not happen due to lack of funding*)
- CATS space lidar validation – 1 flight
- Radiative closure studies
- Validation of new dustsondes

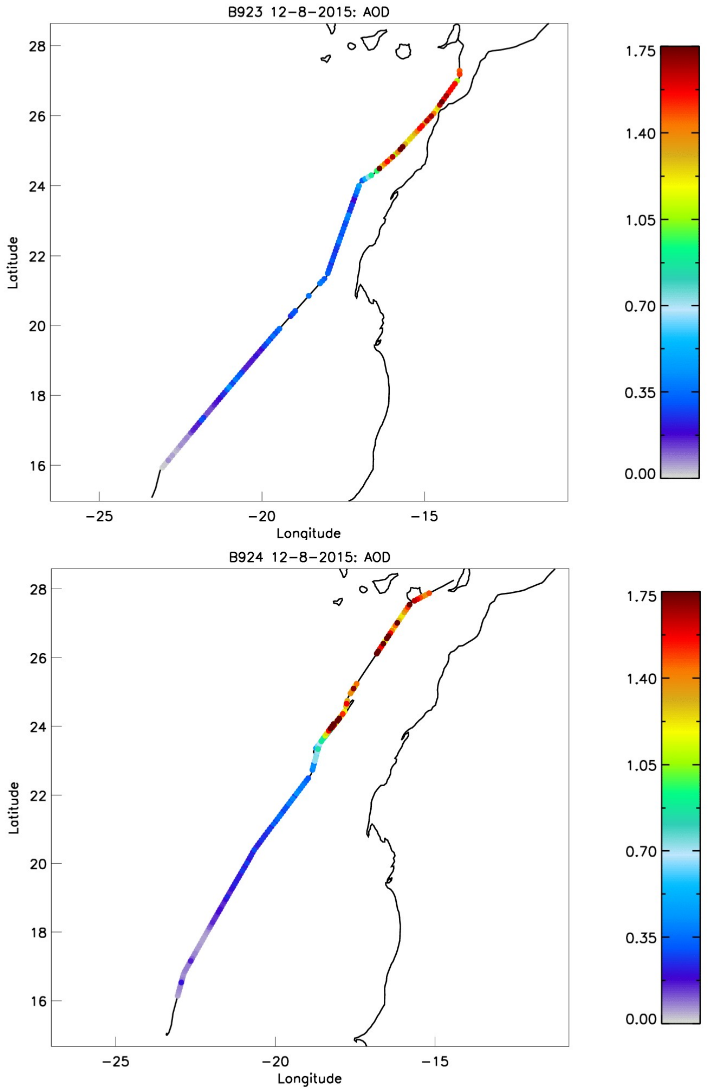
Met Office, U. Reading, U. Valencia, National Observatory of Athens, U. Hertsfordshire

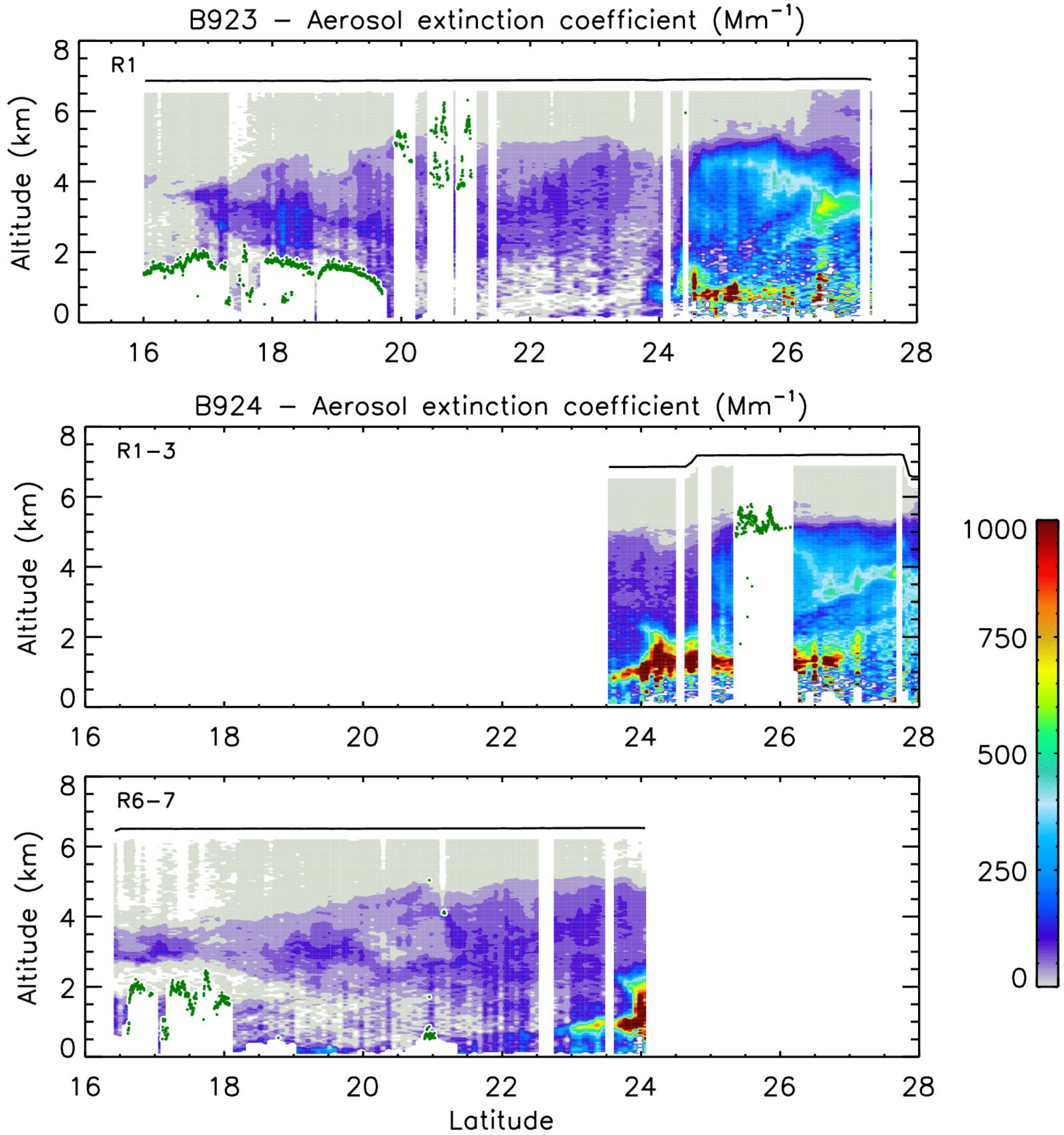
ICE-D / AER-D / SAVEX-D
B923 mapping flight



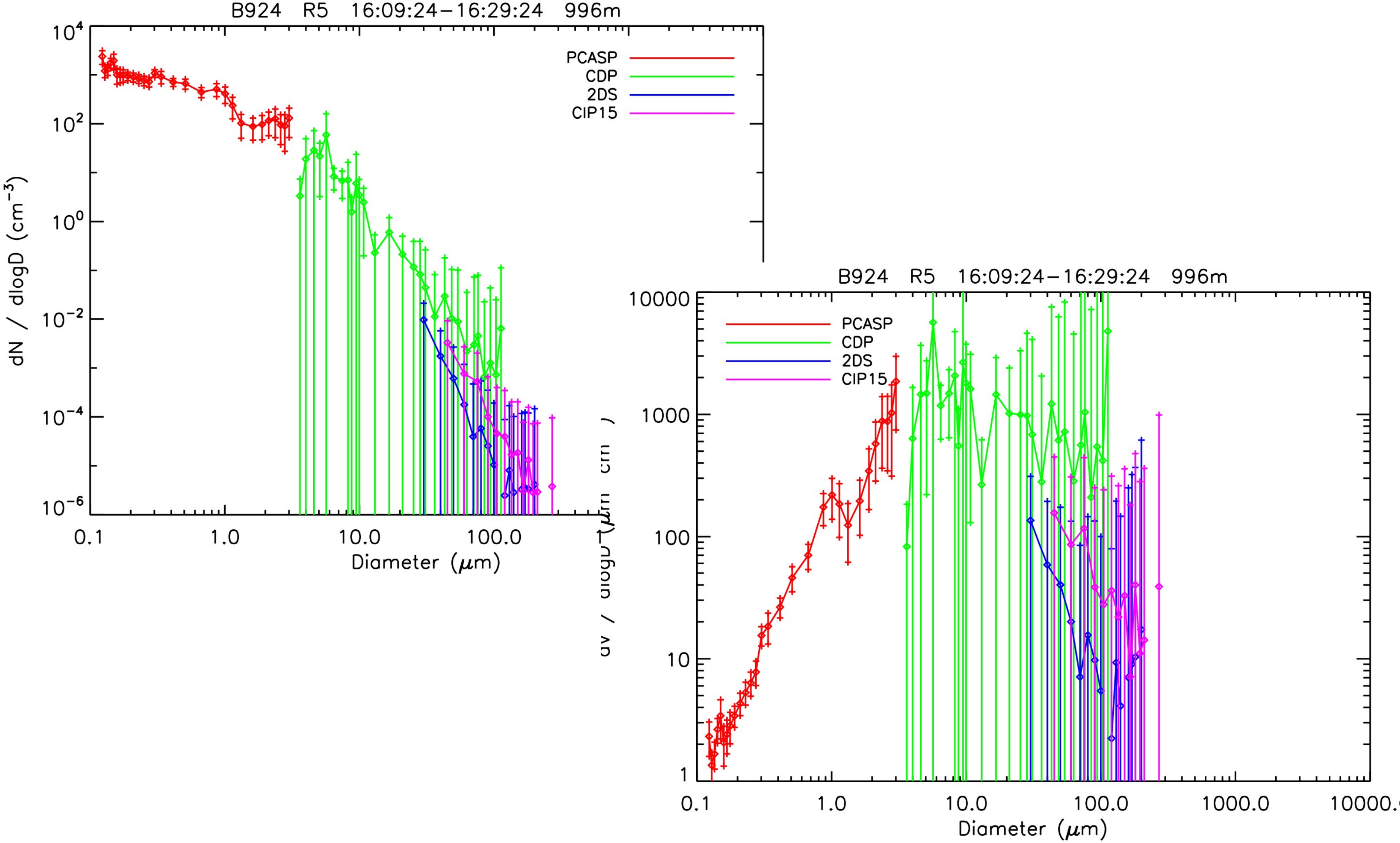
courtesy of Debbie O'Sullivan

Lidar mapping: B923+B924

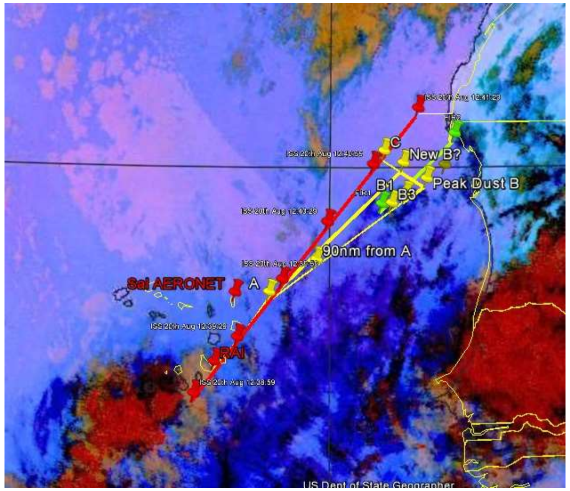


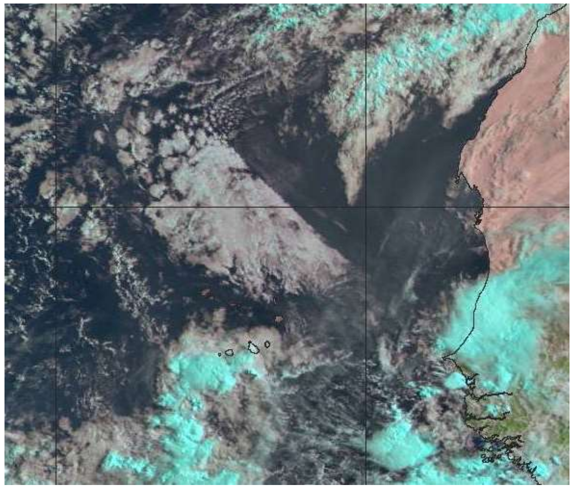


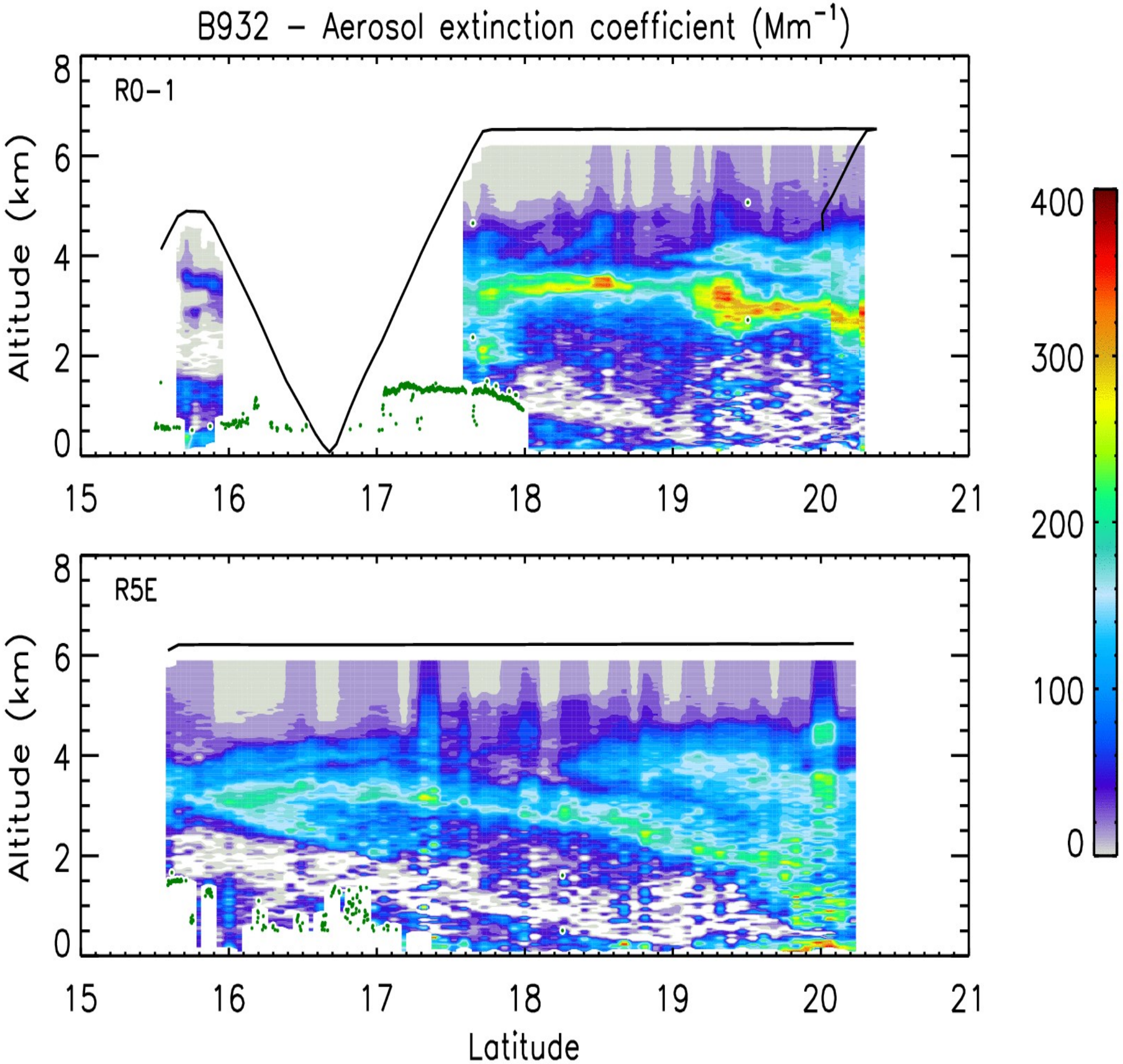
B924: very large dust particles



Lidar mapping: B932







First attempt at SEVIRI 1DVar dust
based on Francis *et al* JGR (2012)

I. Detection

II. Retrieval

$J(x) = (x-x^b)^T \mathbf{B}^{-1}(x-x^b) + (y^{ob}-y(x))^T \mathbf{R}^{-1}(y^{ob}-y(x))$

x: atmospheric state vector (P_{dust}, L, r_{dust}) ⇒ Dust {Pressure, Loading, eff. radius}

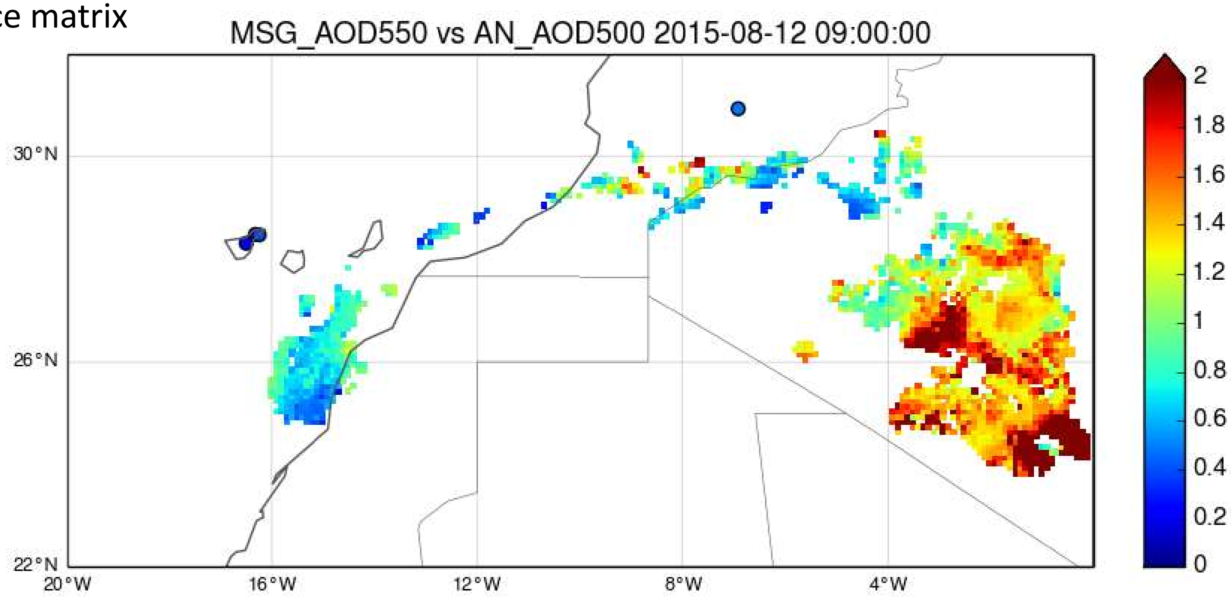
x^b: background state vector

y^{ob}: observation

B: background error covariance matrix

y(x): vector of radiances calculated from atmospheric state x

R: observation error covariance matrix



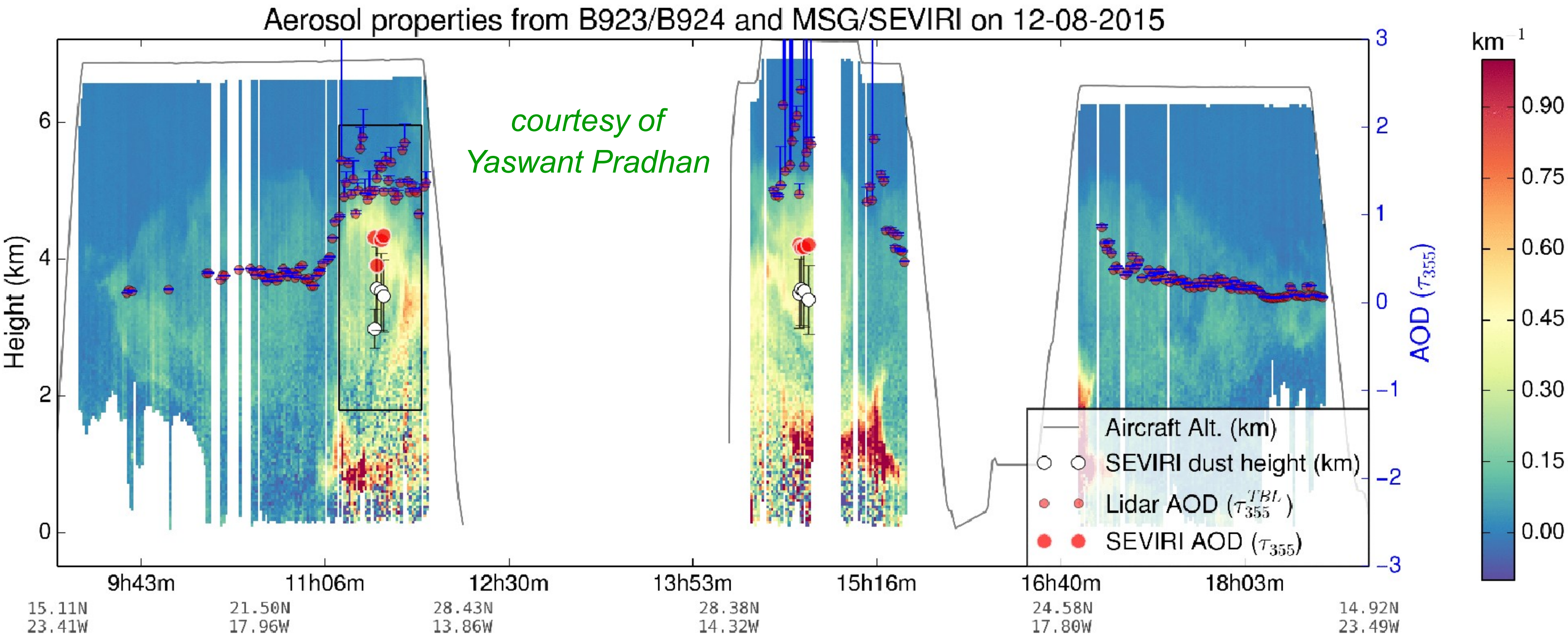
SEVIRI Channels used:

8.7, 10.8, 12 and 13.4 µm

courtesy of Yaswant Pradhan

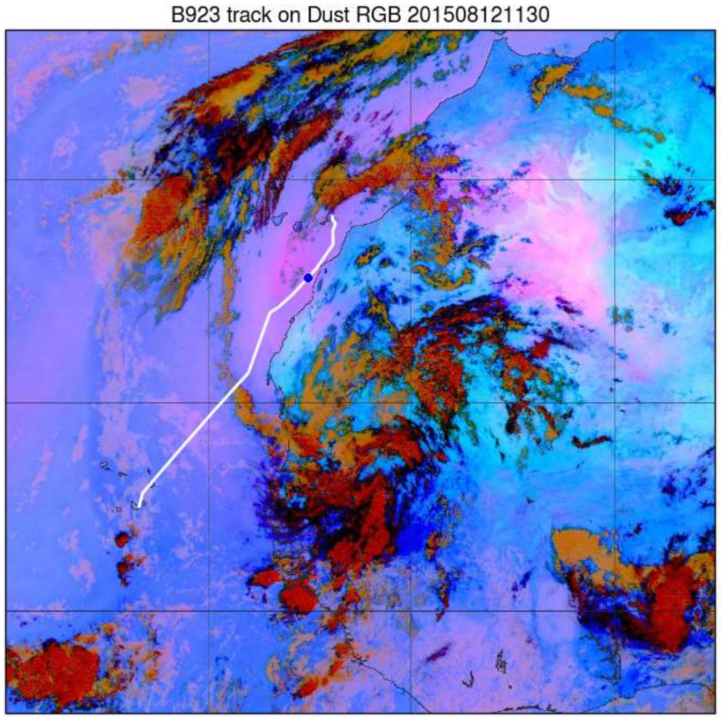
Lidar mapping and SEVIRI 1DVar

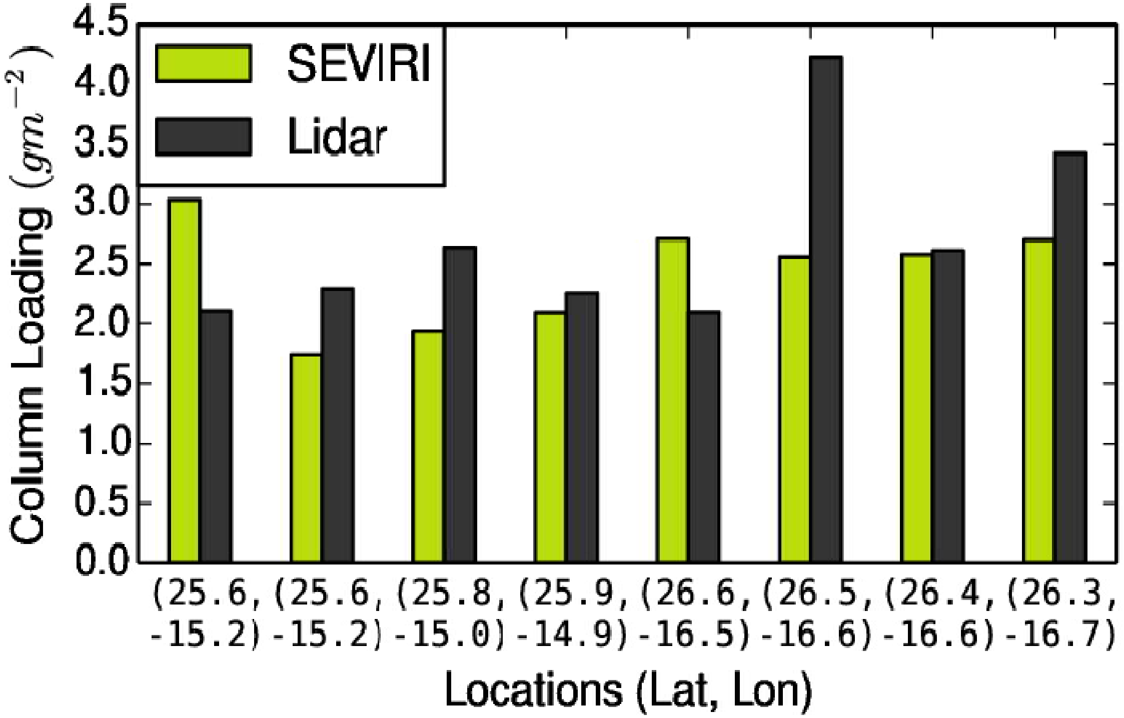
- SEVIRI 1D-Var dust product in development: yields column loading, layer height, and effective radius.
- Long term plan will be assimilation of 1D-Var in UM (currently using MODIS)



Lidar mapping and SEVIRI 1DVar

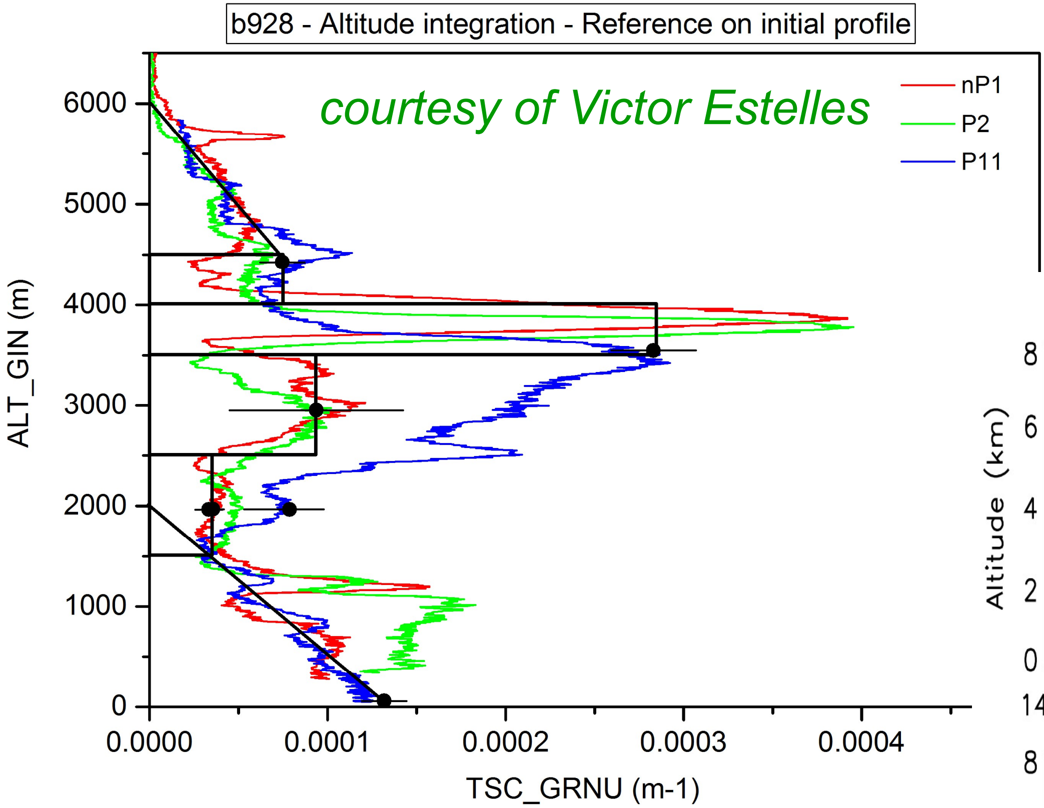
$$K_{ext} \cong 0.6\,\mathrm{m}^2/\mathrm{g}$$

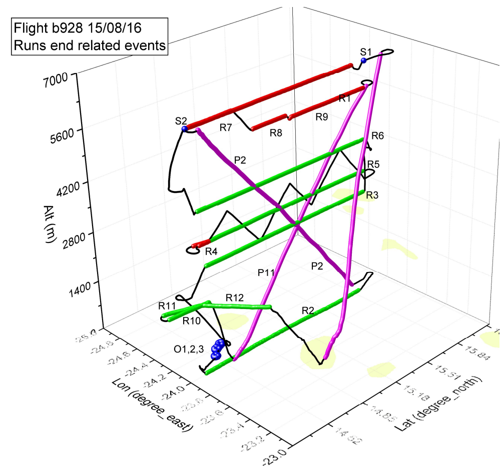


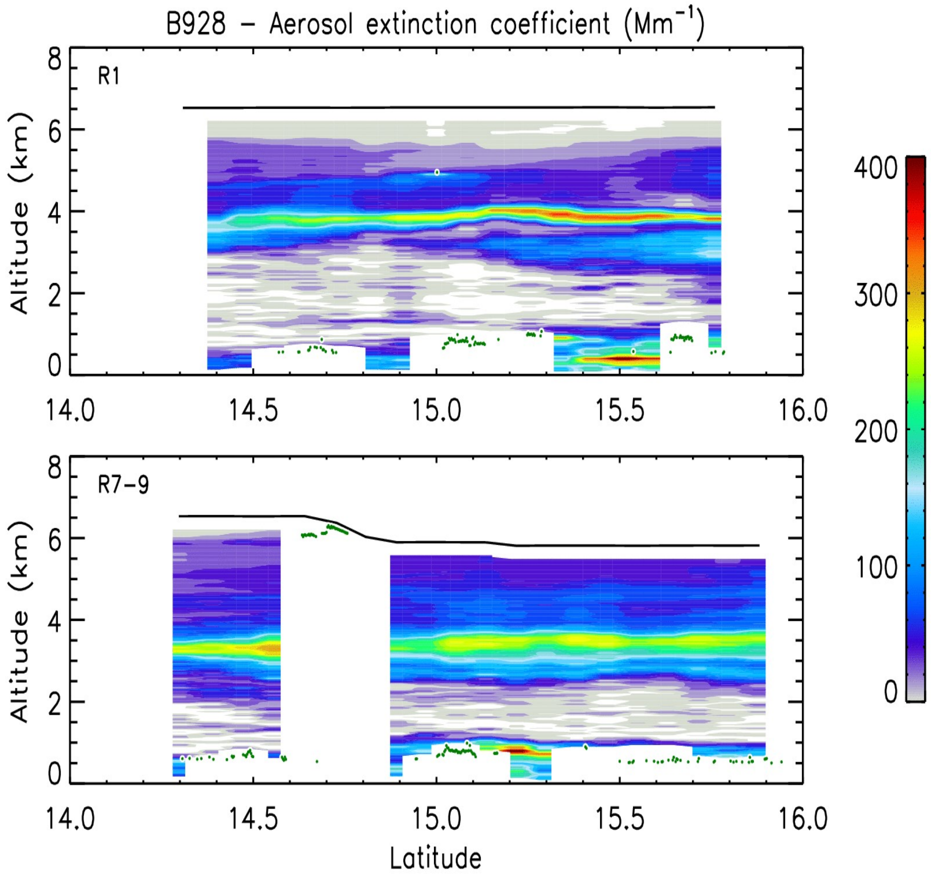


courtesy of Yaswant Pradhan

SAVEX-D

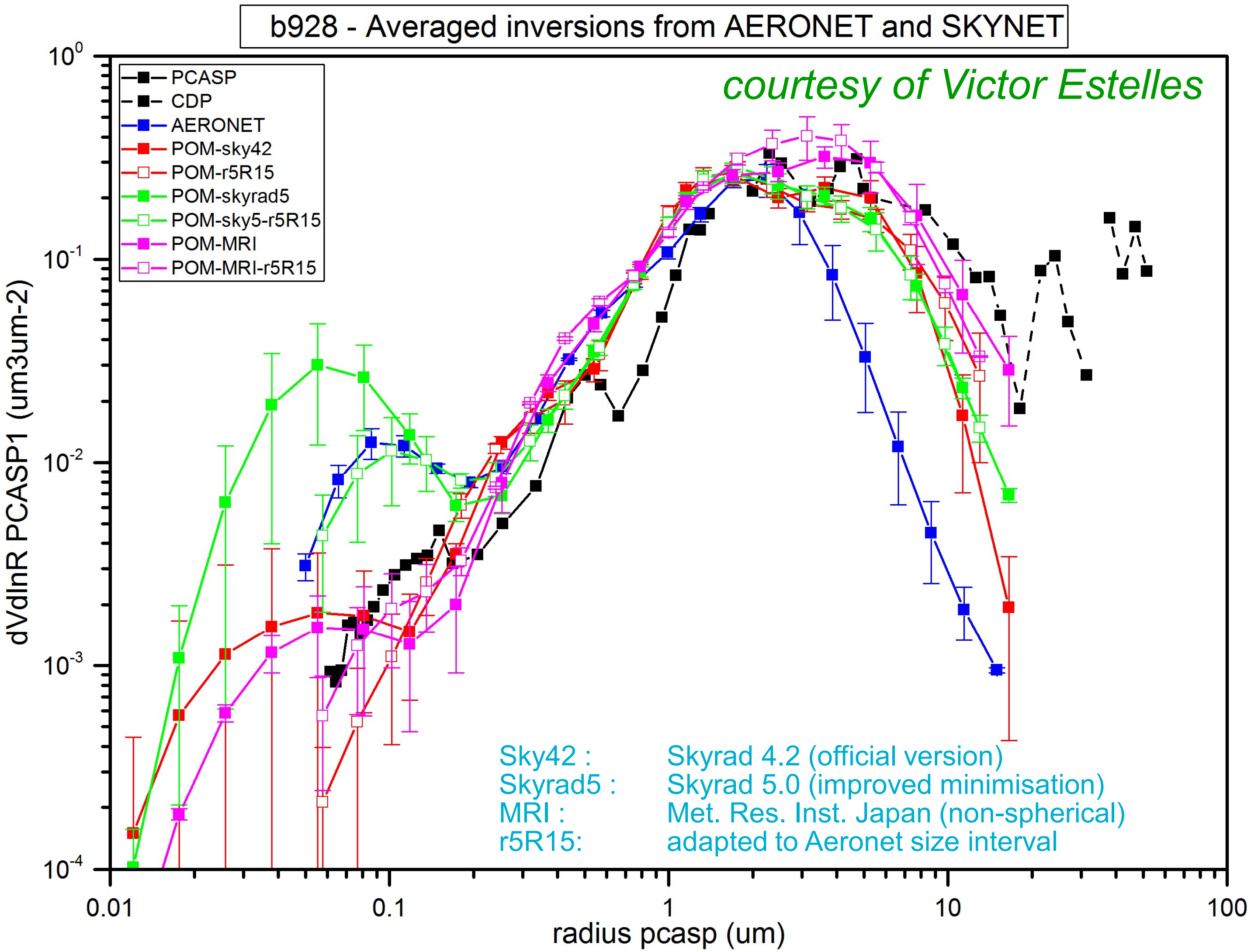

b928 - Altitude integration - Reference on initial profile
courtesy of Victor Estelles
nP1
P2
P11
ALT_GIN (m)
TSC_GRNU (m-1)
6000
5000
4000
3000
2000
1000
0
0.0000
0.0001
0.0002
0.0003
0.0004


Flight b928 15/08/16
Runs end related events
Alt (m)
Lon (degree_east)
Lat (degree_north)
S1
S2
R7
R8
R9
R6
R5
R3
P2
R4
P11
R11
R12
R10
R2
O1,2,3

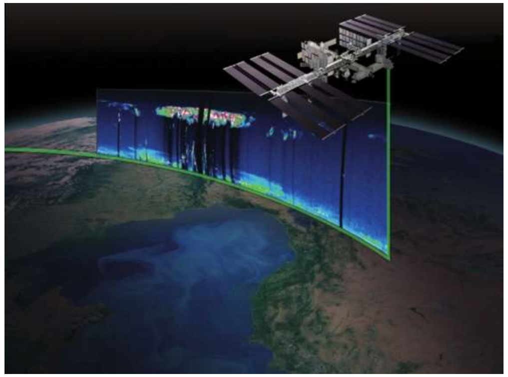

B928 - Aerosol extinction coefficient (Mm^{-1})
R1
R7-9
Altitude (km)
Latitude
14.0
14.5
15.0
15.5
16.0
400
300
200
100
0

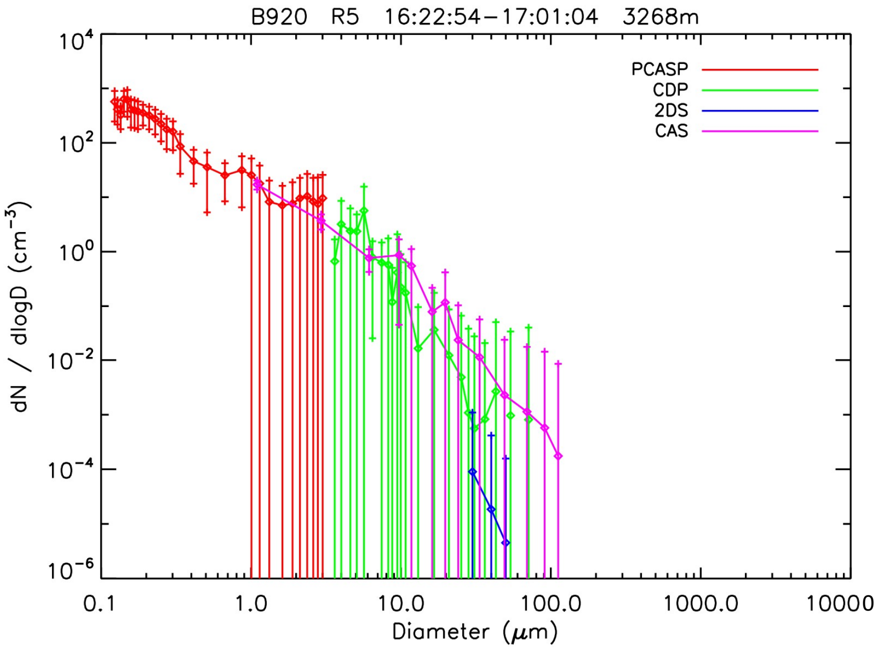
Met Office

SAVEX-D
Aircraft vs. sunphotometer PSD

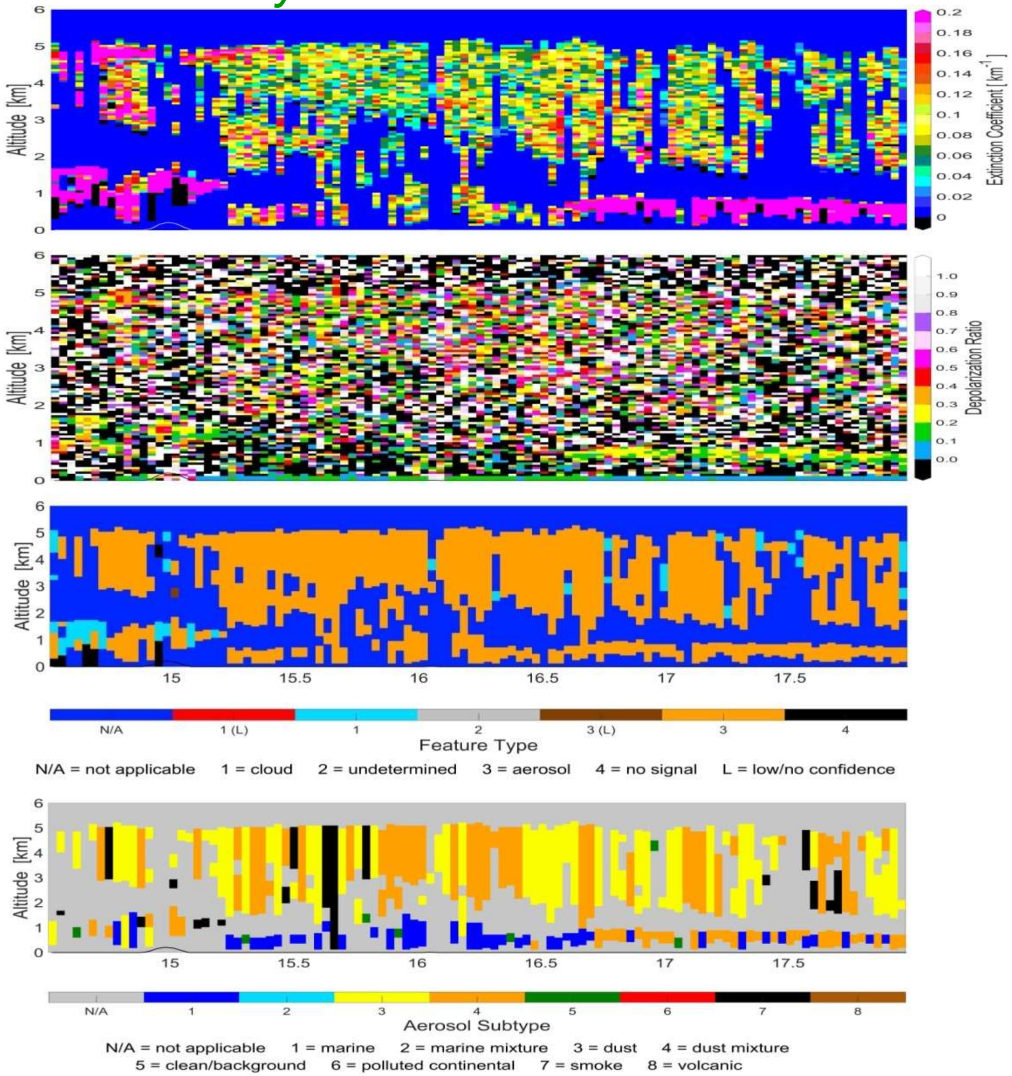


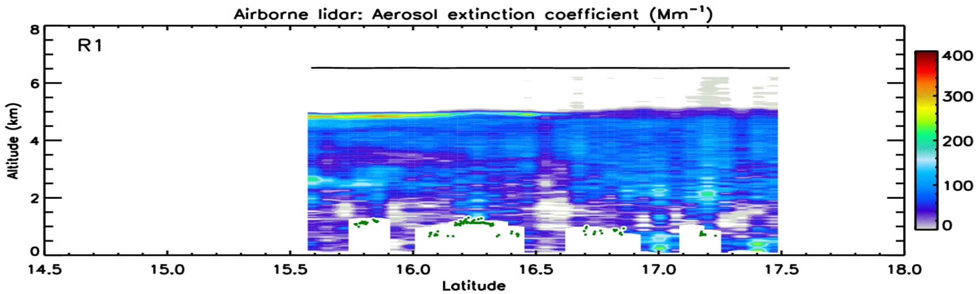
CATS underflight



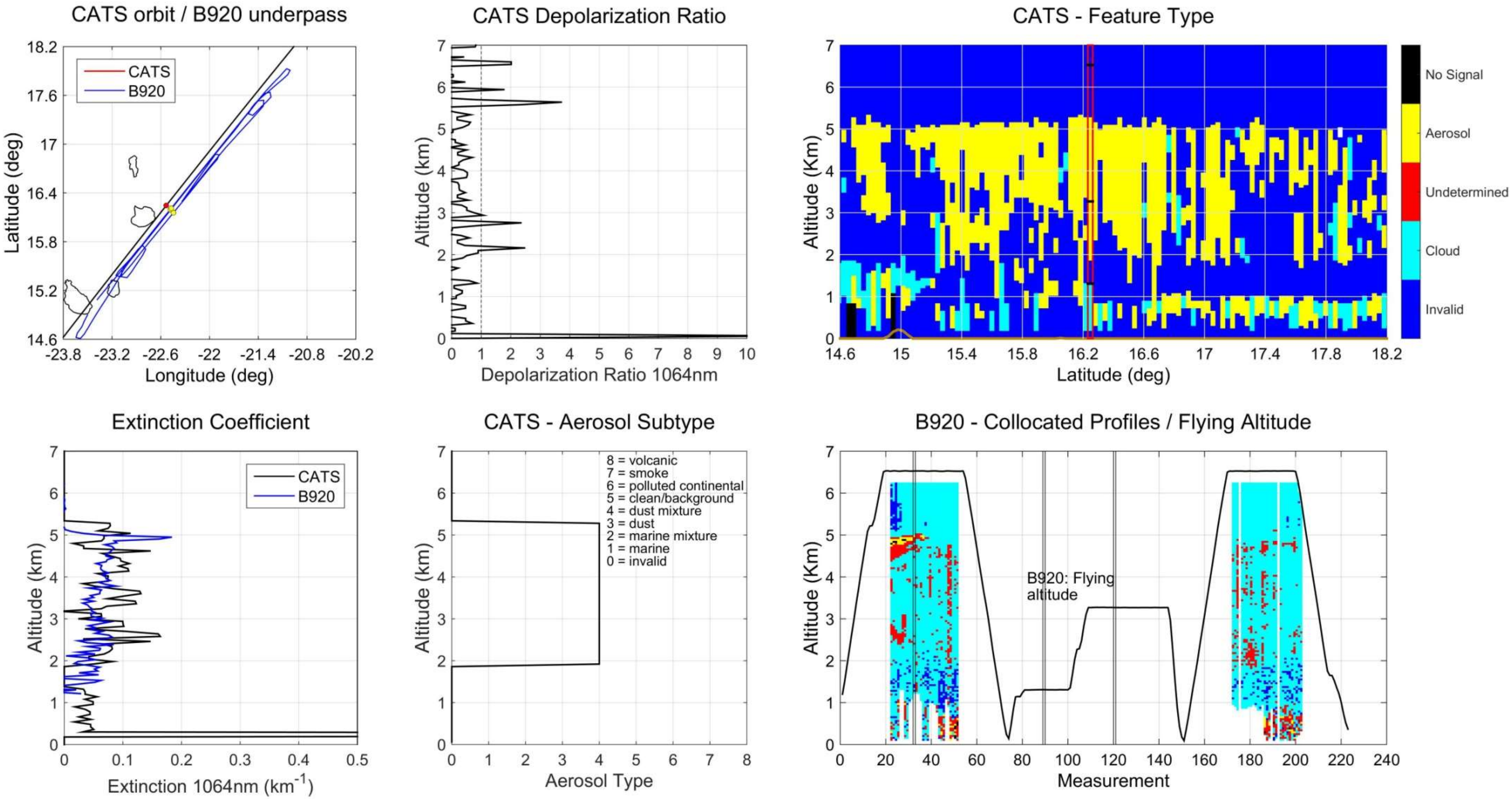


courtesy of Emmanouil Proestakis





CATS underflight



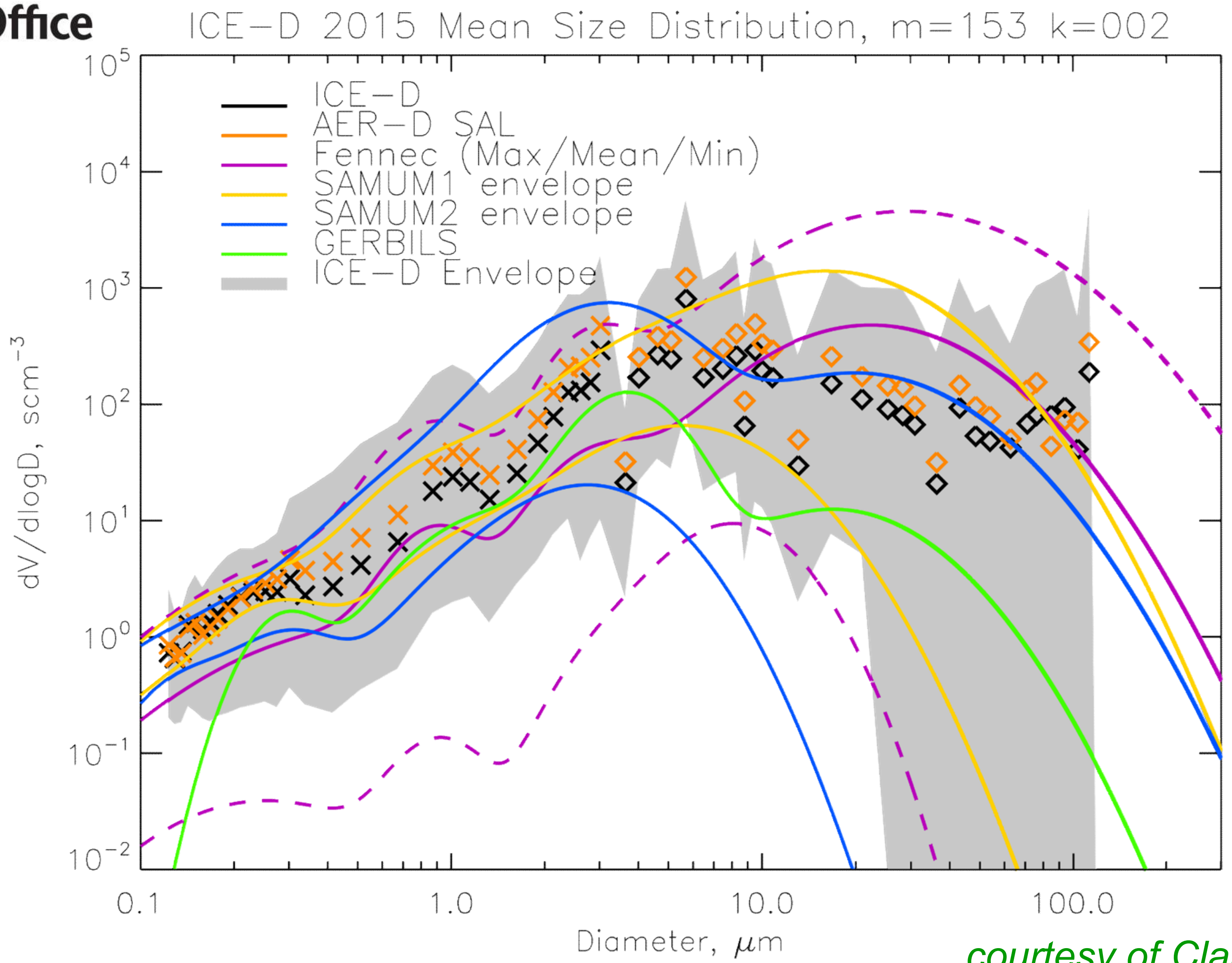
courtesy of Emmanouil Proestakis

CATS underflight plans

- First comparison of CATS and airborne lidar shows a similar pricture
- Plan is closure of dataset from in-situ and remote sensing probes, to infer aerosol properties
- Will follow the IRRA algorithm already used during ACEMED/Aegean-GAME:

http://www.atmos-meas-tech-discuss.net/amt-2016-193/

Dust particle size distribution
(ICE-D compared to other campaigns)



courtesy of Claire Ryder

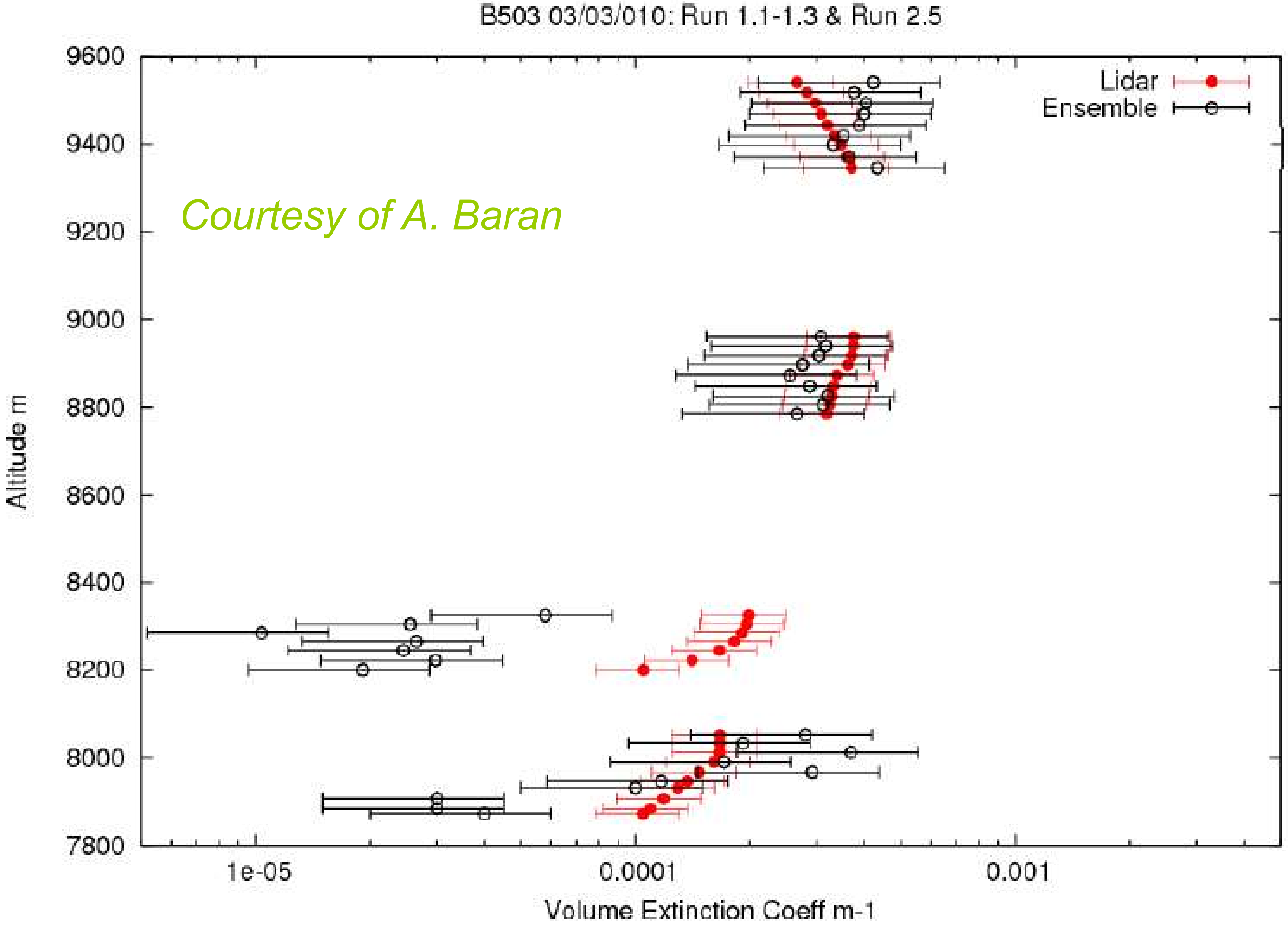
Summary

- A successful campaign
- Lidar mapping → SEVIRI 1D-VAR [SA], MODIS, UM [OBR]
- SAVEX → Sunphotometer validation [U. Valencia]
- CATS → Space lidar validation [NOA]
- UCASS dustsonde → successful [Herts]
- Aerosol characterisation + radiative closure [U. Reading]
- Additional radiative transfer studies [OBR]
- Analysis is in progress

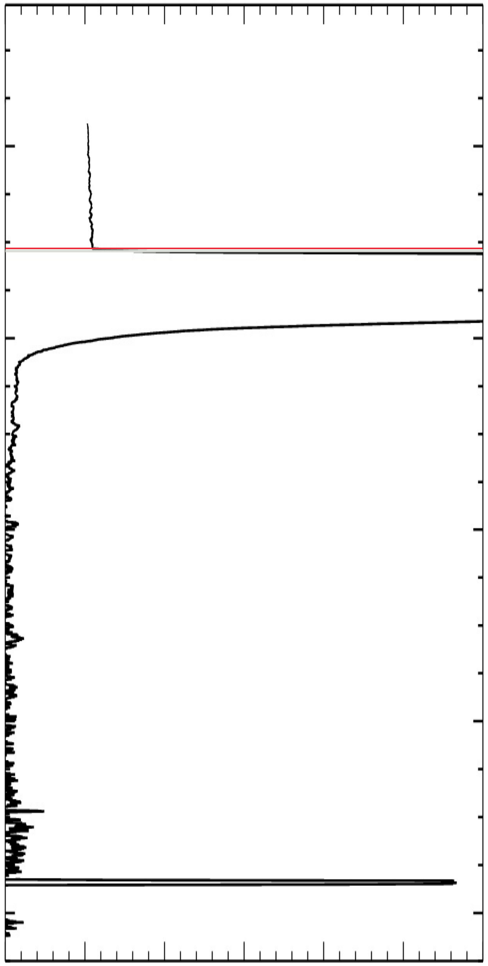
Met Office

Lidar for cloud studies

Verification of cirrus scattering model



Lidar: cloud top detection

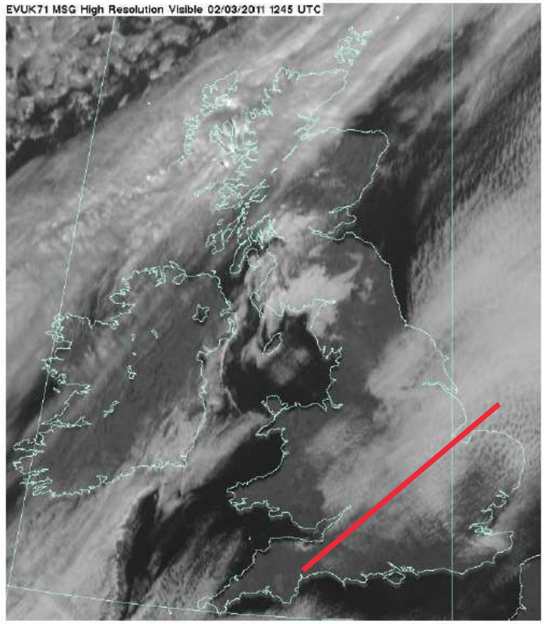


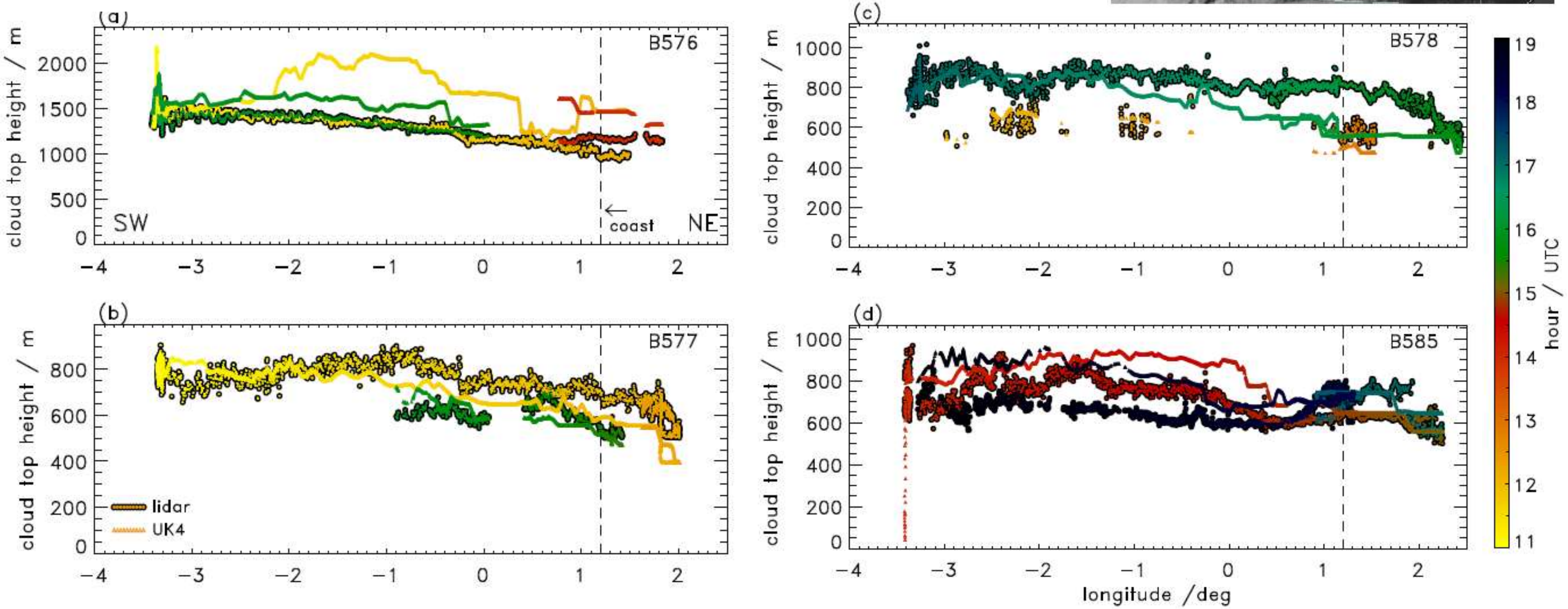
Detect intense peaks with large gradients.
Thresholds are system-dependent.

- P(R) > 4000
- P(R) > 3 × P(R - 200 m)
- no other cloud-top between R - 500 m and R

Allen *et al*, Atmospheric composition and thermodynamic retrievals from the ARIES airborne TIR-FTS system – Part 2: Validation and results from aircraft campaigns, Atmos. Meas. Tech. **7**, 4401 (2014).

Stratocumulus top height





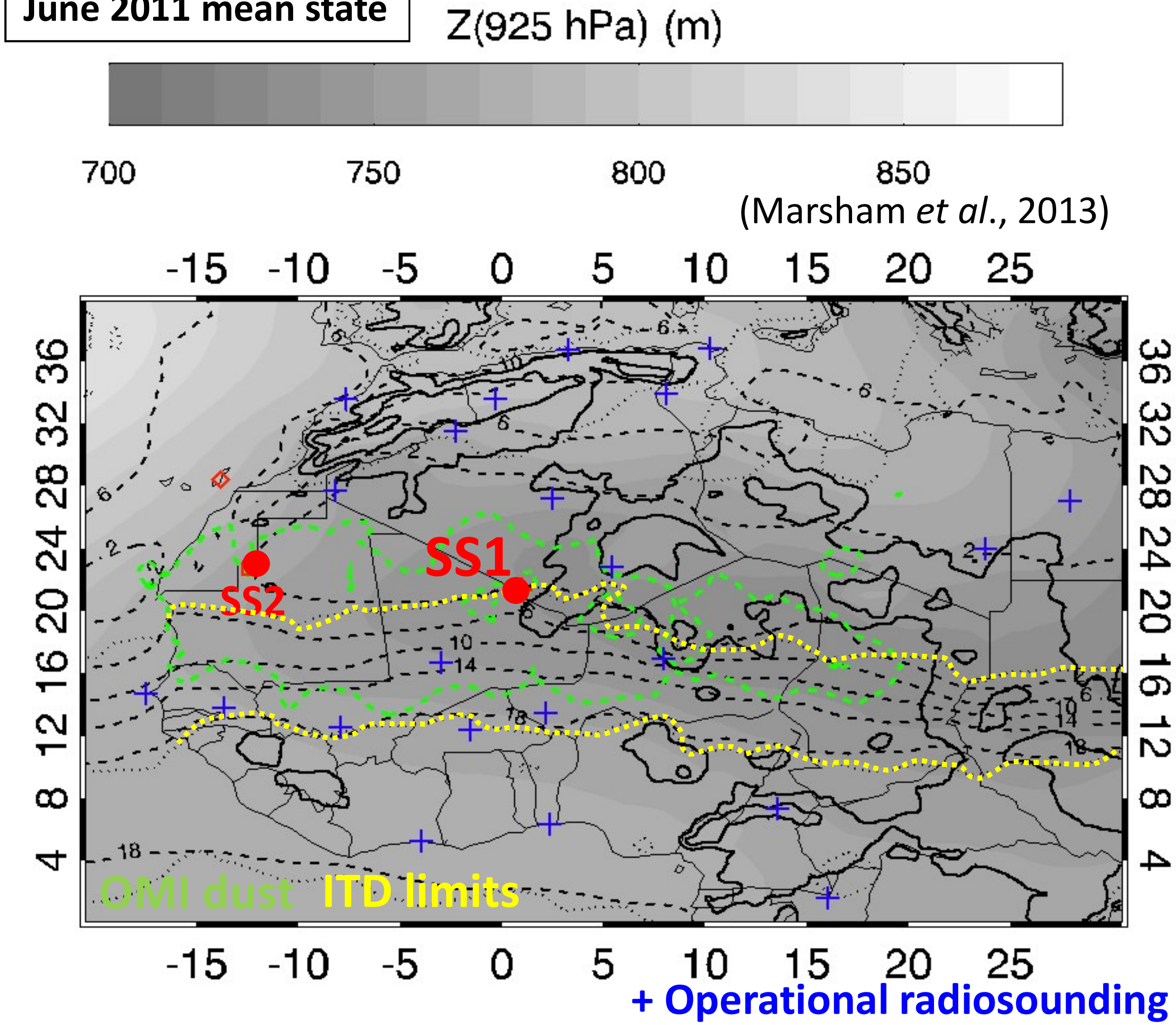
Courtesy of S. Osborne and S. Abel

Fennec (2011+2012)

The Saharan Climate System

The Fennec campaign on Saharan meteorology

June 2011 mean state



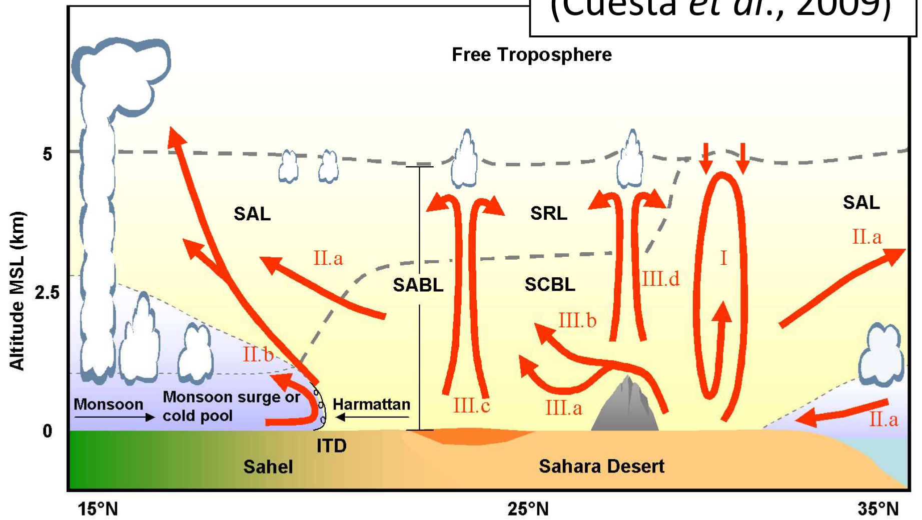
(Marsham *et al.*, 2013)

- The Saharan Heat Low (SHL) is a key driver of the West African Monsoon (Lavaysse *et al.*, 2009)
- *Fennec* provided the most comprehensive dataset for the SHL to date.
- Energy budget of SHL depends on *radiative balance* (includes *clouds*) and *ventilation.*
- Saharan dust is also an effective ice nucleus

Clouds in the Sahara – Fennec

The Sahara is surprisingly cloudy

(Cuesta *et al.*, 2009)



Boundary layer is very dry, but so deep (~5km) that clouds routinely form at its top, fed by dry dusty air.

- Small clouds above dusty desert provide a challenge for remote sensing and models.
- Fennec provides airborne surveys of cloud cover at high spatial resolution
- Evaluate models and remote sensing (e.g. METEOSAT)

Question:

"How do you identify cloud in a satellite image?"

Answer:

"I know a cloud when I see it."

How do we construct a quantifiable and robust satellite cloud product?

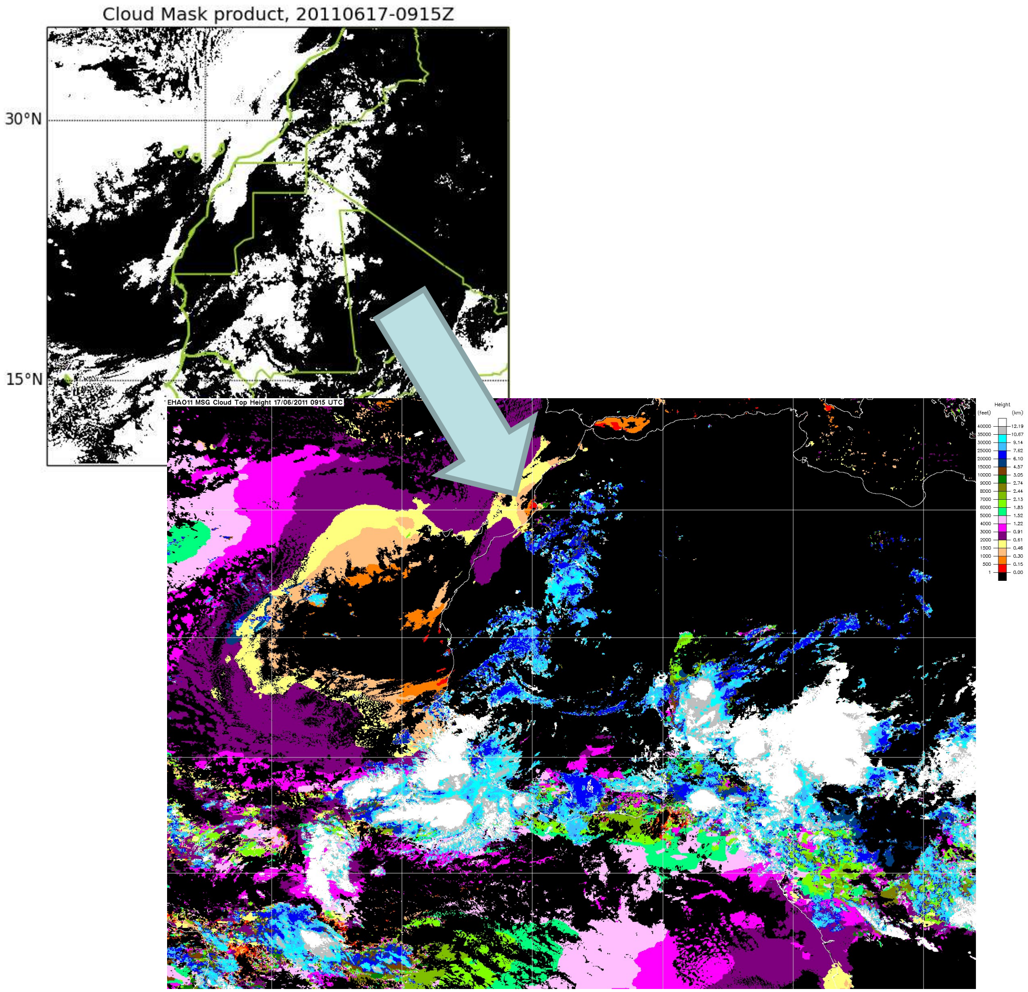
- First - Create a **cloud mask** by applying a variety of **threshold tests**
- These tests include thin cirrus, fog/low cloud, spatial coherence, gross brightness temperature (BT) differencing, mixed scenes, etc.
- Makes use of **Observed brightness temperatures**, **Reflectances**, and **Simulated clear-sky radiances**
- Most notably, the “Gross test”, accounts for ~80% of the cloudy pixels:

$$BT_{(observed\ 10.8\mu m)} << BT_{(model\ sfc\ 10.8\mu m)}$$

Met Office SEVIRI Products:
Cloud-top height

Met Office

- Part of a suite of products for obtaining cloud parameter estimates
- Uses a background UM vertical profile inputted into RTTOV, a fast radiative transfer model
- Uses the spectral wavelengths 10.8 µm, 12.0 µm and 13.4 µm
- In use operationally with SEVIRI data since 2004

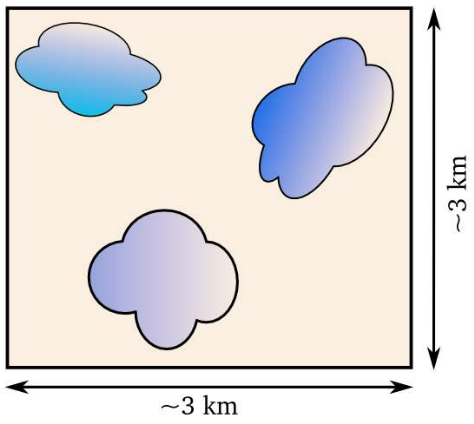


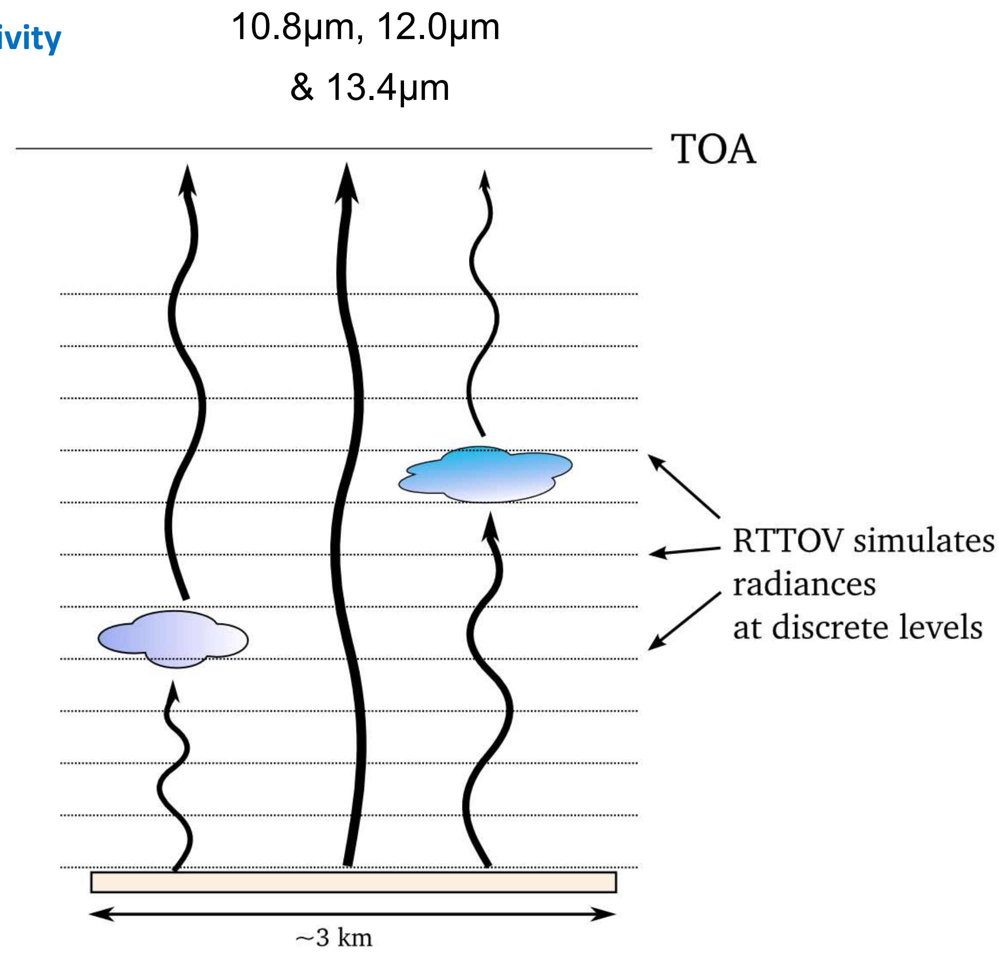
Met Office Cloud-Top Height:

The "Minimum Residual Scheme"

Effective Cloud Amount (ECA) = Cloud Fraction × Cloud Emissivity

- First of three schemes
- Sub-pixel information available
- CTH ⇔ *f*(CTP, ECA)
- Mid- to- high level cloud

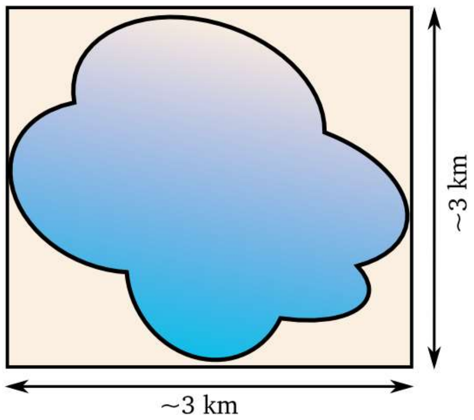


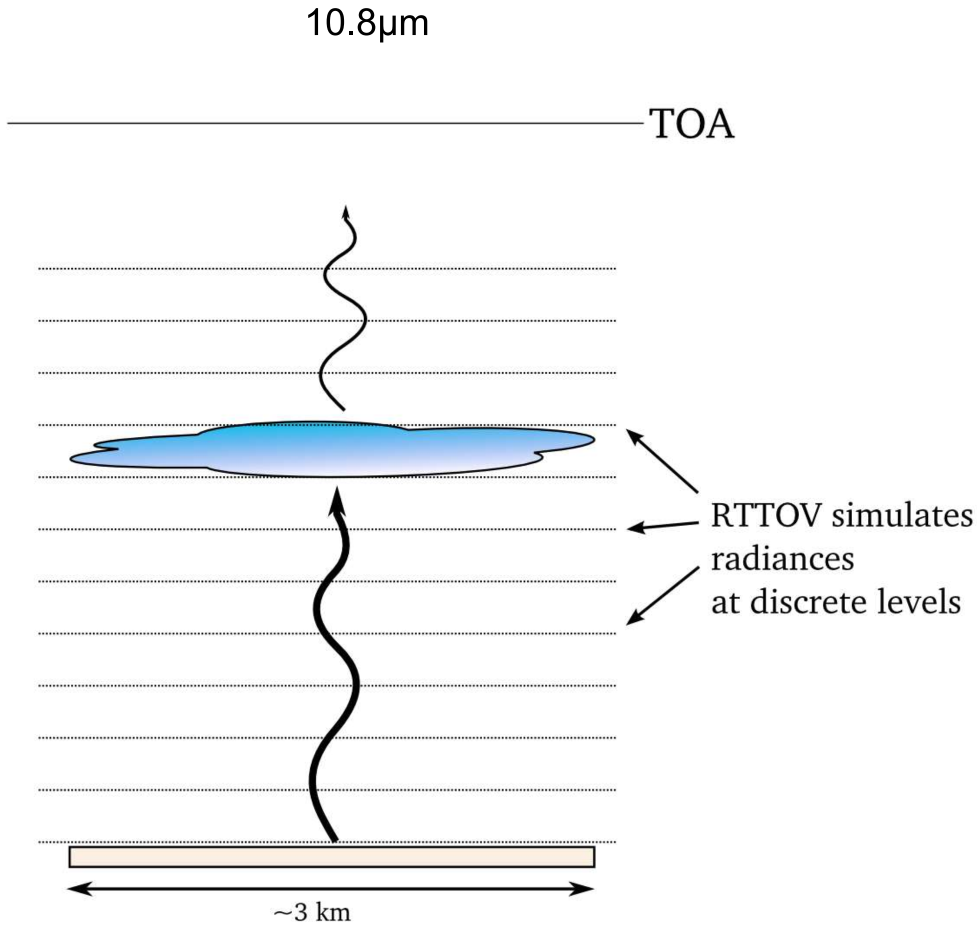


Met Office Cloud-Top Height:

The “Stable-Layers Scheme”

- Matches radiance with closest simulated radiance at 10.8μm
- Weighted to reduce solutions with clouds beneath unstable air



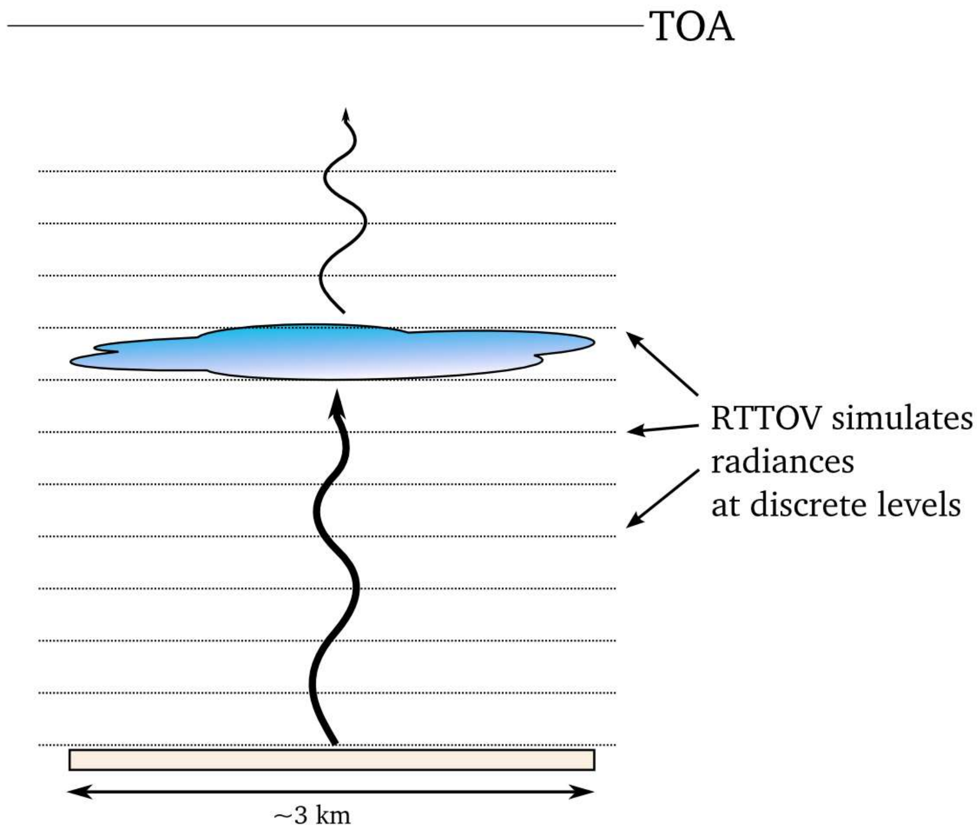


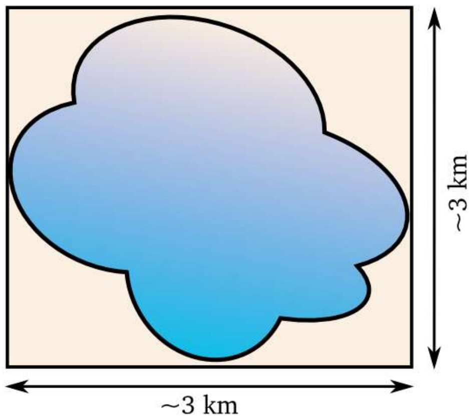
Met Office Cloud-Top Height:

The “Profile-Matching Scheme”

- Assumes fully opaque cloud layer
- Matches radiance with closest simulated radiance at 10.8μm
- Used if other two scheme fail
- Accounts for 4% of pixels globally

10.8μm

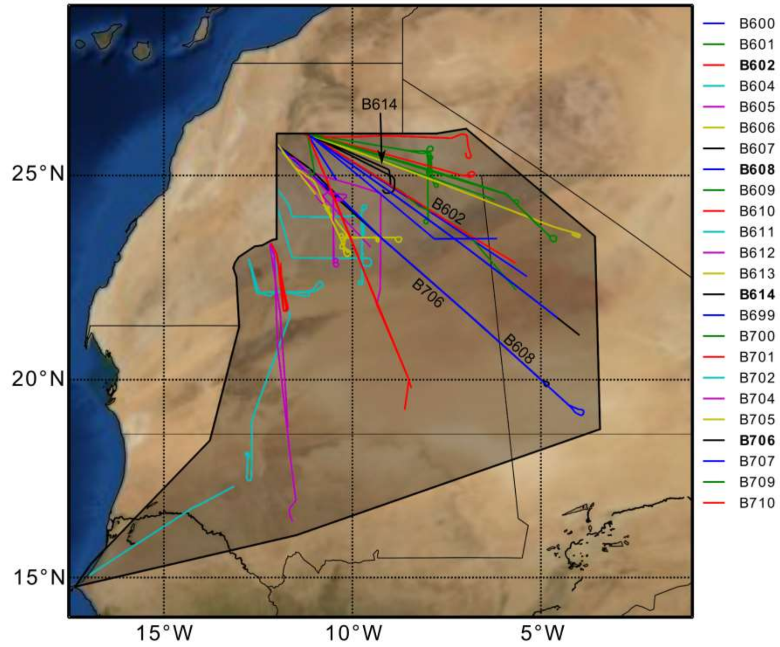




Aircraft cloud detection

Fennec

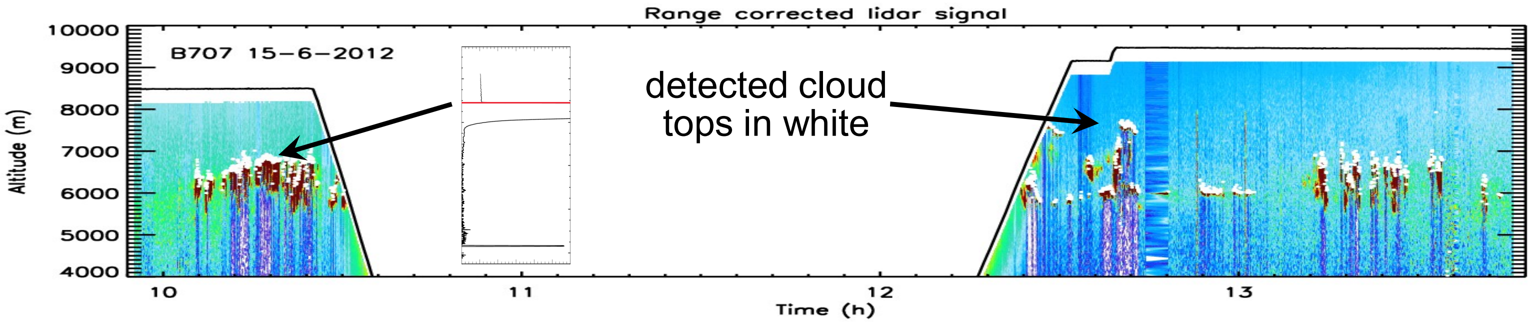
- Saharan Mauritania, Mali, Morrocco, Algeria
- 2 supersites (Zouerate, Bordj Badji Mokhtar)
- Network of remote AWS
- Deployment of 2 airborne platforms: SAFIRE F-20 and FAAM BAe146
    - June 2011 & 2012
    - 24 flights of the FAAM BAe146

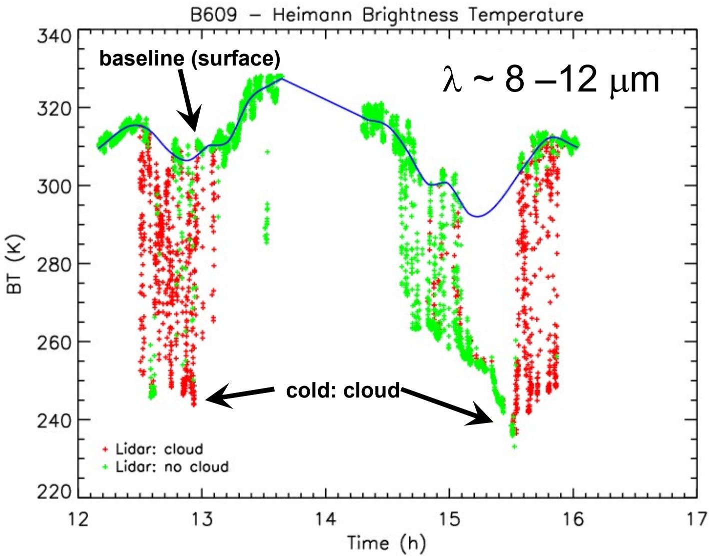


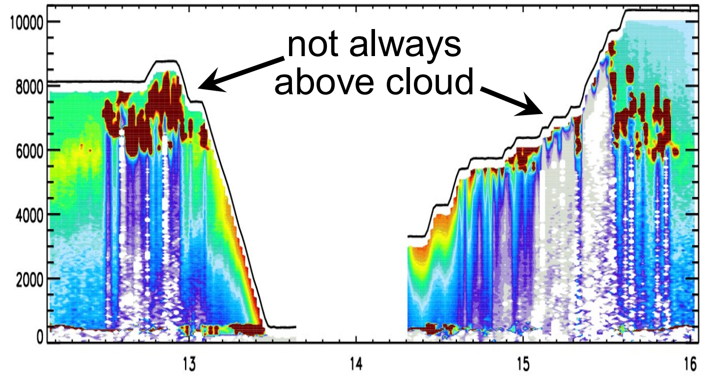
BAe146 Instrumentation

- Leosphere ALS450 backscatter Lidar → **Aircraft cloud-top height**; → **Aircraft cloud mask**
- Heimann KT19 Radiometer → **Aircraft cloud mask**
- SW Broadband Radiometer
    - → Filter for cloud above the aircraft

Lidar + Heimann: cloud detection

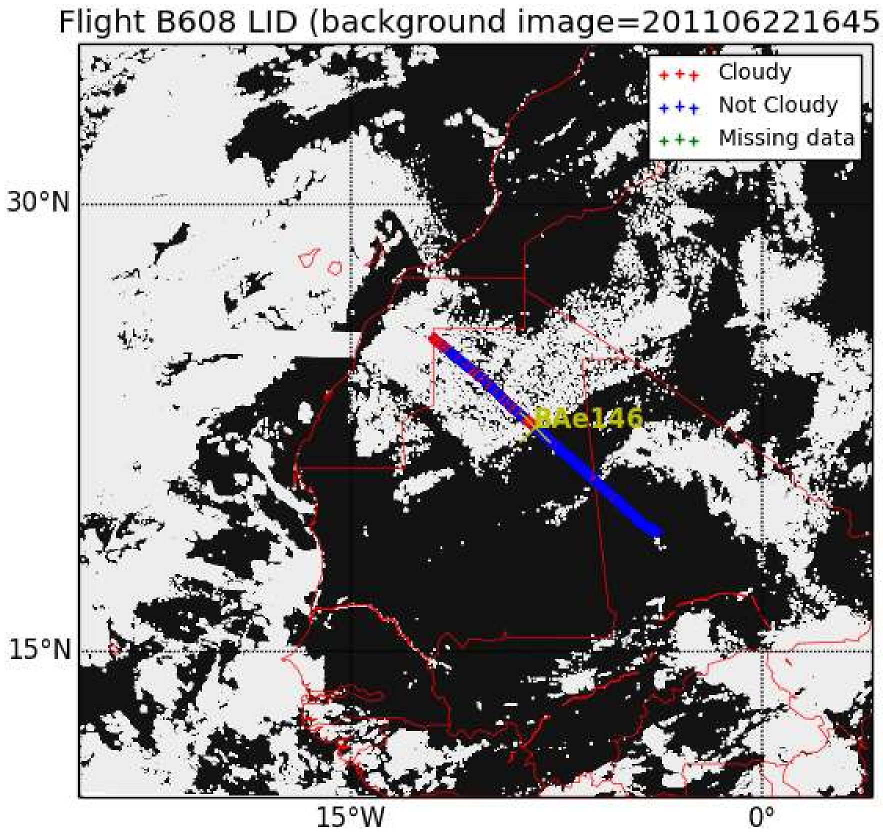


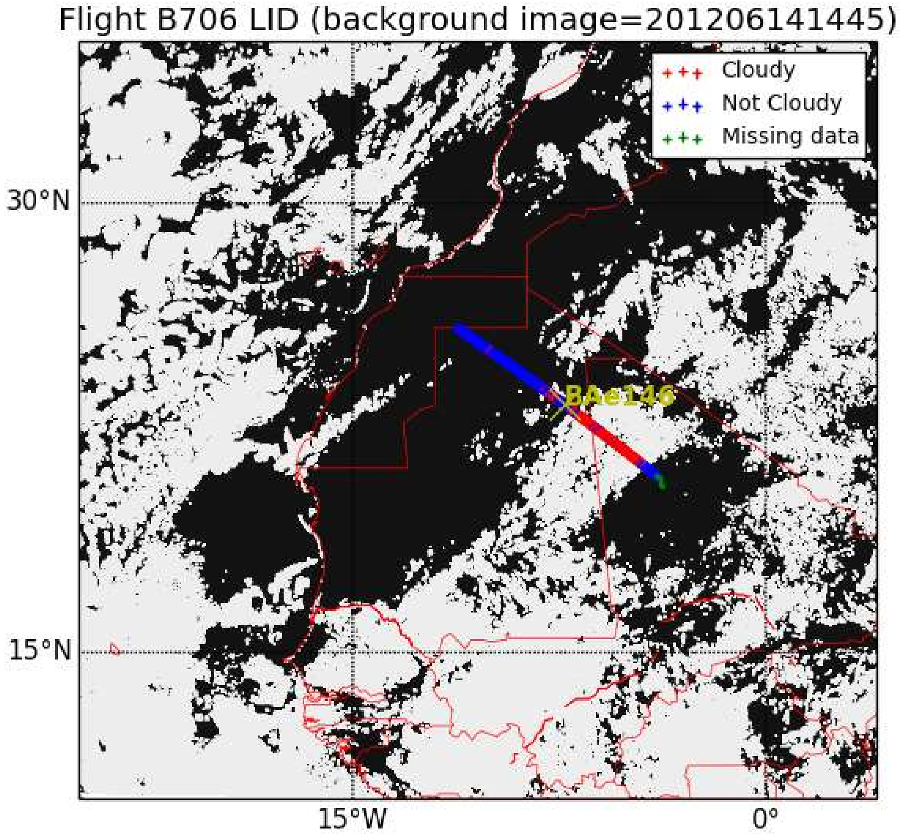




Lidar is necessary to determine the baseline to use with the Heimann

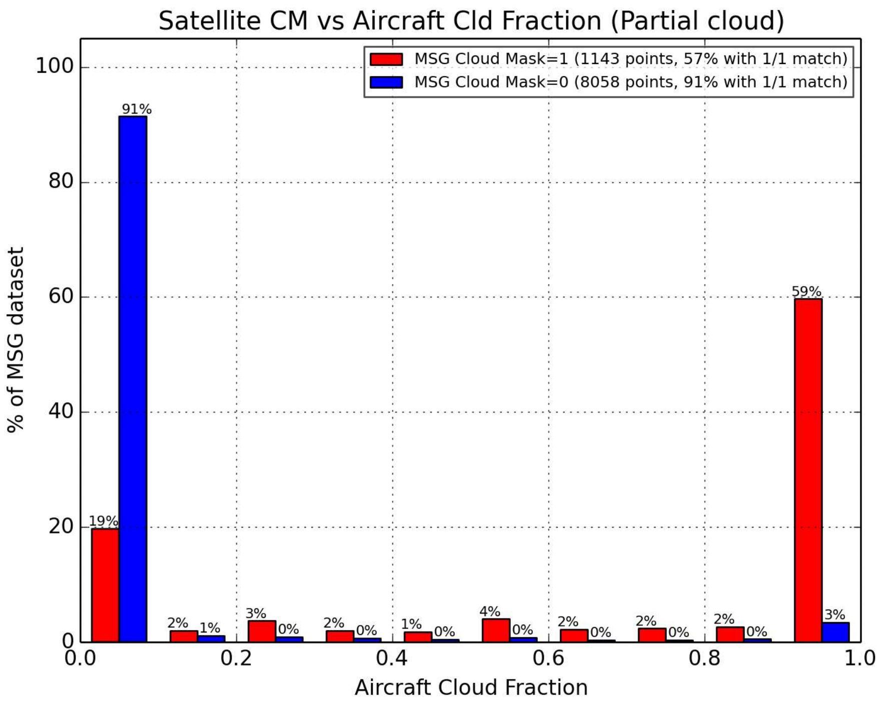
Verify SEVIRI cloud detection

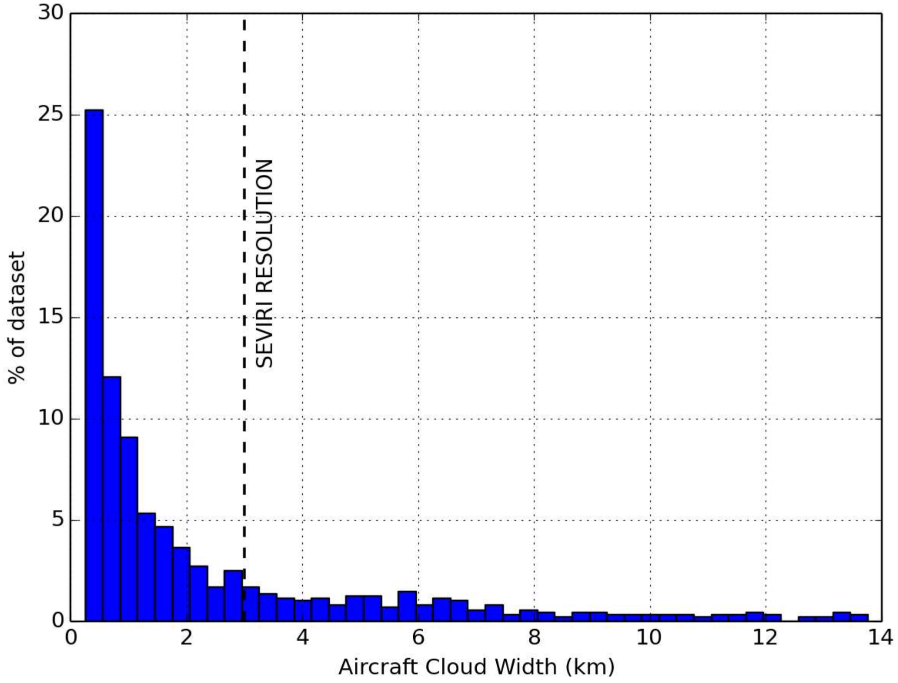




courtesy of John Kealy

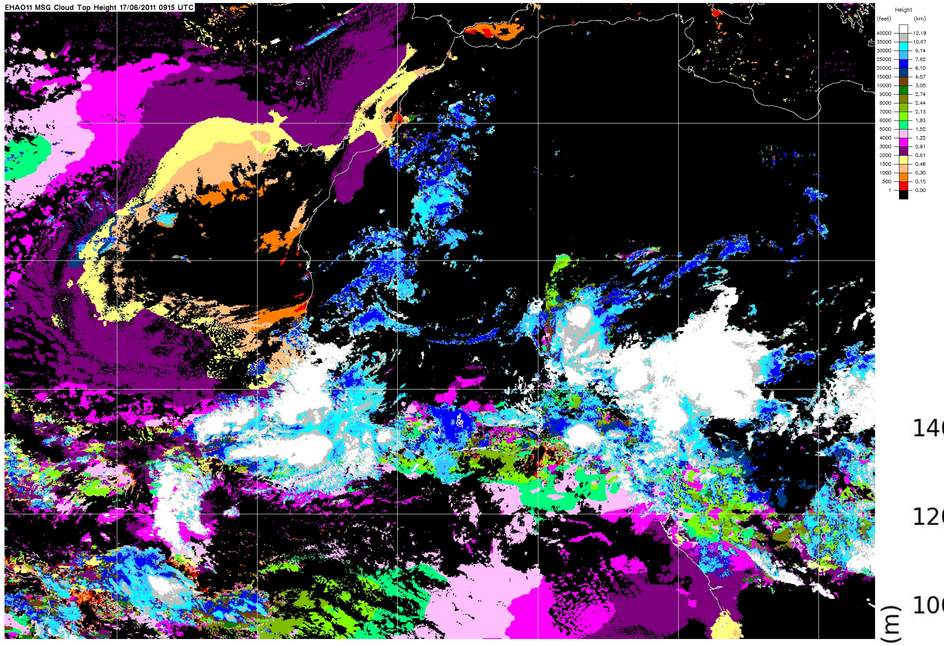
Verify SEVIRI cloud detection

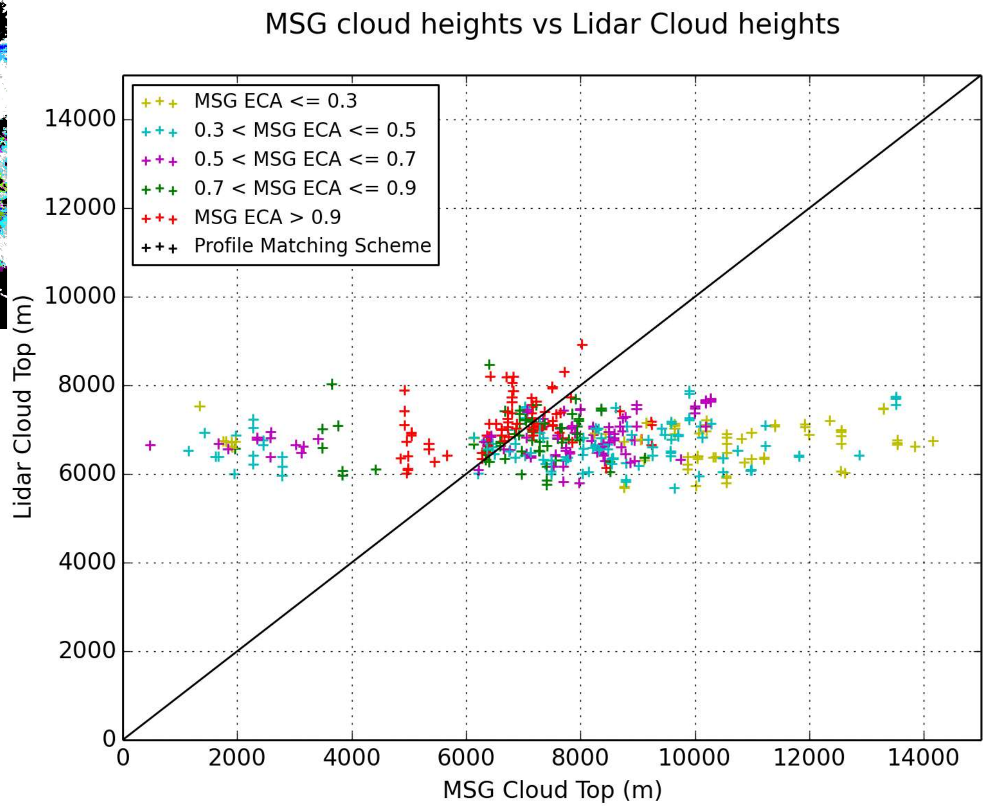




courtesy of John Kealy

Verify SEVIRI cloud top height





courtesy of John Kealy

Clouds in the Sahara: Summary

- Generally good cloud mask, with a slight overall overestimation of cloudiness in SEVIRI
- Underestimate of cloud top height found with the ‘profile matching scheme’
- Overestimates of cloud top height with the ‘minimum residual scheme’
- Estimate of cloud top height linked with estimate of effective cloud amount (ECA)

courtesy of John Kealy

Meteorological Research Flight

- Has a long history (70 years) and is admired internationally
- Major asset to the Met Office and the UK academic community
- Provides independent observations of atmospheric fields
- Permits to complement observations from several instruments
- Provides insight useful for modelling, remote sensing, and processes/parametrizations

BAe-146 airborne lidar

- A short but successful history (6 years)
- Very useful in the handling of the volcanic ash emergency
- Aerosol quantitative 2-D mapping: permits the verification and validation of modelling and satellite application products
- Has been useful in the characterization of cloud processes
- Volcanic ash: has had a direct impact on MO products
- Other campaigns (spec. SAMBBA): potential for a similar impact

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Questions?