Micro Pulse Lidar -
Measuring Atmospheric Aerosols

By Justin Fisher
Vice President Atmospheric Lidar Research,
Droplet Measurement Technologies, LLC

Monday 24th, May 2021

Hosted by Tesscorn Aerofluid, Inc.

Private and confidential, for intended recipient only


WHY?

Case I - Using Micro Pulse LiDAR to study the effects of lockdowns imposed by the COVID-19 pandemic on vertically resolved aerosol profiles

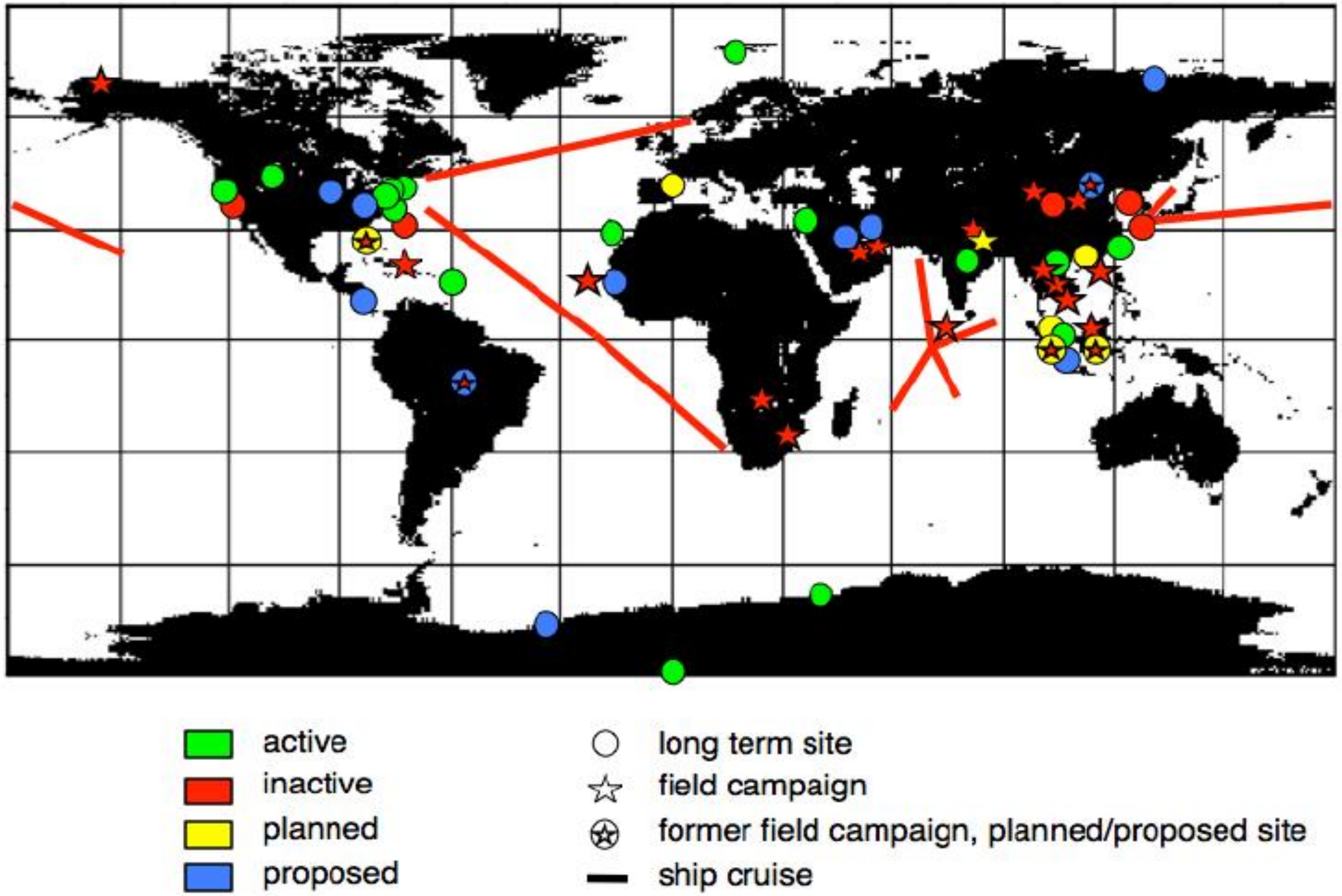
Simone Lolli[1,5], E. J. Welton[2], J.R. Campbell[3], J.R. Lewis[4,2], S. A. Stewart[5] and L. Belcher[5]

1CNR-IMAA, Istituto di Metodologie per l'Analisi Ambientale, Tito Scalo, Italy
2NASA Goddard Space Flight Center, Code 612, Greenbelt, MD 20771, USA
3 Naval Research Laboratory, Monterey, CA 93944, USA
4UMBC-JCET, 1000 Hilltop Road, Baltimore, MD 21244, USA
5 SSAI-NASA Goddard Space Flight Center, Greenbelt, MD, USA

The Micro Pulse Lidar Network (MPLNET): Status of Network

Major focus on SE Asia the past few years. Aircraft have fled the region, but ground pounders still there.
New focus for coming years: Southern Hemisphere (S America and Africa)

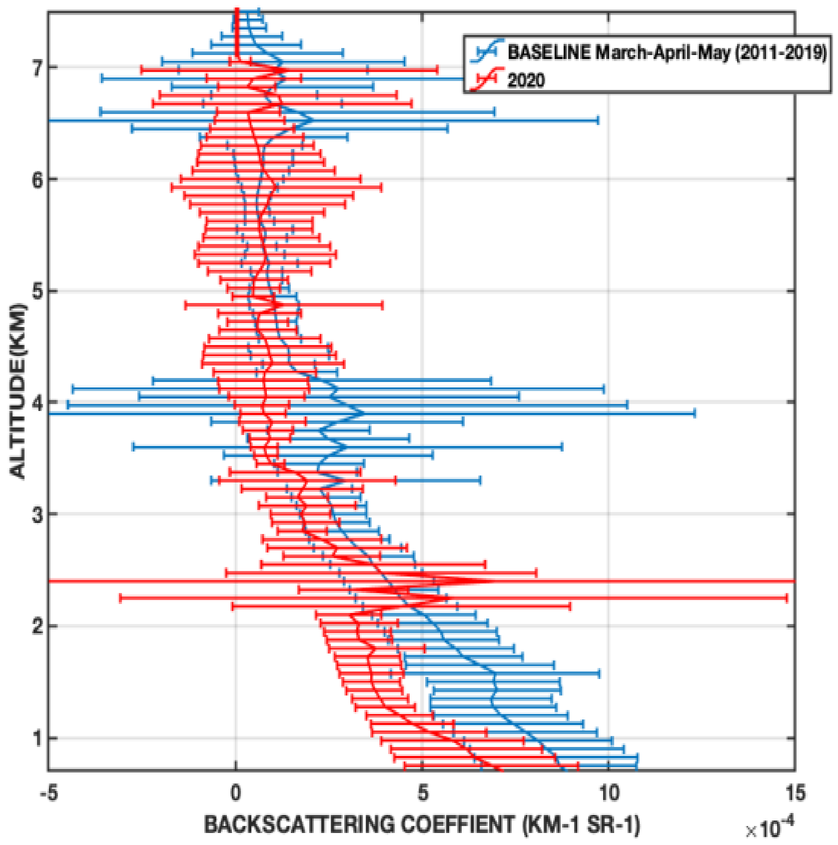
MPLNET Sites: 2000 - current



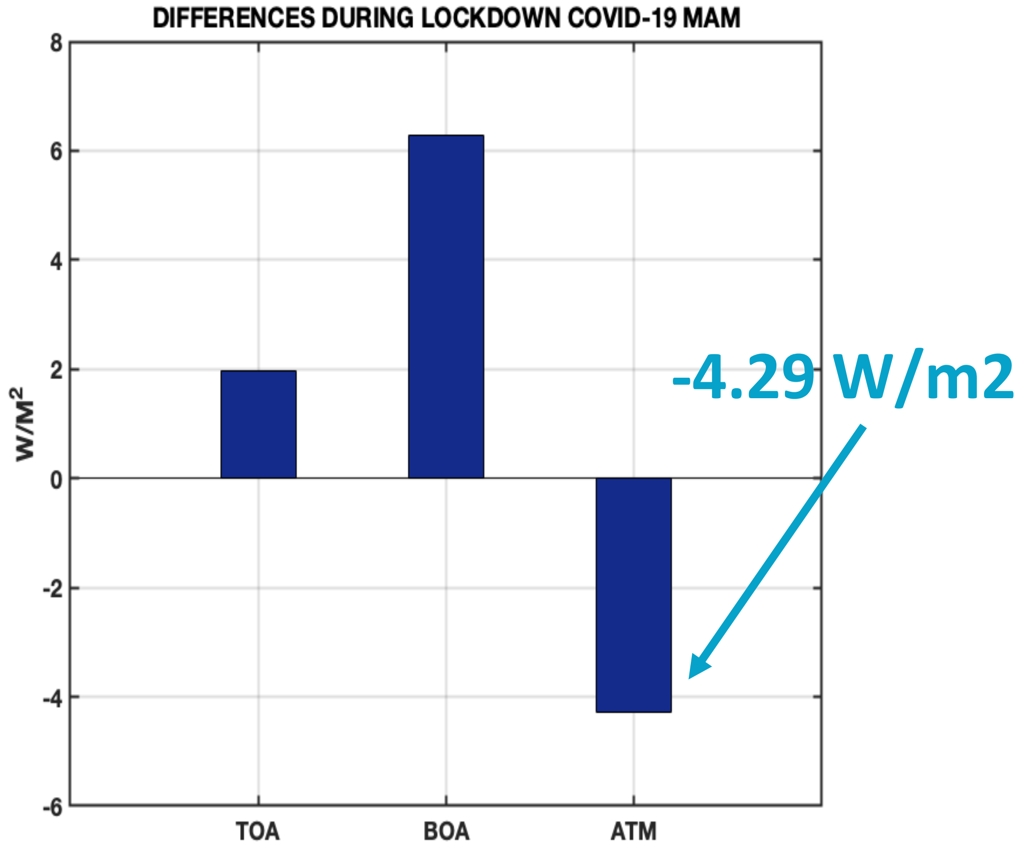
Covid restrictions in Singapore were much stricter than in the USA

- Researchers set out to see if these differences in policy had a measurable affect
- Changes from 9yr baselines were compared at two sites
- Extinction was input into the Fu-Liou-Guo radiative transfer model

Site 1: NASA GSFC (USA) - The aerosol burden decreased almost all over the atmospheric load

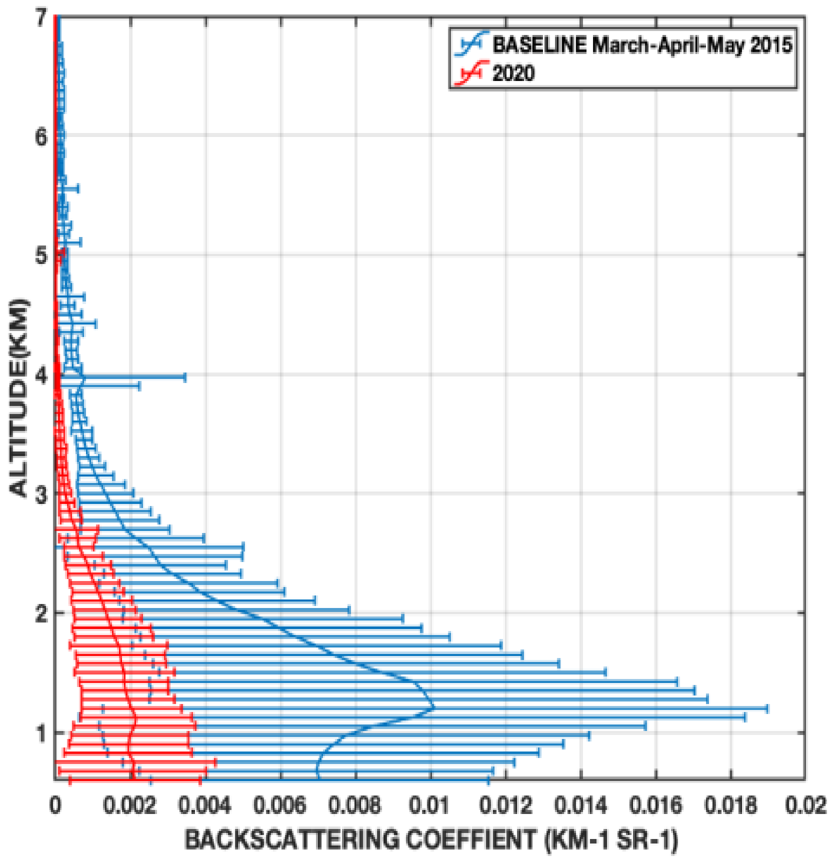


Averaged backscatter profiles for March-May 2020 (Red) against March-May 2011-2019 (Blue)



LOCKDOWN DECREASED INCOMING SOLAR RADIATION AT
SURFACE AND OUTGOING SOLAR RADIATION AT TOA

Site 2: NUS Campus – **Much larger aerosol burden decrease**



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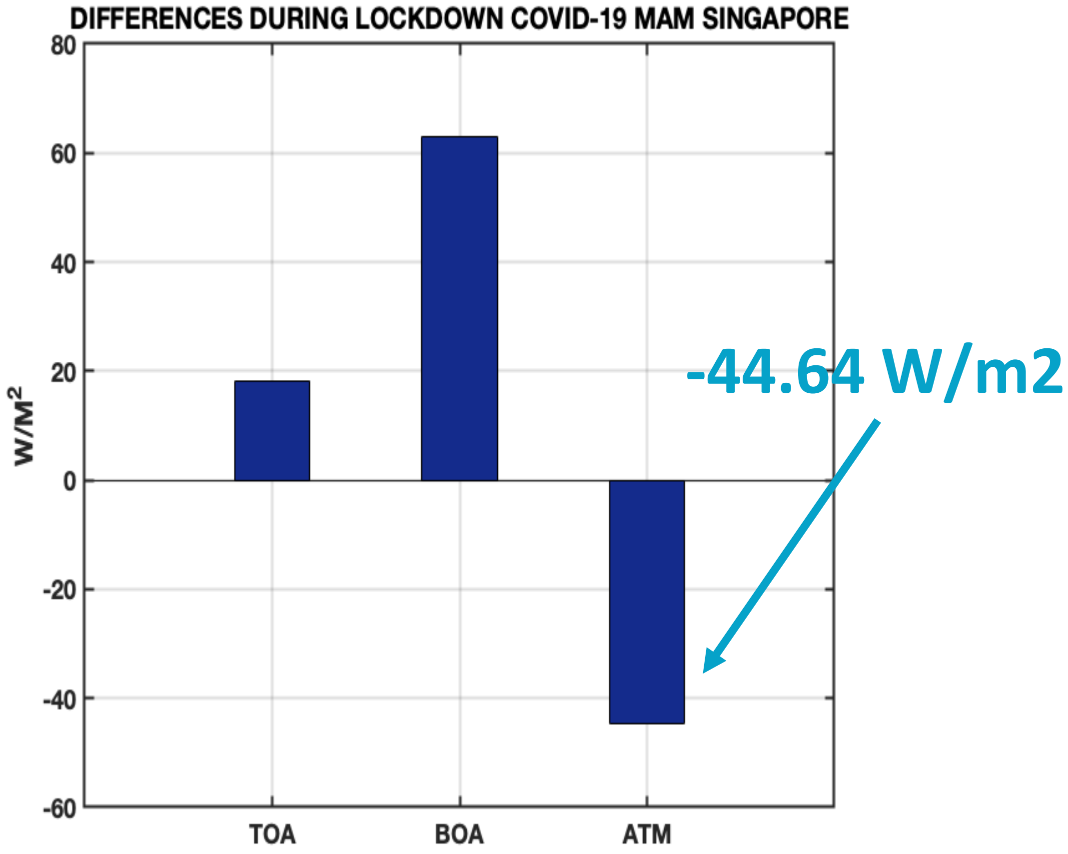


LOCKDOWN DECREASED INCOMING SOLAR RADIATION AT SURFACE AND OUTGOING SOLAR RADIATION AT TOA

MPL's customer base

100's installed worldwide **1000's of publications**

JPL
Jet Propulsion Laboratory
California Institute of Technology

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

INTA

United States Environmental Protection Agency

Teck

China University of Mining & Technology 1909

HARVARD UNIVERSITY
VE RI TAS

ARM
CLIMATE RESEARCH FACILITY

Office of Naval Research
USN ONR
Science & Technology

National Oceanic and Atmospheric Administration
NOAA
U.S. Department of Commerce

METEO FRANCE

UPC

APL
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

AEMet
Agencia Estatal de Meteorología

CALIFORNIA
AIR RESOURCES BOARD

NASA

POSTERA CRESCAM LAUDE
THE UNIVERSITY OF MELBOURNE

MPL's customer base

100's installed worldwide **1000's of publications**

<u>Only</u> Lidar simultaneously approved by

NASA
MPLNET global network

US Dept. Energy
Atmospheric Radiation Measurement program

EUMETNET
European meteorological services network

https://mplnet.gsfc.nasa.gov/

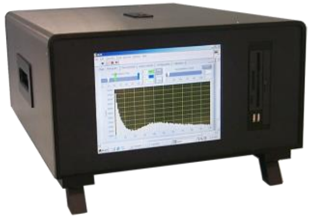
https://www.arm.gov/capabilities/instruments/mpl

https://www.eumetnet.eu/

Micro Pulse Lidar in the Droplet aerosol portfolio

MPL
Micro Pulse Lidar
with Depolarization

MiniMPL
Mini Micro Pulse Lidar
with Depolarization



UHSAS-G
(60 nm – 1 µm)
Ultra-High Sensitivity
Aerosol Spectrometer

WIBS-5/NEO
(0.5 - 30 µm)
Wideband Integrated
Bioaerosol Sensor

Aerosols

Bioaerosols

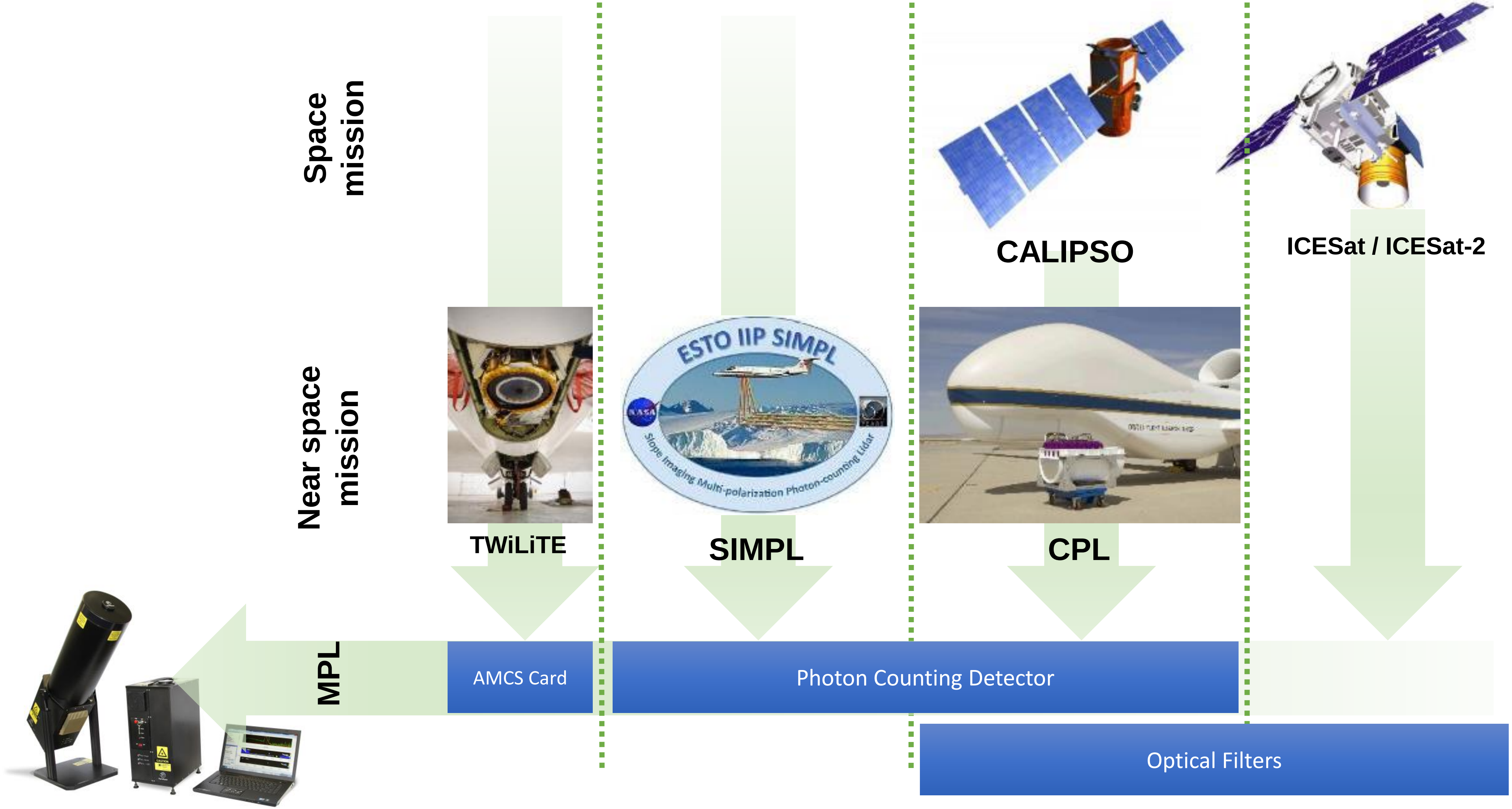
PAX
(< 1 Mm^{-1} – 10,000 Mm^{-1} (870 nm,
60 sec. averaging)
Photoacoustic Extinctiometer

SP2
(200 – 430 nm)
Single Particle Soot
Photometer

SP2-XR
(50 - 800 nm)
Single Particle Soot
Photometer – Extended Range

Black carbon aerosols

Micro Pulse Lidar systems have NASA DNA



DROPLET MEASUREMENT TECHNOLOGIES

Micro Pulse Lidar products

MPL

- Aerosols and clouds up to 25km w/depolarization standard
- 28kg
- Best SNR in class
- MPLNET ready
- < 250 W needed

MiniMPL

- Aerosols and clouds up to 15km w/depolarization standard
- 12kg
- Available with 3D scanning
- Ultra stable opto-mechanically
- < 100 W needed

DROPLET MEASUREMENT TECHNOLOGIES

Micro Pulse Lidar products

- <u>MPLNET Ready:</u> Only lidar compatible with Global NASA MPLNET. The MPL is the gold standard by which all other units are calibrated
- <u>Extreme sensitivity:</u> Reach to the stratosphere (at night), with excellent SNR giving 25km range, per 30 second profile
- <u>Easily integrated software:</u> Software is designed to allow 3rd party integrators easy access to integrate the LiDAR data into their solutions

Aerosols and clouds up to 25km w/depolarization standard

28kg

Best SNR in class

MPLNET ready

< 250 W needed

MPL

DROPLET MEASUREMENT TECHNOLOGIES

Micro Pulse Lidar products

Aerosols and clouds up to 15km w/depolarization standard

12kg

Available with 3D scanning

Ultra stable opto-mechanically

< 100 W needed

MiniMPL

- Low SWAP: Uses less than 100W of power, individual unit weighs less than 13 kg
- Efficient photon management: Low µJ laser and ultra efficient detectors mean it uses air cooled lasers and allows for great mechanical stability
- Mechanically stable: Low power, stable lasers and rigid optics, with vibration isolation, make the MiniMPL extremely flight tolerant with no loss of alignment
- Easily integrated software: Software is designed to allow 3rd party integrators easy access to integrate the LiDAR data into their solutions

Versatile deployment in a range of conditions

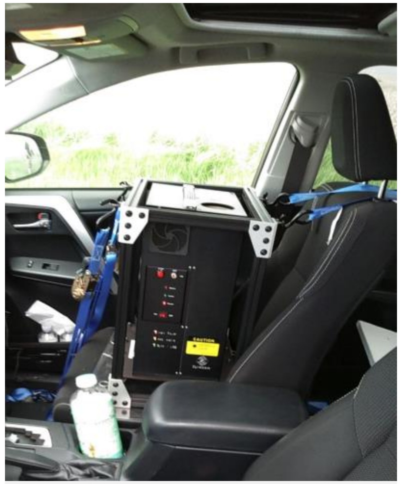
Institute of Urban Meteorology, Beijing, China

Pan/Tilt Tripod installation

Everest Base Camp, Himalayas, China

University of Seoul, Seoul, Republic of Korea

NARIT, Chiang Mai, Thailand



TAMU Car Mount, Texas, USA

Korean Polar Research Institute vessel “Ice Breaker”

Case II - Scanning MiniMPL tracking emissions mining

Justin Fisher[1], Damon Roddis[2], Ashley Martin[2], Liza McDonough[2], John Holdsworth[3]

1. Sigma Space Corporation, USA
2. Pacific Environment Ltd., Australia
3. University of Newcastle, New South Wales, Australia

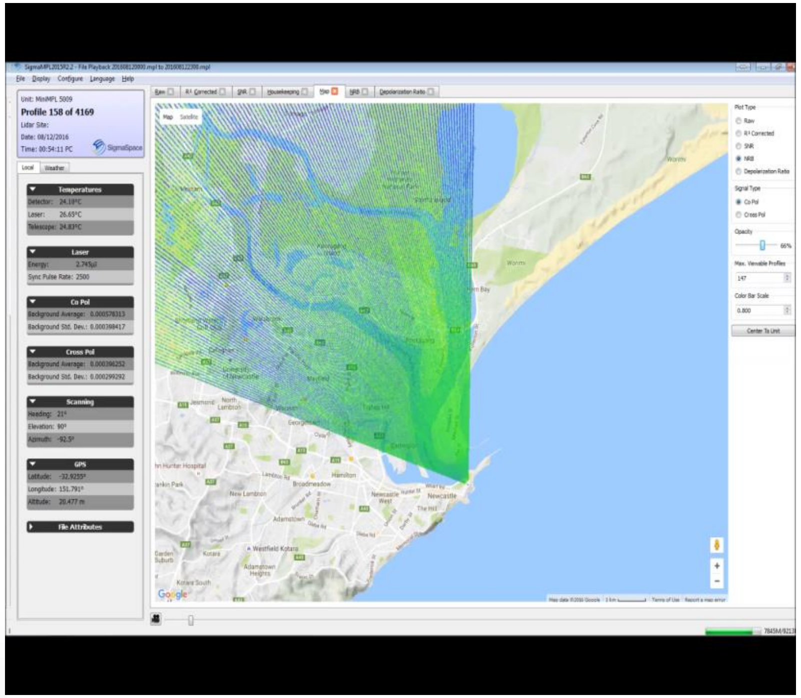
Scanning MiniMPL tracking PM10 at open pit mines and over coal ports
(CASANZ 2017)

Trailer-based scanning MiniMPL deployed on the fence-line of a site, and set to scan across the pit location to field trial real-time monitoring and detection of PM movement across mine

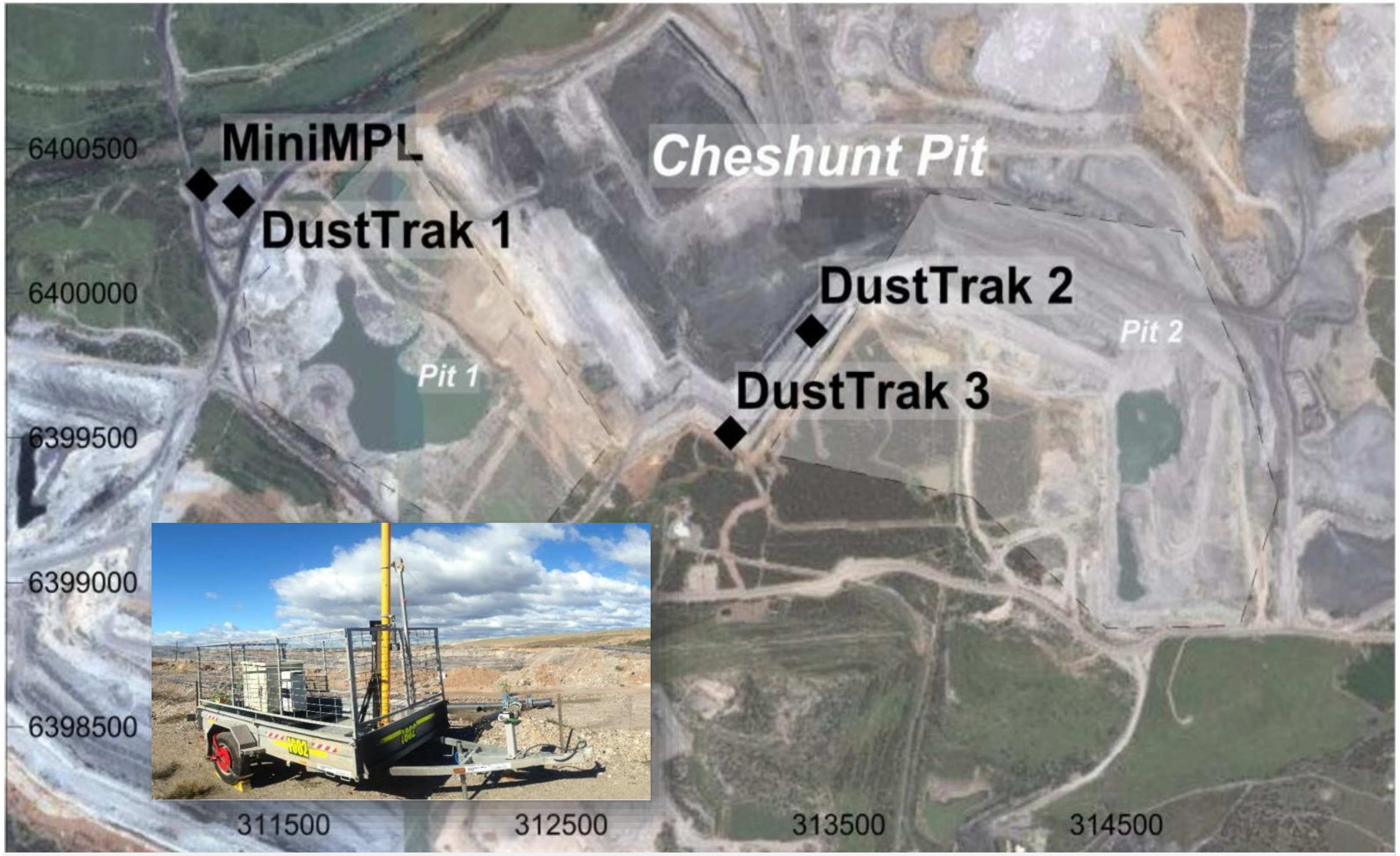
MiniMPL trailer deployed to scan over Port of Newcastle coal shipping channels to detect emissions

DROPLET MEASUREMENT TECHNOLOGIES

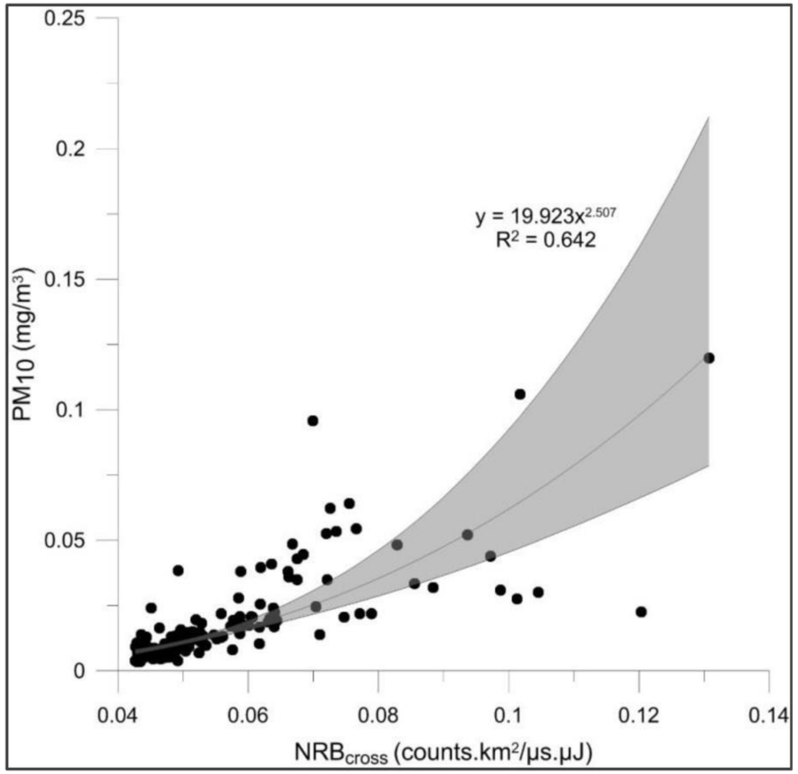
3 days of port scanning at Newcastle, Australia



First NRB_{cross} and PM10 relationship was established in site conditions

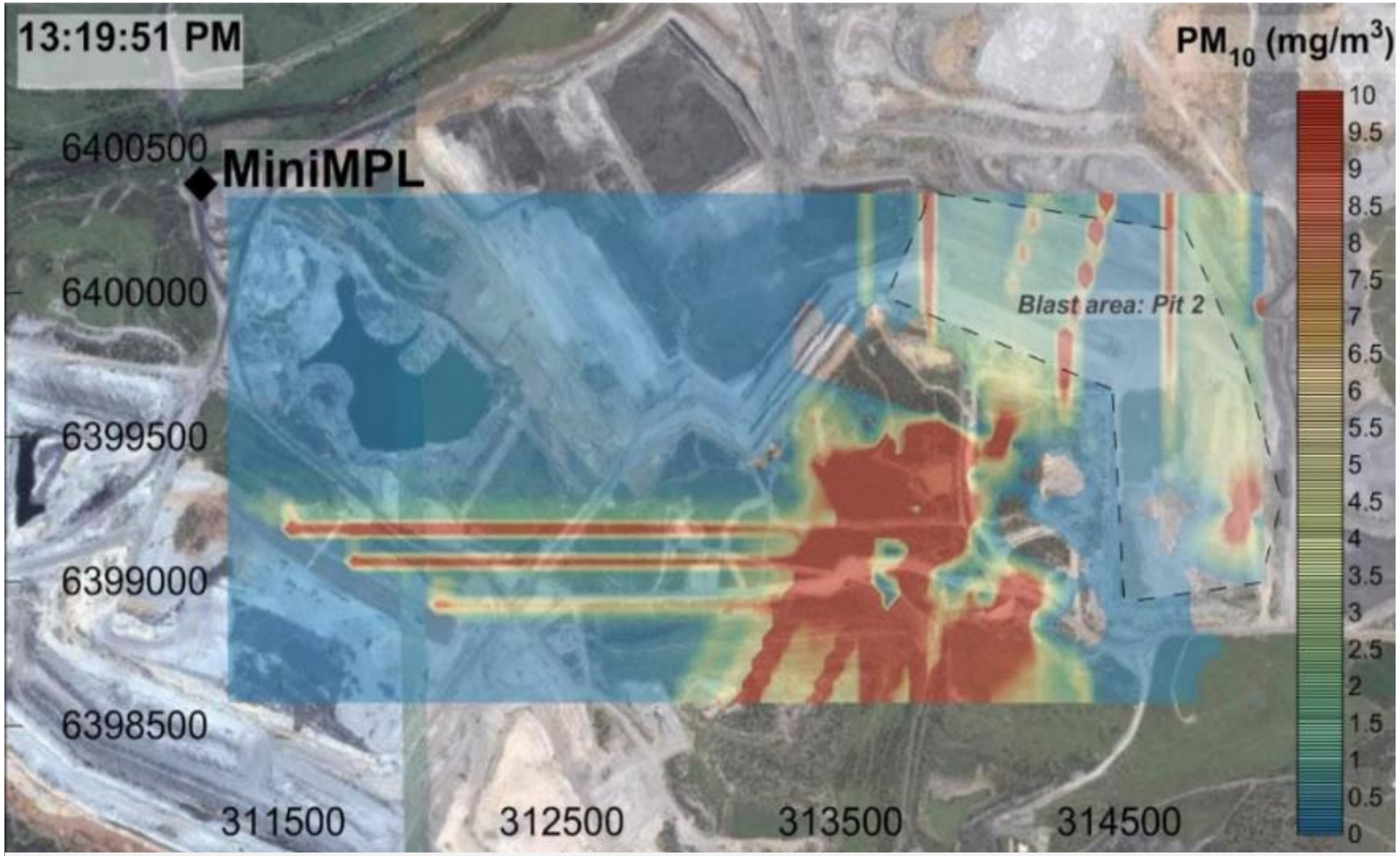


PM10 dust movement map after blast event



Power law equation for PM10 concentrations vs NRB_{cross} created with high confidence

Calibration used to establish PM10 movement map after event



PM10 dust movement map after blast event

- Using NRB_{cross} and DustTrak PM10 sensor correlation Mine Operators created PM10 emission transport maps from blasting, hauling and activities within the pit
- Confirming MiniMPL suitability for detecting PM10 plumes
- Both spherical and non-spherical aerosol plumes identified using depolarization products

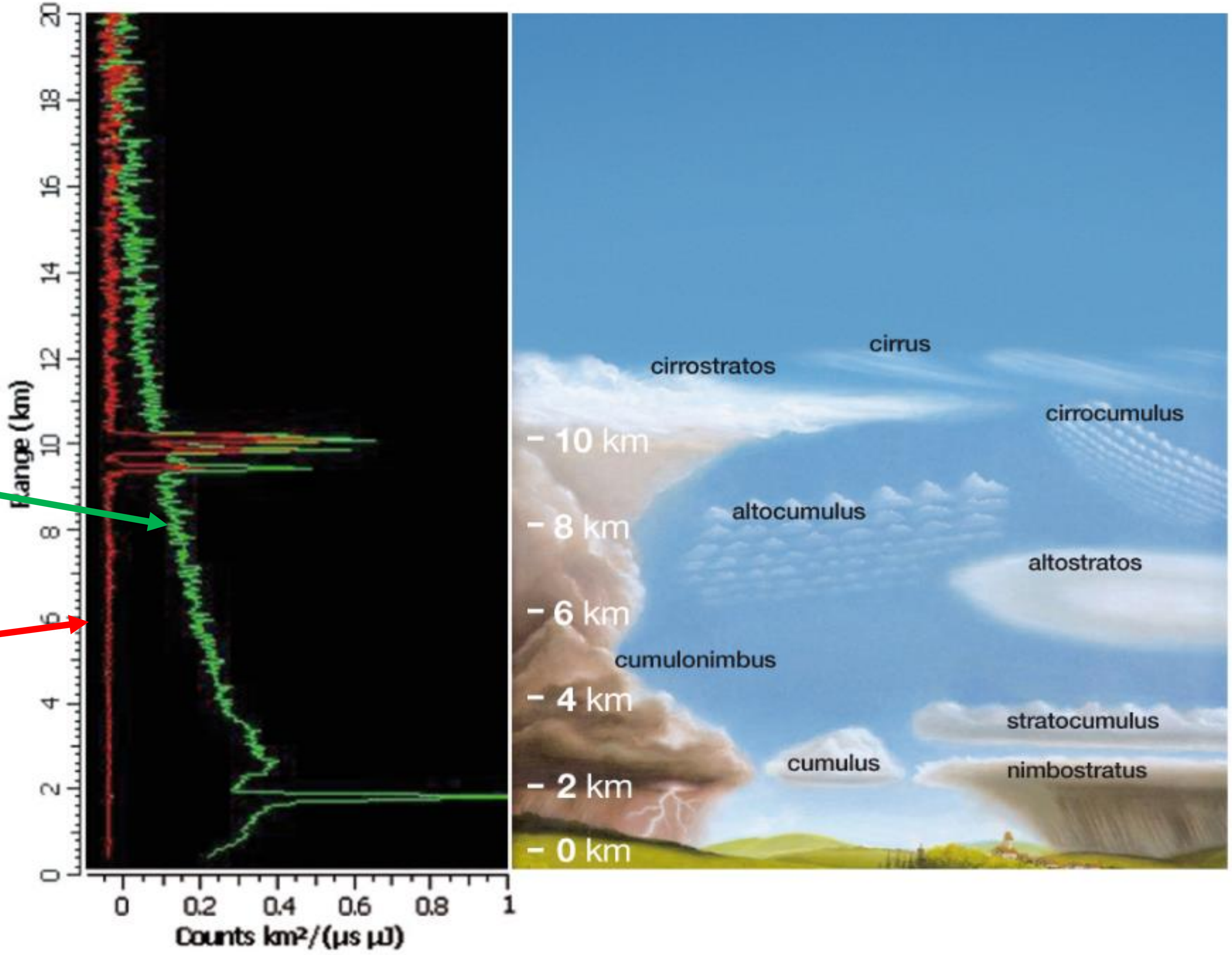
Basics of the measurement

Raw signal is intensity V.S. range

Green is co-pol signal

Red is cross-pol signal

Depolarization ratio is **red** divided by **green**



Laser sends out a triggered pulsed beam that fast switches between states

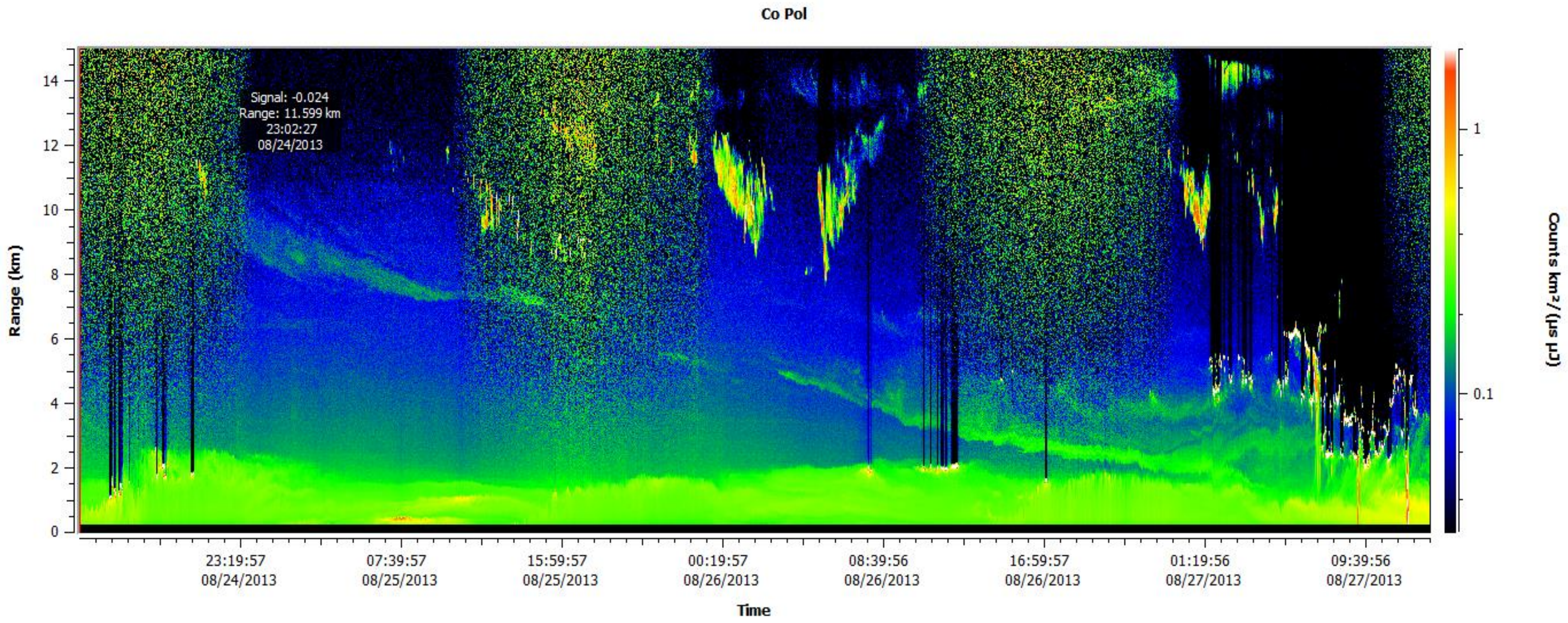
Reflected beam is captured by the receiver

Range is calculated by time of flight

Intensity by counting the photons

Normalized Relative Backscatter (NRB)

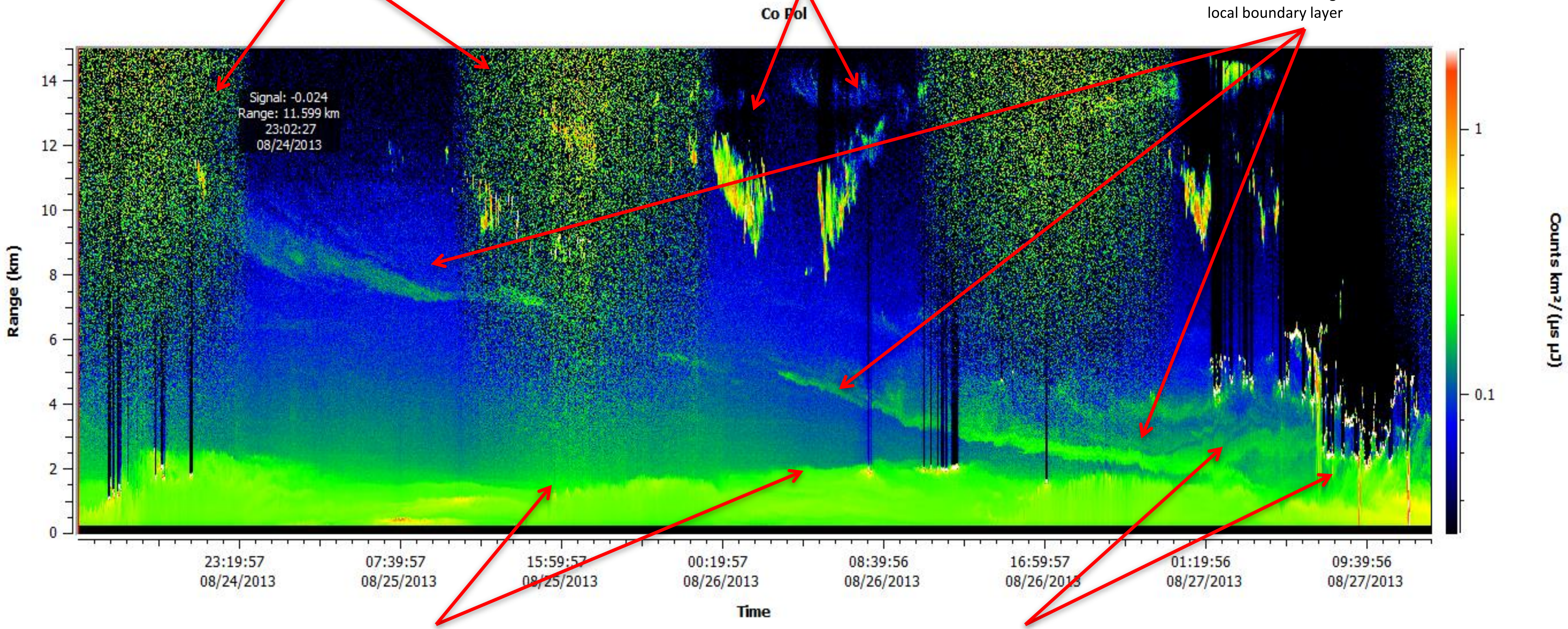
- Backscatter normalized to get rid of instrument-to-instrument variability
- Everything is calibrated to a gold standard
- NRB enables detection of many atmospheric properties
- NRB is measured in co-polarized, cross-polarized and unpolarized modes



Day time solar background noise shows up as speckles

Cloud base height and cloud phase measurement

High altitude aerosol descends and merges into local boundary layer

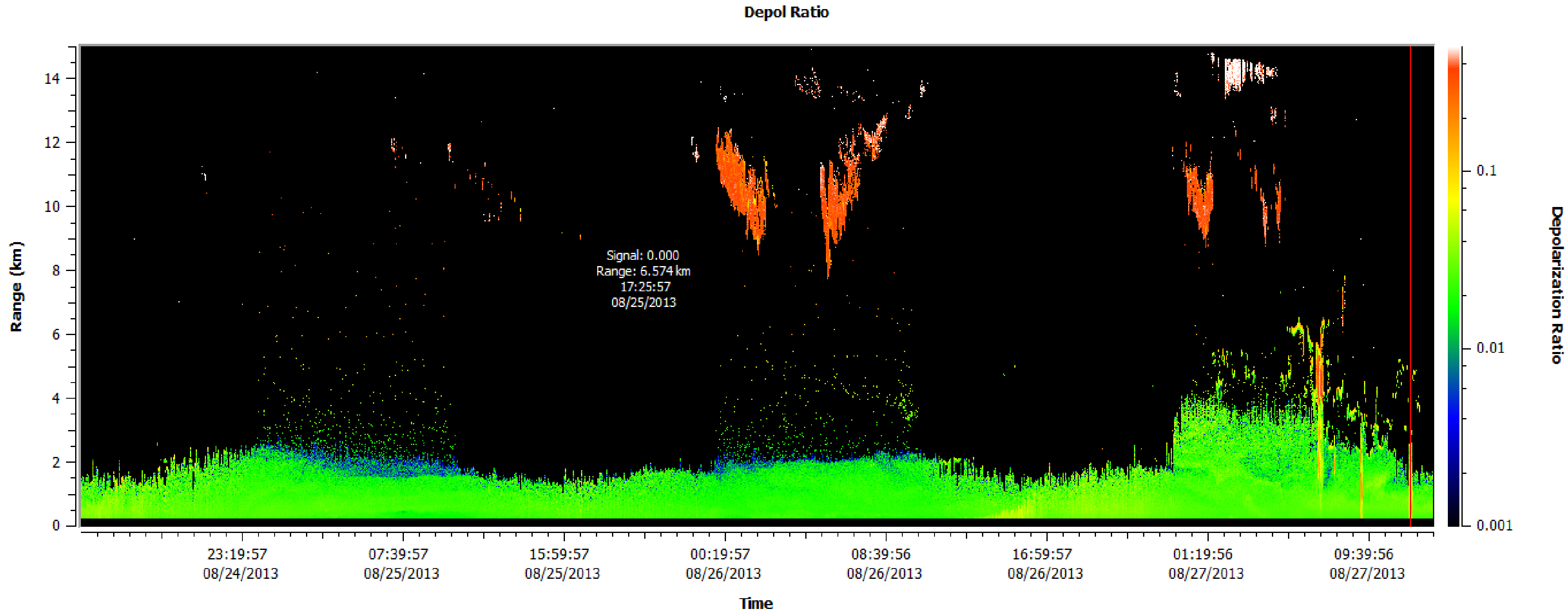


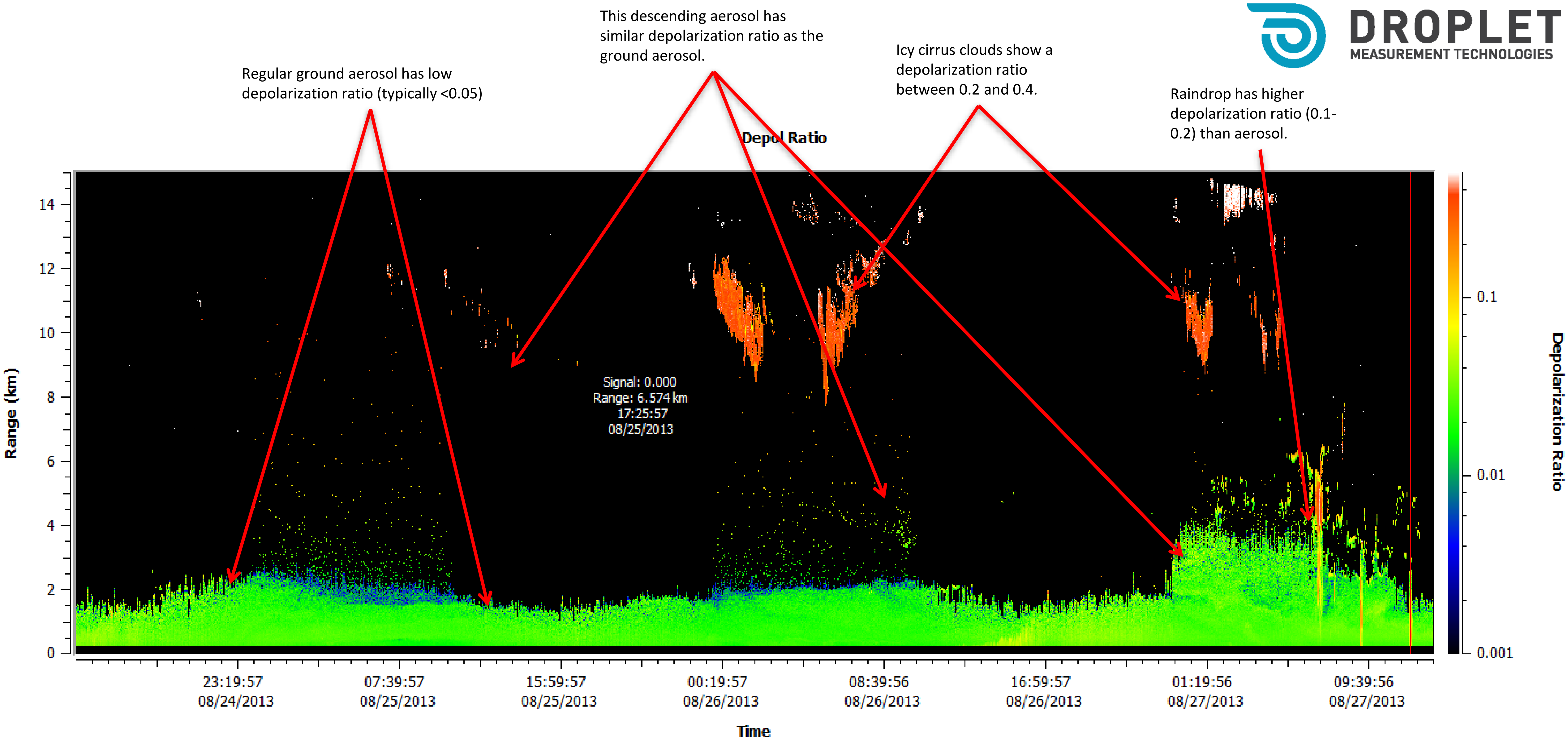
Aerosol and boundary layer structures evolve day and night.

Rain condition measurement. Transient rain captured in this data set

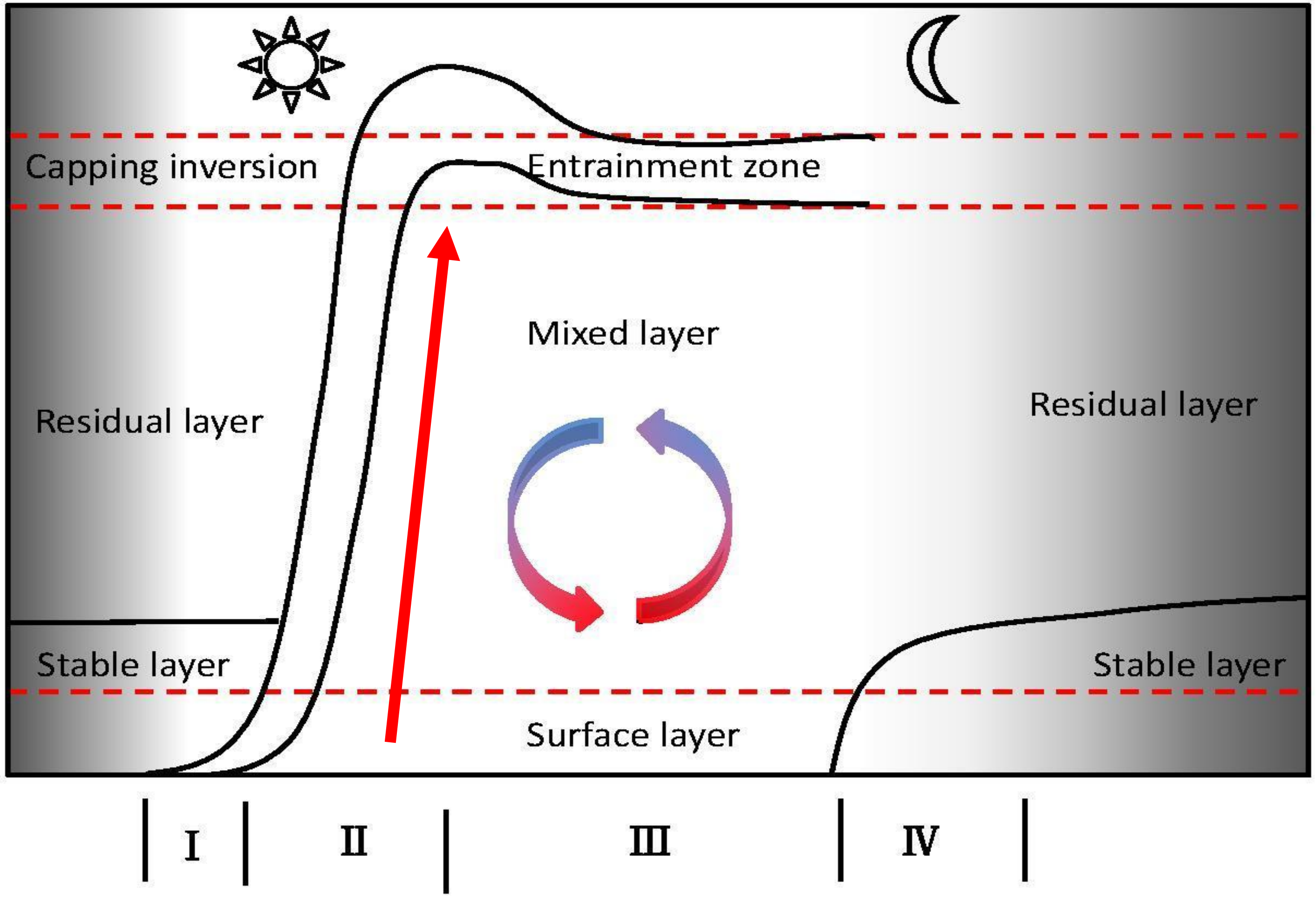
Depolarization ratio

- Depolarization measurement offers information on particle shapes for both clouds and aerosol
- Allows lidar to discriminate particles and see important atmospheric features




Regular ground aerosol has low depolarization ratio (typically <0.05)
This descending aerosol has similar depolarization ratio as the ground aerosol.
Icy cirrus clouds show a depolarization ratio between 0.2 and 0.4.
Raindrop has higher depolarization ratio (0.1-0.2) than aerosol.
Depol Ratio
Signal: 0.000
Range: 6.574 km
17:25:57
08/25/2013
Range (km)
Time
Depolarization Ratio
23:19:57 08/24/2013
07:39:57 08/25/2013
15:59:57 08/25/2013
00:19:57 08/26/2013
08:39:56 08/26/2013
16:59:57 08/26/2013
01:19:56 08/27/2013
09:39:56 08/27/2013

Planetary boundary layer (PBL)



CREDIT: Adapted from Stull 1988 "An Introduction to Boundary layer meteorology" page 11

(I) Formation of a shallow mixed layer

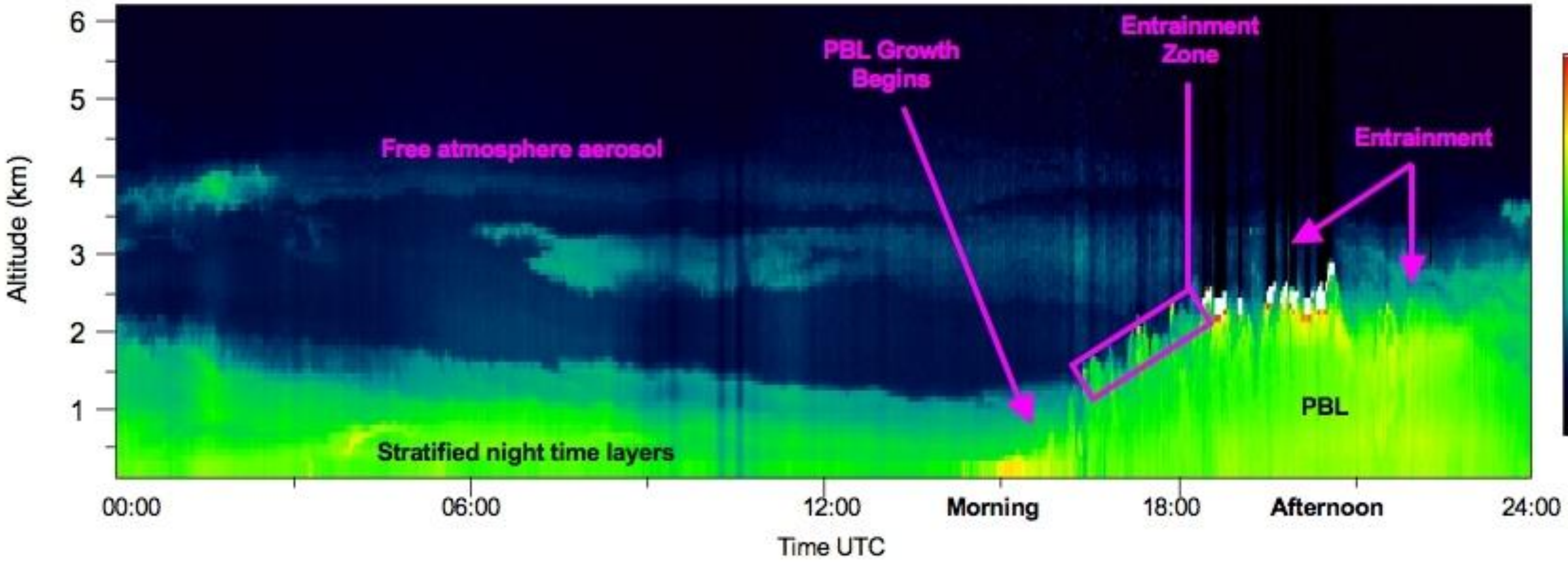
(II) Rapid growth

(III) Deep mixed layer of nearly constant thickness

(IV) Decay

Definition: The planetary boundary layer (PBL) is the lowest part of the atmosphere, whose behavior is directly influenced by its contact with the planetary surface.

Planetary boundary layer (PBL)



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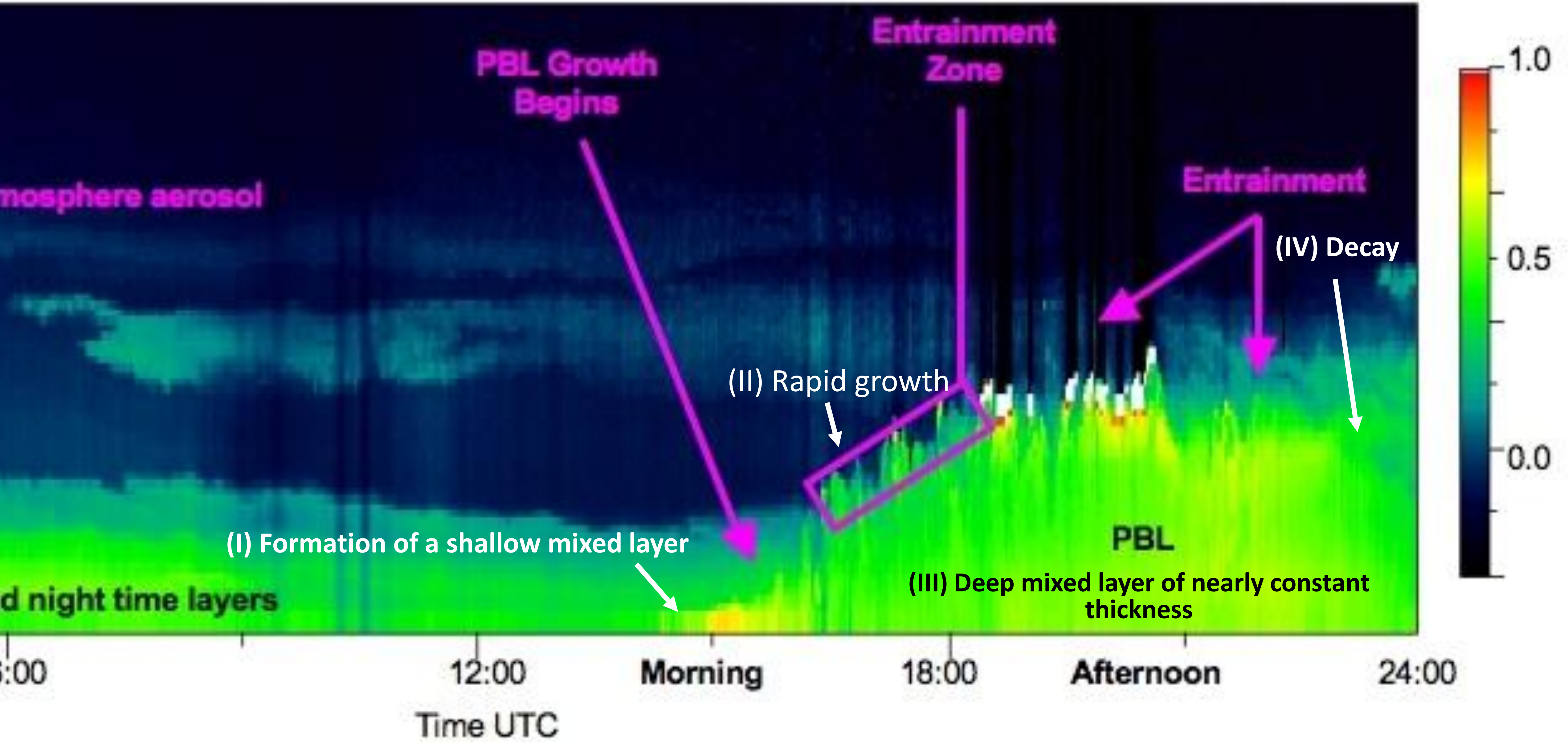
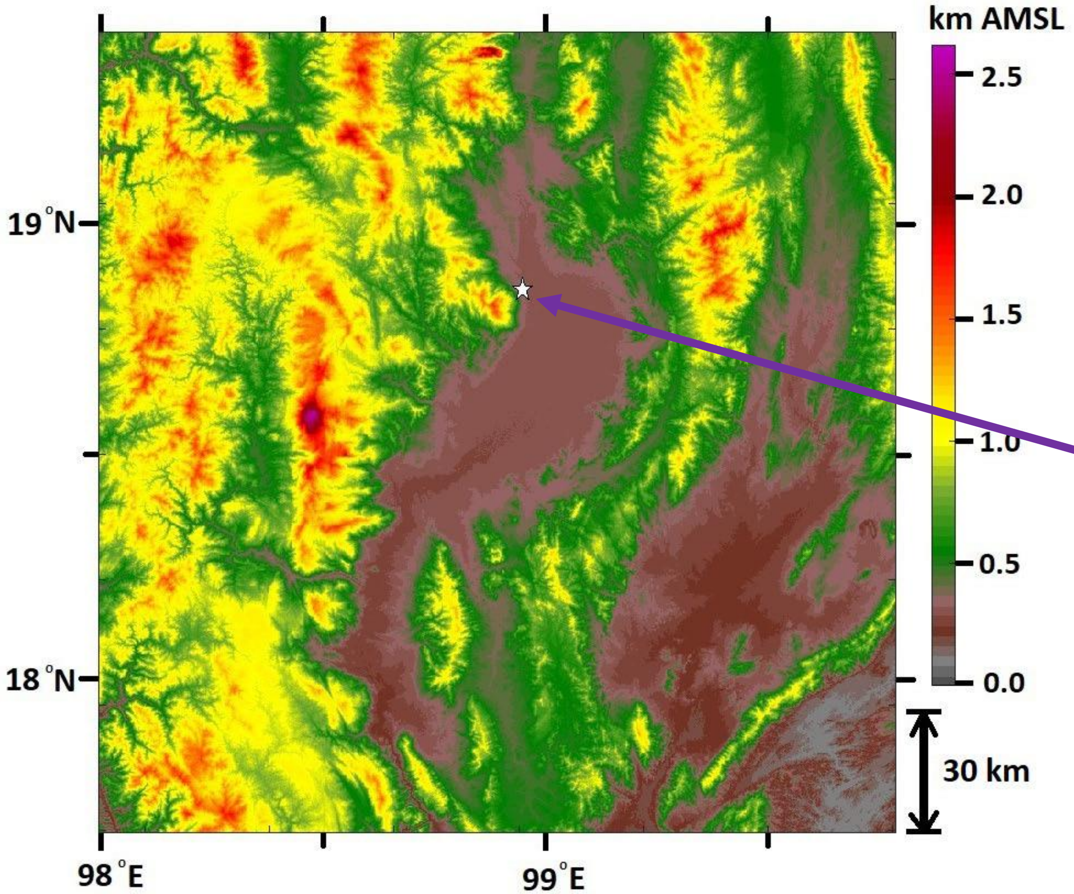


Case III - Mixing layer height retrievals from MiniMPL measurements in the Chiang Mai valley

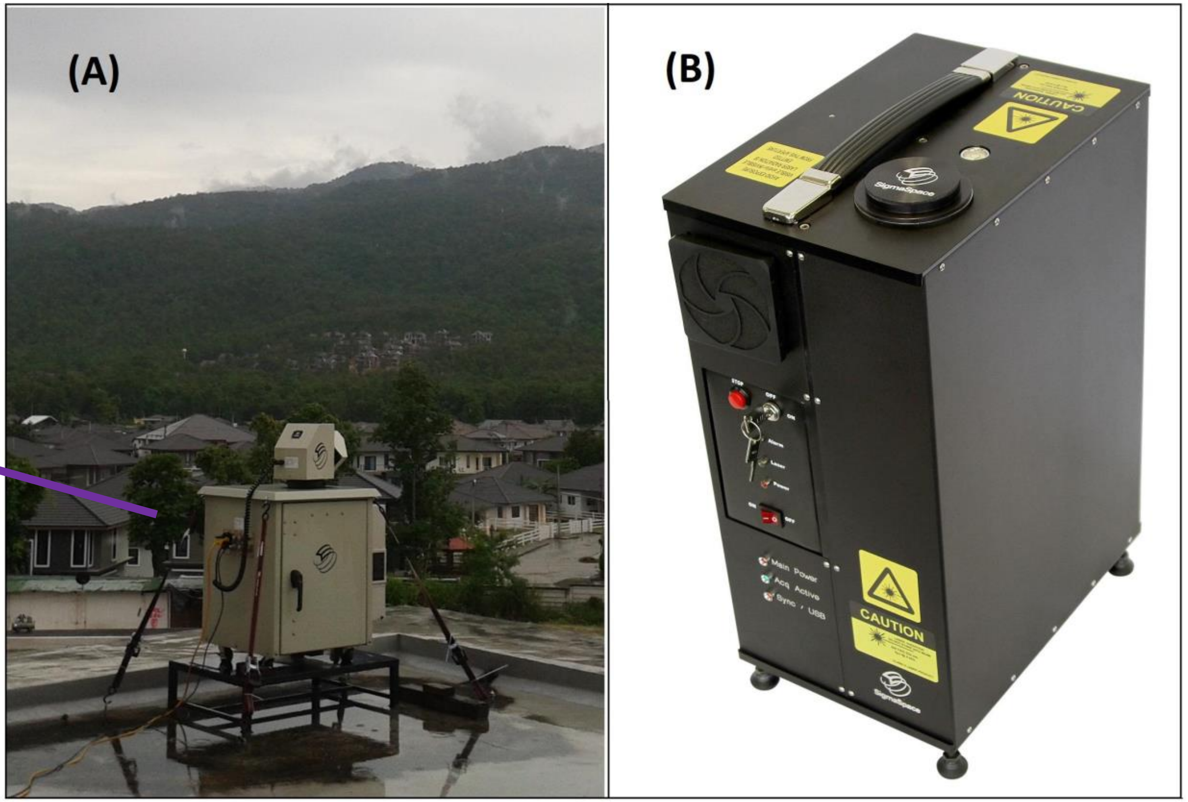
Raman Solanki[1*], Ronald Macatangay[1,2], Vichawan Sakulsupich[1], Thiranan Sonkaew[3] and Parth Sarathi Mahapatra[4]

- [1]Atmospheric Research Unit, National Astronomical Research Institute of Thailand, Chiang Mai, Thailand
- [2]Institute of Environmental Science and Meteorology, University of the Philippines Diliman, Quezon City, Philippines
- [3]Science Faculty, Lampang Rajabhat University, Lampang, Thailand
- [4]International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal

MiniMPL to investigate ML changes over Chiang Mai valley

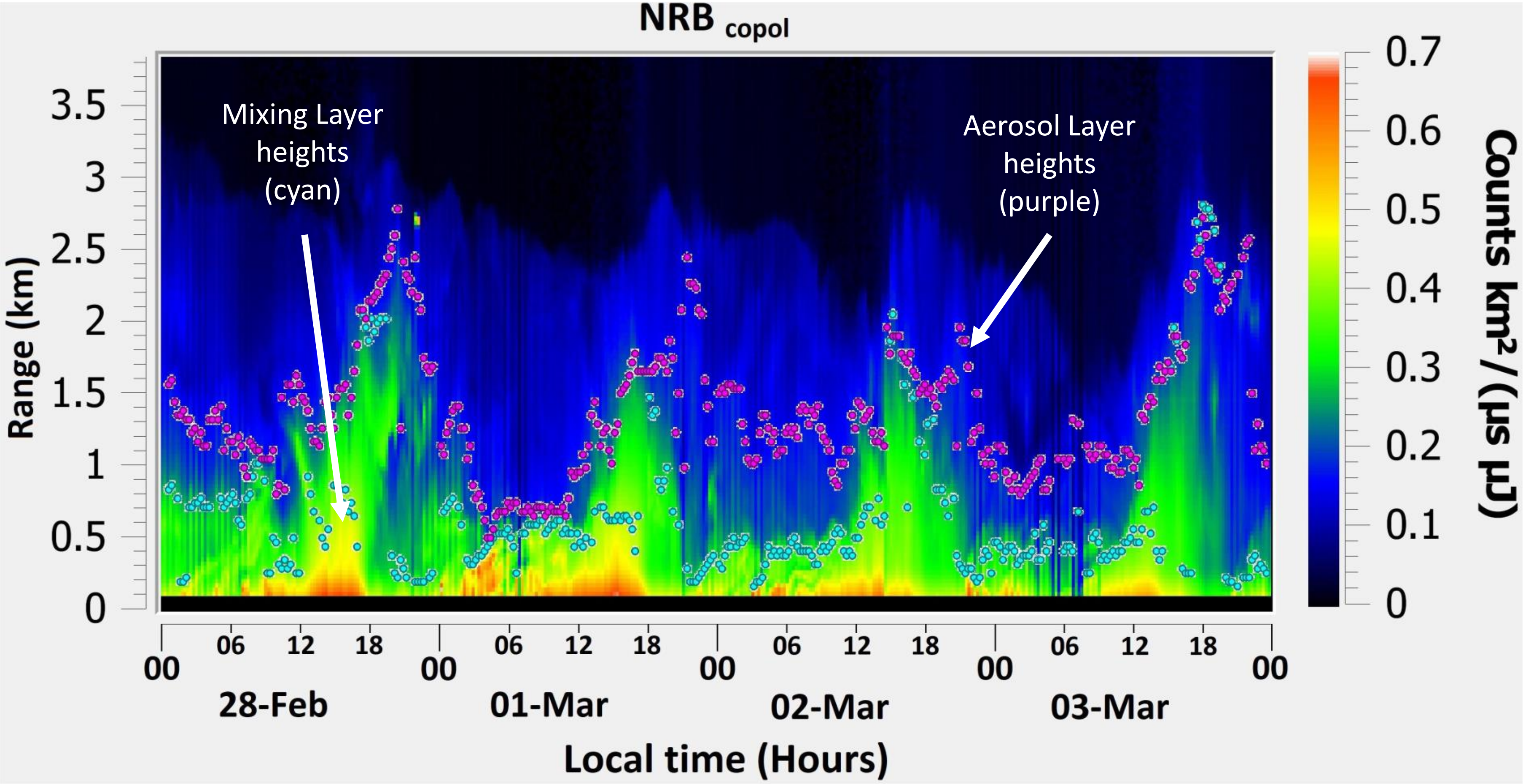


Topography of the region surrounding the valley of Chiang Mai in Northern Thailand. The location of the MiniMPL measurements site is highlighted by the star in white color



Scanning MiniMPL at NARIT Astro Park, Chiang-Mai Thailand

Mixing Layer and Aerosol Layer changes in the lower atmosphere from Feb 28th – March 3rd

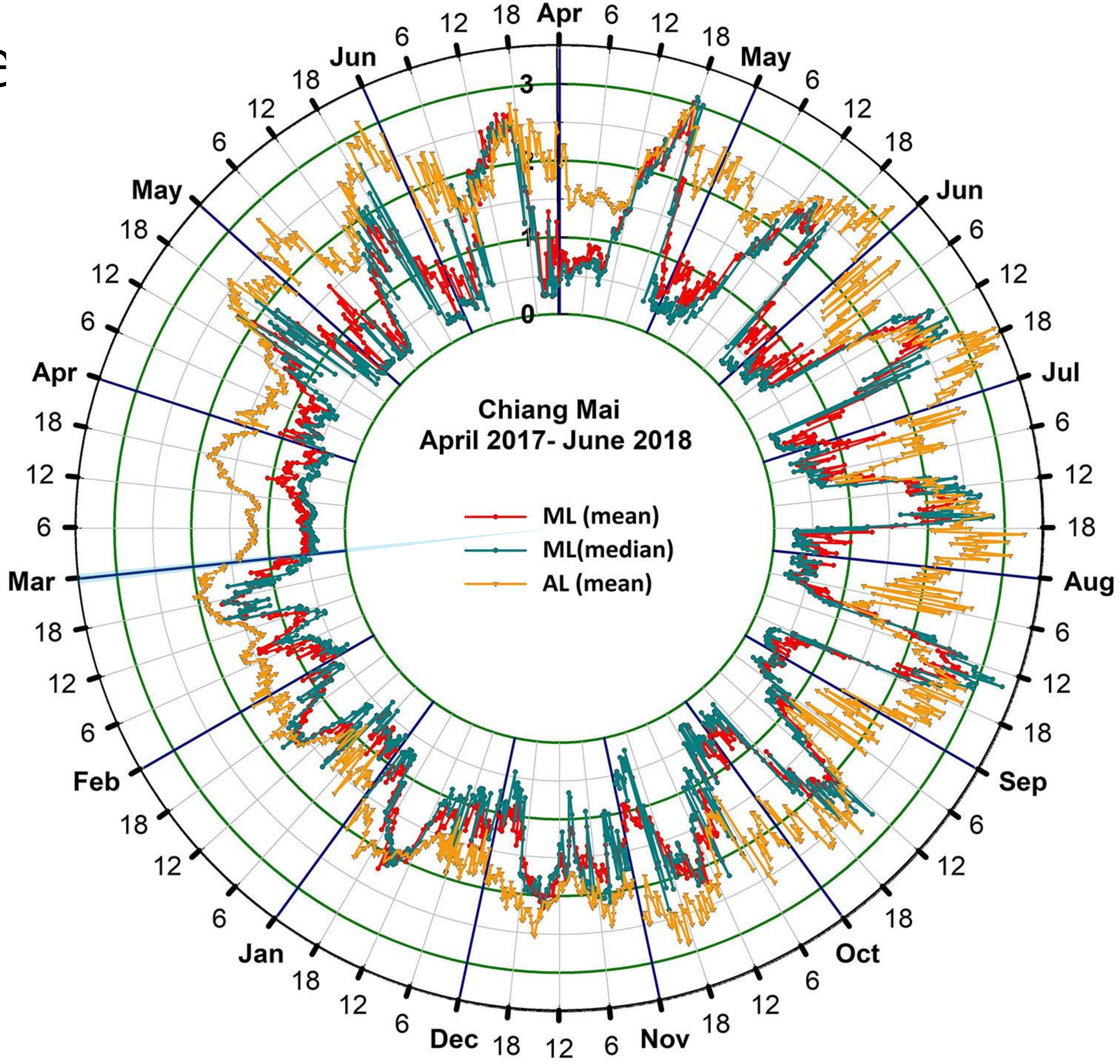


(Copol-NRB, 15 min profiles @ 30 m vertical resolution)

Clear diurnal cycles identifie

Three stages identified:

1. 09–15 local time of gradual growth in ML thickness,
2. 15–19 local time of rapid decrease in ML height, and
3. 20–09 local time of small variations pertaining to stable ML height during nighttime and morning hours



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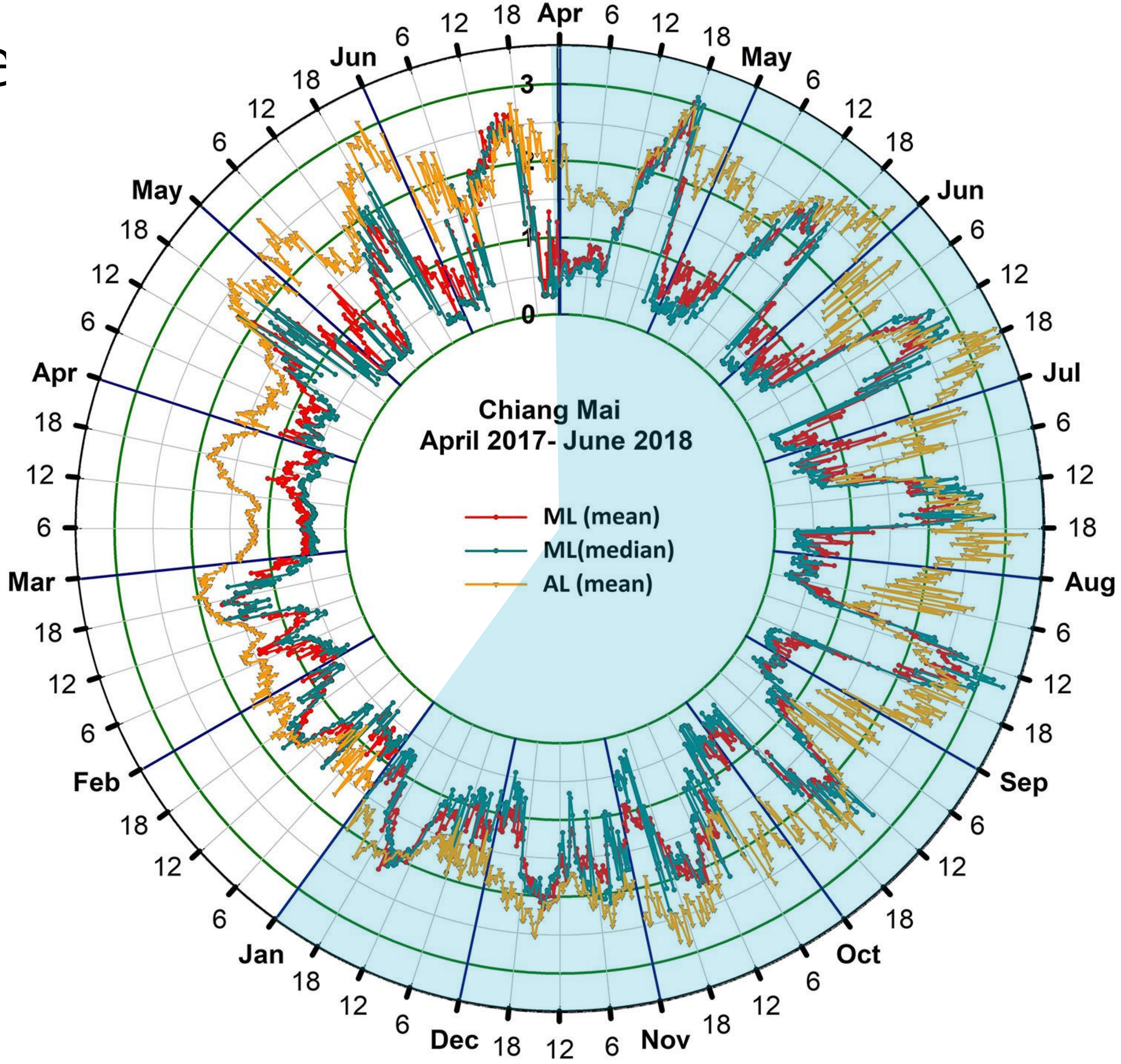

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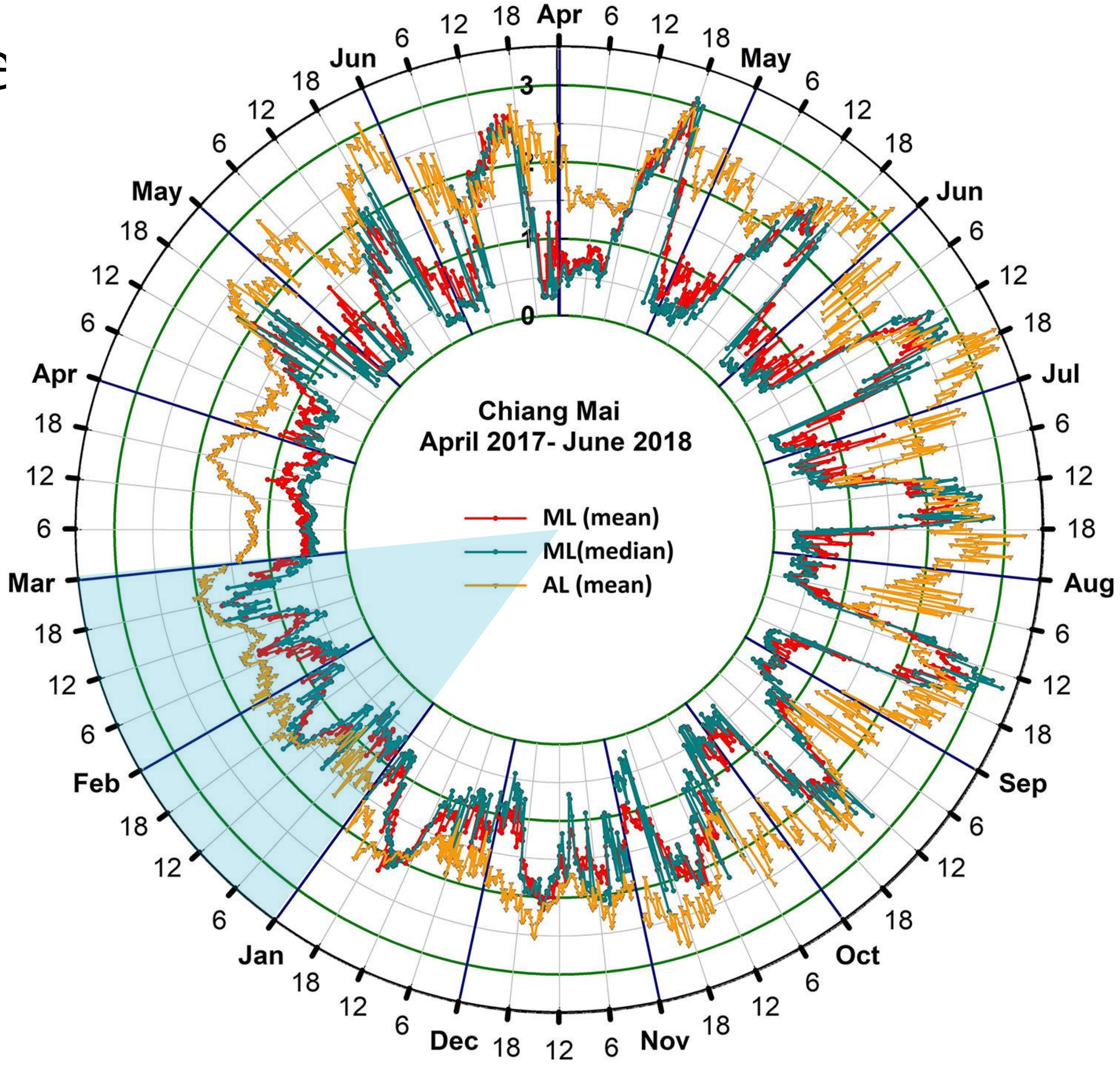

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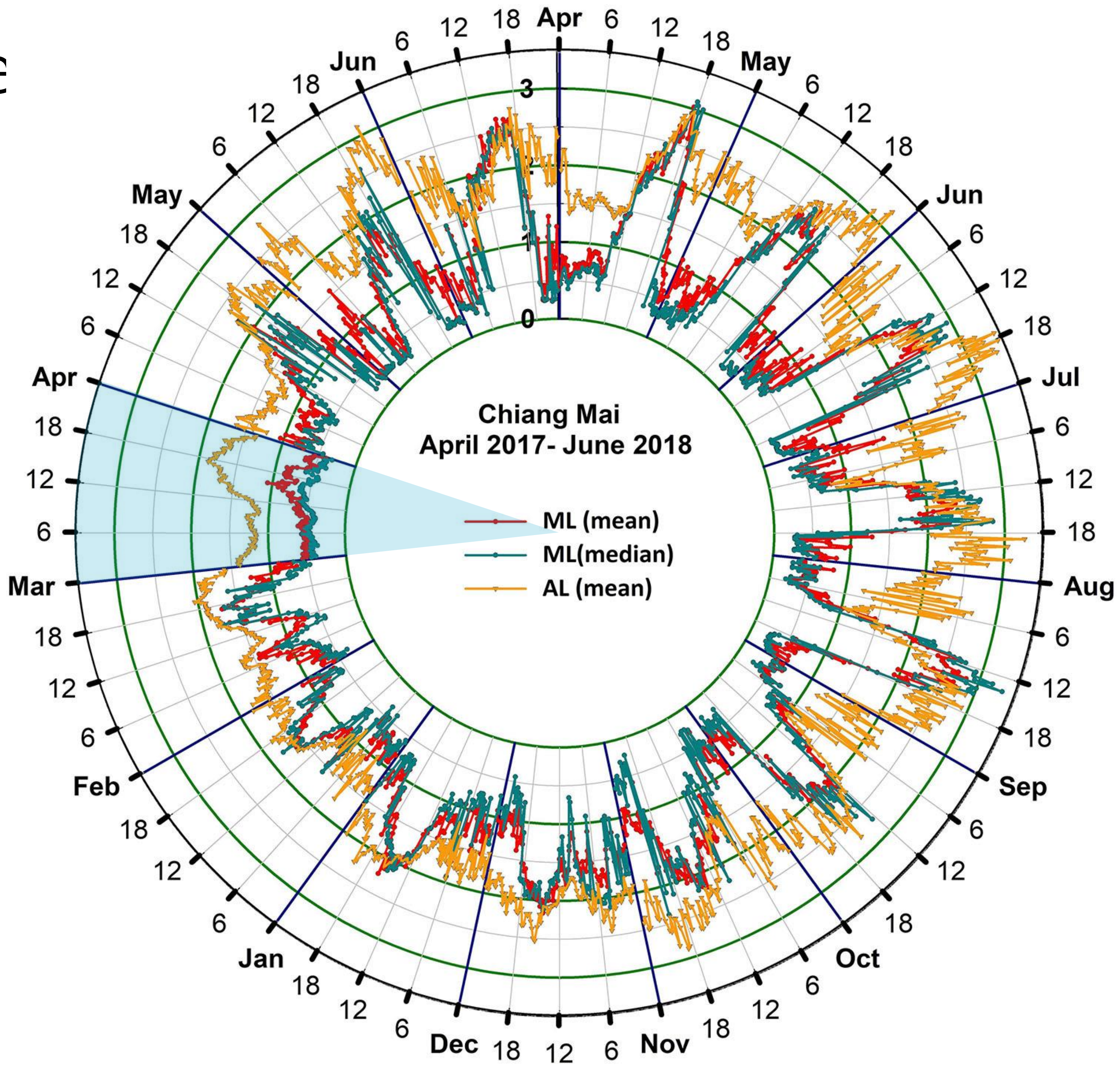

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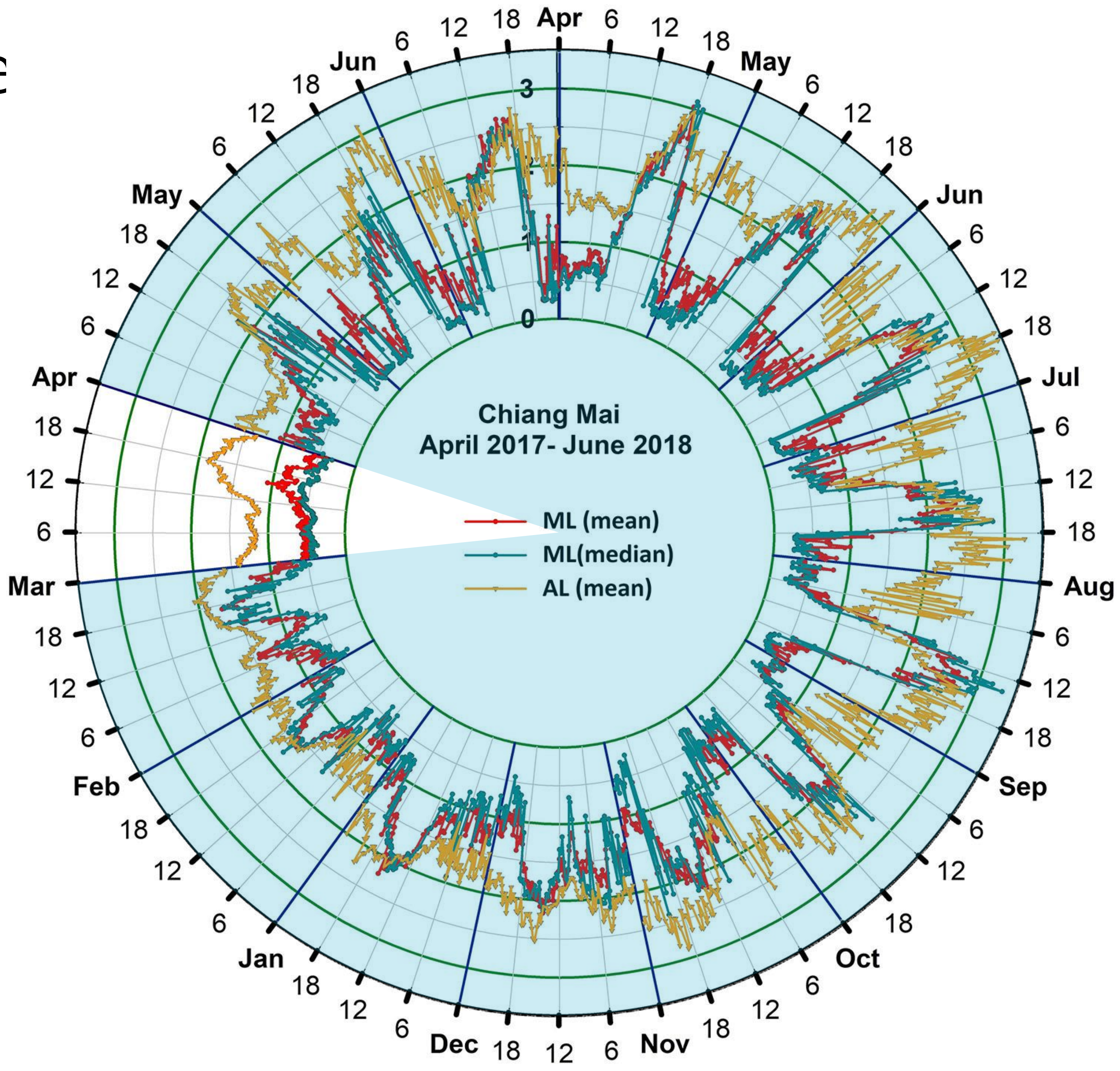

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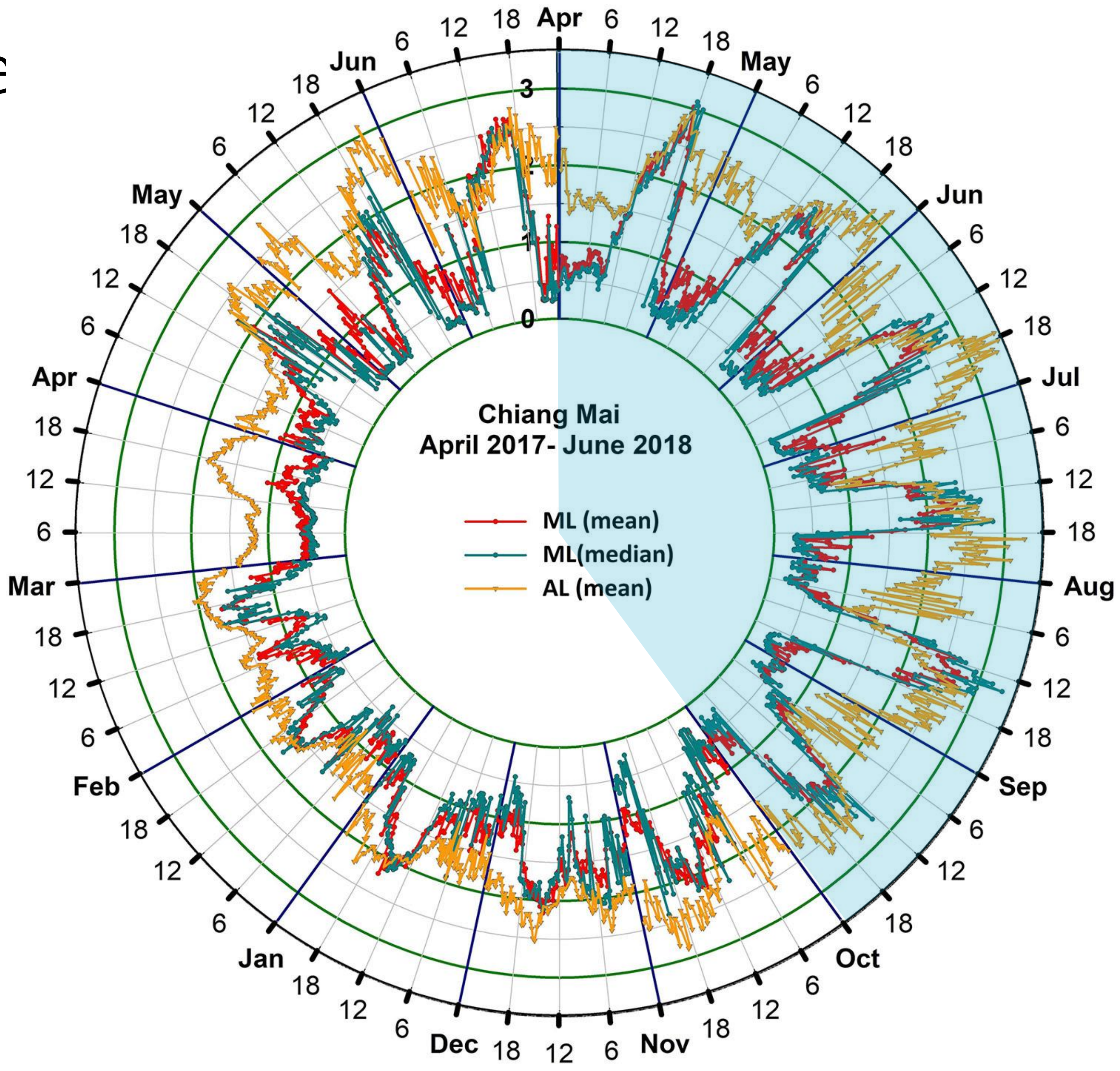

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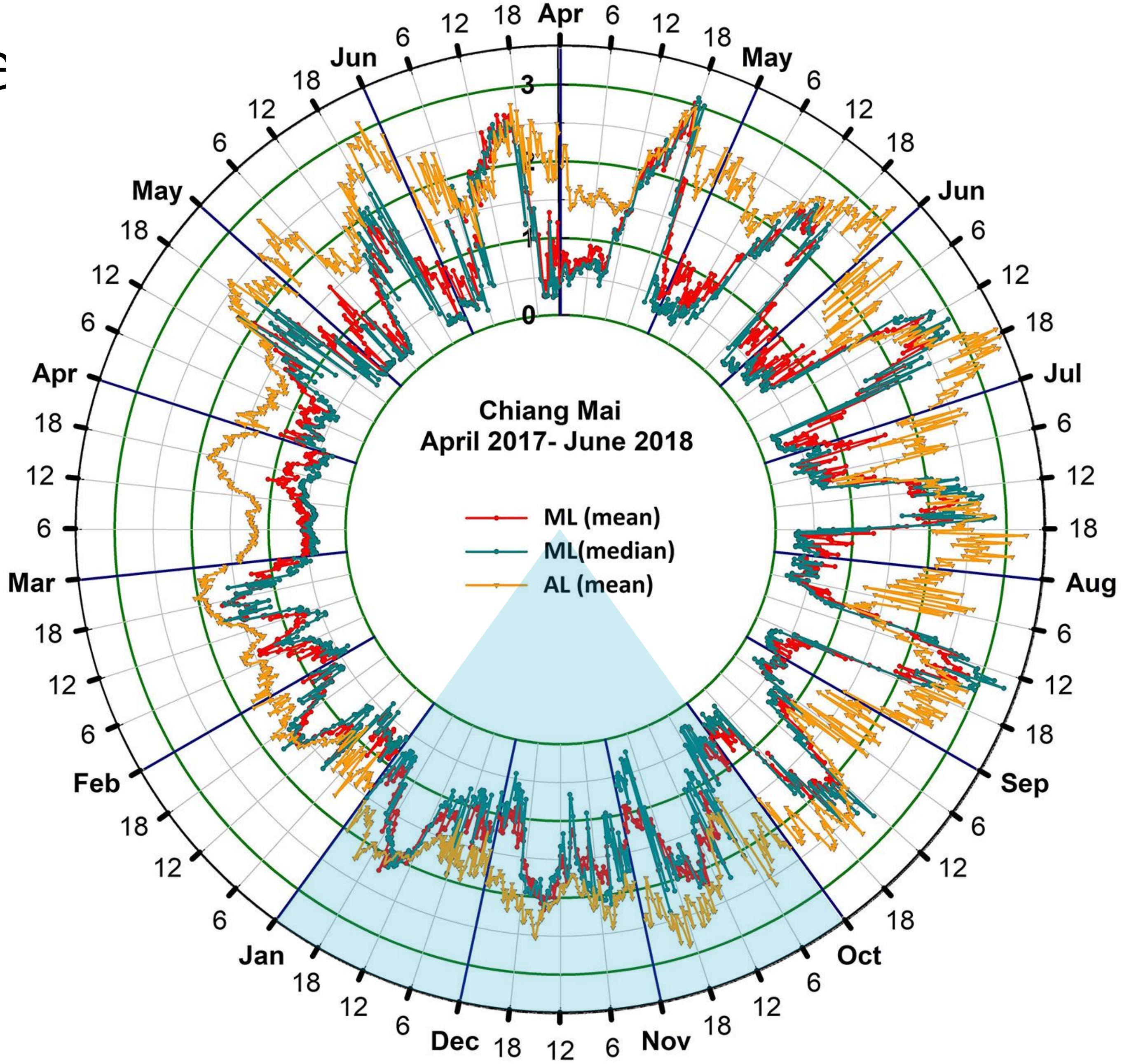

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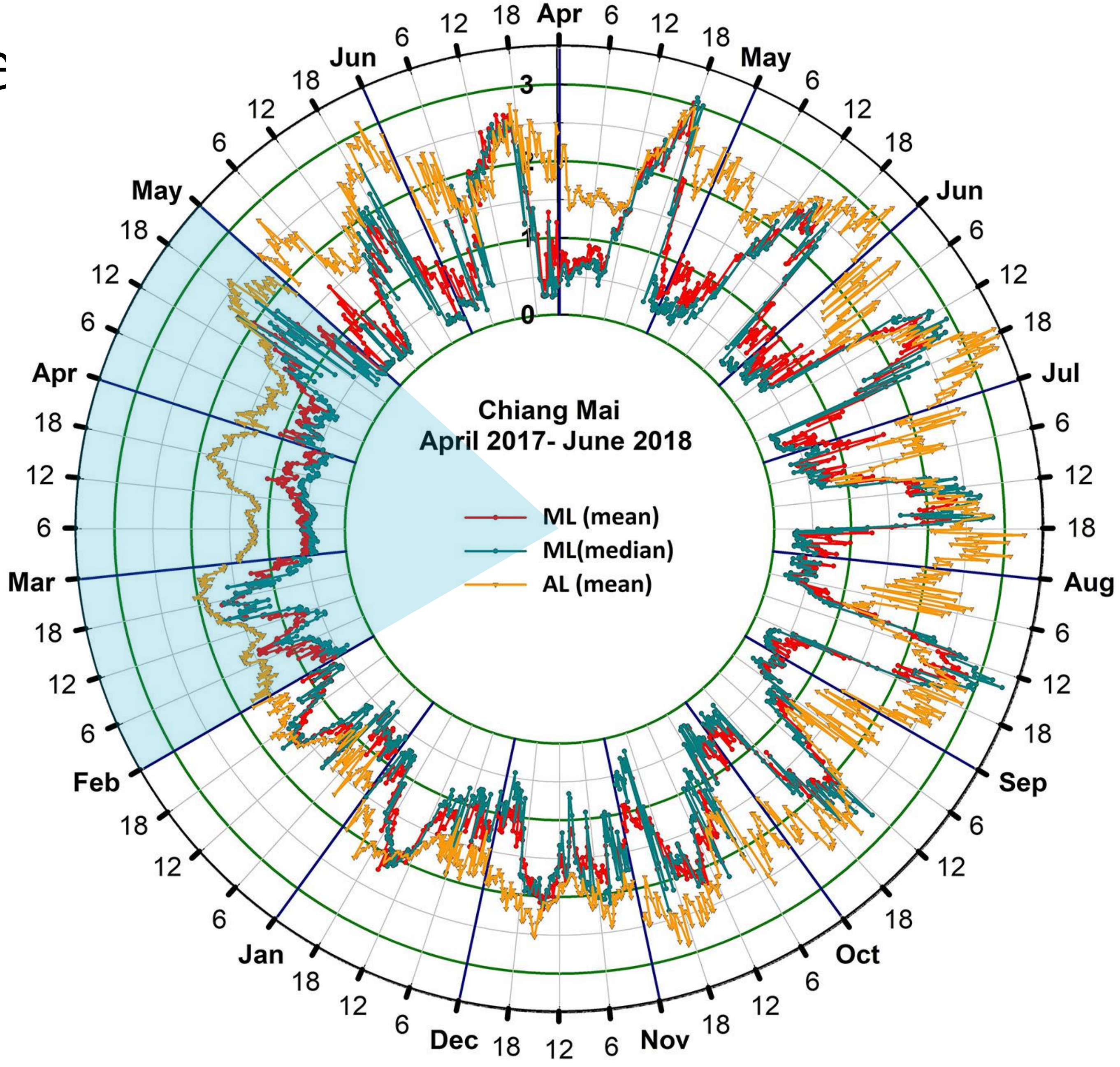
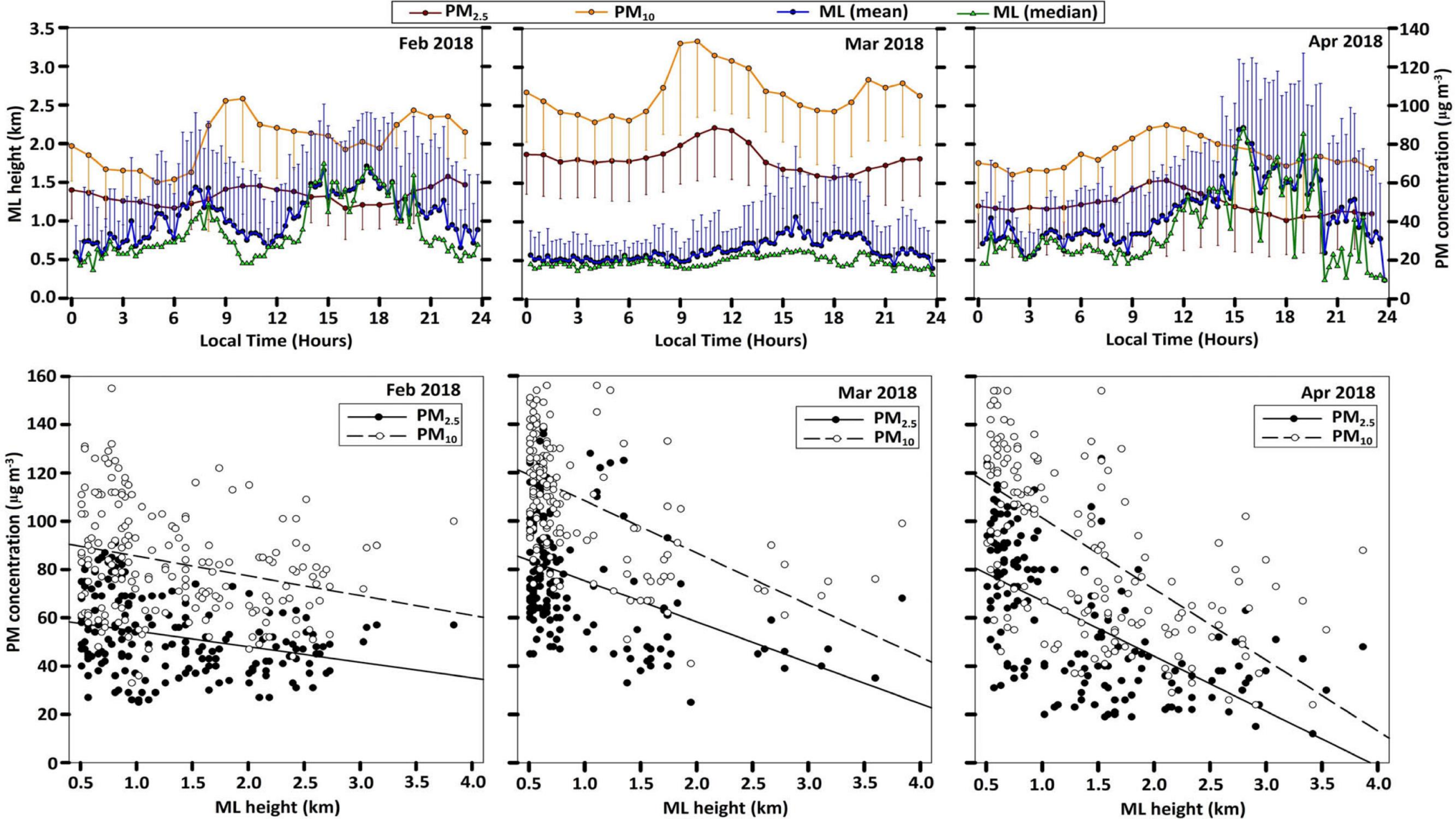


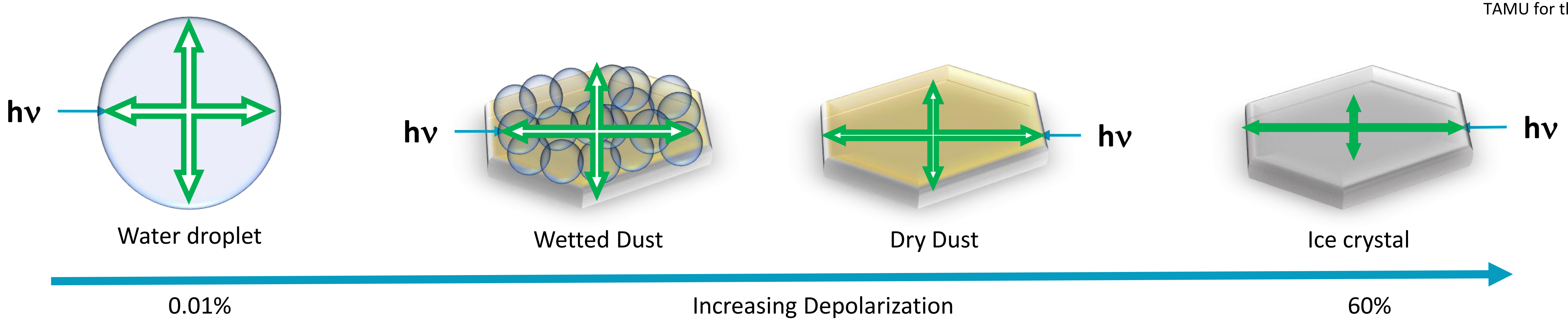


PM2.5
PM10
ML (mean)
ML (median)
Feb 2018
Mar 2018
Apr 2018
ML height (km)
PM concentration (µg m-3)
Local Time (Hours)
ML height (km)
PM concentration (µg m-3)

$$Depolarization = \frac{Crosspol \perp}{Copol \parallel}$$

Depolarization derived products

Thanks to Dr. Tim Logan, TAMU for the graphic

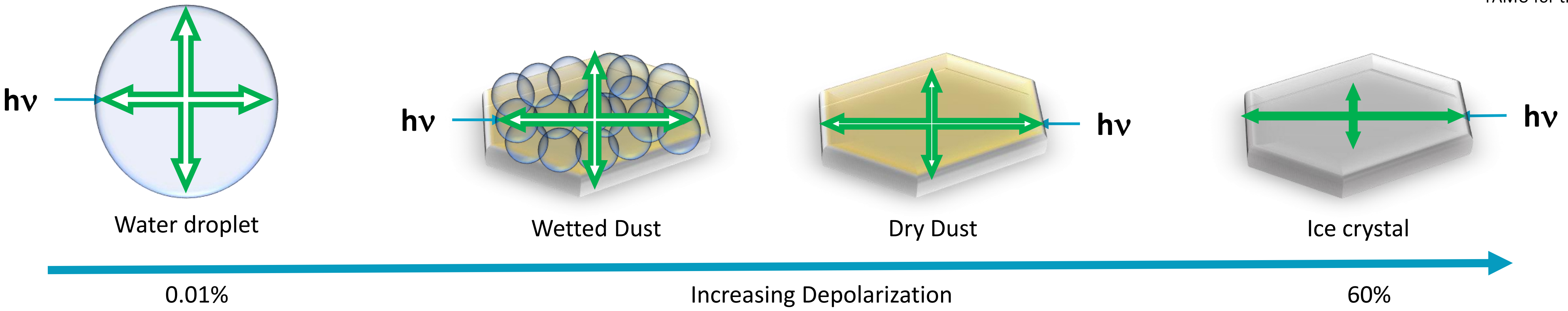


- Depolarization ratio is related to the sphericity of particles
- Light is scattered more equally in rounded particles than non-rounded particles
- Can be utilized to infer particle type

$$Depolarization = \frac{Crosspol \perp}{Copol \parallel}$$

Depolarization derived products

Thanks to Dr. Tim Logan, TAMU for the graphic



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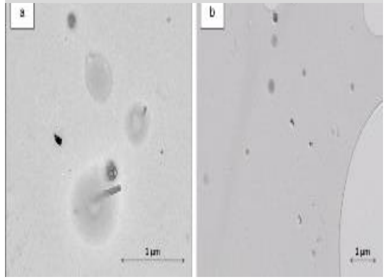
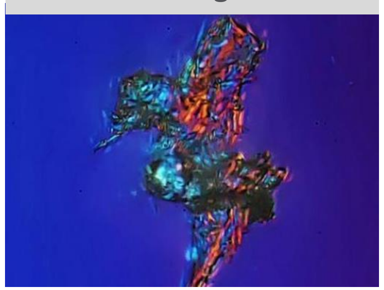
Droplet Nuclei



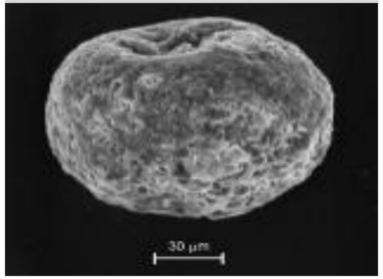
<0.1

Smog



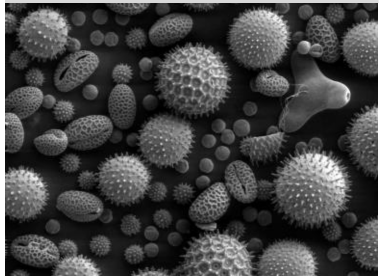
0.01 – 0.1

Dust



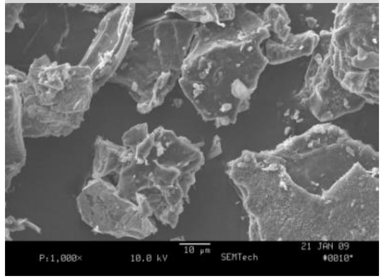
0.2 – 0.4

Pollen



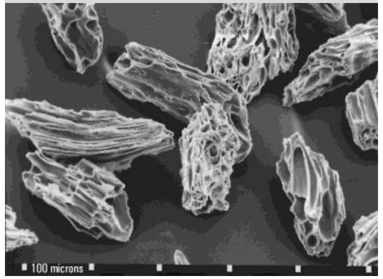
0.2 – 0.4

Mineral Dust

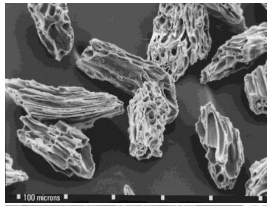
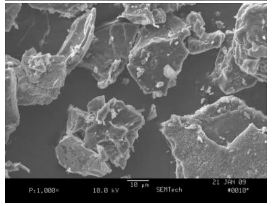
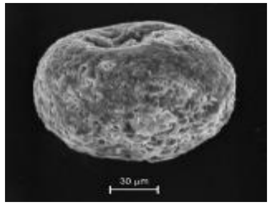


0.2 – 0.4

Volcanic Ash



0.3 – 0.4


100 microns


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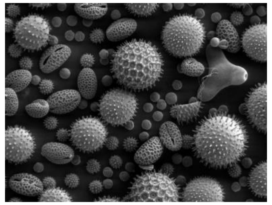
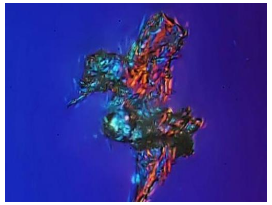

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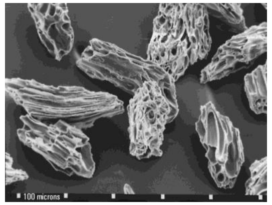
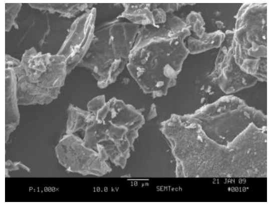
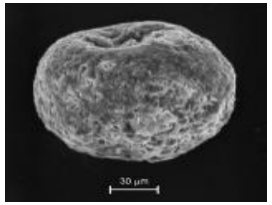
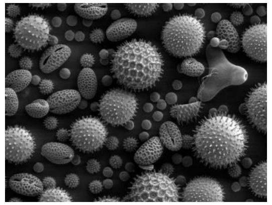
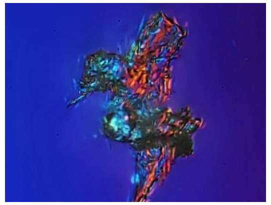
Volcanic Ash over Bariloche Airport, Argentina

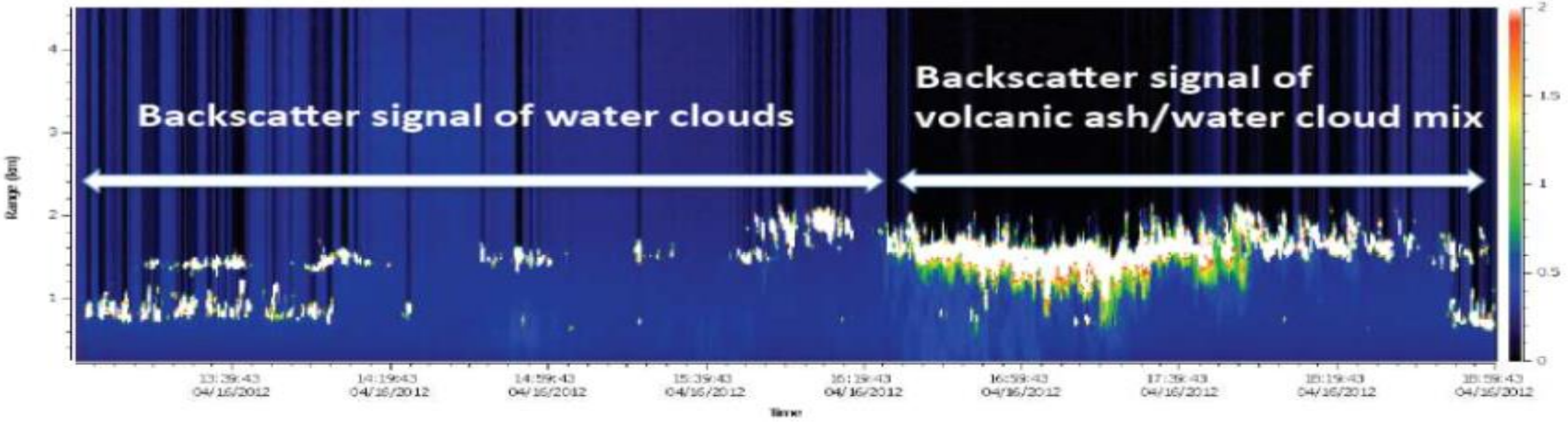


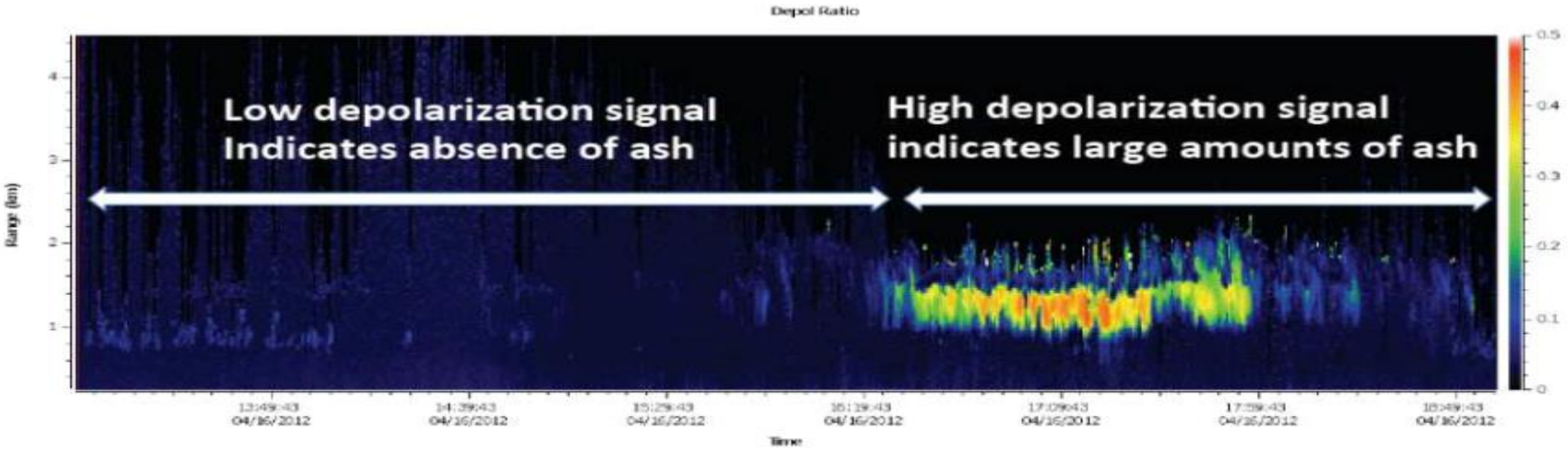




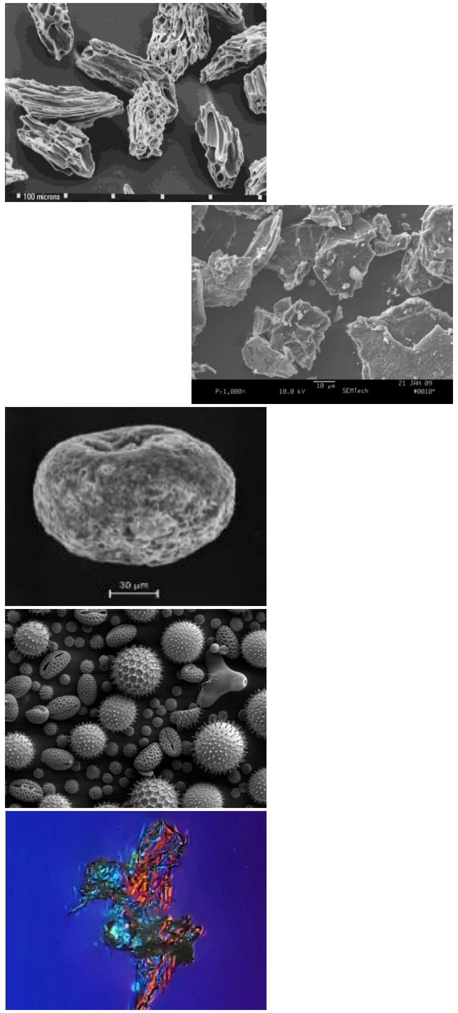


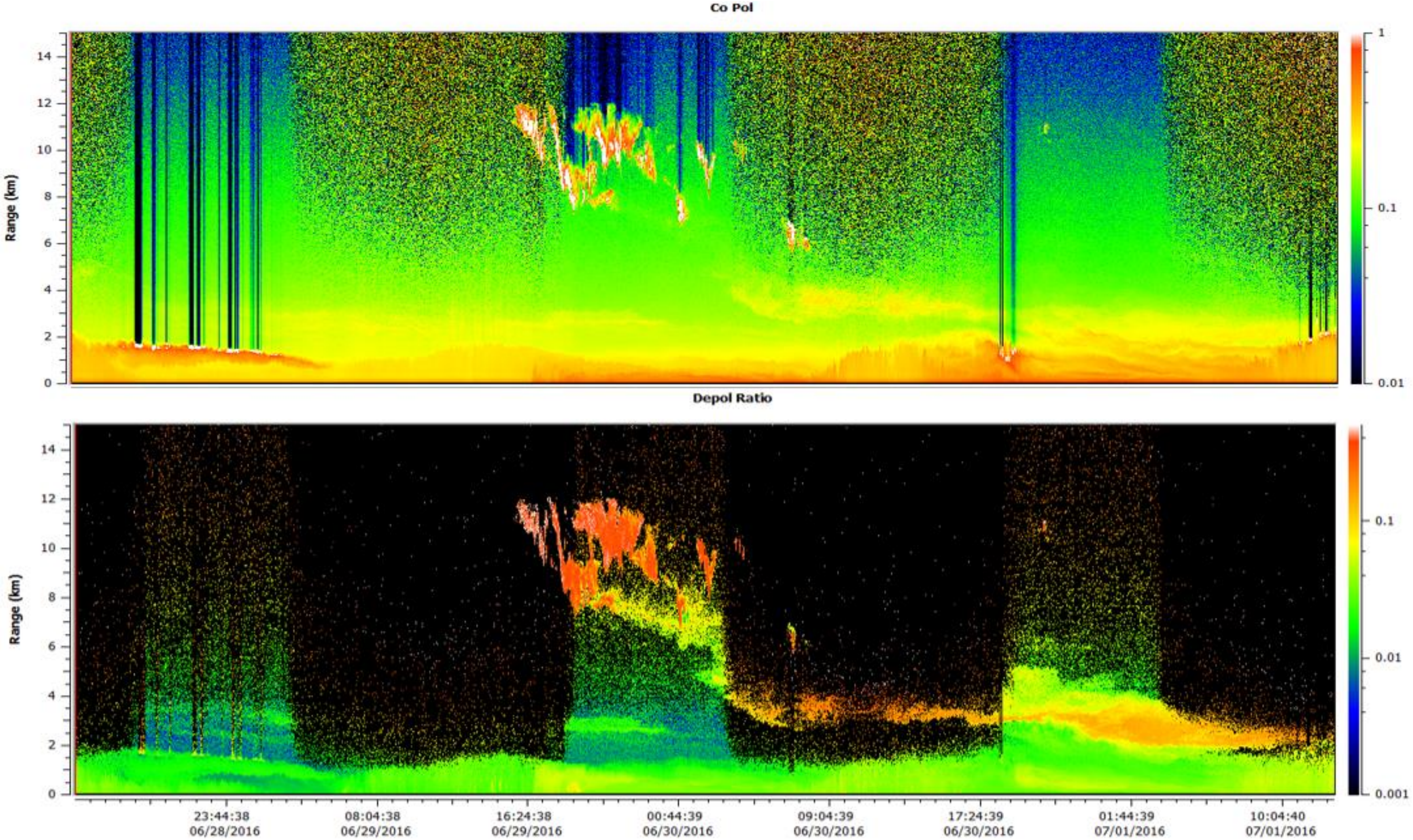




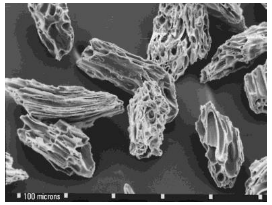


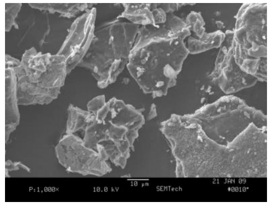
Dust deposition over Potenza, Italy

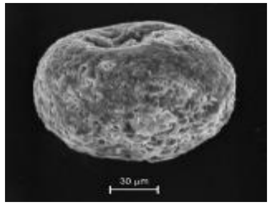


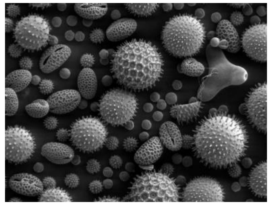


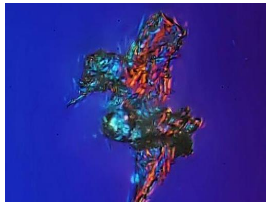
Pollen emissions over Barcelona, Spain

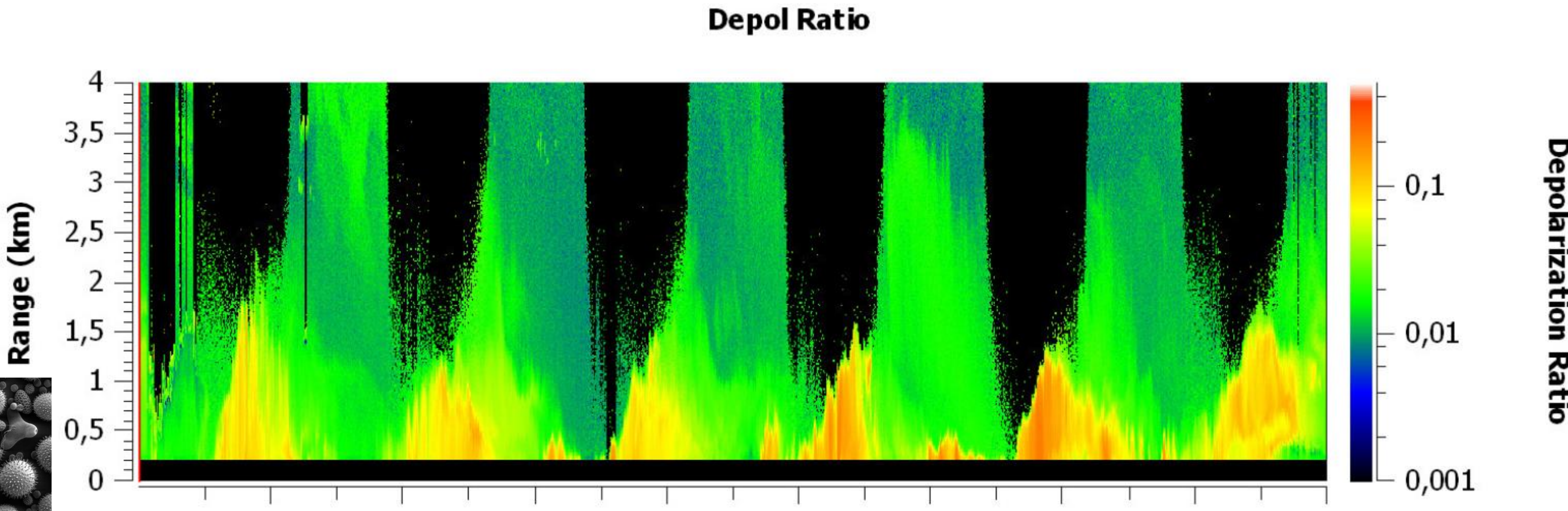






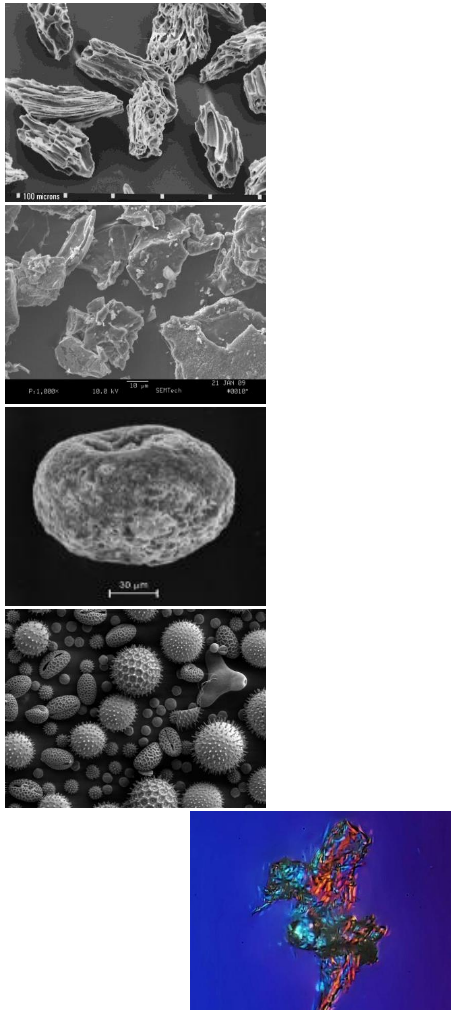


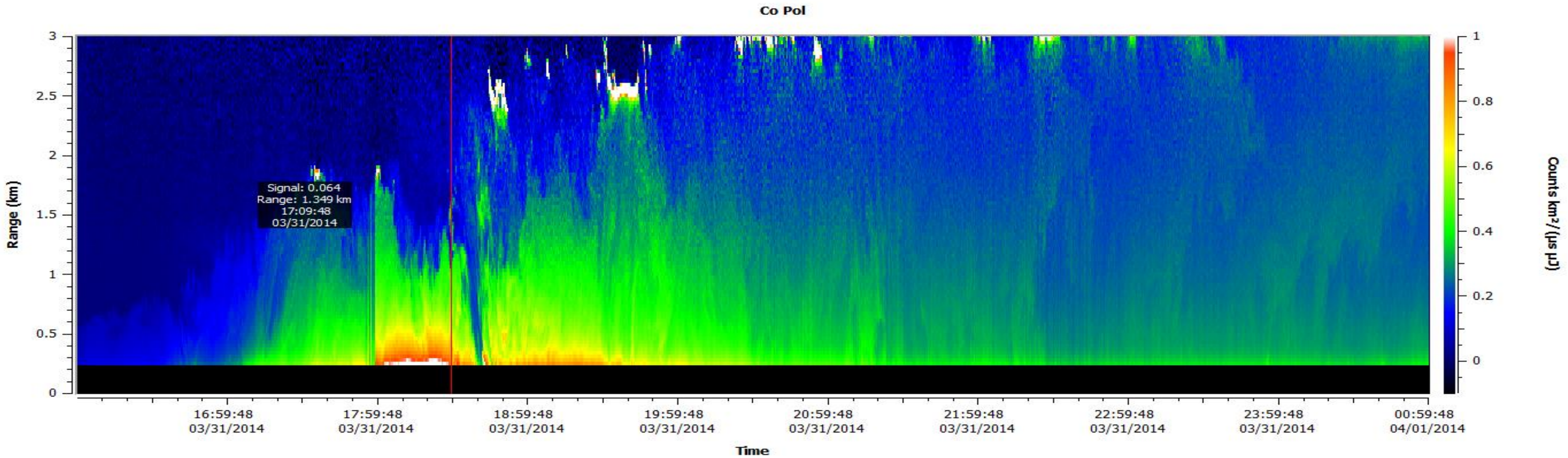


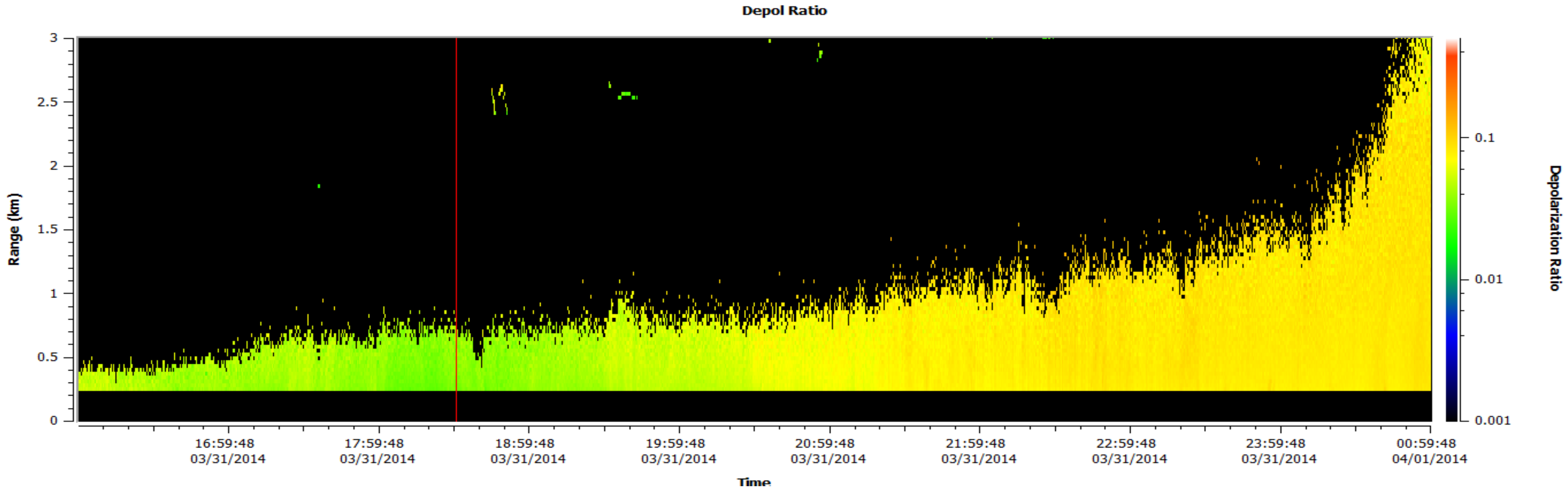


Volume depolarization ratio during 26-31 March, 2015, in Barcelona Spain. The yellow/orange features indicate the presence of pollen.

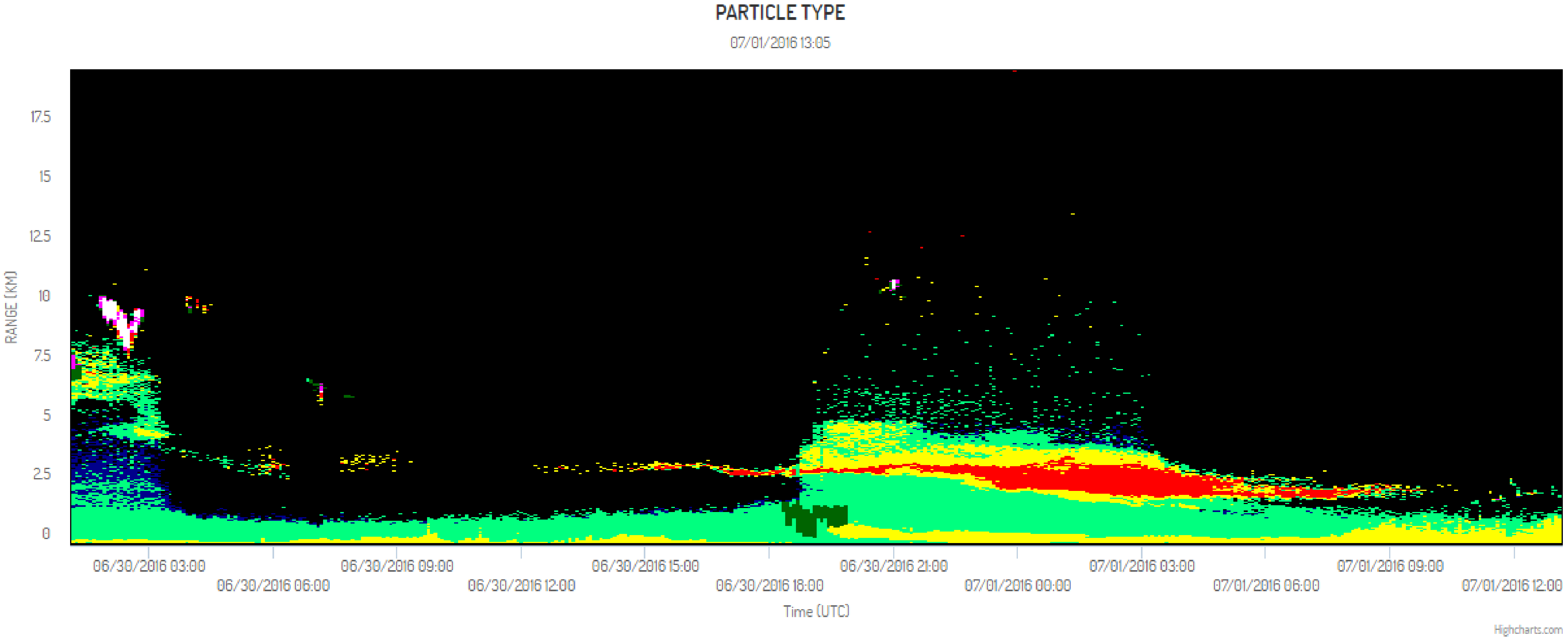
Traffic pollution growth during Mexico City rush hour







Aerosol auto classified in depol ratio data product



Particle Legend

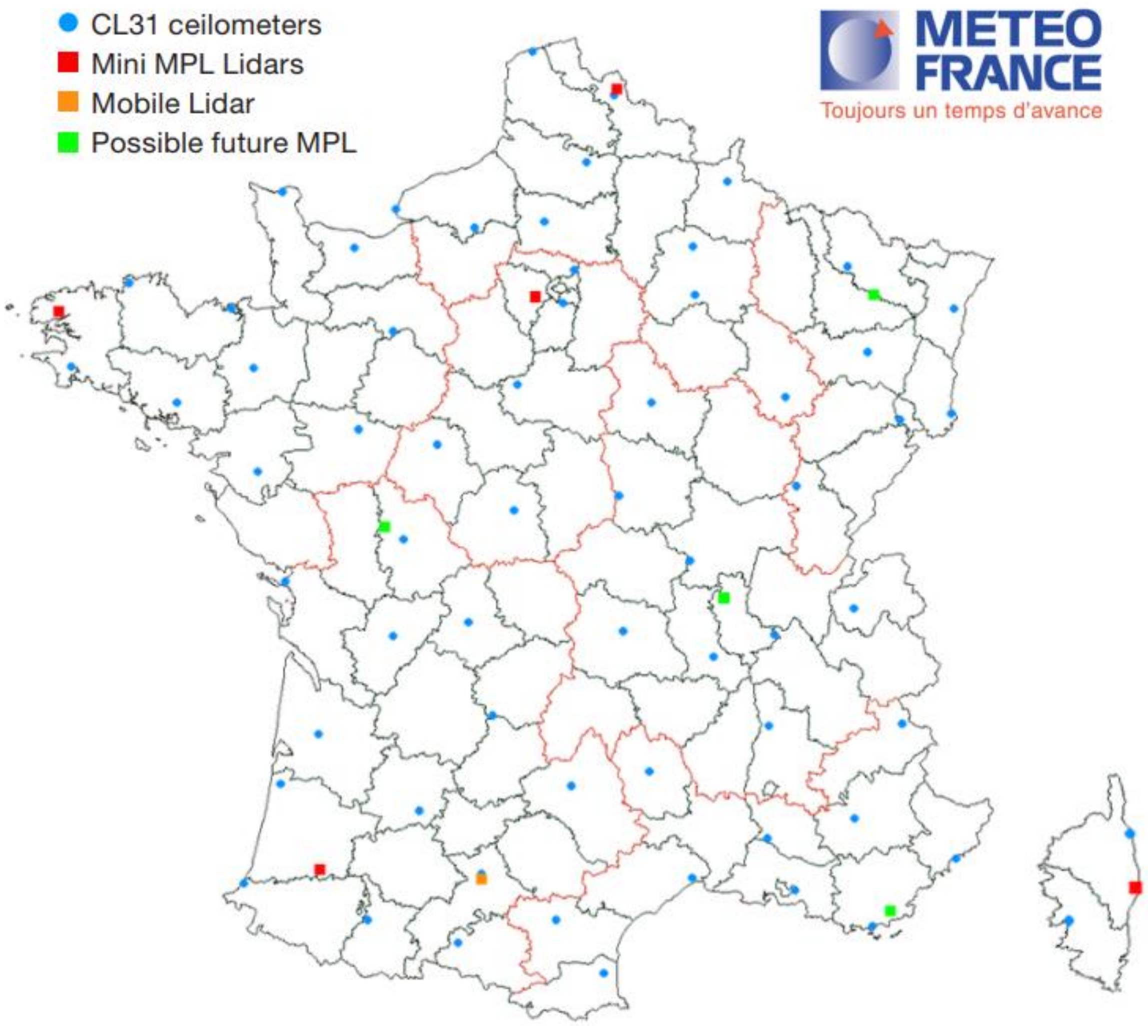
Water Cloud	Mixed Cloud	Ice / Dust / Ash
Rain / Dust	Molecular	Clean Aerosol
Polluted Aerosol	Undefined	

Taken in Potenza, Italy during Interact II campaign

Case IV - Dust events observed by the MétéoFrance Aerosol Lidar Network

Elisa Dubouchet and Gérard Rey, MétéoFrance, France
Justin Fisher, Droplet Measurement Technologies, LLC, USA
February 2017

MétéoFrance network – 97% uptime over 5 years



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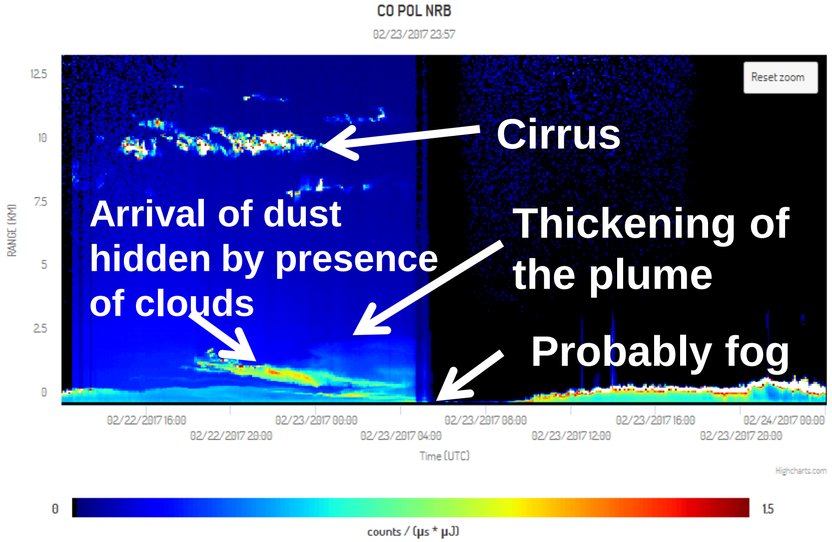
Dust events observed by the MétéoFrance Aerosol Lidar Network

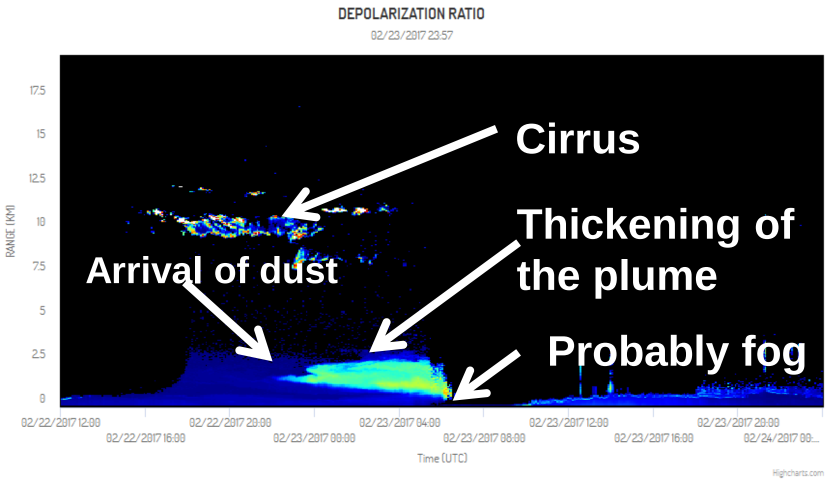
- Situation of February 23rd, 2017
  - During the night of 22-23 February 2017, a large plume of desert dust from North Africa (Sahara) reached southwestern France.
  - The dust event was tracked with observations from 3 lidar in (A) Momuy, (B) Toulouse, and (C) Aléria (Corsica) as the plume moved from the West, to the East across Southern France

2017, February, 27th
Thanks to Elisa Dubouchet and Gérard Rey

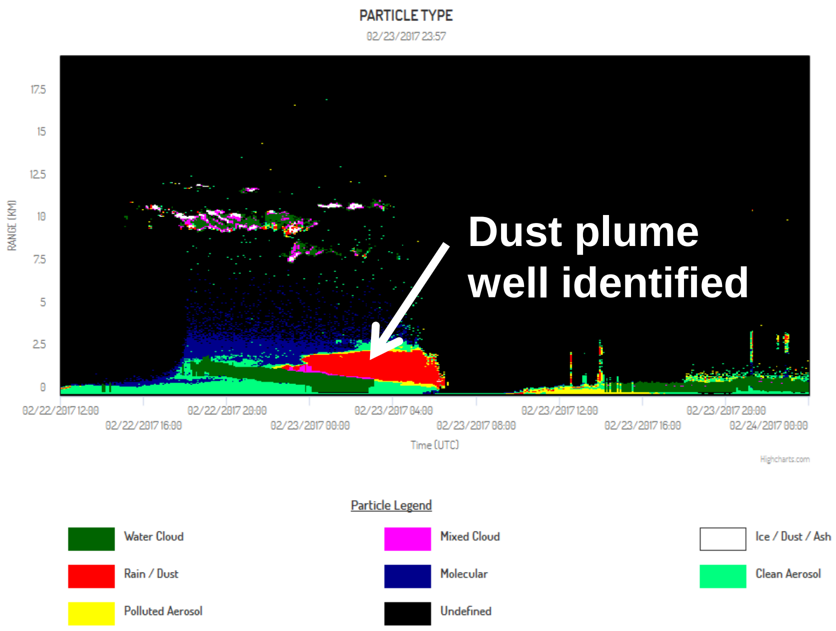
(A) Momuy - Feb 22nd-23rd 2017

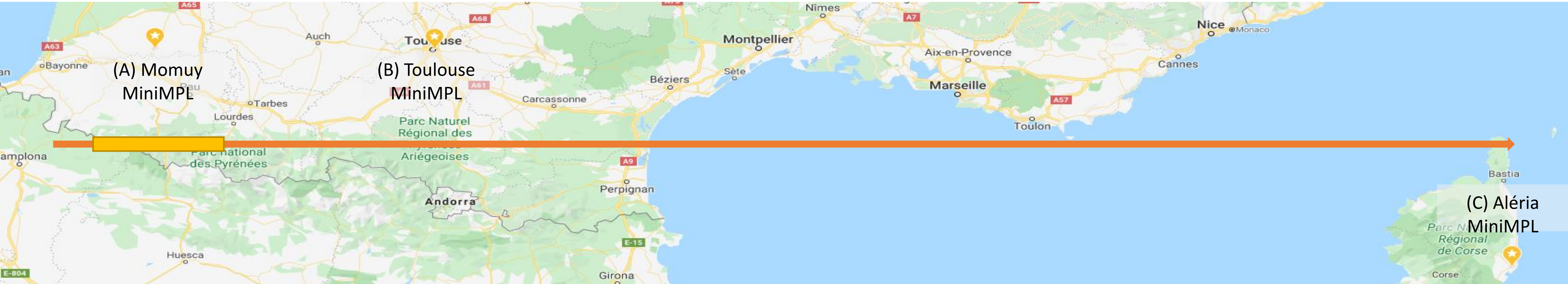


0 counts / (μs * μJ) 1.5

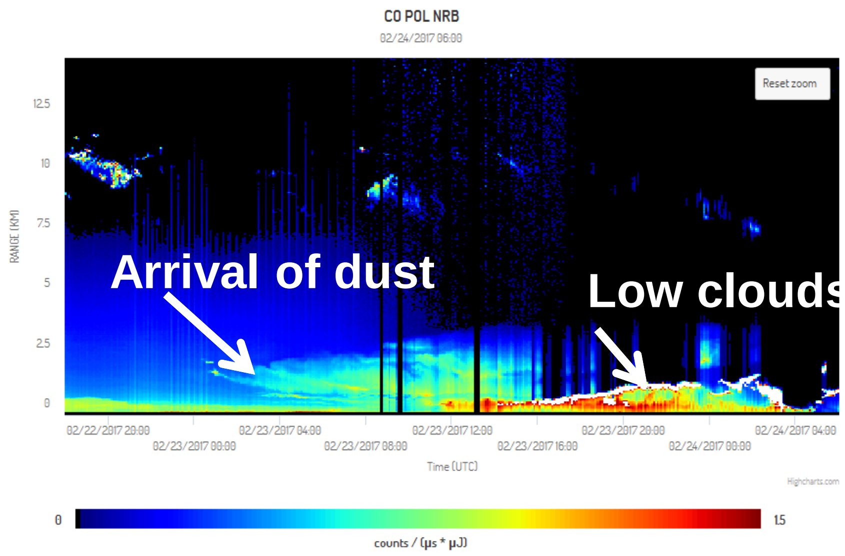


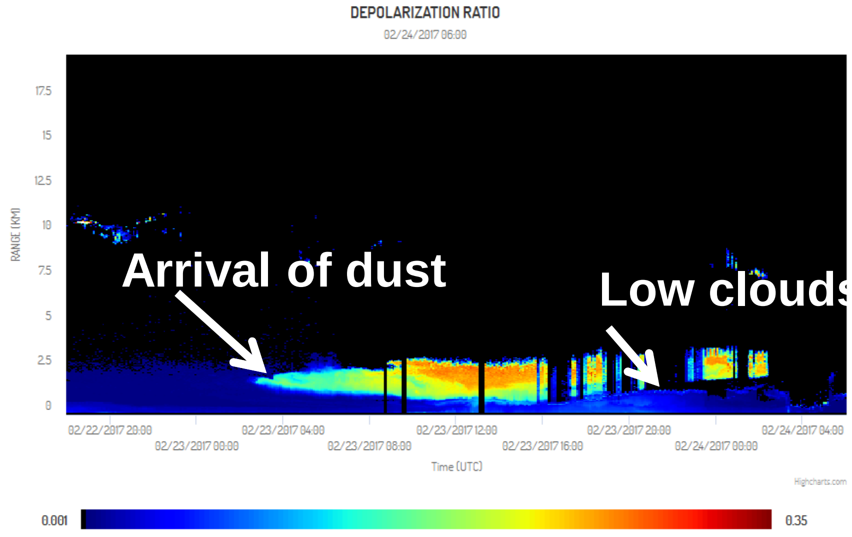
0.001 0.35

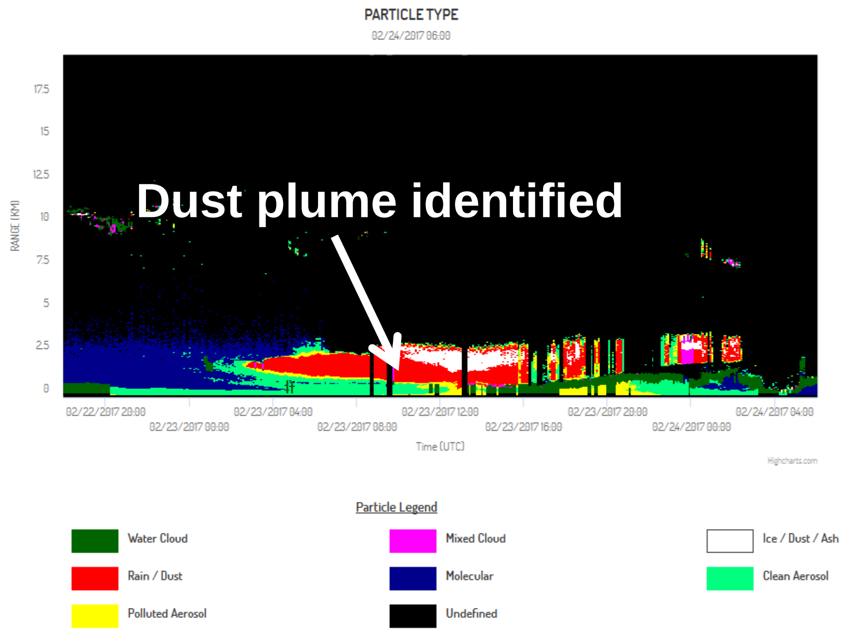


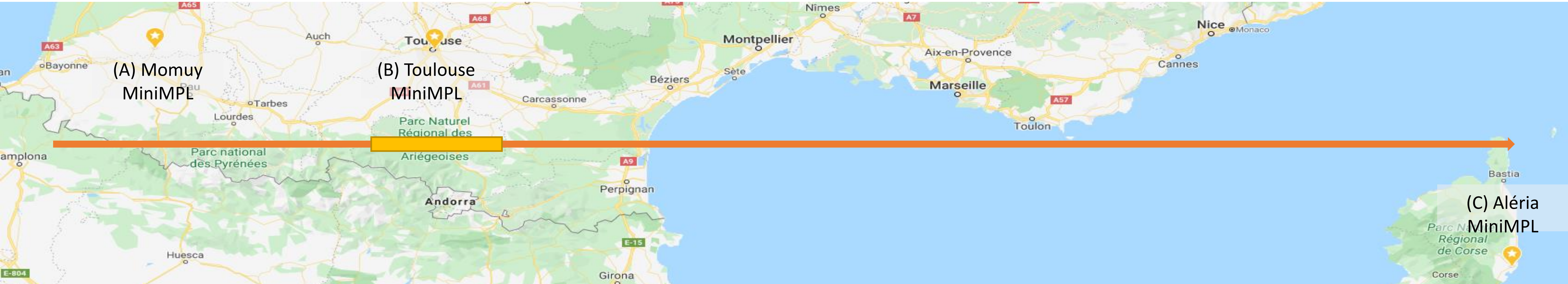


(B) Toulouse - Feb 23rd-24th 2017

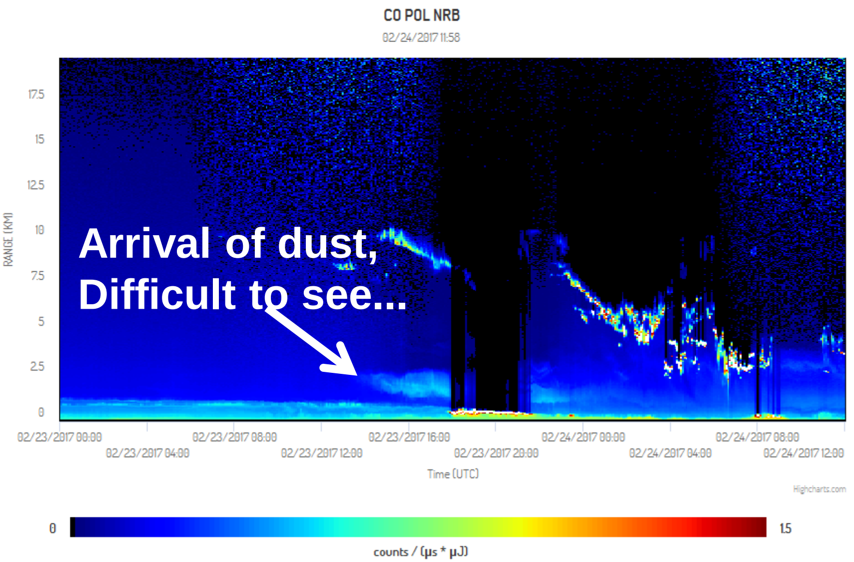


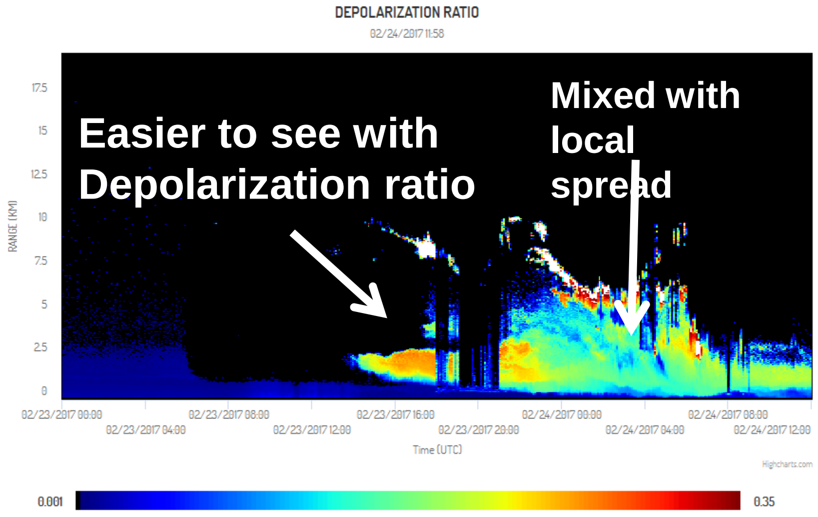


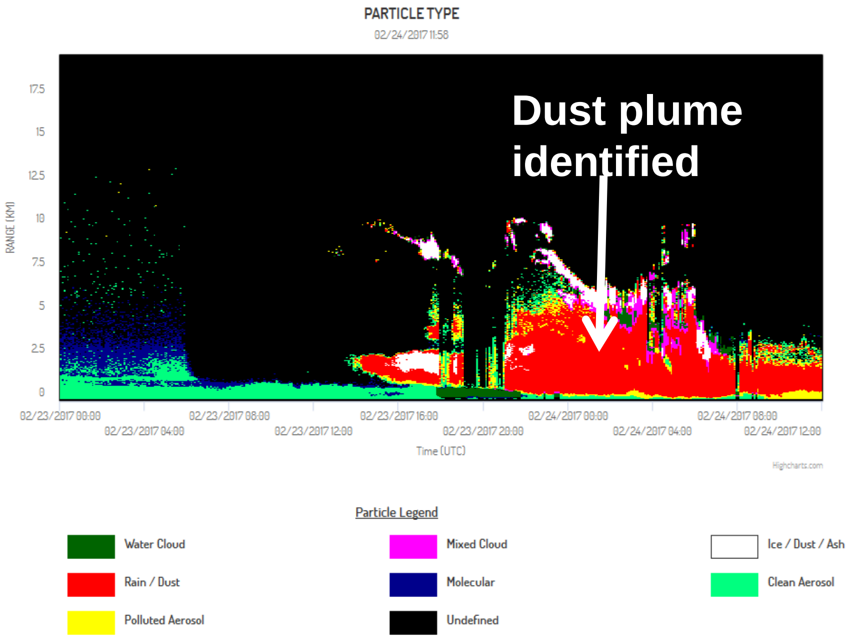


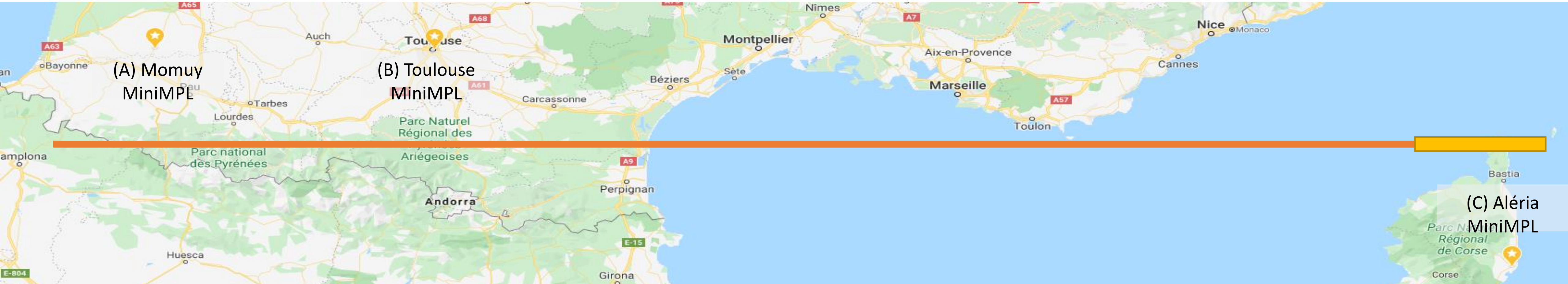


(C) Aléria - Feb 23rd-24th 2017









Micro Pulse Lidar standard products summary

- Normalized Relative Backscatter 1D/ 2D, Cross/ CO/ Unpolarized
- Cloud Base
- Cloud Top
- Cloud Peak (point of highest intensity)
- Planetary Boundary Layer
- Depolarization ratio 1D/ 2D
- Particle Type classification
- Extinction coefficient 1D/ 2D
- Total extinction 1D/ 2D
- Mass Concentration (with local calibration to PM10 and/or PM2.5) 1D/ 2D

Detailed specifications

PERFORMANCE	MPL	MiniMPL
Range resolution	5/15/30/75 m (software programmable)	5/15/30/75 m (software programmable)
Minimum range	250 m	100 m
Accumulation time	1 sec - 15 mins	1 sec - 15 mins
Detection range*	Typically to 25 km	Typically to 15 km
Polarization	Standard	Standard
Scanning	Not available	Optional

OPTICS	MPL	MiniMPL
Laser wavelength	532 nm	532 nm
Laser pulse energy	6 - 8 µJ @ 2500 Hz	3 - 4 µJ @ 2500 Hz
Eye-safety	ANSI Z136.1 2000, IEC 60825	ANSI Z136.1 2000, IEC 60825
Receiver diameter	178 mm	80 mm
Pump laser diode	Guaranteed to 10,000 hours	Guaranteed to 10,000 hours
Detector	Fiber coupled	Fiber coupled, user replaceable

DIMENSIONS	MPL	MiniMPL
Size	300 x 350 x 850 mm	240 x 305 x 480 mm
Weight (portability)	27 kg	13 kg

DATA	MPL	MiniMPL
Operating system	Windows 7/10	Windows 7/10
Computer interface	USB	USB
Data transfer	LAN ethernet	LAN ethernet

ENVIRONMENT	MPL	MiniMPL
Temperature	Operating +10°C to 35°C	Operating +10°C to 35°C
Humidity	0 to 80%	0 to 80%

POWER	MPL	MiniMPL
Supply	110-240 VAC 50-60 Hz	110-240 VAC 50-60 Hz
Consumption	500 W	100 W

** Choosing a coarser resolution results in a longer detection range. Sample data is based on a 30s/30m setting.*

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