# Aerosols

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# Atmospheric Aerosols

**TABLE 1.1 Types of Particulate Suspensions**

| Suspending Medium | Type of Suspended Particles | | |
|---|---|---|---|
| | Gas | Liquid | Solid |
| Gas | — | Fog, mist, spray | Fume, dust |
| Liquid | Foam | Emulsion | Colloid, suspension, slurry |
| Solid | Sponge | Gel | Alloy |

Hinds 1998. Aerosol technology: properties, behavior, and measurement of airborne particles. 2nd edition.

*Aerosol* → A suspension of solid, liquid, or combined solid-liquid particles in a gas, which is usually air.

The term "*aerosol*" includes both the particles and the suspending gas.

# Types of Aerosols

- Based on their **formation processes**, aerosols are either *primary* or *secondary*:
  - **Primary aerosols** are directly emitted to the atmosphere or formed in the atmosphere by condensation or coagulation without chemical reactions.
  - **Secondary aerosols** are formed in the atmosphere by gas-to-particle conversion processes:

- Based on their **sources**, aerosols are either *natural* or *anthropogenic*:
  - **Anthropogenic aerosols** are somehow related to human activities (fossil fuel burning, industrial processes, traffic, burning of biomass or biofuel, agricultural activities, etc.)

# Main Types of Anthropogenic Aerosols

- Categories of anthropogenic aerosols:
- Combustion (energy, transformation industries, non-industrial plants, manufactories, etc.)
- Production processes
- Extraction and distribution of fossil fuels and geothermal energy
- Solvent use and other product use
- Road transport
- Other mobile sources and machinery
- Waste treatment and disposal
- Agriculture

| Type | Origin | Prim./Second. | Typical size |
|---|---|---|---|
| soot | combustion | primary | fine |
| fly ash | combustion | primary | coarse |
| secondary organic aerosol | oxidation of volatile organic compounds (anthropogenic) | secondary | fine |
| sulfate aerosol | oxidation of $SO_2$ emitted by anthropogenic sources | secondary | fine |

# Main Types of Natural Aerosols

| Type | Origin | Prim./Second. | Typical size |
|---|---|---|---|
| sea-salt | sea-surface | primary | coarse |
| desert dust | soil | primary | coarse |
| biogenic | | | |
| type 1 | vegetation | primary | coarse |
| type 2 | oxidation of monoterpenes emitted by trees | secondary | fine |
| sulfate particles | | | |
| type 1 | oxidation of DMS emitted by the sea surface | secondary | fine |
| type 2 | oxidation of $SO_2$ emitted by volcanos | secondary | fine |

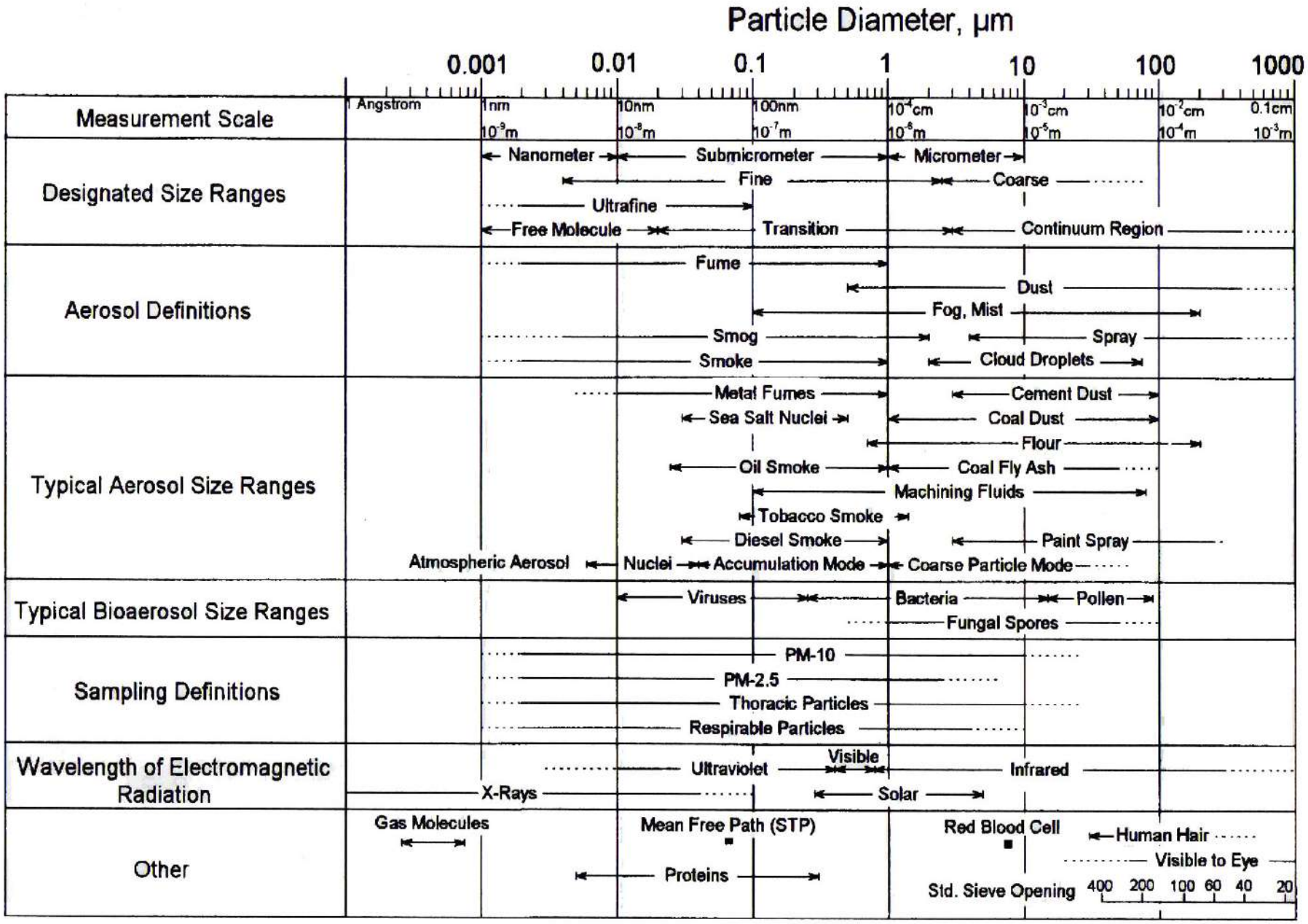
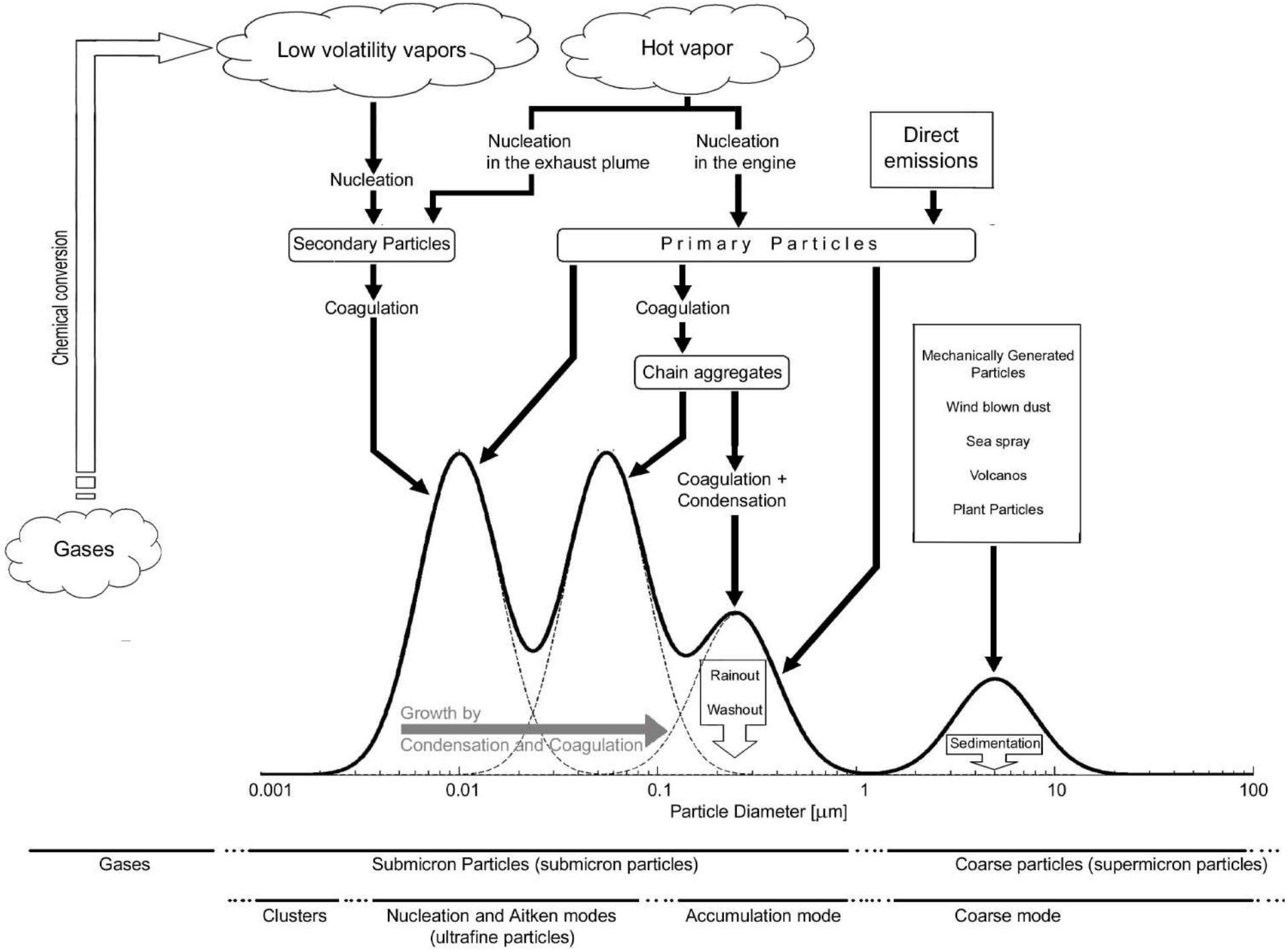



**FIGURE 1.6** Particle size ranges and definitions for aerosols.

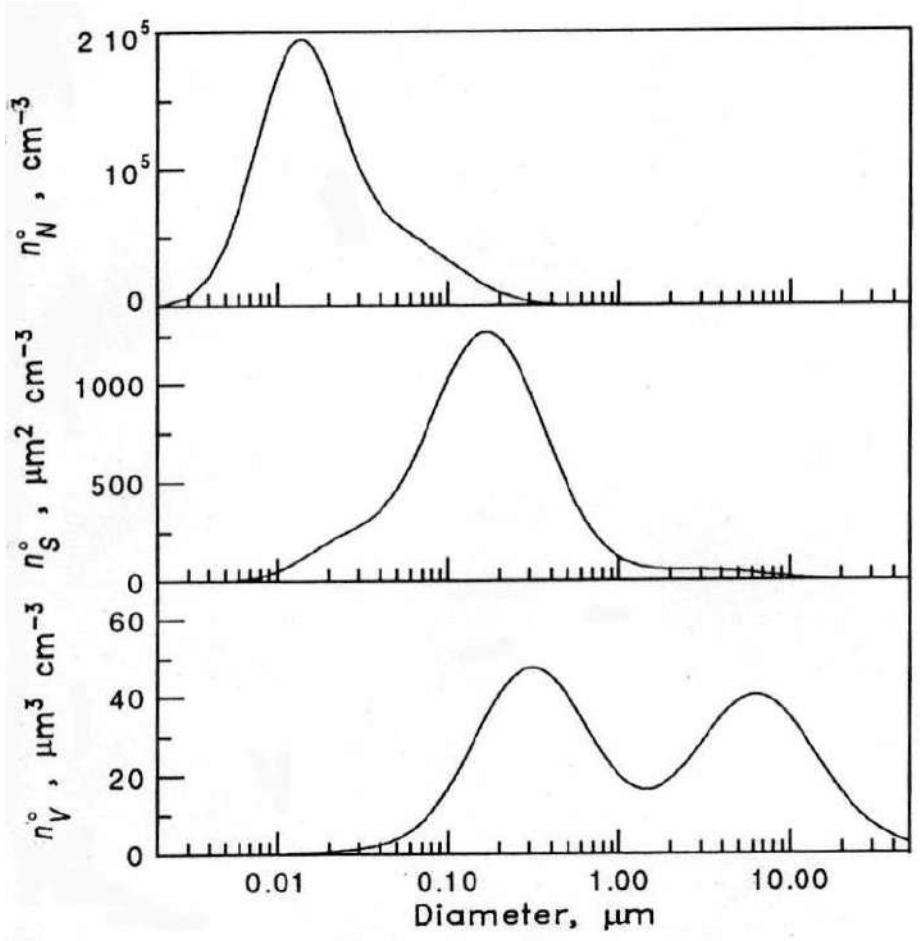
Hinds 1998. Aerosol technology. 2nd edition.


Low volatility vapors
Hot vapor
Nucleation
Nucleation in the exhaust plume
Nucleation in the engine
Direct emissions
Secondary Particles
Primary Particles
Coagulation
Coagulation
Chain aggregates
Coagulation + Condensation
Mechanically Generated Particles
Wind blown dust
Sea spray
Volcanos
Plant Particles
Chemical conversion
Gases
Rainout
Washout
Growth by
Condensation and Coagulation
Sedimentation
0.001
0.01
0.1
1
10
100
Particle Diameter [µm]
Gases
Submicron Particles (submicron particles)
Coarse particles (supermicron particles)
Clusters
Nucleation and Aitken modes (ultrafine particles)
Accumulation mode
Coarse mode

# Representations of Aerosol Concentrations

Aerosol particle concentrations can be expressed by Number, Surface area, Volume, or Mass per unit volume:

- The number concentration is dominated by the ultrafine aerosols.
- The mass concentration is dominated by the coarse and accumulation aerosols.

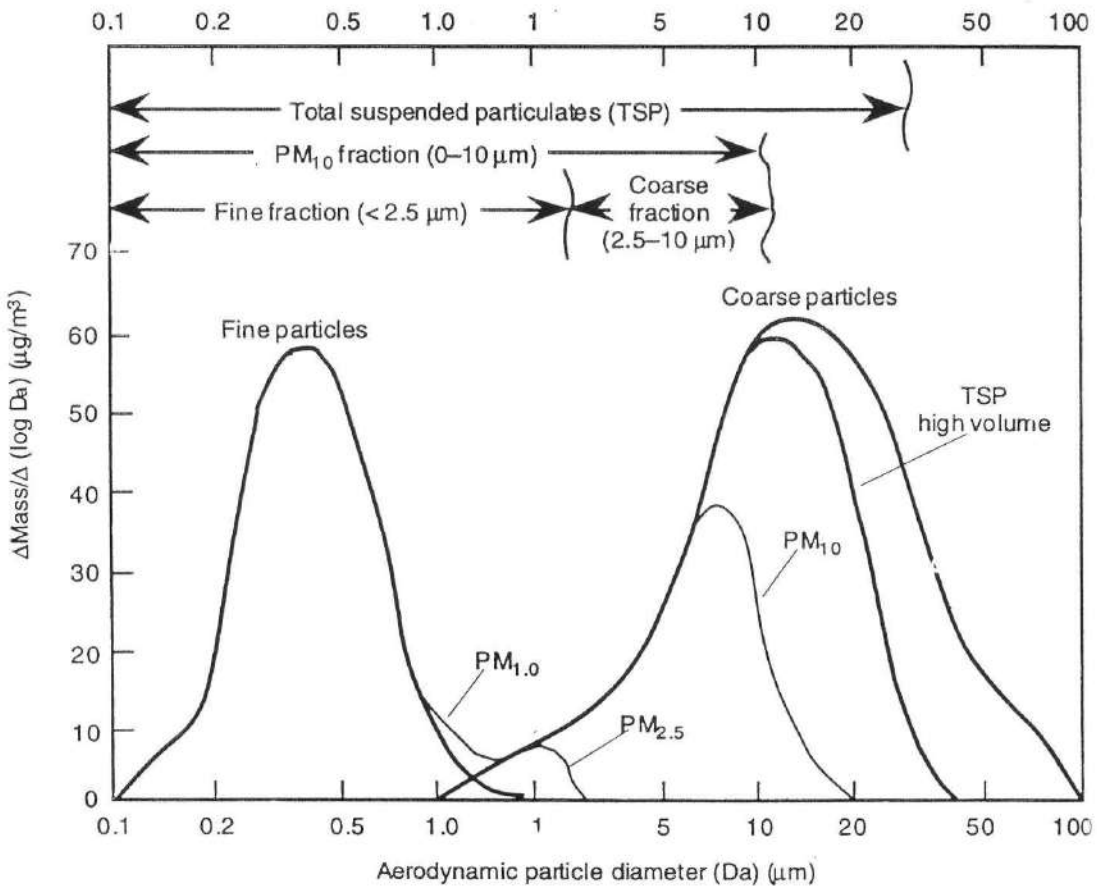


# Particulate Mass Concentration

Particulate Matter (PM) refers to mass concentrations of all aerosol particles smaller than a certain aerodynamic diameter:

$PM_{10}$ → 10 μm

$PM_{2.5}$ → 2.5 μm



# Variation of Aerosol Concentrations

- Concentration varies depending on location and time → high concentrations are encountered nearby sources.

| | PN [$cm^{-3}$] | $PM_{10}$ [$\mu g/m^3$] |
|---|---|---|
| Lower troposphere:<br>-Urban traffic<br>-Urban background<br>-Rural<br>-Marine<br>-Remote | > 100 000<br>10 000 – 50 000<br>500 – 10 000<br>200 – 5000<br>50 – 500 | > 20<br>20 – 100<br>10 – 50<br>5 – 20<br>0.02 – 1 |
| Free troposphere | 100 – 100 000 | 0.02 – 1 |
| Stratosphere (background) | 1 – 20 | 0.02 – 0. |

# Physical Properties

- Particle size is the most important parameter for characterizing the behaviour of aerosols. All properties of aerosols depend on particle size.

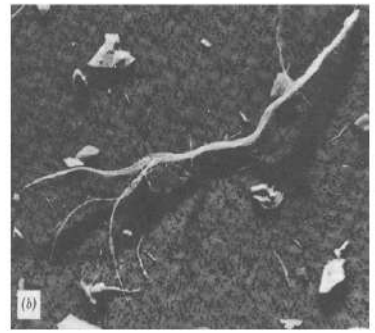
- Shape:
  - Liquid aerosol particles are nearly always spherical.
  - Solid aerosol particles usually have complex shapes.

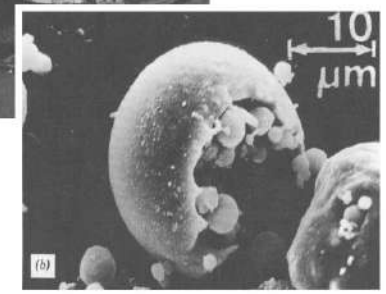
- Density:
  - Liquid particles and crushed or ground solid particles have a density equal to their parent material.
  - Smoke and fume particles may have apparent densities significantly less than that predicted from their chemical composition.

- Surface area.

- Volume.

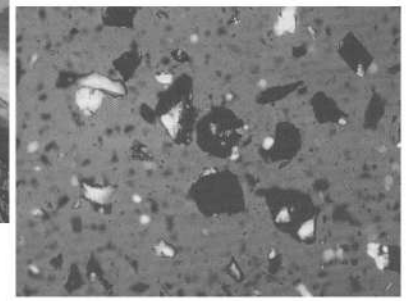
Asbestos

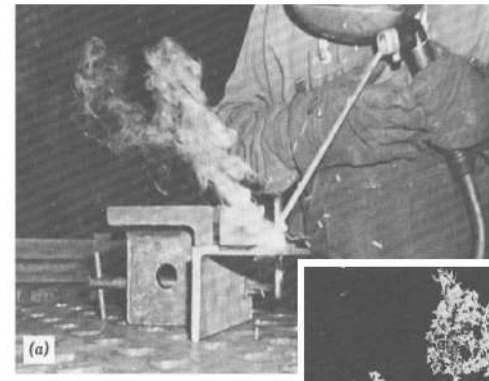


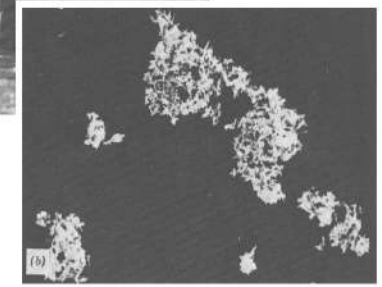



Coal

Volcanoes







Wielding

# Chemical and Elemental Composition

- **Inorganic ions** (sulfate ($SO_4^{2-}$), nitrate ($NO^{3-}$), ammonium ($NH^{4+}$), sodium ($Na^+$), chloride ($Cl^-$), calcium ($Ca^{2+}$), potassium ($K^+$), magnesium ($Mg^{2+}$), etc.)
- **Organic compounds**: About 10–70% of fine aerosols is organic compounds. While the inorganic component of atmospheric aerosol particles is well characterized, information about the organic component is sparse at the present time.
- **Black carbon** (also called “elemental carbon”)
- **Soil-derived compounds** (mainly oxides of Si, Al, Fe, Ca, K, Mg)
- **Trace elements** (heavy metals, etc)
- **Water** (the amount of water on a particle depends on particle hygroscopic properties and atmospheric humidity; at relative humidities >80% typically more than half of the particle mass is made of water)
- Recently, atmospheric aerosol particles were found to have polymeric organic compounds.

# Volatility

- Based on their phase (gas or particle), the organic compounds can be
  - *none-volatile*,
  - *volatile*, and
  - *semi-volatile*.

- The volatile components remain in the gas phase.

- Semi-volatile components are able to transfer reversibly between the gas phase and the particle phase depending on their physical-chemical properties and the ambient conditions.

# Processes Modifying Atmospheric Aerosols

- Processes affecting the concentration and other properties (size, chemical composition) of atmospheric aerosols include:
  - Emissions (primary particles, emissions of aerosol precursor gases)
  - Atmospheric transportation
  - Deposition from the atmosphere to surfaces (ground, vegetation, water)
  - Aerosol dynamics and chemistry

# Significance of Atmospheric Aerosols

- climate change
- Human health effects
- Acidification of soil and water
- Visibility degradation
- Atmospheric chemistry

# Loss of visibility due to traffic and industrial emissions in Cairo, Egypt
# تردي الرؤية بسبب إنبعاثات عوادم وسائط النقل و الصناعة في القاهرة، مصر

A working day
يوم عمل

A weekend day
يوم في نهاية الأسبوع

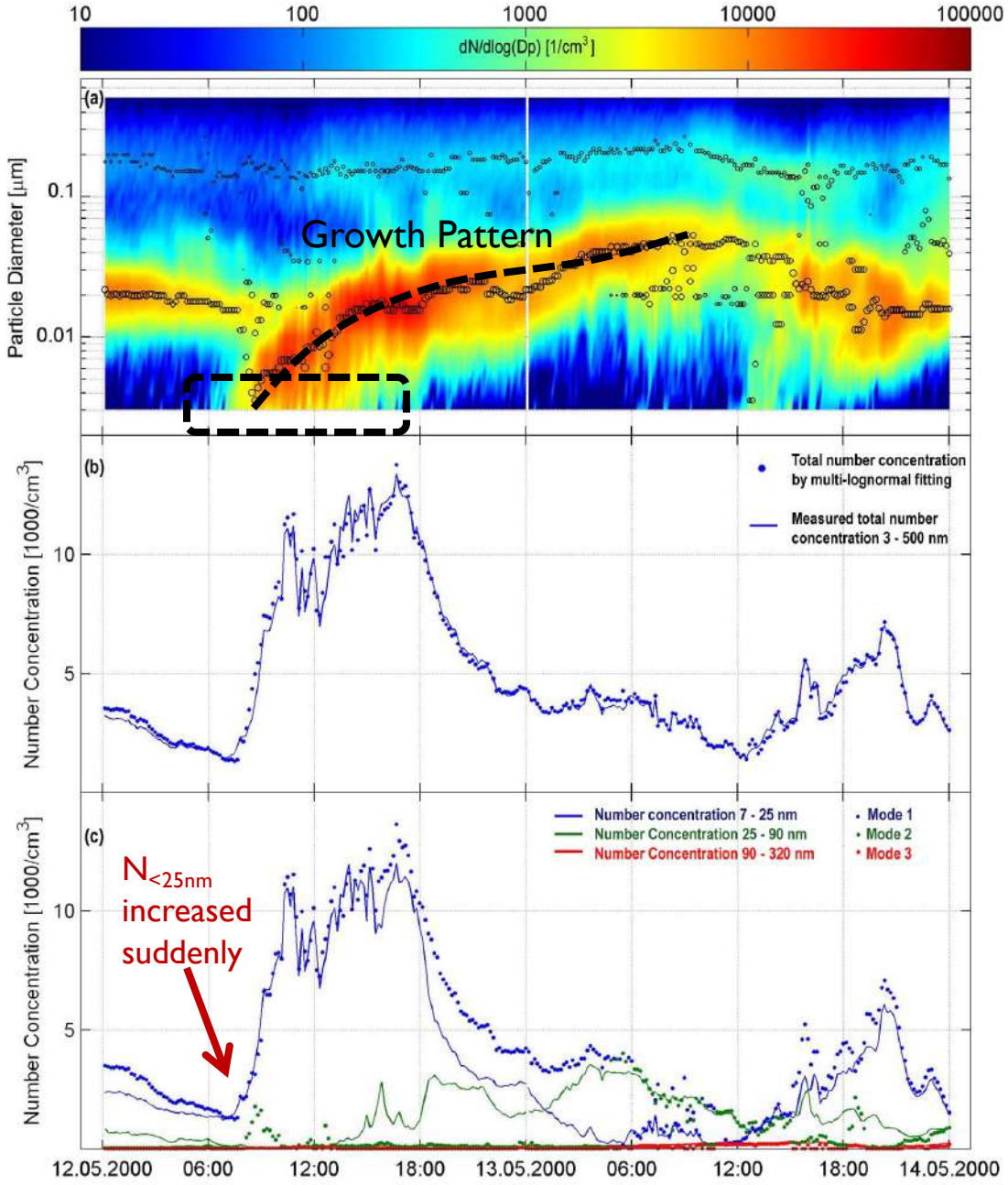
# Loss of visibility due to sand storm episode in Amman, Jordan
# تردي الرؤية بسبب عواصف رمالية في عمان، الأردن

A dusty day
يوم عاصف بالرمال

A clear day
يوم نقي

# Case Studies and Examples

New Particle Formation




An example of new particle formation event observed at SMEAR-II

Boreal forest

Southern Finland

**Why do we observe such a growth pattern after a new particle formation event?!**

# NPF Occurrence

- NPF observations have been reported almost anywhere on the Earth

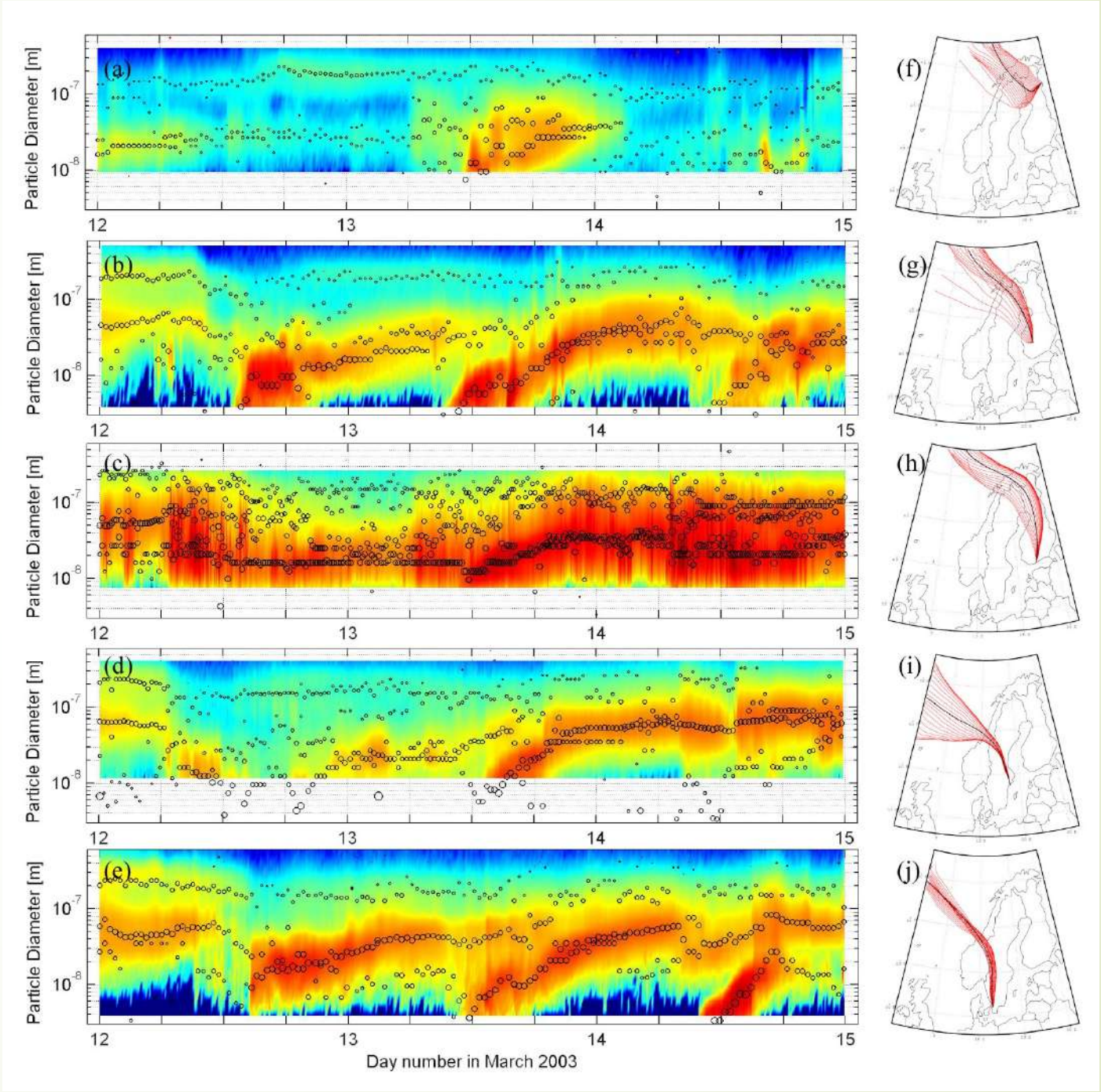
- <u>NPF not observed</u>?!

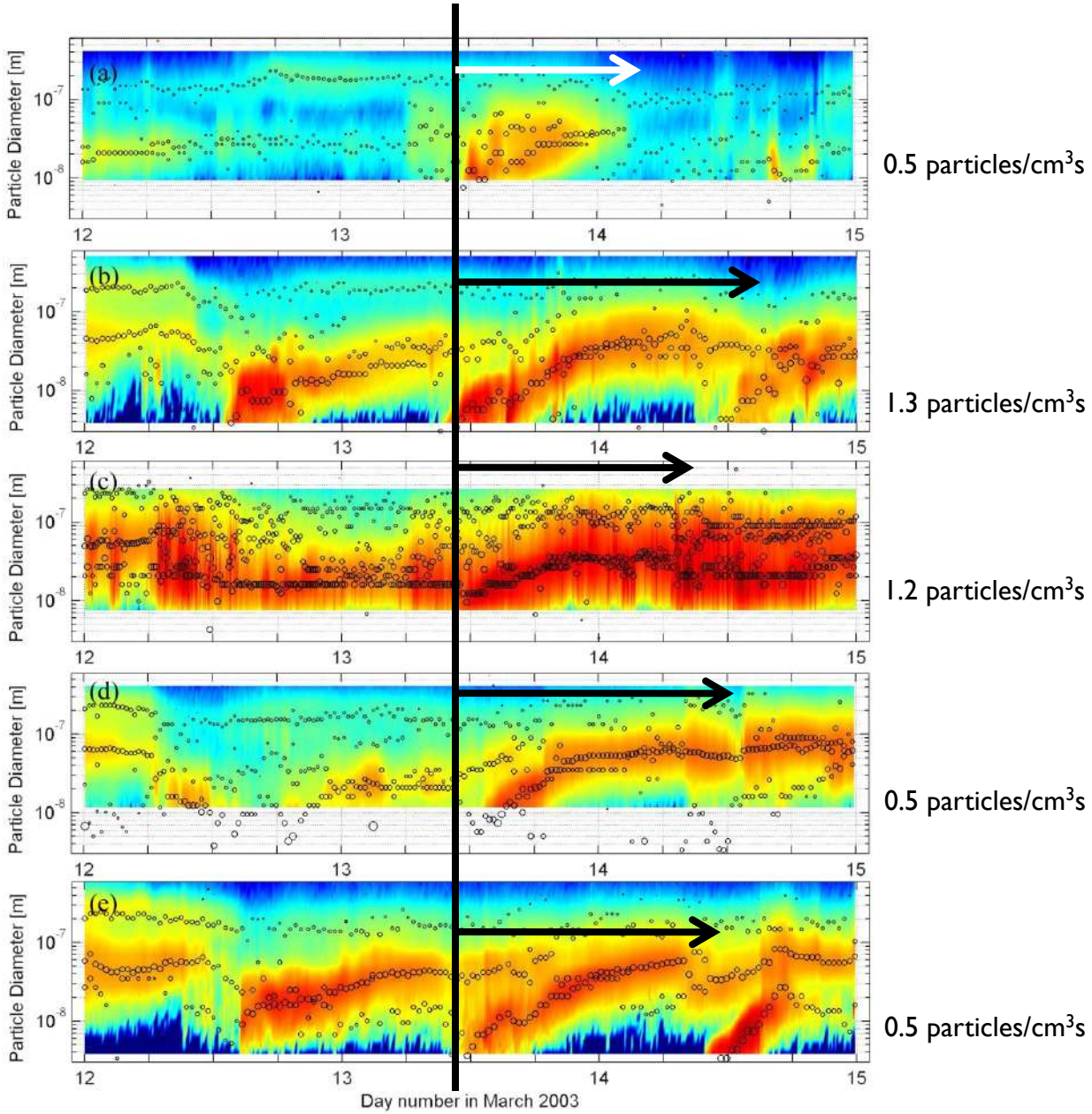
  formed particles survive when their formation rate exceeds their removal rate

  instrument limitations are important factors

  High concentrations

- The longer the time-span of an observed NPF event is the larger the spatial-scale of the event occurrence



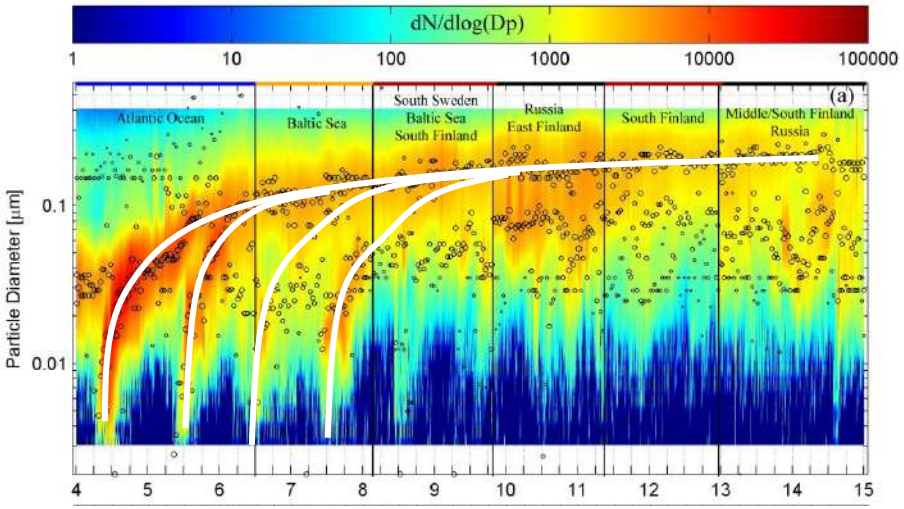



# Case Study I:

**Regional new particle formation over Finland and Southern Sweden:**

Observed at the same time
Similar air masses ±12 hours of the event start time
Time Span 20–24 hours
GR 2–3.5 nm/h
Formation rate varied

**Slight differences!**
Data quality and processing
Measured size-range
Local ambient conditions




**… the suppression of particle formation on the following days …**

- As the first nucleated particle mode grows, it forms a condensation sink, which grows together with the increasing particle diameter, despite the slow decrease of the particle number.
- This sink possibly acts as a sink for both nucleating vapors and fresh particles or clusters, and therefore particle formation on subsequent days is progressively weaker and finally ceases altogether.
- Despite the lack of particle number production, the aerosol mass continues to grow, demonstrating the availability of condensable vapors.

Similar modal structure in Helsinki

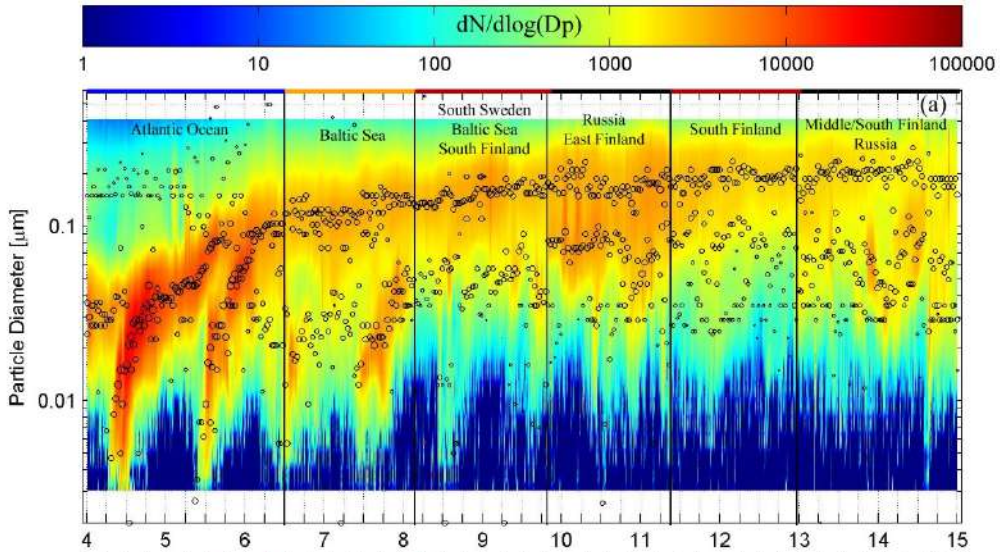
# Case Study II: Long Time Span

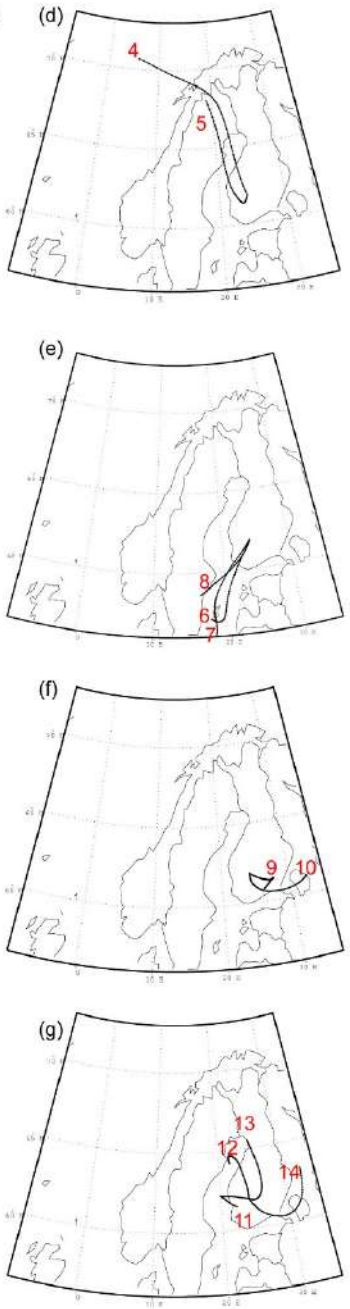
Phase I: clean air from the Atlantic Ocean

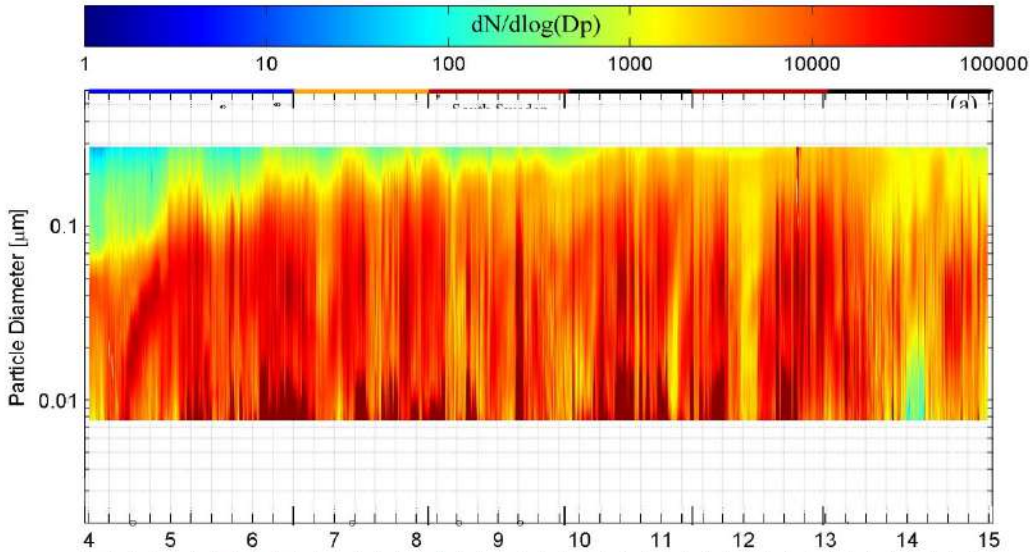
Phases II and III: mixed from the Baltic See and South Sweden

Phase IV: Russia and East Finland

Phases V and VI: South/Middle/East Finland

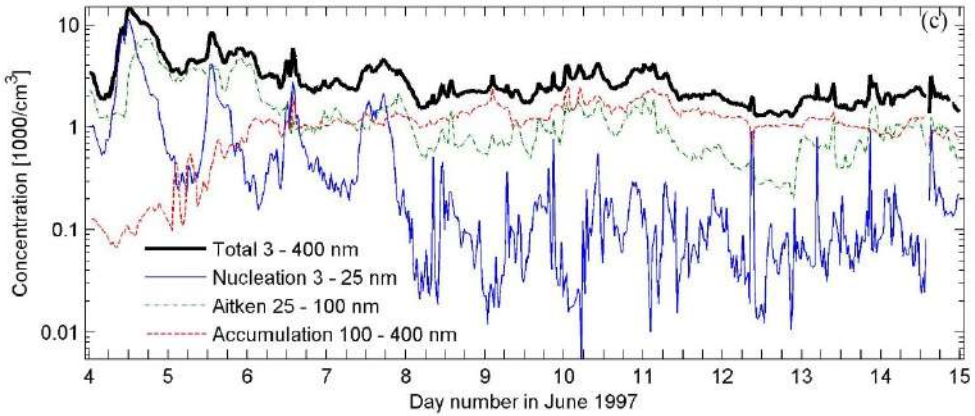


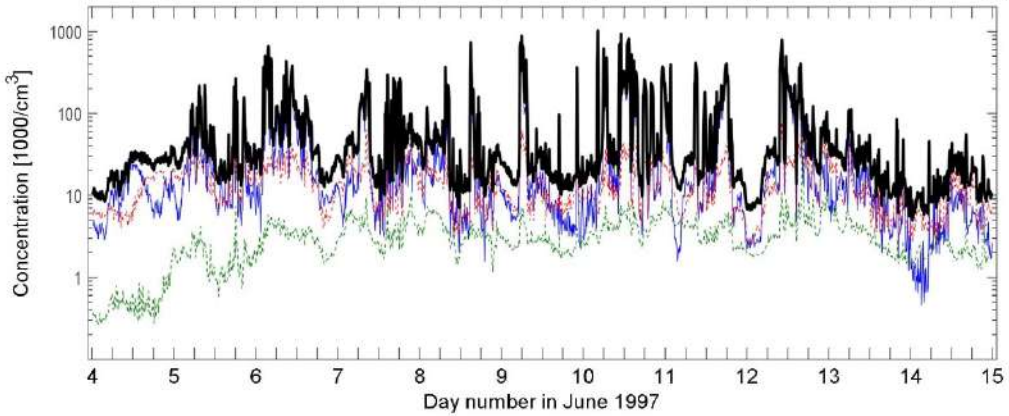



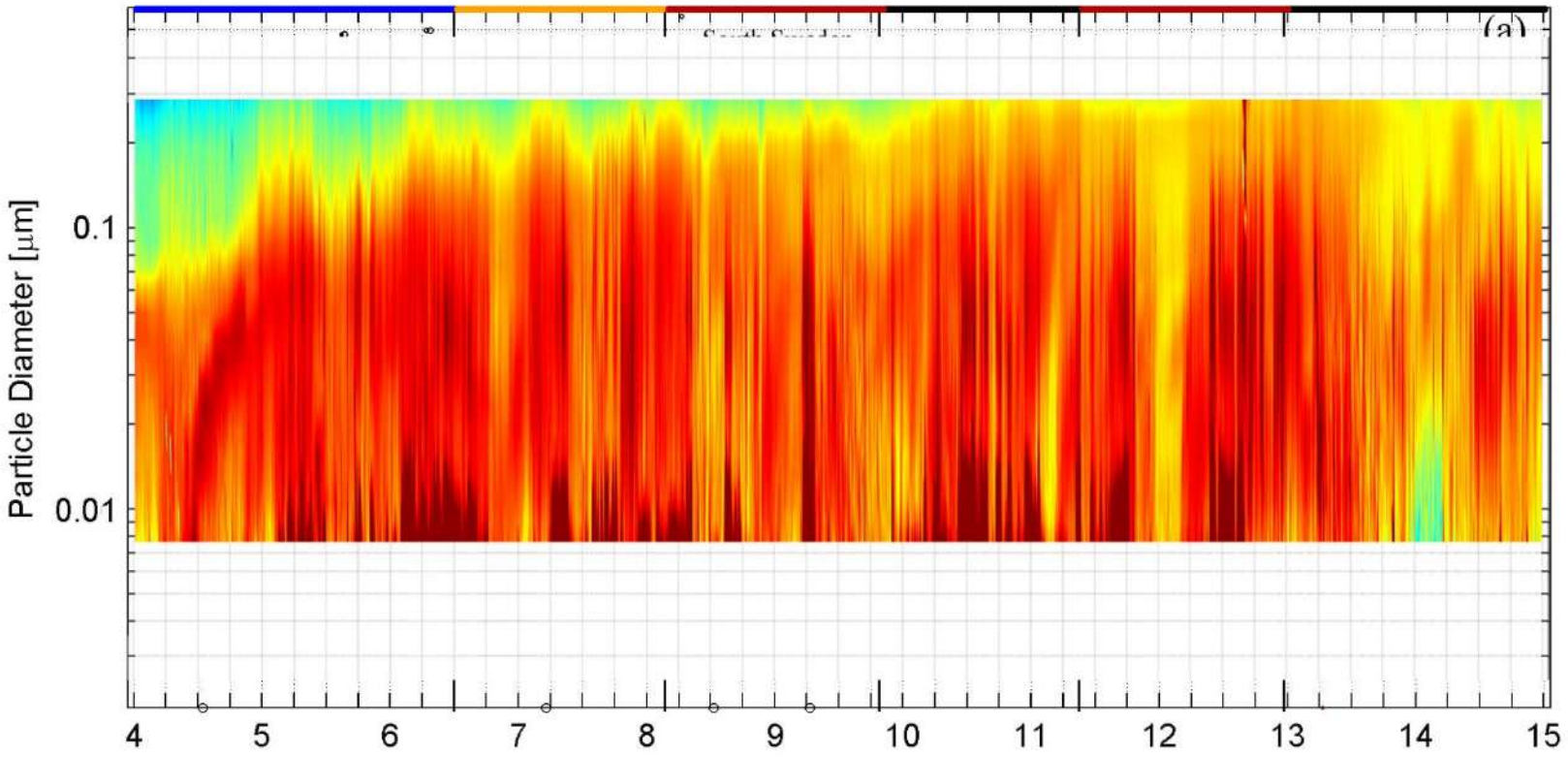



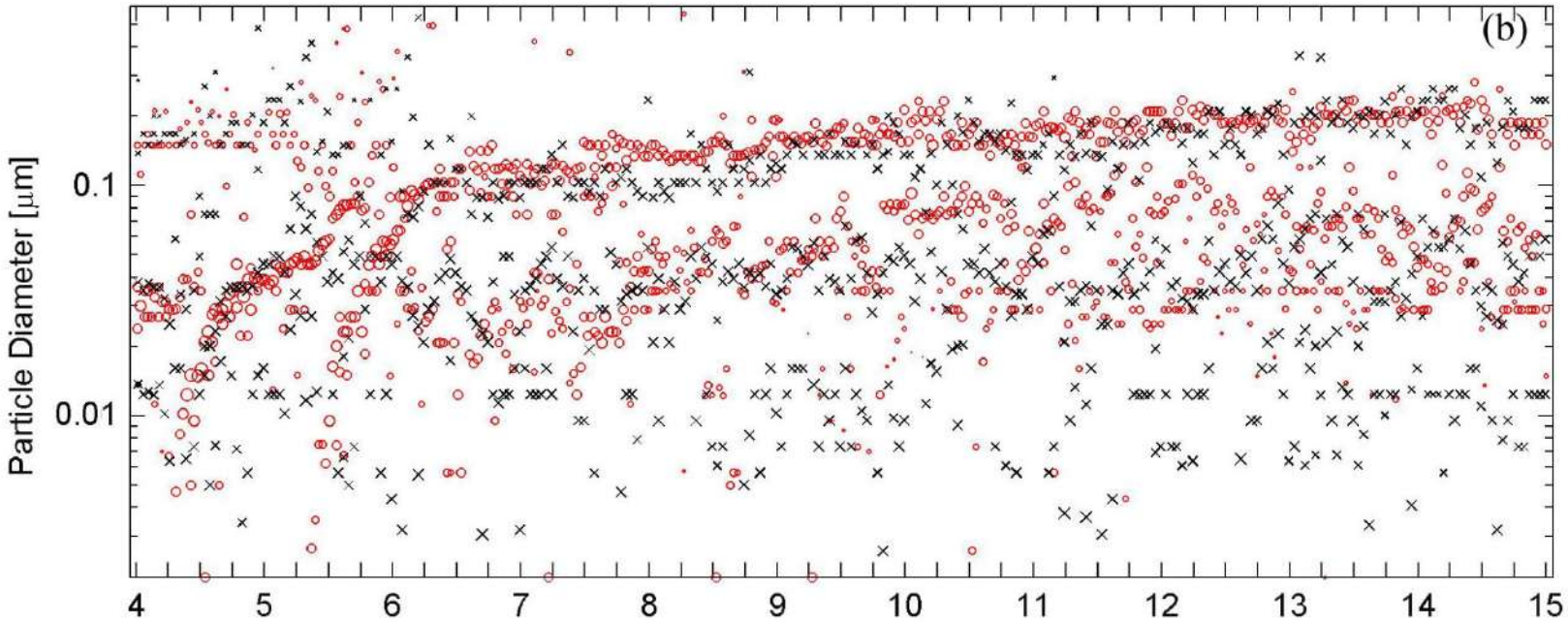

# Boreal Forest Southern Finland

# Urban Southern Finland






In urban areas, high concentrations from other sources may mask the NPF

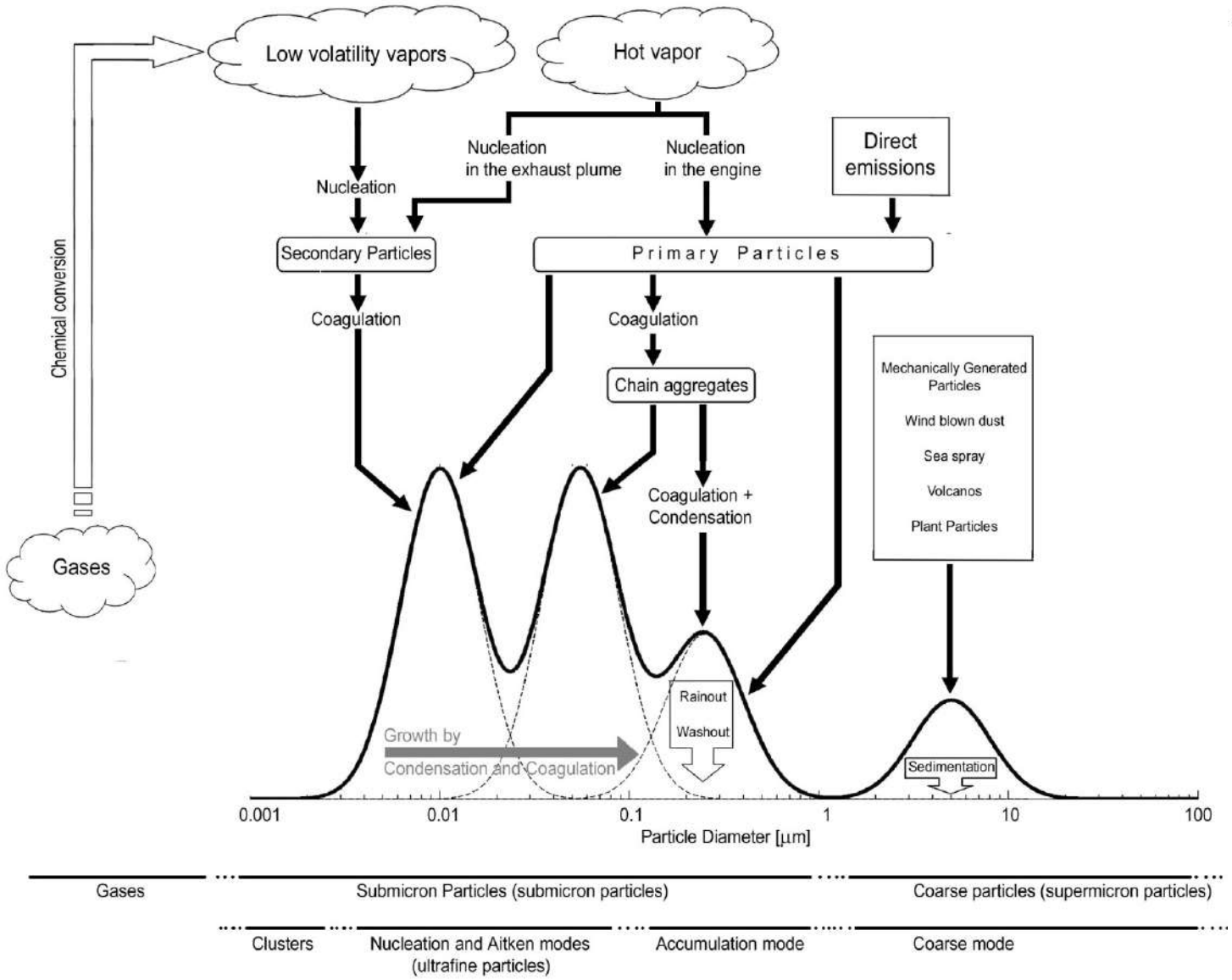
BUT it is happening!

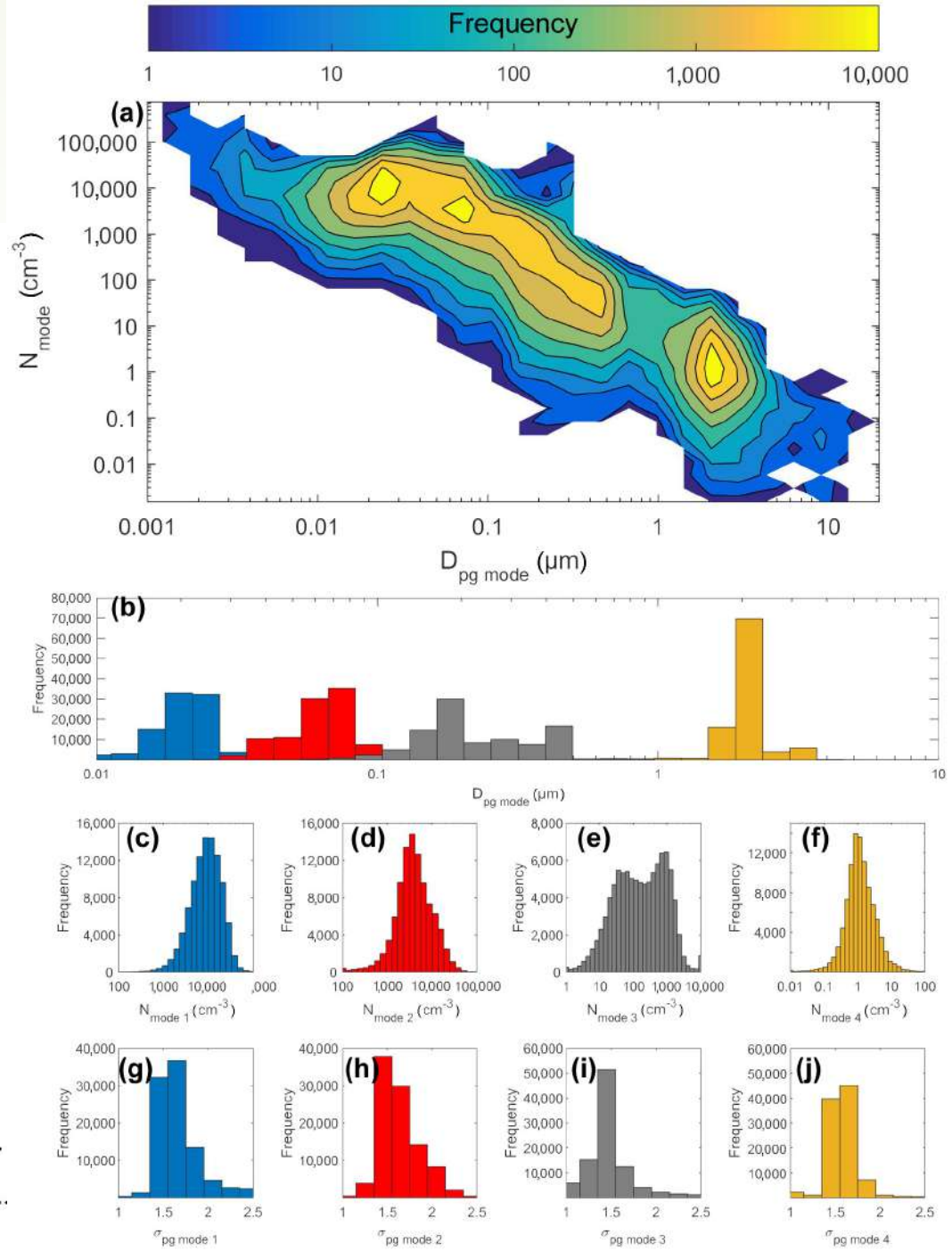
Multi-lognormal analysis might reveal the occurrence of NPF

# Case Studies and Examples

Urban Aerosols Modal Structure

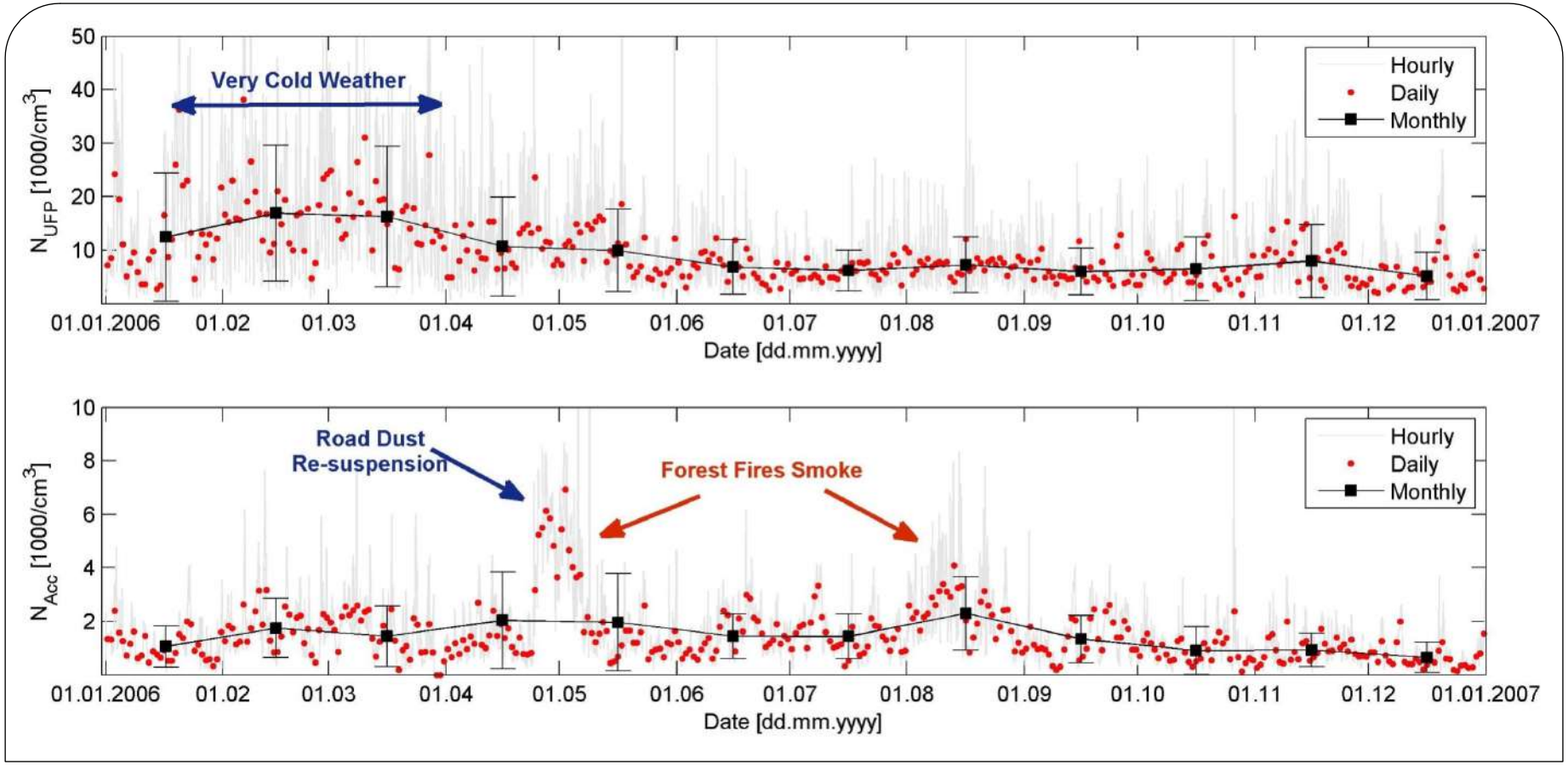
# Modal Structure



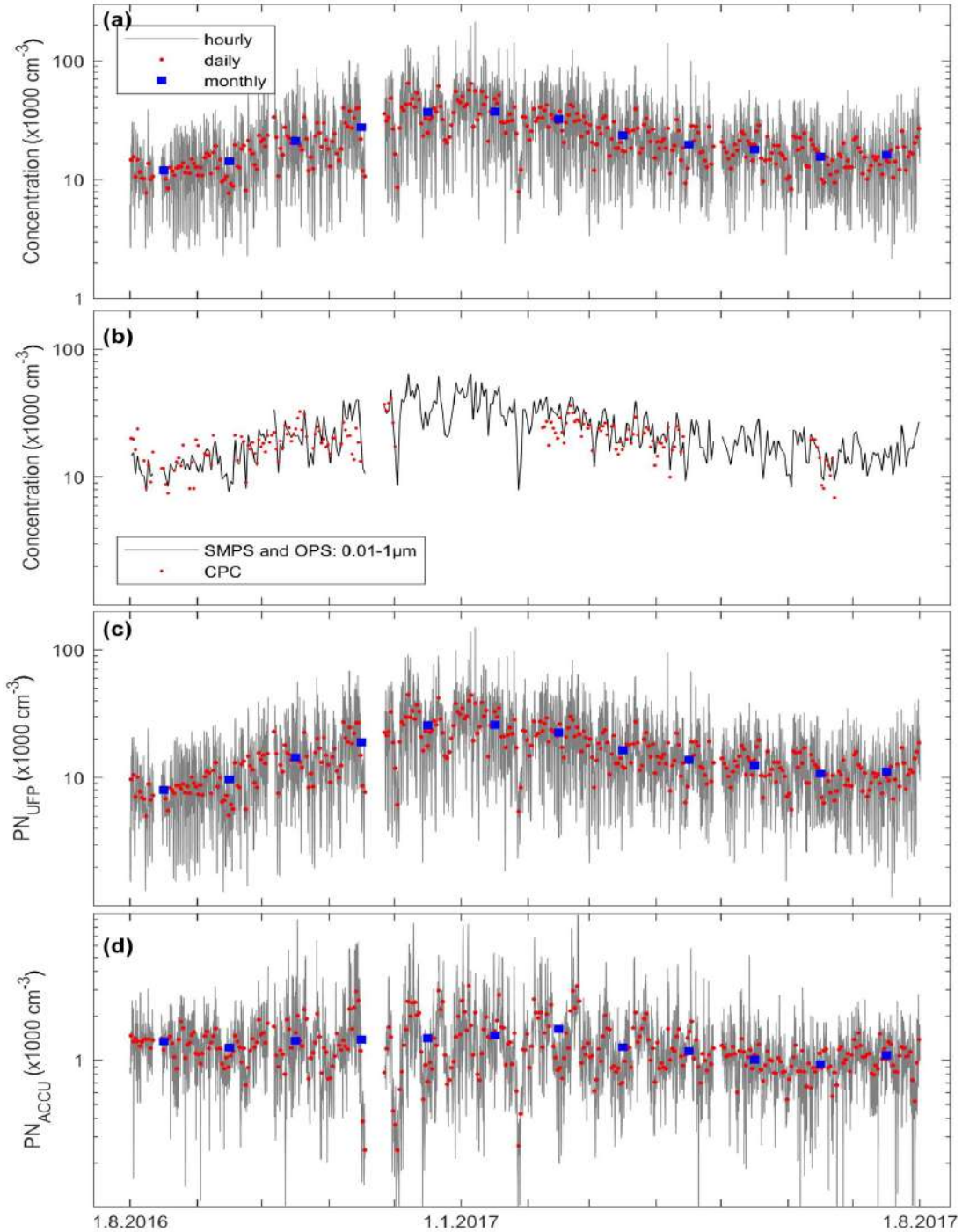



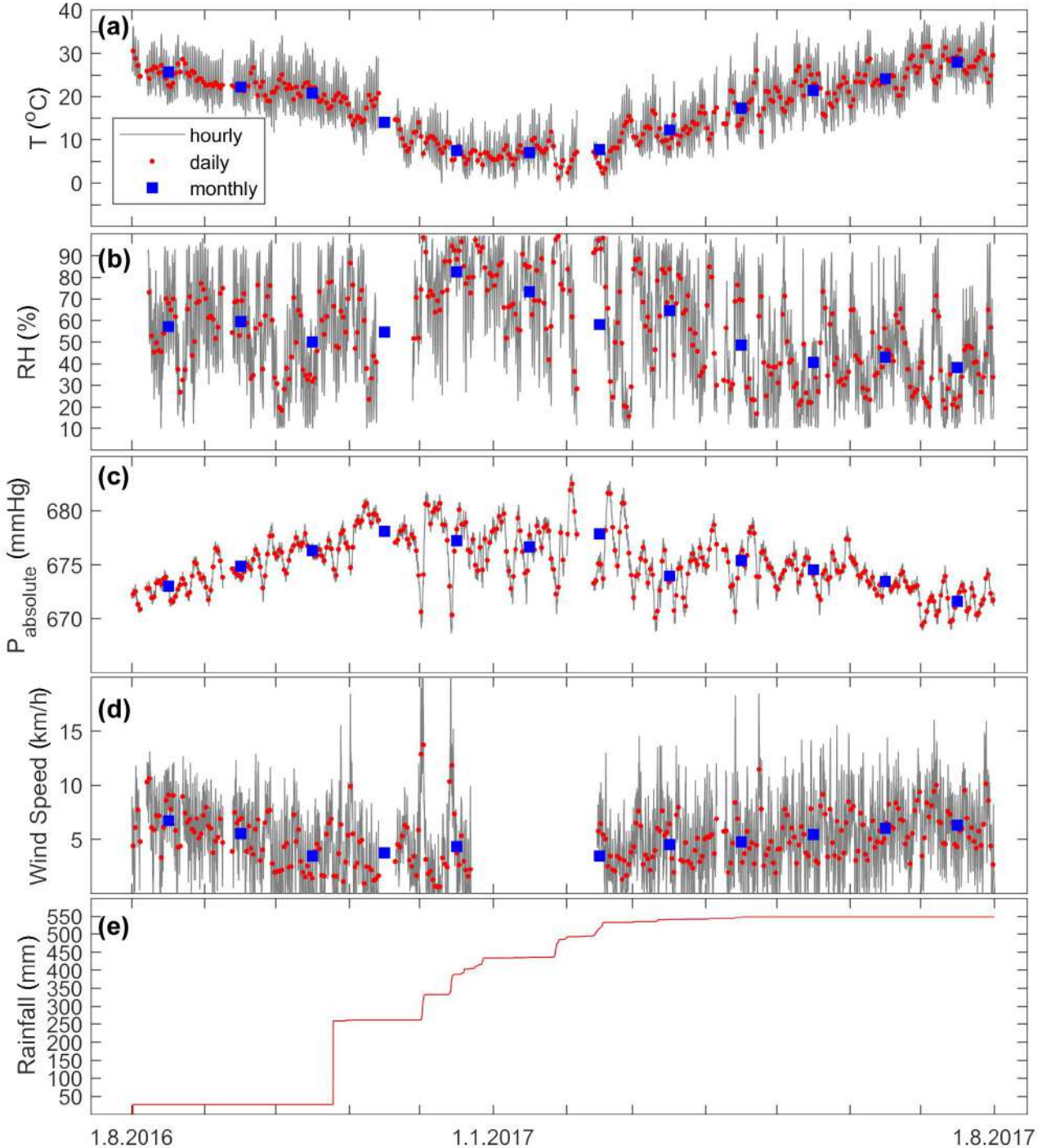
# Case Studies and Examples

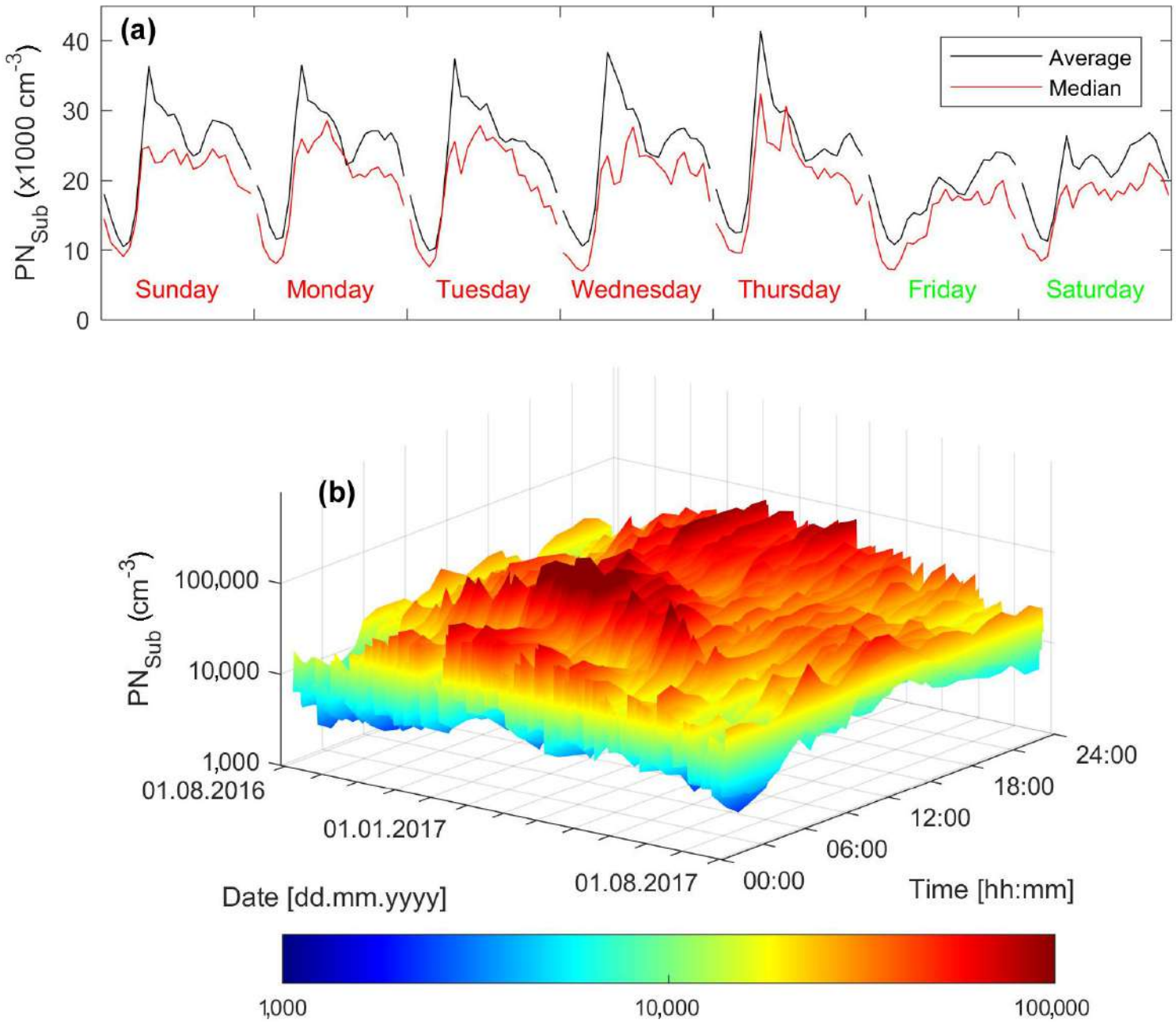
Urban Aerosols Temporal Variation




# Urban aerosols show seasonal variation


(a)
hourly
daily
monthly
Concentration (x1000 cm$^{-3}$)
(b)
SMPS and OPS: 0.01-1μm
CPC
Concentration (x1000 cm$^{-3}$)
(c)
$PN_{UFP}$ (x1000 cm$^{-3}$)
(d)
$PN_{ACCU}$ (x1000 cm$^{-3}$)
1.8.2016
1.1.2017
1.8.2017


(a)
hourly
daily
monthly
T (°C)
(b)
RH (%)
(c)
$P_{absolute}$ (mmHg)
(d)
Wind Speed (km/h)
(e)
Rainfall (mm)
1.8.2016
1.1.2017
1.8.2017

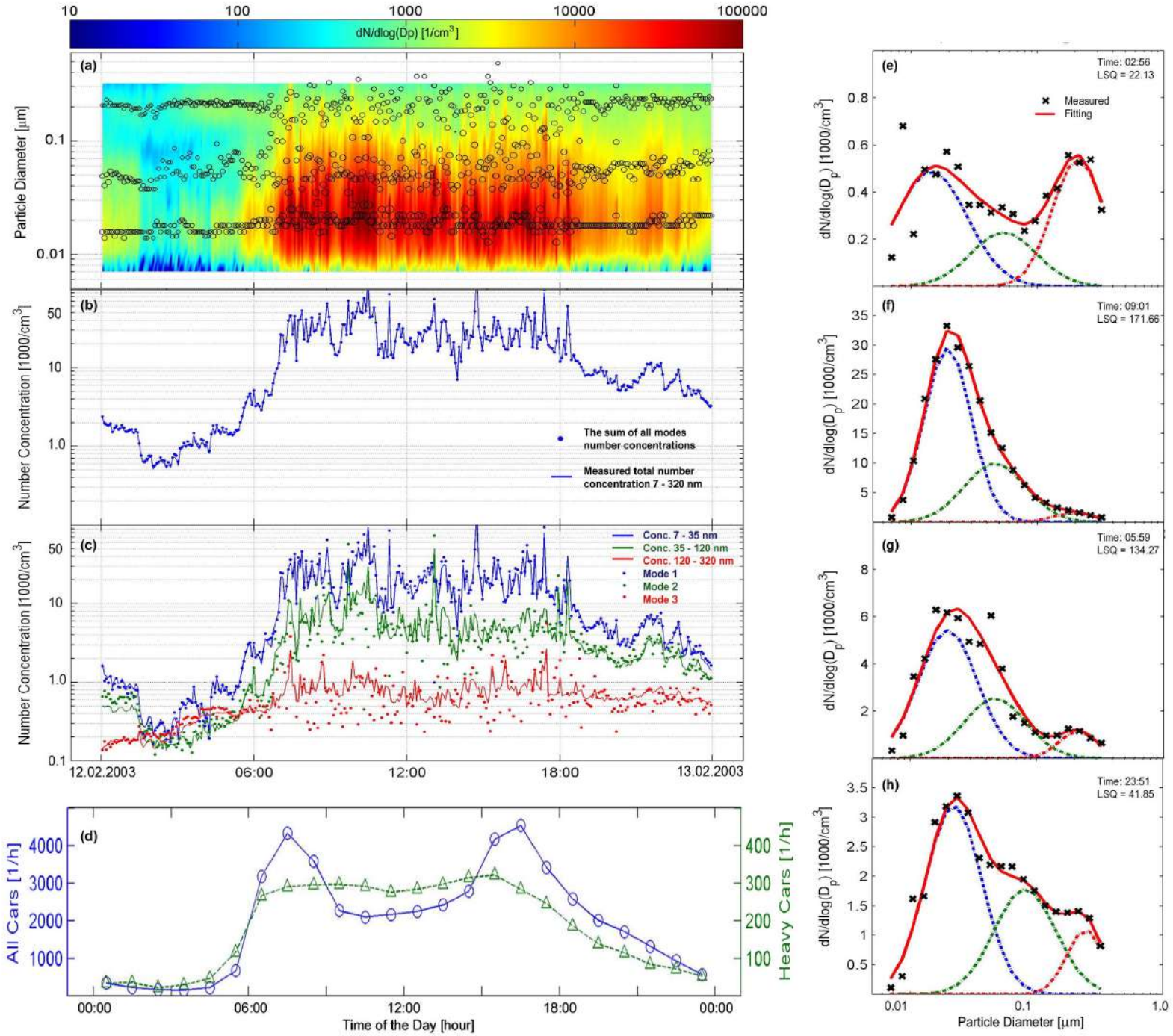



**Seasonal**

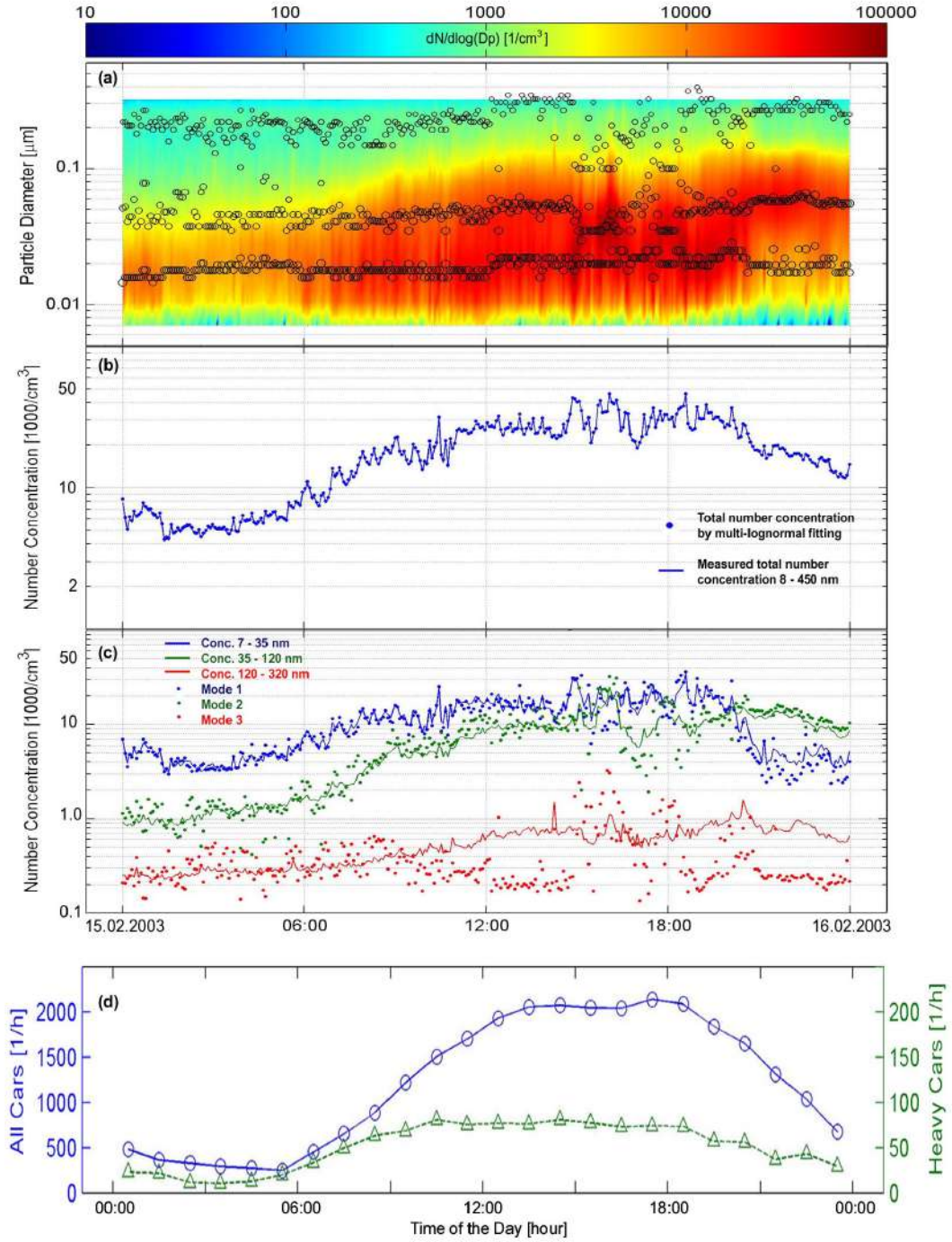
**Weekly**

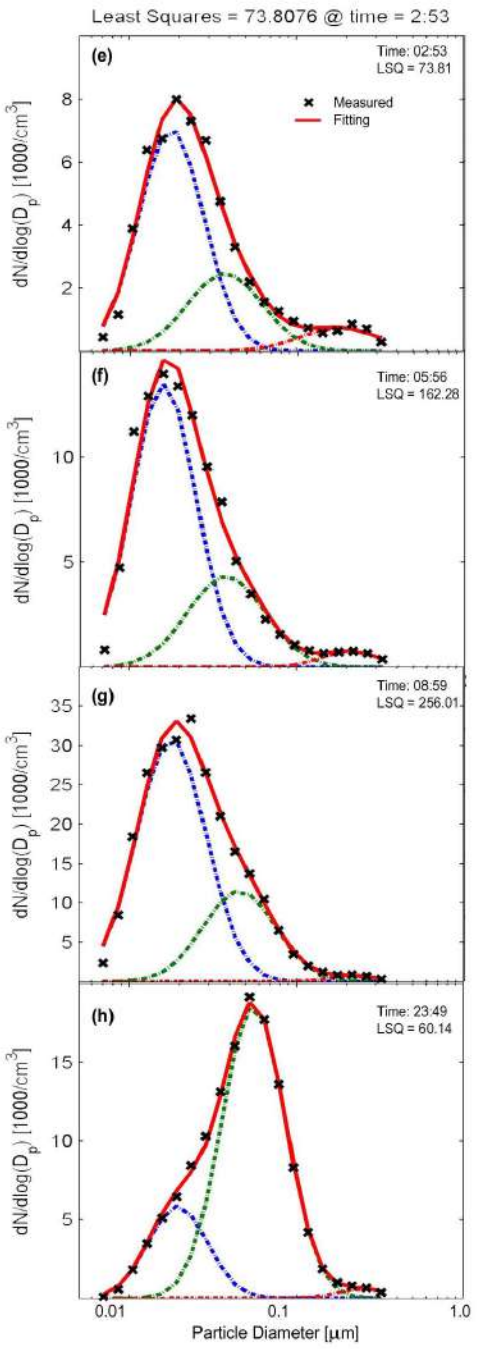
**Daily**

# Typical working Day



# Typical weekend Day



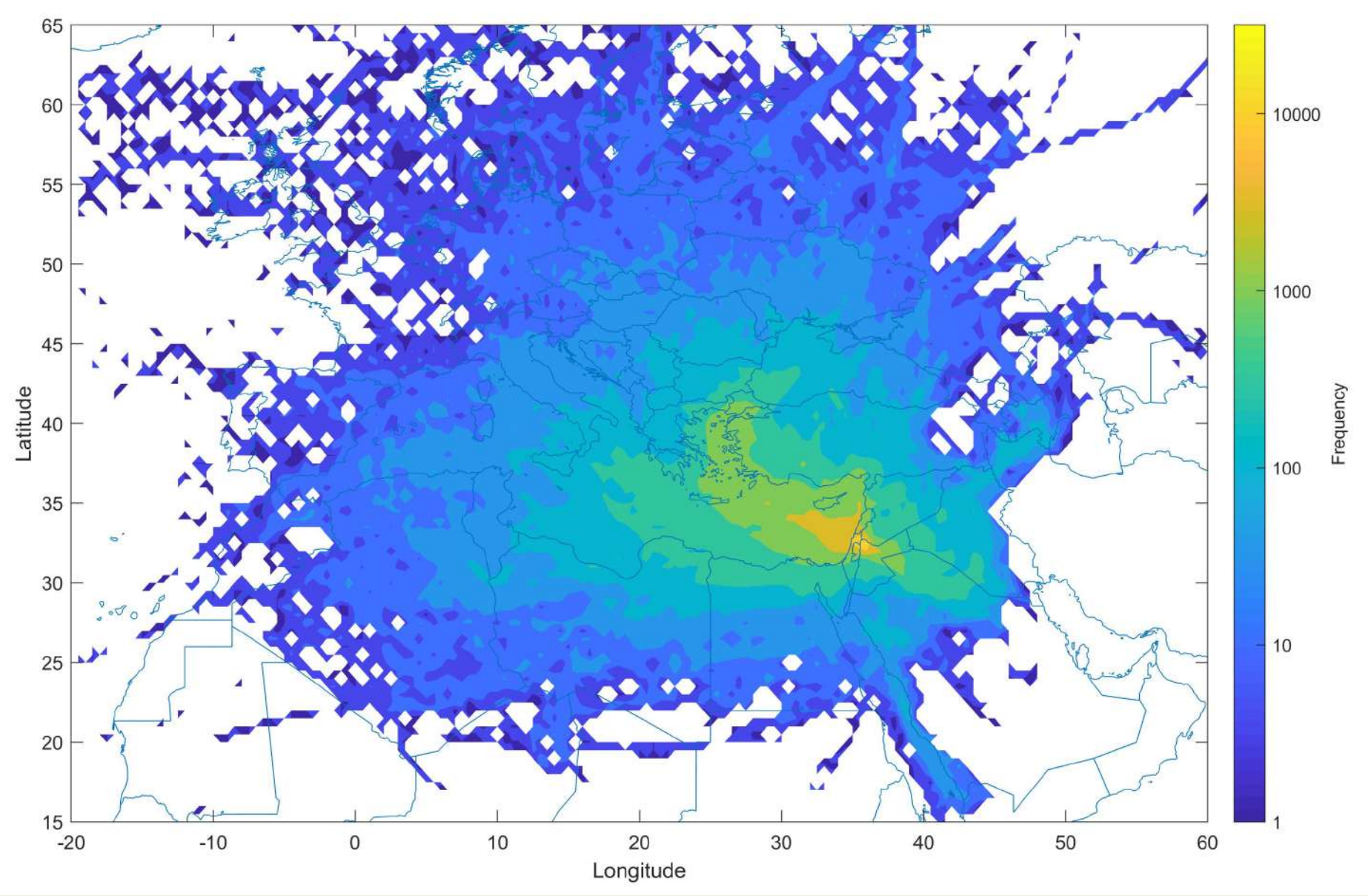



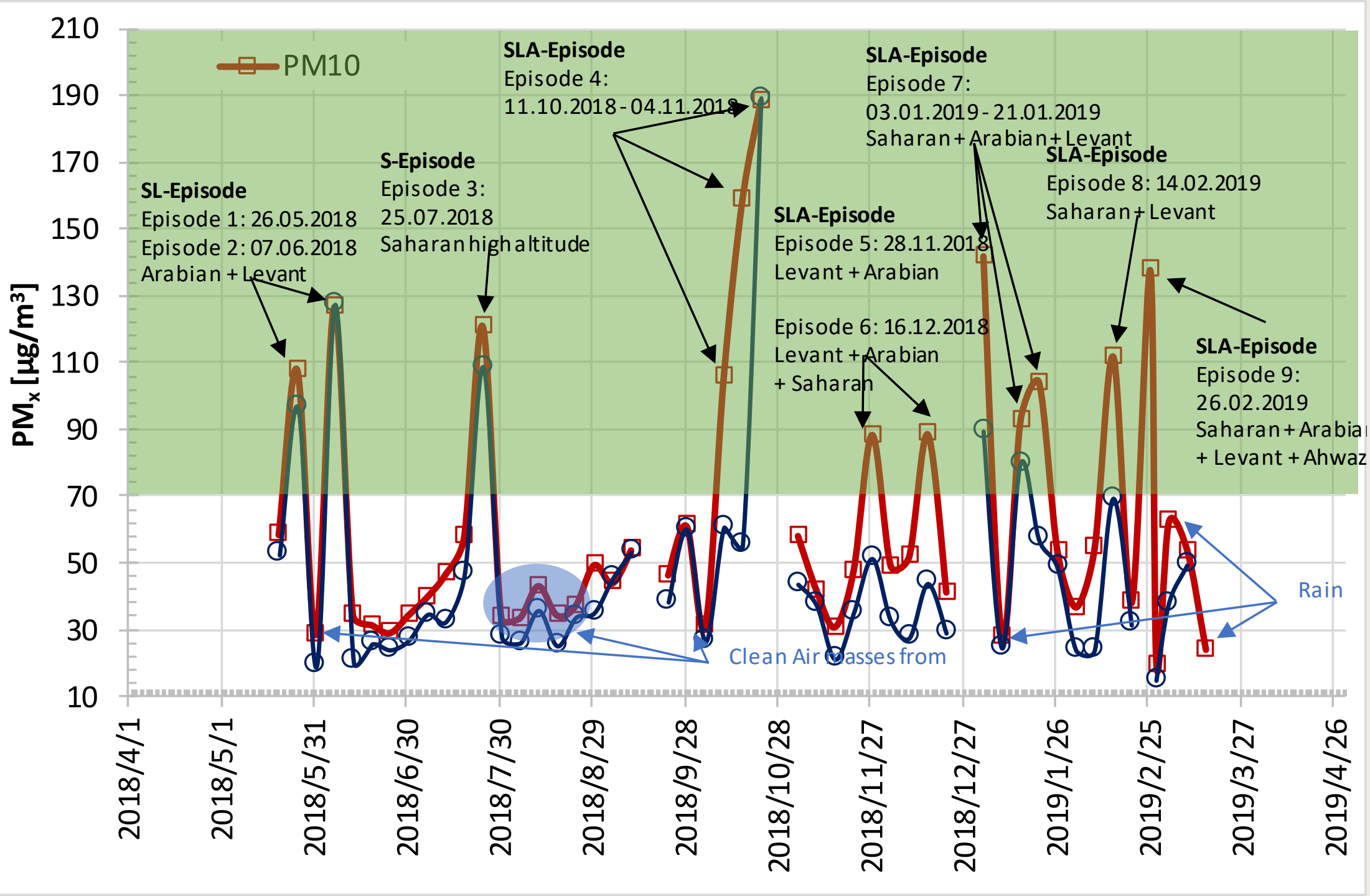
# Middle East and North Africa

MENA

# Back trajectories 2016 – 2017

- FlexPart
- Amman / Jordan
- Arrival height 100 m
- Hourly back trajectories
- 96 hours backward




PM10
SL-Episode
Episode 1: 26.05.2018
Episode 2: 07.06.2018
Arabian + Levant
S-Episode
Episode 3:
25.07.2018
Saharan high altitude
SLA-Episode
Episode 4:
11.10.2018 - 04.11.2018
SLA-Episode
Episode 5: 28.11.2018
Levant + Arabian
Episode 6: 16.12.2018
Levant + Arabian
+ Saharan
SLA-Episode
Episode 7:
03.01.2019 - 21.01.2019
Saharan + Arabian + Levant
SLA-Episode
Episode 8: 14.02.2019
Saharan + Levant
SLA-Episode
Episode 9:
26.02.2019
Saharan + Arabian
+ Levant + Ahwaz
Rain
Clean Air Masses from
PMx [µg/m³]
210
190
170
150
130
110
90
70
50
30
10
2018/4/1
2018/5/1
2018/5/31
2018/6/30
2018/7/30
2018/8/29
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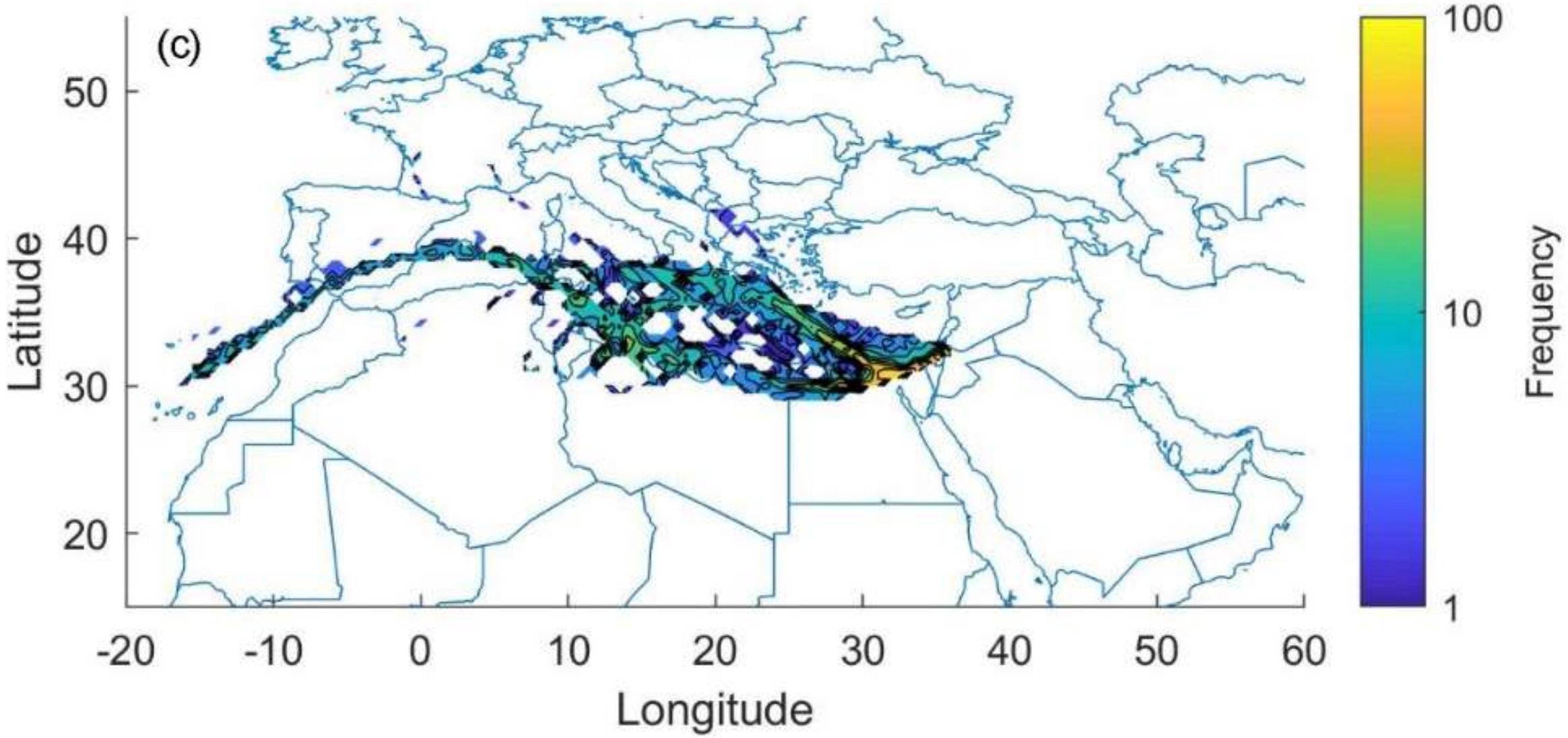
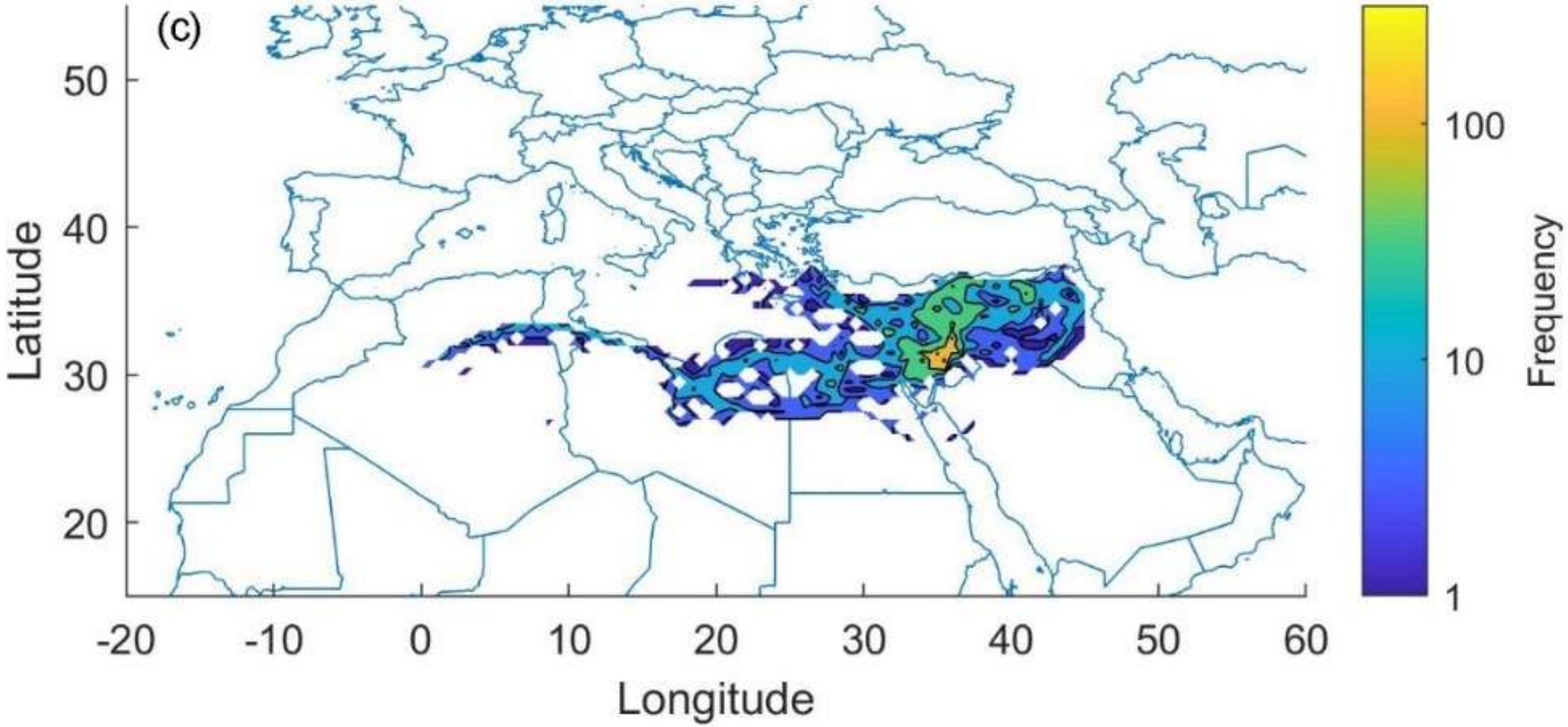
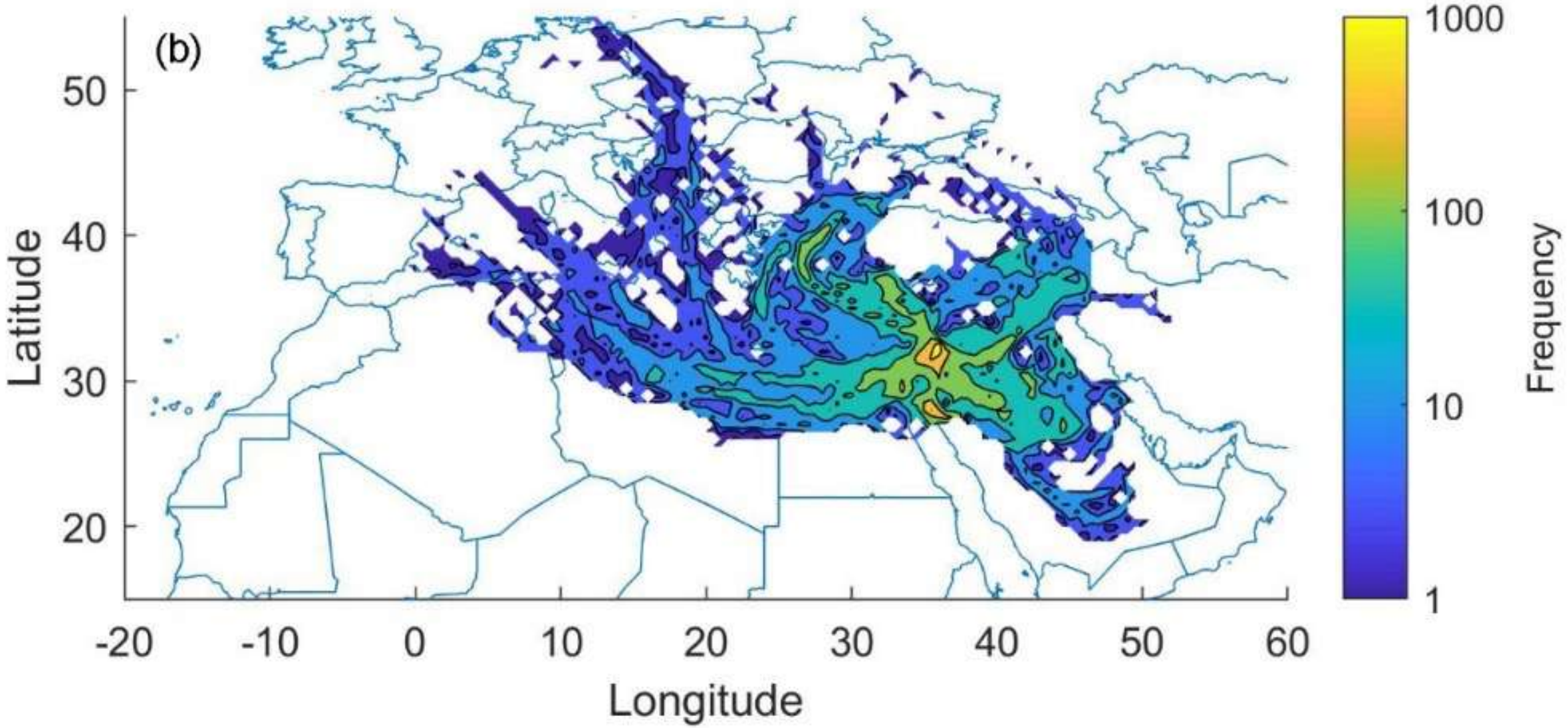
2019/2/25
2019/3/27
2019/4/26



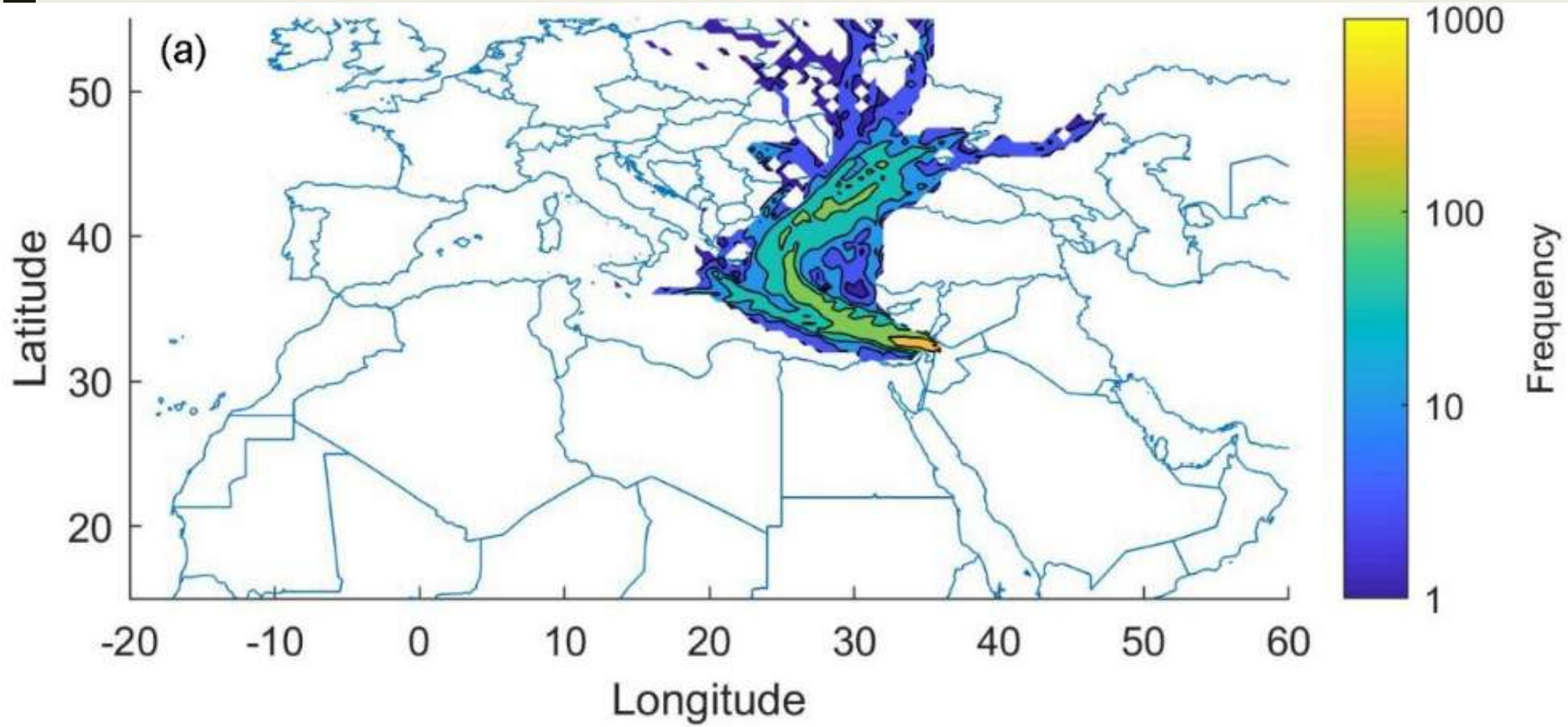

Back trajectories (96 hours) crossing maps during S-type SDS-episodes at arrival height 1500 meters




Back trajectories (96 hours) crossing maps during SL-type SDS-episodes at arrival height 1500 meters



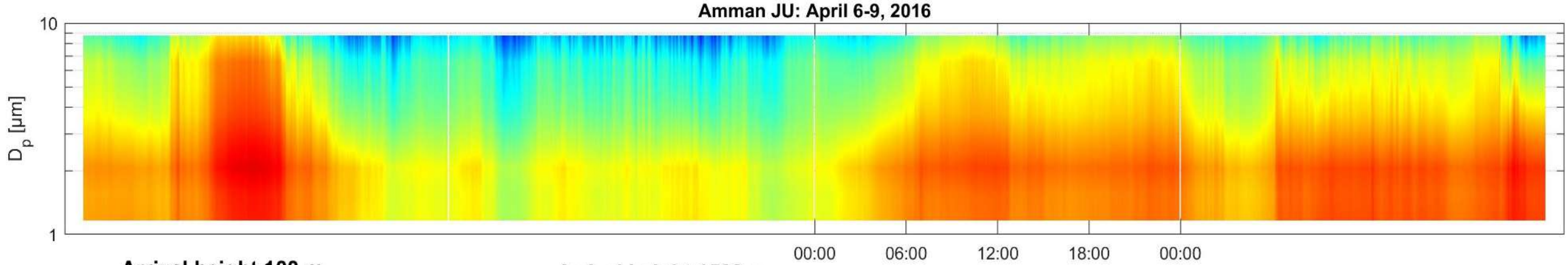

Back trajectories (96 hours) crossing maps during SLA-type SDS-episodes at arrival height 500 meters

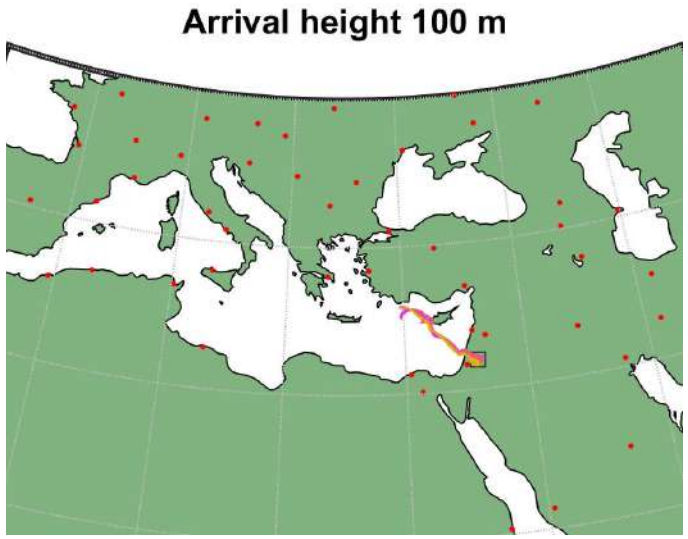


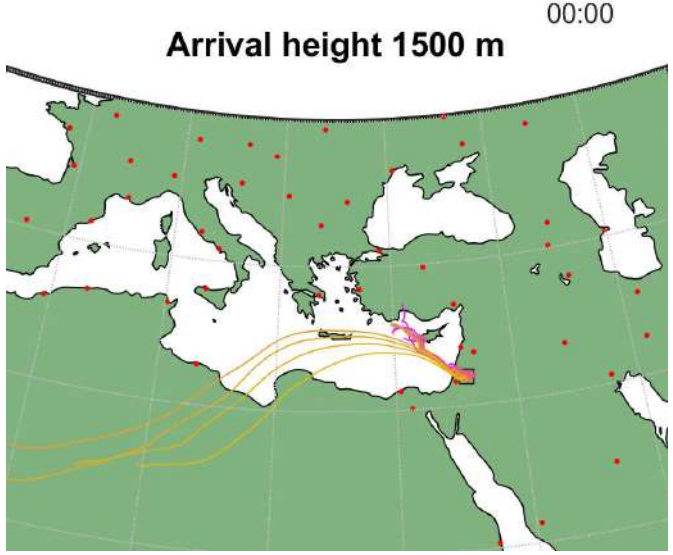

Back trajectories (96 hours) crossing maps during low PM10 concentrations at arrival height 100 meters

# Case Studies and Examples

Saharan Dust Episodes (April 8–13, 2016)



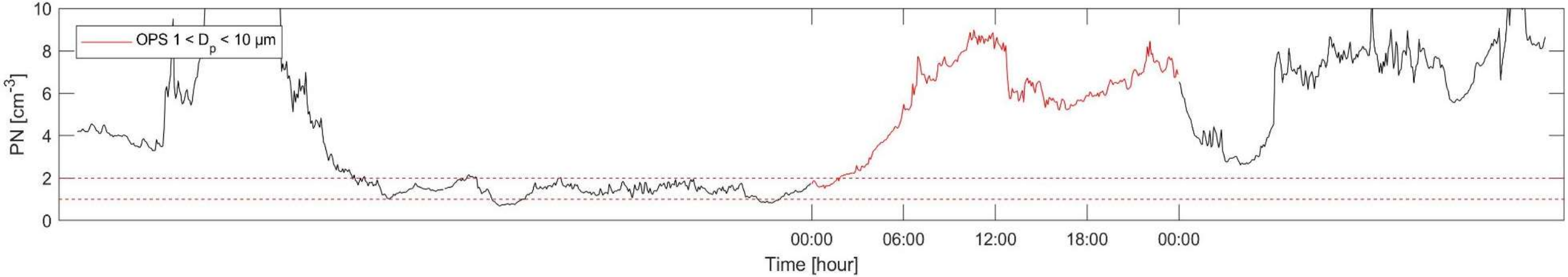



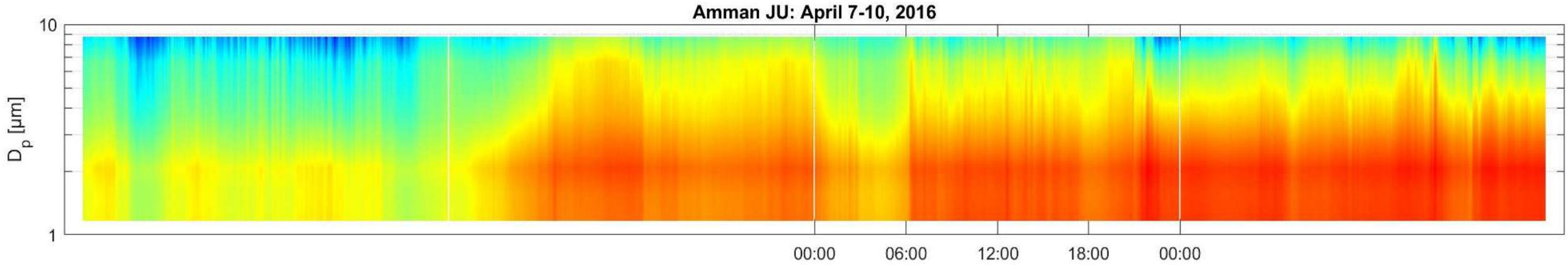



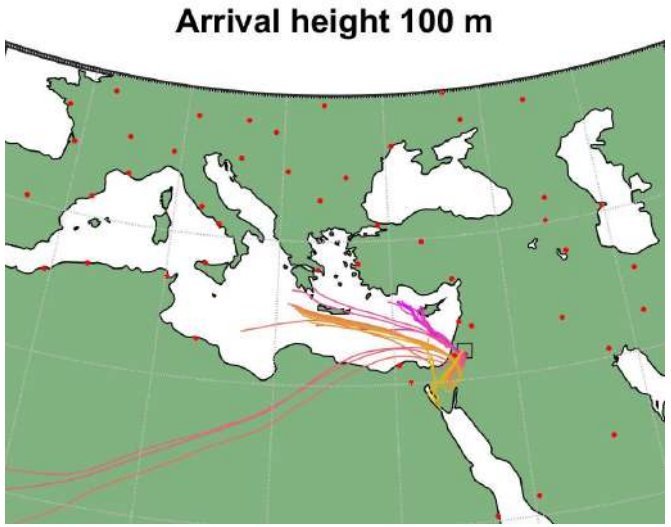

# April 8–13, 2016

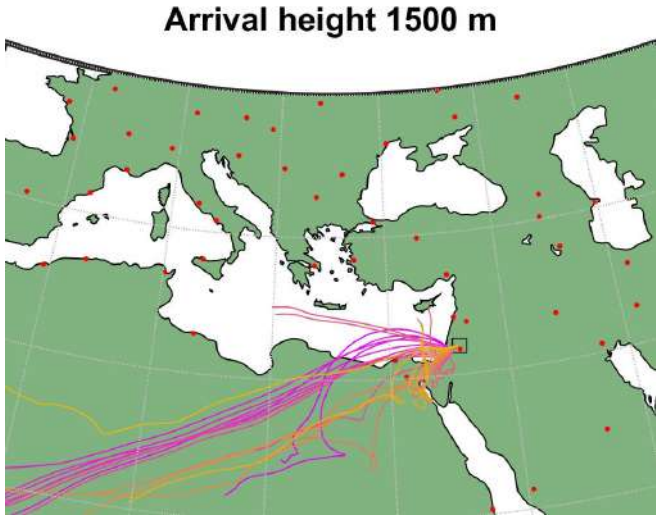
## Saharan Dust Episode

**April 8th:**
100m BT does not indicate dust source region
1500m BT clearly originates from Sahara





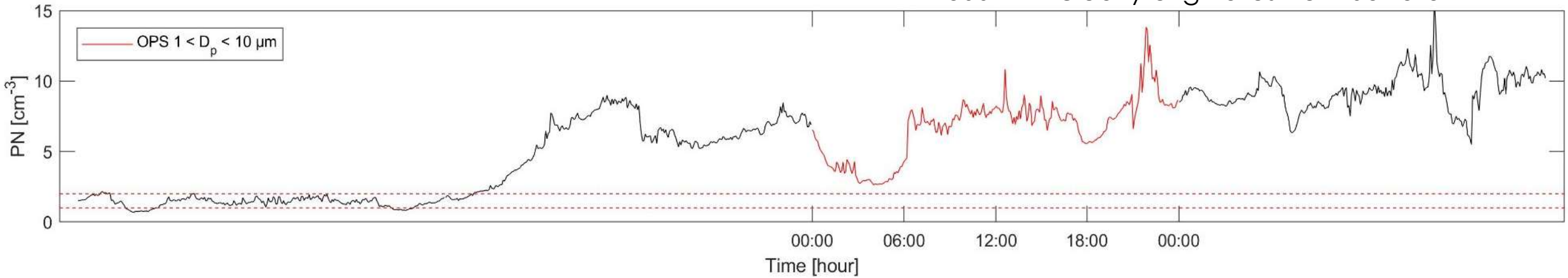



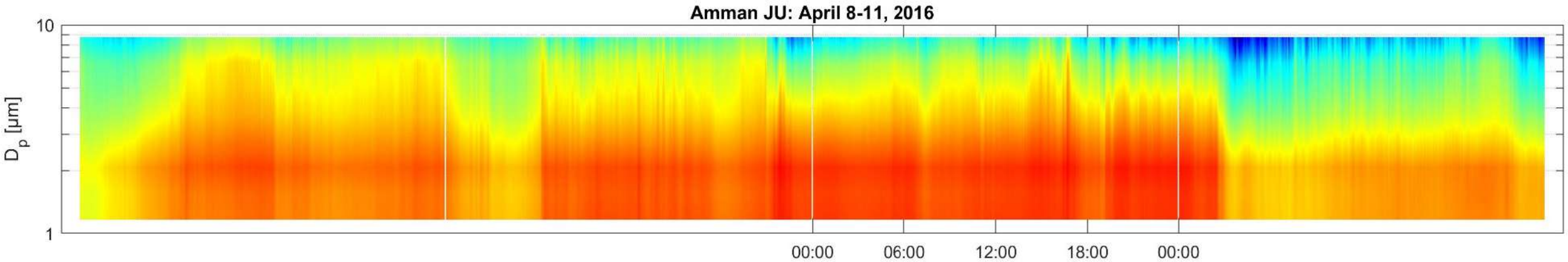



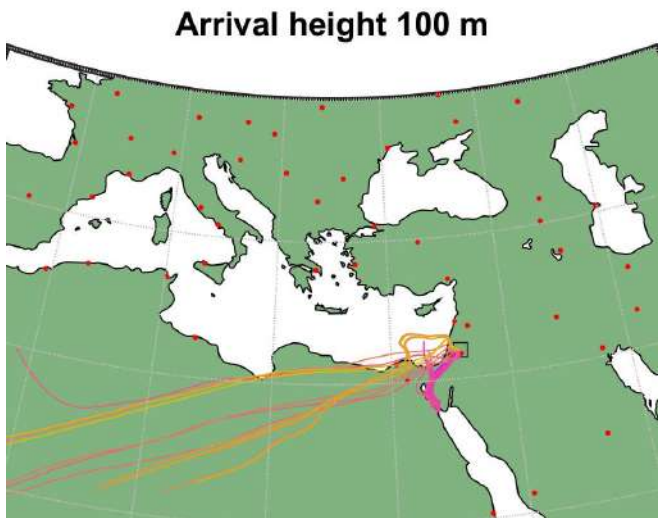

# April 8–13, 2016

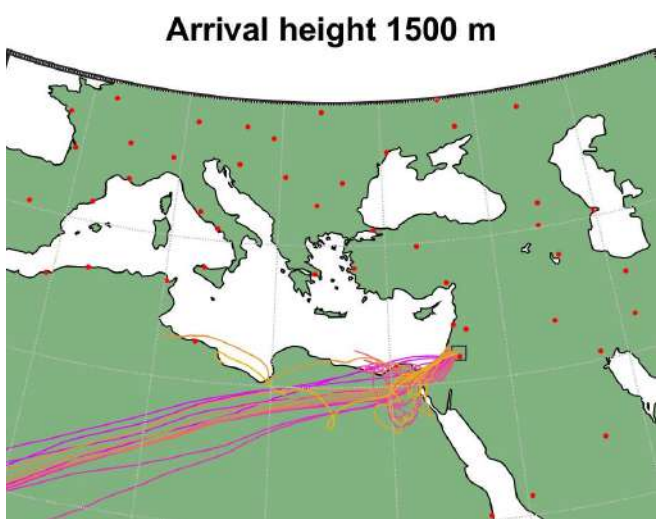
## Saharan Dust Episode

**April 9th:**
100m BT mixed between marine and Saharan
1500m BT clearly originates from Sahara





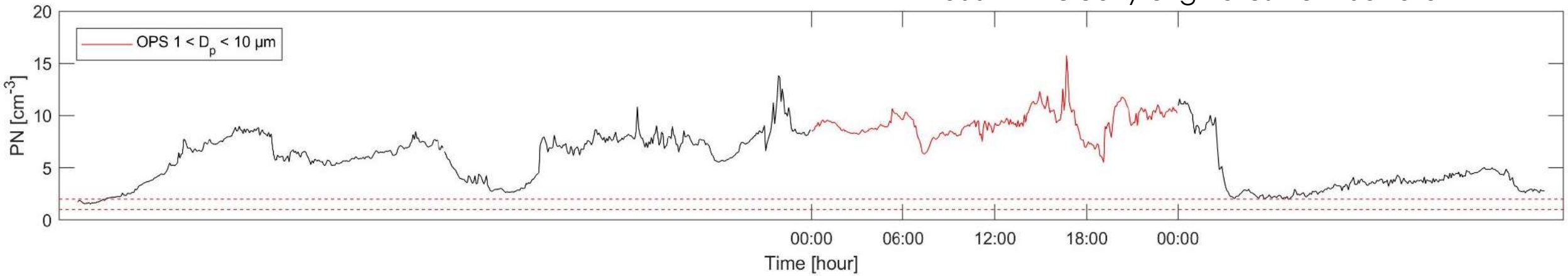



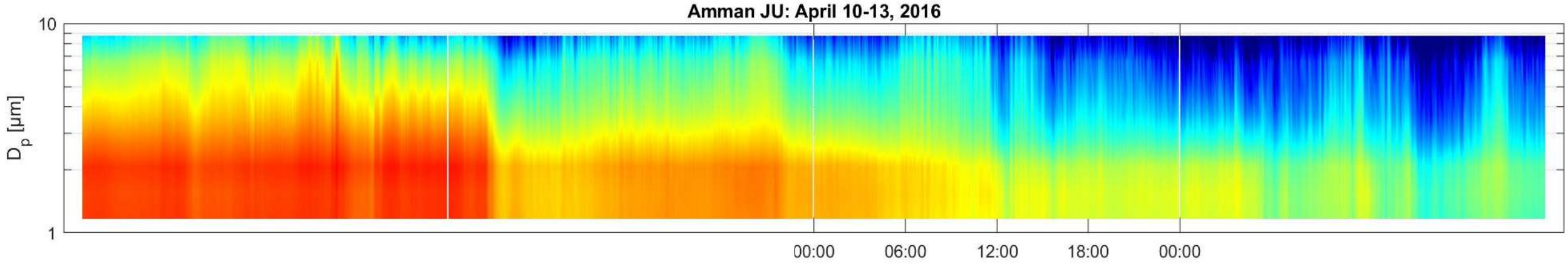



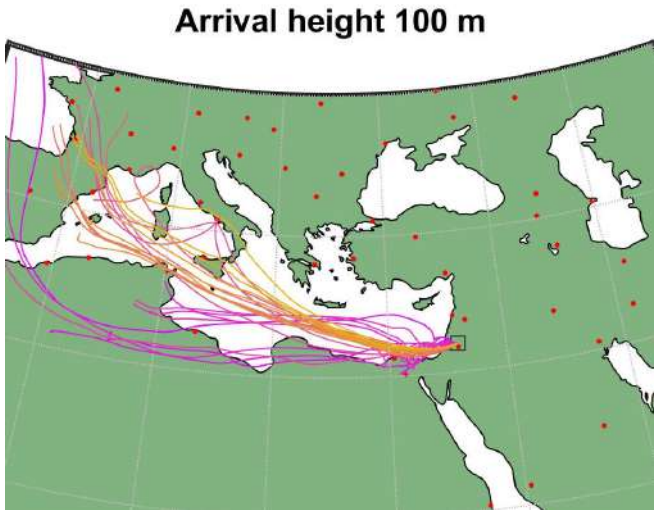

# April 8–13, 2016

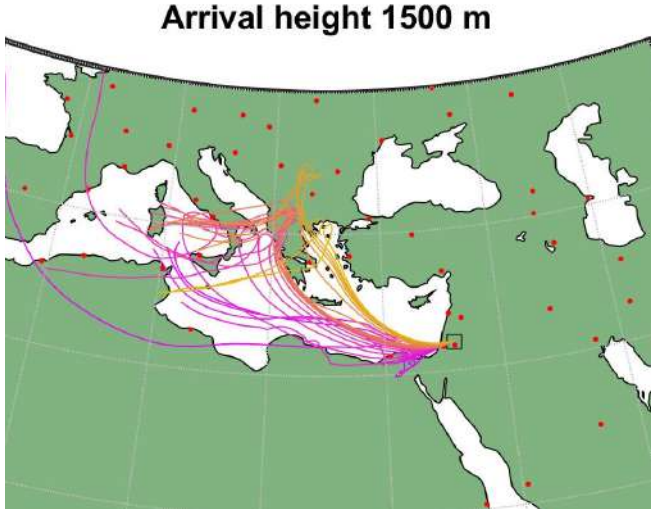
## Saharan Dust Episode

**April 10th:**
100m BT clearly originates from Sahara
1500m BT clearly originates from Sahara





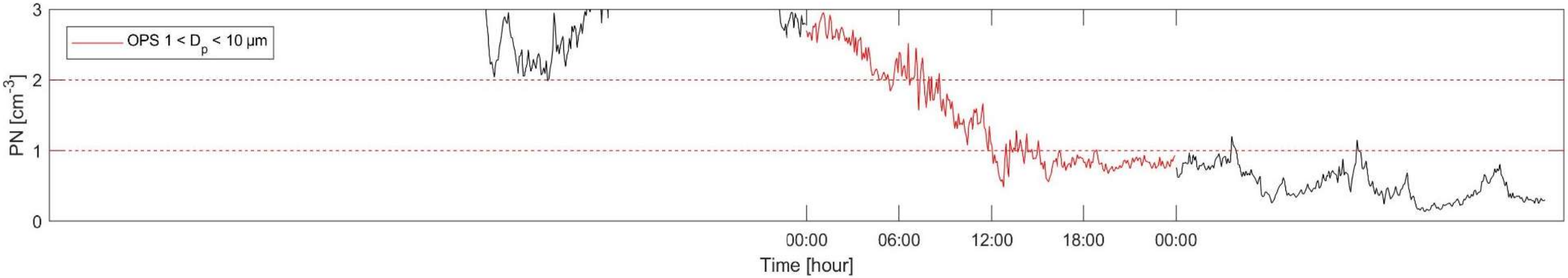




# April 8–13, 2016
## Saharan Dust Episode

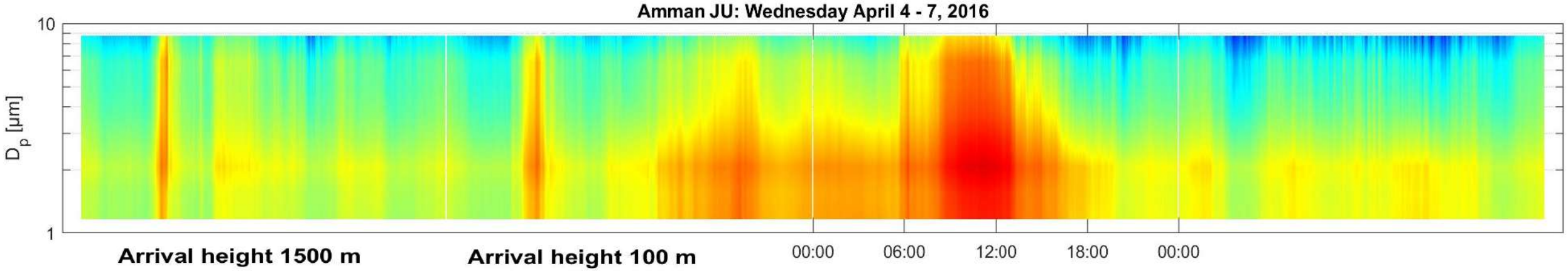
episode **ends on April 13th** / precipitation

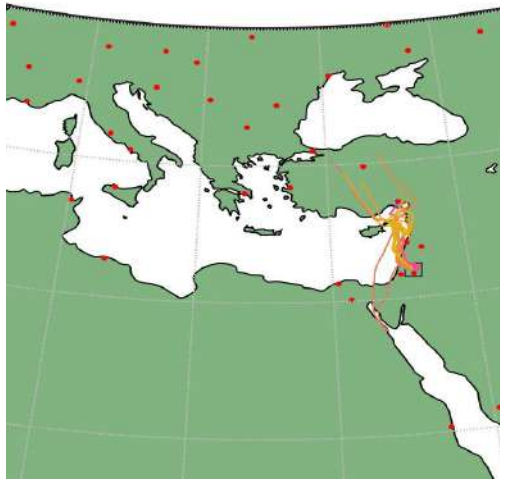
**April 12th:**
100m BT started to be marine
1500m BT started to be marine

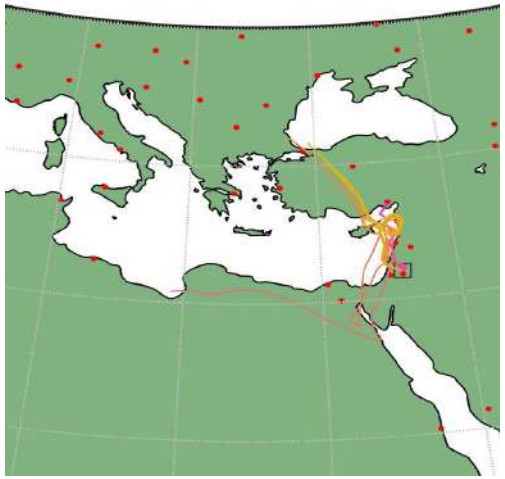


# Case Studies and Examples

Levant Dust Episodes (April 5–6, 2016)

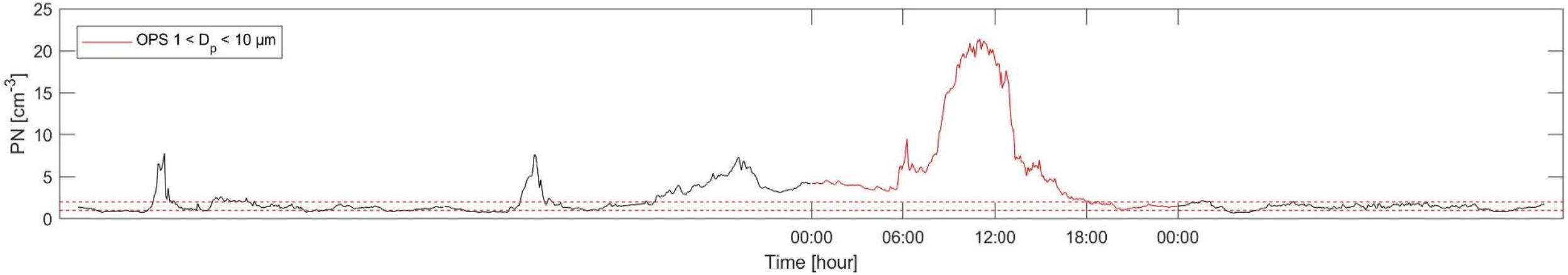


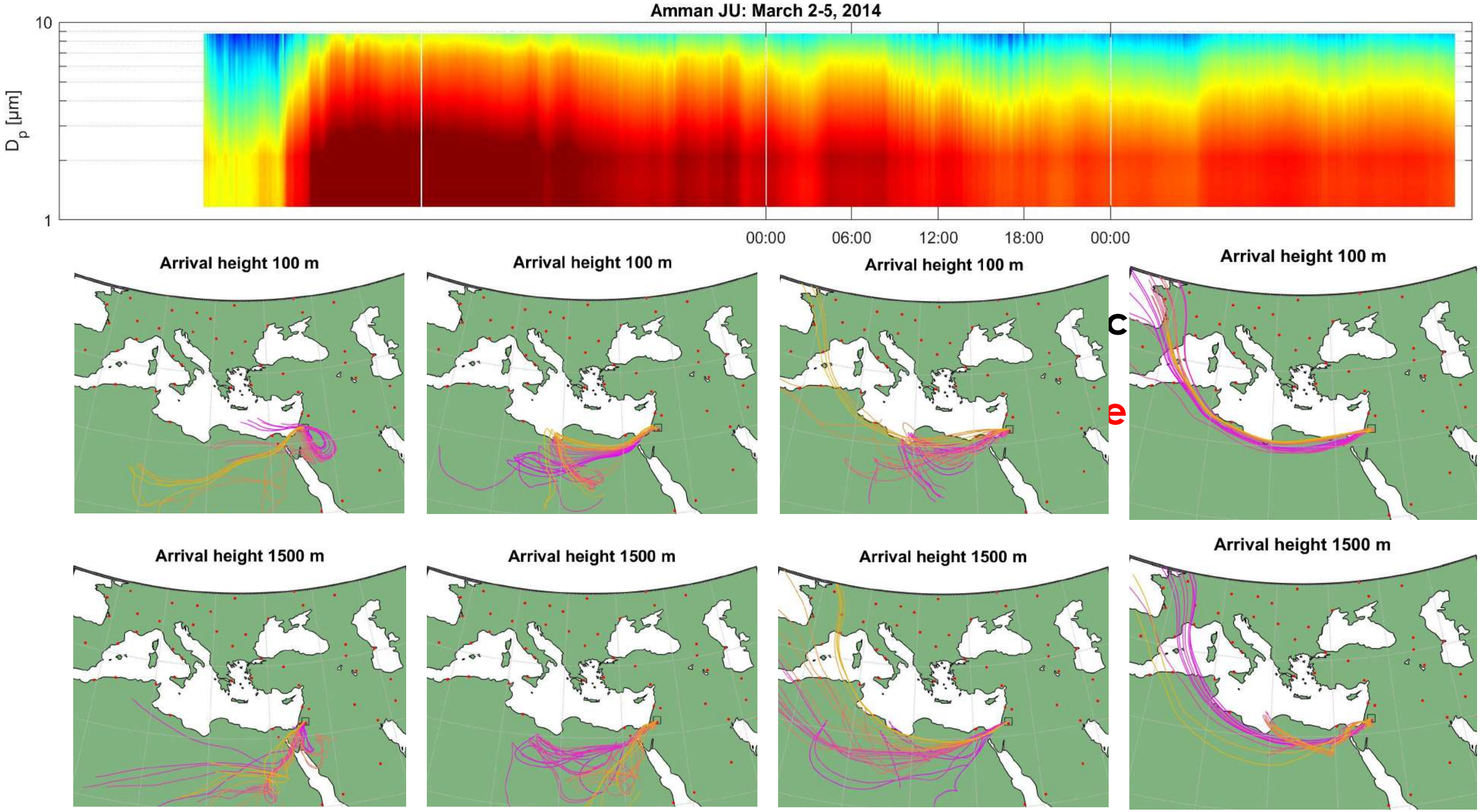

**April 5–6, 2016**

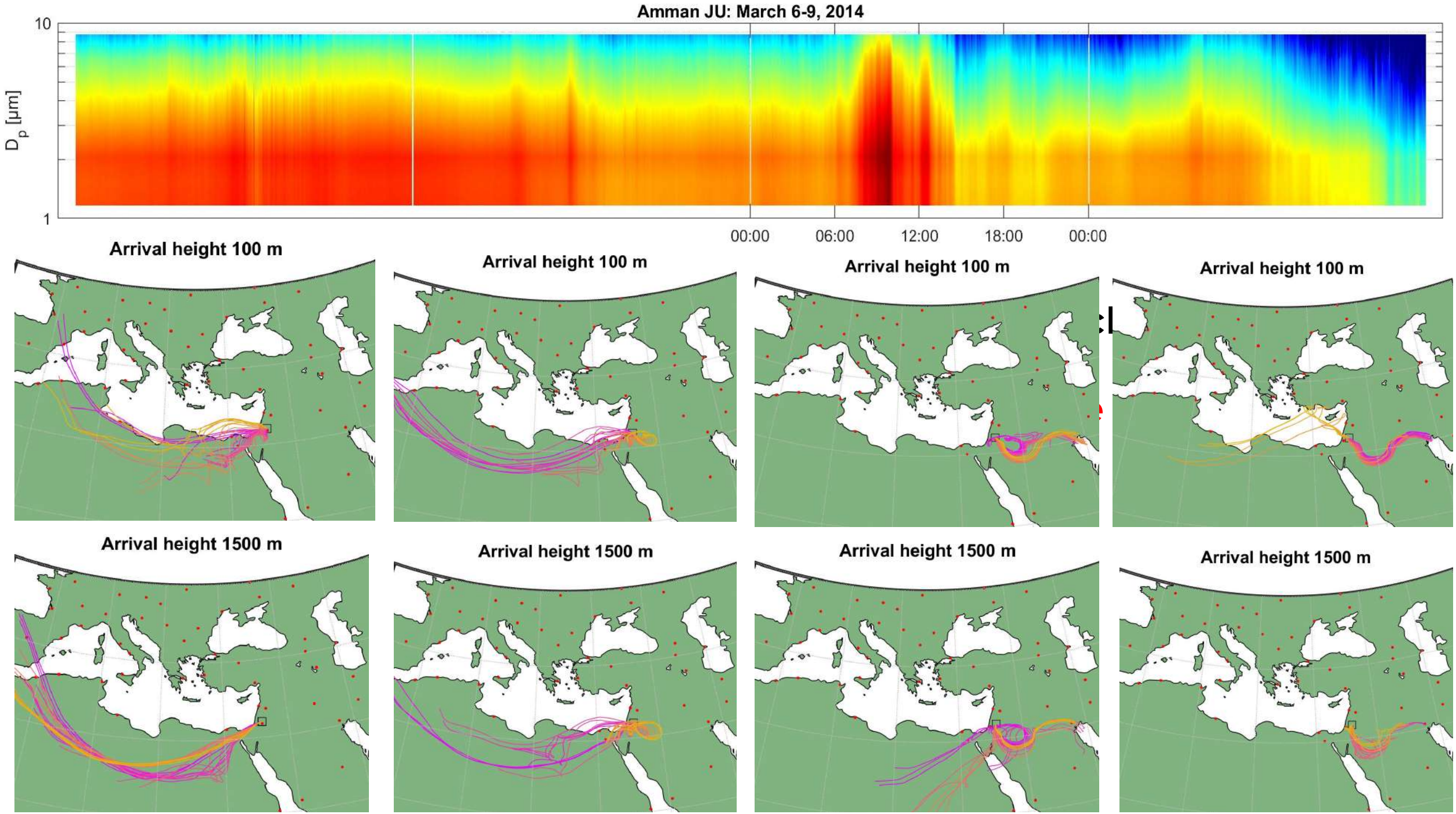
**Short Dust Episode originated within the Levant Region**

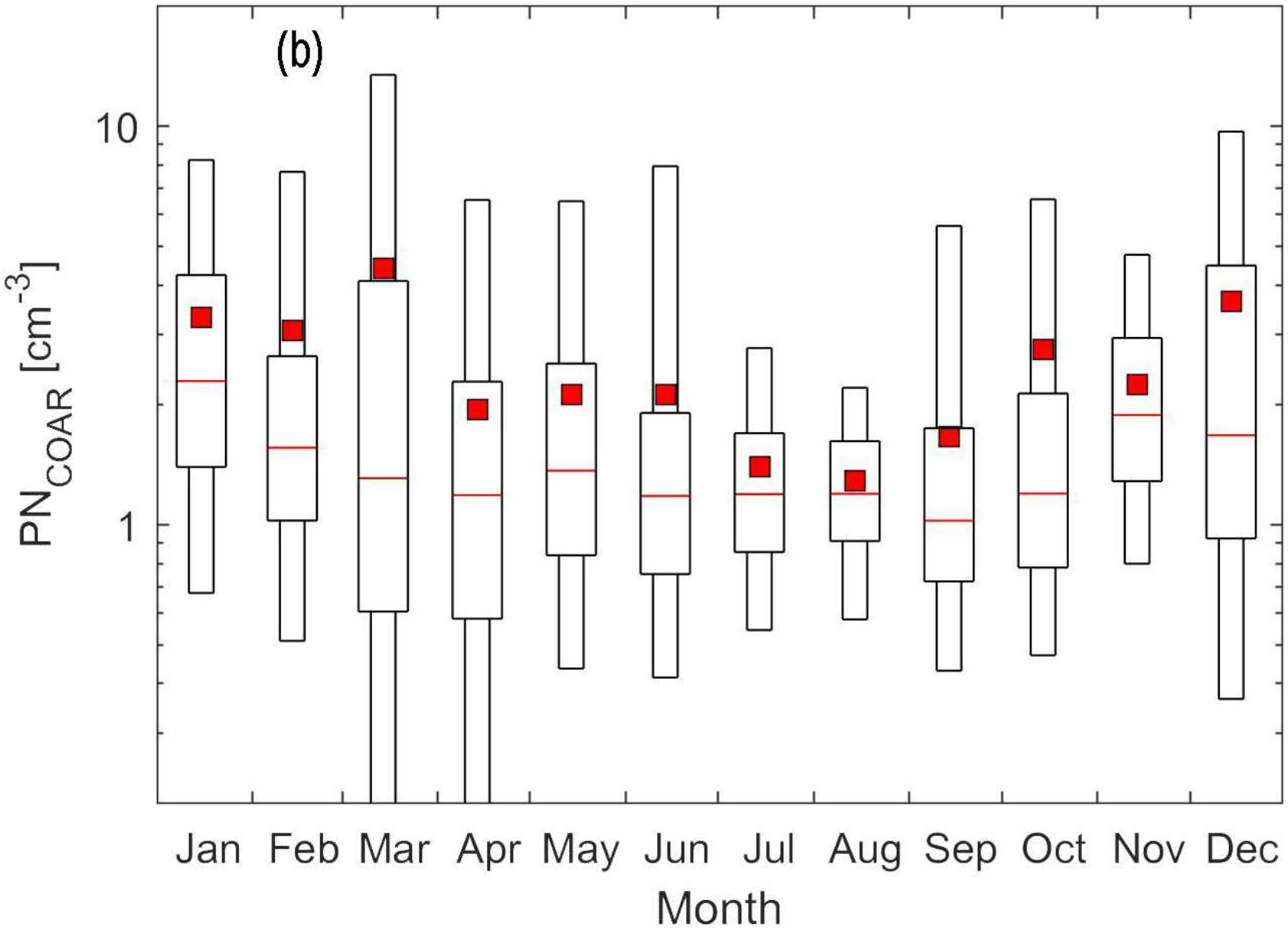


# Case Studies and Examples

Intense Saharan-Levant-Arabian Dust Episodes (March 2 – 9, 2014)

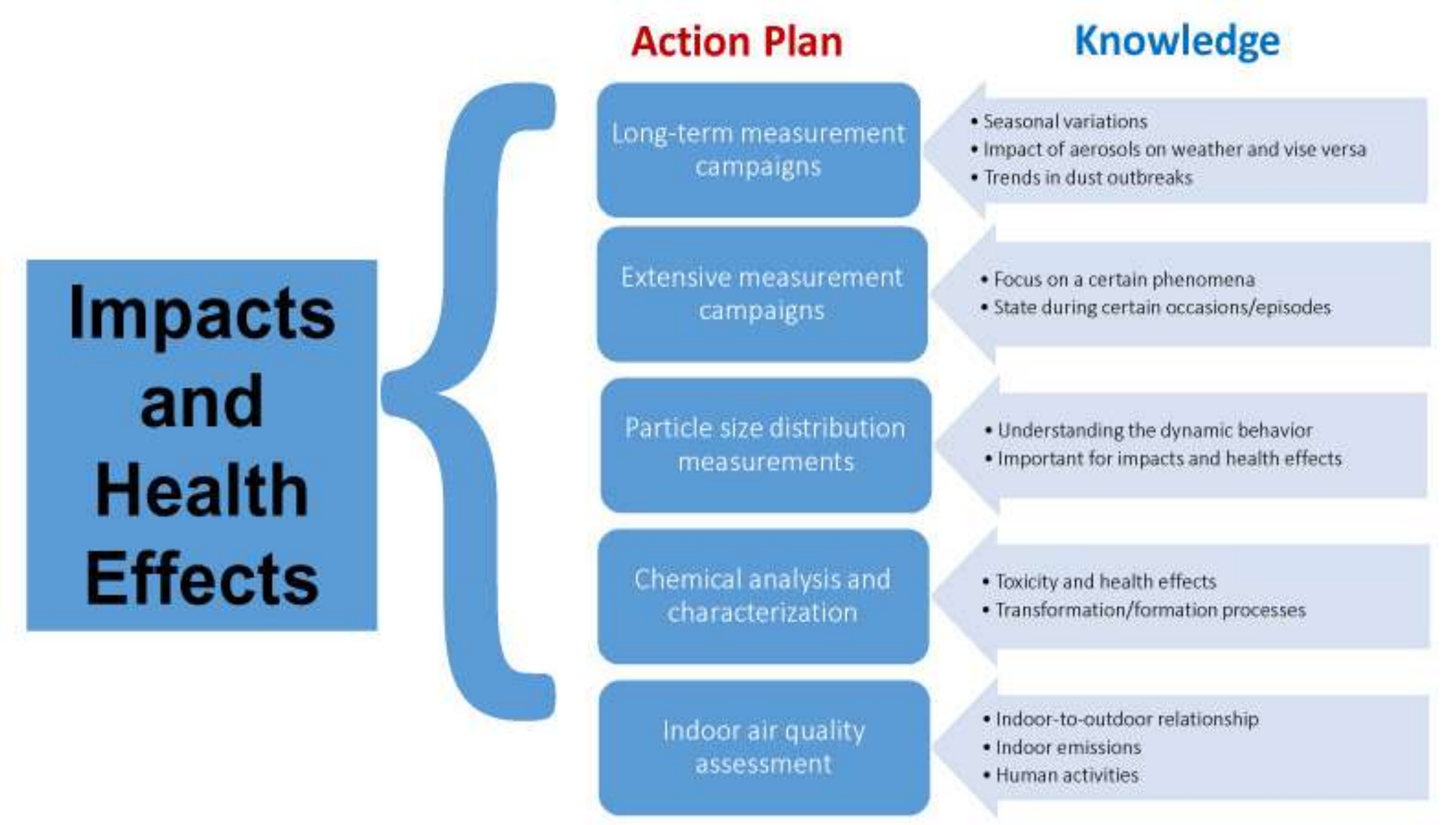

Amman JU: March 2-5, 2014
10
1
$D_p$ [µm]
00:00
06:00
12:00
18:00
00:00
Arrival height 100 m
Arrival height 100 m
Arrival height 100 m
Arrival height 100 m
c
e
Arrival height 1500 m
Arrival height 1500 m
Arrival height 1500 m
Arrival height 1500 m


Amman JU: March 6-9, 2014
10
1
$D_p$ [µm]
00:00
06:00
12:00
18:00
00:00
Arrival height 100 m
Arrival height 100 m
Arrival height 100 m
Arrival height 100 m
Arrival height 1500 m
Arrival height 1500 m
Arrival height 1500 m
Arrival height 1500 m


(b)
10
1
PN_COAR [cm^-3]
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

# MENA CHALLENGES…

# Challenges in the MENA region

- The air pollution research activities in the Middle East, especially in the Arab countries, have not been given enough attention.
- Less than 20% of the studies is suitable for directives
- The aerosol research covered seven main topics:
  - *aerosol optical depth*
  - *airborne dust as a major concern in all countries (monitoring, source region, and transport)*
  - *anthropogenic aerosols*
  - *chemical and elemental analysis*
  - *physical properties*
  - *gaseous pollution (O3, $NO_x$, and $CO_x$)*
  - *particulate matter (PM)*
- Very few studies were focused on particle number concentration
- The research on indoor air quality is almost not touched in the MENA region

# Recommendations…