Optical Remote Sensing of Dust Over the Iran Plateau

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5th Training Course on WMO SDS-WAS Products

Nov. 5-9, 2016

Iran Meteorological Organization, Tehran, Iran


Institute for Advanced Studies in
Basic Sciences

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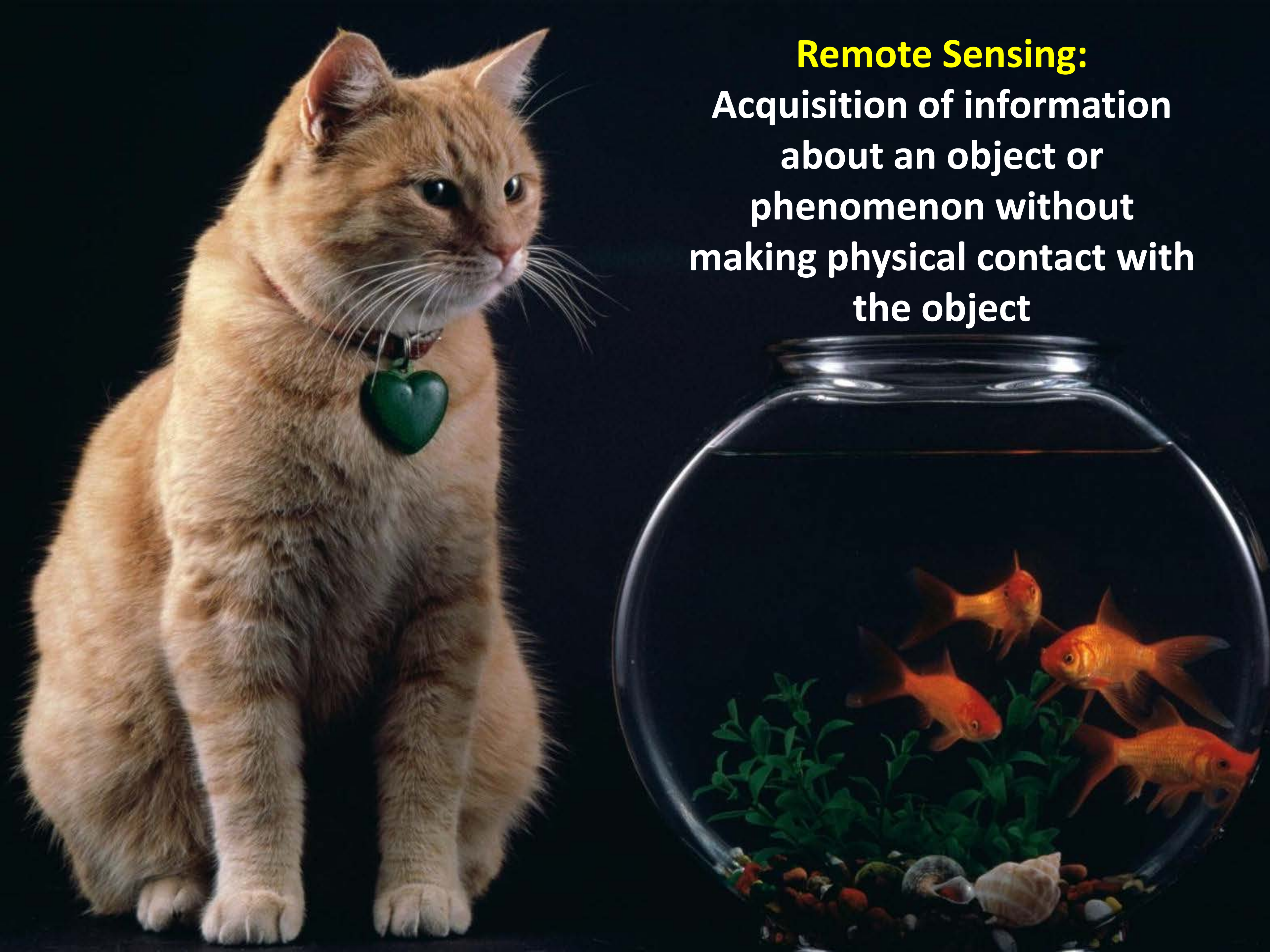
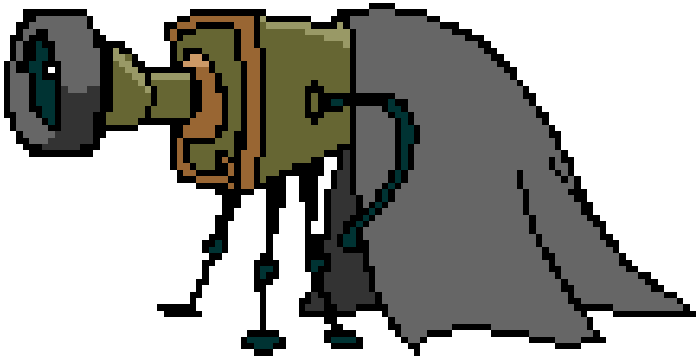

Remote Sensing:
Acquisition of information about an object or phenomenon without making physical contact with the object

Optical Remote Sensing

Passive Remote Sensing

Active Remote Sensing

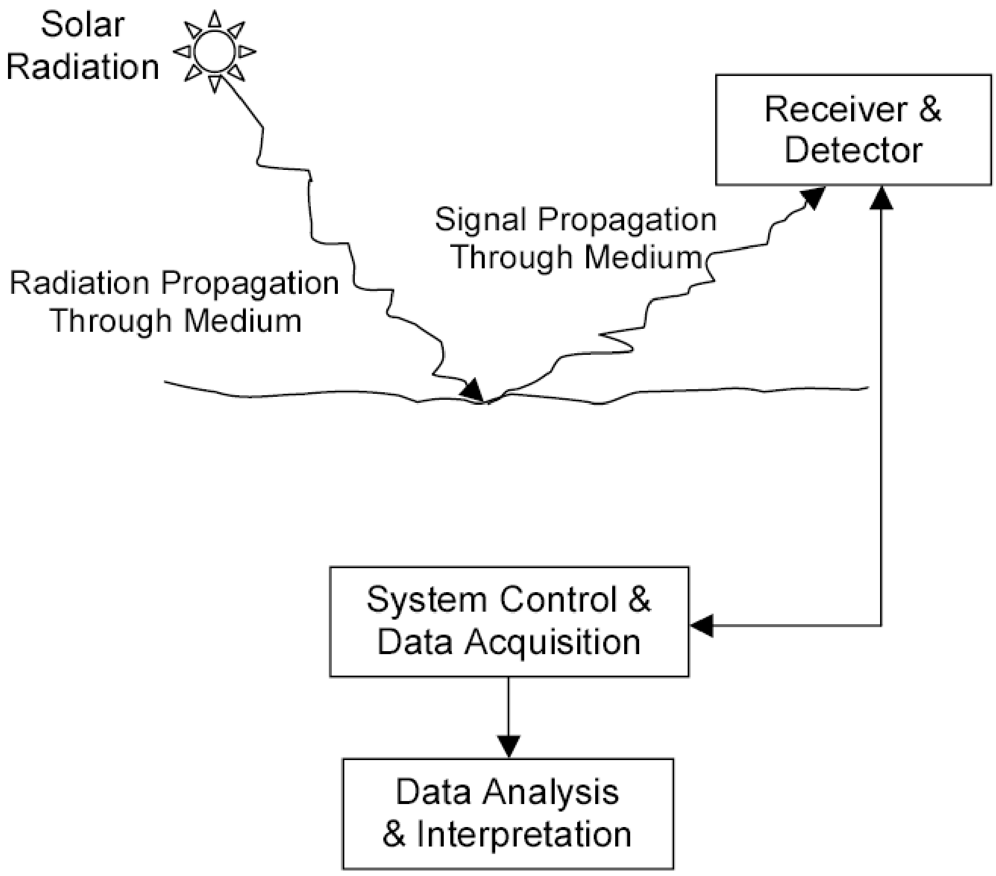


Optical Remote Sensing,
The Earth Atmosphere

- Radar
- Lidar

- Visibility measurement
- Radiometers
- Sunphotometre
- Spectrophotometer

Passive optical remote sensing



Passive optical remote sensing

Visibility observation

- Looking at targets of different size for to measure the visibility at different ranges.

$$\tau(\lambda) = \int_0^h k_{\text{ext}}(\lambda, z)\, dz$$

Passive optical remote sensing
Radiometry

Beer-Lambert-Bouguer attenuation law:

$$I(\lambda) = \frac{I_0(\lambda)}{R^2} \exp\left(-m\,\tau(\lambda)\right),$$

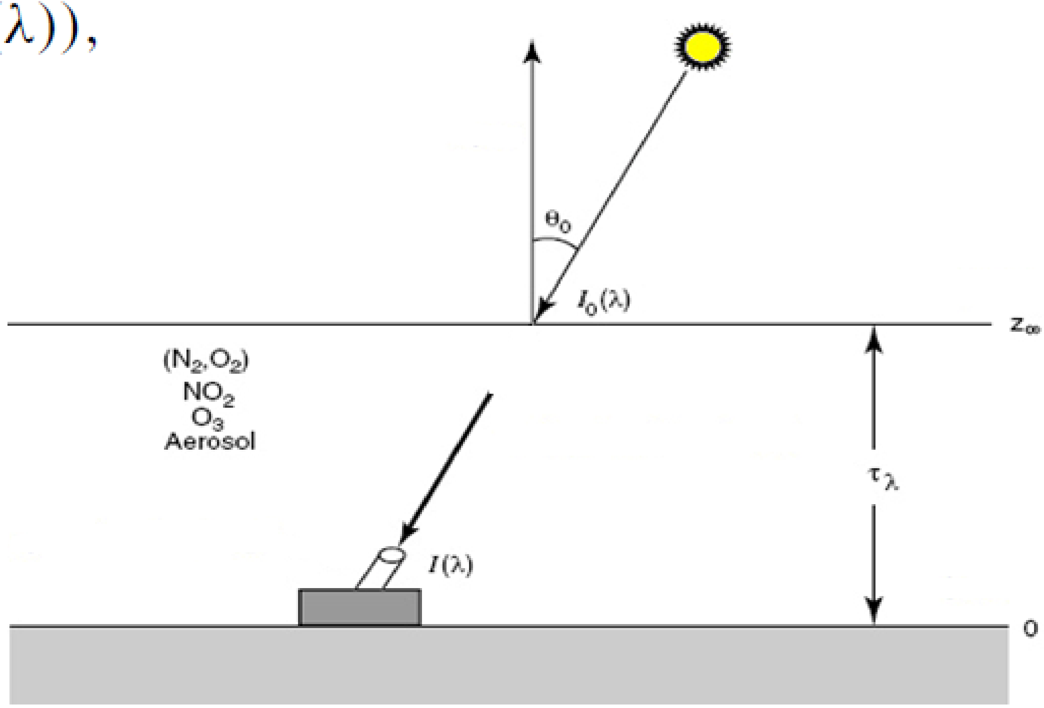
$I(\lambda)$ solar radiance over the SPM

$I_0(\lambda)$ solar radiation behind the atmosphere

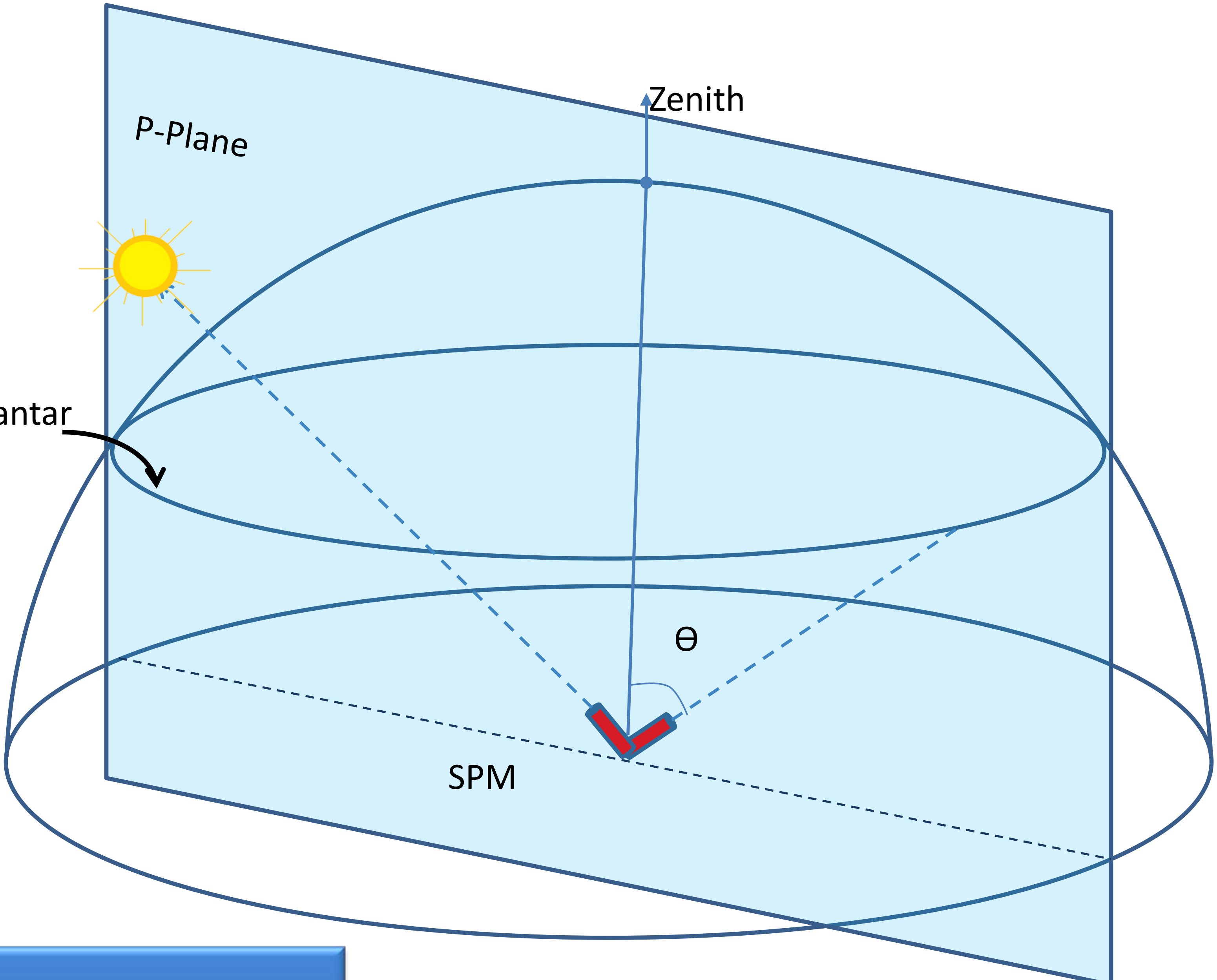
R mean Earth-Sun distance

m relative optical air mass

$\tau(\lambda)$ Total optical depth



K. N. LIOU, An Introduction to Atmospheric Radiation, Second Edition, 2002, Elsevier Science (USA)



Sunphotometer, sun and sky measurement modes

Passive optical remote sensing
Cimel CE-318 Sunphotometer

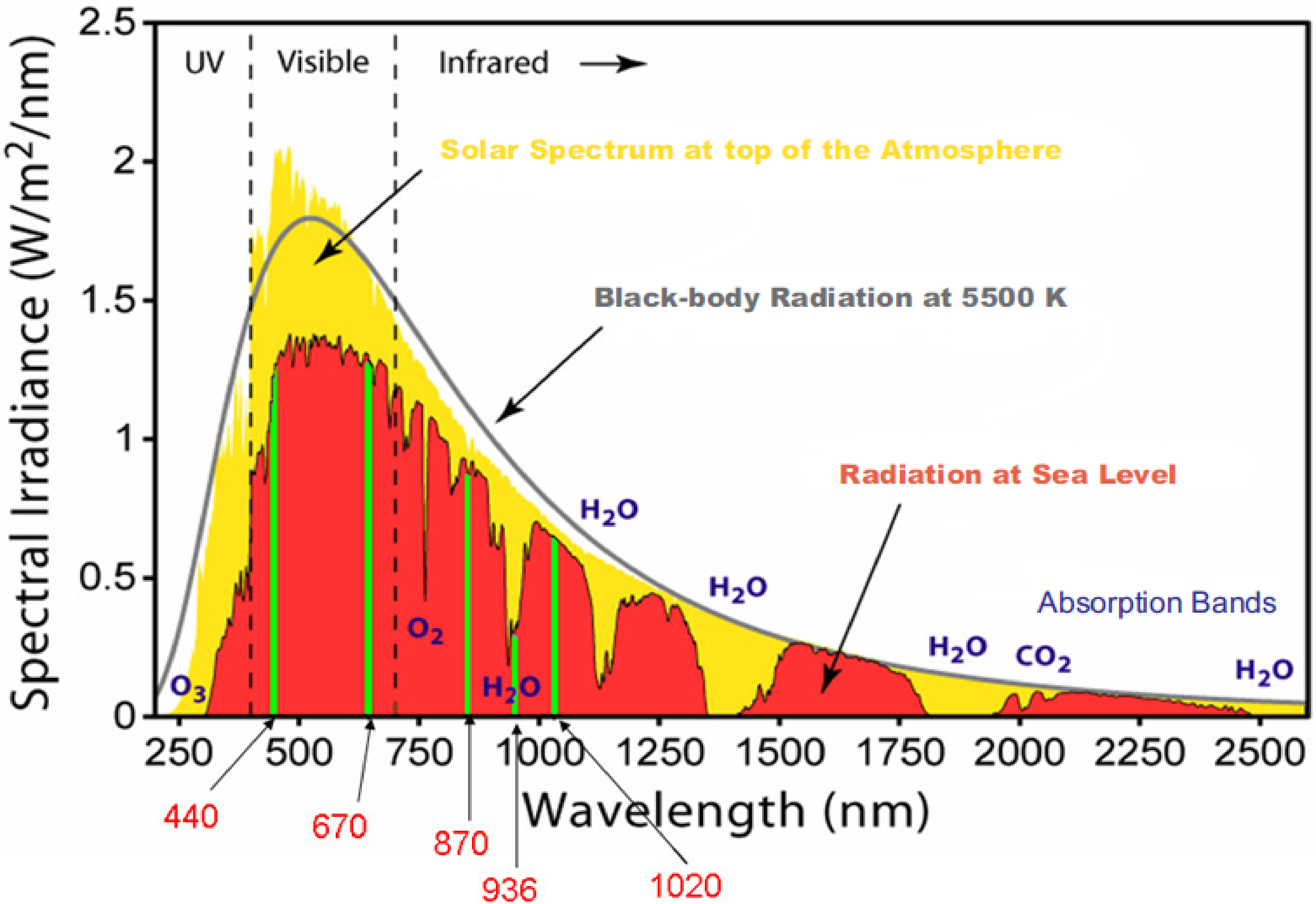
Sun Mode:

- 440, 670, 870, 936, 1020 nm
- Aerosol optical depth
- Columnar optical depth
- Angstrom exponent

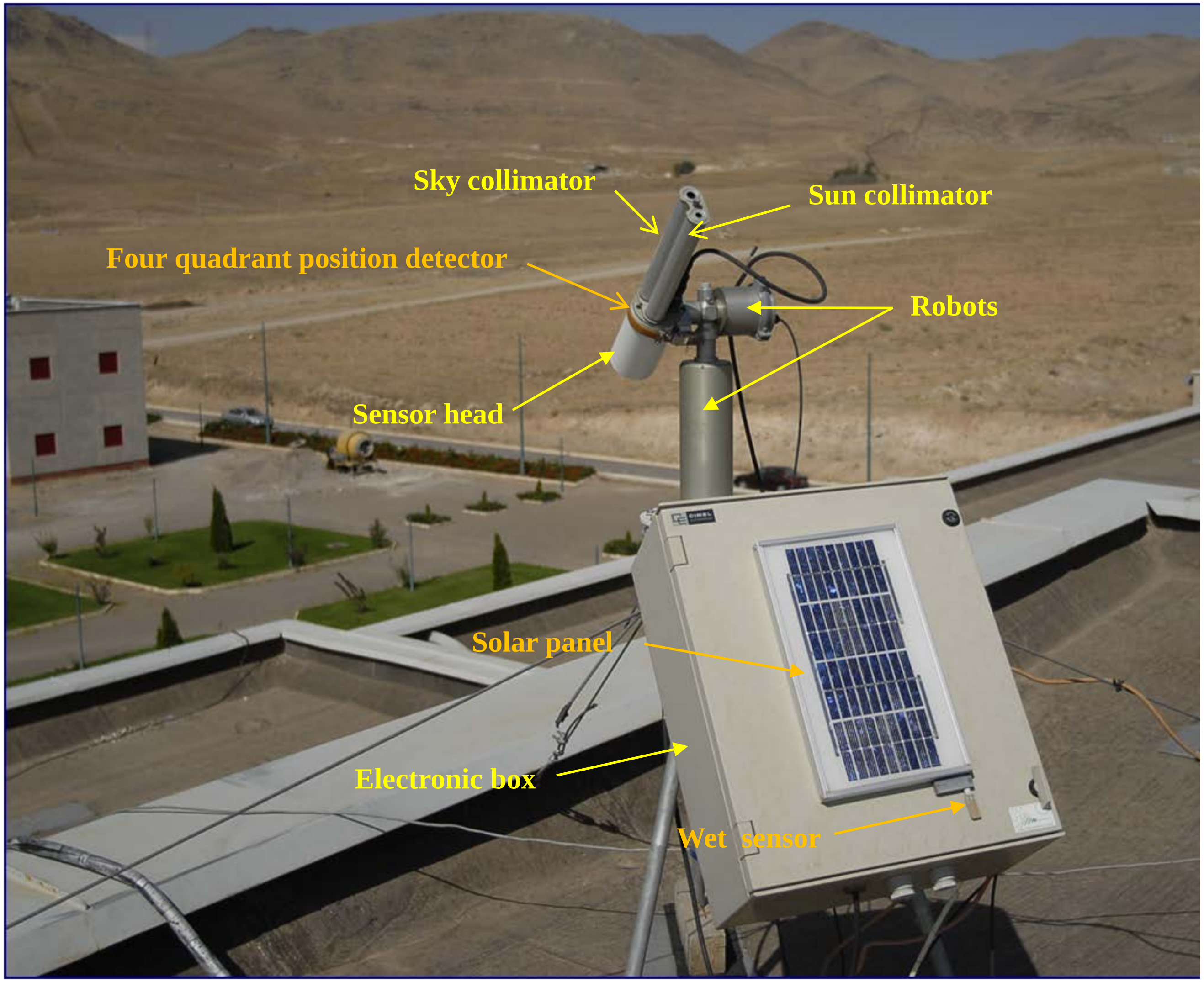
Sky Mode (Principle plane, Almucantar, Polarized principle plane) :

- 440, 670, 870, 936, 1020 nm
- Particle Size Distribution Function
- Phase function and Polarized Phase Function
- Single scattering albedo
- Complex Index of Refraction
- Degree of linear polarization

Holben B.N.1, et al.Remote Sensing of Environment, 1998

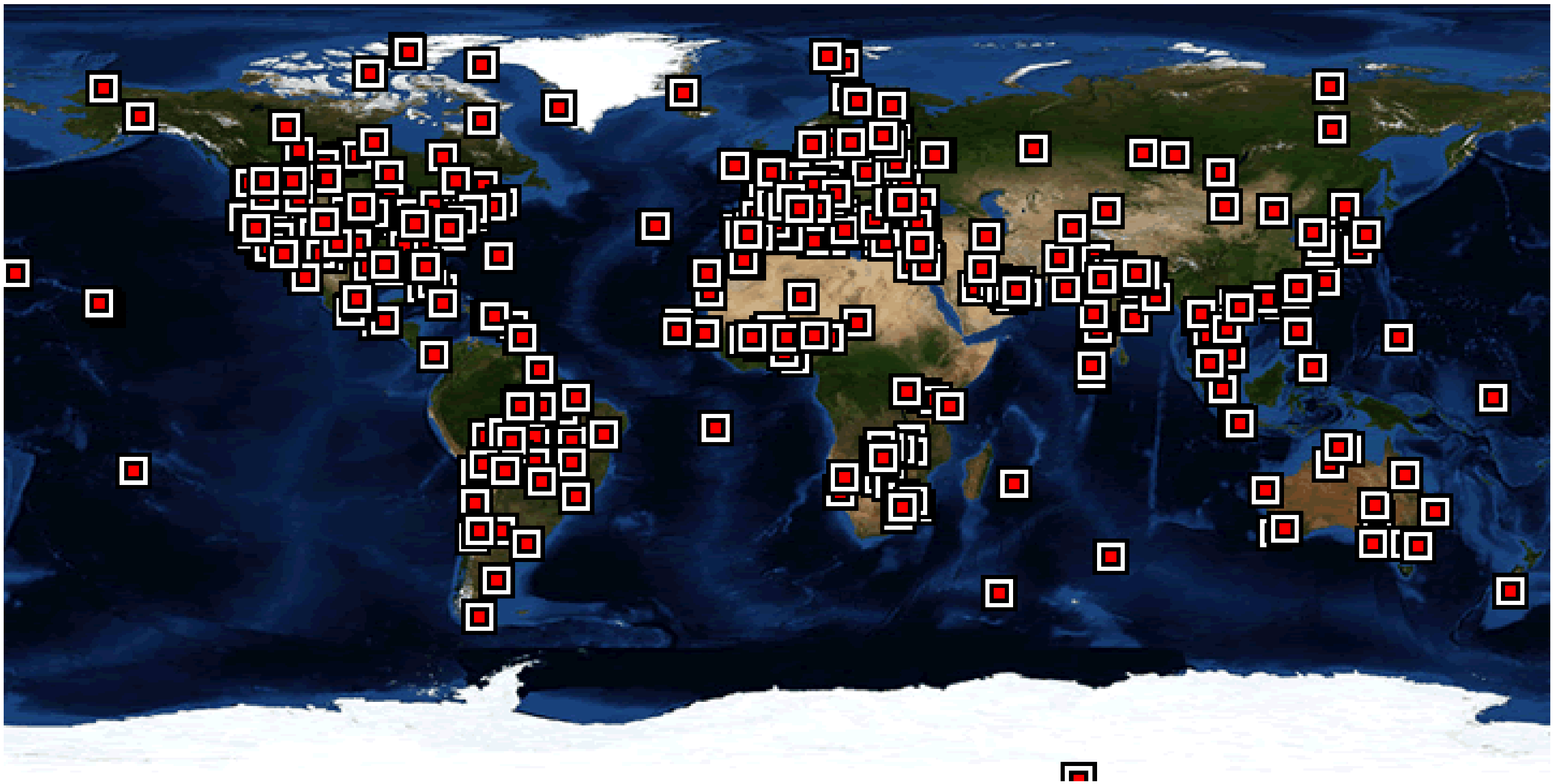


The irradiance spectrum of solar radiation at the top of the atmosphere and at sea level compared with black-body spectral irradiance at 5500 K.



Sunphotometer CE 318-2, IASBS site

Aerosol Robotic Network



Passive optical remote sensing

Cimel CE-318 Sunphotometer / Particle size

An empirical formula to approximate the spectral dependence of the atmospheric extinction caused by aerosols, Angstrom (1929)

$$\tau_{A,\lambda} = \beta\lambda^{-\alpha}$$

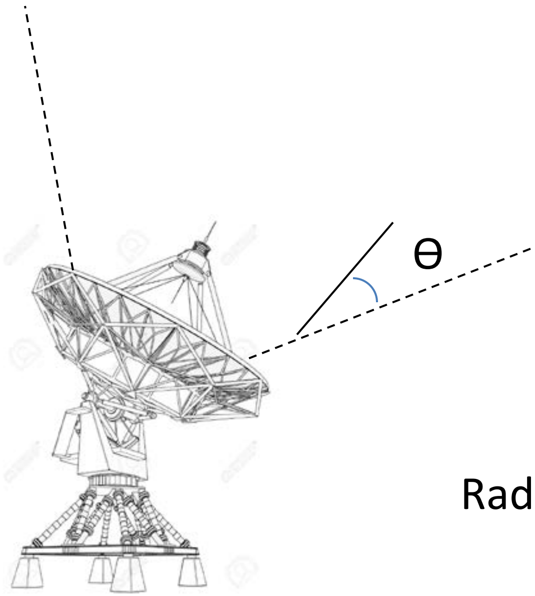
Angstrom exponent, a qualitative measure of particle size

$\alpha < 0.6$	Dust
$\alpha > 0.6$	Other fine mode particles

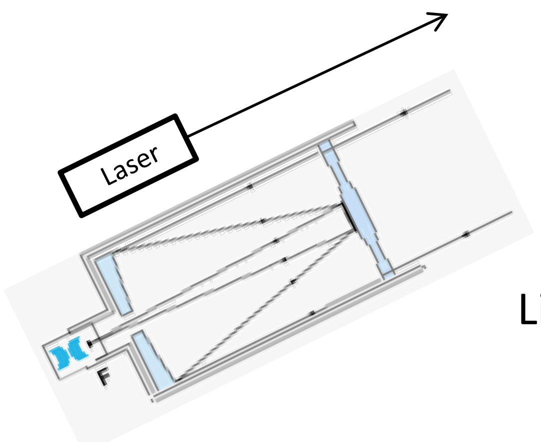
King, M. D. et al., J Atoms. Sci., 1976

Active Remote Sensing

Lidar, Spatial Resolution



Radar



Lidar

Beam width (half angle) and smallest possible Field of view:

$$\theta \cong \frac{\lambda}{D}$$

λ: wavelength
D: antenna diameter

***Radar*: λ=10 cm, D=1 m then $\theta \approx$0.1 rad or 6°**

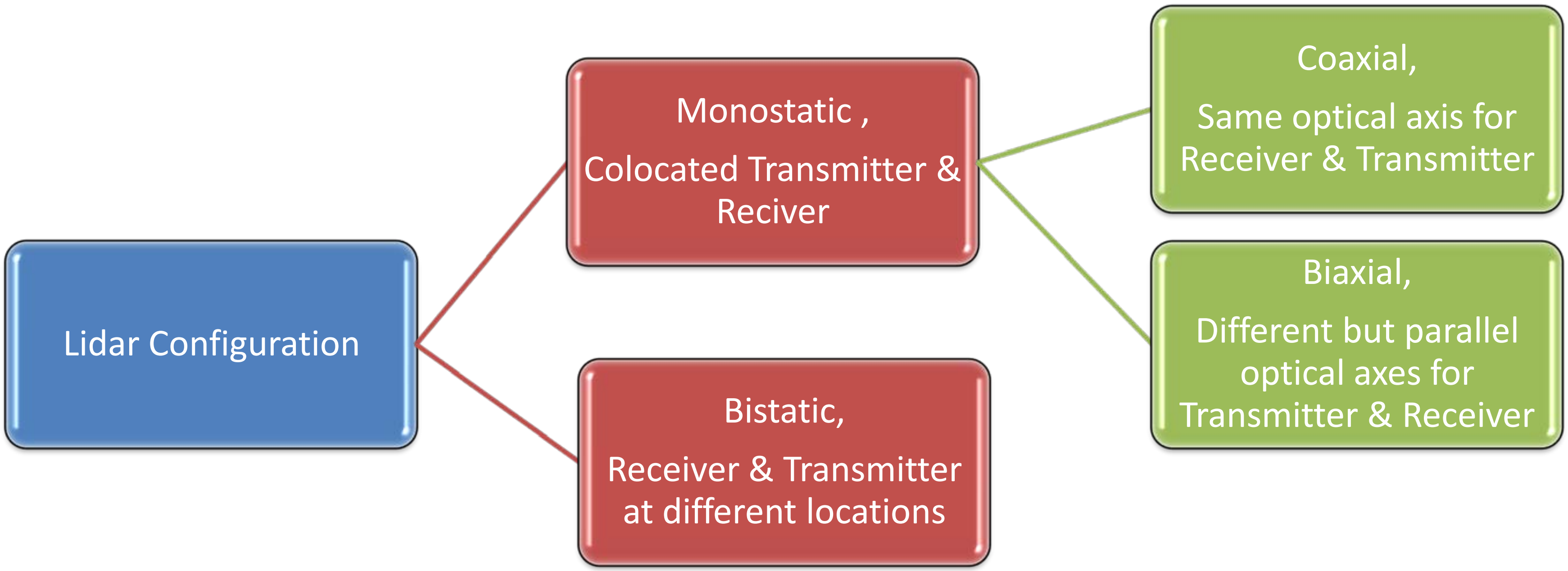
***Lidar*: λ=0.5 µm, D=0.1 m then $\theta \approx$5 µrad or 1''!**

Lidar, Temporal Resolution

Temporal resolution or accuracy on measuring the range, depends on:

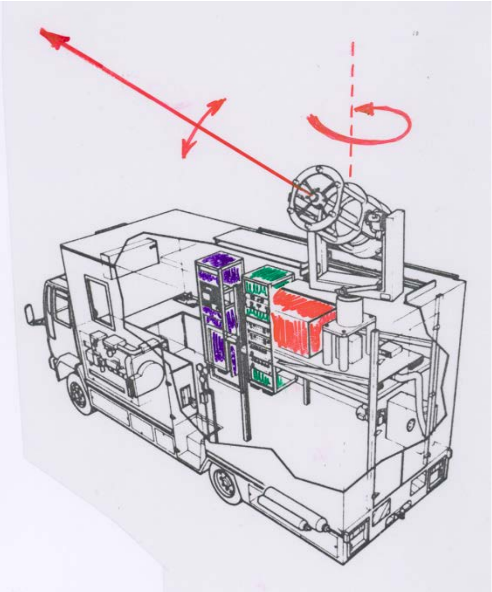
- Laser pulse length,
- Digitization technich.

Lidar, Installation and Structure



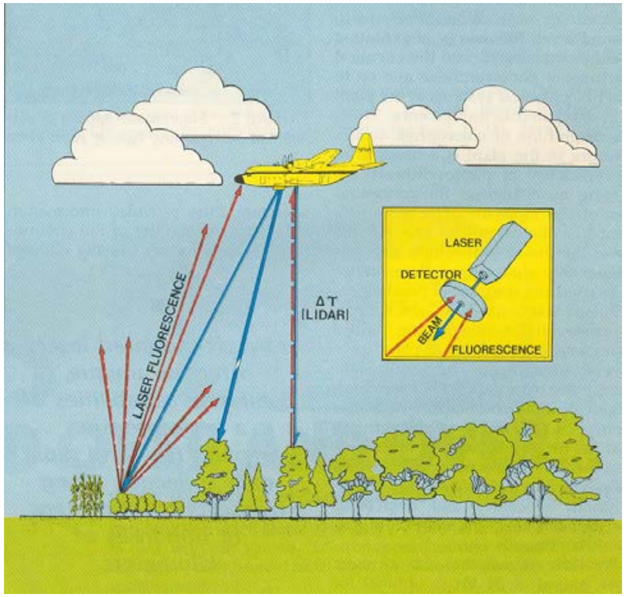
Installation

ground based

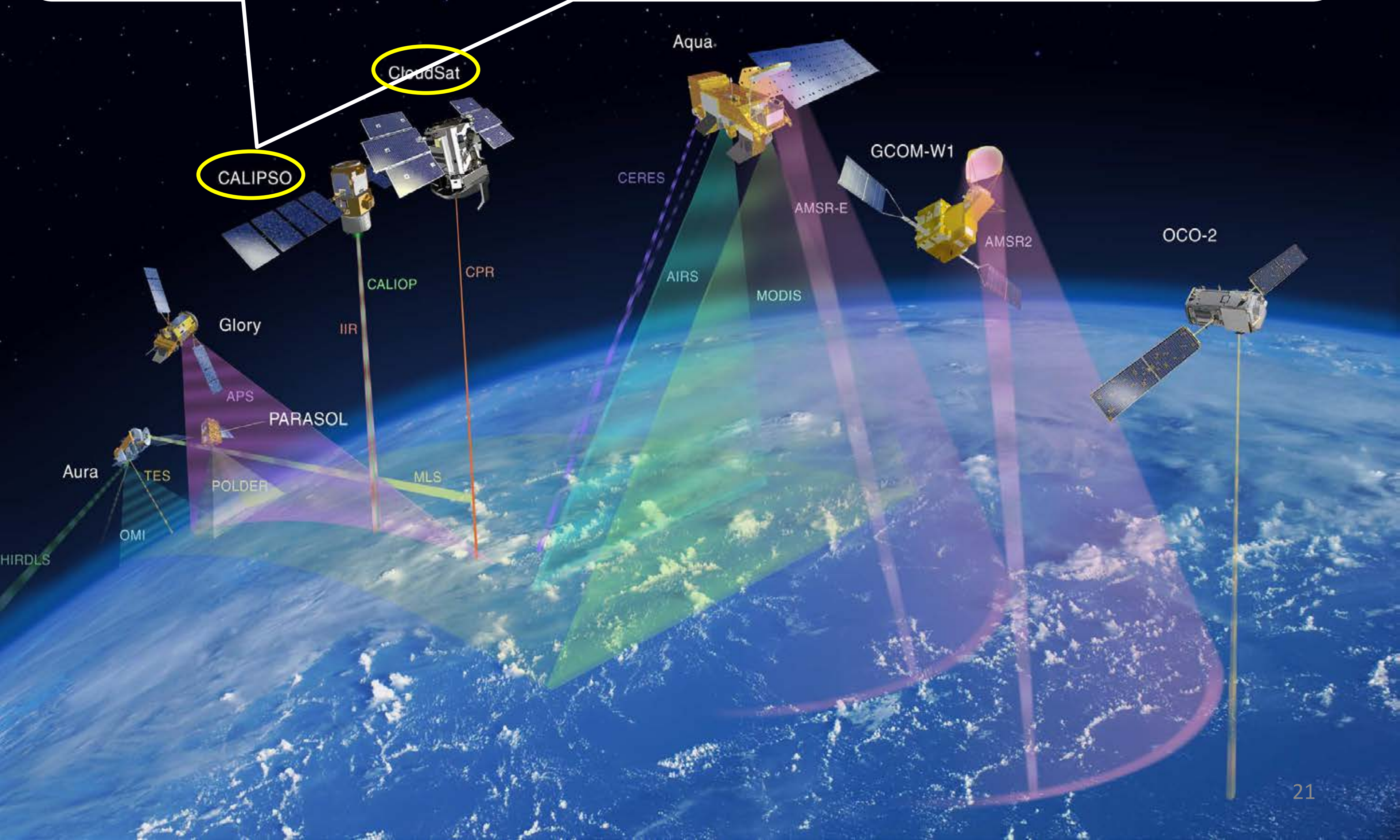


space born

air born

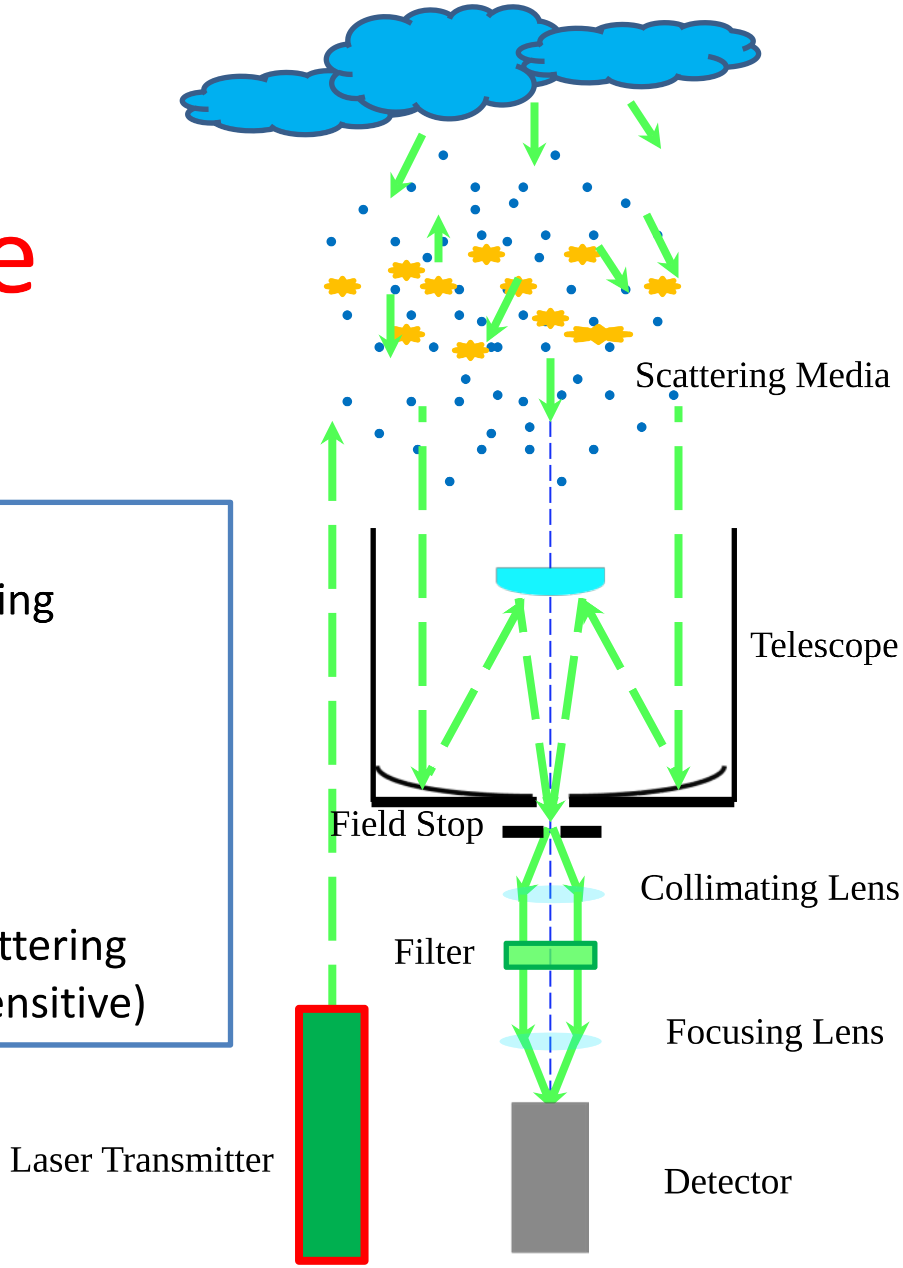


NASA launched the CloudSat and the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) spacecraft to study the role that clouds and aerosols play in regulating Earth's weather, climate and air quality.



Lidar Principle

- Molecules
  - Rayleigh Scattering
- Dust:
  - Mie scattering
- Clouds:
  - Geometrical scattering (Wavelength insensitive)



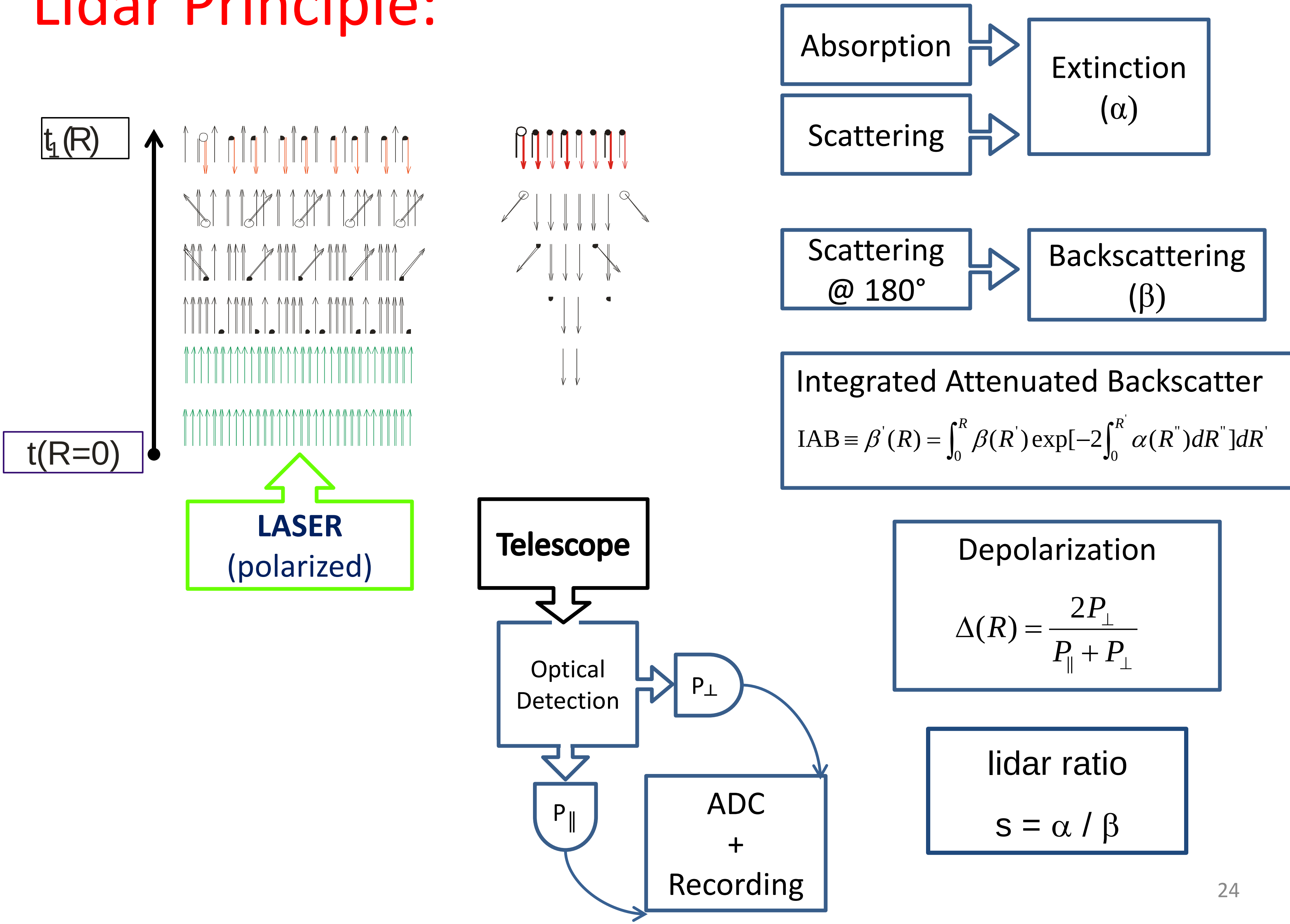
Lidar Equation

$$P_{sig}(R) = \frac{c}{2} E A \mathbf{MG}(R) \frac{\beta(R)}{R^2} \exp\left[-2\int_0^R \alpha(R)dx\right]$$

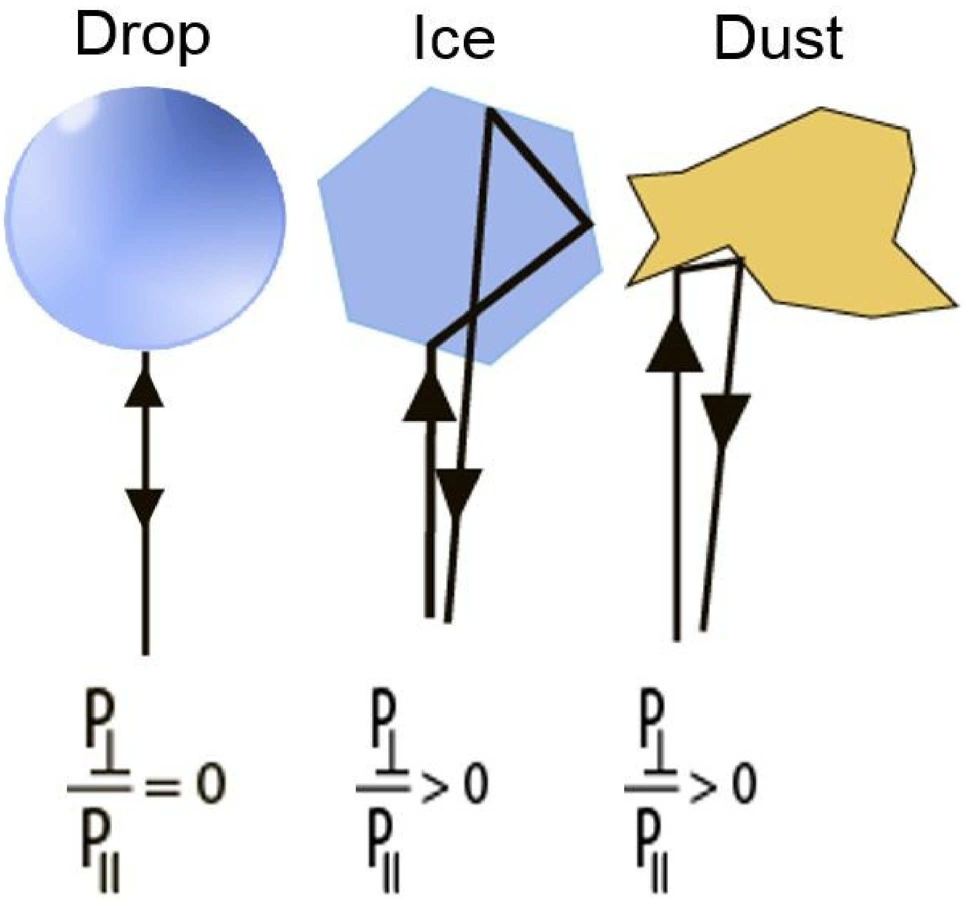
$$P_{sig}(R) = KA_{atm}(z)$$

Parameter	Symbol
Lidar Signal	$P_{sig}(R)$
Laser Energy	E
Telescope Area	A
Correction for Optical Components	M
Overlap Function	G(R)
Backscattering coefficient	$\beta(R)$
Extinction Coefficient	$\alpha(R)$

Lidar Principle:



Depolarization



Problem:
Lidar equation solution?

$$P_{sig}(R,\lambda) = P_{laser}\frac{C(R)}{R^2}\left[\beta_\lambda^{aer}(R) + \beta_\lambda^{mol}(R)\right]\exp\left[-2\int_0^R [\alpha_\lambda^{aer}(r) + \alpha_\lambda^{mol}(r)]dr\right]$$

We have a signal with two unknown variables

1. aerosol volume back scattering
2. Aerosol volume extinction

Raman Lidar a solution for Lidar quation

Elastic Signal

$$P_{sig}(R,\lambda) = P_{laser}\frac{C(R)}{R^2}\left[\beta_\lambda^{aer}(R) + \beta_\lambda^{mol}(R)\right]\exp\left[-2\int_0^R [\alpha_\lambda^{aer}(r) + \alpha_\lambda^{mol}(r)]dr\right]$$

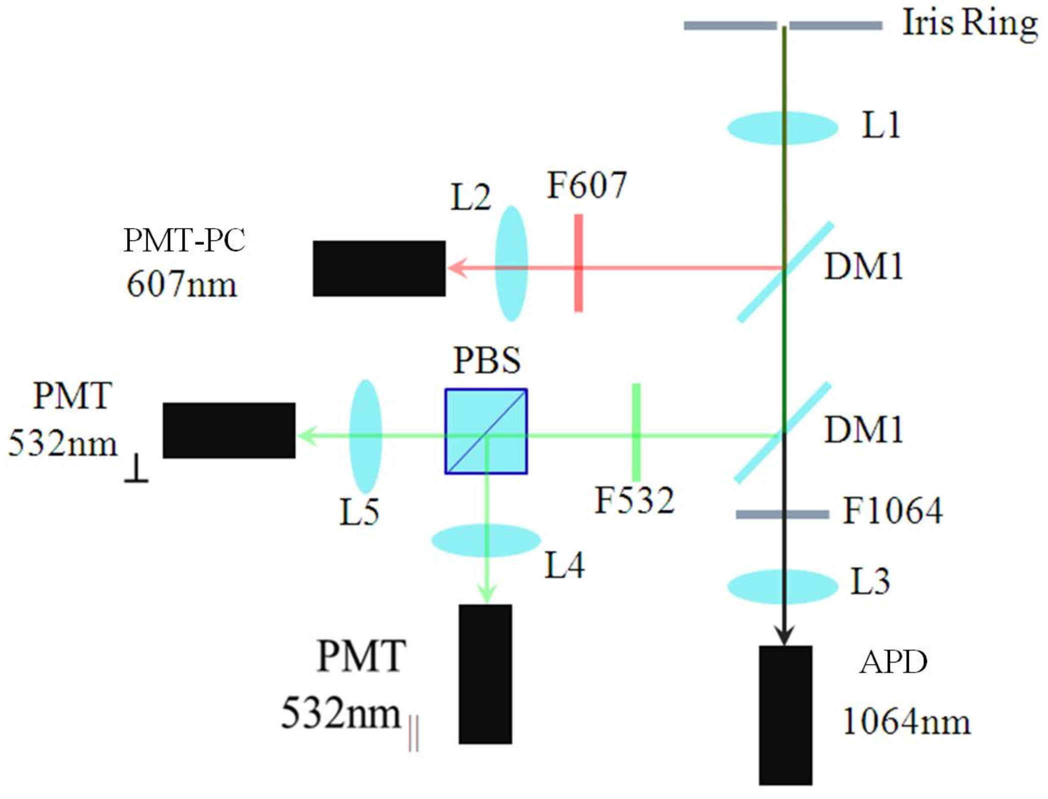
Raman Signal

$$P_{sig}(R,\lambda_{Ra}) = P_{laser}\frac{C(R)}{R^2}\beta_{\lambda_{Ra}}^{mol}(R)\exp\left[-\int_0^R [\alpha_{\lambda_{Ra}}^{aer}(r) + \alpha_\lambda^{aer}(r) + \alpha_{\lambda_{Ra}}^{mol}(r) + \alpha_\lambda^{mol}(r)]\,dr\right]$$

For reducing the unknowns we use from angstrom expoent.

$$\frac{\alpha_{aer}(\lambda_0)}{\alpha_{aer}(\lambda_{ra})} = \left(\frac{\lambda_{Ra}}{\lambda_o}\right)^a$$

The IASBS Raman Lidar



607 nm
Band width : 0.3 nm
Trransmission : 81 %

532 nm
Band width : 1.0 nm
Trransmission : 40 %

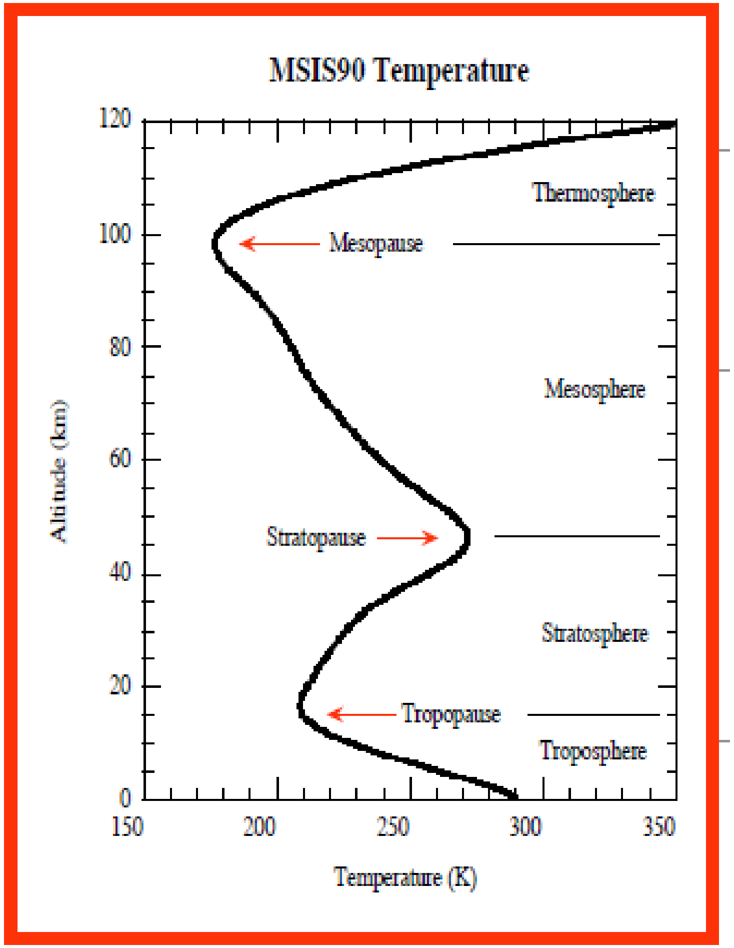
1064 nm
Band width : 3.0 nm
Trransmission : 45 %

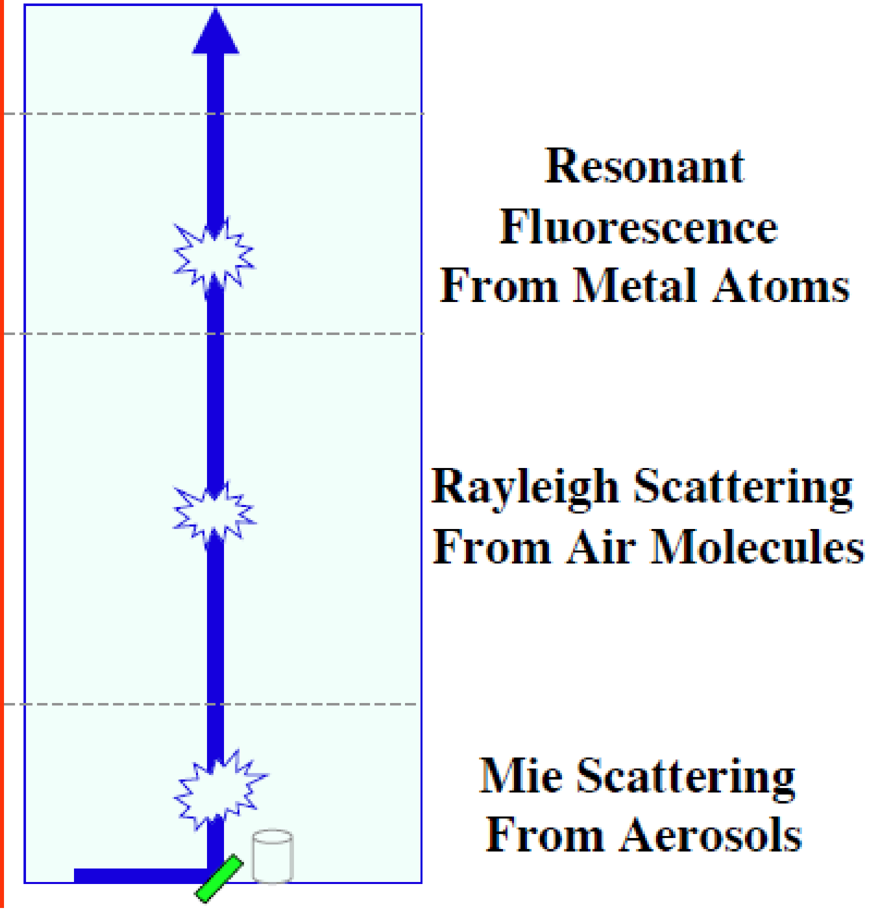
Borzoie, H. PhD Thesis 2013

Lidar and Atmospheric Physics

Lidar	Application
Elastic Backscatter	Clouds, Aerosol, Pollution
Depolarization	Dust, Clouds (Ice or water), Pollution
Raman	Aerosol, Water Vapor, Gases, Pollution, Temperature,
High Spectral Resolution, HSRL	Aerosol, Water Vapor, Gases, Pollution
Doppler	Wind
Differential Absorption Lidar (DiAL)	Water vapor , Ozone, Gases
Ceilometer	Visibility, Cloud height
Fluorescence	Vegetation, Archeology, Bio-aerosols

Lidar, Atmospheric layers



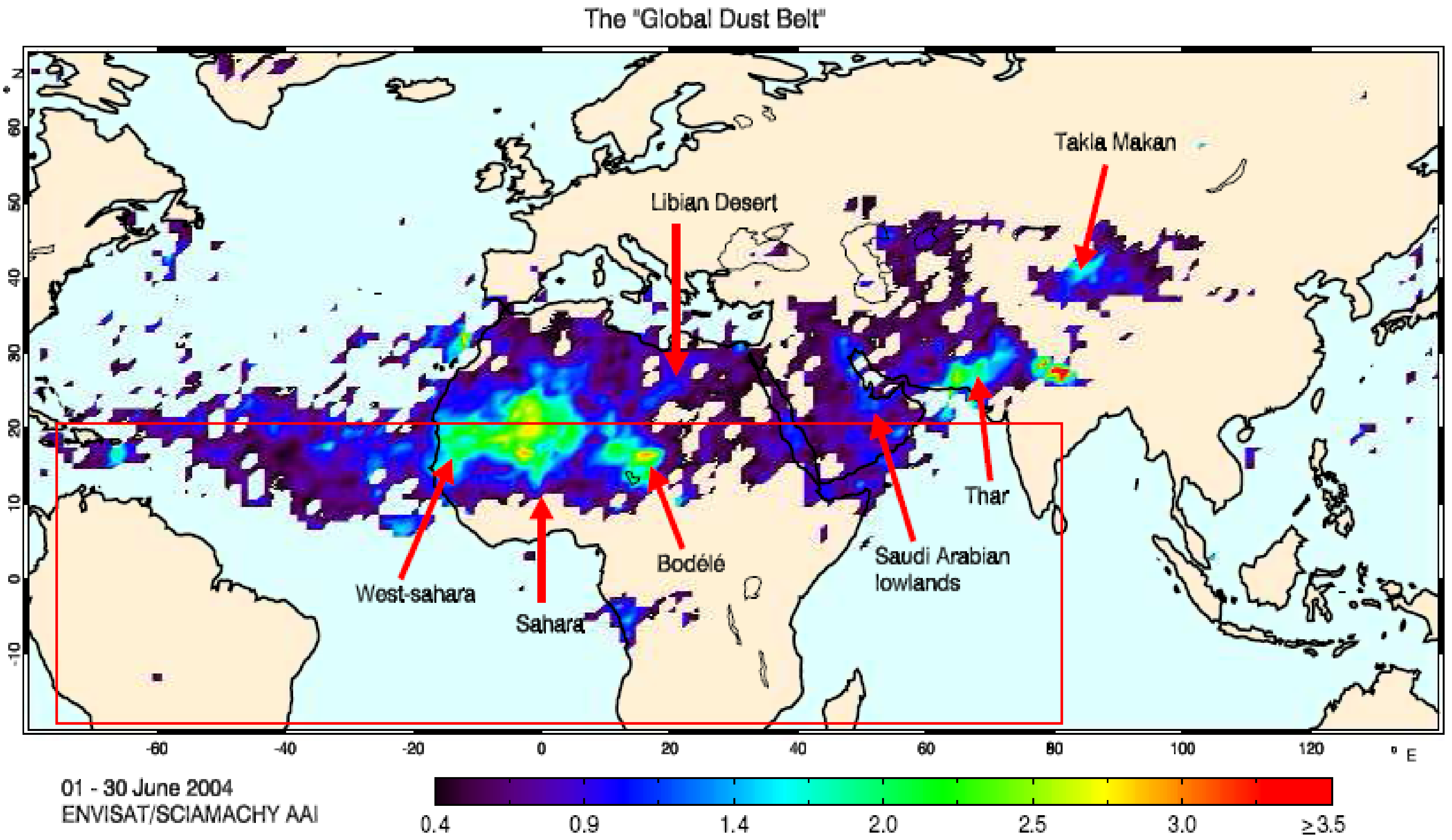


Case Studies

Regions Under Investigation

Region	Ground Based Instruments	Satellite suites	Models	Duration
Northwest Iran (Zanjan)	Raman Lidar, Sunphotometr, Synoptic stations	AQUA MODIS, Terra MODIS CALIPSO	NCEP/NCAR, HYSPLIT, DREAM	2006 - 2013
Tehran	Depolarized, Backscatter Lidar, Air pollution monitoring stations, Synoptic stations			2014 - now
Persian Gulf and Oman sea				2006 - 2015

The Iran Plateau

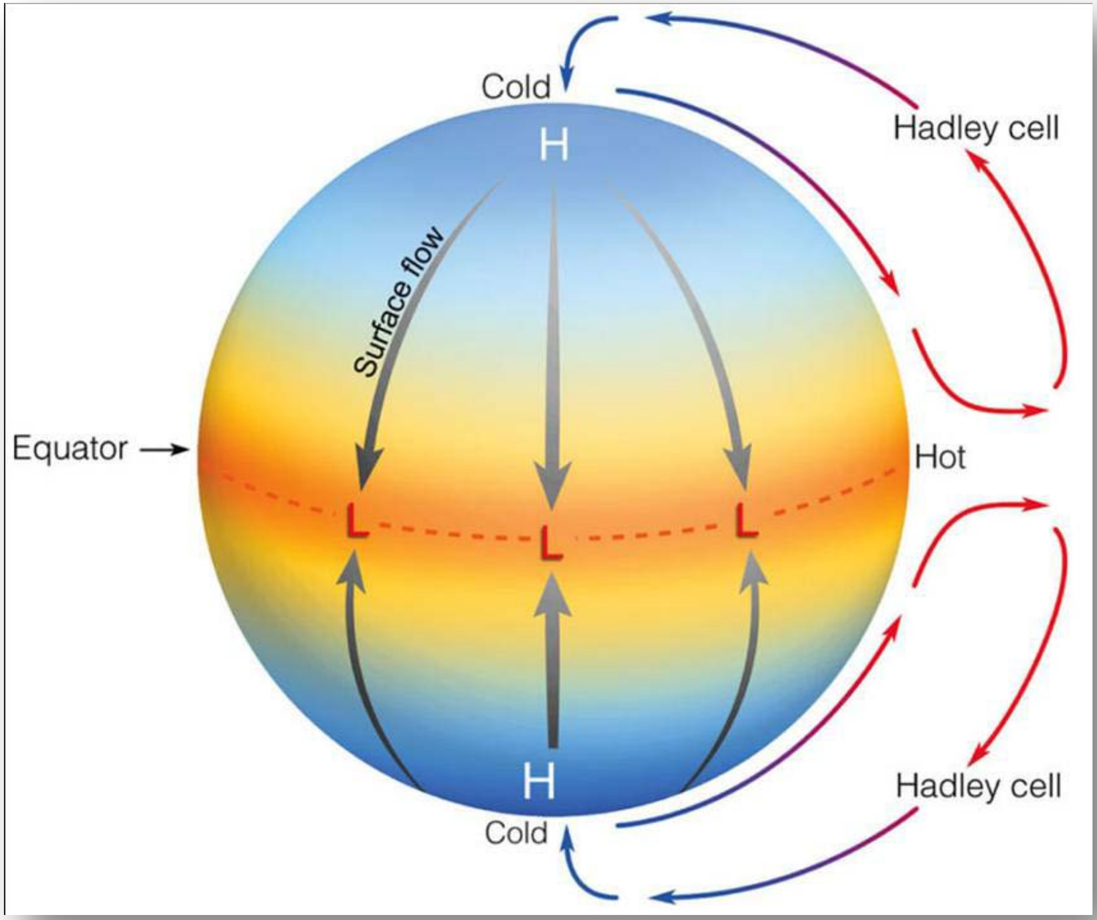


Sahara, Sahel, Arabian Peninsula, Thar desert (Middle East), Aral Sea (Central Asia), Taklamakan desert (China), Gobi Desert (China/Mongolia), Lake Eyre Basin (Australia)

(de Graaf, 2006)

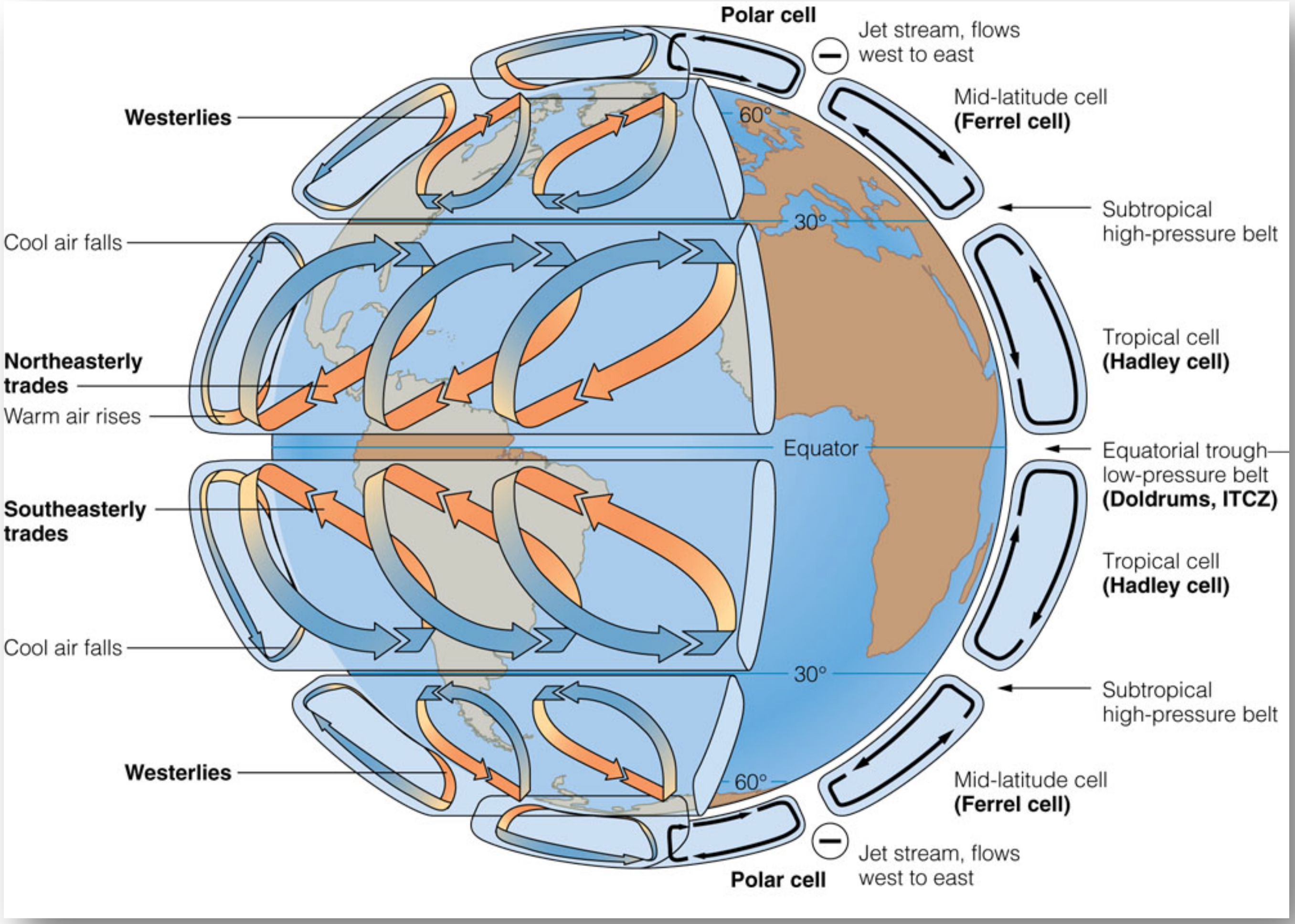
The Atmosphere

Single cell model, Hadley cell



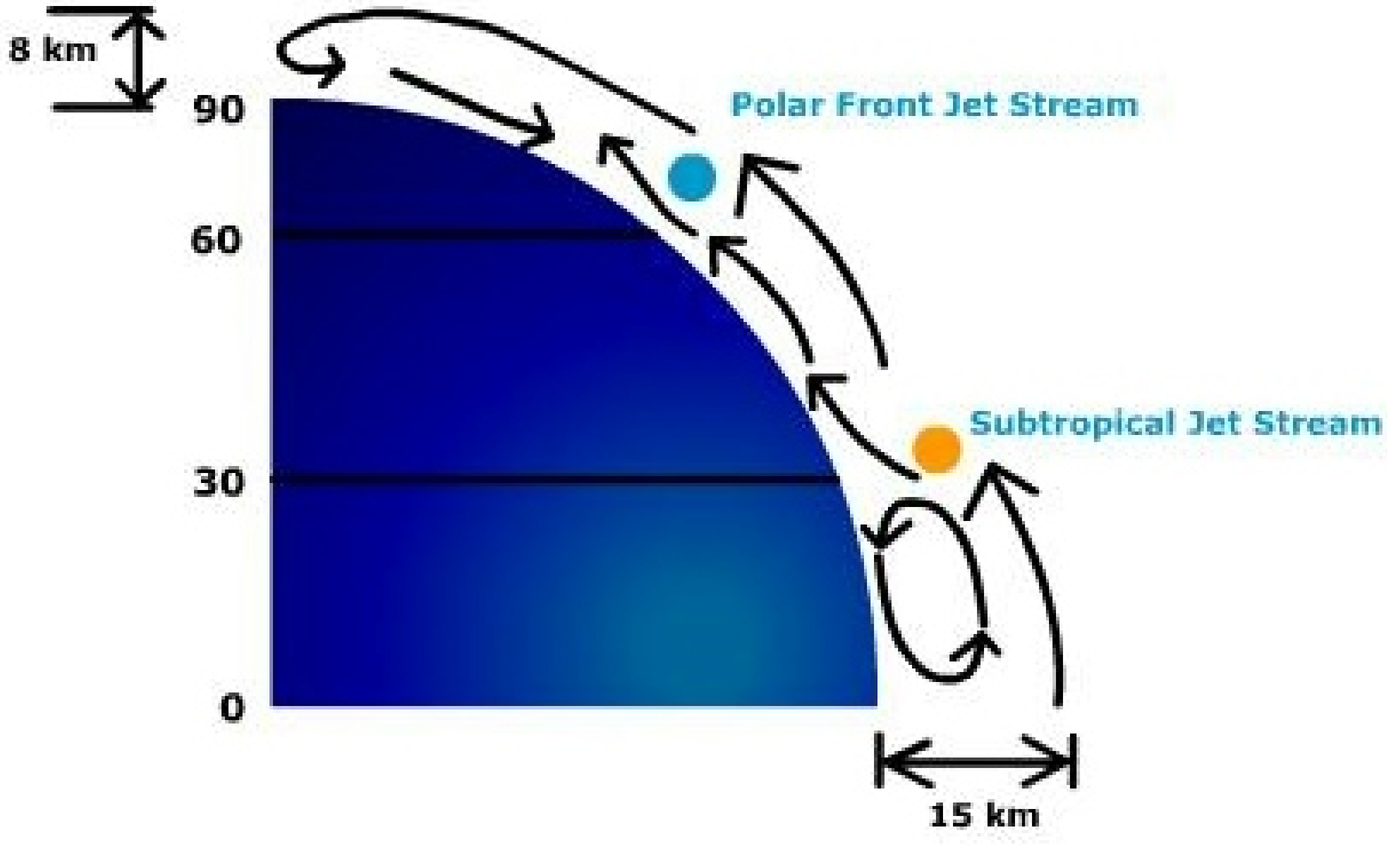
The Atmosphere

Three cell model, Jet streams



The Atmosphere

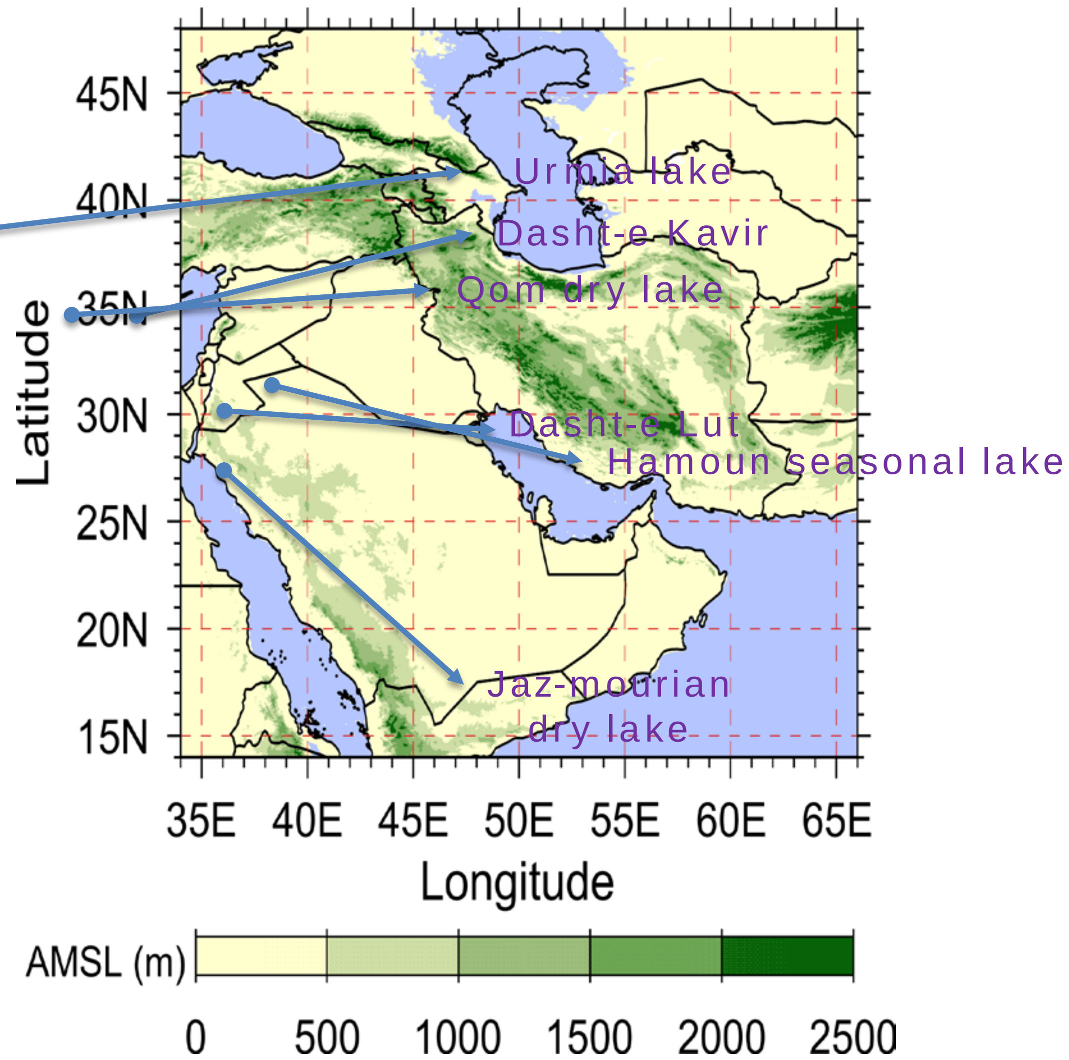
Jet streams & changes in troposphere thickness



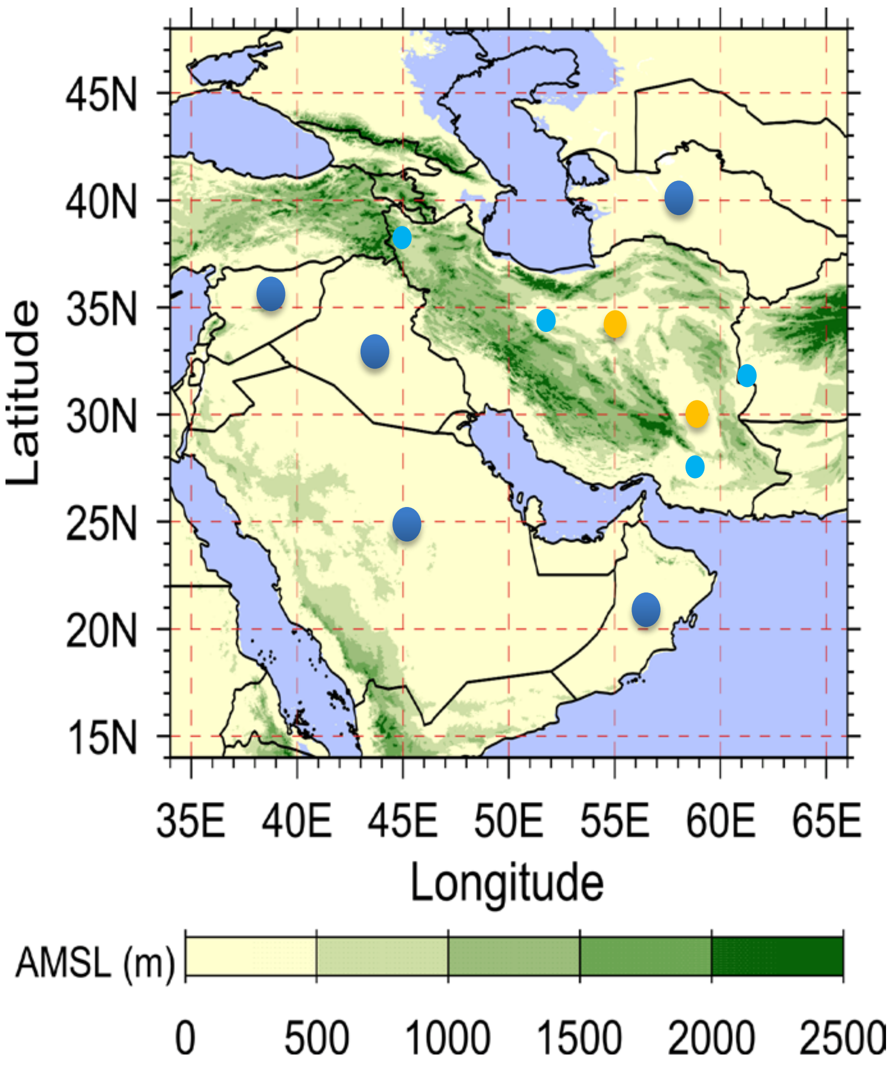
Dust Storm
Zanjan, Jul 5, 2009

Iran in Dust Belt: external sources

Iran in Dust Belt: internal sources



F. Abdi Vishkaee, PhD. Thesis, 2011



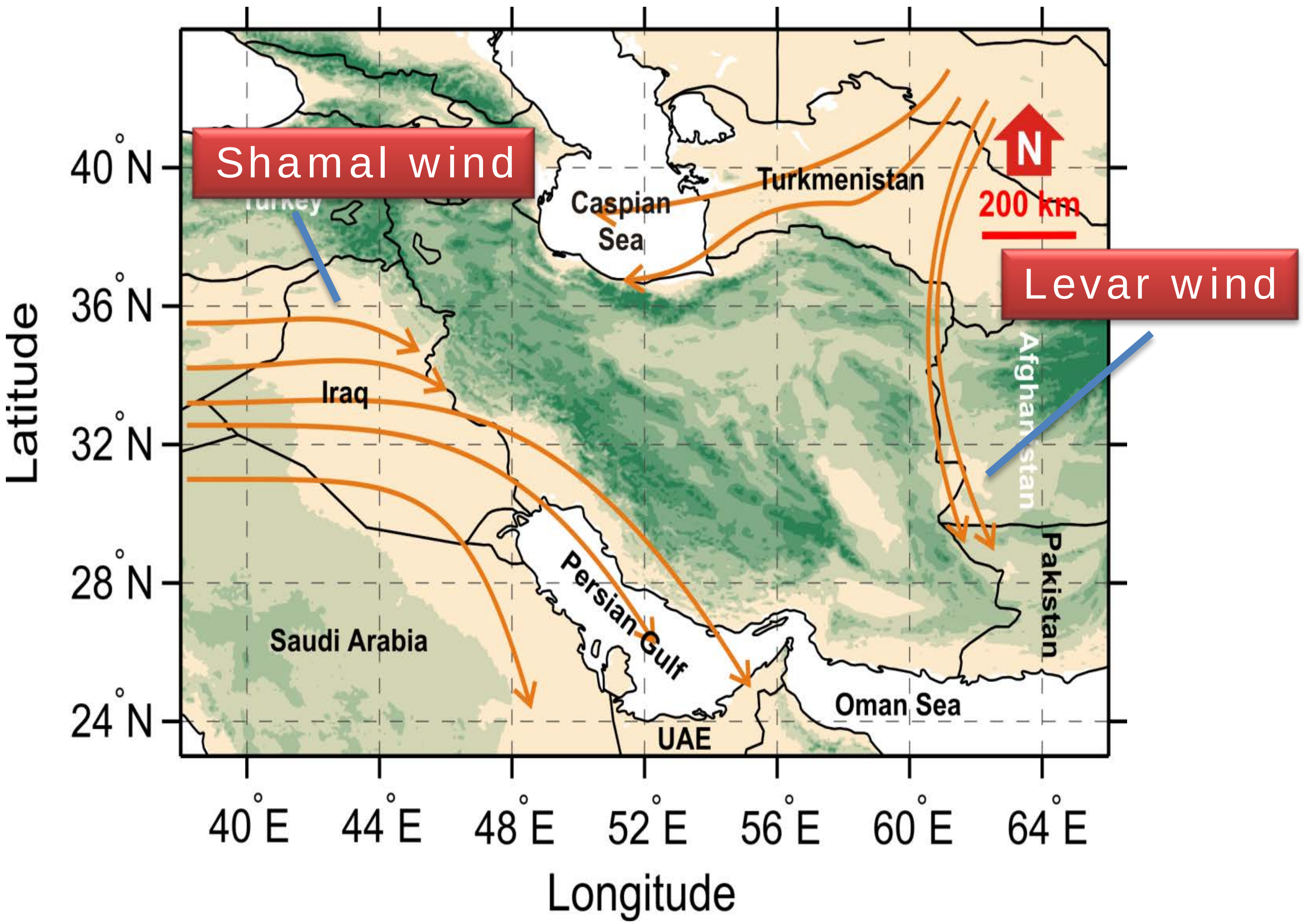
External dust sources

Desrt

Seasonal / dry lakes

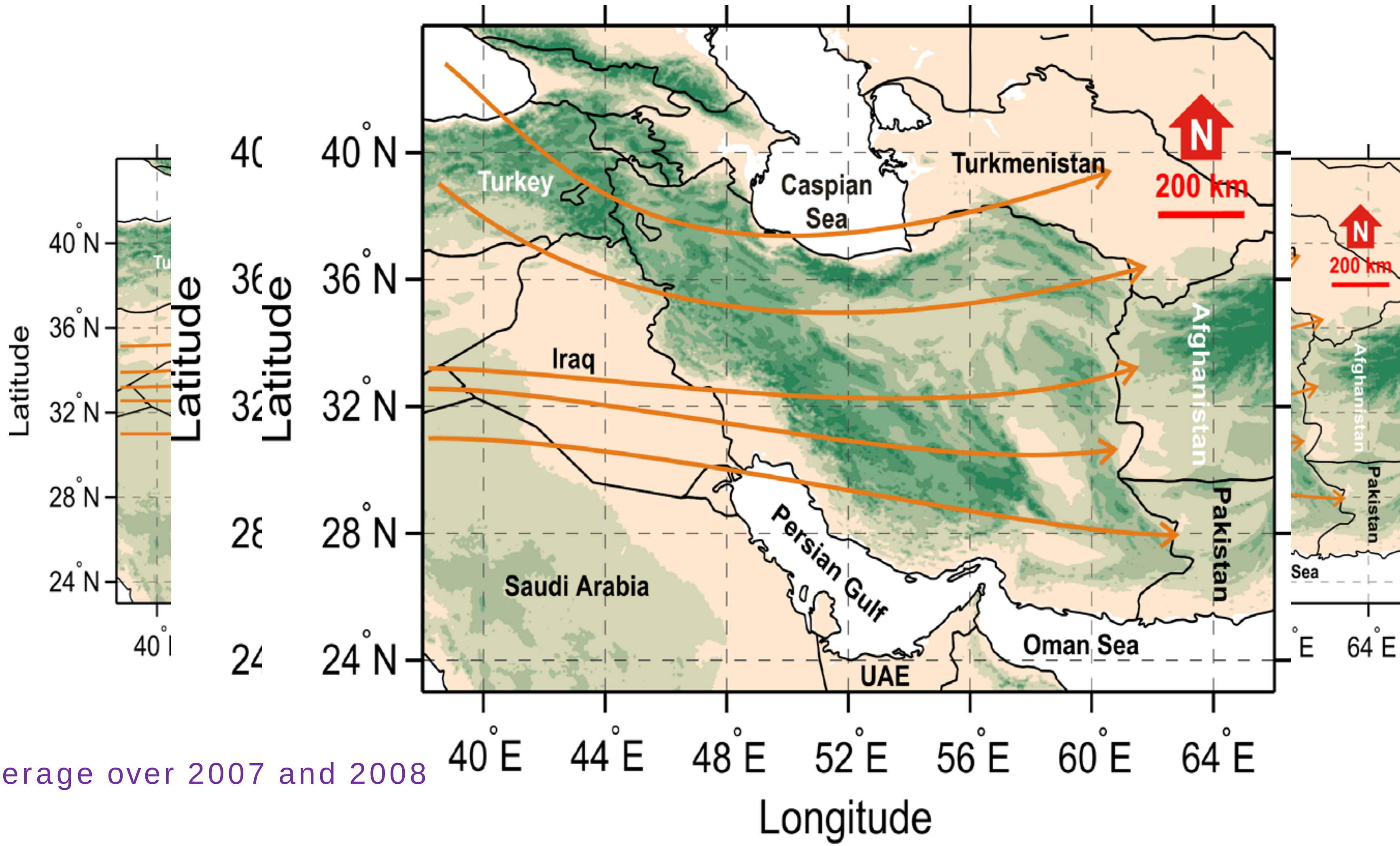
Wind Patterns at Surface

Average over 2007 and 2008



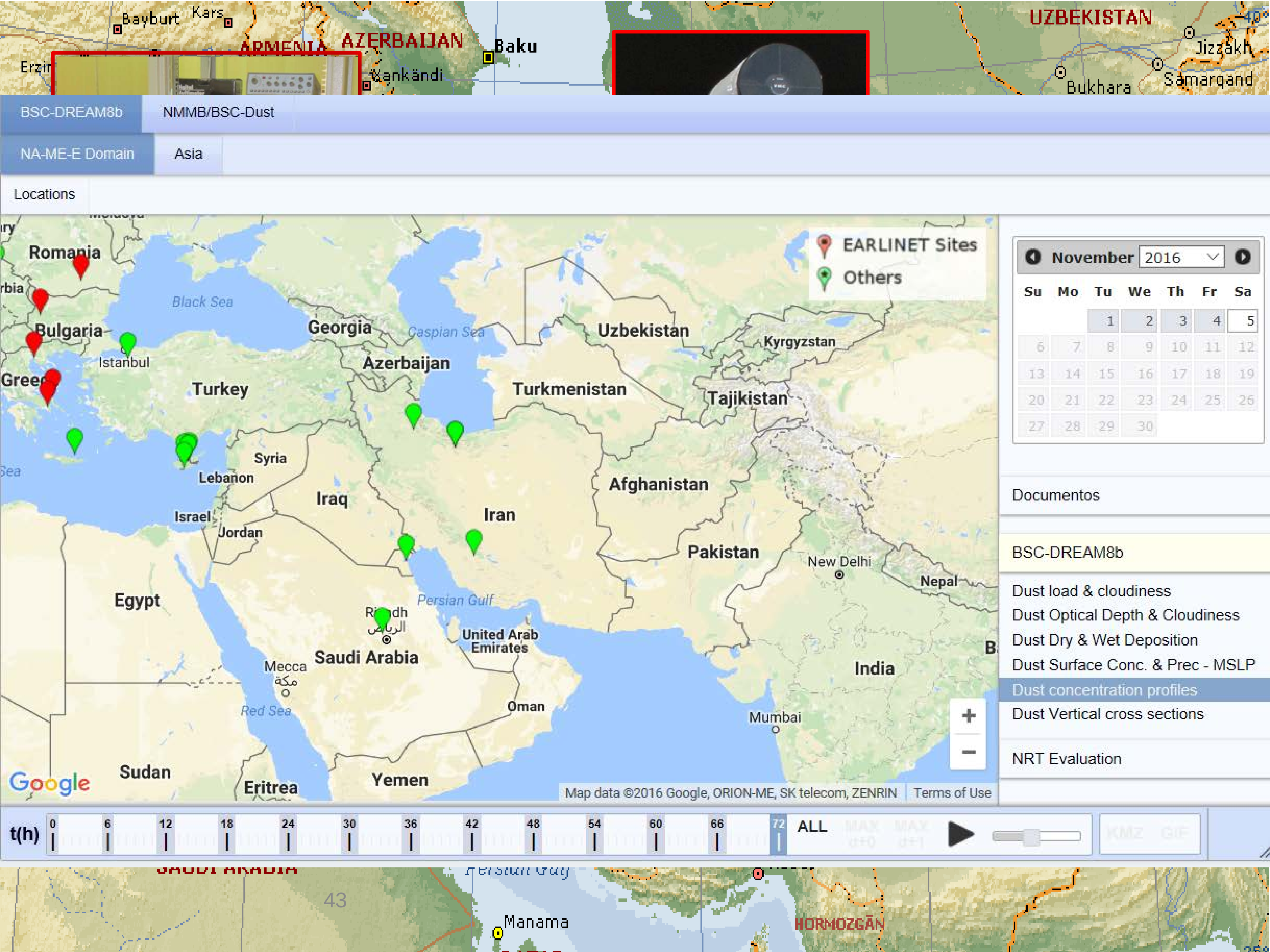
Wind Patterns at 500 hPa

Wind Patterns

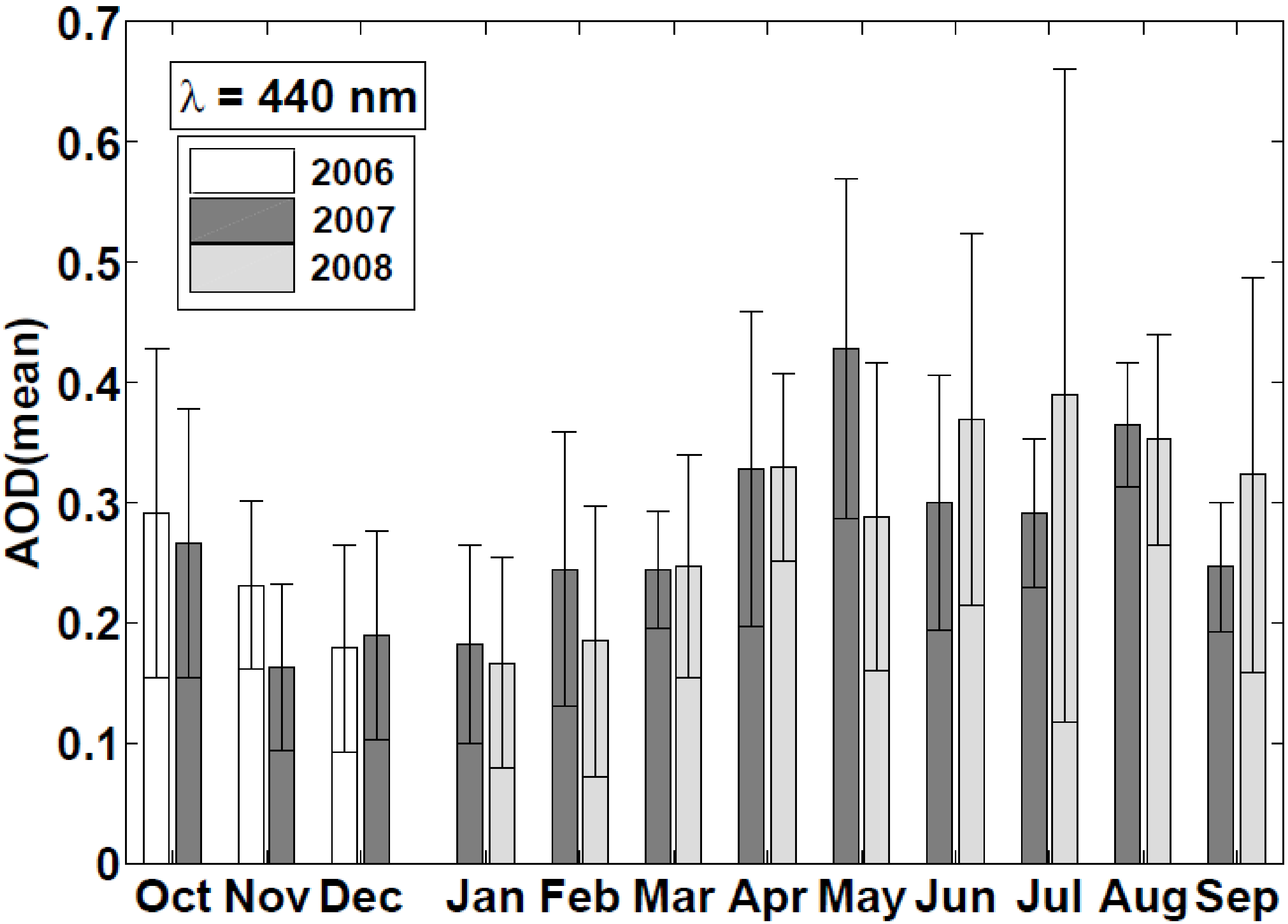


Average over 2007 and 2008

F. Abdi Vishkaee, PhD. Thesis, 2011

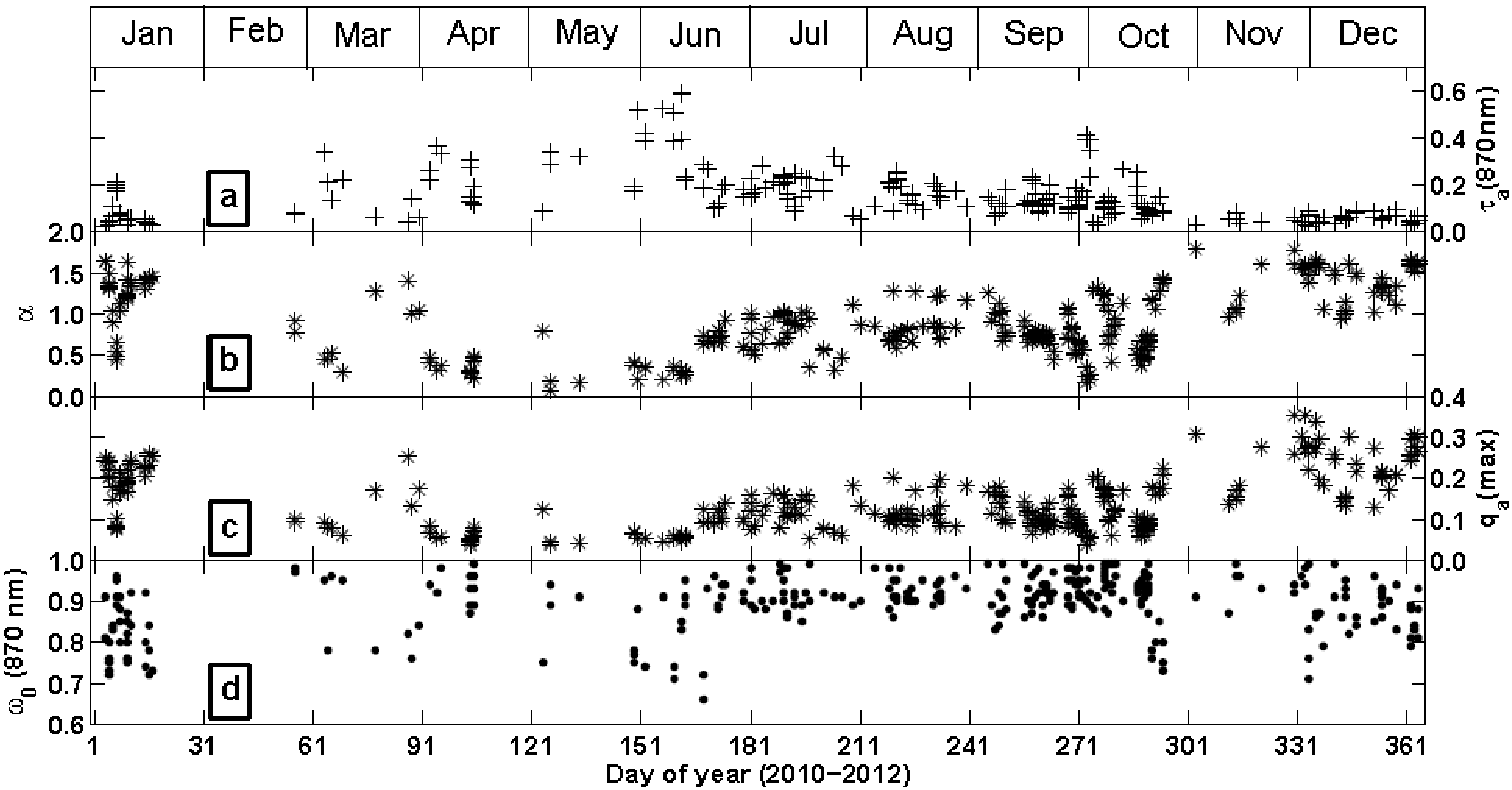

BSC-DREAM8b
NMMB/BSC-Dust
NA-ME-E Domain
Asia
Locations
EARLINET Sites
Others
November 2016
Su Mo Tu We Th Fr Sa
Documentos
BSC-DREAM8b
Dust load & cloudiness
Dust Optical Depth & Cloudiness
Dust Dry & Wet Deposition
Dust Surface Conc. & Prec - MSLP
Dust concentration profiles
Dust Vertical cross sections
NRT Evaluation
Map data ©2016 Google, ORION-ME, SK telecom, ZENRIN
Terms of Use
t(h)
0 6 12 18 24 30 36 42 48 54 60 66 72
ALL

Northwest Iran



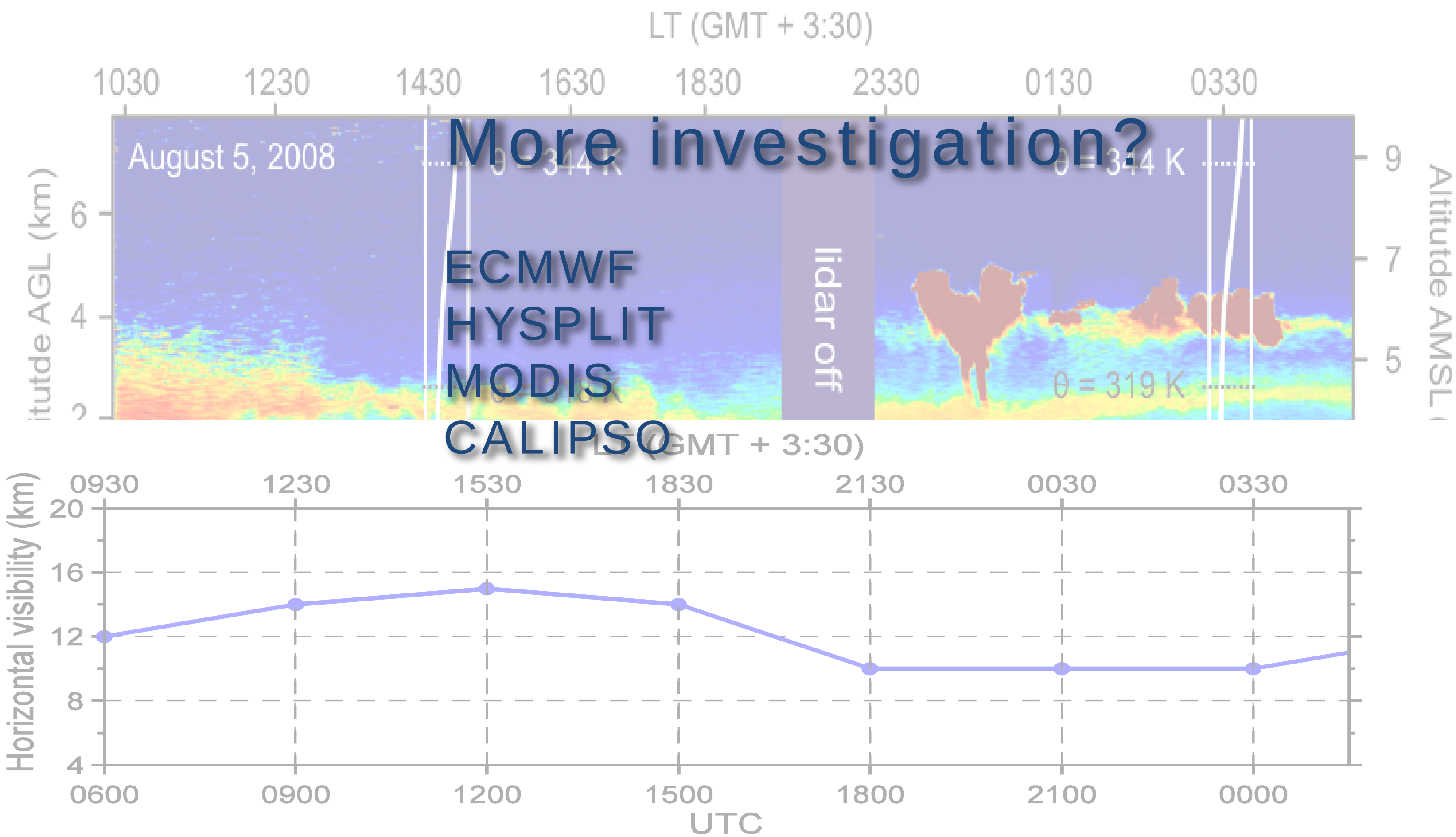
Temporal evolution of AOD (440 nm), monthly averages in Zanjan for the period of October 2006 to September 2008, the IASBS site.

Seasonal variation of aerosol parameters



A. Bayat, et al. Atmos. Meas. Tech. (2013)

Zanjan, August 5, 2007



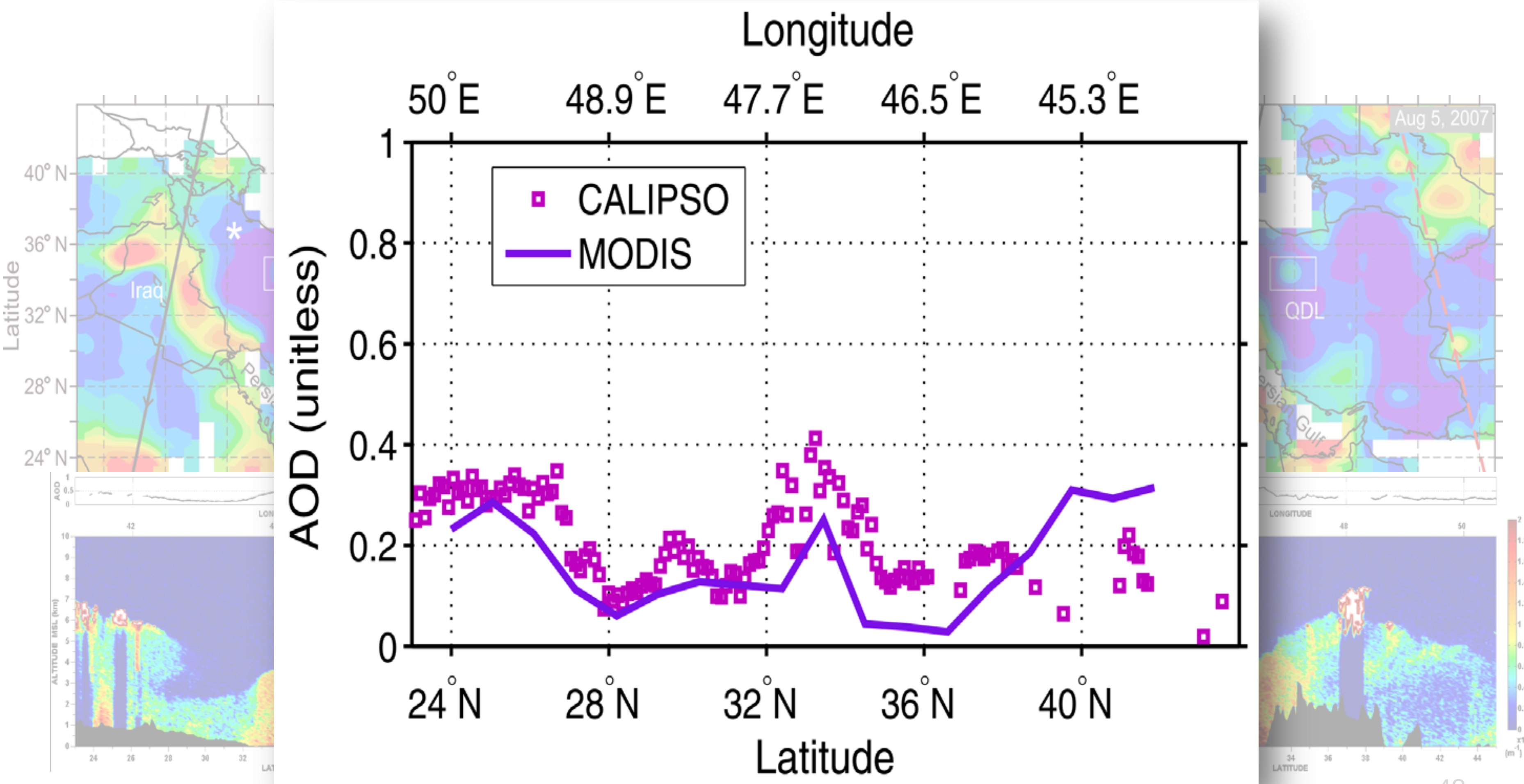
More investigation?

- ECMWF
- HYSPLIT
- MODIS
- CALIPSO

Zanjan, August 5, 2007

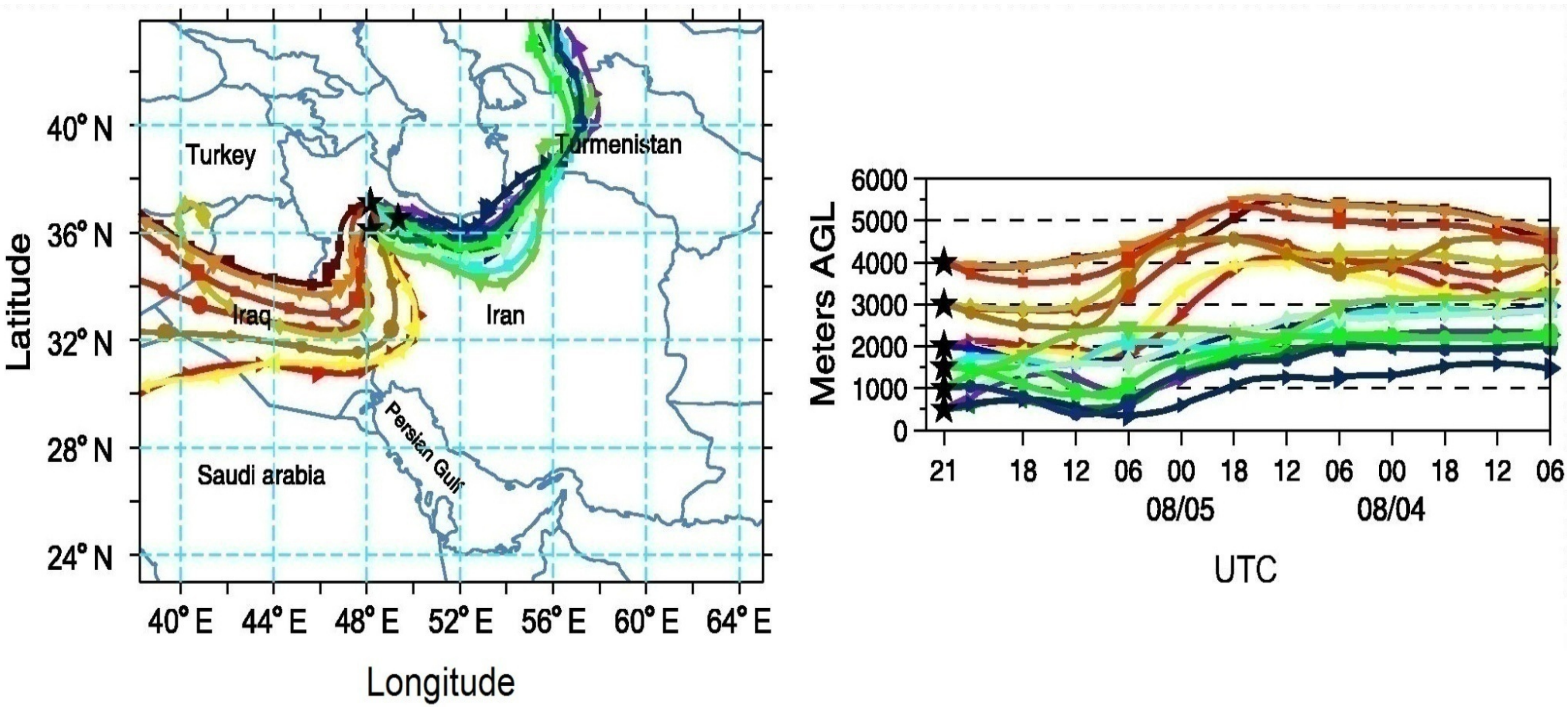
MODIS Deepblue AOD

MODIS vs CALIPSO
4 Aug 2007, daytime



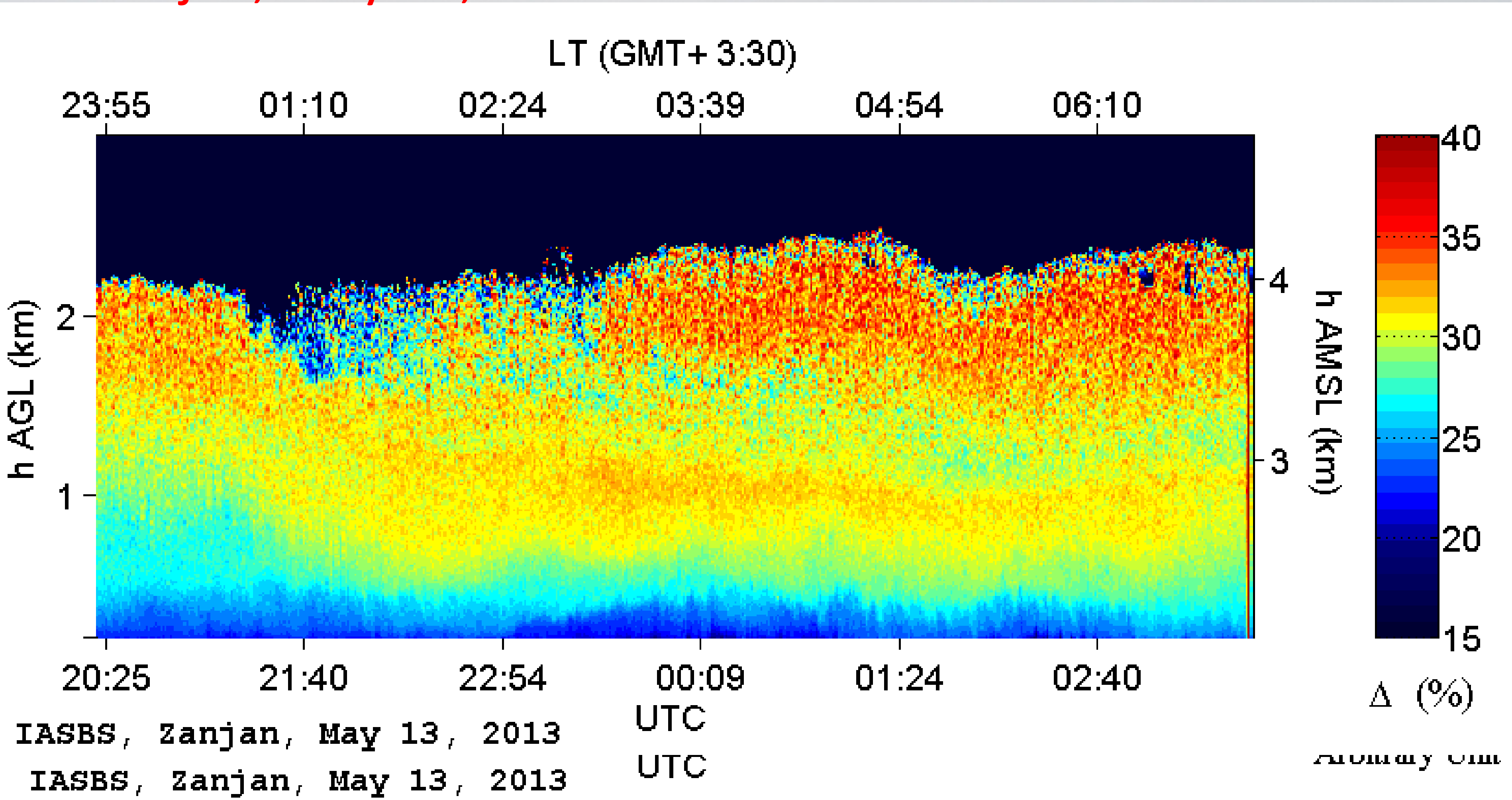
Zanjan, August 5, 2007

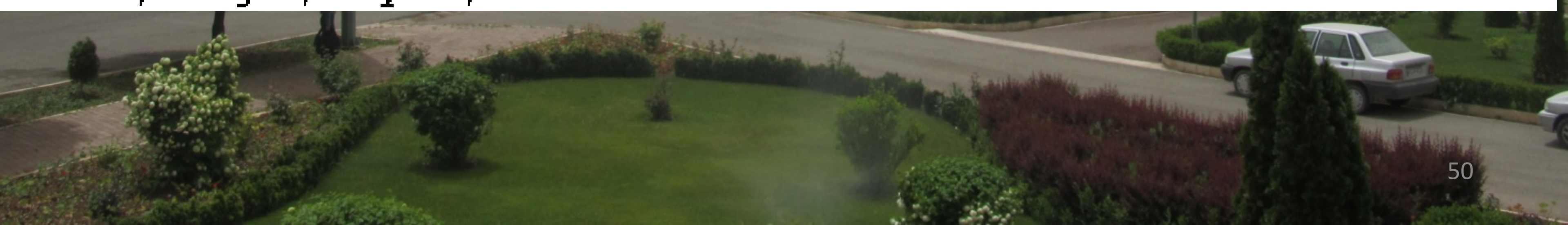
HYSPLIT back-trajectory, 5 Aug 2007
0600 UTC



•**Farhad Abdi Vishkaee et al.,** JGR, 2011.

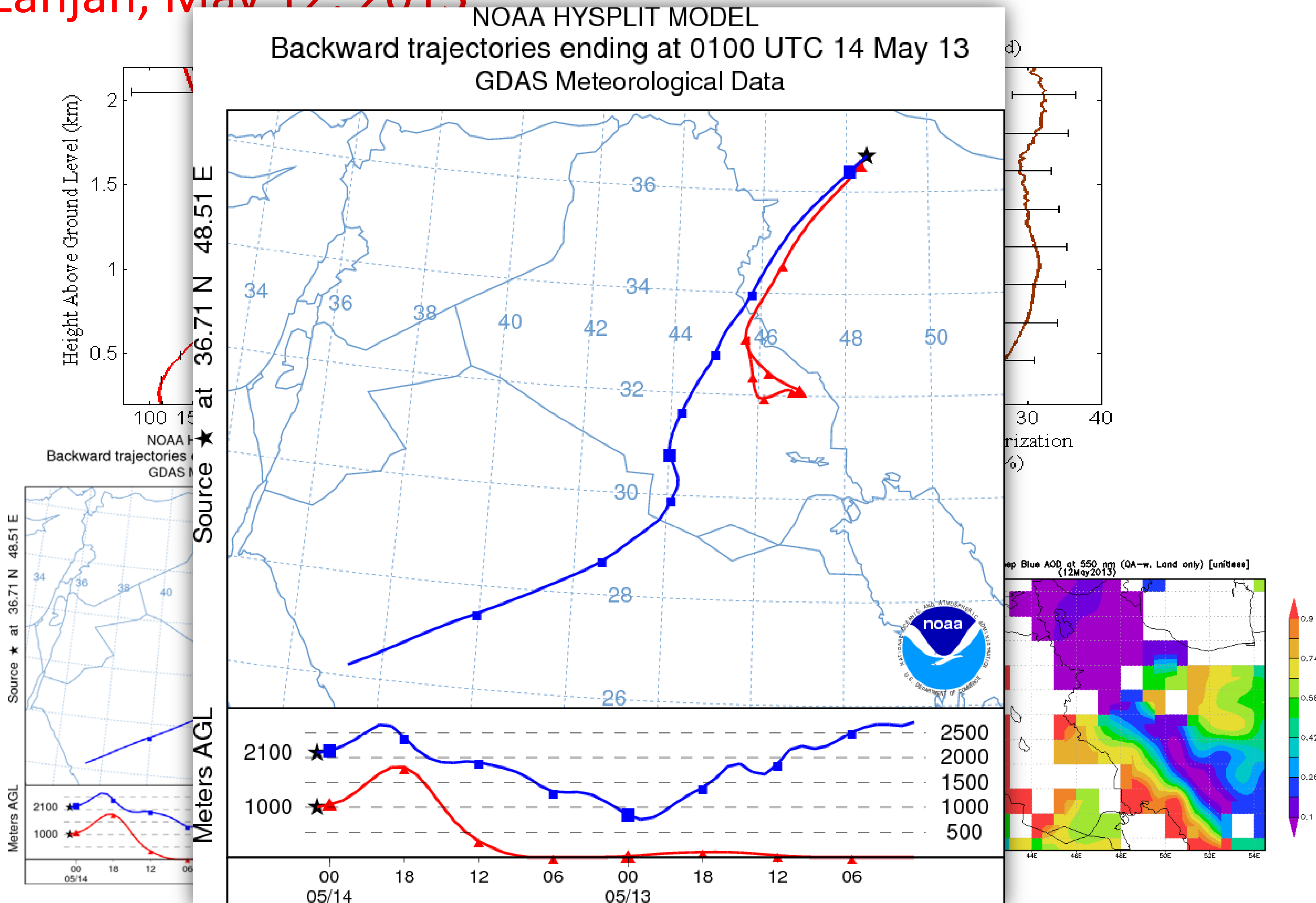
Zanjan, May 12, 2013



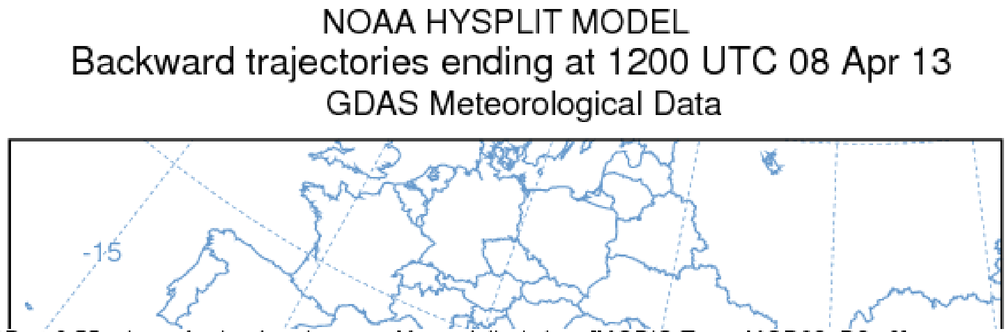


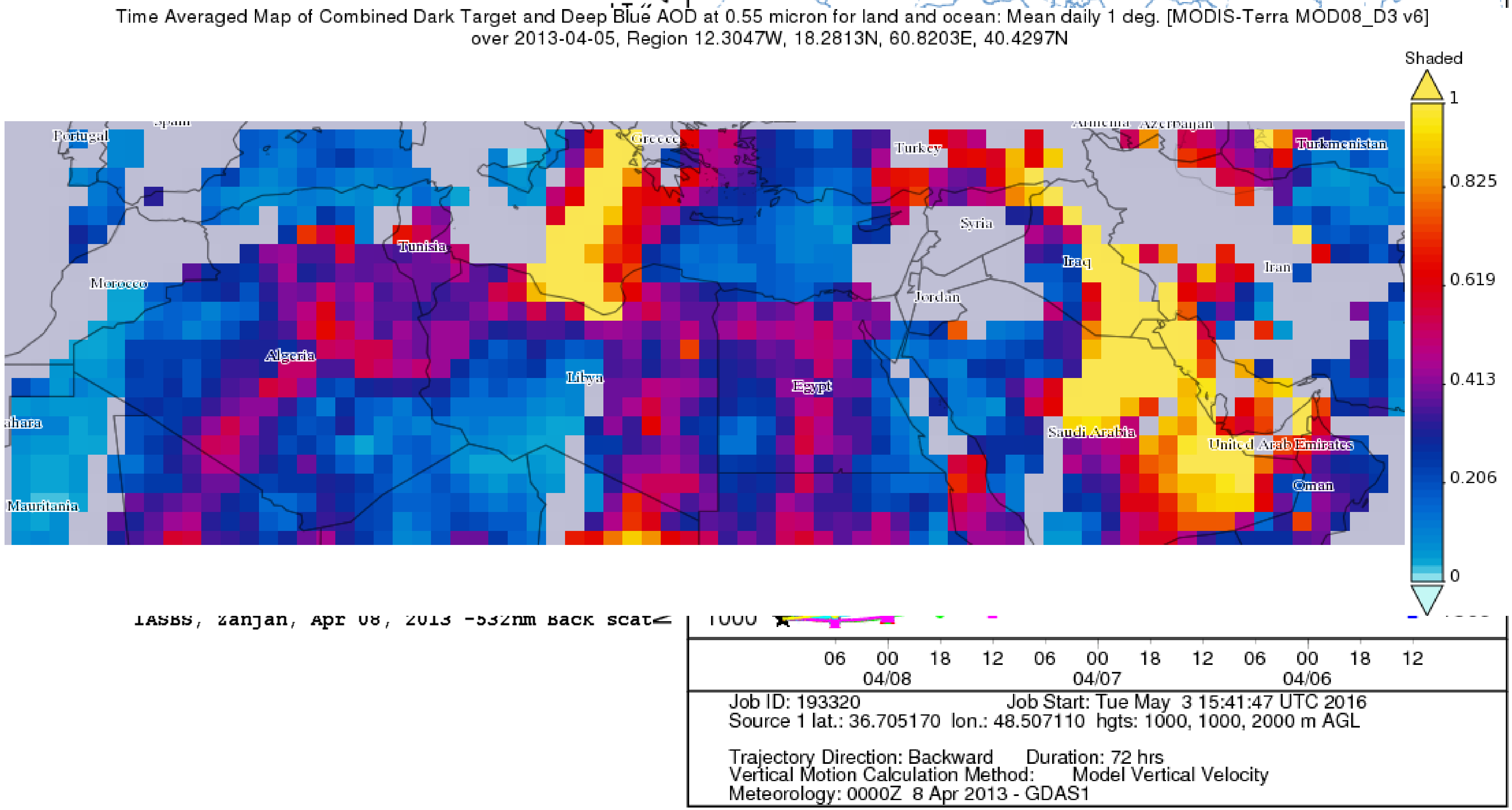
Zanjan, May 12, 2013

HYSPLIT Model



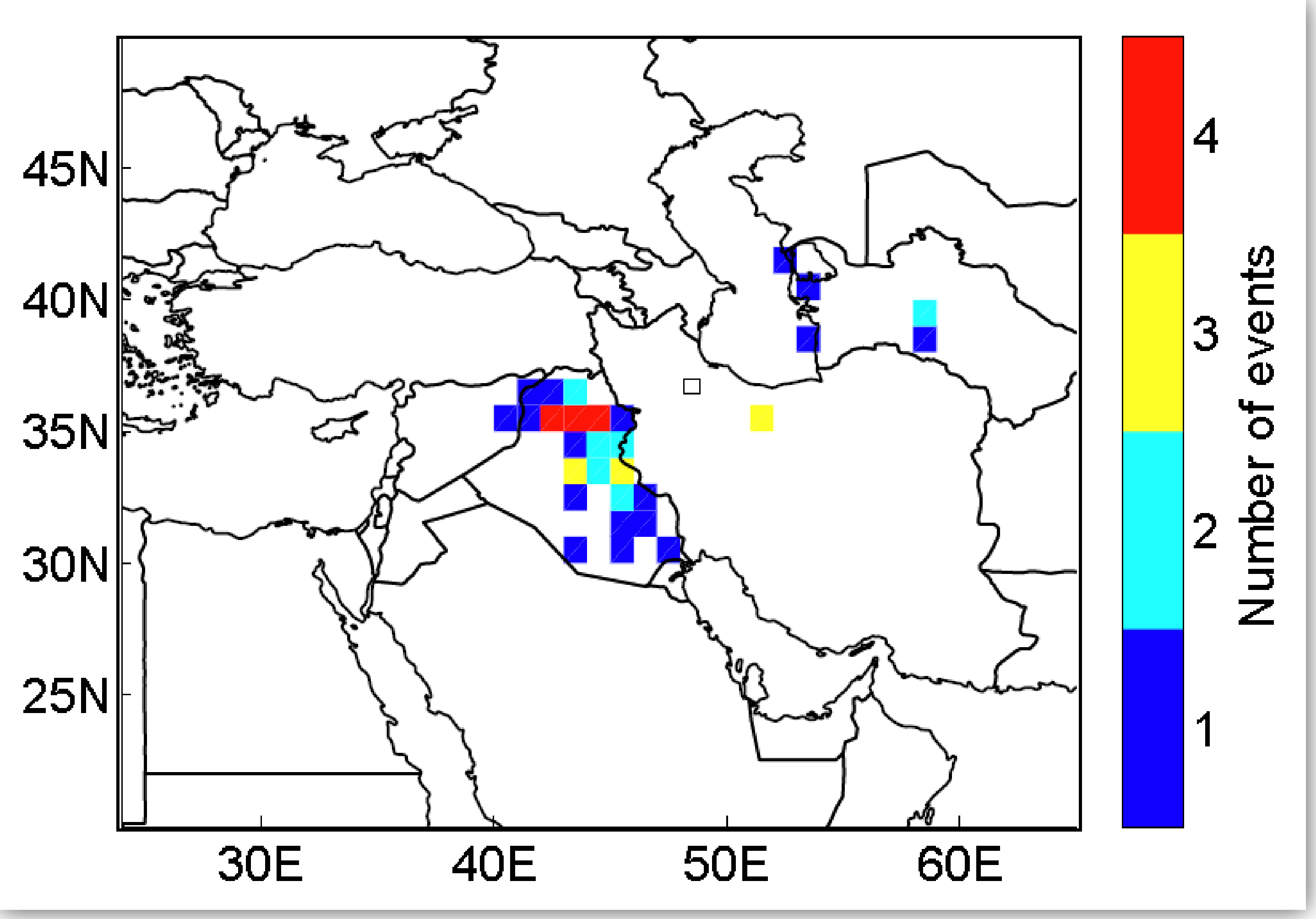
Zanjan, April 08, 2013





IASBS, Zanjan, Apr 08, 2013 -532nm Back scat

Dust sources affecting Northwest Iran

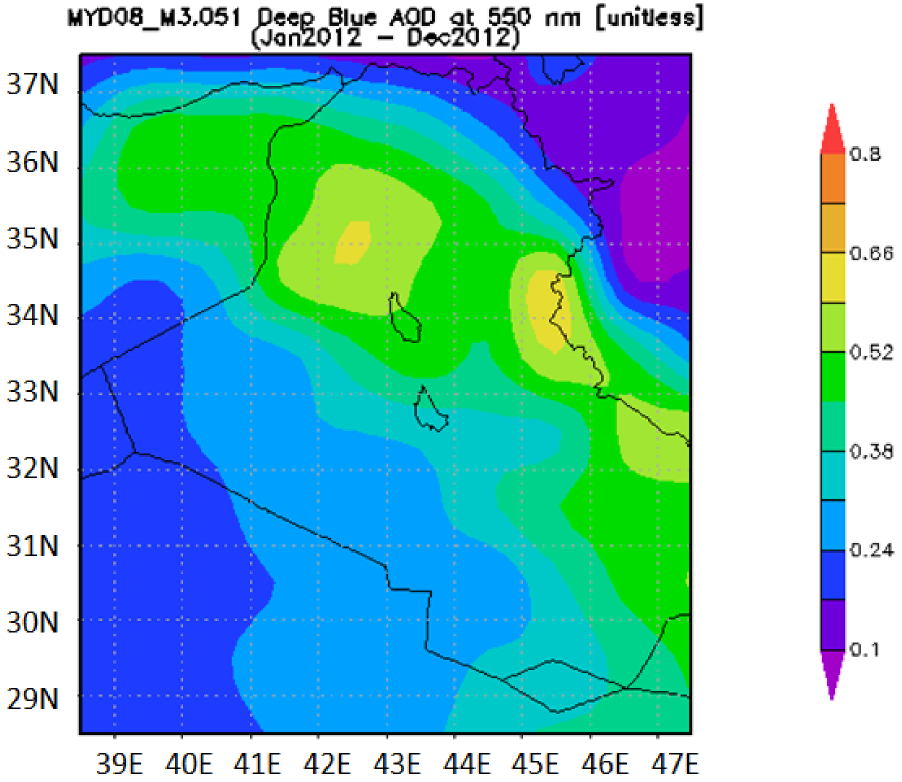


50 dust events recorded from 2007 – 2010, IASBS reomte sensing station

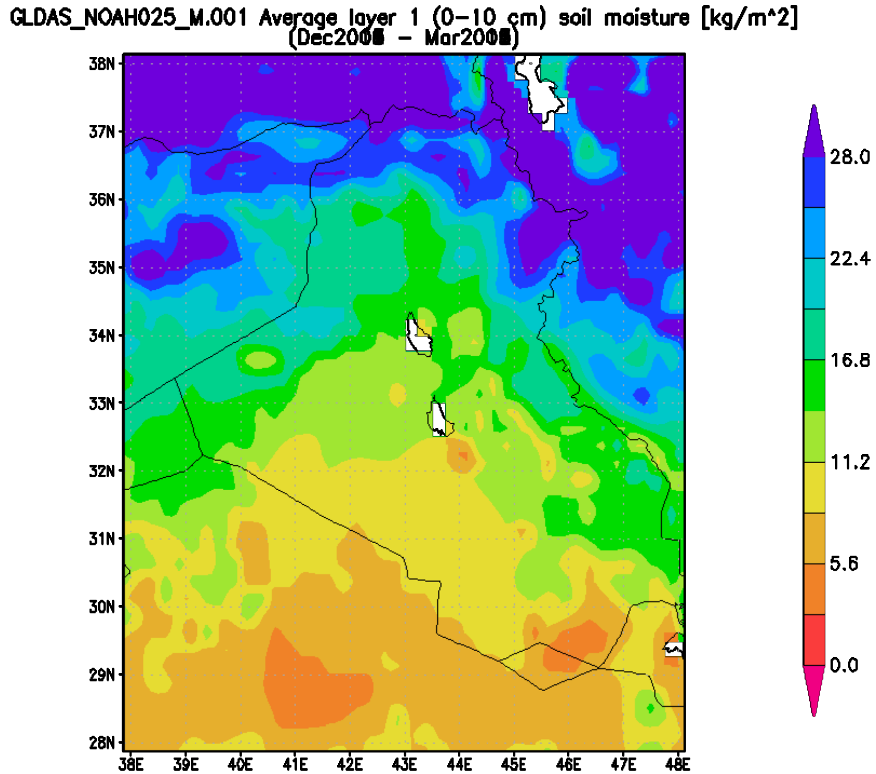
A. Masoumi, et al., Atmos. Res. (2013)

Variations of AOD (550nm) and SM (0-10 cm) 2001-2012

Aerosol Optical Depth (AOD)

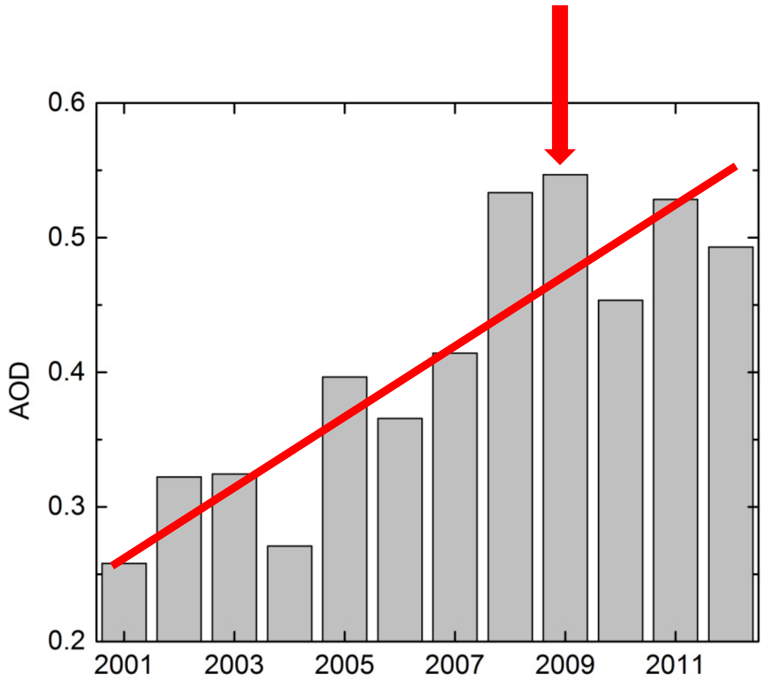


Soil Moisture (SM)

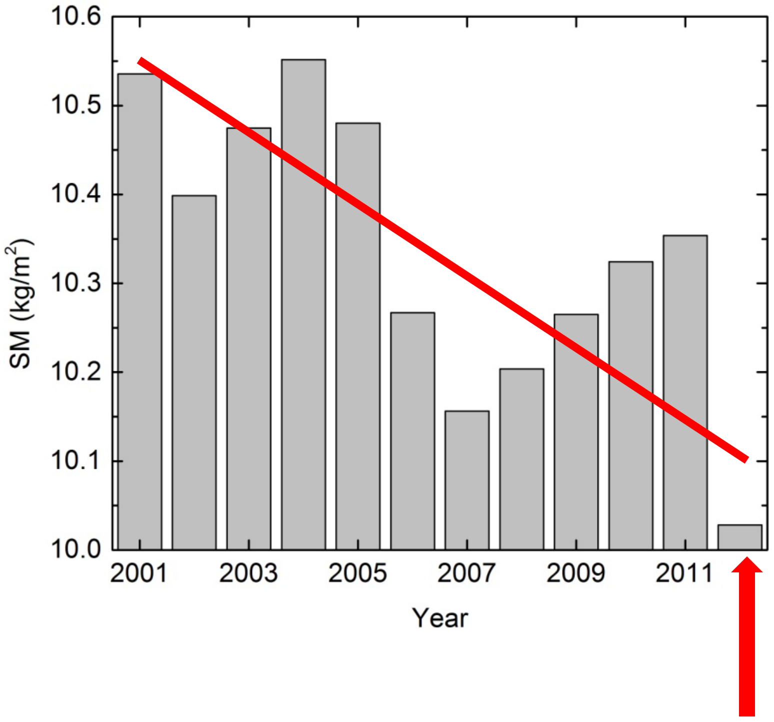


AOD and SM, Annual

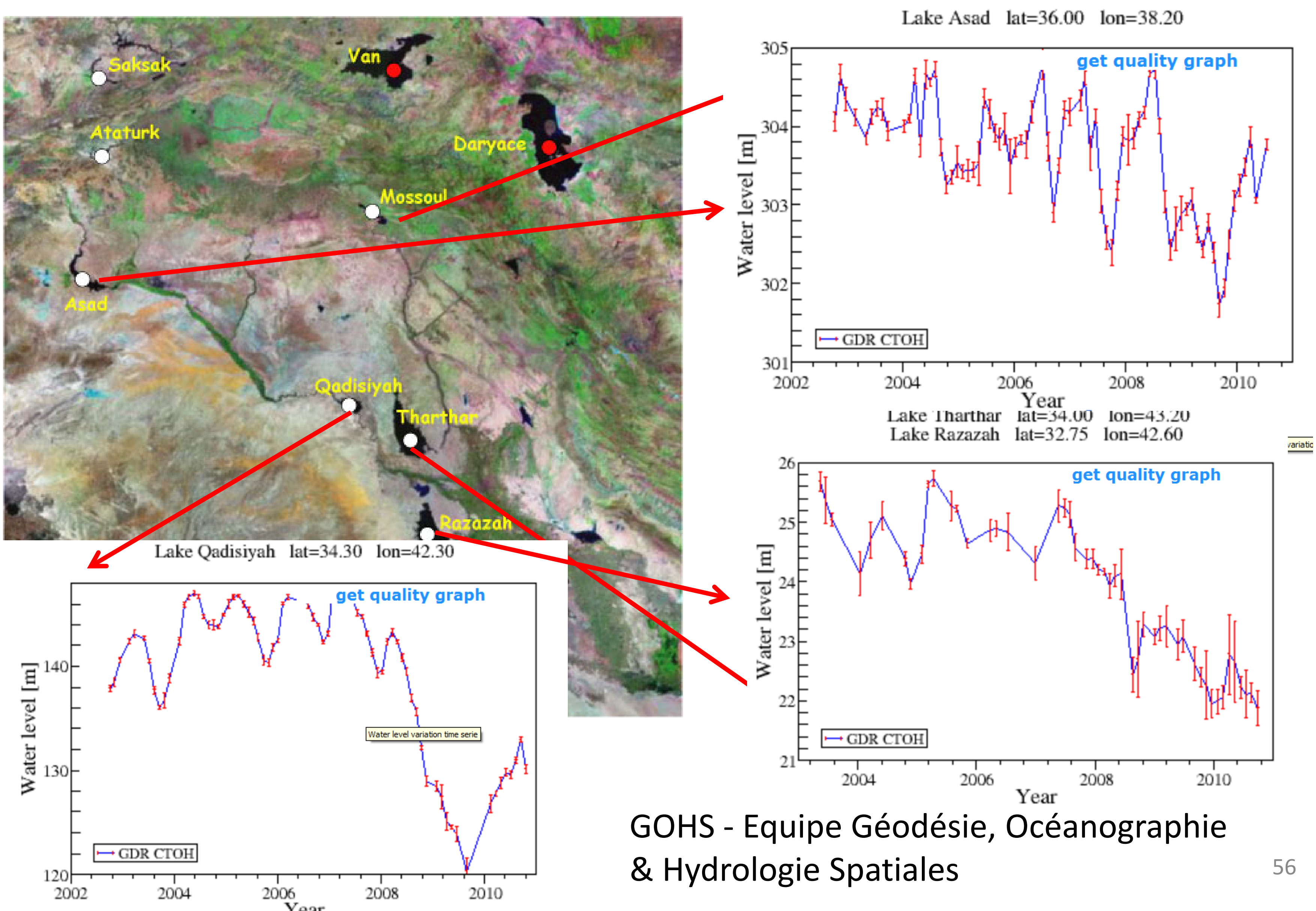
AOD



SM



Small water reservoir



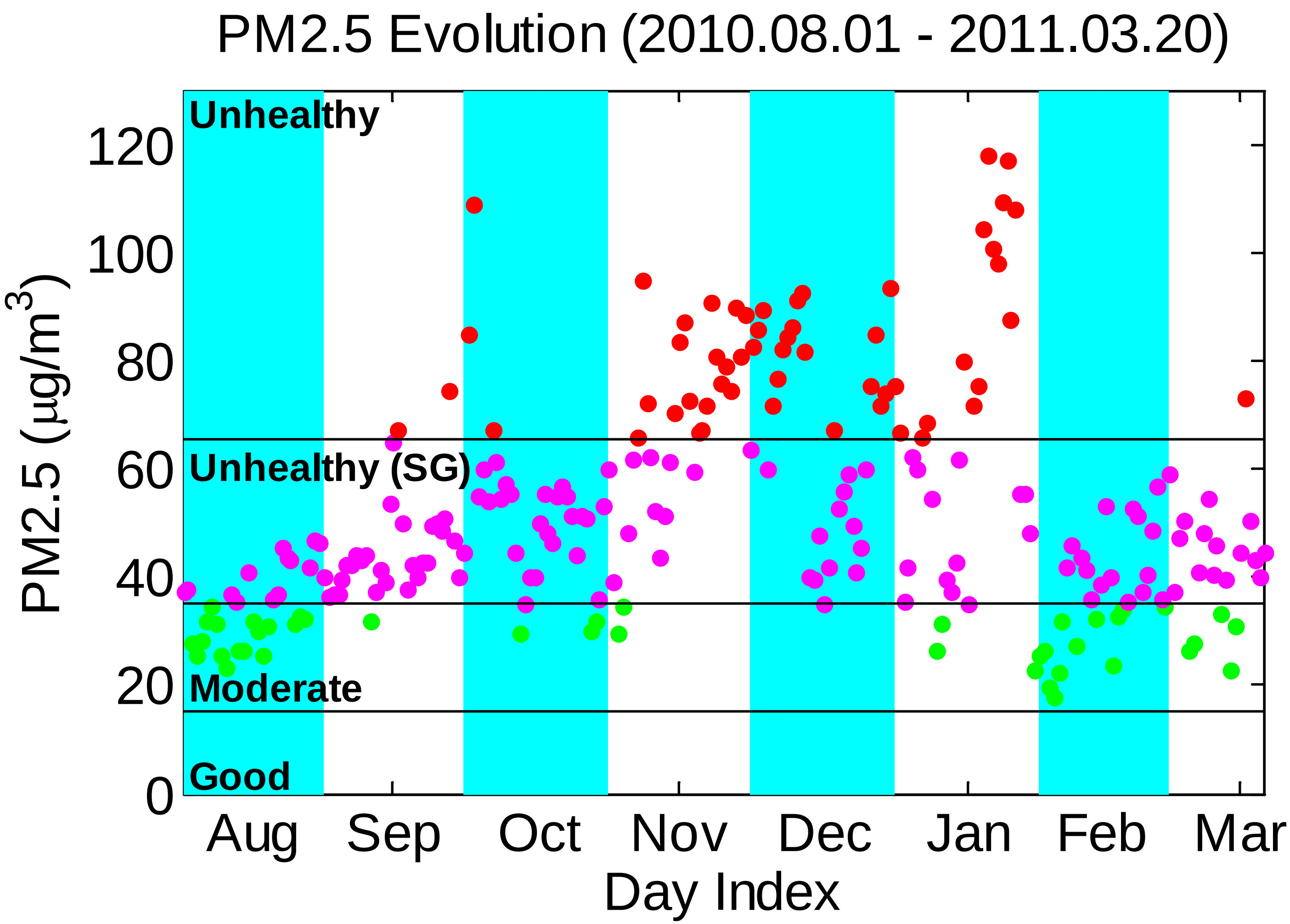
GOHS - Equipe Géodésie, Océanographie & Hydrologie Spatiales

Tehran

- Area : Urban730 km^2
- Elevation: 1,200 to 1,980 m
- Population(2015): 11,950,000
- Cars: ~4,000,000,
- Capacity of streets: ~1,000,000
- Gas consumption: 11.5 MLi/day

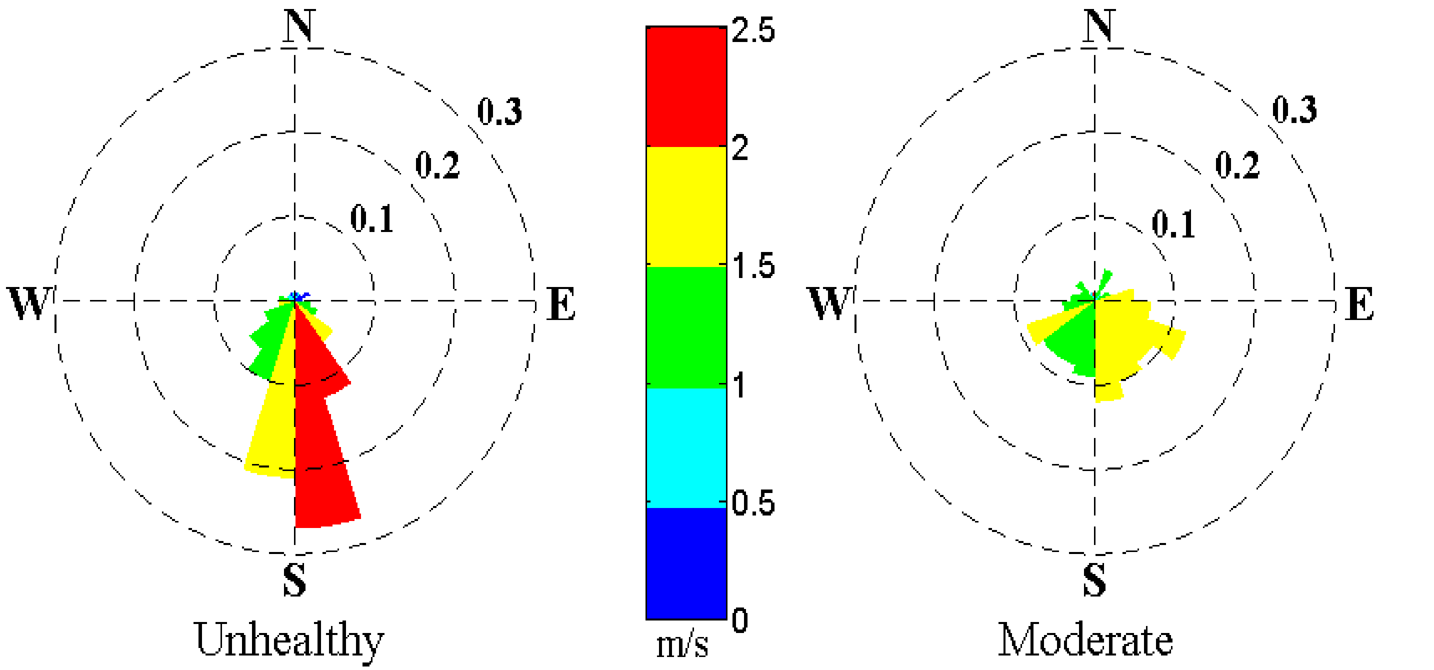
Tehran air pollution

PM 2.5

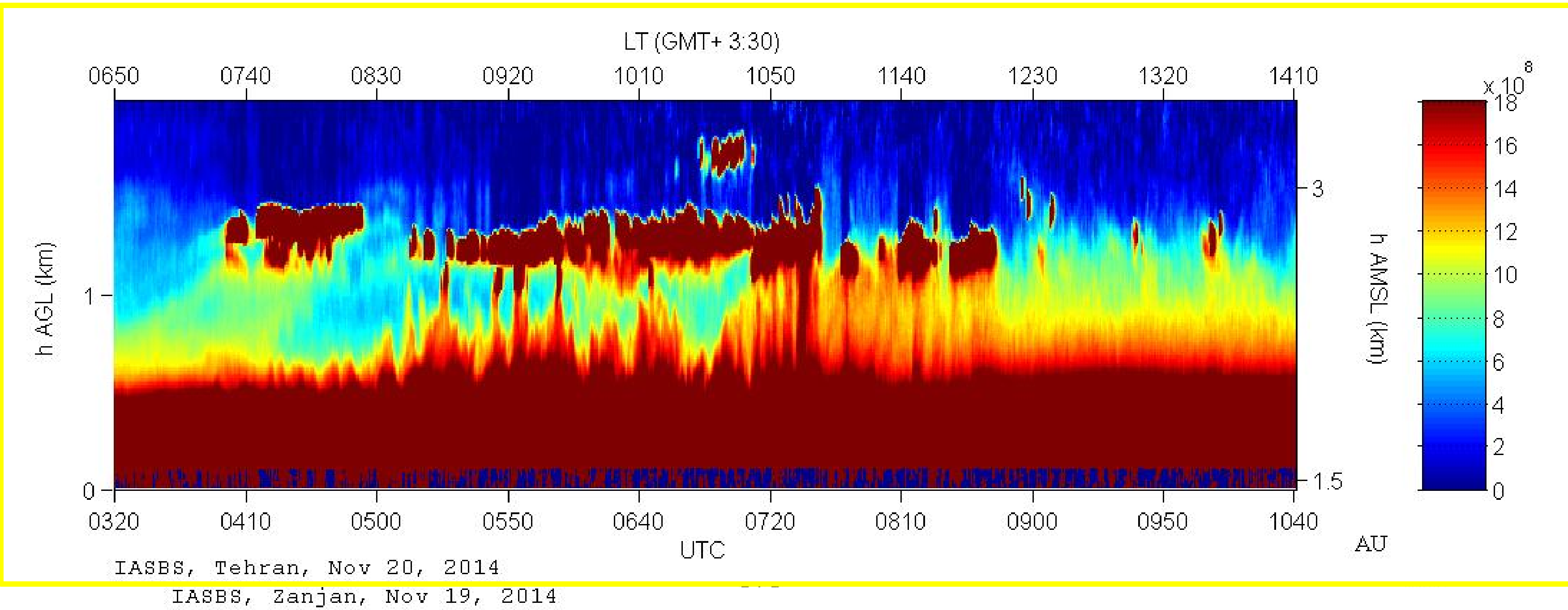


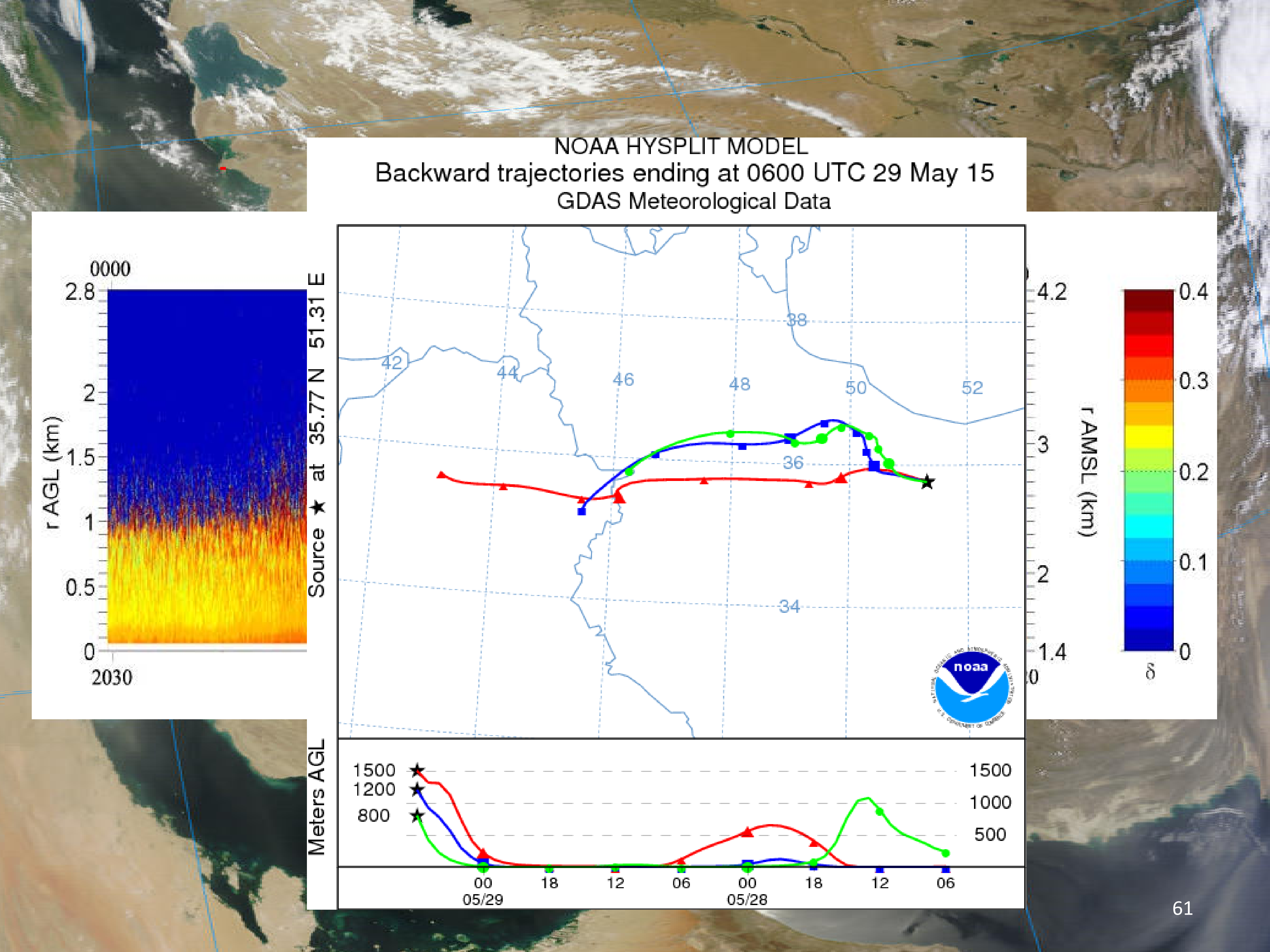
Tehran pollution,

Surface wind



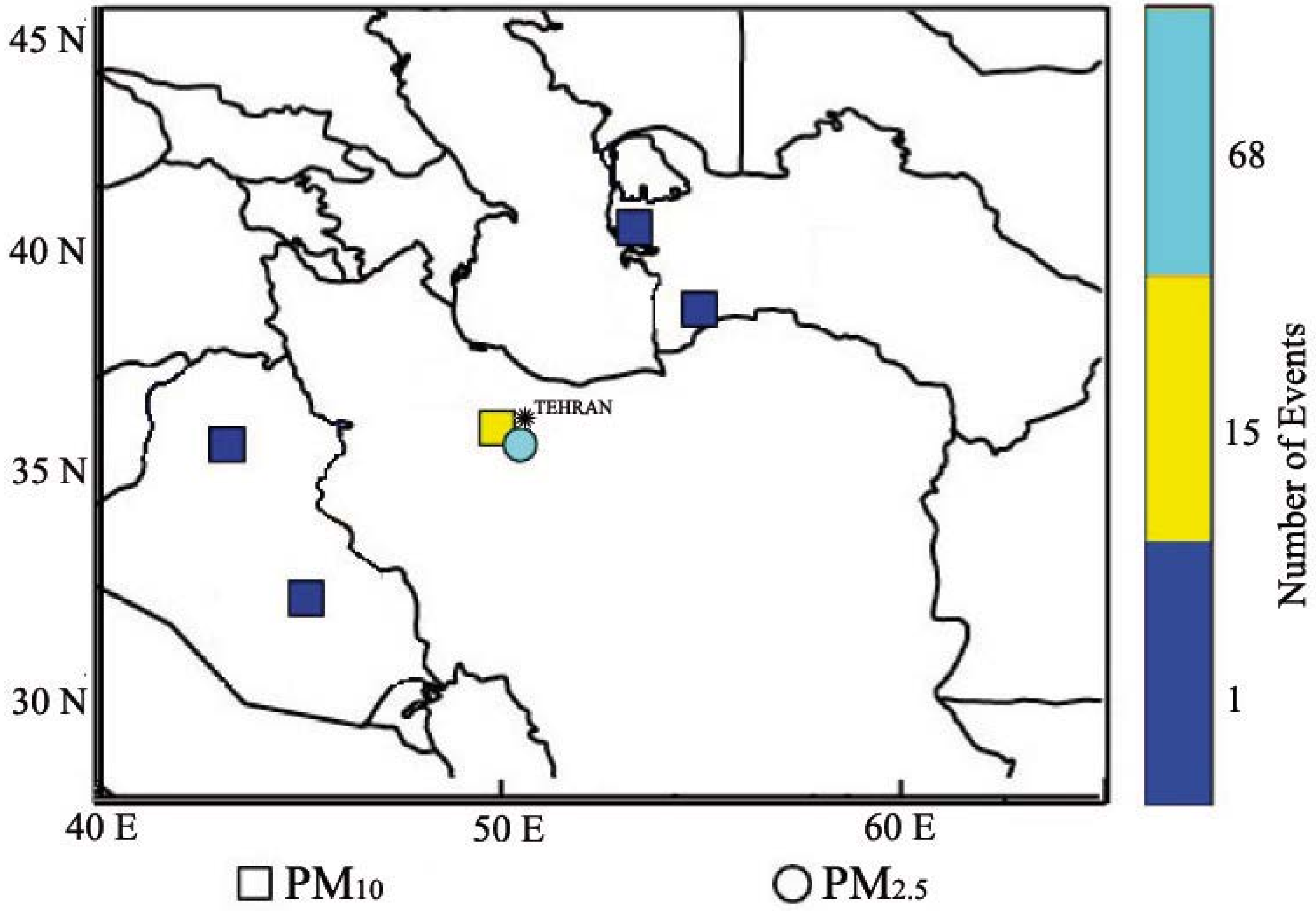
Lidar Measurement



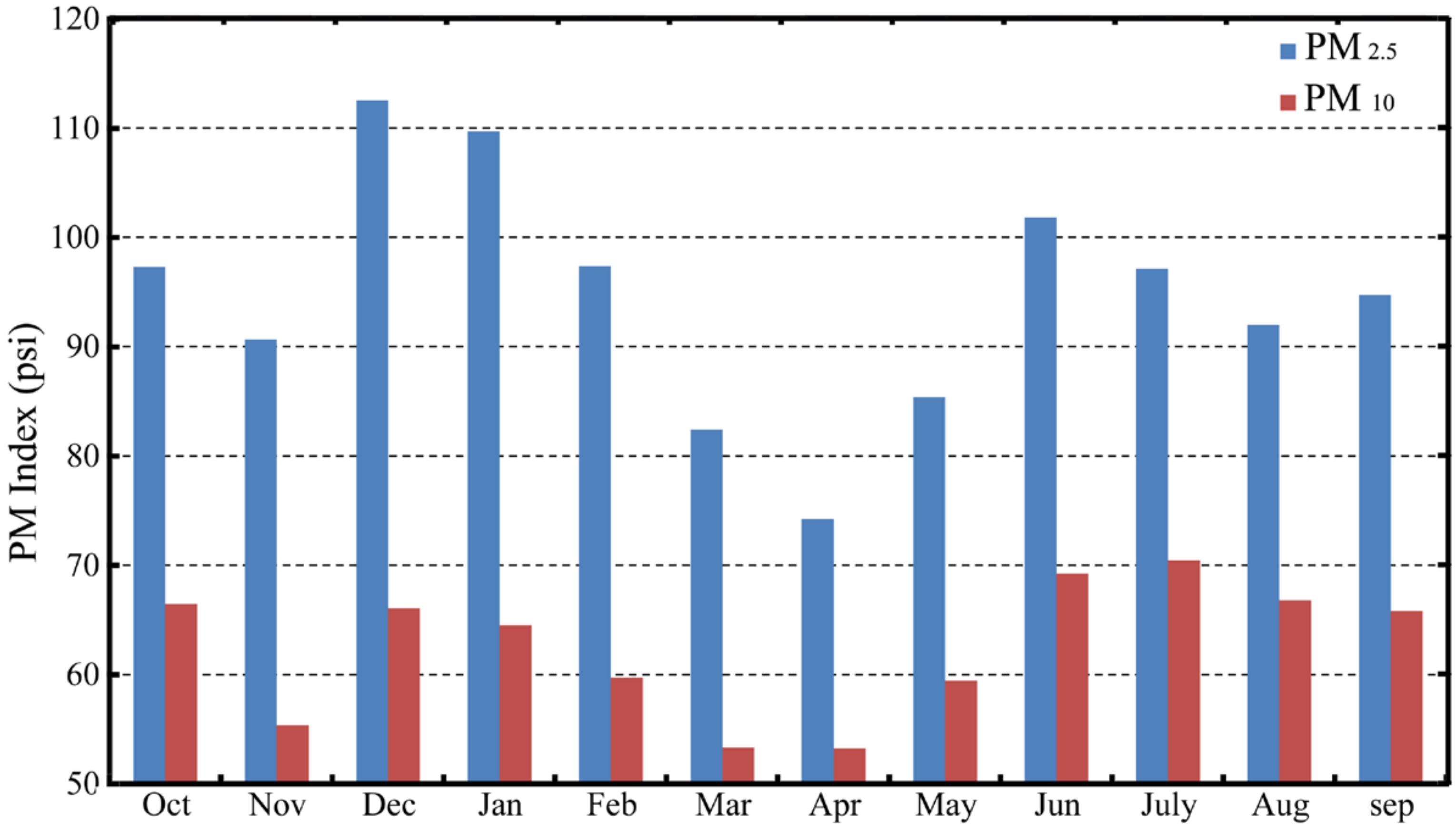


NOAA HYSPLIT MODEL
Backward trajectories ending at 0600 UTC 29 May 15
GDAS Meteorological Data
Source ★ at 35.77 N 51.31 E
Meters AGL
1500
1200
800
1500
1000
500
00
05/29
18
12
06
00
05/28
18
12
06
0000
2030
r AGL (km)
2.8
2
1.5
1
0.5
0
4.2
3
2
1.4
r AMSL (km)
0.4
0.3
0.2
0.1
0
δ
noaa

Sources of the events



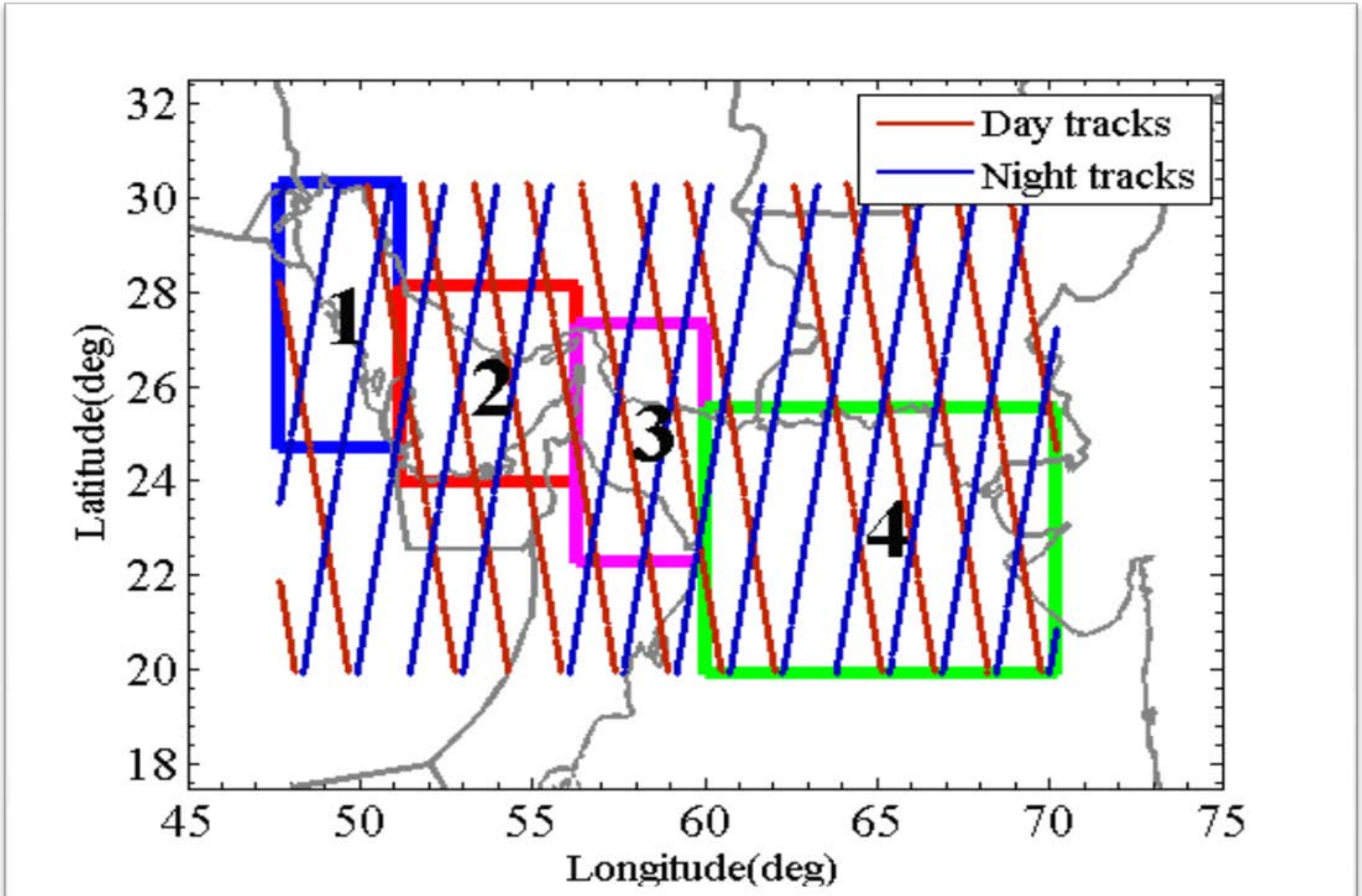
Temporal variations of dust and pollution outbreaks



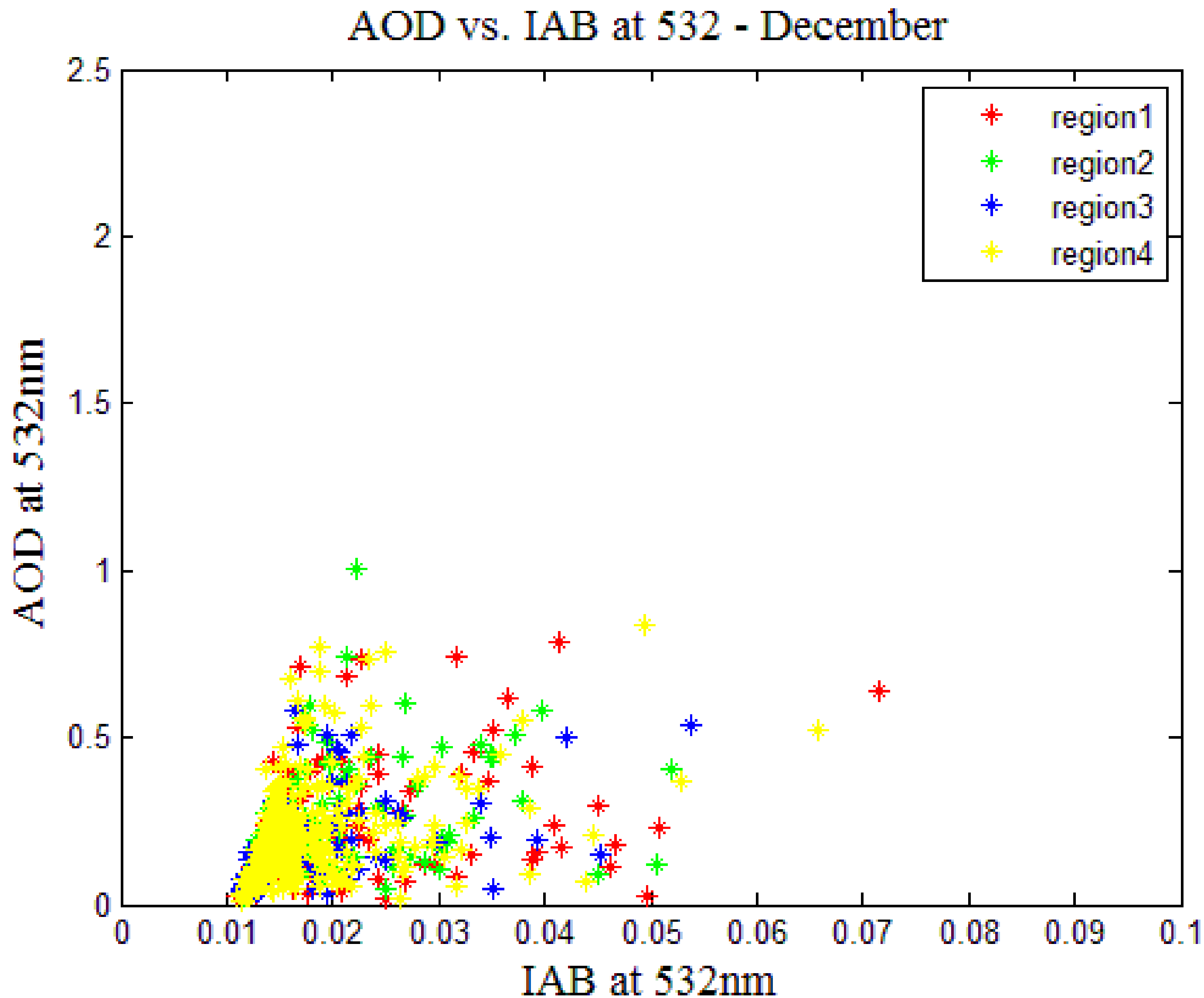
Monthly average values of PM_{10} and $PM_{2.5}$ indices in Tehran, based on recordings of the AQCC pollution monitoring stations, Oct 2011 to Sept 2015,.

Persian Gulf and Oman Sea

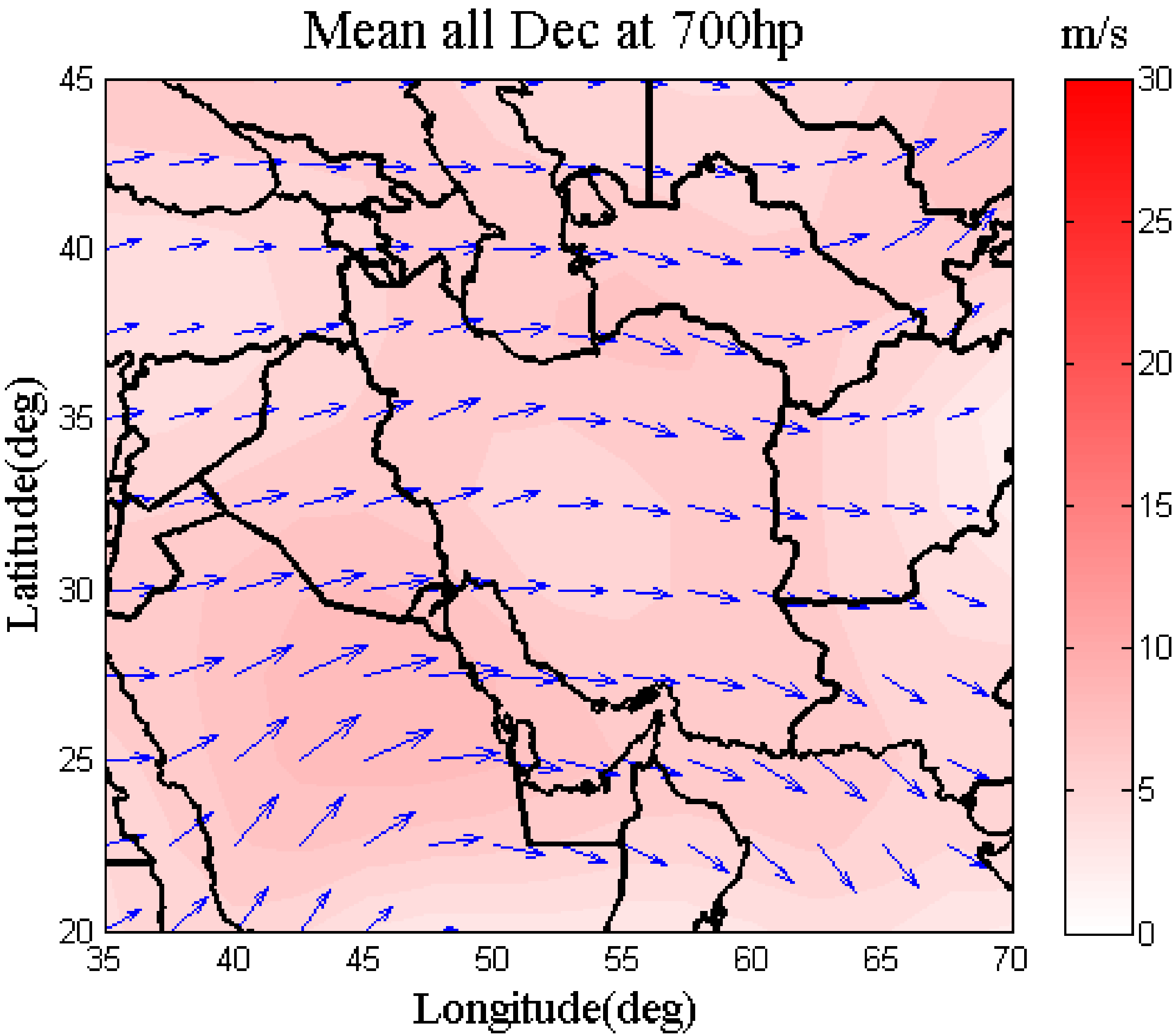
CALIPSO over Iran
16-day ground track



AOD vs. IAB, CALIPSO over Persian Gulf & Oman Sea:

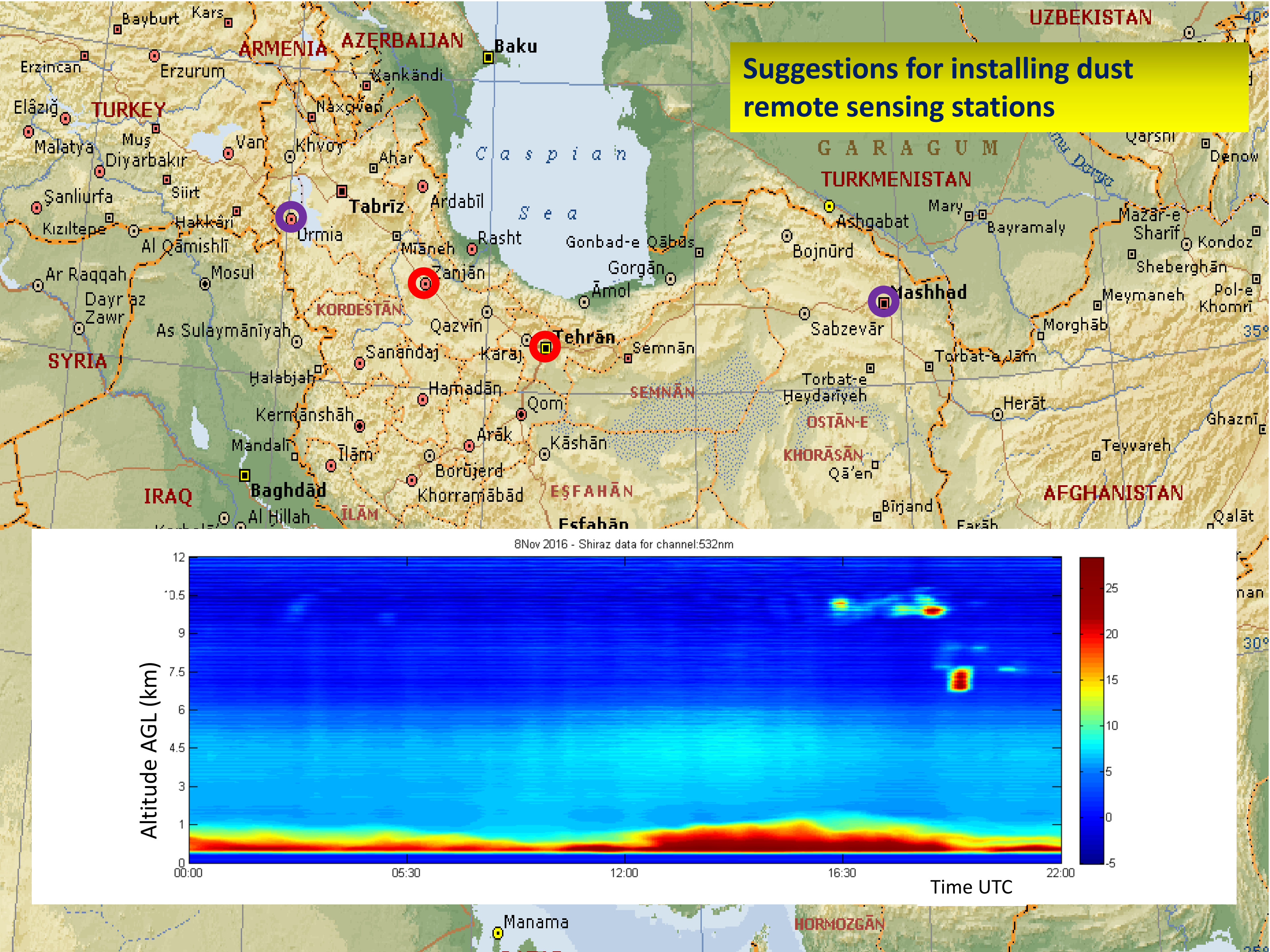


Monthly Wind Pattern at 700hp, NCEP/NCAR



Summary

- Iran, a country in the middle of the dust belt, is under the influence of external and internal dust sources.
- Tigris and Euphrates basin in the west, Arabian peninsula in the south, the dry region between the Caspian and Aral seas in the northeast and the Hamoon lake in east are the main dust sources affecting the region.
- Some rare observations shows transportation of dust from North Africa and Arabian peninsula to Northwest Iran
- Dust from the Hamoon lake some times may be advectted even up the Indian ocean.
- most of the dust outbreaks are happening during spring and summer.


Suggestions for installing dust remote sensing stations
UZBEKISTAN
ARMENIA
AZERBAIJAN
TURKEY
TURKMENISTAN
GARAGUM
SYRIA
IRAQ
AFGHANISTAN
Caspian Sea
Bayburt
Kars
Erzincan
Erzurum
Baku
Xankändi
Naxçıvan
Elâzığ
Malatya
Muş
Van
Khvoy
Ahar
Diyarbakır
Siirt
Şanlıurfa
Tabrīz
Ardabīl
Hakkâri
Kızıltepe
Urmia
Al Qāmishlī
Mīāneh
Rasht
Gonbad-e Qābūs
Bojnūrd
Ashgabat
Mary
Bayramaly
Mazār-e Sharīf
Kondoz
Sheberghān
Ar Raqqah
Mosul
Zanjān
Gorgān
Āmol
Mashhad
Meymaneh
Pol-e Khomrī
Dayr az Zawr
KORDESTĀN
Qazvīn
Sabzevār
Morghāb
As Sulaymānīyah
Sanandaj
Karaj
Tehrān
Semnān
Torbat-e Jām
Halabjah
Hamadān
SEMNĀN
Torbat-e Ḩeydarīyeh
Qom
Herāt
Kermānshāh
OSTĀN-E KHORĀSĀN
Ghaznī
Mandalī
Īlām
Arāk
Kāshān
Qā'en
Teyvareh
Borūjerd
Baghdād
Khorramābād
EŞFAHĀN
Bīrjand
Al Hillah
ĪLĀM
Esfahān
Farāh
Qalāt
Manama
HORMOZGĀN
8Nov 2016 - Shiraz data for channel:532nm
Altitude AGL (km)
12
10.5
9
7.5
6
4.5
3
1
0
00:00
05:30
12:00
16:30
22:00
Time UTC
25
20
15
10
5
0
-5

Special thanks to

PhD Students

- Farhad Abdi
- Ruholah Morad Haseli
- Ali Bayat
- Amir Masoumi
- Hadi Borzu
- Hosein Panahifar
- Farizeh Bayat
- Fatemeh Ghomashi

MSc Students

- Mehdi Gholami
- Javad Khodam


5th Training Course on
"WMO Sand and Dust Storm Warning Advisory and
Assessment System(SDS-WAS) Products"
RTC - Tehran
05 to 09 Nov. 2016
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Thank You