Atmospheric Modeling Applications

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Layout

- Haboobs and modeling/remote sensing synergies
- Introduction to atmospheric modeling
- Numerical modeling applications
- HYSPLIT exercise

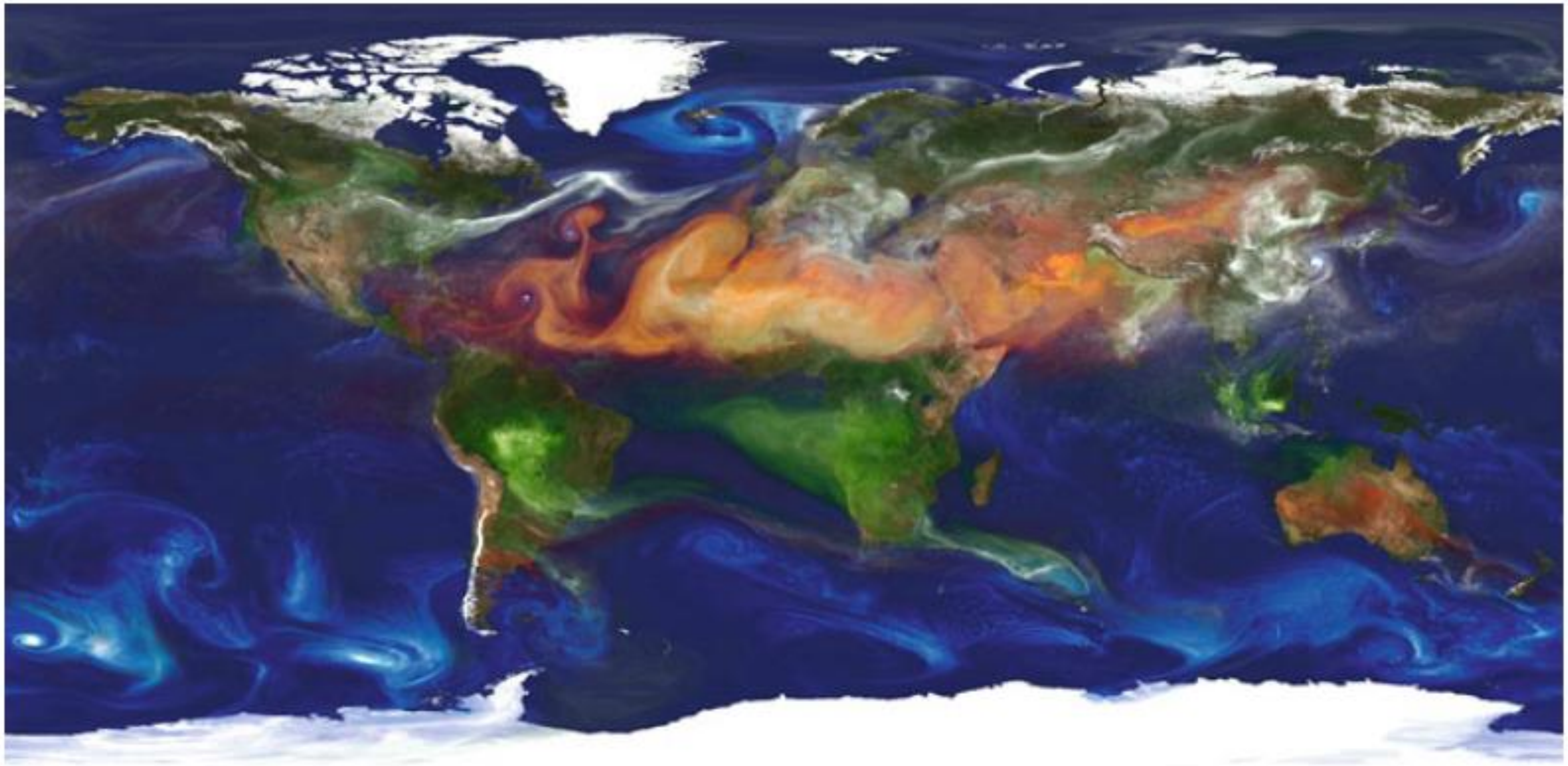
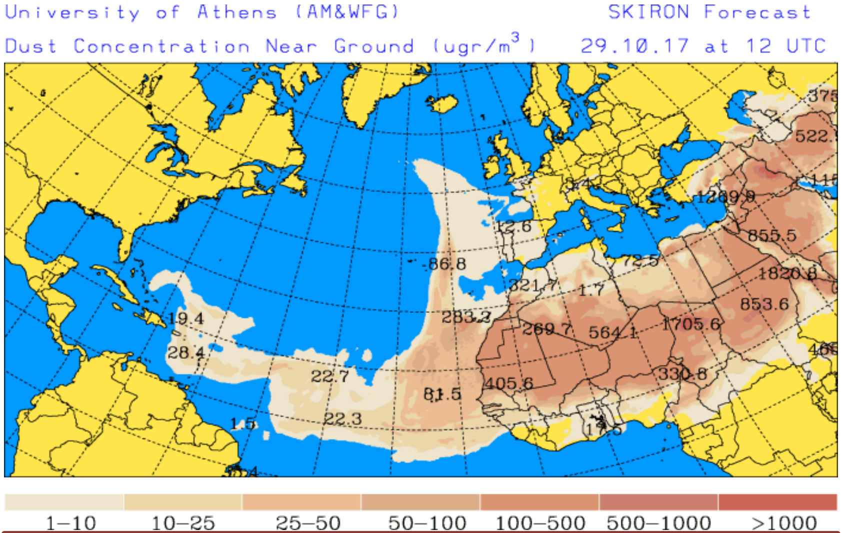


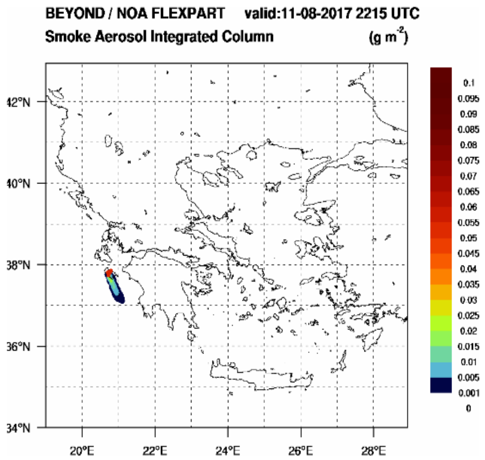
Fig. 1.1 NASA's GEOS-5 simulation, showing the four main aerosols: mineral dust from deserts (*red*), sea salt from spray (*blue*), soot and smoke from fires (*green*) and sulphate particles from fossil fuel combustion and volcanoes (*white*). Source: http://geos5.org

Aerosols from Natural Sources

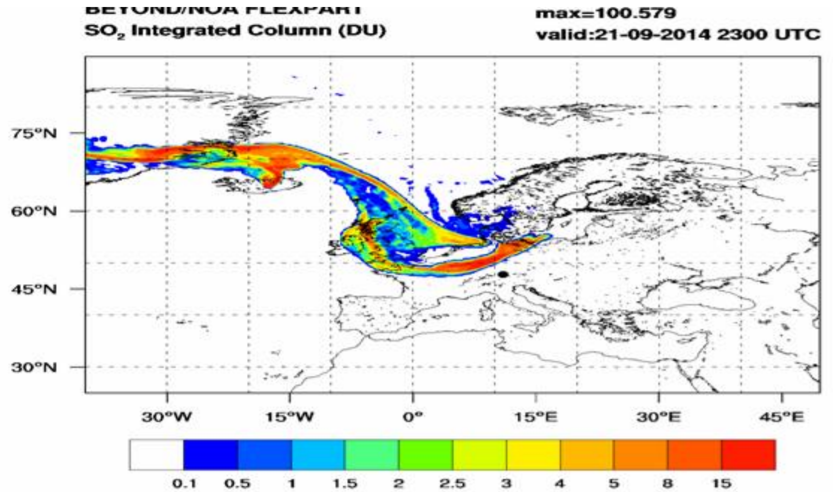
Dust



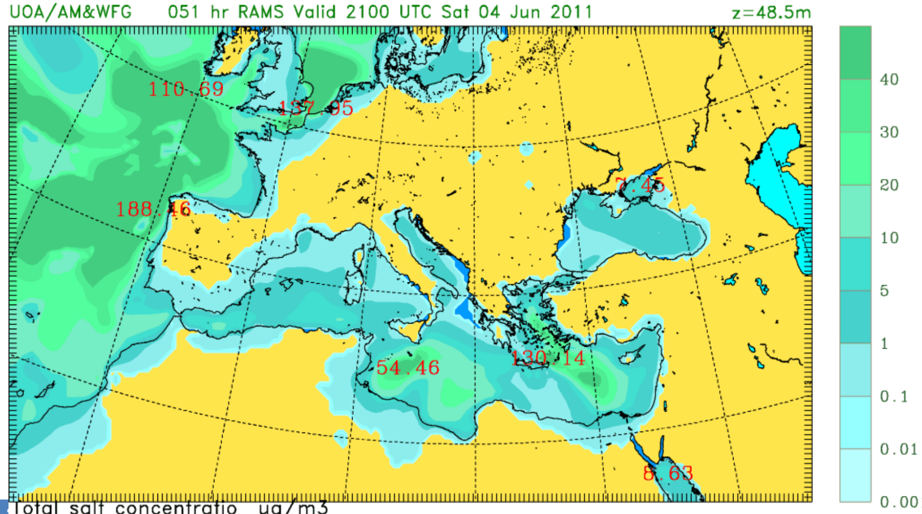
Biomass burning



Volcanic ash



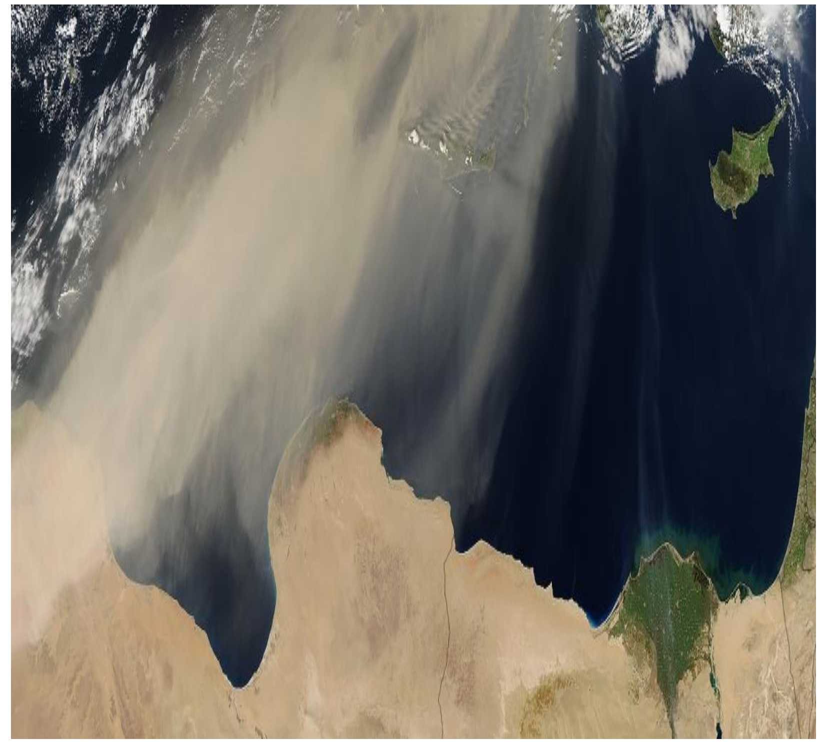
Sea salt



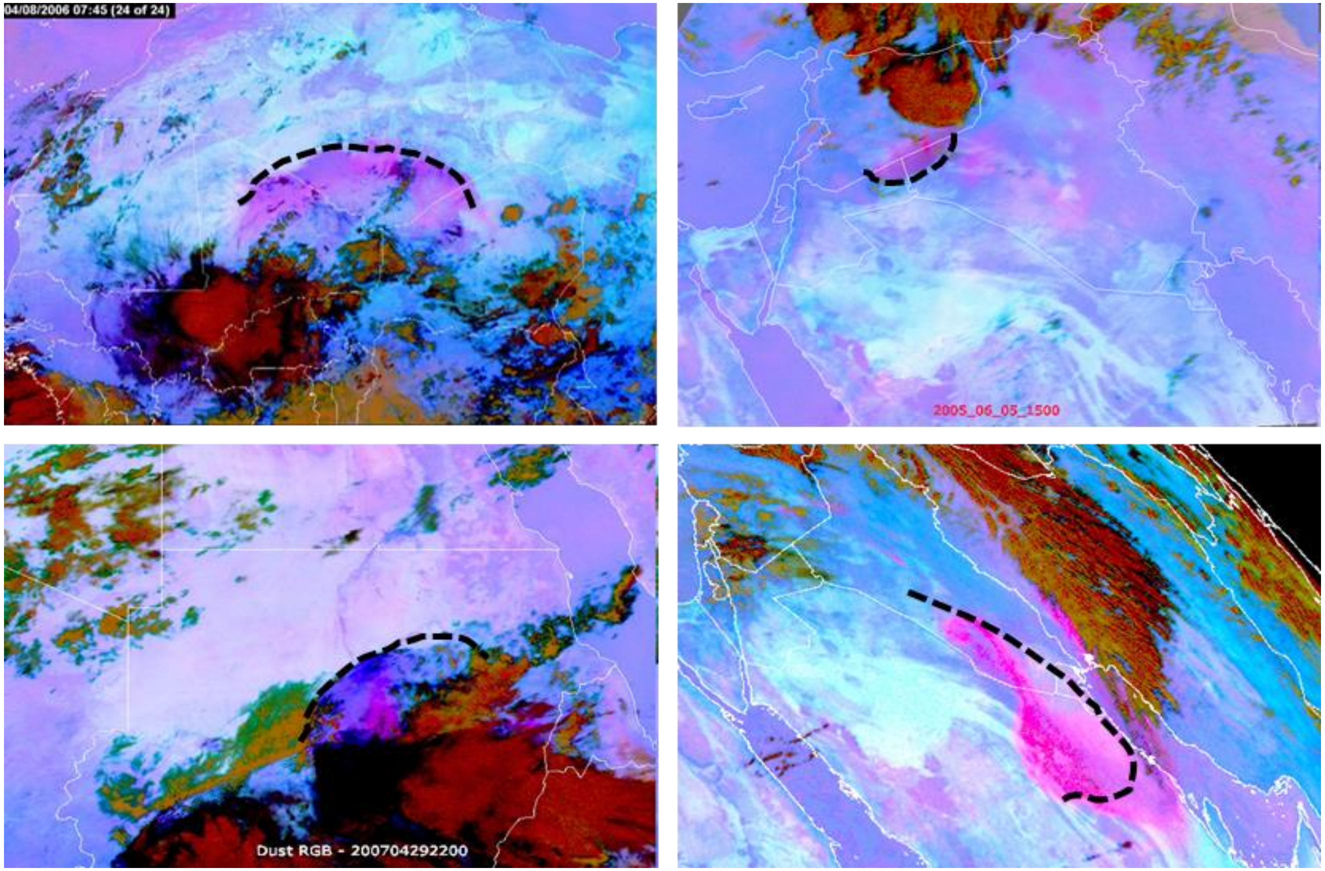
Desert Dust Emissions

Local Sand/dust storms (haboobs)

Long Range Transport



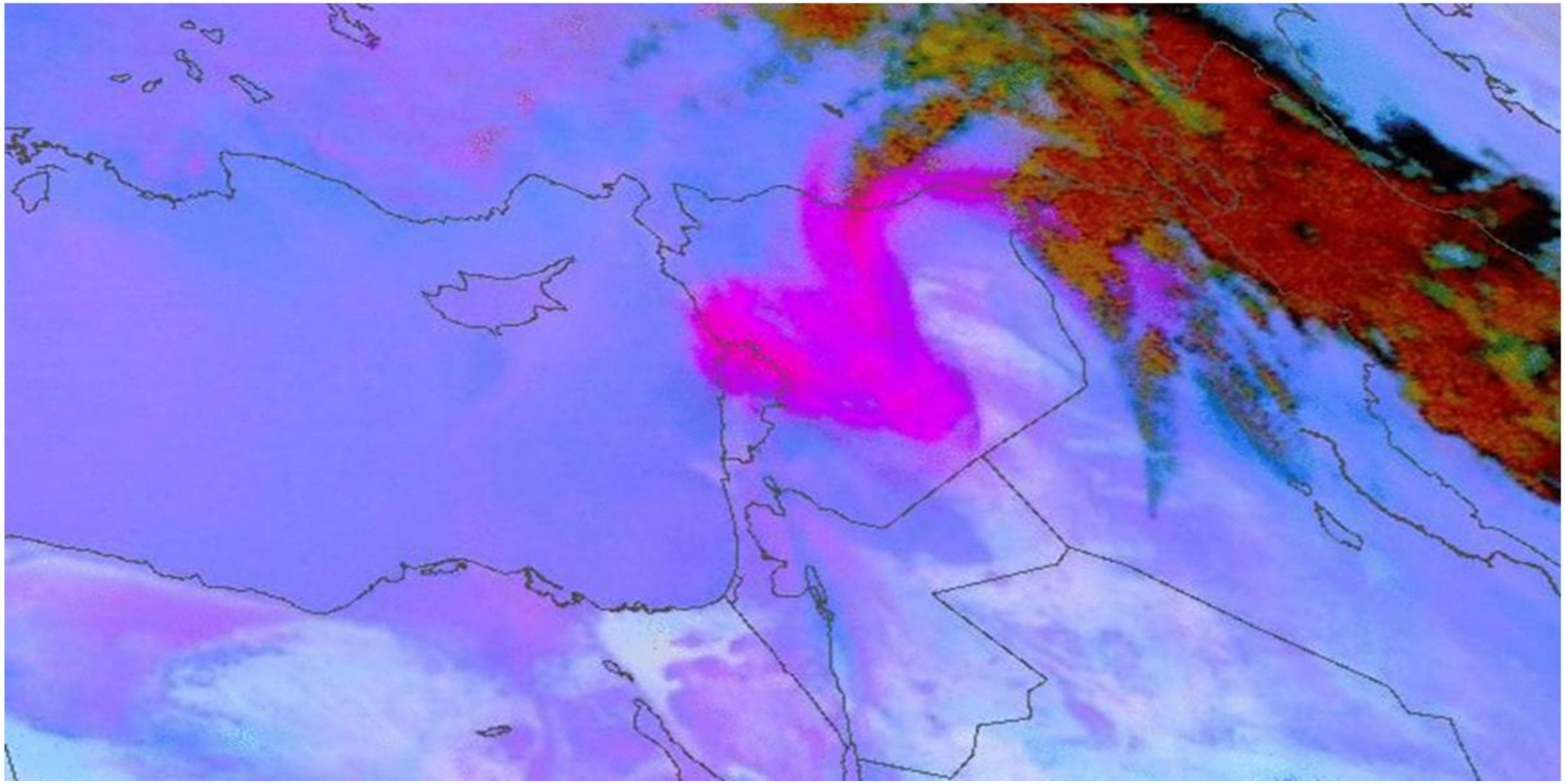
Generation of “haboobs” from Mesoscale Convective Systems



Density currents and associated mobilization of dust is also a common feature for the Middle East and Arabian Penisnula (MSG/SEVIRI images).

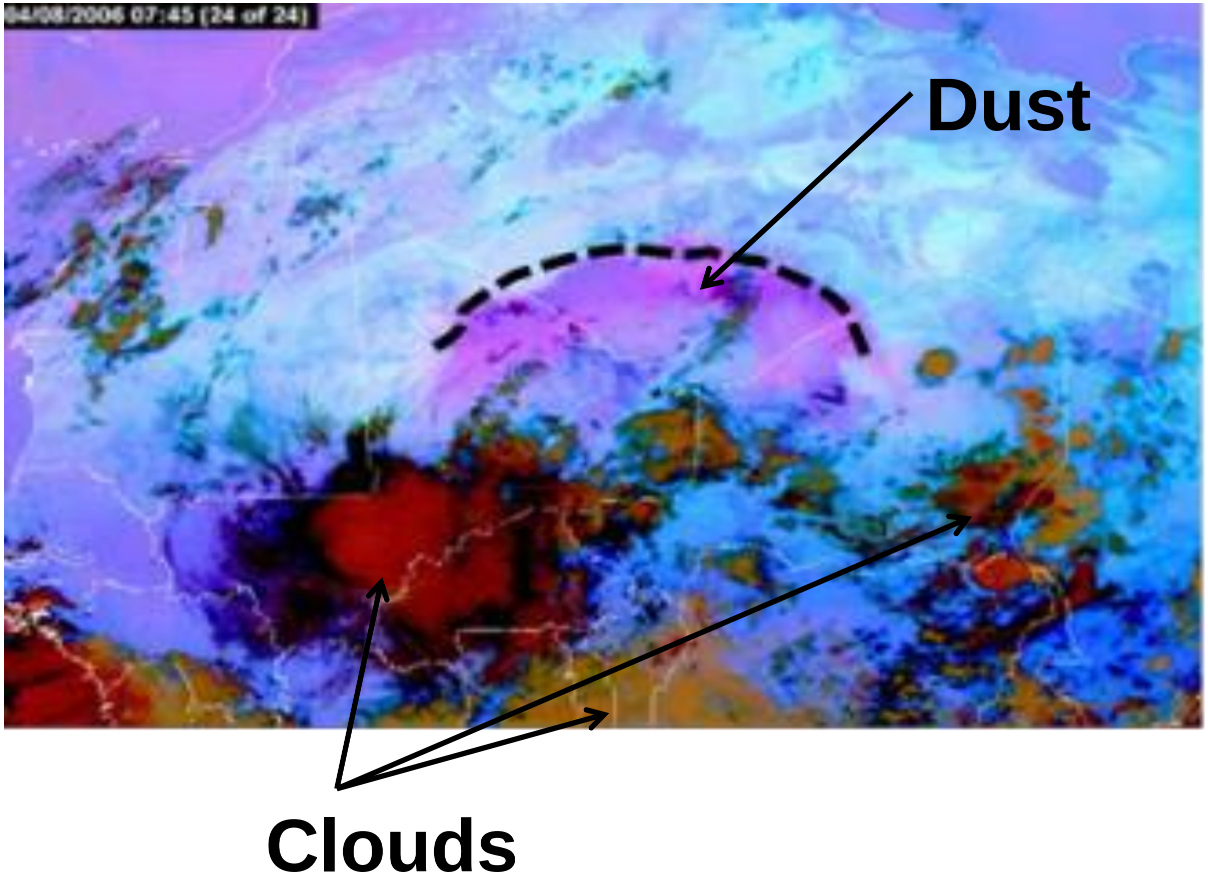
Dust – Haboobs

Very complex systems – Synergistic efforts between land/atmospheric remote sensing and advanced modeling



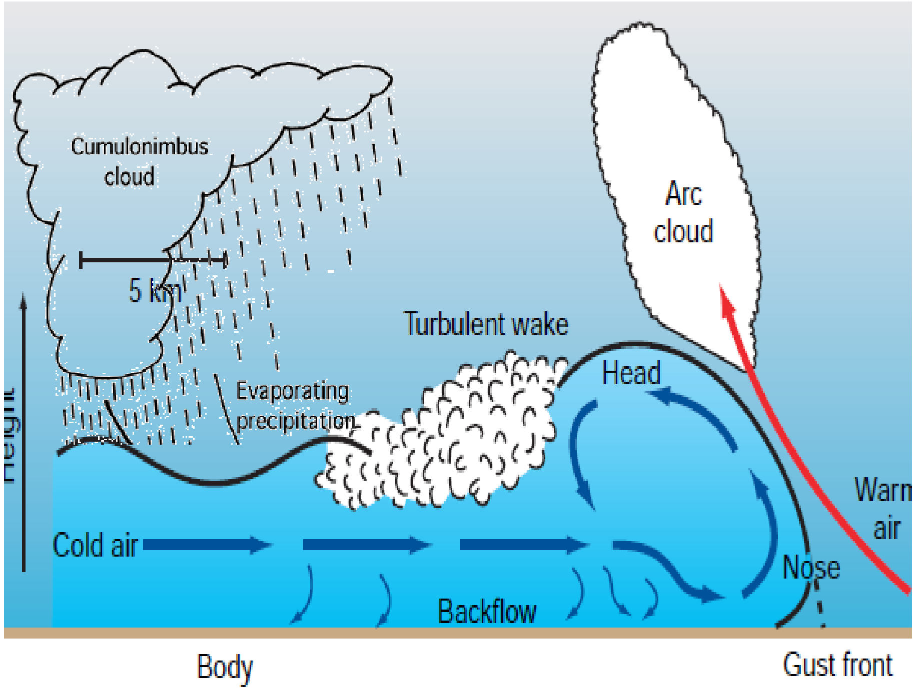
Generation of haboobs by Mesoscale Convective Systems (MCS) *MSG-SEVIRI dust product*

Dust - Haboobs



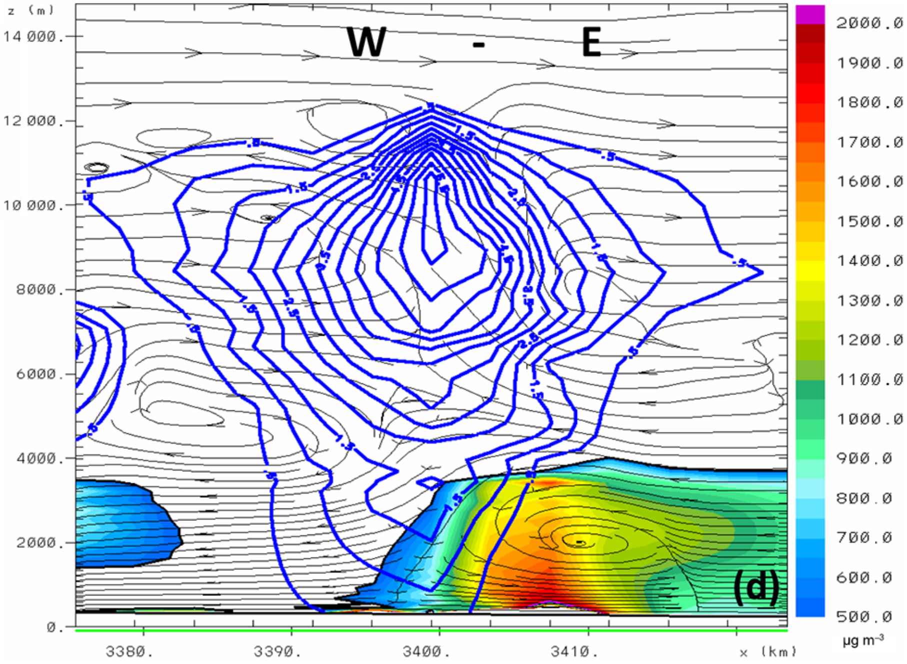
Dust – Haboobs

Atmospheric Density Currents



Schematic diagram of a density current formation

Adopted from Knippertz et al., 2007, JGR



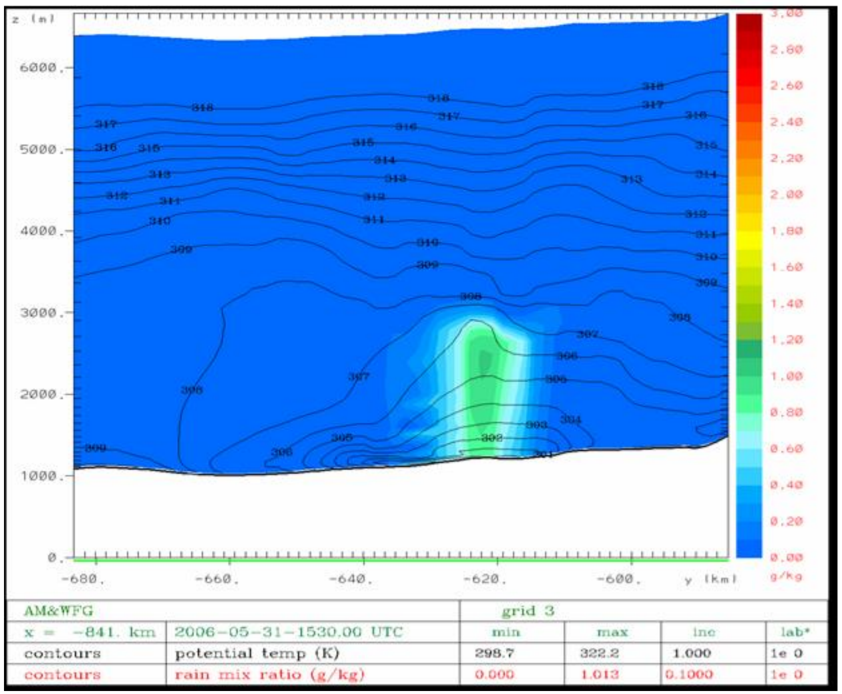
Model reproduction of a density current formation and elevated dust concentration in RAMS

Adopted from Solomos et al., ACP, 2017

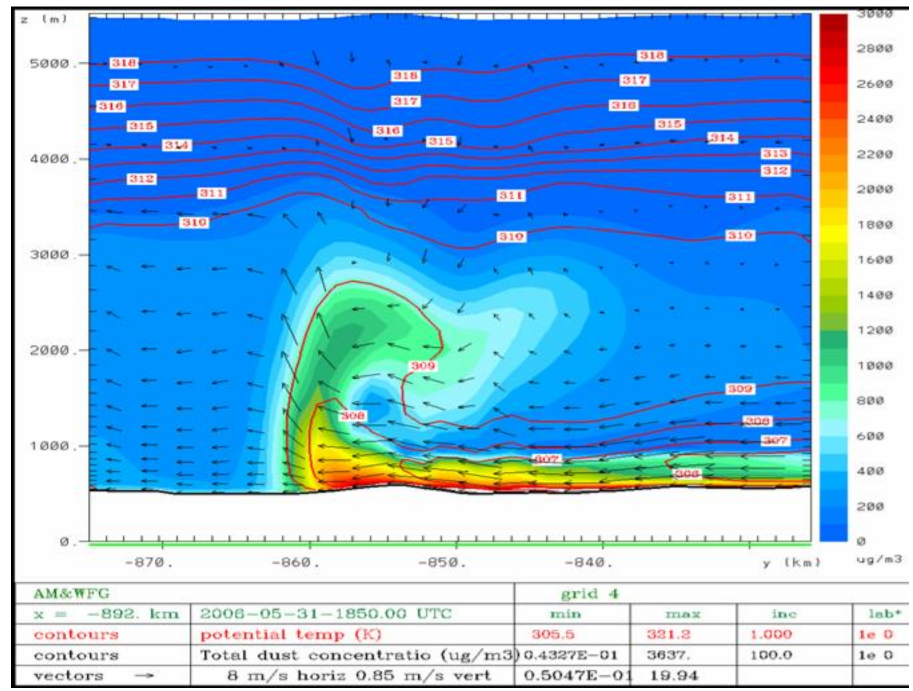
Generation of a Saharan haboob south of Atlas Mountains

Panoramic photographs of the density current approaching the SAMUM measuring site Tinfou on 31 May 2006

Knippertz et al., 2007, JGR

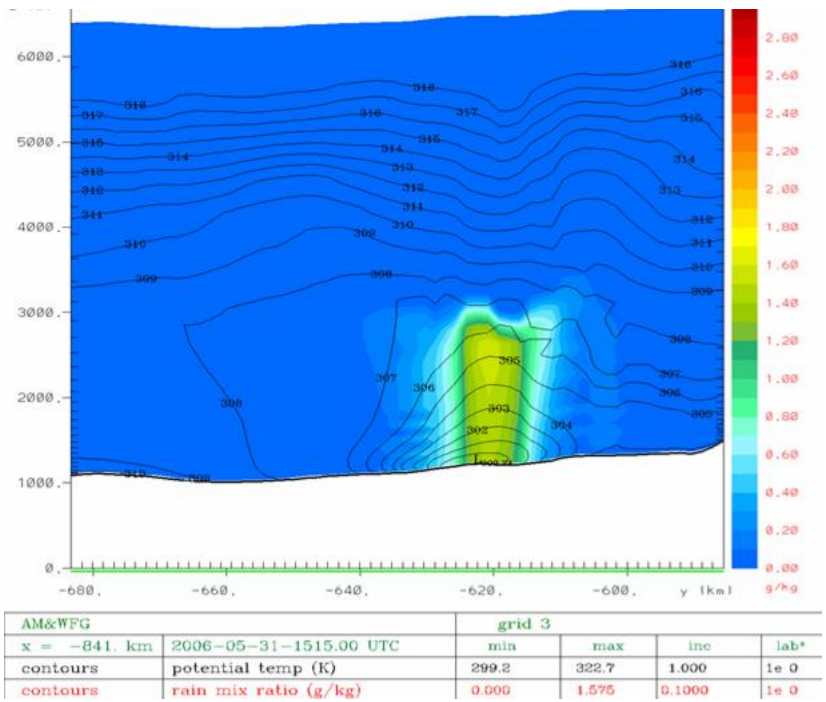


Potential temperature θ (K) and rain mixing ratio (g/kg), *RAMS simulation 31 May 2006,* ***0.8×0.8 km*** *grid space*

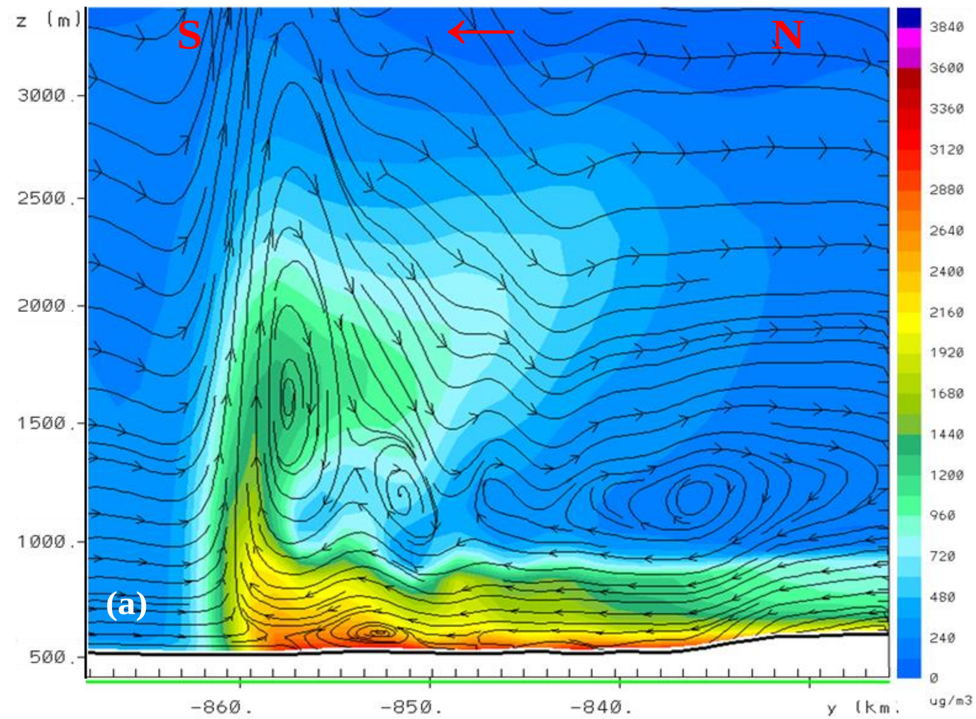


Potential temperature (red contour lines in K) and dust concentration (color scale in μg m^{-3}), *RAMS simulation 31 May 2006,* ***0.8×0.8*** *km grid space*

Dust production along the propagating front (cold pool)



Potential temperature θ (K) and rain mixing ratio (g/kg), *RAMS simulation 31 May 2006,* ***0.8×0.8 km*** *grid space*



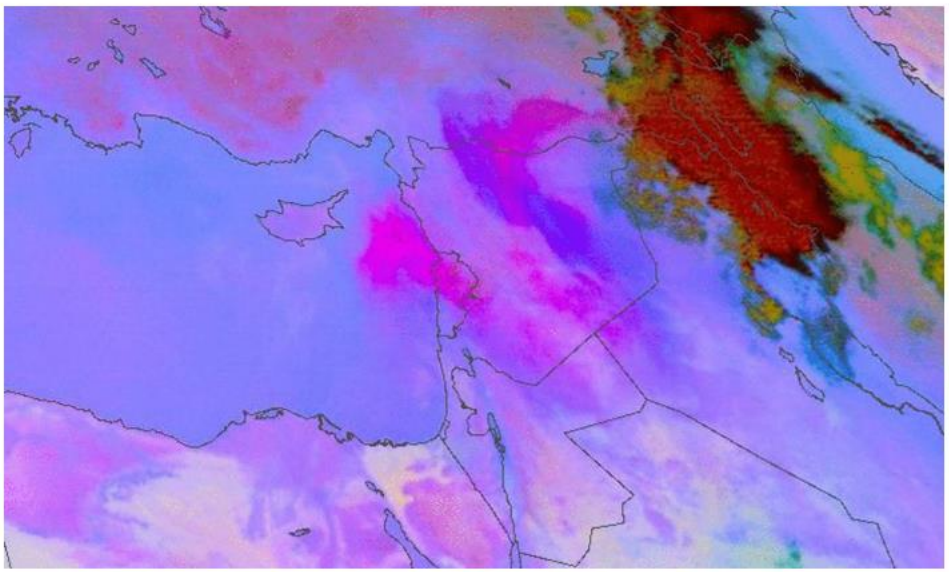
Streamlines and dust concentration (color scale in μg m^{-3} **for a reference frame** relative to the propagating speed of the haboob.

- Upward motions in the head of the system (dust wall)
- Reversal of flow at the lower levels - Kelvin Helmholtz billows on top
- Dust concentration constantly increasing inside the system

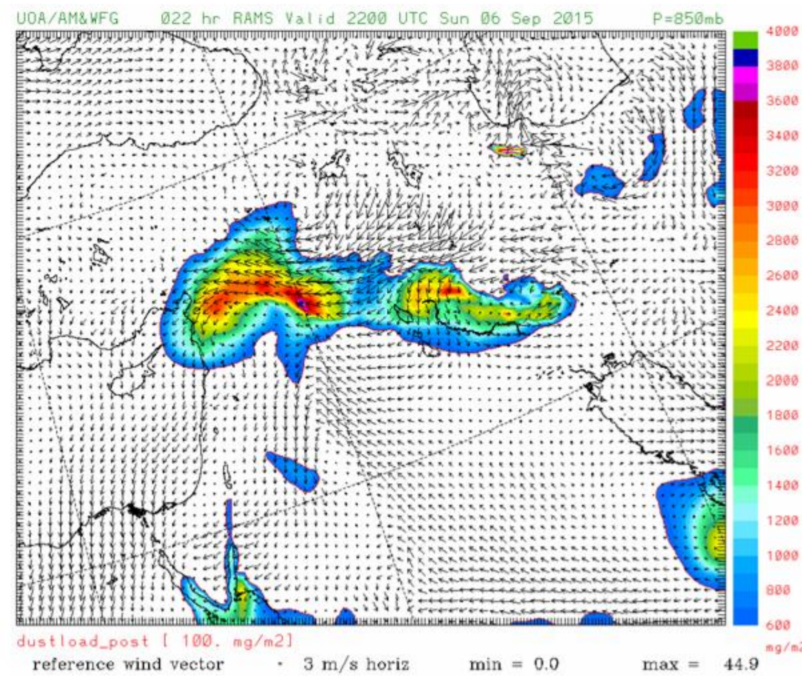
Solomos et al., ACP, 2012

A record-breaking Middle East haboob
6-13 September 2015

MSG / SEVIRI Satellite



RAMS model

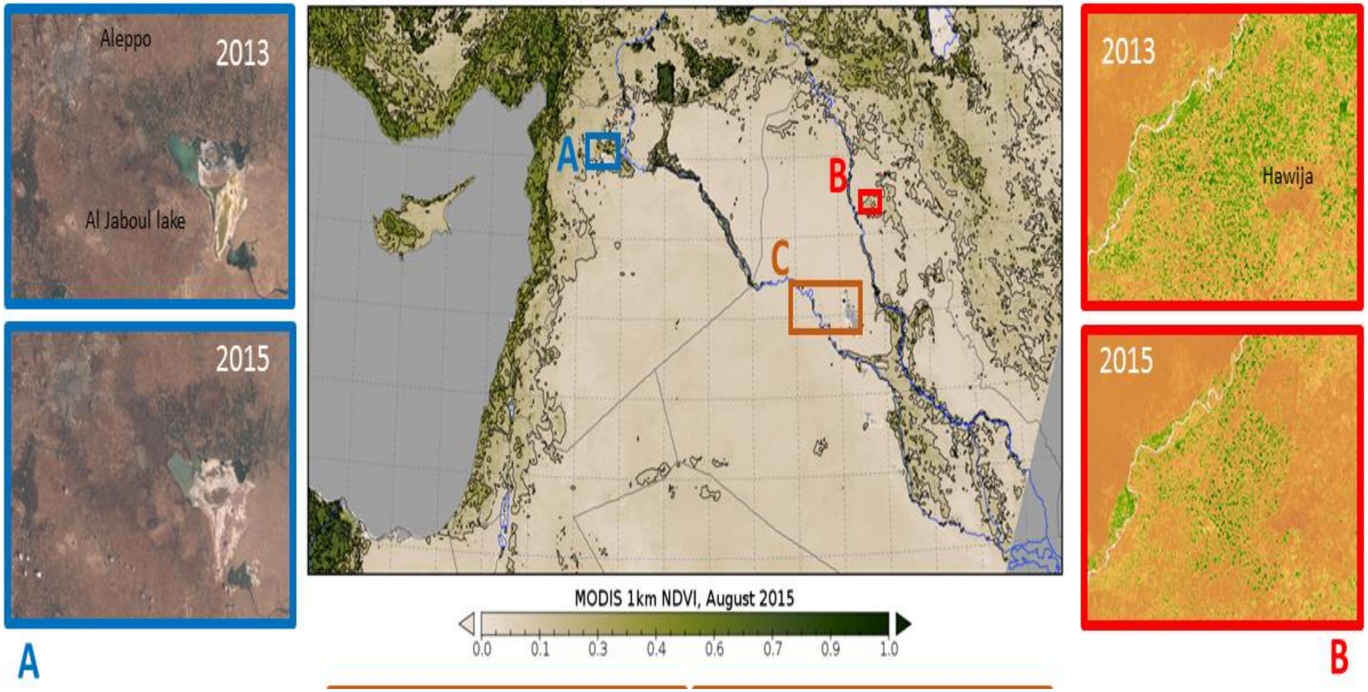


Severe convective downdrafts over the mountainous areas of East Turkey and North Iran resulted in mobilization of dust over Middle East and East Mediterranean.

Mamouri et al., 2016, ACP; Solomos et al., 2017, ACP

A record-breaking Middle East haboob, 6-13 September 2015

Examples of land use changes in 2015

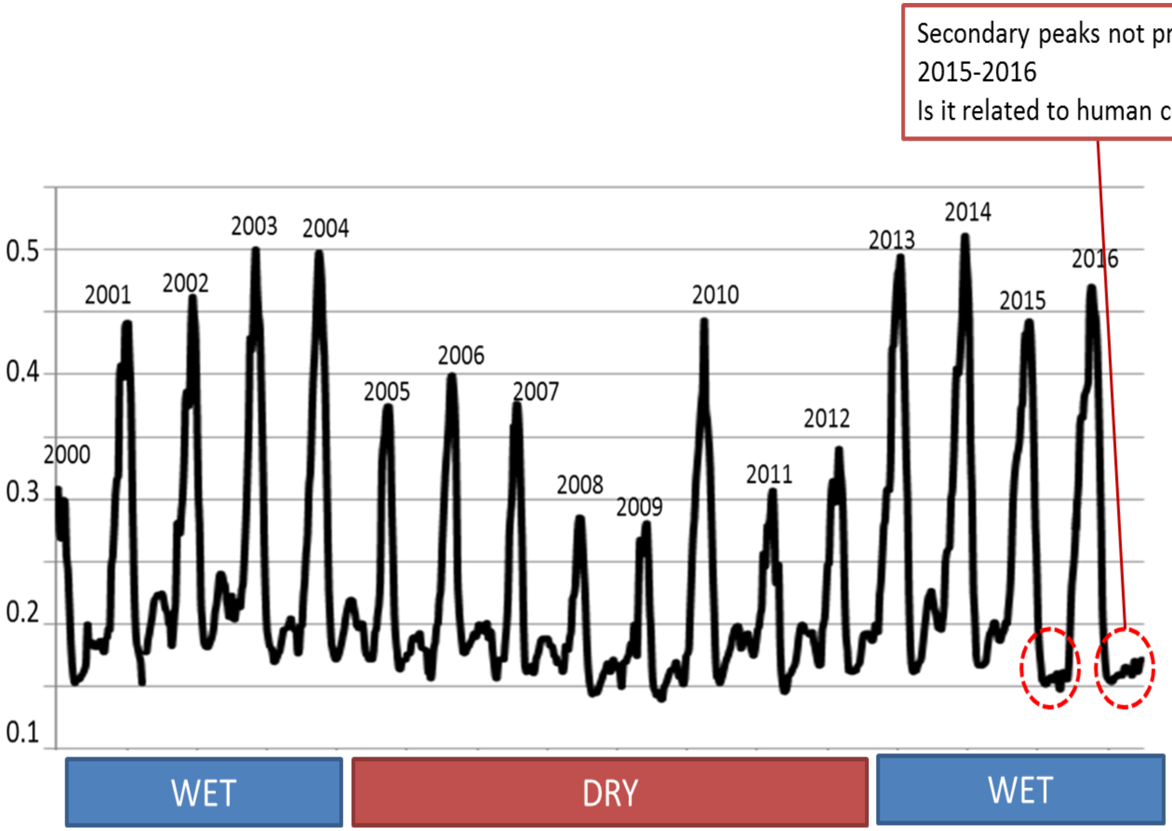


A) Landsat 8 natural color images of Aleppo region, Syria shows changes of cultivation patterns and drying of nearby Al Jaboul lake (e.g. the bright areas of the Al Jaboul Lake - dry parts of the lake - increased from 2013 to 2015)

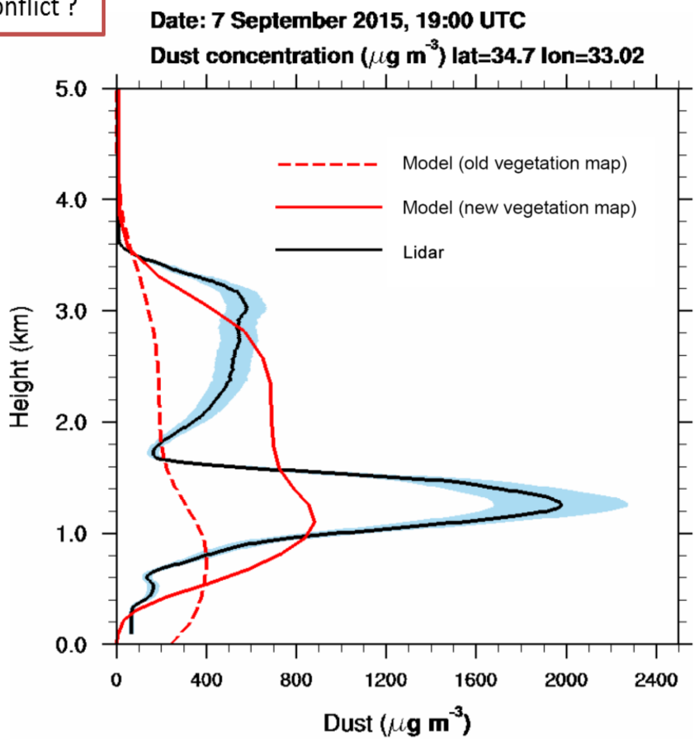
B) Landsat 8 NDVI index images in the region of Hawija, Kirkuk Province, Iraq reveal that large areas remained uncultivated in 2015 (e.g. the 2013 map shows many more green spots - agriculturally used areas - than the 2015 map);

A record-breaking Middle East haboob, 6-13 September 2015

Changes in Landuse affect dust emissions



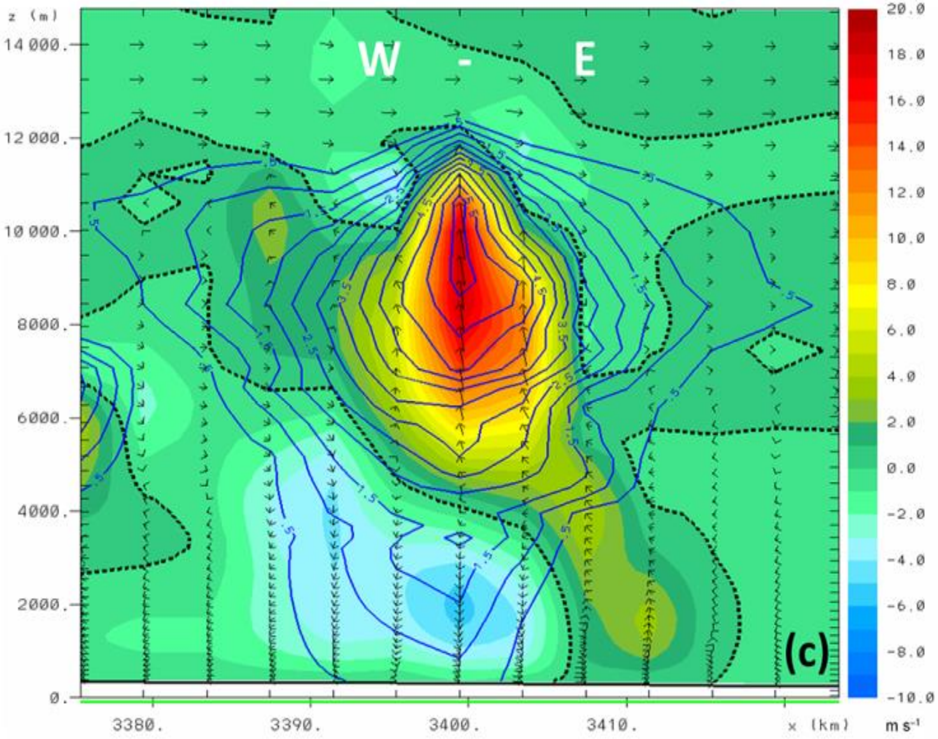
MODIS NDVI (Normalized Vegetation Index) Hawija 2000 - 2016



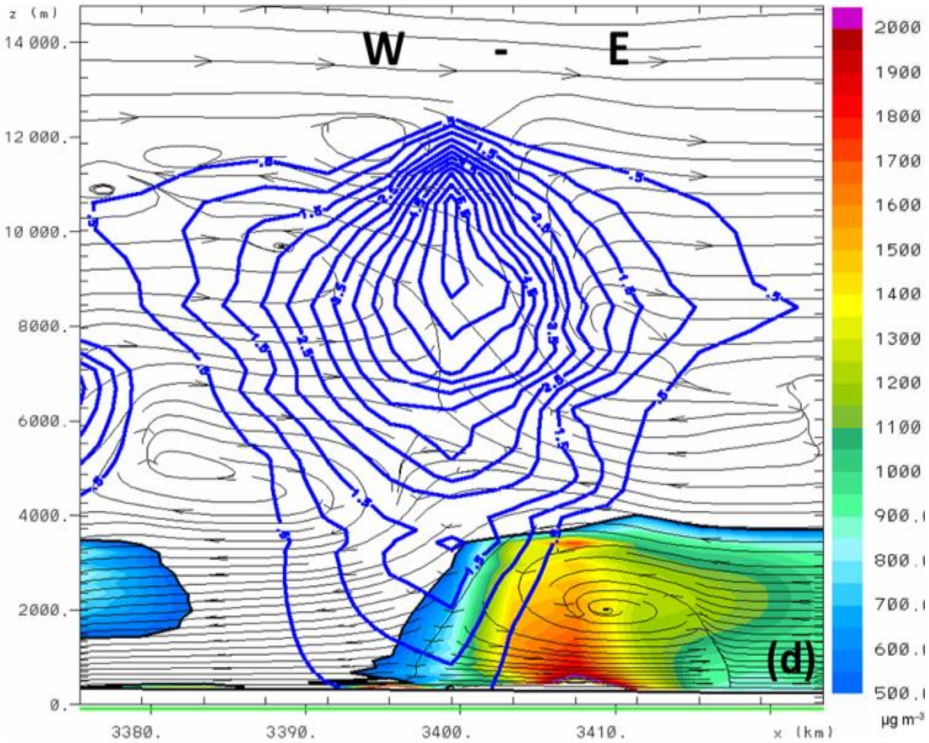
Limassol PollyXT Lidar and RAMS-ICLAMS comparison

Cold pool vertical structure

Total condensate mix.ratio (g/kg) and w (m/s)

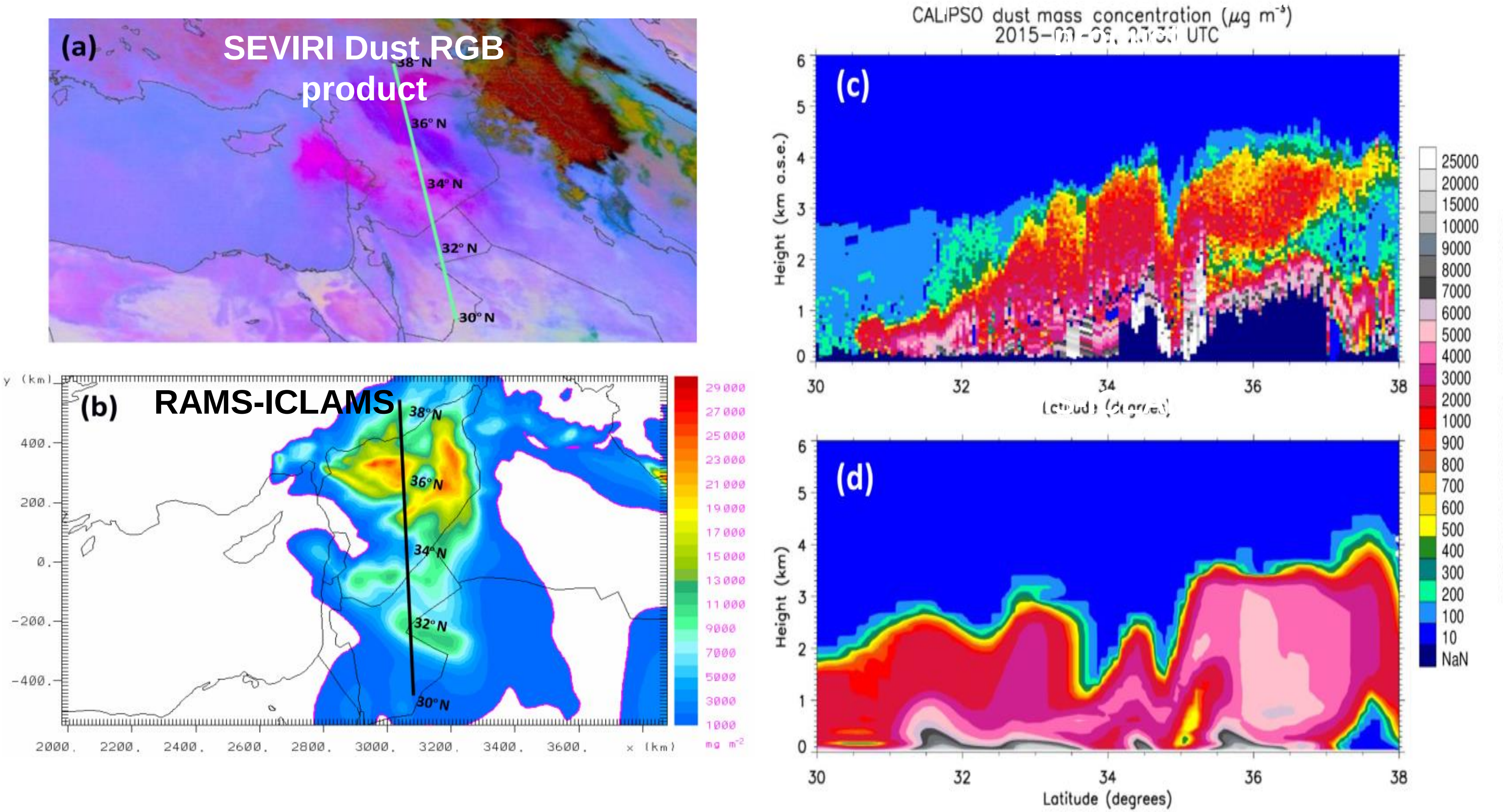


Total condensate mix. ratio (g/kg), dust concentration (μg/m3), and Streamlines



Solomos et al., ACP 2017

Cold pool formations and comparison with SEVIRI and CALIPSO



Modeling and remote sensing analysis reveal the extraordinary nature of this event

Aerosol Monitoring - Models

Cloud scale models:	Integrated Limited area models:	Large scale models (i.e. GCM, climate models):
▪ Explicitly-resolve cloud properties ▪ Explain mechanisms and Interactions ▪ Assume isolated clouds	▪ Resolve cloud properties with adequate detail ▪ Describe the regional atmospheric circulation and air quality properties ▪ Depend on boundary conditions from external source (Reanalysis, larger scale model, emission inventories)	▪ Sufficiently describe atmospheric circulation ▪ Use semi-empirical parameterizations for several sub-grid processes (e.g. convection)

All methods have limitations - Synergies

In situ measurements

- Are very sparse (airborne)
- or at surface stations with little relevance for tropospheric aerosol layers
- Limitations at measuring sizes
- Dry particle measurements

Models

- Rely on external initial and boundary conditions
- Computational errors
- Misrepresentation of physical processes

Remote Sensing

- Sparse networks
- Retrieval algorithm errors
- Lidar near surface overlap

A synergistic use of available methods can provide more insight on specific atmospheric processes

Introduction to Numerical Weather Prediction (NWP)

Navier–Stokes Equations
3 – dimensional – unsteady

Glenn Research Center

Coordinates: (x,y,z)
Velocity Components: (u,v,w)

Time : t   Pressure: p
Density: ρ   Stress: τ
Total Energy: Et

Heat Flux: q
Reynolds Number: Re
Prandtl Number: Pr

Continuity:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

X – Momentum:

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right]$$

Y – Momentum:

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum

$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right]$$

Energy:

$$\frac{\partial(E_T)}{\partial t} + \frac{\partial(uE_T)}{\partial x} + \frac{\partial(vE_T)}{\partial y} + \frac{\partial(wE_T)}{\partial z} = -\frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} - \frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right]$$

$$+ \frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\,\tau_{xx} + v\,\tau_{xy} + w\,\tau_{xz}) + \frac{\partial}{\partial y}(u\,\tau_{xy} + v\,\tau_{yy} + w\,\tau_{yz}) + \frac{\partial}{\partial z}(u\,\tau_{xz} + v\,\tau_{yz} + w\,\tau_{zz})\right]$$

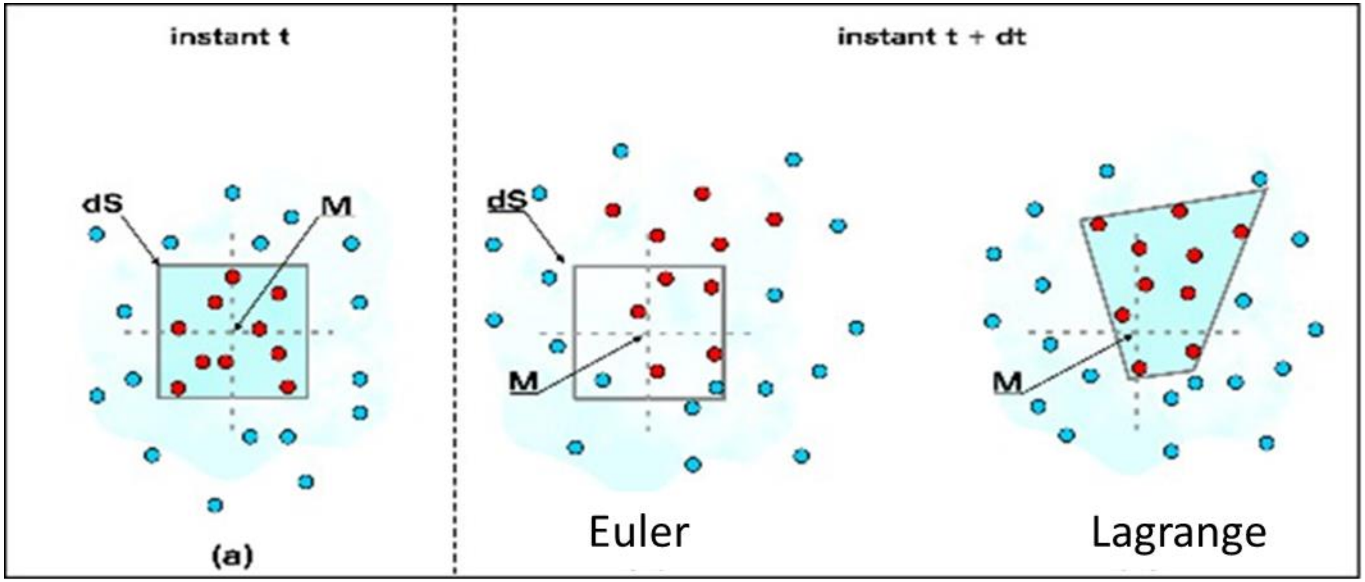
Introduction to Numerical Weather Prediction (NWP)

Lagrangian Description of Flow

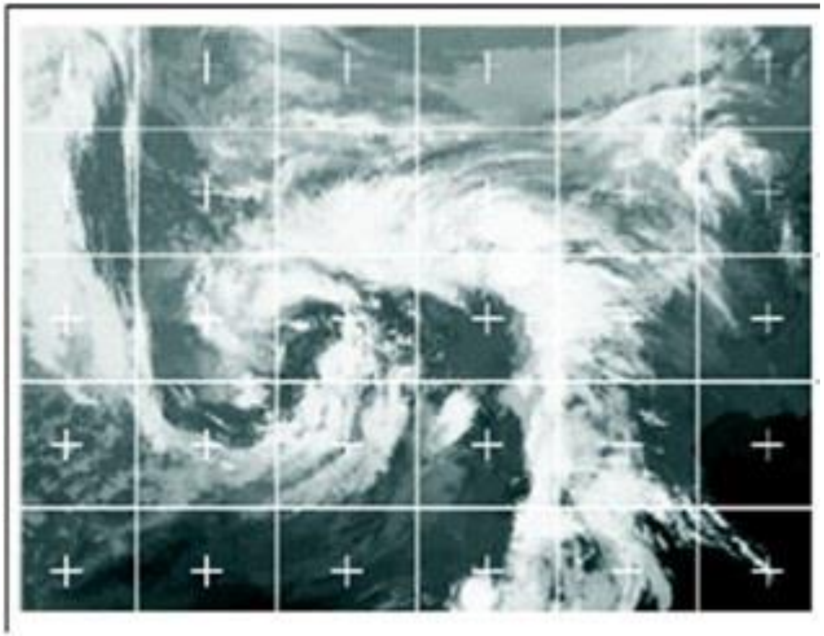
- We follow individual fluid particles (tracers)
- As the particles move their positions and velocities change with time
- The physical laws apply directly to each particle

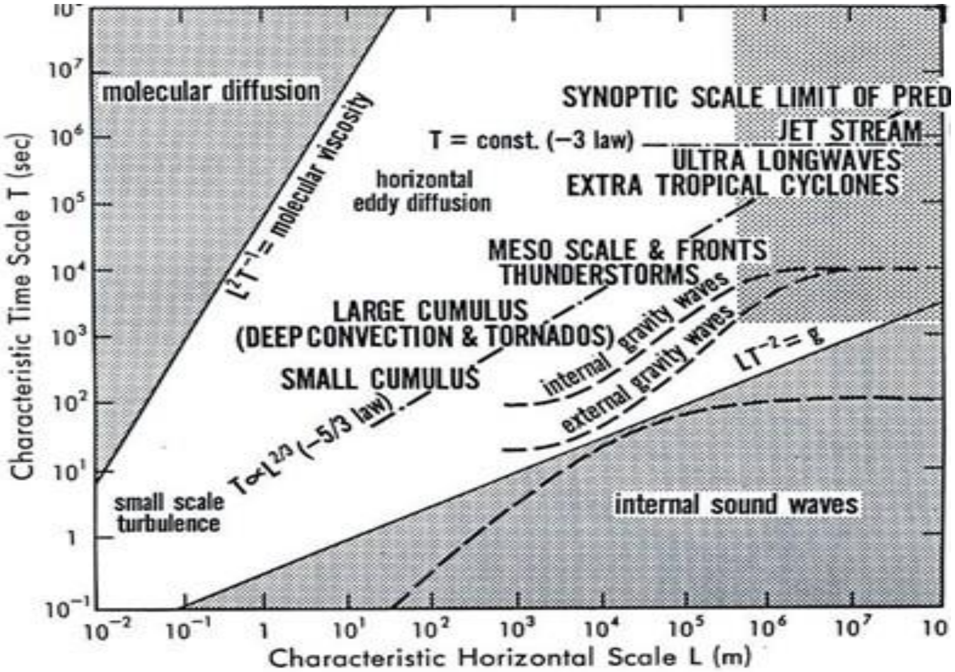
Eulerian Description of Flow

- We define a finite space grid
- The properties of each grid cell change with time
- The physical laws are reformulated to an Eulerian format



Introduction to Numerical Weather Prediction (NWP)





- Practically speaking we need at least 10 grid points to describe a physical phenomenon.
- For example in order to resolve the development of a 20 km diameter convective cloud (Cb) this yields a model grid resolution of 2 × 2 km
- Sub-grid parameterizations for small scale effects
- Convective parameterization remains the biggest problem in atmospheric models

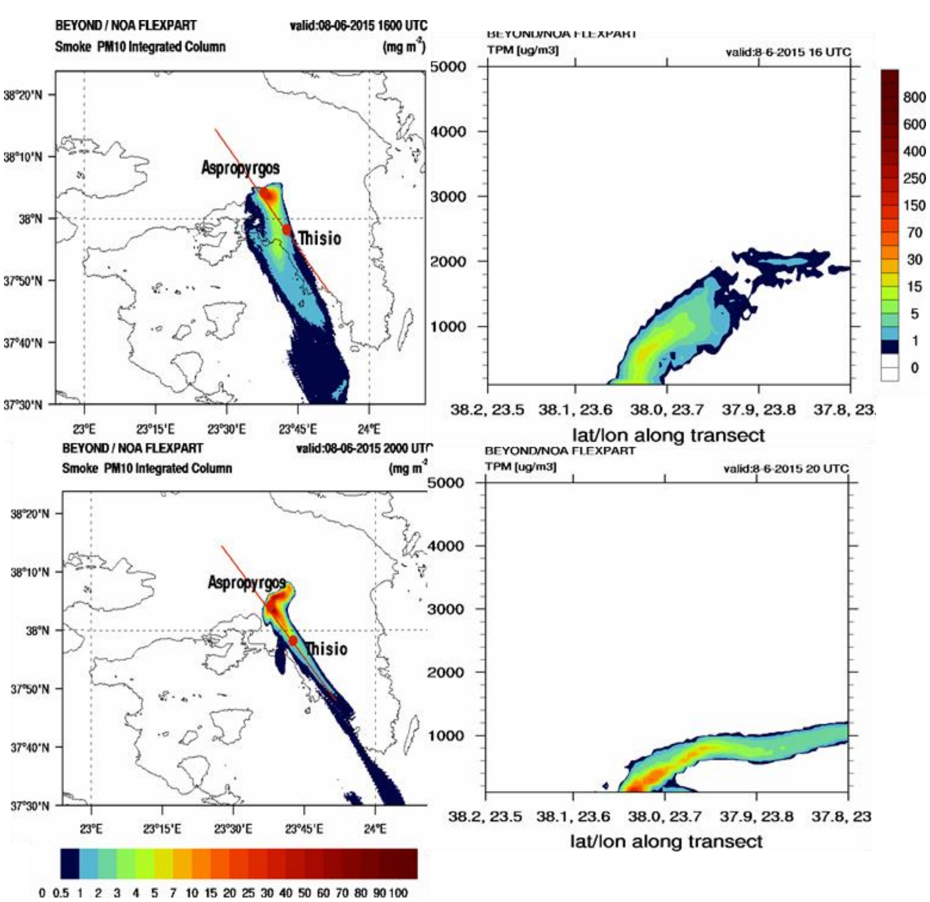
Introduction to Numerical Weather Prediction (NWP)

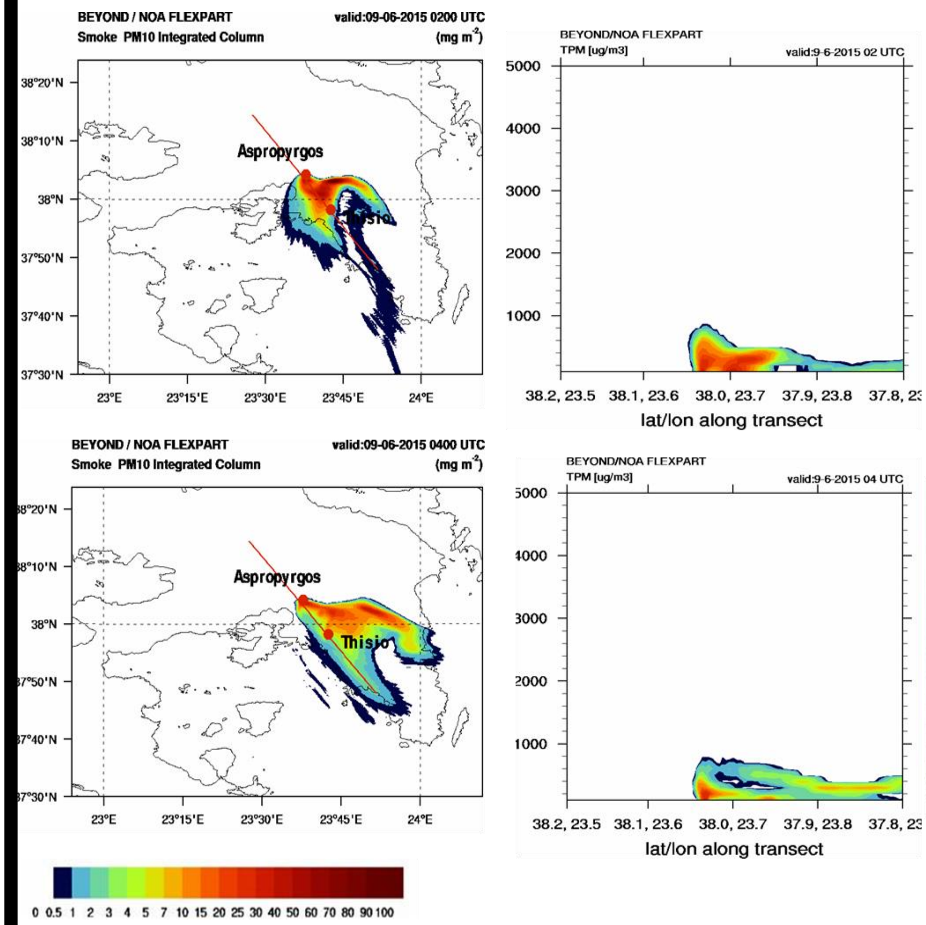
- Most of the important development of primary atmospheric physical processes in NWP models was accomplished by 1990
- Currently we describe everything we know about atmospheric processes (actually, models have mostly caught up with our ability to observe the atmosphere)
- Most important NWP development in past 15-20 years: Cheap computer power (PC, Workstations, Supercomputers) and Multi-processing
- Higher resolution improves model topography, coastlines, treatment of physical processes

Introduction to Numerical Weather Prediction (NWP)

- When using coarse resolution (> 10 km), important weather events (e.g., thunderstorms) are not simulated explicitly
- Need of "parameterizations"
- If a parameterization gives an indication that a forecast thunderstorm occurred in a 10x10 km grid cell, and it actually happened, it was considered a good forecast
- With high resolution (100 m), if a thunderstorm is forecast to occur 200m west of a road, but it actually occurred 200m east of the road:
  - good forecast? bad forecast?

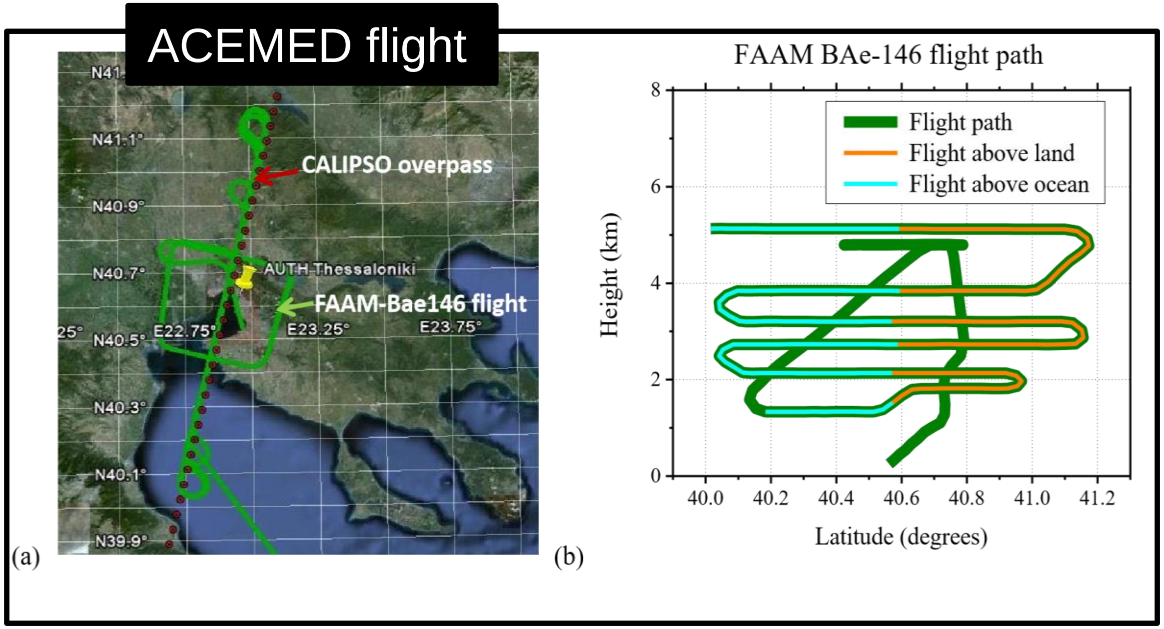
Dispersion Modeling – PBL Considerations

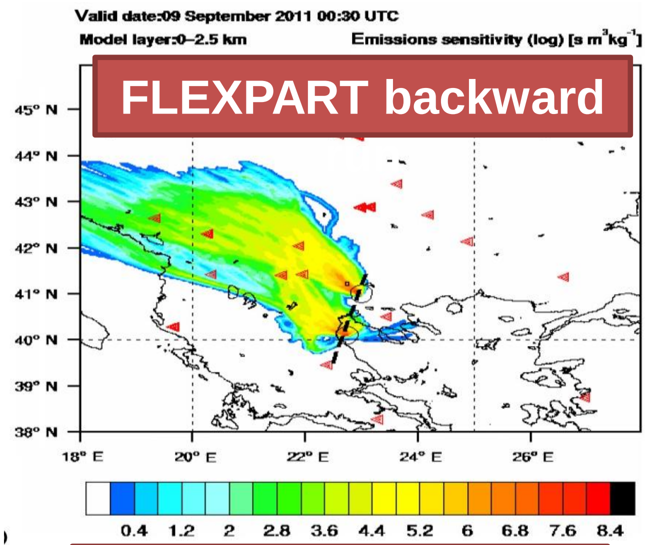


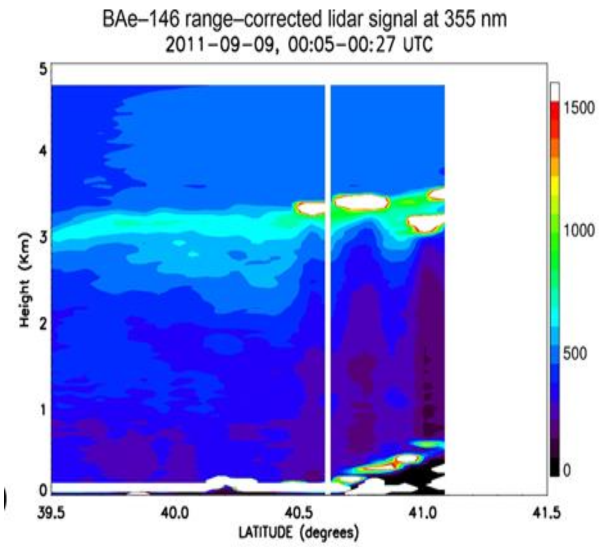


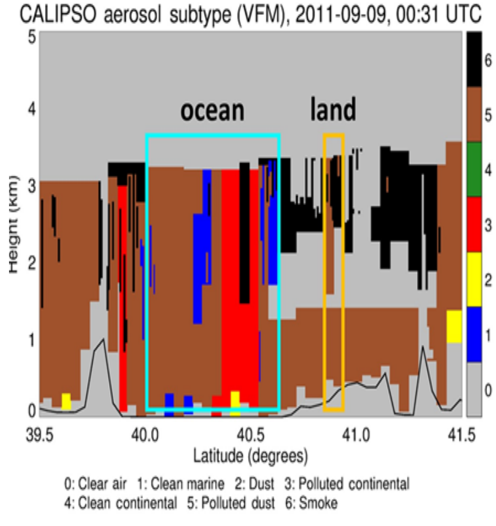
High PBL top - Deep mixing **Low PBL top - Temperature**

Airborne – Satellite –Model combination

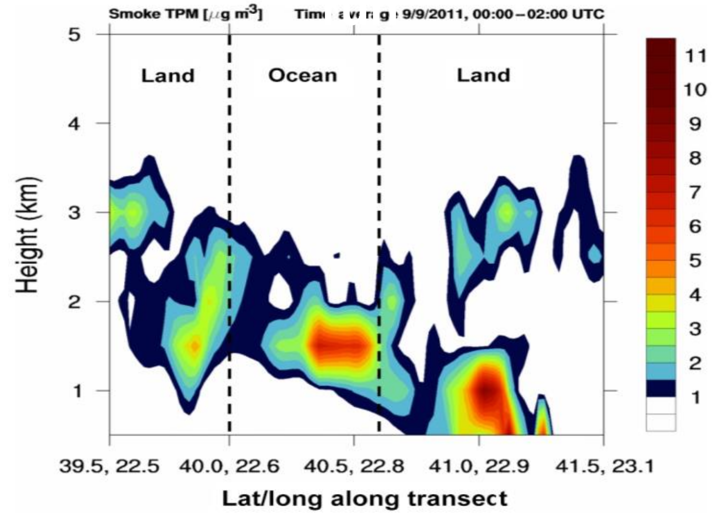








FLEXPART forward



Modeling - Remote Sensing Synergies

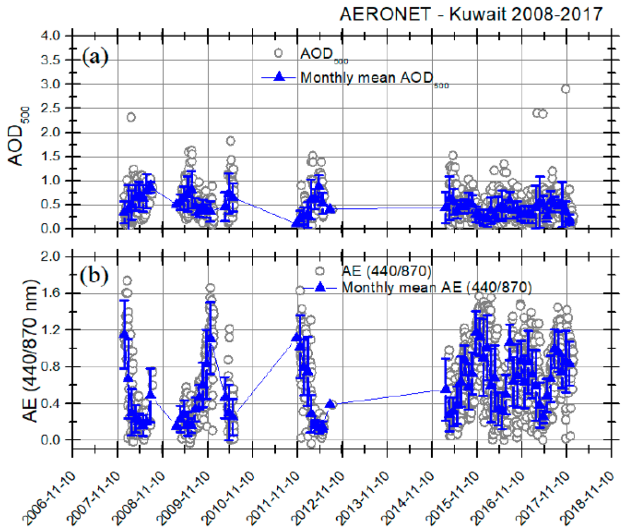


Figure 1. Time series of mean daily (grey circles) (a) AOD values at 500 nm (AOD_{500}) and (b) Ångström exponent (AE), measured over Kuwait for the time period 2008–2017. Blue triangles correspond to their monthly averages and the error bars represent their standard deviation.

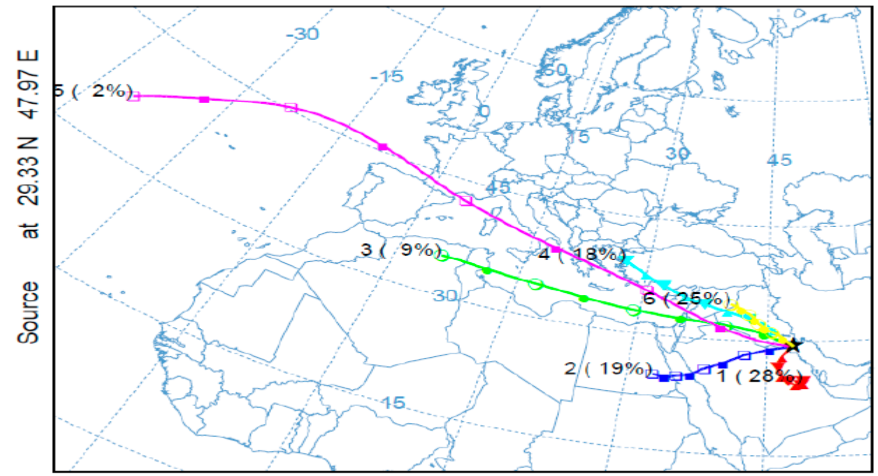


Figure 9. The main six air mass transport paths (centroids) are represented with the colored lines, indicating the central path of air masses with similar characteristics and directions, as determined from the HYSPLIT cluster analysis.

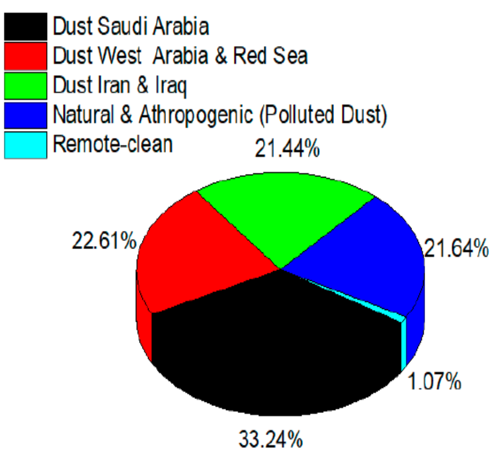
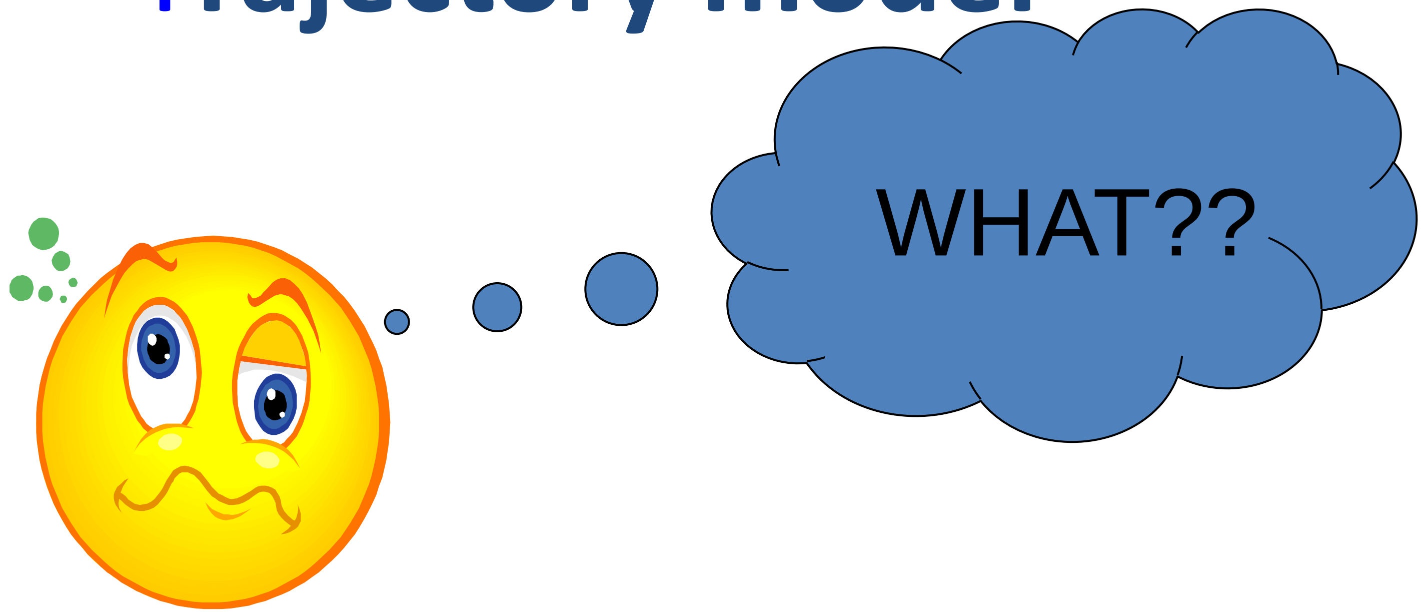


Figure 11. Contribution of the discrete source areas to the statistically mean value of AOD_{500}.

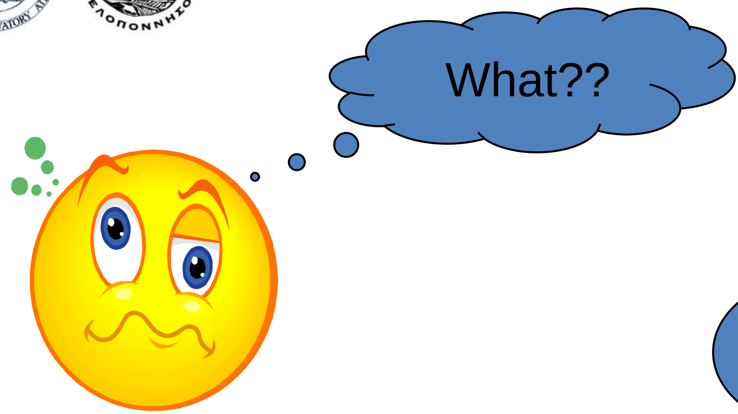
1. **Station measurements (e.g. ASERONET)**
2. **HYSPLIT backtrajectories cluster**
3. **Result analysis to identify source apportionment**

Kokkalis et al., 2018, Remote Sensing

Hybrid Single-Particle Lagrangian Integrated Trajectory model



Slides from the internet



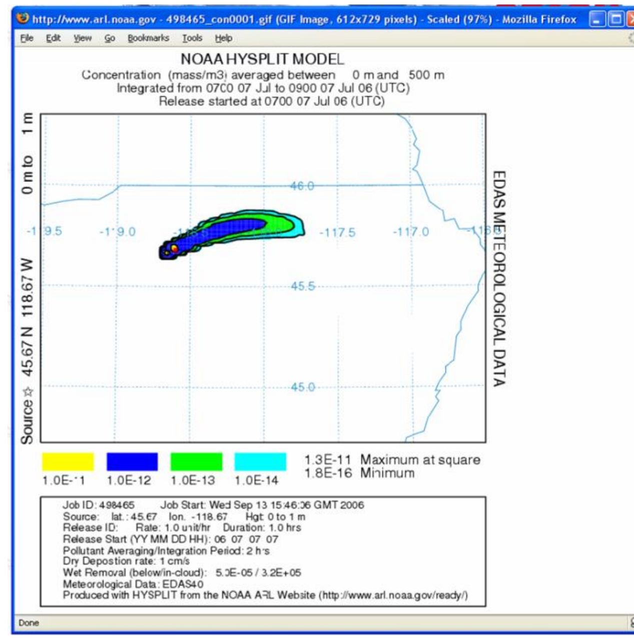
https://ready.arl.noaa.gov/HYSPLIT.php

What HYSPLIT Does

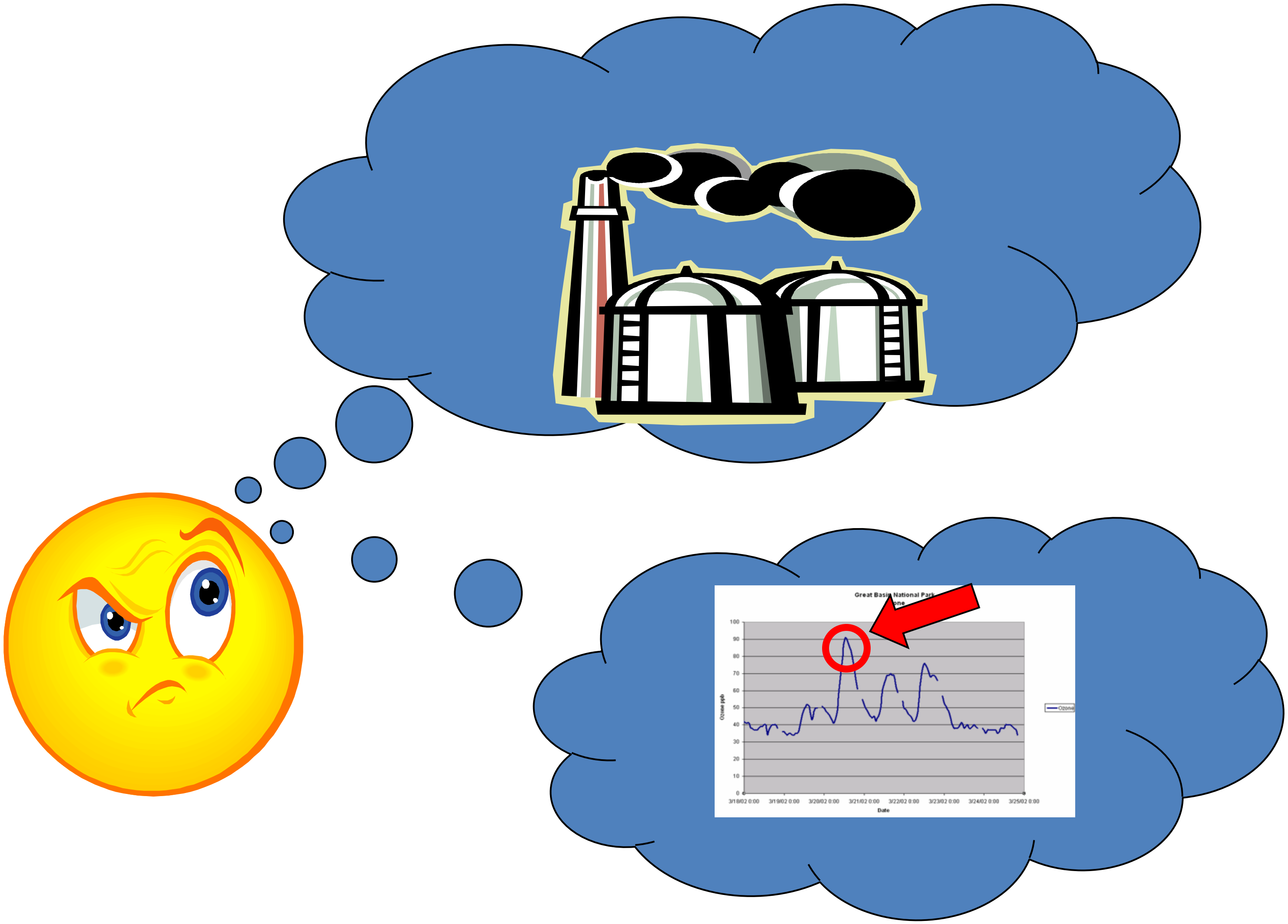
Modeling tool used for computing :

- wind trajectories in three dimensions
- complex pollutant dispersion, deposition patterns
- can be used online or downloaded and used on your computer
- can provide short-term forecasts for pollutant dispersion, or wind trajectories using forecast meteorological data
- can help us predict air quality and explore existing pollution episodes in near-real-time, and increase understanding of past pollution episodes

To Find Out Where is it Going



And Where it Came From



Air Resources Laboratory
Advancing Atmospheric Science and Technology through Research

ARL Home > READY > Transport & Dispersion Modeling > HYSPLIT > HYSPLIT Trajectory Model

HYSPLIT Trajectories
AIR RESOURCES LAB

READY

- Compute *forecast* trajectories
- Compute *archive* trajectories
- Retrieve previous model results
- Restart user session (clear user inputs)
- Current pre-computed U.S. trajectory forecasts
- Trajectory optimization for balloon flights
- Return to main HYSPLIT page

Daily Limits

Users are limited to 500 trajectories per day in order to share the resources available with all HYSPLIT users.

Publishing HYSPLIT results

Publications using HYSPLIT results, maps or other READY products provided by NOAA ARL are requested to include an acknowledgement of, and citation to, the NOAA Air Resources Laboratory. Appropriate versions of the following are recommended:

Citation

Stein, A.F., Draxler, R.R, Rolph, G.D., Stunder, B.J.B., Cohen, M.D., and Ngan, F., (2015). NOAA's HYSPLIT atmospheric transport and dispersion modeling system, Bull. Amer. Meteor. Soc., ***96****, 2059-2077, http://dx.doi.org/10.1175/BAMS-D-14-00110.1*

Rolph, G., Stein, A., and Stunder, B., (2017). Real-time Environmental Applications and Display sYstem: READY. Environmental Modelling & Software, ***95****, 210-228, https://doi.org/10.1016/j.envsoft.2017.06.025 . (http://www.sciencedirect.com/science/article/pii/S1364815217302360)*

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ARL Home > READY > Transport & Dispersion Modeling > HYSPLIT > HYSPLIT Trajectory Model

READY users produced 2753 un-registered HYSPLIT simulations since 00 UTC today!

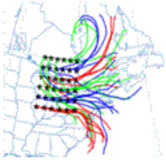
Type of Trajectory(ies)

Number of Trajectory Starting Locations	(●) 1 ( ) 2 ( ) 3 — Note: By choosing just one source location, more options for selecting the location will be presented on the next page, such as choosing by latitude/longitude, by WMO ID, or by plant location. Multiple source locations limit the input to just latitude/longitude positions. This option is ignored for trajectory ensemble and frequency.
Type of Trajectory	(●) Normal ( ) Matrix ( ) Ensemble ( ) Frequency

Next>>

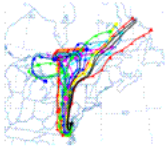
Details

Trajectory Matrix



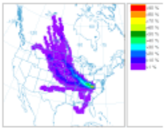
The trajectory matrix option will run a grid of trajectories bounded by the first 2 source locations (trajectory 1 is the lower left grid point and trajectory 2 is the upper right grid point) and evenly spaced with a grid increment given by the distance between the lower left grid point (trajectory 2) and trajectory 3. Only one height is allowed.

Trajectory Ensemble



The trajectory ensemble option will start multiple trajectories from the first selected starting location. Each member of the trajectory ensemble is calculated by offsetting the meteorological data by a fixed grid factor (one grid meteorological grid point in the horizontal and 0.01 sigma units in the vertical). This results in 27 members for all-possible offsets in X,Y, and Z. Note: the starting height should be greater than 250 m for optimal configuration of the ensemble.

Trajectory Frequency



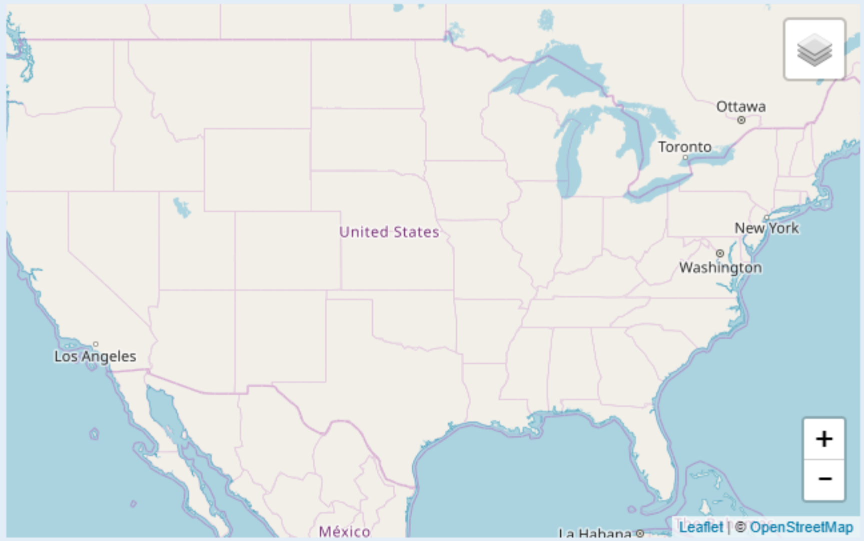
The trajectory fequency option will start a trajectory from a single location and height every 6 hours and then sum the frequency that the trajectory passed over a grid cell and then normalize by either the total number of trajectories or endpoints. A trajectory may intersect a grid cell once or multiple times (with residence time options 1, 2 or 3).

Meteorology & Starting Location(s)

Trajectory Calculation

Meteorology: GDAS (1 degree, global, 2006-present) ▼ More info

Source Location (enter using **one** of the following methods):



Click a location on the map or select from below:

- ◉ Decimal Degrees Latitude: 56.000000 N ▼ Longitude: 161.000000 W ▼
- ○ DDD/MM/SS Latitude: Deg. Min. Sec. N ▼ Longitude: Deg. Min. Sec. W ▼
- ○ City (Country or State: name: lat: lon): ▼
- ○ Airport or WMO ID (i.e., dca): ID Lookup

Reset Form | Next>>

We are looking at 8 August 2017

We are looking at 8 August 2017

Model Run Details

Request trajectory

The archived data file (GDAS1) has data beginning at 08/ 8/17 0000 UTC.

Model Parameters

Trajectory direction:
- (•) Forward
- ( ) Backward (Change the default start time!) More info

Vertical Motion:
- (•) Model vertical velocity
- ( ) Isobaric
- ( ) Isentropic More info

Start time (UTC): Current time: 10:37 — year: 17, month: 08, day: 08, hour: 12 More info

Total run time (hours): 120 More info

Start a new trajectory every: 0 hrs Maximum number of trajectories: 24 More info

Start 1 latitude (degrees): 56.000000 More info

Start 1 longitude (degrees): -161.000000 More info

Start 2 latitude (degrees):

Start 2 longitude (degrees):

Start 3 latitude (degrees):

Start 3 longitude (degrees):

Level 1 height: 10000 (•) meters AGL ( ) meters AMSL More info

Level 2 height: 0

Level 3 height: 0

We are looking at 8 August 2017

Display Options

GIS output of contours?	None	Google Earth (kmz)	GIS Shapefile			More info

The following options apply only to the GIF, PDF, and PS results (not Google Earth)

Plot resolution (dpi):	96				More info	
Zoom factor:	70				More info	
Plot projection:	Default	Polar	Lambert	Mercator	More info	
Vertical plot height units:	Pressure	Meters AGL	Theta		More info	
Label Interval:	No labels	1 hour	6 hours	12 hours	24 hours	More info
Plot color trajectories?	Yes	No				
Use same colors for each source location?	Yes	No			More info	
Plot source location symbol?	Yes	No				
Distance circle overlay:	None	Auto			More info	
U.S. county borders?	Yes	No			More info	
Postscript file?	Yes	No			More info	
PDF file?	Yes	No				
Plot meteorological field along trajectory?	Yes	No	Note: Only choose one meteorological variable from below to plot		More info	
Dump meteorological data along trajectory:	Terrain Height (m) Potential Temperature (K) Ambient Temperature (K) Rainfall (mm per hr) Mixed Layer Depth (m) Relative Humidity (%) Downward Solar Radiation Flux (W/m**2)				More info	

Request trajectory (only press once!)

We are looking at 8 August 2017

ARL Home > READY > Transport & Dispersion Modeling > HYSPLIT > HYSPLIT Trajectory Model Results

READY

HYSPLIT MODEL RESULTS FOR JOB NUMBER 124478

Model Status:

```
SETUP.124478
 NOTICE: using namelist file

Last Changed Date: 2019-03-20 13:31:35 -0400 (Wed, 20 Mar 2019)
Last Changed Rev: 1007
HYSPLIT4 - Initialization
Model submitted on Tue May 28 06:39:45 EDT 2019
```

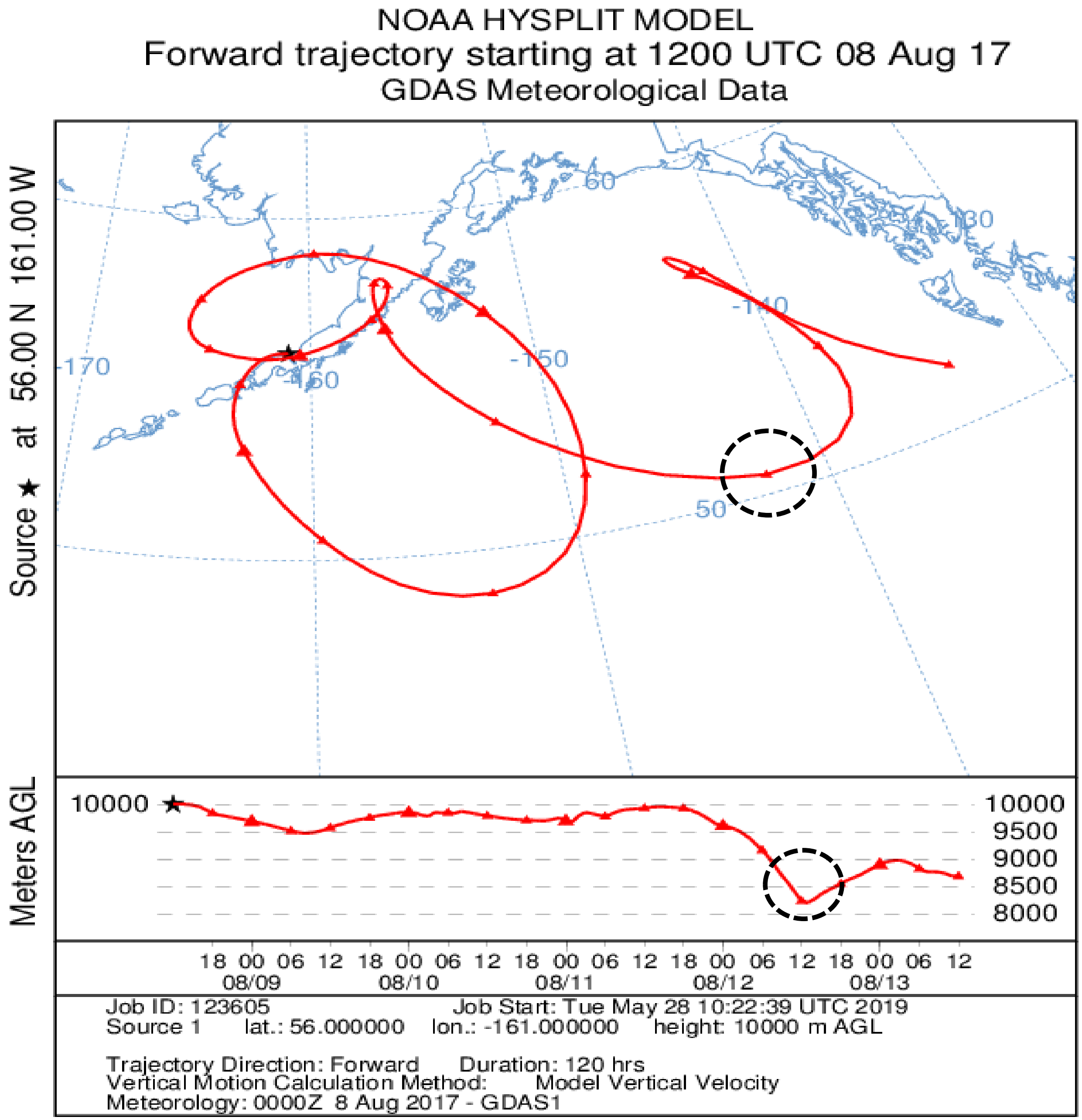
RESULTS	Click on text link to view images in a new window.	
	GIF Plots	PDF Plots
Trajectories	.gif	.pdf

- Modify the trajectory plot without rerunning the model.
- Trajectory endpoints file.
  - Trajectory endpoints format help.
- HYSPLIT SETUP file.
- HYSPLIT CONTROL file.
- HYSPLIT MESSAGE (diagnostics) file.
  - MESSAGE file format help (pdf)

Return to main menu (keep user inputs)

Return to main menu (clear user inputs)

Find the location of the air mass at 12:00UTC 12 AUG 2017



Sheveluch Volcano
56.55 N
161.3 W
8 – 16 August 2017

British Columbia Fires
53.72 N
127.64 W
14-15 August 2017

1. Να εξεταστεί η προέλευση των αερίων μαζών που ανιχνεύονται σε ύψος 2, 4, 6, 8 και 10 km στο σταθμό της Φινοκαλιάς στην Κρήτη για τις 25 Μαρτίου 2019, 12:00 UTC

2. Να εξεταστεί αν για κάποια συγκεκριμένη ημερομηνία μεταξύ 15-25 Αυγούστου 2017 υπάρχει πιθανότητα να συνυπάρχουν αέριες μάζες προερχόμενες από τις περιοχές 1 και 2, καθώς και σε ποιο σημείο στην ατμόσφαιρα μπορεί να συμβαίνει αυτό.

Περιοχή 1
Sheveluch Volcano
56.55 N
161.3 W
8 – 16 August 2017

Περιοχή 2
British Columbia Fires
53.72 N
127.64 W
14-15 August 2017