Report on the visit to the NASA Goddard Space Flight Research Center (5-26 July 2010) in the framework of the CNR Short Term Mobility Program

Francesco Cairo (CNR-ISAC)

During the course of the STM staying, ideas toward an high altitude long endurance aircraft campaign, namely with the Global Hawk aircraft, have been explored. This resulting in a White Paper outlining possible focuses for such endeavour. The White Paper is hereafter reprted.

MeditHARE (Mediterranean High Altitude Research Endeavour)

Ideas toward a Mediterranean Global Hawk deployment

Summary:

The Mediterranean Sea is a unique environment for atmospheric chemistry and aerosol physics. First, it is located between the hot and dry Saharan Desert and the heavily urbanized European continent. Second, it is an ocean basin between Europe and Africa. Third, it is located near the descending branch of the Hadley circulation. Finally, it is located in a heavily populated region with a number of mega-cities lining its periphery. Hence, the Mediterranean is a region that is heavily influenced by pollution, aerosols, and the unique meteorology.

Scence Questions: MeditHARE is a mission to investigate the basic distributions of aerosols and chemical compounds in the Mediterranean basin. Our basic science questions is: **What controls the morphology of tropospheric ozone and aerosols in the basin?** This basic question then breaks down into numerous sub questions. What are the sources of ozone pollution precursors? What are the types, size distributions, sources, and sinks of aerosols in the basin? How does the meteorology influence the distributions of the these aerosols and ozone precursors? Etc.

In order to address our basic question, MeditHARE will require extensive observations of trace gases and aerosols in the Mediterranean basin. During summer, there is a strong maxima of tropospheric ozone in the eastern half of the Mediterranean in contrast to the western side with a somewhat weaker maxima. In addition, aerosol levels are very high in summer with origins from both the Sahara and biomass burning. Observations would include ozone, NOx, various hydrocarbons, aerosols, and meteorological parameters.

The mission will have ground based, satellite, and aircraft components that will be focussed on a summer deployment in the basin. Satellite observations give a broad “global” context to MeditHARE plus a continuous observational data base over the mission duration. Ground based measurement provide 24/7 observations of relevant species at a high temporal resolution. Aircraft observations provide focussed observations across both space and time in the entire basin.

In particular, we plan to employ the NASA Global Hawk unmanned aircraft system (UAS) during MeditHARE. The Global Hawk will be instrumented with a number of remote sensing instruments. We plan to deploy the Global Hawk on Decimomannu airfield from Sardinia. The deployment location combined with the GH’s 30 hour flight duration will provide an opportunity to completely sample the basin both upstream and downstream of the basic flow, and across the Mediterranean on multiple passes.

Significance: The remote sensing observations will be combined with both the satellite and surface observations to yield an unprecedented data set documenting the distributions of aerosols and trace gases in the Mediterranean. This data set will provide information on both air pollution and climate change in the Mediterranean basin. Furthermore, the data will provide support for both the EU and NASA satellite missions that are operational and planned for future flights.

I. Introduction

The summer Mediterranean represents an ideal place for studying both the aerosol impact on the radiation and chemistry of the atmosphere, and the photooxidative chemistry of the lower atmosphere, due to its various extensive aerosol souces, its intense solar irradiation in often cloud-free conditions, its abundance of water vapour and long range or in situ production of pollutant from its heavily urbanized coasts. The region is in fact a crossroad and mixer of fluxes coming from North America and Continental Europe that bring in high level of pollution, Africa which is a major source of aerosol and South East Asia whose polluted boundary layer air is uplifted by monsoon convective activity and transported westward in the upper troposphere.

Moreover, in the summer its southern shores are often plagued by extensive biomass burning, that can inject emissions directly into the free troposphere by pyroconvective activity.

The Mediterranean atmosphere is a high photochemical reactor with high oxidative characteristics that greatly enhance ozone level during summer. Moreover, in the basin, both continental, with marked urban/industrial cheracteristics, marine aerosol and desert dust are heavily present, the latter the most contributing to the large Aerosol optical depth (AOD) often observed.

The Mediterranean is considered to be very sensitive to global climate change. In fact, the basin, because of its geographical position, seems to be prone to receive the full blow of undesired climate modification: several thousands of kilometres of built-up coastal lands make it vulnerable to sea rise. The prevalent weather patterns of its southern regions, make the latter at risk if the basin fluxes are modified or the descending branch of the Hadley cell is displaced northward, enhancing summer droughts to the point that a full scale desertification process becomes possible. Finally, European economic activities are sources of emissions, which, because of changes in prevailing wind patterns, may cause modification of emission distributions in a unpredicted as well as undesirable fashion.

It is thus a region of extreme interest for assessing the manmade impact on chemistry and radiative processes. In the following, a brief outline of the main scientific issues at play in the region is given, and proposal for scientific activities are delineated.

II. Science Section

A. What controls the distribution of tropospheric ozone in the Mediterranean Basin?

Tropospheric ozone is key to tropospheric chemistry and radiative budget.

A general increase of tropospheric Ozone from winter to summer can be seen from the figure 1 showing OMI tropospheric ozone for February (left panel) and August (right panel). Ozone progressively builds up in the basin, starting in Spring and peaking in Summer, when the generally northernly surface winds, more pronounced during the season, transport polluted airmasses from continental Europe to the basin, where the airmasses are generally further distributed from west to east,

and toward middle east and Africa. This summertime enhancement in the entire Mediterranean troposphere renders the region one of the ozone-richest in the Northern Hemisphere.
The ozone distribution peaks in the Eastern part of the basin with a significant impact toward northern Africa and Near East (Duncan et al., 2008) as a product of oxidation of reactive carbon compounds as CO and VOC largely present, catalysed by nitrogen oxides.
Conversely, when little NO_X is present the oxidation of carbon monoxide trigger the catalytic destruction of ozone via the $O – HO_2$ cycle. Thus, the net amount of ozone is controlled by the relative abundances of HO_x, NO_x, and VOC. A simultaneous synoptic view of the basin is then necessary to assess the regions of passage from VOC-sensitive chemistry (high NOx, tipically close to pollution source regions) to NOx-sensitive chemistry.
The ozone distribution throughout the basin are not only controlled by in-situ photochemical formation but as well as mesoscale and large-scale, long-range transport. The western side is surrounded by mountain ridges as high as 1500 m or more, whose southern and eastern flanks, under anticyclonic subsidence and strong insolation in the summer, heats up promoting upslope winds that return aloft, recirculating airmasses. This mechanism is less pronounced in the Eastern part, which is indeed more interested in the in situ chemical processing of the long-range transported air from continental Europe, as well as South Asia

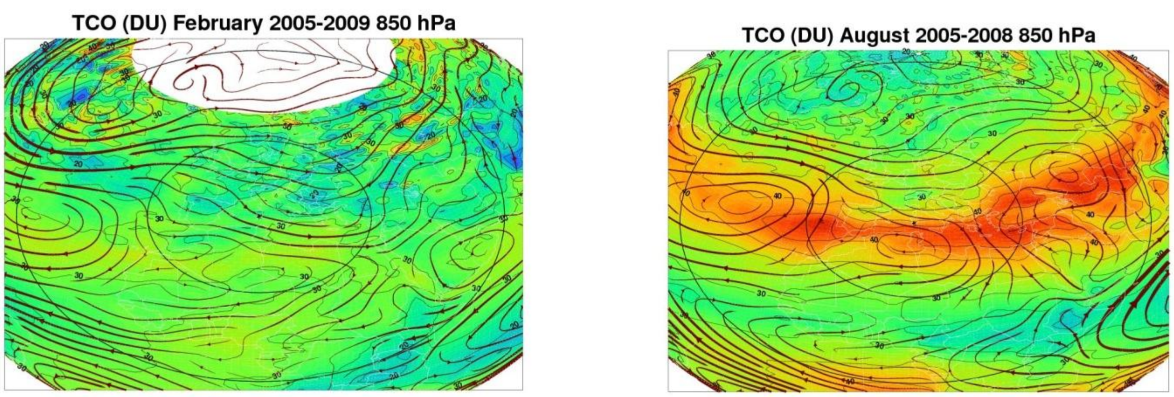


Figure 1: OMI tropospheric column ozone for February (left panel) and August (right panel) The isolines represent the NCEP/NCAR 850hpa wind field.

A series of still open scientific issues are outlined in the following:

- *Transport and transformation of anthropogenic trace components in the Mediterranean low troposphere*

Although the geographical features of the basin create a complicated atmospheric pattern, its main characteristics can be summarized into two prevailing paths: a westerly flow with a stronger component in the colder part of the year, and a northernly flow more pronounced during summer. As we have outlined above, this is able to carry photo oxidants and aerosol particles from central Europe to the Mediterranean basin. There, the synoptic situation in summer is dominated by two large, semi-permanent, weather systems located at each end of the basin: the Azores Anticyclone at its western edge, merging to a low pressure system at its Eastern, extending from the Middle East to the whole of South-western Asia, this latter linked to the South-east Asian Monsoon activity. Since frontal systems approaching from the Atlantic travel mainly North of the Alps, this meteorological situation creates a persistent cloud-free and stable stratification condition over the sea, that can last undisturbed for several days. Hence, due to the high solar radiation intensity, the region is particularly sensitive to air pollution. A very active photochemistry activity leads to a strong oxidants production, particularly hydroxyl radicals impacting ozone budget. These oxidants cause ozone forming reactions and ultimately lead to the formation of acids, including sulphuric and nitric, and secondary aerosol.

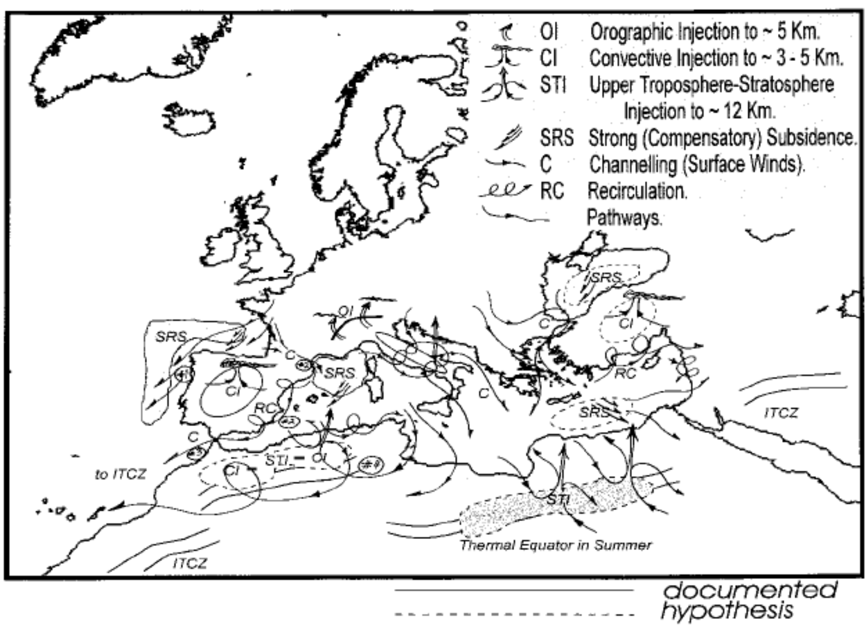


Figure 2: Conceptual model of the atmospheric circulations in the Mediterranean Basin in summer. The graphs show mechanisms which have a diurnal cycle and are well developed by mid-afternoon. The recirculations represent processes with spatial continuity along the coastal areas (after Millán et al., 1997).

The summer Mediterranean Ozone “hot spot”, has ozone level at their highest along the southern and eastern shores. The production and transport pathways are further complicated by the development of mesoscale systems.

Of relevance is the sampling of transport of pollutants from their regional source, as the Po valley and its outflow in the Adriatic sea ultimately impacting the northern African regions. The valley is considered an "hot-spot" in Europe for the high levels of in situ produced pollution which can clearly be seen from satellite images. In recent modeling studies, the Po Valley as a whole has been described as a megacity, due to the high density of inhabitants and industrial settlements. The study of this hot spot can be facilitated by the wide range of supporting ground information and the possibility to organize field campaigns concurrently with the aircraft missions.

Another assessment of relevance is the impact of ship traffic emissions on the budget of ozone and its precursors in coastal areas (nearly 70% of ship emission occurs within 400 km of coastlines (Isaksen et al., 2009) and of air traffic corridors in the free troposphere.

Objective: Assessment of tropospheric photochemistry budget and transport pathways.

- *Contribution of megacities to regional air quality and climate*

A population over 200 million faces the basin, with the presence of two major megacities, El Cairo and Istanbul, with respectively 17 an 15 millions of inhabitants. Moreover, as we have seen, the Po Valley area, with a resident population of about 17 million inhabitants, has megacity features even if it could be better described as urban conglomeration, than as a single metropolitan area. These are hot spot in the basin for the levels of pollution which can clearly be seen from satellite images, impacting air quality at a local as well as a regional scale (Duncan et al., 2008).

Of particular interest is the Po valley, on account of the "isolation" from the general circulation due to its orography and the high number of inhabitants. The study of this hot spot is facilitated by the wide range of supporting ground based informations.

Objectives Study of the urban pollution cycle; Test the satellite instrumentation capabilities for Air Quality monitoring.

- *UTLS processes, long range transport and Stratosphere-Troposphere Exchange*

Mid-latitude UTLS is highly variable in content and distribution of minor constituents. As an exchange region, the Mediterranean is exposed to mixing processes that involve airmasses of very different characteristics, with particular emphasis on their water and ozone content. These processes are of particular interest in the summer, when the basin is roughly divided in two regions: the southernmost part with subtropical characteristics and tropopause at 16-17 km, and the northernmost one, north of 40° N, with airmasses more typically of midlatitudes and tropopause at 11-12 km. Two short airborne

stratospheric campaigns were conducted in the past over the Mediterranean, in July and October 2002, producing evidences of airmasses of very different chemical characteristic.
The transcontinental transport, in the summer months, inject polluted airmasses form North America and Asia in the Mediterranean upper troposphere, able to produce local effects on the weather and the hydrological cycle. The anthropic impact of the chemical composition of the upper troposphere is further enhanced by effective vertical transport due to convective processes in late Summer, creating alteration of the UT composition due both to the high urbanized and industrialized areas in the region, and the mixing of air from two important air traffic corridors to the North Atlantic and the South-East Asia. These corridors make the Mediterranean UT a "source region" itself, due to the high release of pollutants there, perturbing its chemistry and microphysics.
Furthermore, it appears that the Mediterranean, notably its south eastern part in the Summer, may be a preferred location for cross-tropopause exchanges locally impacting the ozone budget, as documented by a, although limited, number of stratosphere-troposphere exchanges (Stohl et al., 2000; Gerasopoulos et al., 2001; Galani et al., 2003), able to influence significantly the upper tropospheric ozone and water budget.

How to characterize the physico-chemical properties of the mediterranean UTLS and relate them to the long range transport pathways?
How to assess the impact of air traffic pollution on aerosol and chemistry in the UTLS?
How to estimate the upward transport of PBL pollutant to the UTLS?

- *Biomass Burning plumes*

Biomass burning impact the budget of trace gases, and has an effect on both air quality and climate, depending on type, location, duration, strength and its atmospheric penetration. Characterization of the source in these emission terms of emission factors and trace gases and aerosol physical and chemical properties is a high priority. Areas of interest where this phenomenon may conveniently be studied are the southern flanks of the Mediterranean basin, where in summer extensive fires often take place.
Despite the current generation of CTMs consider BB emissions as instantaneously well mixed in the boundary layer, there's mounting evidence that BB plumes can reach the free troposphere and sometimes directly be injected into the UTLS. This has serious implications for the understanding of their transport and transformation, and for the impact the BB aerosol has on radiative budget and cloud formation.
The peculiarity of the Mediterranean basin, compared to other areas of the world, would allow to study the interaction of biomass burning (mainly occurring in summer) and other anthropogenic pollution sources in strong photochemically-active conditions.

How can we parametrize BB chemical sources, evolution and fate?

B. What controls the distribution of aerosols?

In the basin, both continental (soil dust, soot, anthropogenic and biogenic organics, pollution sulfate/nitrate), marine particles (seasalts, biogenic sulfates), Saharan desert dust, and biomass burning aerosol are present, [e.g., Mihalopoulos et al., 1997; Sciare et al., 2003; Pace et al., 2006; Fotiadi et al.,2006; Gerasopoulos et al., 2006; Di Iorio et al., 2009]. Often the air masses over the basin - themselves not uniquely characterizable as pure maritime or continental due to the fast evolution of meteorological patterns - have a mixture of such aerosols with varying optical and microphysical properties.

Figure 3 show the 550nm aerosol optical Depths (AOD) over the basin, for the months of February, May, August and November. The flow field is the NCEP/NCAR 850hpa wind field.

As can be discerned, the AOD presents a pronounced seasonality with, Autumn-Winter minima, probably linked to more efficient removal by wet deposition, and Summer maxima due to more extensive Saharan dust transport.

In winter, AOD stays below 0.2 throughout the basin, with increased aerosol loading over landmasses, as in the Po valley, western France and part of Eastern Europe (Barnaba et al., 2003). Aerosol is higher in Spring – it almost doubles over the Po valley – with increased continental aerosol over the north east part of the basin and the Black Sea, and significant dust outbreaks in the central and Eastern part of the basin. Maxima of aerosol are reached in summer, with large presence of aerosol observed over the Adriatic and Aegean Seas, Black Sea, and Gulf of Geneva. During the season, Saharan outbreaks became more common, reaching AOD al large as 0.5-1 in selected area, especially in the Central and Western part of the basin. Frequent biomass burning in the southern shores adds up to the aerosol load. A substantial reduction is observed during Fall, when the impact of Continental aerosol is at its minimum.

Hot spots are present throughout the year, linked to human activities; these are the Po valley and, to a lesser extent, the Nile delta.

The Summer season is of particular interest, since the Mediterranean then is a mixing region for fluxes that, at different altitudes, comes into the basin from North America and Continental Europe - bringing in high level of pollution - Africa - which is a major source of mineral aerosol to the basin - and South East Asia - whose polluted boundary layer air is uplifted by monsoon convective activity and transported westward in the upper troposphere.

Aerosol optical depths are then at their maximum due both to long range transport and local sources. Several studies indicate that aerosol optical depth, and consequently its climatic impact, is among the highest in the world over the summertime Mediterranean.

Aerosol influences climate through many different atmospheric processes, one of which is their effect on the atmospheric radiative budget.
High concentrations of aerosols also affect the cloud formation and lifetime. Not only their presence in an airmass alter its radiative and thermodynamic characteristics, but different types of Cloud Condensation Nuclei (CCN) and ice nuclei (IN) have different abilities in promoting precipitation.
Hence the importance to document the types of aerosols encountered in connection with clouds and precipitation event and to assess the indirect effect of different aerosol in modifying cloud development and precipitation.

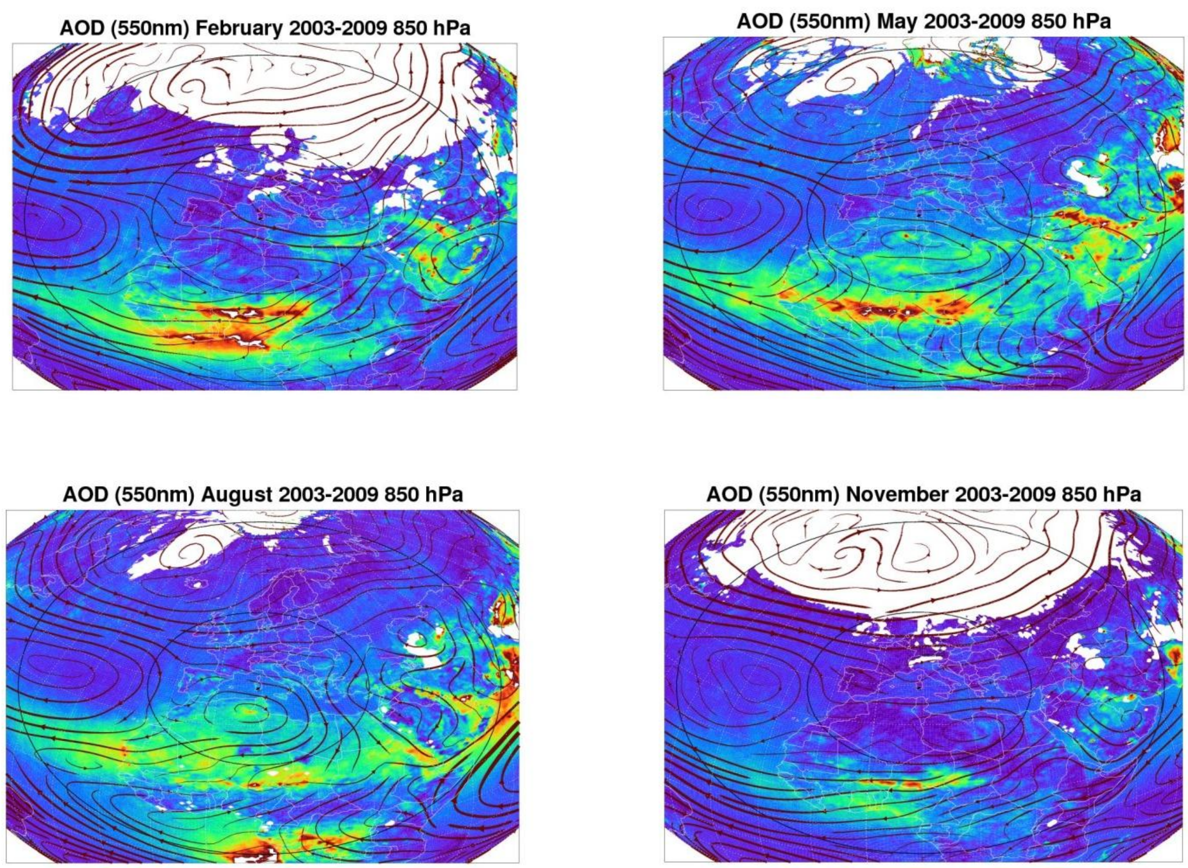


Figure 3: combined 550nm aerosol optical thicknesses from climatology (Peter Colarco, pers. comm.). The flow field is the NCEP/NCAR 850hpa wind field

For a better understanding of their role and a reliable assessment of their future impact, a number of key issues can be highlighted:

- *Aerosol radiative effects*

The influence of aerosols on climate can not be overestimated. Aerosols act to reduce the incoming solar radiation at the ground. Depending on its absorption, they can heat the atmospheric layer where they are in. Moreover, they affects microphysical and radiative characteristics of clouds. All these impacts depend on different aerosol types, their amount, size distribution, absorption properties, vertical distribution, lifetime and effectiveness of removal processes. Moreover, aerosol effect on a regional scale may be much larger than at the global scale due to the large influence of local/regional sources, types and evolution of aerosol. Key questions to be addressed are:

What are the radiative forcing of different aerosol types present in the Mediterranean?

What is their impact on cloud microphysics and radiation?

- *Biomass Burning plumes*

Biomass burning is one of the major contributions to total anthropogenic aerosol emission.

How can we parametrize BB aerosol sources? How can we estimate their impact on the regional aerosol budget?

- *Megacities*

As outlined hereabove, the Mediterranean shores are densely populated with "hot spots" regions which are great sources of aerosol and their precursors.

Can we quantify the contribution of aerosols and their precursors produced in Megacities to local and regional aerosol budget?

- *Saharan aerosol*

The transport of Saharan dust towards Europe is at its maximum over the period May-August. Models are presently available which can provide with a reasonable reliability advance notice (72 hours) of the transport episodes (DREAMS www.bsc.es or NAAPS www.nrlmry.navy.mil). Dust is an important natural forcing agent of climate and at the same time contributes to the levels of aerosol pollution at the ground. Of particular interest is their effect on weather disturbances. In fact, in the Mediterranean area, the occurrence of Saharan Air Layer (SAL) events may influence the development of heavy precipitation systems, as they do for hurricane genesis in the Atlantic west of Africa. In the latter case, several important influences have been noted, including impacts on: (1) microphysical processes during precipitation formation, (2) lower atmosphere destabilization stemming from the production of a deep mixed layer of near zero potential vorticity, (3) upper atmosphere stabilization stemming from the associated capping warm layer, (4) enhanced heating of the lower troposphere due to solar radiation absorption by the Saharan dust itself, (5) vertical and horizontal wind shear, and (6) water budget processes altered by the very dry air within the SAL layer.

The SAL is likely to be a common feature during the lifecycle of many heavy precipitation systems in the Mediterranean area. Thus, the SAL becomes a strong candidate for investigation in conjunction with the aforementioned impacts and any relevant relationships to the formation and maintenance of Mediterranean storms. Studies of Mediterranean floods conducted over the past decade (e.g., Tripoli et al., 2007) have already identified the importance of the SAL in enhancing coastal flash floods both due to its mid-tropospheric capping effects enabling channeled moist surface flows within the Tyrrhenian, Ionian and Adriatic Seas, and its capacity to inhibit upstream rain formation through microphysical interactions – thus enhancing downstream on rain formation as channeled flows begin to interact with mountain terrains situated on and inland of coastal Europe.

How to parameterize Saharan dust plumes origins and fate?
What is their effect on the radiative budget and on cloud formation, development and precipitation?

- *Aerosol production and transport*

Aerosol quality limit in the Mediterranean area are often exceeded during Summer, and the contribution of natural emissions, markedly mineral and maritime aerosol, is believed to be large but is still unquantified (Monks et al., 2008). Mineral dust seems to make the overall largest contribution, while in urbanized areas the anthropogenic source seems to dominate. The summer basin has an intense photochemical activity due to high solar irradiation, humidity and high level of oxidants, ultimately leading to the formation of acids, including sulphuric and nitric, and secondary aerosols. The relative importance of primary to secondary particulate production is not quantified yet. Moreover the basin lie at the crossroad of fluxes coming from North America and Continental Europe that bring in high level of pollution, Africa which is a major source of mineral aerosol to the basin, and South East Asia whose polluted boundary layer air is uplifted by monsoon convective activity and transported westward in the upper troposphere. A quantitative assessment of the mechanisms of aerosol in situ production and transport is of paramount importance for assessing the effectiveness of pollution control policies.

What is the budget of primary to secondary particulate production over the basin?

What is the relative impact of in-situ production and long range transport on particulate distribution in the Mediterranean?

III. Campaign Description

From what has been presented here above, is can be concluded that a summer deployment of remote sensors from a high altitude platform in the months of July-August, may offer the best chances to address the complex chemical and transport processes that are at play in the basin. A scientific effort tackling scientific issues of such complexity must however be developed by exploiting diverse approaches. We plan to complement the aircraft campaign with both the capabilities of instruments on satellites and of the good regional coverage of well established ground stations over the region. Satellite instruments offers a wide variety of complementary datasets, albeit with a revisitation time that is often too long for fully characterize the processes under study: MODIS, OMI, CALIOP, CERES TES, to name some, can all provide useful information on the presence and type of particles and trace species in the timeframe of the campaign. At the same time, the case-oriented data collected during our campaign would refine or promote new algorithms for satellite data processes and interpretation, as well as provide guidance for new designs of the next generation satellite instruments. The presence on the basin of countries of consolidated scientific tradition, make it possible to link the aircraft campaign to an already established network of ground based station, providing measurement of aerosol, trace species and radiative fluxes.

The field deployment of a high altitude research aircraft such as the NASA Global Hawk has to be considered an essential part of the program. The platform has unique characteristics that have already demonstrated new observational capabilities in its recent deployment. It can combine the short time deployment of aircraft on sites and events of interest, with the global coverage the satellite instruments can offer. Its flight altitude – close to the boundary conditions of many radiative processes - allows better spatial resolution than a satellite. Moreover, its endurance provides a sufficiently broad view at timescales relevant for the processes under study. Air pollution processes, biomass burning plume evolution, Saharan dust outbreaks, all these events evolve locally on a timescale of hours, and are subjected to transport to long range distances on a timescale of few days. An exhaustive remote sensing investigation of such phenomenon would imply the presence of geostationary platforms which are presently not available for this purpose. The Global Hawk allows continuous observations over a nearly synoptic area of study for several hours. The use of a tropospheric aircraft equipped for in-situ measurements and capable of performing profile measurements with multiple shorter missions within the endurance time of the Global Hawk, could complement the activity of the platform.

The following are recognized as key measurements: Aerosol, Water Vapour and Ozone profiles; column density of NO_2 and HCHO, as a proxy for VOC; UV-VIS and IR fluxes; surface spectral characteristics.

Column measurements of SO_2, CO, NO_x, CH_4, CO_2, are considered useful but not as essential.

Active remote sensing techniques should ideally be deployed in order to allow measurements during night time. While aerosol, and possibly water vapour as well as ozone profiles are measured by active sensors (LIDAR) and water vapour can be measured by a suitable GPS receiver, trace gas concentrations measured by passive sensors can probably be retrieved only during daylight hours. In situ sensors should be deployed on selected ground stations.

Science investigation concepts:

Observation Plans

The Global Hawk has an endurance long enough to follow the transport of Dust outbreaks, Biomass burning plumes, or outflow from source regions as Megacities, from their origin through its early lifetime. A second mission may necessary to monitor a particular event in its mature stage.

Objective of event oriented flight will be to detect and sample airmasses downwind source areas. Once the regions have been individuated, possibly with the nowcasting capabilities of satellite data for Biomass burning or intensive pollution, the detection of the presence of aerosol and tracers in the tropospheric plume will be accomplished from its source and along its transport pathway. A successive flight, programmed with the aid of transport and diffusion models, will monitor the remnants of the plume in their mature stage. The goal will be to monitor the source region and the evolution of the outflow in the immediate and in the days following events of interest as far as possible in time and distance.

For what concerns radiative budget measurements in background conditions, the Global Hawk, flying at an altitude close to the boundary condition for radiative computations, allow an optimal synergy with simultaneous ground based measurements. Since it allows to study the optical properties of the surface and the atmosphere on a diurnal cycle, its flight should dwell over the same area, measuring the surface albedo and fluxes at different SZA angles.

Such flights should be ideally be performed when different amount of ozone and burdens/types of aerosol are present, over instrumented areas at the surface, able to provide simultaneous measurement of LW and SW fluxes, as well as radiative properties (phase function, complex refractive index, asymmetry factor, single scattering albedo) of columnar aerosols.

A schematic of a possible flight template, is depicted in fig. xx left panel. This is a 26 hrs flight starting from the Italian airbase of Decimomannu (Sardinia), aimed at characterizing the background situation of the Eastern part of the basin, with two overpassing over the Adriatic Sea aimed at detecting photochemistry processes along the Po valley outflow, and two zonal transect off the southern coast of the basin, where the aged outflow can be detected. Red lines superimposed on the map depicts the aircraft space control regions. The flight is designed to have a turning point above the Italian island of Lampedusa, where a ground measuring station is located. On the right panel, the altitude curtain.

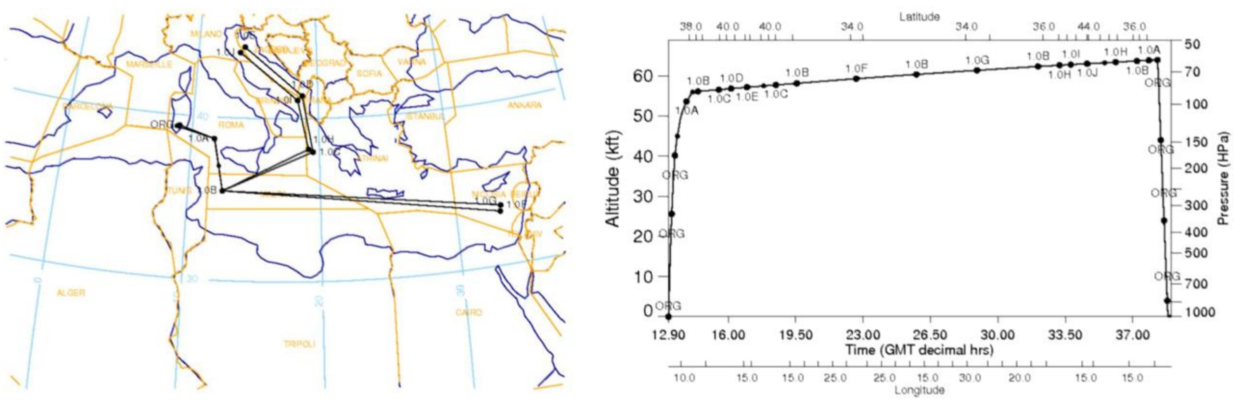


Figure 4: Possible Global Hawk pathway (left) for a 26 hrs flight. The red lines delimit the airspace traffic control zones. Altitude-time diagram is shown on the left.

IV. Implementation

A strong collaboration with partner institution overseas should be sought for. Possible Institutions interested in the project, and points of contacts may be, respectively, for
Italy:
CNR-Consiglio Nazionale delle Ricerche, F. Cairo: f.cairo@isac.cnr.it;
ENEA-Agenzia Nazionale per le Nuove tecnologie, l'Energia e l'Ambiente, Giorgio DiSarra, alcide.disarra@enea.it;
CMCC- Centro Euromediterraneo per lo studio dei Cambiamenti Climatici, to be defined.
France, Centre Nationale de la Recherche Scientifique, CNRS, Celine Mari c.mari@aero.obs-mip.fr;
Francois Dulac francois.dulac@cea.fr

Spain, perhaps CEAM, Fundacion Centro de Estudios Ambientales del Mediterraneo, Millan M. Millan, millan@ceam.es,
Greece, Maria Kanakidou http://ecpl.chemistry.uoc.gr/kanakidou/Kanakidou/MK_html.htm,
Germany, Max Plank Institute for Chemistry, Mark Lawrence (http://www.mpch-mainz.mpg.de/mpg/english/pri0201.htm)
Collaborations with scientists from the southern and eastern shores of the Mediterranean (Algeria, Lybia, Tunisia, Egypt, Lebanon, Israel, Turkey), should also be sought.

Appendix. Mediterranean Climatology

The Mediterranean "sea in the middle of lands" basin has distinctive climatic characteristics due to its position between 30 and 45 °N, i.e. between subtropical high-pressure systems and rain-bearing westerly wind belt, high mountain ridges surrounding the basin, and intense anthropic impact due to long standing societal developments.

The Mediterranean region defines generally the lands that almost completely enclose the Mediterranean Sea and that shares the "Mediterranean climate", characterized by an extreme seasonality of the rain rate, with hot and dry summers and mild autumns and winters during which most of the rainfall occur (Mehta et al., 2008).

The sea covers an area of about 2.5 millions km^2, extended longitudinally for 3800 km (from Gibraltar to Levant). It is connected with the Atlantic ocean by the Strait of Gibraltar to the west, to the Marmara and Black Sea by the Dardanelles and the Bosphorus Strait to the East, and to the Red Sea by the man-made Suez Canal to the South-East.

Figure 5. Geographical map of the Mediterranean basin.

A shallow submarine ridge between Sicily and Tunisia splits the Mediterranean in two: the Western Mediterranean, under the mitigating influence of the Ocean, with generally higher rainfall and milder temperatures and the Eastern Mediterranean, with somehow more continental and extreme characteristics, both in terms of temperatures and summer dryness.

Together with this West-East gradient, a North-South gradient exists, being the southern shores drier and hotter than the northern ones – sometimes with temperature gradients as high as 25 °C from the Alps to the southern shores - with the extreme south east permanently below the subtropical high pressure system, arid and hot as the Sahara desert close southward.

The mountains that surround the Mediterranean Sea, the Pyrenees, the Alps – the highest ridge, with heights as high as 4800m - the Dinaric Alps, the Balkan and Rhodope to the north of the basin and the Atlas Mountain to the south, have a strong influence on the air circulation. In the mountain regions, the climate can be extremely rainy, with rain rate peaks of 3000mm/year. This topography, and the basin itself as a moisture and heat reservoir, are responsible for the complex mesoscale features of the region that make the Mediterranean one of the most active regions of cyclogenesis in the world.

Because of its position, it is a transition area under the influence of both mid-latitudes and tropical variability.

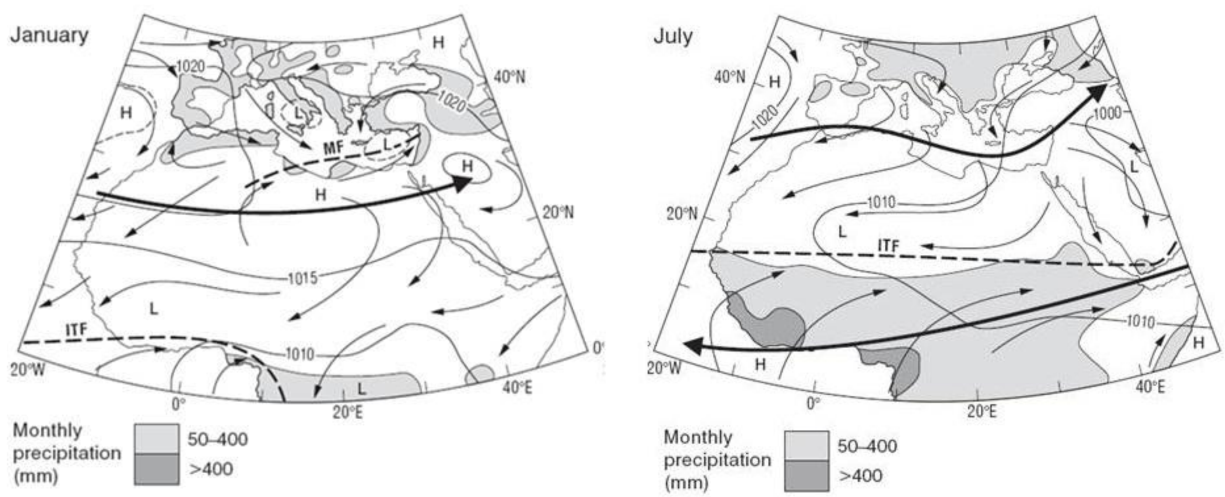


Figure 6. The Mediterranean in relation to the large scale atmospheric circulation patterns, in January (left) and July (right). Grey regions evidence precipitation patterns. (adapted from Barry and Chorley, 1992).

The basin in Winter is characterised by a low mean pressure, with higher pressure to the east associated with the Siberian High, and it is exposed to the westerly wind belt, advecting cyclonic disturbances. In conditions of low pressure difference between the Azores high and the Islandic low (a case of the so called low North Atlantic Oscillation index), blocking systems may form over central Europe and the Basin is exposed to the full blow of the westerlies, bringing in Atlantic depressions.

In summer, ITCZ and Azores high shift to higher latitudes The summertime Mediterranean basin is then directly under the descending branch of the Hadley circulation. Subsidence over the Mediterranean causes drought, affecting ecosystems, agriculture, and drinking water supplies. A particularly strong Indian Monsoon, with significative heating and uplifting of air over India causes increasing subsidence in the Eastern part of the basin promoting even drier conditions.

Azores Isobares spreading over Central Europe weakens then westerly flow: air is then transported from the continent over the basin by northernly winds near the surface, promoting a buidup of photooxidants in a cloud-free region of relatively intense solar radiation.

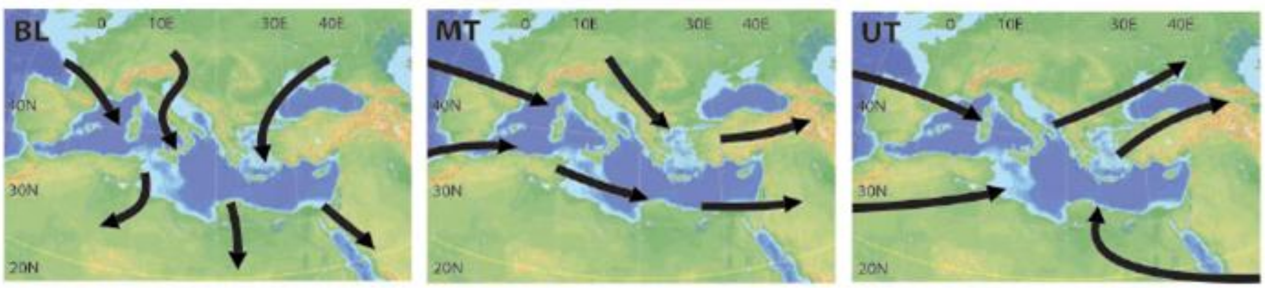


Figure 7: Airflows during the MINOS campaign in August 2001. The arrows indicate atmospheric transport during 2-4 days. (Adapted from Lelieveld et al., 2002)

In the middle and upper troposphere still westerlies dominate, reaching a maximum in the subtropical jet stream located at about 40 °N in summer, with the notable exception, in the south eastern part of the basin, of the so-called tropical easterly jet at 100-200 hPa, originated by the indian monsoon activity promoting an anticyclone over the Tibetan heat low. Over the Mediterranean, this creates at times east-west gradients in the upper atmospheric air composition, respectively influenced by pollution sources in North America and South Asia.

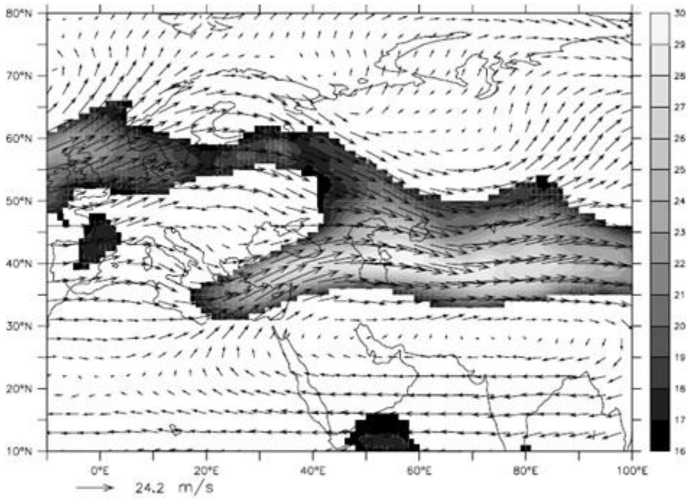


Figure 8: Mean ECMWF wind field in August 2001 at 250 hPa. Regions with flow velocities in excess of 16 m s-1 are highlighted (From Traub et al., 2003).

This air mixes and is then transported back to the East under the influence of the Subtropical Jet stream and the westerlies.

Over the Mediterranean in summer the tropopause strongly slopes downward, from 16-17 km to the south to 12-11 to the north of the basin. The upper troposphere over the eastern Mediterranean Sea and the neighboring countries up to the Black Sea is influenced by both westerly and southerly winds at the western flank of the upper level anticyclones over the Arabian and Asian heat lows. The convergence of these airflows promotes horizontal and vertical wind shear and consequently turbulent mixing of tropospheric and stratospheric air near the tropopause, contributing to tropopause folding events and stratosphere-troposphere exchange over the eastern Mediterranean (see fig. 8).

Climatology of temperature and winds

Temperature and wind monthly averages (color) have been derived from the NCEP/NCAR reanalysis data from 1979-2009, Averages for Nov, Feb, May and August, are displayed in fig. 9 for relevant pressure levels (850, 500, 150, 70 hPa) . Black contours are indicated for every 1 K. The thick solid white lines are the stream lines derived from the zonal and meridional wind averages. The stream line values have been normalized by dividing by the Earth's radius.

At 850 hPa during winter the winds from the Atlantic westerly belt, slightly displaced southward, enter the north-western part of the basin, sweeping the Mediterranean with a constant eastern direction, diverging along the meridians basin. The temperature has a slight east-west positive gradient. In spring summer, the build-up of the Azores High and its merging with the Lybian high diffuses over the basin and southern Europe. A distinctive northerly flow establishes from central Europe to the central and eastern part of the basin. In Autumn the winds became prevalently northernly again.

It has to be noted, however, that the Basin, due to its complex orography, is a region extremely rich of sub-synoptic features. In fact, the typical winds of this area (Mistral, Libeccio, Bora, Ephesians, etc.) are associated with sub-synoptic scale dynamical processes.
Temperature tends to have a positive north-south gradient throughtout the year, with an additional positive east-west gradient in the summer months.

At 500 hPa the flux is mainly northernly throughout the year, steadier in the winter months, more wiggled in the summer. Temperature have a positive north-south gradient throughtout the year, with an additional negative east-west gradient in the summer months.

At 150 hPa there's the notable occurrence of an anticyclonic flow over South Asia during Summer, whose easterly branch extend over Saharan Africa, and southerly branch investiong the eastern part of the basin, where it mixes with the dominating westerly flow and returns to Central Asia .
At 70 hPa the flow is steadily westerly in the winter months, while it becames southerly and, at higher altitudes, easterly during summer. At these level, and more marketly in the higher one, temperatures tend to have a north-south positive gradient to which superimpose a west-east negative gradient in the winter months.

Precipitation
The annual rainfall in the Mediterranean has its maxima localized on the western side of the main orographic features in the region:in the West Iberian peninsula, in the Alps, in the Turkey plateau, and in the Caucasian mountains. The rainrate shows a distinctive seasonality, with wet autumns and winters and dry summers,and an east-west gradient, the west under the mitigating influence of the ocean, with generally higher rainfall and milder summer draughts, and the easterm dryer. Rain is mainly driven by lee depressions (downslope of the Alps, atlas mountains) although the coming of atlantic depressions,and thermal lows (on the hiberian peninsula) may also came into play. Mediterranean is one of the most active regions of ciclogenesis in the world, with emphasis on the gulf of geneve, which is very active in the winter, the aegean sea winter and spring, the black sea throughout the year, north africa in spring. The 80% of rainfall is received between October and March.

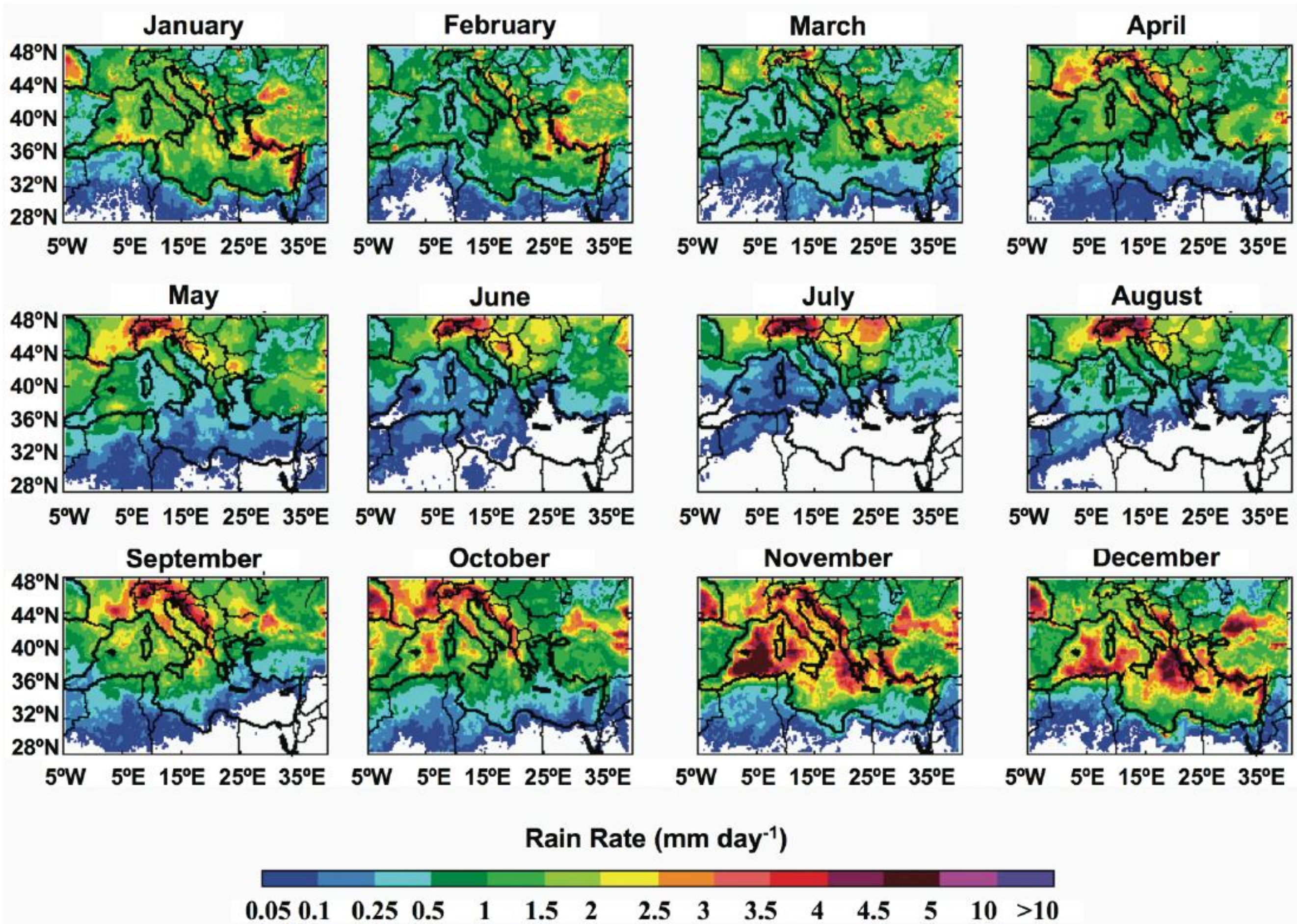
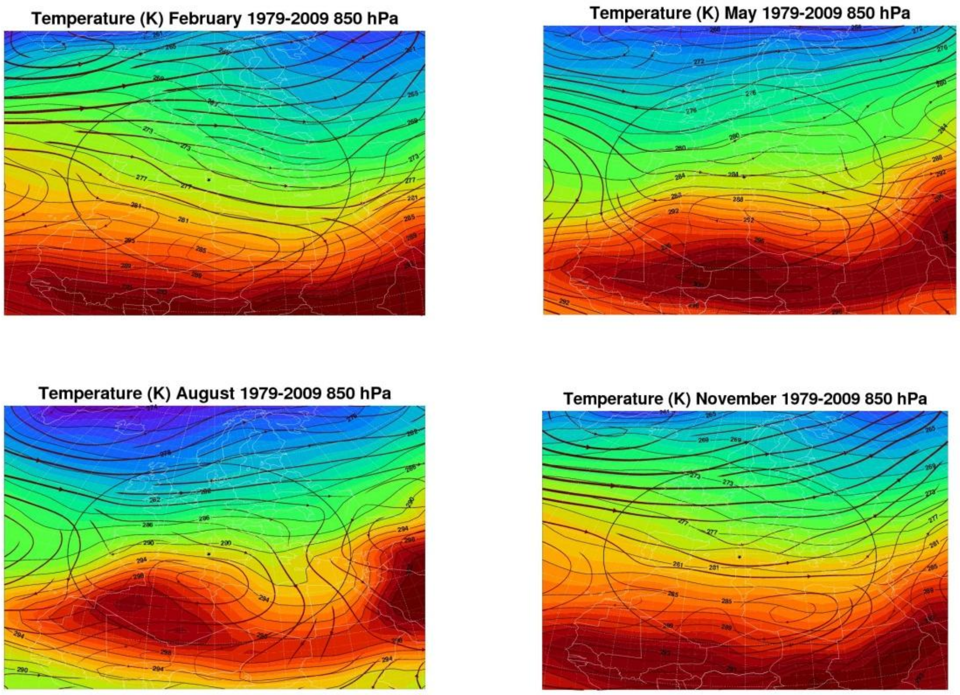
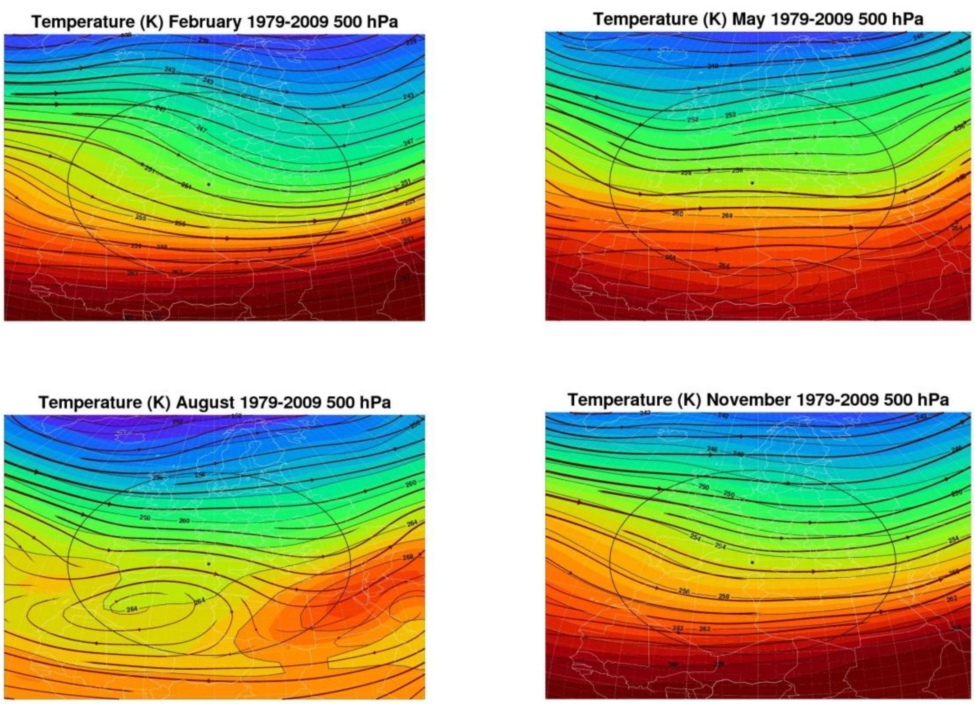


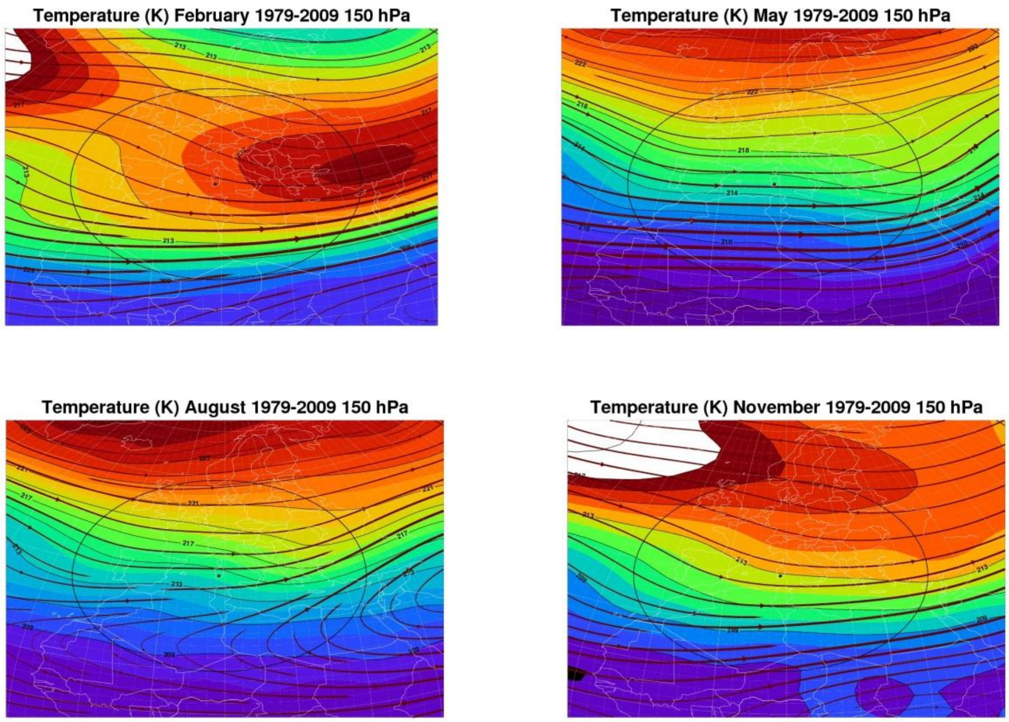
Figure 10: Spatial distribution of mean monthly rainrates for annual cycle over the Mediterranean Basin from January 1998 to July 2007 (from Metha et al., 2008)


Temperature (K) February 1979-2009 850 hPa
Temperature (K) May 1979-2009 850 hPa
Temperature (K) August 1979-2009 850 hPa
Temperature (K) November 1979-2009 850 hPa

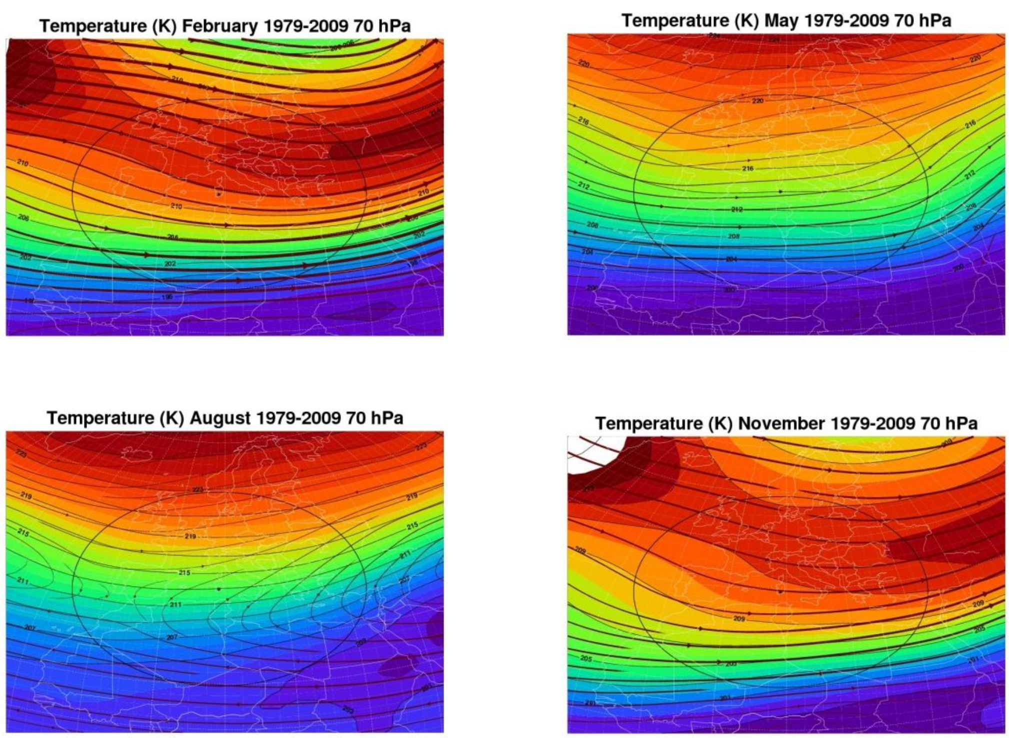
a)


Temperature (K) February 1979-2009 500 hPa
Temperature (K) May 1979-2009 500 hPa
Temperature (K) August 1979-2009 500 hPa
Temperature (K) November 1979-2009 500 hPa

b)


Temperature (K) February 1979-2009 150 hPa
Temperature (K) May 1979-2009 150 hPa
Temperature (K) August 1979-2009 150 hPa
Temperature (K) November 1979-2009 150 hPa

c)


Temperature (K) February 1979-2009 70 hPa
Temperature (K) May 1979-2009 70 hPa
Temperature (K) August 1979-2009 70 hPa
Temperature (K) November 1979-2009 70 hPa

d

Figure 10 (previous two pages): Temperature time averages (color), for February, May, August and November, as derived from the NCEP/NCAR reanalysis data from 1979/2009, for 850 (a), 500 (b), 150 (c), 70 (d) hPa pressure levels. Black contour lines are indicated for every 1K. The thick solid lines are the stream lines derived from the zonal and meridional wind averages. The stream line values have been normalized by dividing by the Earth's radius.

An extensive climatology of temperatures, wind, Aerosol Optical Depths, Outgoing Longwave Radiation, Ozone, relative humidities, Nitric dioxide, can be found at:

http://acdb-ext.gsfc.nasa.gov/People/Newman/italy/italy.html