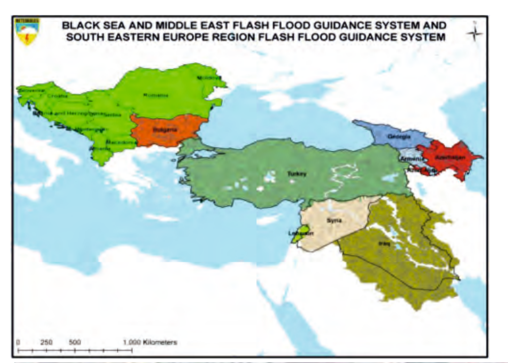
Republic of Turkey
Ministry of Forestry and Water Affairs
Turkish Meteorological Service

BLACK SEA AND MIDDLE EAST FLASH FLOOD GUIDANCE SYSTEM USER GUIDE

RESEARCH DEPARTMENT
HYDROMETEOROLOGY DIVISION

January 2015



National Hydrometeorological Department of Ministry of Ecology and Natural Resources Azerbaijan

National Institute of Meteorology and Hydrology Bulgarian Academy of Science

Hydrometeorological Institute of National Environmental Agency of Georgia

Armenian State Hydrometeorological and Monitoring Service

Black Sea and Middle East
Flash Flood Guidance Project
Project Partners

World Meteorological Organization
(WMO)

Hydrologic Research Center
(HRC)

National Oceanic and Atmospheric
Administration (NOAA)

U.S. Agency for International
Development (USAID)

Prepared by
Ayhan SAYIN

Reviewed by
HRC

Contributors:

Yusuf ULUPINAR
Head of Hydrometeorology Division

A.İhsan AKBAŞ
GIS Expert

Ekrem GÜLSOY
Engineer

Seyfullah ÇELİK
Meteorologist

Serhan KÖSE
System Administrator

Mehmet AKSOY
Meteorological
Engineer

design & press
M.Şevket GÜNEŞ
TSMS printing house

CONTENT

Acknowledgement

Black Sea and Middle East Flash Flood Guidance (BSMEFFG) User Guide was prepared to provide operational in sight of the system. It is a collection of works done during the implementation of BSMEFFG and prior works by Hydrologic Research Center (HRC). The following individuals and organizations deserve deep appreciation for supporting and contributing to the project. Mr. İsmail GÜNEŞ, Director General of Turkish Meteorological Service and PR with WMO; Dr. Mustafa YILDIRIM, Deputy Director General of Turkish Meteorological Service; Mr. Hayreddin BACANLI, Head of Research Department; Mr.Ramaz CHITANAVA, Director General of Hyrometeorological Service of Georgia and PR with WMO; Mr. Levon VARDANYAN, Director General of Hyrometeorological Service of Armenia and PR with WMO Mr.Sahib KHALILOV, Deputy Director General of Hyrometeorological Service of Azerbaijan; Dr.Georgi KORTCHEV, Director General of Hyrometeorological Service of Bulgaria and PR with WMO; Dr. SezinTOKAR of U.S Agency for International Development; Dr. Konstantine GEORGAKAKOS of Hydrologic Research Center; Mr.Robert JUBACH of Hydrologic Research Center; World Meteorological Organization (WMO); National Oceanic and Atmospheric Agency (NOAA); and those colleagues whose names are not cited but assisted and participated in the project including Hydrologic Research Center staff.

Foreword

Flash floods are among the world's deadliest natural disasters with more than 5,000 lives lost annually and result in significant social, economic and environmental impacts. Accounting for approximately 85% of the flooding cases, flash floods also have the highest mortality rate (defined as the number of deaths per number of people affected) among different classes of flooding (e.g.,riverine, coastal). Flash floods have a different character than river floods, notably short time scales and occurring in small spatial scales, which make forecasting of flash floods quite a different challenge than traditional flood forecasting approaches. In forecasting of flash floods, we are concerned foremost with the forecast of occurrence, and here in focused on two causative events, 1) intense rainfall and 2) rainfall on saturated soils. Flash floods occur throughout the world, and the time thresholds vary across regions from minutes to several hours depending on land surface, geomorphological, and hydroclimatological characteristics of the region. However, for the majority of these areas there exists no formal process for flash flood warnings and a lack of capacity to develop effective warnings for these quick response events.

To address the issues associated with flash floods, especially to address the lack of capacity to develop effective flash flood warnings, the Flash Flood Guidance System (FFGS) was designed and developed for use by meteorological and hydrologic forecasters throughout the world. In support of the FFGS programme, a Memorandum of Understanding was signed among the World Meteorological Organization, the U.S. Agency for International Development/Office of U.S. Foreign Disaster Assistance, the U.S. National Oceanic and Atmospheric Administration/National Weather Service, and the Hydrologic Research Center (a U.S. non-profit corporation) to work together under a cooperative initiative to implement the FFGS worldwide. The FFGS programme is a public benefit effort on behalf of the partners. The Black Sea Middle East FFG system was designed and developed as part of this initiative.

A system such as the FFGS is an important tool necessary to provide operational forecasters and disaster management agencies with real-time informational guidance products pertaining to the threat of small-scale flash flooding. The FFGS is a robust system designed to provide the necessary products to support the development of warnings for flash floods from rainfall events through the use of remote-sensed precipitation (e.g., radar and satellite-based rainfall estimates) and hydrologic models.To assess the threat of a local flash flood, the FFGS is designed to allow product adjustments based on the forecaster's experience with local conditions, incorporation of other information (e.g., Numerical Weather Prediction output) and any last minute local observations (e.g., non-traditional rain gauge data) or local observer reports.

The primary purpose of the FFG systems is to provide real-time informational guidance products for flash floods to trained forecasters. If the system is used frequently, implementation experience has shown that the knowledge and experience of trained forecasters increases and they are able to identify their individual strengths and weaknesses in relation to their abilities in flash flood forecasting and forecast uncertainty. They are also able to identify areas where their local knowledge and the FFGS provide applicable and realistic results, as well as gaining a sense of the meteorological and hydrologic conditions likely to lead to flash flooding for their country.

The support of the partners during the implementation of the BSMEFFG system is most appreciated. A special thank you goes to the U.S. Agency for International Development/Office of U.S. Foreign Disaster Assistance for their financial support so critical to the programme. A special thank you also goes to the Turkish Meteorological Service, who as the Regional Center, played an important role in the system development and its operations.

Robert W. JUBACH
General Manager
Secretary - Board of Directors
Hydrologic Research Center

1. Introduction

Studies and observations show that the frequency and intensity of severe storms have increased across the world. Surface observations in Turkey depict that the number of thunderstorms, which are the main causes of flash floods in Turkey , have almost increased fifty percent in the last decades. World Meteorological Organization (WMO) findings show that eighty five percent of floods are flash floods, which cause a considerable amount of property damage and loss of life. A similar situation exists in Turkey where the occurrence of flash floods are widespread particularly along the coastal regions. AFAD (Prime Ministry Disaster Emergency Management Presidency) and DSI (State Water Affairs) government statistics show that annual property damages due to floods are billions of dollars and dozens of people are killed each year.

Because of the fact that flash floods cause a large amount of property damages and loss of life and there are little efforts, not enough trained people and not enough tools to help forecasters to prepare warnings, the WMO, the U.S. Agency for International Development Office of U.S. Foreign Disaster Assistance (USAID/OFDA), the Hydrologic Research Centre (HRC), and the U.S. National Oceanic and Atmospheric Administration (NOAA) partnered on an initiative to implement the Global Flash Flood Guidance System (GFFGS) to cope with these problems. USAID/OFDA is the financial supporter of the GFFGS Program, HRC is the development and implementation organization, the WMO is the Program coordinator and NOAA provides access to required global data. WMO, USAID/OFDA, HRC and NOAA signed a memorandum of understanding in February 2009 to implement the Flash Flood Guidance System with Global Coverage (the MOU was later extended to run through December 2017). The Black Sea and Middle East Flash Flood Guidance (BSMEFFG) Project is being implemented under this MOU.

Four FFG regional centres are already fully operational, including the Black Sea and Middle East Flash Flood Guidance System (BSMEFFG), with the implementation initiated in 2010. The Turkish Meteorological Service (TMS) is the regional centre for the BSMEFFG system and Bulgaria, Georgia, Armenia and Azerbaijan are member states that have sent a Letter of Commitment (LoC) to WMO. The Flash Flood Guidance System is a tool for operational forecasters to be utilized along with conventional meteorological tools like synoptic and mesoscale analysis and nowcasting tools. After the BSMEFFG system installation at the TMS offices in Ankara, Turkey, operational forecasters from the fifteen TMS regional offices and from the analysis and forecasting division at the headquarters offices were given FFG training that consisted of the explanation of the FFG products, synoptic and mesoscale analysis and nowcasting, case studies and preparation of flash flood watches and warnings. In order to help forecasters in daily operations, a Flash Flood Guidance System user manual was prepared in Turkish. After consultation with HRC, it was decided that an English version of the manual might be useful for the forecasters in the other participating countries; thus, Mr.Ayhan Sayin of TMS has taken responsibility to prepare this English version of the FFG user manual. HRC reviewed the draft of the manual and the final version was designed and printed at the TMS printing house. It is our desire that this guide would be beneficial to all forecasters and contribute toward an in depth utilization of FFG system products in real time operations.

2. Background

At the XV congress of the WMO in 2007, it was decided to establish a Flash Flood Guidance System program worldwide. Flash Flood Guidance System, which was developed and is being implemented by HRC and financed by USAID/OFDA in collaboration with NOAA/ WMO acts as the coordination agency.

As Figure-1 shows the flash flood global coverage concept, it is planned to eventually establish a series of regional centres, which will provide flash flood related products and support services to their respective regional participating country National Meteorological and Hydrologic Services (NMHSs). Using those products, those NMHSs can provide flash flood watches and warnings to their own national agencies like emergency management authorities, municipalities, and water resources agencies. In this design concept, regional centres play a crucial role not only in providing services to member states but also close collaboration in various areas during the system implementation and operations. Therefore, close cooperation among the participating countries as well as among the respective national services of each member country are essential to get most benefits from the system.

The initial Black Sea and Middle East Flash Flood Guidance System planning meeting was held in İstanbul, Turkey on 29-31 March 2010. In addition to WMO, HRC and NOAA, delegates from Turkey, Azerbaijan, Georgia, Armenia, Iraq and Lebanon participated. Subsequently, Turkey, Georgia, Azerbaijan and Armenia have submitted a Letter of Commitment (LoC) to WMO to participate in the BSMEFFG Project. Later, Bulgaria also joined the BSMEFFG Project. Even though Lebanon, Iraq and Syria have not submitted a LoC to WMO, FFG products are generated for them encouraging these countries to eventually make a commitment to take advantage of available FFG products.

While the BSMEFFG Project was in progress, the planning meeting for the establishment of a Flash Flood Guidance System for South East Europe (SEE) was held in Ankara, Turkey on 22-24 January 2013. Croatia, Serbia, Slovenia, Romania, Bosnia-Herzegovina, Macedonia, Moldova, Albania and Montenegro as well as Turkey, WMO,HRC and OFDA delegates participated. After very useful technical and scientific discussions, it was agreed to establish South East Europe Flash Flood Guidance System (SEEFFG) making Turkey the regional center. Figure-2 shows geographical coverage area of the BSMEFFG and SEEFFG regions.

Moreover, Jordan and Israel are interested in participating in BSMEFFG project.

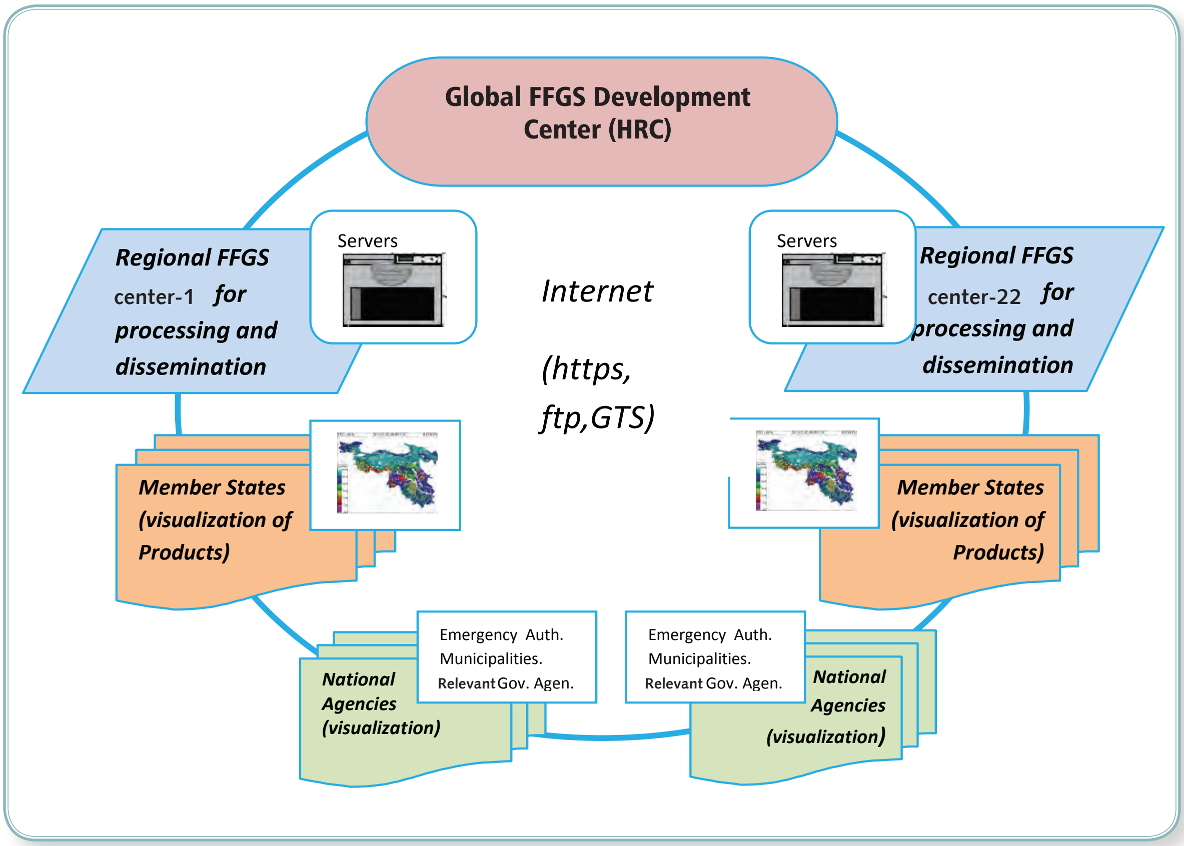


Figure-1 Global Flash Flood Guidance program concept

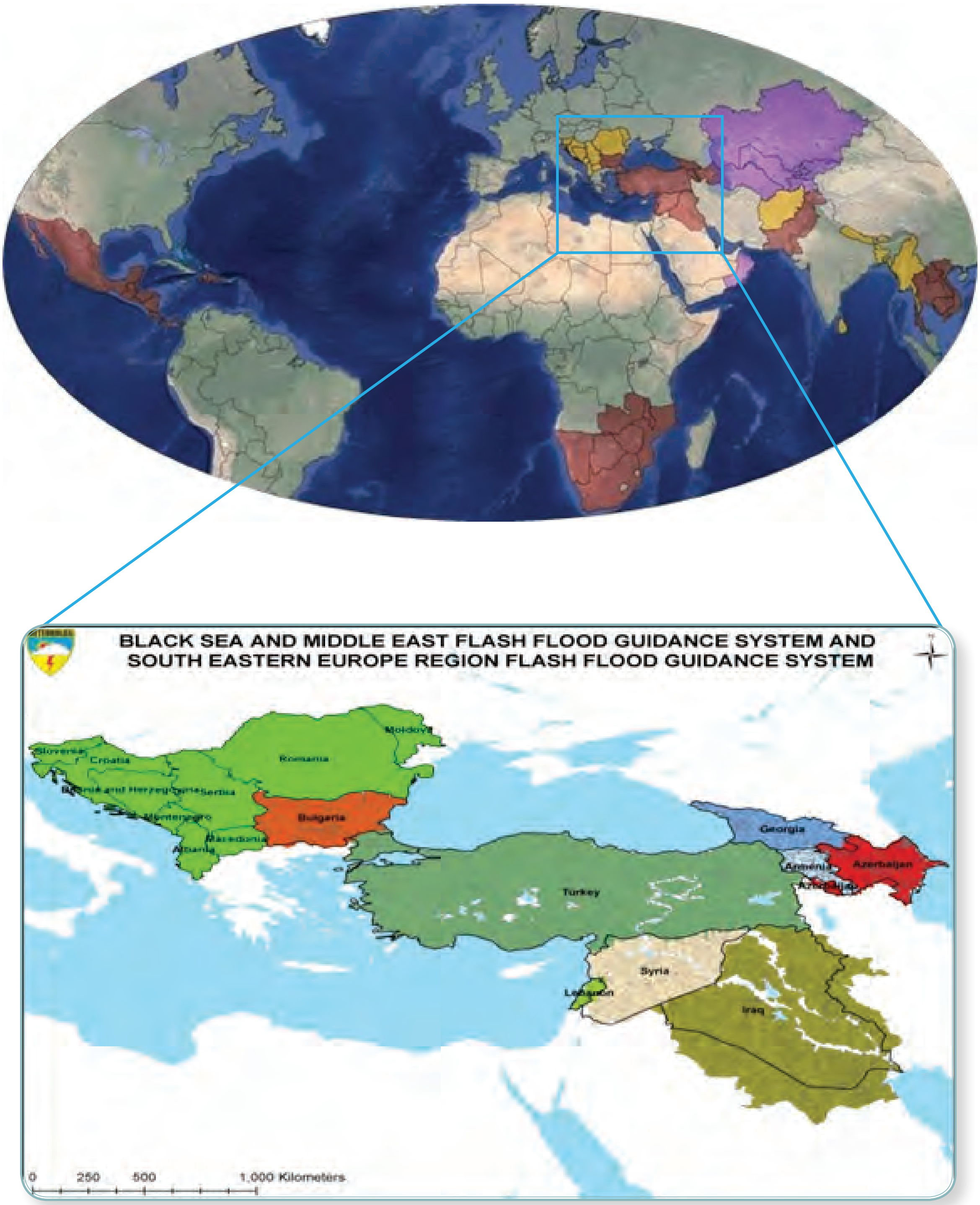


Figure-2 Global FFG coverage (top, shaded countries), and BSMEFFG and SEEFFG (SEEFFG region is shaded in light green)

3. Flash Flood Guidance Model

A major distinction of a flash flood from a river flood is the short basin response time to rainfall that allows for very short lead time for detection, forecast and warning of a flash flood. In contrast, floods in larger rivers have a much longer lead time – up to several days or more. Duration of a flash flood is usually less than 6 hours from the time of heavy or excessive rainfall. Notably, short lead times for forecast, warning and disaster management response make operational flash flood prediction challenging. Flash flood prediction is a hydrometeorological problem (rather than a purely hydrological prediction problem as with generally speaking with river floods). Furthermore, their potential occurrence at any time during a day or night also necessitates 24x7 operations for flash flood forecasting and warning.

The World Meteorological Organization (WMO) defines flash flood as "a flood of short duration with a relatively high peak discharge"; while the American Meteorological Society defines it as " flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area." A more complete definition is given by U.S. National Weather Service as "a rapid and extreme flow of high water into geomorphic low-lying areas - washes, rivers, dry lakes and basins, or a rapid water level rise in a stream or creek above a predetermined flood level. Flash floods occur in less than six hours from the time of the causative event. A flash flood is a local hydrometeorological phenomenon that requires both hydrologic and meteorological expertise for real-time forecasting and warning. It is necessary to have local, up-to-the-hour information for effective warnings including a 24 hour seven days a week operation to maintain constant vigilance. It may be caused by heavy rain associated with a storm, hurricane, or tropical storm or melt water from ice or snow flowing over ice sheets or snowfields. It is important to note that heavy rain may not always be necessary to cause a flash flood, especially during times when soils are saturated and stream levels are high.

Important technical elements of the Flash Flood Guidance System are the development and use of a bias-corrected radar and/or satellite precipitation estimate field and the use of land-surface hydrologic modeling. The system then provides information on rainfall and hydrologic response, the two important factors in determining the potential for a flash flood. The system is based on the concept of **Flash Flood Guidance**[1] and **Flash Flood Threat**[2]. Both indices provide the user with the information needed to evaluate the potential for a flash flood, including assessing the uncertainty associated with the data.

The **flash flood guidance** approach to developing flash flood warnings rests on the real-time comparison of observed or forecast rainfall volume of a given duration and over a given catchment to a characteristic volume of rainfall for that duration and catchment that generates bankfull flow conditions at the catchment outlet. If the observed or forecast rainfall volume is greater than the characteristic rainfall volume then flooding in the catchment is likely. The characteristic rainfall volume for a particular catchment and duration, called **flash flood guidance**, depends on the catchment and drainage network characteristics, and the soil water deficit determined by

[1]Flash Flood Guidance is the amount of rainfall of a given duration over a small stream basin needed to create minor flooding (bankfull) conditions at the outlet of the stream basin. For flash flood occurrence, durations up to six hours are evaluated and the stream basin areas are of such a size to allow reasonably accurate precipitation estimates from remotely sensed data and in-situ data. Flash Flood Guidance then is an index that indicates how much rainfall is needed to overcome soil and channel storage capacities and to cause minimal flooding in a basin.

[2]Flash Flood Threat is the amount of rainfall of a given duration in excess of the corresponding Flash Flood Guidance value. The flash flood threat when used with existing or forecast rainfall then is an index that provides an indication of areas where flooding is imminent or occurring and where immediate action is or will be shortly needed.

antecedent rainfall, evapotranspiration and ground water loss.

The scientific components of the flash flood guidance system utilize the available real time data from in-situ gauging stations and from remote sensing platforms, suitably adjusted to reduce bias, together with physically or conceptually based soil water accounting models to produce flash flood guidance estimates of various durations over small flash flood prone catchments.

At first, under soil saturated conditions the rainfall of a given duration that causes the surface runoff peak from the stream basin to produce bankfull flow at the catchment outlet is estimated. Then, the soil water deficit is computed at the current time from available data, and the transformation of the rainfall required to produce bankfull flow at the stream outlet under saturated soil conditions to that needed for the current soil water deficit (i.e., the flash flood guidance) is made. The estimation of soil water deficit requires good quality input data, and; with radar and satellite data, an adaptive state estimator is employed to reduce bias through the use of data from real time reporting rain gauges.

The Flash Flood Guidance System technical components are depicted in Figure-3. The key model components consist of Threshold Runoff Model (drainage network characteristics) that is computed once for each sub-basin. Estimated precipitation from several sources like satellites, radar as available, and gauges as available are input into a snow model (Snow-17) which estimates snow water equivalent (SWE) and MELT that is inputted into soil moisture accounting model (SAC-SMA) to estimate upper level soil moisture (soil water deficit). Then, the Flash Flood Guidance model is used to estimate the amount of rainfall that is required to cause bankfull flow for a given duration (e.g., one, three and six hours) at the outlet of each sub-basin taking into account of current soil moisture conditions. The Flash Flood Threat is the amount of rainfall of a given duration that is greater than the Flash Flood Guidance value for a basin; meaning that it is the difference between the Flash Flood Guidance value for a given duration and over a basin and the corresponding estimated or forecast precipitation for the same duration and basin.

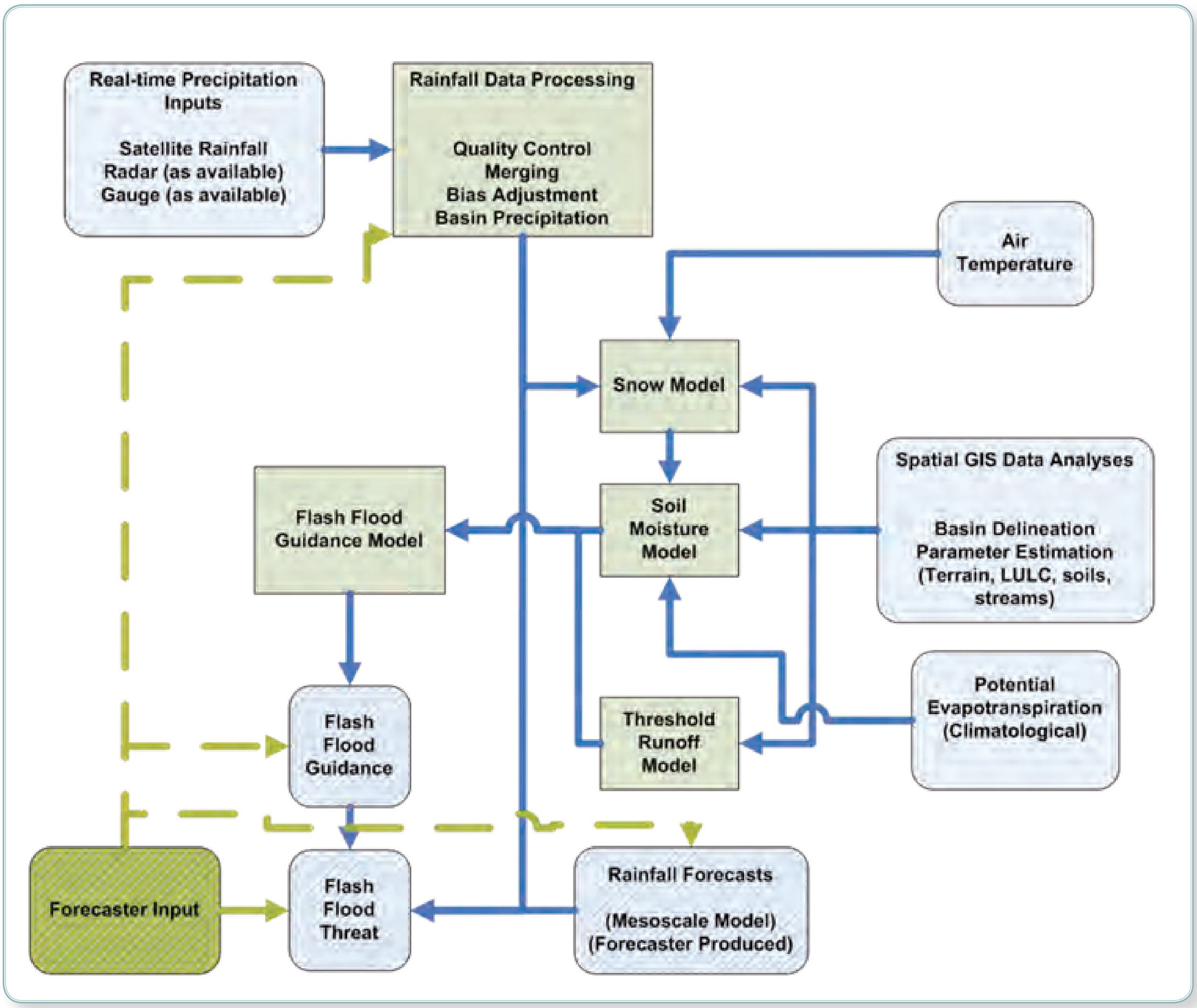


Figure-3 Flash Flood Guidance System technical components

Forecasters should note that Flash Flood Threat itself is not a flash flood warning product but a guide to forecasters using Flash Flood Guidance System products and hydrometeorological analysis to make a decision whether to issue watches or warnings. Therefore, a forecaster's input is essential for the success of the warning process.

4. Establishment of Model Parameters and Calibration

As shown in Figure-4, project implementation is carried out in three phases. First, data for topography, data, soil, vegetation, streams, lakes, reservoirs and hydrometeorological observations are processed using GIS programs to a priori estimate of the model parameters. Second, data from selected collocated meteorological and stream flow stations are used to calibrate the model. In the third stage, the models are run and products are disseminated on the BSMEFFG servers. During system operations, verification of issued watches and warnings is done, normally as a contingency table.

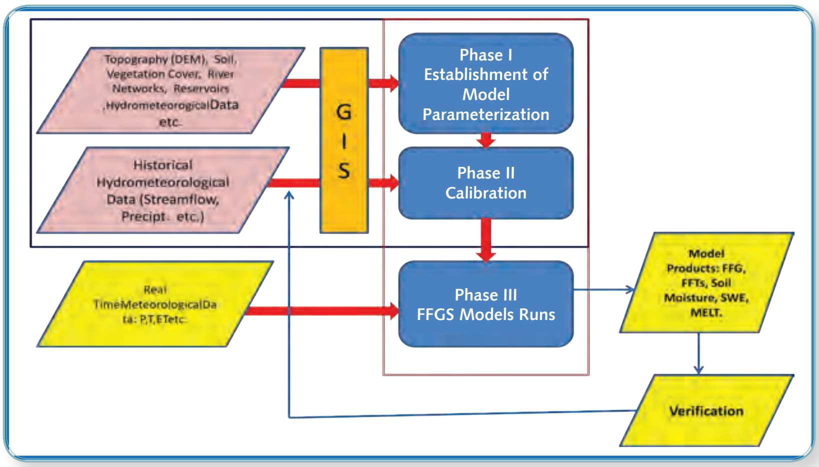


Figure-4 BSMEFFG implementation phases

Flash Flood Guidance System (FFGS) is considered as a semi-distributed model with the hydrologic model configured and the parameters estimated for each sub-basin. Figure-5 shows the sub-basins in the BSMEFFG region where there are more than 6.900 sub-basins with an average drainage area of 100 - 150 square kilometers. The BSMEFFG system ingests precipitation data from the 10 weather radars distributed throughout Turkey. Because the radars provide precipitation estimates at a higher resolution than the satellite estimates (1x1 km v. 4x4 km), basins throughout Turkey (only) were delineated at a higher resolution of approximately 50 square kilometers on average.

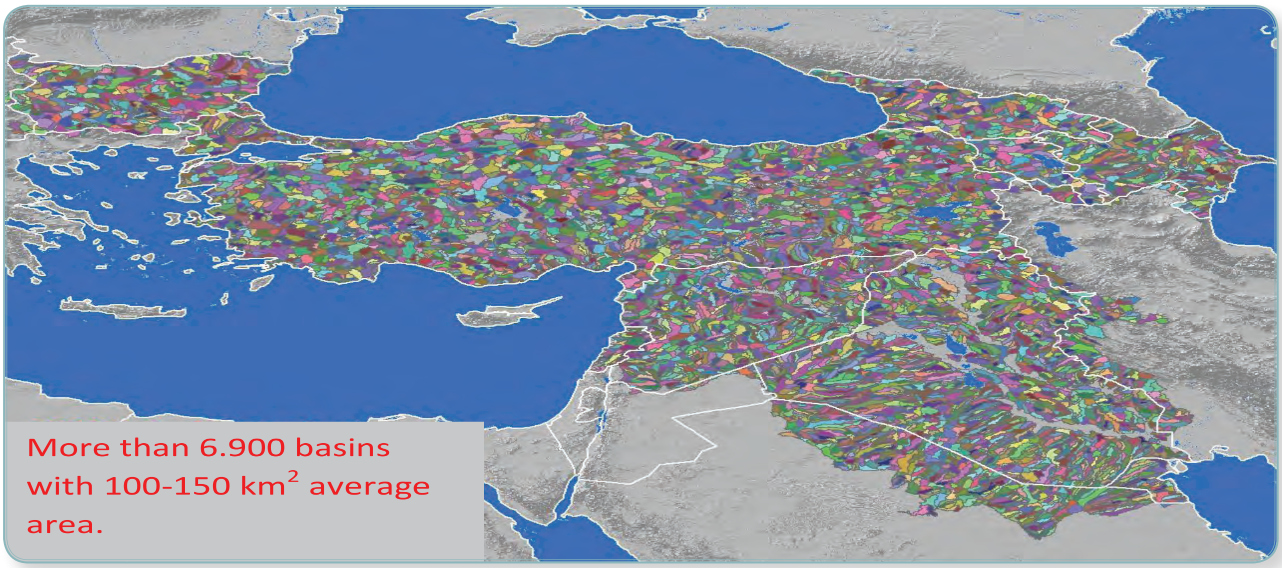


Figure-5 Sub-basin delineations in the BSMEFFG project region

In order to set up model parameters and calibrate the FFGS snow and soil models, available soil depth and types, topographic data and hydrometeorological local data from member states were obtained as much as possible. If required data were not provided by the participating countries, data from international organizations were used. For example, FAO (Food and Agricultural Organization) soil data were used initially (Figure-6) but made modifications in consultations with Turkish, Bulgarian and Georgian colleagues while they were in the long term training at HRC.

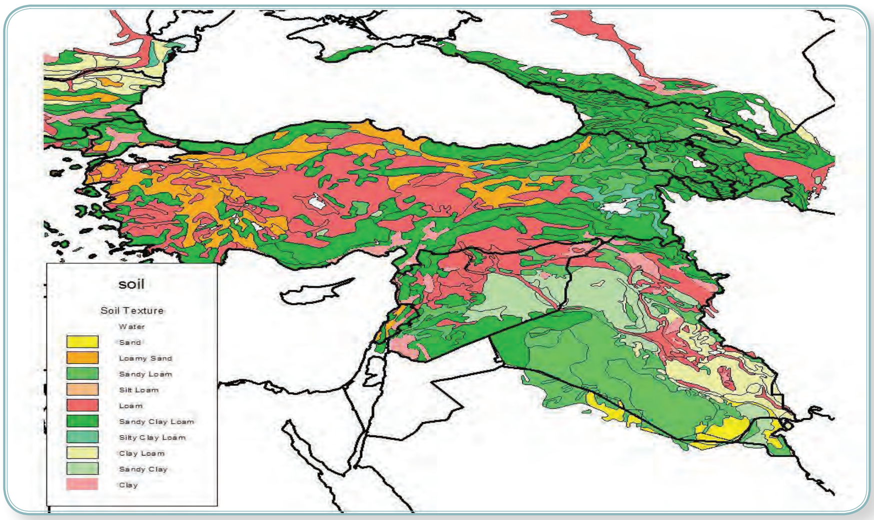


Figure-6 FAO soil data for the project region

Figure-7 depicts vegetation cover for Turkey in 1/100.000 scale with Corine land classification consisting of five base classes and forty four sub-classes such that additional twelve sub-classes are added for Turkey.

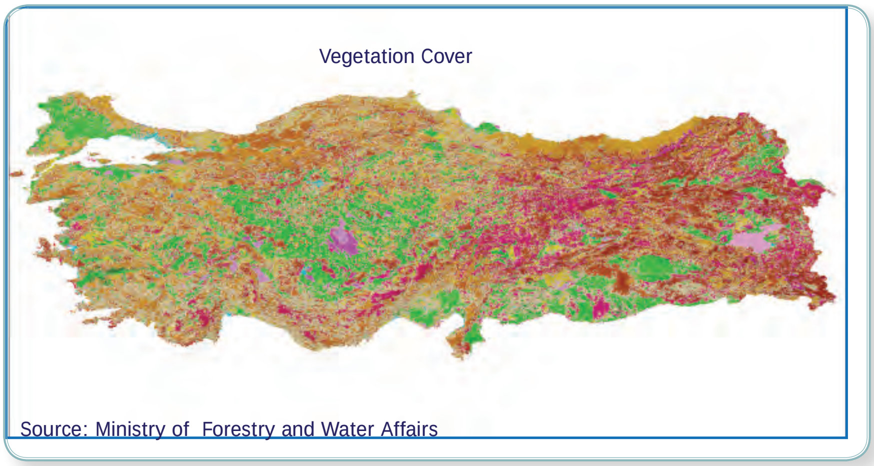


Figure-7 Vegetation cover Turkey

Stream network, reservoirs and stream gauges are an integral part of the hydrometeorological modeling with local data incorporated whenever available. Figure-8 shows stream network, stream gauges, and reservoirs data in 1/250.000 scale obtained from the Directorate of State Water Affairs (DSI).

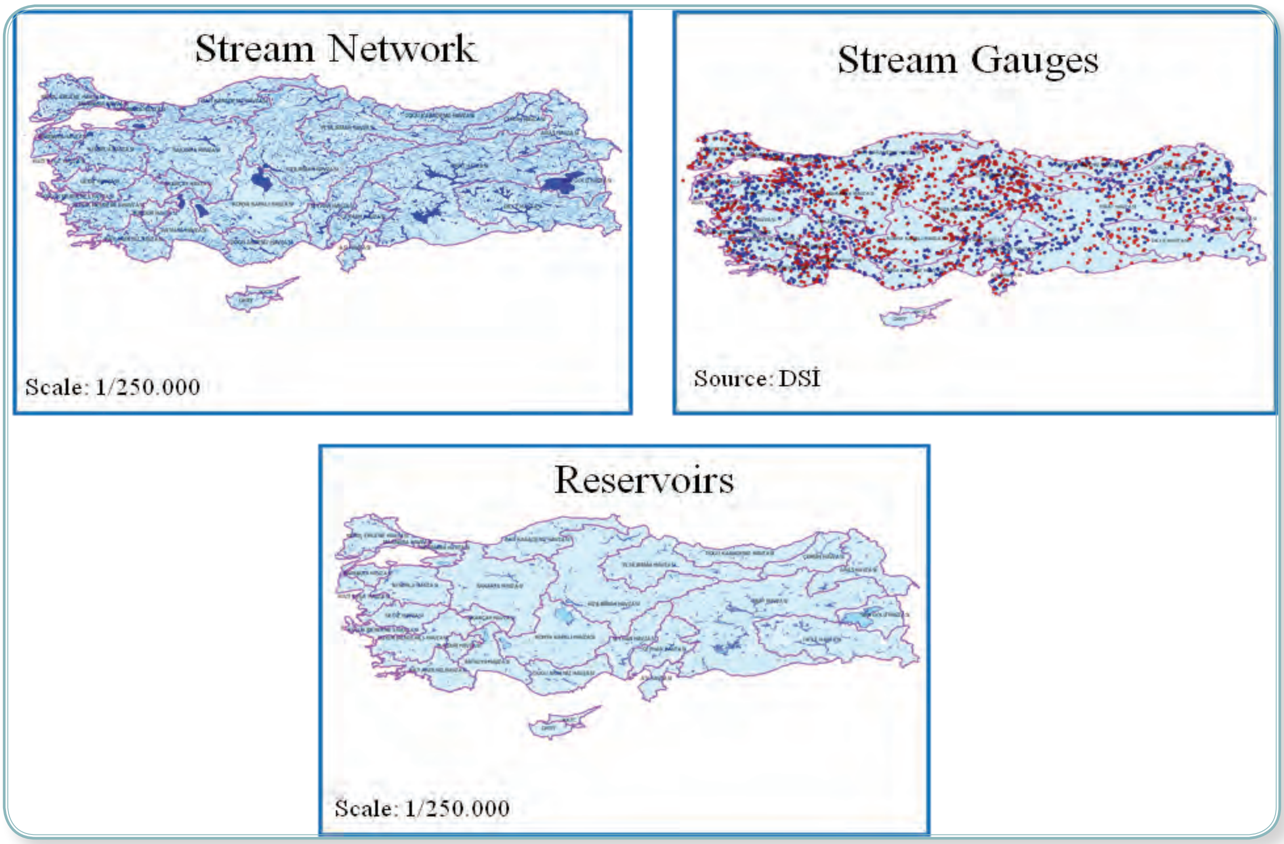


Figure-8 Stream network, stream gauges and reservoirs Turkey

Such historical meteorological measurements as precipitation, temperature, evaporation, radiation, winds, soil moisture and snow depth are used for several purposes. One use of historical gauge precipitation data is for bias estimation of the precipitation estimate from satellites. Figure-9 shows the surface meteorological stations and bias regions (colored) that are used to estimate climatological biases for each region. For the different bias adjustment regions, satellite precipitation bias adjustment values are shown in Figure-10 for February for the period of 2008-2010. It is seen that the satellite overestimates precipitation for most of the regions during February. Similar calculations are carried out for the other months by using satellite rainfall estimates paired with corresponding climatological precipitation data. However, it should be noted that an algorithm that compares near real time satellite and gauge precipitation estimates is implemented in the operational BSMEFFG system for near real time dynamic bias adjustment.

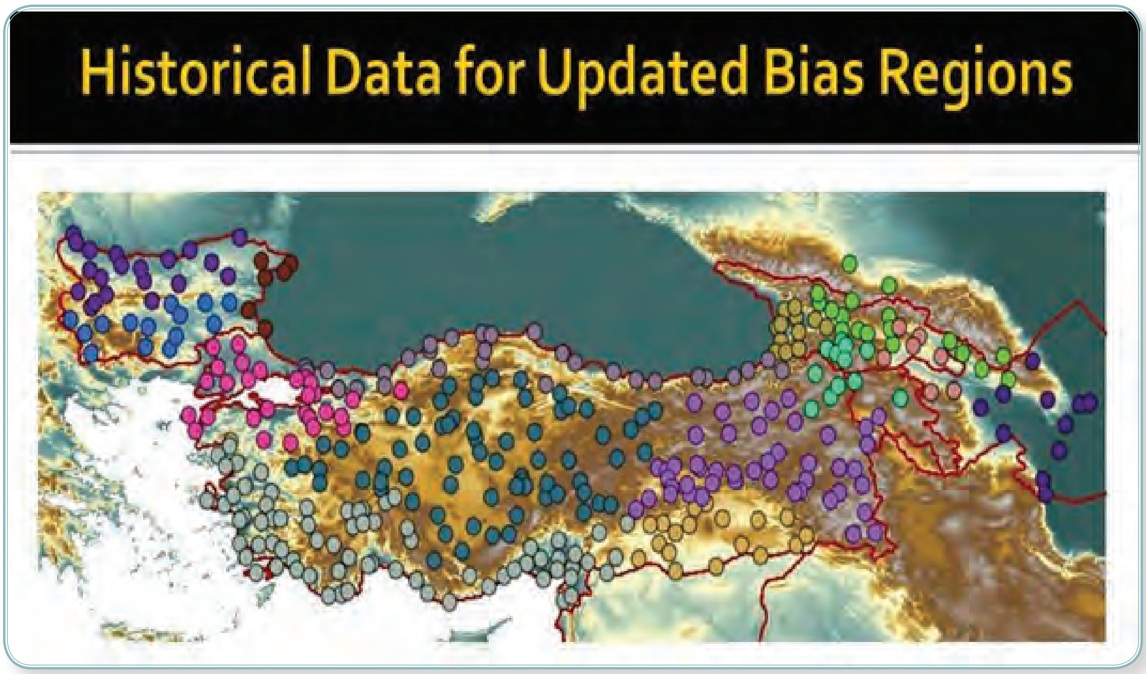


Figure-9 Surface meteorological stations, different colors indicate the climatological bias regions

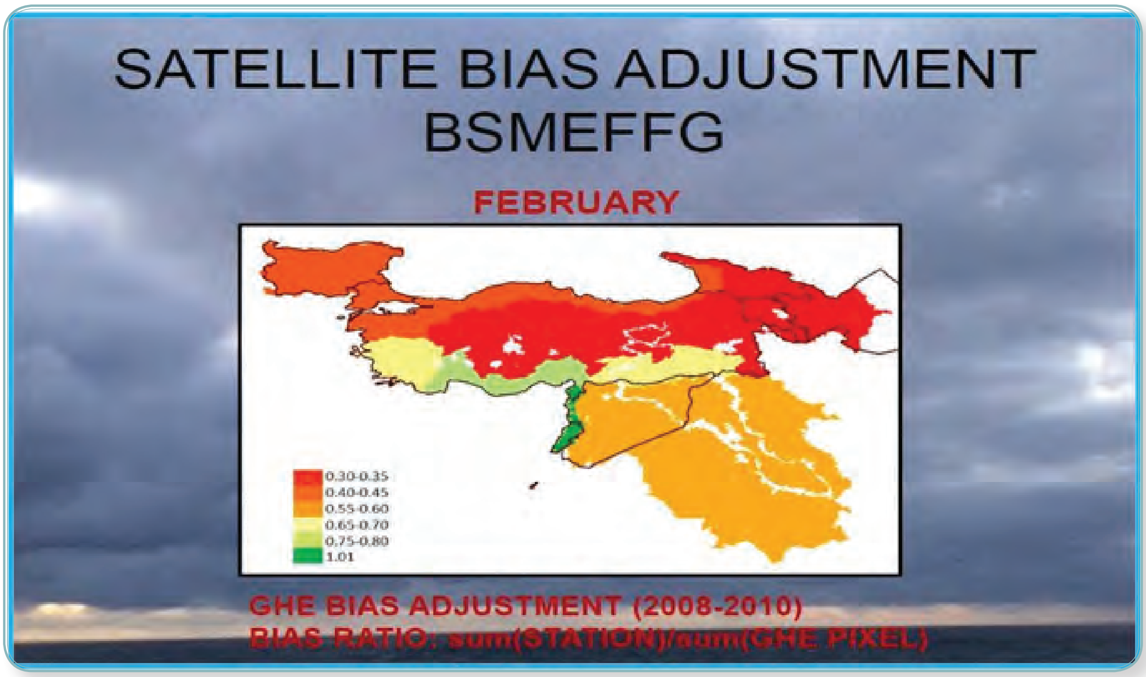


Figure-10 Satellite bias adjustment for February

Figure-11 compares estimated PET (Potential Evapotranspiration) data and measured pan evaporation of one hundred and seventy nine stations in Turkey for a period of 26 years. It is shown that there is a good correlation between observations and model estimations with a 0.83 Pearson correlation coefficient.

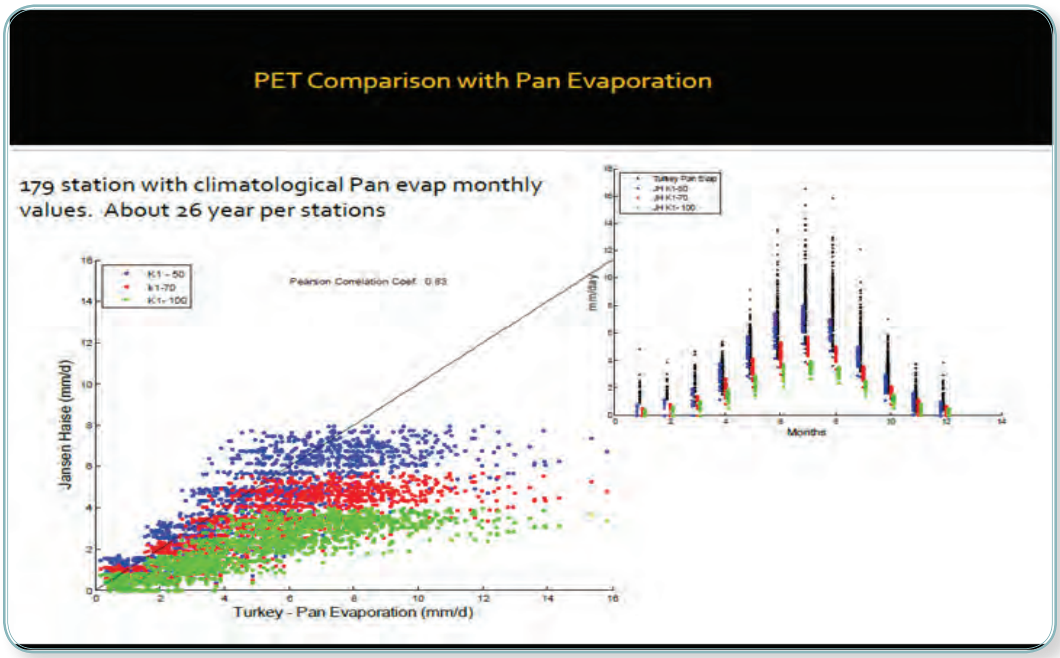


Figure-11 Comparison of PET calculation swith pan evaporation measurements

Figure-12 shows selected surface meteorological stations (black dots) mainly in eastern Turkey and Figure-13 shows a comparison of measured snow water equivalent at the selected stations with their corresponding snow cover estimate from satellite . A very good agreement is seen between the stations reports of snow and the satellite indication of snow cover.

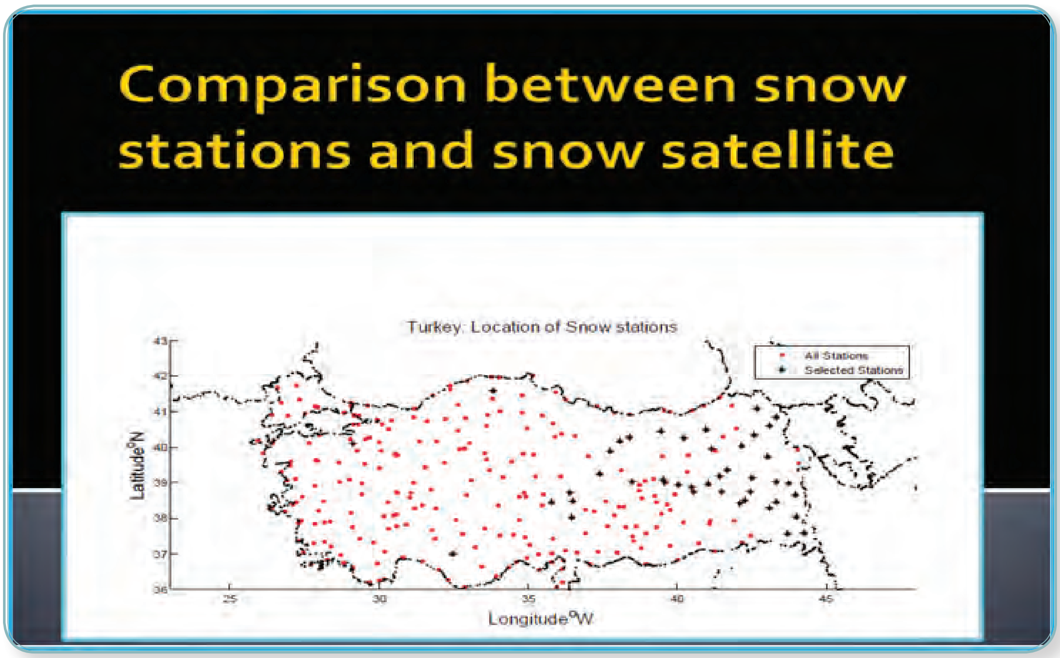


Figure-12 Selected meteorological stations for snow data comparison with satellite data

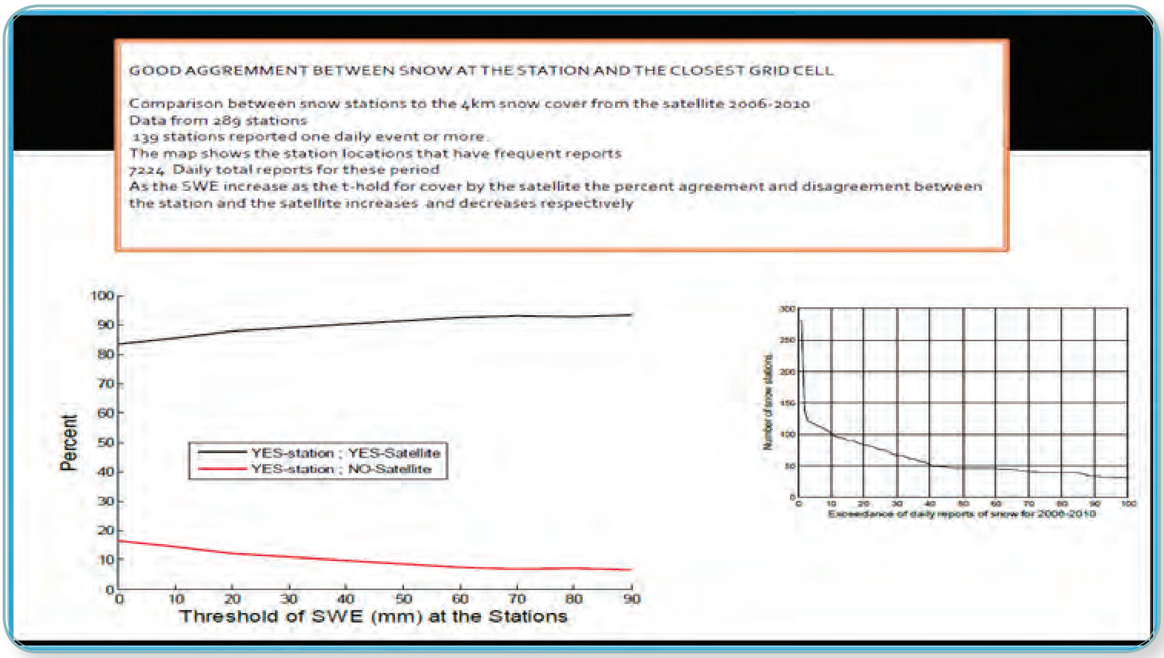


Figure-13 Comparison of SWE surface stations with snow cover satellite data

The above examples clearly show the importance of local data provision to the system developer namely to the Hydrologic Research Center (HRC) in order to set up the model parameters. It is expected that additional local quality controlled datasets will improve the model's skill and performance.

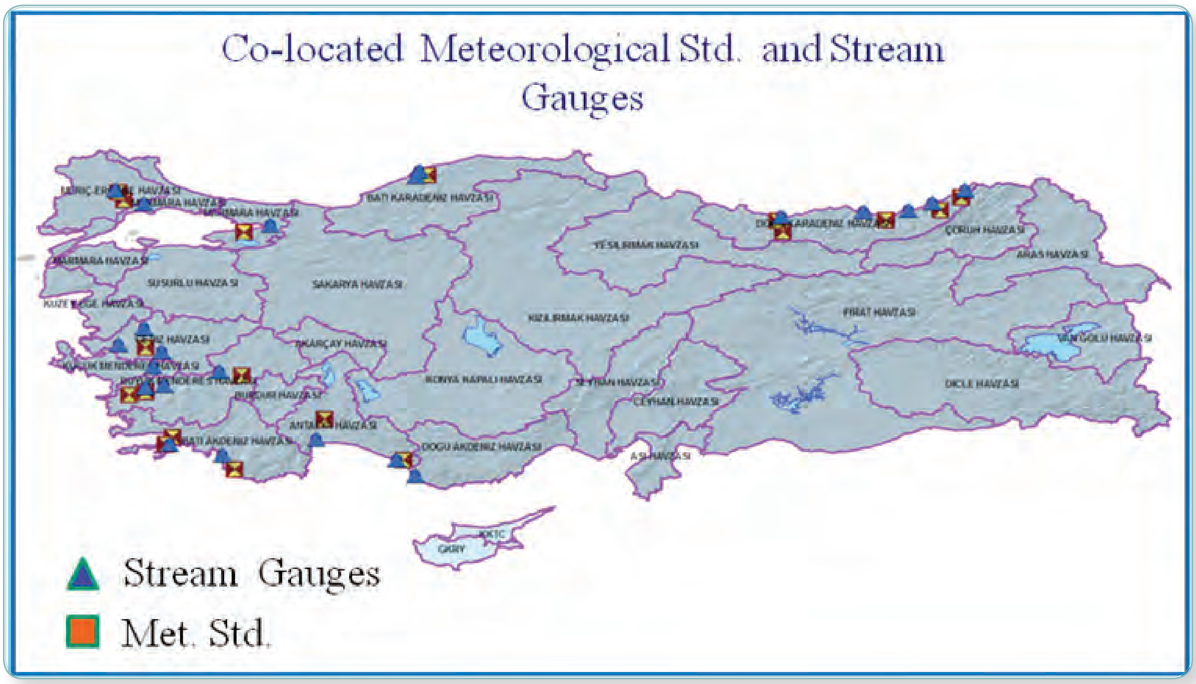


Figure-14 Collocated surface meteorological stations and stream gauges for calibration

5. Access to BSMEFFG User Interface Console

There are two high performance HP servers dedicated to the BSMEFFG system running at the Turkish Meteorological Service in Ankara. The two types of servers are called the Flash Flood Guidance Computational Server (FFGCS) and the Flash Flood Guidance Dissemination Server (FFGDS). These servers contribute differently to the FFG system and its operational provisions. The FFGCS is primarily responsible for all data acquisition, pre-processing, model processing and product export. Once the FFGCS has completed these phases of processing, the resulting products are disseminated to the FFGDS for additional post-processing and provision to authorized users of access to both real-time and recent historical products through a secure web interface. The FFGCS and FFGDS are both responsible for producing graphical output products relevant for a region of interest. All authorized users will log on to the dissemination server to access the BSMEFFG products.

There are two kinds of users who can access the BSMEFFG user interface. The Turkish Meteorological Service users access the BSMEFFG Dissemination Server by using **an internal IP** address.External users,including the member states, access the Dissemination Server by using an **external IP address.**

User Type	IP
Turkish Meteorological Service Users	https://192.168.2.79/CONSOLE
External Users including member states	https://212.175.180.79/CONSOLE

Those who would like to access to the BSMEFFG user interface console shall use one of the tandard web browsers like Internet Explorer (preferred) or Google Chrome as follows:

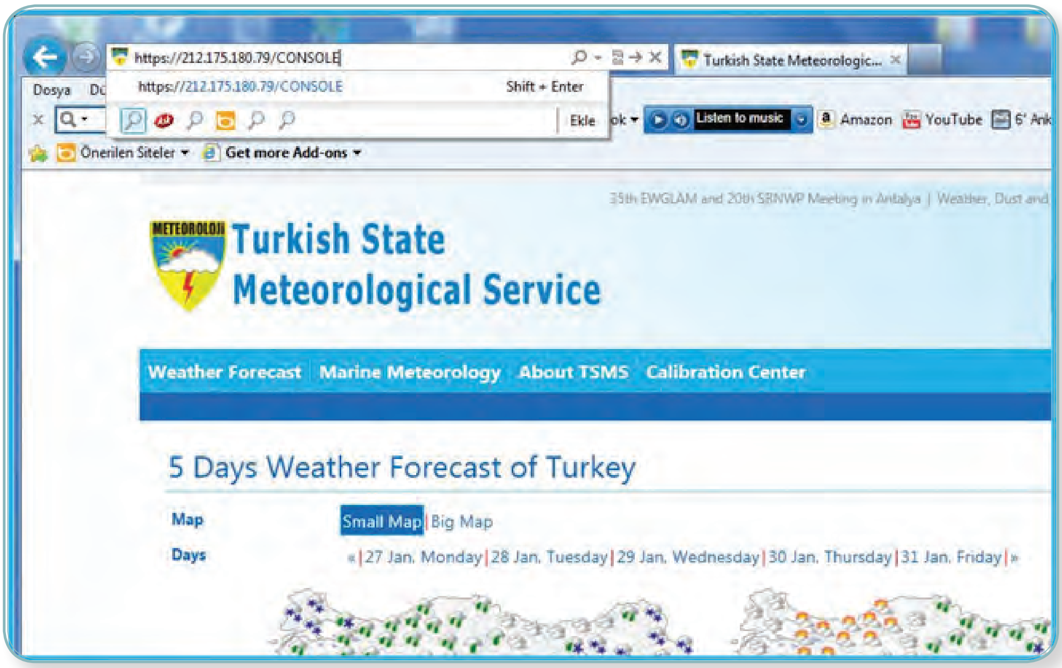


Figure-15 WEB browser access to the BSMEFFG server console

Then click on **"Continue to this website (not recommended)"**

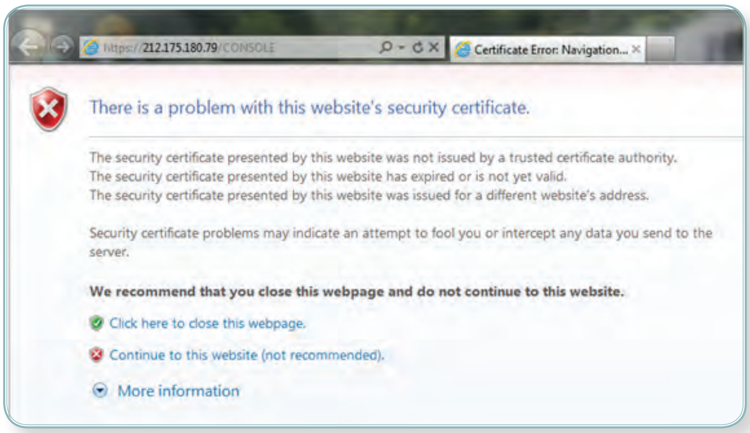


Figure-16 WEB browser to access to the BSMEFFG server console

Next the "User Name" and "Password" Window will be displayed. A user name and password can be obtained from the Hydrometeorological Division of the Research Department of the Turkish Meteorological Service by using contact information given in Section 11.

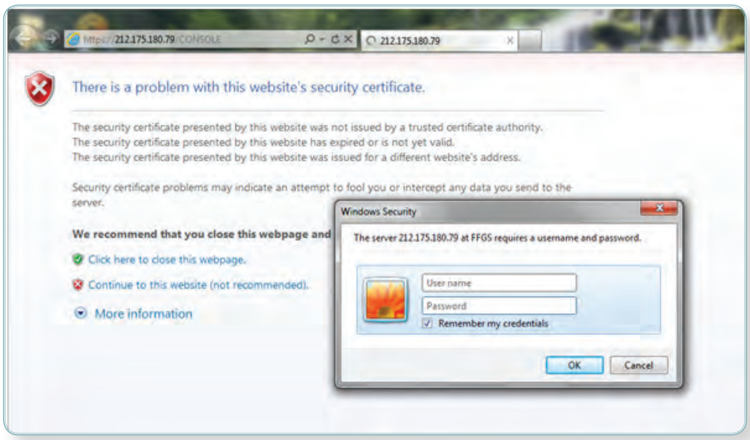


Figure-17 User name and password window

When you log in, you will first be at the system console (Figure-19). At the bottom of the page, "Dashboard " toolbar exists. When you click on "Dashboard" toolbar "Dashboard" console will appear (Figure-18) which is intended for IT staff and, to some degree forecasters, to get a quick look at the system status – specifically the real-time data downloads, data processing and server(s) status.

In order to monitor server processes, the **Dashboard** console has four main toolbars – including Real Time Data Download and Inventory Status (Line 2 shown in Figure-18), Real Time Data Processing Status (Line 3), Computational Server Status (Line 4) and Dissemination Server Status (Line 5).

Even though the Dashboard is designed primarily for system administrators, it also has four different products displayed in windows at the top of the console (Line 1 shown in Figure-18) including – **GHE** (Global Hydrometeor Estimator), Meteorological Station Data Reception Status, **ASM** (Average Soil Moisture) and **FMAP** (Forecast Mean Areal Precipitation). A user can animate these products except the Station Data Status by clicking on the animation bar at the bottom of the window which may give users a first glance of the time series of the products.

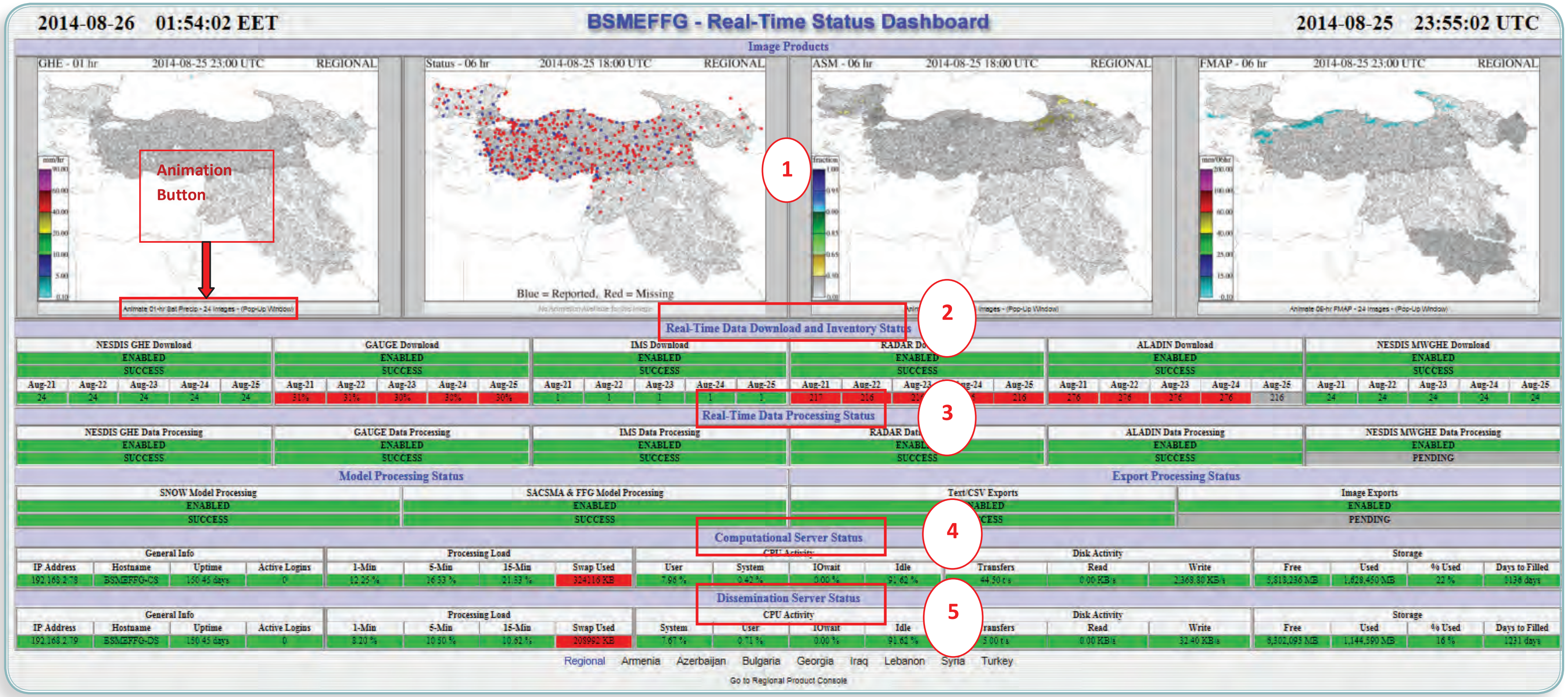


Figure-18 BSMEFFG dashboard console

At the bottom of the dashboard, you can click on a given country and the products displayed in the dashboard will be for that country only. Also, at the bottom there is a link for the product console. Clicking on this link will take you to the forecaster interface. As with the dashboard, you can see products for the entire region or for just a single country on the interface. There is a pull down menu in the navigation pane label led Region that is used to access individual countries, use that to get country-only products. Always press SUBMIT when making changes in the first row of the navigation pane.

Once at the forecaster interface, the BSMEFFG products user interface window will appear on your screen as shown in Figure-19. The products are presented as thumbnails on the interface; clicking on the thumbnail provides a larger image. The main features of the console are as follows:

- At the top of the main page, products, date and time selection toolbars are provided. A user can use this toolbar to navigate to different dates and times and to display products for selected countries.

- BSMEFFG main products are listed consisting of RADAR precipitation (Turkish Meteorological Service Radar network only), MWGHE (Micro Wave adjusted Global Hydrometeor Estimator) precipitation, GHE (Global Hydro Estimator) precipitation, Gauge MAP (Gage Mean Areal Precipitation based on gauge data only), Merged MAP (Merged Mean Area Precipitation), ASM (Average Soil Moisture) , FFG (Flash Flood Guidance), IFFT (Imminent Flash Flood Threat), PFFT (Persistence Flash Flood Threat), ALADIN Forecast, FMAP (Forecast Mean Areal Precipitation), FFFT (Forecast Flash Flood Threat). (Product descriptions are provided in the next section).

- On the left side of the FFGS Products, the time intervals (1, 3, 6, and 24 hour) are displayed.

- Below the FFGS Products, selected surface meteorological observations (Synoptic Stations) from the member states and disseminated through the WMO GTS (Global Telecommunication System) are displayed.
- Snow products including Gauged MAT (Mean Areal Temperature), Latest IMS SCA (Snow Coverage Area), SWE (Snow Water Equivalent), and MELT are displayed at the bottom of the main interface.

- At the bottom of the interface page, products description and system monitoring tools are listed consisting of products description, processing logs, server monitor, static resources and a link back to the Dashboard.

Detailed descriptions of the products are provided in Section 6.

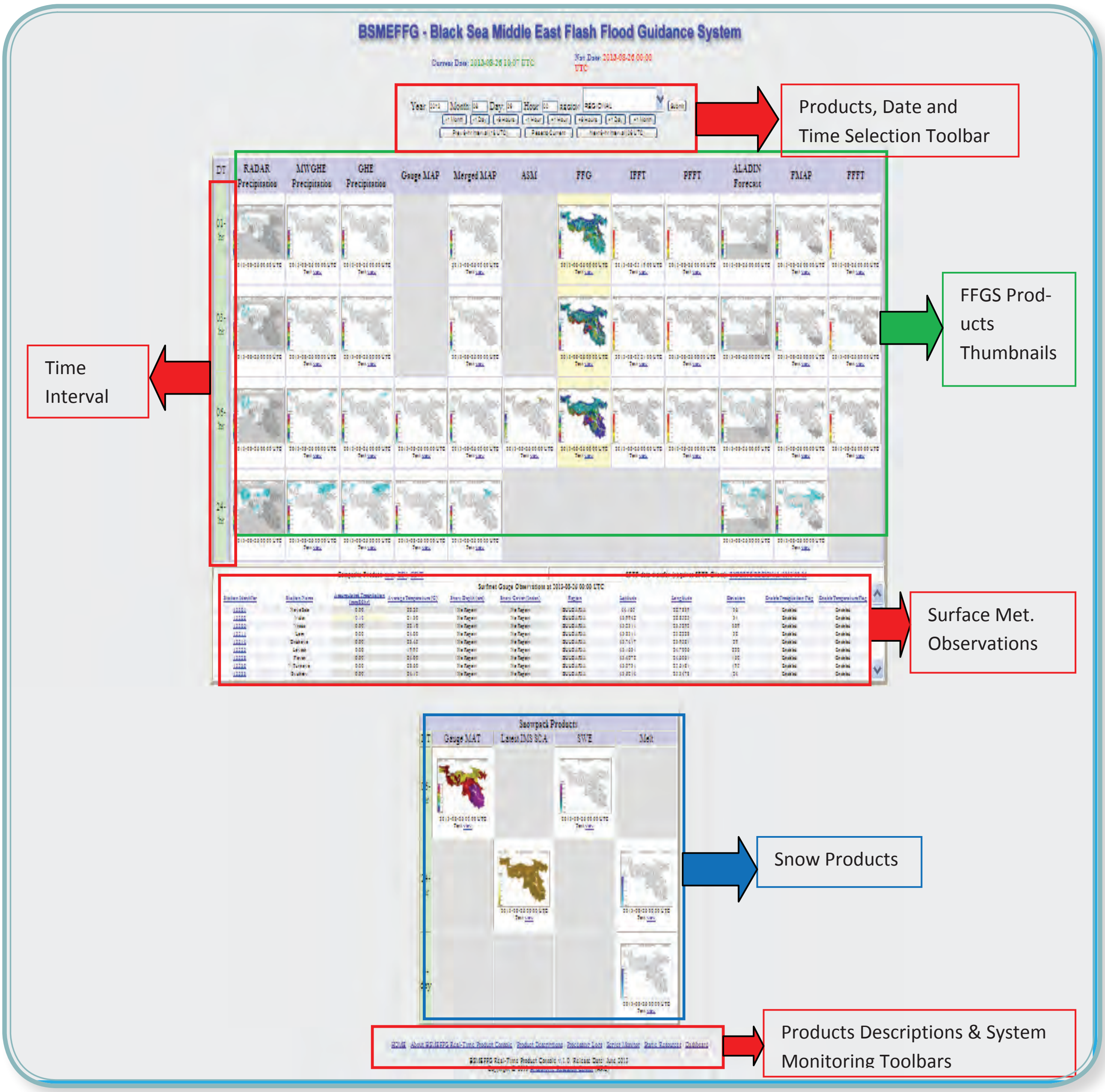


Figure-19 BSMEFFG forecaster interface console

6. Products Descriptions

As shown in Figure-20 and 21 the BSMEFFG system products can be classified into three groups precipitation products, warning products, and snow products. Which will be described in more detail in this section.

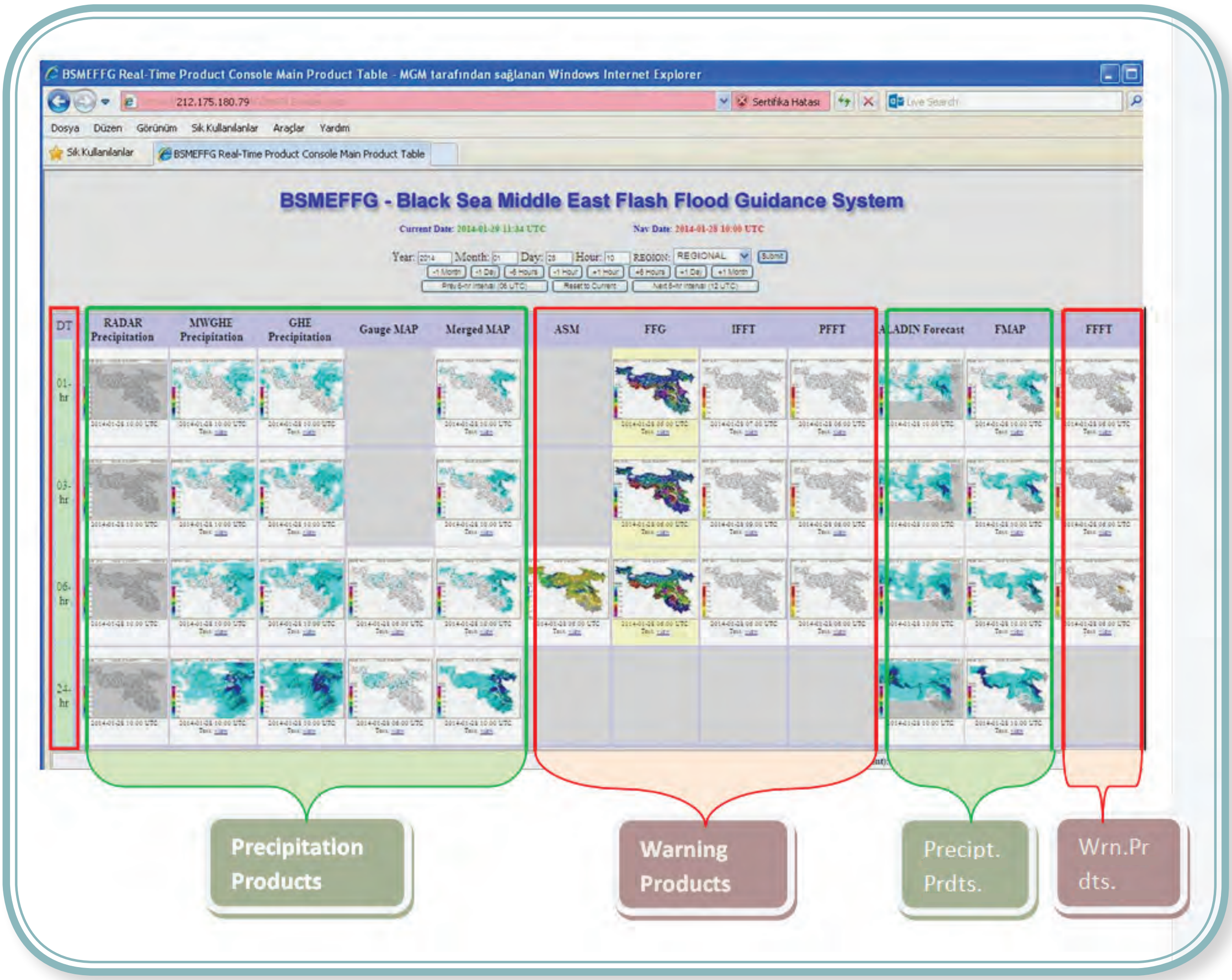


Figure-20 BSMEFFG precipitation and warning products

A) Precipitation Products;

- **RADAR Precipitation**-from the Turkish State Meteorological Service Radar Network,
- **MWGHE Precipitation**-Satellite based Microwave adjusted Global HydroEstimator Precipitation (from NOAA),
- **GHE Precipitation**-Satellite based Global Hydro Estimator Precipitation (from-NOAA),
- **Gauge MAP**-Mean Areal Precipitation based on available gauge data only,
- **Merged MAP**-Mean Areal Precipitation based on radar, MWGHE or GHE precipitation and gauges,
- **ALADIN Forecast**-ALADIN LAM forecast precipitation,
- **FMAP**-Forecast Mean Areal Precipitation based on ALADIN LAM quantitative precipitation forecasts.

B) Warning Products;

- **ASM-**Average Soil Moisture,
- **FFG-**Flash Flood Guidance,
- **IFFT-**Imminent Flash Flood Threat,
- **PFFT-**Persistence Flash Flood Threat,
- **FFFT-**Forecast Flash Flood Threat.

C) Snow Products;

- **Gauge MAT-Gauge** Mean Areal Temperature based on available temperature gauges,
- **Latest IMS SCA-**Fraction of area with snow cover,
- **SWE-**Snow Water Equivalent,
- **MELT-**Snow Melt.

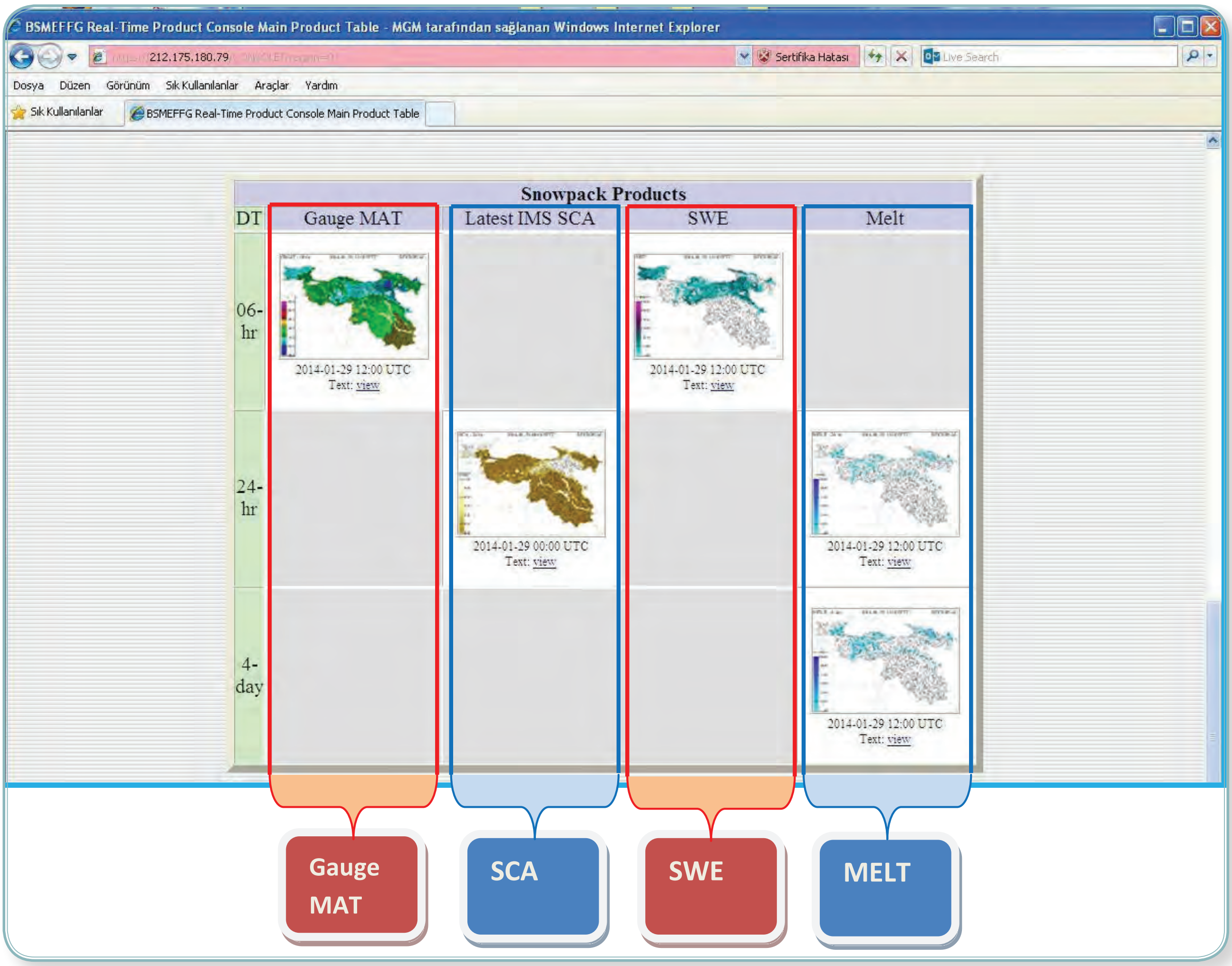


Figure-21 BSMEFFG SNOW products

6.1. RADAR Precipitation

The Turkish Meteorological Service has a ten operational Doppler Weather Radar network which covers mostly the coastal regions. These weather radars produce a number of products used in a nowcast mode by TMS forecasters. One of the main products for hydrological applications is hourly precipitation intensity (mm/hour) called RAIN1 which is re-processed to generate a gridded cumulative precipitation map for the last 1, 3, 6 and 24 hours ending at the product update time. This gridded product is displayed through the BSMEFFG system as shown at the top of Figure-22. For Turkey, radar-based precipitation accumulations are the primary source of precipitation used in the BSMEFFG system.

A radar mask study has been conducted by using past radar hourly precipitation (RAIN1) in order to determine ground clutter, anomalous propagation, bright banding and other error sources that may cause uncertainty in the radar precipitation estimation. A mask calculated for the Istanbul radar is shown in Figure-22 on the lower left. Masking out the non-representative areas of the radar outputs is important for the hydrologic applications in the BSMEFFG system. For these masked areas, satellite-based rainfall estimates are used (MWGHE and/or GHE) or gauges data dependent on what products are available.

Since radar provides near real time two and three dimensional scans of the weather with finer spatial and temporal coverage, it is strongly advised to use radar products in particular vertical cross sections of a storm and its spatial and temporal development for the flash flood Watches/Warnings/Alerts. Particularly, radar is a very good tool to monitor convective activities that may occur in Spring and Summer and that are the main cause of flash floods in the region. These specific radar products are not available through the BSMEFFG system but are available through other TMS systems.

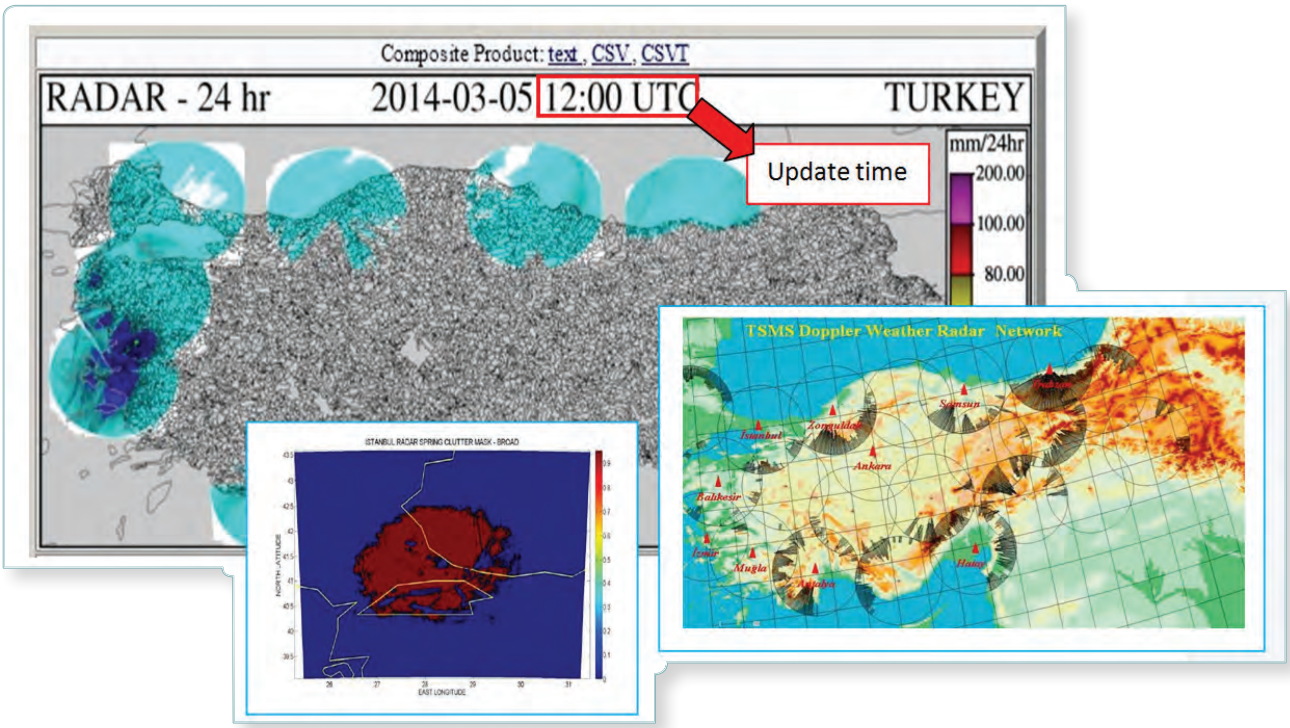


Figure-22 TMS Radar precipitation, radar network (right) and mask (left)

6.2. MWGHE Precipitation (MicroWave adjusted Global Hydro Estimator)

The FFGS is designed to use the NOAA/NESDIS Operational Global Hydro Estimator Satellite Rainfall estimates as a primary precipitation source. There are two satellite based precipitation products used in the FFGS. One of which is infrared (IR) based retrievals called GHE (Global Hydro Estimator) which uses geostationary satellites and other one is microwave based (MWGHE) that uses polar orbiting satellites sensors like AMSU (Advanced Microwave Sounding Unit). The microwave-based estimates use the CMORPH algorithm available from NOAA/Climate Prediction Center. Also possible rewording of sentence. Microwave observations from low orbiting satellites are favourable because they contain more information on lower cloud and precipitation layers as compared to IR based observations. However, while the GHE products from NOAA have a latency of approximately 20 minutes, the CMORPH products have a latency of one-half day or more. Therefore, GHE precipitation that will be explained in the next section is the basis for satellite-based precipitation estimates but is then adjusted by using microwave precipitation data to create the MWGHE (Micro Wave adjusted Global Hydro Estimator) product (Figure-23). Because of the latency issues, these adjustments are not done in real time. Except in areas where representative radar data are available in Turkey, the MWGHE is the primary source for precipitation estimates in the BSMEFFG system for both hydrologic model forcing and for determination of flash flood threats. In Turkey, if radar data are not available, MWGHE precipitation estimates are used.

MWGHE products that are generated for 1-Hour, 3-Hour, 6-Hour and 24-Hour precipitation accumulations ending at the update time.

Forecasters should note that satellite can over- or under-estimate precipitation depending on the time of year, type of the weather system (e.g., convective or stratiform), so that forecasters must analyze and evaluate the satellite precipitation estimate distribution in their particular regions. Also, as noted in previous sections, the satellite estimates are bias-corrected using available gauge data using a dynamic real time adjustment or a previously calculated climatological bias adjustment.

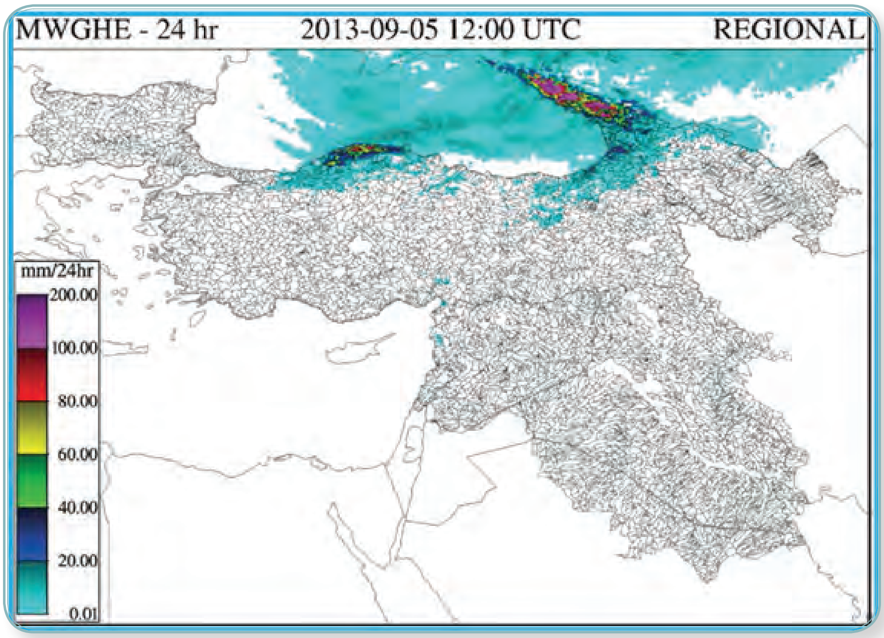


Figure-23 24-Hour microwave adjusted Global Hydro Estimator product

6.3. GHE (Global Hydro Estimator) Precipitation

The Global Hydro Estimator (GHE) precipitation algorithm from NOAA/NESDIS estimates precipitation by using cloud top temperature called Brightness Temperature (Tb) from the infrared (IR) window (11 μm) channels from any of the NOAA Geostationary Environmental Satellite (GOES), MSG (European Meteorological Satellites called Meteosat Second Generation) and MTSAT (Japanese Meteorological Satellite). The basic idea to retrieve rainfall rate from satellite data is to establish a statistical relationship between Brightness Temperature and measured Rainfall Rate that tends to be inverse exponential function ($RR = \alpha e^{-\beta Tb}$) so that one can deduce that the higher the cloud top, the colder the temperature, the higher the rainfall rate.

The GHE products provide composite hourly global precipitation estimates within thirty minutes or less of the observation time. NOAA/NESDIS provides a 1-hour precipitation accumulation that is then used in the BSMEFFG system to determine 1-hour,3-hour,6-hour and 24-hour precipitation accumulations. The non microwave adjusted GHE estimates are used as backup to the MWGHE and radar estimates (Turkey only) for model forcing and flash flood threat analysis. The BSMEFFG system provides 1-hour, 3-hour, 6-hour and 24-hour accumulated GHE precipitation products updated hourly (Figure-24). As it is well known, satellite products and images can provide a lot of information to forecasters who pay attention precipitation as well as storm developments and synoptic and mesoscale features.

GHE precipitation estimates are used in the BSMEFFG modeling and flash flood threat evaluations in areas where neither radar nor MWGHE estimates are available.

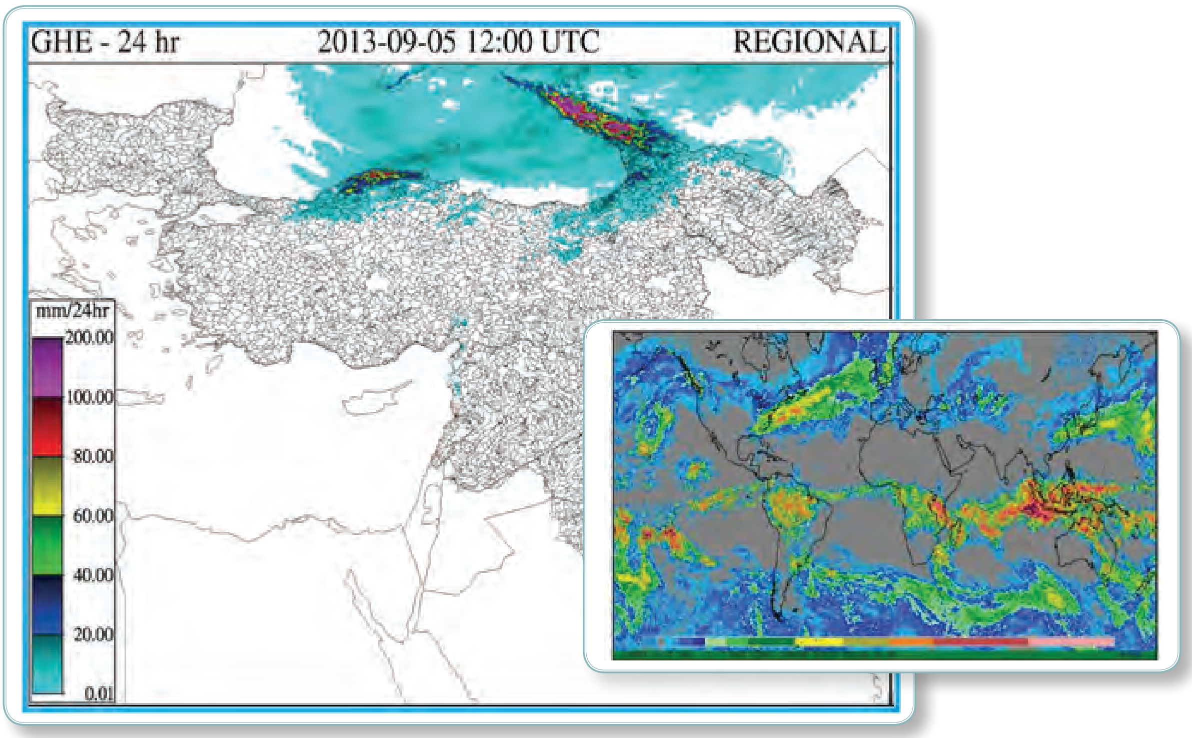


Figure-24 24-hr Global Hydro Estimator (GHE) product

6.4. Gauge MAP (Mean Areal Precipitation)

Gauge MAP (Gauge Mean Areal Precipitation) is generated by using synoptic observations that are disseminated through the WMO Global Telecommunication System (GTS). The more data submitted via GTS by member countries, the more accurate the gauge mean areal precipitation product will be produced. Because surface meteorological measurements are point data and basin areal precipitation is used in hydrologic studies, gauge mean areal precipitation is estimated for each basin. From the practical point of view forecasters the gauge MAP is less than the maximum point measurement in the sub-basins. Gauge MAP is used for the bias adjustments of radar, MWGHE, and GHE precipitation products.

To generate gauge MAP, 396, 32, 12, 7 and 3 real time reporting synoptic stations were used from Turkey, Bulgaria, Georgia, Azerbaijan and Armenia respectively. Reporting stations status are displayed in the BSMEFFG system "Dashboard" and individual station data are be displayed in the "Product console (Forecaster Interface)" by clicking on the station identifier in the "Surfmet Gauge Observations" area.

BSMEFFG provides 6-Hour and 24-Hour gauge MAP products ending at the update time (Figure-25).

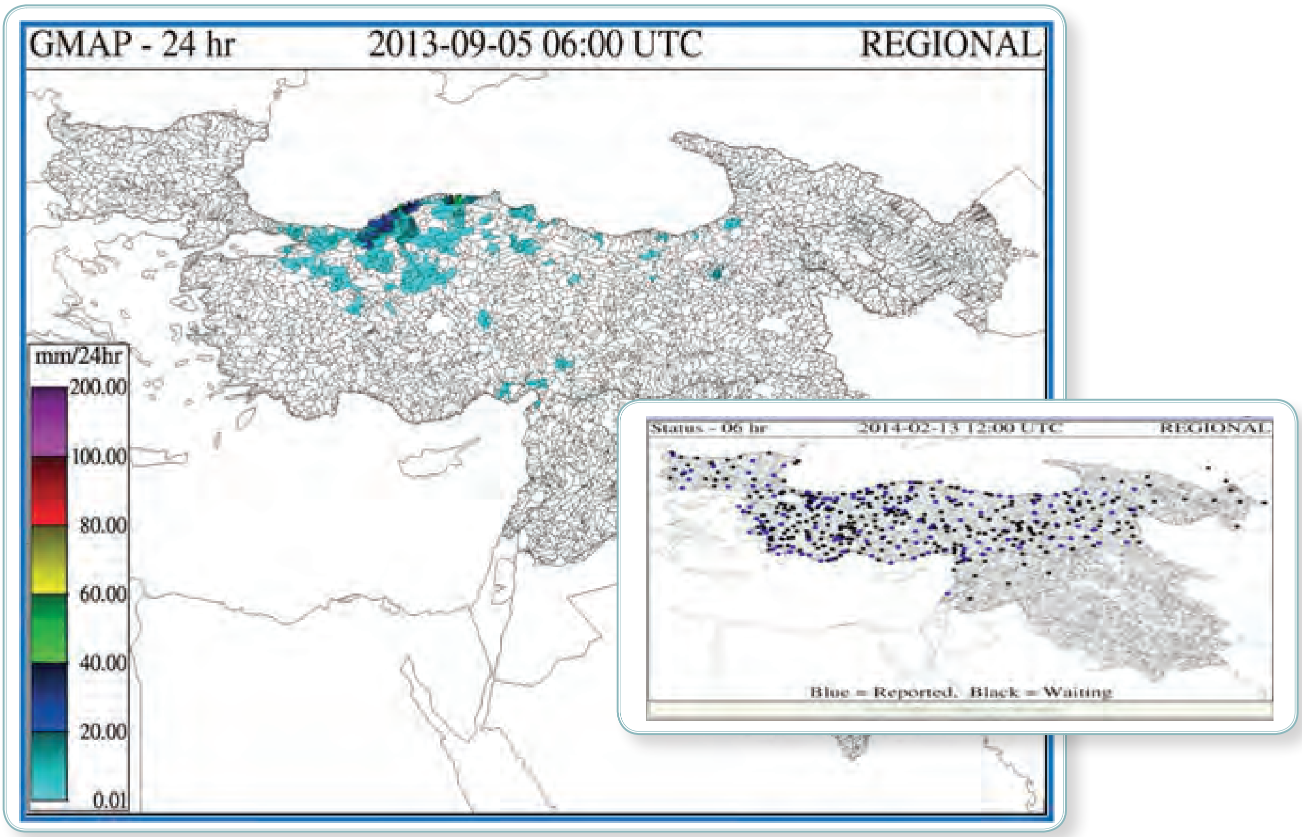


Figure-25 BSMEFFG 24-hr gauge MAP (Mean Areal Precipitation) product

6.5. Merged MAP (Mean Areal Precipitation)

Merged MAP (mean areal precipitation) is a bias-corrected product. The bias-correction is done using available gauge data, radar (Turkey only), GHE (global hydroestimator) or MWGHE (MiroWave adjusted Global Hydroestimator) in that order. BSMEFFG provides 1-Hour, 3-Hour, 6-Hour and 24-Hour merged MAP products ending at the update time (Figure-26). The Merged MAP product provides the data that is quality controlled and ingested into the Snow-17, soil moisture and flash flood threat models.

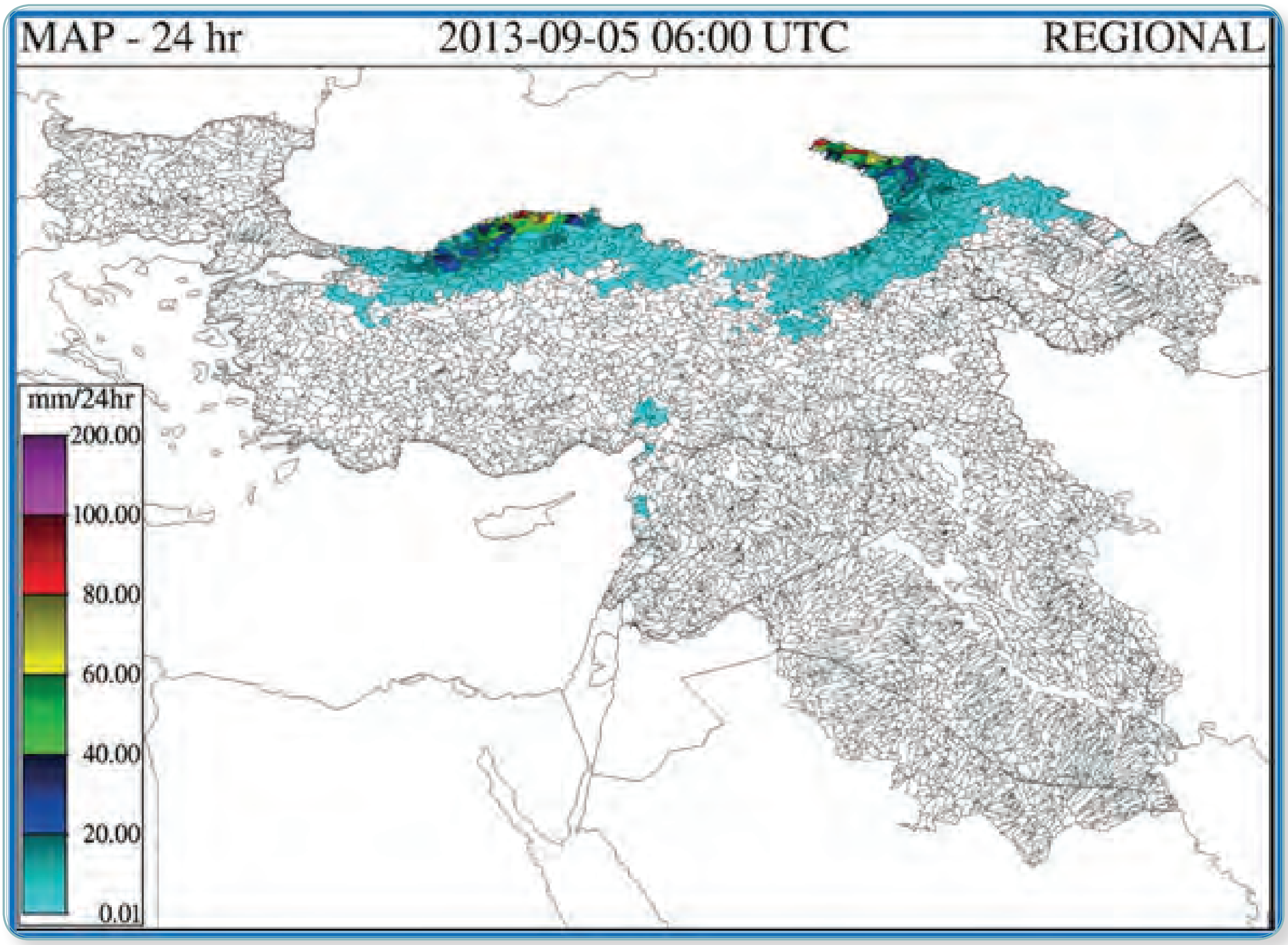


Figure-26 BSMEFFG 24-hr merged MAP product

6.6. Summary of Precipitation Products

The BSMEFFG precipitation bias adjustment process for the satellite-based precipitation products are summarized in Figure-27. The base satellite precipitation product is the GHE (Global Hydro Estimator) generated by NOAA NESDIS, using geostationary Meteorological/Environmental satellites of NOAA, EUMETSAT and JMA. Then, the GHE is adjusted by using microwave-based precipitation products (CMORPH) provided by NOAA Climate Prediction Center, using microwave sensors of polar orbiting satellites of NOAA and EUMETSAT. The microwave adjusted GHE (MWGHE) is then bias adjusted, using surface meteorological synoptic precipitation measurements disseminated through the WMO GTS.

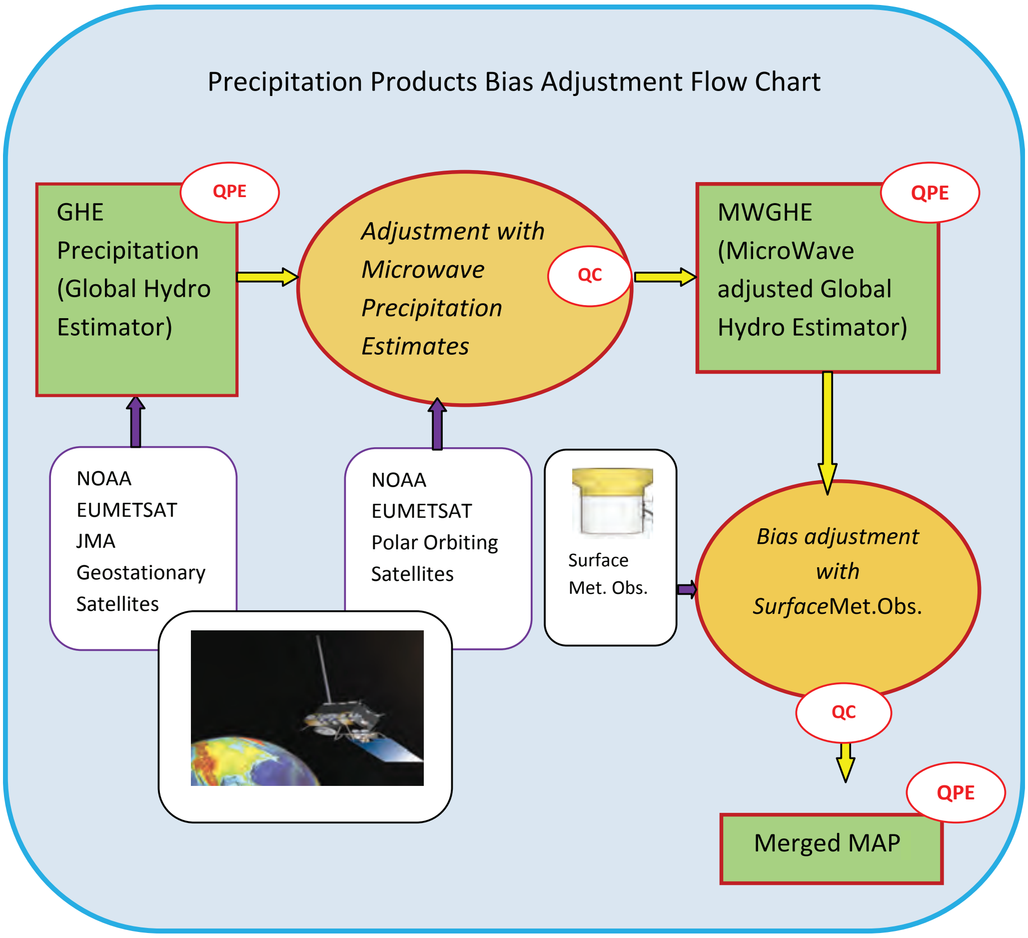


Figure-27 Precipitation products bias adjustment flowchart

6.7. ASM (Average Soil Moisture)

The Average Soil Moisture product shows the fraction of saturation of the upper soil (20-30 cm) for which upper zone tension and free water contents are estimated by using the Sacramento Soil Moisture Accounting Model (SAC-SMA). Real time input parameters for this model are the precipitation while soil, terrain and land cover are ingested into the model as a priori parameters. Saturation of upper zone is very important for flash floods because of the fact that if rainfall continues, most of the rainfall will be surface flow.

ASM is generated and updated every six hours at the model runtimes of 00 UTC, 06 UTC, 12 UTC, and 18 UTC (Figure-28).

It should be noted that ASM is one of the key products for flash flood watches/warnings/alerts. The forecaster must pay attention to its spatial and temporal distribution in any regions and sub-basins. If upper soil moisture saturation fraction is quite high and meteorological models show continuation of rainfall for this region, flash flood occurrence can be a concern depending on rainfall amounts/duration and the FFG values.

Since ASM indicates the upper soil moisture content, its temporal variation is quite rapid, depending on the precipitation intensity and duration.

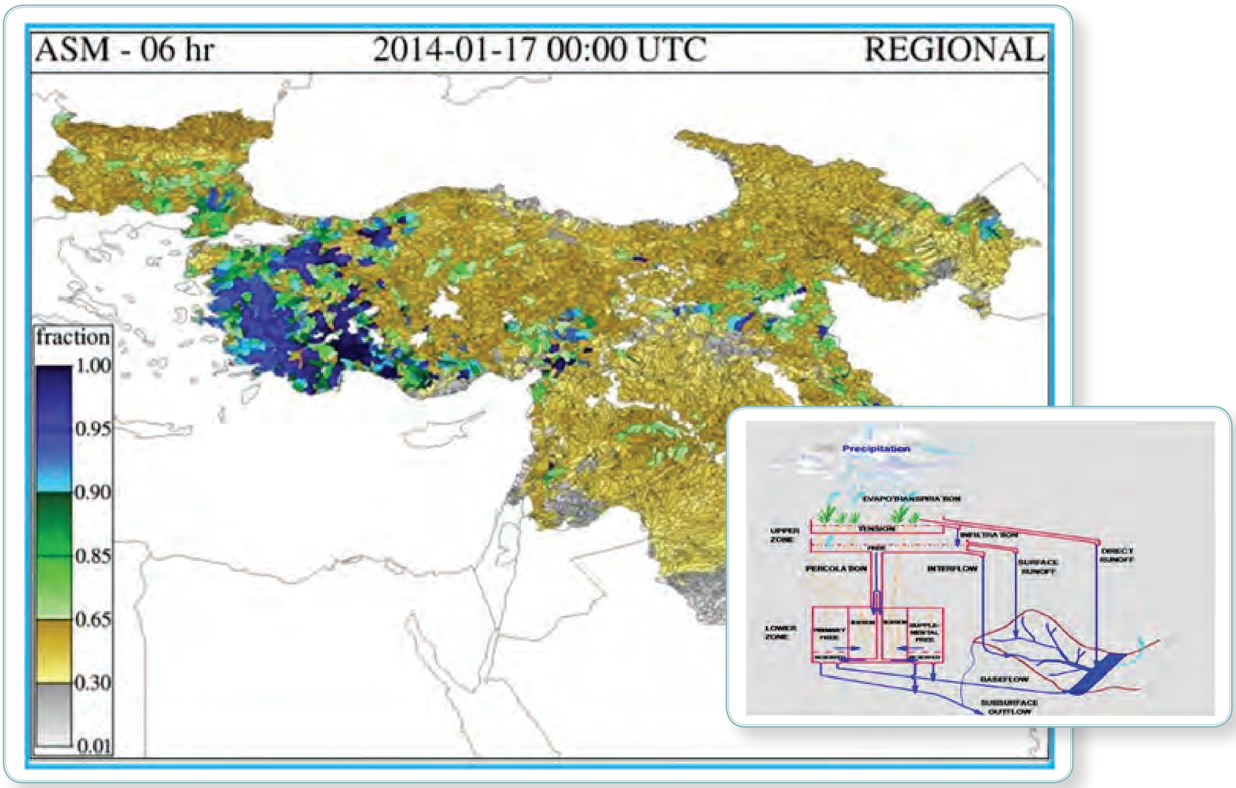


Figure-28 BSMEFFG 6-hr Average Soil Moisture (ASM) product

6.8. FFG (Flash Flood Guidance)

Flash Flood Guidance, is defined as the amount of actual rainfall for a given duration (e.g. 1,3 and 6 hours) that causes bankfull flow at the outlet of the catchment. The FFG is calculated and updated at every six hours at the model runtimes of 00, 06, 12 and 18 UTC and is valid for the next 1,3 and 6 hours. Threshold runoff is an important input of the flash flood guidance model. Threshold runoff is an a priori calculation of the geomorphologic unit hydrograph, drainage channel profiles and catchment characteristics as described in Section 8. Another important component is the SAC-SMA which models soil moisture and is further described in Section 6.7. As shown in Figure-29 (1-hour FFG) FFG values vary by basin. The FFG scale on the left side of Figure-29 is color-coded in mm/hour (for the example in the Figure this is mm for 1 hour duration). Forecasters are advised to pay attention to the inverse relationship between possibility of flash flood occurrence and FFG values. That is, basins with lower values of FFG are more likely to have a flash flood occurrence than basins with higher values once rains begin.

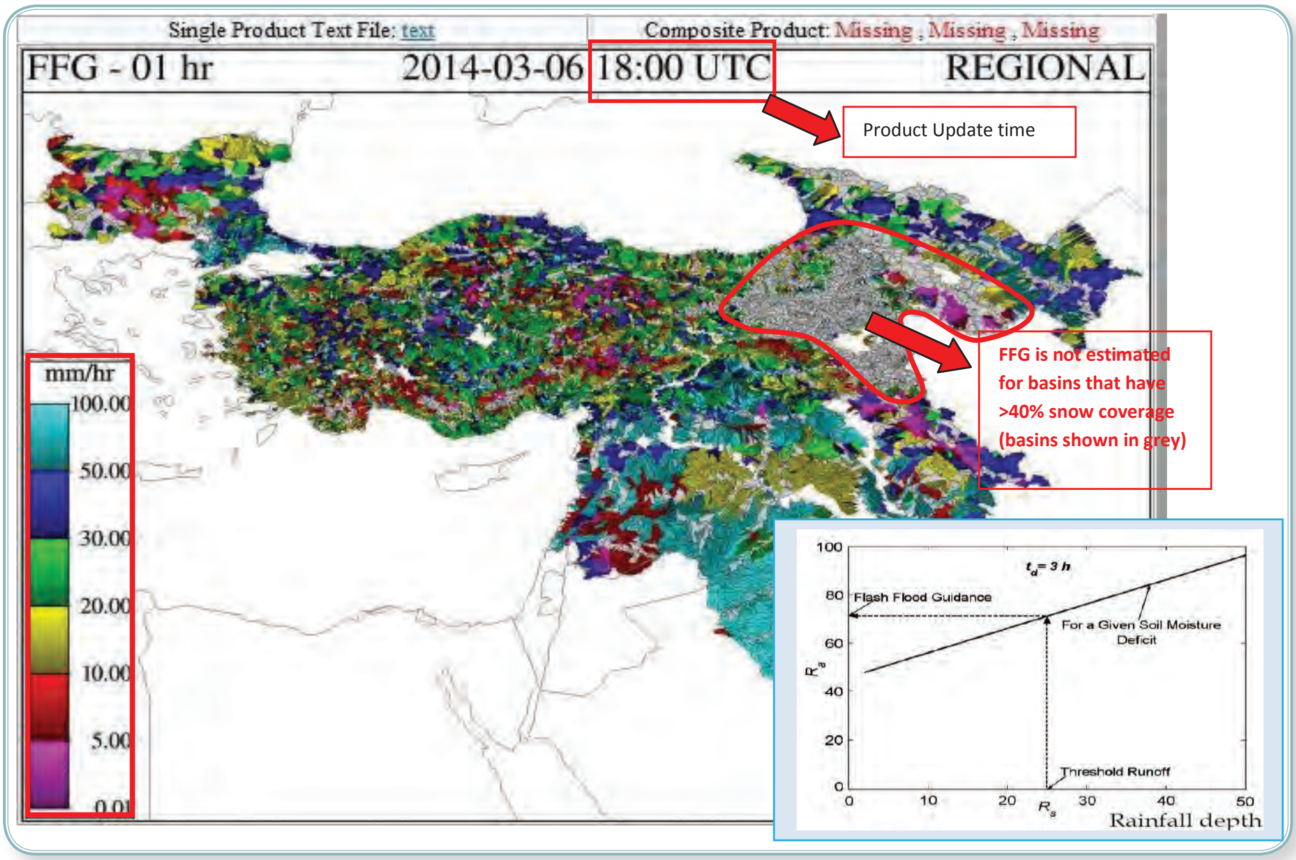


Figure-29 BSMEFFG 1-hr FFG product

6.9. Imminent Flash Flood Threat (IFFT)

Imminent Flash Flood Threat (IFFT) is one of the three flash flood threat products. It is the difference between the corresponding Merged MAP and FFG for the same duration (see the following sections). IFFT indicates that flash flood is happening now or is about to happen very soon (imminent). Therefore, forecasters should investigate the 1,3 and 6 hours spatial and temporal distribution of the IFFT. It should be noted that IFFT is estimated and updated by using current precipitation. Thus, it represents an "observed" weather situation.

1-hour, 3-hour and 6-hour IFFT products are generated and detailed descriptions of them are given below, respectively. Descriptions of the products can be accessed by clicking on the **"Product Description"** button at the bottom of the BSMEFFG Products Console.

6.9.1. 1-Hour Imminent Flash Flood Threat (1h-IFFT)

As depicted in Figure-30, 1-Hour IFFT is valid at 01 UTC, 07 UTC, 13 UTC and 19 UTC such that;

1-Hour IFFT at 01 UTC is the difference between the merged MAP at 01 UTC and current FFG at 00 UTC valid for 01 UTC. Similarly, 1-Hour IFFT at 07 UTC is the difference between the merged MAP at 07 UTC and current FFG at 06 UTC valid for 07 UTC; 1-Hour IFFT at 13 UTC is the difference between the merged MAP at 13 UTC and the current FFG at 12 UTC valid for 13 UTC; and 1-Hour IFFT at 19 UTC is the difference between the merged MAP at 19 UTC and the current FFG at 18 UTC valid for 19 UTC.

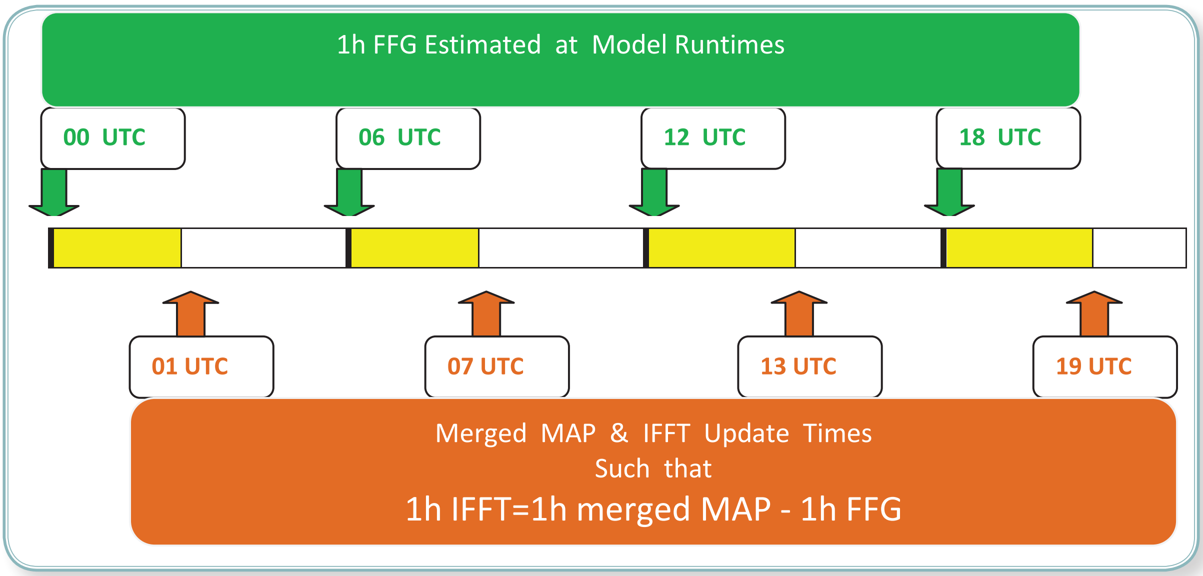


Figure-30 Schematic display of 1-hr IFFT estimation scheme

6.9.2. 3-Hour Imminent Flash Flood Threat (3h-IFFT)

As depicted in Figure-31, the 3-Hour IFFT are valid at 03 UTC, 09 UTC, 15 UTC and 21 UTC such that;

The 3-Hour IFFT at 03 UTC is the difference between merged MAP at 03 UTC and current FFG at 00 UTC valid for 03 UTC. Similarly, 3-Hour IFFT at 09 UTC is the difference between the merged MAP at 09 UTC and the current FFG at 06 UTC valid for 09 UTC; 3-Hour IFFT at 15 UTC is the difference between the merged MAP at 15 UTC and the current FFG at 12 UTC valid for 15 UTC; and 3-Hour IFFT at 21 UTC is the difference between the merged MAP at 21 UTC and the current FFG at 18 UTC valid for 21 UTC.

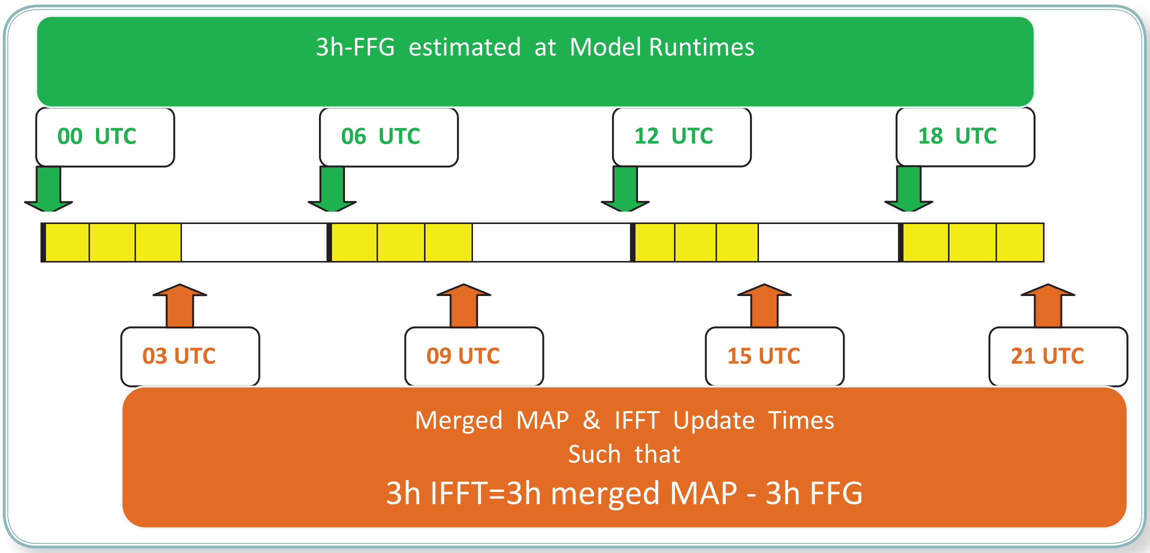


Figure-31 Schematic display of 3-hr IFFT estimation scheme

For example, the 03-Hour IFFT at 09 UTC, 01 October 2013 is shown in Figure-32. IFFT values are noted for basins located in the interior Aegean Sea Region. The IFFT values are 10-40 mm/3h in orange and 0-10 mm/3h in yellow. In the color scale of the product, there distinct color schemes namely yellow, orange and red are applied that forecasters should pay close attention for the catchment that have orange and red color where flash flood has already occurred or were to occur very soon.

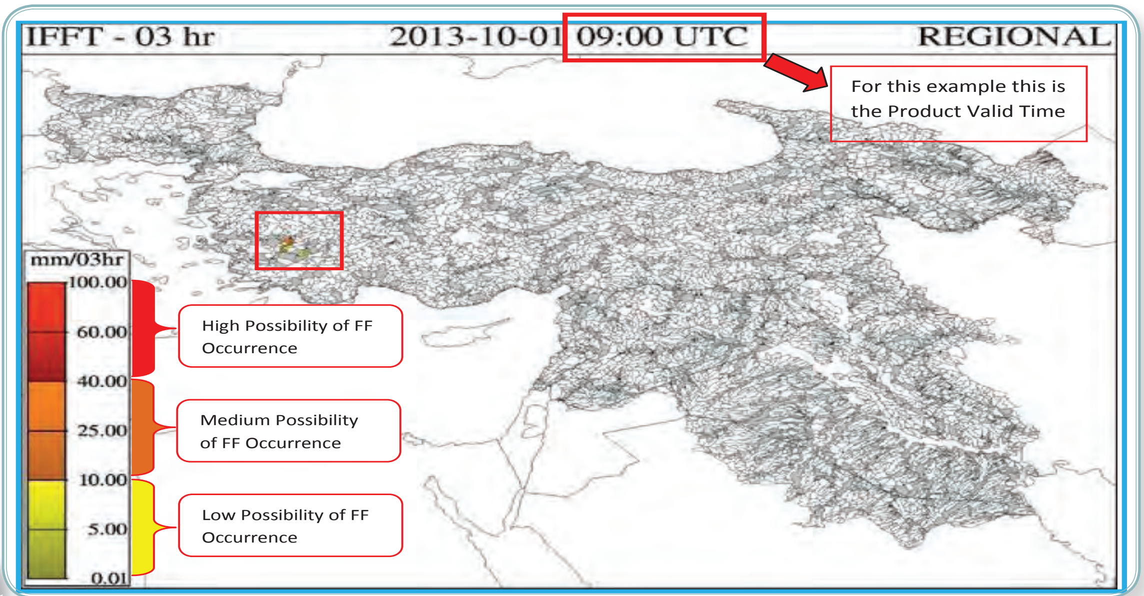


Figure-32 03-hr IFFT at 09 UTC, 1 October 2013

6.9.3. 6-Hour Imminent Flash Flood Threat (6h-IFFT)

As depicted in Figure-33, the 6-Hour IFFT is valid at 00 UTC, 06 UTC, 12 UTC and 18 UTC such that;

The 6-Hour IFFT at 00 UTC is the difference between the merged MAP at 00 UTC and previous FFG at 18 UTC valid for 00 UTC. Similarly, the 6-Hour IFFT at 06 UTC is the difference between the merged MAP at 06 UTC and the previous FFG at 00 UTC valid for 06 UTC; the 6-Hour IFFT at 12 UTC is the difference between the merged MAP at 12 UTC and the previous FFG at 06 UTC valid for 12 UTC; and 6-Hour IFFT at 18 UTC is the difference between the merged MAP at 18 UTC and the previous FFG at 12 UTC valid for 18 UTC.

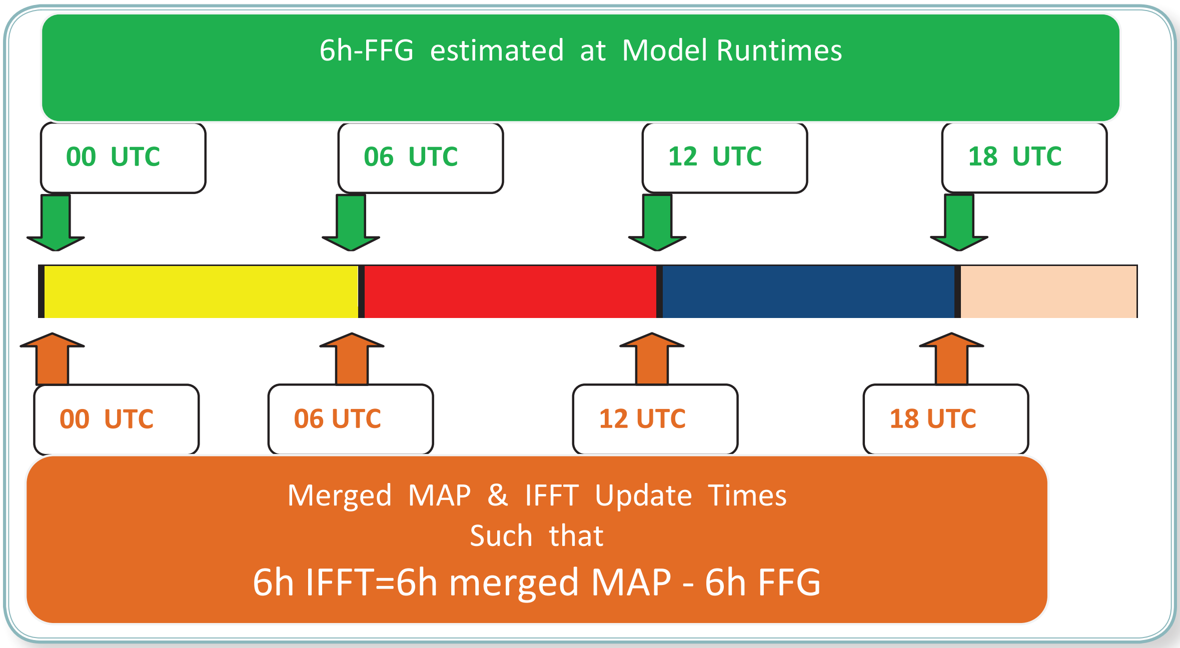


Figure-33 Schematic display of 6-hr IFFT stimation scheme

6.10. Persistence Flash Flood Threat (PFFT)

Persistence Flash Flood Threat (PFFT) is the second of the three flash flood threat products. The concept of PFFT is that previous precipitation of a given duration will persist for the same duration into the future. Therefore, the PFFT is considered a forecast flash flood threat using persistence for the rainfall forecast. PFFT is the difference between the merged MAP estimated and updated at the FFG model runtime and the corresponding FFG value. 1-hour, 3-hour and 6-hour Persistence Flash Flood Threat products are produced at 00 UTC, 06 UTC, 12 UTC and 18 UTC.

Description and schematic view of each PFFT are provided below. One can access the text description by clicking on the **"Product Description"** button at the bottom of the BSM-EFFG Products Console.

6.10.1. 1-Hour Persistence Flash Flood Threat (1h-PFFT)

As depicted in Figure-34, 1-Hour PFFT is estimated and updated at 00 UTC, 06 UTC, 12 UTC and 18 UTC such that;

The 1-Hour PFFT at 00 UTC is the difference between the merged MAP at 00 UTC and current FFG at 00 UTC valid for 01 UTC. Similarly, the 1-Hour PFFT at 06 UTC is the difference between the merged MAP at 06 UTC and current FFG at 06 UTC valid for 07 UTC; the 1-Hour PFFT at 12 UTC is the difference between merged MAP at 12 UTC and the current FFG at 12 UTC valid for 13 UTC; and 1-Hour PFFT at 18 UTC is the difference between merged MAP at 18 UTC and current FFG at 18 UTC valid for 19 UTC.

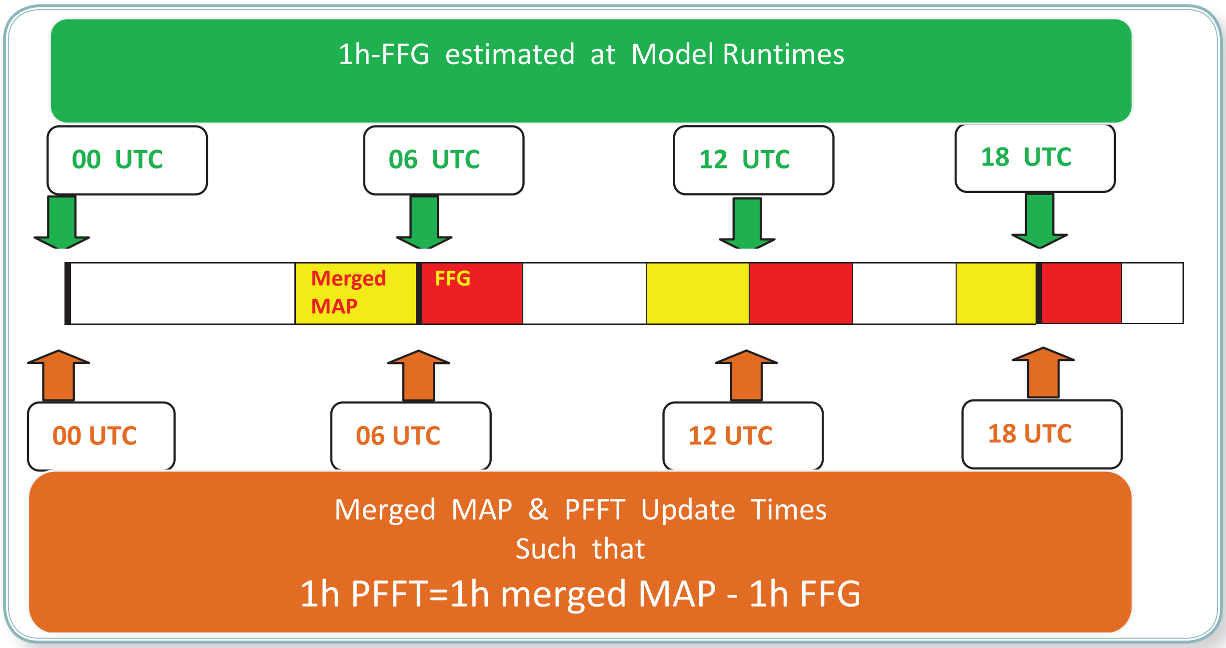


Figure-34 Schematic display of 1-Hour PFFT estimation scheme

6.10.2. 3-Hour Persistence Flash Flood Threat (3h-PFFT)

As depicted in Figure-35, the 3-Hour PFFT is estimated and updated at 00 UTC, 06 UTC, 12 UTC and 18 UTC such that;

The 3-Hour PFFT at 00 UTC is the difference between the merged MAP at 00 UTC and current FFG at 00 UTC valid for 03 UTC. Similarly, the 3-Hour PFFT at 06 UTC is the difference between the merged MAP at 06 UTC and current FFG at 06 UTC valid for 09 UTC; the 3-Hour PFFT at 12 UTC is the difference between the merged MAP at 12 UTC and current FFG at 12 UTC valid for 15 UTC; and 3-Hour PFFT at 18 UTC is the difference between the merged MAP at 18 UTC and current FFG at 18 UTC valid for 21 UTC.

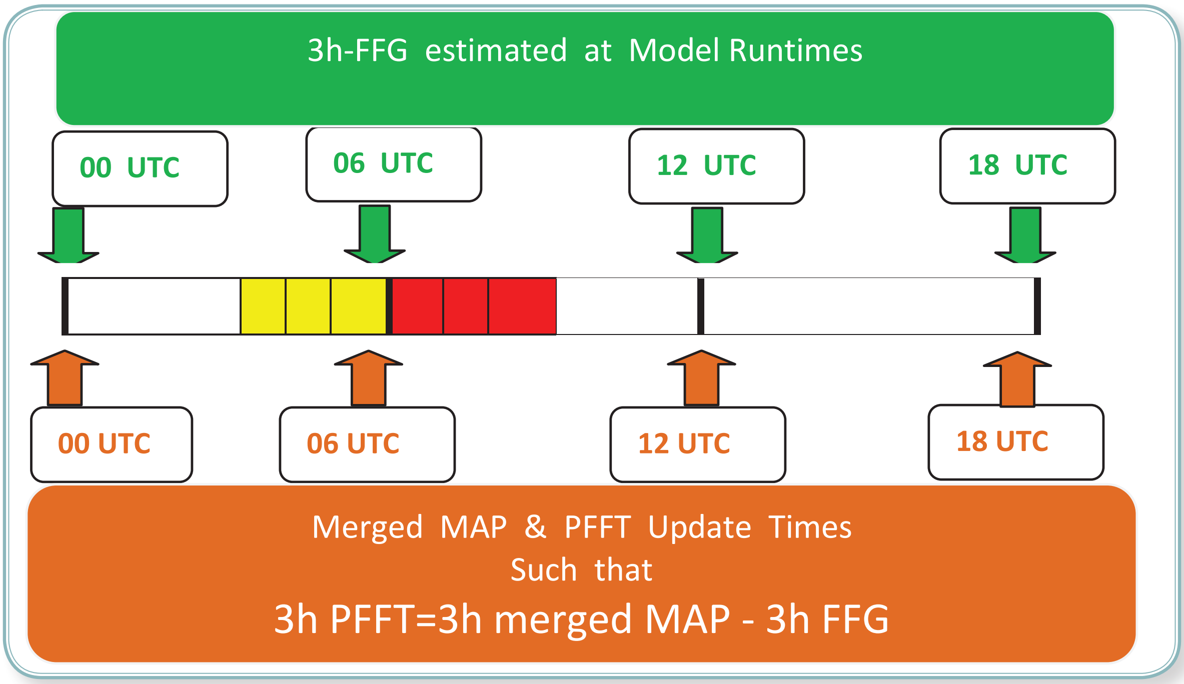


Figure-35 Schematic display of 3-Hour PFFT estimation scheme

For example, the 3-Hour PFFT at 12 UTC, 01 October 2013 is shown in Figure-36. PFFT values were noted in the interior Aegean Sea Region with values of 10-40 mm/3h in orange and 0-10 mm/3h in yellow. In the color scale of the product, the distinct color schemes namely yellow, orange and red are applied that forecasters should pay close attention for the catchments that have orange and red color where flash flood occurrence is most likely if rainfall conditions persist.

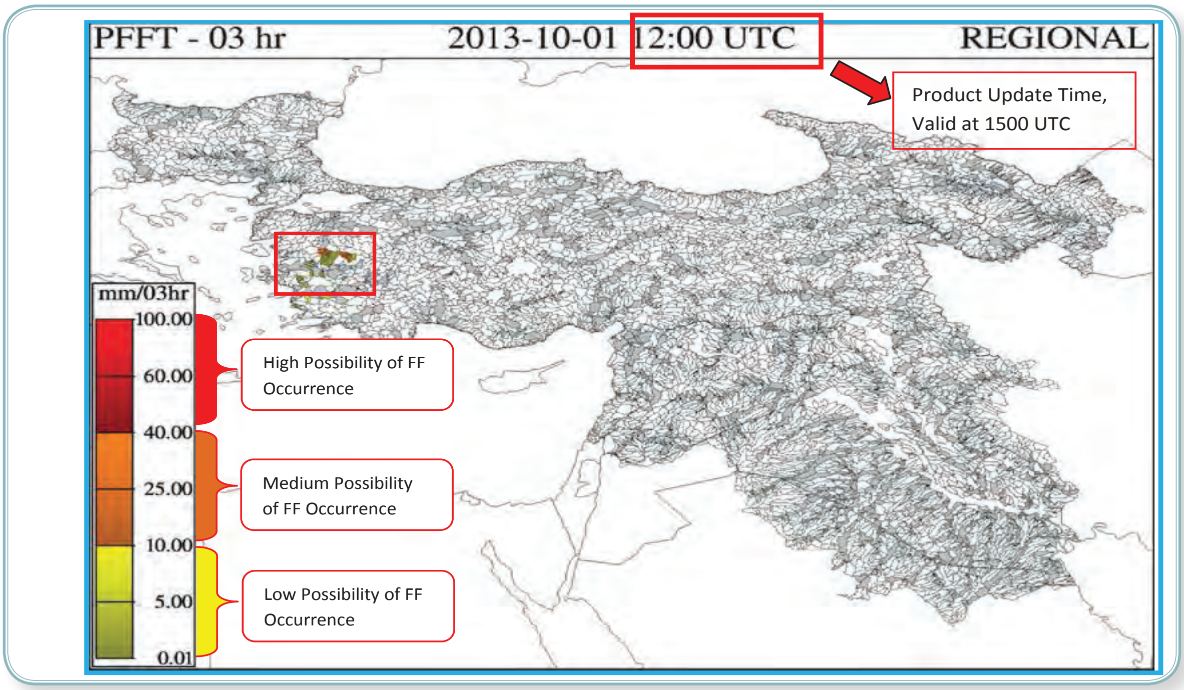


Figure-36 3-Hour PFFT at 12 UTC, 1 October 2013

6.10.3. 6-Hour Persistence Flash Flood Threat (6h-PFFT)

As depicted in Figure-37, 6-Hour PFFT is estimated and updated at 00 UTC, 06 UTC, 12 UTC and 18 UTC such that;

The 6-Hour PFFT at 00 UTC is the difference between the merged MAP at 00 UTC and current FFG at 00 UTC valid for 06 UTC. Similarly, the 6-Hour PFFT at 06 UTC is the difference between the merged MAP at 06 UTC and current FFG at 06 UTC valid for 12 UTC; the 6-Hour PFFT at 12 UTC is the difference between the merged MAP at 12 UTC and current FFG at 12 UTC valid for 18 UTC; and the 6-Hour PFFT at 18 UTC is the difference between merged MAP at 18 UTC and current FFG at 18 UTC valid for 00 UTC.

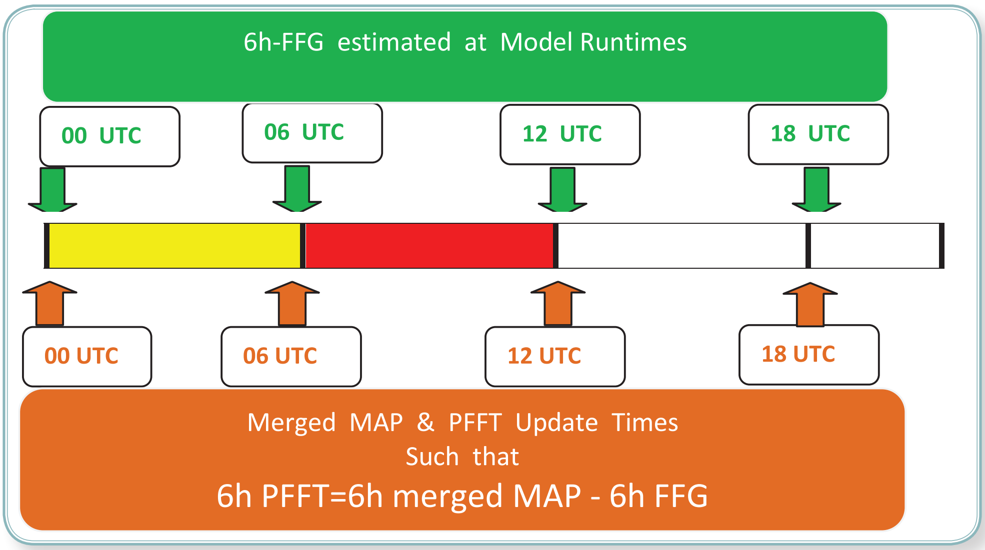


Figure-37 Schematic display of 6-Hour PFFT estimation scheme

The 06-Hour PFFT at 12 UTC, 1 October 2013 is shown in Figure-38. PFFT values were noted in the interior Aegean Sea Region having PFFT values of 10-40 mm/3h in orange and 0-10 mm/3h in yellow. In the color scale of the product, there distinct color schemes namely yellow, orange and red are applied that forecasters should pay close attention for the catchments that has orange and red color where flash flood occurrence is most likely should rainfall conditions persist.

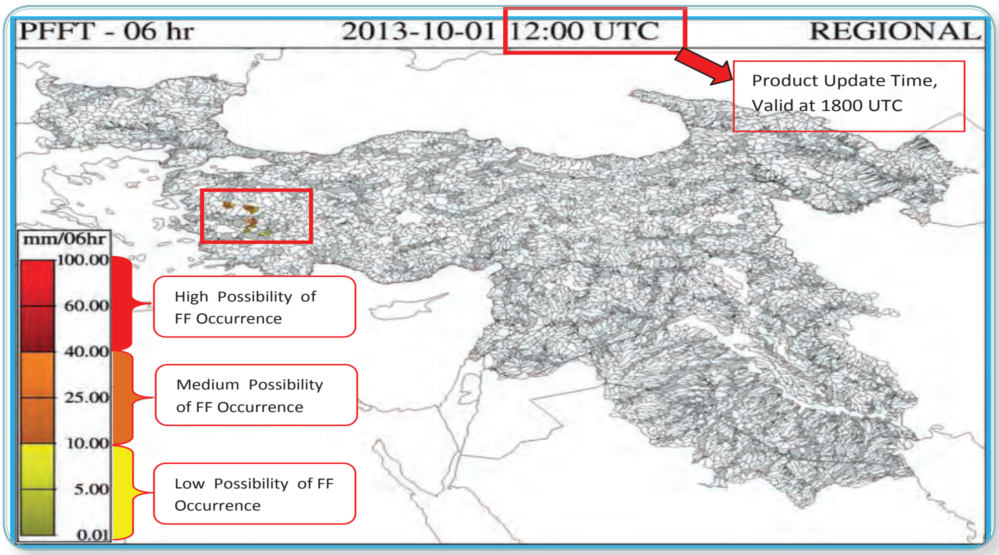


Figure-38 06-Hour PFFT at 12 UTC, 1 October 2013

6.11. ALADIN (ALARO) LAM Precipitation

ALADIN, was commenced in the early 1990s and led by Metéo France and has 15 member Meteorological Services mostly in eastern Europe and Turkey. The model is a high resolution Limited Area Model for short range forecasting. Currently the Turkish State Meteorological Service is running a non-hydrostatic version of ALADIN called ALARO with 4.5 km horizontal resolution. It runs four times a day at 00 UTC, 06 UTC, 12 UTC and 18 UTC producing precipitation forecasts out to 72 hours.

1-hour, 3-hour, 6-hour and 24-hour ALARO precipitation products are generated and updated every hour and displayed in the BSMEFFG Main Products console (Figure-39). It should be noted that the ALARO domain does not cover fully the BSMEFFG coverage area as some parts of Azerbaijan and Iraq are outside the model domain.

A robust precipitation forecast is the key for the estimation of Forecast Flash Flood Threat (FFFT) that might be a very useful tool for forecasters to issue flash flood watches/warnings/alerts taking into consideration existing and forecasted weather conditions. Forecasters should evaluate the ALARO outputs should note that if global and other mesoscale models are supporting the development and propagation of weather systems (e.g., frontal system, depressions over these regions) consistent with the ALARO outputs.

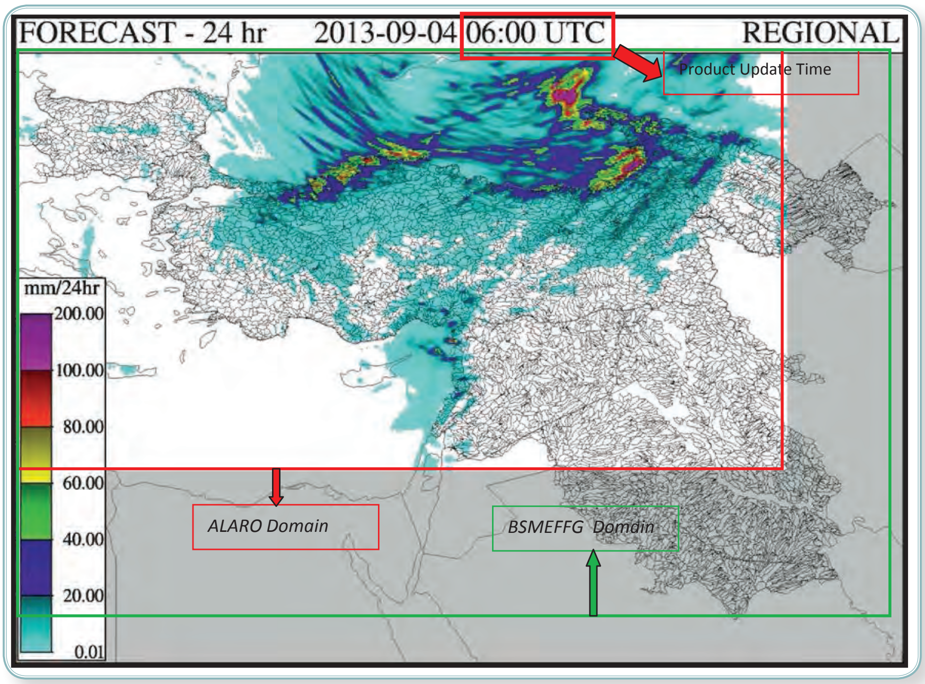


Figure-39 ALADIN limited area model domain as compared to the BSMEFFG domain

6.12. Forecast Mean Areal Precipitation (FMAP)

1-hour, 3-hour, 6-hour and 24-hour Forecast Mean Areal Precipitation products are generated from the ALARO precipitation forecasts for each catchment. Forecasters should analyze the catchments where intense precipitation has occurred and is forecast to occur for a given period and watch these regions during the forecast period.

On 4 September 2013 at 06 UTC, a frontal depression was located over the western Black Sea affecting the western Black Sea coastal region in Turkey as shown in Figure-40. ALARO predicted that depression was propagating north eastward affecting whole Black Sea coast, causing precipitation accumulation of 115 mm in 24 hours (Figure-41). A flash flood event was reported by a local meteorological station.

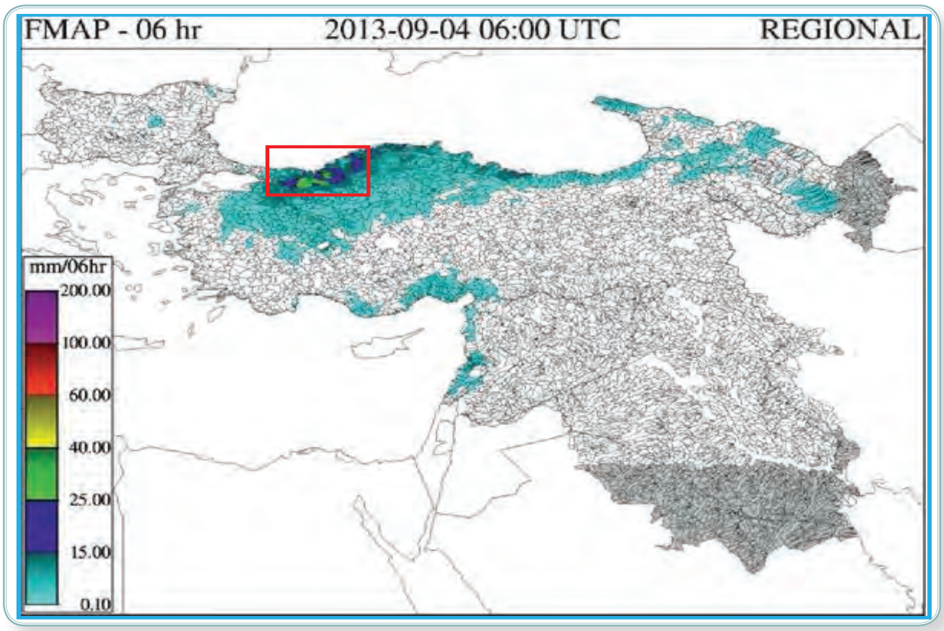


Figure-40 6-Hour accumulatedf Forecast Mean Areal Precipitation

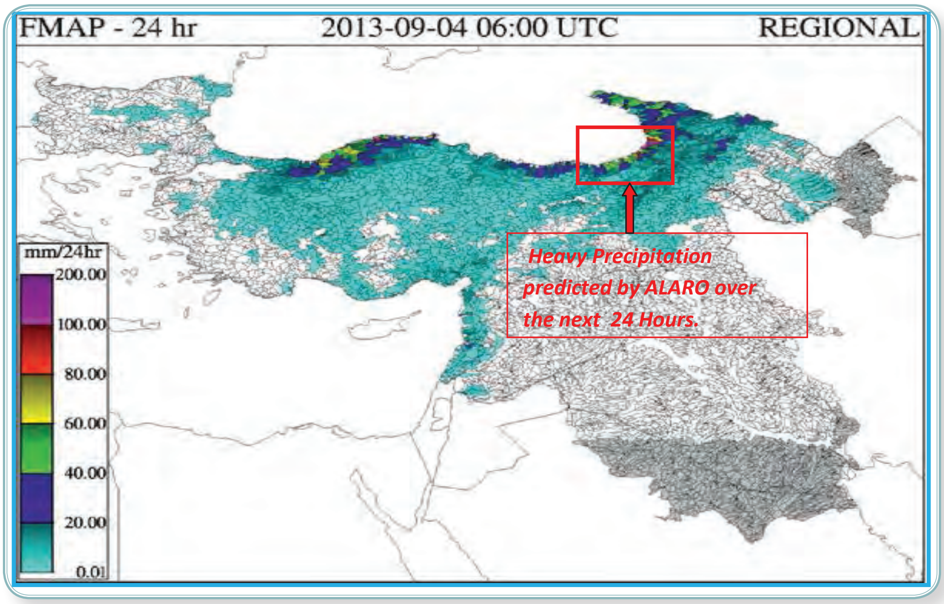


Figure-41 24-Hour accumulated Forecast Mean Areal Precipitation

Forecasters are generally under pressure to make a forecast for the particular regions and locations in a short period of time providing a detailed presentation of local maps showing town, cities and topography. Therefore, BSMEFFG products are further processed by using ArcGIS to produce maps with different layers as shown in Figure-42. One may use any available GIS applications like QGIS to generate similar maps such that product text data and basin ID can be accessed by clicking on "view" button located at the bottom of the product window. To make this post processing easier , work is underway to make a link between the BSMEFFG server to an ArcGIS server located in the Ministry of Forestry and Water Affairs to produce similar maps for all member countries users who will be able to access the GIS server directly.

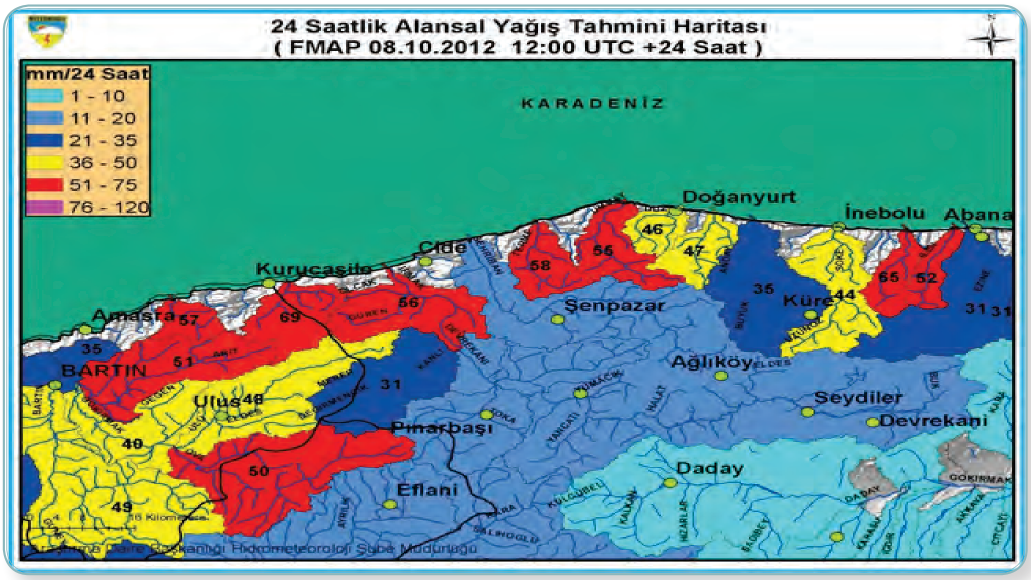


Figure-42 Overlay of 24-Hour FMAP data with Cities, towns and streams layers in western Black Sea region of Turkey using GIS

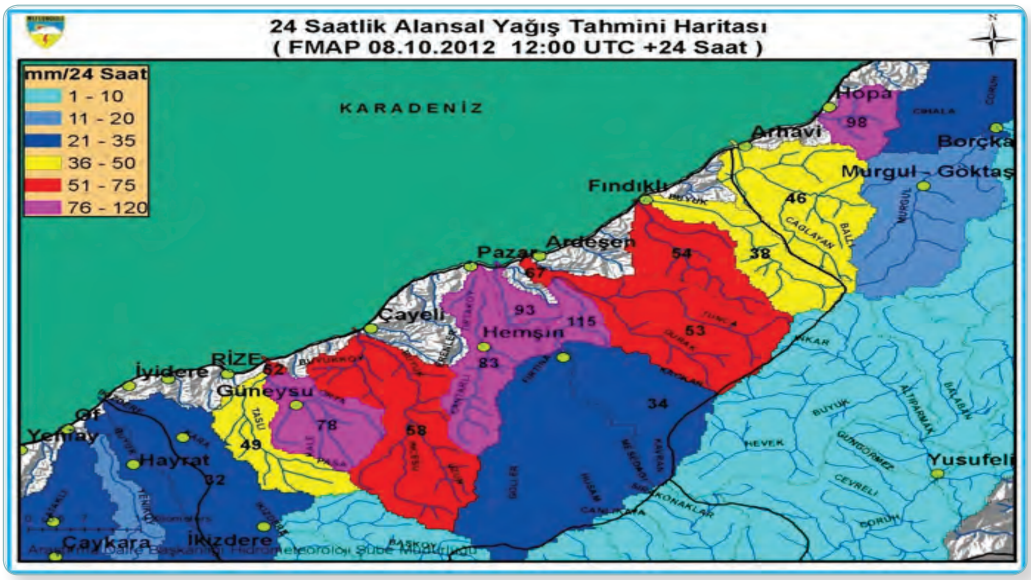


Figure-43 Overlay of 24-Hour FMAP data with cities, towns and streams layers in eastern Black Sea region of Turkey using GIS

6.13. Forecast Flash Flood Threat (FFFT)

Forecasters should note that contrary to IFFT and PFFT that use merged Mean Areal Precipitation generated from bias adjusted radar and satellite measurements (Merged MAP) or gauge surface measurements (Gauge MAP). FFFT estimation uses forecast mean areal precipitation generated from ALARO LAM (FMAP). These two are quite different kind of source of quantitative precipitation. Therefore,forecasters must analyze both types of products carefully.

Forecast flash flood threat which is the differences between forecast mean areal precipitation (FMAP) and FFG, created at the model runtimes of 00 UTC, 06 UTC, 12 UTC and 18 UTC. 1-hour, 3-hour and 6-hour FFFTs are estimated at the model runtimes and schematic definitions of FFFT products are given below.

6.13.1. 1-Hour Forecast Flash Flood Threat (1h-FFFT)

As depicted in Figure-44, 1-Hour FFFT is estimated and updated at 00 UTC, 06 UTC, 12 UTC and 18 UTC such that;

1-Hour FFFT at 00 UTC is the difference between FMAP at 00 UTC and current FFG at 00 UTC valid for 01 UTC. Similarly, the 1-Hour FFFT at 06 UTC is the difference between FMAP at 06 UTC and the current FFG at 06 UTC valid for 07 UTC; the 1-Hour FFFT at 12 UTC is the difference between FMAP at 12 UTC and current FFG at 12 UTC valid for 13 UTC; and the 1-Hour FFFT at 18 UTC is the difference between the FMAP at 18 UTC and the current FFG at 18 UTC valid for 19 UTC.

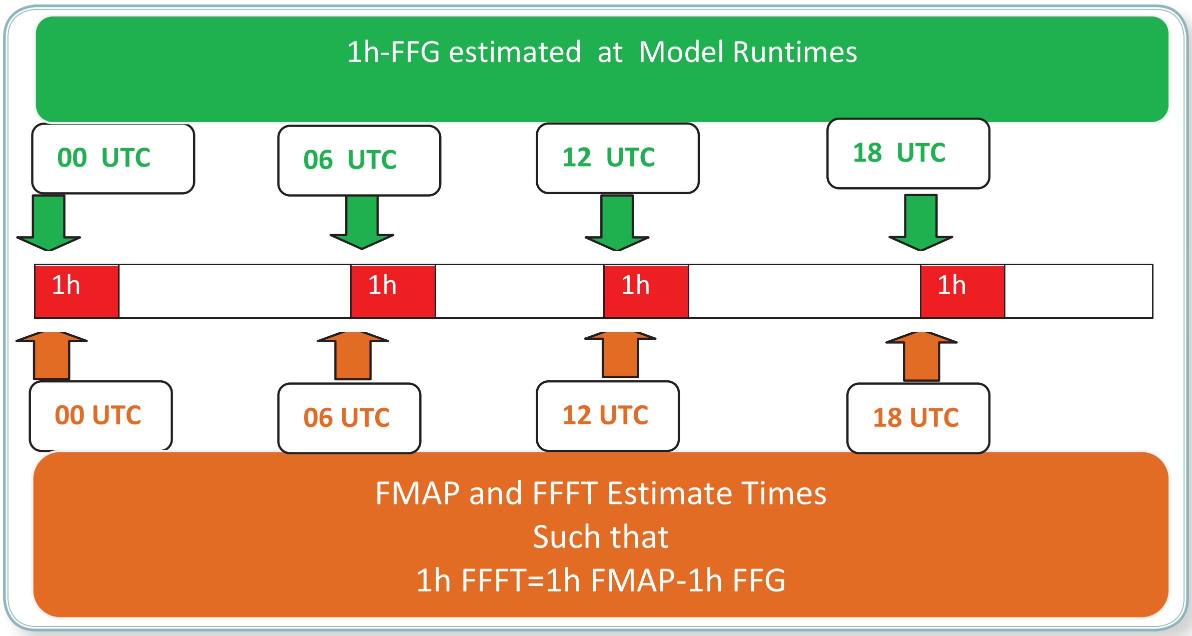


Figure-44 Schematic display of 1-hr FFFT estimation scheme

6.13.2. 3-Hour Forecast Flash Flood Threat (3h-FFFT)

As depicted in Figure-45, 3-Hour FFFT is estimated and updated at 00 UTC, 06 UTC, 12 UTC and 18 UTC such that;

The 3-Hour FFFT at 00 UTC is the difference between the FMAP at 00 UTC and current FFG at 00 UTC valid for 03 UTC. Similarly, the 3-Hour FFFT at 06 UTC is the difference between FMAP at 06 UTC and current FFG at 06 UTC valid for 09 UTC; the 3-Hour FFFT at 12 UTC is the difference between FMAP at 12 UTC and current FFG at 12 UTC valid for 15 UTC; and the 3-Hour FFFT at 18 UTC is the difference between FMAP at 18 UTC and the current FFG at 18 UTC valid for 21 UTC.

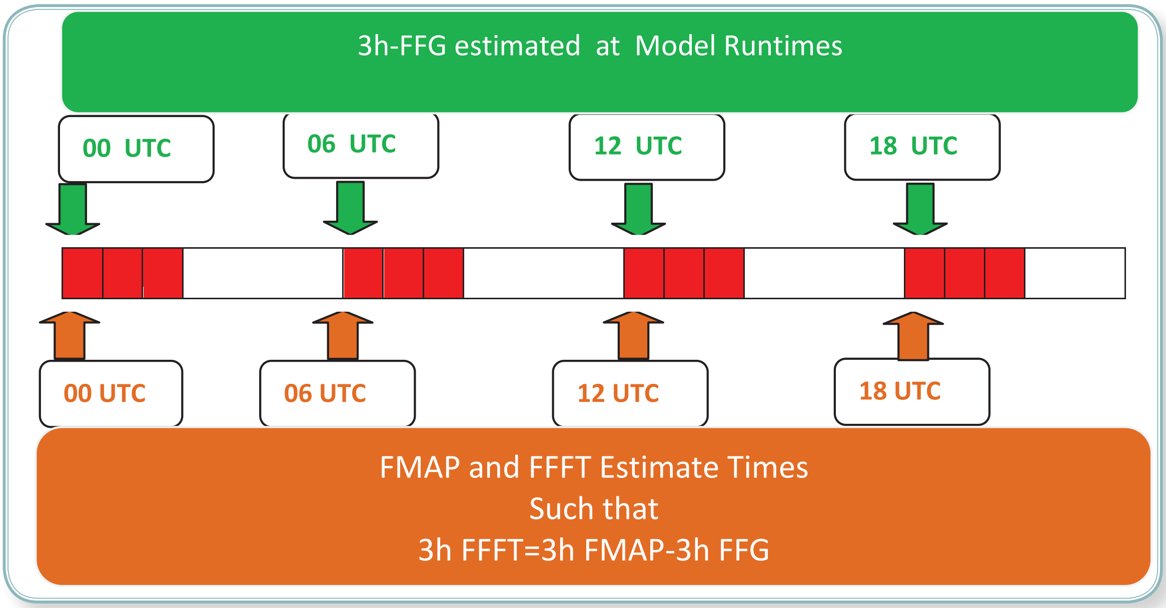


Figure-45 Schematic display of 3-hr FFFT estimation scheme

6.13.3. 6-Hour Forecast Flash Flood Threat (6h-FFFT)

As depicted in Figure-46, 6-Hour FFFT is estimated and updated at 00 UTC, 06 UTC, 12 UTC and 18 UTC such that;

The 6-Hour FFFT at 00 UTC is the difference between the FMAP at 00 UTC and current FFG at 00 UTC valid for 06 UTC. Similarly, the 6-Hour FFFT at 06 UTC is the difference between the FMAP at 06 UTC and current FFG at 06 UTC valid for 12 UTC; the 6-Hour FFFT at 12 UTC is the difference between FMAP at 12 UTC and current FFG at 12 UTC valid for 18 UTC; and the 6-Hour FFFT at 18 UTC is the difference between FMAP at 18 UTC and the current FFG at 18 UTC valid for 24 UTC.

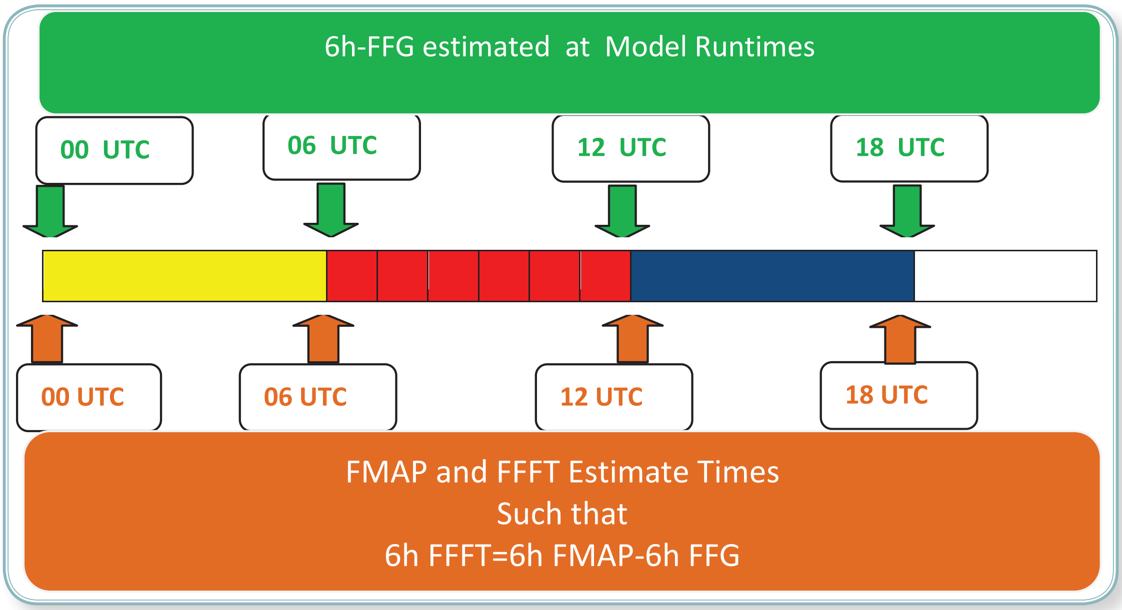


Figure-46 Schematic display of 6-hr FFFT estimation scheme

As 06-h FFFT on 07 February 2012 at 06 UTC is shown in Figure-47, low, medium and high FFFT values (yellow, orange and red) existed in the western Mediterranean, South Aegean Sea regions in Turkey and in Syria.

A flash flood bulletin was prepared to issue warnings for sub-basins in Turkey that have medium and high FFFT values where actually flash floods happened.

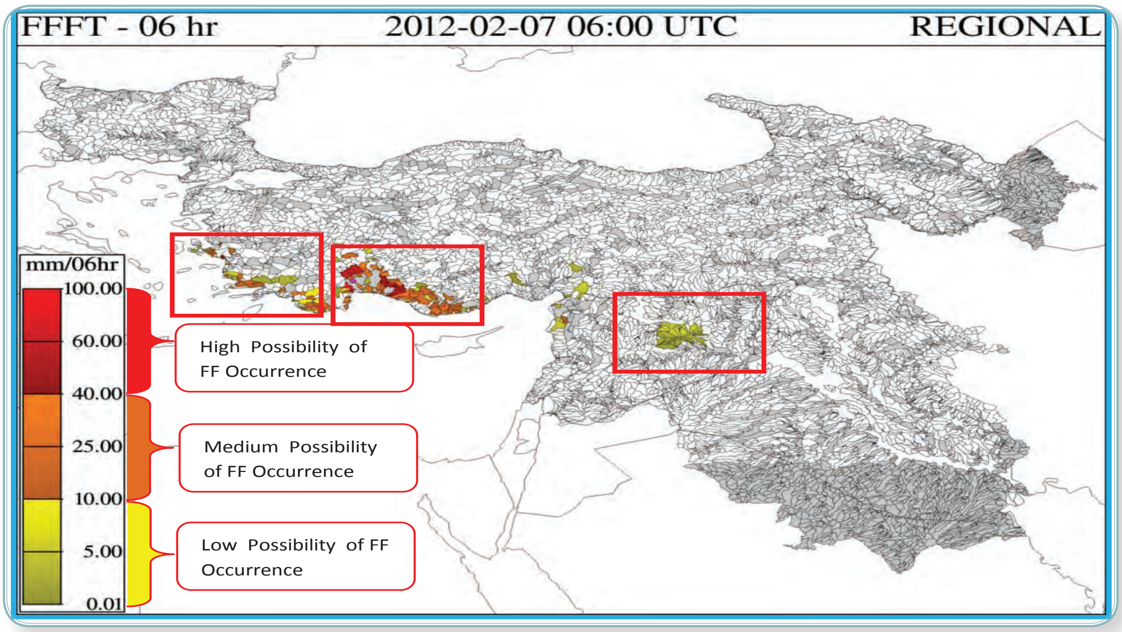


Figure-47 06-hr FFFT at 06 UTC, 7 February 2012

6.14. Gauge Mean Areal Temperature (GMAT)

Gauge Mean Areal Temperature (GMAT) is generated by using synoptic observations that are disseminated through WMO Global Telecommunication System (GTS). The more data submitted via GTS by member countries, the more accurate mean areal temperature product will be produced. Areal temperature is needed for each sub-basin for use in the SNOW-17 model.The areal temperature is generated from the point data from the GTS through interpolation.

GMAT is estimated four times a day over the last 6 hours ending at 00 UTC, 06 UTC, 12 UTC and 18 UTC. Figure-48 shows the 06-Hour GMAT ending at 12 UTC on 20 December 2013.

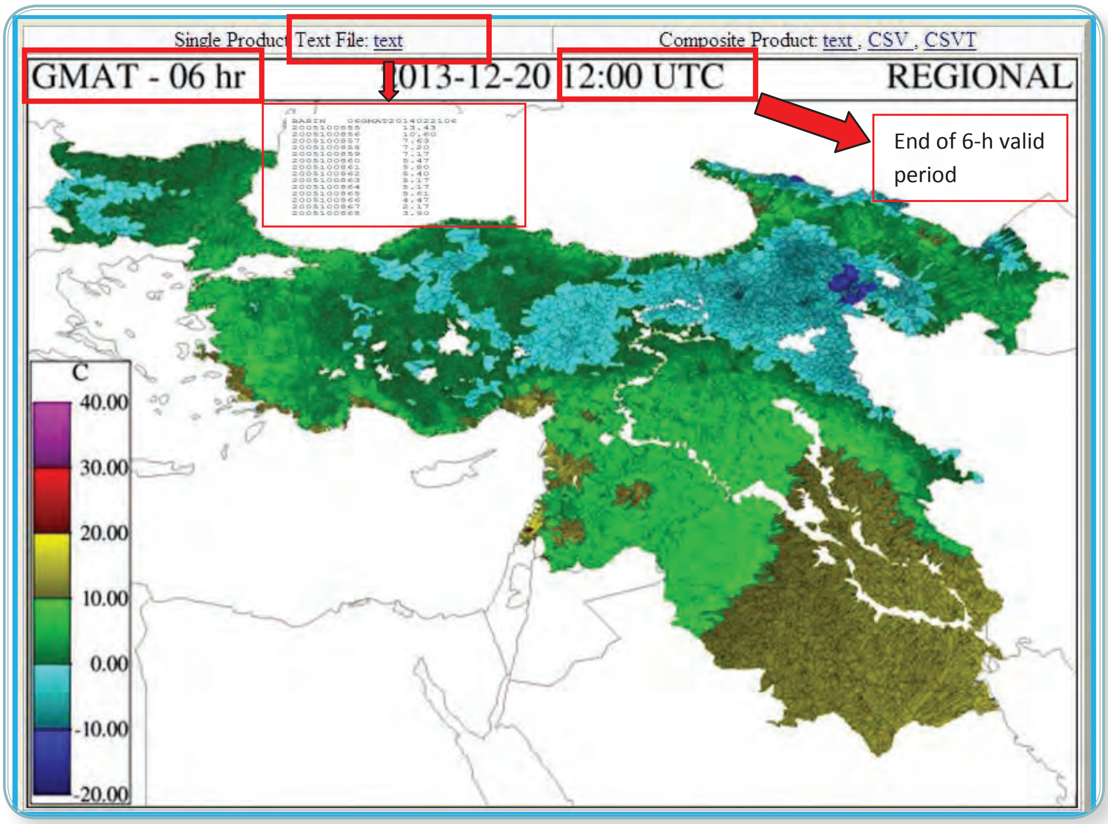


Figure-48 06-hr gauge Mean Areal Temperature (GMAT)

6.15. Latest IMS SCA (Snow Coverage Area)

Multi-sensor snow and ice mapping analysis for the northern hemisphere is performed by NOAA – NESDIS by using polar and geostationary satellites sensors like AVHRR, GOES-I-M, SSM/I. The IMS SCA product with 4 km resolution covers last 24 hours ending at 00 UTC. The NOAA IMS SCA product is then used to provide an FFG system product displaying the fraction of snow coverage for each sub-basin. Figure-49 shows 24-Hour SCA on 20 December 2013 at 00 UTC indicates that most of the Turkey and Georgia are covered by snow (basins with 100% coverage); little snow exists in Bulgaria; Azerbaijan and Armenia are partially covered.

Snow accumulation and melting has significant important for the region for the availability of water resources mostly for hydroelectric power generation and irrigation. On the other hand, flash floods occur due to rapid melting during the Spring.

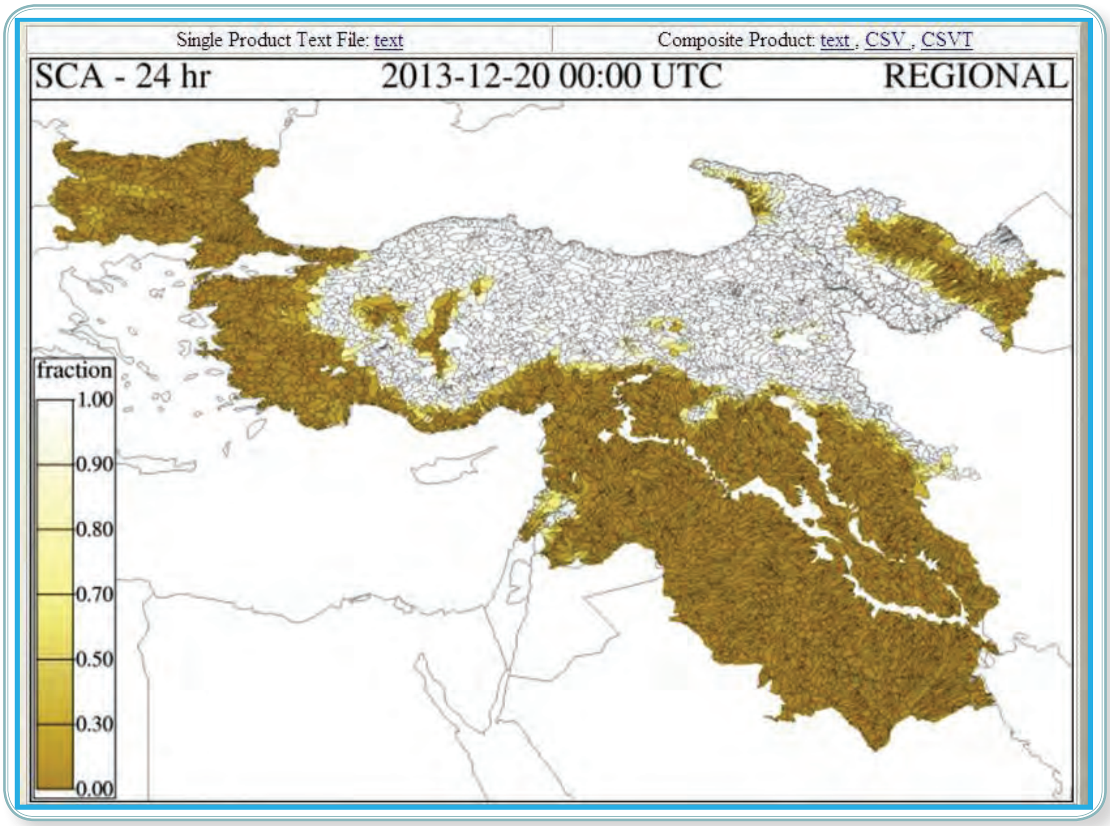


Figure-49 24-hr Snow Coverage Area

6.16. Snow Water Equivalent (SWE)

The Snow Water Equivalent product is a direct output of SNOW-17 accumulation and ablation model in the BSMEFFG and is estimated at 00 UTC, 06 UTC, 12 UTC and 18 UTC (Figure-50).The SNOW-17 model has two input variables namely gauged MAT and merged MAP and simulates a number of products including SWE and MELT (Section 6.17) by using equations that solve for energy and mass balance.

Snow is a crucial source of water for the member countries. Georgia, Armenia and Azerbaijan are located high mountainous Caucasus region where significant snow accumulation takes place during the winter season. In Turkey, the eastern Anatolian Region receives a lot of snow such that average snow height is above two meters feeding two large transboundary rivers – Tigris and Euphrates. There are many dams on the two rivers that are used to generate electricity and provide irrigation water such that almost thirty percent of Turkey's electricity is generated. Bulgaria is also a mountainous country that normally receives quite alot of snow during the winter.

Therefore, SWE is a very important product to show available water content in each subbasin for both water resources and flash flooding.

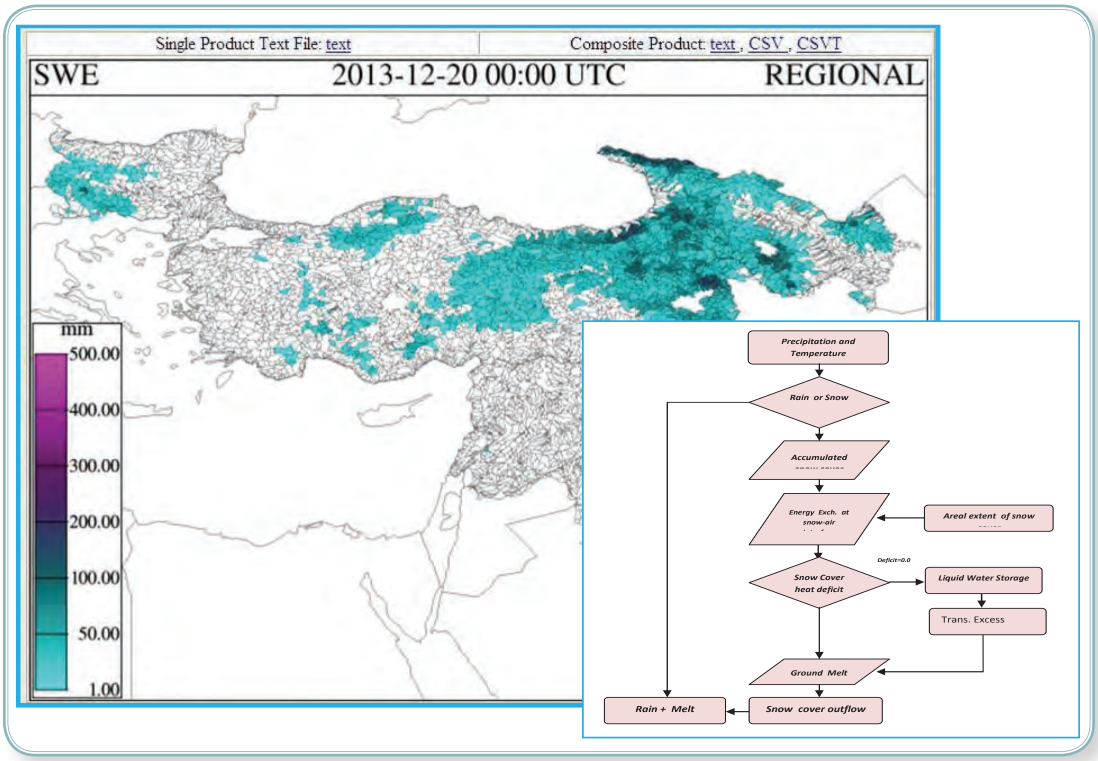


Figure-50 BSMEFFG Snow Water Equivalent(SWE) product and SNOW-17 algorithm flowchart

6.17. MELT

MELT is an estimate of ablation due to melt processes and is a direct output of the SNOW-17 model. MELT is estimated every six hours at the model runtimes of 00 UTC, 06 UTC, 12 UTC and 18 UTC. The product provides six-hour cumulative melt over periods of 24 and 96 hours (Figure-51).

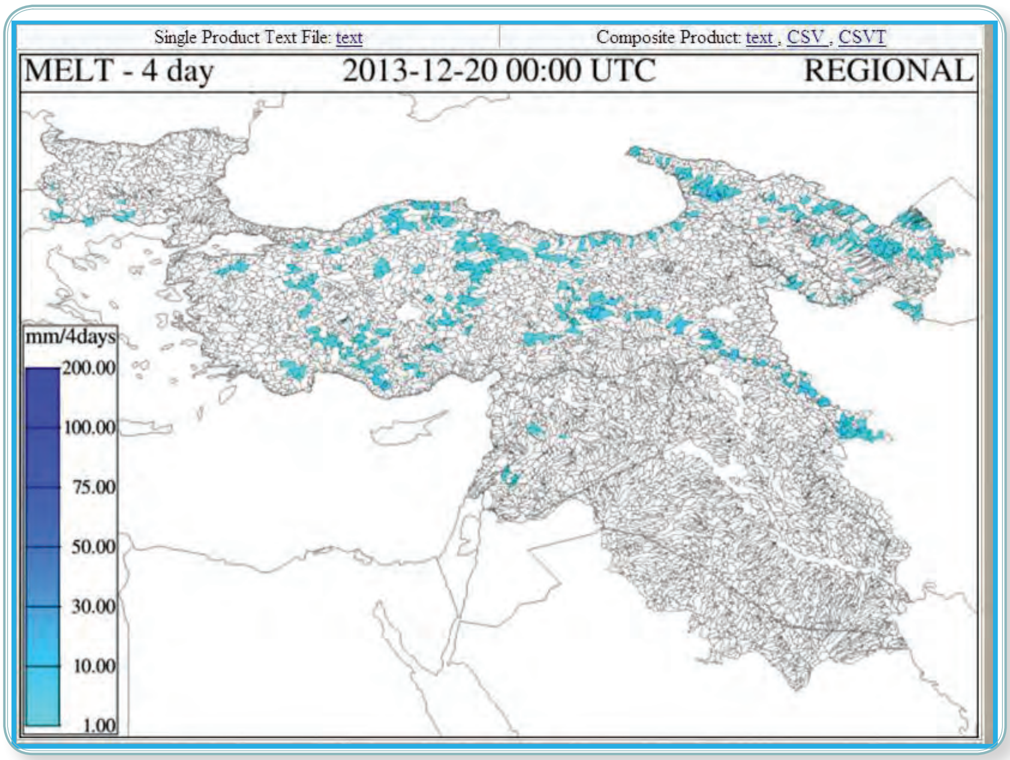


Figure-51 96-hr MELT product

7. Post Processing of Products with GIS

The BSMEEFFG forecaster product console displays products for each sub-basin but does not contain any geographical information like topography, cities, towns, borders, etc. Forecasters would like to see not only products but also additional layers that are displayed with the products so that precise event locations can be determined. Thus, the Turkish Meteorological Service uses ESRI ArcGIS Silverlight to provide two and three dimensional displays of products with additional data/information layers (Figures-52 and -53). This capability to use GIS with BSMEFFG products will also be available for all the member state forecasters through a GIS server hosted by the Turkish Meteorological Service.

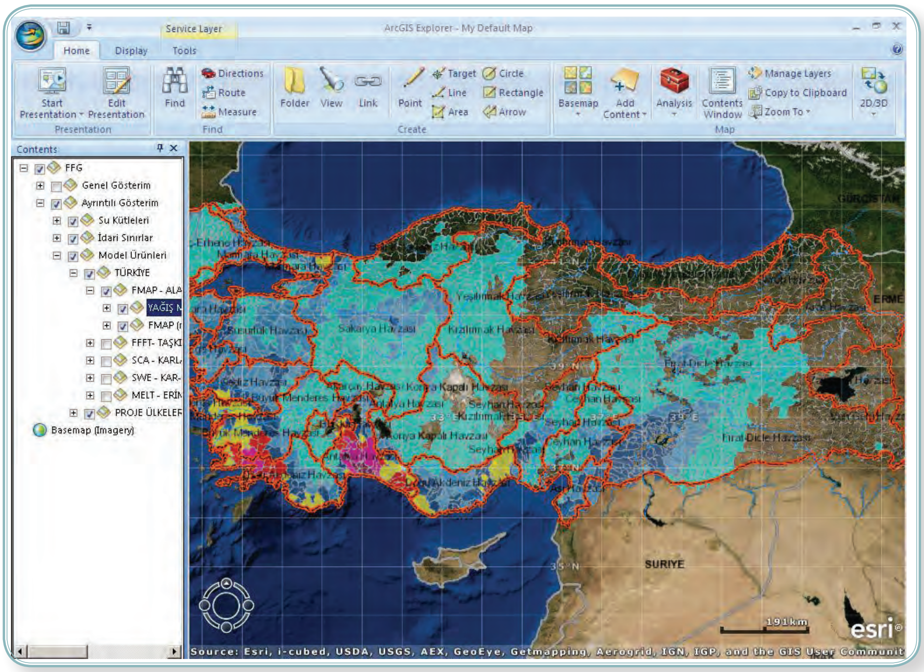


Figure-52 ArcGIS silverlight display of geographical information and BSMEFFG products

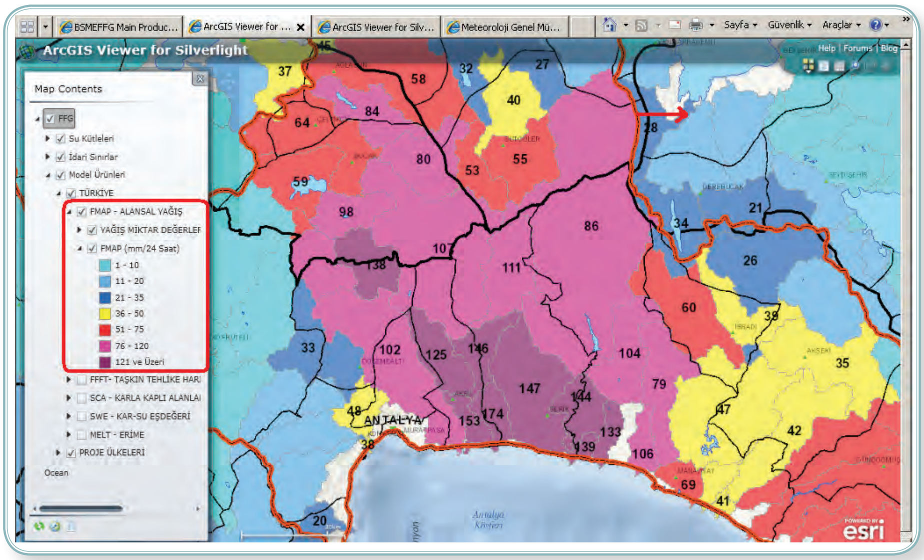


Figure-53 Two dimensional display of FMAP with cities and towns layers

8. Hydrology

The hydrological processes represented in the BSME Flash Flood Guidance System serve to estimate current flash flood guidance (FFG) at each processing time step and for each small watershed defined for the BSME region. FFG is defined as the amount of actual rainfall of a given duration and uniformly distributed over a watershed which is sufficient to cause bankfull flow at the watershed outlet. The computation of FFG is divided into two components: a static component, summarizing characteristics of the watershed, and a dynamic component, which incorporates time-varying changes in soil saturation conditions within each watershed.

The static component consists of analyses to define a characteristic of each watershed called threshold runoff. Threshold runoff (TR) is defined as the amount of effective precipitation of a given duration which produces the volume of runoff required to cause bankfull flow at the watershed outlet of the draining stream. TR is defined based on hydro-geomorphological principles as a characteristic of a given watershed, and is thus a "one-time" or static calculation. TR is calculated using the geomorphologic instantaneous unit hydrograph (GIUH) theory, which relates the peak response of a watershed for a unit rainfall input to catchment physical and geomorphologic characteristics (such as drainage area of catchment, stream length, stream slope), and the bankfull flow, which may be estimated by hydrologic principles based on the channel cross-sectional geometry. The threshold runoff theory was developed to allow for calculation of this characteristic threshold runoff using digital terrain data and GIS processing to define small watersheds at the scale of interest for flash flooding and to derive the physical properties of the watersheds required for the calculation of threshold runoff.

The dynamic component involves the time-varying accounting of soil moisture and evapotranspiration for each watershed to assess the current soil saturation deficit at each processing timestep. The aim of the soil moisture accounting process is to account for the losses in the transformation of rainfall to runoff (e.g., between actual rainfall and effective rainfall). The soil moisture accounting process considers the variation in soil properties and characteristics along with land use characteristics across the BSME region. The current FFG at any timestep and for any given watershed is then computed from the current soil saturation deficit and threshold runoff (FFG = TR + all precipitation losses at the current processing step).

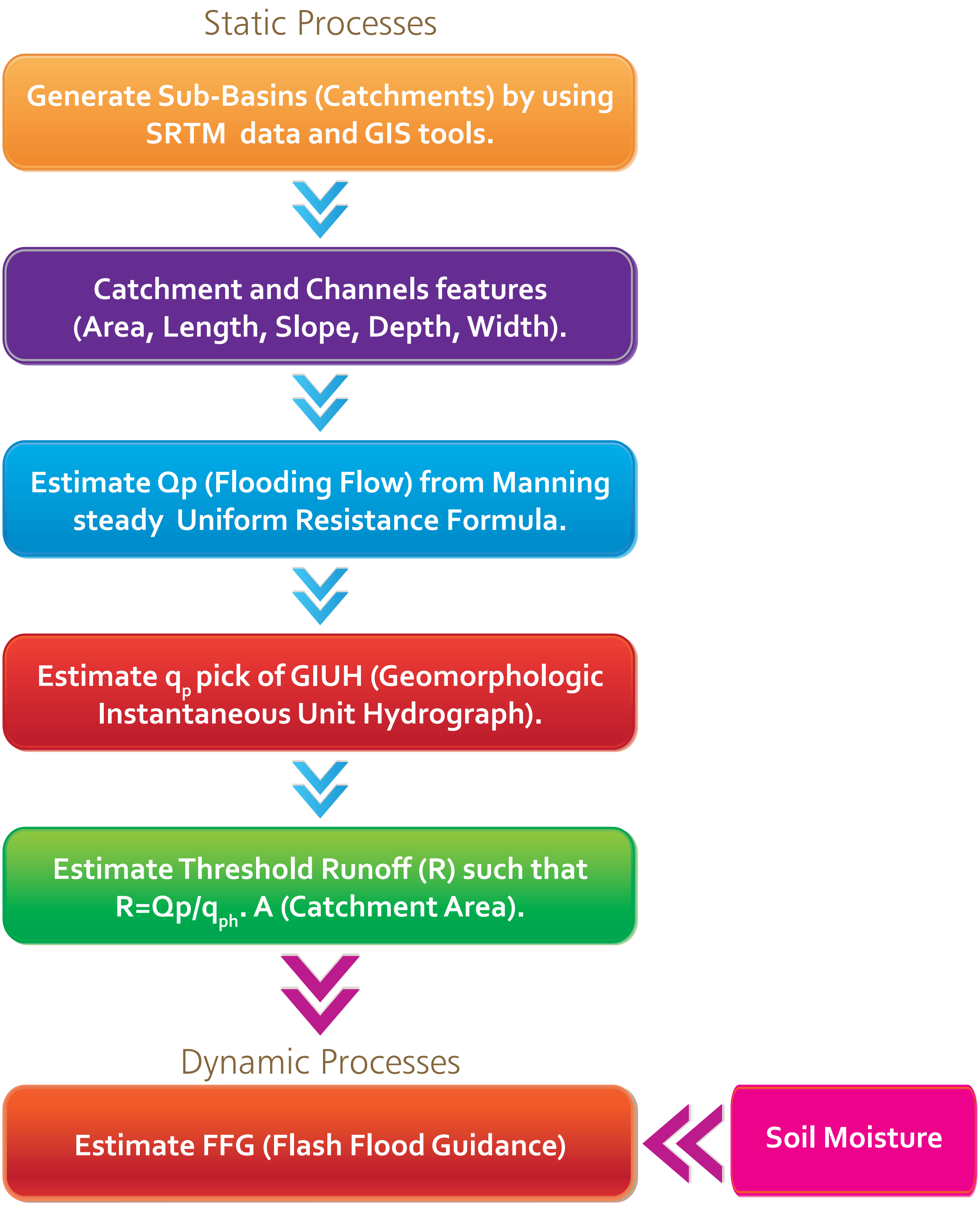


Figure-54 BSMEFFG hydrologic processes flowchart

9. Case Studies

Forecasters should use top down approach in terms of scale to investigate weather situations in a particular region when developing watches or warnings for flash floods. Forecasters should first perform a synoptic scale analysis, followed by a mesoscale analysis and finally a nowcasting analysis and interpretation of FFG products. As it may be stated earlier and depicted in Figure-3, forecasters must utilize available information at their Hydrometeorological Services and put their local experiences before issuing any flash flood watches/warnings/ alerts.

Because of the fact that weather is a dynamic system, past, current and future weather analysis should be performed. One or two days past weather and current analysis should be investigated to see weather developments in the particular regions. Then, regional Limited Area Models (LAM) like ALADIN, WRF and Global Models like ECMWF should be used to watch the propagation and development of the systems at the synoptic scale.

A) Synoptic Analysis

Synoptic analysis should include past two (2) days and future three (3) days of weather forecast outlook for the region by utilizing LAM and Global Models, including:

- **Surface Analysis;**
  - o Current weather,
  - o Low pressure centers and associated frontal system and movement with time,
  - o Pressure tendencies,
  - o Winds.
  - o Precipitation types and amounts.
- **850 hPa Analysis;**
  - o Trough and Ridges,
  - o Warm and cold air advection,
  - o Low level convergence,
  - o Winds directions,
  - o Humidity.
- **500 hPa Analysis;**
  - o Trough and Ridges,
  - o Warm and cold air advection,
  - o Convergence and divergence areas,
  - o Vertical Motion,
  - o Horizontal Winds.
- **JET Streaks;**
  - o JET locations and centers,
  - o Movement with time.
- **Satellite Images;**
  - o VIS and IR animations.
- **Comparison of various models precipitations;**
  - o ECMWF,
  - o ALARO,
  - o WRF.

B) Mesoscale Analysis

Mesoscale weather analysis contain higher scale analysis to monitor more detailed weather features with respect to synoptic scale analysis. At least the following meso-analysis should be performed by the forecast offices;

- Detailed surface analysis in finer scale,
- Dry line,
- Gust fronts,
- Mesoscale features of satellite images.

C) Nowcasting Analysis

Nowcasting is very short range forecasting with high resolution spatial features. The following should be analyzed depending on availability of data and tools:

- RADAR images;
- Instability Analysis;
- Rapid scan METEOSAT images;
    - o Thunderstorm developments,
    - o Weather system developments.
- Monitoring of thunderstorms developments;
    - o Lightening detectors,
    - o Satellite lightening retrieval products,
    - o Ground observations.
- Precipitation.

Preamble

Before the case studies, it is necessary to inform readers about long term annual precipitation distribution and geographical distribution of flash floods in Turkey. Figure-55 shows annual total precipitation normals for the period of 1981 and 2010. Coastal regions receive most of the precipitation. The highest value of approximately 2200 mm is recorded for the eastern Black Sea region. In the Mediterranean region, Antalya and Hatay provinces get quite high precipitation with approximately 1500 mm. In the Aegean Sea region, Marmaris town and its vicinity receive precipitation value of app. 1300 mm. In the eastern Anatolia region, precipitation distribution is patchy such that some areas receive high precipitation while some areas receive much less precipitation. Central Anatolia and south east Anatolian regions get the least precipitation.

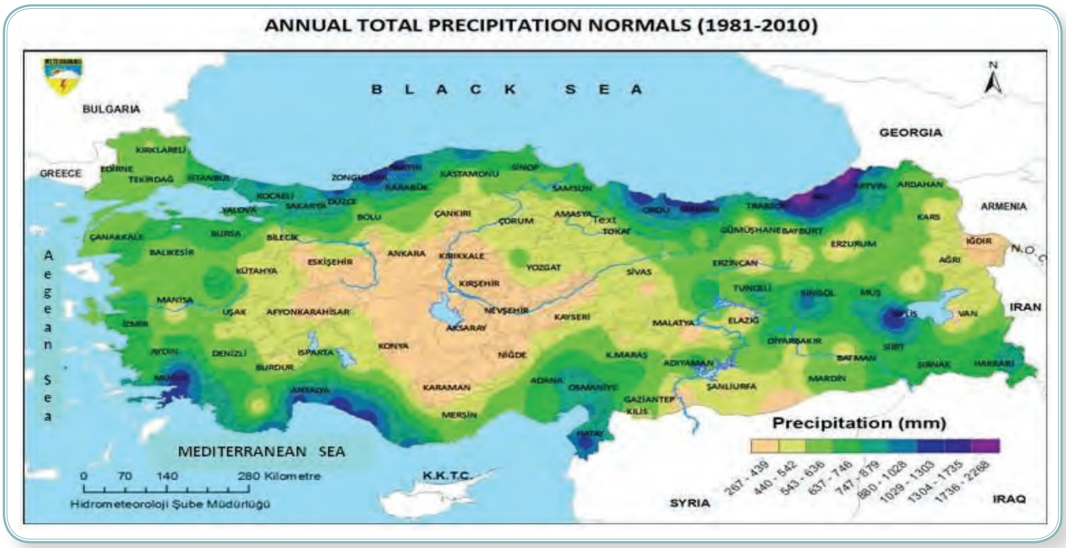


Figure-55 Annual total precipitation normals(1981-2010)

Figure-56 shows geographical distribution of frequencies of floods, urban flooding and flash floods for the period of 1940 and 2010 that inflicted damages. It is obvious that coasts are prone to flooding that is consistent with the convective storm developments and propagation of depressions. There are several regions flooding frequencies which have peak values that are shown as dark blue. They are Balıkesir, İzmir and Muğla provinces in the Aegean Sea region; Antalya province in the Mediterranean region; Ankara province in the central Anatolia region; Rize province in the Eastern Black Sea region; and Kars province in the Eastern Anatolian region.

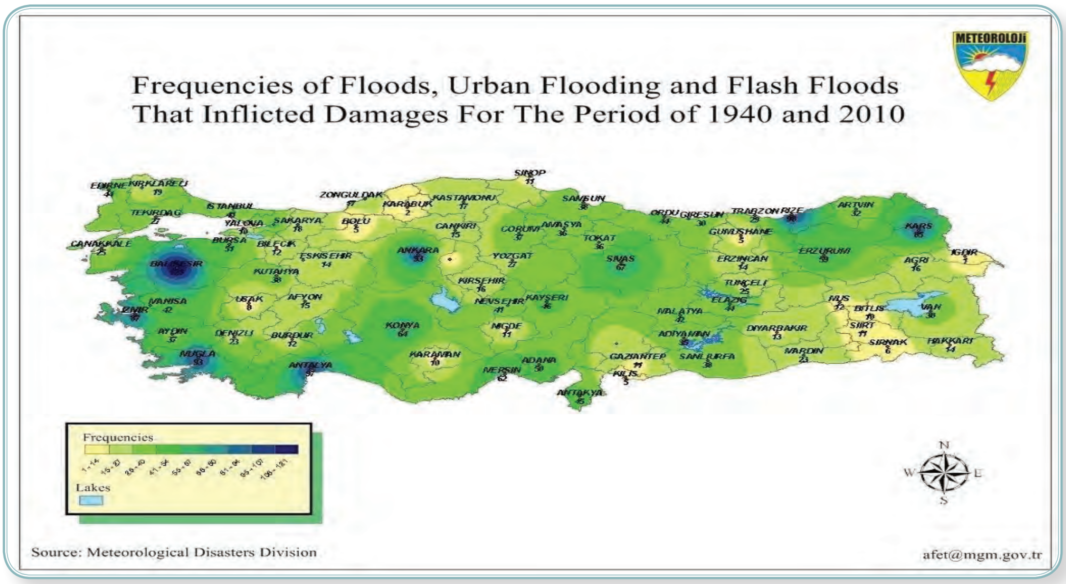


Figure-56 Frequencies of floods, flash floods and urban flooding in Turkey (1940-2010)

Therefore, we are going to investigate four flash flood events as case studies that occurred in Marmaris and Hopa towns and Samsun and Antalya provinces which are the regions prone to flash floods.

9.1. Marmaris Flash Flood Event

Marmaris (36.8395,28.2452; WMO synoptic Station No: 17298), which is located in the southern Aegean Sea Region of western Turkey on Aegean Sea coast, is a very popular touristic town (red dot). Marmaris is prone to flash floods. Eastern Mediterranean depressions, which bring warm and moist air from the south and the southwest are coupled with orographic lifting causing heavy precipitation. Historical hydrometeorological observations show that Marmaris gets very intense storms during autumn, winter and spring making flash floods occurrences very frequent not only in Marmaris but also in the Aegean Sea Region.

On the 21st and 22nd of November there was a deep Mediterranean cyclone over the west of Italy that influenced Greece and western Turkey. ECMWF, ALARO and WRF models up to 72 hours precipitation forecasts predicted heavy and very heavy rainfall over Greece and western Turkey. Marmaris AWOS station reported that precipitation started on the 21st of November at 14 UTC and continued until 23rd at 11 UTC, having 283.2 mm accumulated precipitation. Figure-57 depicts rainfall intensity (mm/hr) on 21-23 November 2013. There are two distinctive peaks with more that 50mm/hr rainfall intensity at 19 UTC on the 21st and at 12 UTC on the 22nd. The flash flood event started at 02 UTC and ended at 14 UTC on the 22nd .

During the same period, flash floods occurred not only in Marmaris and in the southern Aegean Sea Coast of Turkey, but also in Greece on the island of Rhodes which is located just several kilometers away from Marmaris. There were heavy property damages in the region and three people were killed on Rhodes. This is the first case study to analyze meteorological conditions as well as Black Sea and Middle East Flash Flood Guidance products to determine whether to prepare and issue a flash flood bulletin or not.

A top-down approach is used for the analysis meaning that first synoptic scale then mesoscale and nowcasting analysis were carried out and finally flash flood products were reviewed and analyzed.

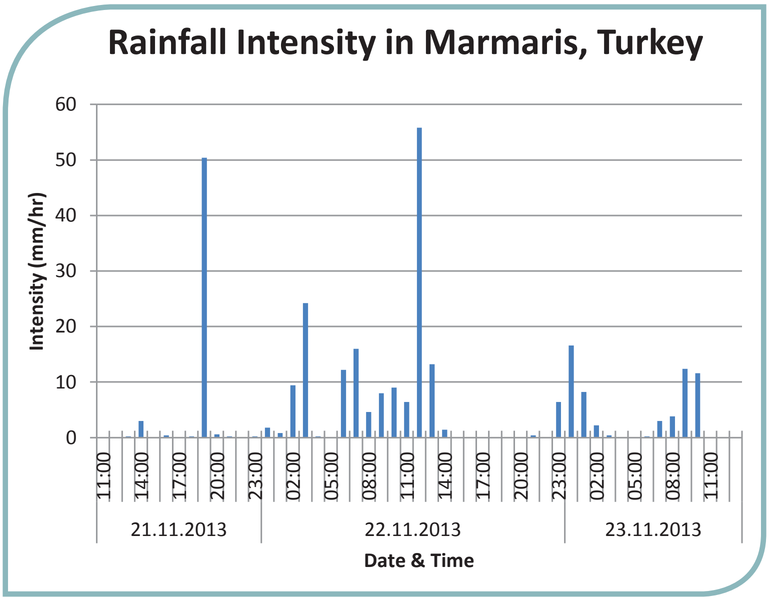


Figure-57 Rainfall intensities recorded at the marmaris AWOS

9.1.1. Synoptic Analysis

Figure-58 shows superimposed (overlaid) surface and 850 hPa charts such that surface contours and 850 hPa contours were shown in bold black and bold red, respectively on 22 November 2013 at 00 UTC and 12 UTC. A low pressure center with 996 hPa value was located in northwestern Italy; while, a secondary low pressure center was located over northern Greece at 00 UTC. The frontal system associated with the low pressure affected western Turkey as surface pressure tendencies had negative values toward the east and the southeast of the low pressure center, indicating that system will move toward the east and the southeast. At 12 UTC, the low pressure center with 996 hPa value moved toward the south over Malta and the secondary low pressure center moved to Crete and to the west of Marmaris.

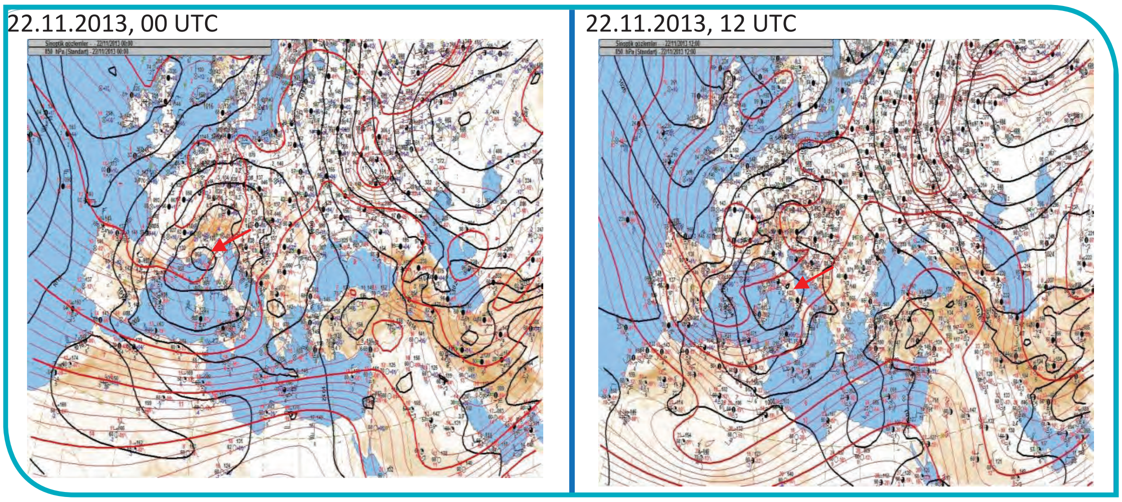


Figure-58 Superimposed surface and 850 hPa charts at 00 UTC (left) and 12 UTC (right) on 22 November 2013

This is a typical Mediterranean depression system causing heavy frontal precipitation ahead of the warm front and along the cold front. At the 850 hPa level, warm air advection from the southwest and cold air advection from the northwest resulted in deepening of the depression.

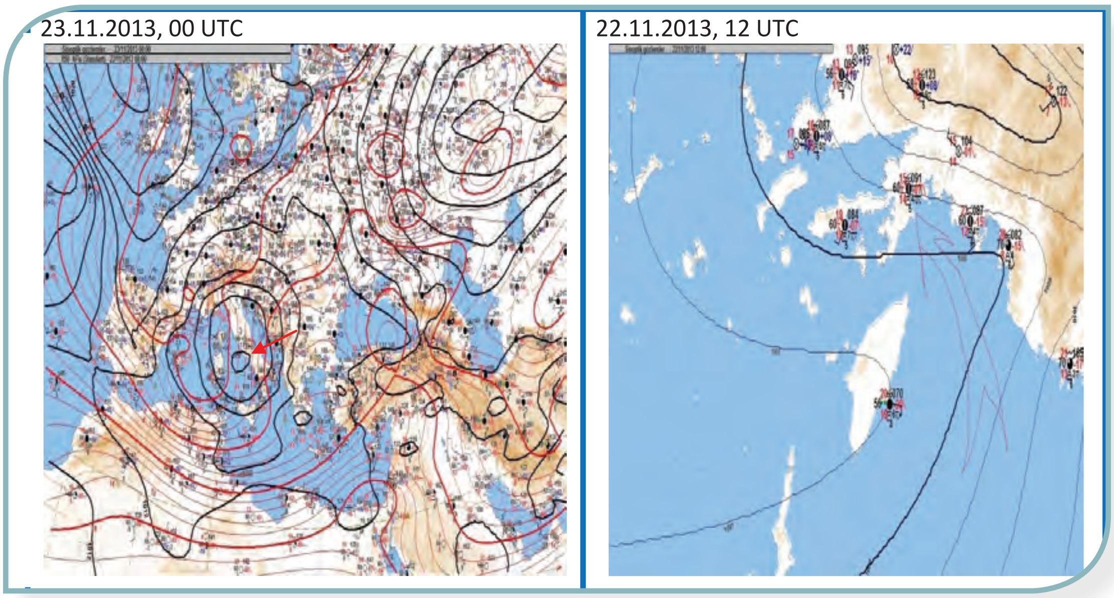


Figure-59 Overlaid surface and 850 hPa charts at 00 UTC on 23 November 2013 (left) and zomed surface chart of Marmaris vicinity at 12 UTC on 22 November 2013 (right)

Figure-59 shows overlay of the surface chart and 850 hPa isotherms, indicating that the low pressure center moved eastward and warm and cold air advection was pronounced. The surface chart depicts that southwesterly warm and moist air propagated toward Marmaris.

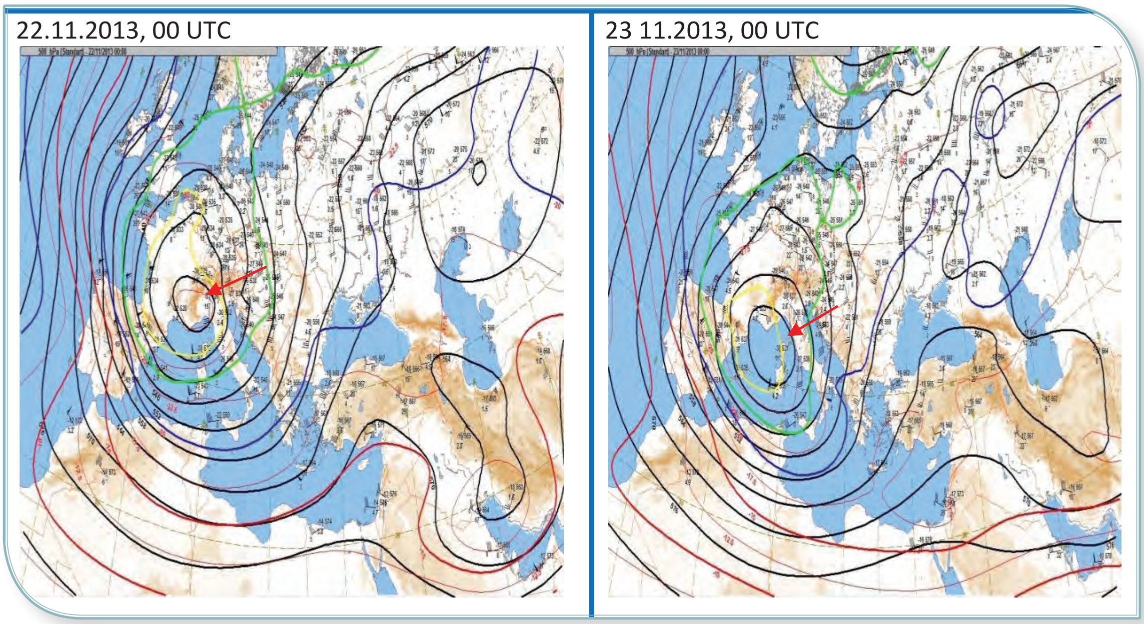


Figure-60 500 hPa at 00 UTC on 22 November 2013 (left) and 00 UTC on 23 November 2013 (right)

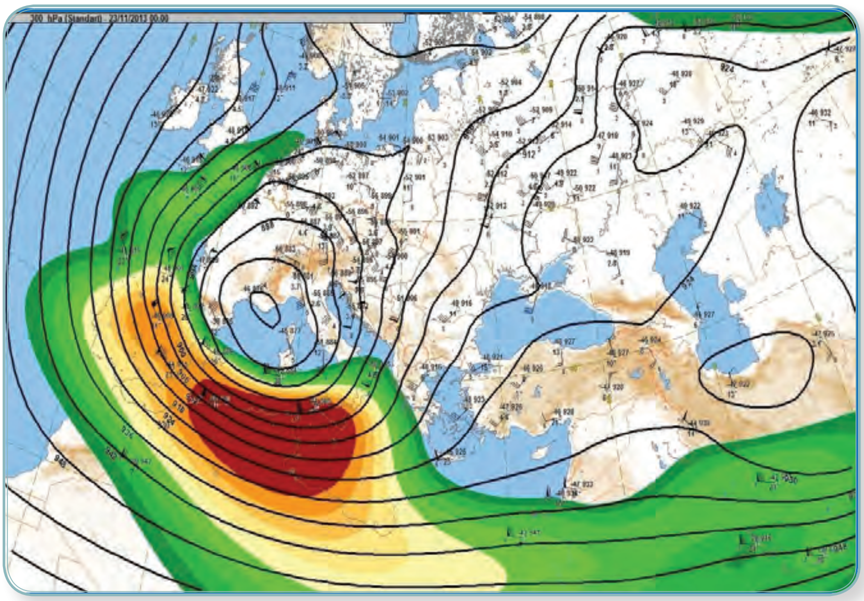


Figure-61 300 hPa Jet Stream at 00 UTC on 23 November 2013

On 22 November 2013 at 00UTC, a 500 hPa low center was located in the south east of France, having 528 hPa geopotential height and -35^{0}C temperature values while the temperature over Turkey was -17^{0}C . A trough was expanding over Tunisia through western Italy. In the west of the trough, geopotential height contours were very close to each other indicating presence of very strong winds. On 23 November 2013 at 00 UTC, the low center propagated southward. Convergences ahead of the low center indicated low level divergence, and upward vertical motion and divergences behind the low center were well pronounced (Figure-60). The polar jet stream, which was associated with the frontal system, had 120 knots maximum wind speed in the jet core (Figure-61).

9.1.2. Instability Analysis

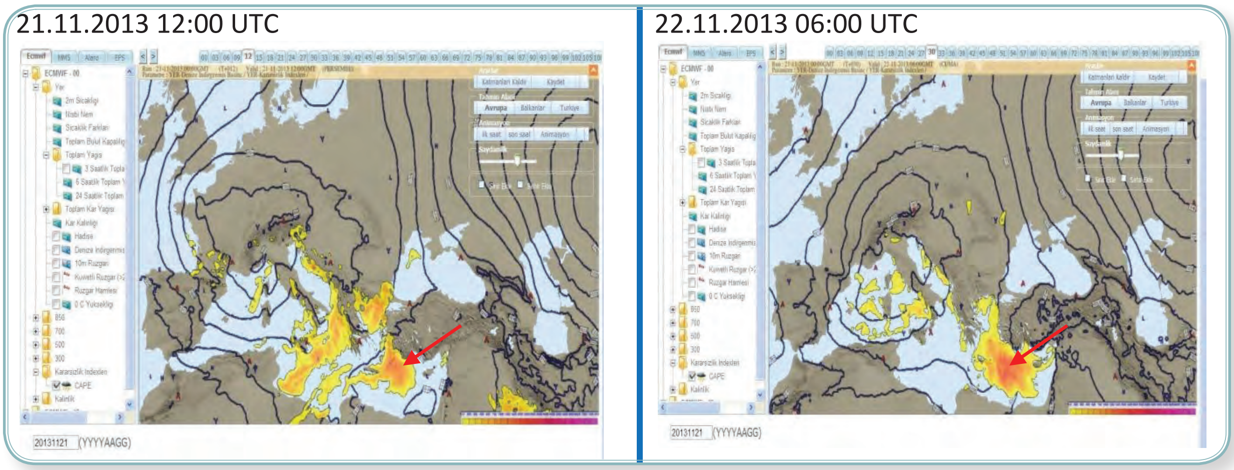


Figure-62 ECMWF CAPE (Convective Available Potential Energy)

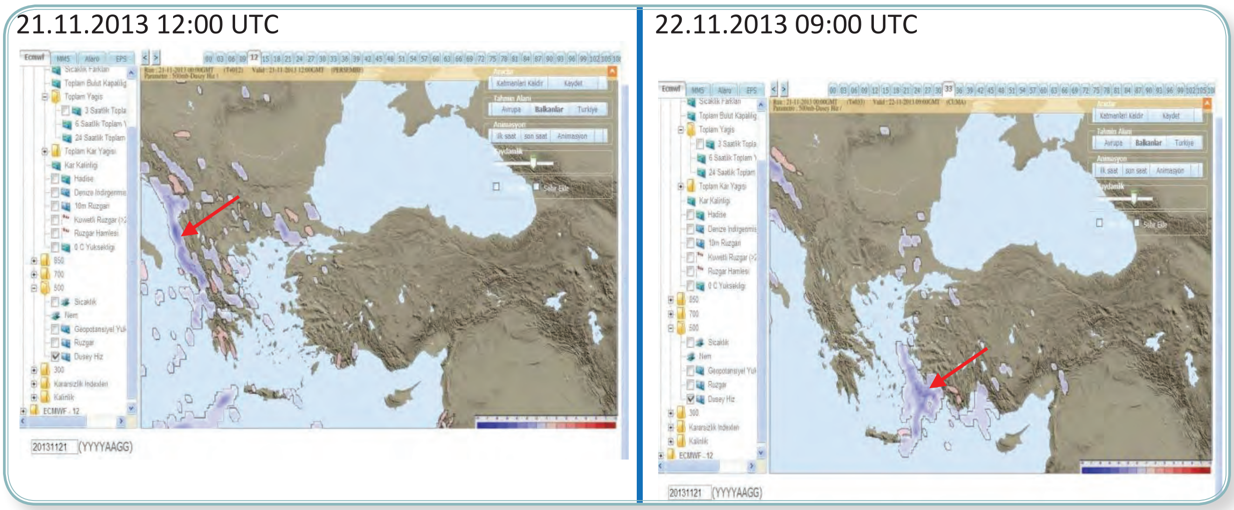
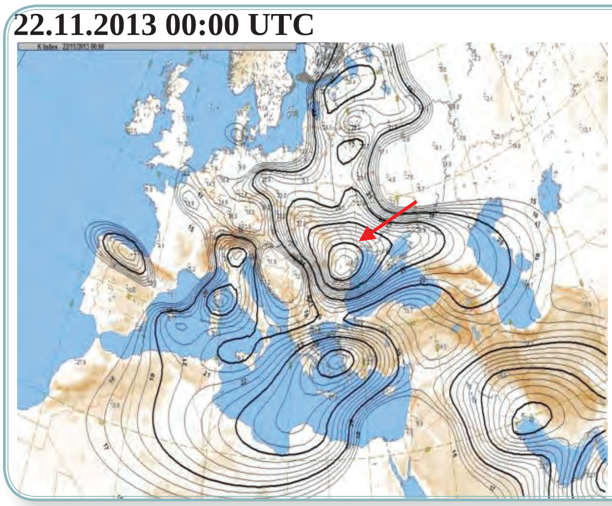


Figure-63 ECMWF 500 hPa vertical motion



Figures-62 and -63 show ECMWF CAPE (Convective Available Potential Energy) which indicate potential atmospheric instability such that the bigger the CAPE values the more instable the atmosphere, having the maximum values of 1250 and 1200 respectively over southern Aegean Sea. Similarly, another instability index called K-Index is shown in Figure-64 such that the highest value of 30 was located in the southern Aegean Sea. Instability analysis show that atmosphere was very instable over Greece and western Turkey indicating that there was a high probability of development of severe thunderstorms.

Figure-64 K-Index

9.1.3. Satellite and RADAR Images

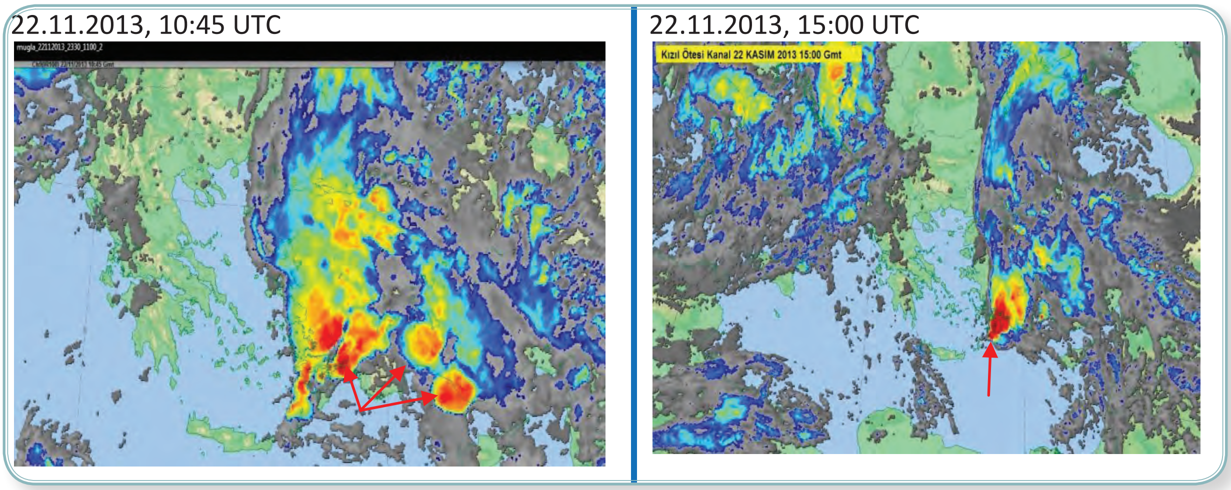


Figure-65 METEOSAT MSG (Meteosat Second Generation) IR (Infrared) RGB images at 10:45 UTC and 15:00 UTC on 22 November 2013

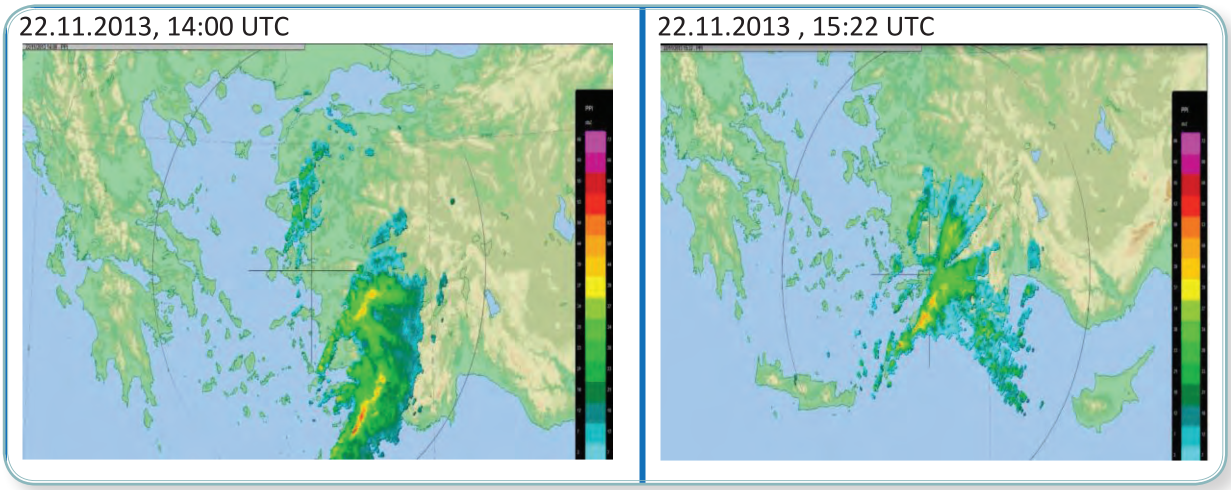


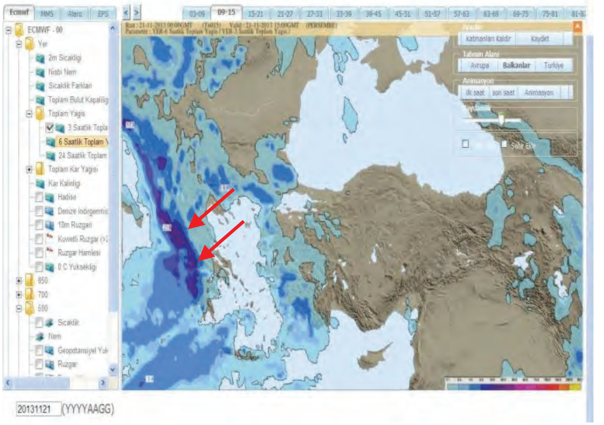
Figure-66 TSMS RADAR PPI peflectivity at 14:00 UTC and 15:22 UTC on 22 November 2013

Figure-65 shows METEOSAT MSG geostationary satellite RGB representative of IR images on 22 November 2013 at 10:45 UTC and 22 November 2013 at 15 UTC indicating high cloud top temperature and convective clouds colored in red over Marmaris, southeast Marmaris and Rhodes island. They were cumulonimbus (Cb) type clouds associated with heavy rainfall.

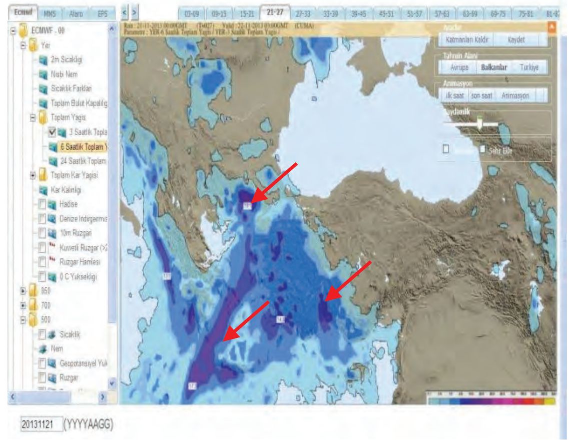
Radar PPI reflectivity images are shown in Figure-66. In the first image (left) a cloud band expanded from central Aegean Sea Region to the south of Rhodes island having the maximum reflectivity over Rhodes island and Marmaris such that the higher the reflectivity the higher the rainfall intensity.

9.1.4. ECMWF Precipitation Forecast

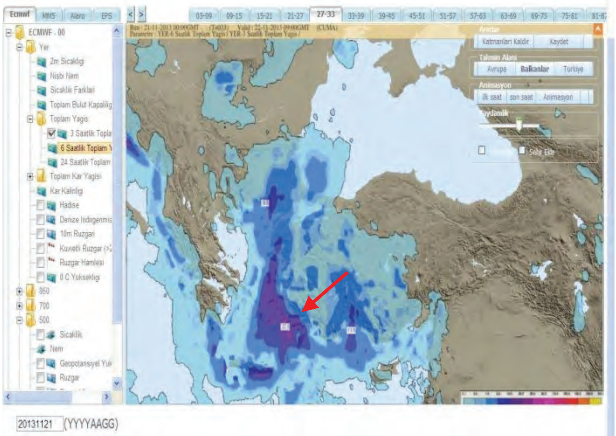
21.11.2013 15:00 UTC



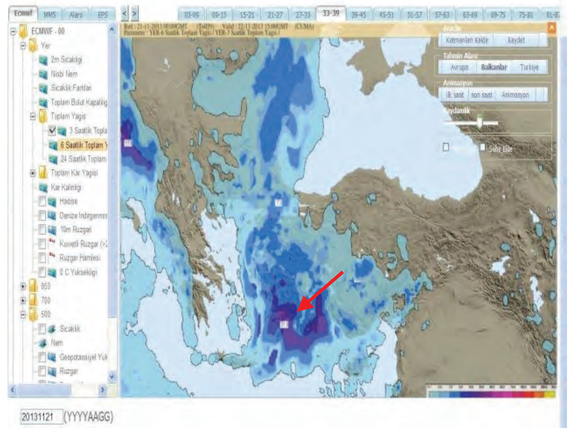
22.11.2013 03:00 UTC



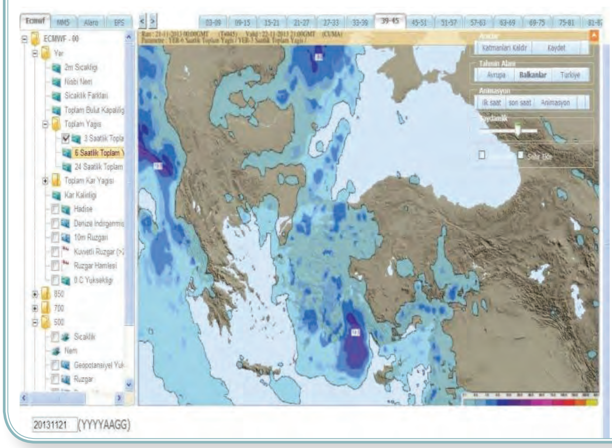
22.11.2013 09:00 UTC



22.11.2013 15:00 UTC



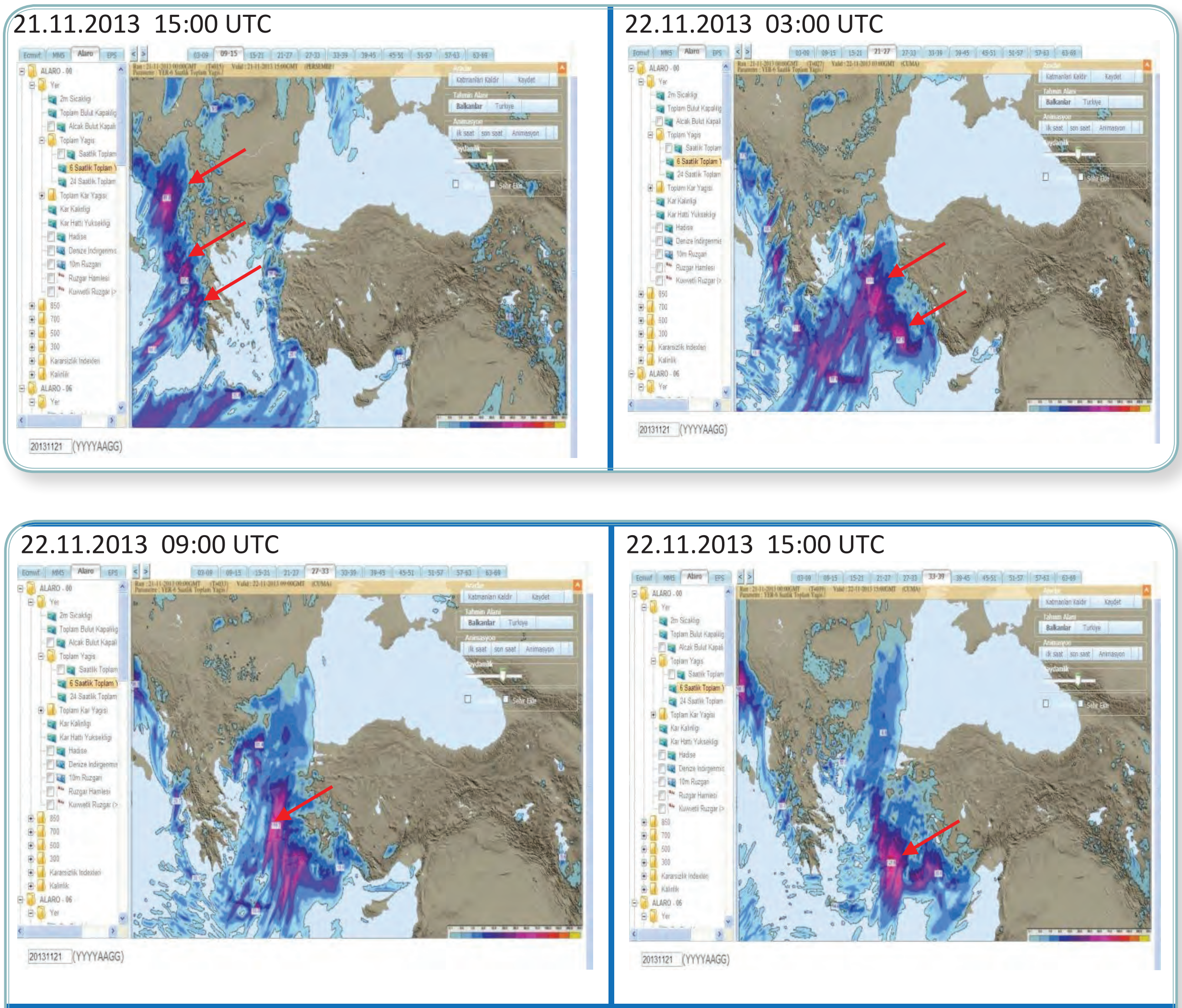
22.11.2013 21:00 UTC

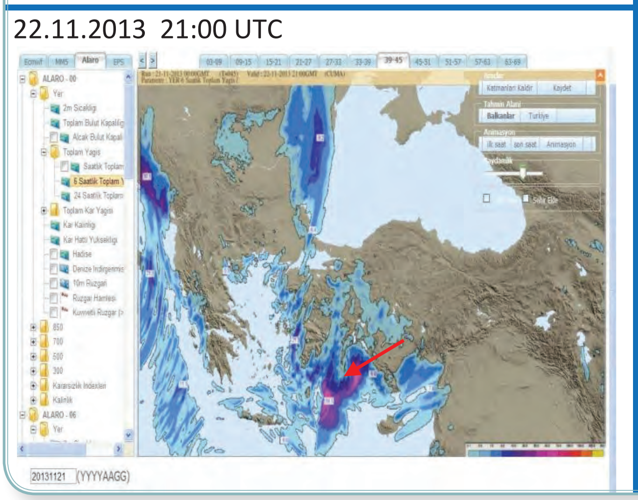


6-hour ECMWF precipitation forecast is presented from November 21 at 15 UTC to 22 at 21 UTC, showing that the precipitation band was located over Greece and propagated to the east and the south east, Rhodes island and Marmaris with the maximum values of 52.2 mm, 24.5 mm, 32.8 mm, 48.5 mm, 37.1 mm respectively.

Figure-67 ECMWF precipitation forecast

9.1.5. ALARO Precipitation Forecast





6-hour ALARO precipitation forecast is presented from the 21st of November at 15 UTC to the 22nd at 21 UTC, showing that the precipitation band was located over Greece then propagated toward western Turkey with the maximum precipitation values of 81.8 mm, 95.6 mm, 119.7 mm, 121.6 mm and 156.5 mm.

When compared with ECMWF 6 hourly precipitation forecasts, it is obvious that ALARO precipitation forecasts were much higher.

Figure-68 ALARO precipitation forecast

9.1.6. BSMEFFG Products

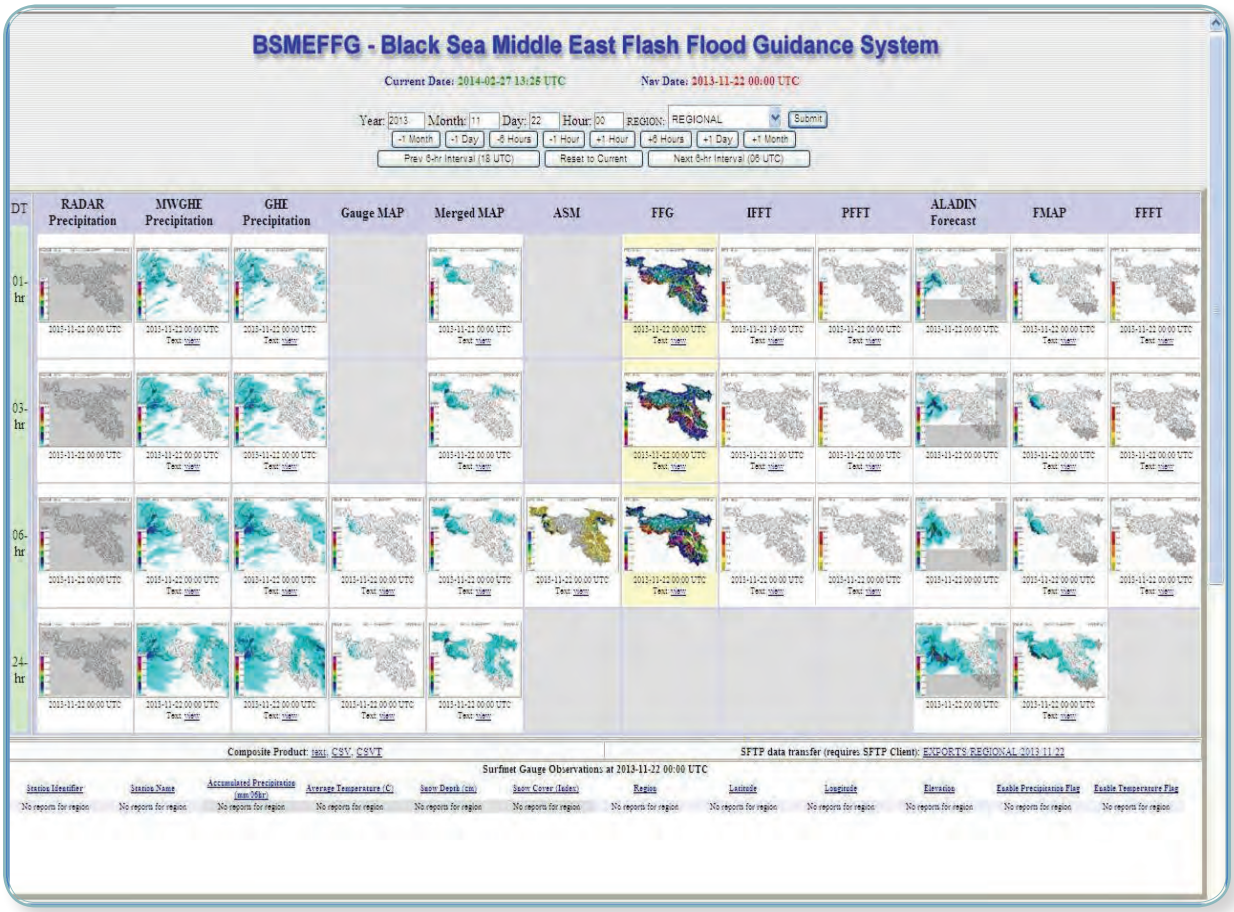


Figure-69 BSMEFFG main console products table

Having analyzed weather situation in the region, it is imperative to analyze BSMEFFG products very carefully. On November 22 at 00 UTC FFG products table is given in Figure-69. GHE, MWGHE and merged MAP showed that 1,3,6, and 24 hours precipitation occur over Bulgaria, Aegean Sea and western Turkey and moved toward the south and the southeast. For the same periods, MWGHE had precipitation maximum values of 10 mm/h, 20 mm/3h, 25 mm/6h, 40 mm/24h with the exception that there was a convective activity over Trace in north western Turkey having maximum precipitation more than 60 mm/6h.

6-hr soil moisture showed that upper soil saturated in Trace, southern Bulgaria and western Turkey, indicating that if rainfall continued over next 6 to 24 hours, most of the rainfall would become surface runoff. Because of the fact that temporal and spatial distribution of upper soil is very important for the flash flood occurrence, Figure-70 shows ASM change over time from November 21 at 12 UTC to 22 at 18:00 UTC. Soil saturation initially started in Trace in northwest Turkey and propagates southward covering all of western Turkey.

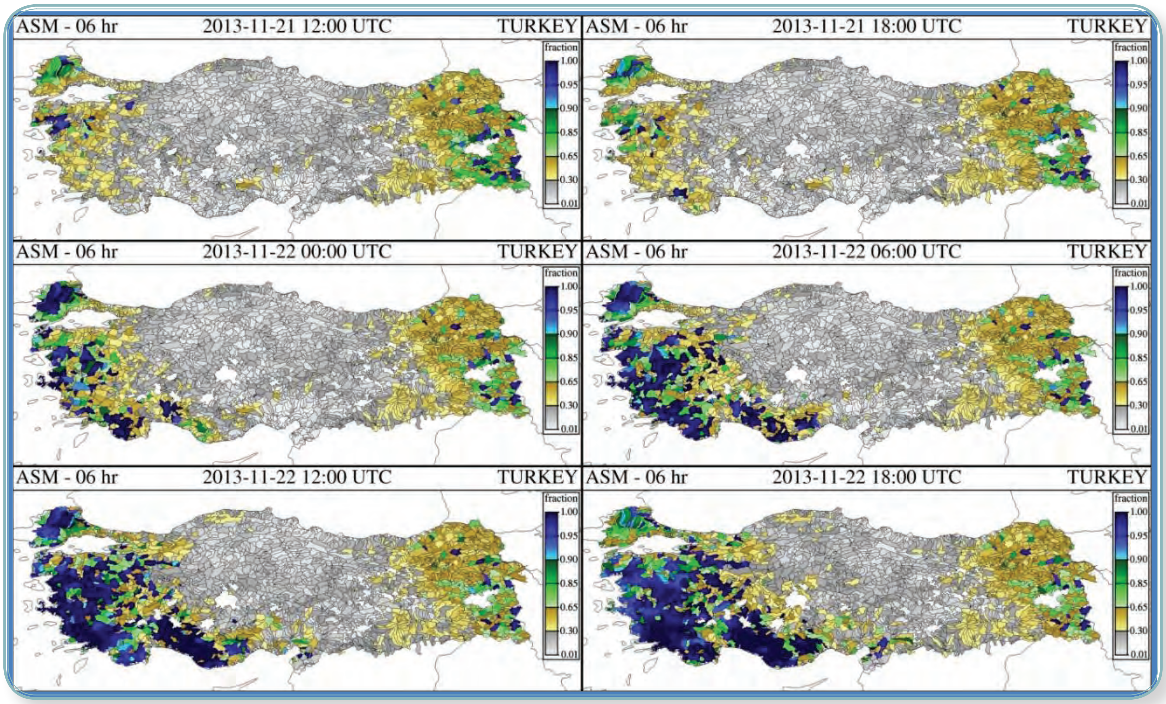


Figure-70 Temporal and spatial distribution of Average Soil Moisture

We were monitoring weather situations till November 22, 00 UTC showing that a depression developed over central Mediterranean and propagated eastward over Greece and Turkey producing light to moderate rainfall over western Turkey. So from this moment on, we had to look forward to the next 6-24 hours to find out that whether the current system will produce more rainfall or dissipate. If rainfall continued, what would be its intensity in 1,3, 6 hours? ECMWF and ALARO models predicted that the system propagated to the east and precipitation intensity increased in the next 6 to 72 hours.

Then, we had to analyze BSMEFFG 1,3,6,24-Hour ALADIN (ALARO) and FMAP precipitation. ALADIN precipitation forecast showed that rainfall intensified over southwest Turkey along the Aegean Sea Region reaching more than 100 mm accumulation in the next 24 hours. 1,3,6, and 24 hours FMAP had the maximum values of 10 mm, 45 mm, 100 mm and 200 mm respectively. Thus, we concluded that significant amount of rainfall would accumulate in the next 6 hours and would continue.

The next step would be how the FFG values changed over time and what their magnitudes were. Figure-71 shows 1,3 and 6 hours FFG products. 1, 3, and 6-hr FFG maximum values in the southern Aegean Sea coast were 10 mm/hr, 20 mm/3hr and 40 mm/6hr respectively.

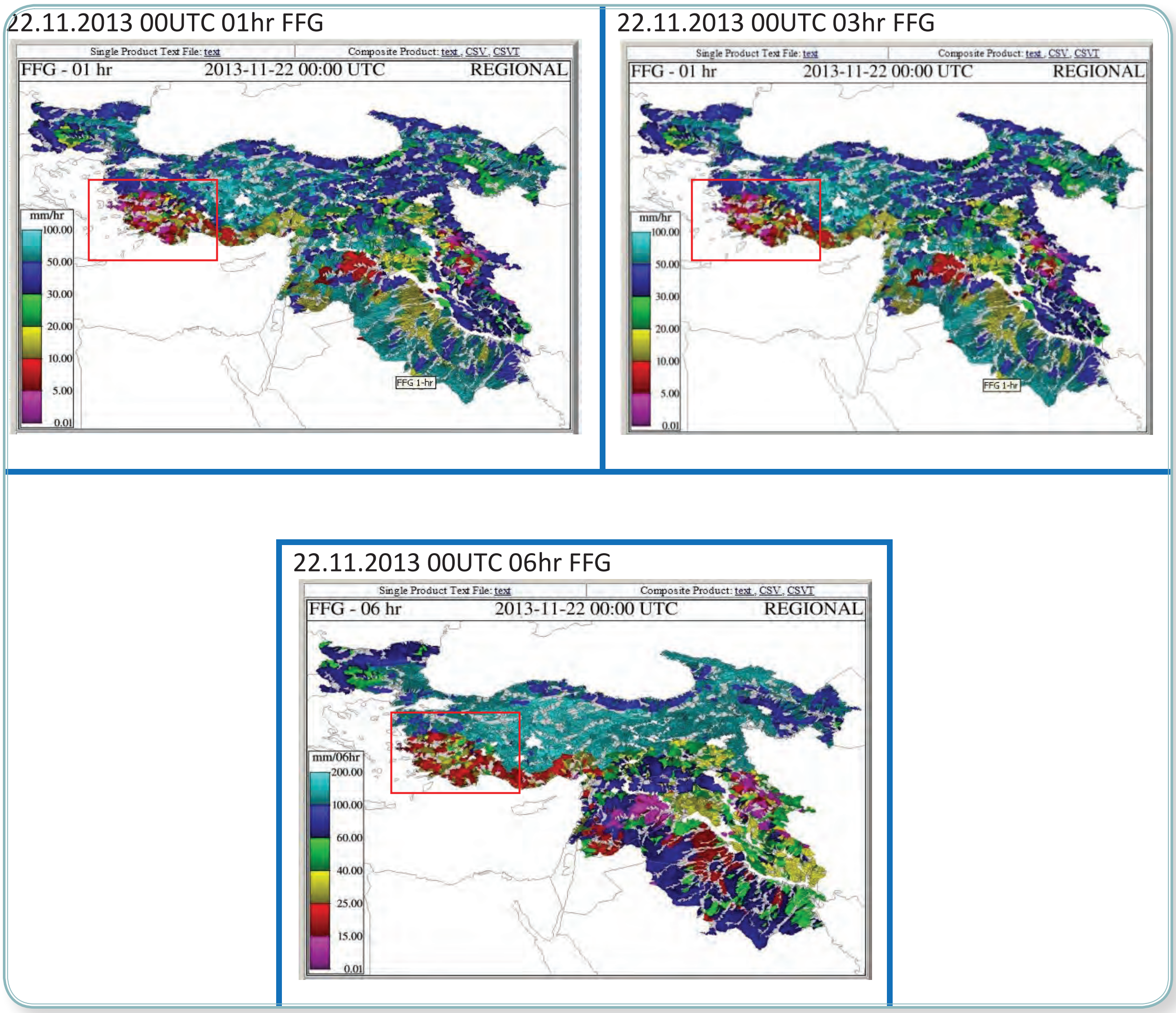


Figure-71 Flash Flood Guidance on 22 November 2013 at 00 UTC

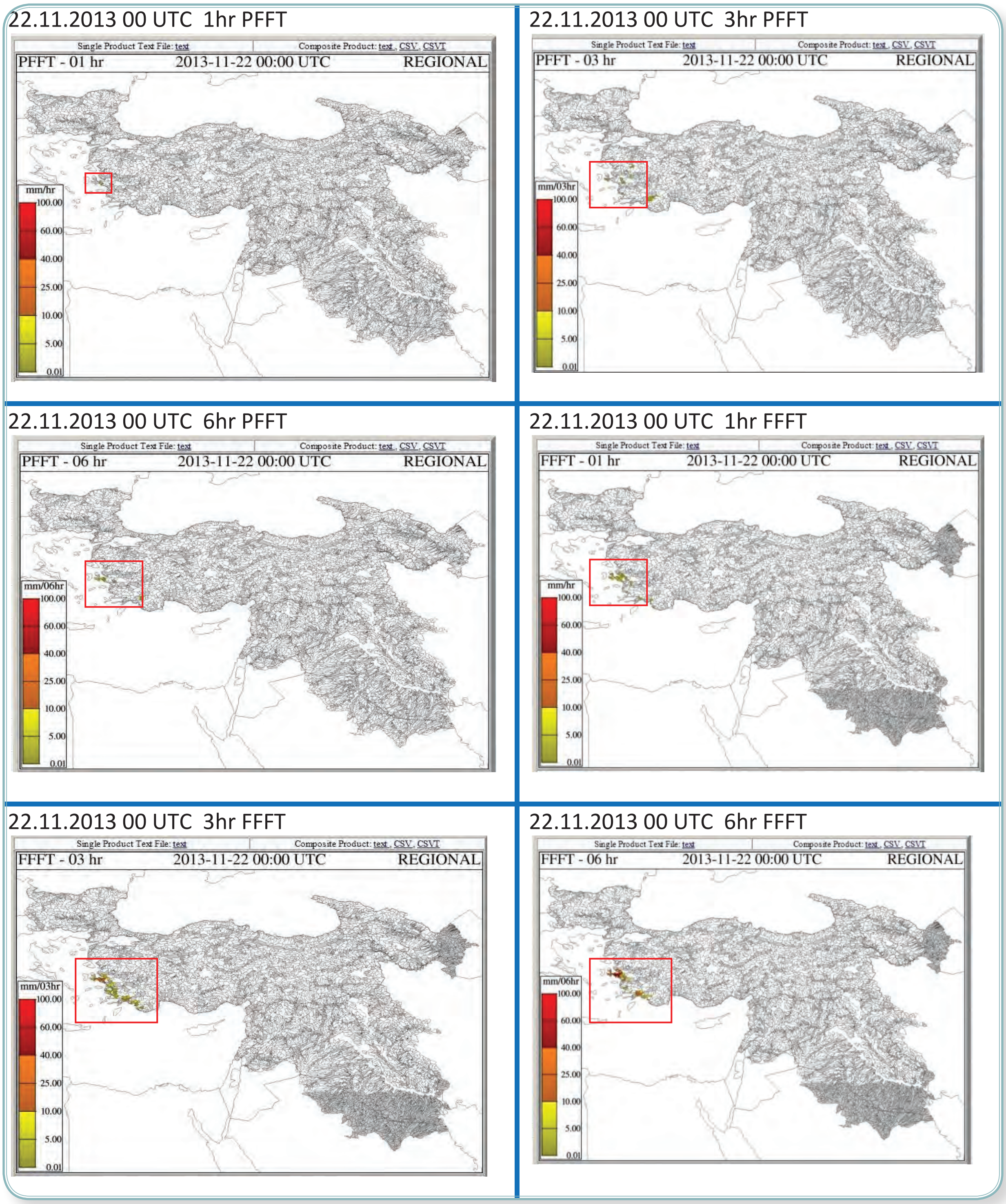


Figure-72 PFFT and FFFT charts on 22 November 2013 at 00 UTC

Finally, we had to analyze threat products namely IFFT, PFFT and FFFT. Figure-72 shows PFFT and FFFT 1,3, and 6-hr charts on November 22 at 00 UTC. Reminding that persistence flash flood threat assumes that past precipitation will persist for the next 1,3 and 6 hours. PFFT existed over İzmir and its vicinity and south Aegean Sea Region having yellow colored sub-basins with a maximum value of 10 mm for 1-hr, 3-hr and 6-hr. On the other hand, 1-hr FFFT existed over İzmir and 3-hr and 6-hr FFFTs extended from Izmir to the south covering Marmaris and surrounding towns where it had a value of 40 mm/6hr.

When there is a pronounced cyclonic depression in Mediterranean Sea, forecasters must pay attention and analyze the system very closely. Experiences show that such systems produce heavy and very heavy precipitation over Italy, Balkans, Greece and Turkey.

Considering all analysis above, it was advised to issue a flash flood warning at 00 UTC on November 22 and monitor the system development and movement until it dissipated. At 06 UTC weather system and BSMEFFG products analyzed again and the existing flash flood warning was updated valid next six hours. As an example, 6-hr FFFT at 06 UTC is shown in Figure-73 indicating maximum FFFT values in Marmaris and its vicinity where maximum rainfall intensity of 55.8 mm/hr was measured at 12 UTC. Then, the cyclone moved to the east over Antalya where a flash flood warning was issued at 12 UTC.

TSMS FEVK observations and newspapers dated November 21-22, 2013 reported flash flood events in the several provinces of southeast Aegean Sea Region including İzmir, Aydın and Muğla causing wide spread property damages and human losses. Moreover, on the Greek island of Rhodes, three (3) people were killed and that it was reported by newspapers that property damages were tens of millions of dollar (Figures-75 and -76).

Forecasters shall note that Mediterranean cyclones have similar patterns that produce heavy precipitation and flash floods in the Aegean Sea and Mediterranean regions of Turkey, Lebanon, Israel, Jordan and Iraq. More about the eastern Mediterranean cyclones can be found in (Alpert,P., 2006). He used ECMWF 1982-1987 analysis to calculate cyclone occurrences and their tracks. Figure-74 shows track density for winter months for the analysis period such that solid lines indicate major track routes.

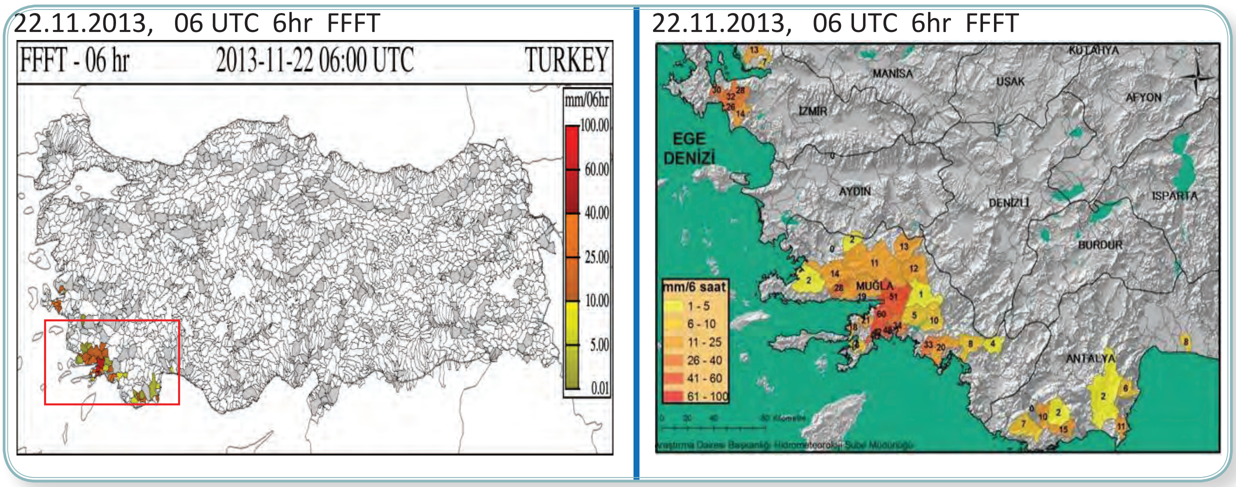


Figure-73 6-hr FFFT at 06 UTC on 22 November 2013

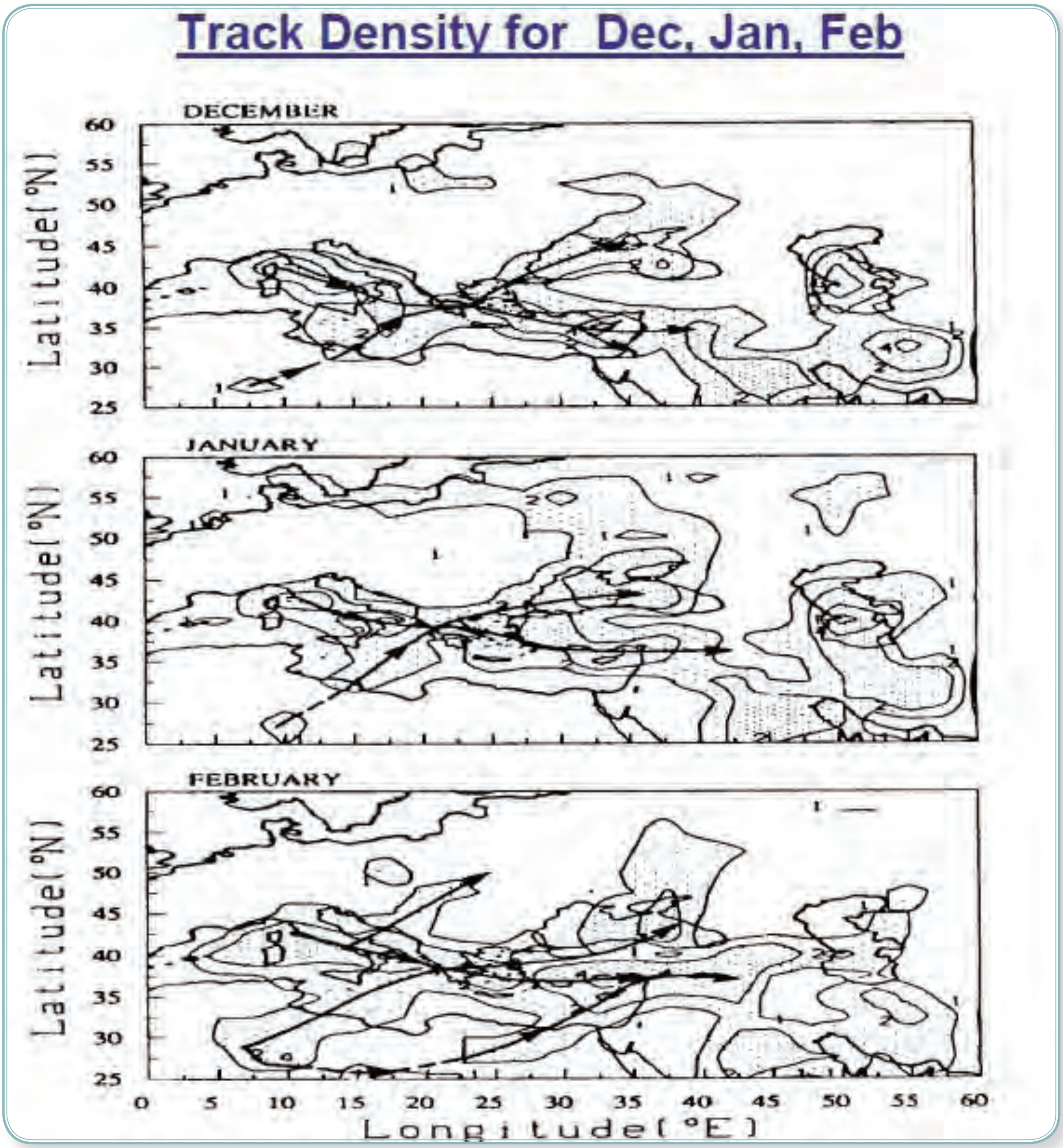


Figure-74 Average number of track occurrences for the winter months (Alpert,P.2006)

Marmaris, 22.11.2013 Bodrum 21.11.2013

Figure-75 Flash floods in Marmaris and Bodrum towns

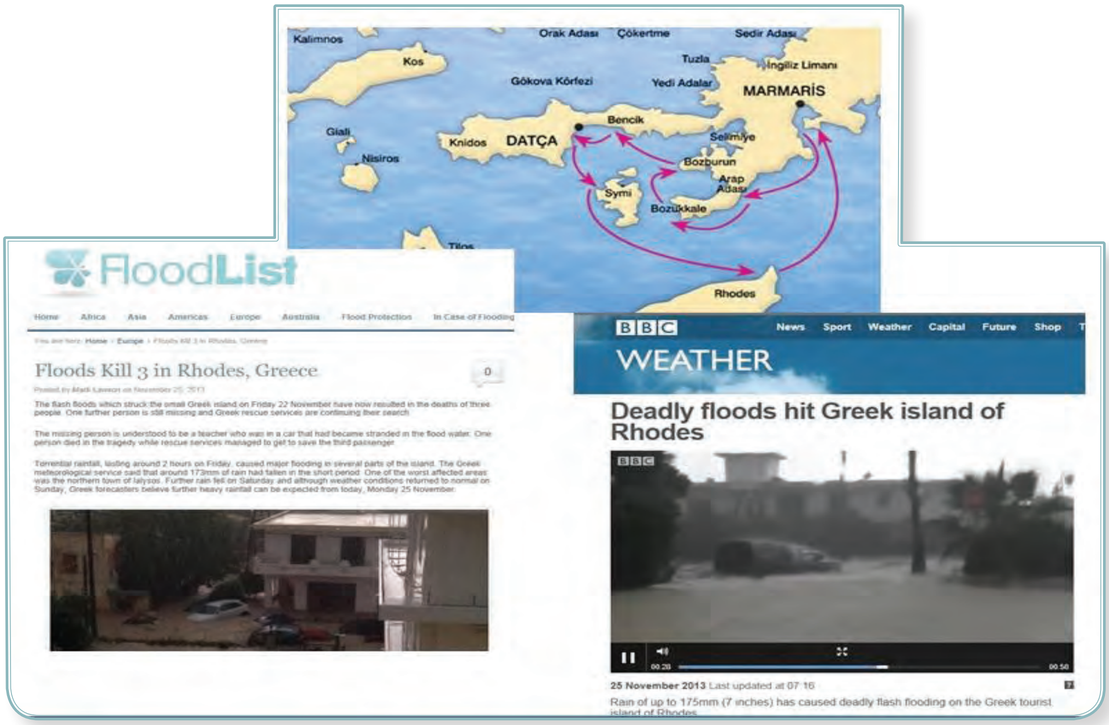


Figure-76 Flash floods on the Greek island of Rhodes on 22.11.2013

9.2. Hopa Flash Flood Event

Hopa town (41.4065, 41.4330; WMO synoptic station No: 17042), which is located in the northeast of Turkey on the Black Sea coast on the border with Georgia (red dot).The regions is one of the most flash flood prone region in Turkey (Figure-56) and has 2250 mm annual total precipitation normally (1981-2010) making it the highest value in Turkey (Figure-56). The region is under the influence of central European and Mediterranean depressions which bring warm and moist air from the south and the southwest and coupled with orographic lifting cause heavy precipitation. Particularly, when a low pressure center is located over the Black Sea, warm and moist northerly and north westerly air flow lifted over steep mountains with app. 4000 meter peak in Kaçkar Mountains in Rize province, which run parallel to the coast, produce intense rainfall in the lee sides. Precipitation due to convection is also significant in the region in summer and in the transition seasons. During winter, the Siberian high pressure center influences the region bringing cold air from the north causing heavy snowfall over mountains. Because of the fact that mountains are very steep along the coast and most population settled along the coast and there are many creeks running from mountains toward the sea, intense rainfall causes not only flash floods but also land slides, causing human losses and extensive property damages.

Flash flood occurrence in Hopa town on September 22 and 23 is to be investigated as a second case study. TSMS FEVK observations reveal that the event started on September 22 at 08.10 UTC and lasted until 23 at 09.00 UTC with 338.7 mm precipitation accumulation.

Figure-77 shows rainfall intensity (mm/hr) from September 22 at 08:00 UTC to 23 at 16 UTC such that there are two peaks. One of which happened on the 22nd, 09 UTC and another one happened on the 23rd, 03 UTC with the values of 44 mm and 49.2 mm respectively. Rainfall started at 08 UTC on September 22 and continued until 18 UTC then it paused until 00 UTC on September 23. The second phase of intense rainfall continued until 06 UTC.

Flash floods were reported in Hopa town and its vicinity from September 22 to 23 causing extensive property damages. Fortunately there were not any human losses. TSMS prepared a flash flood bulletin and issued a warning for the region.

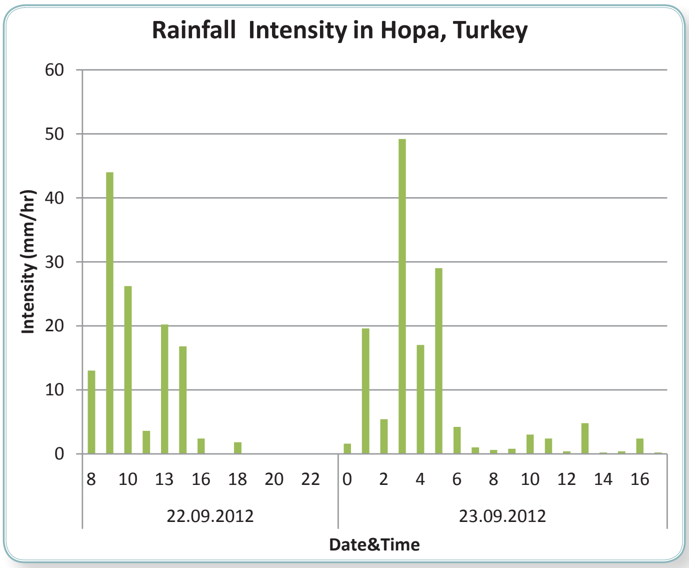
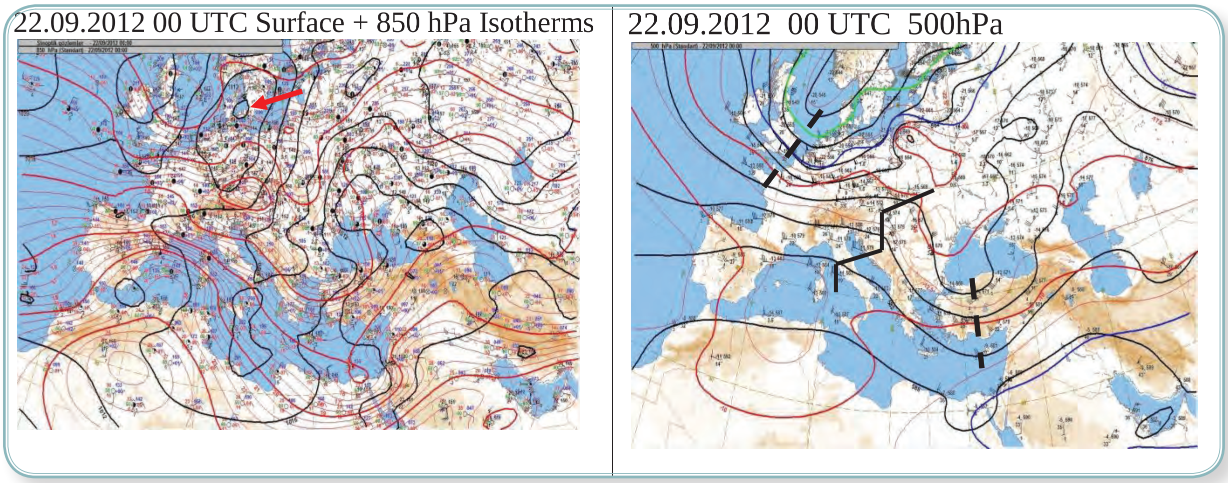


Figure-77 Rainfall intensity measured at the Hopa AWOS station.

9.2.1. Synoptic Analysis



igure-78 Surface isobars and 850 hPa isotherms (left) and 500 hPa geopotantial height and isotherms at 00 UTC, 22.09.2012

Surface analysis (left) at 00 UTC, 22.09.2012 shows that there is a pronounced low pressure center over Denmark and southern Scandinavia with a pressure value of 1008 hPa. Ahead of the low pressure center 850 hPa warm air advection and behind the low center 850 cold air advection existed such that 5°C isotherm passed just south of the low pressure center. On the other hand, over the eastern Black Sea 850 hPa temperature was 15°C. 500 hPa low center was located over Scandinavia with 546 hPa value and -25°C temperature. Moreover, a trough existed over western Turkey extending from Zonguldak province to Cyprus (Figure-78).

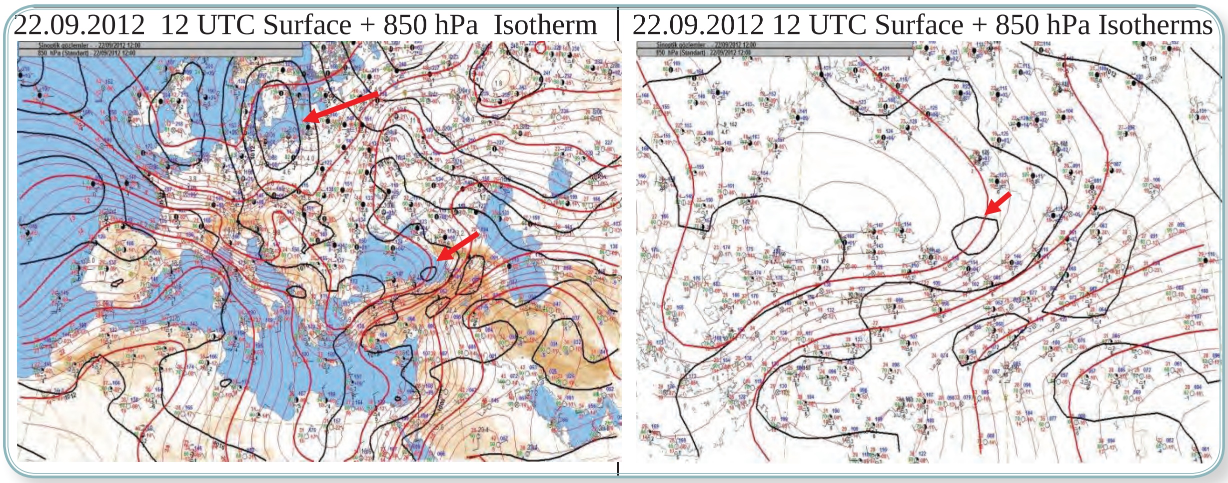


Figure-79 Surface isobars and 850 hPa isotherms (left) and surface isobars and 850 hPa isotherms in Black Sea and its vicinity at 12 UTC, 22.09.2012

At 12 UTC low pressure center over Scandinavia moved eastward. On the eastern Black Sea coast low pressure formed. Wind was blowing from the northwest bringing moist air from the sea. Surface temperature in Topa town was 21°C and dew point temperature was 14°C, while surface temperature and dew point temperature in Trabzon city that is located west of Hopa town were 22°C and 18°C, respectively. In Hopa town, cumulus clouds were reported while in Trabzon city, shower and towering cumulus clouds were reported (Figure-79).

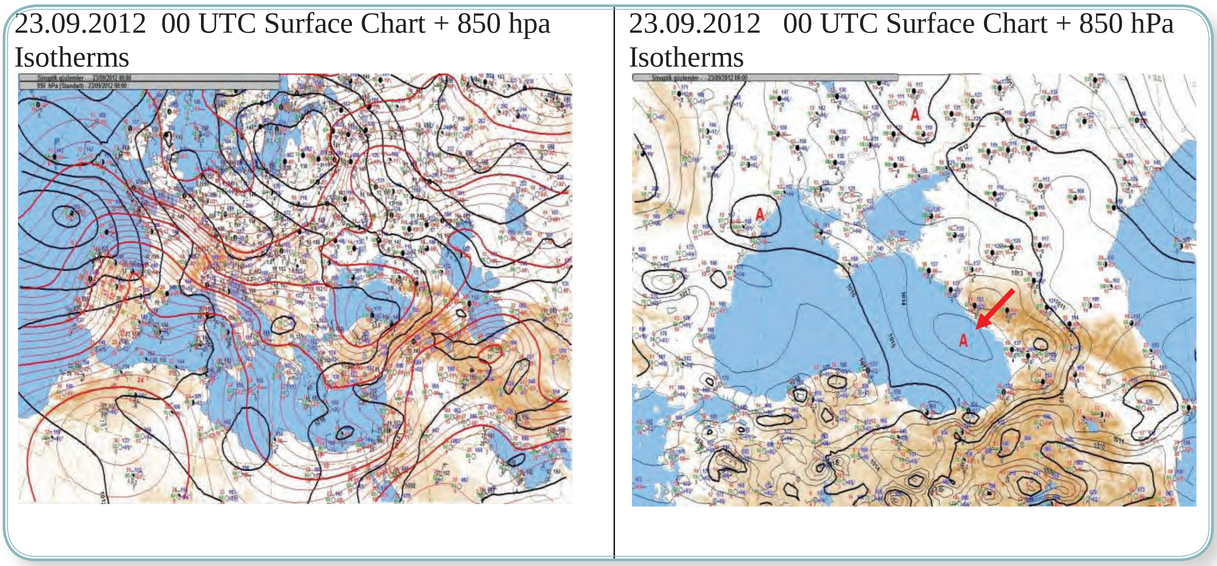


Figure-80 Surface isobars and 850 hPa isotherms s (left) and surface isobars and 850 hPa isotherms in Black Sea and its vicinity at 12 UTC, 22.09.2012

AAt 00 UTC on 23.09.2012 surface low pressure centers moved to the east. Detailed surface analysis and 850 hPa isotherms are given in Figure-80 (right). The surface low pressure center with a value of 1014 hPa was located in the eastern Black Sea in the north of Hopa town and winds were blowing from the northwest. Surface temperature in Hopa town was 20°C and dew point temperature was 18°C. In Hopa town showers were reported, while in Trabzon, which was located to the west of Hopa town, thunderstorms were reported.

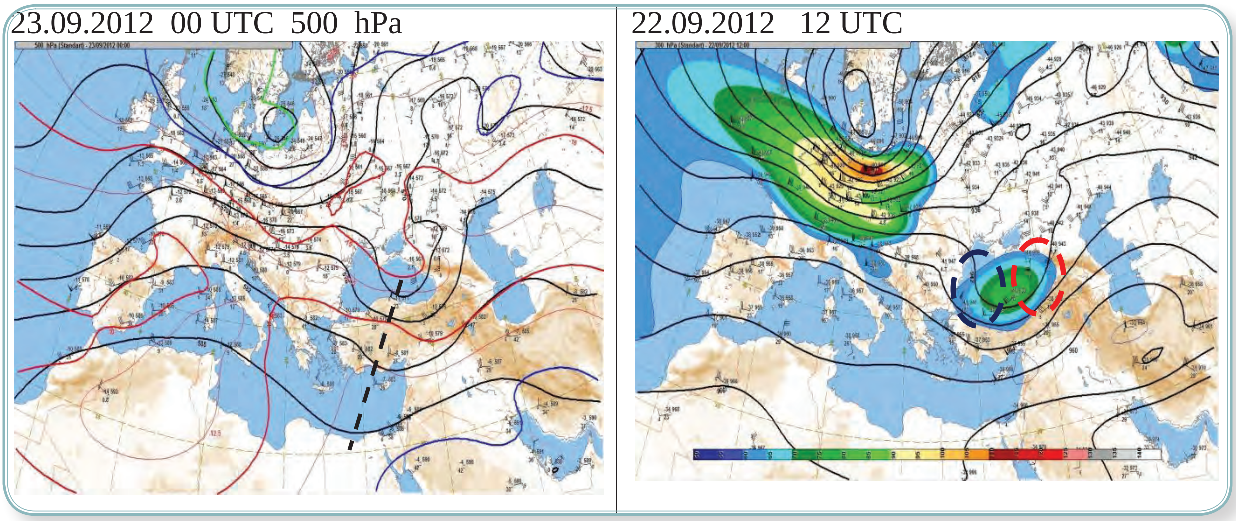


Figure-81 500 hPa chart (left) 23.09.2012, 00 UTC and 300 hPa jet stream (right) 22.09.2012, 12 UTC

500 hPa low center moved to the east from Zonguldak province and a trough was extending from Samsun province to Egypt. Low center had 570 hPa geopotential height value and the temperature was -15°C . There were two radiosonde stations close to Hopa town. One of which was in Samsun city (17030), which was located to the west of Hopa town on the Black Sea coast, reported 50 knots wind speed and -11°C temperature. The other one was Erzurum city (17095), which was located in the south of Hopa town, measured

30 knots wind speed and -12°C temperature. It was very obvious that ahead of the 500 hPa trough, wind speed and direction divergences were very pronounced indicating low level convergence and vertical motion. 300 hPa jet stream analysis shows that there were two distinct jet cores. One of which was located over northern Europe having 110 knots wind and other one was located over the central Black Sea Region of Turkey having 70 knots wind speed. Since the jet stream core was cyclonically curved, it indicated that divergence and upward motion took place in the jet exit region, and convergence and downward motion took place in the jet entrance region (Figure-81).

METEOSAT MSG satellite visible image on 22.09.2012 at 12 UTC is given in Figure-82, showing a low center was located over Black Sea and associated cloudiness.

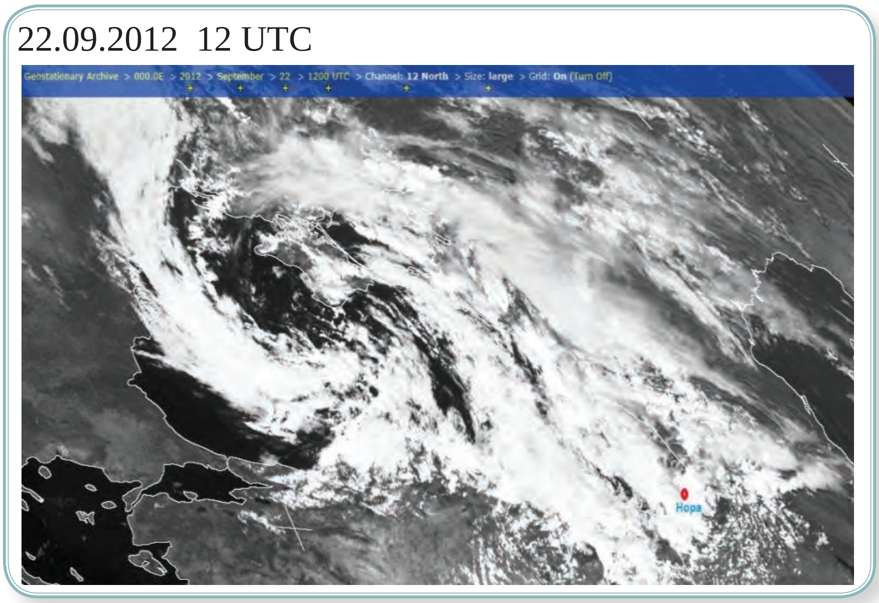


Figure-82 METEOSAT MSG image

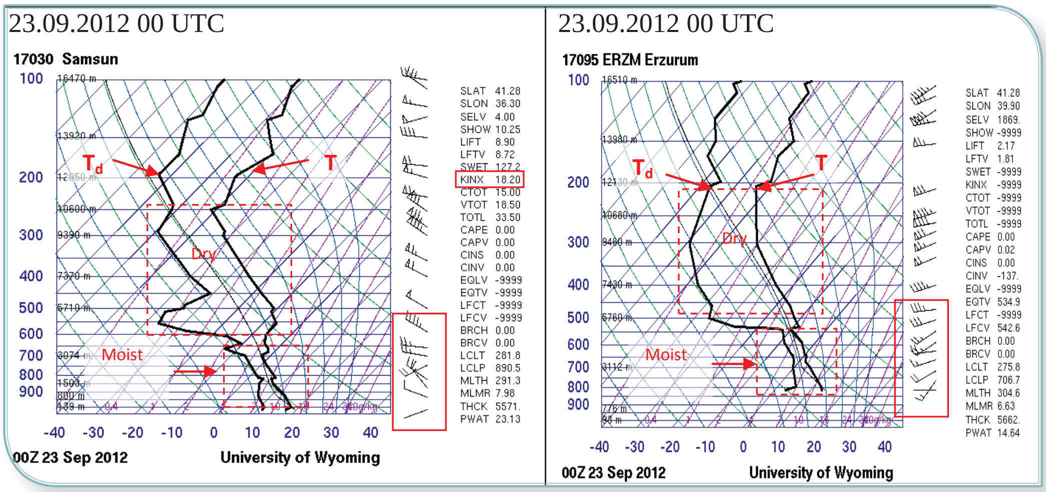


Figure-83 Skew-T Log-p diagram of Samsun and Erzurum radiosonde stations observations at 00 UTC, 23.09.2012

Figure-83 shows Samsun (17032) and Erzurum (17095) skew-T log-p diagram on 23.09.2012 00 UTC. Both sounding data show that the lower and middle troposphere were moist where air temperature and dew point temperature values were very close to each other. In Samsun, in the lower troposphere, there were wind speed and directional shears and K-Index was 18.20. On the other hand, in Erzurum, wind speed shear existed. In both soundings, inversion exited at the 600 and 650 hPa levels. As it is well known that occurrences of thunderstorms depend on availability of moisture in the lower troposphere, vertical wind shear, conditionally unstable atmosphere and triggering mechanism for updraft. It can be inferred from both soundings that these conditions existed for the region.

9.2.2. BSMEFFG Products

Having performed weather analysis, it is imperative now to study BSMEFFG products be-fore the event occurrence. As seen from the Figure-84 precipitation in Hopa began on 22.09. 2012 at 08 UTC and lasted until 18 UTC while the most intense precipitation occurred between 08 and 14 UTC. Precipitation paused until the next day and commenced at 00 UTC on 23.09.2012 until 14 UTC, but the most intense rainfall occurred between 00 and 06 UTC during which flash floods took place.

Therefore, we intended to investigate BSMEFFG products at 06, 12, and 18 UTC on 22.09.2012 and at 00 UTC on 23 .09.2012.

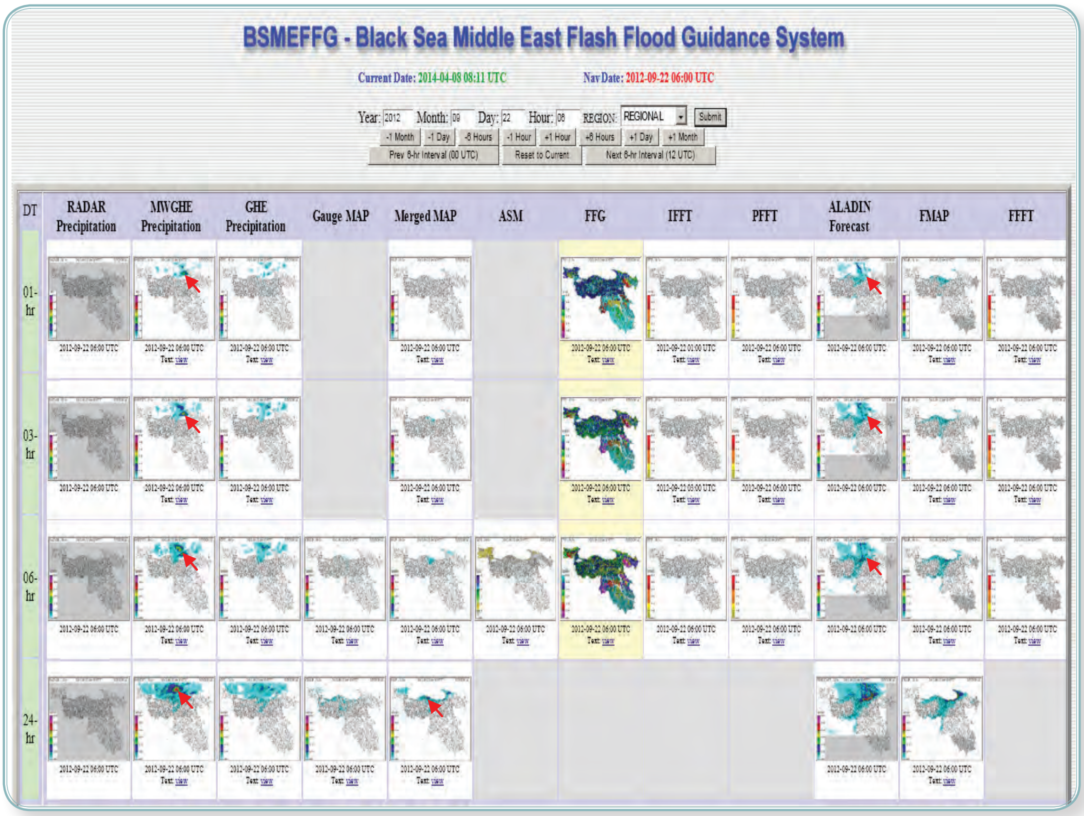


Figure-84 BSMEFFG products on 22.09.22 at 06 UTC

First of all, forecasters should analyze the precipitation products to find out if the precipitation intensifies or diminishes for the last and the next six to twenty four hours, where it propagates and what are the surface station measurements. Secondly, changes of the soil moisture over time shall be monitored to find out how quickly upper soil is getting saturated. Finally, FFG and threat products shall be analyzed to figure out if the model generates warnings. As Figure-84 shows, 1,3,6 and 24-hr MWGHE had 20 mm, 45 mm, 60 mm and 100 mm maximum precipitation values, respectively over eastern Black Sea. Taking into account the shape and structure of precipitation cores, it was very likely that strong convection caused the maximum precipitation formation. On the other hand, merged MAP indicated little rain in the Black Sea Region over 24 hours, having a maximum value of 40 mm over Samsun province. ASM indicates that Thrace, central and eastern Black Sea Regions of Turkey and northern Georgia were partially saturated. After analyzed past precipitation, it was necessary to take a look at several models to compare their precipitation forecasts with each other and pay attention to the regions where the maximum precipitation forecasted. Thus, we investigated 24-hr ALARO precipitation forecast and

FMAP to see whether precipitation was going to intensify or diminish and what their spatial distributions were in the subbasins. ALARO 1-, 3-, 6-, and 24-hr precipitation forecasts show that the system was moving eastward, having the maximum values of 90 mm, 150 mm, 100 mm, 200 mm respectively over the eastern Black Sea. On the other hand, 1-, 3-, and 6-hr FMAP showed maximum 25 mm rainfall, but 24-hr FMAP showed a maximum value of 200 mm rainfall over the coast. That's why one can conclude that light precipitation would continue for the next six hours and then intensify in the next twenty four hours over the coastal region. 1, 3, and 6-hr FFG values varied from 20 mm to 100 mm in the eastern Black Sea Region and threat products did not give any warnings. As a result of above analysis, forecaster may decide to issue a flash flood **"watch"** for the region for the next 24 hours and analyze BSMEFFG products at 12 UTC .

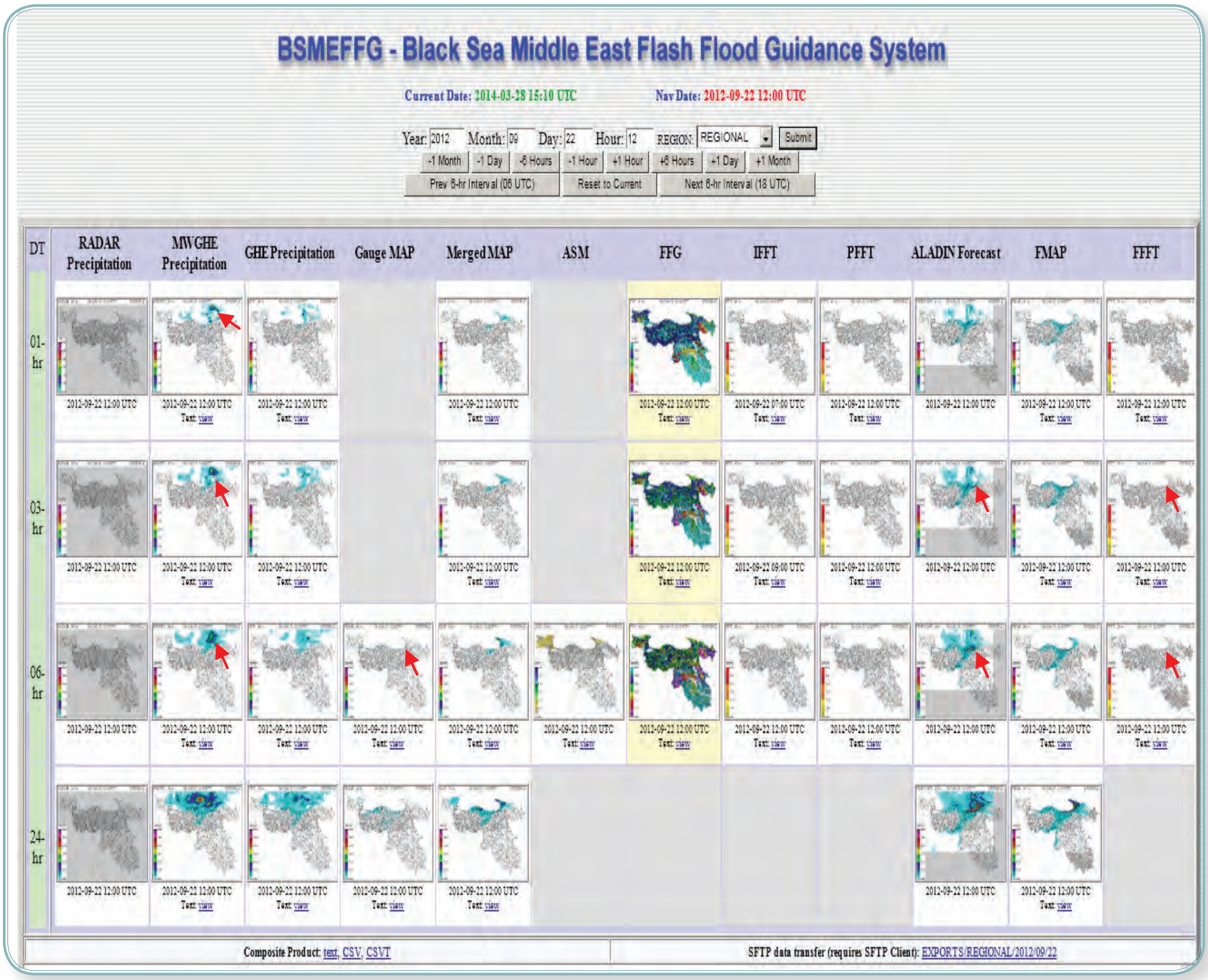


Figure-85 BSMEFFG products on 22.09.22 at 12 UTC

MWGHE showed that system moved eastward and located over northern Georgia having precipitation intensity of 40 mm/6hr. 1-hr MWGHE had two convective cells developed just offshore of Hopa town. It was very likely that they propagated toward the coast and caused precipitation. Figure-77 depicts that rainfall in Hopa started at 08 UTC and resulted in approximately 70 mm accumulation in just four hours that was also clearly shown on 6-hr gauge MAP. The soil moisture fraction was 0.65 in Hopa town and its vicinity. 3-hr and 6-hr ALADIN precipitation forecast values were 70mm and 60mm, respectively.

Taking into account the 3-hr and 6-hr FFG values ranging from 25 to 70 mm in the region, 3-hr and 6-hr FFFTs were generated. It should be noted that 6-hr ALADIN forecast precipitation core was located in the west of Hopa town and propagated eastward in 24-hr having a maximum value of 200 mm. Because of the fact that rainfall started at 06 UTC, accumulating 70 mm precipitation in the last six hours and precipitation forecast showed that it would continue in the next twenty four hours reaching a maximum value of 200 mm, and 3 and 6-hr FFFT existed in Hopa town and its vicinity, it was recommended that a flash flood **"warning"** was to be issued (Figure-85).

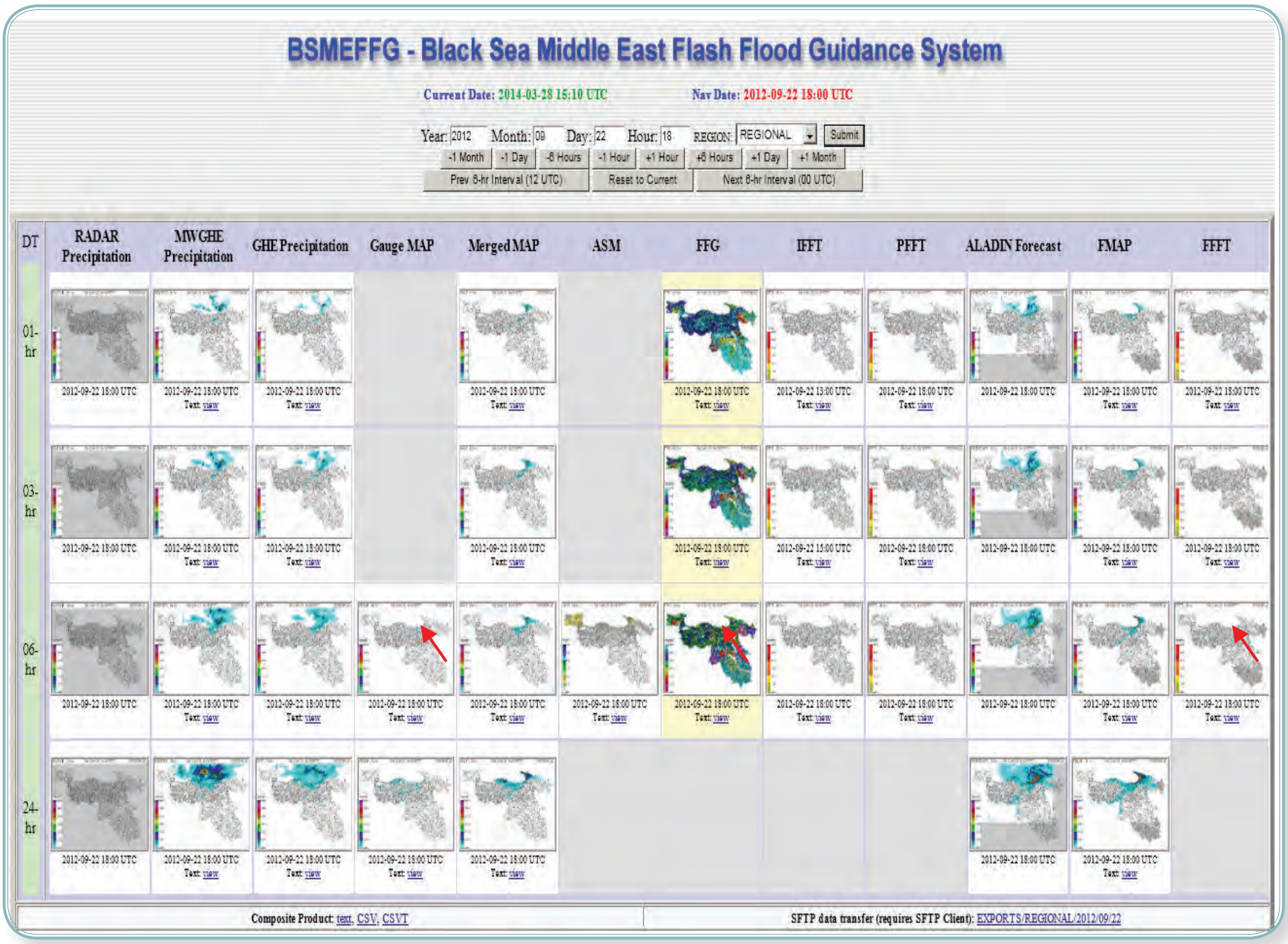


Figure-86 BSMEFFG products on 22.09.22 at 18 UTC

MWFFG showed (Figure-86) that the depression became stationary over eastern Black Sea while Gauge MAP depicted that Hopa received 72 mm precipitation in the last six hours. It is worthwhile to note that Rize and Trabzon provinces, located to the west of Hopa town, and received only 25 mm/6-hr and 6 mm/6-hr precipitation, indicating that heavy precipitation occurrence was very local. ALADIN precipitation forecast showed that heavy precipitation would continue offshore along the coast, then propagate onshore at +6-hr forecast time. 1 and 3-hr FMAP showed moderate rain but heavy and very heavy rainfall for 6-hr and 24-hr FMAP having a maximum value of 200 mm/24-hr. On the other hand, FFG estimates were ranging from 20 to 100, while there were sub-basins having 6-hr FFG values of 25 mm shown in red. Thus, 6-hr FFFT gave warnings; but 1-hr and 3-hr FFFTs did not produce any warnings . Therefore, the existing flash flood **"warning"** was extended to be effective for the next six hours.

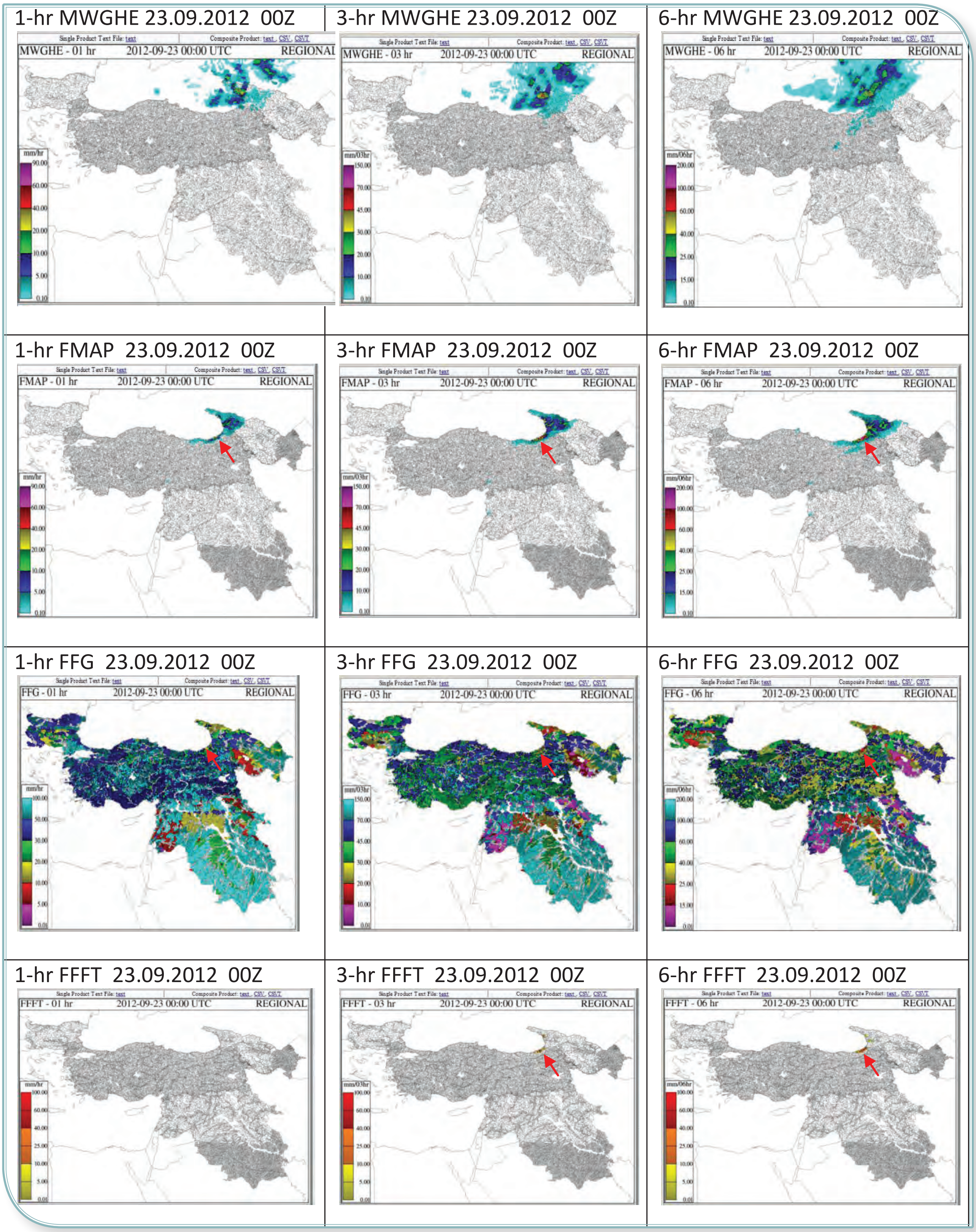


Figure-87 BSMEFFG products on 23.09.22 at 00 UTC

As shown in Figure-87, MWGHE had light rain for the last six hours and gauge MAP had 15 mm/6-hr rainfall in Hopa town and its vicinity that was in line with measured rainfall intensity as shown in Figure-77. ASM had a soil moisture fraction of 0.65. ALADIN forecasts show that precipitation that was located offshore at 18 UTC moved onshore having 40 mm/1-hr, 70 mm/3-hr and 200mm /6-hr FMAP values. FFG estimates varied from sub-basin to sub-basin having values as low as 20 mm/1-hr, 20mm/3-hr and 25 mm/6-hr. That's why, FFG model generated , 3-hr and 6-hr FFFTs. Thus, the existing flash flood **"warning"** was extended again to be effective for the next six hours.

TSMS FEVK observations indicated that approximately fifty small scale landslides happened, bridges and vents were damaged, first floors of houses and shops were flooded, village and district roads were damaged due to landslides in Hopa town and surrounding villages. Fortunately, there was not any human losses (Figure-88).

Hopa 23.09.2012

Arhavi 23.09.2012

Figure-88 Flash floods in Hopa and Arhavi towns on 23-24 September 2012

9.3. Samsun Flash Flood Event

Samsun province (41.3435,36.2553; WMO synoptic station No:17030), which is located in the northeast of Turkey on the Black Sea coast (red dot), is one of the most flash flood prone regions in Turkey (Figure-56). It has approximately 2000 mm annual precipitation normally (1981-2010) according to the TSMS estimations (Figure-55). Synoptically, the Black Sea Region is under the influence of central European depressions, which originate from the north Atlantic. Particularly, when a low pressure center is located over eastern Europe and northern Black Sea, cold northerly air sinks and encounters with warm and moist southerly flow establishing a very pronounced frontal system that produces heavy rainfall along the eastern Black Sea region. During winter, the region is under the influence of the Siberian high pressure center which results in sinking of very cold air over eastern Turkey causing heavy snowfall over the mountains. On the other hand, heavy precipitation occurrences due to convection are quite significant in the region in summer and transition seasons due to the particular orography of the region where a mountain cascade runs parallel to the coast with average height of 2000 meters in the vicinity of Samsun. Rivers and creeks run perpendicular to Black Sea toward north on the steep lee sides of the mountains. Because of the fact that mountains are very steep along the coast and most population settles along the coast and there are many creeks running from mountains toward sea, not only flash floods but also landslides take place very often causing human losses and extensive property damages.

Flash flood occurrences in Samsun province on the 7th and 8th August, 2013, which inflicted heavy property damages and casualties, are to be investigated as a third case study. TSMS observations reveal that the event started on the 7th at 23 UTC and lasted until the 8th at 13 UTC with 216 mm surface rainfall accumulation. On the other hand, rainfall intensity (mm/hr) measurement at the Samsun AWOS station (Figure-89) shows that precipitation started on August 7 at 23 UTC and lasted until 8 at 14 UTC such that peak rainfall intensity of 49.6 mm/hr was measured on August 8 at 04 UTC.

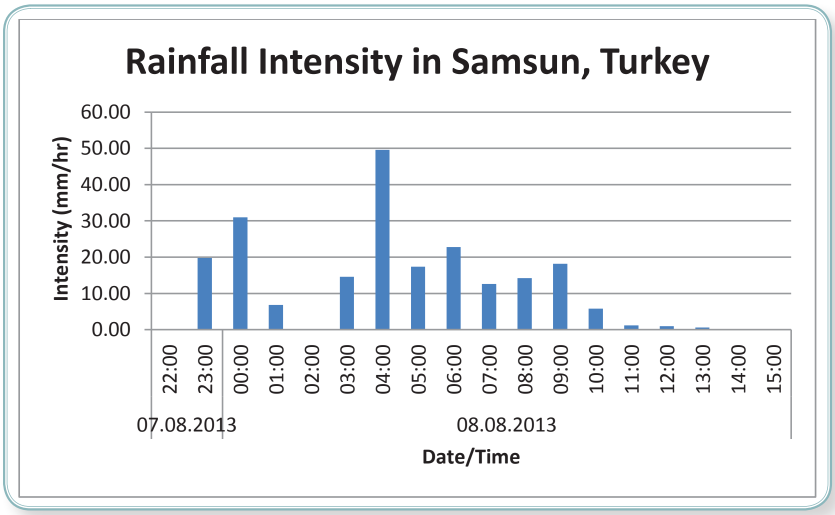


Figure-89 Rainfall intensity measured at the Samsun AWOS station

This is a very good case to investigate because contrary to the previous cases in which flash floods were caused by the depressions associated with frontal systems, in Samsun flash floods were caused by convection due to local instability.

9.3.1. Synoptic Analysis

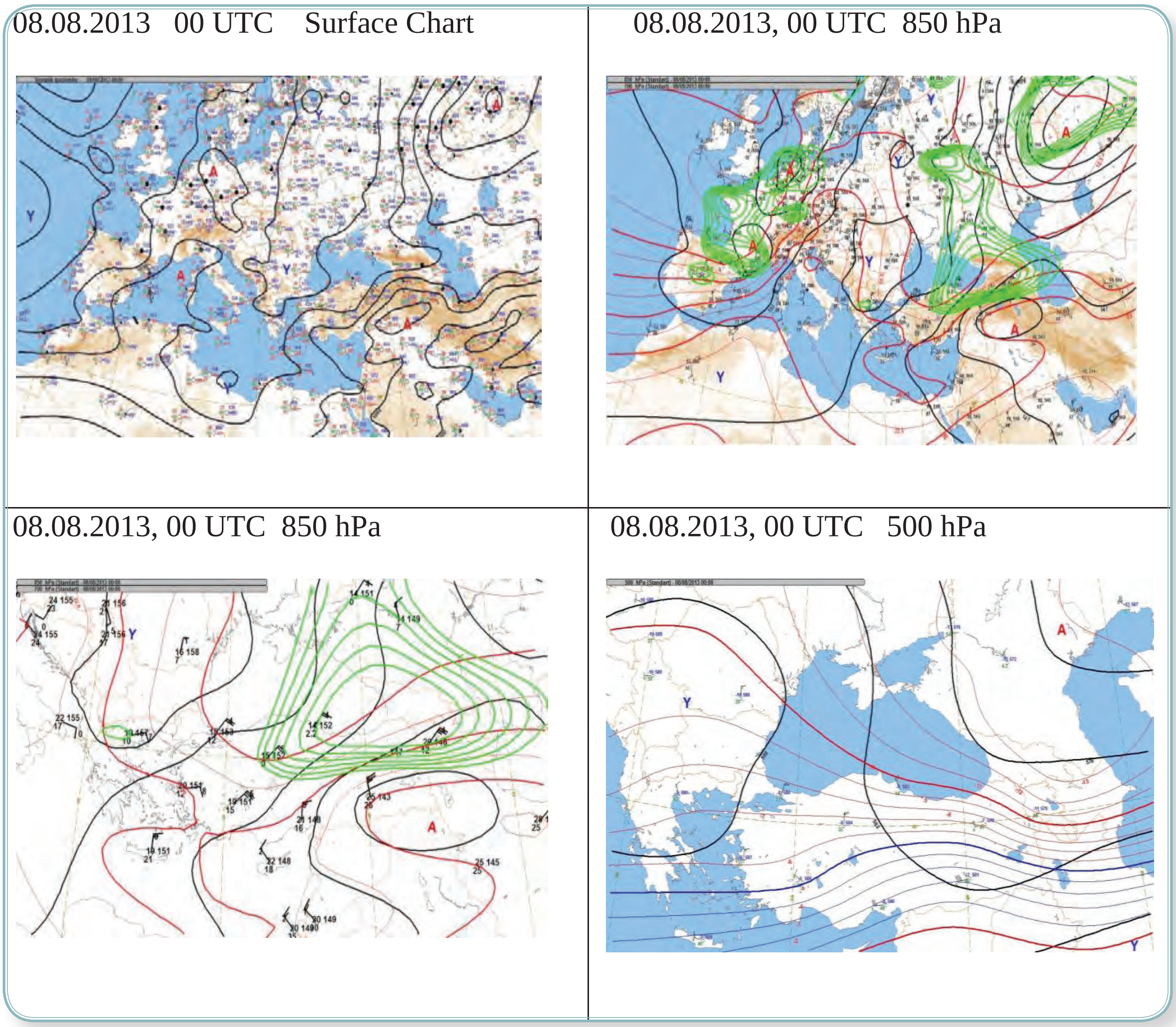


Figure-90 Surface, 850 hPa and 500 hPa charts on 08.08.2013 at 00 UTC

Surface analysis at 00 UTC reveal that a high pressure center with 1016 hPa value was located in eastern Europe, extending from Latvia to Greece while a low pressure center was located over southeastern Turkey with 1000 hPa value so that Samsun province was situated between low and high centers. High pressure gradients were noticeable in the north of low pressure center up to eastern Black Sea and Caucasus. Surface temperature value in Samsun was 20°C while dew point temperature was 17°C, indicating very moist lower layer. 850 hPA analysis at 00 UTC depicts that a high center was located over eastern and southeastern Europe and a low center was located over southeastern Turkey while 500 hPa analysis shows that a high center was located over Balkans and a low center was located over northern Caspian Sea. Surface and mid troposphere circulations show that wind was blowing from the northeast and the north from the sea to the land in Samsun bringing moist air and coupling with orographic lifting. It should be noted that 500 hPa temperature over Samsun was -10°C making the temperature differences with surface 30°C indicating favorable instable conditions for thunderstorm development. For the Black Sea region, forecasters know that when the wind is blowing northerly and unstable atmospheric conditions exist and orografic lifting is significant, thunderstorms develop and produce heavy precipitation on the coastal region and on the lees causing flash floods (Figure-90).

9.3.2. Instability

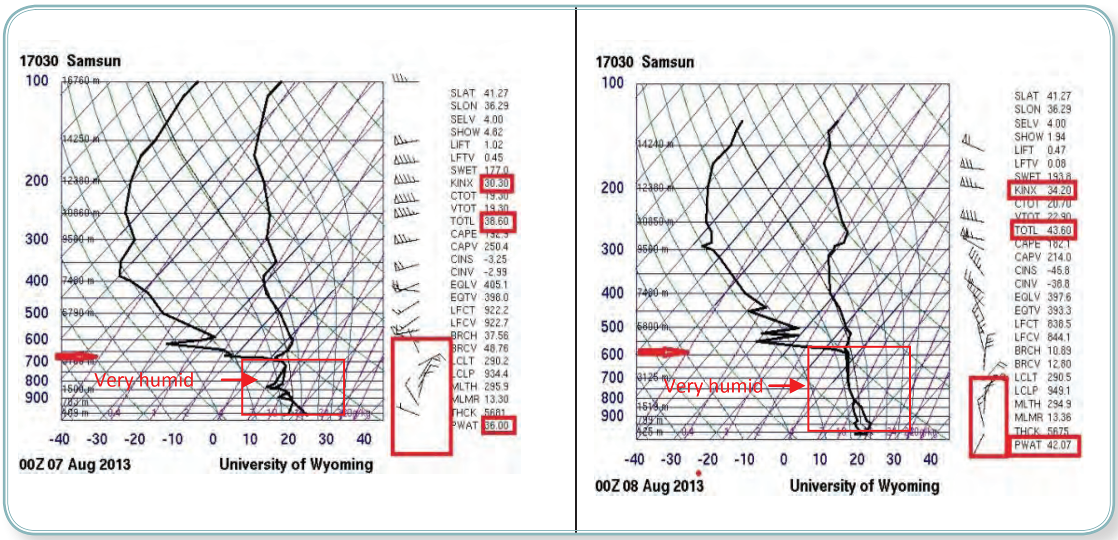


Figure-91 Vertical Soundings of Samsun radiosonde sation on 07-08.08.2013 at 00 UTC

Figure-91 shows sounding data of the Samsun radiosonde station (17030) on the 7th and 8th of August, 2013 at 00 UTC. Both soundings have similar features that dry bulb temperature and dew point temperature were very close to each other and had vertical wind shear indicating low troposphere moist layer. K indices of both soundings were 30.30 and 34.20 on the 7th and 8th, respectively. These are very typical soundings under which severe thunderstorms develop producing heavy precipitation. As we will see in the next section, Satellite and Radar images showed thunderstorm clusters developments along the coast in Samsun province.

9.3.3. Satellite and RADAR Images

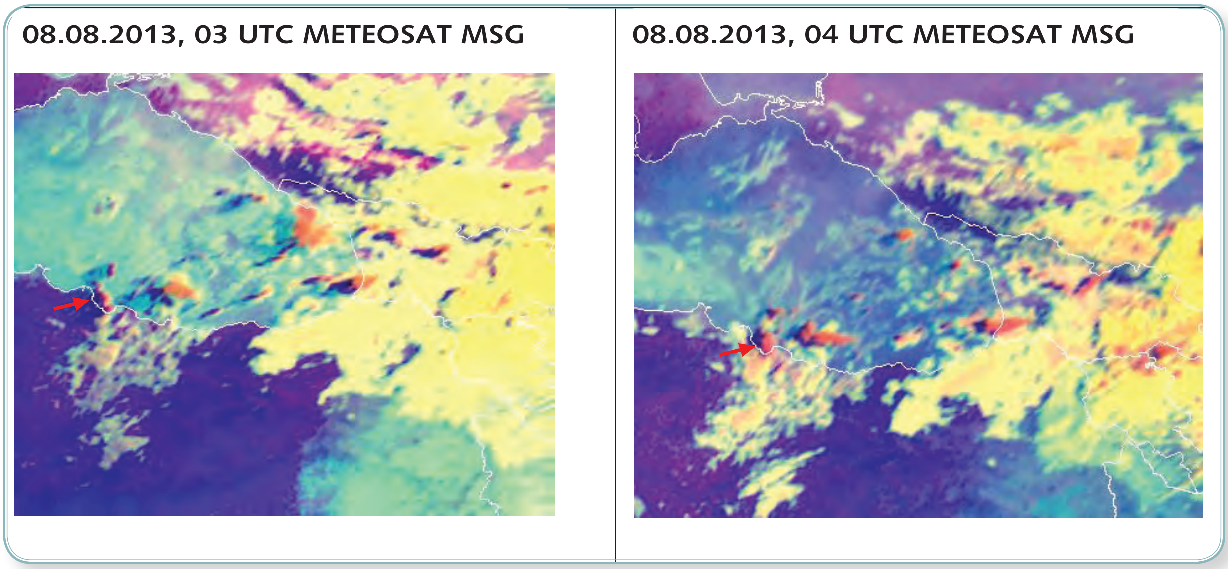


Figure-92 METEOSAT MSG images on 08.08.2013 at 03 UTC and 04 UTC

Figure-92 depicts METEOSAT MSG satellite RGB multichannel image visualization at 03 and 04 UTC showing exiting of cumulonimbus clouds in eastern Black Sea. Clusters of cumu-lonimbus clouds are seen just offshore of Samsun province at 03 UTC (left). One hour later, more pronounced and vertically extended cumulonimbus clouds were present in the same region (right). The meteorological station in Samsun reported thunderstorms with heavy showers and gust. It is notable that line of thunderstorms moved onshore and medium clouds were present inland. High resolution temporal and spatial coverage of successive satellite images can provide good insight of storm developments and movements are a good tool for Nowcasting for which METEOSAT HRV (High Resolution Visible) images would be a perfect tool. Moreover, METEOSAT multichannel imaging instrument (SEVIRI) provide more detailed analysis of local atmospheric conditions like cloud analysis, instability, and moisture by means of RGB composite image.

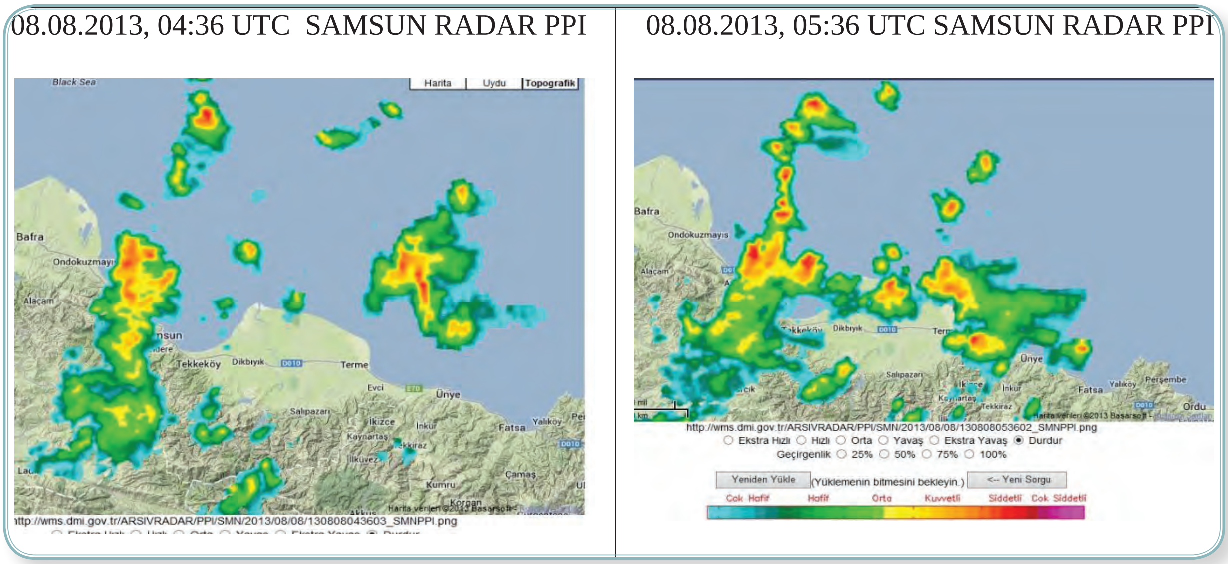


Figure-93 Samsun Radar PPI images on 08.08.2013 at 04:36 UTC and 05:36 UTC

Weather radar images can provide better temporal and spatial coverage as well as 3D visualization and analysis of the storms so that, if they are available, forecasters must monitor storm development and precipitation intensity closely. Radar PPI reflectivity images at 04:36 UTC (left) and at 05:36 UTC (right) are shown in Figure-93 indicating a line of thunderstorms oriented north-south direction over Samsun province. Red colored regions on the images have more than 60 dBz reflectivity values implying severe thunderstorms associated with heavy precipitation. Taking account of thunderstorm features, their development states and sub-basin conditions, one can conclude probability of occurrences of the flash floods was quite high.

9.3.4. Synoptic Observations

SITT60 SAMB 072100 CCA AAXX 07214 17030 41560 71605 10194 20179 30143 40147 51001 79522 87900 333 83930 84833 92437 =

SMTT60 SAMB 080000 AAXX 08004 17030 11670 62103 10197 20185 30139 40143 55004 60601 72598 84250 333 84836 86360 92438 =

SITT60 SAMB 080300 CCA AAXX 08034 17030 41660 72305 10186 20175 30141 40145 53002 78122 85250 333 85833 87358 92437 =

SMTT60 SAMB 080600 AAXX 08064 17030 11556 72002 10195 20184 30150 40154 52009 61452 78222 86950 333 20176 33018 55067 72046 82925 84833 87358 92436 555 00247 =

- Synoptic observations are given above to see the local AWOS stations (17030) reports before and during the flash flood events,
- At 21:00 UTC on the 7th of August, thunderstorms were reported with severity classification of 9 indicating the severest cumulonimbus with showers,
- At 00:00 UTC on the 8th of August, it was reported that there were thunderstorms and showers in the past but not at the time of observation. Last 6-hr cumulative rainfall amount was 60mm,
- At 03:00 UTC, it was reported that there were heavy showers and developed cumulus,
- At 06:00 UTC, heavy rainfall and severe thunderstorm were reported. 12-hr and 24-hr cumulative rainfall amounts were 145 mm and 204.6 mm respectively.

9.3.5. BSMEFFG Products

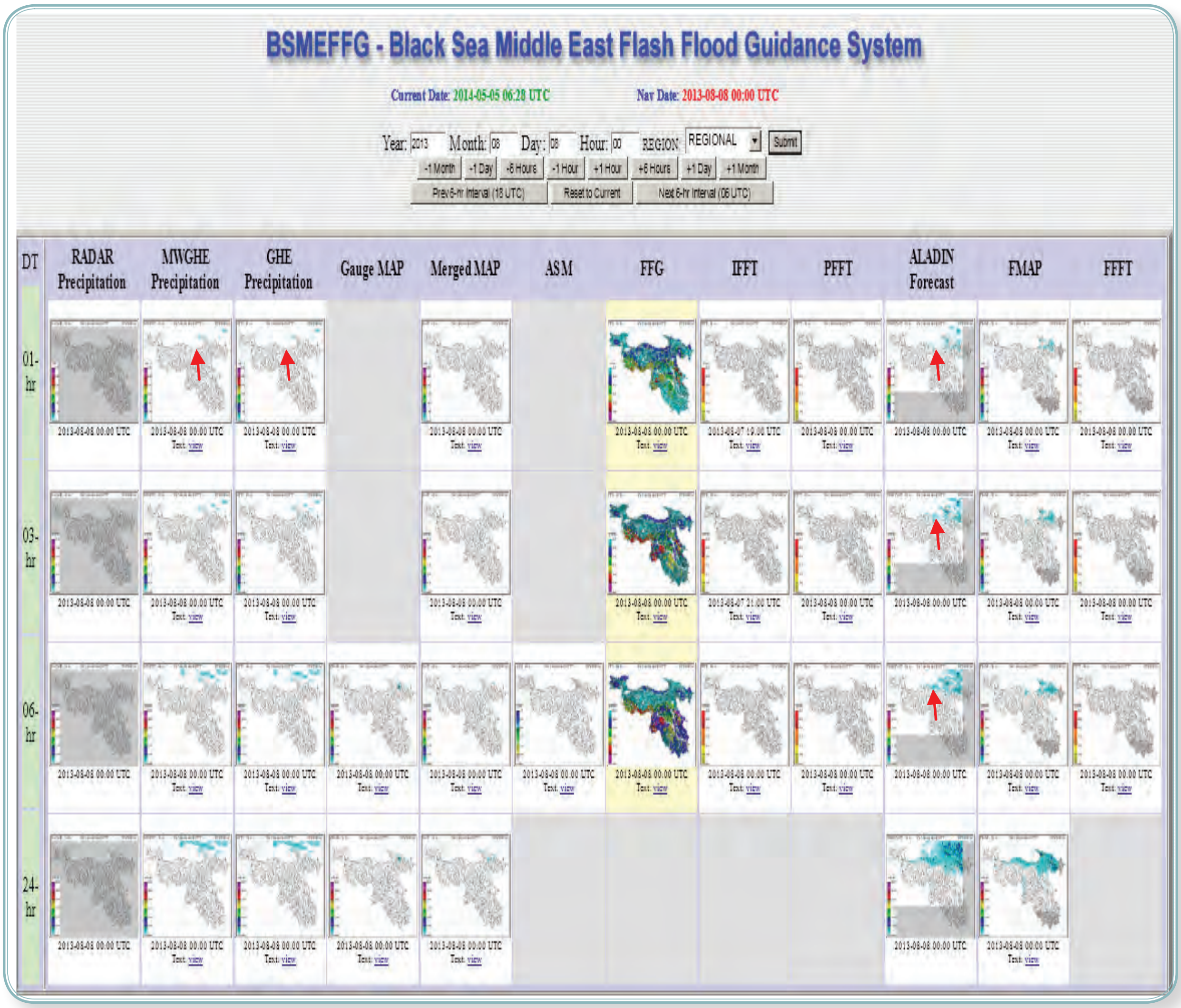


Figure-94 BSMEFFG products on 08.08.2013 at 00 UTC

Unfortunately, as Figure-94 shows, BSMEFFG products did not capture the convective activities and associated precipitation formation in Samsun province and its vicinity. Satellite retrieved precipitation products, GHE and MWGHE did not estimate any precipitation in Samsun province but light precipitation in northern Caucasus. This is the well-known precipitation retrieval problem from the meteorological satellites , particularly geostationary, that it is quite difficult to capture convective activities and estimate associated precipitation from them due to, among others, poor spatial resolution. Forecasters, therefore, pay attention to other tools like nowcasting during the transition seasons and in the summer during which convection might be dominant phenomenon for the flash floods occurrences. Similarly, ALADIN LAM did not capture convection in Samsun province but predicted light precipitation. Studies show that meteorological models including LAMs make quite poor predictions for the local convective storms particularly in the summer months provided that Radar and AWOS data assimilation might improve predictions.

What we have learned from this case study are as follows: 1) Satellite precipitation retrievals are poor comparing with the frontal systems and other large scale circulations. Therefore, it is difficult for BSMEFFG system to produce accurate products because the main input for the FFG system is precipitation such that the better the precipitation estimation the more accurate FFG products are generated. 2) In addition to BSMEFFG products, forecasters must use additional tools and products e.g., weather Radar, high resolution satellite images e.g., METEOSAT HRV, and instability analysis from sounding stations in the summer, autumn and spring months. 3) Knowledge of local micro climatological conditions are essential for preparing BSMEFFG bulletins. 4) When forecasters combine all available tools and products, they will be able to prepare more realistic FFG bulletins. 5) As an alternative precipitation source weather Radar precipitation products, depending on the availability, could be used if they were well calibrated and bias adjusted with ground gauge data.

Press reported that more than 200 houses and shops were flooded as shown in Figure-95.

interpress medya takip merkezi 1940

ZAMAN ORTA KARADENİZ HAFTALIK BÖLGESEL GAZETE EK
İSTANBUL
SİYASİ

Tarih : 14.08.2013
Sayfa No : 1
Tiraj : 1002892
StxCm : 309

Selle mücadeleyi başarıyla yöneten Vali, ilçeyi 36 saatte normale döndürdü

FATİH YALÇINER-SAMSUN

Samsun'da 46 yıl aradan sonra metrekareye düşen 205 kilogramlık sağanak yagmur, 8Agustos'ta Atakum ilçesinde yine sel felaketi yaşanmasına neden oldu. Geçen sene ki sel felaketinden sonra başta Büyükşehir Belediyesi olmak üzere ilgili kamu kurumlarının aldığı alt yapı tedbirleri daha büyük bir felaket yaşanmasına engel oldu. Alt yapı projelerinde gözden kaçan veya tamamlanamayan eksiklikler nedeniyle yine de cadde ve sokaklar ile 200'ün üzerinde ev ve iş yerlerini sular altında bırakan sel, bu kez can alamadı. Sağanak yagış başlamasıyla sel olacağı bilgisini alarak Samsun Valiliği İl Afet ve İl Afet ve Acil Durum Müdürlüğü (AFAD)'da kurulan kriz merkezi yetkilileri acilen toplayan Samsun Valisi Hüseyin Aksoy, önemli bir rekora da imza attı. Geçen yıl şehrin normale dönmesi yaklaşık 2 haftayı bulurken, Vali Aksoy'un kurumları başarıyla koordine etmesi ve sel sonrası çalışmaları titizlikle yürütmesi sebebiyle ilçe 36 saatte normale döndü. SAYFA 02

Figure-95 Press report about the urban flooding in Samsun on 08.08.2013

9.4. Antalya Flash Flood Event

Antalya (36.8851,30.6828; WMO synoptic station No: 17302), is located on the Mediterranean Sea coast (red dot) in the foothills of Taurus mountains. Taurus Mountains run parallel to the Mediterranean Sea west to east and its summit reaches approximately 3.000 meters. The land of the province is 78% mountainous, 10 % plain and 12% hilly. Antalya has typical Mediterranean climate features that it is rainy during the winter, autumn and spring and dry during summer. In winter, cyclonic depressions associated with fronts produce heavy precipitation; on the other hand, in spring and autumn, precipitation is associated with not only the cyclones but also with the convection. When the Mediterranean cyclones propagate toward Antalya, cold air advection occurs from the north and warm and moist air advection occurs from the south coupling with orographic lifting results in heavy precipitation. The Mediterranean depressions tracks are given in Figure-74. Intensive precipitation due to convection is very significant in the region in autumn and spring seasons causing flash floods. Frequencies of flash flood occurrences in Turkey are shown in Figure-56, indicating that Antalya and its vicinity are prone to flash floods.

A flash flood occurrence in Antalya province on the 15th of April, 2013 is to be investigated as a fourth case study. TSMS observations reveal that event started on the 15th of April, at 09 UTC and lasted only for three hours with 67.8 mm surface rainfall accumulation.

Figure-96 shows rainfall intensity (mm/hr) from the 15th of April at 06 UTC to 13 UTC such that peak rainfall intensity occurred at 11 UTC with a maximum value of 30 mm. Flash floods occurred in Antalya and its vicinity causing extensive property damages. Fortunately, TSMS prepared a flash flood bulletin and issued a warning.

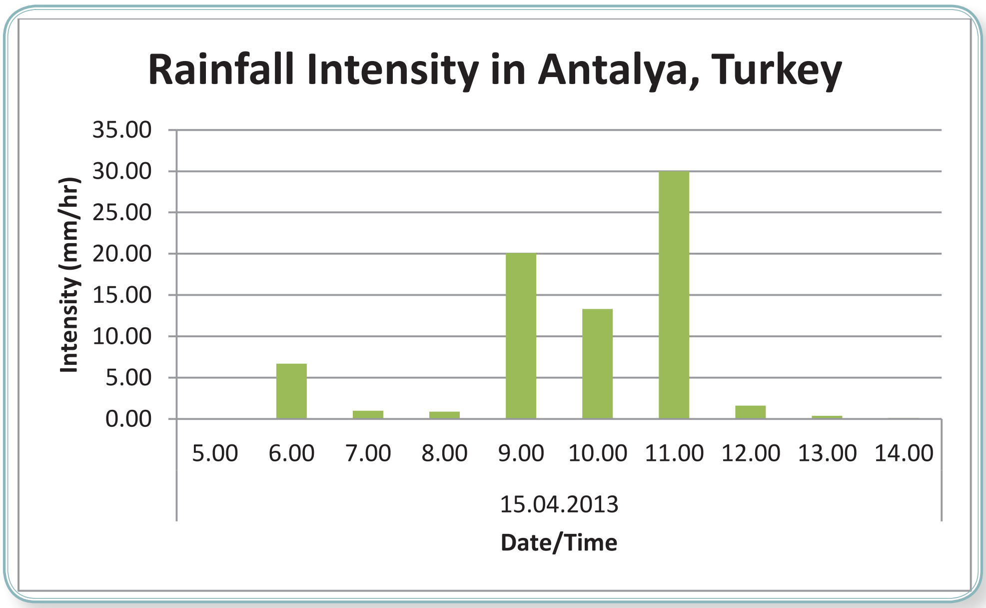


Figure-96 Rainfall intensity in Antalya measured at AWOS station

9.4.1. Synoptic Analysis

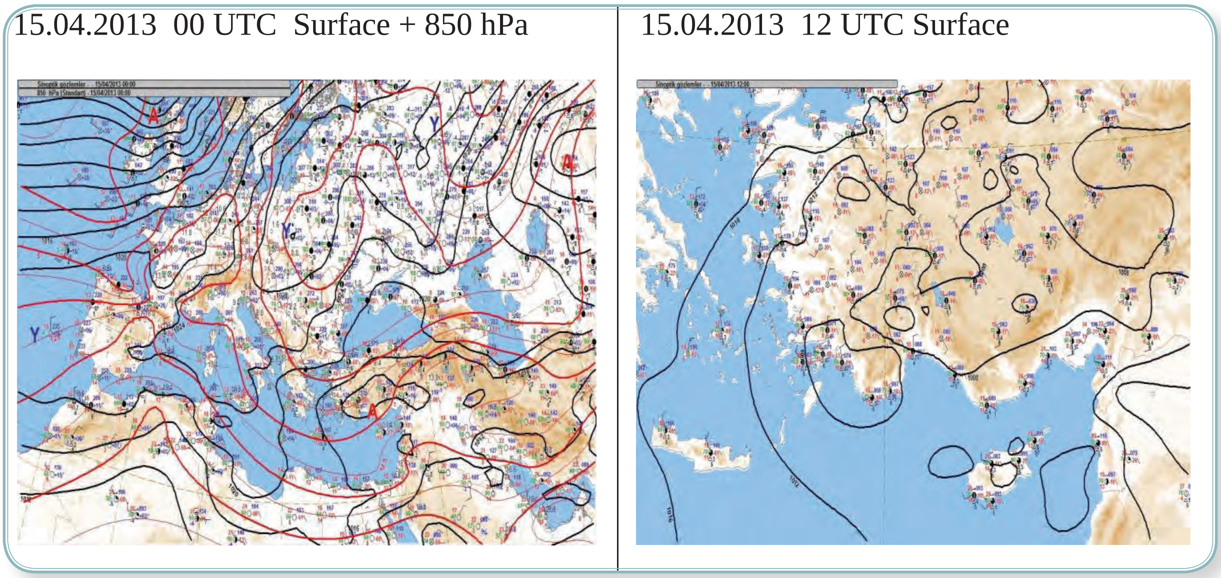


Figure-97 Surface and 850 hPa isotherm charts on 15.04.2013 00 UTC and 12 UTC

As the surface analysis shows (Figure-97), a low pressure center was located over southern Turkey with 1012 hPa pressure value, extending from the western Mediterranean region to the eastern Mediterranean Region at 00 UTC. Cold air advection exited over western Turkey and over Greece blowing from the northeast and the north while warm air advection existed over northeast Turkey blowing from the east at 850 hPa (left). A cold front was extending from Antalya to eastern Egypt while a warm front was extending toward northeast Turkey. This was a typical eastern Mediterranean depression that caused heavy rainfall in the region when frontal lifting was coupled with orographic lifting.

Synoptic observations reported thunderstorms and towering cumulus clouds in the Mediterranean region. Surface temperature was 11^{0}C and dew point temperature was 9^{0}C indicating moist lower troposphere. At 12 UTC of the same day, the low pressure center was more pronounced (deepened) over Antalya with a pressure value of 1008 hPa.

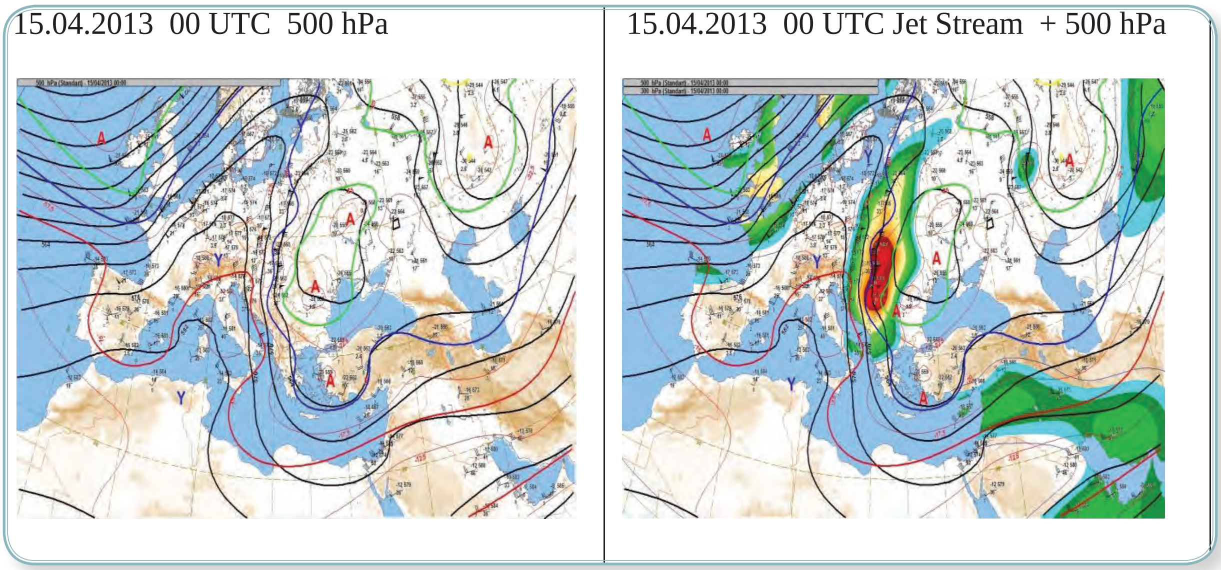


Figure-98 500 hPa Chart and jet stream on 15.04.2013 00 UTC

Figure-98 shows that there was a low center of 560 hPa and associated trough over western Turkey extending toward Egypt. -20ºC isotherm passed through Aegean Sea and Greece at 500 hPa (Blue contour) while -22ºC temperature was reported by Isparta radiosonde station that was located in the north of Antalya indicated the existence of cold air at the mid-troposphere. The temperature differences between surface and 500 hPa over Antalya was 33ºC indicated unstable atmospheric conditions. Jet core was located over eastern Europe with 85 knots winds speed and wind were blowing from the north to the south (right).

9.4.2. Instability

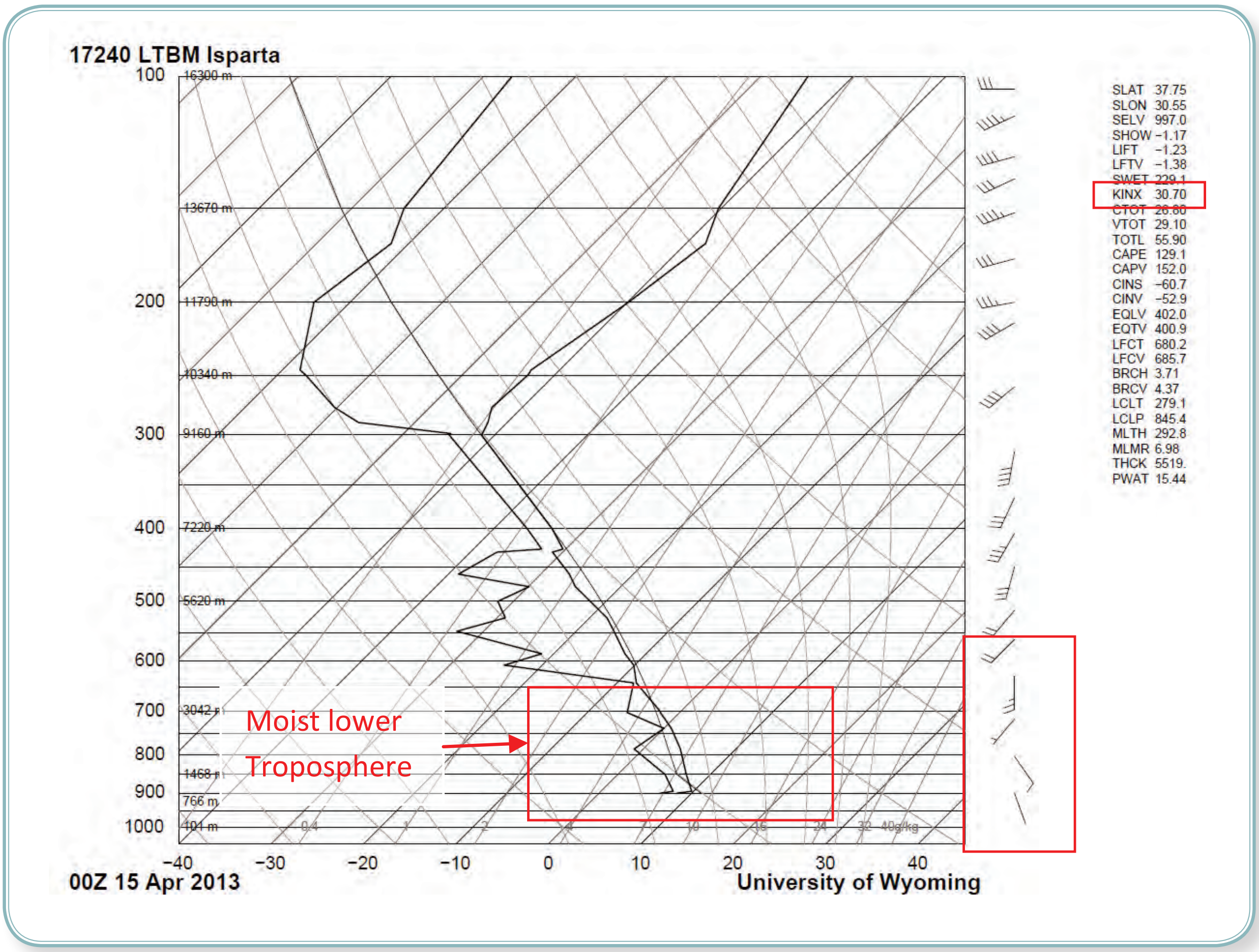
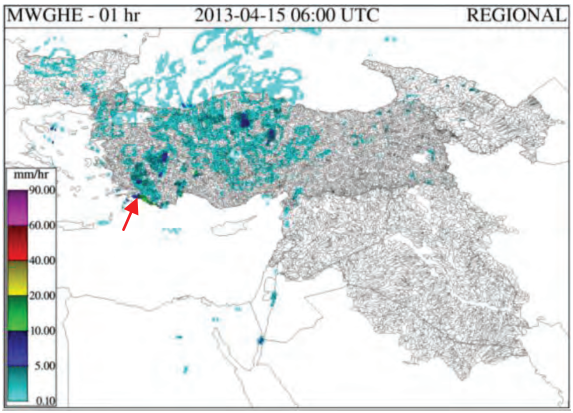


Figure-99 Radisonde station report of Isparta (17240) on 15.04.2013 at 00Z

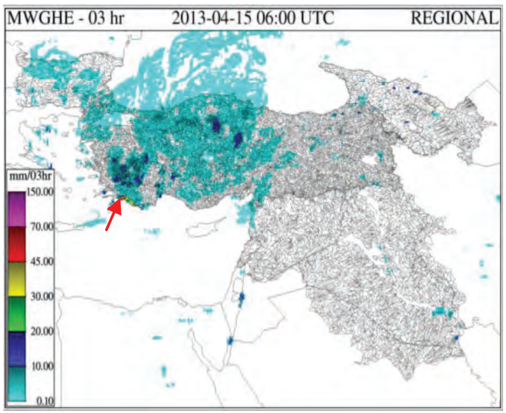
Radisonde station in Isparta(17240) reported at 00 UTC on 15.04.2013 is shown in Figure-99. It is clearly seen from the sounding plot that the lower troposphere was moist, there was low level vertical wind shear, and K-index was 30.70. Forecasters should note that this was a very favorable condition for convective development.

9.4.3. BSMEFFG Products

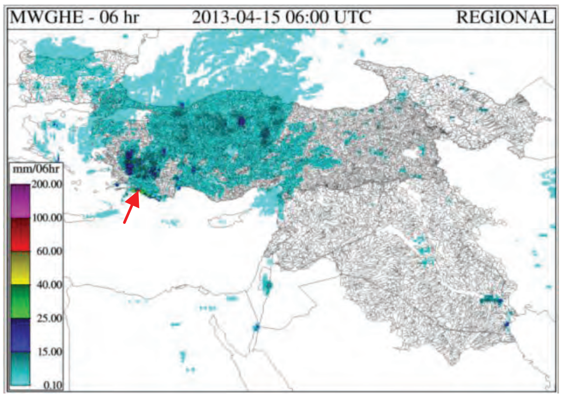
MWGHE 1-hr 15.04.2013 06:00 UTC



MWGHE 3-hr 15.04.2013 06:00 UTC



MWGHE 6-hr 15.04.2013 06:00 UTC



MWGHE products show that precipitation existed in the southern Aegean Sea coast and central Anatolia. 1-, 3- and 6-hr maximum MWGHE values were 40 mm, 70 mm and 100 mm, respectively in the southern Aegean Sea coast (red arrow). Signature of the images indicated that precipitation formation was due to convective cells. So, further development and propaga-tion of the cells were to be monitored as a possible cause of flash floods (Figure-100).

Figure-100 MWGHE precipitation on 15.04.2013 at 06:00 UTC

MWGHE indicates that there was a widespread light to moderate precipitation over western Turkey and there were convective clouds on southern Aegean Sea coast and in central Turkey. Having analyzed the past precipitation pattern, forecasters should ask themselves "will the past precipitation dissipate or continue with the same rate or intensify in the next six hours?" and "Where it will propagate?"

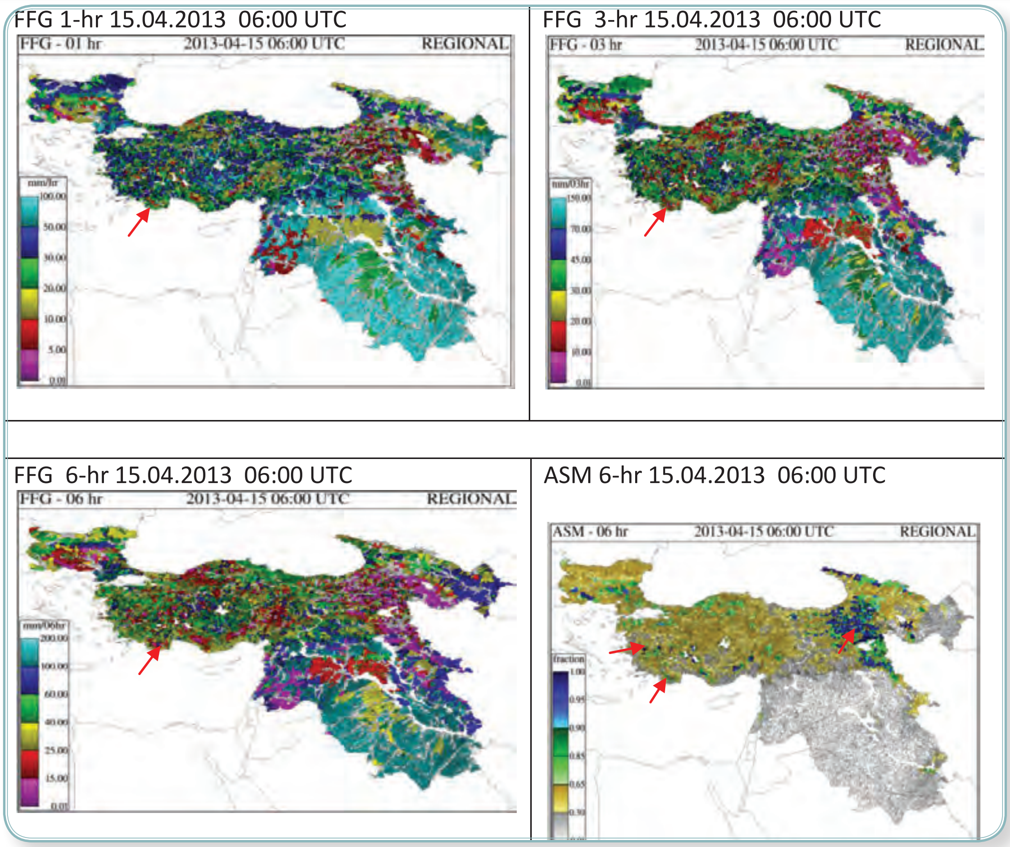


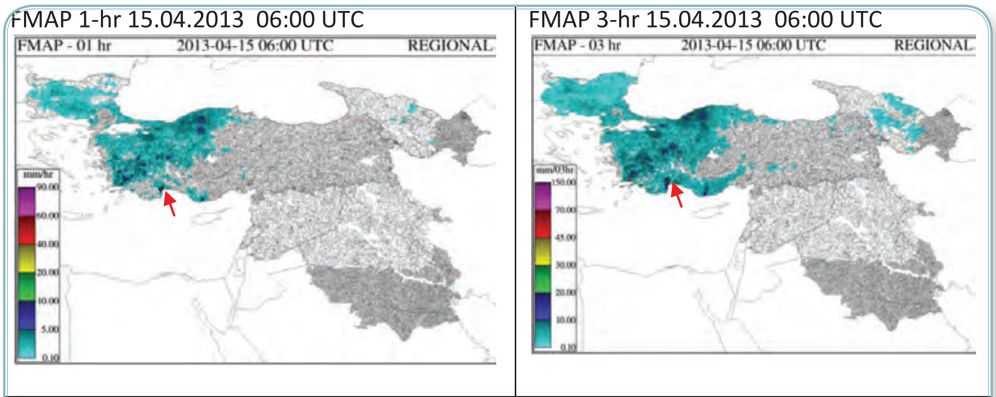
Figure-101 FFG and ASM (Soil Moisture Fraction) on 15.04.2013 at 06:00 UTC

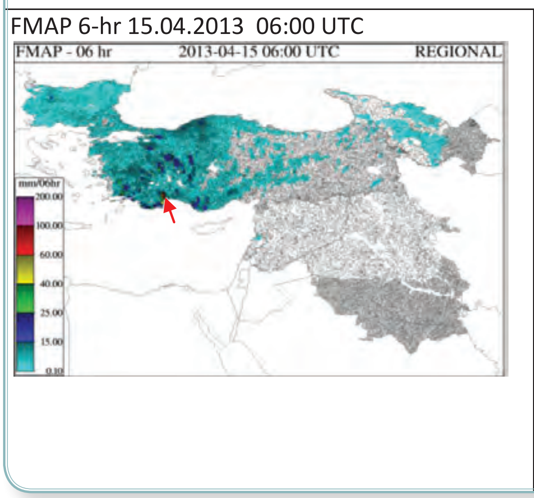
The next step was to investigate soil moisture deficit to find out how the top soil moisture changed wrt precipitation variations in the sub-basins. As shown in Figure-101, soil moisture fraction was approximately 0.65 in the western Mediterranean region but higher in eastern Turkey. However, in western Turkey, where precipitation had occurred in the last six hours, there were a couple of sub-basins that had soil moisture fraction higher than 0.65 so that they must have been monitored by forecasters for the possible flash flood occurrences.

As we recall, the flash flood guidance definition is the actual amount of rainfall that may cause bankfull flow at the outlet of a catchment for a given duration. Figure-101 shows FFG estimates at 06:00 UTC and were valid for the next six hours. In the study region, FFG estimates varied quite a lot among the sub-basins having 1-hr FFG values of 10 mm (red), 20 mm (yellow), and 30 mm (green); 3-hr FFG values of 10 mm (pink), 20 mm (red), 30 mm (yellow), and 45 mm (green); and 6-hr FFG values of 15 mm (pink), 25 mm (red), 40 mm (yellow) and 60 mm (green). If the accumulated rainfall amount for the 1, 3, and 6-hr duration were higher than these FFG values , probability of the occurrences of flash floods was quite high depending on the access amount of rainfall that determined the degree of flash floods threats.

If we recall the definitions of IFFT, PFFT and FFFT, that may guide us in how to interpret these products. IFFT, which takes into account merged MAP at the time of estimation, indicates that a flash flood has already occurred or will occur very soon. PFFT, which assumes that precipitation at the time of FFG estimates will persist in the next 1, 3 and 6 hours. This product has two deficiencies; one of which is that it assumes that precipitation amount will not change in the next 1,3, and 6-hr for the catchments and the second one is that it does not take into account the possibility of storm movement in different directions. Therefore, a forecaster should be very careful with this product and will recognize that threats are generated after the storms pass. FFFT, which is generated by using mesoscale model precipitation forecast e.g. ALADIN or WRF, may have advantages over PFFT that may take precipitation as "stationary" rather than propagating in time and space. However, forecasters must ask themselves how well the concerned mesoscale precipitation forecast is reliable in a particular region. As an example, our experiences show that WRF precipitation forecast is in general higher than ALADIN precipitation forecast and both are quite higher than ECMWF forecasts for all weather conditions. If a Hydrometeorological Service is using more than one precipitation source from weather forecasting models, local verification study must be conducted to find out which model is performing better for the different seasons and for the different type of weather systems e.g., cyclonic depresions or convection. Then, we investigated forecast mean areal precipitation distribution over the next 1,3, and 6-hr and compared them with corresponding FFG values to find out the sub-basins with access amount of rainfall e.g., flash flood threats.

When FMAP and FFG values were compared for the sub-basins in Atalya province, it was clearly seen that there were sub-basins with large differences between FMAP and FFG values indicating possible flash flood occurrence.

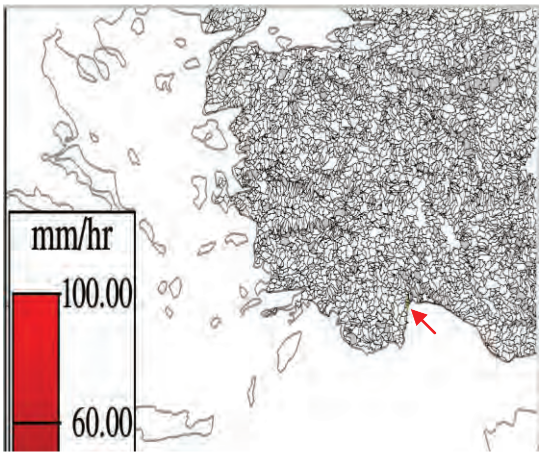




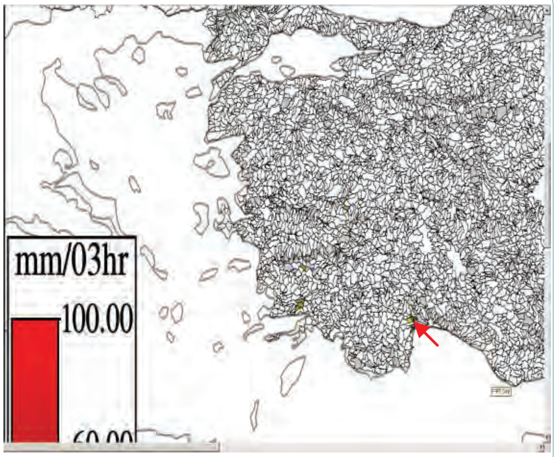
Forecast Mean Areal Precipitation that is generated from ALADIN mesoscale precipitation forecasts are shown in Figure-102. As it is seen that precipitation moves from northwest to South East toward Mediterranean region. 1-hr FMAP values in Antalya provinceranged 10 mm to 40 mm; in 3-hr FMAP, a few catchments had values of 70 mm (red); and in 6-hr FMAP, there were catchments with 100 mm (red) and even one catchment with 200 mm (pink).

Figure-102 FMAP products on 15.04.2013 at 06:00 UTC

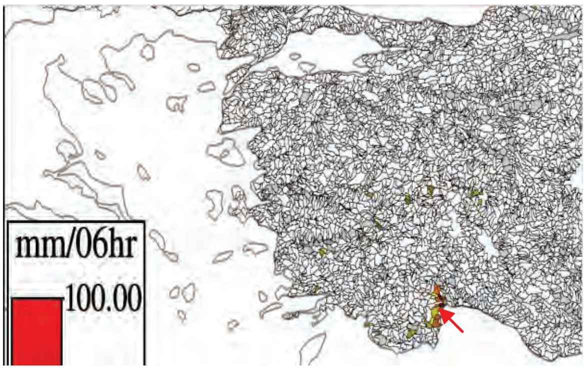
FFFT 1-hr 15.04.2013 06:00 UTC



FFFT 3-hr 15.04.2013 06:00 UTC



FFFT 6-hr 15.04.2013 06:00 UTC



1-hr, 3-hr and 6-hr FFFTs have 10 mm (yellow), 40 mm (orange) and;100 mm (red) respectively as shown in Figure-103.

Figure-104 shows urban flooding and flash floods in rural area in Antalya province on 15.04.2013. Images were obtained from national press.

Figure-103 FFFT products on 15.04.2013 at 06:00 UTC

Figure-104 Urban flooding and flash floods in rular area on 15.04.2013

10. Verification

Verification of flash flood events are not a easy task but very important to evaluate the performances of the FFG system. The most difficult part of verification is to collect information and documents about the actual events from various sources like water management authorities, municipalities, hydrometeorological institutions , and press. In Turkey, official flood reports including flash flood come from three different organizations namely State Hydraulics Affairs (DSI), Prime Ministry Disaster and Emergency Management Presidency (AFAD) and Turkish State Meteorological Service (TSMS). TSMS reports flash floods through local FEVK observations meaning extreme weather events like flash floods, gust, severe storms, hail and frost etc. DSI provides reports of inundations. AFAD collects all kinds of disasters information but in general big events are reported by AFAD. TSMS and DSI reports were used for the verification of FF Bulletins for the period covering from May 21, 2012 to June 17, 2013 (Figure-105). Participating countries should be advised to collect flash flood events reports from the fields as much as possible and create maps and contingency table.

		Observations (Flash Flood Reports: TSMS+DSI+Press)		
		Y	N	Σ
Bulletin (21 May 2012 - 17 June 2013)	Y	43 (a)	25(b)	68
	N	18 (DSI) (c)	306(d)	324
	Σ	61	331	392

Figure-105 Contingency table of FF Bulletins for Turkey

Hit Rate (POD): a / (a+c)	0.70
False Alarm Ratio(FAR): b / (a+b)	0.36
False Alarm Rate (POFD): b/(b+d)	0.07
Threat Score: a / (a+b+c)	0.50

During the verification period, 26 people were killed and there were hundreds of millions of dollars in property damages. Fortunately, only three events in which human losses happened were missed.

Figure-106 shows the location frequencies of flash flood events that were reported by TSMS FEVK observations (left) and DSI (right) in 2013. Sixty two (62) TSMS FEVK and thirty two (32) DSI observations reported 85 flash flood events and 50 flood events in different locations across Turkey, respectively. Spatial distribution reveals that majority of the flash floods occurred along the coastal regions which is inline with the historical flood events distribution (Figure-56). On the other hand, 32 flash flood bulletins were prepared in 2013 being issued warnings for 188 cities and towns (bottom).

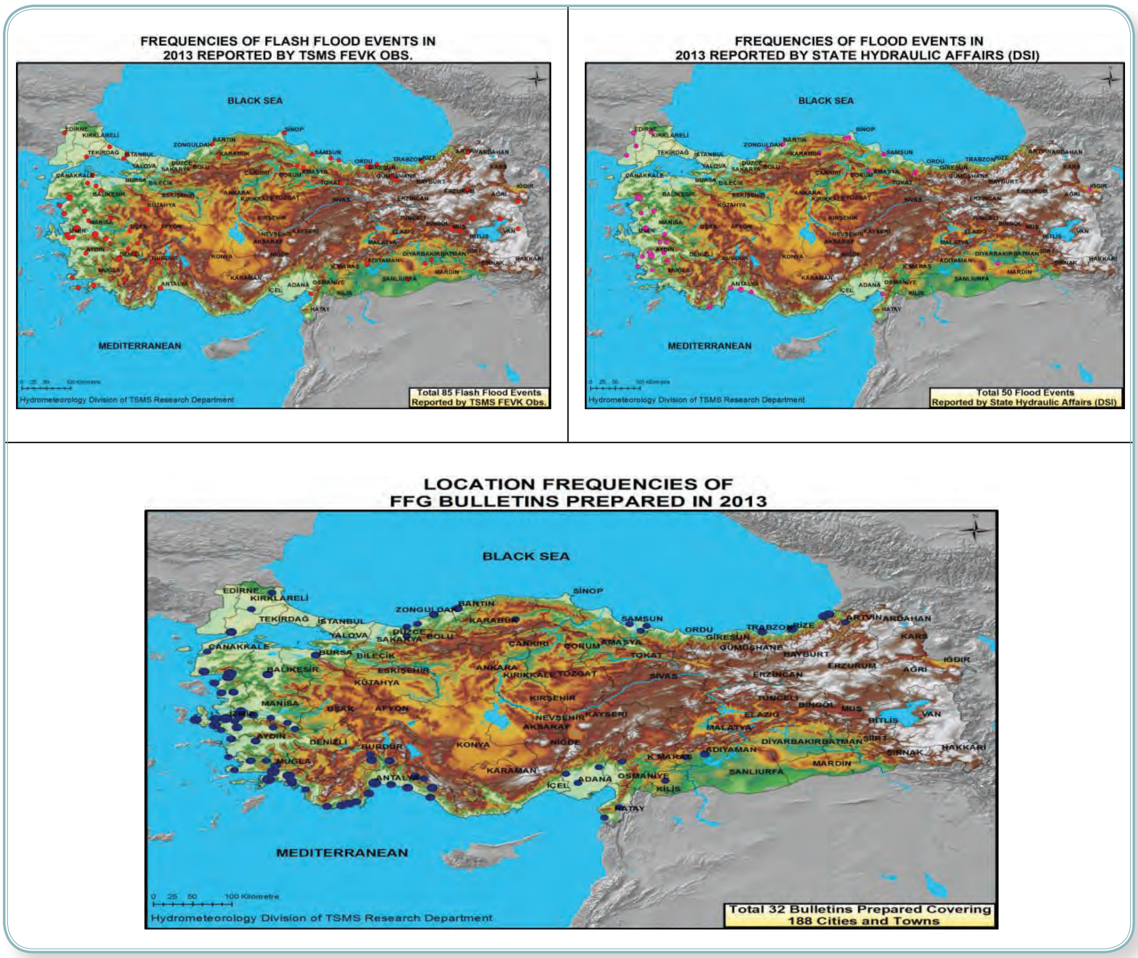


Figure-106 TSMS and DSI flash flood events and FF bulletins frequencies in 2013

11. Contact Points

As a regional center, the following Turkish State Meteorological Service staff are responsible to provide assistance to those who would like to know more about BSMEFFG products, its operation, any further information. Please contact with them by either e-mail or phone for any enquiries.

Name	Subject	E-mail	Phone
Ayhan SAYIN	FFGS	asayin@mgm.gov.tr	+90 312 302 24 72
Yusuf ULUPINAR	Administrative	yulupinar@mgm.gov.tr	+90 312 302 24 70
A.Ihsan AKBAS	GIS	aiakbas@mgm.gov.tr	+90 312 302 24 71

Contact points of the participating countries are as follows:

Country	Name	E-mail	Phone
Bulgaria	Ms.Snazhanka BALABANOVA	sn_balabanova@abv.bg snezana.balabanova@meteo.bg	+359 887 507 406
Georgia	Ms.Marina KORDZAKHIA	marinakordzakhia@gmail.com	+99 599 203 998
Azerbaijan	Mr.Asif VERDIYEV	asifverdiyev@mail.ru	+99 412 566 02 79
Armenia	Ms.Amalya MISAKYAN	miamalya@yandex.ru	+37 493 44 65 10

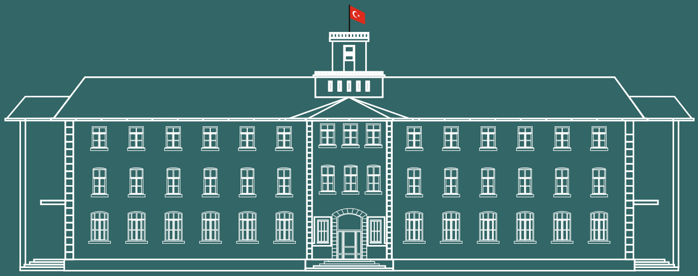
If one would like to contact with HRC, developer of the FFG system, Mr. Robert Jubach, general manager, would be contacted at rjubach@hrcwater.org or rjubach@hrc-lab.org . Those who would like to obtain more information about HRC, please visit HRC web site www.hrc-lab.org or www.hrcwater.org.

12. References

1. Alexandros Ntelekos, Konstantıne P. Georgakakos, Wıtold F. Krajewskı., on the Uncertainties of Flash Flood Guidance: Toward Probabilistic Forecasting of Flash Floods, 2005, Journal of Hydrometeorology.
2. Eylon Shamir, Byong-Ju Lee, Deg-HyoBae, M.ASCE and Konstantine P. Georgakakos., M.ASCE4 Flood Forecasting in Regulated Basins Using the Ensemble Extended Kalman Filter with the Storage Function Method, 2010, Journal of Hydrologic Engineering.
3. Gabriele Villarini , Witold F. Krajewski , Alexandros A. Ntelekos, Konstantine P. Georgakakos , James A. Smith., Towards Probabilistic Forecasting of Flash Floods: The Combined Effects of Uncertainty in Radar-rainfall and Flash Flood Guidance, 2010, Journal of Hydrology.
4. Konstantine P. Georgakakos., Realtime Flash Flood Predictions,1987, Journal of Geophysical Research.
5. Konstantine P. Georgakakos., Hydrometeorological Models forRealtime Rainfall and Flow Forecasting, 2002, Water Resources Publications.
6. Konstantine P. Georgakakos, Dong-Jun Seob, HoshinGuptac, John Schaake, Michael B. Butts., Towards the Characterization of Streamflow Simulation Uncertainty Through Multimodel Ensembles, 2004, Journal of Hydrology.
7. Konstantine P. GEORGAKAKOS., Issues in the Forecast and Management of Natural Floods and flash Floods,2006, Hydroinformatics.
8. Konstantine P. Georgakakos., Analytical Results for Operational Flash Flood Guidance, 2006, Journal of Hydrology.
9. Pinhas, A., MediterrraneanCyclones:Distribution, Tracks and Types, 4-9 June 2006, MSMM, Alghero, Italy.
10. Pinhas, A., Neeman, B,U., Shay-El,Y., Climatological Anaysis of Mediterrainean Cyclones using ECMWF Data",1990, 42A65-77, Tellus.
11. T.M. Carpenter, J.A. Sperfslage, K.P. Georgakakosa, T. Sweeneyc, D.L. Fread., National Threshold Runoff Estimation Utilizing GIS in Support of Operational Flash Flood Warning Systems, 1999, Journal of Hydrology.
12. K.P. Georgakakosa., Covariance Propagation and Updating in the Context of Real-time Radar data Assimilation by Quantitative Precipitation Forecast Models, 2000, Journal of Hydrology.
13. Theresa M. Carpenter, Konstantine P. Georgakakos., Impacts of Parametric and Radar Rainfall Uncertainty on the Ensemble Streamflow Simulations of a Distributed Hydrologic Model, 2004, Journal of Hydrology.
14. Theresa M. Carpenter, Konstantine P. Georgakakos., Intercomparison of lumped Versus Distributed hydrologic Model Ensemble Simulations on Operational Forecast Scales, 2006 , Journal of Hydrology.
15. Theresa M. Carpenter , Konstantine P. Georgakakos., Discretization Scale Dependencies of the Ensemble Flow Range Versus Catchment Area Relationship in Distributed Hydrologic Modeling, 2006, Journal of Hydrology.
16. Theresa M. Carpenter, Konstantine P. Georgakakos., Continuous Streamflow Simulation with the HRCDHM Distributed Hydrologic Model,2006 , Journal of Hydrology.
17. Theodore K. Apostopolos, Konstantine P. Georgakakos., Parallel Computation of Streamflow Prediction with Distributed Hydrologic Model, 1997, Journal of Hydrology.

iPhone

ANDROID



BLACK SEA AND MIDDLE EAST FLASH FLOOD GUIDANCE SYSTEM USER GUIDE

October - 2014

TURKHISH METEOROLOGICAL SERVICES

Kütükçü Alibey cd. No:4 0612 Kalaba, Keçiören / ANKARA / TURKEY
Phone : 0 312 359 75 45 - Fax : 0312 360 25 51
www.mgm.gov.tr