EVALUATION OF THE CONSISTENCY OF STATION-BASED SOIL MOISTURE MEASUREMENTS WITH HYDROLOGICAL MODEL AND REMOTE SENSING OBSERVATIONS OVER TURKEY

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

BURAK BULUT

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

SEPTEMBER 2015

Approval of the thesis:

EVALUATION OF THE CONSISTENCY OF STATION-BASED SOIL MOISTURE MEASUREMENTS WITH HYDROLOGICAL MODEL AND REMOTE SENSING OBSERVATIONS OVER TURKEY

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ABSTRACT

EVALUATION OF THE CONSISTENCY OF STATION-BASED SOIL MOISTURE MEASUREMENTS WITH HYDROLOGICAL MODEL AND REMOTE SENSING OBSERVATIONS OVER TURKEY

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September 2015, 78 pages

Soil moisture is a critical parameter for many subjects like climate, drought, water and energy balance, weather prediction; yet the number of studies involving soil moisture has been limited in Turkey. Soil moisture parameter can be obtained using several different methods. Among the values obtained via different methods, station-based observations have the greatest potential to provide the most accurate soil moisture information, even though station based observations have the representativeness errors over large areas. Additionally, validations of satellite- and hydrological model-based soil moisture estimates are only possible through evaluation against station-based measurements. Soil moisture observations have been made by Turkish State Meteorological Service (TSMS) at 149 different stations since 2007. On the other hand these datasets have not been used in any study before as their accuracy has not been assessed before.

In this study, evaluation of the stations is made by classifying the time-series as “reliable” or “not reliable” depending on their consistency against the station-based precipitation data after applying quality control of data. Soil moisture observations later are compared with both satellite- (ASCAT, LPRM) and hydrological model-based (API, NOAH) soil moisture values. As a result of intercomparison Pearson correlation coefficient (R) between stations and other sources were found as respectively 0.751 for NOAH, 0.638 for API, 0.720 for LPRM and 0.634 for ASCAT. In addition to these values, RMSE values of overall 68 stations were found as follows, NOAH 0.035, API 0.048, LPRM 0.040 and ASCAT 0.046. These results are later inter-compared against the results of similar studies structured on evaluation of station-, satellite-, and model-based studies. Results show station-based soil moisture observations over Turkey showed significant correlation and accuracy results and ability to be used for future studies.

Keywords: Soil Moisture, Station Measurements, Quality Control, Remote Sensing, Hydrological Model, Inter-Comparison, Turkey.

ÖZ

TÜRKİYE GENELİNDEKİ İSTASYON BAZLI TOPRAK NEMİ ÖLÇÜMLERİNİN TUTARLILIĞININ HİDROLOJİK MODEL VE UZAKTAN ALGILAMA GÖZLEMLERİ İLE DEĞERLENDİRİLMESİ

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Eylül 2015, 78 sayfa

Toprak nemi; iklim, kuraklık su ve enerji dengesi ve hava tahmini gibi birçok konuda kritik bir parametre olmasına rağmen, Türkiye'de bu konuda kısıtlı sayıda çalışma bulunmaktadır. Toprak nemi parametresi birçok farklı metot kullanılarak elde edilebilmektedir. İstasyon bazlı gözlemler büyük alanlar üzerinde temsiliyet hatalarına sahip olmasına rağmen, diğer bütün metotlar içerisinde en doğru toprak nemi bilgisini verebilecek potansiyele sahiptir. Buna ilave olarak, uydu bazlı gözlemlerden ve hidrolojik modellerden elde edilen verilerin doğrulaması yalnızca istasyon bazlı gözlemlerden elde edilen verilerle yapılabilir. Türkiye'de toprak nemi ölçümleri Meteoroloji Genel Müdürlüğü (TSMS) tarafından 2007 yılından beri 149 farklı istasyonda yapılmaktadır. Öte yandan, bu veri setlerinin doğruluk değerlendirmesi yapılmadığından, daha önce herhangi bir çalışmada kullanılmamıştır.

Bu çalışmadaki istasyonların değerlendirilmesi, kalite kontrol analizinin yapılmasından sonra, istasyon bazlı yağış verileri ile karşılaştırılarak tutarlılığının "güvenilir" veya "güvenilmez" olarak sınıflandırılması ile yapılmıştır. Toprak nemi gözlemleri, uydu bazlı gözlem verileri (ASCAT, LPRM) hem de hidrolojik model verileri (API, NOAH) ile kıyaslanmıştır. Bu kıyaslamanın sonucunda, istasyonlar ile diğer kaynaklar arasında Pearson Korelasyon Katsayısı (R); NOAH için 0.751, API için 0.638, LPRM için 0.720 ve ASCAT için 0.634 olarak hesaplanmıştır. Ayrıca, RMSE değerleri; NOAH için 0.035, API için 0.048, LPRM için 0.040 ve ASCAT için 0.046 olarak bulunmuştur. Bu kıyaslamadan elde edilen sonuçlar daha sonra istasyon-, uydu- ve model-bazlı benzer değerlendirme çalışmalarının sonuçları ile kıyaslanmıştır.

Sonuç olarak, Türkiye genelinde istasyon bazlı toprak nemi gözlem değerleri önemli korelasyon ve doğruluk sonuçları vermiş ve gelecek çalışmalarda kullanılabileceğini açıkça göstermiştir.

Anahtar kelimeler: Toprak Nemi, İstasyon Ölçümleri, Kalite Kontrolü, Uzaktan Algılama, Hidrolojik Model, Karşılıklı Karşılaştırma, Türkiye.

to My Mother…

Annem'e…

ACKNOWLEDGEMENTS

First of all, I would like to express my sincere gratitude to Asst. Prof. Dr. M. Tuğrul Yılmaz for his guidance, recommendations, and support throughout this research and preparation of this thesis.

Then, I would like to thank my close longtime friends Ali Efesoy, Akanay Avaroğlu, Banu Fatma Özbaş, Berk Bal, Burak Tabağ, Mustafa Can Atan, Özlem Bozkan, Samet Erdoğan, Seçkin Mete, Sevinç Gürdal, Seyithan Dağ and Umur Gündüz for their motivation and support. I owe them my spectacular student years during bachelor and master degree. Although some of us far away, we always together.

I also want to present my special thanks to one of the best friend of mine Osman Göksu. We were together during bachelor and master studies, and without his support and encouragement this thesis would not have been possible.

Finally, I am grateful to my father Cafer Bulut and sister Bilge Ezgi Bulut for their endless patience, encouragement, support, and confidence in me throughout my life.

I want to dedicate this thesis to my mother Ayşe Bulut. She gave me encourage to solve every problem during my life and she always wanted me to be success.

This research is supported by TÜBİTAK ARDEB ÇAYDAG Career Development Program (3501) (Project No: # 114Y676).

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LIST OF ABBREVIATIONS

ALEXI	:	Atmosphere – Land Exchange Inversion
AMSR-E	:	Advanced Microwave Scanning Radiometer - Earth Observing System
API	:	Antecedent Precipitation Index
ARS-USDA	:	United States Department of Agriculture – Agricultural Research Service
ASCAT	:	Advanced Scatterometer
AWOS	:	Automated Weather Observation Station
ECMWF	:	The European Centre for Medium-Range Weather Forecasts
EKF	:	Extended Kalman Filter
ERS	:	European Remote Sensing Satellite
ESA	:	European Space Agency
FDR	:	Frequency Domain Reflectometry
ISMN	:	International Soil Moisture Network
LPRM	:	Land Parameter Retrievals Model
LSM	:	Land Surface Model
MESONET	:	Mesoscale Network
NASA	:	National Aeronautics and Space Administration
NCEP	:	National Centers for Environmental Prediction
OSU	:	Oregon State University
RFI	:	Radio Frequency Interference
RSMD	:	Root Mean Square Deviation
RMSE	:	Root Mean Square Error
SCAN	:	Soil Climate Analysis Network
SMAP	:	Soil Moisture Active Passive
SMM/I	:	Special Sensor Microwave/Imager
SMMR	:	Scanning Multichannel Microwave Radiometer

SST	:	Sea Surface Temperature
SMOS	:	Soil Moisture and Ocean Salinity
TDR	:	Time Domain Reflectometry
TRMM-TMI	:	The Tropical Rainfall Measuring Mission–Microwave Imager
TSMS	:	Turkish State Meteorological Service
TUWIEN	:	Vienna University of Technology
VUA	:	Vrije University Amsterdam
WCR	:	Water Content Reflectometer
WMO	:	World Meteorological Organization

CHAPTER 1

INTRODUCTION

1.1 Introduction

Soil moisture plays very critical roles in many hydrological fields like weather and climate prediction, prediction of natural disasters like flood and drought, estimation of agricultural productivity, and quality of human life and security (Entekhabi et.al, 2010). Soil moisture also plays a significant role in the conversion of the energy from the sun into sensible and latent heat and at the same time controls the water and energy cycle (Dirmeyer et.al, 2009). Soil moisture has a significant impact on atmospheric and climate events through its role in energy and water balance at the surface and its high memory associated with that. Hence, its accurate estimation is critical for understanding and correctly estimating the water, energy and carbon cycles between land and atmosphere. It is possible to make more accurate climate predictions and better predict the size of the expected change via use of more accurate soil moisture information. The soil moisture measurements also can be useful in flood mapping and monitoring because it affects the soil response in terms of infiltration and runoff (Entekhabi et al., 1994). Due to these roles, the soil moisture variable has been added to the list of "essential climate variables" by World Meteorological Organization (GCOS, 2010) while estimation of this variable has been the focus of many satellite missions like Soil Moisture and Ocean Salinity (SMOS) and Soil Moisture Active Passive (SMAP).

Satellite- and hydrological model-based soil moisture products provide very valuable temporally and spatially consistent information. Accuracy estimates of these datasets, critical to many applications like data assimilation type merging methods, immediately require ground-based observations to be used as a validation dataset (Jackson et.al, 2010). This attributes station-based soil moisture observations great significance in calibration and validation studies.

In estimation of soil moisture values through remote sensing-, hydrological model-, and station-based platforms, it is often interesting to merge these datasets to obtain a better quality time-series. However this requires error characteristics of these datasets to be extensively analyzed through inter-comparison and accuracy assessment studies.

1.2 The Scope of the Study

Since soil moisture variable is critical for many disciplines related with water and energy cycle, evaluation of soil moisture site observations is important, yet such evaluations have not been performed before over Turkey, partly because soil moisture observations made by Turkish State Meteorological Service (TSMS) have not been assessed for their consistency and accuracy before. In this study, station-based soil moisture measurements made over 149 stations is analyzed, quality controlled, and inter-compared against other datasets for the first time. The main scope of this study is to evaluate the usability of station-based soil moisture variable for future studies.

1.3 Description of Thesis

This thesis study consists of 5 chapters: research methodology and details about observation techniques of soil moisture are given in chapter 2, analysis and quality control of station-based soil moisture measurements in Turkey are presented in chapter 3, inter-comparison process and inter-comparison results are presented in chapter 4, and final results and conclusion are given in chapter 5.

CHAPTER 2

METHODOLOGY

2.1 General Information

In this chapter, soil moisture data and each different observation methods are discussed in details. On section 2.1, station-based soil moisture measurements in Turkey are explained. On section 2.2, satellite-based soil moisture observations and their characteristics are provided in detail. Finally, on section 2.3, information about model-based soil moisture measurements are given.

2.2 Station-Based Soil Moisture Measurements

Measurements in stations give the most reliable data about soil moisture. These measurements are generally used for calibration and validation process of both satellite and model based observations. Even though station-based observations provide temporally continuous information, they may be retrieved over spatially-limited locations due to financial limitations. Consequently they may often have representativeness errors as a result of the soil moisture pattern difference at the station and the larger areas that contain this station. Even though such representativeness errors exist, station-based soil moisture datasets are used as the primary datasets to validate large scale soil moisture retrievals using satellite-based observations (Jackson et al., 2010, 2012).

At stations, measurements can be done using sensors or directly collecting soil samples and using gravimetric methods. The choice of a particular method depends on the application and available resources. The gravimetric soil moisture measurement methods are simple to apply. Collected samples are weighed before and after oven drying procedure then the difference in mass gives the total soil moisture in the sample. It is a labor intensive method and it is often not preferred to monitor variability of soil moisture in time. On the other hand given that they directly measure the water content of the medium, they are often used in conjunction with sensor-based observations to validate other methods. Soil moisture sensors retrieve medium wetness information using different measurement principles such as time domain reflectometry (TDR), frequency domain reflectometry (FDR), capacitance probes, impedance probes, neutron probes and cosmic ray probes, while such datasets are particularly used to validate the time-series estimates obtained via other platforms like ones that are based on remote sensing or hydrological models.

There are many networks of stations measuring soil moisture in different parts of the world. United States Department of Agriculture Agricultural Research Service (ARS-USDA) established 85 stations in four watersheds (Little Washita, Little River, Renolds Creek, Walnut Gulch) over 1330 km^2. The soil moisture measurements are made at a depth of 0-5cm (Jackson et.al, 2010), while the accuracy of these observations is verified using gravimetric soil moisture measurements (Cosh et al., 2006, 2008). Another example for these networks is the Soil Climate Analysis Network (SCAN) which consists of 150 stations that are located in different parts of the U.S. and measures soil moisture at depths of 5, 10, 20, 50, and 100cm (Schaefer et.al, 2007). Furthermore, MESONET Network (Basara et.al, 2000) makes measurements at depths of 5, 25, 60 and 75 cm in 100 stations located in the U.S state of Oklahoma. Among these networks, ARS-USDA network stations are used for validation of measurements that are obtained from The Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) and Soil Moisture Ocean Salinity (SMOS) missions (Jackson et.al, 2010, 2012; Leroux et.al, 2014). Measurements in basins of ARS-USDA have been continuously made since 2002 using Stevens Hydro Probe sensors. Likewise, OZNET land observation network, established in Australia, makes soil moisture measurements using Campbell Scientific CS615 sensors in 37 out of its 64 stations. These measurements are used for validation of soil moisture product of Advanced Microwave Scanning Radiometer 2 (AMSR-2), which is an incipiently started observing as a follow-up of previous mission (Yee et.al, 2013). There are many other networks measuring consistent soil moisture observations, while data from 47 observation networks consisting of 1993 stations located in different regions of the world is publicly distributed through International Soil Moisture Network (ISMN) (Figure 1). However, these soil moisture networks still do not cover the majority of the global land surface area, which has varying climate, vegetation, and soil conditions. This implies more studies that consist of validation efforts using soil moisture obtained through networks over different regions, are still needed to validate and improve estimates through other platforms.

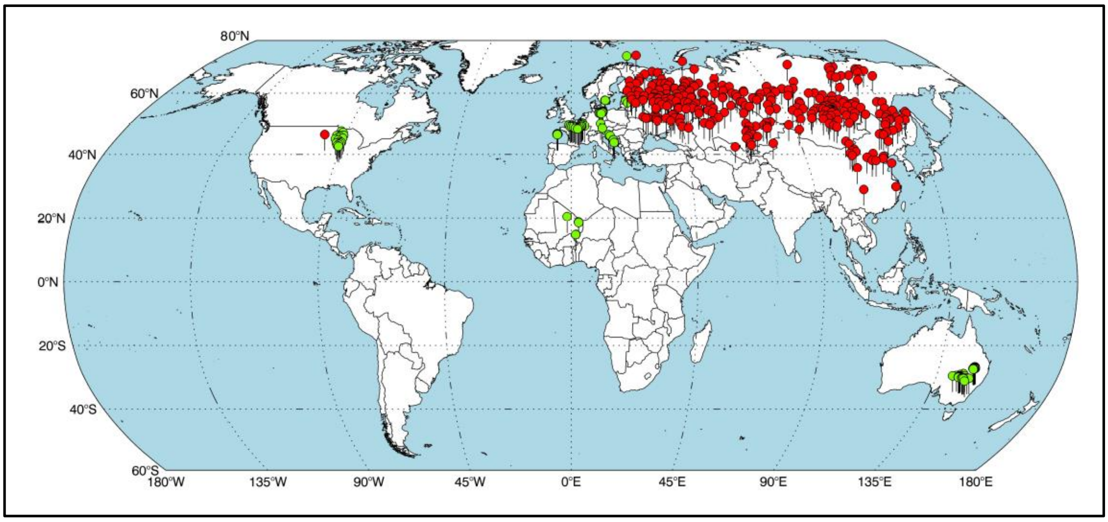

Figure 1 Map of the distribution of networks and stations contained in the ISMN (Dorigo et al., 2011). Green pins indicate active stations, red pins the historical data.

2.2.1 Stations in Turkey

Turkish State Meteorological Service (TSMS) installed around 1200 Automatic Weather Observation Stations (AWOS) between years 2002 and 2004, making various measurements like air temperature, relative humidity, wind speed and direction, precipitation, solar radiation, surface temperature and pressure (Sonmez, 2013). Soil moisture measurements are being made at a depth of 20 cm every 10 minutes along with other parameters listed above since 2007 over 149 of these stations located mostly around Western Turkey (between 26°E and 36°E longitude). Distribution of the stations can be seen on figure below on digital elevation map of Turkey (Figure 2).

Soil moisture measurements are done by using Campbell CS615 water content reflectometer (WCR) at stations in Turkey. WCR is designed to measure volumetric water content in soil or other porous media by using dielectric constant of the medium surrounding the probe rods. The sensor consists of two stainless steel probes, a circuit board and a power supply. WCR uses the dielectric permittivity of the soil that surrounds the probes which is an indirect measurement method to measure water content. A device sensitive to dielectric permittivity can be used to measure water content in soil, while water is the only content in soil other than air that highly effect dielectric permittivity. The fundamental principle is propagating an electromagnetic pulse to probes then measuring the frequency of pulse. If water content increases, the propagation time decreases as polarization of water particles takes more time. By using that relation between probes output frequency and water content, frequency is converted to soil moisture data.

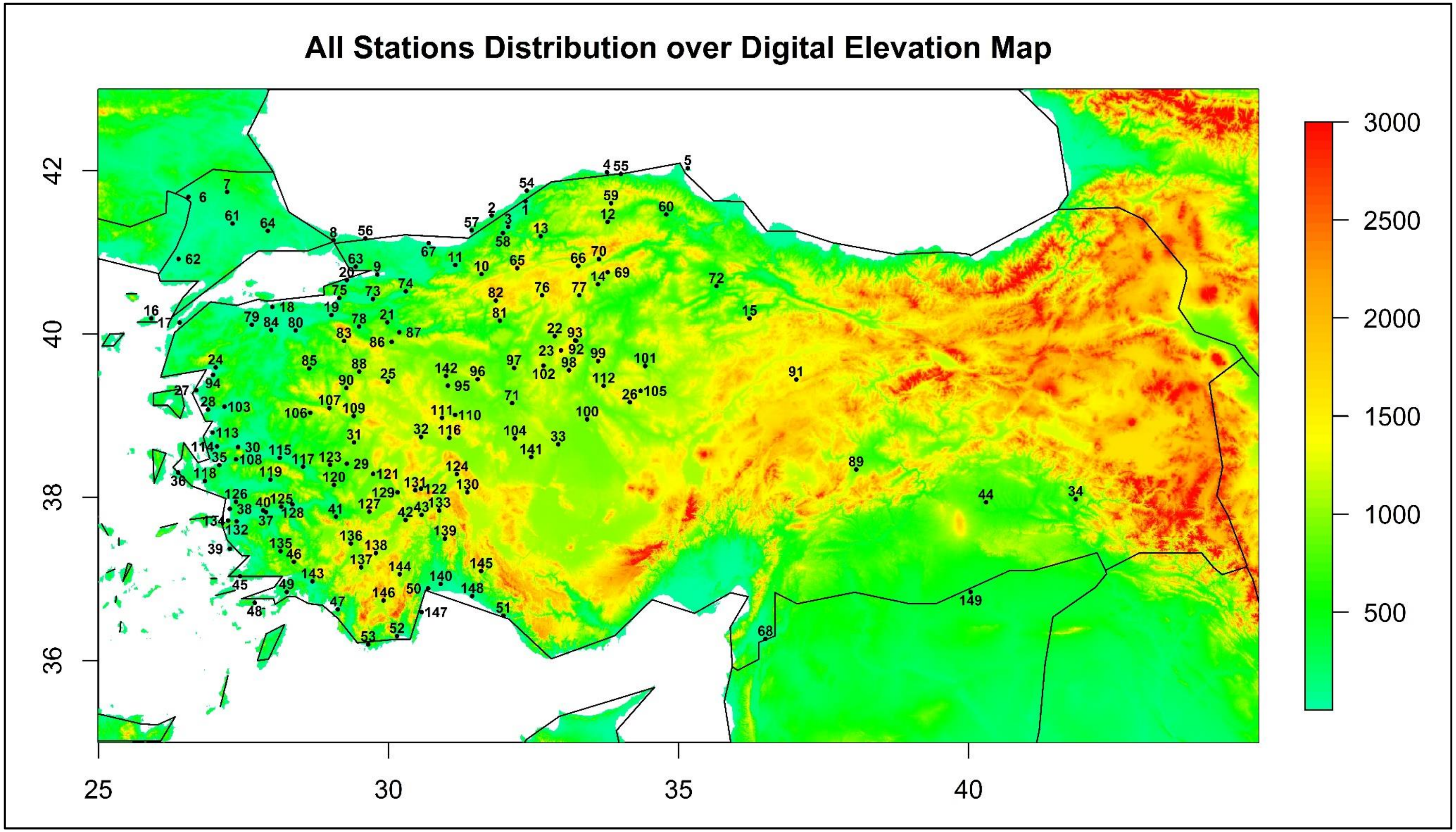

Figure 2 All Stations Distribution over Digital Elevation Map

2.3 Satellite-Based Soil Moisture Observations

Many hydro meteorological applications incorporate soil moisture information obtained over larger domain regions to improved estimates. Since stations are point measurements and often it is not feasible to install networks over remote locations, remote sensing observation-based soil moisture estimates can provide global or continental scale soil moisture knowledge (Albergel et.al, 2012). In general, remote sensing-based retrieval algorithms aim to convert the incoming signal from the surface into soil moisture information using ancillary datasets like vegetation water content and relations between the moisture conditions and the electromagnetic radiation response (Jackson, 1993). Remote sensing systems may be classified into two types depending on the incoming signal sources: (a) radiometers are passive systems that measure the self-emission of Earth's surface, (b) radars are active systems that measure the energy scattered back from the surface (Figure 3).

Remote sensing systems observe soil moisture variable by measuring its effects on the electric or thermal properties of soil. Microwave remote sensing systems are sensitive to the dielectric constant of the soil, while infrared remote sensing systems are sensitive to thermal conditions of the soil. Since these systems are sensible to soil moisture and able to penetrate cloud covers, they provide ability to make global scale soil moisture observations.

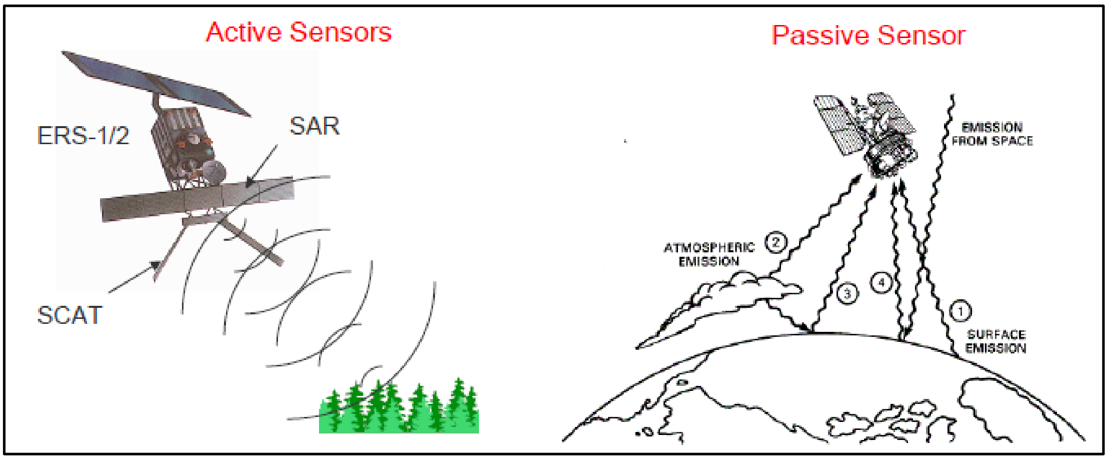

Figure 3 Active and Passive Sensors Measurement Principles

Near surface soil moisture retrievals of both passive and active satellites prove that they are useful at global and regional scale. Also developed retrievals that obtained by merging active and passive systems, produce an improved soil moisture dataset (Y. Y. Liu et al., 2011). Since remote sensing measurements have some impurities, they are the most widely used techniques in soil moisture related studies. Today, several microwave sensors provide operational global soil moisture products such as, AMSR-E, ASCAT, TRMM-TMI (Jackson, 1993), SSM/I (Owe et al., 2008), WindSat (Li et al., 2010), ERS 1 and 2 (Wagner et al., 1999; Scipal et al., 2002). AMSR-E and ASCAT are introduced in detail in this section. Moreover, recently launched special missions dedicated to soil moisture, i.e. the Soil Moisture and Ocean Salinity Mission (SMOS) of the European Space Agency (ESA; Kerr et al., 2001; Wigneron et al., 2007), and the Soil Moisture Active & Passive (SMAP) mission of the United States National Aeronautics and Space Administration (NASA; Entekhabi et al., 2010) provide soil moisture variables.

Different from other precursor sensors mentioned above, SMOS and SMAP missions use lower frequencies in order to overcome the sensitivity problem of the soil moisture estimation to dense vegetation at higher frequencies.

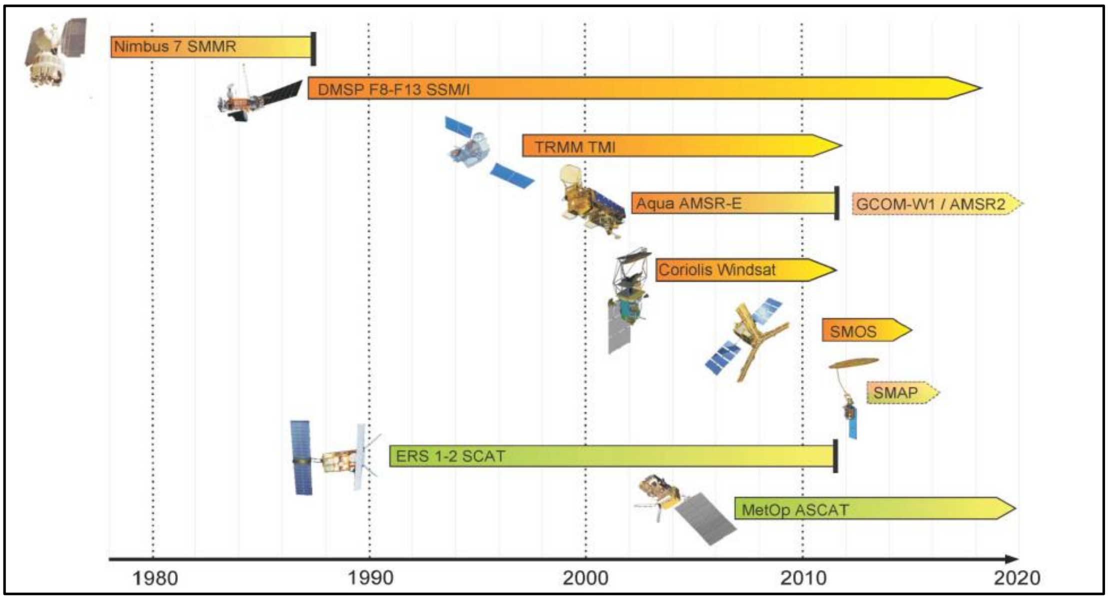

Figure 4 Active and Passive Sensors Operating Life (De Jeu et al., 2010)

Launch of Nimbus-7 with Scanning Multichannel Microwave Radiometer (SMMR) in 1978 can be accepted as beginning of remote sensing soil moisture measurements. In Figure 4 all satellites with active and/or passive sensors that have been used for soil moisture observations are shown. Some of the sensors have completed their missions, on the other hand new missions like SMOS and SMAP are started to produce soil moisture measurements after 2010. In this figure operating life time shown by red to orange are shown passive sensors and green to yellowish shows active sensors. In this study one active sensor AMSR-E and one passive sensor ASCAT are used. These two sensors are the ones that are widely used for the soil moisture related studies.

2.3.1 AMSR-E (LPRM)

Advanced Microwave Scanning Radiometer on the AQUA Earth Observation Satellite (AMSR-E) was launched in May 2002. The instrument is a dual-polarized, conical scanning, passive microwave radiometer. AMSR-E uses C-band (6.9 GHz) and X-band (10.65 and 18.7 GHz) radiance observations to derive near-surface soil moisture (Su et.al, 2013). These bands have different spatial resolution and sensing depths; C-band has topsoil sensing depth of 1-2 cm and a spatial resolution of 74 x 43 km^2 while X-band has smaller resolution with <5 mm penetration depths (Owe et al., 2008). As descripted in National Aeronautics and Space Administration (NASA) web site, AMSR-E measures number of geophysical parameters over oceans such as, sea-surface temperature (SST), wind speed, atmospheric water vapor, cloud water and the rain rate. The capability of seeing through clouds is the key feature of the AMSR-E. That key feature can provide an uninterrupted view of global SST and surface wind fields. While AMSR-E was one of the first sensors that prevalently used for the estimating soil moisture retrievals, it is currently not producing any data since it has stopped producing data in October 2011.

Orbital coverage of the AMSR-E is similar with other polar orbital satellites, as shown in the Figure 5 day time and the night time soil moisture retrievals. AMSR-E overpasses nearly at 1:30 a.m. (ascending) and 1:30 p.m. (descending) local time at the equator. In Figure 5, 24 hour ascending and descending passes of AMSR-E satellite is shown.

In order to estimate soil moisture from AMSR-E retrievals, several algorithms have been developed. Although AMSR-E has several retrieval products, Land Parameter Retrievals Model (LPRM) which is the approach of Vrije Universiteit Amsterdam (VUA) – NASA, shows stronger consistence with in-situ measurements in Europe (Owe et al., 2008). For retrievals of soil moisture and vegetation water content, LPRM uses radiances of AMSR-E's C- or X-bands as an input. The model is an iterative forward physical model inversion method. It simulates observed brightness temperature in order to divide surface emissions into soil and canopy components by varying three land surface variables (vegetation optical depth, topsoil dielectric constant and surface temperature) (Su et.al, 2013). When iteration reaches a result, the model determines the value of surface soil moisture from the optimized dielectric constant by using a global database of soil physical properties and a soil dielectric mixing model. The results of LPRM model soil moisture data are available in the units of volumetric water content (m^3 m^{-3}) on a regular 0.25° global grid. Soil moisture retrievals of AMSR-E sensor that used in this study are provided by NASA Goddard Space Flight Center's Global Change Master Directory.

When using LPRM method in the ascending passes of AMSR-E, complications such as sun glint and temperature gradient are more likely to be encountered (Crow et al., 2010). In order to avoid these complications descending passes retrievals of AMSR-E are used in this study.

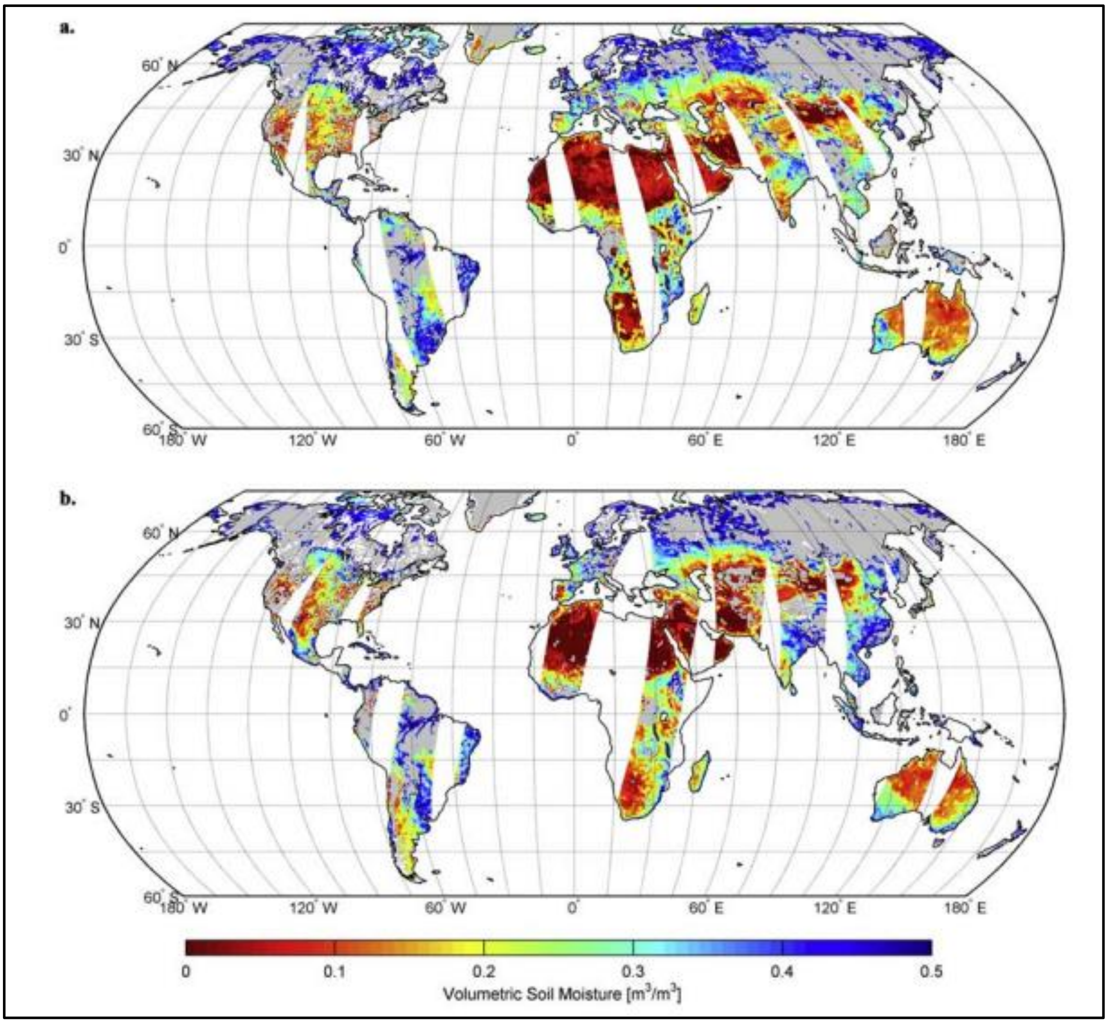

Figure 5 Twenty-four-hour global daytime and nighttime surface soil moisture retrievals at 6.9 GHz from AMSR-E (Owe et al., 2008). a. ascending pass and b. descending pass.

2.3.2 ASCAT

Advanced Scatterometer (ASCAT) is a real-aperture radar instrument on board Meteorological operational satellite – A (MetOp-A) satellite which is used to measure the radar backscatter with reliable radiometric accuracy and stability (Albergel et al., 2012). ASCAT scatterometer conducts and evaluates electro-magnetic waves. It was launched in October 2006 and became fully operational in May 2007. The measurement of the wind speed and direction over the oceans are the main objectives of the ASCAT, though it is also used for studying soil moisture, polar ice and vegetation. The types of electro-magnetic waves that are measured by

ASCAT are VV polarization in C-band with 5.255 GHz. ASCAT sights the Earth's surface with a good resolution that varying from 25 km to 50 km and spacing between grids reaches to 12.5 km for the higher resolution product. The ASCAT uses a fan-beam antenna technology like its predecessor European Remote Sensing Satellite (ERS) scatterometer. Since measurements are generated from both sides of the sub-satellite track, the data from two 550 km wide swaths are obtained. Because of the continuity in operation of ASCAT and having a double swath, it procures more than twice of the ERS scatterometer coverage. C-band microwaves produced by ASCAT have role to measure the soil moisture in the top 0.5 to 2 cm of the soil layer. The result of ASCAT measurement data could classify the saturation of soil as dry (0%) and wet (100%). Although ASCAT could measure the soil moisture at the top layer of the soil, the obtained data from ASCAT could be helpful to make estimation about deeper layers by using techniques like Extended Kalman Filter (EKF) (Walker et al., 2001).

C-band backscatter is sensitive to soil moisture, it is also dependent on vegetation cover (Wagner et al., 2013) and surface roughness (Verhoest et al., 2008). Therefore, converting radar backscatter estimates directly to soil moisture is inaccurate. Time-series based change-detection algorithm is used to overcome these difficulties (Wagner et al., 1999). It assumes land surface characteristic is relatively unchanging for a long time periods under a given incidence angle (40°). By comparing highest and lowest historical values to the instantaneous backscatter coefficient, the relative differences is determined. The soil moisture resultant is therefore measured in relative terms as the degree of saturation (Su et al., 2013). The first trial of evaluation of ASCAT soil moisture observation was done in France (Albergel et al., 2009). The soil moisture over southwestern France was measured with promising results. The data obtained from ASCAT was used to change the detection parameters obtained from the analysis of multi annual backscatter time series using ERS data over a 15-year long period (Albergel et al., 2012).

In this study Vienna University of Technology (TUWIEN) soil moisture retrievals from ASCAT scatterometer data are used.

2.4 Hydrological Model-Based Soil Moisture Simulations

Similar to remote sensing-based observations, model-based observations can also provide large scale soil moisture data. Hydrological models are also able to provide high accuracy soil moisture data. In addition to that, models can provide antecedent soil moisture variables by using forcing data (e.g. precipitation, wind, air temperature, pressure, etc) and parameter (e.g. vegetation cover, soil type, root depth, etc) input information belong to past dates. However, many of the parameters used in algorithms of the hydrological models cannot be validated in a realistic manner through physical observations. Despite these weaknesses, hydrological models have an indispensable role in obtaining soil moisture data in large areas.

High accuracy global soil moisture information retrieval based on station based observations is impeded by the nature of the spatial distribution of stations (i.e. very scares), while satellite-based observations may only penetrate 1-3 cm surface depending on vegetation water content (Yilmaz et al., 2008a, 2008b). Hydrological models can provide required variable by using complete and accurate meteorological data as an input. Moreover, complex hydrological models also use soil and vegetation parameters as inputs, in order to provide more reliable results. Hydrological models are based on water and energy balance. Soil moisture variable in the hydrological system can be basically determined based on the conservation of energy.

First development of land surface models goes back to early 1970's. This first development resulted in the bucket model which was only considered most basic water components such as runoff, rainfall, evaporation and water storage (Manabe, 1969). In those days, implementation of more complex physical process was restricted because of insufficient technology. Recently, computing capacity is increased and model structures became more complex. In this study, soil moisture estimates retrieved from simulations of API and NOAH hydrological models are used.

2.4.1 Antecedent Precipitation Index – API

Antecedent precipitation index (API) is one of the simplest examples of hydrological models to estimate soil moisture variable. Since spatially and temporally reliable soil moisture variables are limited, API uses precipitation data to estimate soil moisture. It calculates single layer soil moisture related to received precipitation. Several studies have been made in order to link precipitation to soil moisture by using API because of the lack of field data (Saxton and Lenz, 1967, Blanchard et al., 1981). API model data is also used in the past studies to determine remote sensing observations errors over U.S by data assimilation techniques (Crow and Zhan, 2007, Crow et al., 2009). Yilmaz and Crow (2013) showed how to optimally calibrate different soil moisture variables to each other within scope of data assimilation by using same API model. In a recent study by Crow et al. (2012), API model retrievals of root zone soil moisture estimates are used to determine effects of agricultural drought on plants' greenness and API showed similar ability with other more complex hydrological models products.

API model based soil moisture calculation is done by using the formula below.

$$API_{t+1} = \gamma\, API_t + P_t \tag{1}$$

Where, *API* represents soil moisture values, γ is a seasonally varying parameter that determines what part of rainfall is stored in soil and P is precipitation amount observed between time t and $t+1$. γ value typically ranges between 0.85 – 0.98. The study of Crow et.al (2005) determined that in the sensitivity tests of API, taking γ parameter as varied rather than as a constant "0.85" reveals little qualitative variation in results. Therefore, in this study γ parameter is taken as constant "0.85". In this study, precipitation data obtained from stations observations are used as forcing data in API simulations to obtain soil moisture estimates.

2.4.2 NOAH Land Surface Model

NOAH land surface model (LSM) is developed by cooperate work of National Centers for Environmental Prediction (NCEP) - Oregon State University (OSU) Dept. of Atmospheric Sciences - Air Force - Hydrologic Research Lab. NOAH model (Ek et al., 2003) as well as other complex hydrological land surface models, uses atmospheric data (temperature, humidity, wind, rain and radiation) to make an estimate of water energy cycle on the surface. In addition to these atmospheric data, soil and vegetation parameters are important inputs for estimates of the model. Model solves energy and water balance equations individually for each point, it calculates variables such as soil moisture and soil temperature for different layers.

The model originates from two layered OSU-LSM in early 1980's (Mahrt and Pan, 1984) and has been constantly subjected to many improvements. These improvements were mainly done by making modifications in the canopy-resistance formulation (Chen et al., 1996), surface runoff infiltration (Schaake et al., 1996), bare soil evaporation and vegetation phenology (Betts et al., 1997), and the addition of frozen soil physics (Koren et al., 1999), and thermal roughness length treatment in the surface-layer exchange coefficients (Chen et al., 1997). With continuous progress, the model is started to be used in studies such as weather prediction, data assimilation, etc. The range capacity of these studies can differ from meters to kilometers. The model can be executed as both a coupled and uncoupled mode in order to simulate the land-surface hydrology. In the coupled mode, atmospheric module are dynamically coupled with atmospheric input variables, while in the uncoupled mode, atmospheric variables are forced in models. The North American Mesoscale (NAM) model, and the Weather Research and Forecasting model (WRF; Skamarock et al., 2005) are some of the weather-prediction models which NOAH has been coupled to.

The NOAH LSM consists of one snow layer, one canopy layer, and four soil layers. The soil layers' depths from the ground level are 10cm, 40cm, 100cm, and 200 cm. The sum of depth of soil column is 2 meter. The root zone is inside the first three layers except for the forest vegetation type. The vegetation type has a major factor that affects the number of root zone layers. Water inside the water column moves only in vertical direction and horizontal interaction between the neighboring grid cells is blocked. The last 1 meter of soil column behaves like a reservoir and water is drained out from the soil column at the bottom because of gravity (Chen and Dudhia, 2001). Figure 6 shows a schematic diagram of NOAH LSM.

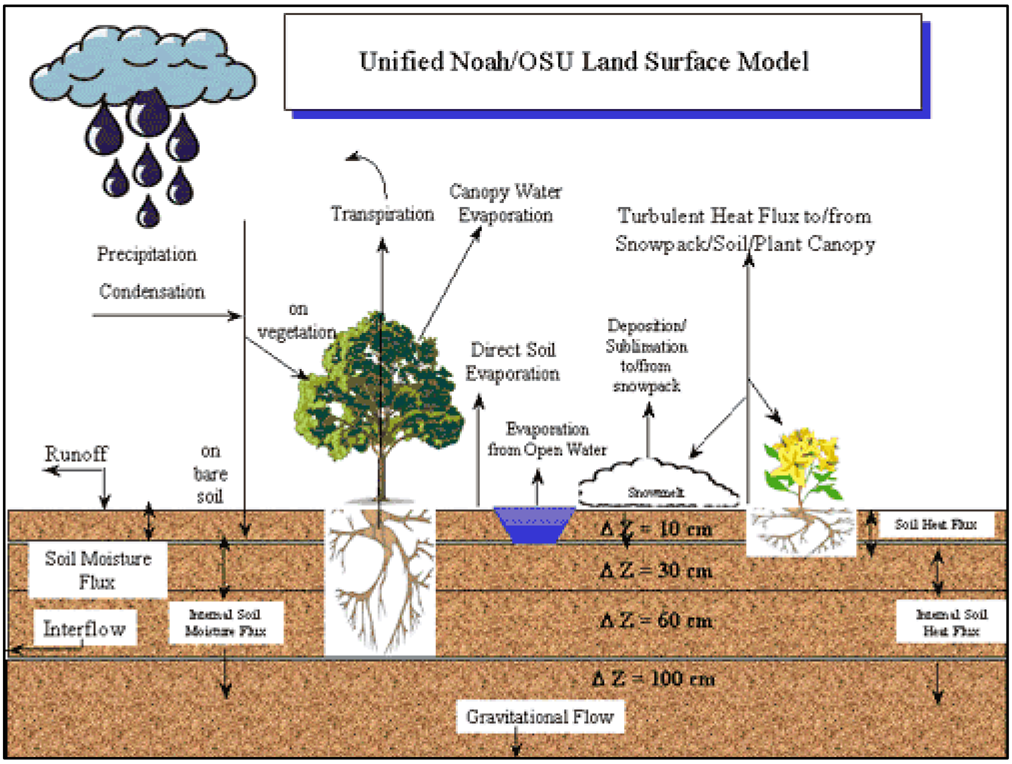

Figure 6 Schema of NOAH Land Surface Model Structure

Parameters are used at many processes in NOAH LSM to make the computations simple. The two main inputs that determine most of the parameters are vegetation type and soil texture. While the model is being run, tables are used to determine these parameters. U.S. Geological Survey (USGS) and Moderate Resolution Imaging Spectroradiometer (MODIS) are the two available options to choose the vegetation classification. MODIS- based classification has 19 categories while the USGS consists of 24 vegetation categories. Moreover, some general parameters are also looked up from table.

Soil temperature, soil moisture, water budget components, and surface fluxes are the components of model output. Time steps of NOAH LSM are generally one hour; however, NOAH LSM could be run in finer temporal resolution like 30 minutes. At least one hour time step is needed to capture the land atmospheric interactions through exchanges of momentum, heat and also to track the movement of water inside surface layer. In Table 1 primary input forcing and parameters used in NOAH simulations are shown. Also used NOAH model version 2.7.1 configuration file can be seen in Appendix C.

Table 1 Primary Input Forcing and Parameters used in Noah Simulations (Yilmaz et al., 2014)

Parameters	Source (Spatial Resolution)
Shortwave radiation	GDAS (0.47°)
Longwave radiation	GDAS (0.47°)
Precipitation	TRMM (25 km)
Albedo	MODIS (1km)
Land cover type	UMD
Greenness	MODIS (1km)
Wind speed	GDAS (0.47°)
Vapor and surface pressure	GDAS (0.47°)
Air Temperature	GDAS (0.47°)
Soil Type	FAO (1 km)
Root depth	Look-up-table based on land cover

The NOAH soil moisture products that are used in this study, are simulated by NASA Earth Sciences Division and published by Goddard Earth Sciences (GES) Data and Information Services Center (DISC) (http://disc.sci.gsfc.nasa.gov). Soil moisture variable are obtained in 3-hour periods from 0-10cm depth with 0.25° spatial resolution.

CHAPTER 3

QUALITY CONTROL OF STATIONS

3.1 Introduction

Quality control is a critical step to determine the reliability of datasets before station-based observations can be used in independent validation studies. As mentioned above, soil moisture observations in Turkey are retrieved over 149 stations operated by TSMS. At these stations, precipitation is also measured in 10 minute period. For quality control, relation between precipitation and soil moisture is used. In general reliable soil moisture observations should have good response to precipitation events. Also data persistence is critical to evaluate stations reliability, hence stations with insufficient data are shall be determined. Quality control process used in this study is shown as a schema in the Figure 7. After quality control of the stations, data from these stations need to be calibrated for more accurate results.

3.2 Quality Control

In this study, quality control procedure is started with determination of the stations with sufficient precipitation and soil moisture data and then continued with control of soil moisture values visually on the precipitation vs soil moisture graphs. Raw soil moisture observations are made at 10 minute intervals. These 10 minute data are initially converted into daily measurements by using arithmetic average method. Temporally subset of daily soil moisture datasets between January 2008 and December 2012 are later retrieved over each station.

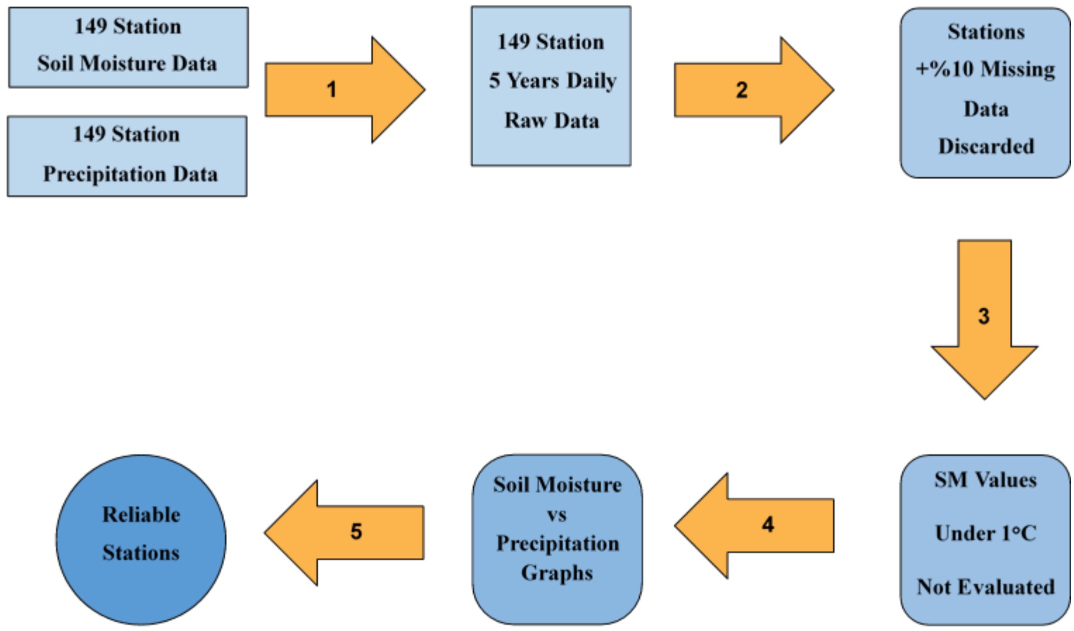

Figure 7 Process Scheme of Quality Control of Soil Moisture Stations

Stations that have more than 10% missing data in 5-year period are considered to have too much gap to have reliable time-series for studies that involve predictions using the current values of the variables. Accordingly, stations that have more than 10% missing data are excluded from the analysis performed in this study. Problems at data transfer phase, errors in sensors and/or data logger can cause missing values in data. At the end of the first step of the quality control, stations with sufficient soil moisture datasets are obtained. Here it is stressed that this 10% threshold is selected only for temporal dependence related future studies, for other applications, this requirement should be relaxed for higher dataset availability for different applications.

Precipitation data measured over the same stations from which soil moisture data are obtained, are used for pre-evaluation of soil moisture data sensitivity. Periods of data show difference between stations but they are all between 1 and 10 min periods. Stations that have more than 10% missing data are not included in the precipitation-data based quality control steps. If missing precipitation data is less than 10%, these gaps filled with regenerated records by taking average of the previous and following precipitation measurements records. After that similar to soil moisture data, precipitation data are also converted from 10 minute to daily values by taking sum of the measurements in 24 hours.

After control of missing data of both soil moisture and precipitation soil moisture measurements are corrected under zero temperature. In practice soil moisture parameter cannot be obtained under zero temperature. In order to overcome this issue, soil moisture values under 1°C soil temperature are converted to “not available” NA values.

In the quality control phase, soil moisture data accuracy is visually inspected using precipitation data to measure the response of the instrument. The details about the precipitation data used in this study is given above. Soil moisture data is expected to respond to precipitation events. After any precipitation event is recorded at the station, soil moisture measurements should show an increase at the same station. Also in the absence of precipitation during dry periods, a smooth and continuous dry-out trend should be observed. This soil moisture response to precipitation analysis is visually performed over 149 stations separately. Soil moisture vs precipitation graph is obtained for each stations and response of soil moisture variables are visually analyzed.

If soil moisture data do not consistently respond to the precipitation data observed at the same station, or they show a fixed value after a precipitation event, or have unexpected fluctuations (e.g. rapid dry-out events), then stations with these soil moisture data are discarded from the analysis assuming that the precipitation data are obtained relatively more accurately and the errors of soil moisture datasets are sensor related. Stations that do not respond to precipitation temporarily are also discarded from the list of stations to be used in this study.

Stations are classified into two as “reliable” and “not reliable” for temporal dependence type of analysis. In first category, reactions of soil moisture data generally acts according with precipitation data. As an example Station #72 (Name: GTHG, ID: 17655) graph can be seen in Figure 8.

It can be seen from the figure that as expected soil moisture values increase after precipitation event and decrease smoothly during dry season. Soil moisture values are affected from previous precipitation events hence, same level of precipitation values may increase soil moisture values in different magnitude. All other stations in category one nearly shows the same reaction to precipitation events. Category 1 stations are accepted as most reliable stations over 149 stations.

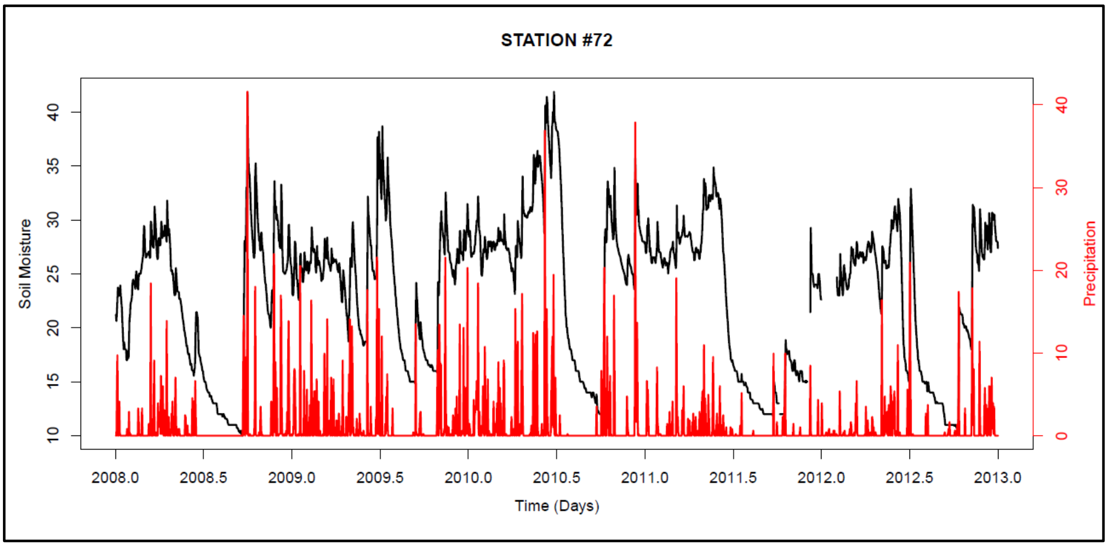

Figure 8 Soil Moisture daily response to Precipitation over Station #72

In category of “not reliable”, most of the stations’ soil moisture values do not correspond with precipitation events. Some of the stations sensors remain flat or show sudden decreases after a precipitation. Also soil moisture content is expected to be under 60% in soil media. Stations that show more than 60% volumetric soil moisture for a period of time are also considered as non-reliable. Sensors at the stations are not controlled periodically which causes sensors to keep sending non-reliable or unrealistic data for a long period of time (Figure 9). These sensors errors do not mean that related station is not possible to use, however in this study 5 year time period selected as quality control phase. Hence, these stations with sensor errors are also added to category 2, to be on the safe side.

As an example to category 2 stations, Station #97 (Name: POLT, ID: 17728) is shown in Figure 9. All criteria that are mentioned above can be observed on Station #97 data. Aim of selecting that station is to show all possible failures in quality control phase. Even though many precipitation events are observed between 2008 and 2011, soil moisture values fluctuate only marginally while above 70% soil moisture values are dominantly observed (i.e. given porosity of soil medium is expected to be less than ~60%, above 70% volumetric soil moisture values are considered as non-reliable). Stations similar with the station that shown in the Figure 9 are added to category 2. Onsite maintenance during a site visit may decrease the number of stations to be added in category 2.

Time series of soil moisture and precipitation obtained over each station are analyzed visually for quality control. In addition to some stations have more than 10% missing data sensor failures are encountered. After the quality control of the time-series, 68 out of 149 stations are initially selected to have very good soil moisture-precipitation response and have long continuous soil moisture time-series, while the remaining 81 stations either did not have sufficient continuous data record or a very good soil moisture response to precipitation for the entire or the partial duration of the study time interval.

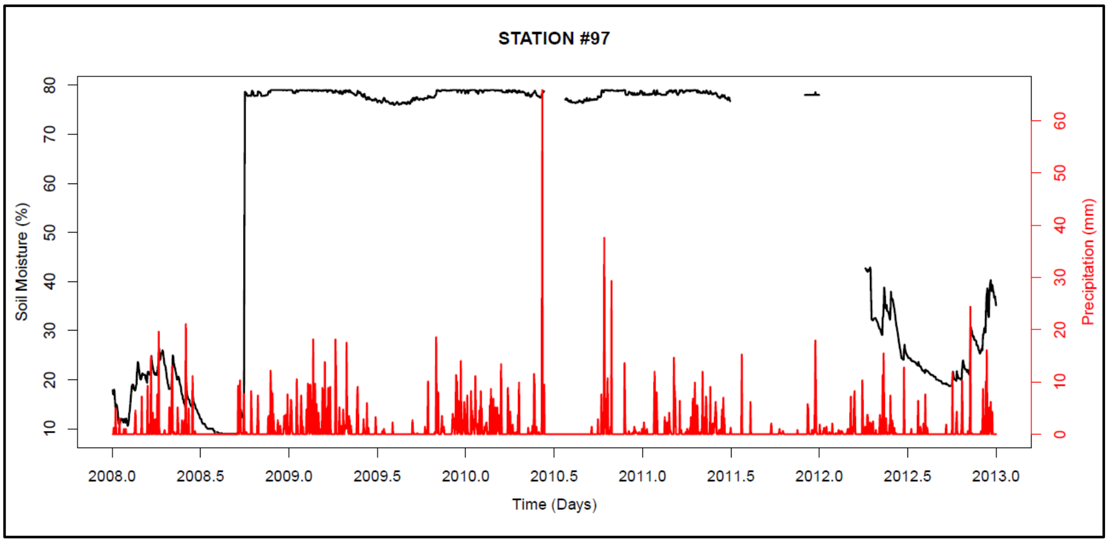

Figure 9 Soil Moisture response to Precipitation over Station #97

Soil moisture values of these 68 stations have good overall response to precipitation: a peak in soil moisture can easily be observed after a precipitation event with a reasonable depth and a slow and persistent decay in soil moisture is noticed in the absence of a significant precipitation event for a long time. Distribution of these 68 stations and remaining 81 stations are shown over DEM map of Turkey (Figure 10).

General information (Station ID, Name, Location, Elevation, Coordinates) about all stations can be seen in the appendix A. Also quality control results of each station can be found in the appendix A with the reasons of stations which are not selected in category-1.

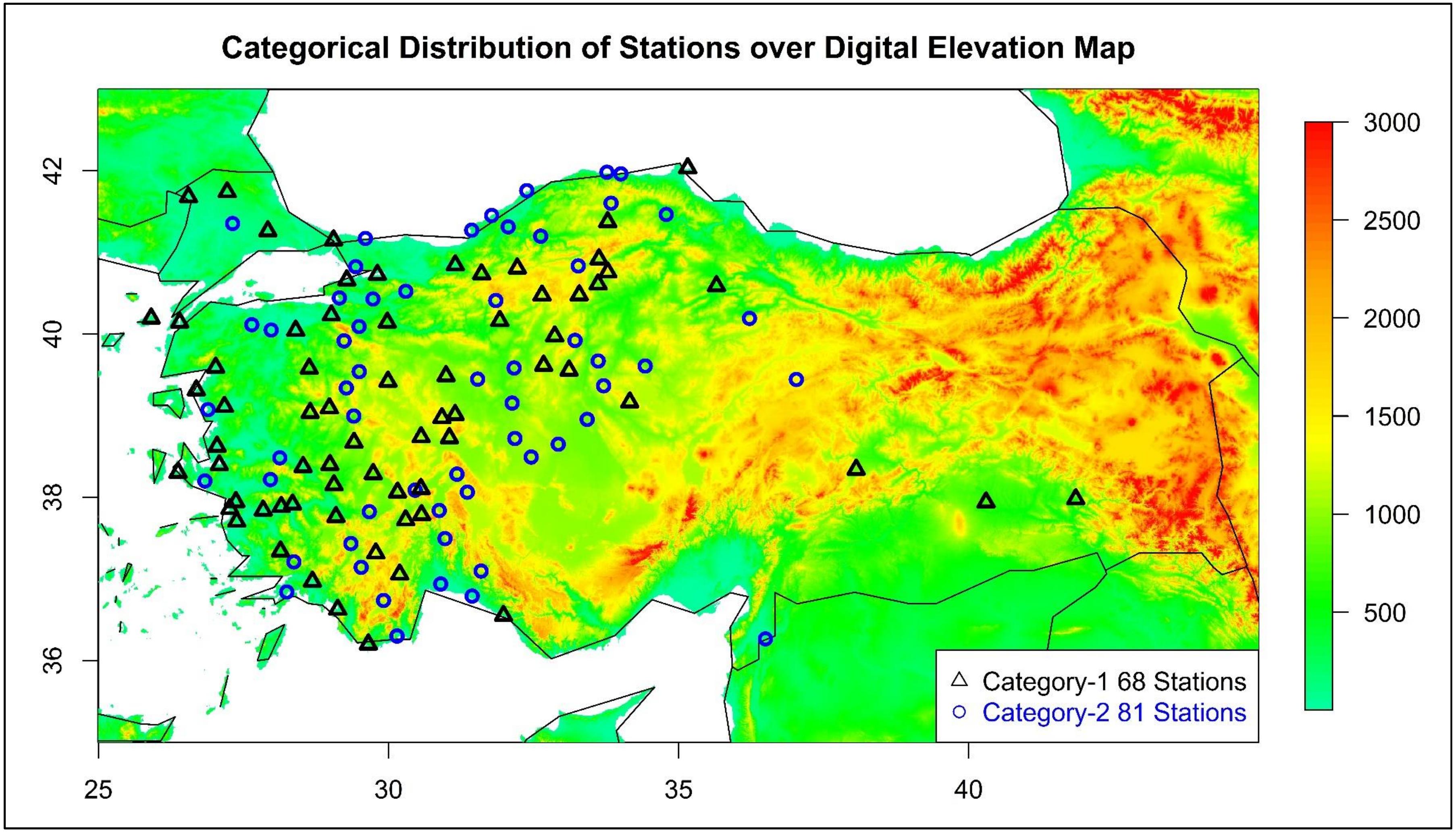

Figure 10 Categorical Distribution of Stations over Digital Elevation Map

3.3 Calibration

Raw soil moisture measurements are made using CS615 instrument at stations which may also require calibration and/or correction against the temperature, the soil type, and the soil electrical conductivity. Such calibration is expected to improve the absolute accuracy of the measurements. These instruments' measurements are related with soil type hence, each station's soil type required to be analyzed. However, Soil moisture measurements obtained from stations over Turkey have not been calibrated against soil type or soil electrical conductivity.

As described in section 2.2.1, the instrument uses two steel probes to measure dielectric constant of the soil media then it converts the signals to water content. Since calibration procedure is not applied in this study, required calibration study can be summarized as follows. After determination of soil type at the stations, each soil type need to be calibrated in laboratory by measuring the soil content with the instrument and calculating bulk density of the specimen. As the result of these controlled experiments calibration curve is plotted to obtain calibration coefficients. Then instruments are calibrated with coefficients of related soil type by use of these coefficients.

On the other hand, linear transformation of the data, such as using variance-, regression-, and triple collocation-based rescaling methods (Yilmaz and Crow, 2013), may alleviate much of the linear biases that might have occurred due to the soil medium the instrument is installed in (Yilmaz et.al, 2013). Such linear bias may not impact the accuracy of the validation datasets (i.e. station-based soil moisture observations) in drought type analysis where the anomaly type information is the required primary information. As a result such soil electrical conductivity- and soil type-based calibrations, which are typically performed using linear equations, have not been performed in this initial evaluation study.

CHAPTER 4

INTER-COMPARISON OF SOIL MOISTURE PRODUCTS

4.1 General Information

In this chapter, soil moisture products that are obtained from two satellite observations (AMSR-E, ASCAT), two hydrological models (API, NOAH) and ground stations observations are compared. All different observation methods have their own formulas and/or techniques, as mentioned in Chapter 2. Since AMSR-E satellite finished its mission in October 2011 and ASCAT products are available from May 2007, years between 2008 and 2012 are selected as the inter-comparison study period. Inter-comparisons are made at daily time-steps using 68 stations that are selected as reliable in chapter 3. Characteristics of each soil moisture source can be seen in Table 2 below.

Table 2 Information of used Soil Moisture Data Sources

Name	Type	Spatial Res.	Temporal Res.	Unit
Station	In-situ Measurement	Point	10 minutes	VWC[a] (%)
API	Hydrological Model	Point	10 minutes	mm
NOAH	Hydrological Model	25 km	3 hours	kg/m^2
LPRM	Passive Microwave	25 km	Daily	$m^3\ m^{-3}$
ASCAT	Active Microwave	25 km	Daily	DoS[b] (%)

[a] Volumetric Water Content, [b] Degree of Saturation

4.2 Rescaling Methods

Since there are different ways to obtain soil moisture time series, it is often desired to merge these different values to obtain a more accurate estimate (Yilmaz et al., 2012). However, due to the nature of these different platforms (e.g. satellites can only monitor the top couple cm depths at relatively coarse resolutions while point in-situ observations have spatial representativeness problems, models have different parameterization, etc.) soil moisture values obtained from different platforms often require a preprocessing (i.e. rescaling) step before they can be meaningfully validated, merged, inter-compared in different applications.

Several linear and nonlinear rescaling methods have been proposed to rescale hydrological variables, particularly soil moisture. Among them Cumulative Density Function (CDF) matching-based method (Reichle and Koster, 2004; Drusch et al., 2005; Yin et al., 2015) particularly received high attention, while variance matching-based (Crow et al., 2005; Crow, 2007; Draper et al., 2009), linear regression-based (Crow and Zhan, 2007; Brocca et al., 2013), Triple Collocation Analysis (TCA) based (Yilmaz and Crow, 2013), and Copula-based (Leroux et al., 2014) methods are also implemented to reduce the systematic differences between time series.

In this study, given linear regression results in the least squared errors when two datasets are regressed to each other (i.e. similar to rescaling), linear regression-based rescaling method is preferred to reduce signal variance differences that may exist between soil moisture time series (Yilmaz and Crow, 2013) obtained from station observations, satellite retrievals, and hydrological model estimates.

Linear rescaling methods are implemented by considering the most general linear relation between a reference dataset (x) and the dataset to be rescaled (y) in the form

$$Y^{*} = \mu_X + (Y - \mu_Y)c_Y \quad (2)$$

Where; Y^* is the rescaled version of Y, μ_X and μ_Y are time-averages of X and Y, and c_Y is a scalar rescaling factor. Here c_Y in this study is found using regression-based linear methods as

$$c_Y^R = \rho_{XY}\, \sigma_X / \sigma_Y \tag{3}$$

Where; c_Y^R is a linear rescaling factor, σ_X and σ_Y are standard deviations of X and Y datasets respectively; and ρ_{XY} is the correlation coefficient between X and Y.

This regression-based rescaling can be mathematically shown to minimize the mean square difference between the rescaled time series and the reference dataset, while Yilmaz and Crow (2013) showed TCA-based rescaling method gives optimal results in data assimilation framework. For more details about these linear methods please see the study of Yilmaz and Crow (2013).

4.3 Inter-comparison

Datasets of soil moisture products obtained from different platforms initially need to be prepared in the same temporal resolution for inter-comparison study. Daily and weekly soil moisture datasets are obtained by using arithmetic average method. 1460 daily and 208 weekly data are obtained for each source from beginning of the year 2008 to end of the year 2011. Since, measurements at stations are made at the depth of 20cm while other sources provide surface soil moisture, weekly datasets are expected to show more reliable results. Also spatial coverage of each source is different as can be seen in Table 2. Since soil moisture products of LPRM, ASCAT and NOAH have 25 km resolution, spatial match over stations is required. Grid selection of remote sensing retrievals and NOAH land surface model estimates are done by using stations coordinates over Turkey. If any of these stations are located between two grids, equal-weighted arithmetic average method is used to obtain soil moisture data for that station. Locations and general information about stations can be seen in Appendix Table A. API soil moisture values are obtained by using precipitation data of stations where soil moisture measurements are also obtained. Hence, these values do not require any spatial match. In Figure 11, 25 km by 25 km grid selection to provide spatial match for each data source can be seen.

In some stations, satellite soil moisture retrievals and NOAH products cannot be extracted because of several problems related with location of stations. If a station is located close to sea or lake, usually most part of the grid overlaps with water surface. In such situations remote sensing retrievals cannot be extracted and also hydrological models like NOAH that uses remote sensing based inputs, cannot provide any soil moisture estimates. Another problem of obtaining soil moisture information over stations is Radio Frequency Interference (RFI). RFI can be simply defined as emissions of an external source which occupy frequency spectrum and cause obstruction to get information on that spectrum. Generally, frequency intervals used by satellite missions are protected according international agreements. The passive microwave sensors are affected from RFI sources mostly over Europe and Middle East (Njoku et al., 2005). Soil moisture retrievals of AMSR-E sensor that uses C-band, may also be affected on some areas over Turkey.

Moreover, vegetation coverage effects retrievals of remote sensing observations, hence different sources with different band intervals are used in this study and their coverage can show differences. In order to provide significant inter-comparison results, at least 25% temporal coverage over each station condition is used. Because of these problems related with location, vegetation cover and RFI, spatial and temporal coverage of LPRM, ASCAT and NOAH model over 68 stations are found as respectively, 54% (37 station), 76% (52 station) and 91% (62 station). Information about number of stations that covered by each source used in inter-comparison can be seen in Figure 12.

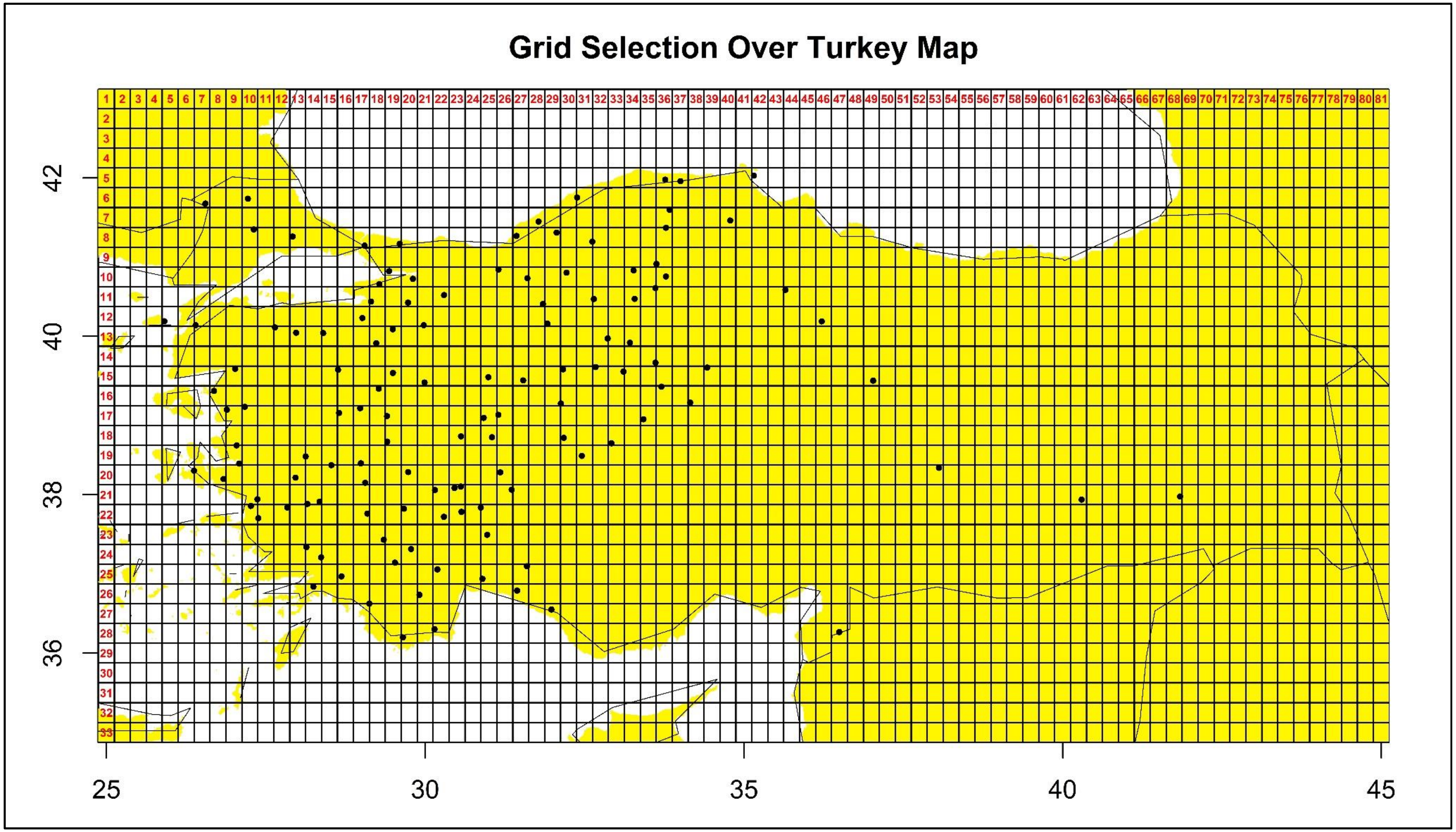

Figure 11 Grid Selection over Turkey Map

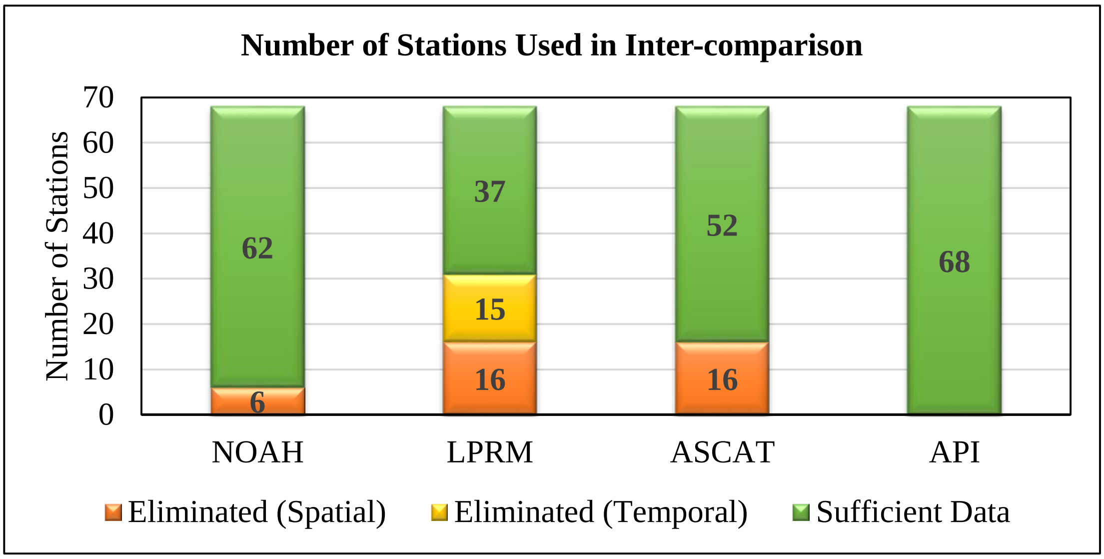

Figure 12 Number of Stations used in Inter-comparison

Correlation coefficient is invariant to linear transformations (like the rescaling method described above); hence the correlation coefficient between station data and rescaled satellite- and model-based datasets remain the same before and after rescaling. In the formula below X and Y refer to reference (station) and raw data (satellite- or model-based data) respectively.

$$\rho_{(X,Y)} = \left[\frac{1}{N-1} \sum_{i=1}^{N} \left((Y - \mu_Y)\,(X - \mu_X) \right) \right] / \left(\sigma_X \sigma_Y \right) \tag{4}$$

Where, N is size of the sample, μ is mean value, σ is standard deviation and ρ(x,y) is Pearson correlation between X and Y.

Root Mean Square Error (RMSE) is another method that can be used to evaluate the mean squared difference between two datasets. However, before RMSE estimation, linear rescaling of datasets were performed using above methodology given under section 4.2. Some of the linear differences of soil moisture measurements due to non-calibrated stations, are also removed by using such scaling methods. Such rescaling methods are performed by splitting the datasets into training and validation for parameter estimation (standard deviation, mean, and correlation coefficient) and independent error estimation, respectively. For validation process remaining data is rescaled by using the same parameters that calculated from training data. For this matter, 3 year period (2008-2010) used as a training data and one year (2011) as validation data. After linearly matched (rescaled) data are obtained, RMSE are calculated by formula below.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Y_i - X_i)^2} \tag{5}$$

Where, Y_i values are rescaled satellite or model based data and X_i values are station based soil moisture data.

All linear rescaling methods presented above also reduce some of the linear errors related with calibration.

4.4 Inter-comparison Results

After calculating Pearson correlation between all soil moisture from different sources for each station, overall weekly and daily correlation values of selected 68 stations can be seen respectively in Table 3 and Table 4 below. Also weekly datasets correlation results of each station can be seen in Appendix Table B.1.

All weekly correlations against station-based observations given in Table 3 are significant. NOAH hydrological model-based observations showed the highest correlation with station based observations (0.751) which implies among other datasets NOAH may have more accurate information content over the areas of interest. LPRM has the highest correlation remote sensing based observation with 0.720. API results also give significant correlation 0.638 with stations and other sources soil moisture products. ASCAT products show the minimum correlation with station observations, 0.634 correlation coefficient is the sign of statically significant relation. Since, NOAH estimates are highly related with seasonality than other sources, it may be the reason of better correlation results against station based observations.

Average results of each sources can be also seen in Table 3. It is shown that, LPRM and NOAH soil moisture estimates are consistent with all other sources with average respectively “0.697” and “0.694” coefficient values. Since, station based observations are the most reliable measurements because of directly measured from soil media, its representativeness errors affect the result of correlation with other sources. While all remote sensing based measurements and NOAH estimates are obtained 25 km resolution, stations and API soil moisture values obtained at point scale. Although, station based observations have spatial representativeness differences, their average correlation value is calculated as “0.686”.

Table 3 Overall (68 Stations) Weekly Datasets Inter-comparison Results (R values)

Source	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.751	NA	---	---	---
LPRM	0.720	0.773	NA	---	---
ASCAT	0.634	0.597	0.668	NA	---
API	0.638	0.654	0.626	0.692	NA
Average	0.686	0.694	0.697	0.648	0.653

Table 4 Overall (68 Stations) Daily Datasets Inter-comparison Results (R values)

Source	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.577	NA	---	---	---
LPRM	0.475	0.689	NA	---	---
ASCAT	0.391	0.541	0.579	NA	---
API	0.358	0.638	0.572	0.645	NA
Average	0.450	0.611	0.579	0.539	0.553

In Table 3, daily datasets correlation results are not significant as weekly datasets results. Station based daily observation correlation against other sources are relatively lower than weekly datasets results, measurement depth may be the reason of that result. Also other sources correlation results decreases when daily datasets are used. It is expected because all soil moisture parameters are directly affected from variation of precipitation events and their results show difference in short time period. Even with significantly lower results, NOAH LSM estimates show higher correlation than other sources with station based observations.

Before computing RMSE values all datasets rescaled respect to station based observations by using linear regression, hence result of RMSE analysis in units of percentage. Cy rescaling factor that explained in section 4.2 is calculated for all sources and variation of these Cy values of each source in daily and weekly time scale can be seen in figure 13.

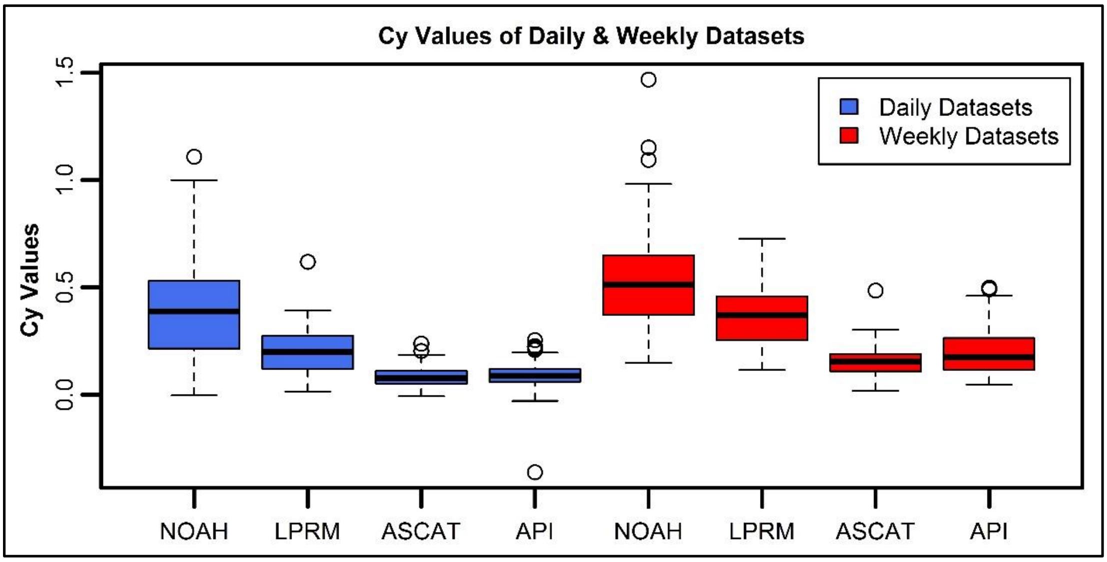

Figure 13 Cy Values of Daily & Weekly Datasets on Boxplot

RMSE values also support the results of Pearson correlation results. In Table 4 RMSE value of NOAH is the smallest “0.035” while comparing with other sources. It can be stated that, all resources RMSE value is less than 5%. Since, satellite missions aim to provide soil moisture with an accuracy better than 4%, because of non-calibrated station observations over Turkey, their accuracy are not satisfying the requirement. On the other hand, all the results are relatively similar with other inter-comparison studies, in order to state that all the sources have high consistency with selected stations observations. Weekly RMSE results for each station can be seen in Appendix Table B.2.

In Table 5, daily RMSE values can be seen. As daily correlation results show less correlation between all sources, daily RMSE values also show higher error rate than weekly datasets.

Table 5 Overall (68 Stations) Weekly Datasets Inter-comparison Results

Period (Training/Validation)	NOAH	LPRM	ASCAT	API
2008-2010	0.032	0.034	0.040	0.041
2011	0.035	0.040	0.046	0.048

Table 6 Overall (68 Stations) Daily Datasets Inter-comparison Results (RMSE values)

Period (Training/Validation)	NOAH	LPRM	ASCAT	API
2008-2010	0.043	0.044	0.048	0.051
2011	0.047	0.049	0.054	0.058

In order to analyze soil moisture products in temporal details, seasonal correlation coefficients between station based observations and all other sources are shown in Table 6. Since 208 weekly data are used for weekly analysis, each season are extracted from these 208 week as a 52 week data sets (13 weeks as a season in a year). It shows that in winter season all correlation values are lower than other seasons. Snow cover or other meteorological parameters may be affected the results. In winter season, ASCAT products and API estimates show the highest relation with station based measurements. In spring, all sources correlations with station based observation show more significant results than winter. NOAH estimates show the most significant correlation with stations in spring season. In summer, NOAH shows the best correlation with stations and also all other sources correlation values are higher than winter and spring seasons. In the last column autumn season can be seen, where all sources show highest correlations with stations. It can be stated that, LPRM soil moisture products give the best correlation in autumn season when comparing with other seasons the difference is clearly provide that result. Also API estimates correlation show better results in autumn than other seasons. NOAH gives the best correlation with the value of “0.781” in autumn season. Even station based observations have not been calibrated yet against soil type and electrical conductivity, Table 6 can give an opinion about selection of the source of soil moisture product related with seasonal criteria.

Table 7 Seasonal R Values of Each Source against Station Observations

Sources	**Seasons**			
	Winter	Spring	Summer	Autumn
NOAH	0.449	0.659	0.725	0.781
LPRM	0.414	0.500	0.591	0.751
ASCAT	0.558	0.551	0.595	0.631
API	0.537	0.616	0.603	0.700

In Figure 14, correlation results of each source with stations observations are shown over Normalized Difference Vegetation Index (NDVI) map. NDVI is basically obtained from the visible and near-infrared light reflected by vegetation. While dense vegetation area absorbs most of the visible light and reflects most of the near-infrared light, rare vegetation area absorbs less visible light and reflects less near-infrared light. NDVI datasets at 16-day temporal and 1 km spatial resolution between 2000 and 2014 are obtained to analyze the stations for their greenness land cover.

Figure 14 is prepared in order to analyze spatial details of each sources soil moisture products. It also give information about the relation between each source soil moisture products and vegetation cover. Correlation results are shown in four different category; red indicates correlation values are between 1 and 0.75, orange indicates correlation values are between 0.75 and 0.50, yellow indicates correlation values are between 0.5 and 0.25, and lastly black indicates that correlation results is less than 0.25.

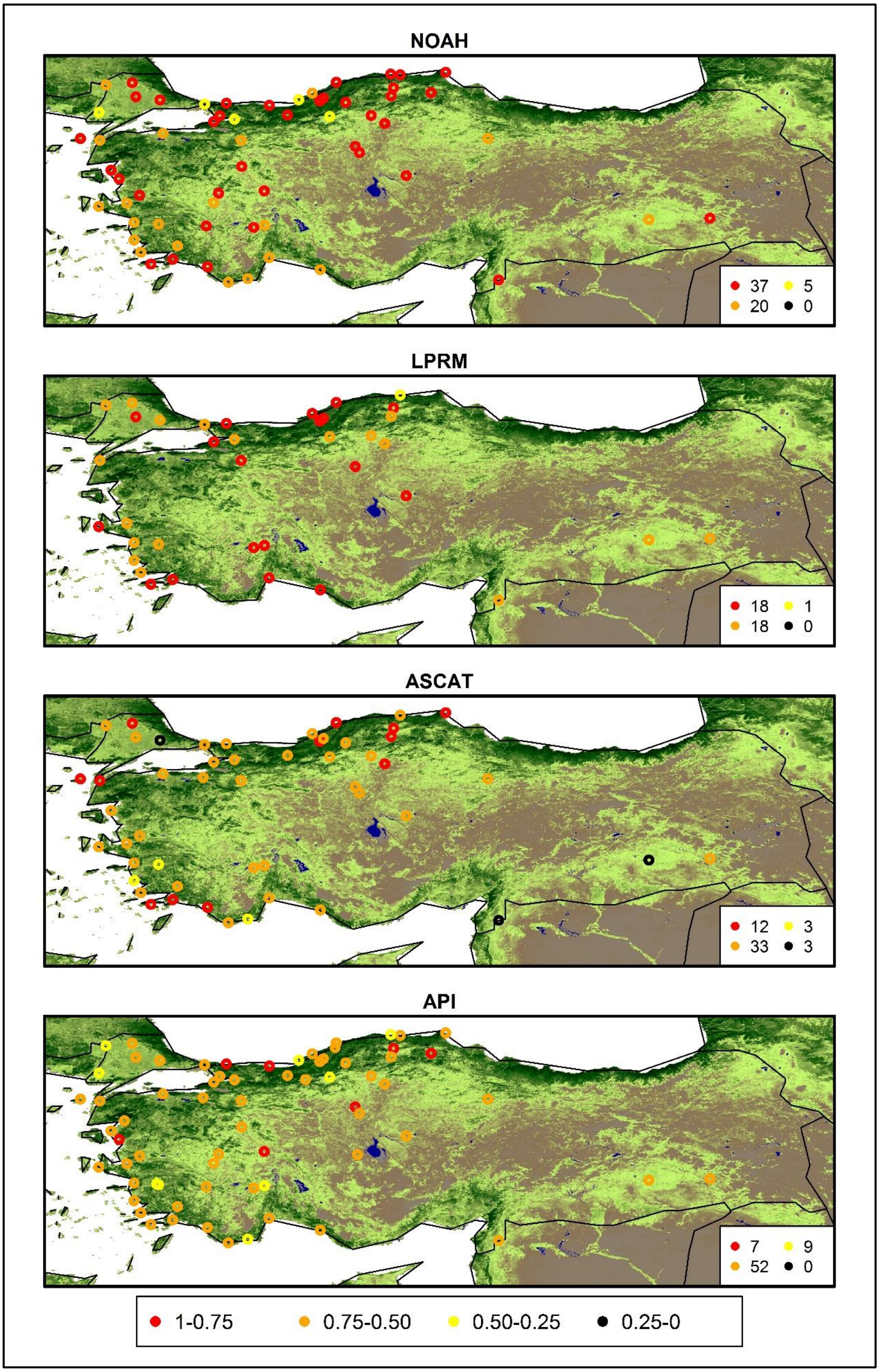

Figure 14 Correlation Results Distribution of Stations with Each Source

In Figure 15, average soil moisture variables obtained over 68 stations from all sources are shown. Weekly datasets between 2008 and 2012 are plotted. In the figure, it can be seen that soil moisture values of NOAH LSM show high consistency with station based observations. It is expected that, since API is simpler model to estimate soil moisture variable, API products consistency is not higher than NOAH model. However, API soil moisture variables still have high consistency with station based observations. LPRM products of soil moisture show high accordance with station observations even at dry periods. In dry periods LPRM and NOAH soil moisture variables decrease to same level with station observations while the other resources decreases in less magnitude. Variation of ASCAT products are relatively higher than LRPM products.

4.5 Similar Inter-comparison Studies

Many such inter-comparison studies have been made to evaluate consistency of different soil moisture information obtained through different platforms. Among them Albergel et al. (2012) used more than 200 stations located in Africa, Australia, Europe and United States to determine reliability of two remote sensing- (ASCAT) and one numerical weather prediction system (ECMWF)-, station-base (from eight different soil moisture station network) were used. Average significant correlations against ASCAT product over 208 stations was found as 0.55 while root mean square difference (RMSD) scores of normalized (unit-less) ASCAT was found as 0.247.

Wagner et al. (2014) performed another inter-comparison study over four watersheds in Unites States. In the study of remote sensing soil moisture products of SMOS, ASCAT and station-based observations over Walnut Gulch (WG) in Arizona, Little Washita (LW) in Oklahoma, Little River (LR) in Georgia, and Reynolds Creeks (RC) in Idaho were used. These watersheds are operated by the ARS-USDA and they are mostly used for validation process of new satellite missions (Jackson et al., 2010 and 2012). As a result of study, ASCAT correlation coefficients were found as 0.64 for WG, 0.75 for LW, 0.55 for LR and 0.69 for RC. RMSE values were given in m^3 m^{-3} and found as 0.033 for WG, 0.073 for LW, 0.083 for LR and 0.069 for RC.

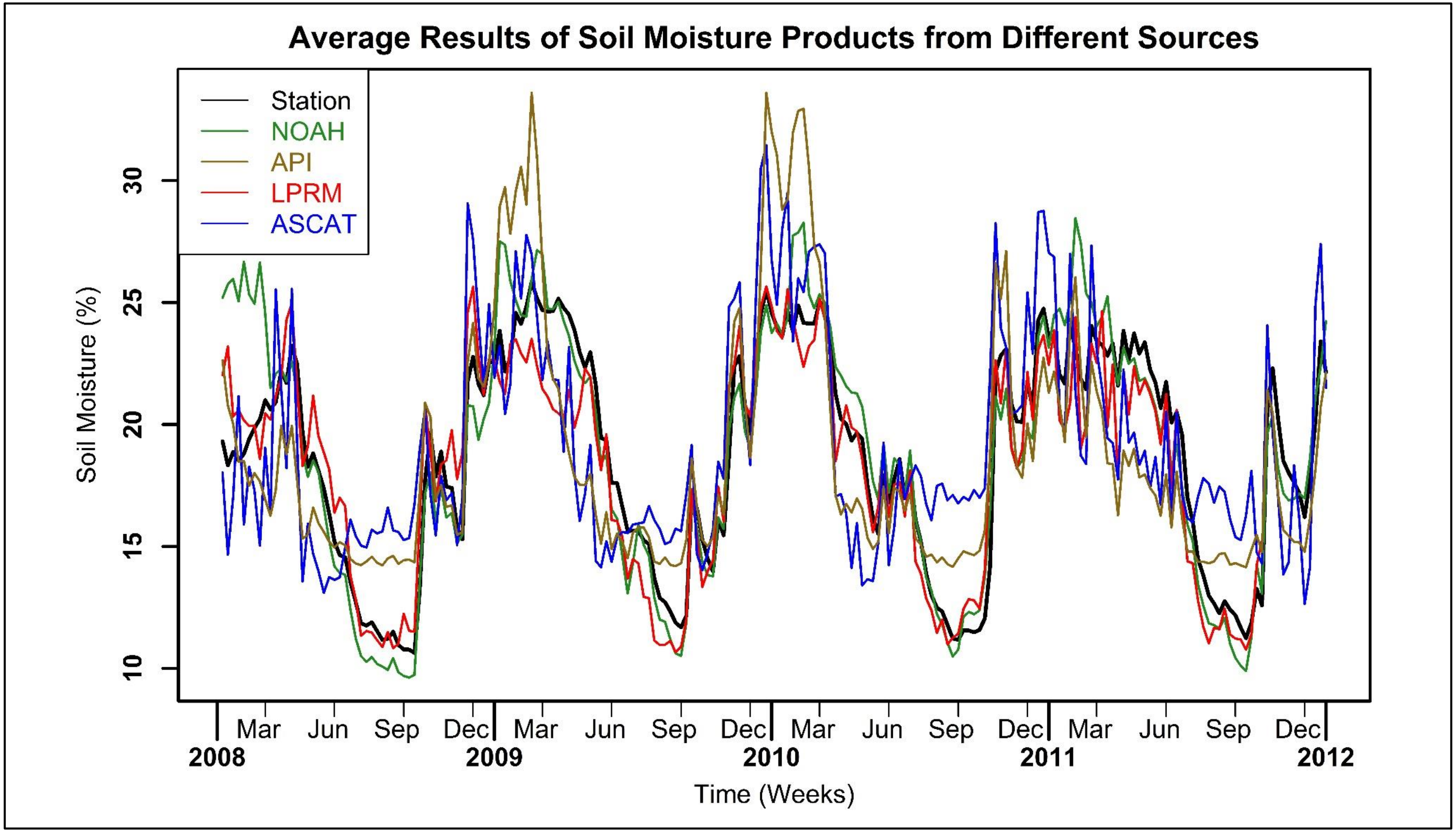

Figure 15 Average Results of Soil Moisture Products from Different Sources

Su et al. (2013) performed another inter-comparison study by using soil moisture observations of OZNET and three microwave satellite soil moisture retrievals; ASCAT, LPRM, and SMOS. After renormalization of the soil moisture products in order to remove systematic differences between the station and satellite data, correlations were calculated. RMSD in units m^3 m^{-3} and correlation coefficient values of LPRM descending soil moisture product were calculated as respectively 0.103, and 0.71. ASCAT descending soil moisture products results were 0.093 for RMSD, and 0.68 for correlation coefficient.

Aim of the study of Yilmaz et al. (2012), was obtaining new soil moisture product by merging thermal infrared remote sensing- (ALEXI), microwave remote sensing- (LPRM), and model- (NOAH) based soil moisture estimates and using triple collocation method. Soil moisture anomalies of these three sources and merged product were validated over two station (in-situ) based observations (SCAN and MESONET). Cross correlation values were shown in three category; surface, vegetation adjusted, and root zone. Results of validation study showed that, LPRM surface soil moisture products correlation values were found as 0.51 for SCAN and 0.52 for MESONET. In addition to LPRM products, correlation values of NOAH LSM surface soil moisture products were found as 0.41 for SCAN, and 0.54 for MESONET.

An inter-comparison and validation study was performed over Europe by Brocca et al. (2011). A total of 17 stations from four different countries; Italy, France, Spain and Luxembourg were analyzed. For inter-comparison study, two satellite based soil moisture retrievals of ASCAT and AMSR-E were used. In details, three different retrievals of AMSR-E were analyzed (LPRM, NASA and PRI). In the study, only ascending passes were used. As a results, average correlation coefficient of 17 stations over 4 European country with ASCAT and LPRM soil moisture product was calculated as 0.708 for ASCAT and, 0.623 for LPRM. In this study, RMSD values were reported in term of relative soil moisture values (between 0 and 1). RMSD values were found as, 0.148 for ASCAT, and 0.163 for LPRM. In conclusion, authors stated that, satellite retrieval products of soil moisture provide good agreement with station-based observations.

Summary of similar inter-comparison studies in details can be seen in Table 7 below. It can be stated that, stations over Turkey show similar results with other stations in different locations.

Table 8 Similar Inter-comparison Studies Results

Author	**Network**	**Location**	**Time Scale**	**Correlation Coeff. (R)**			**RMSE / RMSD**		
				NOAH	**LPRM**	**ASCAT**	**NOAH**	**LPRM**	**ASCAT**
Albergel et al. (2012)	8 Network	(Global)	Daily			0.74			0.247
Wagner et al. (2014)	Walnut Gulch	(United States)	Daily			0.64			0.033
Wagner et al. (2014)	Little Washita	(United States)	Daily			0.75			0.073
Wagner et al. (2014)	Little River	(United States)	Daily			0.55			0.083
Wagner et al. (2014)	Reynolds Creeks	(United States)	Daily			0.69			0.069
Su et al. (2013)	OZNET	(Australia)	Daily		0.71	0.68		0.103	0.093
Brocca et al. (2011)	4 Network	(Europe)	Daily		0.62	0.71		0.163	0.148
Yilmaz et al. (2012)	MESONET	(United States)	Weekly	0.54	0.51				
Yilmaz et al. (2012)	SCAN	(United States)	Weekly	0.41	0.52				
This Study	68 Stations	(Turkey)	Daily	0.58	0.48	0.39	0.047	0.049	0.054
This Study	68 Stations	(Turkey)	Weekly	0.75	0.72	0.63	0.035	0.04	0.046

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Summary

Soil moisture variable is very critical for several related hydrological studies from flood to drought. Remote sensing- and hydrological model-based platforms are commonly used to obtain consistent spatially varying soil moisture information, while calibration and validation of these independently estimated values are necessary to ensure accurate estimates are obtained through these platforms. Such validation efforts are primarily performed using station-data as the truth. Station-based soil moisture observations obtained over 149 stations operated by TSMS have not been used before. In this study, these datasets are analyzed for the first time.

Quality control of stations was required to determine reliable stations that can be used in validation-type studies. For quality control of stations, precipitation data obtained from the same station were used to visually inspect whether or not the soil moisture time-series respond to the precipitation events. The quality control was performed during 5 year time period between 2008 and 2012. In order to maximize analysis datasets, a strict availability rule was applied to datasets: only stations that have less than 10% missing soil moisture data are investigated for their accuracy in this study while the remaining datasets are excluded from the analyses. For different studies with different goals more relaxed thresholds could be selected. Hence, selection of stations as non-reliable stations in this study, do not mean that all stations in that category are suitable to use for future studies.

Remote sensing- and hydrological model-based stations are later retrieved over these stations for inter-comparison efforts. The inter-comparison was performed during a 4 year time period between 2008 and 2012 while the first 3 years were selected as the training and the remaining year reserved for validation. On the other hand station-based datasets used in this study are not calibrated for temperature, soil type and soil electrical conductivity. Such calibrations are expected to improve the relation between station data and other datasets.

Conclusion

Results show station- and other products over Turkey have very similar relation compared to other studies using similar datasets over other locations in other countries even though the soil moisture products used in this study are not calibrated while other compared studies use calibrated datasets. This consistency of non-calibrated datasets implies station-based soil moisture data collected over TSMS stations have high potential to be used in various applications, like validation and verification efforts. These results also imply station based measurements over Turkey are reliable to be used for studies related with soil moisture variable and future validation studies.

Recommendation

It is recommended that, station-based datasets used in this study to be calibrated for their soil type or electrical conductivity to ensure these datasets can be used at their full-potential, like in assimilation-type merging studies and satellite-data calibration/validation efforts. After calibration steps, inter-comparison results are expected to be improved (i.e. higher station-other dataset correlations and smaller RMSE for satellite- and model-based datasets). New missions such as SMOS and SMAP soil moisture data and NOAH estimates with higher spatial resolution may also show better correlation results against station-based observations.

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APPENDIX A

INFORMATION OF STATIONS

Table A Information of Stations and Quality Control Results

#	ID	NAME	LOCATION	LATITUDE	LONGITUDE	ELEV. (m)	Q.C	REASON
1	17020	BART	BARTIN	41.6248	32.3569	33	×	2,4
2	17022	ZONG	ZONGULDAK	41.4492	31.7779	135	×	4
3	17023	LTAS	ZONGULDAK	41.3100	32.0600	13	×	1,6
4	17024	INEB	KASTAMONU	41.9789	33.7636	64	×	4
5	17026	SINP	SİNOP	42.0299	35.1545	32	✓	-
6	17050	EDIR	EDİRNE	41.6767	26.5508	51	✓	-
7	17052	KIRL	KIRKLARELİ	41.7382	27.2178	232	✓	-
8	17061	SARY	İSTANBUL	41.1464	29.0502	59	✓	-
9	17067	GOLC	KOCAELİ	40.7268	29.8066	18	✓	-
10	17070	BOLU	BOLU	40.7329	31.6022	743	✓	-
11	17072	DUZC	DÜZCE	40.8437	31.1488	146	✓	-
12	17074	KAST	KASTAMONU	41.3710	33.7756	800	✓	-
13	17078	KARB	KARABÜK	41.1963	32.6216	259	×	2,4
14	17080	CANK	ÇANKIRI	40.6086	33.6102	751	✓	-
15	17087	LTAW	TOKAT	40.1900	36.2200	558	×	1,6
16	17110	GOKC	ÇANAKKALE	40.1910	25.9075	79	✓	-
17	17112	CNKL	ÇANAKKALE	40.1410	26.3993	6	✓	-
18	17114	BAND	BALIKESİR	40.3315	27.9965	63	×	4
19	17116	LTBE	BURSA	40.2308	29.0133	100	✓	-
20	17119	YALV	YALOVA	40.6589	29.2796	4	✓	-
21	17120	BILC	BİLECİK	40.1414	29.9772	539	✓	-
22	17130	ANKA	ANKARA	39.9727	32.8637	891	✓	-
23	17137	ELMR	ANKARA	39.7985	32.9716	1807	×	6
24	17145	EDRM	BALIKESİR	39.5895	27.0192	21	✓	-
25	17155	KUTH	KÜTAHYA	39.4171	29.9891	969	✓	-
26	17160	KIRS	KIRŞEHİR	39.1639	34.1561	1007	✓	-
27	17175	AYVL	BALIKESİR	39.3113	26.6861	4	✓	-

Table A (Cont'd)

#	ID	NAME	LOCATION	LATITUDE	LONGITUDE	ELEV. (m)	Q.C	REASON
28	17180	DIKL	İZMİR	39.0737	26.8880	3	×	4
29	17185	LTBO	UŞAK	38.4100	29.2800	874	×	1,6
30	17186	MANS	MANİSA	38.6153	27.4049	71	×	4
31	17188	UŞAK	UŞAK	38.6712	29.4040	919	✓	-
32	17190	AFBL	A.KARAHİSAR	38.7380	30.5604	1034	✓	-
33	17191	CIHB	KONYA	38.6503	32.9226	969	×	4
34	17209	LTCL	SİİRT	37.9783	41.8421	612	✓	-
35	17220	GUZL	İZMİR	38.3949	27.0819	29	✓	-
36	17221	CESM	İZMİR	38.3036	26.3724	5	✓	-
37	17227	LTBD	AYDIN	37.8167	27.8873	32	×	4,5,6
38	17232	KUSA	AYDIN	37.8597	27.2652	25	✓	-
39	17233	DIDM	AYDIN	37.3699	27.2645	44	×	1
40	17234	AYDN	AYDIN	37.8402	27.8379	56	✓	-
41	17237	DENZ	DENİZLİ	37.7620	29.0921	425	✓	-
42	17238	BURD	BURDUR	37.7220	30.2940	957	✓	-
43	17240	ISPB	ISPARTA	37.7848	30.5679	997	✓	-
44	17283	LTHB	DİYARBAKIR	37.9390	40.2966	701	✓	-
45	17290	BODR	MUĞLA	37.0328	27.4398	26	×	4
46	17292	MUGL	MUĞLA	37.2095	28.3668	646	×	4
47	17296	FETH	MUĞLA	36.6266	29.1238	3	✓	-
48	17297	DATC	MUĞLA	36.7083	27.6919	28	×	4
49	17298	MARM	MUĞLA	36.8395	28.2452	16	×	4
50	17302	ANTA	ANTALYA	36.8851	30.6828	47	×	6
51	17310	ALAN	ANTALYA	36.5507	31.9803	6	✓	-
52	17375	FINK	ANTALYA	36.3024	30.1458	2	×	4
53	17380	KASD	ANTALYA	36.2002	29.6502	153	✓	-
54	17602	AMSR	BARTIN	41.7526	32.3827	73	×	4
55	17606	BOZK	KASTAMONU	41.9597	34.0037	167	×	4
56	17610	SILE	İSTANBUL	41.1688	29.6007	83	×	4
57	17611	KERE	ZONGULDAK	41.2691	31.4328	19	×	4,5
58	17613	DEVR	ZONGULDAK	41.2347	31.9689	100	×	4
59	17618	DEVK	KASTAMONU	41.5996	33.8345	1050	×	4
60	17620	BOYA	SİNOP	41.4630	34.7853	350	×	2,4
61	17631	LULE	KIRKLARELİ	41.3513	27.3108	46	×	4
62	17632	IPSL	EDİRNE	40.9174	26.3802	10	×	4
63	17639	GEBZ	KOCAELİ	40.8230	29.4342	130	×	4
64	17640	CRKZ	TEKİRDAĞ	41.2607	27.9196	160	✓	-
65	17642	GRDE	BOLU	40.8046	32.2176	1270	✓	-
66	17643	KURS	ÇANKIRI	40.8328	33.2691	1075	×	5

Table A (Cont'd)

#	ID	NAME	LOCATION	LATITUDE	LONGITUDE	ELEV. (m)	Q.C	REASON
67	17644	KRSU	SAKARYA	41.1113	30.6901	4	×	4,5
68	17645	HTTG	HATAY	36.2670	36.4947	62	×	4
69	17647	YPKL	ÇANKIRI	40.7560	33.7774	1225	✓	-
70	17648	ILGZ	ÇANKIRI	40.9156	33.6258	885	✓	-
71	17651	PLTG	ANKARA	39.1525	32.1283	940	×	4,5
72	17655	GHTG	AMASYA	40.5875	35.6517	475	✓	-
73	17661	IZNK	BURSA	40.4267	29.7302	90	×	4
74	17662	GEYV	SAKARYA	40.5214	30.2960	100	×	4
75	17663	GMLK	BURSA	40.4401	29.1504	10	×	4
76	17664	KZLC	ANKARA	40.4729	32.6441	1033	✓	-
77	17665	SABN	ÇANKIRI	40.4742	33.2857	1060	✓	-
78	17670	INGL	BURSA	40.0908	29.4916	280	×	4
79	17674	GONE	BALIKESİR	40.1135	27.6426	37	×	4
80	17675	MKMP	BURSA	40.0425	28.3995	60	✓	-
81	17680	BEYP	ANKARA	40.1608	31.9172	682	✓	-
82	17694	KBRS	BOLU	40.4081	31.8475	1025	×	4
83	17695	KLES	BURSA	39.9150	29.2313	1063	×	4
84	17699	MNYS	BALIKESİR	40.0471	27.9748	50	×	2,4
85	17700	DURB	BALIKESİR	39.5778	28.6322	637	✓	-
86	17702	BOZY	BİLECİK	39.9039	30.0525	754	×	4,5
87	17703	SOGT	BİLECİK	40.0205	30.1850	695	×	4
88	17704	TVSL	KÜTAHYA	39.5384	29.4941	833	×	4,5
89	17706	SSTG	MALATYA	38.3406	38.0586	864	✓	-
90	17707	EMET	KÜTAHYA	39.3391	29.2713	700	×	4
91	17710	ULTG	SİVAS	39.4414	37.0276	1392	×	4
92	17711	ELMD	ANKARA	39.9167	33.2333	1130	×	1,5
93	17715	EBRT	ANKARA	39.9200	33.2125	1102	×	1,6
94	17722	BURH	BALIKESİR	39.4983	26.9755	20	×	4,5
95	17723	CFTE	ESKİŞEHİR	39.3659	31.0209	900	×	4
96	17726	SIVH	ESKİŞEHİR	39.4453	31.5354	1070	×	4
97	17728	POLT	ANKARA	39.5834	32.1624	886	×	4,5
98	17729	BALA	ANKARA	39.5546	33.1089	1300	✓	-
99	17730	KESK	KIRIKKALE	39.6682	33.6118	1140	×	4
100	17731	SRKH	ANKARA	38.9539	33.4218	975	×	4
101	17732	CICD	KIRŞEHİR	39.6067	34.4235	900	×	4
102	17733	HTRM	ANKARA	39.6130	32.6720	1161	✓	-
103	17742	BERG	İZMİR	39.1098	27.1710	53	✓	-
104	17744	ATGM	KONYA	38.7191	32.1750	1002	×	4
105	17745	MLTG	KIRŞEHİR	39.3038	34.3421	1127	×	4

Table A (Cont'd)

#	ID	NAME	LOCATION	LATITUDE	LONGITUDE	ELEV. (m)	Q.C	REASON
106	17746	DMRC	MANİSA	39.0349	28.6482	855	✓	-
107	17748	SIMV	KÜTAHYA	39.0925	28.9786	809	✓	-
108	17749	IMKP	İZMİR	38.4639	27.3705	208	×	1,6
109	17750	GEDZ	KÜTAHYA	38.9947	29.4003	736	×	4
110	17752	EMRD	A.KARAHİSAR	39.0098	31.1463	983	✓	-
111	17753	BAYT	A.KARAHİSAR	38.9715	30.9179	1100	✓	-
112	17756	KAMN	KIRŞEHİR	39.3652	33.7064	1075	×	1,6
113	17787	ALIA	İZMİR	38.7922	26.9682	27	×	5
114	17789	MENM	İZMİR	38.6237	27.0433	10	✓	-
115	17792	SALH	MANİSA	38.4831	28.1234	111	×	4
116	17796	BOLV	A.KARAHİSAR	38.7268	31.0477	1018	✓	-
117	17797	ALAS	MANİSA	38.3730	28.5266	189	✓	-
118	17820	SFHR	İZMİR	38.1990	26.8350	22	×	4
119	17822	ODEM	İZMİR	38.2157	27.9642	111	×	4
120	17824	GUNY	DENİZLİ	38.1515	29.0587	825	✓	-
121	17825	CIVR	DENİZLİ	38.2871	29.7333	840	✓	-
122	17826	SENK	ISPARTA	38.1047	30.5577	959	✓	-
123	17827	ESME	UŞAK	38.3978	28.9898	810	✓	-
124	17828	YLVC	ISPARTA	38.2830	31.1778	1096	×	4
125	17850	SULH	AYDIN	37.8843	28.1504	73	✓	-
126	17854	SELC	İZMİR	37.9445	27.3673	17	✓	-
127	17855	CARD	DENİZLİ	37.8245	29.6678	869	×	1,6
128	17860	NAZL	AYDIN	37.9135	28.3437	84	✓	-
129	17862	DINR	A.KARAHİSAR	38.0600	30.1538	864	✓	-
130	17863	SRKA	ISPARTA	38.0630	31.3558	1158	×	4
131	17864	ULBR	ISPARTA	38.0860	30.4582	1025	×	4
132	17881	SOKE	AYDIN	37.7049	27.3827	75	✓	-
133	17882	EGRD	ISPARTA	37.8377	30.8720	920	×	4
134	17883	GZCM	AYDIN	37.7150	27.2350	30	×	1,6
135	17886	YTGN	MUĞLA	37.3395	28.1369	365	✓	-
136	17890	ACPY	DENİZLİ	37.4337	29.3498	941	×	4,5
137	17891	GOLH	BURDUR	37.1427	29.5260	990	×	4,5
138	17892	TFNI	BURDUR	37.3161	29.7792	1142	✓	-
139	17893	SUTC	ISPARTA	37.4939	30.9721	985	×	5
140	17895	AKTG	ANTALYA	36.9393	30.8980	10	×	5,6
141	17897	GZTG	KONYA	38.4919	32.4563	111	×	5
142	17899	MHTG	ESKİŞEHİR	39.4853	30.9900	882	✓	-
143	17924	KOYC	MUĞLA	36.9700	28.6869	24	✓	-
144	17926	KORE	ANTALYA	37.0565	30.1910	1017	✓	-

Table A (Cont'd)

#	ID	NAME	LOCATION	LATITUDE	LONGITUDE	ELEV. (m)	Q.C	REASON
145	17927	IBRD	ANTALYA	37.0968	31.5952	1036	×	4
146	17952	ELML	ANTALYA	36.7372	29.9121	1095	×	4
147	17953	KEMR	ANTALYA	36.5942	30.5672	10	×	4
148	17954	MNGV	ANTALYA	36.7895	31.4410	38	×	4
149	17968	CPTG	ŞANLIURFA	36.8406	40.0307	360	×	1,5

Legend for Reason	
1	More than 10% precipitation data are missing
2	Station shows more than "60%" soil moisture values
3	Soil moisture values create straight line on graph
4	Sensitivity of soil moisture values are not sufficient
5	Station measurement equipment is defective
6	More than 10% soil moisture data are missing

APPENDIX B

ANALYSIS RESULTS OF EACH CATEGORY – 1 STATION

Table B.1 Category – 1 Stations Weekly Inter-comparison Results (R Values)

#1	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	NA	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.566	NA	NA	NA	NA

#2	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.717	NA	---	---	---
LPRM	0.831	0.890	NA	---	---
ASCAT	0.721	0.588	0.721	NA	---
API	0.684	0.666	0.713	0.669	NA

#3	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.855	NA	---	---	---
LPRM	0.780	0.828	NA	---	---
ASCAT	0.657	0.649	0.675	NA	---
API	0.673	0.613	0.684	0.705	NA

Table B.1 (Cont'd)

#4	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.793	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.485	0.690	NA	NA	NA

#5	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.868	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.844	0.742	NA	NA	---
API	0.643	0.647	NA	0.693	NA

#6	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.518	NA	---	---	---
LPRM	0.541	0.592	NA	---	---
ASCAT	0.584	0.418	0.628	NA	---
API	0.393	0.572	0.616	0.554	NA

#7	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.809	NA	---	---	---
LPRM	0.563	0.679	NA	---	---
ASCAT	0.772	0.644	0.558	NA	---
API	0.531	0.706	0.500	0.480	NA

#8	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.315	NA	---	---	---
LPRM	0.697	0.519	NA	---	---
ASCAT	0.695	0.457	0.688	NA	---
API	0.609	0.512	0.471	0.701	NA

Table B.1 (Cont'd)

#9	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.372	NA	---	---	---
LPRM	0.564	0.758	NA	---	---
ASCAT	0.604	0.500	0.811	NA	---
API	0.510	0.481	0.651	0.685	NA

#10	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	NA	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.670	NA	NA	NA	NA

#11	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.793	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.594	0.779	NA	NA	---
API	0.551	0.660	NA	0.743	NA

#12	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.802	NA	---	---	---
LPRM	0.541	0.584	NA	---	---
ASCAT	0.838	0.697	0.602	NA	---
API	0.690	0.614	0.523	0.762	NA

#13	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.870	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.725	0.725	NA	NA	---
API	0.622	0.598	NA	0.651	NA

Table B.1 (Cont'd)

#14	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.797	NA	---	---	---
LPRM	0.633	0.676	NA	---	---
ASCAT	0.791	0.697	0.572	NA	---
API	0.629	0.558	0.493	0.698	NA

#15	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.612	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.587	0.560	NA	NA	---
API	0.563	0.553	NA	0.672	NA

#16	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.841	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.846	0.816	NA	NA	---
API	0.627	0.656	NA	0.748	NA

#17	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.578	NA	---	---	---
LPRM	0.568	0.483	NA	---	---
ASCAT	0.763	0.552	0.513	NA	---
API	0.673	0.595	0.487	0.746	NA

#18	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.709	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.692	0.582	NA	NA	---
API	0.722	0.653	NA	0.756	NA

Table B.1 (Cont'd)

#19	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	NA	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.667	NA	NA	NA	---
API	0.729	NA	NA	0.720	NA

#20	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.840	NA	---	---	---
LPRM	0.832	0.869	NA	---	---
ASCAT	0.691	0.733	0.754	NA	---
API	0.722	0.740	0.709	0.820	NA

#21	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.705	NA	---	---	---
LPRM	0.780	0.873	NA	---	---
ASCAT	0.560	0.623	0.722	NA	---
API	0.540	0.602	0.674	0.802	NA

#22	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.932	NA	---	---	---
LPRM	0.852	0.874	NA	---	---
ASCAT	0.747	0.730	0.748	NA	---
API	0.764	0.748	0.761	0.785	NA

#23	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.768	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.531	0.467	NA	NA	---
API	0.720	0.712	NA	0.697	NA

Table B.1 (Cont'd)

#24	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	NA	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.592	NA	NA	NA	NA

#25	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.815	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.743	0.725	NA	NA	NA

#26	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.949	NA	---	---	---
LPRM	0.896	0.925	NA	---	---
ASCAT	0.618	0.635	0.712	NA	---
API	0.671	0.717	0.722	0.743	NA

#27	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.941	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.696	0.690	NA	NA	---
API	0.713	0.708	NA	0.739	NA

#28	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.798	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.774	0.665	NA	NA	NA

Table B.1 (Cont'd)

#29	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.671	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.635	0.663	NA	NA	NA

#30	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.779	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.504	0.683	NA	NA	---
API	0.727	0.769	NA	0.710	NA

#31	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.826	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.570	0.768	NA	NA	NA

#32	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.870	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.795	0.754	NA	NA	NA

#33	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	NA	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.715	NA	NA	NA	NA

Table B.1 (Cont'd)

#34	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.884	NA	---	---	---
LPRM	0.747	0.848	NA	---	---
ASCAT	0.700	0.738	0.692	NA	---
API	0.713	0.688	0.593	0.775	NA

#35	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.698	NA	---	---	---
LPRM	0.542	0.503	NA	---	---
ASCAT	0.506	0.497	0.590	NA	---
API	0.662	0.566	0.467	0.587	NA

#36	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.571	NA	---	---	---
LPRM	0.830	0.650	NA	---	---
ASCAT	0.629	0.365	0.731	NA	---
API	0.523	0.453	0.477	0.586	NA

#37	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.523	NA	---	---	---
LPRM	0.621	0.646	NA	---	---
ASCAT	0.491	0.420	0.775	NA	---
API	0.440	0.470	0.599	0.650	NA

#38	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.550	NA	---	---	---
LPRM	0.682	0.812	NA	---	---
ASCAT	0.552	0.454	0.755	NA	---
API	0.526	0.544	0.707	0.796	NA

Table B.1 (Cont'd)

#39	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.545	NA	---	---	---
LPRM	0.654	0.710	NA	---	---
ASCAT	0.455	0.518	0.767	NA	---
API	0.566	0.573	0.596	0.703	NA

#40	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	NA	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.264	NA	NA	NA	NA

#41	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.914	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.725	0.726	NA	NA	NA

#42	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.768	NA	---	---	---
LPRM	0.842	0.844	NA	---	---
ASCAT	0.698	0.638	0.787	NA	---
API	0.666	0.602	0.683	0.790	NA

#43	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.741	NA	---	---	---
LPRM	0.812	0.864	NA	---	---
ASCAT	0.649	0.801	0.843	NA	---
API	0.492	0.695	0.652	0.759	NA

Table B.1 (Cont'd)

#44	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.748	NA	---	---	---
LPRM	0.680	0.840	NA	---	---
ASCAT	0.229	0.043	NA	NA	---
API	0.694	0.620	0.629	0.293	NA

#45	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.668	NA	---	---	---
LPRM	0.647	0.719	NA	---	---
ASCAT	0.692	0.593	0.723	NA	---
API	0.657	0.596	0.664	0.662	NA

#46	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.658	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.64	0.588	NA	NA	---
API	0.748	0.613	NA	0.695	NA

#47	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.916	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.773	0.808	NA	NA	---
API	0.745	0.734	NA	0.816	NA

#48	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.917	NA	---	---	---
LPRM	0.930	0.892	NA	---	---
ASCAT	0.865	0.796	0.838	NA	---
API	0.652	0.630	0.550	0.708	NA

Table B.1 (Cont'd)

#49	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.816	NA	---	---	---
LPRM	0.889	0.855	NA	---	---
ASCAT	0.871	0.748	0.831	NA	---
API	0.718	0.662	0.594	0.779	NA

#50	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.711	NA	---	---	---
LPRM	0.765	0.830	NA	---	---
ASCAT	0.542	0.463	0.669	NA	---
API	0.639	0.686	0.705	0.583	NA

#51	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.632	NA	---	---	---
LPRM	0.803	0.839	NA	---	---
ASCAT	0.669	0.596	0.748	NA	---
API	0.693	0.599	0.660	0.704	NA

#52	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.683	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.479	0.607	NA	NA	---
API	0.491	0.710	NA	0.755	NA

#53	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.697	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	0.574	0.571	NA	NA	---
API	0.726	0.639	NA	0.671	NA

Table B.1 (Cont'd)

#54	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.788	NA	---	---	---
LPRM	0.788	0.959	NA	---	---
ASCAT	0.786	0.797	0.807	NA	---
API	0.721	0.703	0.705	0.834	NA

#55	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.928	NA	---	---	---
LPRM	0.358	0.420	NA	---	---
ASCAT	0.738	0.652	0.318	NA	---
API	0.721	0.698	0.449	0.806	NA

#56	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.861	NA	---	---	---
LPRM	0.824	0.902	NA	---	---
ASCAT	0.569	0.496	0.499	NA	---
API	0.762	0.697	0.667	0.733	NA

#57	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.484	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.448	0.624	NA	NA	NA

#58	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.917	NA	---	---	---
LPRM	0.893	0.947	NA	---	---
ASCAT	0.781	0.786	0.819	NA	---
API	0.745	0.724	0.727	0.832	NA

Table B.1 (Cont'd)

#59	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.831	NA	---	---	---
LPRM	0.774	0.945	NA	---	---
ASCAT	0.755	0.669	0.708	NA	---
API	0.797	0.746	0.700	0.788	NA

#60	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.947	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.840	0.728	NA	NA	NA

#61	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.899	NA	---	---	---
LPRM	0.873	0.944	NA	---	---
ASCAT	0.694	0.657	0.685	NA	---
API	0.648	0.698	0.632	0.714	NA

#62	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.493	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.349	0.650	NA	NA	NA

#63	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.841	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.648	0.710	NA	NA	NA

Table B.1 (Cont'd)

#64	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.907	NA	---	---	---
LPRM	0.650	0.708	NA	---	---
ASCAT	0.023	0.004	0.151	NA	---
API	0.643	0.704	0.677	0.432	NA

#65	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.449	NA	---	---	---
LPRM	0.524	0.761	NA	---	---
ASCAT	0.516	0.430	0.564	NA	---
API	0.402	0.659	0.675	0.625	NA

#66	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.754	NA	---	---	---
LPRM	0.701	0.867	NA	---	---
ASCAT	0.528	0.542	0.758	NA	---
API	0.604	0.613	0.721	0.711	NA

#67	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.885	NA	---	---	---
LPRM	NA	NA	NA	---	---
ASCAT	NA	NA	NA	NA	---
API	0.761	0.787	NA	NA	NA

#68	STATION	NOAH	LPRM	ASCAT	API
STATION	NA	---	---	---	---
NOAH	0.793	NA	---	---	---
LPRM	0.715	0.735	NA	---	---
ASCAT	0.183	NA	0.299	NA	---
API	0.705	0.67	0.628	0.25	NA

Table B.2 Category – 1 Stations Weekly Datasets RMSE Values

Station #		NOAH	LPRM	ASCAT	API
1	5	NA	NA	NA	0.047
2	6	0.018	0.011	0.019	0.023
3	7	0.019	0.036	0.031	0.036
4	8	0.056	NA	NA	0.076
5	9	0.024	NA	0.025	0.039
6	10	0.034	0.035	0.032	0.040
7	11	0.032	0.055	0.037	0.049
8	12	0.037	0.026	0.028	0.034
9	14	0.067	0.079	0.076	0.076
10	16	NA	NA	NA	0.071
11	17	0.035	NA	0.046	0.054
12	19	0.026	0.046	0.029	0.037
13	20	0.013	NA	0.017	0.023
14	21	0.040	0.069	0.038	0.054
15	22	0.053	NA	0.065	0.070
16	24	0.028	NA	0.030	0.044
17	25	0.037	0.062	0.028	0.034
18	26	0.029	NA	0.035	0.026
19	27	NA	NA	0.101	0.114
20	31	0.064	0.050	0.061	0.052
21	32	0.037	0.046	0.044	0.042
22	34	0.036	0.064	0.074	0.072
23	35	0.025	NA	0.031	0.019
24	36	NA	NA	NA	0.069
25	38	0.039	NA	NA	0.035
26	40	0.019	0.019	0.040	0.040
27	41	0.010	NA	0.030	0.030
28	42	0.029	NA	NA	0.031
29	43	0.016	NA	NA	0.021
30	44	0.067	NA	0.105	0.076
31	47	0.064	NA	NA	0.102
32	51	0.014	NA	NA	0.017
33	53	NA	NA	NA	0.045
34	64	0.029	0.028	0.041	0.043
35	65	0.028	0.021	0.032	0.027
36	69	0.054	0.049	0.079	0.084
37	70	0.052	0.065	0.069	0.069
38	72	0.052	0.041	0.061	0.062
39	76	0.062	0.047	0.057	0.050
40	77	NA	0.119	NA	0.136

Table B.2 (Cont'd)

Station #		NOAH	LPRM	ASCAT	API
41	80	0.019	NA	NA	0.037
42	81	0.034	0.037	0.054	0.053
43	85	0.054	0.042	0.058	0.067
44	89	0.032	0.046	0.053	0.038
45	98	0.041	0.045	0.058	0.058
46	102	0.038	NA	0.052	0.048
47	103	0.029	NA	0.037	0.038
48	106	0.029	0.027	0.040	0.061
49	107	0.019	0.021	0.025	0.036
50	110	0.018	0.022	0.026	0.024
51	111	0.022	0.017	0.027	0.026
52	114	0.118	NA	0.113	0.122
53	116	0.021	NA	0.025	0.025
54	117	0.026	0.025	0.030	0.031
55	120	0.017	0.071	0.035	0.041
56	121	0.033	0.041	0.058	0.041
57	122	0.051	NA	NA	0.061
58	123	0.013	0.020	0.032	0.037
59	125	0.016	0.023	0.019	0.017
60	126	0.015	NA	NA	0.024
61	128	0.013	0.025	0.038	0.038
62	129	0.050	NA	NA	0.048
63	132	0.055	NA	NA	0.051
64	135	0.030	0.061	0.053	0.047
65	138	0.029	0.034	0.028	0.031
66	142	0.040	0.049	0.063	0.058
67	143	0.028	NA	NA	0.038
68	144	0.021	0.029	0.036	0.026

APPENDIX C

NOAH MODEL CONFIGURATION FILE

```
-------------------------------------------------
40.01   LATITUDE..(N > 0.00 (+); S < 0.00 (-))
88.37   LONGITUDE.(W > 0.00 (+); E < 0.00 (-))
-1      IBINOUT...(+/-) Output type: +1=Binary(GrADS), -1=ASCII(*.TXT)
1       JDAY......Initial julian day of simulation (1-366)
30      TIME......Initial time "hhmm", where: hh=hour (0-23), mm=min(0-59)
1       NCYCLES...Cycles the forcing data (useful for spin-up runs)
365     SYDAYS....DAYS IN SPIN-UP YEAR (ea. SpUp yr has Sysec/dt t_steps)
.FALSE.         L2nd_data.Uses 2nd forcing data file (useful after spin-up runs)
17520           NRUN......Total # of simulation time steps
3600.0000       DT........Time step for integration in sec (not more than 3600)
4               NSOIL.....Number of soil layers (2-20)
6.0000          Z.........Height (above ground) of the forcing wind vector (m)
0.100  0.300  0.600  1.000      K=1,NSOIL...thickness of each soil layer (m)
 -------------------------------------------------
Filenames of atmospheric data used for input forcing (1 and 2):
 -------------------------------------------------
forcing_basic98.dat
forcing_basic98.dat
-------------------------------------------------
Integer indexes designating soil type, veg type and slope type:
-------------------------------------------------
   2       SOILTYP...Soil type index 1-9
   7       VEGTYP....Vegetation type index 1-13
   1       SLOPETYP..Slope type index 1-9
```

Monthly ALBEDO (snow free albedo):

J*	F	M	A*	M	J	J*	A	S	O*	N	D
0.15	0.16	0.17	0.18	0.18	0.18	0.18	0.17	0.17	0.16	0.16	0.15

Monthly SHDFAC (green vegetation fraction):

J	F	M	A	M	J	J	A	S	O	N	D
0.01	0.02	0.07	0.17	0.27	0.58	0.93	0.96	0.65	0.24	0.11	0.02

0.7500 SNOALB....Max albedo over very deep snow

0 SEA ICE...Sea ice flag (keep as integer 0 to designate non-sea)

Physical parameters:

----

285. TBOT......Annual constant bottom boundary soil temperature (K)

Initial state variables:

263.6909 T1........Initial skin temperature (K)

266.0995	274.0445	276.8954	279.9152	STC*
0.2981597	0.2940254	0.2713114	0.3070948	SMC**
0.1611681	0.2633106	0.2713114	0.3070948	SH2O***

* Initial soil temperature (K), in each soil layer

** Initial volumetric total soil moisture (liquid and frozen) in each layer

*** Initial volumetric liquid soil moisture (unfrozen) in each layer

3.9353027E-04 CMC.......Initial canopy water content (m)

1.0600531E-03 SNOWH.....Initial actual snow depth (m)

2.0956997E-04 SNEQV.....Initial water equiv snow depth (m)

-------------------------END OF READABLE CONTROLFILE -------------------------