EUMETSAT

WORLD METEOROLOGICAL ORGANIZATION

The Seventeenth EUMETSAT Satellite Application Course
Muscat, 20 March 2022

LAND APPLICATION:
(MONITORING SOIL MOISTURE FROM SPACE)

WMO Centre of Excellence for Satellite Applications-Muscat (CoE-Muscat)

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Topics

Part A

1- Introduction

2- Main important satellite programs for monitoring Soil moisture

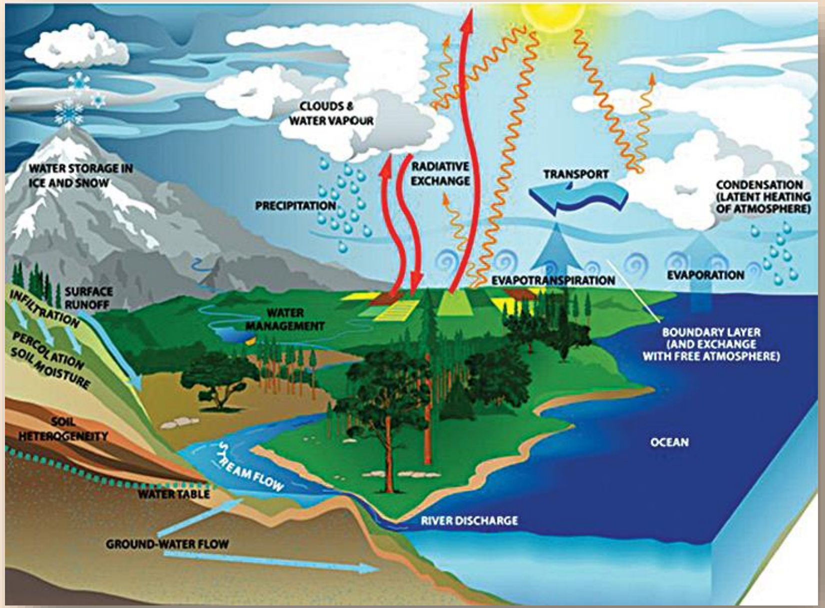
3- Downscalling

Part B

Downloading and Basic Calculations Using R

1-Introduction

- **Soil moisture** is a ***fundamental variable in the Earth's water cycle***, which *governs the exchange of water between the land surface and the atmosphere*.



- Soil moisture plays a key role for many scientific and operational applications including :

- ✓ Hydrological modelling
- ✓ Numerical weather forecasting
- ✓ Flood forecasting and drought monitoring
- ✓ Water resources managements and Water budgeting for irrigation planning
- ✓ Vegetation and crops always depend more on the moisture available at root level than on precipitation occurrence
- ✓ Land surface and climate models assessment from the local to global scales

Applications of Soil Moisture Data

- **Weather and Climate Forecasting**
- **Droughts and Wildfires**
- **Floods & Landslides**
- **Agricultural Productivity**
- **Human Health**
- **National Security**






- **In 2010, Soil Moisture was introduced as one of the Essential Climate Variables (ECV)** established by the World Meteorological Organization (WMO), the Global Climate Observing System (GCOS) and the Committee on Earth Observation Satellites (CEOS), among others, considering it as **"Technically and economically feasible for systematic observation".**

Definition of Soil moisture

- Soil moisture determinations measure either the **soil water content (**the mass or volume of water in the soil**)** or the soil water potential (the soil water energy status).

$$\theta_g = M_{water}/M_{soil}$$

The mass of dry soil that is contained in the sample

The mass of the water in the soil sample

θg is the weight of soil water contained in a unit weight of soil (kg water/kg dry soil) that In meteorology are usually expressed in %

$$\theta_v = V_{watre}/V_{sample}$$

The volume of water in the soil sample

The total volume of dry soil + air + water in the sample

Volumetric water content is a volume fraction (m^3water/m^3 soil)

Measurement methods of soil moisture

1) **Direct and indirect in-situ measurements** such as radiological methods, neutron attenuation, gamma absorption, soil-water dielectrics, microwave probe and etc.
2) **Estimation techniques** (i) Land surface models (ii) Soil moisture modelling
3) **Emerging technologies (Remote Sensing)**

All these methods differ significantly by the accuracy, complexity, technique, and Spatio-Temporal scales.

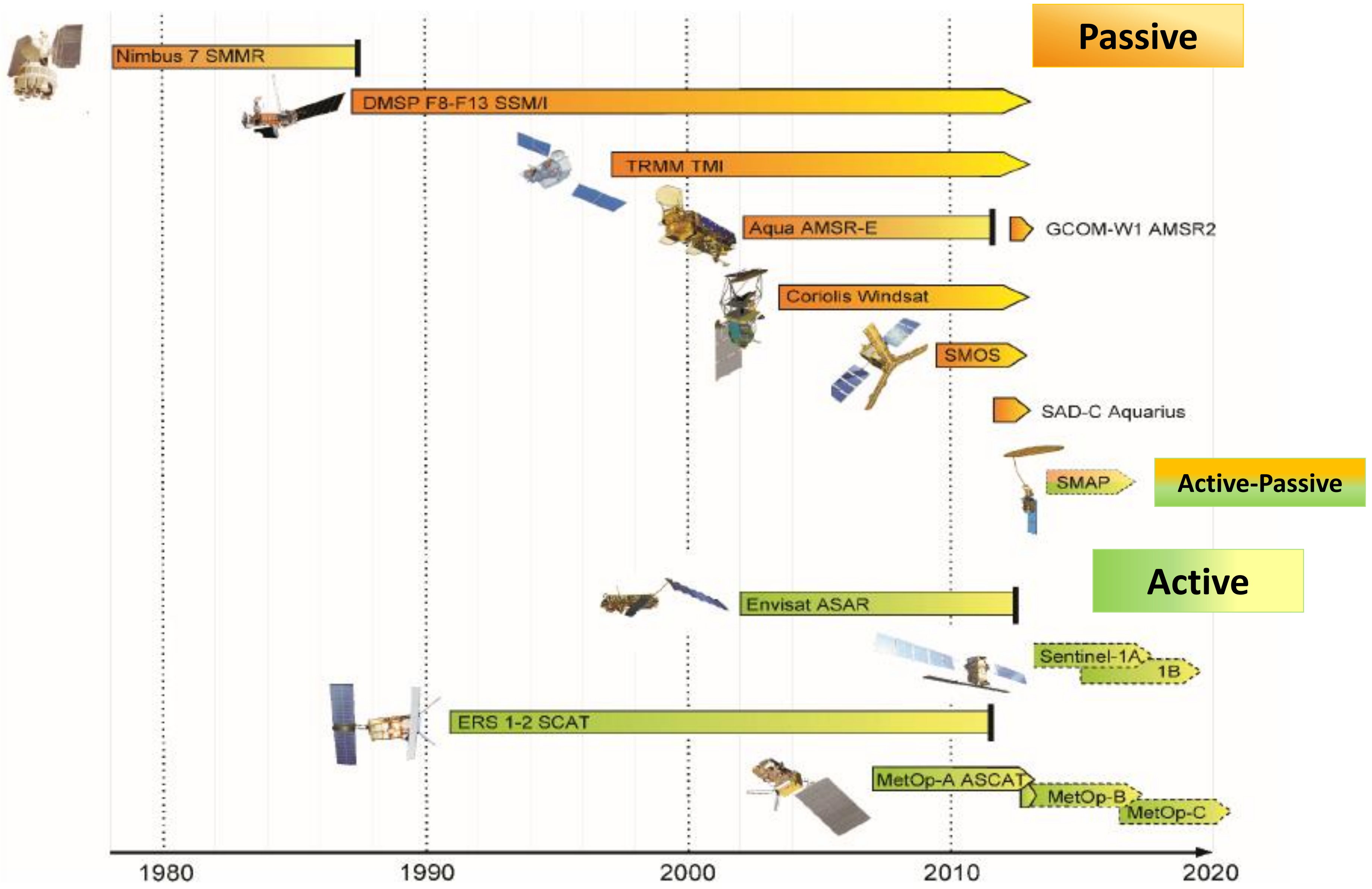
Remote sensing of soil moisture

- The most suitable method for providing global soil moisture data is the remote sensing technique. In recent decades, various optical, thermal infrared, and microwave remote sensing sensors have been used to provide soil moisture data.

- Microwave remote sensing systems have unique abilities, such as atmosphere transparency, cloud penetration, soil penetration, vegetation semi-transparency, high temporal-spatial (active)resolution and a high dependency on the soil dielectric properties.

- Microwave remote sensing instruments at lower frequency (L-band) have high penetration into the soil moisture depth (~5 cm) and vegetation canopy than higher microwave frequencies (C and X-band).
- The attenuation effects of vegetation and atmospheric in the L-band are lower than C and X-band.
- L-band signals (1–2 GHz) are sensitive to measuring soil moisture due to the significant difference between the water and dry soil dielectric constants.
- Therefore, the **L-band is particularly suitable for measuring surface soil moisture.**

Active and passive microwave sensors used for soil moisture retrieval

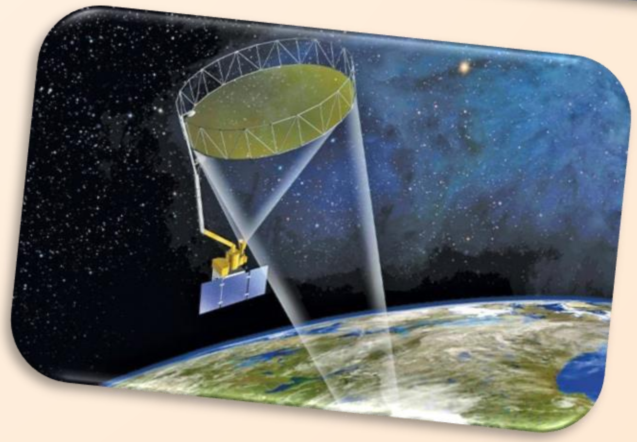


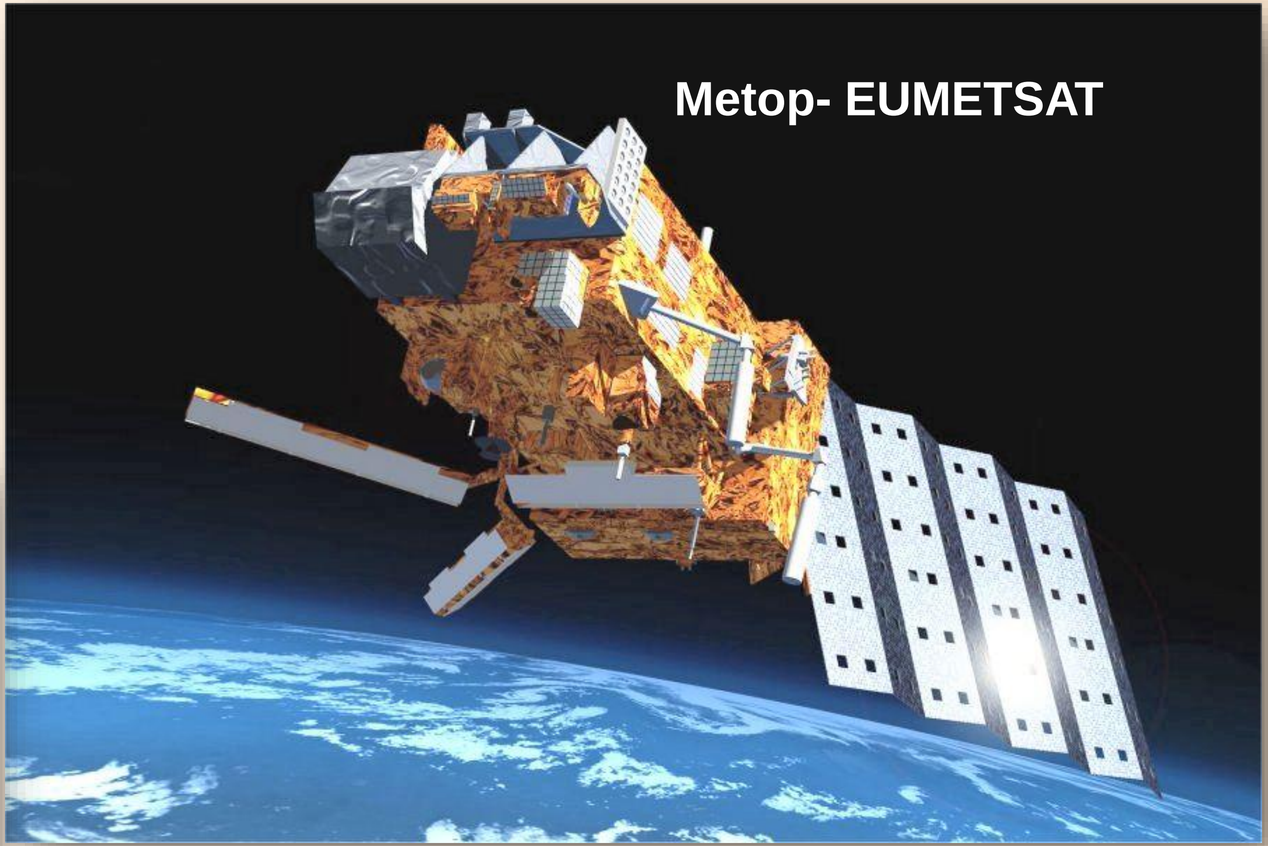
2-Main important satellite programs for monitoring Soil moisture

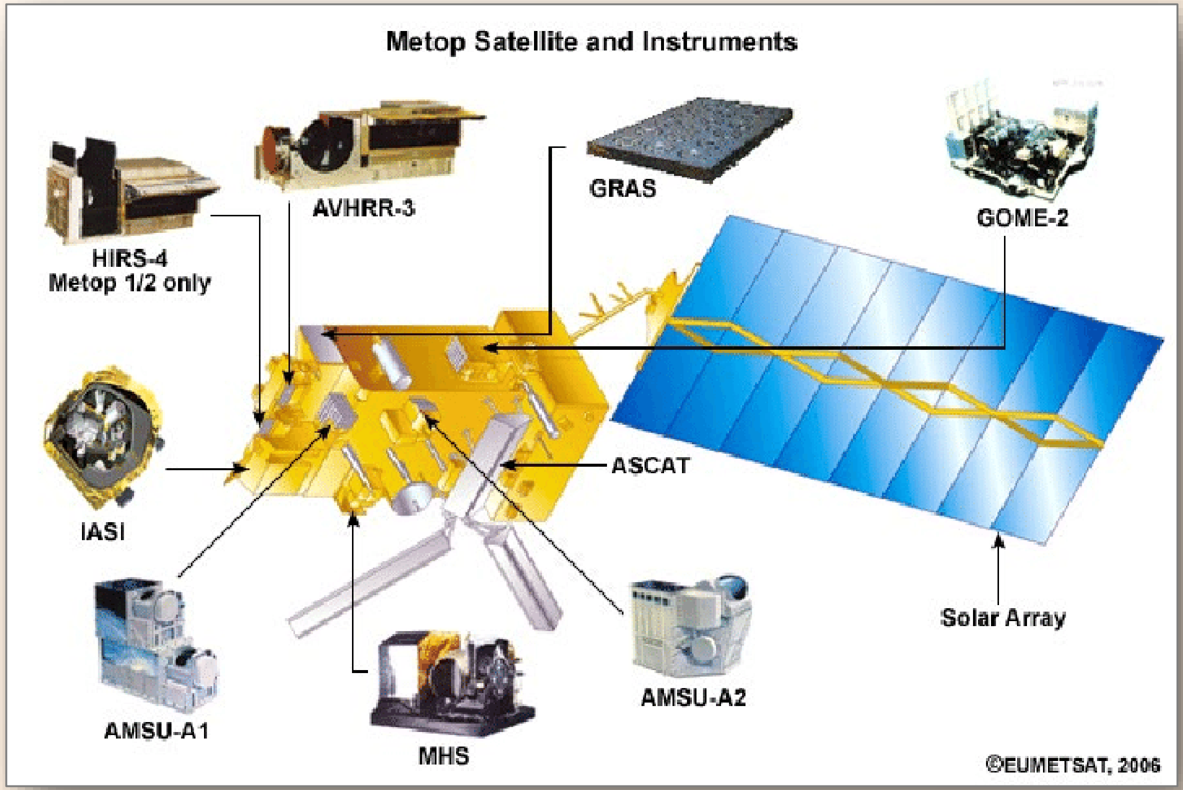
- Metop satellites

- SMOS satellites

- SMAP satellites




Metop- EUMETSAT


Metop Satellite and Instruments
HIRS-4
Metop 1/2 only
AVHRR-3
GRAS
GOME-2
IASI
ASCAT
AMSU-A1
MHS
AMSU-A2
Solar Array
©EUMETSAT, 2006

Metop satellites

- **MetOp** is a series of three polar orbiting meteorological satellites developed by **ESA** and operated by **EUMETSAT.**

Metop

- **Launch:**
  - **Metop-A** (19 October 2006)
  - **Metop-B** (17 September 2012)
  - **Metop-C** (7 November 2018)
- **Orbit: Sun-synchronous orbit**
- **Inclination: 98.7 degrees to the Equator**
- **Repeat Cycle: 29 days**
- **Mean altitude: ~ 817 km**

ASCAT on-board Metop-A, Metop-B, Metop-C

Sensor	Advanced Scatterometer (ASCAT)
Instrument	Active microwave scatterometer
Frequency	C-band, 5.255 GHz
Polarisation	VV
Antenna	six; 3 (quasi) instantaneous independent measurements
Swath	2 x 500 km
Main applications	- Wind measurements - land and sea ice monitoring - soil moisture - snow properties, soil
Spatial Resolution	25 km/ 50 km
Multi-incidence	25-65°
Daily global	coverage: 82 %

- The "EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (**H-SAF**)" started on 2005 as part of the EUMETSAT SAF Network.

- **The H-SAF objectives are:** to provide new satellite-derived products from existing and future satellites with sufficient time and space resolution to satisfy the needs of operational hydrology by mean of the following identified products:
  - precipitation (liquid, solid, rate, accumulated)
  - **soil moisture (at large-scale, at local-scale, at surface, in the roots region)**
  - snow parameters (detection, cover, melting conditions, water equivalent)

H SAF ASCAT Surface Soil Moisture (SSM) Products

ASCAT SSM Near Real-Time (NRT) products

- NRT products for ASCAT on-board Metop-A, Metop-B, Metop-C
- Various spatial resolutions
  - 25 km spatial sampling (50 km spatial resolution)
  - 12.5 km spatial sampling (25-34 km spatial resolution)
  - 6.25 km spatial sampling (15-20 km spatial resolution)
  - 0.5 km spatial sampling (1 km spatial resolution

ASCAT SSM Climate Data Record (CDR) products

- ASCAT data merged for all Metop(A, B, C) satellites
- Time series format located on an Earth fixed DGG
- 12.5 km spatial sampling (25-34 km spatial resolution)
- Re-processed every year

SMOS – Soil Moisture and Ocean Salinity

SMOS satellites

- ESA's **Soil Moisture and Ocean Salinity (SMOS)** mission carries a novel interferometric radiometer that operates in the **L-band** microwave frequency.

- The **goal** of the SMOS mission is to **monitor surface soil moisture** with an **accuracy of 0.04 m^3 m^{-3}** at 5 cm top of the soil surface.
- Main applications of SMOS is **Monitoring soil moisture and ocean salinity.**

SMOS (Soil Moisture and Ocean Salinity) mission

Sensor	Microwave Imaging Radiometer using Aperture Synthesis - MIRAS
Launch	2 November 2009
Instrument concept	Passive microwave 2D-interferometer
Frequency	**L-band (21 cm-1.4 GHz)**
Number of receivers	69 antennas, equally distributed over the 3 arms and the central structure
Orbit	Sun-synchronous
Polarisation	H & V (polarimetric mode optional)
Spatial resolution	35 km at centre of field of view (FOV)
Altitude	758 km
Radiometric resolution	0.8 - 2.2 K
Temporal resolution	3 days revisit at Equator
Mass	Total 658 kg launch mass comprising
Spacecraft Operations Control Centre	Toulouse, France
Data processing Centre	ESAC, Villafranca, Spain

The SMOS data products

Product	Description
Level 1C data	Multi-incidence angle brightness temperatures (15Km, ISEA 4H9 grid)
Level 2 soil moisture data	The retrieved **soil moisture**, **vegetation optical depth** and other ancillary data derive (surface temperature, roughness parameter, dielectric constant, brightness temperature at the top of the atmosphere and at the surface).
Level 3 data	Soil Moisture maps and Ocean Salinity maps
Level 4 data	-The root zone soil moisture for applications in meteorology and water resources management - Daily global map of soil moisture

Validation of the SMOS Level 1C Brightness Temperature and Level 2 Soil Moisture Data over the West and Southwest of Iran

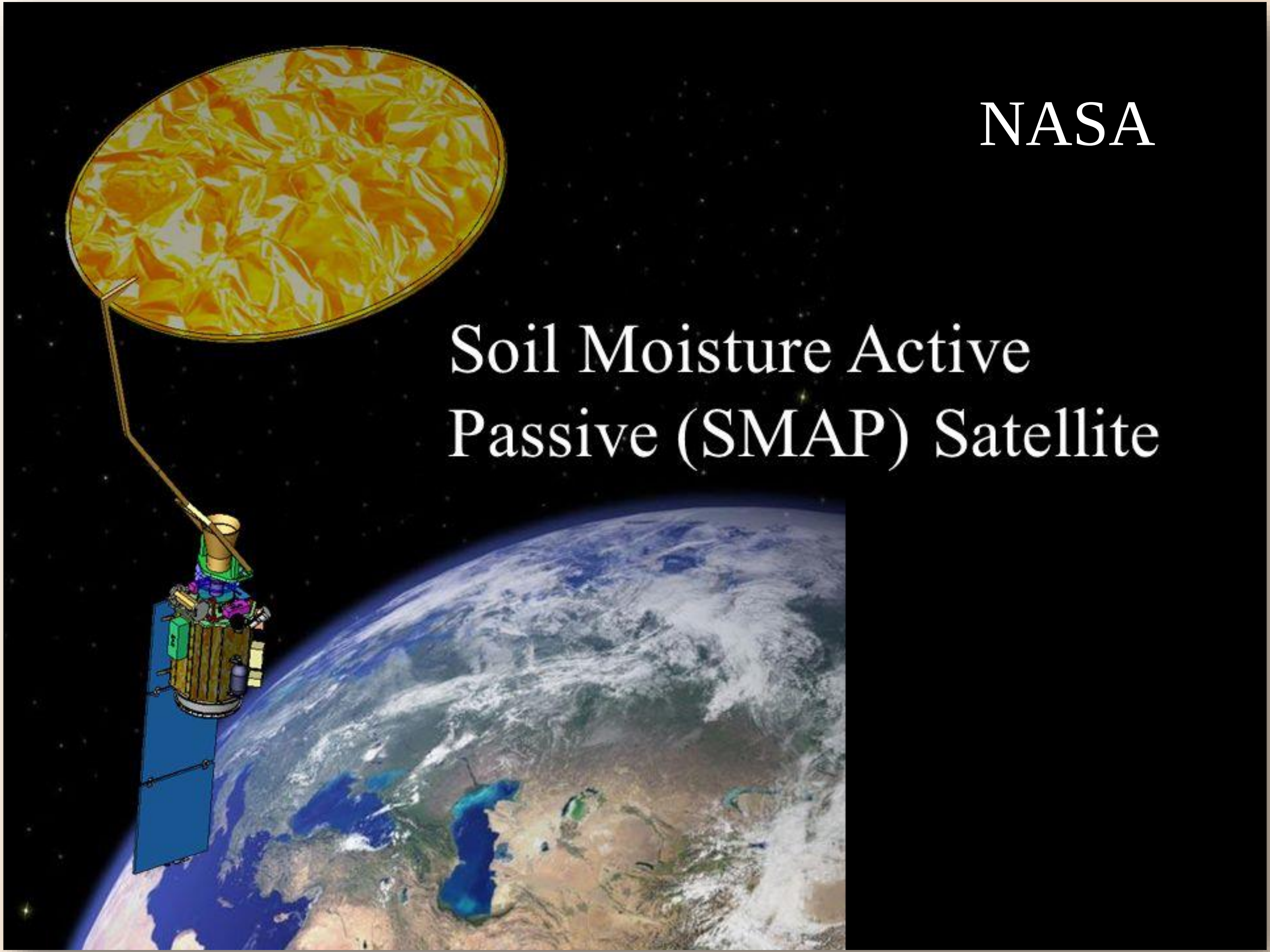
by Mozhdeh Jamei [1,2,*], Mohammad Mousavi Baygi [1], Ebrahim Asadi Oskouei [3] and Ernesto Lopez-Baeza [4]

MDPI

Production of Soil Moisture Maps in Iran from BEC Global Level 3 Products of SMOS Satellite

Ebrahim Asadi Oskouei, Mozhdeh Jamei *

Journal of Watershed Management Research


NASA
Soil Moisture Active
Passive (SMAP) Satellite

SMAP satellites

- NASA's launched the **Soil Moisture Active Passive (SMAP) satellite** carrying an L-band radar (1.26 GHz) and a passive radiometer (1.41 GHz) to provide global monitoring of soil moisture and freeze/thaw.

- SMAP mission provides **global measurements of soil moisture** with an **accuracy of 0.04 cm^3 cm^{-3}** at 5 cm top of the soil surface.

Launch	31 January 2015
Revisit time	global coverage within 3 days
Orbit	sun-synchronous orbit
Altitude	685 km
Polarisation	depends on instrument
Main applications	weather & climate forecasting, drought, floods & landslides

SMAP (Soil Moisture Active Passive) mission

	Radiometer	Radar (failurein July2015)
Frequency	**L-Band Radiometer (1.41 GHz)**	**L-Band Radar(1.26 and 1.29 GHz)**
Spatial Resolution	40 km	3,10 km
Polarizations	H, V	VV, HH, HV (or VH)
Radiometric Uncertainty*: 1.3 K (Includes precision and calibration stability)		**Relative accuracy*: 0.5 -0.7dB** (Includes precision and calibration stability)
Data collection	**Soil Moisture**: ~ 0.04 m^3/m^3 volumetric accuracy	**Soil Moisture:** : ~ 0.04 m^3/m^3 volumetric accuracy **Freeze/Thaw State:** Capture freeze/thaw state transitions in integrated vegetation-soil continuum

The SMAP baseline science data products

Product	Description	Gridding (Resolution)	Latency**	
L1A_Radiometer	Radiometer Data in Time-Order	-	12 hrs	Instrument Data
L1A_Radar	Radar Data in Time-Order	-	12 hrs	
L1B_TB	Radiometer T_B in Time-Order	(36×47 km)	12 hrs	
L1B_S0_LoRes	Low-Resolution Radar σ_o in Time-Order	(5×30 km)	12 hrs	
L1C_S0_HiRes	High-Resolution Radar σ_o in Half-Orbits	1 km (1−3 km)#	12 hrs	
L1C_TB	Radiometer T_B in Half-Orbits	36 km	12 hrs	
L2_SM_A	Soil Moisture (Radar)	3 km	24 hrs	Science Data (Half-Orbit)
L2_SM_P*	Soil Moisture (Radiometer)	36 km	24 hrs	
L2_SM_AP*	Soil Moisture (Radar + Radiometer)	9 km	24 hrs	
L3_FT_A*	Freeze/Thaw State (Radar)	3 km	50 hrs	Science Data (Daily Composite)
L3_SM_A	Soil Moisture (Radar)	3 km	50 hrs	
L3_SM_P*	Soil Moisture (Radiometer)	36 km	50 hrs	
L3_SM_AP*	Soil Moisture (Radar + Radiometer)	9 km	50 hrs	
L4_SM	Soil Moisture (Surface and Root Zone)	9 km	7 days	Science Value-Added
L4_C	Carbon Net Ecosystem Exchange (NEE)	9 km	14 days	

3-Downscaling methods

Downscaling Methods

The different downscaling methods for soil moisture are broadly classified into the following three major groups:

(1) satellite-based methods

- Active and Passive Microwave Data Fusion Methods

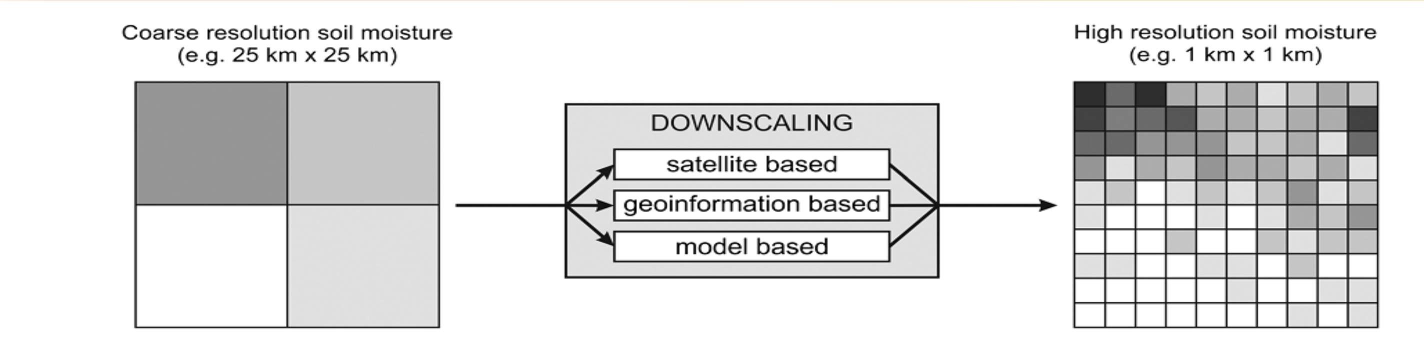
- Optical/Thermal and Microwave Fusion Method

(2) Methods using Geoinformation data,

(3) Model-based methods

- Statistical Models

- Involving a Land Surface Model



Flowchart of soil moisture downscaling methods

Downscaling Methods

(1) satellite-based methods

❑ Active and Passive Microwave Data Fusion Methods

- Both passive and active microwave observations have been widely explored to estimate soil moisture for several decades. The passive microwave radiometers can provide frequent observations but have rather coarse spatial resolutions.

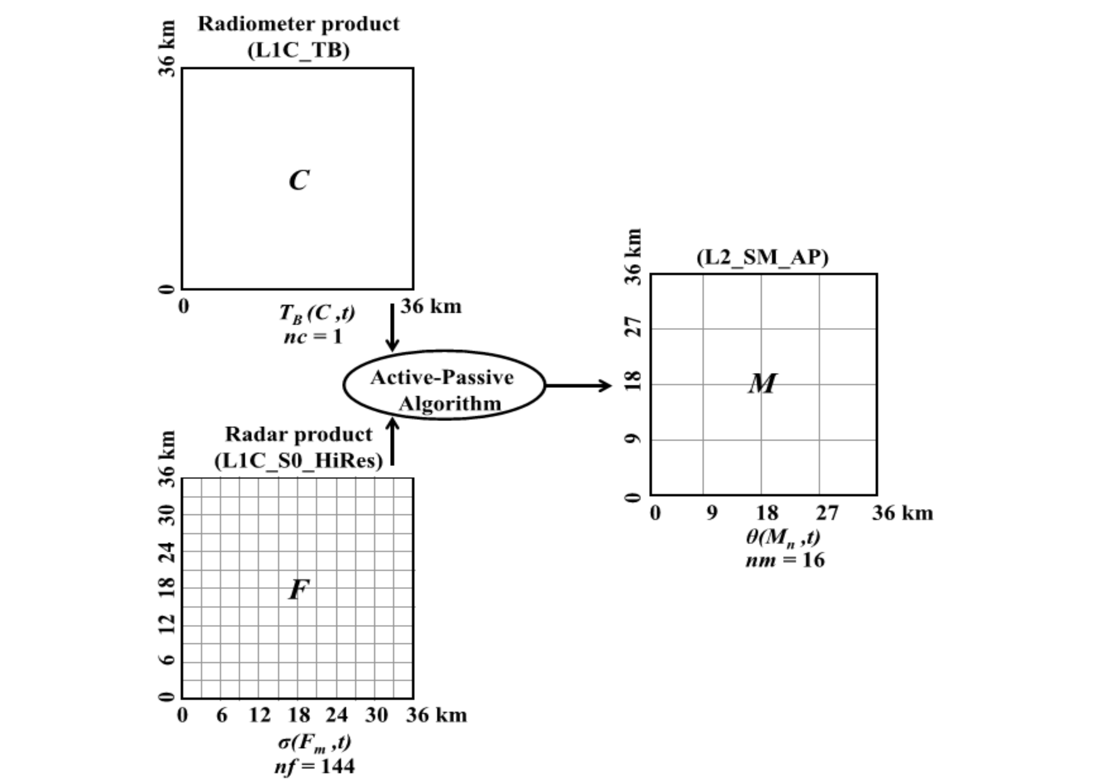
- Active microwave sensors and especially synthetic aperture radars (SARs) are capable of providing much higher spatial resolutions than passive radiometers. However, the retrieval of soil moisture from SAR is often difficult due to the combined effects of surface roughness, vegetation canopy structure, and water content on the backscattering coefficients of SAR.

- Passive microwave observations as well as scatterometer data currently build the basis for globally available soil moisture data sets due to their better temporal sampling. Products derived from AMSR-E, ASCAT, SMOS, and SMAP satellites are therefore widely used.

(1) satellite-based methods

In order to take advantage of radiometer and radar observations, several algorithms such as a **change detection method** and a **Bayesian merging method** have been proposed to **merge radiometer and radar** data to provide **higher solution soil moisture data**.

This figure illustrates the general framework for the fusion of SMAP radiometer with radar products. The letters C, F, and M represent coarse scale (36 km), fine scale (3 km), and medium scale (9 km) for the radiometer, radar, and combined product grid scale, respectively.



Flowchart of the fusion of SMAP radiometer (L1C_TB) and radar (L1C_S0_HiRes) into combined product (L2_SM_AP), where nf and nm are the number of grid cells of radar and combined product within one radiometer grid cell nc. TB, σ, and θ represent brightness temperature, backscatter, and volumetric soil moisture, respectively.

❑ Active and Passive Microwave Data Fusion Methods

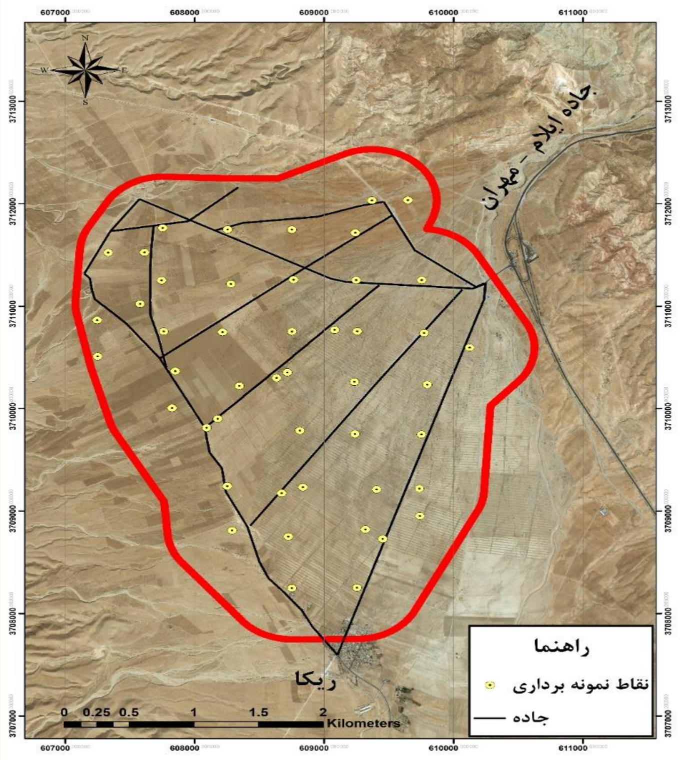
Currently, there are three general groups of methods that have been proposed to fuse active and passive microwave data to derive soil moisture products with improved spatial resolutions:

1- Disaggregation of soil moisture product from passive sensor with backscatter data from an active sensor.

2- Disaggregation of brightness temperature from a passive sensor with backscatter data from an active sensor and subsequent inversion to soil moisture

3- Fusion of soil moisture products from a passive and an active sensor

In general, the active/passive fusion method has great potential for improving the spatial resolution of soil moisture.



Gathering insitu data and preparing a data bank corresponding to the pixels of SMAP and Sentinel 1 satellite products at specified spatial and temporal intervals

Development of codes (in Python and R environments) for using and obtaining validation algorithm and downscaling of raw products of SMAP and Sentinel 1 satellites

Determining the accuracy and consistency of microscale satellite data with ground-based observations using classical statistical indicators such as correlation coefficient (r), root mean square difference (RMSD), root mean squared error (ubRMSE) and mean difference (MD)

Method

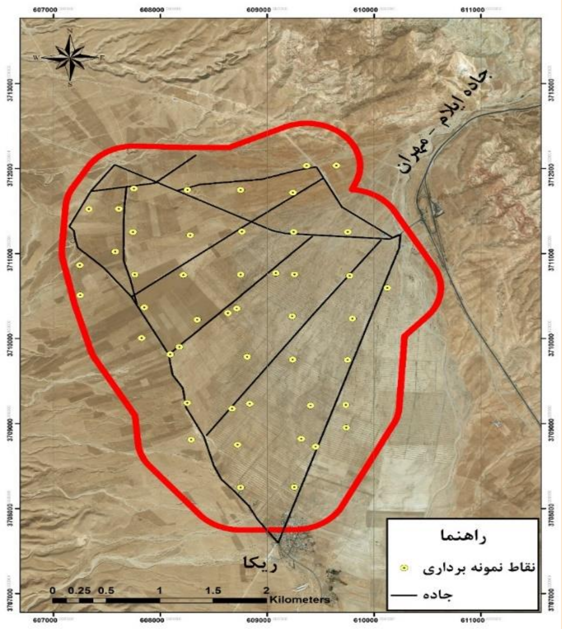
Obtaining of measured soil moisture data from the desired location

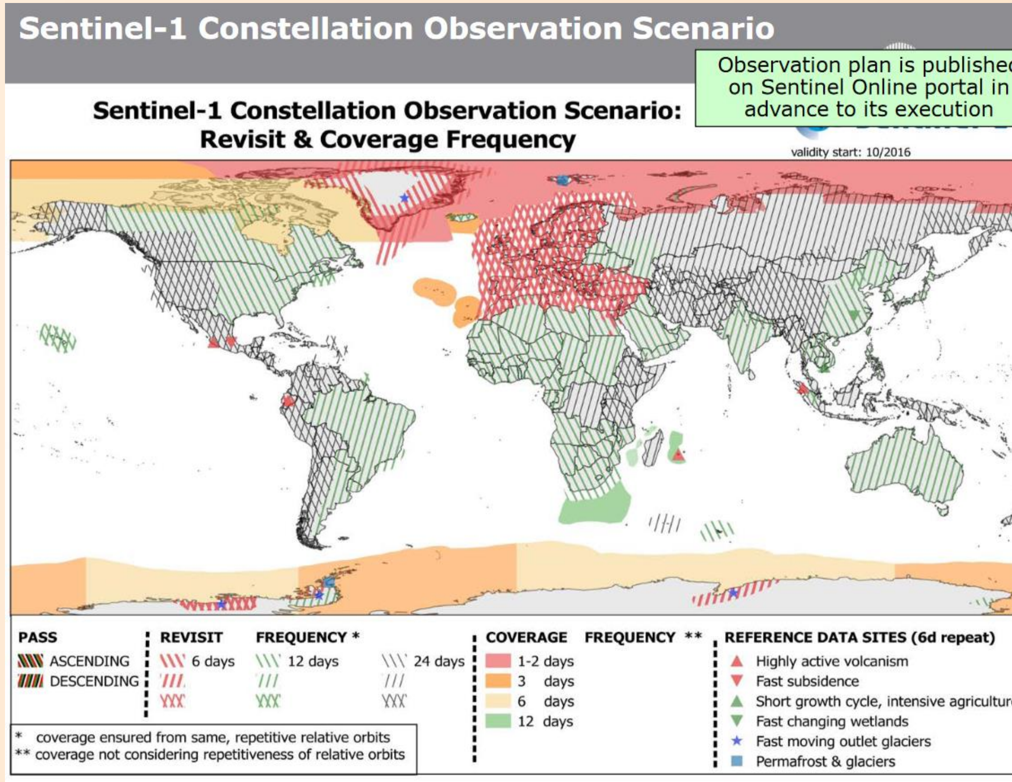
Obtaining satellite soil moisture data at the desired time scale (SMAP, Sentinel1)

Downscaling satellite soil moisture data using different algorithms

Validation of downscaled satellite soil moisture data with in situ soil moisture data

Extraction of soil moisture maps at different time scales and evaluation of temporal and spatial distribution of soil moisture





2 Main Steps of the Project

- Download SMAP satellite soil moisture data for free from the site:
- https://nsidc.org/data/smap/smap-data.html

- Download Sentinel 1 satellite area images for free from the site:
- https://scihub.copernicus.eu/dhus/#/home

Start receiving raw SMAP and Sentinel 1 satellite data

- Selecting the best validation and downscaling method:
- Artificial neural network (ANN)
- Based on soil moisture (SMBDA)

Planning the validation and downscaling model

Preparation of Sentinel 1 spatial database

Download from the site https://scihub.copernicus.eu/dhus/#/home

Extract the values of σ0 with a resolution of 10 ⋆ 10 square meters

6 stages of preprocessing

Use SMAP pixel spatial range to cut (subset) sentinel images

Change the received file format from XSD to Tiff in SNAP software

Change the Aggregate of σ0 values from 10 ⋆ 10 m2 resolution to 1 ⋆ 1 and 36 ⋆ 36 km2

Pre-processing of Sentinel 1 satellite images by SNAP software

Set orbital features → Radiometric calibration and conversion of digital number to radar scattering → Thermal noise removal → Convert image pixels to square shape (multilooking) → Reduce spot noise → Geometric and postal correction

spatial database preparation Level 3 SMAP

Download from the site

https://nsidc.org/data/smap/smap-data.html

Change the coordinate system of images to a geographic coordinate system

Crop and then mask the images for Iran

Extraction of soil moisture values in the time-space range of sampling

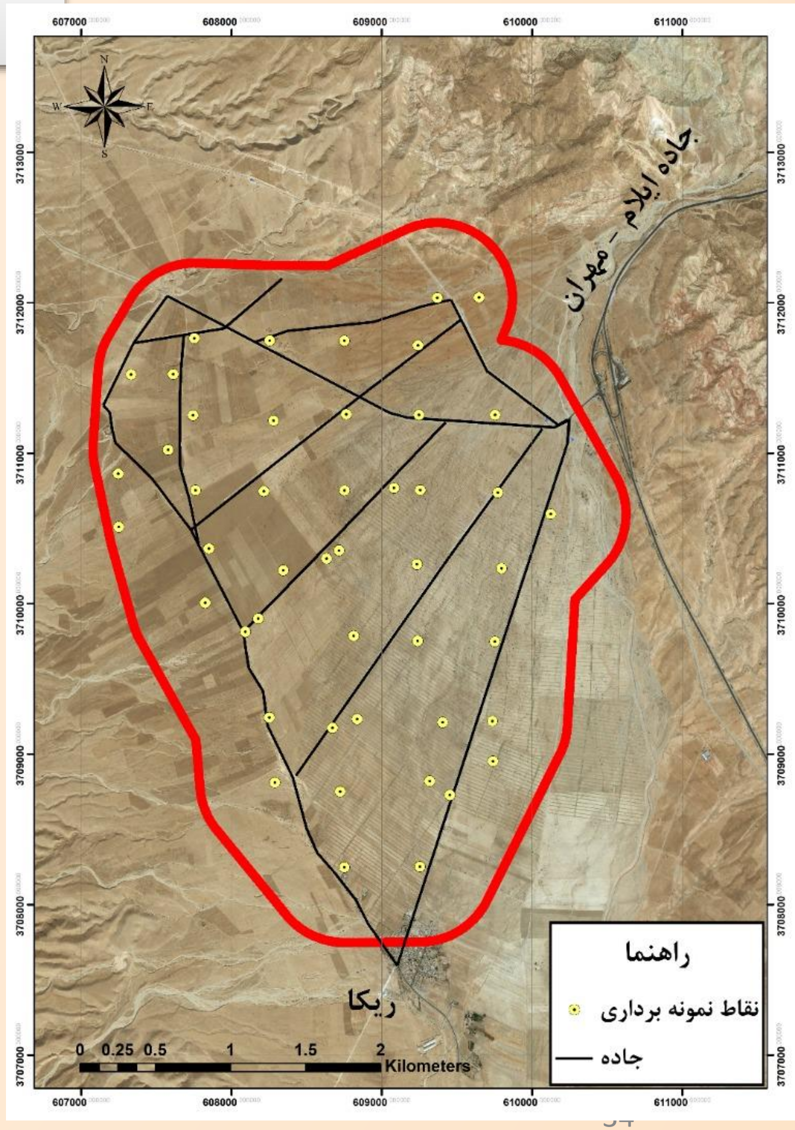
Change the received file format from HDF5 to Tiff

Establish a regular network for in situ data and allocate soil moisture values 1*1 km2

Use from 1*1 km2 SMAP network as in situ data network model

Determine the share of sampling points by weighting and assigning point values to the level of each pixel

Remove some pixels in case of no enough coverage of points



Flowchart of downscaling algorithm based on soil moisture SMBDA

آماده سازی پایگاه داده مکانی SMAP level-4 با رزولوشن ۹ km

Preparing Spatial database SMAP level-4 with 9km resolution

آماده سازی پایگاه داده مکانی Sentinel 1

Preparing the Spatial database Sentinel 1

نمونه برداری در شبکه نیمه منظم ۵۰۰ × ۵۰۰ m^2

Sampling in a 500*500 m2 semi-regular network

توسعه الگوریتم ریزمقیاس سازی

Development of downscale algorithm

تخصیص مقادیر رطوبت خاک، منطبق بر شبکه تصاویر ماهواره ای

Assignment of soil moisture values, consistent with the network of satellite images

ریزمقیاس سازی مقادیر رطوبت خاک در شبکه ۱ × ۱ km^2 (SMBDA)

downscaling of soil moisture values in the network 1*1 km2 (SMBDA)

اعتبار سنجی نتایج ریزمقیاس سازی با داده زمینی

Validation of downscaling results with in situ data

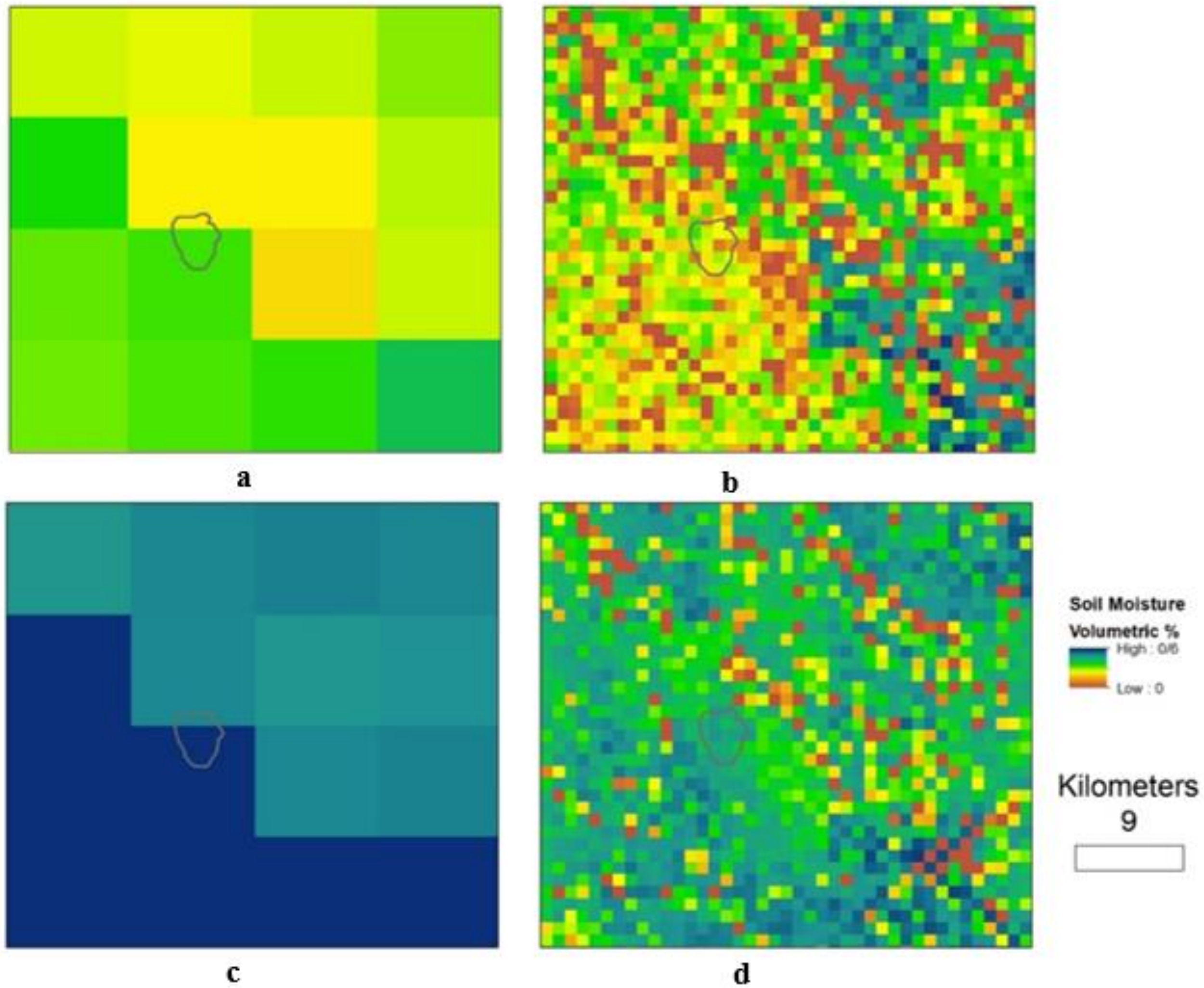
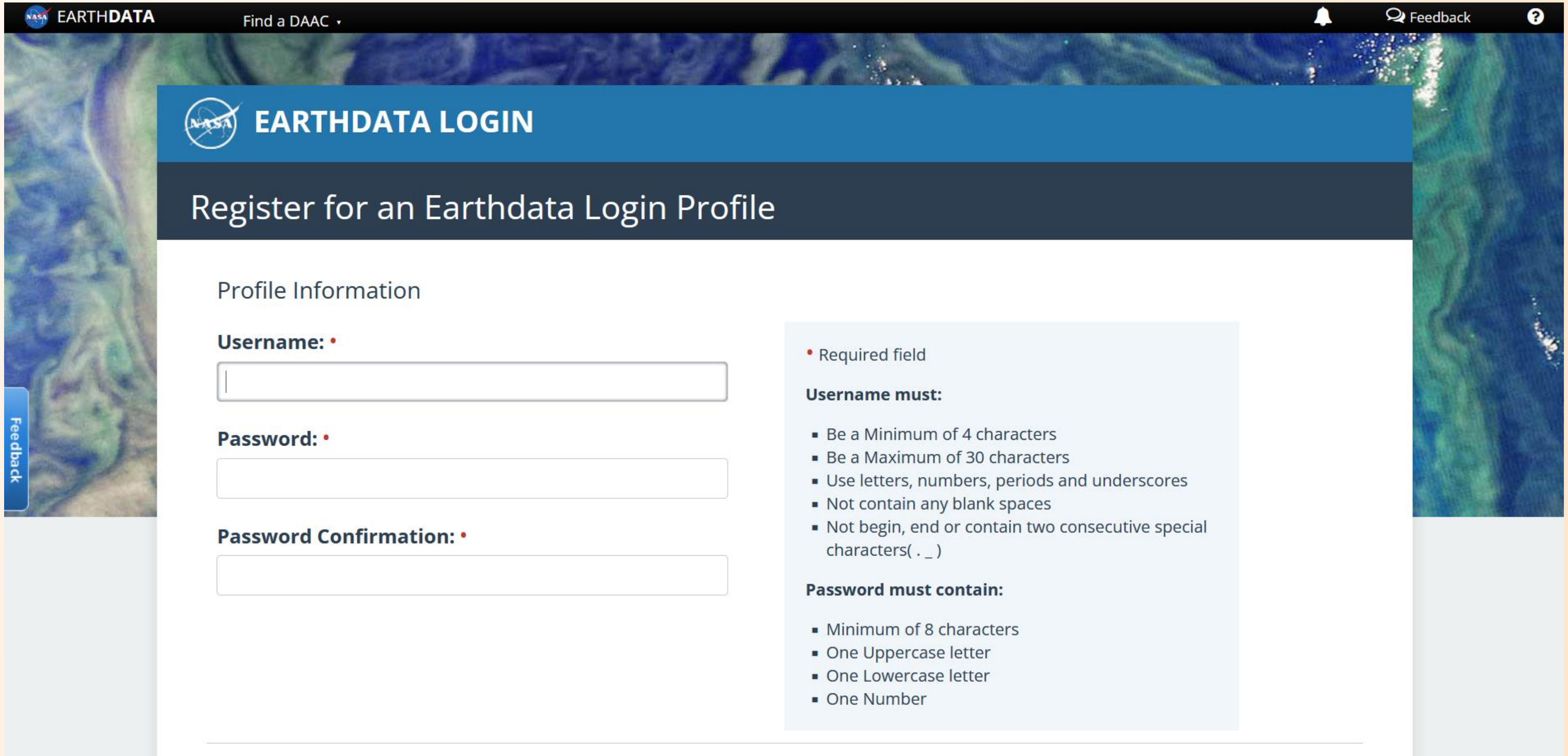


Fig. 8- Map of SMAP soil moisture values with the main scale (9 Km) and the downscaled values by the algorithm (1 Km) in dry Time, respectively;

c and d: Map of SMAP soil moisture values with main scale (9 Km) and downscaled values by algorithm (1 Km) in wet Time, respectively

https://urs.earthdata.nasa.gov/users/new?client_id=KImTfO7IF9gBW0uORyB2Ag&redirect_uri=https%3A%2F%2Fnsidc.org%2Fapps%2Forders%2Fapi%2Fearthdata%2Fauth_finish%2F&response_type=code



Thank You!