Microwave Remote Sensing of Soil Moisture

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Soil Moisture (SM)

- Agriculture
- Hydrology
- Meteorology
Measurement Techniques


In Situ Methods

• Gravimetric
• Nuclear Techniques
• Electromagnetic Techniques
• Tensiometric Techniques
• Hygrometric Techniques
Remote Sensing Methods

- Visible & near IR – Reflected Solar
- Thermal IR – Surface Temperature
- Passive Microwave – Microwave Emission/Brightness Temperature
- Active Microwave – Backscattering coefficient/dielectric properties
Gravimetric Techniques

• Oven drying a soil sample at 105°C for about 12 hours.

\[
\% M_{wt} = \frac{W_{wet} - W_{dry}}{W_{dry}} \times 100
\]

Volumetric Soil Moisture (gm/cm\(^3\))

\[
\% M_{wt} \times Y_d
\]

Y\(_d\) Oven Dry Bulk Density
Fig. 5.2 Soil moisture profiles for loamy soil during drying period. The field was irrigated on March 2, 1971. (Jackson, [81]).
Nuclear Techniques

- Fast neutrons emitted by an Americium 241: Beryllium radioactive source are thermalised (slowed) by hydrogen in the test sample

**Advantages:** SM can be measured at any time, average SM can be measured with depth, system can be interfaced for automatic recording, temporal SM changes can be measured, readings are directly related to SM

**Disadvantages:** Surface soil moisture is not accurate, care must be taken to minimize health risks.
Electromagnetic Techniques

• The technique is based on the electrical properties of the soil that varies with soil moisture. Resistivity or Capacitance between electrodes in a soil is measured for Soil moisture.

Complex Dielectric Constant

\[ \varepsilon = \varepsilon_r + j\varepsilon_i \]
Dig deeper.
Tensiometric Techniques

Measures the capillary tension or the energy with which water is held (suction) by the soil.

Tensiometers consist of porous ceramic cup connected by a continuous liquid column to a vacuum gauge or transducer.

**Advantages**: easy to design, cost little, at any conditions in real time, placed in soil easily,

**Disadvantages**: Only measures soil water suction, but only indirect measurement of soil moisture content; during installation, it may break.
Soil Water Models

\[ SM_t = SM_{t-1} + P - R - L - E - T + C - Q \]

- \( SM_t \) – Soil moisture at time \( t \)
- \( SM_{t-1} \) – Soil moisture at previous time
- \( P \) – Precipitation
- \( R \) – Surface Runoff
- \( L \) - net lateral subsurface outflow
- \( E \) – Evaporation or condensation
- \( T \) – Transpiration
- \( C \) – Capillary rise from lower levels
- \( Q \) - percolation

- USDAHL Model
- NWSRFS model
Fig. 2. Schematic diagram of soil-plant-atmosphere-water (SPAW) system.
Remote Sensing Methods

Visible Technique: Reflected solar energy is measured. 
(0.4 – 1.7 μm)

• Relationship between Reflectance and SM Depends on reflectance of dry soil, roughness, colour, illumination, organic matter, soil texture.
Thermal Infrared Techniques

• Diurnal range of Surface Temperature ($T_{\text{max}} - T_{\text{min}}$) or Measurement of crop canopy – air temperature differential.

• ($T_{\text{max}} - T_{\text{min}}$) depends on internal and external factors

• Internal factors: Thermal conductivity ($K$) and heat capacity ($C$) where $P = (KC)^{1/2}$ is known as Thermal Inertia. $K$ and $C$ increases with Soil Moisture.

• External Factors: solar radiation, air temperature, RH, cloudiness, and wind.
Diurnal Temperature Variation versus Soil Moisture

Fig. 7. Summary of results for the diurnal temperature variation versus soil moisture [Idso et al., 1975a].
MODIS Data from Terra and Aqua Satellites

Swath : 2330 Km and covers the same area 1 or 2 days

Spectral Bands : 36 ; Wavelength : 0.405 – 14.385

Resolution : 250m (bands 1-2, 500m (bands 3-7), 1000m(8-36).

Surface/Cloud
Temperature 31  10.780 - 11.280
              32  11.770 - 12.270

LANDSAT – 7 band-6 (10.4 – 12.5 microns, Resolution 60 m)
Microwave Remote Sensing

0.3 - 300 GHz (wavelength 1 m - 1 mm)

Passive
(Radiation or $T_B$)
Radiometers

$T_B = e \cdot T$
Where $e$ is emissivity and $T$ is physical Temperature

Active
(Backscattering $\sigma_0$ dB)
Radar

$\sigma_0$ depends on dielectric properties of soil, geometric properties and system parameters.
Advantages
• All weather Capability
• Day-night ability
• Penetration through a medium
Penetration

RADAR RESPONSE TO VEGETATION AND SUBSURFACE HORIZONS

MULTIFREQUENCY

X-BAND
3 cm

C-BAND
6 cm

L-BAND
23 cm

MULTIPOLARIZATION

= LIKE-POLARIZED RETURN

= CROSS-POLARIZED RETURN
Passive Microwave Remote Sensing

Emitted Radiation in Passive MRS

\[ T_{B_p} = T_u + e^{-\tau_a} T_{bp} + e^{-\tau_a} R_p \left[ T_d + T_{sky} e^{-\tau_a} \right] \]

\( T_B \): Terrain Emission  
\( T_{DN} \): Atmospheric Downward Emission  
\( T_{UP} \): Atmospheric Upward Emission  
\( T_{SC} \): Scattered Radiation
Brightness Temperature

\[ T_B = eT \]

\( e \) – Emissivity, \( T \) – Physical Temperature

Fresnel Reflection Equations

\[ e_h = 1 - R_h = 1 - \frac{\cos \theta - \sqrt{\varepsilon - \sin^2 \theta}}{\cos \theta + \sqrt{\varepsilon - \sin^2 \theta}} \]

\[ e_v = 1 - R_v = 1 - \frac{\varepsilon \cos \theta - \sqrt{\varepsilon - \sin^2 \theta}}{\varepsilon \cos \theta + \sqrt{\varepsilon - \sin^2 \theta}} \]
Fig. 6. Real and imaginary parts of the dielectric constant for three soils as a function of volumetric soil moisture, $\lambda = 21$ cm. [From Wang and Schmugge (1980).]
# Radiometer Systems and their Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>SSMR in NIMBUS-7</th>
<th>SSM/I</th>
<th>IRS-P4, MSMR</th>
<th>EOS Aqua AMSR-E</th>
<th>ADEOS-II AMSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (GHz.)</td>
<td>6.6, 10.7, 18.0, 21 and 37 GHz</td>
<td>19.3, 22.2 (V), 38.0 and 85.5 GHz</td>
<td>6.6, 10.65, 18, 21</td>
<td>6.6, 10.65, 18.7, 23.8, 36.5, 89</td>
<td>6.6, 10.7, 18.7, 23.8, 36.5, 89, (50.3 V and 52.8 V polarization only)</td>
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<tr>
<td>Polarization</td>
<td>H &amp; V</td>
<td>H &amp; V (except 22.2 GHz)</td>
<td>H&amp;V</td>
<td>H&amp;V</td>
<td>H&amp;V (except last 2)</td>
</tr>
<tr>
<td>IFOV (km x km)</td>
<td>148x95, 91x59, 55x41, 46x30, 27x18</td>
<td>69x43, 60x40, 37x28, 15x13 km</td>
<td>150x144, 75x72, 50x36, 50x36 km</td>
<td>76x44, 49x28, 28x16, 31x18, 14x8, 6x4 km</td>
<td>70x40,46x27,25x14,2 8x17,14x8,6x3,10x6 km</td>
</tr>
<tr>
<td>Swath width (km)</td>
<td>822 km</td>
<td>1400 km</td>
<td>1360</td>
<td>1445</td>
<td>1600</td>
</tr>
<tr>
<td>Revisit coverage(days)</td>
<td>--</td>
<td>1 day</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Incidence angle (deg.)</td>
<td>50.3 (at the surface)</td>
<td>53.3 (at the surface)</td>
<td>43.13</td>
<td>54 (at the surface)</td>
<td>54 (at the surface)</td>
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<tr>
<td>Sensitivity</td>
<td>0.4, 0.5, 0.7, 0.7, 1.1</td>
<td>0.8, 0.8, 0.6, 1.1</td>
<td>0.6, 0.75, 1.05, 1.1</td>
<td>0.3, 0.6, 0.6, 0.6, 0.6, 1.0</td>
<td>0.3,0.6,0.6,0.6,0.6,1.0, 1.3,0.9</td>
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</tbody>
</table>
Polarization

HH, VV are like polarized
HV, VH are cross polarized
SSM/I Satellite

Defense Meteorological Satellite Program (DMSP) Block 5D-2 satellite with the Special Sensor Microwave (SSM/I) located at the upper left.
Fig. 4. SSM/I scan geometry.
Fig. 3. Prototype of the SSM/I in deployed position.
1400 KM SWATH

Earth coverage of the SSM/I in a 24 h period. Only the shaded areas are not observed in this time period.
Average Snow Cover (71–95) & Sea Ice Extent (78–95)
EOS-PM (AQUA-1) Satellite http://www.aqua.nasa.gov

AMSR-E, Launched May 4, 2002
Frequencies (GHz)  Resolution (km)
6.6, 10.65, 18.7, 76x44, 49x28, 28x16,
23.8, 36.5, 89  31x18, 14x8, 6x4

Data Available from Feb. 2003 onwards
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sea-sat</th>
<th>ERS-1,2</th>
<th>JERS -1</th>
<th>Radarsat</th>
<th>SIR-C</th>
<th>ENVISAT</th>
<th>Radarsat-2</th>
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<tr>
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<td>1.275</td>
<td>5.3</td>
<td>1.275</td>
<td>5.3</td>
<td>1.2,5.3,9.8</td>
<td>5.3</td>
<td>5.3</td>
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<td>Waveleng.,cm</td>
<td>23.5</td>
<td>5.6</td>
<td>23.5</td>
<td>5.6</td>
<td>23.5,5.6,3.1</td>
<td>5.6</td>
<td>5.6</td>
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<tr>
<td>Resolution(m)</td>
<td>25</td>
<td>30</td>
<td>18</td>
<td>10 - 100</td>
<td>25</td>
<td>30</td>
<td>10-100</td>
</tr>
<tr>
<td>Swath (km)</td>
<td>100</td>
<td>100</td>
<td>75</td>
<td>35 - 500</td>
<td>15 - 90</td>
<td>150–1km</td>
<td>35 – 500</td>
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<tr>
<td>Look angle</td>
<td>23</td>
<td>23</td>
<td>35</td>
<td>20 - 50</td>
<td>20 - 55</td>
<td>20 - 50</td>
<td>20 –50</td>
</tr>
<tr>
<td>Polarization</td>
<td>HH</td>
<td>VV</td>
<td>HH</td>
<td>HH</td>
<td>HH,VV,HV</td>
<td>HH,VV</td>
<td>HH,VV</td>
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<tr>
<td>Looks</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>1- 4-14</td>
<td>4</td>
<td></td>
<td></td>
</tr>
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</table>
Elements of a Typical Remote Sensing Radar
Concept of an array of real antenna positions forming a synthetic aperture.

- Region ahead of aircraft (signals upshifted in frequency)
- Region behind aircraft (signals downshifted in frequency)
- Region of zero Doppler shift
- Azimuth resolution (set by Doppler processing)
- Range resolution (set by pulse length)

Determinants of resolution in synthetic aperture SAR.
ERS-1 Satellite with C-band VV SAR system

**System Parameters**

- **Launch:** July 91 & Apr ‘95 (ERS2)
- **Frequency:** 5.3 GHz ($\lambda=5.6$ cm)
- **Resolution:** 30 m
- **Swath:** 100 km
- **Look Angle:** $23^\circ$
- **Polarization:** VV
- **Looks:** 4
RADARSAT-I

**System Parameters**

- **Frequency**: 5.3 GHz ($\lambda=5.6$ cm)
- **Resolution**: 10 - 100 m
- **Swath**: 35 - 500 km
- **Look Angle**: 20 - 50°
- **Polarization**: HH
- **Looks**: 4 to 14
Future SAR Systems

ENVISAT  (Launch Date : March 1, 2002)
ENVISAT ASAR Operating Models

- Global monitoring: VV or HH, 1000 m resolution, 405 km swath width
- Wide swath: VV or HH, 150 m resolution, 405 km swath width
- Image: VV or HH, 30 m resolution, up to 100 km swath width
- Alternating polarisation: VV or HH, 30 m resolution, up to 100 km swath width
- Wave: VV or HH, 30 m resolution, 5 x 5 km vignettes
First Image from ENVISAT

Antarctica Larsen B ice shelf
Wide Swath 400 km
150 m resolution
March 18, 2002
Incidence Angle

Local incidence angle
Slant Range to Ground Range
Geometric Effects

Foreshortening  Layover  Shadow

[Diagram of geometric effects with labeled points C, D, A, B, C', D', A', B']

[Images of foreshortening, layover, and shadow effects]
Speckle Reflection,
Diffuse scattering

Corner Reflector

Volume Scattering
Surface Roughness

\[ \sigma = \sqrt{\frac{1}{N-1} \left( \sum (z)^2 - N \bar{z}^2 \right)} \]

<table>
<thead>
<tr>
<th>( \sigma )</th>
<th>X-band</th>
<th>C-band</th>
<th>L-band</th>
</tr>
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<tbody>
<tr>
<td>0.05</td>
<td>smooth</td>
<td>smooth</td>
<td>smooth</td>
</tr>
<tr>
<td>0.5</td>
<td>rough</td>
<td>interm.</td>
<td>smooth</td>
</tr>
<tr>
<td>1.5</td>
<td>rough</td>
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<td>interm.</td>
</tr>
<tr>
<td>10.0</td>
<td>rough</td>
<td>rough</td>
<td>rough</td>
</tr>
</tbody>
</table>
Plot 4 of 1989 field (Pomaz) experiment
POINT TARGETS

DISCRETE TARGET WITH SIMPLE CONFIGURATION
STRONG RADAR RETURN DISPROPORTIONATE TO ITS SIZE

EXAMPLES: BUILDINGS, TRANSMISSION TOWERS, BRIDGES:

A: DIHEDRAL CORNER REFLECTOR

SPECULAR REFLECTION FROM TWO PLANE, PERPENDICULAR SURFACES

B: TRIHEDRAL CORNER REFLECTOR

SPECULAR REFLECTION FROM THREE PLANE, PERPENDICULAR SURFACES
FIGURE 2-6

RADAR EQUATION
RELATES RECEIVED POWER \( (P_r) \) TO RADAR
AND TARGET PARAMETERS

\[
P_r = \frac{P_t \cdot G_t}{4 \pi R^2} \cdot \frac{\sigma_{rt}}{4 \pi R^2} \cdot \frac{A_r}{4 \pi R^2}
\]

ANTENNA
TRANSMITTED POWER \( P_t \), FOCUSED TO
ANGULAR BEAMWIDTH OF TRANSMITTING
ANTENNA \( G_t \)

ANTENNA
APERTURE \( A \)

ISOTROPIC SPREADING

POWER RECEIVED \( (P_r) \)
AT RECEIVING ANTENNA

\[
P_r = P_S \cdot \frac{A_r}{4 \pi R^2}
\]

POWER SCATTERED \( (P_S) \) BY \( \sigma_{rt} \)

\[
\frac{P_t G_t}{4 \pi R^2} \cdot \sigma_{rt}
\]

'AREA' \( \sigma_{rt} \) OF PERFECT REFLECTOR
(RADAR CROSS SECTION)

RADAR BACKSCATTER
COEFFICIENT

\[
\sigma_{rt} = \frac{\sigma_{rt}}{a}
\]

ANTENNA

INCIDENT AREA,
RADAR CROSS SECTION
\( \sigma_{rt} \)

ILLUMINATED
AREA 'a'
Radarsart 2
2003
HH, VV, HV, VH
Advanced Land Observing Satellite (ALOS) 2004

PALSAR (Phased array SAR)
LightSAR (USA & Germany)
L- and X-band
All Polarizations
RISAT (Radar Imaging Satellite)
C-band in 3 modes
Cryosat

Radar Altimeter Mission

Determine the variation in the thickness of the Ice sheets to be planned to Launch 2004

Range
Resolution 4.6 cm, accuracy 1 or 2 cm
Indian RISAT SAR

Launch year - 2006

Frequency = 5.35 GHz

Resolution HRS 1-2 m with Swath 10 x 10 km, single/dual polarization

FRS-1 mode 3-6 m with swath 30 km, single/dual polarization

FRS-2 model 9-12, with swath 30 km, Quad polarization

MRS/CRS mode 25- 50 m, with swath 120/240 km, single/quad