Earth Exploration-Satellite Service (EESS) - Passive Spaceborne Remote Sensing

John Zuzek
Vice-Chairman ITU-R Study Group 7
ITU/WMO Seminar on Spectrum & Meteorology
Geneva, Switzerland
16-17 September 2009
What is a passive sensor?

RR 1.183 - **passive sensor**: A measuring instrument in the earth exploration-satellite service or in the space research service by means of which information is obtained by reception of radio waves of natural origin.

- **Passive sensors** measure the electromagnetic energy emitted and scattered by the Earth and the constituents of its atmosphere.
- **Spaceborne passive microwave sensors** provide the ability to obtain all-weather, day and night, global observations of the Earth and its atmosphere.
Passive sensor operations

• All matter emits, absorbs and scatters electromagnetic energy.
• Passive sensors are *radiometers* which are low noise receivers patterned after radio astronomy instruments.
• Power measured by passive sensors is function of surface composition, physical temperature, surface roughness, and other physical characteristics.
Types of passive microwave sensors

• Imaging sensors
  – Many environmental data products are produced using multivariable algorithms to retrieve a set of geophysical parameters simultaneously from calibrated multi-channel microwave radiometric imagery

• Atmospheric sounding sensors
  – Atmospheric sounding is a measurement of vertical distribution of physical properties of a column of the atmosphere such as pressure, temperature, wind speed, wind direction, liquid water content, ozone concentration, pollution, and other properties

• Microwave limb sounding sensors
  – Limb sounders observe the atmosphere in directions tangential to the atmospheric layers and are used to study low to upper atmosphere regions where the intense photochemistry activities may have a heavy impact on the Earth’s climate
Passive sensor data products (Part 1)

- Measured radiation
  - Occurs naturally
  - Very low power levels
  - Contain essential information on the physical processes
- Radiation peaks indicate presence of specific chemicals
- Absence of radiation from certain frequencies indicates the absorption by atmospheric gases
- Strength or absence of signals at particular frequencies is used to determine whether specific gases are present and, if so, in what quantity and at what locations.
Atmospheric attenuation below 275 GHz

Zenith atmospheric attenuation versus frequency, 1-275 GHz

- Oxygen
- Water vapour tropical
- Water vapour sub-arctic
- Minor constituents

Vertical Opacity (dB)

Frequency (GHz)
Passive sensor data products (Part 2)

• Environmental information is obtained through passive sensor measurements
  – Frequency bands determined by fixed physical properties (molecular resonance)
  – Frequencies do not change
  – Information cannot be duplicated in other frequency bands

• Signal strength at a given frequency may depend on several variables
  – Use of several frequencies necessary to match the multiple unknowns
  – Use of multiple frequencies is primary technique used to measure various characteristics of the atmosphere and surface of the Earth
Multiple frequencies used over oceans

Sensitivity of brightness temperature to geophysical parameters over ocean surface

Salinity

Wind speed

Liquid clouds

Water vapour

Sea surface temperature

\( \frac{\Delta T_b}{\Delta P_i} \) vs. Frequency (GHz)
Multiple frequencies used over oceans

- Measurements at around 1.4 GHz give are best for ocean salinity
- Measurements around 6 GHz offer the best sensitivity to sea surface temperature
- The 17-19 GHz region, where the signature of sea surface temperature and atmospheric water vapour is the smallest, is optimum for ocean surface emissivity.
- Total content of water vapour is best measured around 24 GHz, while liquid clouds are obtained via measurements around 36 GHz.
- Five frequencies (around 6 GHz, 10 GHz, 18 GHz, 24 GHz and 36 GHz) are necessary for determining the dominant parameters.
Multiple frequencies used over land

Sensitivity of brightness temperature to geophysical parameters over land surfaces

Frequency (GHz)

Vegetation biomass
Cloud liquid water
Integrated water vapour
Surface roughness
Soil moisture

\[
\frac{\Delta T_b}{\Delta P_i}
\]
Multiple frequencies used over land

- A frequency around 1.4 GHz is needed to measure soil moisture.
- Measurements in the 5 GHz to 10 GHz range are needed to estimate vegetation biomass once the soil moisture contribution is known.
- Two frequencies are needed around the water vapour absorption peak (typically 18-19 GHz and 23-24 GHz) to assess the atmospheric contribution.
- A frequency around 37 GHz is needed in combination with these frequencies to derive all of the above.
EESS (passive) allocations in exclusive passive bands (RR No. 5.340)

<table>
<thead>
<tr>
<th>Frequency Range (MHz/ GHz)</th>
<th>Frequency Range (MHz/ GHz)</th>
<th>Frequency Range (MHz/ GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1400-1427 MHz</td>
<td>50.2-50.4 GHz</td>
<td>164-167 GHz</td>
</tr>
<tr>
<td>2690-2700 MHz</td>
<td>52.6-54.25 GHz</td>
<td>182-185 GHz</td>
</tr>
<tr>
<td>10.68-10.7 GHz</td>
<td>86-92 GHz</td>
<td>190-191.8 GHz</td>
</tr>
<tr>
<td>15.35-15.4 GHz</td>
<td>100-102 GHz</td>
<td>200-209 GHz</td>
</tr>
<tr>
<td>23.6-24 GHz</td>
<td>109.5-111.8 GHz</td>
<td>226-231.5 GHz</td>
</tr>
<tr>
<td>31.3-31.5 GHz</td>
<td>114.25-116 GHz</td>
<td>250-252 GHz</td>
</tr>
<tr>
<td>31.5-31.8 GHz*</td>
<td>148.5-151.5 GHz</td>
<td></td>
</tr>
</tbody>
</table>

* in Region 2 only
<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>Allocation Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.6-10.68 GHz</td>
<td>54.25-59.3 GHz</td>
</tr>
<tr>
<td>18.6-18.8 GHz</td>
<td>116-122.25 GHz</td>
</tr>
<tr>
<td>21.2-21.4 GHz</td>
<td>155.5-158.5 GHz</td>
</tr>
<tr>
<td>22.21-22.5 GHz</td>
<td>174.8-182 GHz</td>
</tr>
<tr>
<td>31.5-31.8 GHz*</td>
<td>185-190 GHz</td>
</tr>
<tr>
<td>36-37 GHz</td>
<td>235-238 GHz</td>
</tr>
</tbody>
</table>

* in Regions 1 & 3 only
### EESS (passive) bands allocated on a secondary basis or not allocated

<table>
<thead>
<tr>
<th>Frequency Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1370-1400 MHz</td>
</tr>
<tr>
<td>2640-2690 MHz</td>
</tr>
<tr>
<td>4200-4400 MHz</td>
</tr>
<tr>
<td>4950-4990 MHz</td>
</tr>
<tr>
<td>6425-7250 MHz*</td>
</tr>
<tr>
<td>15.2-15.35 GHz</td>
</tr>
</tbody>
</table>

* this band is not allocated to the EESS (passive) but it is used subject to RR No. **5.458**
Atmospheric attenuation above 275 GHz
EESS (passive) use above 275 GHz

- Current Bands in RR No. 5.565:

- WRC-12 Agenda Item 1.6 (Resolution 950) considers revising the passive bands given in footnote 5.565

- Studies within the ITU-R are attempting to define frequency bands of interest to passive services in the 275 – 3 000 GHz range.
EESS (passive) use above 275 GHz
Passive Microwave Remote Sensing

Some Examples
Soil moisture measurements (AMSR-E)

Soil Moisture in 2005

Soil Moisture in 2006
Sea ice over North America – 2007
(AMSR data)
Sea surface temperature measurements
Vertically integrated water content of the atmosphere (kg/sq m)
Atmospheric water vapour measured by microwave limb sounding instrument
ITU-R Recommendations governing passive microwave sensing

- **RS.515**: Frequency bands and bandwidths used for satellite passive sensing
- **RS.1028**: Performance criteria for satellite passive remote sensing
- **RS.1029**: Interference criteria for satellite passive remote sensing
- **RS.1813**: Reference antenna pattern for passive sensors operating in the Earth exploration-satellite service (passive) to be used in compatibility analyses in the frequency range 1.4-100 GHz
- **RS.[PASSIVE_CHARS]**: Technical and operational characteristics of EESS (passive) systems using allocations between 1.4 and 275 GHz (PENDING)
Conclusions

• Passive microwave sensors are particularly sensitive to accumulated radiation from a multitude of emitters on the ground, both from in-band and out-of-band.

• While a single terrestrial emitter may not radiate enough power to cause harm, a large number of these emitters can still be harmful through the aggregation of their signals.

• Perhaps the biggest threat to passive sensing operations is interference that is undetected corrupting data that is then mistaken for valid data leading to flawed conclusions.