Earth surface microwave emission: SMOS

SMOS = Soil Moisture and Ocean Salinity mission.
It is an L-band (1-2 GHz, actually at 1.4 GHz) radiometer.

When over the ocean, SMOS detects:

1. Textra
2. Emission from atmosphere
3. Emission from atmosphere
4. TOA = top of the atmosphere

Ocean = water with a specific salinity or salt content
SSS = sea surface salinity
SST = sea surface temperature

\[ T_{\text{B,TOA}} = \text{brightness temperature at TOA measured by SMOS} \]
\[ = T_{\text{B,sea}} e^{-\text{Textra}} + T_{\text{Atmos,up}} + R_{\text{sea}} T_{\text{Textra,down}} e^{-\text{Textra}} + R_{\text{sea}} T_{\text{sea}} e^{-2\text{Textra}} \]

This is what we want

\[ T_{\text{B,sea}} = \left[ 1 - R_{\text{sea}}(\Theta, \text{Nsea}) \right] \cdot \text{SST} + AT_b(\Theta, \text{other parameters}) \]

\[ \text{Nsea} = f(\text{SST, salinity}) \]

Other parameters include: wind speed, wave height, wave age, atmospheric stability

Sensitive to changes in the salinity of the first centimeter of the ocean
Why measure SSS?

Salinity affects ocean water density and hence thermohaline circulation.

Salinity is an indicator of precipitation and evaporation of ocean water especially in tropical areas.

ENSO: salinity measurements do not help in the assessment of current conditions, but do improve 6-12 month predictions. Discharge of fresh water from large rivers causes salinity to change, can use this information to help quantify river water budget.

How is salinity measured in situ?

Salinity is measured in units of pps-78 = Practical Salinity Scale of 1978 (unitless).

\[ \text{ppps-78} = \frac{\text{electrical conductivity \ of \ water}}{\text{reference \ electrical \ conductivity}} - \frac{\text{g of salt}}{\text{L of ocean water}} \]

average SSS = 35 pps-78

How accurately do we need to measure SSS?

Changes of 0.1 to 1 pps-78 from 1-3 days to up to 6 months.

\[ \text{slope} = \frac{dT_{B - A}}{dSSS} = 0.2 \text{ to } 0.8 \text{ K per pps-78} \]

So we must have a radiometer that can detect changes in T_{B - A} of ~ 0.1 K or better!

SMOS goal: 0.1 - 0.2 pps-78 on a 100 - 200 km grid every 10 - 30 days.

average over larger area average over longer time period
Examine other components for T_{TMS}

2 and 3: $T_{TMS,up} = T_{TMS,down} \cong 1.4 \, \text{GHz} \\
= 2-3 \, \text{K at h-pol}, \text{ but can vary from} \\
3 \, \text{K at v-pol to 6 K at h-pol}

Clouds are negligible at L-band, except perhaps for deep cumulus. The SMOS algorithm does not model the effects of clouds, and instead flags data when it is known that the rain rate exceeds 10 mm·hour⁻¹, and this occurs < 0.2% of the time globally.

1. Reason: $T_{TMS} \cong 2-7 \, \text{K} \text{ but it can be much higher when the Sun contributes!}$

$T_{\text{sun}}(t) = T_{\text{rapid}}(t) + T_{\text{slow}}(t) + T_{\text{quiet}}$ \text{ The "quiet Sun" is } 10^5 \, \text{K at L-band!}

sun spots, flares \text{ as high as } 2 \times 10^6 \, \text{K at L-band}

Again, the SMOS data is flagged when the Sun is in the field of view (FOV).

Other confusing factors:

- Accuracy of SST (must be measured by another satellite!); ocean surface roughness (8 models used by SMOS!);
- Faraday rotation (ionosphere causes polarization axis to rotate; such that v-pol at the satellite ≠ v-pol at ocean surface, for example);
- Radiometer precision and stability (especially change over time, "drift");
- Image reconstruction from interferometric antennas;
- RFI = radio frequency interference;
- Moon glint; variation in T_{TMS};
- Coastline irregularities.

Example: change in $T_{TMS}$ due to $10^{-3}$ wind (roughness) $= 5 \, \text{pss - 75!}$
Relative Permittivity & Liquid Water

Recall definition of complex relative permittivity,

\[ \varepsilon_r = \varepsilon' - j\varepsilon'' = \varepsilon' - j\left(\varepsilon'' + \frac{\sigma}{\omega\varepsilon_0}\right) \]

Here \(\varepsilon''\) is the imaginary part of \(\varepsilon_r\) that is not due to \(\sigma\) = conductivity. \(\text{Re} \varepsilon''\) tells us about energy storage by a dielectric. \(\text{Im} \varepsilon''\) tells us about energy loss / dissipation.

For liquid water,

\[ \varepsilon' - j\varepsilon'' = \varepsilon_r = \varepsilon_{\infty} + \frac{\varepsilon_{\infty} - \varepsilon_{\infty}}{1 + j\omega\tau_w} \]

where \(\varepsilon_{\infty} = 5\) = high frequency limit

\(\varepsilon_{\infty} = 80\) = low frequency limit = \(\varepsilon\) (temperature)

\(f\) = frequency, Hz (not GHz)

\(\tau_w\) = "relaxation time" or relaxation period, s

Water is a polar molecule with a permanent dipole moment \(\mathbf{p}\).

When an electric field is applied, the random orientation of water molecules is destroyed, the molecules "line-up" with the field, and a large-scale polarization \(\mathbf{P}\) is created.

\[ \mathbf{D} = \varepsilon_0 \mathbf{E} + \mathbf{P} = \text{measured energy stored in dielectric} \]

\(\mathbf{P} = \text{polarization density} = \varepsilon_0 \chi_e \mathbf{E} \]

\(\chi_e = \text{electric susceptibility} \]

\(\varepsilon_r = 1 + \chi_e \mathbf{E}\), so \(\chi_e\) tells you how much different the dielectric is compared to free space.

When the electric field is taken away, \(\mathbf{P}\) goes away at a rate characterized by \(\tau_w\).

\[ \mathbf{P}(t) = \mathbf{P}(0) e^{-t/\tau_w} \]

Thermal motion destroys the bulk polarization \(\mathbf{P}\).

Some energy is dissipated \(\varepsilon''\).
The diagram shows the relationship between frequency (Hz) and water relative permittivity. The graph indicates that as frequency increases, the water relative permittivity decreases. The peak value of the curve is at a frequency of approximately 10^11 Hz.

另外，图中还展示了水的折射率（Refractive index）随频率的变化。折射率在整个频率范围内逐渐减小，频率越高，折射率越低。