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MERIT
MELBOURNE ENGINEERING RESEARCH INSTITUTE

L-Band Microwave Emission of High-Saline Soils

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Contents

Soil Salinity: Salt-Affected Areas

Salt-affected areas (Ghassemi et al., 1995)

- 7% of the earth's continental extent
- 20% of the world's irrigated lands
- Reduced crop productivity, soil degradation, increased soil erosion, and etc.
- Estimated damage of $208 million (USD) in the Murray Darling Basin by human-induced salinization.

Salt-affected Australian native trees and pastures

(Source: http://www.abc.net.au)

Salt-affected areas of the world (> 10 Mha)

Region	Area (10^6 ha)
North America	16
Argentina	86
Paraguay	22
Ethiopia	11
India	24
Iran	27
Pakistan	10
China	37
(Former) USSR	171
Indonesia	13
Australia	**357**

(Massoud, 1977)

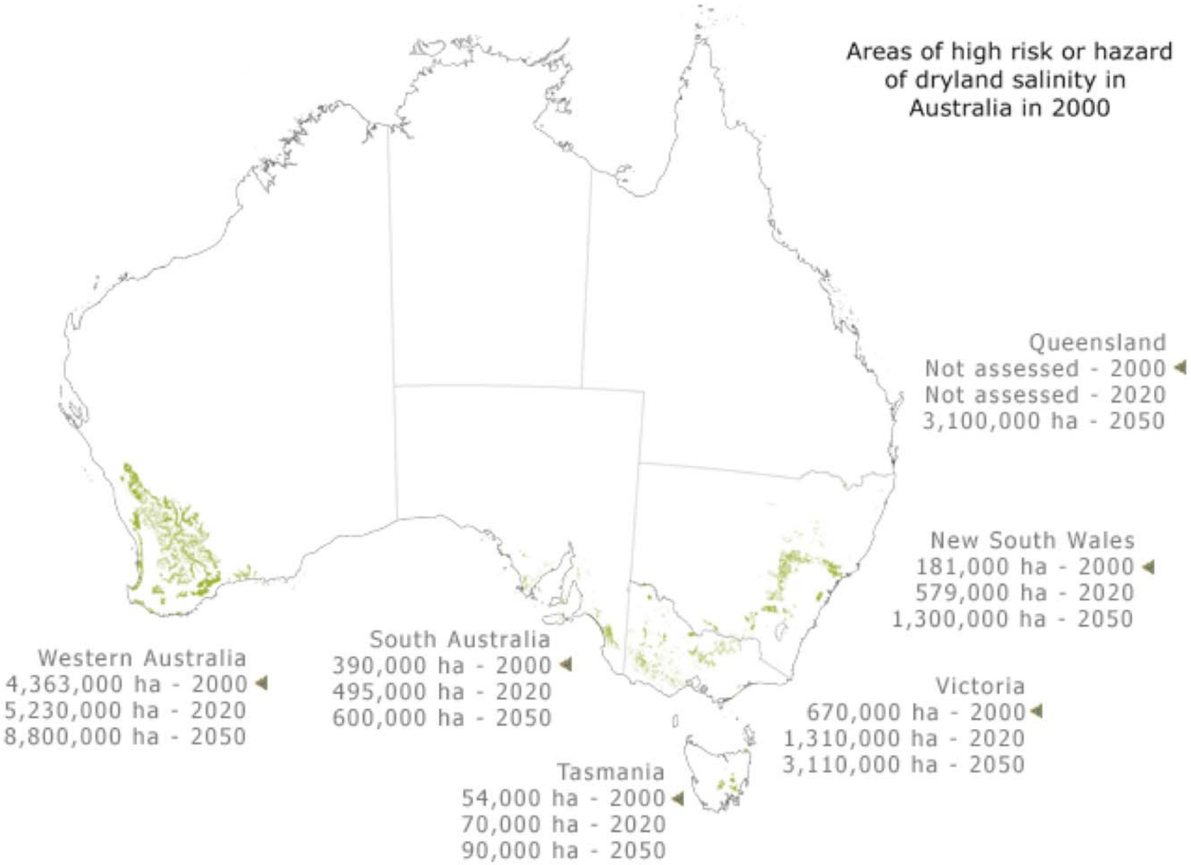
Effect of salinity on crop

Soil Salinity Class	EC of the Saturation Extraction (dS/m)	Effect on Crop Plants
Non saline	0 – 2	Salinity effects negligible
Slightly saline	2 – 4	Yields of sensitive crops may be restricted
Moderately saline	4 – 8	Yields of many crops are restricted
Strongly saline	8 – 16	Only tolerant crops yields satisfactory
Very strongly saline	> 16	Only a few very tolerant crops yield satisfactory

(Source: FAO Natural Resources Management and Environment Department)

Soil Salinity: Salt-Affected Areas

Forecasted areas of high hazard or risk of dryland salinity in 2020 and 2050

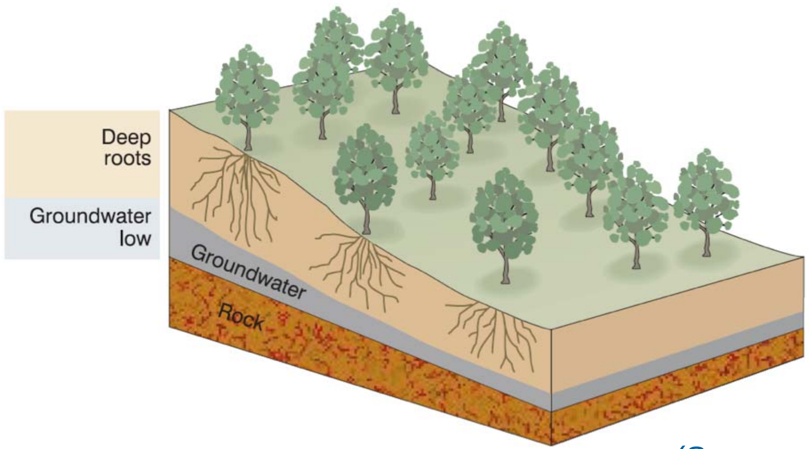


(Source: National Land and Water Resources Audit)

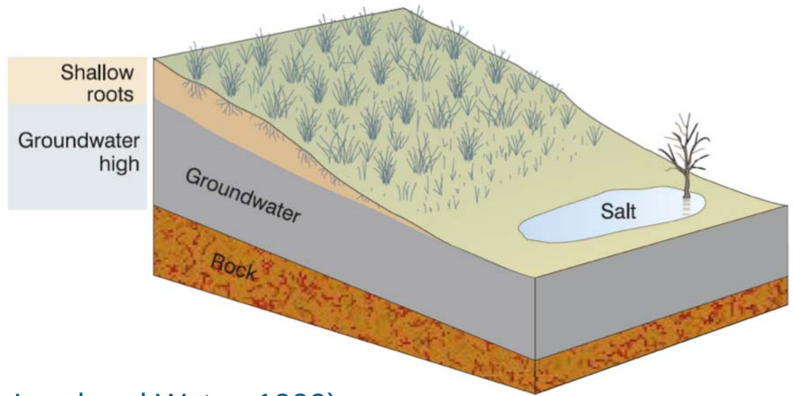
Sources and Salinization Processes

- Old geologic layers, sea salt transported by rain and wind, salty-groundwater discharge, irrigation, and etc.
- Naturally occurring (primary) processes: marine plains and salt lakes.
- Human-induced (secondary) processes: dryland salinity and irrigation salinity.

Native woody vegetation



Crops and pastures



(Source: CSIRO Land and Water, 1999)

Soil Salinity: Definition and Measurement

Water salinity

- The amount of salt contained in the water.
- Expressed in grams of salt per litre of water (g/l ~ per mil, ppt).
- Measured by an electrical device (1 g/l ~ 1.5 mmhos/cm = 1.5 dS/m).

Soil salinity

- The amount of salt contained in the soil.
- Extraction method:
  - Soil sample is saturated and left for 48 hours;
  - Moisture is extracted in a vacuum chamber and conductivity of the solute is measured.
- 1:5 Solution method:
  - Soil sample is mixed with water in a 1:5 ratio by weight;
  - Conductivity of the solution is measured.

Soil salinity by weight and electric conductivity

Salinity level	g/l	dS/m
Non-saline	0 – 3	0 – 4.5
Slightly saline	3 – 6	4.5 – 9
Medium saline	6 – 12	9 – 18
Highly saline	> 12	> 18

(Source: FAO Natural Resources Management and Environment Department)

Mapping techniques

1. Photo/video interpretation
2. Multispectral/hyperspectral imagery
3. Airborne electromagnetic system (AEM)
4. Active/passive microwave imagery

(Source: Fugro Airborne Surveys)

Video/Photo Survey

- Oldest remote sensing technique for regional-scale mapping
- Detection of visible salt on the surface
- Inspection of surrogate measures as stressed vegetation, standing water bodies, landform or drainage lines
- Relatively low cost for instrument purchase and maintenance
- Subjective measure; multiple ancillary information should be combined subjectively.
- Surrogated measures (e.g., stressed vegetation and standing water) can be caused by various factors.

RS of Soil Salinity: Multi-/Hyperspectral

Multi-/Hyperspectral Sensing

- Advanced version of the video/photo survey
- Several ~ hundreds of spectral bands are used to collect detailed information about vegetation, mineralogy, and land surface conditions.
- Quantified measures of reflectance, vegetation condition, and surface features
- Rely on surrogate measures of soil salinity, thus share the limitation of video/ photo survey


(Source: CSIRO Land and Water)

RS of Soil Salinity: AEM

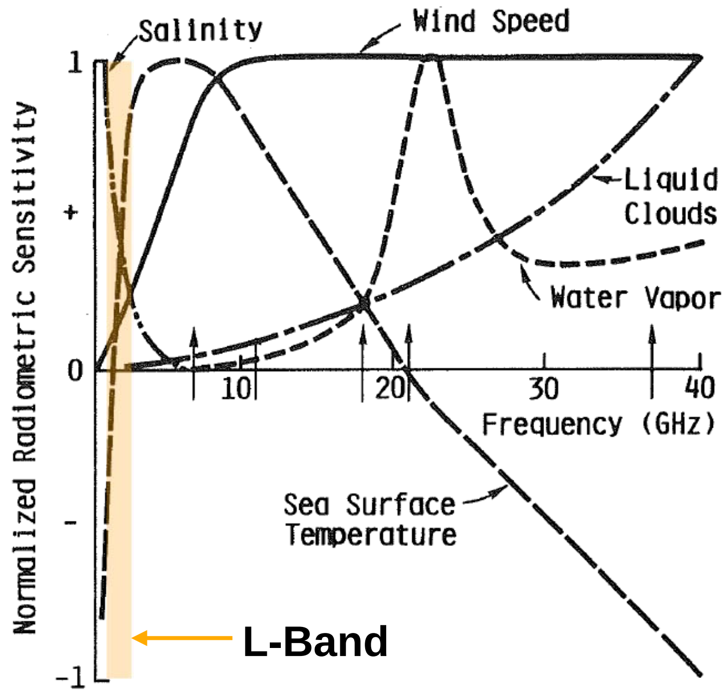
Airborne Electromagnetics

- Maps apparent conductivity of deep soil layers (few m to ~100 m).
- Only airborne systems that can map salinity hazard below the root zone
- Calibration issues for environmental applications
- Limited capability of sensing conductivity at the top few meters
- Unable to resolve thin individual layers

(Source: Fugro Airborne Surveys)

L-Band Microwave Emission from Liquid Water

- Frequency-dependent sensitivity to salinity



Ulaby et al. (1986)

L-Band Microwave Emission from Liquid Water

1. Pure water (Stogryn, 1971)

$$\varepsilon_w = \varepsilon'_w - j \cdot \varepsilon''_w$$

$$\varepsilon'_w = \varepsilon_{w\infty} + \frac{\varepsilon_{w0} - \varepsilon_{w\infty}}{1 + \left(2\pi f \tau_w\right)^2}$$

$$\varepsilon''_w = \frac{2\pi f \tau_w \left(\varepsilon_{w0} - \varepsilon_{w\infty}\right)}{1 + \left(2\pi f \tau_w\right)^2} + \frac{\sigma_i}{2\pi \varepsilon_0 f}$$

where

ε_w = complex dielectric constant of water

ε'_w = real part of ε_w

ε''_w = imaginary part of ε_w

ε_{w0} = static dielectric constant of water

$\varepsilon_{w\infty}$ = high-frequency limit of ε_w

τ_w = relaxation time of water, *s*

f = frequency

σ_i = ionic conductivity of water

ε_0 = permittivity of free space, *F/m.*

L-Band Microwave Emission from Liquid Water

2. **Saline** water (Stogryn, 1971)

$$\varepsilon_w = \varepsilon'_w - j \cdot \varepsilon''_w$$

$$\varepsilon'_w = \varepsilon_{w\infty} + \frac{\varepsilon_{w0} - \varepsilon_{w\infty}}{1 + (2\pi f \tau_w)^2}$$

$$\varepsilon''_w = \frac{2\pi f \tau_w (\varepsilon_{w0} - \varepsilon_{w\infty})}{1 + (2\pi f \tau_w)^2} + \frac{\sigma_i}{2\pi \varepsilon_0 f}$$

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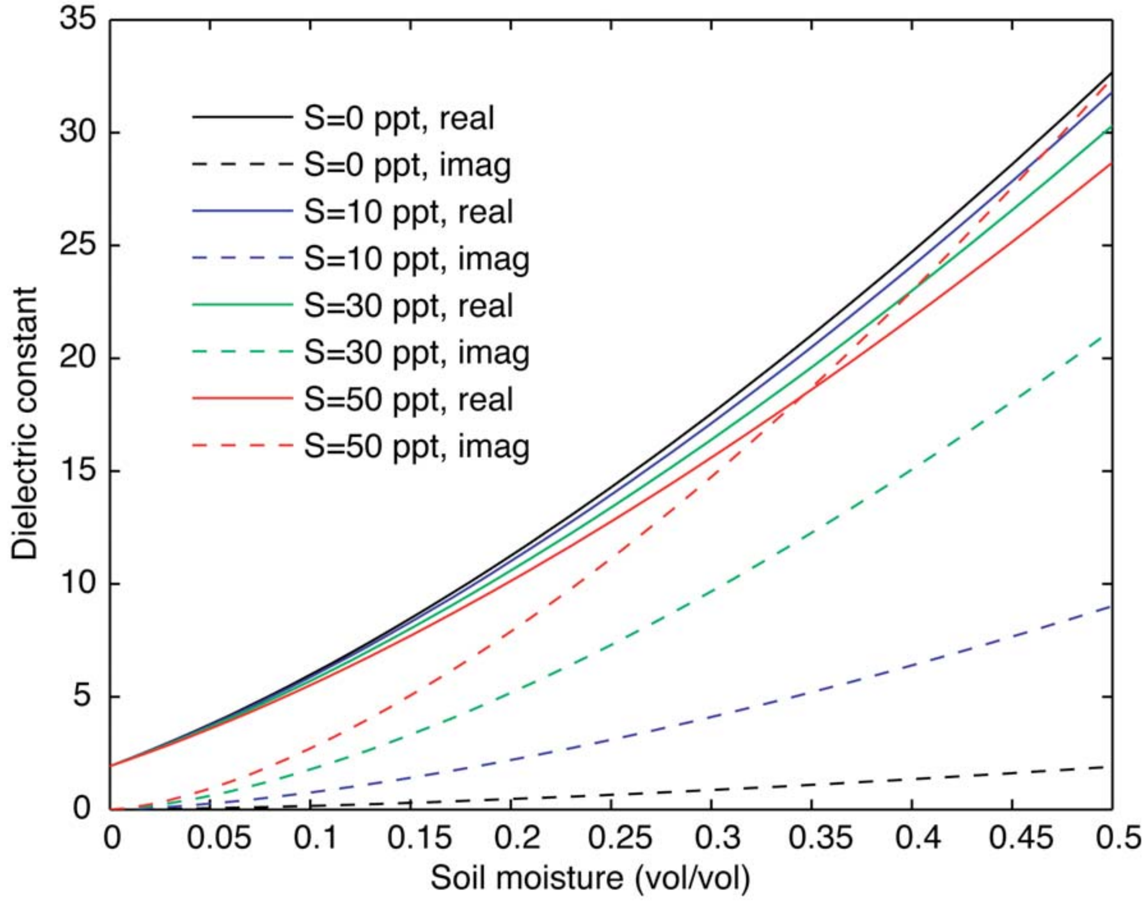
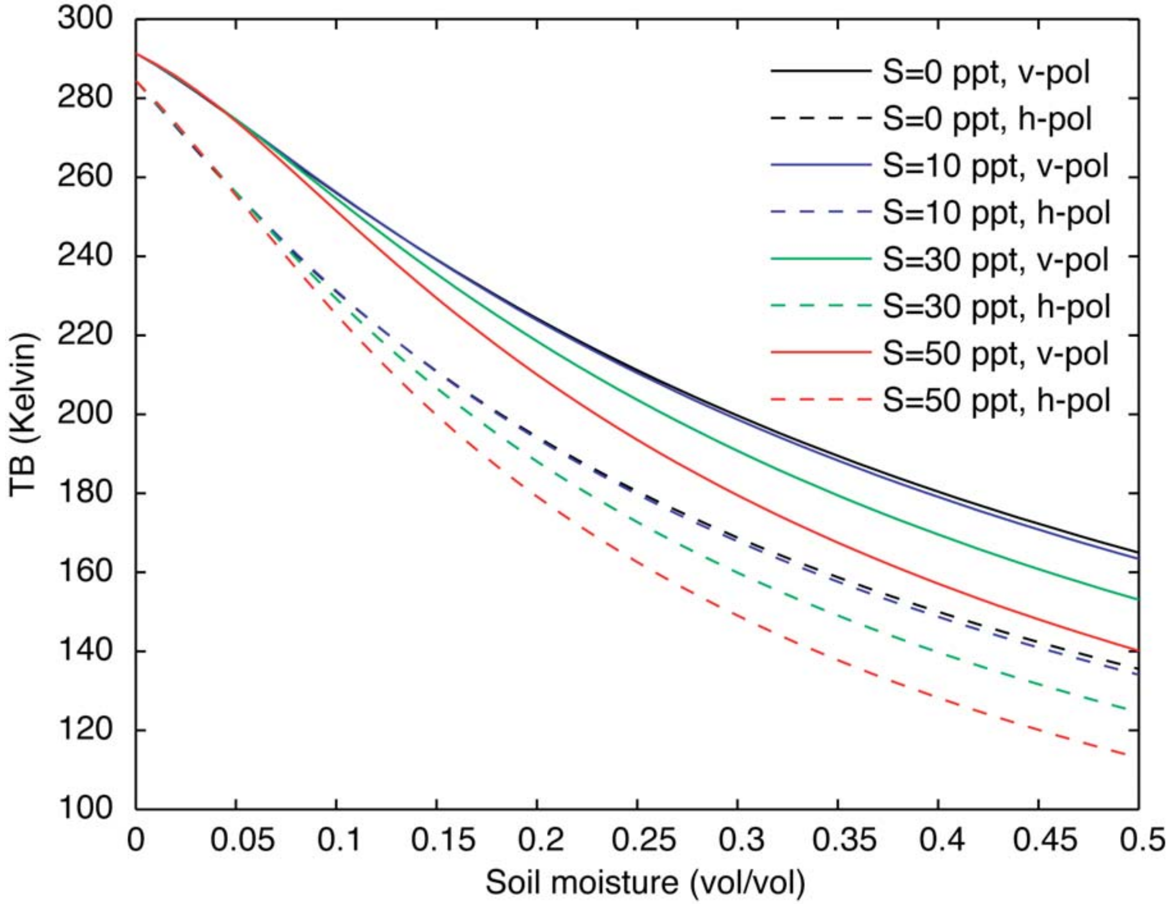
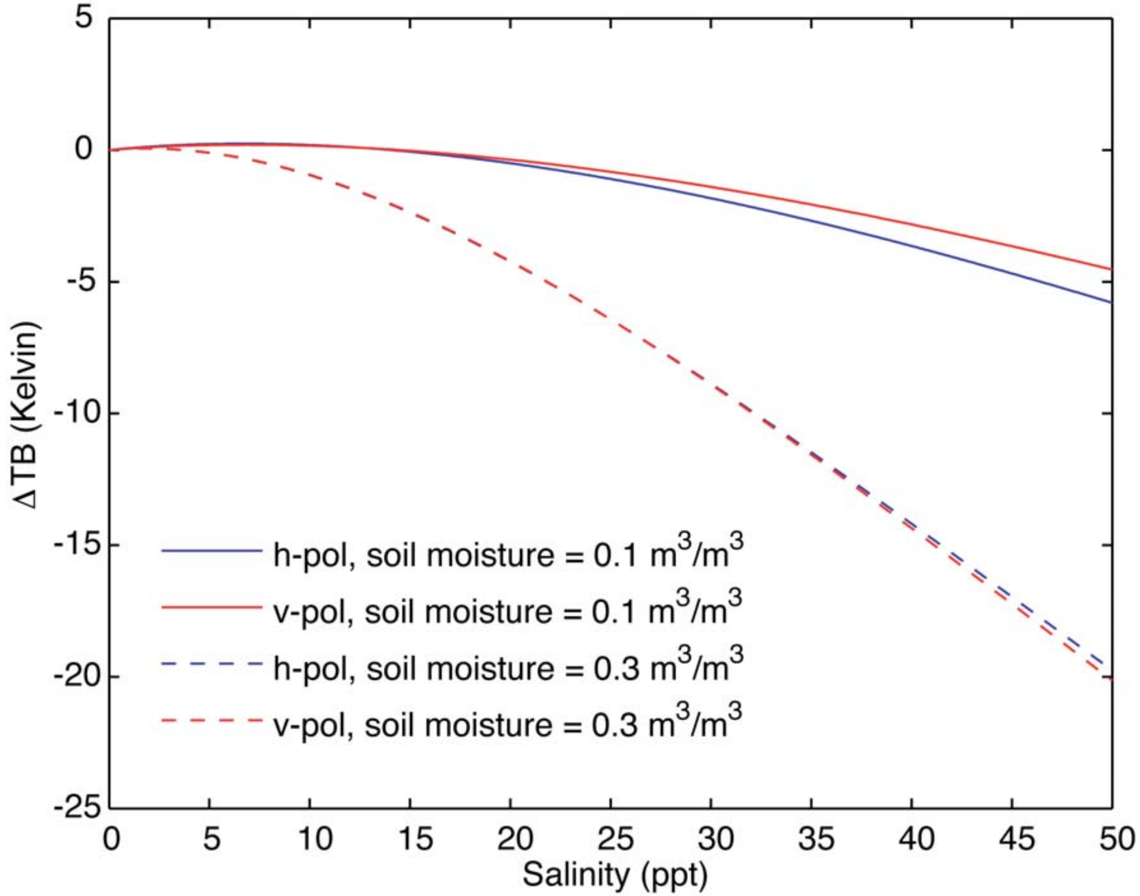
1. Sensitivity of dielectric constant to salinity with varying soil moisture (Sandy loam, T = 23ºC, freq = 1.4 GHz, θ = 30º)



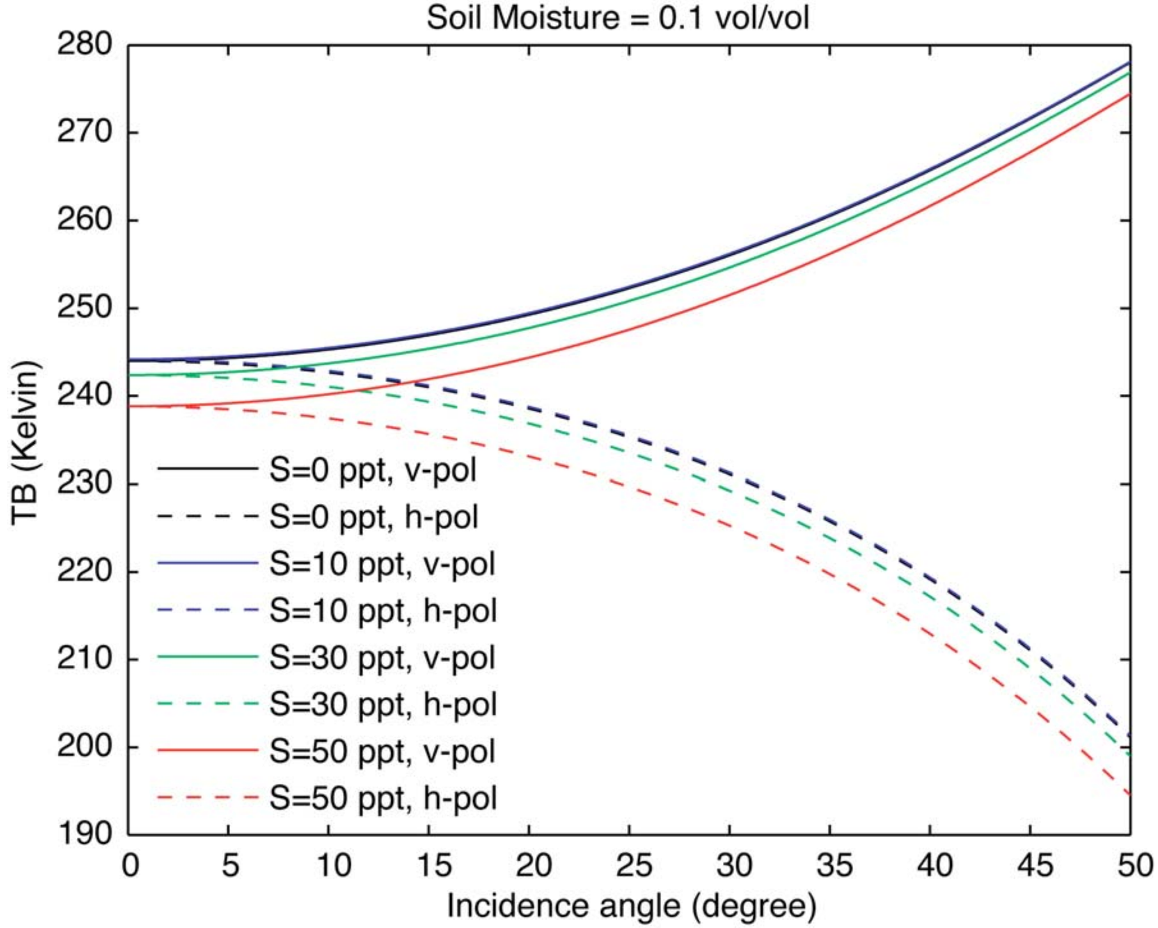
2. Sensitivity of brightness temperature to salinity with varying soil moisture (Sandy loam, T = 23°C, freq = 1.4 GHz, θ = 30°)



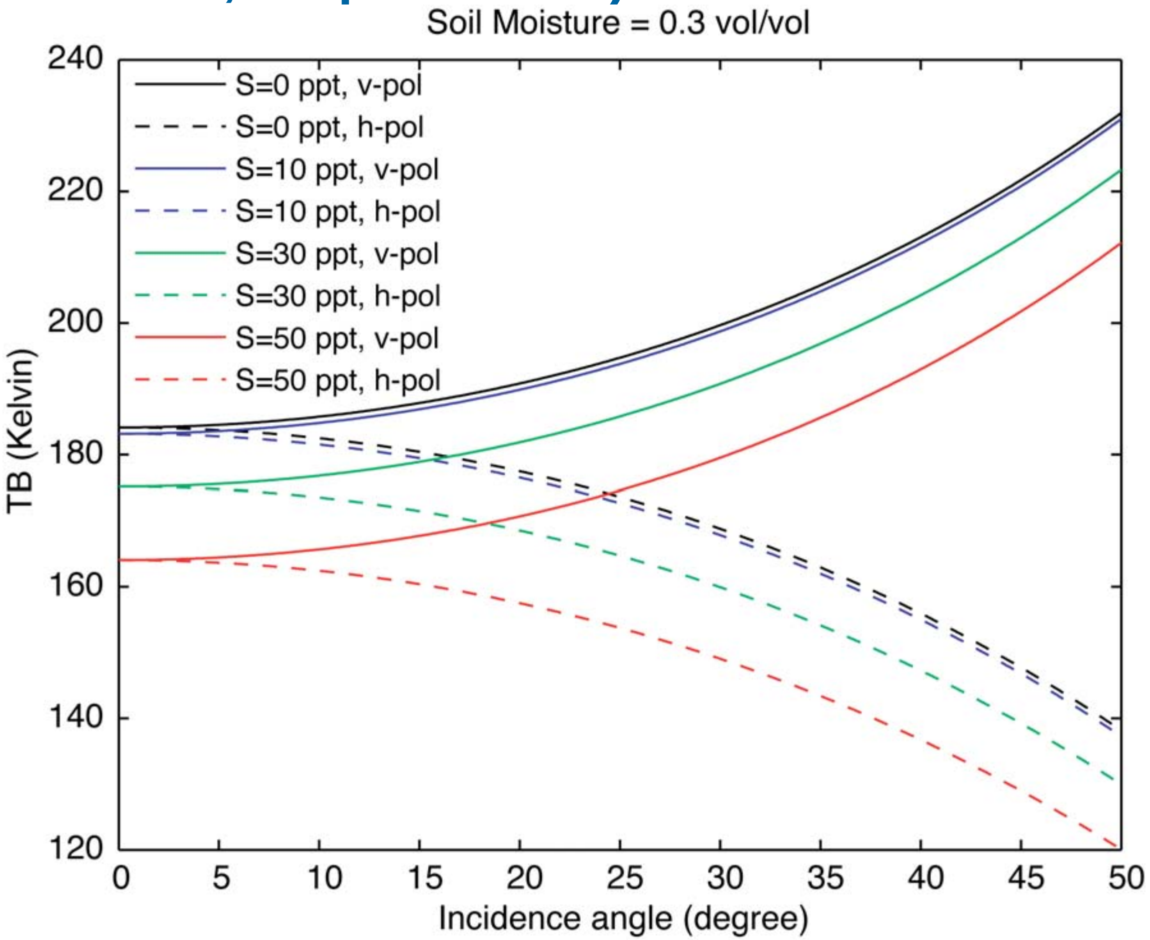
3. Sensitivity of ΔT_B to salinity at SM = 0.1 v/v and 0.3 v/v (Sandy loam, T = 23°C, freq = 1.4 GHz, θ = 30°)



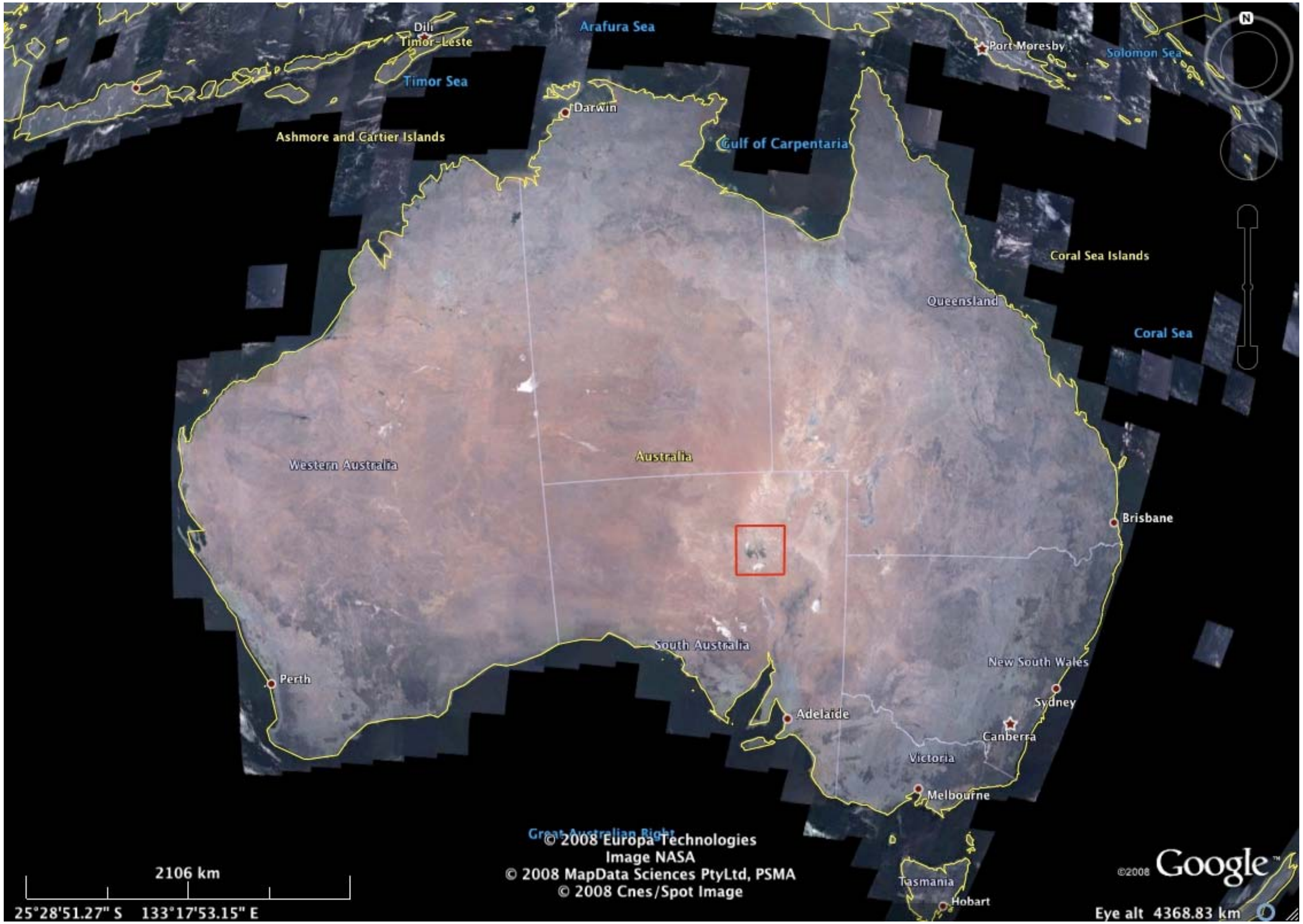
4. Sensitivity of T_B to salinity with varying incidence angle at SM = 0.1 v/v (Sandy loam, T = 23^{o}C, freq = 1.4 GHz)



4. Sensitivity of T_B to salinity with varying incidence angle at SM = 0.3 v/v (Sandy loam, T = 23°C, freq = 1.4 GHz)



Field Campaign: Lake Eyre & Wirrangula Hill



Field Campaign: Extreme Environments

Great Salt Lake and Desert in US

(Source: www.destination360.com)

(Source: www.legendsofamerica.com)

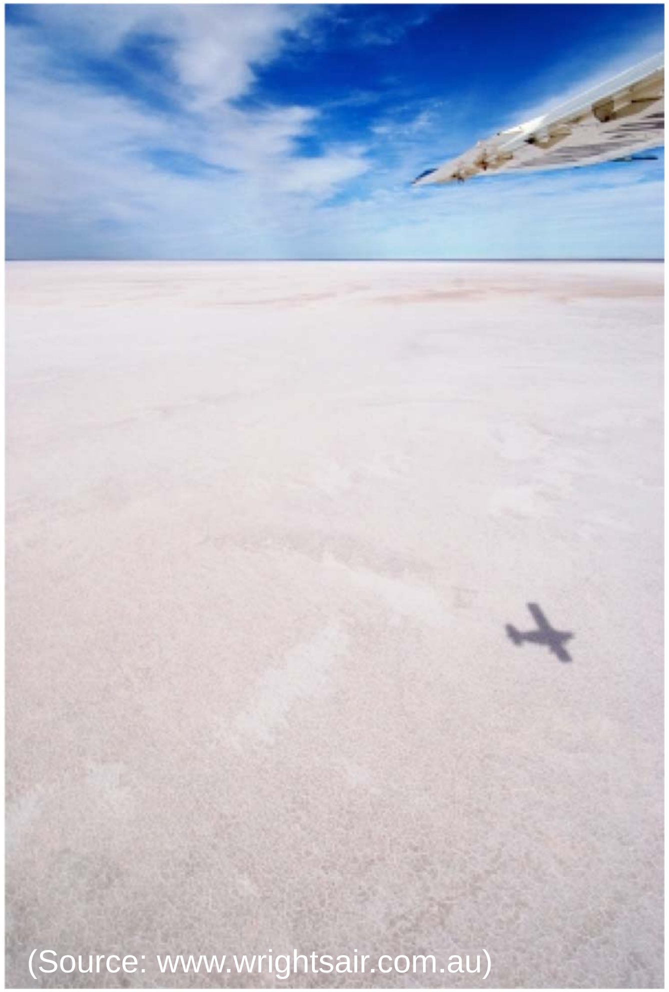
Salar de Uyuni in Bolivia

(Source: Fotos de Bolivie, http://tunari.tripod.com)

Field Campaign: Lake Eyre

- Largest salt lake in Australia
- Dominant source of water is the seasonal stream flows from the northeast (outback Queensland).
- 1.5-m flood every three years and 4-m flood every 10 years
- ~35 ppt over 4 m deep → saturation at 500 mm
- A number of smaller sub-lakes remain even in the dry season.

(Source: www.wikipedia.com)


(Source: www.wrightsair.com.au)

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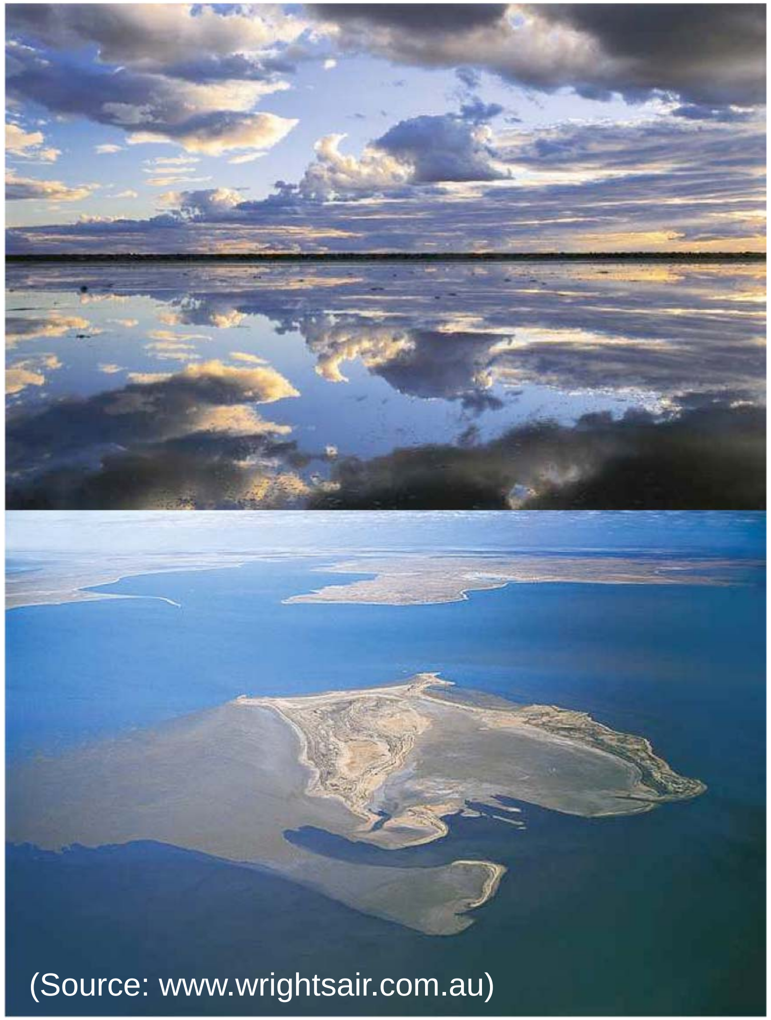

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Field Campaign: Lake Eyre

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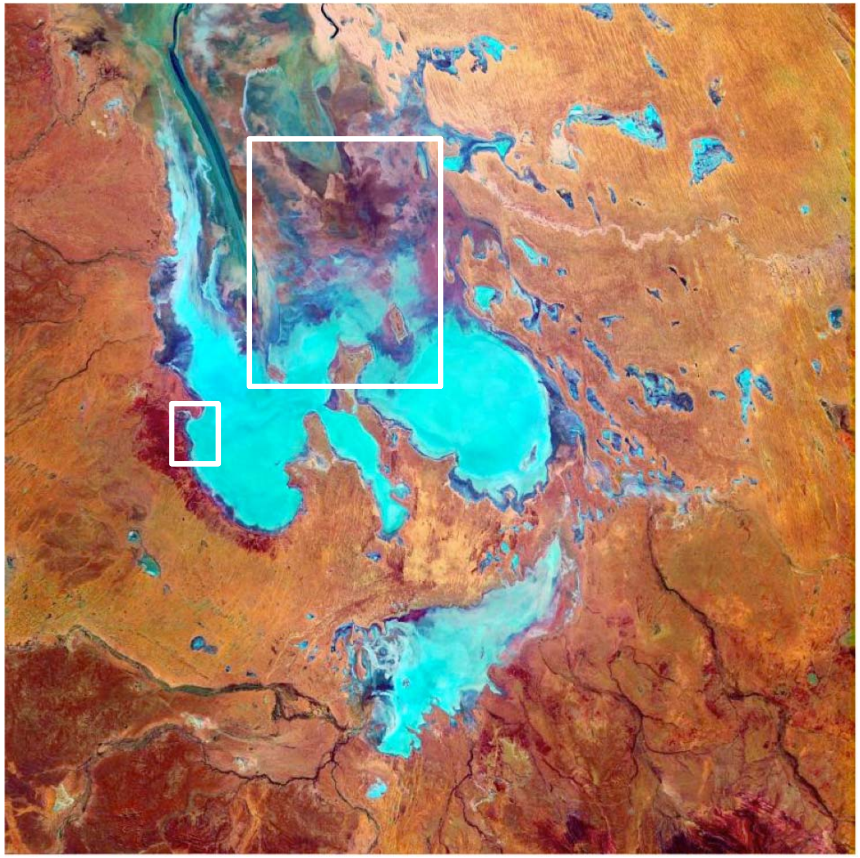
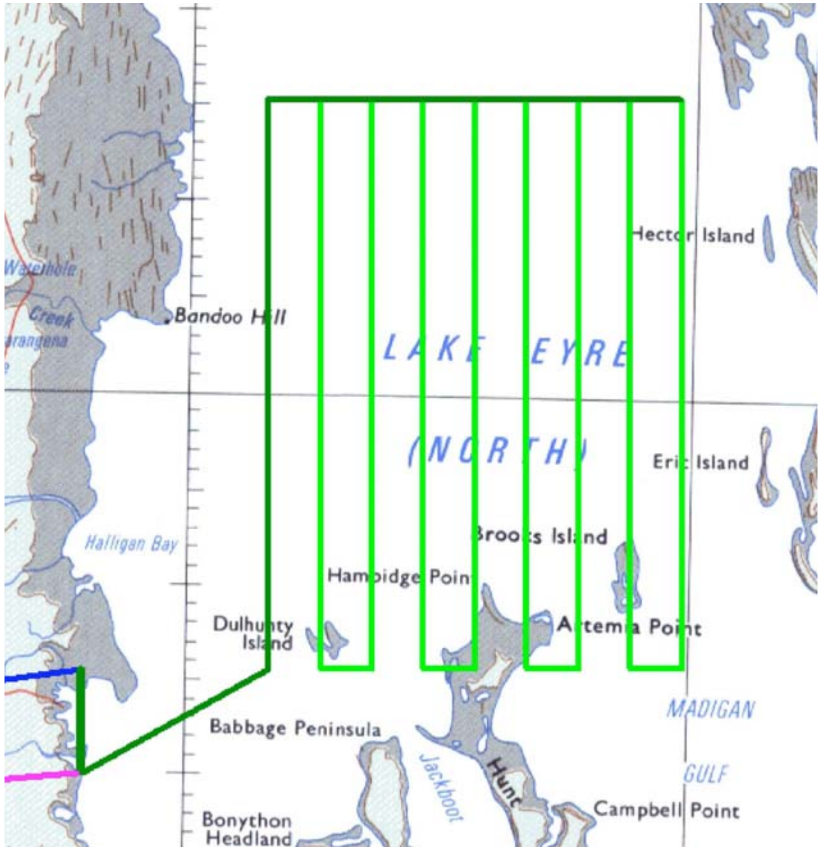


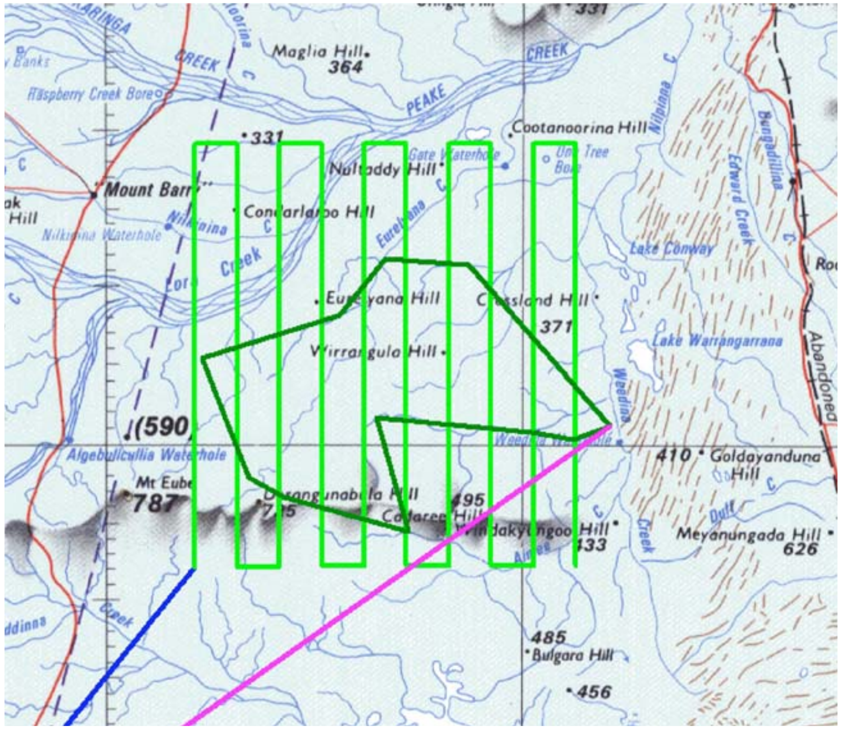
(Source: NASA Earth Observatory)



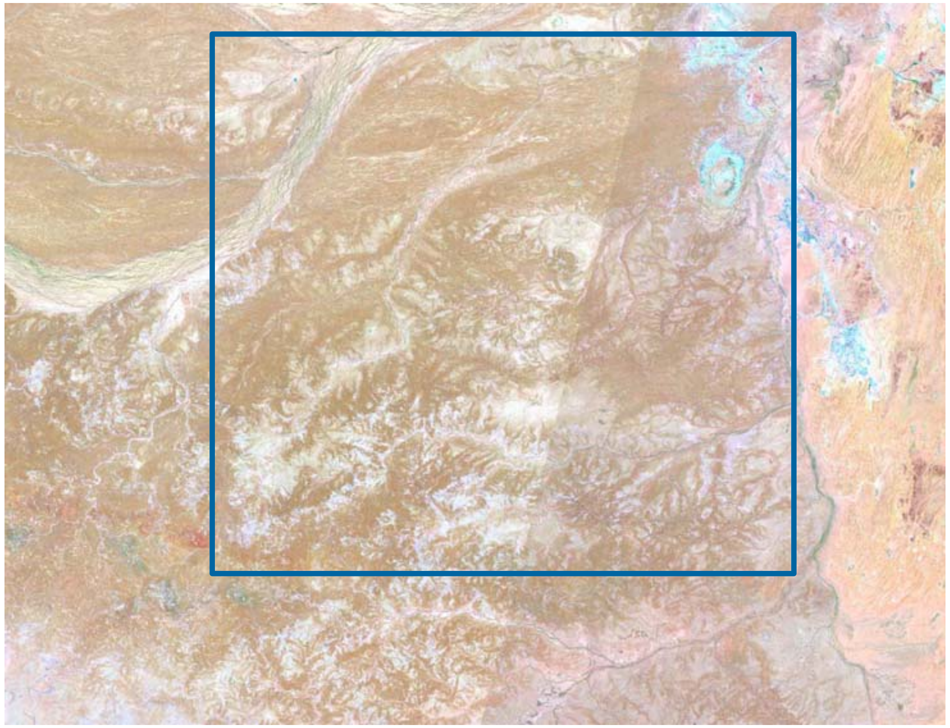
(Courtesy of C. Rüdiger)

Field Campaign: Wirrangula Hill

- Evaporation is a dominant water flux → high salinity in the surface layer
- Saline-groundwater discharge areas



(Courtesy of C. Rüdiger)



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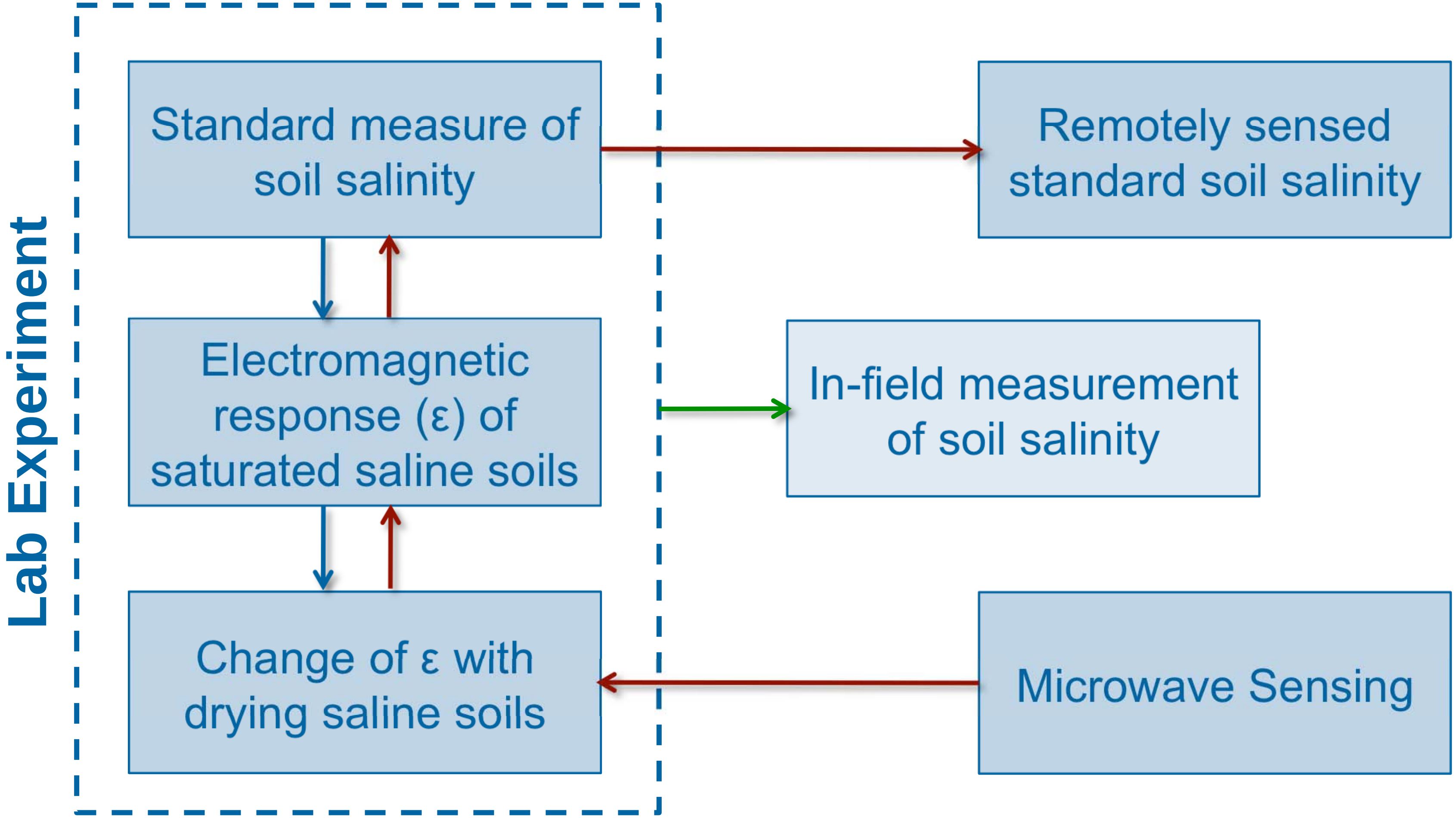
(Source: FAO Natural Resources Management and Environment Department)

- **Standard measure of soil salinity**



Summary

- Soil salinity is a serious problem in many parts of the world and is becoming worse with growing dryland agriculture and irrigation practice.
- Clearing of native vegetation for dryland farming is one of the sources most responsible for the dryland salinity in Australia.
- Soil salinity can be remotely sensed by several airborne/space-borne techniques such as video/photo survey, multi-/hyperspectral imagery, electromagnetics (EM), and active/passive microwave sensing.
- Low-frequency active/passive microwave is best suited to map salinity in the top soil surface.
- Imaginary part of wet-soil dielectric constant is sensitive to the soil salinity and the sensitivity increases with soil moisture.
- Better solutions need to be sought to invert soil moisture and salinity simultaneously and to directly derive the standard measure of soil salinity from the microwave signals of moderately wet soil salinity.