The chott El Djerid, Tunisia: Observation and interpretation of a SAR phase signature over evaporitic soils

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Evaporitic Soils in Arid Environments

→ Salt crust deposits in high evaporating environments (deserts)

→ A sign of past and/or present water resources (shallow aquifers)

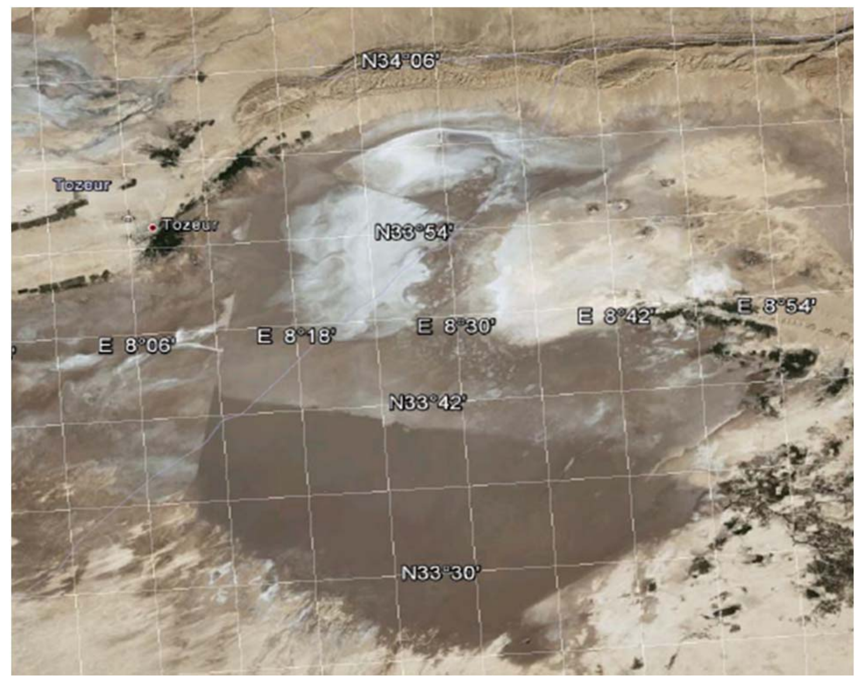
→ High temporal dynamics: flooded / dry surfaces

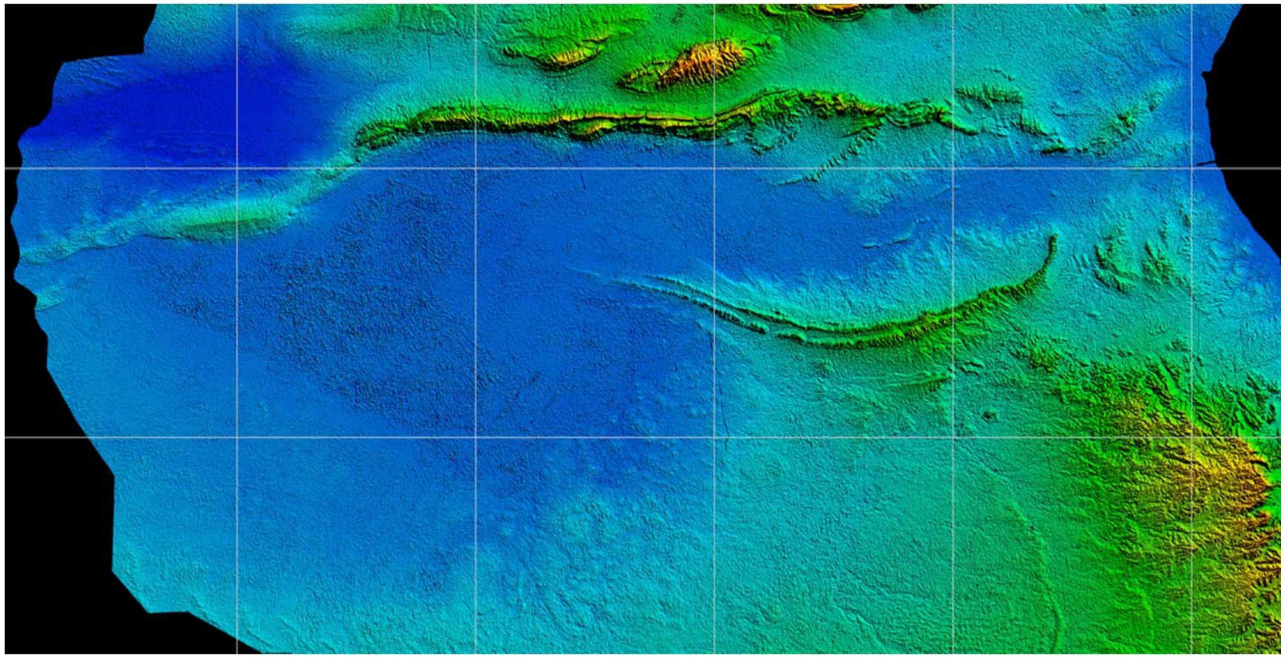
→ High contrast in SAR data: roughness + permittivity change

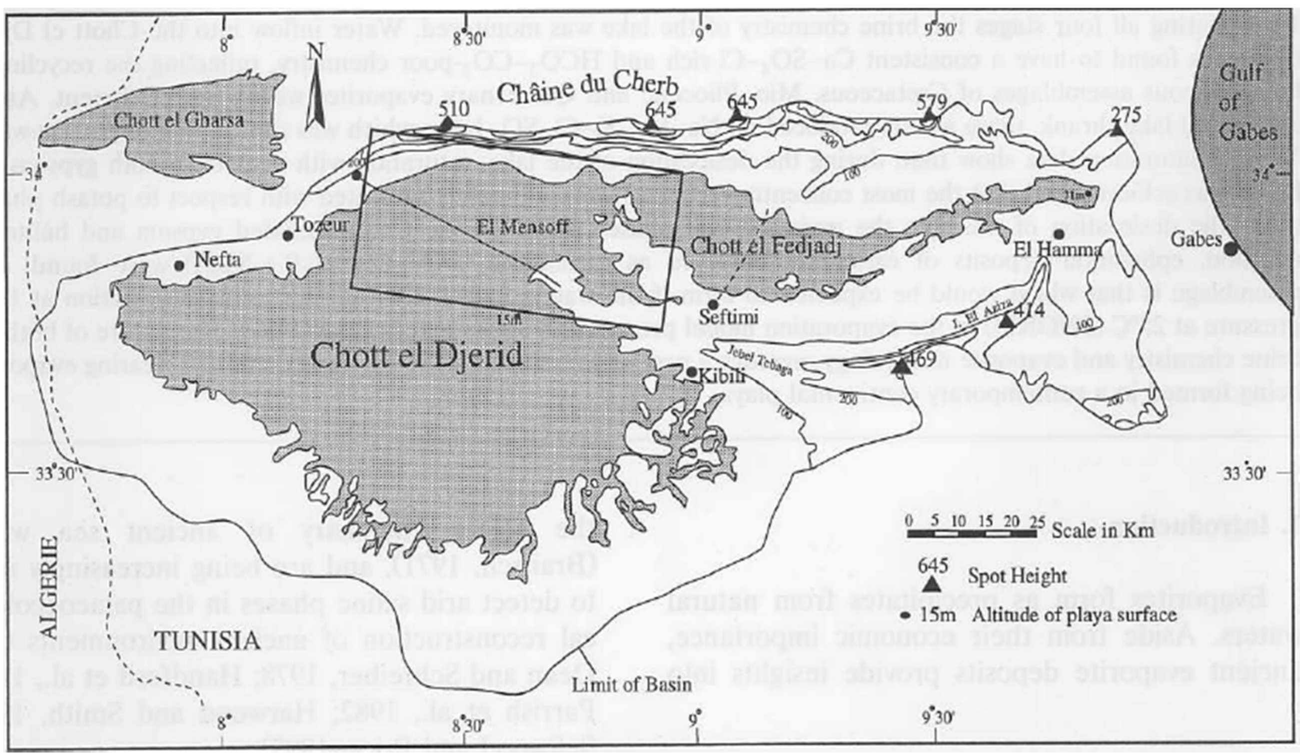
→ A signature in both amplitude and ***phase*** of the radar signal

The Chott El Djerid, Tunisia

A large (80 x 120 km) evaporitic area in southern Tunisia, with high annual variability

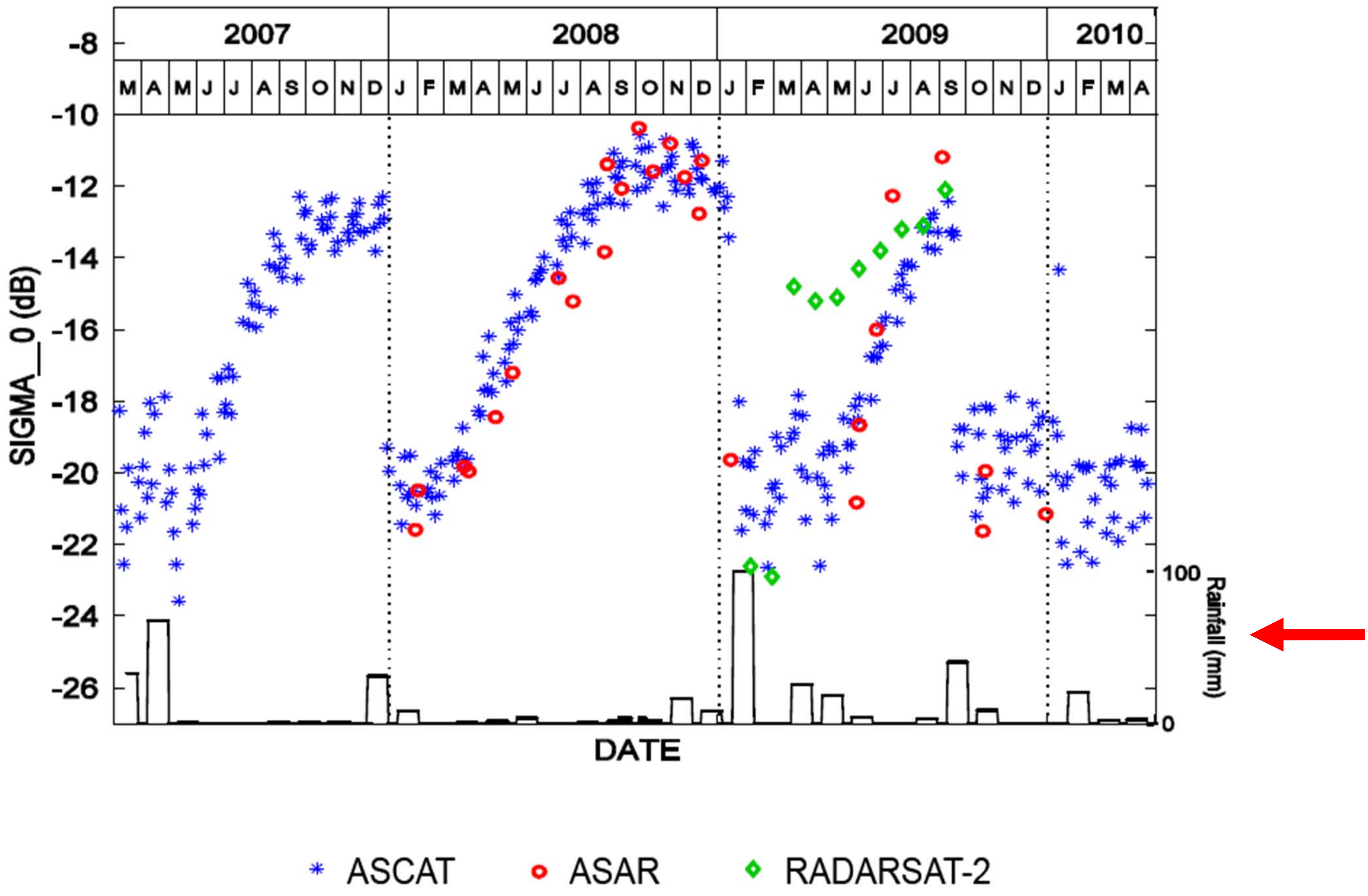




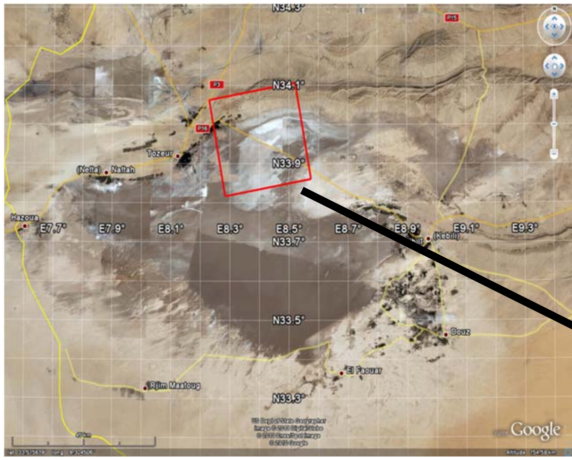

8°
8°30'
9°
9°30'
N
Chaîne du Cherb
510
645
645
579
275
Gulf of Gabes
Chott el Gharsa
34°
Tozeur
El Mensoff
Nefta
Chott el Fedjadj
El Hamma
Gabes
Seftimi
J. El Aziza
414
Jebel Tebaga
Kibili
169
Chott el Djerid
15m
33°30'
ALGERIE
TUNISIA
Limit of Basin
0 5 10 15 20 25 Scale in Km
645 Spot Height
15m Altitude of playa surface

On the field: Flat and salty...

Temporal Variation at C-band (5.2–5.6 GHz)



7 months (Feb. → Aug. 2009) of RADARSAT-2 full-pol C-band acquisitions (5m, 39°) with 24 days rep.



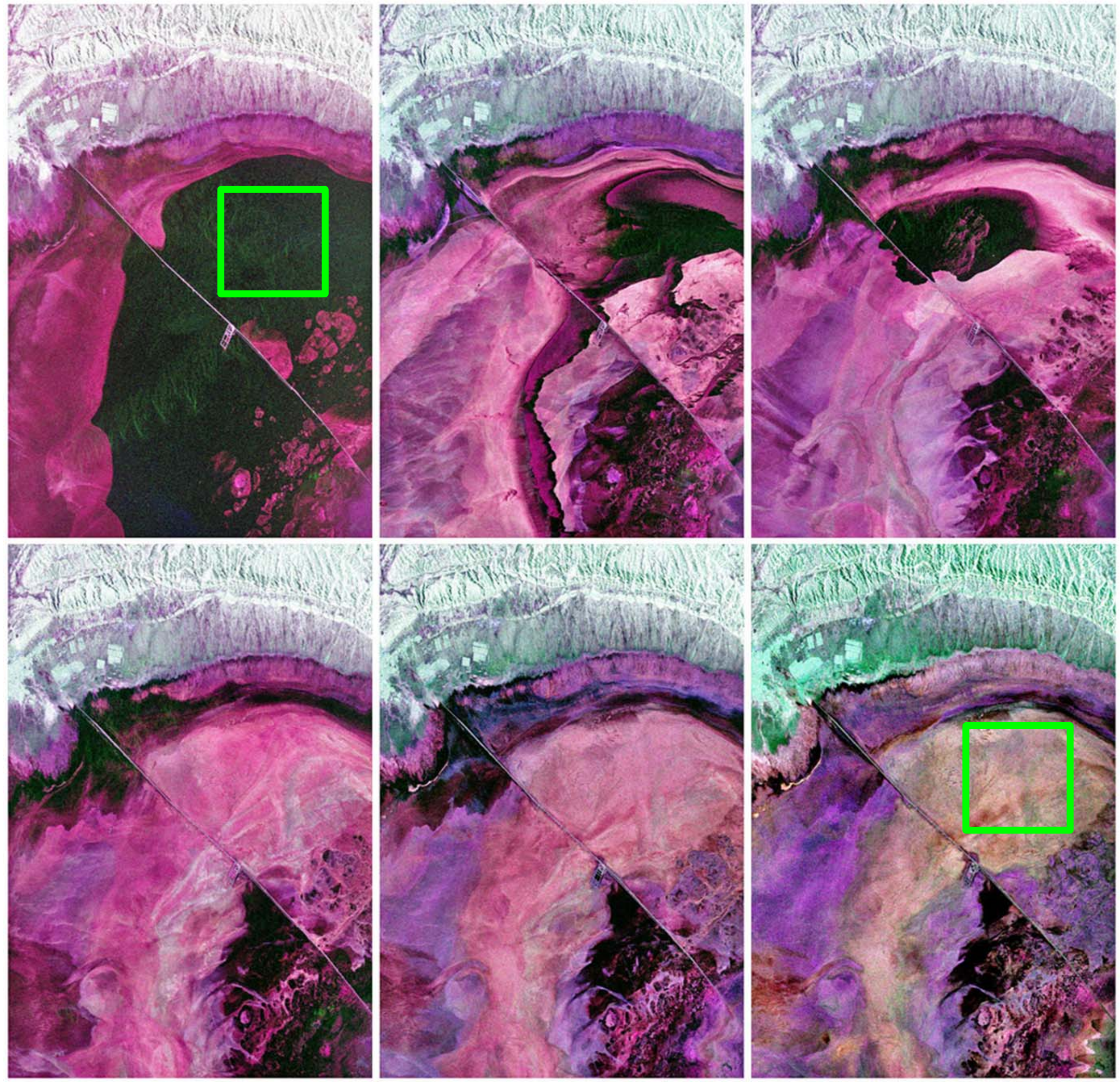
Radarsat-2
SOAR 592

Sinclair decomposition
R=VV G=(HV+VH)/2 B=HH

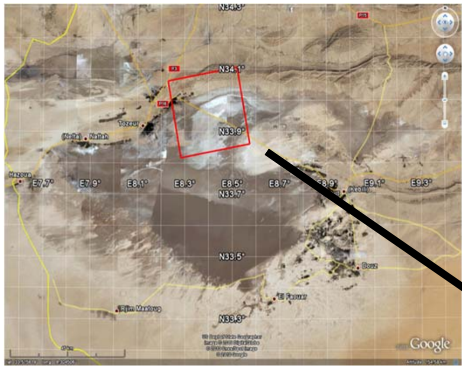
Wet: HH = -34.3 +/- 1.5 dB
VV = -34.2 +/- 1.5 dB
(RDS2 noise level)

Dry: HH = -13.1 +/- 1.5 dB
VV = -10.0 +/- 1.5 dB

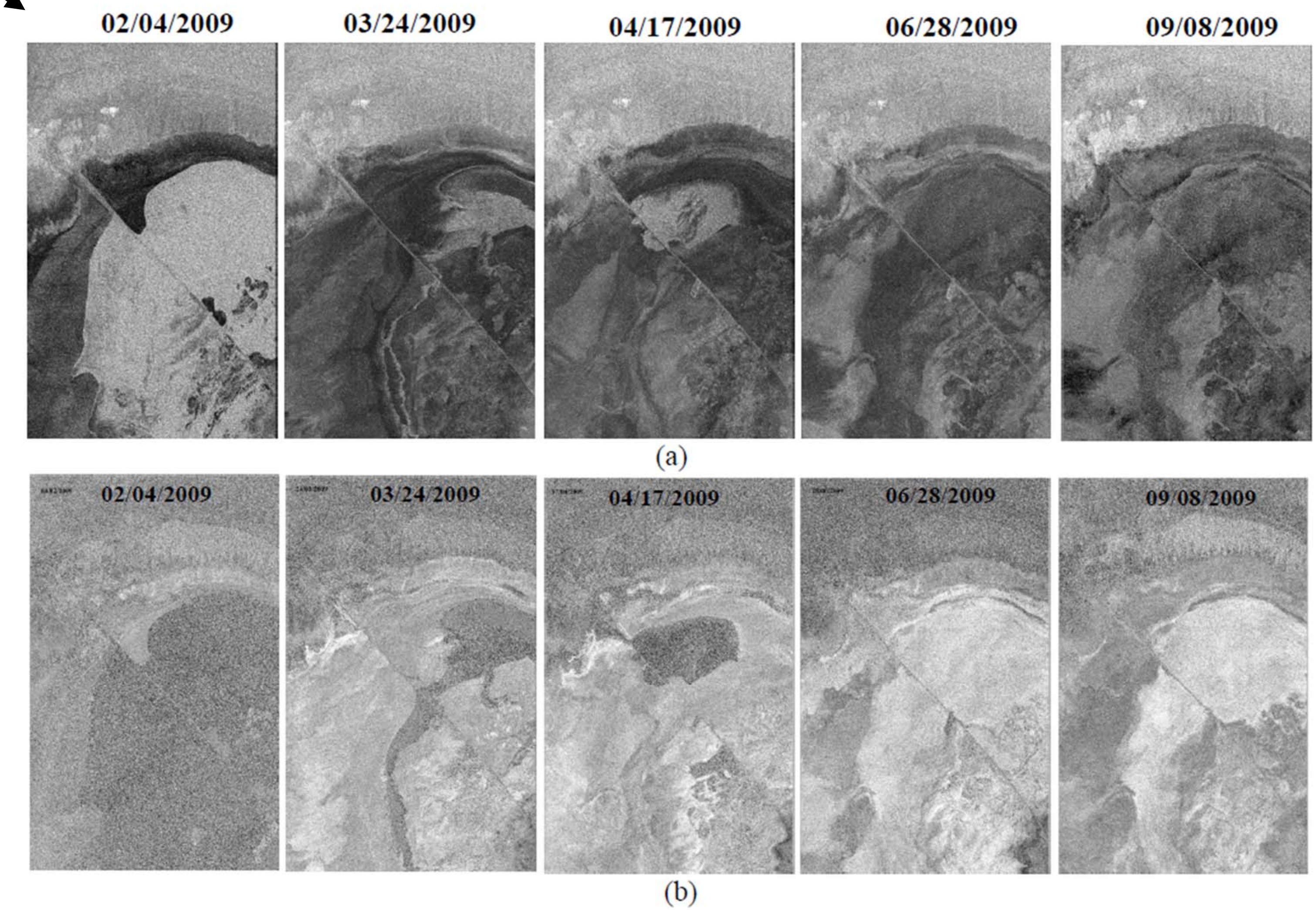
02-28 **03-24** **04-17**



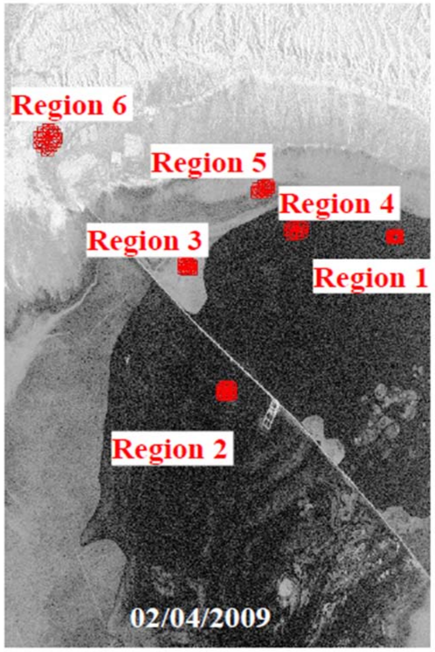
05-11 **06-28** **09-08**



$|HH|/|VV|$ and $\Phi_{HHVV} = |\phi(HH) - \phi(VV)|$

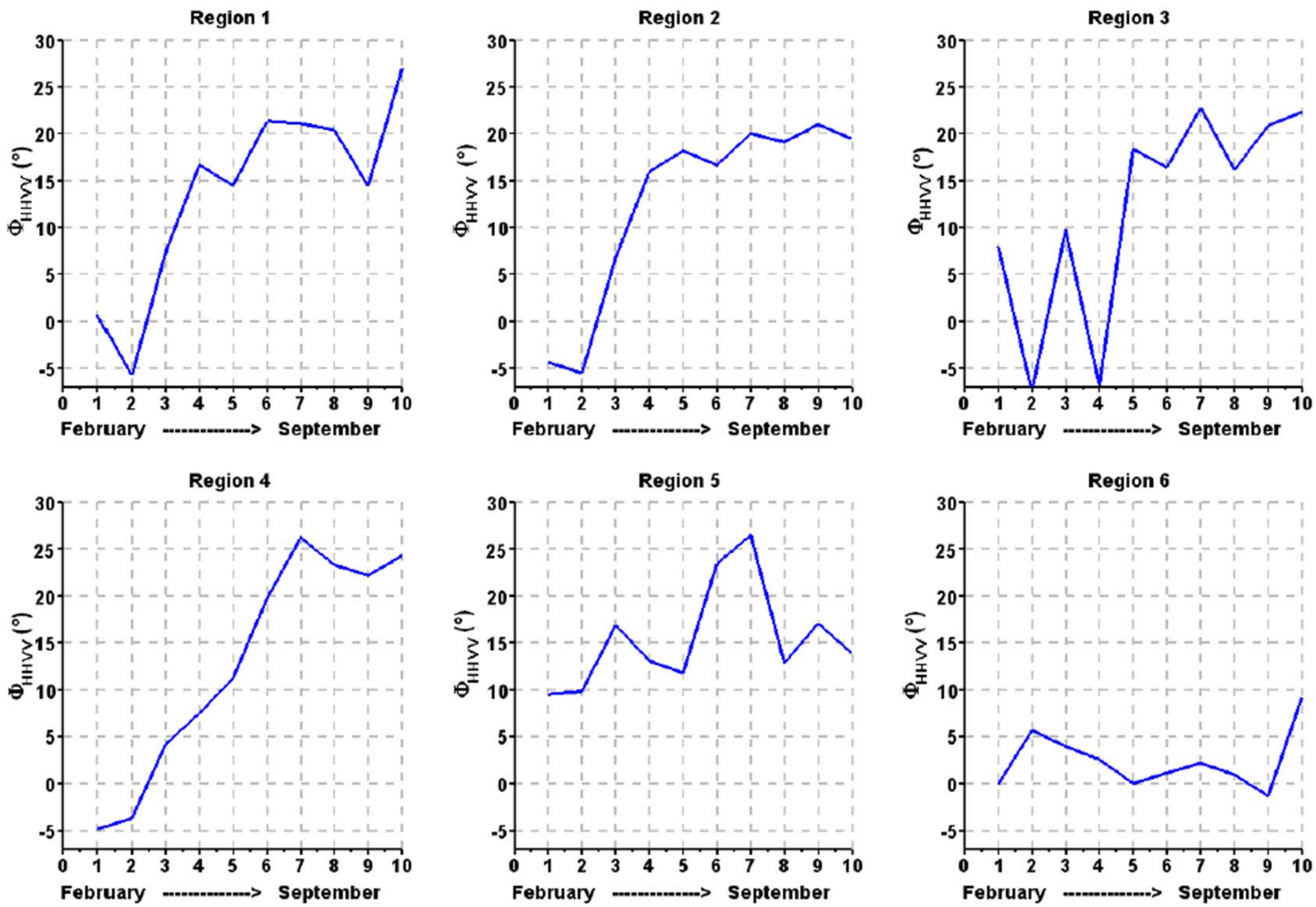


Temporal series of C-band (5.409GHz) Radarsat-2 images of Chott El Djerid: (a) σ_{hh}/σ_{vv} and (b) phase difference $\Phi_{hhvv}=|\Phi(HH)- \Phi(VV)|$. Five images are presented at differerent acquisition dates: the first one, the 4th of February, the last one, the 8th of September 2009

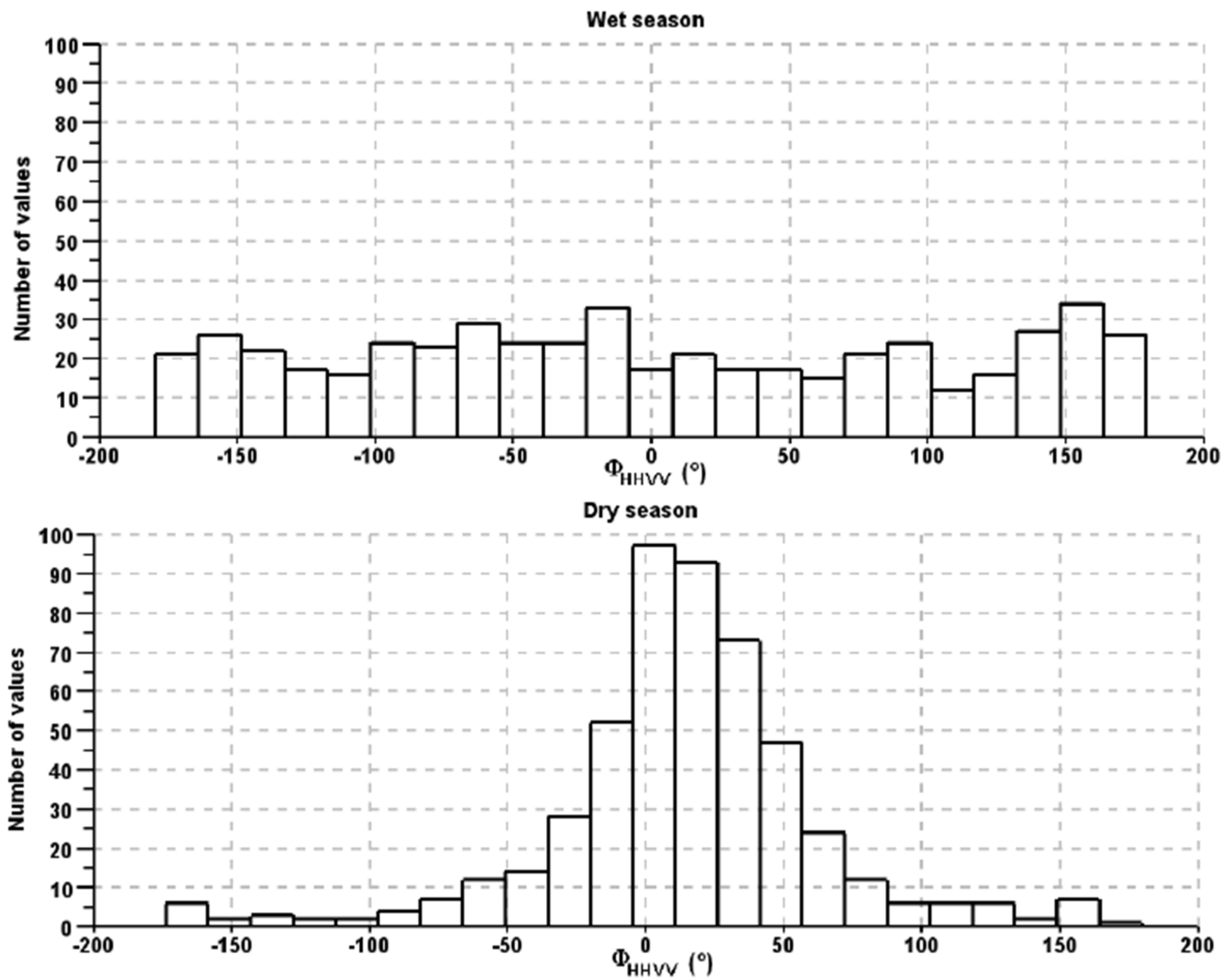


Temporal evolution of the co-pol phase difference:

$$0 < \Phi_{HHVV} < 20^{o}$$



Not only the phase of noise...



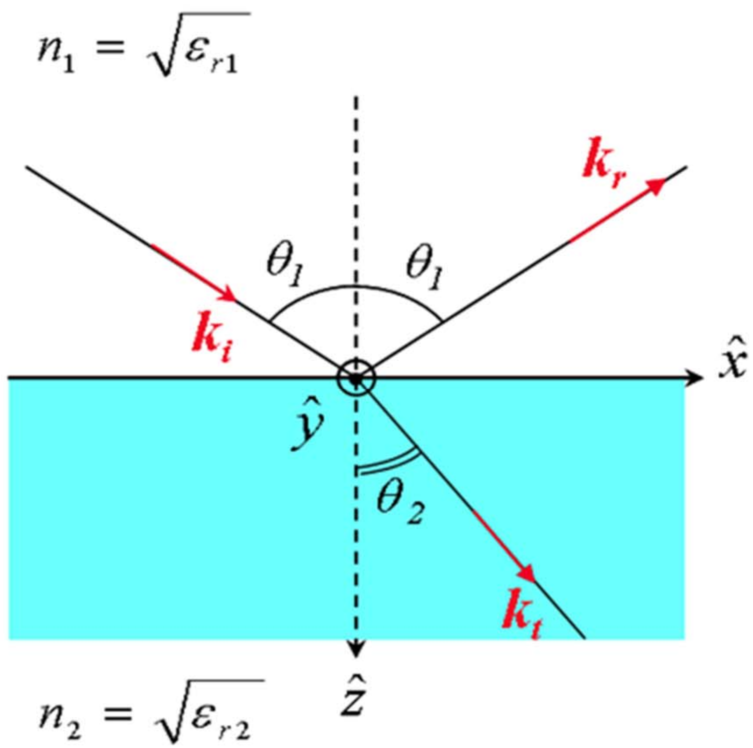
Modeling the Co-pol Phase Difference ?

→ First try: 2-layers system (*Freeman et al., POLINSAR'07*)

→ Explore a simple explanation: a complex ε (due to salt)

→ No radar wave penetration: surface scattering term only

→ First order model: phase of the reflection coefficient

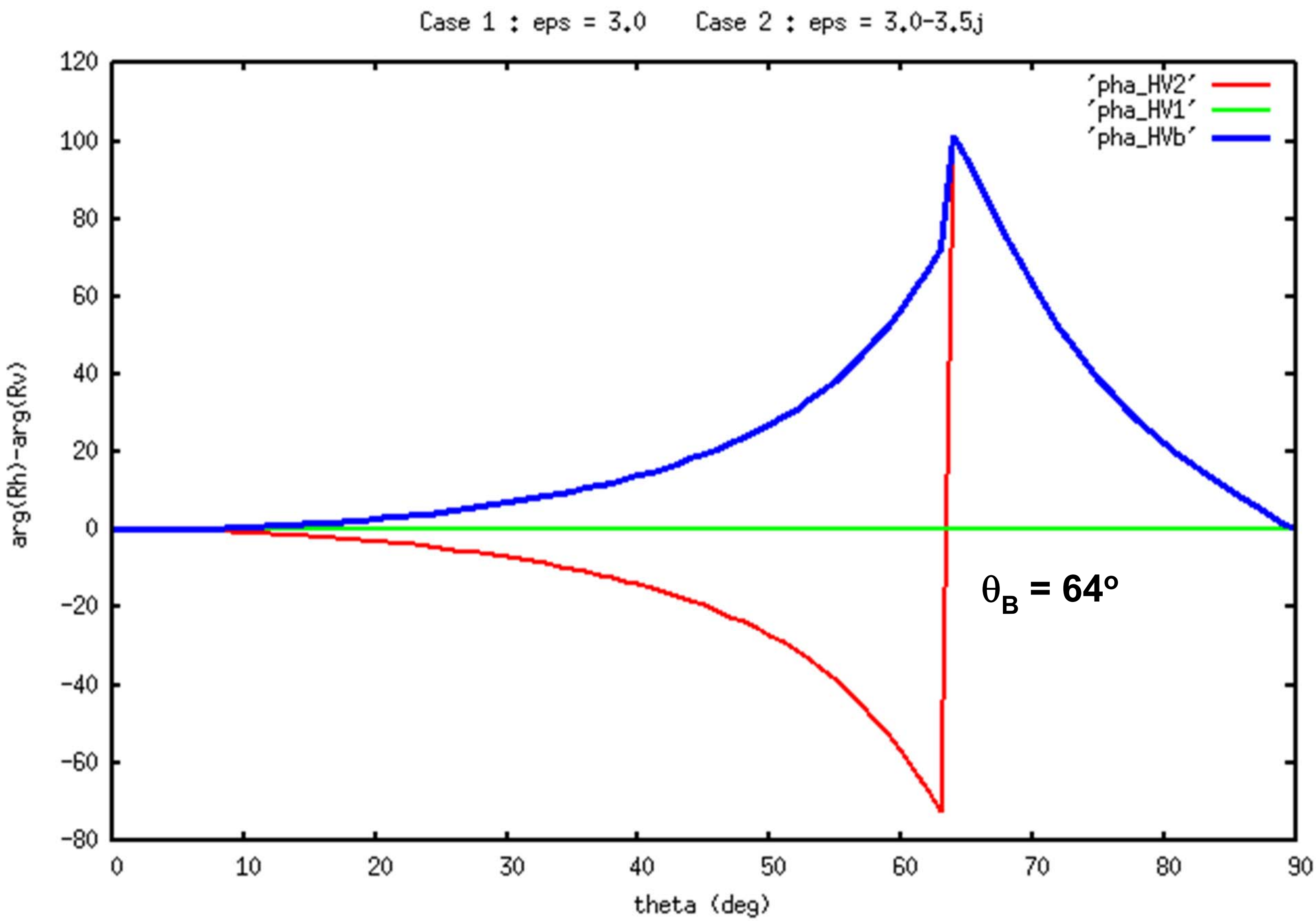


$$\mathrm{R_H} = \frac{n_2 \cos\theta_1 - n_1 \cos\theta_2}{n_2 \cos\theta_1 + n_1 \cos\theta_2}$$

$$\mathrm{R_V} = \frac{n_1 \cos\theta_1 - n_2 \cos\theta_2}{n_1 \cos\theta_1 + n_2 \cos\theta_2}$$

$$\Phi_{HHVV} = \langle \phi(HH) - \phi(VV) \rangle$$
$$= \langle arg(R_H) - arg(R_V) \rangle$$

Only depends on ε and θ


Case 1 : eps = 3.0   Case 2 : eps = 3.0-3.5j
'pha_HV2'
'pha_HV1'
'pha_HVb'
θ_B = 64°
arg(Rh)-arg(Rv)
theta (deg)
120
100
80
60
40
20
0
-20
-40
-60
-80
0
10
20
30
40
50
60
70
80
90

Going further: A second try using IEM

Fung 1992: $E^{s}_{pp} = E^{k}_{pp} + E^{c}_{pp}$ → complex fields (phase)

Kirchhoff field: $E^{k}_{pp} = C E_0 \int f_{pp} \exp j[(k_s - k_i).r] dxdy = C E_0 f_{pp} I_k$

Complementary field: $E^{c}_{pp} = \frac{C E_0}{8\pi^2} \int F_{pp} \exp j[u(x-x') + v(y-y') + k_{s.} r' - k_{i.} r] dxdydx'dxy'dudv$

$$= \frac{C E_0}{8\pi^2} F_{pp} I_c \quad \text{with} \quad C = \frac{-jk}{4\pi R} \exp(-jkR)$$

f_{pp} and F_{pp} coefficients depend on ***dielectric constant*** and ***incidence angle*** only

$$\Phi_{hhvv} = \langle \phi(HH) - \phi(VV) \rangle = \langle arg(f_{hh} I_k + \frac{F_{hh} I_c}{8\pi^2}) - arg(f_{vv} I_k + \frac{F_{vv} I_c}{8\pi^2}) \rangle$$

Case 1: Very rough surface $E^{k}_{pp} \gg E^{c}_{pp}$

$$\rightarrow \Phi^{k}_{hhvv} \approx \langle arg(f_{hh}) - arg(f_{vv}) \rangle = \langle arg(R_H) - arg(R_V) \rangle$$

Case 2: "Intermediate roughness" $E^{k}_{pp} \approx E^{c}_{pp}$ and we make the assumption $I_k \approx \frac{I_c}{8\pi^2}$

$$\rightarrow \boxed{\Phi_{hhvv} \approx \langle arg(f_{hh} + F_{hh}) - arg(f_{vv} + F_{vv}) \rangle}$$

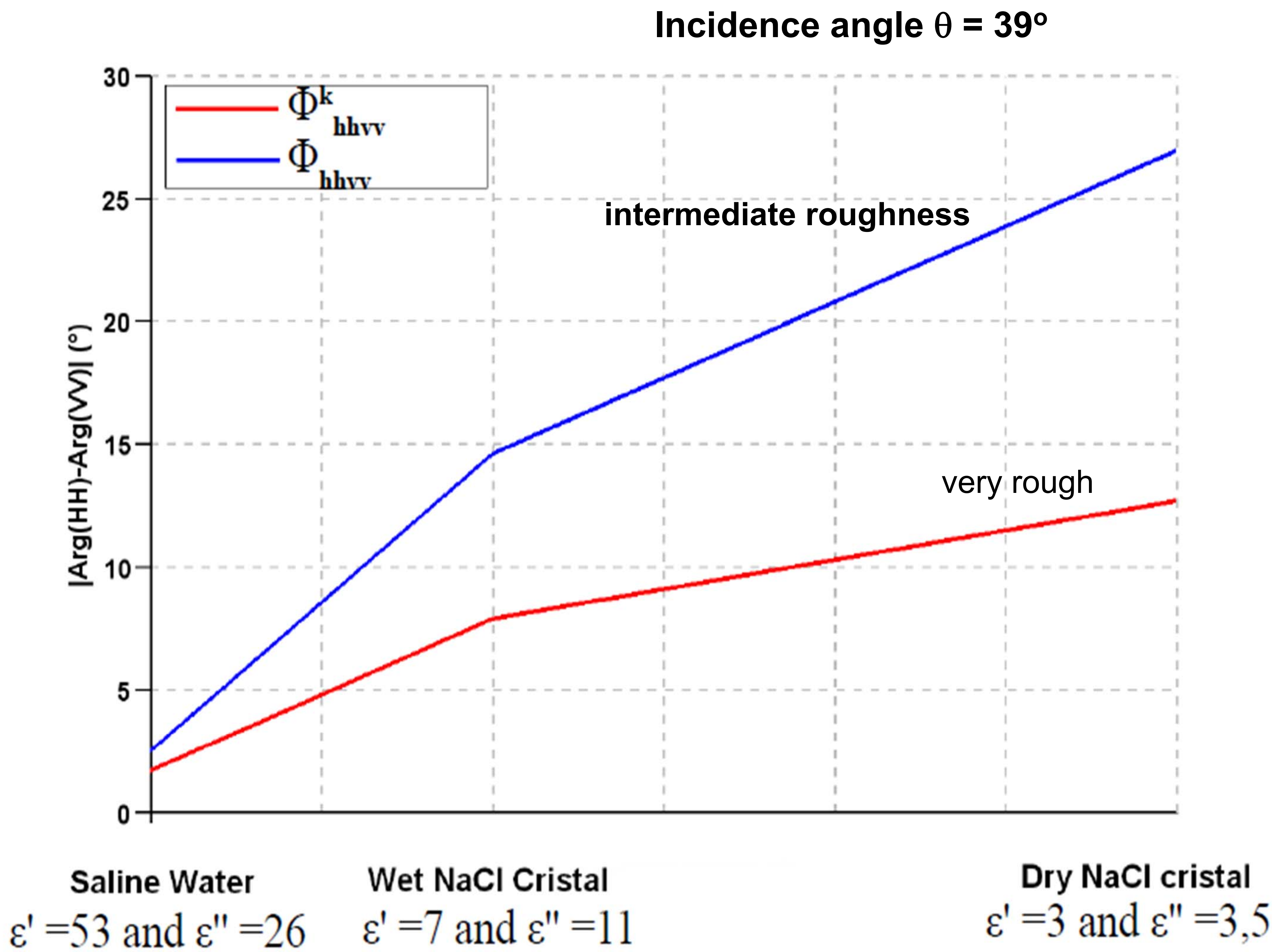
How to get dielectric constant values ?

→ Field measurements: Death Valley (CA)
Lasne, Paillou, et al., IEEE TGARS, 2009

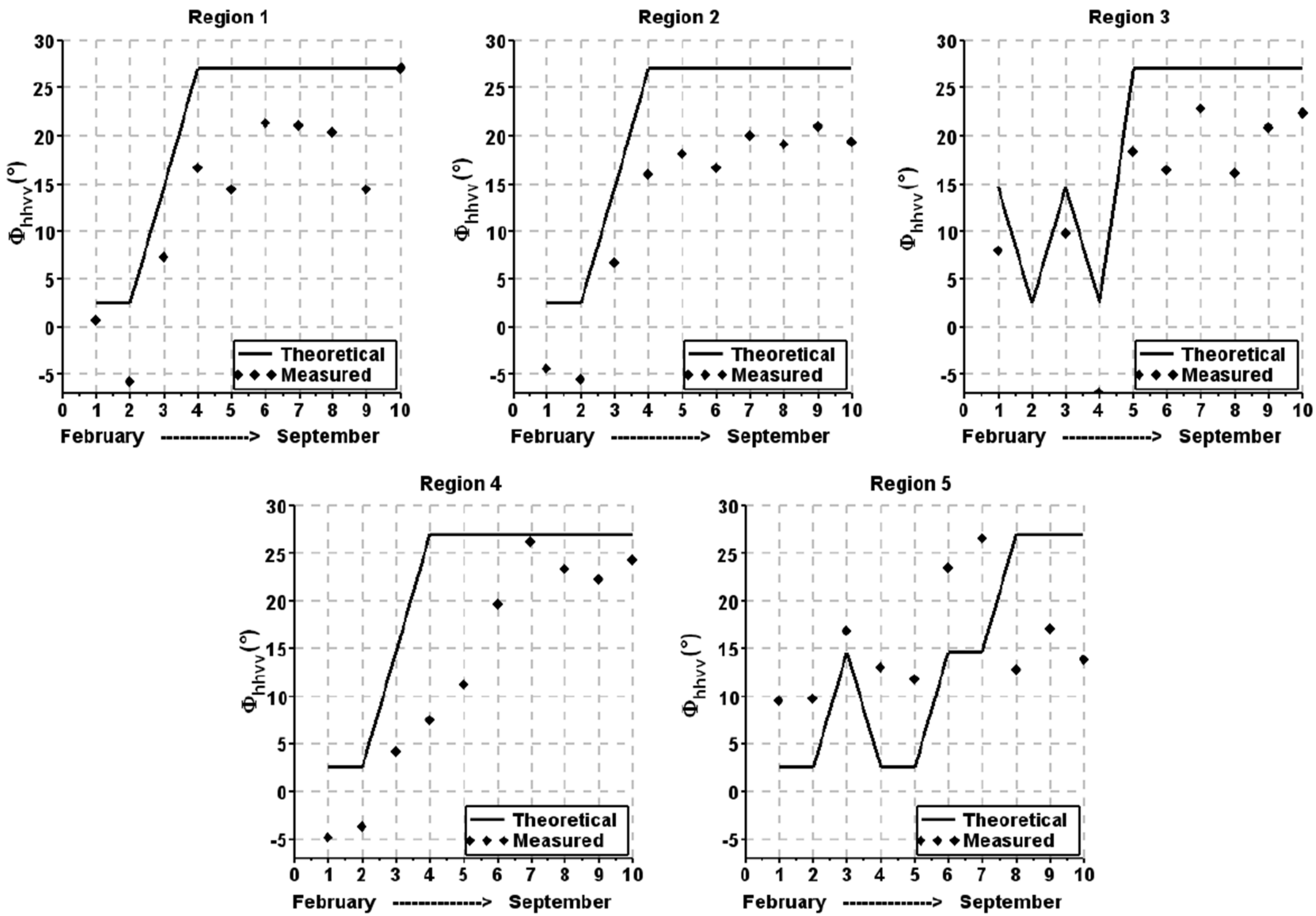
→ Laboratory measurements (water+salt, salts)
Lasne, Paillou, et al., IEEE TGARS, 2008

→ 3 cases considered (wet → dry):

– Saline water $\varepsilon = 53\text{-}26j$
– Wet NaCl crystals $\varepsilon = 7\text{-}11j$
– Dry NaCl crystals $\varepsilon = 3\text{-}3.5j$



Incidence angle θ = 39°
30
25
20
15
10
5
0
|Arg(HH)-Arg(VV)| (°)
Φ^{k}_{hhvv}
Φ_{hhvv}
intermediate roughness
very rough
Saline Water
ε' =53 and ε'' =26
Wet NaCl Cristal
ε' =7 and ε'' =11
Dry NaCl cristal
ε' =3 and ε'' =3,5


Region 1
Region 2
Region 3
Region 4
Region 5
Φhhvv(°)
Theoretical
Measured
February -------------> September
30
25
20
15
10
5
0
-5
0 1 2 3 4 5 6 7 8 9 10

Conclusion

→ Φ_{HHVV} is a promising simple polarimetric signature to detect and monitor salty surfaces

→ The phase difference can be explained by the complex dielectric constant of soils

→ We propose an IEM-derived approach that fits observations, to be further studied + inversion process

→ Need for field work experiments on chott El Djerid (inch Allah)