Analysis of GLORI airborne GNSS-R data for Soil Moisture estimation

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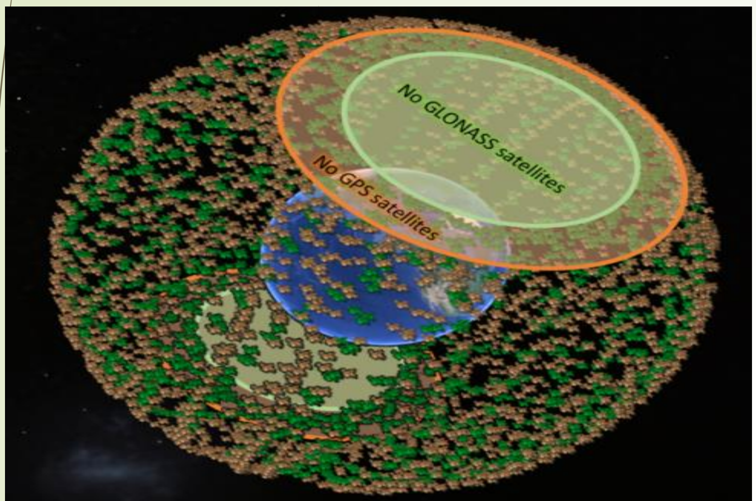
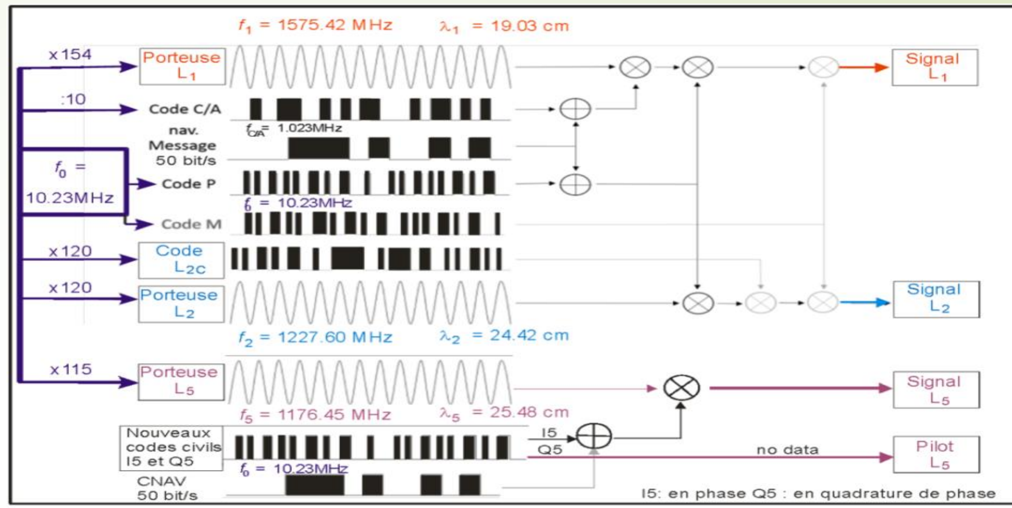
SUMMARY

- GNSS and GNSS-R
- GLORI 2021 CAMPAIGN
- GLORI data processing
- Results on Land Use
- Soil Moisture Estimation
- Conclusion

GNSS SATELLITE MEASUREMENTS



Here we can see the dense coverage of the two oldest GNSS constellations: the American GPS (orange) and the Russian system GLONASS (green).



Structure of the GPS signal (L1 for Glori, soon L5)

WHAT POTENTIEL OF GNSS FOR GEOPHYSICAL MEASUREMENTS?

GNSS-R APPROACH

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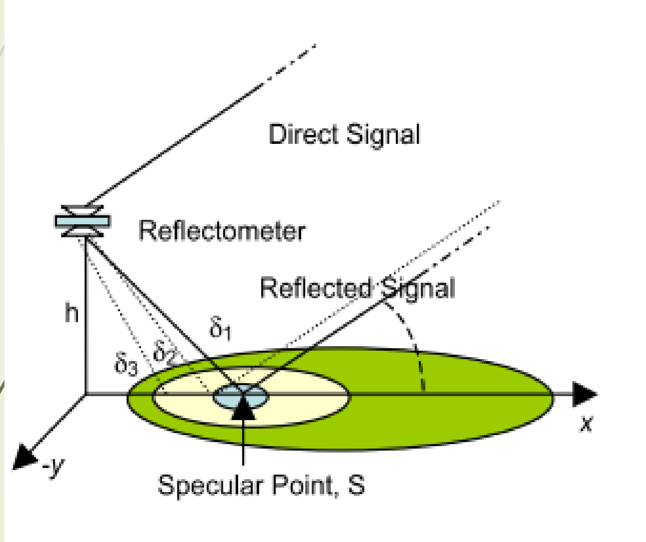
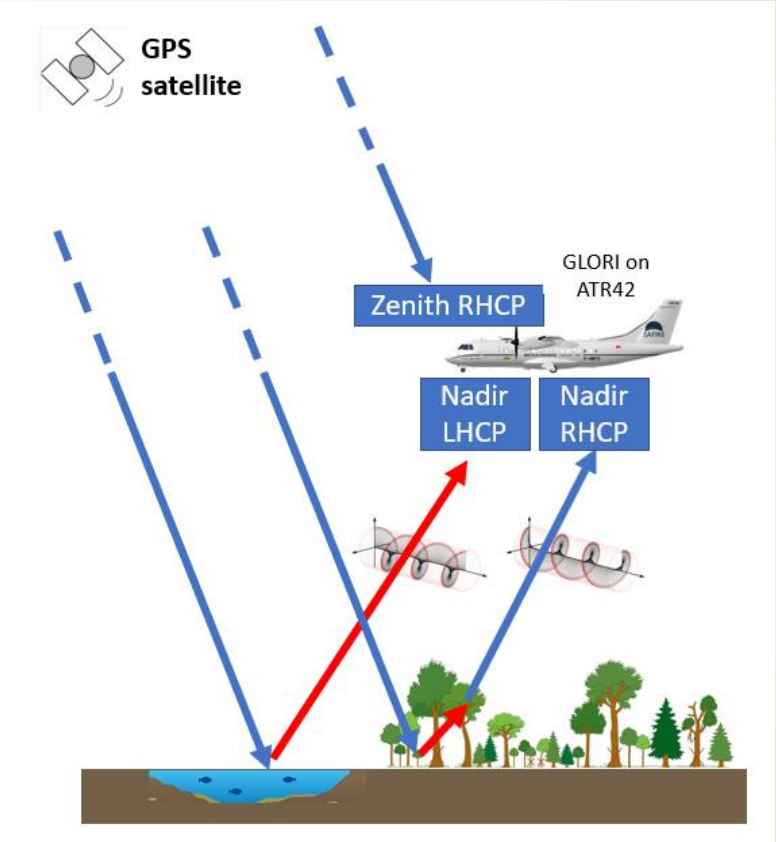
GNSS REFLECTOMETRY (GNSS-R: GLOBAL NAVIGATION SATELLITE SYSTEM - REFLECTOMETRY) is a bistatic radar remote sensing technology (transmitters and receivers are not in the same place) that uses microwave signals of opportunity from radio navigation constellations.





GNSS-R by waveform analysis technique: each antenna pair corresponds to a channel that measures the direct signal with its up-looking antenna and another channel measuring the signal reflected by the surface with its down-looking antenna.

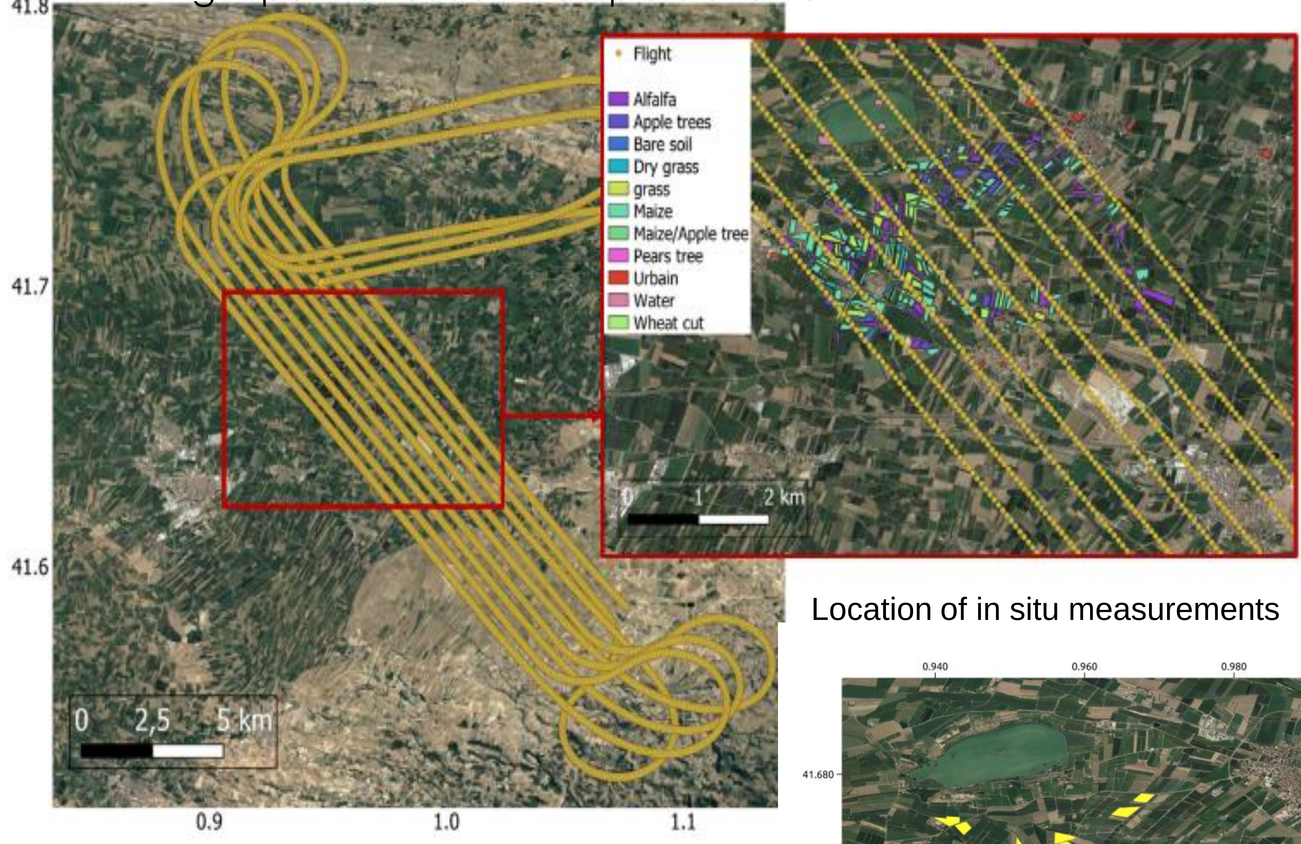
J. Darrozes, N. Roussel, M. Zribi, 2016.

GLORI : GLObal navigation satellite system Reflectometry Instrument

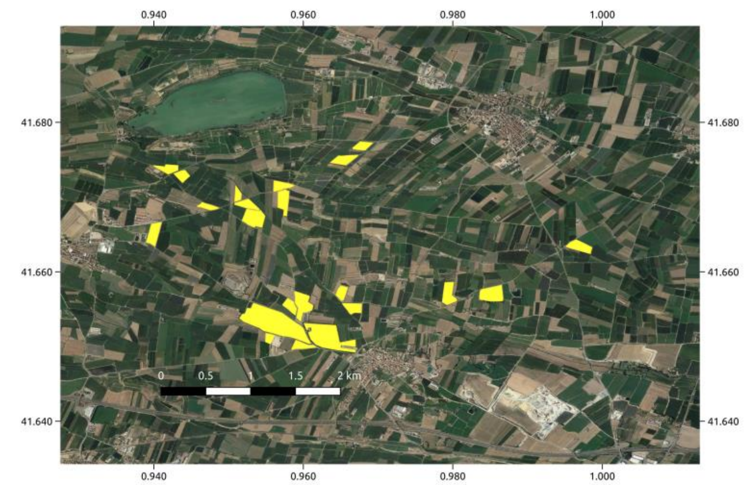
GLORI campaign

GLORI CAMPAIGNS : URGELL

Flight path and identified plots overflown



Location of in situ measurements



IN SITU MEASUREMENTS AND LAND COVER

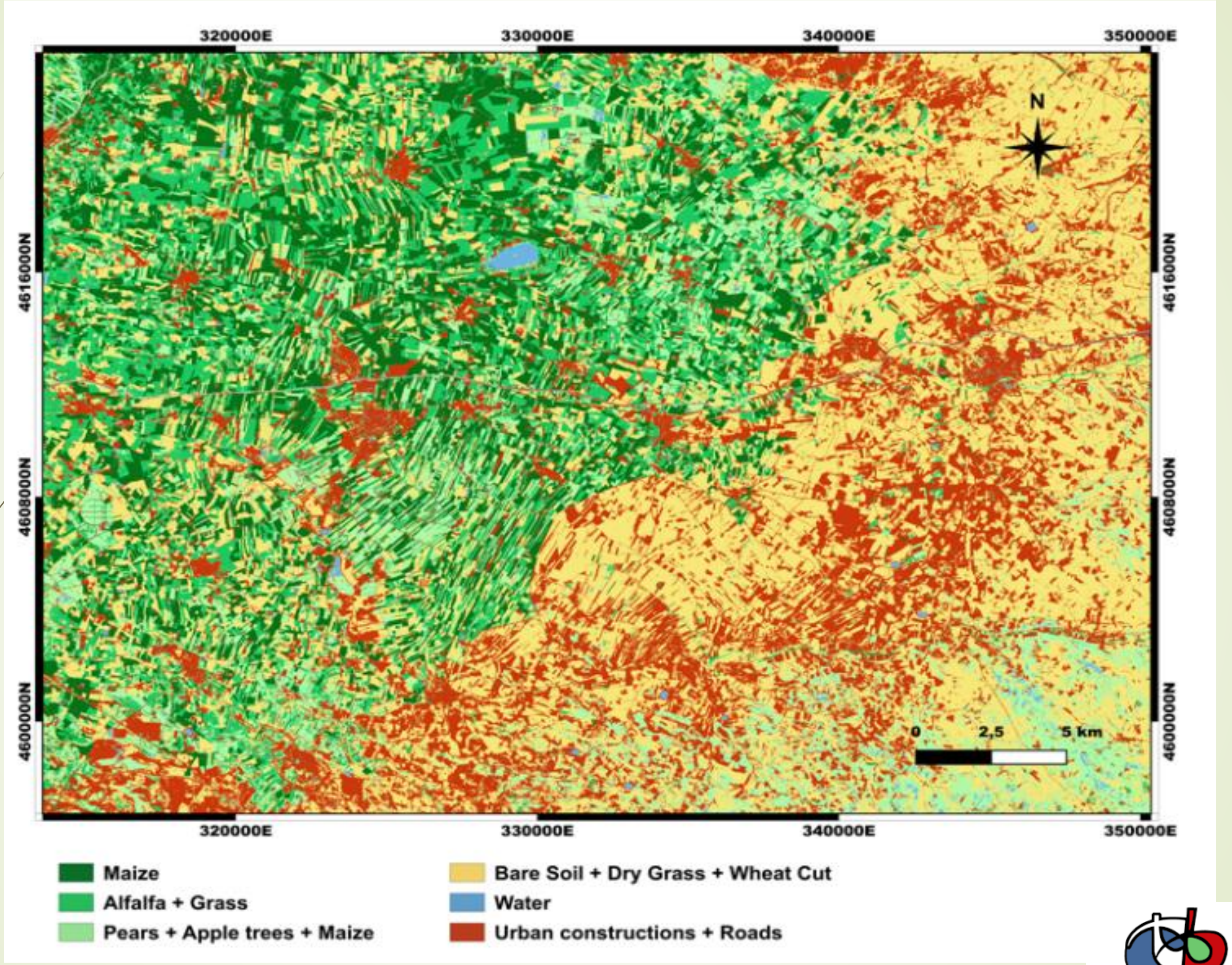





	Hrms (cm)	Lc (cm)	M_v (m^3/m^3)	LAI (m^2/m^2)
22/07/2021	[0.4-1.84]	[4-12.18]	[0.06-0.34]	[0-3.14]
27/07/2021	-	-	[0.12-0.40]	-
28/07/2021	-	-	[0.1-0.43]	[0.14-3.42]

Contact : M. Le Page

LAND USE MAP

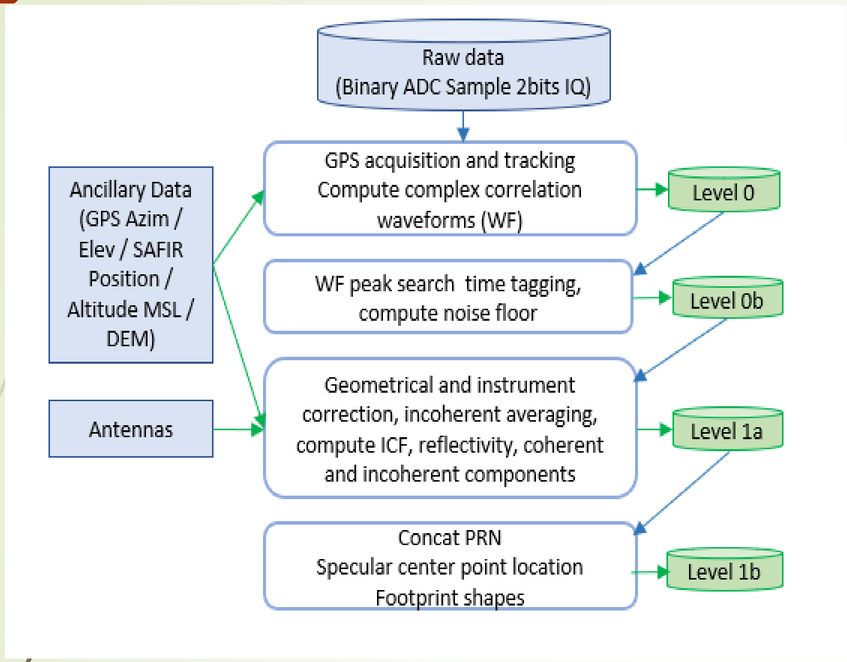


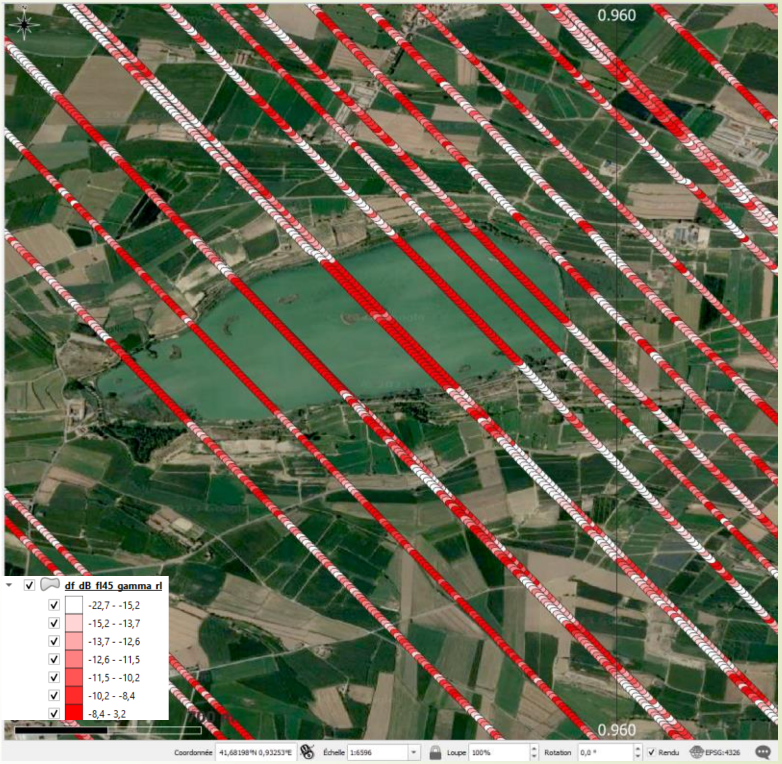
Orfeo Tool Box, Ground Truth data and Sentinel 2 data

ORFEO ToolBox

cnes

GLORI DATA PROCESSING





Cross-correlated waveform : $Y(\tau, f) = \frac{1}{T_i}\int_{T_i} u_{d,r}\, a(t-\tau)e^{i(f_c+f)t}dt$

Corrected ICF = Interferometric Complex Field

$$ICF_{corr} = \frac{|Y_{r,\max}| - B_r}{|Y_{d,\max}| - B_d} e^{j(\phi_{r,\max} - \phi_{d,\max})} \frac{G_d}{G_r}$$

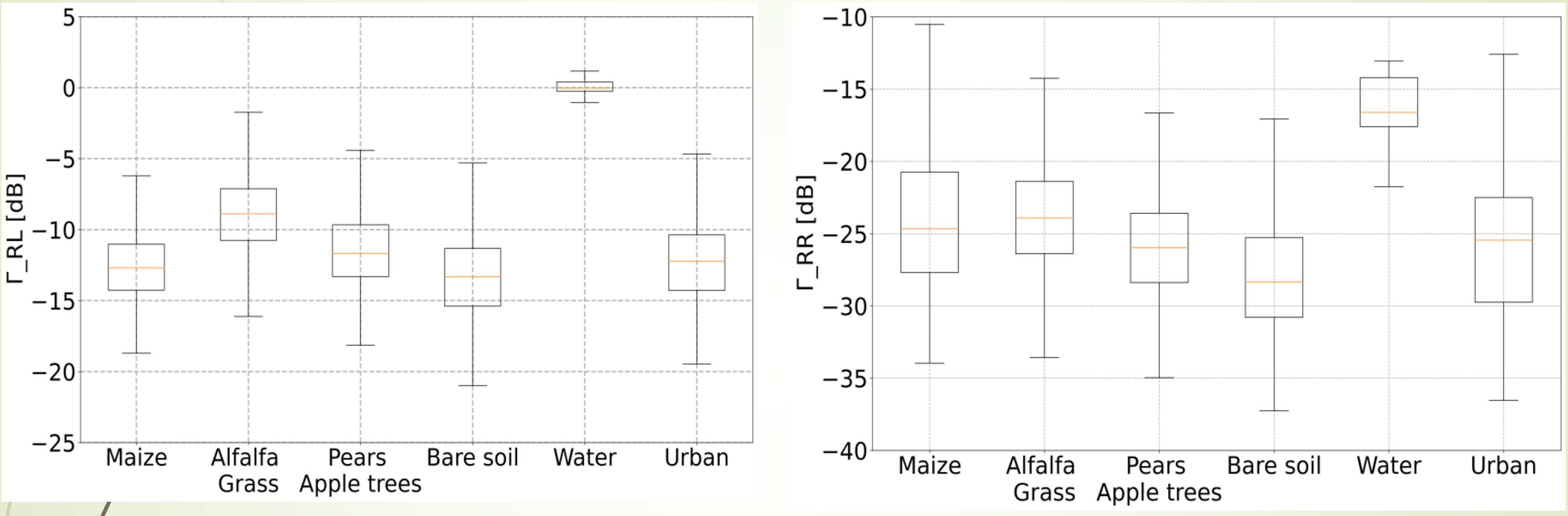
$$\Gamma'_{pq} = \left| \left\langle \frac{Y_{r,q}(\Delta\tau, f)}{Y_{d,p}(0, f)} \right\rangle \right|^2$$

$$\Gamma'_{pq} = \left\langle \left| ICF_{corr,pq} \right|^2 \right\rangle - \sigma^2_{|ICF_{corr,pq}|}$$

E. Motte et al, sensors, 2016
A. Egido et al, IEEE 2014

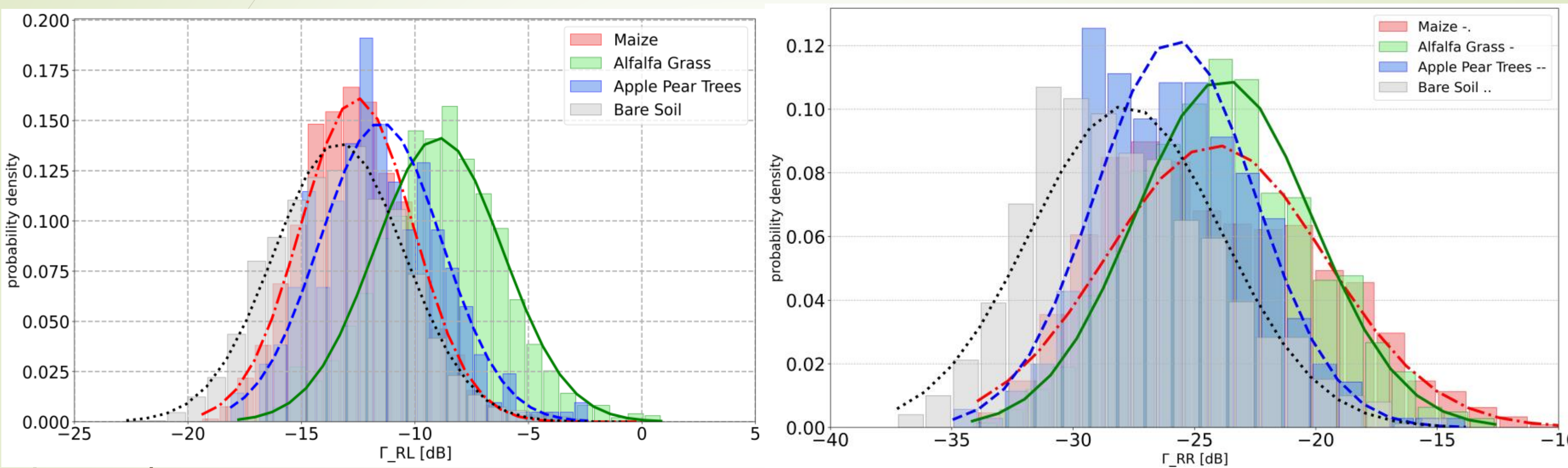
RESULTS ON LAND USE

REFLECTIVITY VARIATIONS : FUNCTION OF LAND USE (1/2)



Analysis of the GNSS-R reflectivity level as a function of land use (flight 45) a) $\boldsymbol{\Gamma_{RL}}$ and b) $\boldsymbol{\Gamma_{RR}}$

REFLECTIVITY VARIATIONS : FUNCTION OF LAND USE 2/2



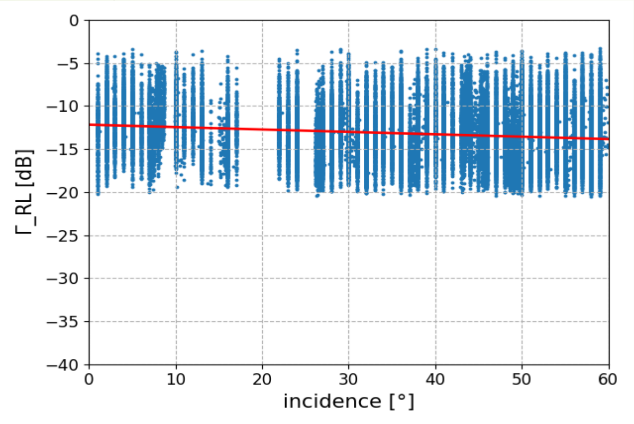
Distributions of the reflectivity for the four agricultural land uses (flight 45)
a) Normal for Γ_{RL} and b) Normal for Γ_{RR}

Flight 45 Land uses	Γ_{RL}		Γ_{RR}	
	μ	σ	μ	σ
Bare soil	-13.34	2.87	-27.82	3.95
Maize	-12.55	2.48	-24.13	4.50
Alfalfa/Grass	-8.96	2.82	-23.81	3.65
Trees	-11.50	2.68	-25.80	3.28

M. Zribi, K. Dassas, V. Dehaye, P. Fanise, E. Ayari, M. Le Page IEEE GRSL, in review, 2023

GNSS-R FOR SOIL MOISTURE ESTIMATION

REFLECTIVITY VARIATIONS : FUNCTION OF INCIDENCE ANGLE



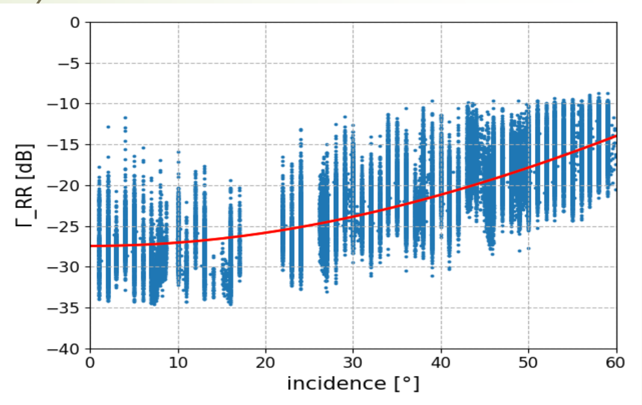
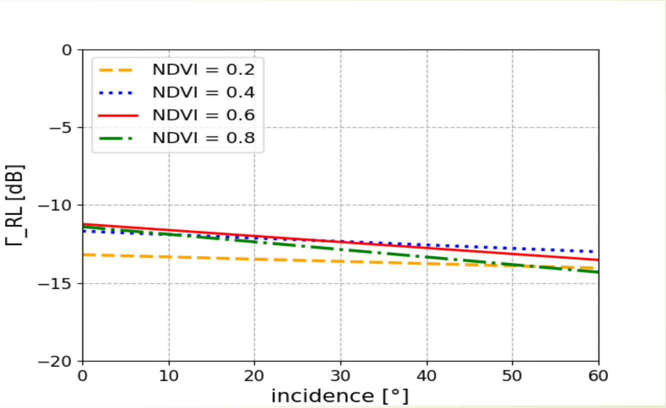
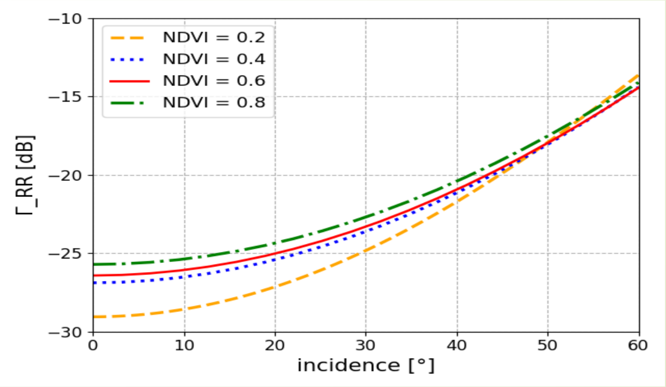


Illustration of GLORI reflectivity data over the Urgell site as a function of incidence angle: a) $\boldsymbol{\Gamma_{RL}}$ and b) $\boldsymbol{\Gamma_{RR}}$



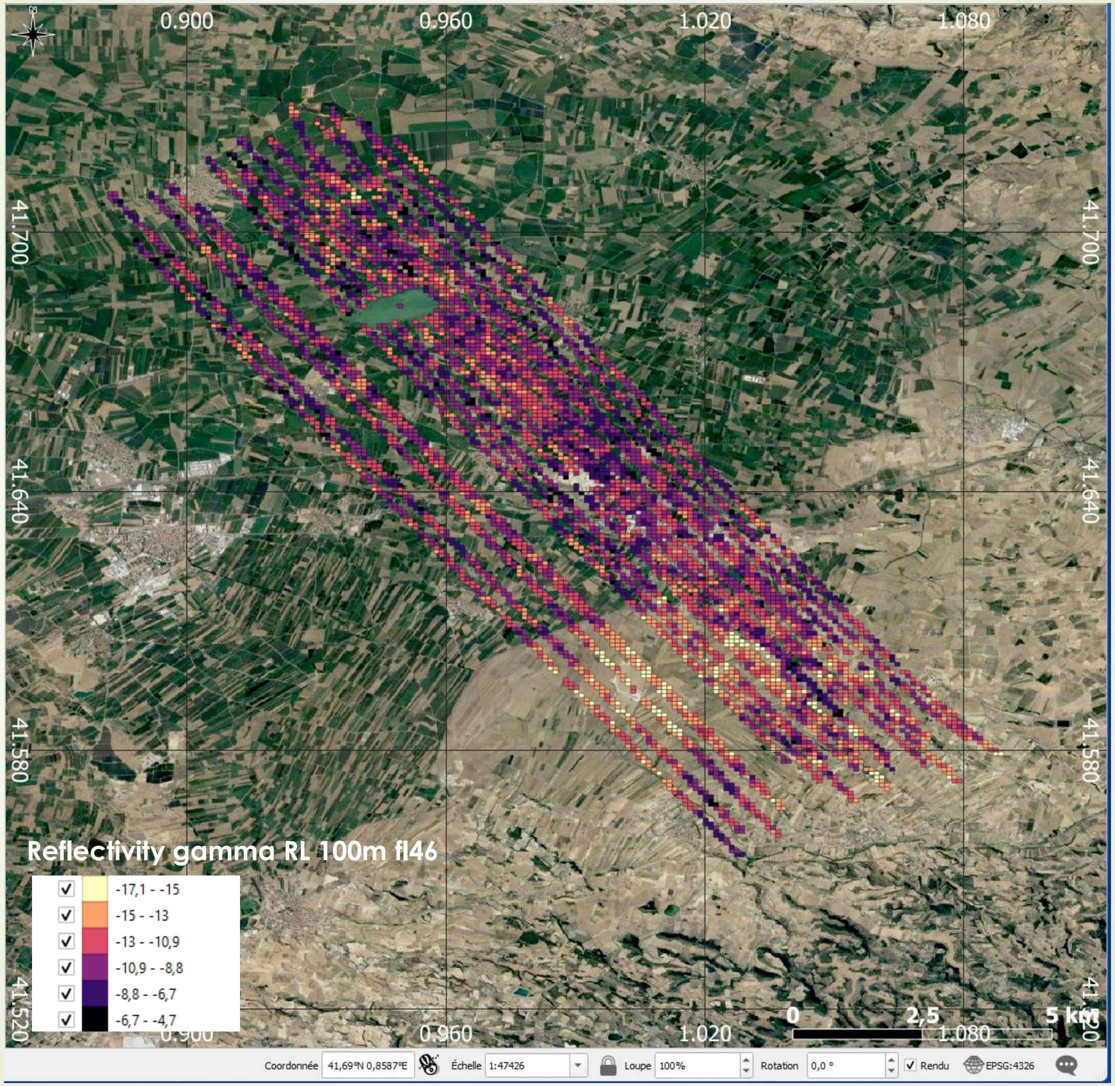
$$\Gamma_{RL}(20°) = \Gamma_{RL}(\theta) + b(NDVI)(\theta - 20°)$$



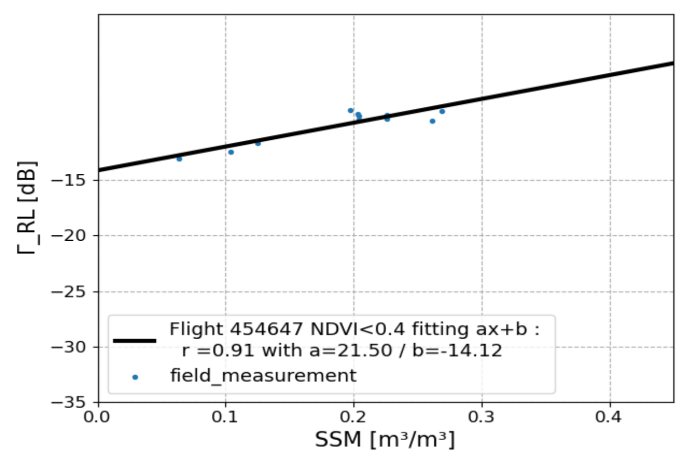
$$\Gamma_{RR}(20°) = \Gamma_{RR}(\theta)\left(\frac{cos(20°)}{cos(\theta)}\right)^{\beta(NDVI)}$$

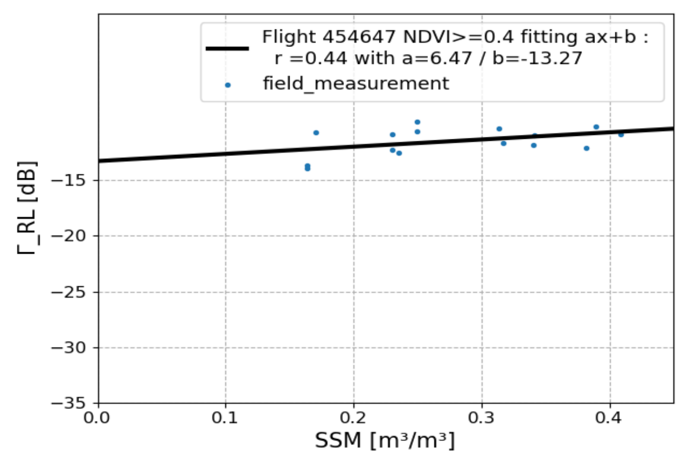
R. Fernandez-Moran et al, Remot. Sens. 2017

NORMALIZED GLORI DATA MAPPING



REFLECTIVITY SENSITIVITY TO SOIL MOISTURE





$$\Gamma_{pq}(\theta) = \Gamma_{pq}^{soil}(\theta).e^{-\frac{2\tau_{pq}}{sin\theta}}\left(1-\omega_p\right)^2$$

V. Zavorotny et al, IEEE 2014

$$\tau_{pq} = c.NDVI$$

$$\Gamma_{pq} = \Gamma_{pq}^{soil}.e^{-2c.NDVI}$$

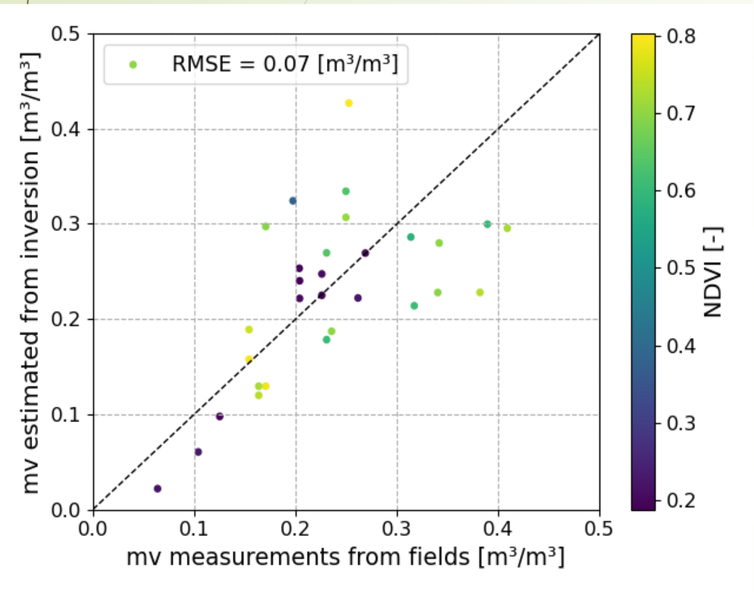
$$\Gamma_{RL\,dB}^{soil} = \gamma\,Mv + \delta$$

$$\boxed{\Gamma_{RL\,dB} = \gamma\,Mv + \mu\,NDVI + \delta}$$

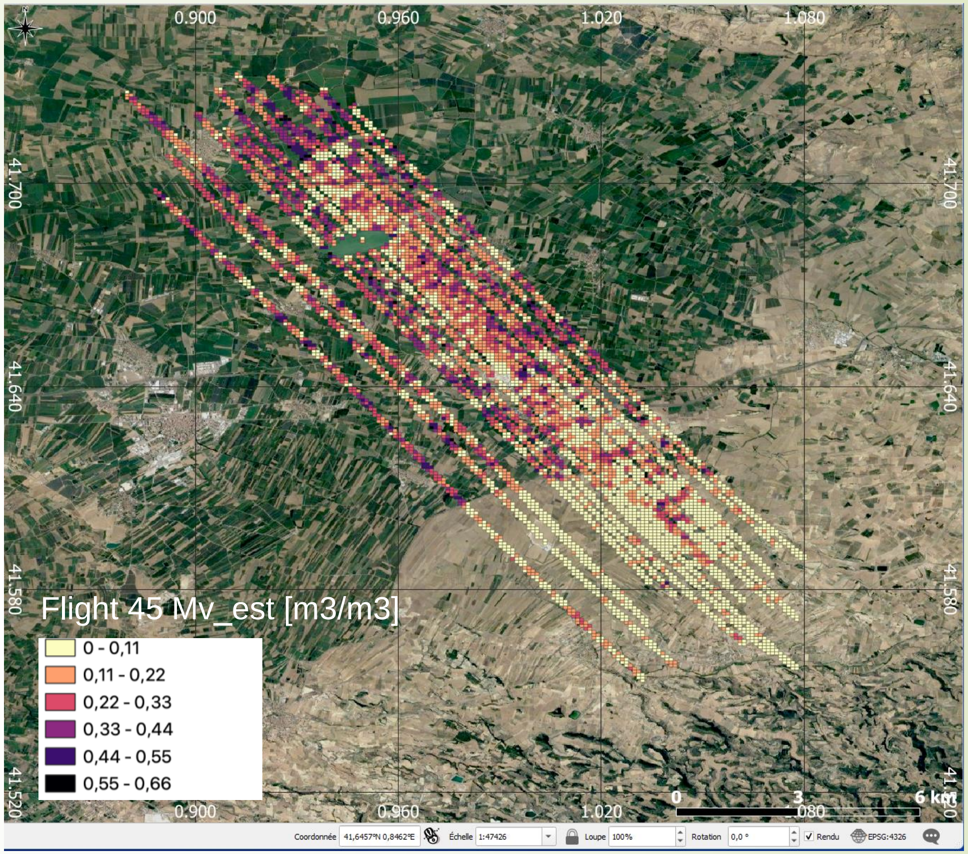
where γ is the sensitivity of the reflectivity to soil moisture, μ is the sensitivity of the reflectivity to vegetation growth through the *NDVI*, and δ is a constant related to the roughness mean effect.

SOIL MOISTURE MAPPING

Calibration of the model with a 3-fold cross-validation approach



Intercomparison between ground measurements and estimated soil moisture from Γ_{RL} data inversion

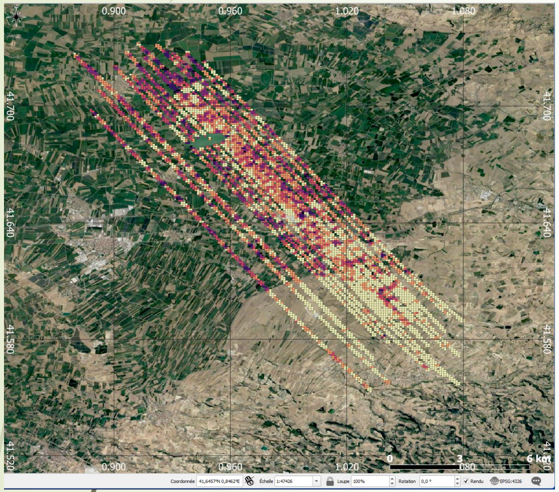


Map of *SSM* retrieved from the Γ_{RL} inversion on 22/07/2021, with a spatial resolution equal to 100 m

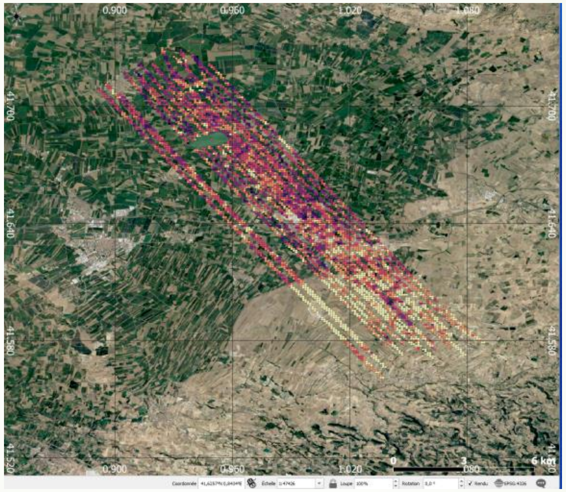
M. Zribi, V. Dehaye, K. Dassas, P. Fanise, M. Le Page, P. Laluet, and A. Boone, IEEE JSTARS, 2022

SOIL MOISTURE MAPPING

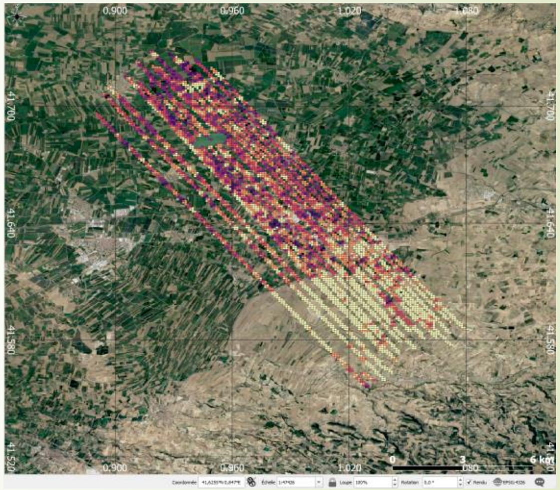
22/07/21 Flight 45 : dry



27/07/21 Flight 46 : wet,
after a precipitation event



28/07/21 Flight 47 : drying process



Mv_est [m3/m3]

- 0 - 0,11
- 0,11 - 0,22
- 0,22 - 0,33
- 0,33 - 0,44
- 0,44 - 0,55
- 0,55 - 0,66

SOIL MOISTURE STATISTICS

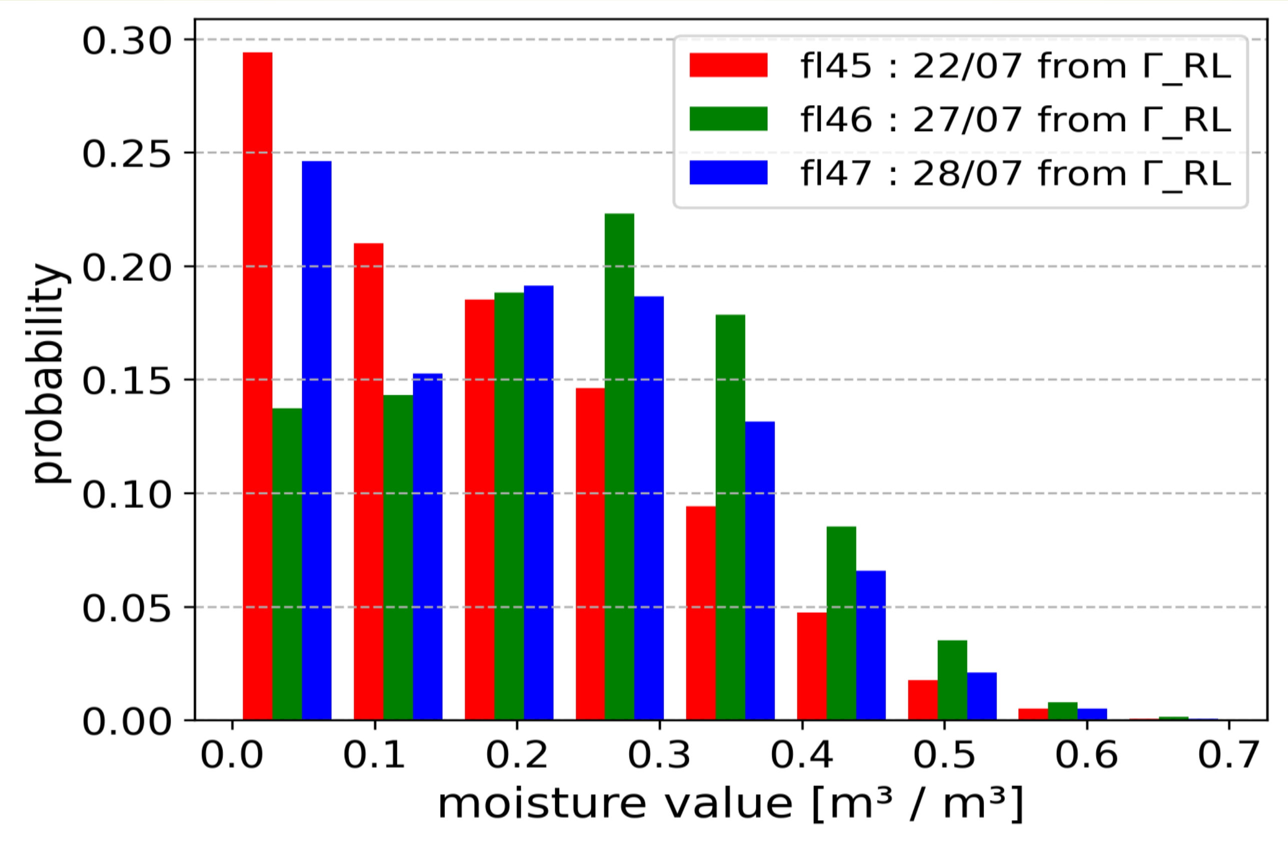


Illustration of soil moisture level distributions over the Urgell site for the three analyzed flights.

CONCLUSION

- At the study site, over water cover, very strong signals for the RL and RR polarizations were observed. The four agricultural classes (maize, bare soil, alfalfa, and trees) considered in this study showed averages over a range of 4.5 dB.

- An analysis of the behavior of GNSS-R reflectivities for the two polarizations RL and RR and as a function of incidence angle is proposed.
- A simplified tau-omega model is proposed to describe the relationship between the measured signals and the two variables *SSM* and the *NDVI* of the vegetation.
- The model validation allowed good precision for Γ_{RL}, with an *RMSE* of 0.07 m^3/m^3. Moisture maps were thus created at a spatial resolution of 100 m for each airborne acquisition, illustrating strong differences between irrigated and non-irrigated areas, as well as temporal variations related to precipitation events.
- Limitations to study SM versus gamma RR, due to heterogeneity of the vegetation. Also limitation due to the number of points. But great potential for further studies (next = L5/E5 to prepare the HydorGNSS)

Thanks for your attention!