# Surface soilmoisture over Sahel derivedfrom ENVISAT radar altimetrybackscattering coefficients

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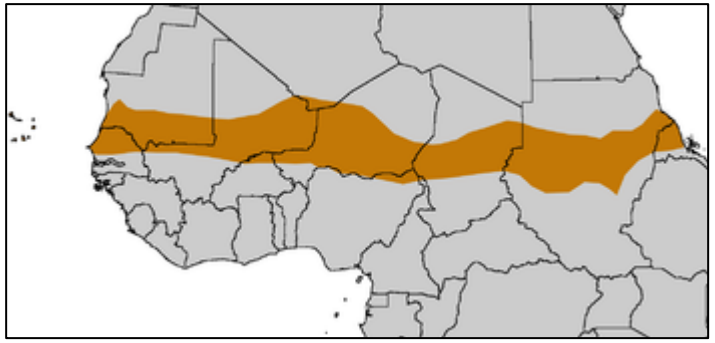
# Context

In the Sahelian region of West-Africa, soil moisture drives many surface processes:

- land surface fluxes
- land surface-atmosphere interactions
- Vegetation productivity
- Soil organic matter mineralization



Sahel belt

Sahel presents one of the strongest feedbacks between surface soil moisture and precipitation (Koster et al. 2004)

# Soil moisture detection using radar techniques

- Active microwave remote sensing has demonstrated considerable capabilities in estimating Surface Soil Moisture (SSM) in semi-arid regions (e.g. Wagner and Scipal, 2000; Mladenova et al., 2010)

- It results from the high sensitivity of radar sensors to the variations of surface dielectric properties mainly linked to changes in SSM

- In semi-arid regions, observations at low incidence angles are strongly correlated to SSM because vegetation effects are minimized (Tansey et al., 1999)

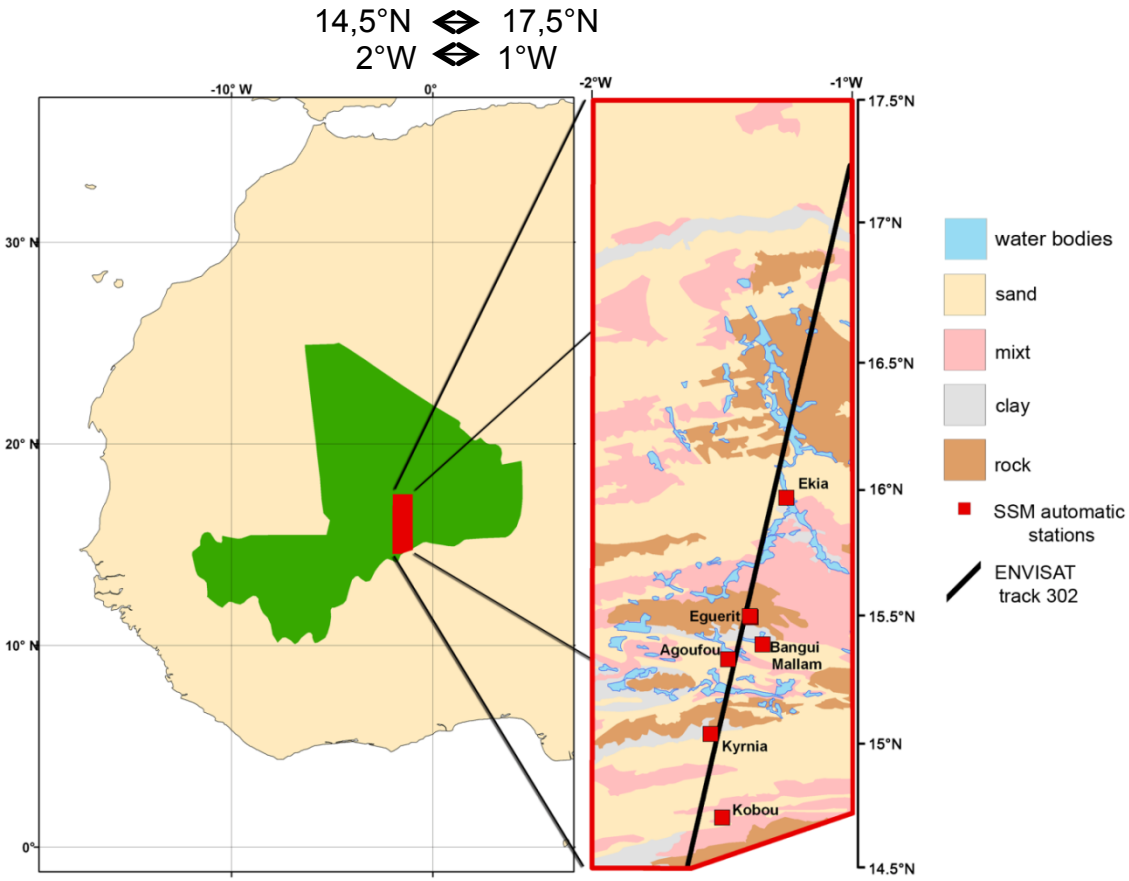
- Few studies use radar altimetry backscattering coefficient, but its spatio-temporal variations can be related to soil roughness and SSM (Ridley et al., 1996)

# Outline

- Study area
- Datasets
- Results
- Spatio-temporal variations along the latitudinal transect
- Time variations of the backscattering coefficient
- Relationships between SSM and backscattering coefficients
- Effect of vegetation on backscattering coefficient
- Surface Soil moisture estimates
- Conclusion
- Perspectives

# Study area

AMMA-CATCH northermost site in West-Africa: Gourma region in mali (Mougin et al., 2009)




Dry season

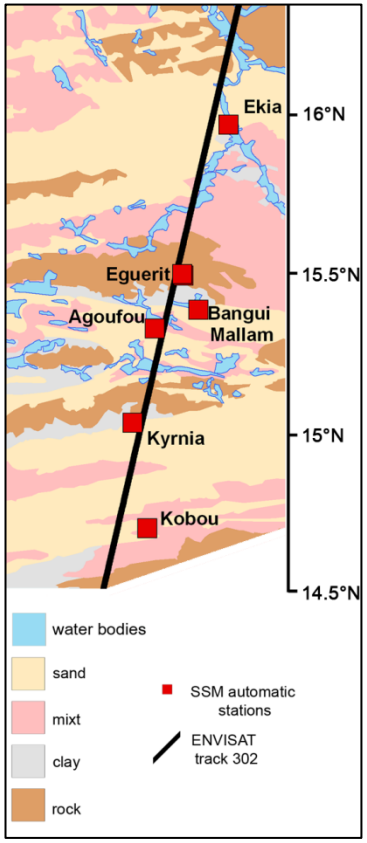
Wet season

Climate: Sahel bioclimatic zone: 100 <rainfall< 450 mm/year
Soil types: sand (58%), rock (23%), mixt (15%), clay(4%)
Vegetation: mostly low herbaceous layer

# Datasets

- **Satellite data: ENVISAT RA-2**
  - Backscattering coefficients atS (λ=9cm) and Ku (λ=2.3cm) bands
  - 4 retracking algorithms

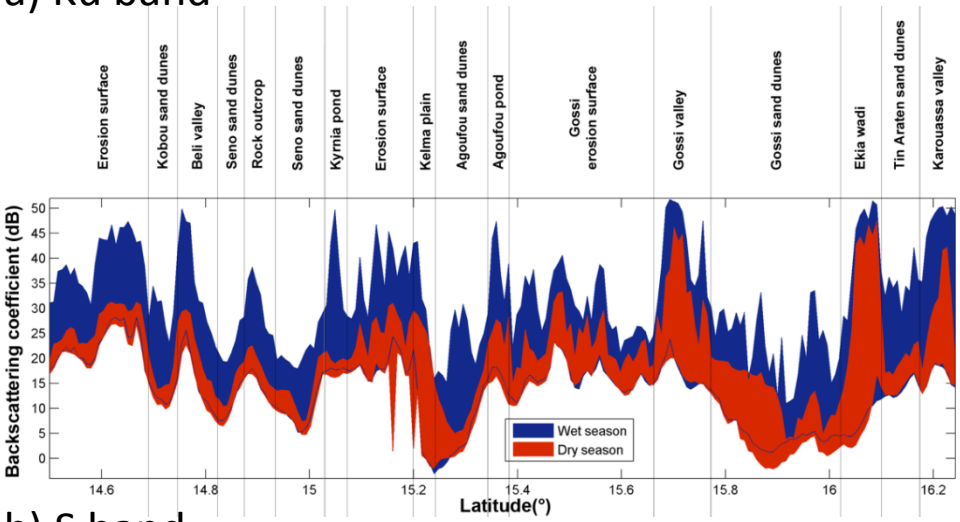
- **Ground data**
  - Soil moisture stations (15mn resolution): 6
  - Rainfall gauges
  - Vegetation: LAI (Agoufou site)



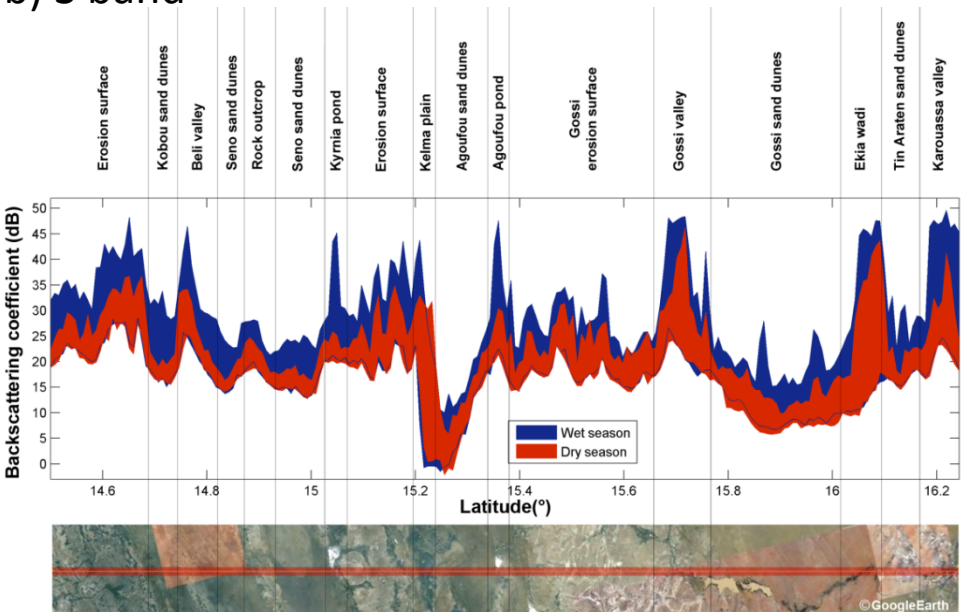

| Site name | | Agoufou | Bangui Mallam | Eguerit | Ekia | Kobou | Kyrnia |
|---|---|---|---|---|---|---|---|
| Latitude | | 15.3453° | 15.3978° | 15.5026° | 15.9651° | 14.7284° | 15.051° |
| Longitude | | -1.47913° | -1.34556° | -1.391° | -1.2534° | -1.502° | -1.546° |
| Soil type | | sand | sand, clay | rock | sand | sand, rock | sand, clay |
| SSM | Period | 2005 -2010 | 2005 -2010 | 2008 -2009 | 2005 -2010 | 2008 -2010 | 2007 -2010 |
| | Depth (cm) | 5, 10, 40 | 5, 10, 30 | 5 | 5, 10, 30 | 5, 10, 30 | 5, 10, 30 |
| | Resolution (min) | 15 | 15 | 15 | 15 | 15 | 15 |
| Rain gauge | Period | 2005 -2010 | 2005 -2010 | 2008 -2009 | 2005 -2010 | 2005 -2010 | 2005 -2009 |
| | Resolution (min) | 5 | 5 | 5 | 5 | 5 | 5 |

# Results

a) Ku band

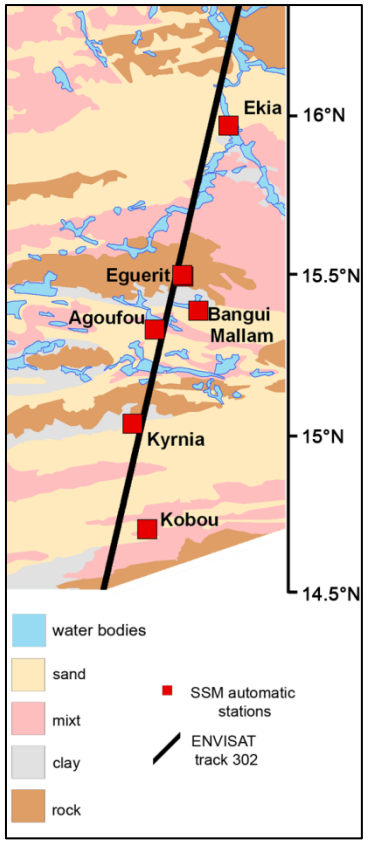



b) S band




**Spatial resolution: 0.08° (~1km)**

**Wetseason: June - September**
**Dry season: December - April**



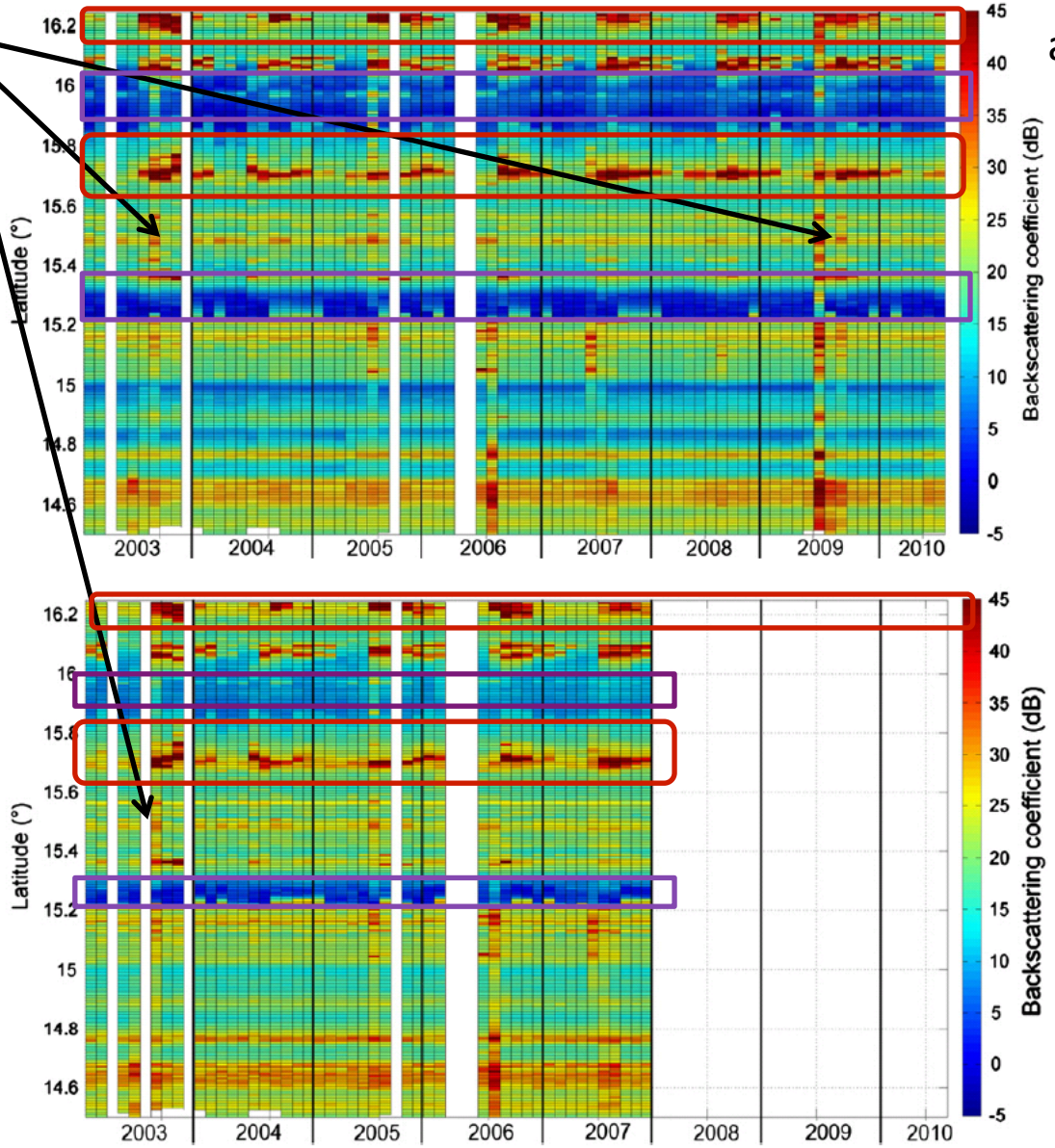

Maxima of $\sigma_0$ during the peak of the rainy season in relation with rainfall and SSM

# Spatio-temporal variations along the latitudinal transect (Ice-1)

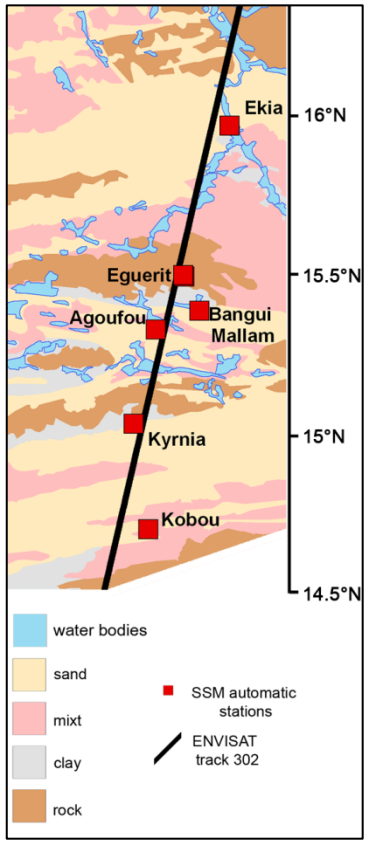
**Rain events**
**$\sigma_0$ is high**

**Seasonality**

**Sand dunes**
**$\sigma_0$islow**



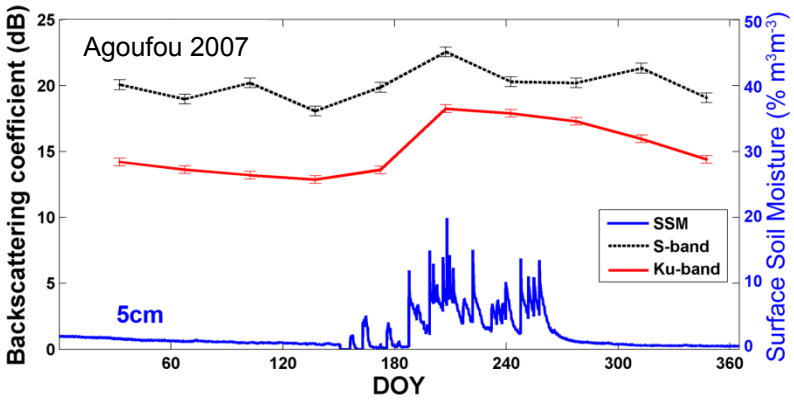

a) Ku band



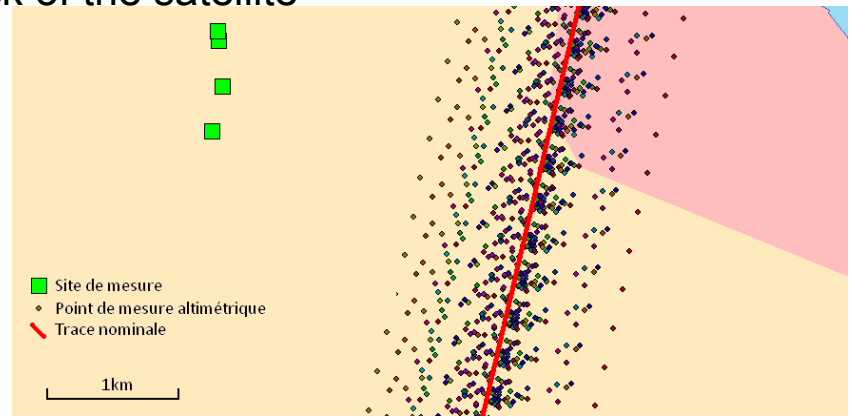

b) S band

# Time variations of the backscattering coefficient Ice-1

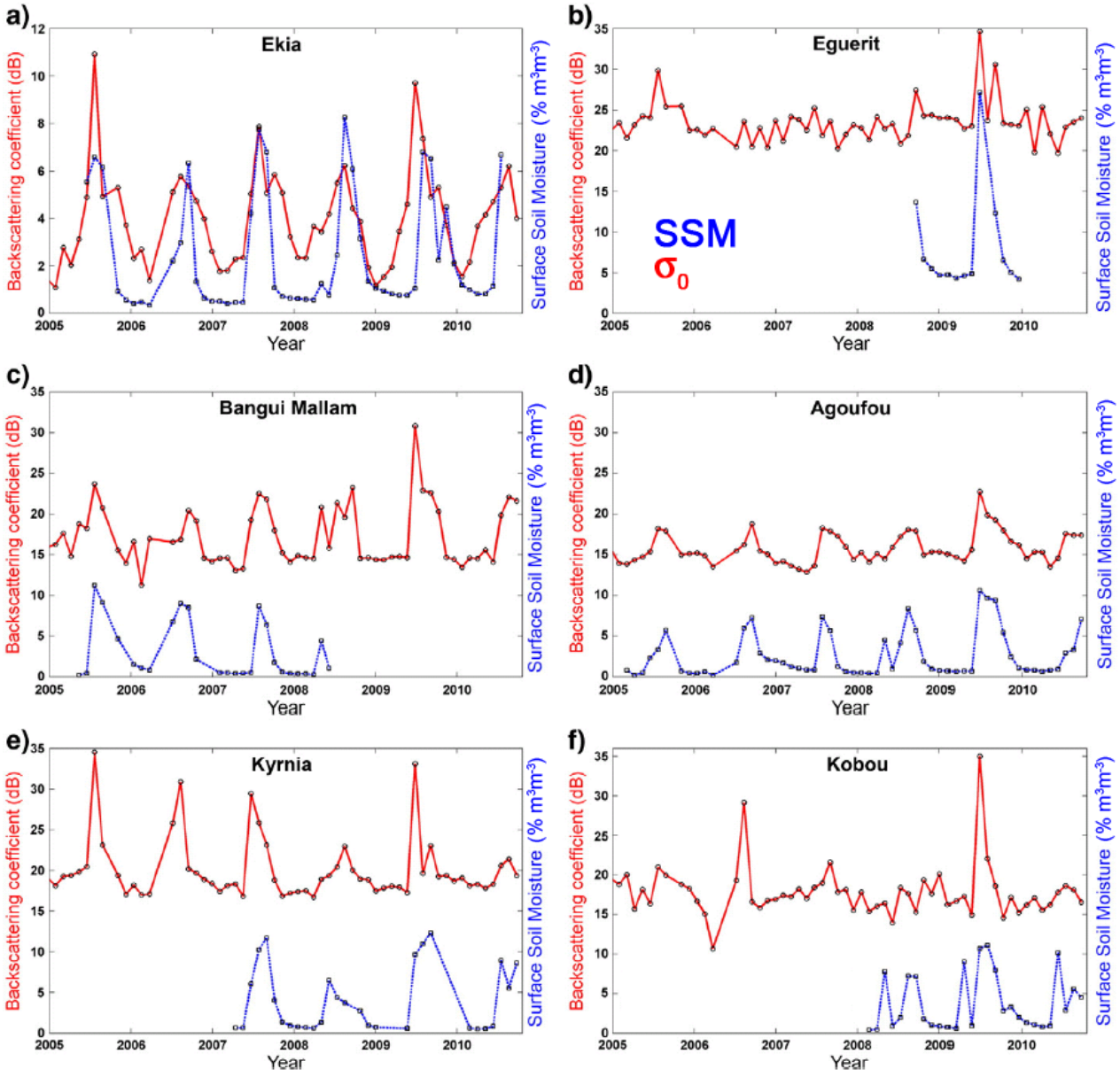
- The variations of $\sigma_0$ during the dry season of about 2 dB
  → instrumental noise ((Ku) 0.29 dB – (S) 0.37dB )

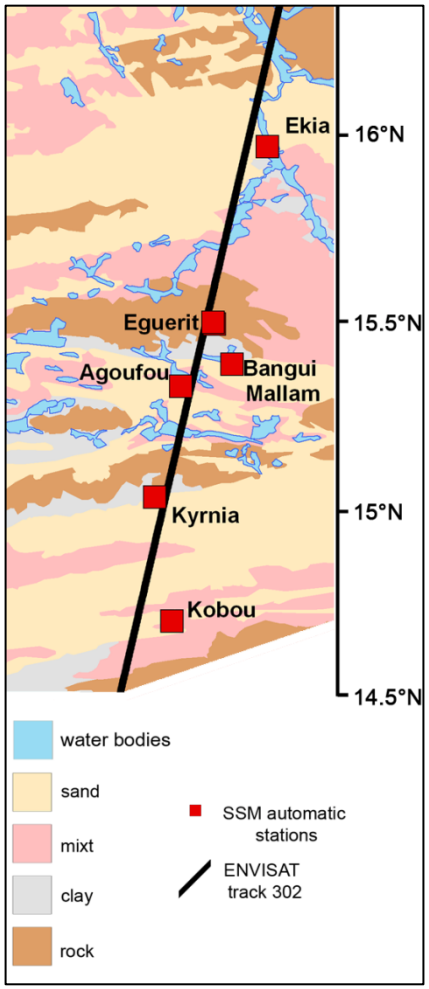



→ changes in the sampled surface caused by variations around the nominal track of the satellite

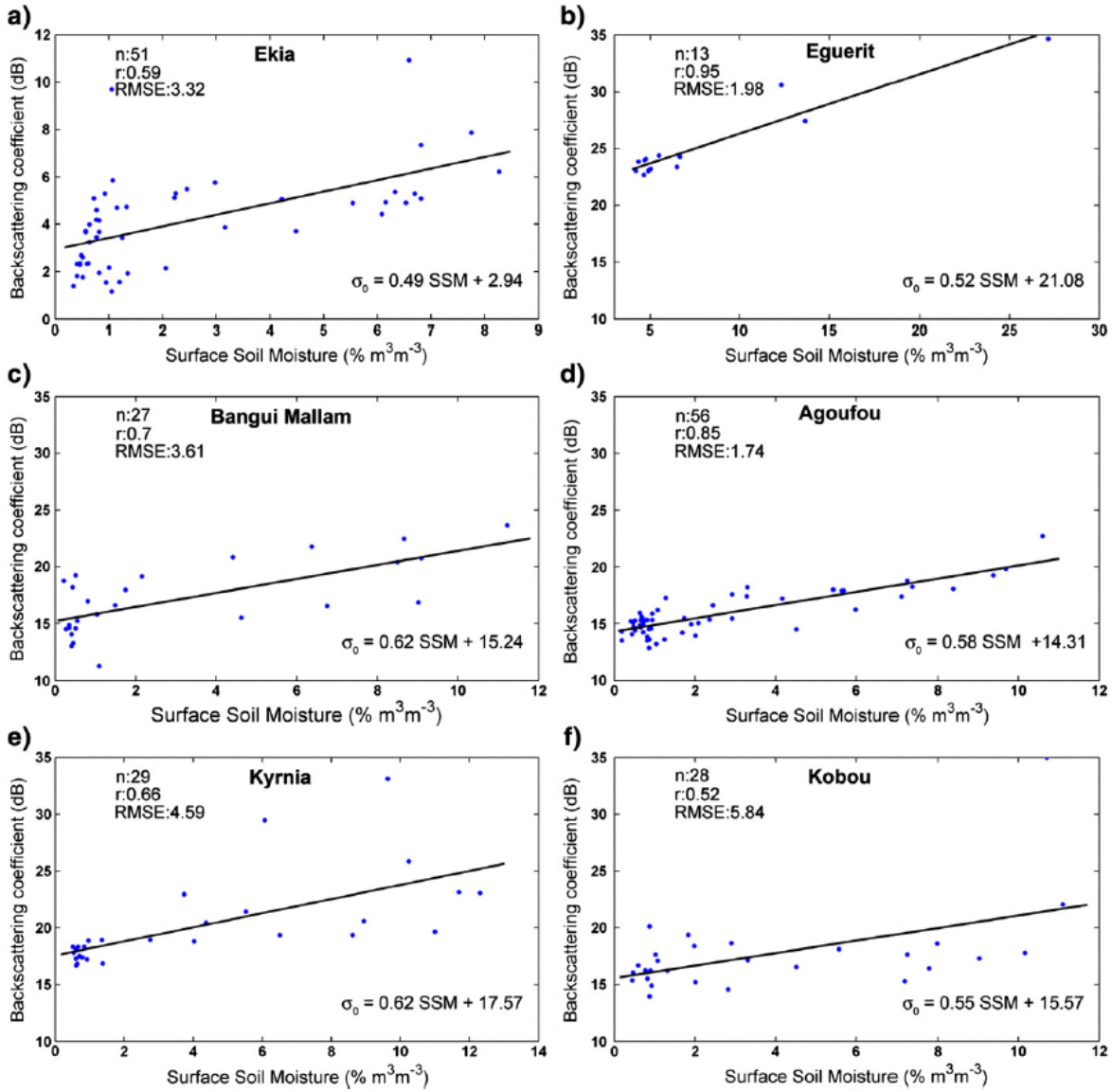


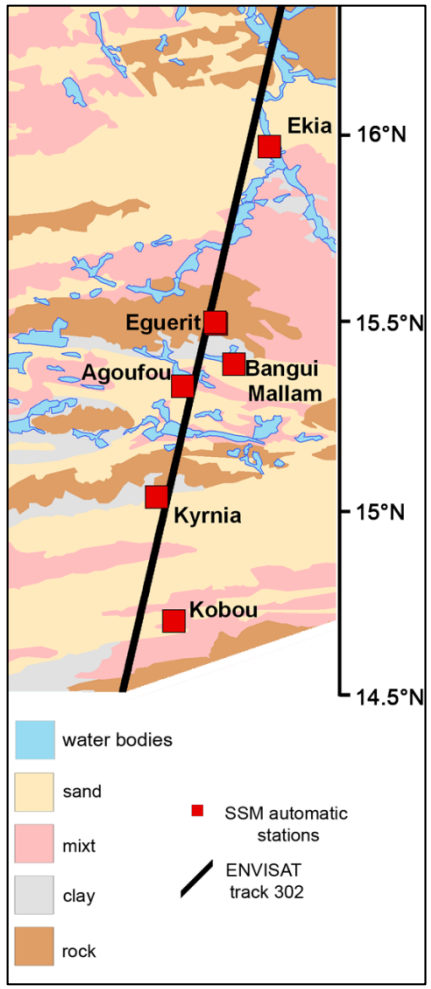
# Time variations of the backscattering coefficient Ice-1



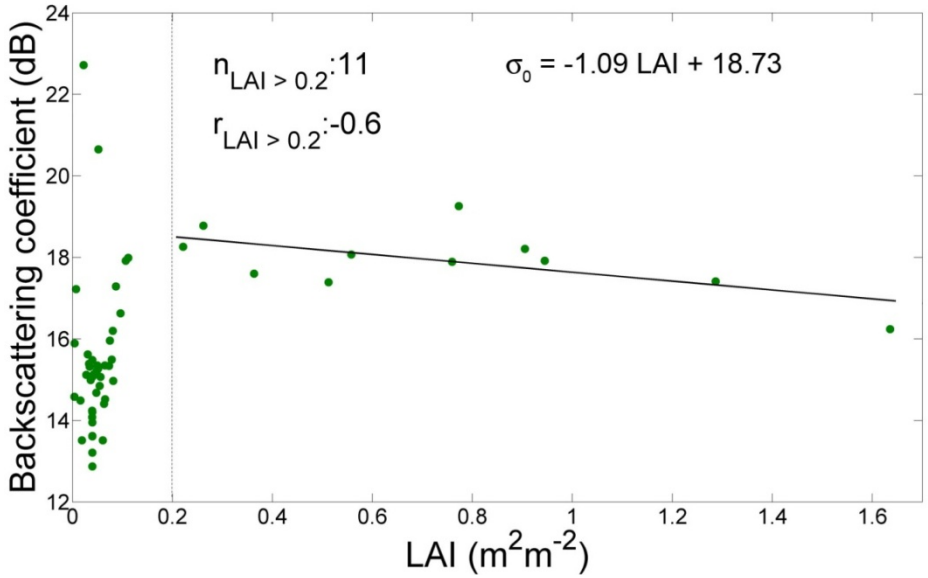



# Relationshipsbetween SSM and backscattering coefficients Ice-1 (Ku band)



# Effect of vegetation on backscattering coefficient

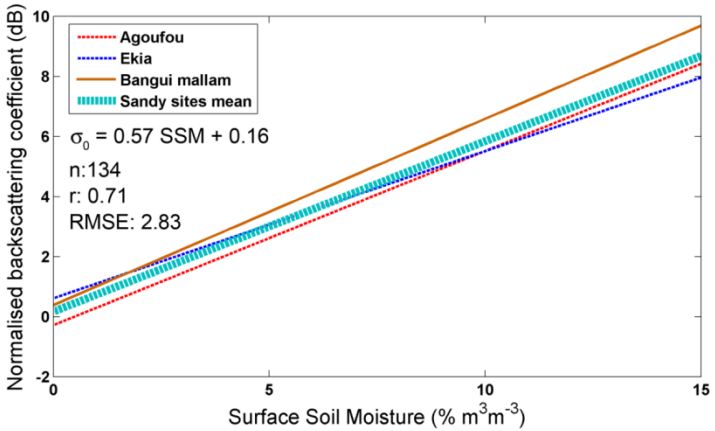



- For LAI>0.2, $\sigma_0$ ↘as LAI ↗ *(*correlation coefficient of -0.6)

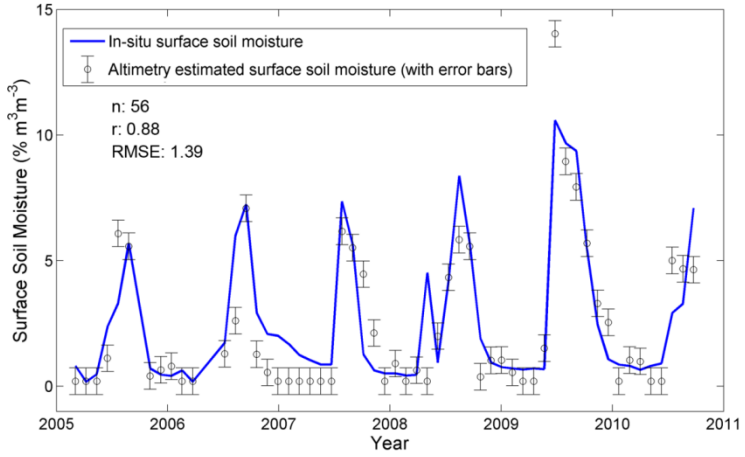
  =>weak attenuation of the radar wave by the vegetation layer due to:
  - → nadir-looking configuration
  - → small vegetation density

- For LAI<0.2: effect of SSM and eventuallyenhancement by soil-vegetation interactions

# Surface Soil moisture estimates

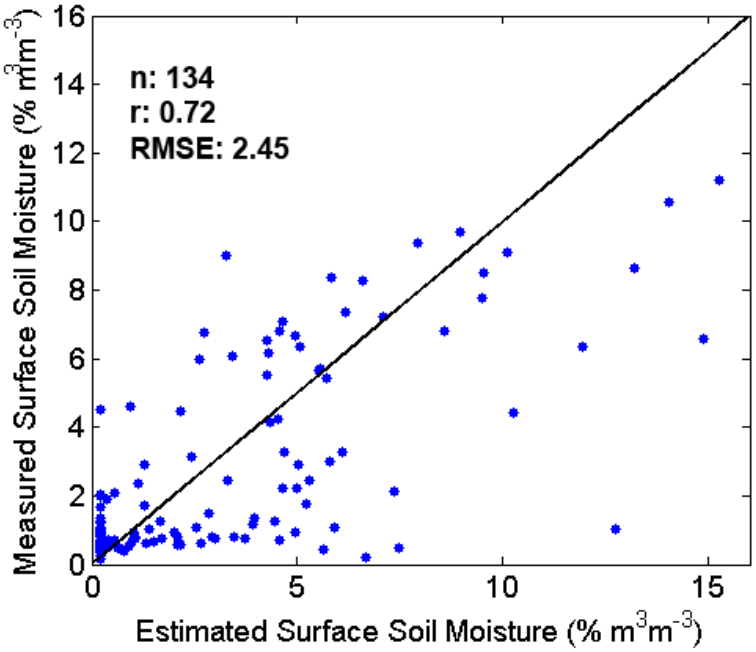



Linear regression of the Ice-1 normalized backscattering coefficient σ0 versus volumetric soil moisture at 5 cm for the sandy sites




Time variation of SSM at Agoufou, measured at 5 cm depth and estimated using the general σ0–SSM relationships

Scatterplot of measured SSM versus altimetry-derived SSM at 5cm depth for the 3 sandy sites



# Conclusion

- A linear relationship between radar altimetry backscattering coefficients and SSM is established for the dominant sandy sites, similar to the ones previously found using ENVISAT-ASAR data over the same study area (see Baup et al., Remote Sens. Env. 2007; Hydrol. Earth Syst. Sci., 2011)

- Better results are obtained for $\sigma_0$ processed with Ice-1, Ice-2, and Sea-Ice algorithms as Ocean retracking algorithm has no 20 Hz measurements available

- The quality of the relationships highly depends on:
  - i) the distance between the measurement site and the altimeter track
  - ii) the presence of open water in the altimeter footprint
  - iii) the topography of the site
  - iv) the density of the vegetation cover and the retracking algorithm

- Only a small attenuation by the vegetation cover is found allowing SSM to be accurately estimated from radar altimetry data without any correction

# Perspectives

- Improvements of altimetry derived SSM are expected from the use of higher spatial resolution altimetry data such as those that will be provided by the French-Indian AltiKa radar altimetry mission to be launched in 2012

- Modelisation of radar altimetry basckattering coefficient is currently under study (variation of dielectric properties of soil, rms height, etc.)

- A comparison between different kind of sensors is also carried out

- To our knowledge, this is the first demonstration of radar altimetry-based SSM in a semi-arid environment

Fatras C., Frappart F., Mougin E., Grippa M., Hiernaux P. Estimating surface soil moisture using ENVISAT RA-2 altimetry, *Remote Sensing of Environment,* Vol.123, pp 496-507.doi: 10.1016/j.rse.2012.04.013.

Thank you for your attention

# Annex A: Time variations of the backscattering coefficient – summary (Ku band)

| Site | | Agoufou | | | Bangui Mallam | | | Eguerit | Ekia | | | Kobou | | | Kyrnia | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | | 2005-2010 | | | 2005-2010 | | | 2008-2009 | 2005-2010 | | | 2008-2010 | | | 2007-2010 | | |
| Mean distance (km) | | 3 | | | 9.5 | | | 2 | 5.5 | | | 9.7 | | | 3 | | |
| SSM depth (cm) | | 5 | 10 | 40 | 5 | 10 | 30 | 5 | 5 | 10 | 30 | 5 | 10 | 30 | 5 | 10 | 30 |
| Number of samples | | 56 | 56 | 56 | 27 | 49 | 49 | 13 | 51 | 51 | 51 | 28 | 28 | 28 | 29 | 29 | 29 |
| Ice-1 | r | 0.85 ** | 0.85 ** | 0.55 ** | 0.7 ** | 0.73 ** | 0.3 * | 0.95 ** | 0.59 ** | 0.63 ** | 0.55 ** | 0.52 ** | 0.33 | 0.54 ** | 0.66 ** | 0.66 ** | 0.6 ** |
| | RMSE (%) | 1.74 | 1.85 | 3.29 | 3.61 | 3.22 | 8.35 | 1.98 | 3.32 | 2.84 | 3.65 | 5.84 | 10.8 | 4.61 | 4.59 | 5.09 | 6.26 |
| Ice-2 | r | 0.83 ** | 0.86 ** | 0.54 ** | 0.7 ** | 0.73 ** | 0.26 | 0.94 ** | 0.59 ** | 0.61 ** | 0.52 ** | 0.55 ** | 0.36 | 0.54 ** | 0.66 ** | 0.64 ** | 0.52 ** |
| | RMSE (%) | 1.85 | 1.76 | 3.4 | 3.54 | 3.23 | 9.67 | 2.36 | 3.33 | 2.99 | 3.94 | 5.34 | 10.03 | 4.66 | 4.51 | 5.38 | 7.79 |
| Sea Ice | r | 0.82 ** | 0.83 ** | 0.54 ** | 0.69 ** | 0.73 ** | 0.3 * | 0.95 ** | 0.58 ** | 0.63 ** | 0.55 ** | 0.52 ** | 0.33 | 0.55 ** | 0.64 ** | 0.64 ** | 0.59 ** |
| | RMSE (%) | 1.9 | 2.02 | 3.4 | 3.66 | 3.19 | 8.32 | 2 | 3.44 | 2.86 | 3.61 | 5.8 | 10.83 | 4.55 | 4.78 | 5.35 | 6.53 |
| Ocean | r | 0.52 ** | 0.54 ** | 0.34 ** | 0.62 ** | 0.71 ** | 0.23 | 0.95 ** | 0.46 ** | 0.54 ** | 0.56 ** | 0.55 ** | 0.39 * | 0.58 ** | 0.53 ** | 0.49 ** | 0.45 * |
| | RMSE (%) | 4.52 | 4.63 | 5.89 | 4.38 | 3.41 | 11.12 | 2.05 | 4.74 | 3.65 | 3.6 | 5.35 | 8.85 | 4.25 | 6.44 | 8 | 9.29 |

* Significance >95%
**Significance >99%

# Annex B: Time variations of the backscattering coefficient – summary (S band)

| Site | | Agoufou | | | Bangui Mallam | | | Ekia | | | Kyrnia | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | | 2005-2007 | | | 2005-2007 | | | 2005-2007 | | | 2007 | | |
| Mean distance(km) | | 3 | | | 9.5 | | | 5.5 | | | 3 | | |
| SSM depth (cm) | | 5 | 10 | 40 | 5 | 10 | 30 | 5 | 10 | 30 | 5 | 10 | 30 |
| Ice-1 | N | 25 | 25 | 25 | 20 | 20 | 20 | 22 | 22 | 22 | 8 | 8 | 8 |
| | r | 0.50* | 0.41* | 0.43* | 0.64** | 0.73** | 0.40 | 0.70** | 0.82** | 0.80** | 0.68 | 0.94** | 0.98** |
| | RMSE (%) | 3.87 | 6.34 | 4.97 | 4.52 | 3.28 | 6.77 | 2.62 | 1.93 | 2.14 | 4.44 | 1.98 | 1.34 |
| Ice-2 | N | 24 | 24 | 24 | 20 | 20 | 20 | 22 | 22 | 22 | 8 | 8 | 8 |
| | r | 0.68** | 0.66** | 0.70** | 0.75** | 0.62** | 0.58** | 0.73** | 0.83** | 0.80** | 0.76* | 0.97** | 0.99** |
| | RMSE (%) | 2.4 | 3.27 | 2.41 | 3.37 | 4.35 | 4.11 | 2.41 | 1.87 | 2.13 | 3.54 | 1.29 | 0.78 |
| Ocean | N | 26 | 26 | 26 | 21 | 21 | 21 | 23 | 23 | 23 | 8 | 8 | 8 |
| | r | 0.27 | 0.36 | 0.41* | 0.65* | 0.64** | 0.34 | 0.55** | 0.70** | 0.70** | 0.73* | 0.96** | 0.99** |
| | RMSE (%) | 7.94 | 7.37 | 5.19 | 4.36 | 4.12 | 7.88 | 3.93 | 2.77 | 2.86 | 3.96 | 1.55 | 0.84 |

* Significance >95%
**Significance >99%