QUANTITATIVE REMOTE SENSING
LAND DIVISION

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U B A

Soil moisture retrieval using Aquarius/SAC-D radiometer and scatterometer observations

Institute of Astronomy and Space Physics

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Contents

- Radar-only soil moisture retrieval using Aquarius scatterometer
- Combined active/passive soil moisture retrieval coupled by the ancillary parameters
- Downscaling Aquarius radiometer-only soil moisture using VTCI (vegetation temperature condition index)
- Summary & Conclusions

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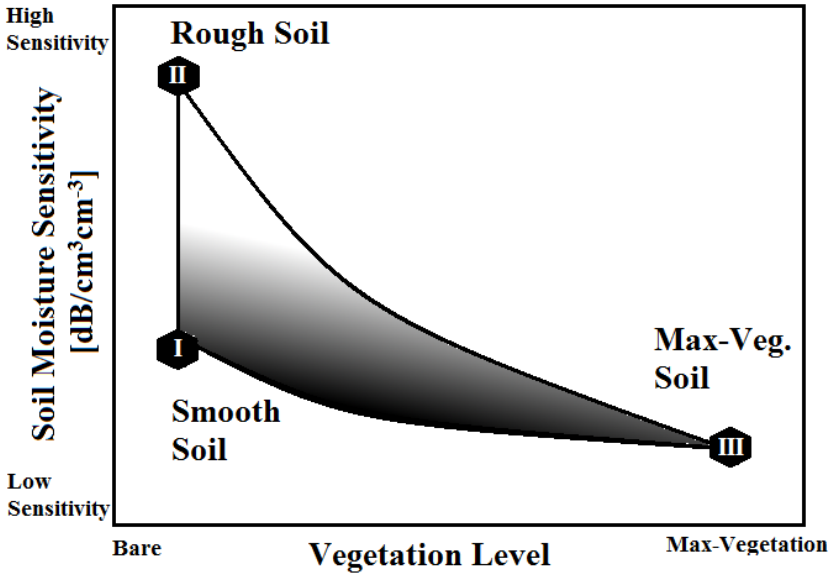
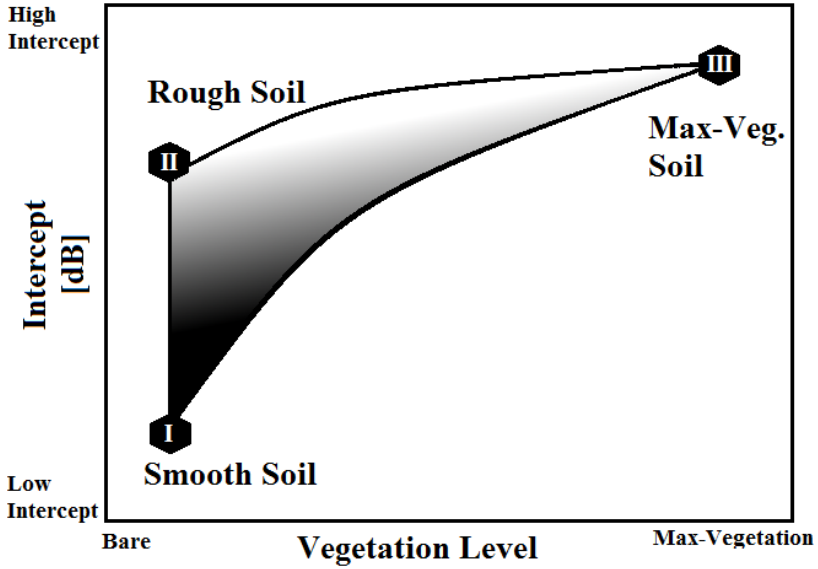
New radar-only algorithm: Conceptual model





$$\sigma_{VV}[dB] = Sensitivity * m_v^{\lambda} + Intercept$$

Sensitivity and Intercept depend on vegetation (Radar Vegetation Index, RVI) and soil roughness (Radar Roughness Index, RRI).
λ is the non linearity coefficient.

Definition of three limiting cases:

- Smooth bare soil (I)
- Rough bare soil (II)
- Maximum vegetation (III)

[REF]: Narvekar, P.S.; Entekhabi, D.; Kim, S.; Njoku, E.G.; , "Soil Moisture retrieval using L-band radar observations ", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing.
[REF]: Bruscantini, C.; Konings, A.; Narvekar, P; McColl, K.; Entekhabi, D.; Grings, F.; Karszenbaum, H.; "L-band radar soil moisture retrieval without ancillary information", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing.

- **Smooth bare soil (I)**

$$\sigma_{VV}^{ss}[dB] = S_S(clf) * m_V^{\lambda} + \sigma_{VV}^{s}(clf)$$

- **Rough bare soil (II)**

$$\sigma_{VV}^{rs}[dB] = S_s(clf)[1 + log(1 + ks)] * m_V^{\lambda} + \sigma_{VV}^{s}(clf) + Clog(1 + ks)$$

- **Maximum vegetation (III)**

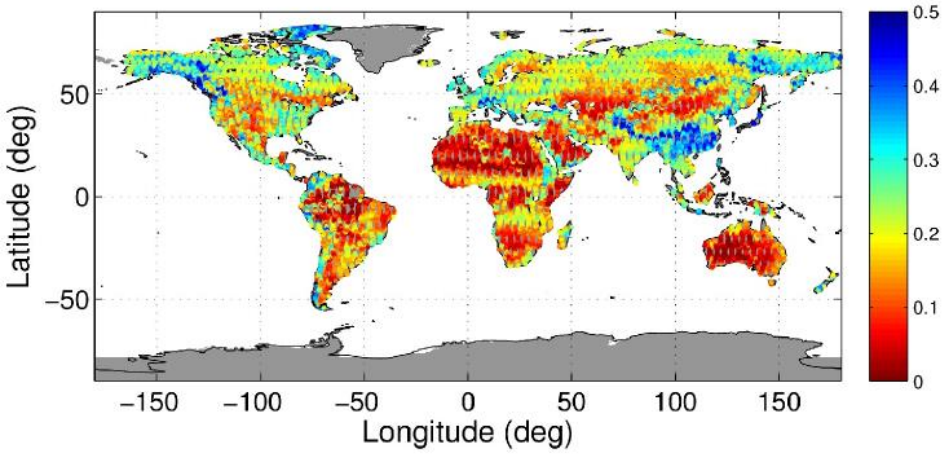
$$\sigma_{VV}^{vvff}[dB] = \gamma * m_V^{\lambda} + \sigma_{VV}^{vf}$$

… linearly combining the end members with the RVI index…

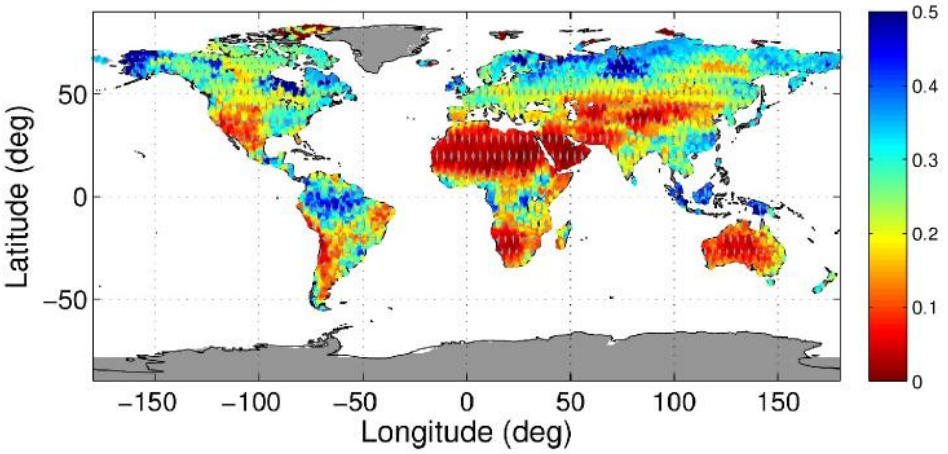
Radar-only soil moisture retrieval

$$\sigma_{VV} = \{RVI\gamma + (1 - RVI)[1 + log(1 + ks)]S_S\}m_V^{\lambda} + RVI\sigma_{VV}^{vf} + (1 - RVI)[\sigma_{VV}^{s} + Clog(1 + ks)]$$

Global temporal mean soil moisture maps

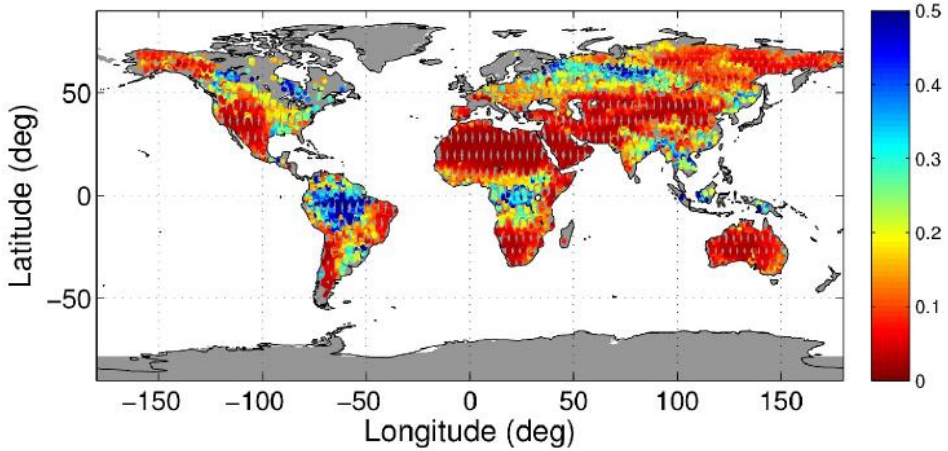


(a) Radar

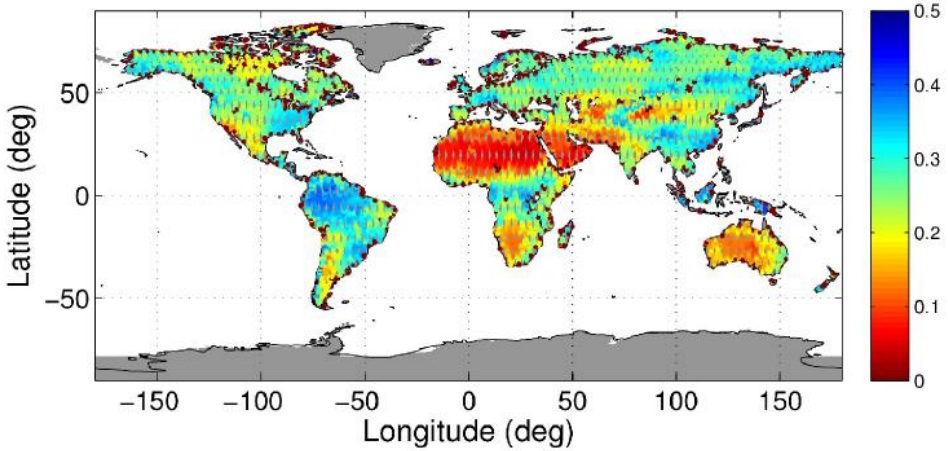


(b) GMAO

Global Modeling and Assimilation Office
SMAP Nature Run version 3



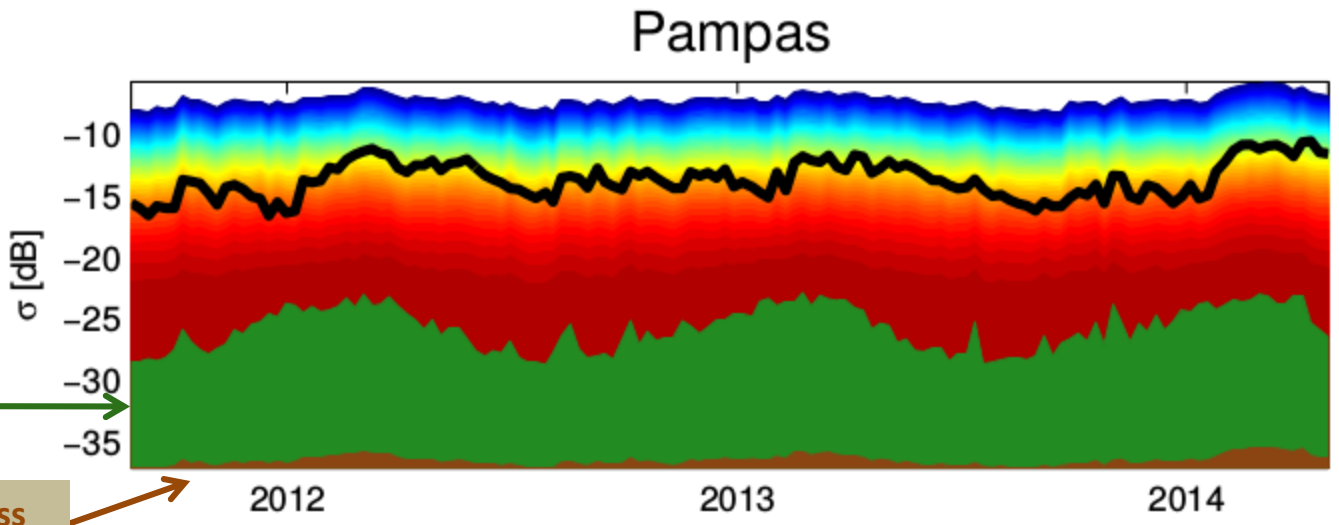
(c) Radiometer

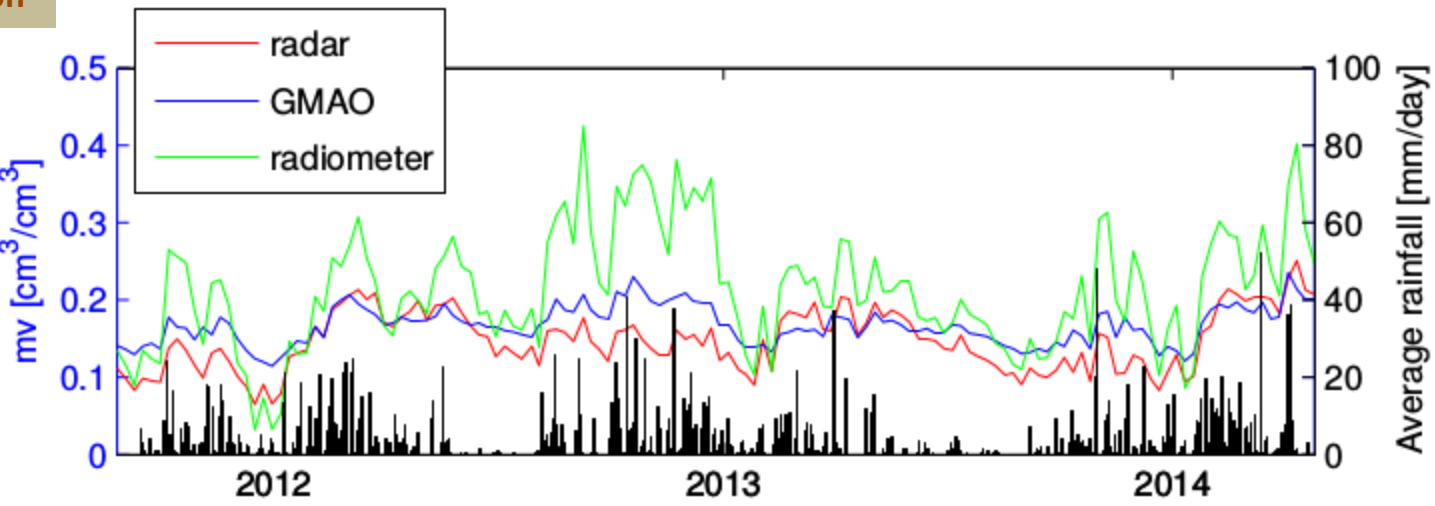


(d) NCEP

National Center for Environmental Prediction
from Global Data Assimilation System

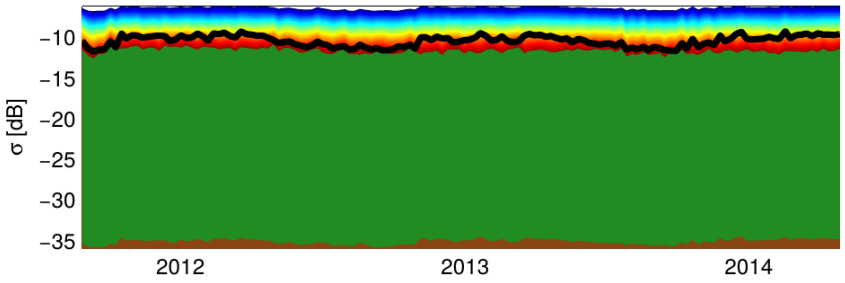
Vegetation and Roughness Contribution to Backscatter

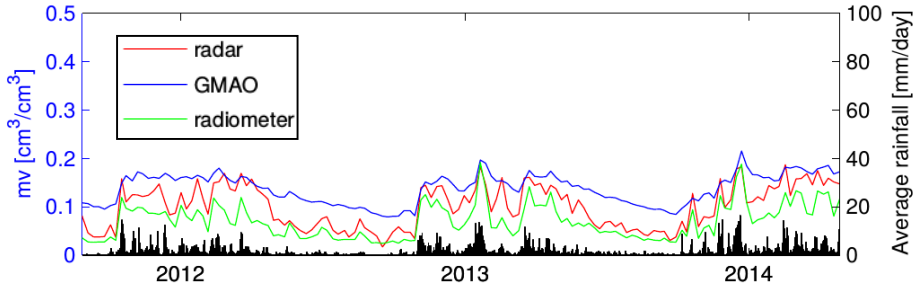




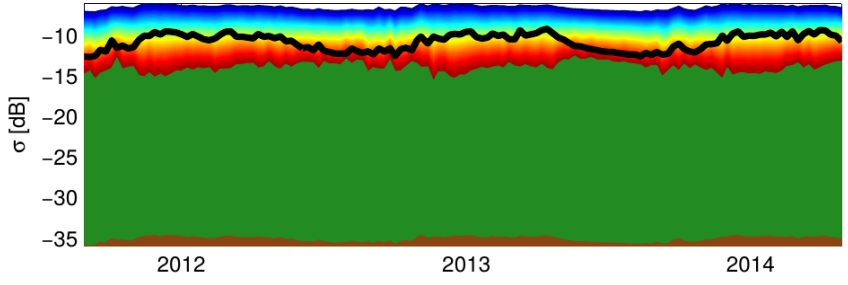
Precipitation from MERRA (Modern-Era Retrospective analysis for Research and Applications)

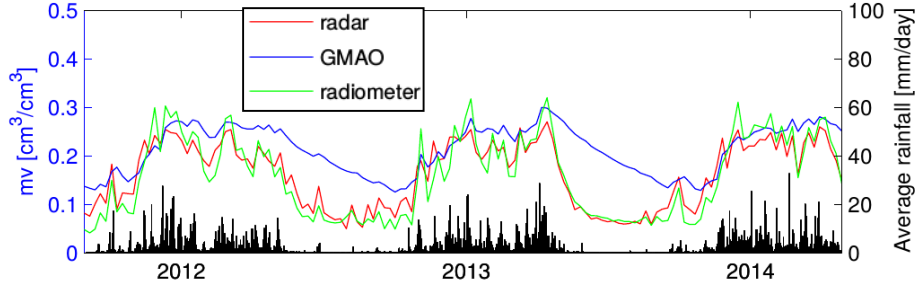
Brazil



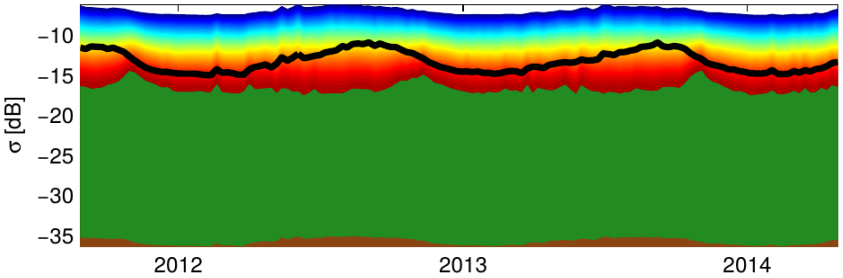


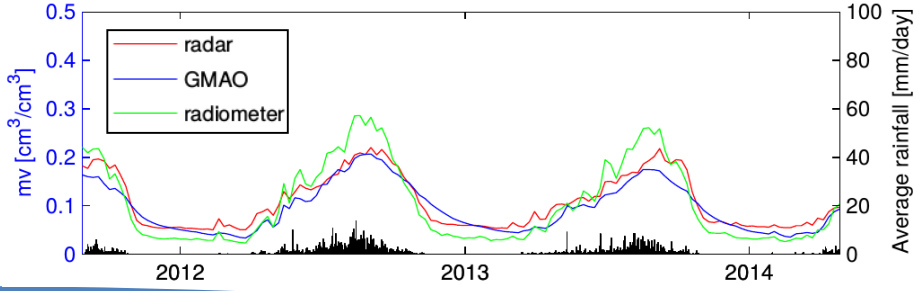
East Africa



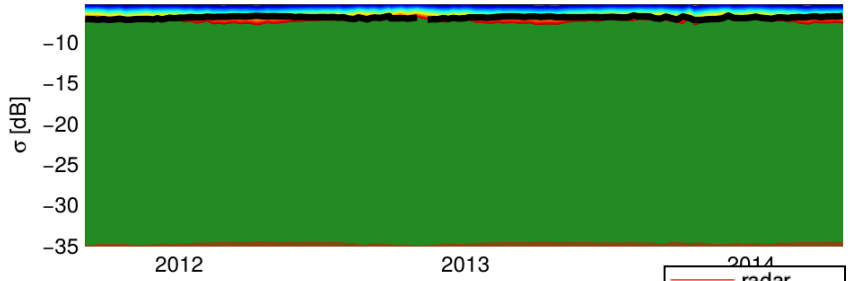


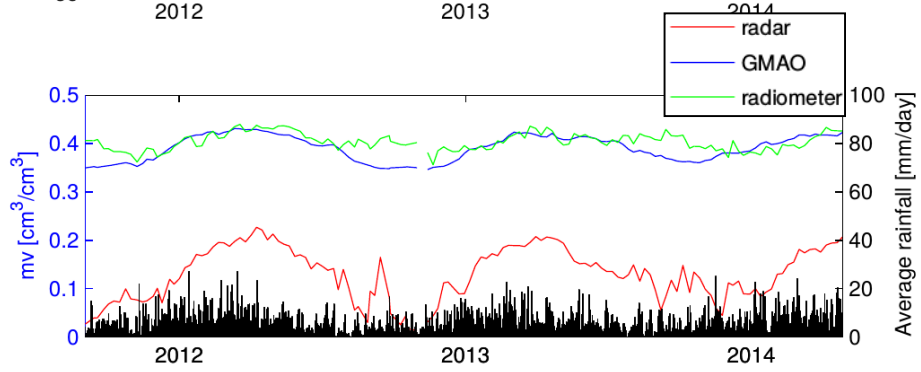
West Africa





Amazon





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Forward models

Passive model: Omega-tau

$$Tb_V = \Gamma\left(1 - r_{sV}\right) Ts + \left(1 - \Gamma\right)\left(1 + \Gamma r_{sV}\right)\left(1 - \omega\right) Tc$$

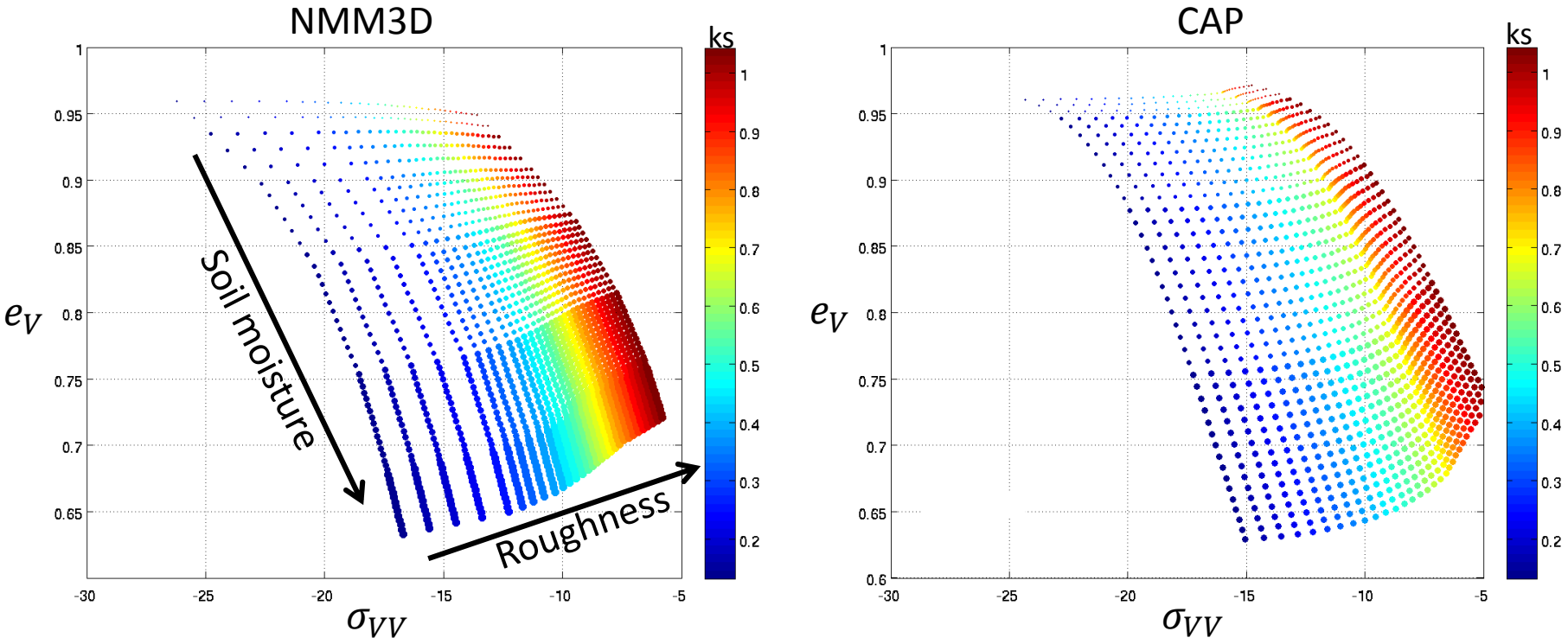
Active model: Radar-only

$$\sigma_{VV}[dB] = Sm_V^{\lambda} + I$$

Coupled by: roughness --> h and ks (*bare soil*)
vegetation --> τ and RVI (*crop dependent*)

[REF]: Bruscantini, C.; Grings, F.; Barber, M.; Franco, M.; Entekhabi, D.; Karszenbaum, H.; "A novel downscaling methodology for intermediate resolution radiometer data for SMAP", in Geoscience and Remote Sensing Symposium (IGARSS), 2015 IEEE International.

Roughness: h and ks (*bare soil*)

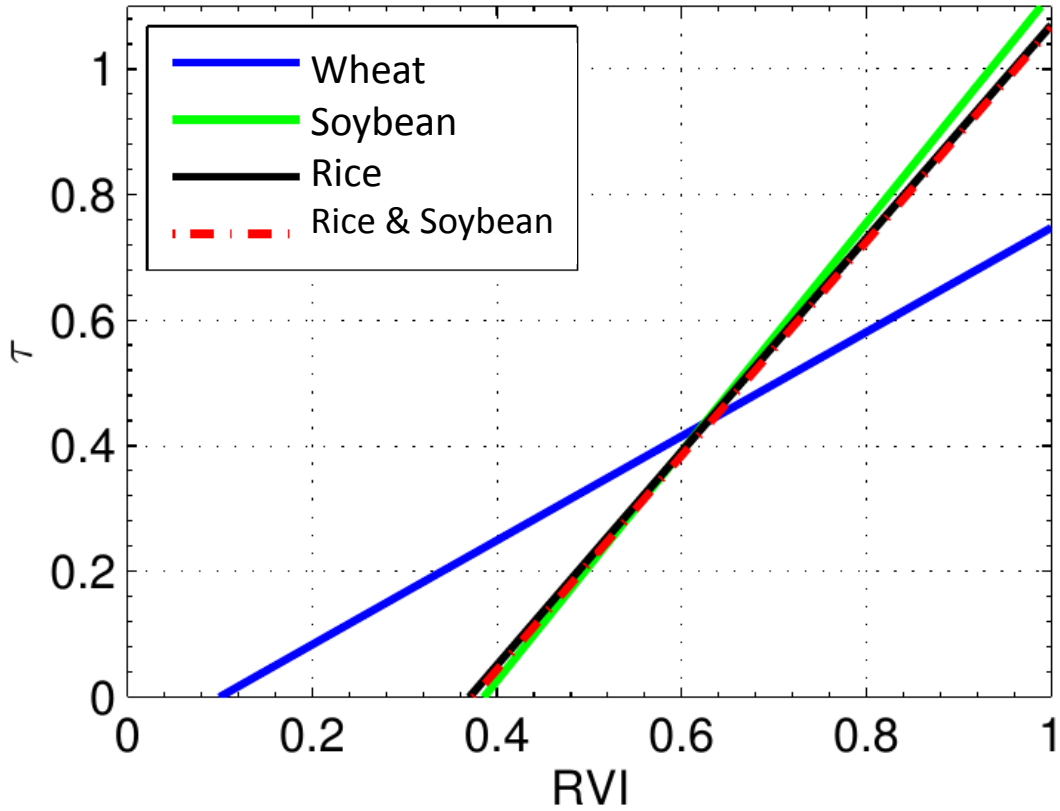


Numerical Maxwell Model of 3D simulations

Coupling equation to fit NMM3D simulation:

$$h = 0.1 \times (2 \times ks)^2$$

Vegetation: τ and RVI (crops)

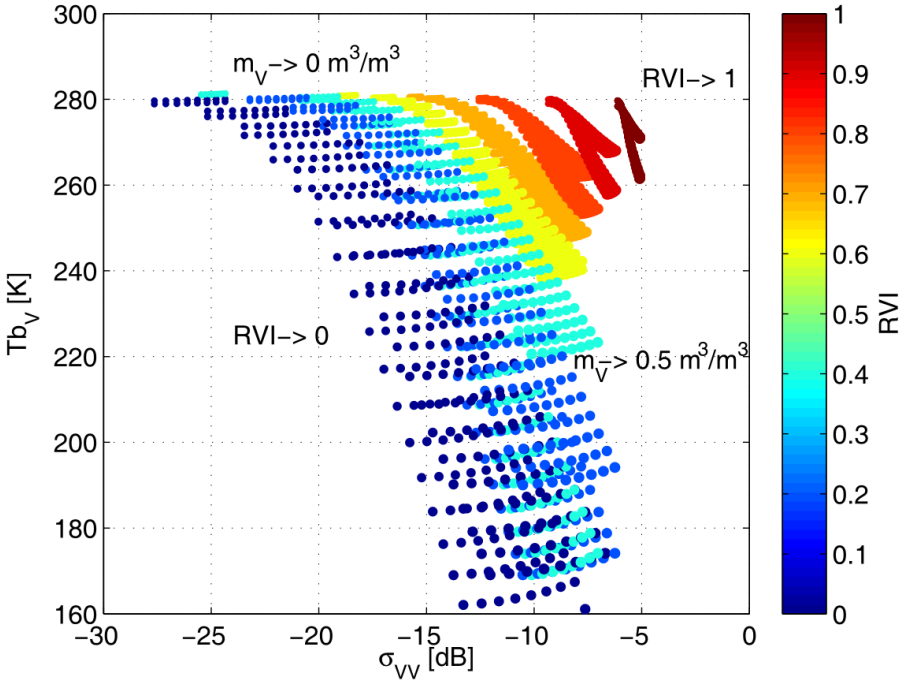


Different τ-RVI coupling equation depending on the crop type.

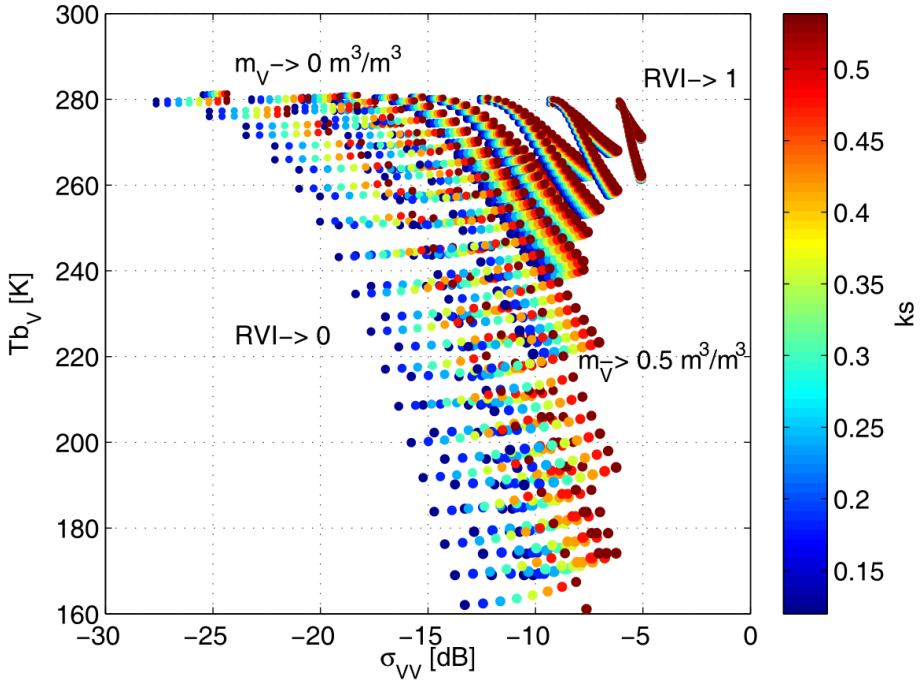
[REF] Yihyun Kim; Jackson, T.; Bindlish, R.; Hoonyol Lee; Sukyoung Hong, "Radar Vegetation Index for Estimating the Vegetation Water Content of Rice and Soybean," in *Geoscience and Remote Sensing Letters, IEEE* , vol.9, no.4, pp.564-568, July 2012.
[REF] Yueh, S.; Dinardo, S.; Chan, S.; Njoku, E.; Jackson, T.; Bindlish, R., "Passive and Active L-Band System and Observations during the 2007 CLASIC Campaign," in *Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. IEEE International* , vol.2, no., pp.II-241-II-244, 7-11 July 2008.

CAP model with the coupled equations

Putting everything together …

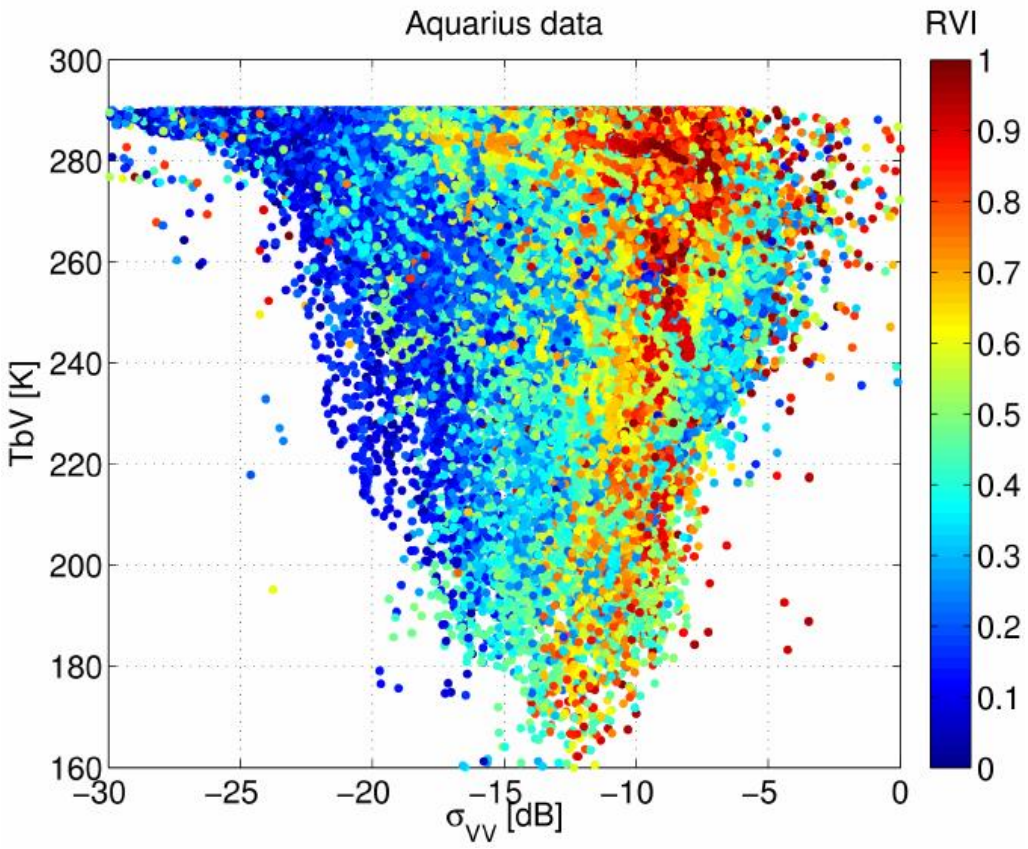


As a function of RVI



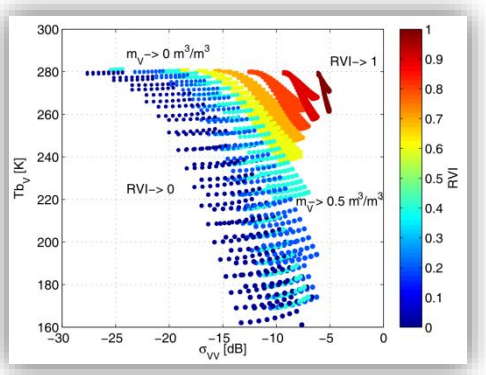
As a function of roughness

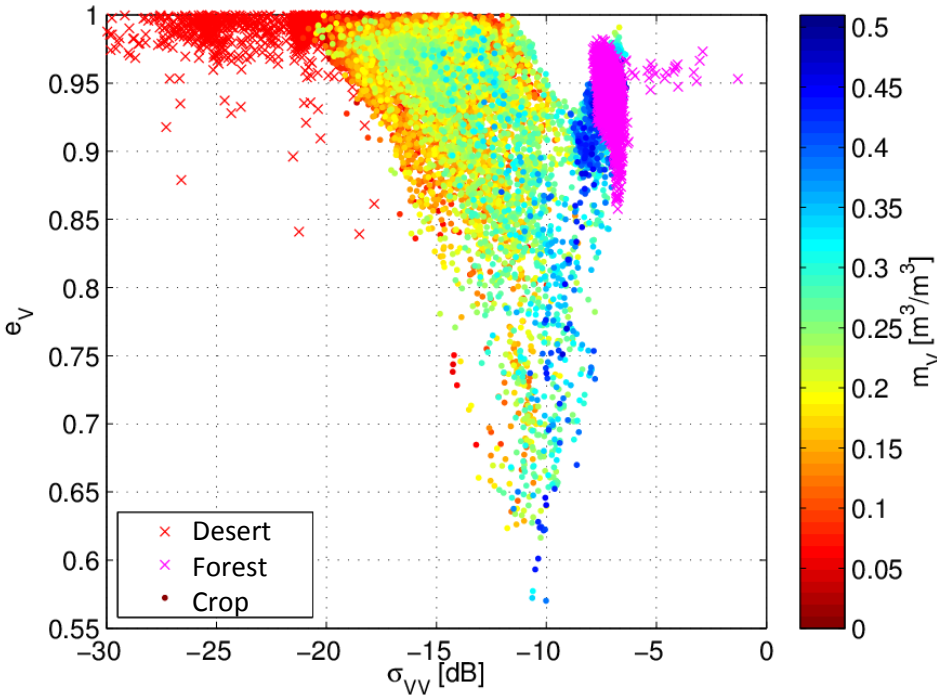
Aquarius Active-Passive global observations



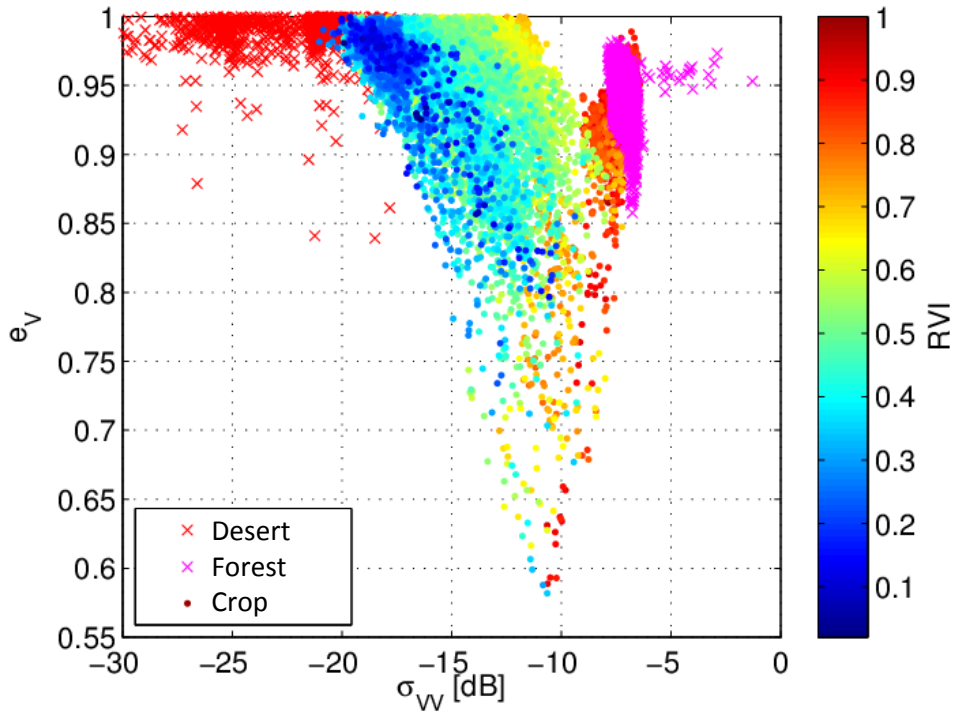
As a function of RVI

Aquarius Active-Passive observations: desert, forest and cropland





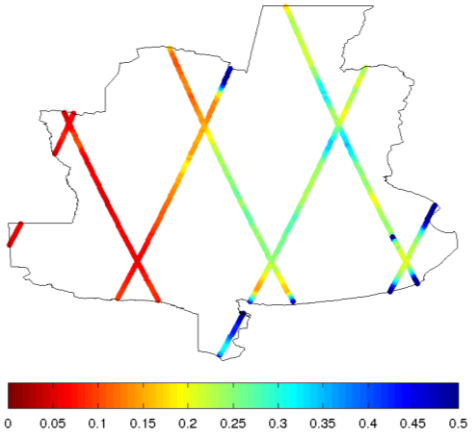
As a function of soil moisture



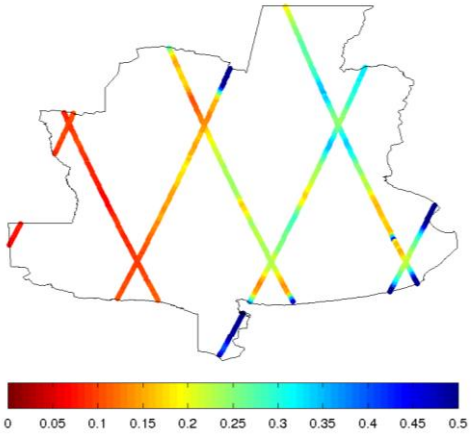
As a function of RVI

Aquarius soil moisture:
Temporal mean maps in Pampas region for 2nd beam

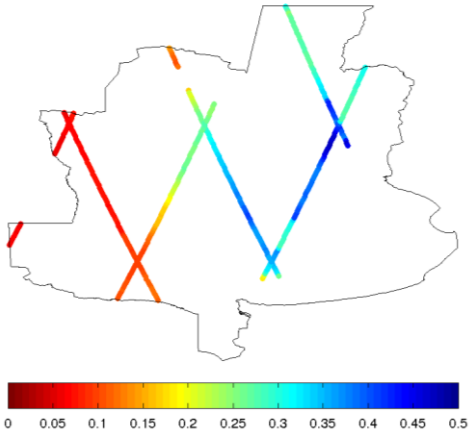
Combined Active-Passive (CAP)



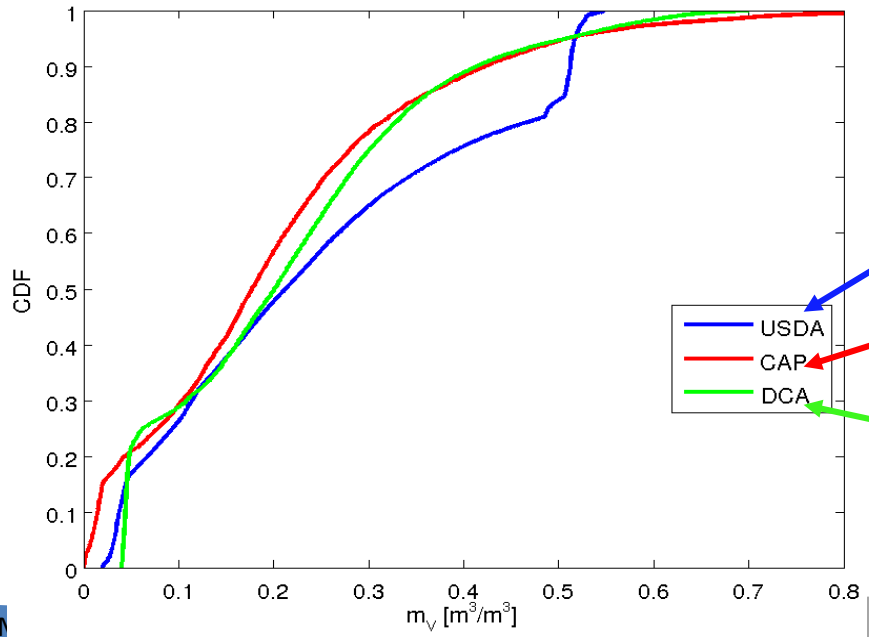
Dual Channel Algorithm (DCA)



Single Channel Algorithm (USDA)



Aquarius soil moisture:
Cumulative distribution function



Uses TbH to retrieve mv.

Uses σVV, TbH and TbV to retrieve mv, ks and τ.

Uses TbH and TbV to retrieve mv and τ.

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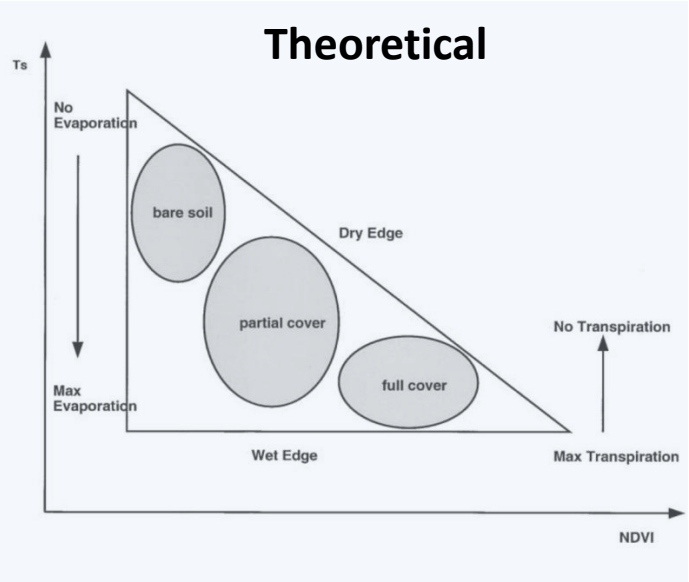
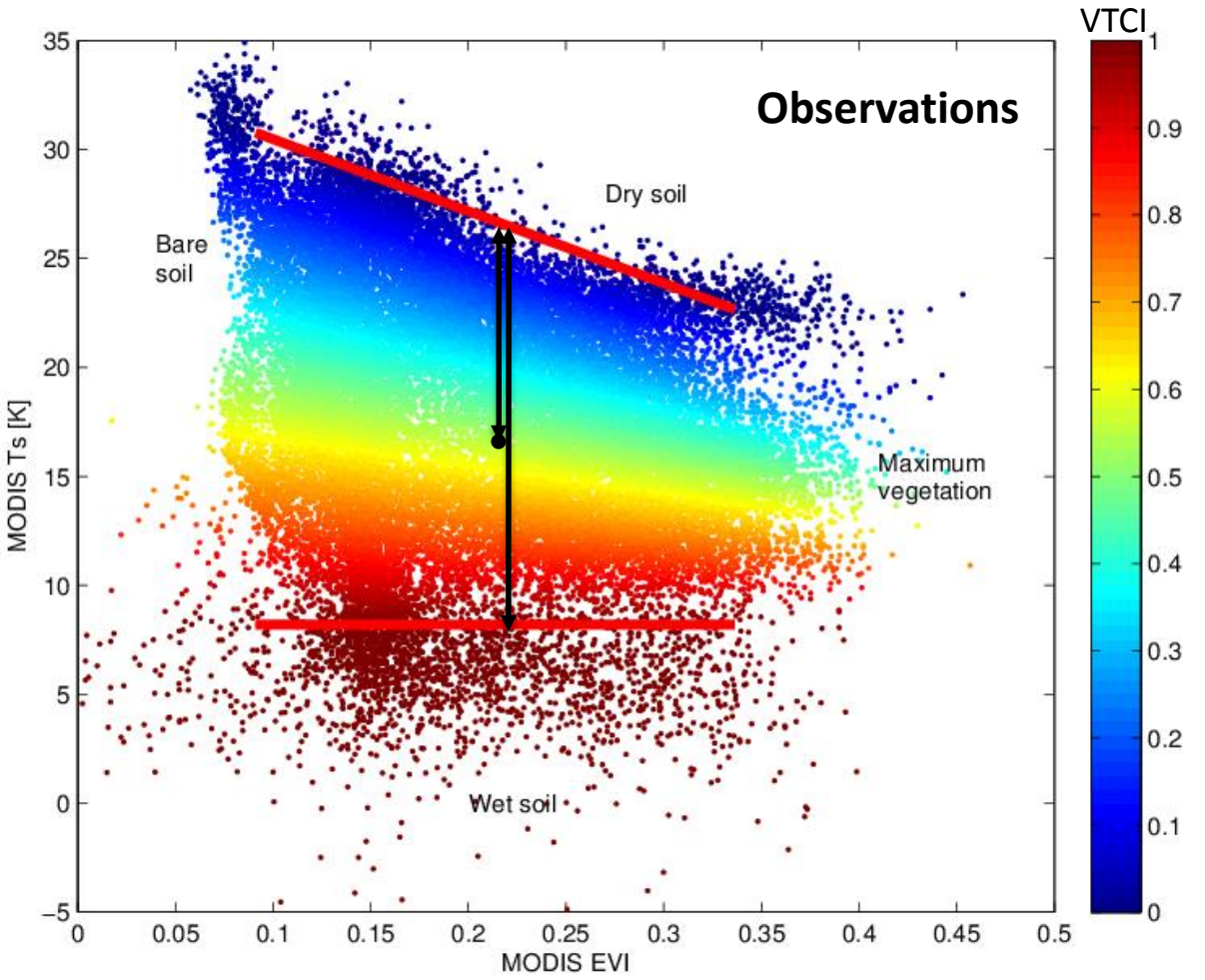
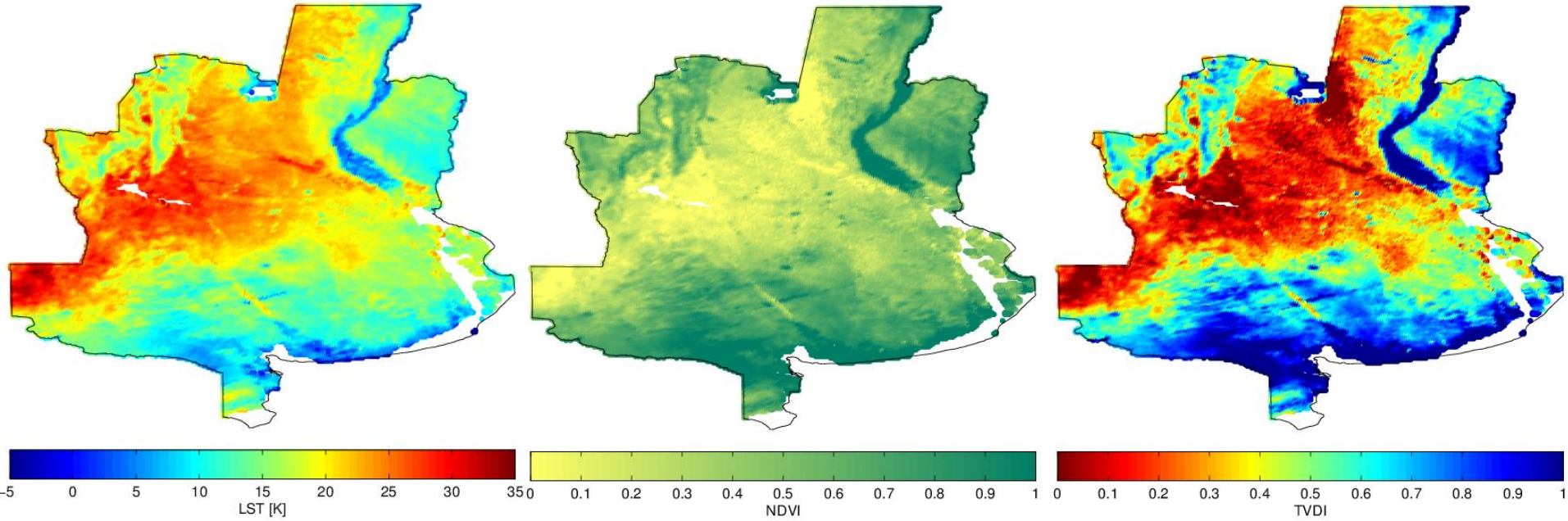
Vegetation temperature condition index (VTCI)



$$VTCI = \frac{Tmax - Ts}{Tmax - Tmin}$$



Maps of LST, NDVI and VTCI



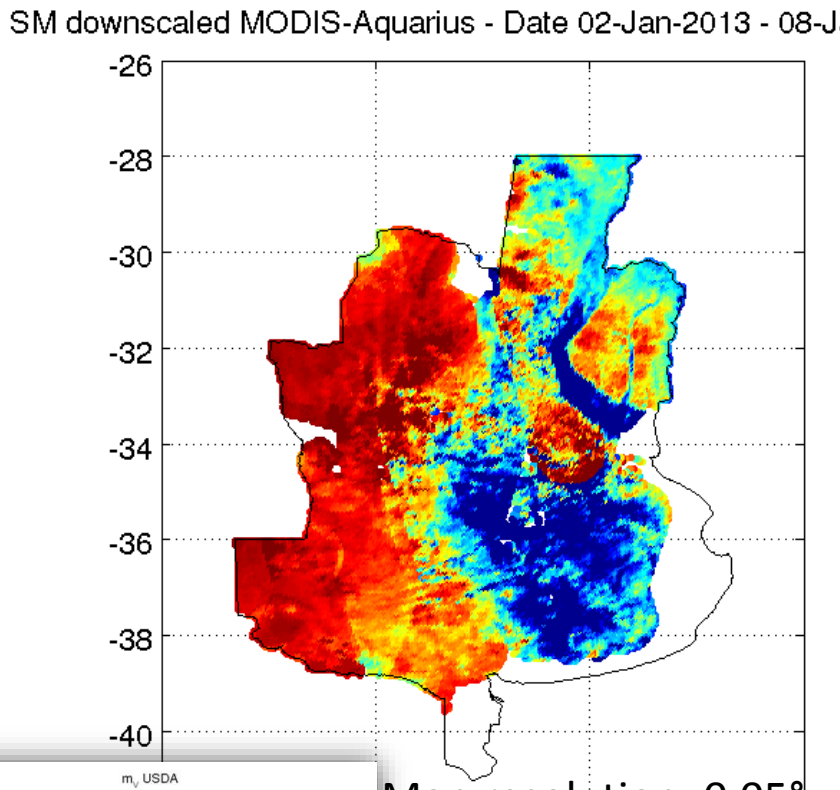
MOD11C1
LST daily L3 global 0.05°

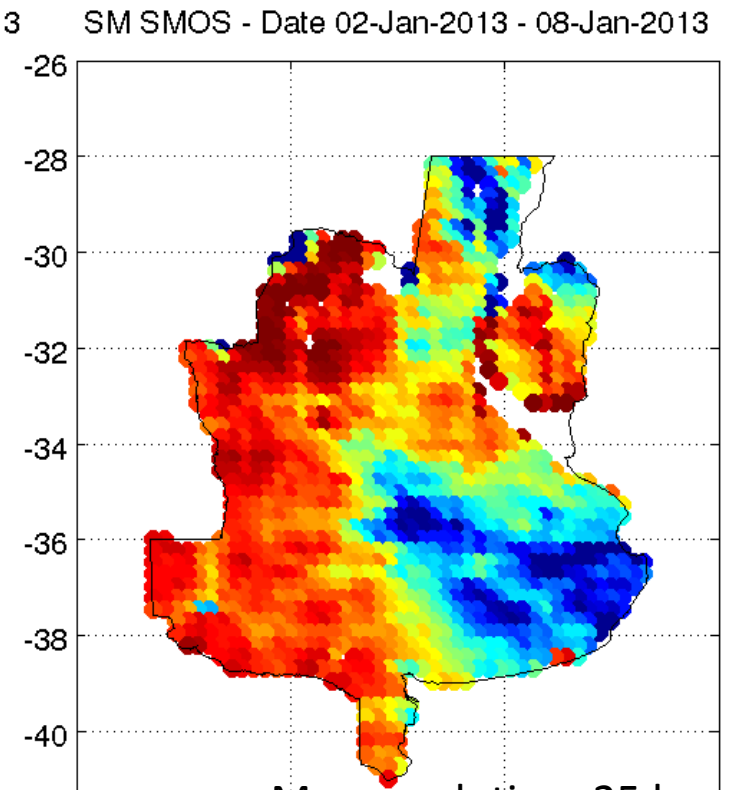
MOD13C1
NDVI 16-day L3 global 0.05°

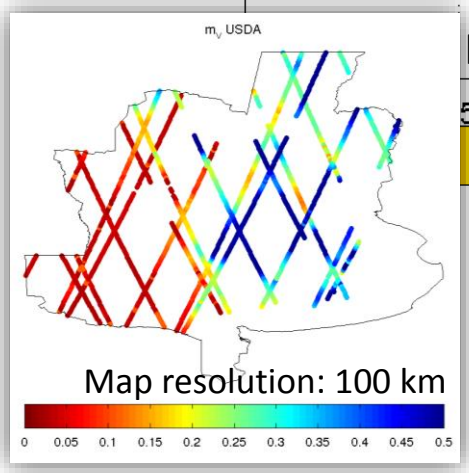
VTCI
daily 0.05°

Maps resolution: 0.05° (~5.6 km)

Maps of soil moisture: weekly Aquarius downscaled (5 km) & SMOS (25 km)







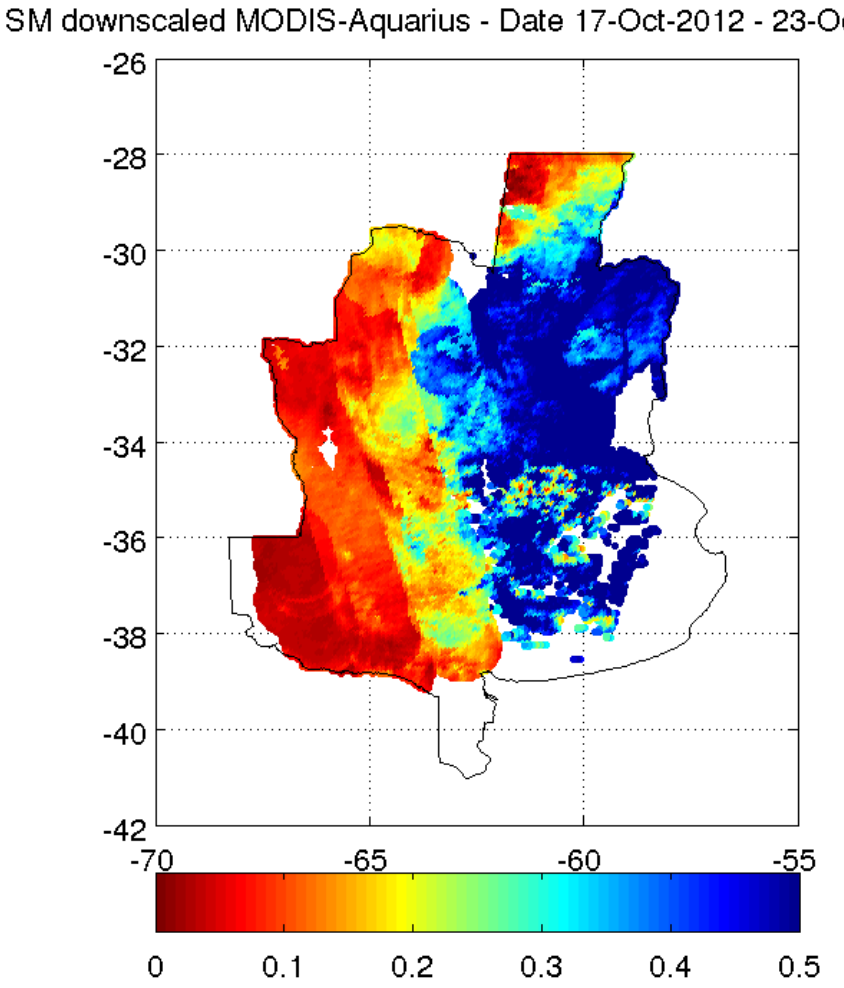
downscaled

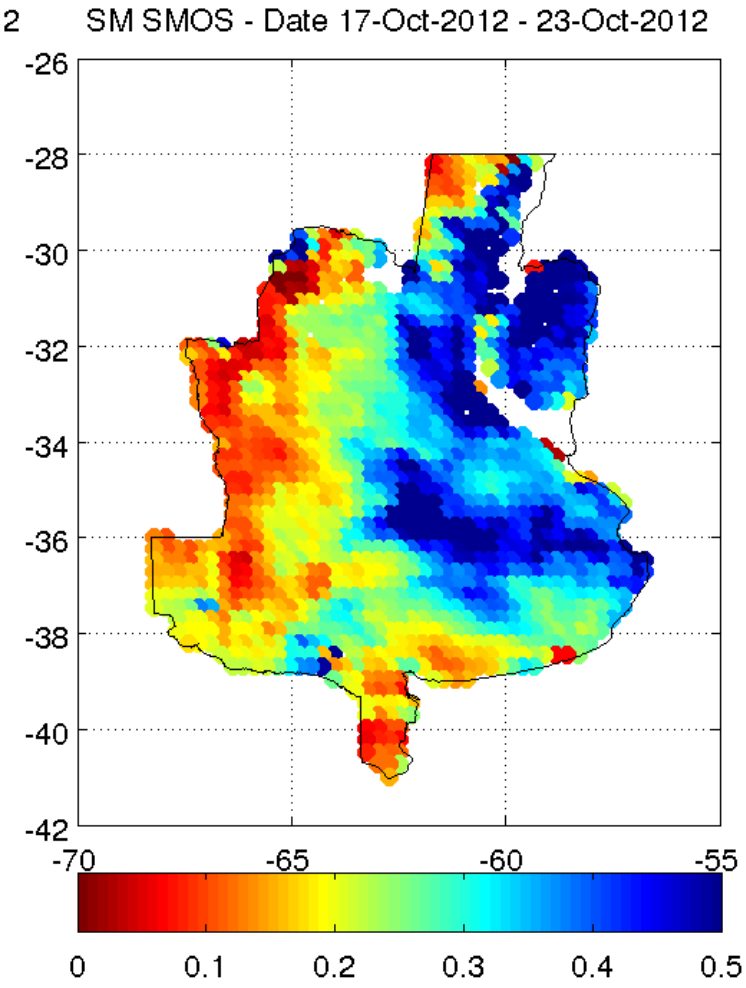
Soil moisture downscaling:

$$SM = VTCI * \frac{\overline{SM}}{\overline{VTCI}}$$

[REF] Peng, J.; Loew, A.; Zhang, S.; Wang, J.; Niesel, J., "Spatial Downscaling of Satellite Soil Moisture Data Using a Vegetation Temperature Condition Index," in *Geoscience and Remote Sensing, IEEE Transactions on* , vol.54, no.1, pp.558-566, Jan. 2016

Maps of soil moisture: weekly Aquarius downscaled (5 km) & SMOS (25 km)





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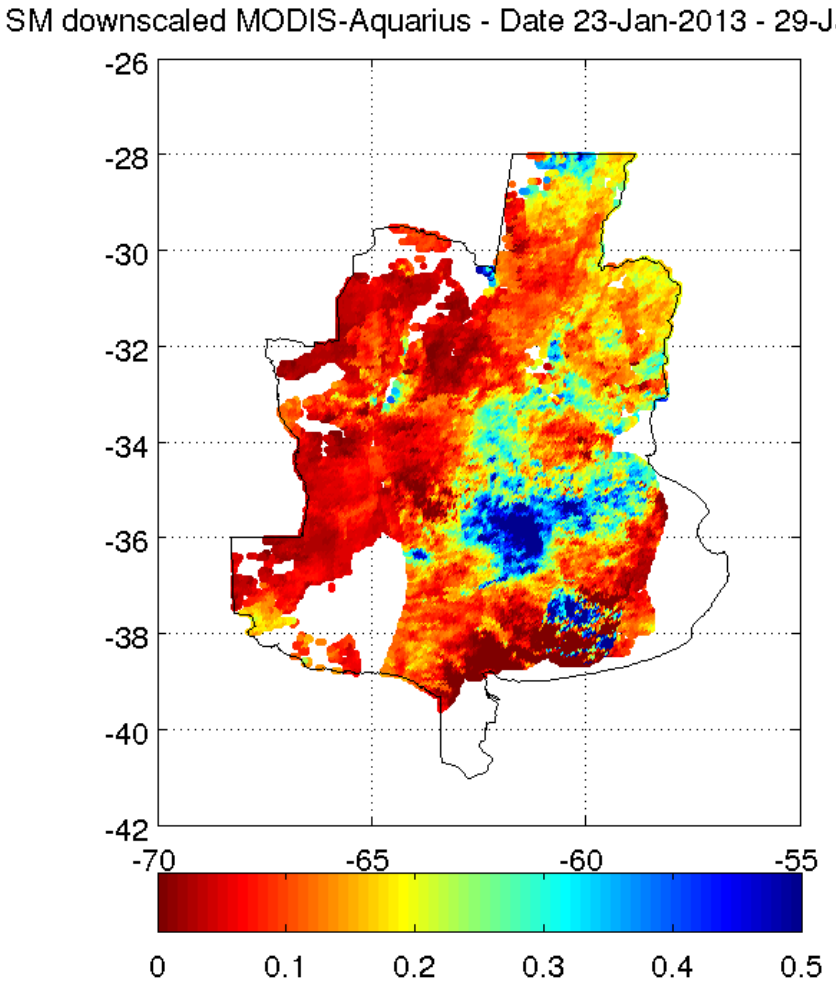

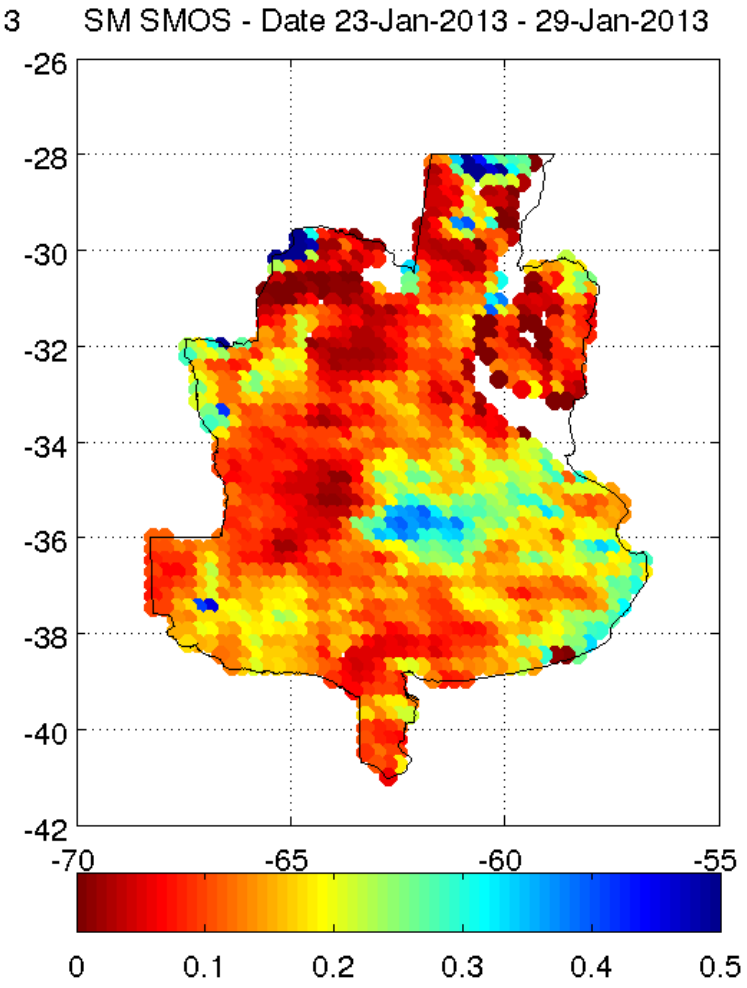

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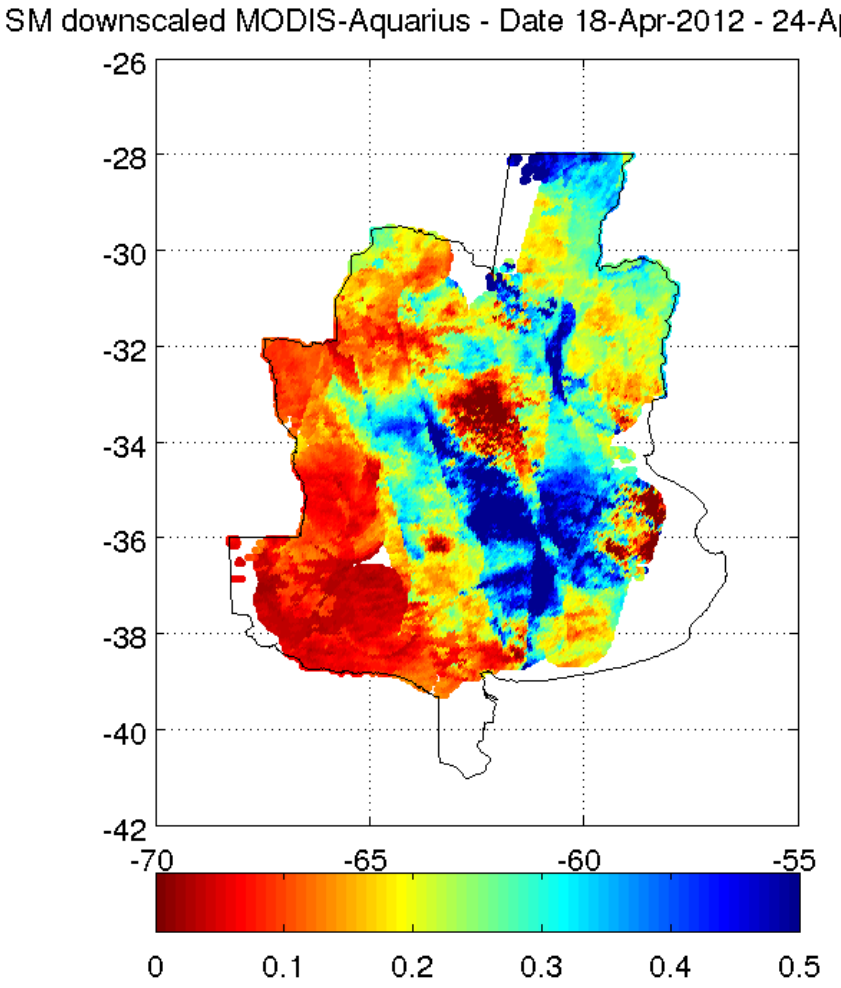

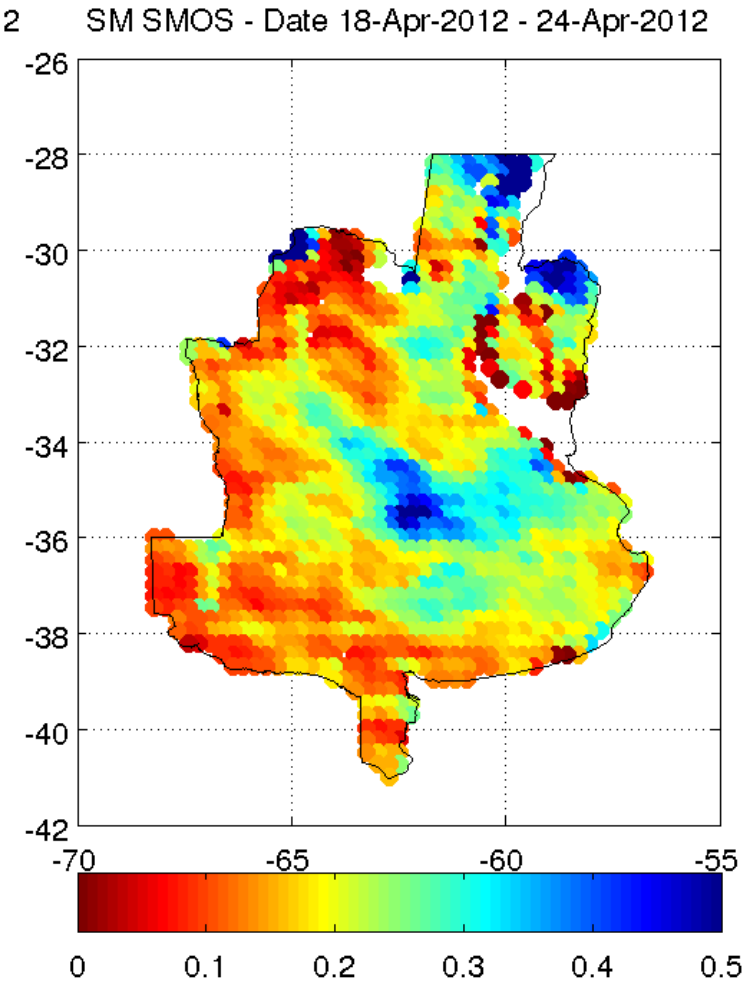

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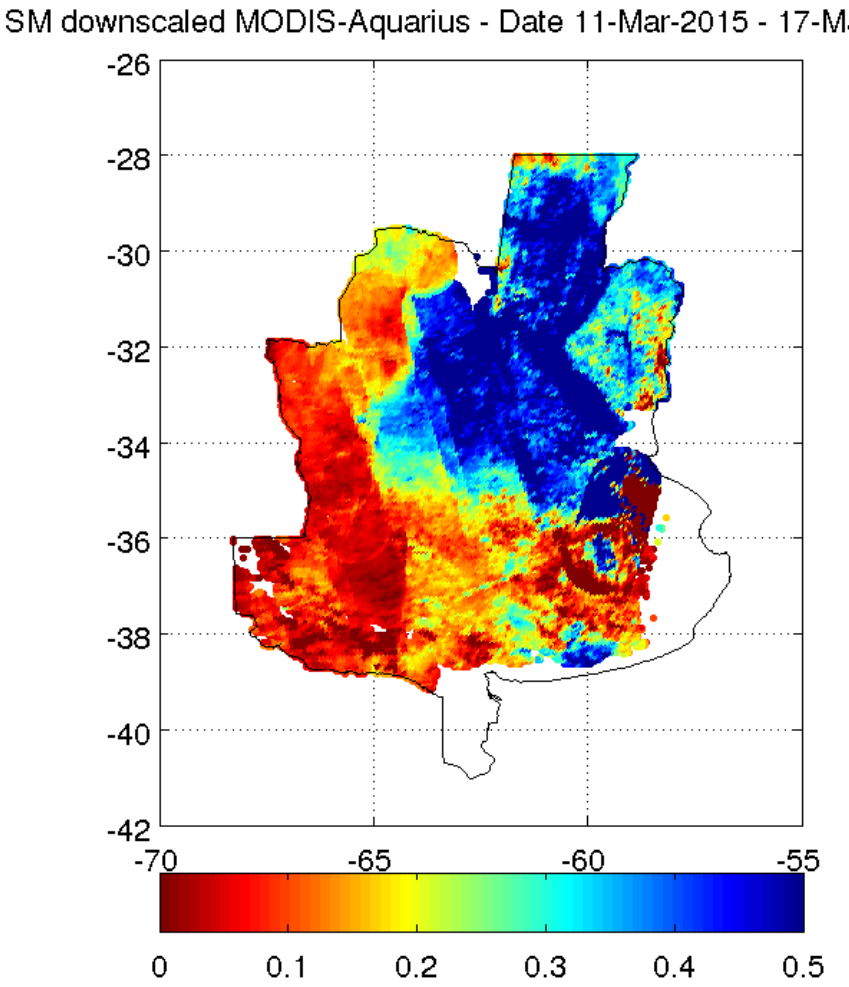

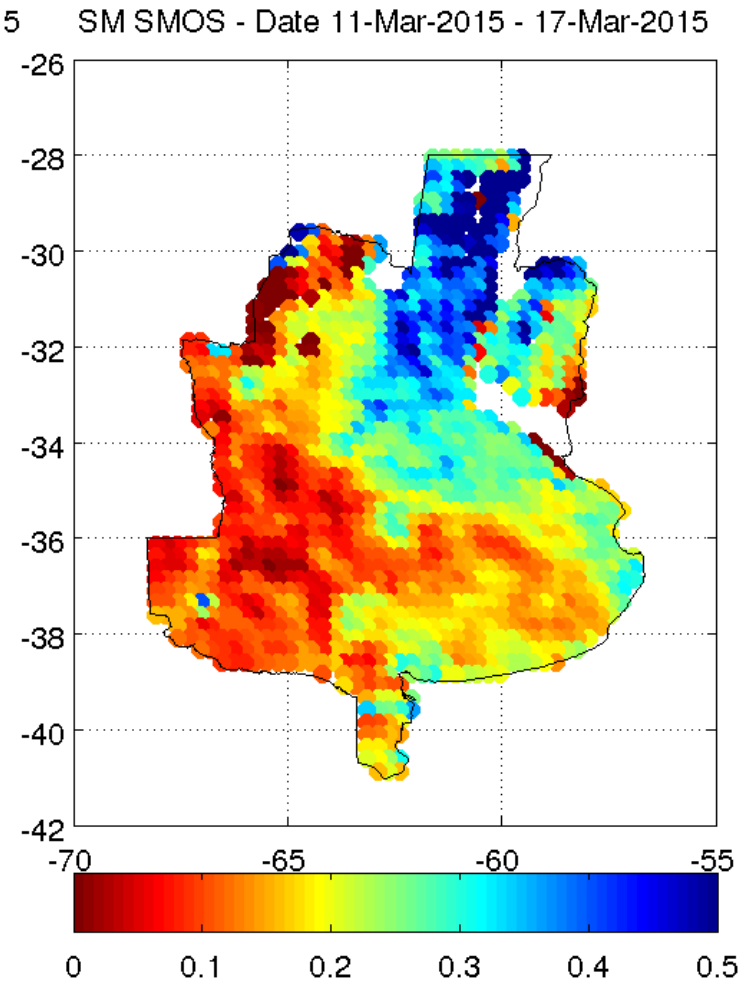

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Summary & Conclusions

✓During the 4 years of the Aquarius/SAC-D mission efforts were made towards developing an algorithm for soil moisture retrieval from scatterometer and radiometer observations. An official soil moisture product from Aquarius radiometer is available in NASA NSIDC webpage that uses **only H-pol radiometer observations** and the single channel algorithm.

✓In this presentation we showed that Aquarius scatterometer observations are also useful for soil moisture retrieval using the **radar-only algorithm**, mainly under low to moderate vegetation conditions. The main advantage of this algorithm is that it does not rely on ancillary information and it could also be applied to better resolution SAR systems, such as SAOCOM.

✓We also used the radar-only algorithm in combination with the omega-tau model in order to derive an Aquarius **combined active/passive** soil moisture retrieval. Simultaneous radiometer and scatterometer observations provide an opportunity to study the behavior of active-passive measurements to soil moisture and their synergy. When a system such as SMAP provides a high resolution radar, the active-passive model allows to retrieve higher soil moisture retrievals with improved accuracy.

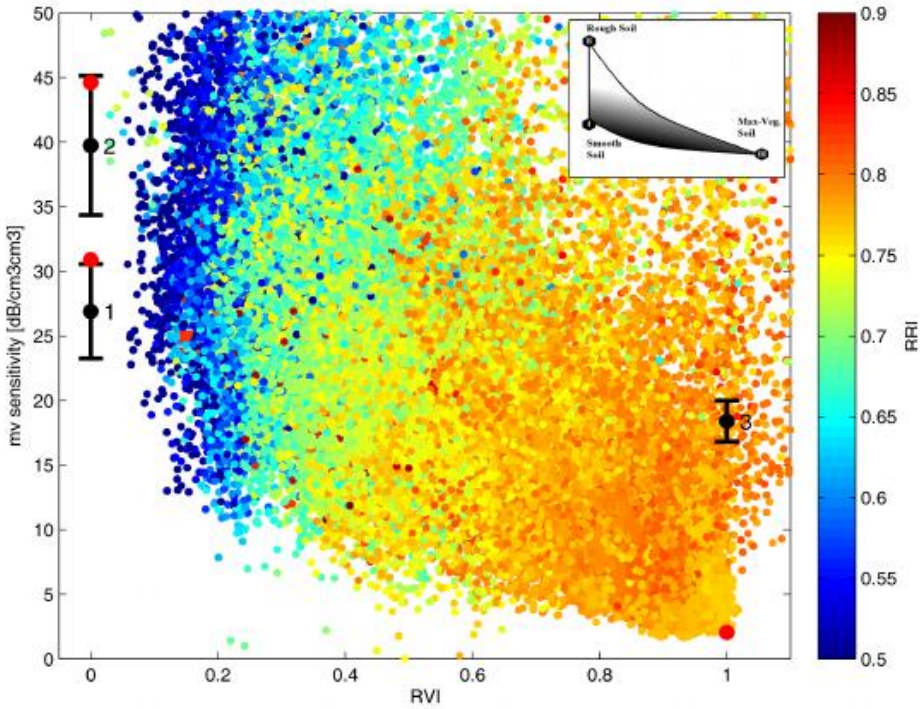
✓ Because of Aquarius coarse resolution, Aquarius soil moisture is not suitable for agricultural applications. Therefore, we investigate the performance of a **downscaled approach** comparing the obtained improved resolution Aquarius soil moisture with SMOS soil moisture.

Back up slides

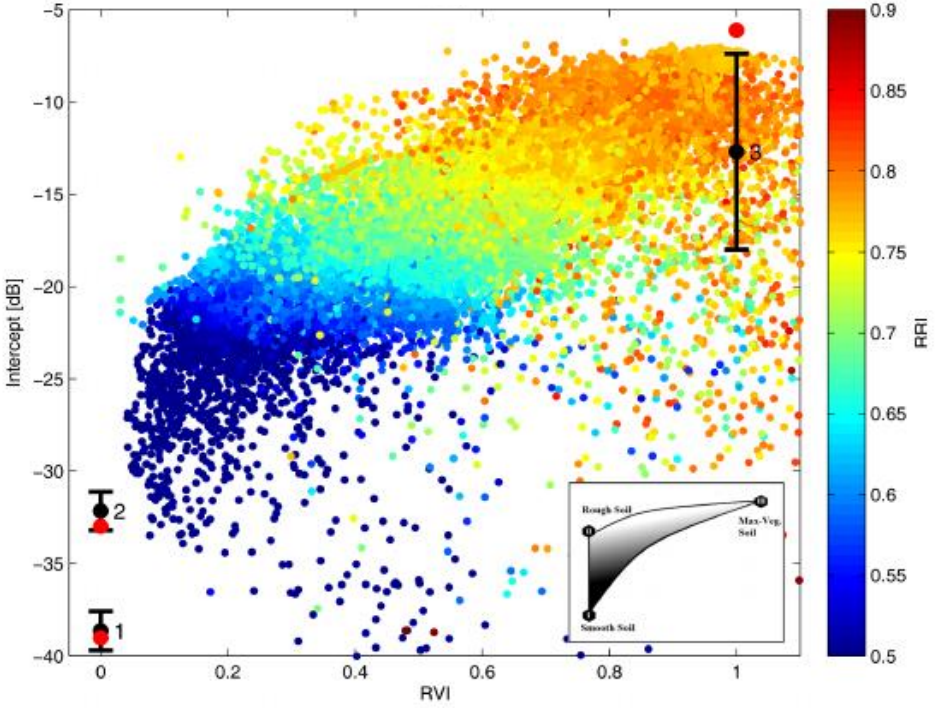
New radar-only algorithm: Sensitivity and Intercept analysis

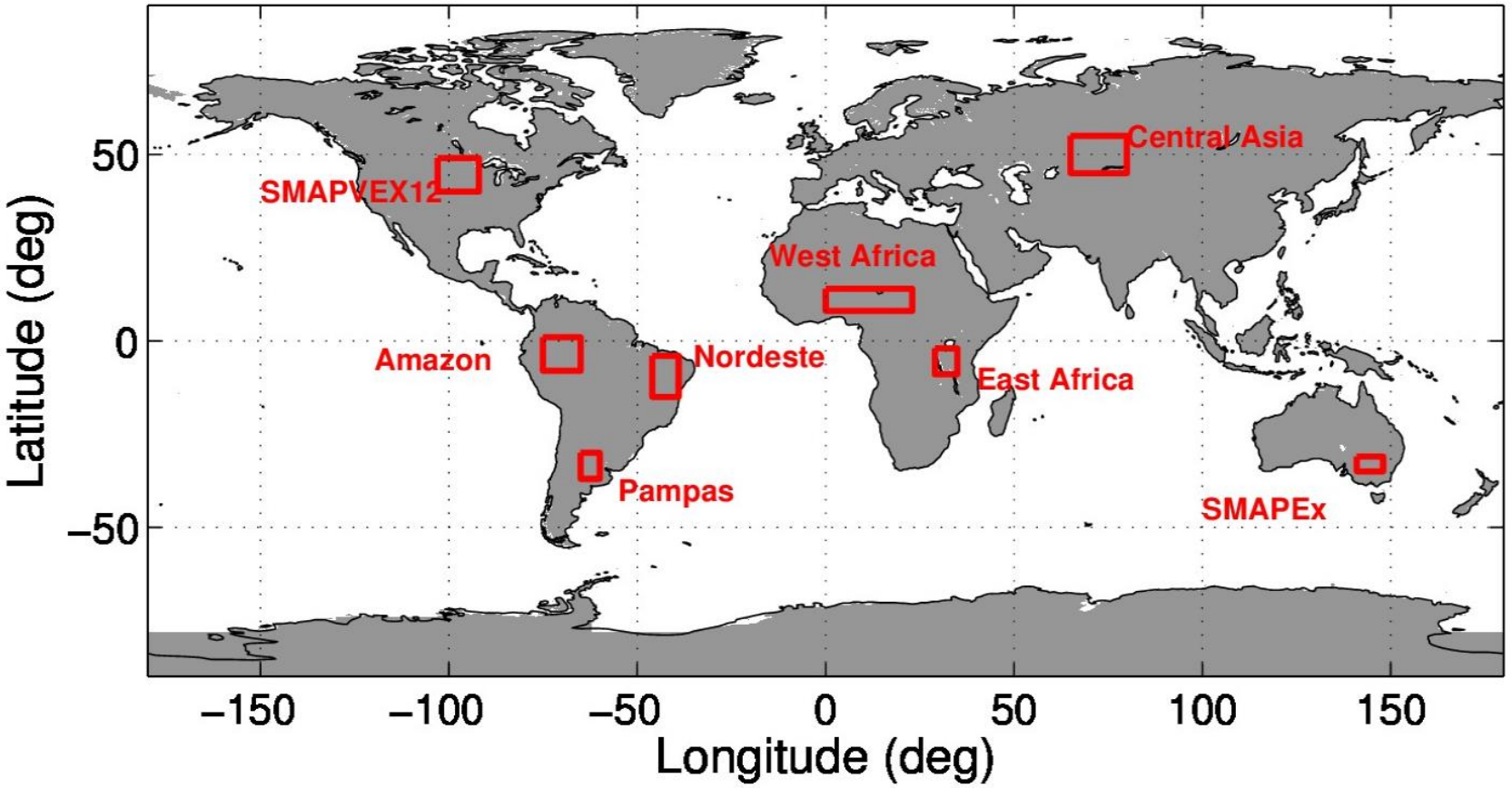
Aquarius global observations

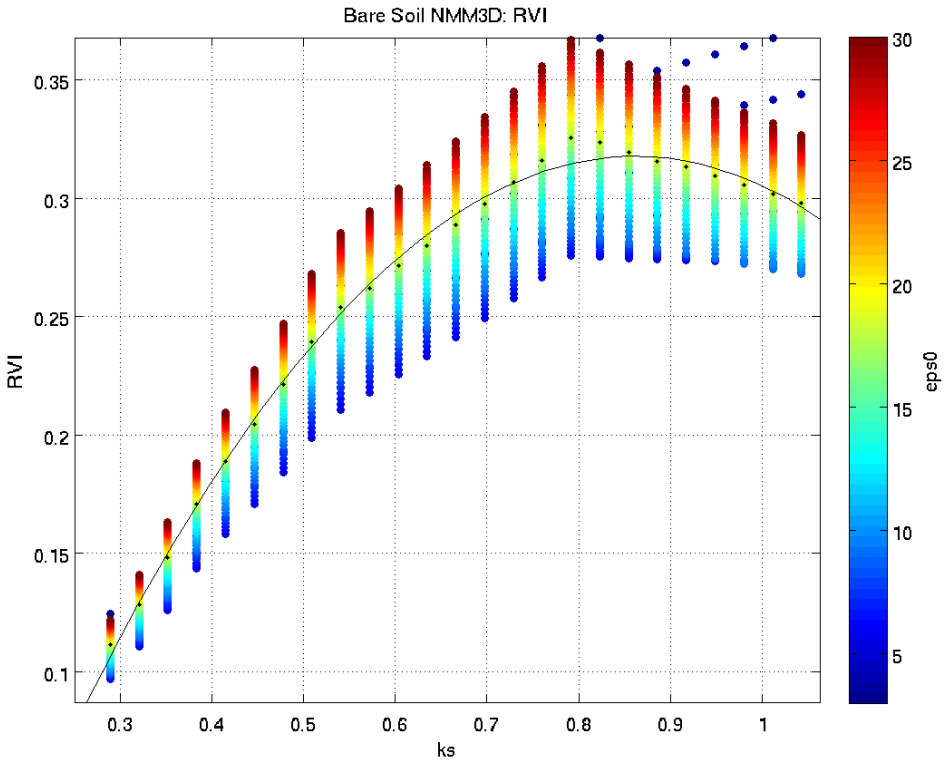
Sensitivity



Intercept




Central Asia
SMAPVEX12
West Africa
Amazon
Nordeste
East Africa
Pampas
SMAPEx
50
0
−50
Latitude (deg)
−150
−100
−50
0
50
100
150
Longitude (deg)



RVI is higher than 0 for bare soil

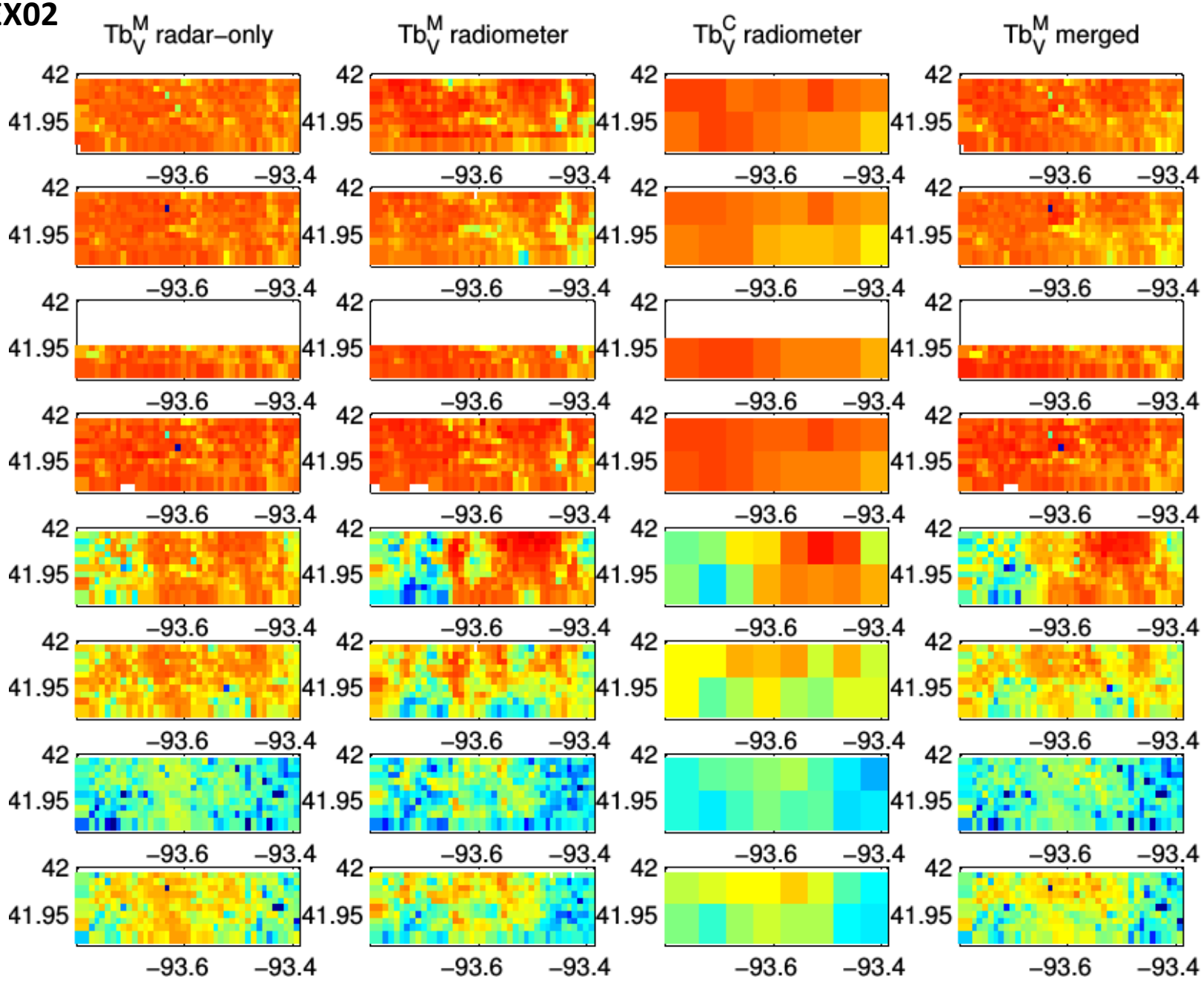
Maximum Likelihood Estimator for merging Tb at different spatial resolution

$$L(Tb_V^{M*}) = \frac{1}{\sqrt{2\pi\sigma_C^2}} e^{-\frac{\left(Tb_V^C - \frac{1}{M_C}\sum_{j=1}^{M_C} Tb_{Vj}^{M*}\right)^2}{2\sigma_C^2}} \prod_{i=1}^{M_C} \frac{1}{\sqrt{2\pi\sigma_i^2}} e^{-\frac{\left(Tb_{Vi}^M - Tb_{Vi}^{M*}\right)^2}{2\sigma_C^2}}$$

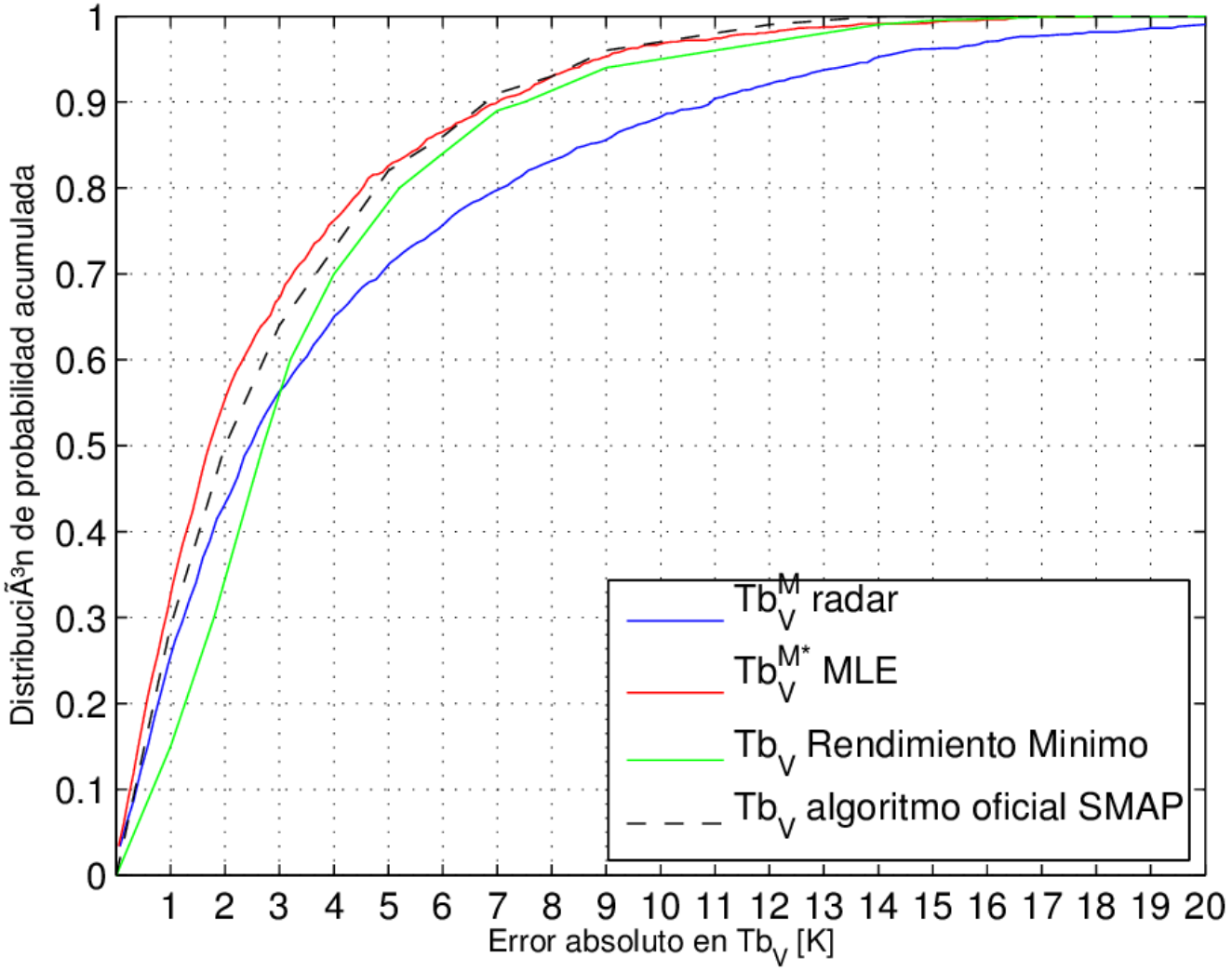
$$\frac{\partial f\left(\vec{Tb}_V^{M*}\right)}{\partial Tb_{Vi}^{M*}} = -\frac{Tb_V^C - \frac{1}{M_C}\sum_{j=1}^{M_C} Tb_{Vj}^{M*}}{M_C\sigma_C^2} - \frac{Tb_{Vi}^M - Tb_{Vi}^{M*}}{\sigma_i^2} = 0.$$

$$\underbrace{\begin{bmatrix} \frac{1}{M_C^2\sigma_C^2} + \frac{1}{\sigma_1^2} & \frac{1}{M_C^2\sigma_C^2} & \cdots & \frac{1}{M_C^2\sigma_C^2} \\ \frac{1}{M_C^2\sigma_C^2} & \frac{1}{M_C^2\sigma_C^2} + \frac{1}{\sigma_2^2} & \cdots & \frac{1}{M_C^2\sigma_C^2} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{M_C^2\sigma_C^2} & \frac{1}{M_C^2\sigma_C^2} & \cdots & \frac{1}{M_C^2\sigma_C^2} + \frac{1}{\sigma_M^2} \end{bmatrix}}_{\boldsymbol{A}} \vec{Tb}_V^{M*} = \underbrace{\begin{bmatrix} \frac{Tb_V^C}{M_C\sigma_C^2} + \frac{x_1}{\sigma_1^2} \\ \frac{Tb_V^C}{M_C\sigma_C^2} + \frac{x_2}{\sigma_2^2} \\ \vdots \\ \frac{Tb_V^C}{M_C\sigma_C^2} + \frac{x_M}{\sigma_M^2} \end{bmatrix}}_{\boldsymbol{b}}$$

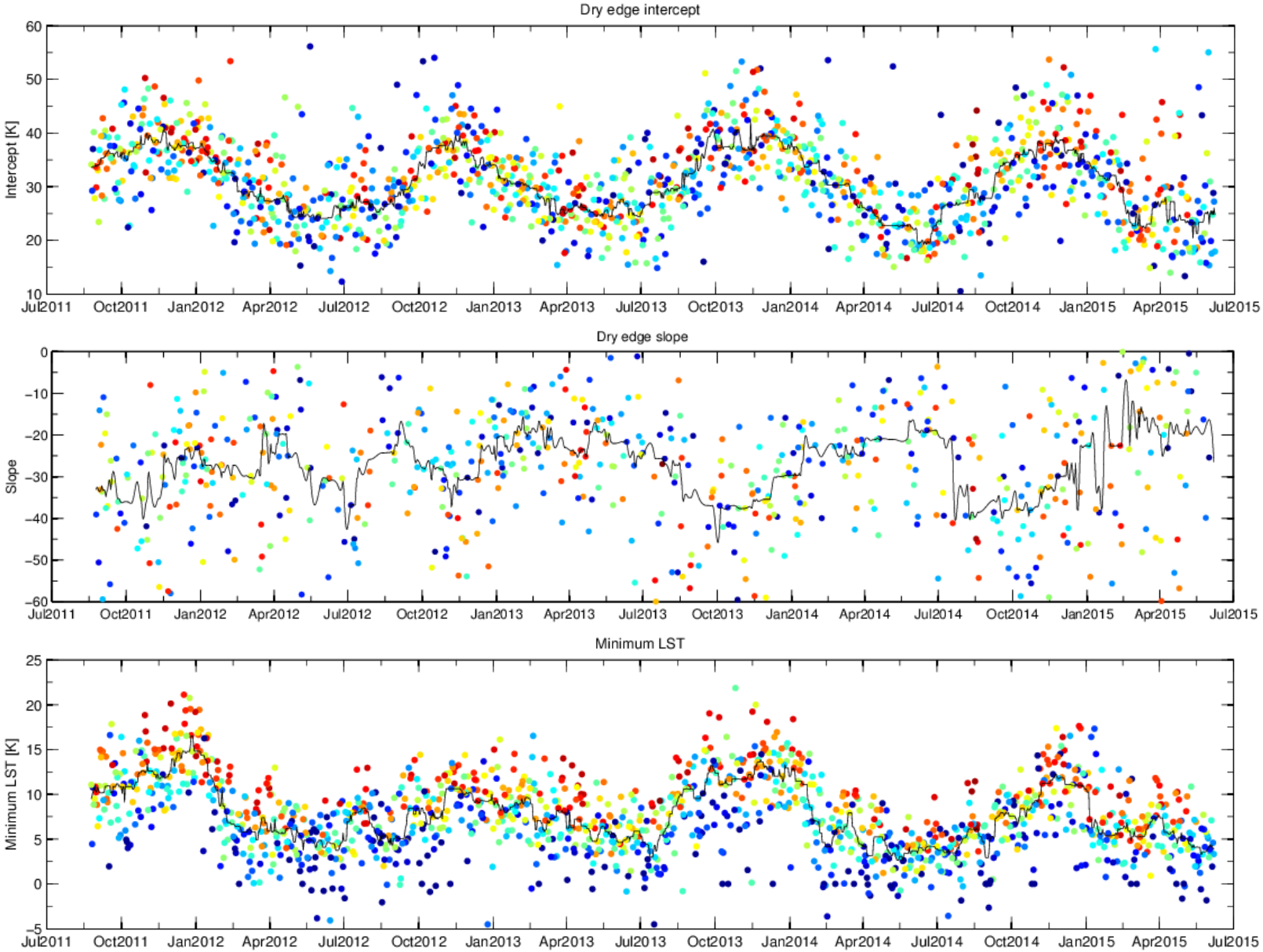
SMEX02


Tb_V^M radar–only
Tb_V^M radiometer
Tb_V^C radiometer
Tb_V^M merged
42
41.95
−93.6
−93.4

Cumulative distribution function of errors

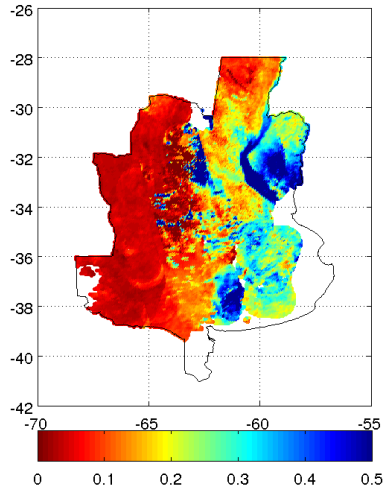


Time series of triangle parameters

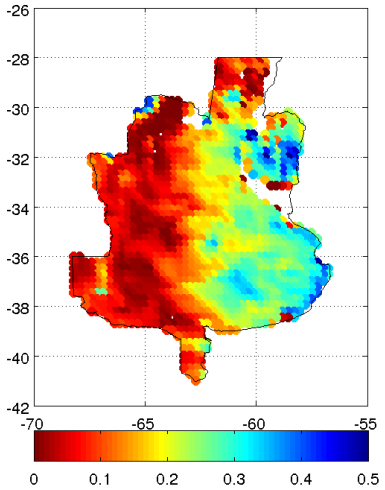


Maps of Aquarius downscaled soil moisture and SMOS

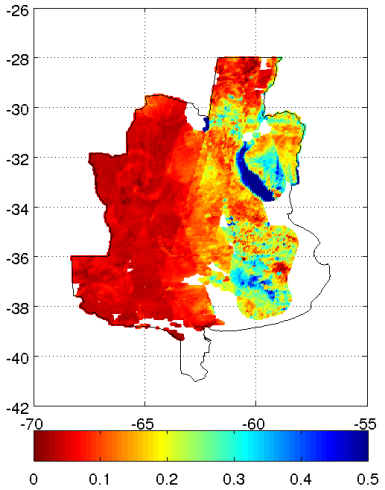
SM downscaled MODIS-Aquarius - Date 31-Aug-2011 - 06-Sep-2011



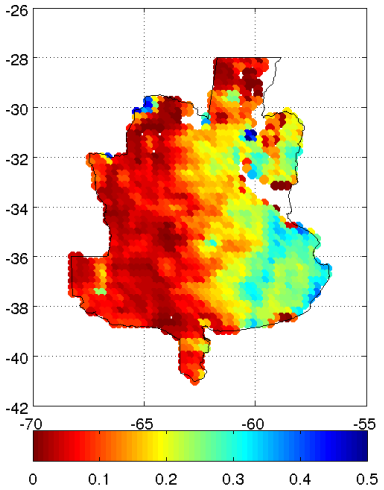
SM SMOS - Date 31-Aug-2011 - 06-Sep-2011



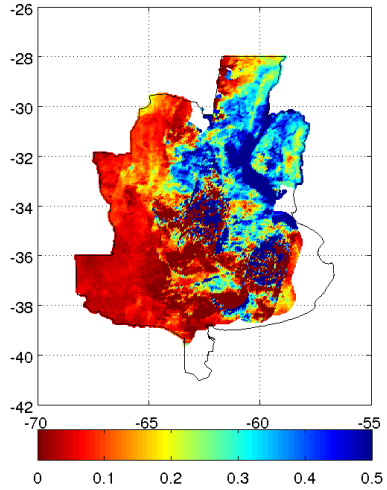
SM downscaled MODIS-Aquarius - Date 07-Sep-2011 - 13-Sep-2011



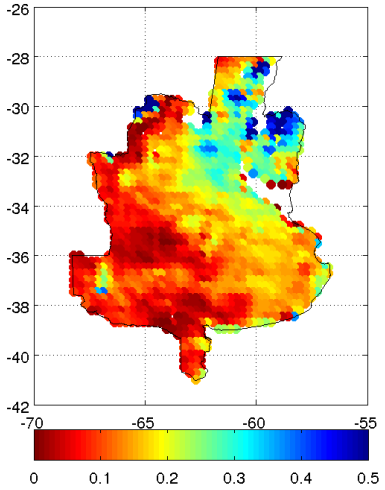
SM SMOS - Date 07-Sep-2011 - 13-Sep-2011



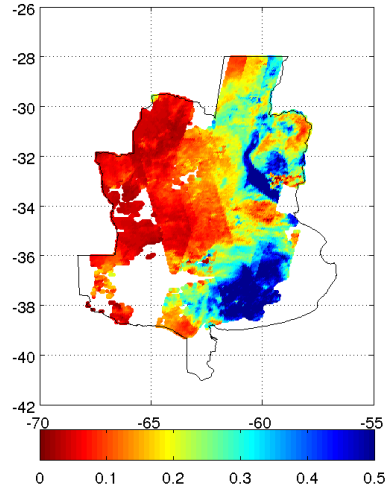
SM downscaled MODIS-Aquarius - Date 02-Nov-2011 - 08-Nov-2011



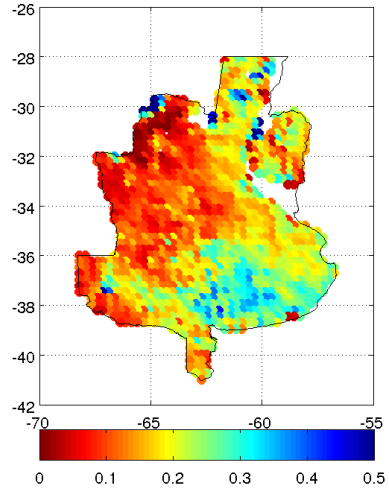
SM SMOS - Date 02-Nov-2011 - 08-Nov-2011



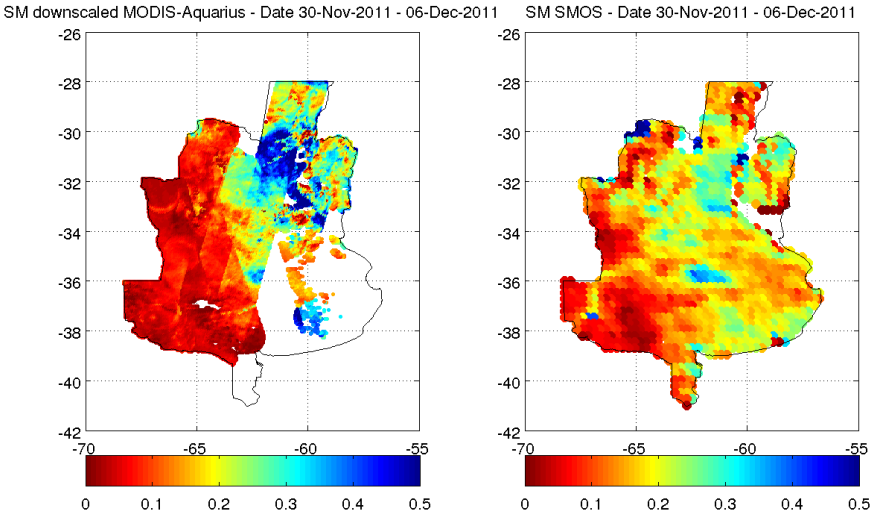
SM downscaled MODIS-Aquarius - Date 09-Nov-2011 - 15-Nov-2011

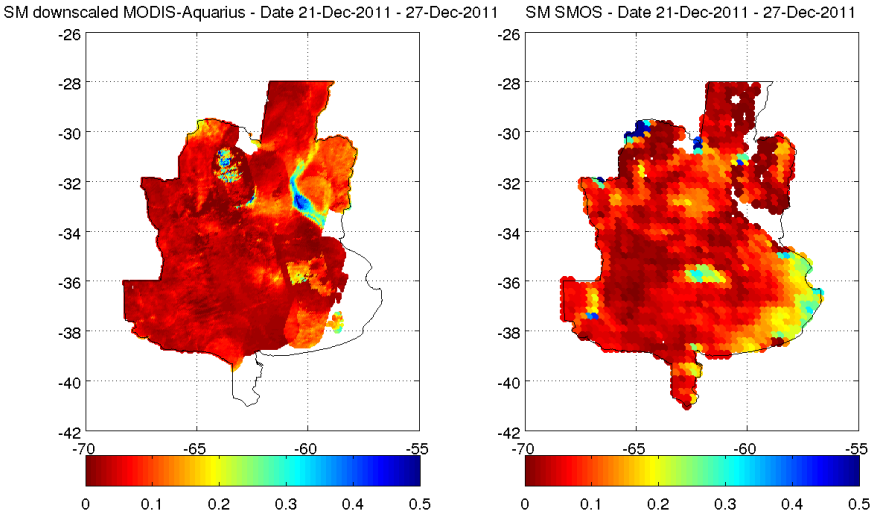


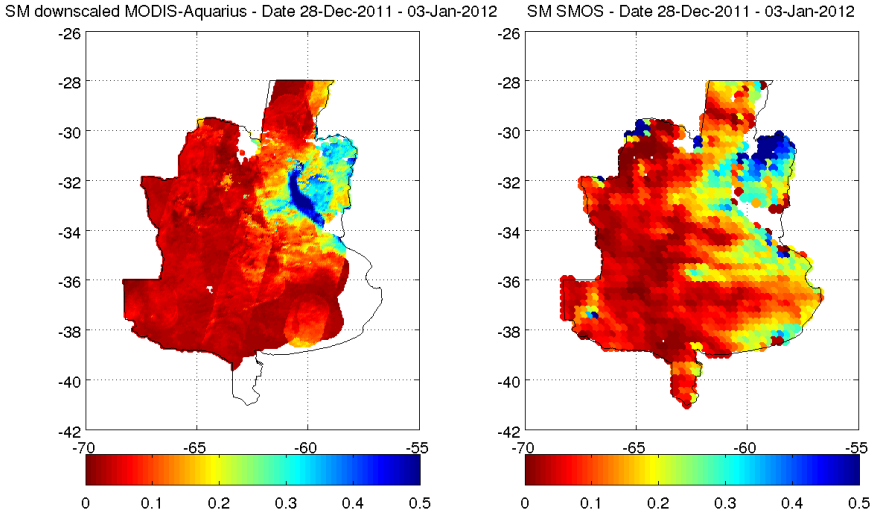
SM SMOS - Date 09-Nov-2011 - 15-Nov-2011

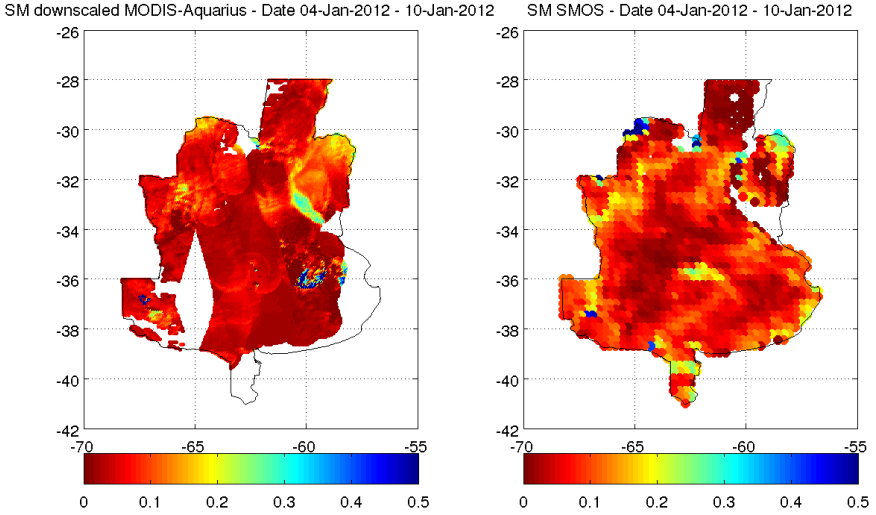


Maps of Aquarius downscaled soil moisture and SMOS

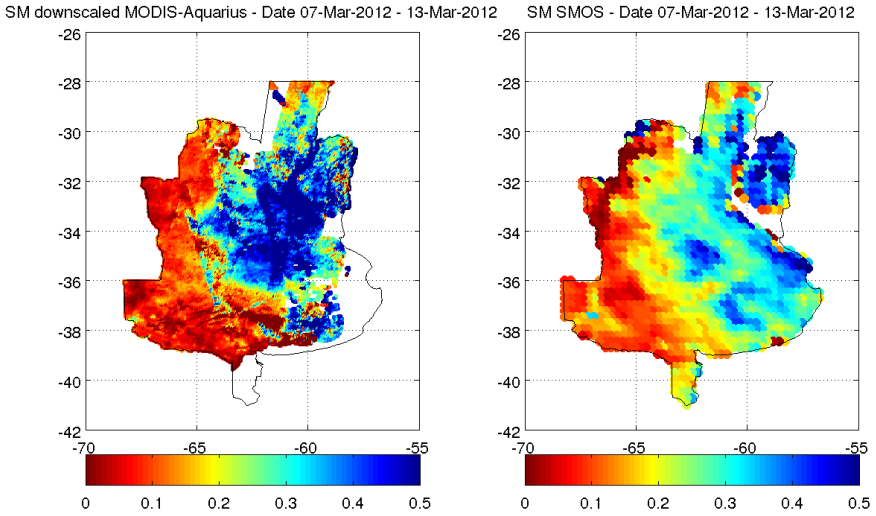


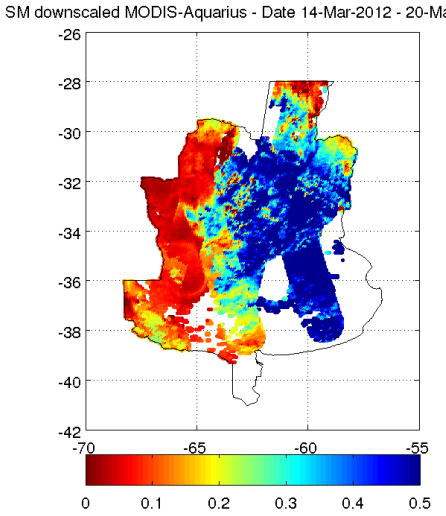


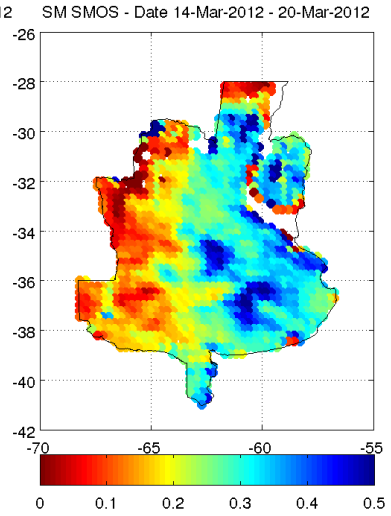


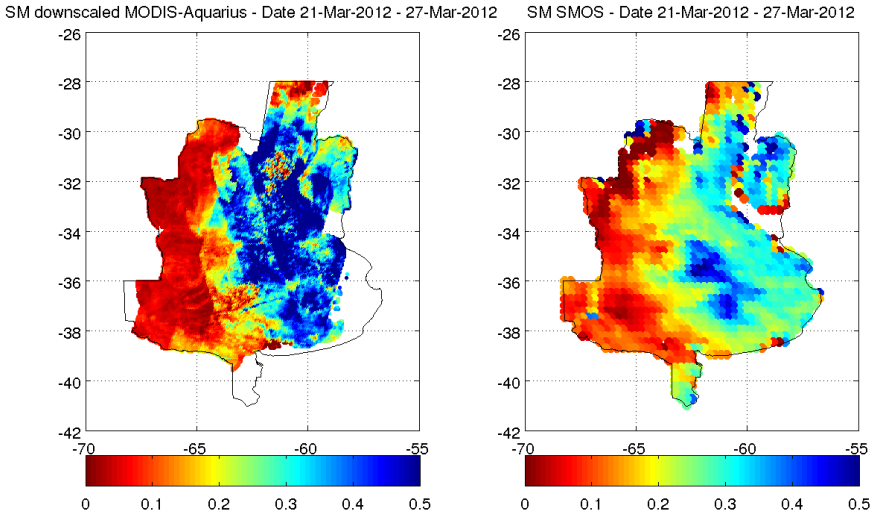


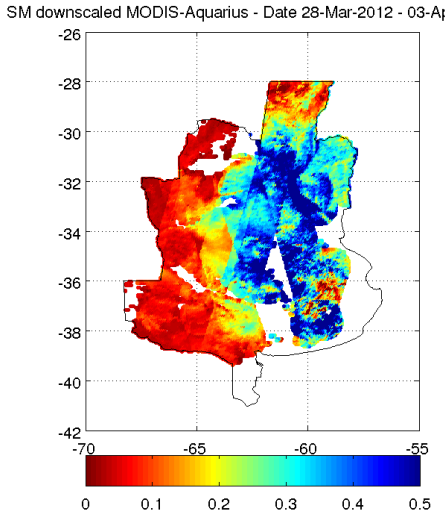
Maps of Aquarius downscaled soil moisture and SMOS

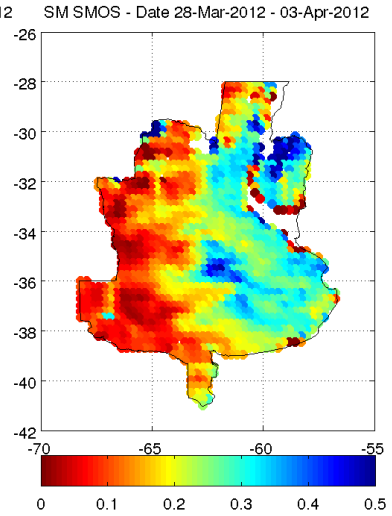




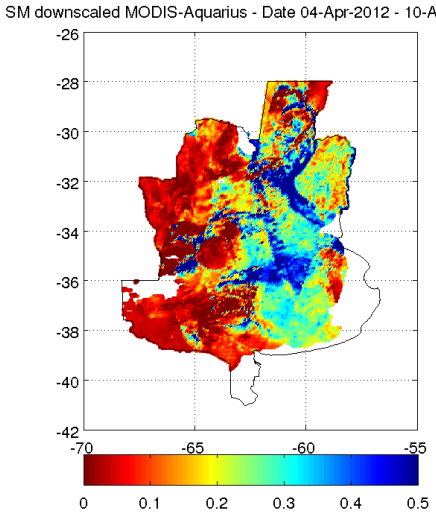


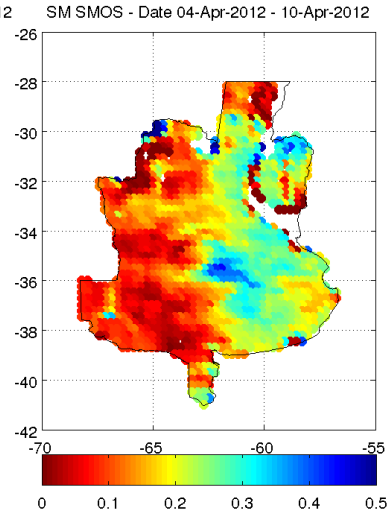


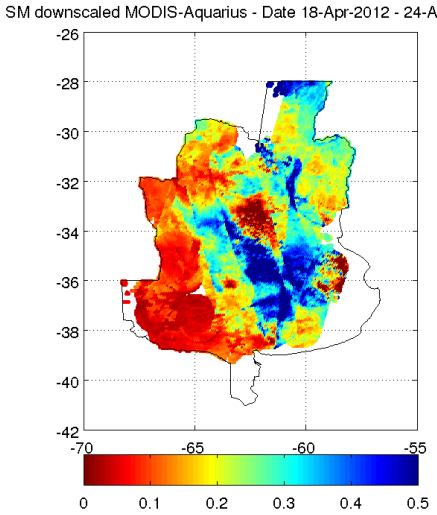


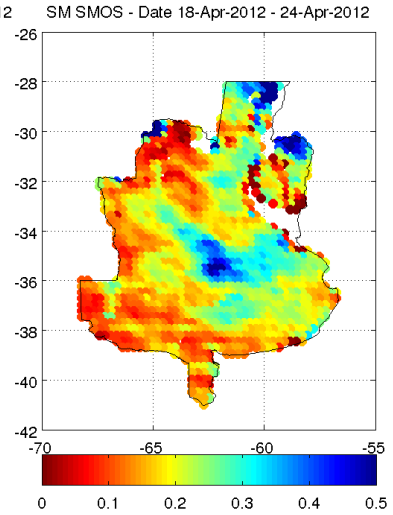


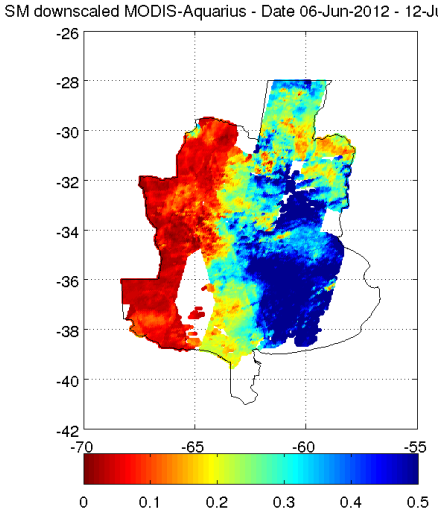
Maps of Aquarius downscaled soil moisture and SMOS

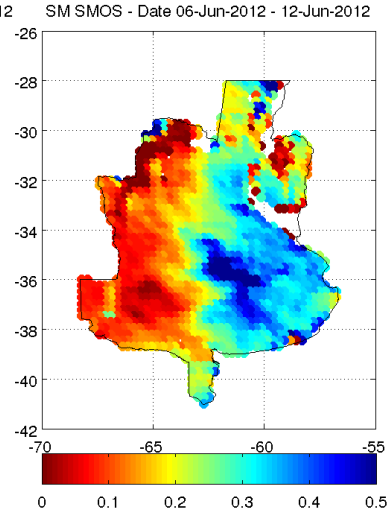


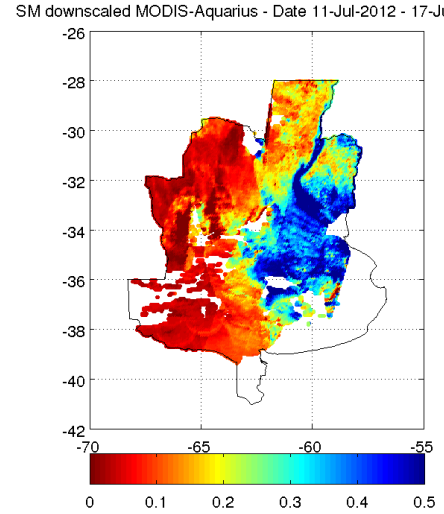


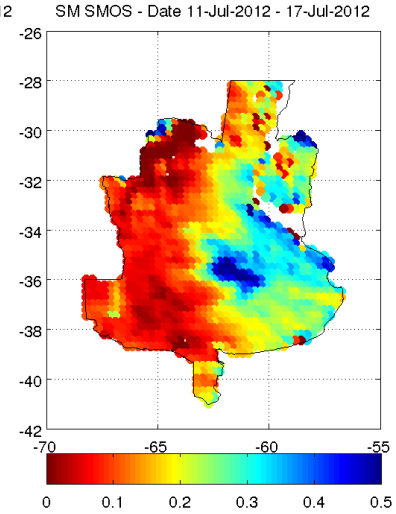




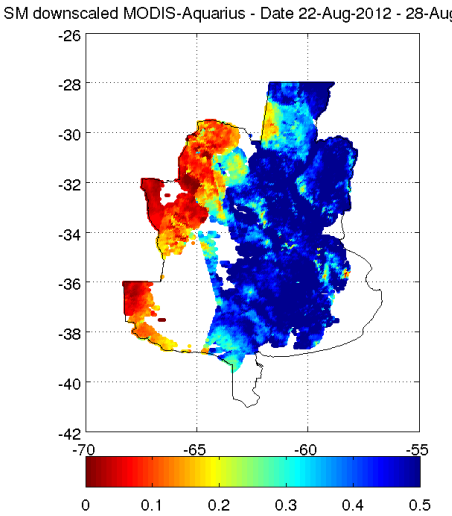


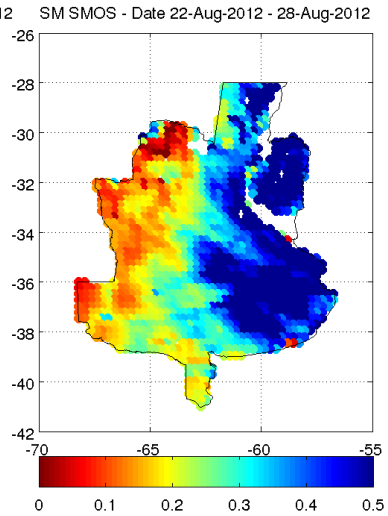


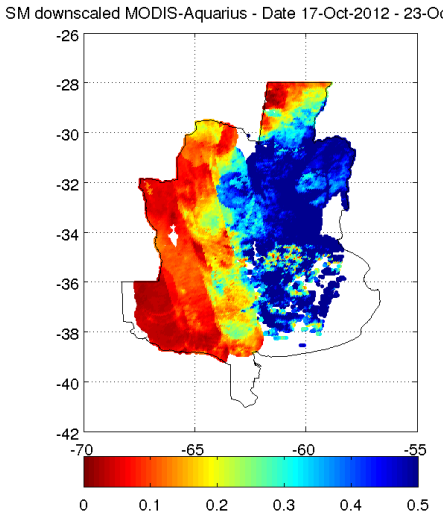


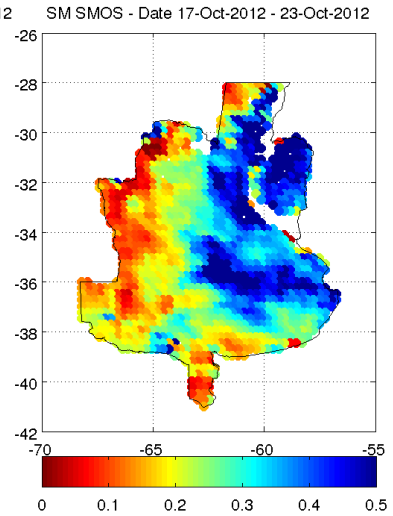


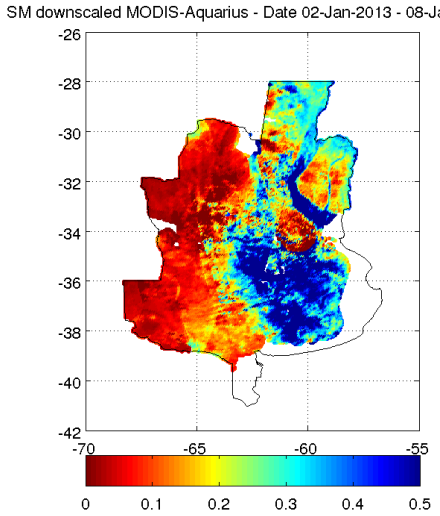
Maps of Aquarius downscaled soil moisture and SMOS

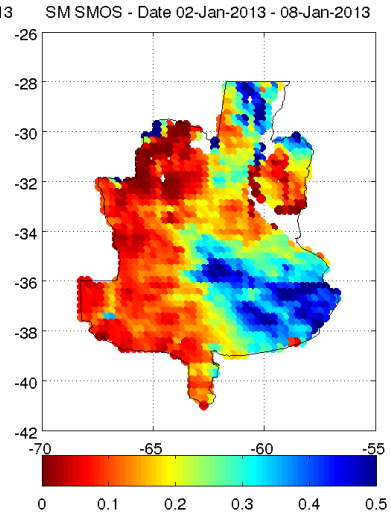


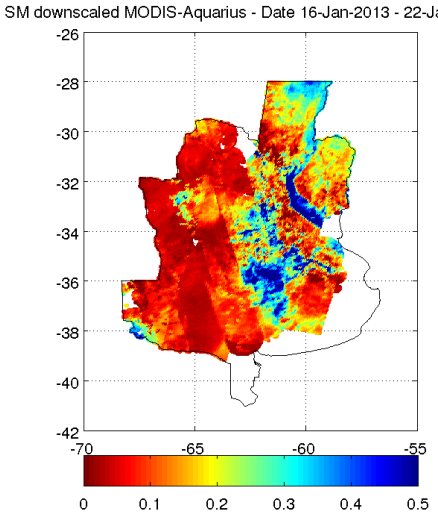


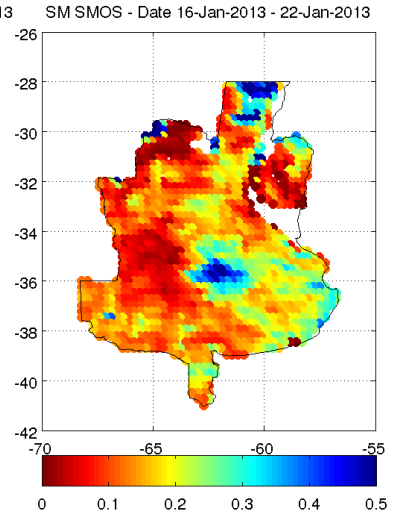




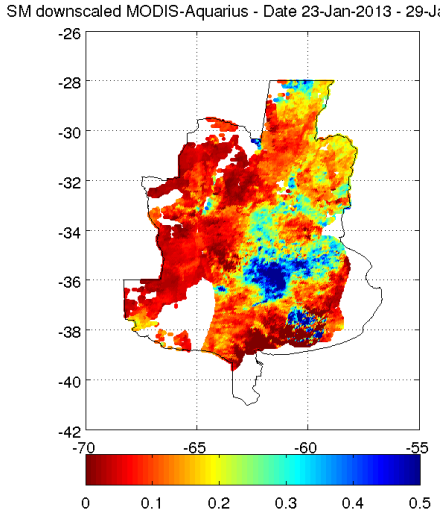


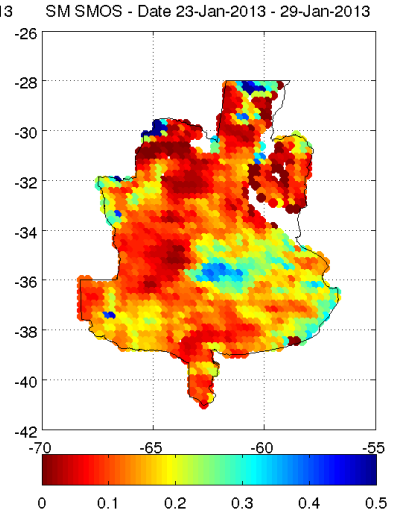


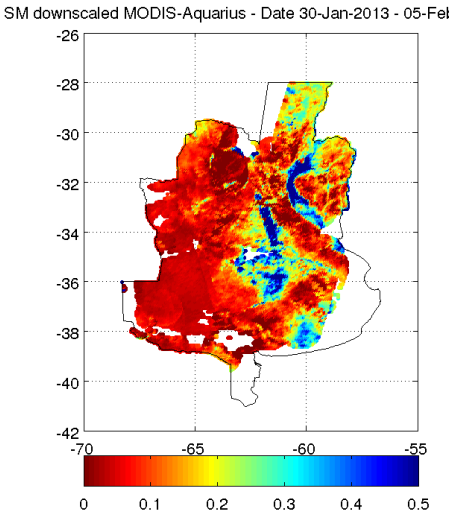


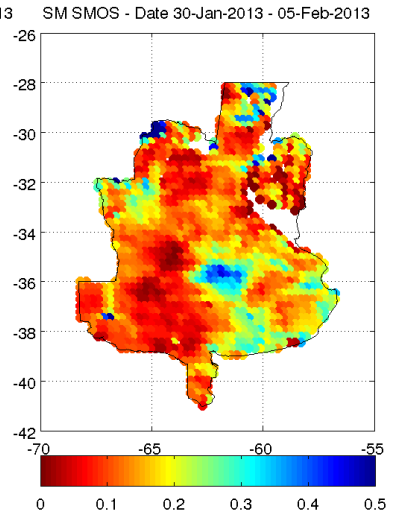


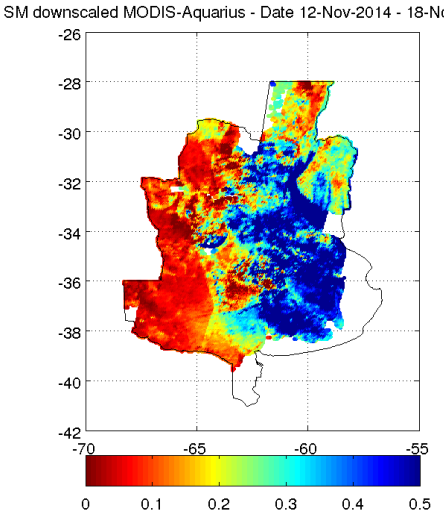
Maps of Aquarius downscaled soil moisture and SMOS

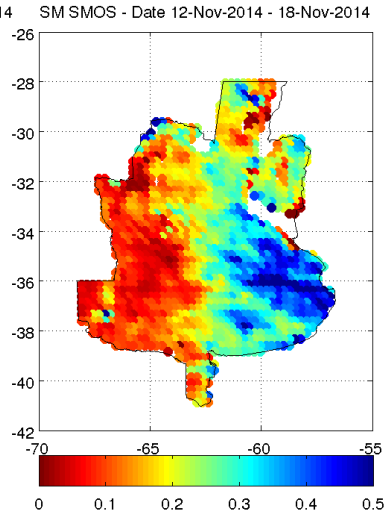


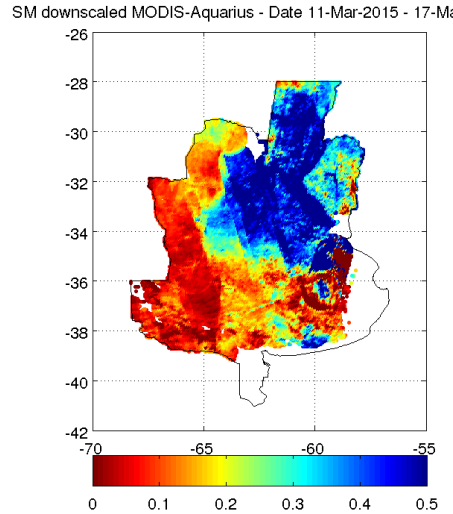


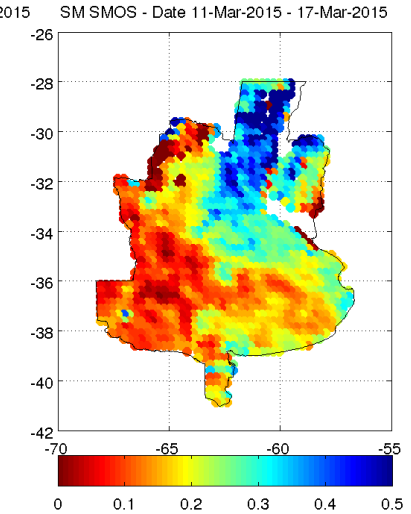




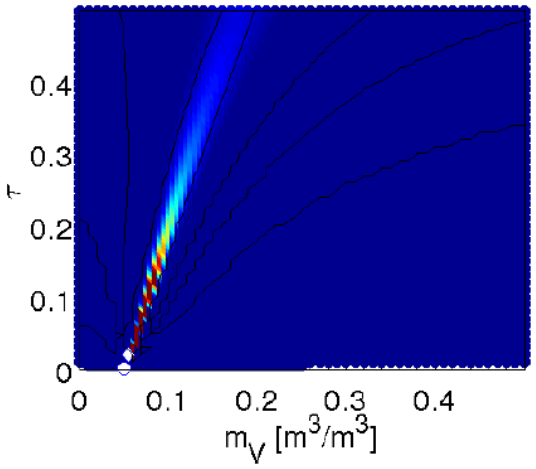




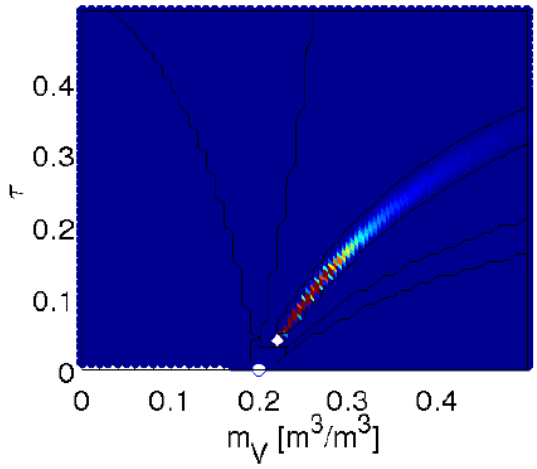




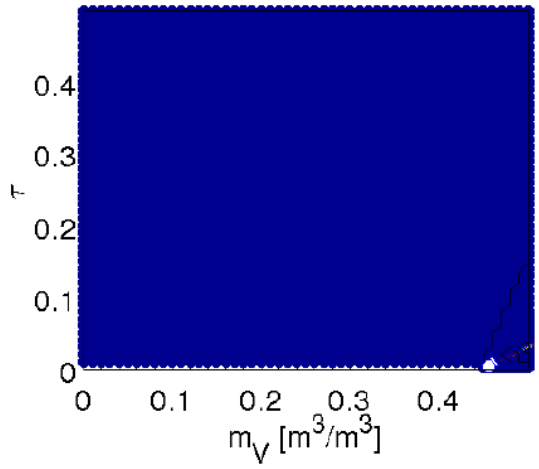
Bayesian soil moisture and τ retrieval



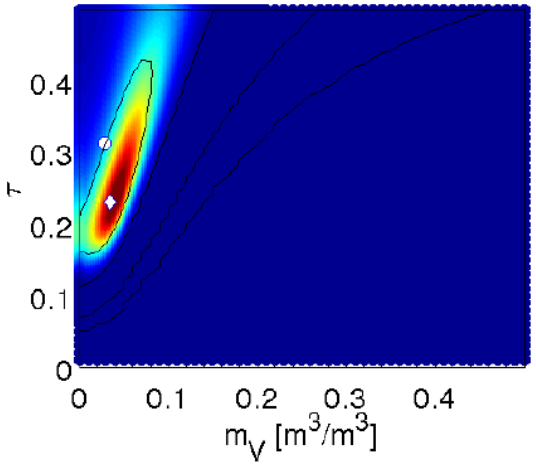
(a) τ=0 y m_V=0.05 $\mathrm{m}^3/\mathrm{m}^3$

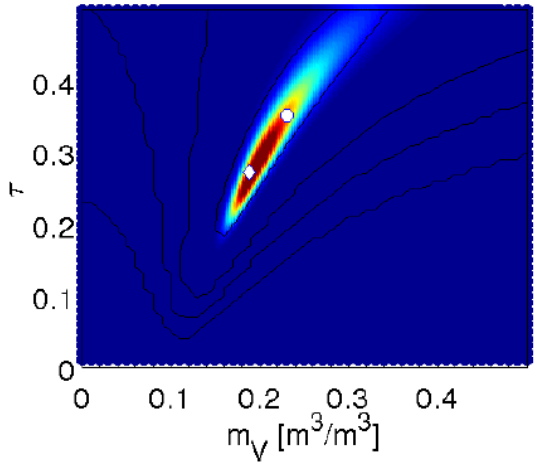


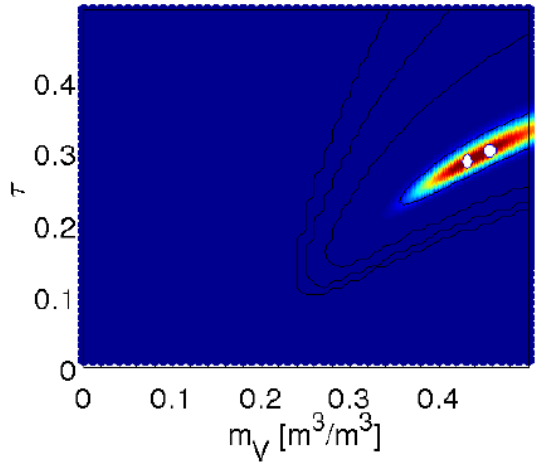
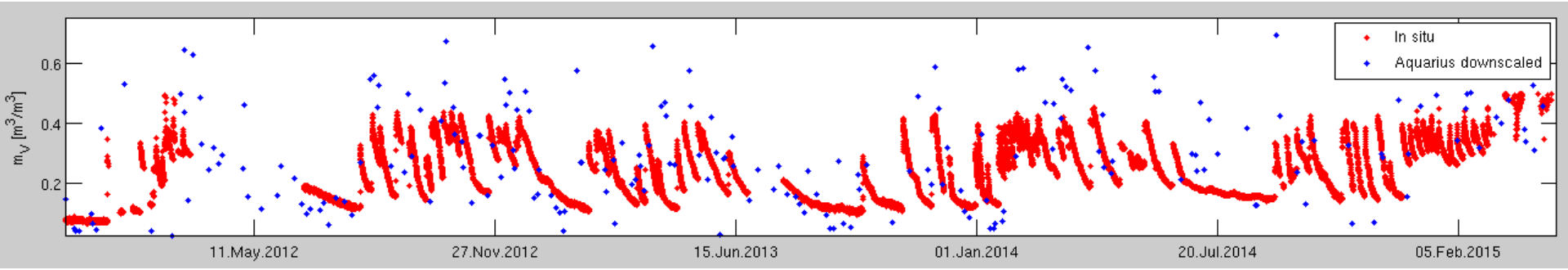
(b) τ=0 y m_V=0.2 $\mathrm{m}^3/\mathrm{m}^3$



(c) τ=0 y m_V=0.45 $\mathrm{m}^3/\mathrm{m}^3$







Aquarius downscaled soil moisture vs. In situ measurements