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SEA SURFACE SALINITY RETRIEVAL UNDER RAIN BASED ON L-BAND COMBINED ACTIVE-PASSIVE(CAP) OBSERVATIONS

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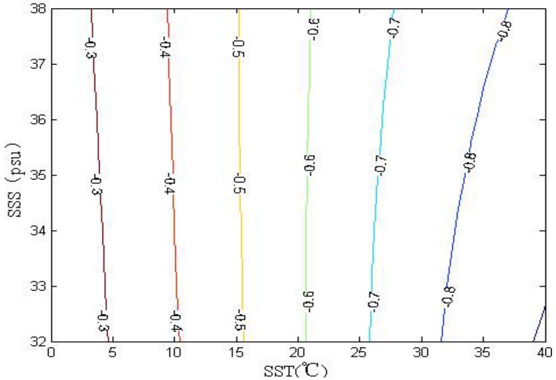
Outline

1. Introduction
2. Data and method
3. Results and discussion
4. Conclusion and future work

1. Introduction

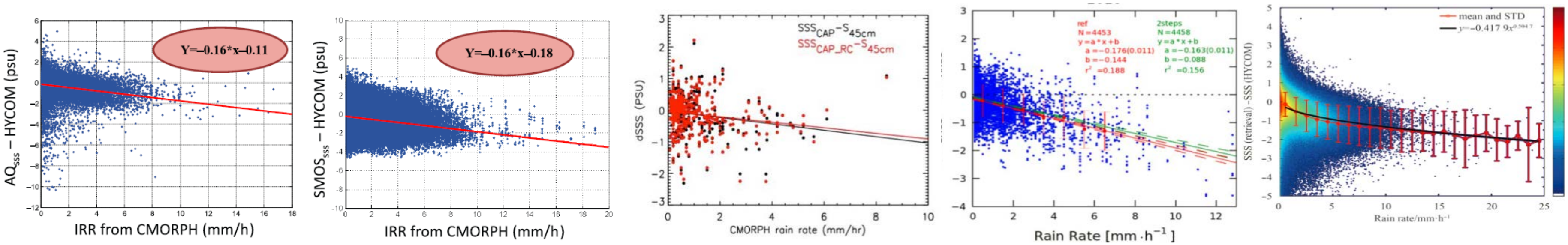
- Sea surface salinity (SSS) is an important influence factor in some process such as the global water cycle and ocean circulation
- SSS remote sensing from space is a very new and challenging area since the signal is weak and noisy
- Rain drops introduce additional difficulty (freshening and roughness)



(Source: ESA, iStockphoto)

1. Introduction

- Numerous studies have indicated SSS retrieval error increases under rain
- Mixing effect of rain-induced roughness and freshening in TB
- How to separate these two effects?
- Active observation is insensitive to the salinity change (Tang et al., 2013)
- Active observation provides important constraint information on the roughness correction

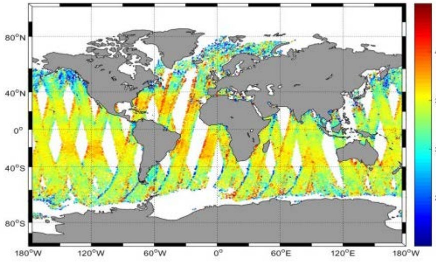


（Santos-Garcia, 2016; Ma, 2015; Tang, 2015; Joutin, 2014;）

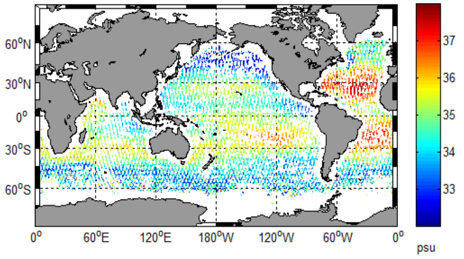
2 Data and Method

2.1 Salinity data

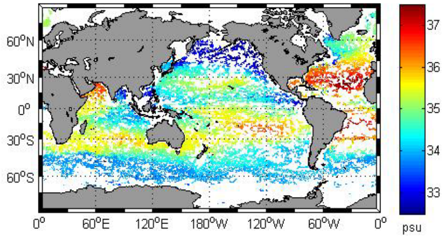
- SMOS L2 data product of 2012 (by ESA)
- Aquarius L2 data product of 2012 and 2013 (by NASA)
- Argo profile data (by IFREMER)
- HYCOM product (in Aquarius data blocks)



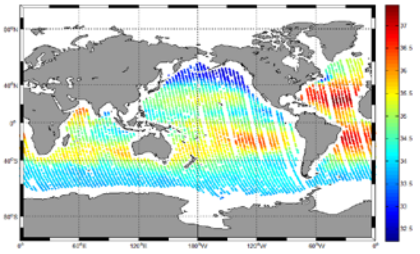
SMOS salinity



Aquarius salinity



Argo salinity

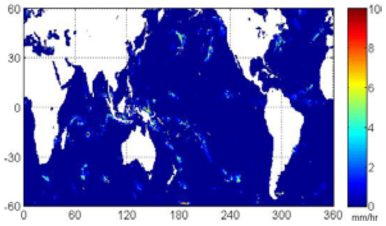


HYCOM salinity

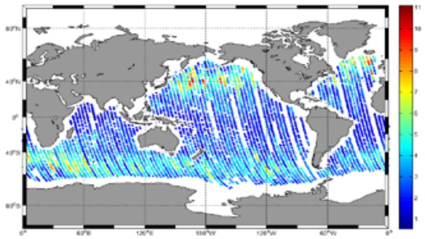
2 Data and Method

2.2 Auxiliary data

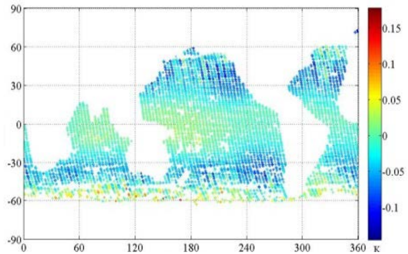
- CMORPH rain data (GMF developing)
- SWH WaveWatch-3 (GMF developing)
- NCEP profile of atmosphere (atmospheric TB correction)
- WindSat SST and wind field data (GMF developing)



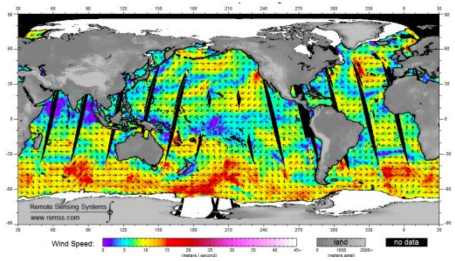
CMORPH rain data



WW3 SWH data



Atmospheric radiation



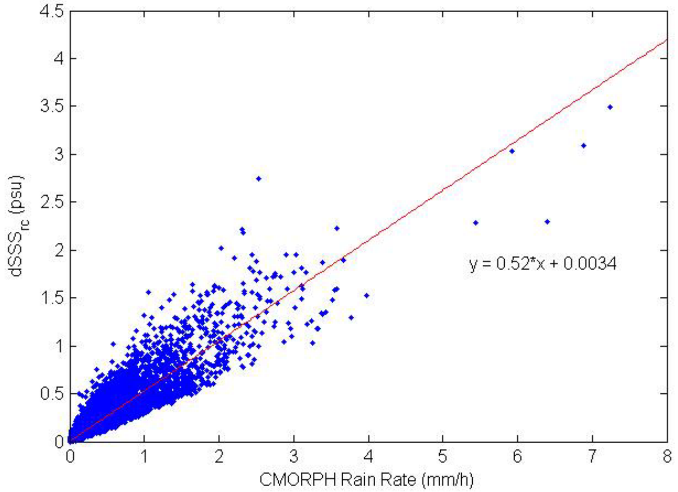
WindSat wind field

2 Data and Method

2.3 Rain correction of HYCOM data by RIM (Rain Impact Model)

$$SSS_{\mathrm{HYCOM\_RIM}} = SSS_{\mathrm{HYCOM}}\left(\prod_{i=1}^{n}\left[1+\frac{A_i}{\sqrt{K_z t_i}}e^{-\frac{z^2}{4K_z t_i}}\right]\right)^{-1}$$

- SSS_{HYCOM} is the HYCOM salinity
- SSS_{HYCOM_RIM} is the SSS after rain correction
- Ai (in meter) is the rain input flux
- Kz is the vertical eddy diffusivity
- ti is the time of rain event



2 Data and Method

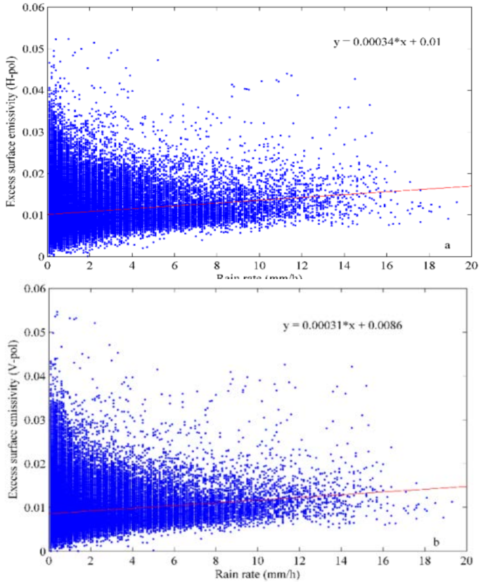
2.4 GMF Developing

- Emissivity of rough sea surface is described as: $$\varepsilon_{rough} = \frac{\dfrac{T_B - T_{BU}}{\tau} - (T_{BD} + \tau \cdot T_{COS})}{T_s - (T_{BD} + \tau \cdot T_{COS})} - \varepsilon_{flat}$$

- Emissivity is averaged within bins of wind speed, wind direction, wave height
- Data range: 2~25m/s(WS), 0° ~360° (WD), 0-10 m (SWH),1-20 mm/h(RR)
- All bins with the amount of data less than 5 are excluded

- Clear positive correlation of emissivity to rain rate with a slope of 0.0003
- It means a 0.9 K TB increment and a 1psu extra salinity error under the rain rate of 10mm/h.

$$\Delta\varepsilon_{norain} = \Delta\varepsilon_{norain}(ws, wd, swh),$$
$$\Delta\varepsilon_{rain} = \Delta\varepsilon_{rain}(ws, wd, swh, rr)$$

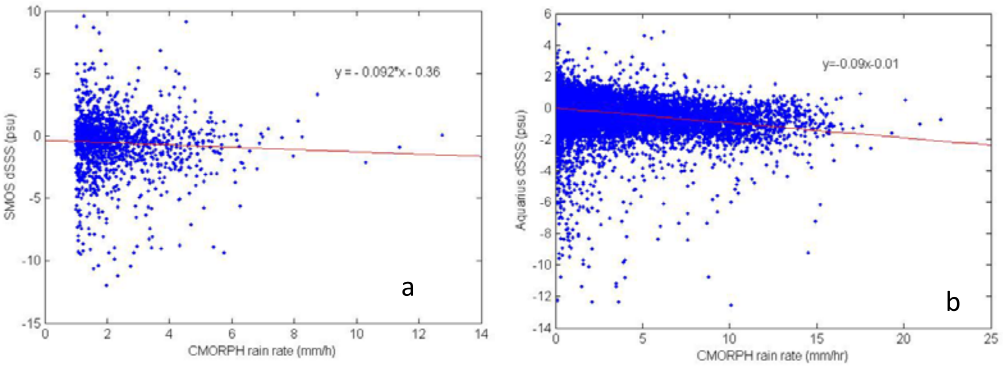


Excess sea surface emissivity versus rain rate (a: H-pol, b: V-pol)

3. Results and Discussion

3.1 SMOS and Aquarius retrieval error under rain

- Satellite salinity data are validated by Argo and HYCOM corrected by RIM
- Errors of both satellites increase with rain rate
- Both satellites share the same slope of 0.09 psu/(mm·h^{-1})
- 10mm/h ~ 0.9psu (coincident with the previous slide)

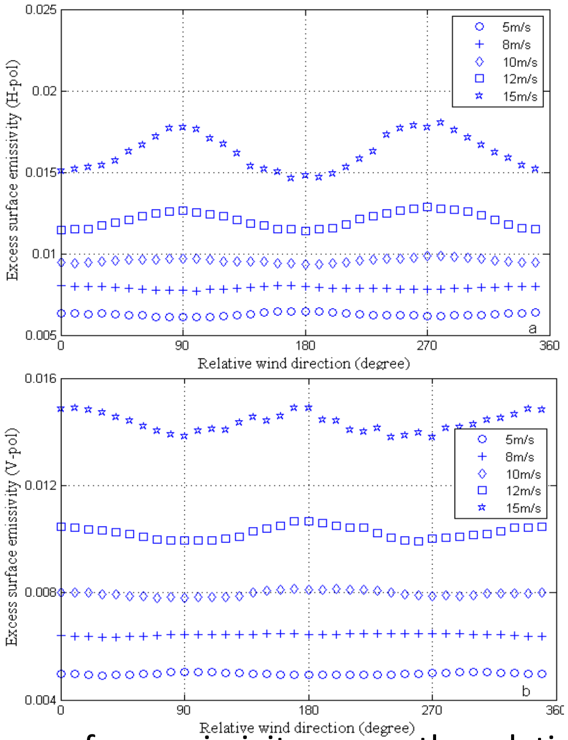


Dependence of dSSS on rain rate (a: SMOS, b:Aquarius)

3. Results and Discussion

3.2 Radiation under no-rain conditions

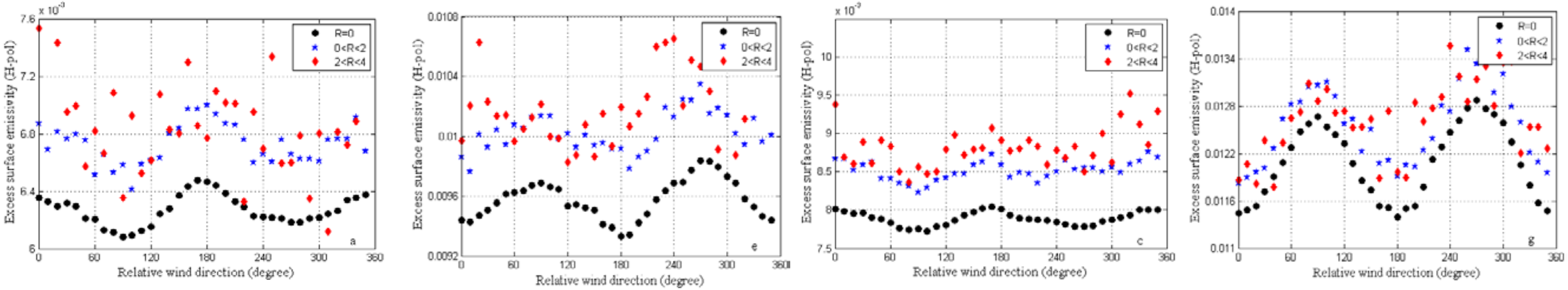
- Clear dependence on wind direction under all wind speed condition
- For H-pol, Positive Upwind-Crosswind (PUC) asymmetry under the wind speed of 5 and 8 $m \cdot s^{-1}$
- For V-pol, negative upwind-crosswind (NUC) asymmetry at the same wind speed



Excess surface emissivity versus the relative wind direction (a: H-pol； b: V-pol)

3.2 Radiation under rainy conditions

- Because of rain induced sea surface freshening and roughness, the emissivity under rain is larger than rain free emissivity.
- Rainy data is noisier than rain-free due to the less data amount and more bins in rainy conditions.
- Fact that the rainy emissivity approaching to the rain free emissivity as the wind speed increasing, indicates the wind generated roughness effect dominate rain effect under the high wind speed.



Excess emissivity versus the relative wind direction under the wind speed of 5m/s , 8m/s , 10m/s, and 12m/s

3. Results and Discussion

3.3 Rain roughness correction

- The excess emissivity under rain:
- Response of radiometer and scatterometer to a given roughness (backscatter) is fixed
- Obtain the ratio of emissivity by rainy and rain-free data sets

$$\Delta e_{\text{rain}} = \boxed{\Delta e_{\text{roughness}}(ws, wd, swh, rr)} + \boxed{\Delta e_{\text{freshening}}(SST, \Delta SSS)}$$

Rain-induced Noise

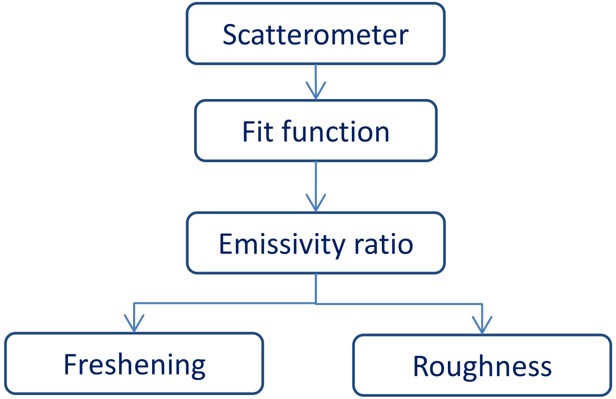
Real salinity signal

$$\frac{\Delta e_{\text{rain}}}{\Delta e_{\text{norain}}} = \frac{\Delta e_{\text{roughness\_rain}} + \Delta e_{\text{freshening}}}{\Delta e_{\text{roughness\_norain}}} = 1 + \frac{\Delta e_{\text{freshening}}}{\Delta e_{\text{roughness}}}$$

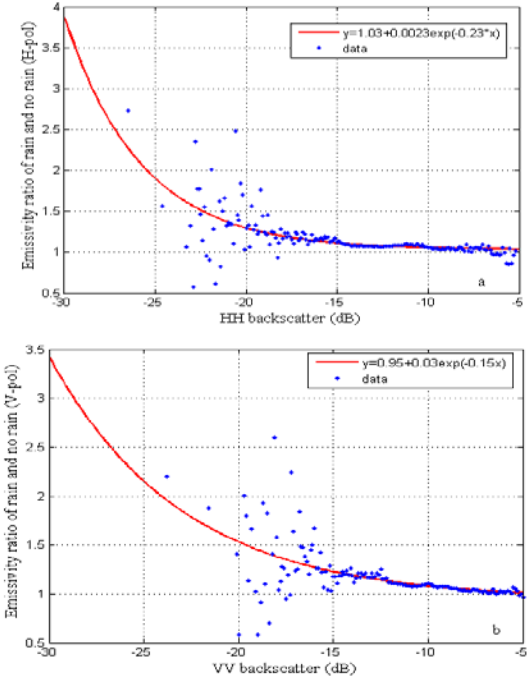
3.3 Rain roughness correction

- Fit function of the emissivity ratio:

$$\frac{\Delta e_{\text{rain}}}{\Delta e_{\text{norain}}} = 1 + \frac{\Delta e_{\text{freshening}}}{\Delta e_{\text{roughness}}} = \begin{cases} 1.03 + 0.0023\exp(-0.23 * x) & \text{H-pol} \\ 0.95 + 0.0030\exp(-0.15 * x) & \text{V-pol} \end{cases}$$



Flowchart of rain correction



Emissivity ratio and its exponential fit function
(a: H/HH; b:V/VV)

3.4 Salinity retrieval and validation under rain

TOA TB

↓

Atmosphere correction

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TB of sea surface

↓

GMF → Roughness correction

↓

TB of flat sea surface

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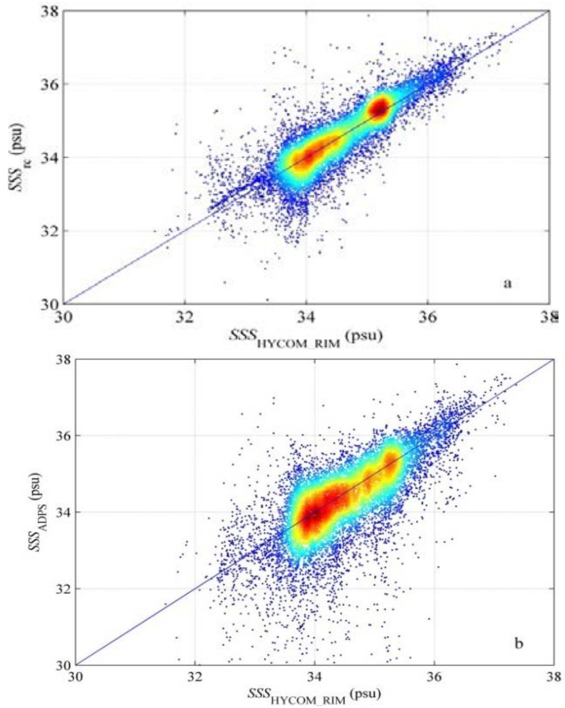
$HYCOM_{RIM}$ → Salinity

SSS retrieval procedure



Compare of SSS_{rc} (a) and SSS_{ADPS} (b) with HYCOM corrected by RIM

3. Results and Discussion

3.4 Salinity retrieval and validation under rain

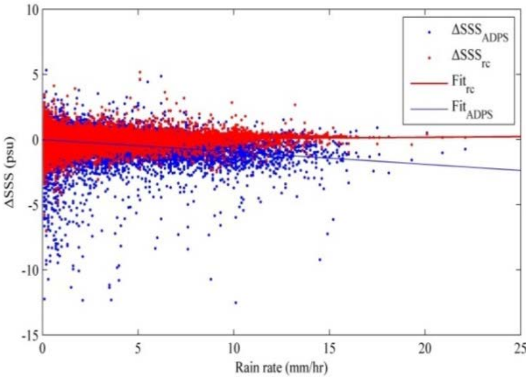
Error statistics of SSS_{rc} and SSS_{ADPS}

Year	2012		2013*	
Data set	SSS_{rc}	SSS_{ADPS}	SSS_{rc}	SSS_{ADPS}
Bias (psu)	<0.01	-0.22	-0.04	-0.19
Standard deviation (psu)	0.49	0.95	0.53	0.86
R^2	0.85	0.63	0.83	0.68

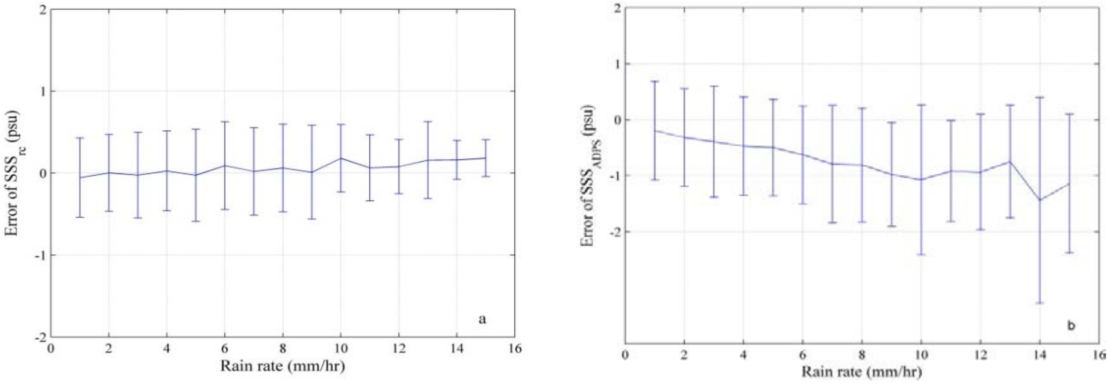
* The data of 2013 are not involved in the development of GMFs and rain roughness correction method

3. Results and Discussion

3.4 Salinity retrieval and validation under rain



Errors of SSS_{rc}(red dots)and SSS_{ADPS} (blue dots) fit functions to rain rate.Straight lines are linear fit functions for SSS_{rc}(Fit_{rc})and SSS_{ADPS} (Fit_{ADPS}). (Fit_{rc}: y=0.01x-0.04; Fit_{ADPS}: y=-0.09x-0.01)



Mean value of error ±1 standard deviation as function of the rain rate (a: SSS_{rc}, b: SSS_{ADPS})

4. Conclusion and future work

- Based on CAP observations, a method to rain correction is obtained and applied to sea surface salinity retrieval
- Validation procedure show that error of SSS_{rc} are superior to SSS_{ADPS} and more stable under all rain conditions
- Whether the roughness effect of rain is similar in character to the roughness caused by wind? (It is a empirical model)
- A theoretical model of rough surface which a rain wave spectrum is introduced in
- Extend the algorithms to other satellite with CAP observation capability

Thank you for your attention!