SMOSops secondary payload assessment: optimal FPIR radiometer configuration for sea surface roughness characterization at L-band

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Introduction

- L-band 2D-interferometer (MIRAS) onboard ESA Soil Moisture and Ocean Salinity (SMOS) mission to be launched in September 2009.
- At L-band, Tb over the ocean is mainly modulated by three geophysical variables: SSS, SST, and roughness.
- Analysis of pre-launch semi-empirical geophysical model functions shows that sensitivities to surface roughness and SSS are of the same order.
- Unlike Aquarius, SMOS does not have a complementary instrument to provide information on roughness
- SMOS follow-on (SMOSops): suitable secondary payload to quantify/correct surface roughness impact on Tb to improve SSS retrievals?
- China (CSSAR) offers ESA an X-band Fully Polarimetric Interferometric Radiometer (FPIR)
- ESA asked SMOS-BEC to review FPIR configuration

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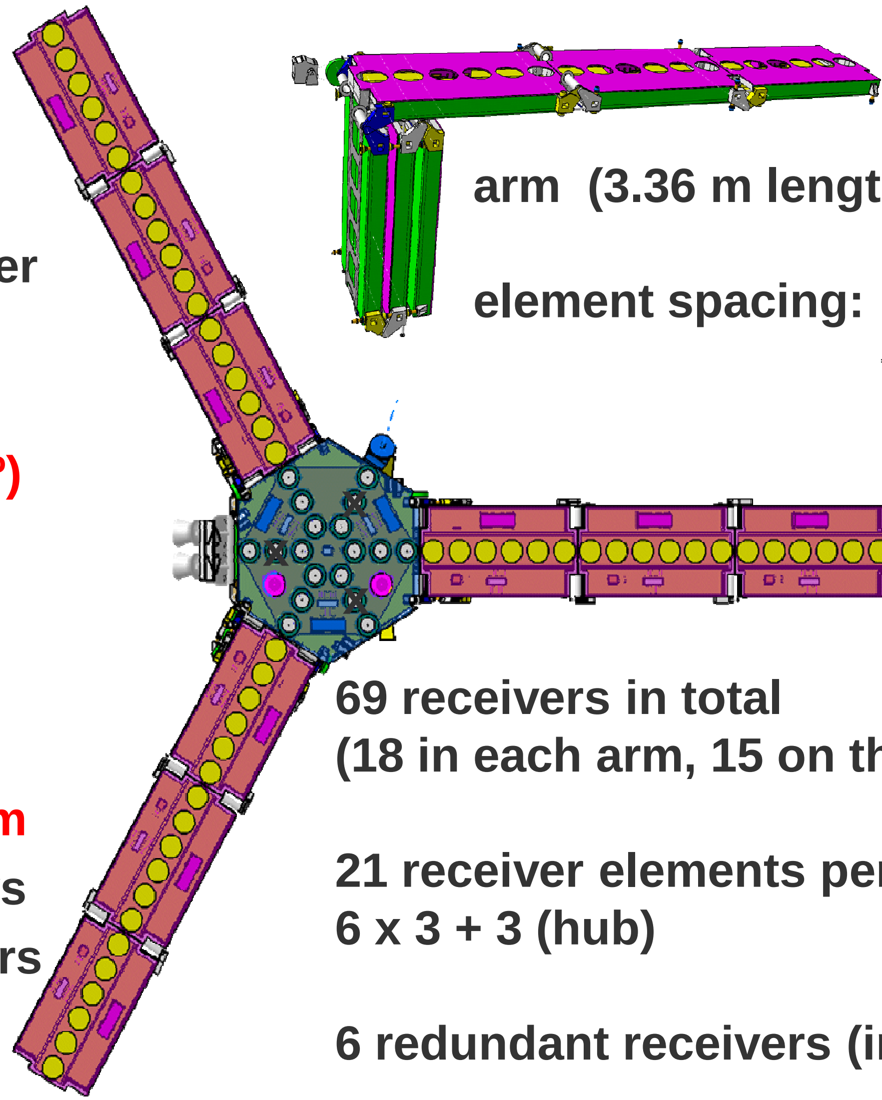
MIRAS Specifications

MIRAS: MIcrowave Radiometer with Aperture Synthesis

- **Passive microwave radiometer (L-band - 1.4GHz)**
- **2D interferometry**
- **multi-incidence angles (0º-60º)**
- **755.5 km altitude**
- **~ 900 km swath (alias free)**
- **polarimetric observations**

- **spatial resolution: 30-50km**
- **revisit time: 1-3 days**
- **mission duration: 3-5 years**

- **30º steer angle**
- **32.5º tilt angle**



arm (3.36 m length)

element spacing: 0.875 λ

69 receivers in total
(18 in each arm, 15 on the hub)

21 receiver elements per arm:
6 x 3 + 3 (hub)

6 redundant receivers (in hub)

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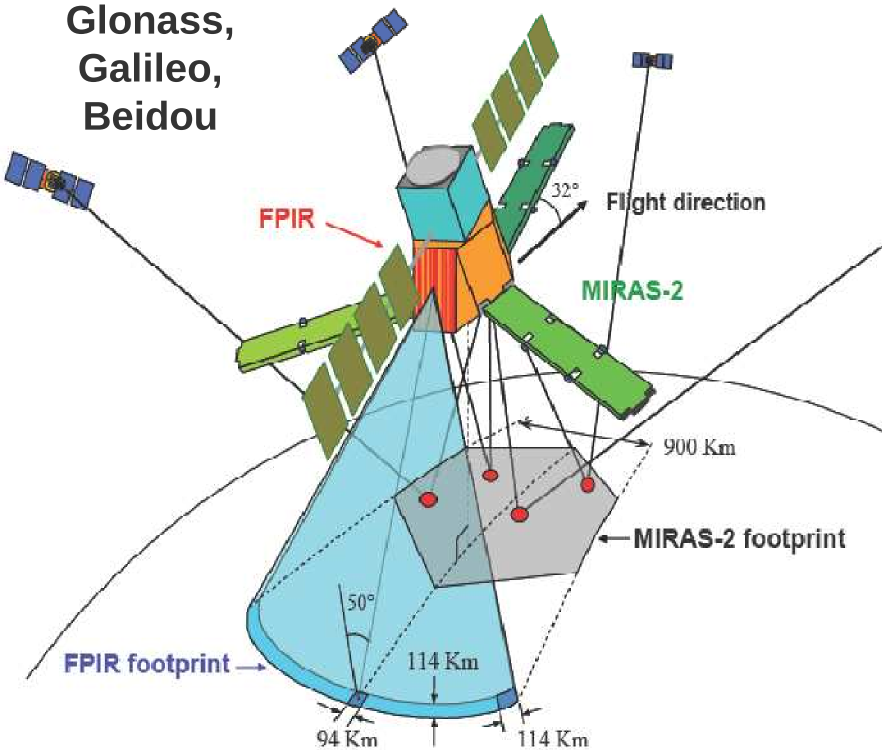
Satellite geometry & FPIR specifications

GPS, Glonass, Galileo, Beidou



system	FPIR(single-channel)	WindSat
Sensitivity	0.46K(full-pol) 0.38K(dual-pol) 0.27K(single-pol)	0.44
polarization	full	Full
Radiometric accuracy	0.5K	0.75/0.25
Spatial resolution	$3.4° \times (4° \sim 5°)$ $106 \times (83 \sim 101) km^2$	$1.13° \times 1.13°$ ~30km
Swath(alias free)	908km[70°@800Km]	950km[68°@830Km]
Revisit time	3 days	N/A
Power consumption	≤35 watts	N/A
Mass	≤25kg	N/A
Array physical size	$0.7 \times 0.4 \times 0.05 m^3$	1.8-m diameter
Electrical size	$25\lambda \times 14\lambda$	N/A
Minimum spacing	0.635λ	N/A
Amount of antennas	8	3 feed-horns
Amount of receivers	8	6
Amount of Correlators	28(cross)+8(auto)	N/A
ADC resolution	3-bits	N/A
Sample rate	25MHz	N/A
Receiver mode	SSB	N/A
Squint angle	47 °	
Incidence angle	50 °	~50 °
Calibration	2 points + FTT(optional)	2 points
Center frequency	10.69GHz	10.7GHz
bandwidth	10MHz	300MHz
Integration time	7.58s(single-pol) 3.79s(dual-pol) 2.52s(full-pol)	3.93ms/pixel

Introduction

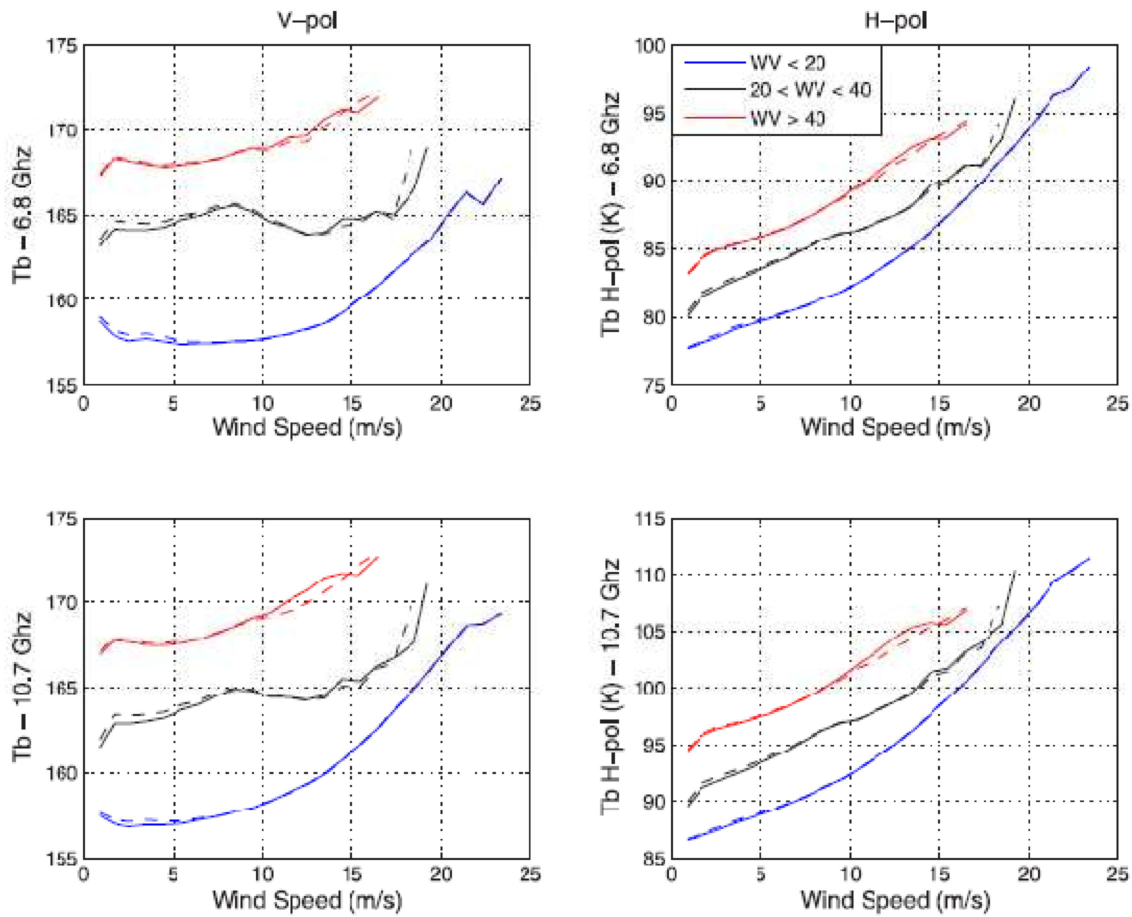
- Initial FPIR assessment study
  - Analyse whether X-band is the optimal frequency
  - Trade-off dual versus full polarisation
- Initial assumptions:
  - Wind is a good proxy for sea surface roughness
  - Only a fixed 50° incidence angle is considered
- Extended study
  - Incidence angle configuration
  - Dual-frequency consideration
  - Spatial resolution

Sensitivities

- Wind Speed
  - The higher the frequency, the higher the sensitivity

C-band

X-band



Quilfen et al., JGR 2007

  - X-band is about 20% more sensitive than C-band

Sensitivities

- Water Vapour / CLC / Rain
  - The higher the frequency, the higher the sensitivity

Red: X-band
Black: C-band

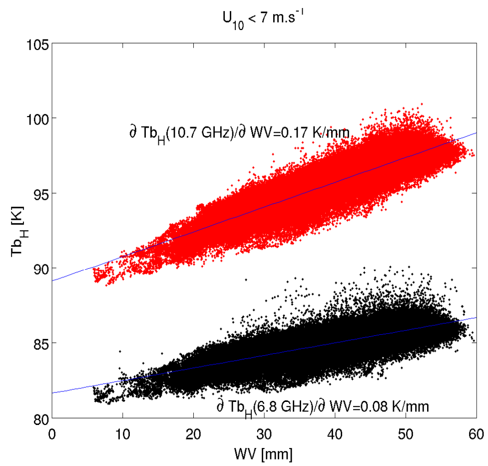


Figure 3: H polarization sensitivity of WindSat channels to water vapour for low to moderate wind speeds (Quilfen et al., JGR 2007)

- X-band is around twice more sensitive to integrated water vapour than C-band.

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Sensitivities

- Wind Direction
  - X-band + higher freqs
    - Tv & Th signal overwhelmed by atmospheric effects (Yueh et al, 2006)
    - U & V little affected by atmosphere
    - Not enough signal modulation below 7-8 m/s
    - Modulation increases with speed and saturates at 15 m/s (3 k peak-to-peak, about 4 m/s, at Ka-band) (Meissner and Wentz, 2006)
    - Directional signal is about 60% smaller at X-band than at 37 GHz
  - C-band
    - Directional signal is about 80% smaller at C-band than at 37 GHz
    - U & V never tested although lower signal than at X-band is expected
  - Directional signal not noticeable at L-band

- SST
  - Small for X-band and higher freqs
  - Noticeable for C-band: may help SSS retrievals since L-band sensitive to SST as well

Sensitivities

- Incidence angle
  - Sea surface roughness impact on MW emissivity
    - Around nadir, short waves (Bragg) are dominant
    - As incidence angle increases, longer wave contribution increases
    - Around 50°, both short and long waves impact emissivity
  - Since MIRAS is multi-incidence (0° to 60°/70°), should FPIR multi-incidence be considered?
  - Coverage has to be taken into account
- Foam
  - Around 50° & V-pol (both for C and X-band), little sensitivity to roughness, except for high winds where it exponentially increases due to presence of foam
  - However, foam induced emissivity not well understood

Roughness is not only induced by (local) wind!

SSS retrieval strategy

- Multi-parameter inversion (SSS, SST, roughness, CLC, WV) or two-step inversion (FPIR-derived roughness for SSS inversion)
  - Can FPIR provide sufficient wind accuracy for improving SSS retrievals? (not according to WindSat experience)
  - SSS inversion more challenging since additional parameters (atmospheric) need to be derived
  - Does the wind well characterize the roughness? (e.g., foam, swell effects)
- Roughness-induced T_B corrections
  - Windsat channel combination mitigates atmospheric effects while preserving most of the wind sensitivity (Meissner & Wentz, TGRS 2008)
  - Likewise, a MIRAS & FPIR channel combination could remove/reduce roughness effects while preserving SSS sensitivity
  - FPIR needs to be multi-incidence & complementary to MIRAS. This is challenging!
  - Moreover, MIRAS & FPIR channel combination should also mitigate atmospheric effects on C/X-band
  - Assumption: C/X-band scales well correlate with L-band scales. At low winds, C-band seems more appropriate than X-band

SSS retrieval strategy

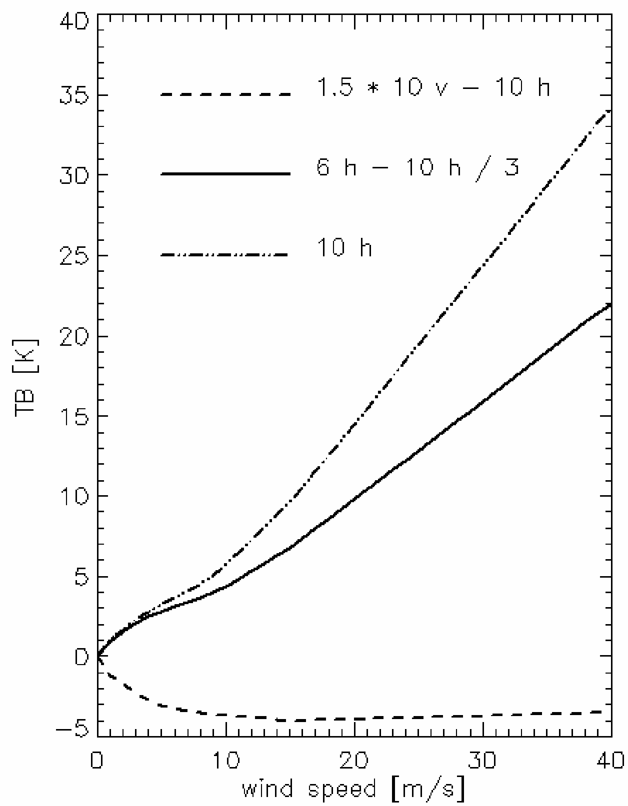

Figure 5. Top of the atmosphere brightness temperature [Kelvin] calculated in Meissner and Wentz (2008) as function of wind speed for various channel combinations: 10h (dashed-dot-dot), 1.5 ∗ 10v – 10h (dashed), 6h - 1/3*10h (solid), where 6h, 10h, and 10v correspond to C-band/H-pol, X-band/H-pol, and X-band/V-pol channels, respectively. For computing the curves we have used an effective temperature of 10°C and a surface rain rate of 5 mm/h [Figure 9 from **Meissner and Wentz, 2008**].

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Conclusions

- For a single-frequency radiometer:
  - 18 GHZ or higher too sensitive to atmosphere
  - C or X-band?
    - C-band is closer to L-band, i.e. better resolves L-band roughness-induced Tb
    - C-band is much less sensitive to atmosphere
    - X-band is more sensitive to wind
    - At X-band, V-pol/H-pol combination reduces atmospheric effects while preserving wind sensitivity up to 10 m/s (Meissner and Wentz, TGRS, 2002); conservative QC
  - **No single freq system able to disentangle roughness & atmosphere**
- Full-pol system needed for solving azimuthal signature?
  - C and X-band relatively low sensitive to wind direction
  - NWP wind direction can do the job, except in seldom cases
  - To beat NWP wind direction accuracy, several full-pol bands needed
  - **Dual-freq/dual-pol system preferred over single-freq/full-pol system**

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Conclusions

- Ideal solution should be fully polarimetric C or X band + higher freq radiometer. Three flavours:
  - C + X : optimal compromise (dry - wet) winds; conservative QC
  - C + other higher freq : better “dry” winds; worse “wet” winds; effective QC
  - X + higher freq : similar to previous case but with larger azimuthal signal

- Spatial resolution
  - X-band FPIR is about 100 km
  - C-band FPIR would be about 150 km
  - Although MIRAS is 30-50 km, SMOS accuracy requirement is 0.1 psu for monthly 2°x 2°gridded SSS product

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Outlook

- Future work
  - End-to-end simulation of FPIR impact on SMOS SSS retrievals
    - Single frequency good enough?
    - X or higher freq?
    - Dual frequency optimal combination? C+X? C+higher freq? X+higher freq?
    - Incidence angle configuration
  - SMOS to be launched in Sep. 2009: collocation experiments SMOS & Windsat / AMSR-E
- Alternative systems:
  - L-band scatterometer
  - GNSS-R system
- Since SMOSops has been postponed (not before 2015), time is not an issue. Any suggestions?