# ESTIMATION DE LA TEMPERATURE DE LA SURFACE OCEANIQUE PAR RADIOMETRIE MICROONDE

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**Etude réalisée dans le cadre du projet MICROWAT de l'ESA**

1 – User requirements for SST

2 – Analysis of the potential of microwaves for SST

3 – Instrument concept

# SST User Requirements

| SST Observation Temperature | Application | Units | Accuracy | | | Spatial resolution Km | | | Revisit time Hr | | | Product timeliness Hr | | | Priority |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | T | B | O | T | B | O | T | B | O | T | B | O | 1:high |
| **Sea surface temperature** | NWP global | K | 1.5 | 0.5 | 0.3 | 250 | 15 | 5 | 120 | 24 | 3 | 120 | 24 | 3 | 2 |
| | NWP regional | K | 1.5 | 1 | 0.5 | 50 | 10 | 1 | 24 | 6 | 1 | 3 | 1 | 0.1 | 2 |
| | NWP seasonal and inter annual | K | 0.5 | 0.2 | 0.1 | 50 | 20 | 1 | 48 | 12 | 1 | 120 | 3 | 3 | 2 |
| | Oceanography global | K | 0.5 | 0.4 | 0.1 | 50 | 10 | 1 | 120 | 48 | 3 | 48 | 1 | 1 | 1 |
| | Oceanography coastal | K | 1 | 0.3 | 0.1 | 10 | 1 | 0.1 | 120 | 24 | 3 | 1 | 0.5 | 0.5 | 1 |
| **Sea ice surface temperature** | NWP global | K | 4 | 1 | 0.5 | 250 | 15 | 5 | 12 | 3 | 1 | 4 | 1 | 1 | 2 |
| | NWP regional | K | 2 | ? | 0.5 | 100 | ? | 5 | 2 | ? | 0.5 | 4 | ? | 1 | 3 |

(Stammer et al. 2007)

# SST User Requirements

- Proposal for SST accuracy : **0.3 K**
  - Would meet breakthrough accuracy requirement for all applications, except seasonal and inter-annual NWP (SST priority = 2)
  - Seasonal and inter-annual NWP accuracy requirement could be met through space/time averaging
- Proposal for SST horizontal resolution : **10 km**
  - Would meet breakthrough horizontal resolution requirement for all applications except coastal oceanography
  - Could allow space averaging for seasonal and inter-annual NWP (see above)
  - Could bring useful information for coastal oceanography, in particular in areas of persistent cloudiness
- Proposal for SST revisit time : **12 h**
  - Would meet breakthrough revisit time requirement for all applications except regional NWP (SST priority = 2)
  - Would provide information on day minus night variation

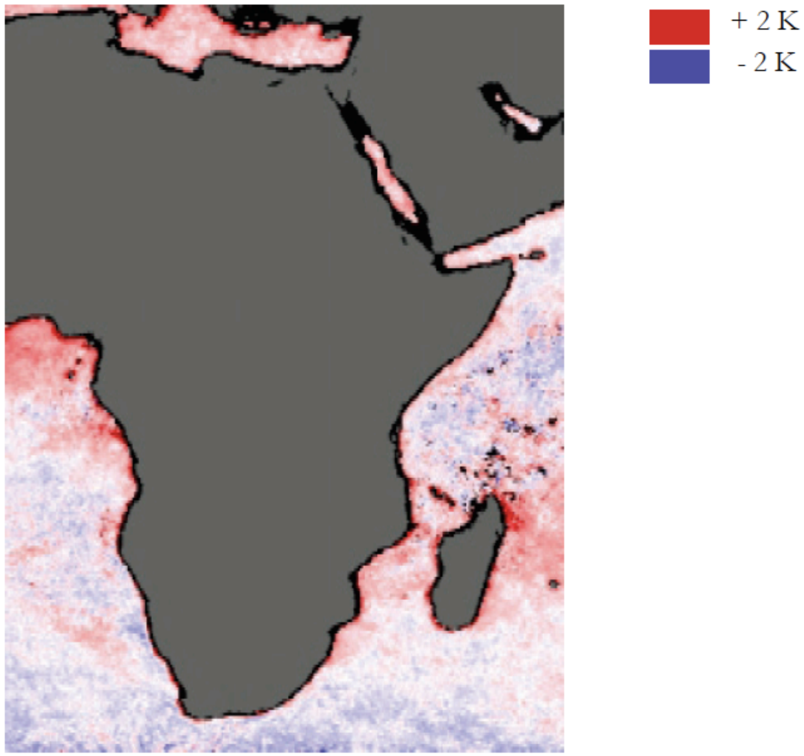
# Comparison with present estimates

**SST estimated errors today from microwave observations: 0.4-0.5 K**

| Derived std dev of error for each observation type (K) | | | |
|---|---|---|---|
| Expt | AATSR bulk (D3) SST | Buoy SST | AMSR-E SST |
| 1 | 0,16 | 0,23 | 0,42 |
| 2 | 0,12 | 0,24 | 0,51 |
| 3 | 0,14 | 0,24 | 0,42 |
| 4 | 0,15 | 0,23 | 0,45 |
| 5 | 0,13 | 0,27 | 0,43 |
| 6 | 0,16 | 0,22 | 0,45 |
| 7 | 0,15 | 0,22 | 0,42 |
| 8 | 0,16 | 0,23 | 0,42 |

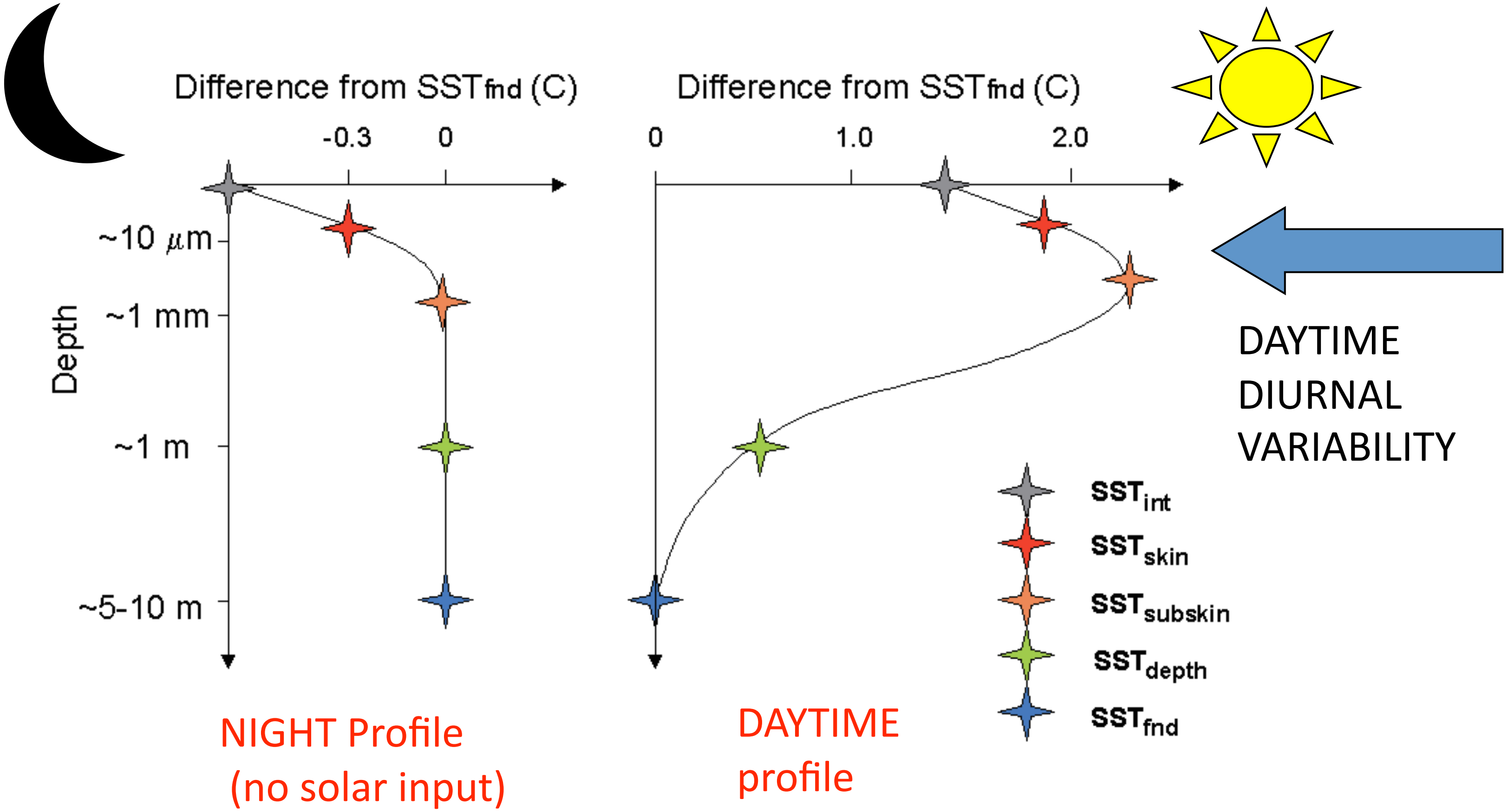
O'Carroll et al., 2007

**Coastal effects (partly related to the lack of spatial resolution 25km)**




Gentemann et al.

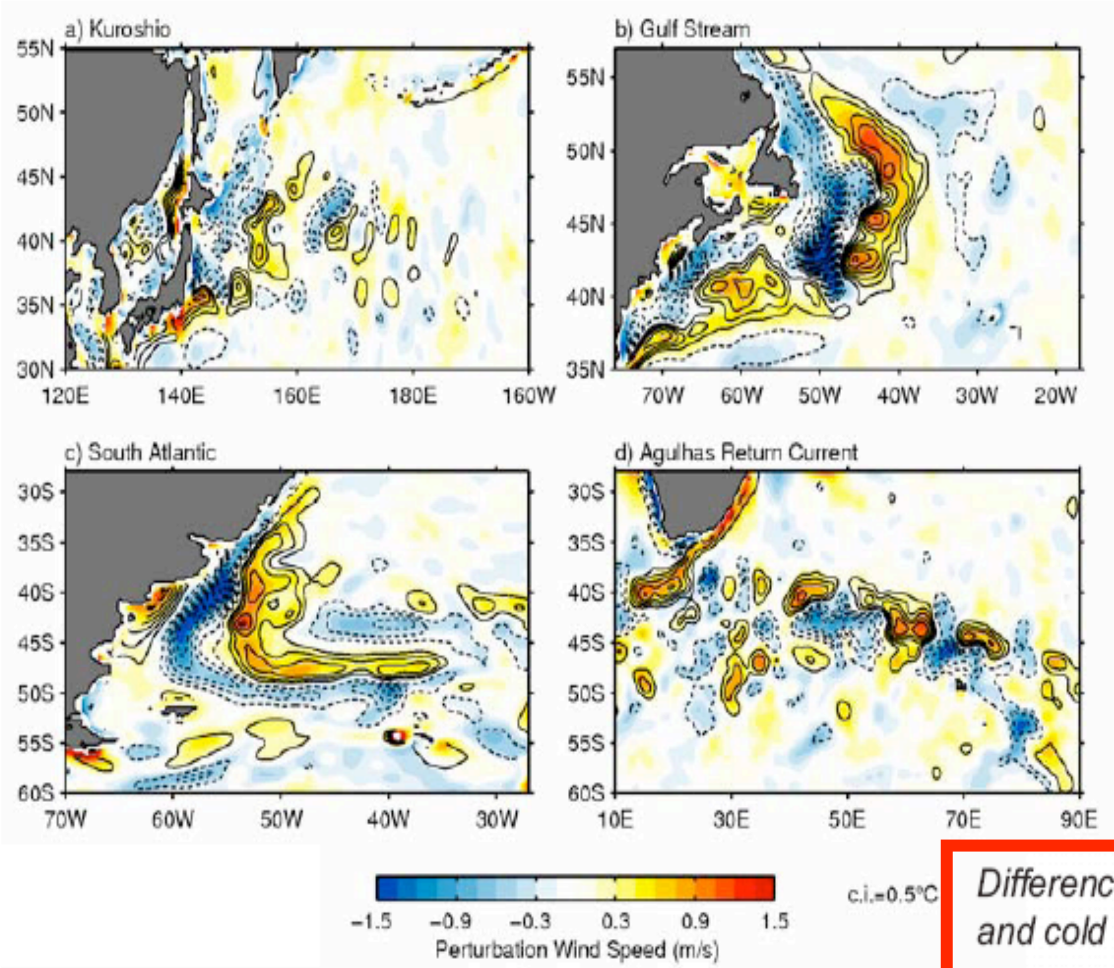
# Benefit of quasi-simultaneous SST and OWV: Understand the state of the ocean




Schematic diagram showing (left) idealised night-time vertical temperature deviations from SSTfnd and (right) idealised day-time vertical temperature deviations from SSTfnd in the upper ocean (from Donlon et al., 2007).

# Benefit of quasi-simultaneous SST and OWV: Understand the state of the ocean

January - December 2003



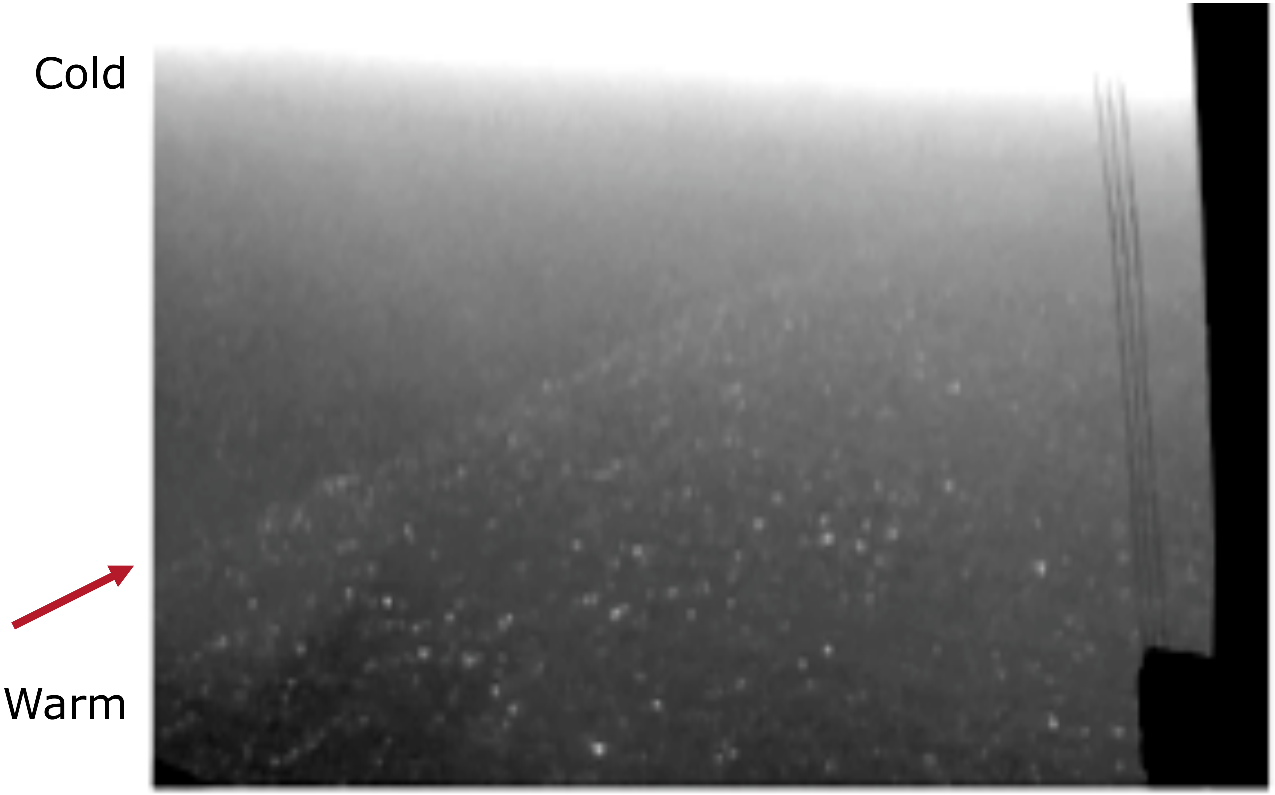

QuickScat winds (in colour) and AMSRE SST (solid contours)

*Differences between warm and cold regions are ~3-5ºC and ~2-3 m/s*

Solid contours = warm SST perturbations
Dashed contours = cool SST perturbations

# Benefit of quasi-simultaneous SST and OWV: Understand the state of the ocean

**SST influence on the marine atmospheric boundary layer**




Photograph taken from the NOAA P-3 aircraft looking northeast across the North Wall of the Gulf Stream. The winds were blowing from the northeast at the time of the photograph. The seas were calm over the colder slope waters to the northwest of the Gulf Stream (the upper left area of the photo) and white caps covered the warmer water to the southeast. (Courtesy of Paul Chang, NOAA.)

1 – User requirements for SST

2 – Analysis of the potential of microwaves for SST

3 – Instrument concept

# Sea Surface Temperature (SST)

- Passive remote sensing only
- Lower frequencies less sensitive to atmospheric contribution
- Frequencies also sensitive to the wind speed (and related presence of foam)
- Retrieval mainly derived from Wentz et al., with a two step algorithm with local fine-tuning
- SST evaluations in the literature shows very impressive accuracy (<0.5K).
  Validation method carefully crafted? Contribution of the a priori information?
- To our knowledge, no convincing sensitivity analysis provided in the literature

# Ocean Wind Vector (OWV)

- Wind speed can be estimated from both passive and active microwave observations
- Wind direction very difficult with passive observations, even with full polarimetry
- Several algorithms developed for both instrument types
- Accuracy of 1m/s in speed with both instruments and 20° in direction with the scaterrometer,
- Saturation effects for high wind speed with the scatterometer, not with the radiometer (complementary)

# Microwave satellite remote sensing of Sea Surface Temperature (SST) and Ocean Vector Winds (OVW)

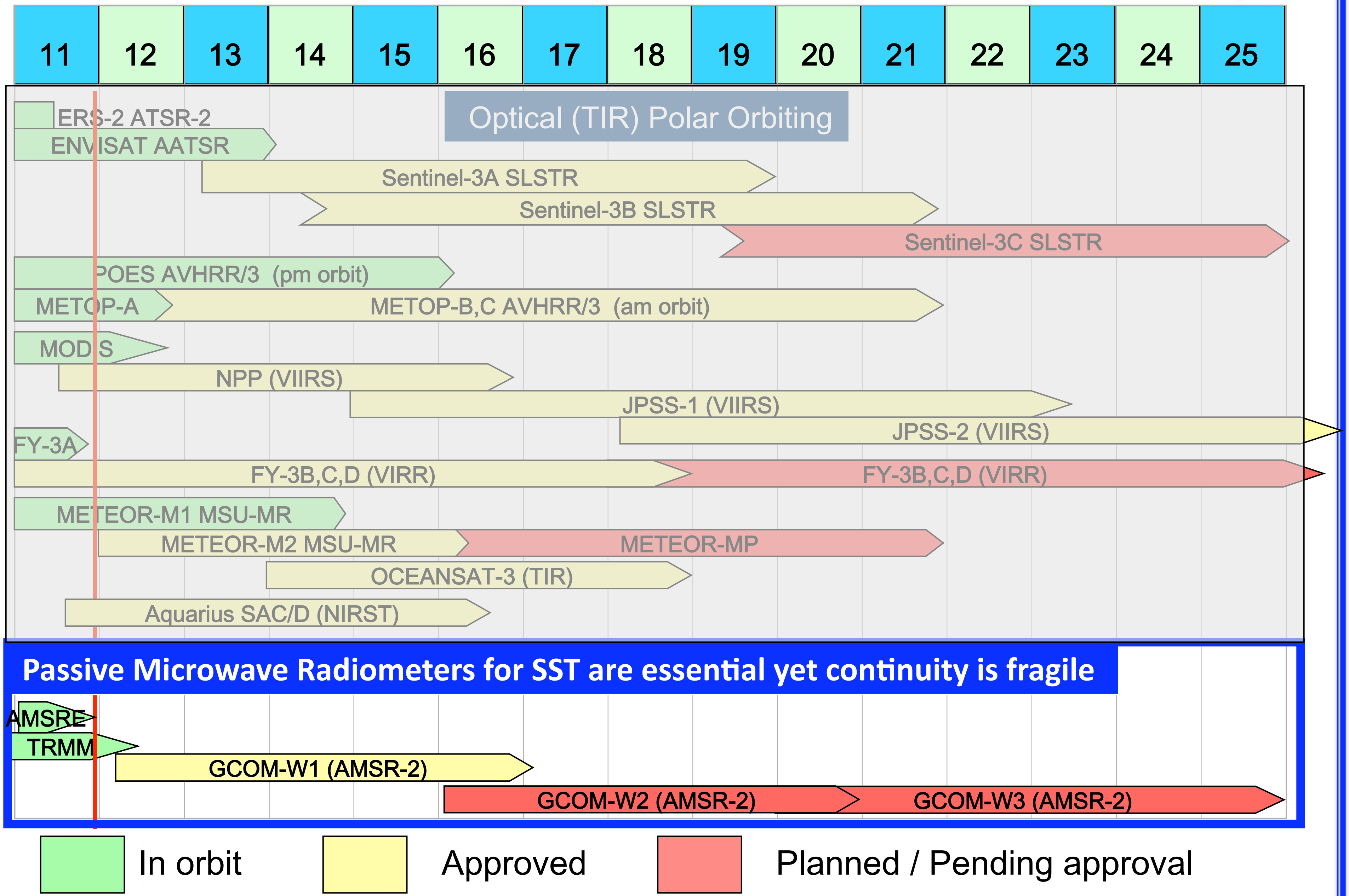
Passive

| Instrument (mission) | Years of operation | Frequencies | Polarizations | Spatial resolution | SST | Ocean Wind Speed | Ocean Wind Direction |
|---|---|---|---|---|---|---|---|
| SMMR (Nimbus 7) | 1978-1983 | 6.6, 10.7, 18, 21, 37 GHz | V&H (except at 22 GHz) | 150 km at 6.6 GHz | YES Milman and Wilheit, 1985 | YES Milman and Wilheit, 1985 | NO |
| SSM/I (DMSP) | 1987- | 19.35, 22.2, 37.0, and 85.5 GHz | V&H (except at 22 GHz) | From 50 km to 15 km | NO | YES Meisner et al., 2001 | NO |
| TMI (TRMM) | 1997- | 10.7 | V&H (except at 22 GHz) | 45 km at 10.7 GHz with a 13 km separation) | YES Wentz et al., 2000 | YES Wentz et al., 2000 | NO |
| AMSR-E (EOS Aqua) | 2002- | 6.9, 10.7, 18.7, 23.8, 37.0, 89.0 | V&H | From 56 km to 5 km | YES Chelton and Wentz, 2005 | YES Wentz et al., RSS | N0 |
| WindSat (Coriolis) | 2003-present | 6.8, 10.7, 18.7, 23.8, and 37.0 GHz | V&H plus the other Stokes vectors for | From 50 km to 10 km | YES Bettenhausen et al., 2006 | YES Monaldo, 2006 | YES Monaldo, 2006 |

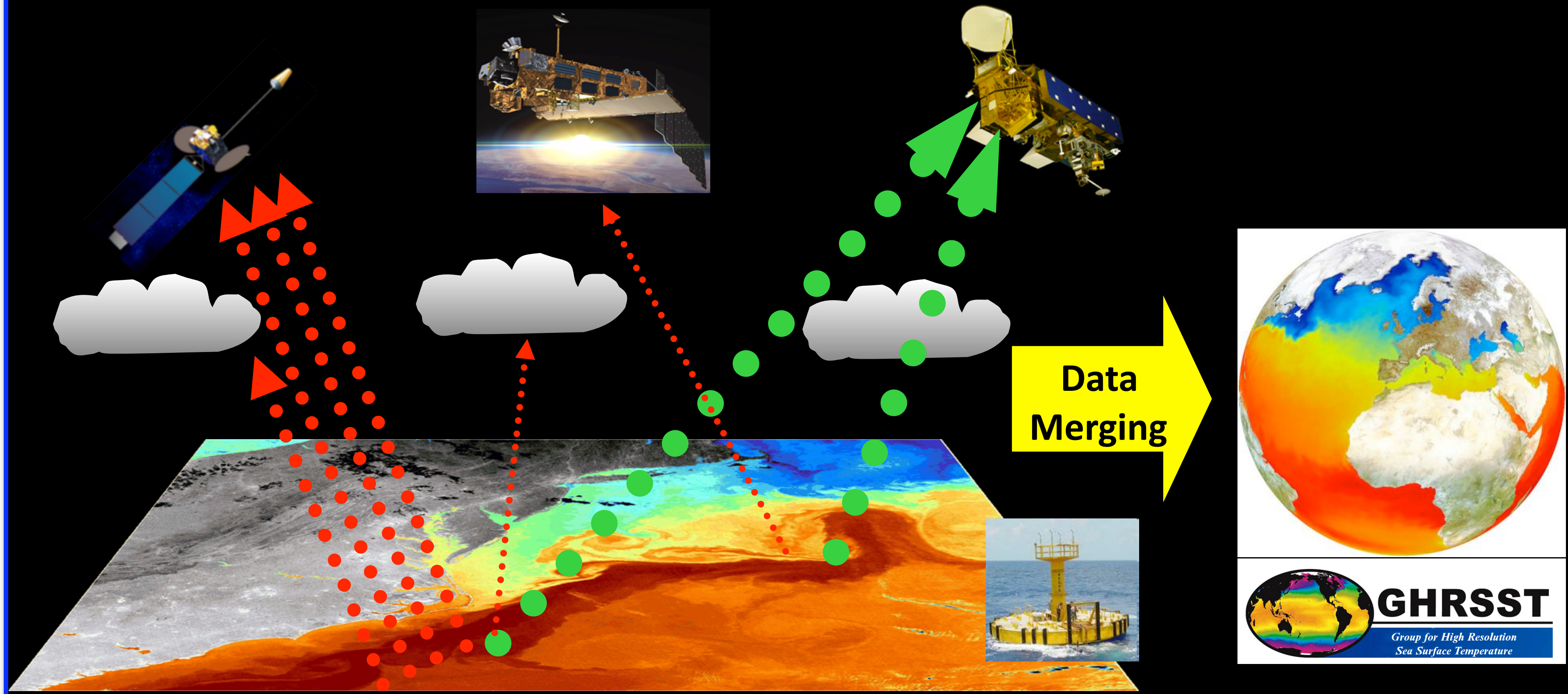
Active

| Instrument (mission) | Years of operation | Frequency and polarization | Spatial resolution and swath | SST | Ocean Wind Speed and Direction |
|---|---|---|---|---|---|
| Wind Scatterometer (ERS) | 1991-2001 (to present for the North hemisphere) | 5.3 GHz (VV) | 50km over 500km (40% coverage in 24hs) | NO | YES |
| SeaWinds (QuikSCAT) | 1999-2009 | 13.4 GHz (VV and HH) | 25km over 1800km (90% coverage in 24hs) | NO | YES |
| ASCAT (MetOp) | 2006- | 5.225 GHz (VV) | 50 and 25km over 2x550km | NO | YES |

# Sea Surface Temperature (polar orbiting)



# SST analyses for NWP and NOP builds on EO complementarities…



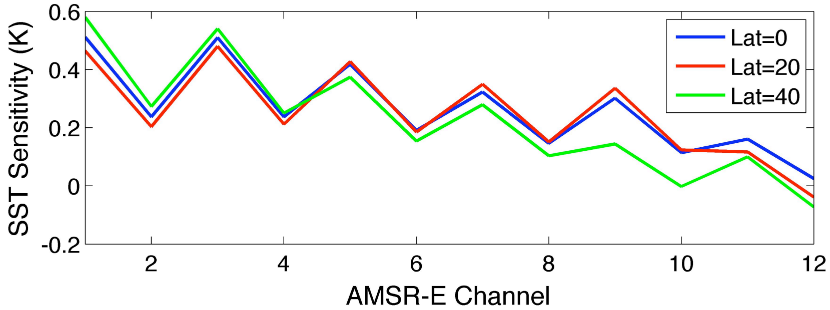

- Polar infrared has ***high accuracy & spatial resolution***
- Geostationary infrared has ***high temporal resolution***
- Microwave Polar orbiting has ***all-weather capability*** *(e.g. High latitude cloud)*
- In situ data provide ***reality in all weather conditions***

# Information Content Analysis of Microwave Observations

- Traditionaly used to define instrument specifications in NWP centers
- Simulations performed at AMSR-E channels
- Radiative transfert (Jacobians): RTTOV
- Database : ECMWF analysis
- Instrument noise specifications

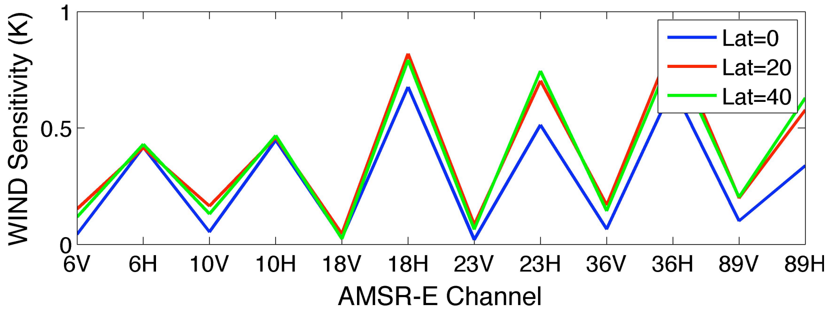
| Freq (GHz) | 6.9 | 10.65 | 18.7 | 23.8 | 36.5 | 89 |
|---|---|---|---|---|---|---|
| NEΔT (K) ASTRIUM/EADS | 0.14 | 0.38 | 0.41 | 0.34 | 0.27 | 0.26 |
| NEΔT (K) AMSR-E | 0.39 | 0.60 | 0.60 | 0.60 | 0.60 | 1.10 |

# Information Content Analysis



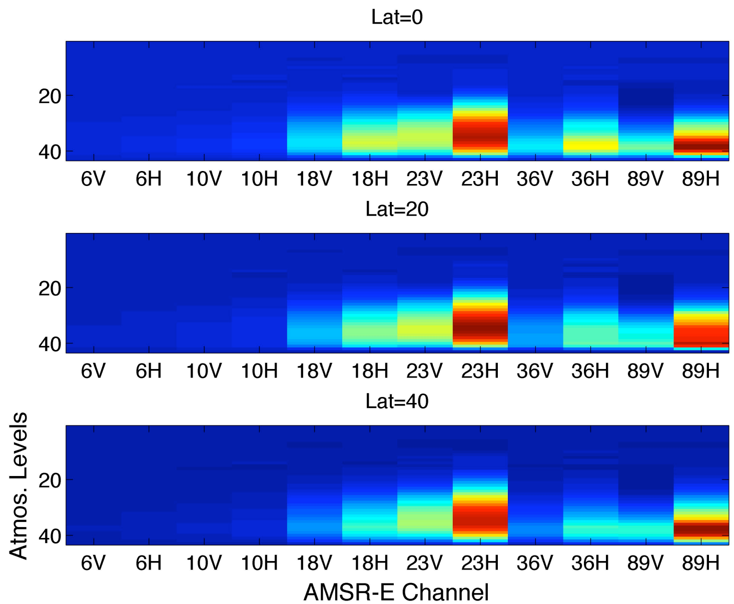

$$= \frac{\partial TB}{\partial SST}$$

$\Rightarrow$ Low frequencies in vertical polarization very senstive to SST




$$= \frac{\partial TB}{\partial WIND}$$

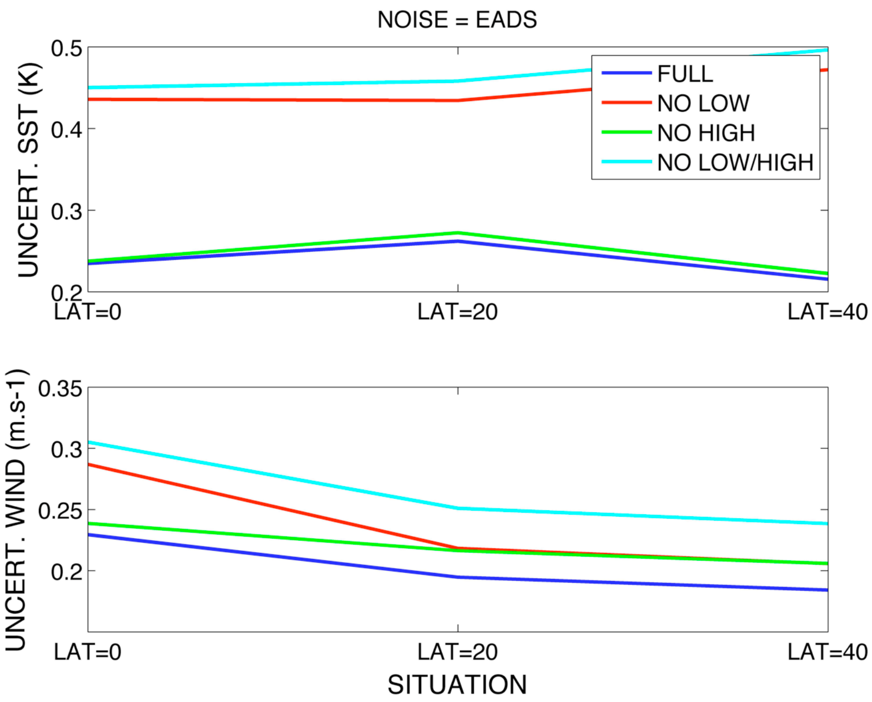
$\Rightarrow$ Horizontal polarization more sensitive to wind speed, and sensitivity increases with frequency.




$\Rightarrow$ Sensitivity to water vapor very limited at frequencies below 10GHz

$$\frac{\partial TB}{\partial Q} =$$

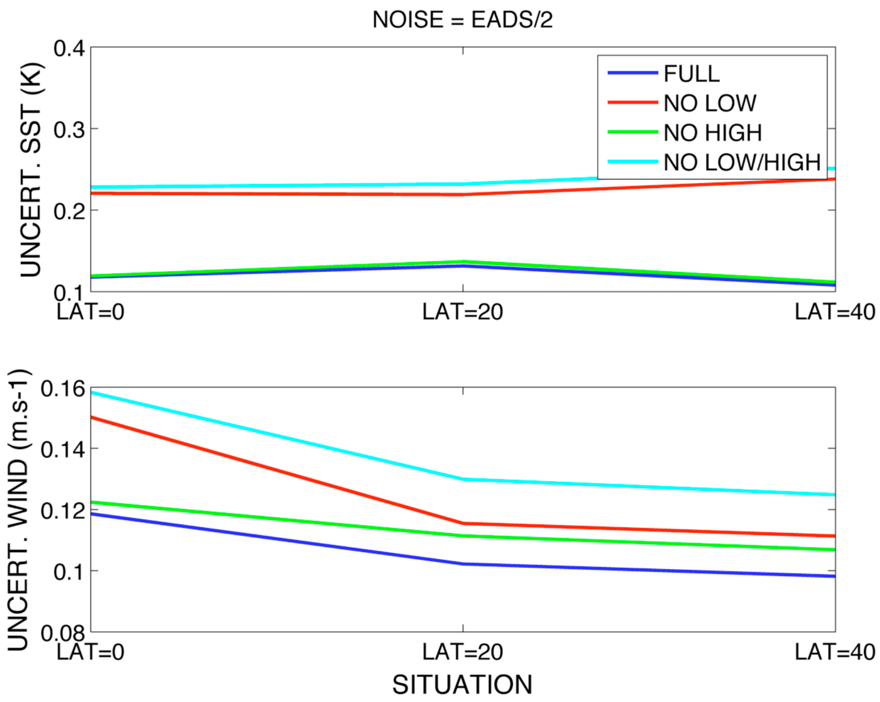
# Sensitivity to frequencies




without 89 & 6 GHz **->** without 6 GHz **->** without 85GH **->** full

⇒The high frequency not important for SST estimate

# Sensitivity to noise



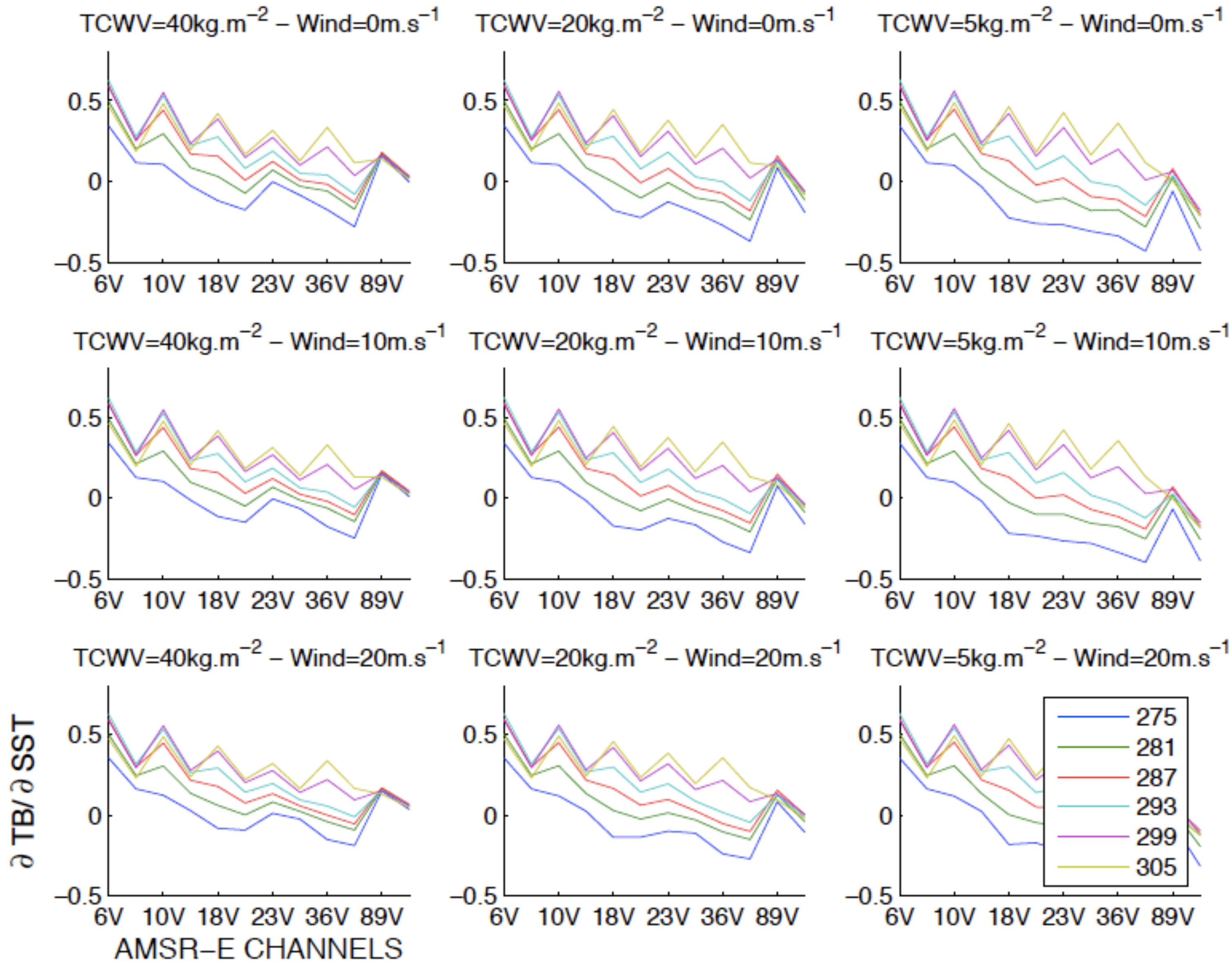

Same but with all noises divided by 2

⇒Reduction of the instrument noise is the key issue for SST estimates, to reach the requested accuracy

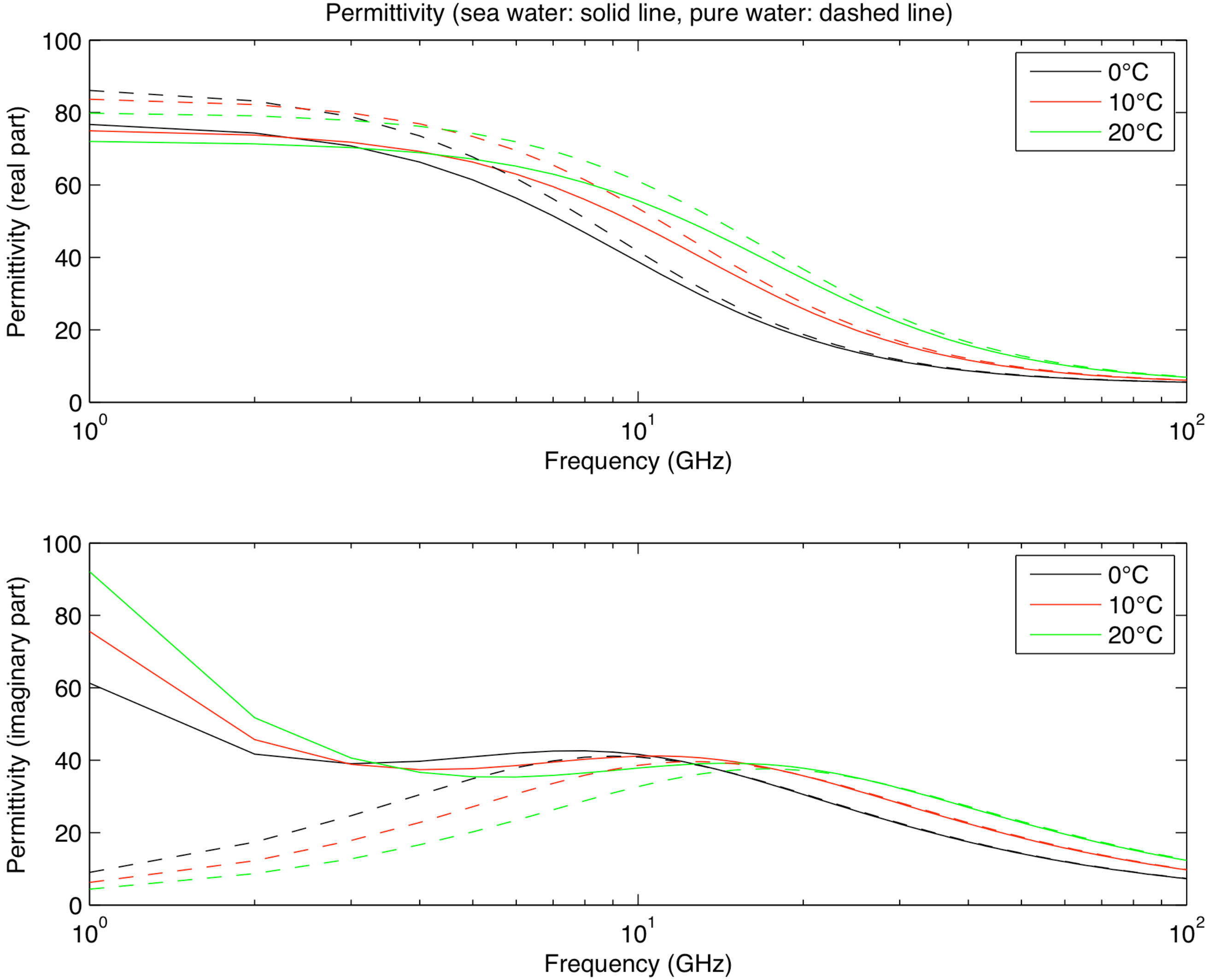
# Preliminary analysis of instrument specification

- For SST, low frequency channels very important, with very low instrument noise to reach accuracy specifications
- For OWV, speed information available from passive microwaves, information on wind direction possible, but less accurate than with scatterometer
- Classical information analysis can be misleading:
  - Nonlinear model more efficient than a linearization: saturation effects, interaction terms
  - Retrieval can make a better use of the available information and the correlation between variables
- Need to take into account all the sensitivities:
  - Real inversion tests more reliable

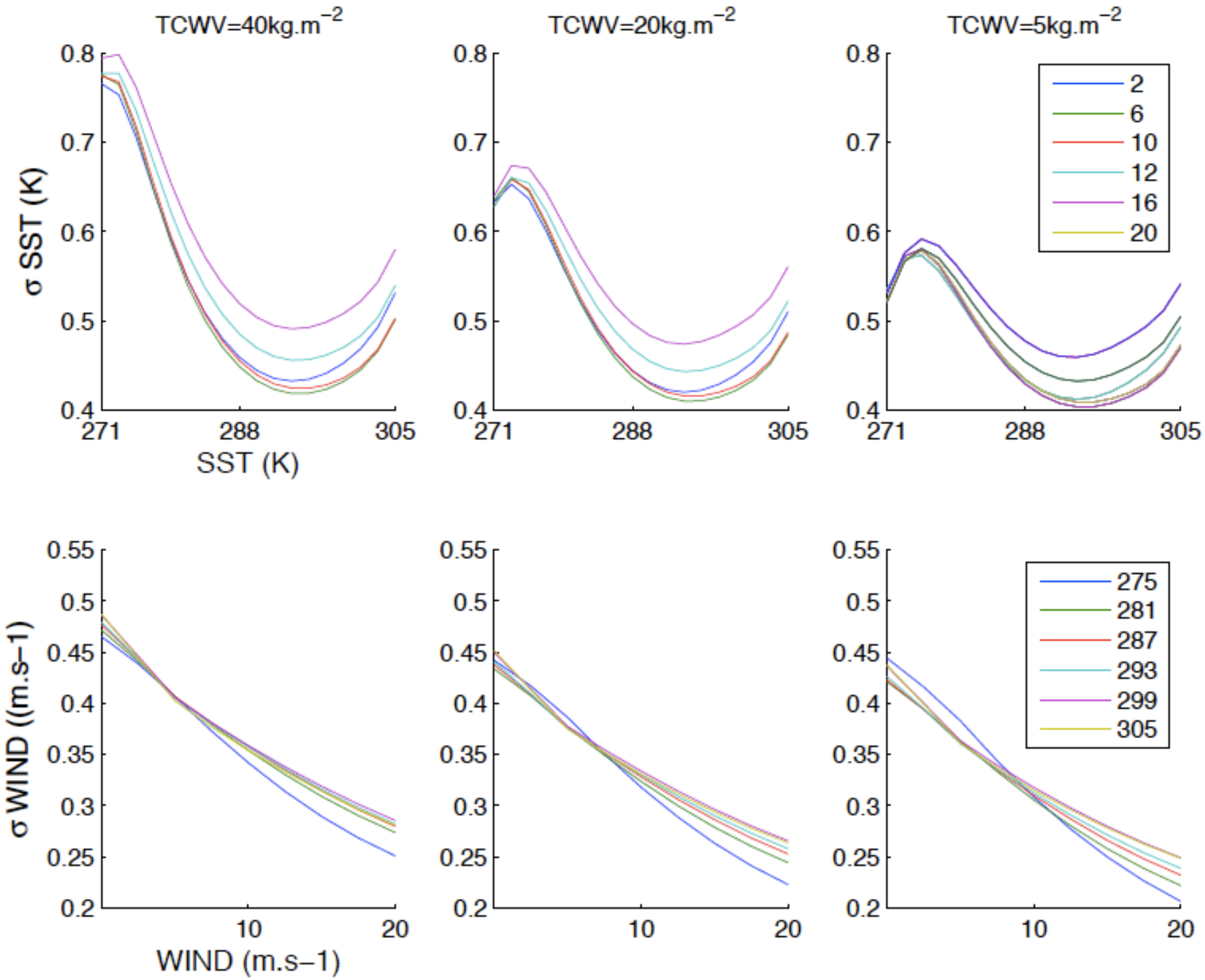
# Jacobian calculation under a large variety of conditions



# Sea water permittivity variation with SST



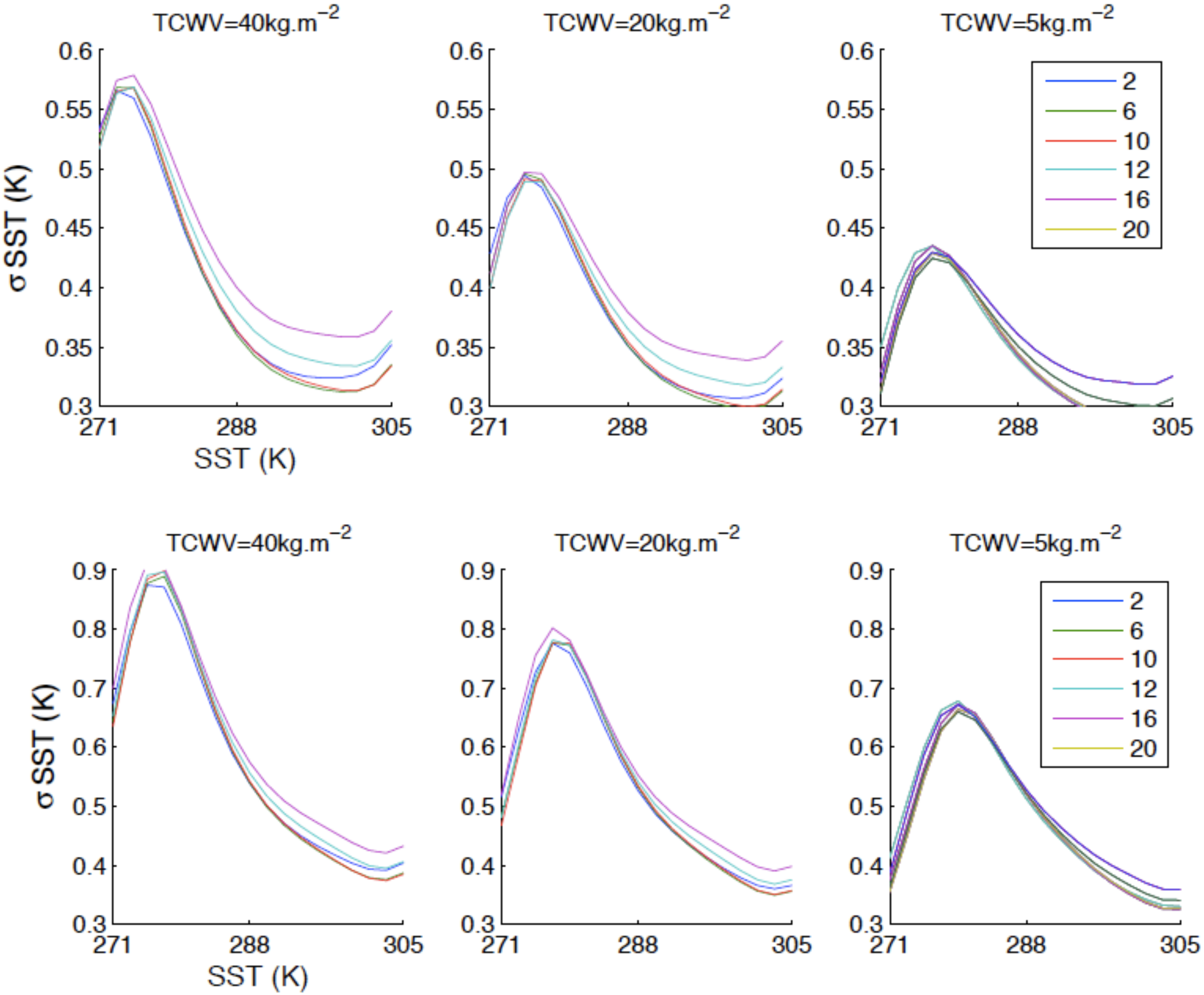
With AMSR-E noise



With 0.3K noise on all channels

All channels

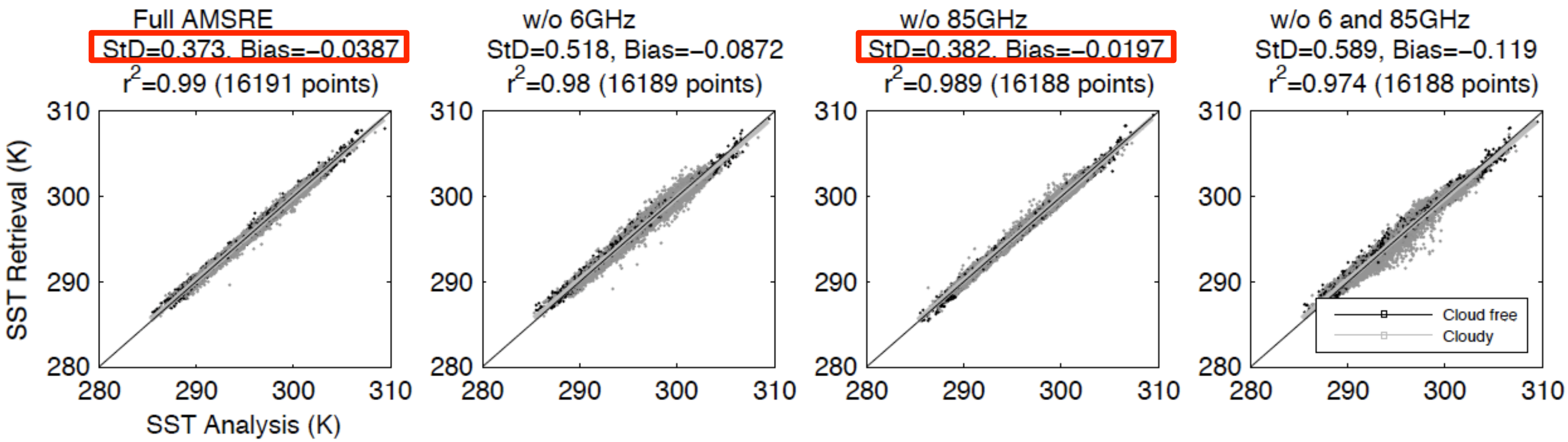
Without 6 GHz



# INVERSION TESTS WITH AMSR-E

**Using AMSR-E and ECMWF analysis. 2 months, +/-30°**

**Theoretical results**



# INVERSION TEST WITH AMSR-E

## Theoretical results and comparisons with buoys

| | $\Delta SST$ | Theoretical errors | | | Buoy departures | | |
|---|---|---|---|---|---|---|---|
| | | $\bar{x}$ | $\sigma$ | RMS | $\bar{x}$ | $\sigma$ | RMS |
| | Analysis | | | | 0.18 | 0.39 | 0.43 |
| | Atlas | 0.00 | 0.83 | 0.83 | -1.10 | 0.84 | 1.40 |
| | Inverse | 0.08 | 0.58 | 0.58 | 0.10 | 0.64 | 0.64 |
| All channels → | 111111111111m | 0.01 | 0.42 | 0.42 | -0.39 | 0.57 | 0.69 |
| Without 6 GHz → | 001111111111m | 0.02 | 0.62 | 0.62 | -0.75 | 0.61 | 0.97 |
| Without 85GHz → | 111111111100m | 0.03 | 0.43 | 0.43 | -0.45 | 0.56 | 0.71 |
| Without 6 and 85 → | 001111111100m | 0.04 | 0.64 | 0.64 | -0.77 | 0.61 | 0.98 |

With the mean value for a pixel used as the first guess:

- Expected behavior
- Theoretical errors above 0.4K…
- When compared to the buoys, above 0.6K. Not surprising…

1 – User requirements for SST

2 – Analysis of the potential of microwaves for SST

3 – Instrument concept

# Microwat concepts
## (ASTRIUM/EADS)

Microwat channel selection

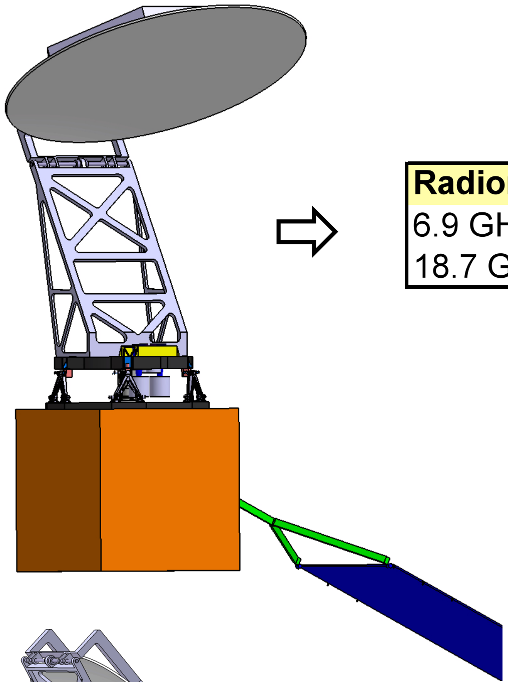
| Channel | 6.9 | 10.65 | 18.7 |
|---|---|---|---|
| Frequency GHz | 6.9 | 10.65 | 18.7 |
| Bandwidth MHz | 825 | 100 | 200 |
| Polarisation | V&H | V | V&H |

Two concepts have been proposed :

- Real aperture radiometer
- Synthetic aperture radiometer

# Microwat concepts : Conical

- Conical scanner :

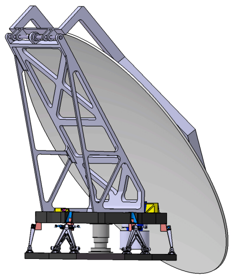


⇨

| Radiometric sensitivity | | |
|---|---|---|
| 6.9 GHz | 0.12 | K |
| 18.7 GHz | 0.26 | K |

⇨

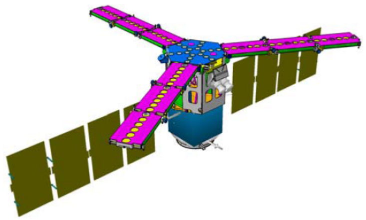
| Final product | | |
|---|---|---|
| **Accuracy** | | |
| SST uncertainty | 0.25 | K |
| Wind speed uncertainty | 0.25 | m/s |
| **Spatial resolution** | | |
| 6.9 GHz | 15 | km |
| 18.7 GHz | 15 | km |

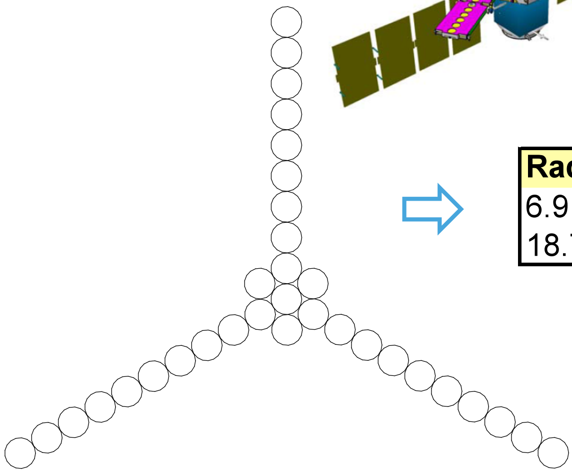


Mass # 300 kg (4m antenna reflector)
Power # 350 W

# Microwat concepts : Interferometer

- Synthetic aperture radiometer : Interferometer





Y shape antenna array
(5.2 m arm length)

| Radiometric sensitivity | | |
|---|---|---|
| 6.9 GHz | 0.83 | K |
| 18.7 GHz | 1.94 | K |

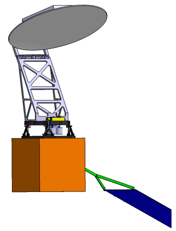
| Final product | | |
|---|---|---|
| **Accuracy** | | |
| SST uncertainty | 0.7 | K |
| Wind speed uncertainty | 0.8 | m/s |
| **Spatial resolution** | | |
| 6.9 GHz | 8 - 20 | km |
| 18.7 GHz | 8 - 18 | km |

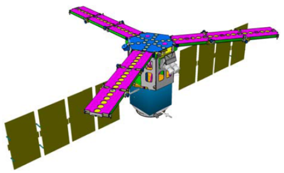
| | |
|---|---|
| Mass | > 600 kg |
| Power consumption | > 2500 W |

(424 receivers at 6.9GHz and 364 at 18.7 GHz….)

# Microwat concepts : Basic comparisons

- **Advantages**
  - Conical scanner
    - Simple, high sensitivity (total power radiometer)
    - Simple calibration processing
  - Interferometer
    - Fixed antenna
    - High spatial resolution





- **Disadvantages**
  - Conical scanner
    - Large antenna reflector (lead to deployable system for high resolution)
    - Rotation reflector (mass and momentum compensation)
  - Interferometer
    - Lower sensitivity compared to conical
    - Complexity (huge number of receivers and correlators)
    - High power consumption

# CONCLUSIONS

- User requirement analysis for SST with special emphasis on the interest for coincident SST and OVW

- Information content analysis to evaluate the impact of the frequency selection as well as the noise factor. Inversion tests with cross checks on in situ data also performed.

- The accuracy of the retrieval directly related to the instrument sensitivity

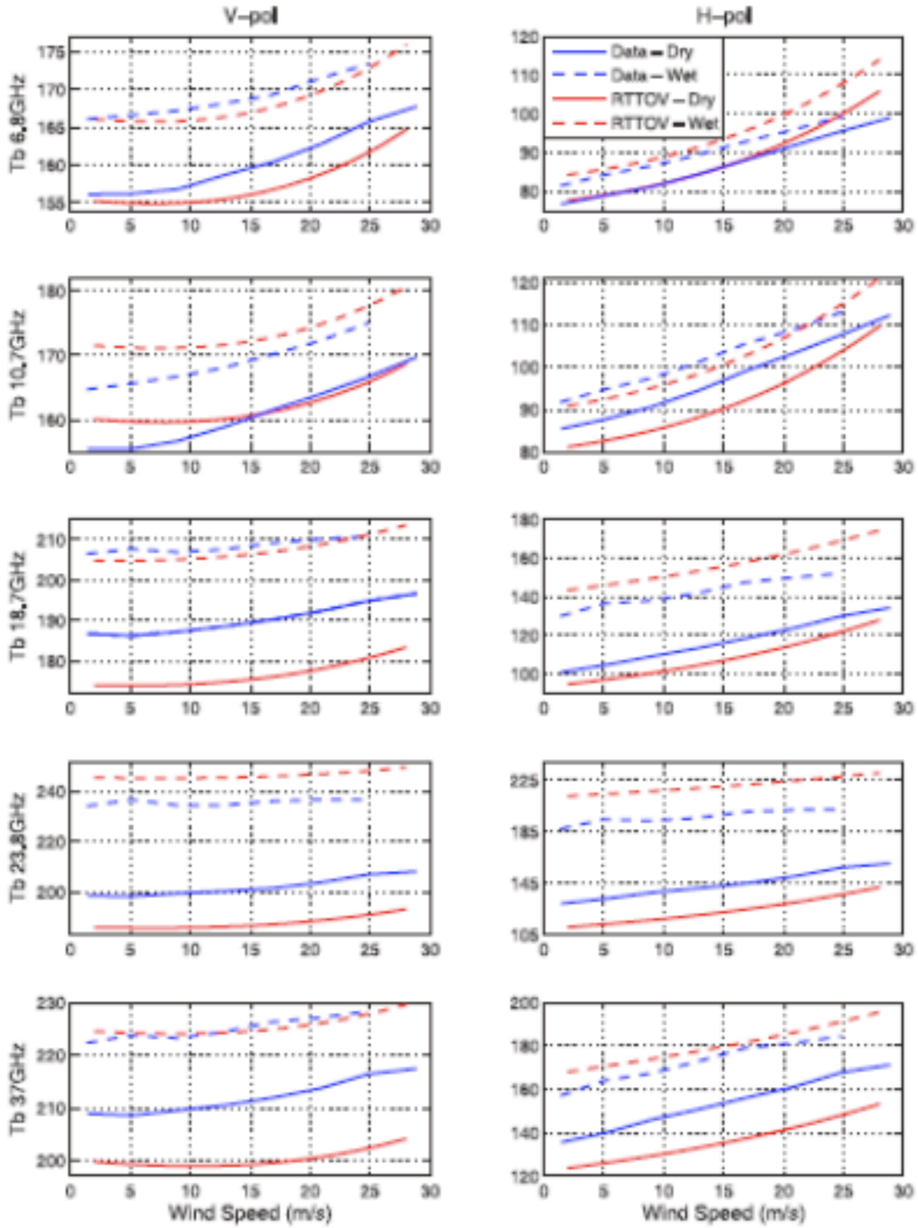
- Definition of missions based on these studies

- Particularly critical instrumentation, with the recent failure of AMSR-E….

# Backup slides

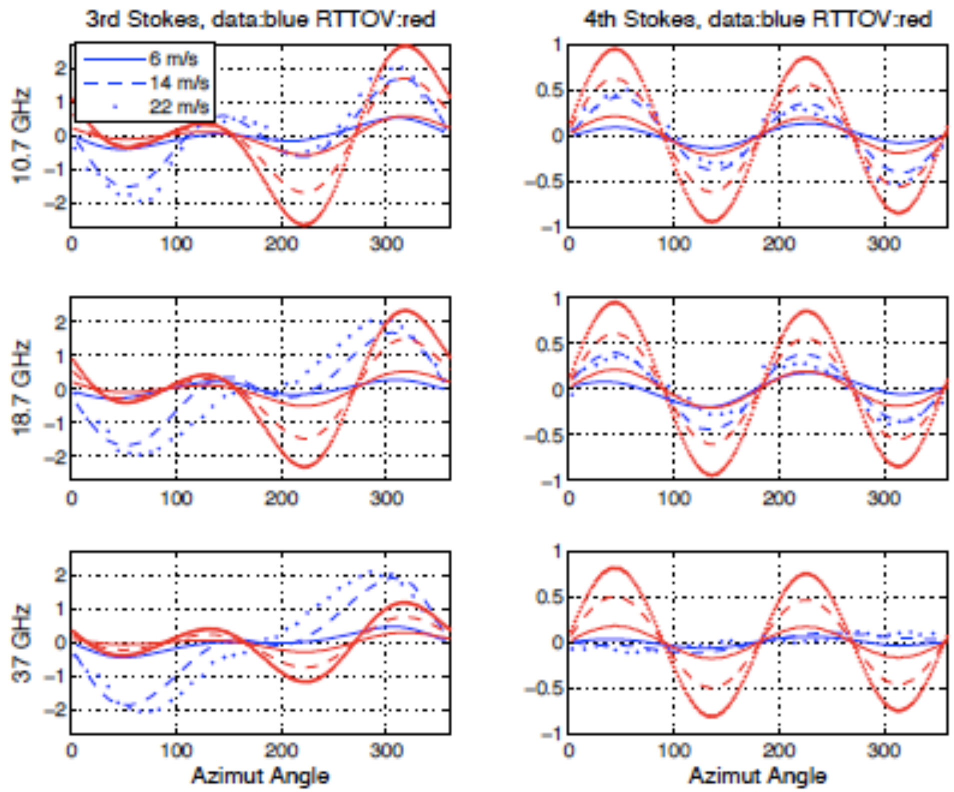
# Ocean Wind Speed with Passive Microwaves

WindSat observations from February 2003 to November 2005 with QuikSCAT observations:
Mean V (left panels) and H (right panels) Tbs binned as a function of QuikSCAT wind speed (m/s), at 6.8, 10.7, 18.7, 23.8, and 37.0 GHz, respectively from top to bottom, for a dry atmosphere: 0 mm < WV < 20 mm (blue lines), and for a wet atmosphere 30 mm < WV < 60 mm (red lines). WindSat data are plotted as solid lines and RTTOV model as dashed lines.

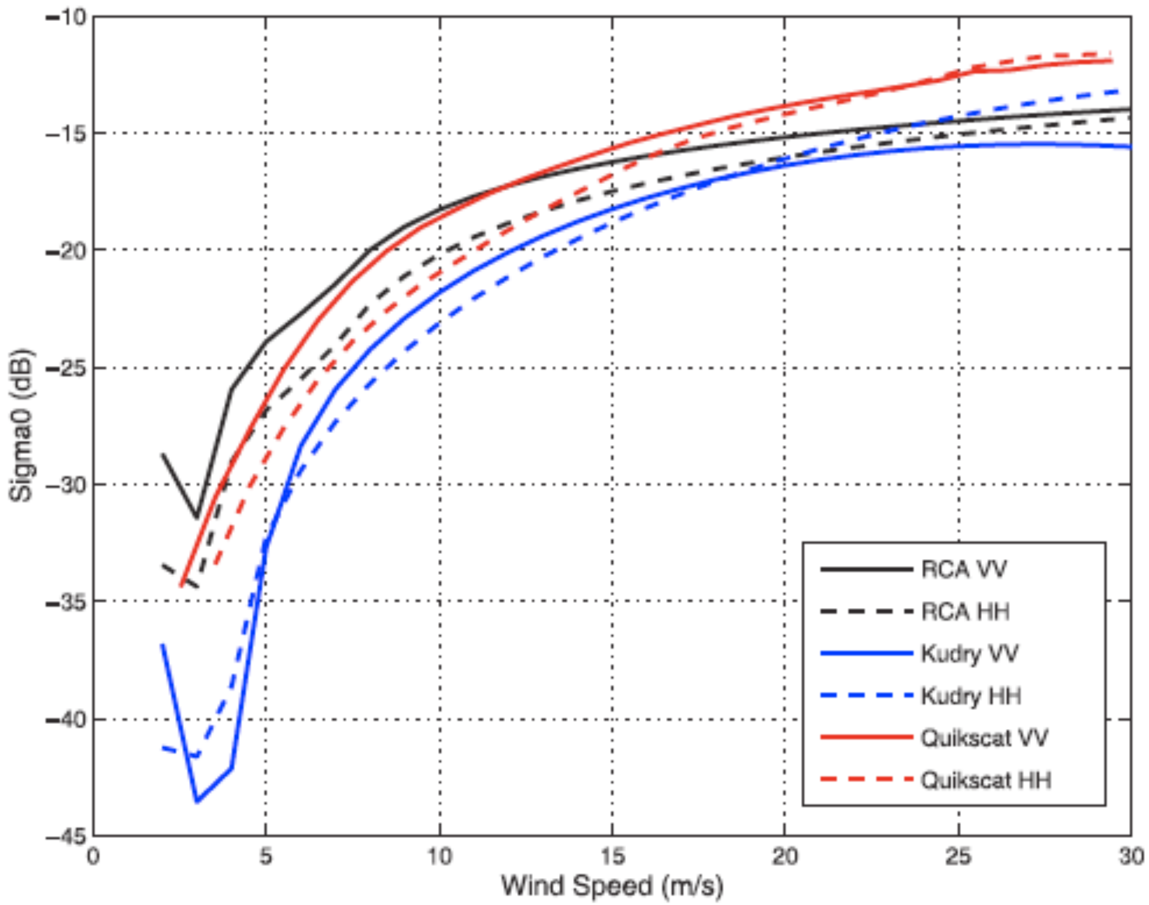


# Ocean Wind Direction with Passive Microwaves

WindSat observations from February 2003 to November 2005 with QuikSCAT observations:
Mean 3rd (left panels) and 4th (right panels) Stokes parameters for WindSat (blue lines) and RTTOV model (red lines) binned as a function of the relative wind direction (°), at 10.7 (top), 18.7 (middle), and 37.0 GHz (bottom), and for different wind speed ranges: 4 m/s < WS < 8 m/s (solid lines), 12 m/s < WS < 16 m/s (dashed lines), 20 m/s < WS < 24 m/s (dashed dotted lines).

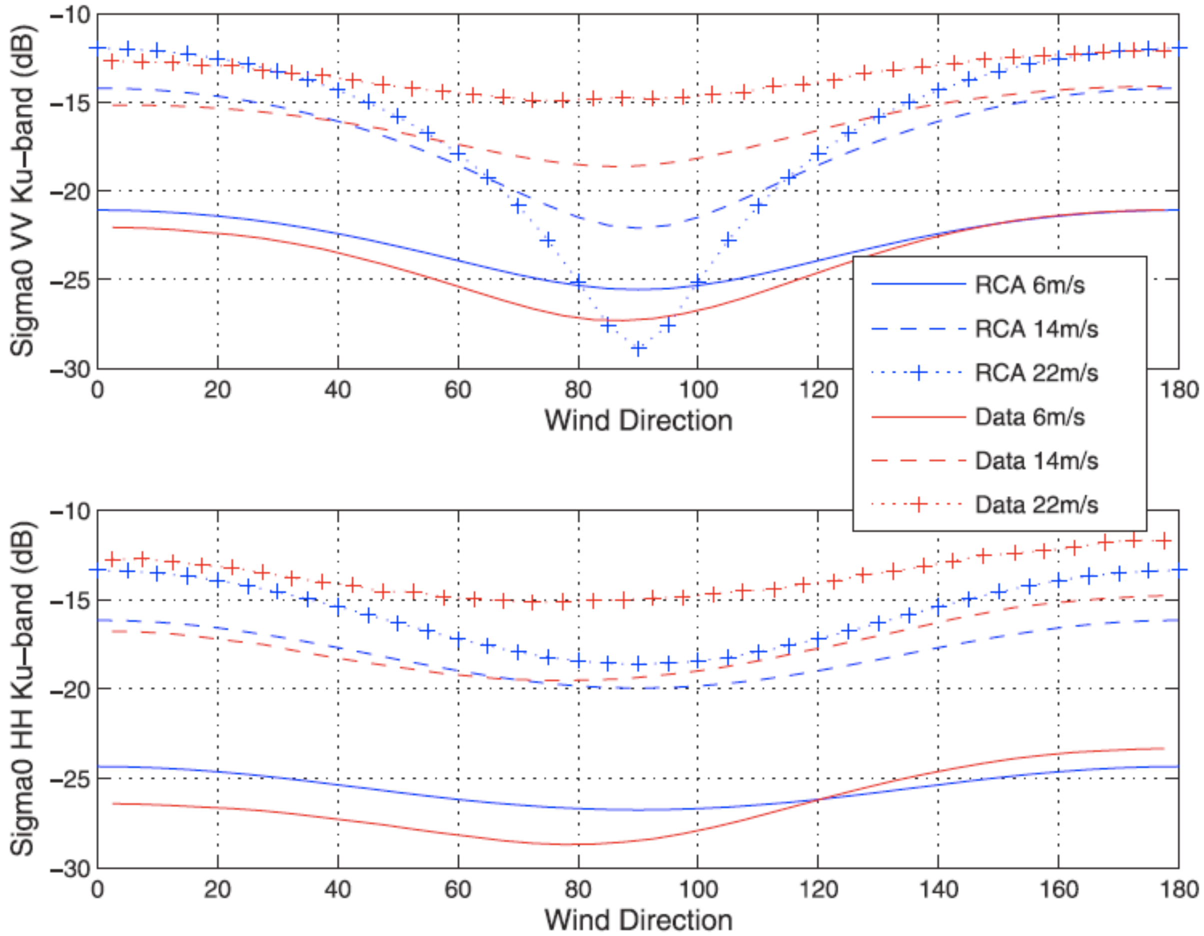


# Ocean Wind Speed with Active Microwaves




Mean Ku-band VV (solid lines) and HH (dashed lines) $\sigma_0$ (dB) computed with the RCA model (black), the Kudryavtsev model (blue), and the QuikSCAT data (red), as a function of wind speed (m/s).

# Ocean Wind Direction with Active Microwaves




Mean Ku-band VV (top panel) and HH (bottom panel) s0 (dB) computed with the RCA model (blue) and QuikSCAT data (red), as a function of the wind direction (degrees), for 6 m/s (solid lines), 14 m/s (dashed lines), and 22 m/s (+) mean wind speed.

# OWV User Requirements

| OVW Observation Wind | Application | Units | Accuracy | | | Spatial resolution Km | | | Revisit time Hr | | | Product timeliness Hr | | | Priority |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | T | B | O | T | B | O | T | B | O | T | B | O | 1:high |
| **Horizontal wind vector components at sea surface** | NWP global | m/s | 3 | 2 | 0.5 | 250 | 100 | 15 | 12 | 3 | 1 | 6 | 0.5 | 0.1 | 1 |
| | NWP regional | m/s | 3 | 1.5 | 0.5 | 50 | 30 | 3 | 6 | 3 | 0.5 | 3 | 0.3 | 0.1 | 1 |
| | Oceanography global | m/s | 3 | 2 | 0.5 | 250 | 100 | 25 | 24 | 6 | 3 | 4 | | 1 | 1 |
| | NWC icing models (speed only) | m/s | 2 | 2 | 1 | 50 | 20 | 1 | 3 | 3 | 1 | 1 | 0.5 | 0.3 | 2 |
| | NWC wave/surf models | m/s | 2 | 2 | 1 | 50 | 50 | 5 | 6 | 6 | 1 | 1 | 0.5 | 0.3 | 1 |
| **Horizontal wind speed and direction at sea surface** | NWC offshore industry, marine transport | m/s | 1 | 0.5 | 0.1 | 20 | 10 | 1 | 12 | 3 | 1 | 1 | 0.5 | 0.3 | 1 |
| | | ° | 20 | 5 | 2 | | | | | | | | | | 1 |
| | NWC marine dispersion | m/s | 2 | 2 | 1 | 5 | 5 | 0.1 | 3 | 3 | 1 | 1 | 0.5 | 0.3 | 4 |
| | | ° | 10 | 10 | 5 | | | | | | | | | | |
| | Oceanography coastal | m/s | 1 | 0.5 | 0.1 | 20 | 10 | 1 | 12 | 3 | 1 | 1 | | 0.3 | 1 |
| | | ° | 20 | 5 | 2 | | | | | | | | | 1 | |

(Stammer et al., 2007)

# OWV User Requirements

- OVW Accuracy: **1 m/s** and **15°** for wind speed and direction
  - It would meet breakthrough accuracy requirements for all ocean applications, except coastal issues.
  - Coastal measurement requires accuracy of 0.5m/s and 5° for wind vector component. However, based on new retrieval techniques, accurate coastal wind data may be estimated from a combination of remotely sensed and in situ data.
- Proposal for OVW horizontal resolution : **12.5 km**
  - Meets breakthrough horizontal resolution requirement for all applications including coastal oceanography
- Proposal for OVW revisit time : **12 h**
  - It would meet breakthrough revisit time requirement for some global applications. However, global oceanography as well as coastal oceanography require higher resolution of 6 and 3 hours. 6-hourly estimates may be derived from multi-platform satellite data.