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Living Science

# GNSS Reflections for Spaceborne Ocean Monitoring

GAMBLE Final Workshop

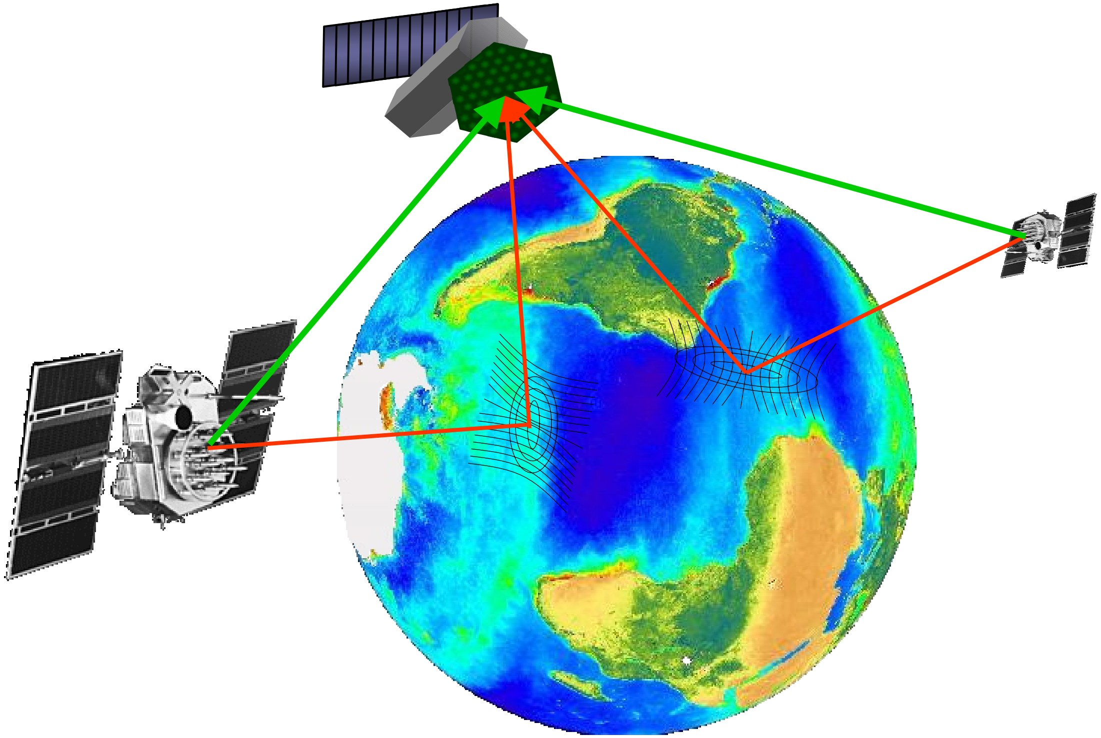
Arles, 17th November 2003

# Contents

- GNSS-R for ocean remote sensing
- A GNSS-R spaceborne altimetric mission
  - User requirements
  - Mission and sensor
  - Scientific impact
- Conclusions

# GNSS-R concept

- GNSS-R: Global Navigation Satellite System - Reflections
- Bistatic radar for reflective surface monitoring (mainly ocean)



# Sensitivity / Potential products

- Surface Topography (SSH)
- Surface Roughness (mainly directional mean-square slope [DMSS] , also SWH)
- Surface Dielectric Properties (salinity, pollution, soil moisture)
- Surface Motion (orbital velocity, large scale currents)
- Atmosphere (ionospheric electron content, surface pressure and/or tropospheric WV)

# Winning themes

- Coverage, potential time/space resolution. By 2008, GPS and Galileo plus augmentation system (EGNOS/WAAS) will provide more than 50 sources
- Rain immune: L-band
- High quality signals: self-calibrating, dual frequency, long-term availability and stability
- Inexpensive: passive, off-the-shelf technology

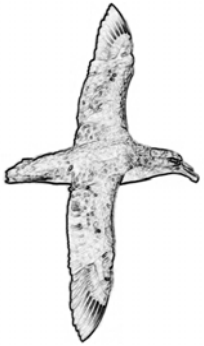
# … and pains [in altimetry]

- Poor altimetric precision
  - Long pulses (C/A code = 300 m, P code = 30 m)
  - Low SNR from space
- Higher sensitivity to antenna pattern
  - since not so much “pulse-limited”

# Niche / Synergies

- Offers co-located altimetric/speculometric measurements over large swath and with high spatio-temporal sampling
  - Science (ocean modelling, climate, AO coupling and fluxes)
  - Operational (mesoscale and coastal altimetry, sea state/winds for ship routing and off-shore mining, pollution monitoring)
- Radar altimeters (Jason, ENVISAT, …)
  - Mesoscale aspects
  - MSL definition; supporting “tie-up”
- L-band radiometry (SMOS/Aquarius)
  - Data source for L-band sea-roughness in salinity retrieval

# A GNSS-R altimetric space mission



- **PETREL**, an Earth Explorer Opportunity Mission submitted in January 2002 did not pass: technical maturity, lack of experimental demonstration mentioned as main causes
- Next target is 2005 !
- Work presented here was carried out under ESA study PARIS-Gamma Phase 1 (TRP ETP 137.A). Acknowledgement to partners for their contributions (EADS-Astrium, CLS and Ifremer)

# User requirements

- Global coverage with samplings below **100 km and 10 days** offer a clear niche for future missions (as discussed later, they would require up to six RAs, especially for V mapping)
- Mesoscale Altimetric Signals (SHA) are of the order **5-30 cm**
- Long term availability and stability are required
- All weather measurements a plus
- Collocated h and dmss a plus

**Sensor precision requirement:**

**100 km, 5 cm → ~20 cm after 1 second (@7 km/s)**

# Altimetric error budget (1/2)

Altimetric precision

$$\sigma_h = \frac{\sigma_r}{2 \sin \gamma}$$

Ranging precision, mainly depends on the reflected delay precision

Sat elevation (best @ nadir)

Reflected delay precision

$$\sigma_{dR} \approx 0.22 \frac{\tau_{chip}}{SNRv}$$

300 m for C/A code

Altimetric precision requirement translates into SNRv (gain)

# Altimetric error budget (2/2)

**Requirement: one-shot SNRv around 5**
**At 500 km altitude, this translates into a 27 dB antenna gain**

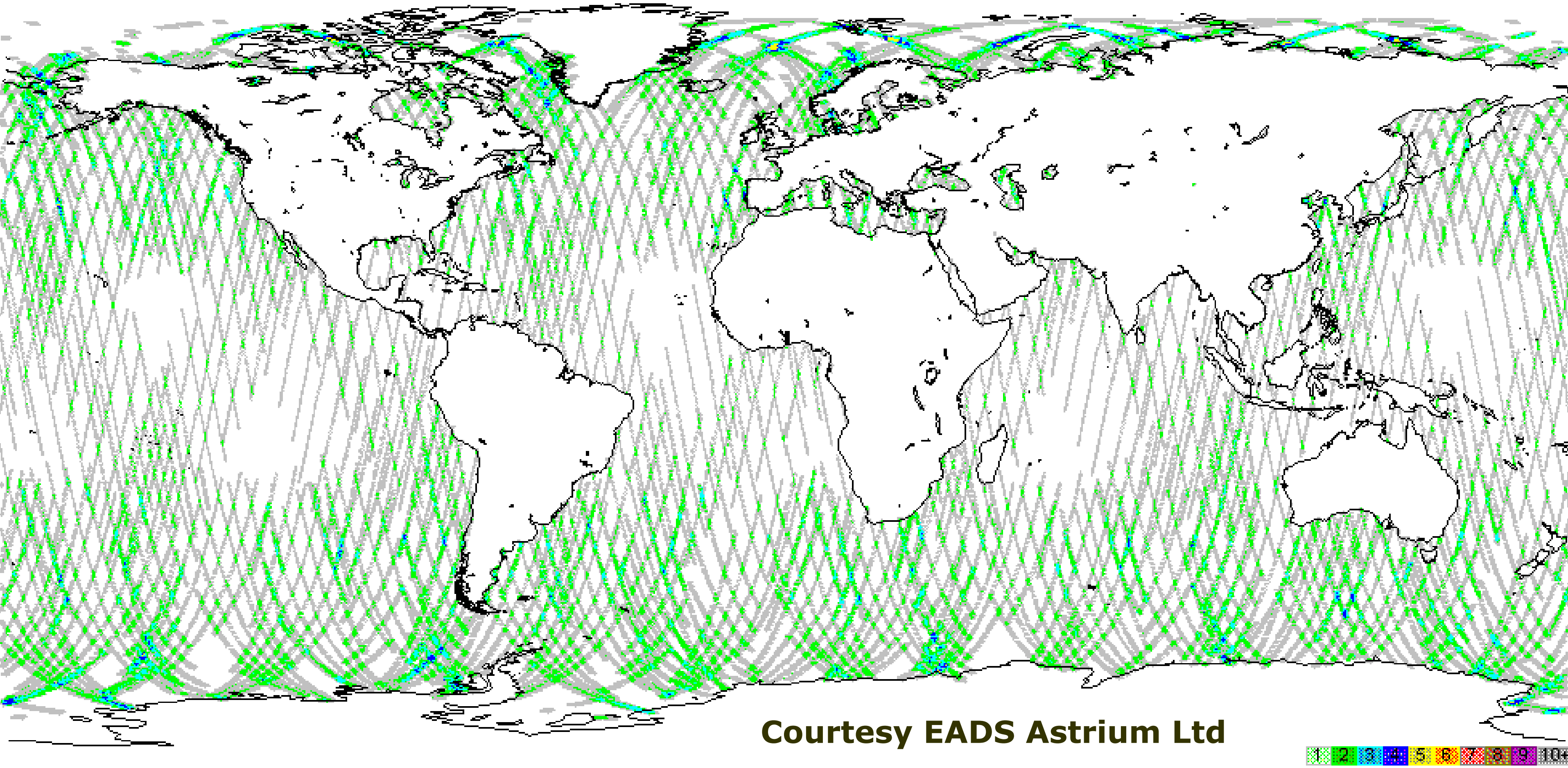
NB: This result was obtained in two equivalent manners:

- absolute: building a SNR budget
- relative: scaling the result of [Lowe *et al*., 2000], the unique reference for spaceborne GPS-R SNR value

|  | **After 1 shot** | **After 1 s (7 km)** | **After 3 s (20 km)** |
|---|---|---|---|
| SNR voltage | 5 | 170 | 290 |
| Reflected delay error | 15 m | 0.40 m | 0.23 m |
| Ranging error | 16 m | 0.43 m | 0.25 m |
| Altimetric error (Nadir / 45$^o$) | **8 / 12 m** | **0.21 / 0.31 m** | **0.12 / 0.17 m** |

# Sampling density

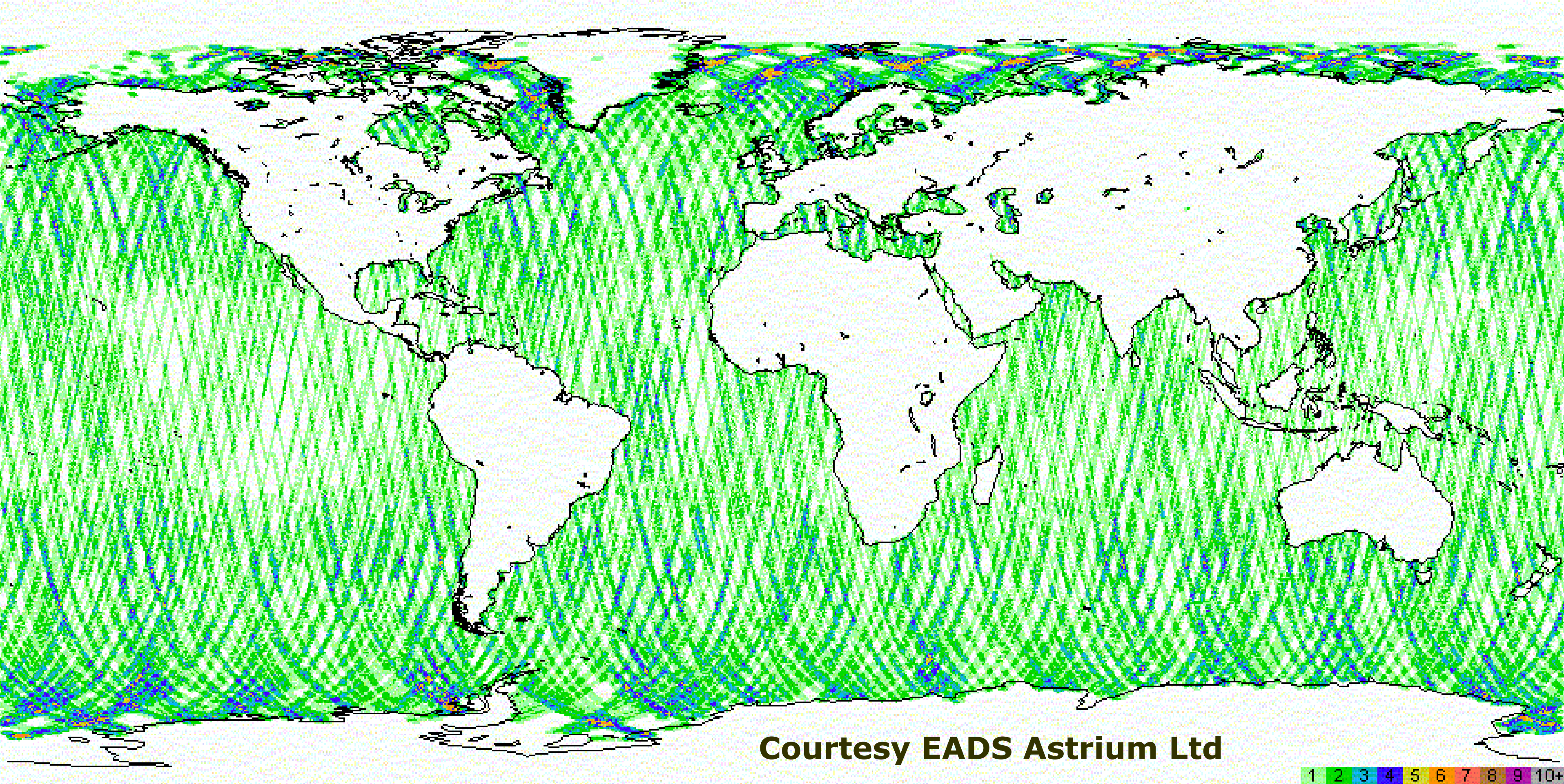
GPS
5-day repeat
60° FoV



Courtesy EADS Astrium Ltd

# Sampling density

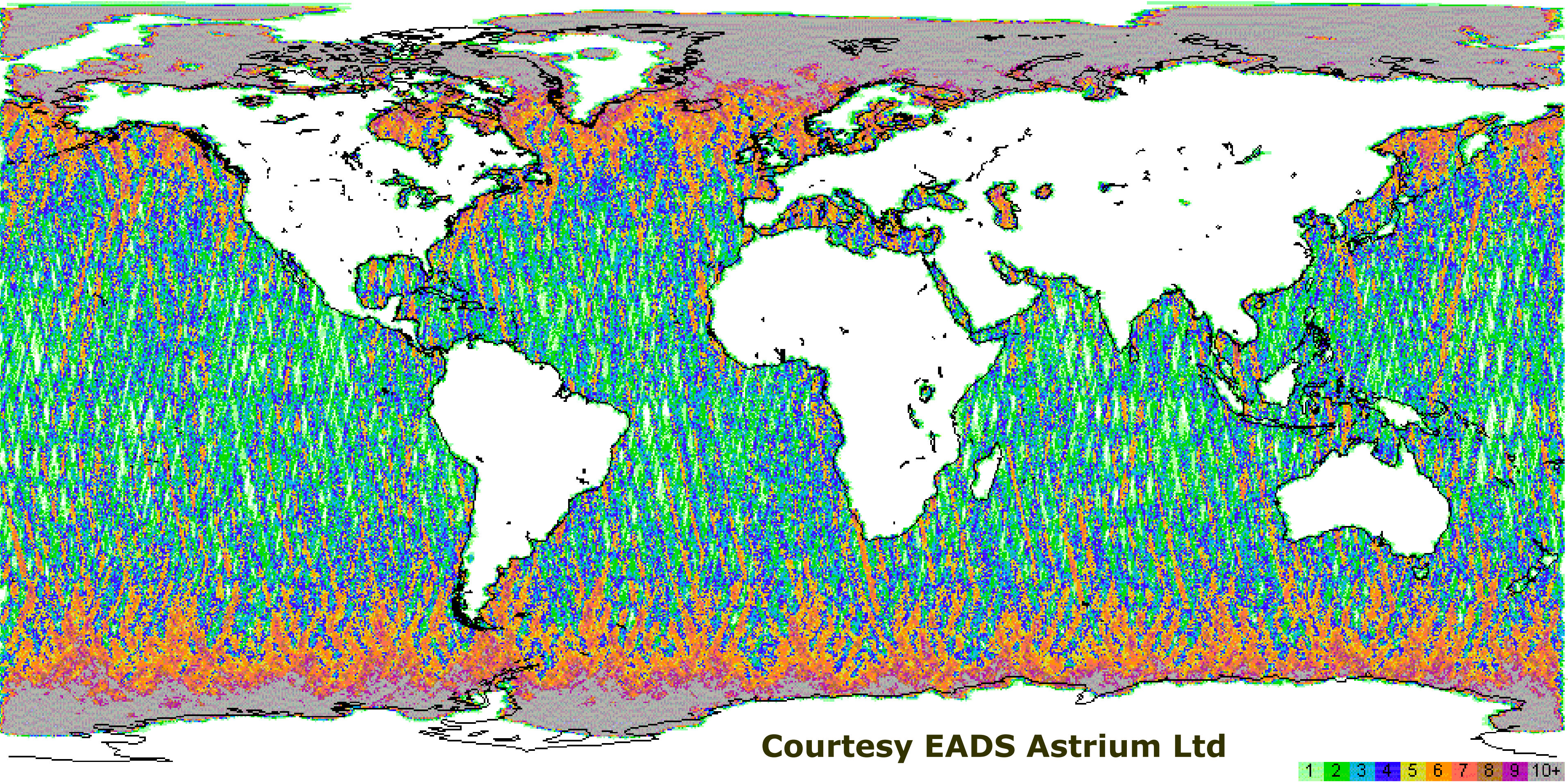
GPS, Galileo and Inmarsat
5-day repeat
60° FoV



Courtesy EADS Astrium Ltd

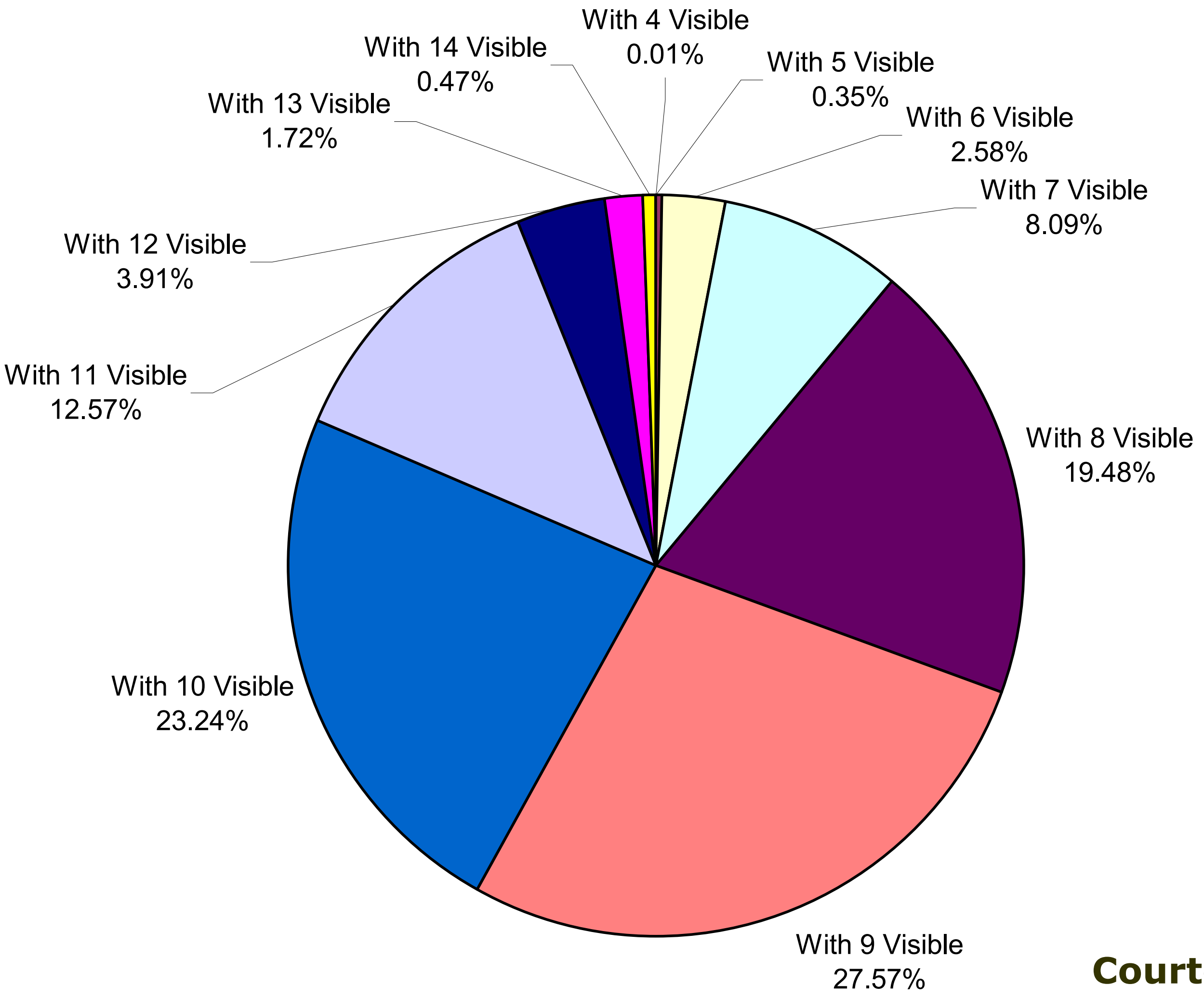
# Sampling density

GPS, Galileo and Inmarsat
5-day repeat
100° FoV



Courtesy EADS Astrium Ltd

# Average number of Specular Points



GPS, Galileo
90° FoV

**Courtesy EADS Astrium Ltd**

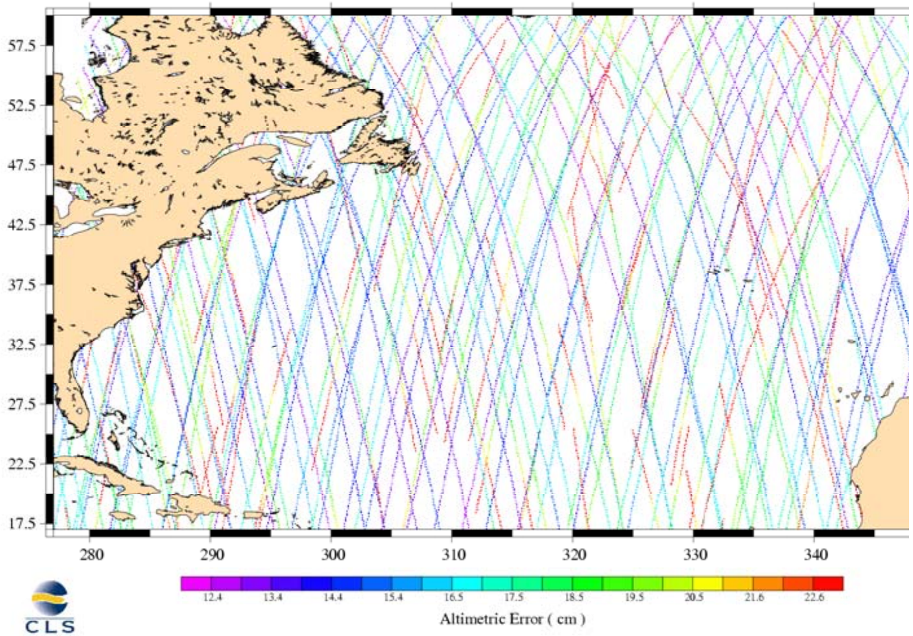
# Mission & Sensor Baseline

- Orbit:
    - 500 km altitude
    - Sun-synchronous, polar inclination
    - 5-day repeat (trade-off coverage / sampling)
- Antenna:
    - 27 dBi gain
    - 90° to 100° Field Of View
    - 8 to 12 Beams
- Frequencies
    - L1/L2 for ionosphere correction
    - L2/L5 for wide-laning
- Available signals: GPS, Galileo and Inmarsat
- Tropospheric delay: wet delay corrected through on-board radiometer or future NWP (TBD)
- Ionospheric error: exploit coherence scales and dual frequency to estimate and correct it out.

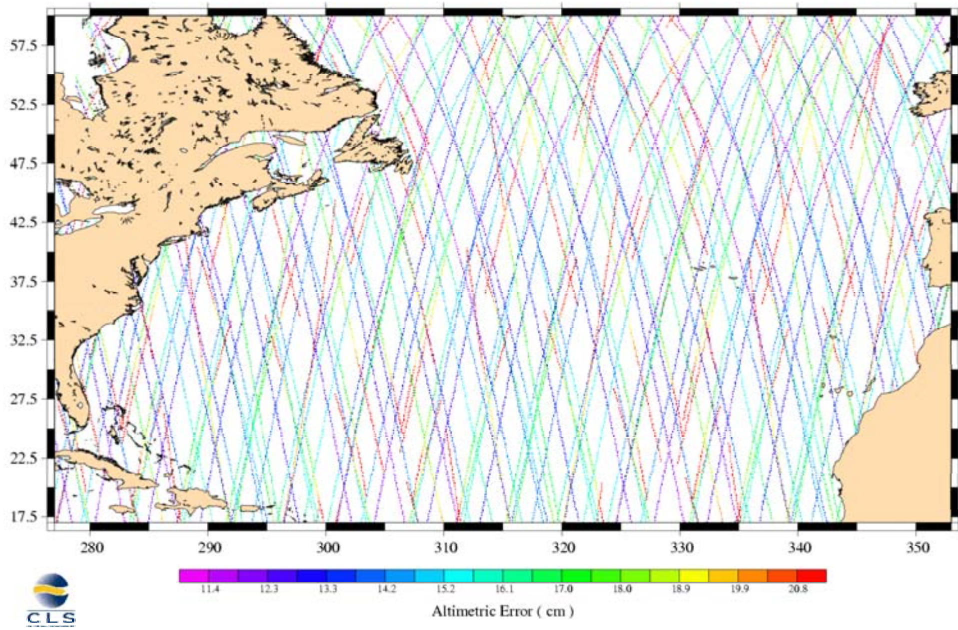
# Scientific impact

- Goal: quantify the contribution of GNSS-R for the mapping of ocean mesoscale variability using the Los Alamos North Atlantic model.
- Model sea level fields are subsampled to simulate the typical space/time sampling of GNSS-R altimeter systems.
- A realistic measurement noise is added to these simulated measurements.
- Simulated measurements are used to reconstruct the initial model reference fields.
- This is achieved using a space/time objective mapping technique that takes into account the GNSS-R measurement noise characteristics and an a priori information on the space and time scales of ocean signals.

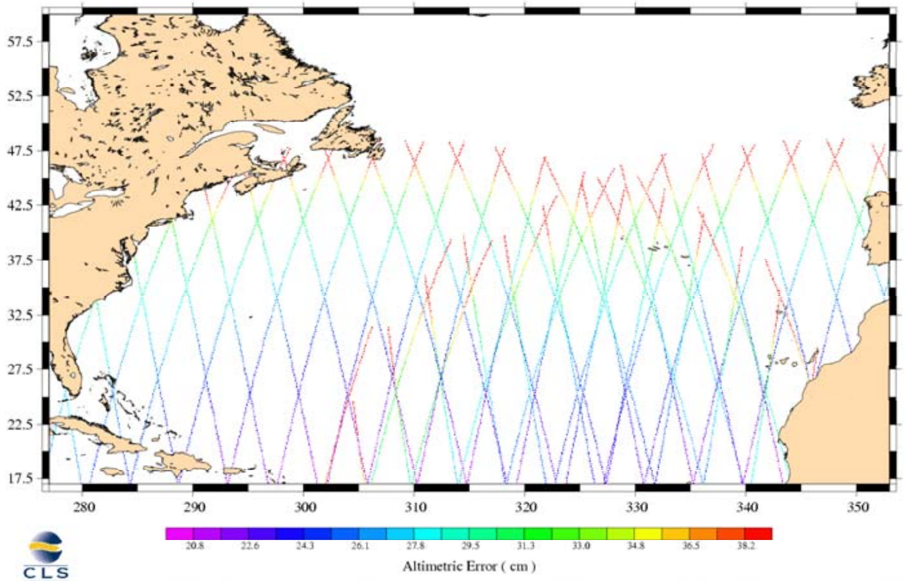
## GPS – Altimetric Error

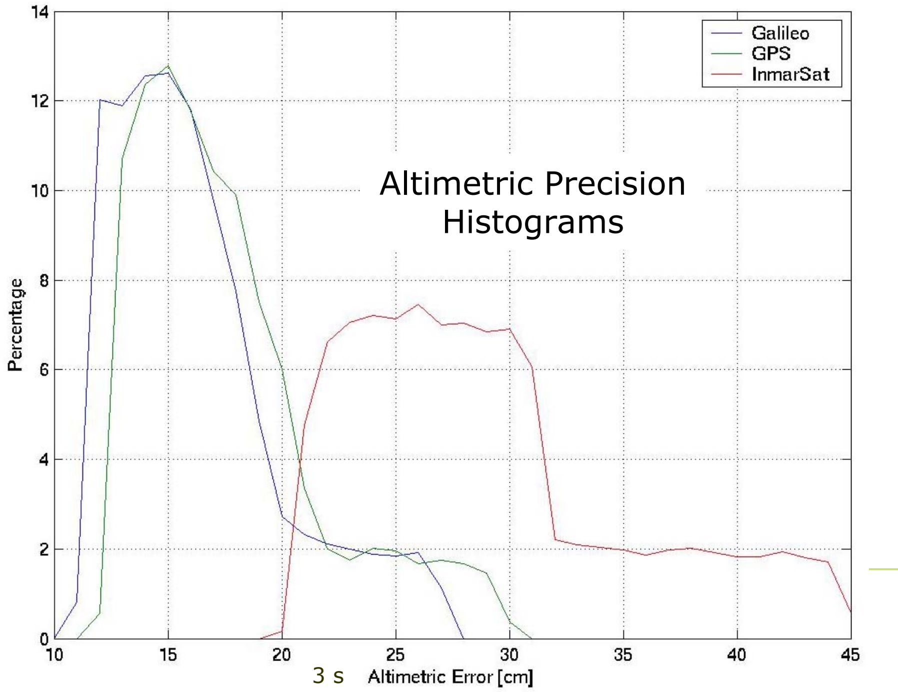


## Galieo – Altimetric Error



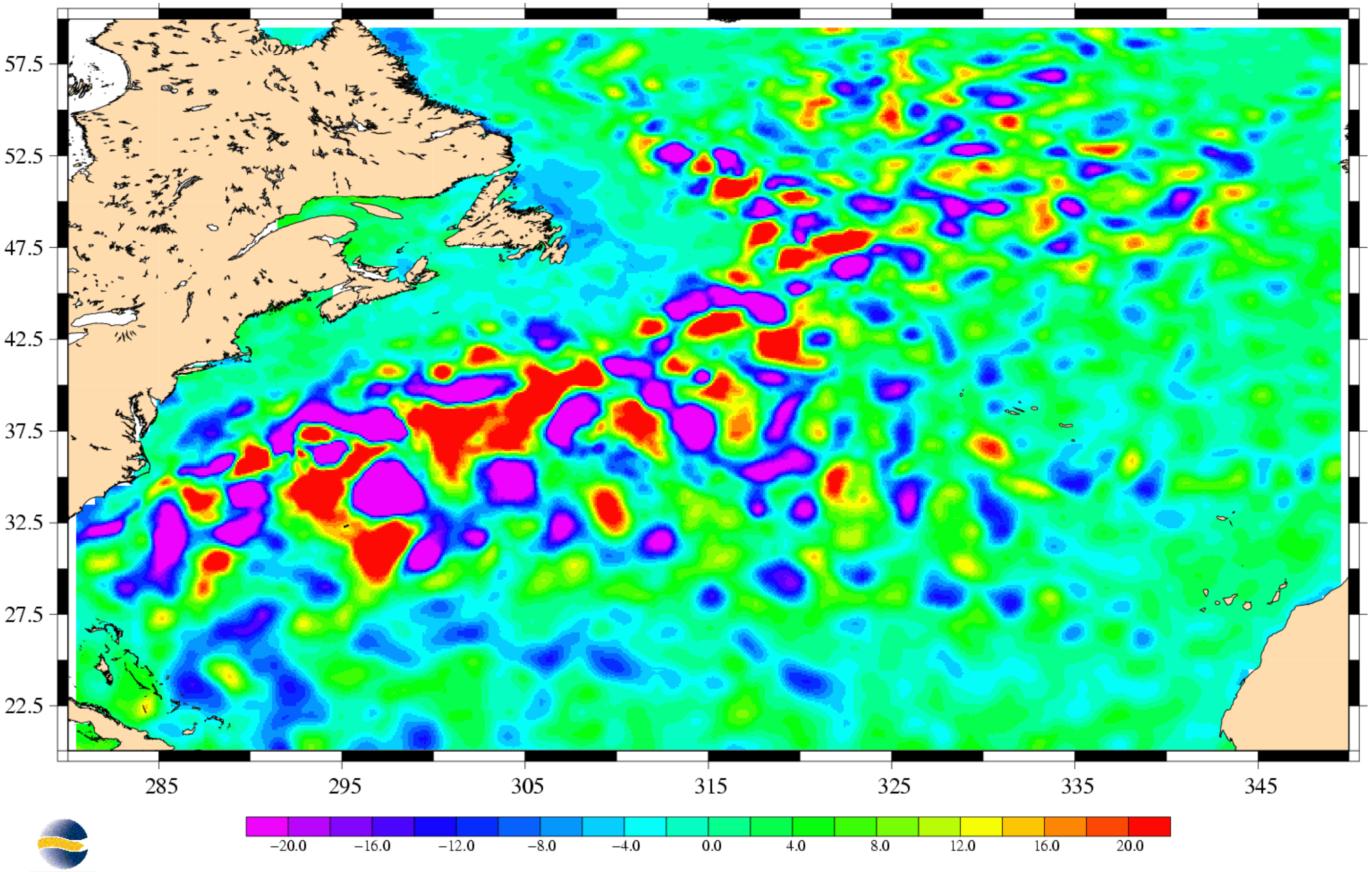
## INM – Altimetric Error



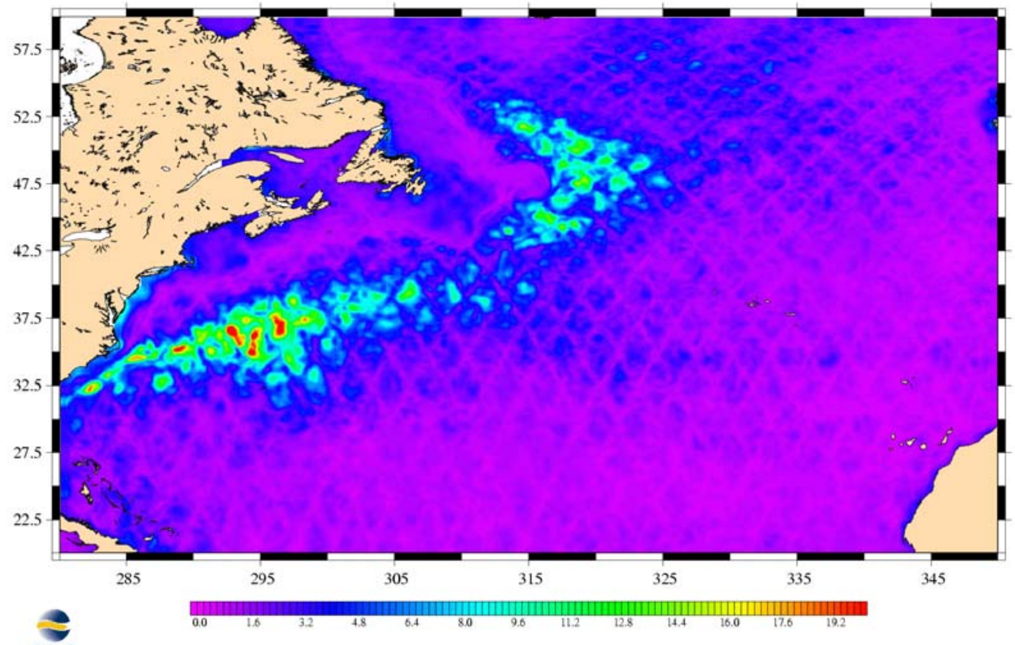


Altimetric Precision
Histograms

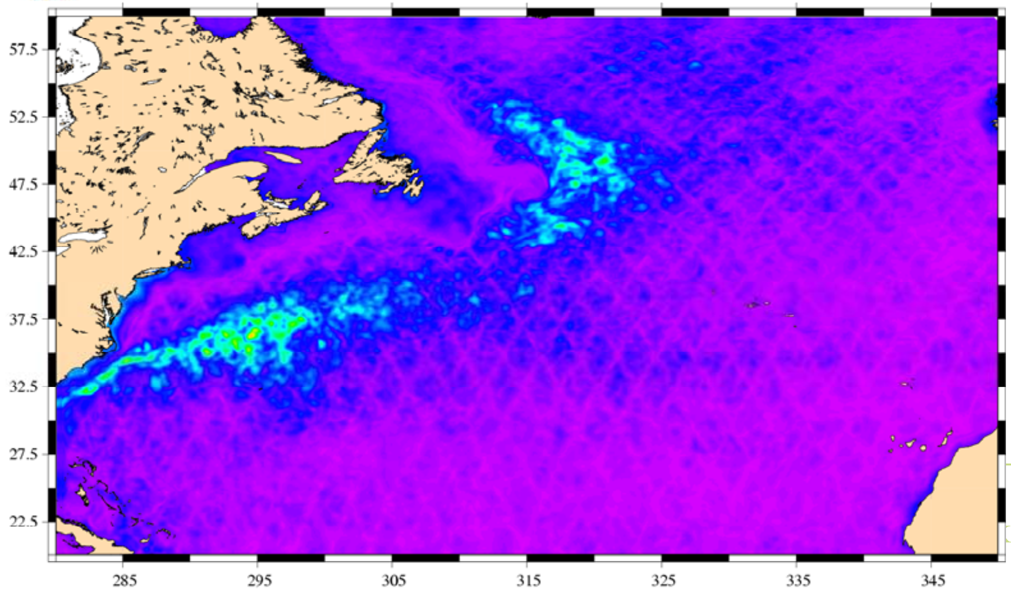
# Simulated Sea Level Anomaly



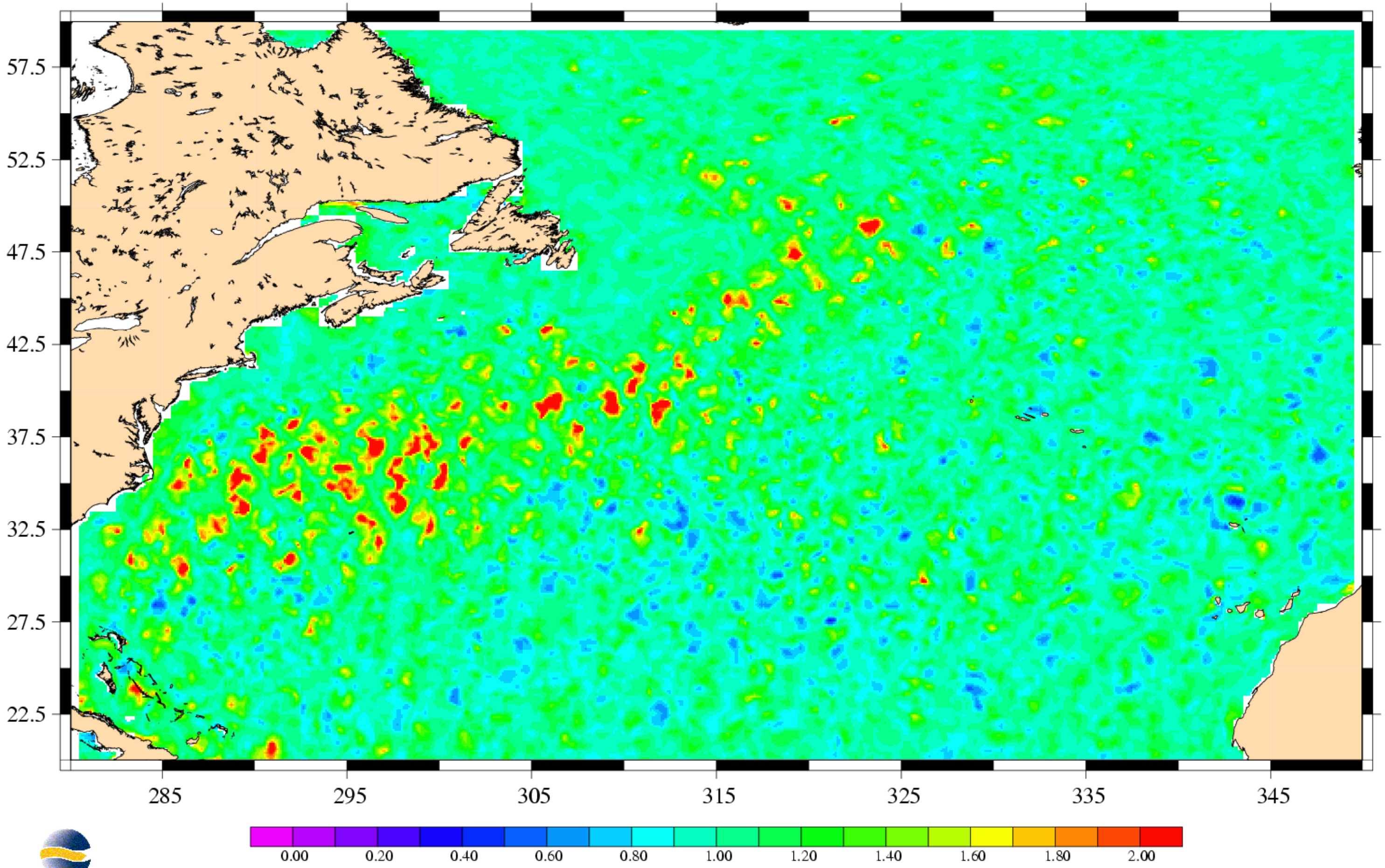
# RMS sea level mapping error



Jason-1 + ENVISAT



Jason-1 + ENVISAT + GNSS-R



$$\frac{\text{RMS (Jason-1 + ENVISAT)}}{\text{RMS (Jason-1 + ENVISAT + GNSS-R)}}$$

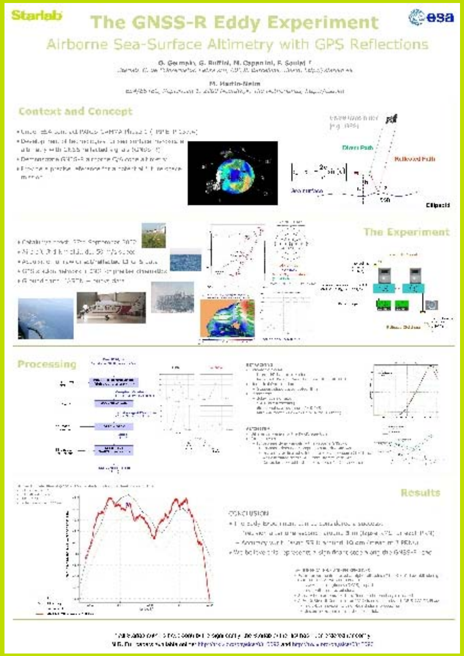
# Conclusions

- User requirements: global coverage, measuring 5 cm signals with 100 km, 10 days sampling
- Sensor requirement: 20-30 cm altimetric precision after 1 second
- 500 km altitude, sun-synchronous, polar inclination, 5-day repeat orbit
- 27dB gain, 100º FOV antenna
- Simulations have shown a very positive scientific impact:
  - GNSS-R + Jason-1 +ENVISAT will improve the sea level mapping compared to Jason-1 +ENVISAT by a factor of 2 to 4
  - GNSS-R should allow a mapping of the mesoscale variability in high eddy variability regions better than Jason-1+ENVISAT.
  - The dense and high frequency sampling offered by GNSS-R is likely to compensate for the large noise level in large eddy variability regions

# Future work

- PARIS-Gamma Phase-2 will yield more airborne data for analysis
- Validate the SNR model from airborne data, and, if necessary, to upgrade it
- Further simulations to ascertain the nature and impact of atmospheric errors on the error budget
- Depending on previous points, a reanalysis of the scientific impact

Thank you for your attention...



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The GNSS-R Eddy Experiment

Airborne Sea-Surface Altimetry with GPS Reflections

O. Germain, G. Ruffini, M. Caparrini, F. Soulat

M. Martin-Neira

Context and Concept

The Experiment

Processing

Results

CONCLUSION

More… See the SWT poster on:

GNSS-R altimetry airborne experiment