La proposition de mission **SWOT**: Surface Water Ocean Topography

- **WSOA**: Wide Swath Ocean Altimetry (annulé sur JASON2, dédié à l’océanographie)
- **WatER**: Water Elevation Recovery (proposition à l’ESA Earth Explorer Core Missions, dédié à l’hydrologie)
- **WATER-HM**: Water And Terrestrial Elevation Recovery – Hydrosphere Mapper (proposition au NRC Decadal Survey, dédié à l’hydrologie et à l’océanographie)
- **SWOT**: Surface Water Ocean Topography (sélection de WATER-HM par le NRC Decadal Survey)
- Études de phase 0 au JPL et au CNES
- Possibilité de coopération bi-latérale NASA-CNES
<table>
<thead>
<tr>
<th><strong>OSTM</strong></th>
<th>Orbit Height</th>
<th>1334 km</th>
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<tbody>
<tr>
<td>Orbit Type</td>
<td>10-day repeat</td>
<td>10-day repeat</td>
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<td>Swath</td>
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<tr>
<td>Frequency</td>
<td>Ku-band</td>
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<td>Height Precision</td>
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<td>5 cm</td>
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<tr>
<td>Spatial resolution</td>
<td>2 km</td>
<td>15 km</td>
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<tr>
<td>Instrument Type</td>
<td>Nadir Altimeter</td>
<td>Real Aperture Interferometer</td>
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</table>
Different Altimeter Coverage Capabilities

OSTM Sampling (10 day cycle)

WSOA Sampling (10 day cycle)

Hydrosphere Mapper (16 day cycle)
Science Objectives:
• Land surface water (hts.+ gradients)
• Sea surface height measurements (continue the Jason/TOPEX series)
• Study mesoscale phenomena
• Ocean bathymetry (surface slopes)

Instruments:
• Ka-band wide-swath radar altimeter
• Ku-band nadir altimeter
• 3-freq. water vapor radiometer
• GPS for POD
• Laser retroflector for POD

Orbit:
• 993 km altitude, 78 deg inclination
• 21-day exact repeat, 10.5 day revisit
• Delta II launch

Programmatics:
• NASA/NOAA/Navy partnership
• Currently no US altimeter planned after Jason-2
• Possible Eumetsat/CNES roles
• Launch date 2012 for continuity with Jason-2
• 5-year mission
• Mission Cost ~ $500M (FY ‘06)

New technology:
• Wide-swath altimeter is a SAR interferometer
• Onboard processing

Mission Concept
Surface Water ESSP Mission

**JPL Experience with Radar Topography**

  - Science applications, algorithms, retracking, ground system, mission management, calibration and validation

  - Instrument design and manufacture, processing algorithms, ground system, mission management, calibration and validation

  - Science applications, instrument manufacture, processing algorithms, ground system, mission management and validation
WATER Measurement Goals for Hydrology

- **Hydraulics Required**: \( h, \frac{dh}{dx}, \frac{dh}{dt} \)
- **Spatial Sampling**: Images with pixels of \(~100\ m\) 
  - Need between track sampling, not just conventional altimeter profiles.
  - Image pixel sizes should be small enough to measure \(~100\ m\) wide channels.
  - Height accuracy needs to be capable of deriving slope from lowland rivers.
  - Geographic coverage to 75 degrees North.
- **Temporal Sampling**: Repeats \(~\)weekly
  - Need to capture the majority of discharge from any basin.
    - Amazon floodwave is regular and lasts almost a year
    - Arctic floods occur during annual spring melt and last for less than a month.
Science Objectives - Land Surface Water

• The Global Water Cycle
  – Where is water stored on Earth’s land surfaces, and how does this storage vary in space and time?

• Flood Hydraulics
  – How much water is stored on a floodplain and subsequently exchanged with its main channel? What are the spatial dynamics of floods and how can we predict them?

• Trans-Boundary Rivers and Basins
  – What are the policy implications that freely available water storage data would have for water management?

Floors are the number one hazard
Science Objectives - Ocean

• Mapping ocean currents and eddies not resolved by conventional nadir altimetry but responsible for 90% of the ocean's kinetic energy.
• Determination of the heat transport by ocean eddies.
• Exploring submesoscale processes in the ocean that are key to understanding the dissipation of ocean currents and eddies and hence the time scales of the ocean's response to climate change.
• Mapping ocean bathymetry from slopes in the ocean water surface topography.
• Mapping the internal tides of the ocean that are key to understanding the mixing in the ocean that is critical to the efficiency of oceanic uptake of heat from global warming.
• Resolve the details of coastal ocean circulation.
• Mapping hurricane's heat potential.
Oceanic Processes Resolved by Different Missions

- TOPEX/Poseidon, Jason, and OSTM are primarily targeting basin scales (broken lines).
- WSOA extends the window to cover large eddies and fronts.
- HM extends the window to cover coastal upwelling and other small-scale processes important to bio-physical interactions.
- Without HM, the details of ocean surface geostrophic currents cannot be fully resolved.
Interferometric Altimeter Concept

- Ka-band SAR interferometric system with 2 swaths, 50 km each
- WSOA and SRTM heritage
- Produces heights and co-registered all-weather imagery
- 200 MHz bandwidth (0.75 cm range resolution)
- Use near-nadir returns for SAR altimeter/angle of arrival mode (e.g. Cryosat SIRAL mode) to fill swath
- No data compression onboard: data downlinked to NOAA Ka-band ground stations

These water elevation measurements are entirely new, especially on a global basis, and thus represent an incredible step forward in oceanography and hydrology.

Courtesy of Ernesto Rodriguez, NASA JPL
Radar Spatial Resolution

- Conventional real-aperture altimeter spatial resolution is determined by iso-range annuli and antenna beamwidth:
  - Left/right/front/back ambiguity
  - Pulse limited circle gives geolocation

- Synthetic aperture processing narrows the along-track (azimuth) cell size:
  - Left/right ambiguity is not resolved
  - Clutter from land is reduced

- Interferometer resolves left/right ambiguity by illuminating only one side of the swath.

Courtesy of Ernesto Rodriguez, NASA JPL
Interferometric Measurement Concept

- Conventional altimetry measures a single range and assumes the return is from the nadir point.
- For swath coverage, additional information about the incidence angle is required to geolocate.
- Interferometry is basically triangulation.
  - Baseline B forms base (mechanically stable).
  - One side, the range, is determined by the system timing accuracy.
  - The difference between two sides ($\Delta r$) is obtained from the phase difference ($\Phi$) between the two radar channels.

\[
\Phi = 2\pi \frac{\Delta r}{\lambda} = 2\pi B \sin \frac{\Theta}{\lambda}
\]

\[
h = H - r \cos \Theta
\]

Courtesy of Ernesto Rodriguez, NASA JPL
Simulated Interferometer Return

The interferometer return signal contains both radar brightness (for water boundary delineation), range, and phase (color) for height estimation.

Image geolocation accuracy given by timing accuracy, not platform attitude, unlike optical imager.

Courtesy of Ernesto Rodriguez, NASA JPL
Meeting Bathymetry Requirements

The bathymetry requirements are (Sandwell et al):

- 1 µrad slope accuracy
- 4 km spatial resolution

Using conventional altimetry (e.g., the proposed Abyss mission) these requirements could be met with a 6-year mission.

- Coverage limited: does not include higher latitudes
- Ocean mesoscale variability may limit slope accuracy

The Hydrosphere Mapper will achieve the goals of the Abyss mission in less than 1-year data collection. Additional time can be used to reduce mesoscale ocean errors.

Current state of knowledge of Geoid Slope

From Sandwell et al.

Hydrosphere Mapper slope accuracy after 14 days

Courtesy of Ernesto Rodriguez, NASA JPL
Interferometer Height and Slope Precision

Height and slope estimates are made by using radar image to isolate water body and fitting a best fit linear height change over the swath.

Precision depends on water brightness and the length and width of the imaged water body.

Courtesy of Ernesto Rodriguez, NASA JPL
Precision vs Averaging Area

This is the performance expected for lakes, wetlands, and oceanography.

For comparison, note that a typical nadir-looking altimeter (Topex/Jason) has a beam limited footprint with a diameter of about 2 km and has a precision of ~2 cm after averaging over 1 sec or ~6.5 km.

Courtesy of Ernesto Rodriguez, NASA JPL
Interferometric Error Budget

Dominant Contributors

\[ \delta h = \delta H - \]

\[ \cos(\theta) \delta r + \]

\[ r \sin \theta \frac{\partial \theta}{\partial \Phi} \delta \Phi + \]

\[ r \sin \theta \delta \theta \]

Other error sources (e.g., baseline length, yaw errors) can be controlled so that errors are smaller by an order of magnitude, or more.

Courtesy of Ernesto Rodriguez, NASA JPL
2. Science Objectives - Bathymetry

A mean-sea-level ocean height deviation due to a gravity anomaly on the ocean floor

Satellite altimeters (Interferometric) provide global uniform coverage in the 16 to 160 km wavelength band.

Seafloor structures (12 to 18 km scale) measurements to be improved by a factor of:
- 5 in vertical precision,
- 2 to 3 in horizontal length
- 4 to 9 in horizontal area.

Short Wavelength Coverage

*Abyss-Lite* would improve slope resolution by an order of magnitude, and spatial resolution by a factor of 3 (avg)

* After ESSP 2001 Proposal to NASA (Smith, Raney, et al.)
  “Altimetric Bathymetry from Surface Slopes”
• Both WatER and HM share an identical radar hardware. HM complements WatER with a water vapor radiometer for making wet tropospheric delay corrections. This is a relatively minor addition since the OSTM radiometer can be used directly.

• In order to reduce cost and increase system stability, a sun-synchronous orbit was chosen for WatER. This orbit selection is not optimal for the observation of tides, since the solar tides are aliased.
  – The oceanographic community is divided about the importance of this: many believe open ocean tides are known with an appropriate accuracy, while others worry about coastal tides, non-linear tides, and long period tidal aliasing in the global sea level rise signal. This is the primary disagreement between the WatER and HM user communities.
  – A solution exists which will meet both the WatER and ocean requirements (including tides) at greater cost than the WatER concept.
  – Many of the HM science goals, which concentrate on ocean mesoscale signals and bathymetry, will be met with the WatER instrument + a radiometer.
Topics for JPL and CNES Joint Studies

• Pre-phase A risk reduction studies
  – Orbits and tidal aliasing; include swath altimetry and sub-cycles (sun-synch., non-SS?)
  – Orbit and precision orbit determination, power, launch
  – Data downlink rates over land, minimum required resolution
  – Wet troposphere corrections over coasts

• Plan to integrate the space agencies and the community
  – Need a pre-mission advisory working group to link CNES, NASA, other agencies, international scientific communities
  – Formal recognition allows organized approach to studies, pre-mission meetings and planning, securing of funds

• Action Items:
  – Form a pre-mission advisory working group
  – Empower the advisory group to prioritize the risk reduction studies
  – JPL works with CNES jointly advocating the mission
  – ~$20M JPL investment in WSOA needs to be leveraged
étude PASO

- Etude d'une mission applications multidisciplinaires en
- Etude de phase 0 menée par le CNES en pour l'application de
  l'interférométrie radar à large fauchée à (mission WatER).
- Nouvelle phase 0 en pour les applications à la mésoéchelle
  océanique et à l'océanographie côtière, dans un contexte de mission
  multidisciplinaire d'océanographie haute résolution et d'hydrologie.

-Trade-off bande Ku / bande Ka à poursuivre pour l'instrument principal (aspect
  physique de la mesure et contraintes technos),
-Taille du bras interférométrique en fonction des performances attendues
-Caractéristiques d'un mode SAR pour les applications exigeant de la haute
  résolution spatiale (côtier et hydrologie continentale en particulier)
- Intérêt de la présence d'un altimètre nadir en bande Ku ou Ka pour assurer la
  calibration de l'altimètre interférométrique, la continuité avec les missions
  antérieures et améliorer l'intercomparaison des produits, utilisation de l'altimètre
  nadir en mode SAR pour améliorer la résolution suivant le défilement du
  satellite. Présence d'un radiomètre bi ou tri-fréquence.
- Aménagement satellite : SCAO (prise en compte des exigences spécifiques de
  l'instrument), énergie bord, débit télémesure, partage bord/sol, certain de ces
aspects ont été rapidement couverts (3 mois) en 2006 pour WatER.