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Satellite Derived Bathymetry
Taking stock of SDB latest developments

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ARGANS Ltd. is a British SME (33 staff members), whose headquarters is in Plymouth, with branches in France and Morocco, member of the ACRI group (some 18 M€ of Y2018 tur-over), which is specialised in Remote Sensing.

Its main business is the development and operation of

- **Payload Data Ground Segments** (PDGS), e.g. it is currently the technical lead of the Copernicus Sentinel-2 and Sentinel-3 *Mission Performance Centres* and the developer of the SMOS L2 processors, and

- **EO user segments** (data hubs, cloud-computing platform,....)

It focuses on Data Sets Quality Control, algorithms & data processors validation, satellite-borne sensors’ radiometric verification & vicarious calibration.

→ knowledge of error budgets and of data reliability is key for customers  
e.g. ARGANS performs the permanent radiometric verification of Sentinel-2, Sentinel-3, Landsat, VIIRS, MERIS… on behalf of ESA
By associating
- Physicists (radiative transfer + oceanography/ geology/ sedimentology) and
- Hydrographers (surveyors + cartographers) with FIG-OHI recognition

ARGANS has developed a unique capacity in **Satellite Derived Bathymetry (SDB)**, which derives from the French Hydrographic Office’s 30 years experience

- similar even better than its competitor EOMAP (DEU) and T-CARTA (USA-UK)

The ESA latest Coastal Charting project, to promote SDB, should include a test site in **Coral Bay**, making it our first attempt at using SDB in Arctic waters.
Last year, in Ottawa, we introduced a proposal by ESA to hold an inter-comparison SDB exercise on the C-TEP,

(as we currently do for NASA and ESA for Atmospheric Correction (ACIX)

ARGANS Ltd sister company, ‘adwäisEO’ manages
- the full VIR data sets of Sentinel-2 A & B worldwide (6 Pbytes) —on behalf of the LU gvt
- all the European remote sensing data since the origin of time (!) —on behalf of ESA

and soon will have all the Sentinel-1 A & B data sets

→ automatic bathymetry/ bathymorphology/ water turbidity/ land use-land cover automatic analysis, i.e. mapping and change detection, worldwide every week (!!!) becomes possible

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Captain Cook and Beautemps-Beaupré used to survey coastlines at a safe distance from the ship crow’s nest. Some official INT charts are still based on the first half of 19th century’s surveys.

Attempts were made to achieve similar results by balloon (Nadar 1858)

During WW2, aeroplanes tried to survey landing beaches and rivers. The results were considered dangerous.

1972: following the Landsat 1 launching, major changes are introduced to charts of reefs and remote islands and satellite topography becomes a routine application.
SDB is the art of deriving depths from optical satellite images. There are 2 main methods: the **Empiric** (e.g. Lyzenga, Stumpf...) and the **Physics-based** (Lee & al.) – which are all based on physics !!!

but the former needs adjustment on ground-truth for the parametrization, whereas the latter is based on empirical formula derived from simulations or a-priori observational experimental knowledge of the parameters

(why are Stéphane Maritorena and André Morel works overlooked ?)
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The basic equation of radiance linking the “brightness” or Luminance $L$, i.e. the quantity of energy received by the satellite sensor, and the depth is a function with a **logarithmic declining shape**, involving the absorption $a$, the scattering $b$, and the bottom reflectivity $\rho$:

$$L = f(Z, a, b, \rho)$$

or

$$Z = f^{-1}(L_{a, b, \rho})$$

$$(Z, a, b, \rho) = F^{-1}(L)$$
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As there are far more unknowns than equations provided by satellite spectral bands (3-4 useful bands with Sentinel-2), SDB amounts to an expert’s recipe, consisting of reducing the unknowns (e.g., by defining homogeneous zones using the same parameters).
Don’t forget we use approximations

\[ L = f(Z, a, b, \rho) \]

\[ L_{\text{obs}} = f_{\text{app}}(Z, a, b, \rho) + \varepsilon \]

\[ (Z, a, b, \rho) \approx f_{\text{app}}^{-1}(L_{\text{obs}}) \]


1990: Shom publication of a first SDB chart, using the Lyzenga “empiric” model $L = f (Z_{a,b}, \rho)$.

No isobaths, but bathymetric layers 0-5, 5-10, 10-15, 15-20 m.

This first chart has been followed by scores of others limited to Tropical waters. These SDB charts are included in the French national chart series.
In 1998, Lee et al introduced the generic so-called “physics-based” model based on the inversion of radiance

\[ Z = f^{-1}(L, a(L), b(L), Ρ(L)). \]

This new method, which is more robust because less empirical, has been used ever since, yet with very few theoretical improvements with regards to the laws of physics, but great engineering progress

- Most similar methods use the HydroLight radiative transfer model (Mobley 1989) to simulate the parameters.
- There are scores of inversion models. ARGANS studied and compared about 20 of these. Most lack calculation of uncertainties and rely heavily on the analyst’s interpretation.

Hydrographers have tried to reconcile models and users’ specifications compliance (e.g. IHO) A first attempt was made in Puerto Morelos, Mexico, in 2014.
Most SDB test sites are in Tropical waters

ARGANS and ARCTUS Northwest Passage test site

1st experience in Arctic waters
Effect of aerosols

Sky radiance correction

Glinted and unglinted images
Secchi, Cutoff and DOP: these 3 similar notions have been theorised:

- DOP is related to IOP and the euphotic threshold for a given target
- Secchi depth is related to the disk black & white contrast and the human eye detection threshold at $\lambda \approx 555$ nm
- Cut-off depth is related to the contrast between sea bottom and deep ocean (first deliveries by François-Régis Martin-Lauzer in 2018 for commercial applications of geophysics exploration)

Nota: depth of penetration (DOP) is used by submariners to avoid detection
DOP provides a security threshold to safe navigation, similar to the Hydrographic wire-sweep of old, hence the new term: “Optical Sweep”

“Optical sweep” can yield thresholds comprised between 5 centimetres (Nile Victoria), 2 metres (Shetland), 22 metres (Andaman Sea) and over 30 metres (Loyalty Islands).

Question: What will be the optical threshold in the North West Passage?
When **processing** satellite images, SDB Analysts must apply a number of masks to get rid of lands, clouds, etc.

- A new mask has to be created to eliminate depths > DOP threshold
- The remaining depths must then be compared to S-44 standards
Sentinel-2 revisit time can help confirming the existence of doubtful shoals.
By refining the approximation of the Radiative Transfer Equations, 

\[ L = f(Z, a, b, q) \]

in particular in very shallow waters

we expects to gain control of uncertainties which presently are either ignored or guessed empirically by the community of Analysts at large

(Until then, SDB vertical precision remains outside S-44 standards)
SDB nonetheless, regardless of its vertical imprecision and thanks to Sentinel-2 revisit time, can offer 100% confirmation of doubtful shoals.

SDB absolute horizontal precision is excellent (better than 12 metres) and within decimetres with control points.

Sentinel-2 revisit performances could be further improved by semi-automatic detection of changes (actually under development by ARCTUS’ Luxembourg sister company).

If confirmed in Coral Harbour, SDB could provide an almost unlimited field of applications in polar waters such as the North West Passage, Greenland and other uncharted Arctic/Antarctic oceans.
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