Mapping ocean currents using SPOT-5 satellite

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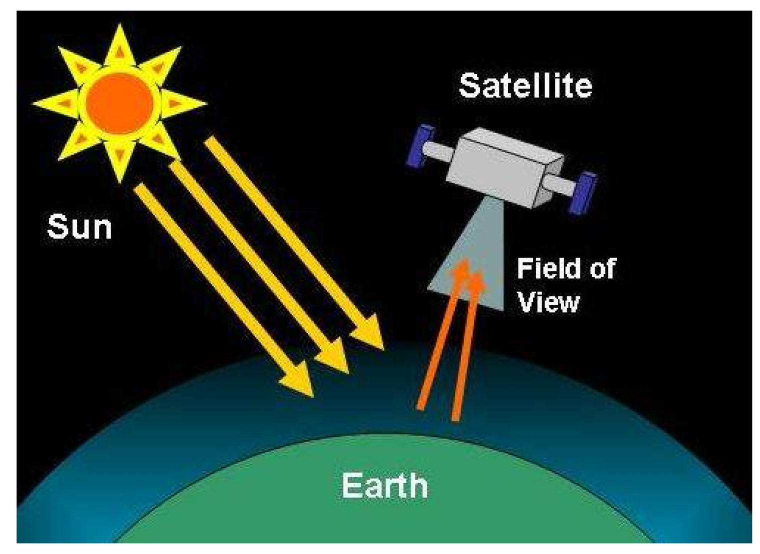
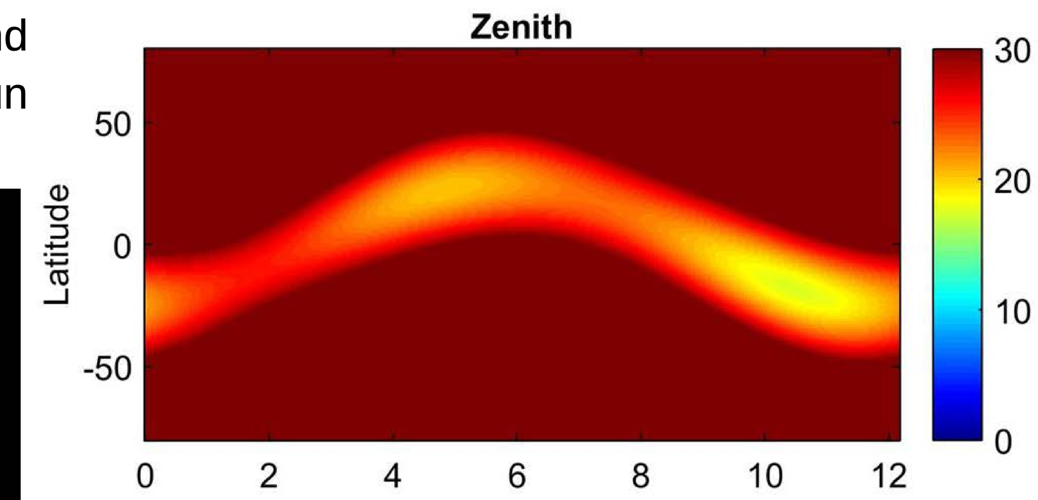
MOTIVATIONS - A number of techniques with complementary characteristics are available to measure ocean surface currents. Satellite imagery is particularly suited for oceanographic investigations in large areas. This study intends to demonstrate the potential transformation of optical images into maps of ocean surface currents. SPOT-5 images are used here, as there is a 12 year worldwide archive ready. The same algorithm is going to be applied to Sentinel-2, just turned operational.

DATA SETS - SPOT-5 provides two images, a panchromatic (PAN) image at 5-m pixel resolution co-registered with a multispectral (MS) image at 10-m pixel resolution. The MS bands correspond to Green, Red, near IR, and midwave IR. We have used orthorectified SPOT-5 images at Level 2A that include orbital parameters. The PAN image is down-sampled from the 5 m pixel resolution to 10 m pixels to match the resolution of the MS image. Features on or very near sea level are used to determine the registration shift between the two images. Marinas and ports are ideal because they have sharp features and are of course at sea level.

Satellite nadir view of Earth surface and sun. For good wave visibility the sun should be 20-30 degrees from nadir.



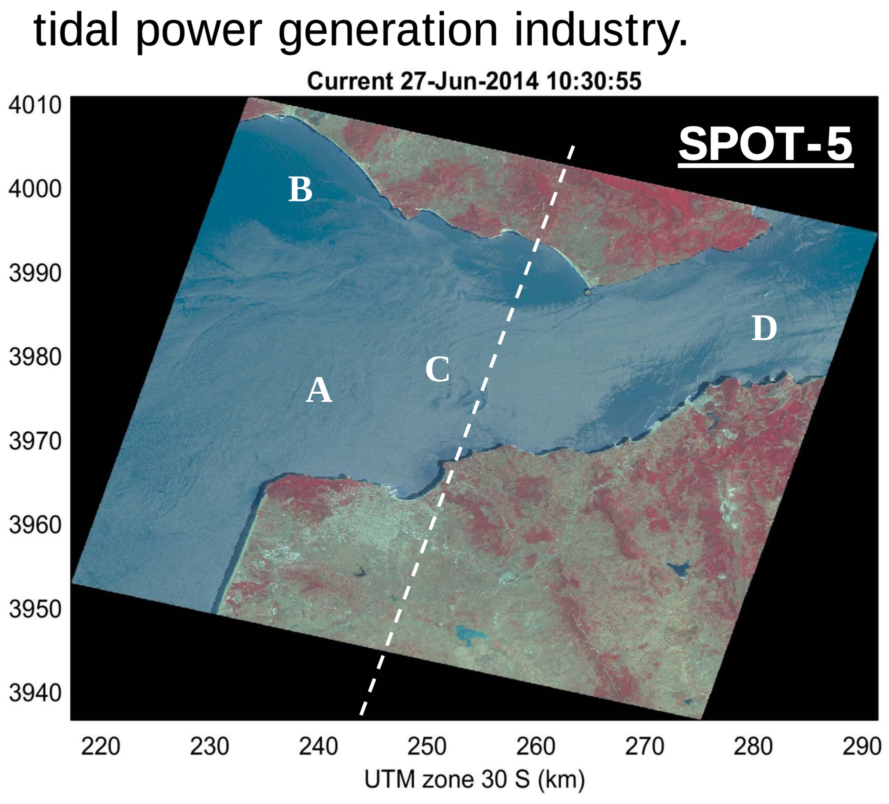


Plot shows the month of year vs. latitude when ocean waves can be imaged. Obviously this tends to summer in places of greatest interest.

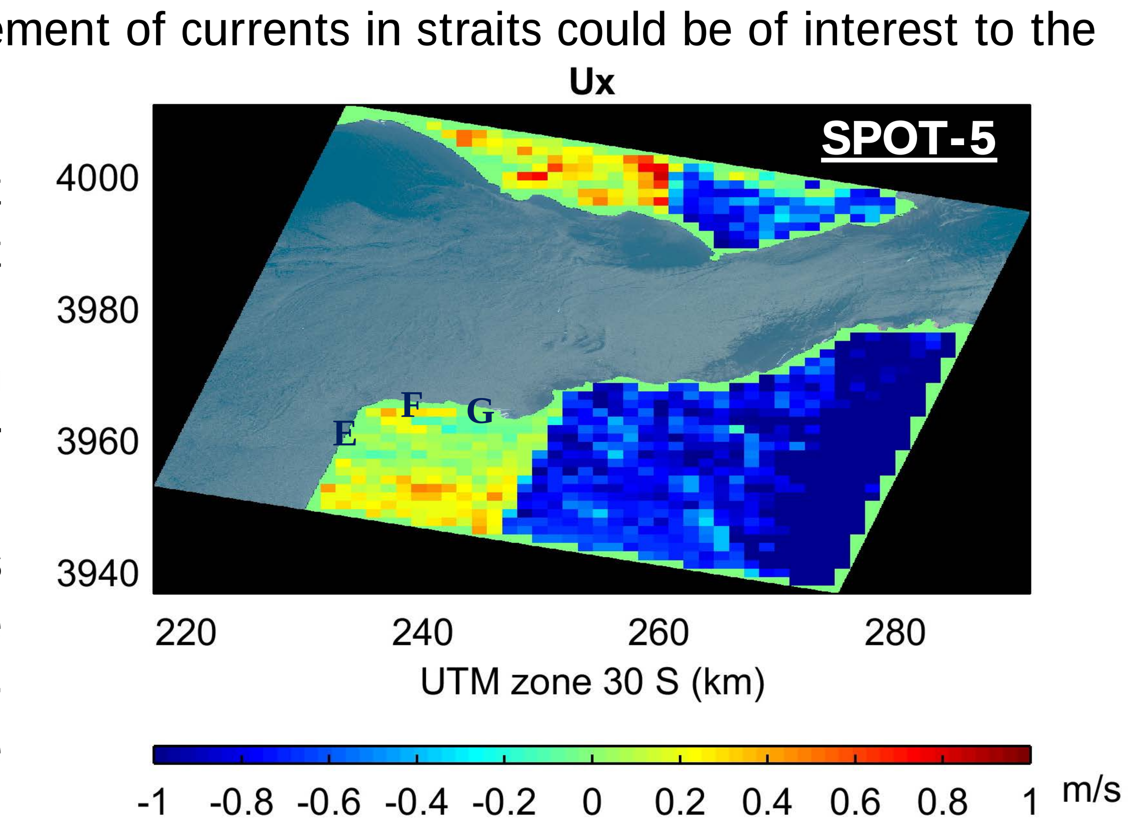
PROCESSING - The processing steps for a bundle are to: (1) measure the mis-registration between the two images using one or several land fiducials, as said previously preferably near sea-level to avoid elevation parallax effects; (2) shift the second image to correct for mis-registration; (3) check image data with coherence analysis; (4) filter noise outside gravity wave wavenumber support space; (5) apply the wave propagation operator on the second image; (6) estimate the current field using optical flow or moving box cross-correlation methods.

CONCEPT - Ocean currents can be measured with remote sensing by tracking the apparent motion of waves. It is exploited the existing delay between the passage of each band over a fixed point on Earth surface. This study uses PAN and Red images in SPOT-5 that are separated by 2.33 sec. The ocean current is sensed by measuring the displacement of ocean waves after adjusting for the gravity wave dispersion velocity. The algorithm separates wave velocity and currents. However, the image has to catch waves to measure currents. This depends on wave direction and sun angle. Also, brightness of waves varies with geometry. SPOT-5 is nadir pointing, so the sun must be high. Radiance from wave surfaces diminishes at greater angles. Sentinel 2 with 4 bits more radiometric range may be able to image waves further, extending the time of year when good wave measurements can be made.

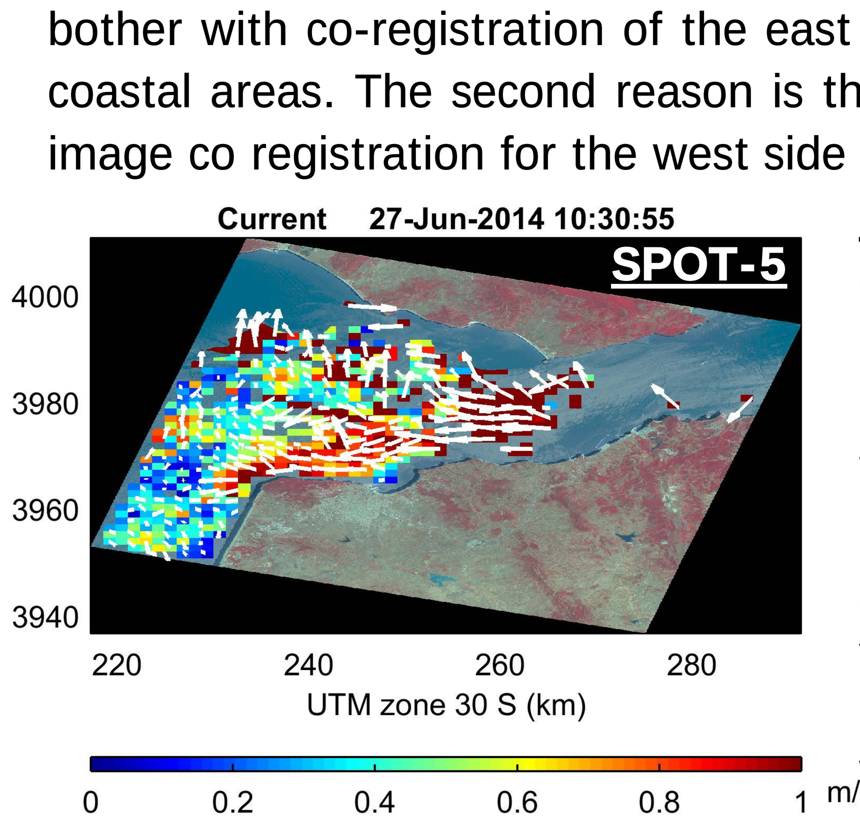
CASE-STUDY OF GIBRALTAR STRAIT USING SPOT-5 - The example here is from SPOT-5 images collected on 27 June 2014 at 10:30 AM. Gibraltar Strait has strong tidal currents. Moreover, there are land references on either sides that provide accurate registration. Also, the measurement of currents in straits could be of interest to the tidal power generation industry.



Area of investigation - A minimum requirement for wave visibility is that there is some sunlight reflection from the ocean. As shown on the left image, most of the ocean surface is lit up. Notably in areas marked A, C, and D. Some ocean areas, such as B, are dark. The most likely explanation is reduced wind in those areas. Not all lit up areas are suitable for measuring currents. Some boxes are contaminated by ships. For example, C. The further East the closer we get to the sun specular point. There is more sunlight but the waves are washed out. In summary, the best wave visibility is on the west side of the image, in the vicinity of A. A semi-automatic algorithm decides which 1.28 km boxes are suitable. The rest are squelched.

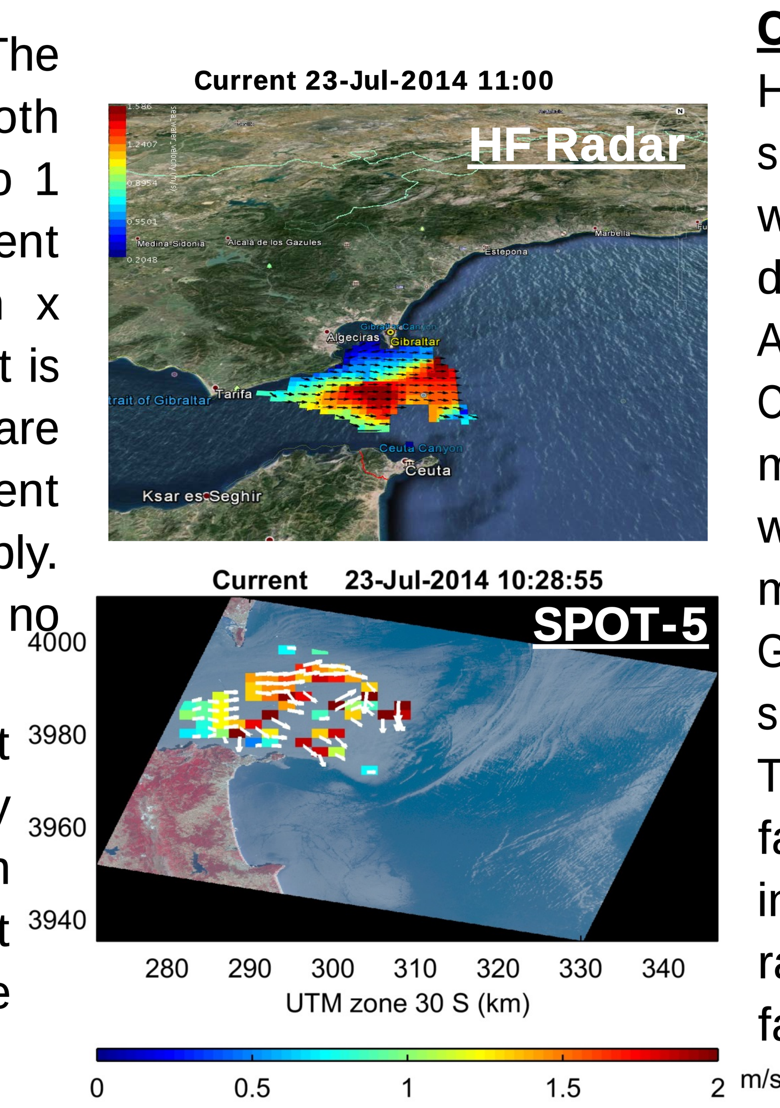


Dichotomy effect – In the above right image, we show the x-component of the velocity measured over land. When the images are properly co-registered the velocity should be 0. There are several complications with co-registration. One is mountains with highly variable DEMs. We have to select flat coastline areas for best co-registration. Another problem is the possible dissimilarities between the MS and PAN images. Since they have different spectral responses they can show remarkably different features which cannot be co-register. This is most serious over farmlands because vegetation has a strong spectral character. The issue is not so great over urban areas where distinct edges of building, roads, and ports can be co-registered without regard for spectral characteristics. So in conclusion, flat coastal cities are best for co-registration. In this case excellent areas are the city of Tangier (E) and vicinity of the Tangier airport (F). In these flats we in fact show Ux = 0 m/s, achieved after appropriate image co-registration. The Remilatt mountains are in between E and F. They show up as a 0.4 m/s Ux anomaly, which is to be expected. This demonstrates the importance of selecting flat coastal urban areas for co-registration. Otherwise very large biases can be introduced in the measurement of ocean currents. The dichotomy effect is clearly visible in the Ux plot. The east side has a -0.5 m/s bias. Possibly even -1 m/s bias on the extreme east end of the image footprint. We did not bother with co-registration of the east side for two reasons. First, it's not easy. The east side of the Moroccan coast is mountainous. It is more difficult to find large flat coastal areas. The second reason is that it would not be that useful anyway because there is diminished wave visibility on the east side. So in conclusion there is good image co registration for the west side of the image space.



Retrieved current field - The current is shown as both magnitude (in color, scale 0 to 1 m/s) and as a vector. The current was measured with 1.28 km x 1.28 km resolution. The current is shown only where there are visible ocean waves of sufficient SNR to measure current reliably. Where there are no waves no current information presented.

The current is an outflow from the Mediterranean. The strongest current is a 5-10 km wide tongue. The main result is the E-W velocity of 0.8 m/s running along the NW Moroccan coastline. Further out in the Atlantic and further north off the Moroccan coast, the current magnitude diminishes to 0.2-0.4 m/s. Some stronger currents are shown east of the mid-line but those are biased up by misregistration.



Comparison with HF radar – The upper image is following HF radar current field observed at 11:00 AM. The HF radar spatial resolution is around 1 km x 1 km. Peak current measured with HF radar is 1.2 m/s and 1.6 m/s respectively, in easterly direction. SPOT-5 image was captured on 23 July 2014 at 10:28 AM. The lower image shows the SPOT5 derived currents. Current vectors are shown at 2 km spacing. The current is 1.5 m/s, also with Easterly heading. Unfortunately wave conditions where suboptimal for both systems. Further complicating matters, the HF currents are mostly in an area just west of Gibraltar, the optical currents are just east of Gibraltar. The spatial overlap is in a sliver of water just south of Gibraltar Rock. These difficulties notwithstanding it is still possible to draw a favourable conclusion. Both systems indicate a 1.5 m/s current in mid-Strait, easterly heading. To first order satellite and HF radar agree and this is as good a validation as we have had so far.

Acknowledgments - SPOT-5 data sets are provided by the European Space Agency within the Third Party Mission Scheme. We wish to express our gratitude for the help provided by Raffaele Rigoli (SERCO SPA), and Josée Bertolaso and Vincent Parage (Airbus Defence and Space). Thanks go also to Jesus Goméz-Enri who provided HR radar current field in the Girbaltar Strait.

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Concluding remarks - This study shows that satellite imagery produces reasonable (but still not fully validated) results. The measured displacements are small fraction of a pixel. This requires attention to sources of noise and biases. The greatest source of uncertainty for SPOT-5 is the misregistration between bands that is corrected with land fiducials. Work is in progress to apply the same principles to Sentinel-2 measuring the Agulhas current system.