Chapter3

A satellite view of lagoons

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Northern New Caledonia. Récif des Français (left), Balade Reef (top-right). Fringing reefs to the north and around Balabio Island are visible (Landsat 7 image).

We use satellite imagery to answer various questions related to oceanic systems. New Caledonia is known for its rich biodiversity, particularly in its marine environment. This aquatic diversity is threatened by many anthropic activities and extreme climatic events, which are important to study in order to better understand and manage the resulting ecological impacts. For this purpose, scientists use several biochemical indicators which provide information about sedimentary and terrestrial elements, compounds that are dissolved in the water, and microscopic organisms containing chlorophyll.

The development of coral reefs relies on several favorable environmental conditions, including temperature, salinity, oxygen, and the availability of food. Symbiotic corals require very clear water for their zooxanthellae to perform photosynthesis. Although some corals can flourish in very turbid conditions, such as in bays, it is known that too much sedimentation can negatively impact their growth. Coral polyps feed on other living organisms, which also have to find food.

Offshore waters, where barrier reefs develop, are generally clear and nutrient poor. However, some episodic enrichments can happen, such as nutrient inputs or upwelling, and this can trigger phytoplankton blooms. Hence, the construction of barrier reefs requires healthy corals, which, in turn, depend on the balanced alchemy of different sea-water components.

Satellite images show that the ocean is not always blue. Although a human eye would not be able to see it, the sensitivity of satellite sensors is such that even the slightest color variation is rapidly detected. Non-stationary satellites can scan and "see", in one go, a substantial breadth of field that spans hundreds or thousands of kilometers with a resolution of 10 to 250 m (camera with a sweep system image sensor at a distance of 700 km).

Because each of the water components (chlorophyll, turbidity, and dissolved organic matter) has a specific color, the concentration of each of them can be estimated. Using this method, it is possible to distinguish between the different inputs of minerals originating from different catchment areas (large particles with high sedimentary rate such as sand grains, or in contrast, thin laterites), and the green and chlorophyll-rich phytoplankton, or the part that is dissolved. The latter, which strongly absorbs UV light, acts as a solar umbrella for tropical corals. Its presence can also be associated with pollutants (such as pesticides) or metals, which are present at a low concentration in the lagoon. Ocean-color satellite data therefore allow for the description and understanding of the environmental dynamics of lagoons and coral reefs (i.e., the levels of turbidity, dissolved matter, and chlorophyll).

The impact of rain on chlorophyll and turbidity

During heavy tropical storms or after prolonged rainfall, the chlorophyll observed by satellites (i.e., the quantity of phytoplankton) is three-fold in lagoons (DUPOUY *et al.*, 2010). This effect is visible up to 50 km offshore (Fig. 1, A and B) and the increase correlates with oceanographic data. With a 3D coupled hydrodynamic-biogeochemical model which integrates the lagoon-ocean interface, it is possible to model the chlorophyll increase inside reef passes and the model can then be validated using MODIS satellite images of chlorophyll in the lagoons (FUCHS *et al.*, 2013).

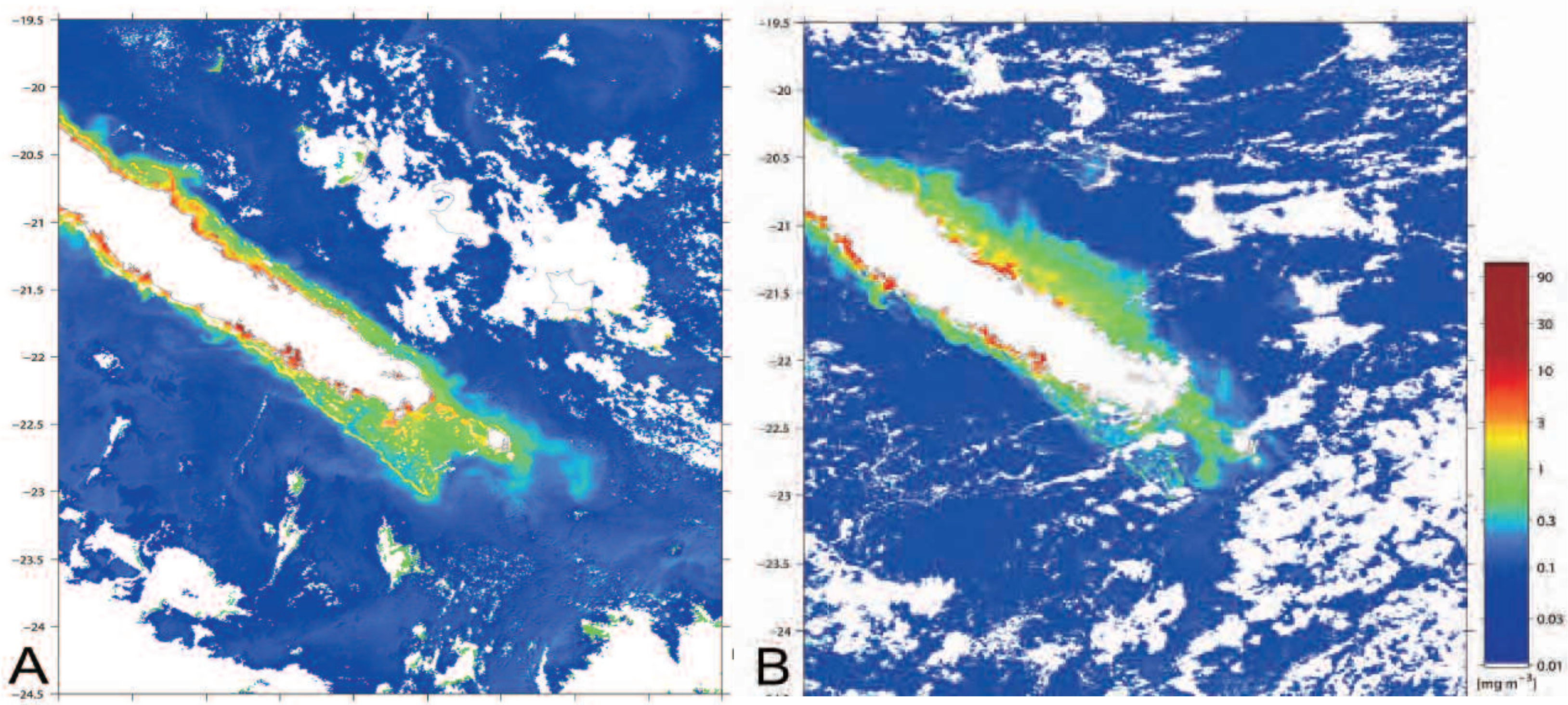

Figure 1: A and B: MODIS images of chlorophyll (mg.m-3) before and after heavy rainfall in March 2008. © H. Murakami

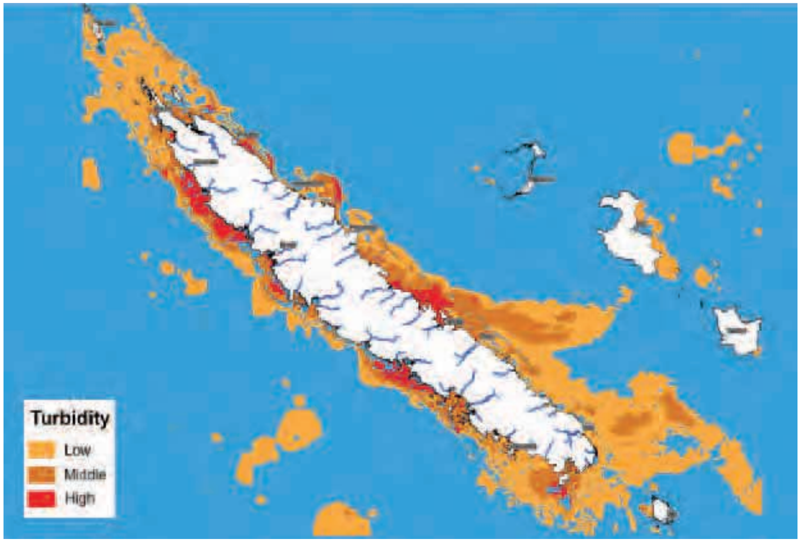

Figure 2: Turbidity (modelled) after the tropical storm Finna in December 2011. © Bluecham SAS

When the lagoon is deeper than 20 m, the water turbidity can be measured using remote sensing and the results are validated using *in situ* measurements. The turbidity plumes that are detected on MODIS images allow the impacts of catchment areas to be estimated. These plumes develop according to the local oceanographic circulation. The east coast is the most often impacted because of the frequency and intensity of rainfall, and the presence of a large ultrabasic and lateritic massif in the south (Fig. 2).

In the Southwestern Lagoon, satellite images indicate a lower chlorophyll concentration in waters surrounding barrier reefs than along the coast demonstrating that the water is clearer around coral reefs. Figure 3 shows the evolution of chlorophyll over time at three sites: an oceanic site offshore from the Dumbéa Pass (OC1), a site in the middle of the lagoon (M33), and one in a bay (Dumbéa Bay, GD10) (Fig. 3A). During spring, the chlorophyll peak appears later outside of the barrier reef (OC1) than in the middle of the lagoon (MD33) or in the bay (GD10) (Fig. 3B). However, in cases of upwelling, offshore waters can sometimes be richer than those inside the lagoon (NEVEUX *et al.*, 2010).

When water is shallow, the color of the bottom substantially influences the satellite signal. The objective is then to detect which part of the effect is due to bathymetry, and which part is due to the color of the bottom (MINGHELLI-ROMAN and DUPOUY, 2014). In these cases, the sea water components are only accessible using more complex calculations (MURAKAMI and DUPOUY, 2013; WATTELEZ *et al.*, 2016, 2017) such as in the Southwestern Lagoon near Nouméa, or near backreefs and shoals (Fig. 3A).

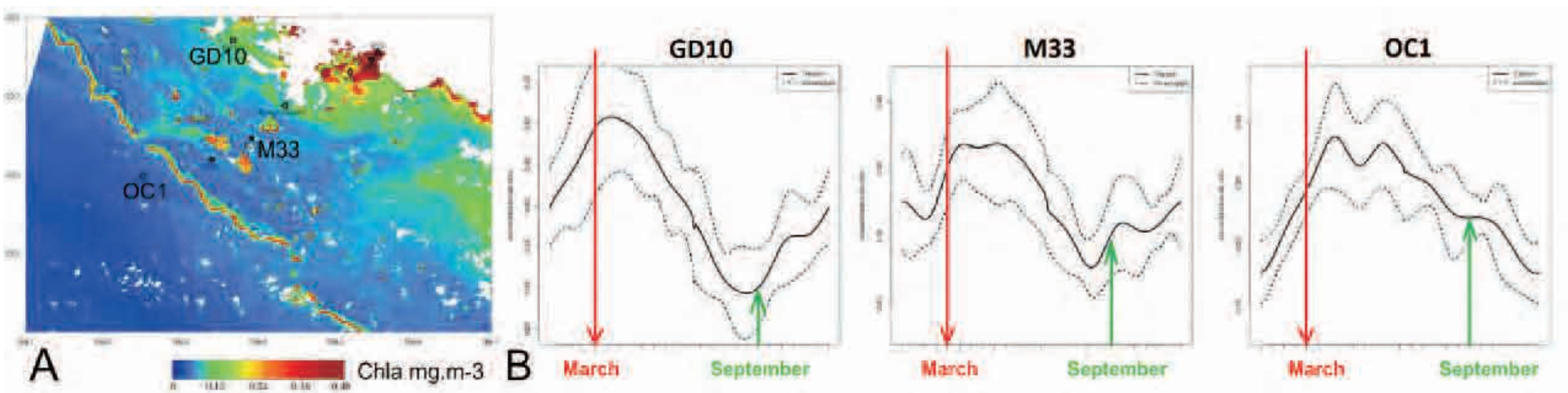

Figure 3: Chlorophyll in the lagoon of Nouméa. A: Chlorophyll estimated from a high-resolution AVNIR image (20 m), after bottom reflexion has been corrected. Adapted from MURAKAMI and DUPOUY, 2013. B: Chlorophyll seasonnal cycle at various sites (oceanic OC1, lagoon M33 and coastal GD10). Adapted from DUPOUY *et al.*, 2011.

Trichodesmium cyanobacterial blooms

The filamentous *Trichodesmium* cyanobacteria accounts for a large part of the chlorophyll offshore and inside lagoons (DUPOUY *et al.*, 2011). These blooms can be observed for over thousands of kilometers off New Caledonia and can drift into the lagoons through the reef passes. Very often, they are visible on satellite images and they aggregate in lines parallel to the barrier reef (Fig. 4). Superficial rafts can be detected using a near infra-red signal and anomalies in reflectance (DUPOUY *et al.*, 2011).

Colored dissolved organic matter

In the lagoons, the quantity of colored dissolved organic matter (CDOM), that protects corals from high UV, is often linked to river inputs, which are abundant on the east coast of New Caledonia. This terrestrial organic matter is transported over long distances to the lagoon, depending on river discharge. CDOM can be combined with metal elements and is therefore a very useful indicator when monitoring coral reef ecosystems as it can be detected using satellite images. Tryptophan, which is also part of the dissolved matter, is produced by coral reefs (MARTIAS *et al.*, 2018), but can only be measured using spectro-fluorescence, an optical analysis.

Chlorophyll and turbidity maps, which are compiled from satellite data, can be produced continuously and, in the future, will be produced in almost real-time. They provide information on sea-water composition, allowing for the detailed and relatively inexpensive characterization of water quality around coral reefs and they show the extension of chlorophyll and turbidity plumes. The analysis of satellite image series since 1998 has traced and quantified the impact of climatic events (seasonal, El Niño, etc.) on lagoon and reef environments.

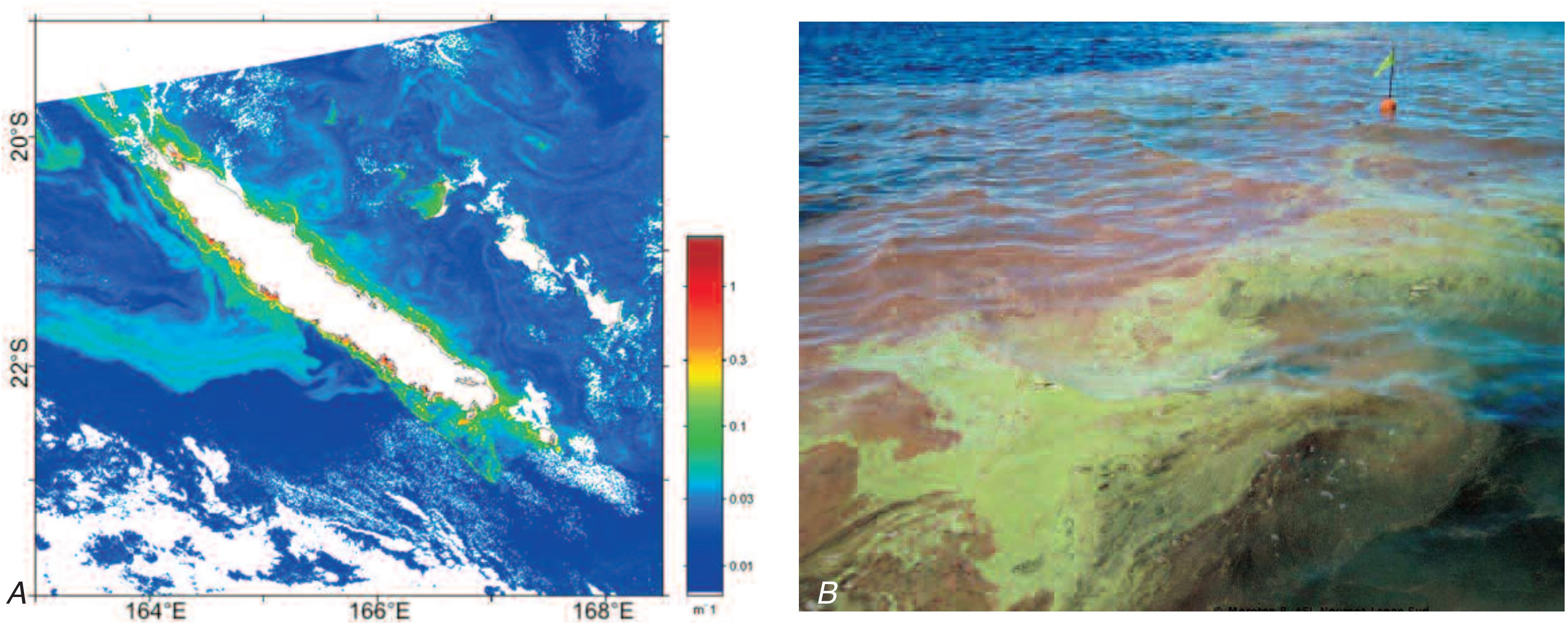

Figure 4: Blooms of the cyanobacteria *Trichodesmium*. A: Blooms around New Caledonia in summer with calm weather (February 2010, MODIS image).
B: A pink coloration of the water is frequently observed near barrier reefs (Prony Bay). © A. E. L. /B. Moreton

Atolls of Ouvéa (center) and Beautemps-Beaupré (top). © (2000, Landsat 7 image)

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