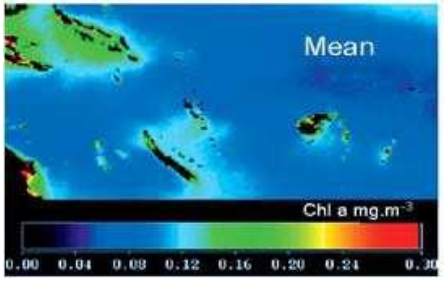
# *Trichodesmium* detection from space and ecological role in the ocean: A review of the state of science, challenges and ways forward

- **Key Questions**

- 1) Optical characteristics (colonies, slicks) of *Trichodesmium*
- 2) Remote sensing detection tools (optical, radar)
- 3) Modeling help for a global assessment
- 
- **14:15 – 14:25:** Introduction/session overview - biogeochemical significance (*Cécile Dupouy, Ajit Subramaniam, Lachlan McKinna)*
- **14:25 – 14:45:** Bio-geochemical modelling with regard to *Trichodesmium* **(***Stephanie*
- *Dutkiewicz***)**
- **14:45 – 14:55:** *Trichodesmium* abundance in the global open and coastal ocean (*Sara Rivero-Calle***)**
- **14:55 – 15:25:** Moderated community discussion (30 min) (*Ajit Subramaniam)*
- **15:25 – 15:45:** Break (20 min)
- 
- **15:45 – 15:55:** IOPs/AOPs- historical overview where we are/state of the art with regard to *Trichodesmium* and limitations/missing measurements or instruments (*Cécile Dupouy, Lachlan McKinna*)
- **15:55 – 16:05:** Passive remote sensing - surface expression of *Trichodesmium*, state-of-the- art and limitations/future work (*Lachlan McKinna*)
- **16:05 – 16:15:** Freshwater Cyanobacterial blooms remote sensing (10 min) – State of science, challenge, methods (*Prof. Ronghua Ma*)
- **16:15 – 16:25:** Hyperspectral Atmospheric Corrections above surface algal blooms (10 min)
- *(Amir Ibrahim)*
- **16:25 – 17:00:** Moderated community discussion of gaps and formulation of recommendations (35 min) (*Lachlan McKinna, Ajit Subramaniam, Cécile Dupouy*)




# Algorithm validation for *Trichodesmium* Strengths and Weaknesses IOP/AOPs

Cécile DUPOUY

**Aix-Marseille University, Toulon Univ. CNRS/IRD, Mediterranean Institute of Oceanography, Marseille**
**Centre IRD de Noumea, New Caledonia**

# Presentation plan

- **I- What's new in the South Tropical Pacific ? Bloom presentation**

- **II- Validation problems for *Trichodesmium***

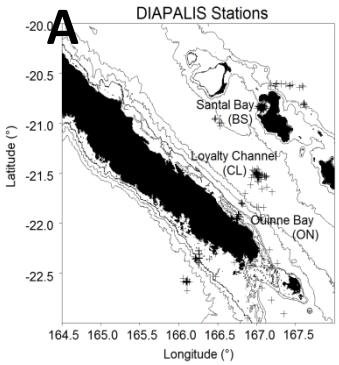
  - ✓ **Spatial heterogeneity**
  - ✓ **Temporal validation problems: hourly change in vertical distribution etc... bloom temporal evolution...**
  - ✓ **Biomass estimates**

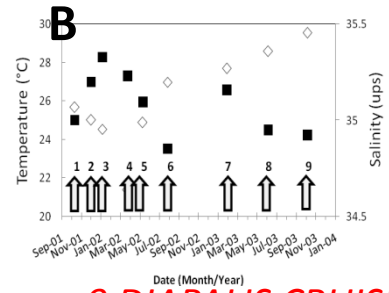
- **III- IOP/AOPs: Spectral validation problems: channel number vs hyperspectral etc…Optical signatures during the 45 days Outpace cruise Noumea-Tahiti**

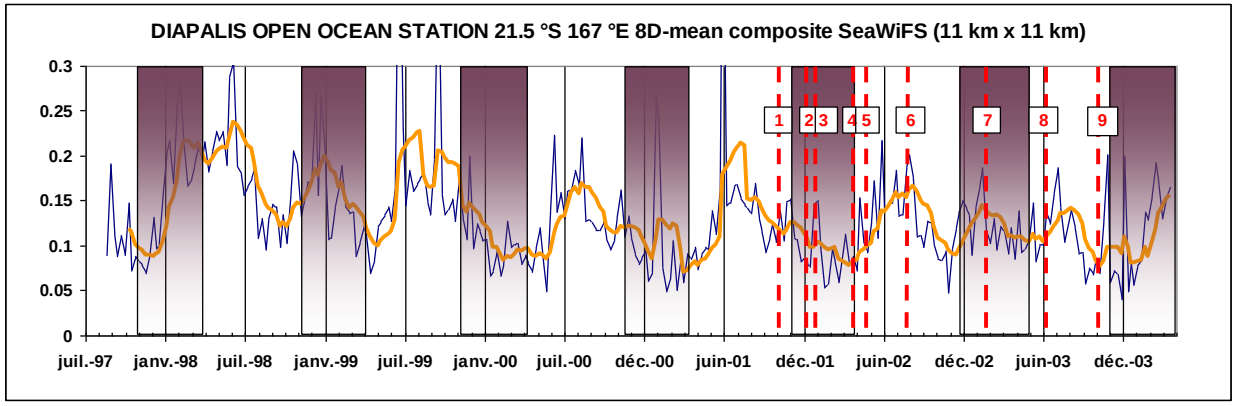
- **IV- Innovation: new Observation systems…need your help!**

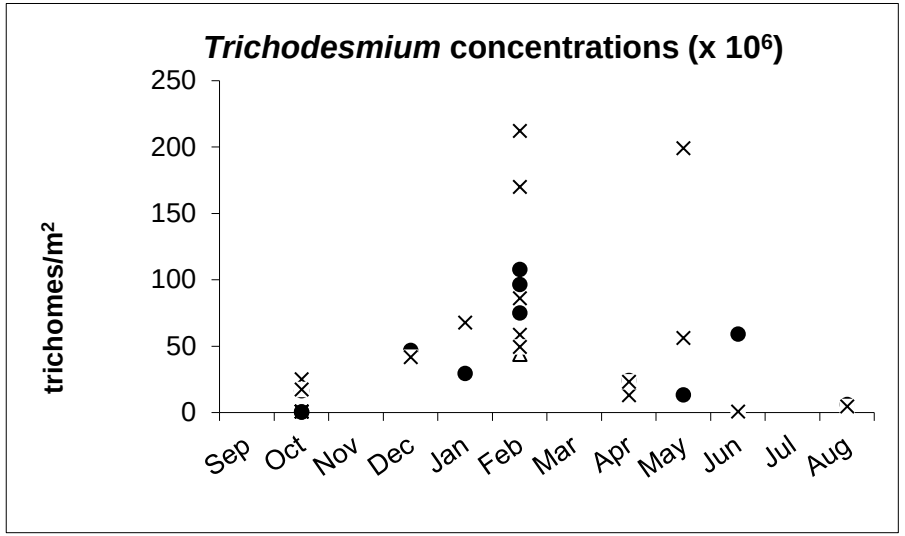
# Presentation plan

- **I- What's new in the South Tropical Pacific ? Bloom presentation**
- ✓
- ✓
- ✓
- 
- 



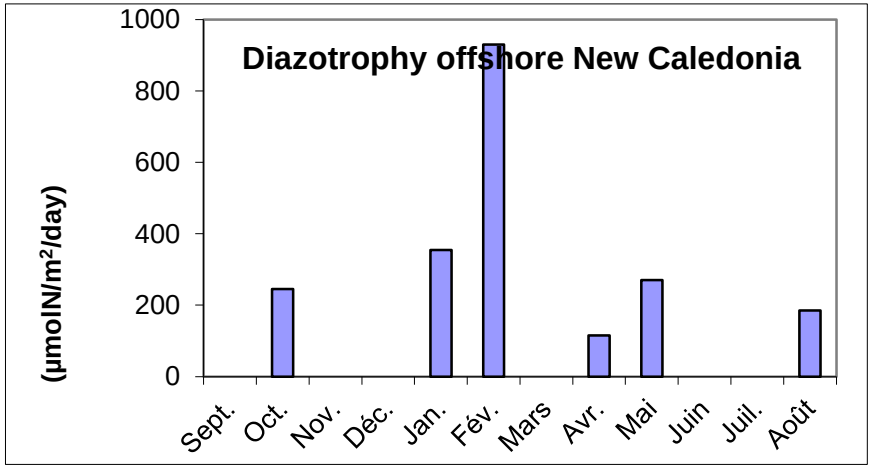

- *9 DIAPALIS CRUISES AROUND NEW CALEDONIA 2001-2003*

Abundance and environment data in:

***Tenorio, Dupouy, Rodier, Neveux et al in revision***

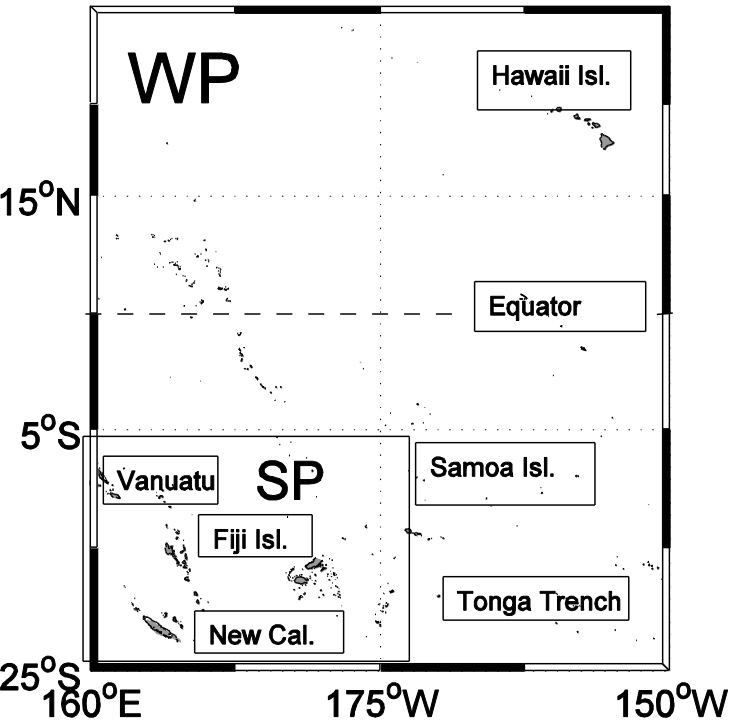
Nitrogen fixation data in:

***Garcia et al., 2007***



# Figure 1

a

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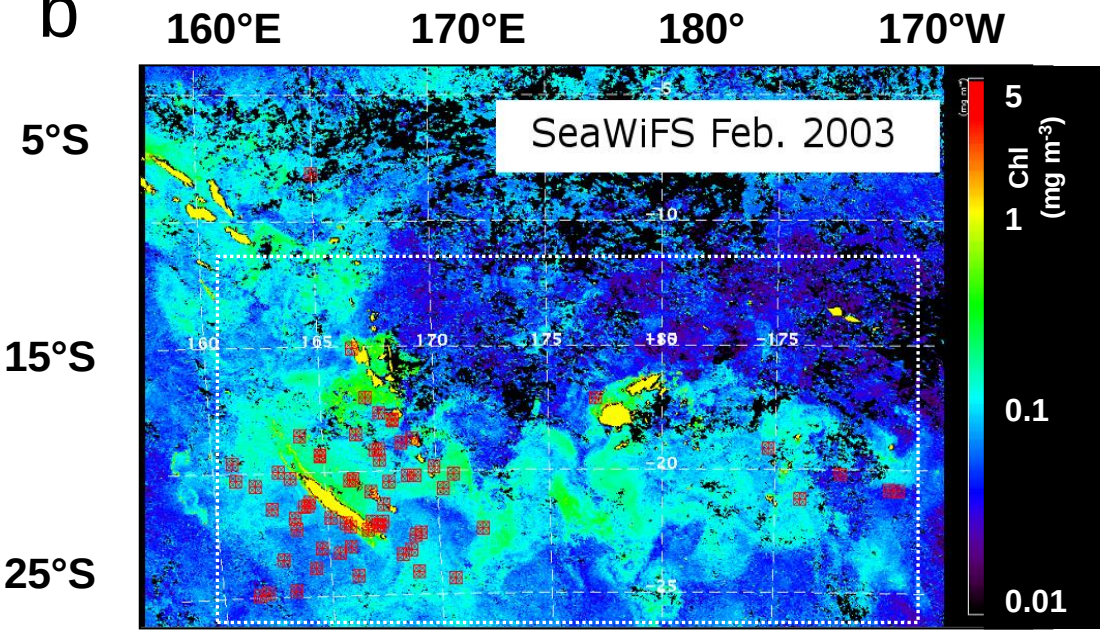


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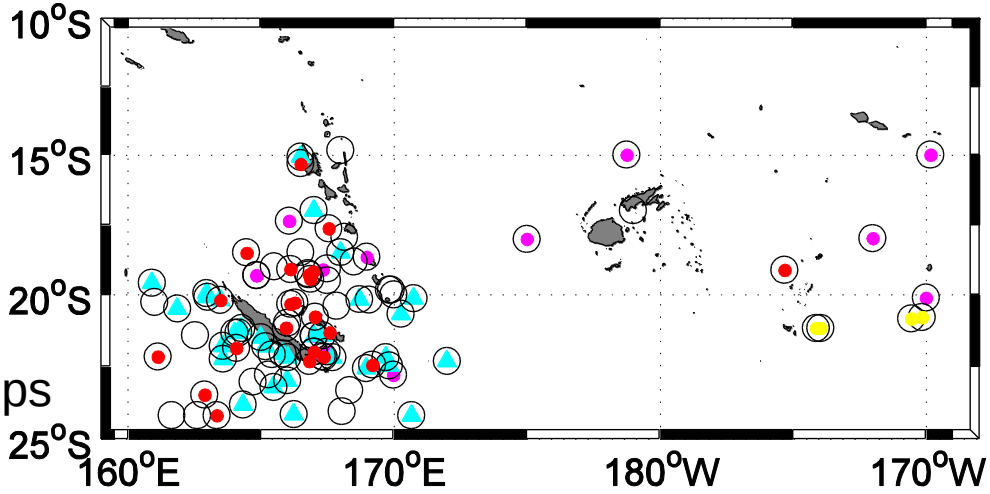



98 observations from planes and ships

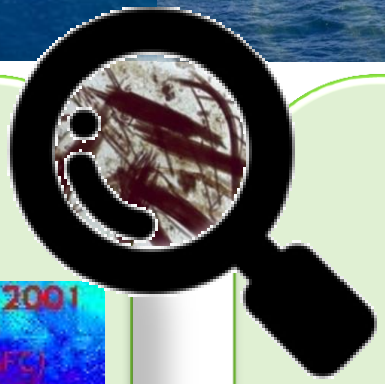
*T. Erythraeum*

*Katagnymene*

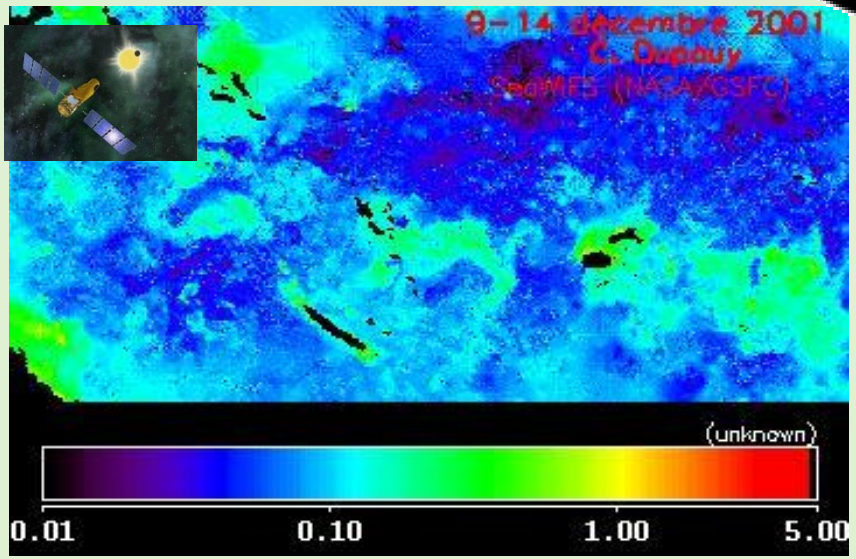
*T. Thiebautii*

***in Dupouy et a., 2011, Biogeosciences***

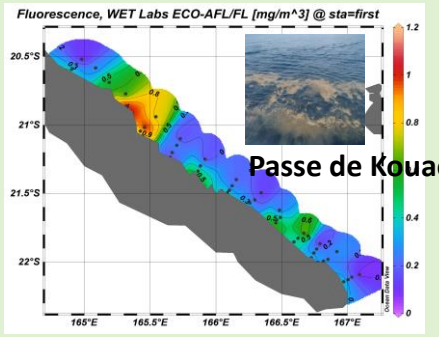
# *Trichodesmium*

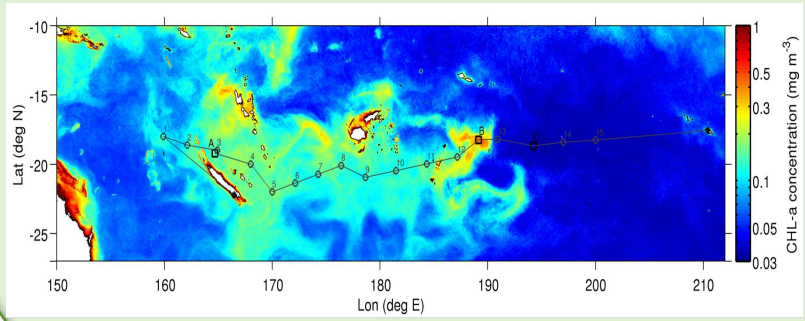
Satellite Seawifs map in December 2001 of *Trichodesmium* blooms in the SWTP around Nouvelle-Calédonie, Vanuatu, Iles Salomon, Iles Fidji, Tonga, Niue, Cook Isl. (C. Dupouy)



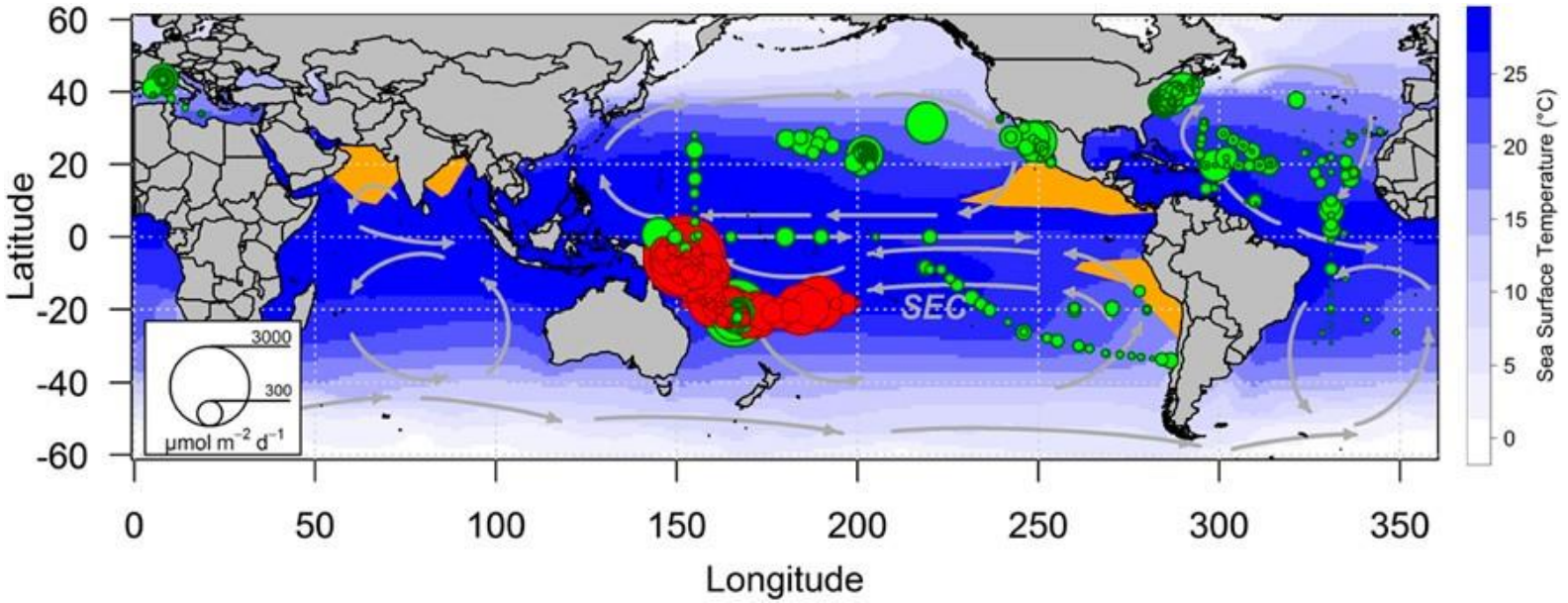

CALIOPE 03 (C. Martias, C. Dupouy)




ANR OUTPACE cruise (T. Moutin/S. Bonnet)



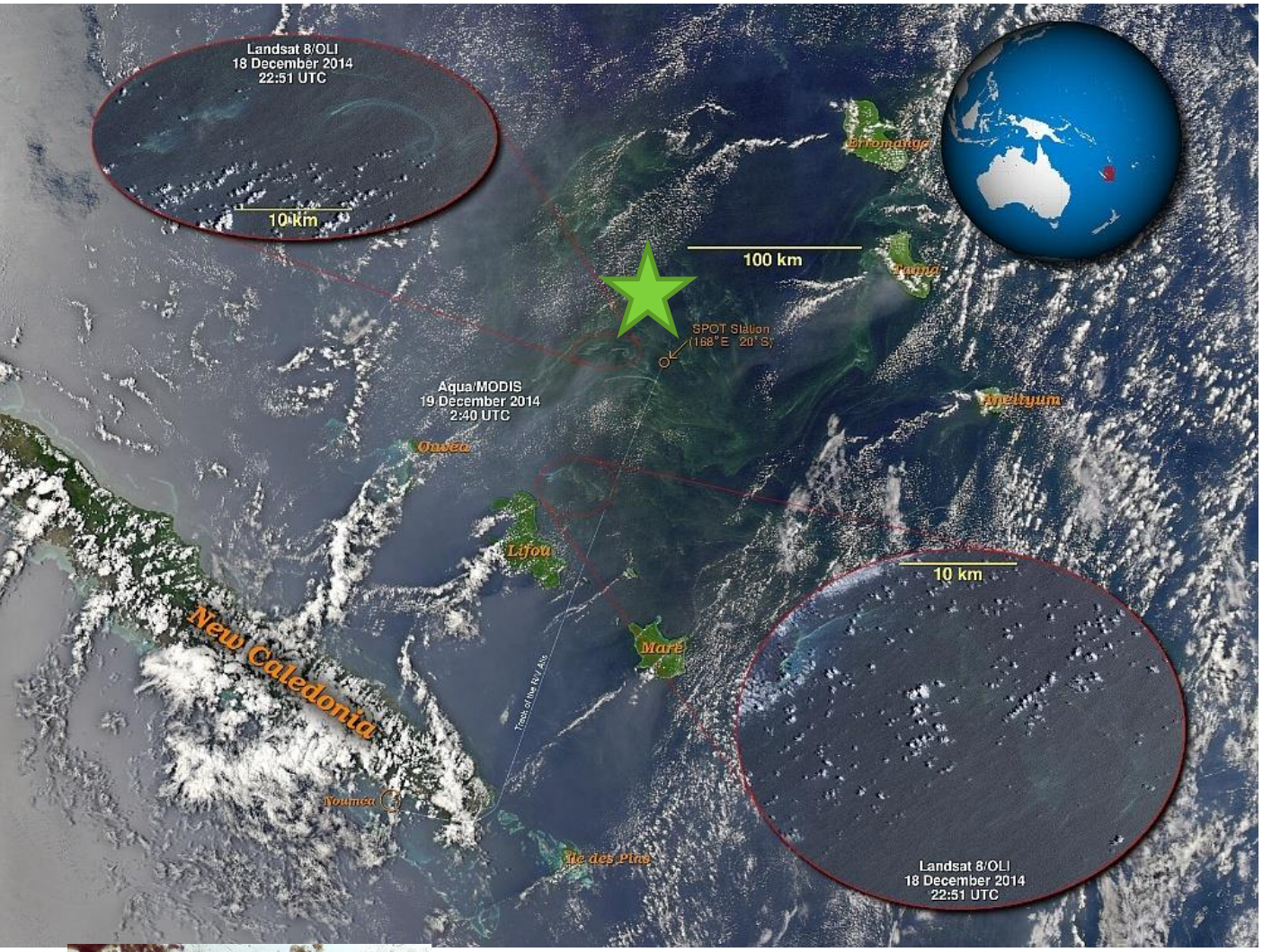
# Nitrogen fixation Hot Spot (PNAS letter)




- : Fig. 1. N2 fixation in the world's oceans quantified using 15N2 incubation-based measurements. Green dots: integrated N2 fixation rates (in micromoles of nitrogen per square meter per day) from the MAREDAT database (4) and Knapp et al. (2). Red dots: N2 fixation rates quantified at 57 stations (WTSP) including data from Bonnet et al. (2015), DOI 10.1002/2015GB005117, using either the 15N2 bubble addition method or the enriched seawater method (10). To ensure accurate rate calculations, the 15N/14N ratio of the N2 pool in the incubation bottles was systematically measured. Discrete rate measurements were depth integrated over the photic layer using trapezoidal integration. Gray arrows: main surface currents. SEC: South Equatorial Current. Orange shaded areas: main OMZs.

- ***Bonnet et al., 2017***

# Seasaw dust: Melanesian *Trichodesmium* 19 decembre 2014 **Dupouy et al., 2014**



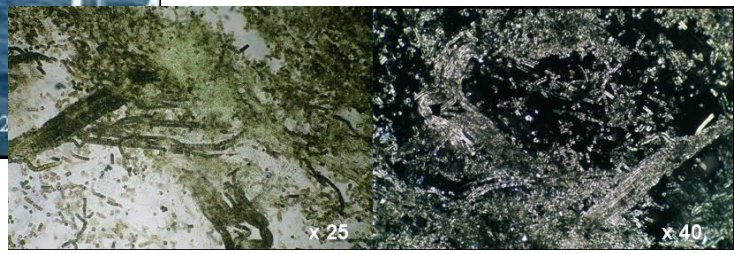

http://oceancolor.gsfc.nasa.gov/MODIS/HTML/MelanesianTricho

Courtesy N. Kuring

http://earthobservatory.nasa.gov/IOTD/view.php?id=85073

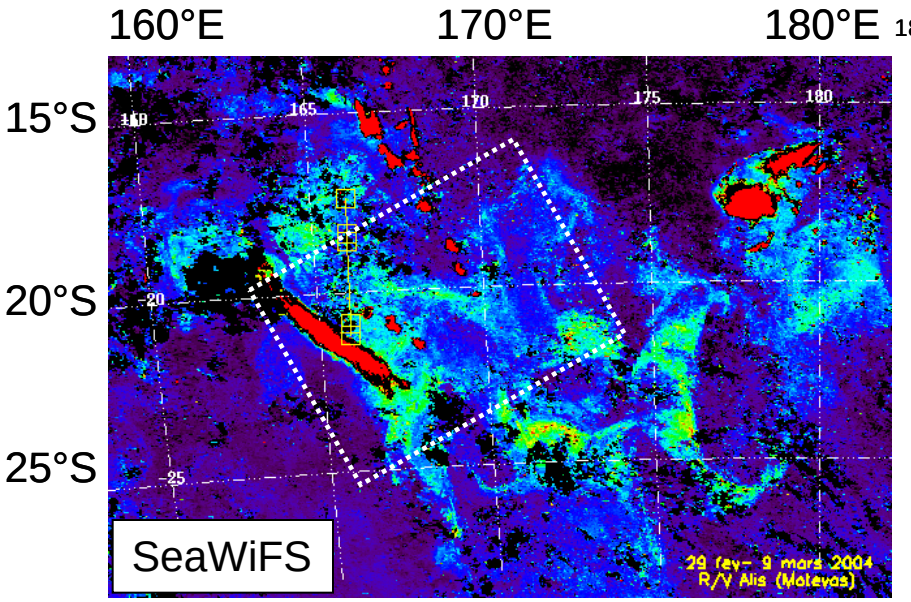
# - Mise en évidence des blooms de *Trichodesmium* dans le PTSO

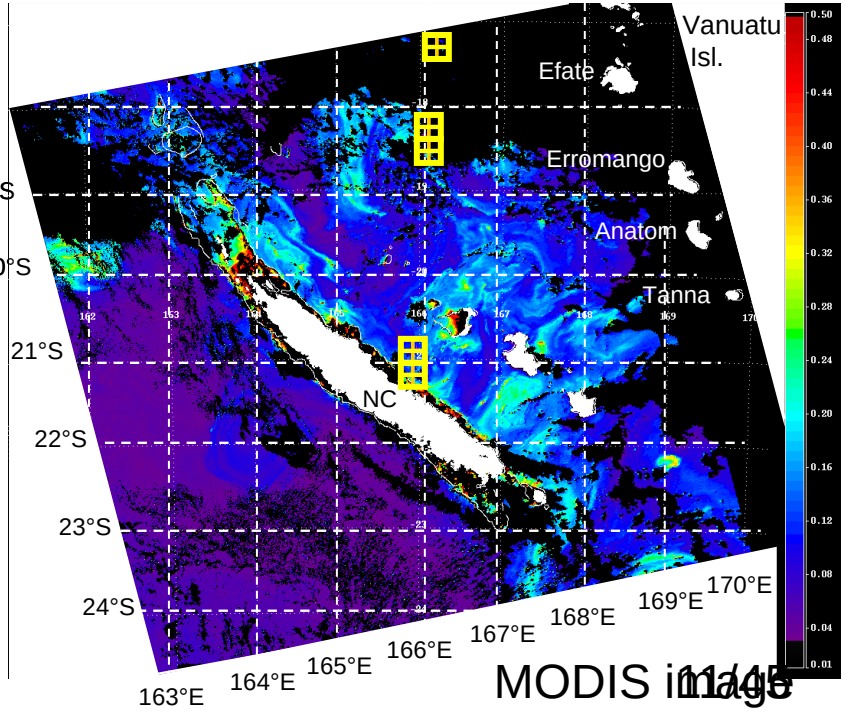

**Mission PIL *Alis. Crédit photographique Hervé Le Houarno***




***In Dupouy et al., 2004, IRD Report, New Caledonia***

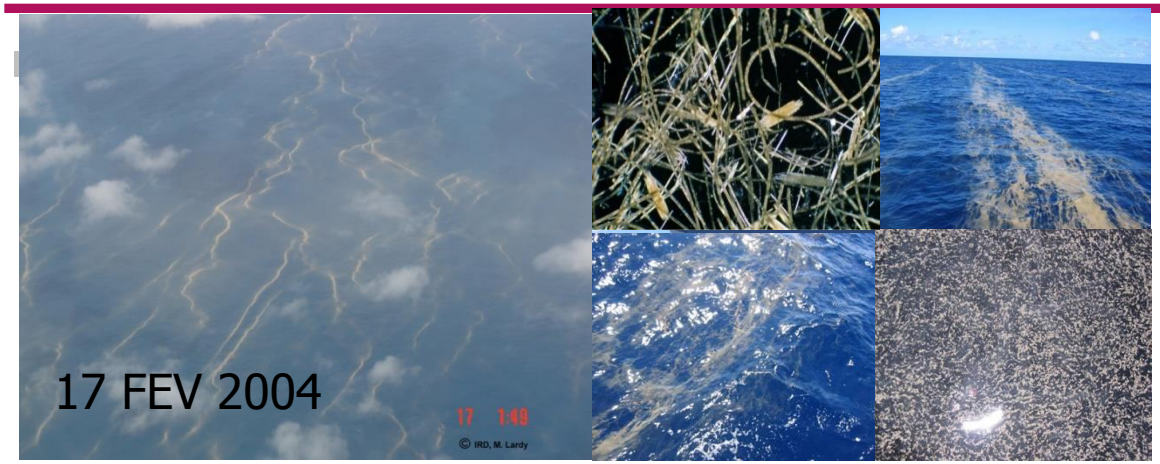
# The general problem is also illustrated here…


***Dupouy et al., 2011, Biogeosciences***

# A fractal problem : surface scums how to quantify ?





**POSTER IOCS 2017**

**Rousset et al., 2017**

**Detection of Trichodesmium mats with MODIS**

# Programme SPOT 20°S-168°E; 4000m

## (South Pacific Ocean Time Series)

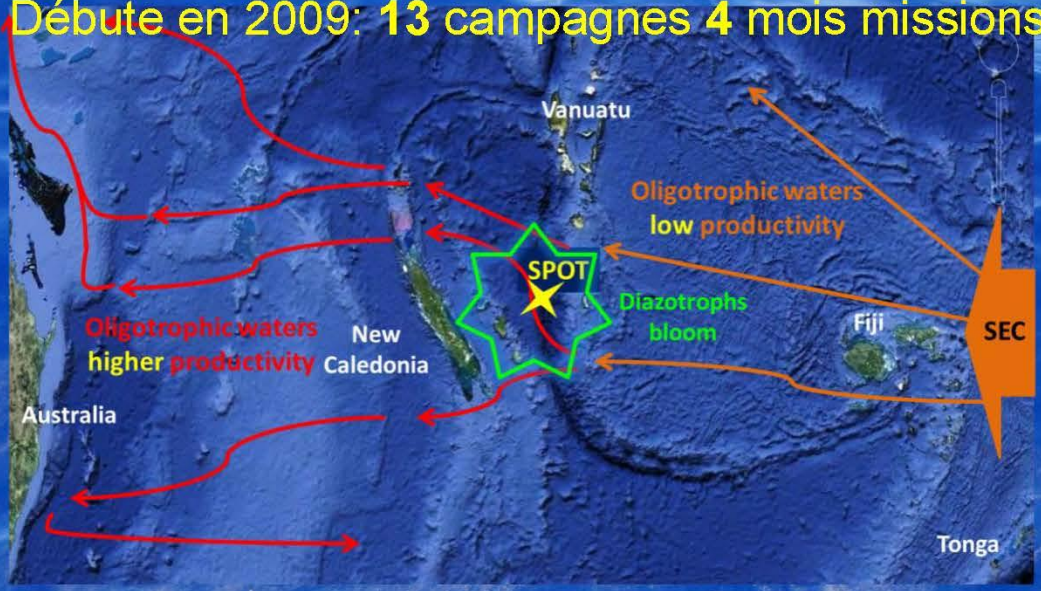
UBC, Scripps, NASA

PI MEB

Co-PI Chimie

Co-PI Physique

Débute en 2009: **13** campagnes **4** mois missions




### Objectifs 2012-16

- Fonctionnement **saisonnier interannuel** de l'écosystème
- Quel rôle **cyanobactéries diazotrophes** dans la **productivité** ?

### Méthodes

**Multidisciplinaire**

Physique, Chimie, Bacterioplancton, Phytoplancton, Zooplancton


### Financements

FISHBOX: 568 k€
IRD: 56 k€
CNFH: 4 k€

### Résultats

**40** communications, **23** innovations en BM

**8** articles :1 en rev, 6 in prep.

**1** Post-doc, **2** PhD, **5** IE et AI, **4** Masters (Fidji)

**2** observateurs/collaborateurs

Une recherche océanographique pour un **développement local** et **régional**

Ouvéa

Vanuatu

Université Nouvelle Calédonie (prévue)

Projet **SPOT-OUVEA**

**productivité tombants UNESCO-2008 & pêcheries** locales

*Biegala et al., 2014, ASLO, Hawaii*

# Presentation plan

## II- Validation problems for *Trichodesmium*

- ✓ **Spatial heterogeneity**
- ✓ **Temporal validation problems: hourly change in vertical distribution etc... bloom temporal evolution...**
- ✓ **Biomass estimates**

# Spatial heterogeneity

Spatial validation problems (pixel, subpixel ? pixel average), surface scums (vertical distribution) etc..., spatial patchiness, sampling problems, floating behaviour...

***"In situ observations… Also I think it is essential that they*** *present information on how big features is – we have no way of telling whether a slick reported was 1m wide, 1 km, 10km or how long."*
*Ajit Subramaniam*

*Maximum width observed in km 7.63, 6.6 km & 2.2 km. A thick patch at 1.43N, 72.93 E (16 km)*
*Elgar Desa, IJRS, 2005*

*We have to deal with the fact that Tricho is probably the most unevenly distributed phytoplankton there is! if it is calm, it might be highly concentrated in surface waters. if it is completely mixed, it is unlikely to be uniquely identifiable!*
*Ajit S*

# Patchiness (2)


***Tenorio, 2006***

Confined accumulations in "slicks" with a few kms extension and a few meters large concentrations show vertical low thickness of these accumulations. The 25 october 2002 **Chl*a* < x 366 higher at 1m** and 7 m depth than in the slick and the Chl*c*1+2/Chl*a* = 0 in surface increased towards the bottom (as cyanobacteria do not have accessory chlorophylls).
On the 29th October, there was a decrease of a factor of 4 between the « slick » and 3 meters deep.

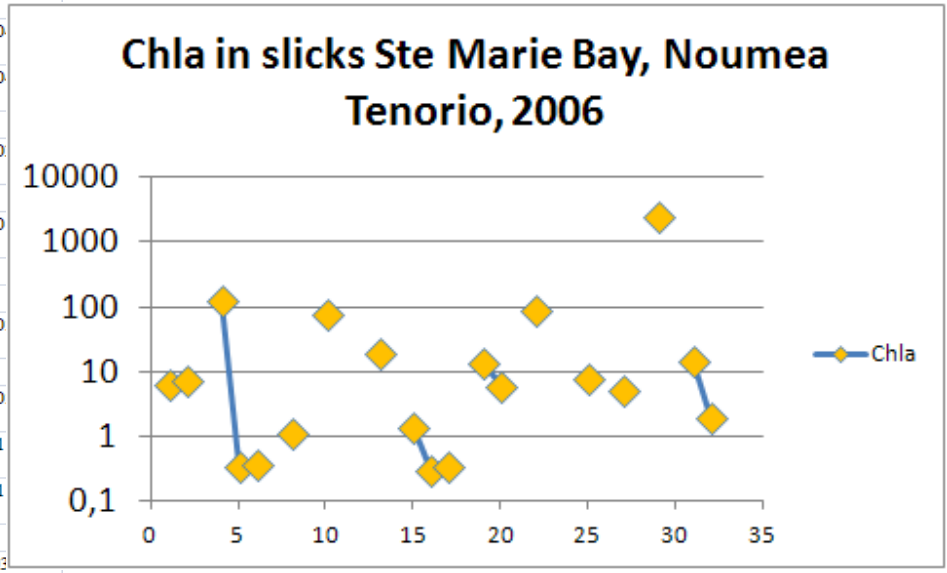
Horizontal distribution also shows abrupt decrease of Chl (a factor of 7) on the 27/12/2002 inside and outside the "slick" Increase of the Chl*b*/Chl*a* and Chl*c*1+2/Chl*a* indicate picoeucaryotic biomass outside the slick

**Figure IV.25-A** : Accumulations of *Trichodesmium erythraeum* Lagoon New Caledonia South West in *Tenorio 2006*

# Weekly Biomass measurements in slicks (*Tenorio, 2006*)

| Local | Date | Heure | Filtration | Profondeur (m) | Chl*a* | Chl*b* /Chl*a* | Chl*c* 1-2/Chl *a* |
|---|---|---|---|---|---|---|---|
| Baie de Sainte Marie | 23/10/2002 | 10h | Totale | "Slick" | 6,86 | 0,000* | 0,011* |
| SP3 | 23/10/2002 | 10h | Totale | "Slick" | 7,94 | 0,000* | 0,005* |
| | | | | | | | |
| Baie de Sainte Marie | 25/10/2002 | 10h | Totale | "Slick" | 131,14 | 0,000* | 0,001* |
| Baie de Sainte Marie | 25/10/2002 | 10h | Totale | 1 | 0,36 | 0,042 | 0,0 |
| Baie de Sainte Marie | 25/10/2002 | 10h | Totale | 7 | 0,38 | 0,042 | 0,0 |
| | | | | | | | |
| Baie de Sainte Marie | 28/10/2002 | 10h | Totale | 0 | 1,17 | 0,008* | 0,0 |
| | | | %Chl*a* | | | | |
| Baie de Sainte Marie | 28/10/2002 | 10h | | 0 | 80 | 0,000* | 0,0 |
| | | | >10µm | | | | |
| | | | %Chl*a* | | | | |
| Baie de Sainte Marie | 28/10/2002 | 10h | | 0 | 20 | 0,062 | 0,0 |
| | | | | | | | |
| Baie de Sainte Marie | 29/10/2002 | 12h | Totale | 0 | 1,46 | 0,022* | 0,0 |
| Baie de Sainte Marie | 29/10/2002 | 12h | Totale | 3 | 0,32 | 0,09 | 0,1 |
| Baie de Sainte Marie | 29/10/2002 | 12h | Totale | 14 | 0,36 | 0,092 | 0,1 |
| | | | | | | | |
| Baie de Sainte Marie | 07/12/2002 | 10h | Totale | "Slick" | 13,97 | 0,000* | 0,003 |
| Baie de Sainte Marie | 07/12/2002 | 12h | Totale | "Slick" | 6,31 | 0,012* | 0,049 |
| | | | %Chl*a* | | | | |
| Baie de Sainte Marie | 07/12/2002 | 12h | | "Slick" | 92,03 | 0,005* | 0,058 |
| | | | >10µm | | | | |
| | | | %Chl*a* | | | | |
| Baie de Sainte Marie | 07/12/2002 | 12h | | "Slick" | 7,97 | 0,054 | 0,087 |
| | | | | | | | |
| Baie de Sainte Marie | 07/12/2002 | 23h | Totale | "Slick" | 5,51 | 0,000* | 0,010* |
| | | | | | | | |
| Baie de Boulari | 13/12/2002 | 13h | Totale | "Slick" | 2608 | 0,000* | 0,003* |
| | | | | | | | |
| Baie de Sainte Marie | 27/12/2002 | 12h | Totale | "Slick" | 14,85 | 0,000* | 0,014 |
| Baie de Sainte Marie | 27/12/2002 | 12h | Totale | Hors "Slick" | 2,01 | 0,017* | 0,177 |

in mg.m$^{-3}$



# Short-term Temporal evolution

- *Hu and Fen, 2014 IEEE letter (GOES : South Florida):*
- Despite the low-signal-to-noise ratio (*~46 : 1* for typical ocean radiance), the 550–750-nm band revealed clear patterns of *Trichodesmium* mats floating on the ocean surface and their temporal changes between 14:15 and 22:30 GMT on May 22, 2004. The area coverage increased by about **eightfold** from midmorning (14–15 GMT) to reach its maximum around 18:30 GMT, whereas the mean intensity of the bloom area increased by *~22% from mid morning to 17:30 GMT.* In the afternoon, while the bloom area remained relatively stable on the water surface, bloom intensity sharply decreased.

- *L. M.* These temporal patterns may be caused by physical aggregation and/or vertical migration of the *Trichodesmium* cells…

- *A.S.* : How much variability is there within a single pixel between when a in situ sample is collected and when the satellite passes over. The dynamics of a surface bloom - how far do they move, how fast due to physical forcing i.e. wind, current, tide ?

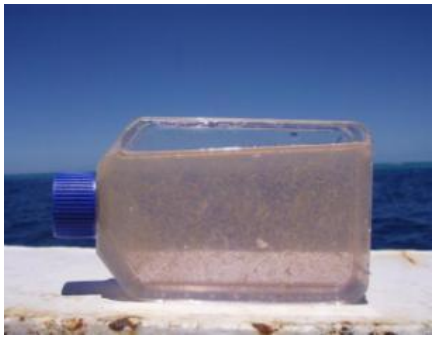
# Biomass estimates caveats

- *A. S.* There are a host of factors that make validating Tricho algorithms :
- - validating by units of chlorophyll ?
- - cell (colony) counts? If you are using chlorophyll, the question is how do you measure tricho specific chlorophyll in a water sample? If you are using cell counts, how do you account for the varying sizes of colonies? Also what about self shading?
- - do you filter by size to catch colonies - if so how about other large cells such as diatoms or the fact that you might be missing trichomes that don't form colonies.

- - 50 µm mesh size nets dragged with a ship ’s speed of 2 knots and continuously obtained from horizons of 25, 20 m, 15 m, and 5 m, respectively (?)

# Pigment concentrations : PE

- *Mc Kinna* Challenges with
- sampling Tricho for validation
- match-up purposes.
- Validation and bio-optics:



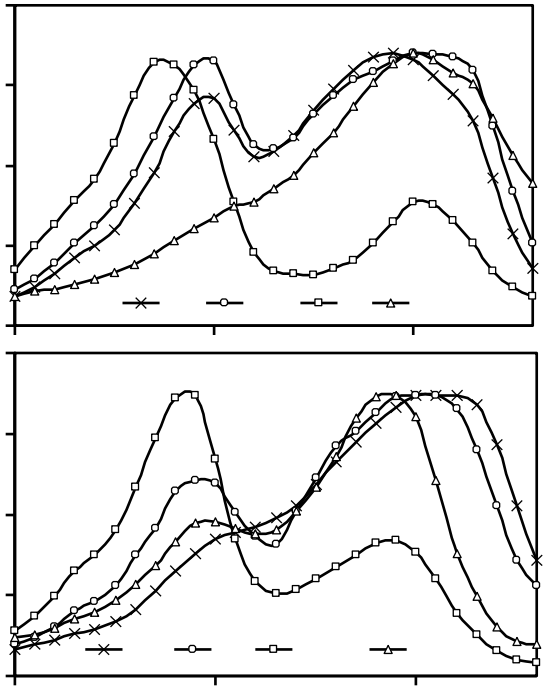
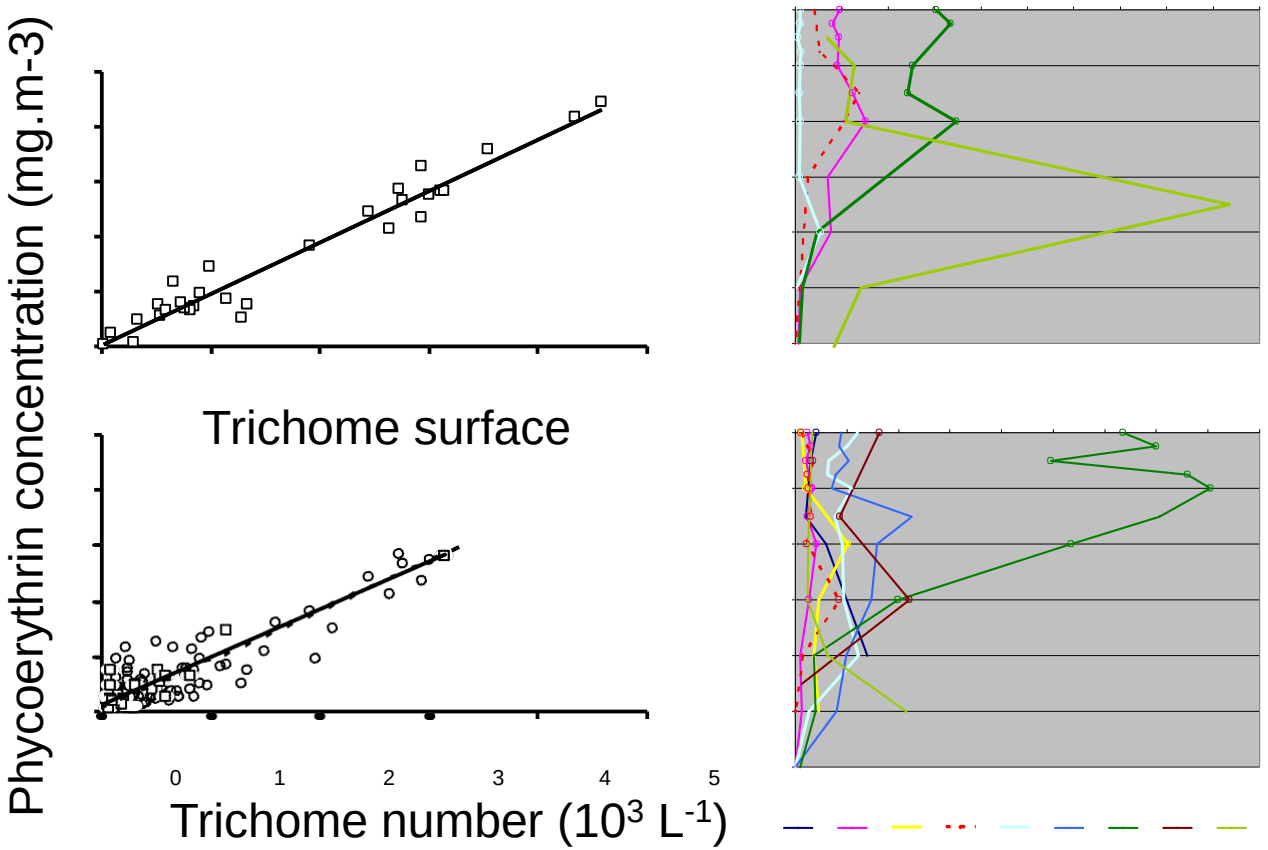


**Figure 1.** Corrected-fluorescence excitation spectra of phycoerythrins (phosphate buffer: 0.1 mol L-1 NaH2PO4; pH = 6.5) in various filamentous cyanobacteria and *Synechococcus* (A) *Trichodesmium thiebautii* (T. th.), *Trichodesmium erythraeum*, (T. e.), *Richelia intracellularis* (R.) and green colonies (G.); (B) High-PUB (HPUB) and High-PEB (HPEB) *Synechococcus*, *Katagnymene spiralis* (K.) and unidentified filament (Un.). Spectra are normalized at the fluorescence excitation maximum.

***In Neveux et al., 2006***

# Relationship between PE and trichome counts




- T*richodesmium* counts dataset:
  - ✓ MAREDAT : trichomes + nifH copies, chla
  - ✓ Other cruises: DIAPALIS: trichome, $chla_{f>10\mu m}$
    - PANDORA: nifH copies, chla

# Recommandations Biomass estimates (2)

- *L. Mc*. Perhaps encourage the community to routinely sample accessory
- phycobilin pigments !

- *A.S.:* Phycoerythrin algorithms will need more spectral resolution that we have in any sensor right now but is a hope for the future.

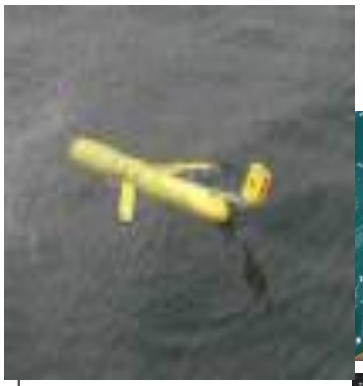
- *Dupouy, Tenorio, Neveux:*
- Determine all biomass parameters in at least a 8L volume
- Spectrofluorometry (cheap!). Nets do not provide quantitative measurements ! PE < and > 10 µm fractions

# Presentation plan

- 
- 
  - ✓
  - ✓
  - ✓
- **IOP/AOPs: Spectral validation problems: channel number vs hyperspectral etc…Optical signatures**
- 

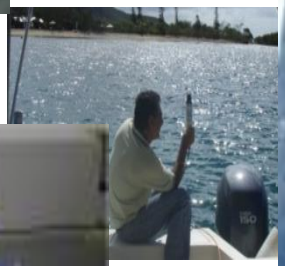
# Pbs and solution Optical signature

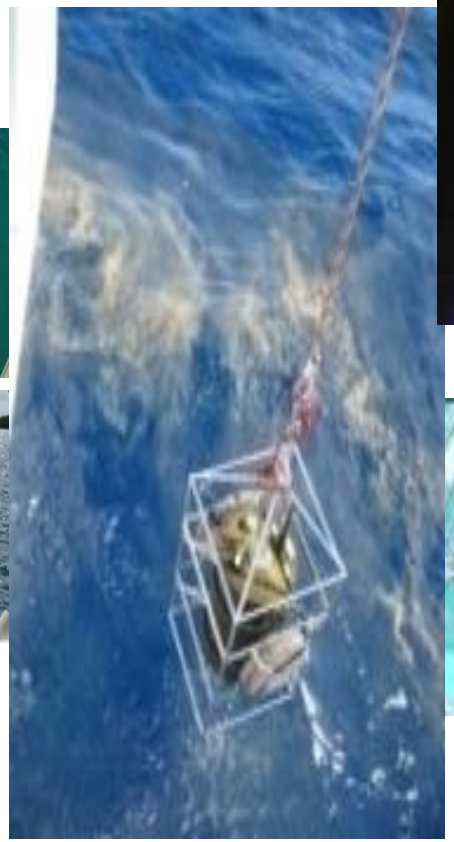
*McKinna:* Routine spectral measurements of Trichodesmium bb are tricky, especially if its floating near the surface its hard to immerse the sensors. Also, current bb sensors (HS6 BB9) are only multispectral.



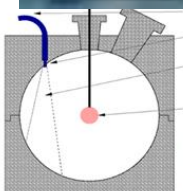
TRIOS

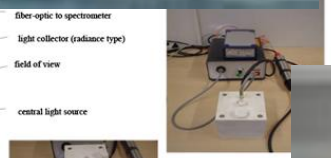
$R_{rs}$





$b_b$



PSICAM

$a_{tot}$

Helmholtz-Zentrum Geesthacht

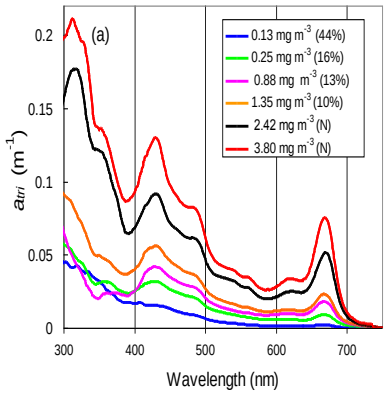
Centre for Materials and Coastal Research

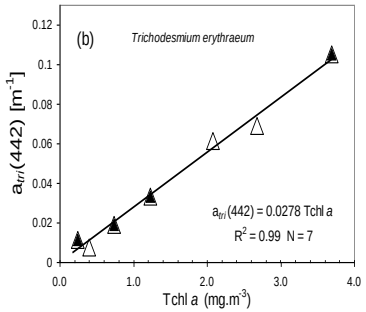

Ultrapath

$a_{cdom}$

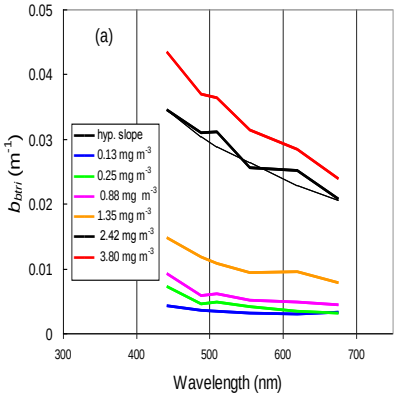
# *Trichodesmium* IOP's (Tricho Bleu Workshop)

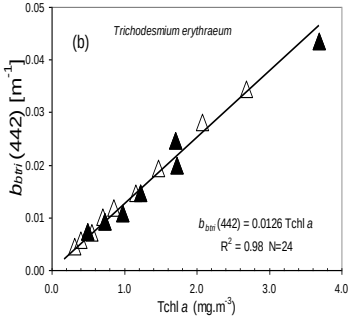
## $A_{part}$ m$^{-1}$




## $b_{bp}$ m$^{-1}$



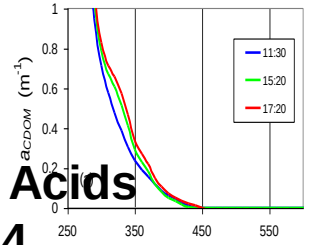



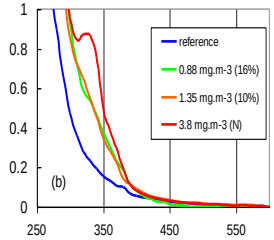

MAA's
330nm, 360nm

## $A_{cdom}$ m$^{-1}$

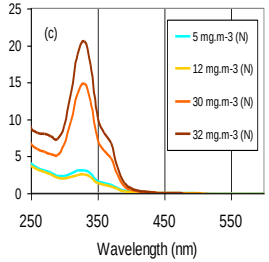
Troughs at 440nm, 550nm

**Mycosporine-Like Amino Acids (shinorine & Porphyra-334**



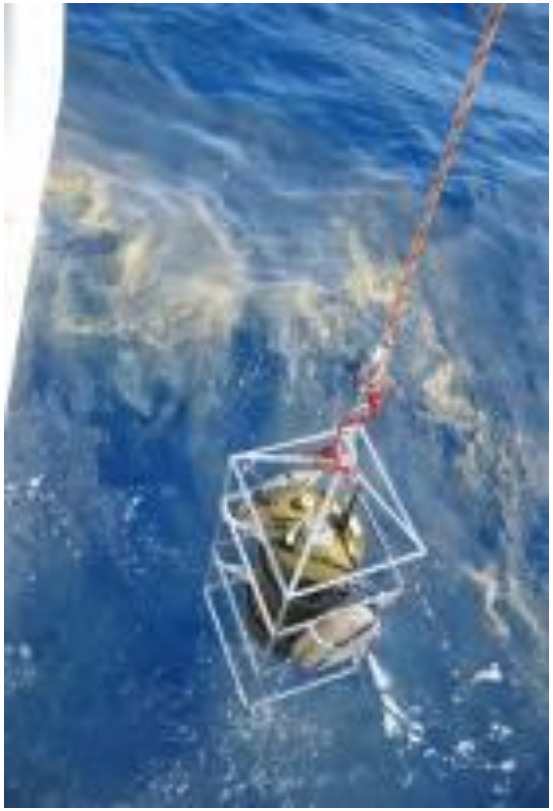

MAA's
330nm, 360nm

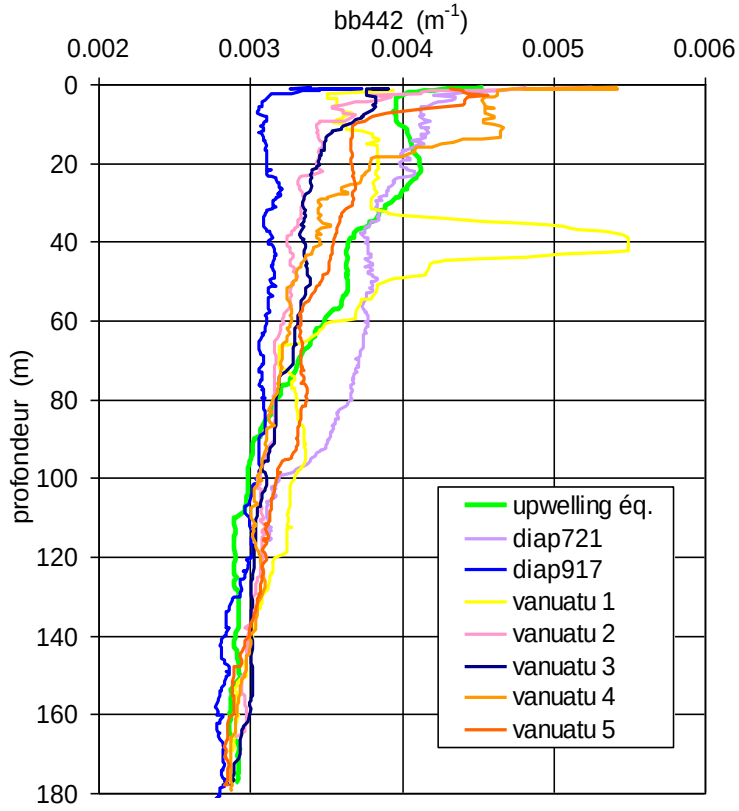



***In Dupouy et al., 2008, JARS***

# IOPs of *Trichodesmium* spp

*McKinna:* We know Tricho exhibits spectral dependencies in bb based on previous measurements, these features are hard to resolve with HS6 or BB9. Does the community support the need for bb sensors with improved spectral resolution?

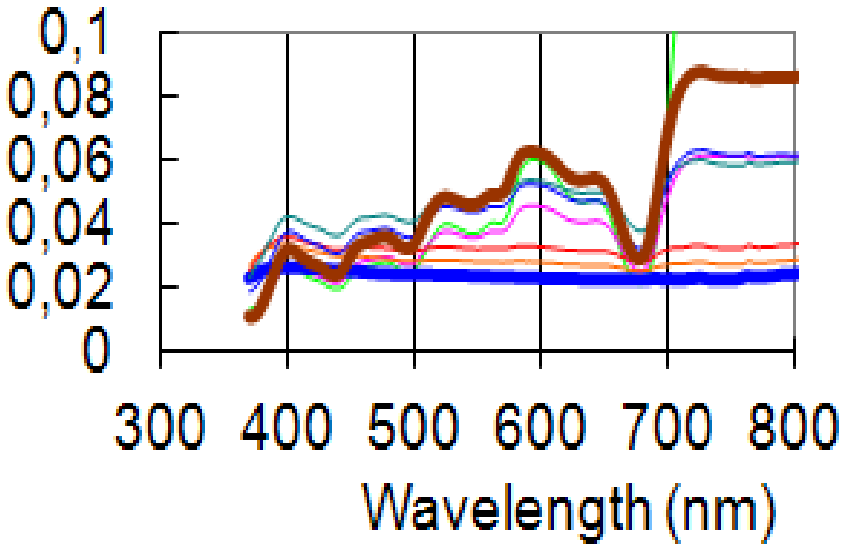





- Gaz vacuoles are backscattering, phycoerythrins absorb at 555 nm

***Dupouy et al., 2008, JARS***

# *Trichodesmium (floating)*



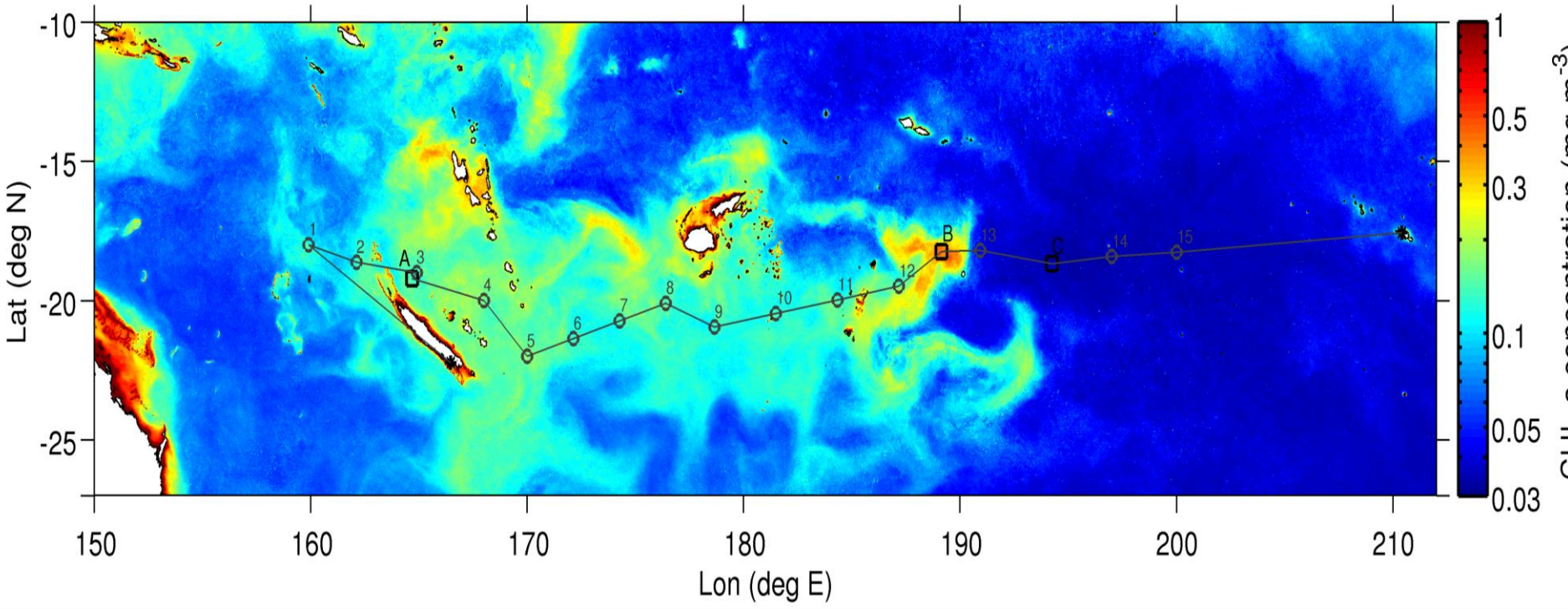

**Need a Hyper-Spectral sensor**

***Rrs of accumulation above water***

- maximum at 555 nm
- minimum at 443, 490, 520, 670
- increasing suspensions
- above water blooms

***Dupouy, Neveux, Ouillon et al., 2008, JARS***
***McKinna et al., 2011***

# IOP/AOPs during the Outpace cruise April 2015




- 45 Days
- Stations LDA LDB LDC:
- Trichos/Trichos/Oligotrophic waters

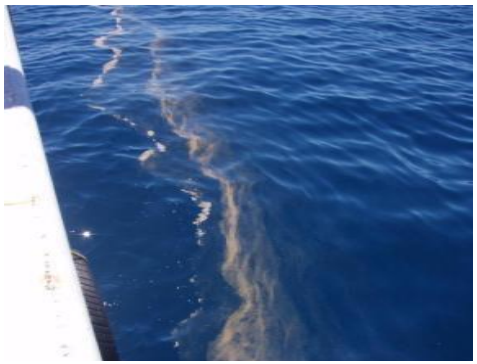
# Reflectance measurements

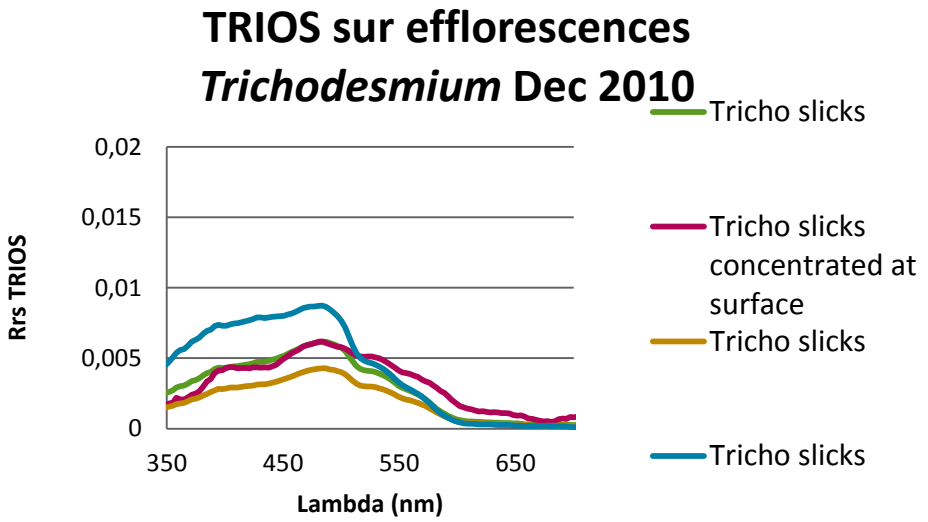
- - Must be hyperspectral to detect troughs and bumps of pureTricho spectrum.
- - Above and inside the bloom ! Trios may be too deep already ….(inside the bloom, not above)
- - Use of hyperspectral above-water measurement

- For sub-bloom concentrations, use Satlantic profiles (hyperspectral) and all hyperspectral iop's. *Mc Kinna:* Improved understanding of the effect the vertical distribution of Tricho has on water-leaving radiometry is important. It would have been very useful to know what effect a sub-surface bloom at different depths in the water column has on the spectral shape and magnitude of Rrs. This could be linked to diurnal vertical migration.
- - *Mc Kinna:* Also, the proposed PACE sensor will extend into the UV - interesting aspect for Tricho leaching MAAs into the CDOM pool.
- I would recommend above-water or in-water radiometry collection simultaneously occuring at the same time as IOP profile sampling.

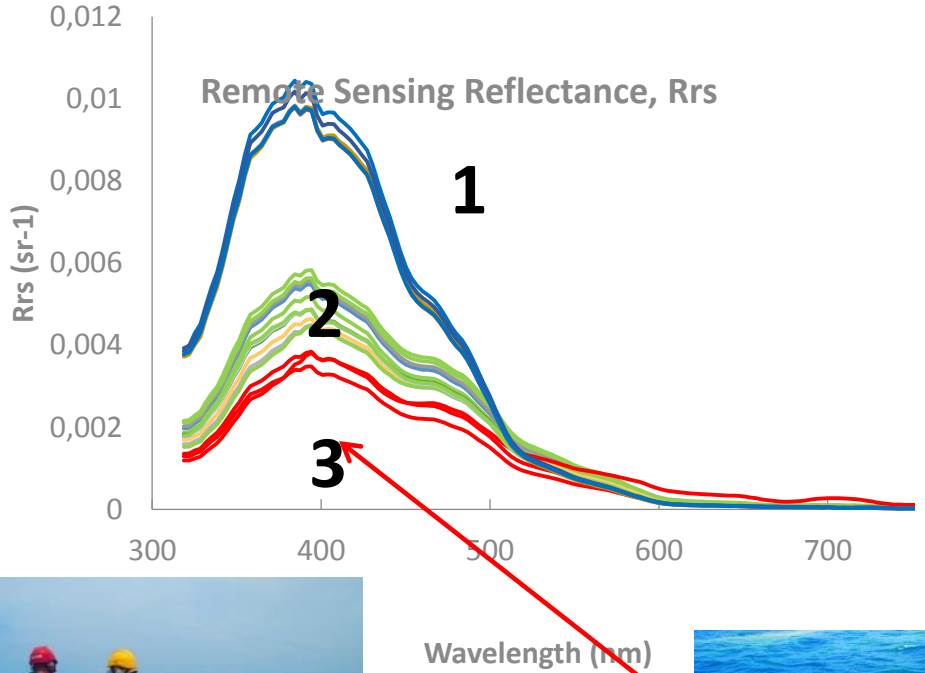
# *Rrs of a in situ Trichodesmium* slick

- *Elgar Desa:* There is a further logistic problem of measuring Trichodesmium spectra from a ship, as the act of lowering the radiometer into a Trichodesmium patch tends to separate and break the patches. This is because Trichodesmium is highly buoyant, and tends to be driven apart by the smallest disturbance on the sea surface



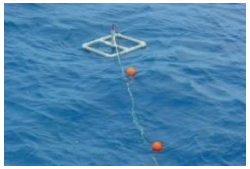


# JAXA Trios-RAMSES Measurements



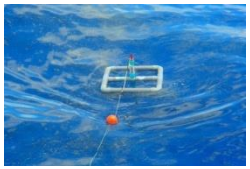

**1** blue waters

RRS_2015-03-24 (LDC-Day1)



**2** Green waters

RRS_2015-03-02 (LDA-Day5)



**3** *Trichodesmium* slicks

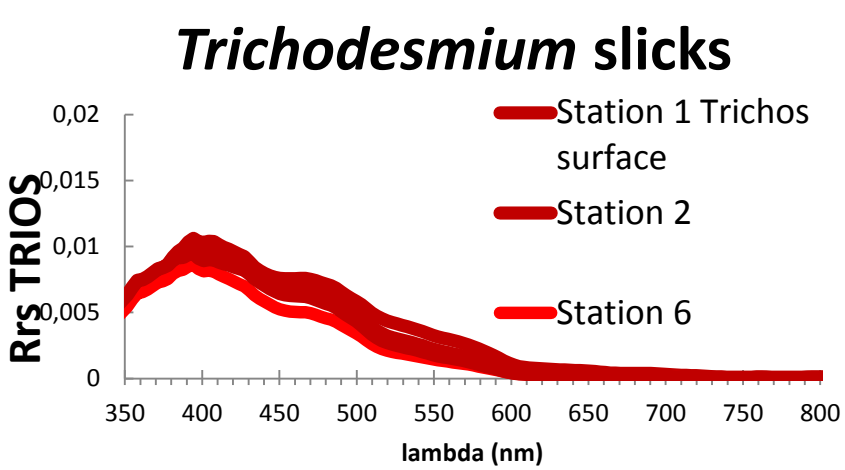
RRS_2015-02-28 (LDA-Day2)

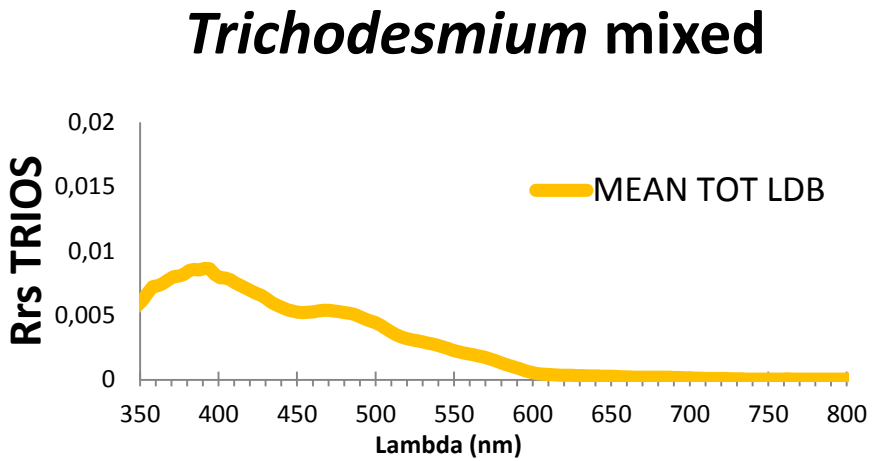
Rrs on a floating frame : Lu at 5 mm under the surface / Es (reference Deck)

Rrs high in the blue for oligotrophic waters and decreases as Chla increases (min LDA) *Trichodesmium* dominate

***In Dupouy et al., 2017, Outpace report***

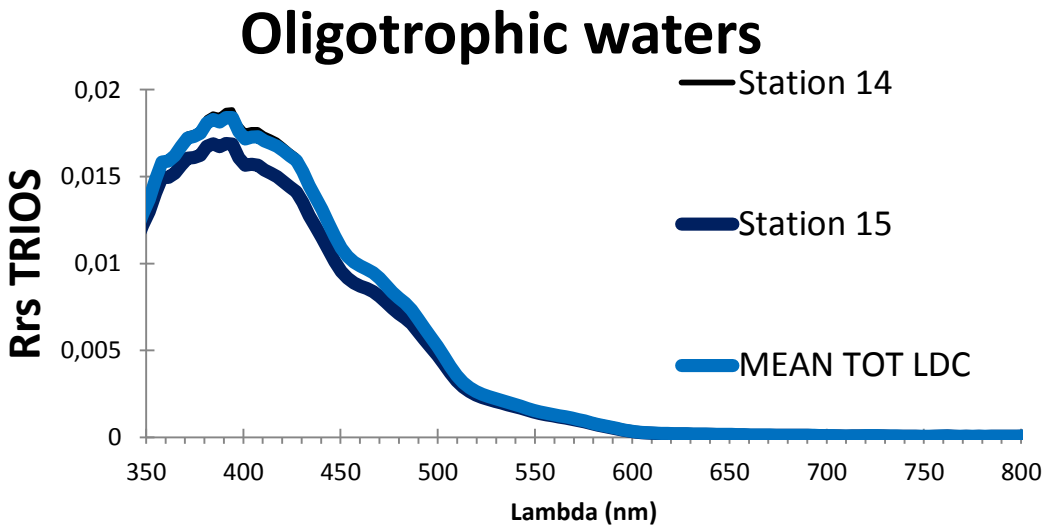
# 3 groups of TRIOS Ramses April 2015



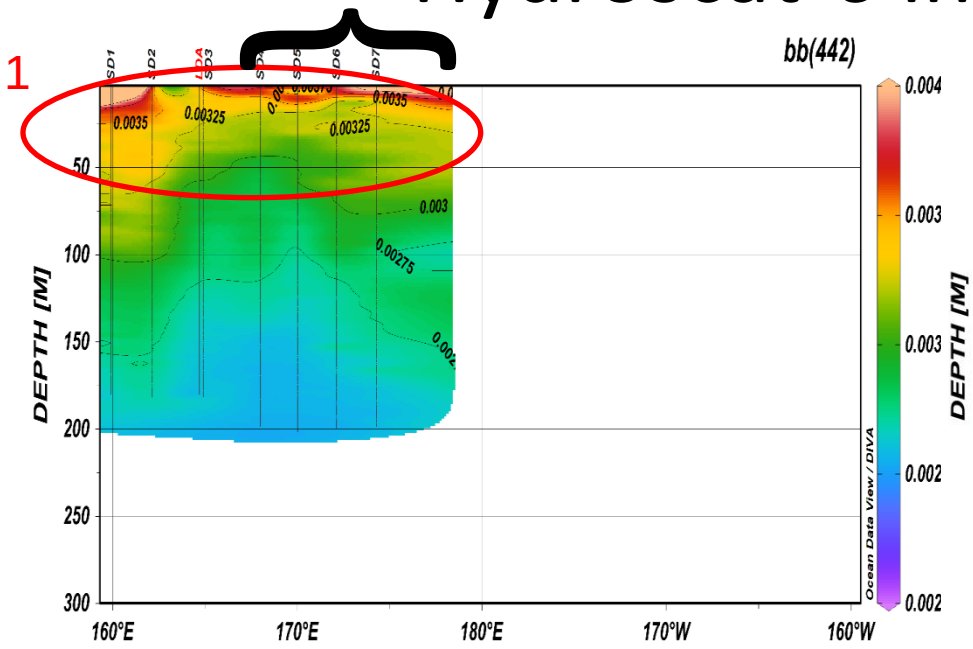

**(a) Higher reflectance in the green due to (b) Higher Rrs in the UV 250-400nm :lack of CDOM absorption *Trichodesmium* slicks**

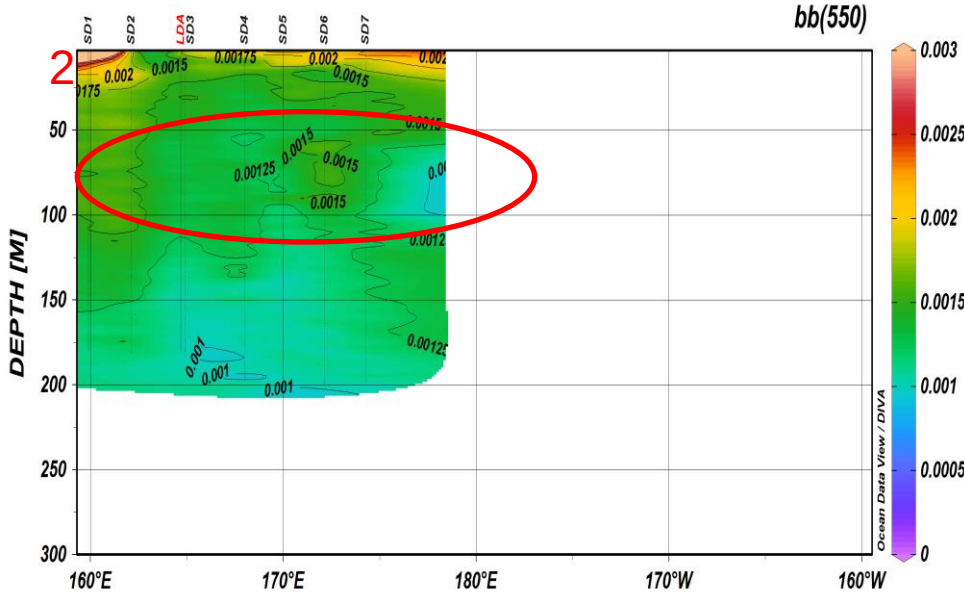
**c) High Rrs in the UV-Blue part of the spectrum**

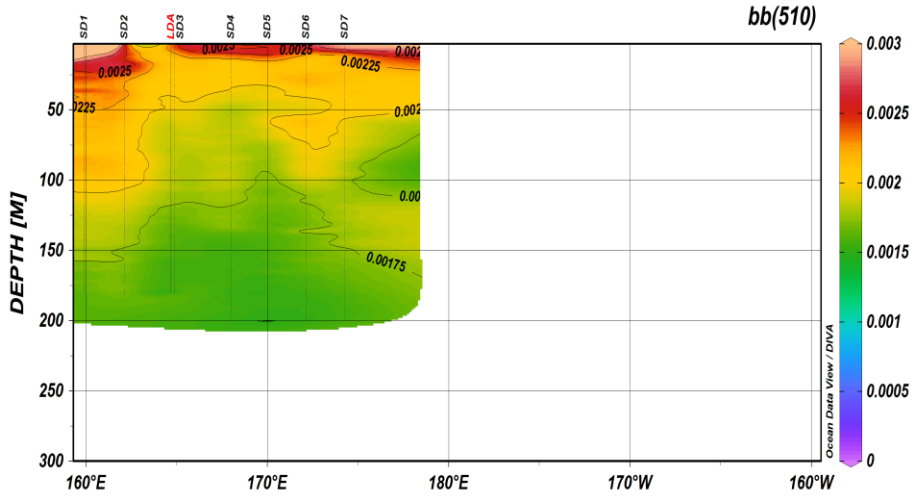



***In Dupouy et al., 2017, Outpace report***

# Hydroscat-6 in Trichos mats



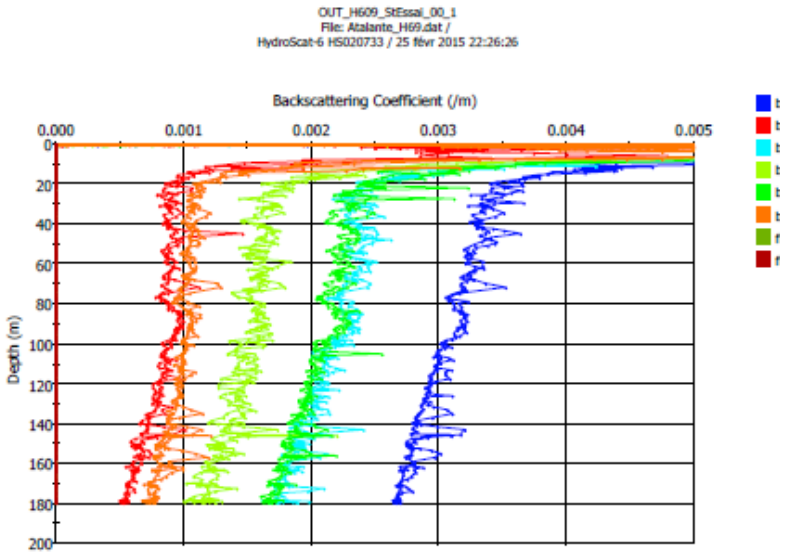




- 1- High backscattering in the 5-30 meters SD1-SD7
- 2- $b_b$550 > $b_b$440 SD6 50-100m
- $b_b$ not related to high CDOM between SD4 & SD7

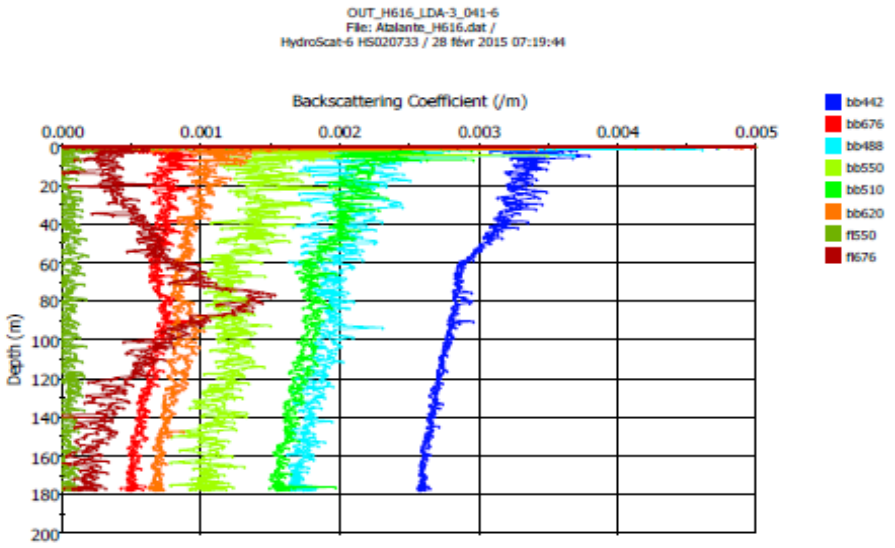
***In Dupouy et al., 2017, Outpace report***

# Hydroscat-6 profiles Trichos mats/oligo

## Trichos slicks 0-10m




## Without Trichos slicks 0-10m

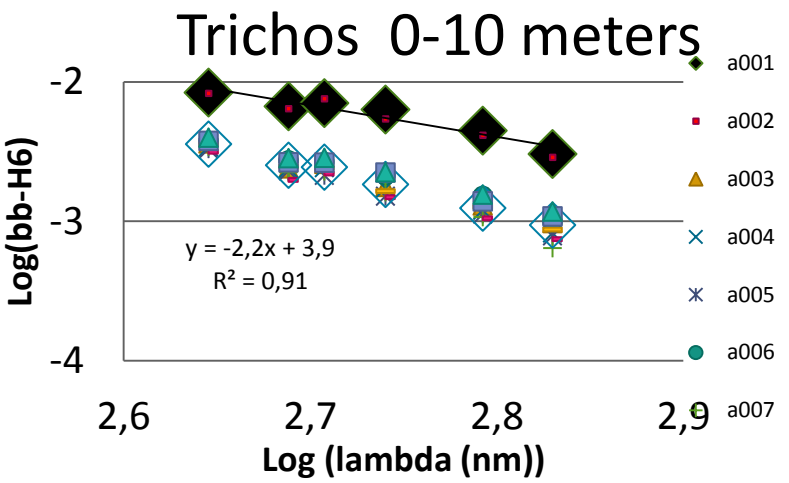


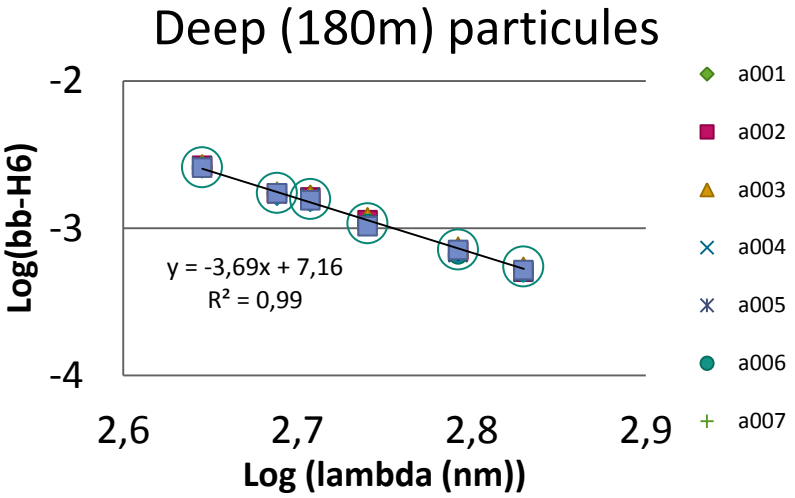

High (left) and low (right) values depending on the presence of Trichodesmium slicks from 0-10m. Left: station Essai 2 25/02/2015. Right: LDA-Day3.

The Deep chla maximum is seen in fluorescence (dark red curve) at 80 meters (Station LDA-Day 3)

***In Dupouy et al., 2017, Outpace report***

# Hydroscat-6 backscattering spectrum




12 H6 stations only but…nice !

Slopes are of about -2.2 at the surface in Trichos slicks (0-10m) (left), black

.

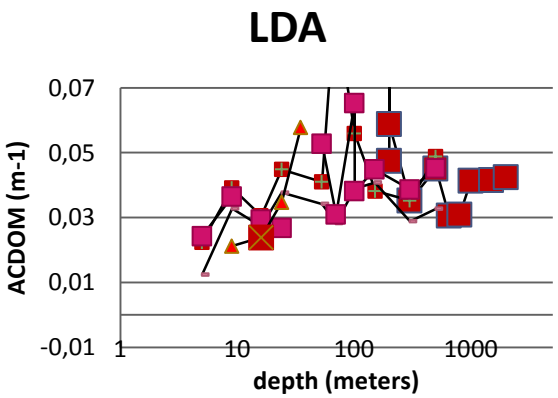
Slopes are - 3.67 at 180m for detrital particles

***In Dupouy et al., 2017, Outpace report***

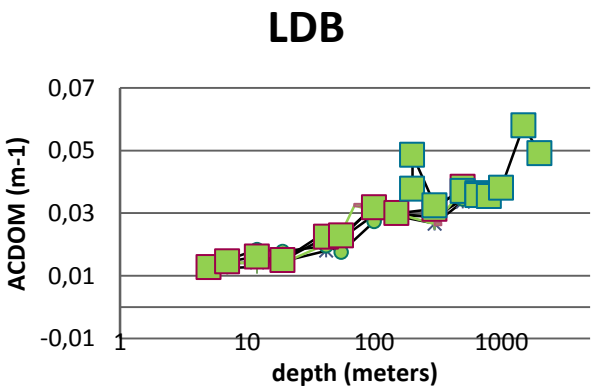
# CDOM in Trichos mats

## LWCC on board

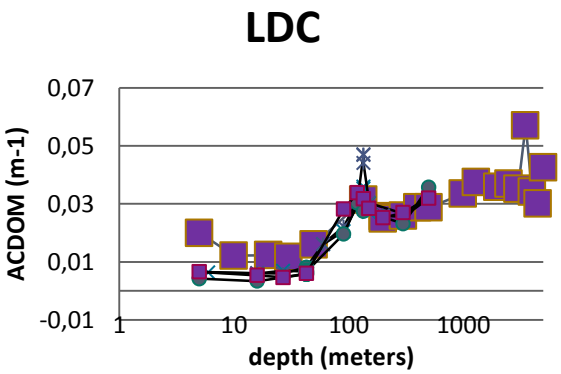
Trichos ++++




Trichos+++, 0 CDOM

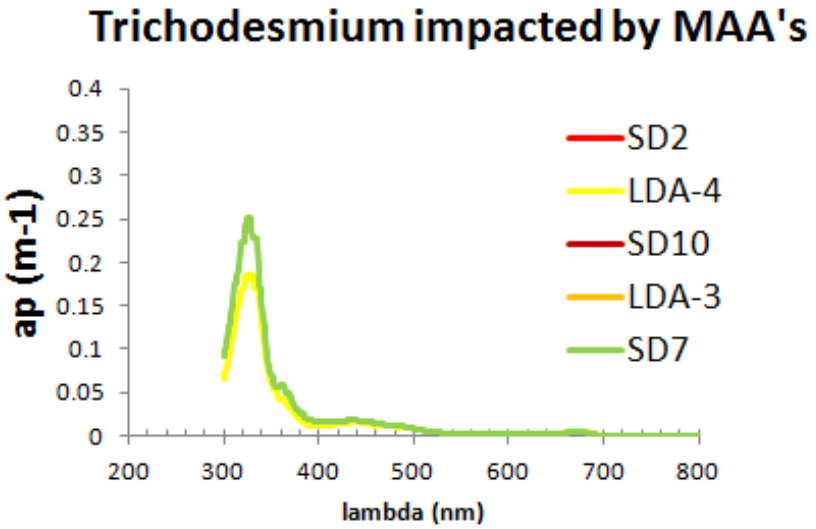


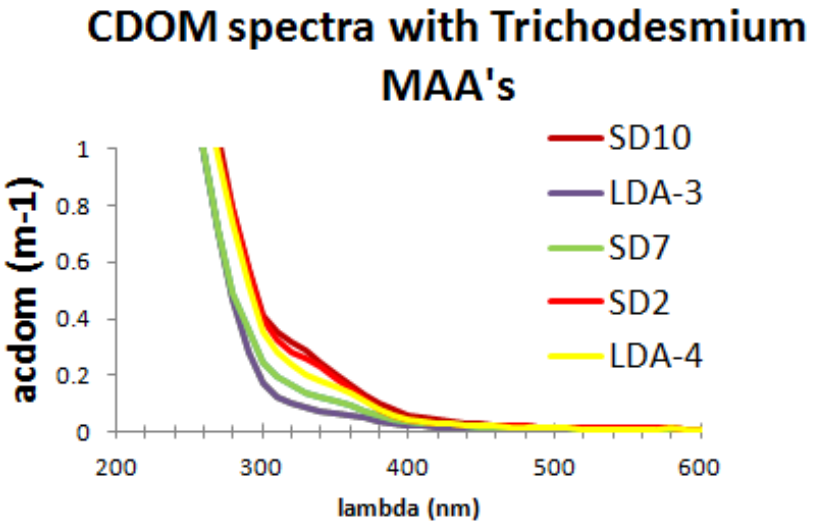

Oligo




***In Dupouy et al., 2017, Outpace report***

# Outpace cruise Aps & CDOM in Trichos patches




- ***In Dupouy et al., 2017, Outpace report***

# Sampling material : revolutions

- *Elgar Desa*: Shallow water AUV in a process study of Trichodesmium
- An AUV could solve the problem of recording high-resolution Trichodesmium spectra, and the way would be to make the AUV ride **below** a Trichodesmium patch. In this mode the optical sensors of radiance and irradiance could be deployed outwards from the AUV body for spectral collection. Other parameters of interest are temperature, chlorophyll, nitrates, and particle backscatter coefficients.

- *Elgar Desa:* Scientific sensor payloads for AUV's : Fortunately, off-the-shelf sensors of small size are now available for most oceanographic parameters. They have built in data loggers with serial outputs, low power requirements, and low costs. Some examples are: Miniature high resolution multi-spectral radiometers that measure the complete spectrum from 280-720 nm ( see www.trios.de ) Multi parameter sensor packs combining CTD and fluorescence in one unit ( see www.chelsea.co.uk or www.falmouth.com )

# Himawari-8 (JAXA) followed a *Tricho* bloom

- ftp://suzaku.eorc.jaxa.jp/pub/GLI/murakami/NewCaledonia/NewCale_daily_20161021_201703ss.gif

- ftp://suzaku.eorc.jaxa.jp/pub/GLI/murakami/NewCaledonia/S3A_OL_1_EFR____20170119_NewCaledonia_chla_cl3.jpg

- OLCI has more than 1200-km swath and the one scene can cover full area of the New Caledonia islands.
  - Thanks to Hiroshi Murakami !

# Aknowledgements

Thanks to all contributors :

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M. Thyssen
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Nausch, White, Hu…