Inexpensive but robust approaches for determining optical and biogeochemical properties

Mike Twardowski and Wayne Slade

Harbor Branch Oceanographic Institute, Florida Atlantic University, USA

The problem: sensors are too expensive to be deployed at large quantities on the scales of interest to coastal populations (e.g. resolve tides, weather and beaches, be deployed in the developing world).

=> limits significantly the relevant and available data.

Why is it so?

1. Pressure-resistant housing (most in-situ sensors are rated to 600m).
2. Accuracy requirement (e.g. to trace deep water masses).
3. Limited market.
4. Limited resources for some research groups and communities.

What can we do to change this situation?

1. Much of the data of interest is near surface.

2. Near the surface natural variability is large.

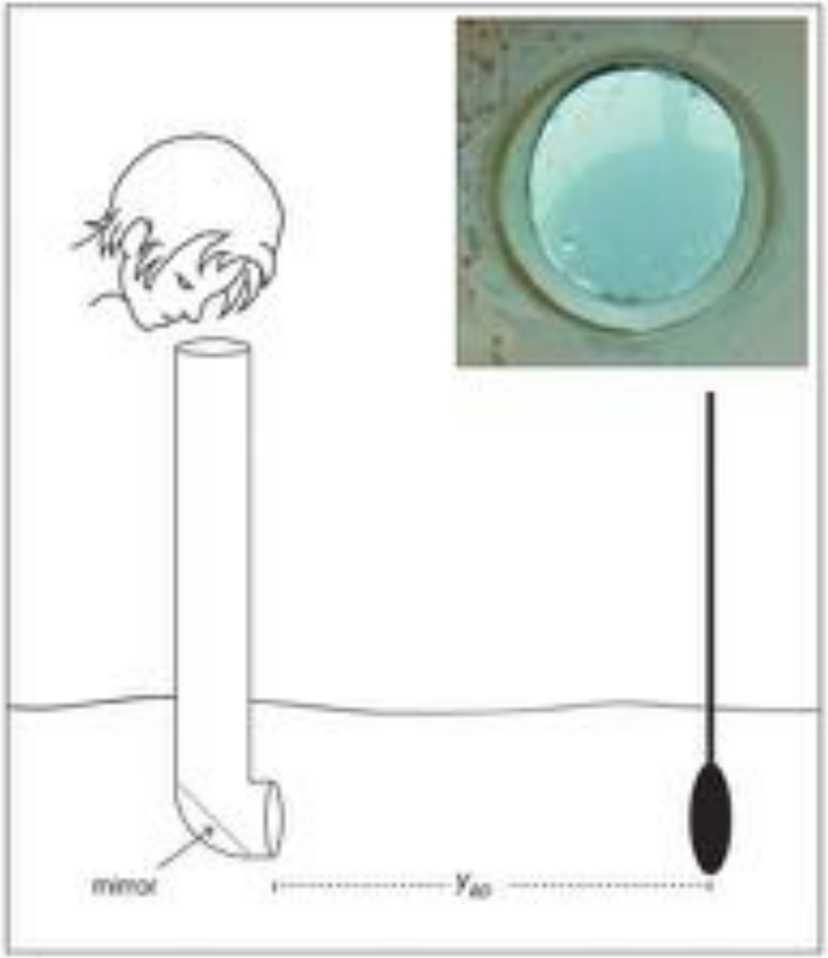
3. Bringing in industry (aquaculture, fisheries, tourism) creates a much larger market than science.

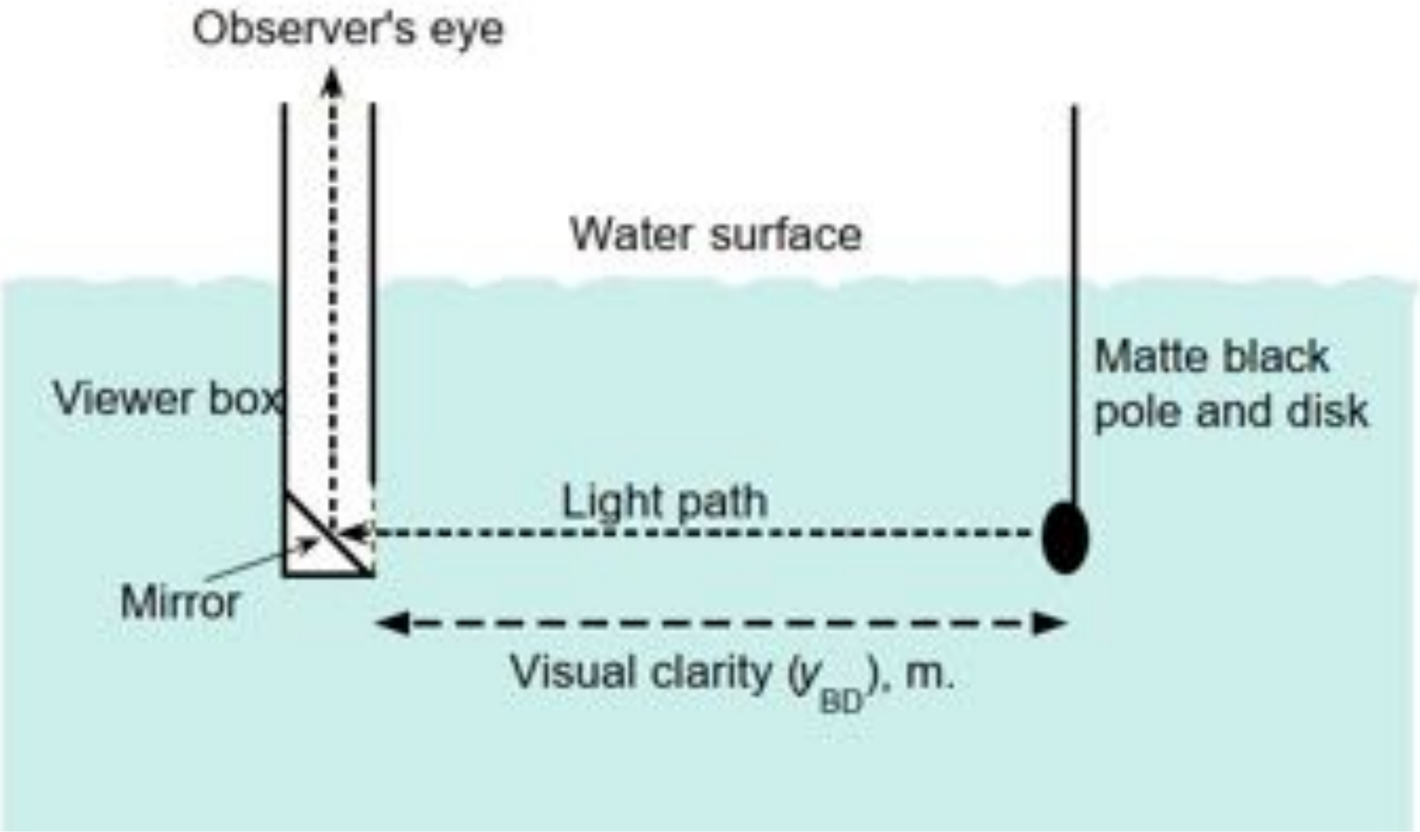
4. There are inexpensive but robust alternatives in some cases.

Additionally, a revolution is going on ➔ cheap electronics processors, communication and sharing.

1. Cheap microprocessors such as Arduino and Raspberry Pi have made building a sensor and/or a sensing platform a Lego-like activity.
2. Communication via cell-phone, Wi-Fi and sat-com, provide near-real time data (e.g. for QC and adaptive sampling and incorporation to forecast).
3. Sharing of ’recipes’ and ideas within/across communities allow for fast evolution and bug fixes (e.g. GitHub, instructables, Make magazine).
4. However, it is critical that uncertainties be associated with all measurements. Better to have no measurements than bad ones.
5. Full sensor characterizations essential for any custom device.

Attenuation (c) from horizontal vis with a black disk





Equipment list

Black disc method

tape measure

black disc viewer

black disc pole

Zaneveld and Pegau (2003)

V = 4.8/α

α = photopic attenuation

$\alpha = c_{pg}(532)*0.9 +0.081$

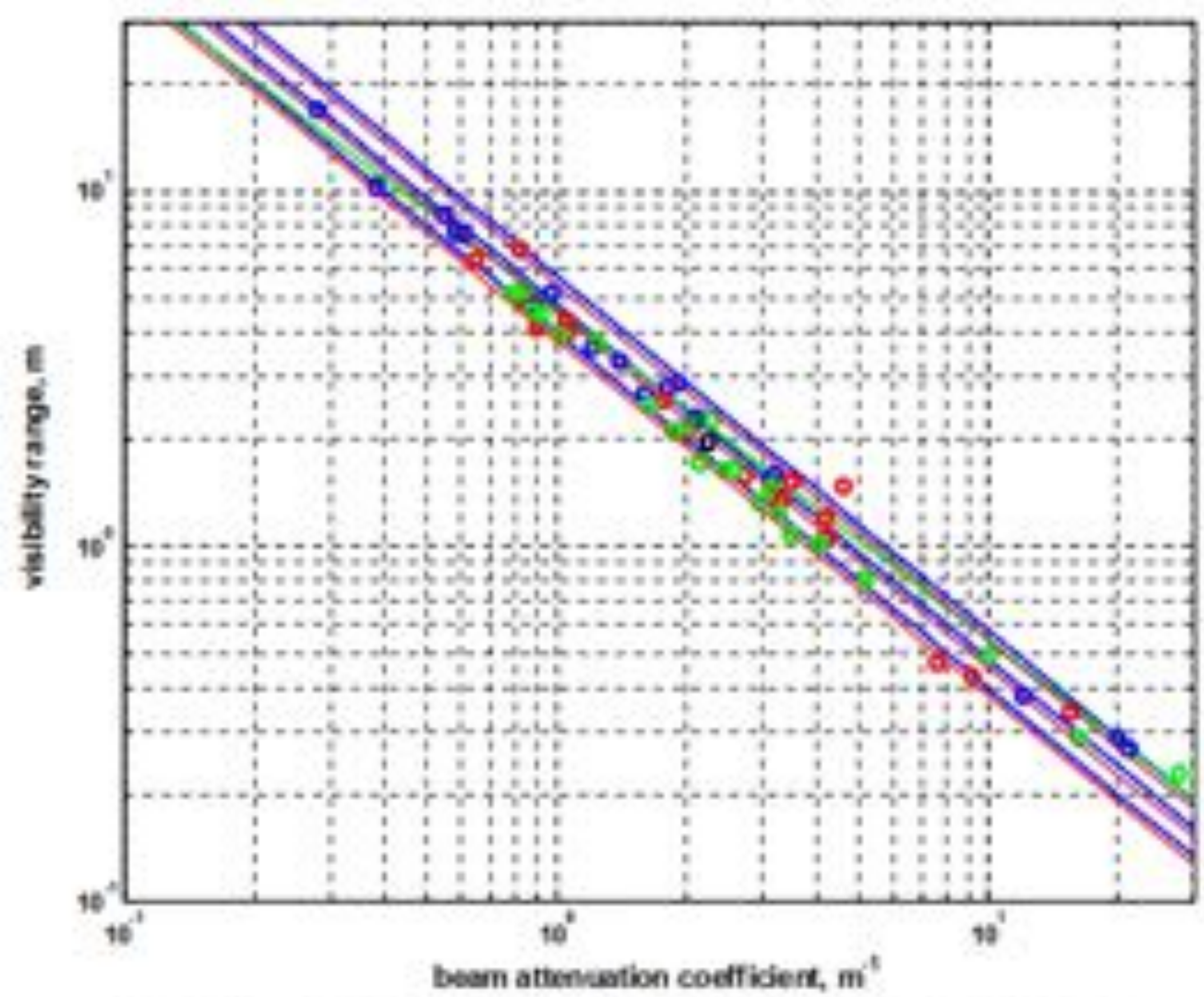


Fig. 3. Horizontal visibility of a 200 mm diameter black target. Blue points, Davies-Colley, "green" c-meter; red points, Zaneveld, $c(532)*0.9+0.081$; black point, Twardowski $c_{pg}(532)*0.9+0.081$; green points, Pegau, $c_{pg}(532)*0.9+0.081$;
blue lines vis. range = $y = 4.8/\alpha$ and +/- 20% lines;
green line vis. range= $y = (5.207 - 0.568 \ln\alpha)/\alpha$;
red lines vis. range = $y = 4.55/\alpha$ and +/- 20% lines; $r^2 = 0.985$.

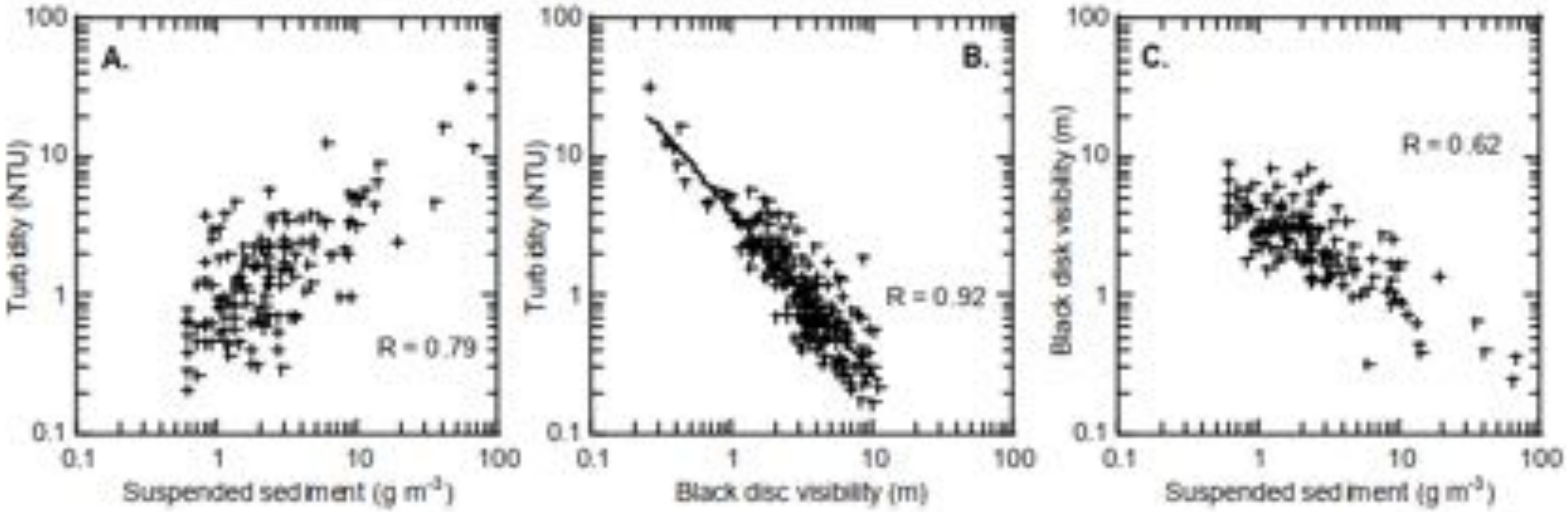
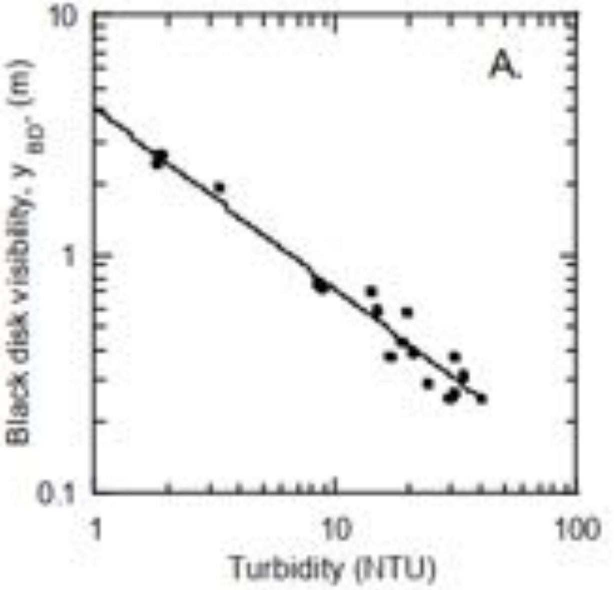


Figure 2. Mutual relationships of visual clarity, turbidity (Hach 2100A) and suspended sediment concentration in 97 New Zealand rivers (each river site sampled up to three times—$n = 274$ in total). Panel A. turbidity versus suspended sediment, B. turbidity versus black disc visibility, C. black disc visibility versus SSC. (Figure 3 of Davies-Colley and Close, 1990—used with permission)



Smith and Davies-Colley

Faecal contamination and visual clarity in New Zealand rivers: correlation of key variables affecting swimming suitability

Rob Davies-Colley, Amanda Valois and Juliet Milne

Journal of Water and Health
2018

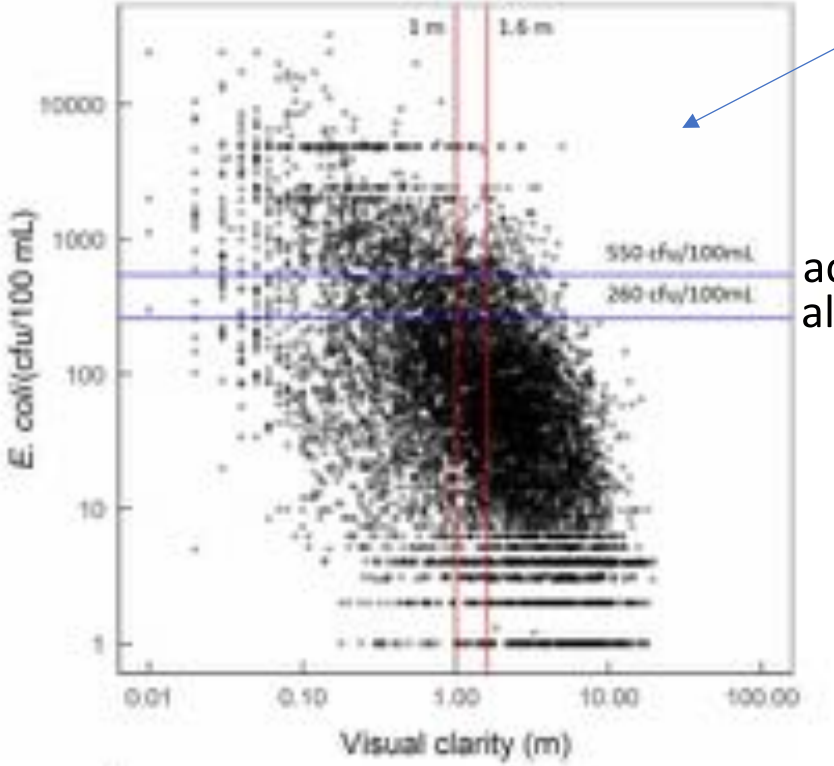


Figure 6 | *E. coli* vs visual clarity at 64 river sites in the NRWQN, 2006–2015, in relation to existing guidelines for swimming water quality in NZ. The horizontal lines represent ALERT (260 cfu/100 mL) and ACTION (550 cfu/100 mL) levels for *E. coli* from MfE/MoH (2003); the vertical lines represent guidelines for visual clarity (1.6 m is from MfE (1994) and 1.0 m an indicative – informal – guideline for visual degradation of water appearance). Only about 1% of points fall into the top-right sector representing relatively high microbial risk (>550 cfu/100 mL) when water is relatively clear (>1.6 m).

<1% samples fall
in high E. coli,
high vis quadrant

action
alert

<1.6 horizontal vis has been official Ministry for the Environment criteria for safe to swim in NZ since 1994

https://environment.govt.nz/assets/Publications/Files/microbiological-quality-jun03.pdf

Tube with black disk

Depending on arm length, one person can take a clarity tube reading (far right), or it may be easier with two people.

Ministry for the Environment 1994. “Water Quality Guidelines No. 2: Guidelines for the Management of water colour and clarity”. Ministry for the Environment, Wellington, N.Z

Equipment list

Clarity tube method

bucket

clarity tube

magnets


50
AQUA MEDIC

520 New Zealand Journal of Marine and Freshwater Research, 2002, Vol. 3

Fig. 1 SHMAK clarity tube for measuring water clarity. (Photo: Helen Ricketts.)

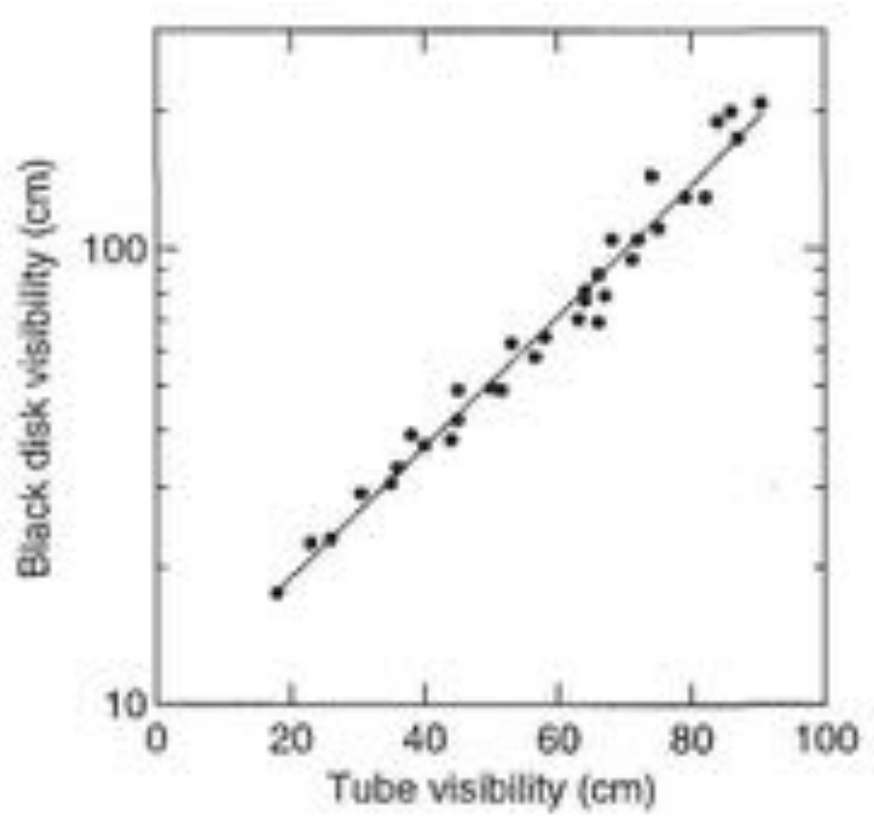


Fig. 4 Black disk readings (logarithmic scale) versus clarity tube readings (y_{BD} versus y_{CT}) (black background).

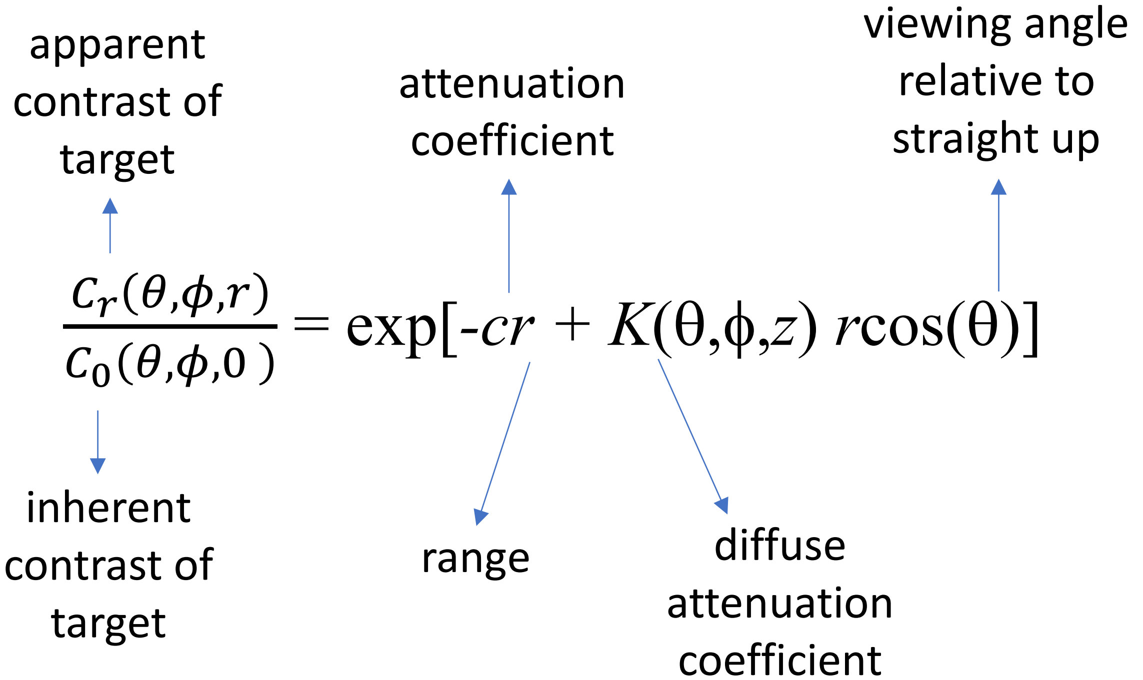
$$y_{BD} = 7.28 \times 10^{[y_{CT}/62.5]}$$

NZ safe to swim: >1 m vis with black disk in tube

Kilroy and Biggs (2002)

Secchi disk depth: theory

Contrast reduction theory for detecting target for any direction:



apparent contrast of target

attenuation coefficient

viewing angle relative to straight up

$$\frac{C_r(\theta,\phi,r)}{C_0(\theta,\phi,0)} = \exp[-cr + K(\theta,\phi,z)\, r\cos(\theta)]$$

inherent contrast of target

range

diffuse attenuation coefficient

Parameters are for *photopic* spectral response

Preisendorfer (1963), Duntley (1976) but work originated in 1940’s; extensively validated

Secchi disk depth: theory

Contrast reduction theory for detecting target for any direction:

$$\frac{C_r(\theta,\phi,z)}{C_0(\theta,\phi,z_T)} = \exp[-cr + K(\theta,\phi,z)\, r\cos(\theta)]$$

At some range, contrast between a target and background will no longer be discernible, i.e., the limiting contrast threshold will have been reached:

$$C_L \equiv \frac{C_r(\theta,\phi,z)}{C_0(\theta,\phi,z_T)} \text{ , and}$$

$$V = -\ln(C_L) / [c - K(\theta,\phi,z)\cos(\theta)]$$

For Secchi disk: $Z_{SD} = -\ln(C_L) / [c + K]$

Issues ….

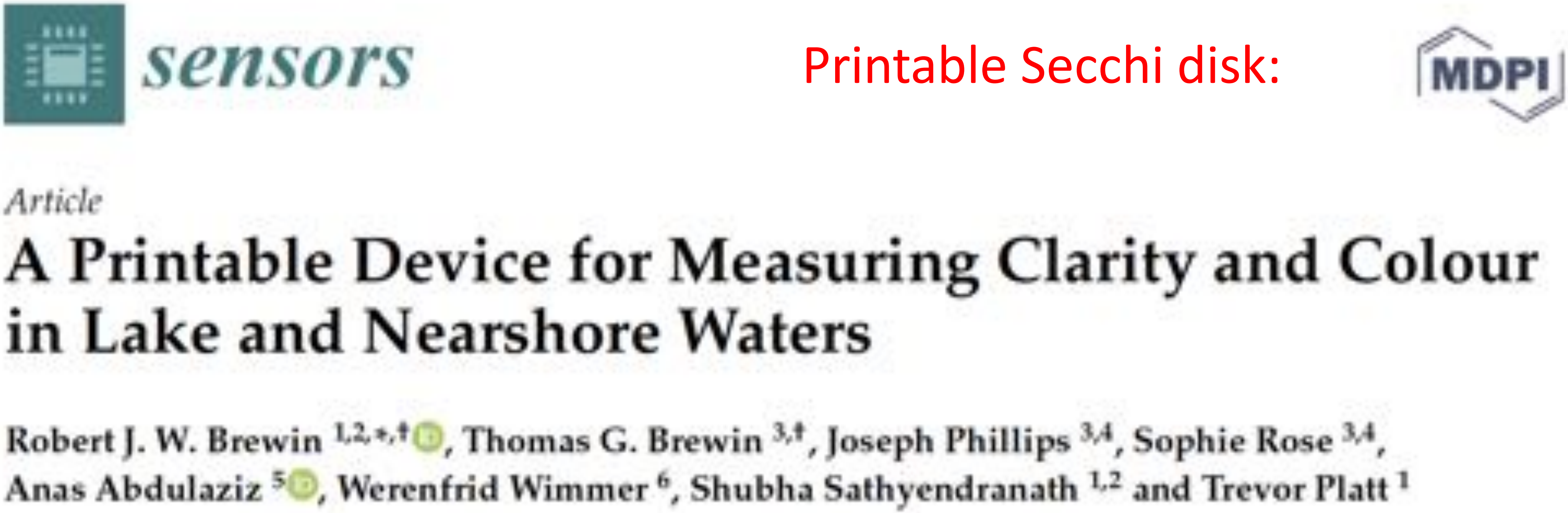
For Secchi disk: $Z_{SD} = -\ln(C_L) / [c + K]$

- When Z_{SD}, *c*, and *K* are determined, large range observed in $-\ln(C_L)$
- White vs black vs black/white quadrants
- Size of disk
- Reflectivity of disk
- Shady side vs sunny side (i.e., glint)
- Cloudy vs sunny
- Wavy surface
- Sun elevation
- Scattering albedo (b/c)
- Eye adaptation to ambient lighting
- Observing altitude above water

$-\ln(C_L)$ typically varies from ~5-10 (Bukata 2005)

All noted by Secchi in 19th century (Pitarch 2020)

Printable Secchi disk:



sensors

MDPI

Article

A Printable Device for Measuring Clarity and Colour in Lake and Nearshore Waters

Robert J. W. Brewin [1,2,*,†], Thomas G. Brewin [3,†], Joseph Phillips [3,4], Sophie Rose [3,4], Anas Abdulaziz [5], Werenfrid Wimmer [6], Shubha Sathyendranath [1,2] and Trevor Platt [1]

Using a view box

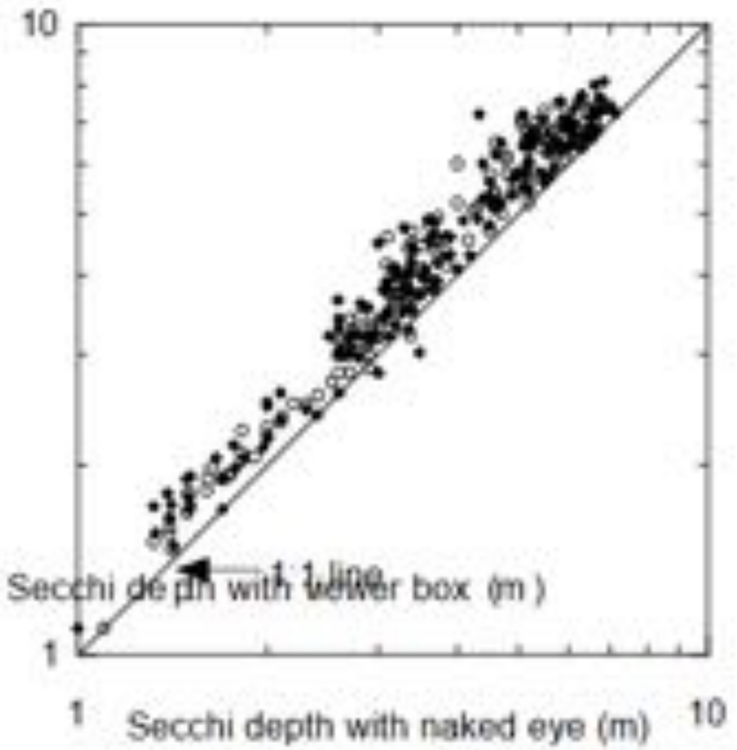
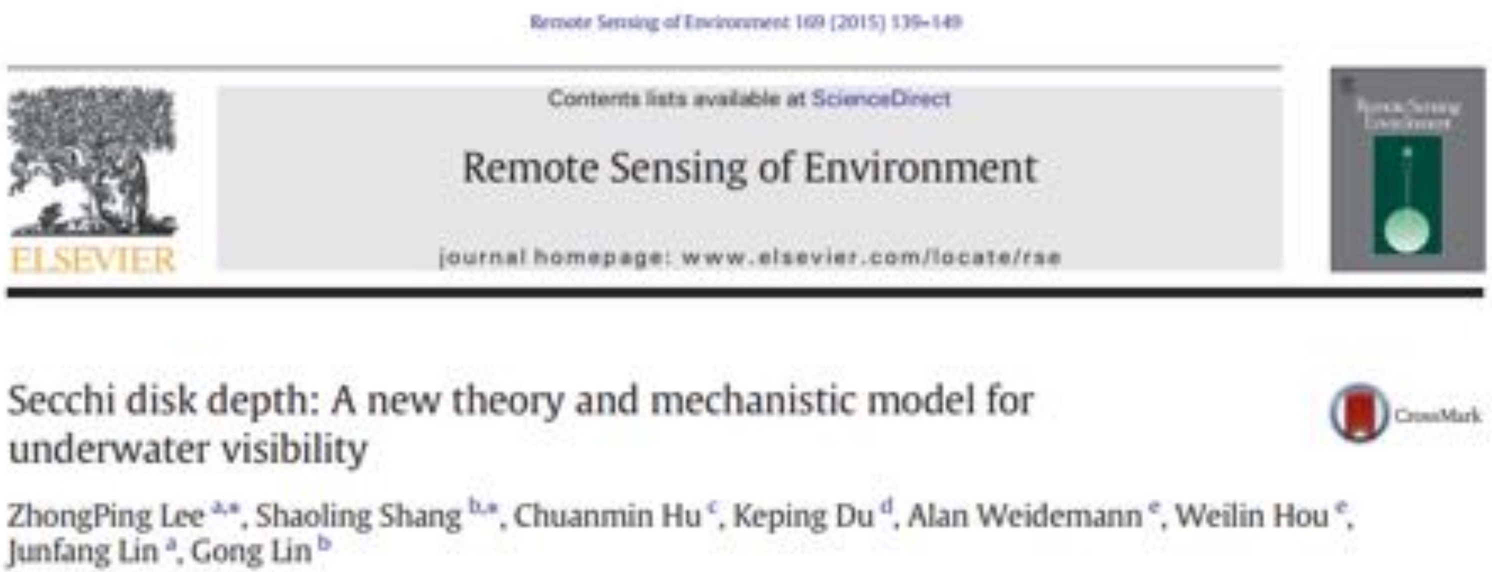


Figure 1. Relationship between Secchi depth measurements made with the aid of a viewer box and the naked eye. The open and closed symbols refer to measurements made on the sunny and shady side of the boat, respectively.

David Smith, Director of Aquatic Studies, New York City's DEP, https://acwi.gov



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Secchi disk depth: A new theory and mechanistic model for underwater visibility

ZhongPing Lee [a,*], Shaoling Shang [b,*], Chuanmin Hu [c], Keping Du [d], Alan Weidemann [e], Weilin Hou [e], Junfang Lin [a], Gong Lin [b]

Earth & Environment | ZhongPing Lee

A new theory for Secchi depths

For 150 years, oceanographers have assessed water clarity using a simple, robust method first devised by an Italian priest. Until recently, however, researchers have struggled to match field observations made using these 'Secchi disks' to theoretical models. Through dedicated research, Dr ZhongPing Lee at the University of Massachusetts, Boston, and colleagues from other institutes in China and the USA, have revolutionised the theory and model regarding this depth, and obtained results consistent with nearly a century of past observations. The methods have become

Covering roughly 71% of our planet's surface, the water contained in oceans and lakes underpins the survival of many different ecosystems, both marine and land based. Yet increasingly, human activities are altering several key characteristics of aquatic environments worldwide – including their temperatures and populations of microscopic organisms – each of which are inflicting various levels of damage on the ecosystems. To determine the influence of these changes, researchers have developed a wide variety of techniques to assess water quality.

Among the most popular and important probes for the quality of water is its

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Some controversy….

LIMNOLOGY and OCEANOGRAPHY

ASLO

Limnol. Oceanogr. 00, 2018, 00–00
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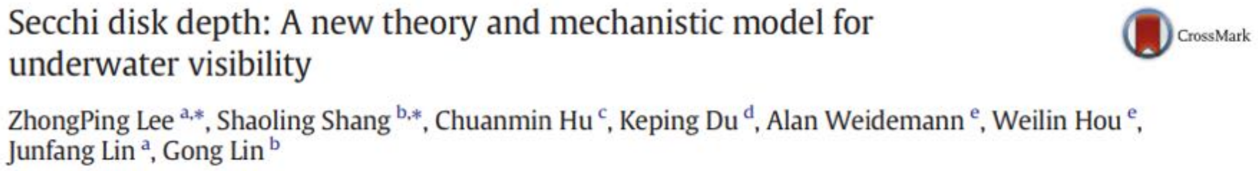
doi: 10.1002/lno.10940

Resolving the long-standing puzzles about the observed Secchi depth relationships

Zhongping Lee [1,*] Shaoling Shang [2,*] Keping Du,[3] Jianwei Wei [1]
[1]School for the Environment, University of Massachusetts Boston, Boston, Massachusetts
[2]State Key Lab of Marine Environmental Science, Xiamen University, Xiamen, China
[3]State Key Laboratory of Remote Sensing Science, School of Geography, Beijing Normal University, Beijing, China

Lee et al. (2015)



Secchi disk depth: A new theory and mechanistic model for underwater visibility

ZhongPing Lee [a,*], Shaoling Shang [b,*], Chuanmin Hu [c], Keping Du [d], Alan Weidemann [e], Weilin Hou [e], Junfang Lin [a], Gong Lin [b]

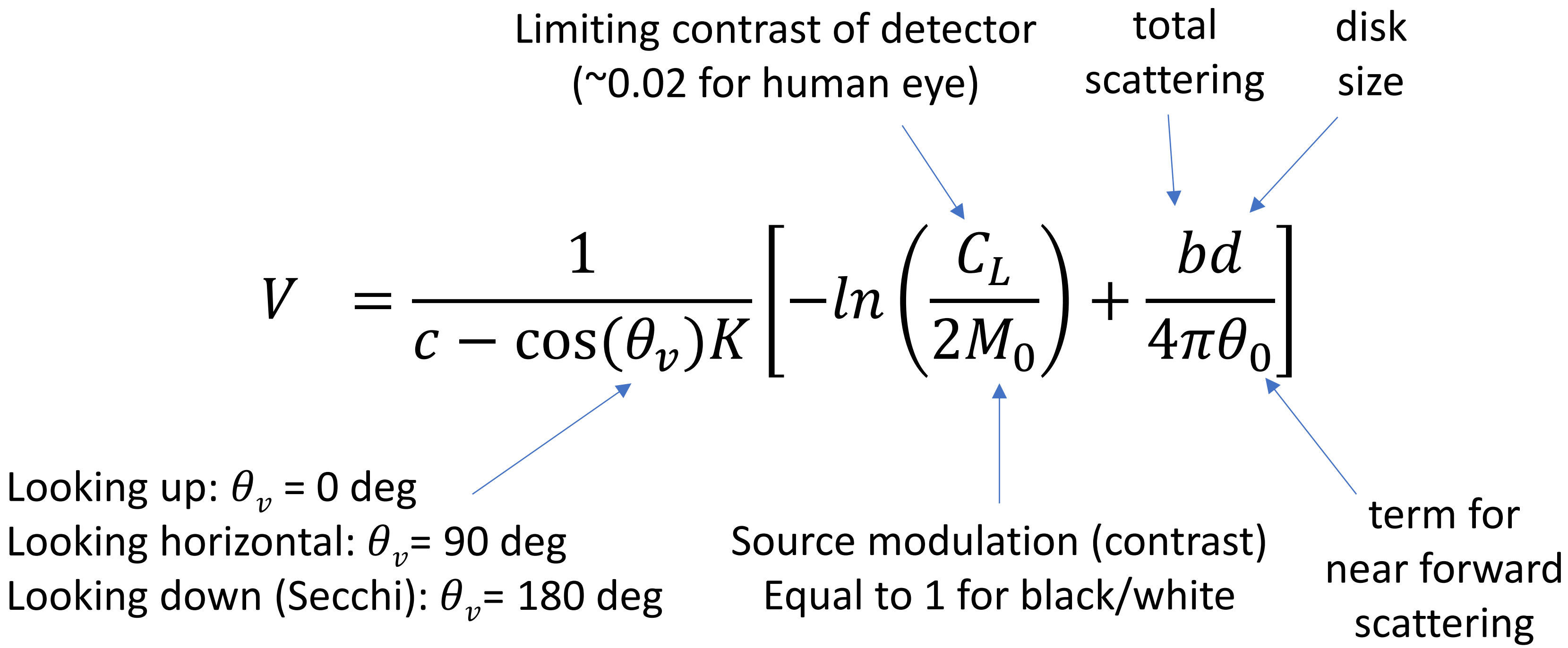
1. Questions path radiance being same over target vs adjacent background
   - Background path radiance will be brighter directly adjacent to a white disk target, but this effect diminishes to nil near secchi disk depth
   - Makes an exception for horizontal viewing: “This may occur because most of the surrounding light over the target and the background are strong radiances in the horizontal directions as demonstrated with field observations (Zaneveld and Pegau, 2003).”
2. Questions contrast definition as $[L_T - L_B]/ L_B$
   - This is Weber contrast definition that has been validated extensively throughout many disciplines
   - Suggests we should be using absolute radiance differences only

Justification given as size of disk relative to spatial resolving capability of human eye

- “Due to this extremely fine resolution of the human eye, the relationship between the pixel size of the collected image and the size of a target will depend on the distance (z) and the size of the target”
  - This is spatial frequency (Hou et al. 2007)
  - But doesn’t obviously explain reasoning for 1+2 (at least for me)

Visibility ranges from modulation transfer function (MTF) imaging theory

Using relationships from Hou, Lee, Weidemann (2007), the following can be derived:



Limiting contrast of detector
(~0.02 for human eye)

total
scattering

disk
size

$$V = \frac{1}{c - \cos(\theta_v)K}\left[-ln\left(\frac{C_L}{2M_0}\right) + \frac{bd}{4\pi\theta_0}\right]$$

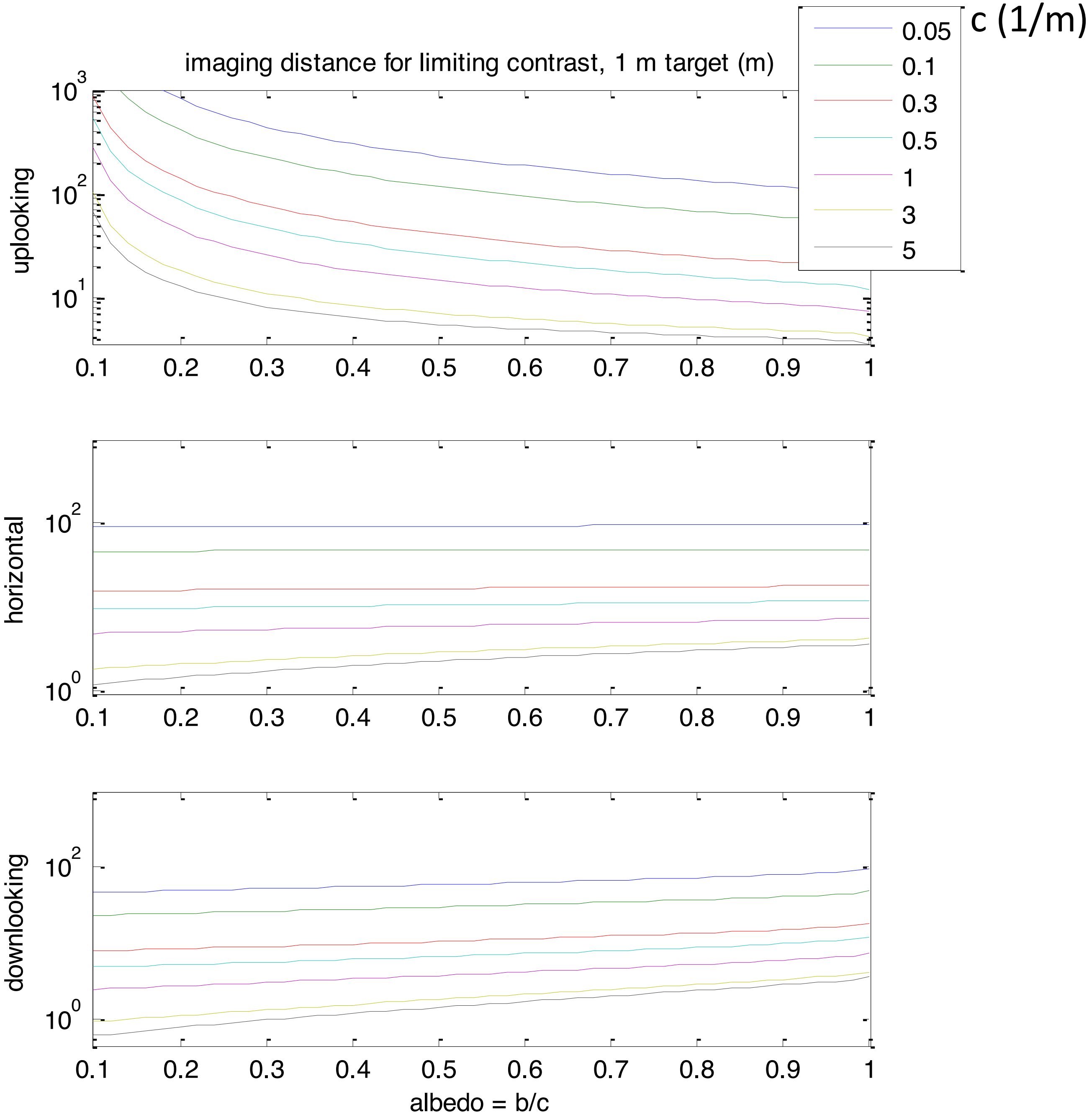
Looking up: θ_v = 0 deg
Looking horizontal: θ_v= 90 deg
Looking down (Secchi): θ_v= 180 deg

Source modulation (contrast)
Equal to 1 for black/white

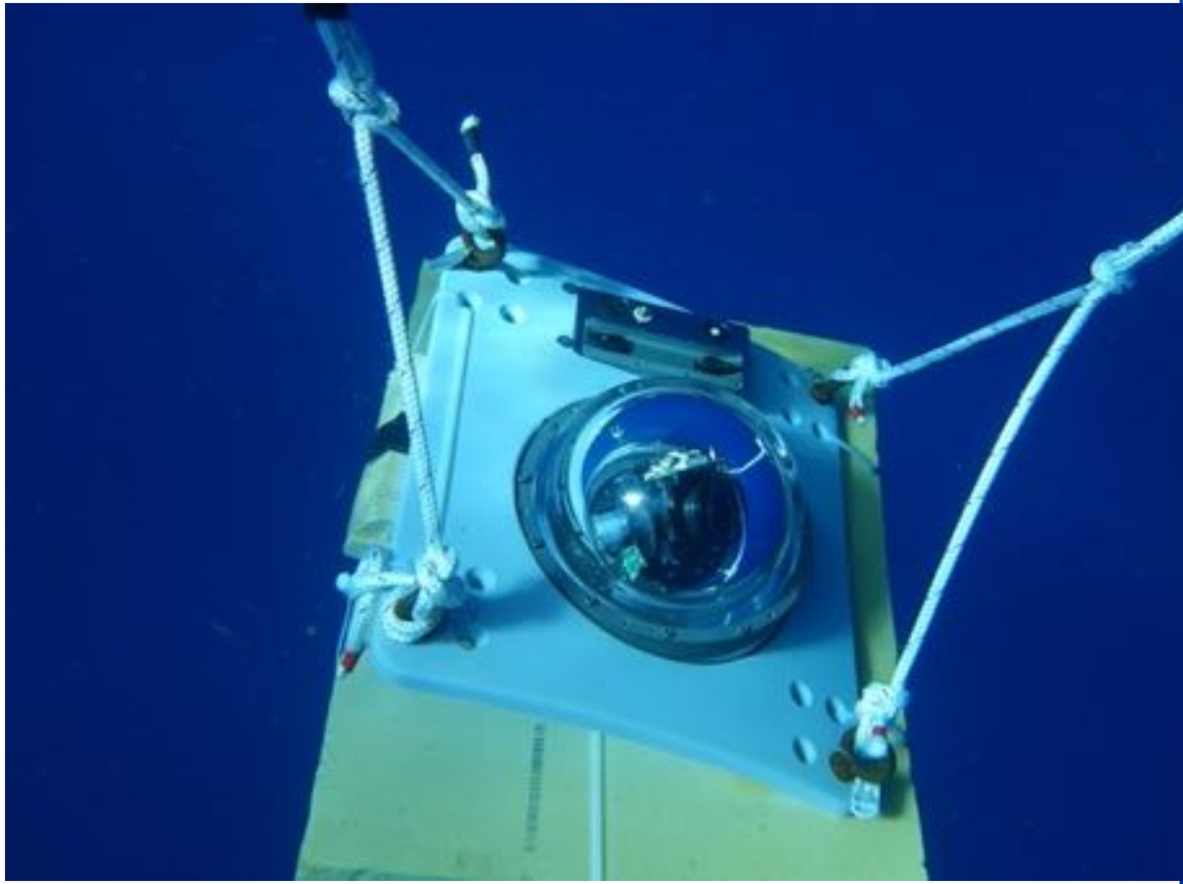
term for
near forward
scattering

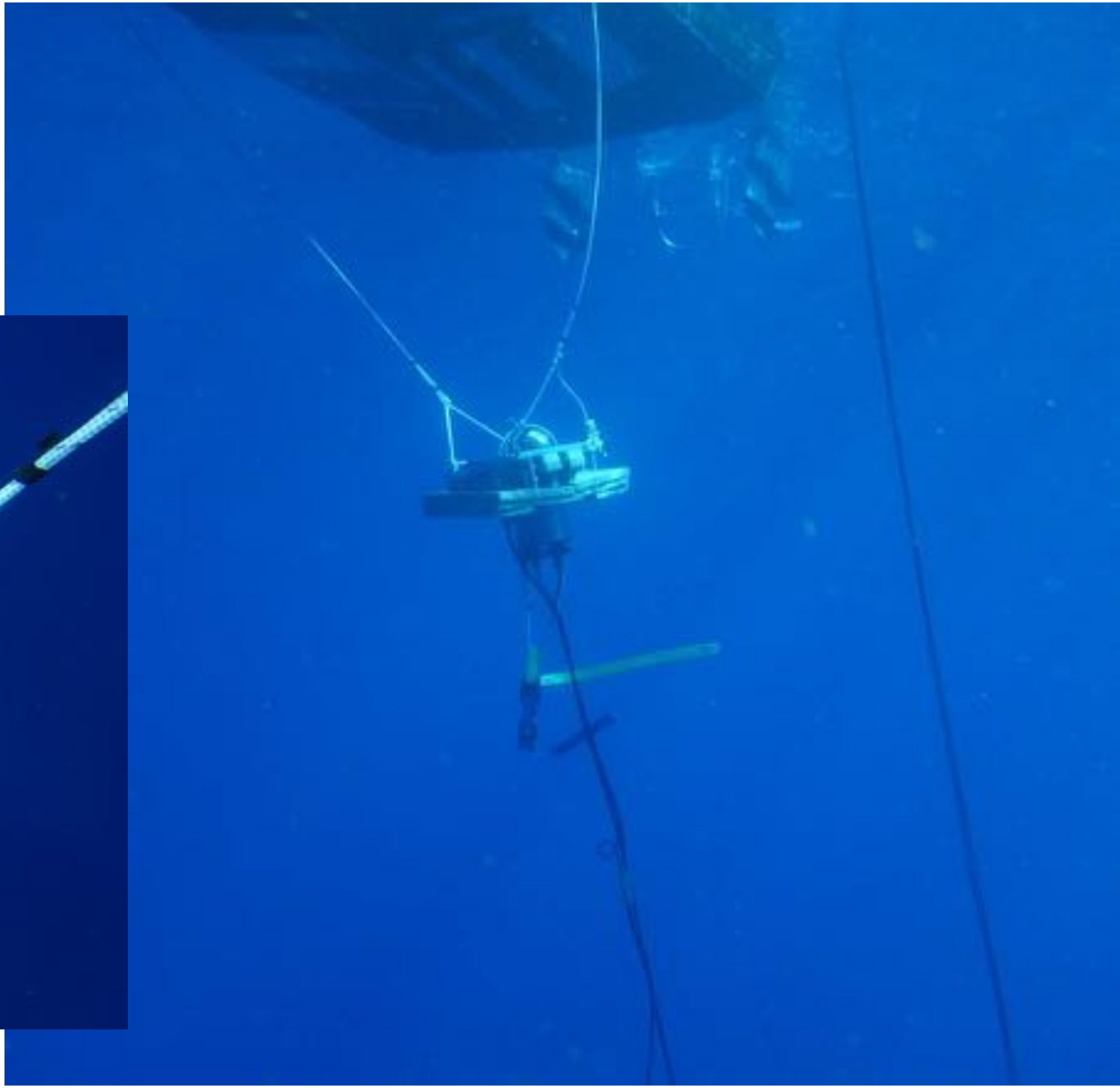
Note:
a = K$\bar{\mu}$ (Gershun's Eq)
and
c = a + b

Consistent with Contrast Reduction Theory but includes terms for disk contrast and size


imaging distance for limiting contrast, 1 m target (m)
c (1/m)
0.05
0.1
0.3
0.5
1
3
5
uplooking
horizontal
downlooking
10^3
10^2
10^1
10^0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
albedo = b/c

It works



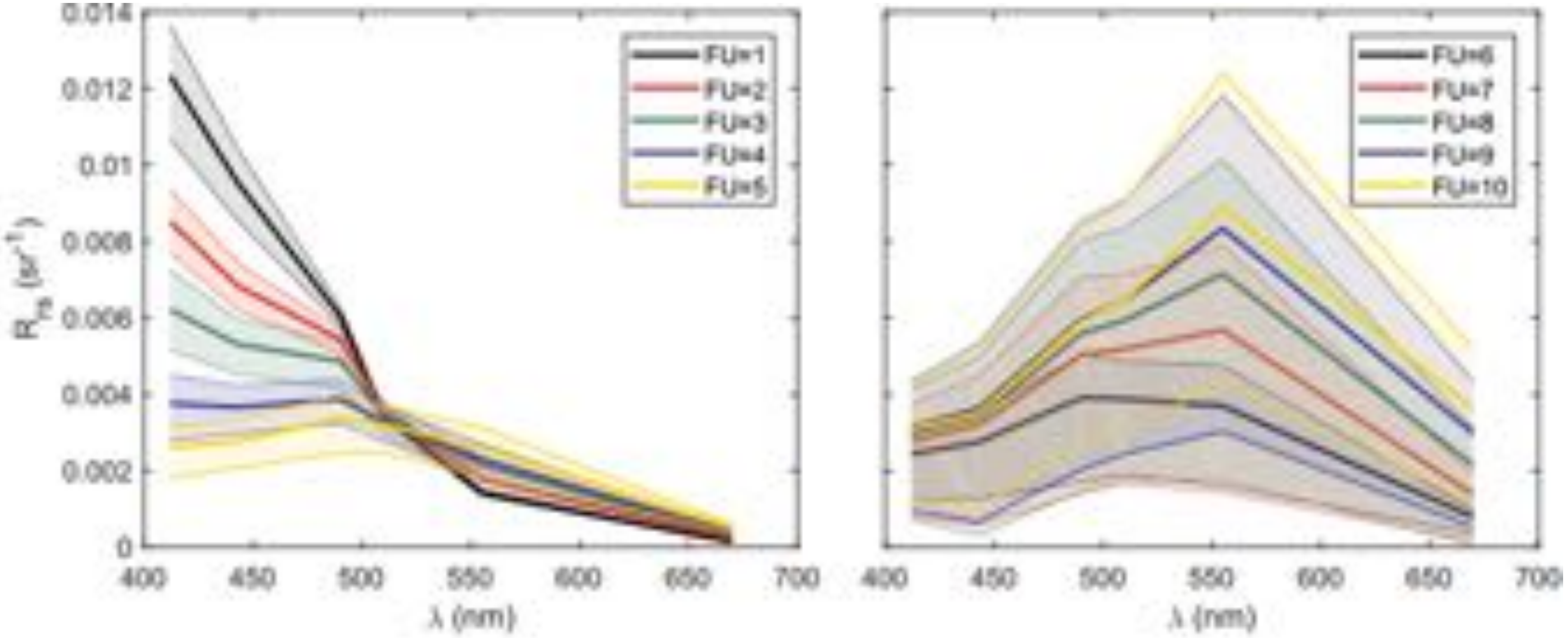


Forel-Ule color scale

- Pitarch et al. (2019)
    - Can derive Kd
    - Other parameters with increasing errors…

Deploy over white Secchi disk

Pitarch et al. (2019) RSE



Bold traces outlining gray areas are 25%-75% of cases

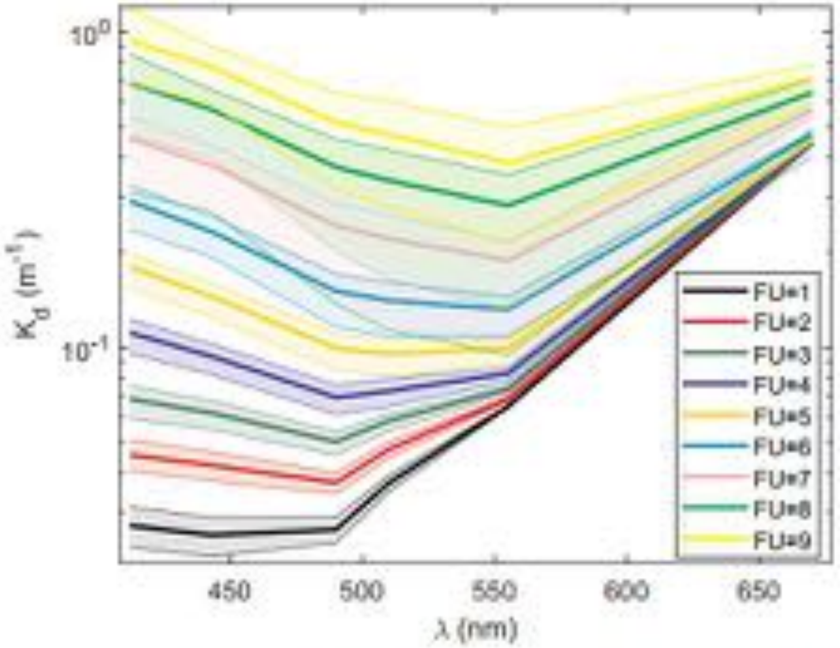


Fig. 9. Diffuse attenuation coefficient of downwelling irradiance of the first 9 FU classes, representing the median in bold line and the interval between the 25th and 75th percentiles in shaded band. For a complete description, the reader is referred to Table A2.

As an example, can derive light profiles for PAR with reasonable accuracy

Recap - derived optical parameters

can potentially solve for:

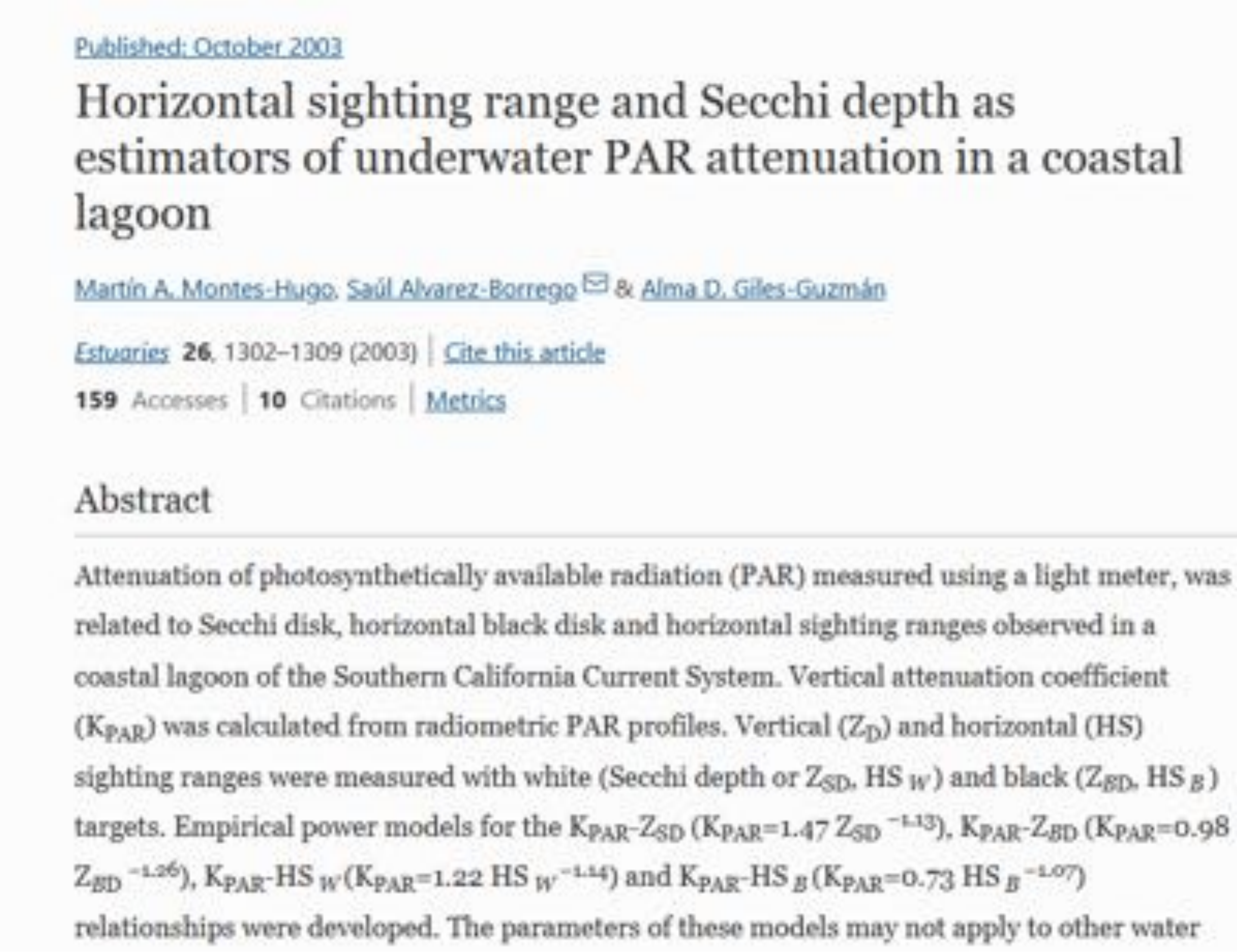
- Attenuation c
- Diffuse attenuation K_d
- Absorption a
- biogeochemical properties via proxies (or measure directly…)

Note:

$a = K\bar{\mu}$ (Gershun's Eq)

$c = a + b$

$K_d \sim a + b_b$



Published: October 2003

Horizontal sighting range and Secchi depth as estimators of underwater PAR attenuation in a coastal lagoon

Martín A. Montes-Hugo, Saúl Alvarez-Borrego & Alma D. Giles-Guzmán

Estuaries **26**, 1302–1309 (2003) | Cite this article

159 Accesses | **10** Citations | Metrics

Abstract

Attenuation of photosynthetically available radiation (PAR) measured using a light meter, was related to Secchi disk, horizontal black disk and horizontal sighting ranges observed in a coastal lagoon of the Southern California Current System. Vertical attenuation coefficient (K_{PAR}) was calculated from radiometric PAR profiles. Vertical (Z_D) and horizontal (HS) sighting ranges were measured with white (Secchi depth or Z_{SD}, HS_W) and black (Z_{BD}, HS_B) targets. Empirical power models for the K_{PAR}-Z_{SD} ($K_{PAR}=1.47\ Z_{SD}^{-1.13}$), K_{PAR}-Z_{BD} ($K_{PAR}=0.98\ Z_{BD}^{-1.26}$), K_{PAR}-HS_W ($K_{PAR}=1.22\ HS_W^{-1.14}$) and K_{PAR}-HS_B ($K_{PAR}=0.73\ HS_B^{-1.07}$) relationships were developed. The parameters of these models may not apply to other water

Inexpensive digital sensors

An ongoing revolution in inexpensive electronic and optical components, and 3D printing provides new opportunities to develop inexpensive, robust sensors.

For example:

AOPs, IOPs, turbidity, fluorescence, micro-imaging

Moorings/buoys, underway systems, citizen science

Much of the concept and content inspired by or borrowed from Emmanuel Boss

KduPRO low-cost DIY moored instrument for Kd

ORIGINAL RESEARCH article

frontiers | Frontiers in Marine Science

Front. Mar. Sci., 16 December 2022

Sec. Ocean Observation

Volume 9 - 2022 | https://doi.org/10.3389/fmars.2022.1004159

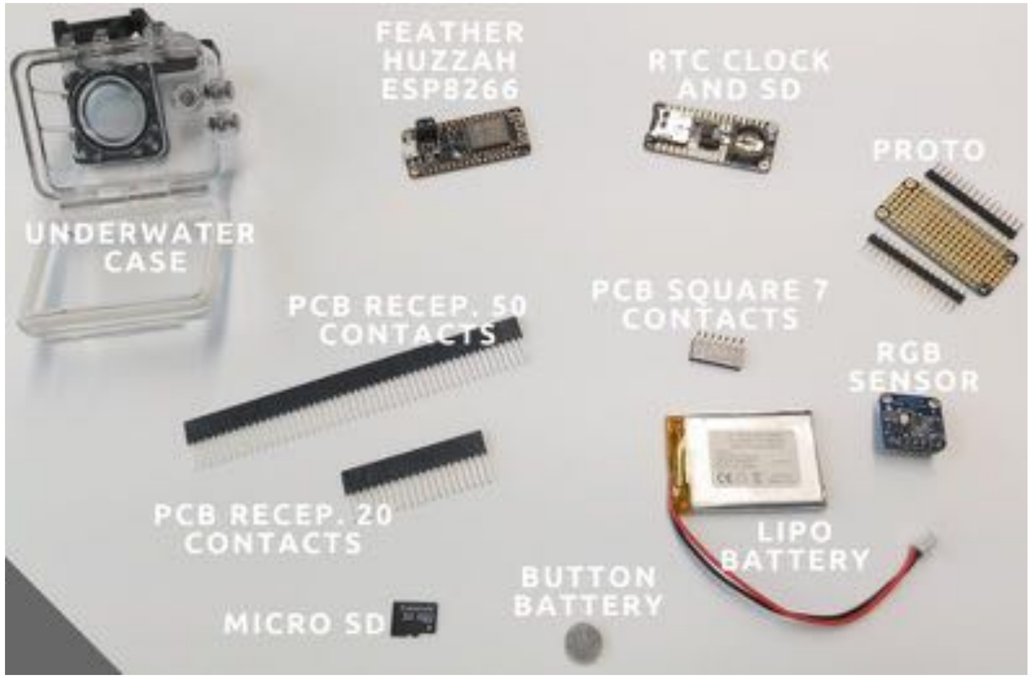
Operational monitoring of water quality with a Do-It-Yourself modular instrument

Carlos Rodero[1*] Raul Bardaji[2] Estrella Olmedo[3] Jaume Piera[1]

[1] Environmental and Sustainability Participatory Information Systems (EMBIMOS) Research Group, Department of Physical and Technological Oceanography, Institute of Marine Sciences, Spanish National Research Council (CSIC), Barcelona, Spain

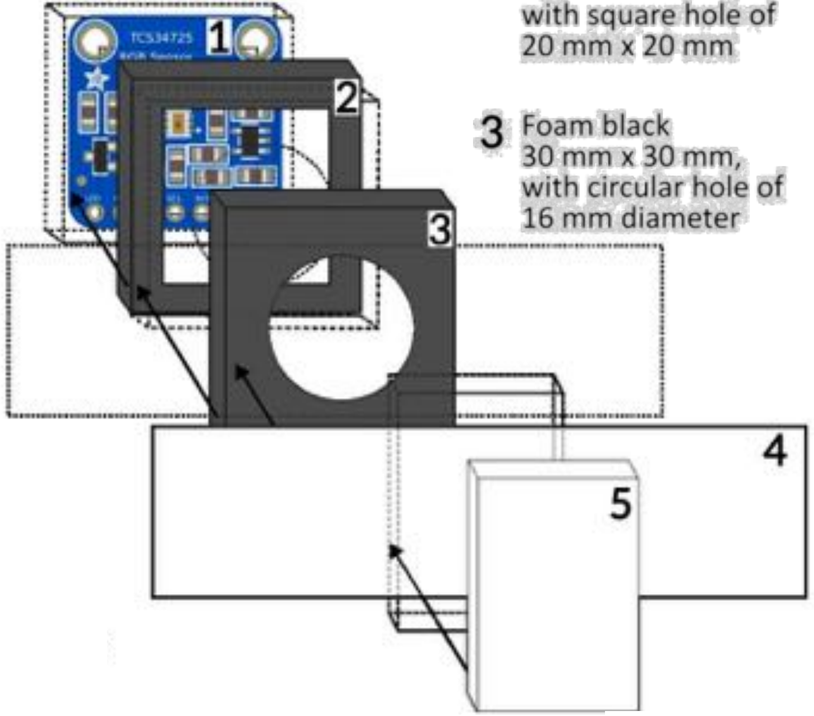
[2] Marine Technology Unit, Spanish National Research Council (CSIC), Barcelona, Spain

[3] Department of Physical and Technological Oceanography, Barcelona Expert Center, Institute of Marine Sciences, Spanish National Research Council (CSIC), Barcelona, Spain



~100 EUR parts per irradiance instrument
https://git.csic.es/kduino/kdupro

https://www.icm.csic.es/en/staff/carlos-rodero-garcia-1860



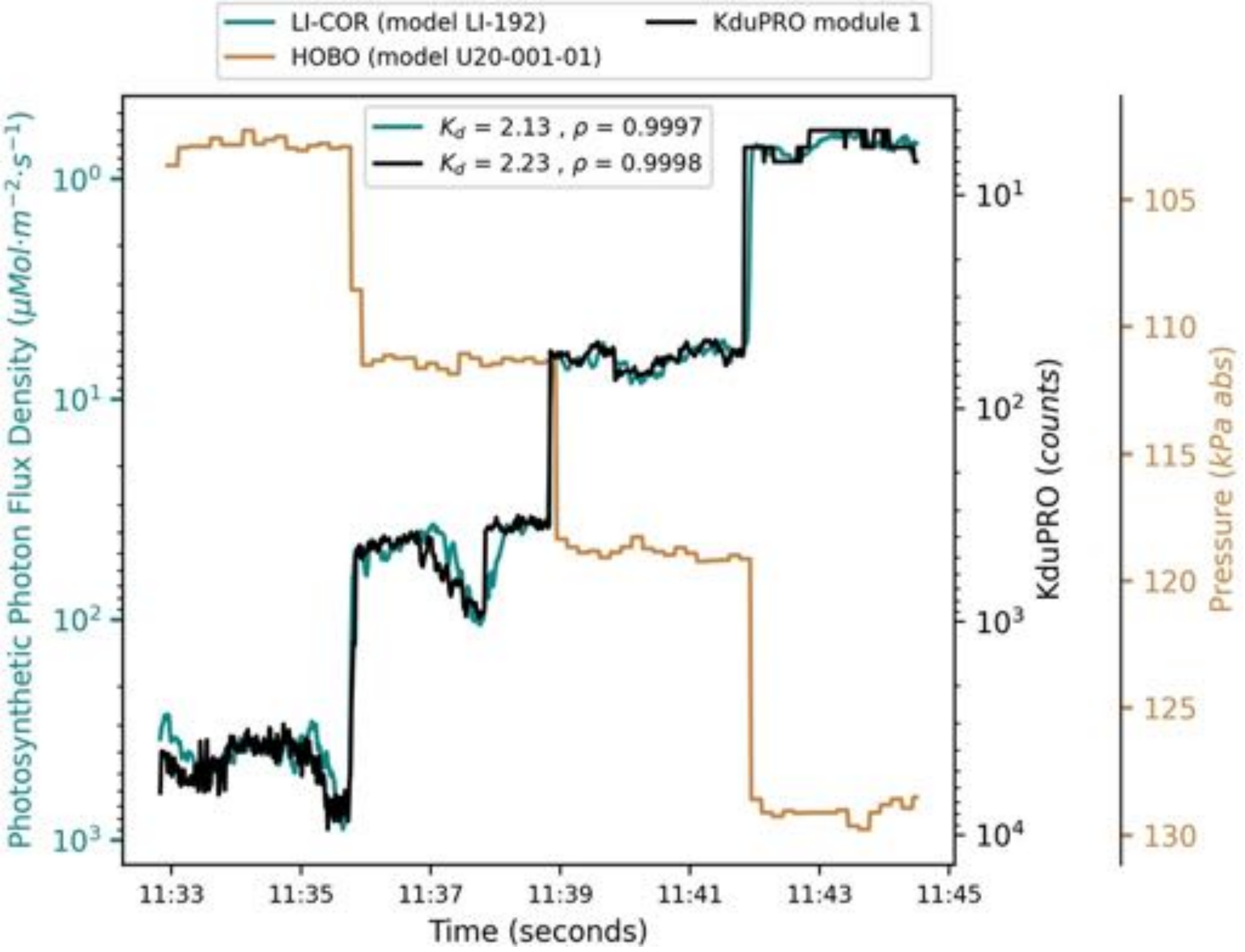
1 TCS34725 RGB
Sensor with IR filter

2 Foam black
30 mm x 30 mm,
with square hole of
20 mm x 20 mm

3 Foam black
30 mm x 30 mm,
with circular hole of
16 mm diameter

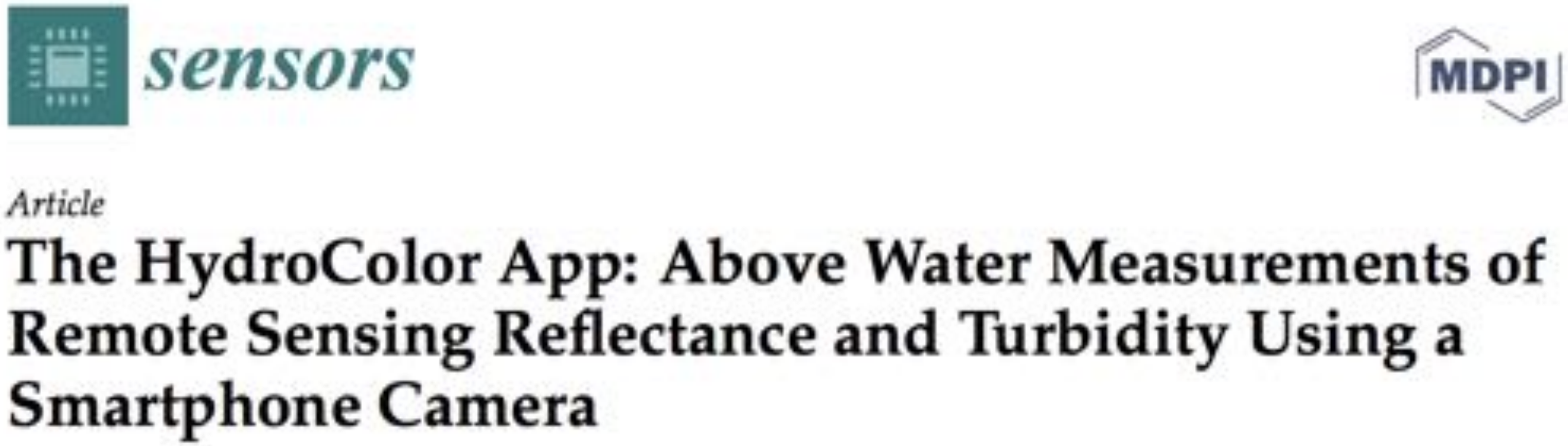
4 PTFE (polytetrafluoroethylene) tape
20 mm x 60 mm

5 Transparent glass methacrylate plate
28 mm x 20 mm



Comparison of instrument against LI-COR

Can use as profiling instrument or deploy in a customizable array



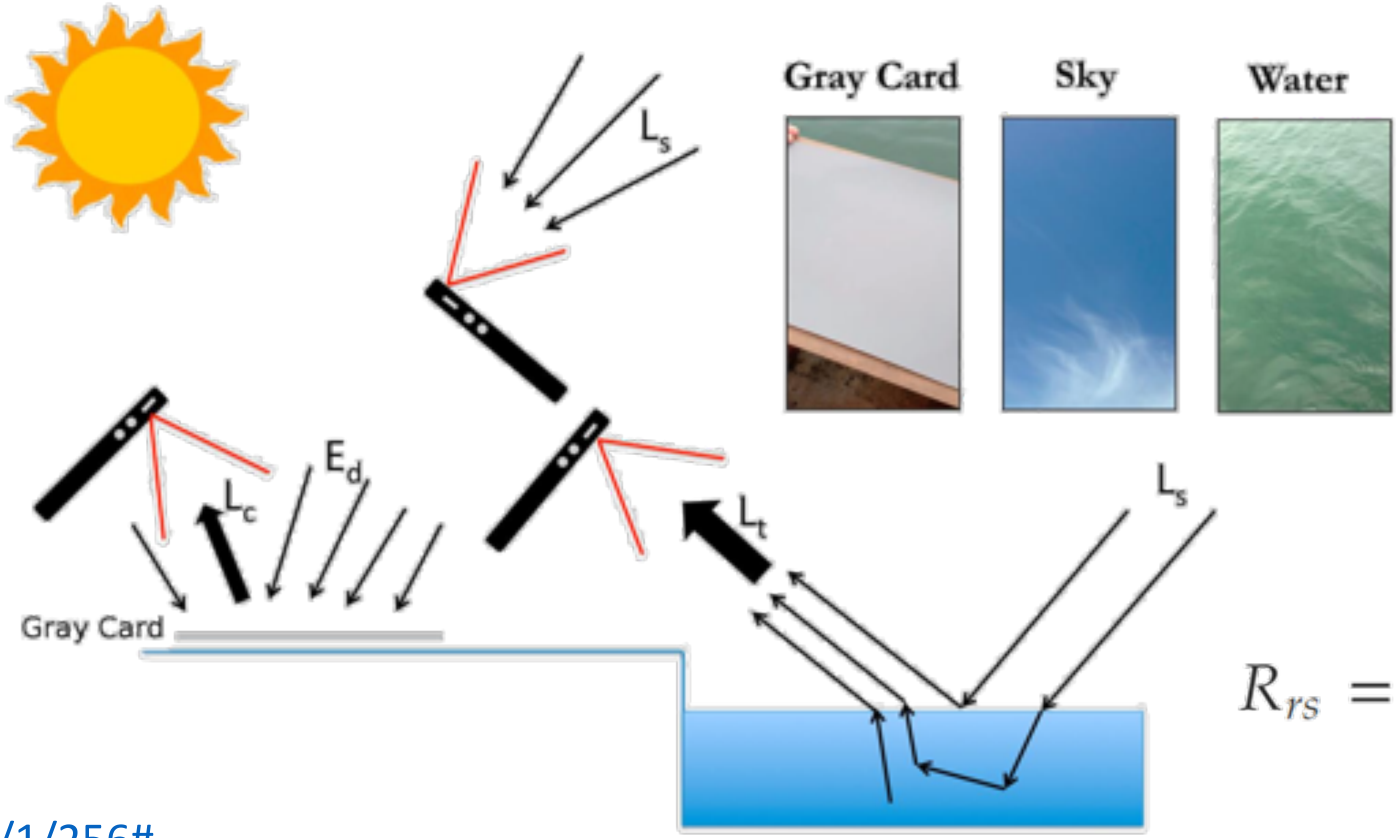
sensors

MDPI

Article

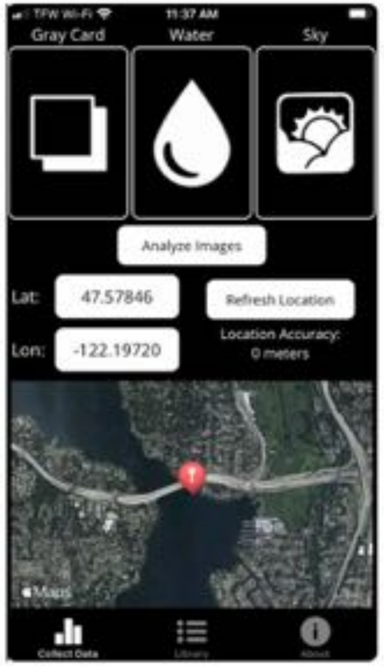
The HydroColor App: Above Water Measurements of Remote Sensing Reflectance and Turbidity Using a Smartphone Camera

Thomas Leeuw [1,*] and Emmanuel Boss [2]



$$R_{rs} = \frac{L_t - \rho L_s}{\frac{\pi}{R_{ref}} L_c}$$

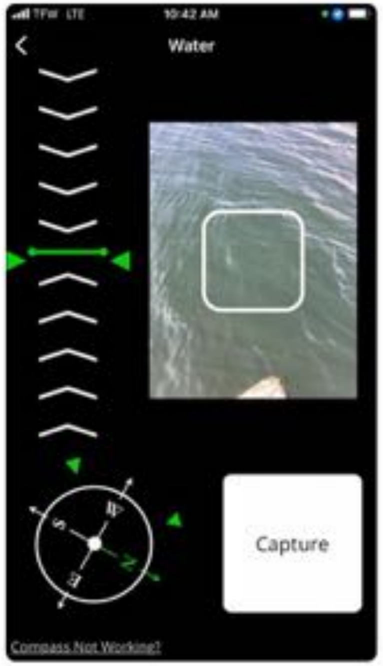
https://www.mdpi.com/1424-8220/18/1/256#



Lat: 47.57846

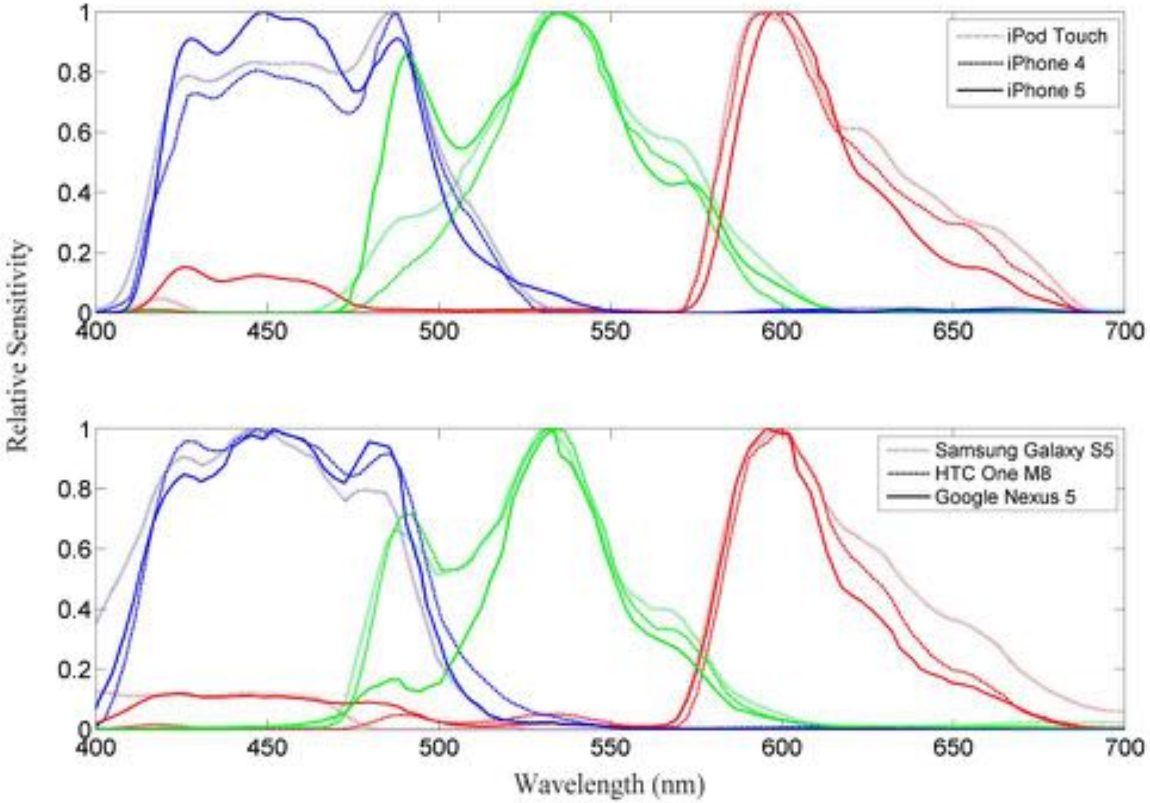
Lon: -122.19720

Location Accuracy:
0 meters



Date:	3/5/2023	
Time:	10:41:32 AM	Local
Lat:	47.57848	Deg.
Lon:	-122.19715	Deg.
Turbidity:	1 ± 1	NTU
SPM:	1 ± 1	mg/L

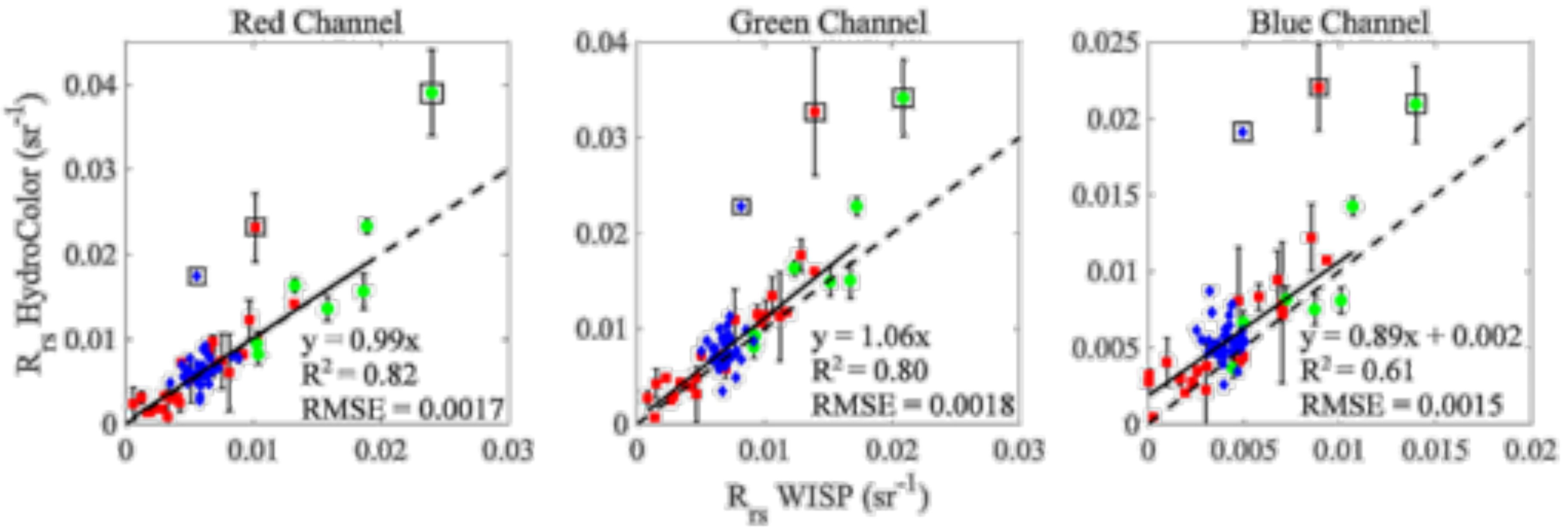
Characterization of phone cameras



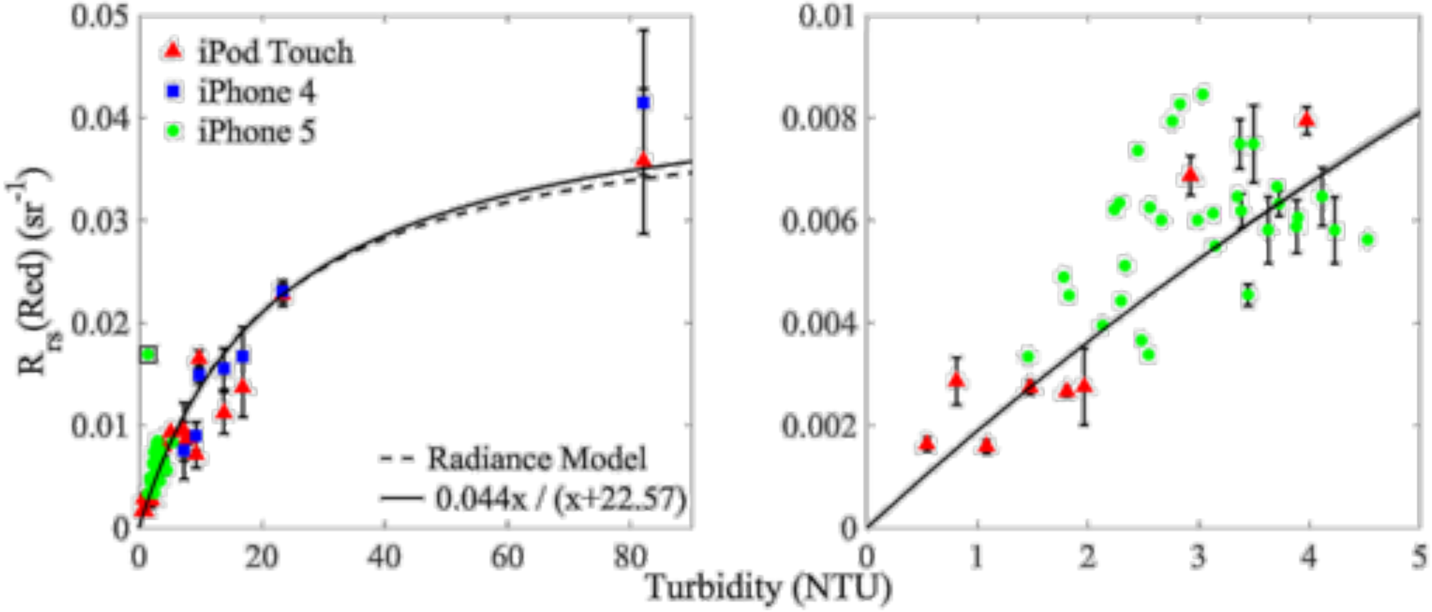
HydroColor

https://play.google.com/store/apps/details?id=com.h2optics.hydrocolor
https://apps.apple.com/us/app/hydrocolor-water-quality-app/id816427169

Comparison of HydroColor Rrs with WISP Rrs



Relationship between turbidity and HydroColor Rrs(red)



remote sensing

MDPI

Article

Is Ocean Reflectance Acquired by Citizen Scientists Robust for Science Applications?

Yuyan Yang [1,*], Laura L.E. Cowen [1] and Maycira Costa [2]

Mounted Hyper-SAS on BC ferry, compared against HdroColor data from trained and untrained users

> “The main findings show that the HydroColor citizen data are accurate compared with hyperspectral instrument data for most bands and band ratios; however, citizen level of training and environmental conditions play a role in the data quality.”

https://www.mdpi.com/2072-4292/10/6/835

pySAS

AUTONOMOUS SOLAR TRACKING SYSTEM FOR SURFACE WATER RADIOMETRIC MEASUREMENTS

By Nils Haëntjens, Kyle Forsythe, Bradley Denholm, James Loftin, and Emmanuel Boss

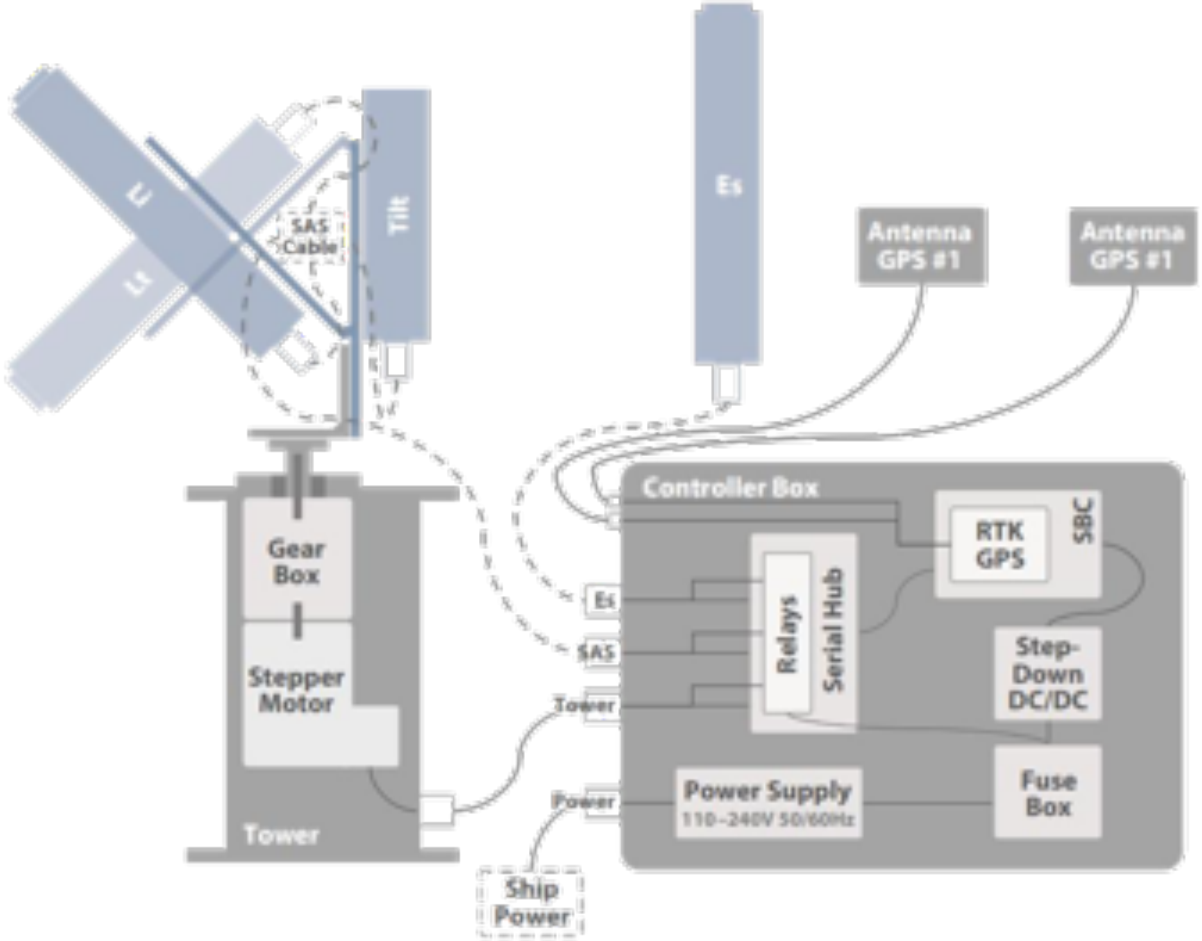


FIGURE 1. Schematic of pySAS hardware, not to scale. The Sea-Bird Scientific HyperSAS radiometers, tilt sensor, support (colored in blue), and cables (dashed) are not included in the pySAS materials list.

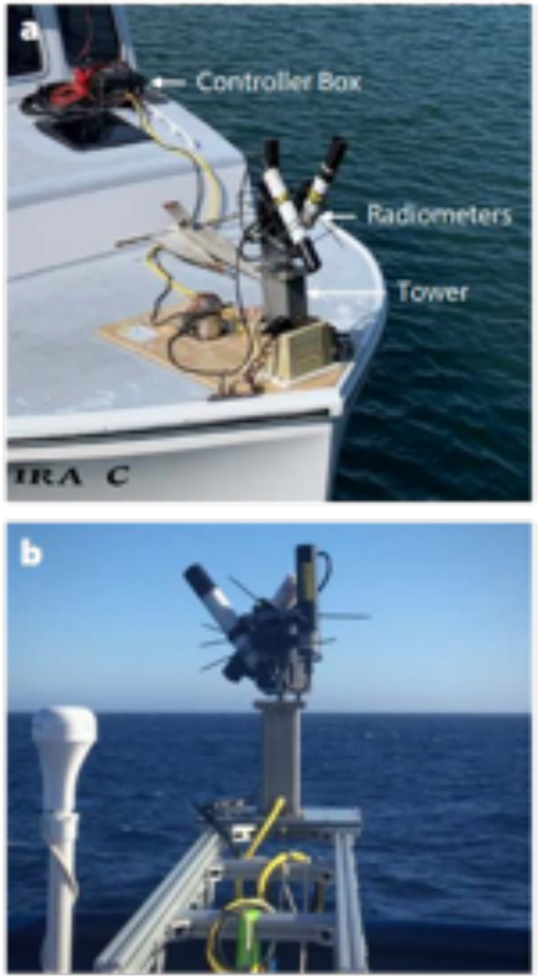
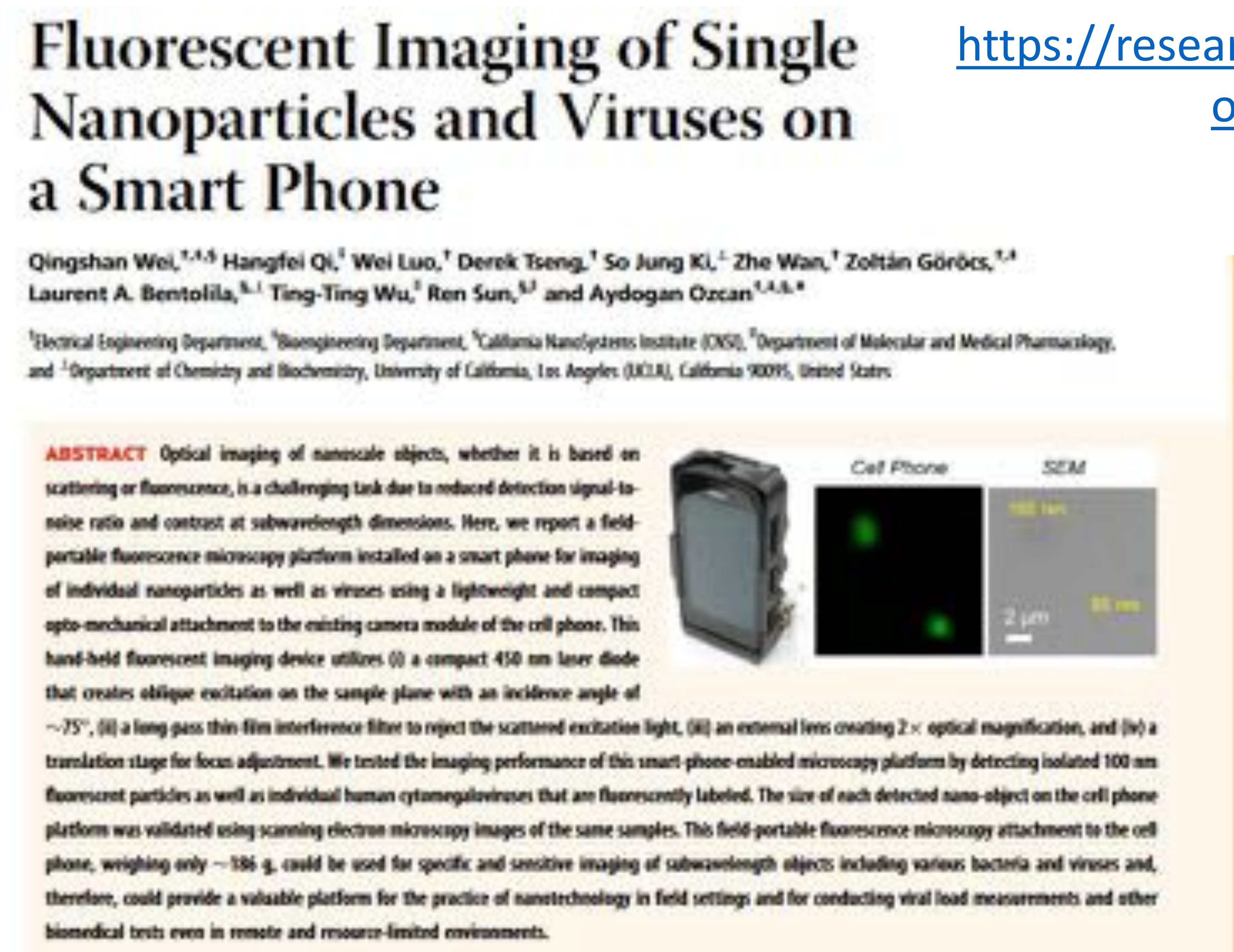


FIGURE 2. pySAS was mounted on the bows of (a) R/V *Ira C* and (b) R/V *Roger Revelle*.

https://doi.org/10.5670/oceanog.2022.210

https://github.com/OceanOptics/pySAS

https://research.seas.ucla.edu/ozcan/



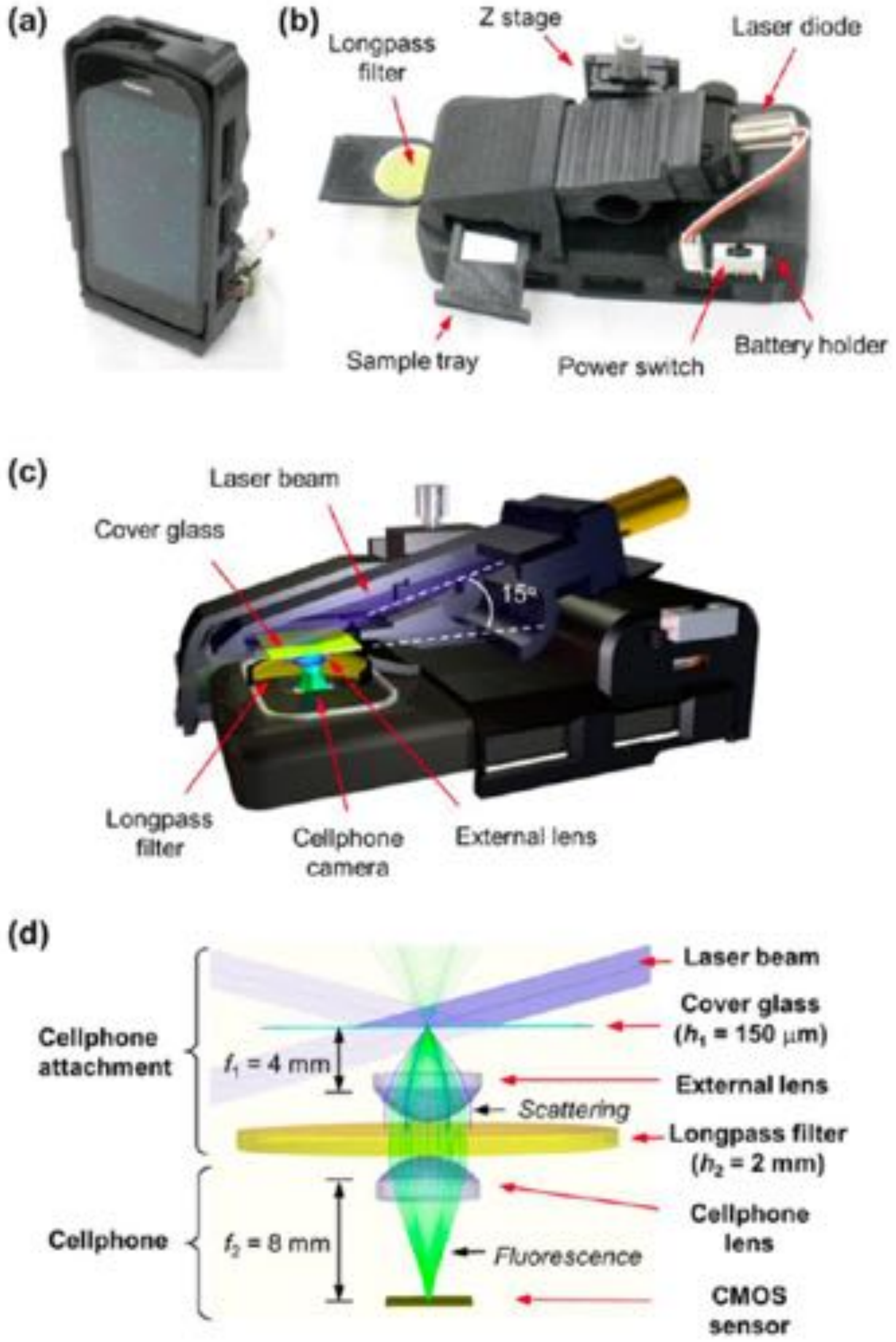
Fluorescent Imaging of Single Nanoparticles and Viruses on a Smart Phone

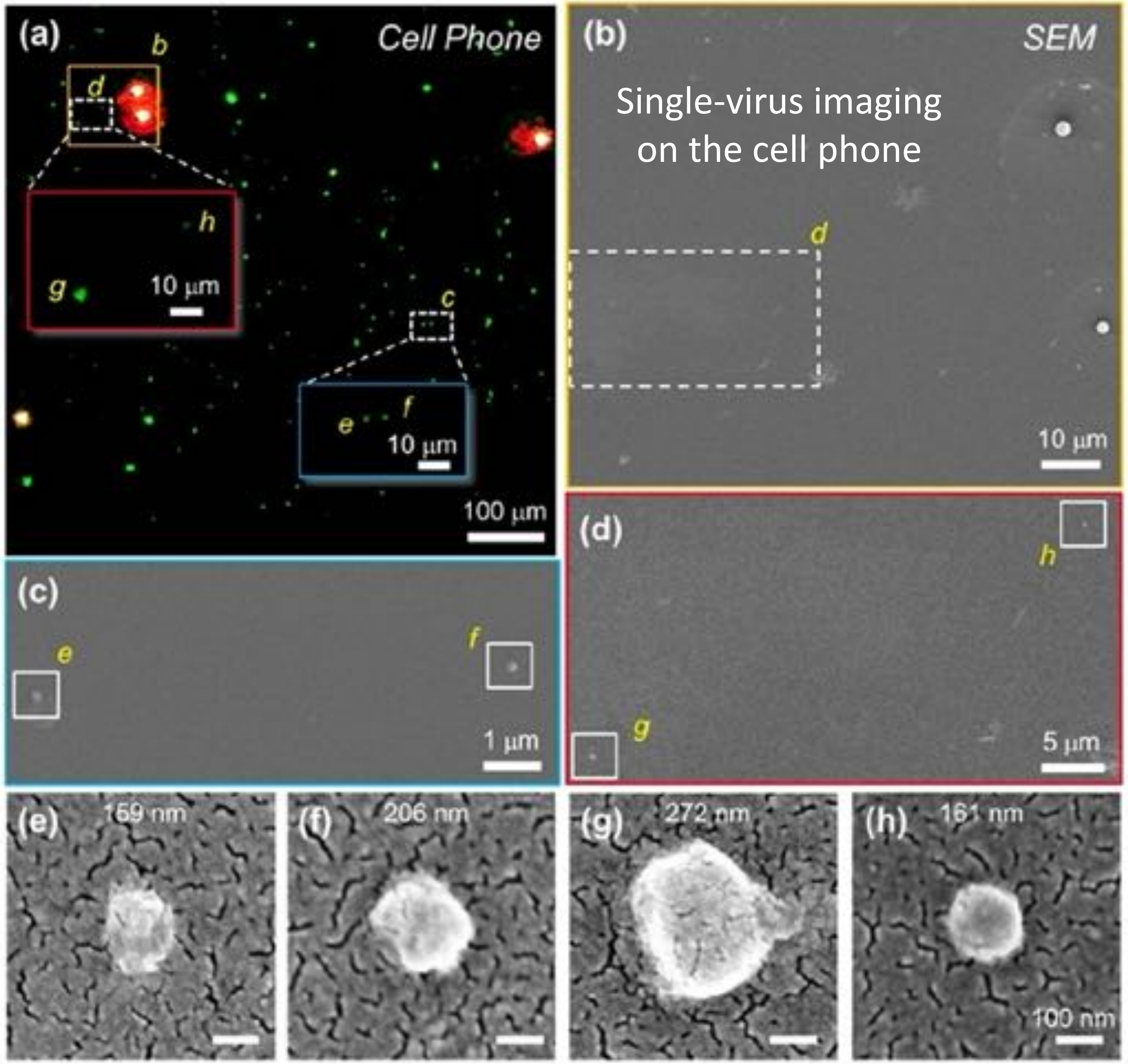
Qingshan Wei,[†,‡,§] Hangfei Qi,[∥] Wei Luo,[†] Derek Tseng,[†] So Jung Ki,[⊥] Zhe Wan,[†] Zoltán Göröcs,[†,‡] Laurent A. Bentolila,[§,⊥] Ting-Ting Wu,[∥] Ren Sun,[§,∥] and Aydogan Ozcan[†,‡,§,*]

[†]Electrical Engineering Department, [‡]Bioengineering Department, [§]California NanoSystems Institute (CNSI), [∥]Department of Molecular and Medical Pharmacology, and [⊥]Department of Chemistry and Biochemistry, University of California, Los Angeles (UCLA), California 90095, United States

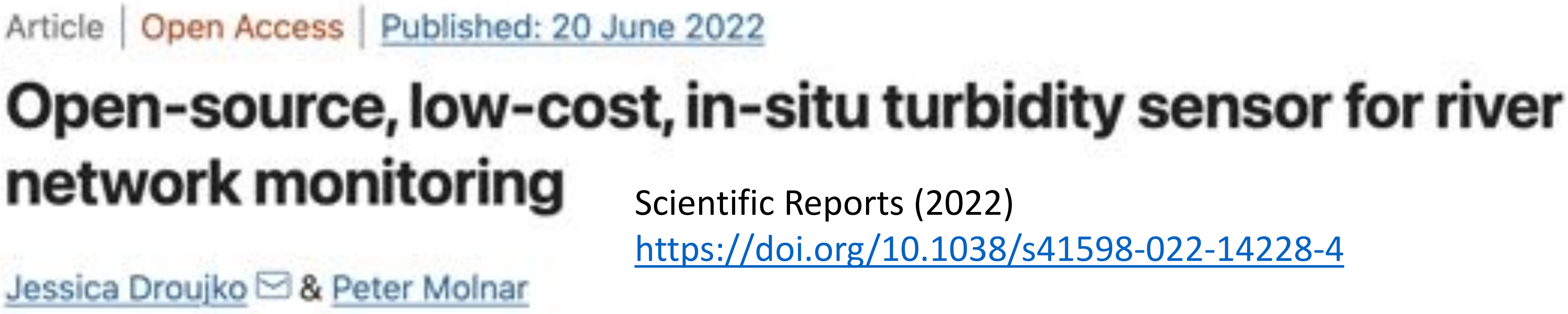
ABSTRACT Optical imaging of nanoscale objects, whether it is based on scattering or fluorescence, is a challenging task due to reduced detection signal-to-noise ratio and contrast at subwavelength dimensions. Here, we report a field-portable fluorescence microscopy platform installed on a smart phone for imaging of individual nanoparticles as well as viruses using a lightweight and compact opto-mechanical attachment to the existing camera module of the cell phone. This hand-held fluorescent imaging device utilizes (i) a compact 450 nm laser diode that creates oblique excitation on the sample plane with an incidence angle of ~75°, (ii) a long-pass thin-film interference filter to reject the scattered excitation light, (iii) an external lens creating 2× optical magnification, and (iv) a translation stage for focus adjustment. We tested the imaging performance of this smart-phone-enabled microscopy platform by detecting isolated 100 nm fluorescent particles as well as individual human cytomegaloviruses that are fluorescently labeled. The size of each detected nano-object on the cell phone platform was validated using scanning electron microscopy images of the same samples. This field-portable fluorescence microscopy attachment to the cell phone, weighing only ~186 g, could be used for specific and sensitive imaging of subwavelength objects including various bacteria and viruses and, therefore, could provide a valuable platform for the practice of nanotechnology in field settings and for conducting viral load measurements and other biomedical tests even in remote and resource-limited environments.

ACS Nano (2003)
https://doi.org/10.1021/nn4037706





Single-virus imaging on the cell phone

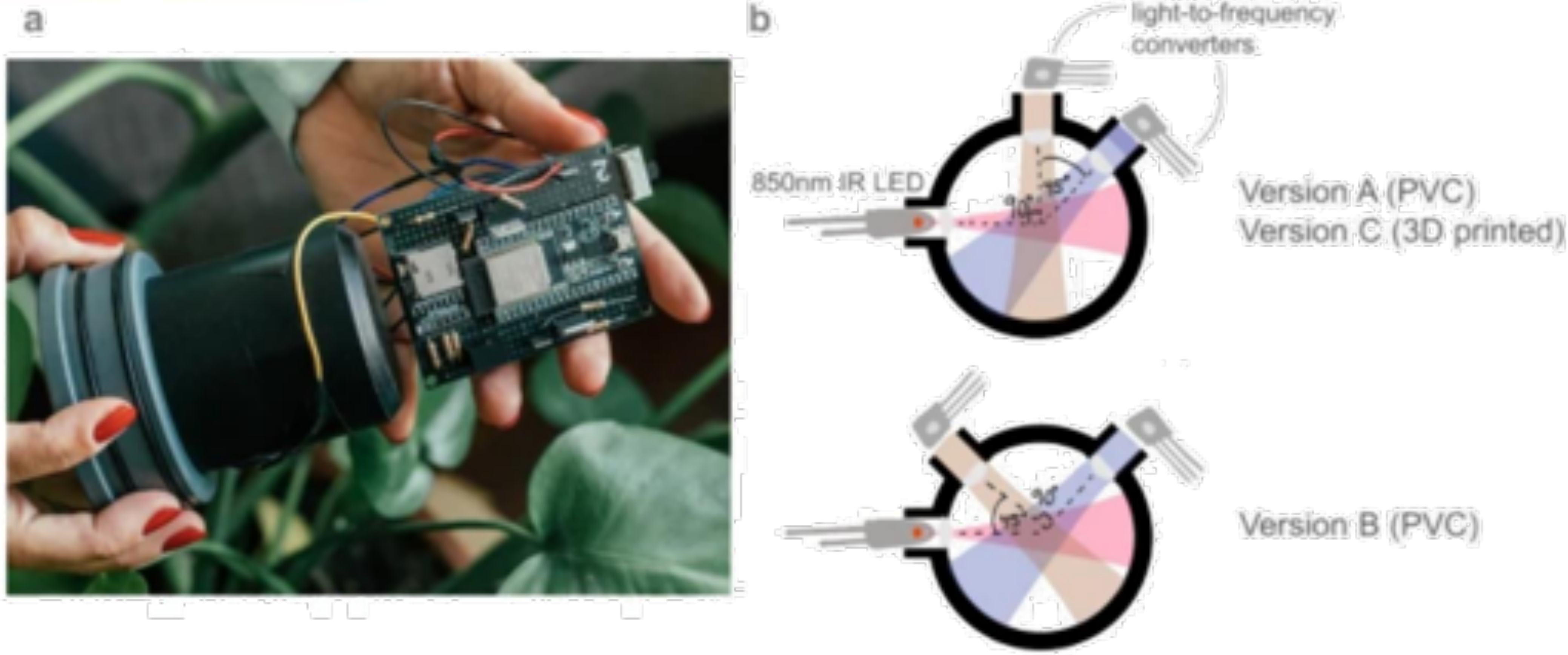


Article | Open Access | Published: 20 June 2022

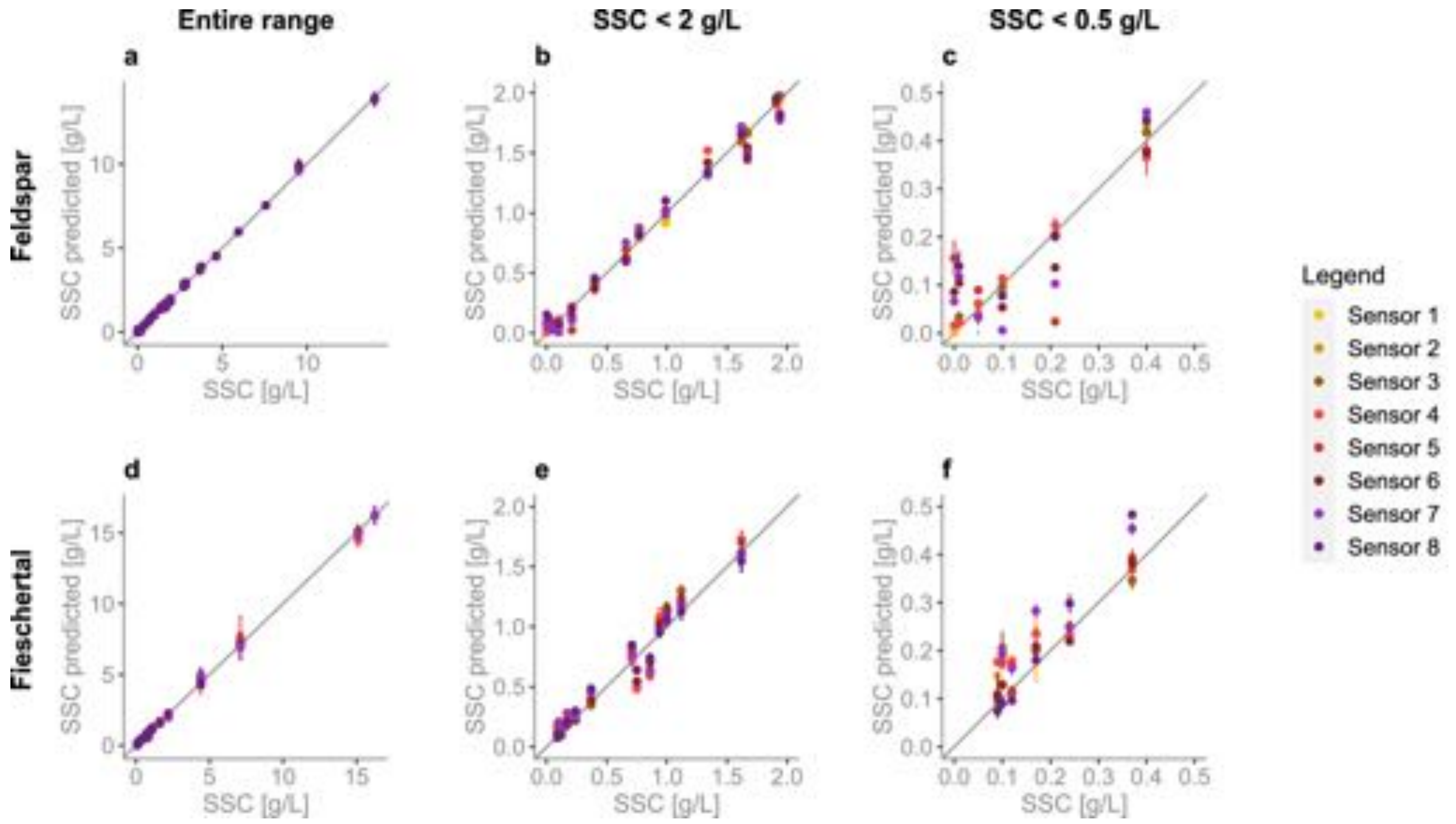
Open-source, low-cost, in-situ turbidity sensor for river network monitoring

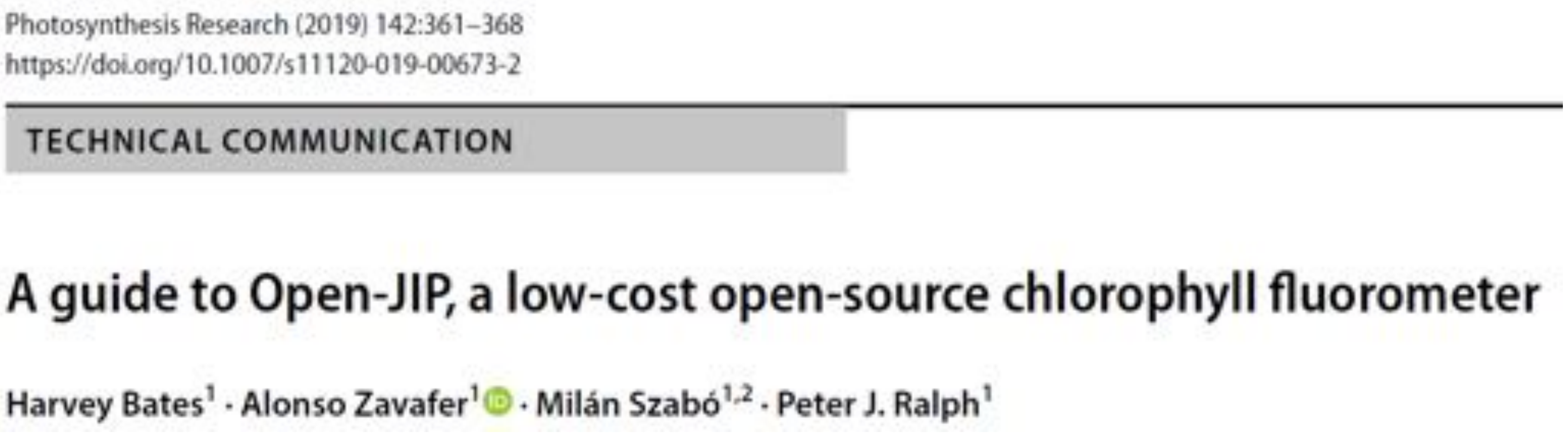
Jessica Droujko ✉ & Peter Molnar

Scientific Reports (2022)
https://doi.org/10.1038/s41598-022-14228-4



SSC measured vs. predicted for Feldspar (a–c) and Fieschertal (d–f) sediments (fourth order multiple linear regression SSC models)



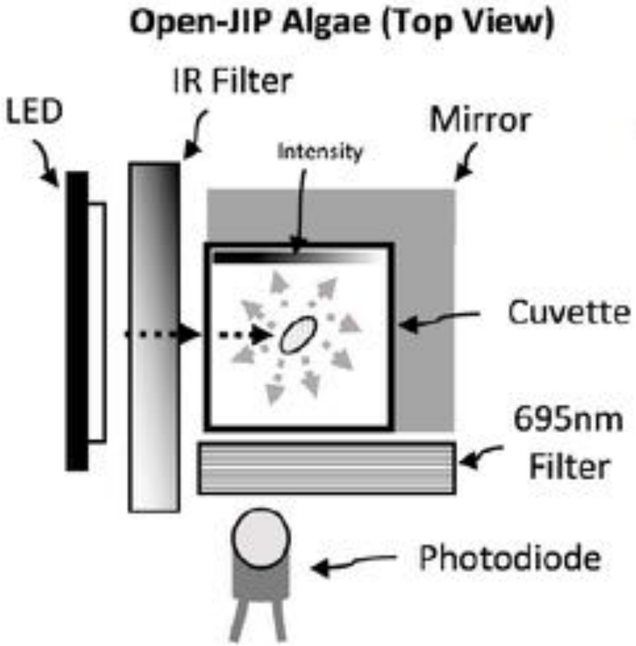


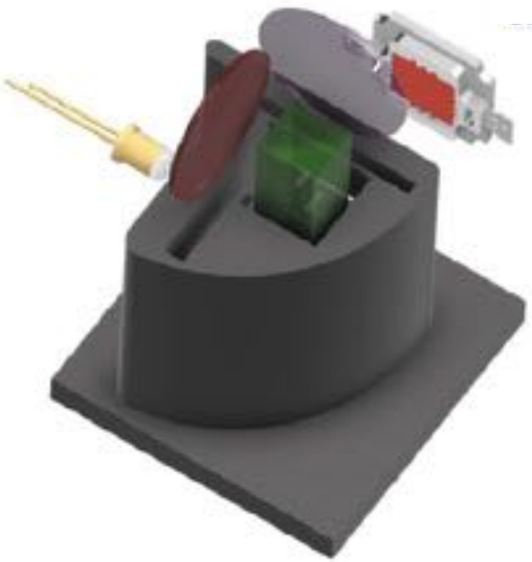
Photosynthesis Research (2019) 142:361–368
https://doi.org/10.1007/s11120-019-00673-2

TECHNICAL COMMUNICATION

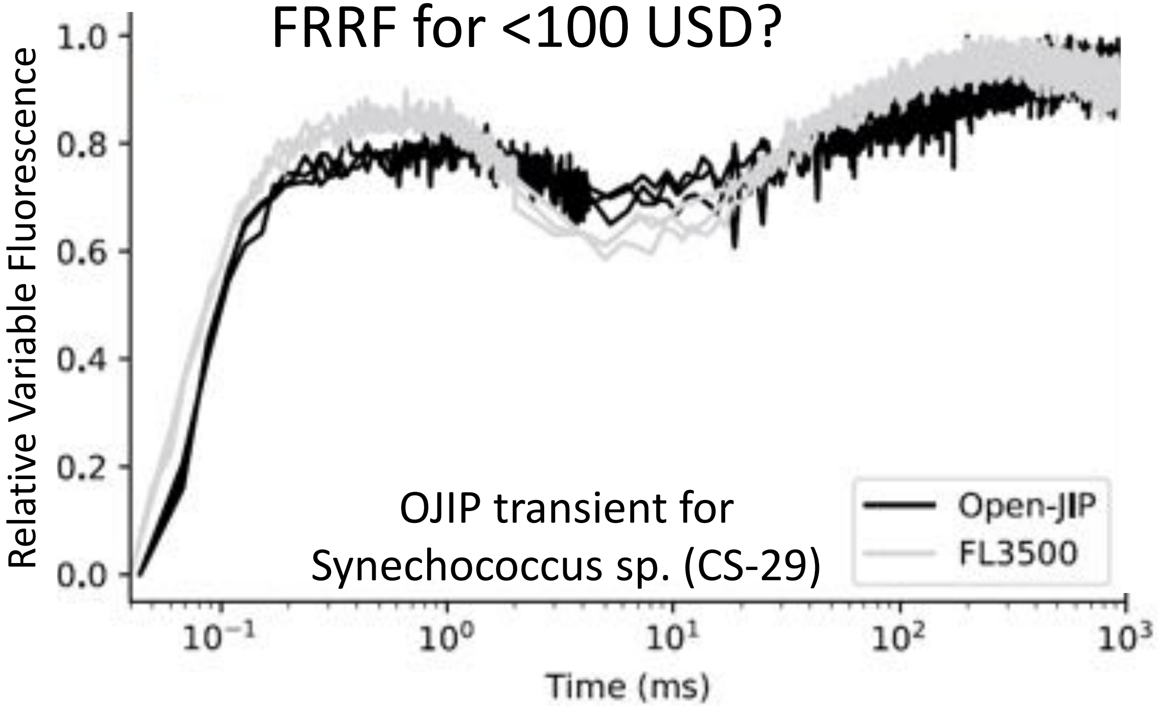
A guide to Open-JIP, a low-cost open-source chlorophyll fluorometer

Harvey Bates[1] · Alonso Zavafer[1] · Milán Szabó[1,2] · Peter J. Ralph[1]



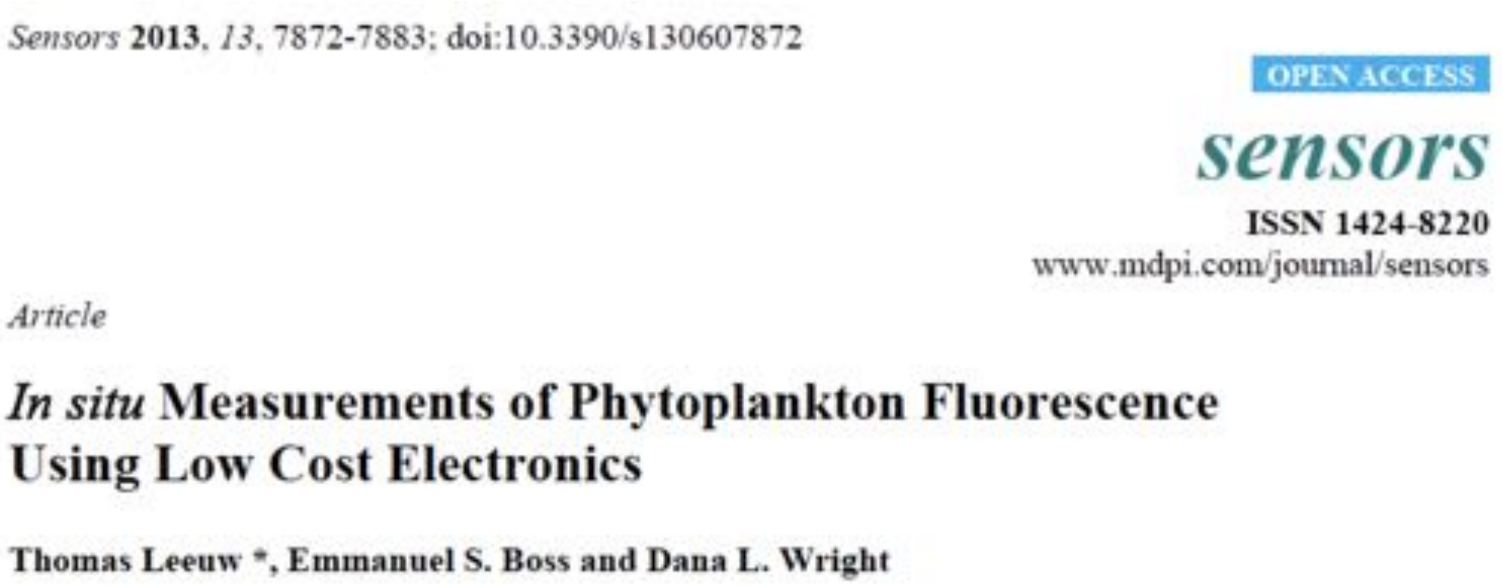


FRRF for <100 USD?



OJIP transient for
Synechococcus sp. (CS-29)

https://github.com/Open-JIP/Open-JIP



Sensors **2013**, *13*, 7872-7883; doi:10.3390/s130607872

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sensors

ISSN 1424-8220

www.mdpi.com/journal/sensors

Article

In situ Measurements of Phytoplankton Fluorescence Using Low Cost Electronics

Thomas Leeuw *, Emmanuel S. Boss and Dana L. Wright

Simple in situ fluorometer in an OtterBox, ~150 USD

Handheld turbidity instrument in 3D printed case, <50 USD

Sensors **2014**, *14*, 7142-7155; doi:10.3390/s140407142

OPEN ACCESS

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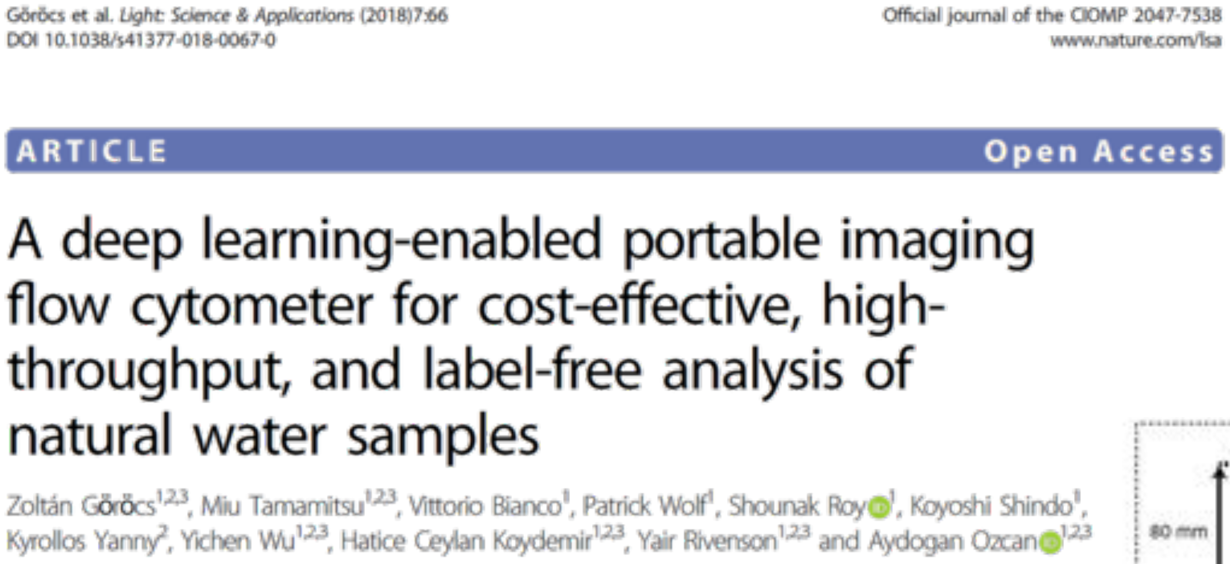
ISSN 1424-8220

www.mdpi.com/journal/sensors

Article

An Affordable Open-Source Turbidimeter

Christopher D. Kelley [1,*], Alexander Krolick [2], Logan Brunner [1], Alison Burklund [1], Daniel Kahn [1], William P. Ball [1] and Monroe Weber-Shirk [3]



Göröcs et al. *Light: Science & Applications* (2018)7:66
DOI 10.1038/s41377-018-0067-0

Official journal of the CIOMP 2047-7538
www.nature.com/lsa

ARTICLE Open Access

A deep learning-enabled portable imaging flow cytometer for cost-effective, high-throughput, and label-free analysis of natural water samples

Zoltán Göröcs[1,2,3], Miu Tamamitsu[1,2,3], Vittorio Bianco[1], Patrick Wolf[1], Shounak Roy[1], Koyoshi Shindo[1], Kyrollos Yanny[2], Yichen Wu[1,2,3], Hatice Ceylan Koydemir[1,2,3], Yair Rivenson[1,2,3] and Aydogan Ozcan[1,2,3]

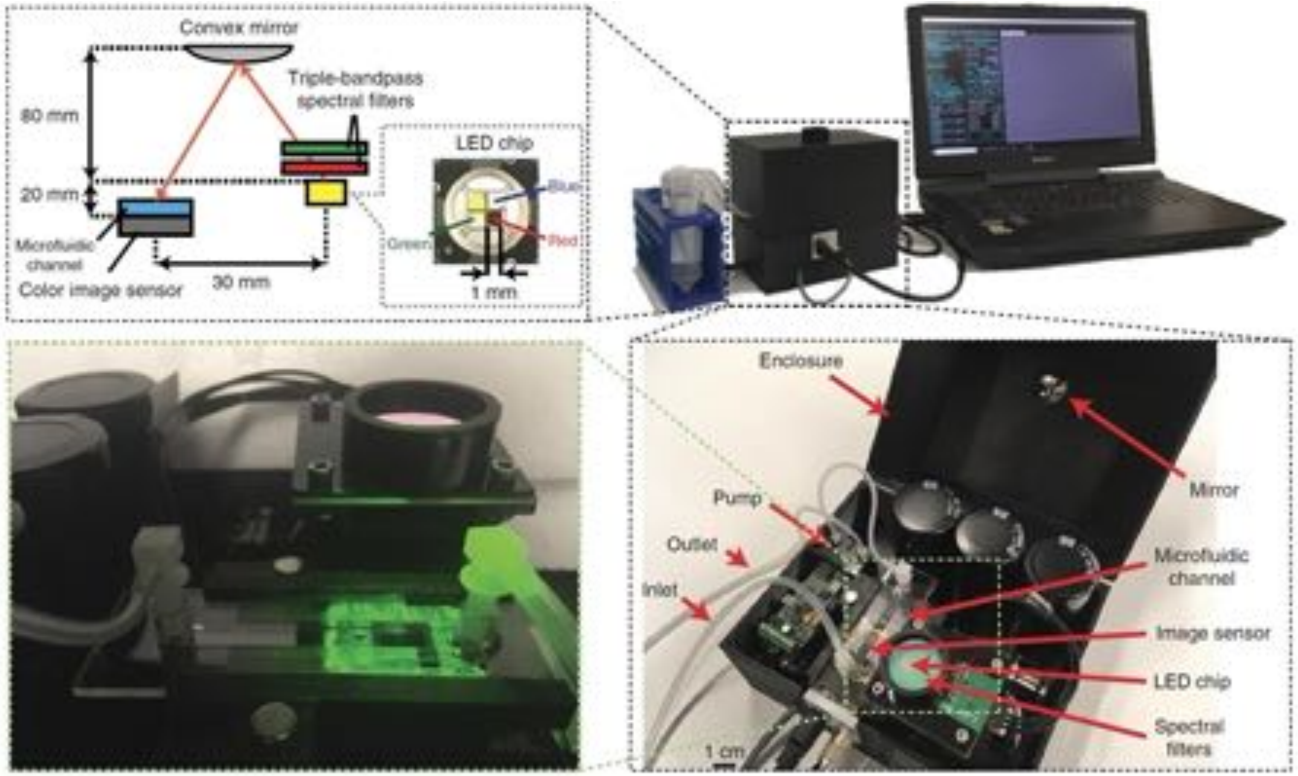


Fig. 1 Photos and schematic of the imaging flow cytometer device. The water sample is constantly pumped through the microfluidic channel at a rate of 100 mL/h during imaging. The illumination is emitted *simultaneously* from red, green, and blue LEDs in 120-μs pulses and triggered by the camera. Two triple-bandpass filters are positioned above the LEDs, and the angle of incidence of the light on the filters is adjusted to create a <12 nm bandpass in each wavelength to achieve adequate temporal coherence. The light is reflected from a convex mirror before reaching the sample to increase its spatial coherence while allowing a compact and lightweight optical setup

Patent pending, but cost of parts for instrument could be <2500 USD


b-1
100 µm
b-2
100 µm
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100 µm
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b-5
100 µm
b-6
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frontiers | Frontiers in Marine Science

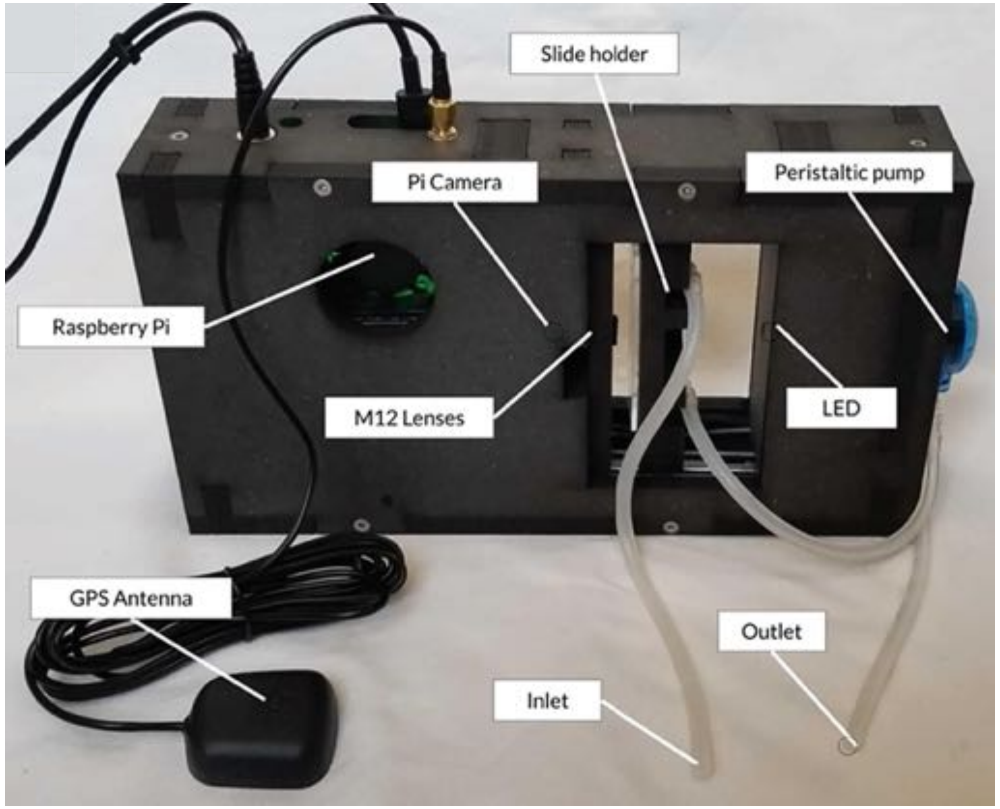
METHODS
published: 22 July 2022
doi: 10.3389/fmars.2022.949428

PlanktoScope: Affordable Modular Quantitative Imaging Platform for Citizen Oceanography

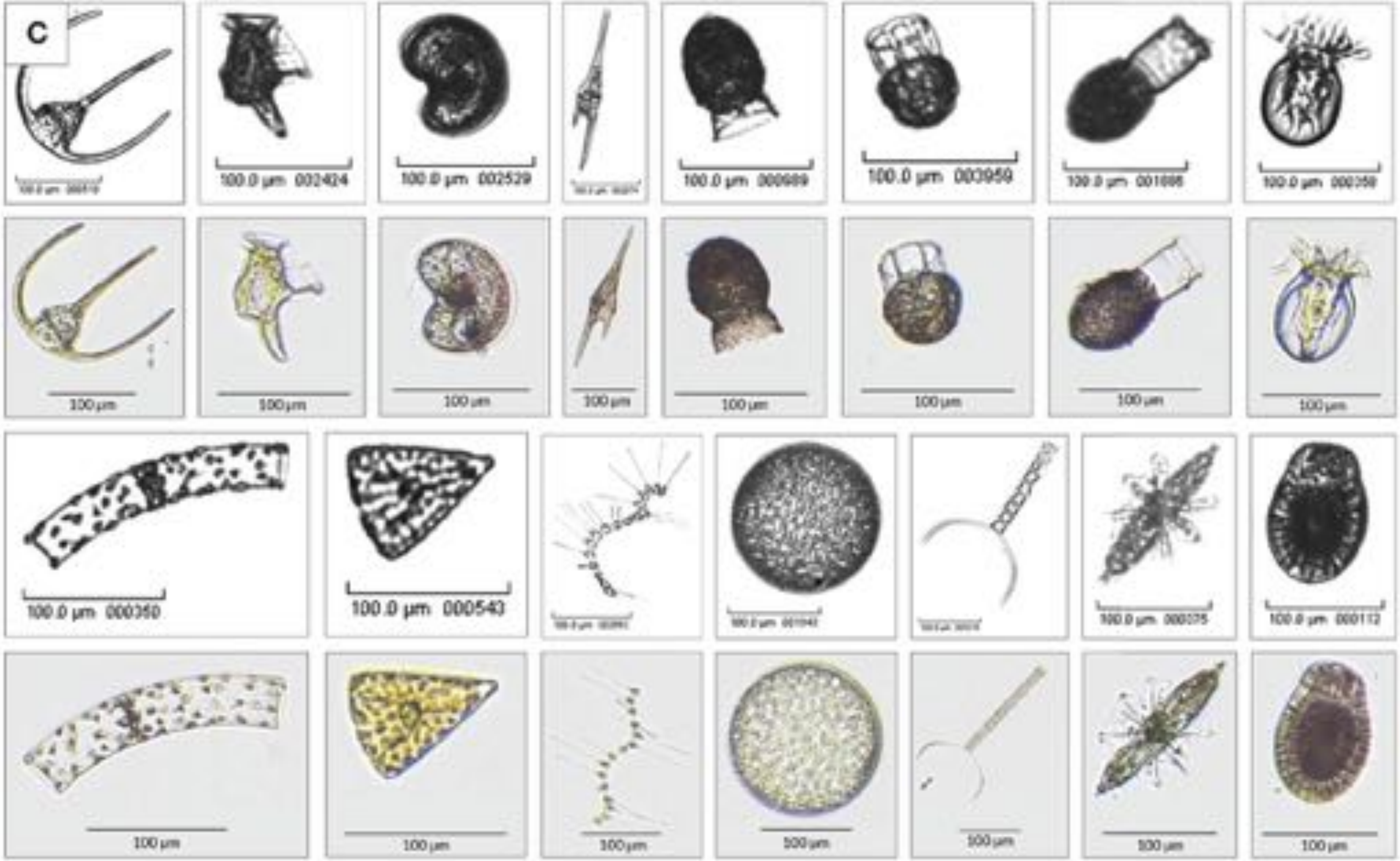
Thibaut Pollina[1,2†], Adam G. Larson[1,2†], Fabien Lombard[2,3,4,5], Hongquan Li[1], David Le Guen[2], Sébastien Colin[2,6], Colomban de Vargas[2,3,7] and Manu Prakash[1,2*]*

https://github.com/PlanktoScope/PlanktoScope

https://www.planktoscope.org/



Benchmarking PlanktoScope against commercial FlowCam



Color images: PlanktoScope
Mono images: FlowCam

Inlinino

A MODULAR SOFTWARE DATA LOGGER FOR OCEANOGRAPHY

By Nils Haëntjens and Emmanuel Boss

Oceanography (2020)
DIY-Oceanography

https://inlinino.readthedocs.io/en/latest/

Using IoT tools to broadcast data to phones/tablets

Software based datalogger.

Time stamps and logs data from analog and digital sensors

Graphical interface – real time data

Works on PCs, Macs and Linux

Used to log: AC-S, LISST, Eco-bb3, Seapoint fluoromter, Hyper-bb, CTD… All simultaneously on the same computer.

Buoy system using chains of compact, off-the-shelf Hobo loggers

Aquacultural Engineering 80 (2018) 28–36

Contents lists available at ScienceDirect

Aquacultural Engineering

journal homepage: www.elsevier.com/locate/aque

Design and operation of a low-cost and compact autonomous buoy system for use in coastal aquaculture and water quality monitoring

Wiebke Schmidt[a,b,*], David Raymond[b], David Parish[b], Ian G.C. Ashton[a,b], Peter I. Miller[c], Carlos J.A. Campos[d], Jamie D. Shutler[a]

Hindawi Publishing Corporation
Journal of Sensors
Volume 2015, Article ID 920168, 23 pages
http://dx.doi.org/10.1155/2015/920168

Research Article

Oceanographic Multisensor Buoy Based on Low Cost Sensors for Posidonia Meadows Monitoring in Mediterranean Sea

Sandra Sendra, Lorena Parra, Jaime Lloret, and José Miguel Jiménez

Homegrown sensors...

Final Thoughts

These are only a few examples… Expect to see many more disruptive developments in ocean optics and ocean sciences in places like GitHub in the future!

An ongoing revolution in inexpensive electronic and optical components and 3D printing provides new opportunities to develop inexpensive, robust sensors

Robust analog methods exist for potentially determining c and K… a, b, b_b may also be potentially derived

Validation and closure between methods is highly desirable to quantify uncertainties

Analog methods are useful if expensive optical sensors are not available for research, but can also be very useful metrics as a gut check on highest quality measurements

Many applications relating to water quality and imaging can accommodate larger uncertainties associated with many of these methods