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 a key tool for researchers assessing the quality of aquatic environments and their ongoing changes due to human activities and climate change.

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.

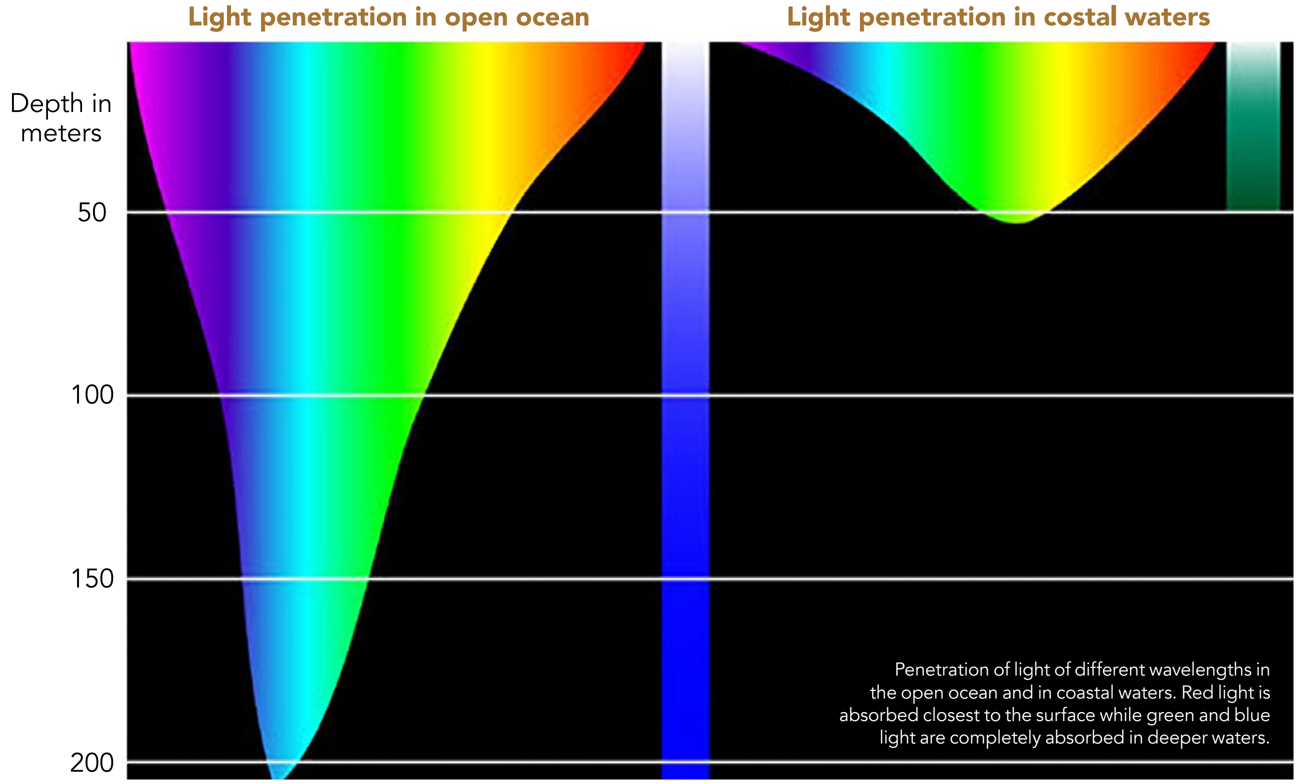
Among the most popular and important probes for the quality of water is its clarity – defined as the depth to which an object in water can still be observed at the surface. This depth is subject mainly to the absorption of constituents in water, where the absorption process doesn't occur all at once in the ocean: due to their longer wavelengths, photons of red light will be absorbed closest to the water's surface. Deeper down, photons towards the blue end of the visible spectrum will then be completely absorbed, until no visible light remains. Depending on the properties of the water, the depths of this clarity can vary significantly and will generally decrease as the water quality becomes worse. In their assessments, therefore, it is important for oceanographers to measure the depths as precisely as possible.

MEASURING SECCHI DEPTHS

In 1865, an Italian priest named Angelo Secchi, also noted for his work in astronomy, devised a simple yet highly effective technique for measuring these depths. His method was based around a plain, circular disk, measuring 30 centimetres across. His original disk was completely white, though later designs divided the disk into alternating black and white quarters. When the disk is dipped just beneath the surface of water, it initially primarily reflects the sun's light – and continues to appear white to an observer. Yet as it is lowered deeper into the oceanic waters, redder wavelengths will be absorbed by the water before being reflected by the disk, and the disk will appear greener. Eventually, there will be too few photons reflected for human eyes to detect, and the disk will disappear entirely.

Angelo Secchi was a priest and astronomer.

The point at which the disk is no longer discernible by human eyes is called the 'Secchi disk depth' or 'Secchi depth', and provides a robust technique for researchers assessing the quality of water. Since Secchi's lifetime, a wide variety of more sophisticated technologies have been developed, exploiting the latest advances in optics and electronics – yet many clear advantages of Secchi disks remain. Not only is the technique inexpensive and easy to operate in the field, the body of data it has now gathered is also expansive, allowing oceanographers to reliably assess how marine environments have changed over the past 150 years. As a result, Secchi disks are still used in applications ranging from monitoring visibility in SCUBA diving, to studies of the impact of climate change. However, the continuing use of Secchi disks has not come without challenges.



Penetration of light of different wavelengths in the open ocean and in coastal waters. Red light is absorbed closest to the surface while green and blue light are completely absorbed in deeper waters.

The Secchi disk provides a robust technique for researchers assessing water clarity.

DISCREPANCIES IN CLASSICAL MODELS

For many decades, researchers have struggled to overcome a key discrepancy between the measurements of Secchi depths and its theoretical relationship. Over this time, a diverse range of practical measurements have shown that these depths display a certain relationship with an optical property named the 'diffuse attenuation coefficient', which provides a measure of how quickly solar radiation attenuates with the increase of depth. Specifically, if this value is multiplied with the Secchi depth, they produce a single, nearly constant value – roughly between 1 and 2. At the same time, however, theorists using entirely mathematical techniques have predicted an entirely different relationship. The math derivations are rooted in the radiative transfer, which describes how radiance is transferred through media, and how these transfers are affected by processes like absorption and scattering.

Because this theoretical model is expressed using an entirely different equation to the general relationship obtained from field measurements, Secchi depths must be predicted with an entirely different set of values. Therefore, as researchers have attempted to develop accurate models to predict how Secchi depths will vary in different waters, a clear inconsistency has emerged between their results and field measurements. The discrepancy has mystified oceanographers for nearly 70 years, and with no clear solution to the problem until recently, theorists and experimentalists have continued to gather conflicting conclusions about how Secchi depths should be used to probe water clarity.

ASSESSING MISTAKES

Through their research, Dr Lee and his colleagues have carried out a careful review of the physical processes involved in the appearance (and disappearance) of Secchi disks at certain depths. In a 2015 study, they discovered that existing classical theories have a number of serious shortcomings, particularly relating to three assumptions about observers of the disks. The first of these is that historical theorists treated a Secchi disk as a point to human eyes, which is not supported by reality, where a 30 cm large disk in a distance about 50 m or so is far greater than an idealised point.

Secondly, classical models assume that observers are using the entire visible range for the detection of a Secchi disk in water. In reality, observers are only using blue or green parts (for most natural waters) of the spectrum, since they are the wavelengths that solar radiation can penetrate the most in natural environment.

Finally, the models make inaccurate assumptions about the mechanisms our eyes use to distinguish an object from their surroundings – namely, a Secchi disk surrounded by water. Dr Lee's team have now shown that these three inaccurate assumptions are at the heart of the discrepancy between real observations and classical models of Secchi depths. Having identified these issues, the researchers found solutions to fix them.

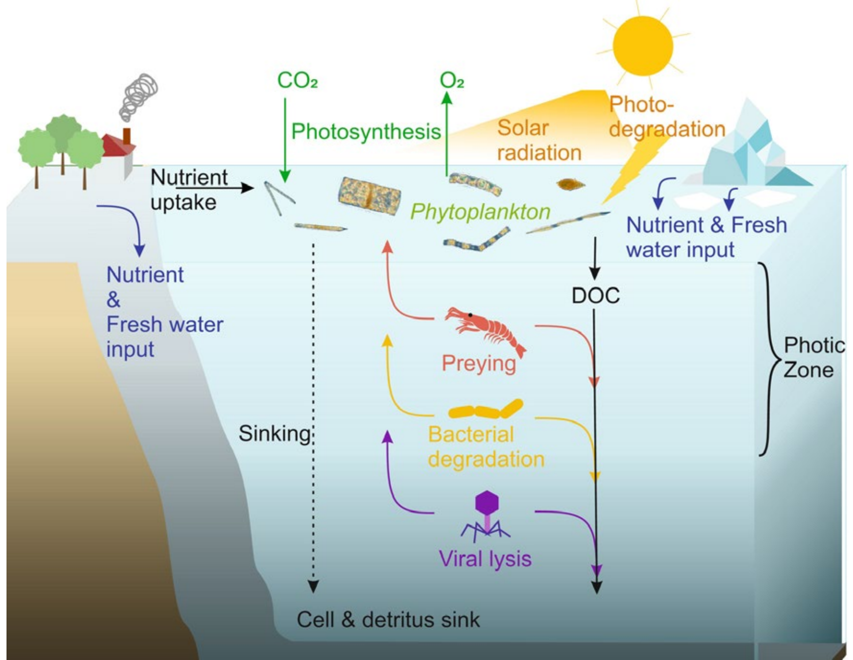
BUILDING A NEW MODEL

Through their latest research, the team have now developed a new theory, also based on radiative transfer, for how Secchi depth can vary in different situations. By treating a Secchi disk as a large areal target to human eyes, they obtained an equation of Secchi depth that relies only on the diffuse attenuation coefficient at water's transparent window – the wavelength at which solar radiation can reach the deepest depths. To verify their conclusions, Dr Lee and his colleagues assembled published data of Secchi depth and diffuse attenuation coefficient over a nine-decade timespan covering oceans, coastal waters, and inland lakes, and found that observations and theoretical predications are in excellent agreement. These results clearly demonstrated its advantages over previous classical models. The outcome resolved a mystery which has puzzled optical oceanographers for decades, and opened up many opportunities for future studies aiming to measure water clarity in different environments from satellite ocean colour remote sensing.

STUDYING AQUATIC ECOSYSTEMS

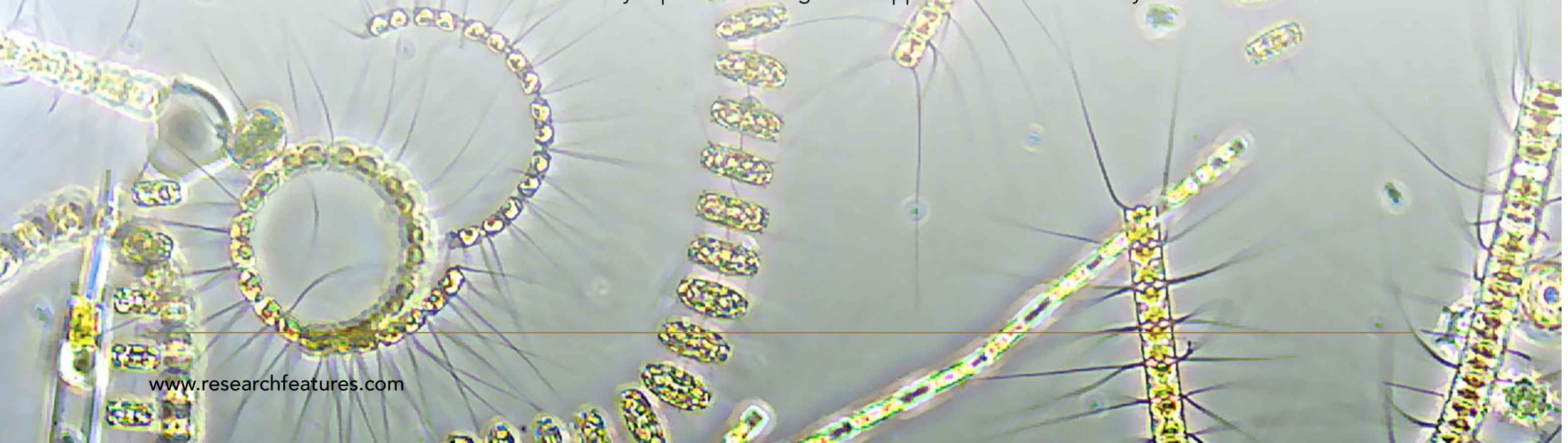
One of the most useful studies enabled by the team's updated model relates to tiny organisms named phytoplankton, which are widely found in aquatic environments across the globe. Forming the foundation of food chains in many marine ecosystems, these organisms gain their energy from the sun through photosynthesis. For many phytoplankton populations to survive, it is often critical to have adequate sunlight in the water column where they reside, and water clarity can be an important measure of this energy source for phytoplankton. However, this process can be hindered by effects including suspended sediments or blooms of opaque algae on the water's surface.

In addition, sunlight penetration is a key aspect of heating in the upper layers of the ocean. Due to climate change, our oceans are now absorbing ever increasing amounts of heat and distributing it globally, an effect which has particularly comprehensive and drastic consequences for Earth's polar regions. With the new theory and model from Dr Lee's team, researchers could soon be far better equipped to assess the changes of water clarity globally over the past decades through satellite measurements. Furthermore, his team's theory may offer some insights about visibility in the air, where a target is also assumed as a point to human eyes in its classical theory. The team will continue to improve their approach even further; solidifying the value of a 150-year-old technique in helping us to understand the future of Earth's ecosystems.



Dr Lee's research has enabled closer study of phytoplankton, tiny organisms that gain energy through photosynthesis.

The outcome resolved a mystery which has puzzled optical oceanographers for decades.



Behind the Research

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Research Objectives

Dr Lee's main research interests are in optical oceanography and ocean colour remote sensing.

Detail

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Bio

Dr ZhongPing Lee got his PhD in 1994 from the University of South Florida. He is currently a Professor at the School for the Environment, University of Massachusetts, Boston, and a Fellow of the Optical Society of America. Dr Lee's main research interests are in optical oceanography and ocean colour remote sensing. He led the development of the widely used Quasi-Analytical Algorithm (QAA) and the hyperspectral algorithm (HOPE) for processing both optically deep and shallow waters, along with various applications of satellite ocean colour products. He has authored or co-authored around 160 peer-reviewed journal articles and is a member of many science teams for ocean colour remote sensing.

Funding

- University of Massachusetts Boston (UMB)
- National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce

Collaborators

- Prof Shaoling Shang, Xiamen University, China
- Prof Chuanmin Hu, University of South Florida, USA

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Personal Response

What inspired you to conduct this research?

" It has been perceived in the ocean colour community that the theoretical aspect of the Secchi disk depth has been completed in the past decades through a series of classical publications by pioneers in ocean optics. However, it was found that the new measurements from colleagues in China can hardly be interpreted with the classical model. Along with the empirical relationships developed from field measurements by various groups in the past century, which are completely different from the theoretical model, we were tipped to examine the details of the theoretical work. "

How could your model be used to aid the research of climate change?

" It is critical to obtain global and multi-decade data to quantitatively evaluate climate change, where it is rare to have century-long data of any ocean property. Secchi disk depth, a measure of water clarity, due to its expansivity and extreme longevity, offers us a unique opportunity to look back of the oceans in the past century. On the other hand, although observations of the oceans by satellites are indispensable for global effects, a robust model applicable to satellite measurements is the key. The new theory and model provide this crucial aspect to bridge satellite measurements of water clarity in our modern age with historical data from the most primitive but effective technique, thus the global and nearly century-long data product could be assembled to help characterise, and diagnose, the impact of climate change on ocean's clarity. "