The Blueness of Lake Tahoe Quantitative Estimates of Water Color and Evidence of Change

Shohei Watanabe[1,2,3], Warwick F. Vincent[3]
John E. Reuter[2], Geoffrey Schladow[2]

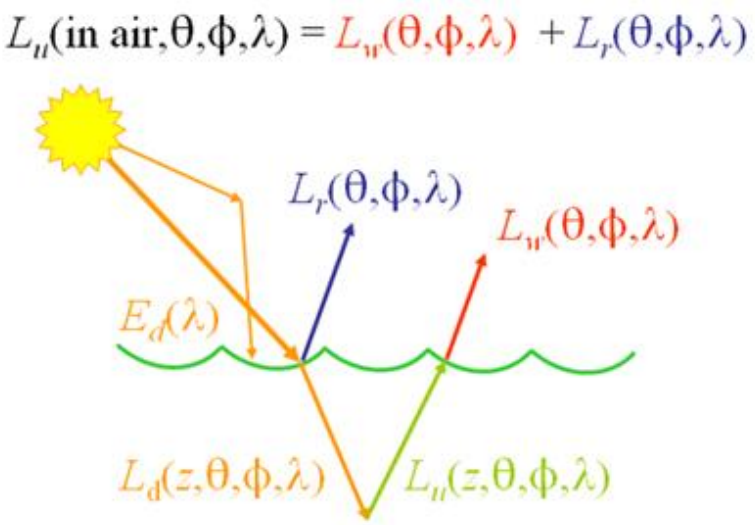
[1]Center for Spatial Technologies and Remote Sensing, Department of Land, Air and Water Resources, University of California, Davis
[2] Tahoe Environmental Research Center, University of California, Davis
[3]Center for Northern Studies, Laval University, Canada

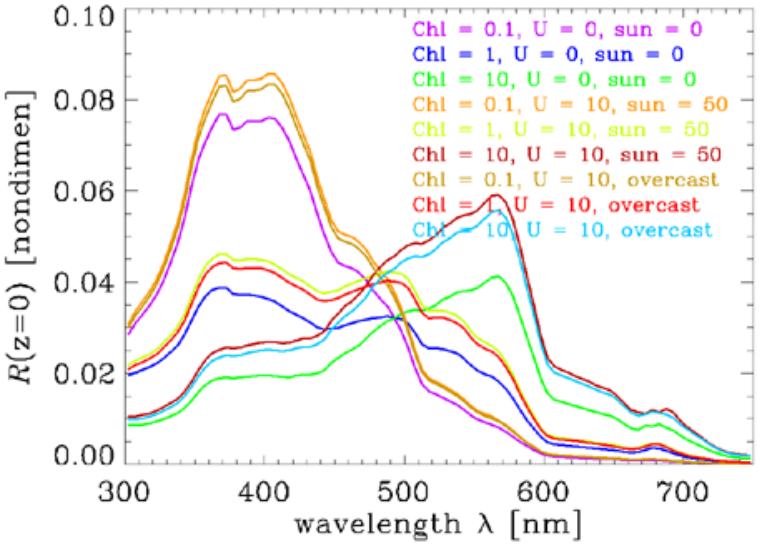
Importance of Water Color

- Value of natural resources

Importance of Water Color

- Remote sensing application

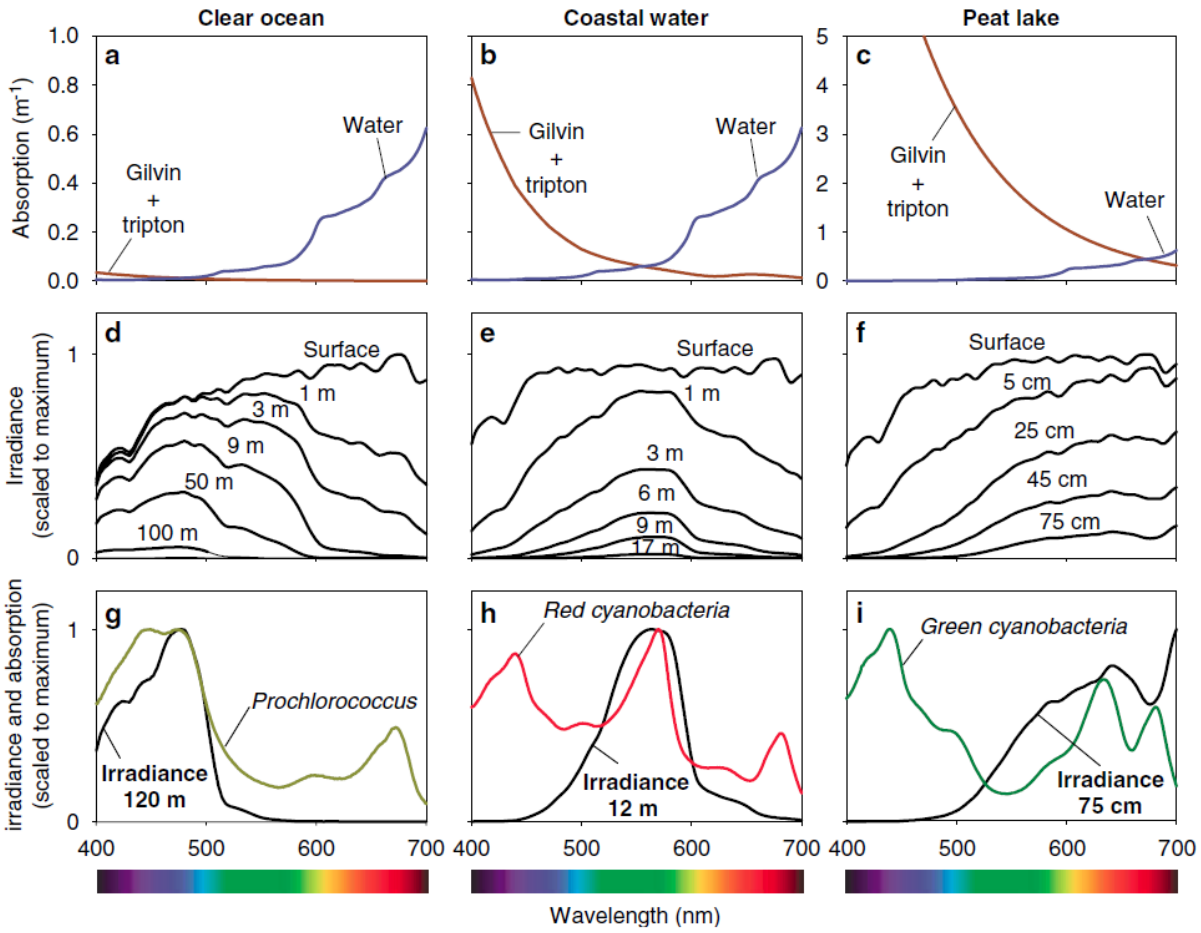




Ocean Optics Webbook (http://www.oceanopticsbook.info/)

Importance of Water Color

- Ecological studies



Objectives

Describe spectral characteristics of Lake Tahoe optical properties by using the state-of-the-art filed/laboratory instruments.

Obtain quantitative measure of Tahoe blueness and compare with other systems and previous data from Lake Tahoe

Field Radiometric Measurements

- Spectroradiometer system

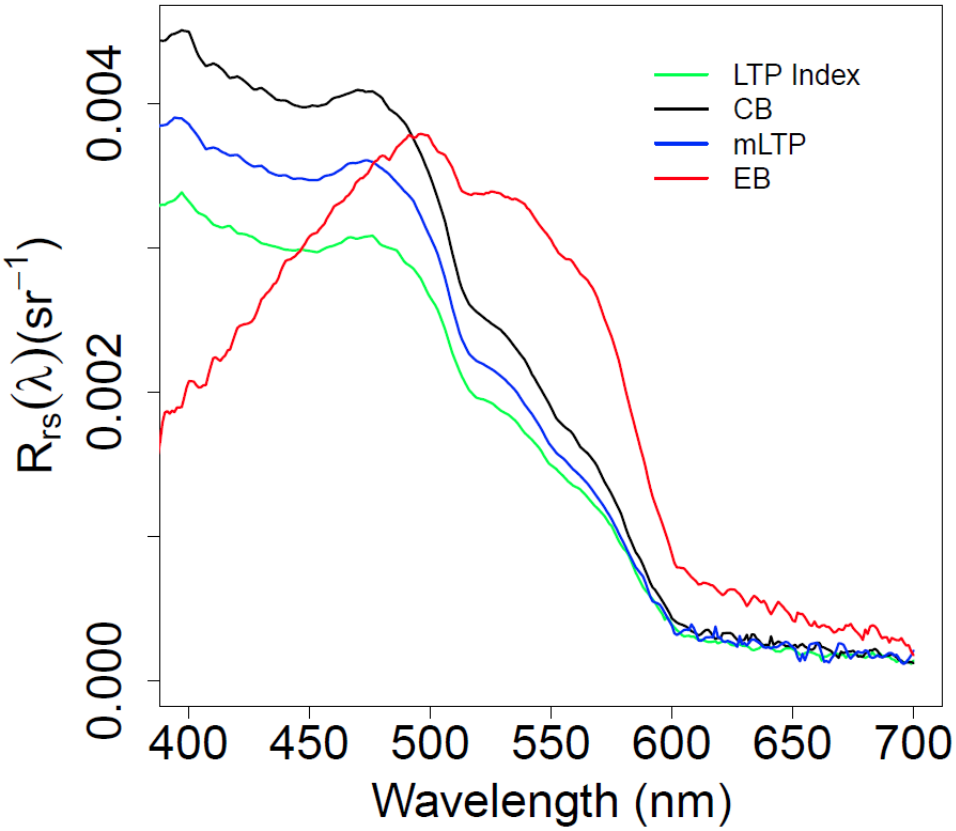
Measures

1. The downward spectral irradiance
   $E_d(\lambda)$ $(W\ m^{-1}\ nm^{-1})$
1. The upward spectral radiance
   $L_u(\lambda)$ $(W\ m^{-1}\ nm^{-1}\ sr^{-1})$

Each sensor measures about 140 data points in the spectral range 350-780 nm

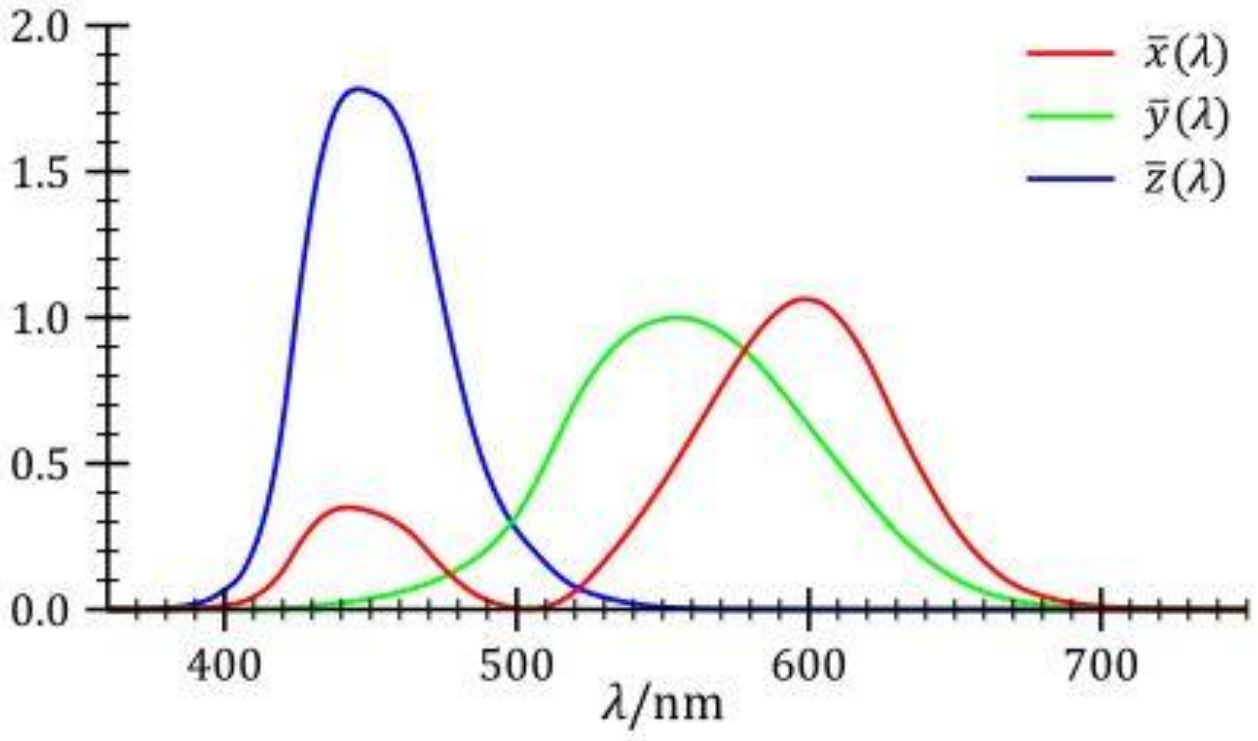
Remote Sensing Reflectance

- $R_{rs}(\lambda) = L_s(\lambda)/E_s(\lambda)$



Color Quantification

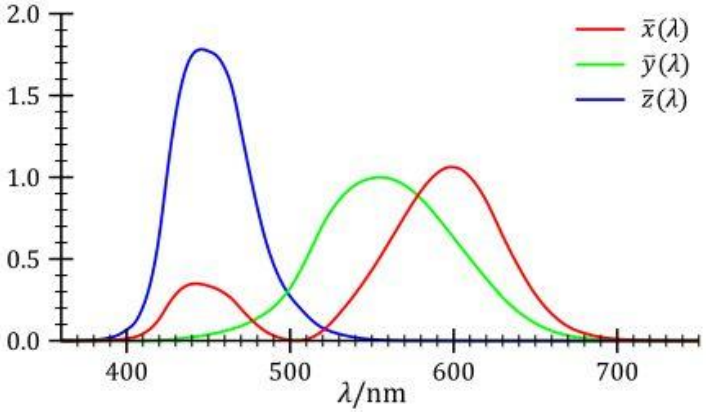
Response of human eyes

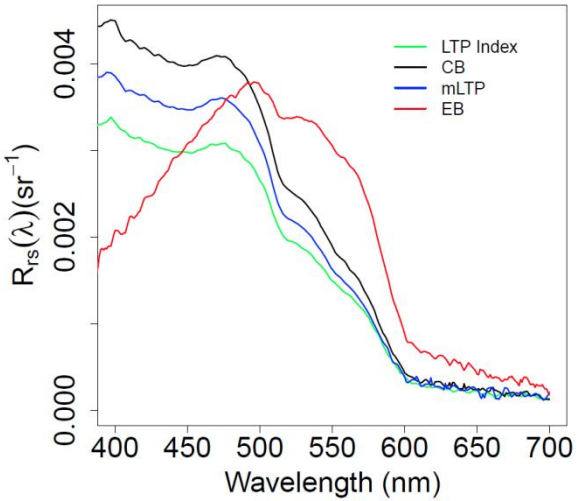


The CIE 1931 standard observer color matching functions

Color Quantification

Response of human eyes



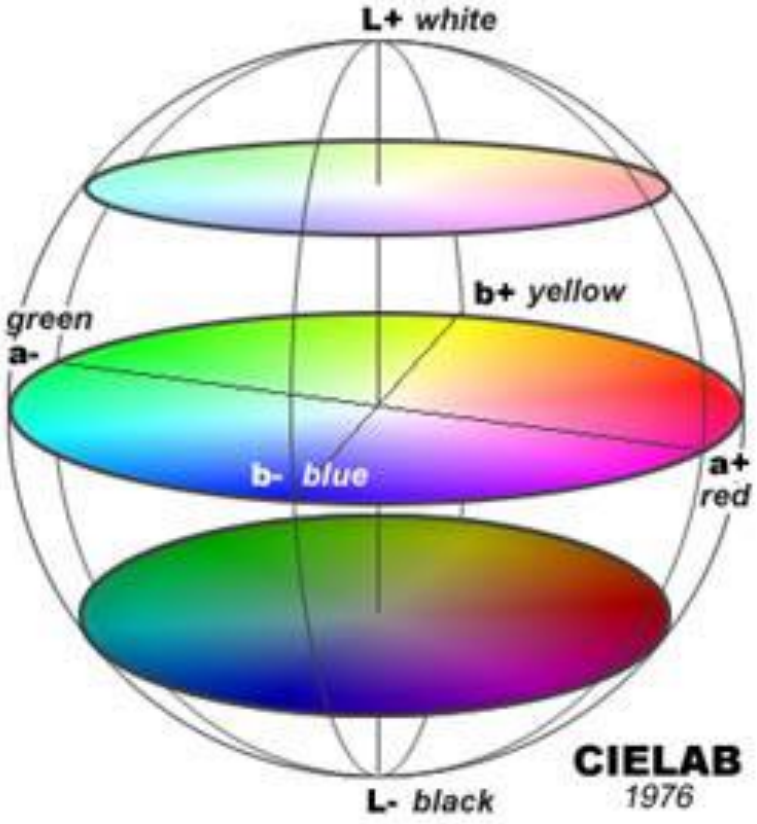


$$X = k \sum_{\lambda=380}^{780} R(\lambda) \cdot S(\lambda) \cdot \bar{x}(\lambda) \Delta\lambda$$

$$Y = k \sum_{\lambda=380}^{780} R(\lambda) \cdot S(\lambda) \cdot \bar{y}(\lambda) \Delta\lambda$$

$$Z = k \sum_{\lambda=380}^{780} R(\lambda) \cdot S(\lambda) \cdot \bar{z}(\lambda) \Delta\lambda$$

Color Quantification



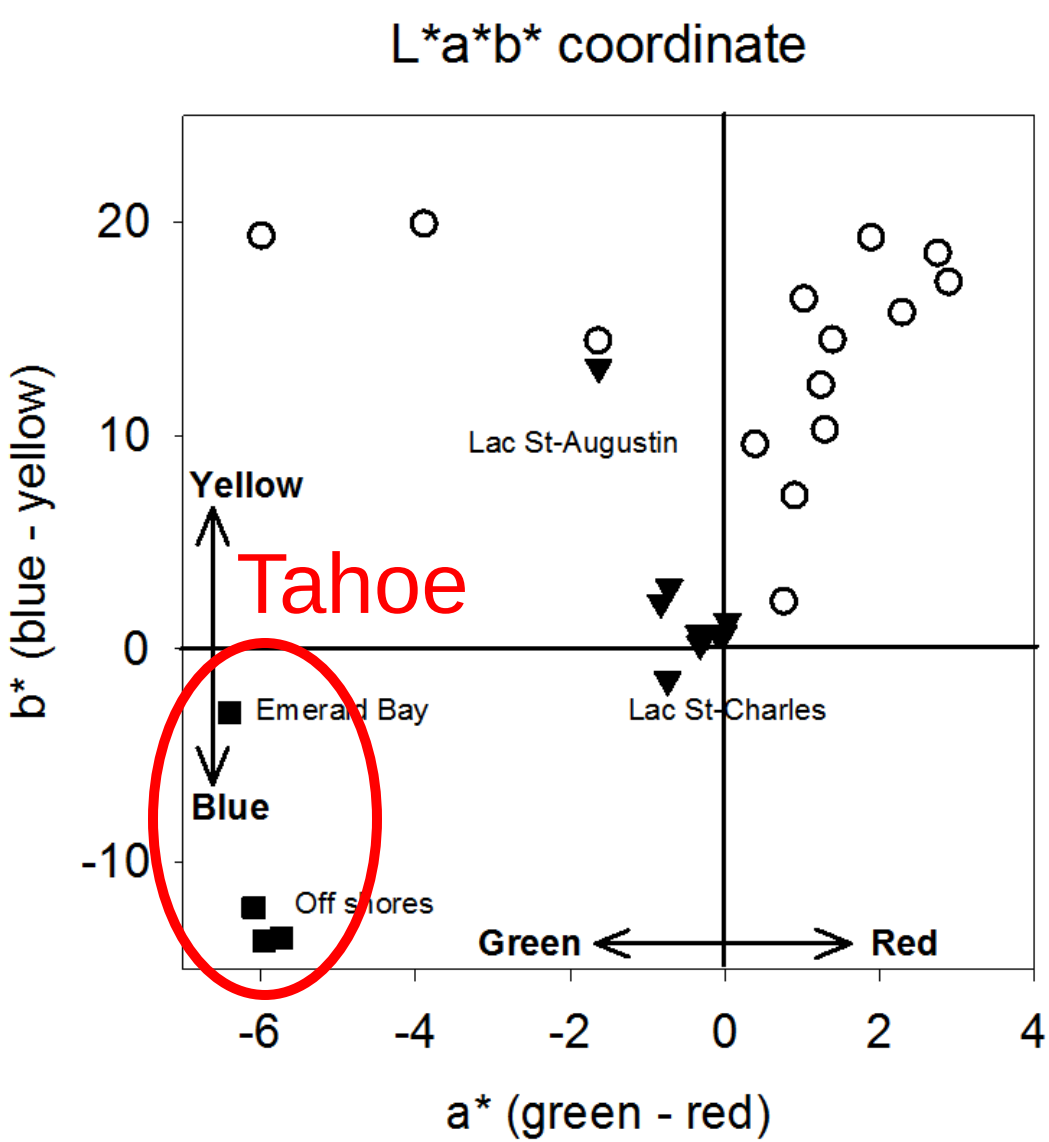
CIE *L*a*b color space**

$$L^* = 116\left(\frac{Y}{Y_n}\right) - 16$$

$$a^* = 500\left[\left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right]$$

Color Quantification



Previous Study

LIMNOLOGY
AND
OCEANOGRAPHY

March 1973

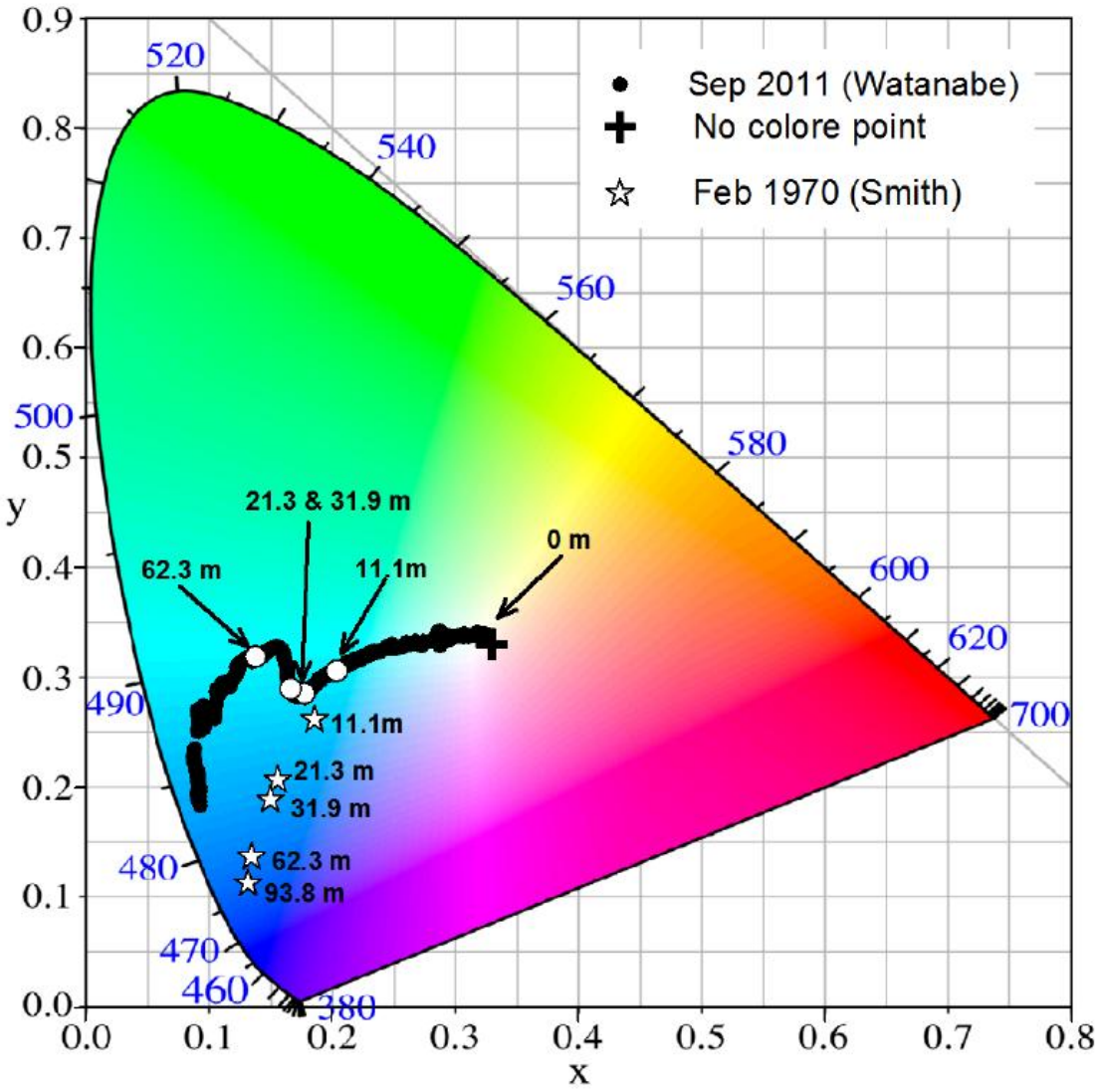
VOLUME XVIII

NUMBER 2

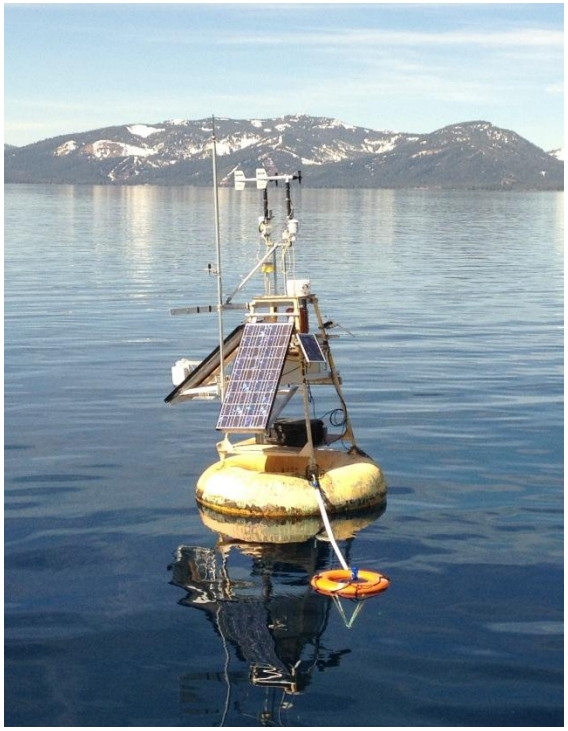
OPTICAL PROPERTIES AND COLOR OF LAKE TAHOE AND CRATER LAKE[1]

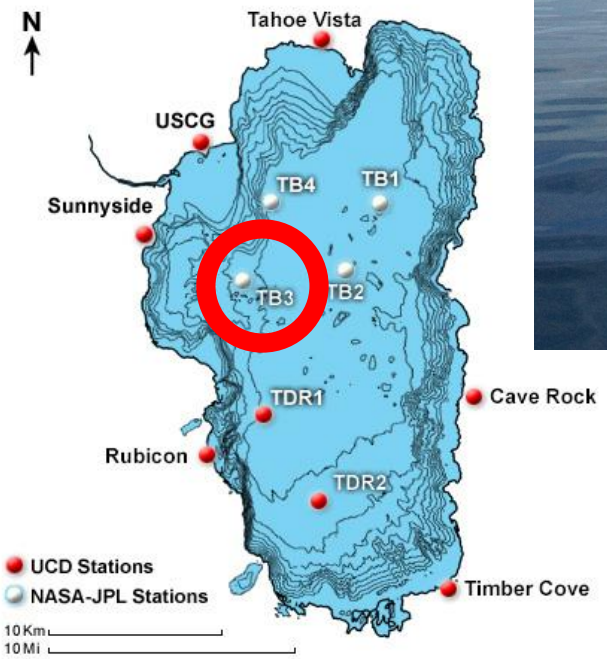
Raymond C. Smith, John E. Tyler,
Visibility Laboratory, Scripps Institution of Oceanography, University of California, San Diego, La Jolla 92037
and
Charles R. Goldman
Division of Environmental Studies, University of California, Davis 95616

1970 vs 2011


Sep 2011 (Watanabe)
No colore point
Feb 1970 (Smith)
21.3 & 31.9 m
62.3 m
11.1m
0 m
11.1m
21.3 m
31.9 m
62.3 m
93.8 m
520
540
560
580
600
620
700
500
490
480
470
460
380
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
y
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
x

Continuous Radiometric Measurements





- The spectral remote sensing reflectance
- The spectral attenuation coefficient

Summary and future possibilities

- Hyperspectral radiometry & photometry can contribute to
  - Color monitoring (believe to be as interesting as clarity decline monitoring)
  - Lake condition monitoring
    - Field measurements
    - Upcoming hyperspectral satellite sensors
  - Better understanding of regime shift of Tahoe ecosystem

Thanks

Department of
LAND, AIR AND WATER RESOURCES
University of California, Davis
Climate Change • Sustainable Agriculture
Environmental Quality • Landscape Processes

Boat Drivers and lab assistance at TERC

Lab assistance at U. Laval