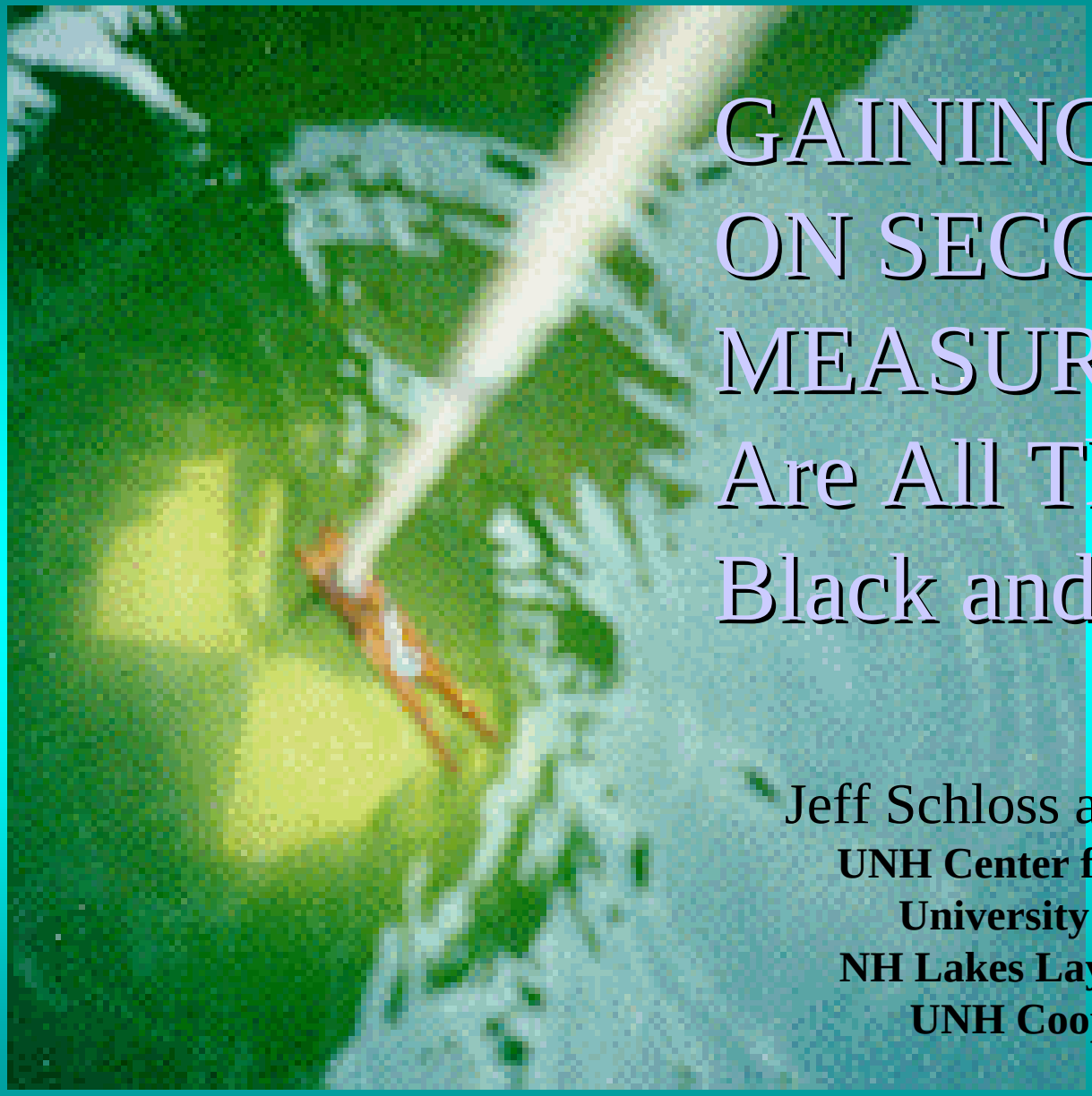
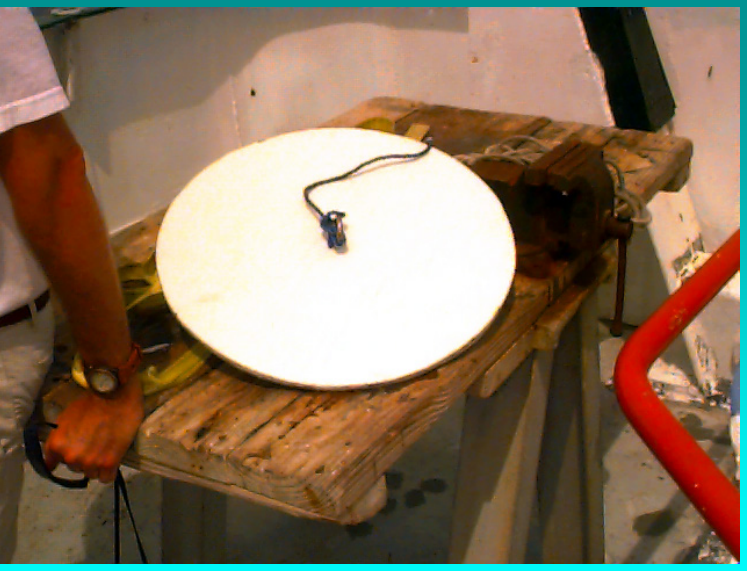


GAINING CLARITY ON SECCHI DISK MEASUREMENTS II: Are All Things Really Black and White?

Jeff Schloss and Robert Craycraft

UNH Center for Freshwater Biology
University of New Hampshire
NH Lakes Lay Monitoring Program
UNH Cooperative Extension

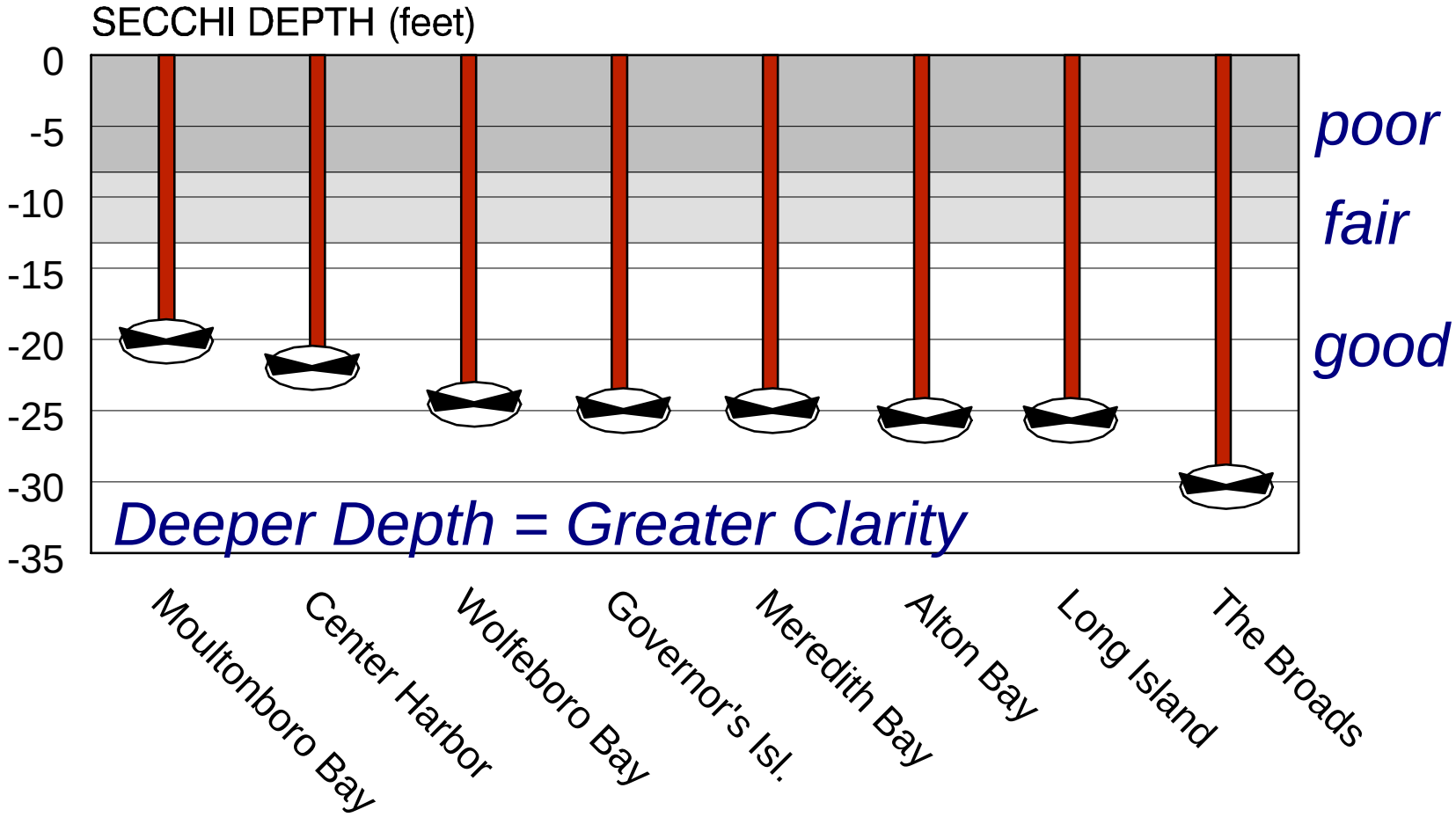


Limnological SD
Black & White
20 cm (8”)

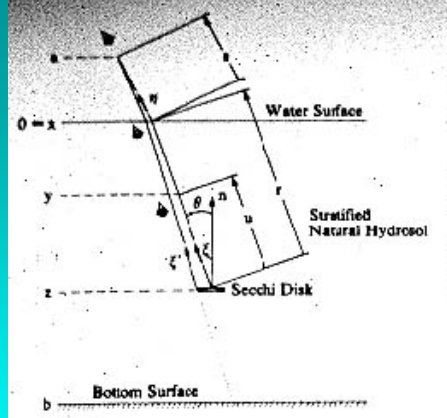
Oceanographic SD
All white
40-60 cm

Secchi Disk Transparency

Lake Winnipesaukee



Average of 1980-2005 NH LLMP and CFB Data



Geometry of the Secchi Disk Sighting

Fig. 1. Geometry for the derivation of the Secchi disk formulas.

normal to ξ. The photons are of wavelength λ within a unit wavelength interval (in nanometer = nm). Thus $N(y,\xi,\lambda)$ has units W m^{-2} sr^{-1} nm^{-1}. The depth rate of change of radiance $N(y,\xi,\lambda)$ for fixed ξ and λ is given by the *equation of transfer*

$$-\mu \frac{\mathrm{d}}{\mathrm{d}y} N(y,\xi,\lambda) = -\alpha(y,\lambda) N(y,\xi,\lambda) + N_*(y,\xi,\lambda) \qquad (1)$$

where the *path function* (in W m^{-3} sr^{-1} nm^{-1}) is defined as

$$N_*(y,\xi,\lambda) = \int_Z N(y,\xi',\lambda)\sigma(y;\xi';\xi,\lambda)\,\mathrm{d}\Omega(\xi'). \qquad (2)$$

Here $\sigma(y;\xi';\xi,\lambda)$ (in m^{-1} sr^{-1}) is the *volume scattering function* which gives the amount of radiance produced per meter along ξ by scattering of photons incident along ξ' on an element of volume at depth y. In most natural media, $\sigma(y;\xi';\xi,\lambda)$ depends, for each y and λ, only on $\xi' \cdot \xi$, so that we have *isotropy* of scattering. $\mathrm{d}\Omega(\xi')$ is an element of solid angle (in sr) along ξ', and Z is the set of all directions (unit vectors) ξ. Moreover, if n is the vertical upward direction then $\mu = \cos\theta = \xi \cdot n$ (Fig. 1) and $\alpha(y,\lambda)$ (in m^{-1}) is the *volume attenuation function*.

Radiance-difference law

One may formally integrate Eq. 1 along the path, of length r and direction ξ, from depth z to depth x, where $x = z - r\cos\theta$. Thus if $N_0(z,\xi,\lambda)$ is the *inherent radiance* perceived at z, then the *apparent radiance* $N_r(x,\xi,\lambda)$ perceived at x, a distance r along the photon path, is given by

$$N_r(x,\xi,\lambda) = N_0(z,\xi,\lambda)T^0_r(z,\xi,\lambda) + N^*_r(x,\xi,\lambda) \qquad (3)$$

where the *path radiance is*

$$N^*_r(x,\xi,\lambda) = \int_0^r N_*(y,\xi,\lambda)T^0_{r-u}(y,\xi,\lambda)\,\mathrm{d}u \qquad (4)$$

and the *beam transmittance*, of a path of length r along direction ξ for initial depth z in the hydrosol, such that $x \le z$, is given by:

$$T^0_r(z,\xi,\lambda) = \exp\left[-\int_0^r \alpha(y,\lambda)\,\mathrm{d}u\right] \qquad (5)$$

$$y = z - u\cos\theta, \qquad \cos\theta = \xi \cdot n.$$

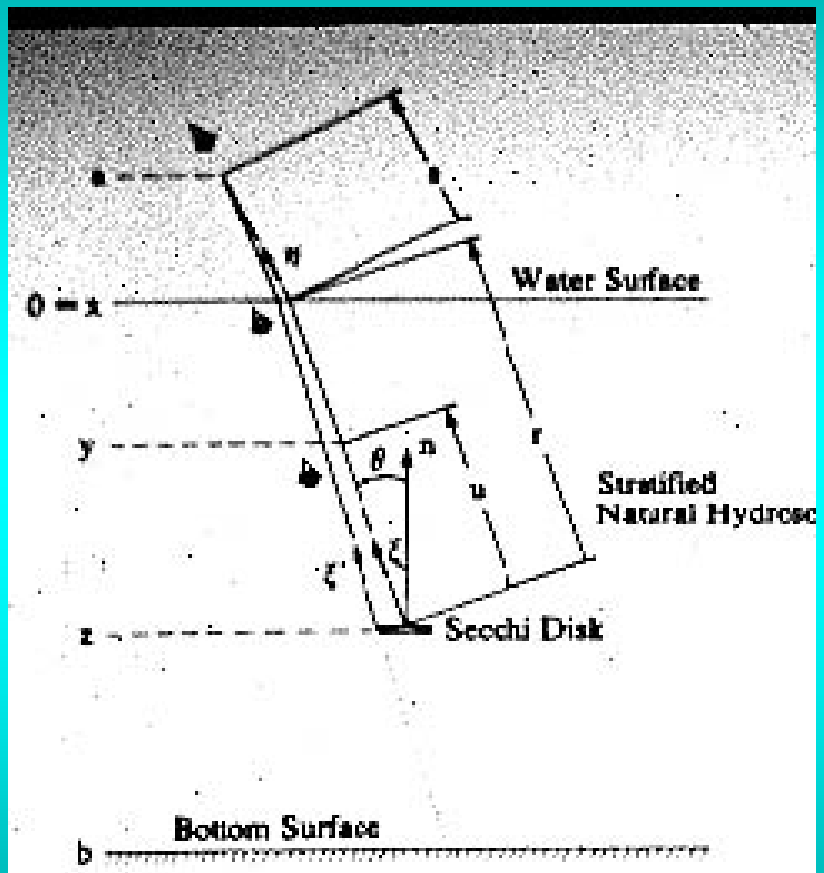
Suppose we have two photon paths in the stratified medium having arbitrarily close directions ξ' and ξ (i.e. $\xi' \cdot \xi \simeq 1$), and going from level z to level x. (*See Fig. 1.*) Then if $\alpha(y,\lambda)$ and $\sigma(y;\xi';\xi,\lambda)$ vary continuously with depth y for fixed λ, it can be shown, by reasoning from Eq. 1, that the relations

$$T^0_r(z,\xi',\lambda) = T^0_r(z,\xi,\lambda) \qquad (6a)$$

and

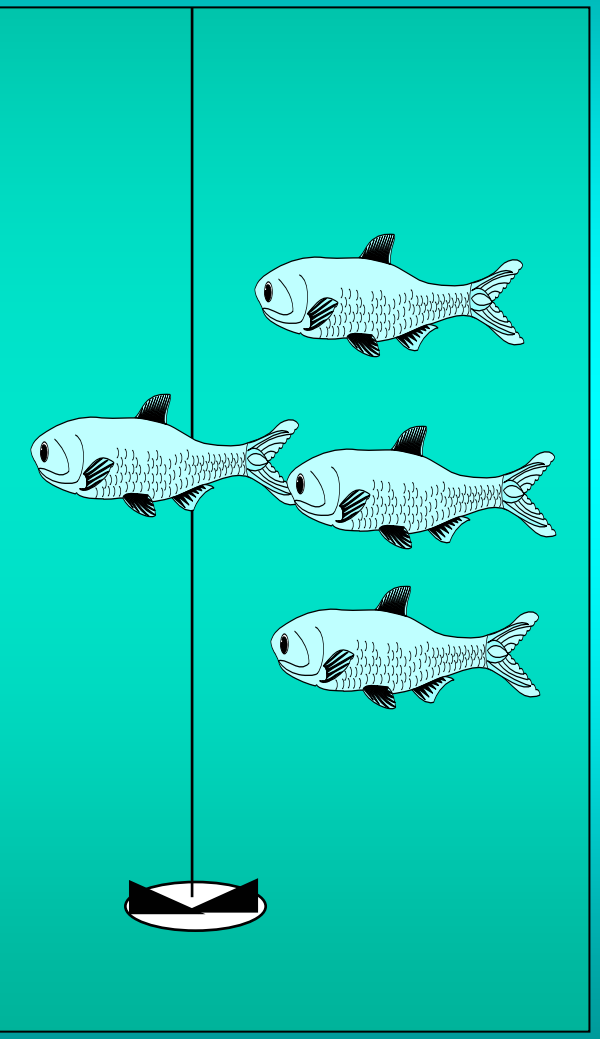
$$N^*_r(x,\xi',\lambda) = N^*_r(x,\xi,\lambda) \qquad (6b)$$

are satisfied arbitrarily closely. We can write Eq. 3 for each of these directionally close paths, and on taking differences of corresponding sides, we find, by Eq. 6a, b, that



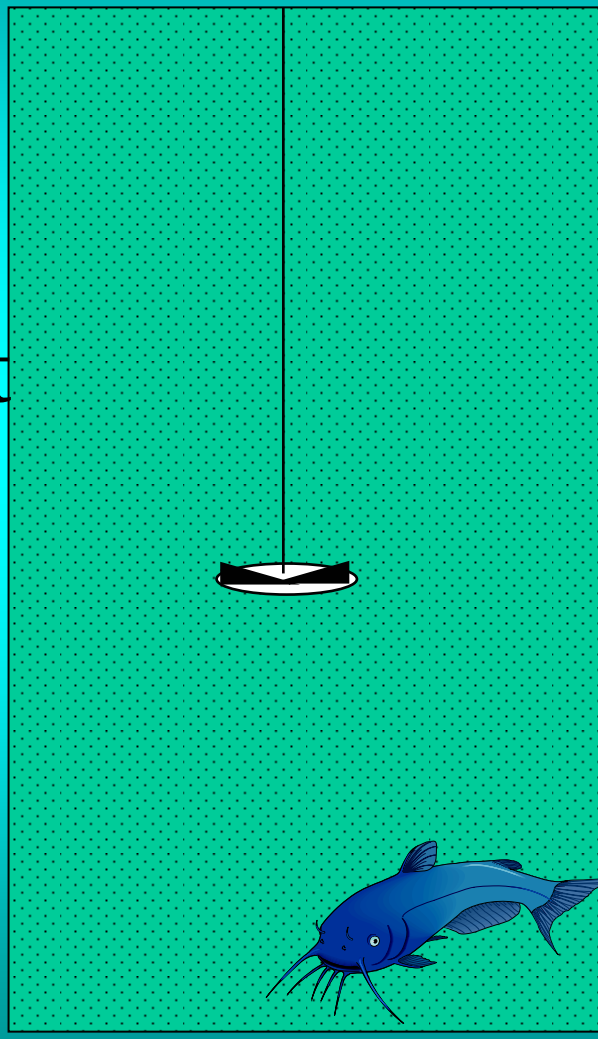
Geometry of the Secchi Disk Sighting

Water Clarity
(Secchi Disk Depth)



Absorption &
Scattering of Light
by

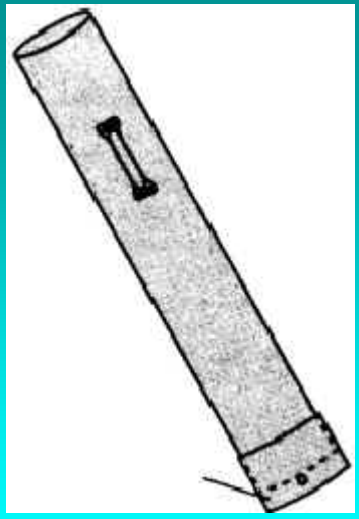
Sediment
Algae
Detritus
Dissolved Color

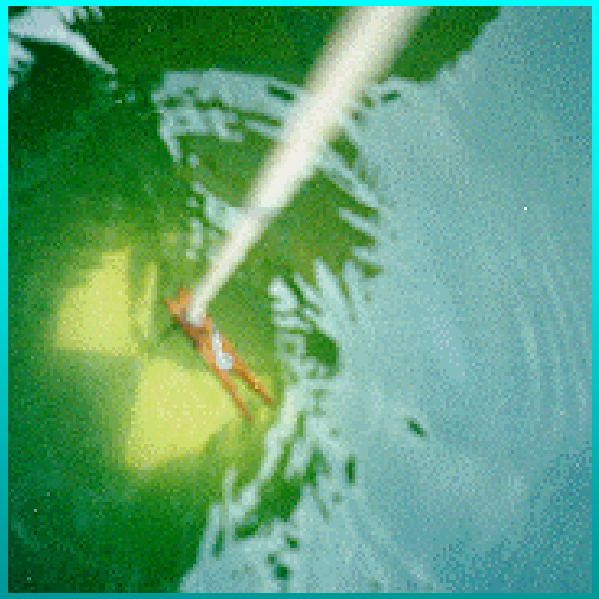


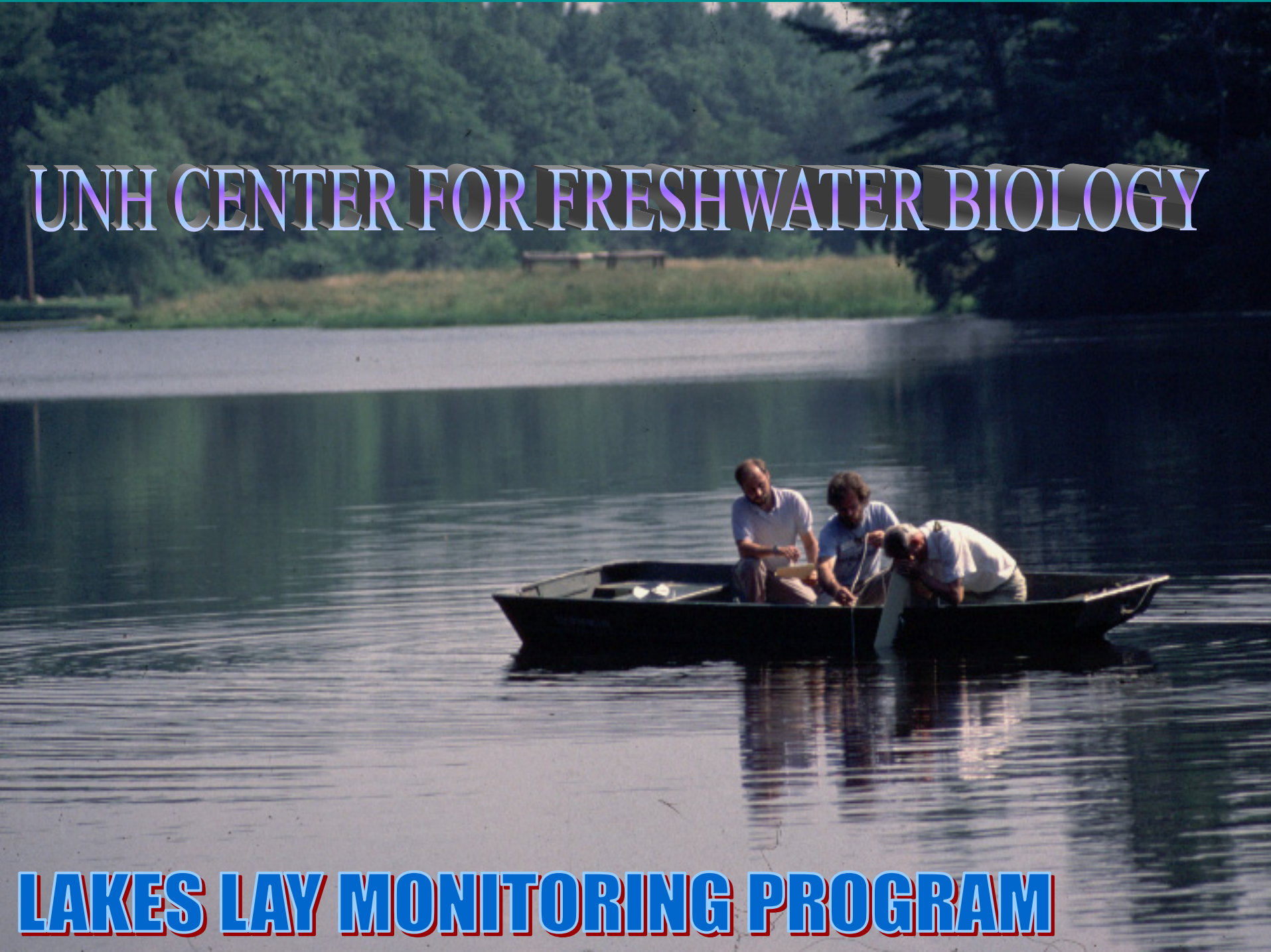
No Standard Method!

- Shady Side vs Sunny Side?
- Depth of Disappearance/Reappearance?
- View Scope or Not?
- Time of Day?
  - Sun Directly Overhead (Welch 1948)
  - 10 am to 2 pm (Cole 1982)
  - 9 am to 3 pm (Lind 1968)
  - 10 am to 4 pm (Michigan)
  - see Verschuur
    (Lake and Res. Mngmt 1997)

What about reflection?






UNH CENTER FOR FRESHWATER BIOLOGY
LAKES LAY MONITORING PROGRAM

STUDY DETAILS

- 1996-1999 Data set for Volunteers and Professionals
- May - October sampling
- Average depth of disk disappearance and re-appearance

Shady side with and without view-scope
Sunny side with or without view-scope
Replicate readings recorded

Recorded water/sky conditions

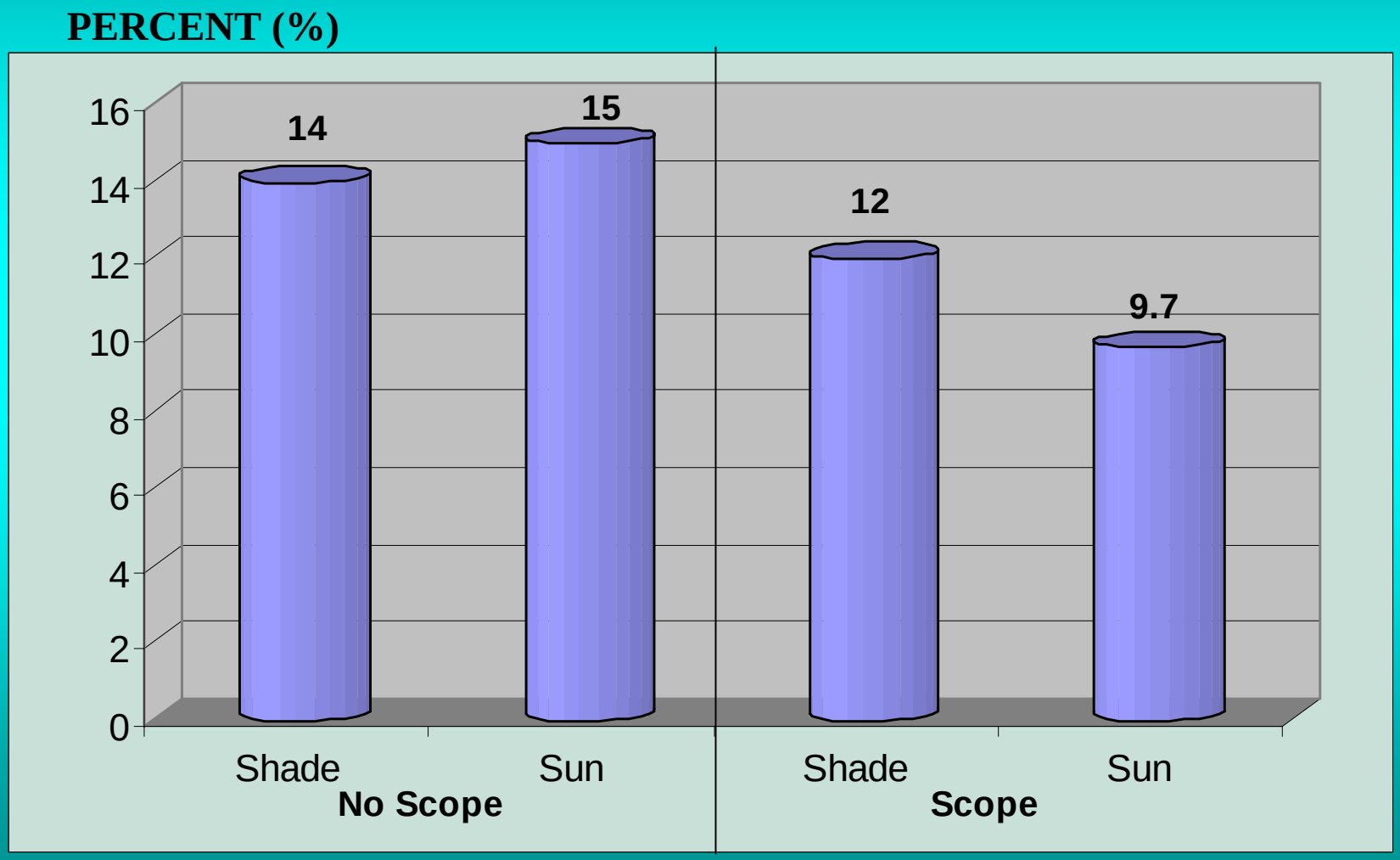
Table 1: Secchi Disk Transparency Study Weather Data.

Sky:	Clear	Hazy	Cloudy	Overcast
Lake:	Calm	Ripples	Waves	White Caps
Wind:	Calm	Breezy	Gusty	Windy

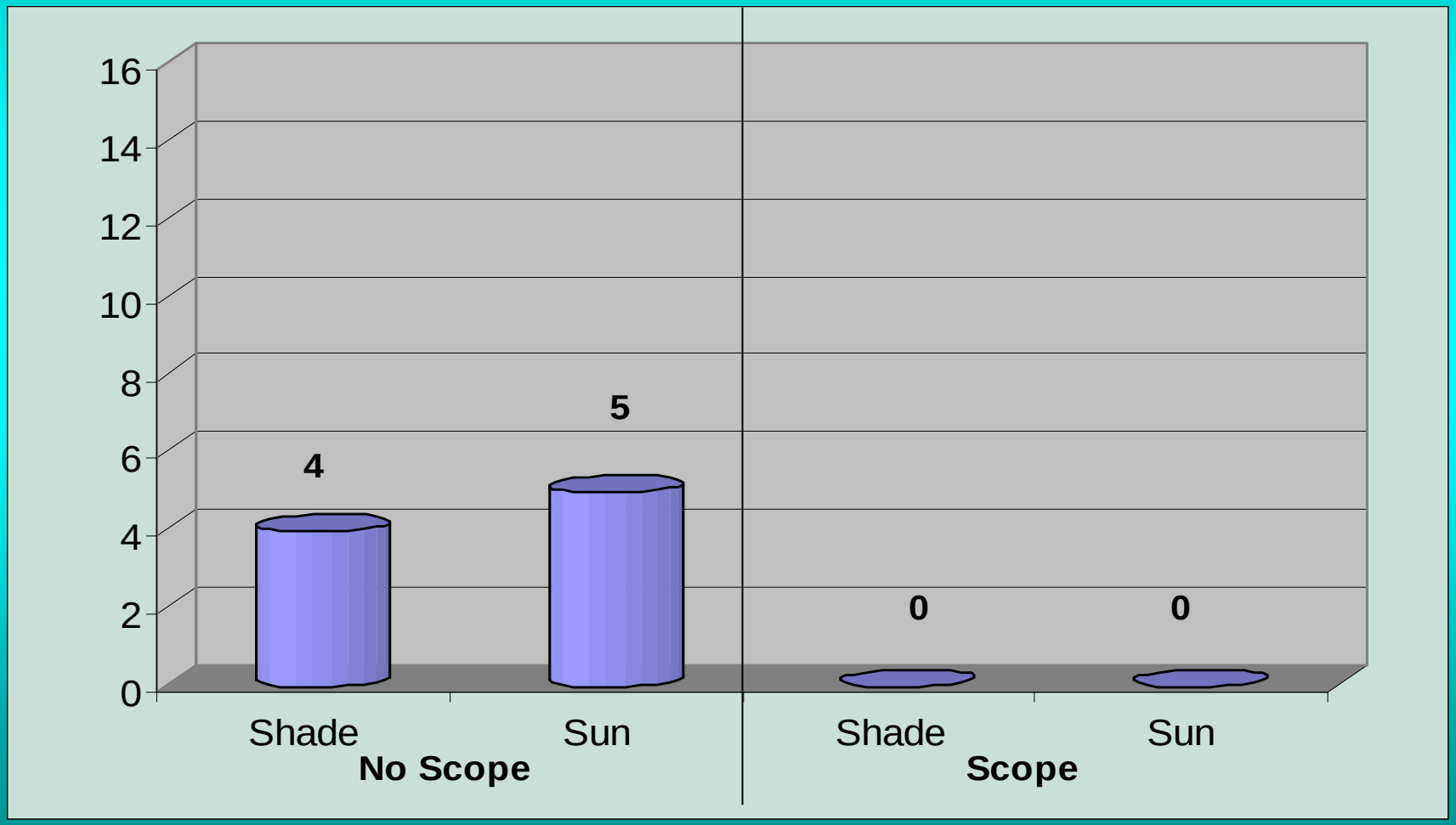
Analysis

- What is the reproducibility (precision) using different protocols?
- How comparable are the protocols?
- What effect do reflection and surface condition have on precision and comparability?

PERCENT VOLUNTEER READINGS EXCEEDING 10% PRECISION



PERCENT PROFESSIONAL READINGS EXCEEDING 10% PRECISION



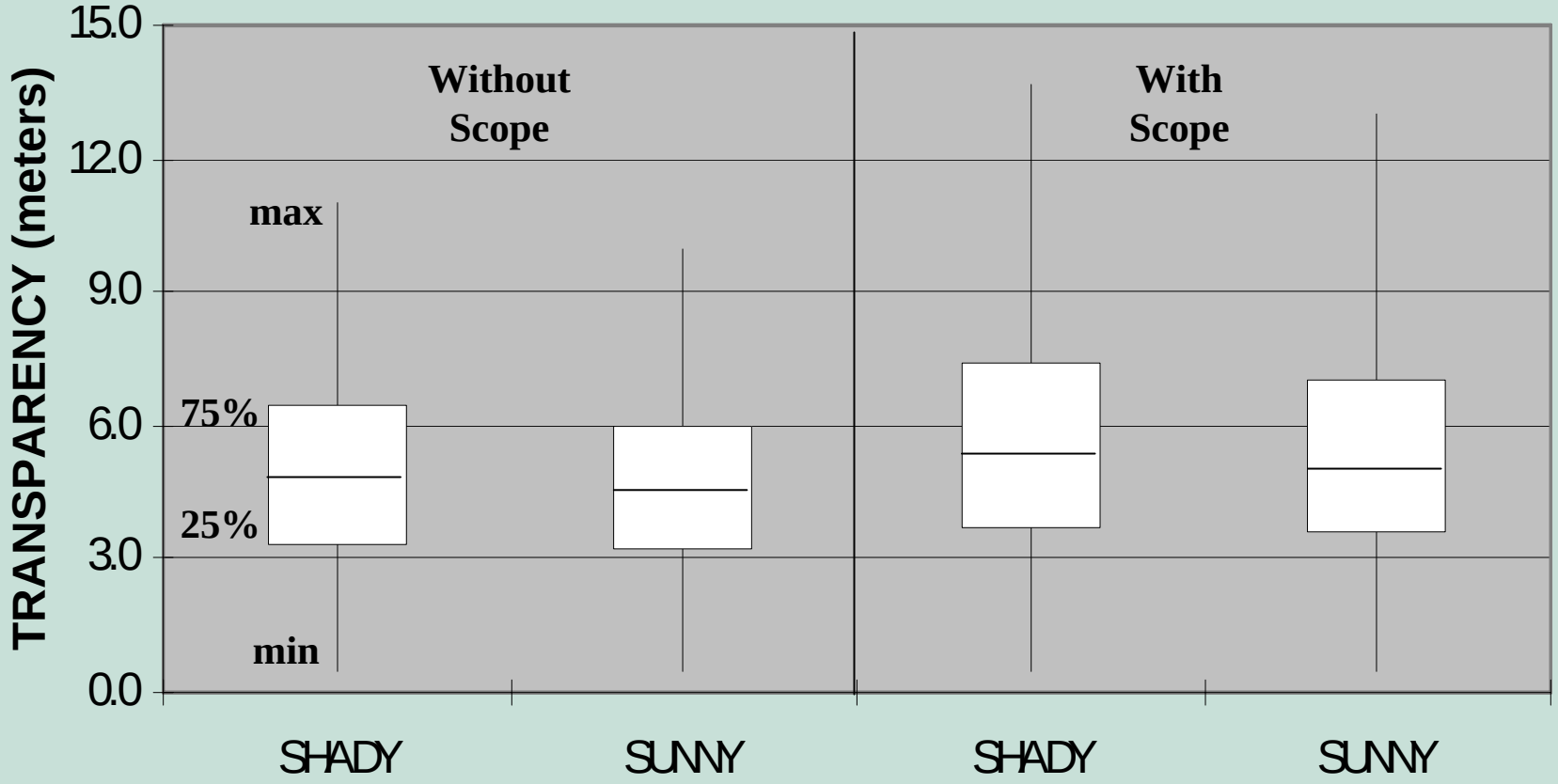
All Complete Paired Data

N=644

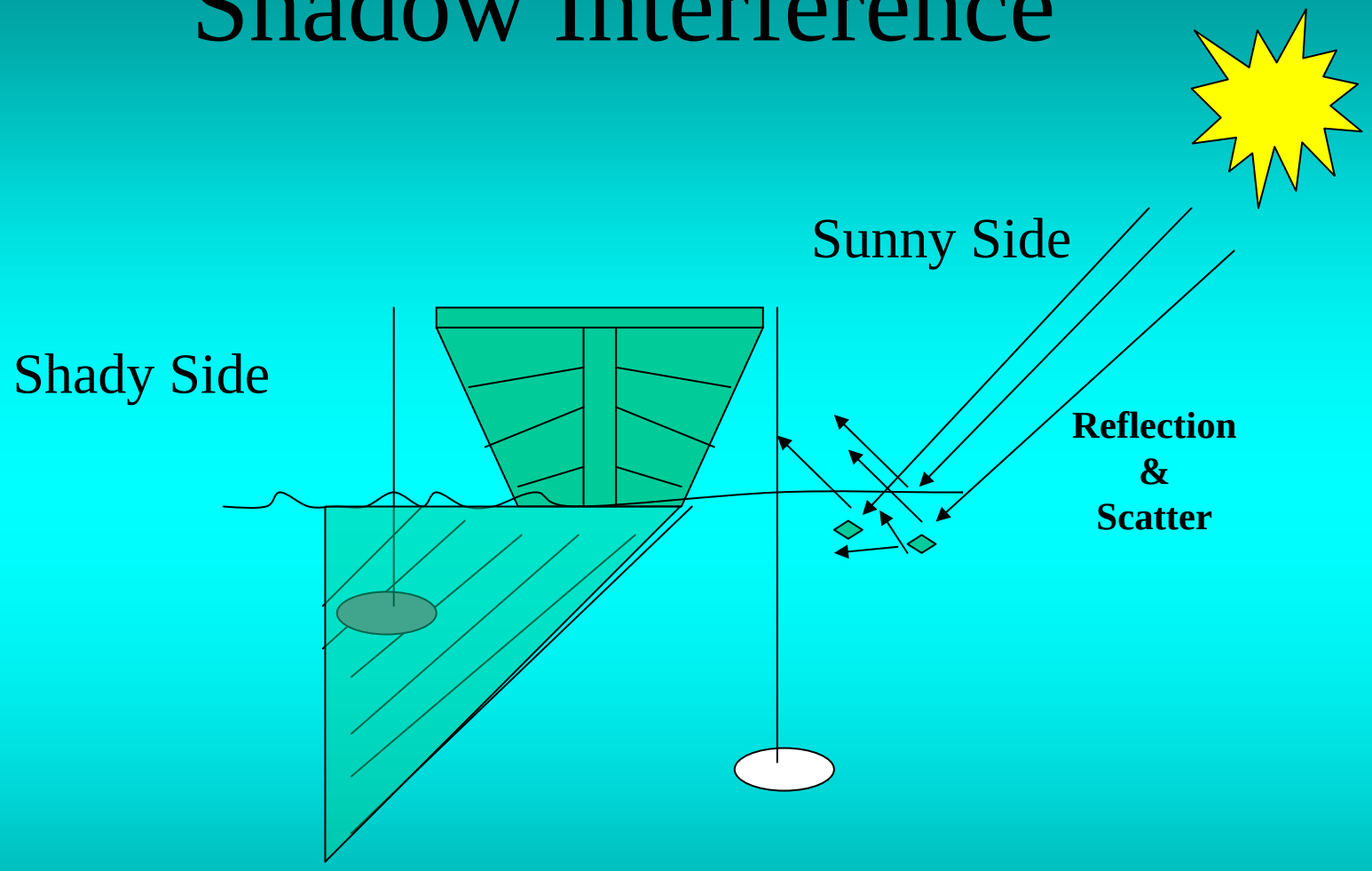
Box and Whisker Plot

1996-1999

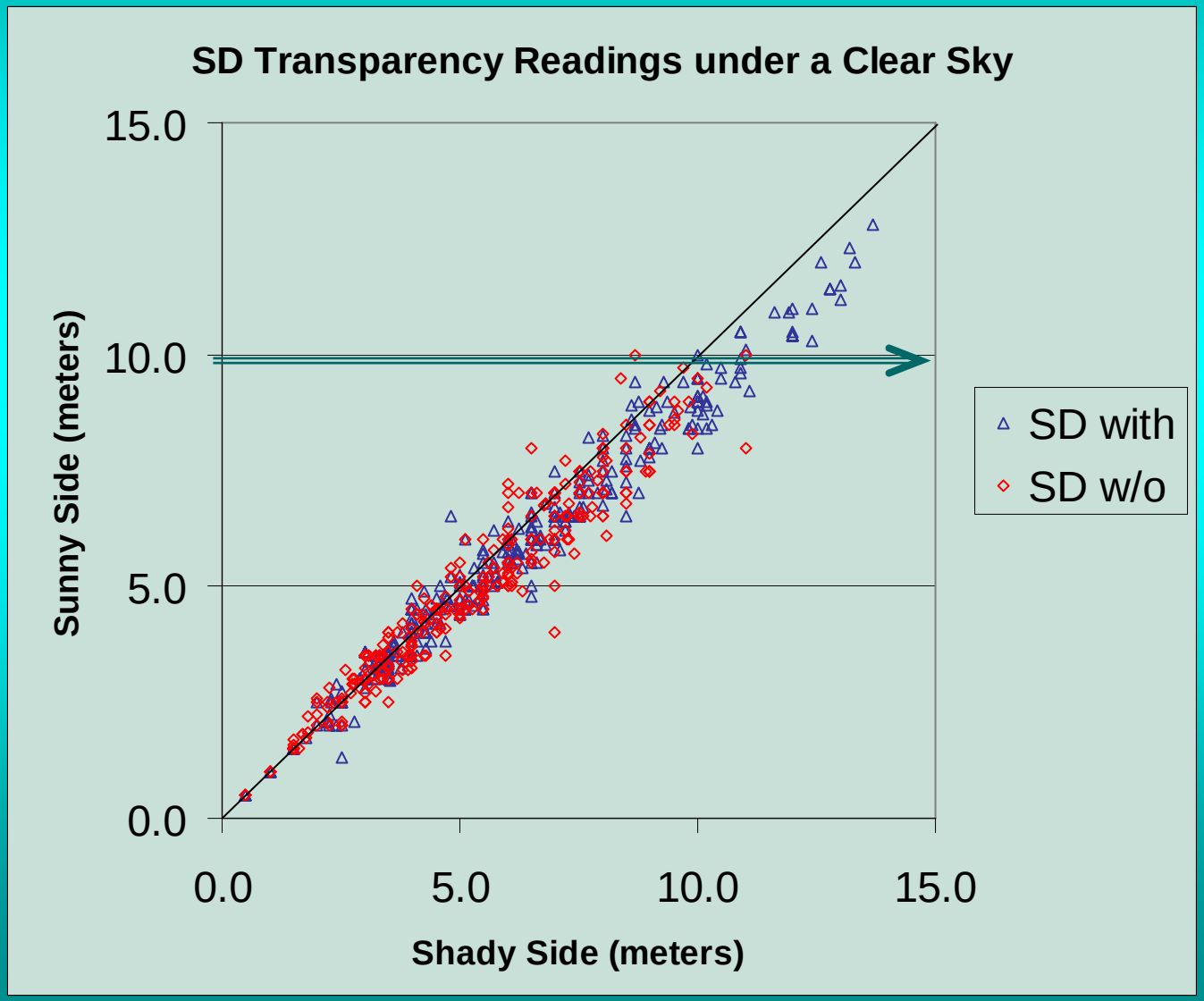
Volunteer Monitoring Data

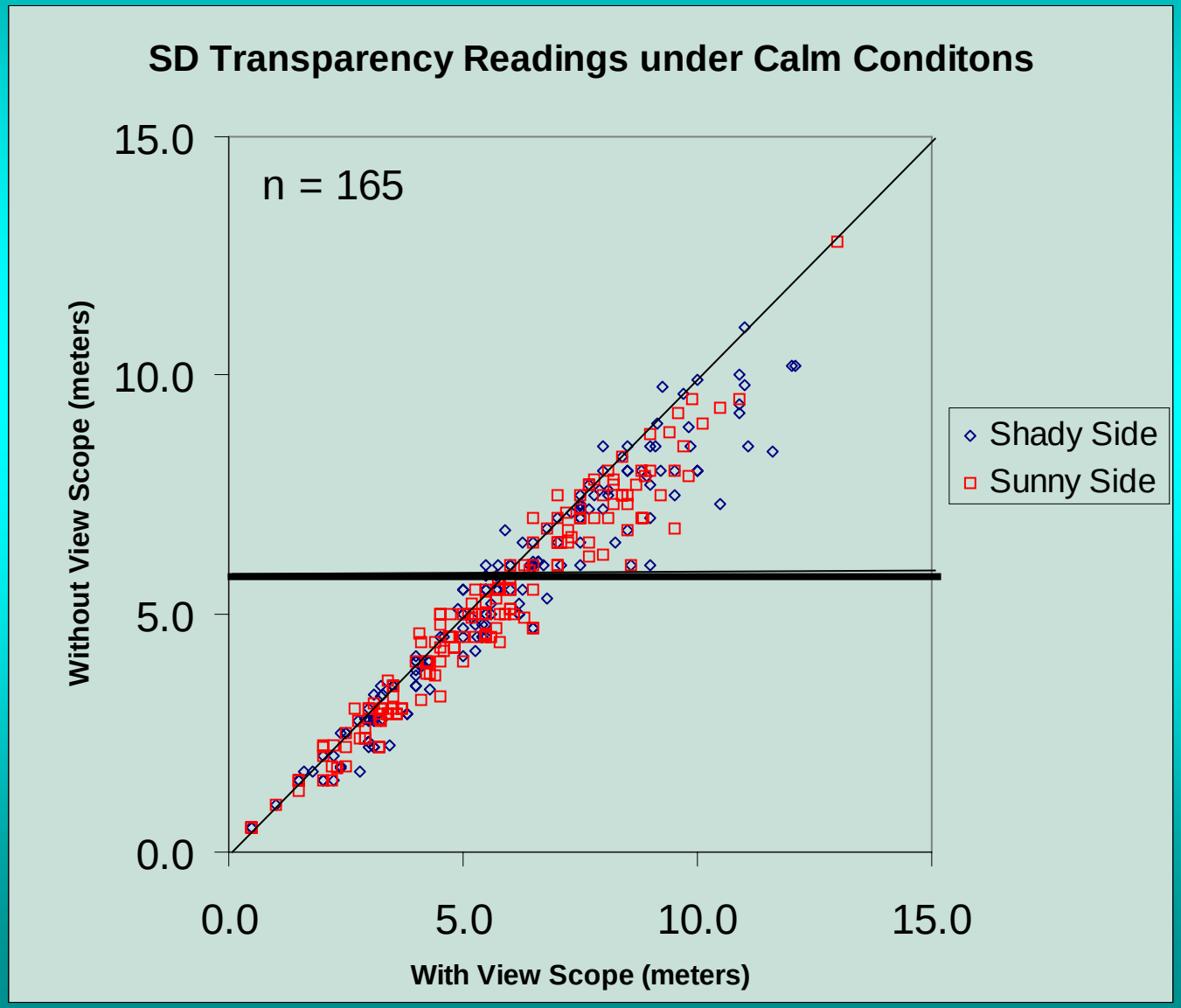


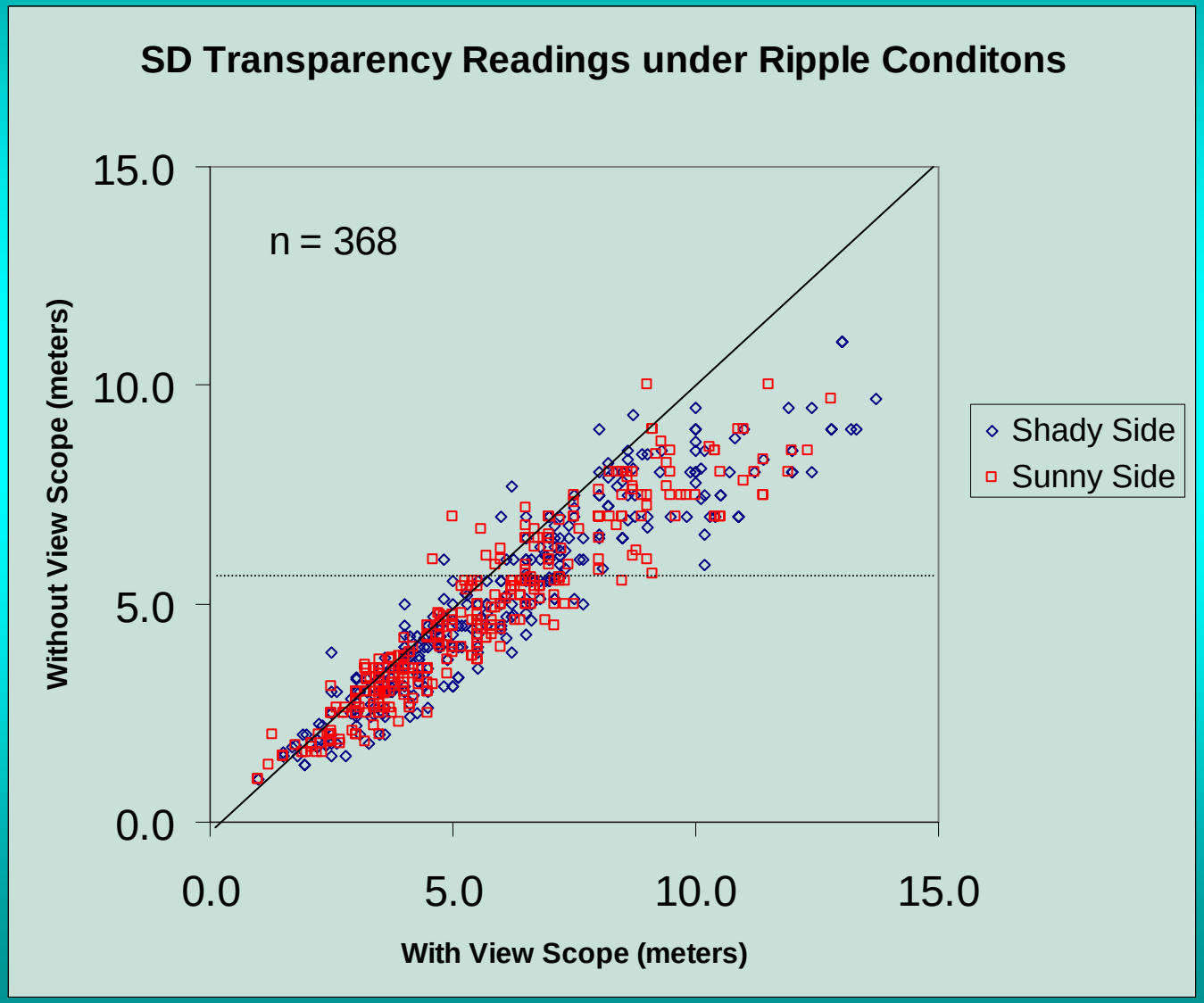
Shadow Interference



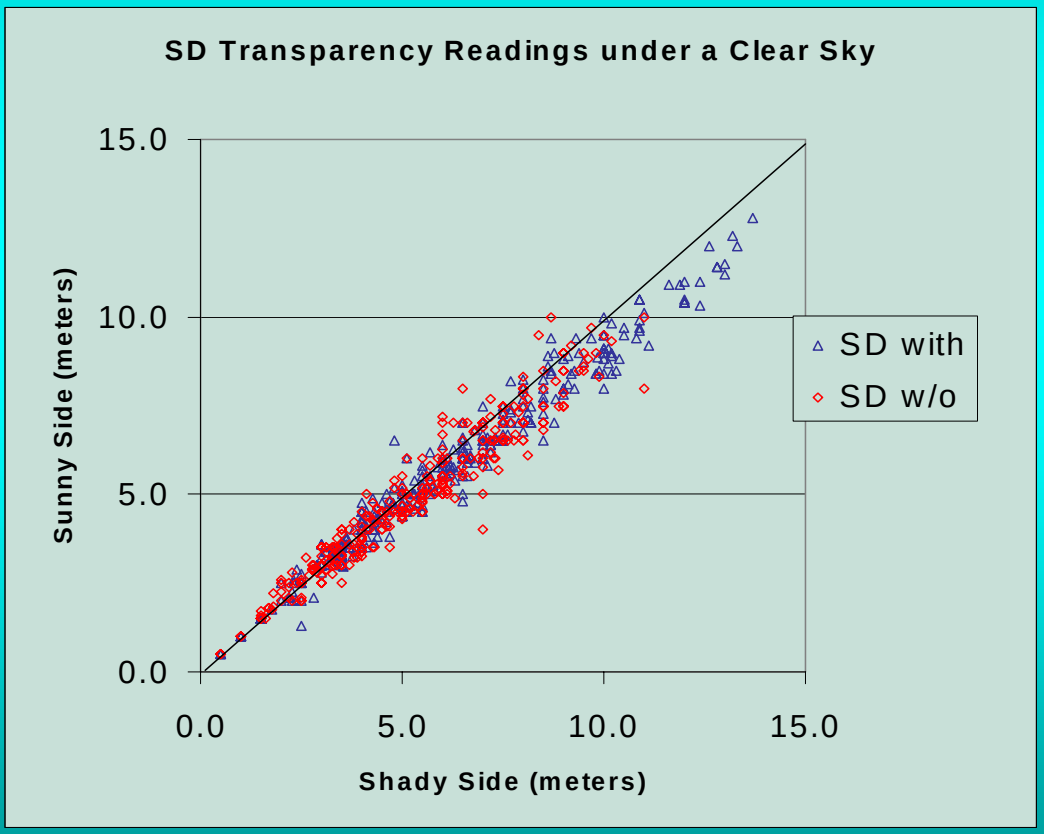
W/O Scope: Lose deep secchi sensitivity



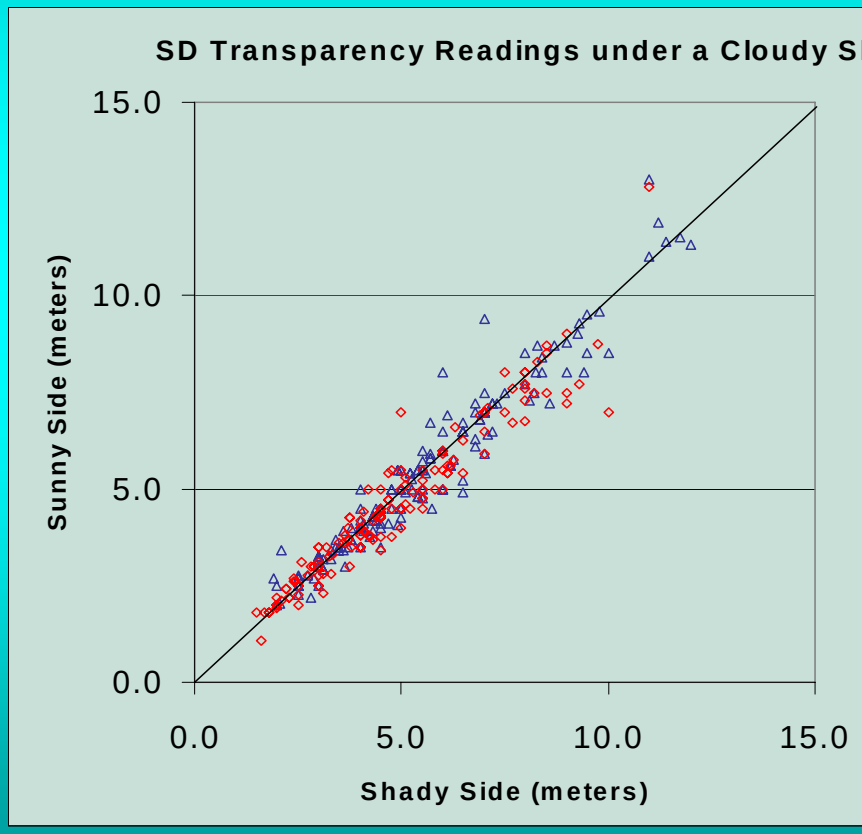

SD Transparency Readings under Calm Conditons
n = 165
15.0
10.0
5.0
0.0
0.0
5.0
10.0
15.0
Without View Scope (meters)
With View Scope (meters)
Shady Side
Sunny Side


SD Transparency Readings under Ripple Conditons
n = 368
15.0
10.0
5.0
0.0
0.0
5.0
10.0
15.0
Without View Scope (meters)
With View Scope (meters)
Shady Side
Sunny Side

CLEAR SKY



CLOUDY SKY

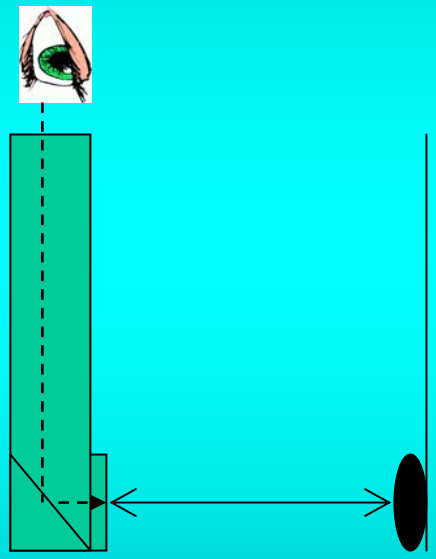


SUMMARY I

- Overall precision by volunteer monitors was excellent compared to professionals (1%-3%).
- Less outliers when viewscope was used.
- Higher sensitivity of measurement with scope in clear lakes especially SD >10m.
- Interference increased as the lake surface became more rough or reflective (>15-20%) especially for SD > 6m (both treatments).

Enter the Black Disk……..

Davies-Colley (1988 Limnol Ocean.)



Comparative Precision

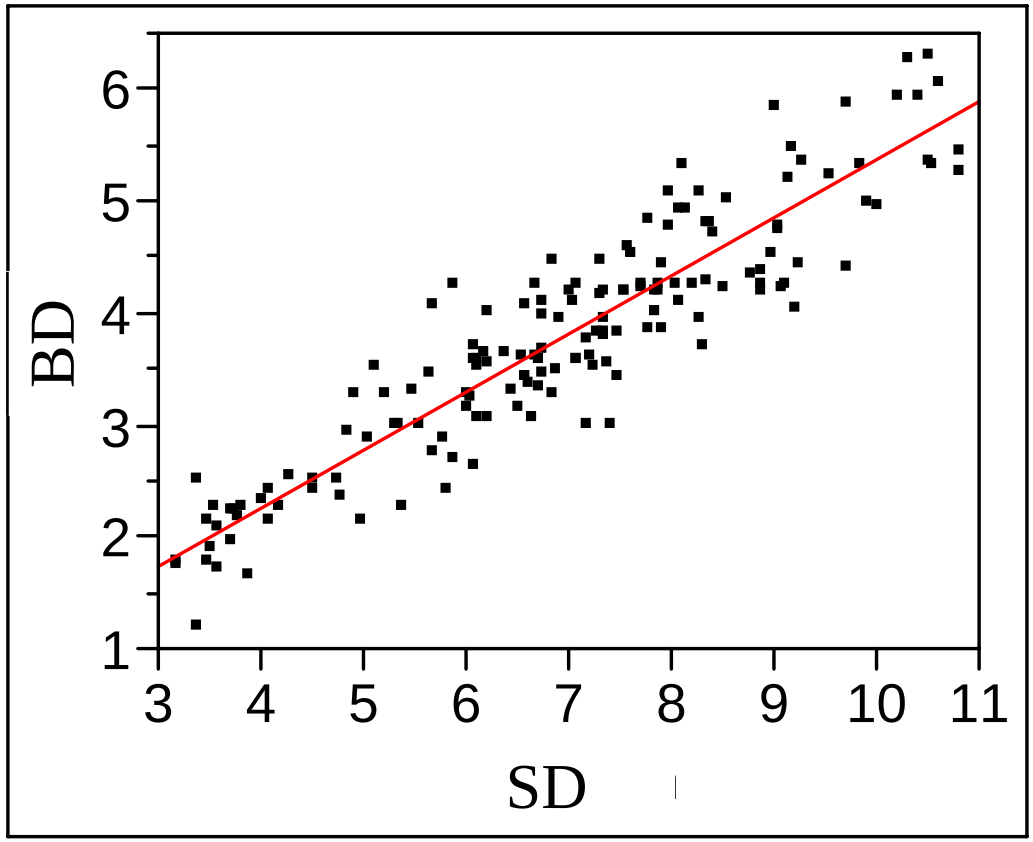
Protocol	**Exceeding 5% / 10%**	**Average Precision (+/-)**
SD shady w/o scope	10% / 1%	2.3 %
SD shady w/ scope	2% / 0%	1.2 %
SD sunny w/o scope	6% / 3%	2.2 %
SD sunny w/ scope	3% / 0%	1.4 %
BD sunny w/ scope	20% / 4%	3.3 %

2003 – 2005 UNH CFB Surveys, N= 160

Secchi Disk vs Black Disk

R-square = 0.829

BD = 0.52 * SD + 0.19



Surrogate Regression Results I

Treatment	R-Square	
1/SD v ln CHL	0.690	
1/SD v ln Color	0.545	>= 20 ptu; 10m SD
1/SD v ln CHL, ln Color	**0.791**	

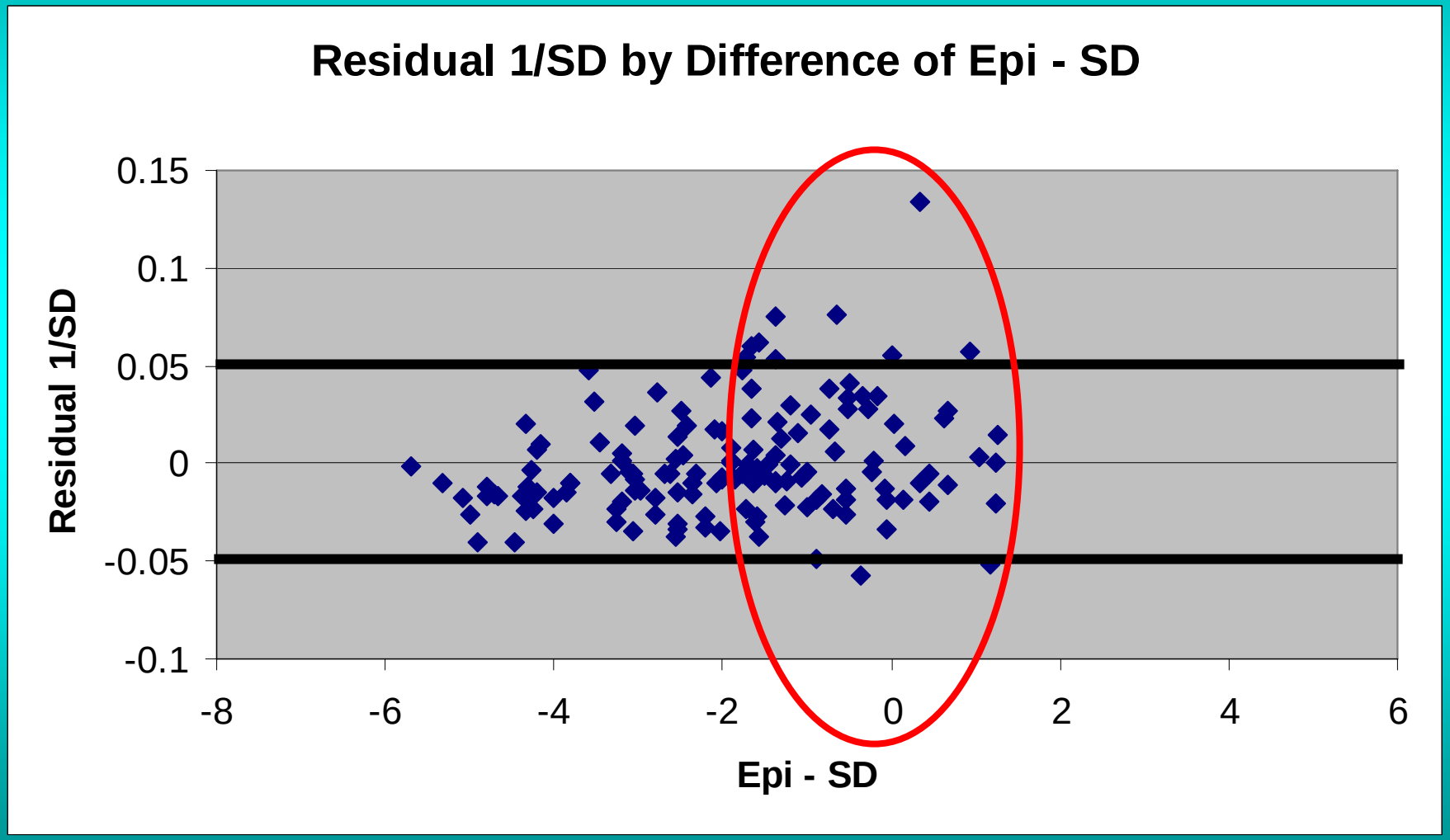
N=61; 1999 50 Lake Study

Surrogate Regression Results II

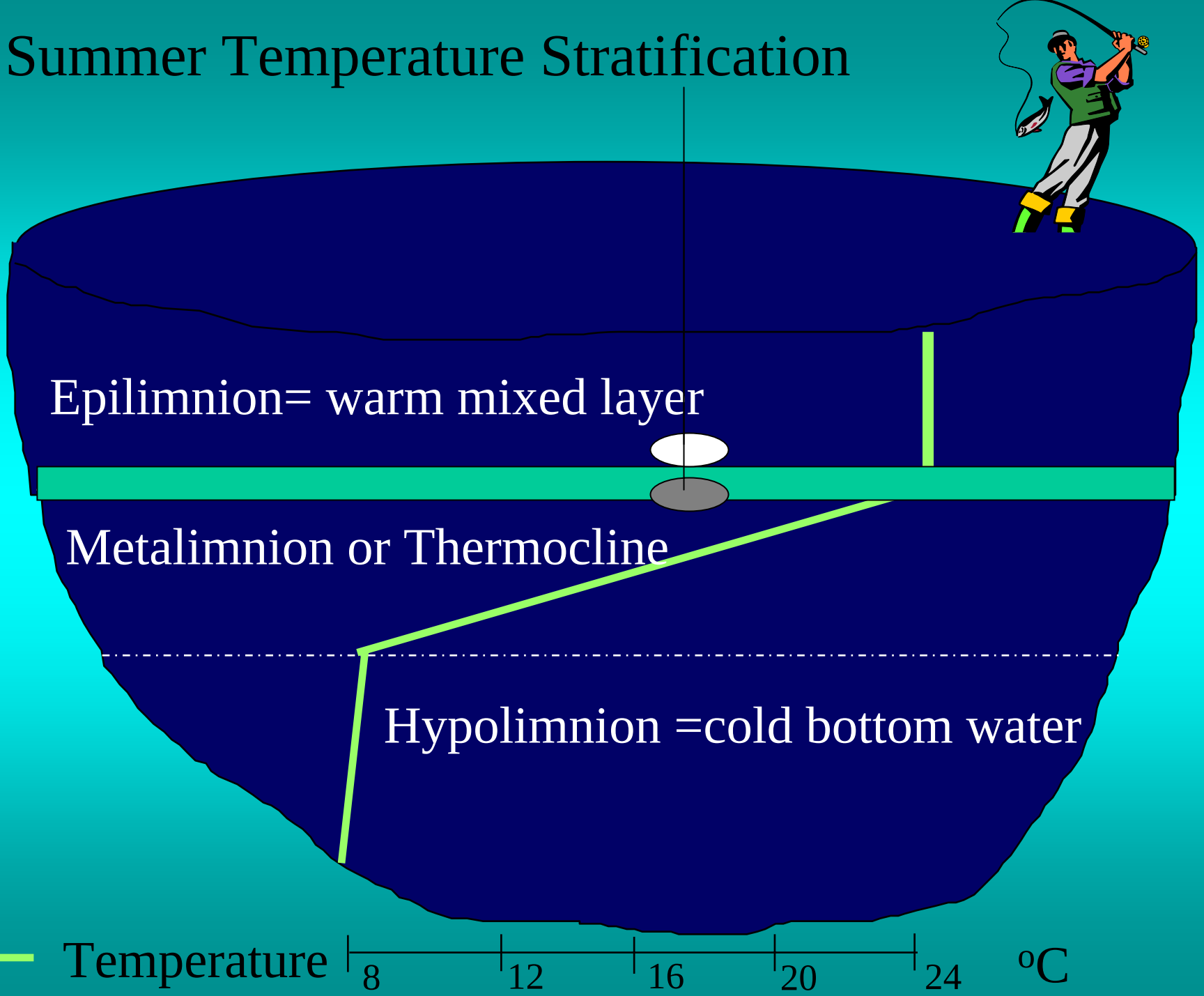
Treatment	1/SD R-Square	1/BD R-Square
v CHL	0.482	0.513
v Color	0.589	0.403
v CHL, Color	**0.723**	**0.626**

N=149; 2002-2005 CFB Surveys

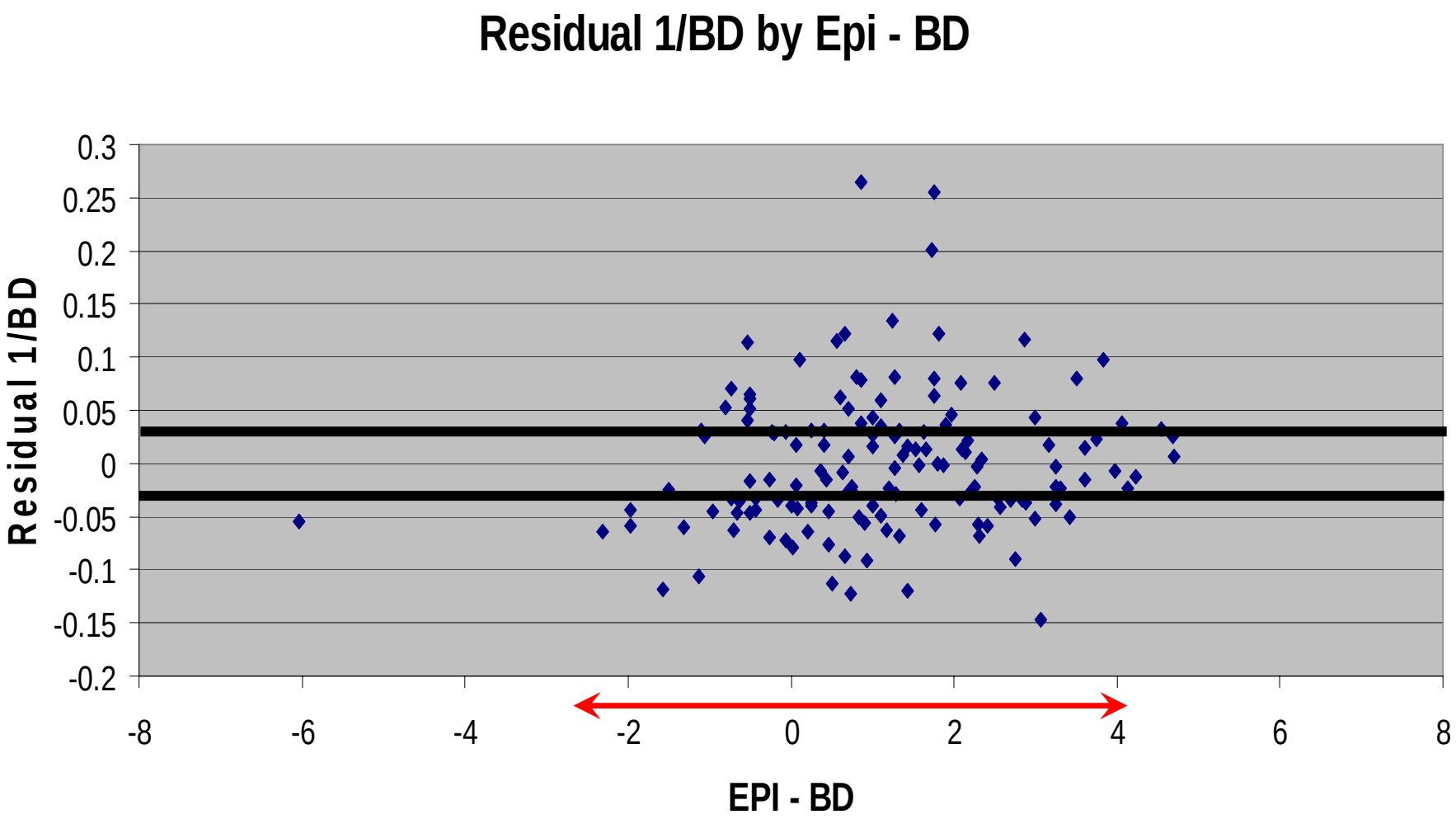
Residual Analysis



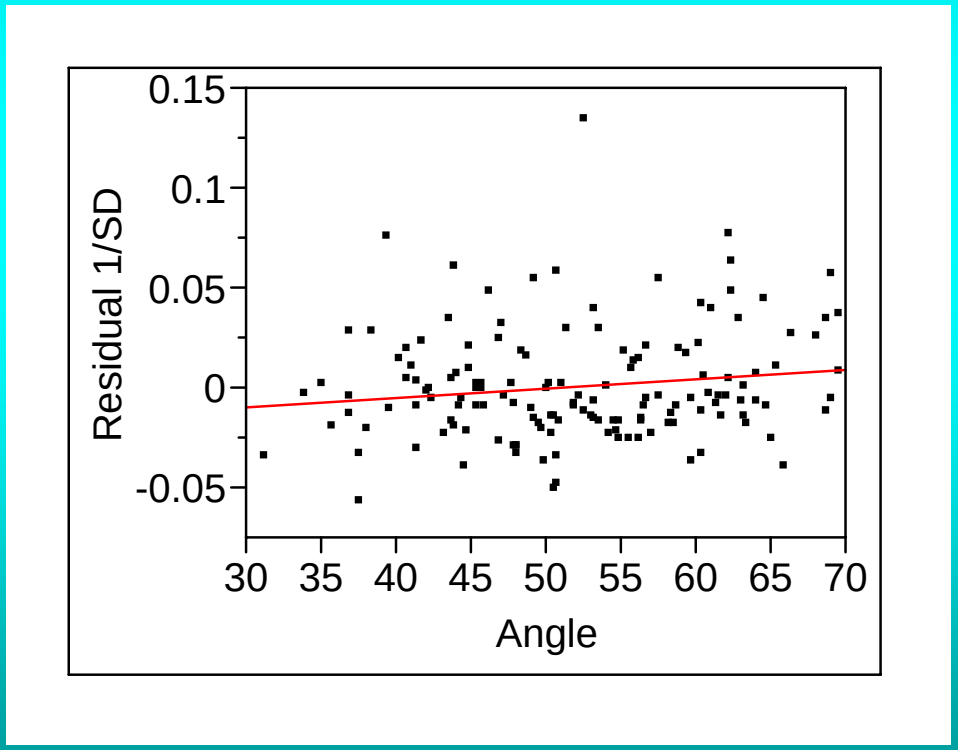
Summer Temperature Stratification



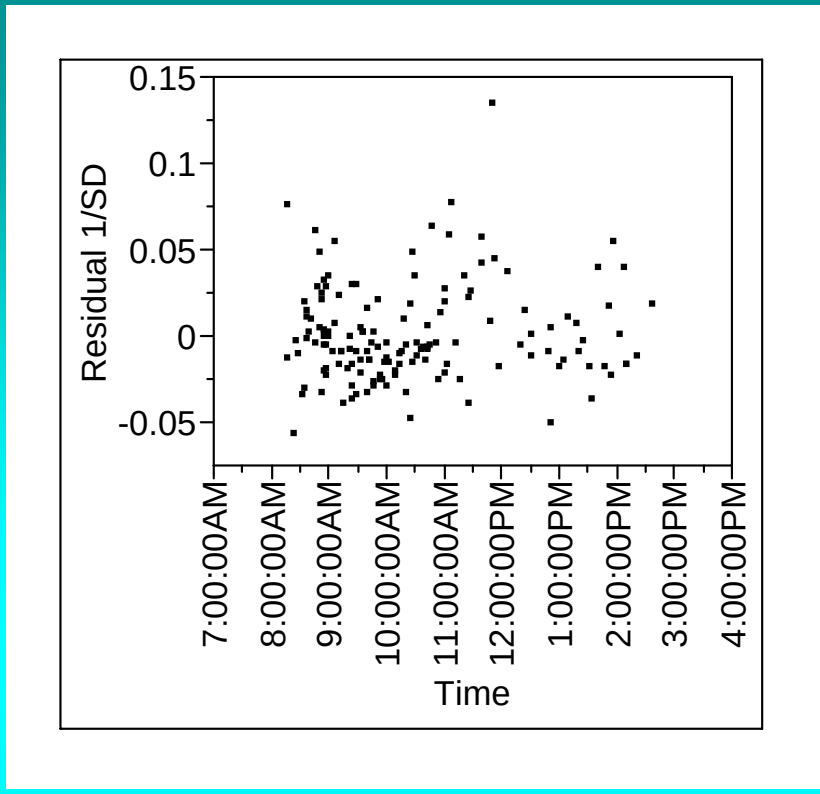
Residual Analysis



Residuals for 1/SD



Sun Angle (Degrees)



Solar Time

How does SD compare to optical measurements?

Extinction Coefficient is measured with an underwater light meter (irradiometer).

It represents the decrease in light with depth.

$$I = I_o e^{-kz}$$

where:

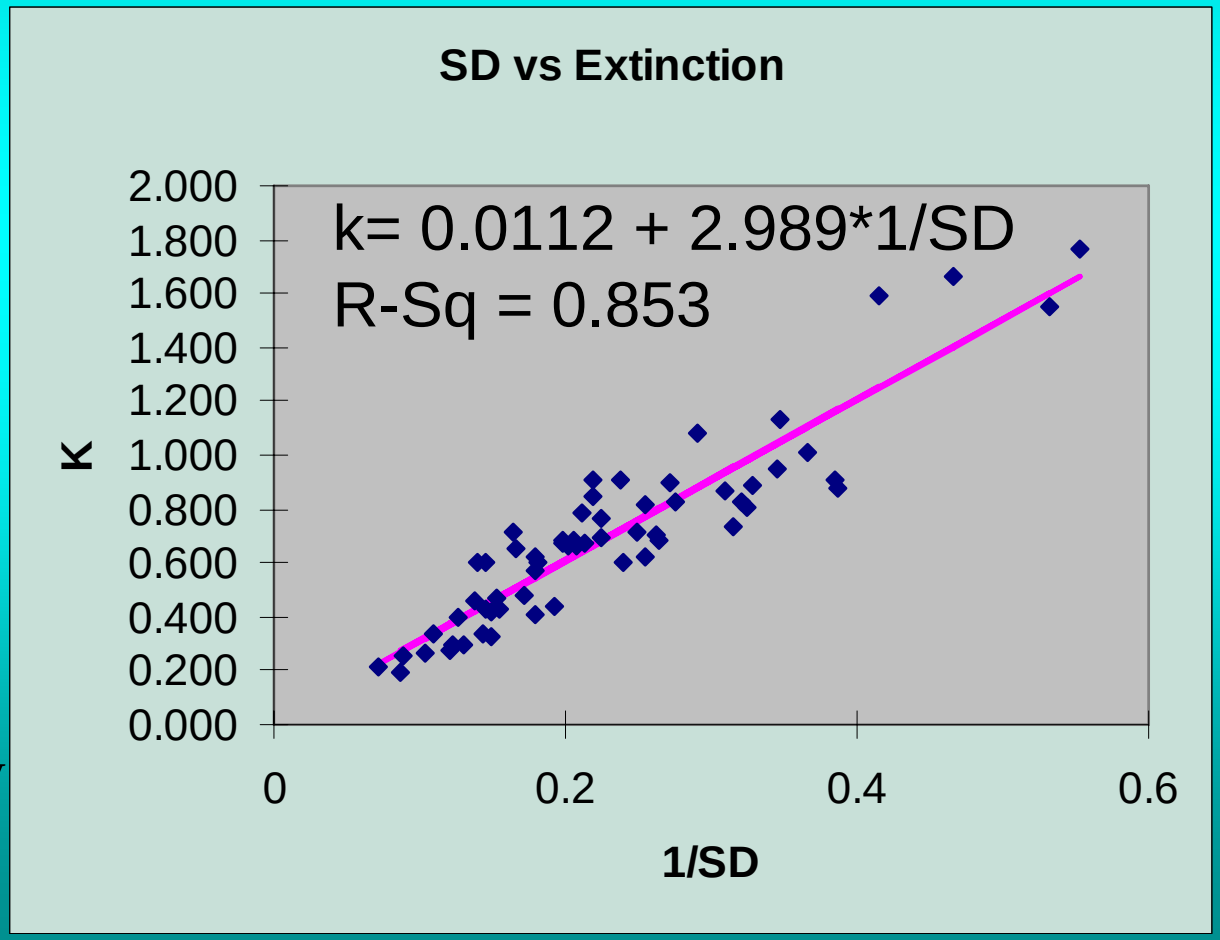
I= Light level at depth z

Io=Light at surface

e= exponential

k= Extinction coefficient

z=depth



N=61; 1999 50 Lake Study

SUMMARY II

- The vertical black disk measurements were more difficult to make and less precise than SD. However precision, was still very good overall.
- Black disk reading were a little over 2x the SD reading.
- Black disk readings correlated slightly better to CHL while SD readings did the same with Color; SD regressed stronger in the multiple regessions.
- Neither Sun Angle nor Solar Time seemed to impact the surrogate regressions nor the BD to SD relationship.
- Residual Analysis suggests that disk readings near the metalimnion may be affected