UCDAVIS
TAHOE ENVIRONMENTAL
RESEARCH CENTER

Lake Clarity Model: Development of Updated Algorithms to Define Particle Aggregation and Settling in Lake Tahoe

Goloka B. Sahoo

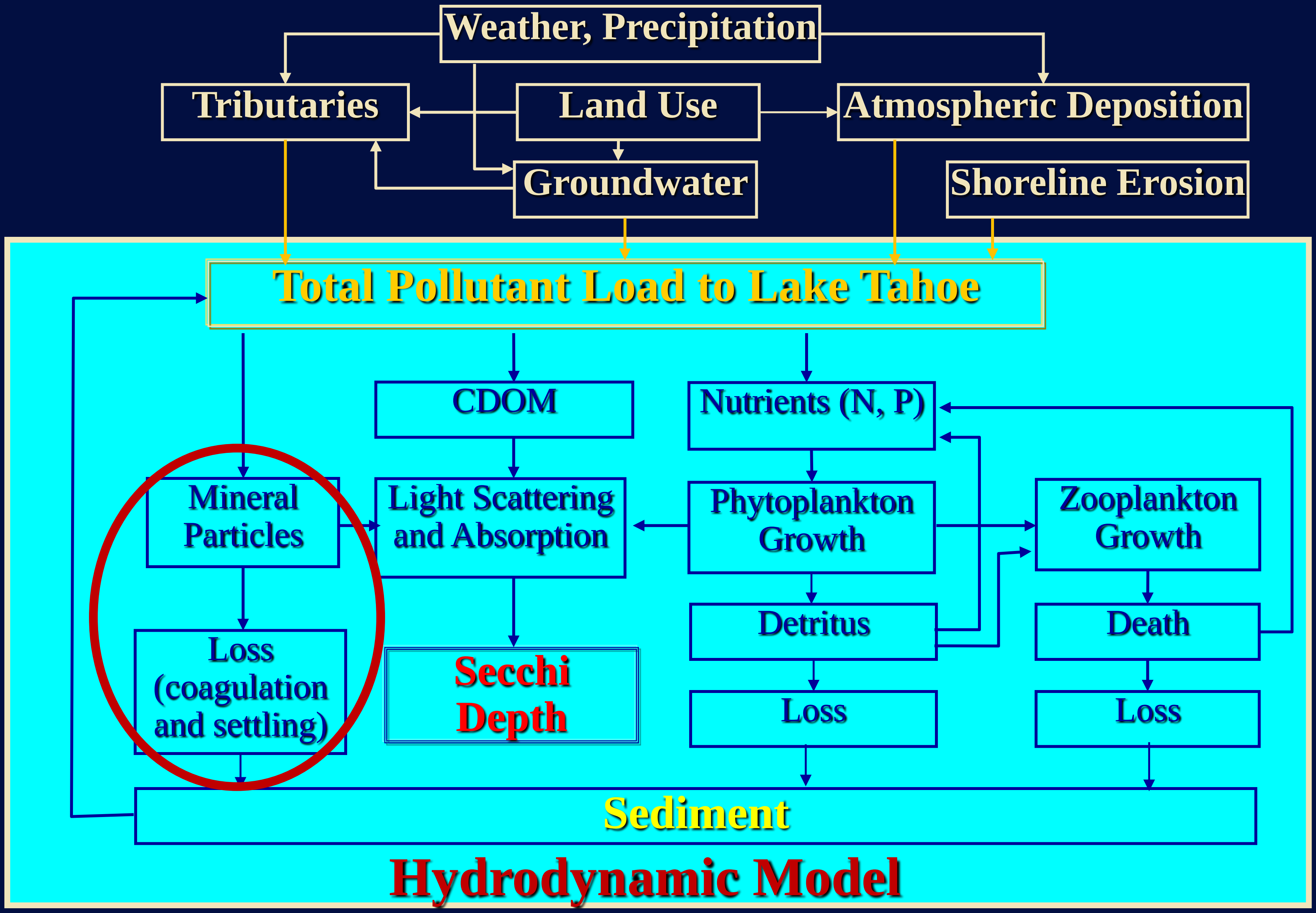
S. Geoffrey Schladow

John E. Reuter

Daniel Nover

David Jassby

Lake Clarity Model



LCM Modification after 2010

- **Lake Clarity Model** (Sahoo, G. B., Schladow, S.G. and Reuter, J. E. (2010) Effect of Sediment and Nutrient Loading on Lake Tahoe (CA-NV) Optical Conditions and Restoration Opportunities Using a Newly Developed Lake Clarity Model. *Water Resources Research*, doi:10.1029/2009WR008447)

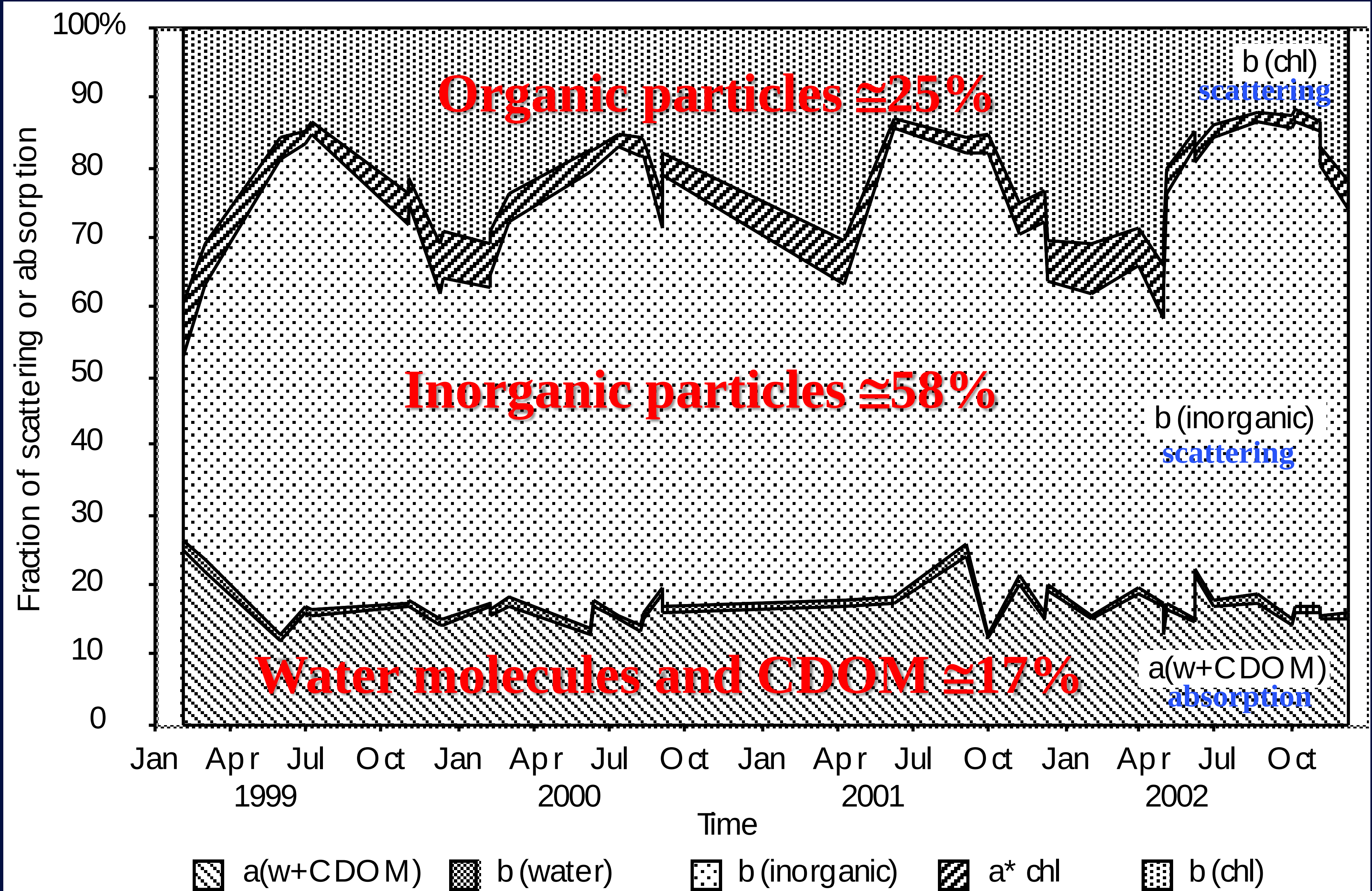
  Lahontan and Nevada Division of Environmental Protection (NDEP), 2010. Lake Tahoe Total Maximum Daily Load Technical Report. 340 p.

- **Introduction of Turbulent Diffusion Model to LCM**
  (Sahoo, G. B., Schladow, S.G. and Reuter, J. E. (2012) Dynamics and Hydrologic Budget of a Large Oligotrophic Lake to Hydro-meteorological Inputs using Predictive Model, under Revision for Journal of Hydrology

- Updated stream particles using measured data 2002-2010 (D. Nover, 2011).
- Fractal particle aggregation model (D. Jassby 2006 and Sahoo after 2006).
- Probability of aggregation

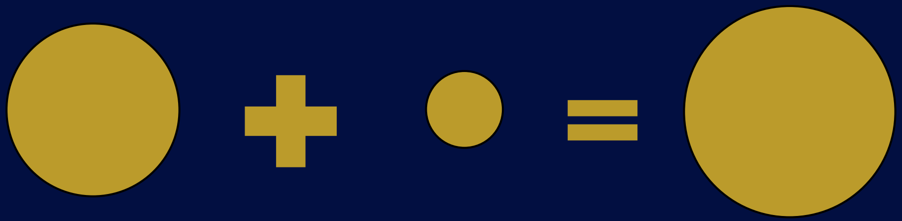
UCDAVIS
TAHOE ENVIRONMENTAL
RESEARCH CENTER

Swift (2004) and Swift et al. (2006)

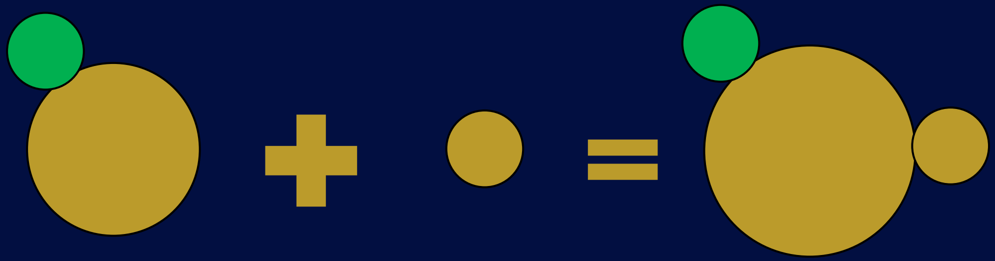


Particle Aggregation Theories

1. Solid Particle Aggregation (SPA) Model (O’Melia, 1985)



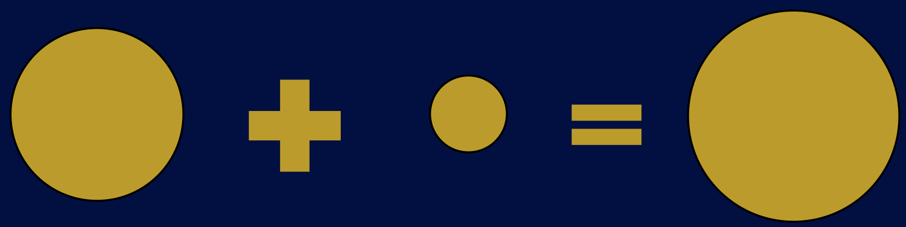
2. Fractal Particle Aggregation (FPA) Model (Jackson, 1995, 2001)



UCDAVIS
TAHOE ENVIRONMENTAL
RESEARCH CENTER

Previous Particle Model

1. Solid Particle Aggregation (SPA) Model



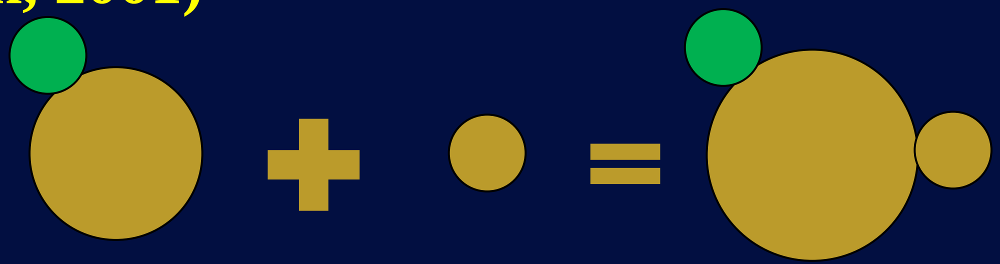
2. Constant value for probability of aggregation (α)

$$\frac{\partial c_{i,n}}{\partial t} = \frac{1}{2}\sum_{l+m\to n} \alpha\beta(l,m)_i c_{i,l} c_{i,m} - c_{i,l}\sum_{l=1}^{\infty}\alpha\beta(l,m)_i c_{i,n} \pm w_{i,n}\frac{\partial c_{i,n}}{\partial z} + \frac{\partial}{\partial z}\left(E(n,z)_i \frac{\partial c_{i,n}}{\partial z}\right)$$

where c_l, c_m, and c_n are number concentration of particles (# m^{-3}) of size l, m, and n, respectively, α is a collision efficiency factor, reflecting the stability of the particles and the surface chemistry of the system, β(l, m) is a collision frequency that depends on the inter-particle (particles of size l and m) contacts, w_n (m s^{-1}) is the settling velocity of particles of size n, and E(n, z) is an exchange coefficient, accounting for turbulent and molecular effects. The expression $l + m \rightarrow n$ under the summation denotes the condition that $M_l + M_m = M_n$, thus ensuring conservation of mass.

New algorithms

1. Fractal Particle Aggregation (FPA) Model (modified Jackson, 2001)



$$\frac{d\,n(m,\lambda,l_i)}{dt} = 0.5\,\alpha \int_0^{m}\int_0^{\lambda} \beta(m_1,\lambda_1,l_i,m-m_1,\lambda-\lambda_1,l_i)\,n(m_1,\lambda_1,l_i)\,n(m-m_1,\lambda-\lambda_1,l_i)\,dm_1\,d\lambda_1$$

$$-\alpha\, n(m,\lambda,l_i)\int_0^{\infty}\int_0^{\infty} \beta(m,\lambda,l_i,m_1,\lambda_1,l_i)\,n(m_1,\lambda_1,l_i)\,dm_1\,d\lambda_1 - w(m,\lambda,l_i)\,\Delta z^{-1}\,n(m,\lambda,l_i)$$

$$+w(m,\lambda,l_{i-1})\,\Delta z^{-1}\,n(m,\lambda,l_{i-1})$$

2. Variable probability of particle aggregation (α)

We postulated that probability of aggregation is function of particle size distribution, particle concentration, and phytoplankton concentration.

$$\alpha = C_a\left[\max(\mathrm{Chla},1)\right]\left[2\left(\frac{1}{r_i}+\frac{1}{r_j}\right)\right]\left[\{\log 10(cp_i)\}^2 + \{\log 10(cp_j)\}^2\right]$$

Modification contd.

Chlorophyll a: Literature (Passow, 2011) suggests that Transparent Exopolymeric Particles (TEP) highly correlates with Chl a. TEP accounts for particles' stickiness.

Particle Concentration: The probability of aggregation increases as the concentration of particles increases.

Particle size distribution: **as** smaller particles concentration is higher to large particles α is inversely proportional to particle size (r)

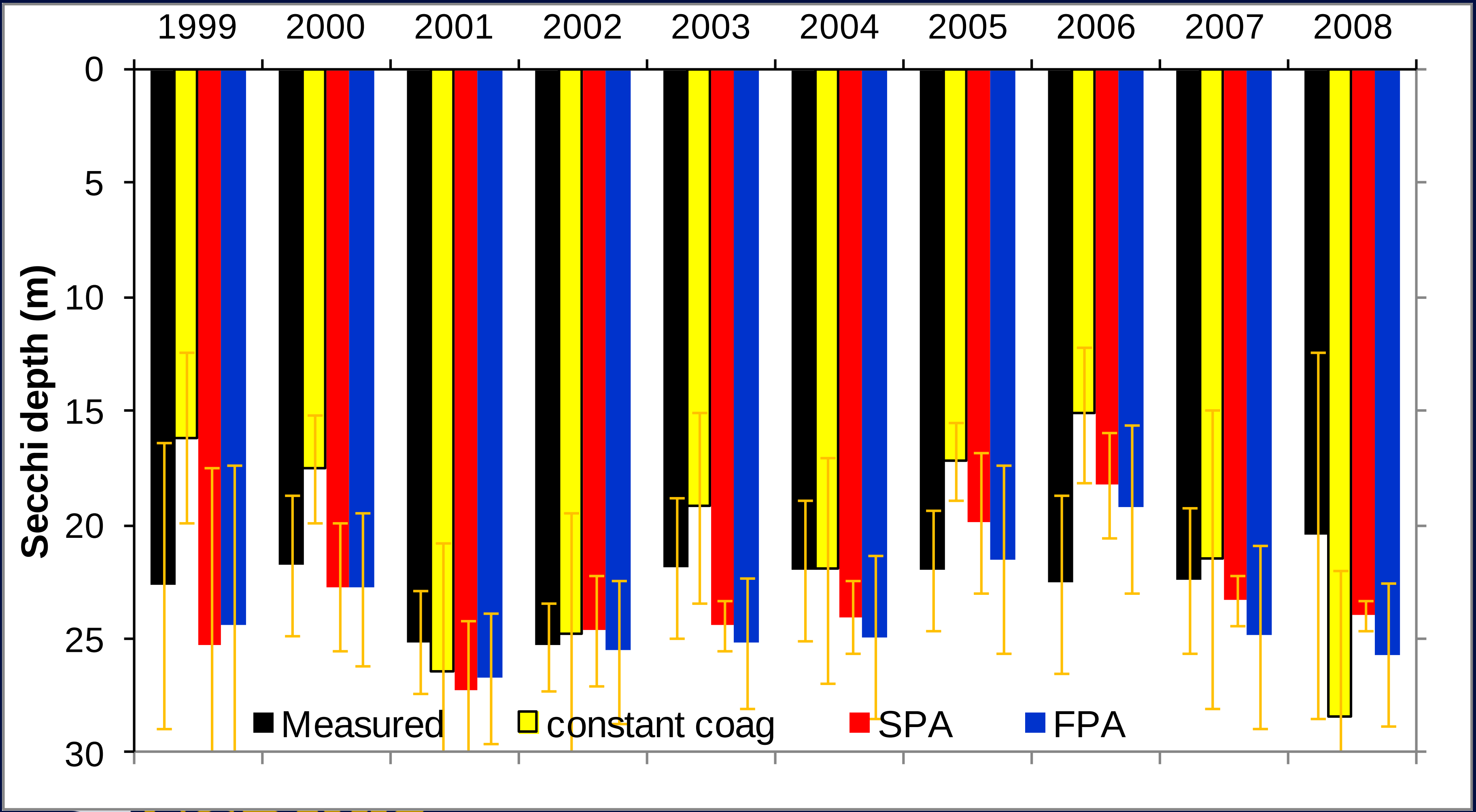
The constant (C_a): Calibrated

3. Both SPA and FPA conserve mass though the area available for collision is more for the case of FPA (Lee et al. 2000; Burd and Jackson, 2009). The new α was used for both SPA and FPA.

4. Stoke's law estimates settling velocity for SPA. For FPA, settling velocity is based on fractal dimension. Both use the three different processes: Brownian diffusion, fluid shear, and differential settling for collision frequency.

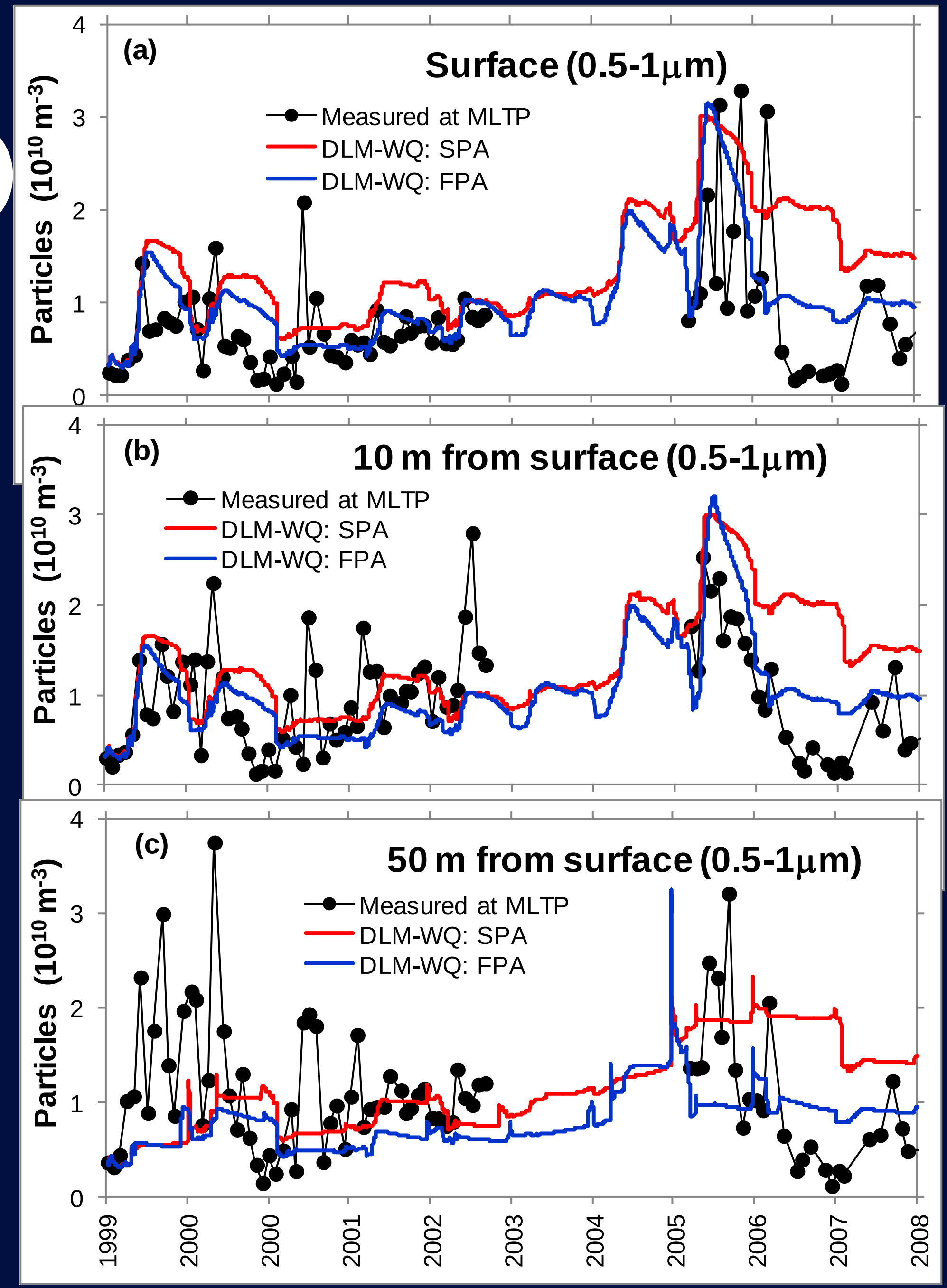
UCDAVIS
TAHOE ENVIRONMENTAL
RESEARCH CENTER

Results (Annual Average SD)



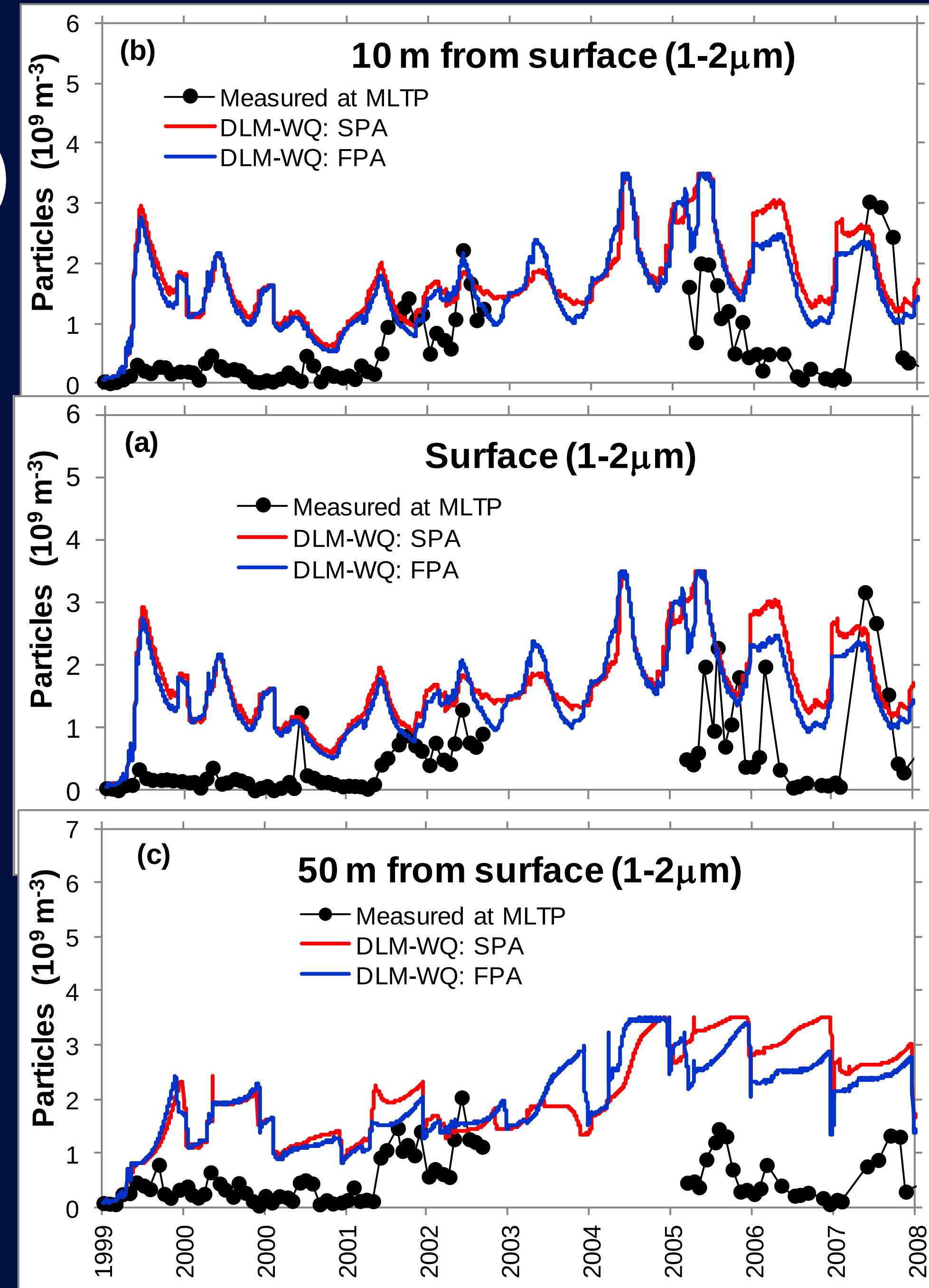
UCDAVIS
TAHOE ENVIRONMENTAL
RESEARCH CENTER

Results (Lake Particle 0.5-1μm)



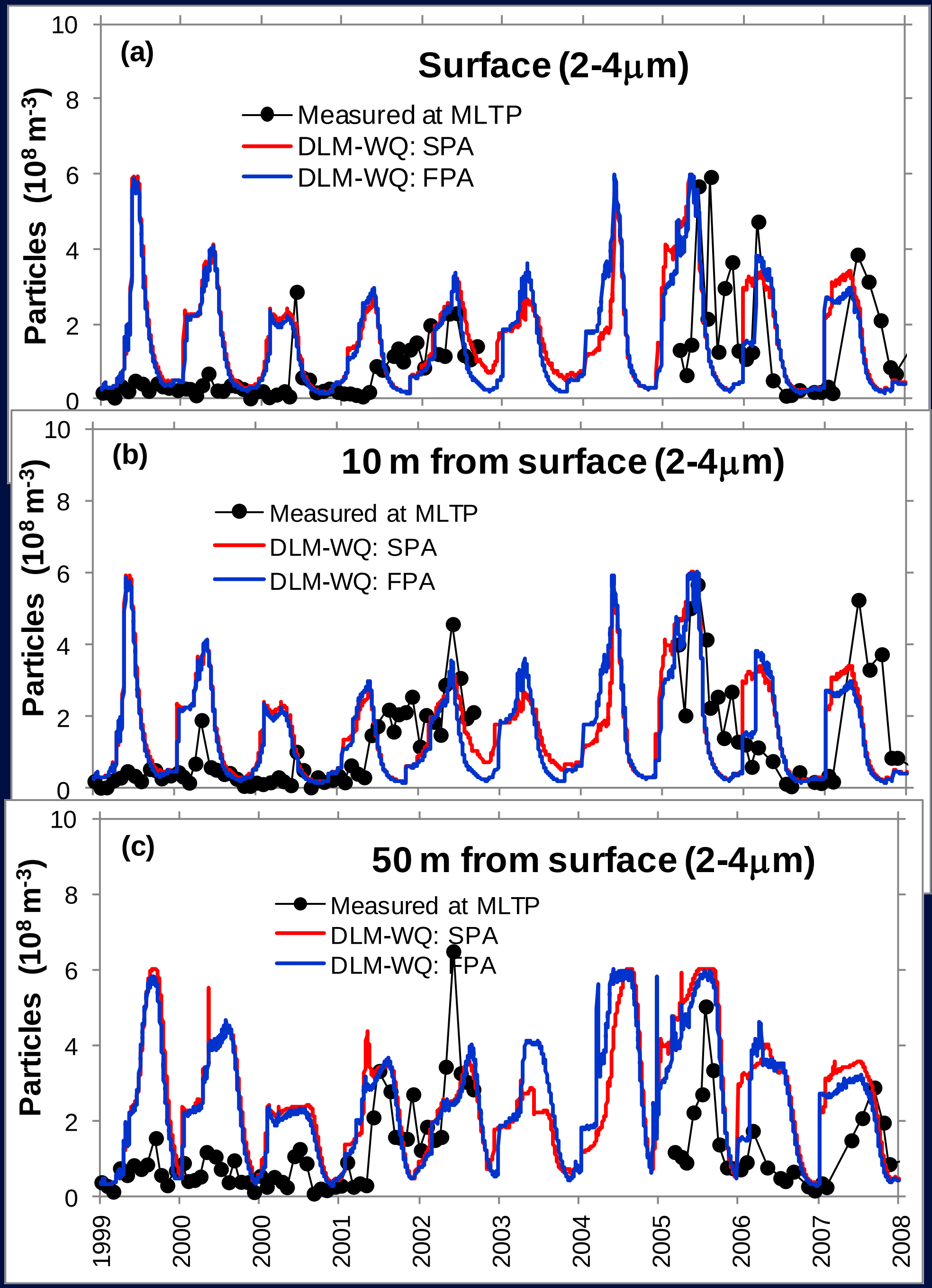
UC DAVIS
TAHOE ENVIRONMENTAL
RESEARCH CENTER

Results (Lake Particle 1-2μm)



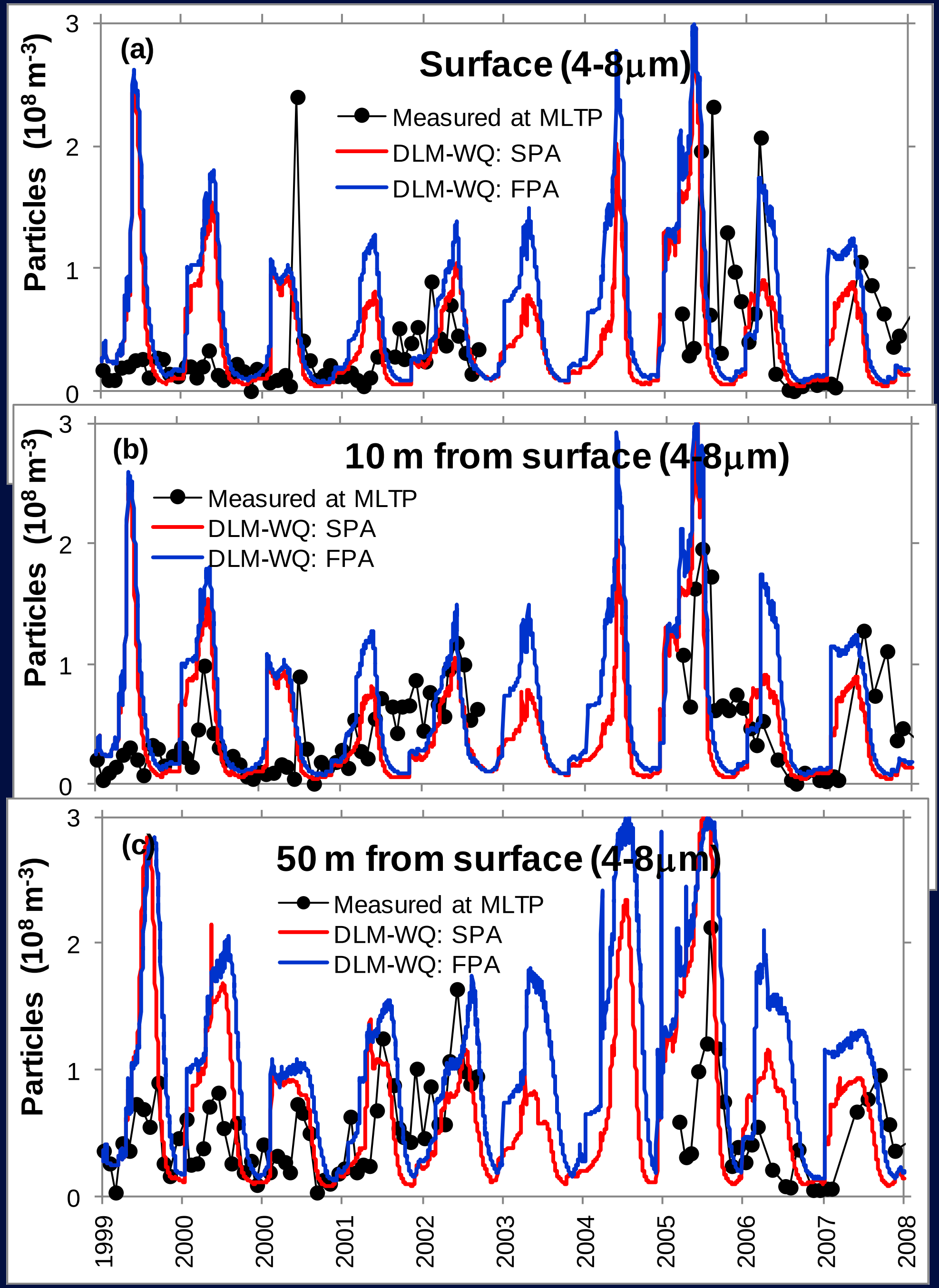
UC DAVIS
TAHOE ENVIRONMENTAL
RESEARCH CENTER

Results (Lake Particle 2-4μm)



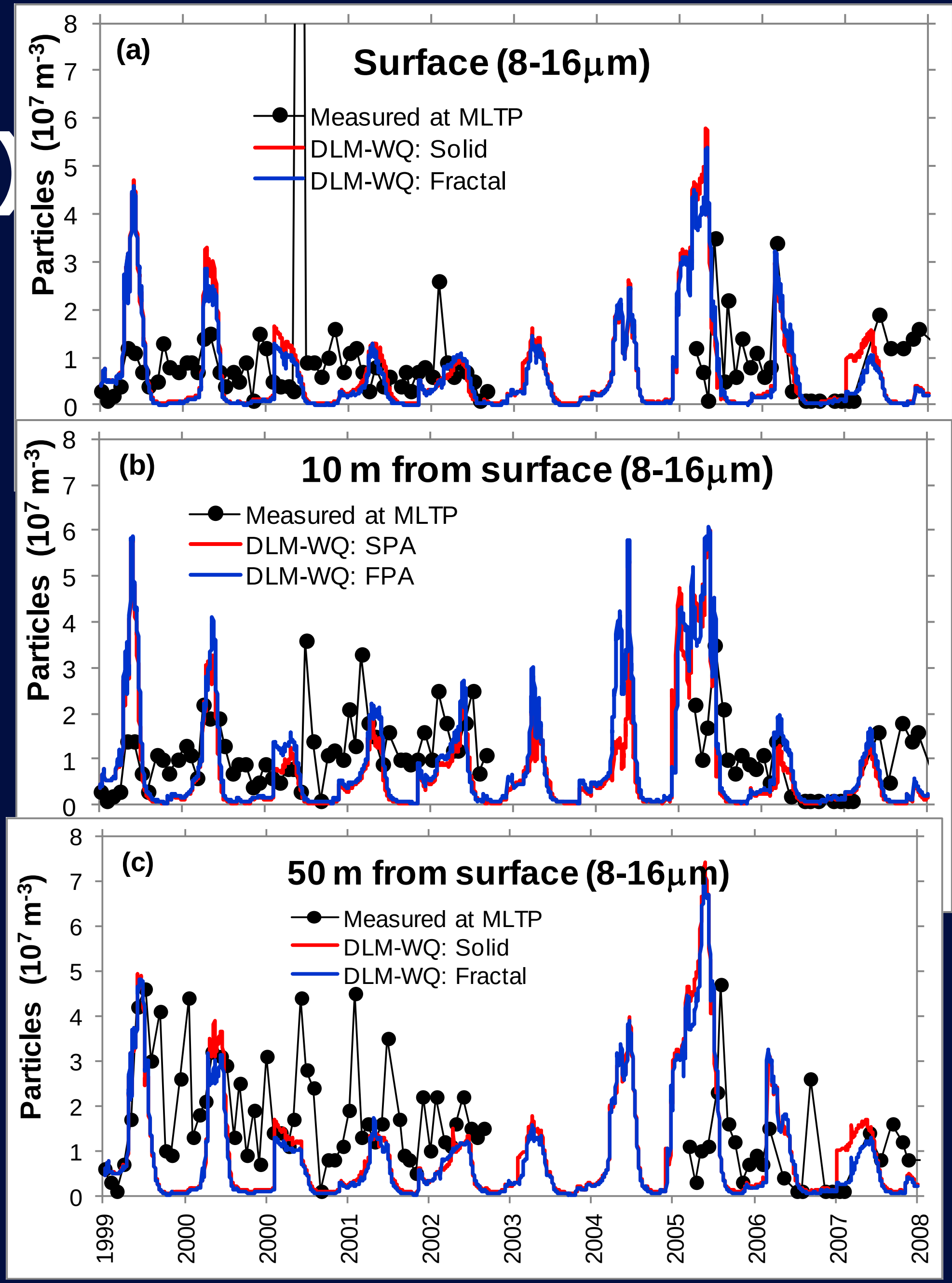
UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

Results (Lake Particle 4-8μm)



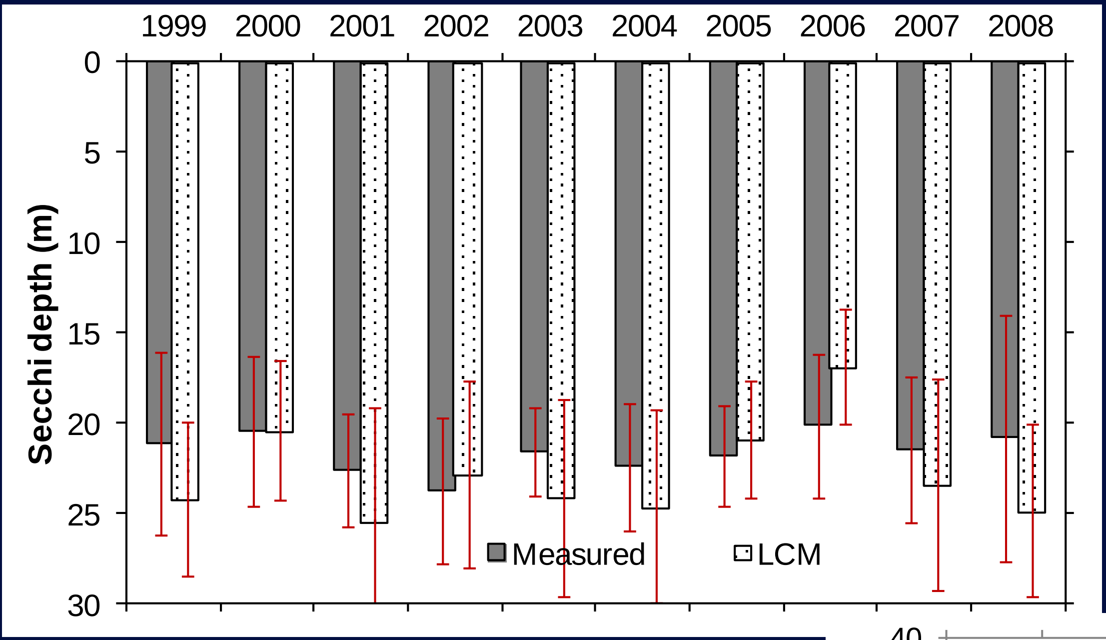
UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

Results (Lake Particle 8-16μm)



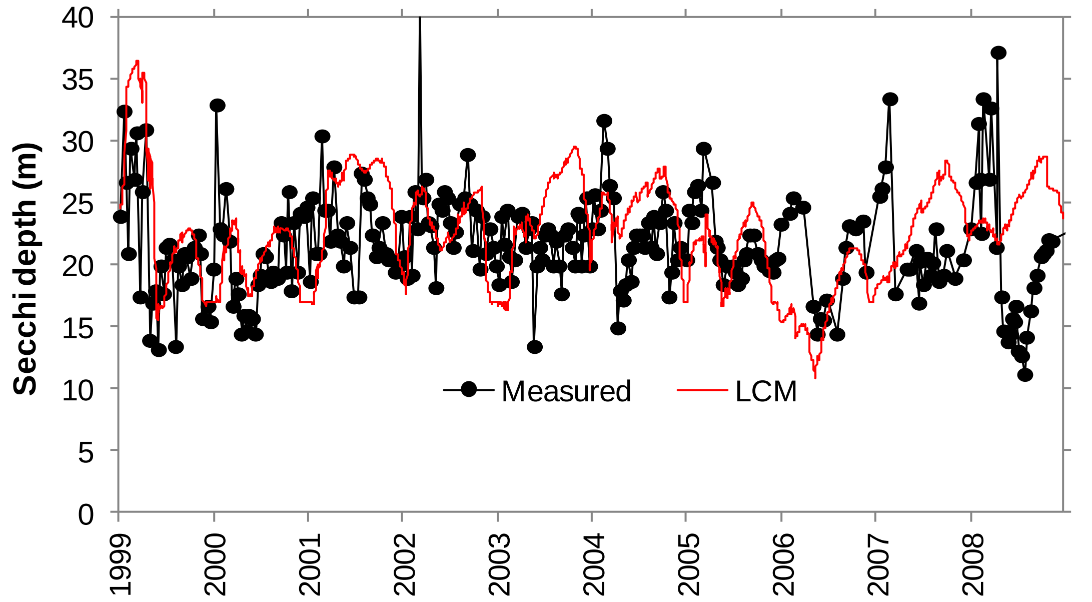
UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

Results using new α and Solid Particle Algorithm Model



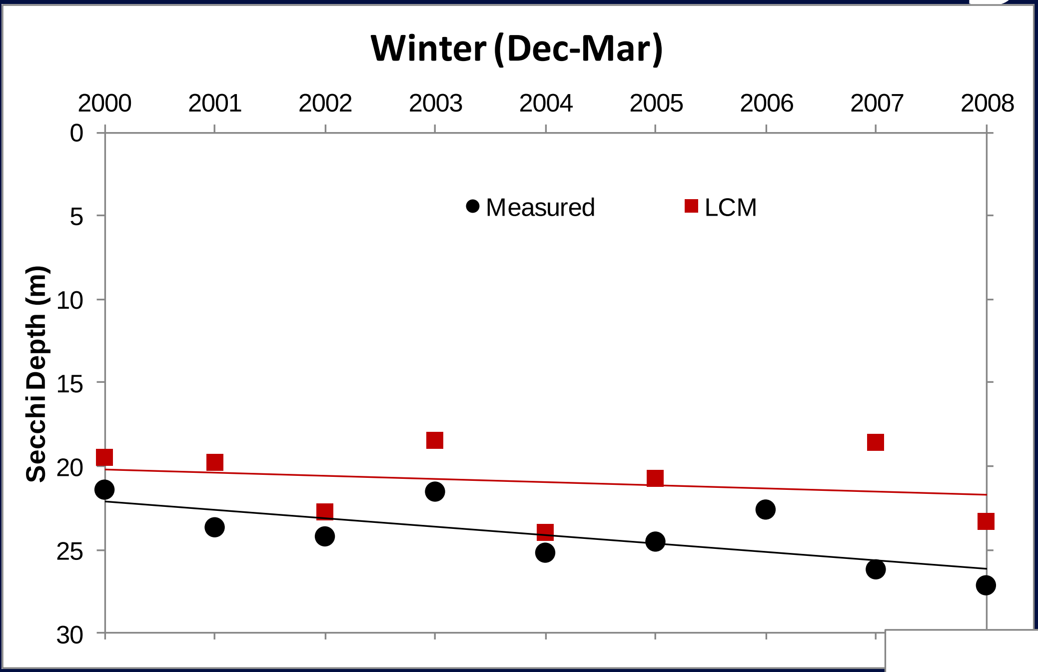
Annual Average

Daily

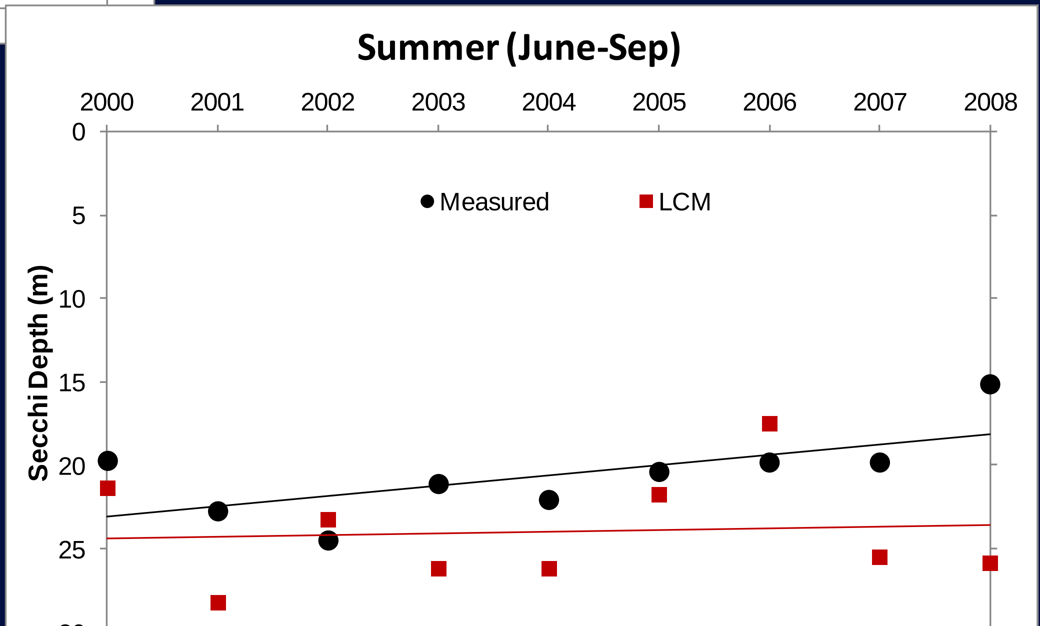


UC DAVIS
TAHOE ENVIRONMENTAL
RESEARCH CENTER

Results using new α and Solid Particle Algorithm Model



Seasonal trend



UC DAVIS
TAHOE ENVIRONMENTAL
RESEARCH CENTER

Summary

• Long term measured lake and stream particle data helps to estimate the trend and calibrate the model well

• The new probability of aggregation term captures well the seasonal and interannual Secchi depth variation compared to constant number.

• Both FPA and SPA conserve mass though area available for collision is more for FPA case. So, smaller particles are aggregated at higher rate for the case of FPA. Because of that predicted Secchi depth using FPA is little higher to using SPA.

• This is not the end of modification. Availability of new dataset will help to find the ground truths of many processes and will ask for modification.

UC DAVIS
TAHOE ENVIRONMENTAL
RESEARCH CENTER

ACKNOWLEDGEMENTS

This research is supported by University of California Davis and grants from the USDA Forest Service Pacific Southwest Research Station using funds provided by the Bureau of Land Management through the sale of public lands as authorized by the Southern Nevada Public Land Management Act.