SMS-618, Particle Dynamics, Fall 2009 (E. Boss)

Answers to assignment # 2 (some based on a compilation of the student's answers):

1. Describe properties of particles that affect their 'behavior' in the environment which are dependent on:

a. Size.

Drag: Settling velocity, swimming.
Particle encounter rate
Scattering cross-section
Ecosystem function (prey-predator interaction)
Brownian motion
Surface processes- diffusion in and out of the particle, dissolution

b. Shape.
Any departure from a sphere increases surface area/volume ratio and hence will affect all processes that depend on surface area. Note, however, that the effect of shape is most often a 2^{nd} order effect compared to size, that is size (whichever way it is estimated) is much more important.

Drag: Settling velocity, swimming
Effective cross-section for optical and acoustical interactions.
Surface processes- diffusion in and out of the particle, dissolution.
Prey-predator interaction- handling.

c. Composition.

Density and hence settling and acoustical properties
Index of refraction – hence optical properties
Ecosystem function (prey-predator interaction, e.g. nutritional value, toxicity)
Aggregation (stickiness).

2. Describe more than five methods to estimate particulate size distribution (in number of particles per volume per size bin). For each method provide:
   a. What is actually being measured?
   b. What are the assumptions relating to obtaining the PSD?
   c. If you find a good web site describing the method/instrument please provide a link (I may use it to compile a table on the class's web site).

There exists a whole book on the subject of methods to size aquatic particles:

Principles, Methods and Applications of Particle Size Analysis J.P.M. Syvitski (Editor), Cambridge University Press, Cambridge, 1991, 368 pp.

Here are some representative methods:

Sieves/filters

a. *Measures: mass (or optical property) of particles crossing a physical sieve. Diameter is inverted from sieve chareacteristics (e.g. smallest cross-section). Sorts particles.*
b. *Assumes: particles are spheres. Need density or optical model to convert from mass to numbers of particles.*
c. *Known problems: breaks fragile particles.*

Electrical impeence (e.g. Coulter, Elzone):

a. *Measures: Change in conductivity of individual particles as they pass within an electric field in an aperture as they are transported by a conducting fluid. The change is proportional to the solid volume of the particle. Measurement is done within the environmental fluid in the lab. Diameter is inverted from volume. Assumptions: when translated to size, volume is converted to size assuming sphericity.*
d. *Some known limitations Small particles (relative to aperture) tend to be underestimated in numbers due to small effect on the electric field Aggregates are broken (e.g. Jackson et al., 1997). Measures only particles within aperture domain.*

http://www.science-prtojects.com/Coulter/Coulter.htm

Diffraction (near-forward scattering) based sensors (LISST, Malvern):

a. *Measures: near forward scattering due to a bulk sample. Most sensitive to cross sectional area of the particle. Both lab and in-situ sensors exist. Diameter is inverted from a measurement most sensitive to optical cross section. Bulk sample analysis.*
b. *Assumption: inversion assumes particles are spherical and of a given composition (index of refraction).*
c. *Some known limitations: Useful for particles larger than a few microns for which near forward scattering has sufficient structure. Inversion suffers from aliasing for smallest and largest bins (Traykowsky and Agrawal, xxxx).*

http://www.coastalwiki.org/coastalwiki/Image:H5643figure1b.jpg

Settling column - weight:

a. *Measures weight of particles settling as function of time in a fluid of known properties. Diameter is inverted from hydrodynamics (settling in fluid). Lab technique. Sorts particles.*
b. *Assumptions: density of particles is knows and the particles are assumed to be spherical. A conversion equation (usually Stokes settling law) is used to assign a size to the mass.*
c. *Known limitations: shape decreases settling speed, Stokes law is strictly applicable for the smallest particles only (modifications are available) and particle density may vary with size.*

Settling column – transmission (LISST-ST, x-ray sedigraph):

a. *Measures changes in attenuation as function of time following settling of particles in the path between a source and detector. Diameter is inverted from hydrodynamics (settling in fluid). Lab and field technique. No sorting*
b. *Assumptions: EM attenuation is used proxy of concentration for a given size. Assumes a known relation between settling speed and size (known shape and density).*
c. *Known limitations as with other settling methods, shape and variable (unknown) composition will affect settling. In addition EM attenuation as function of particle concentration is sensitive to composition (which needs to be assumed).*

Dynamic light scattering (Malvern, Dawn).

a. *Measures variability in the beam intensity passing through a suspension of particles. Temporal correlation in intensity is related to movement of particles in the fluid. Diameter is inverted from hydrodynamics (Brownian motion). No sorting. Lab technique.*
b. *Assumes motion of particles is due to Brownian motion and that the particles are spheres, hence particles settling and convection are assumed negligible.*
c. *Known problems: Provides a single <size> for the suspension. Convection within container affects measurements.*

Confocal microscopy (MAPPER) silhouette imaging (LOPC)

a. *Measures A thin sheet is illuminated by a laser. Size is derived from optical cross section. Image analysis of shadow or scattered light provides size (in-situ, Lab). No sorting.*
b. *Assumes particles >> wavelength of light (geometric optics). Software is trained to recognize pattern.*
c. *Known problems: variable alignment of non-spherical particle relative to light provides a variable size.*

www.brooke-ocean.com/lopc.html

Microscopy, photography, video:

a. *Measures pixels occupied by signal higher than a threshold. No sorting. In-situ or Lab.*
b. *Assumes sphericity when converting shadow to size.*
c. *Known problems: sensitive to threshold. Number of particles within a single frame is limited. At too high a concentration particles may shadow each other.*

Particle sorters (Flow Cam, flow cytometer):

a. *Measure optical properties or take an image of a single particle at a time as they flow through the measurement chamber. Lab and field techniques.*
b. *Assume relationship between optical property or shadow area to size.*
c. *Known problems: will tend to break aggregate and large phytoplankton chains.*

3. A coulter counter output file is provided on the web site (052.xls). It provides a number of size distributions (2 per depth) collected south of Martha's Vinyard at about

70m water depth. Note that there is one ‘diameter size’ more than the number of ‘channels’. This is because the diameter sizes are the boundaries of each size bin. Choose a specific depth for which you would like to perform the analysis. For the data from that depth:

a. Plot the number, area and volume distribution in each bin as function of the geometric mean size of that bin (assume spherical particles). Provide correct units on the graph. Choose plot axes (e.g. linear or logarithmic) such as to convey the most information about the data.
b. In order to obtain a size distribution that does not depend on the bin size, divide the number in each bin by the size of the bin (e.g. divide by 3microns a bin spanning from 15 to 18microns). Plot the new PSDs and provide correct units on the graph. For three oceanic processes of your choice, choose the most relevant PSD.
c. Don’t forget to add uncertainties to the plotted PSDs. How did you compute them?

See plots and program attached.

```
clear all
%file to read the 60m coulter data from the spreadsheet
size_coulter = xlsread('0521','052','B45:B173'); %position of bins
boundary in microns
bin_size=diff(size_coulter); %width of bins in microns
numbers_1 = xlsread('0521','052','C45:C172'); %number of particles per
bin
numbers_2 = xlsread('0521','052','J45:J172'); %number of particles per
bin
%To compute volume sampled I took the volume computed in the worksheet
(in um^3/l) and divided it by the number of particles time their volume
(in um^3). I got 2000 l^-1 or 0.5ml.

%all plots are log-log plots given the large dynamic range in the data
(at least an order of magnitude)

%uncertainty can be computed in several ways. First, the coulter can
only count a single, whole particle at a time. We have two realization
of the spectra; we can use the min and max as the range of the likely
values in the field. It is not very satisfying but this is all we got.
I add 0.5 particle given the resolution of the coulter. There is also
%an uncertainty is size (when computing volume or area): particles can
be of any size between largest and smalles bin size. Hence:

number=mean([numbers_1';numbers_2']);
number = number /0.5; % normalize to obtain number of particles per ml;
uncertainty_number=(abs(numbers_1-numbers_2))'+0.5;
min_area=pi*size_coulter(1:128).^2/4;
max_area=pi*size_coulter(2:129).^2/4;
min_vol=pi*size_coulter(1:128).^3/6;
max_vol=pi*size_coulter(2:129).^3/6;

for i=1:length(size_coulter)-1
```

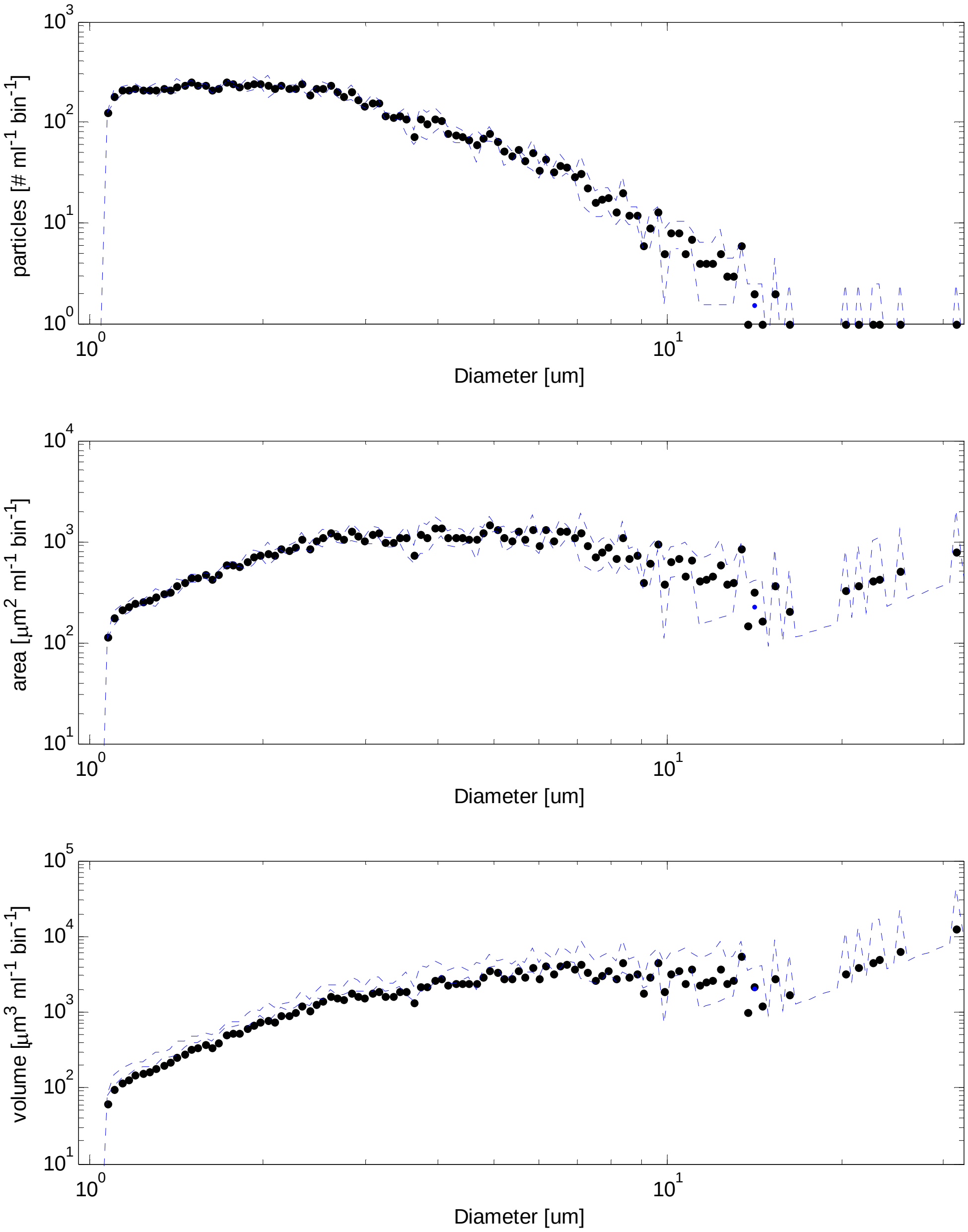
```
    size(i)=sqrt(size_coulter(i)*size_coulter(i+1)); %compute the
geometric mean diameter
end

figure(1)

subplot(3,1,1)
loglog(size,number,'k.')
hold on
loglog(size,number+uncertainty_number,'b:')
loglog(size,number-uncertainty_number,'b:')
hold off
xlabel('Diameter [um]')
ylabel ('particles [# ml^{-1} bin^{-1}]')
axis([min(size), max(size), 1, 10^3])

subplot(3,1,2)
loglog(size,number*pi.*size.^2/4,'k.')
hold on
loglog(size,(number+uncertainty_number).*max_area','b:')
loglog(size,(number-uncertainty_number).*min_area','b:')
hold off
xlabel('Diameter [um]')
ylabel ('area [\mum^2 ml^{-1} bin^{-1}]')
axis([min(size), max(size), 10, 10^4])

subplot(3,1,3)
loglog(size,number*pi.*size.^3/8,'k.')
hold on
loglog(size,(number+uncertainty_number).*max_vol','b:')
loglog(size,(number-uncertainty_number).*min_vol','b:')
hold off
xlabel('Diameter [um]')
ylabel ('volume [\mum^3 ml^{-1} bin^{-1}]')
axis([min(size), max(size), 10, 10^5])

figure(2)
subplot(3,1,1)
loglog(size,number'./bin_size,'k.')
hold on
loglog(size,(number+uncertainty_number)'./bin_size,'b:')
loglog(size,(number-uncertainty_number)'./bin_size,'b:')
hold off
xlabel('Diameter [um]')
ylabel ('particles [\mum^{-1} ml^{-1}]')
axis([min(size), max(size), 1, 10^4])

subplot(3,1,2)
loglog(size,number'./bin_size*pi.*size'.^2/4,'k.')
hold on
loglog(size,(number+uncertainty_number)'./bin_size.*max_area,'b:')
loglog(size,(number-uncertainty_number)'./bin_size.*min_area,'b:')
hold off
xlabel('Diameter [um]')
ylabel ('area [\mum ml^{-1}]')
axis([min(size), max(size), 10^2, 10^5])
```

```
subplot(3,1,3)
loglog(size,number'./bin_size*pi.*size'.^3/6,'k.')
hold on
loglog(size,(number+uncertainty_number)'./bin_size.*max_vol,'b:')
loglog(size,(number-uncertainty_number)'./bin_size.*min_vol,'b:')
hold off
xlabel('Diameter [um]')
ylabel ('volume [\mum^2 ml^{-1}]')
axis([min(size), max(size), 10^3, 10^5])
```

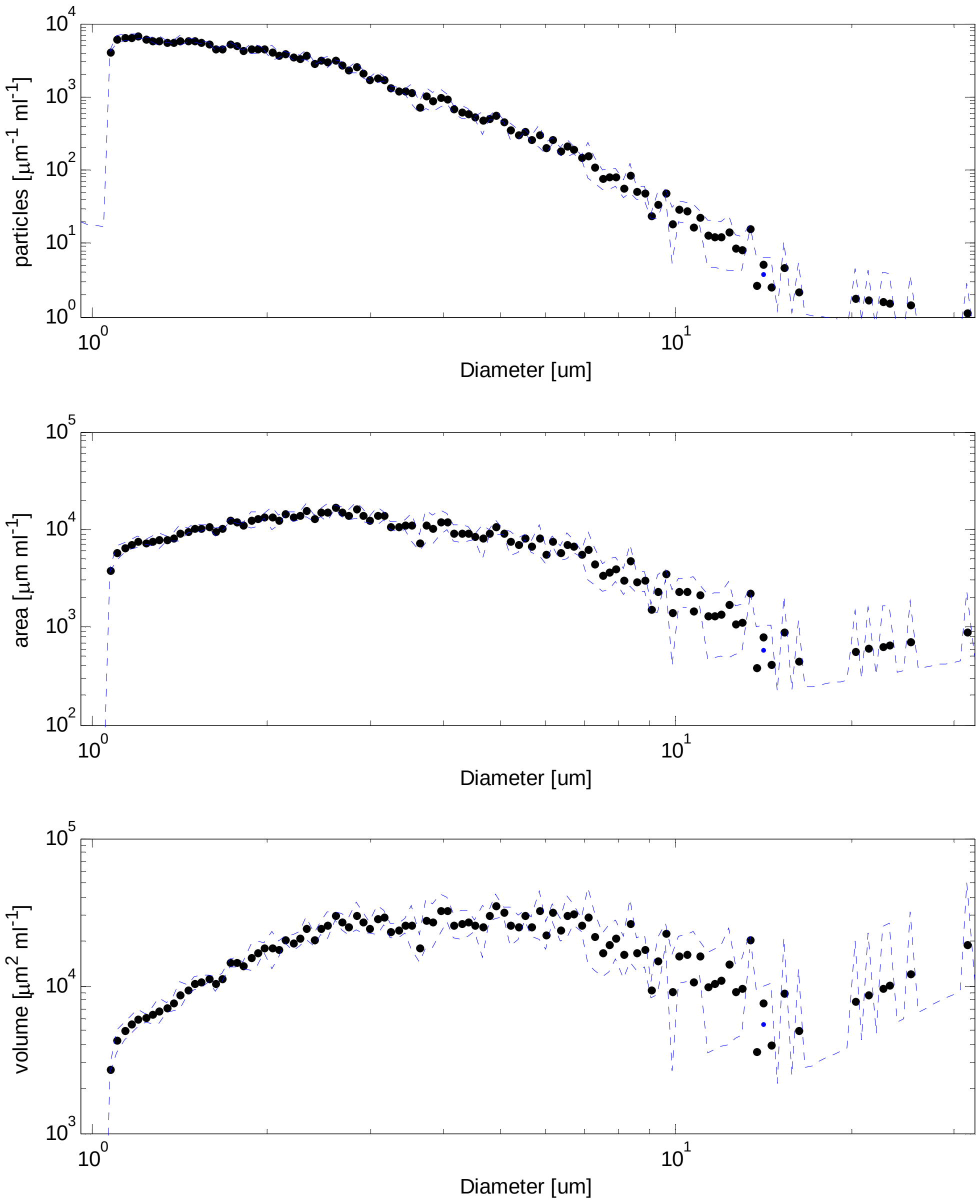
Continued: For three oceanic processes of your choice, choose the most relevant PSD:

1. For nutrient uptake, exudation, photo-dissolution: cross sectional area distribution.
2. For carbon/particulate mass, prey/predator: particle volume distribution.
3. For aggregation, encounter-rate: number distribution.

4. Non-bin-normalized data:



Bin-nomalized data.



a. uncertainty can be computed in several ways. First, the coulter can only count a single, whole particle at a time. We have two realization of the spectra; we can use the min and max as the range of the likely values in the field. It is not very satisfying but this is all we got. I add 0.5 particle given the resolution of the coulter. There is also an uncertainty is size (when computing volume or area): particles can be of any size between largest and smallest bin size.