Footnotes to EXPORTS measurement table

*These notes are keyed to the 81 items in the EXPORTS measurements table, and contain comments from Science Definition Team members regarding measurement types, attributes and purpose. It should be seen as a guide to help describe the desired measurement types and procedures, not as an absolute recommendation or endorsement of using a particular method or piece of equipment***.**

1 Proxies converted to biomass using direct biomass measurements on Langrangian ship. Taxonomic resolution to functional groups. Taxonomic classification resolved to at least the following basic levels: prokaryote, picoeukaryote, diatom, dinoflagellate, coccolithophorid, chryptophyte, other (mixotroph). For autonomous deployment cruise, can preserve samples for later analysis. Needed for development of optical proxies. e.g., flow cytometry for smaller cells, digital imaging microscopy such as Flow CytoBot or FlowCAM for larger cells; inverted microscopy if required for larger, rarer types. Size spectrum of autotrophic community, with a size spectrum from 1 μm to >100 μm, including chains. If feasible, it would be useful to characterize plankton community composition in the mesopelagic, particularly for spores and viable cells. Concentrations are likely very low and would require large sample volumes making a routine assessment.

2 Analytical measurements of phytoplankton C. Minimum requirement is total phytoplankton biomass using sorting FCM. When large cells present, sorting flow cytometry should be combined with assessment of biomass for cells > 60 μm (multiple techniques are available i.e. microscopy).

3 Abundance of decomposers and remineralizers. For autonomous deployment cruise, team can preserve samples for later analysis via FCM or epifluorescence microscopy. Expert only if FCM on board. Needed for estimation of living carbon biomass. Bacterial abundance to provide numbers at lower end of particle size distribution spectrum; bacterial carbon; also virus sized particles. Provides numbers for estimates for bacterial carbon demand.

4 H-flagellates to be stained and analyzed by FCM, preferably on board; larger cells can be preserved and analyzed on shore by microscopy. For autonomous deployment cruise, team can preserve samples for later analysis. Size spectrum of heterotrophic protistan community and heterotrophic carbon content of protists. Estimate of grazer / mixotrophic populations. These data will be used to assess composition of food web responsible for organic matter production and partitioning. Estimation of living carbon biomass. Estimate predation pressure on bacterial/archaea component; For SQ2d- need protozoan abundance (on aggregates and free-living) for mesopelagic C demand calculations. For all of SQ2, this may not be a very accessible measurement as concentrations are so low per m3, but, they will be measureable on particles, for example, and we need to characterize patchiness.

5 Interpretation confounded with solar fluorescence quenching

6 Filter and preserve filters. These measurements provide more detailed community profile for '10' day state process studies. Could also link with gene expression data. Use to resolve metabolic fingerprint of different functional groups for DIC, DOC uptake and processing and carbohydrate metabolism. Also to resolve whether changes in photosynthetic efficiency are attributed to different functional groups, and to resolve metabolic partitioning for many nutrient processing pathways between functional groups. Need to consider physical sample repository/libraries for genomics samples.

7 Filter and preserve filters. These measurements provide more detailed community profile for '10' day state process studies. Could also link with gene expression data. Need to consider physical sample repository/libraries for genomics samples. Functional diversity of decomposers and remineralizers, including Eubacteria and Archaea. Community profiling for qualitative assessment of diversity. Provide relative contribution of individual OTU to overall community structure. These data will be used to assess similarity and differences between Euphotic and Mesopelagic microbial consortia. Metagenomes provide information about metabolic potential i.e. what genes are present in the sample. Samples could be used to construct genomes or large contig. This does not inform what is being expressed.)

8 Filter and preserve filters. These measurements provide more detailed community profile for '10' day state process studies. Could also link with gene expression data. Need to consider physical sample repository/libraries for genomics samples.

9 Nucleic acids and / or proteins can be archived for later. Matrix of nutrient amendment incubations combined with DNA based taxonomic profiling, metagenomic, metaproteomic and metatranscriptomics can indicate whether C fixation by specific functional groups is constrained by a specific nutrient, metatranscriptomics from incubations can help resolve metabolic partitioning and metabolism in the in situ samples.

10 Mass spec for underway sampling optimal on survey ship. Preserved water samples for vertical discrete water samples possible on process ship (also useful for shore based triple oxygen3isotopes.

11 NCC = net cocco calcification; include with 14C Phyotosynthesis using microdiffusion technique on same water samples. Requires no more water since technique separates 14C-POC and 14C-PIC. Incubation on ship PvsE approaches. on same water sample; incubations likely ship based. Size fractionated preferred

12 Useful to compare to NCP

13 Useful to compare to NCP; incubations are likely ship based

14 Mitomycin C experiments will allow assessment of lysogenic viral infection. Electron microscopy would allow for detection of infectin and potential burst size. Mortality due to viral infection; conversion of POM to DOM (competes with flux by converting POM into DOM); most effective on bacteria & picoplankton. Coordinate with microzooplankton grazing experiments.

15 Used to estimate bacterial carbon demand when combined with estimates of bacterial growth efficiency.

16 Remineralization experiments are used to estimate OM bioavailability, persistence and export potential, bacterial growth efficiency Necessary to assess the %bioavailability / persistence of seasonally produced DOM to extant microbial assemblages. These experiments are also provide estimates of bacterial growth efficiencies necessary to estimate bacterial carbon demand

17 simple vertical tow, not MOCNESS or other larger multi net vertical resolved

18 Needed to resolve spatial patchiness. Concurrent net tows are essential for 'calibration' of acoustic biomass and signal interpretation -development of zooplankton biomass proxy.

19 Essential to quantify for both fecal pellet production and active vertical transport of matter and energy. Stratified tows (e.g., MOCNESS) necessary due to diel migrations. Taxonomic resolution to genus, life stage if possible. Important to try to resolve carnivore or omnivore (which could eat phytoplankton). Useful for metabolic rates. Need to be done when acoustic measurements are collected, to interpret acoustics. Need to consider physical repository for archiving zooplankton materials. Estimate of zooplankton carbon content. Important to assess for lipid rich species, e.g., Calanus prior to diapause.

20 Experiments to include controlled studies of mesozooplankton sloppy feeding & other processes related to zooplankton feeding and motions. Typically monitor in situ particle size spectra changes (time-series) along with zooplankton abundance during on board experiments

21 Important to supplement algorithms for weight specific metabolic rates (with known temp and animal sizes). Data still lacking for TZ species. Conducted via incubation experiments with dominant taxa, measuring bulk changes in respiration (e.g., optical oxygen sensor spots) and in excretory products, or using tracers; proxies such as ETS (electron transport system measurement); laboratory culture experiments where applicable.

22 Microzooplankton sampling with CTD/Rosette, coordinate with viral dilution experiments for estimate of bacterial mortality. Fluorescence can be used to assess phytoplankton mortality in the surface but fluorescence will be very low in TZ and beyond ability of existing methods to detect consumption. The experiments can be used for grazing on bacteria, also, could do some small volume DNA fingerprinting to look at changes in microbial community (before and after grazing)

23 Zooplankton sampling with vertical net tows. Grazing rate on aggs, feces and suspended particles (as function of size) and selectivity in terms of size, including hunger level at time of study. Includes measuring bulk changes in cell/particle numbers (or pigments), gut fluorescence, omics (freeze and archive). Experiments with collected particles and live zooplankton will be conducted on board.

24 None

25 To determine day/night diel migration with better spatial variability using bioacoustics from hull mounted on ship and possibly autonomous platforms

26 Autonomous neutral density traps are optimal (listed also under AUV platforms on process cruise). Some collection with drifting arrays or net traps possible, but not flux with moored traps time series traps. Include traps from base of EZ (or ML if deeper) and 5 depths to 500m+; multiple deployments with 3-5 day times scales and 10's km space scale (particle source area); core direct measurement for EXPORTS of major flux components from Lagrangian ship. Splitting of samples likely for additional measurements.

27 Include measurements in traps of stable isotopes, organic and other biomarkers in traps to relate to EZ and TZ processes; possible stains for swimmers; indicators of food web processes.

28 Use molecular methods to link what is sinking to food web processes in EZ and transformations in EZ and TZ. Trap samples can be frozen/archived.

29 Deploy polyacrylamide gel traps on same traps as flux measurements; links between EZ and export include microscopic enumeration of sinking particle shape, size, fecal ID changes with depth; better if microscopic work done at sea; compare data with cameras to provide additional estimate of sinking speed by comparing particle size/abundance in traps vs. water column

30 Can increase spatial and temporal estimates of flux with vertical profiles (8-12 depths) with 3-D time-series sampling of particle source regions; can recalculate fluxes at any depth of the profile; best in EZ and waters 50-100m below EZ; flux tracer on few day-weekly time scales; repeat sampling reduces non-steady state and other assumptions; combine with C/Th and other ratios (from pumps/traps) to convert to major elemental fluxes

31 Longer half-lives allow for particle flux to be resolved on longer time scales (mo's-years) and deeper in water column

32 Need to use in-situ pumps to sample larger volumes (>1000 L) to collect enough material for small & large sinking particles. Conduct same analyses on filters/screens as in traps; size fractionated filtration recommended (2-3 size classes, 1-100 um range); important to match to 234Th profiling & particle camera (UVP) type studies. Optimal on survey ship to sample mesoscale variability in particle size distribution. Splitting of filters for multiple analyses likely.

33 Optics on profiling floats provides longer time series and integrates larger spatial scales; optics on sediment trap platform provides calibration for float. Examples include vertically mounted transmissometer

34 New developments in cameras on neutrally buoyant floats and traps may provide better constraint on sinking rates and/or fluxes and particle types. Particle size spectrum on same platform/depth as flux measurements is useful

35 Multiple approaches may be needed for wide range of sizes from 10 um to > 1mm; deploy cameras from both ships on CTD/Rosette; profiling floats likely restricted to LOPC or UVP. Best way to get highly resolved 3-D times series of particle size spectra. To derive flux need sinking rates or temporal changes in particle stock. Assessments need to be careful to maintain particle size, shape, numbers. or non-destructive sampling of particle abundance and size spectra (for example if pumping underway). Multiple methods needed to distinguish between different types of aggregates, e.g., phytoplankton vs. mucous/feeding web aggregates. Essential to assure that camera deployment method does not break aggregates.

36 Camera sampling important for gelatinous species, which are damaged by nets and under sampled by acoustics. Cameras also necessary for aggregates. Possible deployments on autonomous platforms

37 Need sinking rates to go from particle fields/stocks to export flux; Limitations due to physical changes as particles settle on rotating sphere prior to in situ settling column

38 Need sinking rates to go from particle fields/stocks to export flux; limitations of deckboard studies; need to know sinking velocities of aggregates and fecal pellets (m/d). Collection, handling and storage of fragile particles can easily change their physical characteristics and settling speeds.

39 These experiments are based on changes in O2. There is not as much ancillary data compared to dilution culture / remineralization experiments (i.e. Change in cell #, direct estimates of DOM use or DNA sampling) but still useful.

40 Measurements on sinking particle samples from traps (swimmers excluded). Based on changes in O2.

41 Experiments may need to be conducted/continued at sea and on land after cruise; Experiments to include measurements such as changes in size spectrum, mass and sinking speed as a

consequence of controlled processes. Experiments may include aggregation formation in rolling tanks; grazing by zooplankton or loss by microbial activity; role of turbulence; viral infection impacts

42 This is important for photosynthetic models and euphotic depth determination.

43 This requires a long-path cell. Refrigerated, discrete samples can be analyzed on shore. Contribution of CDOM to total absorption (for remote sensing interpretation) and accumulation of CDOM on seasonal scales are most important, so the measurement is most important on the survey ship. Measurements should be made both in the euphotic and twilight zones.

44 These measurements provide validation for partitioning acs total absorption spectra into phytoplankton and detrital components. A diaphragm pump must be used for surface underway sampling. Samples should be co-located with acs measurements. Method for partitioning into pigmented/non-pigmented particulate absorption should follow Mueller et al, "Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4, Volume IV: Inherent Optical Properties: Instruments, Characterizations, Field Measurements and Data Analysis Protocols".

45 Spectral particulate absorption measurements need to be simultaneous with phytoplankton and detritus filter pad absorption measurements to build proxies. All acs sensors must be cross-calibrated. Water sampled continuously from underway system should be passed through an in-line, 0.2 μm filter periodically for baseline correction. The acs will be also be part of the optics package for vertical profiles in the euphotic zone, to aid in the interpretation of remote sensing and radiometric data.

46 Beam attenuation at 650 nm is a proxy for POC, and the power-law slope of spectral beam attenuation is a proxy for PSD. Beam attenuation spectra need to be measured simultaneously with particle size and POC measurements to build these proxies. All beam attenuation instruments must be cross-calibrated (see also the "single-wavelength beam c" line in this table). Water in underway system should be passed through an in-line 0.2 μm filter periodically for baseline correction. The acs will be part of optics package for vertical profiles in the euphotic and twilight zones.

47 Multiple-wavelength backscattering is low-cost and should be on as many platforms as possible to provide context for remote sensing and radiometric measurements and as a proxy for small particle size. Multiple-wavelength backscattering is essential for remote sensing validation of IOP and particle size products, particularly with upcoming PACE hyperspectral capabilities. Sensors (angles and wavelengths) should be standard. At least two wavelengths should be used on autonomous and towed platforms, with more as possible from platforms with higher power (CTD, optics package, underway system). All sensors must be cross-calibrated to a redundant set of "reference" sensors co-deployed at intervals and alongside LISST, Coulter, and other PSD measurements.

48 This should be measured on some floats & gliders as a link to satellite observations. Profiles should be simultaneous with sat. overpasses/local noon.

49 Above water radiometry is a critical tie to satellite data, most important around noon/satellite overpass, but also important to provide radiometry paired with underway optical measurements outside the time of satellite overpass or under cloudy conditions. Data quality can be good if properly collected (see Mueller et al., "Ocean Optics Protocols For Satellite Ocean Color

SensorValidation, Revision 4, Volume III: Radiometric Measurements and Data Analysis Protocols")

50 This measurement is important for NASA goals in using remotely-sensed data for understanding particle optics beneath the top optical depth; would serve as tie to potential aircraft operations and provide information on particle vertical distribution in the euphotic zone.

51 Optical properties to relate to particles and satellite products; provides way to get greater spatial/temporal coverage

52 This measurement could provide info on calcite concentration to interpret remote sensing and mineral ballasting of particles at depth. Birefringence is not specific to calcite, so a good calibration against bottle samples will need to be demonstrated. Profiles should be collected in the euphotic and twilight zones.

53 This proxy (surface underway backscattering with inline dissolution of coccolithophore calcite) must be cross-calibrated vs. water samples for PIC concentration. This proxy is useful to interpret remote sensing observations and refine the backscattering proxy for POC.

54 To derive flux need sinking rates or temporal changes in particle stock. (small particles from backscatter, large particles from "spikes" in median-filtered profiles)

55 Combination of measurements to provide closure on particle size distribution and for comparison with surface properties. For some measurements, signal-to-noise is problematic in low particle water (hence "essential" only on vertical casts, and in euphotic zone only). Profiles must be very well calibrated and careful analysis performed (e.g. Traykovski et al. 1999; Andrews et al. 2011; Barone et al. 2015; White et al., 2015).

56 In addition to providing info about physical structure of the water column, this is essential for intercalibration. Also, O_2 and NO3 data will be used for estimates of NCP and remineralization. NCP from Lagrangian ship and Lagrangian float (days to weeks); BioArgo like floats (longer time scales); survey ship will collect nutrients & O_2, so might be possible to determine large scale NCP

57 In situ Chl fluorescence should be measured on all platforms. All sensors (on all platforms) must be cross-calibrated to a redundant set of "reference" sensors co-deployed at intervals and alongside HPLC pigment samples. Calibration casts should be conducted during both day and night to allow quenching correction. Measurements should be made in the euphotic and twilight zone (the latter to capture sinking, live plankton). Spikes in fluorescence data are useful for detecting recently sunk, fresh material and characterizing patchiness

58 simultaneous optics and phytoplankton "taxonomy". For survey ship, underway sampling 4-8 times a day.

59 Needed for autonomous Chl fluorometer calibration (can do more measurements vs. HPLC pigments). Calibration casts required next to (<0.5 km) platforms (CTD, glider, float, towed vehicle) carrying acs and chlorophyll fluorometers; also at intervals to compare with underway sensors on survey ship. provides important link from biology to remote sensing.

60 Essential for intercalibration

61 For autonomous platforms, NO3 sensor; ammonia is necessary if values NH4 is expected to be > 0.5 μM. • vertical profiles over the surface 1000 m for general nutrient distribution and

integrated inventories of inorganic nutrients.
• DIN are essential to estimate DON i.e. TDN- DIN = DON- - minimum of 15 samples/ profile

62 DOM from 3D time-series of CTD profiles; fluxes determined in conjunction with studies of mixing and subduction; need winter/other end members.

63 Refrigerated samples can be analyzed on shore. Measurements should be made both in the euphotic and twilight zones.

64 Characterization data will provide insight to microbial transformation of organic matter. This will be conducted on targeted profile in both the survey and Lagrangian. Team for collection, expert for analysis. Chemical characterization of organic matter will provide insight into diagenetic state of the dissolved and suspended organic matter. This will help to assess lability of accumulated compounds

65 Estimates of DON are most accurate when DIN values are low (<10 μM NO3). Propagation of error becomes high as NO3 concentrations increases. All Samples are filtered through inline combusted glass fiber filters. Analyses will be conducted at shore laboratories.

66 Measuring 2 of the 4 parameters allows for the calculation of the other two variables. Constraint of the carbonate system would provide insight into estimates of NCP. * pCO2 could be measured with equilibrator with bow intake but is constrained only to surface. Floats and gliders could be equipped with pH sensors.

67 Trace metal clean techniques are needed for productivity incubations. In NE Pacific TM such as Fe may need to be measured to address controls on community structure as it relates to export and remineralization.

68 Essential for development of optical proxies for POC, PON. Calibration casts required next to (<0.5 km) platforms (CTD, glider, float, towed vehicle) carrying backscattering, beam attenuation, polarized attenuation sensors; also at intervals to compare with underway sensors on survey ship.

69 None

70 Samples for calibration of PIC optical proxies, collocated with polarizing transmissometer and acid-labile backscattering sensor. Filtered at sea and processed at home using ICPOES; For <1 liter samples provides standing stock of coccolithophore PIC.

71 None

72 This could be conducted on targeted profiles.

73 Resolve spatial scales of days and lateral scales of 5-10 km. Quasi-synoptic surveys using towed, undulating profilers and hull-mounted ADCP during intensive observing periods. High-resolution, 4D (x,y,z,t) maps of mesoscale fields support omega-equation style approaches for estimating mesoscale vertical transport (subduction) and inverse/budget calculations. Estimates of lateral and vertical advection at the mesoscale. Microstructure and shear also support aggregate modeling. (u, T, S, microstructure, O2, Fchl, backscatter/beam-c, PAR, no3, zooplankton acoustics, spectral radiation, spectral absorption/attenuation).

74 Resolve spatial scales of hours and lateral scales of <1 km. System could use: (i) Survey vessel for focused, submesoscale surveys with towed, undulating profiler, (ii) Lagrangian vessel for collecting biological/biogeochemical measurements at key locations identified by the

submesoscale surveys and (iii) Process study autonomous glider and floats to capture the larger O(10km) structure at coarser temporal resolution (nested system resolves multiple scales and provides necessary biological/biogeochemical measurements with as good of a match in temporal and spatial scales as possible. A system of multiple floats and gliders might also serve this purpose, but with a more restricted sensor suite and likely coarser resolution. Each realization of this submesoscale survey would occupy 2-4 days. Requires well-planned and executed protocol for calibration and proxy-building for BGC sensors. Real time analysis should include weather forecast, remote sensing and real-time data return required to guide adaptive sampling. Data used to create 4D (x,y,z,t) maps for investigating frontogenesis, restratification and vertical exchange due to submesoscale instabilities (e.g. symmetric and baroclinic instability, interactions with near-inertial waves). Concurrent measurements of physical and biological/biogeochemical properties will allow quantification of impact on export. Microstructure and shear also support aggregate modeling. Focus on key submesoscale processes identified for each region and time period. (u, T, S, microstructure, O2, Fchl, backscatter/beam-c, PAR, no3, zooplankton acoustics, spectral radiation, spectral absorption/attenuation).

75 satellite observations and reanalysis products (wind stress, wind stress curl, surface heat flux, light, etc)

76 Attention will be required to ensure that ship met packages are freshly calibrated for cruises. Expert attention will be required for QC and analysis. Complement atmospheric fields from products,

77 None

78 Time series of maps from remotely sensed surface geostrophic velocity and state estimates. Continuous- spans entire observing period. Collection, archiving and dissemination will require dedicated effort.

79 Microstructure measurements on a not-to-interfere basis alongside 'E' activities. This means: microstructure on long-endurance floats and gliders, microstructure on CTD rosettes (OSU Chi-pod as an example of how this it currently done).

80 Maps of mesoscale fields from combined floats, gliders and ships.

81 Distributed profiles with O(100 km) separation and long glider sections spanning hundreds of km. Time resolution of weeks. Duration spans an annual cycle. Three elements: (1) Array of bio-Argo float, (2) Lagrangian array of central float and accompanying gliders and (3) Repeat larger scale sections by long-endurance gliders. T, S, biological/biogeochemical sensors essential, u and microstructure wherever possible. Minimal parameters: pressure, temperature, conductivity. Ideally all sampling devices should carry same core range of BGC sensors too. Data for statistical approaches and mapping but not for synoptic dynamical investigations. Platforms and sensors should be associated with PIs rather than technical service. Requires well thought-out calibration and proxy building protocol for BGC sensors. Data used to investigate evolution of vertical (e.g. stratification, MLD) and horizontal structures, Spatial and temporal patterns of diapycnal mixing; integrated impacts of smaller scale processes; fingerprints of submesoscale activity; bridge to upscale smaller scale measurements to basin/seasonal scale; context for cruises; targeting data for cruises. Microstructure and shear also support aggregate modeling (T, S, microstructure, O2, Fchl, backscatter/beam-c, PAR and maybe: u, no3, zooplankton acoustics, spectral radiation).