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THE ACOUSTIC PARAMETER CLIMATOLOGY

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This article describes the U.S. Navy's new global gridded monthly climatology of ocean acoustic parameters. It is constructed on a ¼° grid based on evaluation of these parameters using sound speed calculated directly from temperature and salinity profiles in the Navy's Master Oceanographic Observational Data Set that pass high quality control standards. Following an approach developed at the Naval Oceanographic Office (NAVOCEANO), acoustic parameters are first computed for each observation profile and then binned in time and interpolated to the global monthly climatology. By computing acoustic parameters for individual profiles rather than starting with a gridded temperature and salinity climatology, the details of vertical ocean structure are better preserved for more accurate acoustic parameter representation. In order to characterize the full water column, observation profiles are filled to the bottom using the existing Navy technology, the Improved Synthetic Ocean Profile (ISOP) system. The filled profiles are then analyzed by the Navy's Reference Publication 33 (RP33) software package to derive Navy-relevant ocean acoustic parameters defined by NAVOCEANO's Fleet Oceanographic and Acoustic Reference Manual. The resulting acoustic parameters are interpolated in space and time over a global ocean ¼° regular grid, resulting in a high quality monthly global climatology for 14 different RP33 acoustic parameters.

I. INTRODUCTION

This paper describes a new product of gridded, Navy-relevant ocean acoustic parameters compiled in a global monthly climatology. The 14 different acoustic parameters included in the climatology form a practical summary of ocean properties and variability that can have significant impact on sound propagation and acoustic detection. These parameters, for example sonic layer depth (SLD) and deep sound channel axis depth (DSCA), are defined and described in the Fleet Oceanographic and Acoustic Reference Manual (known as Reference Publication 33 or RP33).[1] Described further in Section II, the parameters quantify acoustically-relevant attributes of a sound speed profile from the ocean surface to seafloor, providing a shorthand assessment of how conditions in the ocean interior will influence transmission of acoustic energy.

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The term climatology is used to describe combining of data from multiple years to provide fields of acoustic parameters representing average conditions of the ocean over some time and spatial range, in this case typical monthly conditions over a regular spatial ¼° longitude, latitude grid. Traditionally, climatological fields of ocean acoustic parameters are constructed using sound speed derived from fields of temperature and salinity that are themselves already gridded as a monthly climatology, such as those from the Navy's Generalized Digital Environmental Model (GDEM).[2] The resulting profiles of average sound speed are then used to create a climatology of acoustic parameters. This is referred to as the climatology-first approach, since the climatological averaging is done before the acoustic parameters are computed. The problem with the climatology-first approach is that climatological ocean data tend to have an overly smooth vertical structure. Because acoustic parameters are sensitive to vertical sound speed gradients, the smooth vertical sound speed profiles computed from gridded temperature and salinity climatological data tend to produce biased or otherwise inaccurate estimates of acoustic parameters. For example, Section VI shows that sonic layer depth tends to have a shallow bias when calculated using the climatology-first approach.

In the past, regional acoustic parameter climatologies have been constructed on an as needed basis by the Naval Oceanographic Office (NAVOCEANO). Such a climatology would begin with calculation of sound speed profiles from a regional collection of temperature and salinity profiles. Acoustic parameters would be computed from the profiles of sound speed following the RP33 definitions. The resulting data are then used to construct monthly climatologies of each parameter separately. Such a procedure eliminates the unrealistic smoothing of the sound speed vertical structure caused by climatological time and space averaging. Instead, full details of individual in situ profiles are retained and available when the acoustic parameters are computed. Appropriate treatment of individual profiles leads to more accurate computation of acoustic parameters. This new parameter-first approach has proven by operational use at NAVOCEANO to be superior to prior methods but previously not been applied globally for all months of the year. This document describes the methods and results of the first global monthly acoustic parameter climatology (APC) for 14 RP33 acoustic parameters and transitioned to NAVOCEANO for operational use.

In Section II, the acoustic parameters are introduced, and the historical background and the general approach for the APC are described. The in situ ocean observations are described in Section III, while other aspects of the methods are described in Sections IV. The results are given in Section V, followed by a discussion in Section VI, and a summary and conclusion in Section VII.

II. BACKGROUND

The Acoustic Parameters

The document titled, "The Fleet Oceanographic and Acoustic Reference Manual,"[1] sometimes referred to as RP33, describes the acoustic properties of the ocean that are relevant for Navy operations. The last version of the RP33 software was obtained from NAVOCEANO on September 12, 2012. A next generation version, designated APARMS 1.0,[3] is available in an untested beta version from OAML. Since APARMS 1.0 was not ready at the start of this effort, it is the prior RP33 software that is used in the initial version of the APC. Of the 27 different acoustic parameters computed by the RP33 software, 14 are included in the baseline APC version. Tables 1 and 2 list the parameter names and a brief description.

Because the gridding procedure is dependent on the numerical values, the acoustic parameters are organized into groups with the same units. The first group contains parameters that represent depth and are in units of meters: sonic layer depth (SLD), deep sound channel axis depth (DSCA), deep sound channel top (DSCTOP), depth excess (DEXCESS), and critical depth (CD). Figure 1 shows two typical sound speed profiles from the Pacific Ocean. The depth location of these acoustic parameters as described in Tables 1 and 2 are labeled in the figure. The profile in Fig. 1(a) is a mid-latitude ocean case where CD and DEXCESS exist, and the profile in Fig. 1(b) is a tropical ocean case where CD and DEXCESS do not exist. In many profiles, DSCTOP is equal to SLD (Fig. 1(a)) but not in cases with intermediate sound channels or no DEXCESS. CD and DEXCESS are undefined or do not exist in cases where the sound speed at the SLD is greater than the sound speed at the bottom (Fig. 1(b)).

Table 1 – The list of deep sound channel acoustic parameters computed by the OAML APARMS 1.0 beta software package

Deep Sound Channel parameters		
#	Variable Name	APARMS Parameter Description
1	DSCA	Deep Sound Channel Axis Depth (m)
2	DSCTOP	Deep Sound Channel Top Depth (m)
3	DEXCESS	Depth Excess (m)
4	CD	Critical Depth (m)
5	DSC_COFF	Deep Sound Channel Cutoff Frequency (Hz)
6	DSCA_SSP	Sound Speed at Deep Sound Channel Axis Depth (m/sec)
7	BOT_SSP	Sound Speed at Bottom (m/sec)
8	CD_SSP	Sound Speed at Critical Depth

Table 2 – The list of surface duct acoustic parameters computed by the OAML APARMS 1.0 software package

Surface Duct parameters		
#	Variable Name	APARMS Parameter Description
9	SLD	Sonic Layer Depth (m)
10	SLD_COFF	Cutoff Frequency of Surface Duct (Hz)
11	SLD_BLG	Below-layer Gradient (Delta Sound Speed over 300 ft)
12	ILG	In-layer Gradient (Sound Speed at SLD Minus Surface Sound Speed)
13	SLD_SSP	Sound Speed at SLD (m/sec)
14	SURF_SSP	Surface Sound Speed (m/sec)

Mixed layer depth (MLD), while not one of the APC parameters, is a property of ocean dynamics that is often linked with SLD, as discussed in Helber et al., 2008.[4] Figure 2 shows a typical profile where the SLD and the MLD are identical, which is the case where temperature and salinity are uniform in the mixed layer. In results section of this paper (Section V), the ocean dynamics associated with MLD are used to explain the seasonal variability found in the acoustic parameters.

The second group of parameters encompasses sound speed gradients, which consists of below layer gradient (SLD_BLG) and in-layer gradient (ILG) and is reported with units m/sec per 100 ft. For SLD_BLG, the sound speed change is computed over 300 ft and then divided by 3. Where the sonic layer depth (SLD) exists, the ILG parameter is computed as the difference (bottom minus top) of sound speed in the sonic layer scaled by the ratio of 100 ft (approximated as 30 m) divided by the SLD. Figure 3 shows two types of profiles each with different gradient properties, ILG and SLD_BLG. Figure 3(a) is a very typical case where the ILG is 0.49 m/sec per 100 ft, while Fig. 3(b) is a relatively rare case of large ILG due to surface freshwater input. The seasonal properties of ILG and SLD_BLG are discussed in more detail in Section V.

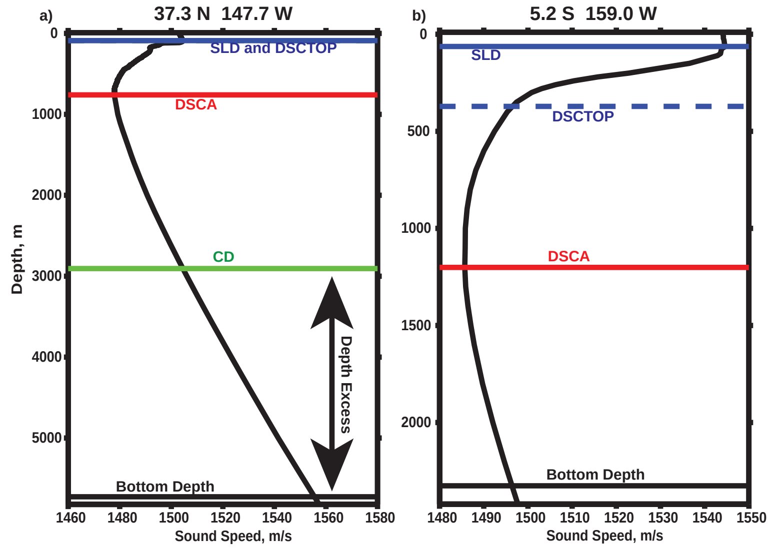

Fig. 1 – Two typical profiles from (a) mid-latitudes where depth excess occurs and (b) the tropics where depth excess does not occur. The black curve is sound speed versus depth at the two locations identified by the latitude and longitude listed at the top. The blue horizontal lines are SLD (solid) and DCSTOP (dashed). The red horizontal line is the DSCA, while the horizontal green line in (a) is the CD.

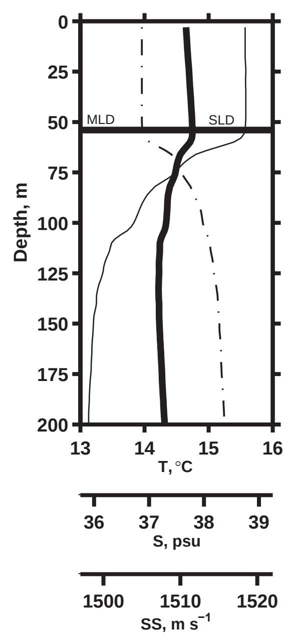

Fig. 2 – A typical profile pair of observed temperature (thin) and salinity (dash-dot) with computed sound speed (thick) versus depth. SLD and MLD coincide

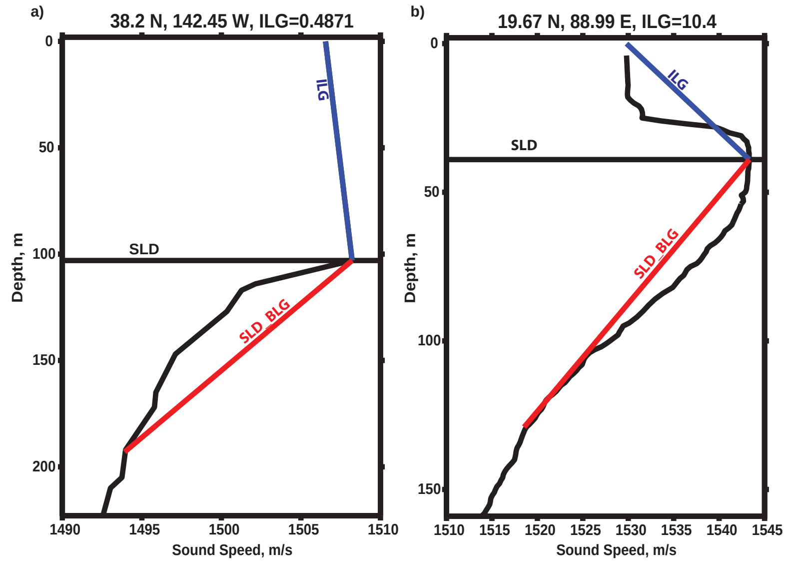

Fig. 3 – Two example sound speed profiles plotted versus depth with (a) a very common ILG value and (b) a ILG value that occurs only in regions of the ocean where strong surface freshwater input exists. The profile in (a) is from a mid-latitude in the Pacific Ocean, and (b) is from the Bay of Bengal, which is influenced the Ganges River outflow.

The third group of parameters have units of sound speed, m/sec. These include sound speed values at the sonic layer depth (SLD_SSP), surface (SURF_SSP), deep sound channel axis (DSCA_SSP), bottom (BOT_SSP), and if defined, critical depth (CD_SSP).

The fourth group has units of frequency and is gridded using their log base 10 values. These include sonic layer depth minimum cutoff frequency (SLD_CUTOFF) and deep sound channel minimum cutoff frequency (DSC_CUTOFF), which have units of Hz and vary over several orders of magnitude.

The RP33 software operates on profiles of sound speed as a function of depth extending from the ocean surface to the sea floor. Sound speed can be derived from temperature, salinity, and pressure, and thus the hydrographic properties of a region are linked to typical distributions of sound speed and therefore to the acoustic parameters.

For the APC, 14 RP33 parameters described in Tables 1 and 2 are computed from quality controlled in situ profiles on the observation depth levels. This application of the RP33 software in the construction of the APC differs from its ordinary use, which anticipates relatively smooth numerical model output or smoothed observations on fairly coarse standard depths. Applying the RP33 software to raw profiles on high-resolution observation depths proved to be problematic. The RP33 software frequently failed to determine acoustic parameters, most commonly at high latitudes. For the APC, alternate, more robust software was used to compute the acoustic parameters in cases where RP33 failed. For example, SLD was computed using the methods of Helber et al.[4] Simple software solutions were also sought to replace bad RP33 values for DSCA, DC, and DEXCESS. The behavior of these new software patches for RP33 parameters DSCA, CD, and DEXCESS have not been fully tested and should be investigated for future versions of the APC and successor versions of RP33. A new version of the RP33 software has recently been developed by NAVOCEANO, and it may resolve some of the issues found in the present RP33 software. Called APARMS,[3] it is currently (at the time of writing) in an untested beta version submitted to the Navy's Oceanographic and Atmospheric Master Library (OAML).

Since APARMS is pre-operational, the present operational version of RP33 software is used to compute the acoustic parameters for the initial version of the APC as described in this article. Future versions of the APC will be constructed using APARMS 1.0 or later.

The acoustic parameters described in the Fleet Oceanographic and Acoustic Reference Manual[1] beyond the 14 applied here are related to physical oceanography or dependent on the existence of one or more secondary sound channel(s) and/or acoustic source depth(s). Secondary sound channels are omitted from the APC because they are highly episodic in the ocean, and standard climatological methods are not well suited for characterizing intermittency. The probability of occurrence for the secondary sound channels might be a more appropriate field to consider. In addition, parameters dependent on acoustic source depths are also outside the scope of the current version of the APC. Future versions may include these and other statistical measures or source depth information.

Making Acoustic Climatologies

NAVOCEANO produced its first regional acoustic parameter climatology for the region surrounding Taiwan in 2005. Since then, many other regions have been produced including the North Atlantic and Pacific. All of these products are currently used operationally by the Navy for operational applications supporting anti-submarine warfare (ASW), assessment and interpretation of new observations, and general Navy planning for operations influenced by the understanding of the acoustic environment. Because of the popularity of the regional products, NAVOCEANO specifically requested that a monthly global gridded APC be constructed.

Construction of the global monthly acoustic parameter climatology leverages data and methods of NAVOCEANO and Naval Research Laboratory (NRL) transitioned products. The in situ ocean observations of temperature and salinity are primarily those from NAVOCEANO's Master Oceanographic Observational Data Set (MOODS).[5] In order to compute both near surface and deep ocean acoustic parameters, observation profiles must extend all the way to the ocean bottom. The method for extending the observed profiles to the ocean bottom employs the data and methods of NRL's Improved Synthetic Ocean Profile (ISOP)[6] system. The ISOP system, traditionally used for ocean data assimilation, provides a method to project surface ocean data into the subsurface ocean to produce a full water column estimate of the ocean temperature and salinity consistent with the surface observations. These subsurface ocean estimates of temperature and salinity are then used to fill incomplete observations to cover the full ocean depth. Once the profile database is filled and complete, NAVOCEANO's RP33 software is used to compute 14 acoustic ocean parameters for each profile. Gridding the acoustic parameters uses the methods of the GDEM[2] climatology.

Beginning with 8.4 million raw unedited profiles from MOODS and other sources,[5] editing and quality control criteria regarding observation sampling identified 3.9 million high quality ocean profiles suitable for computing acoustic parameters. At each of these historical observation locations, the ISOP system is used to extend the profiles to the bottom, filling any missing or unavailable temperature or salinity values. The filled profiles are then passed to the RP33 acoustic parameter software, which produces 14 acoustic parameters for each profile of paired temperature and salinity. Each acoustic parameter is then gridded monthly on a global ¼° regular grid using GDEM methods. Because the acoustic parameters are computed first and then the climatological averaging is applied, this is called parameter-first approach.

The APC described in the document represents the first global capability of its nature. In addition, this product is an improvement to prior capabilities due to introduction of a robust method of filling the initial profile observations using the ISOP system, use of the RP33 software to provide consistent standards for summarizing acoustic conditions, and application of appropriate GDEM interpolation methods in gridding the acoustic parameters globally.

III. THE OBSERVATIONS

Ocean acoustics is governed by the sound speed structure of the ocean. However, sound speed is not routinely measured in situ but instead derived from measured temperature and salinity using the Chen, Millero[7] and Li[8] equation. The in situ temperature and salinity observations used to compute sound speed for the APC are those used to create and validate ISOP 1.0 and GDEM 4.0. The data consist of temperature and salinity observations in vertical profiles extending from near the surface down into the ocean reaching variable depths. Each profile has a horizontal location and time/date stamp, which represents the location and time/date that observation was made. The sources of the data are the U.S. Navy's Master Oceanographic Observation Data Set (MOODS),[4] the National Ocean Data Center (NODC) World Ocean Dataset (WOD),[9] and Argo.[10]

The total number of raw observation profiles is 8,418,337, but many of those profiles are deemed unusable. For example, many of the older profiles were made by Mechanical Bathythermograph (MBT) devices that are notoriously unreliable. Also, many profiles, even those made using modern Conductivity, Temperature, and Depth (CTD) probes, are flagged as having errors of unknown origin that were not eliminated by the quality control procedures of MOODS, NODC, or Argo. Some profiles are even miss-located over land while others have missing depths and large vertical gaps or no data near the surface. As a result, the data have undergone editing procedures, and all profiles must satisfy basic sampling requirements. Only profiles that pass an extensive manual editing procedure to remove unwanted erroneous data are used in the APC. The editing procedure includes the use of a visual profile data browser that compares the new observations to all nearby historical observations. These are described in more detail in the validation test report for the ISOP system.[6] The basic sampling requirements have two groups of profiles that exist in ocean regions with water depths (1) greater than 125 m and (2) less than or equal to 125 m. For the deep water profi les of Group 1, each profile, after all missing depth levels are removed, must have at least 6 depth levels, extend to at least 125 m depth, and have a first depth level shallower than 12 m. The depth sampling requirements retain only profiles that sample near the surface (<12 m) and extend down to at least 125 m, criteria designed to ensure that observations sufficiently resolve near surface acoustic parameters such as the sonic layer depth and below- and in-layer gradients. After data editing and the sampling requirements are applied, there are a total of 3,898,314 deep water profiles remaining (Fig. 4). Of those, 2,692,000 profiles have only temperature data, while 1,200,486 profiles have paired observations of both temperature and salinity.

For the shallow water profiles of Group 2, each profile, after all missing depth levels are removed, must have at least 3 depth levels, a first depth level shallower than 12 m, and water depth less than 210 m. These shallow water data add an additional 391,262 profiles (Fig. 5) for computing 6 of the 14 acoustic parameters (Table 2) that represent the near surface sound speed structure near the coasts in water depth less than 125 m.

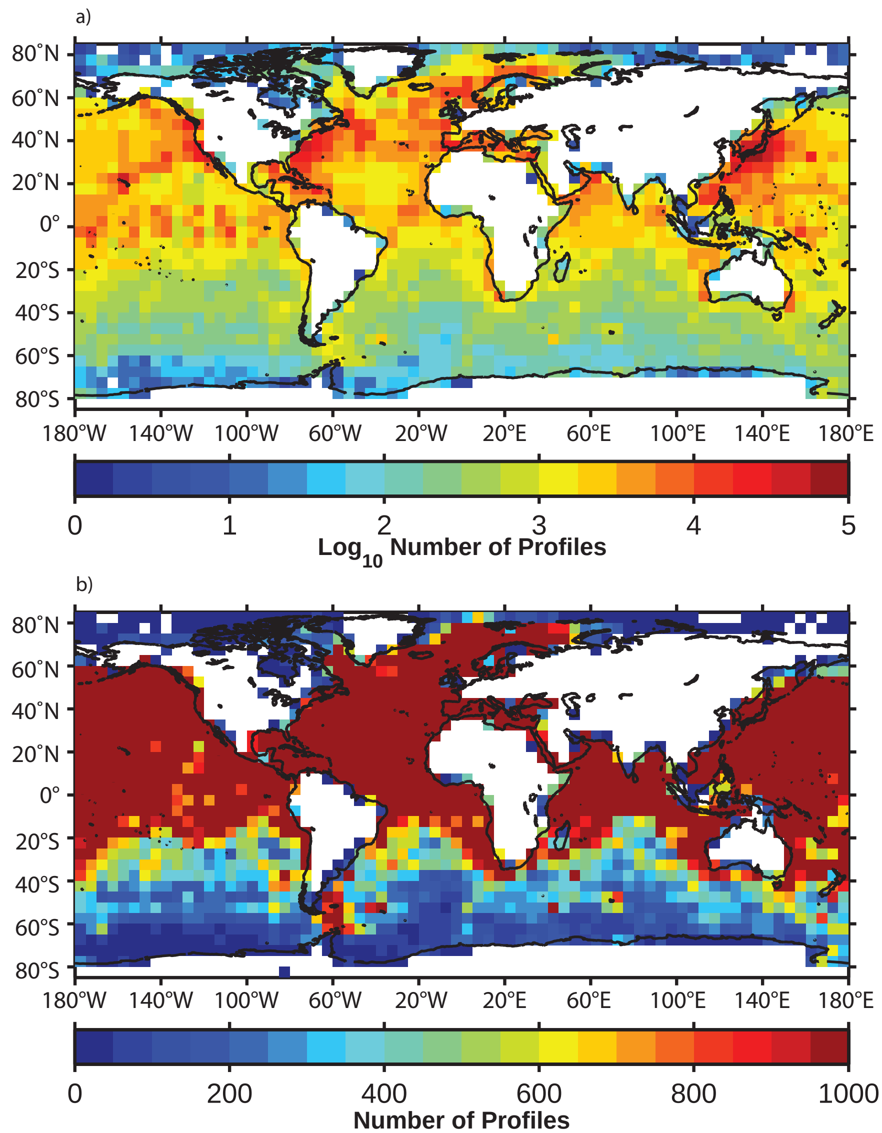

Fig. 4 – The log base 10 (a) and absolute (b) number of usable observation profiles available after initial editing criteria are applied. Each square represents a 5° by 5° degree square region of the ocean. The total number of profiles is 3,898,314.

To compute sound speed to the ocean bottom, temperature, salinity, and pressure are required. Typically, only the observation depths are recorded, not pressure. Fortunately, pressure can be recovered from the depth information to a good approximation using the UNESCO[11] equations. In the initial edited observation data used here, every salinity measurement has a corresponding temperature record. However, many temperature measurements do not have a corresponding observation of salinity. Furthermore, most deep water observations (see Fig. 5, Group 1) do not extend to the ocean bottom. Estimating missing salinity values and extending these profiles to the bottom are described in the next section.

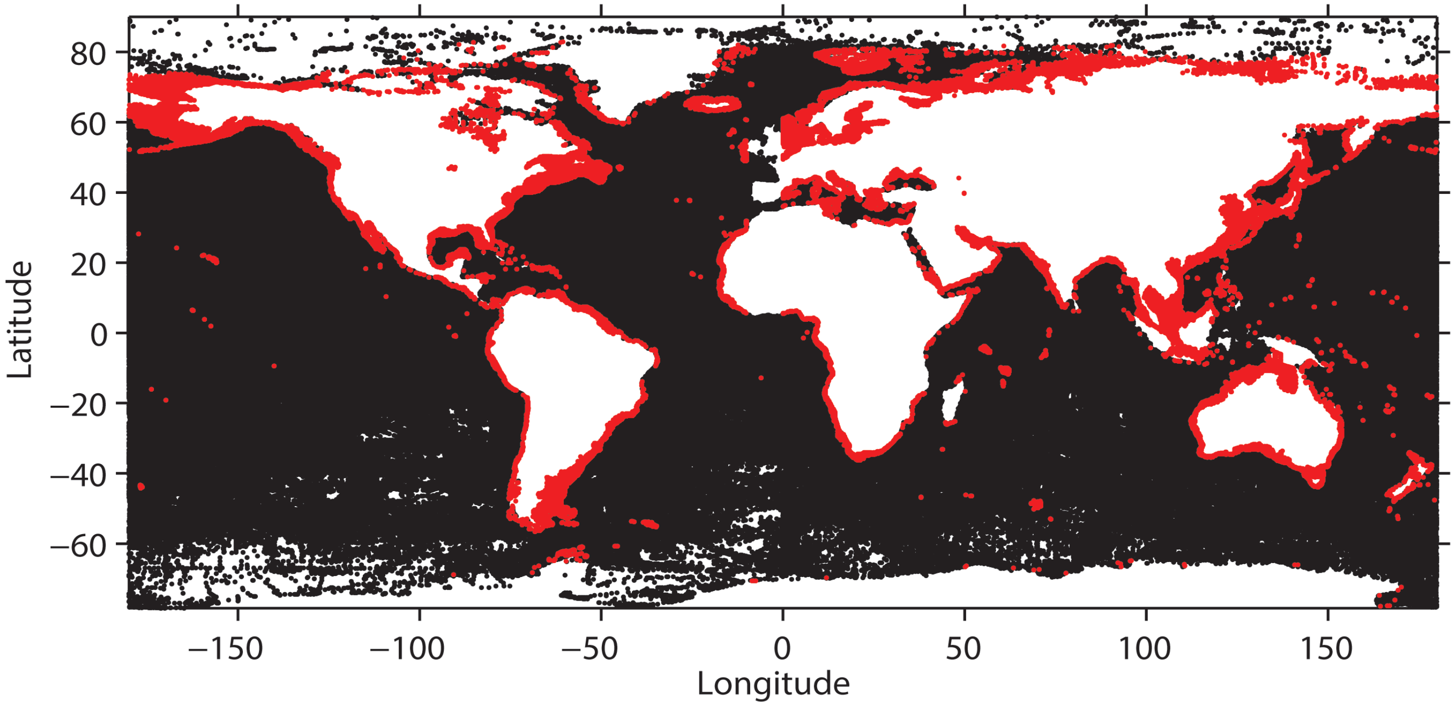

Fig. 5 – The latitude and longitude locations of deep ocean (Group 1) profiles plotted as black dots with shallow water (Group 2) profile locations plotted in red. The total number of shallow water profiles is 391,262.

IV. METHODS

Gap Filling

A requirement of the RP33 acoustic parameter software is that input sound speed profiles must extend all the way to the bottom of the ocean. This is a challenging requirement to satisfy for profiles in deep water. First, salinity must be estimated where temperature data exist, enabling subsequent computation of sound speed from paired temperature and salinity. The ability to estimate the corresponding salinity saves valuable temperature profiles that would otherwise be unusable for the APC. Second, most observation profiles in deep water do not extend all the way to the bottom of the ocean and therefore must be extended downward over unobserved depths with estimates of temperature and salinity. These requirements can be met using the ISOP system, which was developed for data assimilation and that produces estimates of subsurface temperature and salinity profiles from surface observations. The resulting ISOP profiles are called synthetics or synthetic profiles and consist of temperature and salinity values that extend to the bottom of the ocean. These synthetics are used to fill the observation profiles, where salinity is unavailable, and extend both temperature and salinity from the deepest observation in the profiles to the bottom of the ocean.

Since the actual bottom depth of the global ocean is not known exactly, estimates of the ocean depth at any particular point often differ from the bathymetry database DBDB2[12] used to construct ISOP (A caution to the reader: The depths used to create this APC database could vary from the Navy standard, which in itself has variations among the levels—meaning that for variables such as depth excess, the APC could be quite different from a similar svp in an operational setting.) For this reason, ISOP synthetics extend below the depth prescribed by DBDB2 using the below bottom filling methods of GDEM. As a result, the ISOP system is able to extend the observed profiles deep enough to allow for any differences that may occur in estimates of bottom depth.

The first step in the profile filling procedure is to create an ISOP synthetic for each of the 3,898,314 observation profile locations in deep water (Group 1, described in Section III). Each synthetic is created using inputs from the near surface values of the observation profiles. The synthetics are created in an iterative manner until each synthetic profile matches the observations as well as possible. The metric for fitting the synthetic to the observation is the root mean square (RMS) temperature error over the depth range of the observation. The iterative process is terminated when the ISOP synthetic RMS error is as small as possible or after five iterations of a bracketed bisection iteration scheme. Creating the ISOP synthetics is the most computationally demanding and time consuming aspect of creating the APC.

Once ISOP synthetics are created for all observation profiles, the synthetics are then blended with the observations. If there are no salinity values in an observation profile, the ISOP salinities are interpolated to the observation depths to provide matching salinity estimates to pair with the temperature values. To extend the profile below the last observed depth, observation values are extrapolated with depth toward the ISOP synthetic values. An example is given in Fig. 6.

The method for extrapolating the observations with depth employs an e-folding length scale of 800 m, which allows for a smooth blending transition at the base of the observation profiles. For a small number of test cases, the 800 m length scale blended the observed values gently with the synthetic values without any unrealistic sharp kinks (Fig. 6). Future versions of the APC may revisit the use of the 800 m length scale, quantifying the impact of changing the e-folding length. In cases where the ISOP synthetic is close to the observation profiles, the importance of the length scale is small. The length scale choice is most significant in cases where the ISOP synthetic has a relatively large difference from the observation profile.

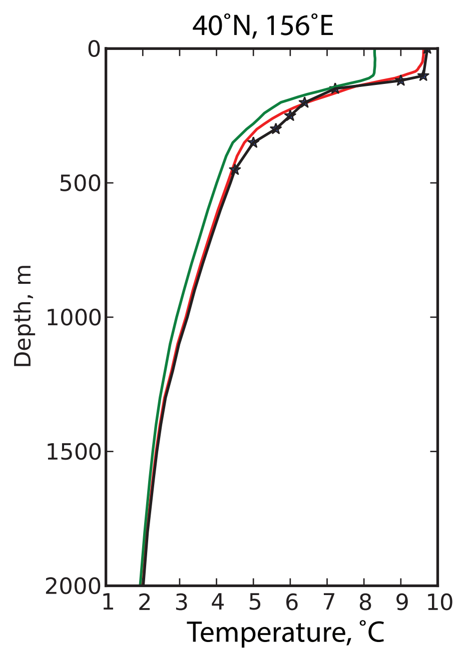

Fig. 6 – An example of an observation merged with an ISOP synthetic. The observations (black stars) are shown relative to the ISOP synthetic (red), the GDEM climatology profile (green), and the resulting merged profile (black).

For profiles in shallow water (Group 2, described in Section III), the ISOP system is not needed because most coastal profiles extend to the bottom. Shallow water profiles that do not have salinity values, GDEM salinities for the month of the profile are interpolated to the location of the profile and the observation depth levels. Sound speed is then computed from the paired temperature and salinity values.

Ten by Ten Degree Regions

The total data set of 8,418,337 profiles is approximately 18 GB in size. To make processing of this data more manageable, the data are split into 10° longitude by 10° latitude geographical regions. The motivation for such a split is data management, as the numbers of profiles in each geographical bin are more manageable though non-uniform; following the processing that is distributed across the bin, the data are recombined into a global set before interpolation to the uniform grid and subsequent treatment or plotting. The most heavily sampled geographical 10° by 10° region is in the North Pacific, 30° to 40° N and 130° to 140° W, with 271,536 profiles (see Table 3). The next most sampled bin has nearly half as many profiles, and the number of profiles in subsequently ranked regions rapidly decreases. Over all 10° by 10° bins, the median number of profiles is 2223, and the mean number of profiles is 7383. Note that while the bins are equally sized in degrees of longitude, the corresponding area decreases toward the poles, and some regions cover only a small area in the ocean.

Table 3 – The number of profiles in 10°by 10° bins with their relative rank and longitude and latitude ranges

Rank	Longitude range	Latitude range	Number of profiles
1	130 to 140 E	30 to 40 N	271,536
2	140 to 150 E	30 to 40 N	134,005
3	70 to 80 W	30 to 40 N	100,026
4	120 to 130 E	20 to 30 N	71,299
5	120 to 130 W	30 to 40 N	68,663
264	80 to 90 W	40 to 50 S	2224
265	50 to 60 W	60 to 70 S	2222
524	80 to 90 W	80 to 90 S	1
525	160 to 170 E	70 to 80 N	1
526	60 to 70 W	30 to 40 S	1
527	50 to 60 W	20 to 30 S	1
528	90 to 100 W	50 to 60 N	1

Splitting the data into regions allows for the data processing to progress region by region in order from most populated to the least populated. Procedural programming is developed for a single region until suitable and then run on all subsequent regions. Once all data regions are processed and the data filling and acoustic parameters are computed, all regions are merged for gridding.

Gridding

The APC climatology is rendered for all 12 months and annually on a ¼° regular grid. The first step for constructing the smoothly gridded data is to collect the parameter data into overlapping data sets for each month such that the sets include data within 22.5 days of the center of each month. For example, for the month of June, the month's set of parameters includes data within the span from 0 hours UTC on 25 May through 12 midnight UTC on 8 July.

Each resulting temporal bin of data spans 45 days centered on the midpoint of its calendar month. Because some of the data allocated for June are also included within the sets for May or July, the result is a more smoothly varying climatology from month to month. This overlapping approach is used for every month of the year. In addition, an annual climatology is also provided that includes data for all months of the year.

Once the overlapping data sets are created, the next step is to grid the data using the horizontal gridding methods described in the GDEM validation test report.[2] The approach is to minimize the squared slope and data misfit to the analyzed gridded value defined in the cost function

$$J = \sum_m \sum_n \left[\left(\frac{T_{n+1,m} - T_{n,m}}{\Delta x_m / \Delta y} \right)^2 + \left(\frac{T_{n,m+1} - T_{n,m}}{1} \right)^2 + \sum_k \left(T_{m,n} - \theta_{m,n,k} \right)^2 \right]. \quad (1)$$

In Equation (1), n and m, represent the indexes of longitude and latitude grid points in the ocean, respectively. The summation is over all ocean points where T is the analyzed parameters value, θ is the observed parameter value at k observation locations associated with the (m, n) grid point. Since the zonal distance between regular grid points varies with latitude, the zonal grid spacing, Δx_m, has a subscript m. The meridional grid point spacing, Δy, is constant.

A standard least-squares procedure is applied to minimize the cost function (Eq. 1), thereby determining the analysis values for each month separately. This method results in a system of Poisson equations that effectively diffuses the parameter values into regions of the ocean that have no data. Boundary conditions are applied to ensure that zero-horizontal gradients occur at the coastline. The final gridded product is smoothly varying over the ocean without gaps. Further details on these methods are provided in the GDEM validation test report.[2]

V. RESULTS

Seasonal Variability

In this section, the seasonal variability of each acoustic parameter listed in Tables 1 and 2 is described using the gridded ¼° monthly climatology shown in the Figs. 7, 8, 9, 11, 14, 15, 16, 17, 18, 19, 20, 21, 22, and 23 that display each acoustic parameter's climatology for the months of February, May, August, and November. The months of February and August tend to represent the seasons of extreme conditions (winter and summer), while the months of May and November are seasons of transition (fall and spring), depending on the Earth's hemisphere being described. The parameters that characterize the near surface ocean are presented first, proceeding in order of the type of quantity, depth, sound speed gradient, sound speed, and sound frequency. The parameters that characterize the deep ocean will be presented last.

Near-Surface Ocean: Sonic Layer Depth

The sonic layer depth (SLD) is one of the most important near surface acoustic parameters because it describes the depth of the near surface acoustic duct that can trap acoustic energy of sufficiently high frequency near the surface. The SLD is also closely linked with the MLD, which is an ocean dynamical parameter that defines the depth at which the near surface ocean is well mixed with uniform temperature and salinity. Figure 2 shows a typical ocean profile where the SLD and MLD that are the same. By definition, the MLD is the depth over which both temperature (T) and salinity (S) are uniform. Due to the increase in sound speed (SS) with pressure, sound speed increases with depth of over the mixed layer.[4] At the base of the mixed layer, sound speed is maximum and defines the SLD (see Table 2). While SLD and MLD are similar for most of the ocean most of the time, during spring at high altitudes, SLD and MLD tend to dif fer.[4] This section describes the dynamics behind MLD, to explain the seasonality of SLD, while Section VI provides further discussion regarding additional details of SLD variably.

The seasonal cycle is characterized by deep MLD and SLD during winter in both the Northern and Southern Hemispheres, when surface cooling and wind forcing deepen the well mixed surface layer. During summer in both the Northern and Southern Hemispheres, surface warming tends to shoal both SLD and MLD. This variability can be seen in the SLD monthly means in Fig. 7. In the summer hemisphere latitudes 30° to 60° (Northern Hemisphere during August in Fig. 7(c), and Southern Hemisphere during February in Fig. 7(a), the SLD is the shallowest. In the winter hemisphere latitudes 30° to 60° (Northern Hemisphere during February in Fig. 7(a), and Southern Hemisphere during August in Fig. 7(c), the SLD is the deepest. During the transition seasons, the SLD is moderate around the Earth (May and November shown in Fig. 7, (b) and (d)), except in the southern ocean due to special dynamics associated with the Antarctic Circumpolar Current. This overall seasonality variability is found also in MLD climatologies.[13,14,15]

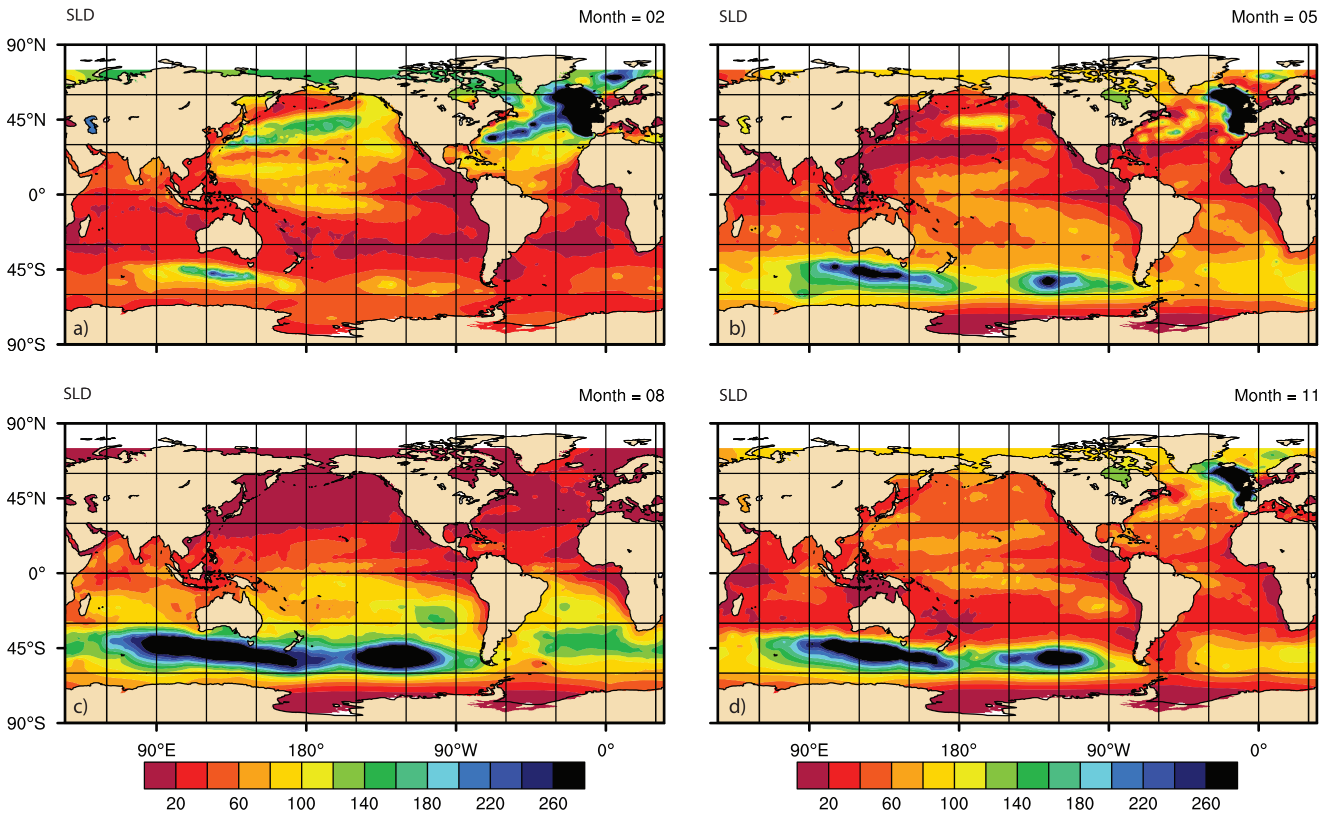

Fig. 7 – Climatology averaged SLD, in meters (m), for the months of (a) February, (b) May, (c) August, and (d) November

In February, SLD is deep in the Northern Hemisphere, particularly in the North Atlantic south of Greenland, where nearly uniform vertical temperature profiles result in sound speed profiles that increase with pressure all the way to the bottom of the ocean. In August, SLD is deep along the Antarctic Circumpolar Current, where a complicated balance of inertial forces and surface wind and buoyancy forcing result in the deep zonal circumpolar current and meridional overturning circulation.[16] In summer hemispheres, SLD tends to be shallow, except for south of Australia where there is an area along the Antarctic Circumpolar Current that has deep SLD year round. The details of the deep SLD south of Australia is associated with a density compensated layer where the effects of temperature and salinity compensate for their effects on density[13] and therefore sound speed. In Fig. 7, regions of the ocean colored dark-red, have a climatological average of less than 20 m. Profiles with no surface duct have SLD values equal to zero and are averaged together with all the other non-zero SLD profiles. As a result, regions of the ocean that are dark-red may on average have no duct at all, or if a duct exists, it is less than 20 m.

Near-Surface Ocean: Deep Sound Channel Top

The deep sound channel top (DCSTOP) is the near surface depth where the sound speed is equal to the sound speed at the bottom of the deep sound channel, if the deep sound channel exists. As a result, the DSCTOP is identical to SLD in cases where depth excess (DEXCESS) exists (see Fig. 1(a)). The DSCTOP becomes deeper where the bottom of the ocean is shallow (Figs. 8 and 1(b)). In these areas, the bottom of the ocean (and the bottom of the deep sound channel) has a sound speed that is lower than the SLD sound speed (SLD_SSP). DSCTOP is relatively deep in areas along continental margins, in the Southeast Asia Maritime Continent, and along the mid ocean ridge in the Atlantic Ocean. The DSCTOP also becomes deep when the SLD is deep, for example, in the north Atlantic in February (Fig. 8(a)).

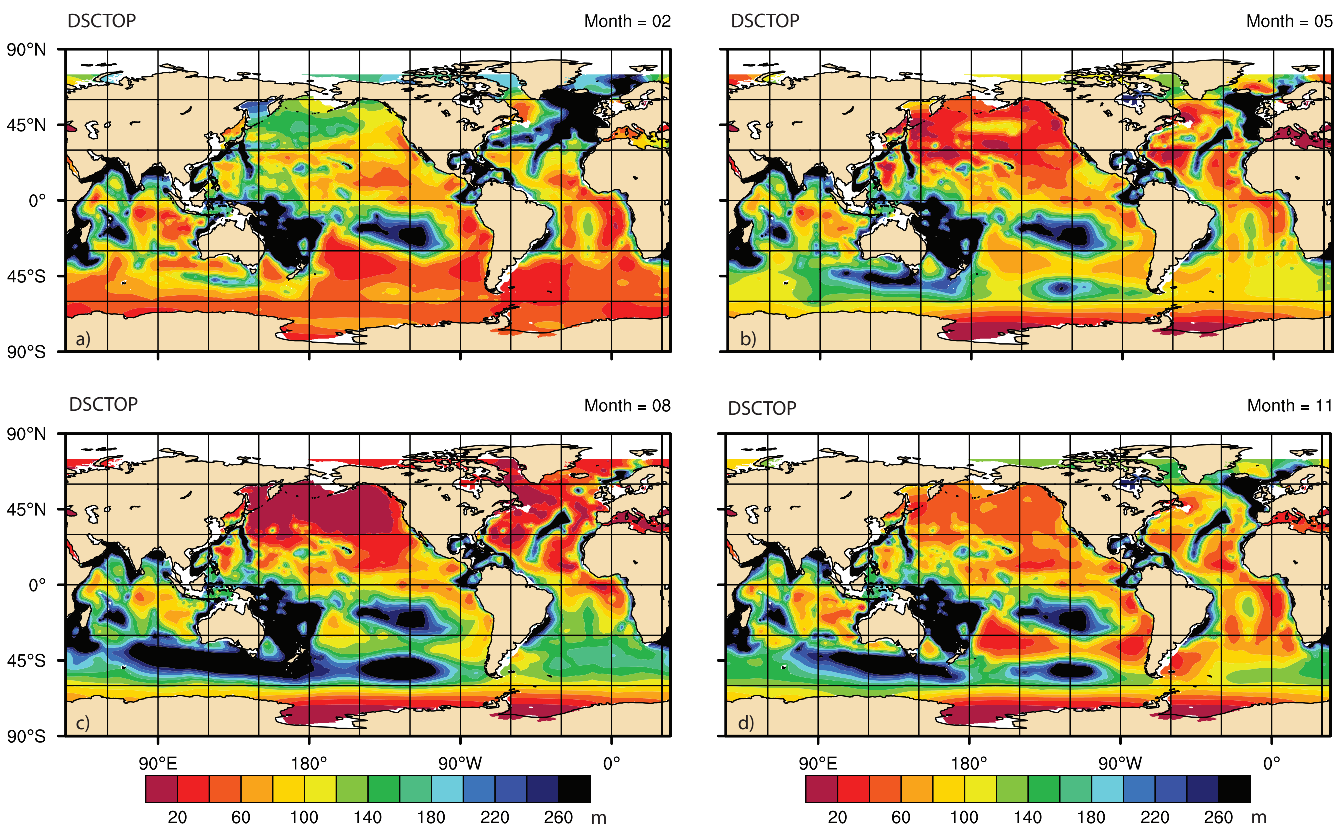

Fig. 8 – Climatology averaged DSCTOP, in meters (m), for the months of (a) February, (b) May, (c) August, and (d) November

Near-Surface Ocean: Below Layer Gradient

The below layer gradient (SLD_BLG) as computed in RP33 software is the gradient in sound speed below the SLD reported in units of m/sec per 100 ft. It is computed as one third of the change in sound speed that occurs over the 300 ft below the SLD (for the BLG calculation, regions of the ocean where there is less than 300 feet of water depth below the SLD, BLG is plotted with a zero value). If there is no surface duct, SLD is equal to zero, SLD_BLG is still defined. For surface ducts that do exist, a stronger SLD_BLG indicates stronger trapping and therefore a stronger surface waveguide. The seasonal variability of SLD_BLG is shown in Fig. 9.

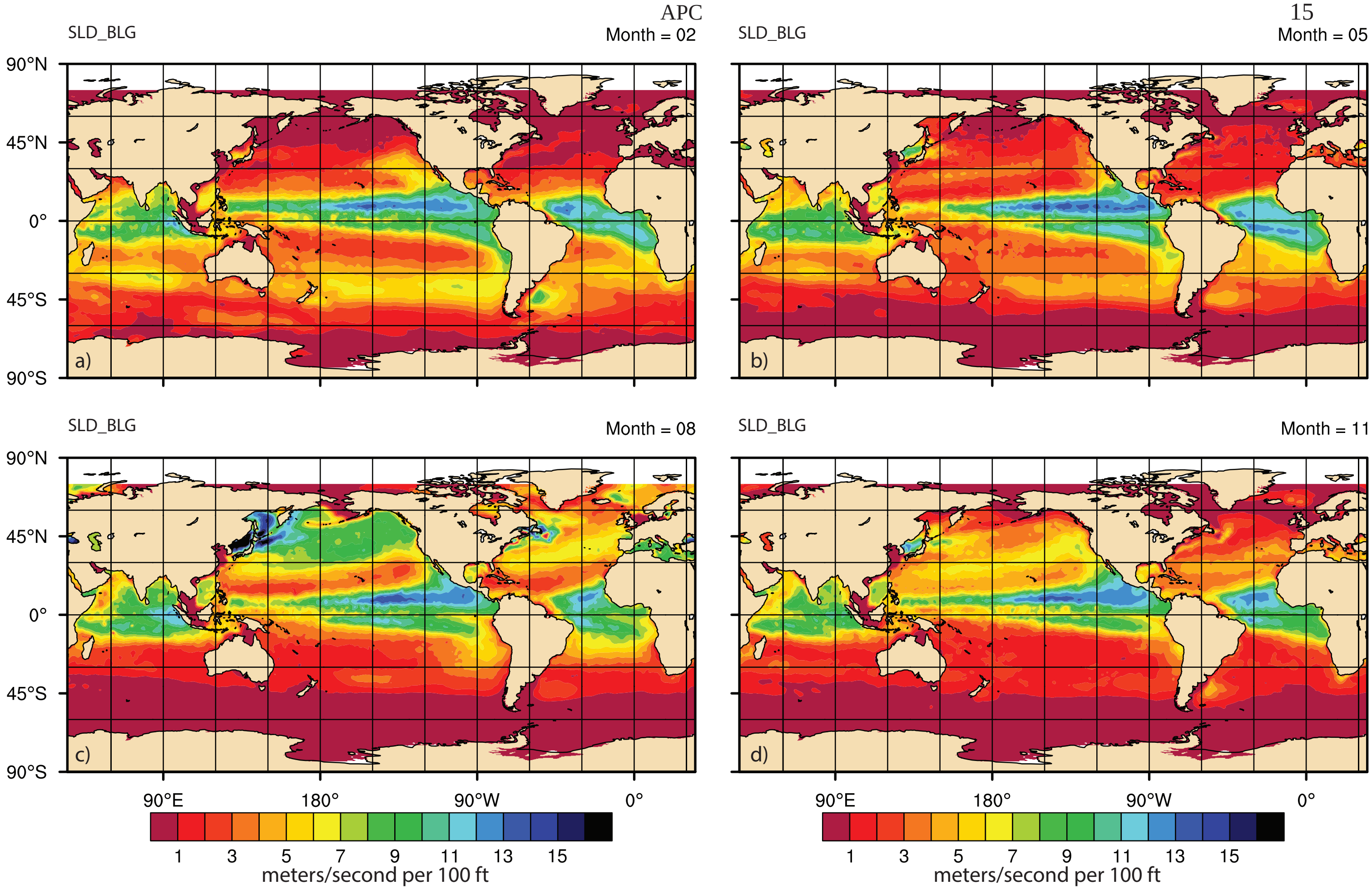

Fig. 9 – Climatology averaged SLD_BLG, in meters/second per 100 ft, for the months of (a) February, (b) May, (c) August, and (d) November

In general, SLD_BLG tends to be large when the SLD is shallow, an inverse relationship. This behavior is due to the nature of the surface mixed layer, which typically defines the SLD (see SLD discussion above). The reason SLD_BLG tends to be larger for shallower SLD is because shallow SLD is associated with shallow MLD caused by surface warming that creates surface stratification. Ocean surface warming makes the near surface water warmer and less dense. At the bottom of these new warm surface layers, temperature gradients can be large, with temperature rapidly decreasing with depth. Since sound speed is strongly dependent on temperature, the sound speed gradient is also large, rapidly decreasing with depth. As a result, SLD_BLG is also large, when the SLD and MLD is shallow, resulting in the inverse relationship between SLD and SLD_BLG. This can be seen in the North Atlantic during February, where SLD is very deep (Fig. 7(a)) and SLD_BLG is small (Fig. 9(a)). During August, this inverse relationship is seen in the Antarctic Circumpolar Current; compare Figs. 7(c) and 9(c) at longitudes near 45° S.

A quantitative comparison of the inverse relationship of SLD and SLD_BLG can be seen in Fig. 10. Because of the logarithmic property, $\ln(1/x) = -\ln(x)$, plotting the natural logarithm of SLD versus SLD_BLG should show a linear relationship with a negative slope if the two are related inversely. Figure 10 shows a noisy linear relationship with a negative slope. As SLD becomes larger, SLD_BLG tends decrease, although there is a large scatter because a simple linear relationship does not account for all of the process responsible for the structure of the upper ocean.

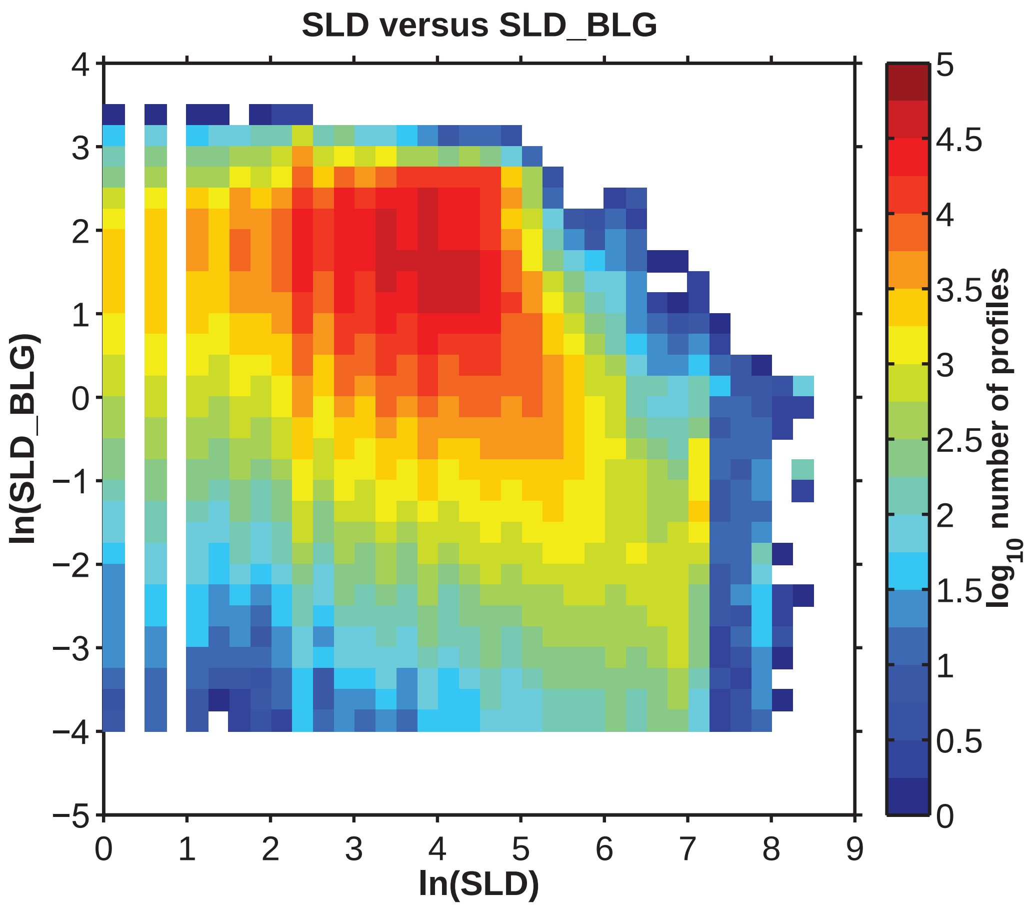

Fig. 10 – The density scatter plot of the natural logarithm of SLD versus SLD_BLG in 0.25 bins. The logarithm base 10 of the number of profiles in each bin is color coded.

Another notable feature of the global distribution of SLD_BLG is the large tongue of large SLD_BLG straddling the equator in the Pacific Ocean. Along the equatorial ocean, SLD_BLG tends to be relatively large in the tropics north and south of the equator with a local minimum along the core of the equator itself. This phenomenon is likely due to equatorial upwelling,[17] where cool thermocline water is brought to the surface due to Ekman pumping associated with the change in sign of the vertical component of the Coriolis force, which passes through zero at the equator. It is interesting to note that right along the equator, the inverse relationship between SLD_BLG and SLD breaks down since both tend to be small/shallow at the equator.

There is also a difference in the SLD_BLG in the North Pacific versus the North Atlantic. Starting in July, SLD_BLG is large in the North Pacific but not in the North Atlantic. These large North Pacific SLD_BLG values (Fig. 9(c)) last until October and are nearly gone in November (Fig. 9(d)). The southern ocean SLD_BLG is similar in both the Atlantic and Pacific.

Near-Surface Ocean: In-Layer Gradient

The gradient in sound speed within a surface acoustic duct of depth SLD is called the in-layer gradient (ILG) and reported in units of m/sec per 100 ft. Where the sonic layer exists, ILG is computed as the difference in sound speed (bottom – top) across the sonic layer scaled by the ratio of 100 ft (approximated as 30 m) divided by the sonic layer depth.

The seasonal variability of ILG is remarkably small (Fig. 11). There are only a few isolated regions where ILG varies seasonally, and those tend to occur where there is a large input of surface fresh water. To understand this tendency, the relationship of the surface acoustic duct relative to temperature and salinity variability in the surface mixed layer must be understood. In a surface duct that is perfectly uniform in temperature and salinity (isothermal and isohaline), the ILG is a constant independent of the SLD, since the nearly linear increase in sound speed with pressure (or depth) is counterbalanced by dividing by SLD. This case is shown in Fig. 2(a), and this behavior is responsible for the vast majority of ocean profiles that have an ILG very near to 0.49 m/sec per 100 ft.

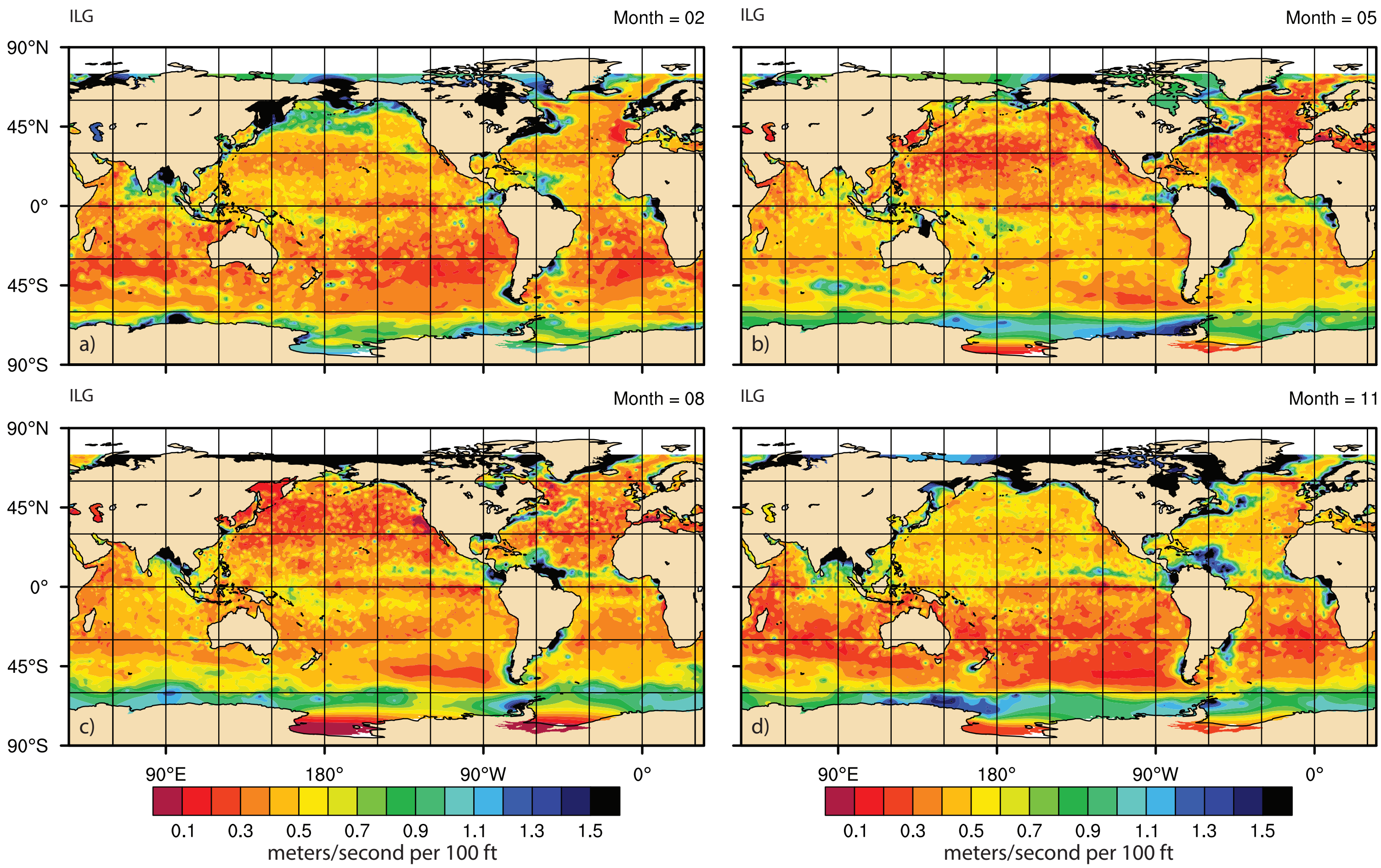

Fig. 11 – Climatology averaged ILG, in meters/second per 100 ft, for the months of (a) February, (b) May, (c) August, and (d) November

For the relatively few cases where ILG differs from the uniform layer case, the SLD and the MLD are not identical.[4] For these cases, there tends to be a gradient layer below the mixed layer[13] that changes the ILG when SLD is greater than MLD. This effect can be seen in Fig. 12, the histogram of the percentage of profiles that have non-zero SLD versus ILG (black). The red histogram is the ILG that would occur if the ocean mixed layer were vertically uniform in temperature and salinity. Scaled down by 50%, the red histogram is computed as the ILG for a vertically uniform ocean mixed layer at surface temperature and salinity values indicating the pressure only gradient of sound speed with depth (approximately 0.49 m/sec per 100 ft).

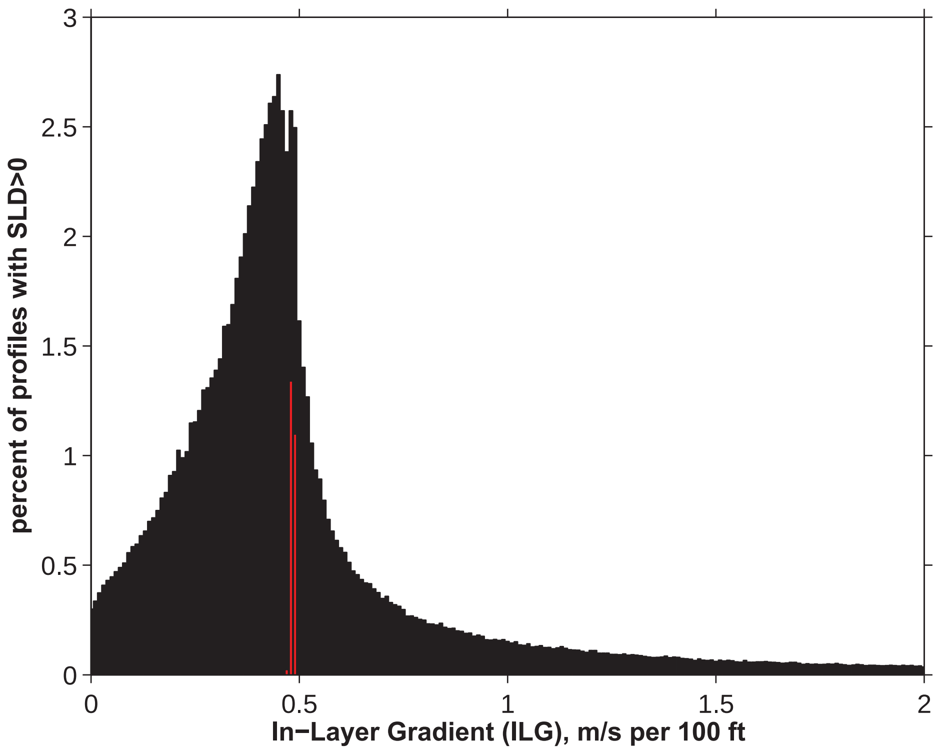

Fig. 12 – The histogram of the percentage of profiles that have non-zero SLD versus ILG

The weak ILG (approximately 0. 49 m/sec per 100 ft) associated with uniform temperature and salinity in the surface duct, tends to occur over most of the ocean (Fig. 11). The regions with large ILG occur where freshwater inputs are large such as in the Bay of Bengal and western tropical Atlantic just north of the equator due to the outflow of the Ganges and Amazon Rivers, respectively. Figure 2(b) is an example from the Bay of Bengal, where the ILG is very large. Other areas where ILG becomes large include the North Pacific and the western equatorial warm pool. All of these areas associated with large ILG are regions where freshwater input creates differences in MLD and SLD.[4,13]

An interesting region for large ILG occurs in the North Atlantic slope sea region north of the Gulf Stream off the coast of North America from North Carolina and northward. The slope sea is characterized by having relatively cold fresh water flowing southward around the Newfoundland Grand Banks from the Labrador Sea (Fig. 13). The warm salty water of the Atlantic mixes with the fresher slope sea along a front north of the Gulf Stream. In Fig. 11, the ILG is large in the slope sea region and likely associated with the convergence of water masses in this region.

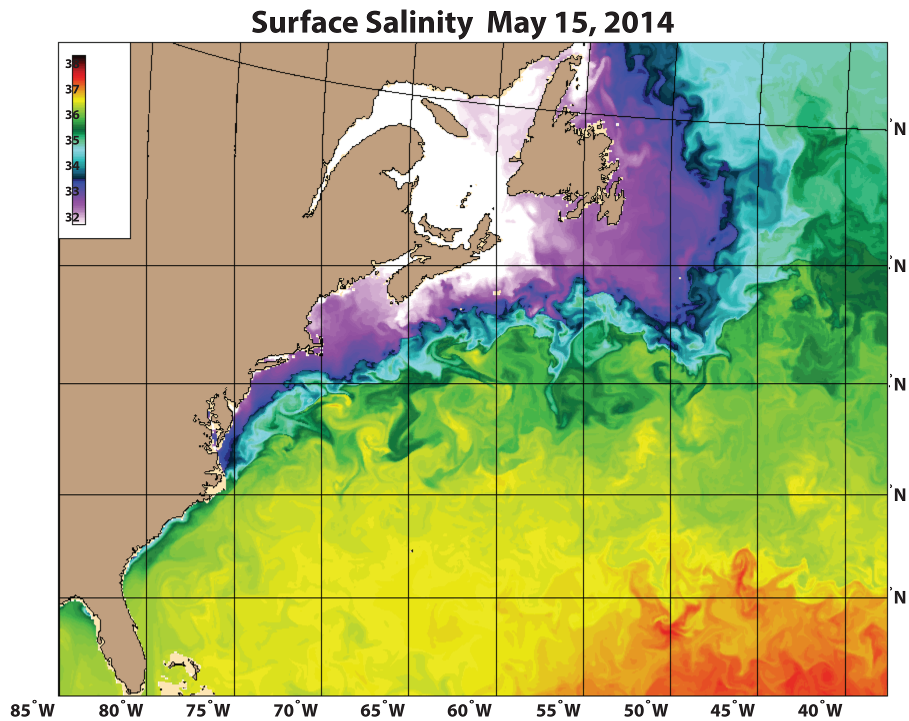

Fig. 13 – Sea surface Salinity from the Navy's Global Hybrid Coordinate Ocean Model (HYCOM) newscast/forecast system

Near-Surface Ocean: Surface Sound Speed

The surface sound speed (SURF_SSP), an acoustic parameter closely linked to sea surface temperature (SST), is shown in Fig. 14. Sound speed is faster when sea water is warmer based on a non-linear relationship.[7,8] The global pattern of SURF_SSP is characterized by high sound speed in the tropics decreasing towards the Earth's poles due to the cooling of the sea surface temperatures towards the poles. The circulation of the subtropical gyres can be seen in the SURF_SSP, since the northward flowing warm western boundary currents of the oceans tend to have large SURF_SSP, while the eastern boundaries have smaller SURF_SSP associated with the cooler southward flowing water.

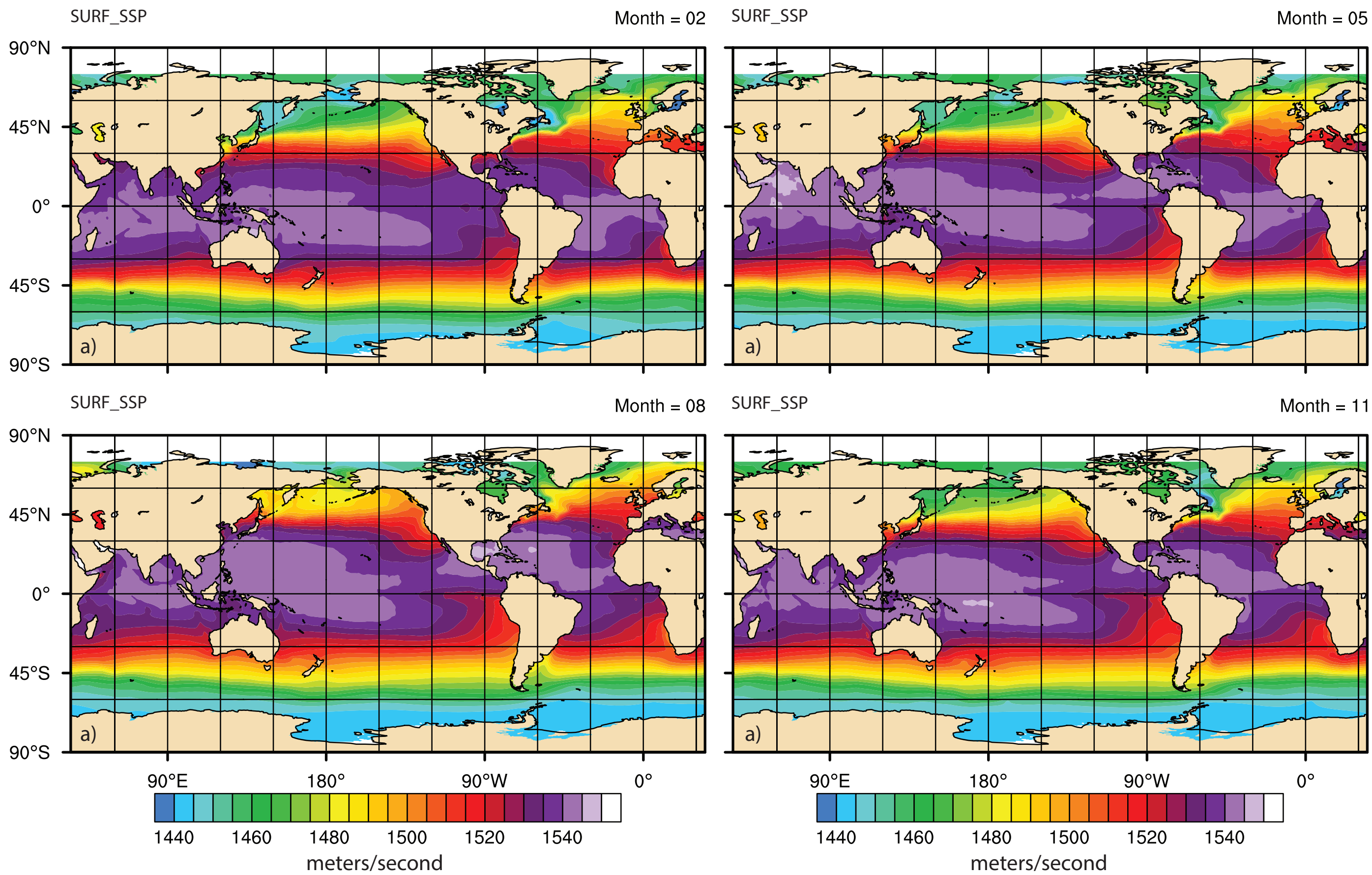

Fig. 14 – Climatology averaged SURF_SSP, in meters/second (m/sec), for the months of (a) February, (b) May, (c) August, and (d) November

Near-Surface Ocean: Sonic Layer Depth Sound Speed

The sonic layer depth sound speed (SLD_SSP) is very similar to the SURF_SSP because for most of the ocean, the temperature and salinity at the surface is very close to that at the SLD. This is because the SLD tends to occur at the mixed layer depth for most of the ocean.[4] For this reason, qualitatively SURF_SSP and SLD_SSSP are nearly identical (Fig. 15).

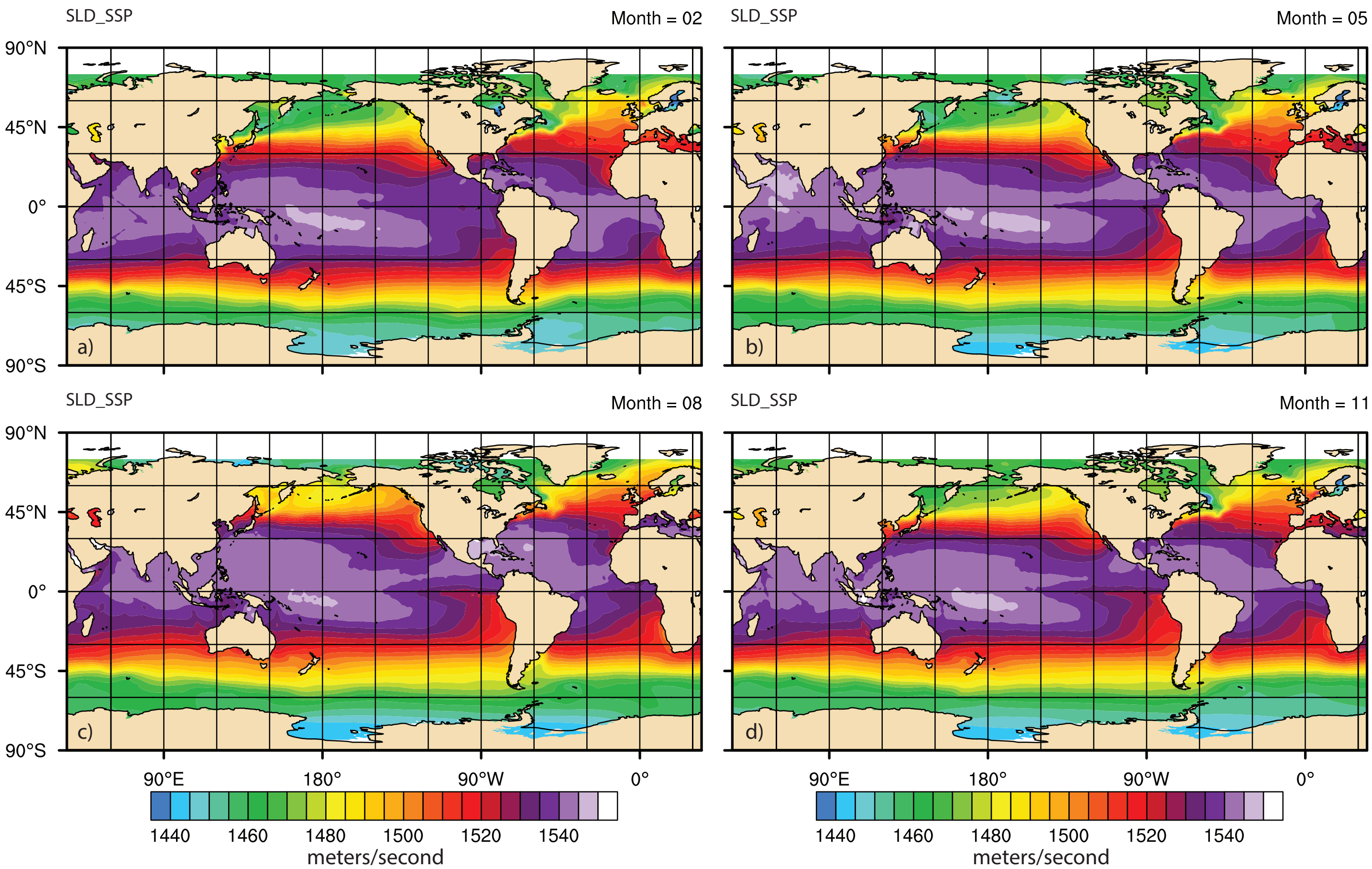

Fig. 15 – Climatology averaged SLD_SSP, in meters/second (m/sec), for the months of (a) February, (b) May, (c) August, and (d) November

Near-Surface Ocean: Surface Duct Cutoff Frequency

The surface duct cutoff frequency (SLD_COFF) is the minimum frequency of sound in the ocean that will become 'trapped' in the surface duct. Sound that is produced within the SLD at a frequency higher than the SLD_COFF will be trapped and propagate within the duct. Sounds at lower frequencies than the SLD_COFF, will have wavelengths that will not be trapped in the surface duct. SLD_COFF has units of Hz for frequency and is plotted in Log10 because frequencies occur over five orders of magnitude (Fig. 16). The seasonal cycle of SLD_COFF is identical to that of SLD (see Fig. 7) and have an inverse-like relationship.

Deep Ocean: Deep Sound Channel Axis

The deep sound channel axis (DSCA) represents the depth of the minimum sound speed of the deep sound channel and is the first deep ocean acoustic parameter discussed in this section (Fig. 17). The patterns in the distribution of the DSCA are in some ways the opposite of corresponding patterns of near surface acoustic parameters. For example, SLD, SLD_COFF, SURF_SSP, and SLD_SSP all become smaller at high latitudes, whereas the DSCA exhibits the opposite behavior, increasing at high latitudes, though that is an over simplification. The regions of the ocean with the deepest DSCA are in the North Atlantic west of the Strait of Gibraltar, the Arabian Sea, and the Bay of Bengal. The seasonal cycle of the DSCA is small compared to those of the near surface acoustic parameters.

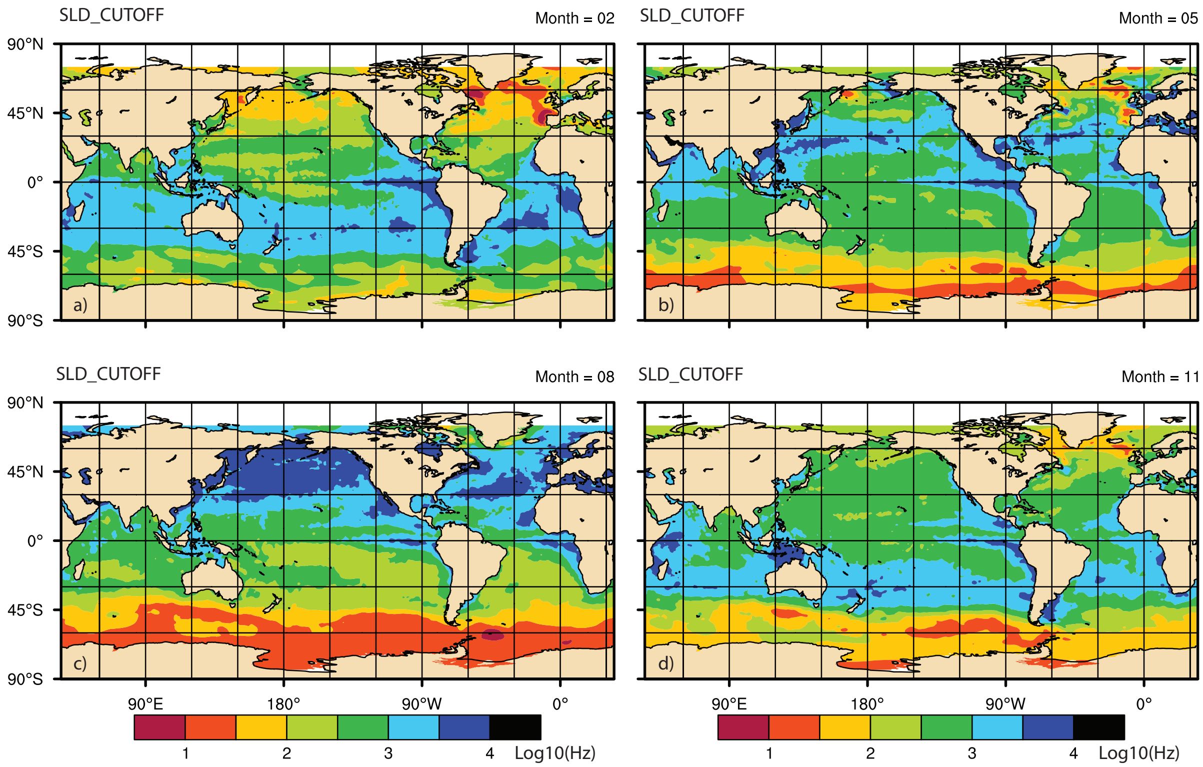

Fig. 16 – Climatology averaged SLD_COFF, in Log10 (Hz), for the months of (a) February, (b) May, (c) August, and (d) November

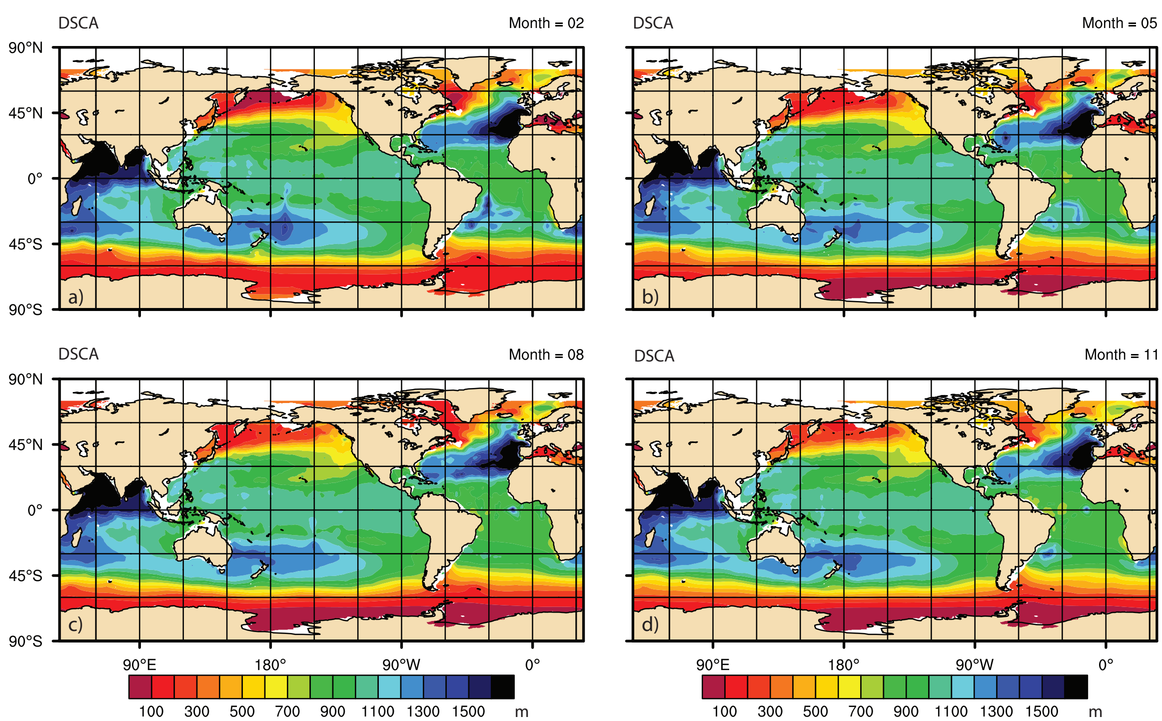

Fig. 17 – Climatology averaged DSCA, in meters (m), for the months of (a) February, (b) May, (c) August, and (d) November

Deep Ocean: Critical Depth

The critical depth (CD) is the depth below the deep sound channel where the sound speed is equal to the sound speed at the SLD. The seasonal cycle for CD is relatively small as can be seen in Fig. 18. For much of the ocean, the CD does not exist and is shown as the white areas in Fig. 18. The CD tends to disappear in the tropics because the warm surface waters make for high surface sound speeds (Fig. 14) that exceed the sound speed at the bottom of the ocean (see Fig. 1(b)). Generally at higher latitudes, CD does exist. In these cases, there is depth excess (DEXCESS) below the deep sound channel. These deep CD values are represented by blue and black regions in Fig. 18. The seasonal cycle in CD is larger than that for DSCA because the top of the deep sound channel is influenced by the surface variability (see Fig. 8). In the Northern Hemisphere winter (Fig. 18(a)), the CD is shallower than in the Northern Hemisphere summer (Fig. 18(c)). This shows again that the deep ocean acoustic parameters are opposite to those near the surface, which tend to be larger in the winter.

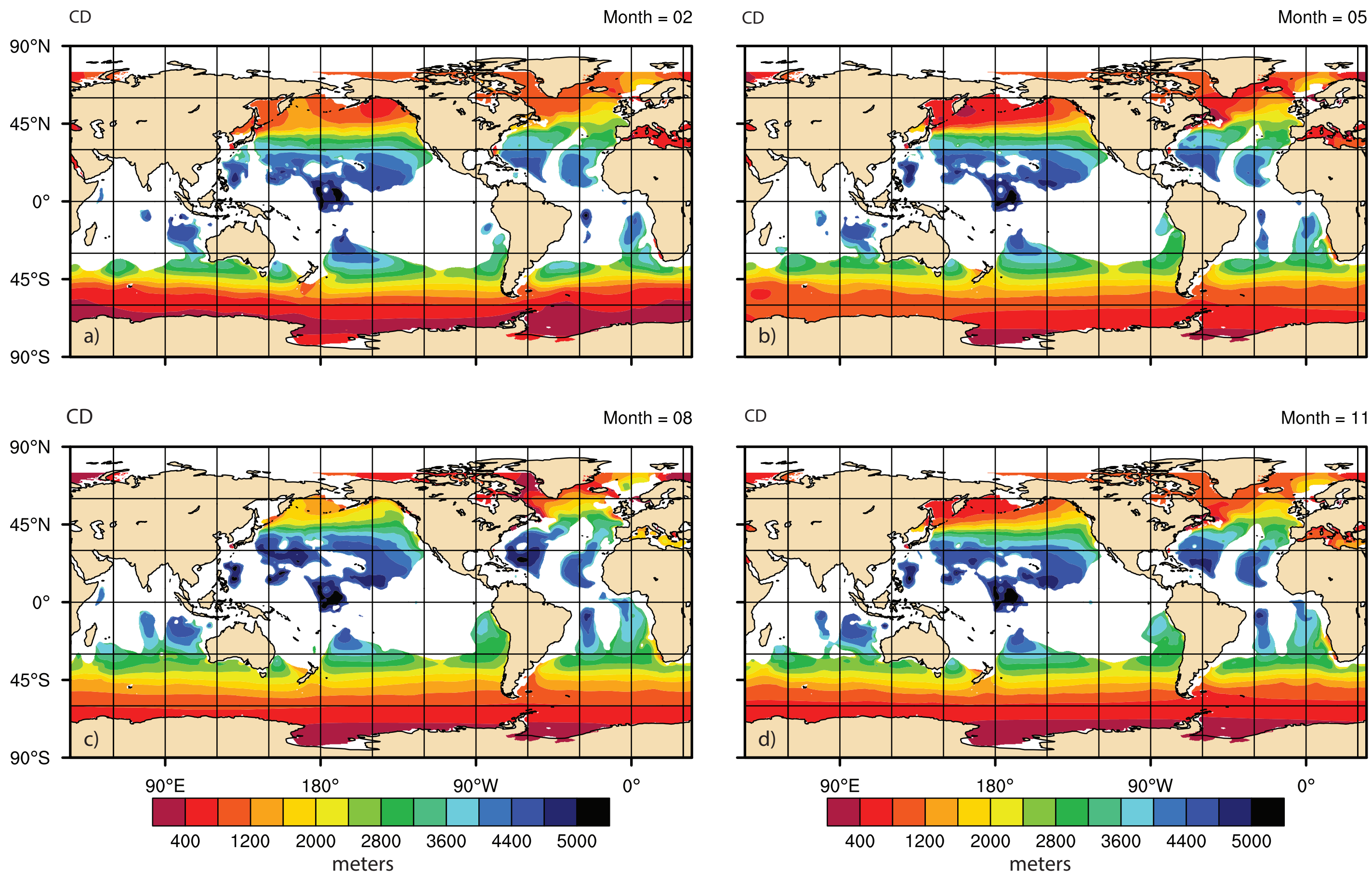

Fig. 18 – Climatology averaged CD, in meters, for the months of (a) February, (b) May, (c) August, and (d) November. White areas indicate that on average no CD exists.

Deep Ocean: Depth Excess

The depth excess (DEXCESS) is the depth range below CD to the ocean bottom that is upward refracting in sound speed. The DEXCESS does not exist if CD does not exist, as indicated by the white regions in Fig. 19 that tend to occur in the tropics. The white areas tend to occur when either the surface sound speeds are high or the bottom depth is shallow. This is why there is no CD or DEXCESS in the tropics and long the mid-Atlantic ridge (Figs. 18 and 19). The DEXCESS tends to becomes large in the high latitude ocean where the deep sound channel becomes shallow and the surface sound speeds are small.

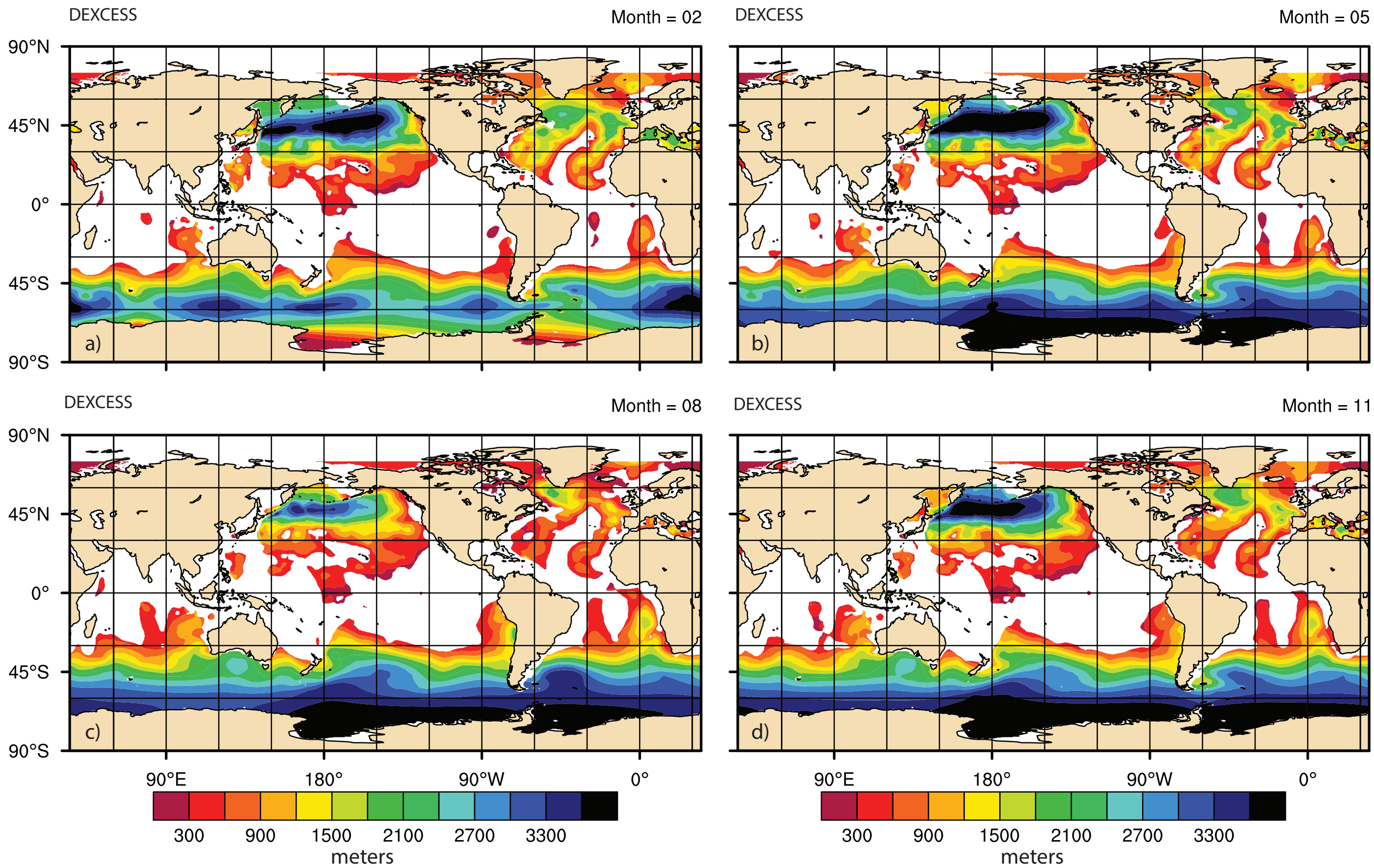

Fig. 19 – Climatology averaged DEXCESS, in meters (m), for the months of (a) February, (b) May, (c) August, and (d) November. White areas indicate that on average no DEXCESS exists.

Deep Ocean: Deep Sound Channel Sound Speed

The sound speed at the deep sound channel axis (DSCA_SSP) varies depending on the depth of the DSCA. The DSCA_SSP is larger when the DSCA is deeper because sound speed increases with depth. For this reason, the DSCA_SSP has similar spatial patterns to that of DSCA, though the units are different (Fig. 20).

Deep Ocean: Critical Depth Sound Speed

The sound speed at the critical (CD_SSP) varies depending on the CD. The CD_SSP is larger when the CD is deeper because sound speed increases with depth. For this reason, the CD_SSP has similar spatial patterns to that of CD, though the units are different (Fig. 21). The white areas again indicate where the CD does not exist.

Deep Ocean: Bottom Sound Speed

The sound speed at the bottom of the ocean (BOT_SSP) is nearly constant throughout the year (Fig. 22). The largest changes are due to gridding in low data sampling regions at very high latitudes. Because there are very few data in high latitude winters, the gridding methods are more likely to extrapolate to unrealistic values. For example in May (Fig. 22(a)), the low sound speed values for BOT_SSP near Antarctica are due to extrapolation errors during Southern Hemisphere winter in a region with very few data (see Fig. 4). Future versions of APC may find better ways to address this issue.

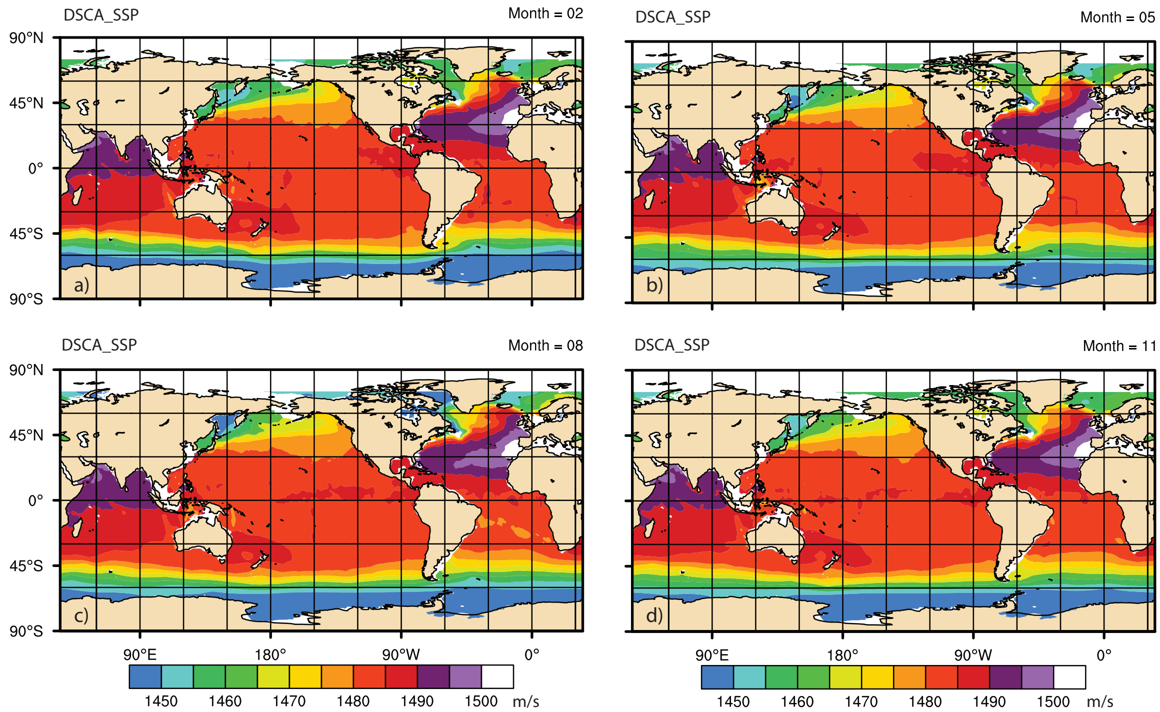

Fig. 20 – Climatology averaged DSCA_SSP, in meters/second (m/sec) for the months of (a) February, (b) May, (c) August, and (d) November

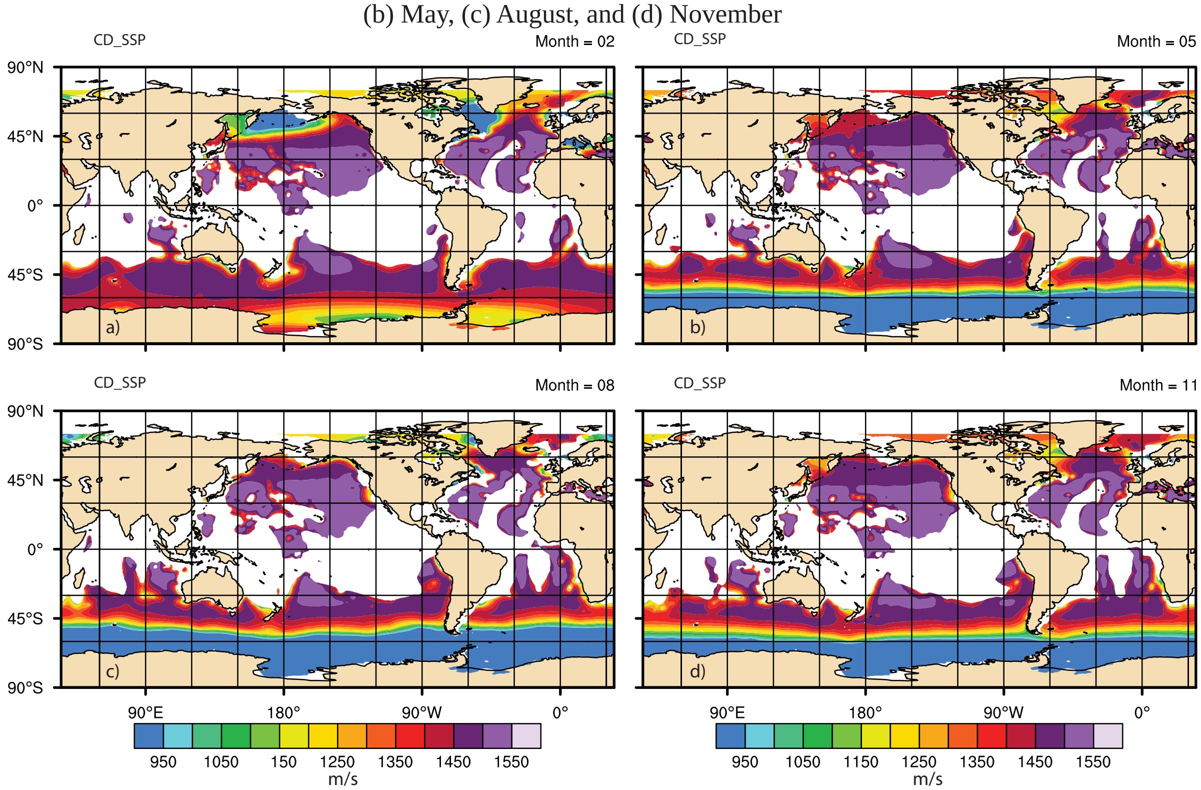

Fig. 21 – Climatology averaged CD_SSP, in meters/second (m/sec) for the months of (a) February, (b) May, (c) August, and (d) November. White areas indicate that on average no CD exists.

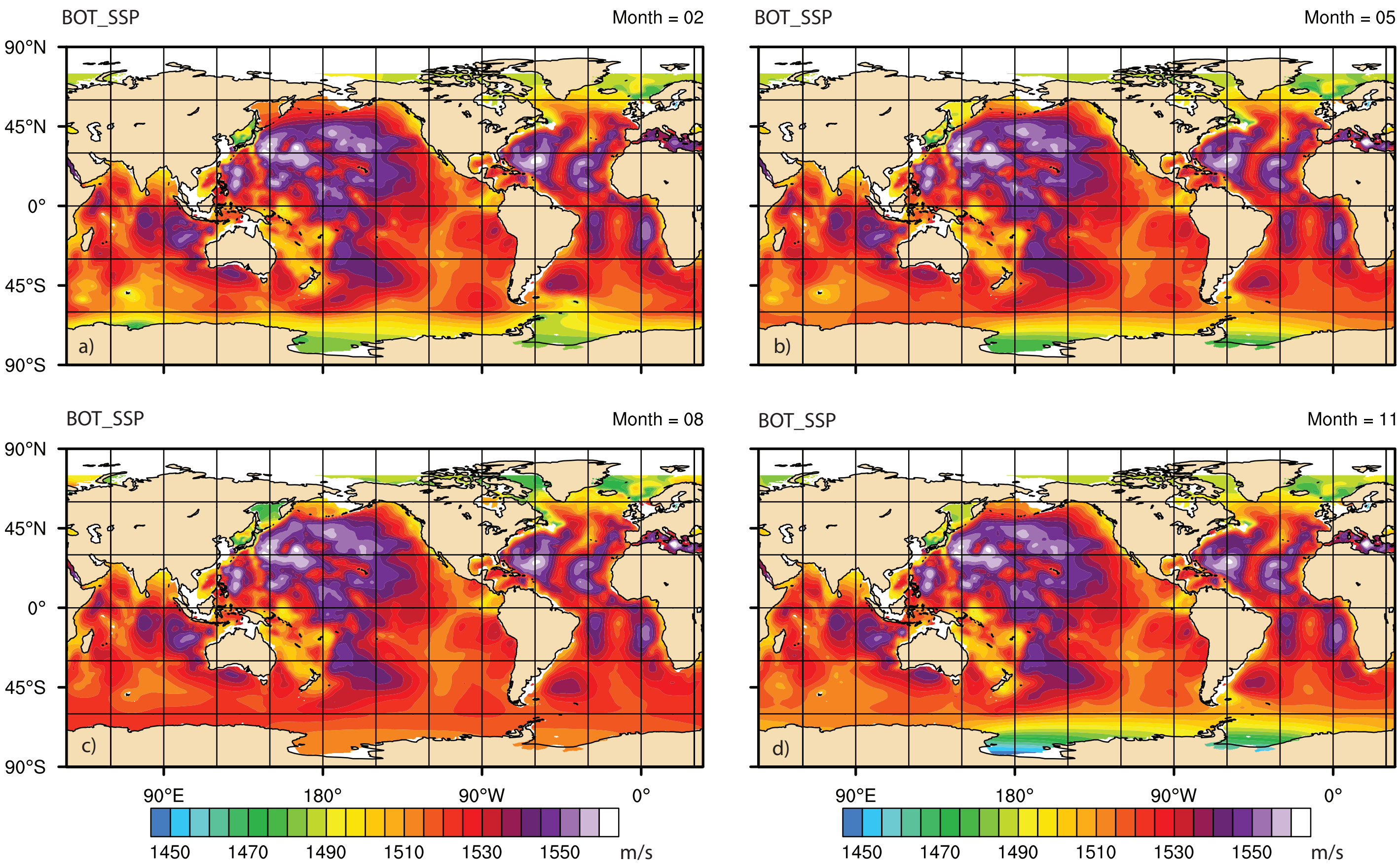

Fig. 22 – Climatology averaged BOT_SSP, in meters/second (m/sec), for the months of (a) February, (b) May, (c) August, and (d) November

Deep Ocean: Deep Sound Channel Cutoff Frequency

The deep sound channel cutoff frequency (DSC_COFF) is the minimum frequency of sound in the deep sound channel that will become trapped and propagate in the waveguide (Fig. 23). Because the location of the DSCTOP varies with season, the DSC_COFF also show seasonal dependencies. In the Northern Hemisphere, the DSC_COFF is larger in the winter than in the summer. The deep sound channel exists even when critical depth does not.

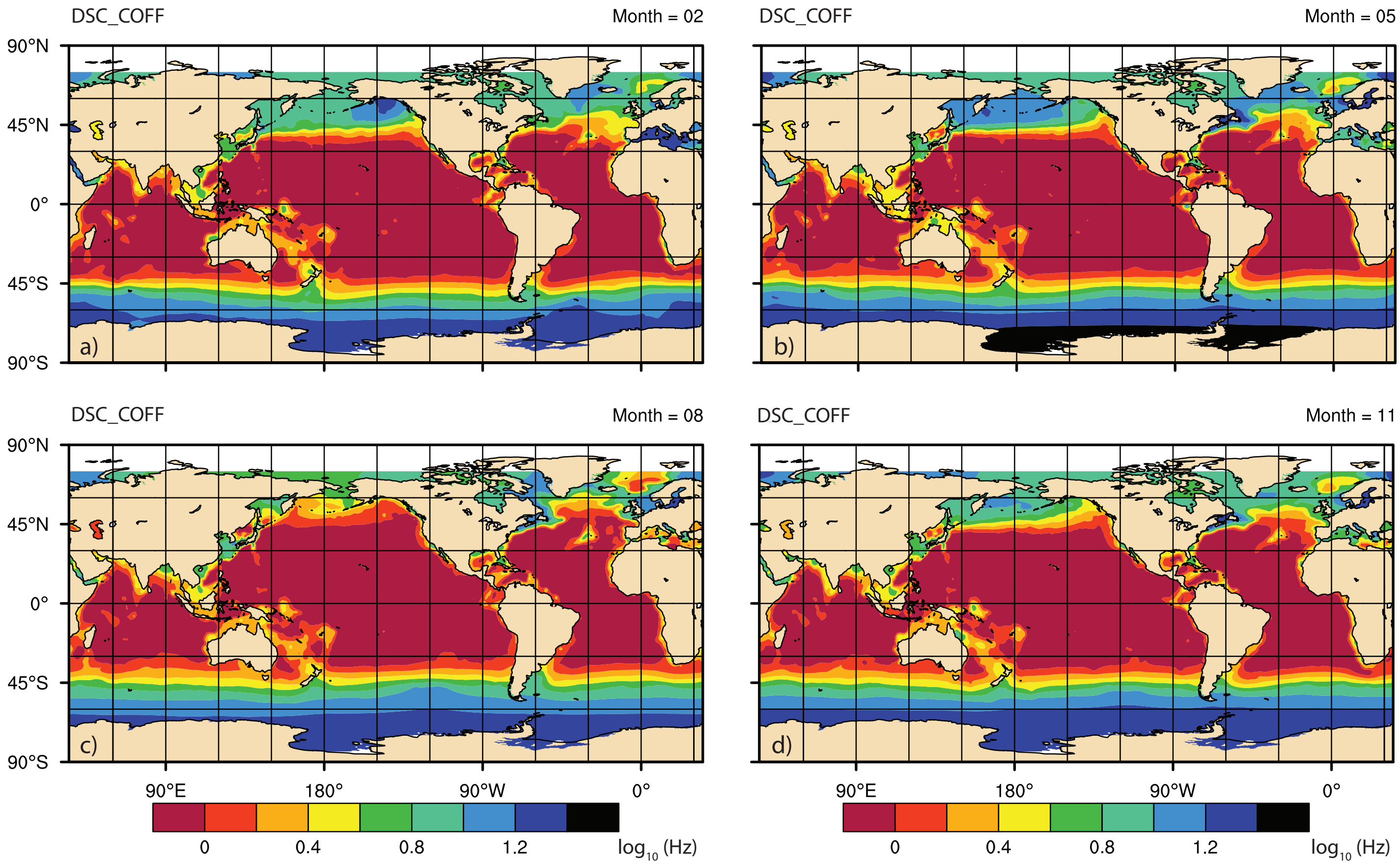

Fig. 23 – Climatology averaged DSC_COFF, in Log10 (Hz), for the months of (a) February, (b) May, (c) August, and (d) November

VI. DISCUSSION

The global ¼° regular gridded monthly climatology of acoustic parameters is available for Department of Defense (DoD) and DoD contractors at the secure webpage located: https://www7320.nrlssc.navy.mil/ISOP/APC/. The user name and password are available upon request. Figure 24 is a screen shot of the webpage for the parameter sonic layer depth (SLD). Figures for all 14 acoustic parameters are available for viewing as monthly animations and as individual monthly or annual fields. Some of the acoustic parameters also have the standard deviation displayed on the webpage. The possibility of having the APC webpage located on the SIPRNet is being investigated at the time of writing.

Statistics in 5° by 5° regions

To gain an understanding of the statistical variability of the data, acoustic parameters are binned in 5° by 5° geographical regions. The binned data are then used to compute the minimum, maximum, mean, median, standard deviation, and inter-quartile range for each 5° by 5° region. For example, the maximum and minimum sonic layer depths (SLD) for the month of March are shown in Fig. 25. During March, nearly every region of the global ocean has at least one profile that returns a zero sonic layer depth. The maximum sonic layer depth is more variable around the global ocean.

The statistical distribution of sonic layer depth is in some regions non-Gaussian, which is evident because its mean differs from its median (Fig. 26). For example in the North Atlantic, the mean sonic layer depth is more than 200 m deep, while the median is closer to 80 m. Differences between the mean and median and thus non-Gaussian distributions of sonic layer depth occur primarily at high latitudes.

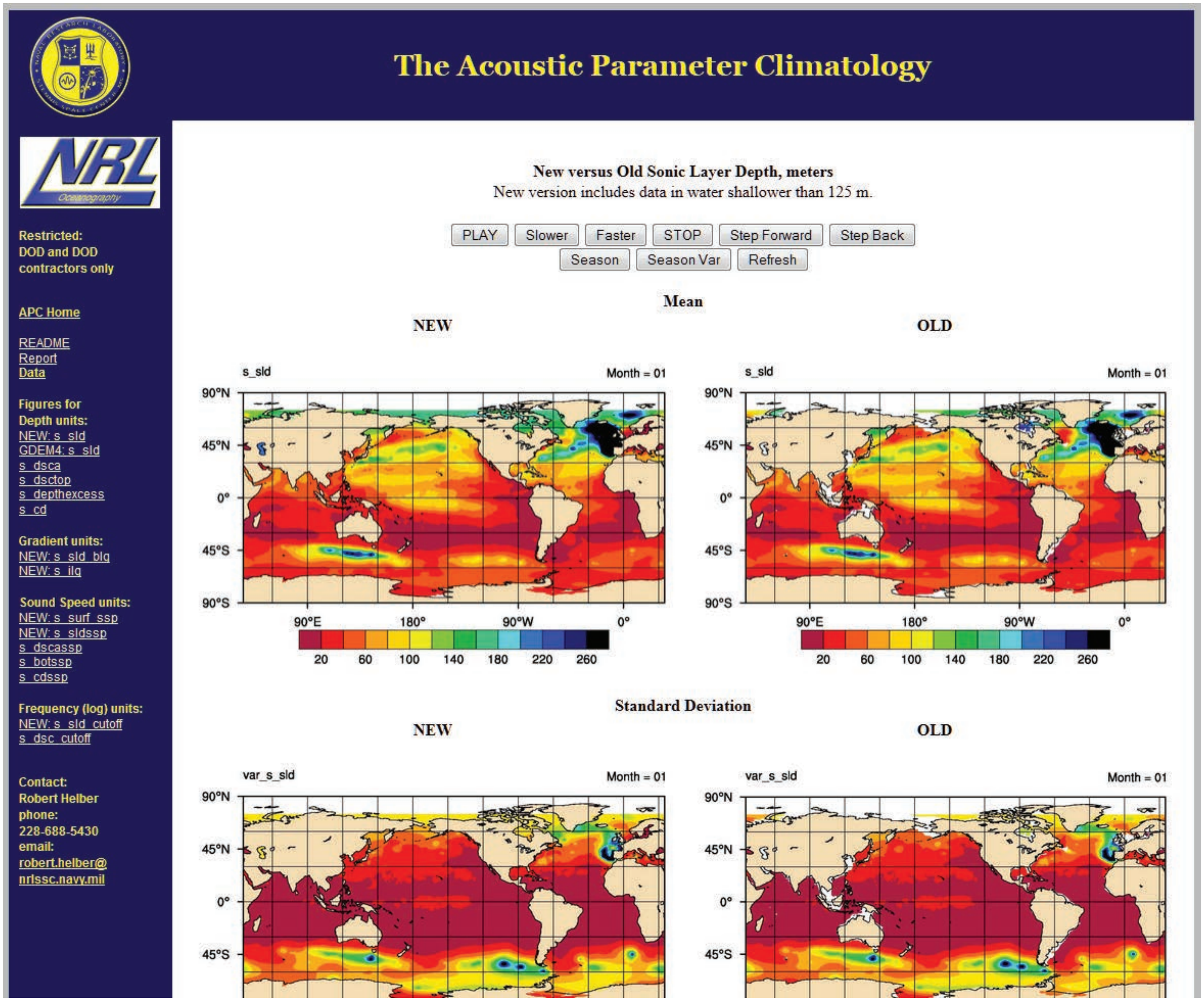

Fig. 24 – A screen shot of The Acoustic Parameter Climatology located at https://www7320.nrlssc.navy.mil/ISOP/APC/ for the sonic layer depth (SLD) parameter. The website is password protected.

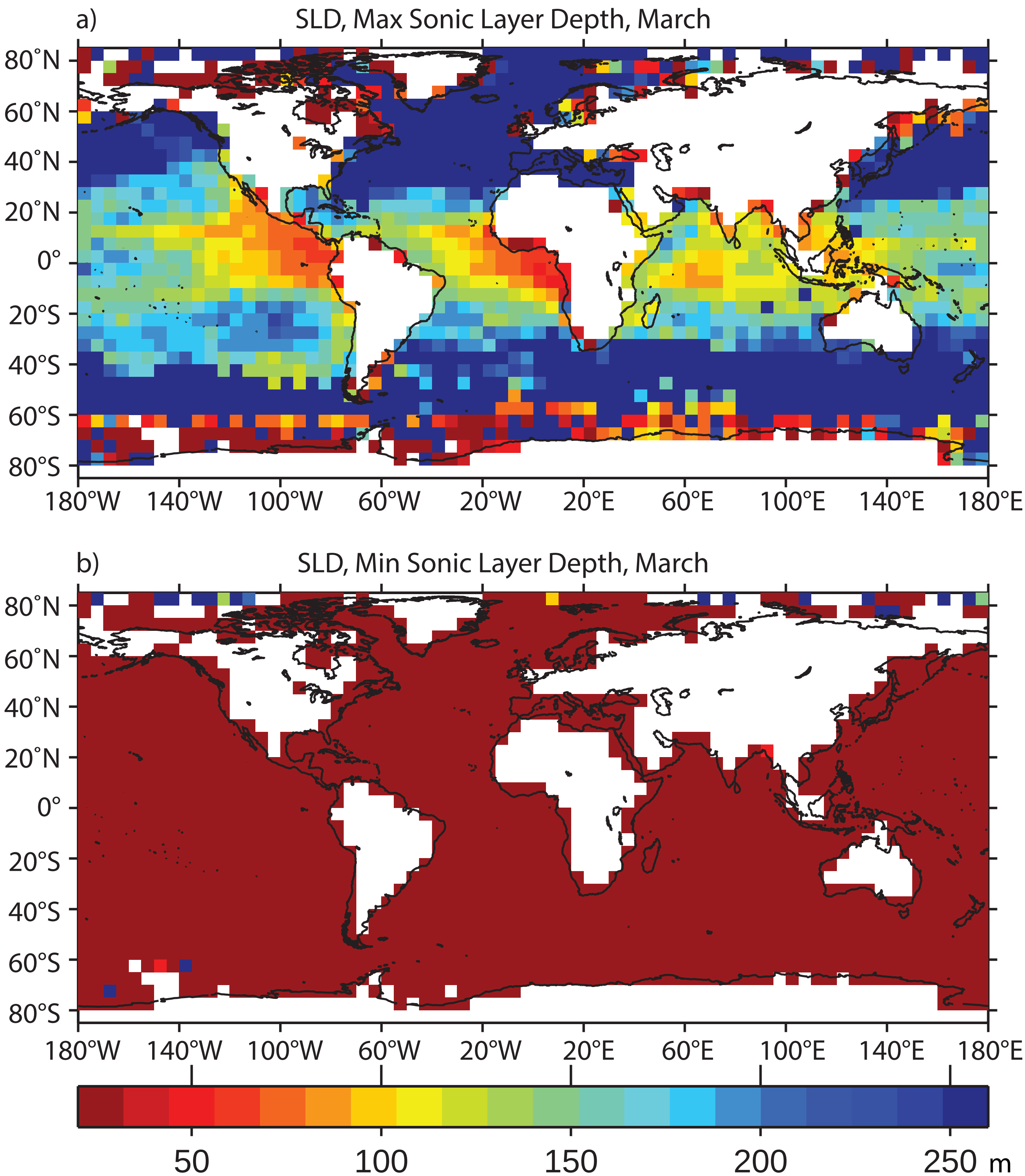

Fig. 25 – The maximum (a) and minimum (b) sonic layer depth (SLD), in meters (m), binned in 5° by 5°degree geographical boxes for the month of March

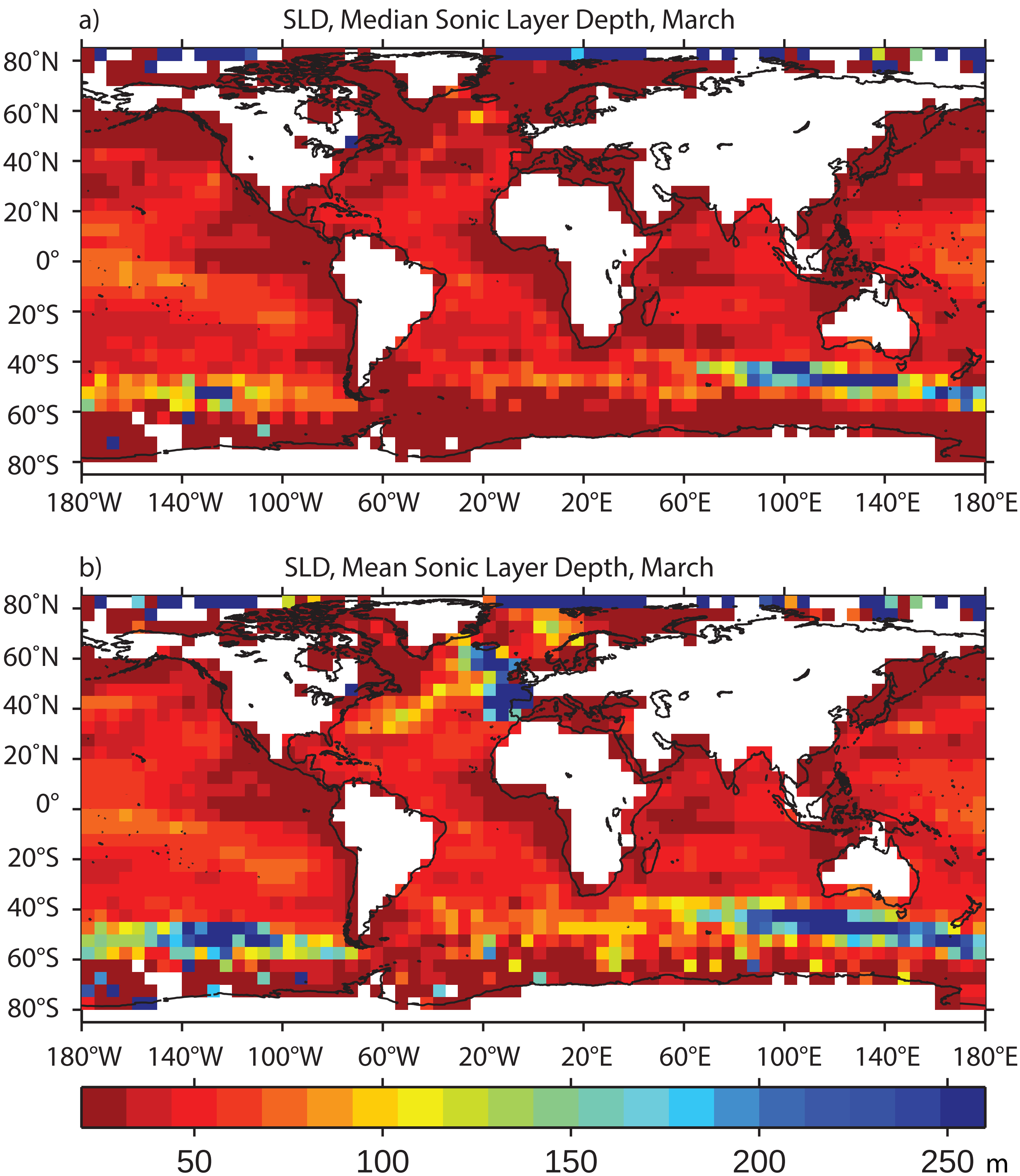

Fig. 26 – The median (a) and mean (b) sonic layer depth (SLD), in meters (m), binned in 5° by 5° degree geographical boxes for the month of March

Further insight into the regional variability and distribution of the parameters can be seen by examining the standard deviation and inter-quartile ranges of the binned data (Fig. 27). The North Atlantic and the Antarctic Circumpolar Current regions tend to have large sonic layer depth variability. There are regions in the South Atlantic where standard deviations are large but inter-quartile ranges are small. This suggests that the large standard deviations are caused by a few outlier profiles with a greater fraction of data more tightly clustered about the median. Outlier data points tend to influence standard deviation calculations more than calculations of inter-quartile range. Another region where this occurs is in the South Pacific just west of Chile, suggesting that extreme outliers have also been observed here.

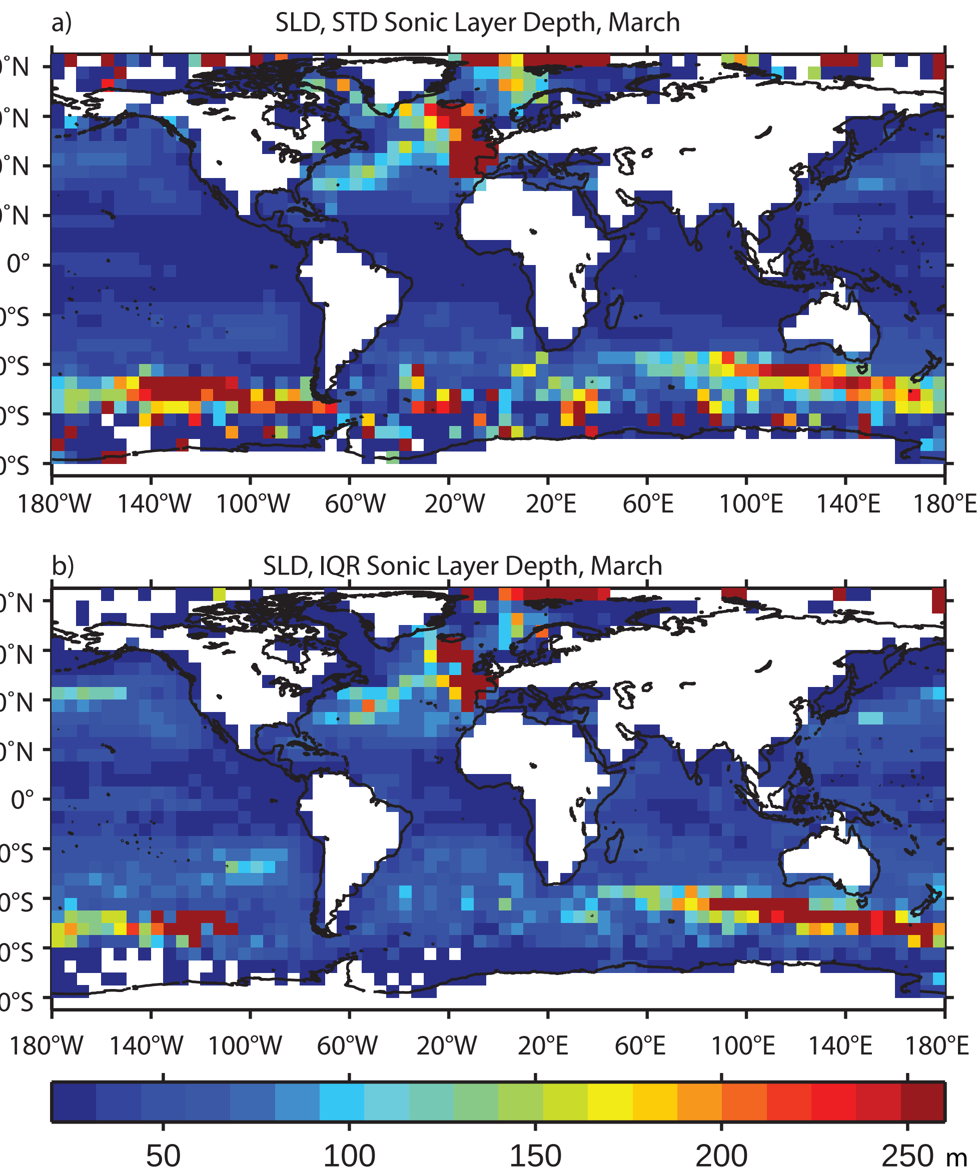

Fig. 27 – The standard deviation (a) and inter-quartile range (b) for sonic layer depth (SLD), in meters (m), binned in 5° by 5° degree geographical boxes for the month of March

While this article shows the binned statistics for sonic layer depth only during March, other parameters have been examined in this way for all months. These statistical measures are used to diagnose parameter algorithm problems and flag potentially bad data. Analyses of the statistical data will help in the development of future improved versions of the APC.

Climatology-First versus Parameter-First Approach

In the introduction and background sections, two approaches for constructing parameter climatologies are described. The climatology-first approach uses already available temperature and salinity climatology values to compute sound speed and then acoustic parameters. The drawback of this method is that the process of creating a climatological average of temperature and salinity smoothes important vertical structure features of the ocean. As a result, this method produces inaccurate parameter values. The approach for the present acoustic parameter climatology is to compute the parameters first and then form the climatological averages of the resulting parameters. In this section, the resulting differences between these two approaches are shown, and it is argued that the parameter-first approach is superior. This idea that ocean parameters are best computed before averaging is not new and has been used by the oceanographic research community for more than a decade.[14]

Figure 28 shows a comparison between the SLD computed from the GDEM climatology minus the SLD computed for the present APC. This figure shows that the GDEM SLD is shallower for most of the ocean for all months. This general result is due to the fact that the vertical shape of the GDEM temperature and salinity profiles is smoothed. The sharp change in sound speed that occurs at the base of the mixed layer, resulting in a sound speed maximum, and thus the SLD, is smoothed in GDEM. As a result, the sound speed maximum occurs shallower than in actual observed profiles. This occurs generally for all months of the year.

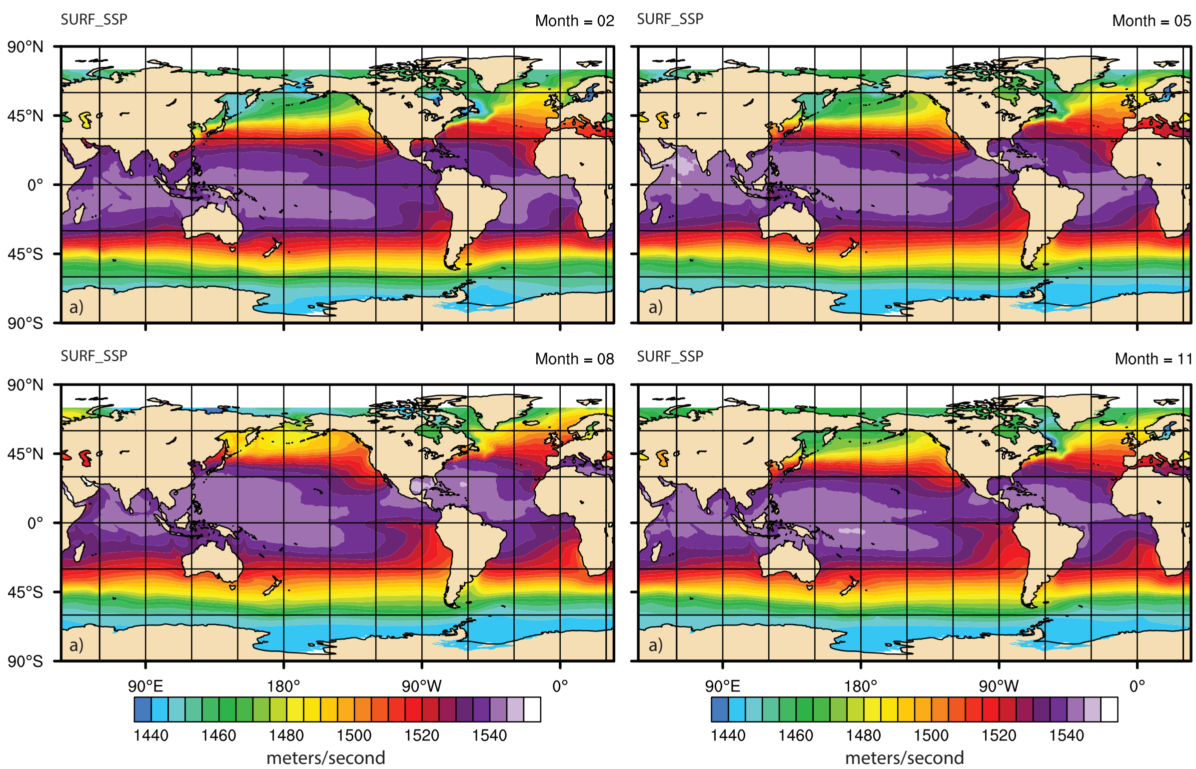

Fig. 28 – The difference in SLD in meters computed from the GDEM4 climatology (climatology-first approach) minus SLD computed from the present version of the APC (parameter-first approach) for the months of (a) February, (b) May, (c) August, and (d) November

At high latitudes, differences between GDEM and APC SLD can be drastic. In these cases, the smoothing of GDEM completely erases the true location of the SLD. This tends to occur at high latitudes in the Northern Hemisphere spring due to the delicate balance of temperature and salinity that occurs at that time and location.[4] In the southern ocean for most of the year (Fig. 28(b), (c), and (d)), the GDEM SLD is very deep due to a failure of the RP33 software. Accurate SLD is computed for the APC due to a software patch that was applied at high latitudes that was not applied in the GDEM SLD case (see Section IV).

VII. SUMMARY AND CONCLUSIONS

The APC is the first global monthly climatology of 14 RP33 acoustic parameters. This new product includes 12 monthly and one annual averaged ¼° fields for each parameter. There are six near surface parameters and eight deep ocean parameters that characterize aspects of the ocean's full three-dimensional acoustic properties. This article describes the global seasonal characteristics of each acoustic parameter shown in the figures for February, May, August, and November.

To explain the reason for the seasonal variability found in the acoustic parameters, the ocean dynamical surface parameter MLD is discussed. For most of the ocean, most of the time, MLD is nearly equal to SLD. As a result, SLD is also associated with ocean mixing driven by the seasonal cycle of surface cooling and heating. The result, regarding in-layer gradient (ILG), indicates that for most of the ocean ILG is relatively constant with a value near 0.49 m/sec per 100 ft. This value is associated with uniform temperature and salinity within the SLD. ILG values tend to deviate from this value mostly where large input of surface freshwater exists.

The methods for constructing the climatology are designed to maintain important gradients and inflection points that might be obscured by traditional approaches. The acoustic parameters are computed from the edited and filled ocean observations, and then the parameters are gridded. For the APC, these methods are superior to traditional methods of computing acoustic parameters from gridded field of temperature and salinity as shown in Section VI.

This article describes the beta version of the APC that uses an operational version of RP33 software. There is a new version of the RP33 software in the OAML software library, released after the bulk of the work had been completed on the APC. The new version, called APARMS 1.0, has an improved method for computing duct cutoff frequencies. The next version of the APC will use the updated APARMS software.

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