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GLOBAL OCEAN SOUND SPEED PROFILE LIBRARY (GOSSPL), AN RDATA RESOURCE FOR STUDIES OF OCEAN SOUND PROPAGATION

Jay Barlow

NOAA Fisheries
Southwest Fisheries Science Center, NMFS
Marine Mammal and Turtle Division
8901 La Jolla Shores Drive
La Jolla, CA 92037

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Jay Barlow

NOAA Southwest Fisheries Science Center, Marine Mammal and Turtle Division, 8901 La Jolla Shores Drive, La Jolla, California 92037, USA

ABSTRACT

Ocean sound speeds are estimated from a database of global ocean model of temperature and salinity, and these sounds speeds are made available to users of the R programming language as an Rdata structure. Sound speeds are estimated with the Mackenzie approximation which estimates sound speed as a function of temperature, salinity and depth. Monthly average temperature and salinity data are taken from Version 3.0.1 of the Generalized Digital Environmental Model – Variable resolution (GDEM-V). Resulting sound speeds cover most seawater areas from 82°S to 90°N at a spatial scale of 0.25 degrees, a temporal scale of monthly averages, and a variable depth scale. The resulting Rdata structures are made publically available. R programming scripts for the creation of these structures and for reading from these structures are included in appendices.

INTRODUCTION

Knowledge of sound speeds in seawater is critical for studies of sound propagation in the ocean and for studies of acoustic localization and tracking. Sound speed varies with temperature, salinity, and depth, and ocean temperature and salinity vary with season and location. Estimates of ocean sound speed are available as MATLAB data files[1] and from many sources; however, these data are not readily available to researchers using R programming language (R Core Team 2017). Increasingly, acoustic researchers are using freely available R programming tools in their studies of ocean acoustics. The release of R packages like *seewave* (Sueur et al. 2008) and *tuneR* (Ligges et al. 2018) have contributed to this movement. Here I describe the creation of R script files and Rdata structures that will allow easy access to global ocean sound speed estimates for researchers using the R programming language.

METHODS

The Mackenzie (1981) model of sound speed in seawater is used with a global model of average monthly temperature and salinity to create global estimates of ocean sound speeds. The Mackenzie model is based on temperature, salinity and depth (pressure). Version 3.0.1 of the Generalized Digital Environmental Model – Variable resolution (GDEM-V) (Carnes 2009a; Carnes 2009b) is used as a source

[1] http://staff.washington.edu/dushaw/WOA/

of monthly average values of temperature and salinity as a function of depth. In that model, location (latitude and longitude) resolution is at gridded intervals of 0.25 degrees and the depth resolution is at 78 points on a variable scale from 2 m at the surface to 200 m at the maximum depth of 6,600m (depth values are: 0, 2, 4, 6, 8, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 220, 240, 260, 280, 300, 350, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1800, 2000, 2200, 2400, 2600, 2800, 3000, 3200, 3400, 3600, 3800, 4000, 4200, 4400, 4600, 4800, 5000, 5200, 5400, 5600, 5800, 6000, 6200, 6400, and 6600 m). The model was fit to oceanographic data collected from 1900 to 2000, with the vast majority of data coming from the second half of the 20th Century (Carnes 2009a).

The R package *ncdf4* is used to extract temperature and salinity data from the uncompressed GDEM-V data files using the R script given in Appendix 1. That script uses the function *wasp* in the R package *seewave* to estimate sound speeds for each gridded value of latitude, longitude and depth using the Mackenzie (1981) model. The 3-D matrix of monthly sound speed estimates and the gridded values of latitude, longitude and depth are saved as an Rdata structure.

An example R script to read these Rdata structures and to estimate a profile of sound speeds at the nearest grid point to a given location is given in Appendix 2. The profile of sound speed is provided for the gridded depth values from the surface to the maximum depth that is above the seafloor at that location. A generalized additive model (from the R package *gam*) with high-dimensional spline function (30 knots) is used to smooth the sound speed profile and to interpolate sound speeds on a 1-m depth scale.

RESULTS

The twelve monthly Rdata structures containing global ocean sound speeds and associated information are approximately each approximately 240 MB in size. The covered areas include most of the world's sea surface (Figure 1). Rdata files can be downloaded here. An example of the discrete and smoothed sound speed profiles for a location in the Catalina Basin (off Southern California, USA) is given in Figure 2.

DISCUSSION

The GDEM-V model of mean monthly salinity and temperature values was based on oceanographic data collected in the 20th Century. The actual sound speed profile for any specific location and time will vary from those calculated from mean values due to natural year-to-year variation in oceanographic conditions. Long-term trends in ocean sound speeds can also be expected given global climate change. The best estimates of sound speed would be based on near-real-time measurements at the location of interest. Failing that, better estimates could be based on estimated values of temperature and salinity from a regional ocean circulation model (ROMS). However, for many applications, the use of long-term averages provides sufficient precision. We leave it to individual users to evaluate whether long-term averages are sufficient for their purposes. Estimates of the precision and accuracy of the GDEM-V model for predicting a given year are not readily available, so we are not able to provide confidence limits on our estimates of sound speed.

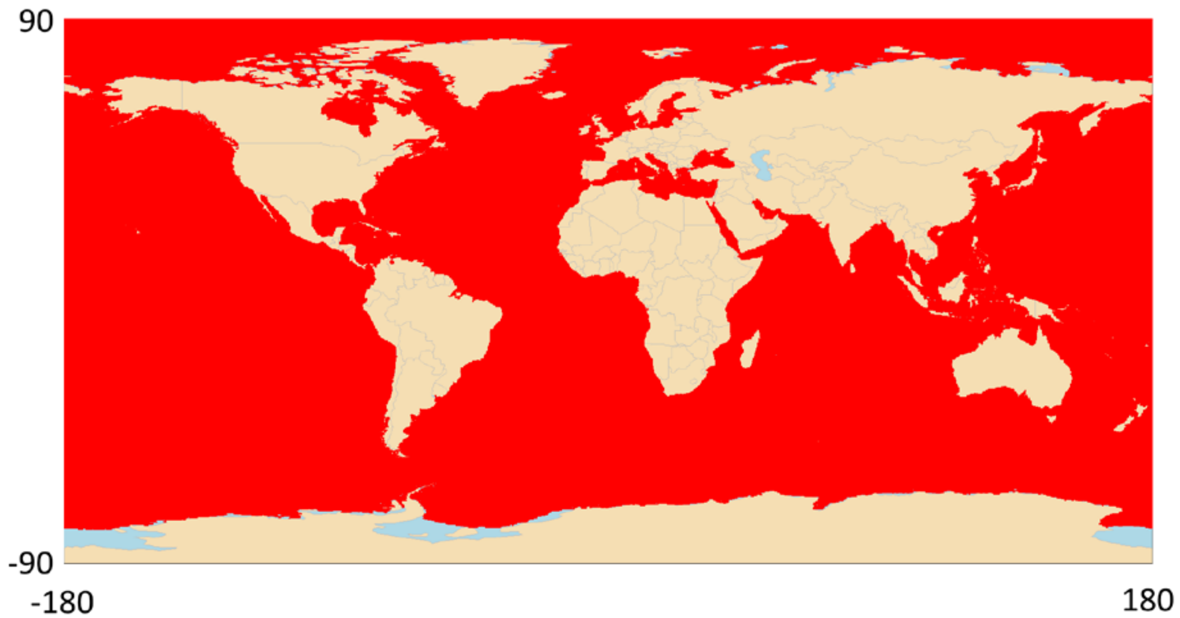

Figure 1. Locations (red) where ocean sound speed profiles are available. Ocean and seas that are colored in light blue are not included.

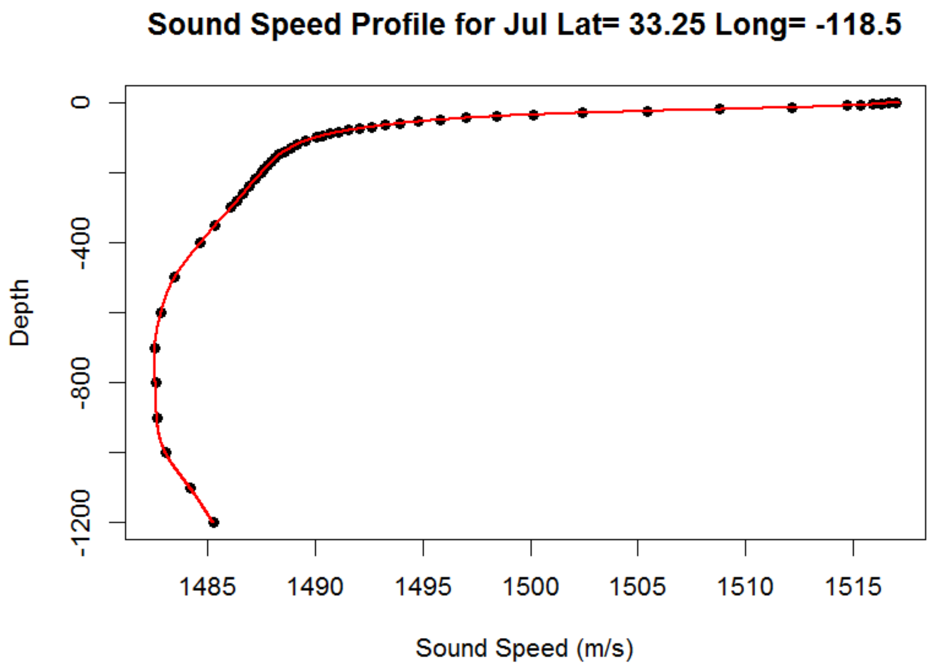

Figure 2. Estimated July sound speed profile for a location in the Catalina Basin at 33.25°N and 118.50°W. Black circles represent estimates at discrete depths in the Rdata structure, and the red line represents smoothed values at 1-m resolution from a spline fit to those data.

REFERENCES

Carnes, M.R., 2009a. *Description and Evaluation of GDEM-V 3.0* (No. NRL/MR/7330--09-9165). Naval Research Lab, Stennis Space Center, MS, Oceanographic Data Bases Division.

Carnes, M.R., 2009b. Database description for the Generalized Digital Environmental Model – Variable Resolution (GDEM-V) Version 3.0.1 (U). OAML-DBD-72F. Naval Oceanographic Office, Stennis Space Center, MS, Oceanographic Data Bases Division. NRL/MR/7330--09-9165. 21pp.

Ligges, U., Krey, S., Mersmann, S., and Schnackenberg,S. 2018. tuneR: Analysis of Music and Speech. URL:https://CRAN.R-project.org/package=tuneR

Mackenzie, K.V., 1981. Nine-term equation for sound speed in the oceans. *The Journal of the Acoustical Society of America*, *70*(3), pp.807-812.

R Core Team 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sueur J., Aubin T., Simonis C. 2008. Seewave: a free modular tool for sound analysis and synthesis. Bioacoustics, 18: 213-226.

APPENDIX 1

R script file ("Read ncdf4 oceo data and save WoldwideSoundSpeedMatrices.r") used to read monthly mean temperature and salinity GDEM-V data files and compute ocean sound speeds.

```
# ncdf4 access to sound speed oceanography
# this package requires pre-installation of the following libraries:
#   netCDF4.5.0-rc3-NC4-DAP-64.exe
#   HDF5-1.8.19-win64.msi

# written by Jay Barlow (2018)
# last revised 24 August 2018

library("ncdf4")
library("seewave")

# oceanographic temp & salinity data files location
setwd("S:\\SoundSpeedWorldwideData\\WorldOceanogrData by Month\\GDEM-V uncompressed")

Months= c("01","02","03","04","05","06","07","08","09","10","11","12")

for (iMonth in 1:12) {
 Month= Months[iMonth]       #text version of month number for input file names
 aMonth= month.abb[iMonth]    #abbreviated month names for naming output files

 SalData= nc_open(paste("sgdemv3s",Month,".nc",sep=""))
 SalMatrix= ncvar_get(SalData)

 TempData= nc_open(paste("tgdemv3s",Month,".nc",sep=""))
 TempMatrix= ncvar_get(TempData)

 #get longitude values
 LongUnits= TempData$var$water_temp$dim[1][[1]]$units
 LongValues= TempData$var$water_temp$dim[1][[1]]$vals
 LongValues[LongValues>180]= LongValues[LongValues>180] - 360  #transform west longitudes to be negative

 #get latitude
 LatUnits= TempData$var$water_temp$dim[2][[1]]$units
 LatValues= TempData$var$water_temp$dim[2][[1]]$vals

 #get depth
 DepthUnits= TempData$var$water_temp$dim[3][[1]]$units
 DepthValues= TempData$var$water_temp$dim[3][[1]]$vals

 # create matrix of depths
 Dimensions= dim(TempMatrix)
 DepthMatrix= array(NA,dim=Dimensions)
 for (i in 1:Dimensions[1]) {
  for (j in 1:Dimensions[2]) {
```

```
    DepthMatrix[i,j,]= DepthValues
   }
 }

 # calculate sound speeds using the Mackenzie approximation in the wasp function in seewave
 SoundSpeeds= wasp(f=30000, t = TempMatrix, s = SalMatrix, d = DepthMatrix, medium = "sea")
 SoundSpeedMatrix= SoundSpeeds$c

 # save WorldSoundSpeedData matrix
 ReadMe= "World sound speed data calculated from the gridded Naval Oceanographic Office GENERALIZED
DIGITAL ENVIRONMENTAL MODEL-VARIABLE RESOLUTION (GDEM-V) Version 3.0.1, using the Mackenzie
approximation in the wasp function in seewave. Matrix has dimensions of longitude (at 0.25deg), latitude (at
0.25deg) & depth (at 78 values)."

save(SoundSpeedMatrix,LongValues,LatValues,DepthValues,ReadMe,file=paste("WorldSoundSpeedData_",aMont
h,".RData",sep=""))

 cat(" done with month ",aMonth,'\n')
}
```

APPENDIX 2

R script file ("GetNearestOceanSoundSpeedProfileForLocation&Month.r") which provides an example of reading from the Rdata sound speed structure and extracting a profile of sounds speed vs. depth for the nearest grid point to a given location.

```
# Load world sound speed data from saved data files and plot & save sound speed profile
#   for specific month and nearest locations gridded at 0.25-degree scale
# Sound speed depths are saved for the actual depths in Oceanographic data files and as
#   smoothed values at 1-m depth intervals
# Written by Jay Barlow, last modified 8/21/2018
library("gam")    #needed to produce smoothed sound speed profile at 1-m scale

# Example location and month
Lat= 33.25; Long= -118.5; iMonth= 7; aName="_ExampleLocation"

setwd("S:\\SoundSpeedWorldwideData\\WorldSoundSpeedData by Month")
aMonth= month.abb[iMonth]    #abbreviated month names for naming output files
load(paste("WorldSoundSpeedData_",aMonth,".RData",sep=""))

# plot sound speed profiles (south and west are negative lat/long)
iLat= which.min(abs(LatValues-Lat))
iLong= which.min(abs(LongValues-Long))
SoundSpeedMatrix[iLong,iLat,1:78]
imaxDepth= which(is.na(SoundSpeedMatrix[iLong,iLat,1:78]))
imaxDepth= imaxDepth[1]-1
SoundSpeed= SoundSpeedMatrix[iLong,iLat,1:imaxDepth]
Depths= DepthValues[1:imaxDepth]
maxDepth= max(Depths)
plot(SoundSpeed,-Depths,xlab="Sound Speed (m/s)",ylab="Depth",main=(paste("Sound Speed Profile
for",aMonth,"Lat=",LatValues[iLat],"Long=",LongValues[iLong],sep=" ")))

# smooth and plot the sound speed profile for given location
gamout= gam(SoundSpeed~s(Depths,30))
newdata= data.frame(Depths=0:maxDepth)
predicted= as.numeric(predict(gamout,newdata=newdata))
par(cex=1.3)
plot(SoundSpeed,-Depths,pch=19,xlab="Sound Speed (m/s)",ylab="Depth",main=(paste("Sound Speed Profile
for",aMonth,"Lat=",LatValues[iLat],"Long=",LongValues[iLong],sep=" ")))
lines(predicted,-(0:maxDepth), col="red", lwd= 2)

setwd("S:\\SoundSpeedWorldwideData\\OutputProfileFiles")
SoundSpeedByDepth= data.frame(Depth=Depths,SoundSpeed=SoundSpeed)
write.csv(SoundSpeedByDepth,file=paste("SoundSpeedByDepth",aName,".csv",sep=""),row.names=FALSE)
SmoothedSoundSpeedByDepth= data.frame(Depth=0:maxDepth,SoundSpeed=predicted)
write.csv(SmoothedSoundSpeedByDepth,file=paste("SmoothedSoundSpeedByDepth",aName,".csv",sep=""),row.n
ames=FALSE)

cat("Nearest Gridded Location=",LatValues[iLat],LongValues[iLong])
```