Gael Forget
MIT, Jan. 15th 2015

Independent Activities Period

Introduction to ocean data-model analysis

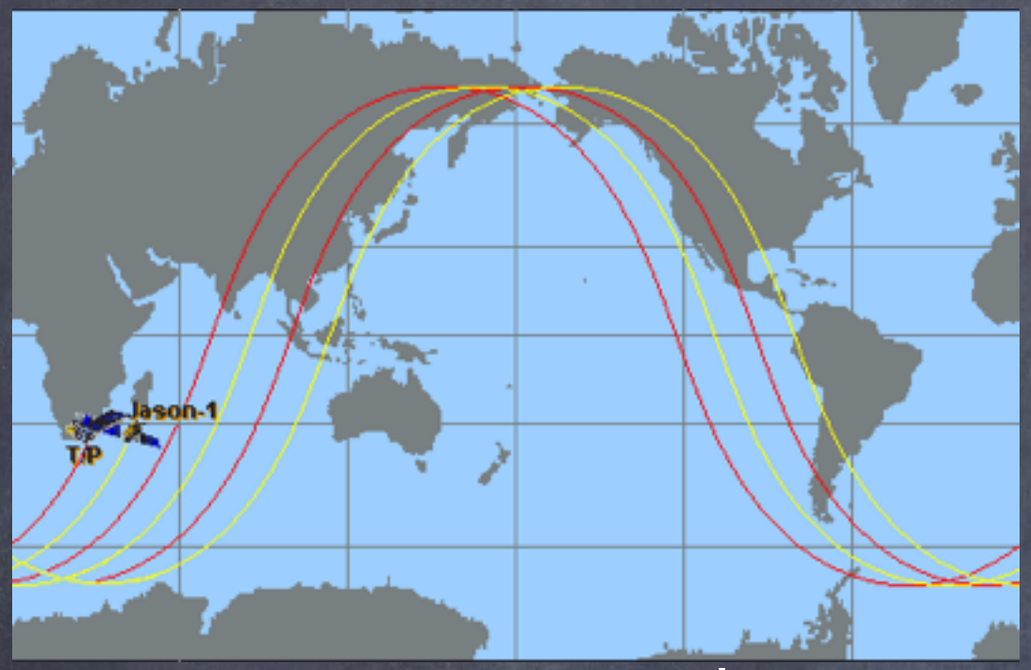
course 1 : observations

1. collected data (sampl., calib., low-lev. proc.)
2. formatted data (profiles, section, T-S, etc)
3. data statistics (var. map, vol. census, etc)

4. interactive session : Argo
5. resources, bibliography

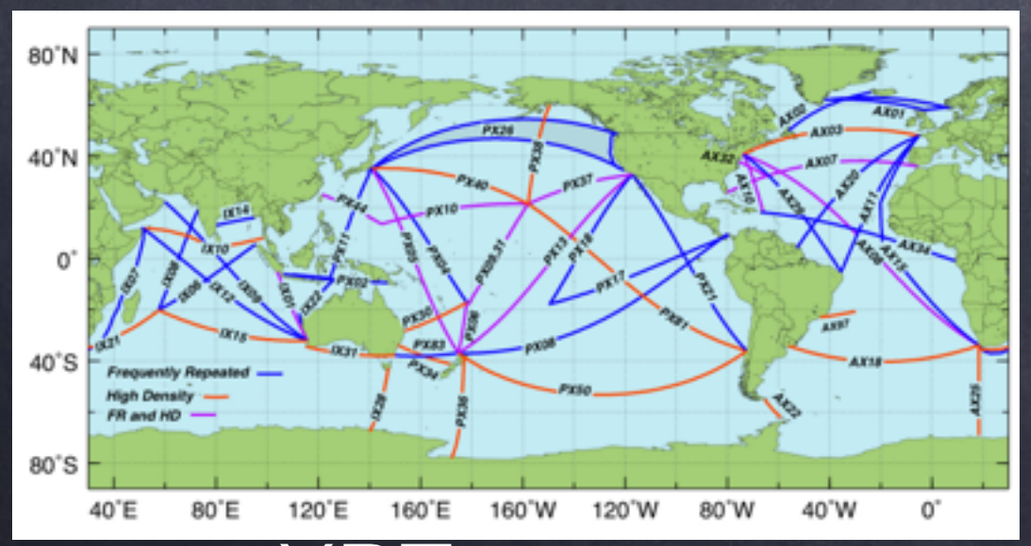
… course 2 : interpolated and model data

(1) collected data



remote sensing

WOCE repeat



XBT repeat

Argo

(1) collected data

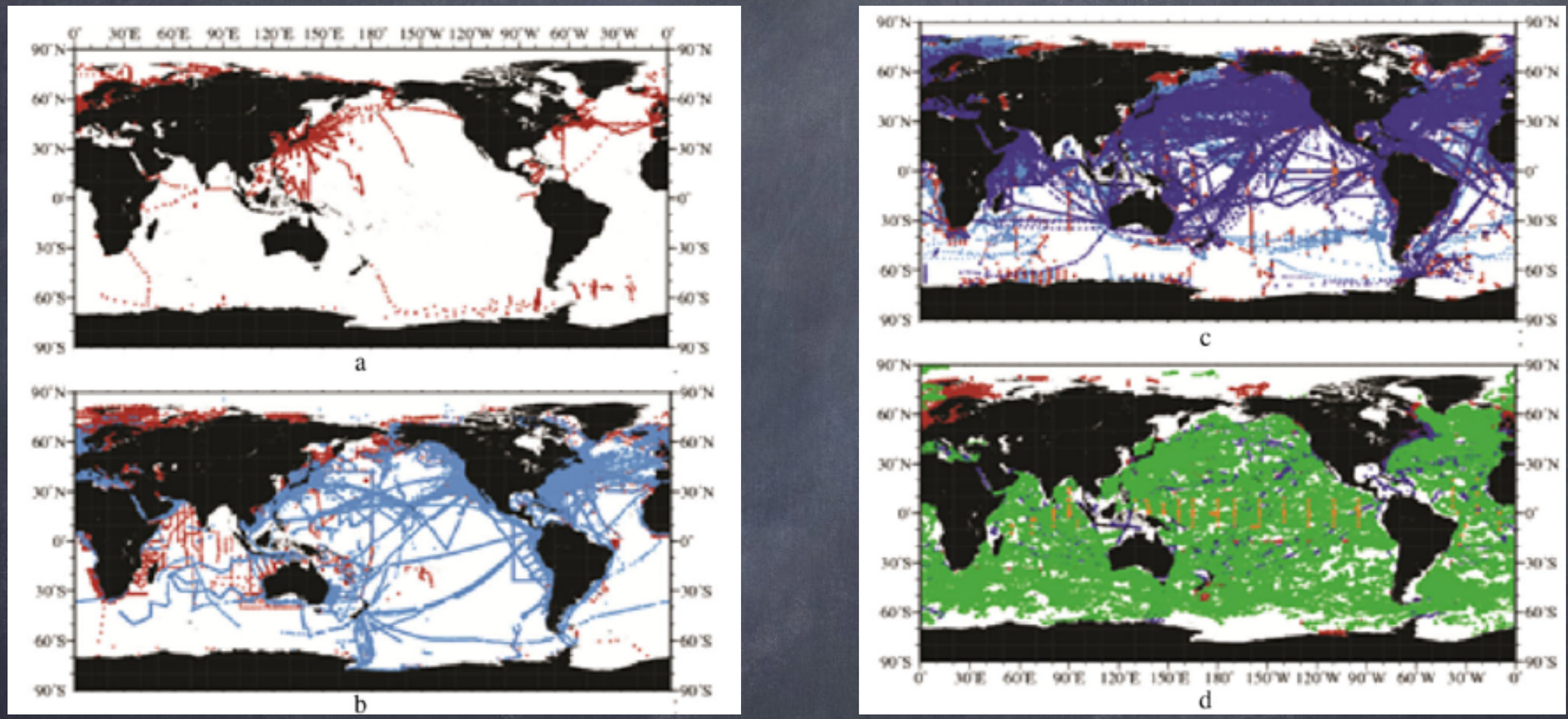
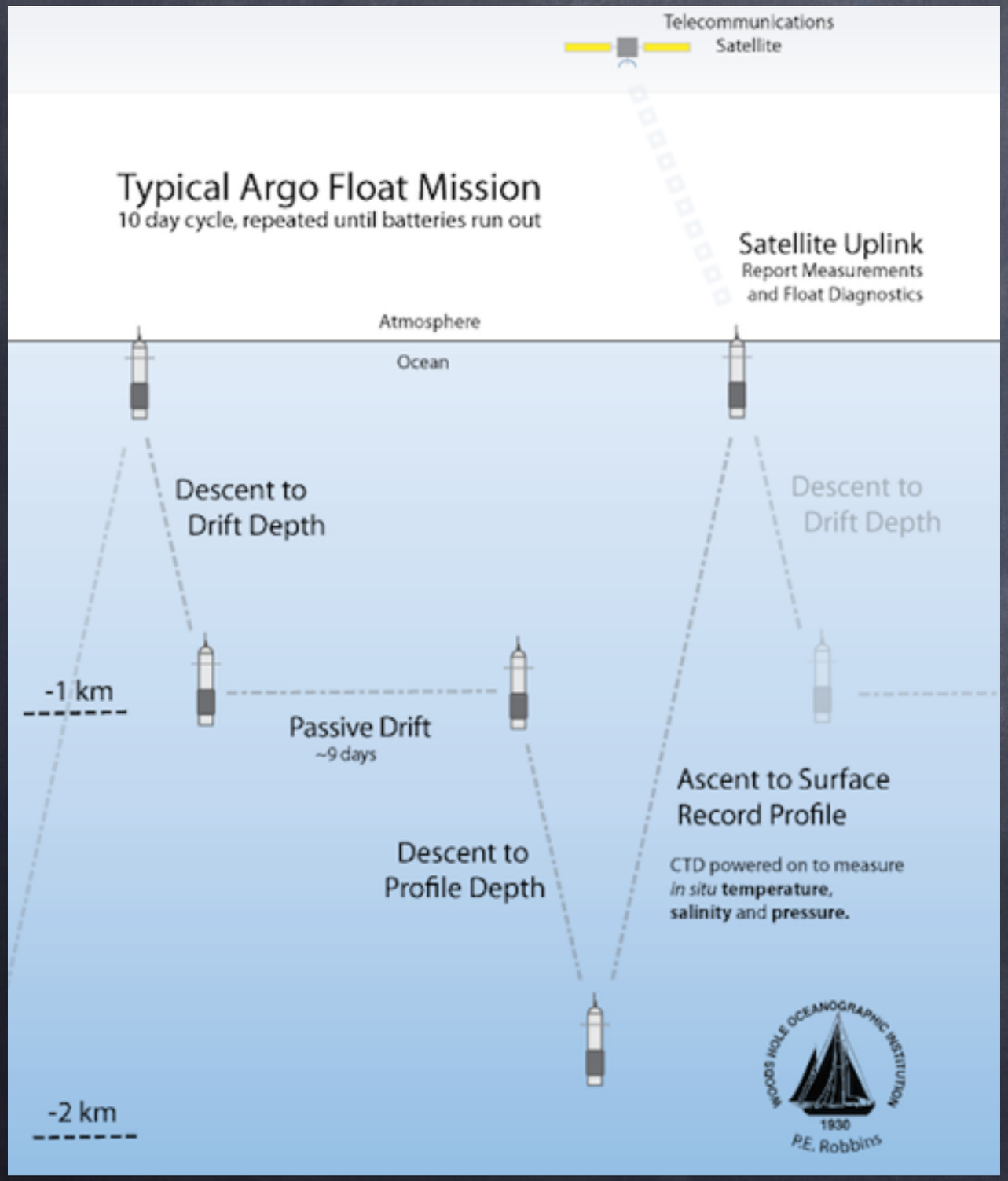
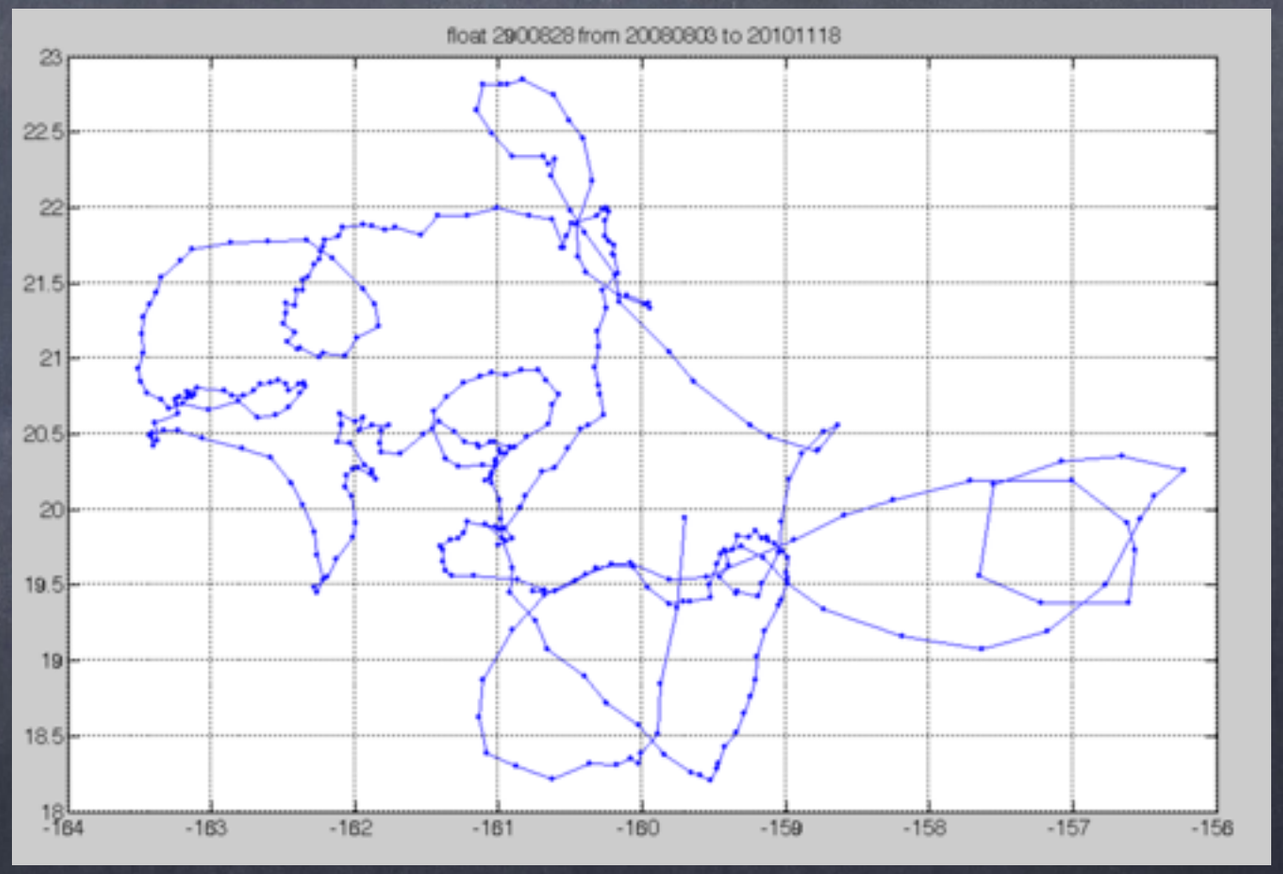


Figure 1. Geographic distribution of subsurface temperature profiles for (a) 1934, (b) 1960, (c) 1985, and (d) 2009. Red = Nansen bottle or conductivity-temperature-depth (CTD), light blue = mechanical bathythermograph (MBT), dark blue = expendable bathythermograph (XBT), orange = tropical moored buoy, green = profiling float.

Focused research on Argo decade

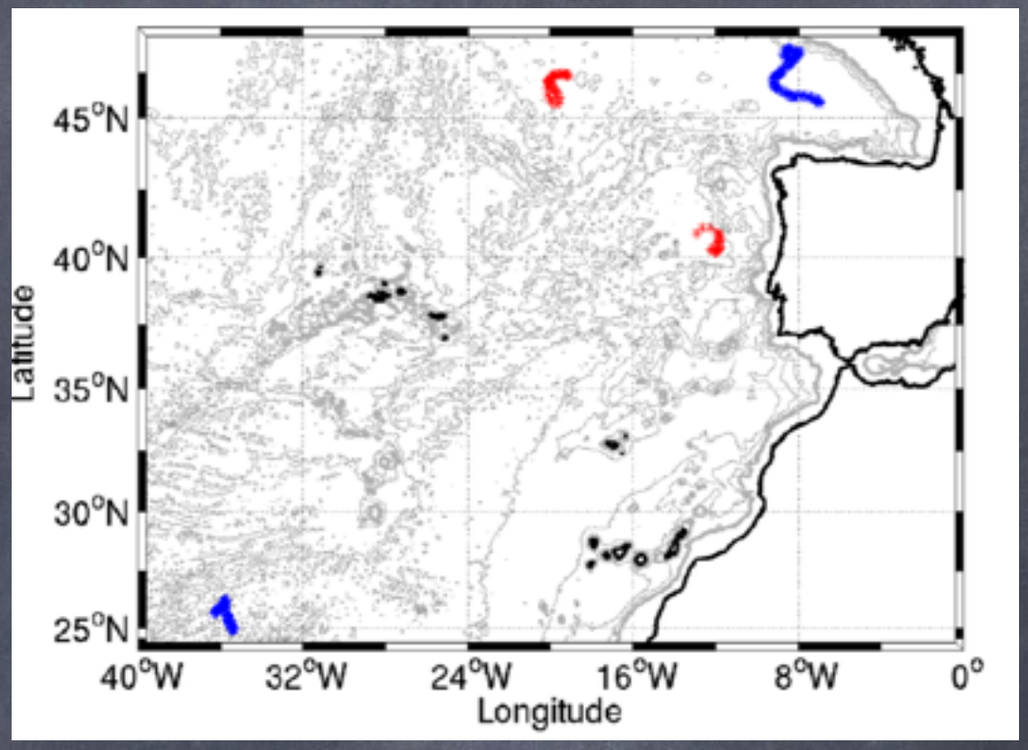
(1) collected data

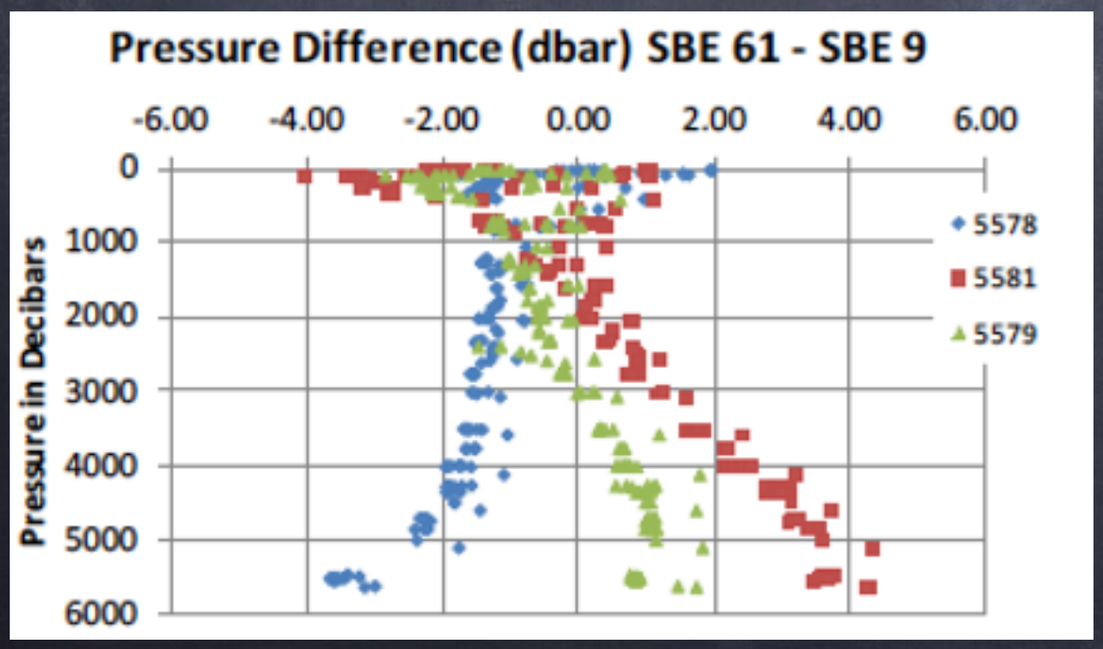


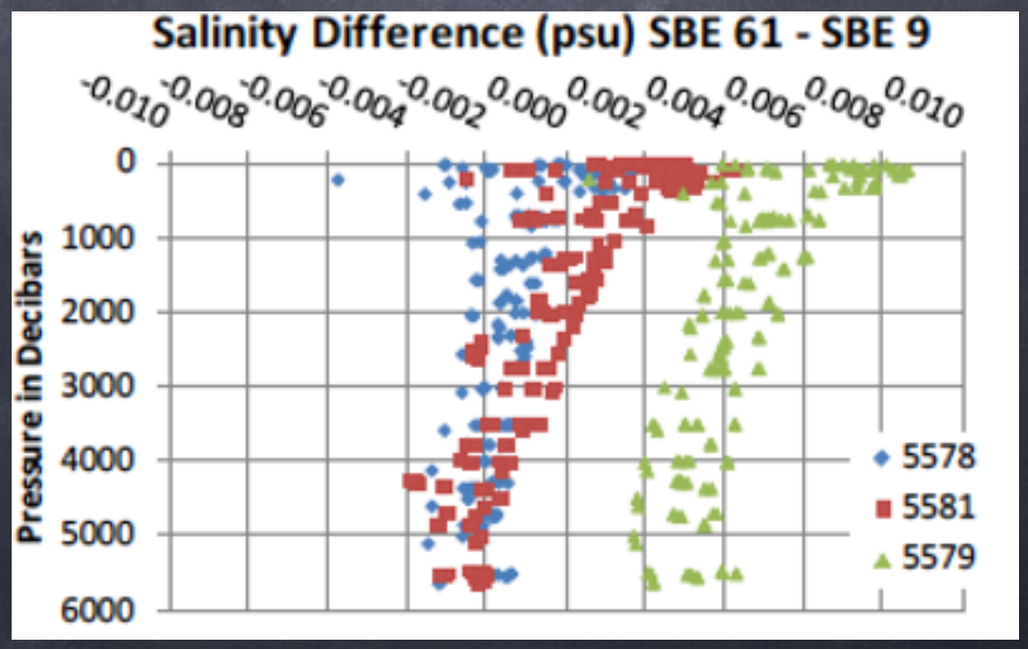


… interactive session

(1) collected data







(2) formatted data

```
Cruise  Station Type    yyyy-mm-ddThh:mm:ss.sss Longitude [degrees_east]        Latitude [degrees_north]        Depth [m]
ture [°C]       QV:WOD  Salinity [psu]  QV:WOD  QV:ODV:SAMPLE
WOD09_AU002711  7483082 8       1985-10-08T01:21        60.0238 -59.319 0.0     0                       1
                                                10.0    0       -0.948  0       33.9270 0       1
                                                20.0    0       -0.947  0       33.9260 0       1
                                                30.0    0       -0.955  0       33.9270 0       1
                                                50.0    0       -1.064  0       33.9490 0       1
                                                75.0    0       -1.044  0       33.9510 0       1
                                                100.0   0       -1.036  0       33.9500 0       1
                                                125.0   0       -1.030  0       33.9510 0       1
                                                150.0   0       -0.966  0       33.9710 0       1
                                                200.0   0       1.464   0       34.4320 0       1
                                                250.0   0       1.761   0       34.4510 0       1
                                                300.0   0       1.871   0       34.5120 0       1
                                                400.0   0       2.024   0       34.6110 0       1
WOD09_AU002711  7483083 8       1985-10-08T07:46        60.0150 -59.526 0.0     0       -1.813  0       33.9400 0       1
                                                10.0    0       -1.823  0       33.9450 0       1
                                                20.0    0       -1.822  0       33.9450 0       1
                                                30.0    0       -1.822  0       33.9490 0       1
                                                50.0    0       -1.818  0       33.9490 0       1
                                                75.0    0       -1.814  0       33.9500 0       1
                                                100.0   0       -1.809  0       33.9510 0       1
                                                125.0   0       -1.806  0       33.9520 0       1
                                                150.0   0       -1.360  0       34.0610 0       1
                                                200.0   0       1.285   0       34.4370 0       1
                                                250.0   0       1.592   0       34.5200 0       1
                                                300.0   0       1.771   0       34.5760 0       1
                                                400.0   0       1.874   0       34.6420 0       1
```

```
#------------------------------------------------------------------------------,
CAST                          ,,        7674844,WOD Unique Cast Number,WOD code,
NODC Cruise ID                ,,29-1103         ,,,
Originators Station ID        ,,              80,,,integer,
Originators Cruise ID         ,,07290           ,,,
Latitude                      ,,          40.940,decimal degrees,,
Longitude                     ,,          2.6467,decimal degrees,,
Year                          ,,            1990,,,
Month                         ,,               2,,,
Day                           ,,              10,,,
Time                          ,,            8.45,decimal hours (UT),,
METADATA,
Country                       ,,              29,NODC code,SPAIN
Accession Number              ,,       9900172.,NODC code,,
Platform                      ,,          1324.,OCL code,GARCIA DEL CID (R/V; TA-2-166
Bottom depth                  ,,          1720.,meters,,
probe_type                    ,,             4.,OCL_code,CTD,
Database origin               ,,             5.,WOD code,MEDAR/MEDATLAS,
Instrument       ,Temperature,               4.,WOD code,CTD: TYPE UNKNOWN,
Instrument          ,Salinity,               4.,WOD code,CTD: TYPE UNKNOWN,
VARIABLES ,Depth     ,F,O,Temperatur,F,O,Salinity  ,F,O,,
UNITS     ,m         , , ,degrees C , , ,PSS       , , ,,
Prof-Flag ,           ,0, ,          ,0, ,          ,0, ,,
        1,       3.0,0, ,    13.465,0, ,    38.126,0, ,
        2,       4.0,0, ,    13.463,0, ,    38.125,0, ,
        3,       5.0,0, ,    13.466,0, ,    38.125,0, ,
        4,       6.0,0, ,    13.466,0, ,    38.125,0, ,
```

```
netcdf \20060101_prof {
dimensions:
        DATE_TIME = 14 ;
        STRING256 = 256 ;
        STRING64 = 64 ;
        STRING32 = 32 ;
        STRING16 = 16 ;
        STRING8 = 8 ;
        STRING4 = 4 ;
        STRING2 = 2 ;
        N_PROF = 29 ;
        N_PARAM = 3 ;
        N_LEVELS = 115 ;
        N_CALIB = 3 ;
        N_HISTORY = UNLIMITED ; // (0 currently)
variables:
        char DATA_TYPE(STRING16) ;
                DATA_TYPE:comment = "Data type" ;
                DATA_TYPE:_FillValue = " " ;
        char FORMAT_VERSION(STRING4) ;
                FORMAT_VERSION:comment = "File format version" ;
                FORMAT_VERSION:_FillValue = " " ;
        char HANDBOOK_VERSION(STRING4) ;
                HANDBOOK_VERSION:comment = "Data handbook version" ;
                HANDBOOK_VERSION:_FillValue = " " ;
        char REFERENCE_DATE_TIME(DATE_TIME) ;
                REFERENCE_DATE_TIME:comment = "Date of reference for Julian days" ;
                REFERENCE_DATE_TIME:conventions = "YYYYMMDDHHMISS" ;
                REFERENCE_DATE_TIME:_FillValue = " " ;
        char DATE_CREATION(DATE_TIME) ;
                DATE_CREATION:comment = "Date of file creation" ;
                DATE_CREATION:conventions = "YYYYMMDDHHMISS" ;
                DATE_CREATION:_FillValue = " " ;
        char DATE_UPDATE(DATE_TIME) ;
                DATE_UPDATE:long_name = "Date of update of this file" ;
                DATE_UPDATE:conventions = "YYYYMMDDHHMISS" ;
                DATE_UPDATE:_FillValue = " " ;
        char PLATFORM_NUMBER(N_PROF, STRING8) ;
```

… interactive session

(2) formatted data

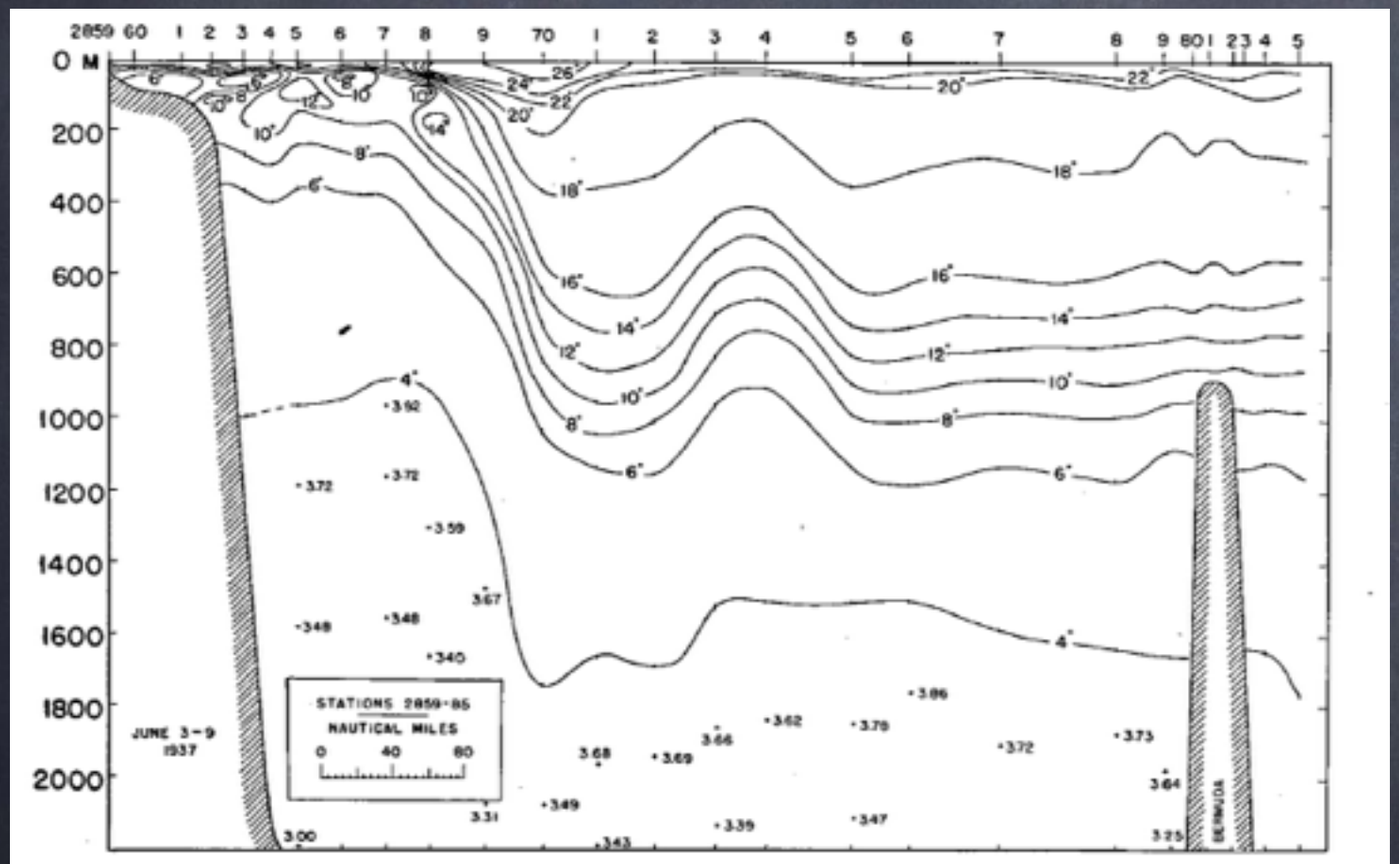


FIG. 2. Temperature section, Montauk Point to Bermuda, June 3–9, 1937.

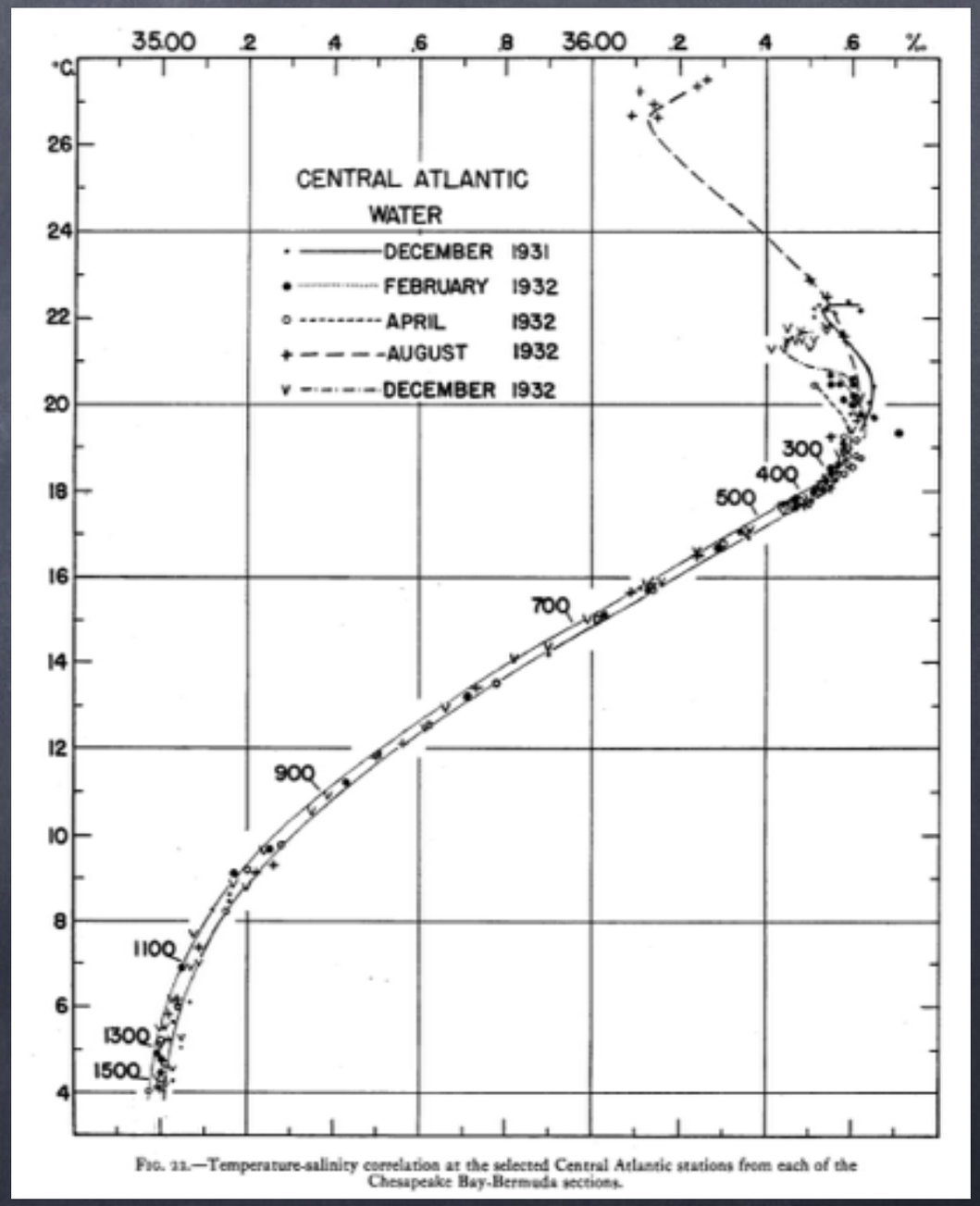
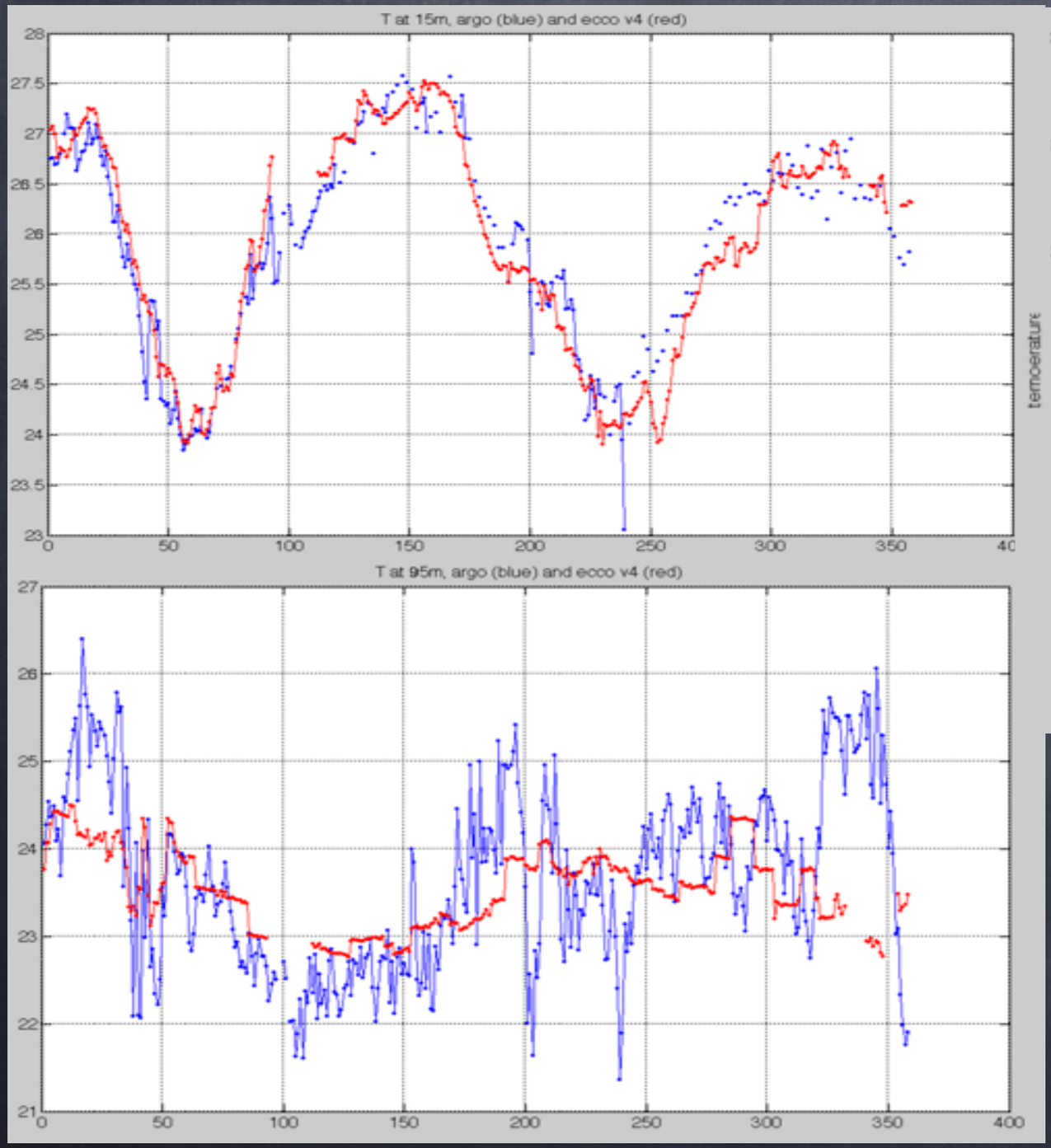
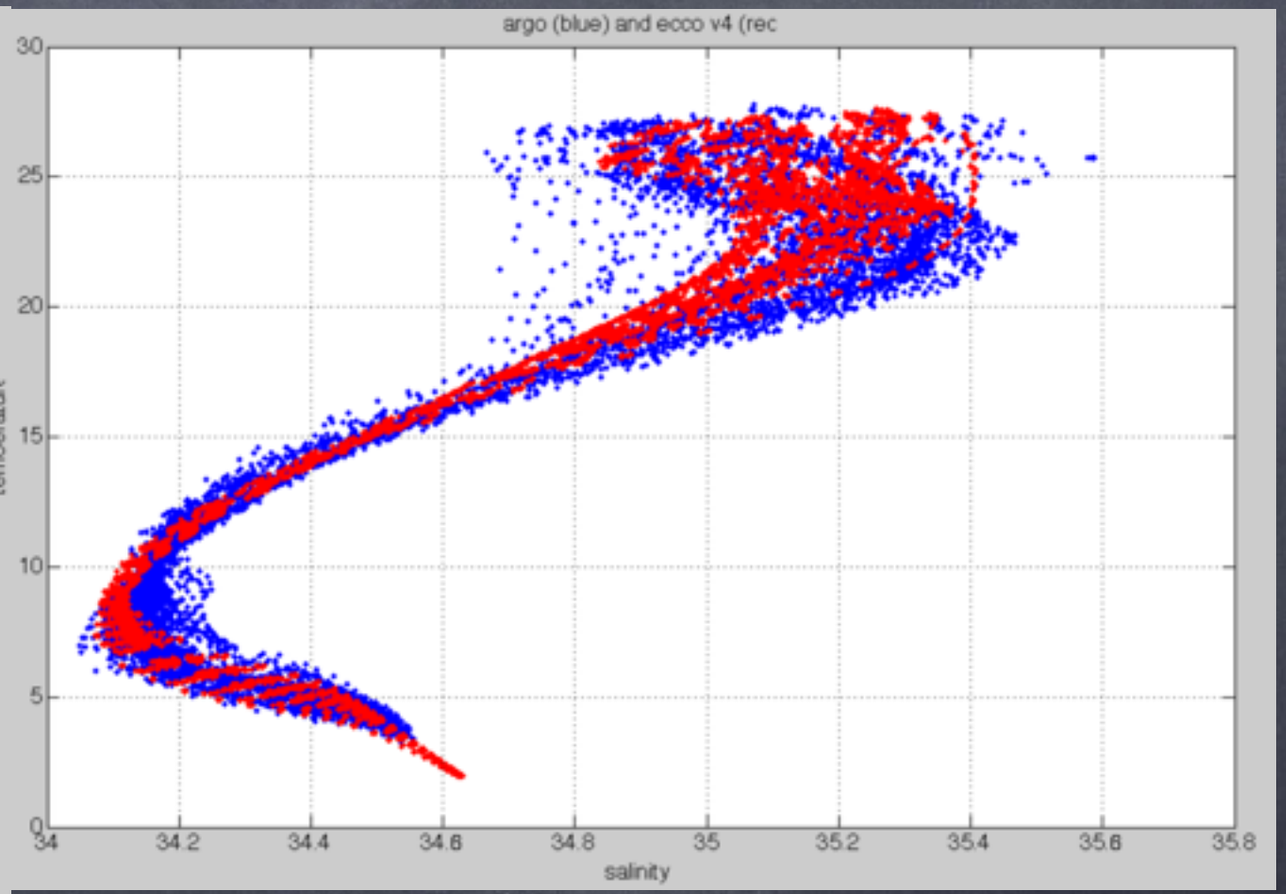


FIG. 22.—Temperature-salinity correlation at the selected Central Atlantic stations from each of the Chesapeake Bay-Bermuda sections.

(2) formatted data





… interactive session

(3) data statistics

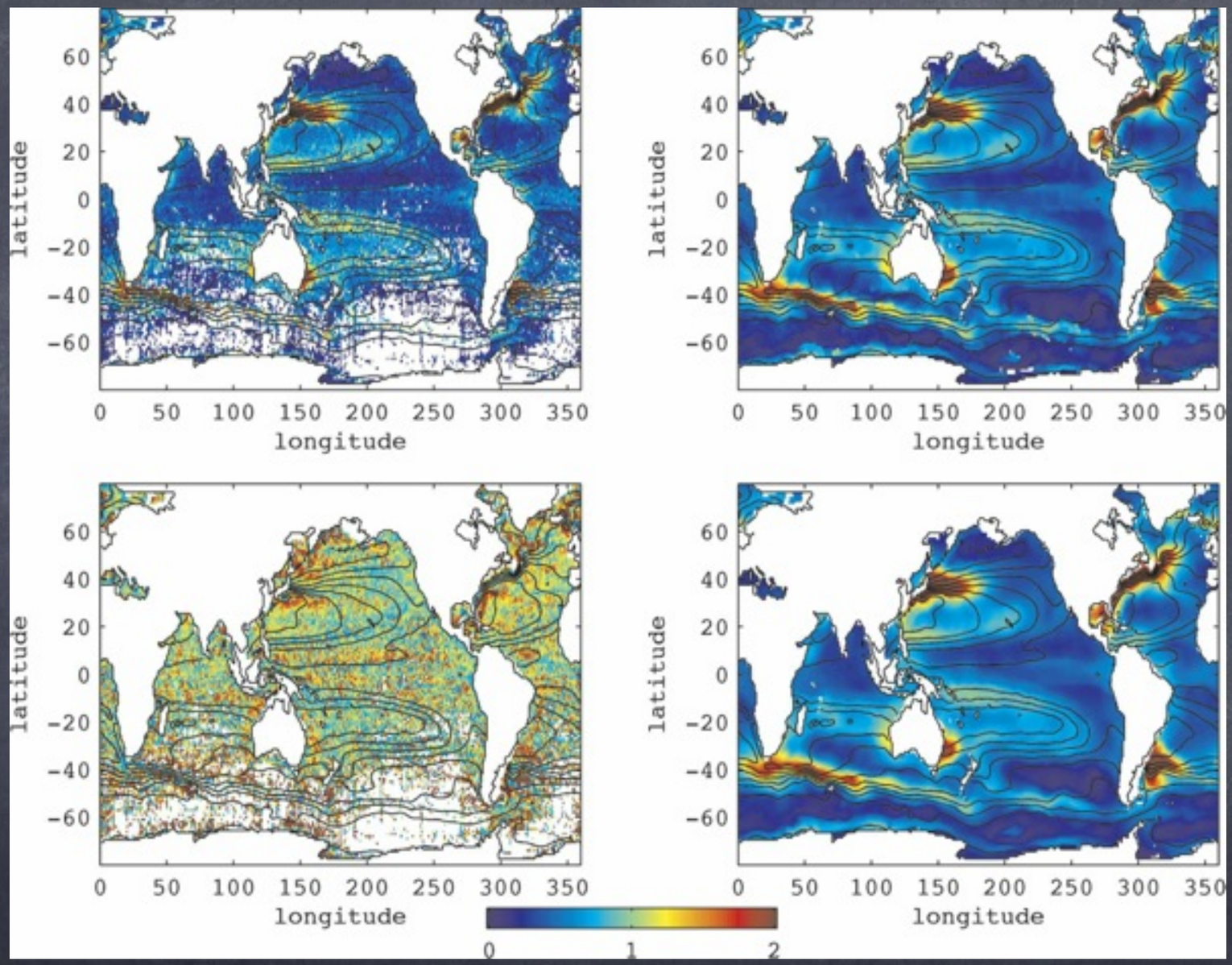


FIG. 3. Illustration of the methodology (see text) for T at 300 m: (top left) pointwise, (top right) mapped, and (bottom right) estimated standard deviations of T (°C); and (bottom left) the ratio of the mapped to the pointwise standard deviations. Superimposed contours: annual mean climatological T ($\overline{T}$) from Stephens et al. (2002) with an interval of 2°C.

(3) data statistics

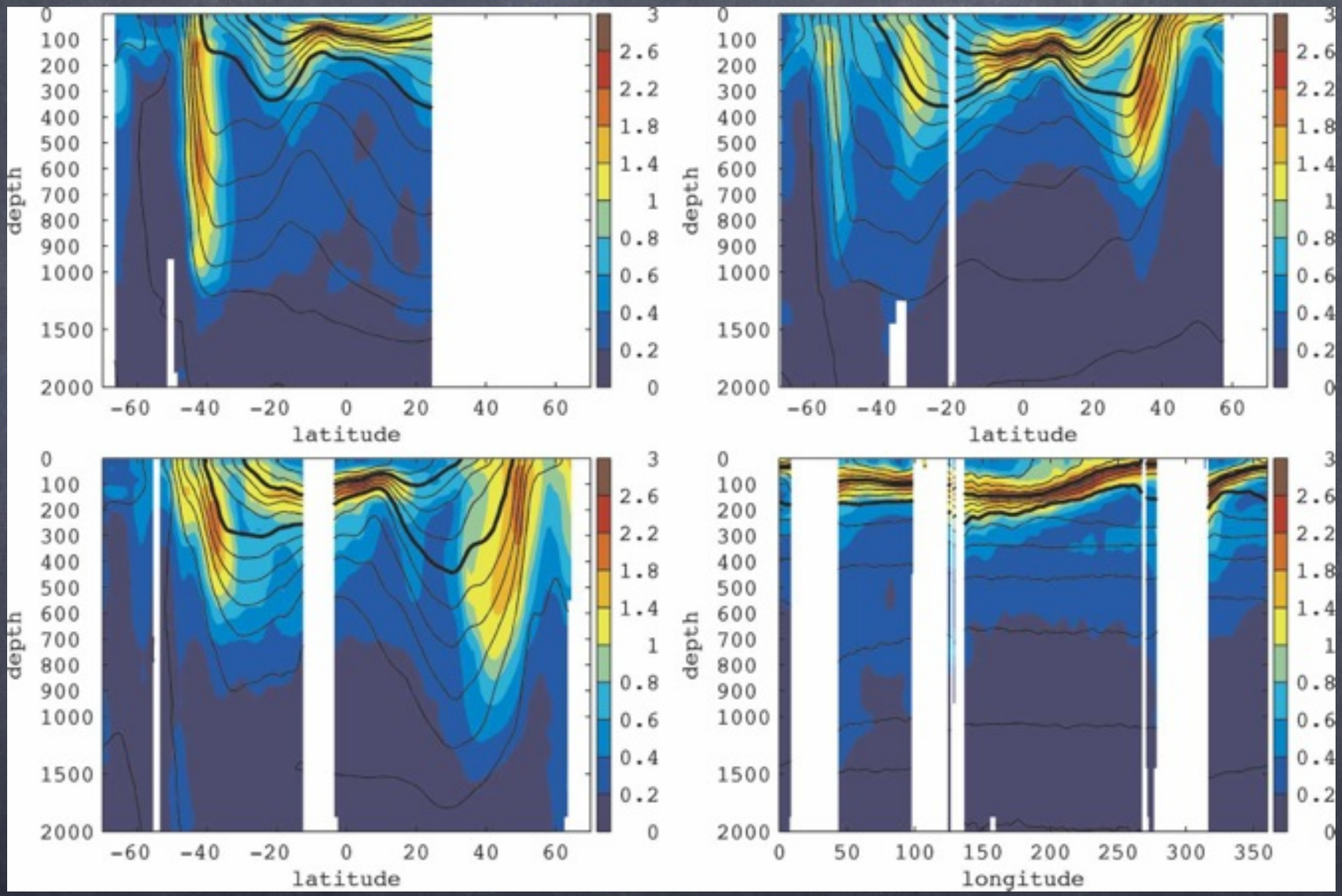
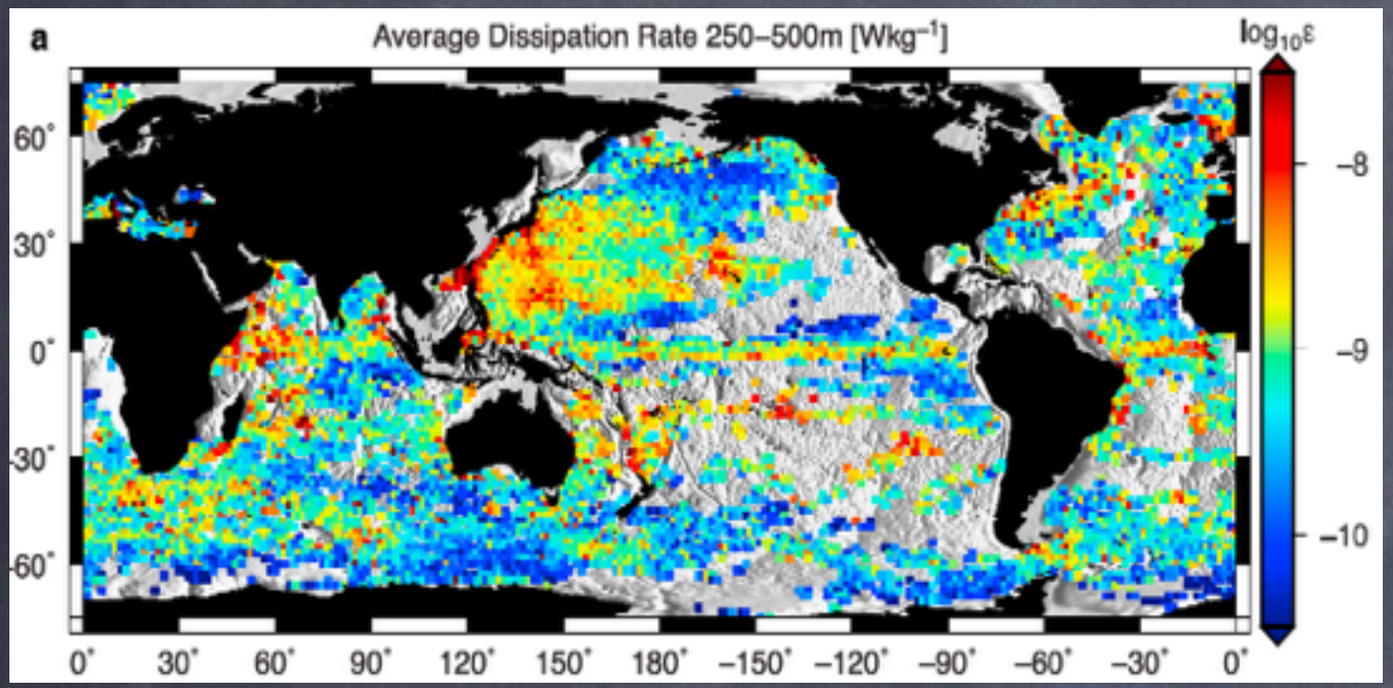
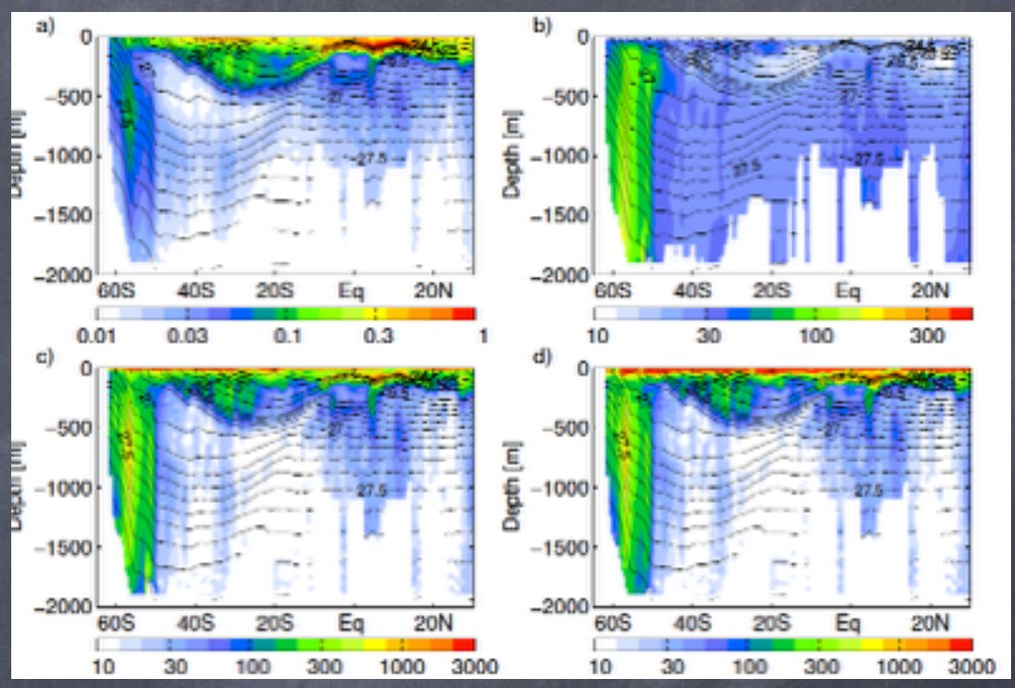
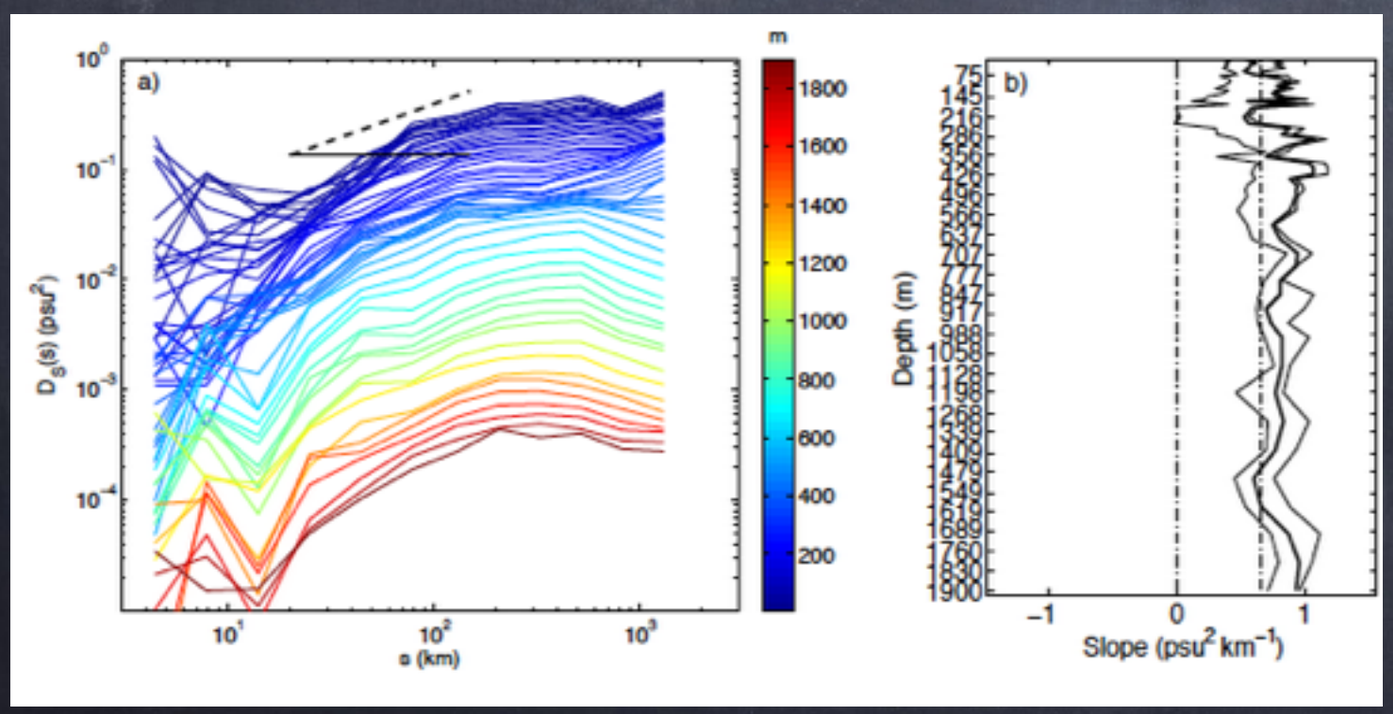


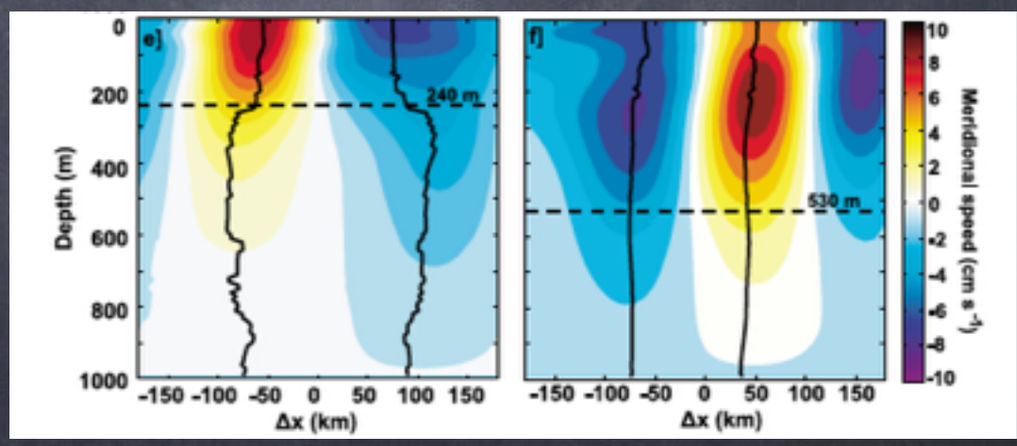
FIG. 5. Estimated standard deviation of T ($\tilde{\sigma}_T$; °C; colors) in (top left) the Indian Ocean at 64.5°E, (top right) the Pacific Ocean at 164.5°E, (bottom left) the Atlantic Ocean at 322.5°E, and (bottom right) along the equator at 0.5°S. Superimposed contours: $\overline{T}$, with an interval of 2°C. Thick contours denote the $\overline{T}$ = 14°C and $\overline{T}$ = 22°C isotherms.

(3) data statistics





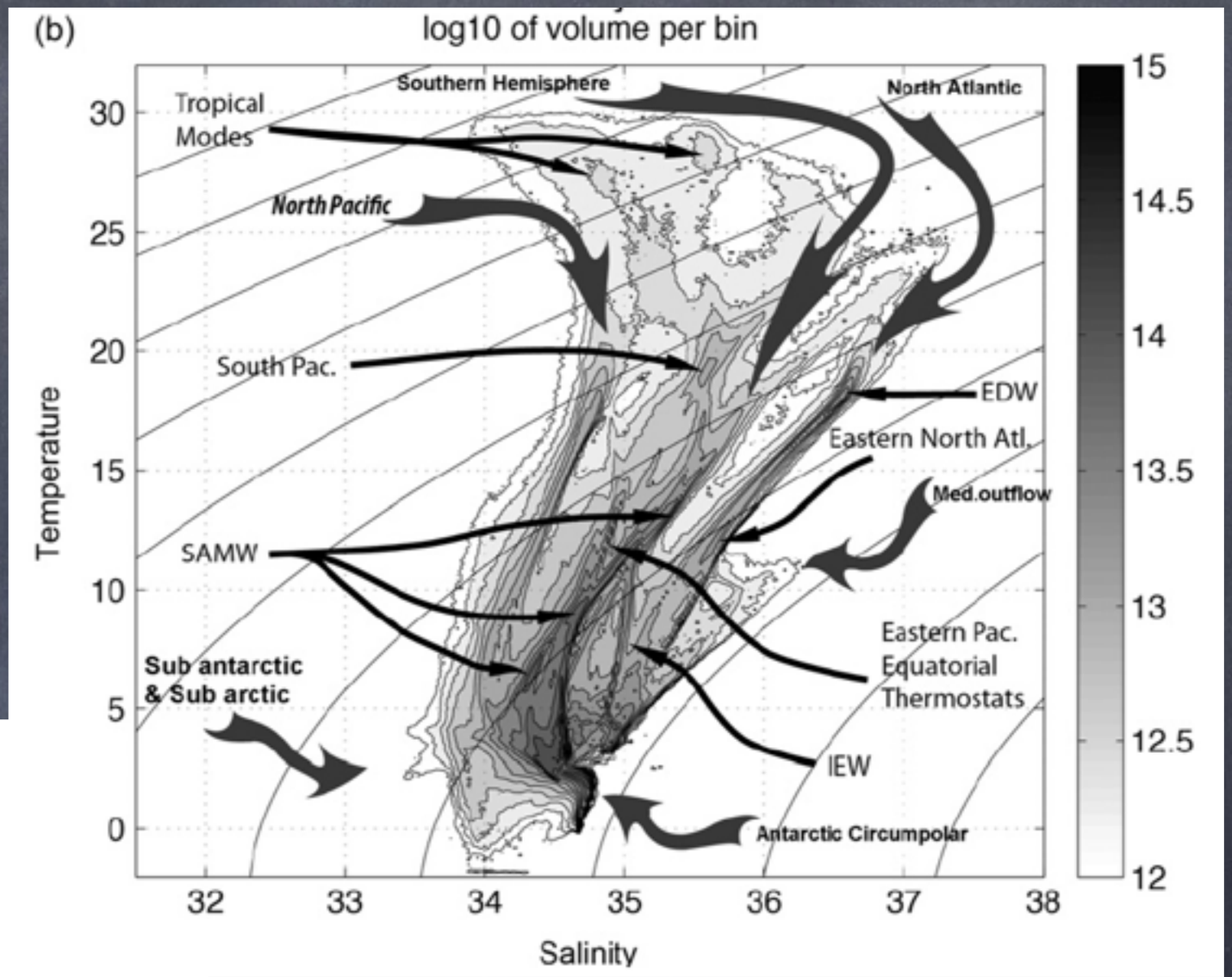




an expanding field of research

(3) data statistics

Volumetric census



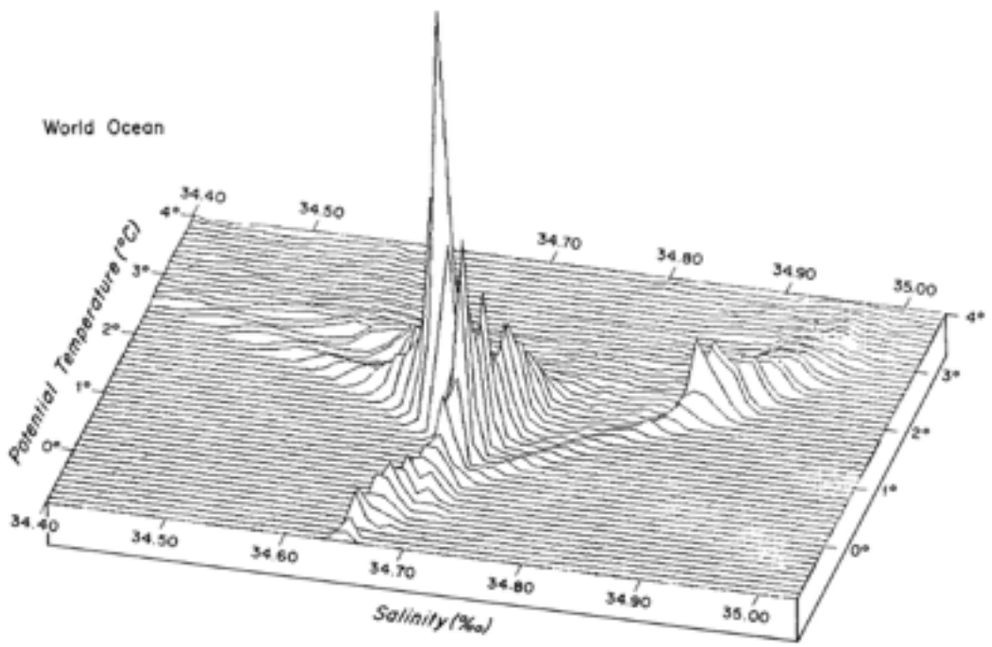
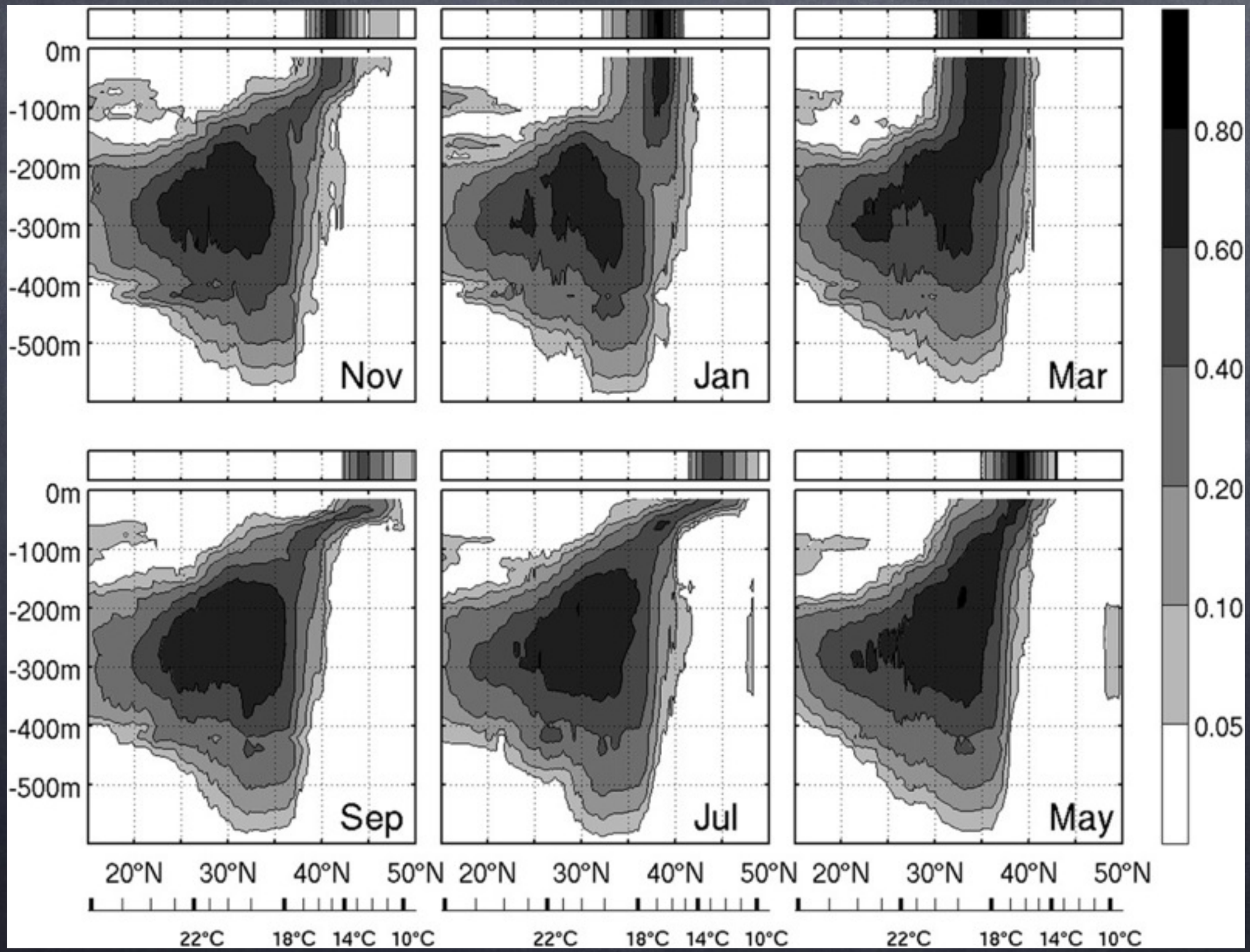


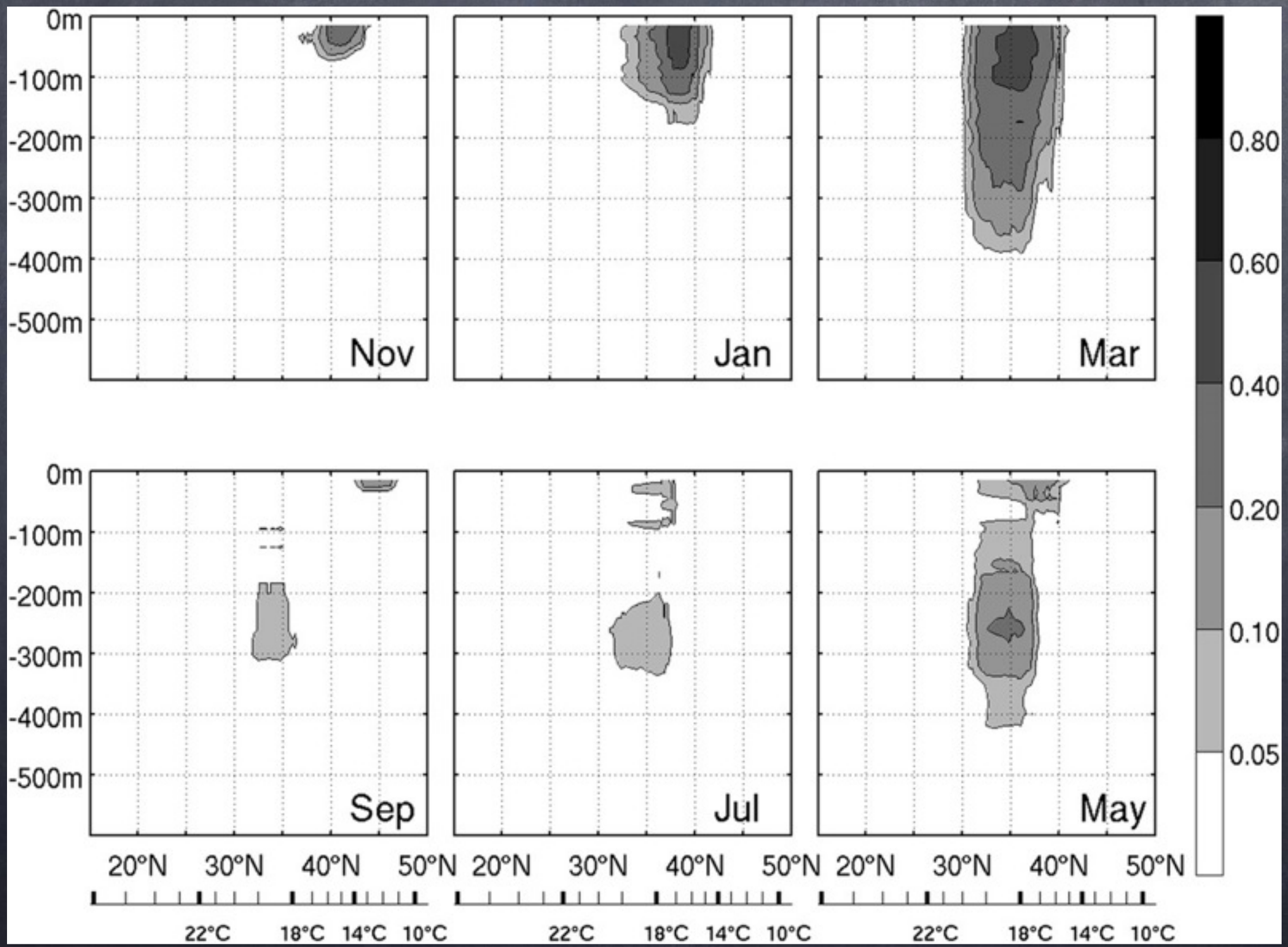
Figure 2.2 Simulated three-dimensional T-S diagram of the water masses of the world ocean. Apparent elevation is proportional to volume. Elevation of highest peak corresponds to 26.0×10^6 km^3 per bivariate class 0.1°C × 0.01‰.

water mass analysis

(3) data statistics



(3) data statistics



(4) interactive session : Argo

Data Set	T profiles	S profiles	origin
Argo profiles	833033	800269	IFREMER
WOA09 CTD	379012	333266	NODC
WOA09 XBT	597009	0	NODC
ITP	18033	17745	Toole et al. [2011]
SEaOS	103117	87806	Roquet et al. [2011]
CLIMODE bobbers	7894	0	D. Fratantoni
CLIMODE CTD	161	161	L. Talley

Available standardized data sets

(4) interactive session : Argo

Table 13: Netcdf file header illustrating the MITprof format used in MITgcm/pkg/profiles.

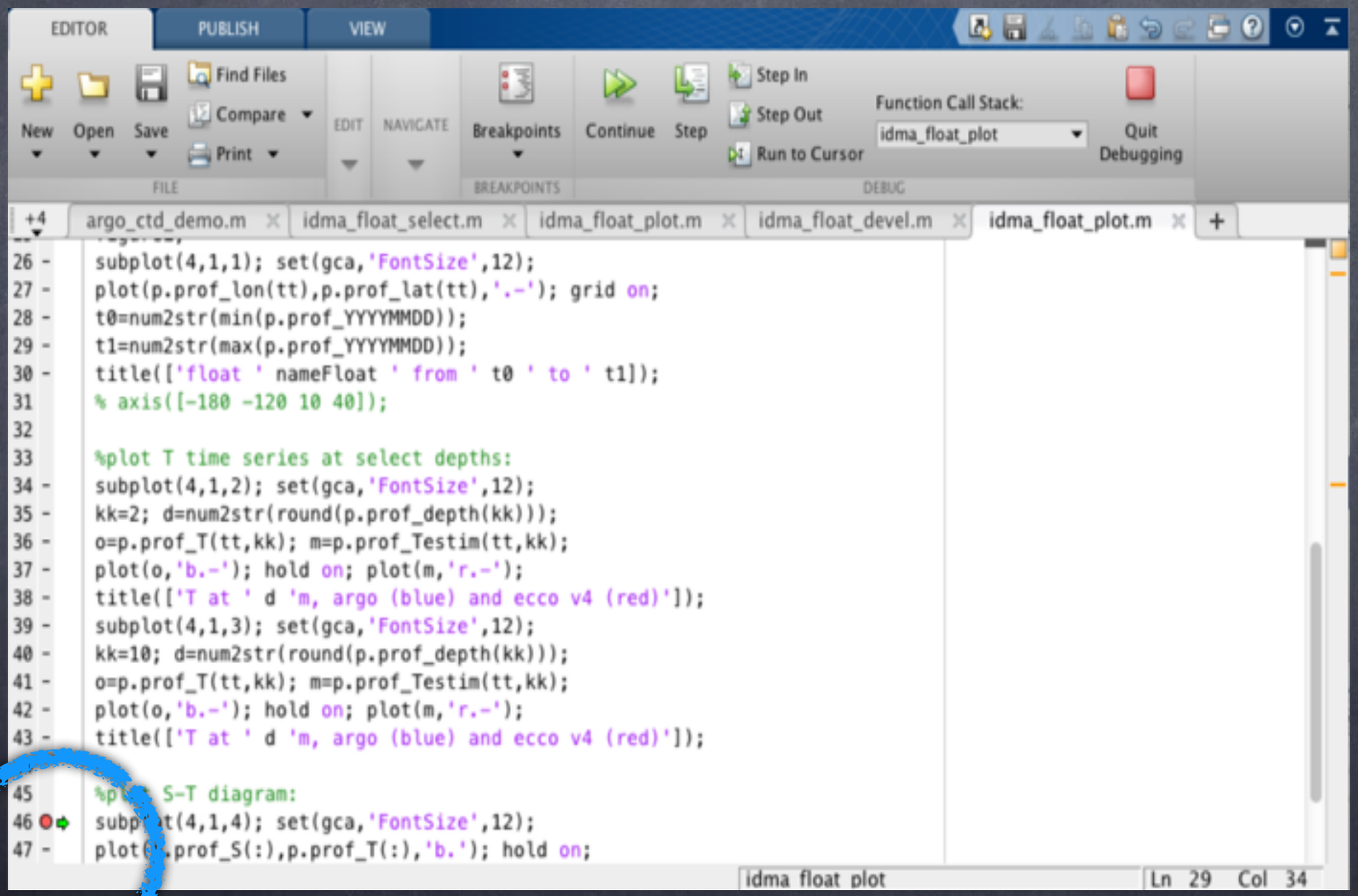
```
netcdf argo_feb2013_2008_to_2010 {

...
        double prof_T(iPROF, iDEPTH) ;
                prof_T:long_name = "potential temperature" ;
                prof_T:units = "degree C" ;
        double prof_Tweight(iPROF, iDEPTH) ;
                prof_Tweight:long_name = "least-square weight" ;
                prof_Tweight:units = "(degree C)^-2" ;
        double prof_Testim(iPROF, iDEPTH) ;
                prof_Testim:long_name = "pot. temp. estimate" ;
                prof_Testim:units = "degree C" ;
...
        double prof_depth(iDEPTH) ;
        double prof_YYYYMMDD(iPROF) ;
        double prof_HHMMSS(iPROF) ;
        double prof_lon(iPROF) ;
        double prof_lat(iPROF) ;
        char prof_descr(iPROF, lTXT) ;
                prof_descr:long_name = "profile description" ;
...
}
```

MITprof format: unified, simplified, but also augmented

… MITgcm/pkg/profiles

(4) interactive session : Argo



matlab?

(5) resources, bibliography

- from http://mitgcm.org/ follow links ('Source code', 'CVS code browser', 'Parent Directory', 'MITgcm_contrib/', 'gael/') to:
- 'http://mitgcm.org/viewvc/MITgcm/MITgcm_contrib/gael/'
- there is the class material: comm/course-idma2015/, setup_gcmfaces_and_mitprof.csh, and verification/setup_these_exps.csh

- Argo : http://www.argodatamgt.org/, http://argoweb.whoi.edu
- google 'argo float 2900828' to find: http://argoweb.whoi.edu/argo_database_web/index.html?wmo=2900828

(5) resources, bibliography

- Iselin, 1936, A study of the circulation of the western North Atlantic
- Iselin, 1940, Preliminary report on long-period variations in the transport of the Gulf Stream system
- Abraham et al, 2013, A review of global ocean temperature observations: Implications for ocean heat content estimates and climate change
- Forget and Wunsch, 2007, Estimated Global Hydrographic Variability
- Chaigneau et al, 2011, Vertical structure of mesoscale eddies in the eastern South Pacific Ocean: A composite analysis from altimetry and Argo profiling floats
- Whalen et al, 2012, Spatial and temporal variability of global ocean mixing inferred from Argo profiles
- Roullet et al, 2014, Global Interior Eddy Available Potential Energy Diagnosed from Argo Floats
- McCaffrey et al, revised, Estimates of Ocean Macro-turbulence: Structure Function and Spectral Slope from Argo Profiling Floats
- Worthington, 1981, The Water Masses of the World Ocean: Some Results of a Fine-Scale Census
- Forget et al, 2011, Estimated seasonal cycle of North Atlantic eighteen degree water volume
- Speer and Forget, 2013, Global Distribution and Formation of Mode Waters
- Forget et al, to be subm., ECCO version 4: an integrated framework for non-linear inverse modeling and global ocean state estimation