NOAA Atlas NESDIS 14

SEASONAL VARIABILITY OF MIXED LAYER DEPTH FOR THE WORLD OCEAN

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U.S. DEPARTMENT OF COMMERCE
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Grigory Monterey and Sydney Levitus
National Oceanographic Data Center
Ocean Climate Laboratory
Silver Spring, Maryland 20910

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NOAA/NESDIS E/OC1
SSMC3, 4th Floor
1315 East-West Highway
Silver Spring, MD 20910-3282

Telephone: (301) 713-3277

Fax: (301) 713-3302

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Acknowledgments

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The data sets and products represented by this atlas are distributed internationally without restriction in accordance with ICSU/IOC data management policies and U.S. Climate and Global Change policy in support of Global Change Research.

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SEASONAL VARIABILITY
OF THE GLOBAL OCEAN MIXED LAYER DEPTH

Grigory Monterey and Sydney Levitus
Ocean Climate Laboratory
National Oceanographic Data Center / NOAA

Silver Spring, Maryland

ABSTRACT

This atlas presents climatological monthly mean maps of mixed layer depth (MLD) for the World Ocean as well as their deviations from the climatological annual mean. The MLD is computed from climatological monthly mean profiles of potential temperature and potential density based on three different criteria: a temperature change from the ocean surface of 0.5°C, a density change from the ocean surface of 0.125 (sigma units), and a variable density change from the ocean surface corresponding to a temperature change of 0.5°C. The MLD based on the variable density criterion is designed to account for the large variability of the coefficient of thermal expansion that characterizes seawater. The difference between the MLD based on the temperature criterion 0.5°C and the MLD based on the variable density criterion accounts for the effects of salinity on the MLD. Such situations occur in many regions located in equatorial and subpolar latitudes.

1. INTRODUCTION

There is a wide range of meanings attached by different authors to the concept of the ocean surface mixed layer. The definition of the mixed layer can be based on different physical parameter (*e.g.*, temperature, density, salinity) and may represent averages over different time intervals *(e.g.*, months, days). For each parameter, the criteria for computation of the Mixed Layer Depth (MLD) commonly used in the literature fall into two categories: a gradient criteria or a difference criteria. The gradient criteria based *(e.g.*, on monthly mean vertical profiles of temperature) require that the vertical derivative of temperature in the surface layer be small compared to that in the underlying layer. These criteria imply existence of a thermocline.

The difference criteria (based, *e.g.*, on the monthly mean profiles of temperature) require that within the surface layer the deviation of temperature from its magnitude at the surface does not exceed a certain fixed or geographically adjustable value. These criteria are more universal in the sense that they are applicable in geographical regions and during time periods where/when the seasonal thermocline does not exist. As shown in a recent experimental study by Brainerd and Gregg (1995), the MLD based on the difference criteria is more stable than the MLD based on the gradient criteria.

In this atlas we present the MLD based on difference criteria applied to climatological monthly mean vertical profiles of potential temperature and potential density. The effects of salinity on the MLD are taken into account via the variable density criterion (see below). Values of the temperature and/or density difference used in the MLD criteria indicated above are chosen in such a way that the MLD coincides with the depth of the seasonal thermocline/pycnocline. Hereafter, we call the mixed layer defined in such a way, the seasonal mixed layer.

Note that within the seasonal mixed layer there is a sublayer of higher vertical uniformity which corresponds to the diurnal mixed layer. The theoretical and experimental foundations of the concepts of diurnal and seasonal mixed layers are described in detail by Brainerd and Gregg (1995) who use the terms 'mixing layer' and 'mixed layer' corresponding to our terms 'diurnal mixed layer' and 'seasonal mixed layer'. The depth of the diurnal mixed layer is determined by the length scale of turbulent overturning and may vary daily by a factor of ~10 (Brainerd and Gregg, 1995). The depth of the seasonal mixed layer is the maximum depth of the diurnal mixed layer over its daily cycle. As shown by Brainerd and Gregg (1995) based on *in situ* measurements, determination of the diurnal MLD requires measurements of turbulent overturning length scale or turbulent dissipation rate, while the seasonal MLD can be adequately determined by processing vertical profiles of temperature and/or density. In the present work we only address the seasonal MLD.

2. THE MLD CRITERIA

We consider three difference criteria for computation of the seasonal MLD:

- fixed temperature criterion,

$$\Delta t = 0.5^0 C \qquad \textbf{(1)}$$

- fixed density criterion

$$\Delta\sigma_t = 0.125 \qquad \textbf{(2)}$$

- variable density criterion

$$\Delta\sigma_t = \frac{\partial\sigma_t}{\partial t}\Big|_{s,p}(s_0, t_0, p_0)\ \Delta t \qquad \textbf{(3)}$$

in which Δt and $\Delta\sigma_t$ represent the temperature difference in ^{0}C and the density difference in sigma units (*e.g.*, $\sigma_t = 26.5$) between the ocean surface and the bottom of the mixed layer. On the right side of (3) $\Delta t = 0.5^0$C and the term $\partial\sigma_t/\partial t$ are computed at each location based on the International Equation of State of sea water (Fofonoff and Millard, 1983) where s_0, t_0, p_0 are the salinity, temperature and pressure at the ocean surface.

The MLD criteria (1), (2), (3) are applied at every point of the $1^0 \times 1^0$ grid to the vertical profiles of the climatological monthly mean potential temperature and potential density at 19 standard levels from the ocean surface to the 1000 m depth level. The 1000 m depth limit is chosen due to insufficient data coverage at deeper levels. If the corresponding MLD criterion were not met at a certain grid point, the MLD value at this grid point is set to 1000 m. Hereafter the mixed layer depths determined using the criteria (1), (2), (3) are denoted as MLD1, MLD2, MLD3 respectively.

Many MLD computations presented in the literature are based on a temperature criterion. A value of 0.5^{0}C in the temperature criterion (1) is chosen following Levitus (1982).

A density criterion is introduced to account for the effects of salinity as well as temperature on the MLD. For example, in some areas located in subpolar latitudes one observes nearly isothermal conditions (to within 0.5^{0}C) to a depth of 1000 m but with a strong halocline near the surface. The existence of such a halocline results in the existence of a pycnocline even in the absence of a thermocline. The upper boundary of such a pycnocline can be detected by a density criterion. Typically, a density criterion detects the minimum of the depths of seasonal thermocline and seasonal halocline. In some limited areas and during certain months, the vertical profiles of temperature and salinity may exhibit a thermocline and a halocline which compensate each other in such a way that density remains quasi-uniform to within, say, 0.125 in sigma units. In this case the MLD2 may be larger than the MLD1. Such areas are indicated in Section 4.

A value 0.125 of the density difference in the density criterion (2) approximately corresponds to the temperature difference of 0.5^0C for water with salinity of 35 pss (practical salinity scale) and temperature in the 17^0C to 19^0C range. A value 0.125, used in the density criterion (2), was chosen by Levitus (1982) because it corresponds to the water mass characteristics of Subtropical Mode Water in the North Atlantic.

A global comparison of the MLD1 and MLD2 fields is not consistent because the density change corresponding to a temperature change of 0.5^0C depends on temperature and salinity and thus varies considerably throughout the World Ocean. This is due to the coefficient of thermal expansion varying by an order at magnitude over the range of oceanic temperature and salinities that occur at the sea surface. For example, at a salinity of 35 pss, the density change in sigma units corresponding to 0.5^0C temperature change is approximately 0.075 in the 6^0C to 10^0C temperature range and 0.15 in the 24^0C to 26^0C temperature range. Therefore, we consider also a variable density criterion (3) where the density change which corresponds to the temperature change of 0.5^0C is computed at each geographical location based on equation (3). The variable density criterion was suggested by Levitus (1982) and has been used by Sprintall and Tomczack (1990).

3. DATA FIELDS

The data we use are climatological monthly mean *in-situ* temperature and salinity fields for the World Ocean on $1^0 \times 1^0$ degree grid at 19 standard levels from the ocean surface to 1000 m depth. Detailed description of these temperature and salinity fields is given by Levitus and Boyer (1994) and Levitus *et al.* (1994). First, we used these data to compute the climatological monthly mean potential temperature and potential density fields on the same grid based on the algorithm for computation of potential temperature and the International Equation of State endorsed by UNESCO (Fofonoff and Millard, 1983). Next, these potential temperature and potential density fields were used to compute the climatological monthly mean MLD based on the three difference criteria described in the Section 2.

4. GLOBAL MIXED LAYER DEPTH DISTRIBUTIONS

Appendices A through G contain maps of the global distributions of climatological monthly mean MLD1, MLD2 and MLD3, their deviations from their corresponding climatological annual means, as well as the difference between the monthly MLD1 and MLD3 means.

Common for the MLD distributions based on these three criteria, is obvious seasonality with shallower mixed layer in summer compared to winter in each hemisphere. In high latitudes (50^0- 60^0), the changes of MLD between summer and winter are of the order of ten. In mid-latitudes (20^0-40^0), these changes are of the order of a factor of two. In the lower equatorial latitudes (10^0S - 10^0N) these changes are ~ 10-20% of the annual mean MLD.

In high and mid-latitudes, where the seasonal cycle of the MLD is well expressed, the deepening of the MLD from the Summer to Autumn seasons occurs gradually over 5-6 months, while the shoaling of the MLD during the Spring season occurs abruptly over one month. For example, as one can see in Figs. A1-A12, the MLD1 in the subpolar North Pacific deepens gradually from ~10 m in July to ~75 m in December, while it shoals abruptly from ~ 500 m in April to ~50 m in May. Similar variations take place during the corresponding seasons in subpolar latitudes all over the globe.

Note that during the year, the shallowest MLD1 in the mid and subpolar latitudes of the Northern Hemisphere (Fig. A7, July) is ~ 10 m while the shallowest MLD1 in the same latitudes of the Southern Hemisphere (Fig. A1, January) is ~ 50 m. The deepest MLD1 occurs in January-April in the Northern Hemisphere and in June-October in the Southern Hemisphere and is ~ 500 m. The MLD1 reaches these maximum values in the subpolar latitudes (50^0- 60^0) and shoals towards the poles.

Our results indicate that values of the MLD depend considerably on the criterion being used for its computation. Comparison of the MLD1, MLD2, and MLD3 shows the following. In mid-latitudes the MLD1, MLD2, and MLD3 agree to within ± 10 m during all seasons. In equatorial latitudes they differ in certain areas during certain months by 25-50 m. In polar latitudes during the cold season (January-April for the Northern Hemisphere, July-October for the Southern Hemisphere) these differences between the MLD1 and MLD3 can reach 500 m. As explained in Section 2, the MLD3 is specifically designed for consistent comparison with the MLD1 over the whole range of latitudes by taking into account the variable coefficient of thermal expansion. The difference between the MLD1 and MLD3 is caused by the effects of salinity. That the MLD3 is shallower than the MLD1 implies the presence of a halocline above a thermocline. Values (in meters) of the MLD1 minus MLD3 are shown in Figs. G1-G12. Regions where the isohaline layer is shallower than the isothermal layer are the central and western equatorial Pacific, the western equatorial Atlantic and parts of the equatorial

Indian Ocean. In all these regions the MLD3 is 25 to 50 m shallower than the MLD1 during all four seasons (see Figs. G1-G12). Lukas (1988), Godfrey and Lindstrom (1989) suggest heavy rainfall (with the effect of horizontal advection taken into account) as a most likely cause of formation of a layer that is isothermal but salt stratified. In the coastal portions of these regions, river runoff is an additional source of fresh water.

Other regions where the isohaline layer is shallower than the isothermal layer include parts of the subpolar North Atlantic and subpolar North Pacific as well as parts of the Southern Ocean. In these regions during the winter and spring seasons, the MLD3 is shallower than the MLD1 by 200-500 m (see Figs. G1-G12). This is because water in subpolar regions is highly isothermal during January-April for the Northern Hemisphere and August-October for the Southern Hemisphere. Also, because the thermal expansion coefficient for sea water is smaller at lower temperatures, the density difference $\Delta\sigma_t$ in the variable density criterion (3) decreases at lower temperatures and a pycnocline (caused by a halocline) is observed by the variable density criterion. In these regions the winter-spring MLD(1) based on the temperature criterion 0.5°C is typically ~500 m while the winter-spring MLD(3) based on the variable density criterion is typically ~ 100 m.

During December-April the difference between the MLD1 and the MLD3 exhibits fronts corresponding to the positions of the North Atlantic Current and the North Pacific Current (Figs. G1-G12). The correlation between the positions of oceanic fronts and variations of the MLD have been noted in the literature (Roden, 1979; Welander, 1981).

Negative (-25 m to -50 m) values of the MLD1 minus MLD3, corresponding to an isothermal layer shallower than the isopycnal layer, occur inside the subtropical gyres in the North Atlantic and in the North Pacific during March-April, (Figs. G3-G4) as well as inside the subtropical gyres in the South Atlantic and in the South Pacific during September-October (Figs. G9-G10). Those are the months immediately preceding the abrupt shallowing of the MLD in the subpolar latitudes from its cold season values of ~200-500 m to its warm season values of ~10-100 m.

5. SUMMARY

New climatological monthly mean fields of temperature and salinity that have recently became available to scientific community, due to expansion of the global hydrographic data base, are used for the systematic computation and mapping of the global climatological monthly mean mixed layer depth on a $1^0 \times 1^0$ grid.

Three different criteria are utilized for the MLD computation. First, a temperature criterion of 0.5°C is used. Next, a sigma-t criterion of 0.125 is used. The density difference of 0.125 in sigma units approximately corresponds to the temperature difference of 0.5°C at temperatures and salinities typical for the oceanic surface layer in mid-latitudes. This value also agrees with the recommendation for detecting the seasonal MLD based on recent experimental study by Brainerd and Gregg (1995). The influence of salinity on the MLD is taken into account via the variable density criterion (3). This criterion is based on the density change corresponding to a temperature change of 0.5°C which is computed based on the coefficient of thermal expansion at surface values of temperature and salinity. Therefore, the difference between the MLD based on the temperature criterion 0.5°C and the variable density criterion must be caused by the effects of salinity.

Analysis of the MLD based on different criteria shows strong seasonality in mid and high latitudes. The MLD gradually deepens during the Summer-Autumn seasons and abruptly shallows during one month in the Spring season. The MLD1 based on the temperature criterion 0.5°C and the MLD3 based on the variable density criterion exhibit significant differences. The latter is shallower than the former in some regions located in equatorial and subpolar latitudes due to formation of a strong halocline above a thermocline.

REFERENCES

Brainerd K.E., and M.C. Gregg, 1995: Surface mixed and mixing layer depths. Deep-Sea Res., **42**, No. 9, 1521-1543.

Fofonoff, N.P., and R.C. Millard, 1983: Algorithms for computation of fundamental properties of seawater. *UNESCO Technical Paper in Marine Science* **44**, UNESCO,.

Godfrey, J.S. and E. Lindstrom, 1989: The heat budget of the equatorial western Pacific surface mixed layer. *J. Geophys. Res.*, **94**: C6, 8007-8017.

Levitus, S., 1982: Climatological Atlas of the World Ocean. *NOAA Professional Paper* **13**., U.S. Gov. Printing Office, Washington, DC., 173 pp.

_______, T. Boyer, 1994: World Ocean Atlas 1994, Vol. 4: Temperature. *NOAA Atlas NESDIS 4*, U.S. Gov. Printing Office, Washington, D.C., 117 pp.

_______, R. Burgett, T. Boyer, 1994: World Ocean Atlas 1994, Vol. 3: Salinity. *NOAA Atlas NESDIS 3*, U.S. Gov. Printing Office, Washington, D.C., 99 pp.

Lukas, R., 1988: On the role of the western Pacific air-sea interaction, In the El Nino/Southern Oscillation phenomenon. *Proc. Of the U.S. TOGA Western Pacific Air-Sea Interaction Workshop*, R. Lukas and P. Webster (eds.) U.S. TOGA 8, Univ. Corp. Atmos. Res., 43-69.

Roden, G.I., 1979: The depth variability of meridional gradients of temperature, salinity and sound velocity in the western North Pacific. *J. Phys. Oceanogr.*, **9**, No. 4, 756-767.

Sprintall, J., and M. Tomczak, 1990: Salinity considerations in the oceanic surface mixed layer. Report No. 36, Ocean Sciences Institute, University of Sydney, 170 pp..

Welander, P., 1981: Mixed layers and fronts in simple ocean circulation models. *J. Phys. Oceanogr.*, **11**, 148-152.

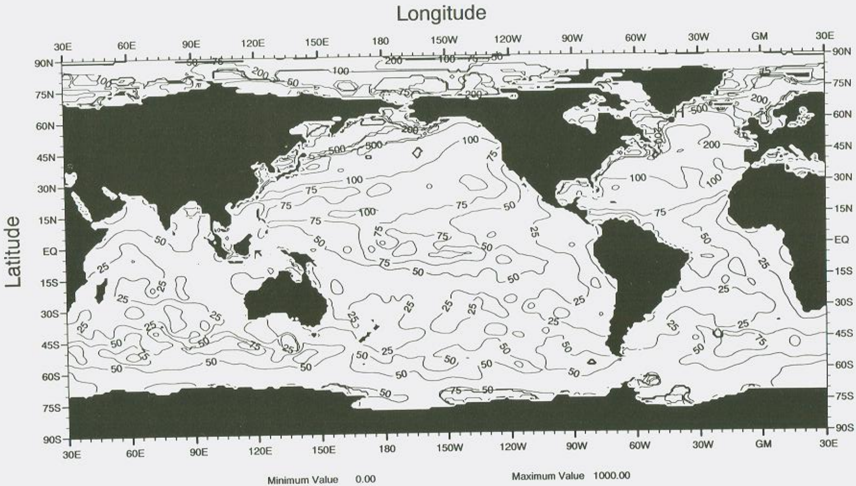


Fig. A1 January mean MLD (m) based on a temperature criterion 0.5°0C

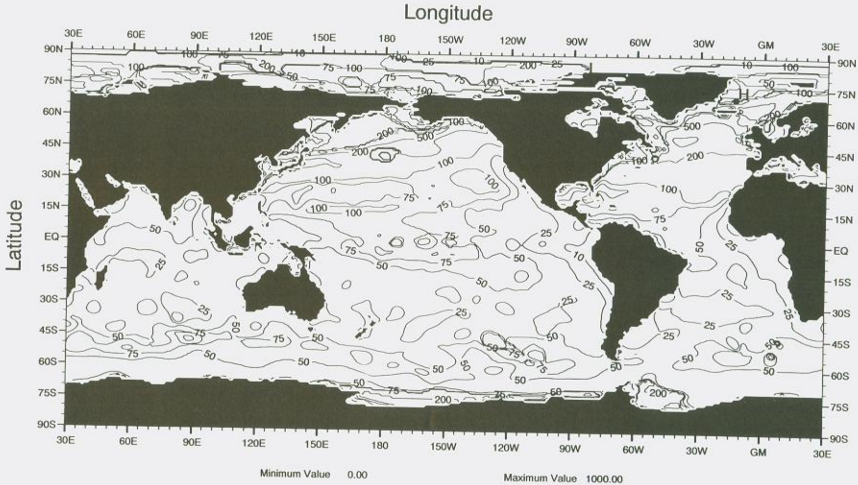


Fig. A2 February mean MLD (m) based on a temperature criterion 0.5°0C

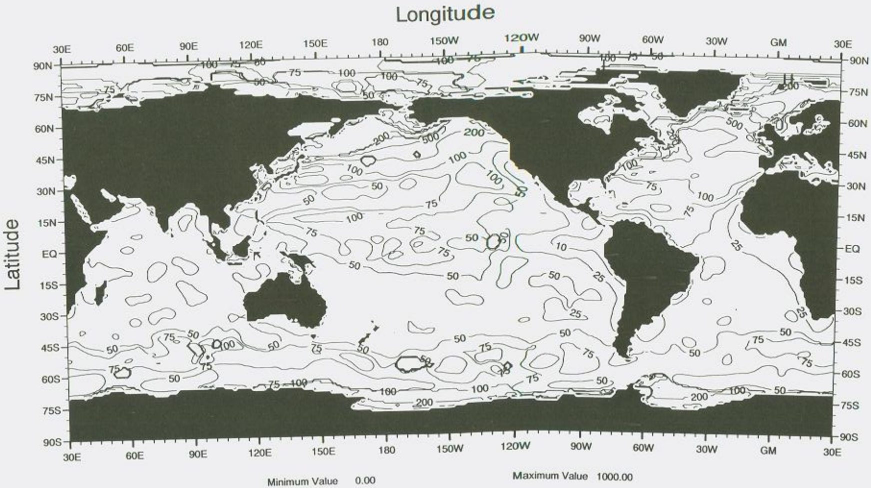


Fig. A3 March mean MLD (m) based on a temperature criterion 0.5°0C

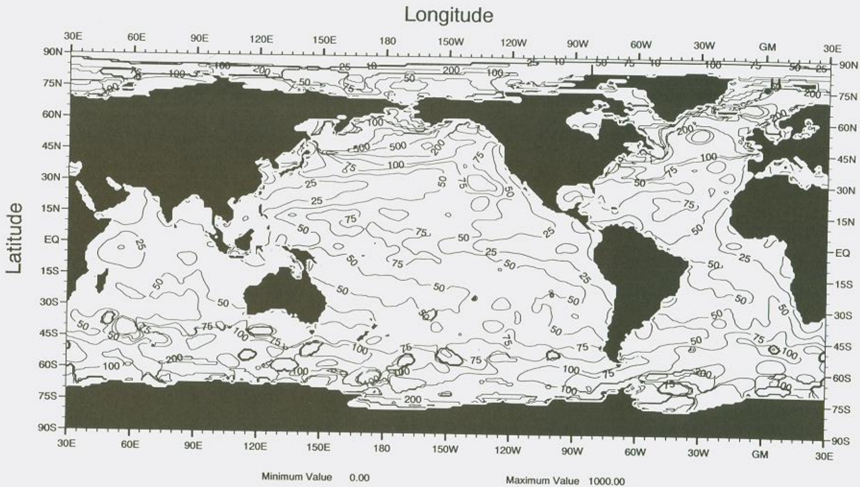


Fig. A4 April mean MLD (m) based on a temperature criterion 0.5°0C

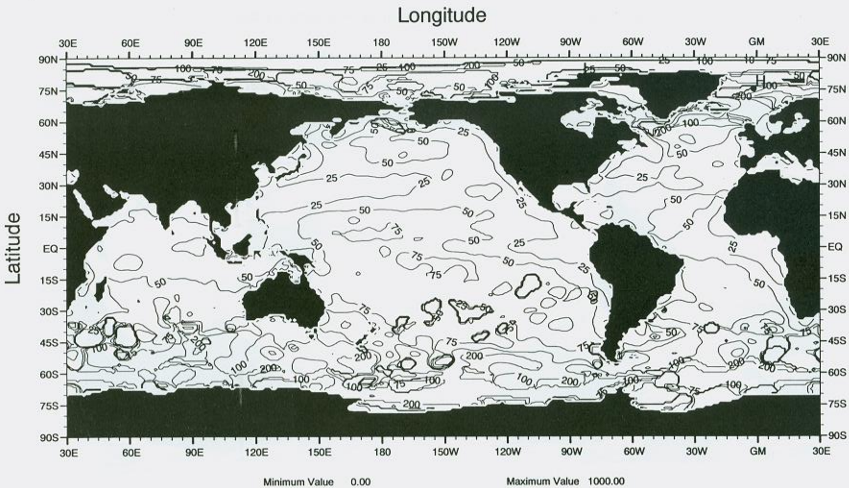


Fig. A5 May mean MLD (m) based on a temperature criterion 0.5°0C

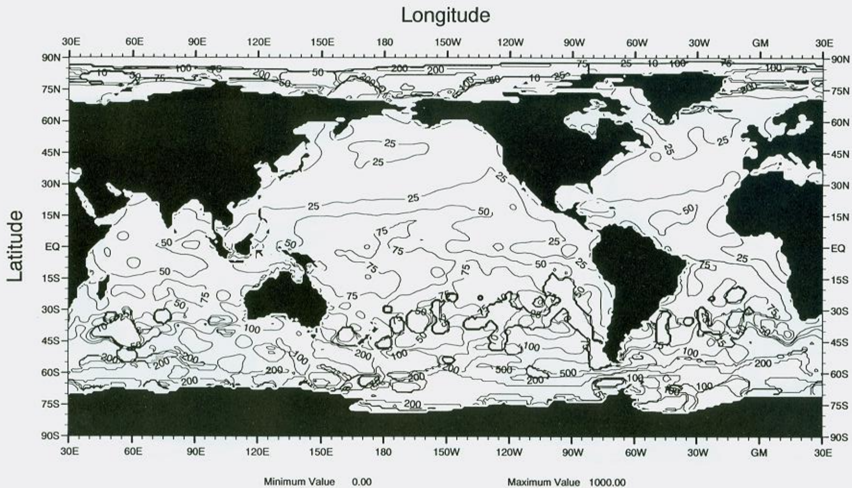


Fig. A6 June mean MLD (m) based on a temperature criterion 0.5°0C

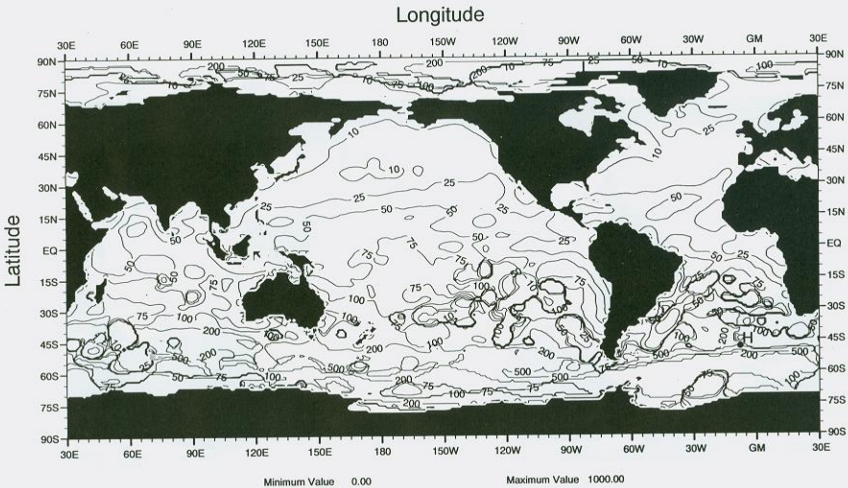


Fig. A7 July mean MLD (m) based on a temperature criterion 0.5°0C

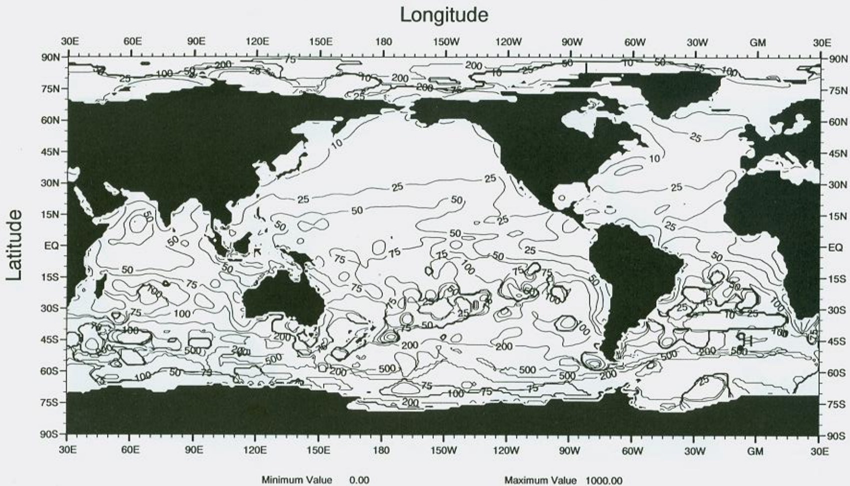


Fig. A8 August mean MLD (m) based on a temperature criterion 0.5°0C

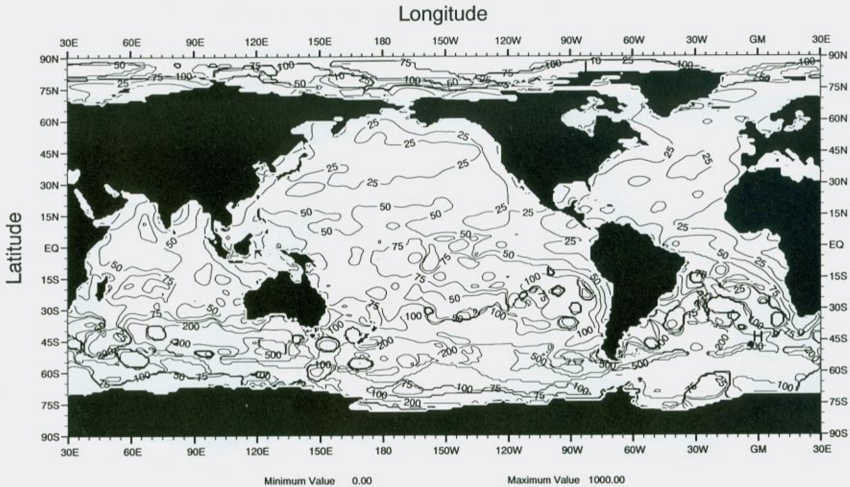


Fig. A9 September mean MLD (m) based on a temperature criterion 0.5°0C

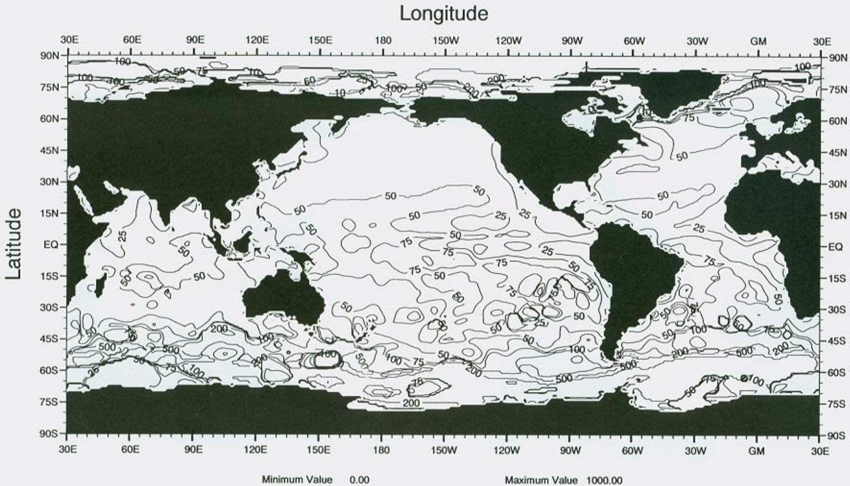


Fig. A10 October mean MLD (m) based on a temperature criterion 0.5°0C

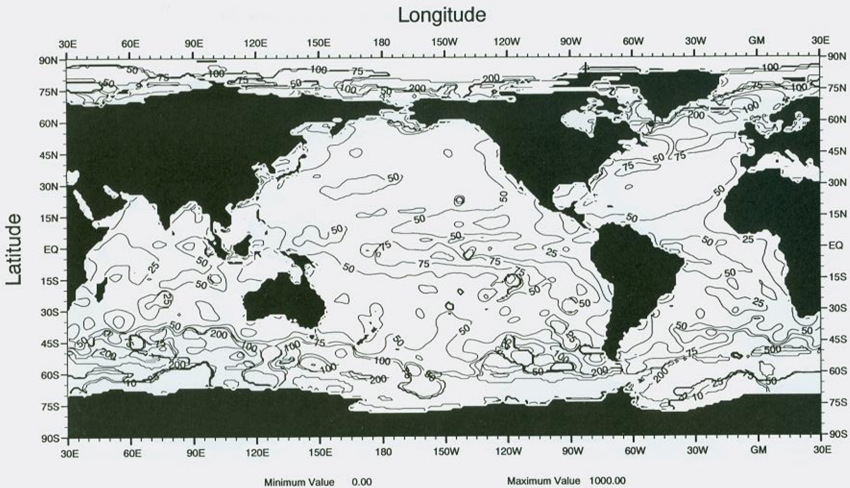


Fig. A11 November mean MLD (m) based on a temperature criterion 0.5°0C

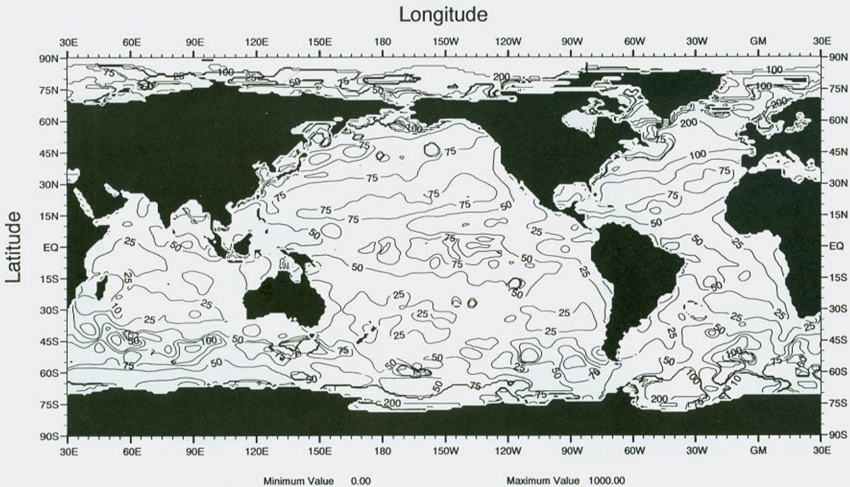


Fig. A12 December mean MLD (m) based on a temperature criterion 0.5°0C

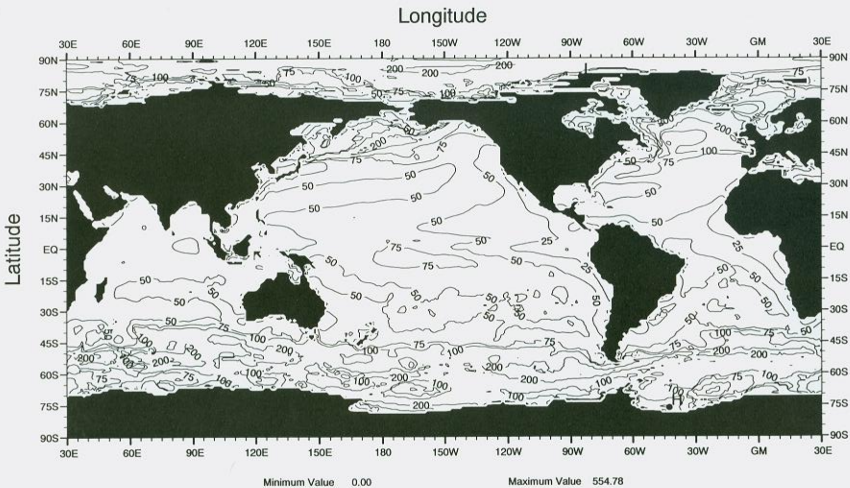


Fig. A13 Annual mean MLD (m) based on a temperature criterion 0.5°0 C

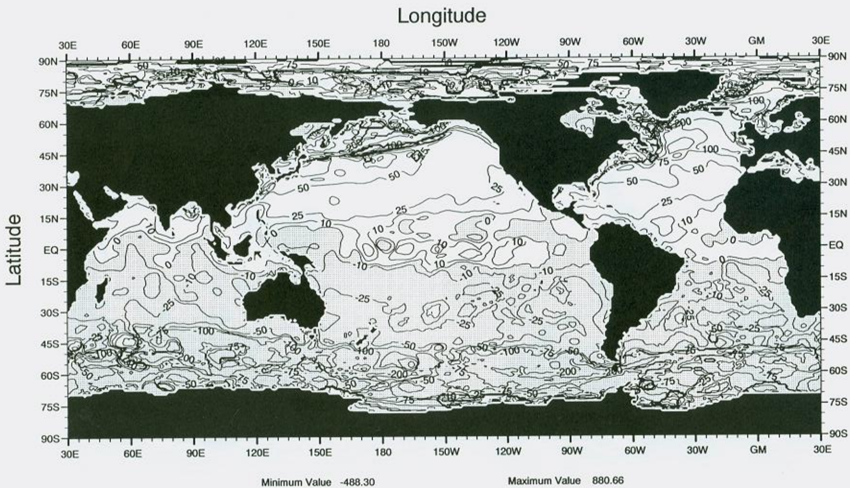


Fig. B1 January minus annual mean MLD (m) based on a temperature criterion 0.5°C

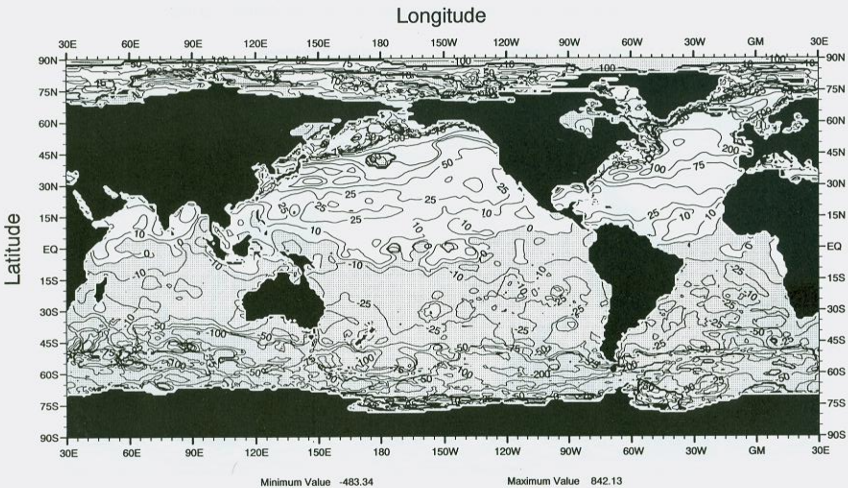


Fig. B2 February minus annual mean MLD (m) based on a temperature criterion 0.5°C

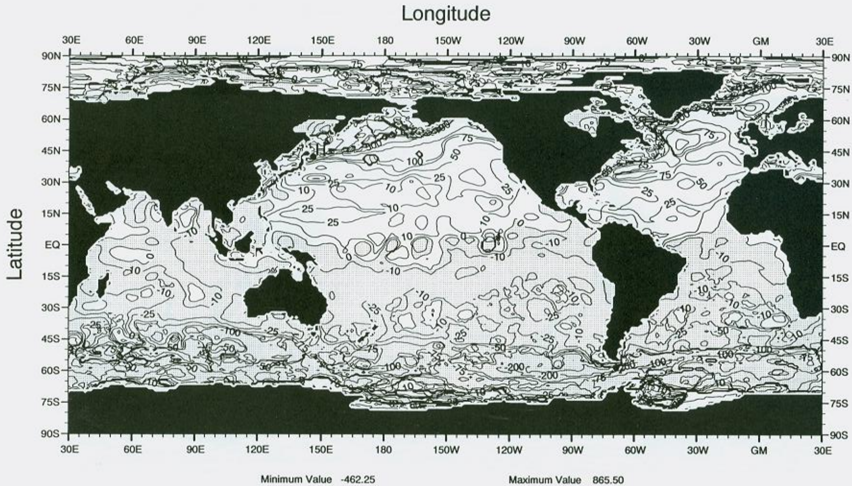


Fig. B3 March minus annual mean MLD (m) based on a temperature criterion 0.5°C

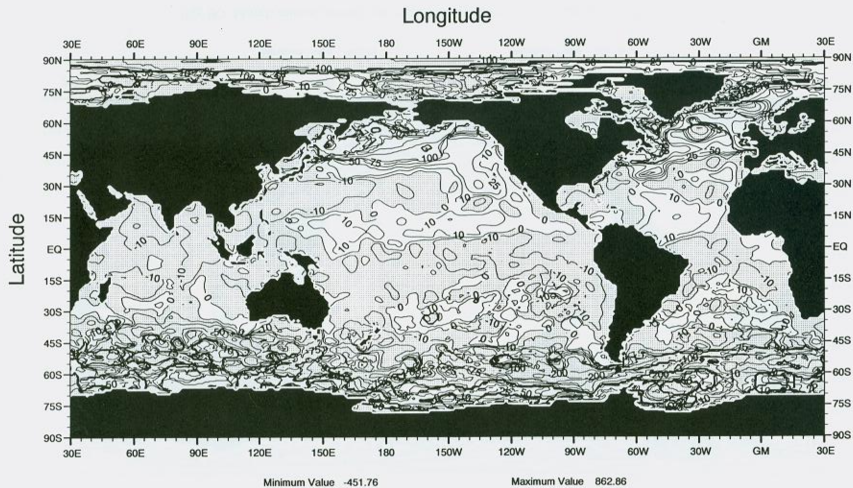


Fig. B4 April minus annual mean MLD (m) based on a temperature criterion 0.5°C

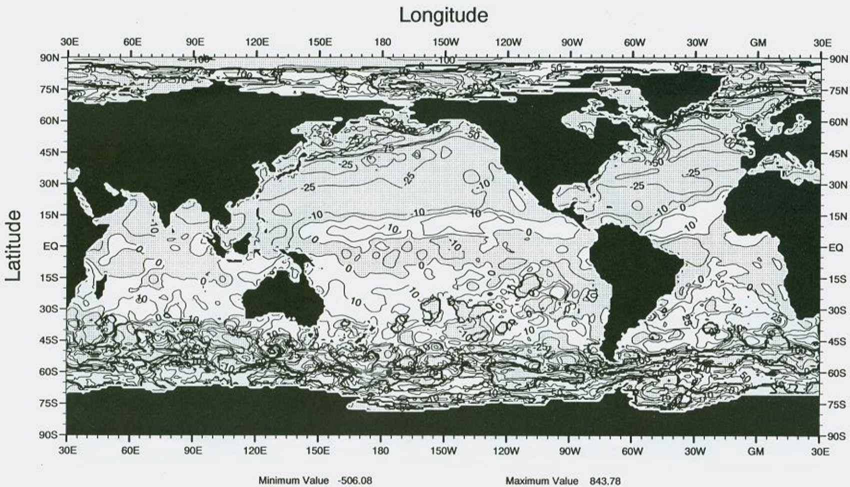


Fig. B5 May minus annual mean MLD (m) based on a temperature criterion 0.5°C

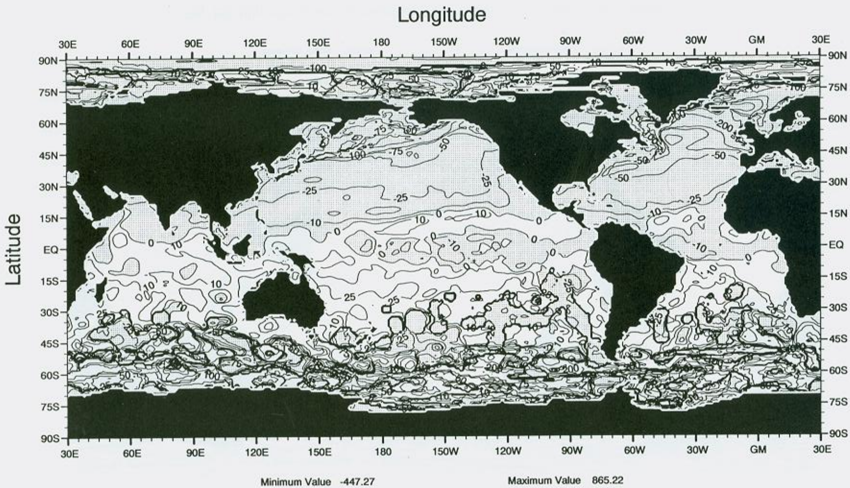


Fig. B6 June minus annual mean MLD (m) based on a temperature criterion 0.5°C

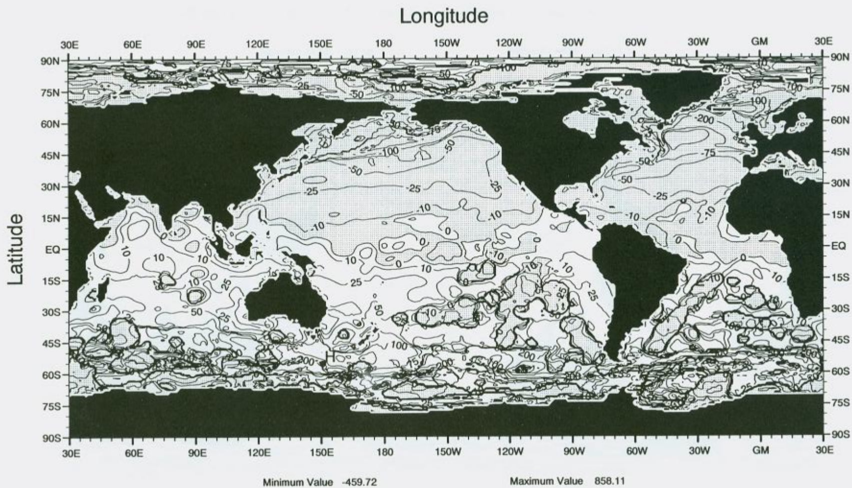


Fig. B7 July minus annual mean MLD (m) based on a temperature criterion 0.5°C

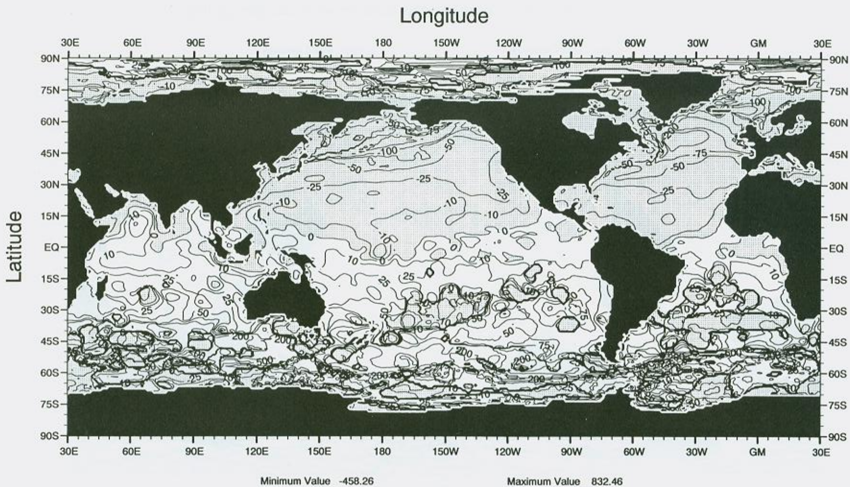


Fig. B8 August minus annual mean MLD (m) based on a temperature criterion 0.5°C

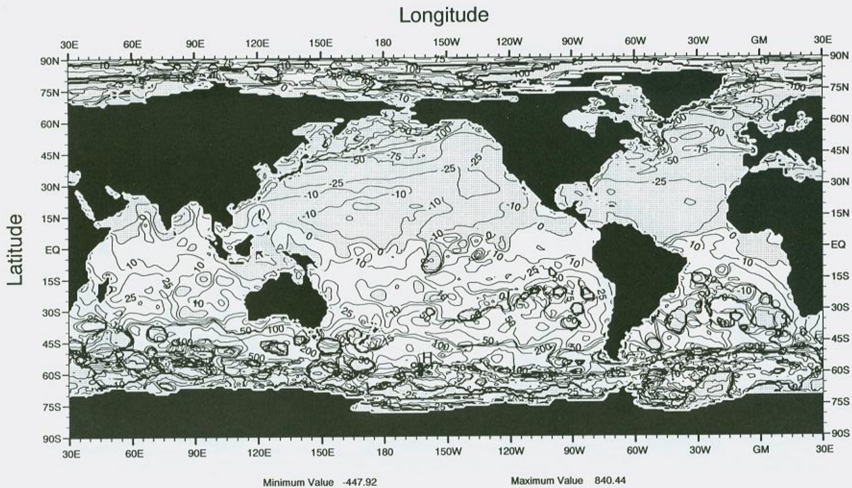


Fig. B9 September minus annual mean MLD (m) based on a temperature criterion 0.5°C

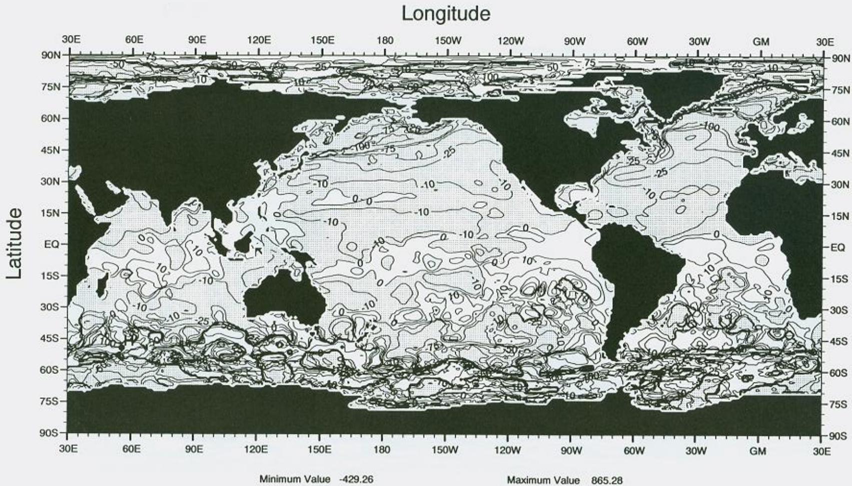


Fig. B10 October minus annual mean MLD (m) based on a temperature criterion 0.5°C

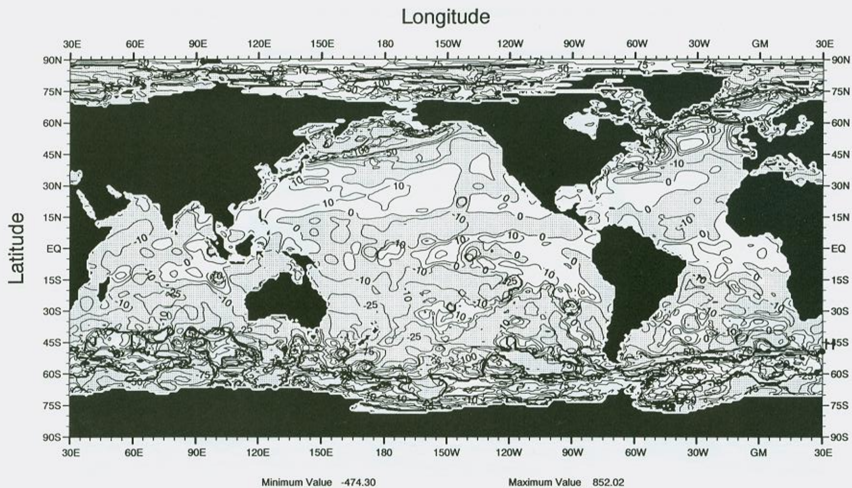


Fig. B11 November minus annual mean MLD (m) based on a temperature criterion 0.5°C

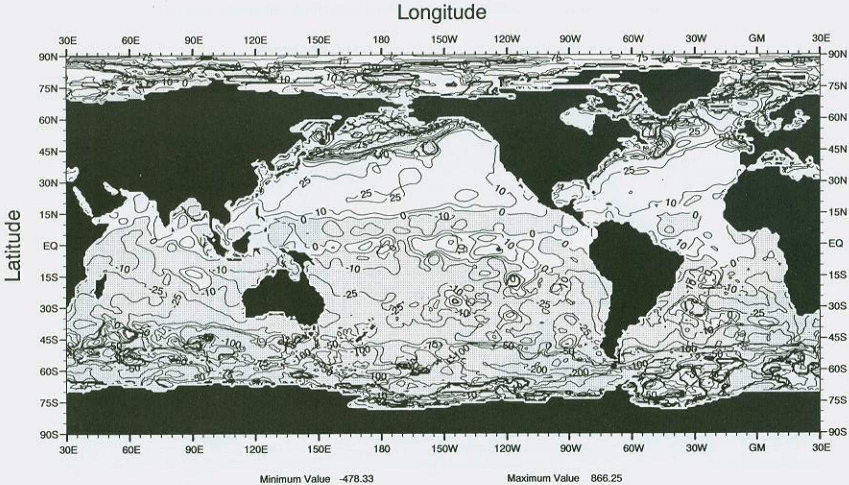


Fig. B12 December minus annual mean MLD (m) based on a temperature criterion 0.5°C

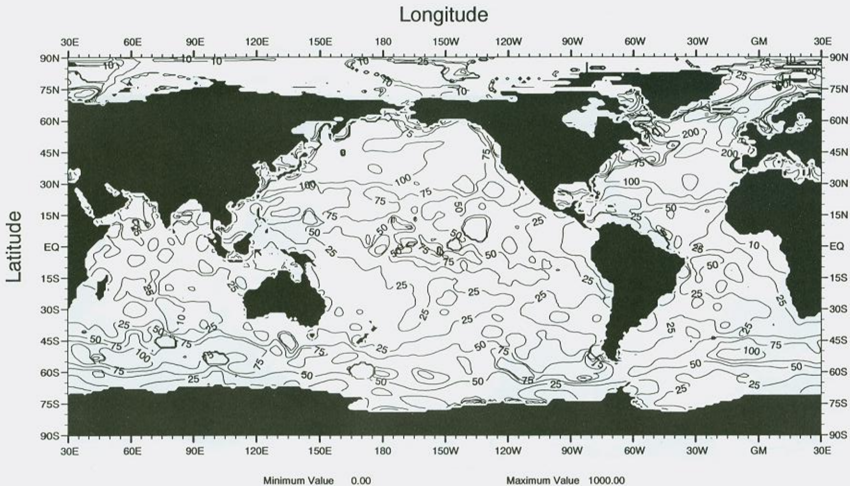


Fig. C1 January mean MLD (m) based on a sigma-t criterion 0.125

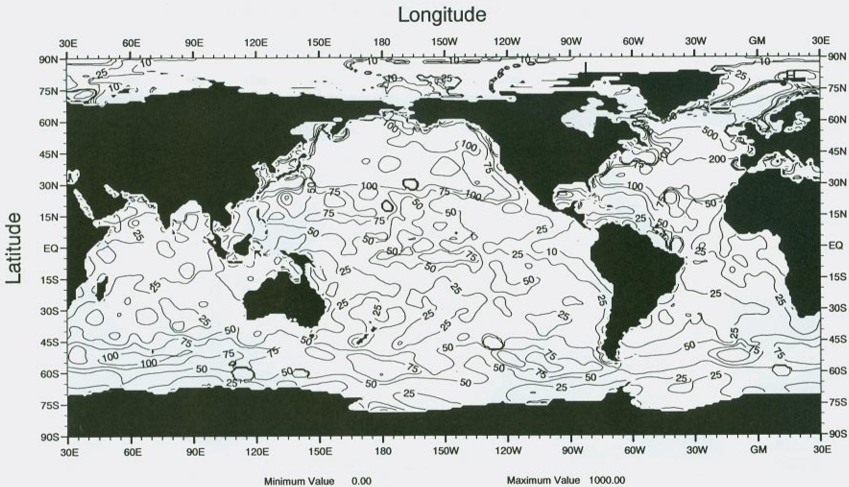


Fig. C2 February mean MLD (m) based on a sigma-t criterion 0.125

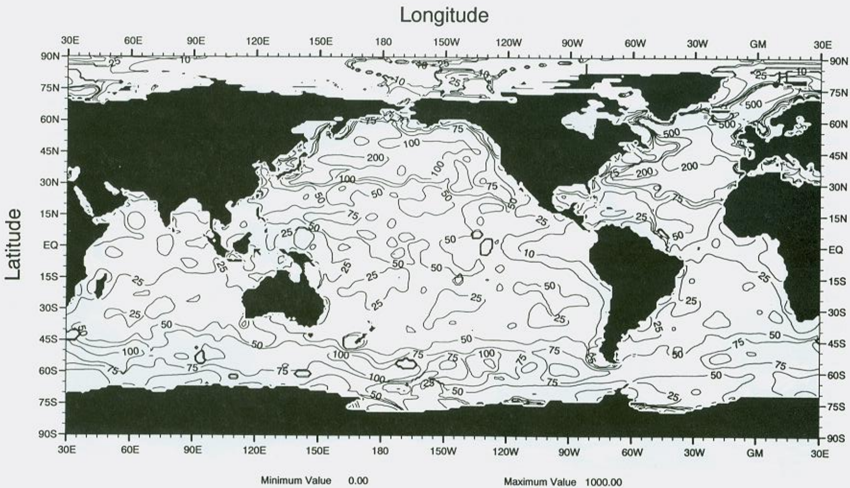


Fig. C3 March mean MLD (m) based on a sigma-t criterion 0.125

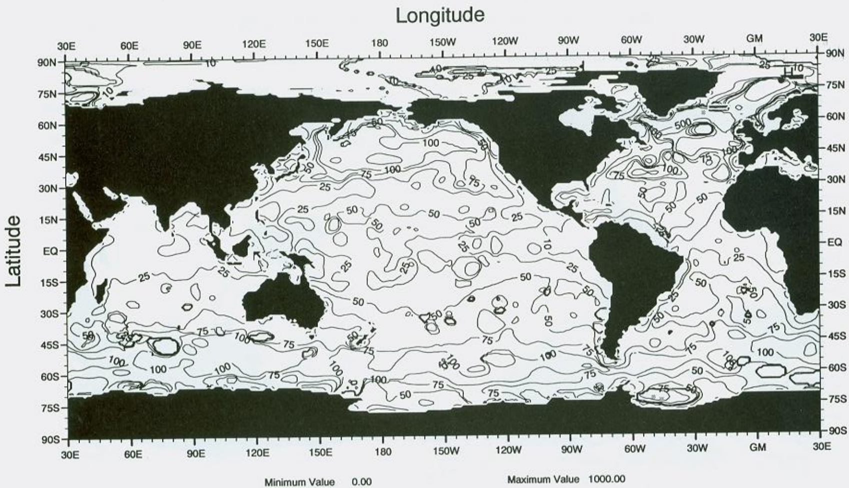


Fig. C4 April mean MLD (m) based on a sigma-t criterion 0.125

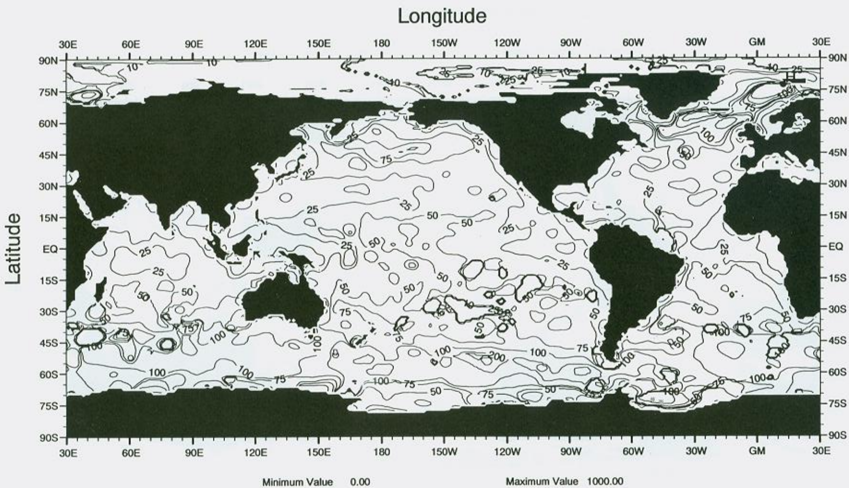


Fig. C5 May mean MLD (m) based on a sigma-t criterion 0.125

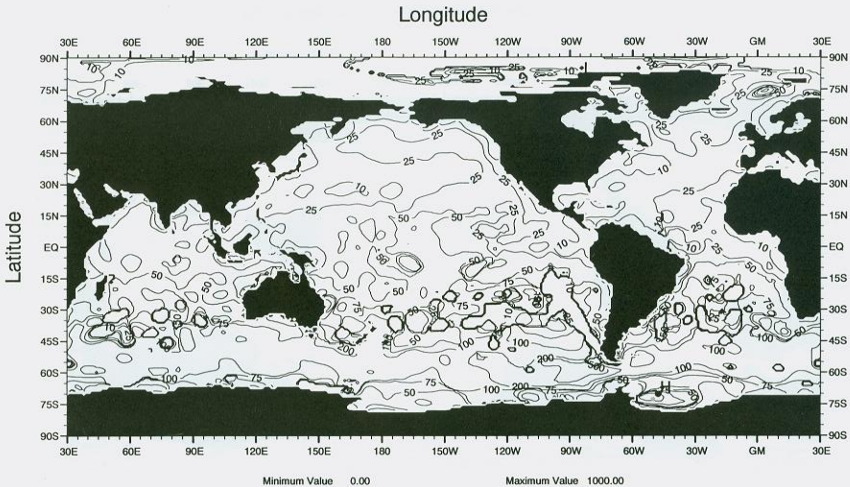


Fig. C6 June mean MLD (m) based on a sigma-t criterion 0.125

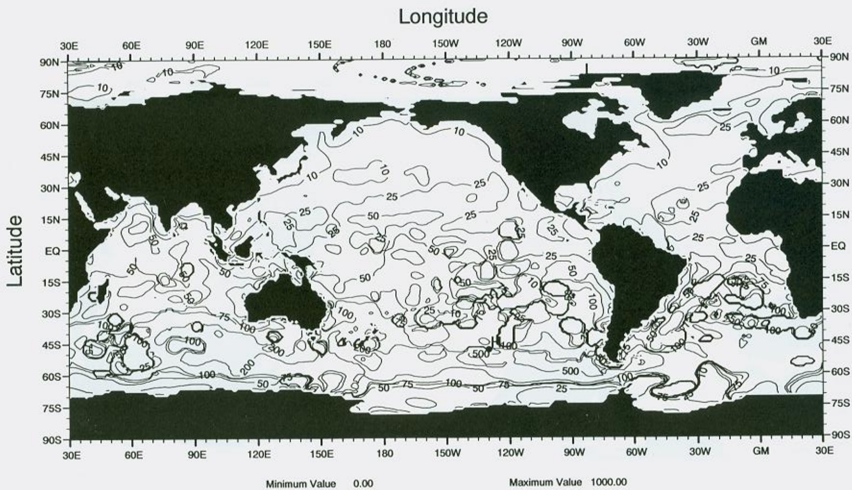


Fig. C7 July mean MLD (m) based on a sigma-t criterion 0.125

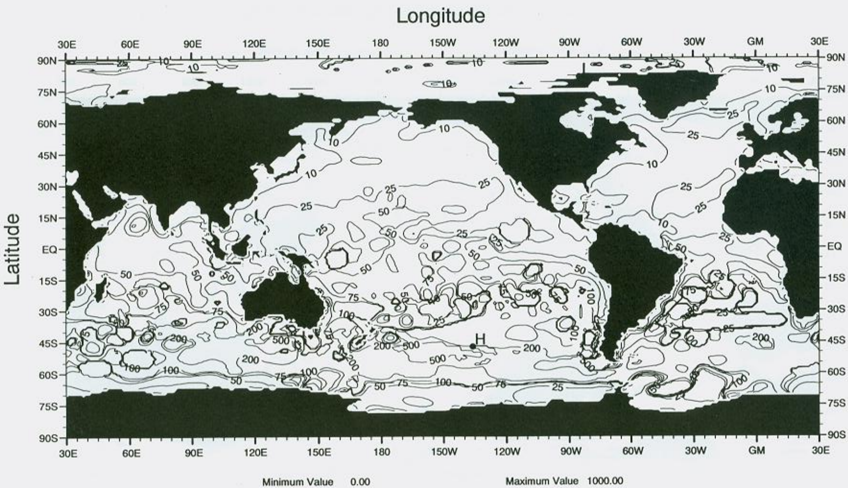


Fig. C8 August mean MLD (m) based on a sigma-t criterion 0.125

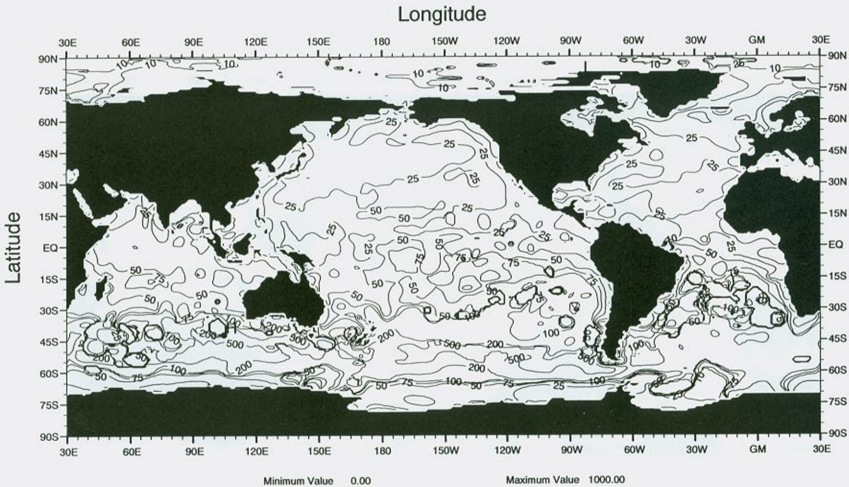


Fig. C9 September mean MLD (m) based on a sigma-t criterion 0.125

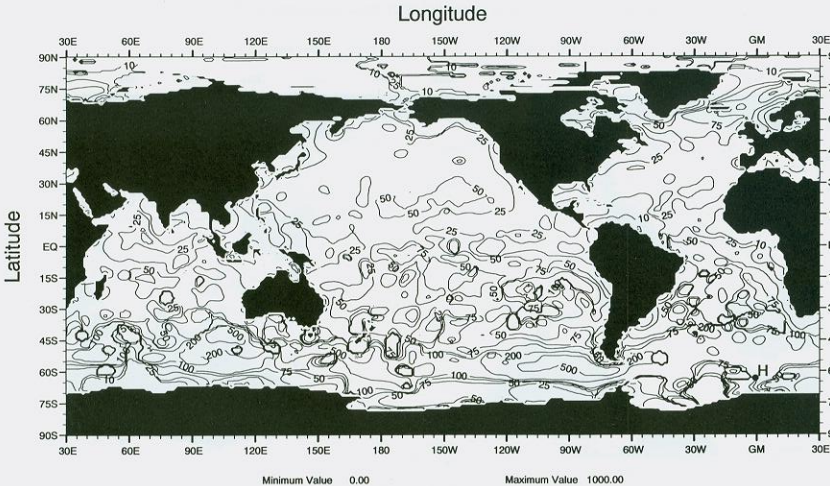


Fig. C10 October mean MLD (m) based on a sigma-t criterion 0.125

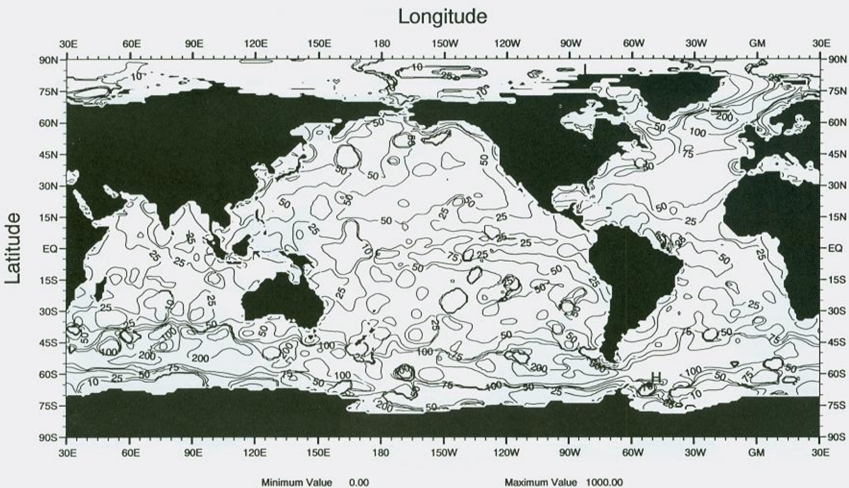


Fig. C11 November mean MLD (m) based on a sigma-t criterion 0.125

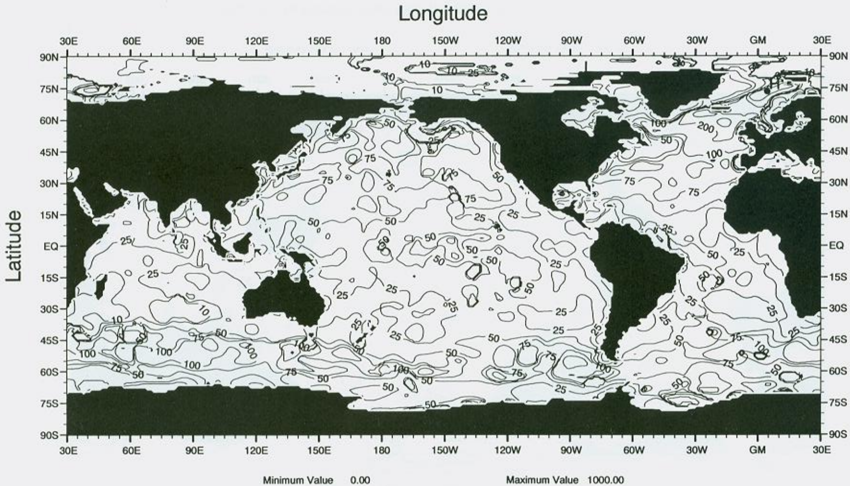


Fig. C12 December mean MLD (m) based on a sigma-t criterion 0.125

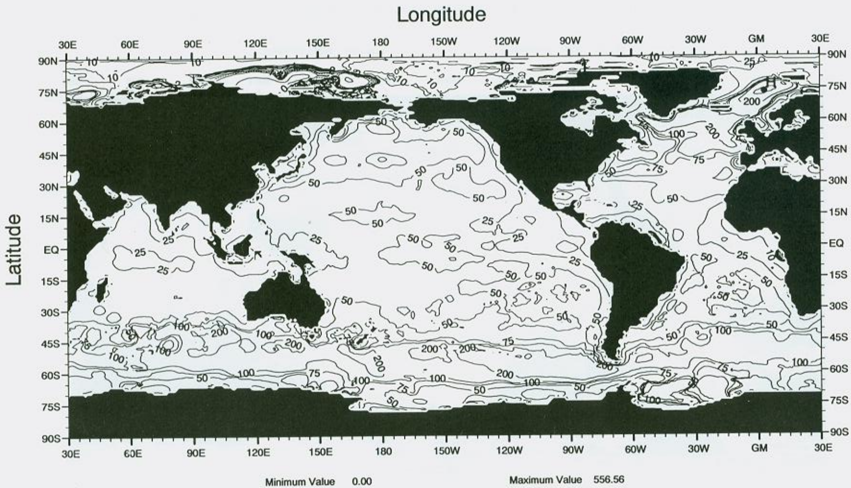


Fig. C13 Annual mean MLD (m) based on a sigma-t criterion 0.125

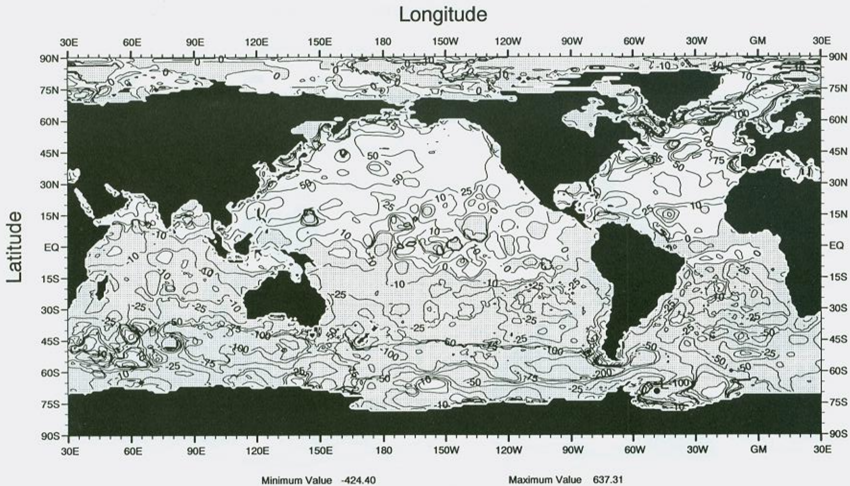


Fig. D1 January minus annual mean MLD (m) based on a sigma-t criterion 0.125

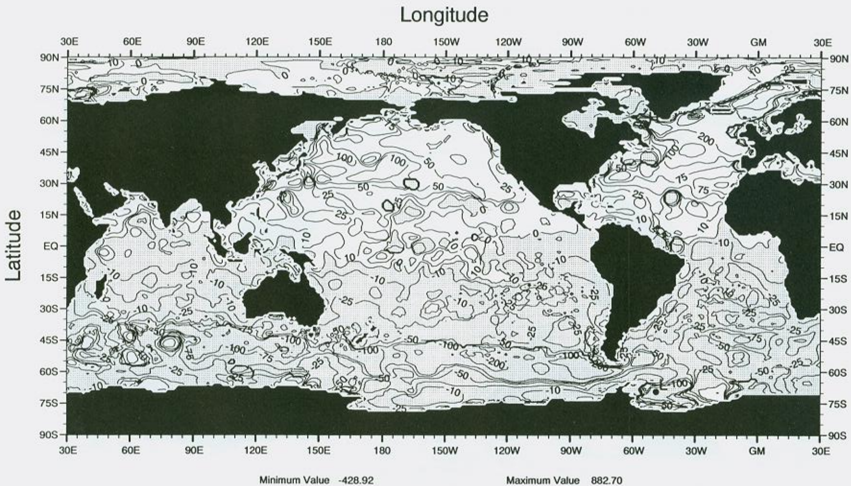


Fig. D2 February minus annual mean MLD (m) based on a sigma-t criterion 0.125

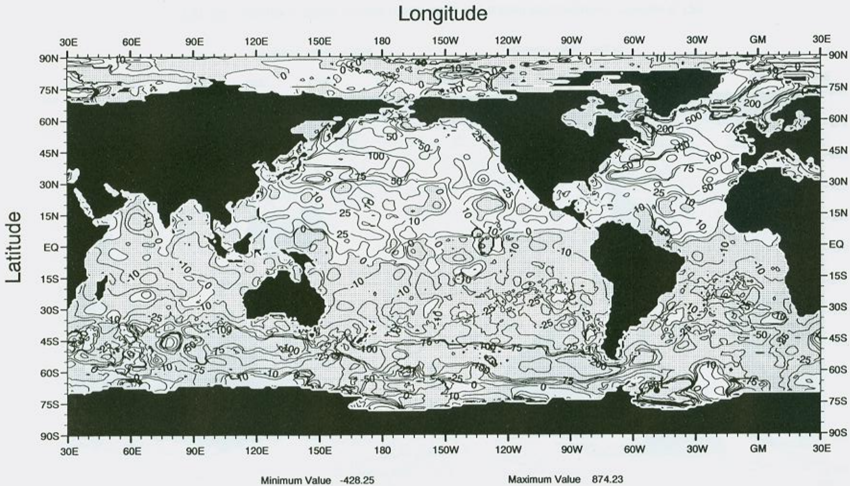


Fig. D3 March minus annual mean MLD (m) based on a sigma-t criterion 0.125

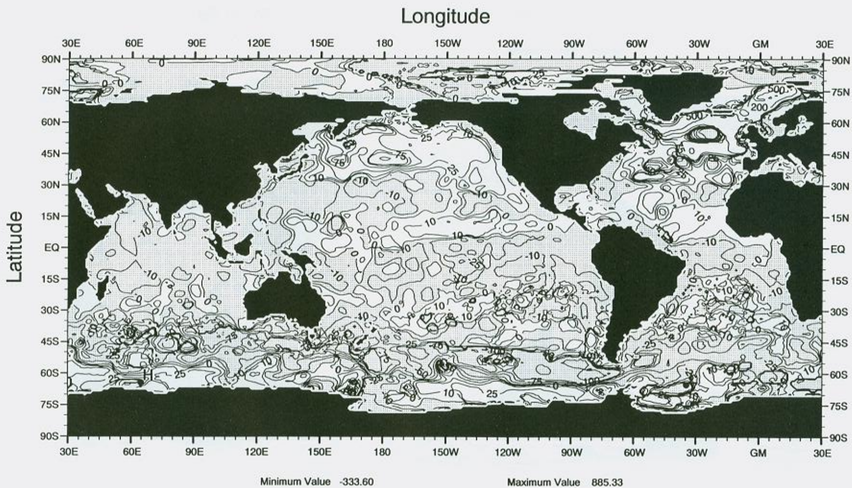


Fig. D4 April minus annual mean MLD (m) based on a sigma-t criterion 0.125

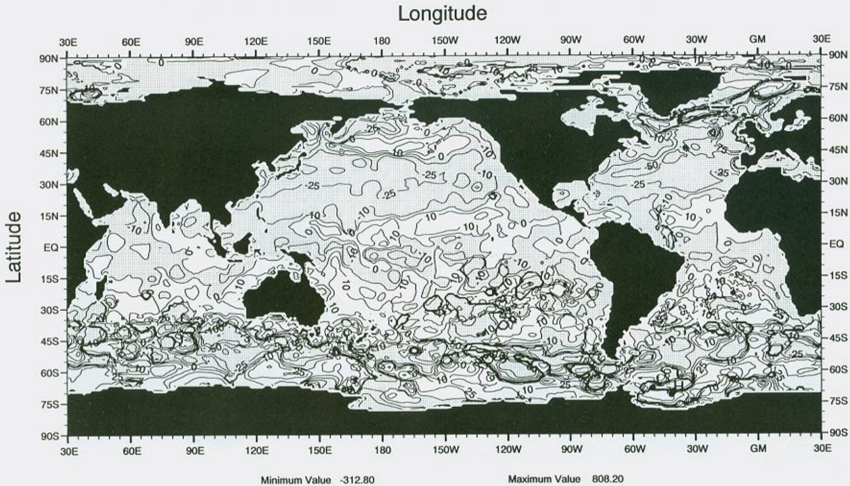


Fig. D5 May minus annual mean MLD (m) based on a sigma-t criterion 0.125

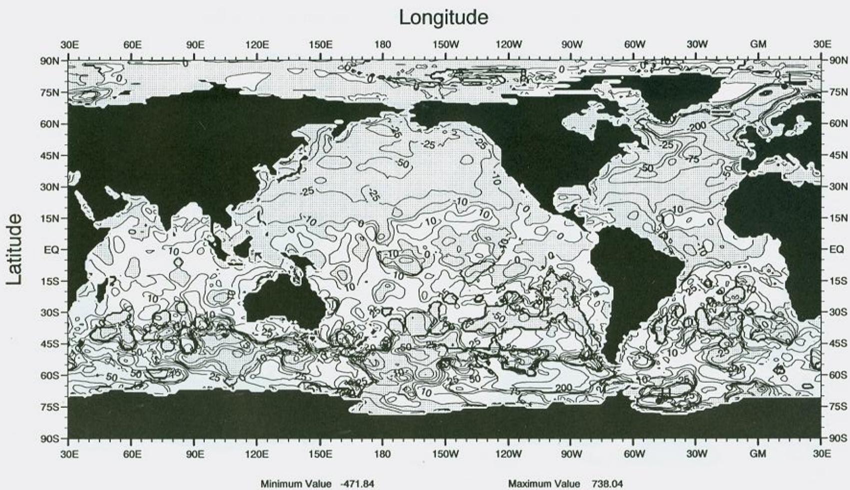


Fig. D6 June minus annual mean MLD (m) based on a sigma-t criterion 0.125

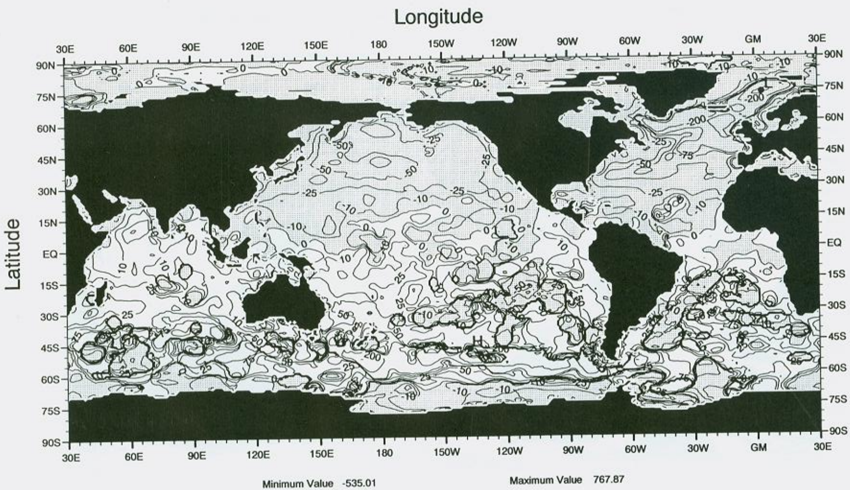


Fig. D7 July minus annual mean MLD (m) based on a sigma-t criterion 0.125

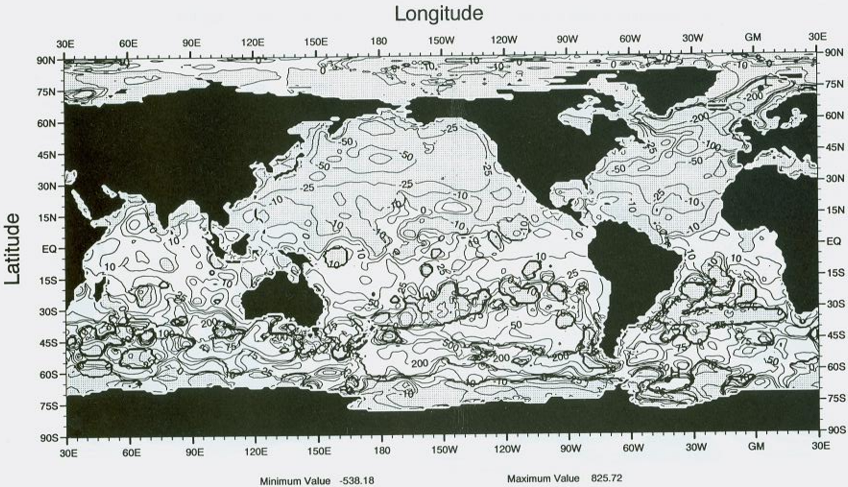


Fig. D8 August minus annual mean MLD (m) based on a sigma-t criterion 0.125

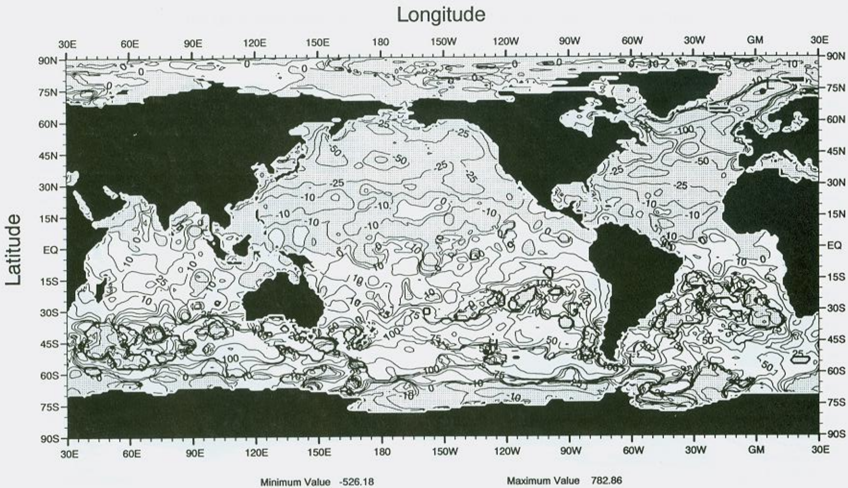


Fig. D9 September minus annual mean MLD (m) based on a sigma-t criterion 0.125

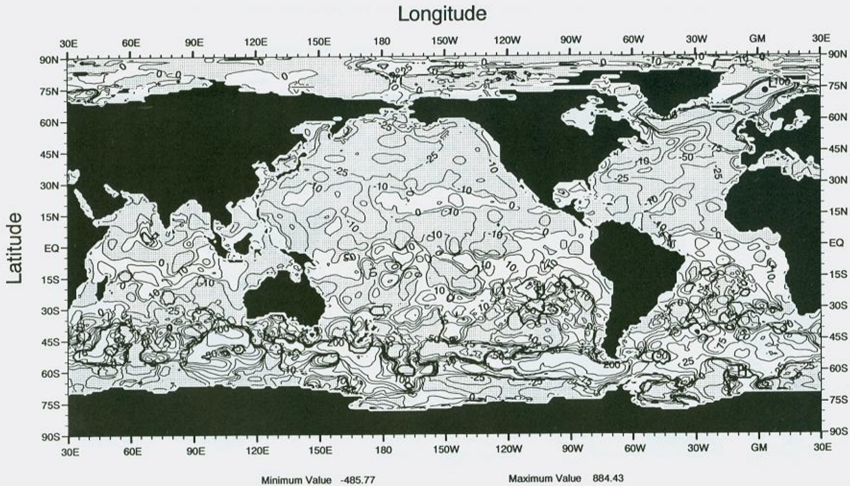


Fig. D10 October minus annual mean MLD (m) based on a sigma-t criterion 0.125

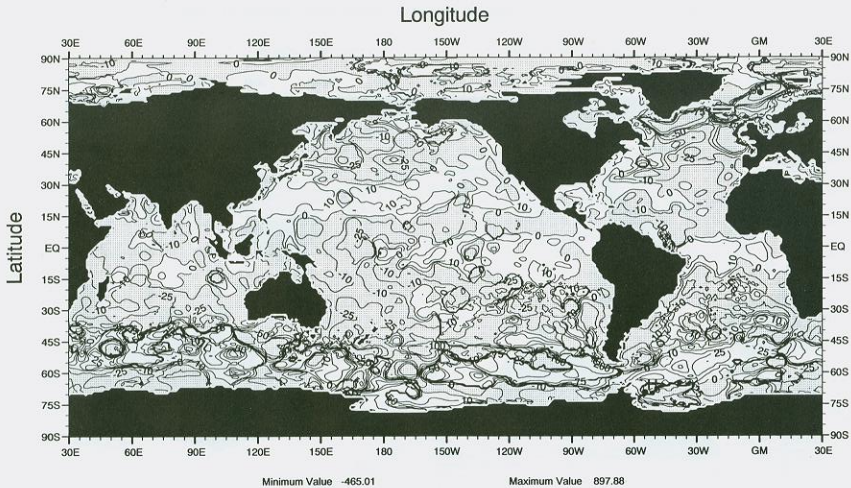


Fig. D11 November minus annual mean MLD (m) based on a sigma-t criterion 0.125

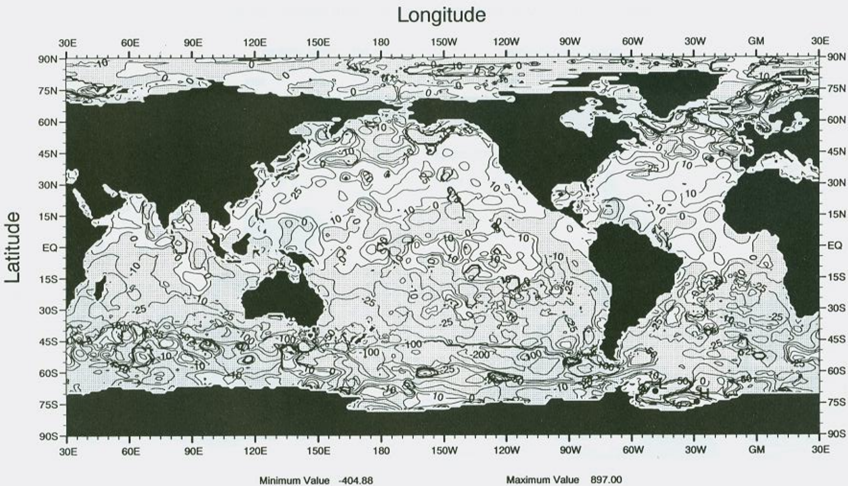


Fig. D12 December minus annual mean MLD (m) based on a sigma-t criterion 0.125

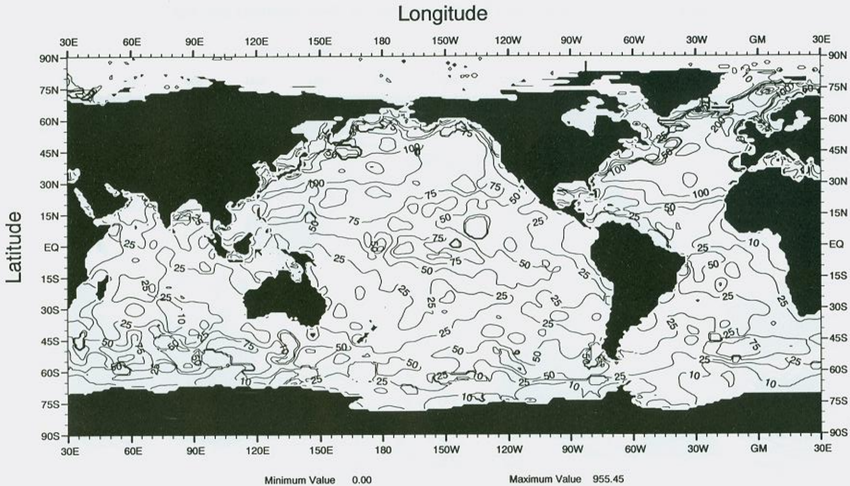


Fig. E1 January mean MLD (m) based on a variable sigma-t criterion

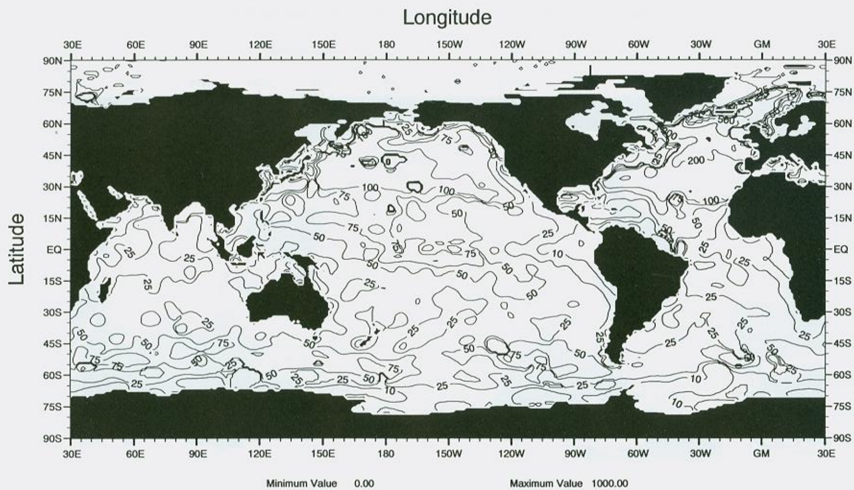


Fig. E2 February mean MLD (m) based on a variable sigma-t criterion

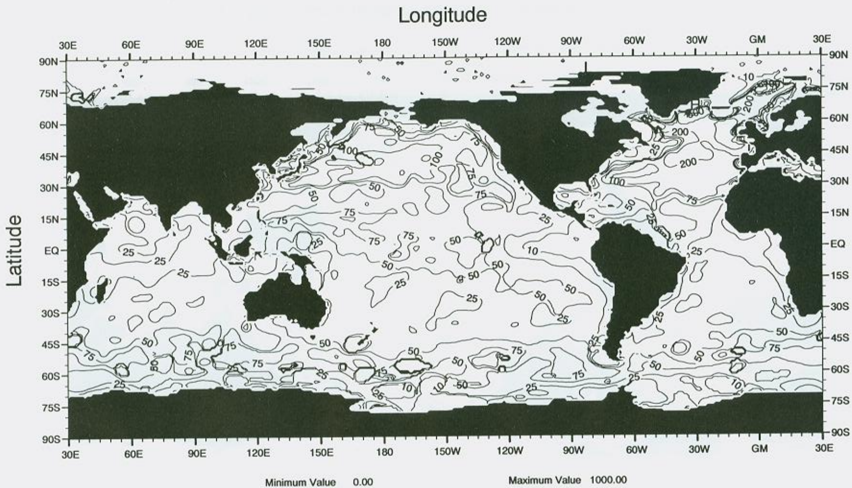
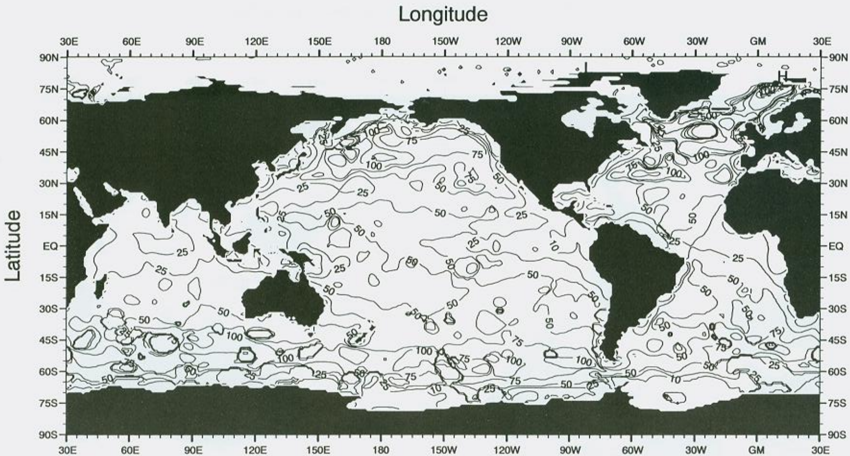


Fig. E3 March mean MLD (m) based on a variable sigma-t criterion



Minimum Value 0.00 Maximum Value 1000.00

Fig. E4 April mean MLD (m) based on a variable sigma-t criterion

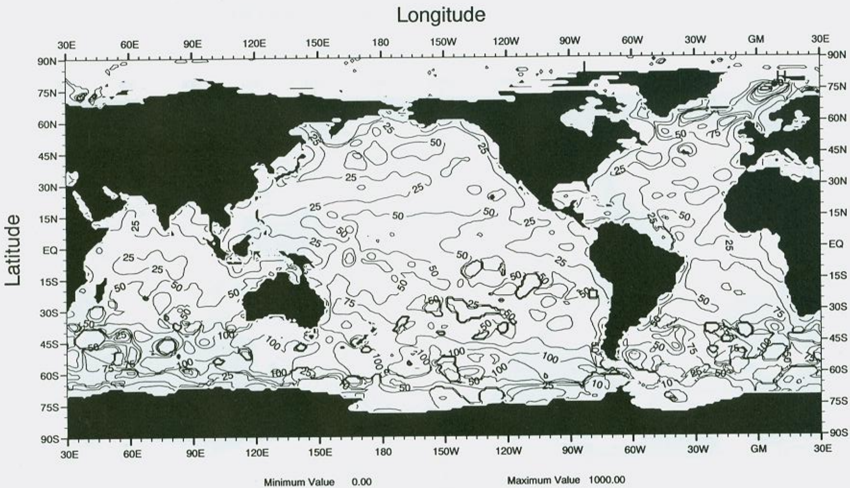


Fig. E5 May mean MLD (m) based on a variable sigma-t criterion

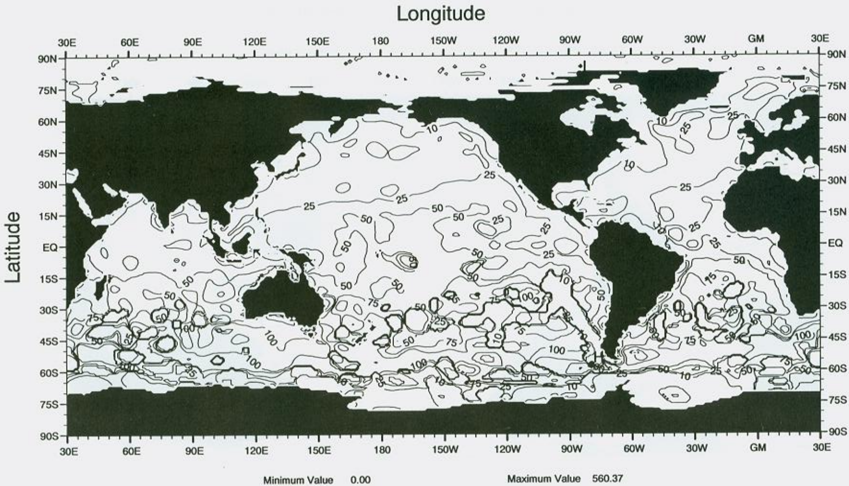


Fig. E6 June mean MLD (m) based on a variable sigma-t criterion

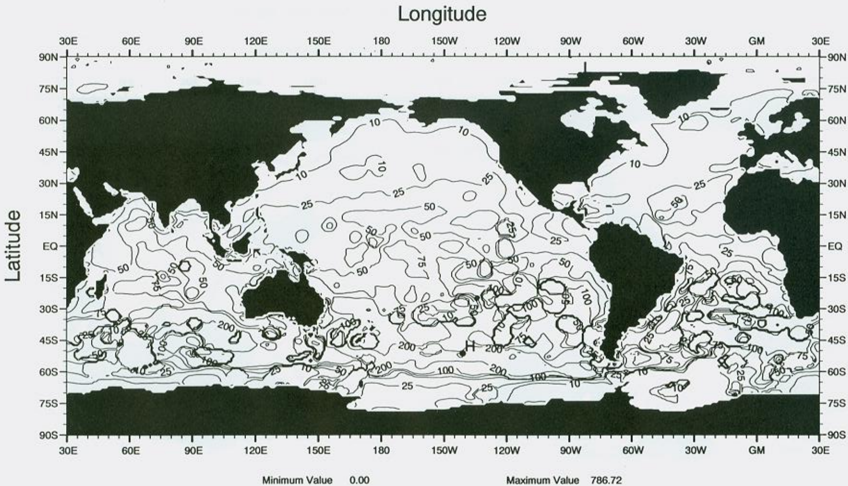


Fig. E7 July mean MLD (m) based on a variable sigma-t criterion

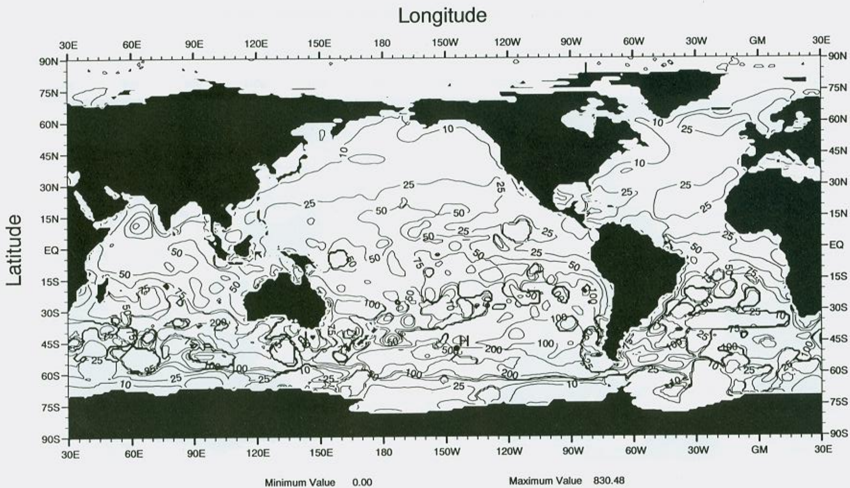


Fig. E8 August mean MLD (m) based on a variable sigma-t criterion

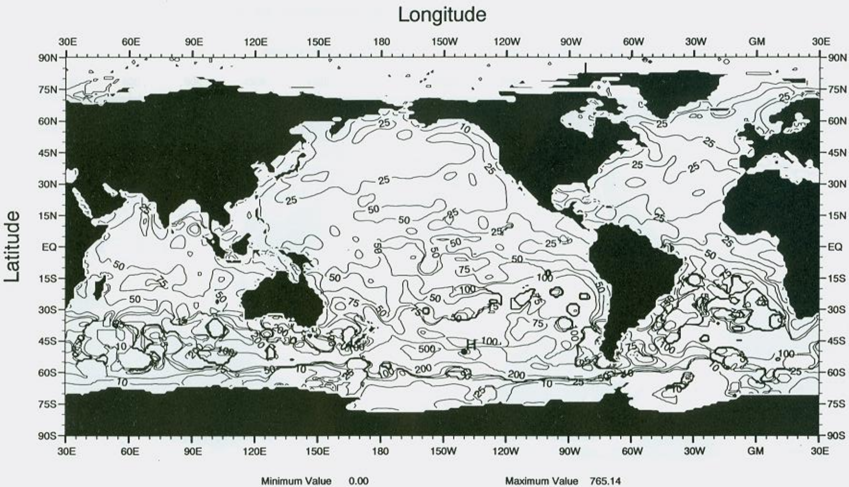


Fig. E9 September mean MLD (m) based on a variable sigma-t criterion

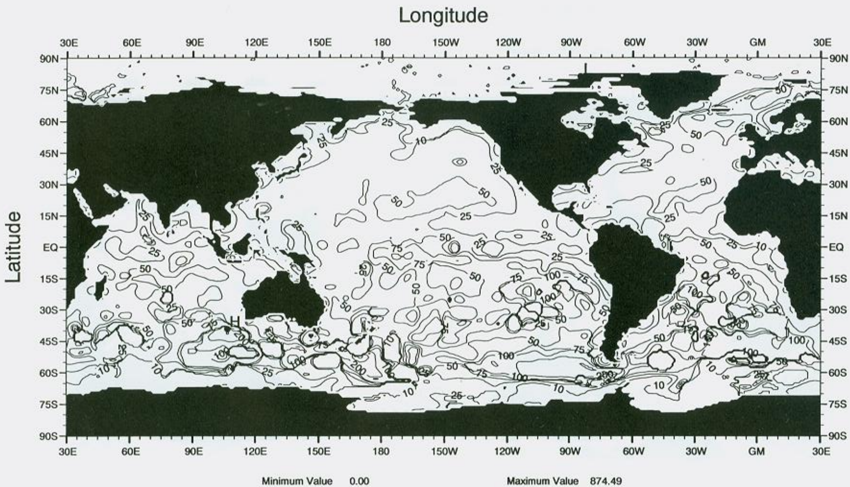


Fig. E10 October mean MLD (m) based on a variable sigma-t criterion

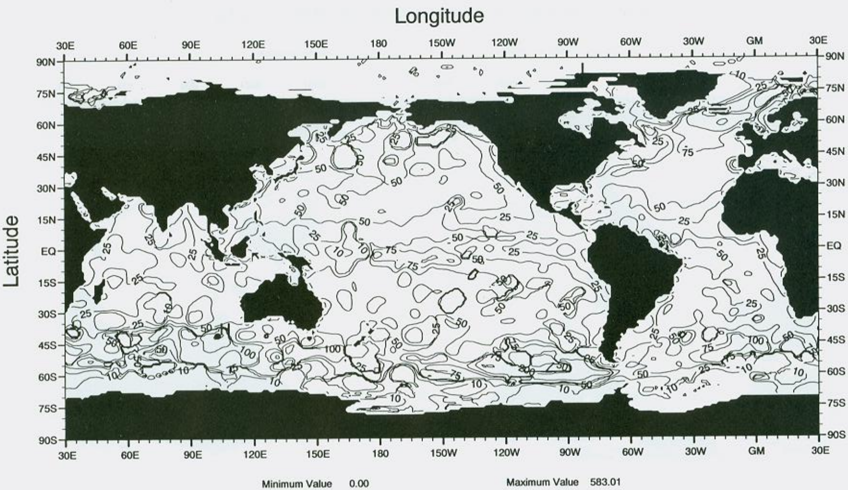


Fig. E11 November mean MLD (m) based on a variable sigma-t criterion

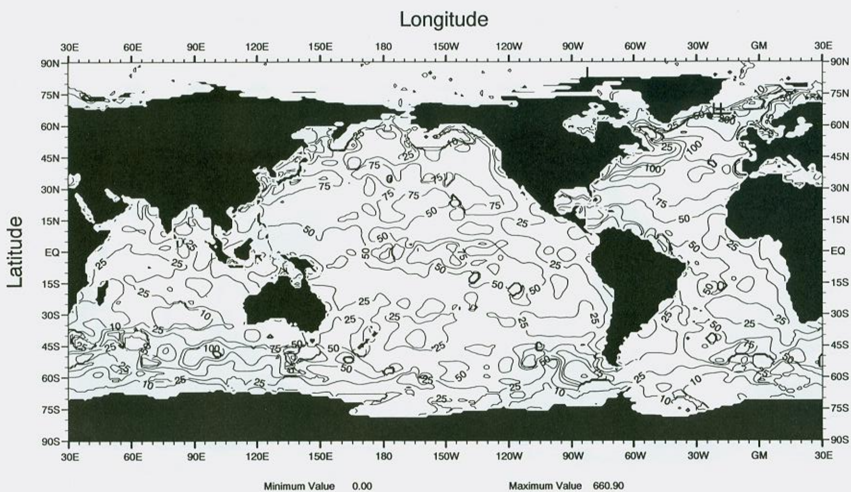


Fig. E12 December mean MLD (m) based on a variable sigma-t criterion

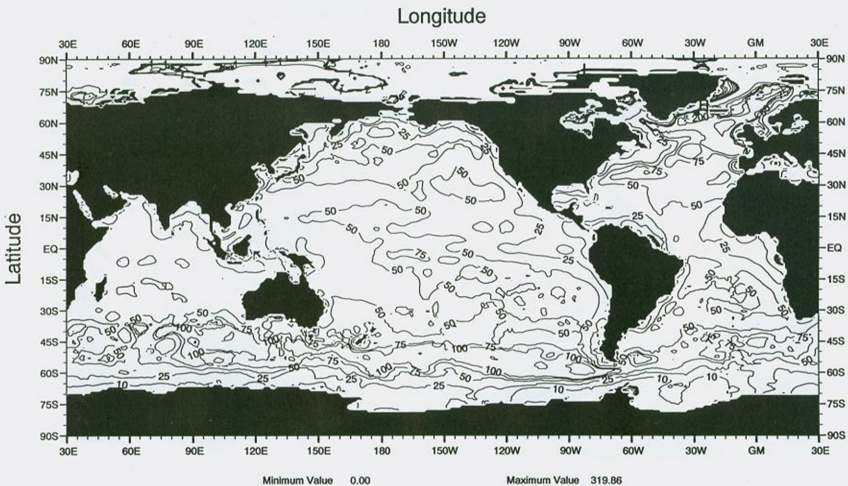


Fig. E13 Annual mean MLD (m) based on a variable sigma-t criterion

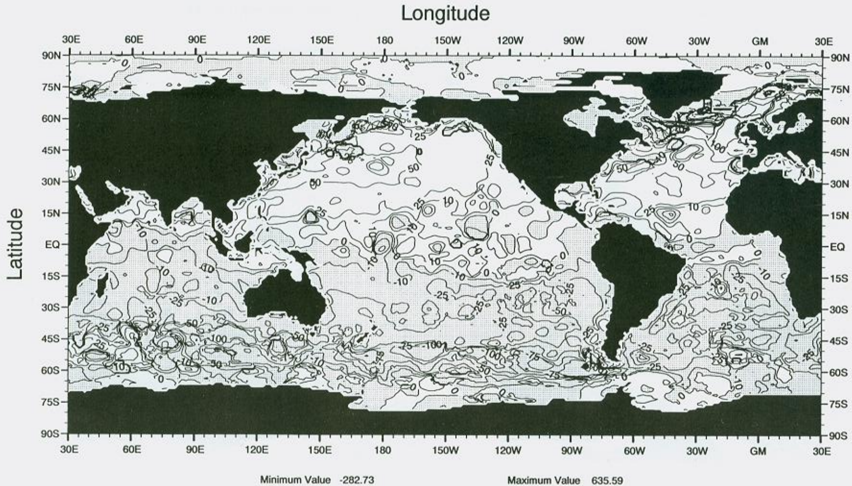


Fig. F1 January minus annual mean MLD (m) based on a variable sigma-t criterion

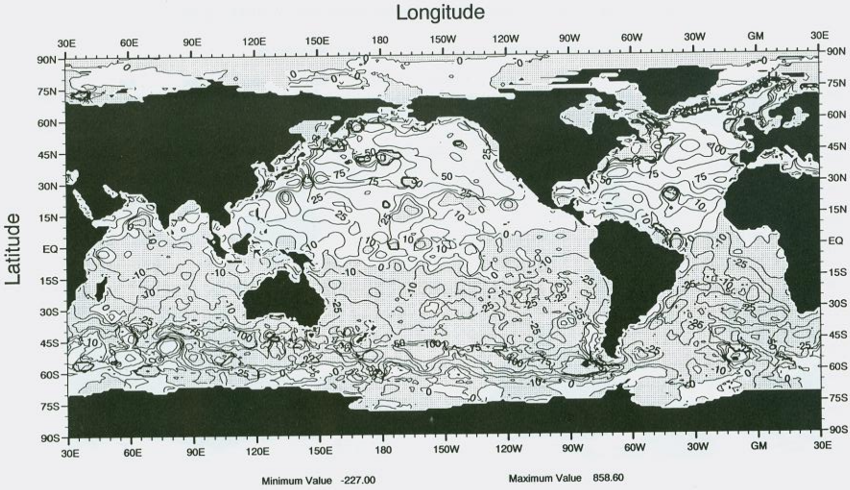


Fig. F2 February minus annual mean MLD (m) based on a variable sigma-t criterion

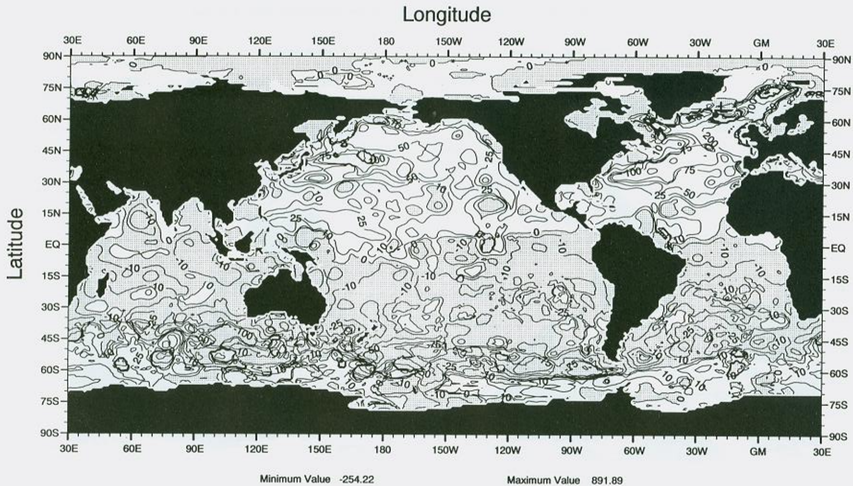


Fig. F3 March minus annual mean MLD (m) based on a variable sigma-t criterion

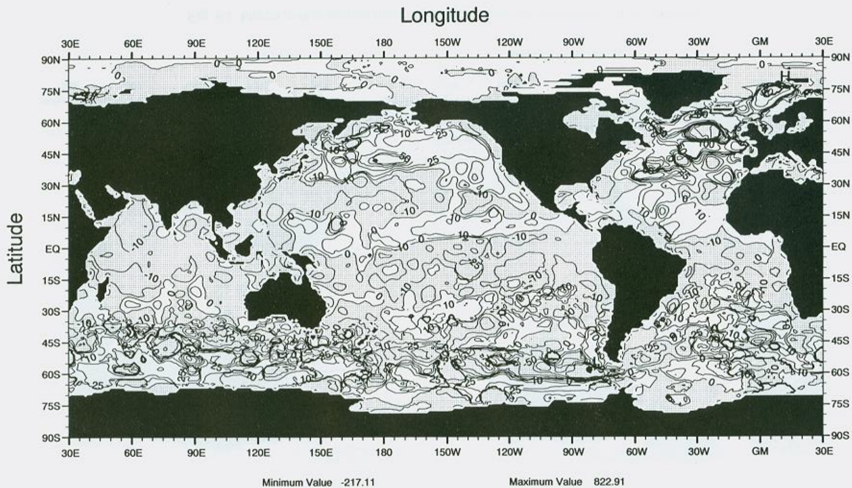


Fig. F4 April minus annual mean MLD (m) based on a variable sigma-t criterion

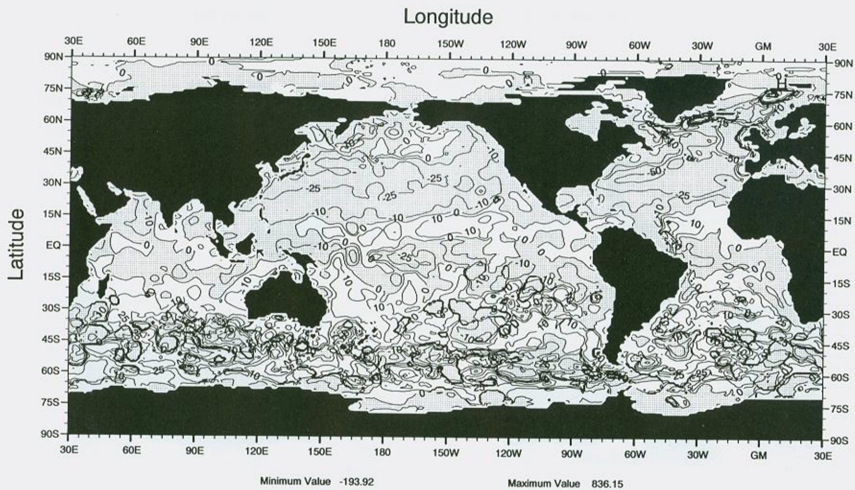


Fig. F5 May minus annual mean MLD (m) based on a variable sigma-t criterion

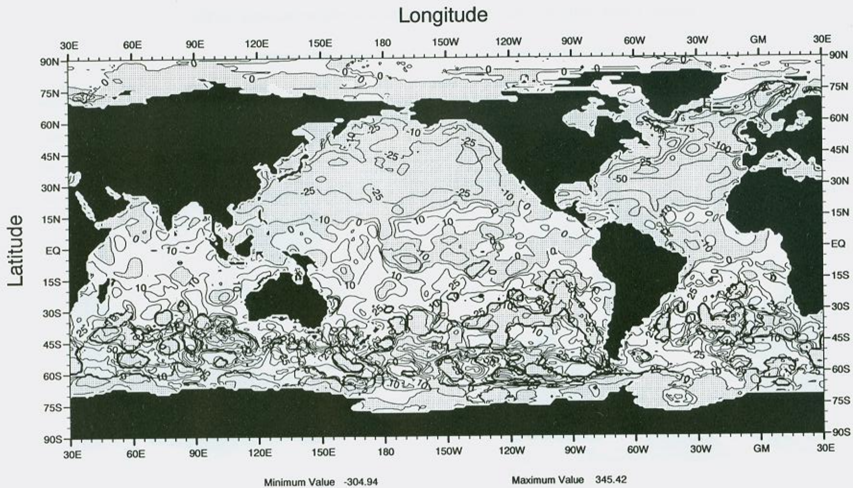
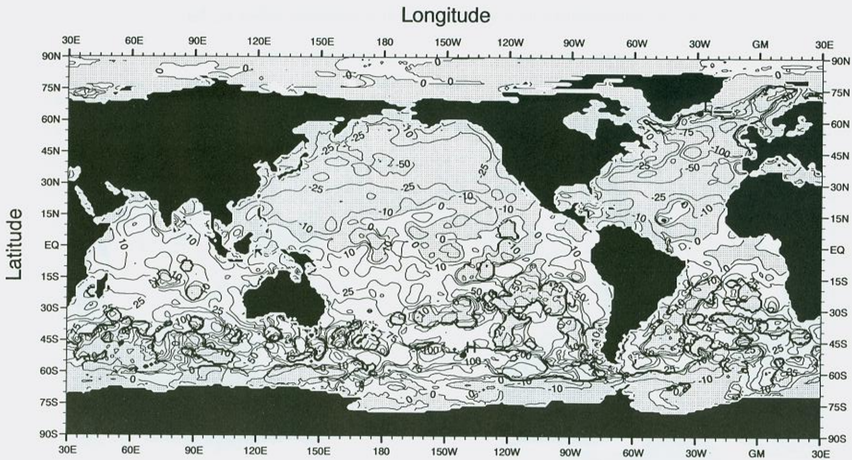


Fig. F6 June minus annual mean MLD (m) based on a variable sigma-t criterion



Minimum Value -312.95 Maximum Value 592.44

Fig. F7 July minus annual mean MLD (m) based on a variable sigma-t criterion

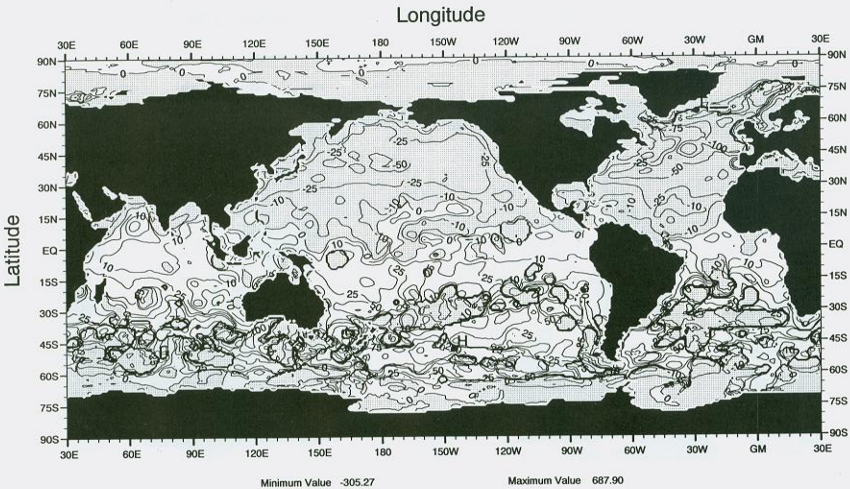


Fig. F8 August minus annual mean MLD (m) based on a variable sigma-t criterion

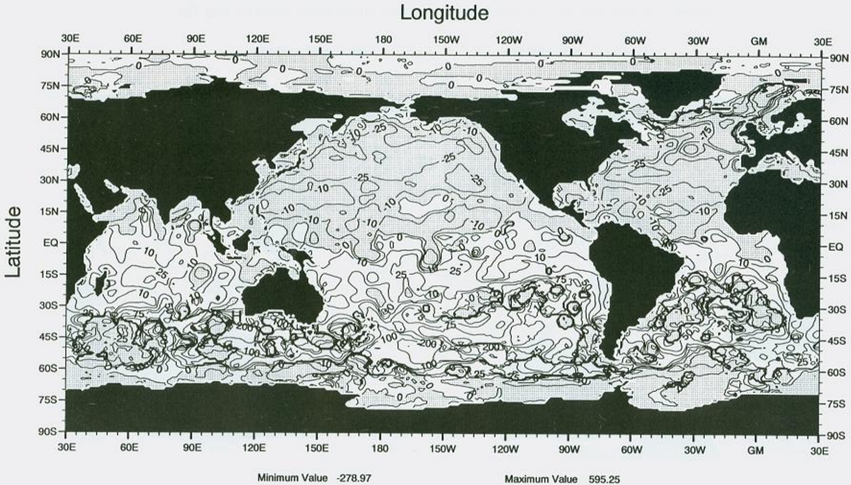


Fig. F9 September minus annual mean MLD (m) based on a variable sigma-t criterion

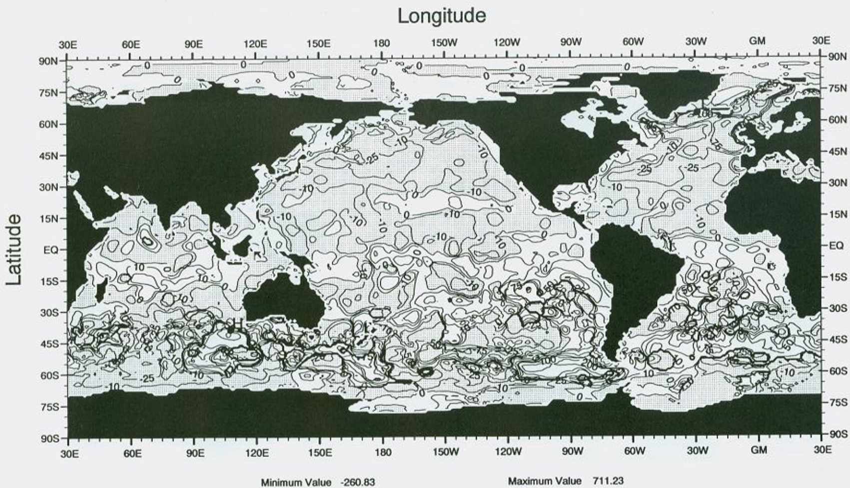


Fig. F10 October minus annual mean MLD (m) based on a variable sigma-t criterion

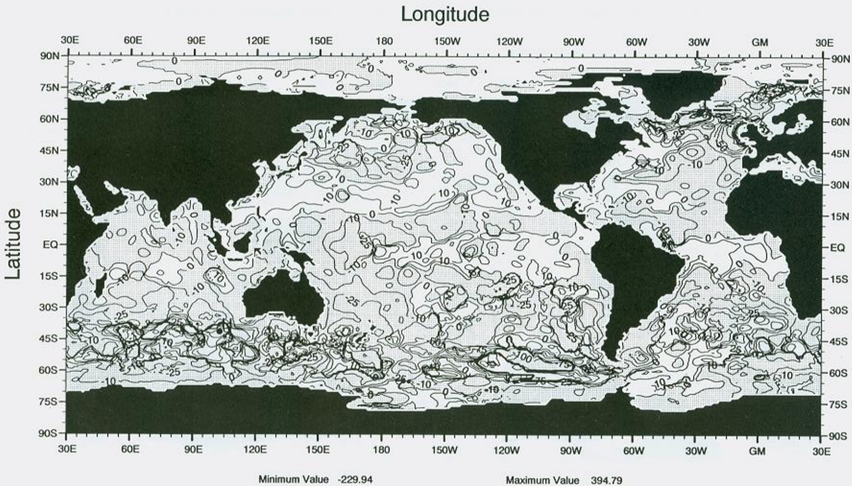
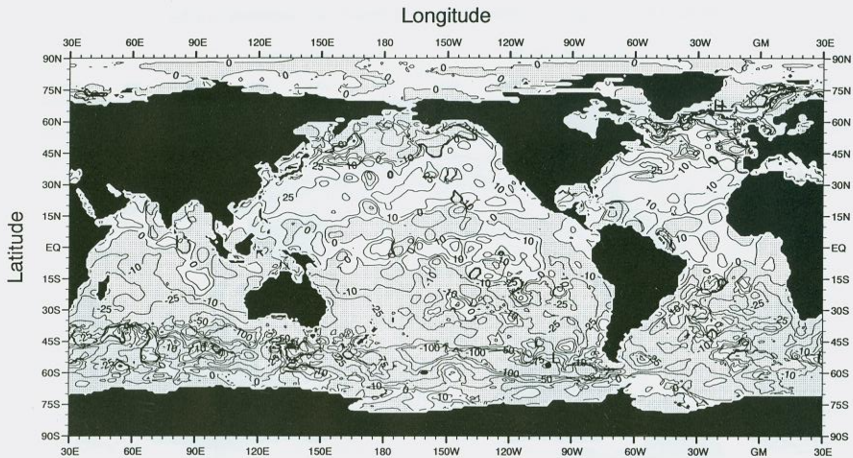


Fig. F11 November minus annual mean MLD (m) based on a variable sigma-t criterion



Minimum Value -211.85 Maximum Value 416.70

Fig. F12 December minus annual mean MLD (m) based on a variable sigma-t criterion

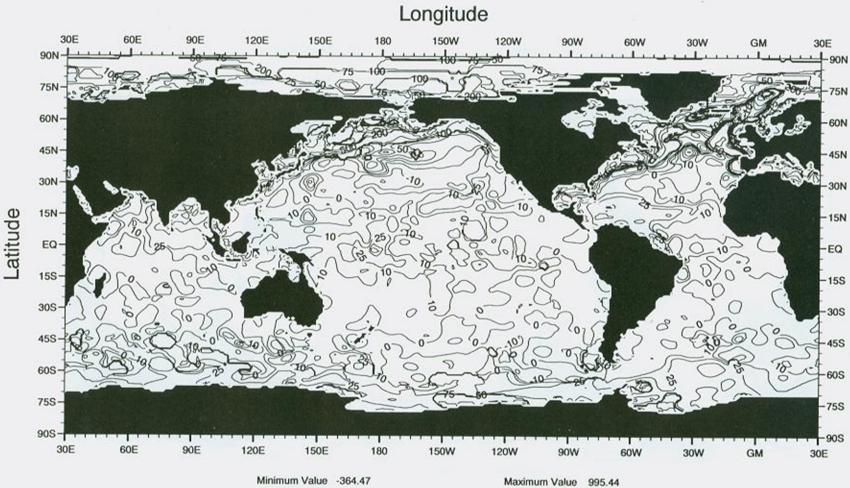


Fig. G1 January mean MLD (1) minus MLD (3)

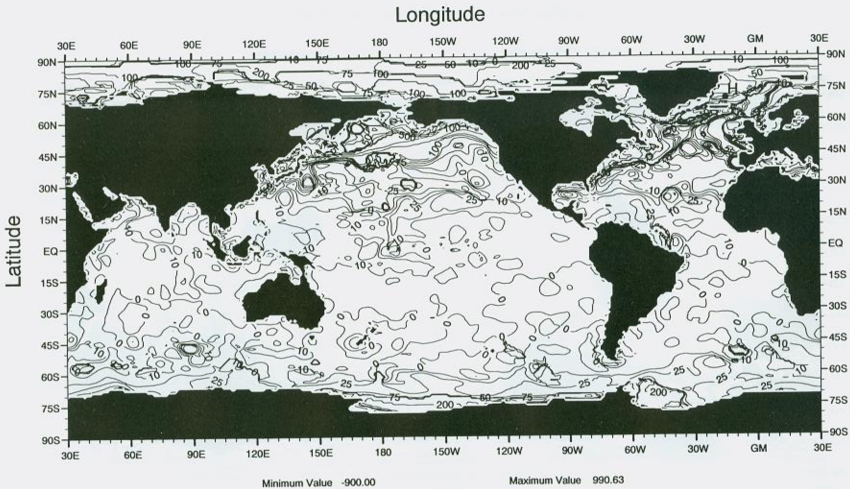


Fig. G2 February mean MLD (1) minus MLD (3)

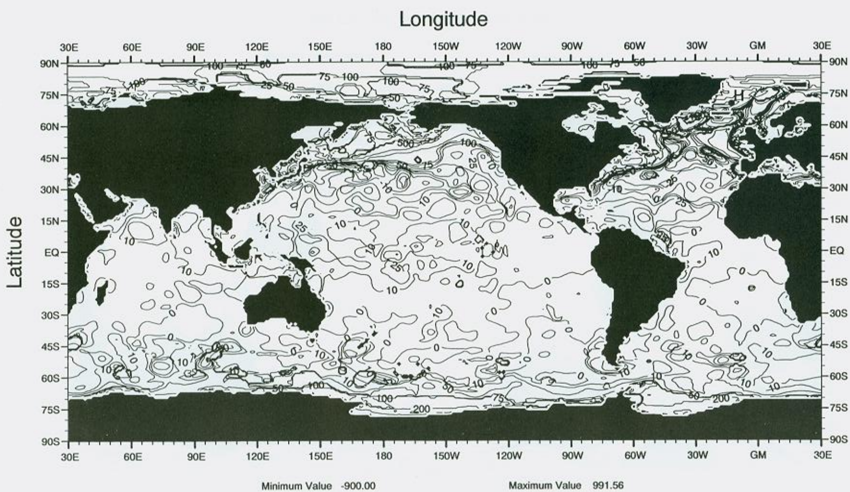
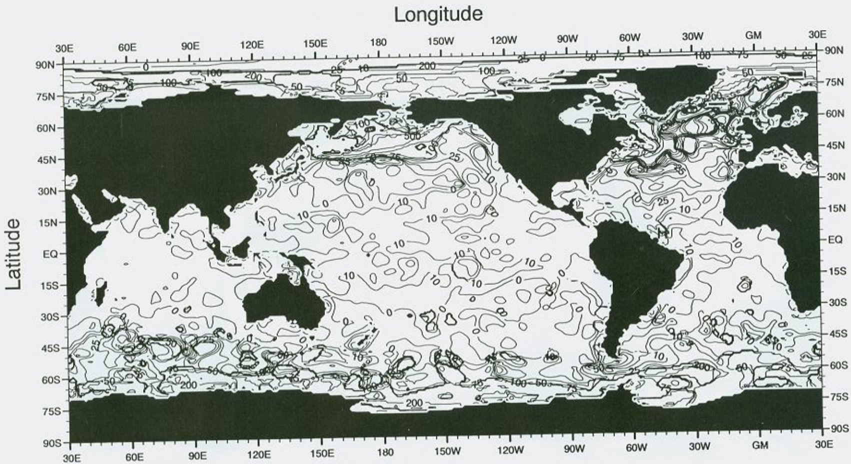


Fig. G3 March mean MLD (1) minus MLD (3)



Minimum Value -697.14

Maximum Value

Fig. G4 April mean MLD (1) minus MLD (3)

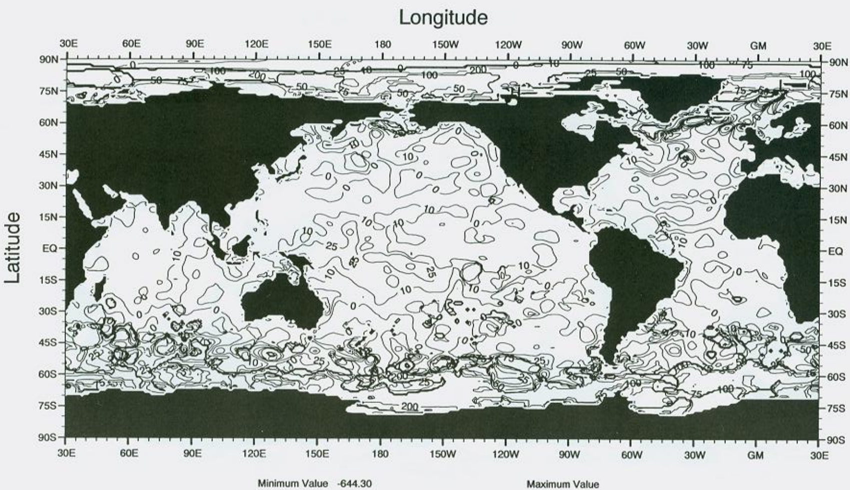
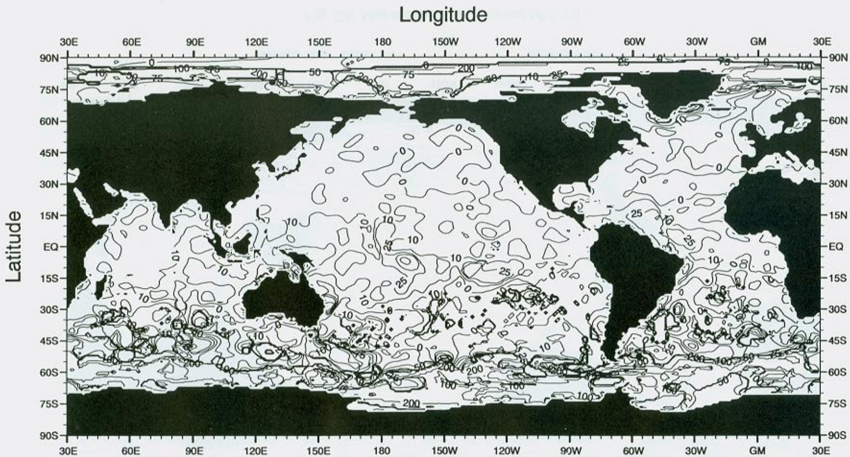


Fig. G5 May mean MLD (1) minus MLD (3)



Minimum Value -349.71 Maximum Value

Fig. G6 June mean MLD (1) minus MLD (3)

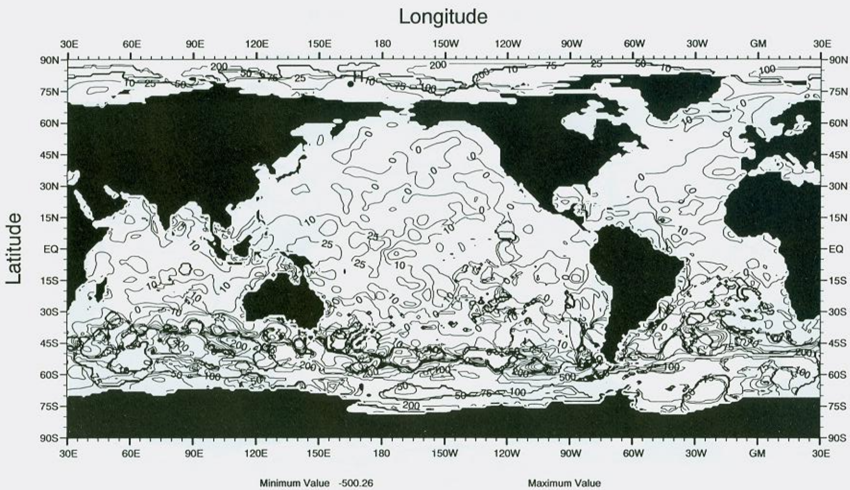


Fig. G7 July mean MLD (1) minus MLD (3)

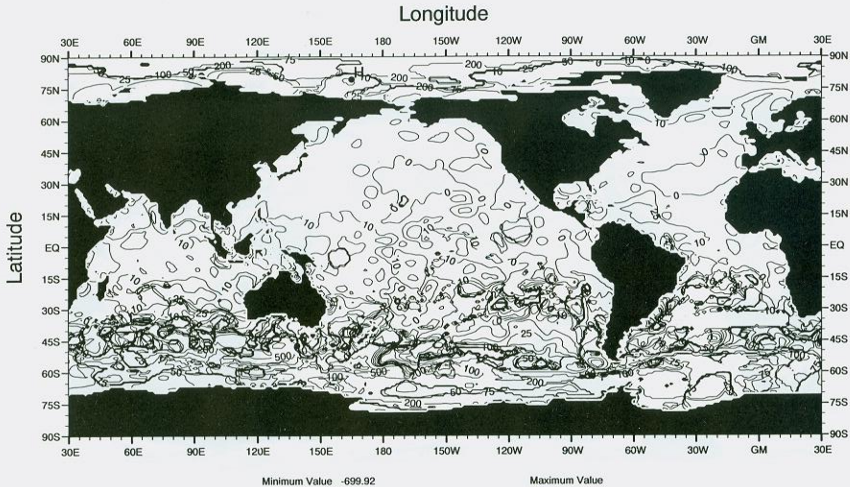


Fig. G8 August mean MLD (1) minus MLD (3)

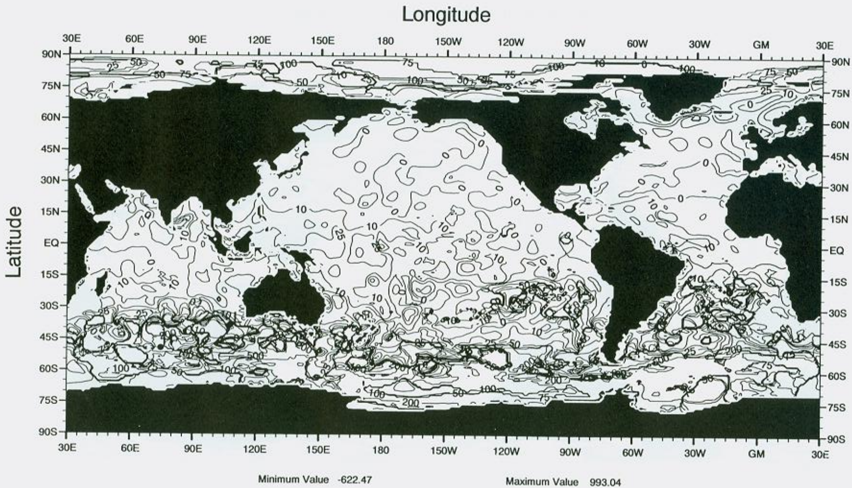


Fig. G9 September mean MLD (1) minus MLD (3)

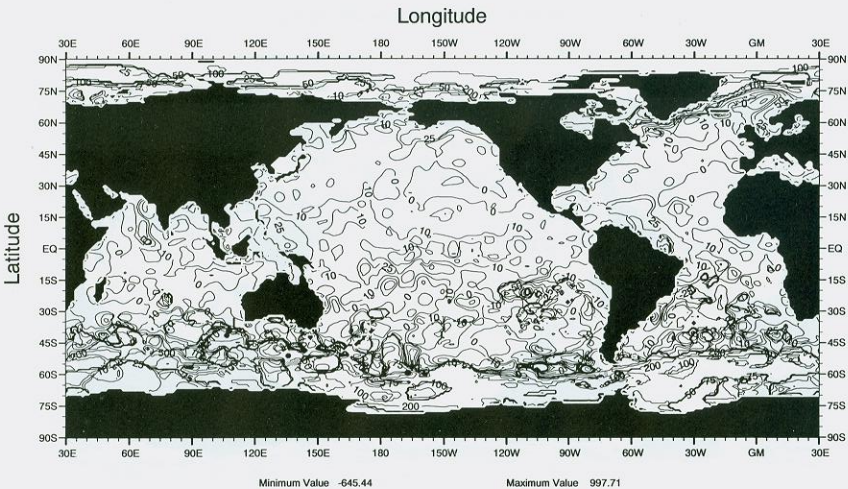
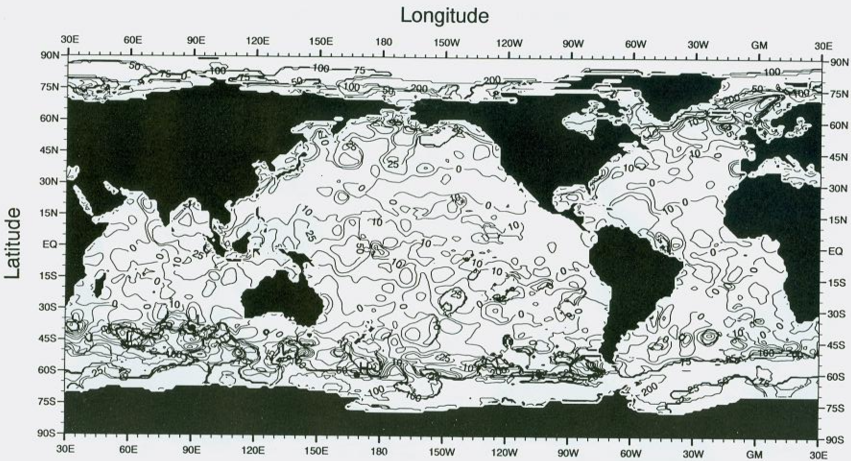


Fig. G10 October mean MLD (1) minus MLD (3)



Minimum Value -331.12 Maximum Value 994.58

Fig. G11 November mean MLD (1) minus MLD (3)

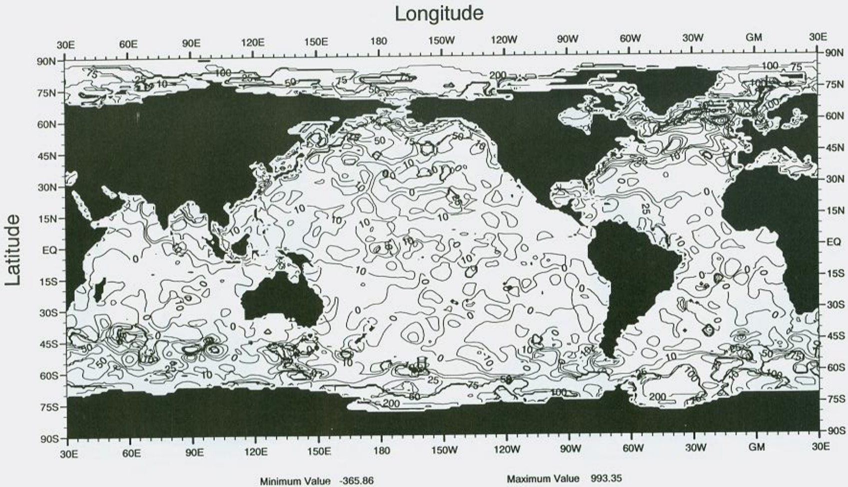


Fig. G12 December mean MLD (1) minus MLD (3)

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NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of the solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

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National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service
Washington, D.C. 20233