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SEASONAL VARIABILITY OF GLOBAL MIXED LAYER DEPTH FROM WOD98 TEMPERATURE AND SALINITY PROFILES

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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U.S. DEPARTMENT OF COMMERCE
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National Marine Fisheries Service
Penelope Dalton, Assistant Administrator for Fisheries

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Seasonal variability of global mixed layer depth from WOD98 temperature and salinity profiles

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Abstract

Global monthly mean mixed layer depths (MLD) are calculated using three different criteria applied to individual vertical profiles of temperature and salinity from the World Ocean Data Base 1998. The MLD calculated from the individual profiles are averaged within climatological months and 1° by 1° boxes. This approach yields mean MLD values as well as standard deviations and number of observations. The ASCII data files and color maps of the global monthly mean MLD, standard deviations of MLD, and number of observations are available via the Internet at http://www.pfeg.noaa.gov/products/PFEL_Products/monthly_observational_means/WOD98/WOD98.html.

Comparison of the MLD computed from the individual profiles of temperature and density versus the MLD computed from the climatological profiles of temperature and density shows quantitative differences in dynamically active areas of the world ocean such as Kuroshio and Gulf Stream extensions, Labrador Current, Alaska Current and Oyashio Current. Comparison of the MLD based on the temperature criterion versus the MLD based on the density criteria shows their similarity in mid-latitudes and qualitative differences in subpolar latitudes as well as in dynamically active areas such as Kuroshio and Gulf Stream extensions.

1. Introduction

Variations in mixed layer depth (MLD) have been shown to have an important effect on biological productivity in the ocean. A recent study (Hobday and Boehlert, 1999) determined that seasonal MLD variations might be a leading indicator of the survival of North American salmon. Other studies (Polovina et. al., 1995; Freeland et. al., 1997) suggest that MLD may also be an important mechanism in decadal scale changes in productivity. Unfortunately, long time series of MLD are scarce, and in addition, the concept of mixed layer depth is not well defined.

In this report we present global 1-degree monthly averages of mixed layer depth computed from three definitions of MLD using data from the World Ocean Data Base 1998 (WOD98, Levitus et al., 1998). The method is similar to that of a previous study of seasonal variability of mixed layer depth (Monterey and Levitus, 1997), with several exceptions. The major difference between the two is that in this study MLD is calculated from individual raw temperature and salinity profiles and then averaged, while in the previous study MLD was computed from climatological averages. The present method allows for the computation of statistics of mixed layer depth variability that were lacking in the previous study.

2. Method

Mixed layer depth fields were calculated from the individual temperature and salinity profiles available from the WOD98, and then averaged within climatological months and 1° by 1° boxes. The MLD criteria (Monterey and Levitus, 1997) described in Section 3 were applied to the vertical profiles of temperature and density. The density profiles were computed from temperature and salinity profiles taken at the same location. No horizontal interpolation was applied. The mean mixed layer depth and standard deviation were then computed for each month and 1° box. MLD for 1° boxes with no observations were treated as missing. This approach yields mean mixed layer depth values as well as standard deviations and number of observations. The standard deviations are computed for all months and 1° boxes that have two observations or more.

The WOD98 standard level data provides vertical profiles of temperature and salinity at 40 depths (Conkright et. al., 1998). MLD calculated from these profiles are not rounded to the standard levels, but rather linearly interpolated between them. Because the data coverage rapidly decreases with depth below about 500 m level, the MLD criteria were applied in the upper 500 m (standard levels 1 through 14). If an MLD criterion were not met within this depth range the MLD was set to missing. Such a cut off is relevant to limited polar areas during late winter / spring season.

3. The MLD criteria

There is a wide range of meanings attached by different authors to the concept of the ocean surface mixed layer. A definition of the mixed layer can be based on different parameters, for example temperature or density. For each parameter the MLD criteria used in the literature fall into two categories: the difference criteria and the gradient criteria.

The difference criteria detect the shallowest depth where the difference of temperature or density from its magnitude at the sea surface exceeds a fixed or geographically adjustable critical value.

The gradient criteria detect the shallowest depth where the vertical derivative of temperature or density exceeds a given critical value. These criteria assume an increased vertical derivative of temperature or density beneath the monthly mean mixed layer. In other words, they assume the existence of a seasonal thermocline or pycnocline.

The difference criteria are more universal, as they are applicable in geographic areas or within time periods where (when) the seasonal thermocline (pycnocline) does not exist. MLD based on difference criteria is also more stable compared to MLD based on gradient criteria (Brainerd and Gregg, 1995). As illustrated by the maps of MLD described below, MLD based on the temperature difference criteria and MLD based on the density difference criteria with the appropriately chosen values of the parameters are about the same in mid-latitudes. However, these quantities are somewhat different in subequatorial latitudes and significantly different in subpolar latitudes due to effect of salinity on MLD. Preference for a temperature as opposed to a density based criterion depends on the application: temperature criteria may be more relevant for studying heat capacity of the mixed layer, whereas density criteria may be more relevant for studying vertical mixing.

The following three criteria were used to produce the MLD maps shown in Appendixes 1,2:

- The fixed temperature difference criterion

$$\Delta T = 0.5\,^{\circ}C \qquad (1)$$

where $\Delta T = T(z{=}0)-T(z{=}MLD)$, T is the *in-situ* temperature. The temperature criterion based on the potential temperature would require use of the salinity profiles along with the *in-situ* temperature profiles hence would significantly reduce MLD coverage.

- The fixed density difference criterion

$$\Delta\sigma = 0.125 \text{ (sigma units)} \qquad (2)$$

where $\Delta\sigma = \sigma(z{=}0)-\sigma(z{=}MLD)$, $\sigma = (\rho(g/cm^3)-1)*10^3 = \rho(kg/m^3)-1000$, ρ is the potential density computed from the temperature and salinity based on the international equation of state of sea water (Fofonoff and Millard, 1983).

- The variable density difference criterion

$$\Delta\sigma = (\Delta\sigma/\Delta T)|_{S,P}(S_0,T_0,P_0)*\Delta T \text{ (sigma units)} \qquad (3)$$

where $\Delta T = 0.5^{\circ}C$ and the term $(\Delta\sigma/\Delta T)|_{S,P}$ is computed for sea surface values of salinity, temperature and pressure, S_0,T_0,P_0, at each geographical location based on the international equation of state of seawater. The criterion (3) specifies the variable density difference $\Delta\sigma$ that corresponds to the fixed temperature difference $\Delta T = 0.5^{\circ}C$

taking into account the geographic variability of the sea surface temperature and salinity. The concept of a variable density criterion was introduced by Levitus (1982) and has been used for MLD computations by Sprintall and Tomczak (1990) and by Monterey and Levitus (1997).

MLD criteria based on density account for the effects of salinity as well as temperature on MLD. Typically, a density criterion detects the minimum of the depths of the seasonal thermocline and the seasonal halocline.

The value 0.125 in the fixed density criterion (2) approximately corresponds to a temperature difference of 0.5 °C for water with salinity of S = 35.0 ‰ and temperature in the 17 °C to 19 °C range, which is characteristic for the mid-latitudes.

4. MLD Maps

Mixed layer depth results were visualized using the graphical software analysis package Ferret developed at PMEL/NOAA (http://ferret.wrc.noaa.gov/Ferret). In order to realistically depict data coverage, we have chosen to represent mixed layer depth by shading the results for each 1° box rather than use any contouring or extrapolation techniques. Boxes with no observations are not shaded.

ASCII data files and colored GIF images of monthly mixed layer depth and standard deviation for every criterion defined in Section 3 are available for viewing and downloading (http://www.pfeg.noaa.gov/products/PFEL_Products/monthly_observational_means/WOD98/WOD98.html). Also available is an animation of the seasonal cycle of the MLD computed from individual observations (mld.obs).

Maps of mld.obs for every month and every criterion as well as maps of standard deviation and number of observations are included in the Appendix 1. These maps are identified by the upper titles, which stand for:

mld.t - MLD based on the fixed temperature criterion (1)
mld.pd - MLD based on the fixed potential density criterion (2)
mld.pdvar - MLD based on the variable potential density criterion (3)

Suffixes 01 through 12 in these titles refer to the month.

Maps of mld.t have considerably better data coverage than the maps of the mld.pd and mld.pdvar. This is because salinity observations are much sparser than temperature observations. Estimates of mld.t are based solely on temperature, whereas estimates of mld.pd and mld.pdvar require both temperature and salinity observations taken at the same location.

5. General features of the MLD fields

The seasonal cycle, with a shallower mixed layer in summer than winter, is evident in both hemispheres in the MLD fields calculated using all three criteria. The winter MLD is deeper than the summer MLD by a factor of ten in high latitudes (50° - 60°), by a factor of two in mid-latitudes (20° - 40°), and by 10-20% in equatorial latitudes (10°S - 10°N). The spring transition, the abrupt shoaling of the MLD during spring compared to its gradual deepening during autumn and winter, is also evident in both mid- and high latitudes.

As illustrated by the maps of the mld.t, which have nearly complete data coverage in the northern hemisphere, there is a correspondence between the mld.t and the regional scale features of ocean dynamics such as subtropical gyres and upwelling areas. This correspondence is visible during the deep phase of the MLD (December through April, mld.t.12 through mld.t.04) whereas during the shallow phase the MLD distribution is more homogeneous (see mld.t.7 through 10). As one can see on maps mld.t.12 through mld.t.04, the mld.t is deeper along the perimeters of the subtropical gyres compared to their interiors. In the eastern equatorial parts of the oceans, mld.t, mld.pd, and mld.pdvar remain shallow (< 50 m) all year round. The latter areas of shallow MLD have a tongue extending westward along the equator and become narrower as one moves northward or southward from the equator fading out at about 40 °N and 40 °S.

6. Comparison of MLD computed from individual observations and climatology

A previous study of seasonal variability of the global mixed layer depth (Monterey and Levitus, 1997) was based on the climatologically averaged vertical profiles of temperature and salinity available from the World Ocean Data Base 1994 (WOD94, Levitus and Boyer, 1994; Levitus et. al., 1994). In this approach individual temperature and salinity profiles were first averaged within the climatological month and 1° by 1° boxes, and horizontally interpolated to fill in the gaps due to missing data. Comparisons between these values of MLD and those produced in the present study follow, with the same MLD criteria used in both studies.

Color figures in Appendix 2 identified by the upper titles

mld.t.obs-clim

mld.pd.obs-clim

mld.pdvar.obs-clim

show MLD computed from individual observations (.obs), the MLD computed from climatology (.clim) and their differences (.obs-.clim) based on the fixed temperature criterion (1) (mld.t), the fixed density criterion (2) (mld.pd) and the variable density criterion (3) (mld.pdvar) respectively. These fields are shown for two months, January (01) and July (07).

The two upper maps of these figures show that spatial patterns of the MLD calculated from the individual profiles and those calculated from climatology are qualitatively similar. However, the difference between the mld.obs and mld.clim (bottom maps) show a pattern of coherent quantitative differences between the mld.obs and the mld.clim in the Kuroshio and Gulf Stream extension areas as well as in subpolar latitudes.

In particular, as one can see on Figure mld.t.obs-clim.01, Appendix 2, in the case of MLD based on temperature criterion (1) the difference mld.obs-mld.clim exhibits fronts which visually coincide with the Gulf Stream and Kuroshio extensions. The difference mld.obs-mld.clim has opposite sign on different sides of these fronts. The mld.obs and mld.clim themselves do not have fronts in these areas. Figure mld.pd.obs-clim.01 shows that in case of the MLD based on density criterion the difference mld.obs-mld.clim exhibits a different pattern.

7. Comparison of MLD based on different criteria

Colored figures included in Appendix 2 identified by the upper titles

mld.t-pd-pdvar

show the differences between

mld.t and mld.pd,

mld.t and mld.pdvar,

mld.pd and mld.pdvar,

for January (01) and July (07). These figures show that in subpolar latitudes, as well as in the Kuroshio and Gulf Stream extension areas, the winter mld.t is deeper than the winter mld.pd and mld.pdvar by 50-150 m. As discussed in Monterey and Levitus (1997), the difference between mld.t and mld.pd or mld.pdvar in subpolar latitudes is due to the effects of salinity. The differences in the Kuroshio and Gulf Stream areas are new features of the MLD based on individual profiles. They are not present on the MLD maps based on the climatological temperature and salinity profiles (see, e.g., Monterey and Levitus, 1997, Fig. G1). The Kuroshio and Gulf Stream extension areas are also characterized by increased values of standard deviations of MLD. These maps show that the difference between the mld.pd.-mld.pdvar is much smaller than the difference between the mld.t and mld.pd or the difference between the mld.t and mld.pdvar and illustrate that the mld.pdvar is defined in such a way as to coincide with the mld.pd in mid-latitudes.

8. Conclusion

Computation and visualization of MLD fields computed from individual observations and then averaged within climatological months and 1° boxes are qualitatively similar to MLD fields computed from the climatologically averaged temperature and density profiles. Differences are associated with the dynamically active areas of the world ocean such as Kuroshio and Gulf Stream extensions as well as Labrador Current, Alaska Current and Oyashio Current. MLD fields computed from individual observations are accompanied by standard deviations and number of observations for every month and 1° box. The standard deviation is a measure of variability required for estimation of statistical significance of climatic shifts of MLD. The number of observations for temperature and salinity profiles shows that the MLD based on the temperature criterion has much better data coverage compared to the MLD based on the density criteria which require both temperature and salinity data. Preference for the MLD criterion depends on the application. The MLD based on temperature criterion and the MLD based on density criteria are similar in most mid-latitude areas but differ in subpolar latitudes as well as in dynamically active areas such as Kuroshio and Gulf Stream extensions.

Acknowledgements

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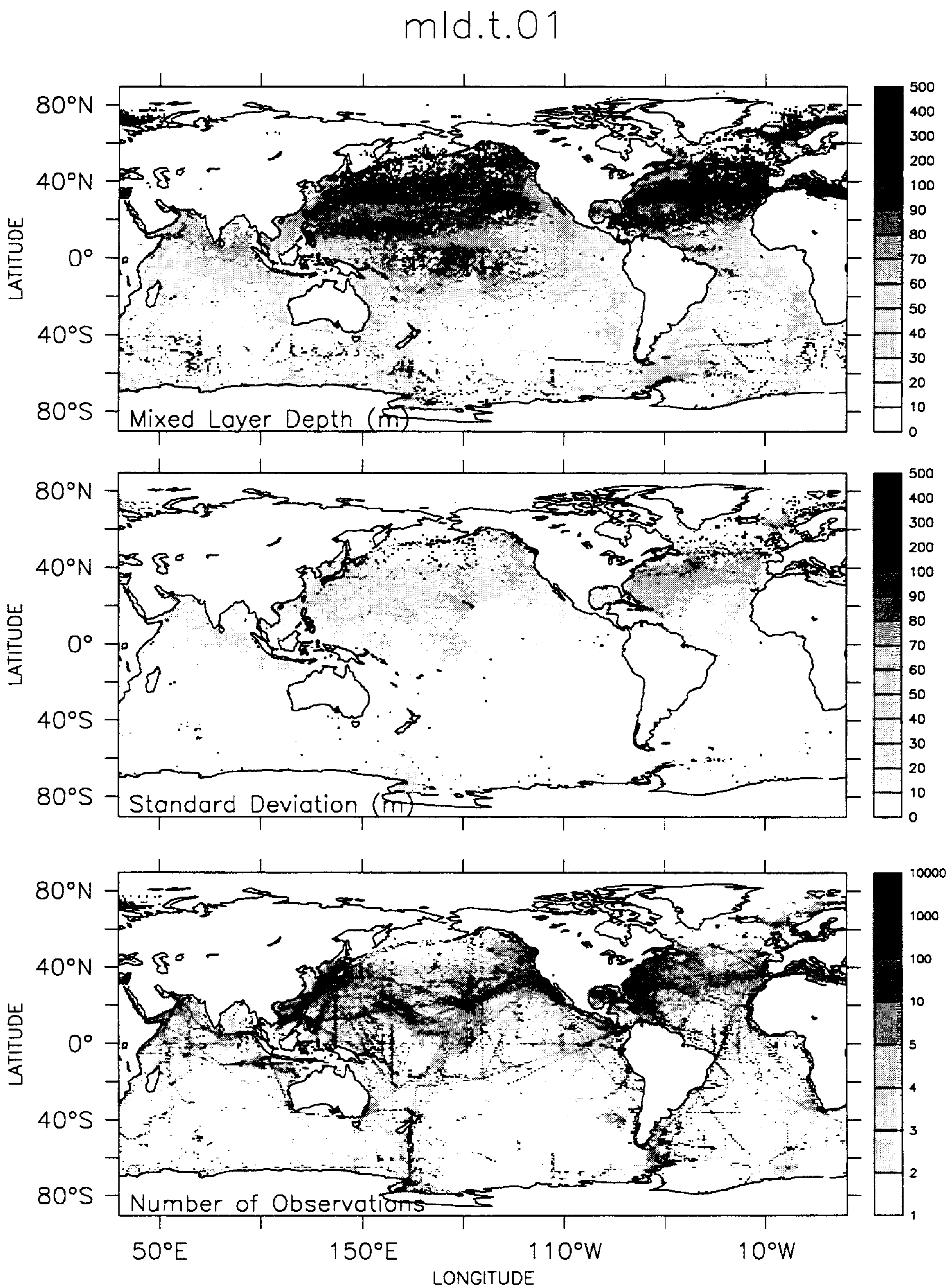
Appendix I

Monthly Mixed Layer Depth Maps


mld.t.01
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
LATITUDE
LONGITUDE
80°N
40°N
0°
40°S
80°S
50°E
150°E
110°W
10°W
500
400
300
200
100
90
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70
60
50
40
30
20
10
0
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1000
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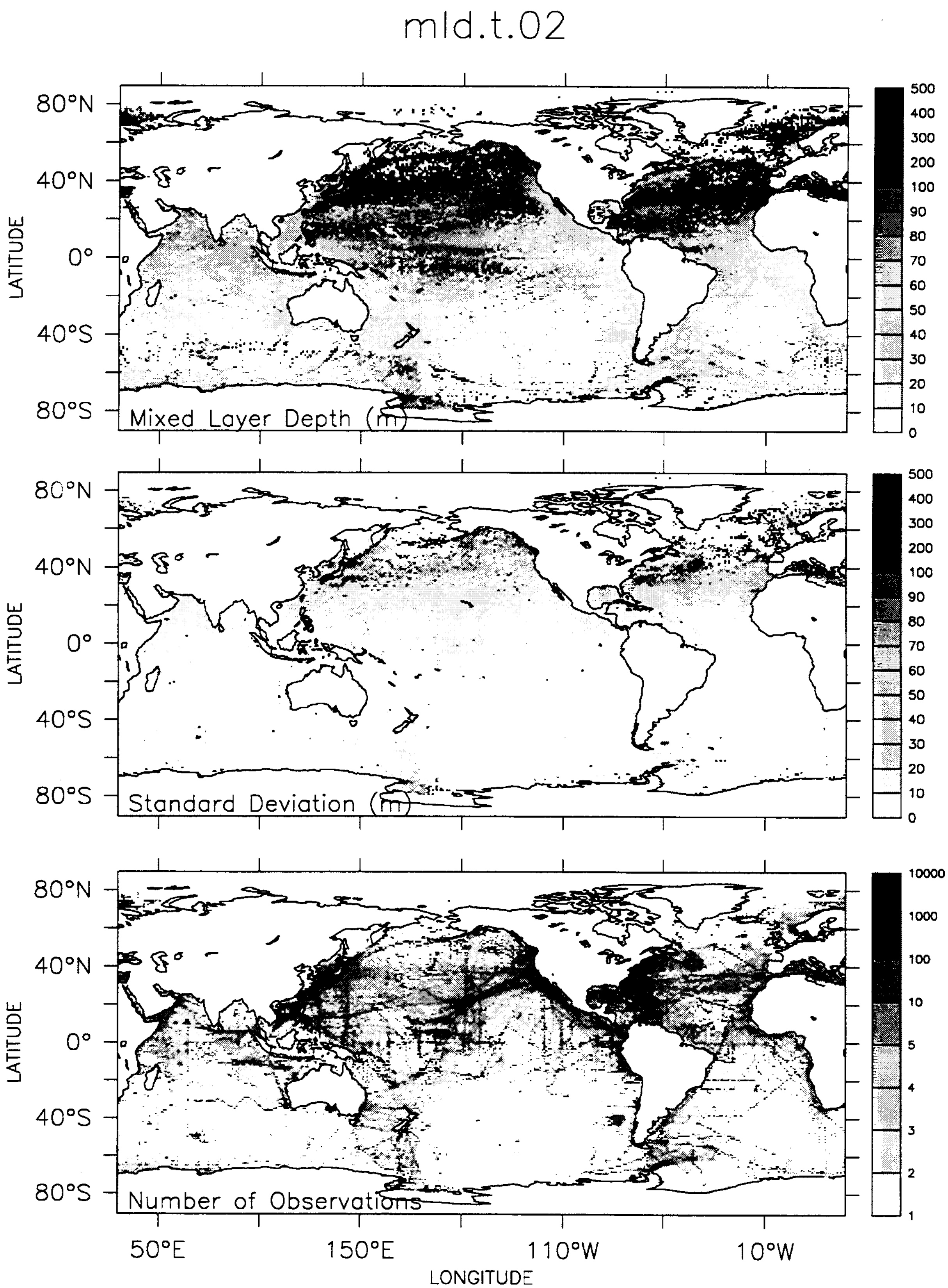
10
5
4
3
2
1



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Standard Deviation (m)
Number of Observations
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LONGITUDE
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40°N
0°
40°S
80°S
50°E
150°E
110°W
10°W
0
10
20
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40
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2
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5
10
100
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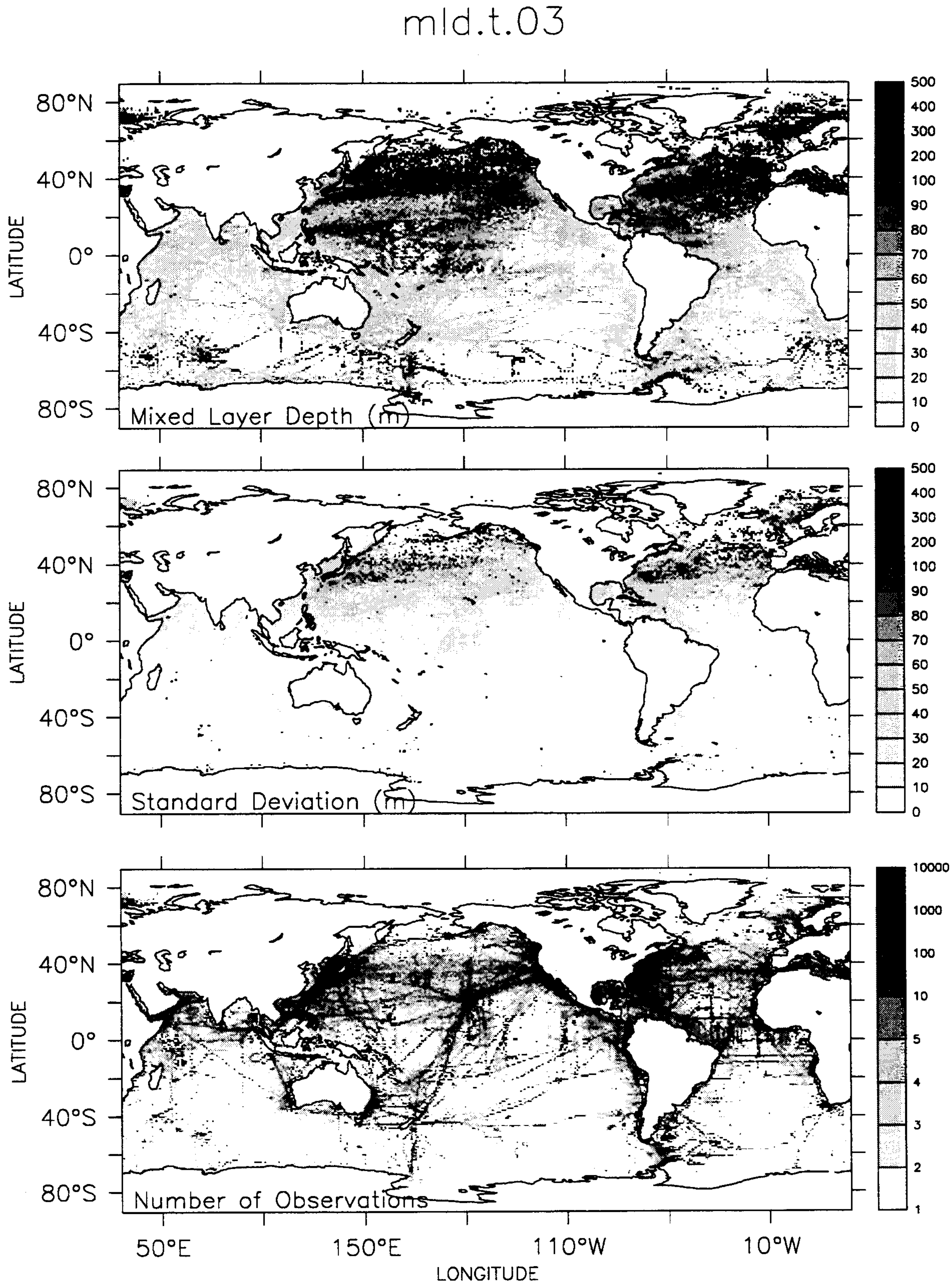
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50°E
150°E
110°W
10°W
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400
300
200
100
90
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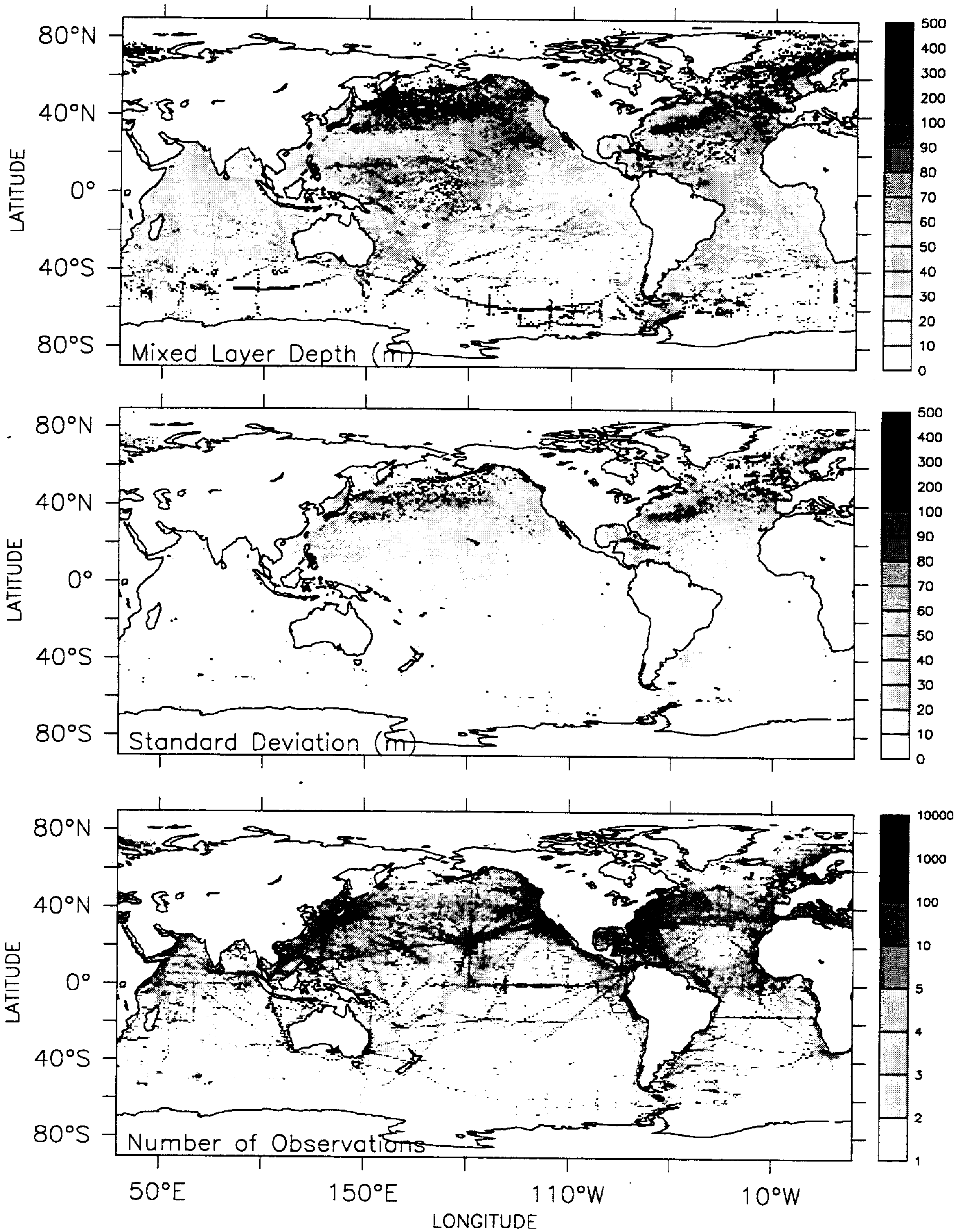
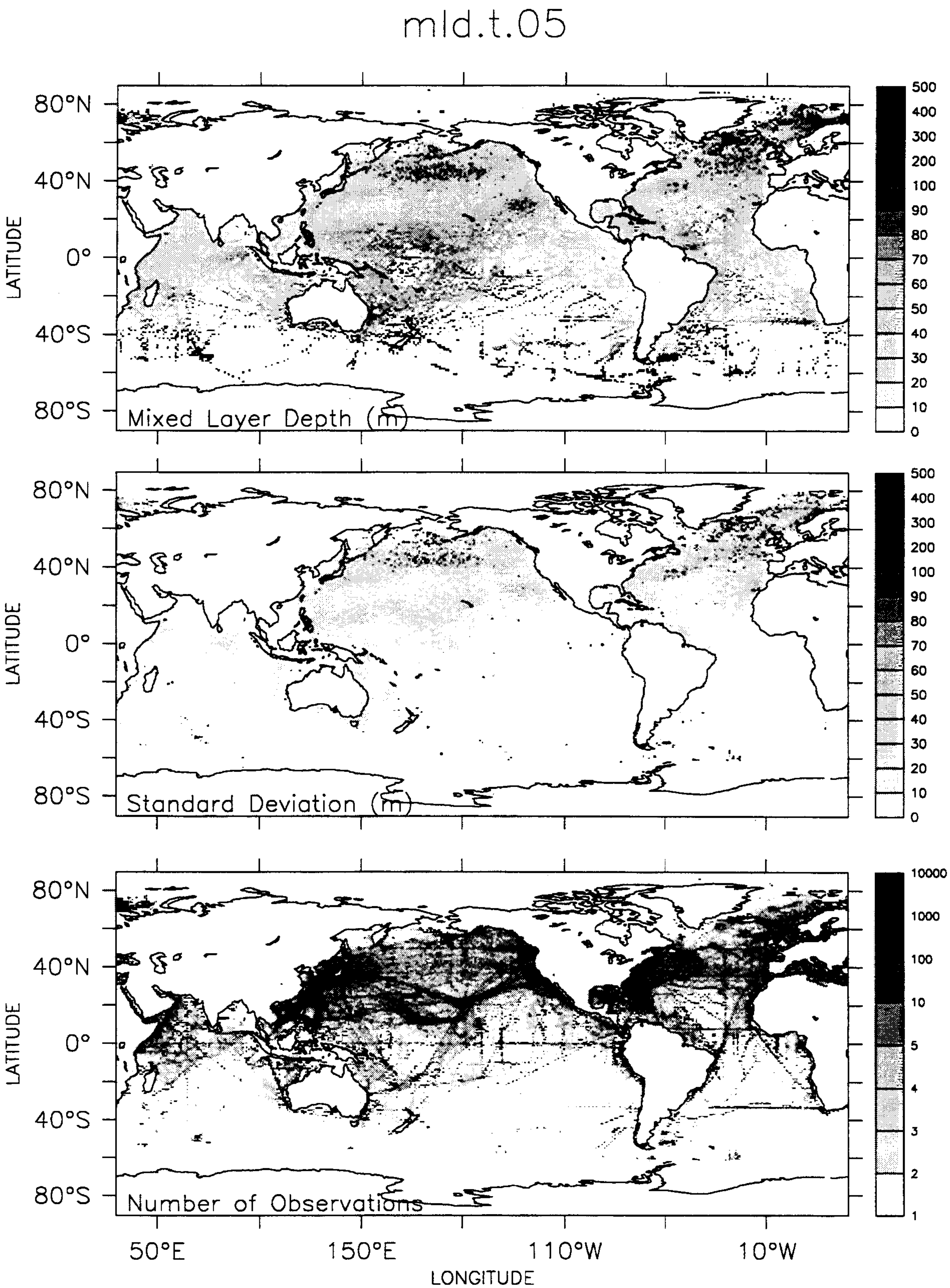
5
4
3
2
1

mld.t.04



80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE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80°S
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90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
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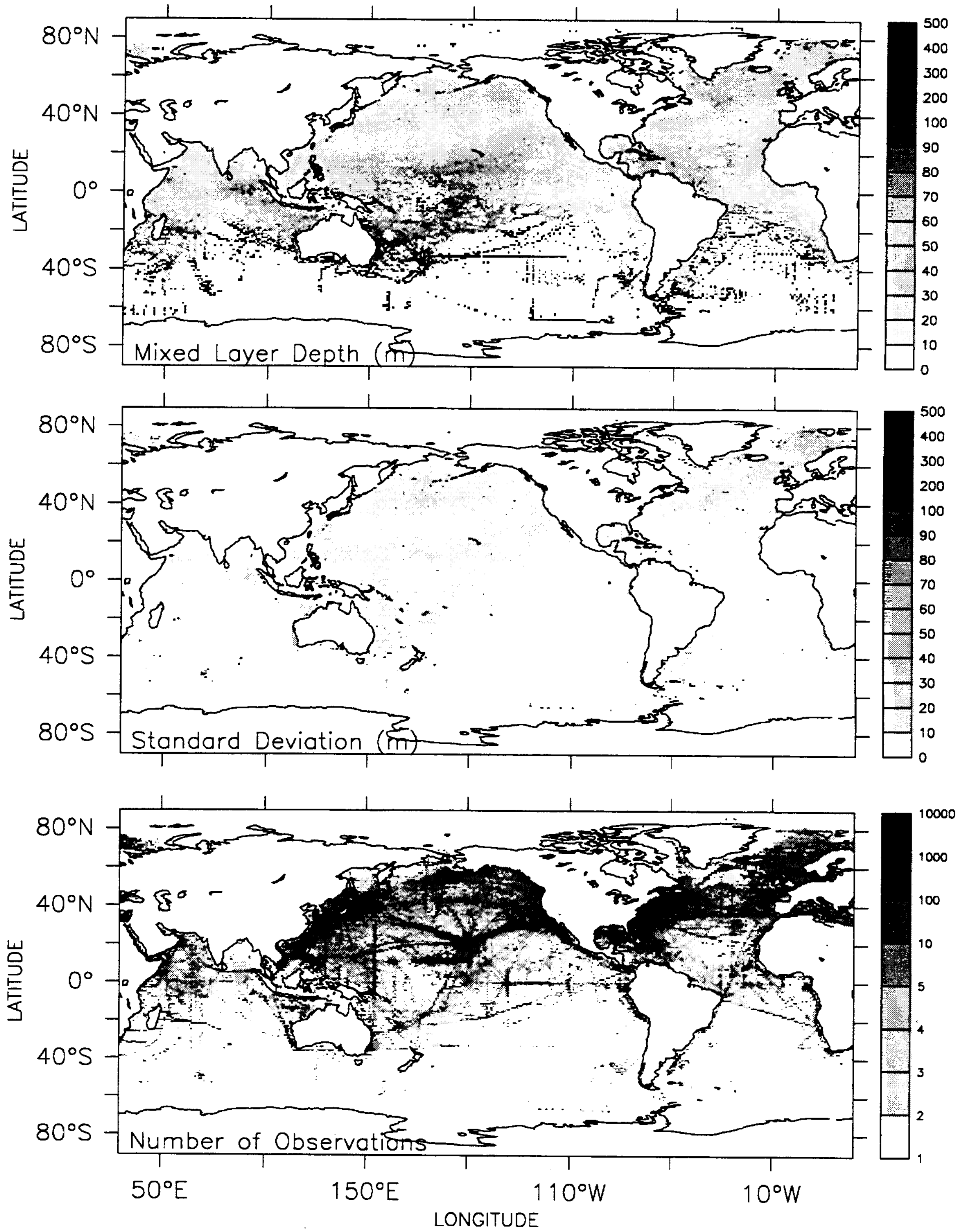
10°W
LONGITUDE

mld.t.06



Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
LATITUDE
80°N
40°N
0°
40°S
80°S
LONGITUDE
50°E
150°E
110°W
10°W
0
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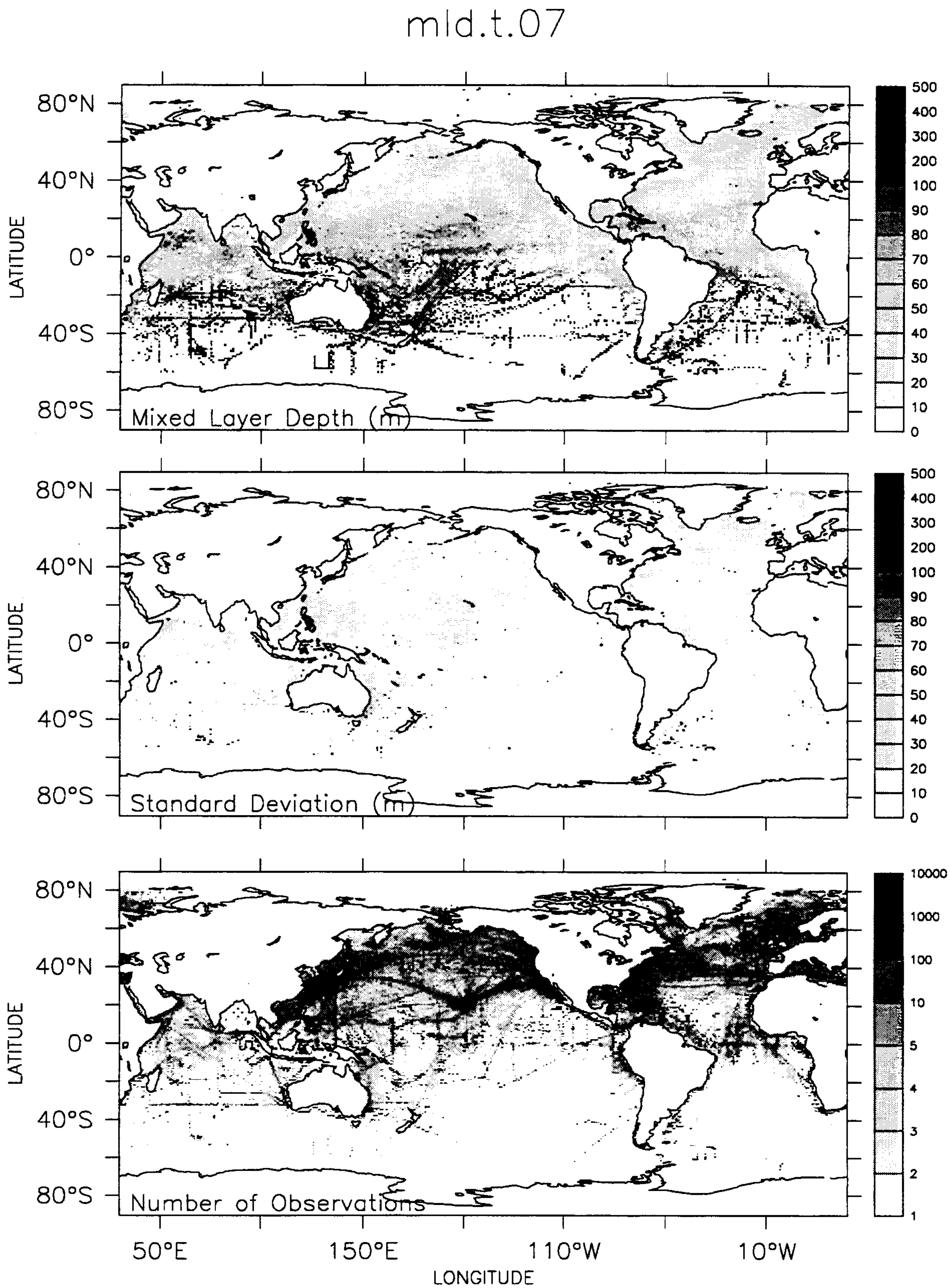

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150°E
110°W
10°W
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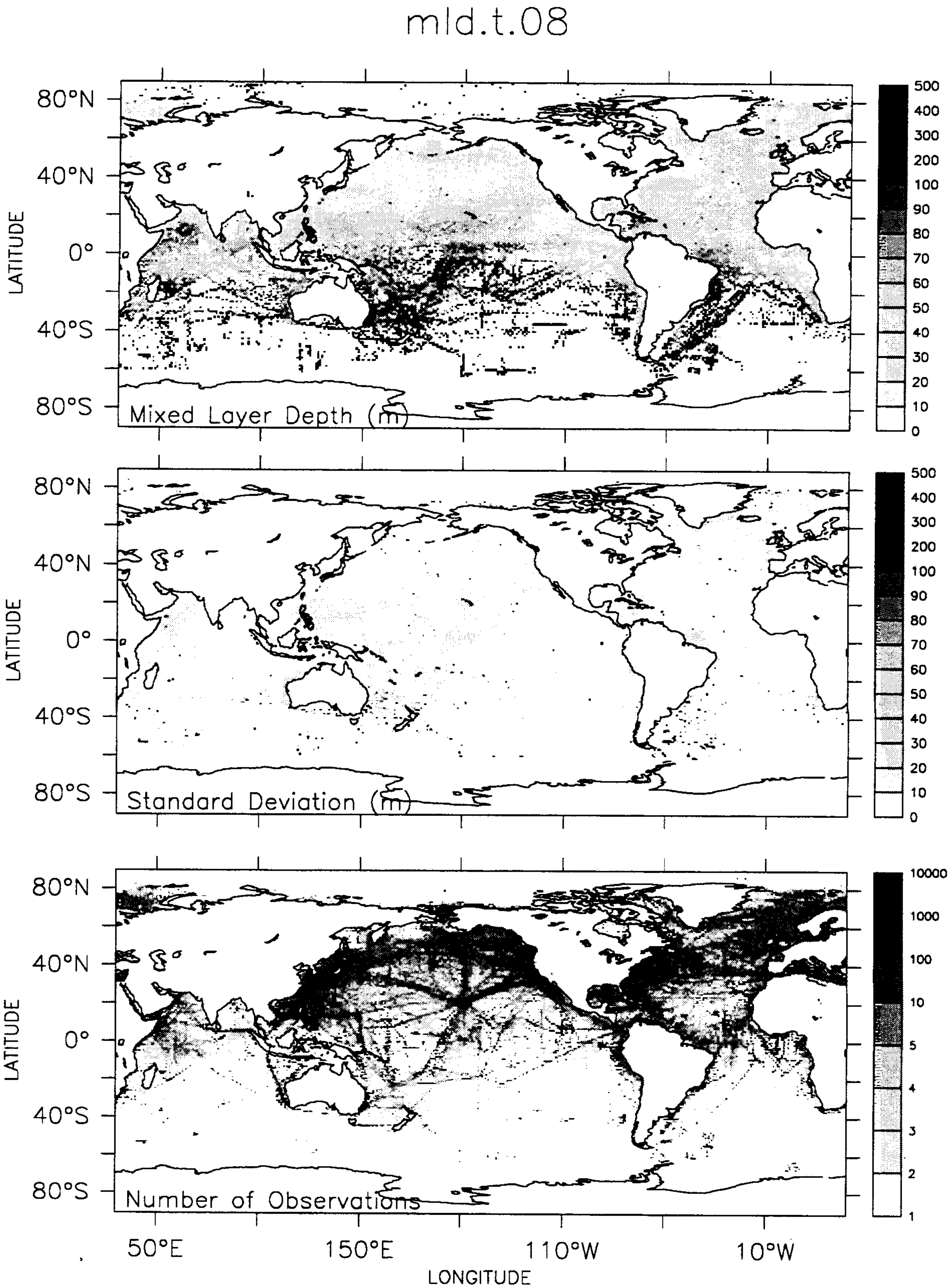
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Standard Deviation (m)
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100
90
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70
60
50
40
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2
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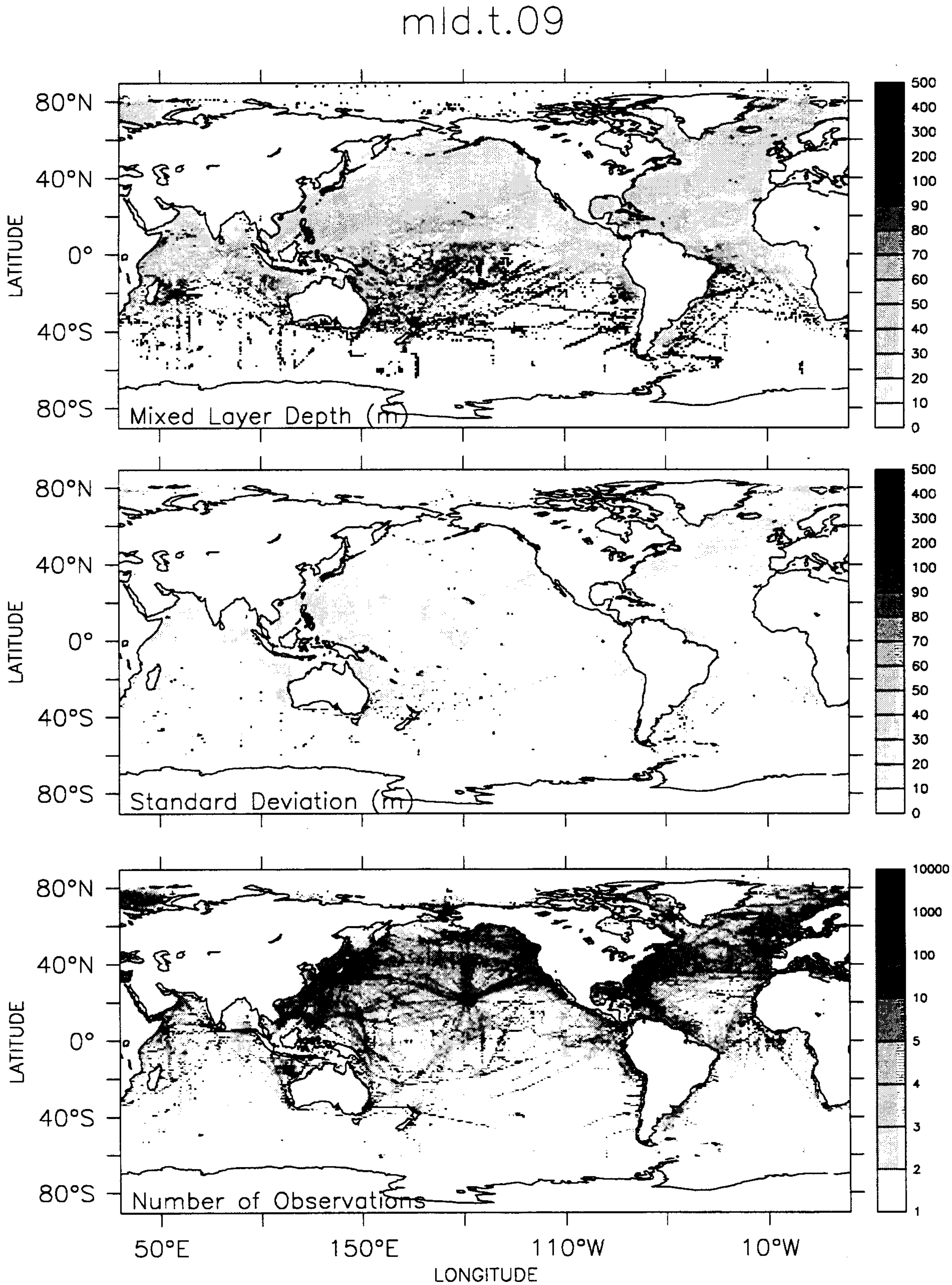
LONGITUDE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150°E
110°W
10°W
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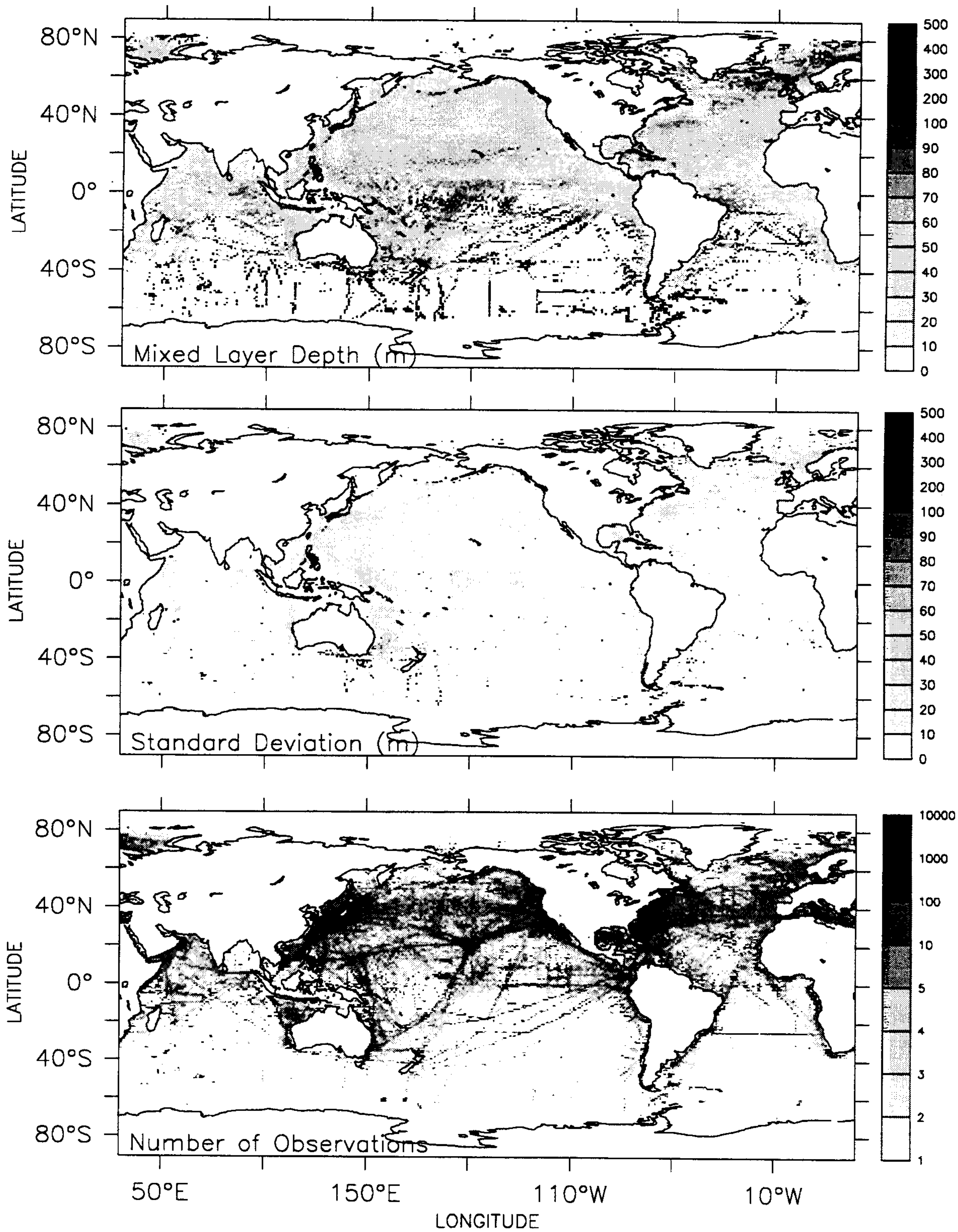

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40°N
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40°S
80°S
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Standard Deviation (m)
Number of Observations
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400
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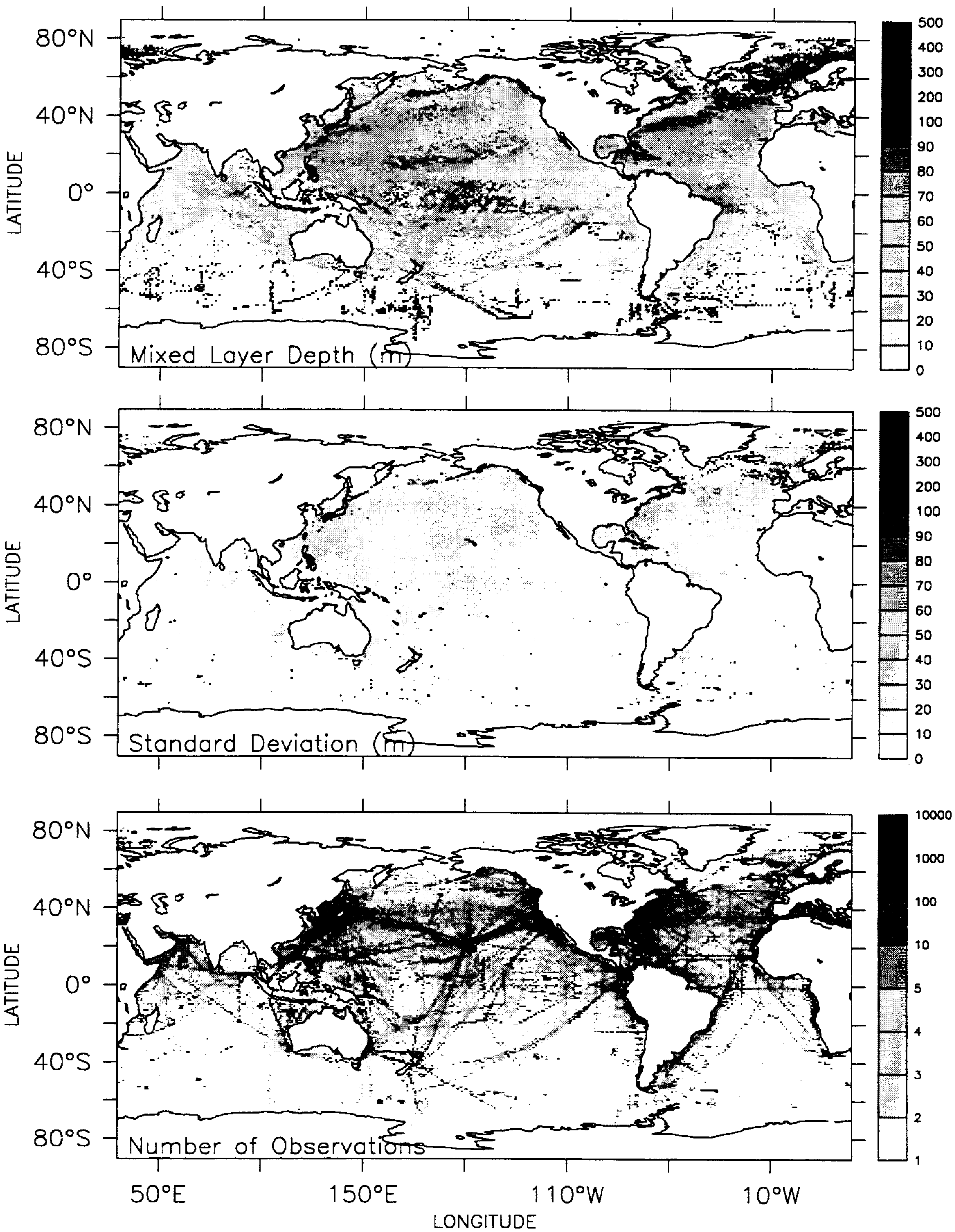
LONGITUDE

mld.t.11



80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
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Standard Deviation (m)
Number of Observations
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50°E
150°E
110°W
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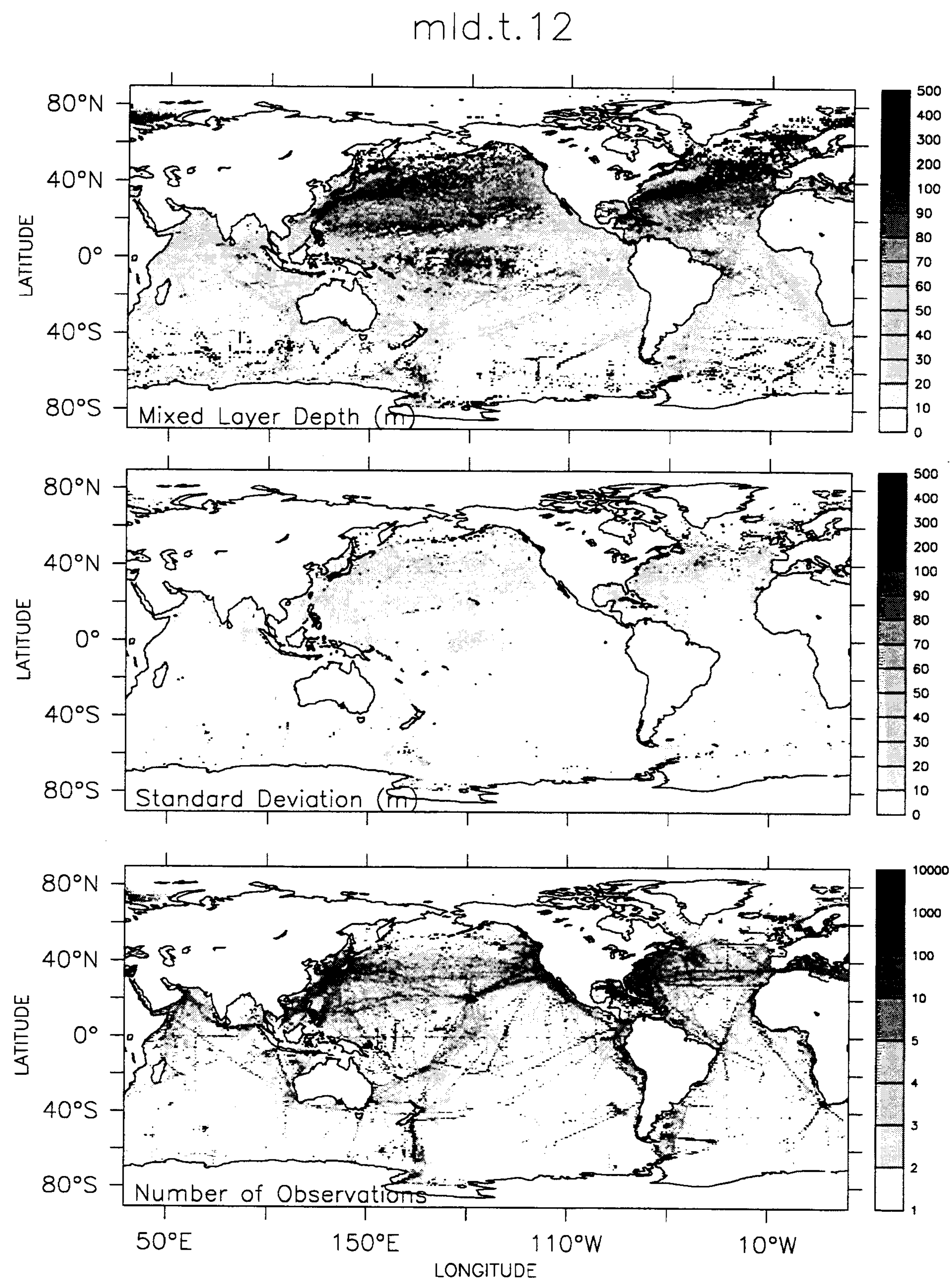
LONGITUDE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Mixed Layer Depth (m)
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10
0
Standard Deviation (m)
Number of Observations
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4
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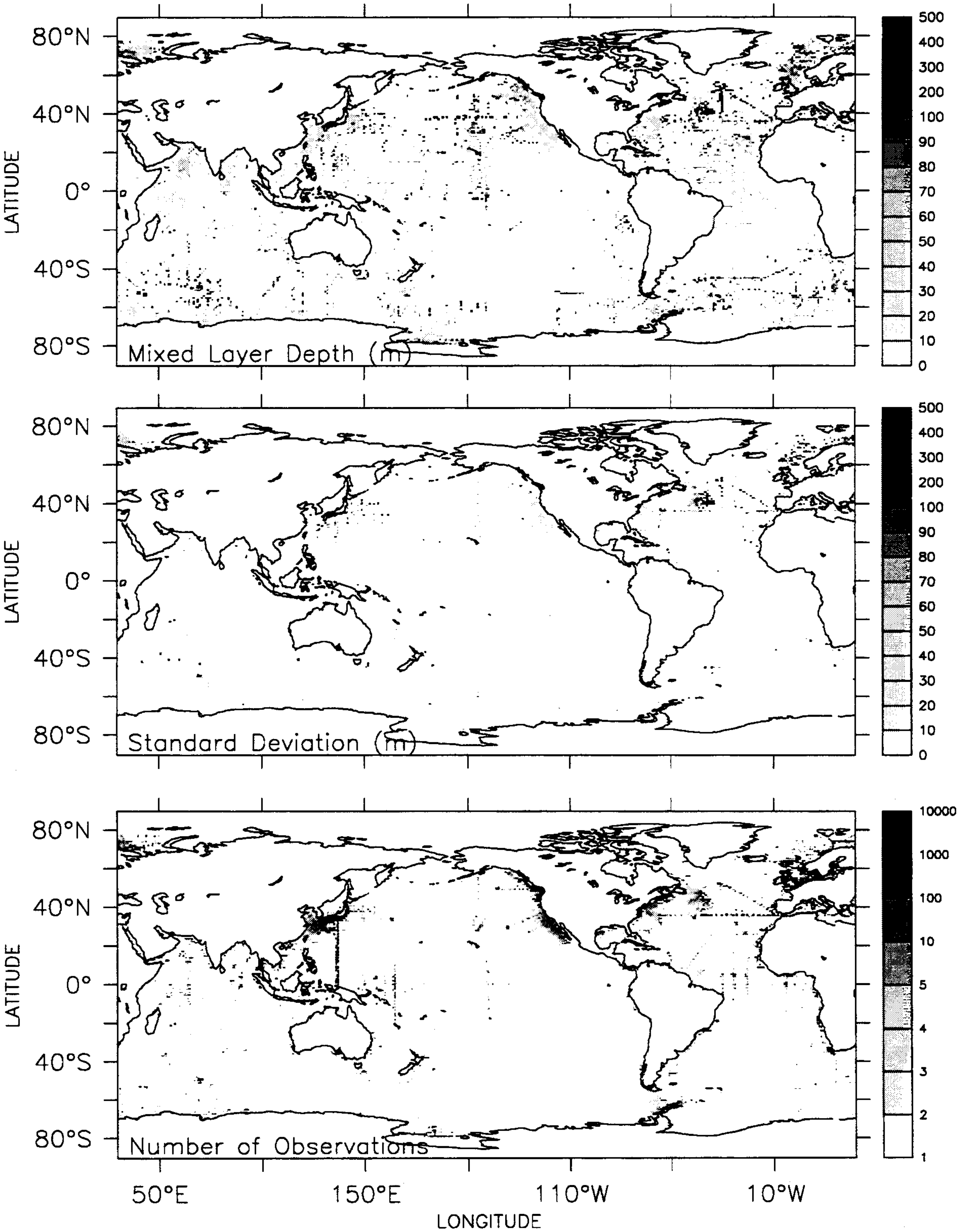
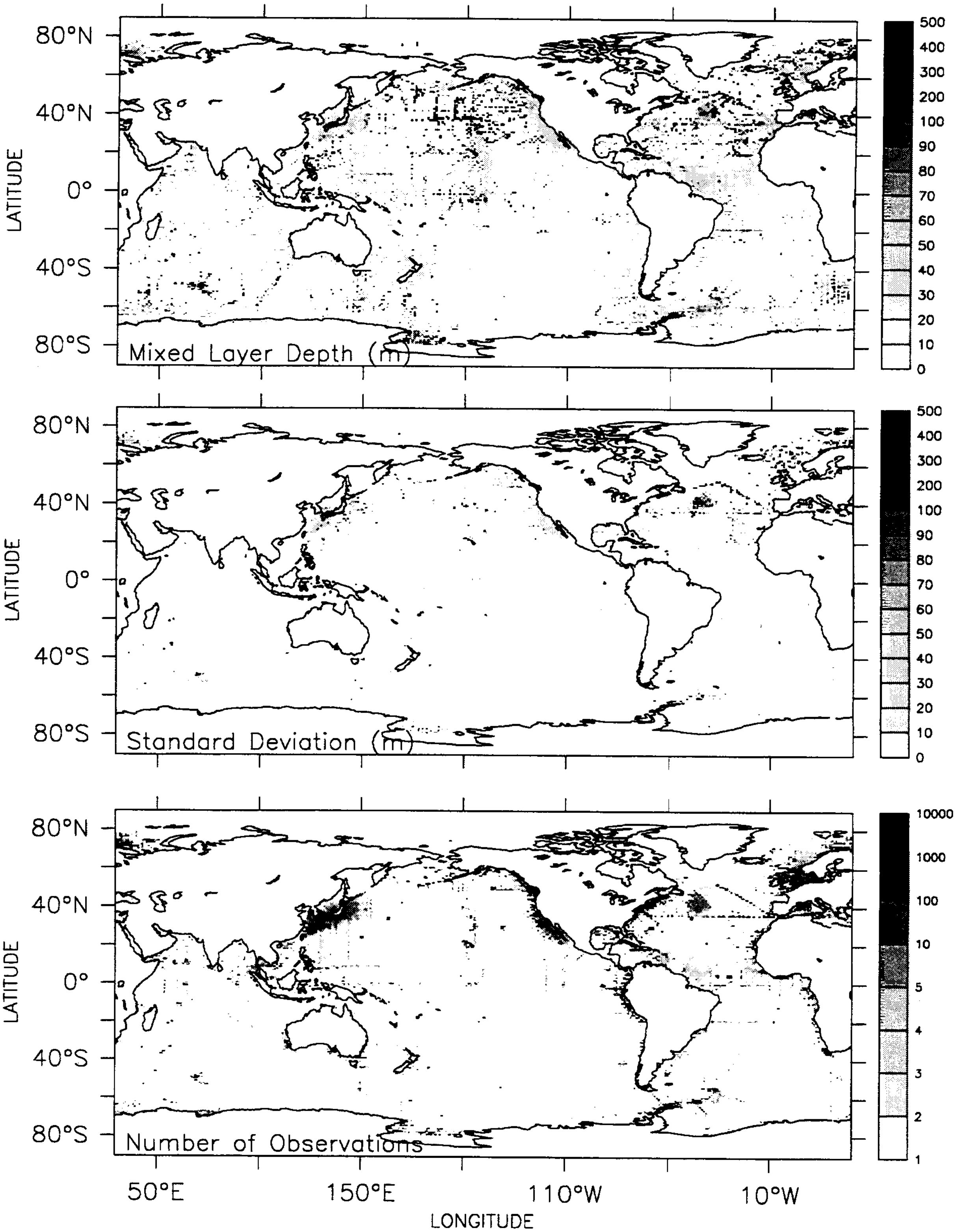
50°E
150°E
110°W
10°W
LONGITUDE

mld.pd.01



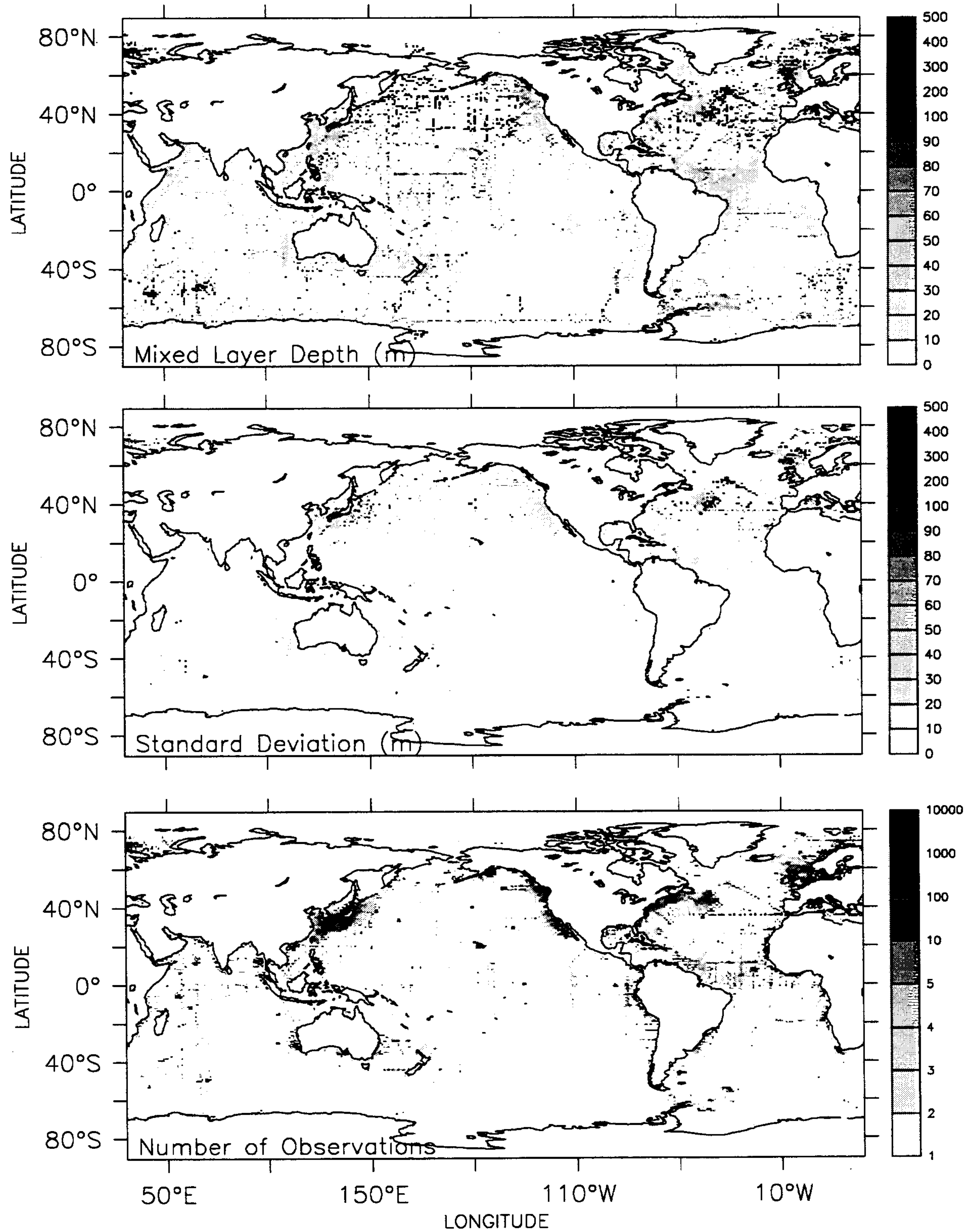
80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE

mld.pd.02



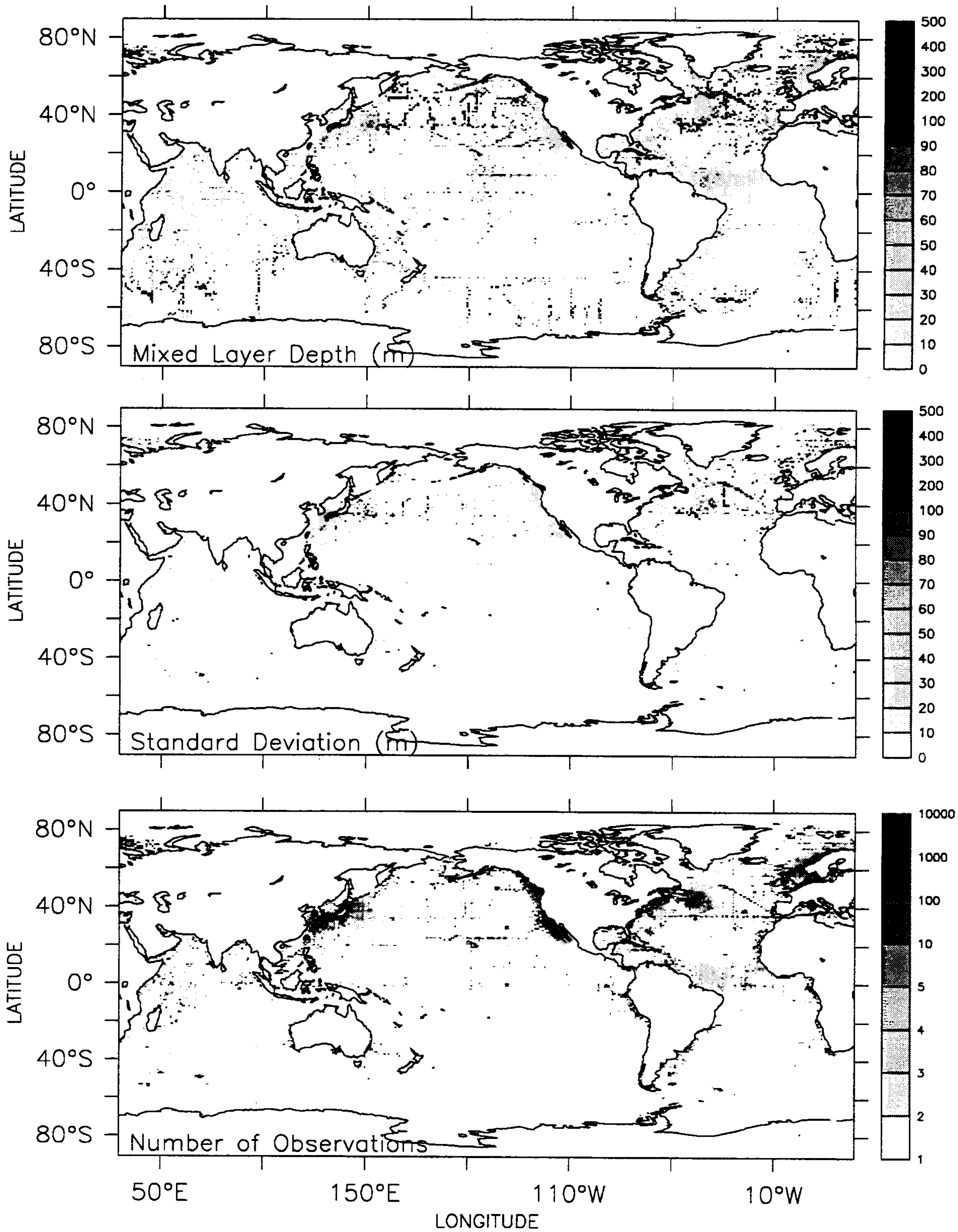
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
80°N
40°N
0°
40°S
80°S
LATITUDE
50°E
150°E
110°W
10°W
LONGITUDE
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1

mld.pd.03



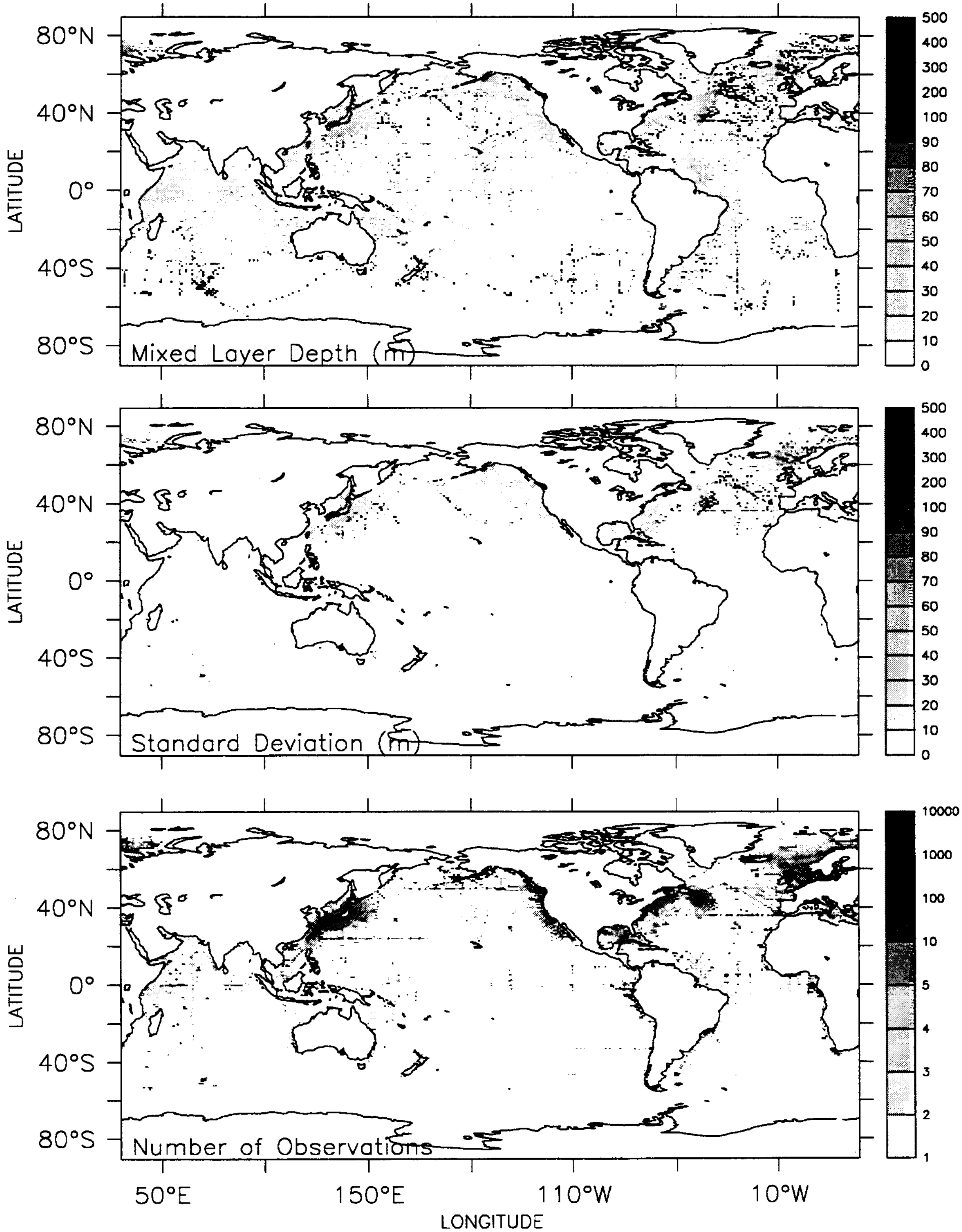
80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE

mld.pd.04

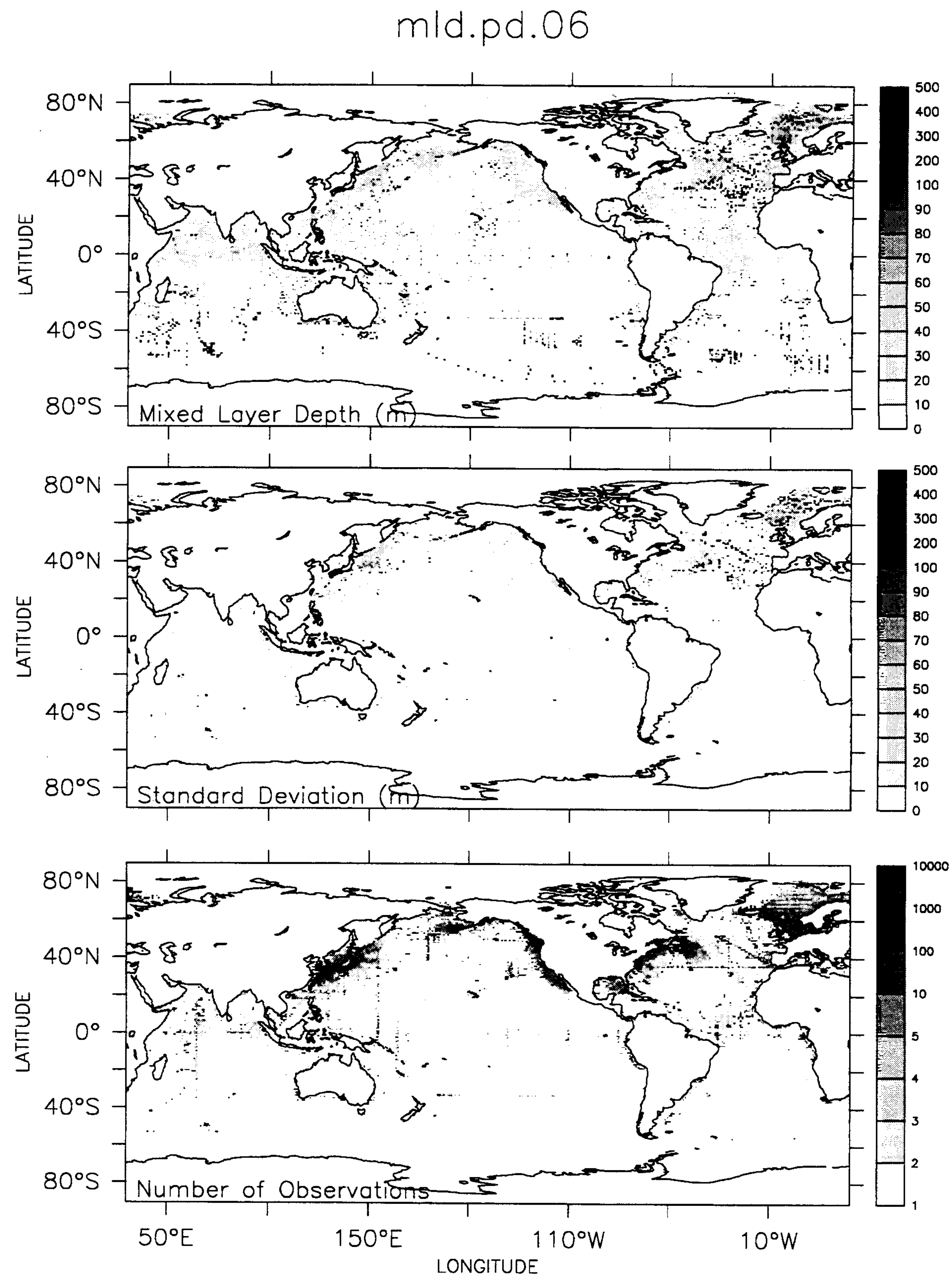


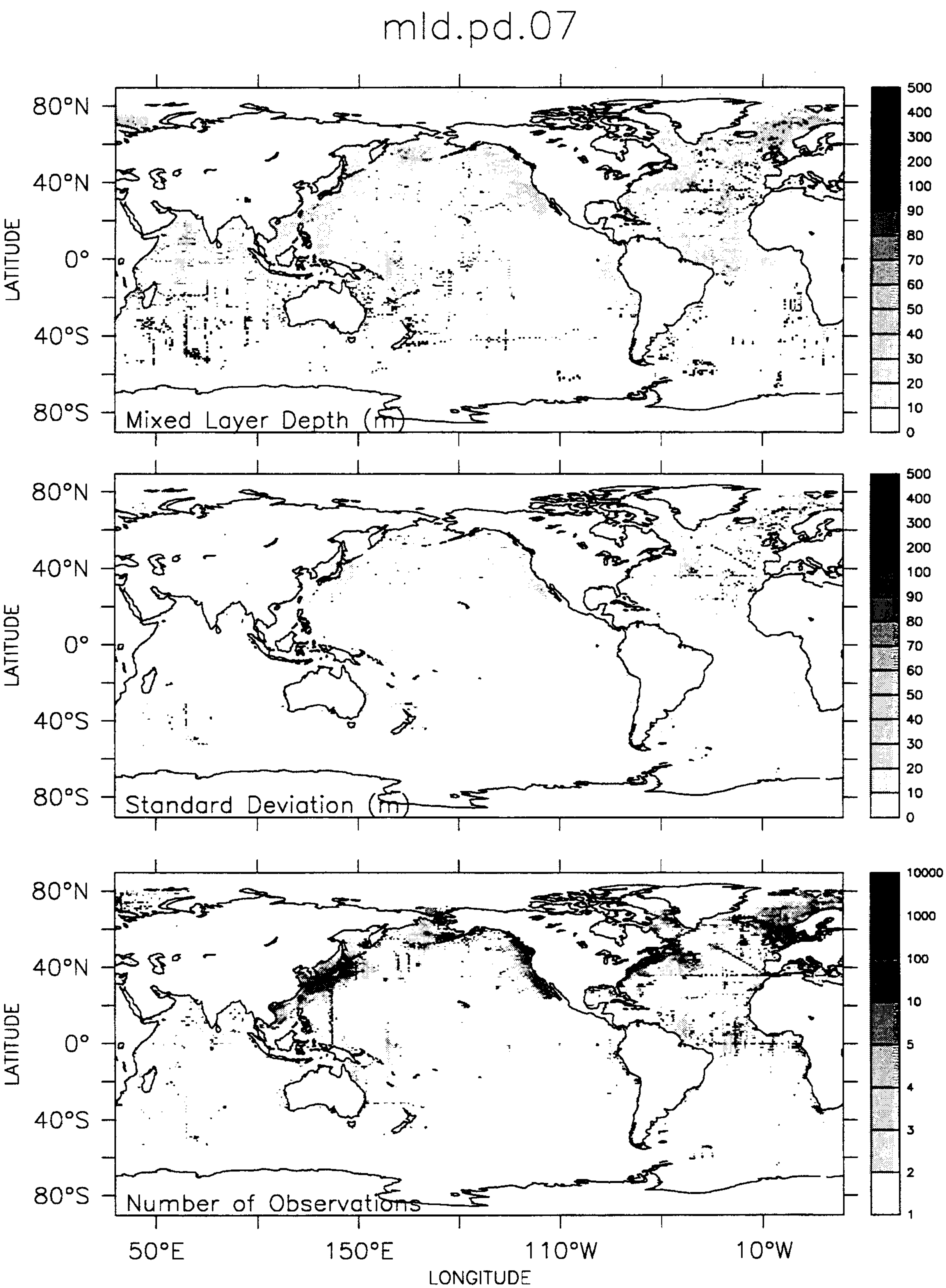
80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
500 400 300 200 100 90 80 70 60 50 40 30 20 10 0
10000 1000 100 10 5 4 3 2 1
50°E
150°E
110°W
10°W
LONGITUDE

mld.pd.05

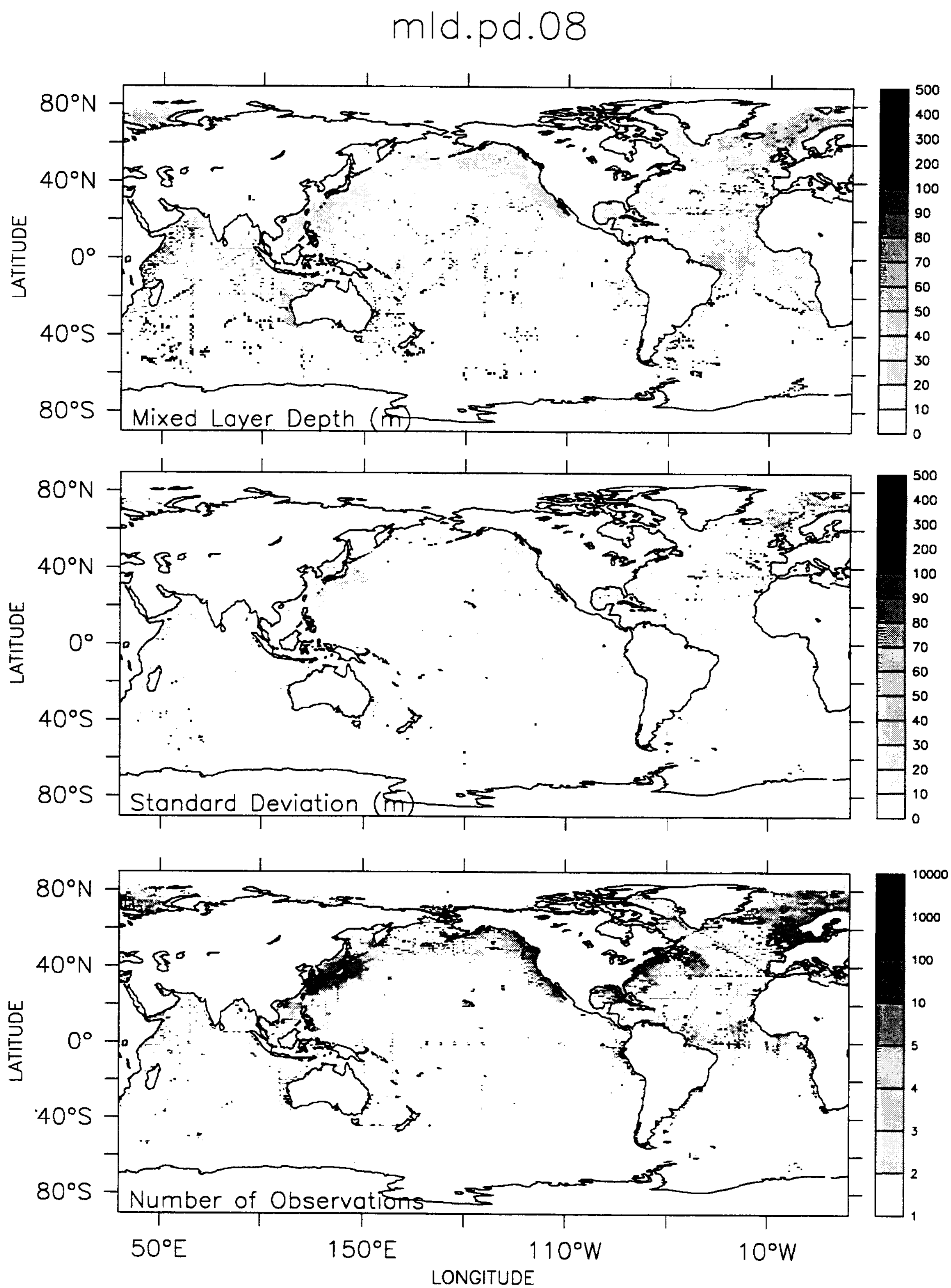


80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE

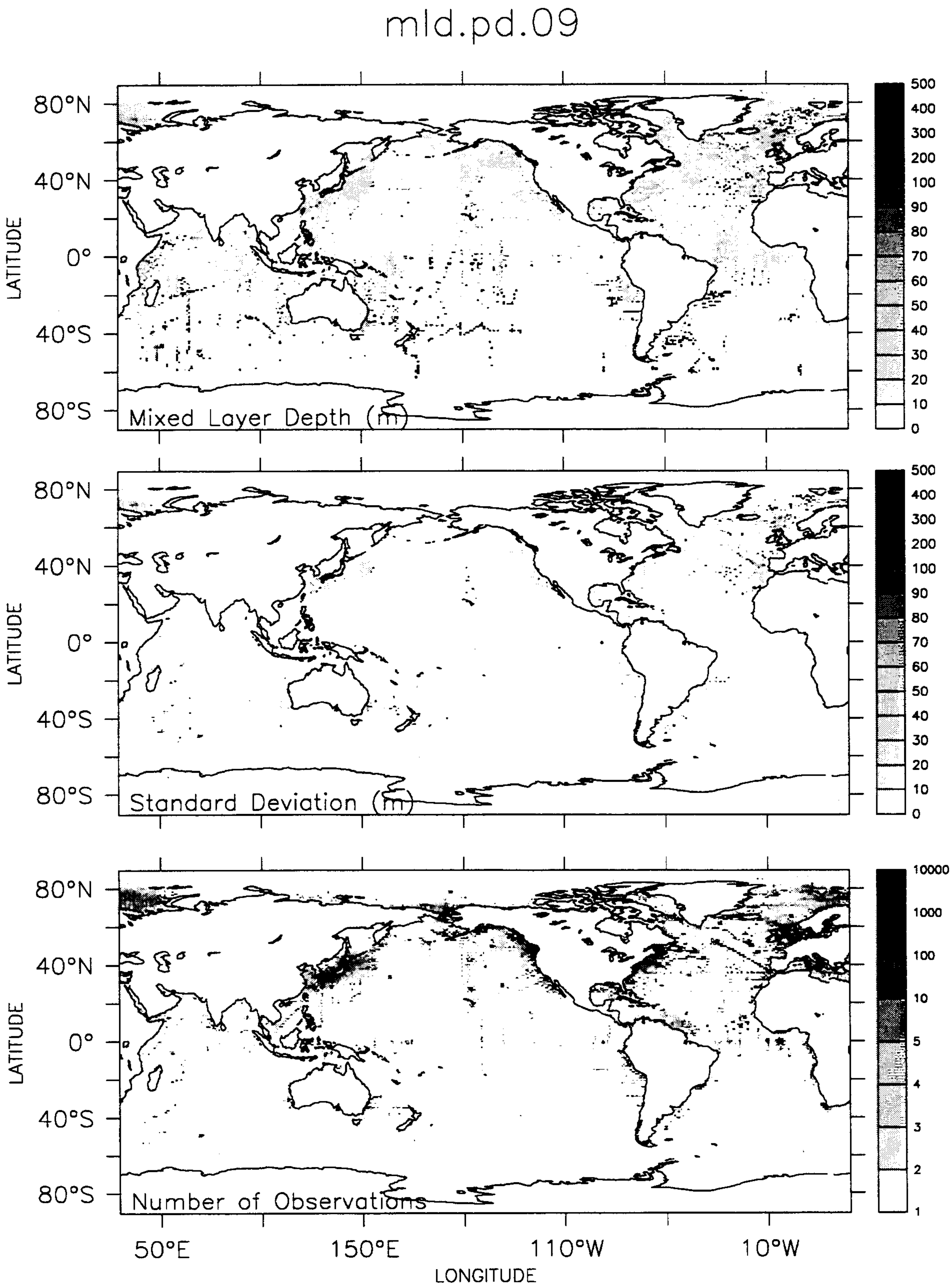

mld.pd.06
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
LATITUDE
80°N
40°N
0°
40°S
80°S
LONGITUDE
50°E
150°E
110°W
10°W
0
10
20
30
40
50
60
70
80
90
100
200
300
400
500
1
2
3
4
5
10
100
1000
10000

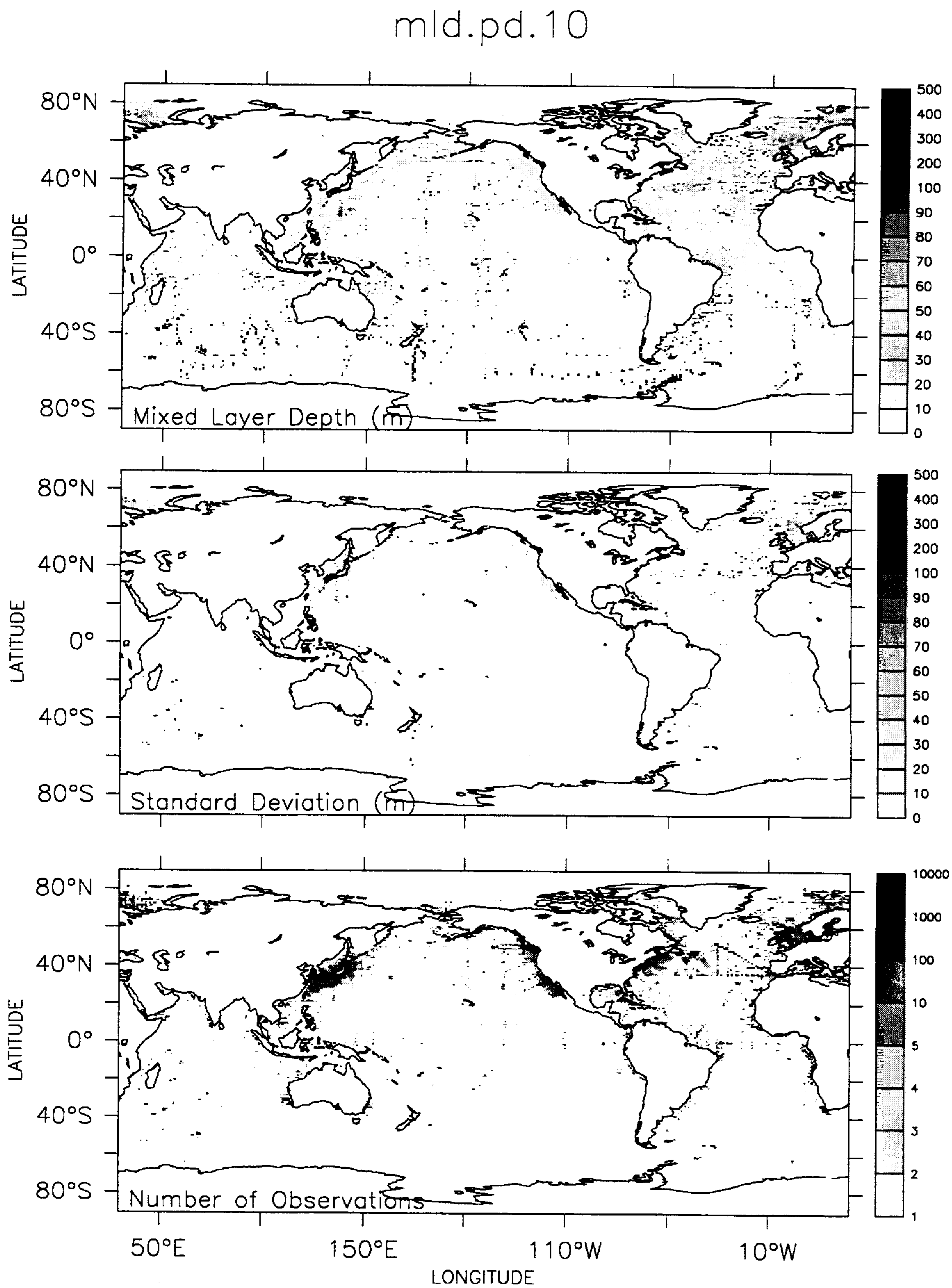


mld.pd.07
80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE



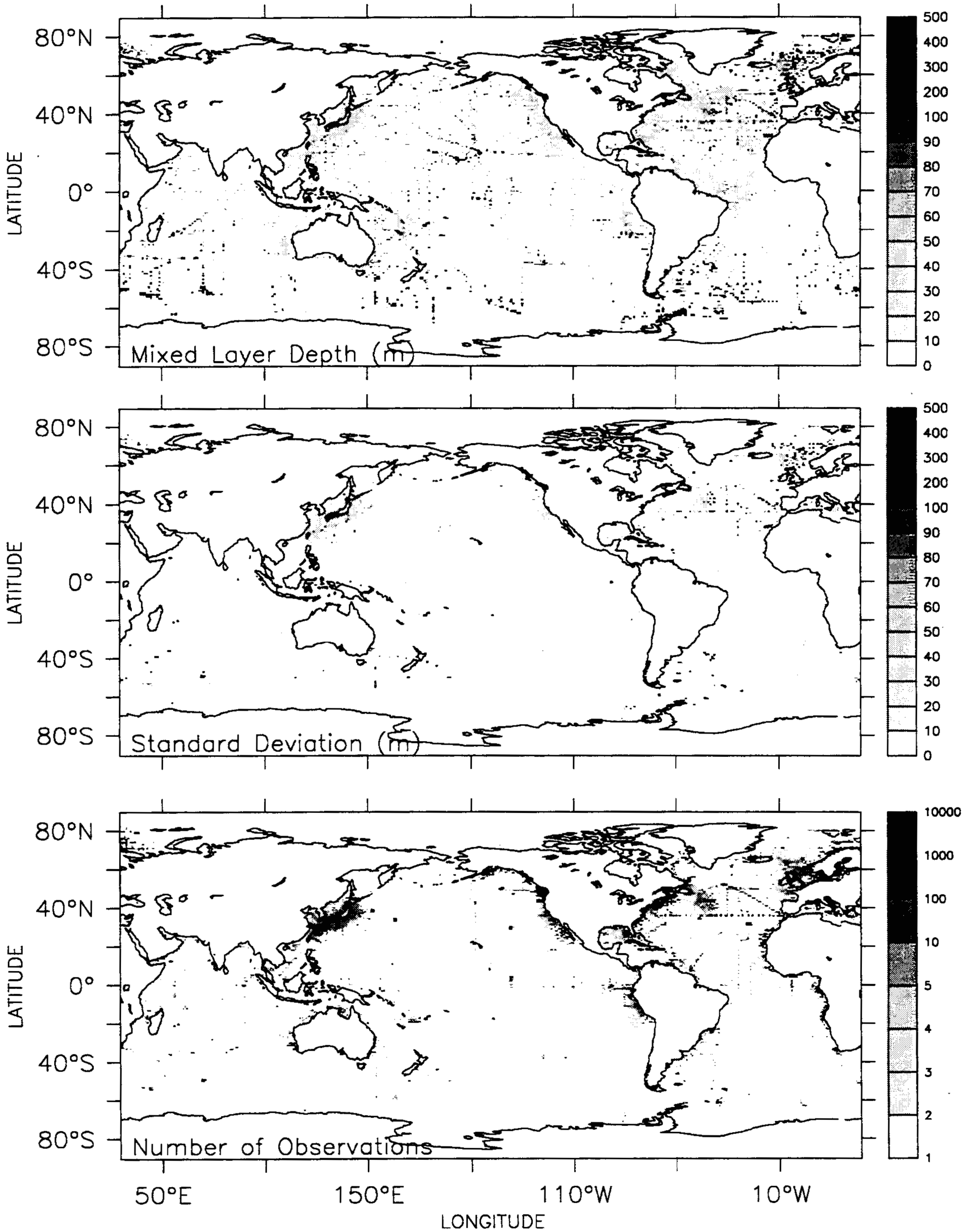
mld.pd.08
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
80°N
40°N
0°
40°S
80°S
LATITUDE
50°E
150°E
110°W
10°W
LONGITUDE
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1


mld.pd.09
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
80°N
40°N
0°
40°S
80°S
LATITUDE
50°E
150°E
110°W
10°W
LONGITUDE
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1



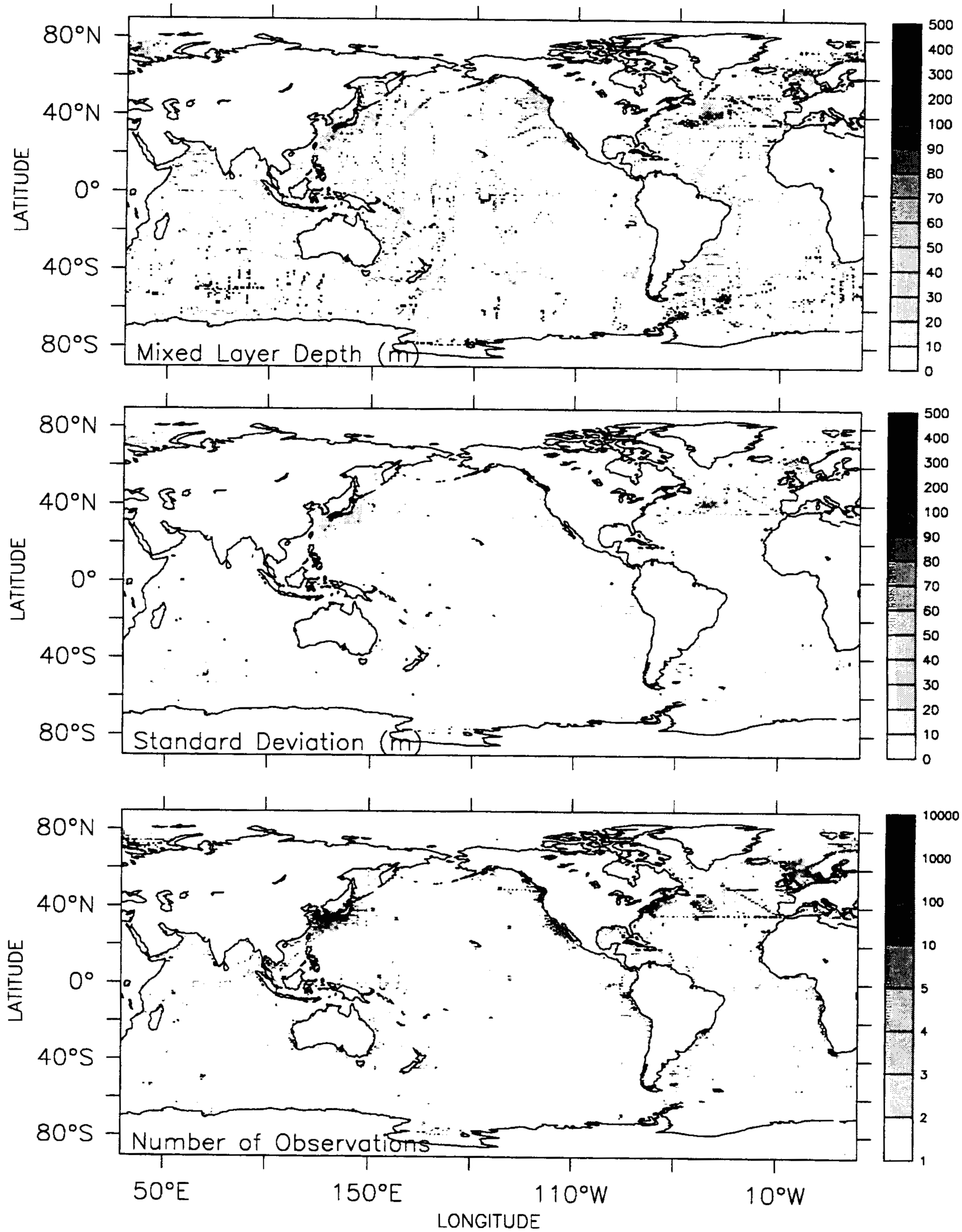
mld.pd.10
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
80°N
40°N
0°
40°S
80°S
LATITUDE
50°E
150°E
110°W
10°W
LONGITUDE
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1

mld.pd.11

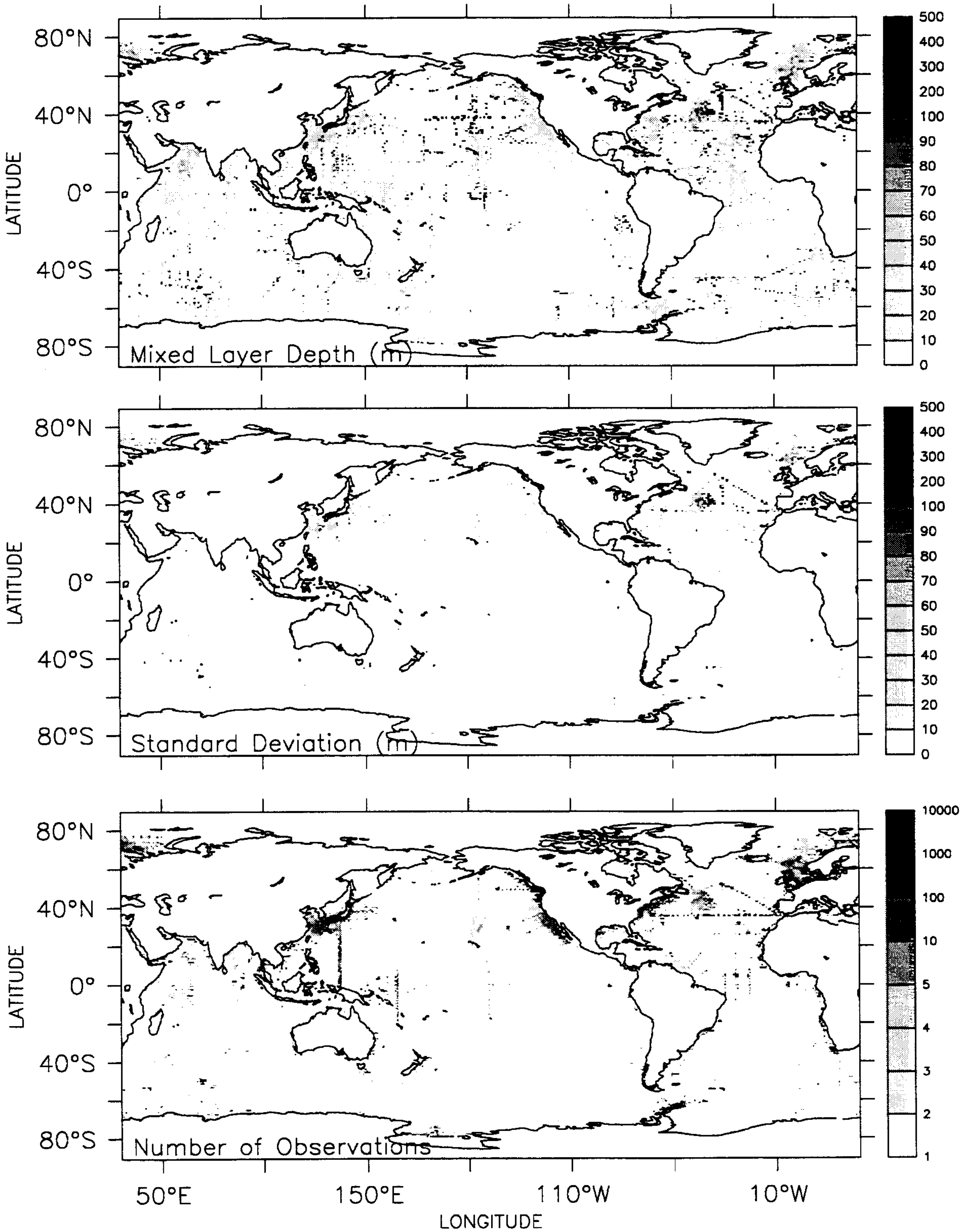


80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE

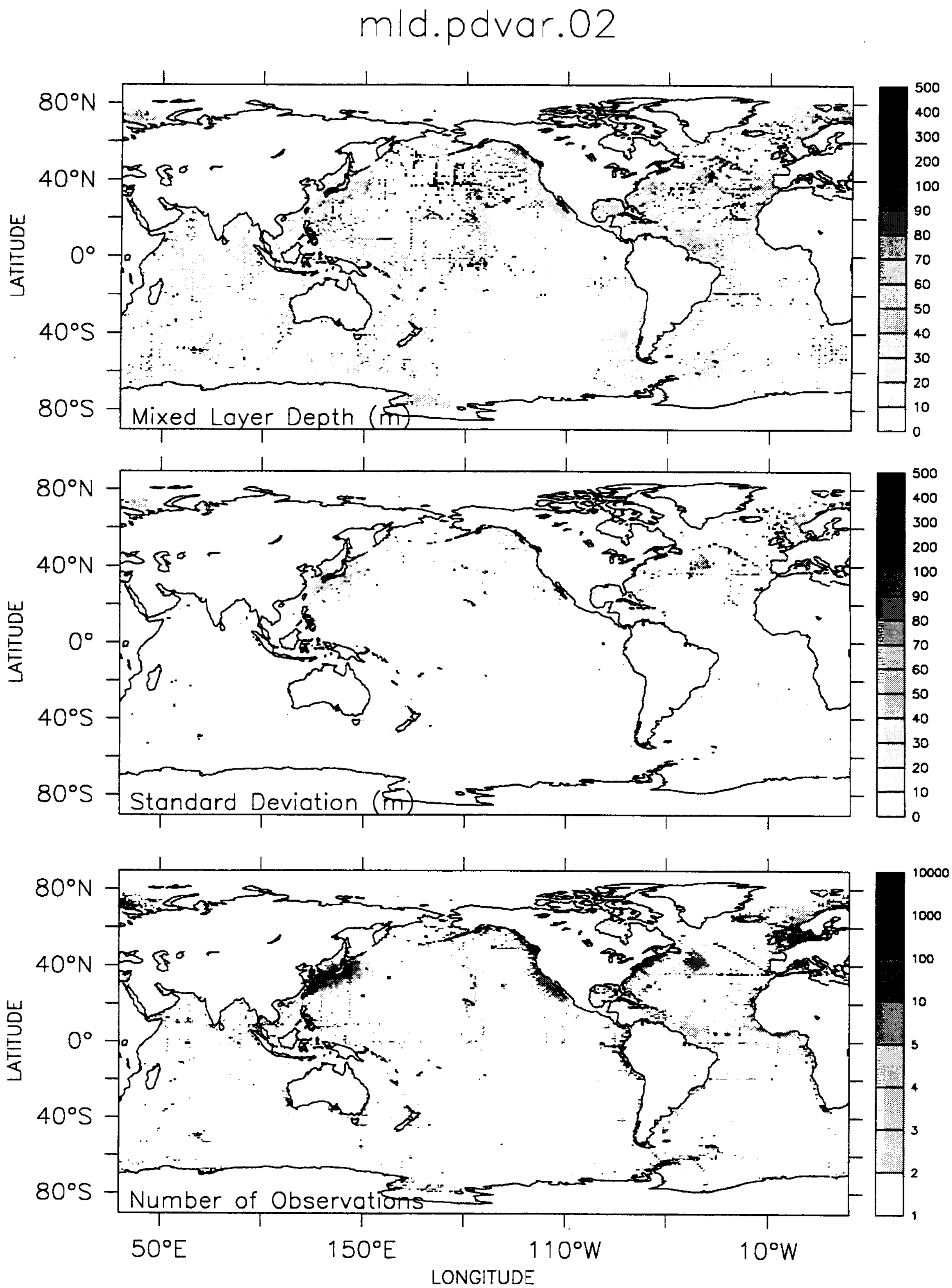
mld.pd.12


80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE

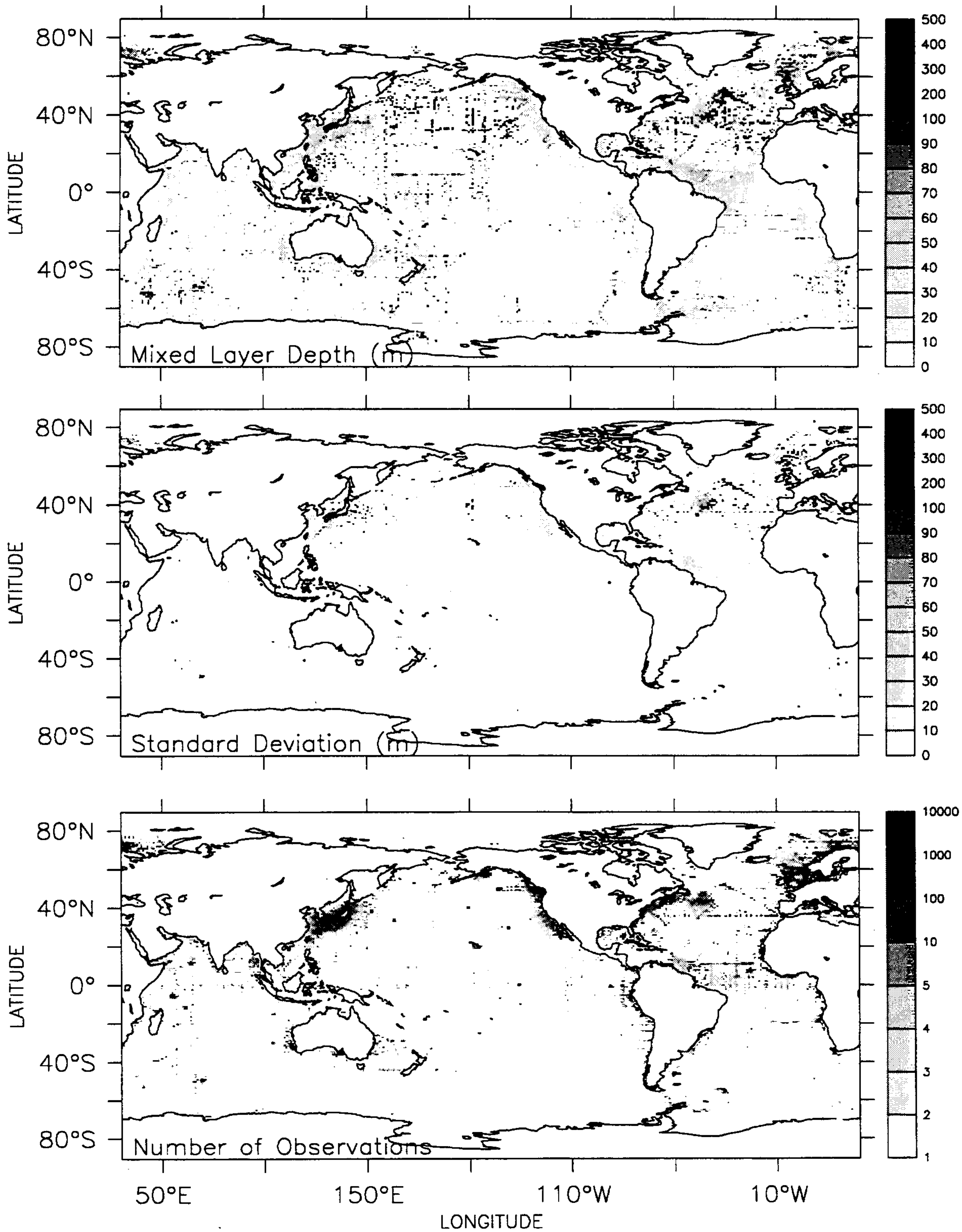
mld.pdvar.01



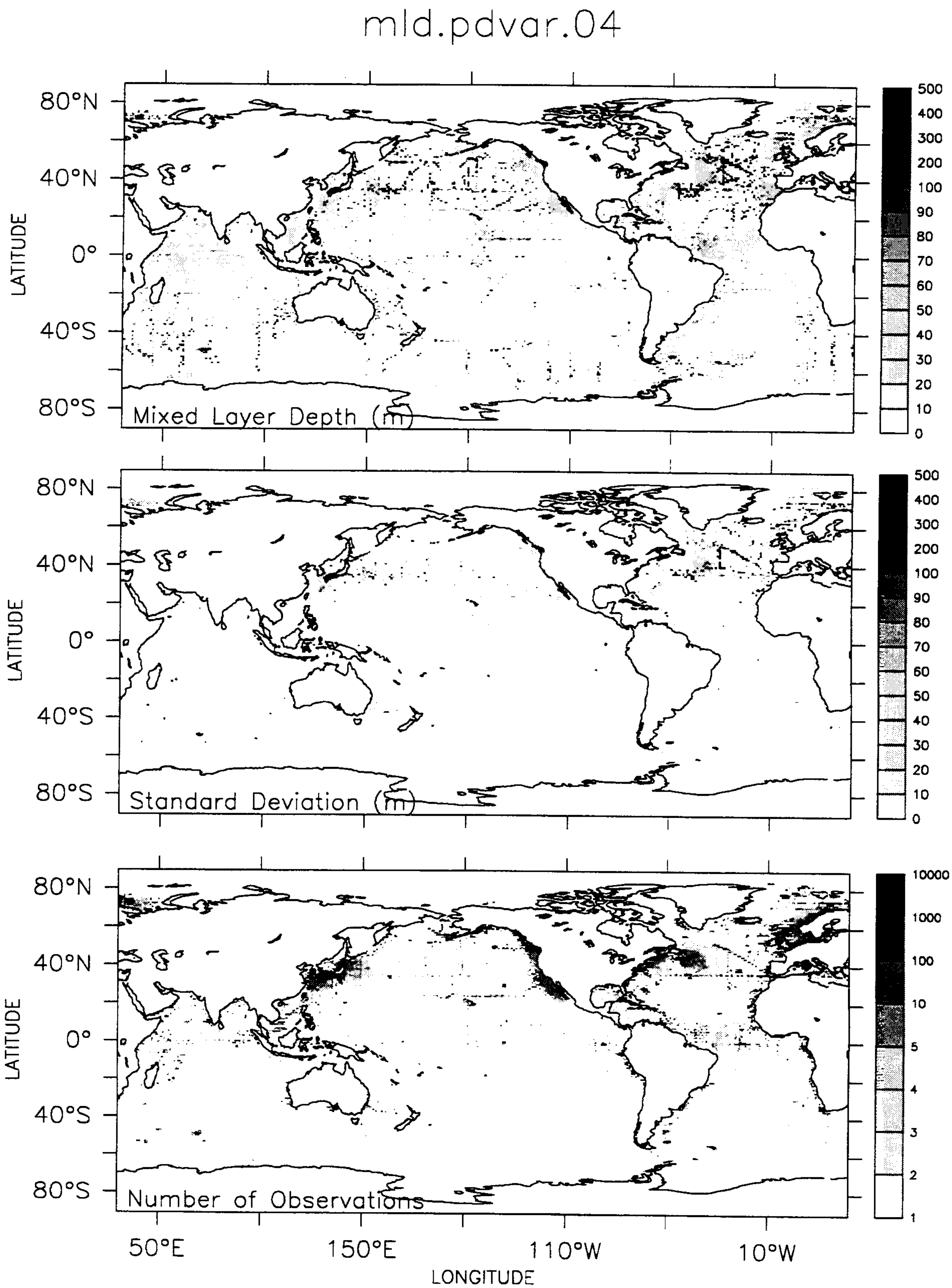
80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE


mld.pdvar.02
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
80°N
40°N
0°
40°S
80°S
LATITUDE
50°E
150°E
110°W
10°W
LONGITUDE
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1

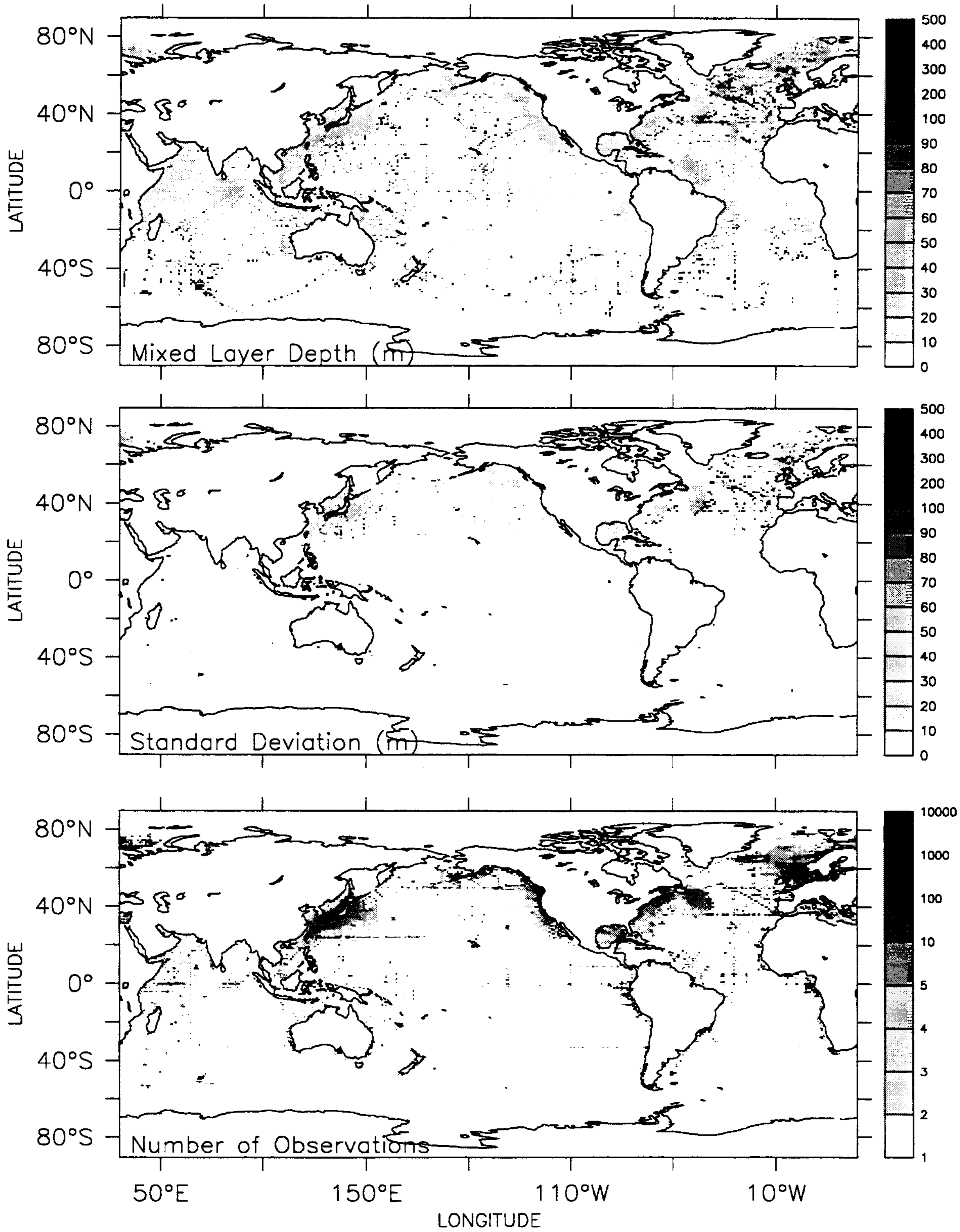
mld.pdvar.03



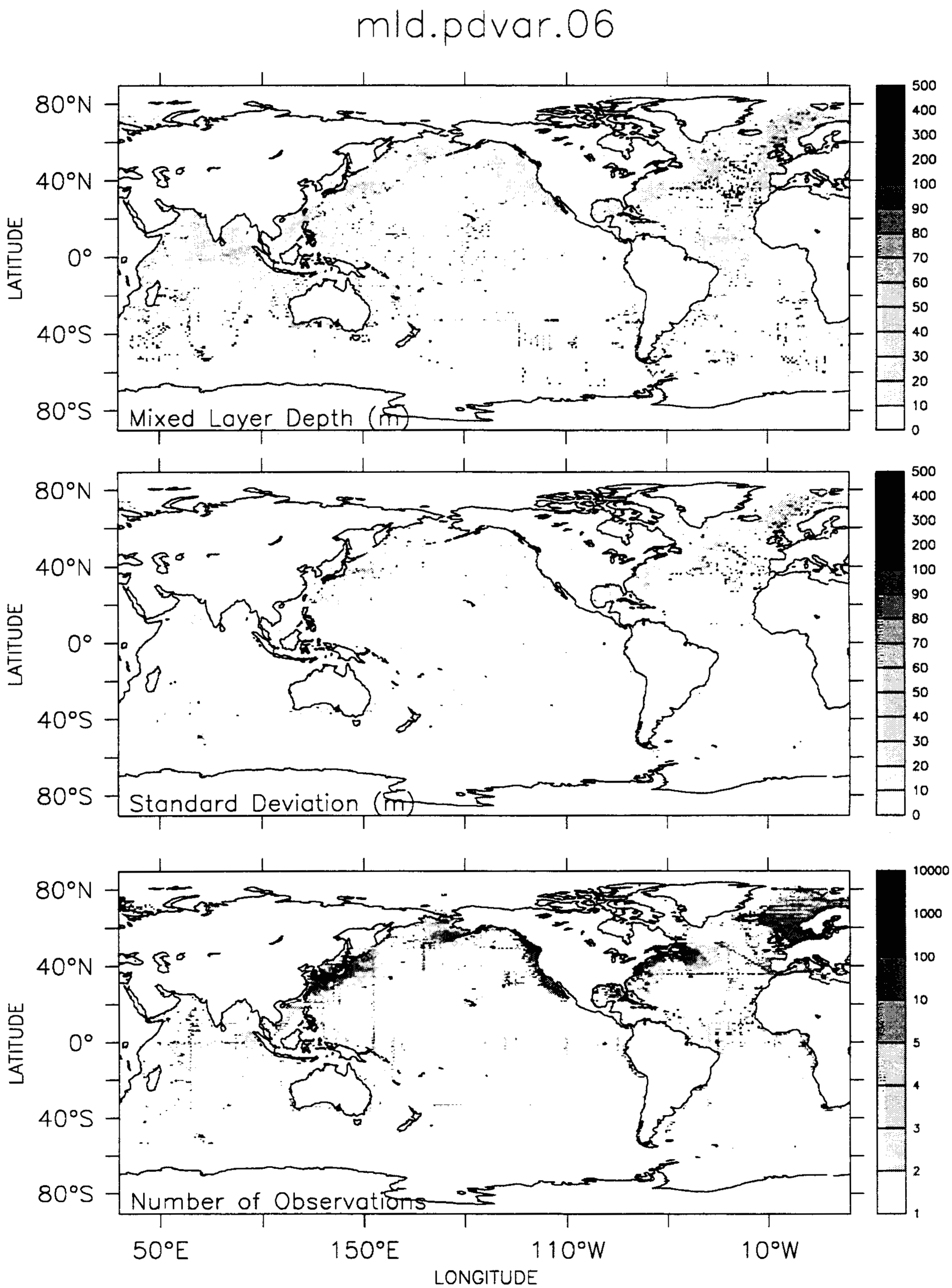
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
LATITUDE
LONGITUDE
80°N
40°N
0°
40°S
80°S
50°E
150°E
110°W
10°W
0
10
20
30
40
50
60
70
80
90
100
200
300
400
500
1
2
3
4
5
10
100
1000
10000


mld.pdvar.04
80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE

mld.pdvar.05

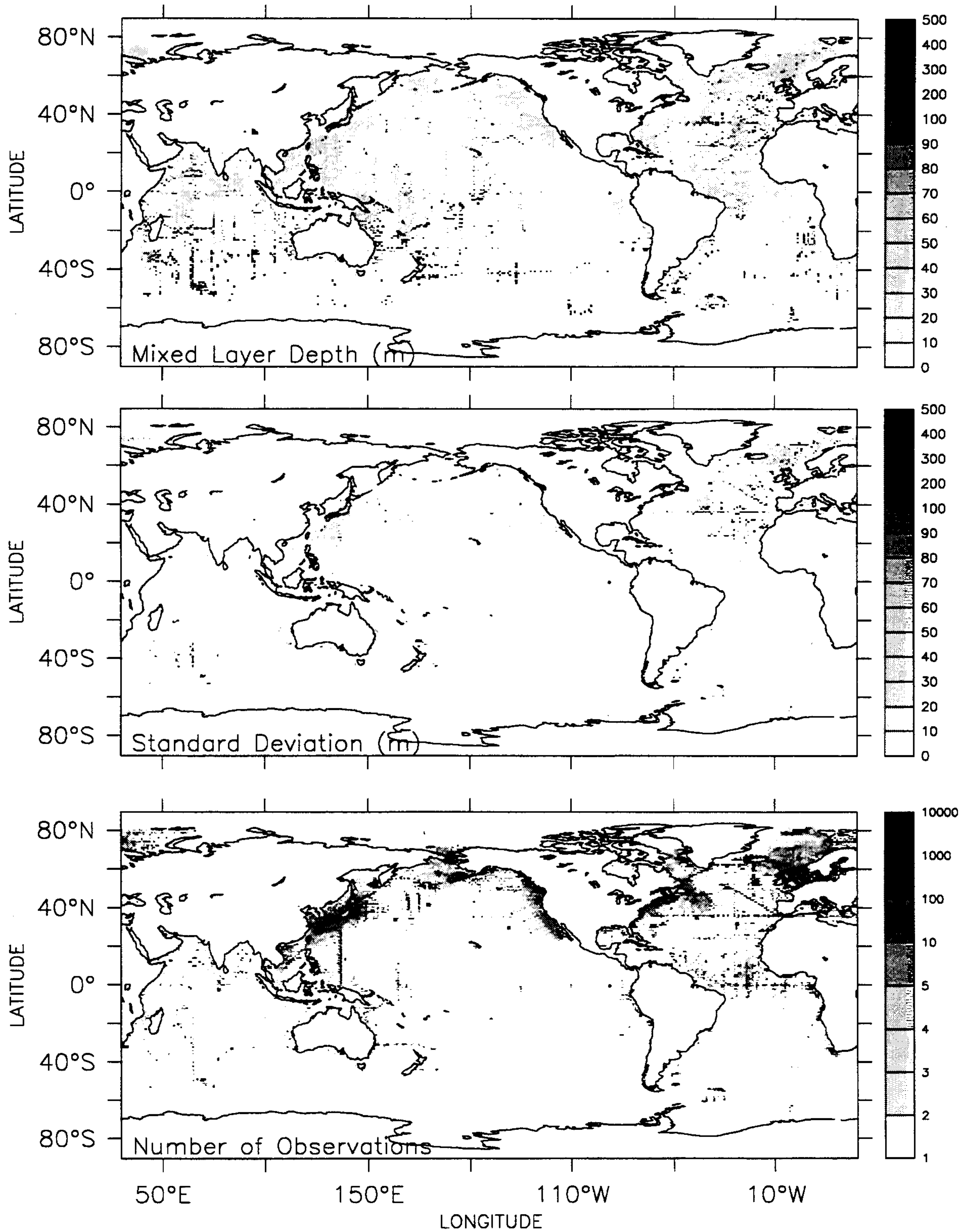


80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE



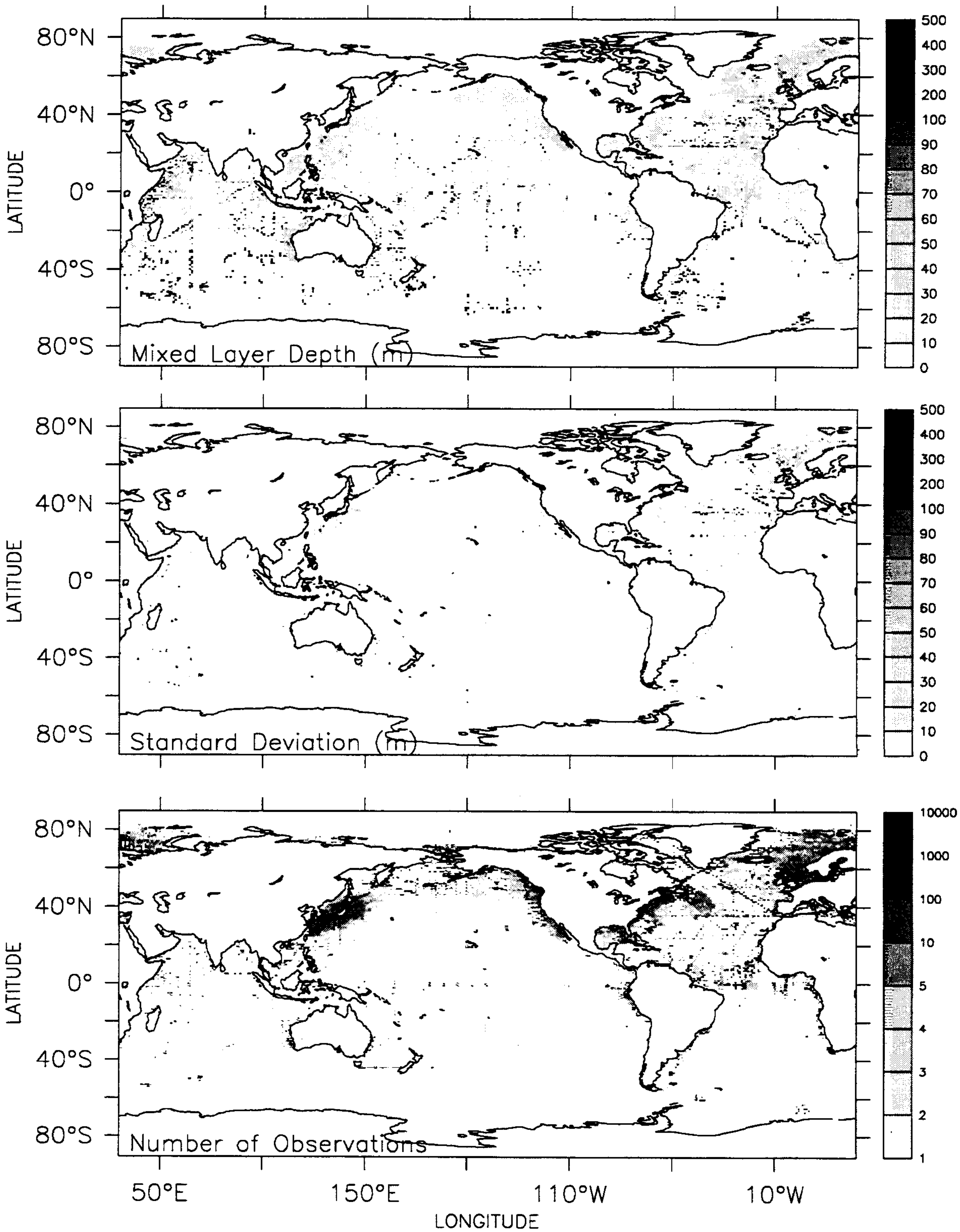
mld.pdvar.06
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
80°N
40°N
0°
40°S
80°S
LATITUDE
50°E
150°E
110°W
10°W
LONGITUDE
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1

mld.pdvar.07



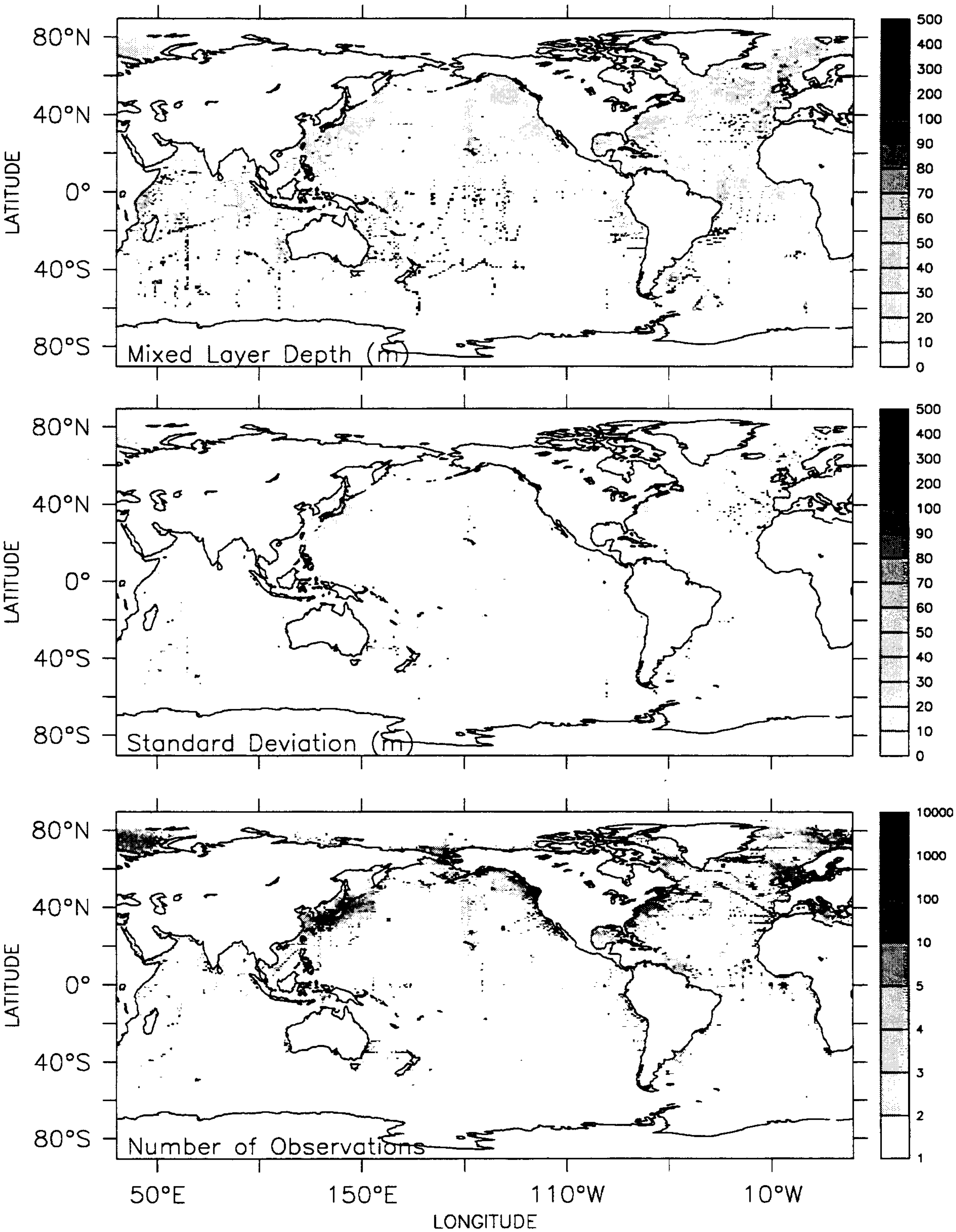
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
LATITUDE
LONGITUDE
80°N
40°N
0°
40°S
80°S
50°E
150°E
110°W
10°W
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1

mld.pdvar.08



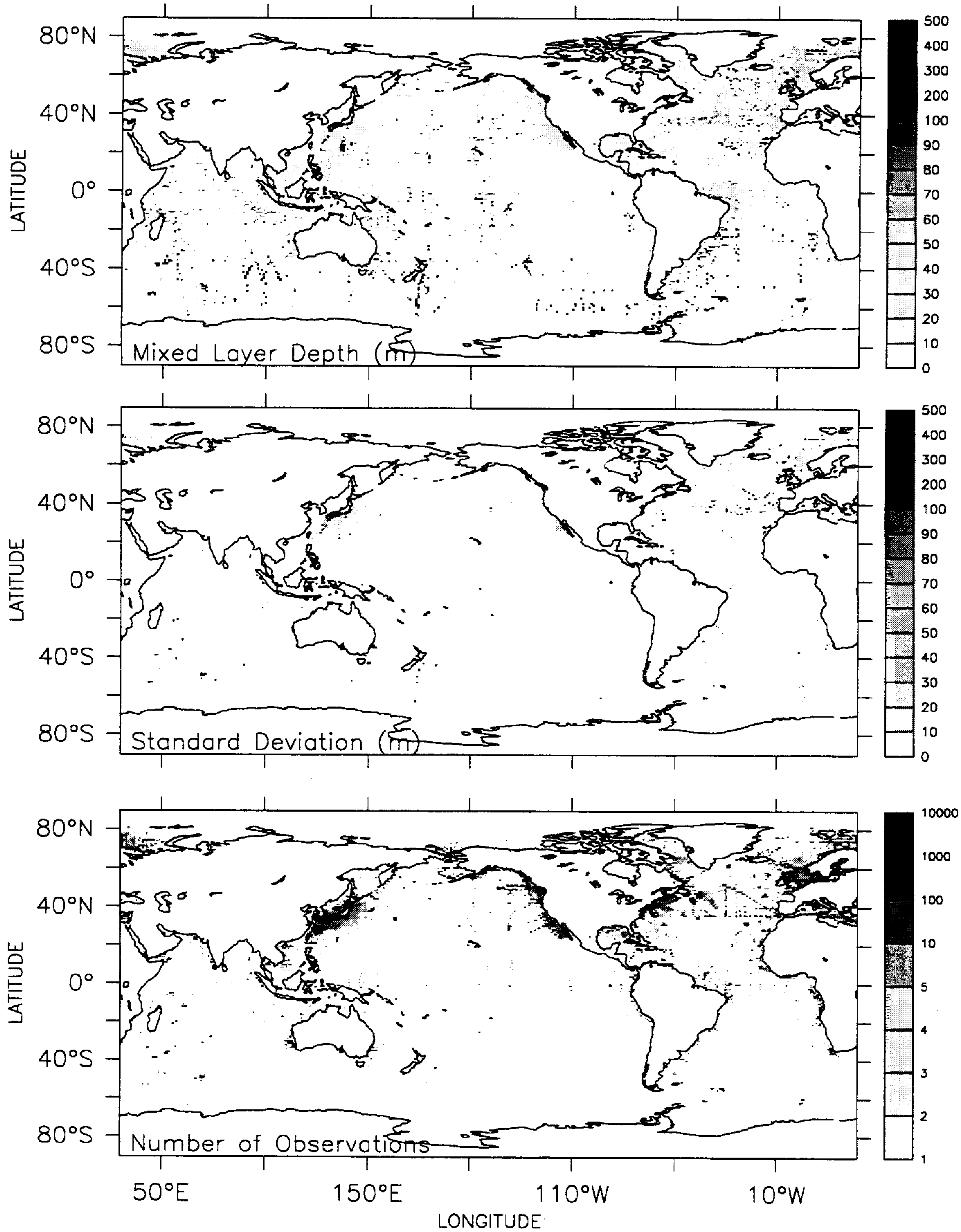
80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE

mld.pdvar.09

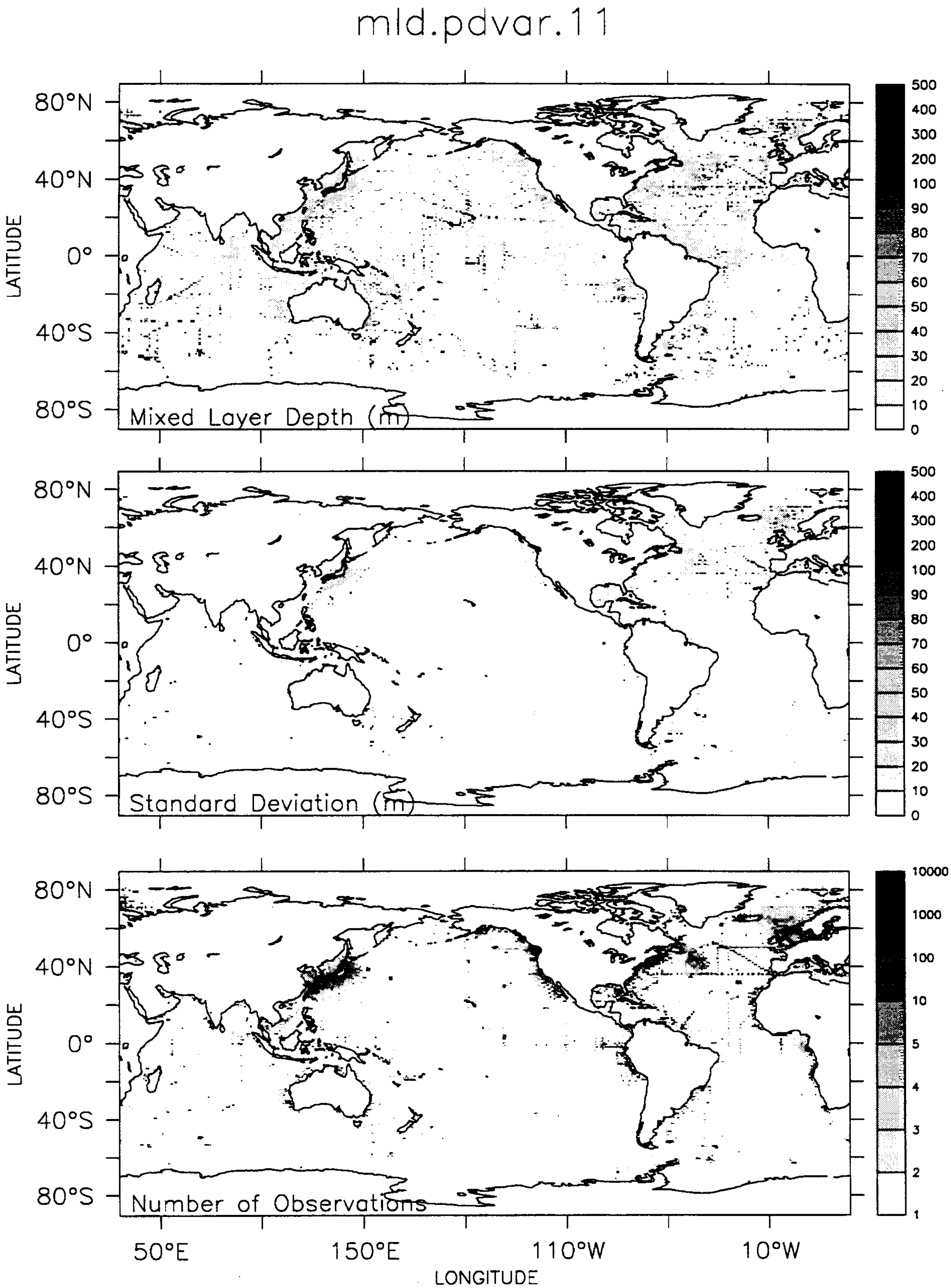


80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE

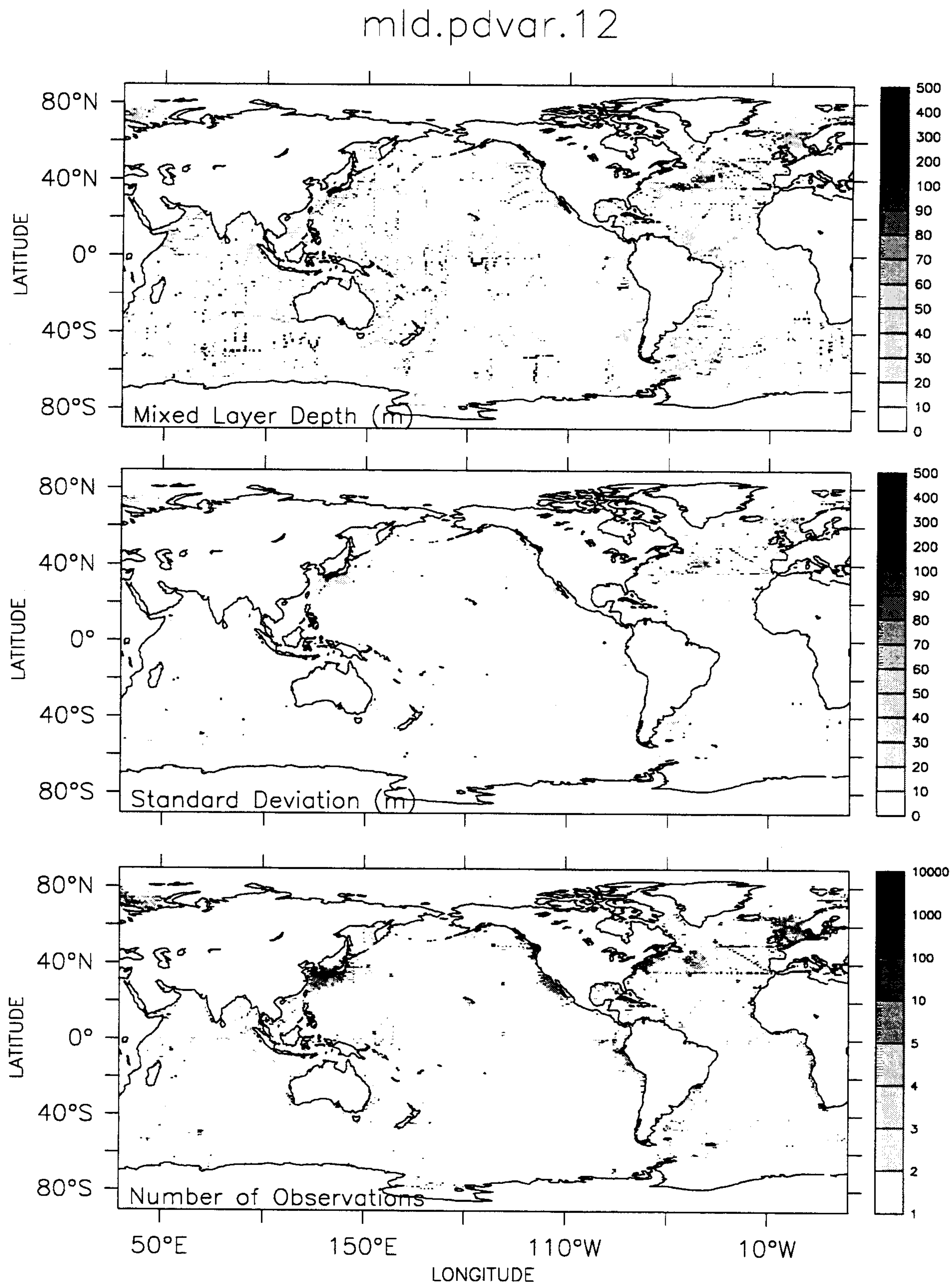
mld.pdvar.10



80°N
40°N
0°
40°S
80°S
LATITUDE
Mixed Layer Depth (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
Standard Deviation (m)
Number of Observations
10000
1000
100
10
5
4
3
2
1
50°E
150°E
110°W
10°W
LONGITUDE



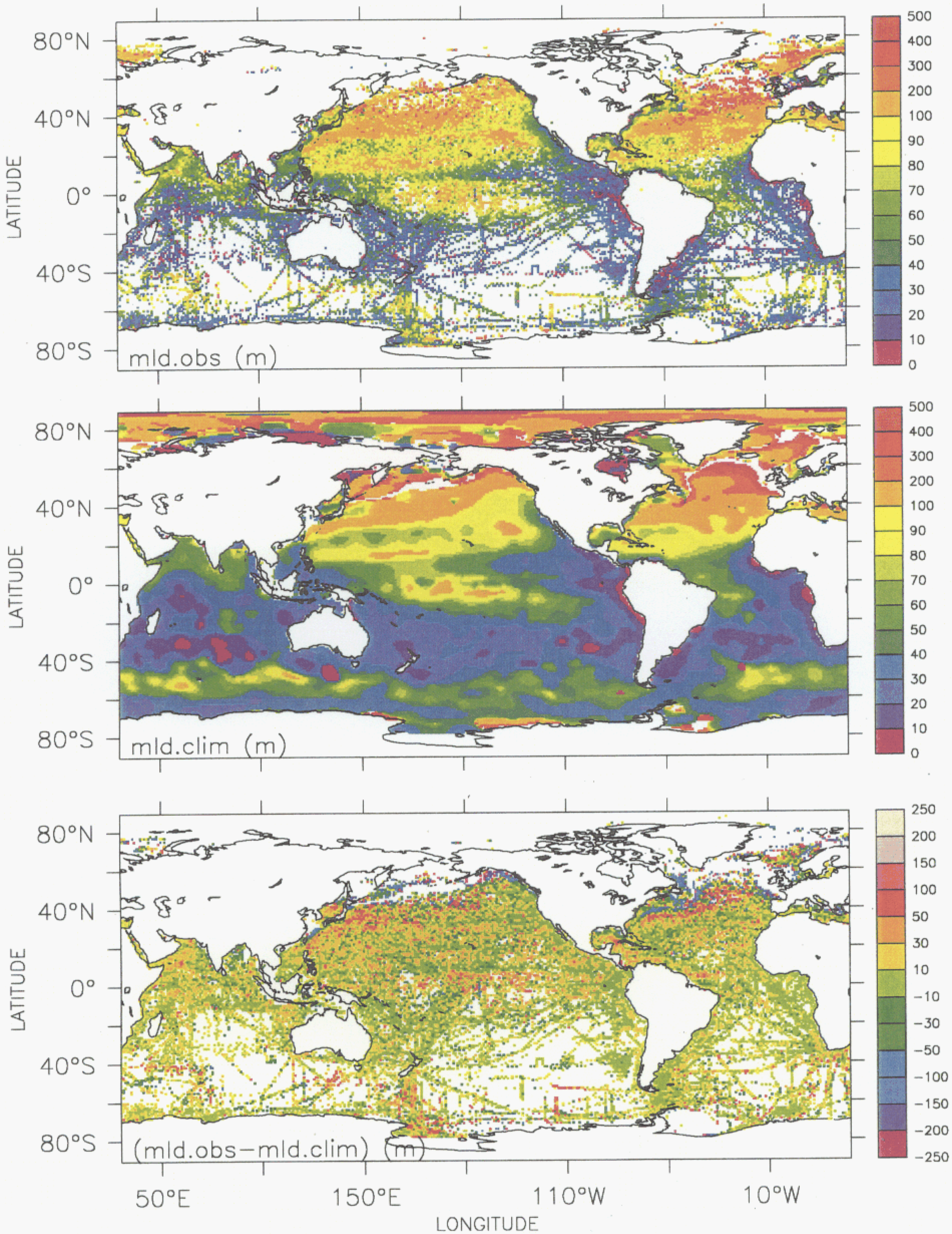
mld.pdvar.11
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
LATITUDE
LONGITUDE
80°N
40°N
0°
40°S
80°S
50°E
150°E
110°W
10°W
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1

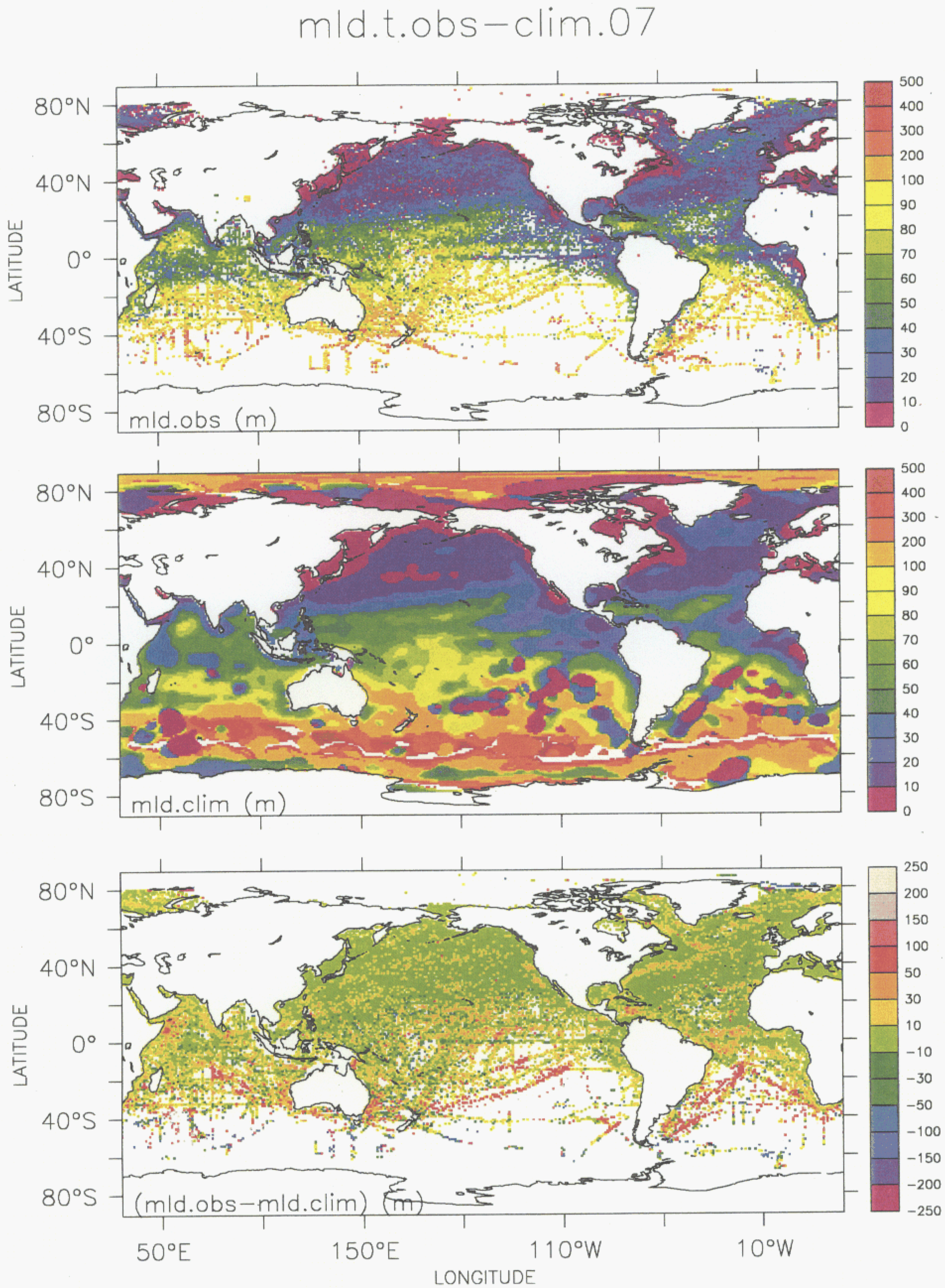

mld.pdvar.12
Mixed Layer Depth (m)
Standard Deviation (m)
Number of Observations
80°N
40°N
0°
40°S
80°S
LATITUDE
50°E
150°E
110°W
10°W
LONGITUDE
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10000
1000
100
10
5
4
3
2
1

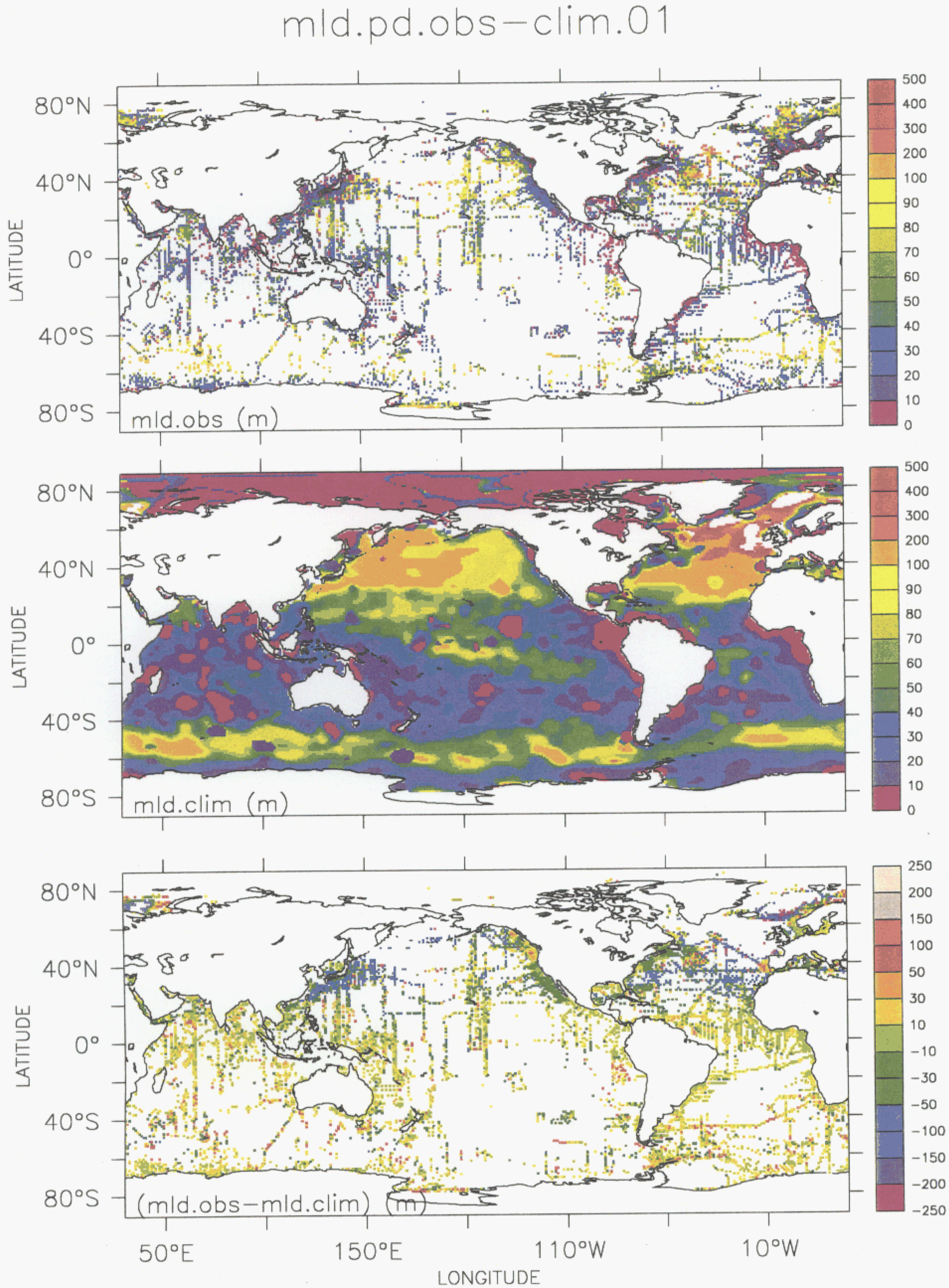
Appendix II

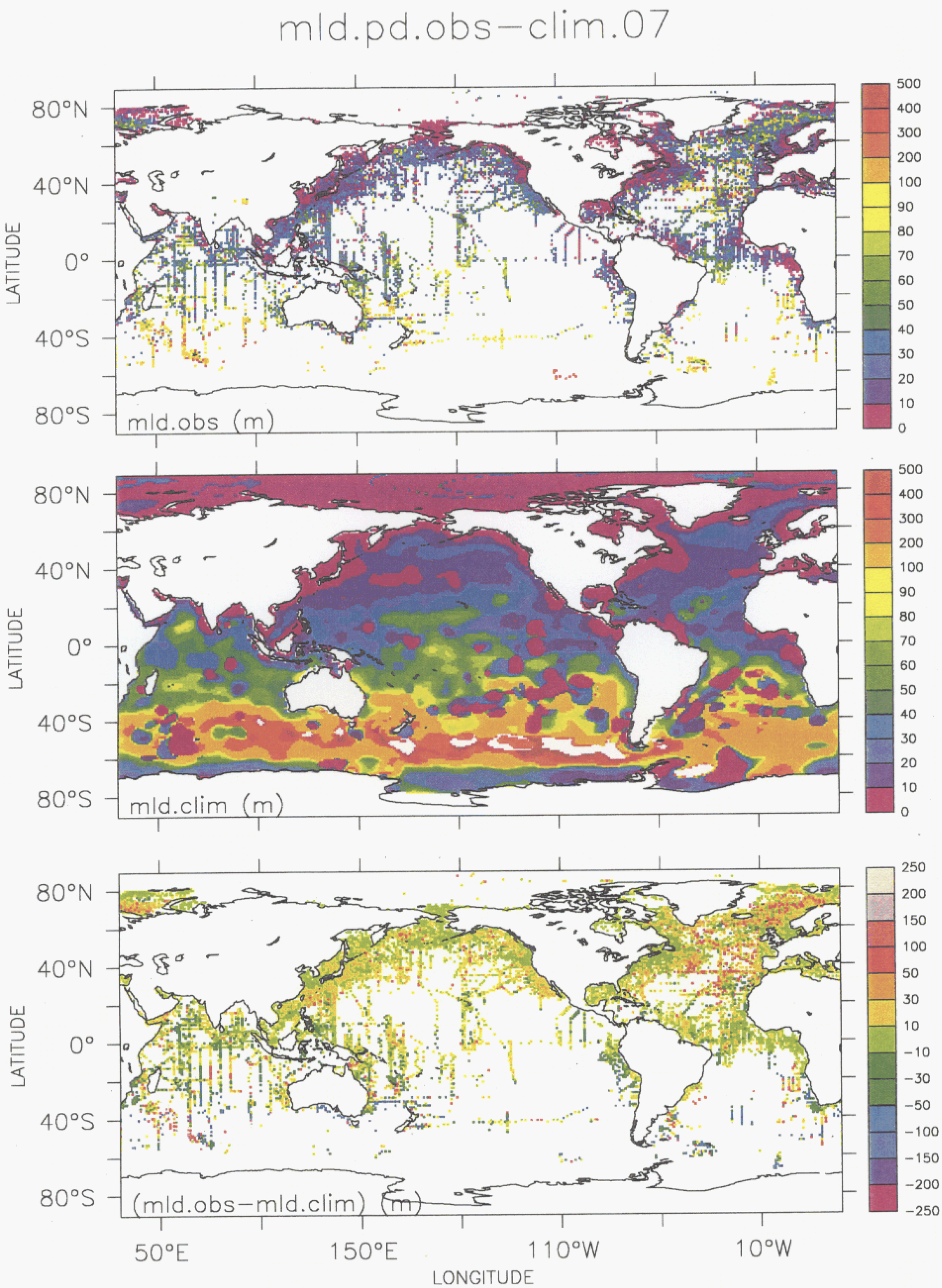
Comparison of MLD computed from individual observations and from climatology

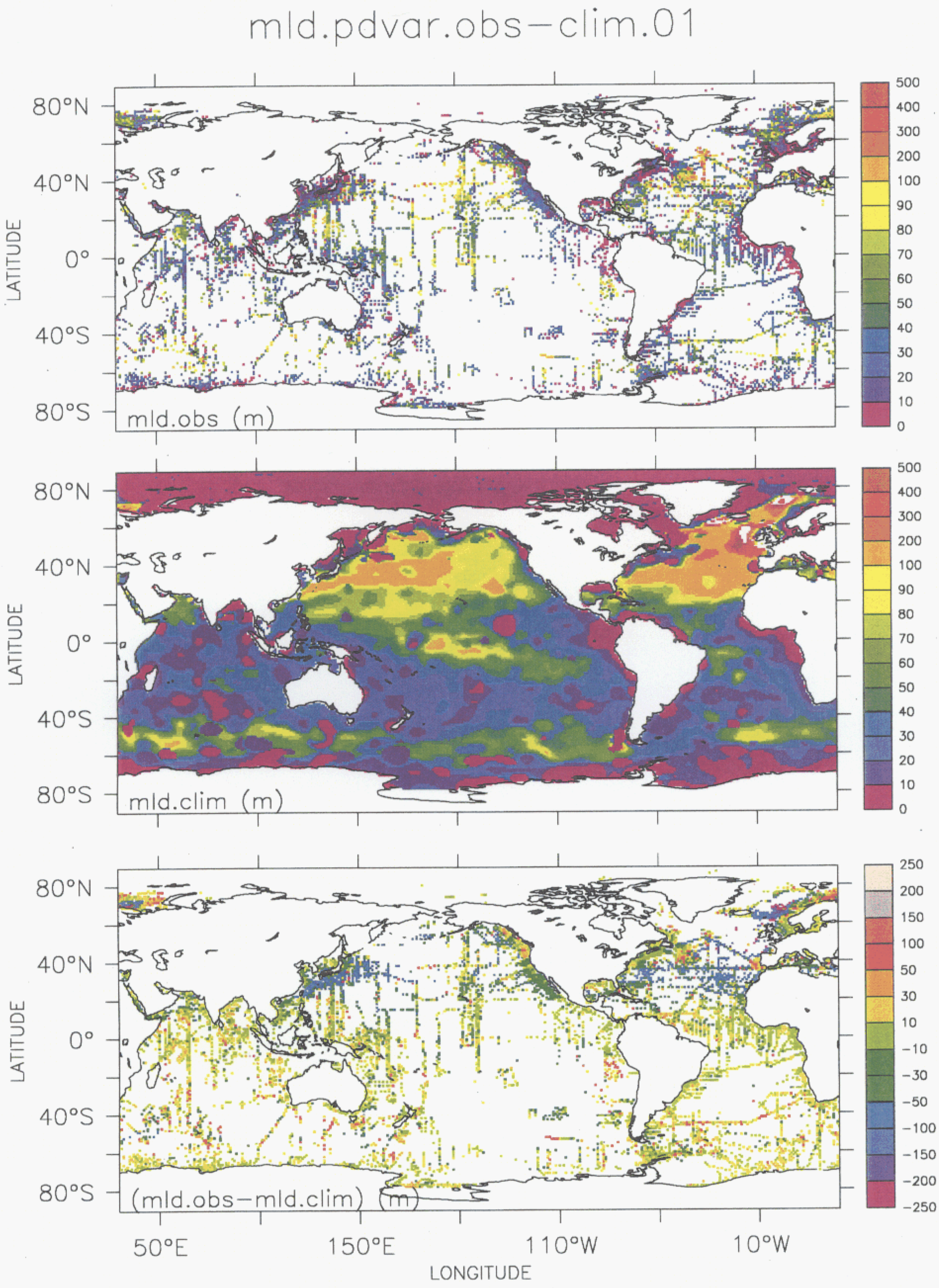
mld.t.obs−clim.01

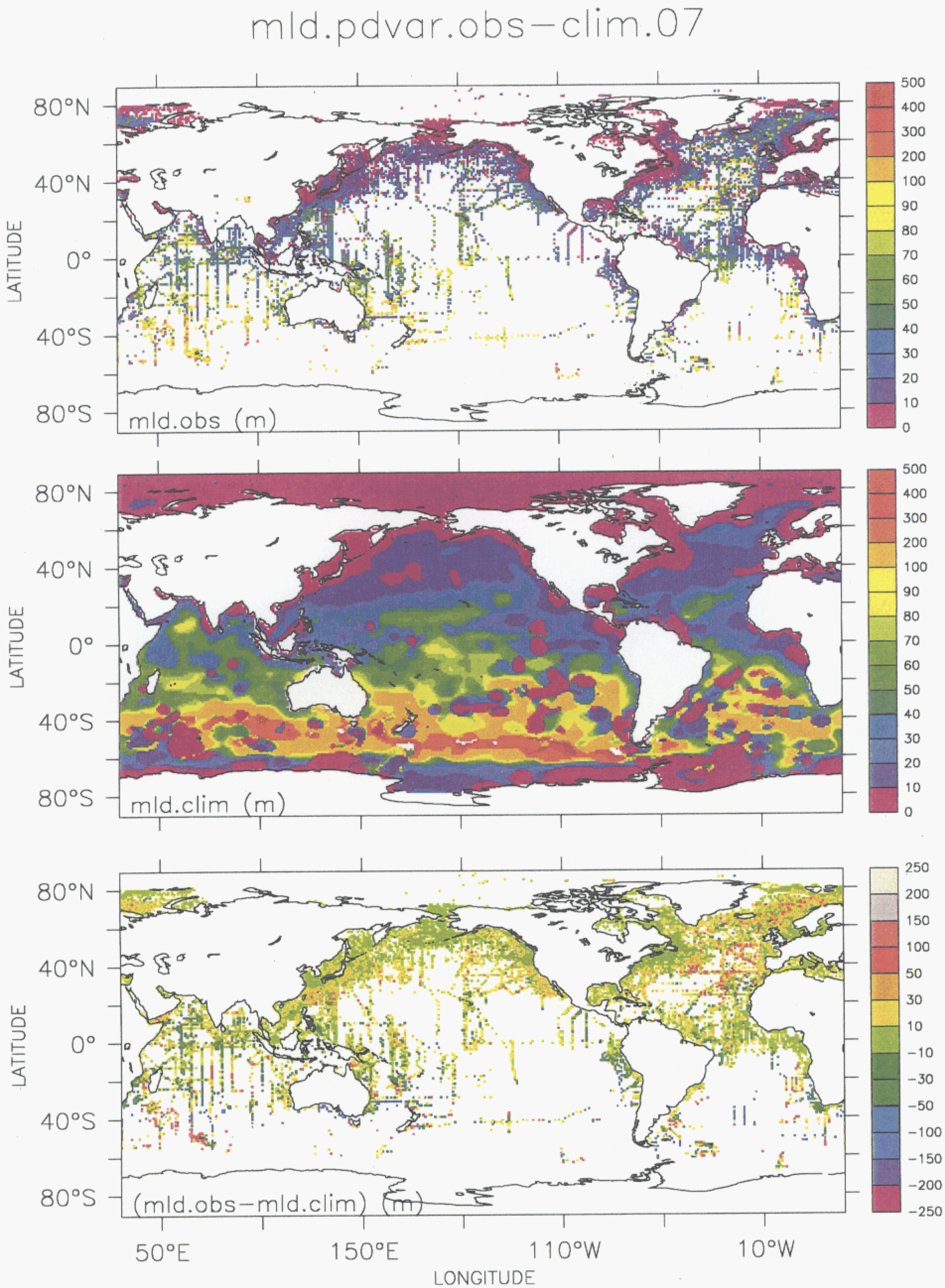



mld.t.obs−clim.07
80°N
40°N
0°
40°S
80°S
LATITUDE
mld.obs (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
mld.clim (m)
(mld.obs−mld.clim) (m)
250
200
150
100
50
30
10
−10
−30
−50
−100
−150
−200
−250
50°E
150°E
110°W
10°W
LONGITUDE


mld.pd.obs−clim.01
mld.obs (m)
mld.clim (m)
(mld.obs−mld.clim) (m)
LATITUDE
80°N
40°N
0°
40°S
80°S
LONGITUDE
50°E
150°E
110°W
10°W
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
250
200
150
100
50
30
10
−10
−30
−50
−100
−150
−200
−250

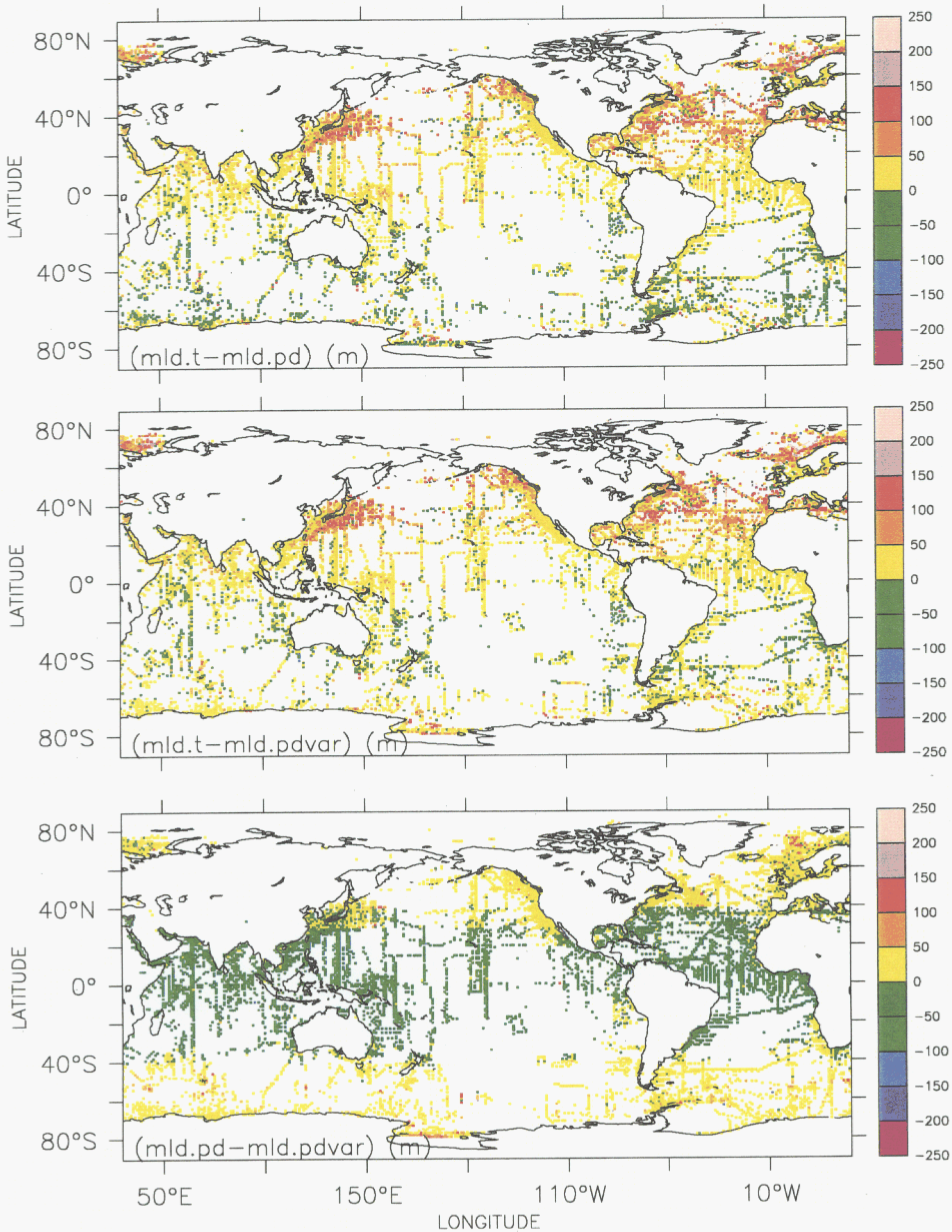

mld.pd.obs−clim.07
80°N
40°N
0°
40°S
80°S
LATITUDE
mld.obs (m)
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
mld.clim (m)
(mld.obs−mld.clim) (m)
250
200
150
100
50
30
10
−10
−30
−50
−100
−150
−200
−250
50°E
150°E
110°W
10°W
LONGITUDE

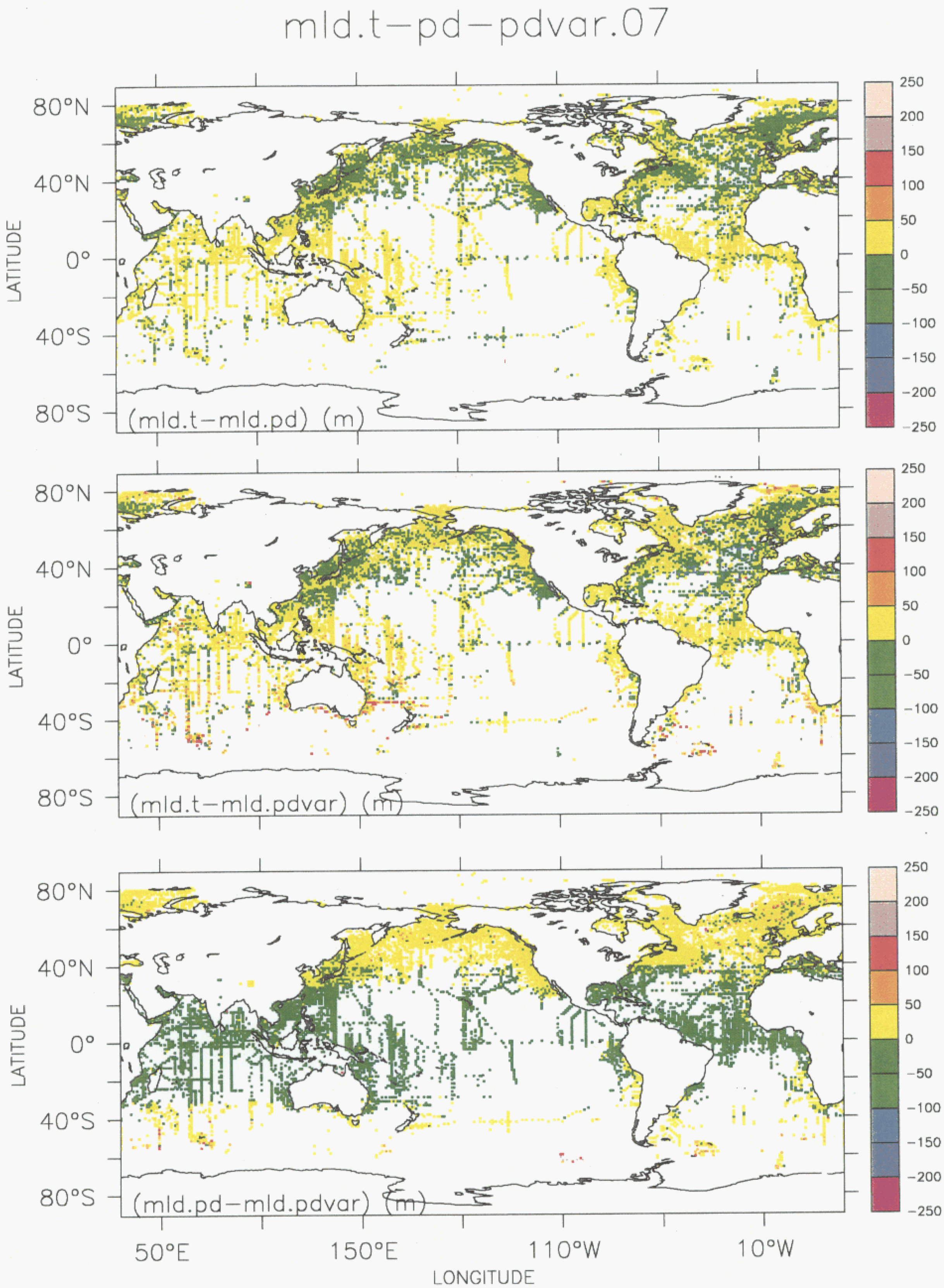

mld.pdvar.obs−clim.01
mld.obs (m)
mld.clim (m)
(mld.obs−mld.clim) (m)
LATITUDE
LONGITUDE
80°N
40°N
0°
40°S
80°S
50°E
150°E
110°W
10°W
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
250
200
150
100
50
30
10
−10
−30
−50
−100
−150
−200
−250



mld.pdvar.obs−clim.07
mld.obs (m)
mld.clim (m)
(mld.obs−mld.clim) (m)
LATITUDE
LONGITUDE
80°N
40°N
0°
40°S
80°S
50°E
150°E
110°W
10°W
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
250
200
150
100
50
30
10
−10
−30
−50
−100
−150
−200
−250

mld.t−pd−pdvar.01





mld.t−pd−pdvar.07
80°N
40°N
0°
40°S
80°S
LATITUDE
(mld.t−mld.pd) (m)
(mld.t−mld.pdvar) (m)
(mld.pd−mld.pdvar) (m)
250
200
150
100
50
0
−50
−100
−150
−200
−250
50°E
150°E
110°W
10°W
LONGITUDE

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