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The sea-surface level in the Northwestern Pacific as an indicator of local and global tendencies in the climate change

Our investigations based on satellite altimetry information for the Northwestern Pacific, including its Japan Sea, Okhotsk Sea, and Bering Sea, have had at focus the following:

- Principal mechanisms governing the sea level variation;
- Climatic trends in sea-level oscillations;
- Statistical analysis of the sea-level variation;
- Wavelet analysis of the sea-level variation;
- Non-linear effects of seasonal sea-level variation in the Pacific
- etc.

There are two methods of sea-surface level observation:

1. **Gauge metering at coastal or open-sea tidal stations at which very long data series have been collected;**

2. **The satellite altimetry that has a shorter history of level observations. It started after the launch of satellite Topex/Poseidon in 1992. And then were missions ERS-2 (1995), GFO-1 (GEOSAT Follow On) (1998), Jason-1 (2001), Envisat (2002) and OSTM/Jason-2 (2008).**

Numerals in brackets mean the year of launch.

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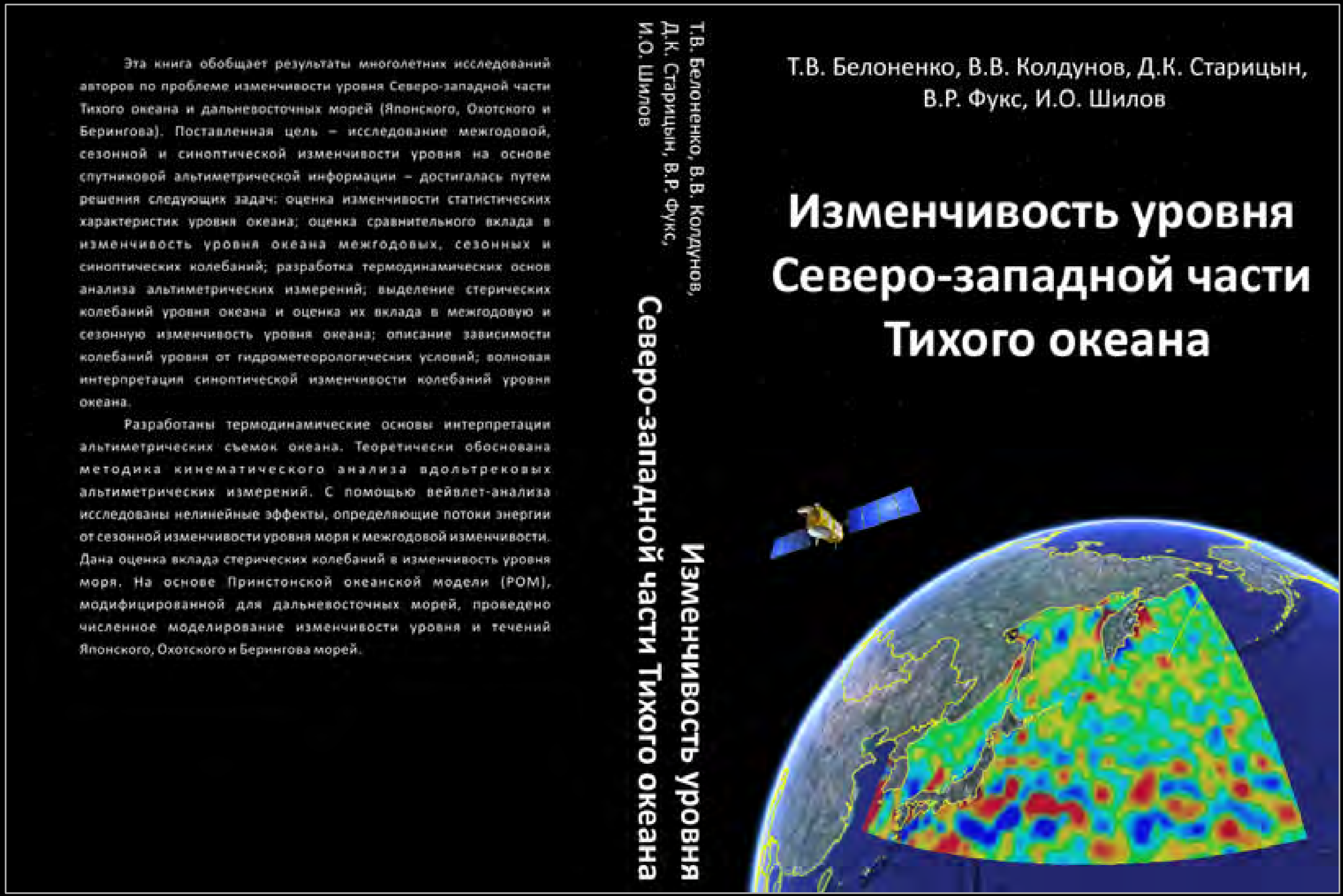

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ATLAS

Sea-Surface Level Variability in the Northwestern Pacific

Saint Petersburg
2011

This Atlas is based on the Joint Archive for Sea Level (JASL) and altimetry data series obtained from the data bank **AVISO** (http://www.aviso.oceanobs.com/) (Archiving, Validation and Interpretation of Satellite Oceanographic data) in the project **DUACS** (Data Unification and Altimeter Combination System) for accomplishing processing of the multi-mission altimetry data (SSALTO) under the auspice of France Space Agency CNES. The system exercises processing of the data from satellites Jason-1/2, TOPEX/Poseidon, Envisat, GFO-1, ERS1/2 and GEOSAT and provides two forms of processed data:

1. **Along-track data** are given in a chronological sequence of different satellites;

2. **Gridded data** are given at nodes of a regular grid. The data set of such a type combines measurements from all the said satellites into a spatially-temporally homogenous set of SSL data.

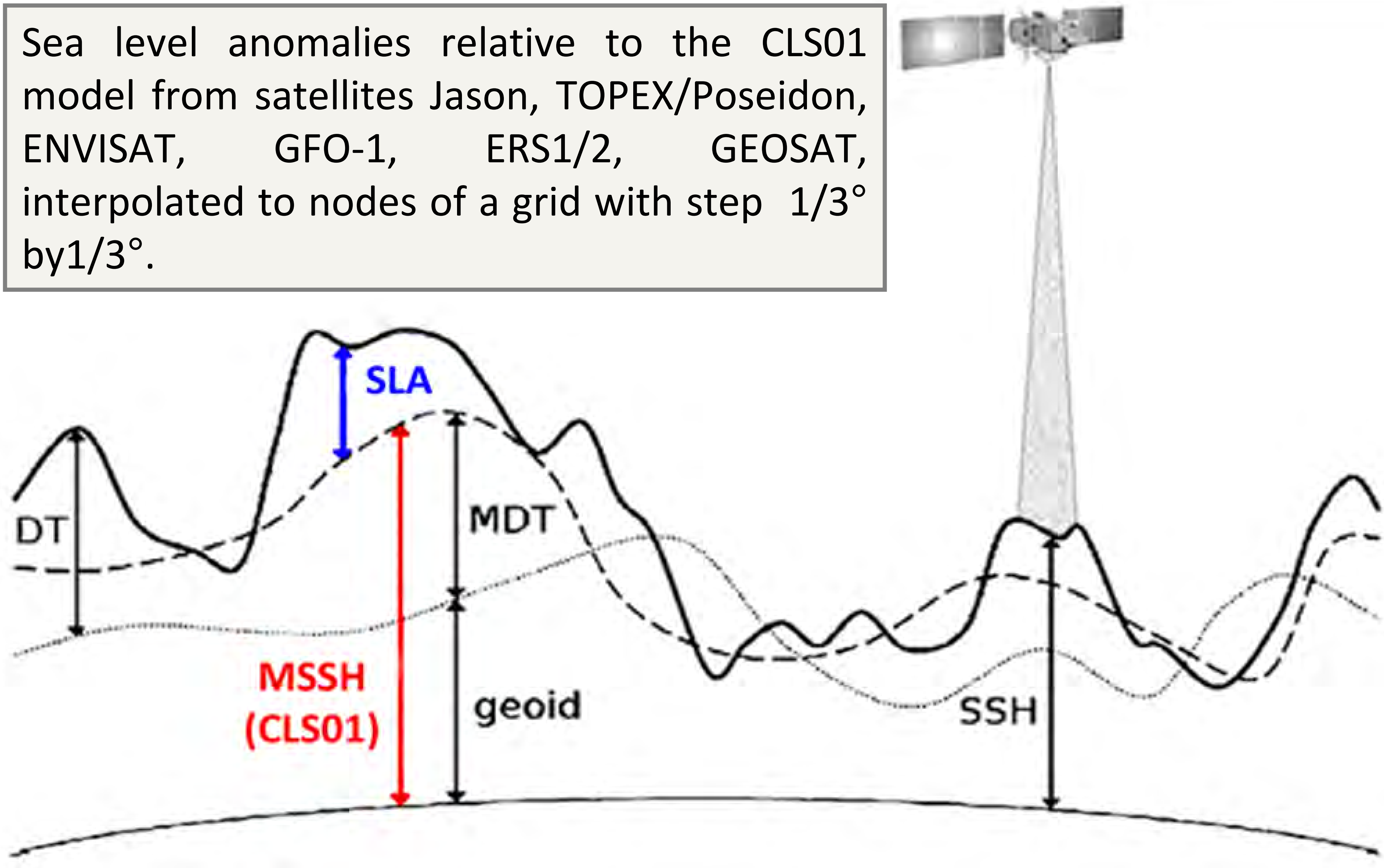
Two types of data are dealt with in this Atlas:

ADT which means Absolute Dynamic Topography; and **SLA**, or Sea Level Anomaly.

The ADT set characterizes deviation of the sea-surface height from a geoid (geopotential sea surface); and SLA is deviation of the sea surface height from its mean value estimated by averaging the heights for several years (1993-1999) (These for 1993-1999 are stored in the data file MSSH (Mean Sea Surface Height) and calculated by formula SLA = SSH – MSSH).

Principle of satellite altimetry

Sea level anomalies relative to the CLS01 model from satellites Jason, TOPEX/Poseidon, ENVISAT, GFO-1, ERS1/2, GEOSAT, interpolated to nodes of a grid with step 1/3° by1/3°.

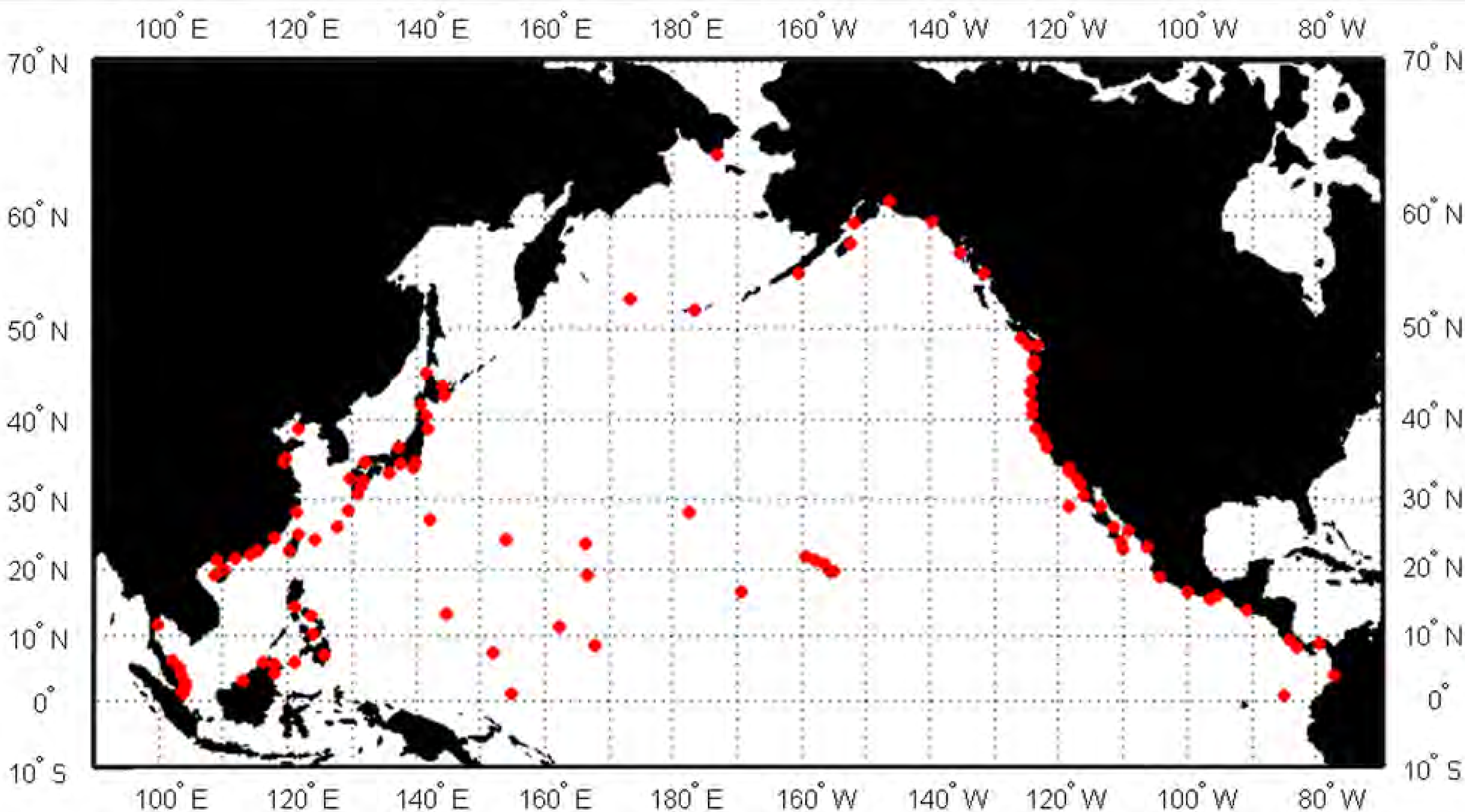


SLA = SSH – MSSH

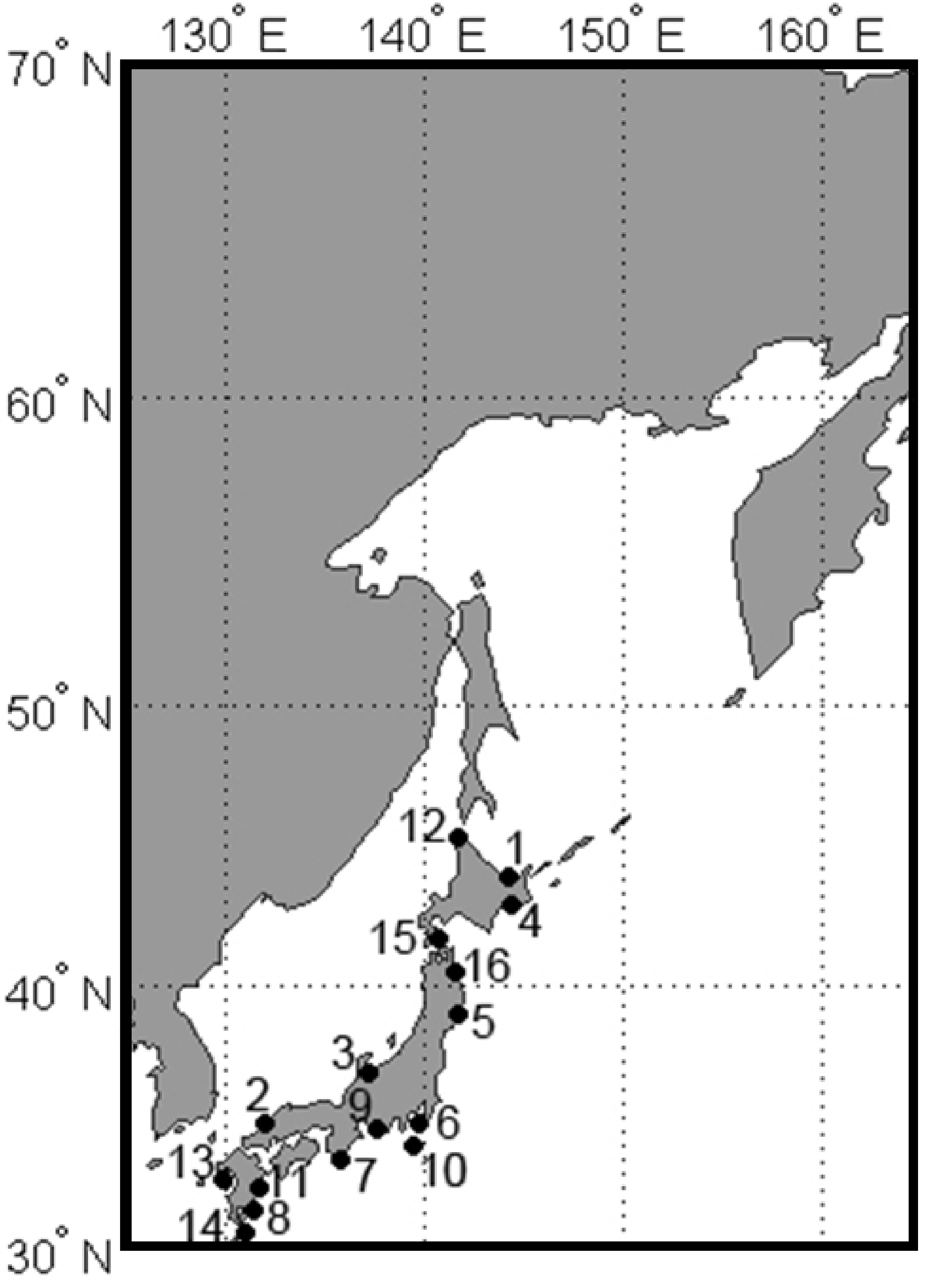
MDT = MSSH - h_{geoid}

ADT = SLA + MDT

JASL tide stations



File of the initial data includes the daily average values of a sea level measured on 130 coastal posts



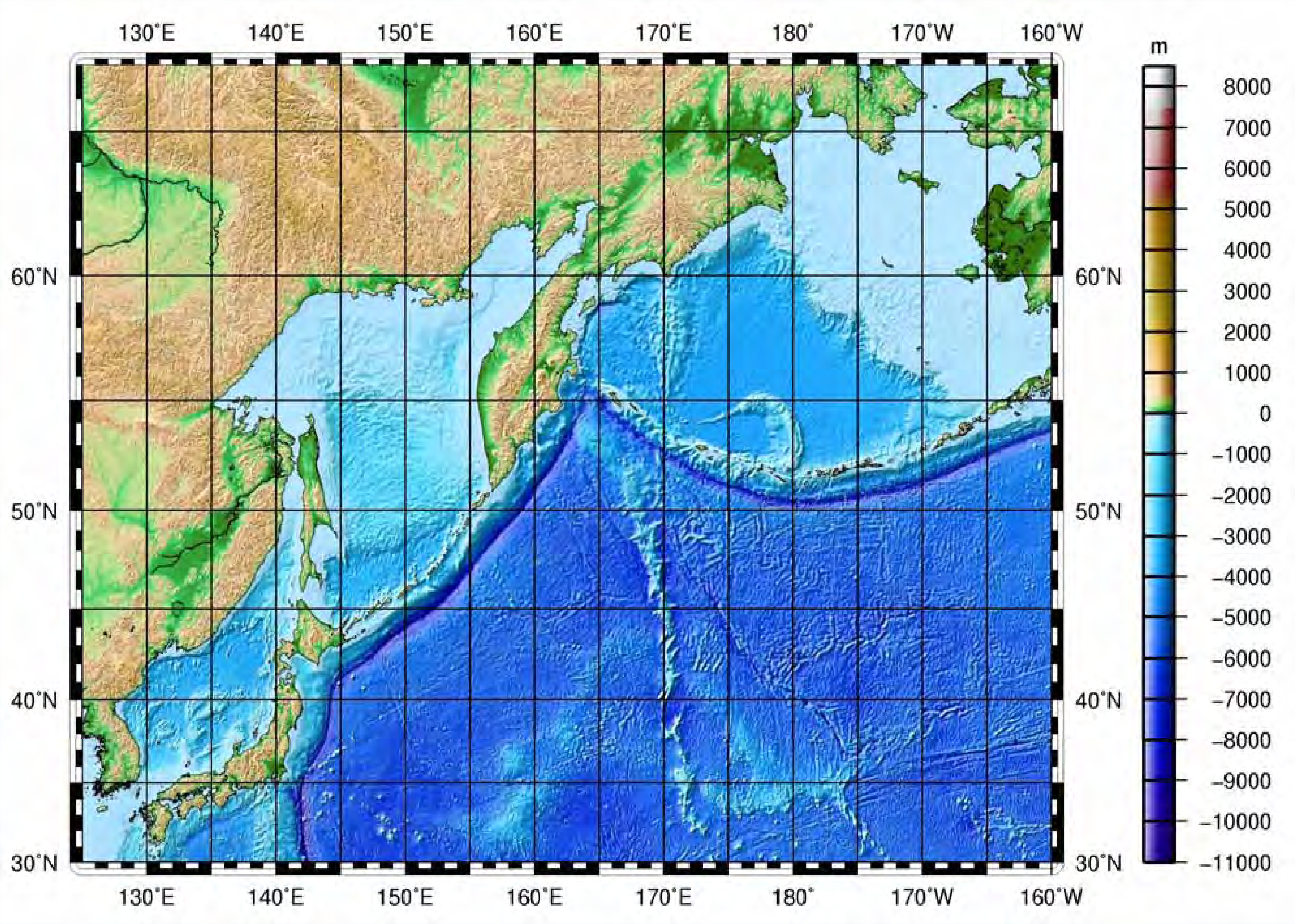
Tidal stations in the northwestern Pacific Ocean

16 tide stations have been allocated from the JASL file for exploring water area of the northwestern part of the Pacific Ocean.

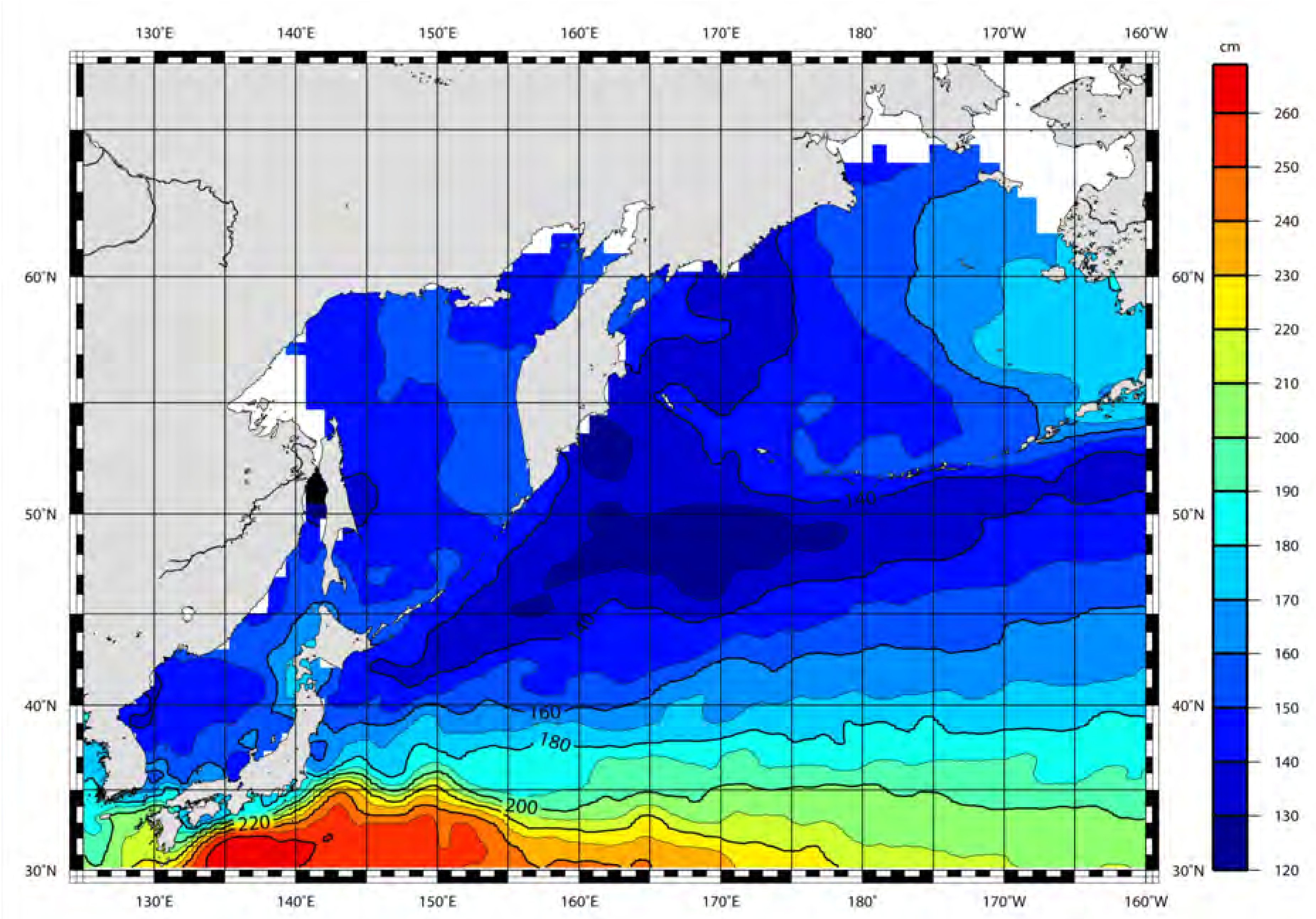
Sea-Surface Level Variability in the Northwestern Pacific

Introduction

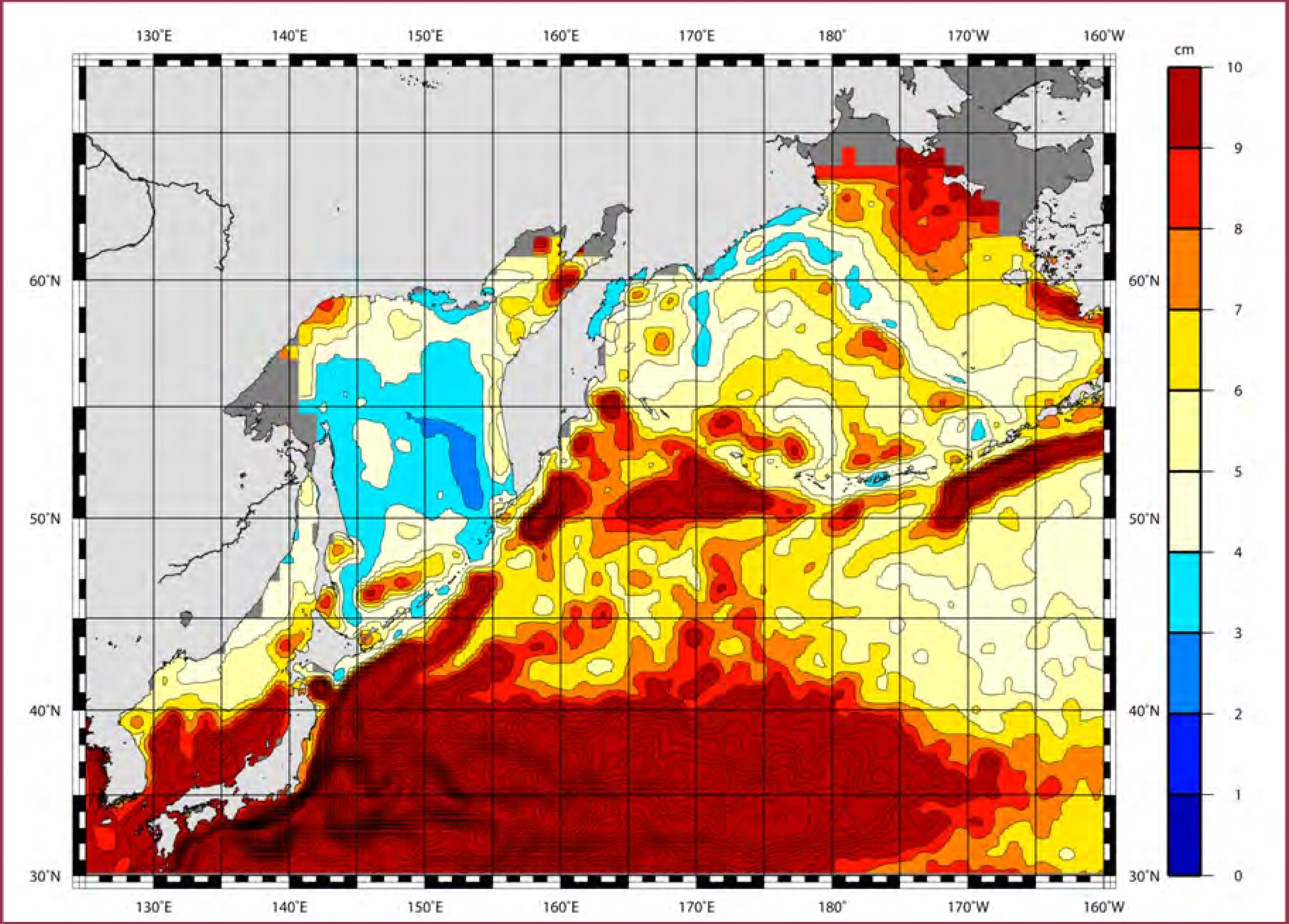
1. Hydrographical description of the region and along-track satellite measurement
    - 1.1. Bathymetry map
    - 1.2. Main reference satellite tracks
    - 1.3. The along-track isopleths of sea-surface level
2. Dynamical sea-surface topography (averaged for 1992-2007).
    - 2.1. Mathematical expectation of the absolute dynamical sea-surface topography
    - 2.2. The root-mean-square deviation from the mean multiyear values of absolute dynamical sea-surface topography
    - 2.3. Variation coefficient of the mean multiyear values of absolute dynamical sea-surface topography
    - 2.4. Mean multiyear divergence of full flows



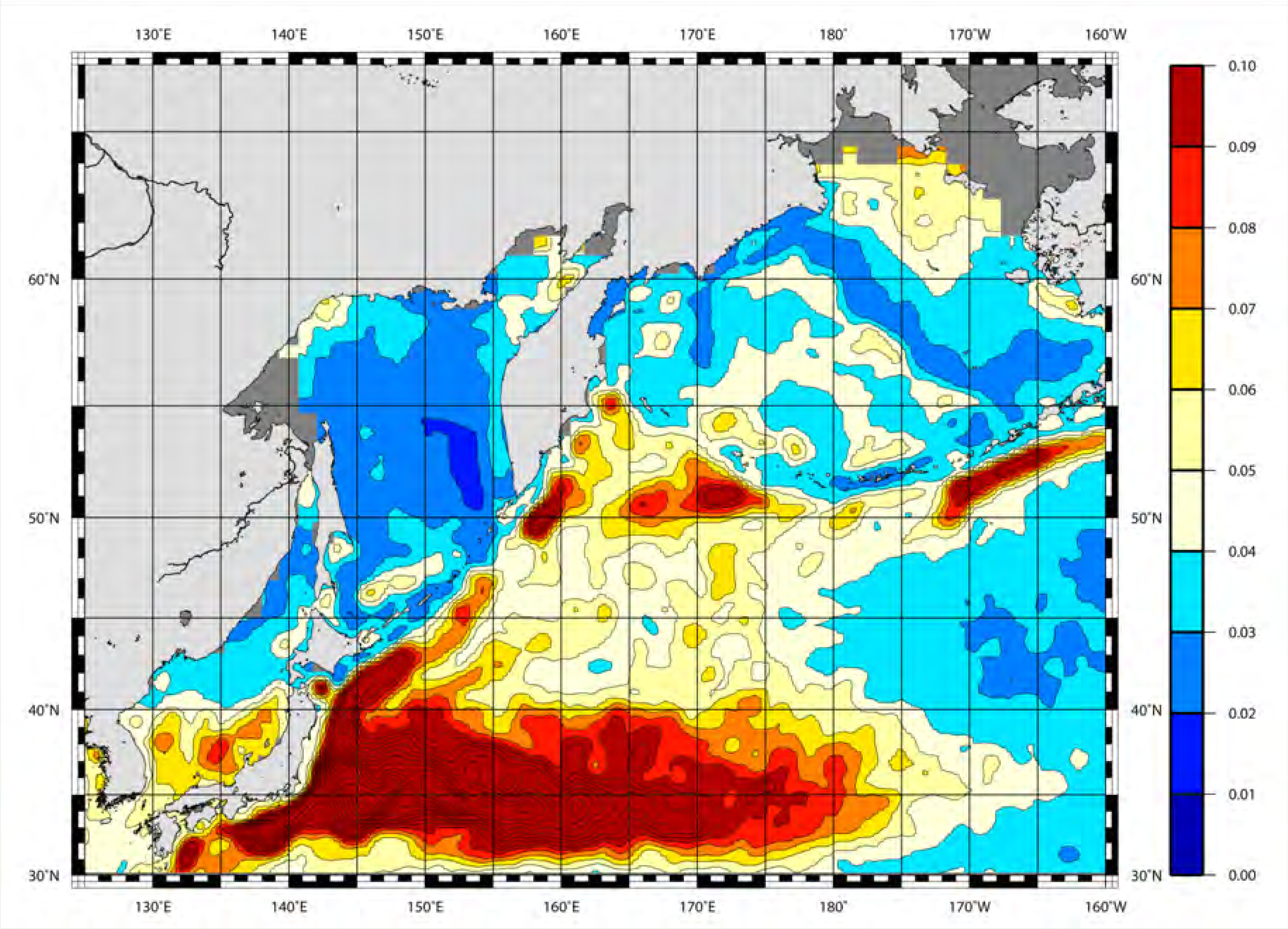
Bathymetry map



Mathematical expectation of the absolute dynamical sea-surface topography



The root-mean-square deviation from the mean multiyear values of absolute dynamical sea-surface topography



Variation coefficient of the mean multiyear values of absolute dynamical sea-surface topography

Let's consider divergence of full flows, calculated by the speed of change of level $\frac{\partial \xi}{\partial t}$.

If we neglect fresh balance, from the equation of continuity of weight, integrated from the sea surface to the bottom $z = H(x, y)$, for these time scales, we will receive:

$$\frac{\partial \xi}{\partial t} = -\operatorname{div} \vec{V} H - \int_0^H \frac{1}{\rho} \frac{d\rho}{dt} dz$$

where

$\overline{V}$ - average speed of a flow on a vertical,

H – depth of the sea,

$\vec{V}H$ makes sense as a full flow (Fuks, 2003).

The first term in the right part of this equation is dynamic speed, and the second term is steric speed of sea level changes.

In conditions when steric effects are small,

$$\frac{\partial \xi}{\partial t} = -\operatorname{div} \vec{V} H$$

If the divergence of a full flow is positive, the sea level falls; when it is negative, level raises.

For constant depth the equation of continuity of this system can be written down like this:

$$\frac{\partial \xi}{\partial t} = -H \cdot \mathrm{div}\vec{V}$$

where

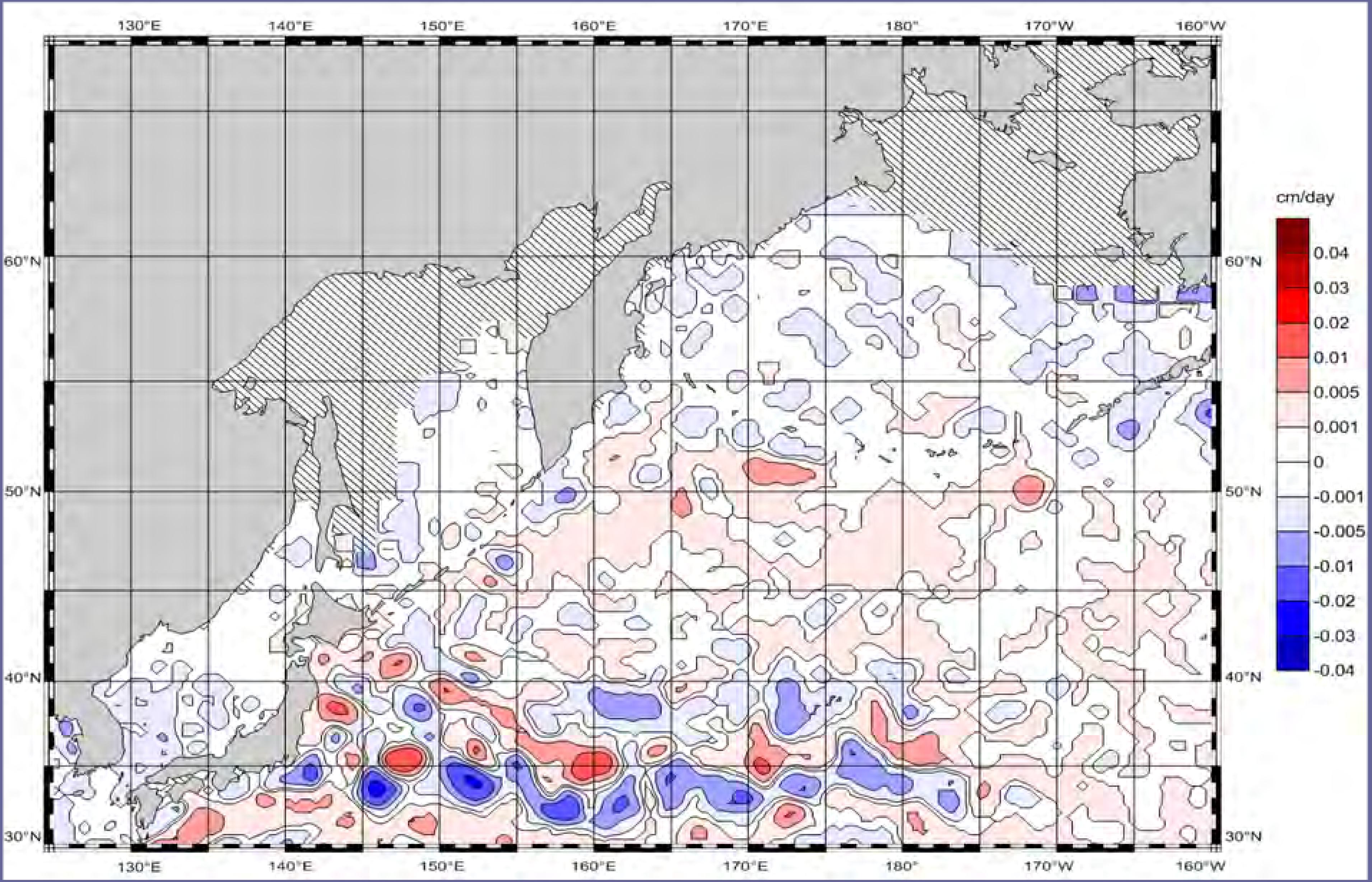
$$\mathrm{div}\vec{V} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$$ - the divergence of the flow's speed $\vec{V}$

$\vec{V}$ - vector of average speed of flow, integrated on depth.

At the divergence of full streams ($\operatorname{div}\vec{V}H > 0$), the sea level goes down. So we have a zone of **downwelling**.

At convergence of full streams ($\operatorname{div}\vec{V}H < 0$) the sea level raises, and the zone of **upwelling** formes.

In this Atlas we see speeds of change of the sea level $\frac{\partial \xi}{\partial t}$ for a northwest part of Pacific.



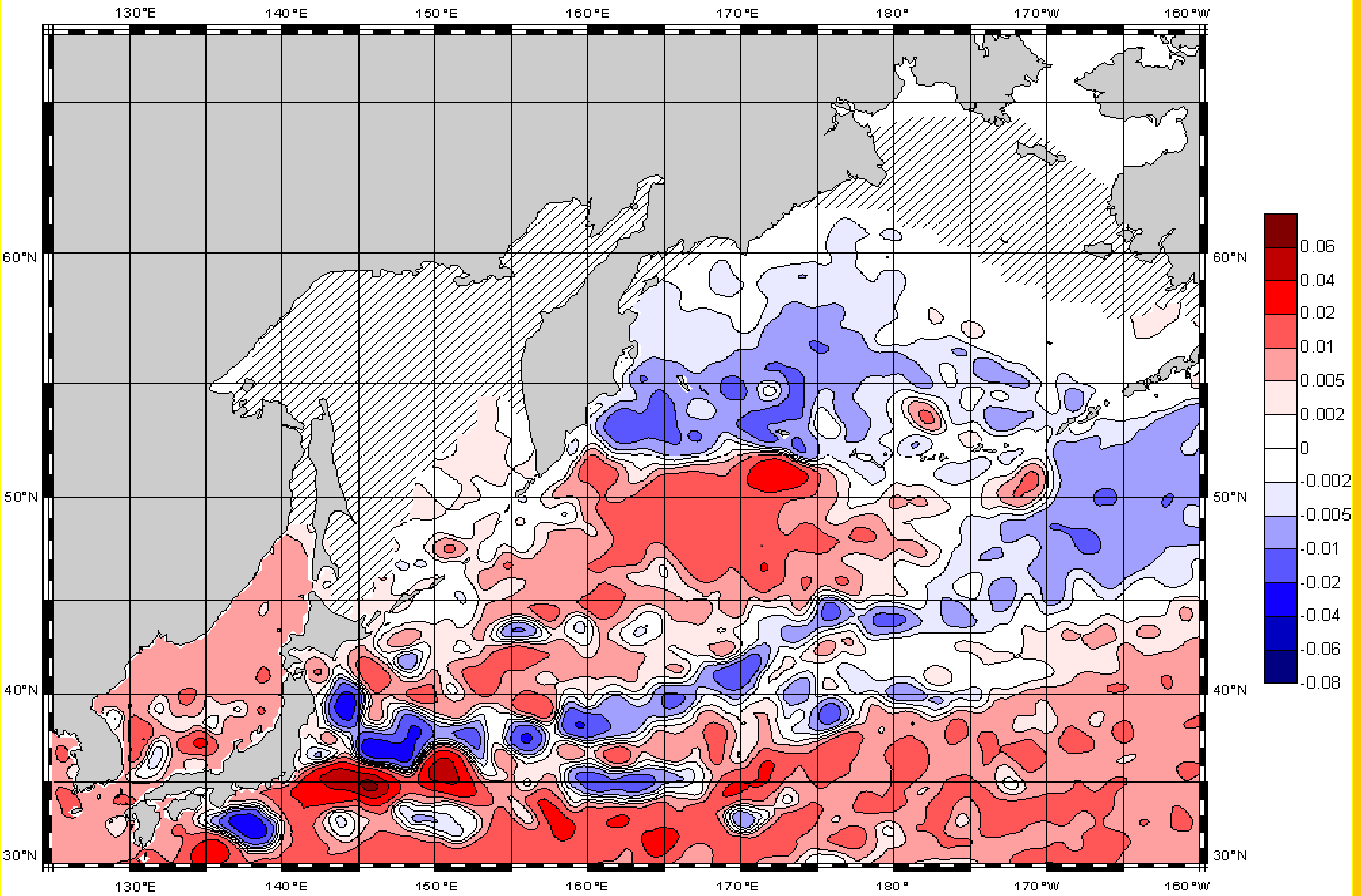
Mean multiyear divergence of full flows

3. Yearly averaged dynamical sea-surface topography

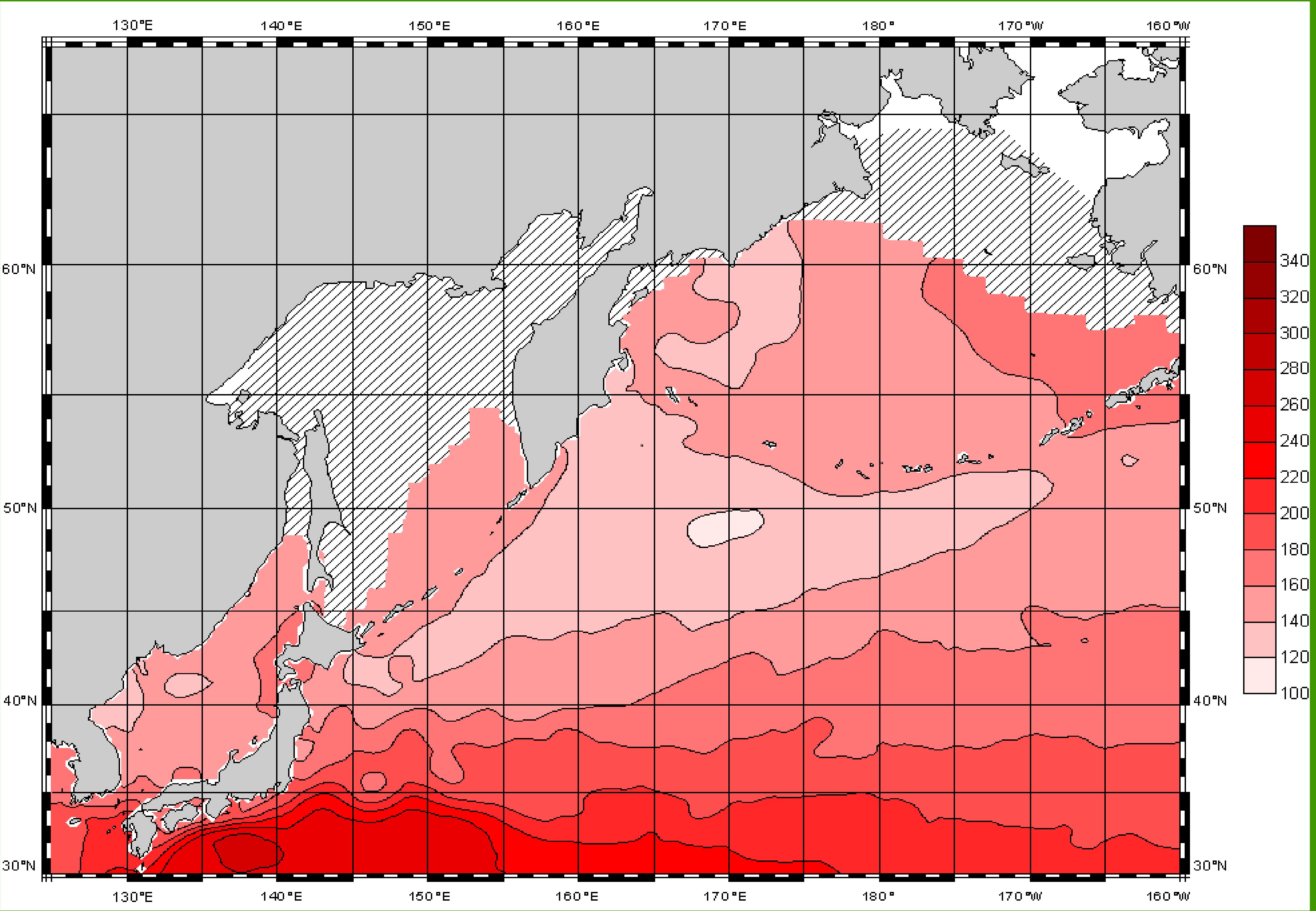
3.1. Annual sea levels at gauge stations
3.2. Annual sea-surface topography
3.3. Trends in the sea level
3.3.1 The sea-level trends at reference gauge stations
3.3.2. The sea-level trends according to satellite altimetry data
3.4. The root-mean-square deviation of the dynamic topography at yearly averaging mode
3.5. Annual divergence of the full flows

4. Monthly averaged dynamical sea-surface topography

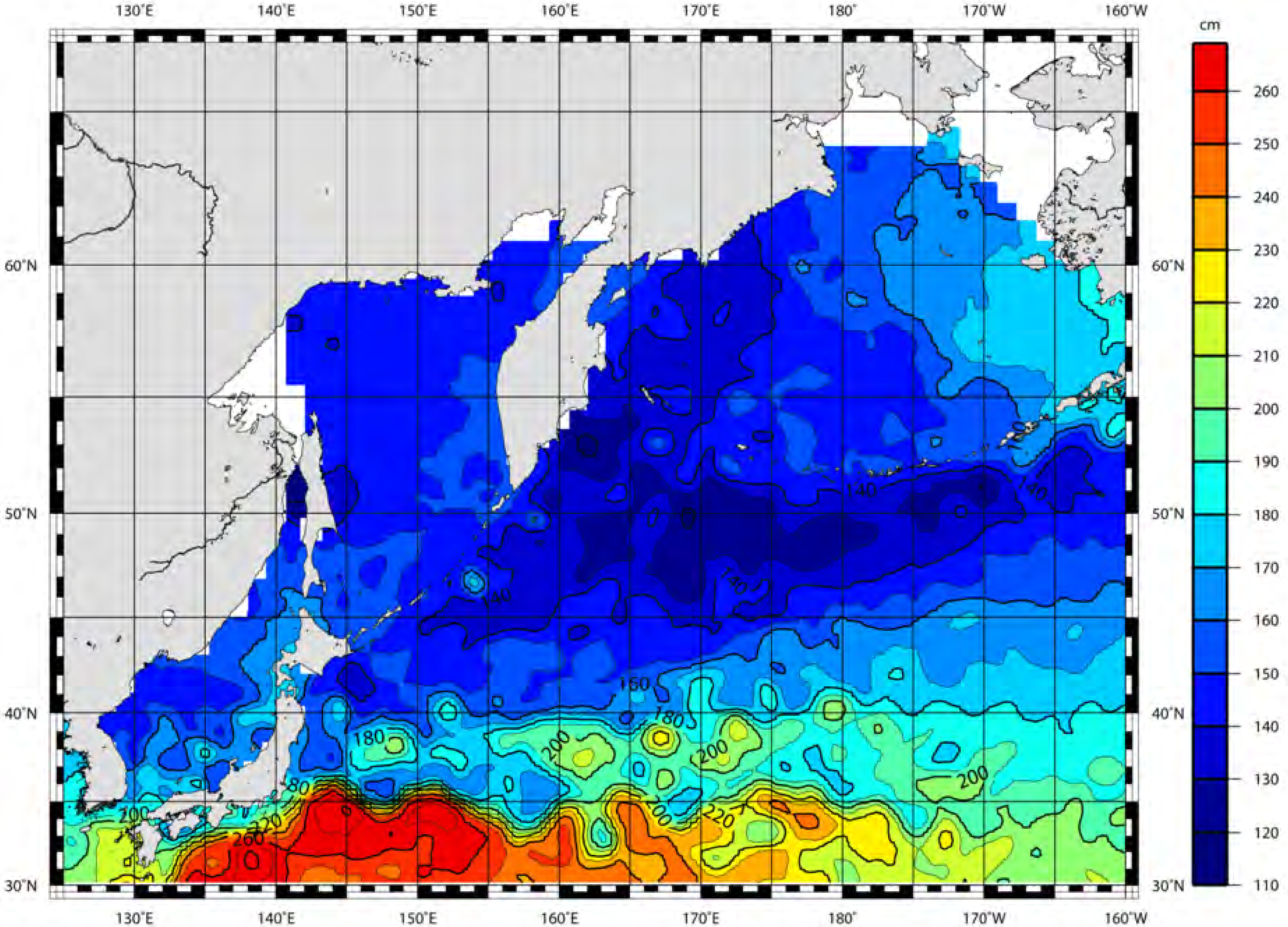
4.1. The monthly sea levels at reference gauge stations
4.1.1. Multiyear seasonal alteration of the sea level
4.1.2. Spectral and wavelet analyses of the sea level fluctuations at gauge stations
4.1.3. Wavelet pictures of the dynamical sea-surface topography in certain points of the region
4.2. Multiyear monthly values of the absolute dynamical sea-surface topography
4.3. The root-mean-square deviation of multiyear monthly values of the absolute dynamical sea-surface topography
4.4. Seasonal variation of the full flow divergence



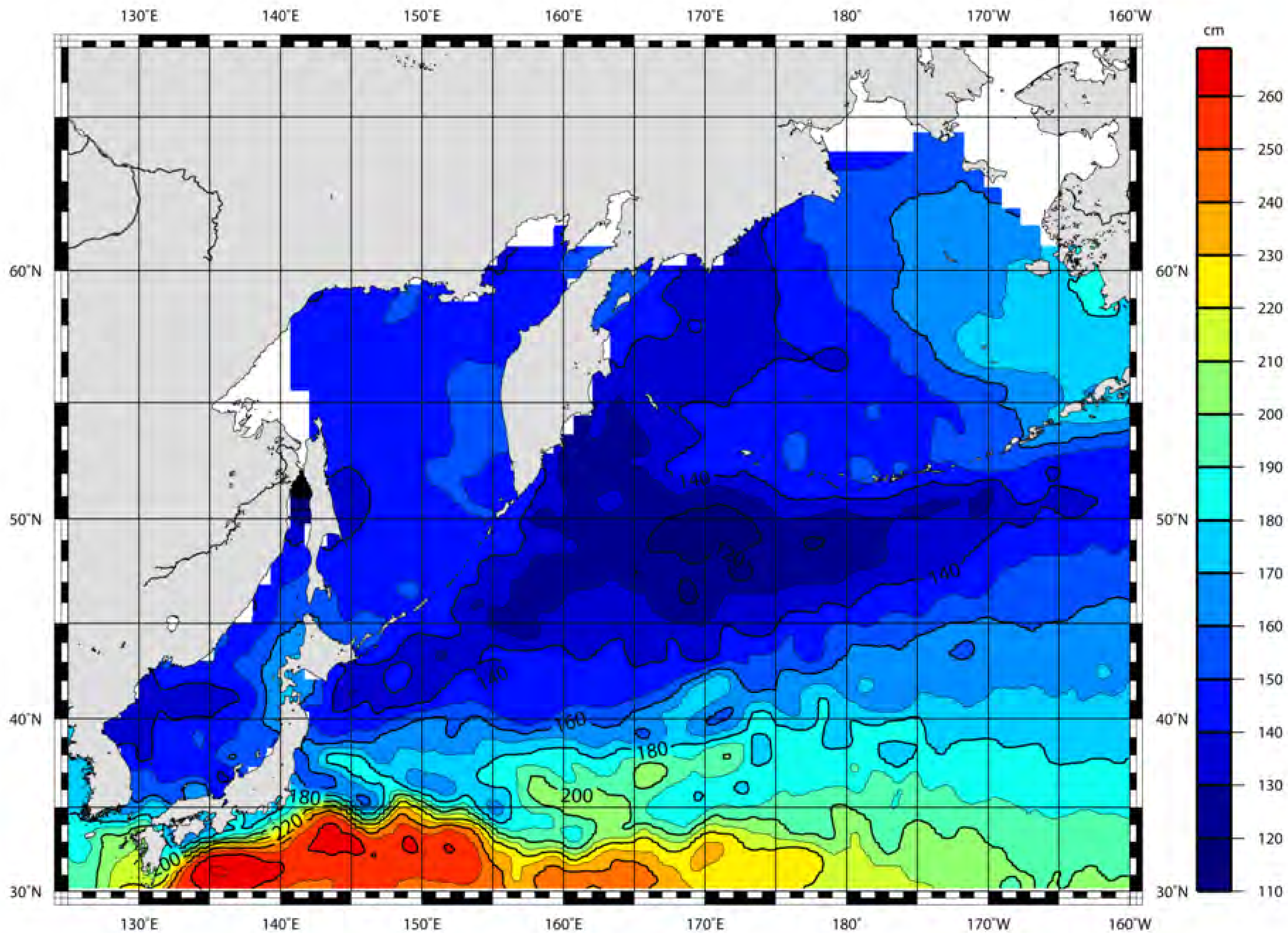
The sea-level trends according to satellite altimetry data, field "b"
ξ = b t + c.



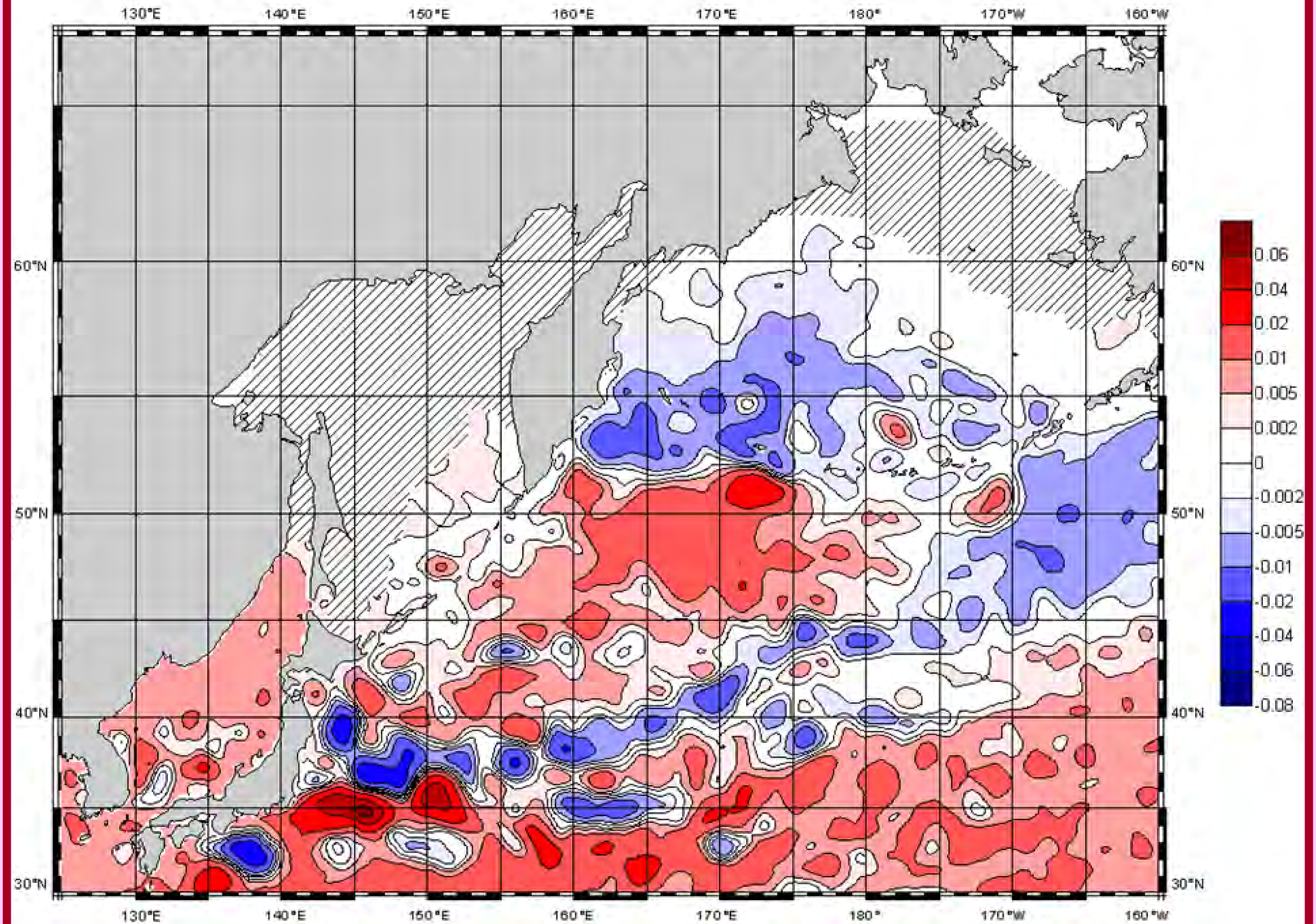
The sea-level trends according to satellite altimetry data, field "c"
$\xi = b\,t + c.$



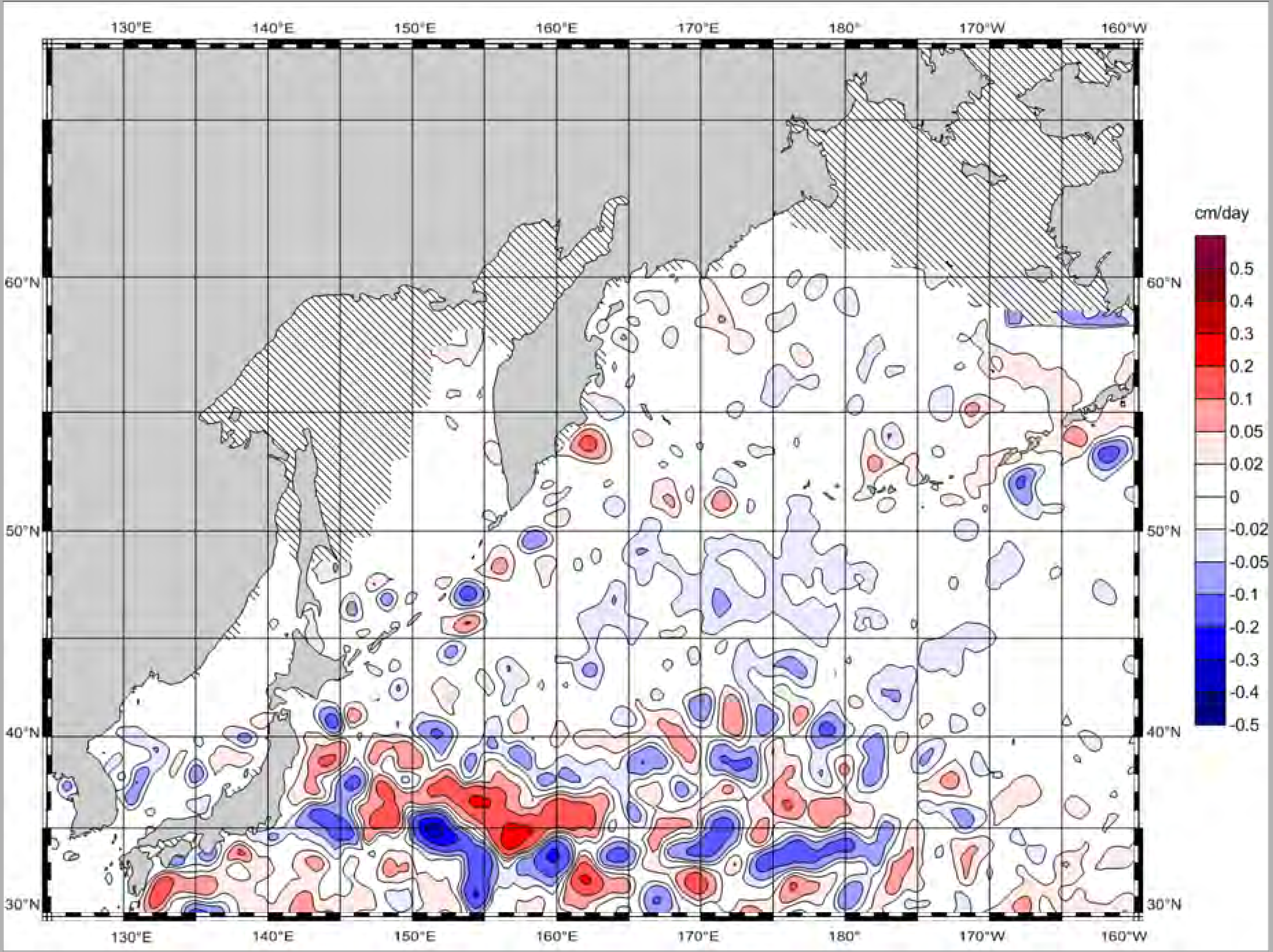
Annual sea-surface topography: 1992



Annual sea-surface topography: 1993



The root-mean-square deviation of the dynamic topography at yearly averaging mode:1993

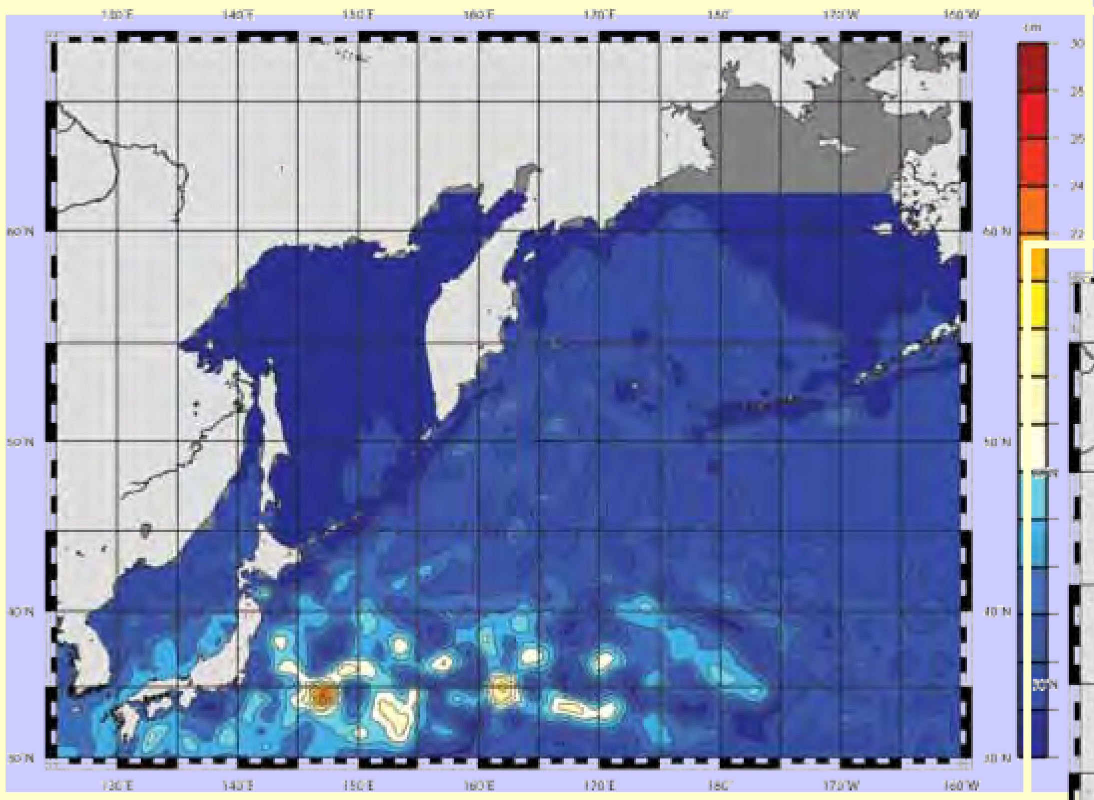


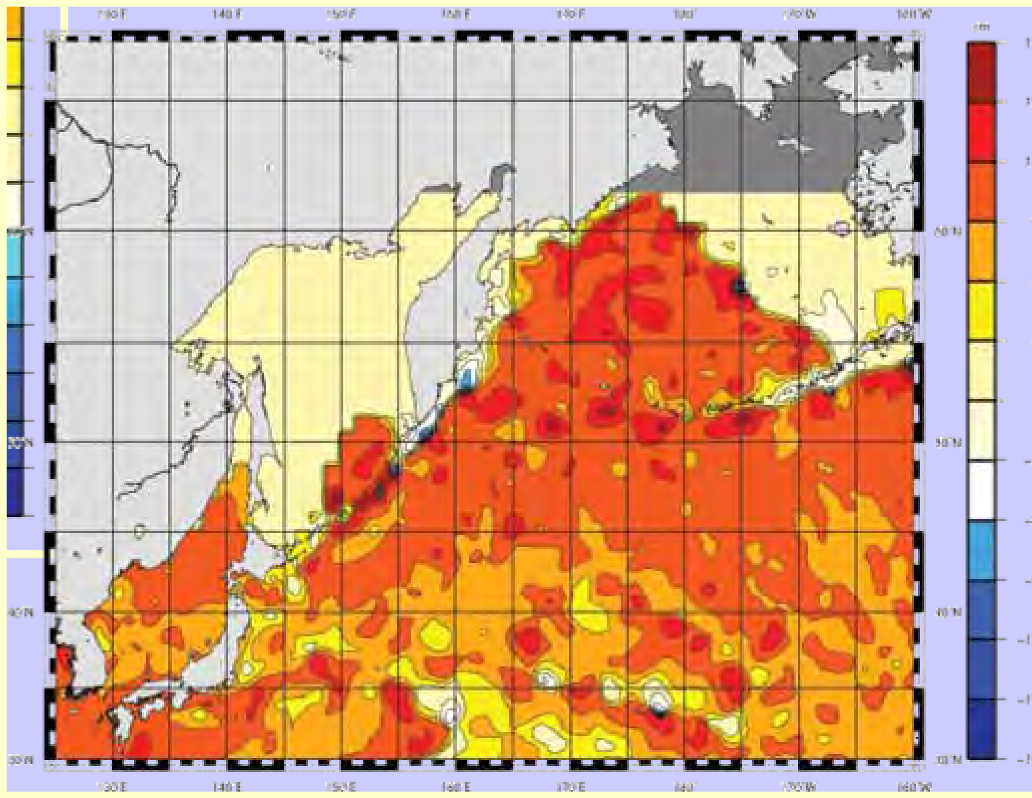
Annual divergence of the full flows: 1993

5. Annual and semiannual fluctuations of the sea-surface level

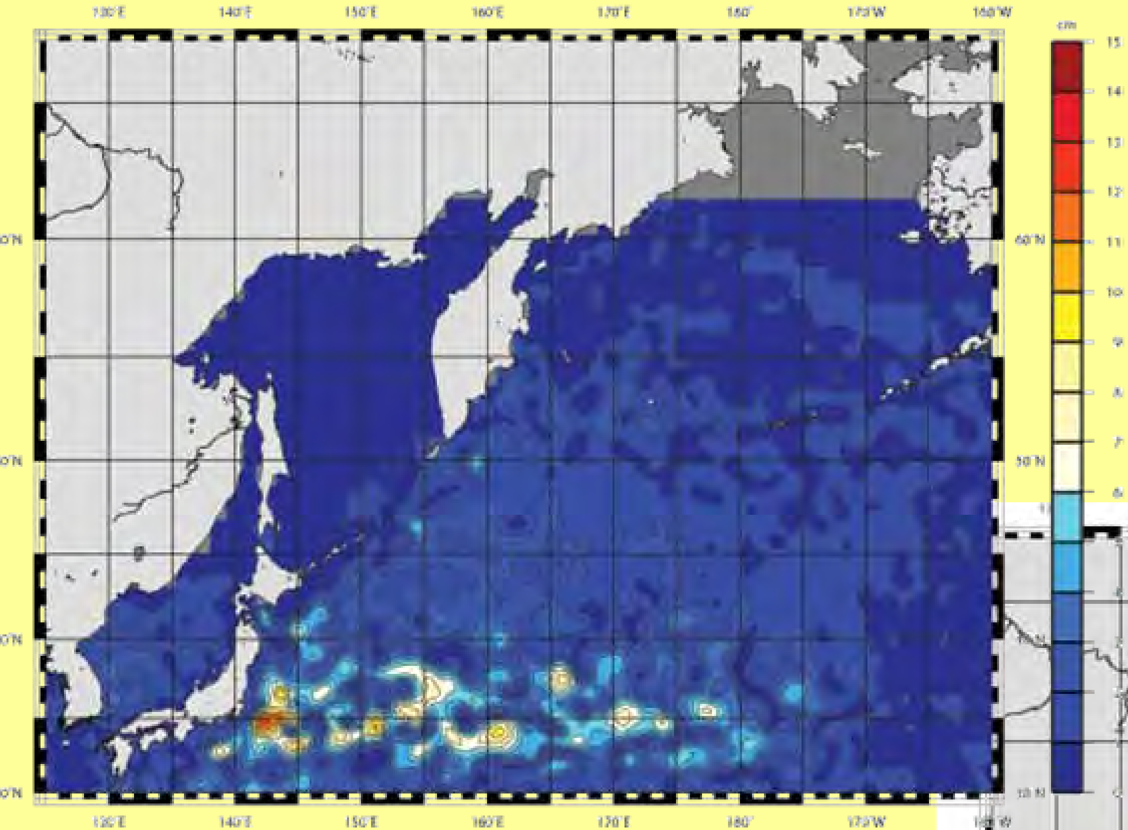
5.1. Variation of amplitudes and phases of the annual and semi-annual harmonics at reference gauge stations.

5.2. Variation of amplitudes and phases of the annual and semi-annual harmonics according to altimetry data.

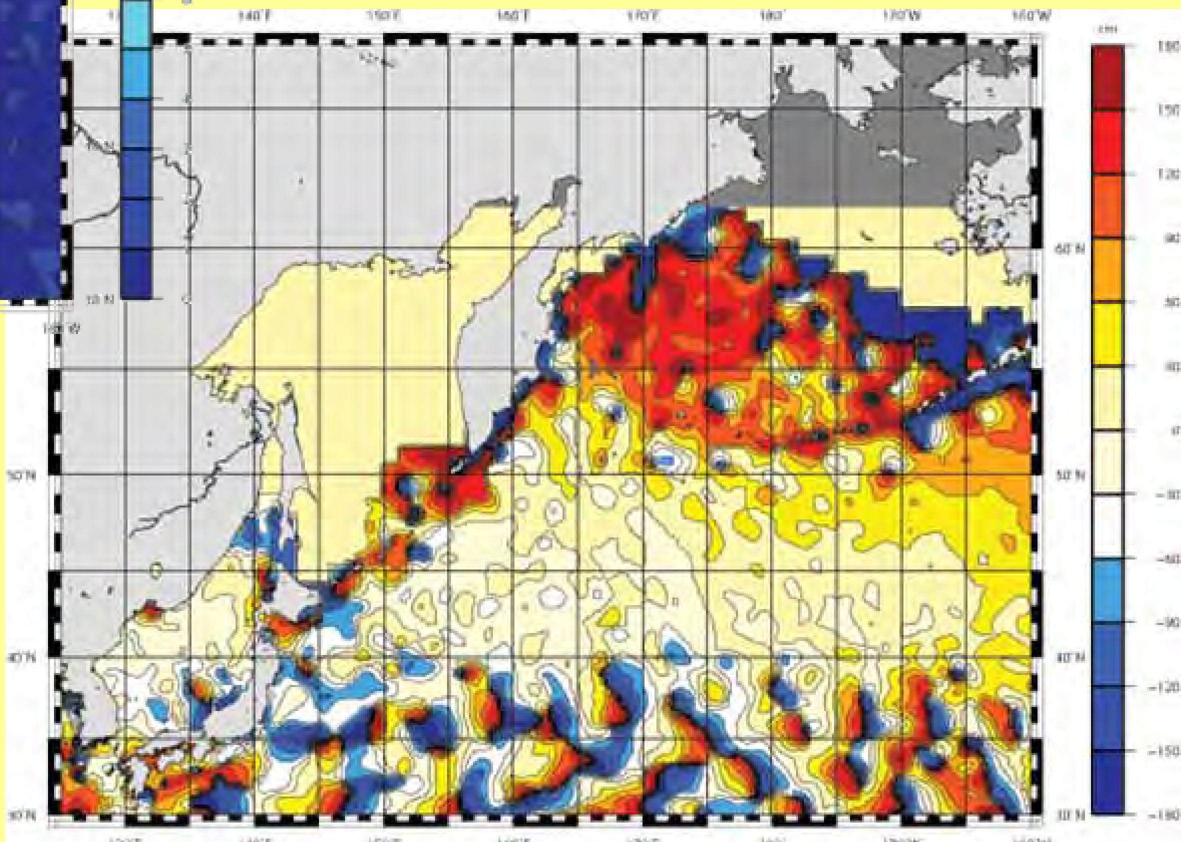




Variation of amplitudes and phases of the annual harmonics according to altimetry data.

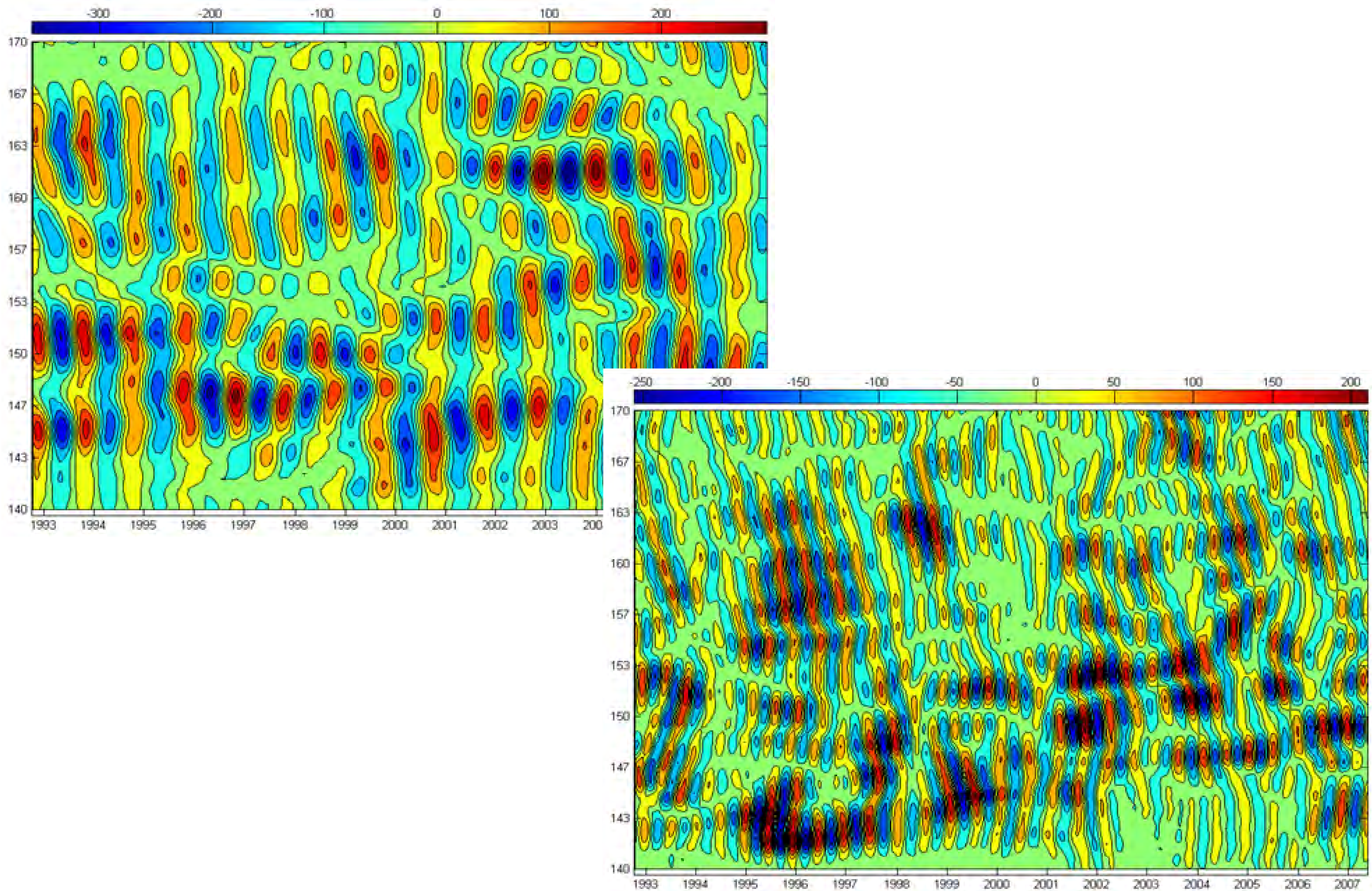


5.2. Variation of amplitudes and phases of the annual and semi-annual harmonics according to altimetry data



Variation of amplitudes and phases of semi-annual harmonics according to altimetry data

5.3. Isopleths of the wavelet coefficients for annual and semi-annual fluctuations of the sea-surface level on longitudinal and latitudinal sections (35º N)



6. Geostrophical currents

6.1. Mean multiyear currents calculated from the absolute dynamical sea-surface topography

6.2. Mean multiyear currents calculated from the relative dynamical sea-surface topography

6.3. Mean annual currents calculated from the absolute dynamical sea-surface topography

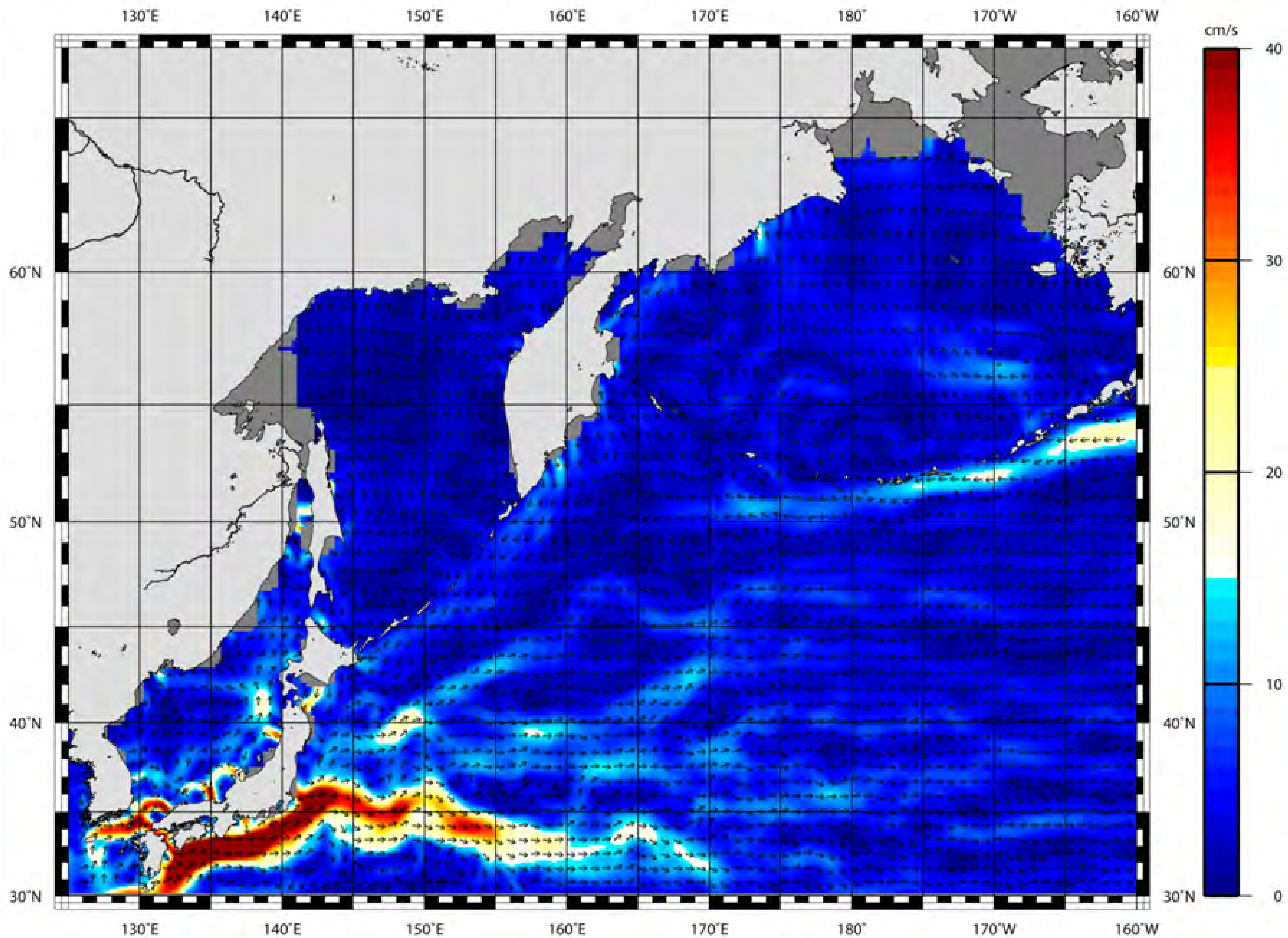
6.4. Annual currents calculated from the relative dynamical sea-surface topography

6.5. Monthly currents calculated from the absolute dynamical sea-surface topography

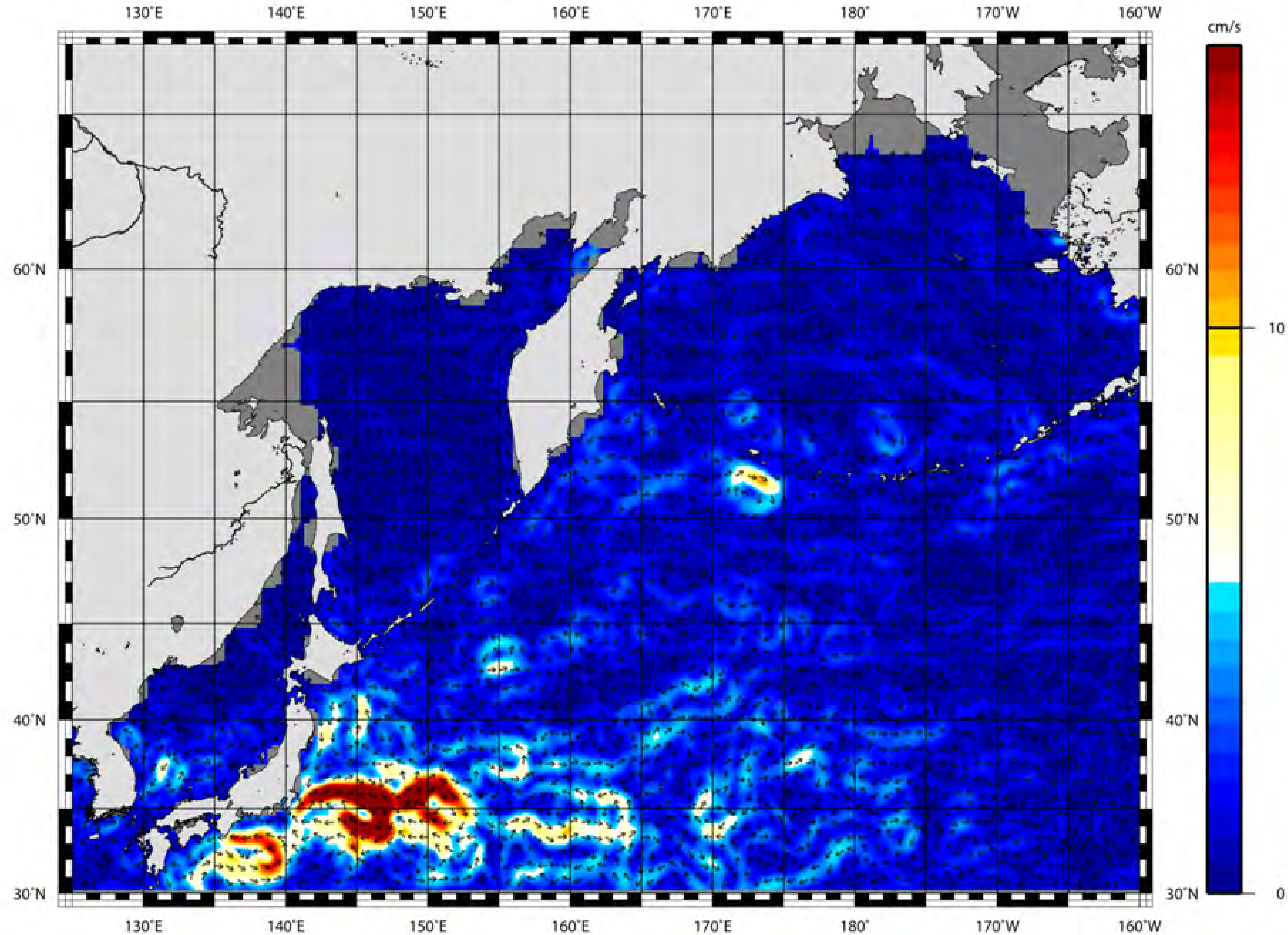
6.6. Monthly currents calculated from the relative dynamical sea-surface topography

7. Tidal fluctuations of the sea-surface level

8. Tidal currents



Mean multiyear currents calculated from the absolute dynamical sea-surface topography



Mean multiyear currents calculated from the relative dynamical sea-surface topography