Similarities and differences between the Kuroshio Extension and a baroclinic jet in a channel

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There are many similarity in PV structure between the Kuroshio Extension (KE) and a baroclinic jet in a channel (hereafter, just a baroclinic jet). PV along the front has a sharp contrast in the upper layer and nearly homogeneous in the lower layer. For the baroclinic jet, it is proposed that PV contrast is generated due to the suppressed mixing across the front and vigorous mixing at their flanks, resulting in the formation of a eastward narrow jet. Despite the distribution similarity, it is difficult to apply the proposed mechanism directly to the formation of the KE. The PV contrast along the KE is the strongest at the separation and disappears into the interior Sverdrup region, suggesting that its primary source is from the western boundary rather than the barrier effect along the fronts. In fact, eddies reduce the PV contrast in the upstream part of the KE. In addition, the barrier effect is not so simple for the Kuroshio Extension. The KE is a blender for Kuroshio-origin water, whereas it is a barrier for other water masses in the upper layer. From these fact, it seems that the formation and maintenance of the Kuroshio Extension seems essentially different from those of the baroclinic jet. Some diagnostic approaches will be also discussed.

Keywords: Kuroshio Extension, baroclinic jets

Structure of the Transition Domain observed with drifting buoys

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The North Pacific transition domain is the area where seawater exchange between subtropical and subarctic is carried out and it is very important area for oceanographic, meteorological, and biological. This study aims to clarify the flow structure and the process of the seawater exchange in the transition domain based on the results of drifting buoys observation and particle trajectory analysis using the lagrangian trajectory code TRACMASS (Döös 1995, Blanke and Raynaud 1997).
The trajectory of the drifting buoys visualized the flow structure around the Isoguchi jet (Isoguchi et al., 2006, Wagawa et al., 2014) and the transition domain. The frequency distribution of modelled particle trajectory shows the flow along the bottom topography in the west side of the transition domain and the flow via the gap of the bottom topography in the east side of the transition domain. These flow suggest seawater transport paths from the subtropical to the subarctic.
High frequency region is also distributed around 42˚N −155˚E. The high frequency region corresponds to the swirling flow of the drifting buoys. The cause of the swirling flow may be barotropic flow with the small bottom topography located at 42.5˚N −157˚E and baroclinic flow with baroclinic instability near the surface. The swirling flow may contribute to the seawater exchange between subtropical and subarctic in the transition domain.

Keywords: transition domain, Isoguchi jet, drifting buoy observation, bottom topography

Generation and backreaction of spontaneously emitted inertia-gravity waves -An update of the ocean energy budget-

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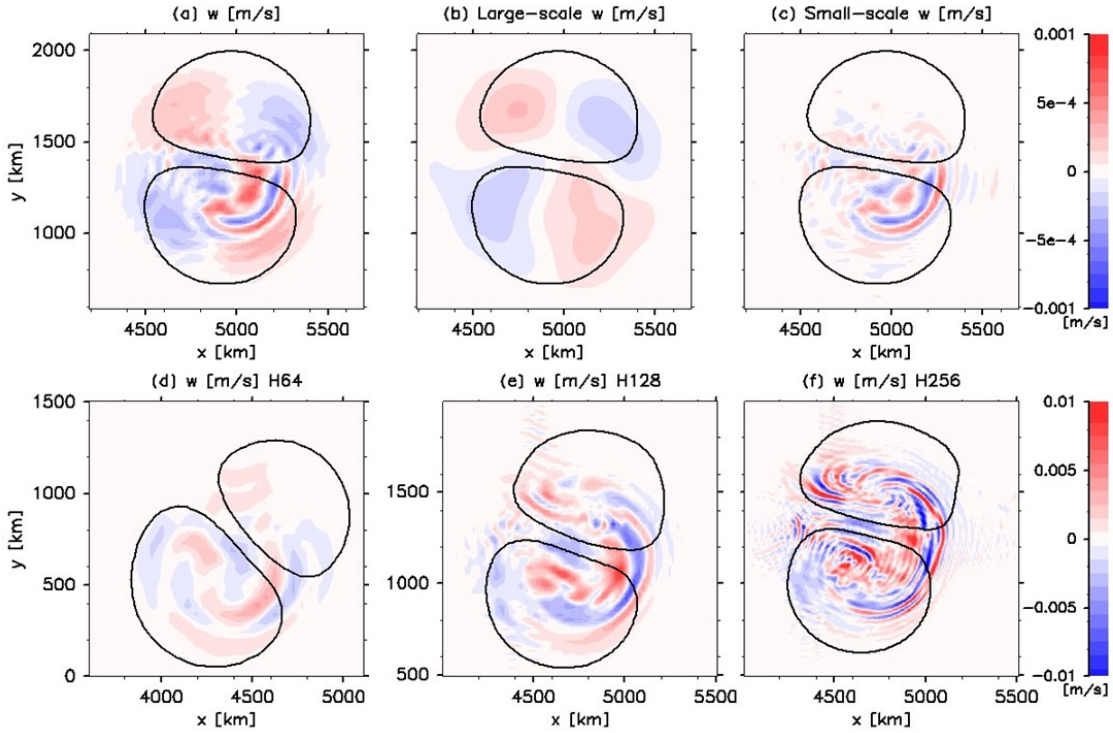
Spontaneous generation of inertia-gravity waves from balanced flows is investigated in idealized simulations of dipoles. Long integrations are performed for dipoles with different Rossby numbers (Ro) to identify the backreaction of the waves. Emission of waves is detected only for large enough Ro (>0.15), and it then leads to a slow decay of the dipole's kinetic energy. A major finding is that this decay is well captured by the simulations, although positions of the waves appear still sensitive to the resolution, and their maximum vertical velocity increases linearly with resolution. The interpretation is that the emission process is well resolved and fairly insensitive to resolution, while the propagation and dissipation at small scales remains sensitive to resolution. The implication is that the simulations yield an estimate of the leakage of energy from balanced motions to gravity waves, providing a useful estimate of a poorly constrained flux in the ocean's energy budget.

Keywords: inertia-gravity wave, spontaneous emission, backreaction



Dynamics and Predictability of Downward Propagation of Stratospheric Planetary Waves Promoting Blocking Formation over the North Pacific: A Case study for March 2007

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The atmospheric blocking is one of the most important circulation features in the troposphere causing anomalous weather in the extratropics. Recent theoretical studies have revealed that the blocking is basically maintained against dissipative processes through the selective absorption of synoptic anticyclones due to vortex-vortex interactions. On the other hand, its formation mechanism still remains controversial, but our recent observational studies indicate that downward propagating planetary waves from the stratosphere into the troposphere is a key to promote the blocking formation, especially over the North Pacific. However, the dynamics and predictability of the downward propagation of stratospheric planetary waves have not been revealed as yet.

In this study, predictability of a downward propagating event of planetary waves in the lower stratosphere observed in early March 2007 is examined by conducting ensemble forecasts using an AGCM. It is detected that the predictable period of this event is about 7 days. Regression analysis using all members of an ensemble forecast also reveals that the downward propagation is significantly related to an amplifying quasi-stationary planetary-scale anomaly with barotropic structure in polar regions of the upper stratosphere. Moreover, the anomaly is 90˚ out of phase with the ensemble mean field. Hence, the upper stratospheric anomaly determines the subsequent vertical propagating direction of incoming planetary waves from the troposphere by changing their vertical phase tilt, which depends on its polarity. Furthermore, the regressed anomaly is found to have similar horizontal structure to the pattern of greatest spread among members for predicted upper-stratospheric height field, and the spread growth rate becomes maximum prior to the occurrence of the downward propagation. Hence, we propose a working hypothesis that the regressed anomaly emerges due to the barotropic instability inherent to the upper stratospheric circulation.

In fact, the stability analysis for basic states comprised of the ensemble-mean forecasted upper-stratospheric streamfunction field using a non-divergent barotropic vorticity equation on a sphere supports our hypothesis. Thus, the barotropic instability inherent to the distorted polar vortex in the upper stratosphere forced by incoming planetary waves from the troposphere determines whether the planetary waves are eventually absorbed in the stratosphere or emitted downward into the troposphere.

Keywords: blocking, planetary wave, downward propagation

Vortex-vortex interactions for the maintenance of atmospheric blocking: The selective absorption mechanism

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Atmospheric blocking is a quasi-stationary anticyclone with a radius of ~5000 km persisting for about 1 week or more, characterized by a pronounced meandering of the middle-latitude westerly jet stream. To clarify why blocking anomalously persists beyond the typical time scale of synoptic eddies has been an important issue for the blocking dynamics. In this stream, we proposed a new maintenance mechanism for atmospheric blocking, the selective absorption mechanism (SAM). According to this mechanism, which is based on vortex-vortex interactions (i.e., the interactions between a blocking anticyclone and synoptic eddies with the same polarity), a blocking anticyclone actively and selectively absorbs synoptic anticyclones (strictly, air parcels with low potential vorticity) from the storm-track regions in mid-latitudes. The blocking anticyclone, which is thus supplied with low potential vorticity of the synoptic anticyclones, can subsist for a prolonged period, withstanding dissipation. The SAM is one of the eddy-feedback mechanisms that describes the interaction between blocking and synoptic eddies with different time scales each other. At first, through the comparison with the famous maintenance mechanisms proposed in the previous studies, uniqueness and distinction of the SAM from other previously proposed maintenance mechanisms are discussed. And then, the SAM was verified in case studies and idealized numerical experiments.
In the case studies, trajectory analyses were conducted by using a reanalysis dataset provided by the Japan Meteorological Agency and the Central Research Institute of the Electric Power Industry. Ten actual cases of blocking were examined. Trajectories were calculated by tracing parcels originating from synoptic anticyclones and cyclones located upstream of the blocking. Parcels starting from anticyclones were attracted to and absorbed by the blocking anticyclone, whereas parcels from cyclones were repelled by the blocking anticyclone. The numerical experiments performed here were based on the nonlinear equivalent-barotropic potential vorticity equation, with varying conditions with respect to the shape and amplitude of blocking, the characteristics of storm tracks (displacement and strength), and the characteristics of background zonal flow. The experiments indicate that the SAM effectively maintains blocking, independently of the above conditions. The above results verify that the SAM is an effective general maintenance mechanism for blocking.

Keywords: Atmospheric blocking, Storm tracks, Potential vorticity, Tropopause, Dynamical meteorology

Formulation and application of phase-independent evergy conversions for quasi-geostrophic eddies

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Estimating energy conversions could be useful to clarify dynamics of low-frequent variability of quasi-geostrophic disturbances. Energy conversion terms are composed of quadratic terms in disturbance amplitudes and shear terms of basic flows, so that they can mean energy conversions between disturbance fields and the basic flows. The quadratic terms in the energy conversions are usually expressed by the velocities of the disturbances, such as momentum transports u’ v’, so that they inherently include an oscillatory component of one-half wave-length. Therefore, in traditional forms of the energy conversions, phase-averaging such as time-averaging should be needed to express energy-conversion distributions in the phase-independent forms.
In this study, a new formulation of energy conversions for quasi-geostrophic eddies is proposed under an assumption that a eddy is almost a plane wave in the WKB sense. Because of a phase-independent form, the new formulation can be applicable to estimating energy conversions for stationary eddies or snapshot of transient eddies. Actual applications of the new form of the energy conversions to the data analysis will also be given.

Keywords: quasi-geostrophic eddy, energy conversion, low-frequent variability in the extra-tropics

Towards a seamlessly diagnosable expression for the energy flux associated with both equatorial and mid-latitude waves

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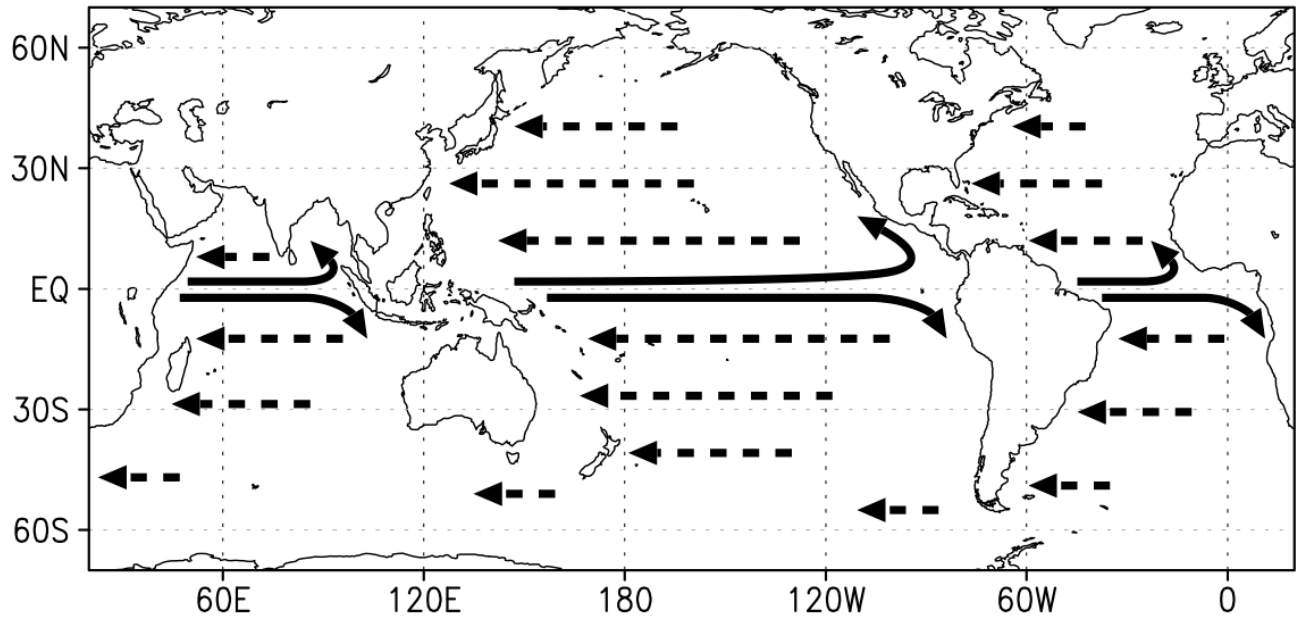
For mid-latitude Rossby waves (RWs) in the atmosphere, the expression for the energy flux for use in a model diagnosis, and without relying on a Fourier analysis or a ray theory, has previously been derived using quasi-geostrophic equations and is singular at the equator. By investigating the analytical solution of both equatorial and mid-latitude waves, the authors derive an exact universal expression for the energy flux which is able to indicate the direction of the group velocity at all latitudes for linear shallow water waves. This is achieved by introducing a streamfunction as given by the inversion equation of Ertel' s potential vorticity, a new and novel aspect when considering the energy flux. For ease of diagnosis from a model, an approximate version of the universal expression is explored and illustrated for a forced/dissipative equatorial basin mode simulated by a single-layer oceanic model that includes both mid-latitude RWs and equatorial waves. Equatorial Kelvin Waves (KWs) propagate eastward along the equator, are partially redirected poleward at the eastern boundary of the basin as coastal KWs, followed by the shedding of mid-latitude RWs that propagate westward into the basin interior. The connection of the equatorial and coastal waveguides has been successfully illustrated by the approximate expression of the group-velocity-based energy flux of the present study, which will allow for tropical-extratropical interactions in oceanic and atmospheric model outputs to be diagnosed in terms of an energy cycle in a future study.

Keywords: group velocity, model diagnosis, tropical-extratropical interactions



Generation of internal solitary waves by frontally forced intrusions in geophysical flows

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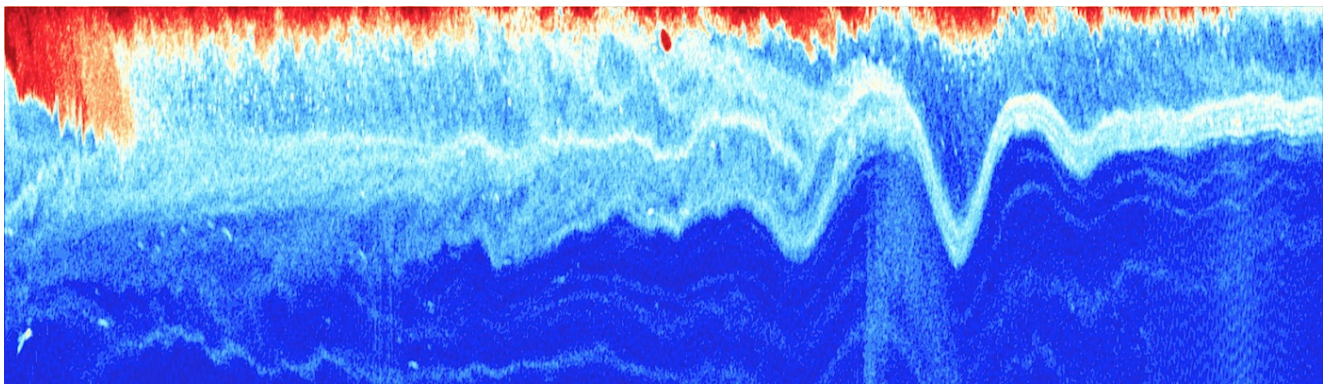
Internal solitary waves are hump-shaped, large-amplitude waves that are physically analogous to surface waves except that they propagate within the fluid, along density steps that typically characterize the layered vertical structure of lakes, oceans and the atmosphere. As do surface waves, internal solitary waves may overturn and break, and the process is thought to provide a globally significant source of turbulent mixing and energy dissipation. Although commonly observed in geophysical fluids, the origins of internal solitary waves remain unclear. Here we report a rarely observed natural case of the birth of internal solitary waves from a frontally forced interfacial gravity current intruding into a two-layer and vertically sheared background environment. The results of the analysis carried out suggest that fronts may represent additional and unexpected sources of internal solitary waves in regions of lakes, oceans and atmospheres that are dynamically similar to the situation examined here in the Saguenay Fjord, Canada.

Keywords: internal solitary waves, front, intrusion



Near-inertial Gyroscopic Wave in the Bottom-layer Water of the Japan sea

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We focus on a behavior of near-inertial Gyroscopic Wave (GsW) in the vertical homogeneous Bottom-layer Water (BW) with N~0 (N is the buoyancy frequency) in the abyssal Japan Sea. Whether a near-inertial internal wave/GsW can intrude into the BW or not, depend on its direction of propagation from east-westward to southward. When a near-inertial GsW reflects at the sea bottom, its vertical wavenumber largely changes from low to high. Therefore, the reflected GsW propagates as creeping along the sea bottom. It is inferred that such GsW might contribute to vertical mixing within the BW.

Keywords: horizontal component of Coriolis parameter, Near-inertial frequency, Gyroscopic Wave, Bottom-layer Water

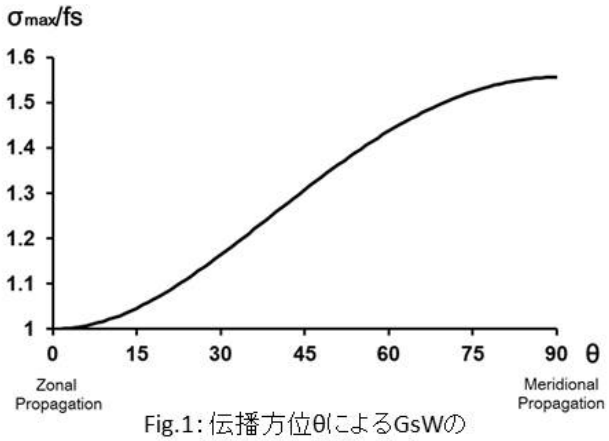

Fig.1: 伝播方位θによるGsWの存在最大周波数分布

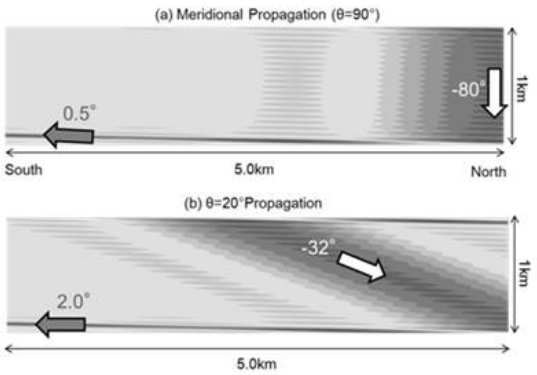

Fig.2: 伝播方位(a)θ=90°，(b)θ=20°のケースにおけるBW内の近慣性波

Impact of Ocean Surface Waves on Air-Sea Momentum Flux

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In this study, we investigated the structure of turbulent air flow over ocean waves. Observations of wind and waves were retrieved by air-sea interaction spar (ASIS) buoys during the shoaling waves experiment (SHOWEX) in Duck, NC in 1999. It is shown that the turbulent velocity spectra and co-spectra for pure wind sea conditions follow the universal forms estimated by Miyake et al [1970]. In the presence of strong swells, the wave boundary layer was extended and the universal spectral scaling of u'w' broke down [Drennan et al, 1999]. On the other hand, the use of the peak wave frequency (fp) to reproduce the "universal spectra" succeeded at explaining the spectral structure of turbulent flow field. The u'w' co-spectra become negative near the fp, which suggests the upward momentum transport (i.e., negative wind stress) induced by ocean waves. Finally, we show the relationship between the turbulent flow structures and roughness of the sea surface.

The excitation location of external gravity waves traveling across the Pacific Ocean and its seasonal variation

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At deep seafloor, large amplitude of external gravity wave, i.e., infragravity wave (IGW), is persistently observed at frequencies of 0.003–0.03 Hz (30–300 s) in noise spectrum of pressure records. Previous works reported that the generation of the IGW is possibly related to ocean swell and its location is near shoreline. In this study, we investigate the characteristics of the IGW propagating in the ocean, by examining a spectral analysis and an interferometric method. Comparing these observations with the spatio-temporal distribution of ocean swell, we try to find possible locations where the IGW observed off Aogashima is generated.

Off Aogashima in the Izu-Ogasawara region, south of Japan, 10 pressure gauges with a station spacing of 10 km were deployed during May 2014 and May 2015. The locations are 50–100 km east of Aogashima, and the water depth ranges from 1400 to 2300 m. The sampling rate is 4 Hz.

In the obtained results, we found the following three remarkable observations relevant to the IGW observed off Aogashima. Firstly, we calculated running spectrum, i.e., spectrogram, of ambient noise records for a time-period of four months (June–Sep. on 2014). As a result, we found temporal and frequency variations of the IGW amplitude. For example, there are several events that show large amplitude at lower frequencies (0.003–0.01 Hz), and also at higher frequencies, e.g., 0.03 Hz, but with a time-delay of 3 days relative to that at lower frequencies (one example is shown by an arrow in Fig. 1a). The amount of the delay is continuous as a function of frequency. Secondly, we investigated the propagation direction of the IGW. We extracted the IGW propagating between all pairs of two pressure gauges deployed off Aogashima by using an interferometric method, and performed an array analysis. As a result, the IGW is persistently coming from east in summer. If we calculate the ray path of the IGW eastward from the station, it reaches to the shoreline in South America. Moreover, the propagation times between South America and one station off Aogashima were approximately 360,000 s and 95,000 s at frequencies of 0.03 Hz and 0.007 Hz, respectively, resulting in 265,000 s (3.07 days) in differential time; the differential propagation speed as a function of frequency is caused by dispersion of the IGW. This is in good agreement with the observation of the time delay of 3 days. Thirdly, as mentioned above, several events with relatively large IGW amplitude can be seen in the running noise spectrum. It seems that the occurrences of these events correlate with the timings at which strong swell in the southern hemisphere approaches eastward to the shoreline in South America, rather than swell observed around Aogashima (Fig. 1b). Based on these observations, we interpret that the IGW observed off Aogashima in summer is excited near the shoreline in South America. On the other hand, in winter in the northern hemisphere, it seems that the excitation location of the IGW is changed to the shoreline in North America.

Keywords: external gravity wave, deep seafloor observation

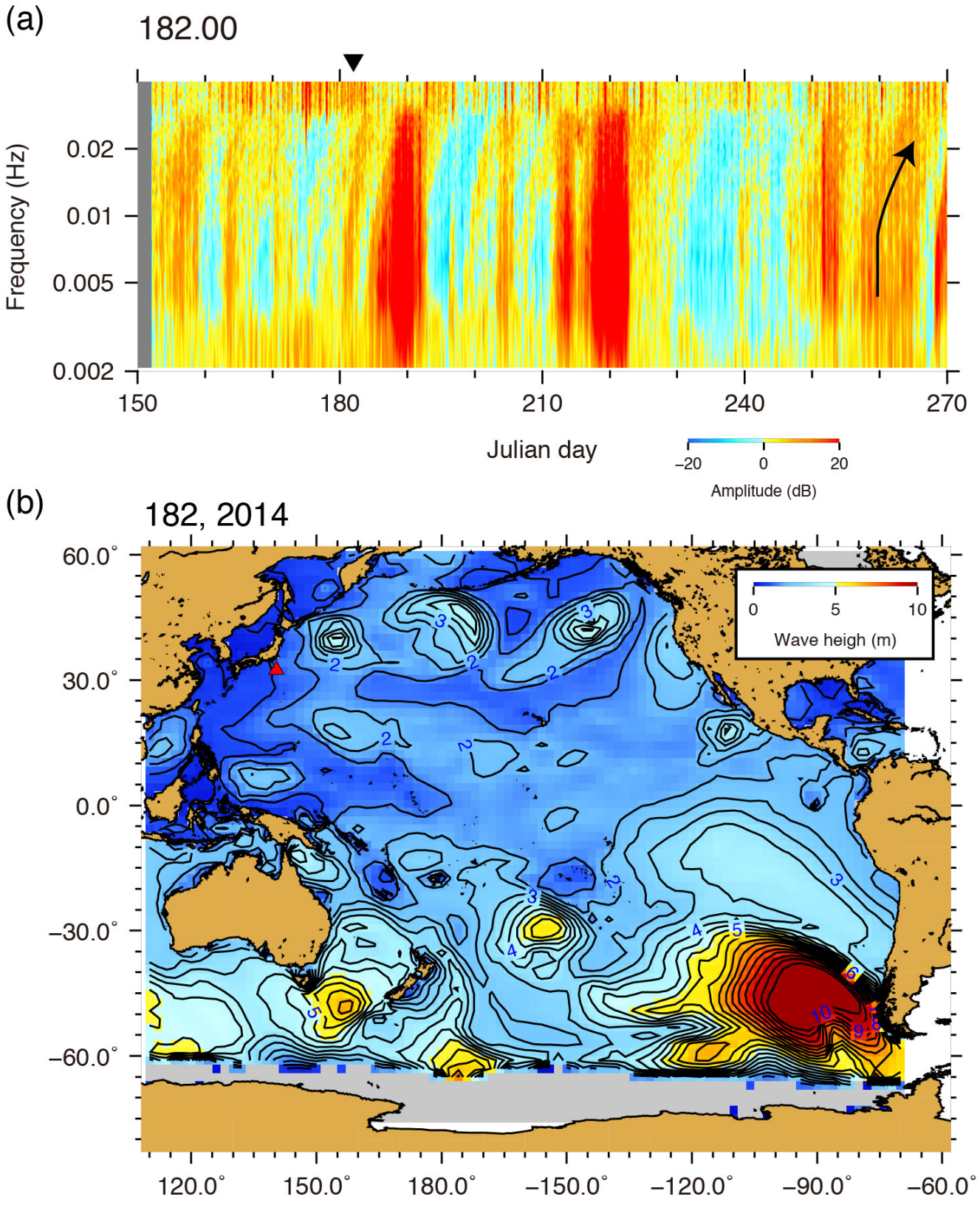

Figure 1. (a) Perturbations of the IGW amplitude as functions of time (day) and frequency, i.e., running spectrum. (b) Wave height distribution on 182 (julian day), 2014, from WAVE WATCH III (Tolman, 2005). A strong swell can be seen near South America, and a large IGW amplitude can also be seen on 182, indicated by inverted triangle in Fig. 1(a).

Topography-dependent relation between offshore wind field and swell-dominant surface waves observed inside bays on the Sanriku ria coast of Japan

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Real-time monitoring of wind and surface waves in Otsuchi Bay, a ria in the Pacific coast of Sanriku, the northeastern portion of Japan, has been continued since October 2012, using a mooring buoy with an ultrasonic anemometer and a single-mode GPS wave sensor. We analyzed two-dimensional energy spectra of surface waves and wind data monitored hourly over four years in order to assess the variability and occurrence of wind and waves and to elucidate the main reasons for wave variation in Otsuchi Bay. The monitoring data revealed in all seasons that surface waves in the bay were predominantly affected by swells propagated from the northeastern offshore region and that the wave height was significantly correlated with the component of wind velocity toward the bay in the northeastern offshore region that faces the bay mouth. The offshore wind field was expected to provide information useful for predicting coastal waves in rias bays in Sanriku such as Otsuchi Bay. More interestingly, comparison of the horizontal distribution of strong correlation between the offshore wind field and the significant wave height in rias bays, Miyako and Kamaishi Bays close to Otsuchi Bay clarified that the offshore wind field which affects predominantly surface waves in rias bays depends heavily on the topographic shape of the bay.

Keywords: surface wave, ria bay, swell, offshore wind

