MULTISENSORY SATELLITE STUDY OF MESOSCALE CYCLONES

OVER THE NORTHERN PACIFIC

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1. INTRODUCTION

The intense mesoscale cyclones (MCs) with a comma or spiral cloud system are often observed over the North Pacific Ocean in a cold season. Their size is 100-1000 km and they exist from a few hours till three days. MCs are usually accompanied by gale winds seriously disturbing transport and fishery operation at the sea due to high waves, sea ice drift, ship icing etc. The small sizes and sparse hydrometeorological in situ data over the ocean complicate their revealing on weather maps and forecasting (Rasmussen and Turner, 2003). The best technique for MC research is satellite multisensor sensing. Visible and infrared (IR) images acquired from Aqua and Terra MODIS and NOAA AVHRR since October 2003 till April 2011 have been used for MC detection over the Northern Pacific Ocean. QuikSCAT- and MetOp ASCAT-derived wind fields, ADEOS-II AMSR- and Aqua AMSR-E-retrievals provided quantitative information about the atmospheric and ocean surface parameters important for MC research. AMSR and AMSR-E original retrieval algorithms were built up with the use of database of the simulated brightness temperatures computed by numerical integration of microwave radiative transfer equation in the atmosphere-ocean system. Ship and island radiosonde data and constructed vertical profiles of cloud liquid water content served as input data. Retrievals include the total water vapor content, total cloud liquid water content and sea surface wind speed (Bobylev et al., 2010; Mitnik and Mitnik, 2003, 2011; Mitnik et al., 2009). Besides, the weather maps and radiosonde data from island and coastal stations were collected. Envisat Advanced Synthetic Aperture Radar (ASAR) images and CloudSat Cloud Profiling Radar (CPR) sections have been obtained for some MCs.

2. STATISTICS

150-250 MCs the size of 100-1000 km and with wind speed ≥ 12 m/s were formed over the Japan, Okhotsk and Western Bering Seas during the cold periods (October-April) 2003-2011 (Figure 1a). MCs from 200 to 400 km in extent prevailed. The peak of mesoscale cyclogenesis was observed in December-February (Figure 1b). The number of MCs at a definite

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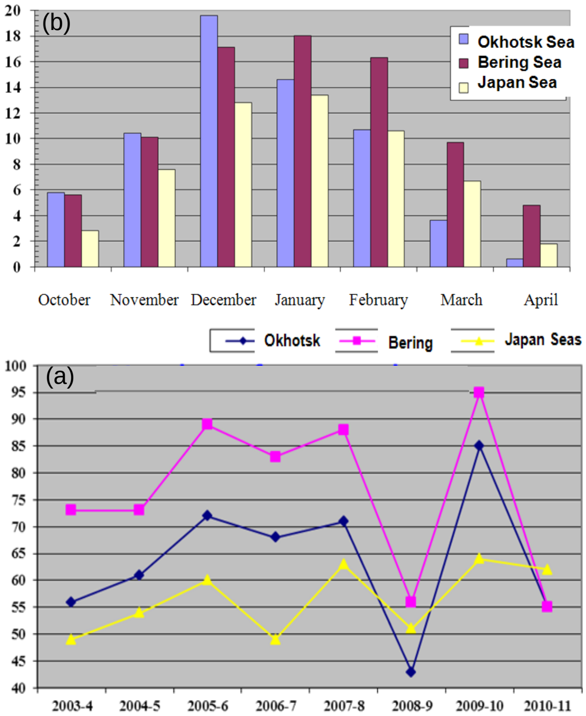

Figure 1. Interannual variability (a) and monthly mean number (b) of mesocyclones over the Japan, Okhotsk and western Bering seas

season depended on the total duration of cold air outbreaks. Spatial and time variability in MC formations was often connected with trajectories of synoptic scale cyclones (Gurvich et al., 2008).

3. CASE STUDIES

The most intense mesocyclones over Northern Pacific Ocean were selected for detailed study. The main attention was given to availability of satellite passive and active microwave sensor data allowing tracing evolution of spatial structure of sea surface wind speed *W*, total water vapor content *V*, and total cloud liquid water content *Q* in the MC area independently on sun illumination. These sensors included ADEOS-II AMSR, Aqua AMSR-E and Russian Meteor-M N 1 MTVZA-GYa (Cherny et al., 2010) radiometers, QuikSCAT SeaWinds and MetOp ASCAT scatterometers, Envisat ASAR and CloudSat

CPR. They are onboard several satellites and observe the studied weather systems with better temporal resolution and at different frequencies.

3.1. Okhotsk Sea

Two mesoscale cyclones over the Okhotsk Sea were observed on MODIS visible image and on AMSR-E T_B(89H) microwave image acquired on 15-16 February 2010 (Figure 2). ASCAT-derived wind speed in the MC areas reached 12-15 m/s. Maximum wind speed retrieved from the AMSR-E brightness temperatures (Mitnik and Mitnik, 2011) was approximately 20 m/s and observed in the southwestern part of MC 1. Intensity of the MC 1 was higher compare to the MC 2: its clouds are brighter and a circle with storm winds is wider. Calm areas are in the almost cloudless centers of mesocyclones.

The brightness temperatures at frequency of 36 GHz with horizontal (H) polarization measured by AMSR-E with the resolution of 8 km x 14 km and MTVZA-GYa with resolution of 30 km x 67 km were used to trace MC evolution (Figure 3). Spatial structure of MCs is mapped better by AMSR-E due to higher resolution, at the same time both MCs are clear distinguished in MTVZA-GYa data. The areas of the increased water vapor content and a flow of dry cold air in the central parts of MCs are seen in T_B(36H) fields as well as in the *V*-field retrieved from AMSR-E measurements. The sharp T_B(36H) changes mark the boundaries between wet and dry air masses. These boundaries are smoothed in the MTVZA-GYa T_B(36H) data. However, the MC locations and the boundaries dividing wet and dry air are visible reasonably distinct.

Sequence of measurements carried out by two satellites allowed to determine MC trajectories and estimate velocities of their movement. MCs displaced

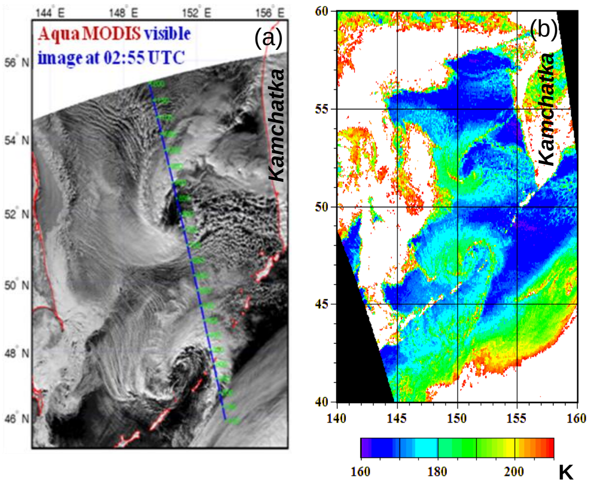

Figure 2. Mesocyclones over the Okhotsk Sea on 16 February 2010 at 02:55 UTC: (a) MODIS visible image and (b) AMSR-E brightness temperature at 89.0 GHz with horizontal polarization. Blue line marks ascending CloudSat overpass path.

south-southeastward. Average velocity of MC **1** was 16 km/h and MC **2** - 20 km/h.

Southern MC **2** displaced mainly eastward and at 10 UTC crossed the Kuril Islands (Fig. 3b). Formation of MC **3** near the ice edge is well seen in AMSR-E T_B(36H) at 16:30UTC. It also displaced southeastward and deepened that follows from the increase of a width of band with T_B(36H) ≈ 150-155 K caused by development of its cloudiness. Thus a time series consisting of T_B at the same or close frequencies from two satellites improves temporal resolution. This is essential for studying and forecasting of short-living baric formations.

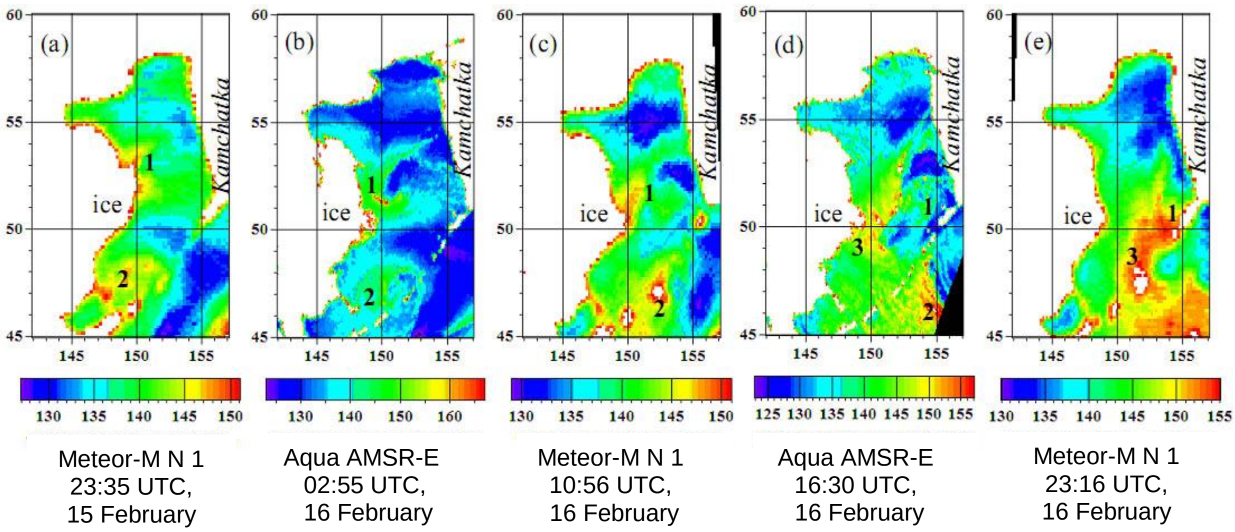

Figure 3. Evolution of mesoscale cyclones 1 and 2 over the Okhotsk Sea presented by sequence of the brightness temperatures at frequency of 36.5 GHz with H-polarization measured by MTVZA-GYa (a,c,e) and AMSR-E (b, d) microwave radiometers. 3 – new mesocyclone developing in the Northern Kuril Island area.

Vertical structure of cloudiness in the MCs was investigated using the CloudSat Cloud Profiling Radar (CPR) operating at 94 GHz and providing a measurement of radar reflectivity versus height in a nadir slice along the satellite track (Stephens et al., 2002; Tanelli et al., 2008). Blue line crossing the center of MC **1** and cloud spiral of MC **2** in Figure 2 marks CPR track. Figure 4 shows a cross section of CPR reflectivity measurements corresponding to this CloudSat overpass.

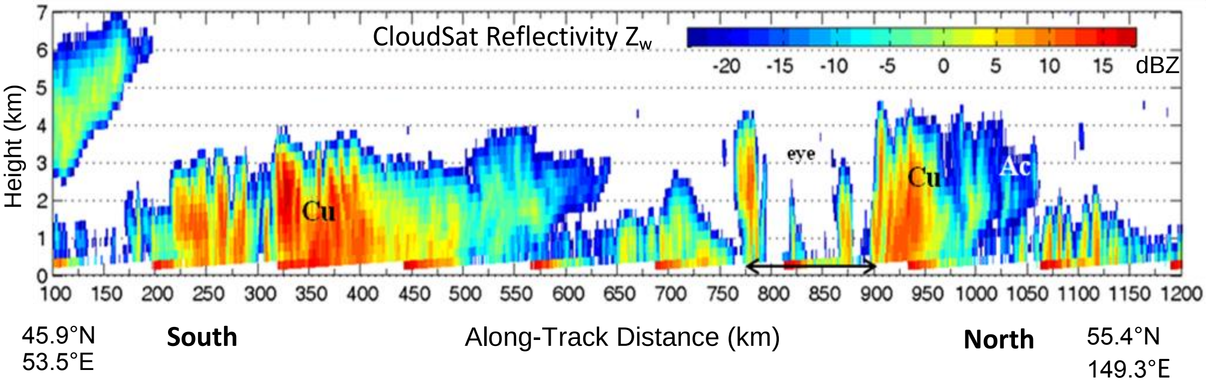

Figure 4. The vertical cross section of CloudSat measurements for two mesoscale cyclones observed in the Okhotsk Sea on 16 February 2010 at 02:55 UTC

High reflectivity Z_w corresponds to cumuli (Cu) clouds. The most intense convection appears in the CloudSat profile over northern MC **1** with cloud tops generally around 4 km. Reflectivity of altocumuli (Ac) to the north of the MC **1** eye is low. The size of the eye surrounded by Cu clouds is approximately 130 km. Cloud tops reach 3 km in the southern MC **2**. High Z_w values here are likely due to precipitation.

3.2. Japan Sea

The Japan Sea is a region of formation of intense MCs (Rasmussen and Turner, 2003). MC the size of approximately 200-250 km with spiral structure of cloudiness was observed over the northern Japan Sea on 6 March 2010 (Figure 5b). Structure of sea surface wind is revealed by scatterometer data (Figure 5c) as well as by the brightness variations of the ASAR image (Figure 5a). These variations result from the mesoscale changes of the sea surface wind speed and direction. They correlate with cloud field structure as follows from the comparison with a practically simultaneous Terra MODIS visible image (Figure 5b). An almost cloudless center of the MC corresponds to the dark gray tone area on ASAR image that indicates weak winds. Maximum gradients of surface wind are observed under crossing of the narrow zones 1 and 2 which mark the location of frontal boundaries near the sea surface. Their width is around 1 km. Enlarged fragments (Figure 6) show wind field structure near the boundaries. Scatterometer smoothes high wind speed gradients and the boundaries practically are not detected in Figure 5c.

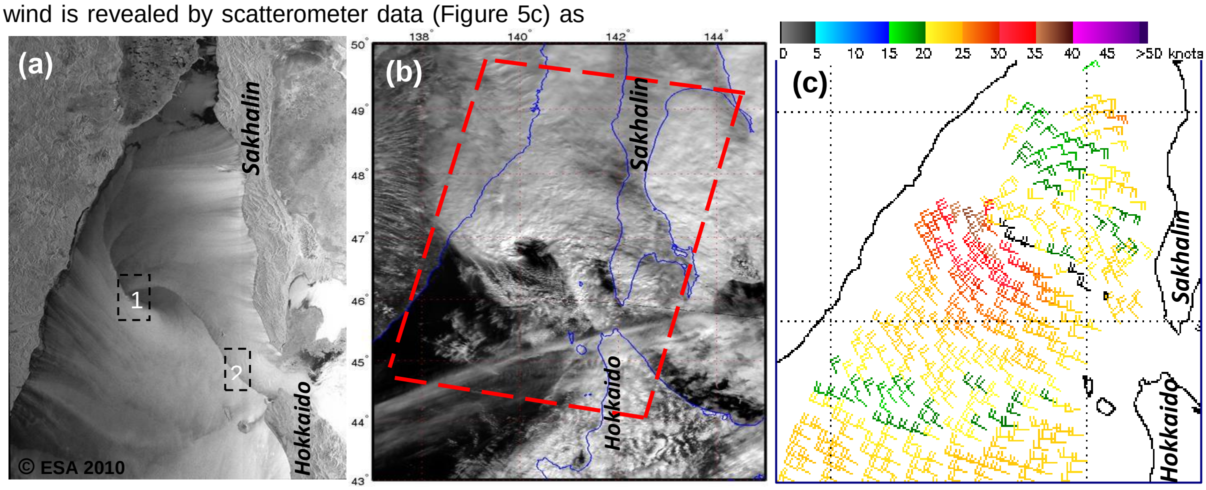

Figure 5. Mesocyclone over the Japan Sea near southwestern Sakhalin on 6 March 2010: (a) Envisat ASAR image acquired at 00:50 UTC, (b) Terra MODIS visible image at 00:55 UTC and (c) MetOp ASCAT-derived wind field at 01:13 UTC. Dotted rectangle 1 and 2 mark the location of two fragments shown in Figure 6. Red dotted lines in (b) mark the ASAR image boundaries.

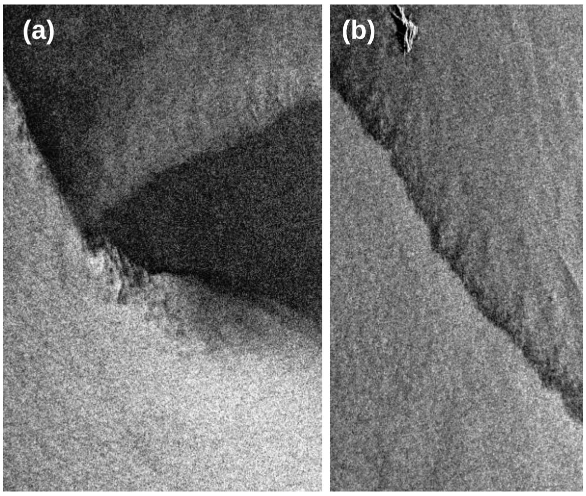

Figure 6. Enlarged fragments of ASAR image marked by dotted rectangle in Figure 5 showing fine structure of surface wind: (a) central part of mesoscale cyclone and (b) convergence of western and eastern winds near frontal boundary 2.

The brightest area on ASAR image is located in the southwestern sector where scatterometer winds are 15-17 m/s. Scatterometer data present the wind field in the whole MC, however, without information on wind in the coastal zone, its mesoscale variability and spatial gradients. ASAR image allows estimating wind speed in the coastal zone where influence of orography is significant and also determining the change of wind speed and direction under crossing of frontal boundaries.

3.2. Bering Sea

Mesoscale cyclones are frequently observed in the vicinity of the Bering Islands (Mitnik, 2008). Wind fields retrieved from measurements carried out by Coriolis Windsat microwave radiometer at 06:02 UTC, MetOp ASCAT scatterometer at 09:55 UTC and Aqua AMSR-E microwave radiometer at 14:35 UTC depicted in Figures 7 a,b,c demonstrate efficiency of multisensory /multisatellite approach for study of short-living weather systems that is essential for polar areas with sparse in situ data. Envisat ASAR image acquired at 10:26 UTC (Figure 7d) shows the location of atmospheric fronts near the sea surface where strong gradients of wind speed are observed within narrow zones. These data can be used for study mesoscale processes such as polar lows which are accompanied by storm winds and improving their forecast.

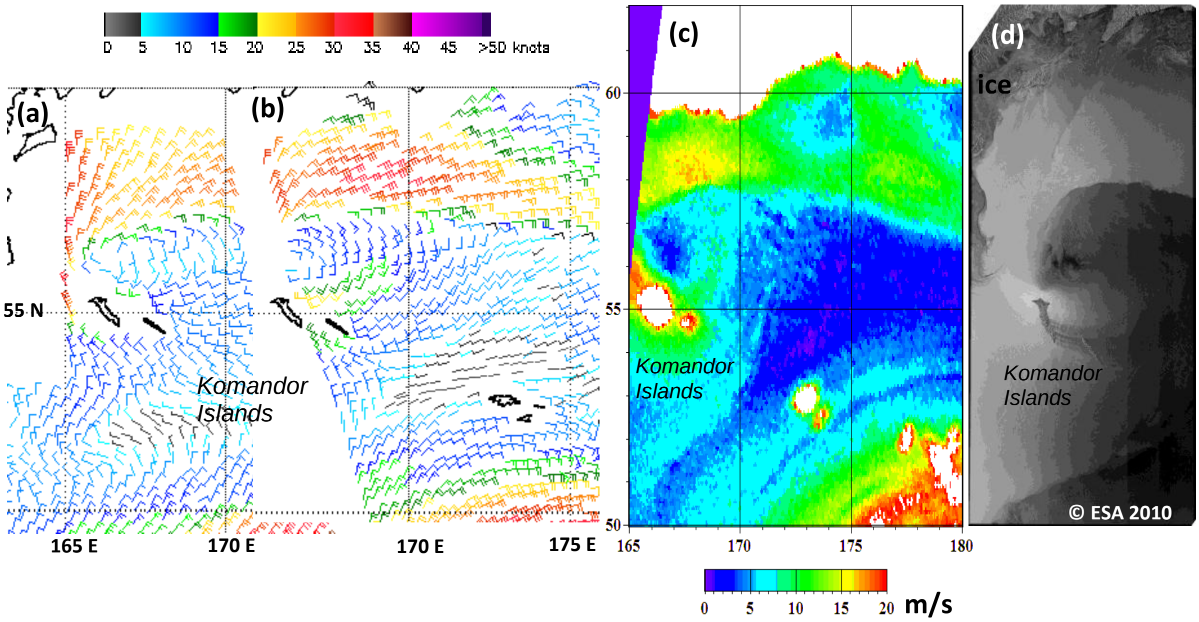

Figure 7. Changes of sea surface wind field in mesoscale cyclone in the Bering Sea derived by different satellite sensors on 7 April 2010 from 06:02 UTC to 14:35 UTC

4. SUMMARY

The joint analysis of satellite passive and active microwave sensing data in combination with measurements in other spectral bands is the best approach for investigation of characteristics and structure of mesoscale cyclones during their life cycle. Time series of satellite measurements is also important for operational applications providing the quantitative information on trajectory, storm wind zones and precipitation location. Data from NASA's NPP spacecraft launched on 27 October 2011 and from GCOM-W1 satellite planned to launch in May 2012 will enhance volume and quality of quantitative data about MCs and other marine weather systems.

5. ACKNOWLEDGEMENT

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