1.10 MODIFICATION OF THE MARINE BOUNDARY LAYER ACROSS THE JAPAN SEA DURING WINTER

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1. INTRODUCTION

In the winter of 1999/2000, an international team of scientists undertook to examine the oceanography of the Japan Sea (Fig. 1) that included investigation of the atmospheric forcing. Special atmospheric measurements were made, including ship and aircraft observations, to understand the nature of the atmosphere as well as sea surface momentum and heat fluxes. Here we focus on the modification of the eastern Russian air in the atmospheric boundary layer as it moves over the Japan Sea. The typical winter condition is that cold Asian air (CAA) originates above Northern China, moves over the Russian coast, crosses the Japan Sea, then passes over Japan. Occasionally, the cold air over the Japan Sea is replaced for a few days by very cold Siberian air outbreaks (VCSAO) with strengthened northerly winds.

2. SURFACE CONDITIONS

The Japanese Meteorological Agency (JMA) January 2000 mean analyses is used here to represent the typical winter conditions in the Japan Sea. The coldest sea surface temperatures, near 0 ^{o}C, are found along the Russian central and southern coast, including near Vladivostok (Fig. 2). The sea surface temperature increases to the south and east, with the warmest water next to Japan. This means that as a cold air parcel crosses the Japan Sea it is both warmed by the sea and

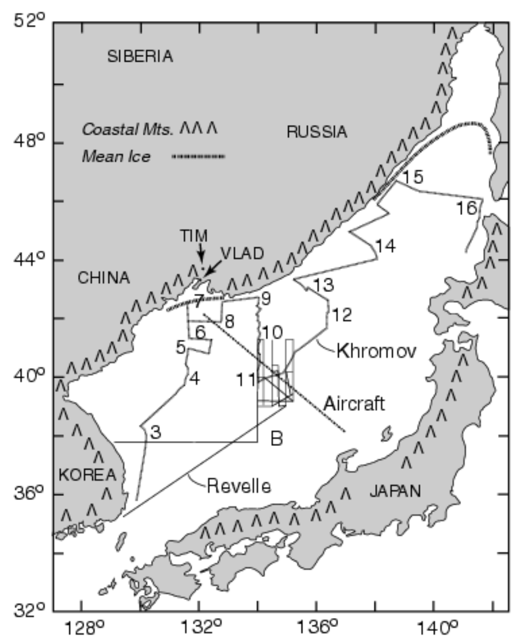

Figure 1. VLAD=Vladivostok surface station and sounding station (Sad-Gordod), B=Japanese Meteorological Buoy 21002, and TIM = Timiryazevsky surface station. Revelle=RV Revelle ship track 4 - 17 January. Aircraft (heavy dashed line) = aircraft track on 3 February. Khromov (light dashed line) = Khromov track 3-16 February. The heavy dotted is the mean ice edge (Yakunin 1996).

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moving across progressively warmer seawater. The result is that the air-sea temperature difference tends to change little or not at all across the central portion of the Japan Sea .

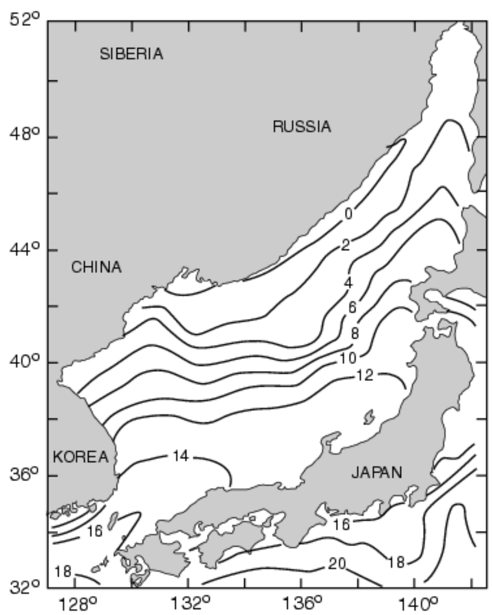

Figure 2. January 2000 mean sea surface temperature (^{o}C) from Japan Meteorological Agency.

To compare the winter surface events across the short axis of the Japan Sea, surface station data collected at Vladivostok, Revelle, and JMA Buoy 21002 are presented in Figs. 3 and 4. Vladivostok and buoy data are presented for 11 January 2000 - 5 February 2000, while the Revelle data begin on 17 January.

The surface air temperature increases from the Russian coast to JMA Buoy 21002 on the southeastern side, where the sea temperature is always warmer than the air. The wind speeds tend to be 50% faster for the ship than the buoy, while Vladivostok is much weaker than both.

Wind directions are more from the NNW at the ship and more N-NNE at the buoy, while the wind direction at Vladivostok is aligned with the NNE-oriented valley. Finally, the solar insolation (incident short-wave radiation) is greater at Vladivostok, with its tendency for clear skies and offshore air movement, than at the Revelle where the presence of a well-defined, moist, deep marine boundary layer encourages marine layer clouds as well as more storm-generated clouds from disturbance centers that tend to pass over the south side of the Japan Sea.

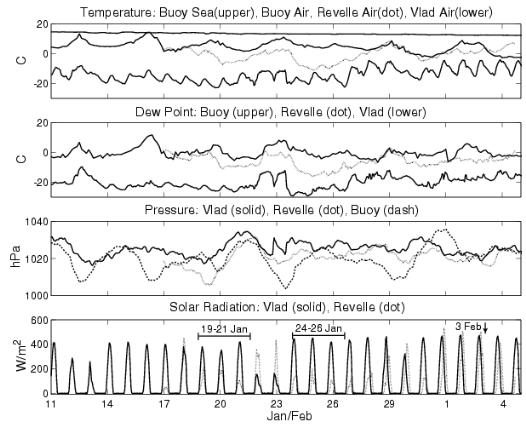

Figure 3. JMA buoy, RV Revelle and Vladivostok air temperature, dew point, pressure and solar radiation for 11 January 2000 - 5 February 2000.

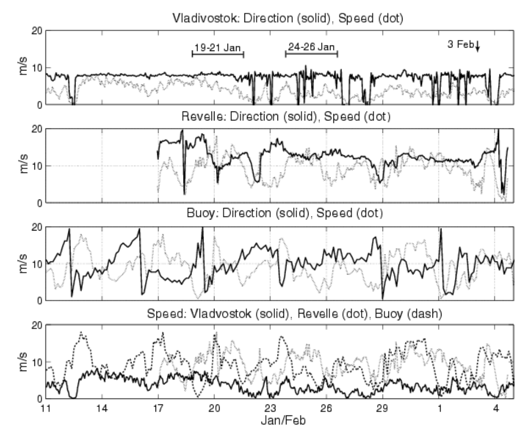

Figure 4. JMA buoy, Revelle and Vladivostok wind speed and direction for 11 January 2000 - 5 February 2000.

Special events are also noted in Figs. 3 and 4. The Siberian High expands southward causing a Very Cold Siberian Air Outbreak (VCSAO) to occur from 24 to 26 January. During 19-21 January, a weak cyclone moves across the north side of the Japan Sea, followed by a short duration VSCAO as the cyclone moves east. In contrast, routine Cold Asian Air (CAA) moves in on 3 February, resulting in average cold temperatures for the season.

3. HEAT FLUXES AND CLOUDS

The net surface flux and its components exhibit large variability on time scales from several hours to synoptic event scales during the Revelle cruise (Fig. 5). The mean fluxes over the 19-day cruise are: Qnet = -288 W m^{-2}; Qsw = 53 W m^{-2}; Qlw = -45 W m^{-2}; Qsen = -138 W m^{-2}; and Qlat = -158 W m^{-2}. Much of this heat loss is due to the sensible and latent fluxes, which ranged from 0 to -400 W m^{-2} on synoptic (2-8 day) event scales. The incoming short-wave flux was generally lessened by marine clouds, which also reduced the net outgoing long-wave heat flux. The net flux Qnet varies from -800 to +200 W m^{-2}, but is mostly negative, indicating that the central part of the Japan Sea is losing heat during almost the entire Revelle cruise.

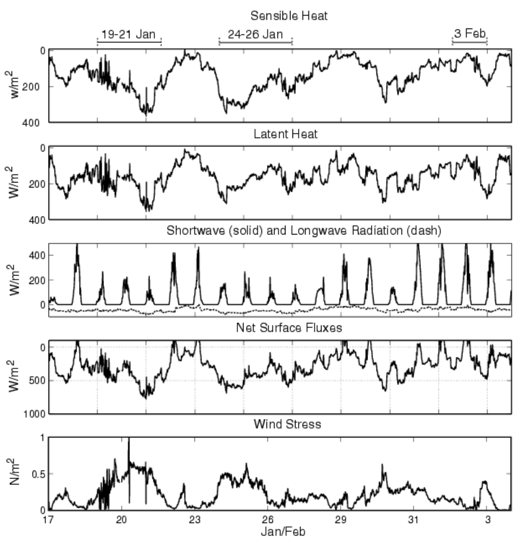

Figure 5. Surface heat flux and wind stress during the RV Revelle January-February cruise.

The largest net heat flux losses occurred on the 21st, 24th, and 30th. The large loss on the 24th is expected since it occurred during the very cold Siberian air outbreak (VCSAO) noted above. The large loss on the 21st also occurs during a weak VCSAO event. However, the large loss on the 30th occurred during northwest flow and with out roll clouds (usually seen a during VCSAO event), indicating that cold dry air was moving rapidly across the sea. It appears then that northwest flow events are just as capable of extracting large amounts of heat out of the Japan Sea as are cold air outbreaks.

Stationary satellite visual images of boundary layer stratus sheet clouds filling the Japan Sea during very cold air events show both the wind direction and give a clue to the nature of the boundary layer dynamics. An example is on 26 January (Fig. 6). Other than in the immediate

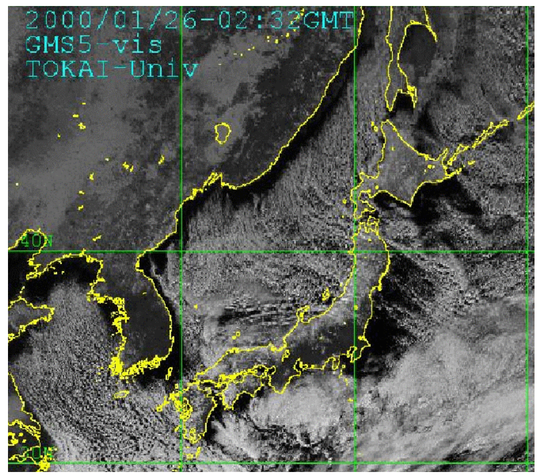

Figure 6 Stationary satellite visual image for 0232 UTC 26 January 2000.

lee of the Coast, a marine stratus sheet covers the Japan Sea with individual roll clouds extending from near the Russian coast to Japan. The increase of clouds over Honshu is due to cold air damming. Cloud lines caused by the gaps and low points in Honshu and extending further down wind, confirm that both the wind speeds are vigorous and that the air-sea temperature difference remains substantial over the Pacific.

4. A SCHEMATIC MODEL

We now consider why the air temperatures on the Russian coast apart from Vladivostok are relatively warm during CAA conditions (Fig. 7). During these conditions, the Russian coastal air temperature is -10 ^{o}C to -5 ^{o}C, whereas the surface air temperature on the northwestern side of the coastal mountains is -15 ^{o}C to -10 ^{o}C. This colder air does not make it over the coastal mountain ridge. The strong surface inversion capped by a deep isothermal layer (measured at Vladivostok) and the weak northerly winds suggest that the Russian coastal mountains block the surface air. In addition, the reduced drag over the sea causes surface divergence. Air from above the Russian coastal ridge-top near 1000 m is pulled down into the lee of the coastal mountains, which results in sea-level air temperatures of around 10 ^{o}C warmer than would be if the topography were flat.

Since the Vladivostok 850 hPa potential temperature is typically between -3 ^{o}C to 3 ^{o}C, descent from elevations of 500 - 1000 m to sea-level would warm the coastal air to a temperature close to that of the sea surface. During VCSAO's, both the surface and lower level air temperatures over the Russian continental interior decrease to -20 ^{o}C and -30 ^{o}C, greatly reducing the stability and even eliminating the surface inversion. The result is that the air, originating from 500 - 1000 m elevation inland, moves over the Russian coastal range and, although adiabatically warmed, it is still much colder than that observed in CAA conditions. In addition, the greater wind speeds associated with the VCSAO's cause greater heat fluxes, surface evaporation, and boundary layer mixing, which generate cloud sheets that extend across the Japan Sea.

5. CONCLUSIONS:

The Russian coastal mountain range plays an important role in significantly warming the air that normally moves over the Japan Sea. These mountains block the lowest, coldest continental surface air from moving over the sea. Divergence in the lee causes air from 500 - 1000 m to descend and warm to temperatures close to sea-surface temperature, reducing sea-surface heat, sea temperature difference, and heat losses.
During very cold Siberian Air outbreaks, the air just above the Russian coastal mountains is so much colder that even with adiabatic warming, it is more that 10 C colder than the sea surface. These large sea-surface temperature differences and faster winds generate stratus cloud sheets that cover the Japan Sea.

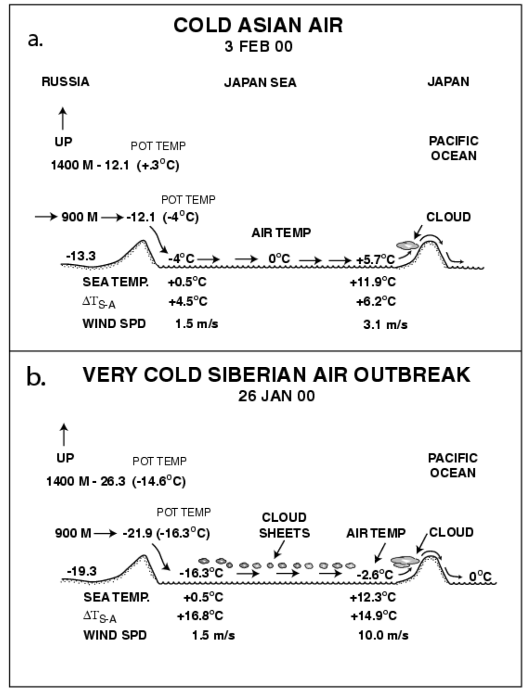

Figure 7. A schematic on the role of Russian Coastal mountains in lee side warming of air moving over the Japan Sea.

6. REFERENCES

Yakunin, L. P., 1999: Ice drift and thickness in the Sea of Japan. Proceedings from the Fourth CREAMS Workshop, February 1996. Far-Eastern Regional Hydrometeorological Research Institute, 24 Fontannaya St, Vladivostok, 690600. Russia. pp 203-205.