Air-Sea Fluxes and Boundary-Layer Structure Over the Japan/East Sea During Winter Cold-Air Outbreaks

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INTRODUCTION

Strong northwesterly wintertime winds resulting from the incursion of dry and cold air masses from the Eurasian continent into the Japan/East Sea (JES) known as “cold-air outbreaks” greatly enhance the air-sea interaction over JES. In particular, an area about 150 km in diameter off Vladivostok (referred to as the “Flux Center” by Kawamura and Wu, 1998, Fig.1) experiences very large fluxes of momentum, sensible and latent heats. We present results of air-sea fluxes and boundary-layer aircraft measurements obtained under such conditions during the Winter 2000 JES experiment.

APPROACH AND METHODS

The NPGS/CIRPAS Twin Otter aircraft (Fig. 2) was instrumented with fast-responding wind, temperature, humidity, IR sea temperature, aircraft motion, and navigation sensors. Thirteen research flights were flown from Misawa NAF, Japan, over the Japan/East Sea. Three basic research goals were addressed with different flight patterns (as shown in Fig. 3):

- Internal Boundary-Layer Growth (IBLG): after transit to the "Flux Center" south of Vladivostok, a line of soundings from 100 to 3000-5000 feet was flown following an approximate streamline across the JES.
- Flux Mapping (FM): after transit to the “Flux Center” south of Vladivostok, the surface-layer fluxes were mapped in a grid pattern at 100 feet with soundings to 5000 feet.
- Flux Divergence (FD): after transit to the “Flux Center” south of Vladivostok, a vertical stack pattern was flown to determine the flux divergence profile in the boundary layer.

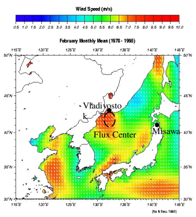

Figure1. February monthly mean wind speed (1978-1995).

Figure 2. CIRPAS Twin Otter Aircraft with turbulence instrumentation

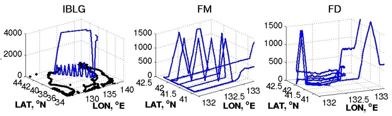

Figure 3. Flight Patterns during JES.

RESULTS

An example of the boundary-layer growth across the JES is shown in Fig. 4a for Feb 3 2000. The flight track was to the SW, and the boundary-layer height as given by the jump in potential temperature varies from about 300 to 1200 meters. Many of the interesting features of the JES MABL are revealed. Down the streamline we observe internal boundary-layer growth which is accompanied by warming and moistening of the MABL and decay and backing of the wind. Honshu's orography may play a role in the thickening of the IBL as well as on the wind direction backing. Also, the sharp increase in the IBL around 134°E seems to be a response to the crossing of the SST front. Thus there may be *two* internal boundary layers across the JES in cold-air outbreak conditions: the initial IBL and the second IBL caused by the SST front. On Feb 18 2000 which was also an IBLG flight (Fig. 4b), the much stronger winds seem to induce a faster growth of IBL.

The MABL vertical structure as revealed by the maps in in Fig. 5 show colder, dryer and faster moving air close to Vladivostok . In both cases moisture and heat are picked up by the advected air mass. The winds decayed after 250-350 km into the JES and picked up while approaching Honshu.

A linear fit of the MABL height (determined from the individual soundings) to the square root of the fetch is given in Fig. 6 for both days. The fit is very reasonable especially for the stronger winds day (flight 000217). The growth rate of 1.82 $m^{1/2}$ for Feb 3 2000 is close to the 1.91 $m^{1/2}$ found near shore by Hsu (1986). One particularity of the wintertime JES is that the temperature difference between the air and the sea surface remains fairly the same (8-9 °C) across the JES. This is due to the SST north-south gradient across the JES which seems to balance the increase in air temperature as the air above crosses the JES.

Prof. Qing Wang of USNPGS has run the COAMPS model for Feb 03 200 and found it predicted boundary-layer growth but at a different rate than the observed (see Fig. 7) and did not show the jump at the SST front. This may be due, at least partially, to the fact that the COAMPS SST used was different from the observed and where, in particular, the SST front was not represented.

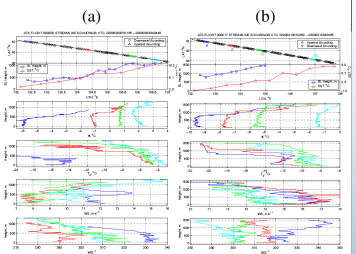

Figure 4. Vertical structure and growth of JES MABL along an approximate streamline for flights 000202 (a) and 000217 (b).

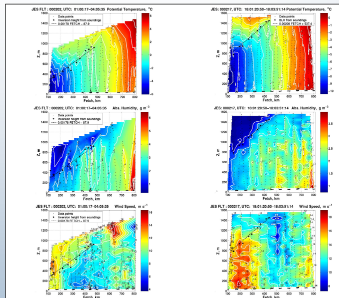

Figure 5. Vertical streamline-wise cross-sections showing the structure of potential temperature, absolute humidity, and wind speed of the MABL for flights Feb 02 2000 (left) and Feb 17 2000 (right).

RESULTS (Continued)

Eddy correlation fluxes for flight 000217 were estimated along the 5-6 minutes deck level runs flown at roughly 40 m between each sounding pair. The results are summarized in Fig. 8 for along-wind momentum, sensible heat and latent heat fluxes. It can be observed that the combined fluxes are the largest inside the “flux center”. This is in agreement with Kawamura and Wu (1998) who used only satellite (NSCAT) and ECMWF results which indicated the presence of the high flux area. They decreased considerably (more than 50% for sensible heat) immediately outside the flux center. They started to increase again past the 40°N which is roughly the location of the SST front. Both latent and sensible heats fluxes increased greatly in the vicinity of Honshu as a result of the relatively warmer water and the island’s orography .

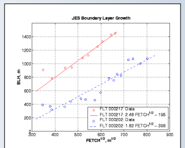

Figure 6. Internal boundary-layer growth with fetch $^{1/2}$ for flights 000202 and 000217.

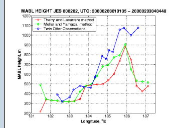

Figure 7. Comparison of observed (Twin Otter) MABL height to COAMPS results of Qing Wang (USNPGS).

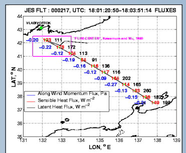

Figure 8. Surface turbulent fluxes for flight 000217.

CONCLUSIONS

- Turbulence instrumentation performed reasonably well given the extreme meteorological conditions.
- A dramatic growth of the internal boundary layer (IBL) as a response to the cold and dry continental air outbreak into the JES (flights 000202 and 000217) was observed.
- A smaller secondary IBL due to the mid-JES SST front was also observed.
- Flight 000217 showed larger fluxes in the “Flux Center” in agreement with Kawamura and Wu.
- Data suggest Honshu's orography may play a significant role in the southern part of the JES.

BIBLIOGRAPHY

1. Kawamura, H. and P. Wu, “Formation Mechanism of Japan Sea Proper Water in the Flux Center off Vladivostok,” J. Geophys. Res., **103**, no. C10, pp. 21,611-21,622 (1998)
2. Hsu, A, “Note on Estimating the Height of the Convective Internal Boundary Layer Near Shore,” Bound.-Layer Meteor. **35**, 311-316 (1986).