Ocean Predict '19   *May 6 2019*

Coastal Acoustic Tomography under Stratified Conditions in Lake Biwa, Japan

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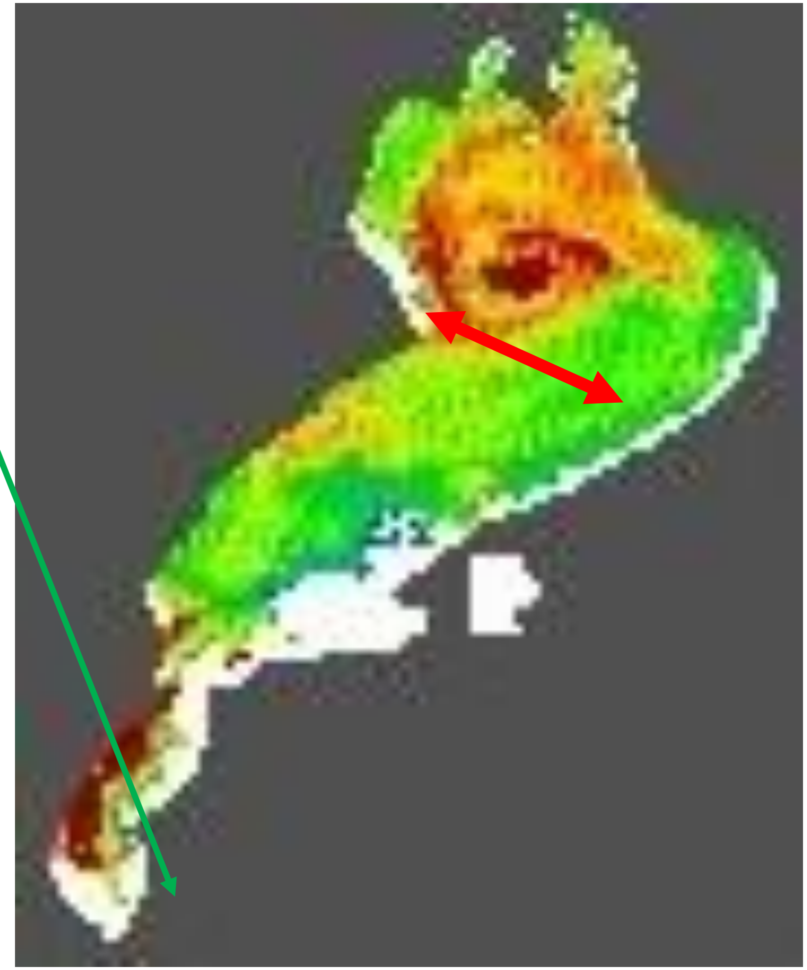
We present results from Coastal Acoustic Tomography (CAT) at horizontal ranges up to 14 km believed to be the first field demonstration of CAT in a lake under stratified conditions. Our purpose is to track currents and temperature fields, thence motion of pollutant, cyanobacteria *etc.*) by assimilating CAT data into an operational forecast system.

Small but consistent differences in travel times between reciprocal paths were observed, whence we estimate path-averaged currents along the dominant acoustic path on the order of 5 cm/s, which is not inconsistent with expected magnitudes at this site. To our knowledge this is the first reported estimate of currents by Acoustic Tomography in a lake.



MODIS   2015/7/20/ 10:35 JST

"Chlorophyll a" (red: high conc.)

Long-term Aim: Assimilate Information on Acoustic Travel Time into Hydrodynamic simulations

From pairs of TR in a network:

→ Average travel times constrain average sound speed (-> avg. temp)

→ Differential travel times relate to average parallel currents

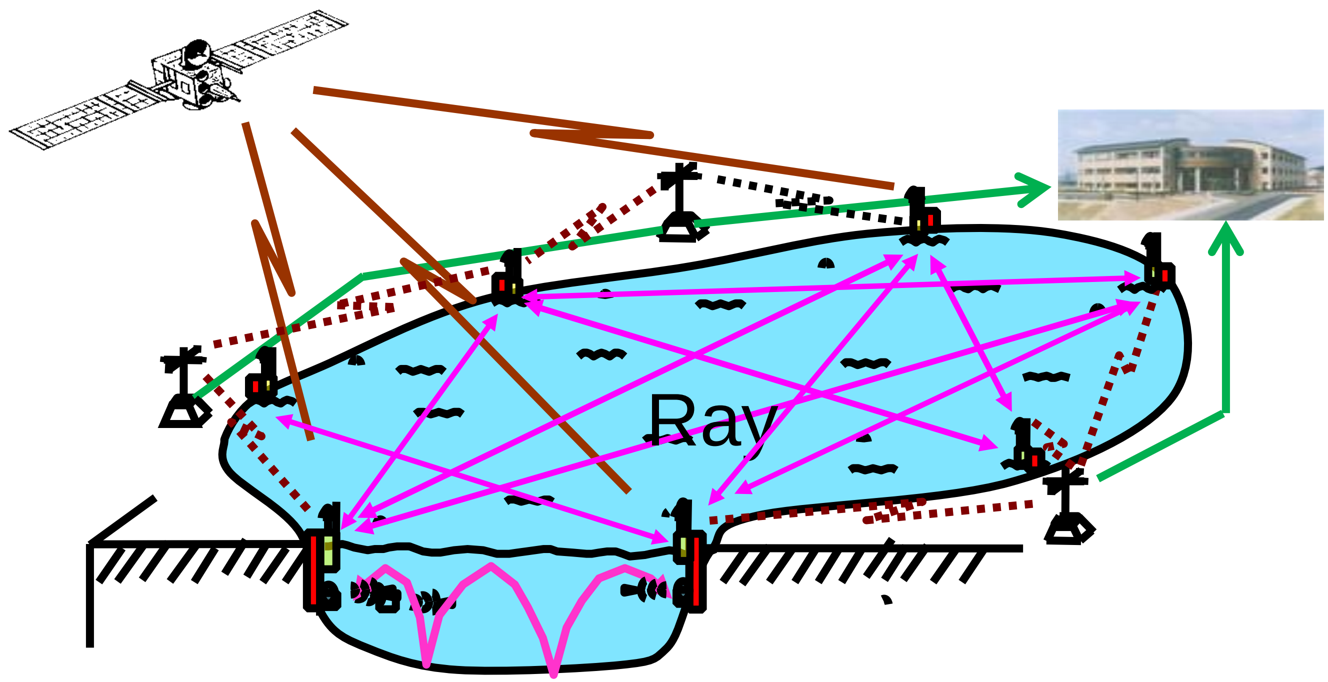


Fig. : A. KANEKO

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RESEARCH ARTICLE
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Key Points:
- Coastal acoustic tomography data were assimilated into a triangular mesh ocean model for the first time
- Velocities obtained from assimilation agreed with ADCP data better than those from inversion or simulation
- Assimilation with a triangular mesh fits complex coastlines well and enables reasonable circulation calculations

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Assimilation of coastal acoustic tomography data using an unstructured triangular grid ocean model for water with complex coastlines and islands

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Abstract For the first time, we present the application of an unstructured triangular grid to the Finite-Volume Community Ocean Model using the ensemble Kalman filter scheme, to assimilate coastal acoustic tomography (CAT) data. The fine horizontal and vertical current field structures around the island inside the observation region were both reproduced well. The assimilated depth-averaged velocities had better agreement with the independent acoustic Doppler current profiler (ADCP) data than the velocities obtained by inversion and simulation. The root-mean-square difference (RMSD) between depth-averaged

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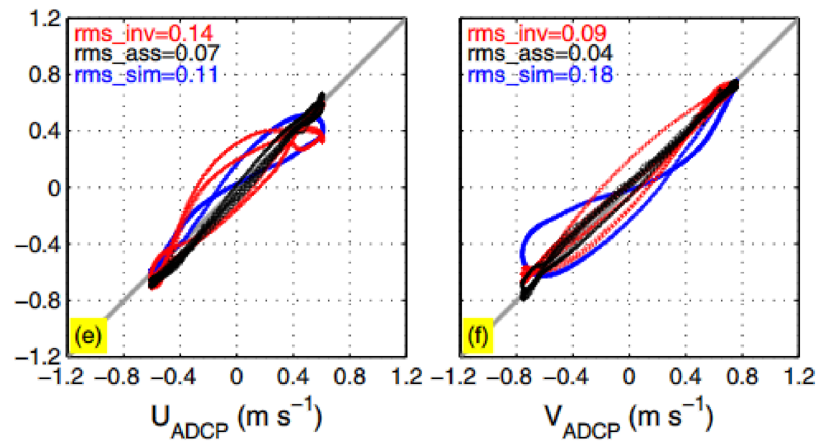
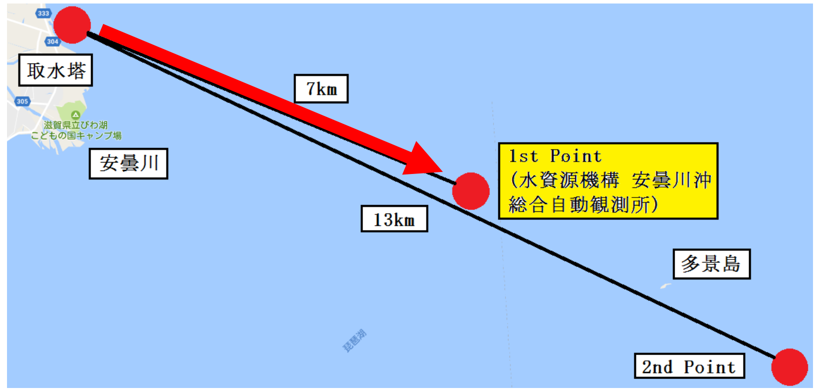
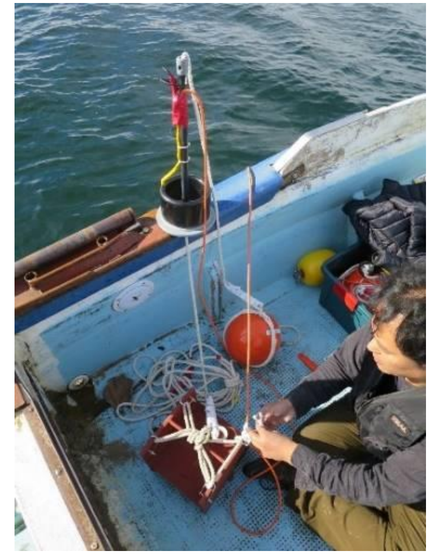
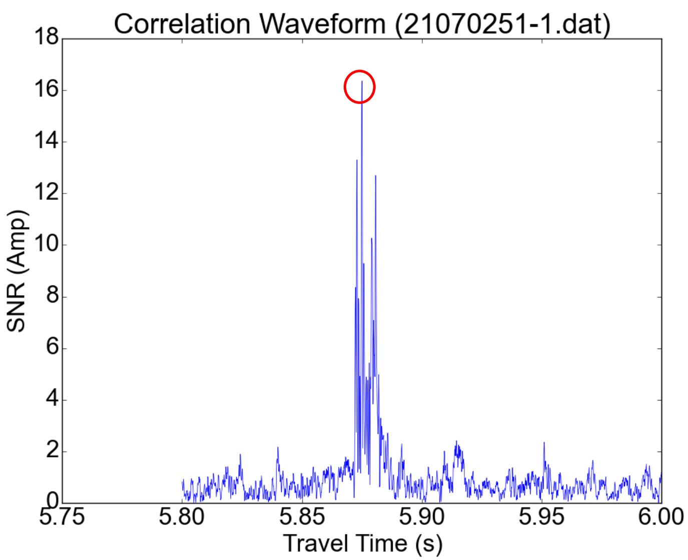


Figure 7. Scatter plots of (left) eastward and (right) northward velocity components with respect to ADCP at stations (top) A1, (middle) A2, and (bottom) A3. The RMSDs between the ADCP and the inversion, assimilation, and simulation are shown in the top left of each figure (in m s^{-1}).

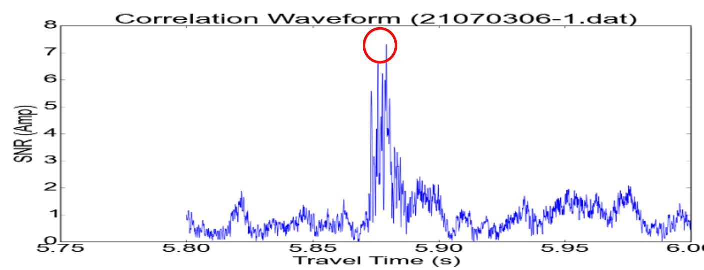
Sample “correlograms” of received intensity (unstratified winter conditions)







“Best” (strongest peak SNR)



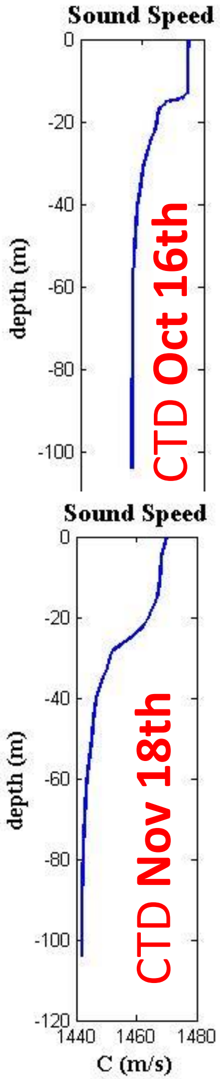
Worst

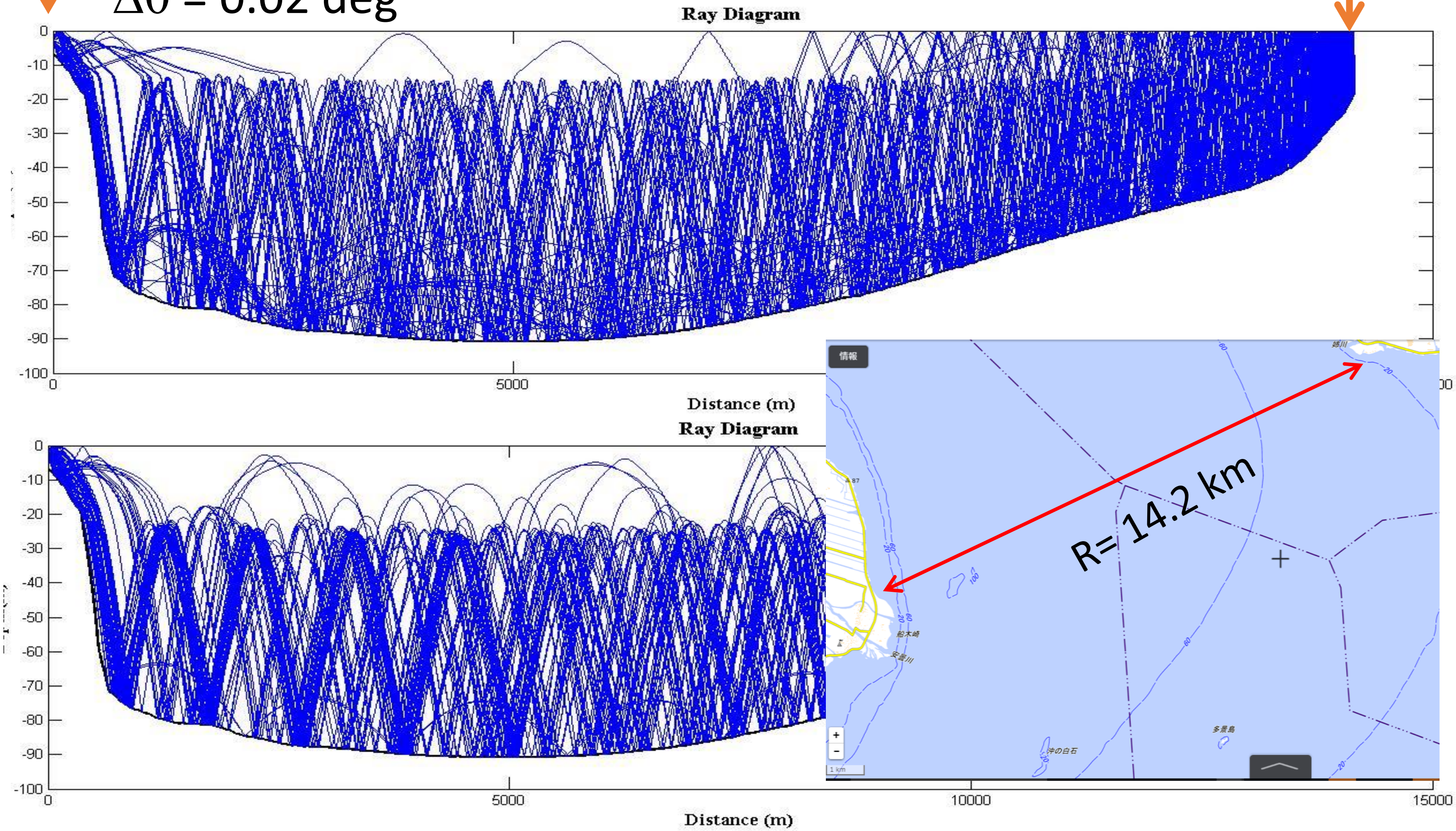
Sample of Acoustic Ray Tracing West -> E Shore, R = 14.2 km

“Brown Tower”

nr Ane River mouth

$\Delta\theta$ = 0.02 deg

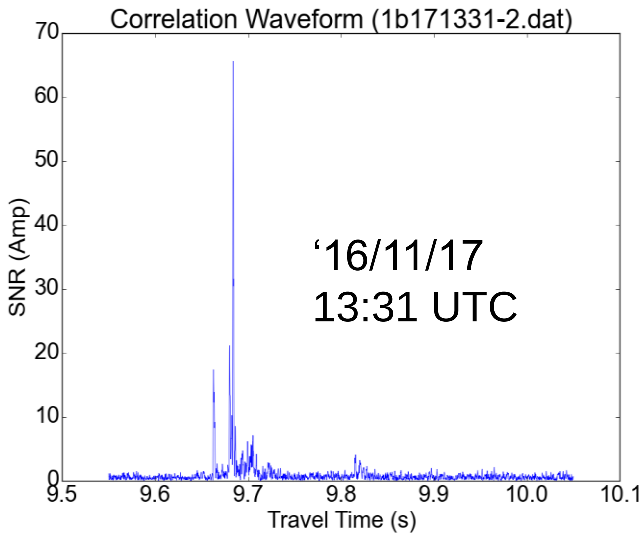




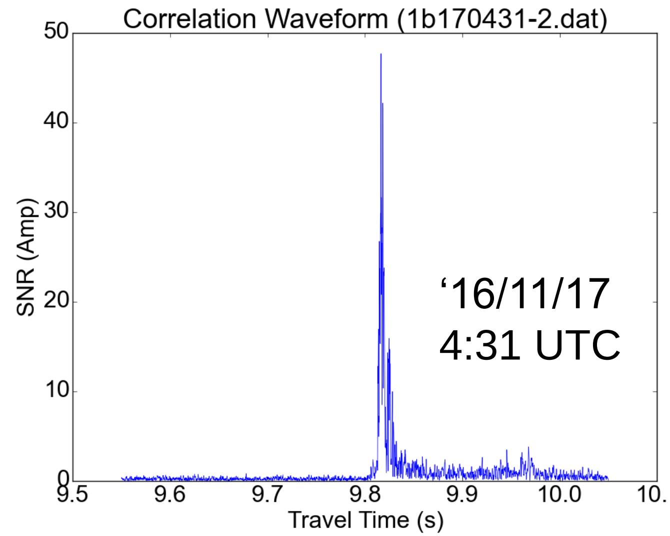
→ locked my thinking into “deep water transmission” (Nov ‘16)

A month later, BS student Onishi discovered two distinct sets of arrival times
(from 5 day mooring '16 Nov 13-18, R = 14.2 km, 5KHz carrier, M11 sequence*9 reps.)

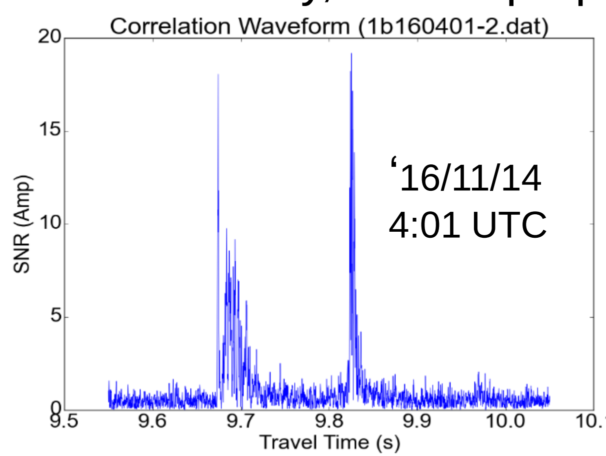
Near 9.7 sec

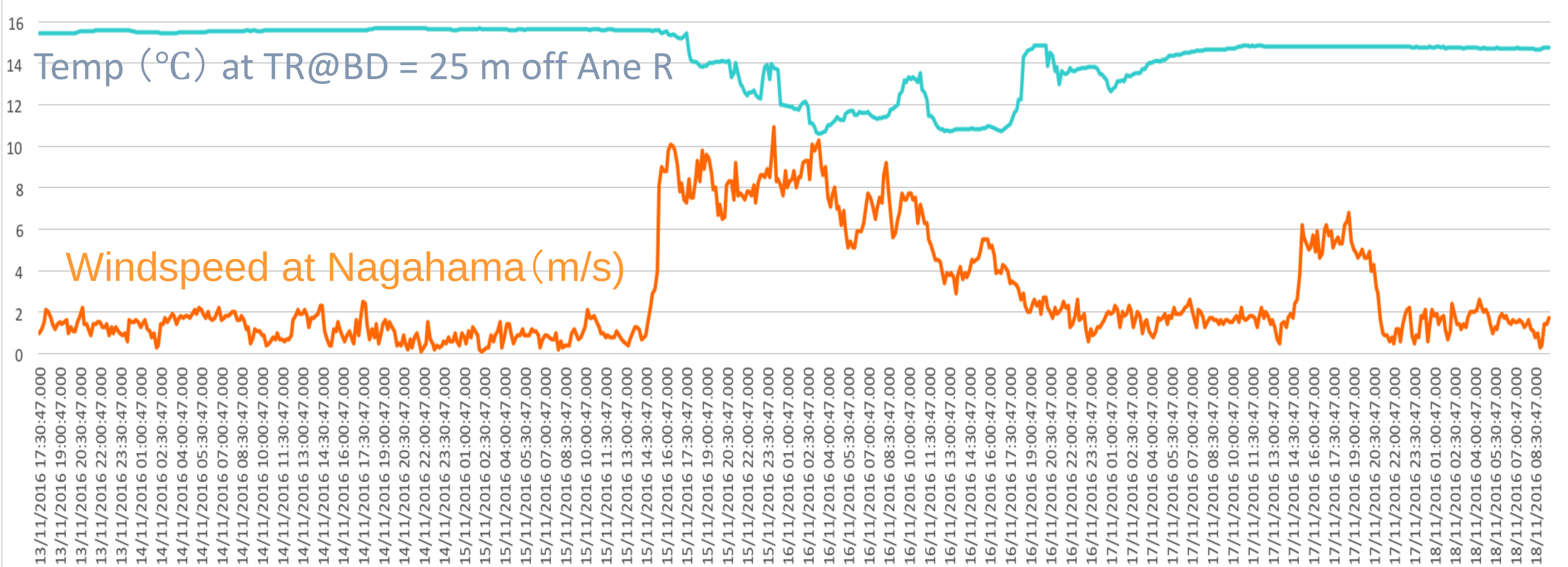


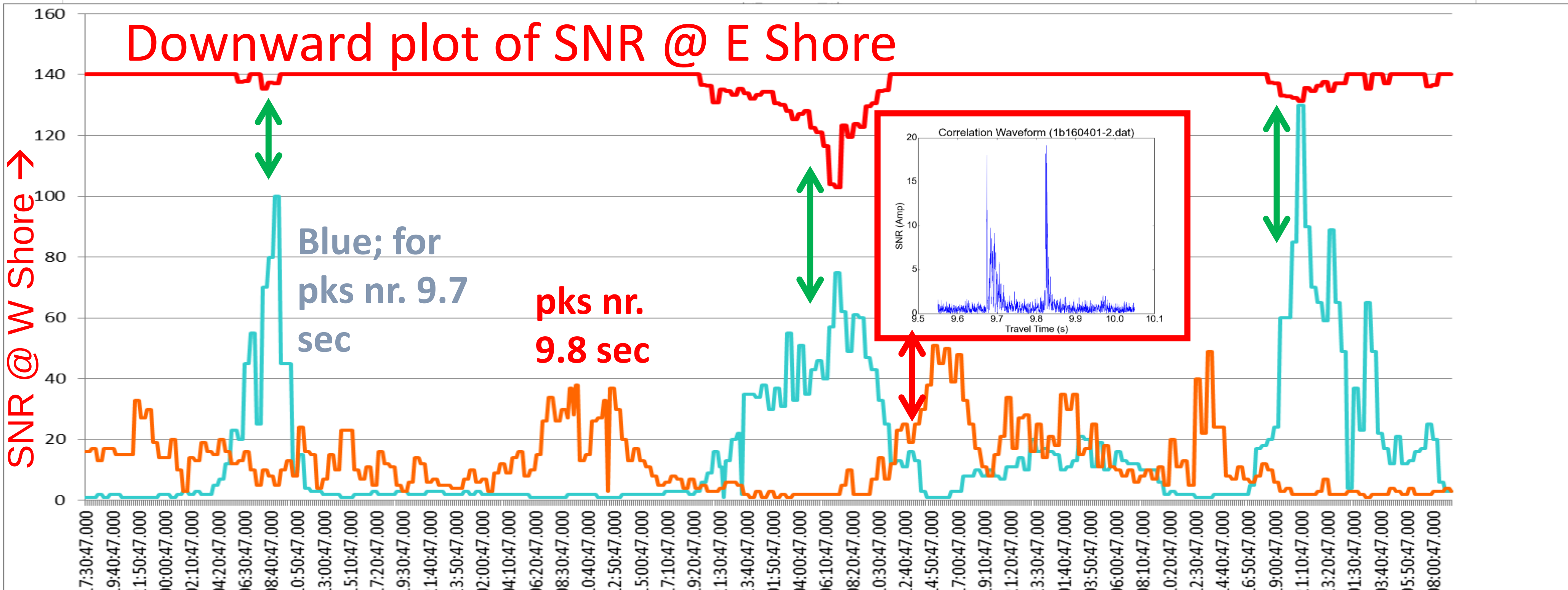
Near 9.7 sec



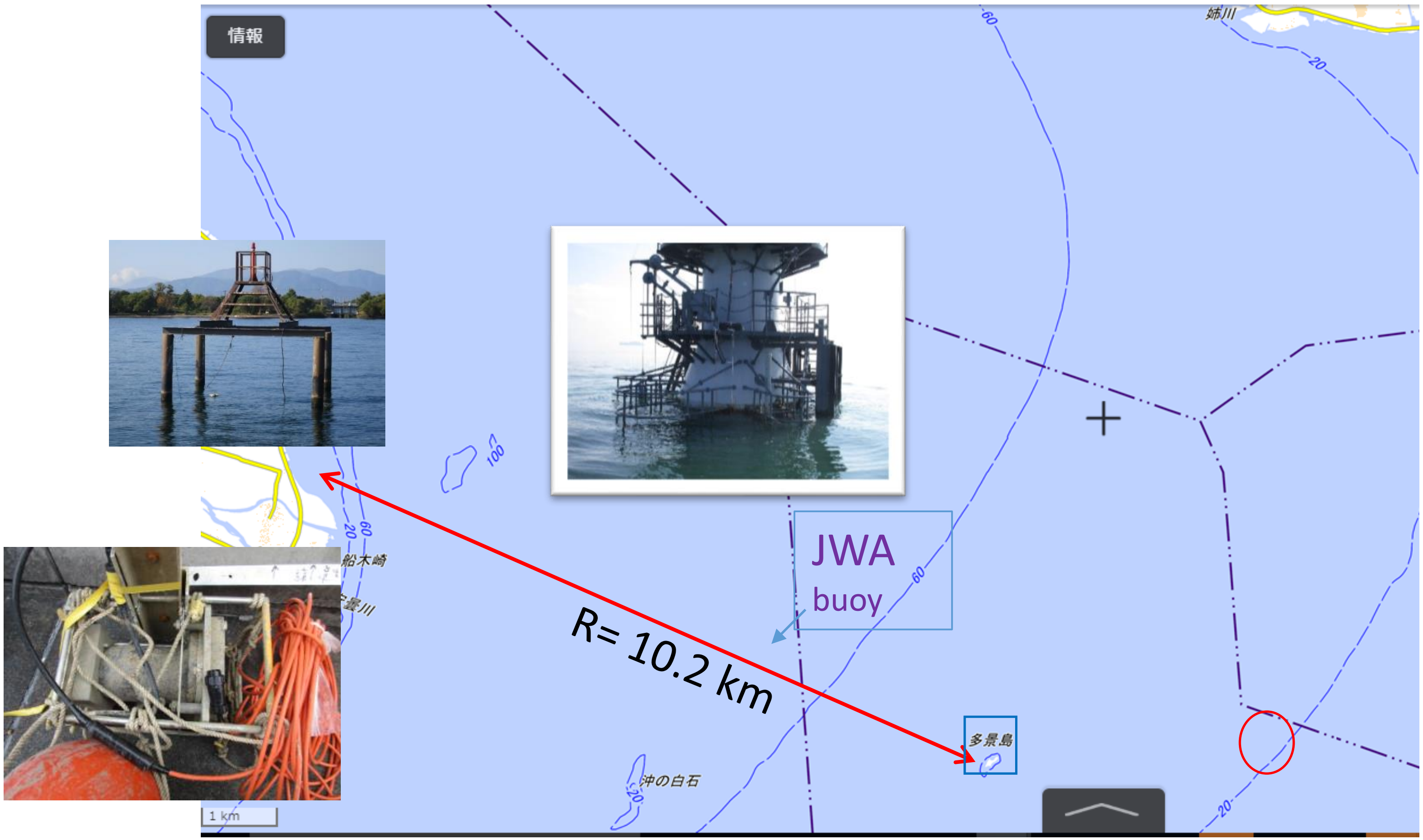
Occasionally, both superpose



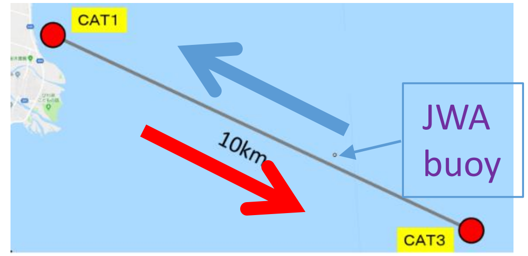

Temp（℃）at TR@BD = 25 m off Ane R
Windspeed at Nagahama（m/s）


Downward plot of SNR @ E Shore
SNR @ W Shore →
Blue; for pks nr. 9.7 sec
pks nr. 9.8 sec
Correlation Waveform (1b160401-2.dat)
SNR (Amp)
Travel Time (s)

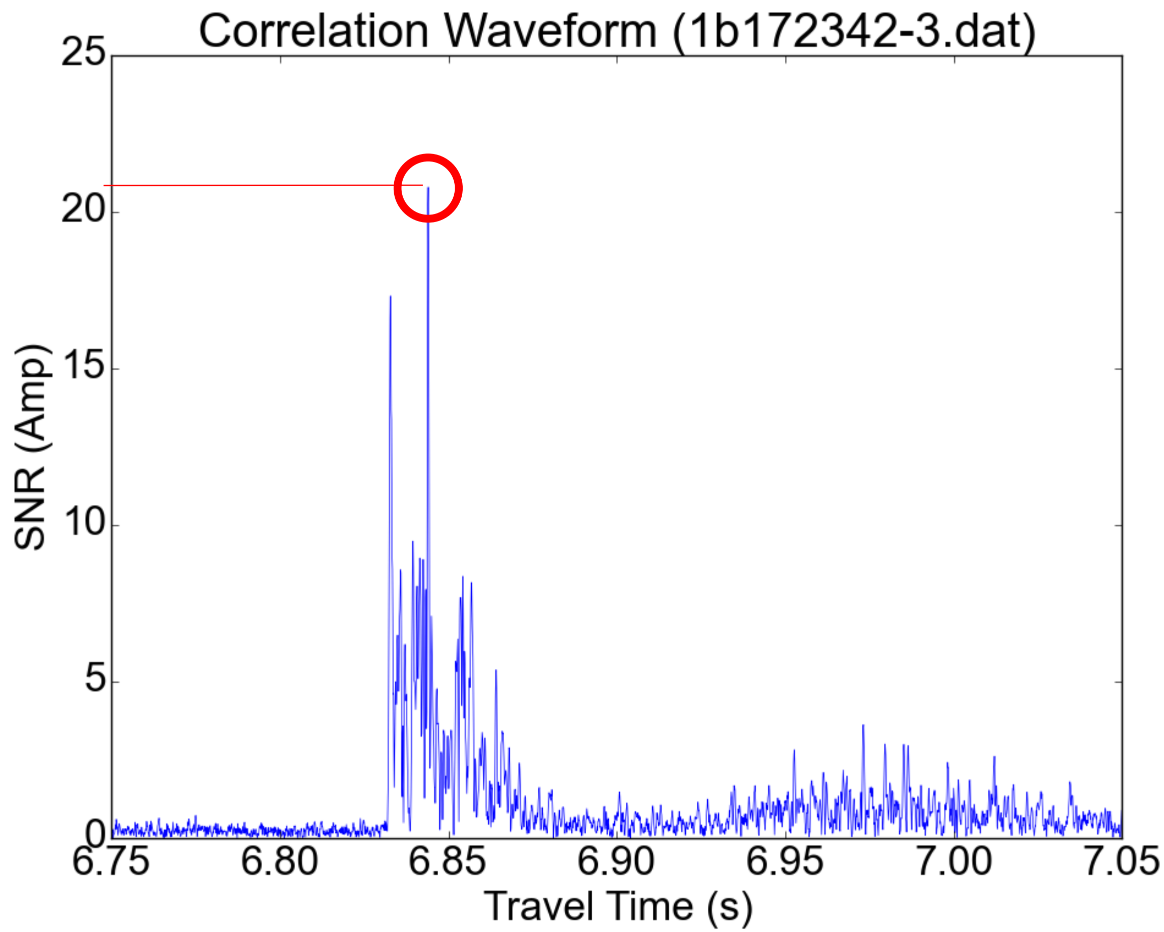
Nov. 2017; after hardware upgrade w/ stronger emission, E station to Takeshima (“land-based” deployment); TR 2.5 m above Bottom@49 m. M11 * 6 repeats (~7 sec ping).



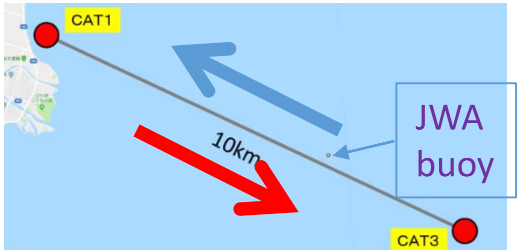
Nov ‘17 Trials



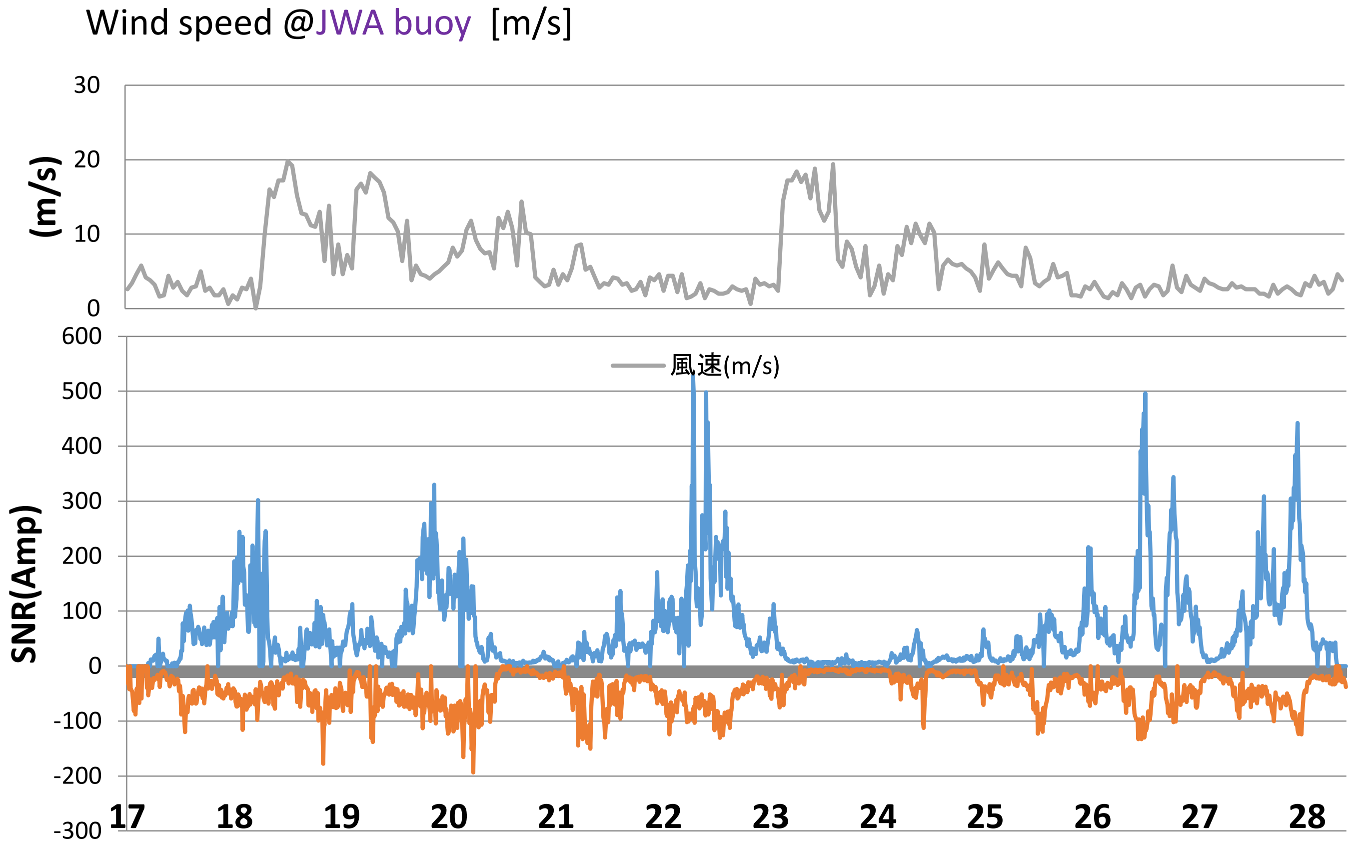
First, consider evolution of **Peak normalized correlation**



evolution of **peak normalized correlation**



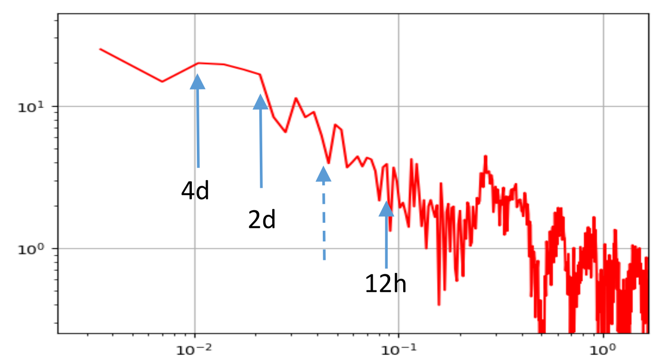
At R = 10.2 km, reception strength varies widely *(Similar variability at R = 6.6 km)*



Rec'd CAT1 : +

Rec'd CAT3 : — inverted plot

Nov. 2017

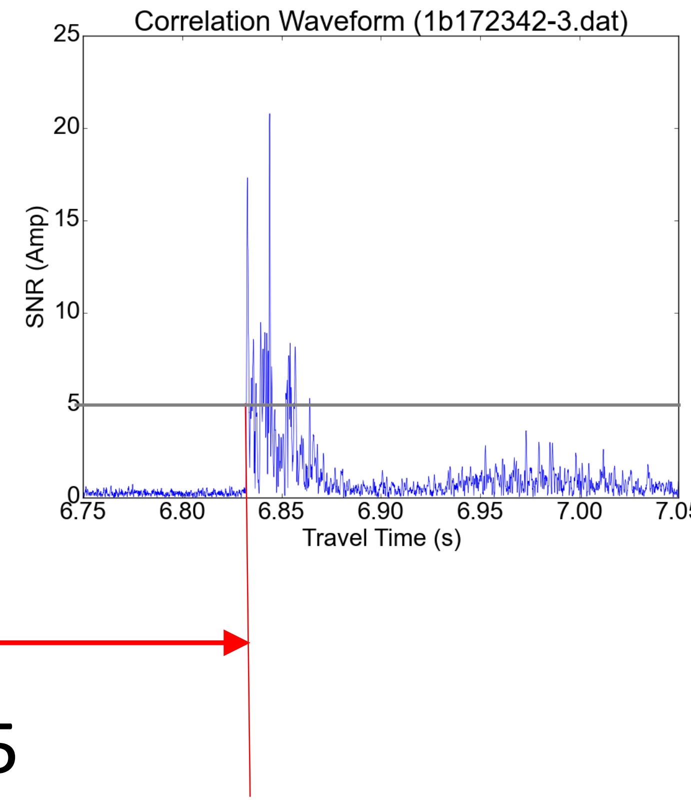


→ **quasi-periodicity ? (*cf.* Nov. 2016)-> *?due to internal waves modulating the sound channel?***

Note multiple peaks in correlogram!

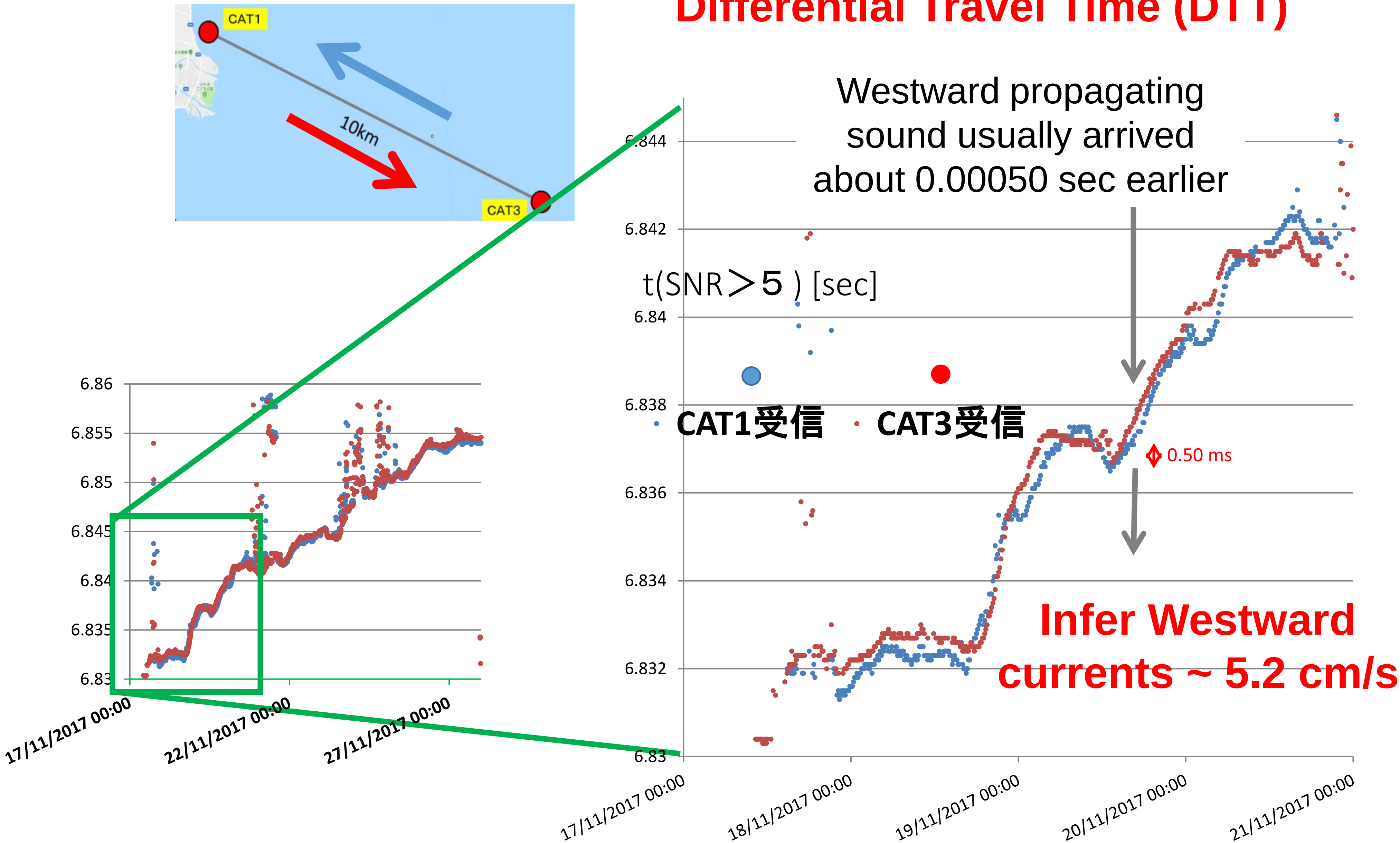
→ so we'll judge acoustic "arrival time" by a threshold exceedance time

Next slide shows how this time evolved



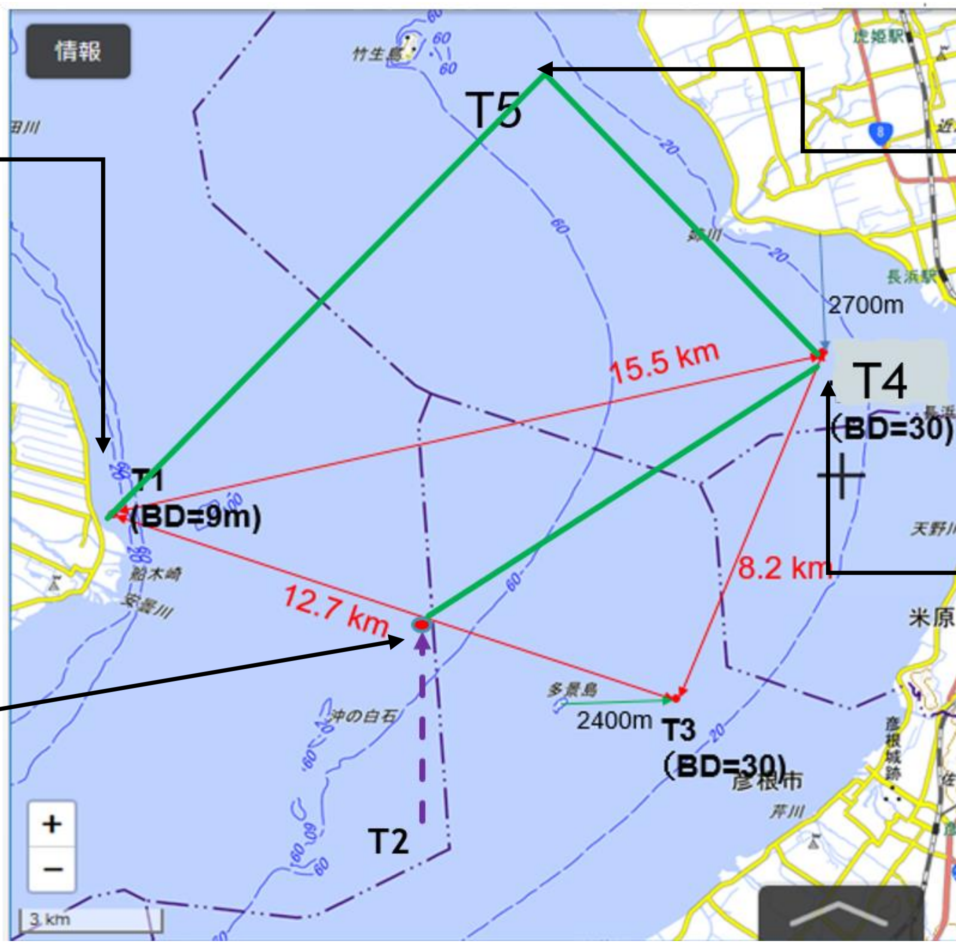
$t_{\mathrm{SNR}>5}$

Differential Travel Time (DTT)

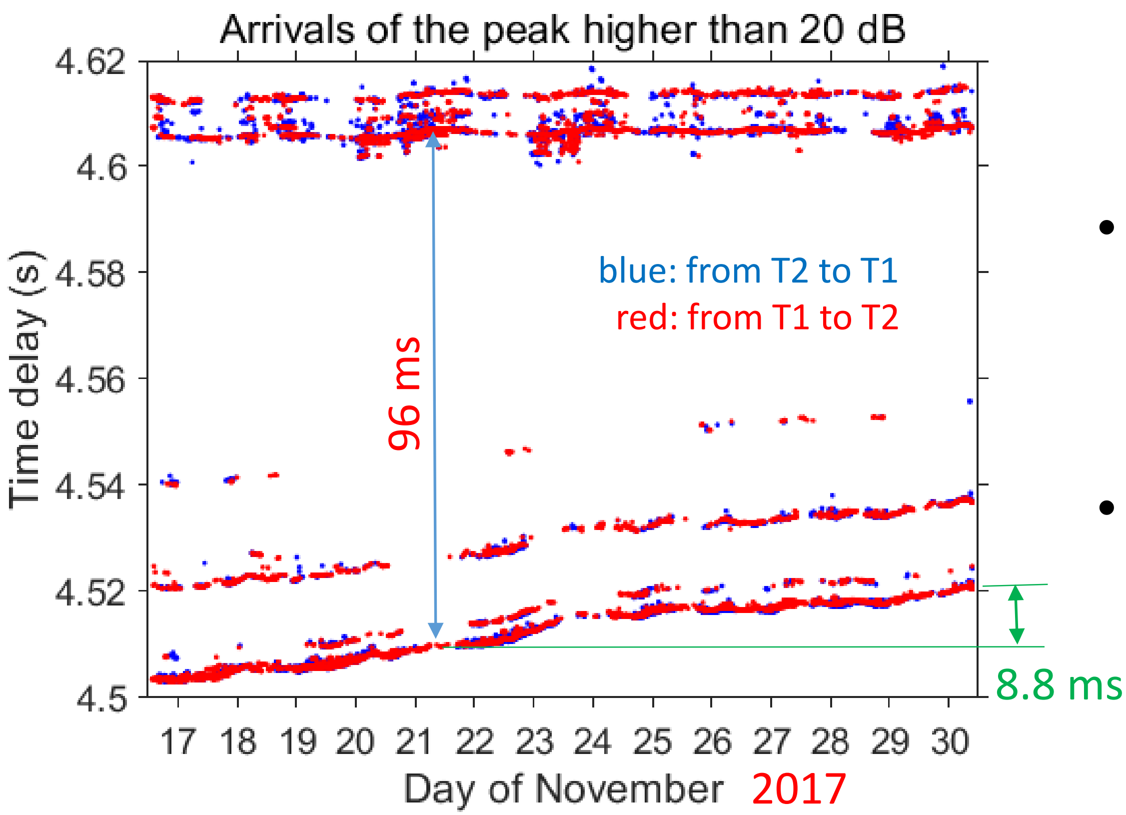


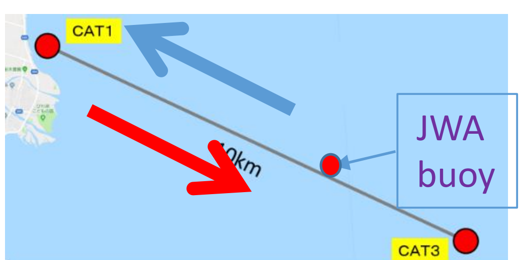
Autumn ‘18 (mostly Nov.); up to 5 TR

- T1-T2; fixed as in ‘16
- T3 – T5; moored, BD 30 to 50 m



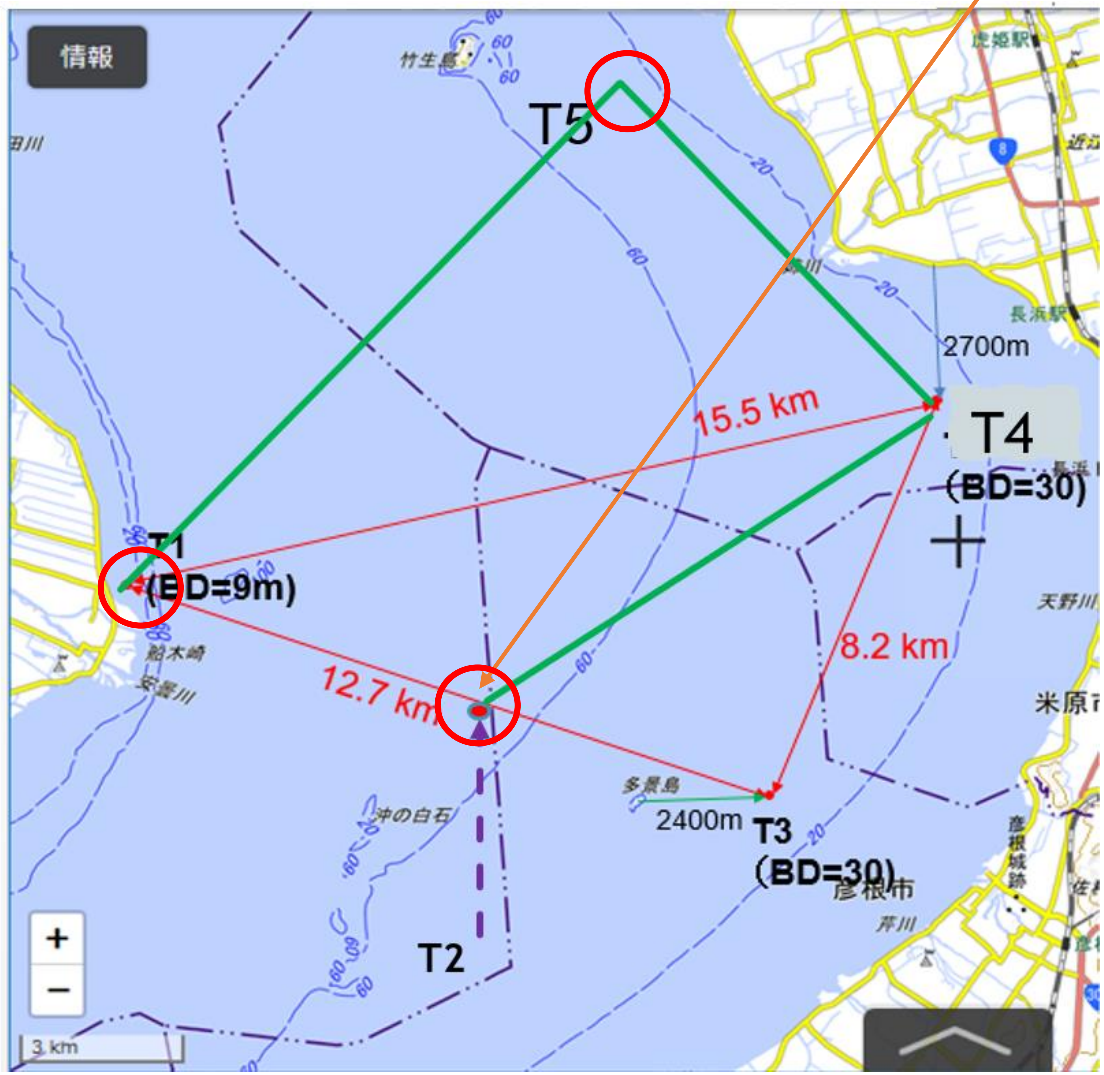
New hypothesis: **surface waveguide also acting?** (at least in autumn)



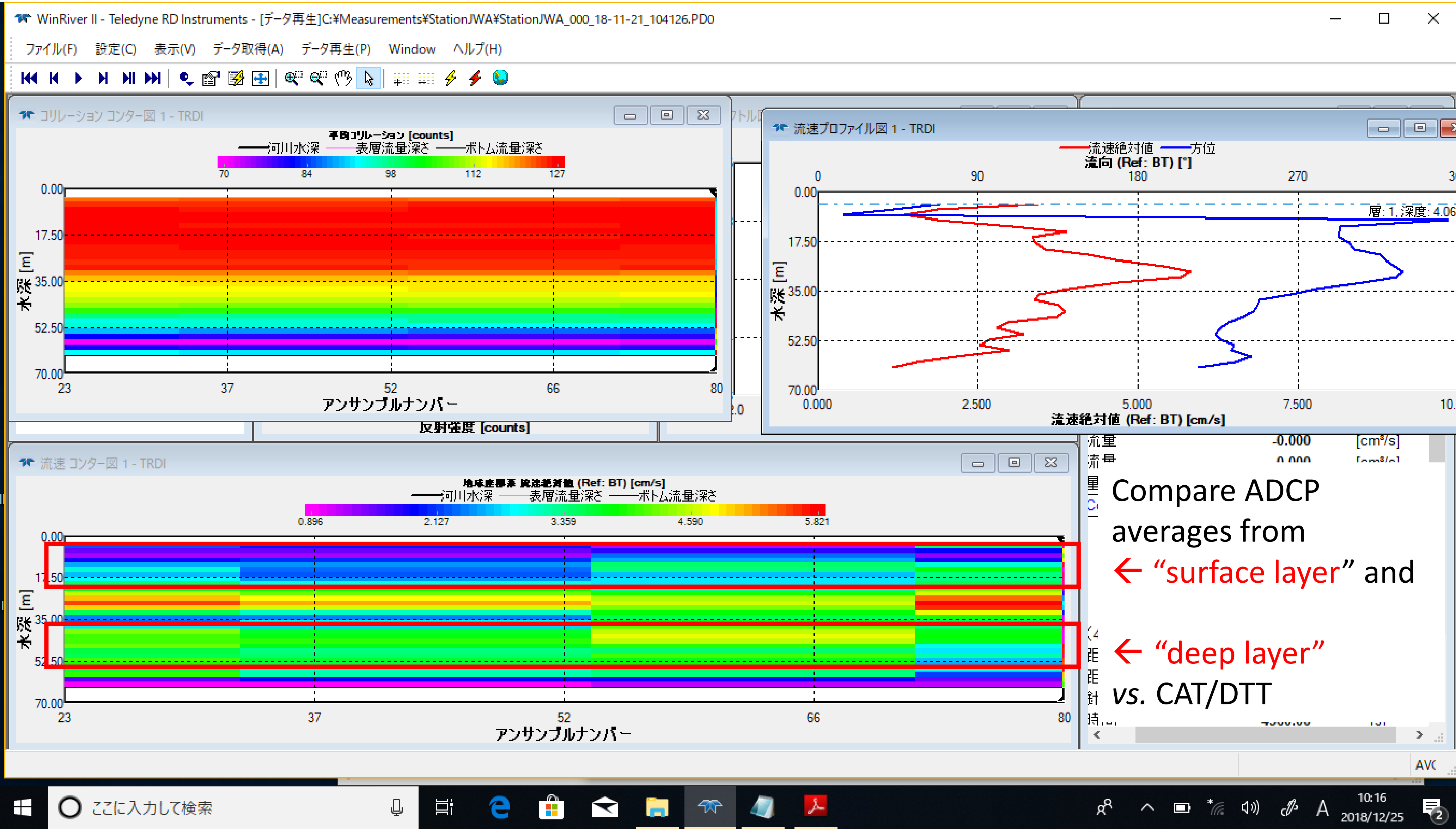


- Between T1 and T2 (R = 6.6 km) there were two arrival groups (ca. 4.5 and 4.6 s).
- The strongest peak is sometimes in the first group, other times in the slower group (*cf.* Nov '16, R= 14.2 km).
- The arrival times of the first group get slower (i.e., average sound speed decreases), but not those of the later arrival group
- Temps @T2 on Nov 21, namely 16.4 C @d=10m, 7.9 C @d= 60m, explain the observed difference of first arrivals in each group, 96 ms, to within 1 ms!
- Surface layer cooling observed between Nov 21 and 29 (16.4 -> 14.6 C) explains observed slowing of 8.8 ms

ADCP ground-truthing of currents inferred by Differential Travel Time (DTT); 80’ @noon, Nov 21, 600 kHz RDI Workhorse at T2



ADCP@T2: Stable 20’ averages.



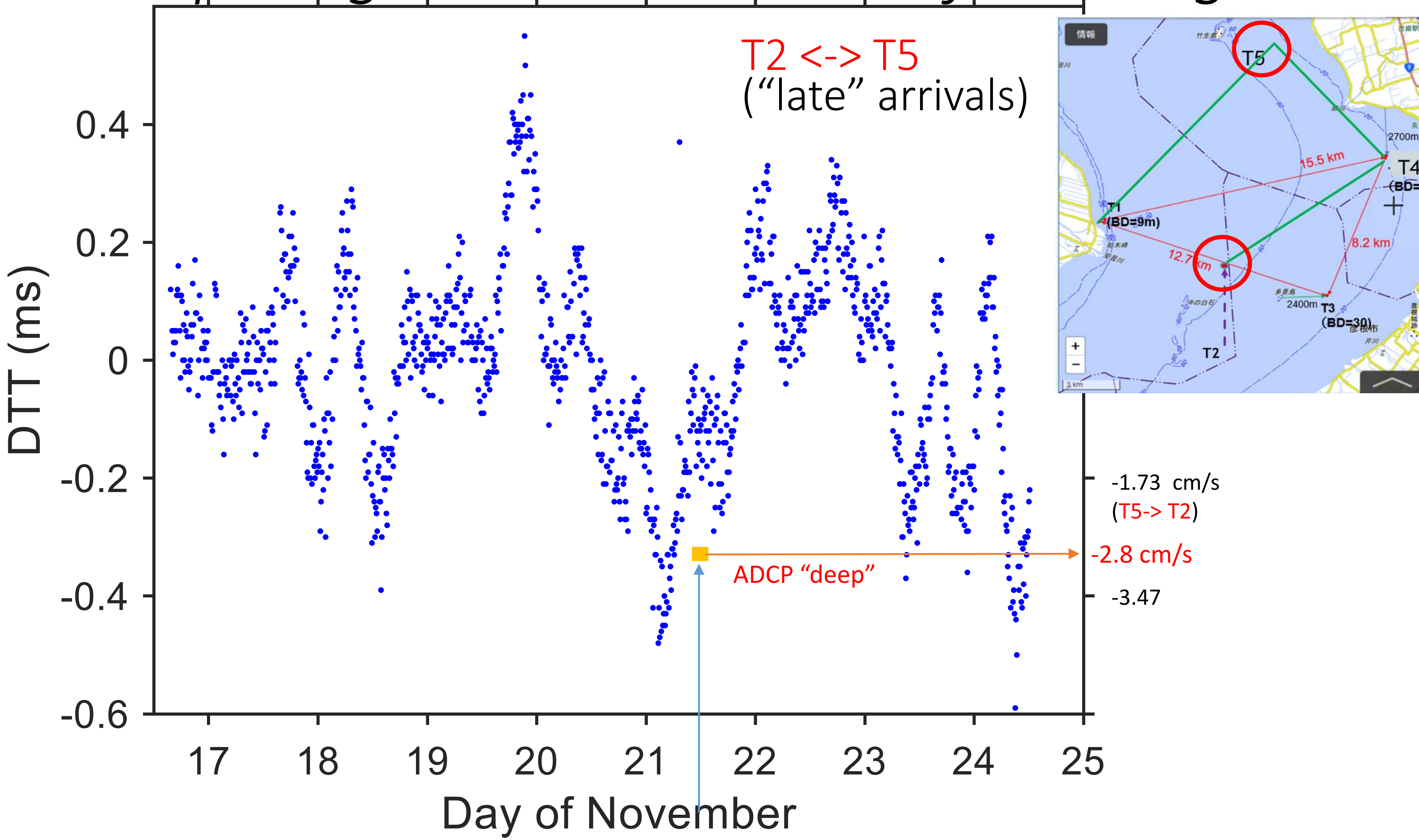
Compare ADCP averages from

← “surface layer” and

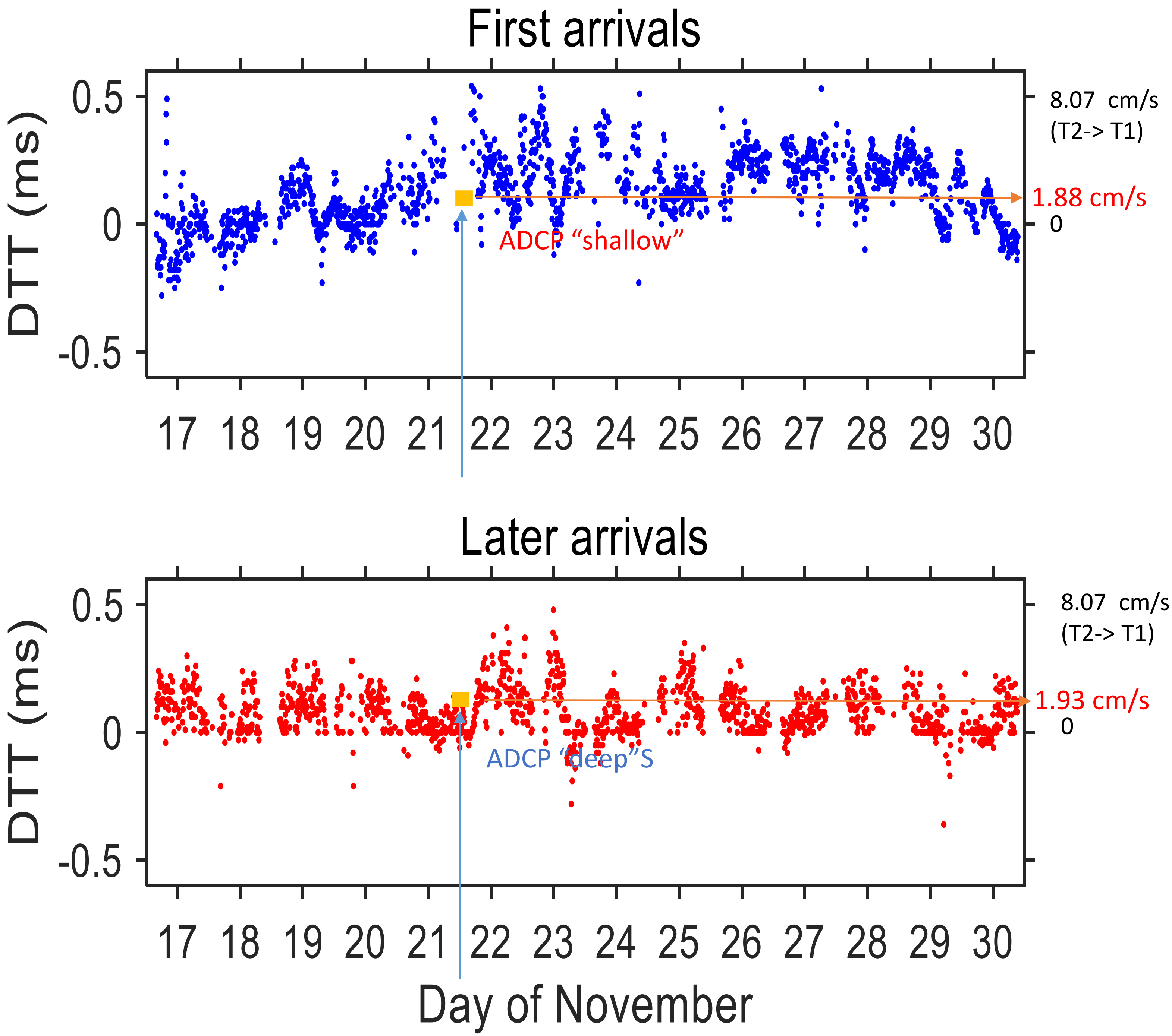
← “deep layer”

vs. CAT/DTT

differential travel time (DTT) determined *by computing cross-correlation of correlograms*



T1 <-> T2



Only compute cross-correlation when the SNR>17 dB

Summary : With implementation of 6x repeat of M11, and further hardware upgrade, fairly consistent two-way transmission has been achieved across the N Basin (R=10.2 km) under stratified conditions. Between T1 and T2 (R=6.6 km) , first arrival times slowed correspondingly with the change in near-surface temperature, with suggest they passed through a surface duct. Later arrival times did not trend slower, and were consistent with temperature in the deep water.

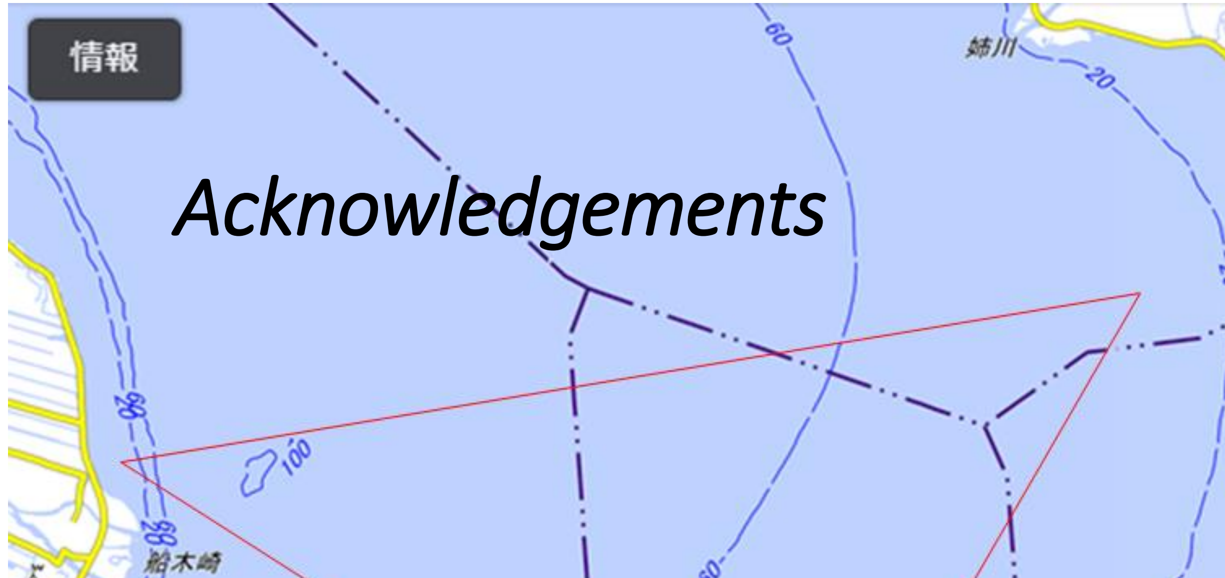
Small but consistent differences in travel times between reciprocal paths were observed, whence we estimate path-averaged currents along the dominant acoustic paths on the order of 2~5 cm/s, which is not inconsistent with simulated magnitudes at this site, and with a 80’ ADCP measurement at T2. To our knowledge this is the first reported estimate of currents by Acoustic Tomography in a lake.

Next: How did sound get from the “surface duct” down to T2 at BD = 68 m? ➔ Comparison w/ hydro model + ray-tracing simulations that account for refraction by du/dz, and perhaps surface scattering

"**Plan** for a followup three-month test scheduled to start late July 2019 . I solicit suggestions for designing this and future tests to best contribute to understanding of Continental-Coastal Ocean interactions.

L Biwa is a well-documented, well instrumented/sampled tide-free "test bed" for comparative research!

Topographic effects,
Orographic effects,
Lovely internal waves/seiches,
"World's most beautiful" lacustrine gyre…



Acknowledgements

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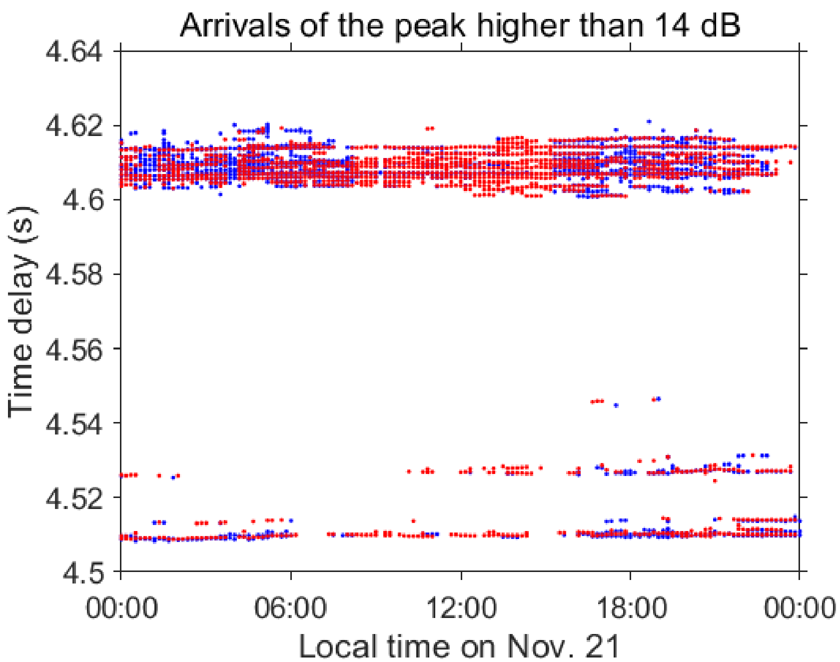
・Dr. Y. Aota, Dr. G. Auger, Prof. A. Kaneko, Prof. N. Goda

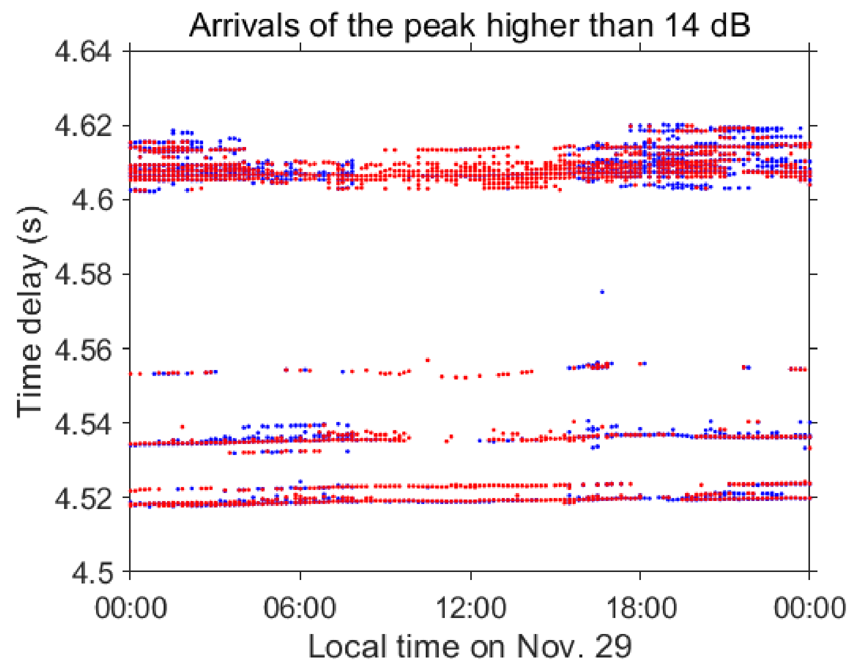
・MEXT "Shidai Senryaku" Fund,

・Ritsumeikan Univ.'s   R-GIRO fund

・Messrs ONISHI, UEDA, OHARA, INOUE, KAWABATA, former Ritsumeikan undergrad

On Nov. 21 and 29:

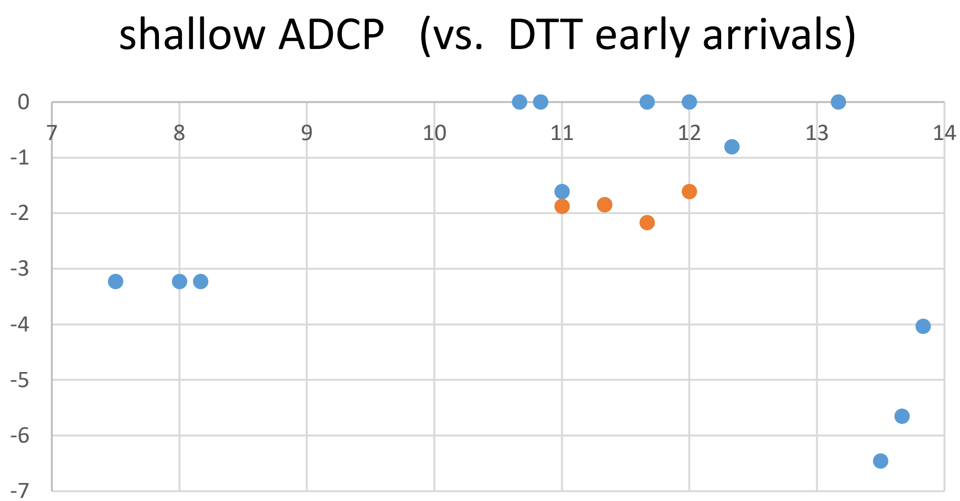


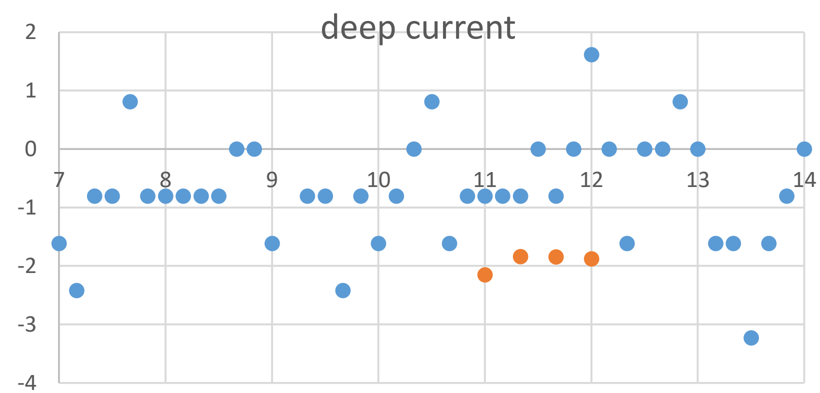


Component T1 -> T2

ADCP vs. CAT/DTT (*"ZOOM", sign reversed…)*

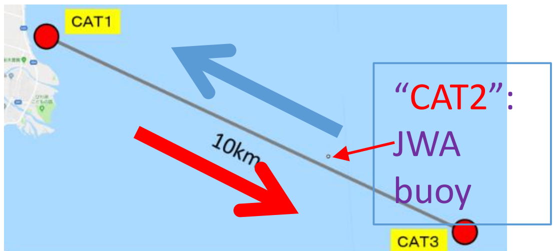
cm/s



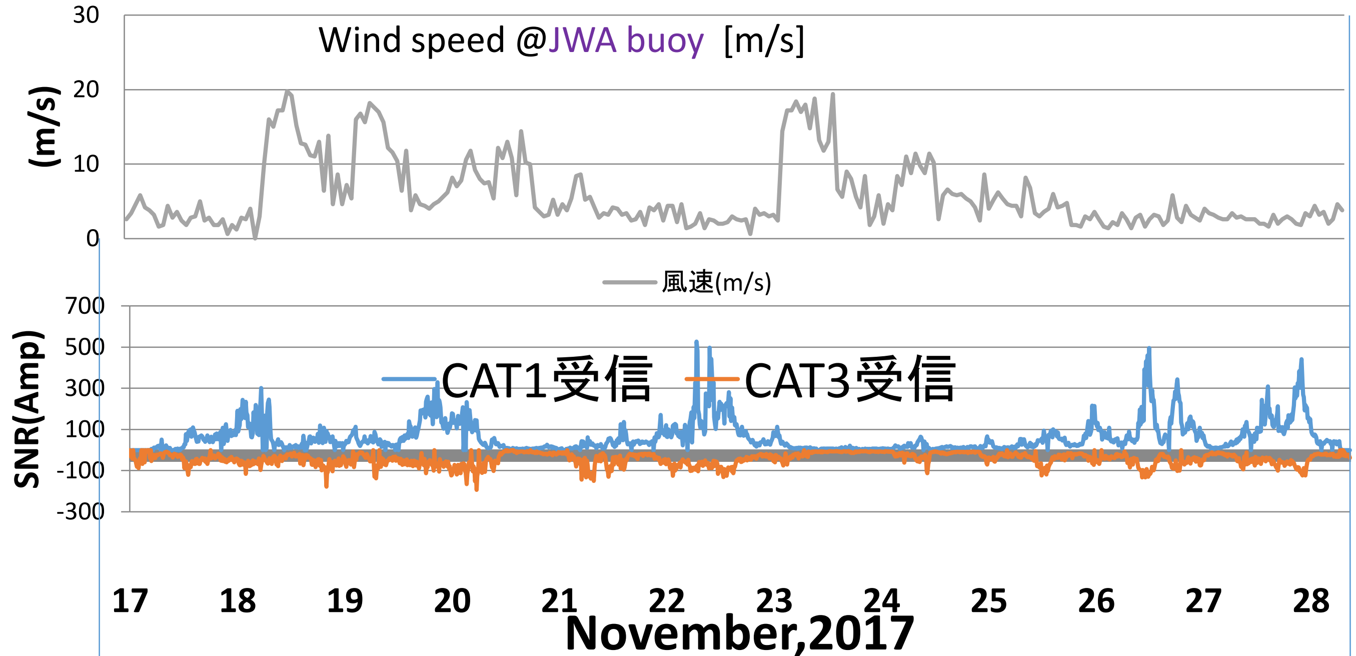


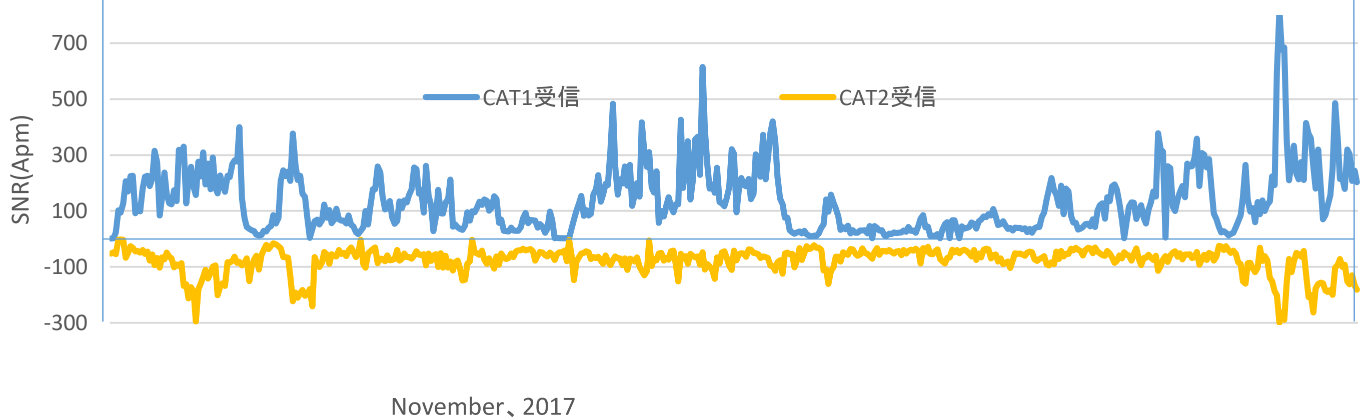
Only compute cross-correlation when the SNR>17 dB

evolution of **peak normalized correlation**



At R = 10.2 km, reception strength varies widely! Some intervals have rather low signal. This may explain inconsistent behavior at R = 14.2 km in Nov 2016





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