Monitoring of the Soya Warm Current by HF Ocean Radars since 2003

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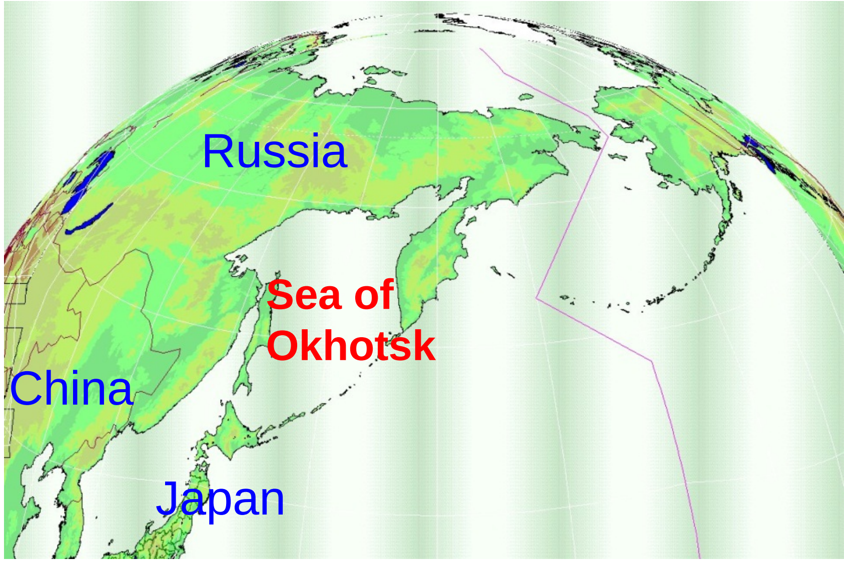
Outline

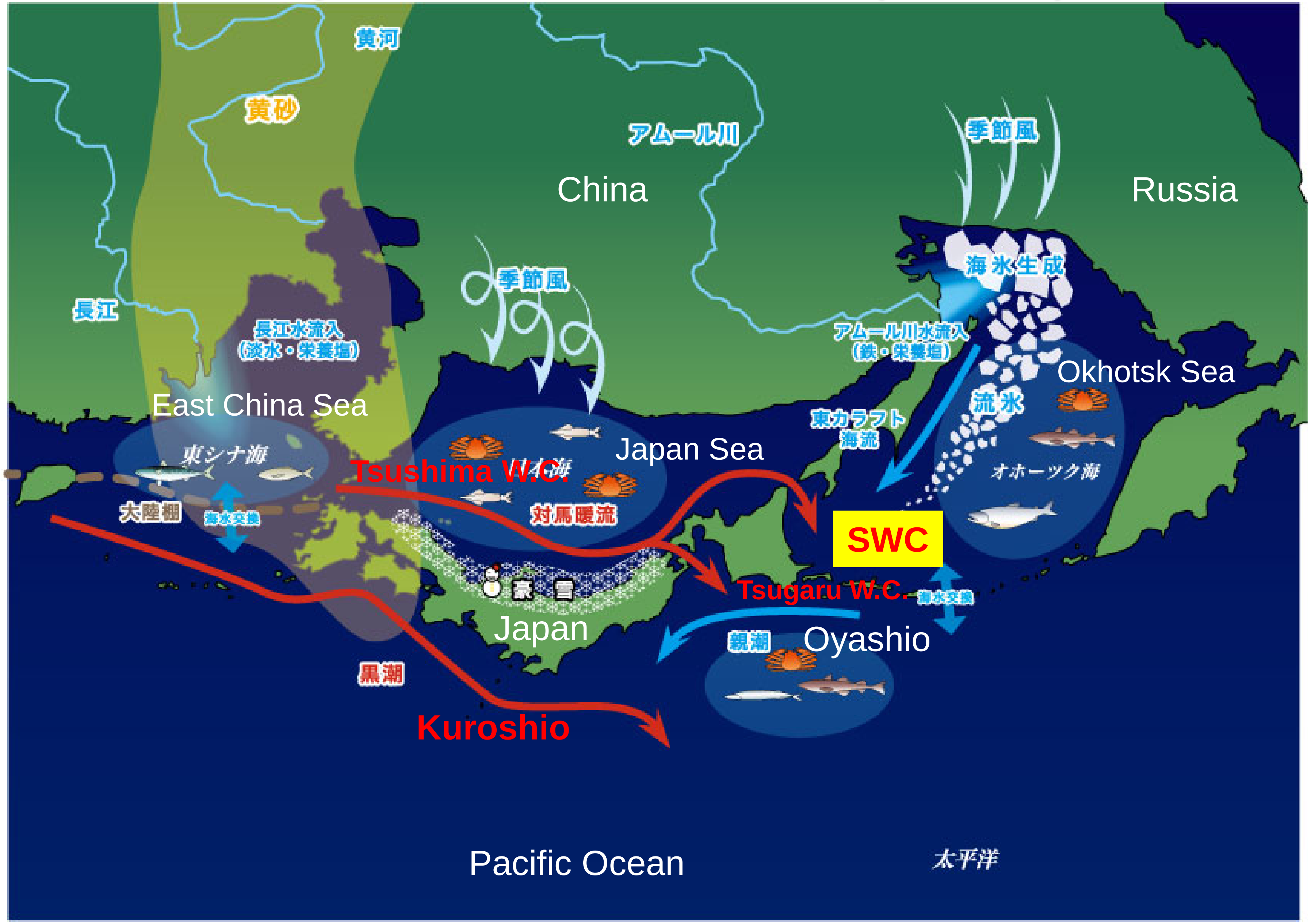
1. Sea of Okhotsk, Soya Strait and Soya Warm Current
2. ILTS/HU HF ocean radar system
3. Seasonal variations in surface velocity of the SWC
4. Vertical structure of the SWC and estimation of the volume transport
5. Correlations with sea level difference along the strait
6. Summary

Sea of Okhotsk

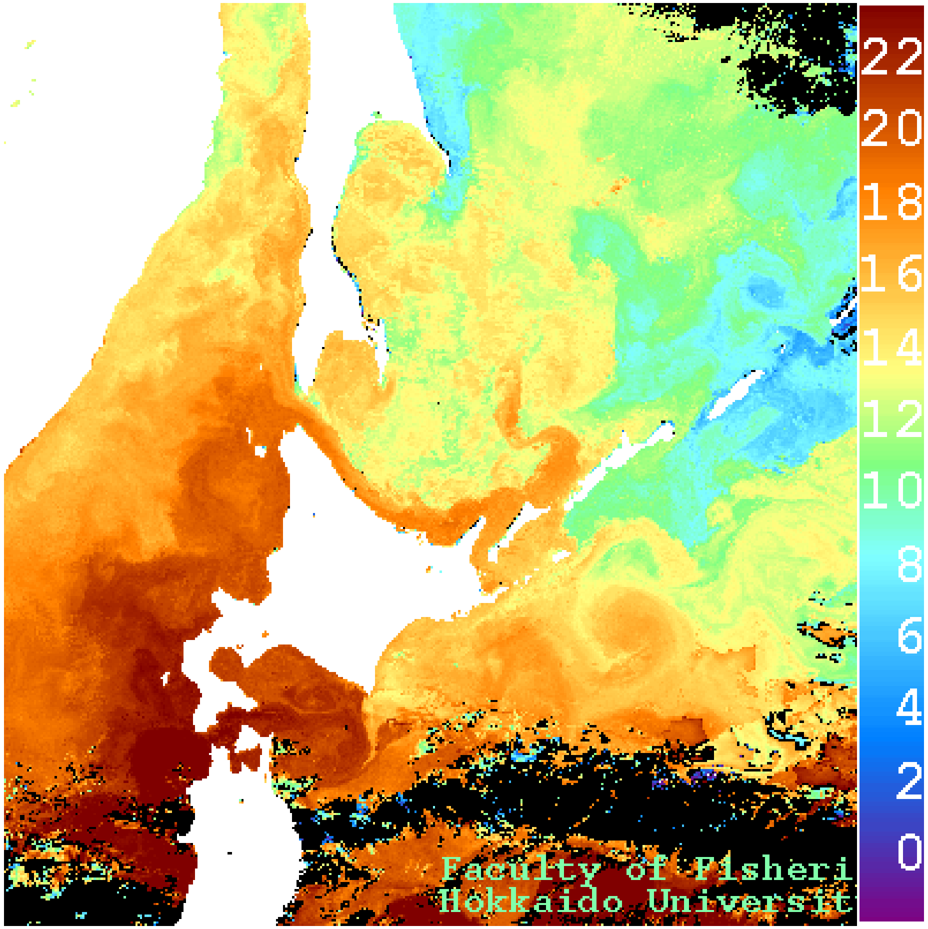


- Source of the North Pacific Intermediate Water (NPIW)
  - Talley (1991), Yasuda (1997)
- Southernmost seasonal sea ice zones in the Northern Hemisphere
- Transport from the Sea of Japan by the SWC
- Active primary productivity and fishery
- Risks of oil spill from Sakhalin oil field

Soya Warm Current (SWC)



Soya Warm Current (SWC)



NOAA/AVHRR SST image
28 Sep 1998

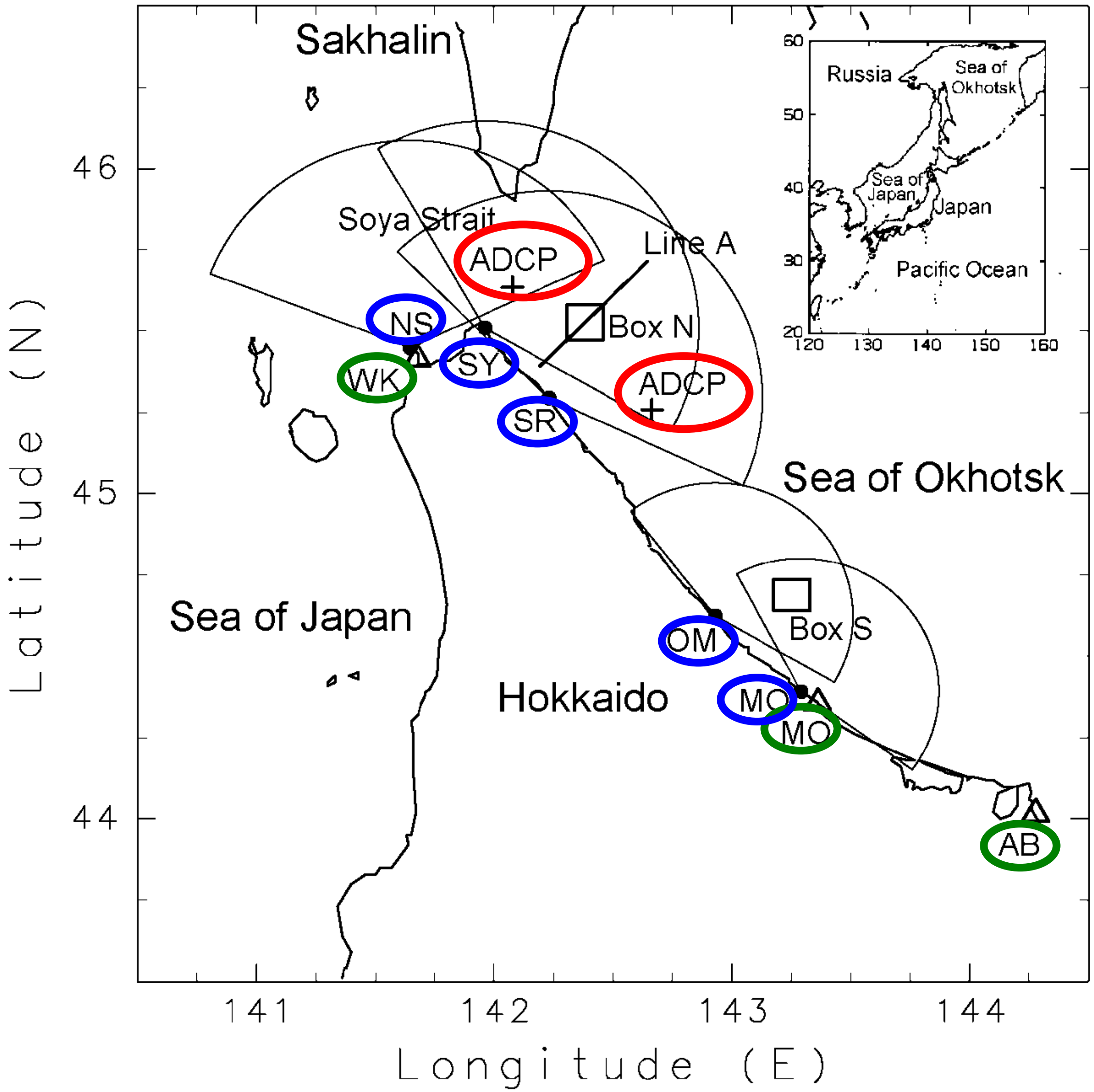
Difficulties in Observations of SWC

- Political issues in the boarder strait
- Severe weather in winter
- Sea ice
- High fishing activity => difficult to install moorings
- Barotropic structure of the SWC

  => need of direct current observations
- Strong diurnal tidal current

  => need of repeat observations

Monitoring System



- HF radars
- Tide gauges
- ADCP
  (Bottom mounted)
- Satellite Altimetry

HF Ocean Radar Stations

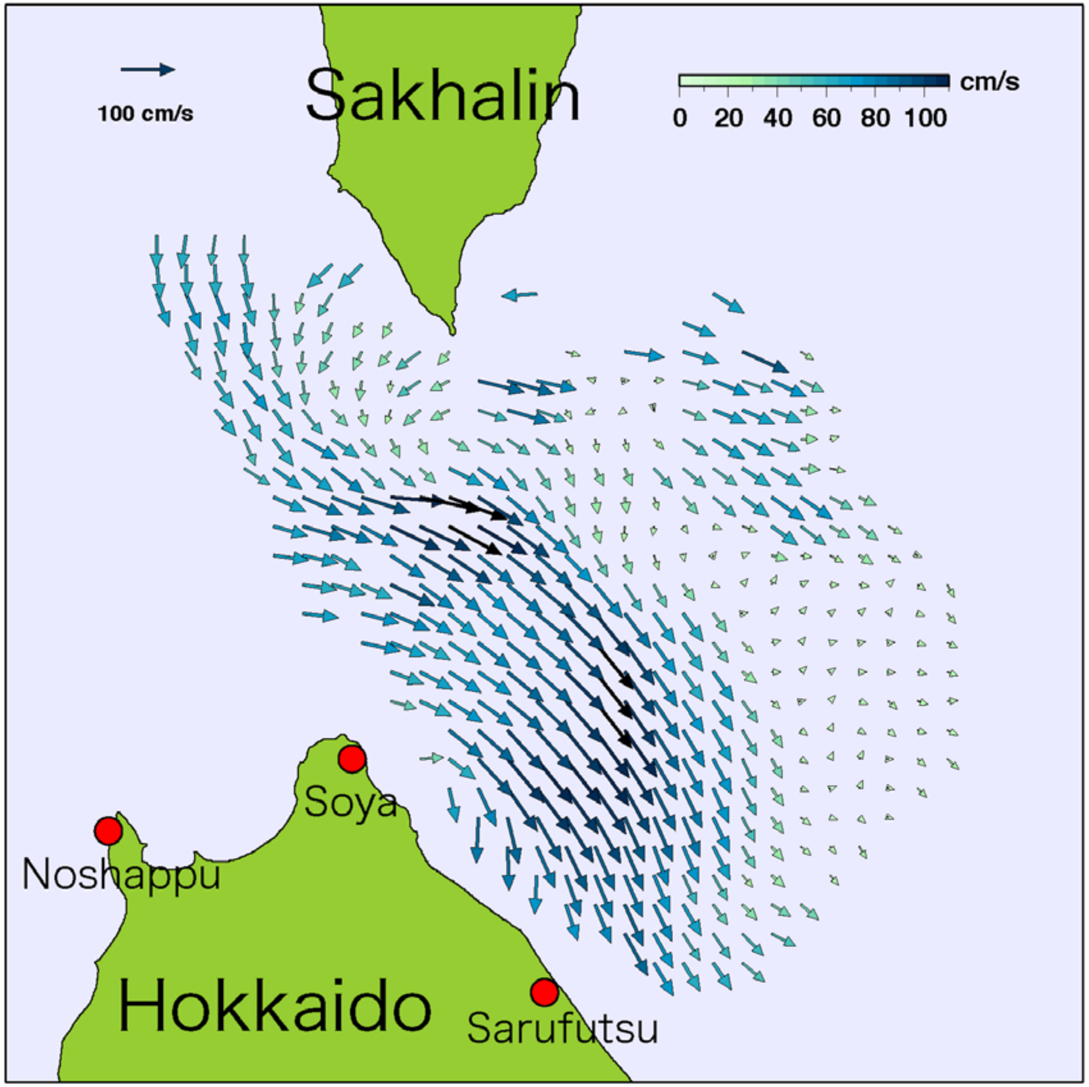
- CODAR SeaSonde/FMICW
- Center frequency: 13.946 MHz
- Detection range: 70 km
- Range resolution: 3.0 km
- Azimuth resolution: 5 deg.

Tx

Rx

Instruments

Example of Observed Snapshot

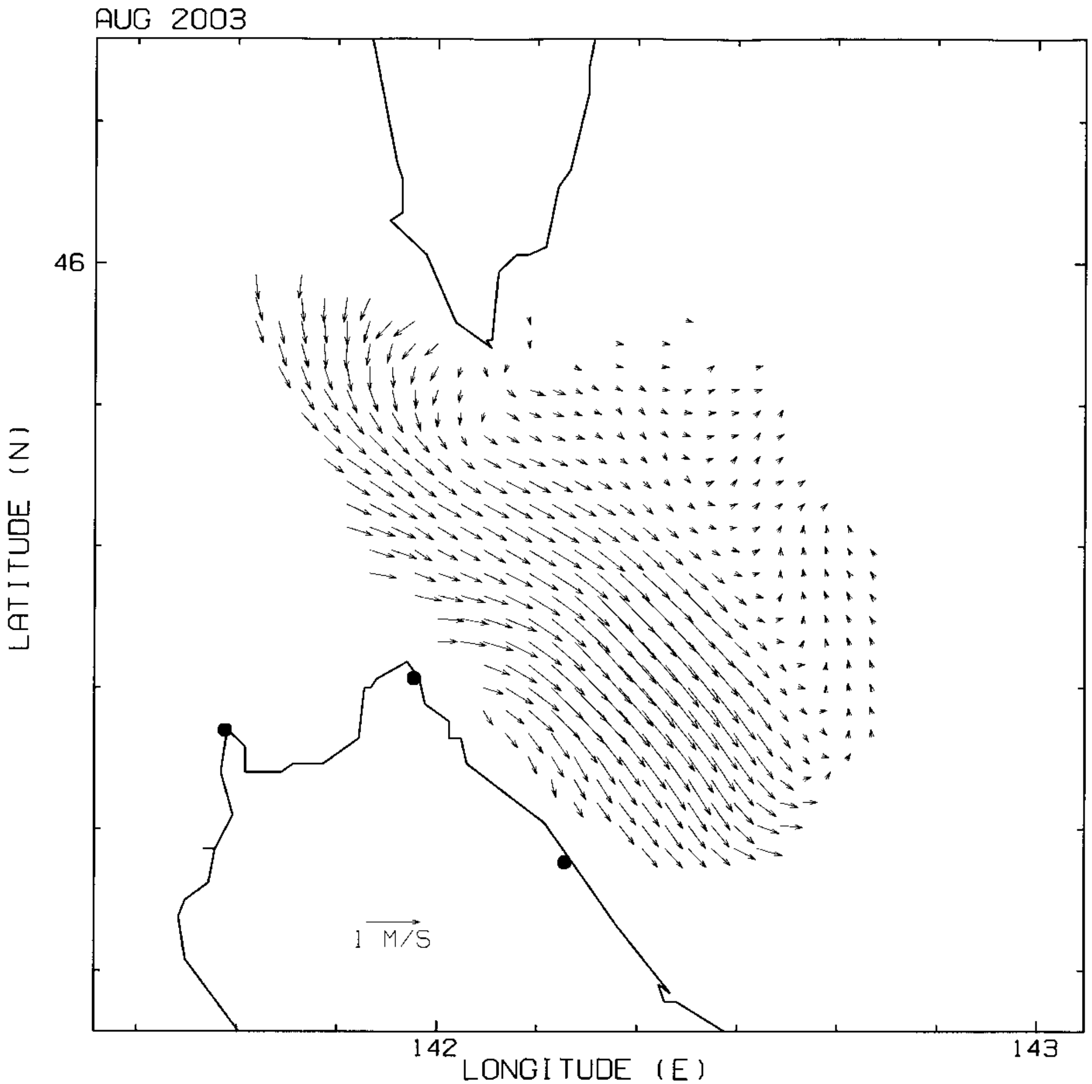


17h20m (JST)
3 Aug 2003

Real-time current maps are available from our web site.
http://wwwoc.lowtem.hokudai.ac.jp/hf-radar/index.html

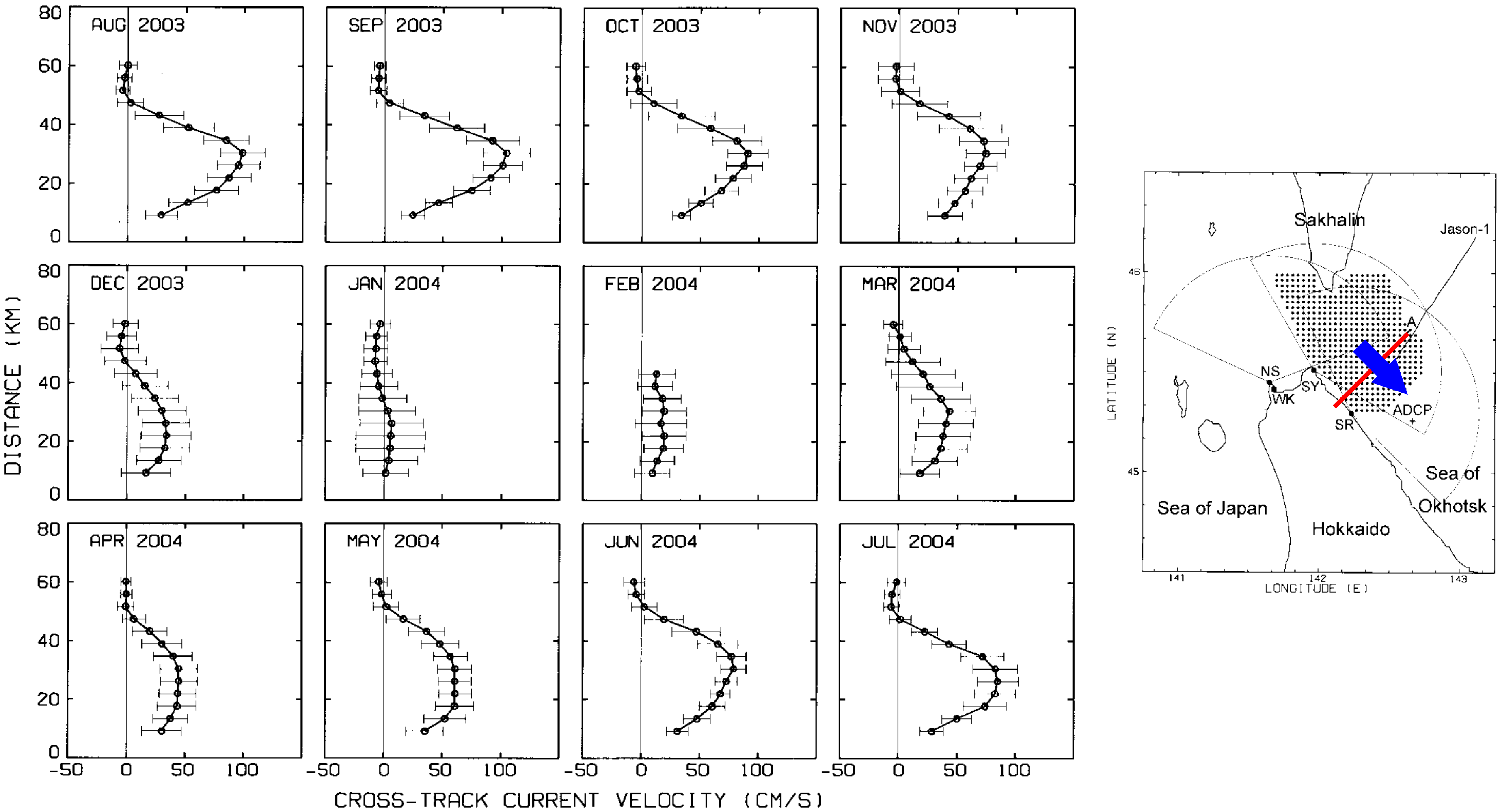
Monthly Averaged Current Field

August 2003



Hourly obs.
|
25-hr running average
|
Daily mean
|
Correction for wind drift
(Zhang et al., 2016)
|
Monthly mean

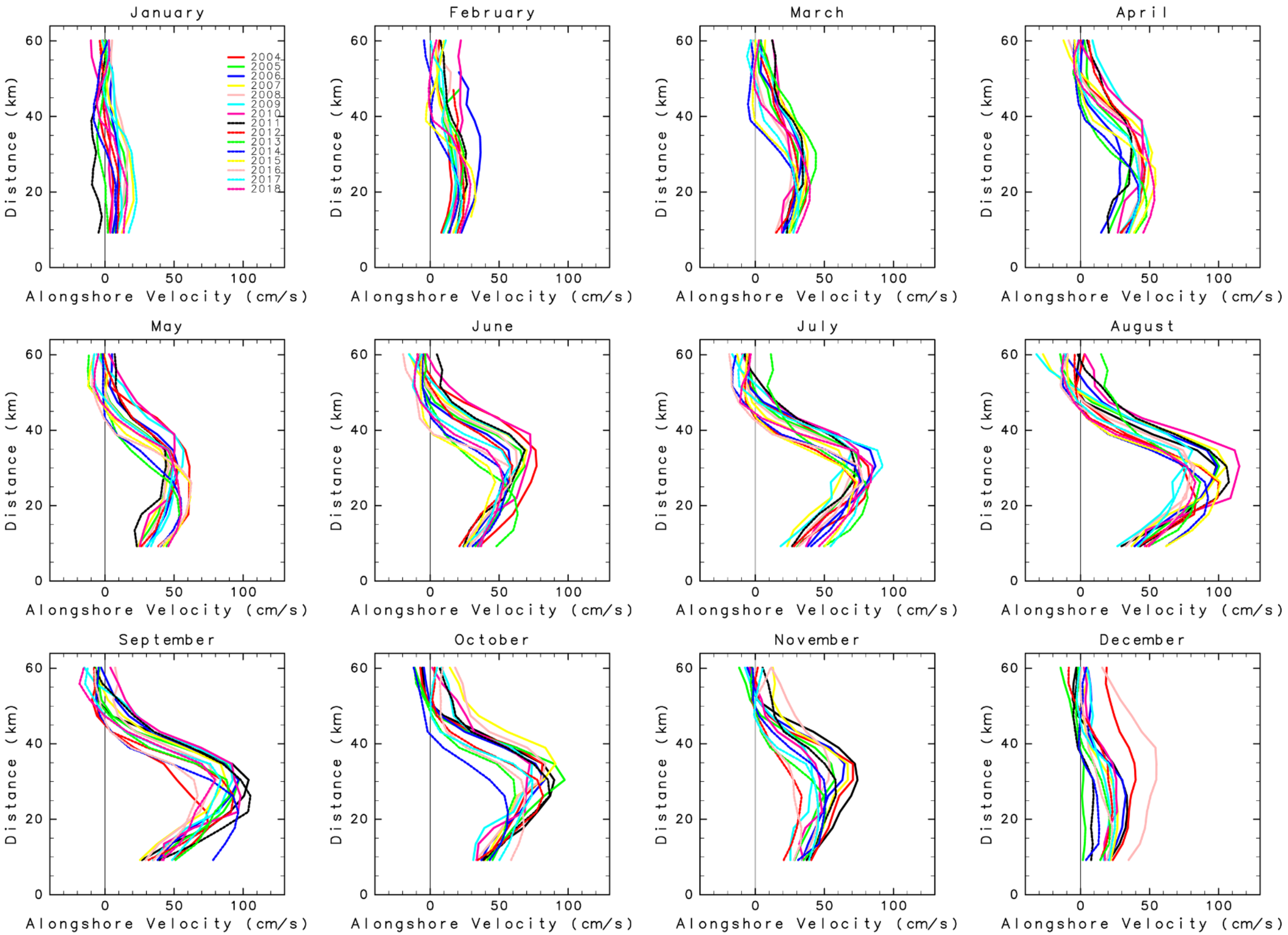
Seasonal Variation of Velocity Profiles



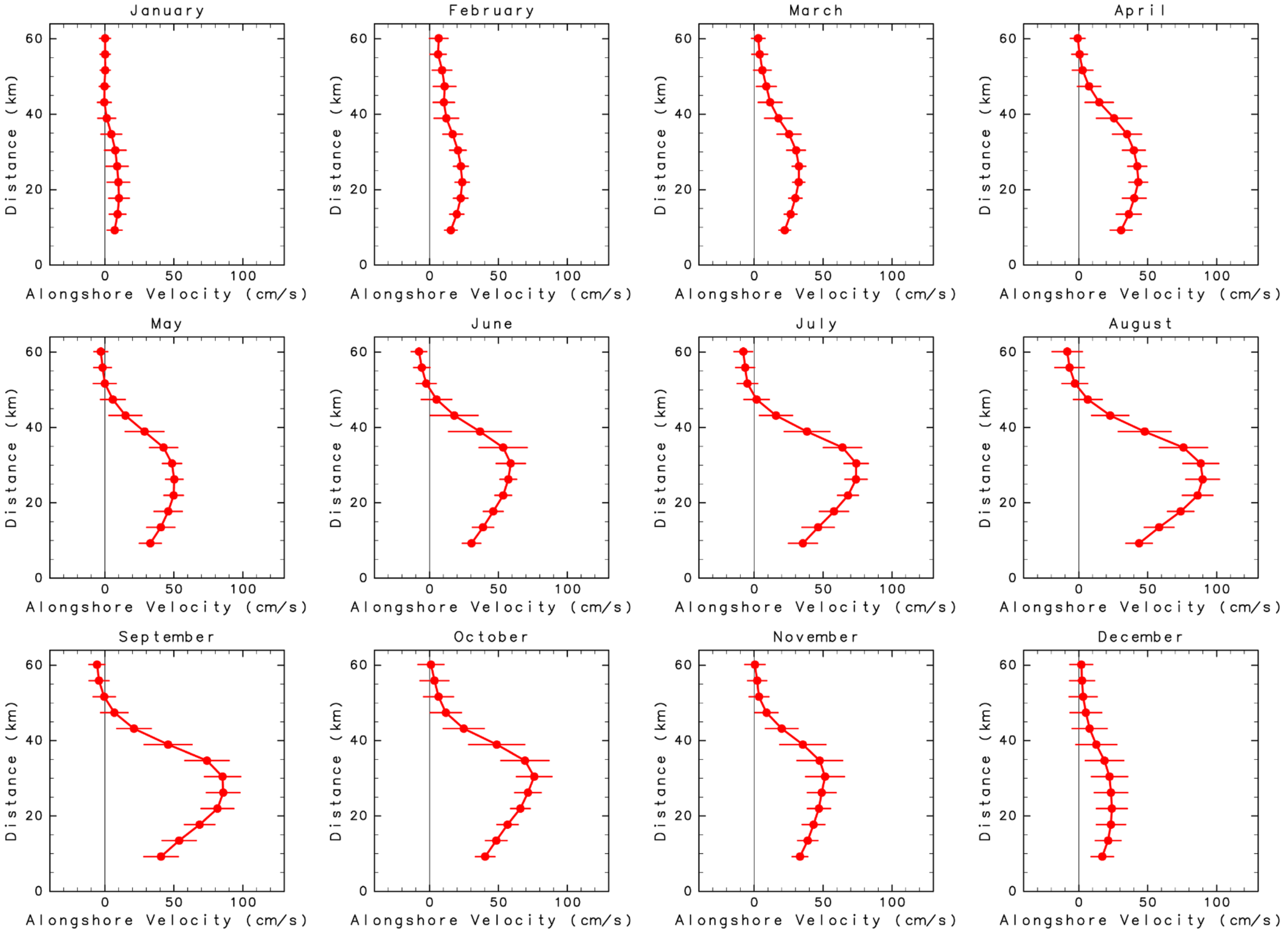
Alongshore (south-east) current component

(Ebuchi et al., 2006)

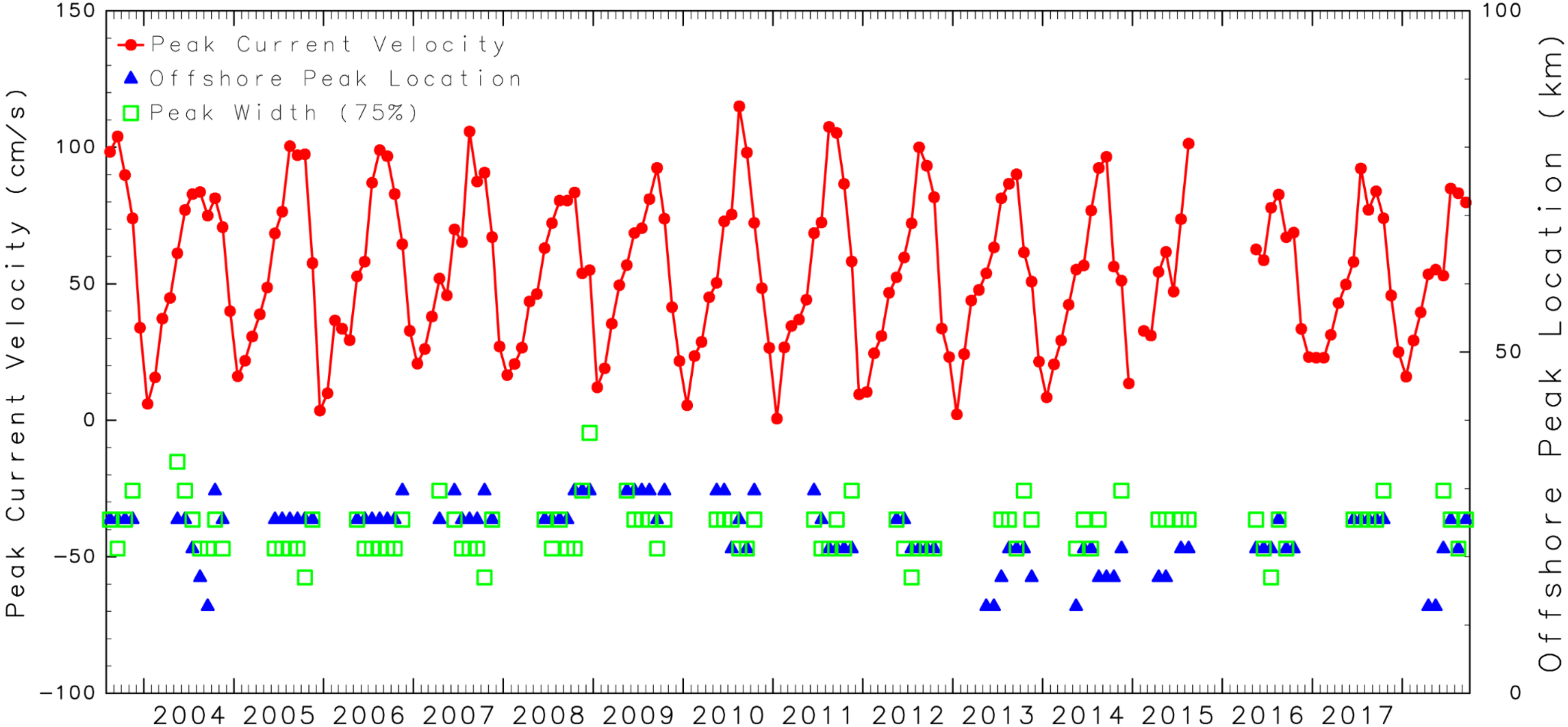
Interannual Variation of Monthly-mean Velocity Profiles



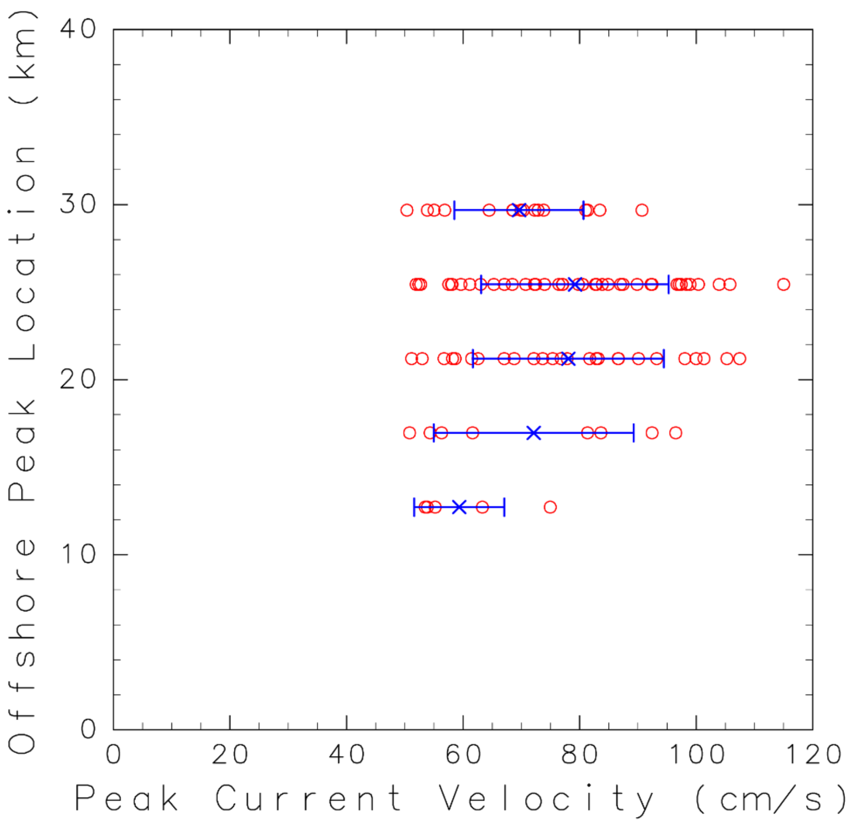
16-year Averages of Monthly-mean Velocity Profiles

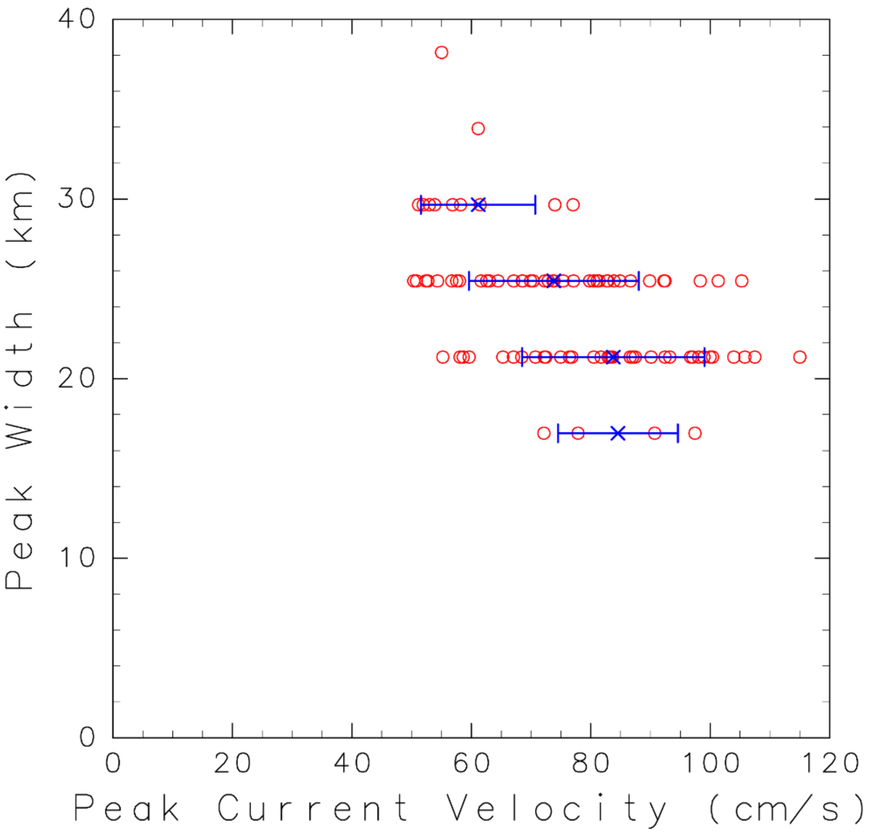


Peak Current Velocity, Peak Location and Peak Width (1)

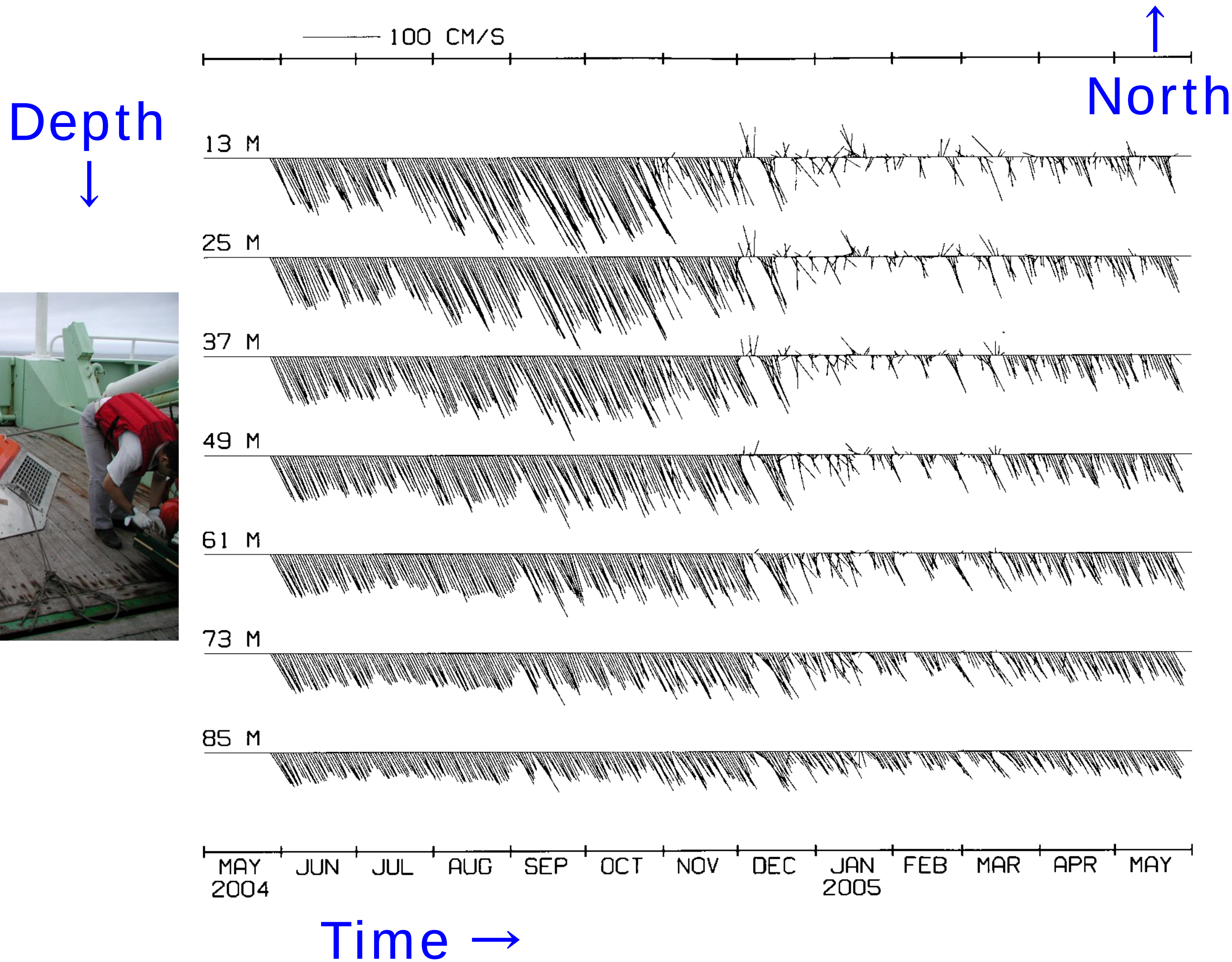


Peak Current Velocity, Peak Location and Peak Width (2)

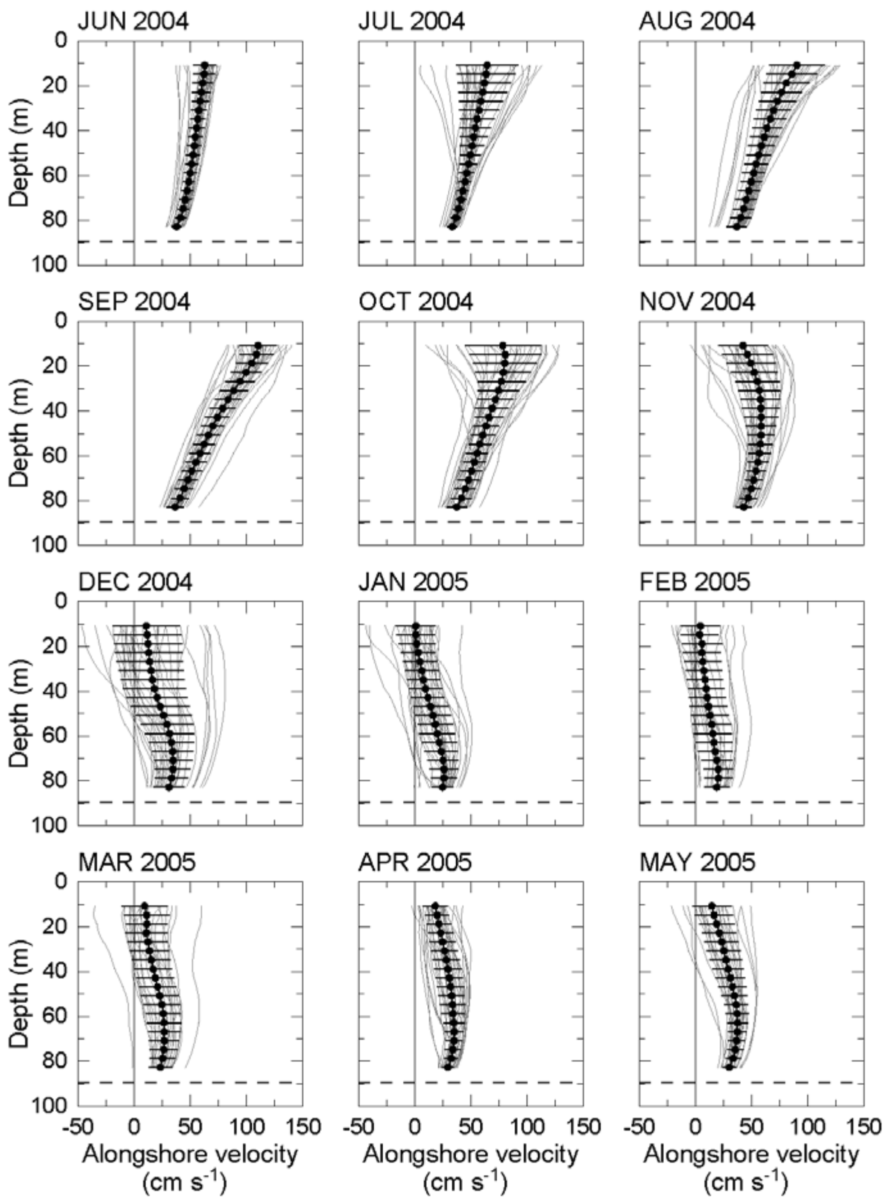




Vertical structure of the SWC observed by TRBM-ADCP



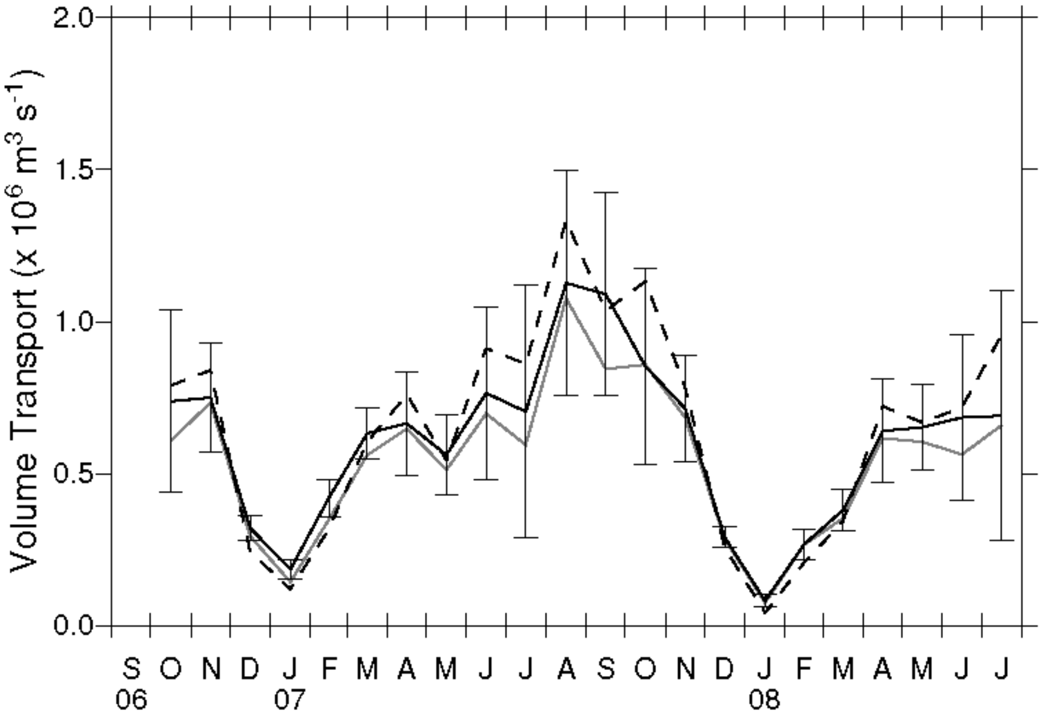
Monthly-Mean Vertical Profiles



(Fukamachi et al., 2005)

Estimation of Volume Transport of SWC

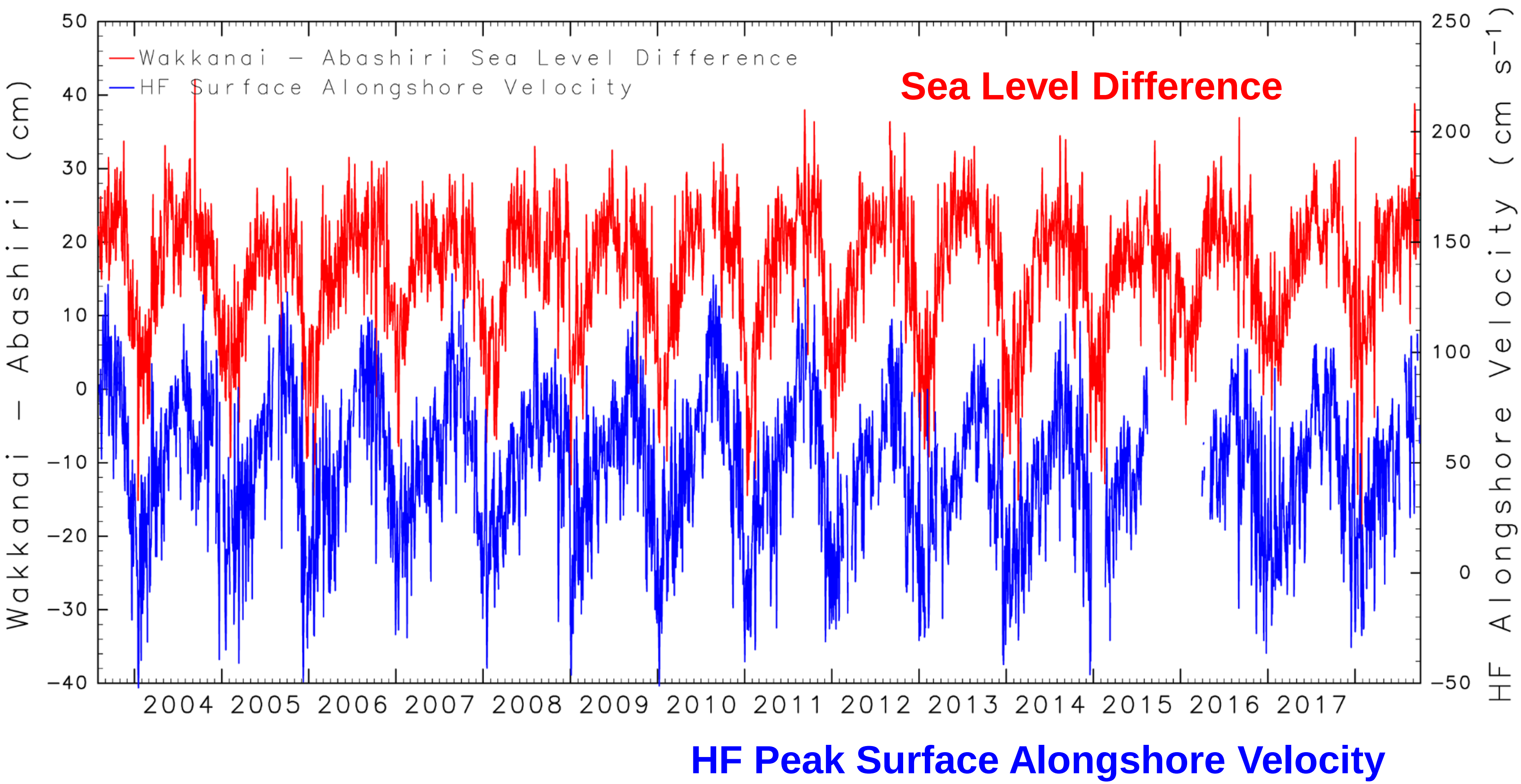
Volume Transport of the SWC is estimated by combination of the surface current fields from the HF Ocean Radars with vertical current profiles from the ADCP.



- Wind drift in the HF radar velocity was removed.
- Yearly-average = 0.65 ± 0.20 Sv
- Maximum of 1.08 Sv in Aug. 2007
- Minimum of 0.08 Sv in Jan 2008

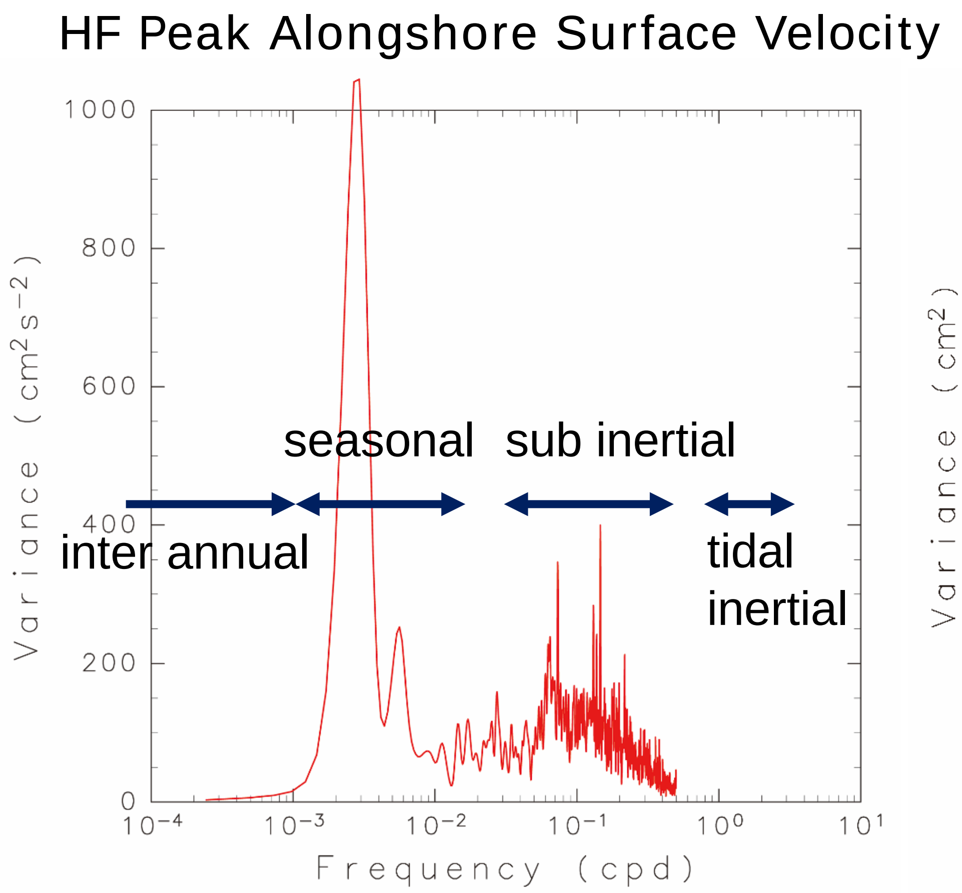
(Fukamachi et al., 2010)

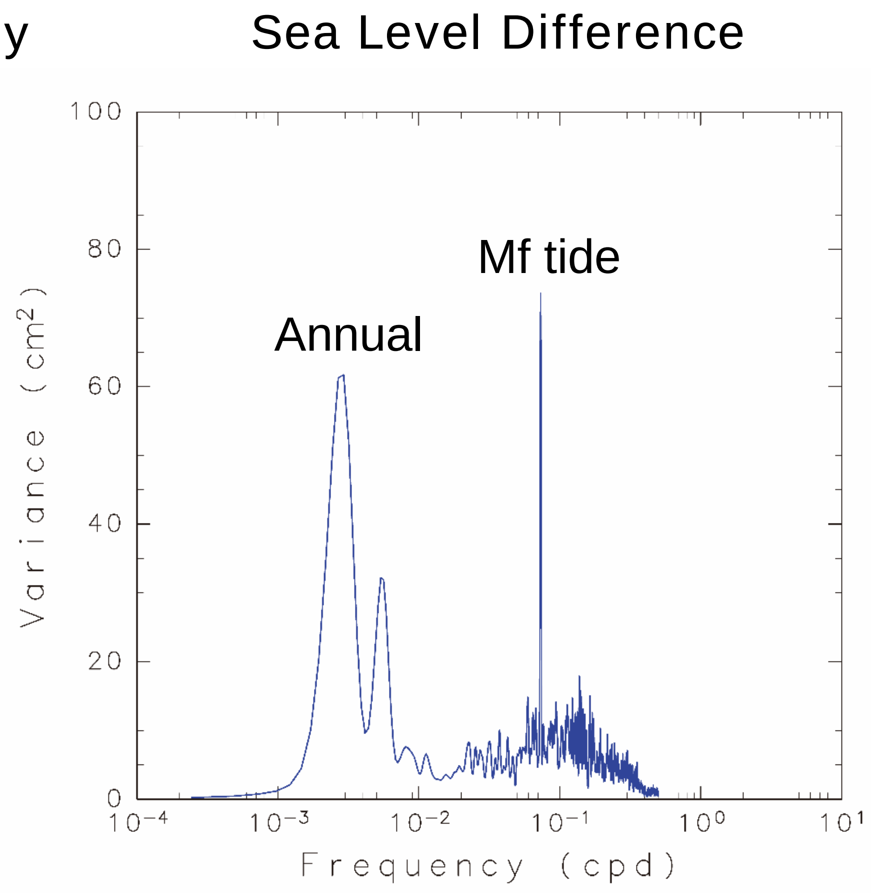
Variations of Along-shore Current Velocity and Sea Level Difference along the Strait



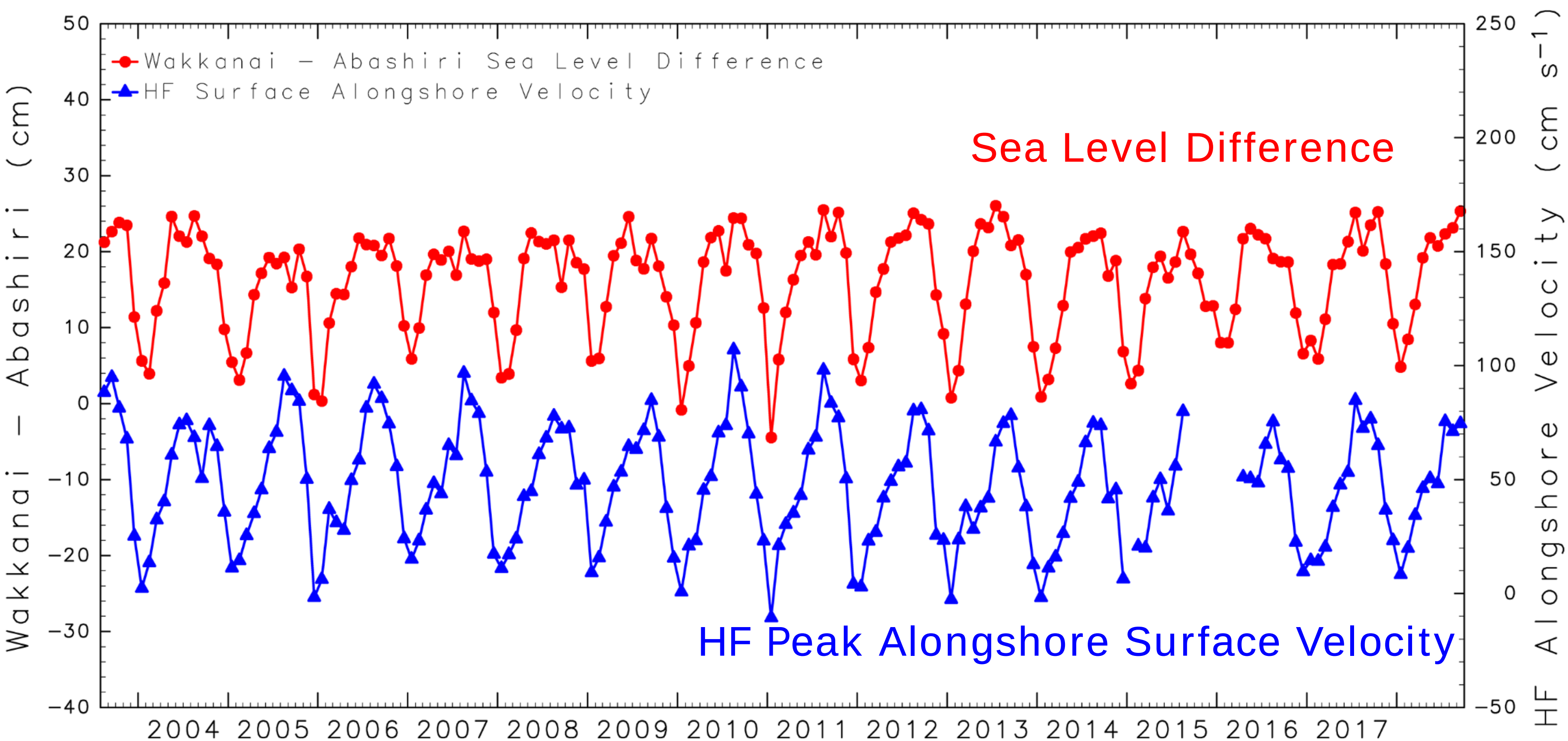
Correlation coefficient = 0.770

Power Spectra of Sea Level Difference and Peak Alongshore Velocity



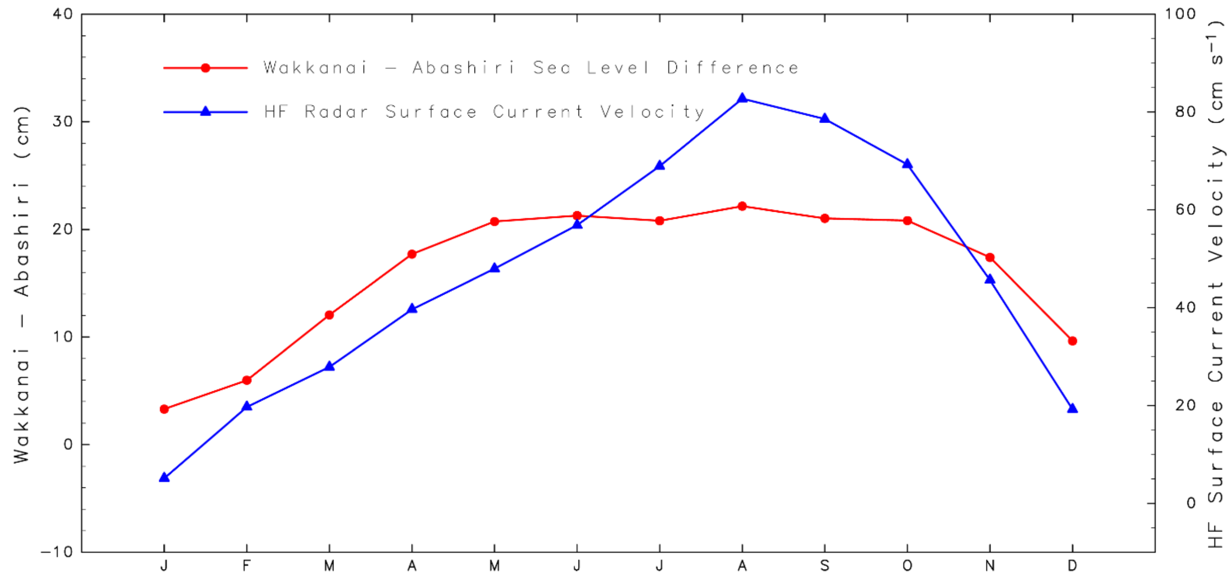


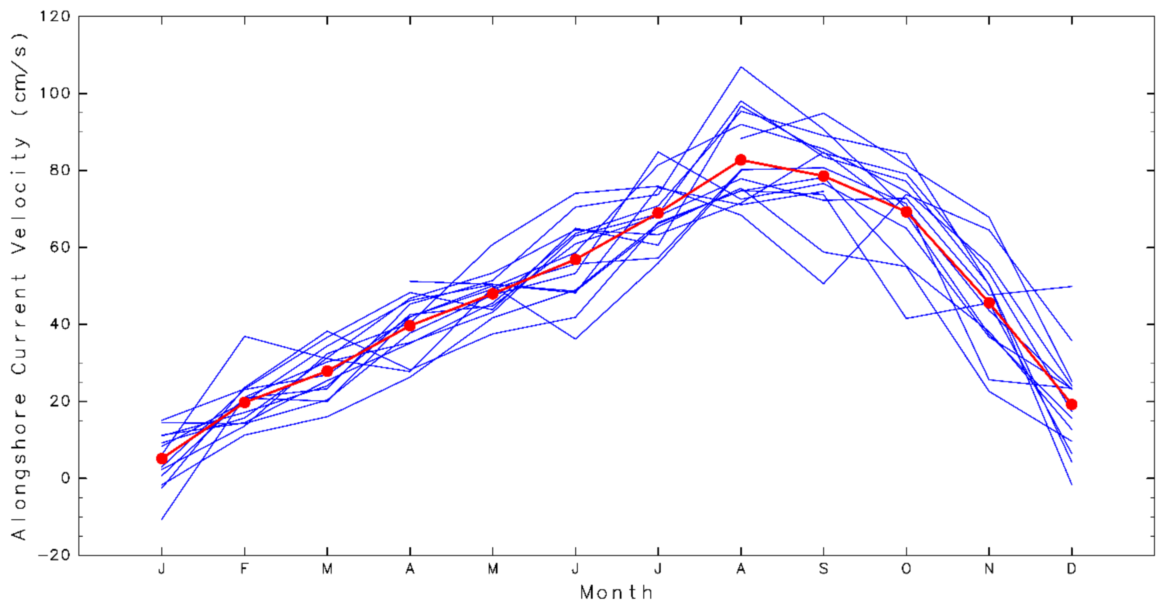
Monthly-mean Alongshore Velocity and Sea Level Difference along the Strait



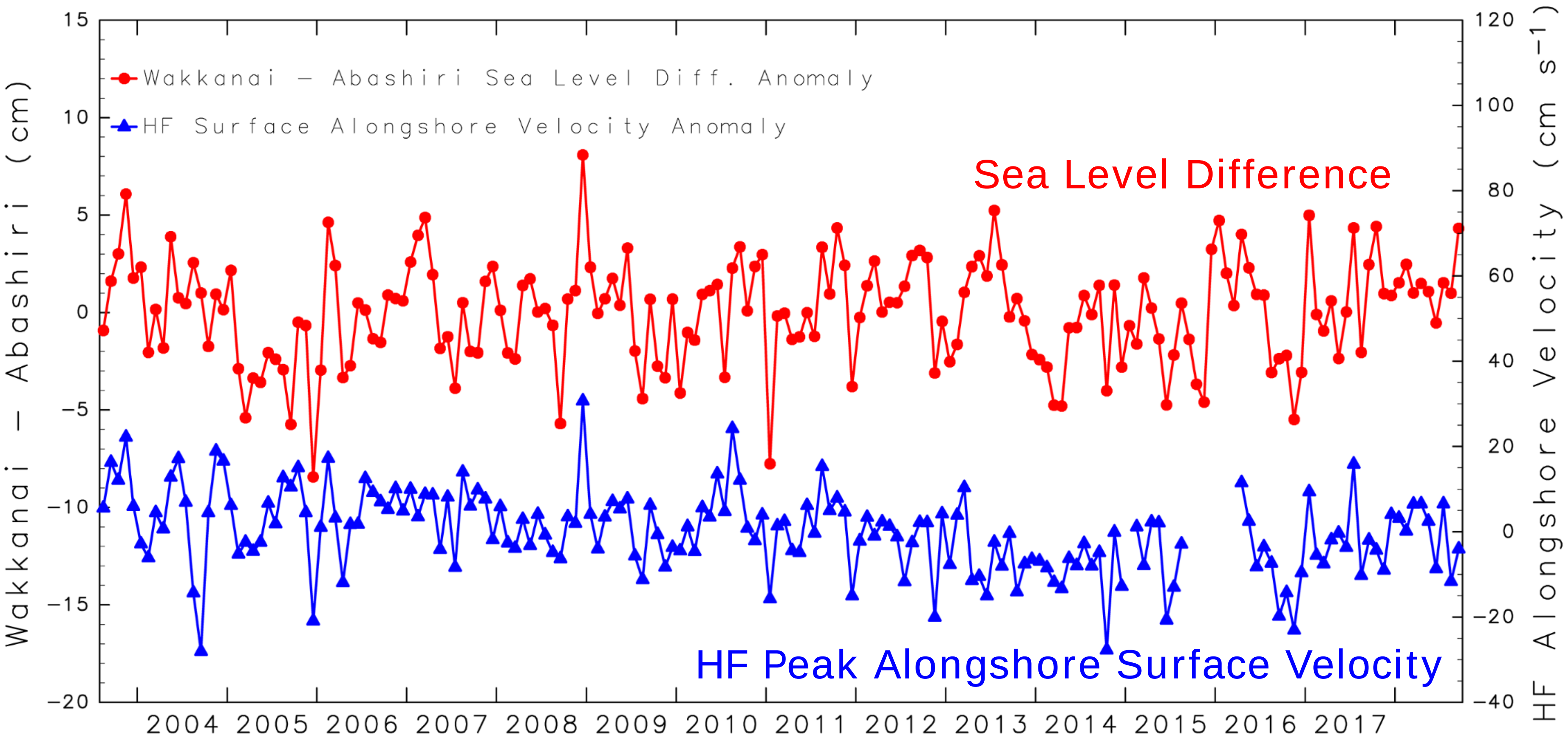
Correlation coefficient = 0.857

Seasonal Variation in the Surface Velocity and Sea Level Difference





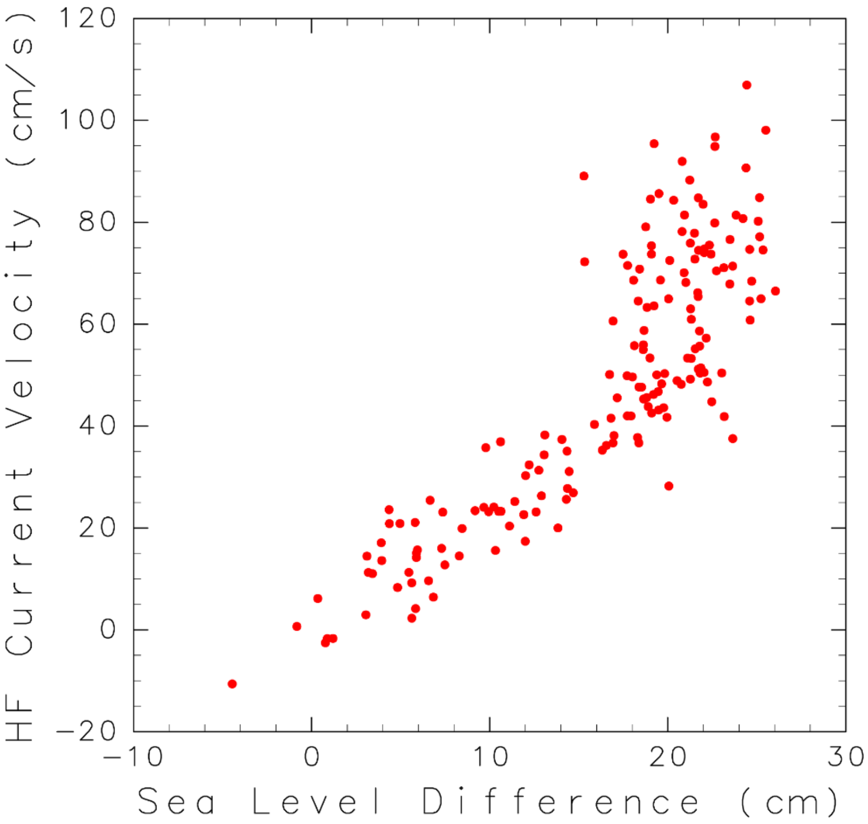
Anomalies of Monthly-mean Alongshore Velocity and Sea Level Difference



Correlation coefficient = 0.519

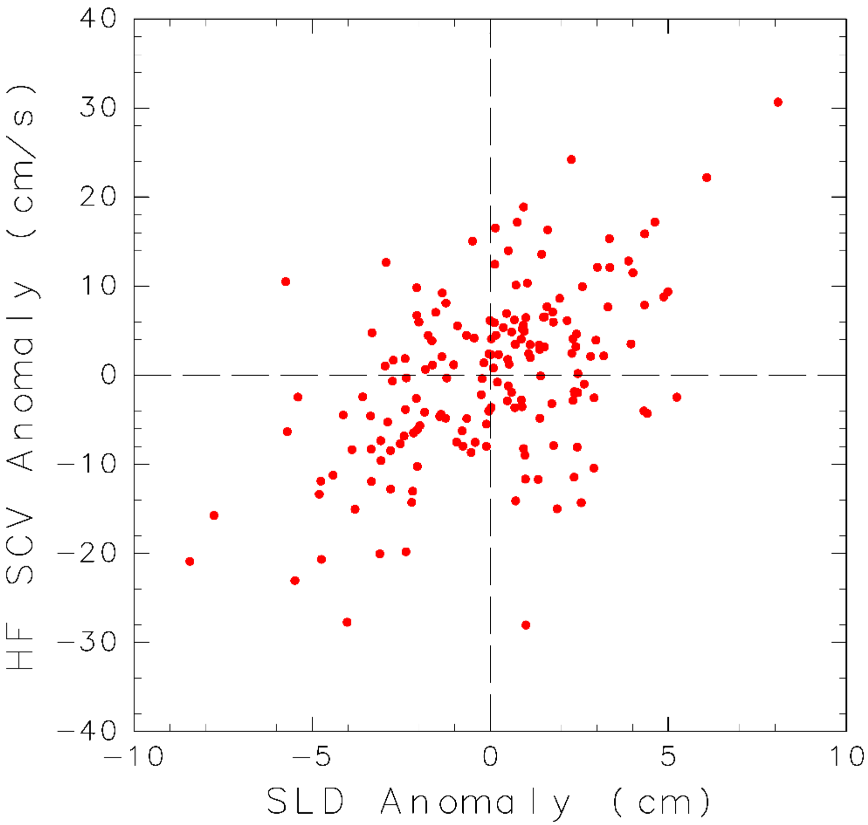
Correlation of Sea Level Difference and Alongshore Velocity

Including Seasonal Variations



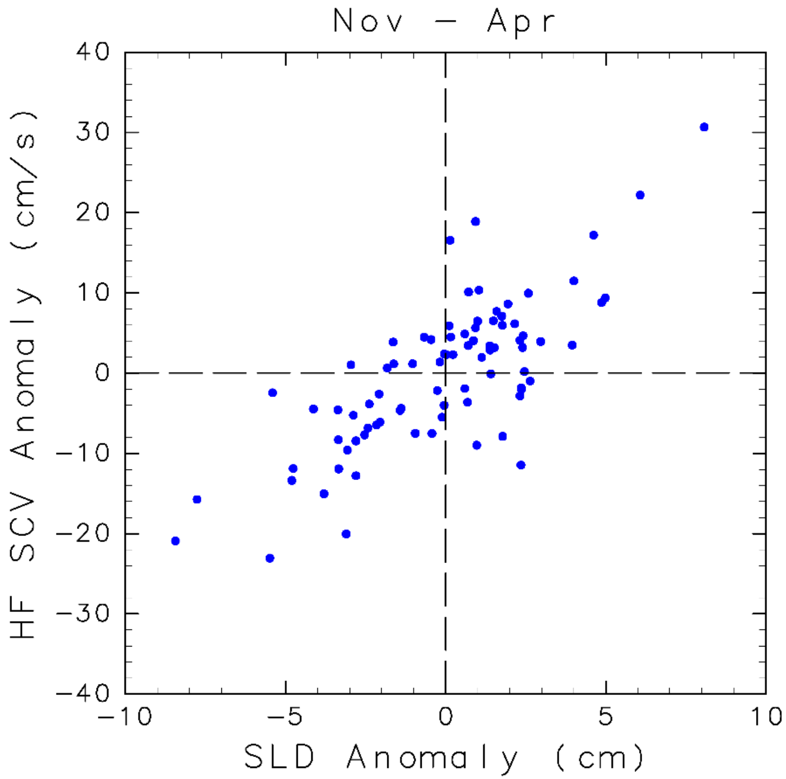
Correlation coefficient = 0.857

Anomaly

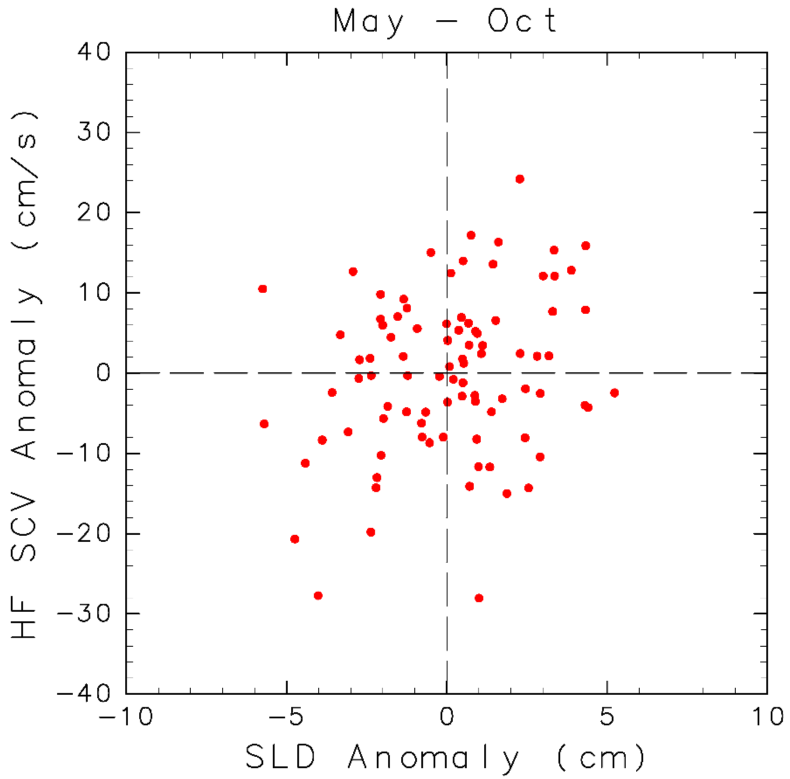


Correlation coefficient = 0.517

Correlation of Sea Level Difference and Alongshore Velocity Anomalies



Correlation coefficient = 0.763



Correlation coefficient = 0.264

Summary

- Continuous monitoring of the surface current fields in the Soya Strait was started since August 2003. The HF radars clearly capture spatial and temporal variations in the Soya Warm Current (SWC).
- The volume transport of the SWC is estimated by combining data from the HF radars and ADCP.
- The alongshore surface velocities of the SWC shows high correlation with the sea level difference between the Seas of Japan and Okhotsk, if the seasonal variation is included.
- However, anomalies of the SLD and SWC alongshore velocities exhibit lower correlation, especially in spring and summer.
- The sea level difference is not appropriate for representing interannual variations in the surface current velocity or volume transport of the SWC throughout the year.

Published Articles

Ohshima, K. I., D. Simizu, N. Ebuchi, S. Morishima, and H. Kashiwase, 2017: Volume, heat, and salt transports through the Soya Strait and their seasonal and interannual variations. *J. Phys. Oceanogr.*, **47**(5), 999-1019.

Zhang, W., N. Ebuchi, Y. Fukamachi, and Y. Yoshikawa, 2016: Estimation of wind drift current in the Soya Strait. *J. Oceanogr*., **72**(2), 299-311.

Fukamachi, Y., K.I. Ohshima, N. Ebuchi, T. Bando, K. Ono, and M. Sano, 2010: Volume transport in the Soya Strait during 2006-2008. *J. Oceanogr.*, **66**(5), 685-696.

Ebuchi, N., Y. Fukamachi, K.I. Ohshima, and M. Wakatsuchi, 2009: Subinertial and seasonal and variations in the Soya Warm Current revealed by HF radars, coastal tide gauges, and bottom-mounted ADCP. *J. Oceanogr.*, **65**(1), 31-43.

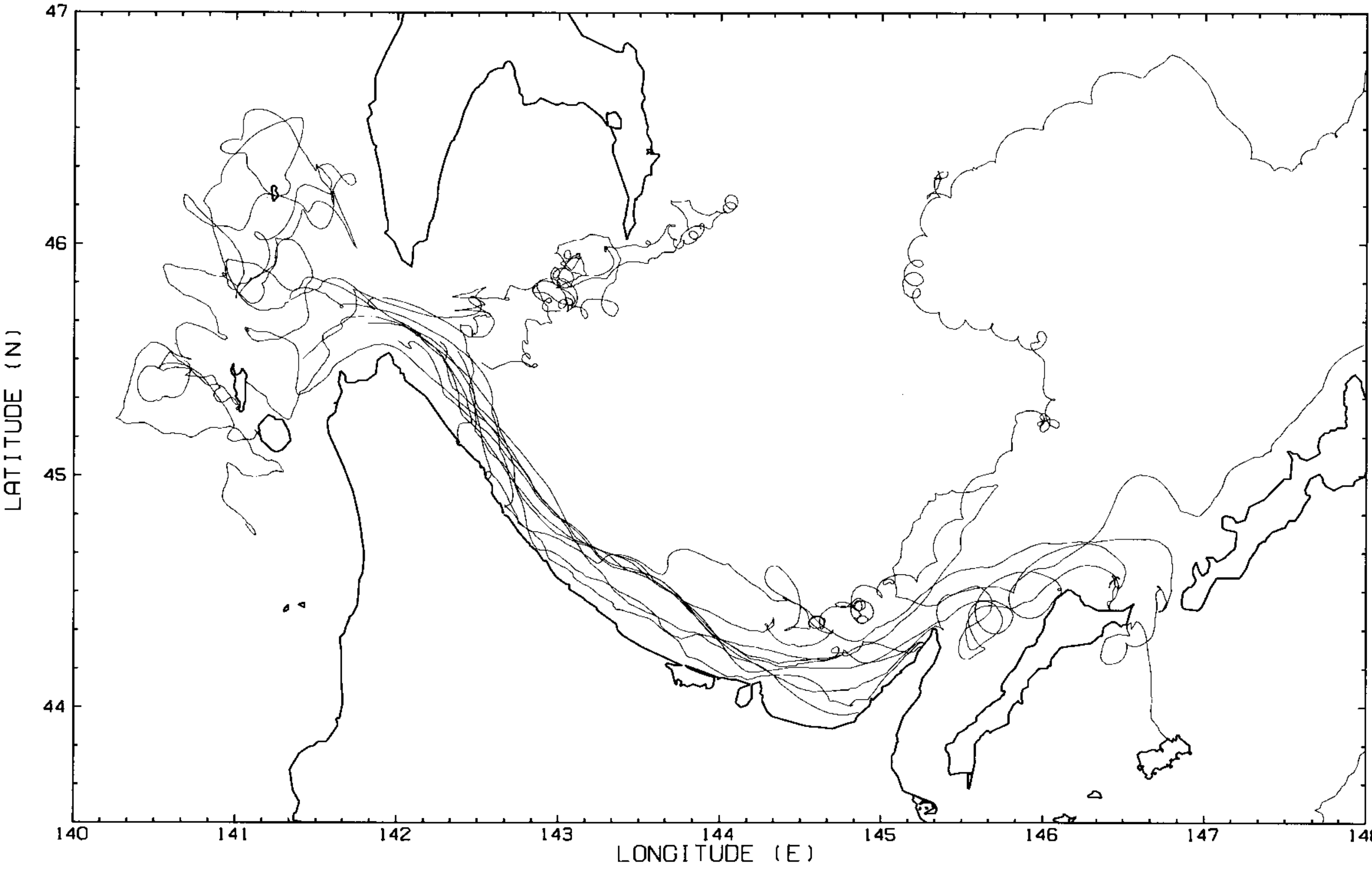
Fukamachi, Y., I. Tanaka, K.I. Ohshima, N. Ebuchi, G. Mizuta, H. Yoshida, S. Takayanagi, and M. Wakatsuchi, 2008: Volume transport of the Soya Warm Current revealed by bottom-mounted ADCP and ocean-radar measurement. *J. Oceanogr.*, **64**(3), 385-392.

Ebuchi, N., Y. Fukamachi, K.I. Ohshima, K. Shirasawa, M. Ishikawa, T. Takatsuka, T. Daibo, and M. Wakatsuchi, 2006: Observation of the Soya Warm Current using HF ocean radar. *J. Oceanogr.*, **62**(1), 47-61.

Drifting Buoys

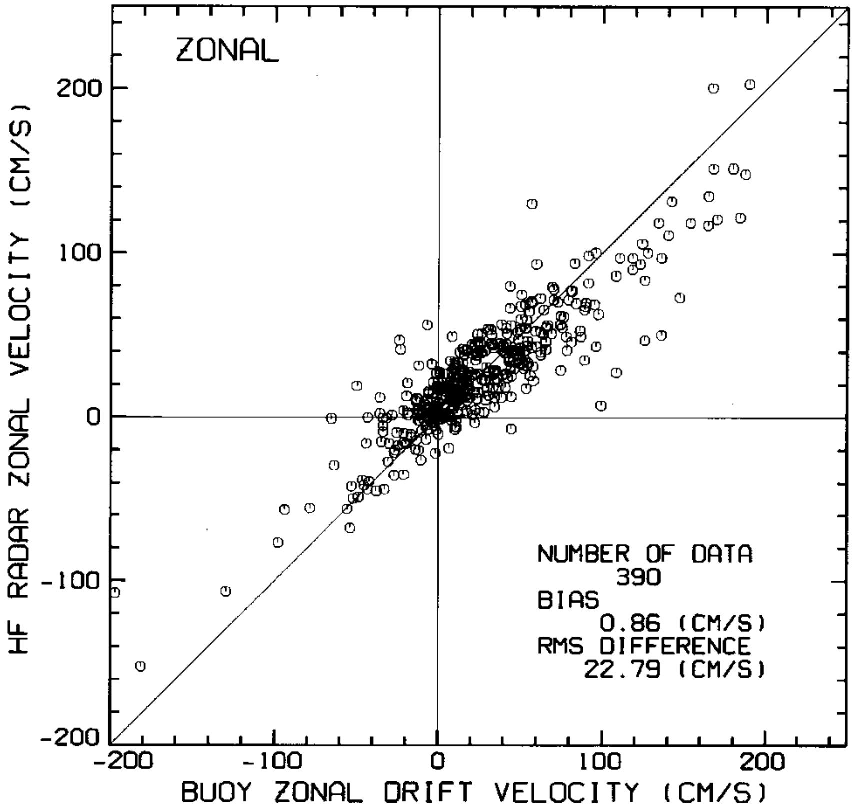
- Dimensions:
  34 cm in diameter
  30 cm in height
  6.5 kg in weight
- Positioning:
  GPS system
  1-hour interval
- Data transfer:
  Orbcomm system
  1-hour interval

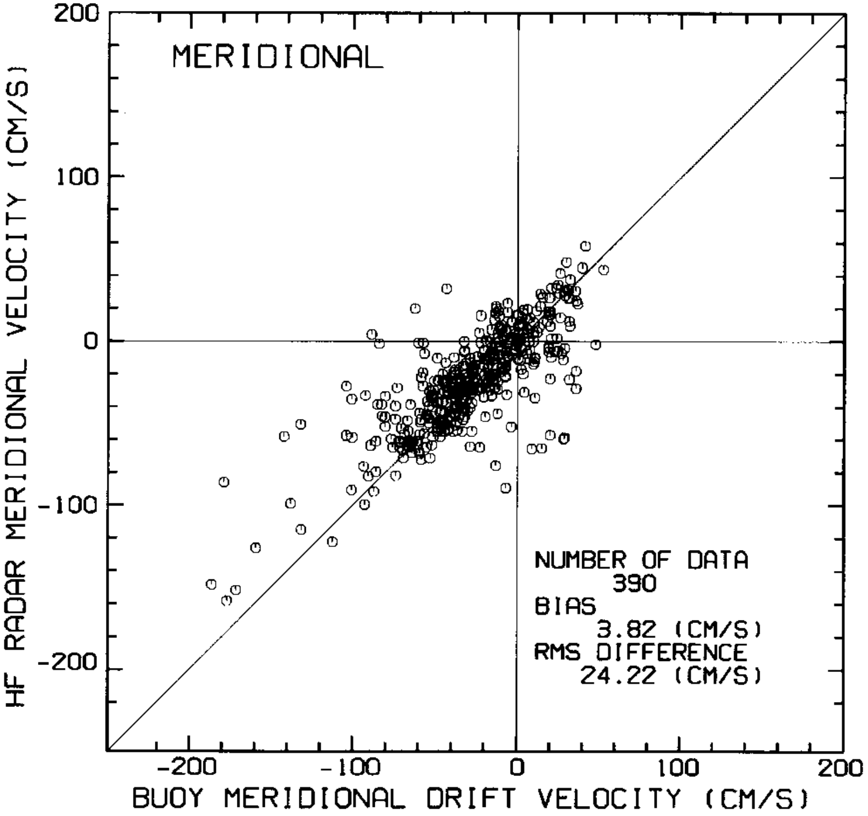
Trajectories of drifting buoys



13 buoys were deployed in 2003-2005

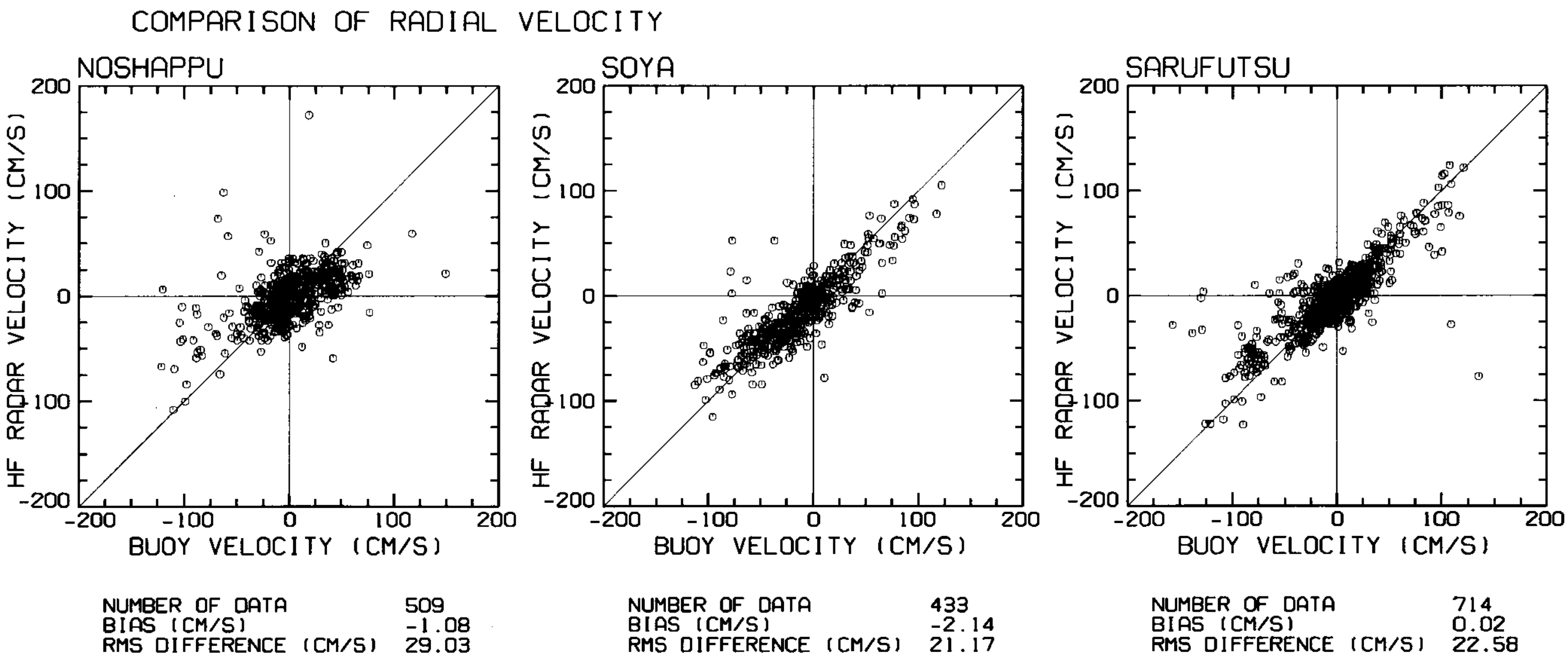
Comparison of Zonal and Meridional Components with Drifting Buoys





Ebuchi et al. (2006)

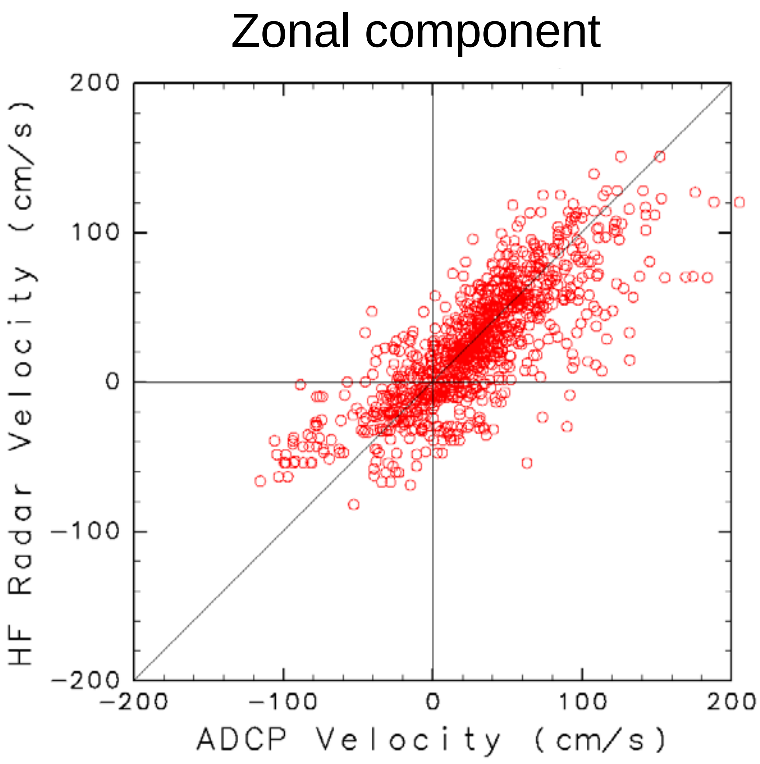
Comparison of Radial Velocity Components for the Three Stations



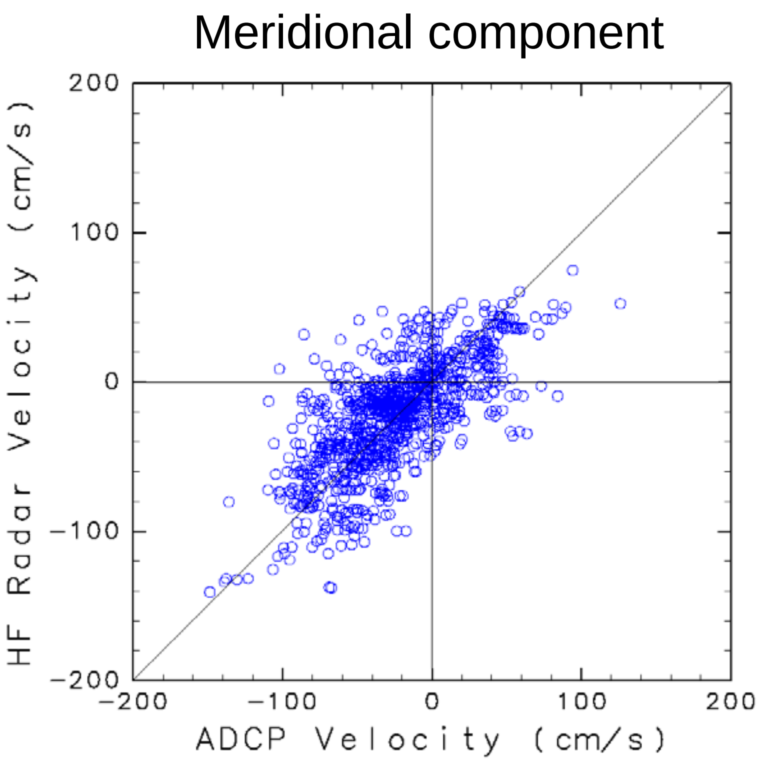
Shipboard ADCP

- ADCP = Acoustic Doppler Current Profiler
- Provided by Japan Coast Guard
- Installed on patrol ships
- Typical observation depth = 5-10 m

Comparison of Zonal and Meridional Components with Shipboard ADCP Obs.



Number of data 1111
Bias -2.9 cm/s
Rms difference 27.8 cm/s

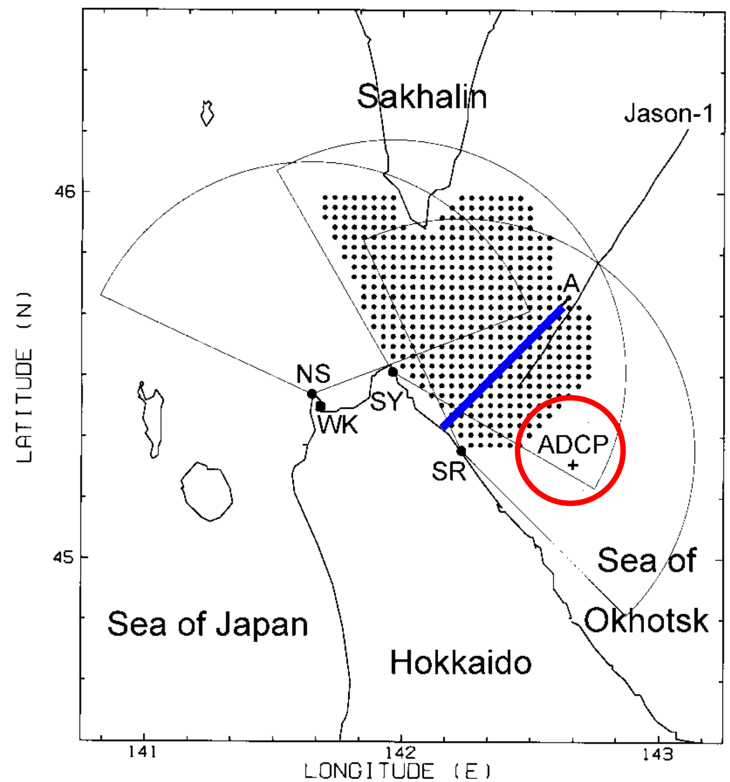


Number of data 1111
Bias 1.8 cm/s
Rms difference 27.7 cm/s

(Ebuchi et al., 2006)

Observation of Vertical Structure of the SWC using TRBM-ADCP

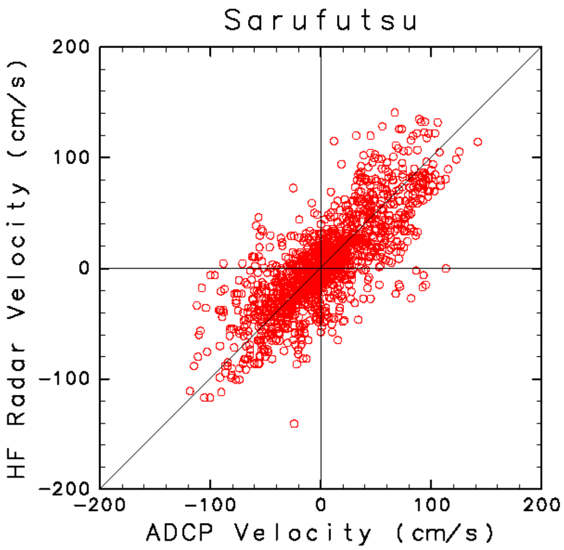
29 km offshore
Water depths 91 m
May 2004 – May 2005



Depth bin size = 4 m
Hourly-average observation

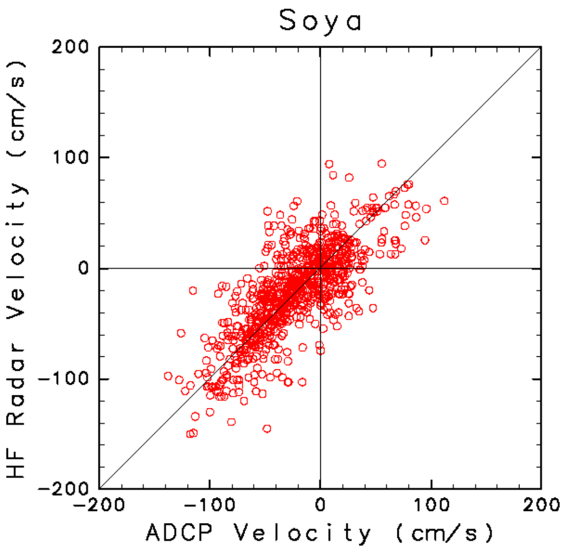
Comparison of Radial Velocity with Shipboard ADCP Observations

SR Station



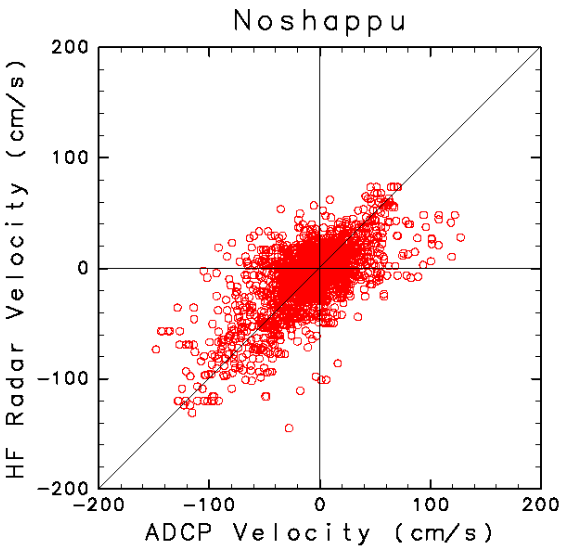
Number of data 1537
Bias 0.3 cm/s
Rms difference 27.5 cm/s

SY Station



Number of data 866
Bias 1.8 cm/s
Rms difference 27.0 cm/s

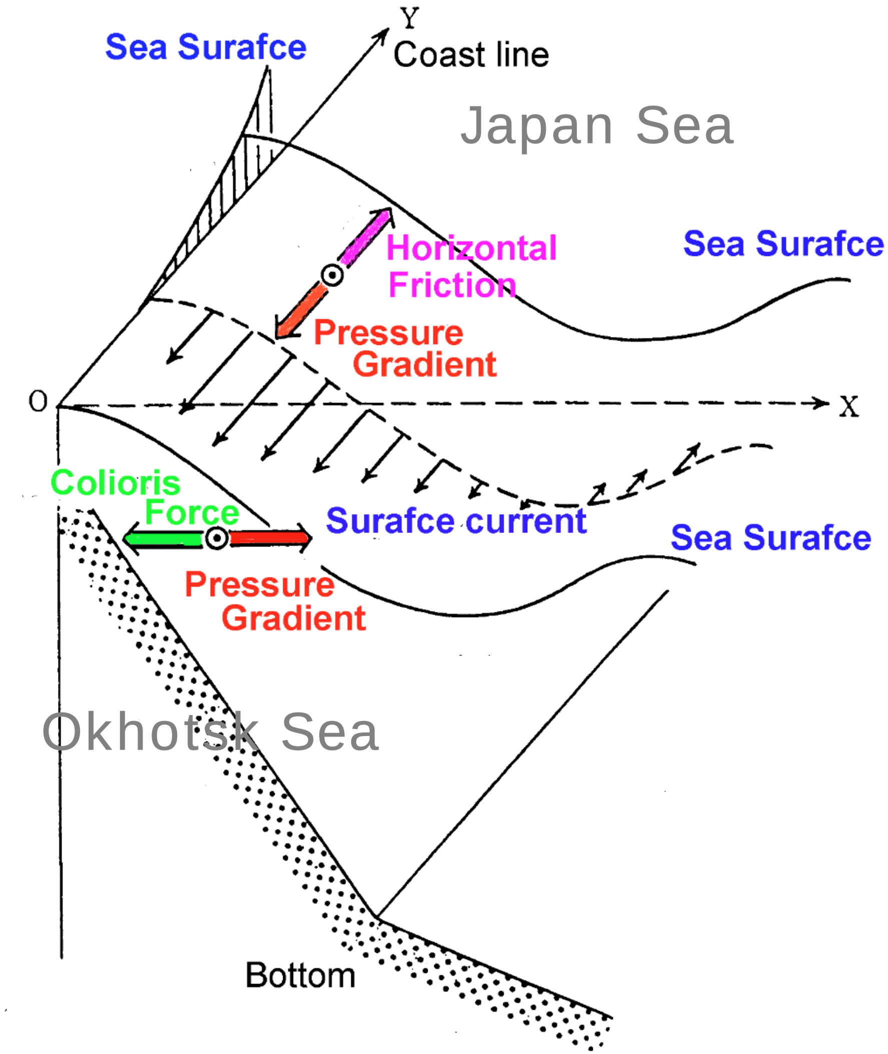
NS Station



Number of data 1949
Bias 0.0 cm/s
Rms difference 27.6 cm/s

Dynamic Balance of the SWC

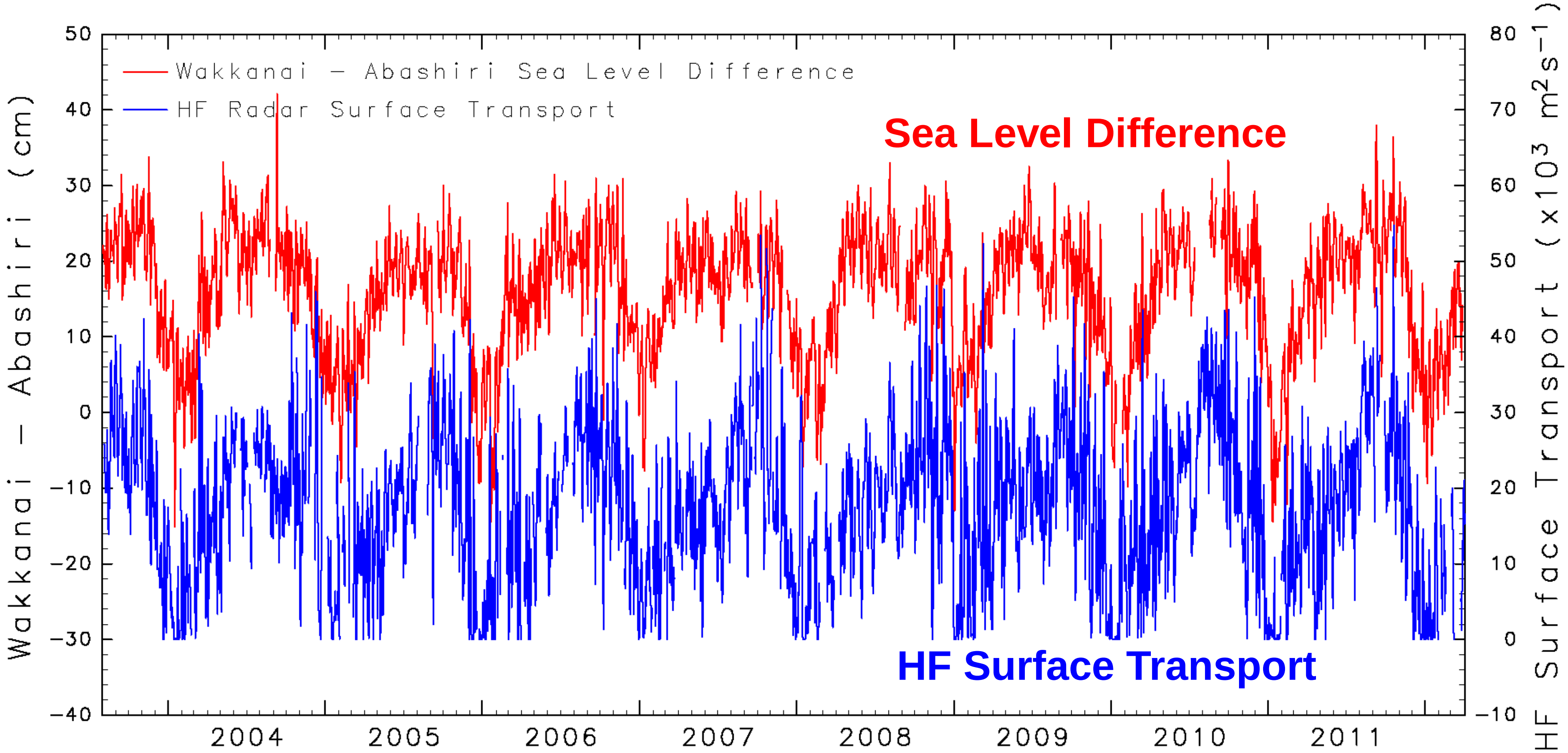
(Aota, 1984)



The SWC is driven by the sea level difference between the Japan Sea and Okhotsk Sea

The SWC is in geostrophic Balance in the cross-shore direction.

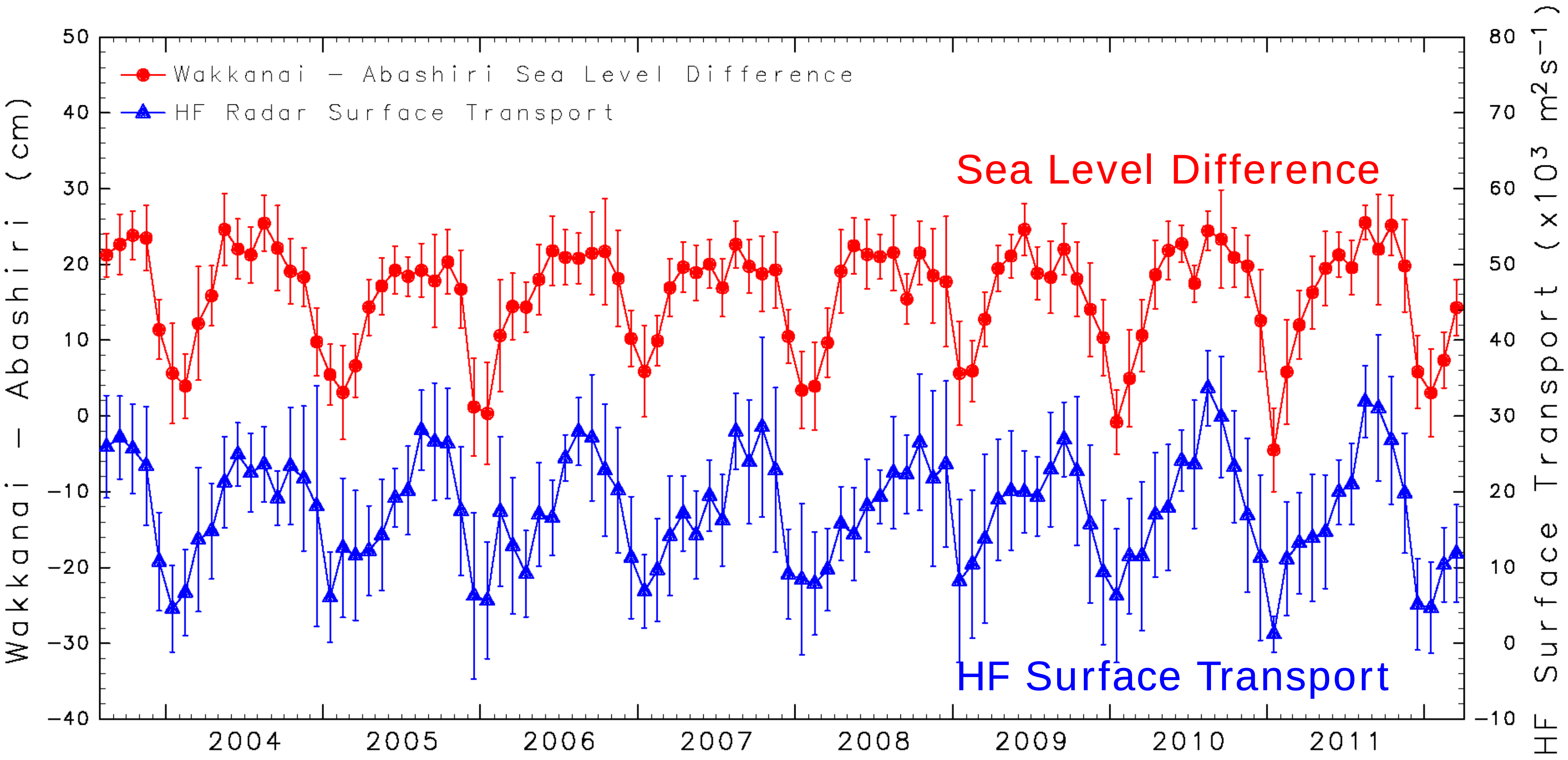
Variations of Surface Transport and Sea Level Difference along the Strait



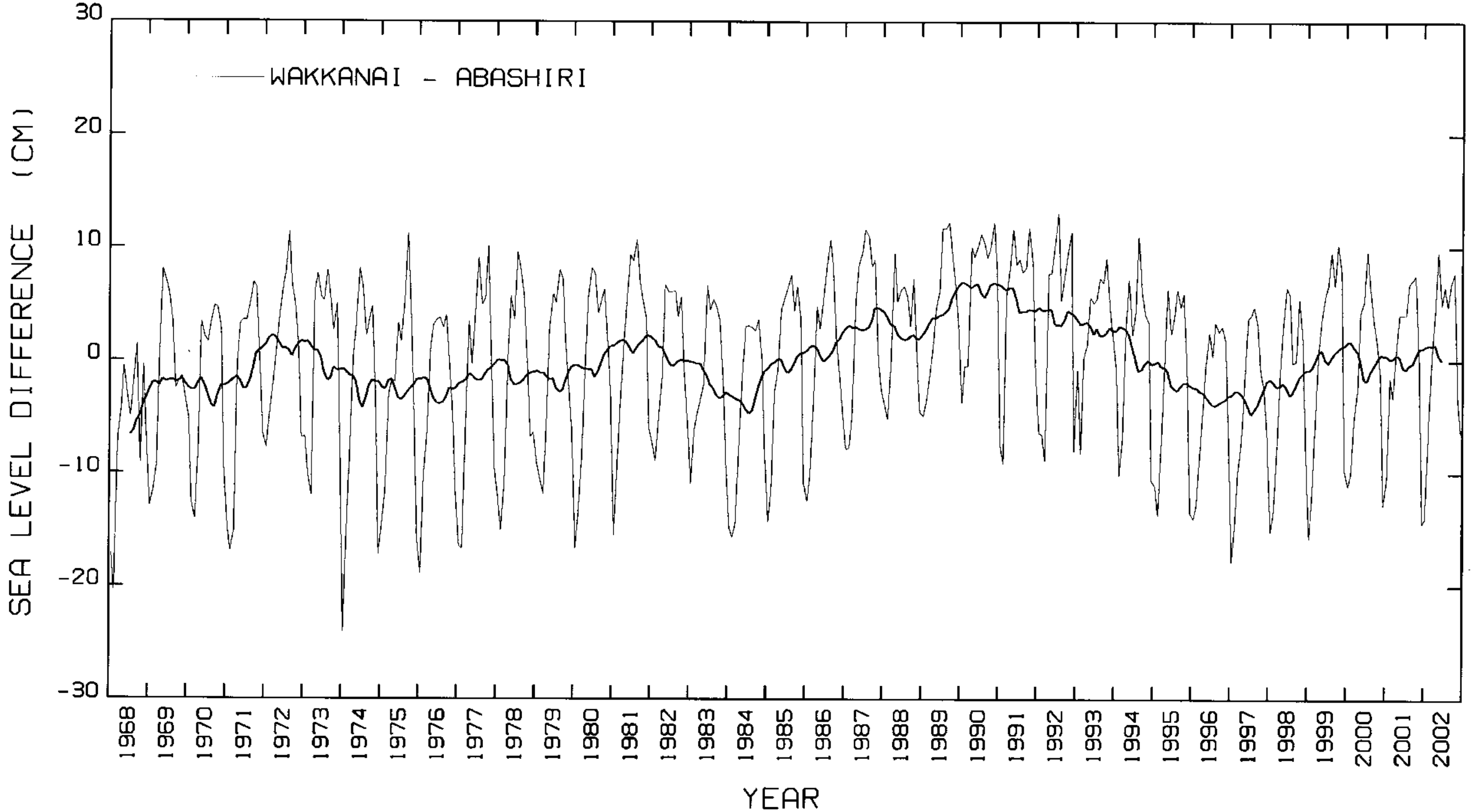
Surface transport = integral of South-east current component along the Line-A

Correlation coefficient = 0.774

Monthly mean surface transport and along-shore sea level difference

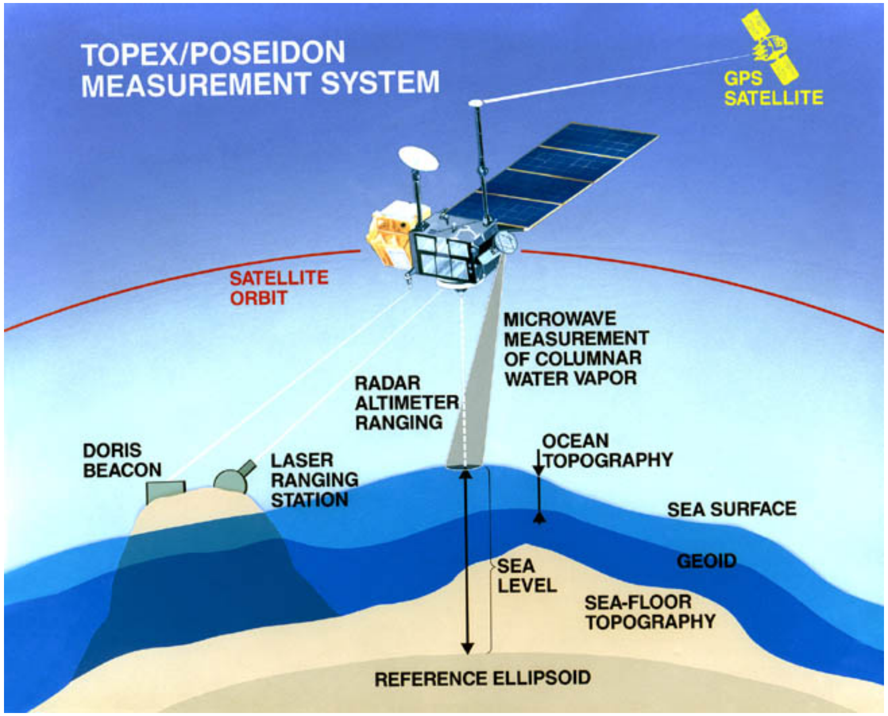


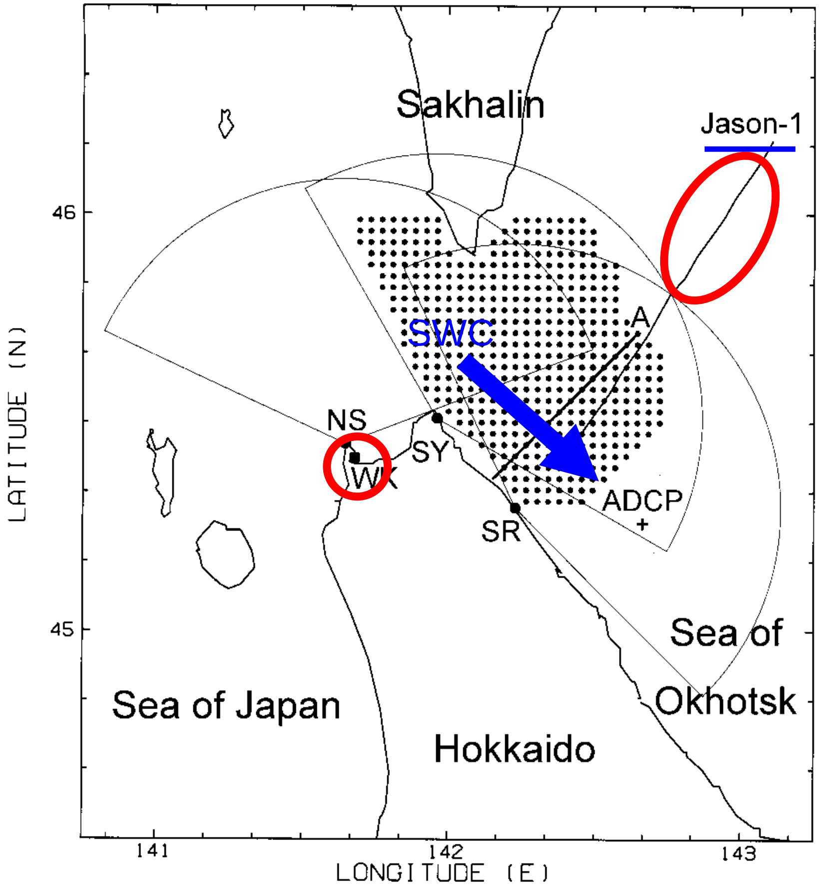
Historical Tidal Record since 1968



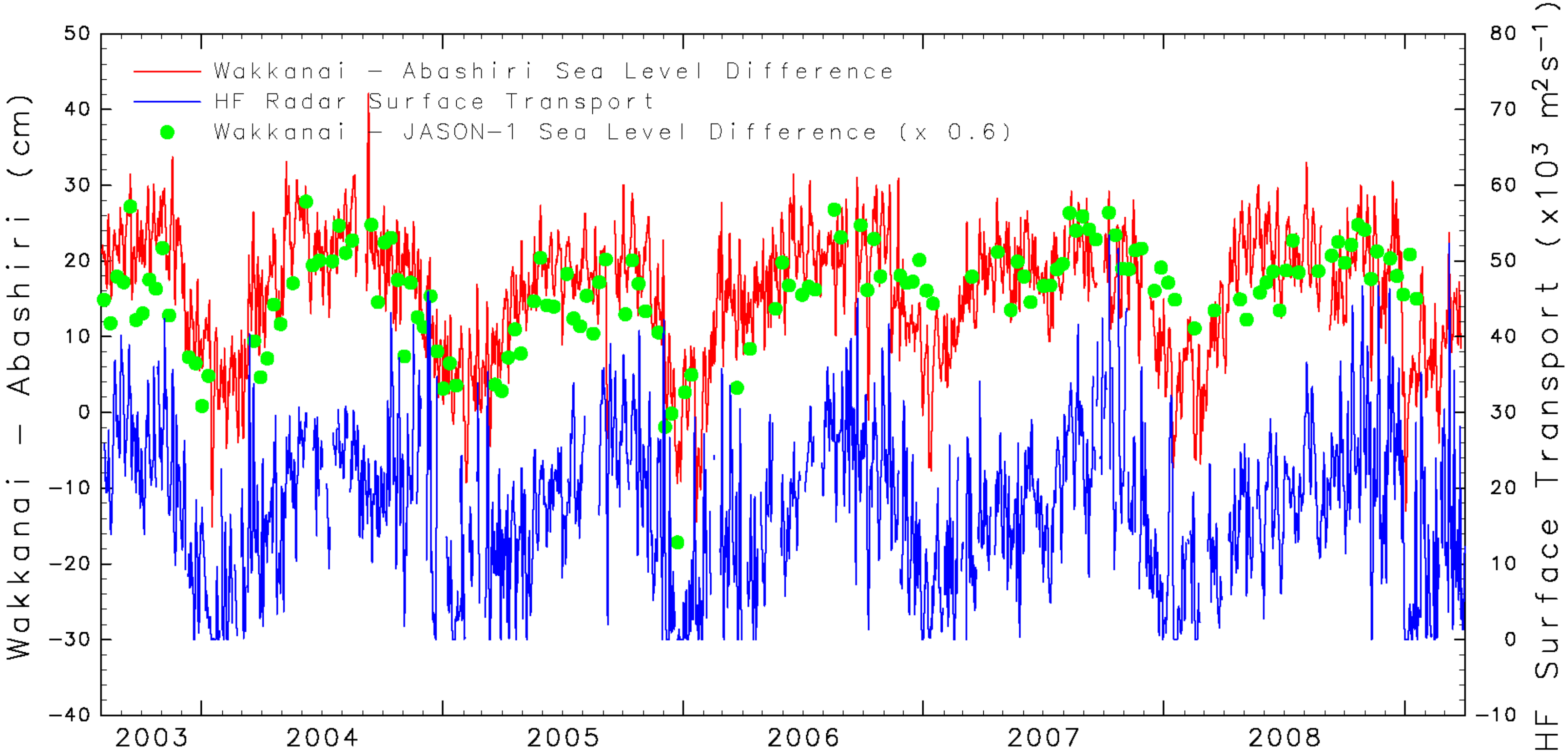
Decadal variation?

Utilization of Satellite Altimeter Data to Monitor Sea Level Difference across the SWC



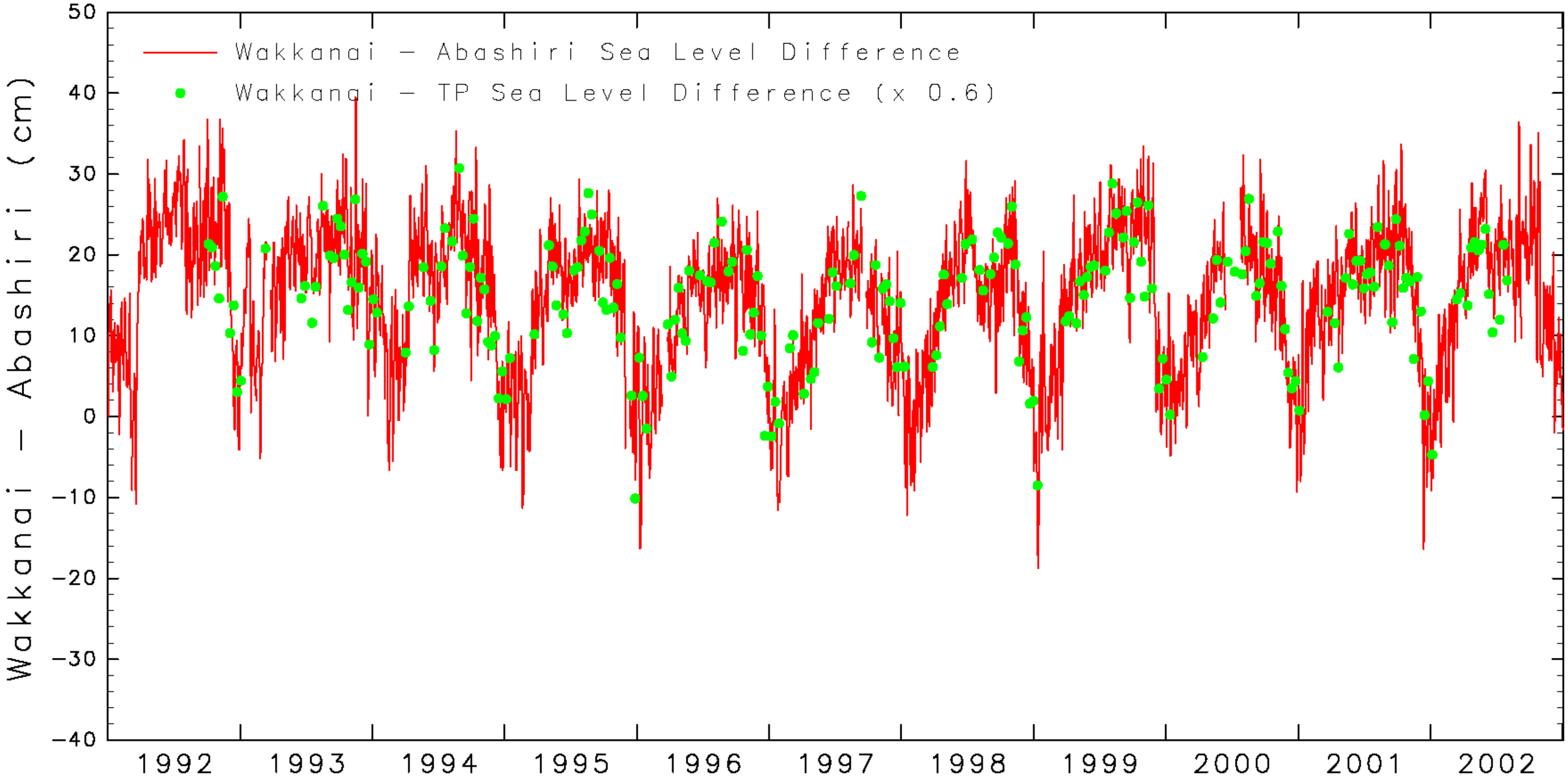


Surface Transport and Sea Level Differences along and across the SWC



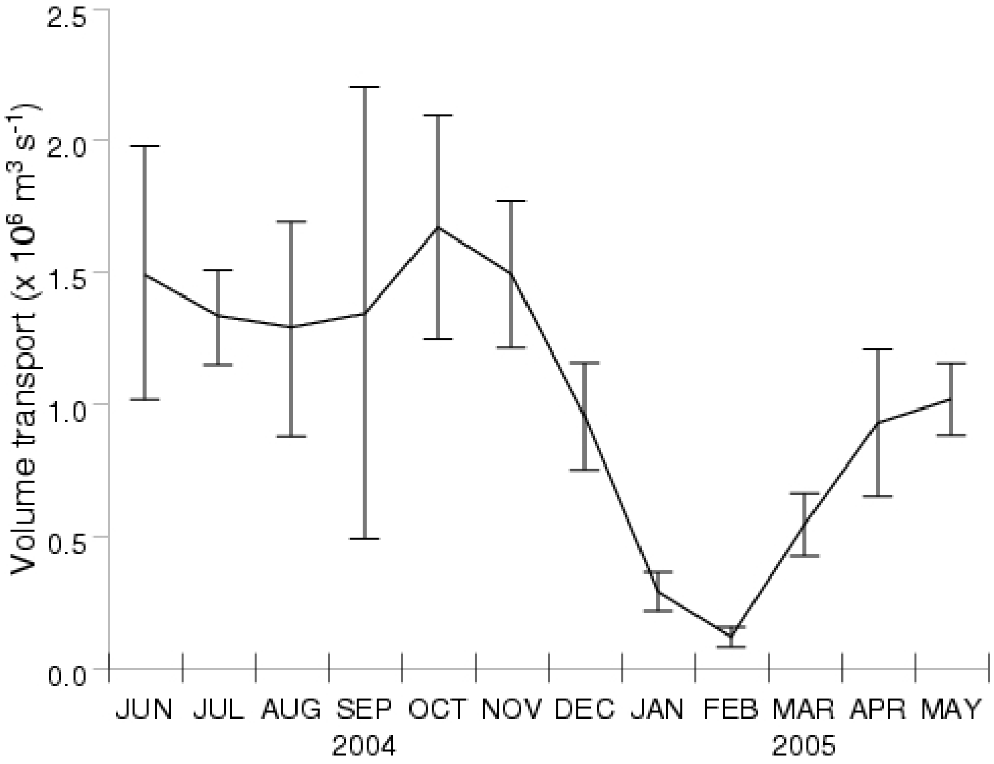
Correlation coefficient = 0.716

Correlation of Sea Level Differences along and across the SWC in T/P Era



Estimation of Volume Transport of SWC

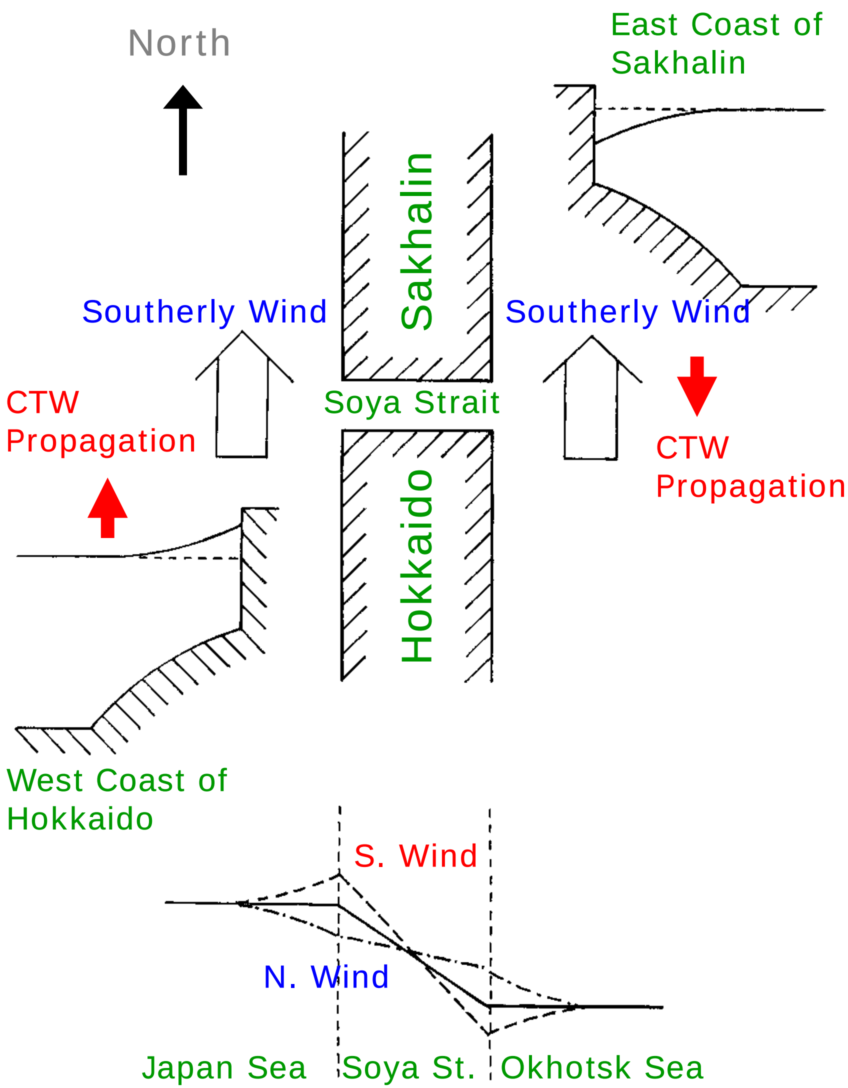
Volume Transport of the SWC is estimated by combination of the surface current fields from the HF Ocean Radars with vertical current profiles from the ADCP.

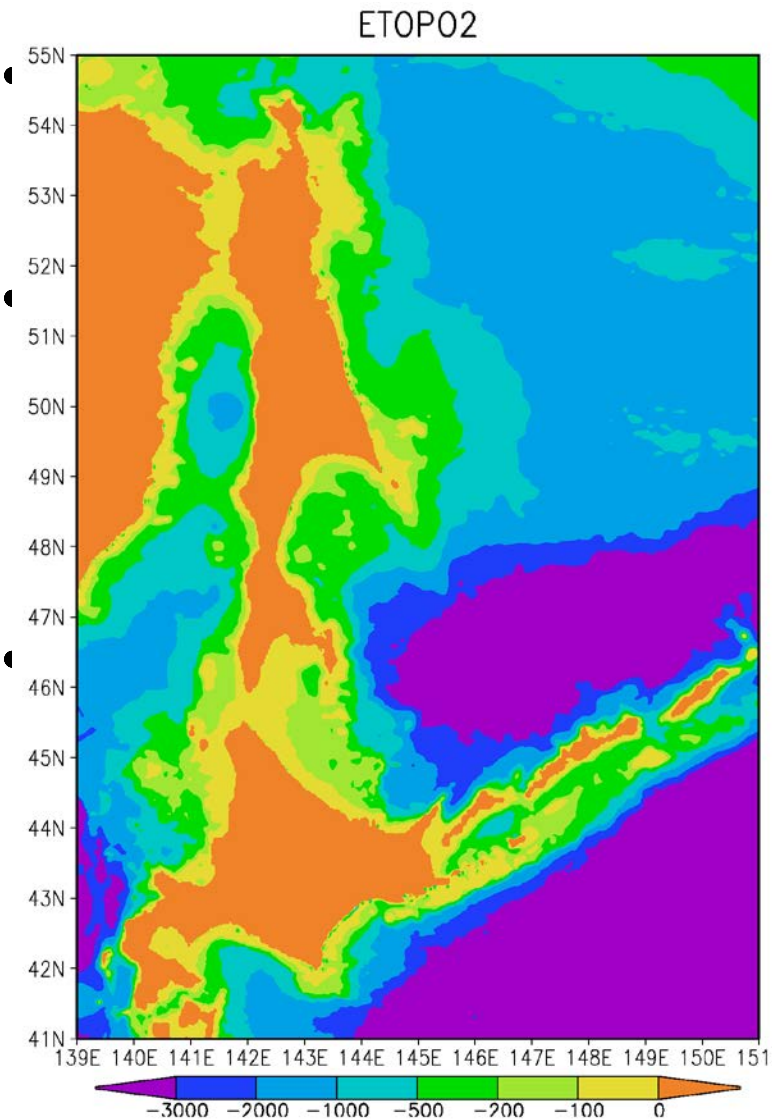


- Wind drift in the HF radar velocity was removed.
- Yearly-average =1.04 ± 0.29 Sv
- Maximum of 1.67 Sv in Oct.
- Minimum of 0.12 Sv in Feb.

(Fukamachi et al., 2005)

Effect of Wind-induced Coastally Trapped Waves





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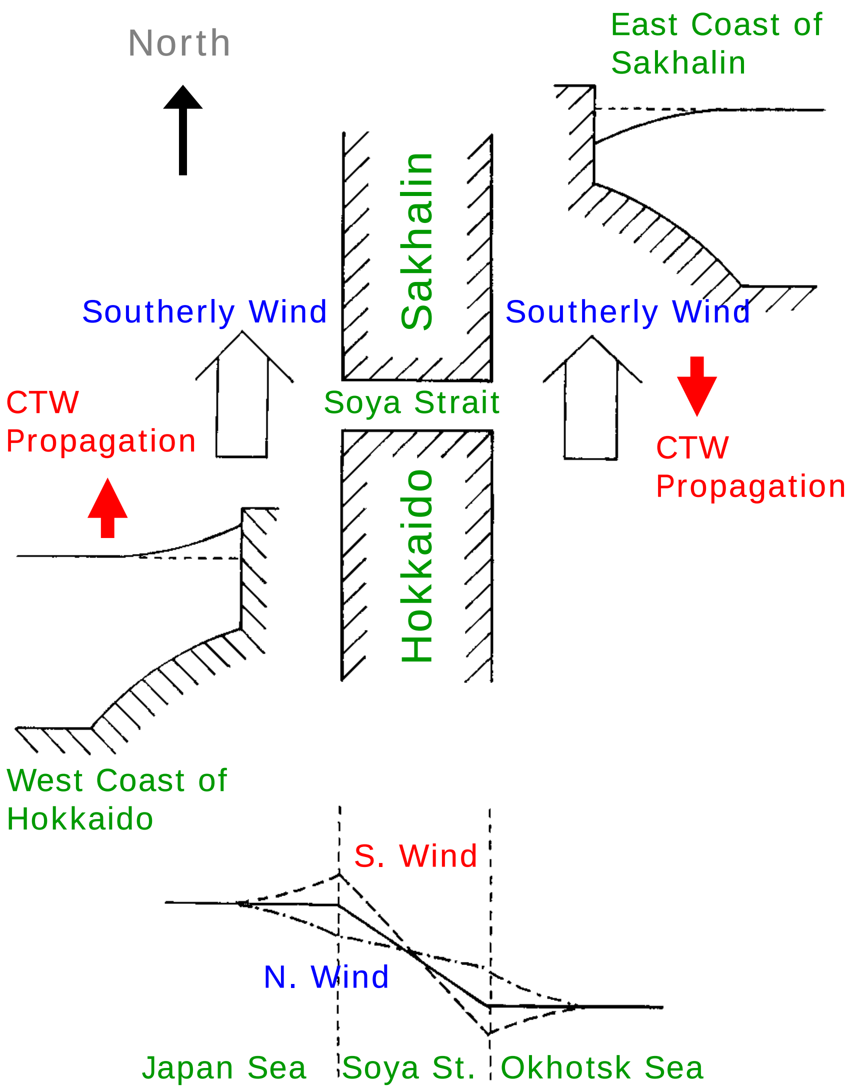
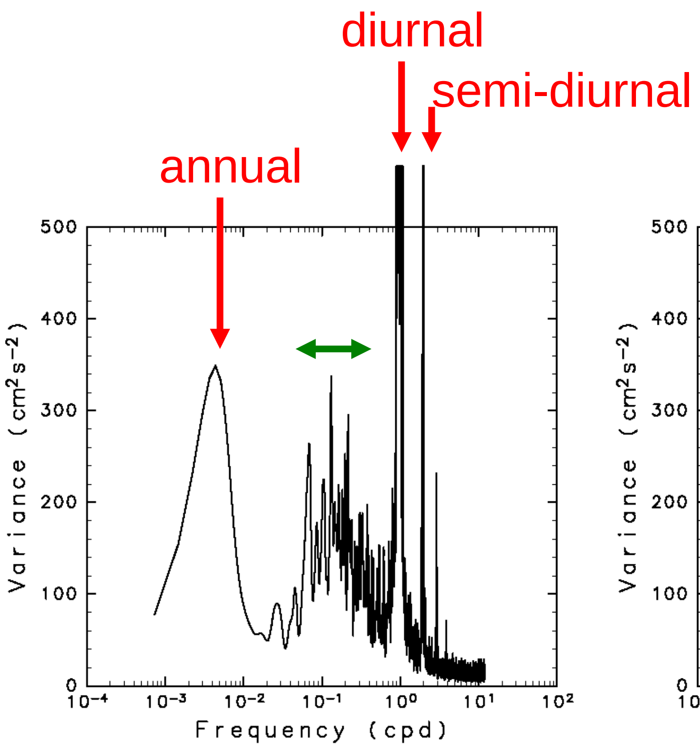
Wind-Induced Coastally-Trapped Waves

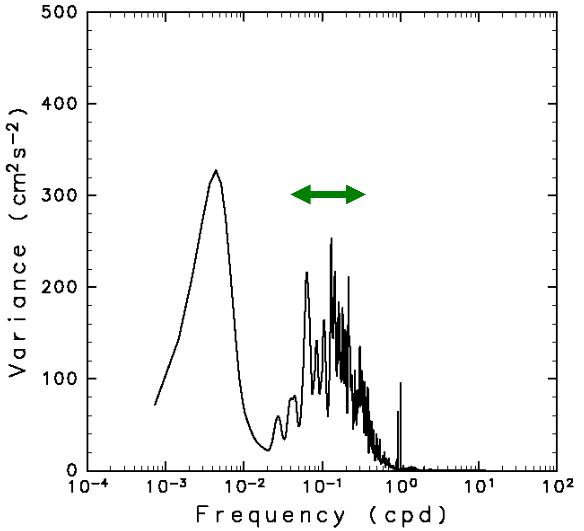


- Assume homogeneous meridional wind stress around Soya Strait.
- Consider wind-induced coastally-trapped waves (CTW) along the east coast of Sakhalin and west coast of Hokkaido.
- Southern (Northern) wind enhances (reduces) the sea level difference between the Japan Sea and Okhotsk Sea.

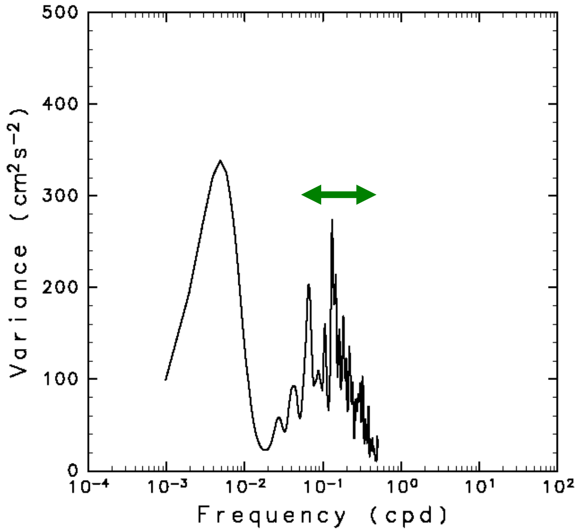
Removal of tidal components by using 25-hr running average



Power spectrum calculated from raw hourly data

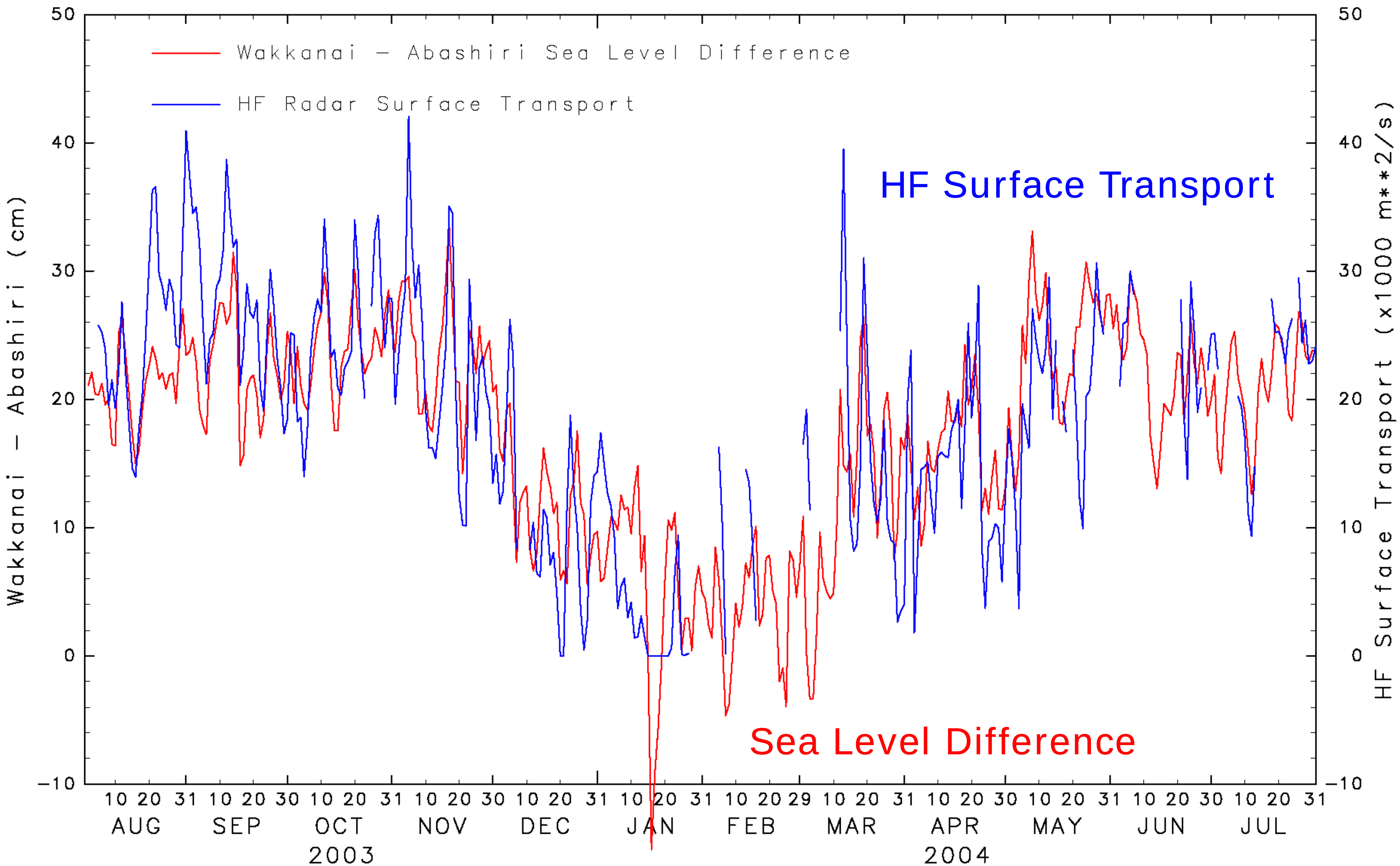


Power spectrum calculated from hourly data with 25-hr running average

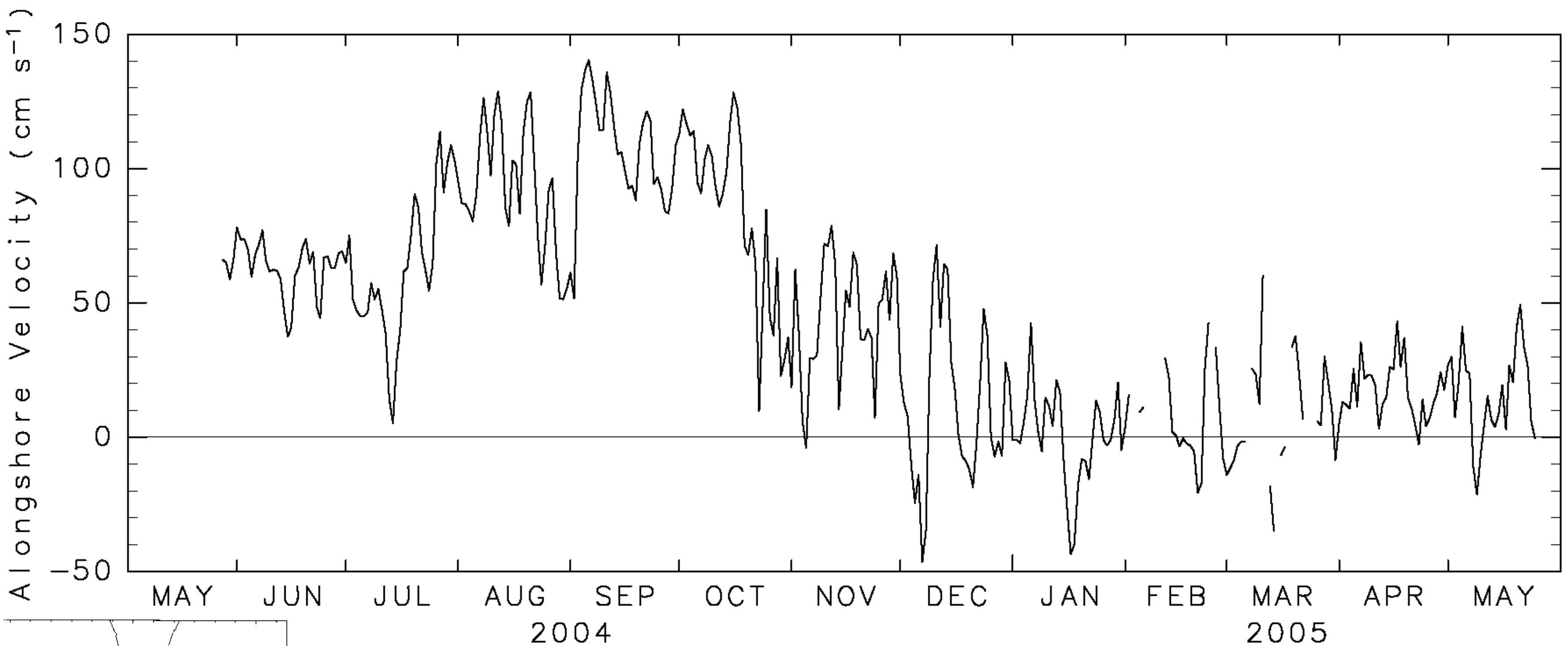


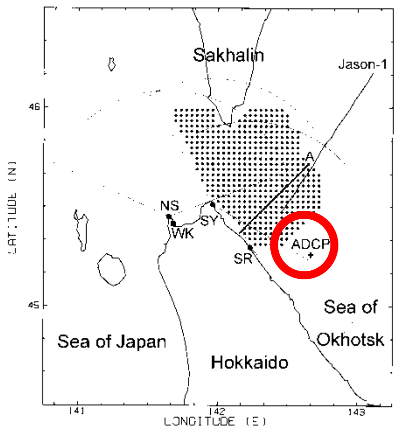
Power spectrum calculated from daily mean data

Subinertial variations in the sea level difference and surface transport



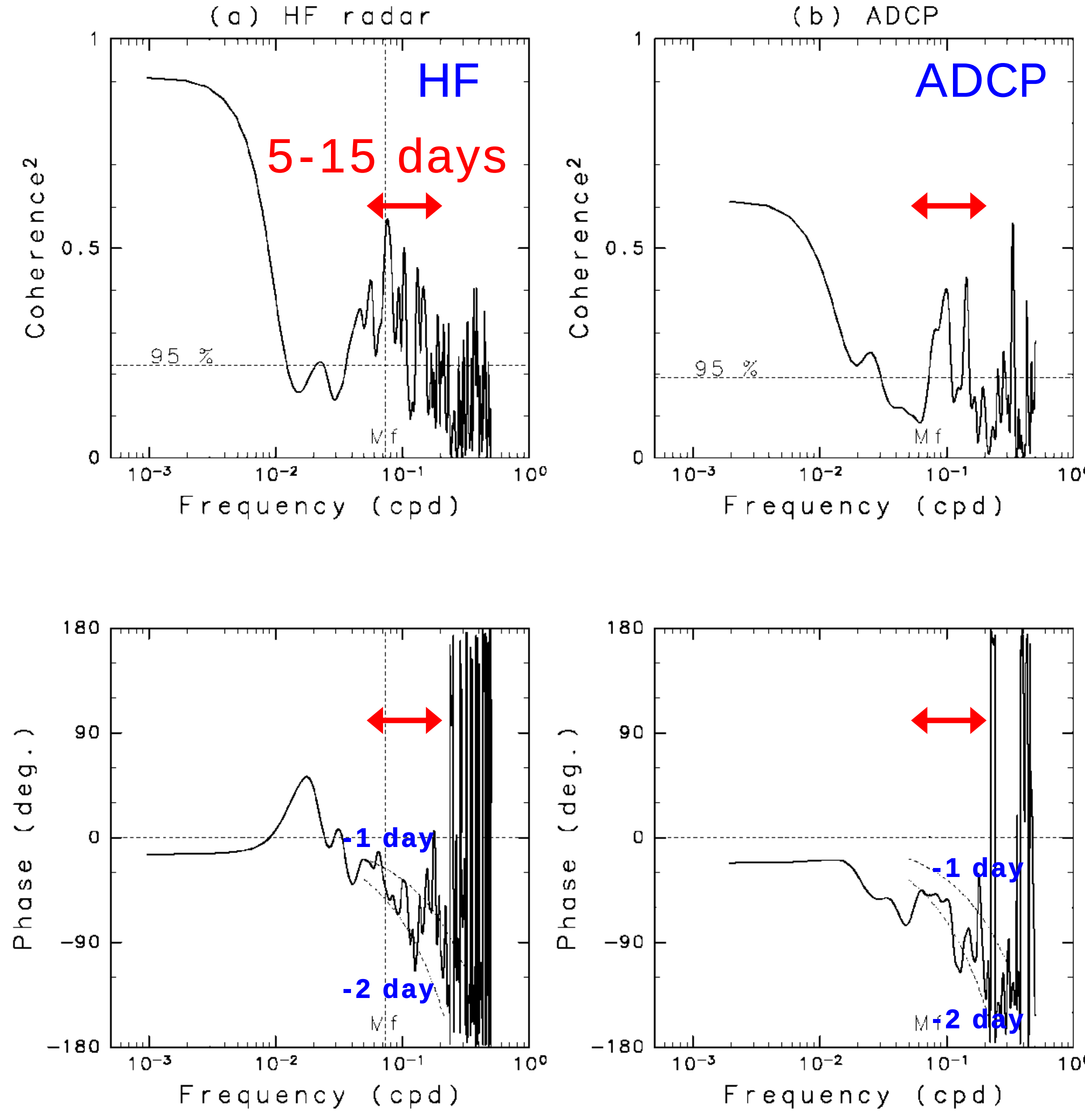
Alongshore component of near-surface current observed by TRBM-ADCP



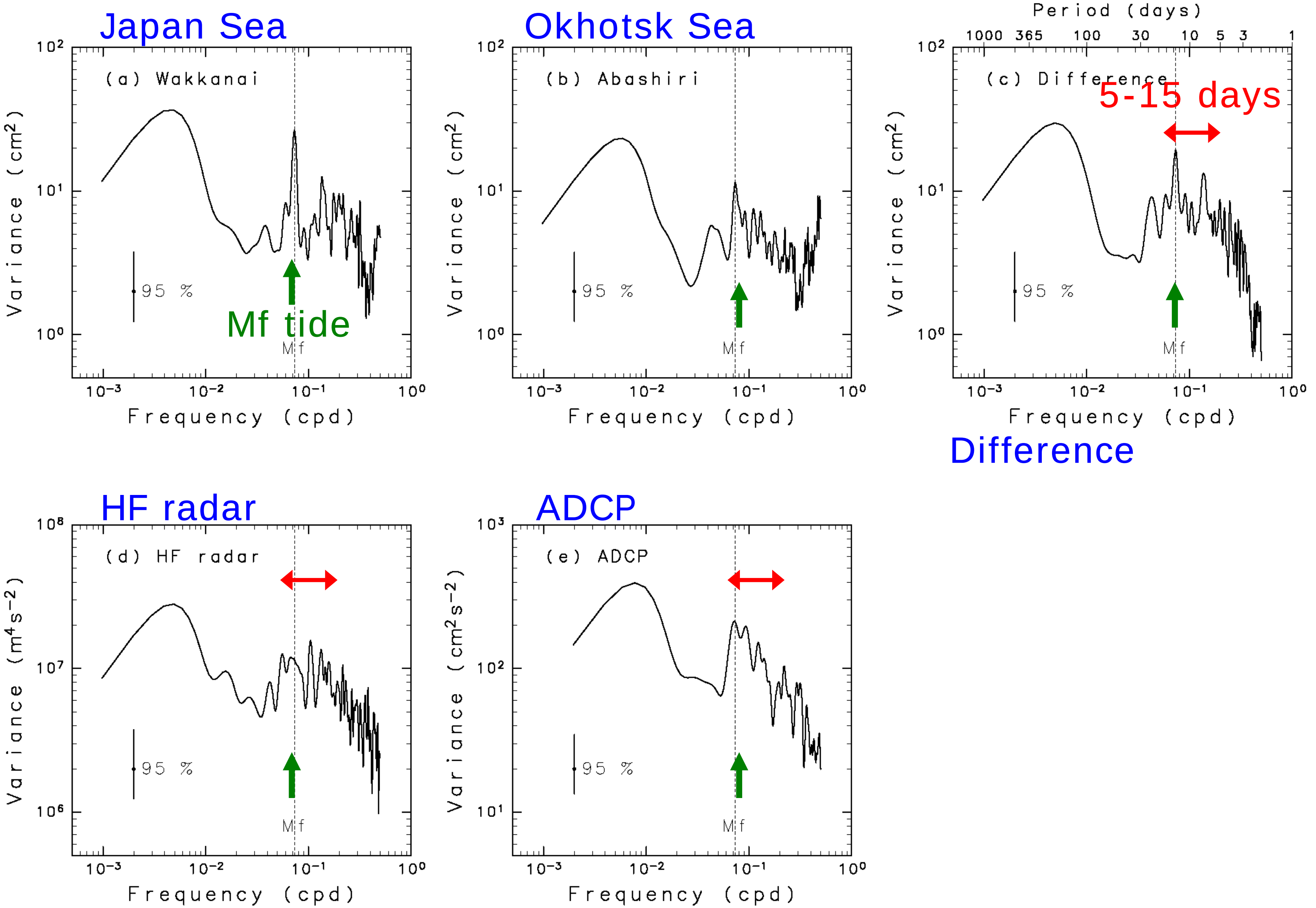


Depth = 9-13 m

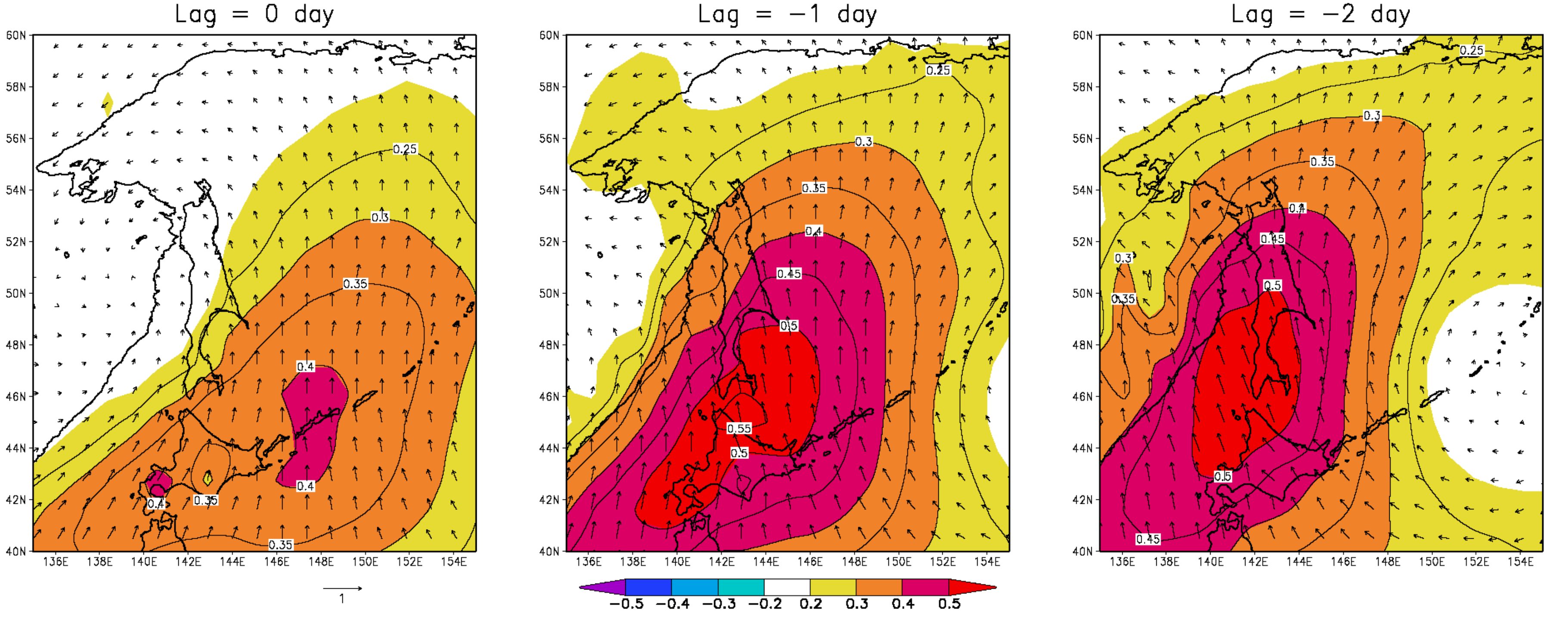
Cross Spectra of the ECMWF Meridional Wind Stress with the HF Radar Surface Transport and ADCP Near-surface Velocity



Power Spectrum of HF Surface Transport, ADCP Surface Current and Sea Level Difference



Lag Correlation between the Sea Level Difference with Wind Speed and Direction of ERA40 (1967-2002)



Azimuth direction of the wind component, which gives the maximum correlation with the sea level difference, is shown by the direction of arrows, and the maximum correlation coefficient is shown by the length of arrows and contours.

Cross Spectra of the ERA40 Meridional Wind Stress with the Sea Level Difference

(1967-2002)