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Detection of Regional Infrasound Signals Using Array Data - *Testing, Tuning, and Physical Interpretation*

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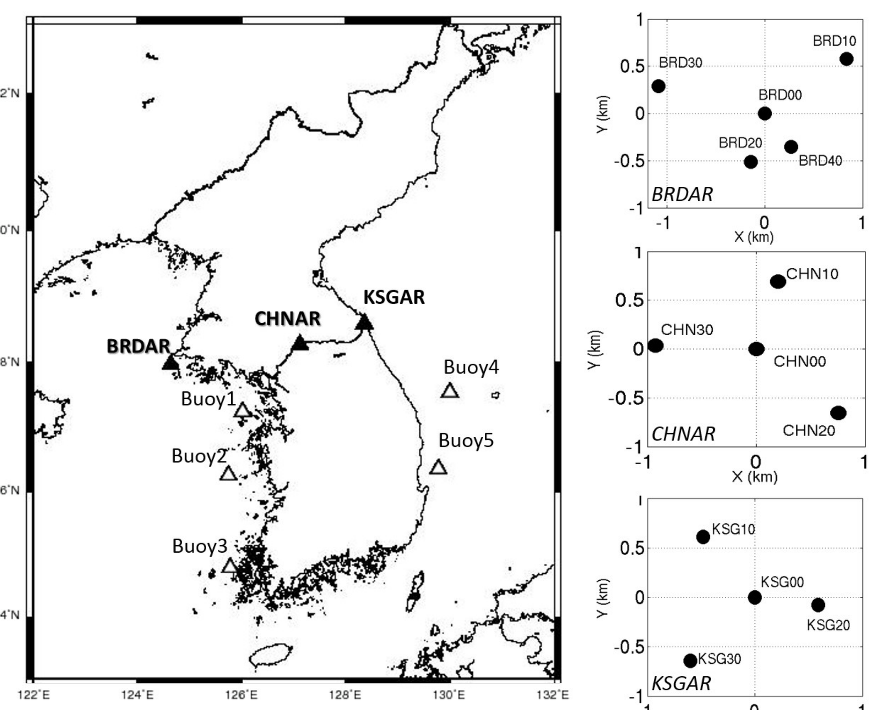
ABSTRACT

This work quantifies the physical characteristics of infrasound signal and noise, assesses their temporal variations, and determines the degree to which these effects can be predicted by time-varying atmospheric models to estimate array and network performance. An automated detector that accounts for both correlated and uncorrelated noise is applied to infrasound data from three, seismo-acoustic arrays (BRDAR, CHNAR, and KSGAR) in South Korea, cooperatively operated by Korea Institute of Geoscience and Mineral Resources (KIGAM) and Southern Methodist University (SMU). The ocean arrays have higher noise power than the continent array, consistent with both higher wind speeds and seasonably variable ocean wave contributions. Based on the adaptive F-detector utilizing the time variable environmental effects, the time-dependent scaling variable is shown to be dependent on both weather conditions and local site effects. Significant seasonal variations in infrasound detections including daily time of occurrence, detection numbers, and phase velocity/azimuth estimates are documented. These time-dependent effects are strongly correlated with atmospheric winds and temperatures and are predicted by available atmospheric specifications. This suggests that commonly available atmospheric specifications can be used to predict both station and network detection performance, and an appropriate forward model improves location capabilities as a function of time.

STUDY AREA

A one-year dataset (12/2009-11/2010) recorded at infrasound arrays in South Korea (right figure) was used for this study.

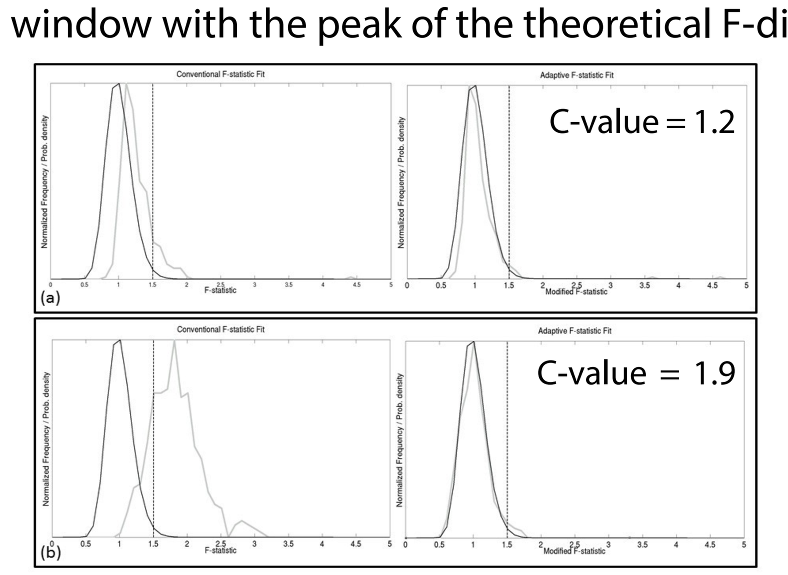
Analysis focuses on seasons.
Winter: Dec 2009 - Feb 2010
Julian days 335(2009)–059(2010)
Spring: Mar - May 2010
Julian days 060-151 (2010)
Summer: Jun - Aug 2010
Julian days 152-243 (2010)
Fall: Sep - Nov 2010
Julian days 244-334 (2010)



The location of infrasound arrays (black triangles) – BRDAR, CHNAR and KSGAR and buoy stations (white triangles) - Deokjeokdo (Buoy1), Oeyundo (Buoy2), Chilbaldo (Buoy3), Donghae (Buoy4), and Pohang (Buoy5) in South Korea. Black circles in the right designate the location of individual array elements.

ADAPTIVE F-DETECTOR (AFD)

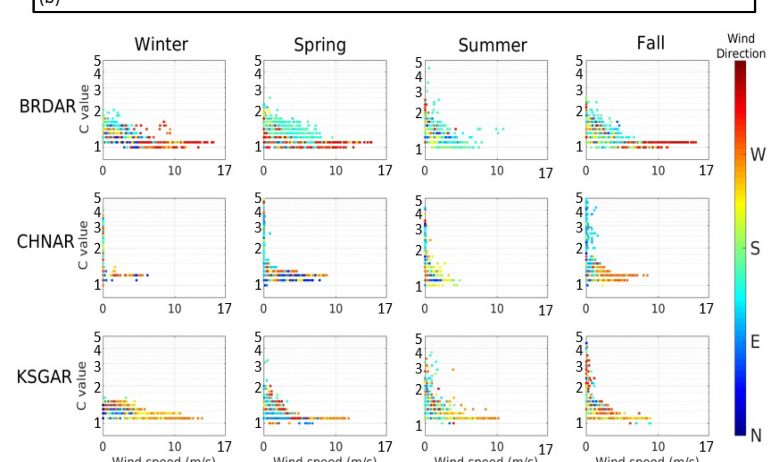
AFD (Arrowsmith et al., 2009) is a modification to F-detector that accounts for temporal changes in noise by using an adaptive window to update the detection distribution. The scaling factor, C, aligns the peak of the F-distribution in the time window with the peak of the theoretical F-distribution.



Two panels are displayed for each hour of BRDAR data for Julian day 081, 2010 (a) 06:00:00~07:00:00 UTC and (b)14:00:00~15:00:00 UTC.

The left panel without adaptation and the right after adaptively remapping the empirical distribution.

The theoretical (black) and empirical (gray) F-distribution is included in each panel with the 99% threshold (dashed black line).



Dependence of C-value on surface wind speed and wind direction and at BRDAR, CHNAR, and KSGAR for the one-year time period divided into winter, spring, summer, and fall.

CHNAR results during the winter lacks complete weather data as a result of an equipment failure.

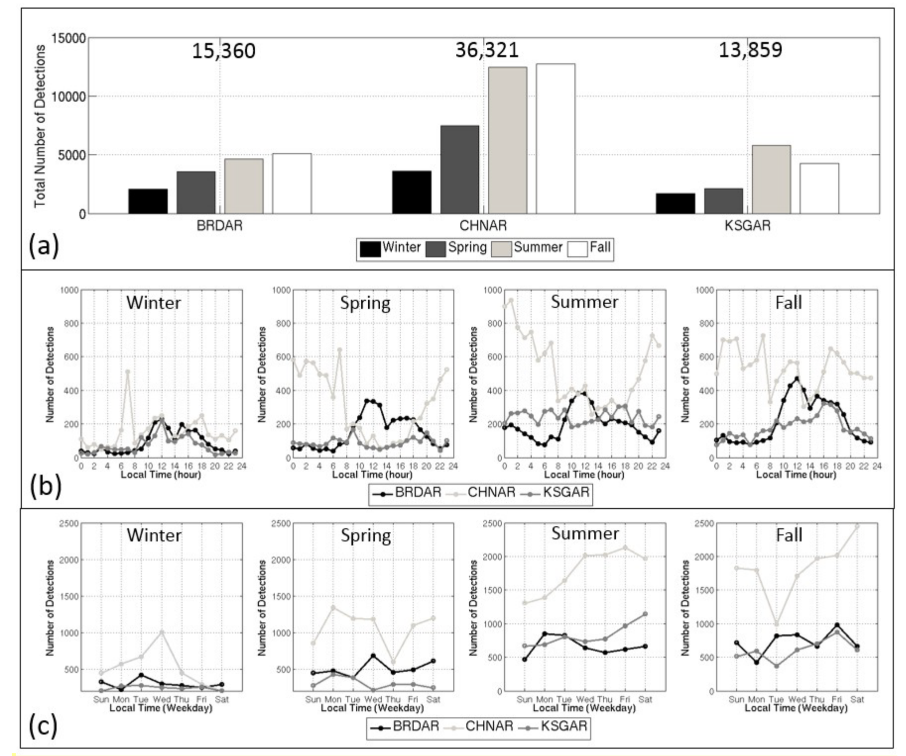
The lower surface wind speed, the higher C-values, illustrate that during these quite conditions that local sources with coherent energy impact the detection statistics.

DETECTION RESULTS

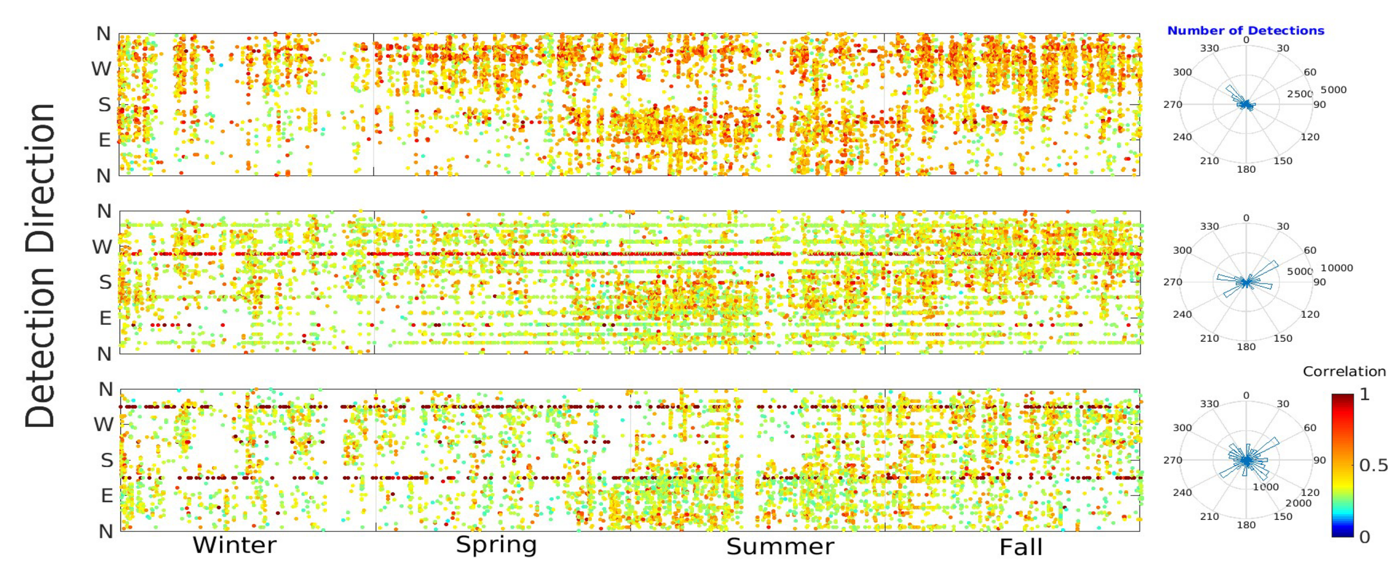
The analysis illustrates that infrasound detections are dependent on a combination of local, weather conditions and local site environment, thus producing complex seasonal variations.

1) The automated detections, shown in terms of total number of detections, hour of the day, and day of the week (right figure), suggest that many infrasound detection across the Korean Peninsula are affected by human activities.

2) Correlation values and estimated detection azimuth also vary with season (bottom figure). Detections at BRDAR have relatively high correlations, especially for sources from the NE with many detections.



(a) Total number of detections displayed by array (BRDAR, CHNAR, and KSGAR) for one-year separated into winter, spring, summer, and fall. The total number of detections are summarized at the top. The number of infrasound detections as a function of (b) hour of the day and (c) day of the week at BRDAR, CHNAR, and KSGAR using the one-year dataset.

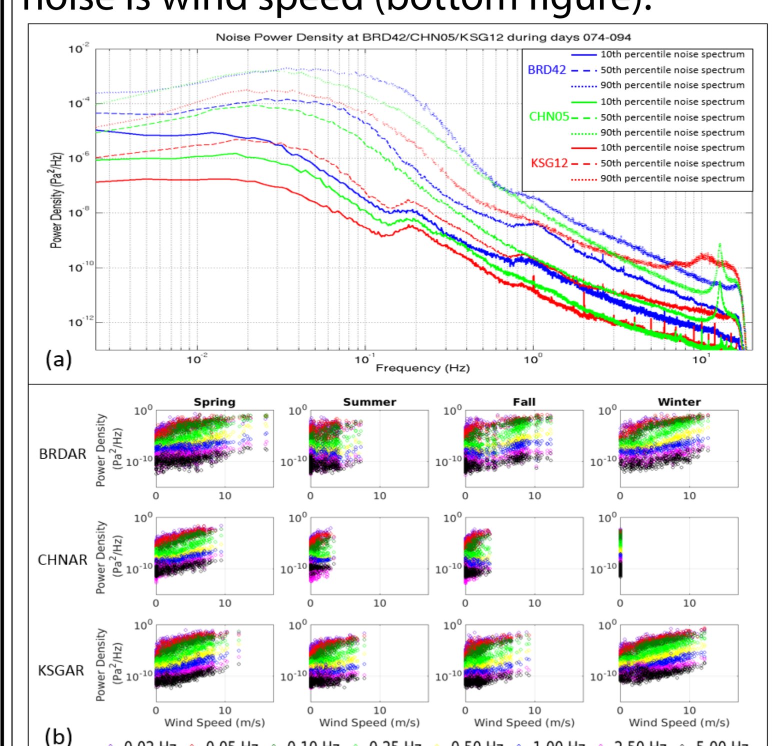


Automated detections at BRDAR, CHNAR, and KSGAR using the one-year data set; winter, spring, summer, and fall. The color of individual detections represents the correlation value and is plotted against detection direction and time. The rose diagrams to the right summarize the total detections as a function of azimuth for the entire time period.

PHYSICAL EXPLANATION OF OBSERVATION

1. Local Wind Effects

Based on infrasound noise estimates using Welch's method (Welch, 1967), BRDAR has higher noise levels than other arrays, suggesting the primary effect on background noise is wind speed (bottom figure).

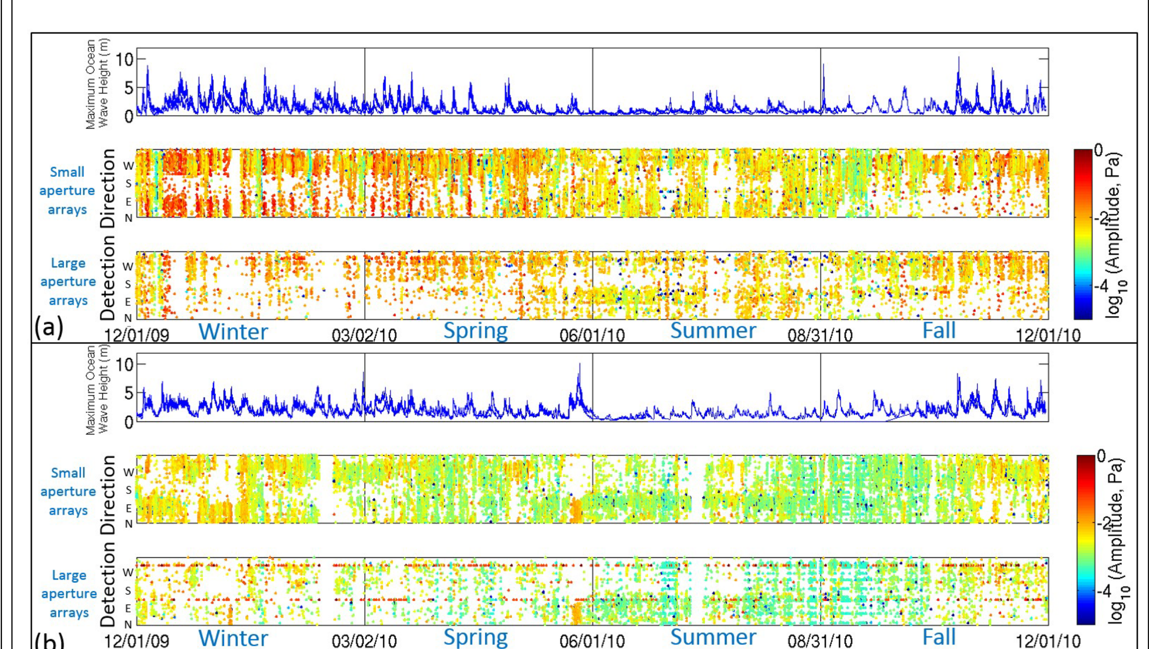


(a)Infrasonic noise power density estimates using Welch's method (Welch, 1967) for BRD42 (blue), CHN05 (red), and KSG12 (green) for Julian days 074-094 (2010). (b)Infrasonic noises at BRDAR (BRD42), CHNAR (CHN05), and KSGAR (KSG12) are plotted against wind speed for frequencies of 0.02, 0.05, 0.10, 0.25, 0.50, 1.00, 2.50, and 5.00 Hz for spring, summer, fall, and winter. CHNAR result during the winter lacks complete weather data as a result of an equipment failure.

2. Ocean Wave Effects

Average RMS amplitudes for the detected signals at BRDAR and KSGAR compared to maximum ocean wave heights as a function of time and azimuth (bottom figure).

Correlation between signal amplitude and ocean wave energy is stronger during the winter and spring than the summer when ocean wave height decreases.



Maximum ocean wave heights as a function of time (blue lines, top) are compared to the average RMS beamforming amplitude in log scale (Pa) of the detected infrasound signals (color-coded points) using small (middle) and large (bottom) aperture arrays for the one-year dataset (winter, spring, summer, and fall) at (a) BRDAR and (b) KSGAR.
Bouy 1, Buoy 2, and Buoy 3 are superimposed for comparison with BRDAR detections (a) and Buoy 4 and Buoy 5 are superimposed for comparison with KSGAR detections (b).

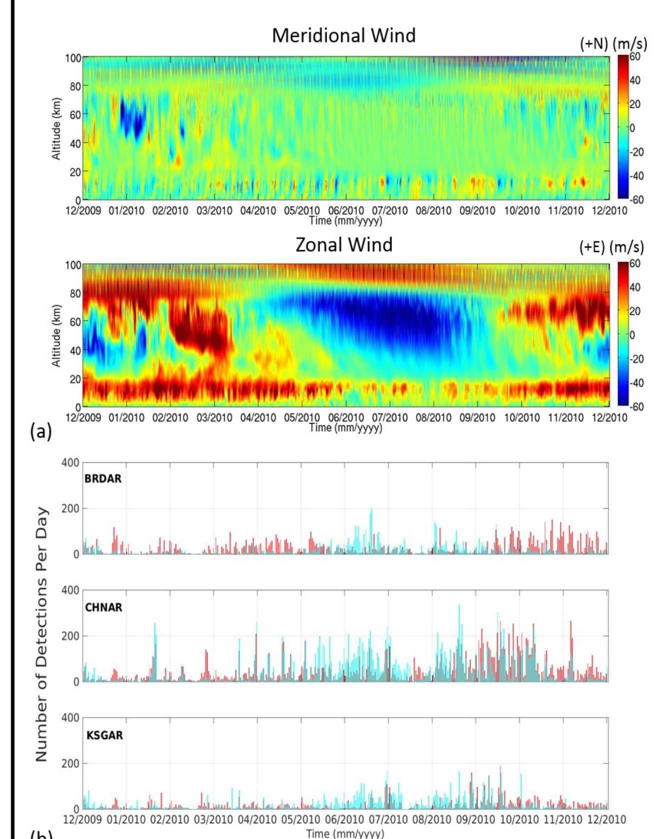
3. Atmospheric Effects and Model Prediction

Seasonal variations in infrasound detections at three arrays are compared with variations in atmospheric estimates from the G2S atmospheric specifications (Drob et al., 2003).

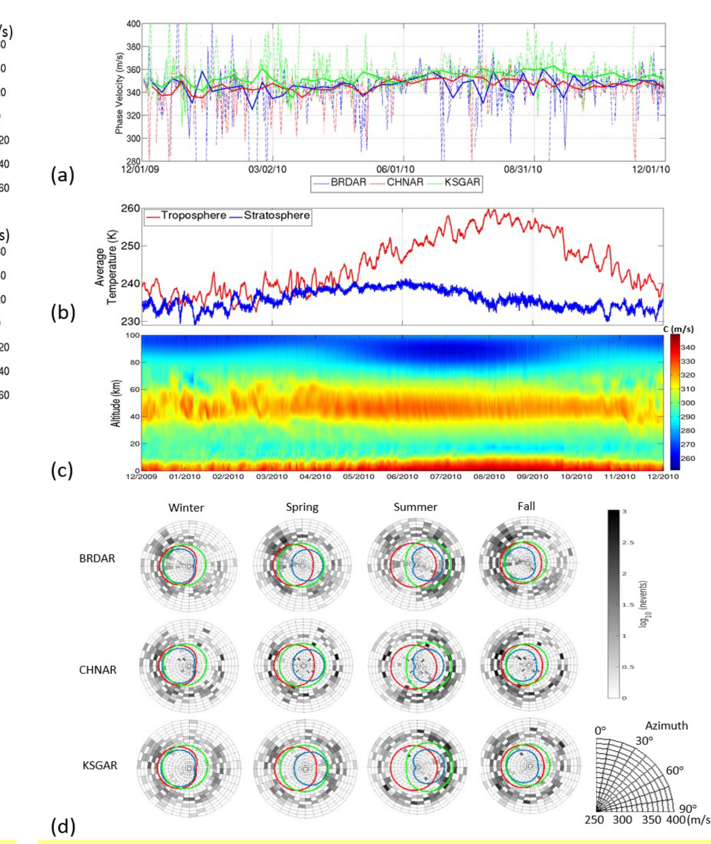
1) There is strong correlation between seasonal changes in detection azimuths and the seasonal reversal of tropospheric and stratospheric winds. However, the number of detections (180° < az <360°) during the winter is reduced, indicating that stratospheric winds produce a mixture of eastward and westward propagation (i.e. sudden stratospheric warmings) (bottom left figure).

2) Phase velocity can also be affected by seasonal variations of temperature, static sound speed and effective sound speed from G2S estimates (bottom middle figure).

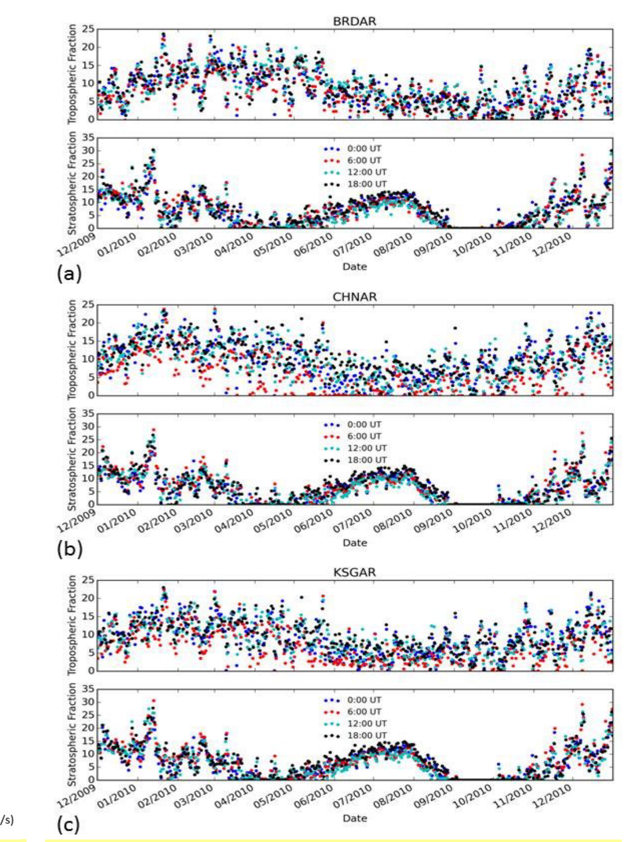
3) Based on the omnidirectional G2S ducting fractions, calculated percentage of energy ducted in a particular mode, different tropospheric fractions are predicted for three arrays, with similar stratospheric fractions for each array (bottom right figure).



The correlation between seasonal variations in infrasound detections and atmospheric winds estimated for 6-hour time intervals (0, 6, 12, and 18 hour in UTC) from the G2S specifications (Drob et al., 2003) in Korea for the time period (12/2009-11/2010). (a) Meridional (top) and zonal (bottom) winds at CHNAR as a function of day for the one-year time period. (b) Seasonal variations in the number of infrasound detections per day from the west, 180°≤azimuth<360°, (red) and from the east, 0°≤azimuth<180° (blue), at BRDAR, CHNAR and KSGAR.



(a) Seasonal variations in phase velocity at BRDAR, CHNAR, and KSGAR using the one-year dataset (12/2009 - 11/2010). Each bold line indicates the 1-week moving window averaged phase velocity. (b)The vertically averaged temperature for troposphere (altitude<15km) and stratosphere (15km<altitude<70km) and (c)the static sound speed estimated for 6-hour interval (0, 6, 12, and 18 hour in UTC) from the G2S specifications in Korea. (d)The total number of detections as a function of detection azimuth and phase velocities with the average effective sound speeds for troposphere (red lines; 5km<altitude<10km) and for stratosphere (green lines; 40km<altitude<60km and blue lines; 60km<altitude<80km) plotted by seasons.



The omnidirectional G2S ducting fractions (tropospheric arrivals < 15 km and 15 km < stratospheric arrivals < 70 km) from the 6-hour intervals (0, 6, 12, and 18 hour in UTC) at (a) BRDAR, (b) CHNAR, and (c) KSGAR for the time period of 12/2009-11/2010.

CONCLUSIONS

An adaptive F-detector (AFD; Arrowsmith et al., 2009) utilizing the time variable environmental effects is applied to infrasound data (BRDAR, CHNAR, and KSGAR in South Korea) for the one-year dataset (12/2009-11/2010).

The temporal adaptation of AFD is dependent on both weather conditions and local site effects. C-value, scaling factor for background noise level, increases with decreasing wind velocity.

Infrasound detections (number of detections, correlation value, phase velocity and azimuth estimates) show daily and seasonal variations and these observations are affected by environmental conditions such as local wind, ocean wave and atmospheric condition.

Ocean arrays have higher noise conditions than continental array and their infrasound detections are strongly related with ocean energy (the higher ocean wave height the higher RMS amplitude of the detected signals).

Seasonal changes in the distribution of infrasound detections are consistent with wind changes as predicted by G2S specification (Drob et al., 2003). Many infrasound detections in the Korean Peninsula are dependent on troposphere condition during the winter, spring, and fall, while stratospheric propagation condition is favorable during the summer but weak during the winter possibly due to sudden stratospheric warmings.

ACKNOWLEDGMENTS

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