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Complex seismological investigations near Bulgarian Antarctic Base

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Abstract

Bulgarian Antarctic seismic station LIVV was operational during three astral summers between 2015 and 2018 on Livingston Island, Antarctica. The estimated performance of the seismic equipment shows the capability of the station to register seismic events of different nature. More than 12000 seismic events were recorded, most of them related to the seismicity of glaciers. A large number of local earthquakes was also registered. Two methods were used for earthquake location. First one used data from only LIVV station and was based on Golitsyn's method and Vincenty formula. Second one applied DHypo software with different velocity models and seismic phases from four Spanish stations deployed on Deception Island Volcano and two Argentinean-Italian (AI) stations. To study the glacial seismicity we used different technics and procedures: 1) for epicenter estimations of one type of icequakes a developed code for a single station location was applied; 2) GNSS measurements at the surface of glacier Perunika were conducted and meteorological data were collected.

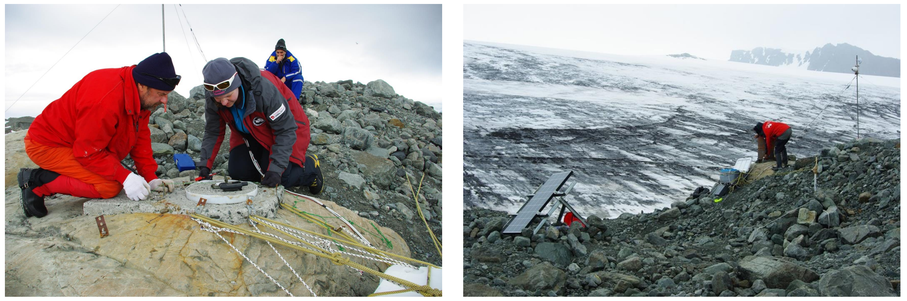


Fig. 1 (left) Installation of seismic station LIVV; (right) Seismic station LIVV and glacier Perunika

Geology and seismicity of South Shetland Islands

Livingston Island is second largest from South Shetland Islands archipelago. This region represents a continental fragment situated in the transition zone between Drake microplate in the North and Antarctic plate in the South. The geological setting of the region is considered to be unique because of its current transformation from subduction to spreading zone. This complex geodynamics is reflected by the presence of active volcanoes in the present and shallow and intermediate seismicity. Even the Bransfield strait is an active rifting zone the subduction is still active along the South Shetland Trench. It is considered as last active part of a subduction zone from that was once extended all along the western margin of the Antarctic Peninsula .

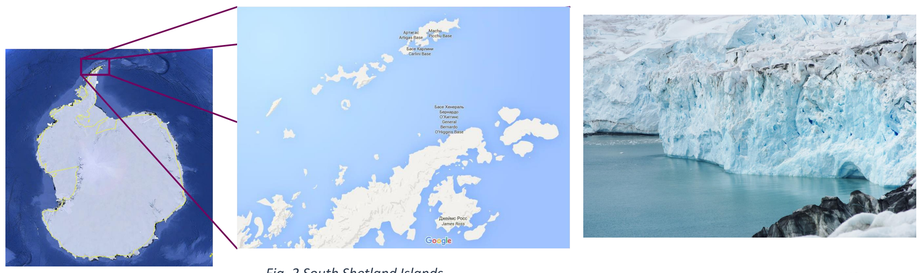


Fig. 2 South Shetland Islands

Seismicity

For all nine months (three astral summers) operational time of the station LIVV more than 12000 seismic events with different origin were registered. 2/3 from the events are identified as icequakes generated mostly due to movement of the closest glacier Perunika. Local, regional and long distant earthquakes and some other signals with natural origin are also registered in the station.

Tectonic events with origin near Livingston Island were separated in three groups using the time difference of P and S onsets (Ts-p) as follow:

- T1 group - earthquakes with time difference Ts-p = 5s;
- T2 group - contains the earthquakes with time difference 5s < Ts-p < 30s ;
- T3 group - recorded earthquakes with Ts-p > 30s were classified as regional or teleseismic events.

Looking for earthquakes in the region of the South Shetland Islands listed in the bulletins of the International Data Centers gave no results and no event located in the interested region during the deployment period (2015-2018) of the LIVV station was found. We suggest that the main reasons for lack of such information are small number of seismic stations in the region, low magnitude of the recorded earthquakes and short deployment period of LIVV station. Events from groups T1 and T2 were localized by two methods – using single station localization technique developed by Golitsyn and with standard minimization procedure. In addition, we used data recorded by permanent stations deployed in the region of Livingston Island. Continuous data of Argentinean - Italian (AI) Network for the astral summers in the period December 2015 - March 2018 were downloaded from the Incorporated Research Institutions for Seismology (IRIS) web site. Data for the period December 2015 - March 2016 of Spanish stations BASE, OBS, C70 and CHI, deployed at Deception Island, were provided by Spanish colleagues.

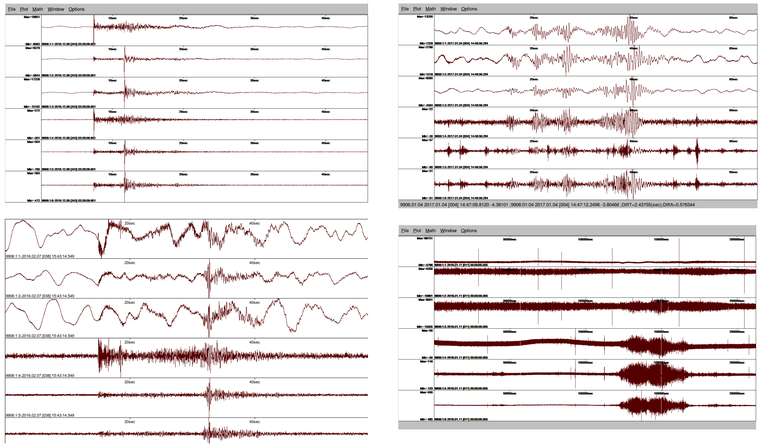


Fig. 3 Waveforms of events and signals recorded on LIVV station. Left: T1 and T2 earthquakes; right: ice generated event and storm

Single station method for earthquakes localization

This method developed by Golitsyn is based on analysis of the seismic signals recorded at one three-component seismic station. Distance to the earthquake's epicenter is computed from the difference between arrival times of P- and S-waves and travel-time tables. Velocity model for the Back arc region of South Shetland Islands limited up to 70 km depth was used to compute the travel time table.

The back azimuth of the epicenter is computed by formula:

$$tg\alpha = \frac{Ae}{An}$$

where Ae is the amplitude of P phase, registered on E-W component of the seismogram, An is P phase amplitude from N-S component and α is the back azimuth (BAZ) of the earthquake. Both amplitudes are measured positive or negative. The sign of P phase from vertical component estimates the real back azimuth.

After the BAZ and distance of each event are computed Vincenty direct equation is used to compute the geographic coordinates of the epicenter.

For automatic localization of events a software code based both on Golitsyn's method and Vincenty formulae was developed. Part of the code is presented below.

References:

L. Dimitrova, G. Georgieva, R. Raykova et al. "Exploring seismicity of Livingston Island (Antarctica) and surroundings using records of Bulgarian broadband seismological station LIVV during the astral summer 2015-2016 ", Compt. Ren. de l'Acad. Bulg. de Sc., 70, 12, 2017, 1709-1718

L. Dimitrova, G. Georgieva et al. "Seismic activity of South Shetland Islands: Results from first Bulgarian broadband seismic station in Antarctica", Ann. de l'Univer. de Sofia, 2019 (in press)

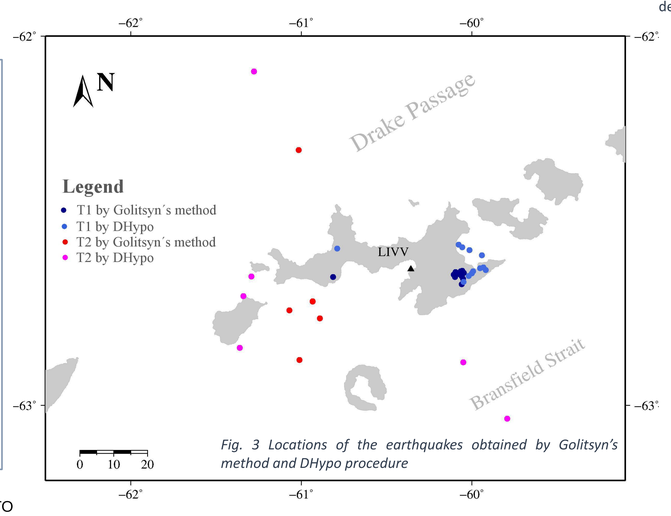
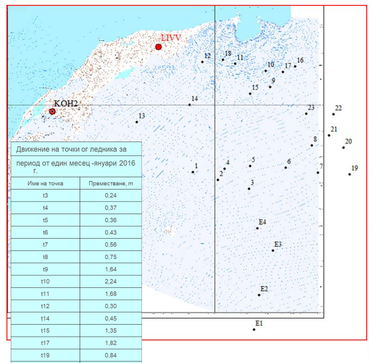


Fig. 3 Locations of the earthquakes obtained by Golitsyn's method and DHypo procedure

```
def compute_baz_Golitcin(An1,Ae1,Az1):
    azim = math.fabs(math.degrees(math.atan(int(Ae1)/int(An1))))
    print "Initial azimuth", azim
    if any( [
       all( [An1>0, Ae1>0, Az1<0] ),
       all( [An1<0, Ae1<0, Az1>0] )
     ] ):
       baz = azim
       print "Case azs=az, azimuth is:", baz
    elif any( [
        all( [An1>0, Ae1<0, Az1>0] ),
        all( [An1<0, Ae1>0, Az1<0] )
     ] ):
       baz = 180-azim
       print "Case azs=180-az, azimuth is:", baz
    elif any( [
        all( [An1>0, Ae1>0, Az1>0] ),
        all( [An1<0, Ae1<0, Az1<0] )
     ] ):
       baz = 180+azim
       print "Case azs=180+az, azimuth is:", baz
    elif any( [
       all( [An1>0, Ae1<0, Az1<0] ),
       all( [An1<0, Ae1>0, Az1>0] )
     ] ):
       baz = 360 - azim
       print "Case azs=360-az, azimuth is:", baz
    return baz
```

Seismic activity in glacier Perunika

To study the seismicity of the nearest glacier to the Base a set of different data was collected during the recording period of seismic station LIVV. This are GNSS measurements, meteorological data, video records and visual observation on the glacier terminus.



Име на точка	Преместване, m
t3	0,24
t4	0,37
t5	0,36
t6	0,43
t7	0,56
t8	0,75
t9	1,64
t10	2,24
t11	1,68
t12	0,30
t14	0,45
t15	1,35
t17	1,82
t19	0,84
t20	1,17
t21	1,21
t22	1,58
t23	1,01

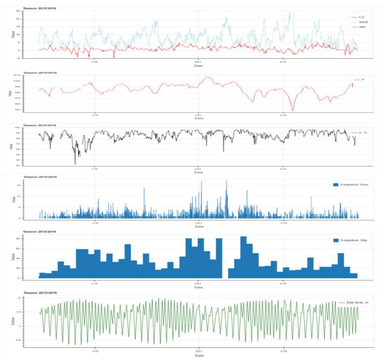
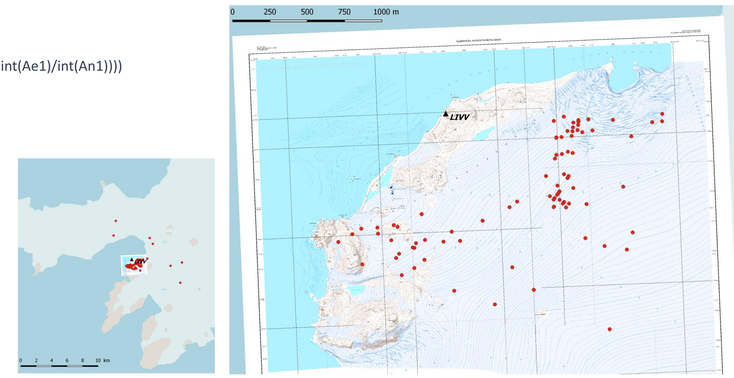


Fig. 4 Left: Points from glacier surface where GNSS measurements were conducted and estimated velocities; right: comparison between meteorological data, icequakes daily rate and sea level.

Seismic activity in glacier Perunika

Ice generated seismic events were separated in five groups according to waveform and P-S time. For one of the groups P and S onset times were estimated and coordinates of events epicenters were computed using the developed code for earthquakes single station localization. Below the maps with icequakes epicenters is presented. Three clusters can be seen – two in the active part of the glacier and one in the small glacier near the port of the Base.



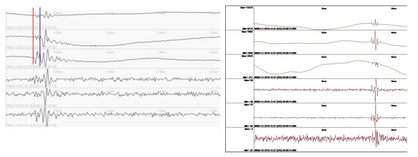


Fig. 5 Up: Maps with estimated icequakes epicenters (red dots);
Down: Typical waveforms of ice generated events from the selected group. Red and blue lines show the P and S phases.

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