# Supplement to manuscript 'A monitoring system for spatiotemporal electrical self-potential measurements in cryospheric environments'

March 4, 2020

# S1: Measurement flowchart

| schedule | measured parameter | action |
|---|---|---|
| daily<br>hourly for $V_{bat}$ > 12.3 V<br>**or**<br>6-hourly for $V_{bat}$ < 12.2 V | contact resistances<br>electrode temperatures | measure<br>measure |
| **5 am - 8 pm**<br>10 min, if $V_{bat}$ > 12.6 V<br>hourly,<br>if $V_{bat}$ > 12.3 V; < 12.5V<br>6-hourly, if $V_{bat}$ < 12.2 V | SP-voltages<br>battery voltage<br>air-temperature<br>solar voltage | |
| **8 am - 5 pm**<br>30 min, if $V_{bat}$ > 12.6 V<br>hourly,<br>if $V_{bat}$ > 12.3 V; < 12.5V<br>6-hourly, if $V_{bat}$ < 12.2 V | SP-voltages<br>battery voltage<br>air-temperature<br>solar voltage | |
| 6-hourly<br>daily | | send data by email<br>update logger time to UTC using ntp |

Table 1: Measurement schedule of the measurement system. Note that data upload and ntp schedules have been varied over time to reduce power consumption and increase system reliability
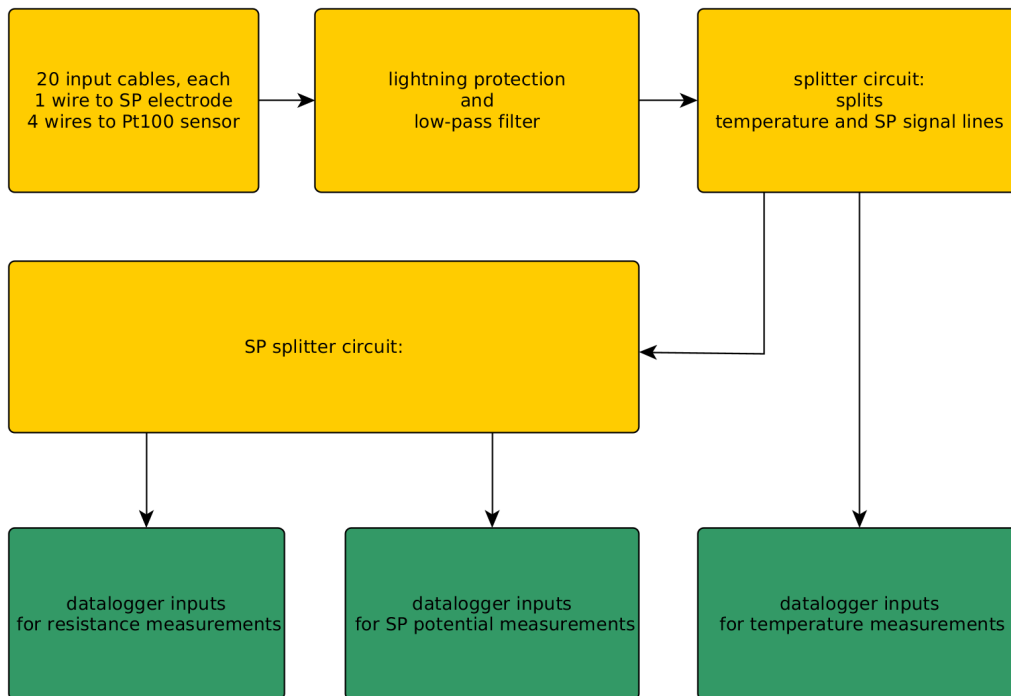
# S2: Internal signal flow



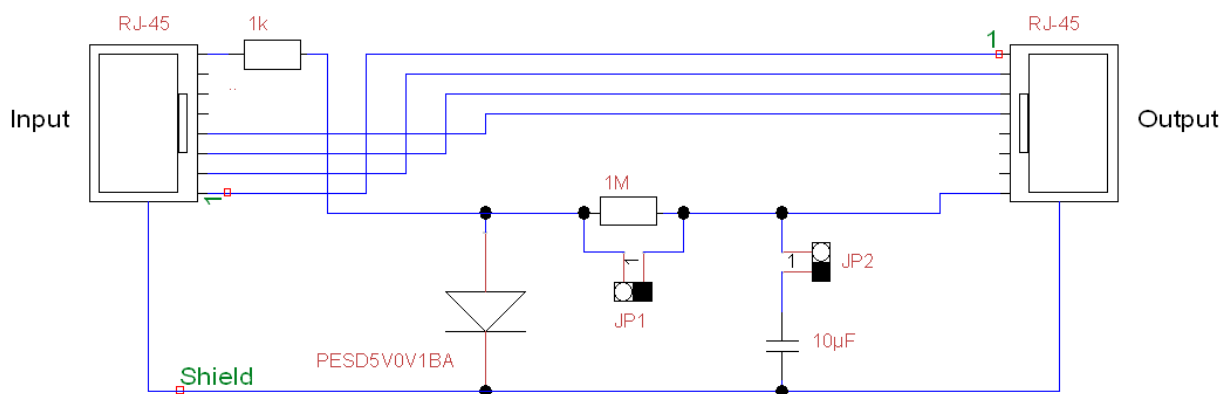Figure 1: Signal flow in the measurement system



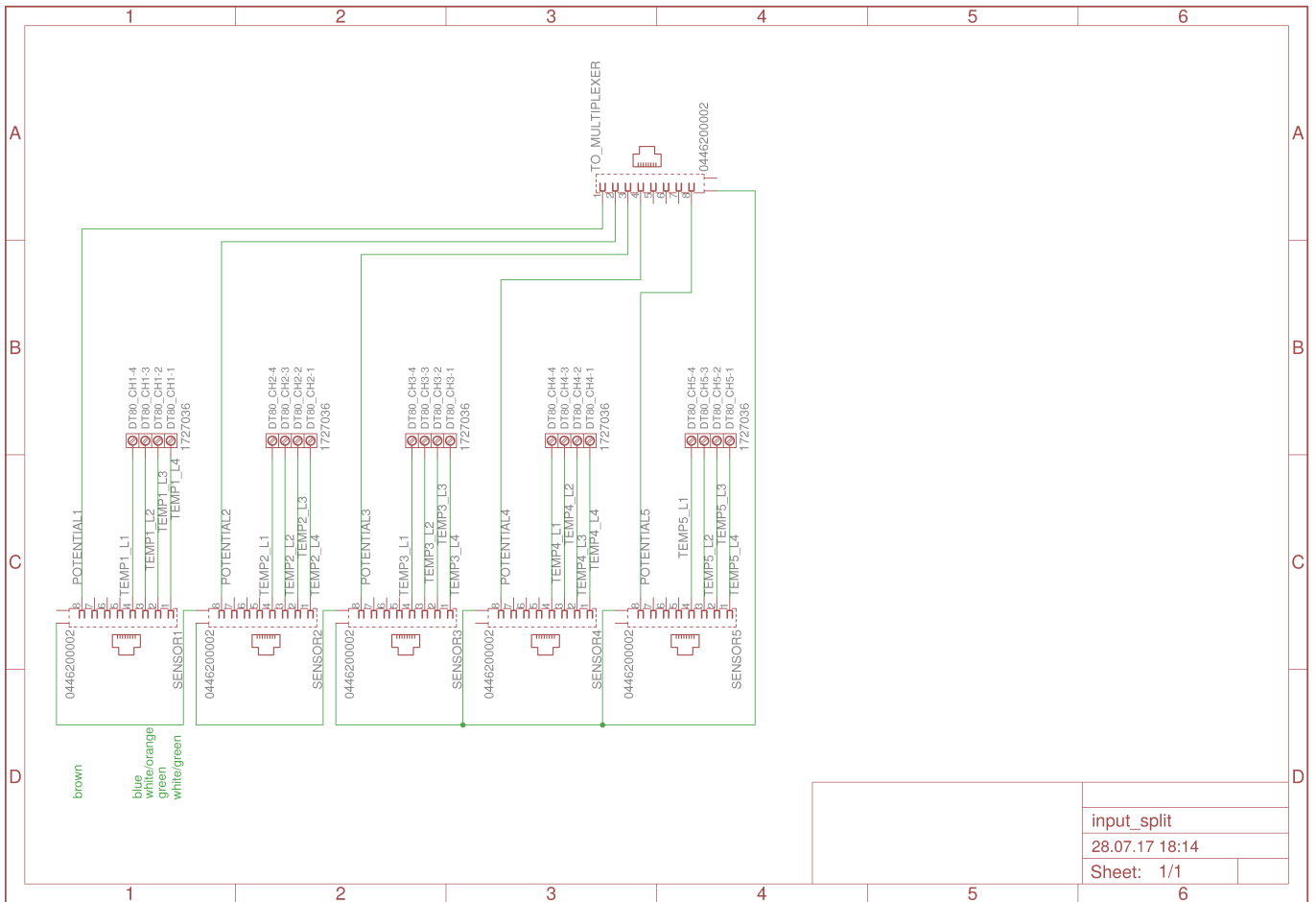Figure 2: Lightning protection and low-pass circuit, applied to each SP electrode input line.

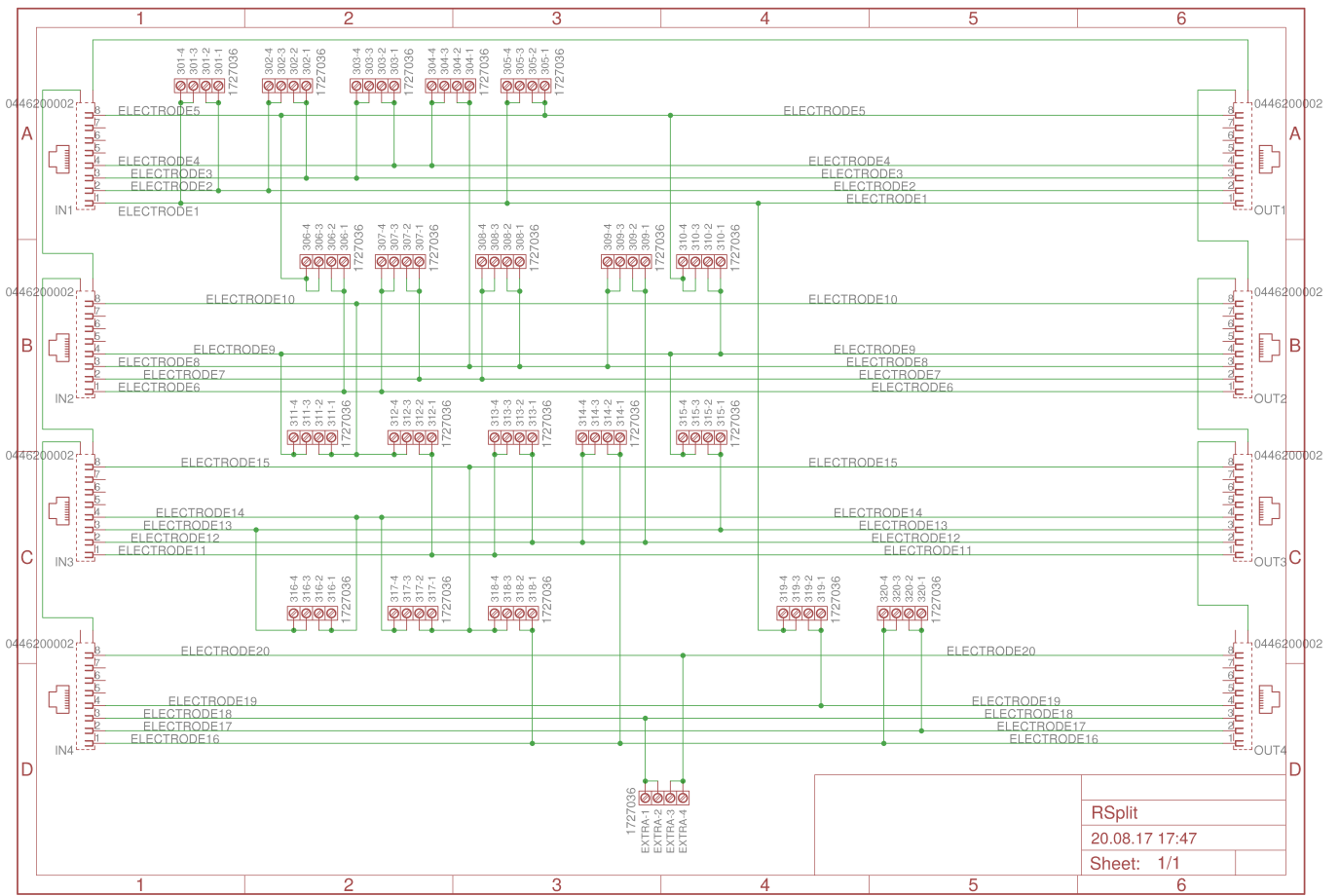Figure 3: Input splitter diagram, splitting temperature and SP signal lines

Figure 4: Resistance multiplexer diagram, multiplexing electrode lines to separate inputs for resistance measurements
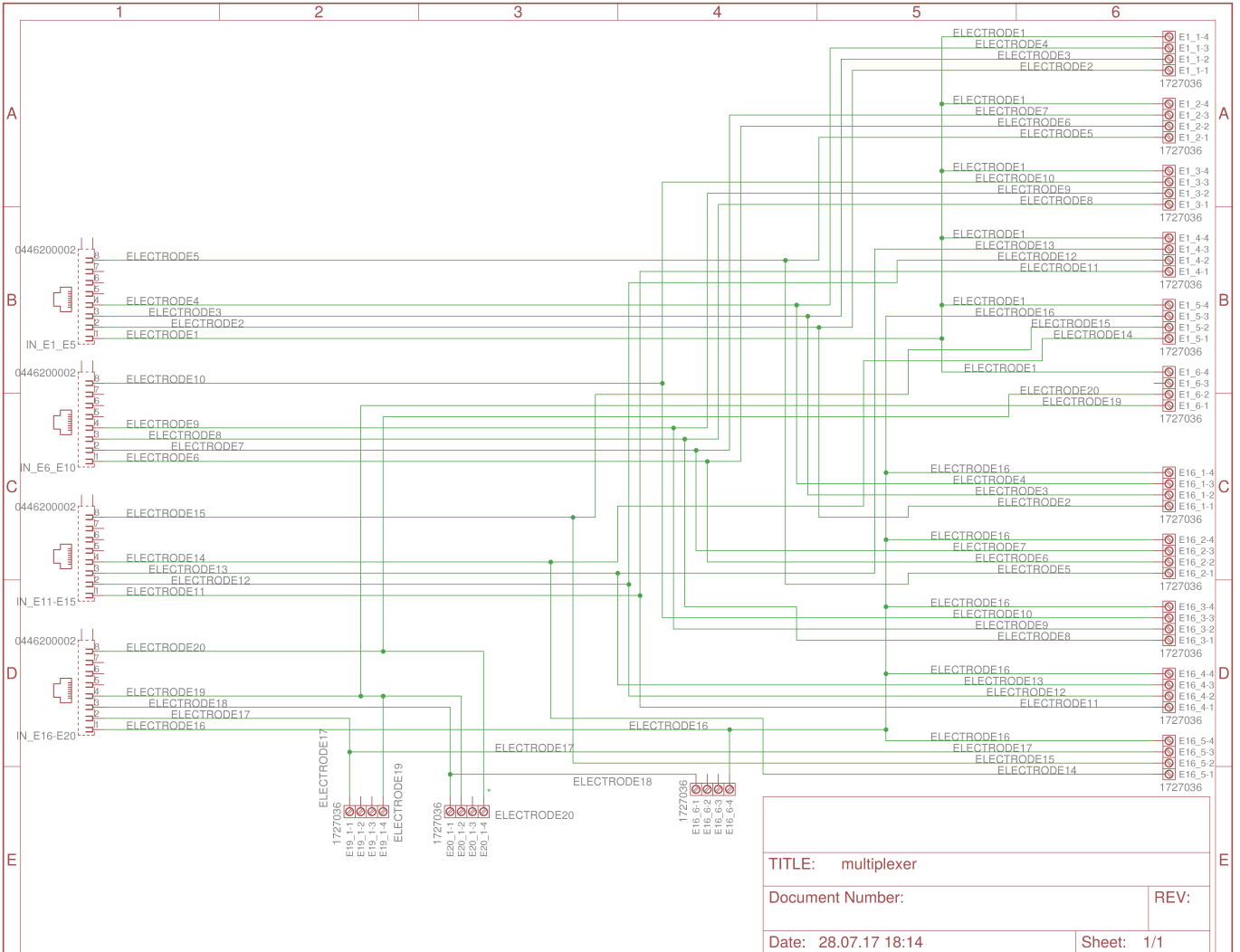
Figure 5: Multiplexer circuit diagram multiplexing SP input lines to specific inputs of the data logger
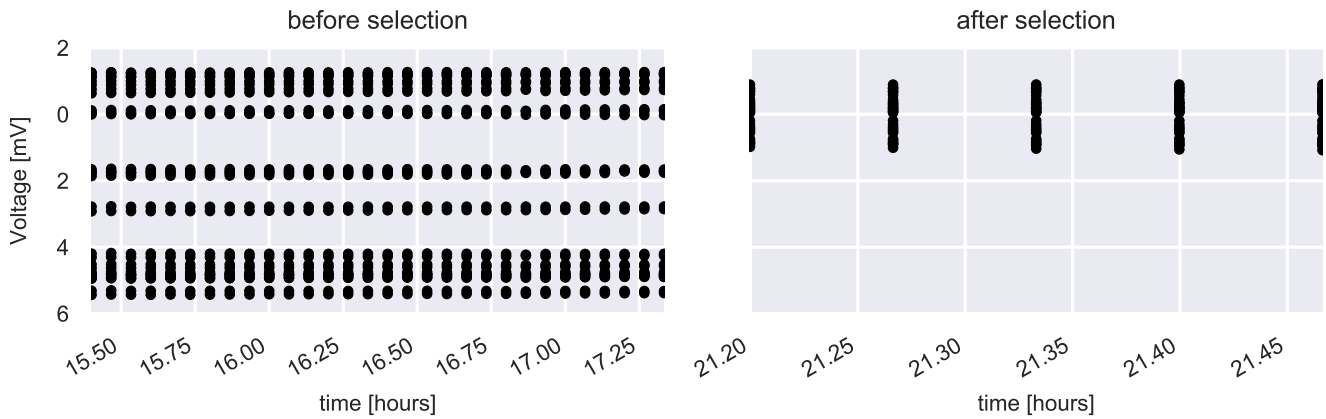
# S3: Electrode matching



Figure 6: Test measurements of base-line electrical offsets in saline solution. Left: Voltage measurements for 20 randomly selected SP electrodes, right: Voltage measurements for 20 matched SP electrodes

The absolute potentials of SP electrodes changes with age, chemical environment, and usage history. As such, it is commonly advised to check the baseline potential difference between electrodes before measurements commence (e.g., Corwin, 1989), in order to not confuse the offsets with process-based signals. Out of the pool of available SP electrodes, we initially selected 20 random electrodes. This yielded voltages with respect to electrodes 1 and 16 of down to -5.4 mV (Fig. 6, left). Following this, electrodes were selected out of the available pool to minimize this offset voltage, resulting in a maximum voltage difference of $\pm 1$ mV (Fig. 6, right).

# S4: SP data filtering



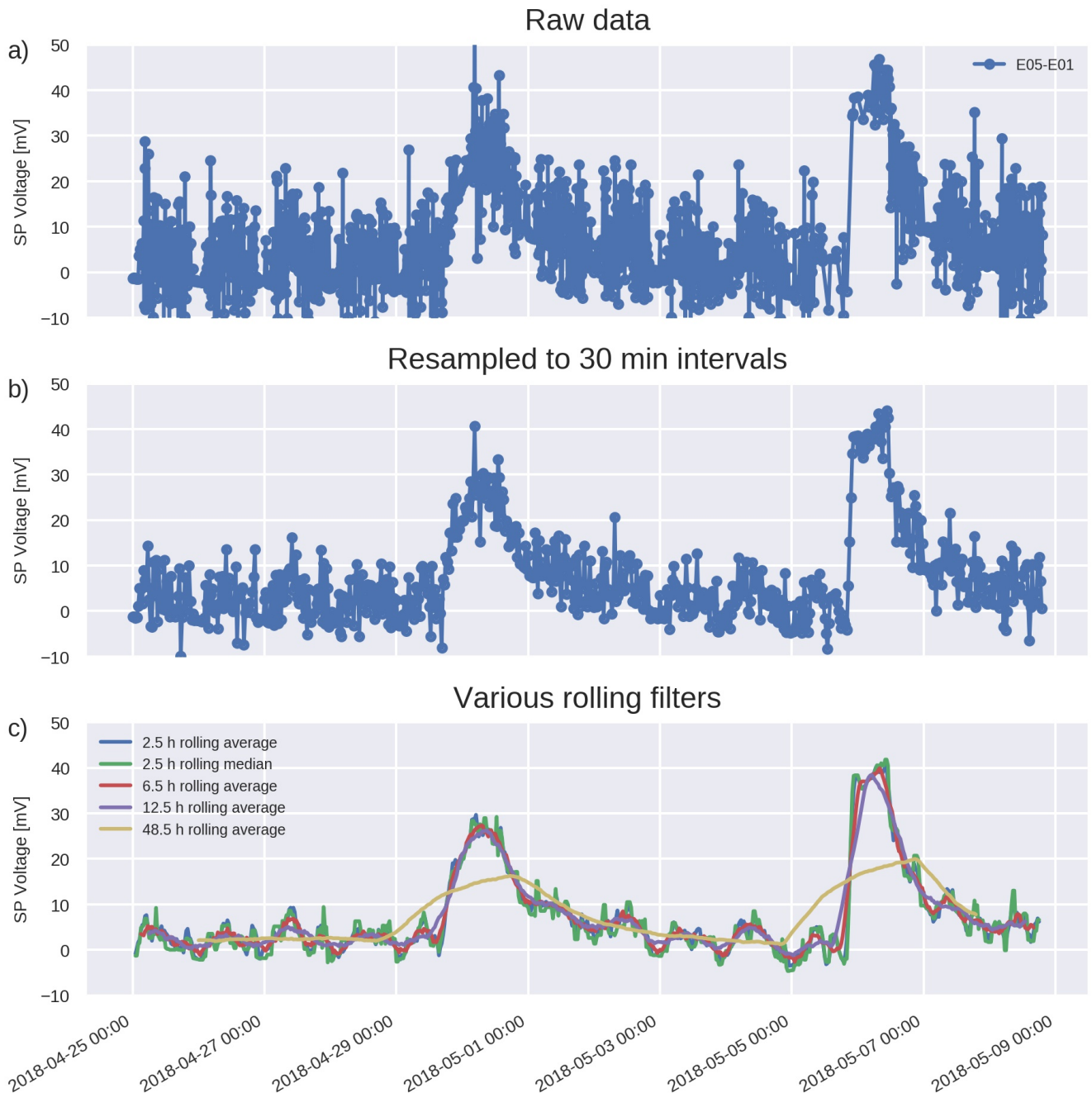Figure 7: Data processing steps applied to SP data presented in this study, shown for the dipole E5-E1.

Captured SP data presented in this study exhibits quite large noise levels (e.g., Fig. 7a). This is caused by aliasing artifacts, as well as anthropogenic noise due to the operation of the cable-car to the summit and corresponding touristic operations. As such data was processed as follows: First, data was resampled to

30 minute intervals, using linear interpolation and averaging. The effect of this operation is exemplarily shown in Fig. 7b. Depending on the specific application, in the following various rolling mean filters are applied to the data, serving as simple, yet crude, low-pass filters. The effects of various window sizes is presented in Fig. 7c.

We fully acknowledge that the use of rolling average filters is not necessarily optimal for frequency-domain filtering. In addition, other filters, such as the rolling median or the alpha-trimmed-mean filter (Gersztenkorn and Scales, 1988), are known to better preserve transient spikes. Yet, in the present study we only aimed at presenting certain characteristics or concepts, which allowed us to use the robust and simple rolling average filter.

# S5: Wavelet analysis of noise data
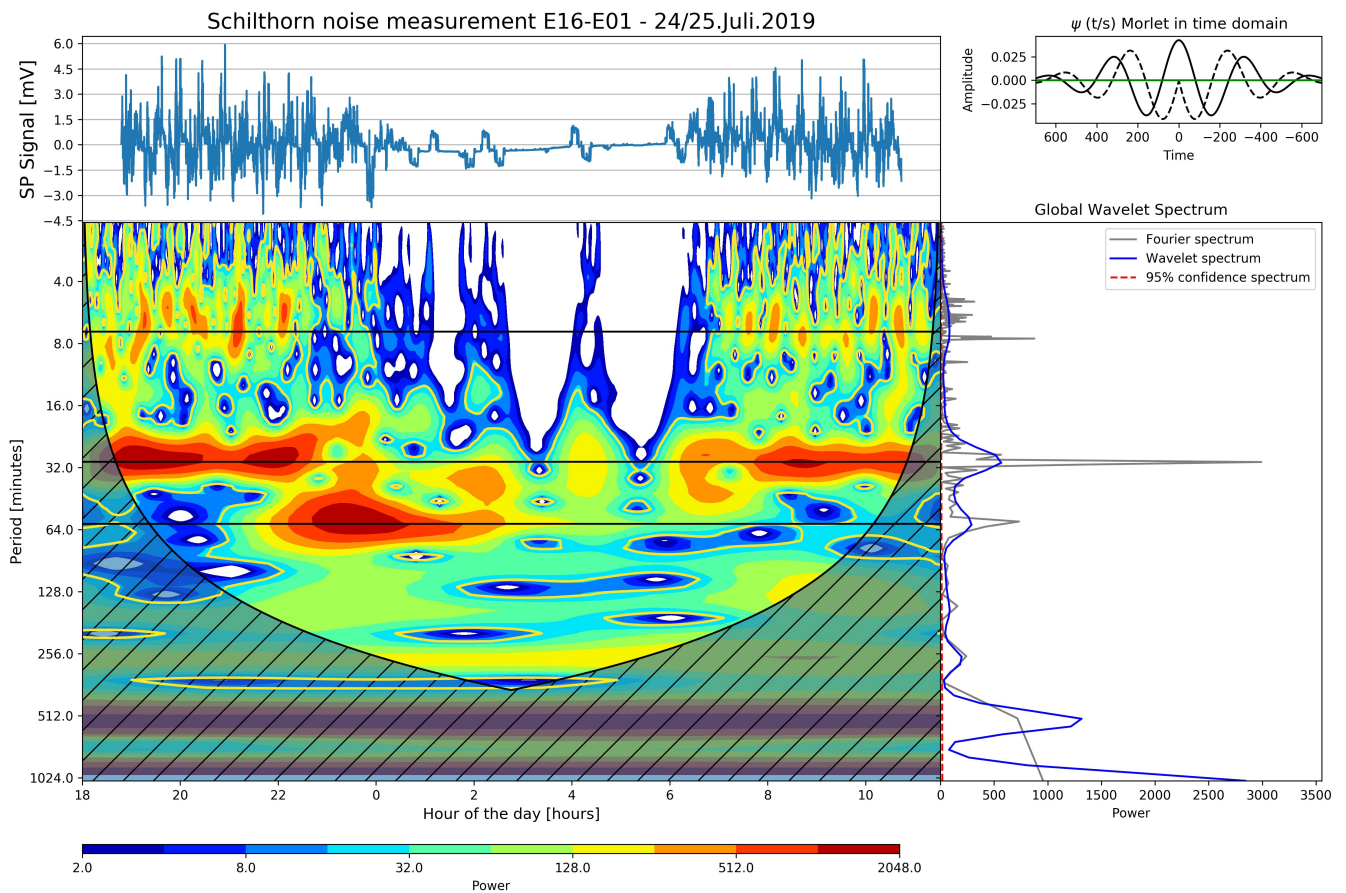


Figure 8: Wavelet analysis of the noise measurements 2019

In order to gain more information on spatio-temporal spectral content, a wavelet-based analysis (e.g., Grinsted et al., 2004) was conducted on the noise measurements conducted in 2019. The analysis shows strong 30 minute components during the day, a section of a few hours with 60 minute components just before night, and no significant spectral components during night-time hours (Fig. 8).

# 1 Data Logger programming

```
' DT80M program Schilthorn SP system 2017


' reset the logger
session stop
session clear
cevtlog
cerrlog
deld job=* archive=y
deljob *


' restore settings to default
factorydefaults


' some debug infos
profile parameters P56=1


' we operate on UTC
profile locale time_zone=+0H


' sim:
profile modem service=gsm_preferred
profile modem MIN_SIGNAL_FOR_DATA_DBM=-110


' coop mobile CH internet settings
profile modem pin=XXXX
profile modem apn=click
profile modem apn_account=""
profile modem apn_password=""
profile modem_session smtp_server=XXXX
profile modem_session smtp_account=XXXX
profile modem_session smtp_password=XXXX


PROFILE UNLOAD FTP_RETRIES=10


' mains frequency [Hz]
profile parameters p11=20


' sleep while on power, but not if USB is connected
profile parameters p15=1


' 5V power output while the measurement system is on
PWR5V=1


' should prevent some debug messages
profile http_server enable_wdg=no


' reduce power by disabling ethernet
profile ethernet enable=no
profile ethernet ip_address=192.168.21.10
profile ethernet subnet_mask=255.255.255.0


' define functions for the yellow button
profile function f1_label = "mail data"
profile function f1_command = "copyd start=new \
      dest=mailto:XX@XX.XX?&subject=sch17_01&priority=high&interface=modem \
      format=dbd merge=N"
```

```
profile function f2_label = "PWR5V"
profile function f2_command = "PWR5V=1"


profile function f3_label = "session signal"
profile function f3_command = "session signal"


profile function f4_label = "download all"
profile function f4_command = "COPYD job=* dest=a: merge=N format=dbd; \
        servicedata a:\\\\servicedata.txt; removemedia"


profile function f5_label = "servicedata to usb"
profile function f5_command = "SERVICEDATA a:\\\\servicedata.txt"


profile modem_session sTART_CRON=0:5:10:*:*:*
profile modem_session stop_CRON=0:20:10:*:*:*
profile modem_session timing_control=cron
' [ seconds : minutes : hours : day : month : weekday ]


BEGIN "sch17_01"

        ' measure voltages
        RA"SPV"("B:",data:ov:370D)10M
                101*V("E02-E01",ES10)
                101+V("E03-E01",ES10)
                101-V("E04-E01",ES10)
                102*V("E05-E01",ES10)
                102+V("E06-E01",ES10)
                102-V("E07-E01",ES10)
                103*V("E08-E01",ES10)
                103+V("E09-E01",ES10)
                103-V("E10-E01",ES10)
                104*V("E11-E01",ES10)
                104+V("E12-E01",ES10)
                104-V("E13-E01",ES10)
                105*V("E14-E01",ES10)
                105+V("E15-E01",ES10)
                105-V("E16-E01",ES10)
                106*V("E19-E01",ES10)
                106+V("E20-E01",ES10)
                107*V("E02-E16",ES10)
                107+V("E03-E16",ES10)
                107-V("E04-E16",ES10)
                108*V("E05-E16",ES10)
                108+V("E06-E16",ES10)
                108-V("E07-E16",ES10)
                109*V("E08-E16",ES10)
                109+V("E09-E16",ES10)
                109-V("E10-E16",ES10)
                110*V("E11-E16",ES10)
                110+V("E12-E16",ES10)
                110-V("E13-E16",ES10)
                111*V("E14-E16",ES10)
                111+V("E15-E16",ES10)
                111-V("E17-E16",ES10)
                112*V("E18-E16",ES10)
                113*V("E18-E20",ES10)
                113+V("E19-E20",ES10)
                114*V("E17-E19",ES10)
```

```
        115*HV("Battery")
        116PT385("TempOutside",4W)
        117*HV("RH_INSIDE")
        118*HV("RH_OUTSIDE")
        119*HV("RAIN")
        120*HV("SOLAR")
        VEXT


' measure temperatures
RB"TEMPS"("B:",data:ov:370D)1H
        201*V("T1Voltage")  201PT385("Temp01",4W)
        202*V("T2Voltage")  202PT385("Temp02",4W)
        203*V("T3Voltage")  203PT385("Temp03",4W)
        204*V("T4Voltage")  204PT385("Temp04",4W)
        205*V("T5Voltage")  205PT385("Temp05",4W)
        206*V("T6Voltage")  206PT385("Temp06",4W)
        207*V("T7Voltage")  207PT385("Temp07",4W)
        208*V("T8Voltage")  208PT385("Temp08",4W)
        209*V("T9Voltage")  209PT385("Temp09",4W)
        210*V("T10Voltage") 210PT385("Temp10",4W)
        211*V("T11Voltage") 211PT385("Temp11",4W)
        212*V("T12Voltage") 212PT385("Temp12",4W)
        213*V("T13Voltage") 213PT385("Temp13",4W)
        214*V("T14Voltage") 214PT385("Temp14",4W)
        215*V("T15Voltage") 215PT385("Temp15",4W)
        216*V("T16Voltage") 216PT385("Temp16",4W)
        217*V("T17Voltage") 217PT385("Temp17",4W)
        218*V("T18Voltage") 218PT385("Temp18",4W)
        219*V("T19Voltage") 219PT385("Temp19",4W)
        220*V("T20Voltage") 220PT385("Temp20",4W)
        REFT 1REFT 2REFT 3REFT


' Resistances
RC"RES"("B:",data:ov:1MB)[0:5:6]
        301R("R01-02",III) 301*V("V01-02")
        302R("R02-03",III) 302*V("V02-03")
        303R("R03-04",III) 303*V("V03-04")
        304R("R04-08",III) 304*V("V04-08")
        305R("R01-05",III) 305*V("V01-05")
        306R("R05-06",III) 306*V("V05-06")
        307R("R06-07",III) 307*V("V06-07")
        308R("R07-08",III) 308*V("V07-08")
        309R("R08-12",III) 309*V("V08-12")
        310R("R05-09",III) 310*V("V05-09")
        311R("R09-10",III) 311*V("V09-10")
        312R("R10-11",III) 312*V("V10-11")
        313R("R11-12",III) 313*V("V11-12")
        314R("R12-16",III) 314*V("V12-16")
        315R("R09-13",III) 315*V("V09-13")
        316R("R13-14",III) 316*V("V13-14")
        317R("R14-15",III) 317*V("V14-15")
        318R("R15-16",III) 318*V("V15-16")
        319R("R01-19",III) 319*V("V01-19")
        320R("R16-17",III) 320*V("V16-17")
        VLITH
        R100
        VREF
        VZERO
```

```
    ' at night we increase measurement intervals
RD[0:5:20] IF(115*HV>12.6){RA30M}
RE[0:5:4] IF(115*HV>12.6){RA10M}


    RF6H
            DO{copyd start=new2 dest=mailto:XXX@XXX.XX?&\
                    subject=sch17_01&priority=high&interface=modem format=dbd merge=N}


    ' Alarm section
    RH2H
            ALARM1(115*HV>12.6)"Battery larger than 12.6 V"{RA10M RB1H}
            ALARM2(115*HV><12.3,12.5)"Battery below 12.5, but above 12.3 V"{RA1H RB1H}
            ALARM3(115*HV<12.2)"Battery below 12.2 V"{RA6H RB6H}
            DO{PWR5V=1}


    ' update clock
    RX[0:10:11:*:*:*] do{ntp}


    LOGON
END

' disable debug
profile parameters P56=0
```

Listing 1: Programming of the DataTaker DT80M – Series 4 logger

# References

Corwin, R.: Data quality for engineering self-potential surveys, in: Detection of Subsurface Flow Phenomena, edited by Merkler, G.-P., Militzer, H., Hötzl, H., Armbruster, H., and Brauns, J., pp. 49–72, Springer Berlin Heidelberg, Berlin, Heidelberg, https://doi.org/10.1007/BFb0011630, 1989.

Gersztenkorn, A. and Scales, J. A.: Smoothing seismic tomograms with alpha-trimmed means, Geophysical Journal International, 92, 67–72, https://doi.org/10.1111/j.1365-246X.1988.tb01121.x, 1988.

Grinsted, A., Moore, J., and Jevrejeva, S.: Application of the cross wavelet transform and wavelet coherence to geophysical time series, Nonlinear processes in geophysics, 11, 561–566, https://doi.org/10.5194/npg-11-561-2004, 2004.