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Rigging Recommendations For Dual Radiosonde Soundings

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Abstract

This document gives a recommendation for the payload configuration for performing dual soundings with two radiosondes. General guidelines are specified which aides the operator to prepare a payload for dual soundings. The recommendation is partly based on the results of Vaisala RS92-RS41 dual soundings performed at Lindenberg observatory using various configurations of the payload. In addition, general rules and guidelines are proposed for rigs with multiple-device payloads.

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1 Introduction

Comparison measurements are an essential part of the GRUAN measurement strategy. They are generally an important tool for the assessment of data integrity (e.g. revealing biases or systematic effects). In particular they help to ensure long-term stability of data records when instrument changes occur. An example is the upcoming transition within GRUAN from the RS92 to the RS41. This transition will occur within the next few months at numerous GRUAN sites. For reasons of comparability and consistency it is important to harmonize the payload configuration between sites that perform intercomparison measurements. This document gives a recommendation for the configuration of the payload for twin-soundings with two radiosondes.

It is essential that payloads for radiosonde intercomparisons should be configured in such a way to ensure that:

- both sondes sample the same air column,
- that heat- and water vapour contamination from the rig or the balloon does not occur,
- that the overall profiling operation is in all aspects as similar as possible to routine single soundings.

This will ensure that radiosondes are compared under identical conditions. However, the actual configuration of the rig determines to what extent these criteria are met.

Heating of the sensor by solar radiation is the main error source for daytime soundings in the stratosphere. This error can manifest itself as strong systematic deviations in the measured profile. The time scale of these deviations ranges from seconds (the time-resolution of the sounding) to minutes. The shape, width, amplitude, and occurrence of the radiation induced features is influenced by the configuration of the payload. When these features propagate in the processing chain, i.e. they are not removed from the profile by e.g. filtering, they will affect statistical properties of the profile, such as the variance, and possibly even introduce biases in the data.

In Section 2 we present the results of an investigation into the influence of the payload configuration on systematic effects in coincidentally measured profiles during twin soundings. In this study, various configurations were systematically tried and tested. The findings of these experiments form the foundation of the considerations and recommendations given in Section 3 for the payload configuration which is to be used for radiosonde intercomparisons. Further recommendations for extended payloads consisting of multiple instruments, such as radiosondes plus ozone sondes, are given in Section 4.

In the context of this document, a comparison measurement is a single sounding consisting of two or more radiosondes attached to the same balloon. This is the preferred method for intercomparisons, because other methods, such as launching in an alternating sequence or quasi-simultaneously with two or more separate balloons cannot guarantee that the radiosondes in question have encountered identical air masses and experienced the same measurement conditions, whereas precisely these two criteria are essential when performing an instrument intercomparison.

2 Systematic deviations

Apart from calibration issues, measurement errors, i.e. the difference between the values measured by the sensors and the true state of the atmosphere are the result of the sensor's behavior under specific environmental conditions. Examples of this are wetting or icing of the temperature sensor during a cloud passage and subsequent cooling by evaporation, or the temperature-dependent response time (“time-lag”) of capacitive humidity sensors. An important systematic error for the temperature measurements is caused by heating of the sensor by solar and diffuse radiation. The radiation error becomes more important with increasing altitude, due to the less efficient cooling of the sensor at low pressures. In the stratosphere, the daytime solar radiation-induced temperature error is dominant, and the ever-changing orientation of the sensor boom with respect to the Sun due to pendulum motion and rotation of the rig, introduces quasi-periodic structures in the data, most notably in the temperature profile. In the stratosphere, wetting due to clouds and subsequent evaporative cooling are unlikely due to the very low humidity levels that prevail in this part of the atmosphere. However, humidity measurements in the stratosphere can be affected by moisture evaporating off the balloon or the rig.

We conducted several test-soundings, in which various configurations for a rig consisting of two Vaisala RS92 and two RS41 radiosondes were tested. The primary purpose of these tests was not to quantify the radiation error, but to get a taste of the shape and nature of the structures that are introduced in the temperature profile as a result of the radiation effect.

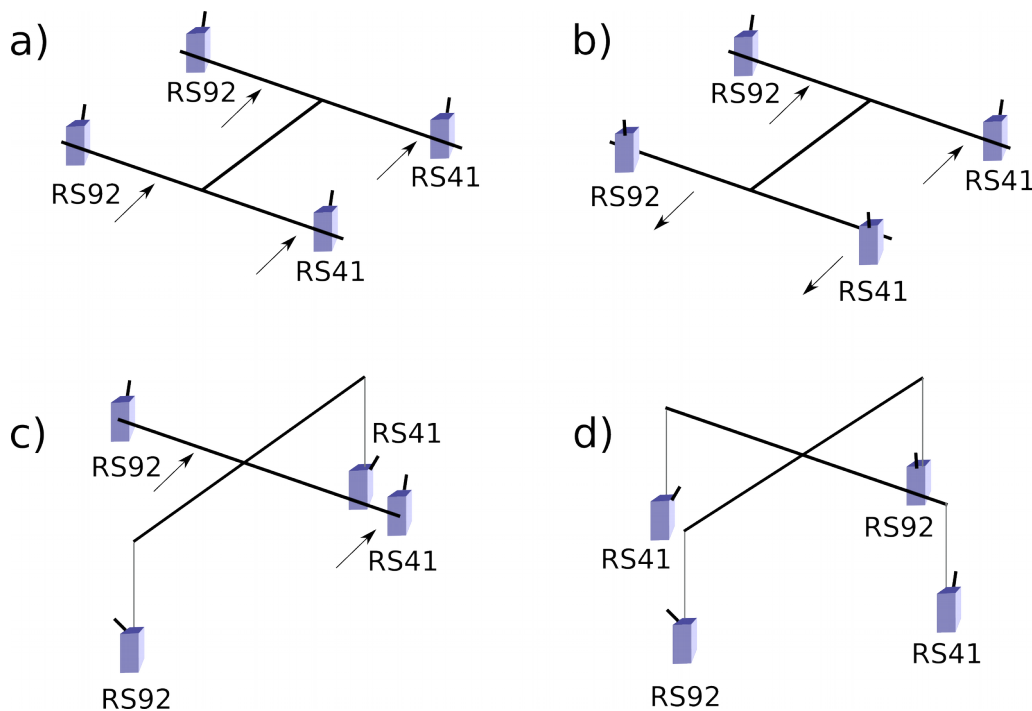


Figure 1: Sketch of four different rig configurations used to investigate the influence of sensor orientation on radiation-induced effects in radiosonde intercomparisons. **a)** Radiosondes attached to the rod with the sensor booms pointing in the same direction (parallel). **b)** Radiosondes attached to the rod, with the sensor booms away from each other (anti-parallel). **c)** Mixed configuration; of each type one radiosonde is attached and one is hanging, rotating freely. The sensor booms of the attached sondes (different type) are oriented parallel. **d)** All sondes hanging and rotating freely.

Figure 1 gives a schematic overview of the four setups that were used in the test-soundings. In the first setup (Figure 1a), the sondes were attached with tape to a rod with the sensor booms all pointing in the same direction, as indicated by the arrows. For this parallel configuration it is expected that temperature differences between identical sondes do not depend on the sensor orientation with respect to the sun, but that these differences are random instead. Typical results for this setup are shown in Figure 3 and discussed below. In the second setup (Figure 1b), the sondes were again fixed to the rod, with the backs of the radiosondes facing each other, i.e. out of phase by half a revolution around its length axis. For this anti-parallel setup, with the sensor booms mounted in opposite directions, it is expected that large differences in the temperature profiles occur due to the rotation of the rig and the different orientation of the sensor booms with respect to the Sun. In the third setup (Figure 1c) one of each type (RS92 or RS41) is taped to the rod where the other radiosonde is connected with a string and spinning freely. In the last setup (Figure 1d) all radiosondes are connected with a string and spinning freely. In these last two setups it is expected that the hanging radiosondes are spinning in a random fashion with the result that structures due to solar heating are random and fully uncorrelated.

Figure 2 shows two exemplary sections of raw temperature records measured with the first and last setup, respectively. Figure 3 presents the differences between the raw temperatures in the stratosphere of identical sonde types for the four setups flown at daytime. Figure 3a shows that for setup 1, with all sensor booms oriented parallel. The temperature differences are small and mostly random. This is as expected because all sensor booms have the same orientation with respect to the

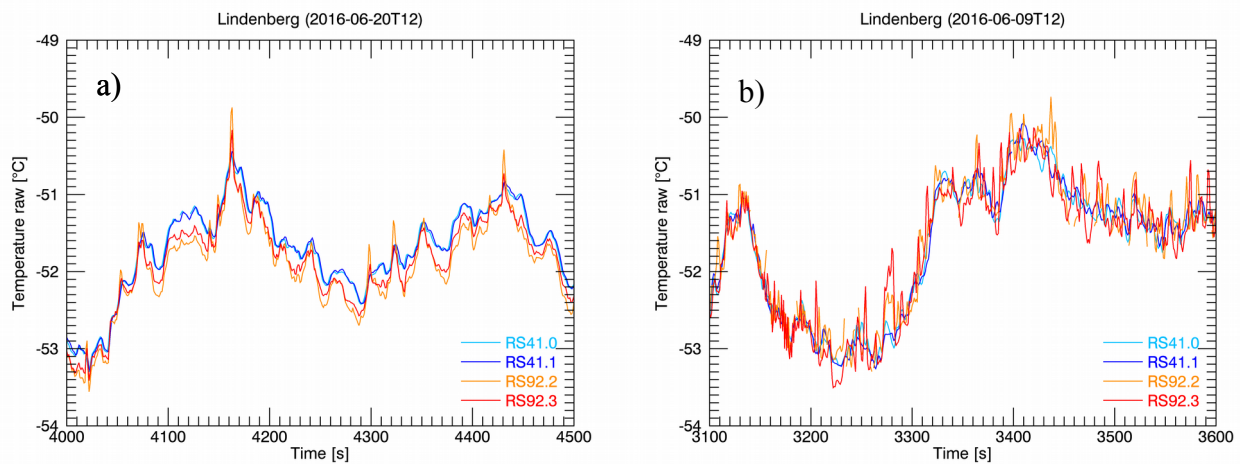


Figure 2: Plots of (raw) temperature data for soundings in the stratospheric between 17 and 25 km, plotted versus time. **a)** Parallel sensor boom orientation (setup 1). **b)** All sondes rotating freely (setup 4). For the parallel setup the time series there is a strong correlation of the sondes' timeseries, in contrast to the uncorrelated time series for the freely rotating sondes. This indicates that a significant portion of the variations in the temperature profile is the result of systematic directional effects (the orientation of the sensor boom with respect to the Sun).

sun and the ambient radiation field. Still, small periodic structures persist, which currently cannot be explained. As shown in Figure 3b, the setup where the sensor booms are mounted anti-parallel, leads to large oscillatory structures in the temperature differences, with amplitudes up to 1 K.

These oscillations are fairly uniform and by far exceeded the resolution and calibration uncertainties of the temperature sensors. The amplitude of the oscillations depends on the sonde type. The oscillatory pattern persists over long parts of the profile in the stratosphere. In other parts of the profile (not shown here) systematic shifts in the averaged value indicate that the rotational movement of the payload was temporarily halted, so that the sensor booms had the same orientation towards the

Sun for a prolonged time.

The temperature difference profiles for the setups with fixed orientation (setup 1 and 2) exhibit oscillations with various frequencies and amplitudes. This is partly attributed to the pendulum motion, where the period of the oscillation is determined by the length of the balloon rope. The other oscillations with longer periods than the pendulum motion are probably due to the rotating rig and are subject of further investigation. The temperature difference profiles for setups 3 and 4, with one or more hanging sondes, is dominated by erratic peaks which is consistent with random rotation of the hanging sondes (Figure 3c-d). This erratic pattern is superimposed on a relatively small oscillatory background. This oscillatory structure is stronger when one of the sondes is fixed (Figure 3). Table 1 provides statistical metrics (mean and standard deviation) of the difference profiles for identical radiosonde types shown in Figure 3. This shows that the average differences are small (<0.02 K for RS41 and <0.07 K for RS92, respectively) and seem not to be related to the payload configuration. The standard deviation, however, depends strongly on the payload configuration:

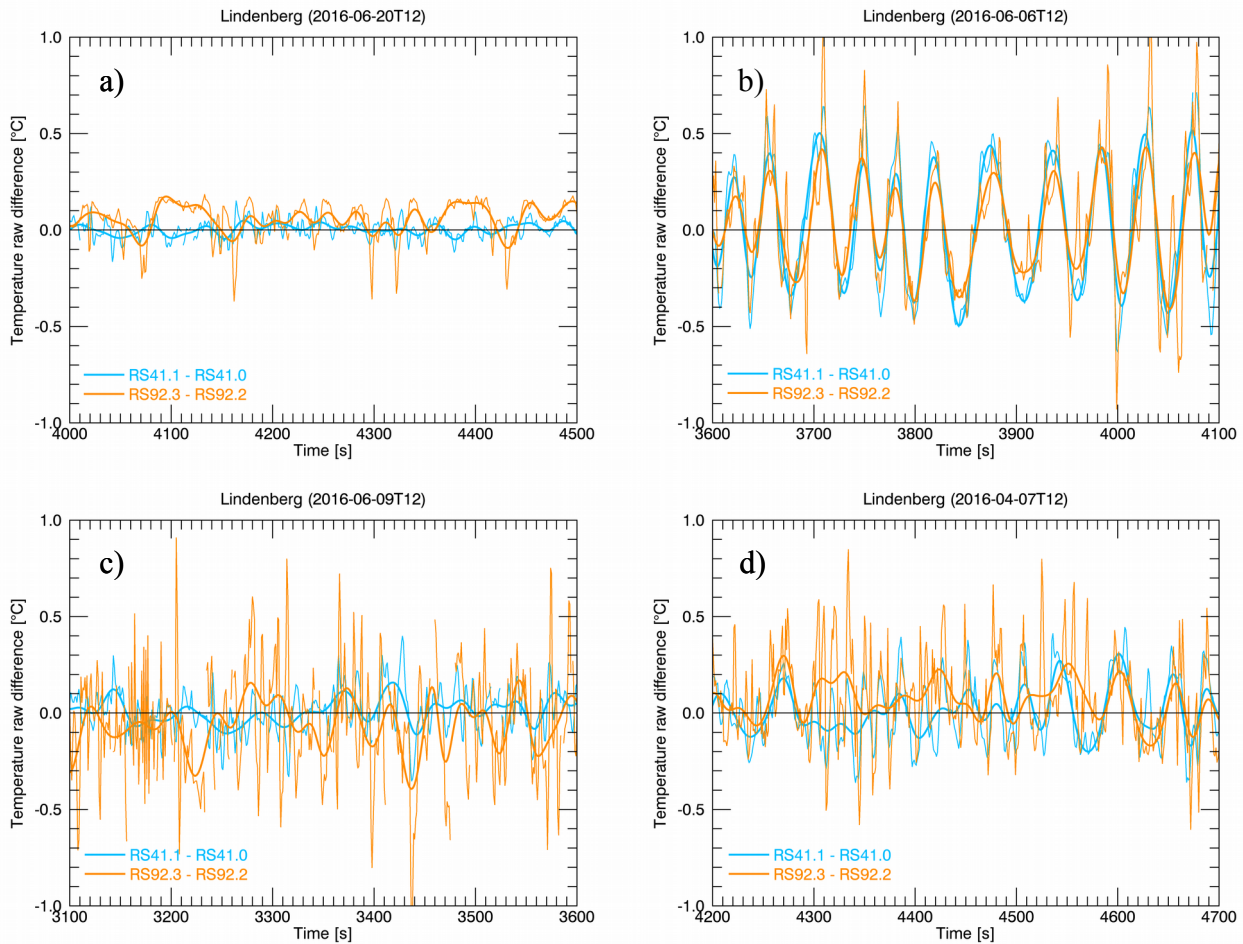


Figure 3: Plots of temperature differences (raw measurement data) between identical radiosondes during twin soundings, plotted versus time. The shown intervals correspond to stratospheric sections roughly between 17 and 25 km. Data are displayed at 1s-intervals with overlying smoothed curve ($N=15$). **a)** Setup 1 (parallel sensor booms). **b)** Setup 2 (anti-parallel sensor booms). **c)** All sondes rotating freely. **d)** Mixed configuration (setup 4).

The small differences in a) are not the result of the “optimal” configuration because the structures that are visible in the original data (see Figure 2) are to a wide extent cancelled out due to the parallel orientation of the sensor booms. c) Shows the results for the recommended setup for radiosonde intercomparisons, as discussed in Section 3.

with smallest value for the parallel configuration (setup 1) and the largest value for the anti-parallel configuration (setup 2). The standard deviation for the hybrid setups (one or more hanging sondes) lie between these extremes. These findings should be interpreted as follows: the temperature differences between two identical radiosondes is minimized by using a configuration which ensures parallel orientation of the sensor booms, i.e., setup 1. However, the fact the differences are smallest for this configuration does not necessarily mean that the radiation error itself is small as well. The measurements and payload configurations described in this document are not suited to fully characterize and quantify the radiation error. As a matter of fact, that is not the purpose of intercomparison measurements. For a proper characterization of the radiation error measurements with a different set up are necessary, as is described by Dirksen et al. (2014).

Table 1: Calculated mean and standard deviations (σ) of the raw temperature differences for the data in Figure 3, in each case for the complete given interval, i.e. 500 s corresponding to ~ 2500 m.

Configuration	Difference RS41 in K		Difference RS92 in K	
	mean	σ	mean	σ
a) fixed parallel	0.004	0.046	0.058	0.095
b) fixed antiparallel	0.020	0.326	0.025	0.312
c) mixed	0.012	0.172	0.067	0.228
d) all hanged	0.009	0.115	-0.063	0.286

It should be noted that the standard deviation given in Table 1 has limited significance as a measure of uncertainty for the mean temperature differences because the dominant contribution to the variability is not by stochastic effects (“noise”) but by systematic effects of variable magnitude, e.g. the oscillations in Figure 3b. It depends on the considered time scale if an effect appears stochastic or not. This scale dependence has important consequences for the evaluation of data from radiosonde intercomparisons. When averaging is applied over large enough time scales, structures introduced by the pendulum-motion or rotation of the rig will average out, making the way the radiosondes are mounted (fixed or hanging) less important. On the other hand, when averaging is applied over short time-scales, the mounting of the sondes becomes relevant because the long-period structures introduced by the rig's orientation with respect to the Sun appears to be a bias.

Our first investigations suggest that the transition between both regimes lies between 50 s and 100 s (250 – 500 m altitude range). Below 50 s the averaging width approaches that of systematic radiative effects. When comparing sondes for smaller averaging times, it is recommended to attach the radiosondes to the rod according to setup 1 (parallel sensor booms) in order to exclude radiation effects due rotational and pendulum motion.

We assume that the behaviour observed for the Vaisala radiosondes can be applied to other radiosonde types where the sensor booms is pointing in the diagonal upwards direction away from the sonde casing.

3 Rig recommendations for comparison soundings using two radiosondes

Here we summarize essential aspects concerning an optimal rig configuration for dual soundings. A crucial point for an optimal rigging is to prevent heat and water vapour contamination of the sampled air by parts of the setup. Besides the specific requirements for weight and mechanical stability, the rod should especially consist of material (or should have surface properties) which in turn avoids heat and humidity contamination of the air measured by the successive sensors during ascent. Wooden rods (e.g. bamboo) make a good choice. The diameter of the rod should be as small as possible in order to minimize contamination of the temperature and humidity profile. To minimize temperature and humidity contamination from the ascending balloon, the distance to the rig should be at least 60 m (e.g., Shimizu and Hasebe, 2010). The sondes should be installed in a horizontal arrangement close to each other to ensure that both are exposed to the same air column. However, possible telemetry interferences and radiative interaction from the device housings as well as the clearance necessary for the free movements in case of hanging devices require a certain horizontal distance. Therefore the rig should consist of a rod of ≥ 1.5 m length, horizontally hung to the balloon, with the sondes attached close to the opposite ends of the rod (see Figure 4).

Following the discussion in Section 2 we specify the consequences of the method of sonde attachment (fixed or hanged) to the rod:

- Hanging allows an independent irregular turning of the sondes. The variance of the data is still dominated by radiative heating, but expected to be “closer” to a stochastic nature. However, the proper motion of hanged sondes is in detail not investigated so far.
- Fixing the sondes to the rod, with the sensor boom pointing diagonally upward, enables resolving and characterizing the orientation dependent heating as a short term effect and allows for a “finer” sonde comparison down to scales reaching the time resolution. The systematic imprinted solar radiative effect, which correlates strongly for unidirectionally fixed sondes, can largely be separated from the “true” atmosphere configuration. The small remaining differences basically reflect the different sensitivities in case different individual models are compared. This configuration with varying relative orientations of the fixed sondes is interesting and necessary to quantitatively investigate the solar irradiation effect as a basis for correction models.

To ensure a standardized proceeding among all stations contributing to sonde comparisons and based on the results discussed in Section we suggest to configure the rig with freely hanged radiosondes in the case of simple comparisons of two radiosondes. The sondes should be hanged at a length of 0.7 m using thin flexible, water-repellent ropes. This length – in relation to the rod length defined above – is an acceptable compromise, which on the one hand prevents the sondes from too strong pendulum motions or even collisions with each other, and on the other hand keeps the contamination risk from the rod reasonably low. Note that longer strings might produce trouble with the

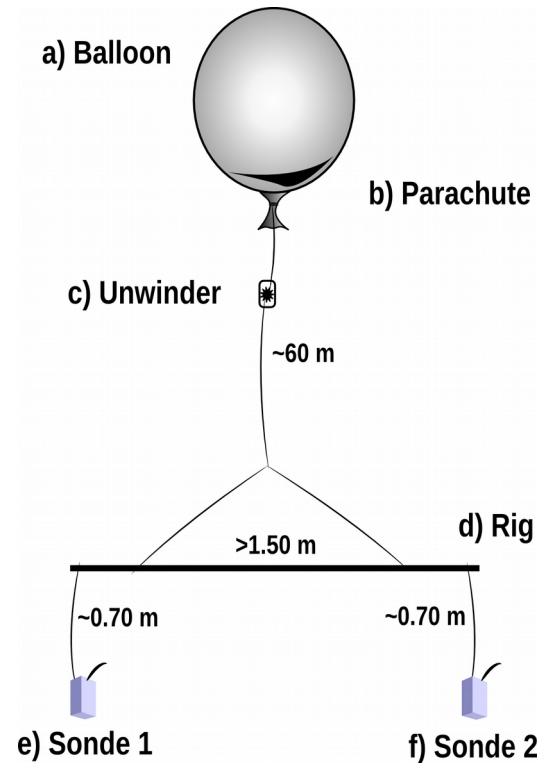


Figure 4: The recommended setup

handling during the launch procedure, particularly when the launch has to be performed by a single person of limited height. All string or twine connections to the rod should be secured using water-proof tape.

Another argument in favor of this recommendation is the fact that this configuration closely resembles the configuration used for routine operation with single soundings. Furthermore, the free turning of the sondes may provide a more reliable basis for further statistical parts of the data evaluation (smoothing, gridding, etc.).

4 Configurations including further instrumentation and other constraints

In some cases it is desired to extent the comparison with further instrumentation on the same rig, e.g. with hygrometers as reference instrument, ozone sonde, etc. These additional instruments are generally larger than the radiosondes and require fundamental changes of the configuration which may result in less optimal arrangement of the sondes. A typical example is a twin-sounding where one of the radiosondes in question is used as telemetry unit for the additionally mounted instrument (see Figure 5). Typically, the sonde is connected to the device by a cable of limited length, which rules out the possibility of hanging the radiosonde. This means that it must be fixed on the rod close to the device box or even directly attached to it. In such configurations it is important to arrange the radiosonde in a way that the sensor boom is oriented away from the surface of the device-casing and is pointing as much as possible upwards into the undisturbed atmosphere in order to minimize radiative coupling. If possible, rods or spacers should be used.

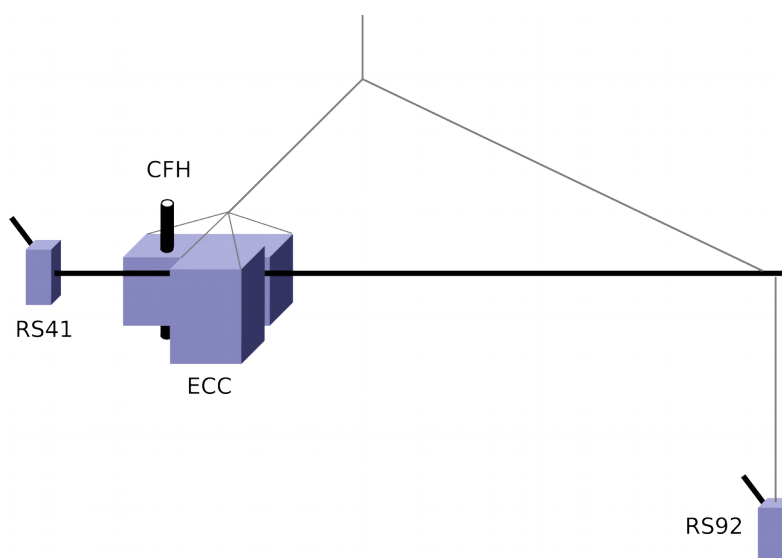


Figure 5: Typical rigging example for an extended payload including two radiosondes, CFH (Cryogenic Frostpoint Hygrometer), and ozone box. The RS41 sonde is used as telemetry unit for CFH/ozone. The maximal distance between CFH box and RS41 is limited by the cable connection. The setup is concentrated to the humidity measurement with the CFH. Therefore it is not optimal in all aspects for comparison of the two radiosondes: The close distance of the RS41 to the CFH most likely involves radiative heat contamination of the RS41 sensors. So far it is also not clear if sticking the RS41 to the CFH box or keeping a (short) distance is the preferable option. It is recommended to hang the RS92, although only in case a large enough distance to the box package, e.g. by a rod, can be assured.

Based on the considerations in Section 3 we recommend to arrange the other radiosonde freely hanged.

The following most common constraints or restrictions for optimal sounding practice, which also may be forced by e.g. legal provisions or by restrictions in manpower, involve certain risk of suboptimal sounding results:

- Unwinders shorter than ~60 m significantly enhance the risk of contamination by the balloon
- Too short ropes of hanging sondes enhance the risk of contamination by the rod (Nash et al., 2011)
- Fixing the sondes to the rod or fixing both sondes relative to each other increases the regularity of directional effects by radiation (oscillations), also at night-time
- Too long rods (several meters) may enhance the probability of measuring real spatial variations of the atmospheric parameters which should be avoided in comparison flights
- Arrangement of the two sondes one below the other, e.g. by use of a second unwinder, increases the risk of sounding of different air masses
- In case of extended payload consisting of multiple instruments, hanging the sondes too close to other instruments may lead to contamination of the humidity profile.

5 Pre-launch procedures and metadata

The preparation procedures for dual soundings should closely follow the standards defined for GRUAN procedures and enclose those for routine GRUAN soundings. All preparatory steps prescribed by the manufacturers should be followed for each radiosonde. This includes the reconditioning and recalibration steps that are part of the manufacturer ground-check procedures, e.g. GC25 for the Vaisala RS92 radiosonde. A GRUAN radiosounding requires an additional manufacturer-independent ground-check to ensure that the recordings of all sondes are consistent at least before launch under controlled ground conditions. A humidity and temperature check, ideally in an SHC (Standard Humidity Chamber, Section 6.3 in Dirksen et al., 2014) at 100 %RH using a separate calibrated thermometer, is strongly recommended.

Measurements following the GRUAN requirements also include the saving of extensive metadata. The metadata collection essentially contains all information which is relevant to fully understand, process, and archive the actual measurement data. Accordingly, additional information about the rig configurations of dual or multiple soundings shall be documented thoroughly. This includes:

- information on the measurement event (station, start and end times, operator, type)
- local conditions during launch (p, T, RH, clouds, wind, ...)
- diverse launch information:
 - indication of sizes (balloon dimension and filling, unwinder length, rod dimensions, string lengths of hanged units)
 - materials used (balloon, rod)
 - sonde installation (fixed or hanged, orientation (up, down), relative orientation if fixed)
 - instrument specifications (manufacturer, sonde type, serial number, ground check, calibration, telemetry, radio frequency, software, operator)

The GRUAN RsLaunchClient accordingly predefines fields in tables to be filled with metadata (see

Table 2). Optional information (e.g. operator comments, photographs, setup sketches) are welcome and can be very useful. However, because the metadata are automatically archived in the GRUAN metadata base (GMDB), a systematic metadata recording using the RsLaunchClient is preferred.

Table 2: Examples for detailed descriptions of specific properties assigned to the components of dual radiosonde launch setups.

Component	Property	Description
Balloon	Pretreatment	Pre-treatment of used balloon [Warming, Oil/Kerosene dipping, Warming + Oil/Kerosene dipping, None]
Balloon	WithInsideParachute	Balloon with enclosed parachute
Unwinder	StringLength	String length of unwinder
Rig	LengthX	Length X of rig (please use this as length for a single or the first rod)
Rig	LengthY	Length Y of rig (please use this as a second length in case of rig type T-RIG, H-RIG, CROSS and so on.)
Rig	Material	Material of rods
Sonde	AttachmentType	Type of attachment which is used to attach this sonde to the rig. [taped, free hanging]
Sonde	AttachmentStringLength	Length of string [m] if this sonde is attached to rig with type 'free hanging'.
Sonde	Orientation	Orientation of mounting if this sonde is mounted to rig with type 'taped'. [default, up, down, sideways]
Sonde	RelativeOrientation	Relative orientation of mounting (related to defined axis of orientation) [deg] if this sonde is mounted to rig with type 'taped'.

6 References

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