Vaisala Radiosonde RS41 Data Processing

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About the Speaker

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Product Line Manager at Vaisala

- M.Sc in Applied Mathematics
- More than 20 years of experience on radiosonde measurements in various roles at Vaisala
- Member of WMO Expert Team on Upper-Air Measurement (ET_UAM)

Introduction to Vaisala Radiosonde RS41

Vaisala Radiosonde RS41 Family

- Sensors **specifically designed and optimized** for upper-air measurement
  - Robust, stable
  - SI-traceable calibration
- **400MHz** telemetry link
- **Easy to use**
- Two versions
  - **RS41-SG** with GPS derived height and pressure
  - **RS41-SGP** with a silicon pressure sensor

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Vaisala Radiosonde RS41 Family

- Light weight
  - 80/84 grams
- Unwinder
  - 55 meter string, weight 25 grams
  - String strength < 115 N
  - Unwinding speed 0.35 m/s
- String guide sets the sensor boom automatically to correct position

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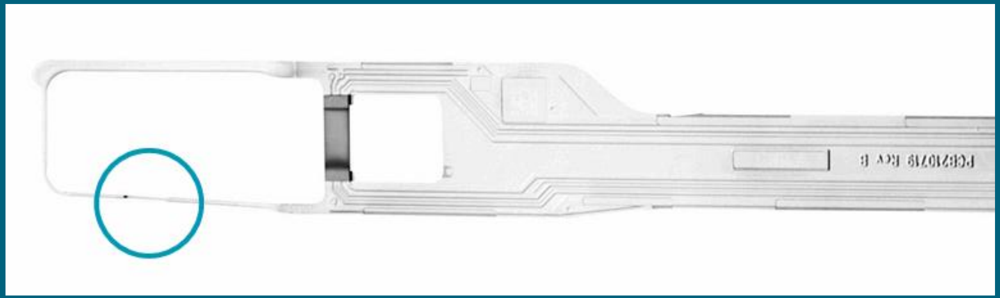
Temperature Measurement



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Vaisala Radiosonde RS41 Temperature Sensor

- **Platinum resistor**
  - Linear and repeatable sensor over the whole temperature range
  - No need for ground correction
  - Stabile technology
- **Protection from evaporating cooling**, no compensation needed for wet bulb
- **Short response time**, time lag correction
- **Small effects of solar and infrared radiation**
- **Robust**
- **SI-traceable** calibration

Temperature Sensor Response Time

- The response time (63.2%) tested in various pressure and ventilation conditions
- Time lag correction is applied to sounding data resulting in negligible residual measurement uncertainty, below 0.02 °C

Pressure, hPa	Sensor response time 63.2% without time lag correction, flow 6 m/s, s
1000	0.5
100	1.2
10	2.5

Temperature Sensor and Solar Radiation

- Small size and special coating of the sensor reduce both long-wave and short-wave absorption
- Sensor boom design significantly reduces noise in temperature measurement originating from the solar radiation
- The solar radiation correction is applied based on the heat transfer balance mainly affected by incoming radiation and outgoing convective heat
- The uncertainty of the applied solar radiation correction is typically below 0.2°C (k=2) in the troposphere

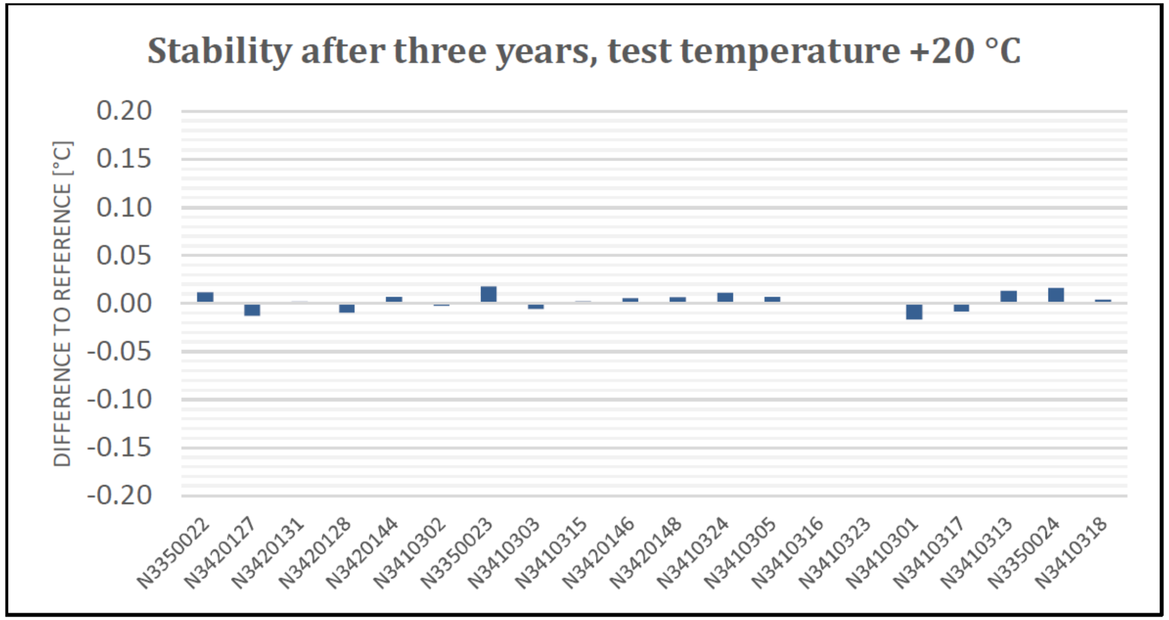
Solar Radiation Correction

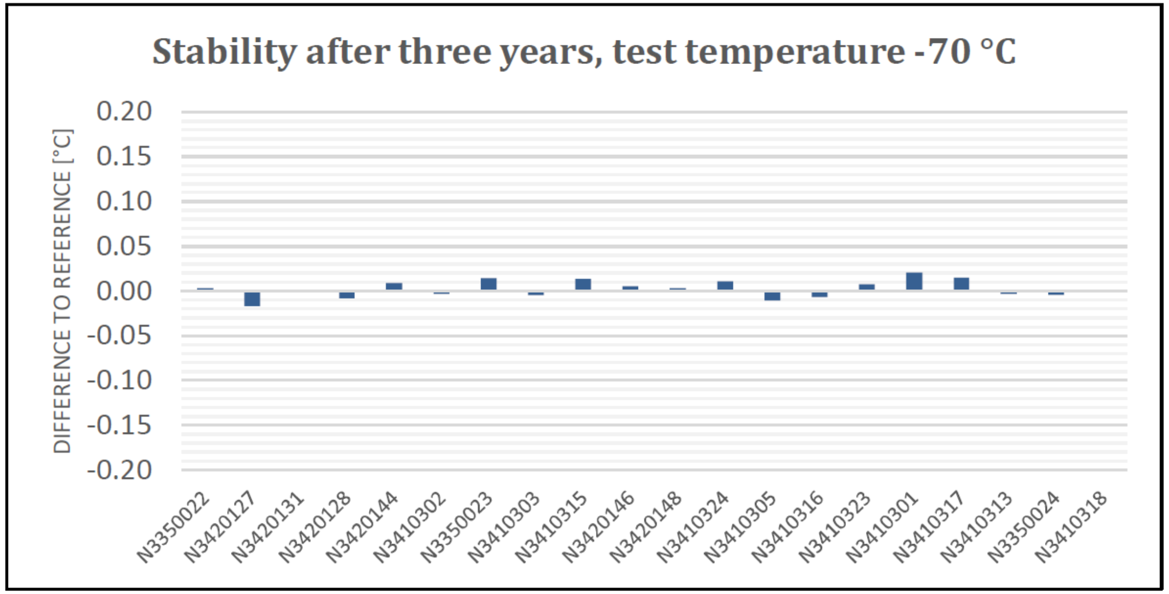
hPa/deg.	-7.0	-4.0	-2.0	0.0	3.0	10.0	30.0	45.0	60.0	90.0
1000	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.10	0.11	0.11
500	0.00	0.00	0.02	0.03	0.05	0.09	0.15	0.17	0.18	0.19
200	0.00	0.02	0.06	0.09	0.13	0.19	0.27	0.29	0.31	0.32
100	0.00	0.05	0.10	0.16	0.21	0.29	0.39	0.42	0.44	0.45
50	0.00	0.10	0.18	0.24	0.32	0.42	0.55	0.58	0.60	0.62
20	0.01	0.18	0.29	0.39	0.49	0.63	0.81	0.85	0.88	0.9
10	0.05	0.27	0.42	0.53	0.65	0.83	1.04	1.10	1.14	1.16
5	0.09	0.37	0.55	0.68	0.83	1.05	1.31	1.39	1.42	1.45

Radiation correction of Vaisala Radiosonde RS41 temperature measurement at various pressure levels and solar angles at ground level, ventilation speed 6 m/s.

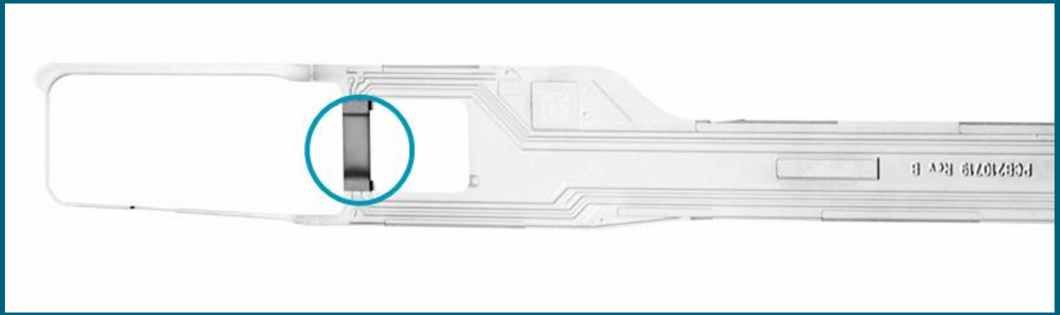
Temperature Sensor Check

- Temperature sensor check
  - Comparing temperature sensor (T) to humidity sensor’s temperature sensor (Tu)
- Difference typically less than ± 0.2 °C in office environment, can exceed due to environment
- No correction applied for temperature sensor





Humidity Measurement



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Vaisala Radiosonde RS41 Humidity Sensor

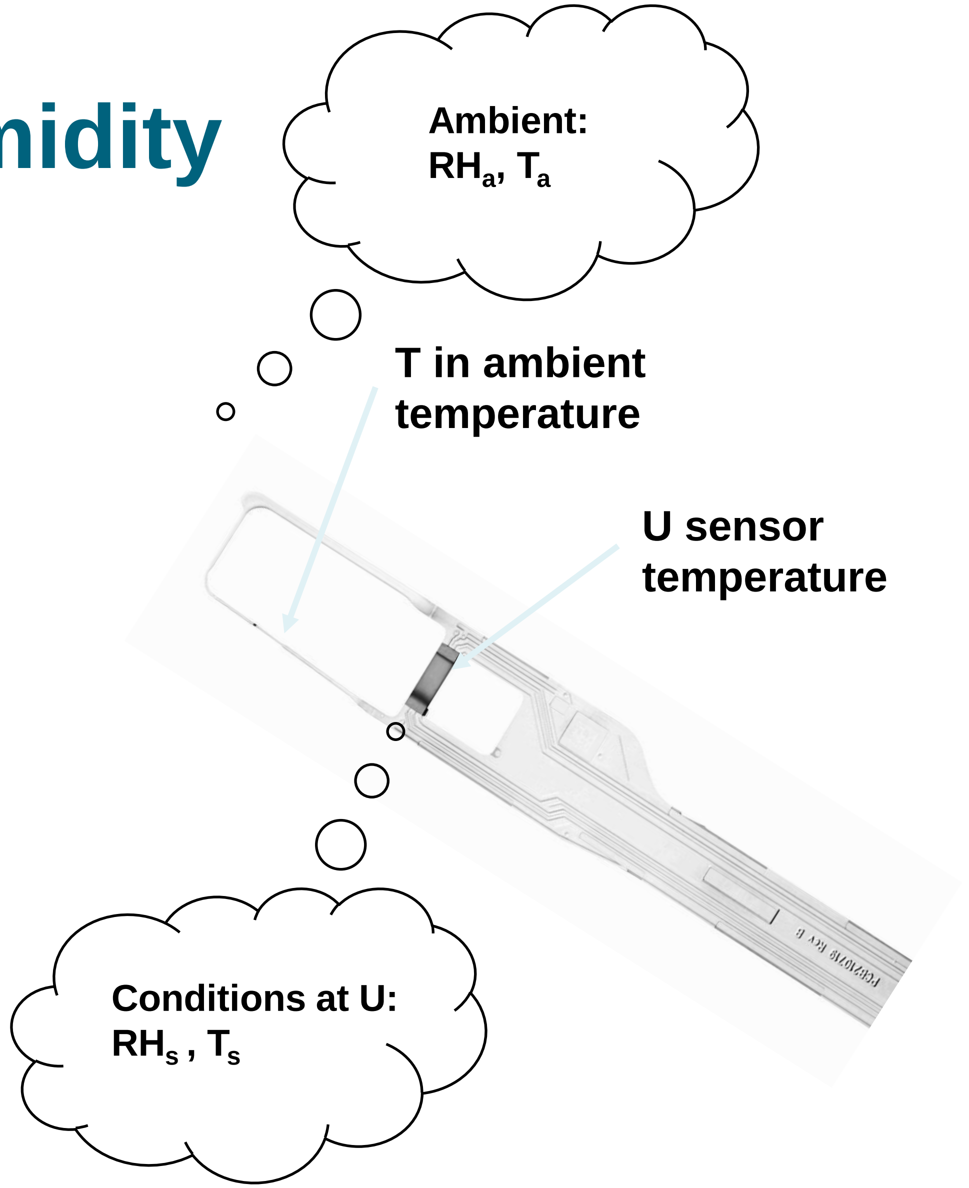
- Accurate
  - Proven, stable polymer is the active material
    - **Low hysteresis, accurate calibration**
  - **Reconditioning** during ground check removes any sensor contamination acquired during storage
- **Integrated temperature sensor**
  - Radiation error compensated
- **Fast response time**
  - Enables monitoring of the fine structures of clouds
- Sensor element with **heating** possibility
  - Enables active in-flight de-icing
  - Improved accuracy close to 100 %RH
- **SI-traceable calibration**

Basic Properties of Relative Humidity Integrated Temperature Sensor

- No specific solar radiation correction applied
- The equation of saturated water vapor (ITS-90 compatible Wexler's formula by Hardy) used in calculation of relative humidity involves temperatures

$$U_{air} = \left(\frac{e_s\left(T_{sensor}\right)}{e_s\left(T_{air}\right)} \right) * U_{sensor}$$

where:
U_{air} = humidity of air
U_{sensor} = humidity measured by the sensor
T_{air} = air temperature
T_{sensor} = temperature of the sensor
$e_s(T)$ = saturation vapor pressure of water at temperature T

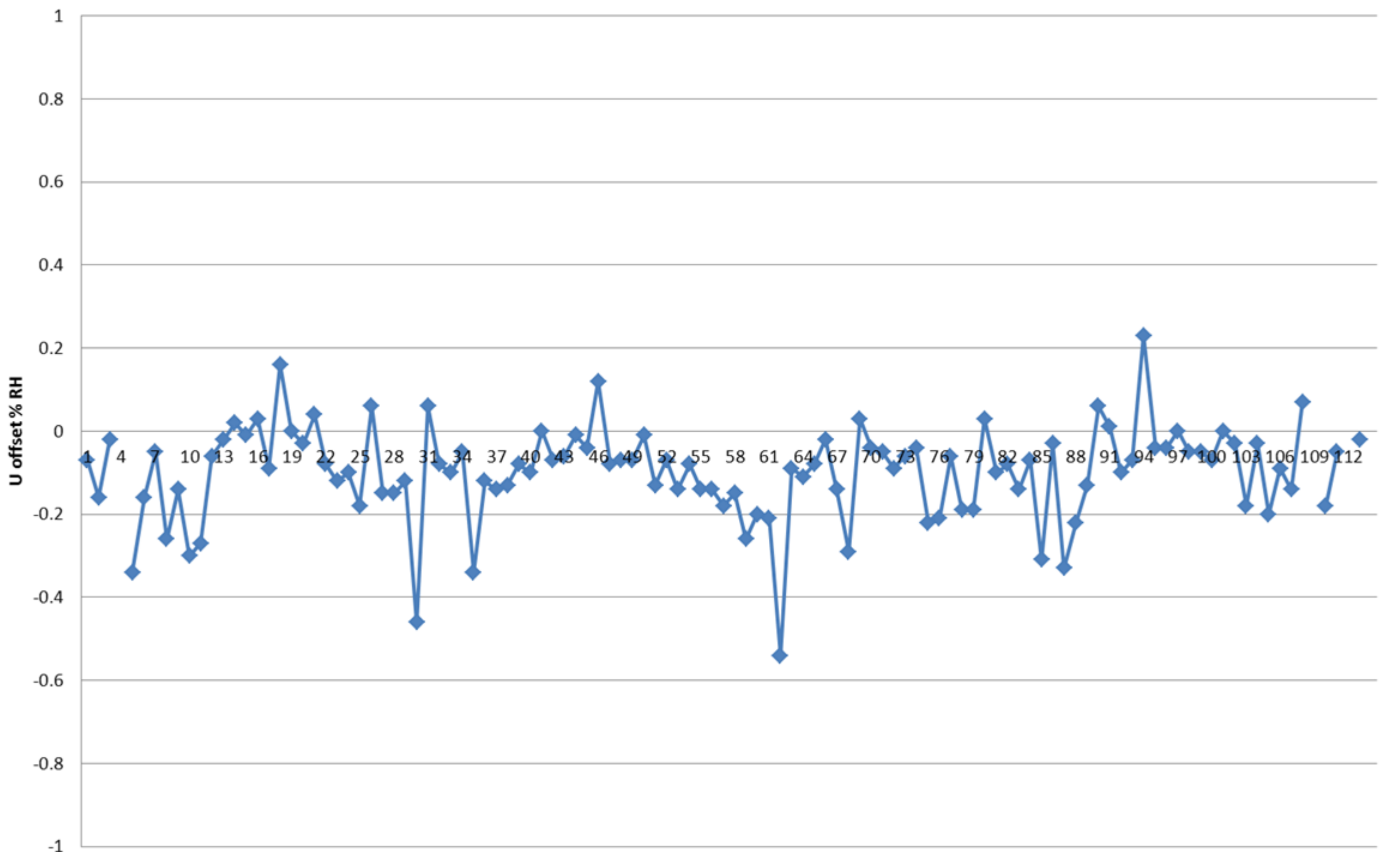


Reconditioning and Physical Zero Humidity Check

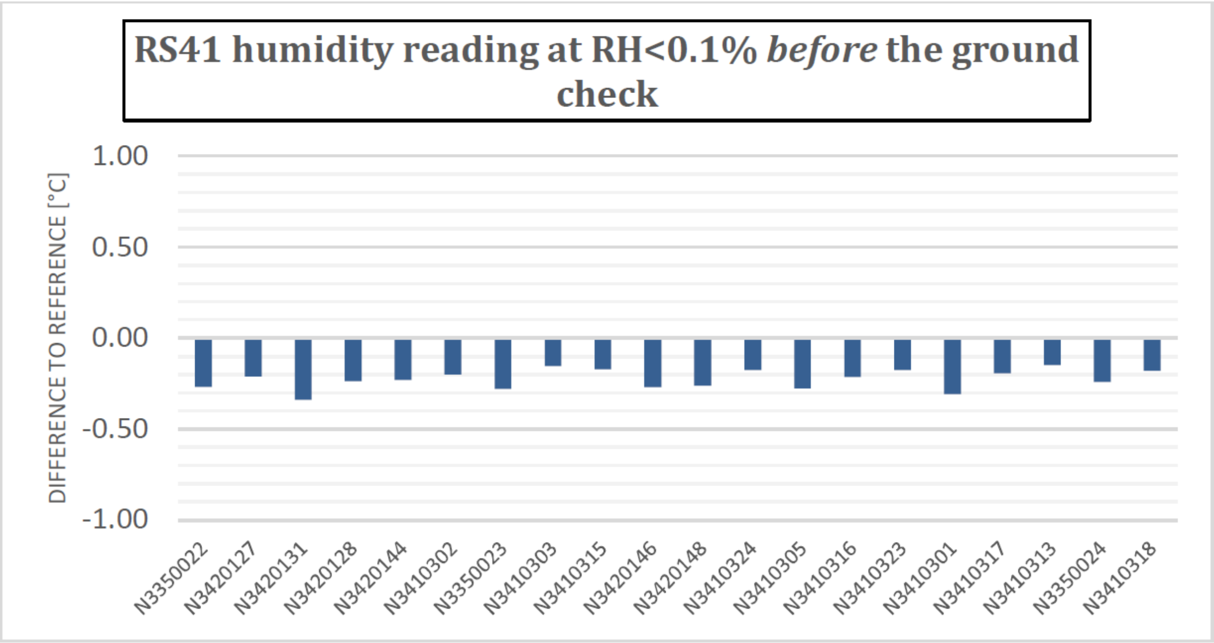
- Humidity sensor is reconditioned automatically during ground check to restore the factory calibration
  - Removes chemical contaminants originating from packaging or other sources
- The radiosonde measures the deviation of humidity measurement at 0 %RH (physical zero) and fine tunes the humidity measurement accordingly

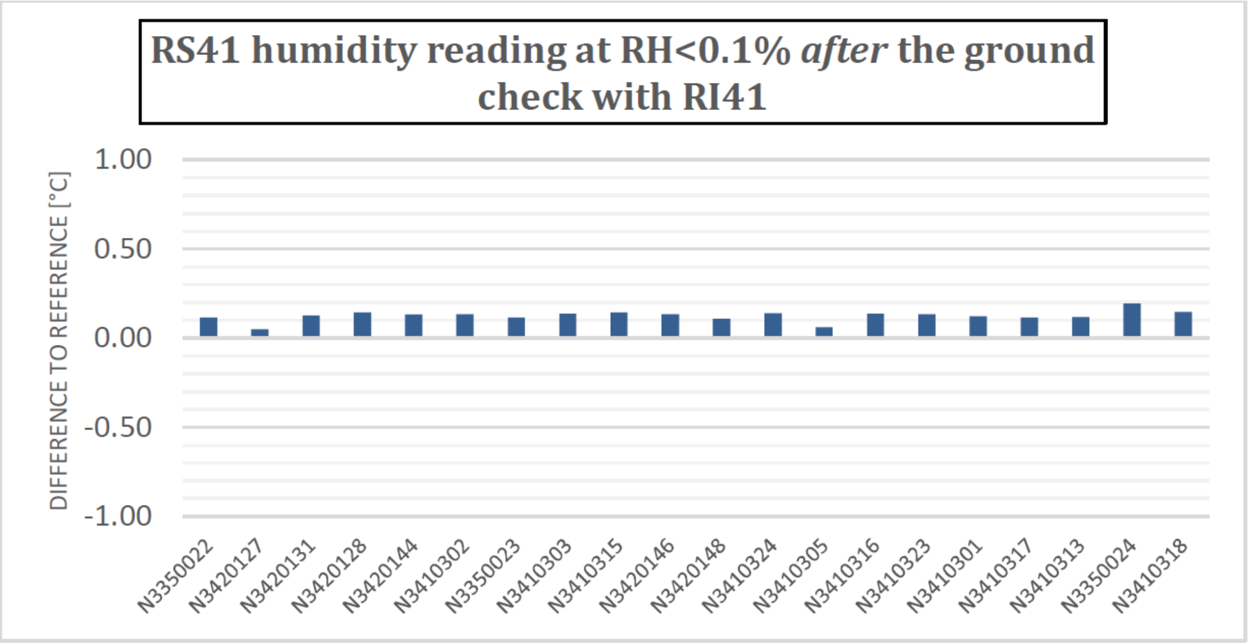
Reconditioning and Physical Zero Humidity Check

- Difference and correction typically less than ± 0.4 %RH
- The correction is applied based on the measured difference
- Applied already in raw data



RS41 Humidity Sensor Stability Test Results



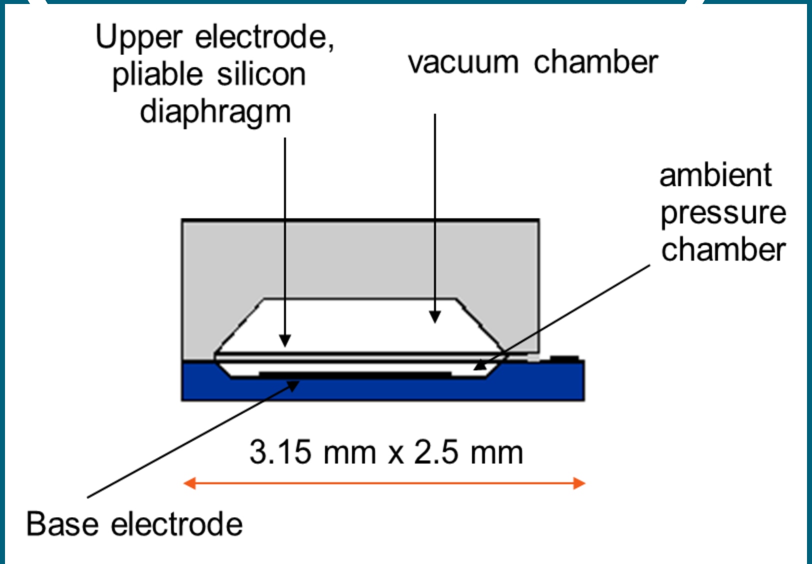


Humidity Time Lag Correction

- Response time of a polymer-based capacitive humidity sensor is dependent on the ambient temperature
- Time Lag Correction applied to the processed data to diminish errors in cold dynamic conditions

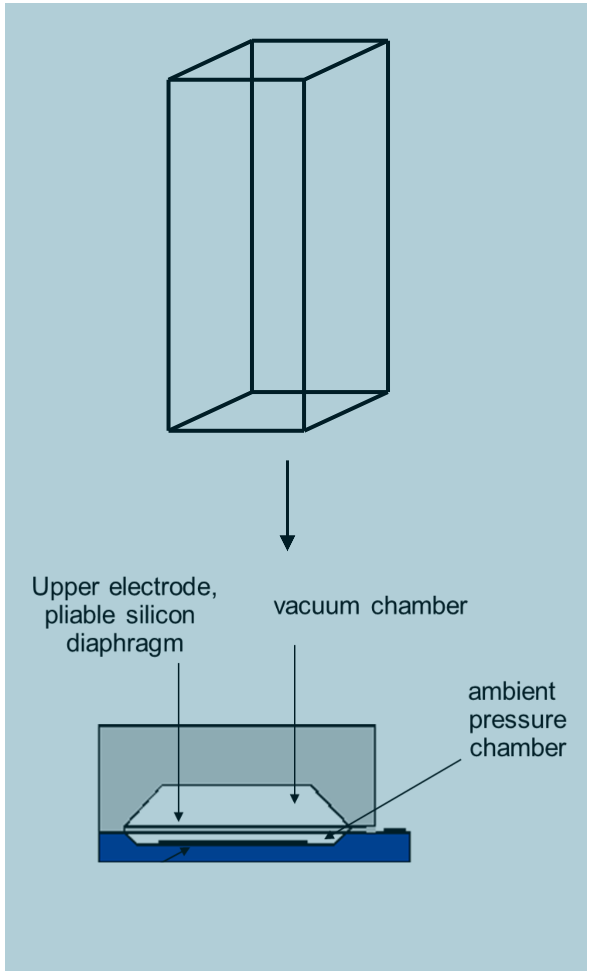
Condition	Sensor response time 63.2% without time lag correction, flow 6 m/s
1000 hPa, +20°C	< 0.3 s
1000 hPa, -40°C	< 10 s

Pressure Sensor Measurement (RS41-SGP)



Pressure Measurement Using Sensor

- Direct measurement:
  - Measure the force coming from the weight of the air column above
  - Capacitive measurement
- Vaisala silicon pressure sensor
  - Same sensor as in RS92
  - Excellent stability, wide dynamic range, shock-resistant
  - Revised electronics and calibration for RS41



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Sensor-Based Geopotential Height (gpm)

- Similar to deriving pressure from GPS measurements
- The hypsometric equation is solved for change in height (δZ)

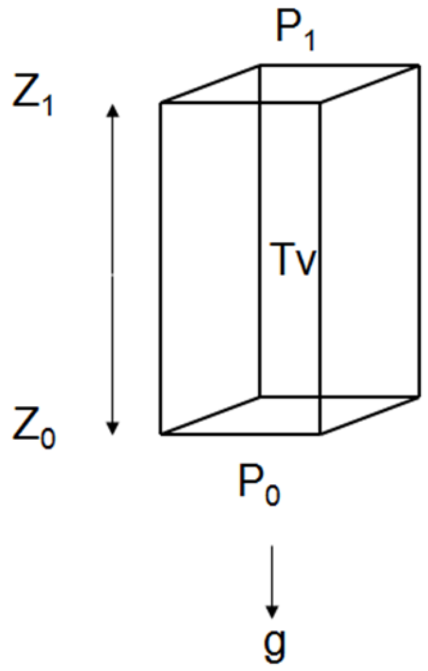
$$\frac{\delta P}{P} = -\frac{g \cdot \delta Z}{R_a \cdot Tv}$$

P = pressure

Tv = virtual temperature (calculated from radiosonde T, U)

Ideal gas law, hydrostatic assumption

- Height is converted into geopotential height



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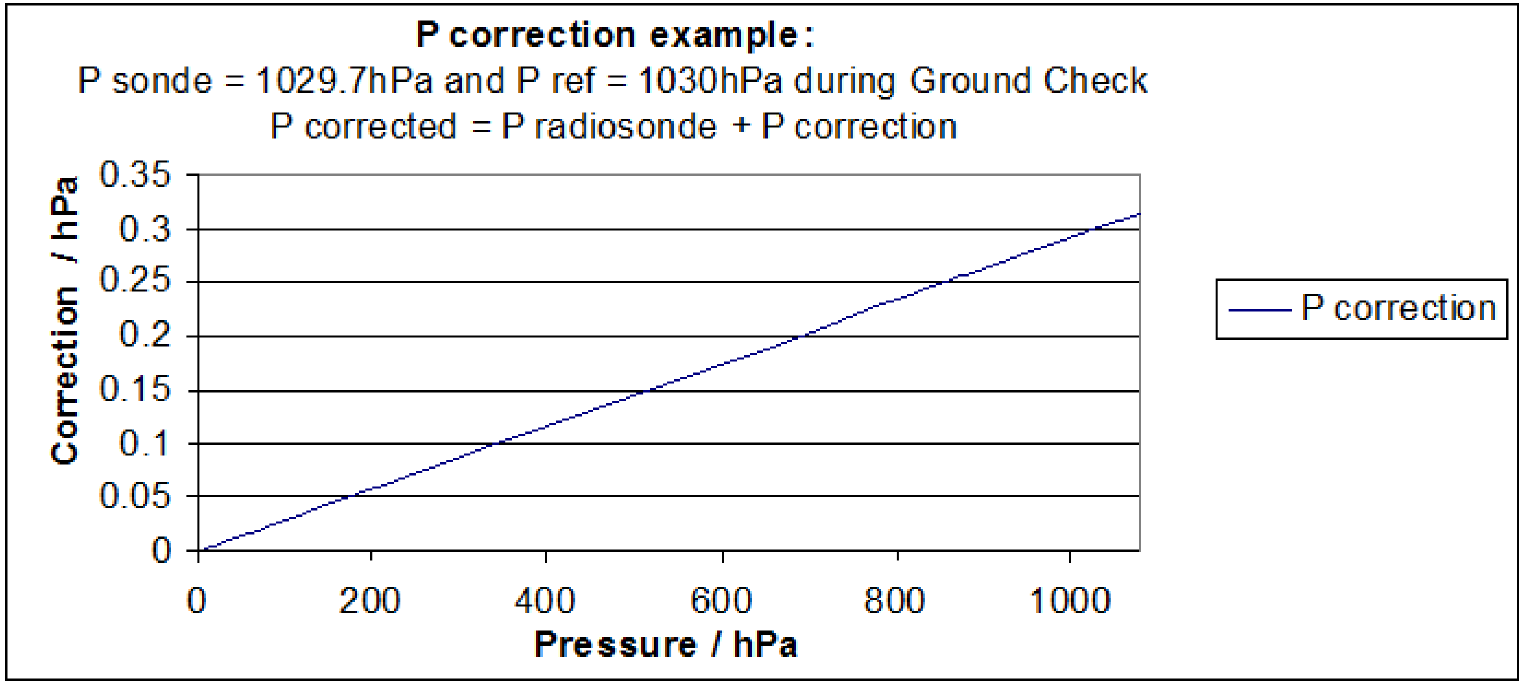
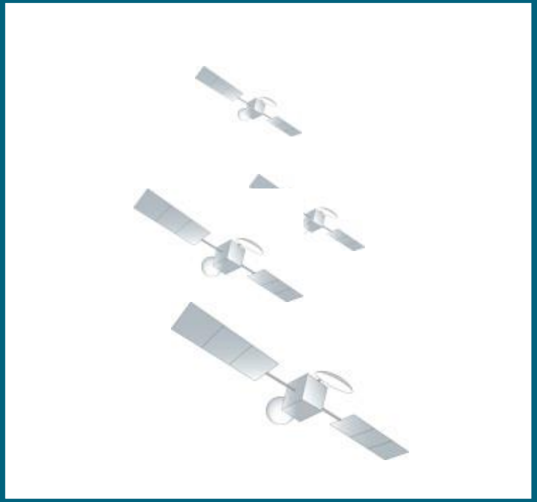
Pressure Sensor Ground Check and Correction

- Pressure sensor is automatically checked against Vaisala barometer module inside RI41-B (option)
- The correction is applied based on the measured difference against reference
- With an external barometer, the reference value can be entered in MW41 user interface



GPS Measurement



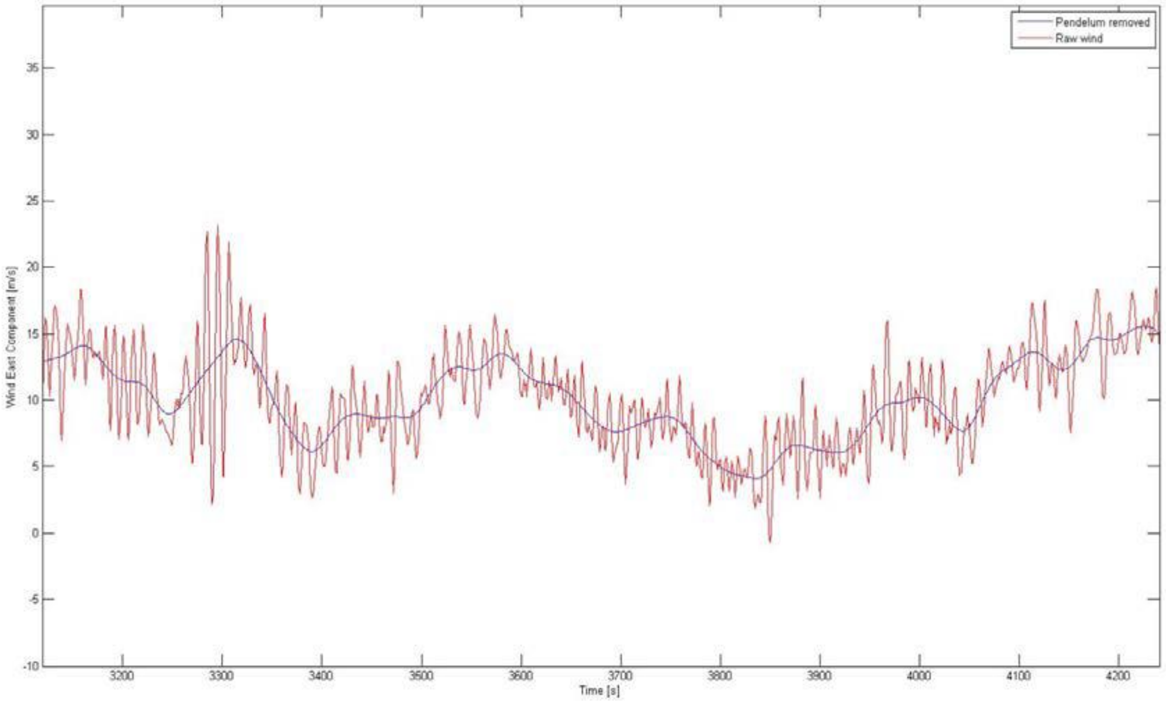
GPS use in Radiosondes

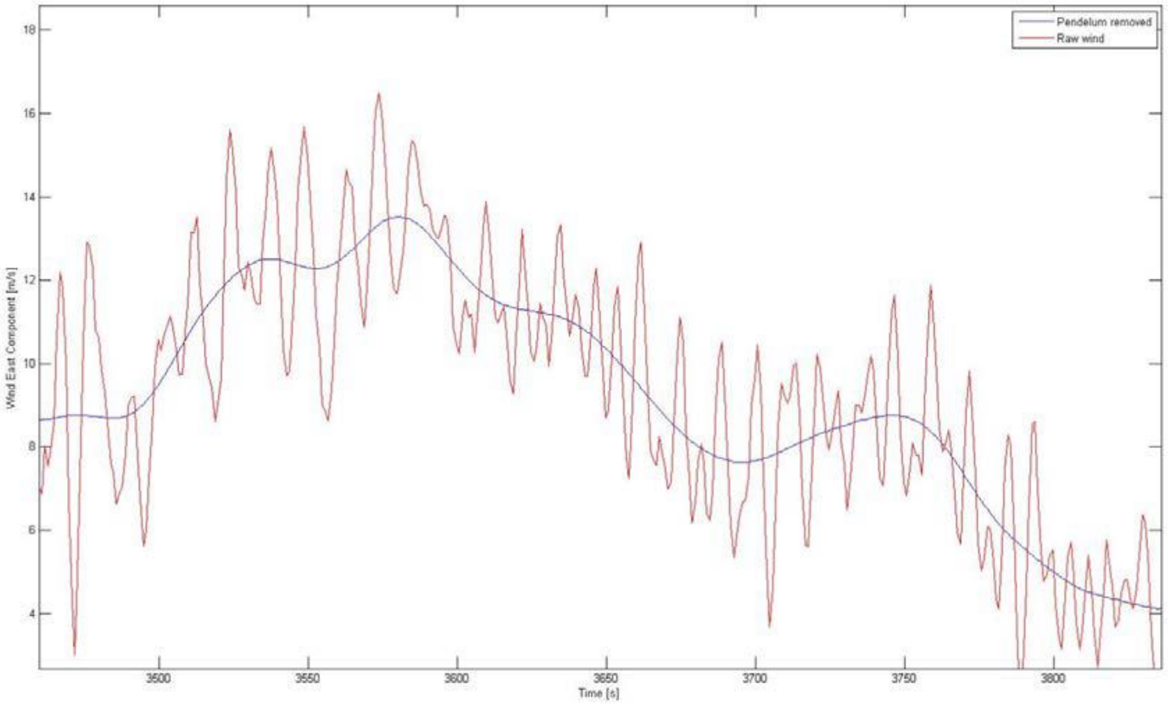
- **Wind**
  - Speed and direction
- **Horizontal location**
  - Latitude and longitude
- **Height**
- **Pressure calculation**
  - Calculated from height, temperature and humidity
- **Differential** GPS for position calculation

GPS Derived Wind

- Velocity (wind) calculation is based on the satellite carrier frequency changes, that is, Doppler frequencies.
  - Momentary velocity, calculated every one second
  - Provides very high accuracy
  - It is robust against multipath effects and most atmospheric disruptions
- Wind calculation does not use differential corrections
- Wind calculation is independent from height measurement
- Outlier removal, interpolation of missing data

Wind Pendulum Filtering
Effectiveness of the Algorithm





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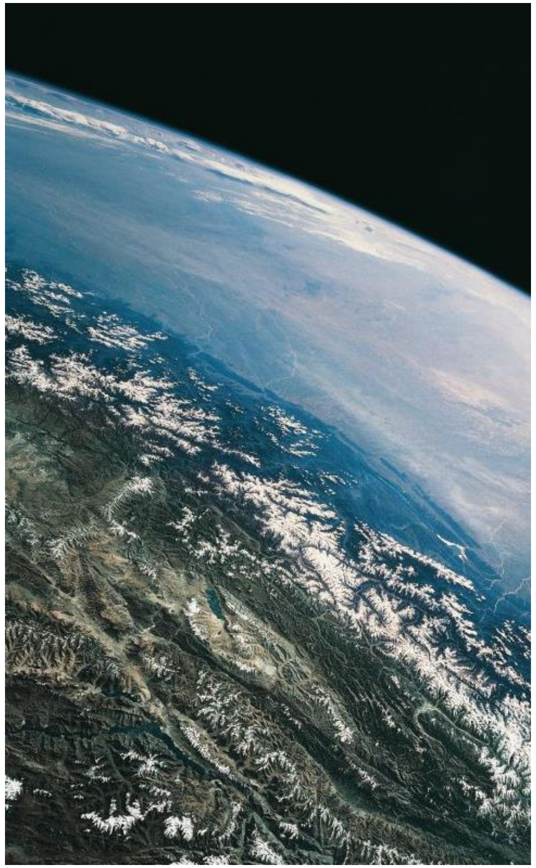
Calculation of GPS Geopotential Height

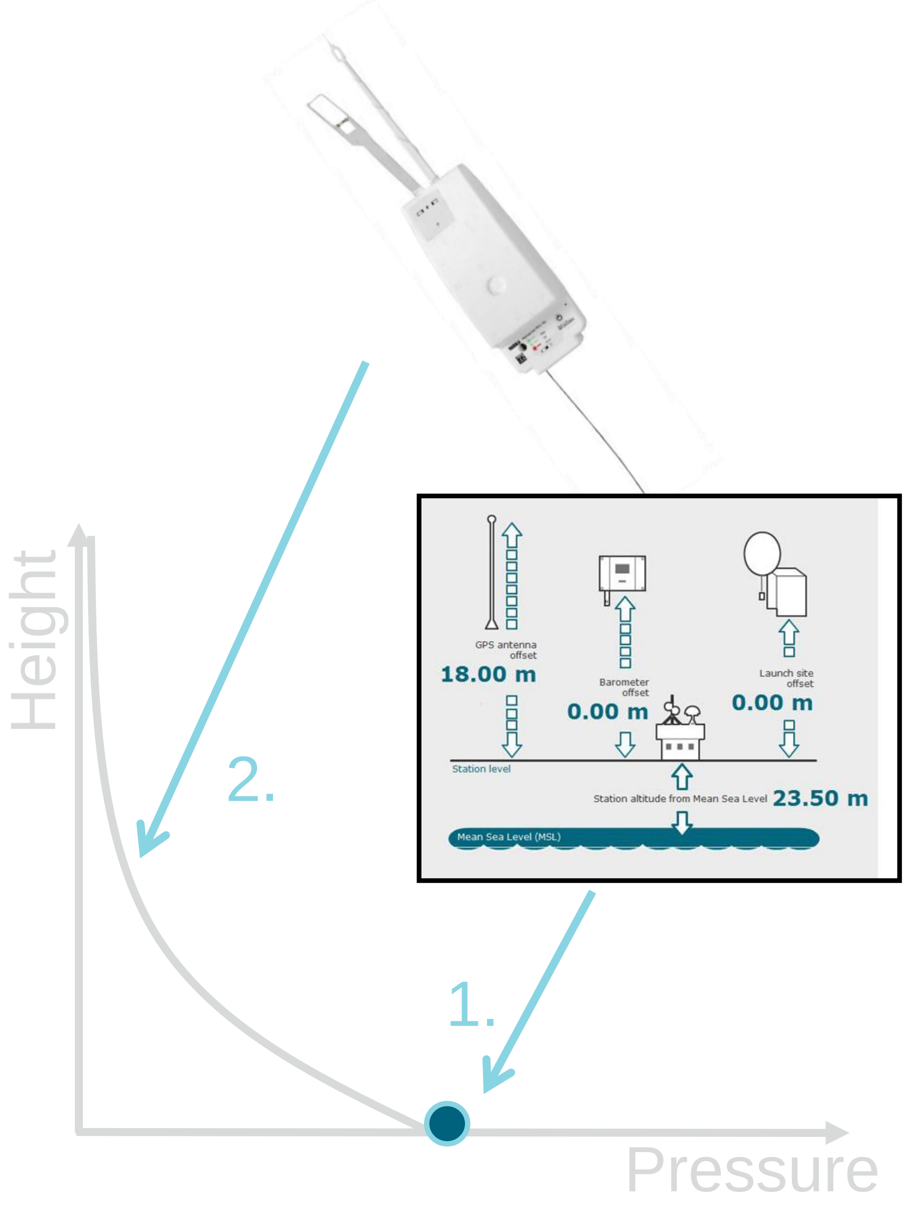
1. Raw GPS height is expressed relative to the WGS 84 reference ellipsoid model of the Earth
2. Converted to MSL height, expressed relative to EGM96 Earth geoid model
3. Converted to geopotential height
   – ”Height” in TEMP and BUFR



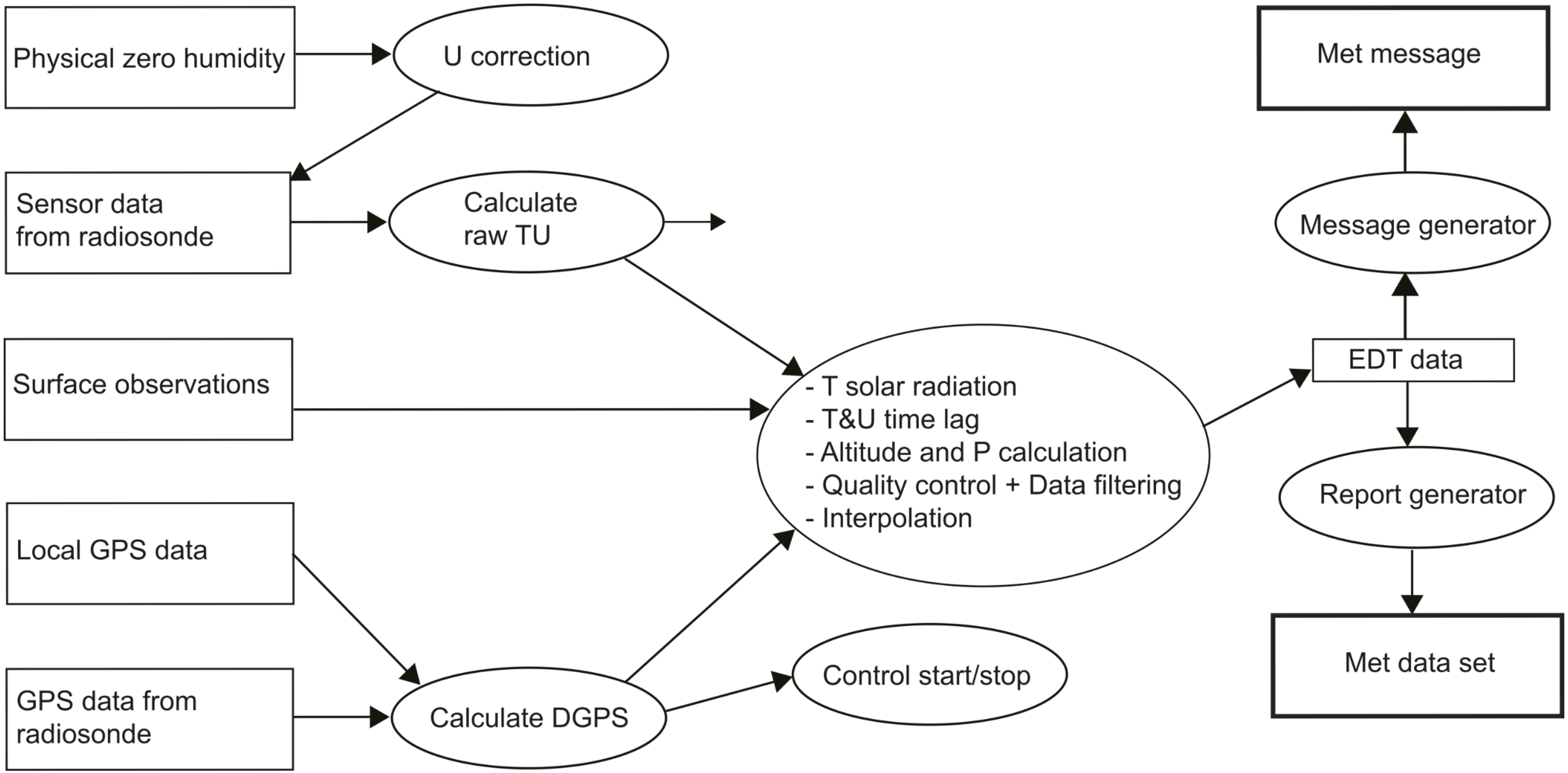
GPS Derived Pressure

1. Measurement is initialized with ground station values
   - Pressure from ground station barometer
   - Height of ground station
2. Pressure is calculated as an integral from ground to radiosonde height
   - Using height, temperature and humidity of each point

$$\frac{\delta P}{P} = -\frac{g \cdot \delta Z}{R_a \cdot Tv}$$



Overview of the RS41 Data Processing Flow



Data Continuity

- Web page available at Vaisala web page
  - RS41 Data Continuity
  - RS41 vs. RS92 Data Continuity
  - RS92 Data Continuity
- Significant changes in the Vaisala Radiosonde RS41 family and the related ground equipment
- Contains also significant changes that do not have any effect on time series

Link: https://www.vaisala.com/en/sounding-data-continuity

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