Deutscher Wetterdienst
Wetter und Klima aus einer Hand

# RS41 Uncertainties of positioning, pressure and wind - General revision for GDP BETA 2

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Virtual

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# Processing Scheme of RS41-GDP



| General & ground check | Pressure & altitude | Ventilation & wind | Temperature | Humidity |
|---|---|---|---|---|
| Make time axis steady | Calculate position (XYZ → LLA) | Pendulum analyse | Position of sun | Time-lag correction |
| Combine & grid data sources | Pressure calibration | Calculate ventilation | Estimate radiation (RTM simulations) | Smoothing (time-lag related) |
| Quality control of all input vars. | Recalculate alt. MSL, GPH | Calculate wind speed & direction | Radiation correction | Recalculation (internal T to air T) |
| Detect launch points | Calculate pressure using alt. (GNSS) | Smoothing (pendulum effects) | Smoothing (pendulum effects) | Estimate uncertainties |
| Detect & analyse SHC / shelter | Estimate uncertainties | Estimate uncertainties | Estimate uncertainties | Calculate further humidity variables |
| | Quality control of pressure & alt. | Quality control of wind | Quality control of temperature | Quality control of humidity |

# All uncertainties in this presentation are for k=1!

# Uncertainty types



Uncorrelated uncertainty:

- Random
- Affects the relationship between neighboring points
- Applicable to relative measurements

Correlated uncertainty:

- Systematic
- Affects all points in a profile
- Applicable to absolute measurements

Full uncertainty:

- Pythagorean sum of correlated and uncorrelated

$$a \oplus b = \sqrt{a^2 + b^2}$$

# RS41 GPS positioning

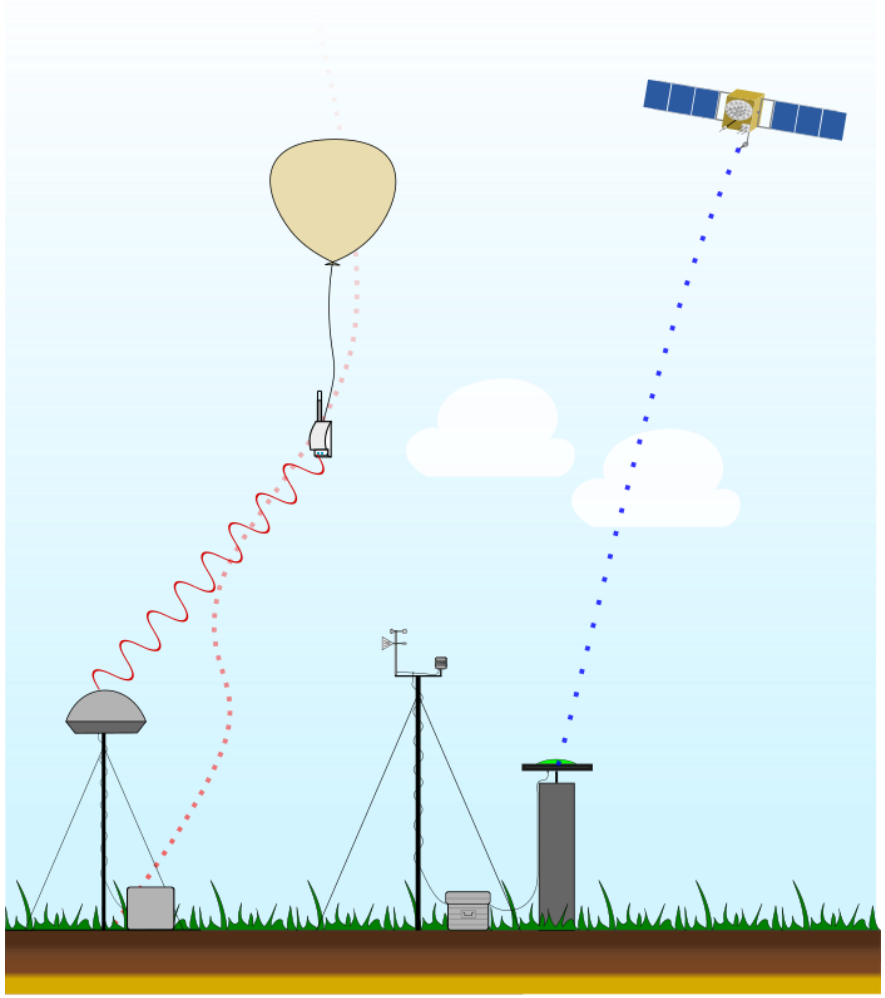
Altitude uncertainty

Pressure uncertainties

Lon/Lat uncertainties

Wind speed uncertainties

Conclusions and outlook



# RS41 GPS positioning system



RS41 radiosonde GPS module:

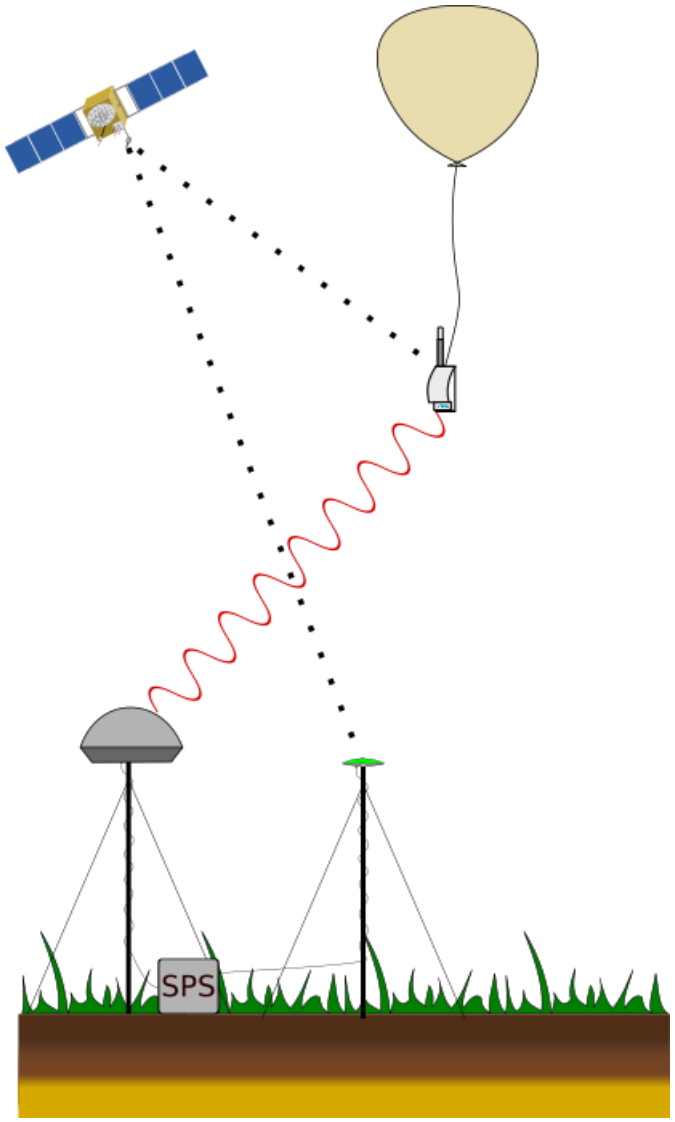
- ublox 6 chip
- Single frequency, GPS-only receiver
- update rate 1Hz
- passive patch antenna

Ground station equipment

- ublox 6 chip
- active antenna

Radiosonde positioning modes:

- Independent
- Differential



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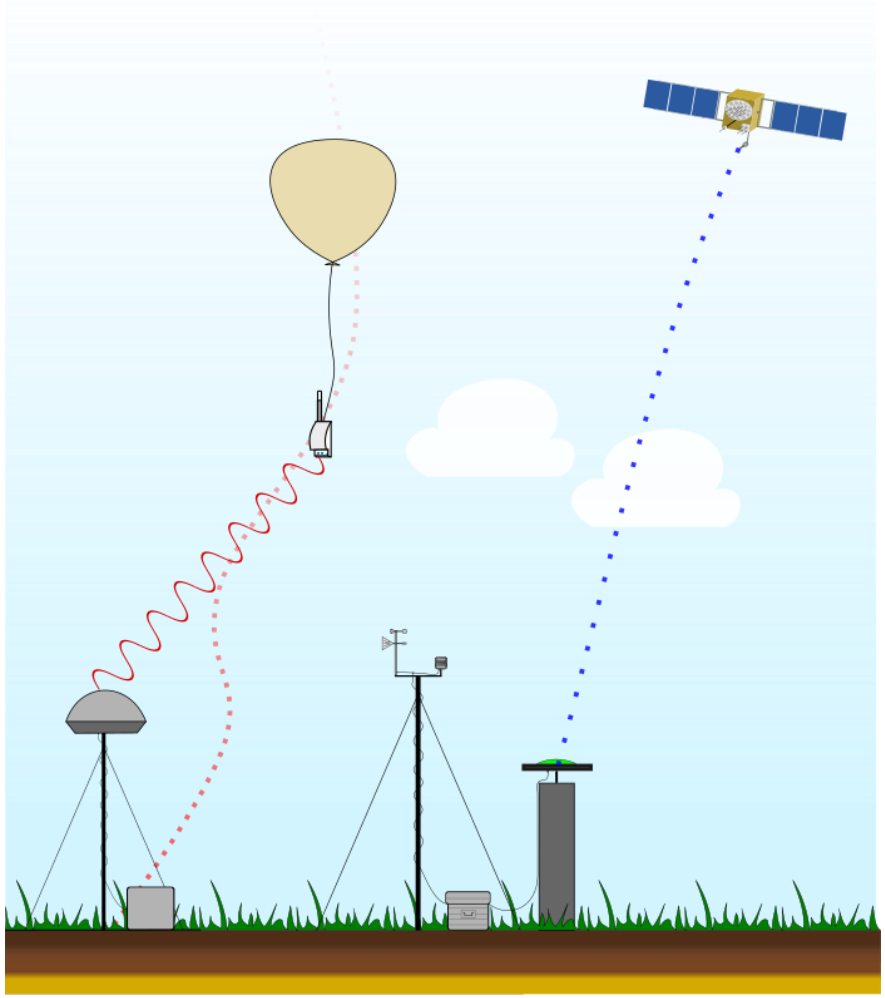
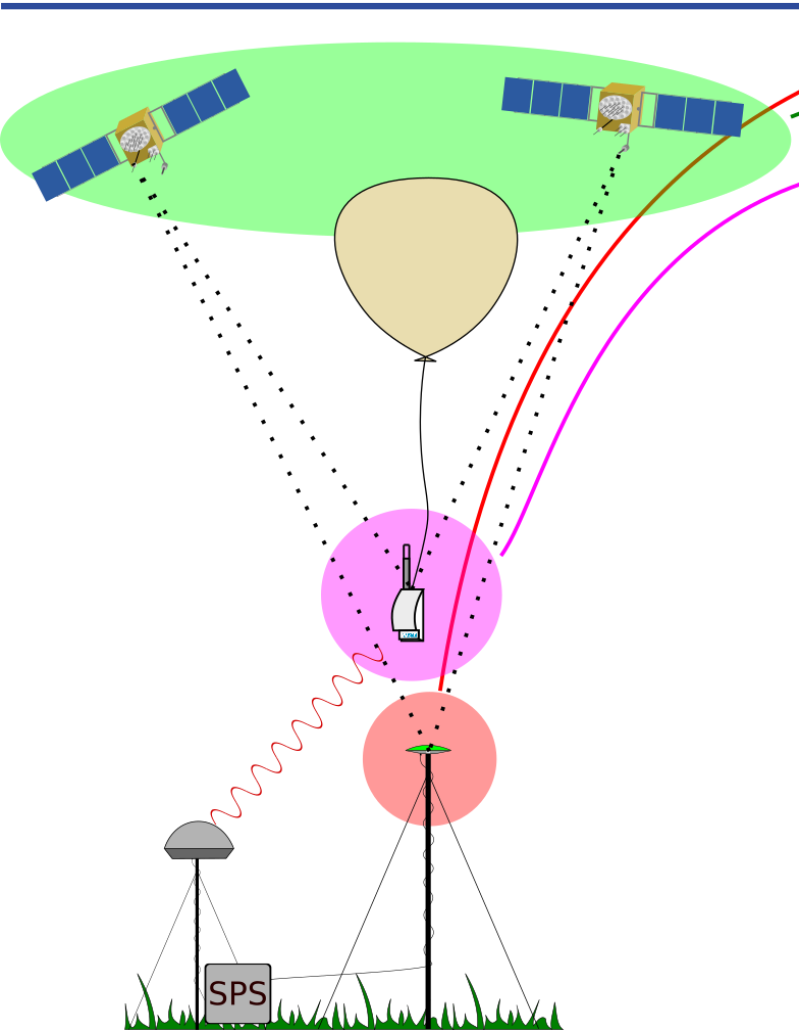
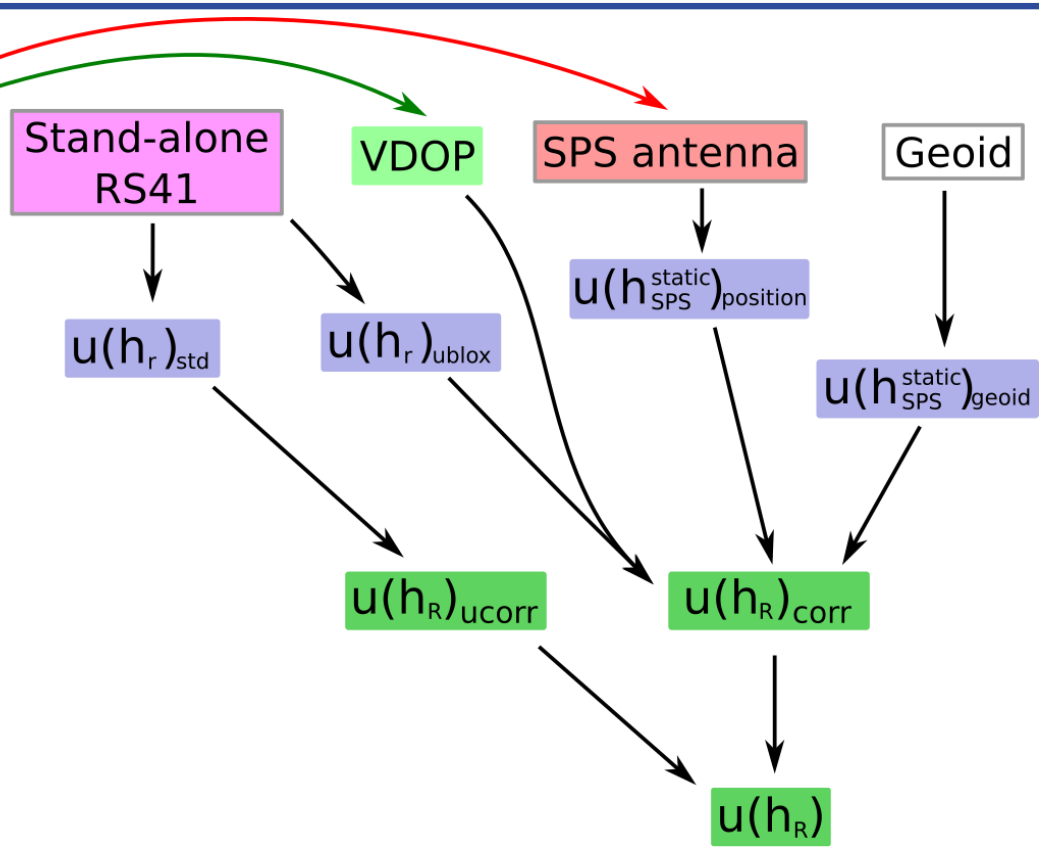


# RS41 Altitude uncertainty

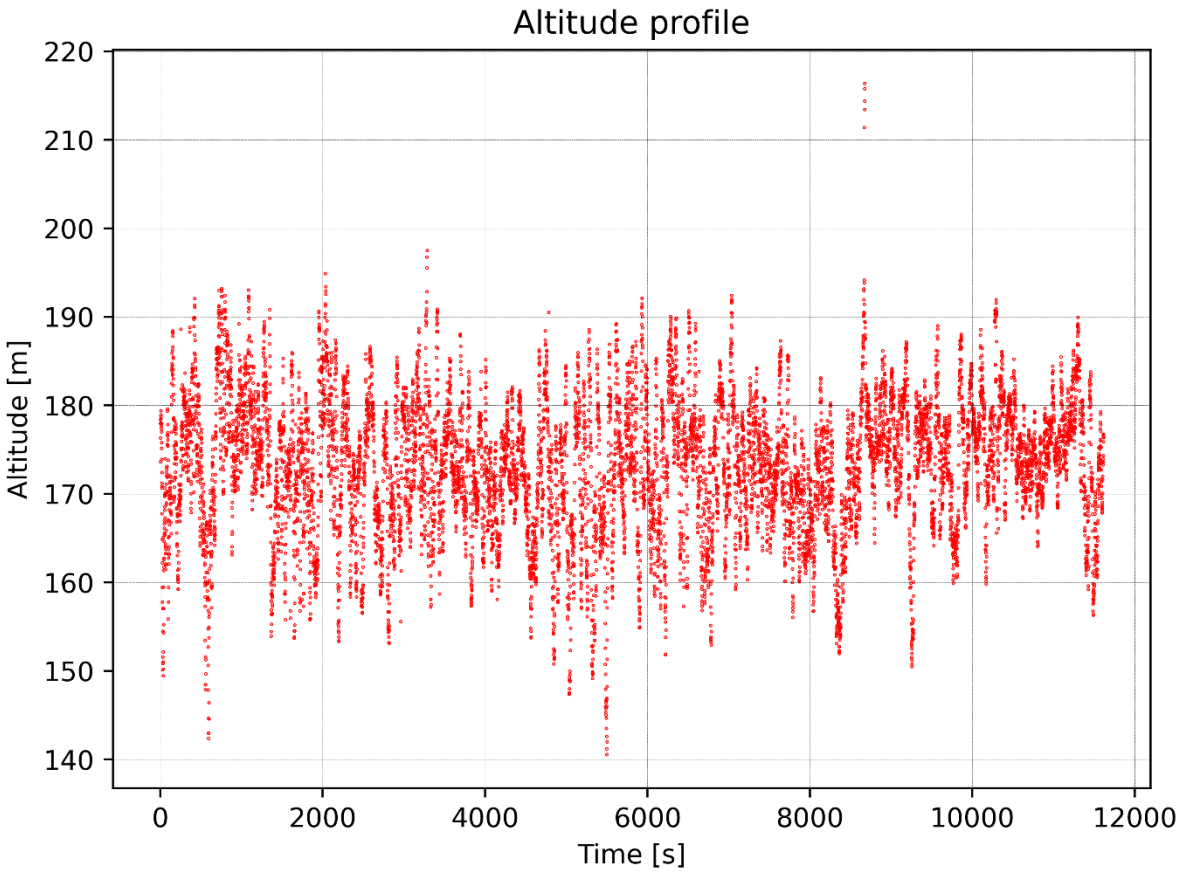


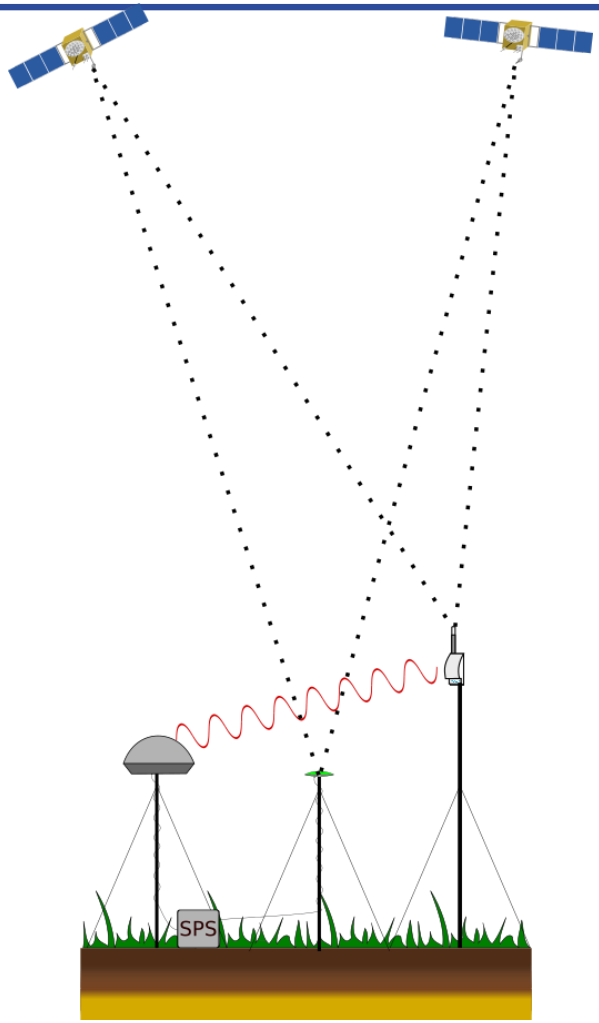


# Altitude uncertainty experiment





# Altitude uncorrelated uncertainty

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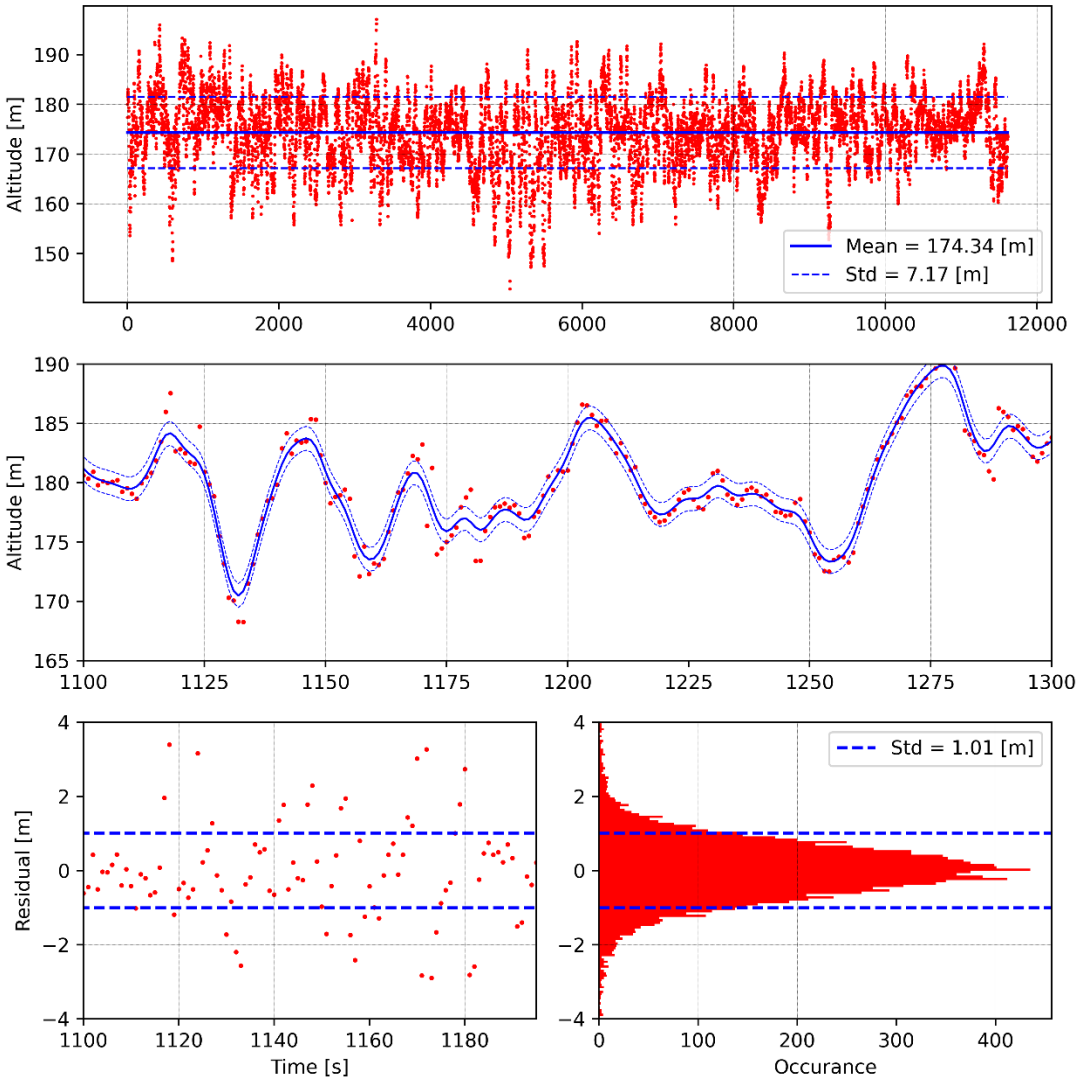
Stationary RS41 radiosonde:

- All coordinates: attitude, latitude and longitude are normally distributed
- All coordinates show systematic behavior
- Systematic behavior is modelled using Gaussian smoothing
- Standard deviation of the residuals is used as uncertainty of the measurement
- Uncertainty of Stand-alone RS41 Altitude = 1m

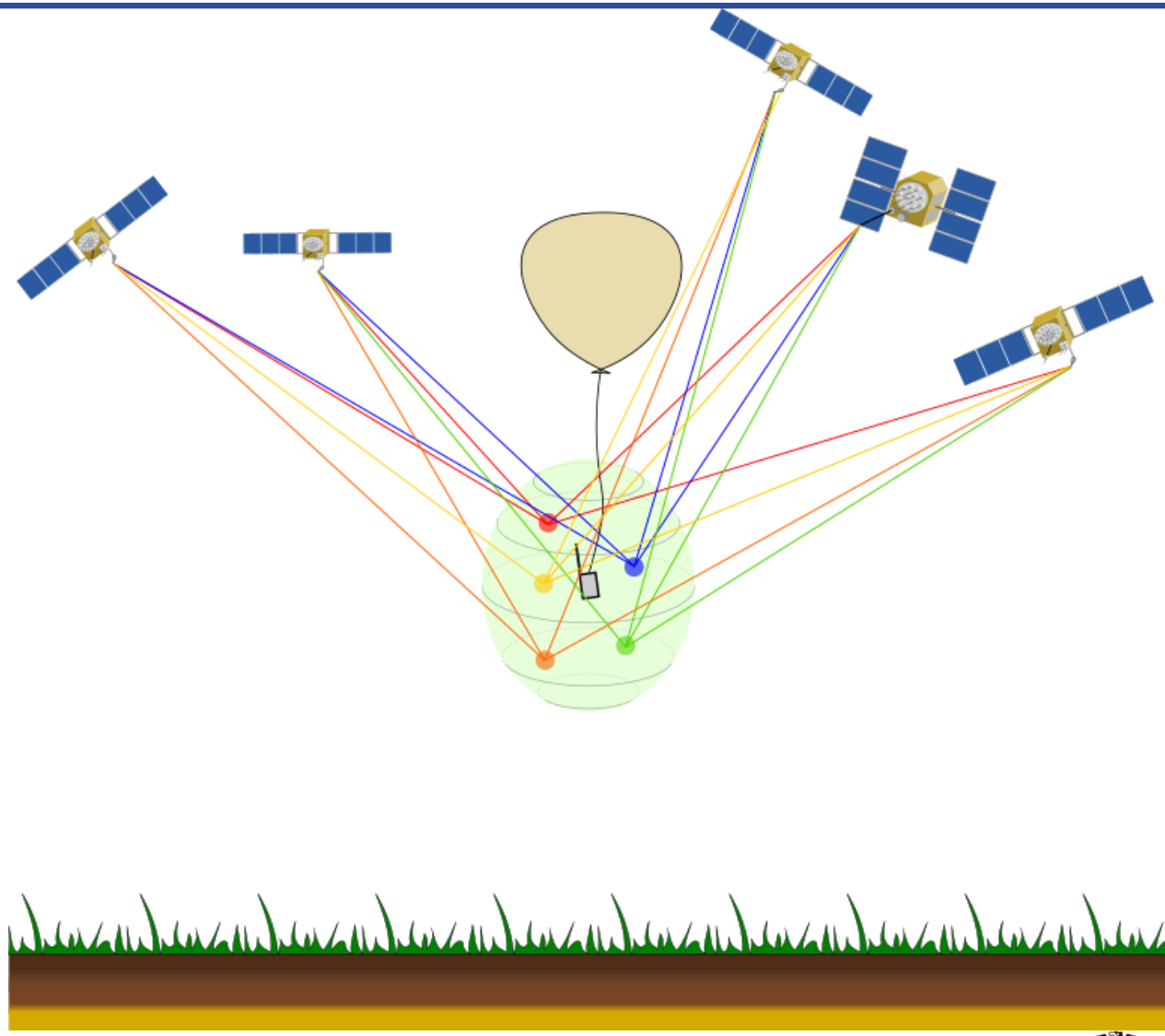


# Why systematic behaviour?



GPS parameters:

- 4-12 satellites used for a fix
- Satellite orbital period 12 hours
- Satellite signal is bent by the Ionosphere and the neutral atmosphere



# Altitude correlated uncertainty



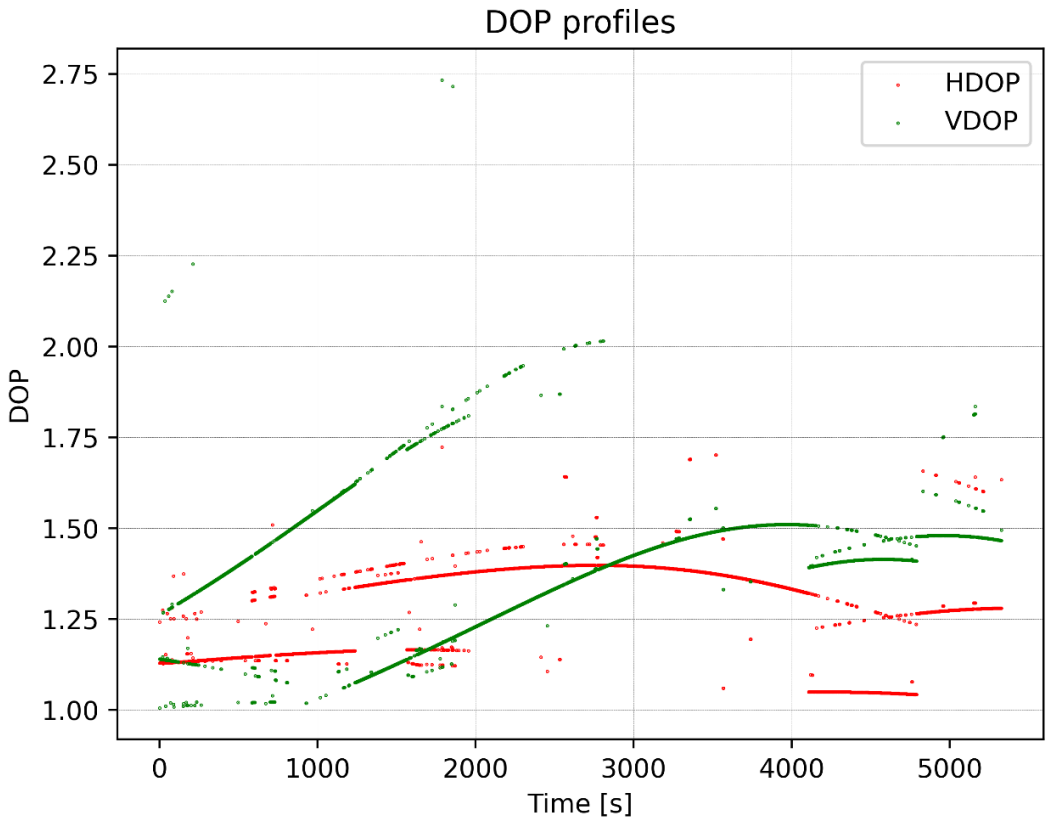
Stand-alone RS41 radiosonde:

- Accuracy of ublox receiver
  = 5m for altitude
- Vertical Dilusion of Precision

$$u(h_r)_{\text{corr}} = \text{VDOP} \cdot u(h_r)_{\text{ublox}}$$

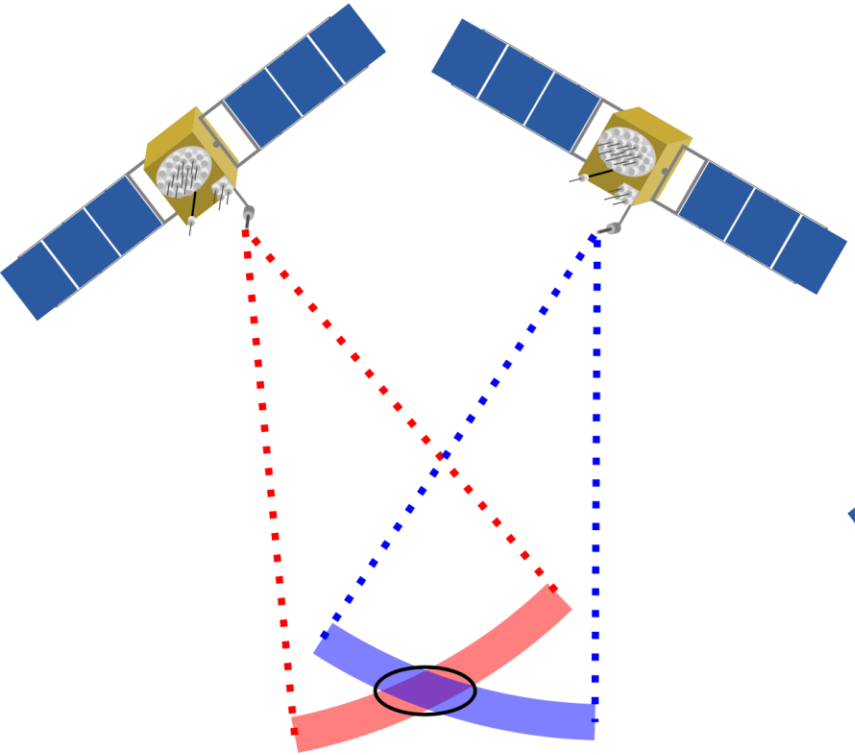
Uncertainties of the ground station:

- Ground-based GPS station uncertainty position
  = 0.2m for altitude
- EGM2008 Geoid uncertainty
  = 0.5m for altitude

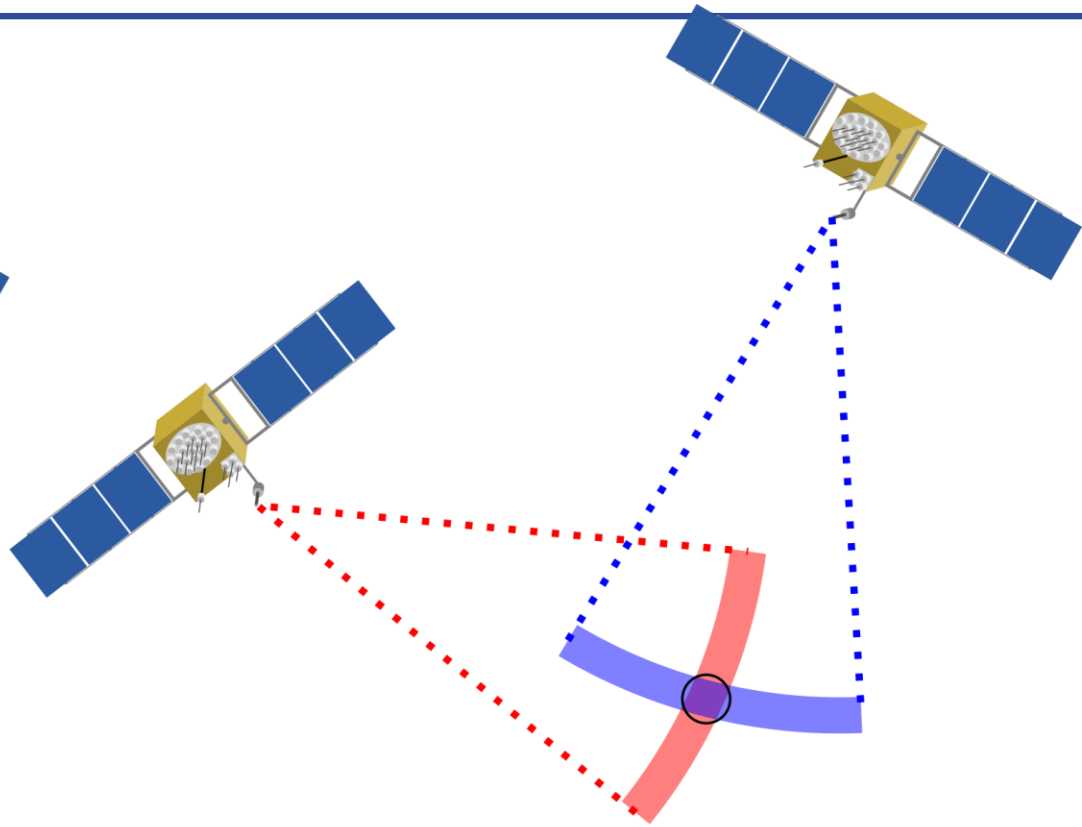


# Delusion of Precision (DOP) in GPS





High DOP

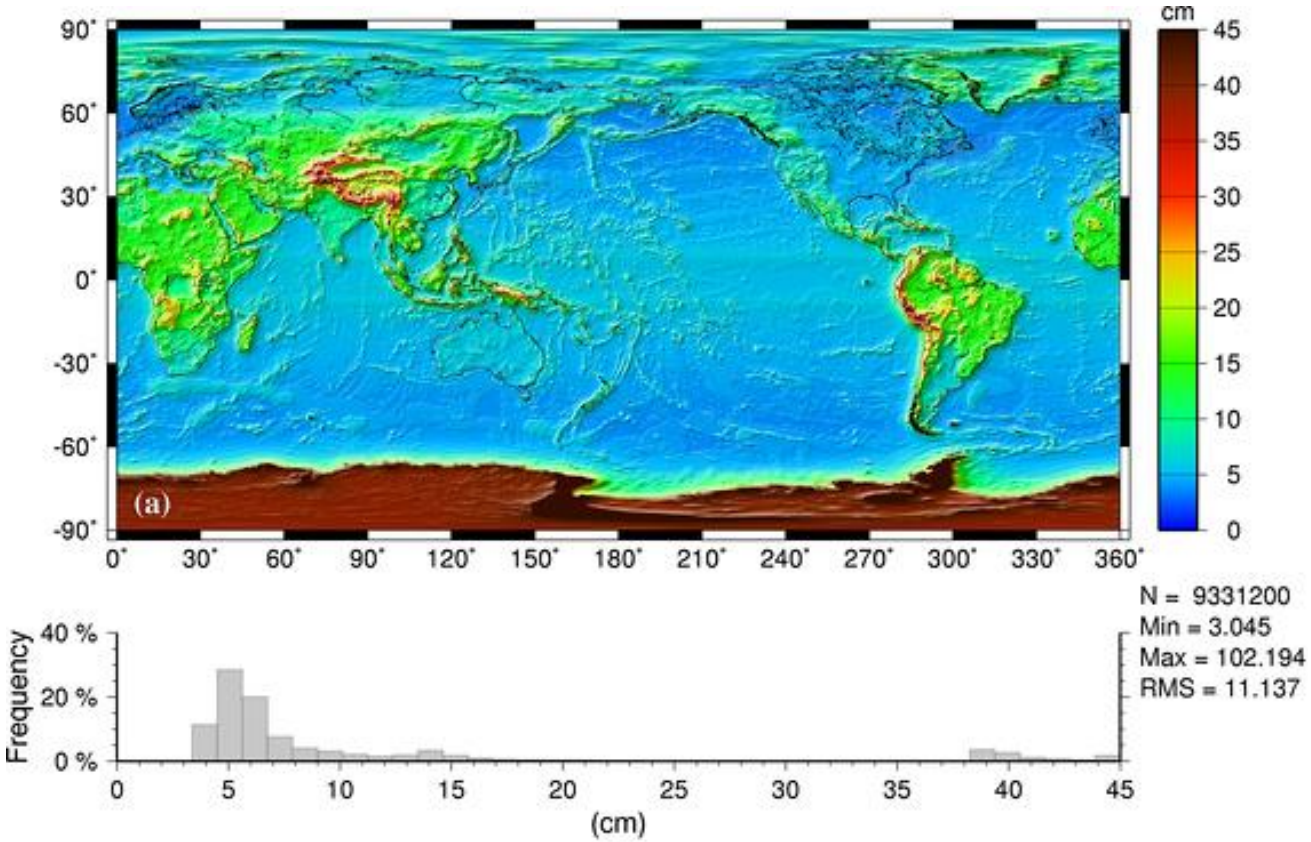


Low DOP

# EGM2008 Geoid



## GDP uses EGM2008 Geoid, Vaisala uses EGM96 Geoid




Commission error of the EGM2008 Geoid.

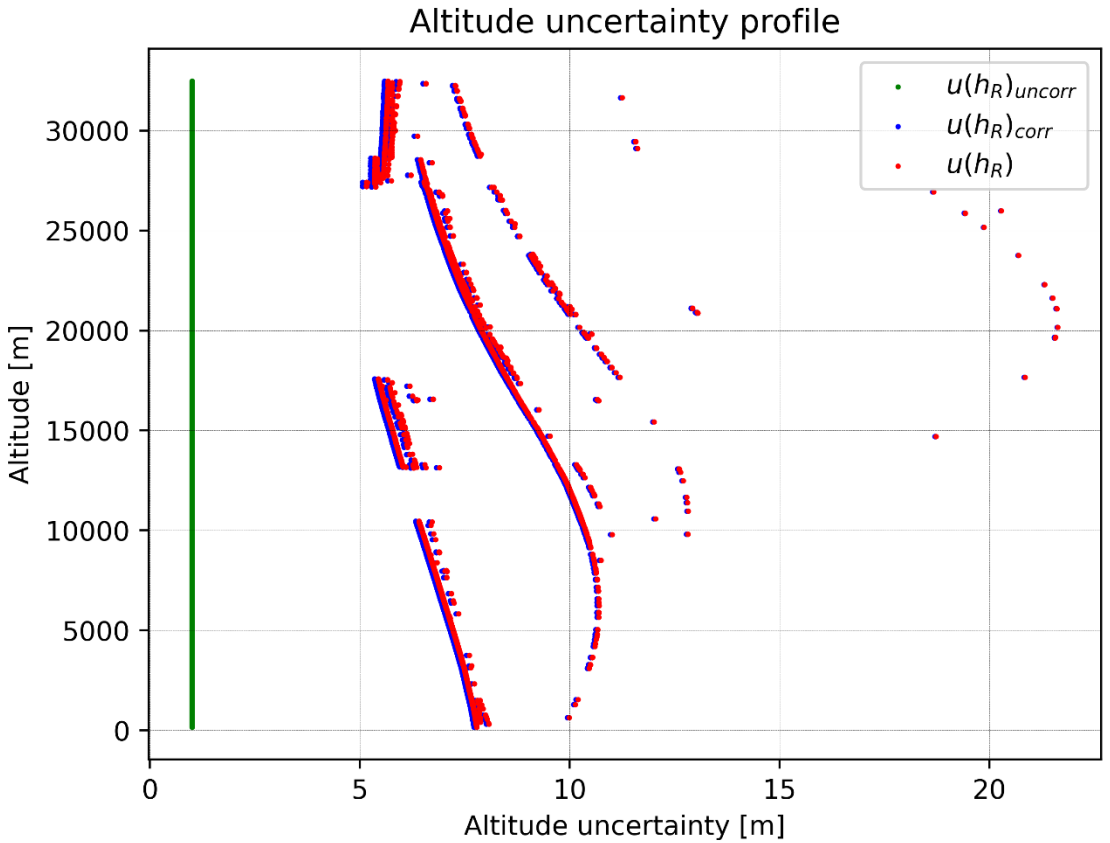
Pavlis, Nikolaos K., et al. "The development and evaluation of the Earth Gravitational Model 2008 (EGM2008)." *Journal of geophysical research: solid earth* 117.B4 (2012).

# Altitude uncertainty



Full Altitude uncertainty dependent on:

- Stand-alone RS
- VDOP of GPS
- Ground station position
- Geoid




$$u(h_R) = \sqrt{u^2(h_r) + u^2(h^{\text{static}}_{\text{SPS}})_{\text{geoid}} + u^2(h^{\text{static}}_{\text{SPS}})_{\text{position}}}$$

RS41 GPS positioning

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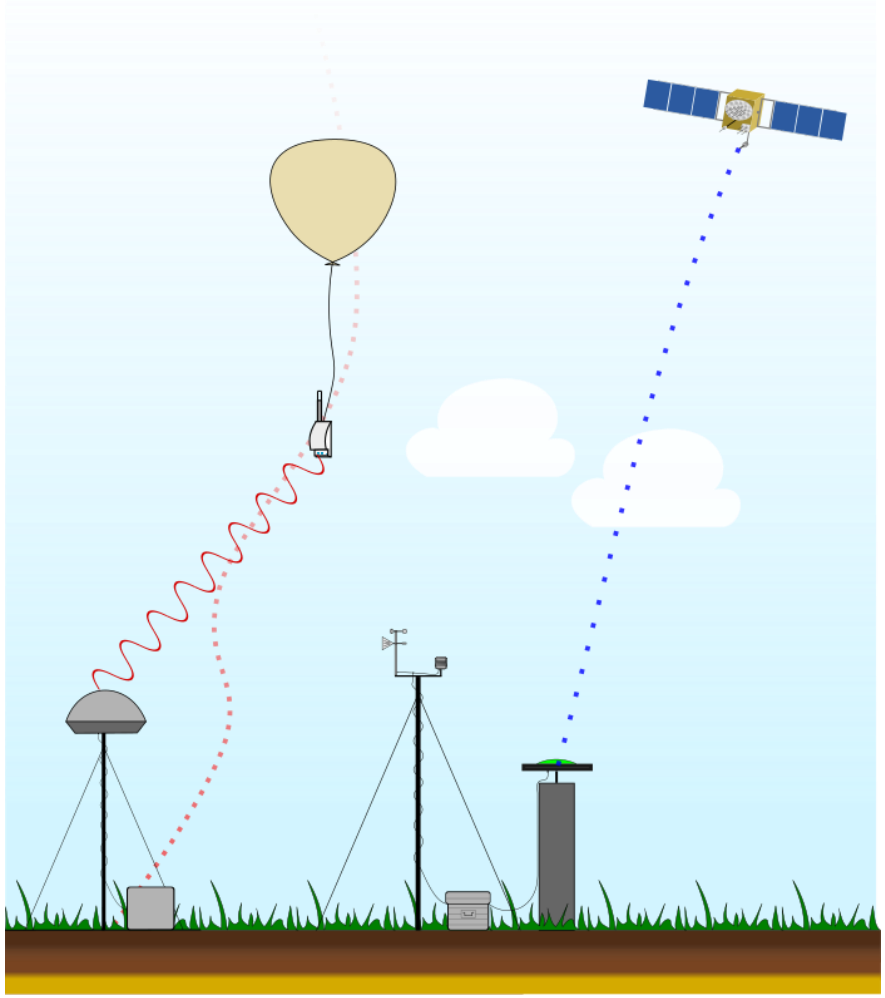
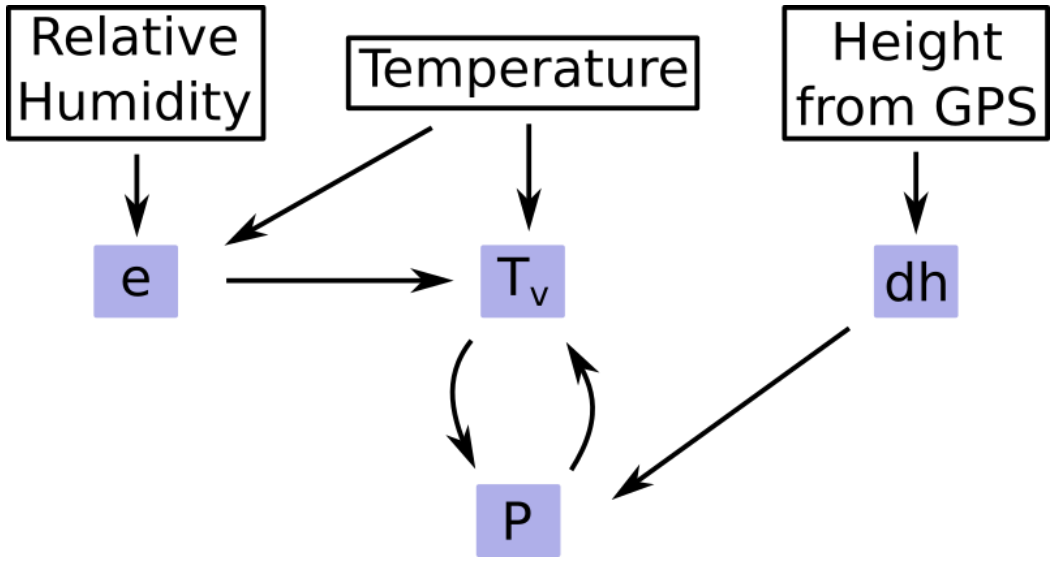


# RS41 Pressure from altitude



- P – Pressure
- e – partial pressure of water vapour
- Tv – virtual temperature




$$dh_i = h_{i+1} - h_i$$

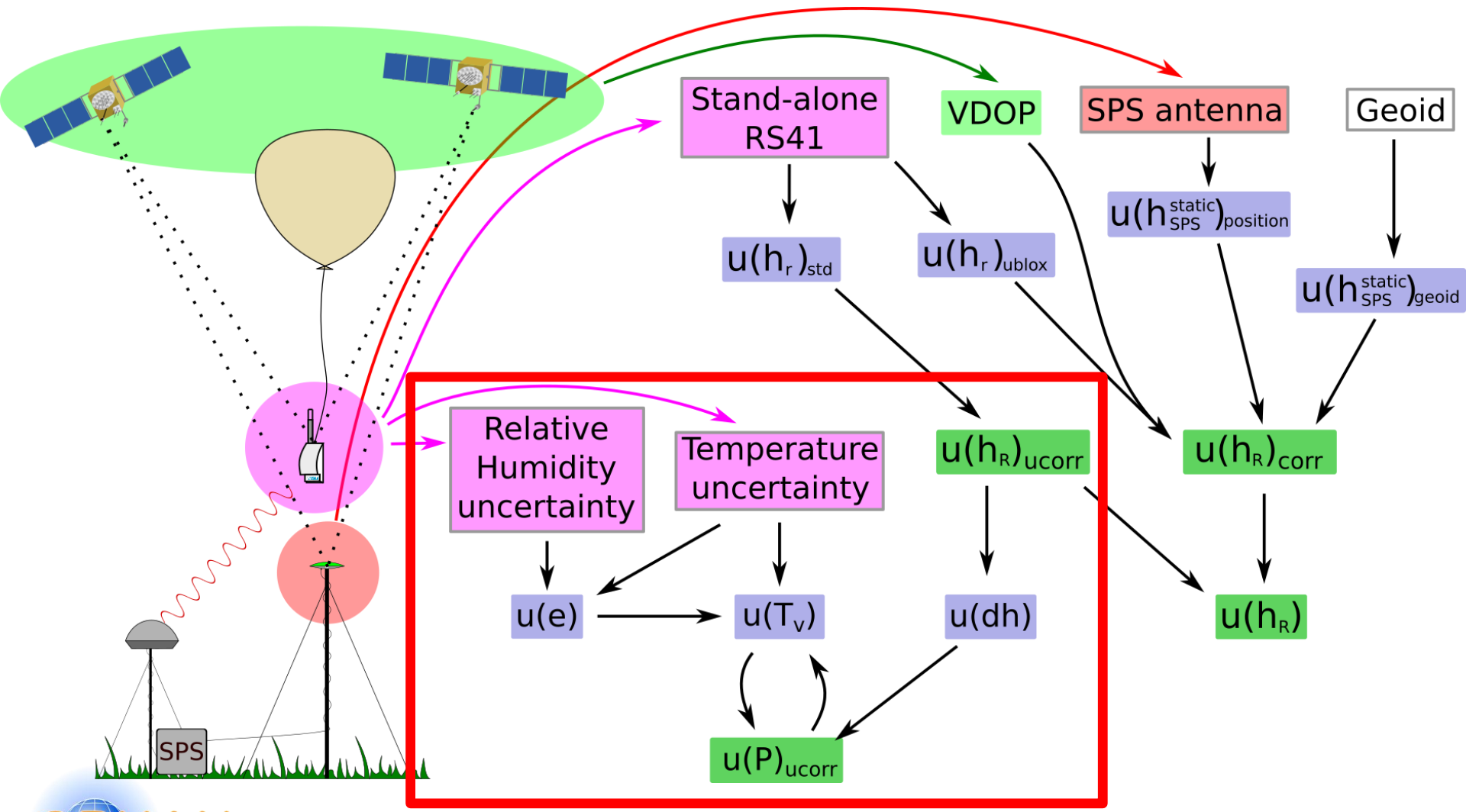
$$T_v = \frac{T_m}{1 - \frac{e}{p}(1 - \epsilon)}$$

$$e = 0.01 \cdot U_m \exp\left(\frac{c_1}{T_m} + c_2 + c_3 T_m + c_4 T_m^2 + c_5 T_m^3 + c_6 \log(T_m)\right)$$

$$p_{i+1} = p_i \exp\left(\frac{-M \cdot g \cdot dh_i}{R_u \cdot T_v}\right)$$

# RS41 Pressure from altitude uncertainty





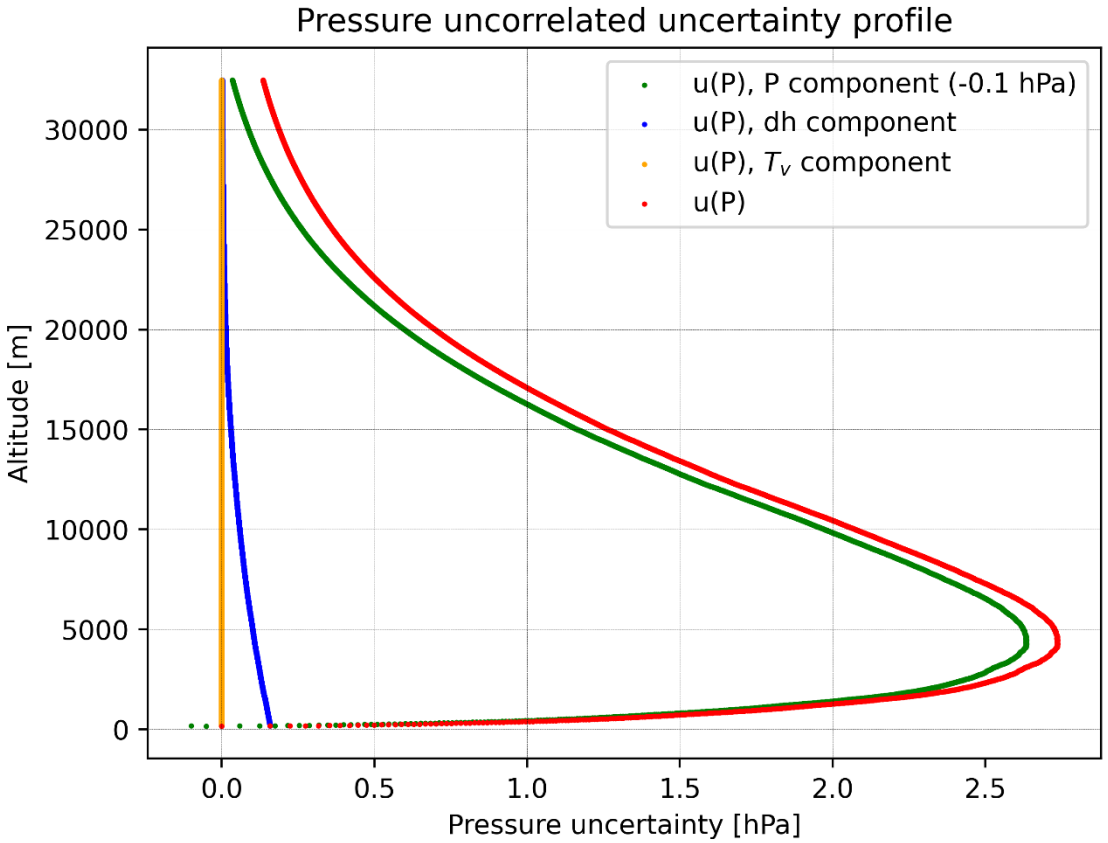
# RS41 Pressure from altitude uncorrelated uncertainty



Uncorrelated pressure uncertainty from GPS Altitude:

- Barometric formula
- Virual temperature uncertainty
- Altitude uncorrelated uncertainty
- Partial pressure uncertainty

Uncorrelated pressure uncertainty for difference between neighboring points




$$u(p_i)_{\text{ucorr}} = p_i \cdot \sqrt{\left(\frac{u(p_{i-1})_{\text{ucorr}}}{p_{i-1}}\right)^2 + \left(\frac{g \cdot dh_i}{R_d T_v^i}\right)^2 \left(\left(\frac{u(dh_i)}{dh_i}\right)^2 + \left(\frac{u(T_v^i)}{T_v^i}\right)^2\right)}$$

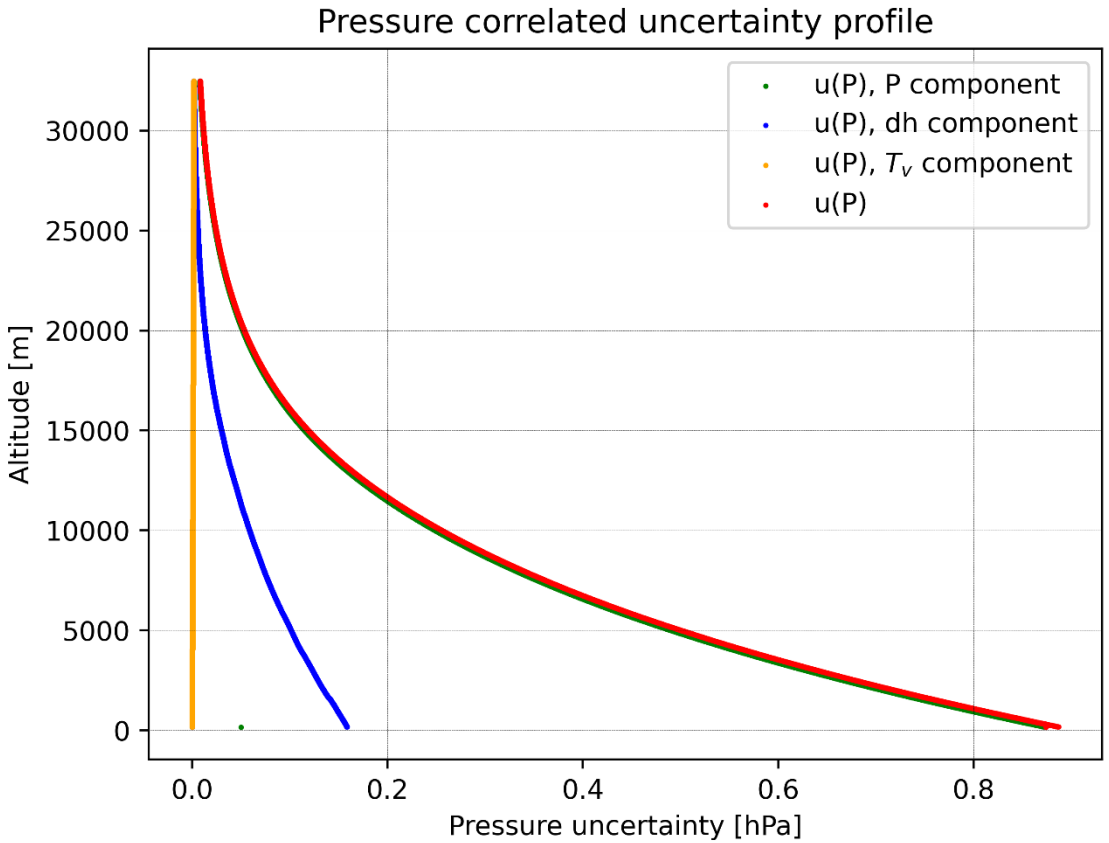
# RS41 Pressure from altitude correlated uncertainty



Correlated pressure uncertainty from GPS Altitude:

- Barometric formula
- Virual temperature uncertainty
- Altitude uncorrelated uncertainty
- Partial pressure uncertainty

Correlated pressure uncertainty for difference between each point and launch point



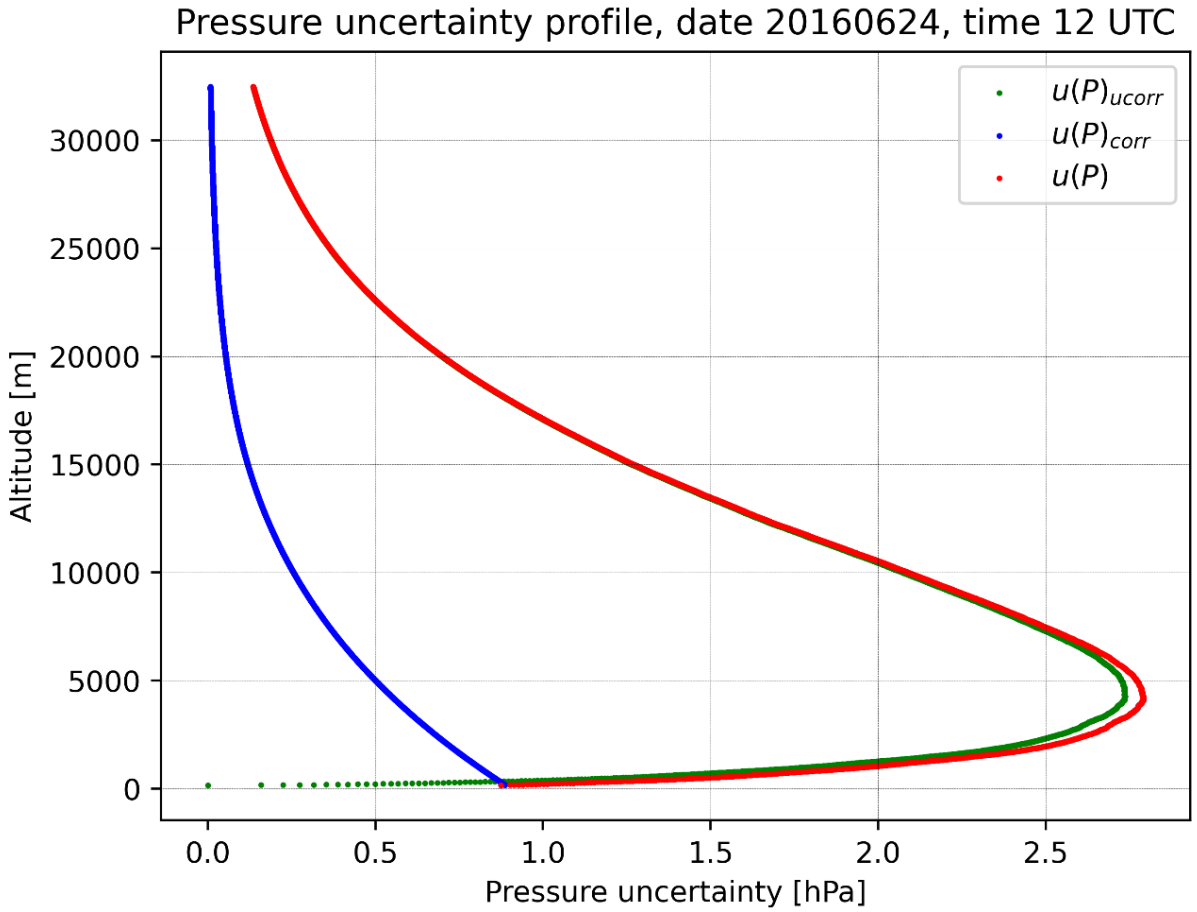

$$u(p_i)_{\text{corr}} = p_i \cdot \sqrt{\left(\frac{u(p_{sb})_{\text{corr}}}{p_{sb}}\right)^2 + \left(\frac{g \cdot dh^i_{sb}}{R_d T^i_v}\right)^2 \left(\left(\frac{u(dh^i_{sb})}{dh^i_{sb}}\right)^2 + \left(\frac{u(T^i_v)}{T^i_v}\right)^2\right)}$$

# RS41 Pressure from altitude full uncertainty



Full pressure uncertainty from GPS Altitude:

- Correlated pressure uncertainty
- Uncorrelated pressure uncertainty




$$u(p) = \sqrt{u(p)^2_{\text{corr}} + u(p)^2_{\text{ucorr}}}$$

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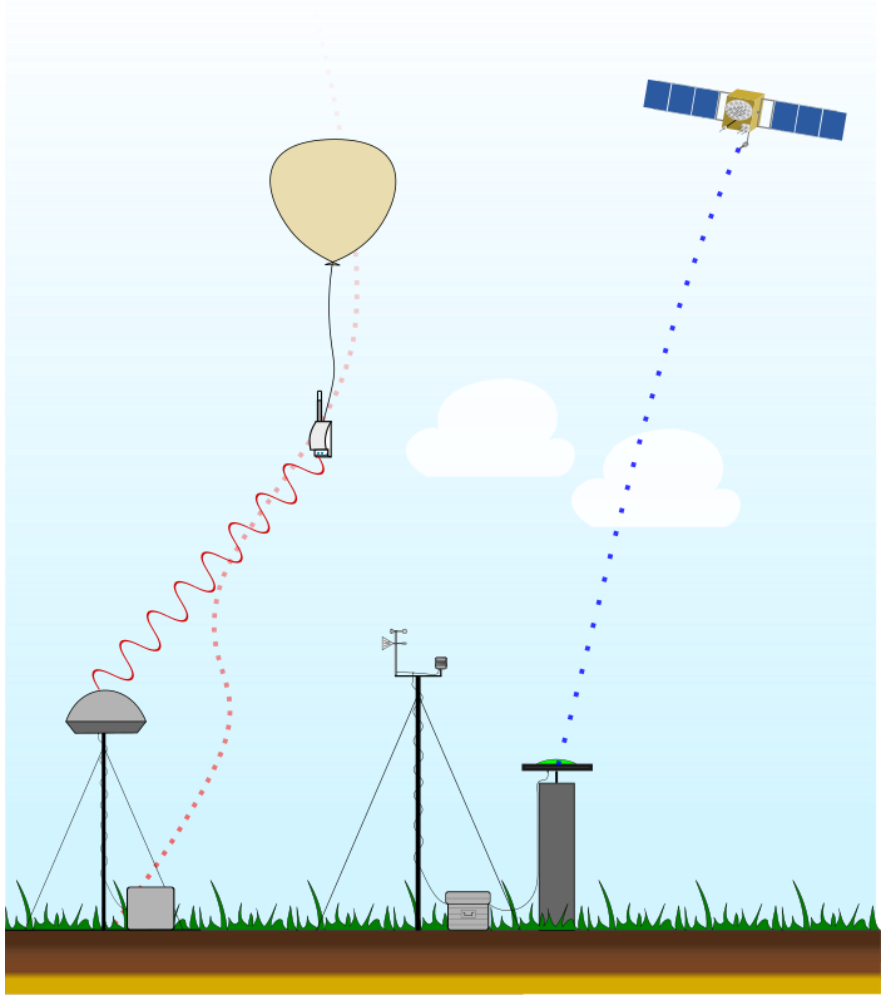
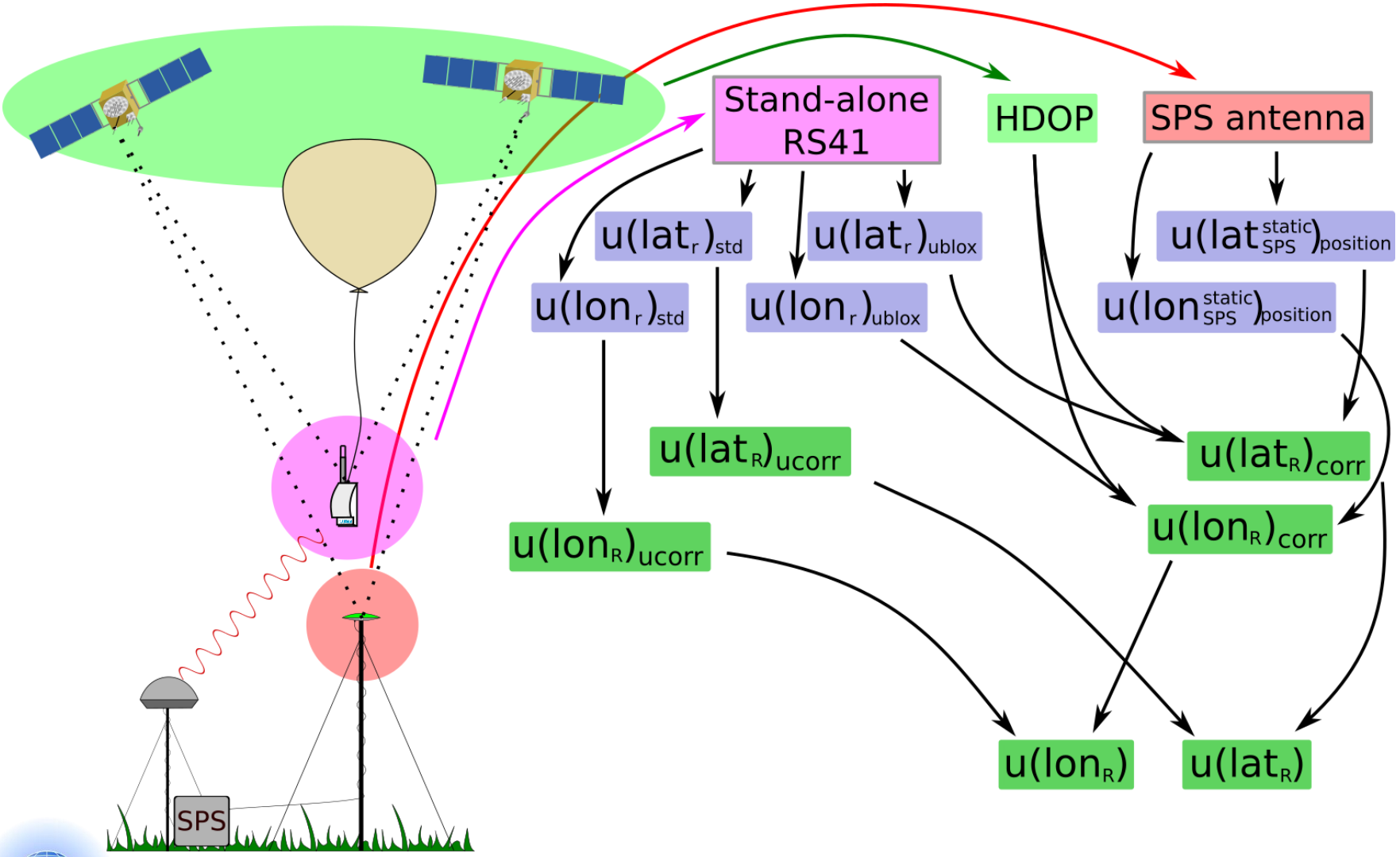


# RS41 Horizontal coordinate uncertainties



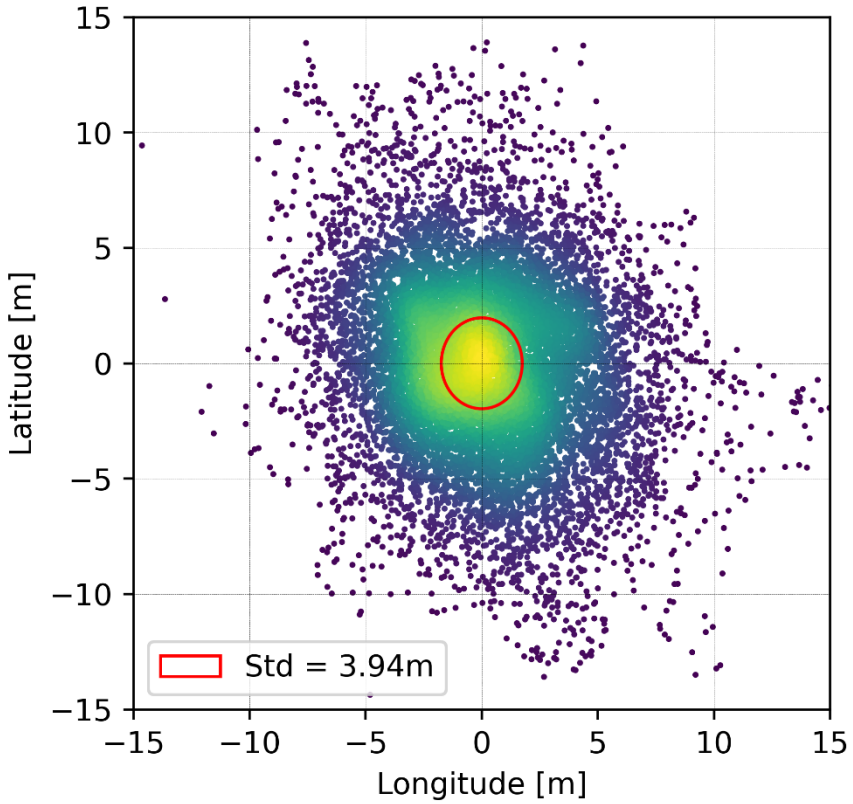


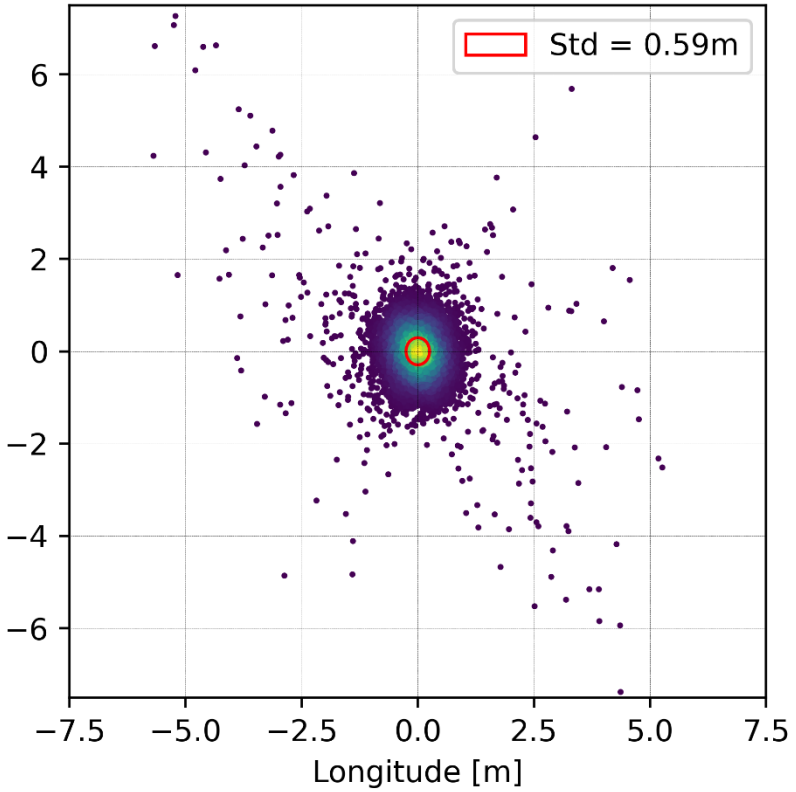
# Uncertainty of horizontal position



Uncorrelated horizontal coordinates uncertainty from GPS:

$$u(lon_r)_{ucorr} = u(lon_r)_{std} = 0.6[\mathrm{m}],$$
$$u(lat_r)_{ucorr} = u(lat_r)_{std} = 0.6[\mathrm{m}].$$



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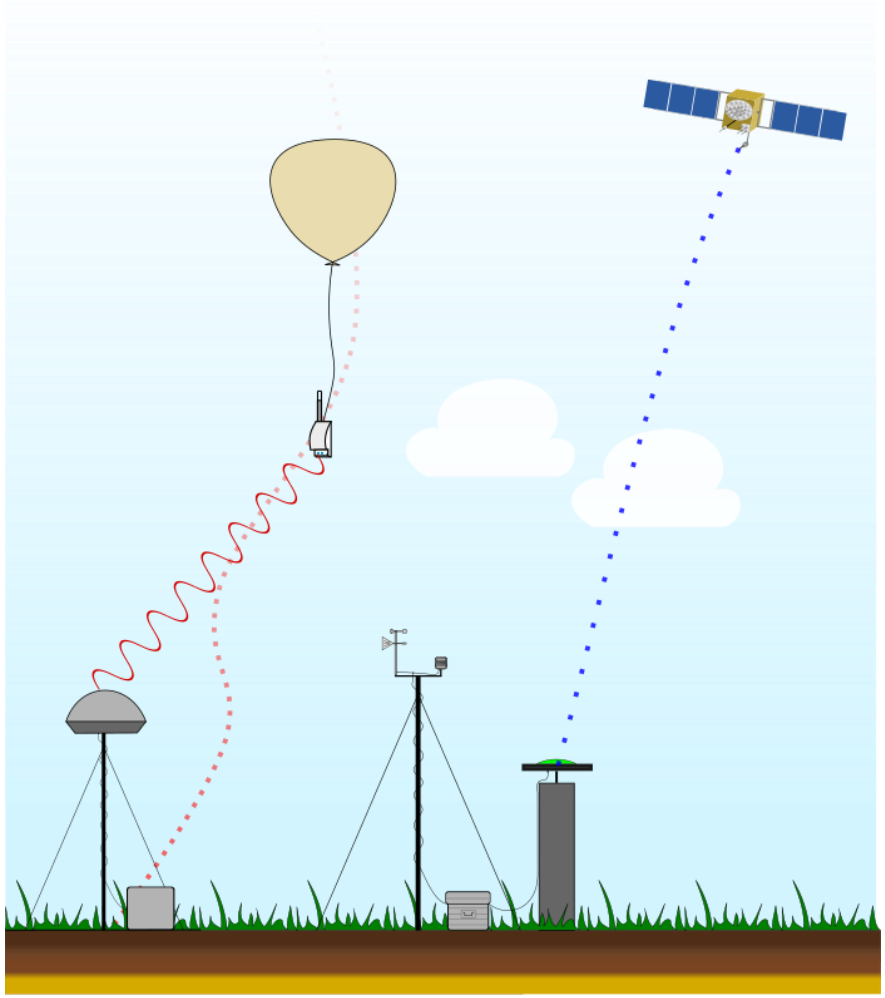
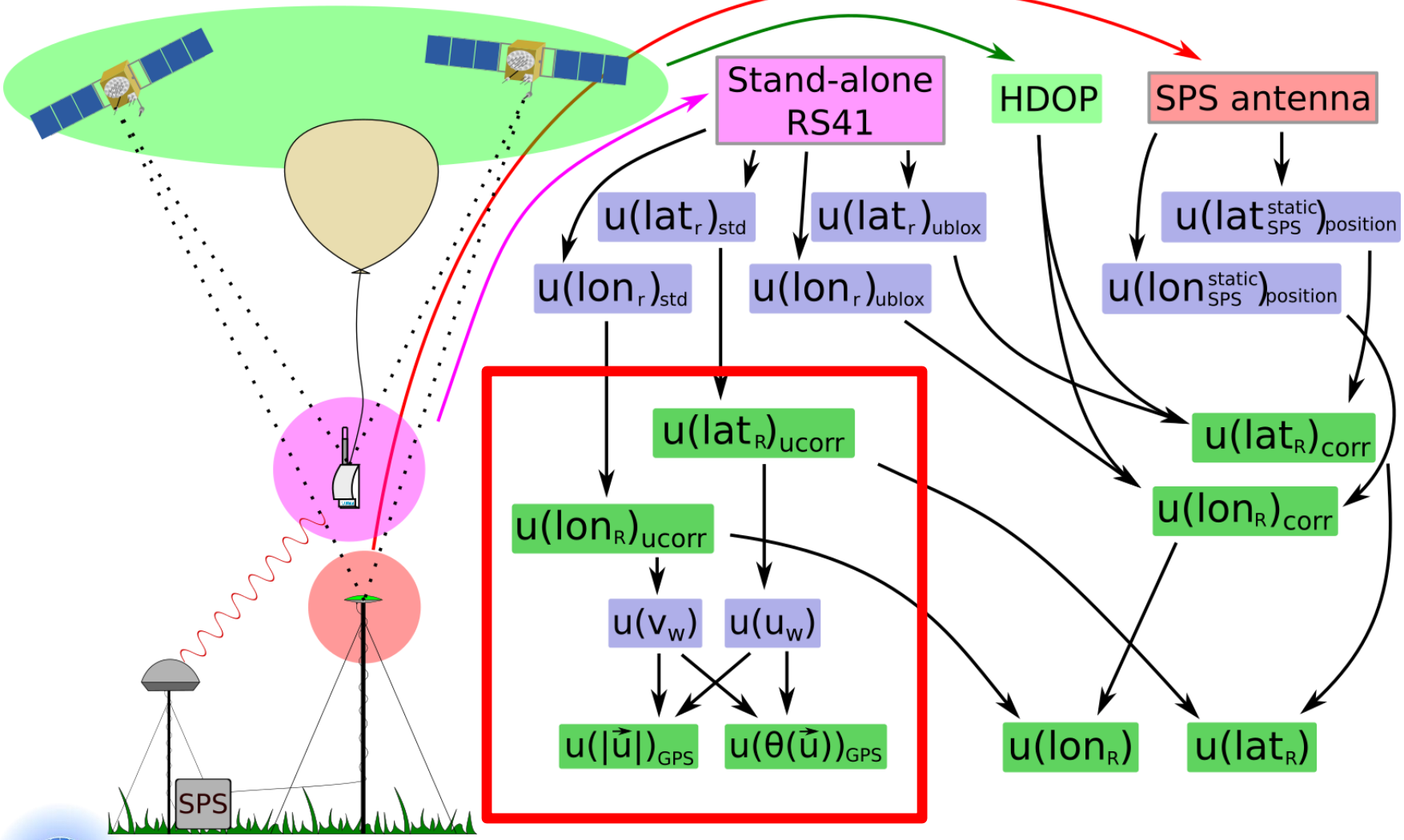


# RS41 Wind uncertainty





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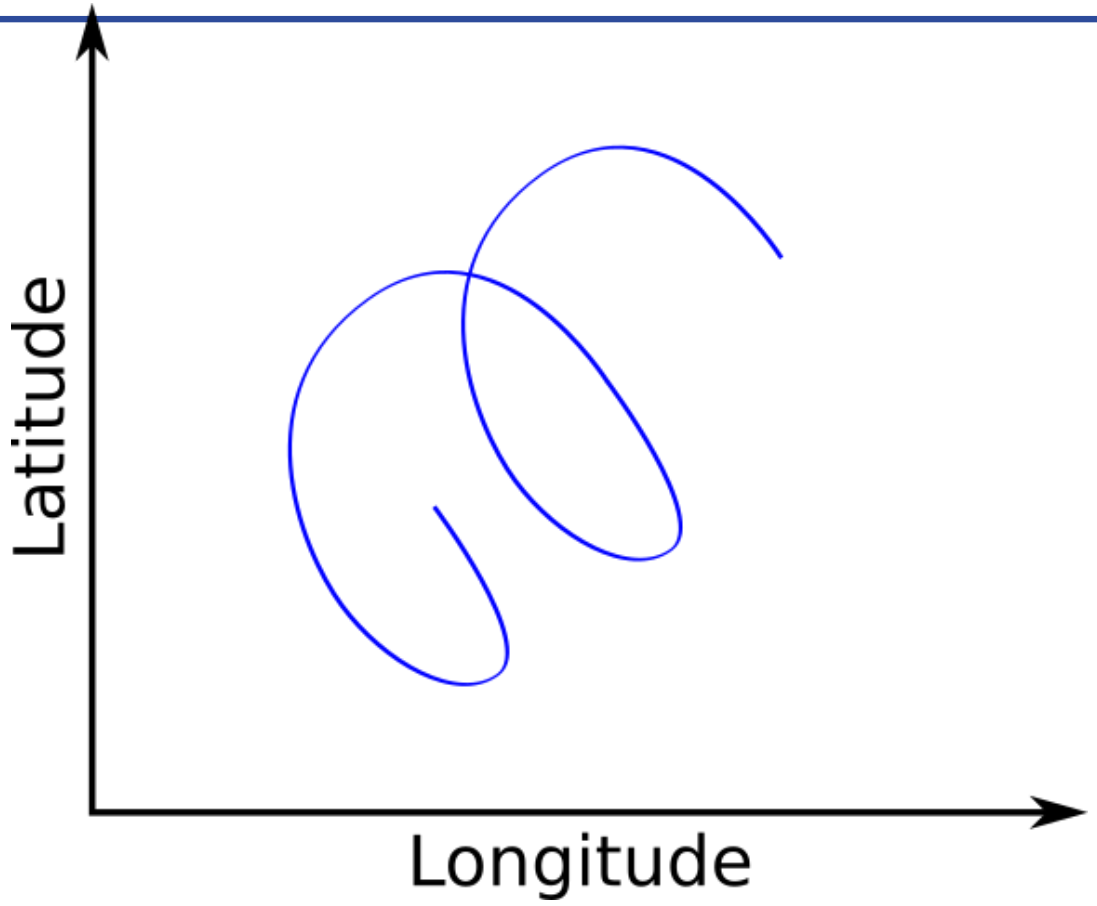
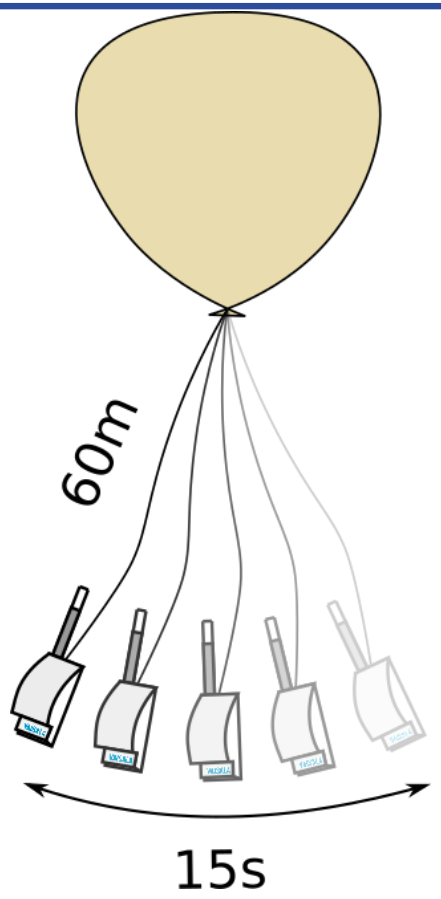
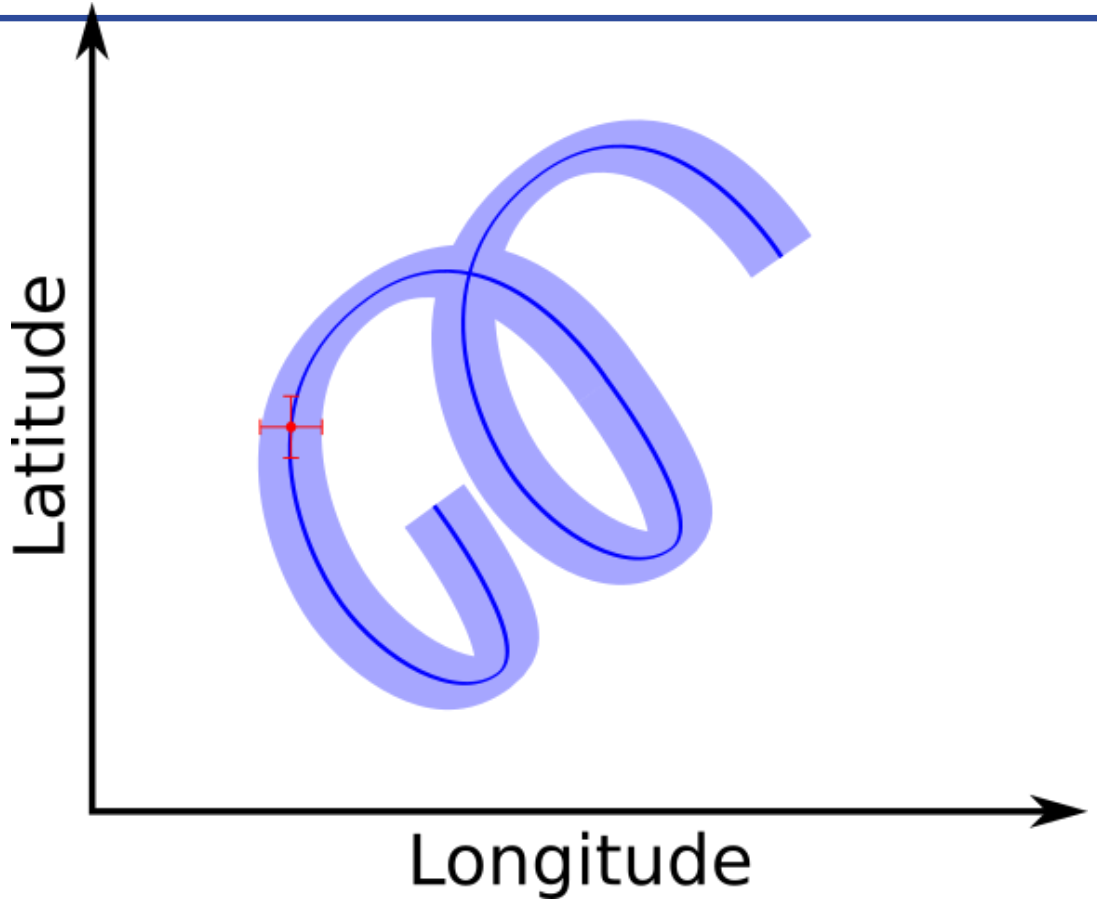
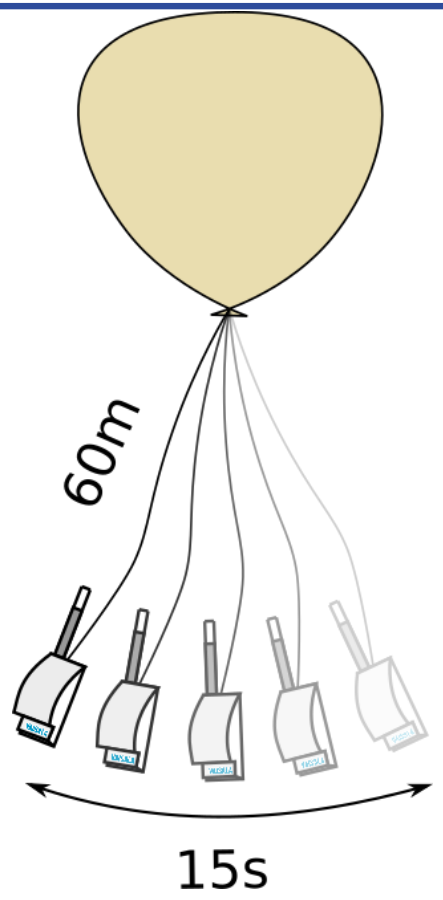


# RS41 Wind uncertainty





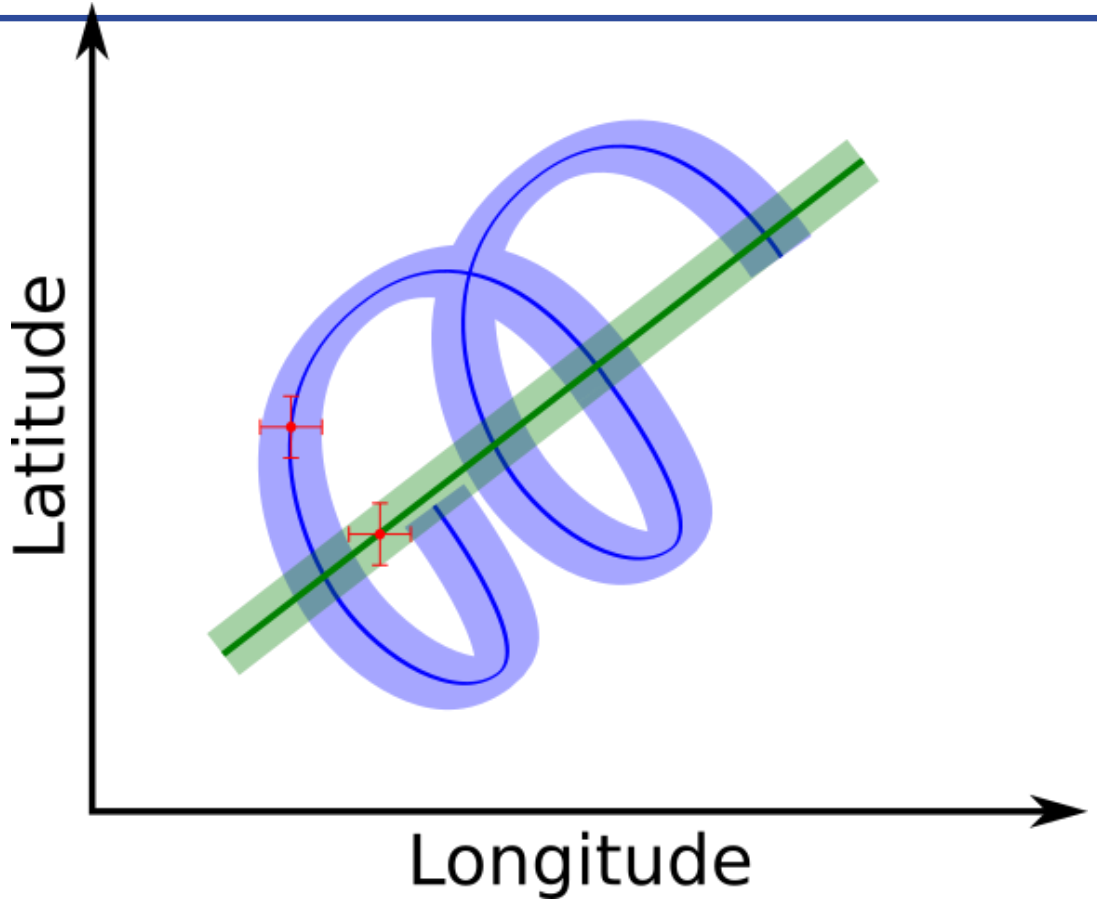



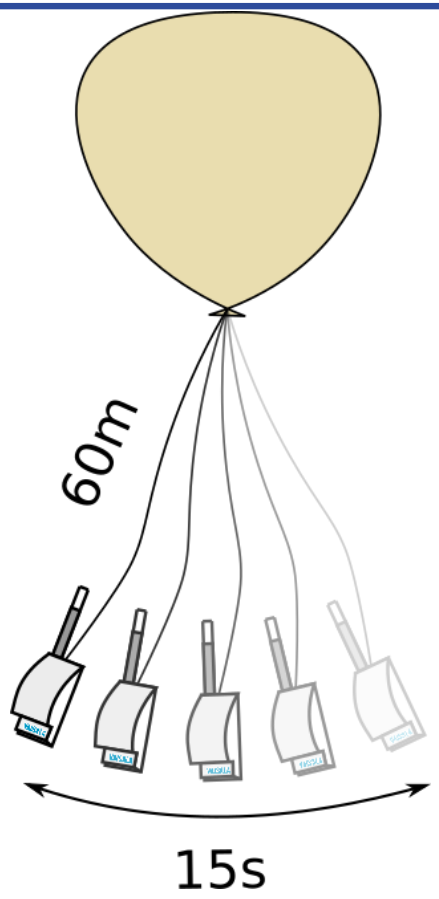

$$u(u_w) = \sqrt{2 \cdot u(lat_r)^2_{\text{ucorr}}} = \sqrt{2} \cdot u(lat_r)_{\text{ucorr}} \approx 0.85[\text{m/s}],$$

$$u(v_w) = \sqrt{2 \cdot u(lon_r)^2_{\text{ucorr}}} = \sqrt{2} \cdot u(lon_r)_{\text{ucorr}} \approx 0.85[\text{m/s}].$$

# RS41 Wind uncertainty



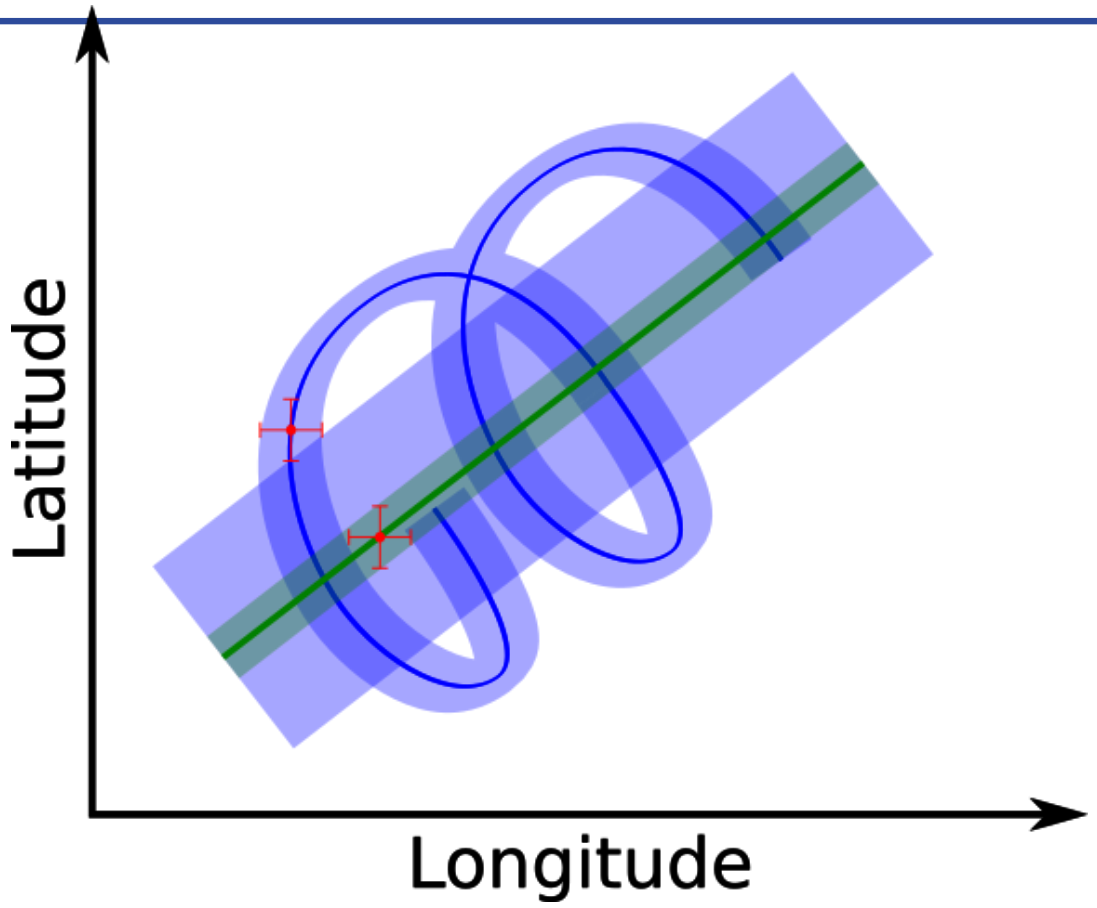


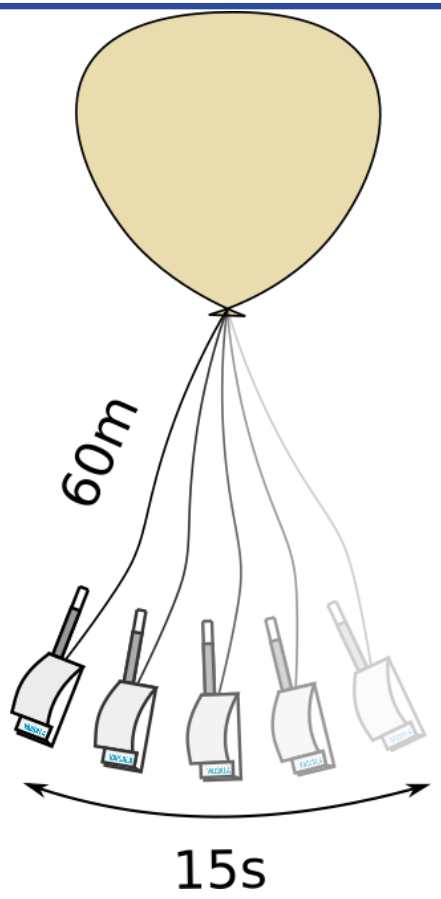




$$u(|\vec{u}|)_{\mathrm{GPS}} = \frac{\sqrt{u_w^2 \cdot u^2(u_w) + v_w^2 \cdot u^2(v_w)}}{|\vec{u}|} = u(v_w) \cdot \frac{\sqrt{u_w^2 + v_w^2}}{|\vec{u}|} \approx 0.85[\mathrm{m/s}]$$

# RS41 Wind uncertainty






$$u(|\vec{u}|) = \sqrt{u(|\vec{u}|)^2_{\mathrm{GPS}} + u(|\vec{u}|)^2_{\mathrm{smooth}}}$$

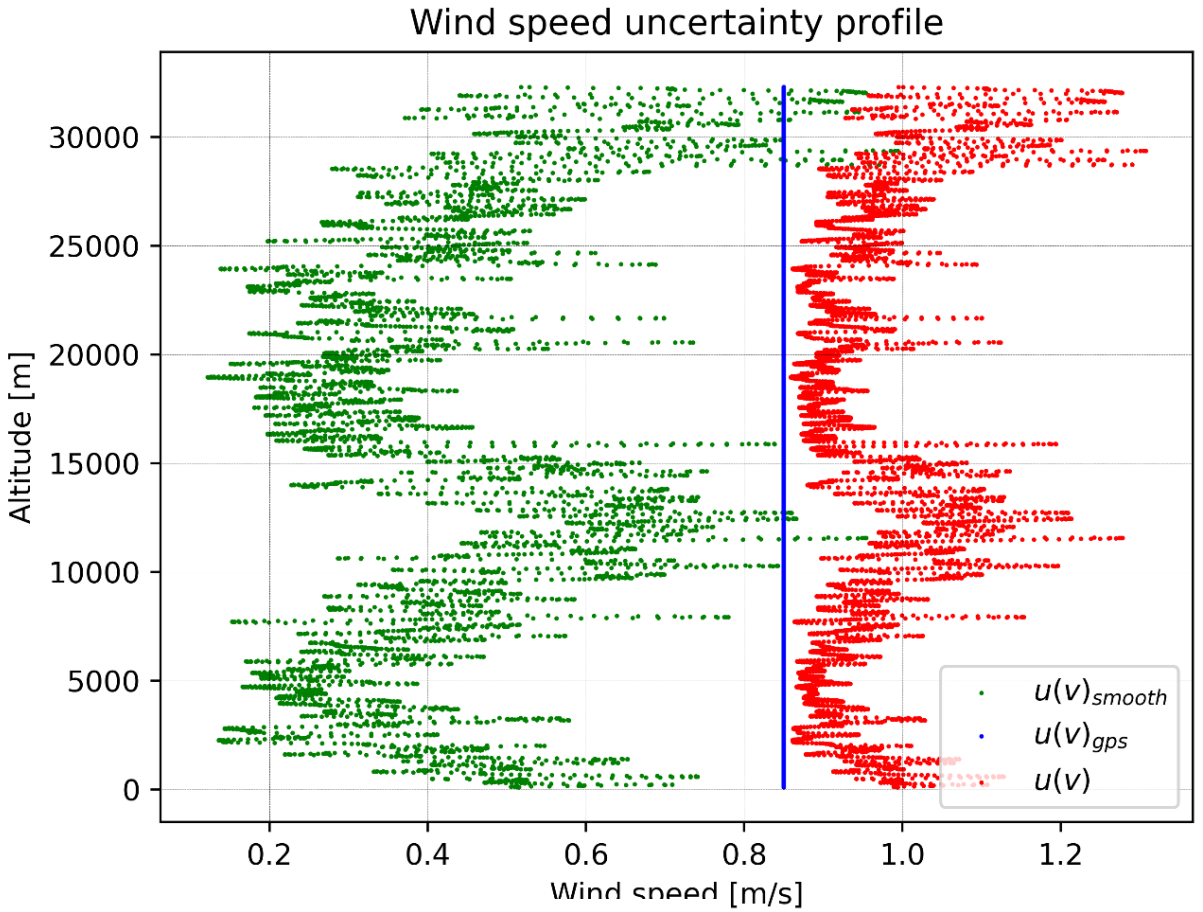
# RS41 Wind speed uncertainty



Full wind speed uncertainty:

- GPS random Lat/Lon uncertainties
- Smoothing residual standard deviation

- Both wind speed uncertainties are uncorrelated
- No correlated wind speed uncertainty

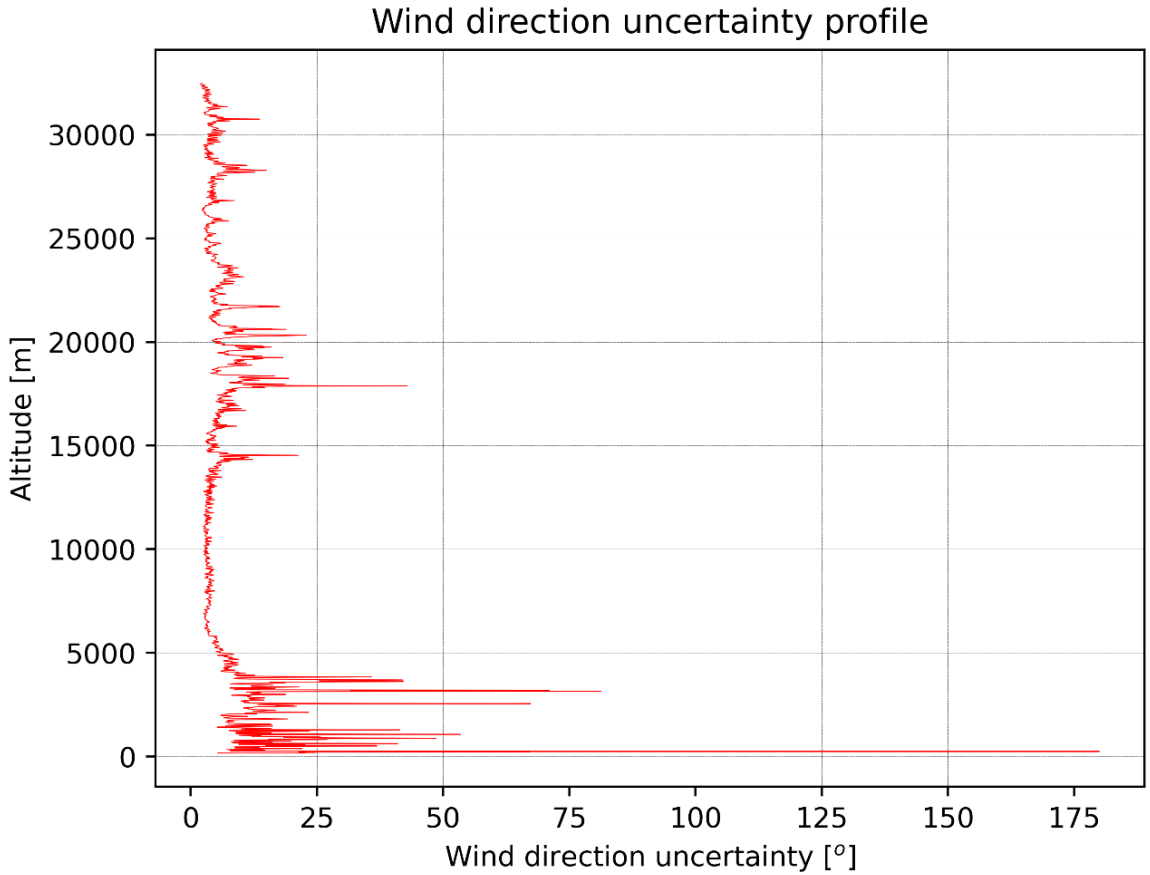



$$u(|\vec{u}|) = \sqrt{u(|\vec{u}|)^2_{\text{GPS}} + u(|\vec{u}|)^2_{\text{smooth}}}$$

# RS41 Wind direction uncertainty



## Full wind direction uncertainty is uncorrelated only




$$u(\theta(\vec{u})) = \frac{180^\circ}{\pi} \frac{\sqrt{u^2 \cdot u^2(v) + v^2 \cdot u^2(u)}}{\vec{u}^2}.$$

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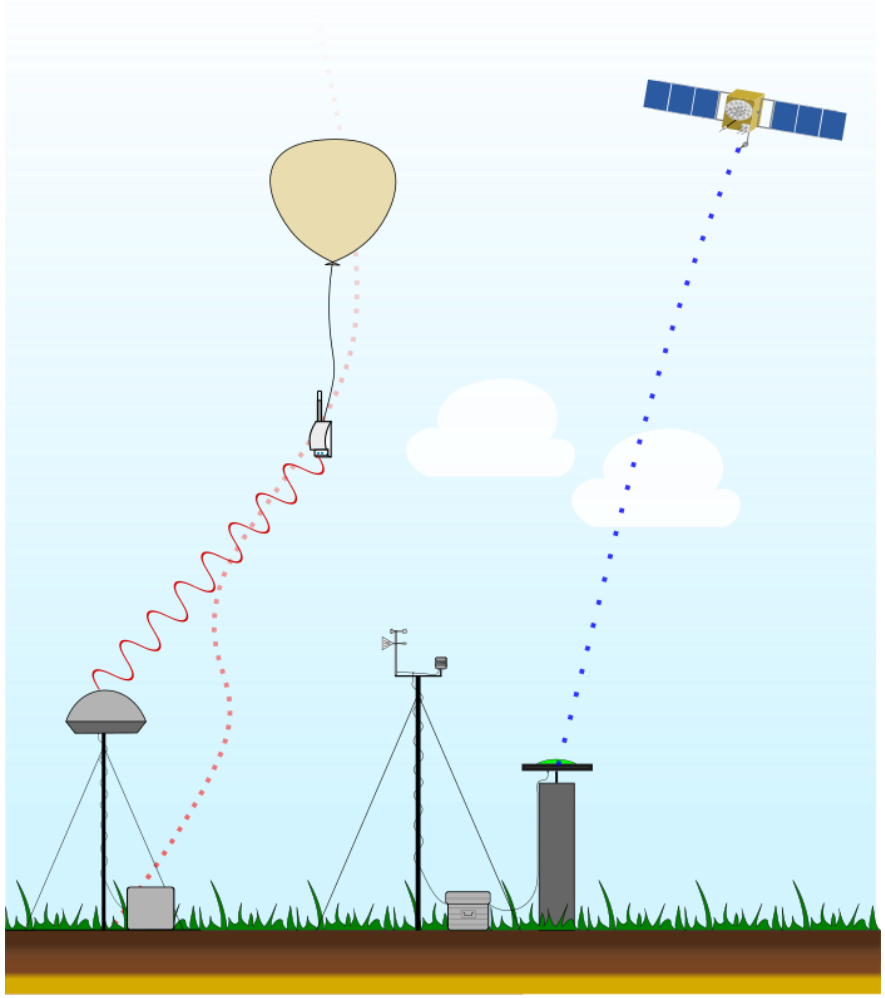
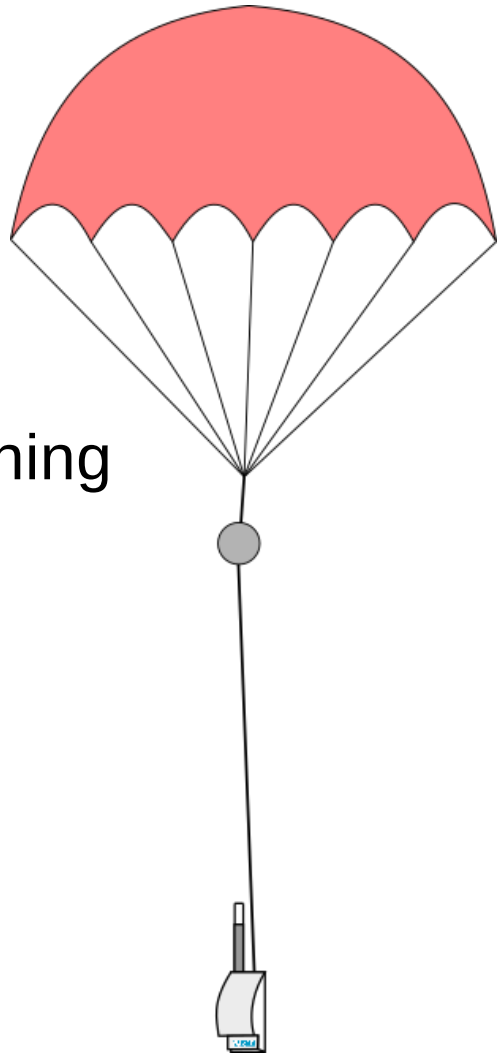


# Summary





What will be included in RS41 GDP BETA 2?

- New full uncertainties of RS41 GPS positioning
- New uncertainties of pressure from height
- New uncertainties of wind components
- New uncertainties of ventilation


# Thank you for your attention !