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Harmonization of radiosounding climate data records for the Copernicus Climate Change Service.

F. Madonna, E. Tramutola, M. Proto, S. SY, A. Fassò, P. Thorne, K. Kreher, T. Gardiner, K. Rannat, J. Notholt, G. Braathen, M. De Mazière and F. Hendrick

Lead Contractor: National Research Council of Italy (CNR-IMAA)

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RATIONALE

- Radiosonde observations are often subject to inhomogeneities (due to changes in station location, instrument, etc.). Quite often changes are not documented in the metadata.
- Primarily made to provide the data needed to constrain weather forecasts, little attention has been paid to ensuring the long-term homogeneity of the radiosonde data records which typically fall short of the standard required to reliably detect changes in climate.
- Much effort has been spent attempting to remove discontinuities in radiosounding data records using different approaches (e.g. Durre et al., 2005; Free et al., 2004, 2005; McCarthy et al., 2008; Sherwood et al., 2008; Haimberger et al., 2008; Seidel et al., 2009, 2011; Thorne et al., 2012; Haimberger et al., 2012).
- The recent advent of GRUAN (GCOS Research Upper-Air Network) allows the community to access traceable ”Reference” traceable radiosonde data records with evaluated uncertainties. In addition, WMO/CIMO intercomparisons datasets enable to quantify bias and uncertainty for several sonde types.

RADIOSONDE HARMONIZATION

QUESTION: How can we use **Reference** radiosonde data records to improve the quality of the historical **Baseline** radiosonde time series?

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C3S IN-SITU REFERENCE AND BASELINE

In the frame of Copernicus Climate Change Service, a contract named **C3S 311a Lot3** started on March 1st, leaded by CNR-IMAA in cooperation with 8 subcontractors, with the aim to:

- Improve access to open and free observational records and data streams from selected in-situ GCOS-relevant Baseline and Reference networks since 1-1-1979 to present.
- Develop consistent quality control algorithms for in situ climate data arising from Baseline and Reference networks at various time scales (hourly, daily, monthly, annually).
- Develop methods to detect and adjust for inhomogeneities due to issues such as, instrumentation changes, calibration drifts, observing station relocations,
- To provide/quantify uncertainty in a consistent and metrologically rigorous manner.

C3S 311a Lot3 will facilitate access to data from the following networks:

- **Temperature/humidity/wind (profiles): GRUAN, GUAN, RAOB;**
- Surface Temperature: USCRN, RBSN, GSN, RBCN;
- Ozone (concentration, columns and profiles): NDACC, SHADOZ, GAW Networks;
- CO, CO2, CH4 (concentration, columns and profiles): TCCON, GAW networks;
- Integrated water vapour (from GNSS zenith tropospheric delay only): IGS, EUREF, all international GNSS networks.

RADIOSOUNDINGS: DATA SOURCES

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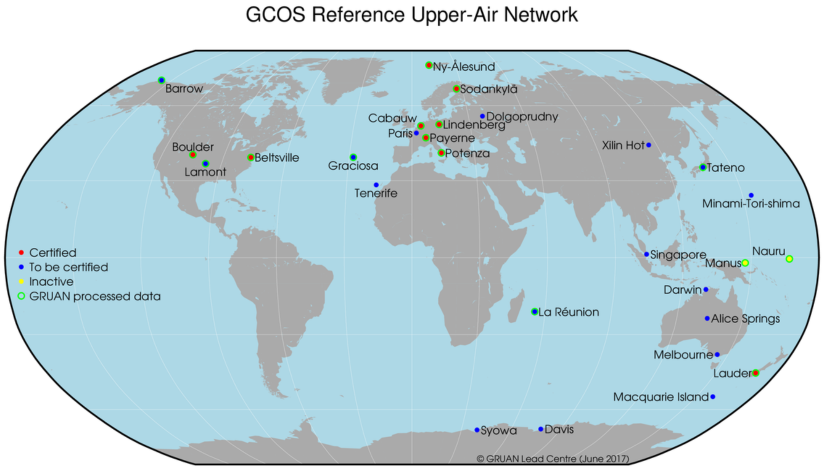

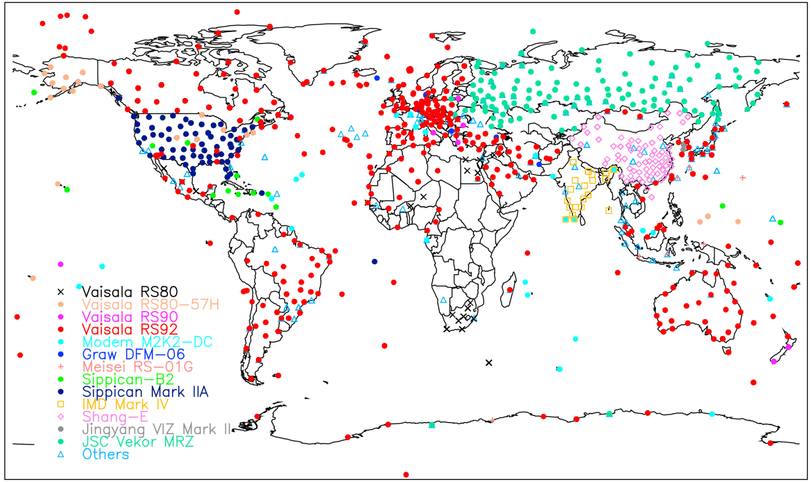

GRUAN

GCOS Research Upper-Air Network

Reference, traceable measurements, uncertainty budget

RAOB

the universal RAwinsonde OBservation program

Global baseline observations, no uncertainty

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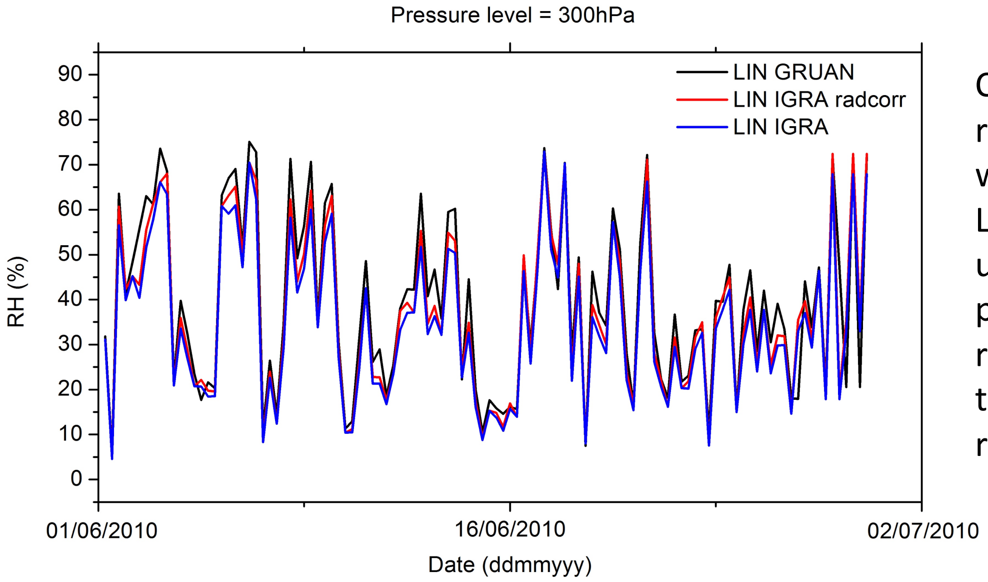
ADJUSTMENT AND UNCERTAINTIES – STEP 1

To harmonize historical RAOB time series, an approach, named RHARM (Radiosounding HARMonization), has been developed to adjust systematic effects.

RHARM consists of **two** major steps.

Algorihtm step 1: "Physical" harmonization using a "GRUAN-like" data processing (e.g dry-bias correction, sensors time lag correction, etc, only for Vaisala RS92 sondes).



Comparison of the time series of the relative humidity at 300 hPa measured with the radiosondes launches in Lindenberg in June 2010 and processed using the manufacturer software (blue), processed applying the GRUAN radiation correction (red) and applying the full GRUAN data processing on the raw high-resolution data.

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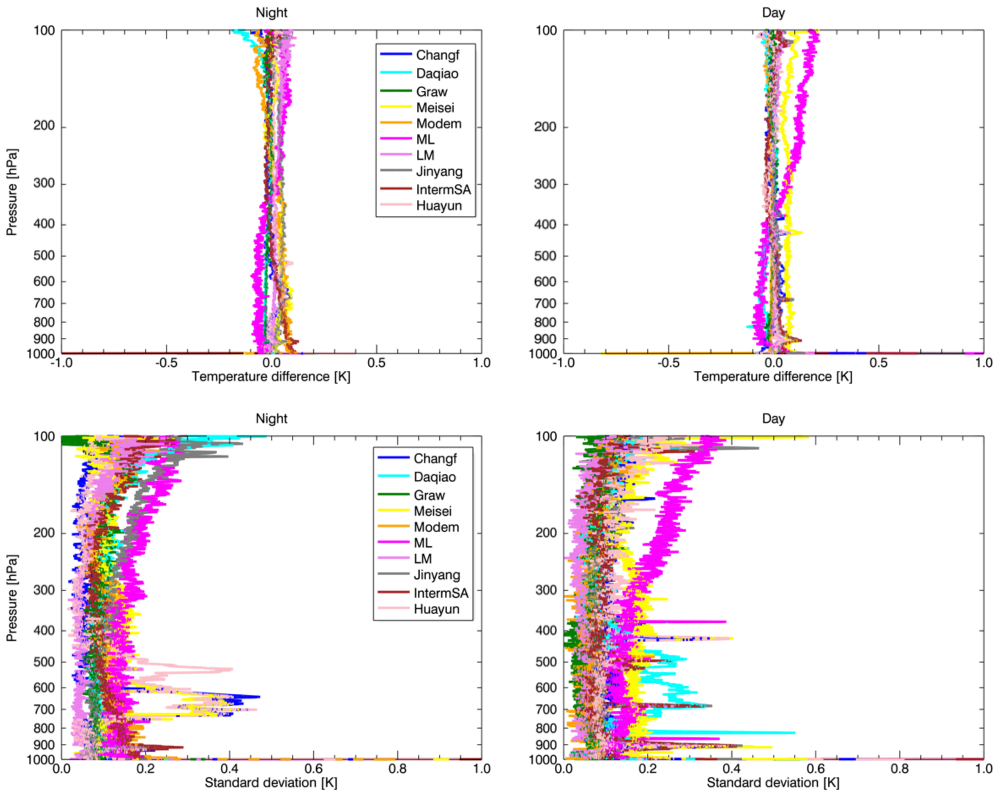
WMO-CIMO INTERCOMPARISON DATA



Each historical time series of T or RH available at a single radiosounding station flying radiosondes other than Vaisala is adjusted using the information inferred from the 2010 WMO/CIMO radiosonde intercomparison dataset (Nash et al. 2010)

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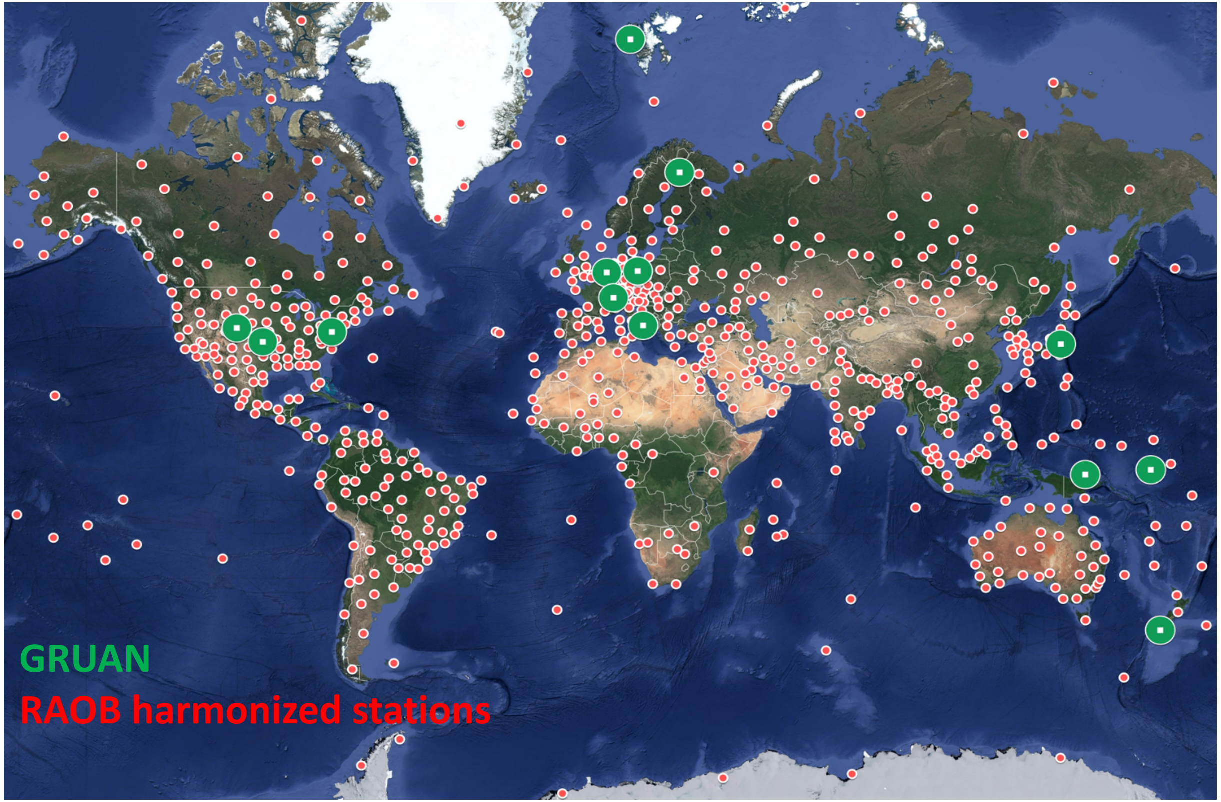
RADIOSOUNDINGS: HARMONIZED STATIONS



Global distribution of **GRUAN** Reference station (green large dots) and of a subset of IGRA stations harmonized using RHARM approach (red dots).

All the data and metadata will be provided to C3S users using a Common Data Model developed within C3S 311a contract family compliant with **ECMWF ODB, ISO, WIGOS, CF convention**.

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ADJUSTMENT AND UNCERTAINTIES – STEP 2

Algorihtm step 2: “Statistical” harmonization, detection of breaks, adjustment of mean (**physical harmonization is limited to data from about 2006 to present**).

- Each station series is firstly divided in two subseries to separate nighttime and daytime measurements (only 00 UTC and 12 UTC launches).
- Assuming that T and q profiles arise at each pressure level from a normal distribution, can be represented using an additive model:

$$x(p,t) = Tr(p,t) + S(p,t) + \varepsilon(p,t)$$

where x is the time series of T or RH, Tr is the unknown climate trend, S is the climate variability, and $\varepsilon \sim N(0,\sigma^2)$ represent the residuals which depends on the local meteorological variability and on the measurements uncertainties.

- Profiles are harmonized at all the mandatory pressure levels (1000 hPa -10 hPa)
- Data harmonization extended at significant levels by interpolation.

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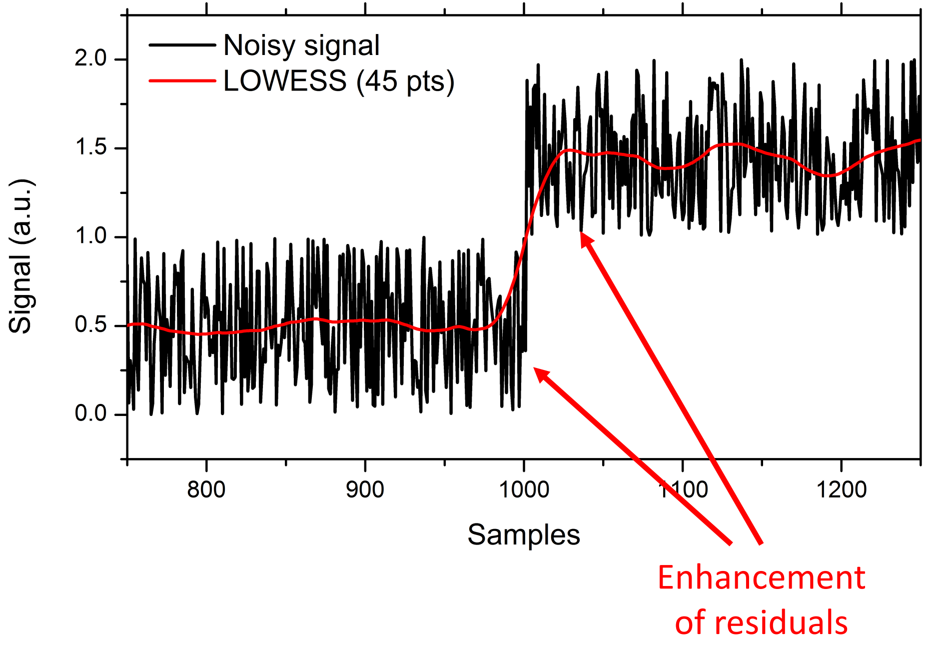
SYSTEMATIC EFFECT: IDEALIZED CASE

Detection of structural breaks

Systematic effects in $x(p,t)$ = Step-like changes in $x(p,t)$



- LOWESS is used to model seasonality and trend.
- Absolute value of residuals will be enhanced by breaks in the time series.
- RHARM automatic break identification is based on the Cumulative SUMming (CUSUM) approach (Aue et al., 2014).
- Isolated outliers are removed using the Median Absolute Deviation (MAD) test.

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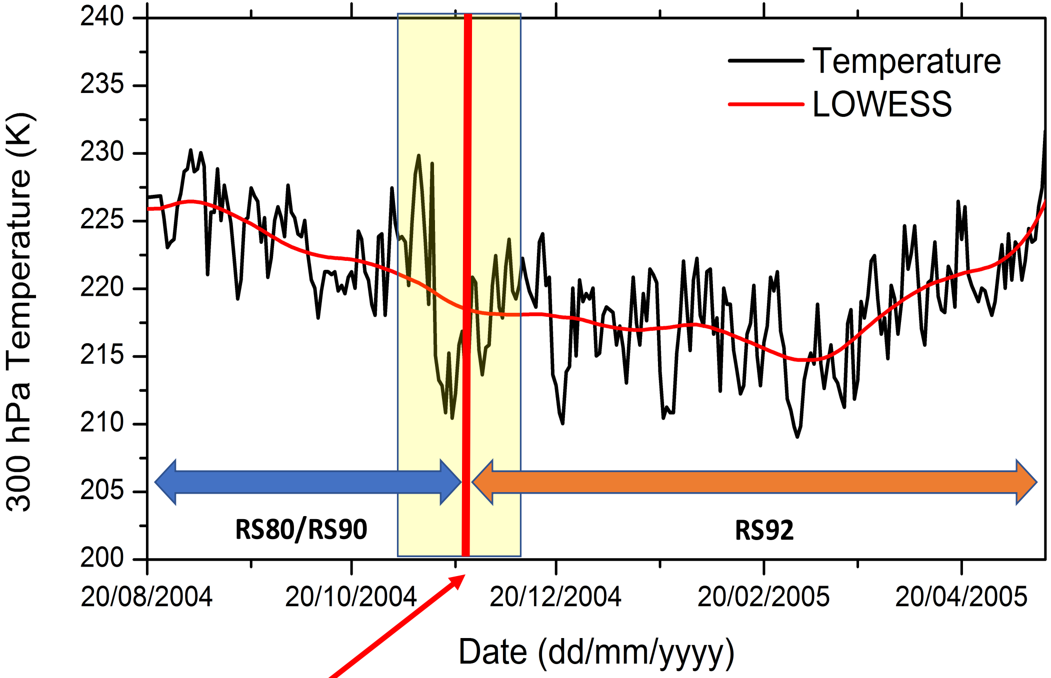
CHANGE DETECTION: EXAMPLE



Documented metadata change in IGRA data archive

Autocorrelation ranges within 0.1-0.3 AR(1), at all the pressure levels.

A D J U S T M E N T

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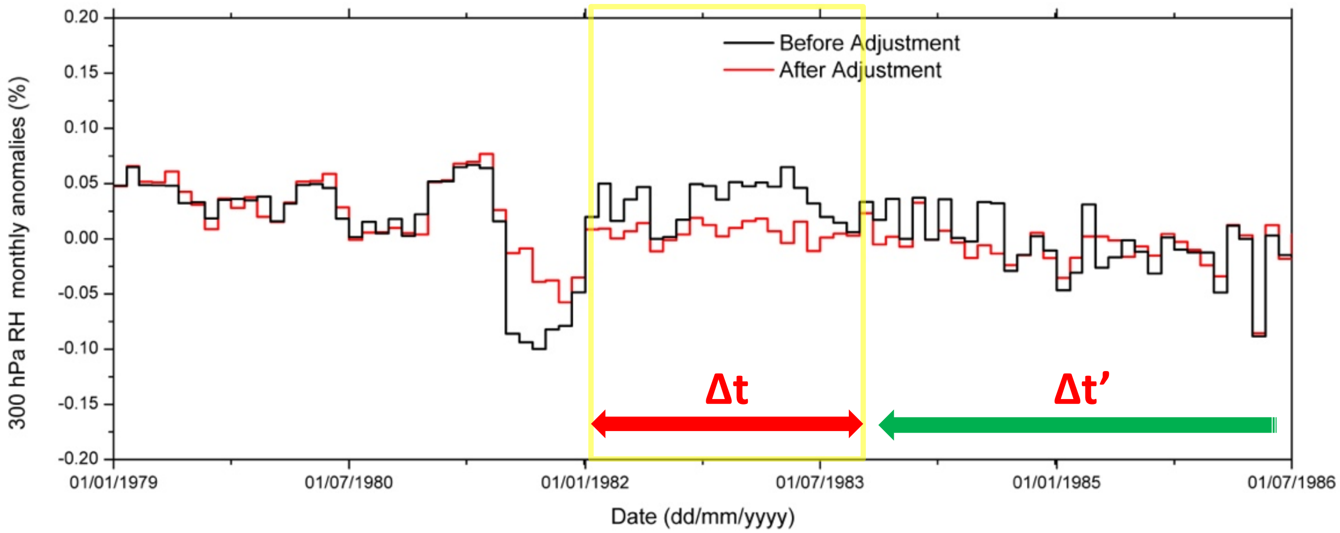
Three different options will be part of RHARM. Given a time period Δt between consecutive breaks, where $\Delta t = t_i - t_j$ (i>j>0):

1. T and RH means in the temporal window Δt are adjusted to the corresponding mean in the time period Δt', at each pressure level (current option under testing).
2. O-B residuals for both T and RH for the period Δt are adjusted to the residual for Δt' using ECWMF reanalysis data (under development).



Relative Humidity monthly anomalies before and after the application of RHARM algorithm, calculated at 300 hPa for Sodankyla station are reported for the period from 01/01/1979 to 01/07/1986.

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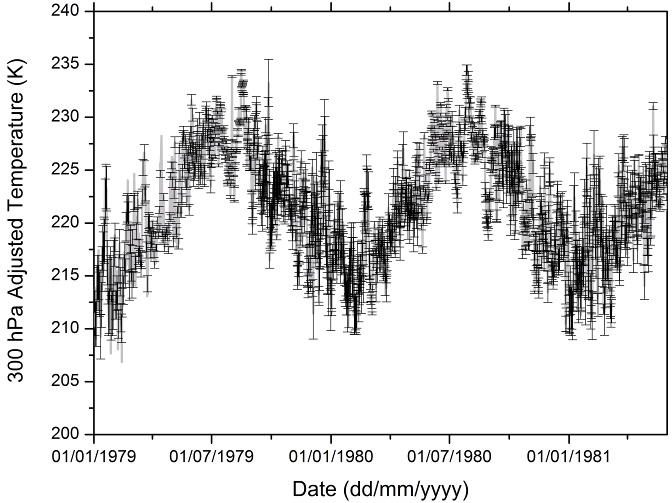
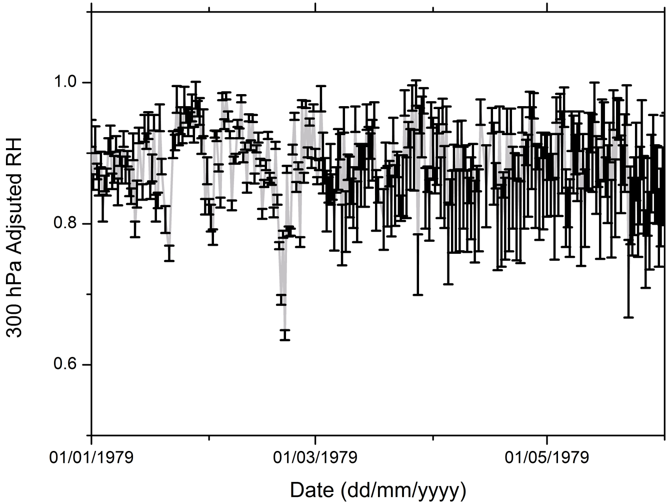
UNCERTAINTIES

Uncertainties are calculated as the sum of two contributions:

1. Difference between the standard deviation of monthly residuals for Baseline and for Reference time series.
2. Measurements uncertainty estimated from Reference measurements.





Left panel, temperature time series for the Sodankyla station with the uncertainties calculated using RHARM for the period from 01/01/1979 to 01/06/1981. Right panel, same as left panel but for relative humidity and in the period from 01/01/1979 to 01/07/1979. A smaller number of points has been used for relative humidity to increase the clarify of the plot.

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OUTLOOK

- Historical and near-real time data will be served through RHARM (original and harmonized time series, Madonna et al., in preparation). Both products and software will be made available within 2018 via the Copernicus Climate Data Store.

- Other existing harmonized radiosonde datasets will be provided such as:
  - Radiosonde Atmospheric Temperature Products for Assessing Climate (RATPAC) by NOAA;
  - RAdiosonde OBservation COrrection using REanalyses (RAOBCORE) and Radiosonde Innovation Composite Homogenization (RICH), by the University of Wien and part of the current input data stream of ERA5 reanalysis;
  - HadAT2, Hadley Centre's radiosonde temperature product v2, by MetOffice

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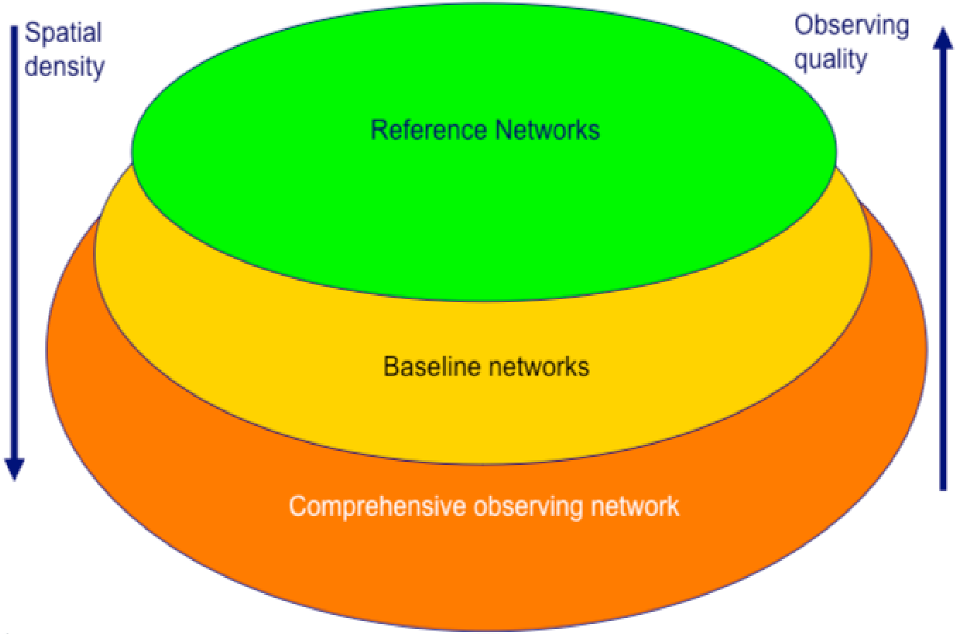
QUESTIONS?

Reference vs Baseline



Proposed tiers in a system of systems approach elaborated within GAIA-CLIM H2020 project is adopted in C3S 311a Lot3.

Thorne, P. W. et al., "Making better sense of the mosaic of environmental measurement networks: a system-of-systems approach and quantitative assessment", Geosci. Instrum. Method. Data Syst., 6, 453-472, https://doi.org/10.5194/gi-6-453-2017, 2017.

DETECTION OF BREAKS - 2

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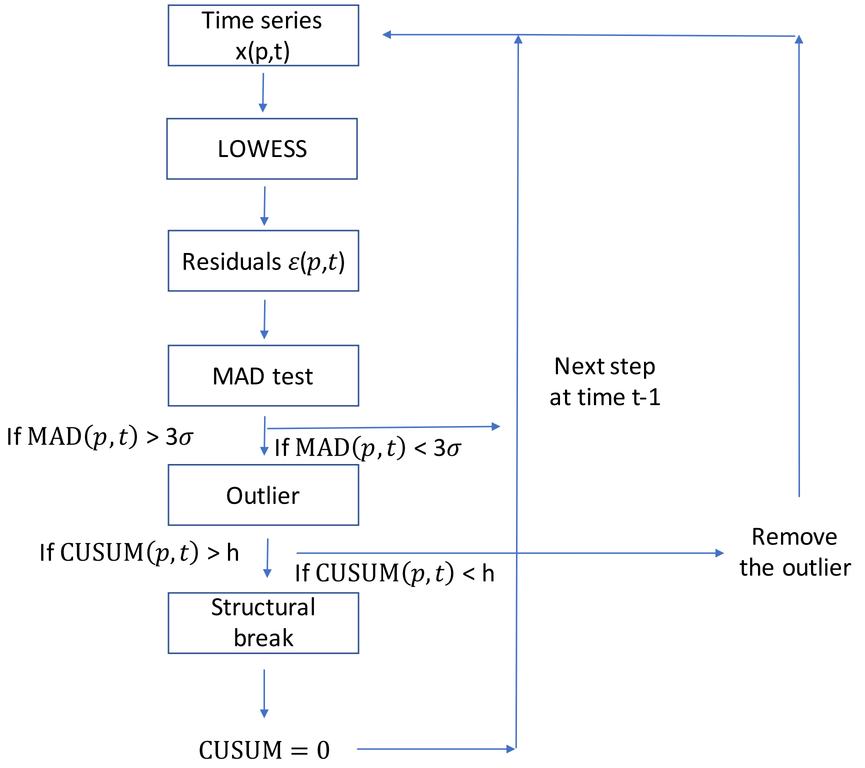
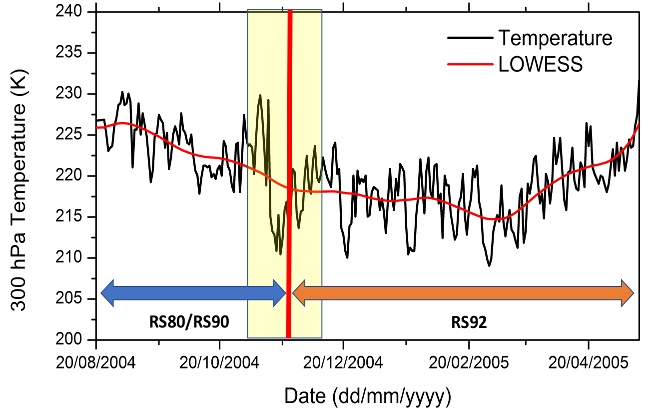
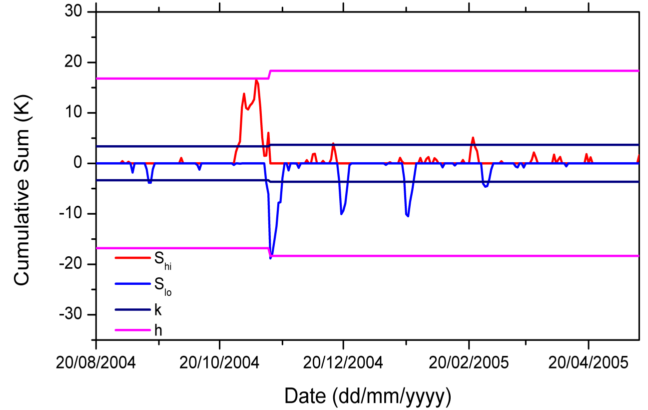


Decision tree in the RHARM algorithm used to identify structural breaks in the time series and remove outliers using the Median Absolute Deviation (MAD) test and the Cumulative SUMming (CUSUM) approach (Aue et al., 2014).





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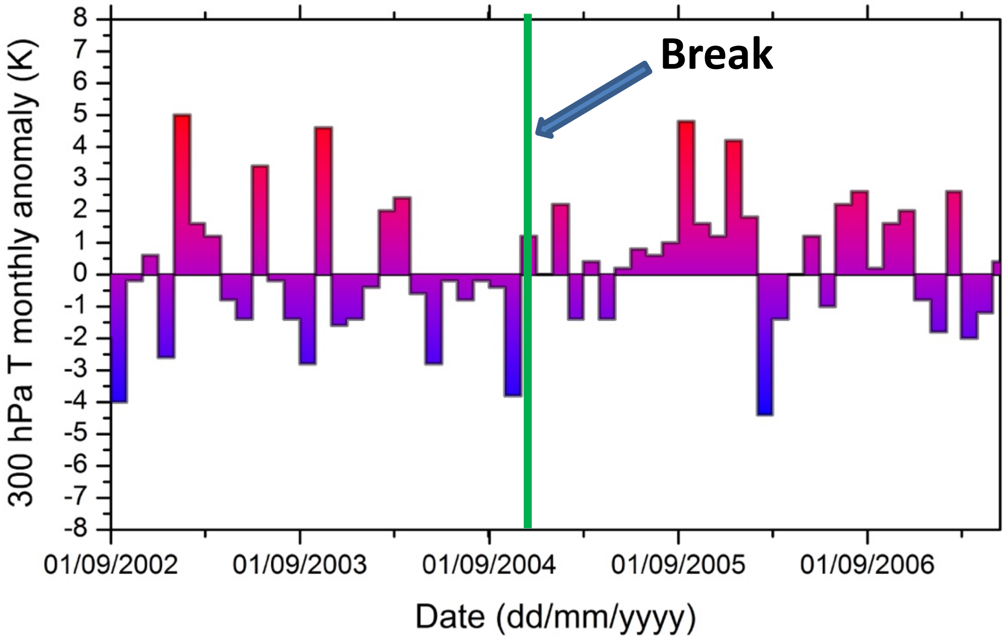
DETECTION OF BREAKS - 1



Monthly anomalies of 300 hPa IGRA radiosounding temperature measured at Sodankyla station from 01/09/2002 to 15/05/2006. The area under the step plot is gradually colored from blue to red for anomalies ranging from very negative to very positive values.

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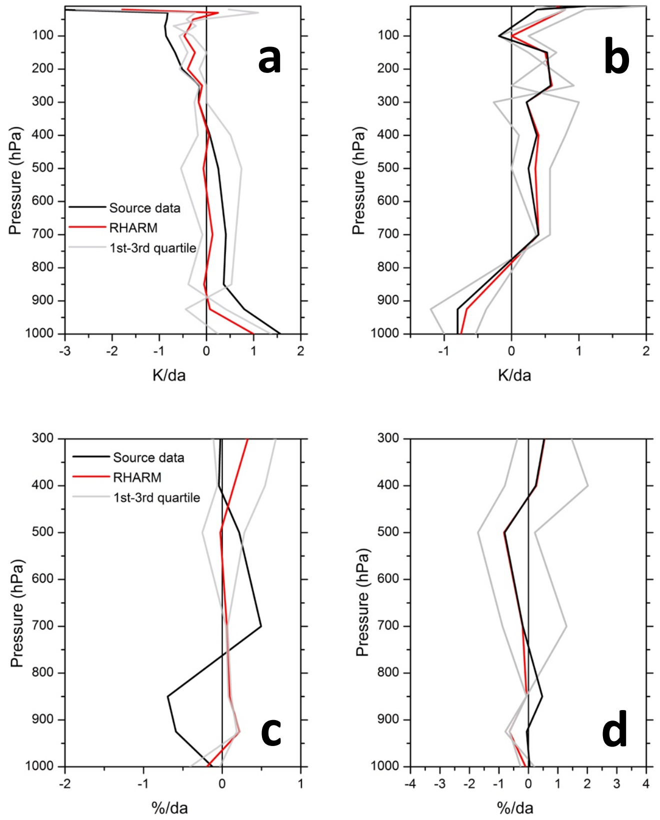
DECADAL TRENDS



- Temperature (panel a) and relative humidity (c) profiles calculated at mandatory pressure levels between 1000 hPa and 20 hPa (T) and 1000 hPa and 300h Pa (RH) for the Sodankyla station in the period 1-1-1979 to present for the source data (black) and adjusted data (red).

- The trends have been calculated according a robust slope estimation technique.

- Right panels, the same as left panels is shown for Lindenberg station (52.21N, 14.12E, 98 m, WMO index=10393) for temperature (panel c) and relative humidity (panel d), respectively.