

GAIA-CLIM H2020 project overview

Characterizing satellite measurements using in-situ,
ground-based and sub-orbital capabilities

May 2015

Peter Thorne

With thanks to Anna Mikalsen, Fabio Madonna, Karin Kreher,
Jean-Christopher Lambert, Bill Bell, Joerg Schulz, Martine de
Maziere



This project has received funding from the
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Genesis

First H2020 call had a program call EO3 which stated:

“The proposal is expected to lead to significant advances in greater consistency and cross-calibration/validation of long term space based measurements with ground-based historical references, providing a better overview of uncertainty of available data to generate Climate Data Records, including impacts information of space data. Based on the work done, best practices regarding calibration/validation campaigns should be promoted.”



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Proposal ethos

- A group led by several of the leads of GRUAN, NDACC and TCCON drafted a proposal concentrating upon:
 - High quality measurement networks
 - Traceability and uncertainty quantification
 - Delivering user tools



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Toy example



A lidar – red points



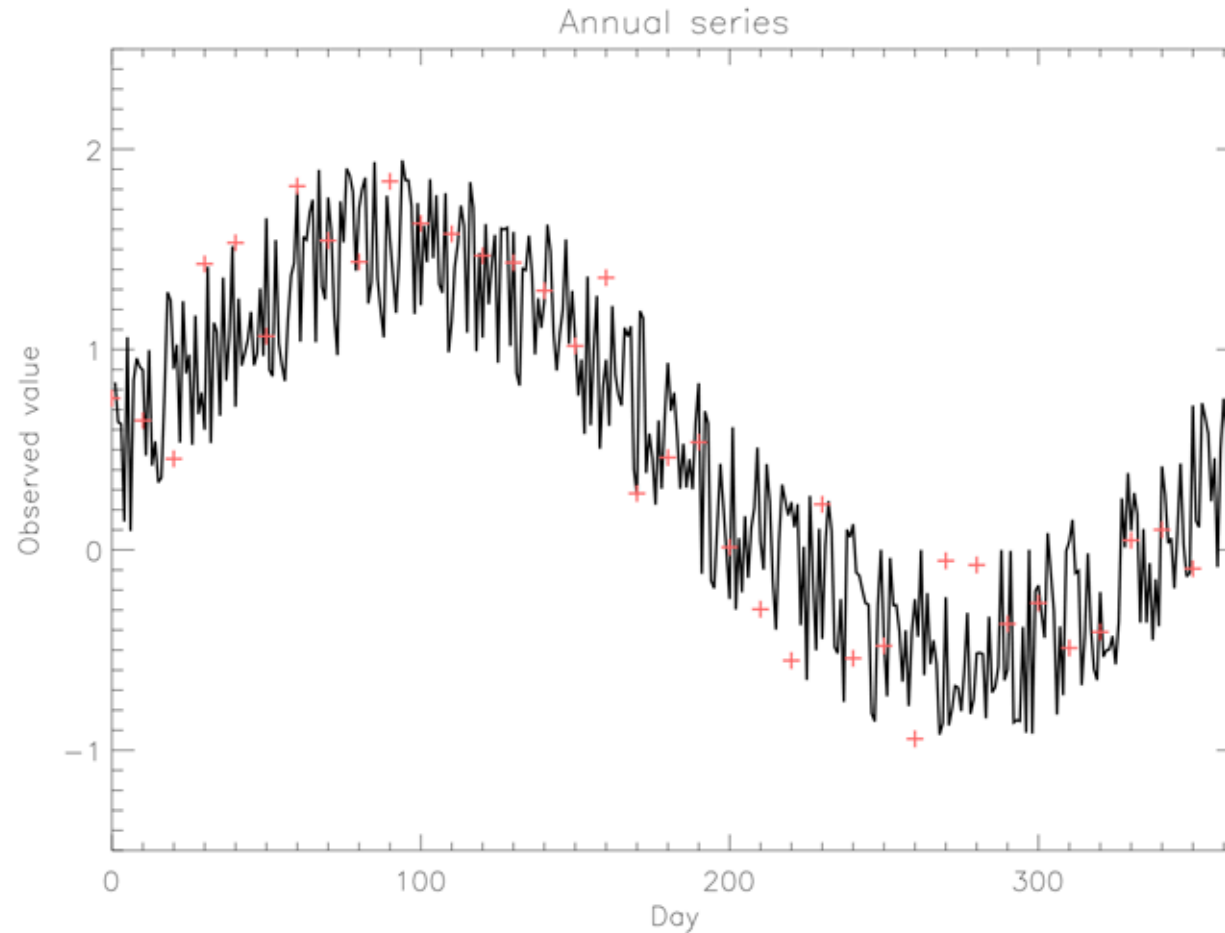
A satellite – black line



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Toy example series



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Measurement A \neq Measurement B



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Project rationale

- To date satellite to in-situ comparisons have been ill-posed if we desire definitive answers.
 - Comparing two imperfect measures of a non-coincident snapshot of a fluid dynamical system they will always differ.
 - Q. Does that difference matter?
- To answer that need to fully understand at least one of the two measurements and the expected geophysical difference arising from non-coincidence.



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Establishing Uncertainty

- Error is replaced by uncertainty
 - Important to distinguish contributions from systematic and random effects in the measurement
- A measurement is described by a range of values
 - m is corrected for known and quantified systematic effects
 - u is random uncertainty (generally assumed gaussian but does not need to be)
 - generally expressed by $m \pm u$

Literature:

- Guide to the expression of uncertainty in measurement (GUM, 1980)
- Guide to Meteorological Instruments and Methods of Observation, WMO 2006, (CIMO Guide)
- Reference Quality Upper-Air Measurements: Guidance for developing GRUAN data products, Immler et al. (2010), Atmos. Meas. Techn.



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Focus on reference in-situ observations

In the GCOS Reference Upper Air Network, a reference observation is defined as having the following characteristics:

- ✓ Is traceable to an SI unit or an accepted standard
- ✓ Provides a comprehensive uncertainty analysis
- ✓ Is documented in accessible literature
- ✓ Is validated (e.g. by inter-comparison or redundant observations)
- ✓ Includes complete meta data description

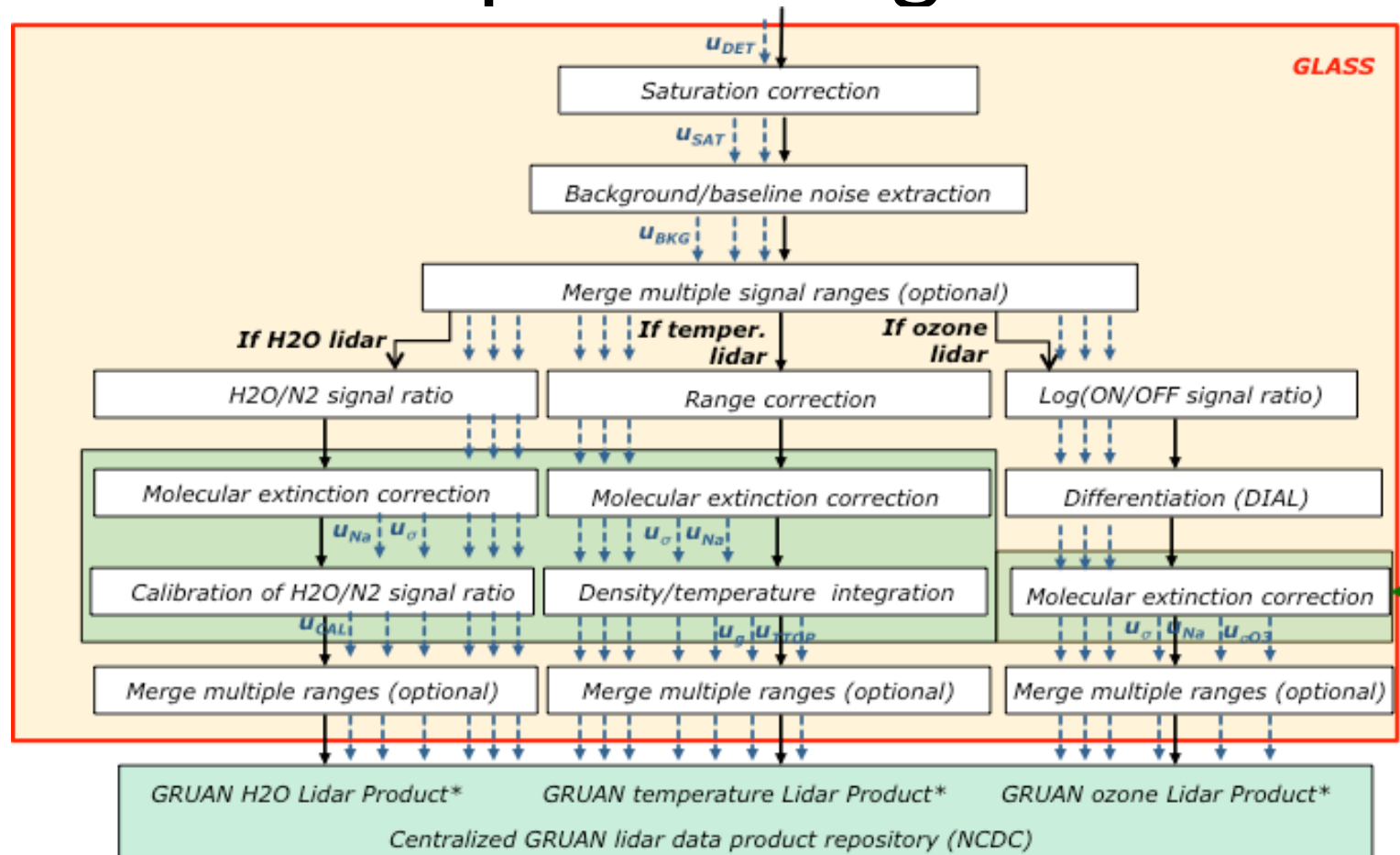


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Lidar processing

Courtesy T. Leblanc, NASA JPL



* Product is tailored to user need and/or science application (determined by time and vertical sampling options)



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Example : Ny-Ålesund, water vapor (courtesy T. Leblanc)

7-hour average
(daytime, winter)

Left plot:

Red, purple and blue solid lines:
lidar, individual ranges

Black solid line:
lidar, combined ranges

Black dotted line:
lidar, total uncertainty

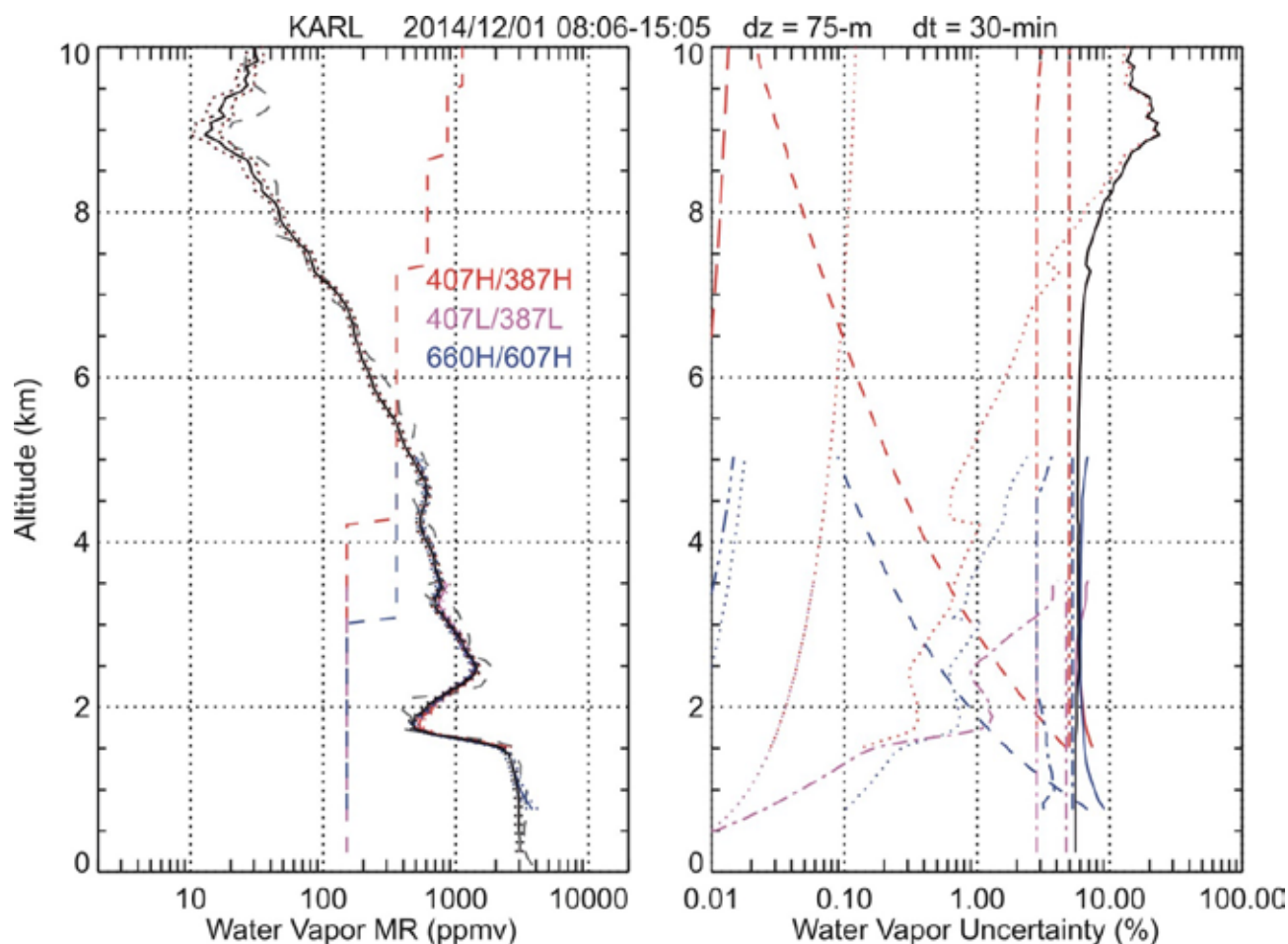
Red, purple and blue dashed lines:
lidar, vertical resolution, in meters
(NDACC-standardized)

Grey dashed line:
co-located radiosonde

Right plot:

Solid lines:
Combined Uncertainty

Dotted, dashed, dash-dotted, etc. lines:
Individual uncertainty components



➔ Example of suitable GRUAN product for climatology and trends

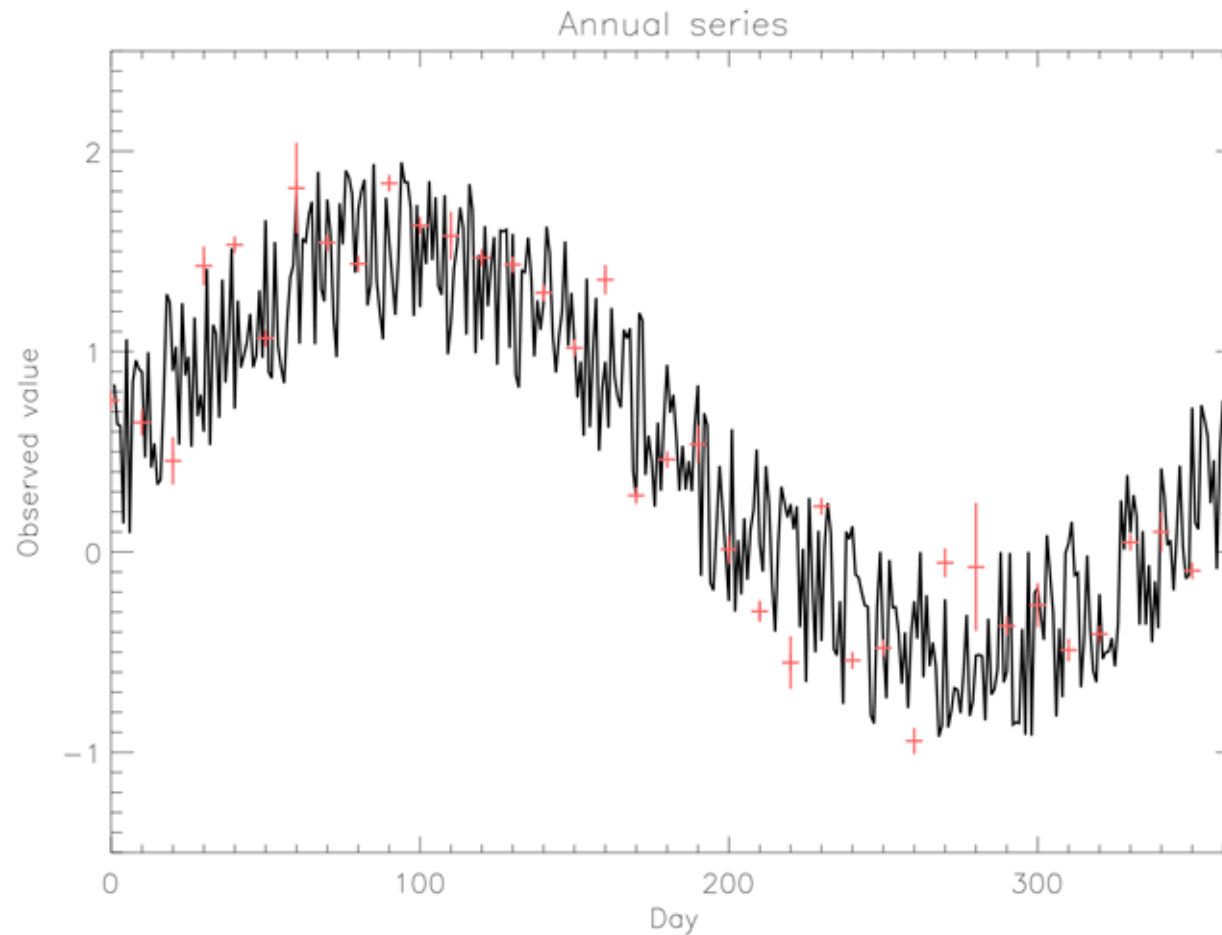


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Raw lidar data provided by
Christoph Ritter,
AWI, Potsdam

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Lidar measurements with uncertainties



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But what about the satellite?

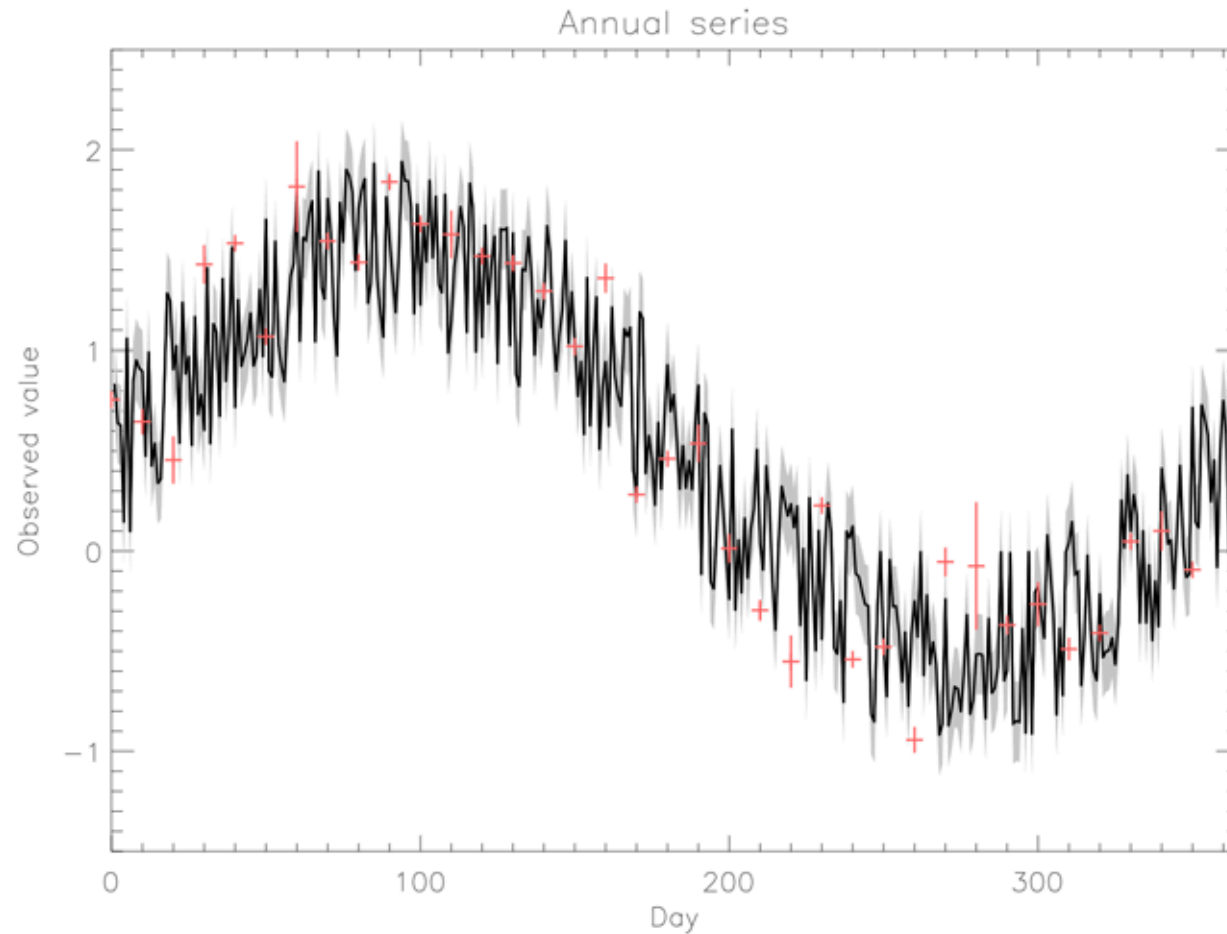
- In the absence of other information a useful test is whether the satellite is performing within design build specification ...
- But I'd rather be using



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Satellite measurements with design specification ranges



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Consistency for perfectly co-located measures

- Reference quality in-situ (m_1) and satellite measurements (m_2) should be consistent:

$$|m_1 - m_2| < k\sqrt{u_1^2 + u_2^2}$$

- ✓ No meaningful consistency analysis possible without uncertainties
- ✓ if m_2 has no uncertainties use u_2 = satellite instrument specification

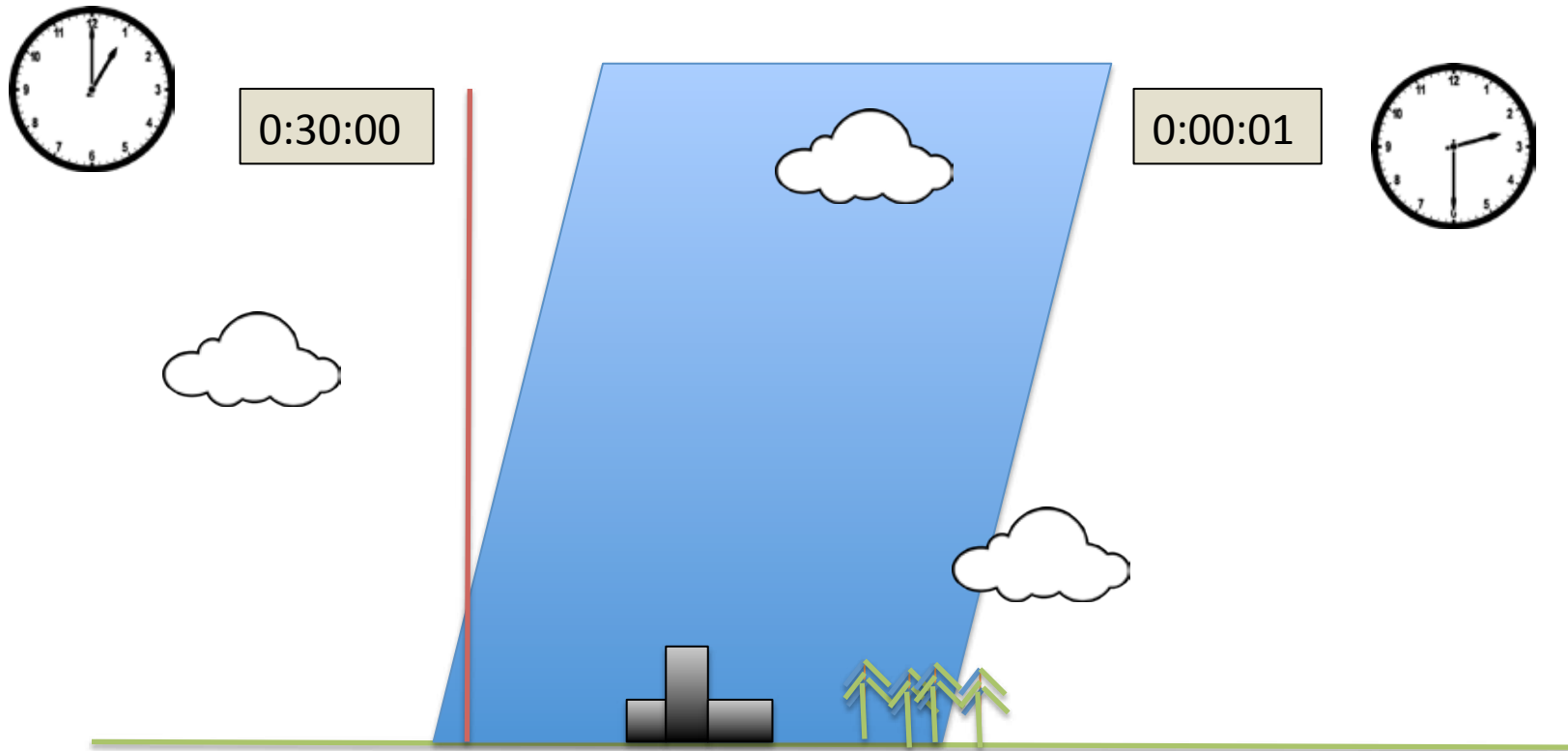
$ m_1 - m_2 < k\sqrt{u_1^2 + u_2^2}$	TRUE	FALSE	significance level
k=1	consistent	suspicious	32%
k=2	in agreement	significantly different	4.5%
k=3	-	inconsistent	0.27%



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Co-location uncertainties



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Consistency in a finite atmospheric region

- Co-location / co-incidence matters and inflates the expected difference
- Determine the variability (σ) of a variable (m) in time and space from measurements or models
- Two observations on different platforms are consistent if

$$|m_1 - m_2| < k\sqrt{\sigma^2 + u_1^2 + u_2^2}$$

- ✓ This test is only meaningful, i.e. observations are co-located or co-incident if:

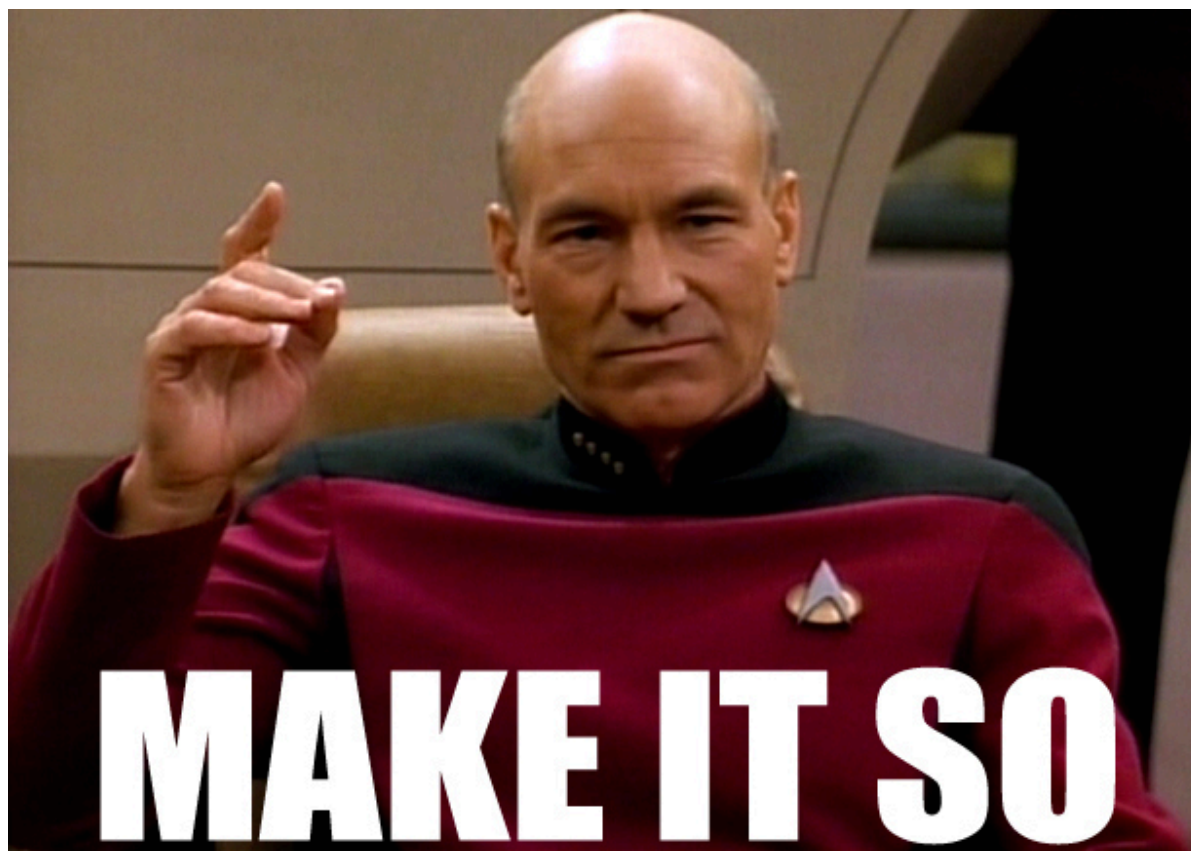
$$\sigma < \sqrt{u_1^2 + u_2^2}$$



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From theory to practice



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WP1: Mapping capabilities

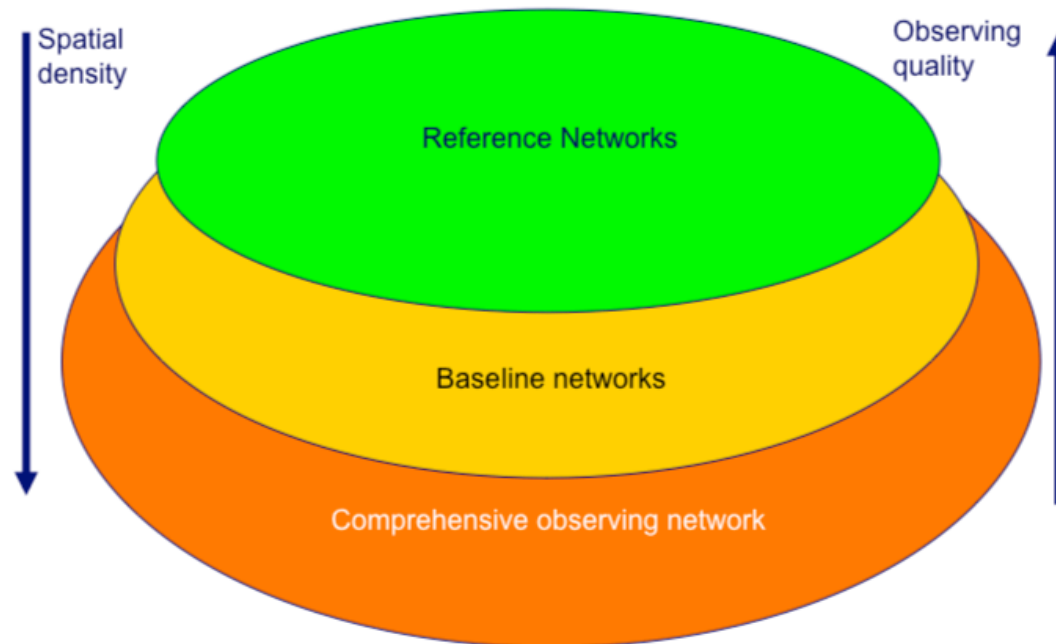
- Define tiers of data quality based upon their characteristics through extension of the CORE-CLIMAX maturity matrix to measurement qualities such as traceability, measurement metrological maturity and sustainability
- Map these capabilities
- Provide mapping tool to visualize the capabilities
- Assess geographical gaps in capabilities



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A tiered system of systems approach



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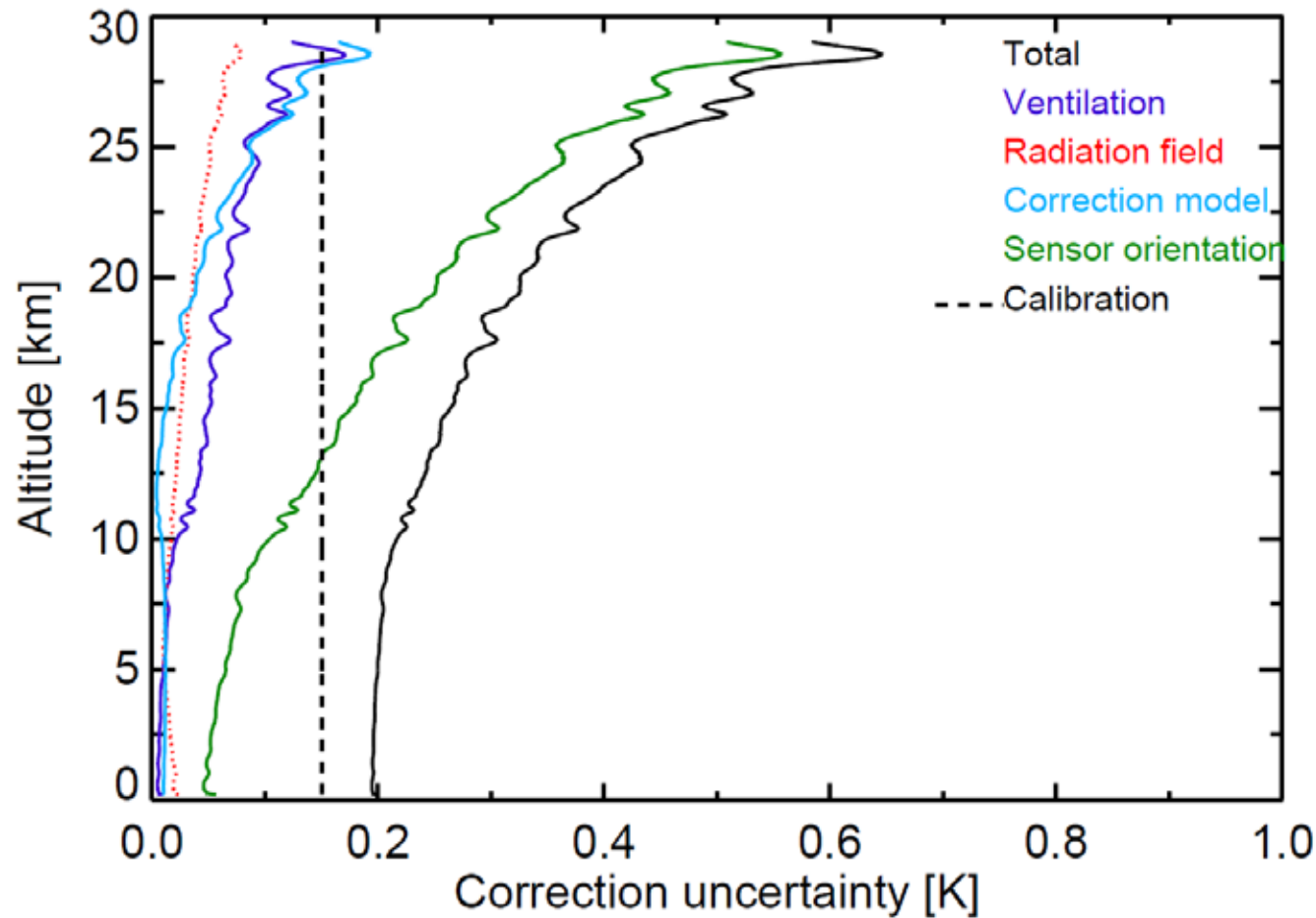
Visualize observational capabilities



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WP2: Quantifying measurement uncertainties



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Instruments / programme	T	q	CO ₂	CH ₄	O ₃	Aerosols	CO	HCHO	NO ₂
Pre-existing / already in process on GAIA-CLIM timescales									
Radiosondes (RS92 and various others)									
Frostpoint hygrometer sondes									
Ozonesondes									
QA4ECV project (various instruments)									
Planned in GAIA-CLIM									
Lidars									
Microwave radiometers									
FTIR / FTS									
UV/visible spectroscopy									
MAX-DOAS/Pandora									
GNSS-PW									



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From the complete list of key ECVs targeted within this project (see table on previous slide), a subset of ECVs measured with techniques mature enough to be very likely candidates for data streams of reference quality has been selected:

- **Microwave Radiometers:**
T and H₂O profiles



- **Fourier Transform Spectrometers:**
CH₄, CO₂, O₃ and H₂O
columns and profiles



- **LIDAR:**
Aerosol, H₂O, O₃ and T profiles



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- UV/visible spectroscopy:
O₃ total column



- MAX-DOAS/PANDORA:
Tropospheric O₃



- GNSS:
H₂O total column



To achieve reference quality, we need to establish full traceability and uncertainty quantification for each instrument type and a clear definition of measurement protocols.



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WP3: Measurement mismatch uncertainties

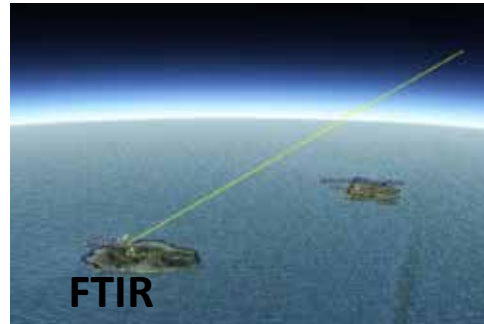
- Satellites and other measures will never measure the exact same volume over the exact same interval.
 - Differences in time of observation (including measurement time integral mismatch and diurnal cycle effects)
 - Differences in horizontal geolocation, including such time-varying effects as drift of balloon borne measures
 - Differences in vertical registration, especially in presence of altitude uncertainties/shifts
 - Differences in vertical smoothing (need for vertical averaging kernels for both columnar and profile measures)
 - Differences in horizontal smoothing (consider e.g. an in situ sonde with respect to a 300 km satellite horizontal resolution)
 - Vicarious data issues such as cloud impacts if comparing to radiances in the IR spectrum.



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Spatial representativeness of an FTIR measurement



Percentage of column	Latitude (°)	Longitude East (°)	Altitude (km)	Distance (km)
0	-20,900	55,480	0,05	0,0
20	-20,906	55,511	1,8	3,3
40	-20,912	55,546	3,8	7,0
60	-20,921	55,596	6,6	12,3
80	-20,934	55,666	10,6	19,7

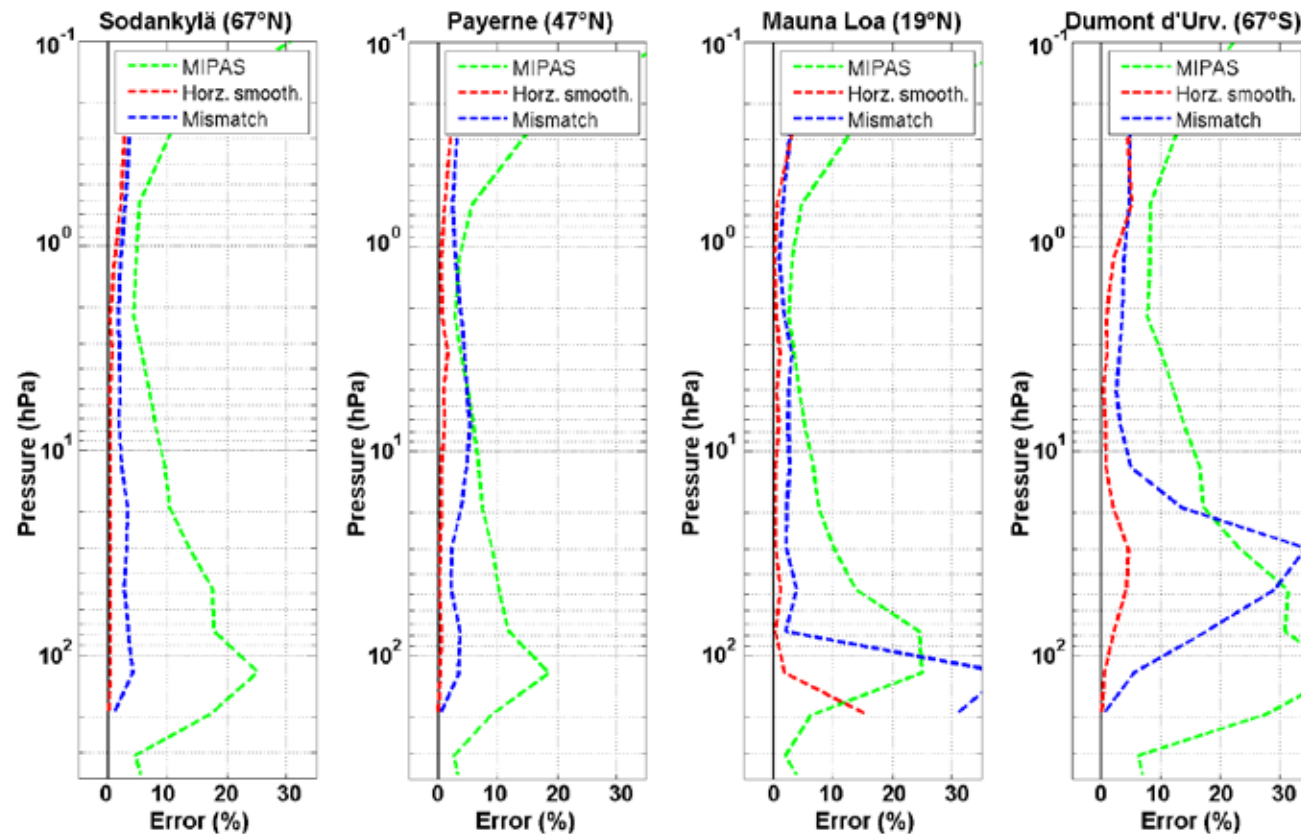
Table 1. Example of a ray tracing output for an FTIR measurement of CH₄ at St Denis (-20.9°S, 55.5°E), Ile de La Réunion, on 25/1/2011 04:04 UT for a solar zenith angle of 62° and an azimuth angle of 101° measured from N (0°) to E (90°). The Table provides the geographical location of the points along the line of sight corresponding to a percentage of the total CH₄ column.



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- WP3 will use model and statistical approaches to quantify the effects.



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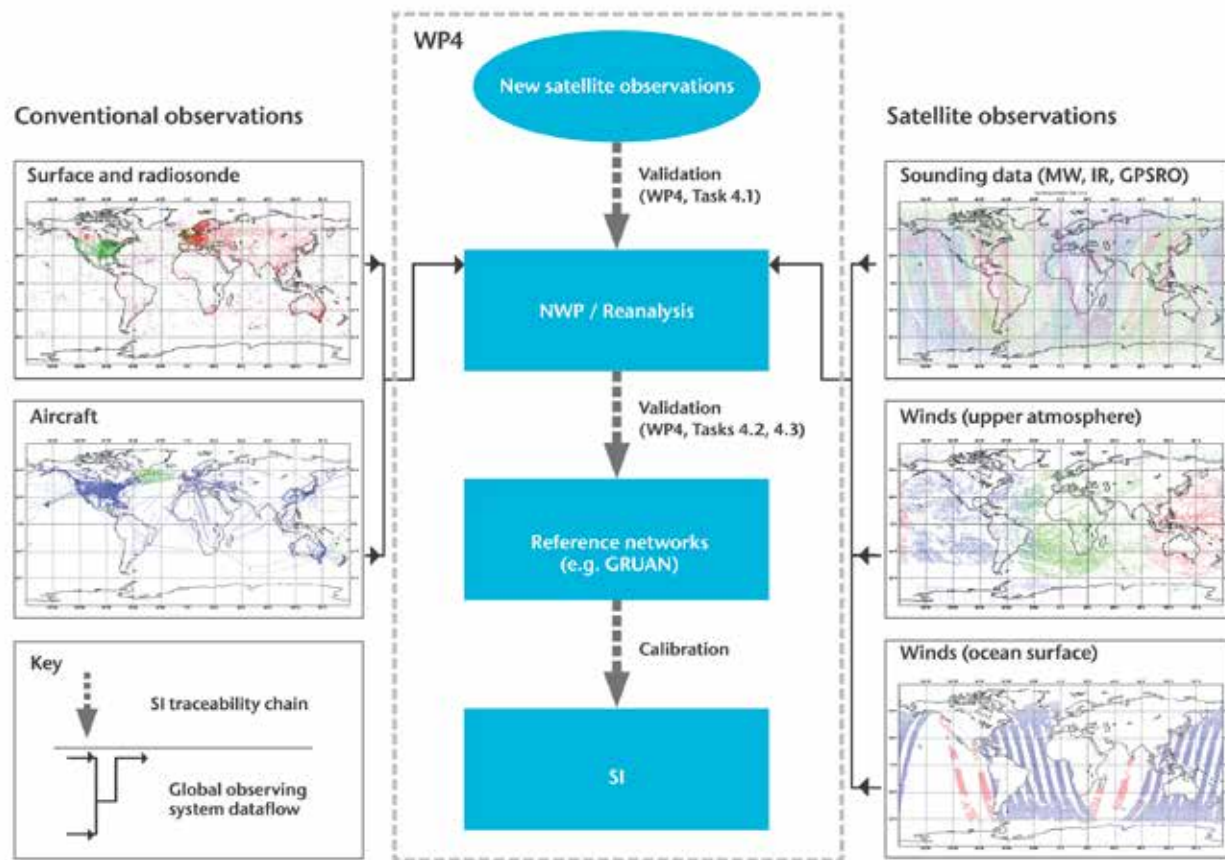
WP4: Use of data assimilation as integrators

- Investigate the value of use of data assimilation and reference quality measurements
 - Constrain / better understand biases in data assimilation
 - Propagate information from point measures to more regionally / globally complete estimation
 - Use in both NWP and reanalyses to be investigated



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WP5: Virtual observatory

- Make the outcomes of previous WPs useable and actionable
 - Collocation database build
 - Availability of Level 1 (radiance) / 2 (geophys retrieval) satellite to in-situ data comparisons including uncertainties
 - Graphical display and user interface
 - Build with expectation of becoming a sustainable



service

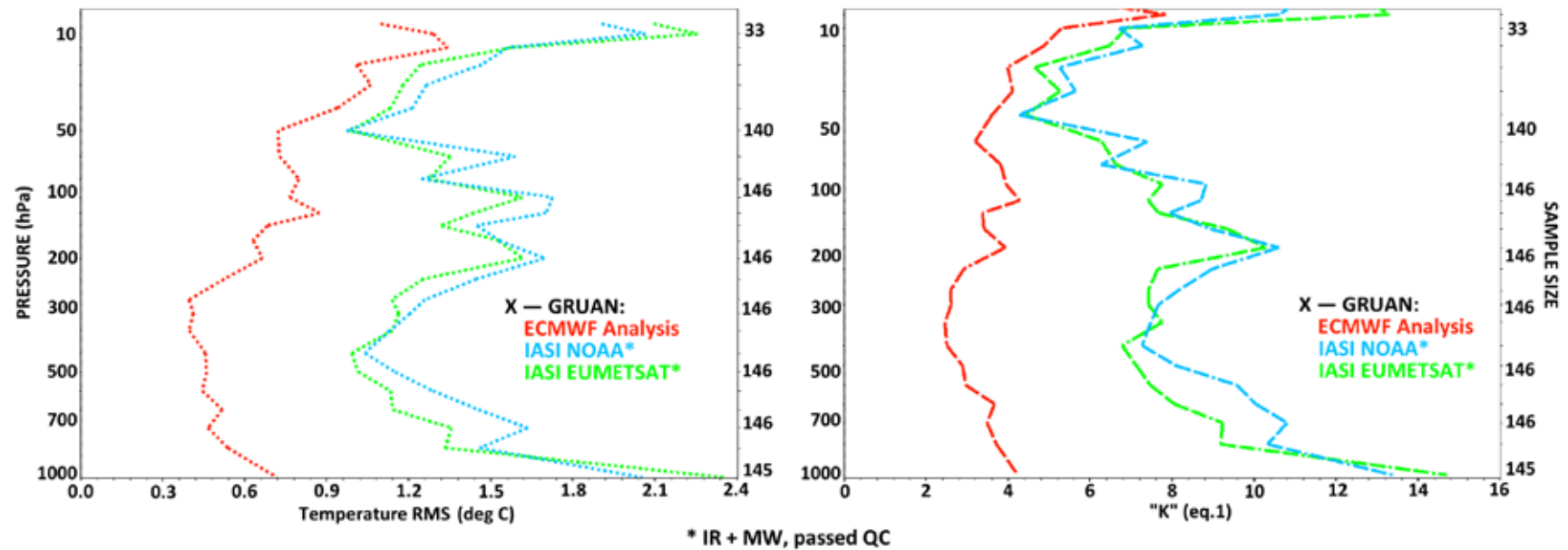


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NPROVS + 14 July 2013 — 19 January 2014



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WP6: Outreach and gaps assessment

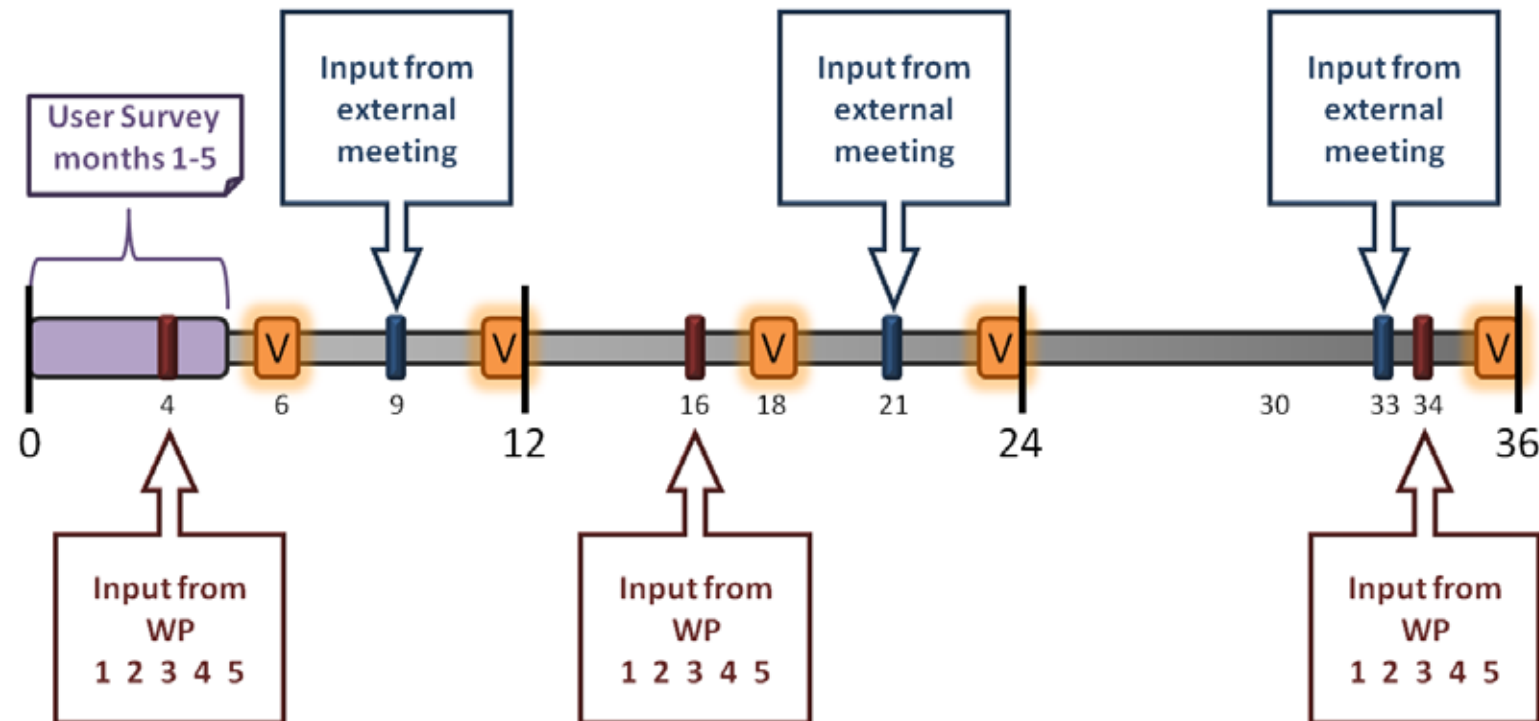
- Gaps in geographical coverage and their impacts
- Gaps in knowledge of measurement properties and uncertainties
- Gaps in understanding of the impact of measurement mismatches
- Open issues regarding how to use dynamical model and data assimilation techniques as integrators
- Issues that remain in enabling easy use of reference quality measures as cal/val tools.
- Gaps between user needs and current observational and analysis capabilities
- Consideration to the somewhat fractured nature of observing systems.
- Prioritising potential gap remedies and improvements in capabilities



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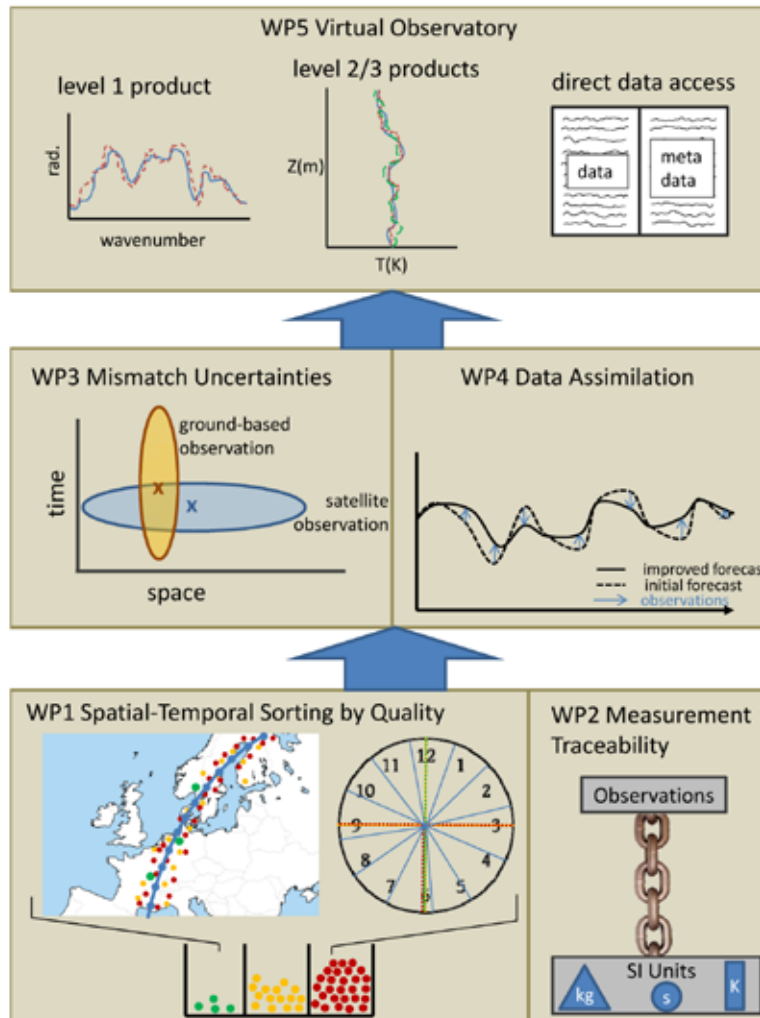
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Gap assessment is iterative with community



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- Define data quality attributes and map by capabilities
- Improve metrological quantification of in-situ ground-based and sub-orbital measurements
- Robustly quantify the impacts of inevitable measurement mismatches
- Use Data Assimilation to improve the usefulness of high quality measurements
- Provide useable and actionable information to end users to improve the value of both satellite and non-satellite data



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Thanks for your attention

- GAIA CLIM User survey
<http://tinyurl.com/gaia-clim-survey>.

Deadline: June 15 ! (only 10' work):

- Save the date:

GAIA-CLIM first user workshop, Rome, 6 Oct.

- focusing on
 - ✓ user requirements for a Virtual Observatory
 - ✓ uncertainties: terminologies and definitions, use of uncertainties, propagation of uncertainties, toolsets, level 1 uncertainties and their significance

Suggestions are welcome



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