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 European Union's Horizon 2020 research and innovation programme under grant agreement No 640276.

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National University of Ireland Maynooth

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Ministry of Infrastructure and the Environment

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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in greater consistency and cross-calibration/validation of long term space based measurements with ground-based historical references, providing a better overview of uncertainty of available data to generate Climate Data Records, including impacts information of space data.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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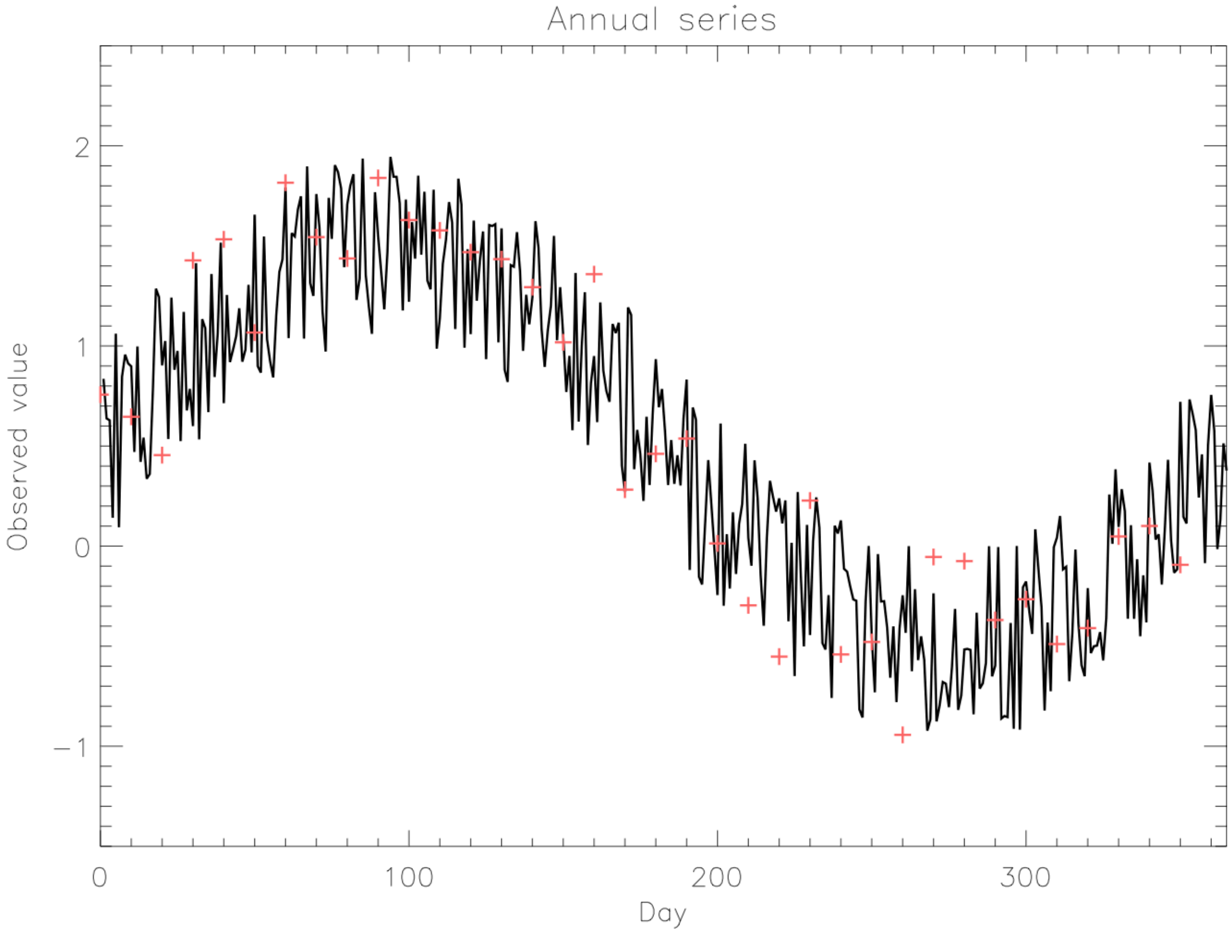
Toy example series



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Measurement A /= 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

- Official BIPM terminology (VIM/GUM) is applied, e.g., uncertainty is used instead of often misused error and accuracy
  - 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 ± 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 charactersistics:

- ✓ 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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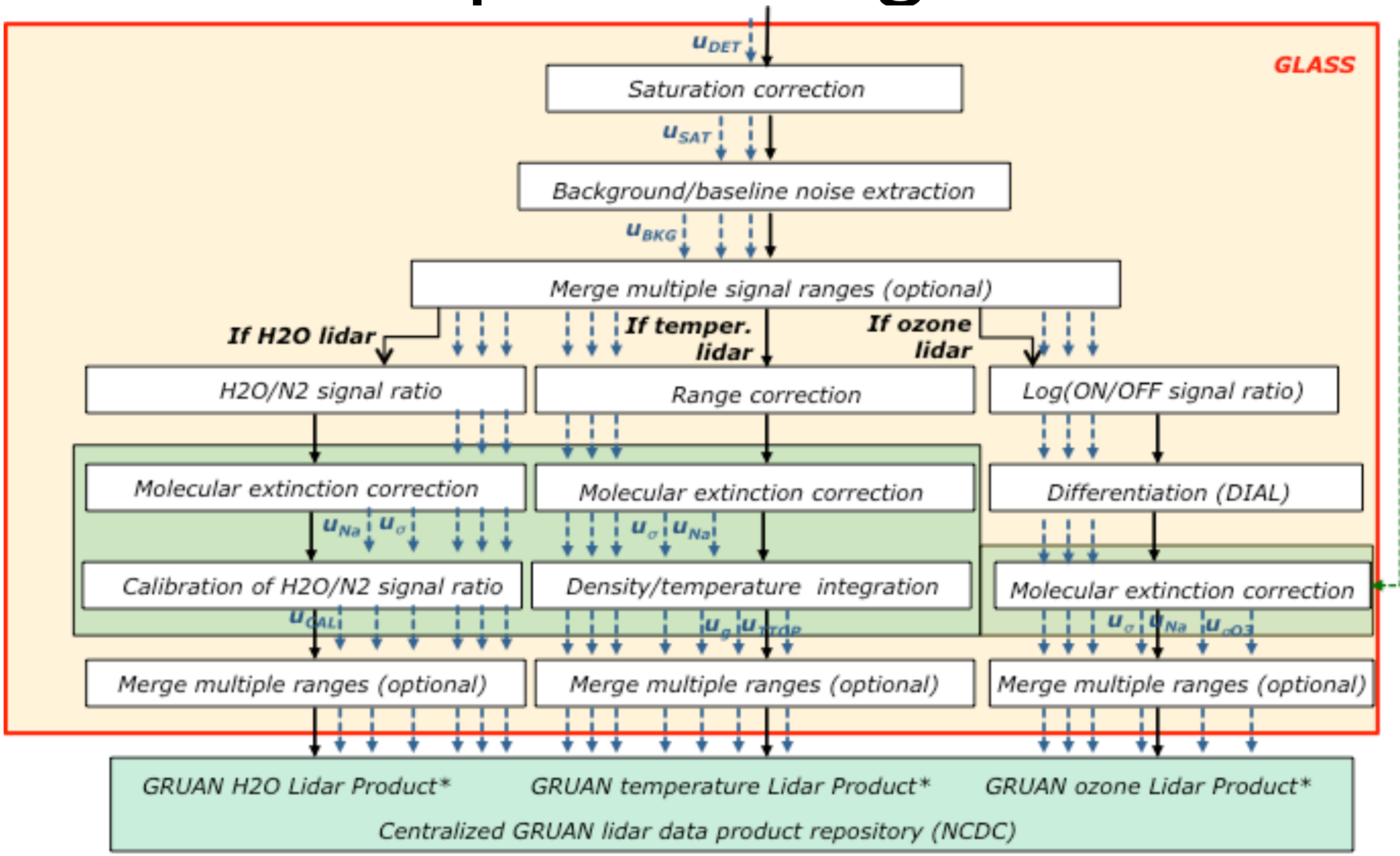
Lidar processing

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

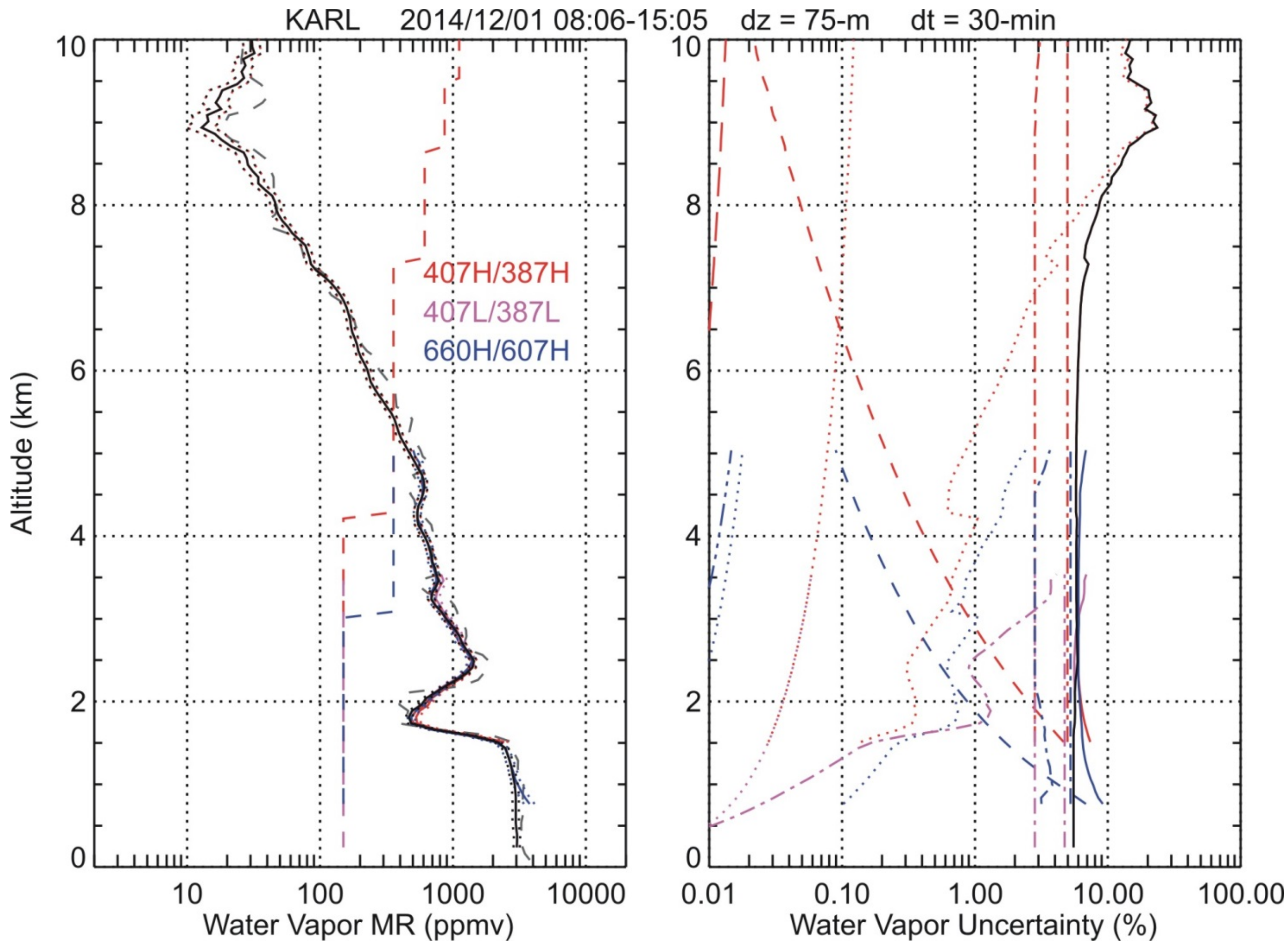
Red , purple and blue dashed lines: lidar, vertical resolution, in meters (NDACC-standardized)

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**

Raw lidar data provided by Christoph Ritter, AWI, Potsdam

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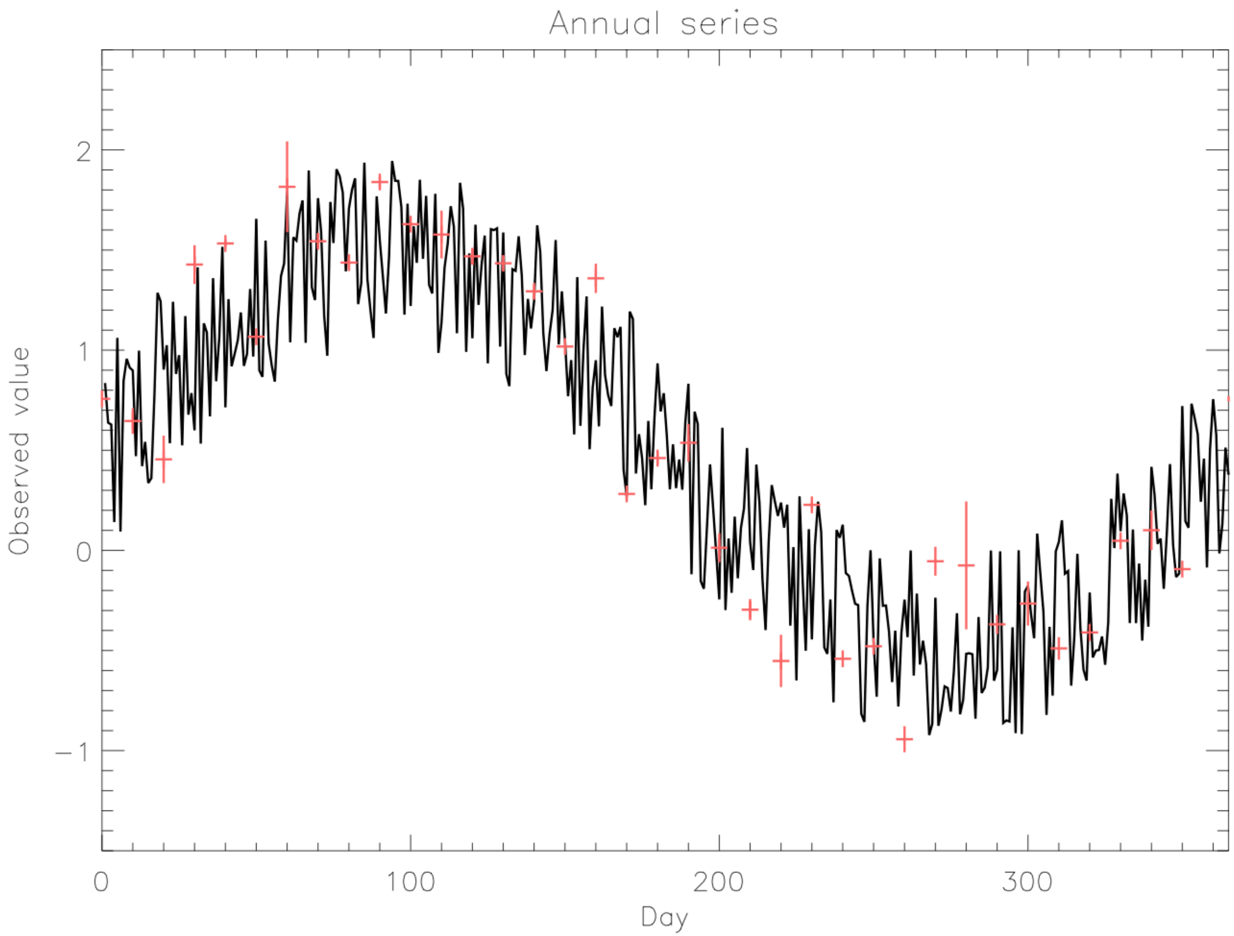
Lidar measurements with uncertainties



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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 FIduceo

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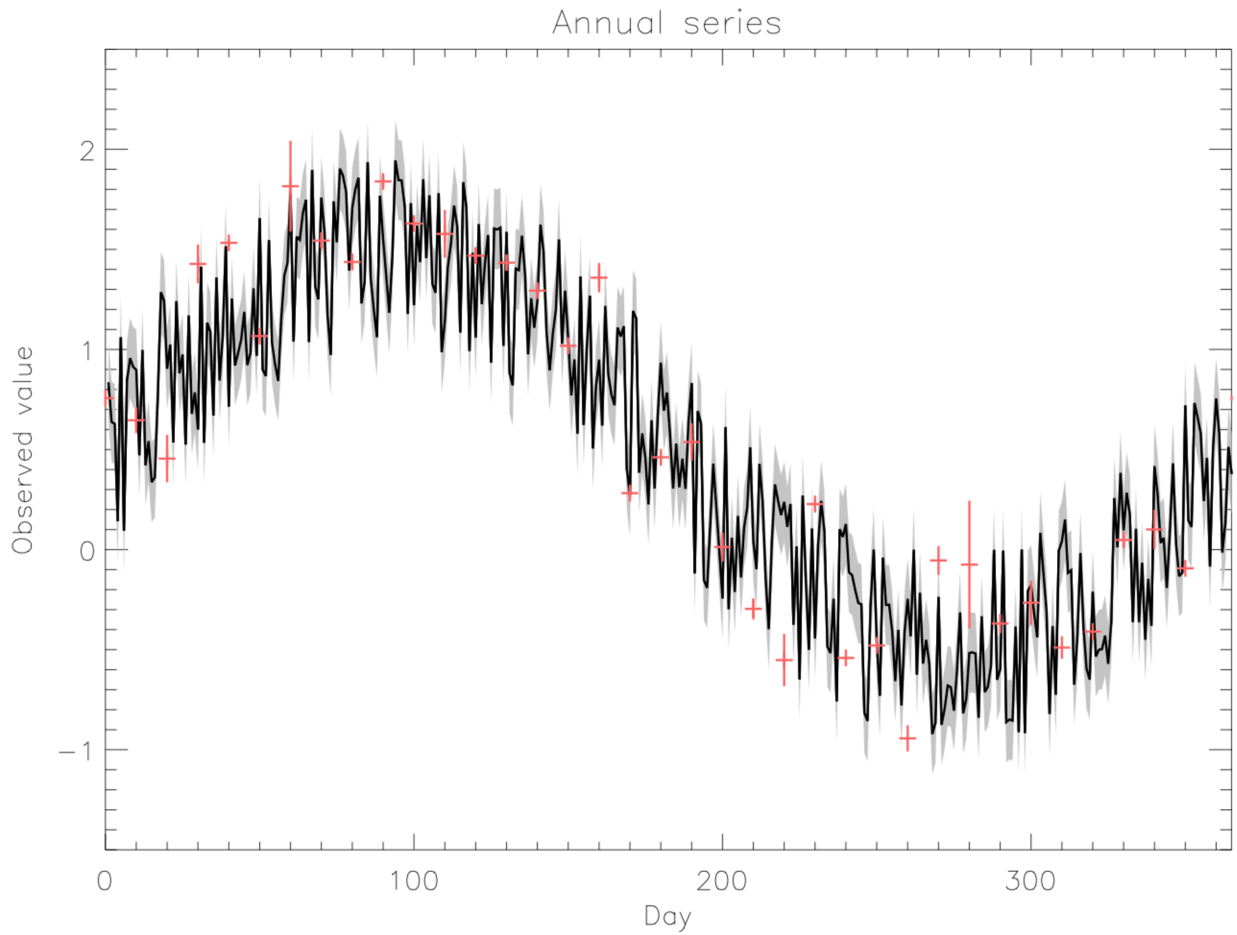
Satellite measurements with design specification ranges



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Consistency for perfectly co-located measures

- Reference quality in-situ (m1) and satellite measurements (m2) 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

$\lvert m_1 - m_2 \rvert < k\sqrt{u_1^2+u_2^2}$	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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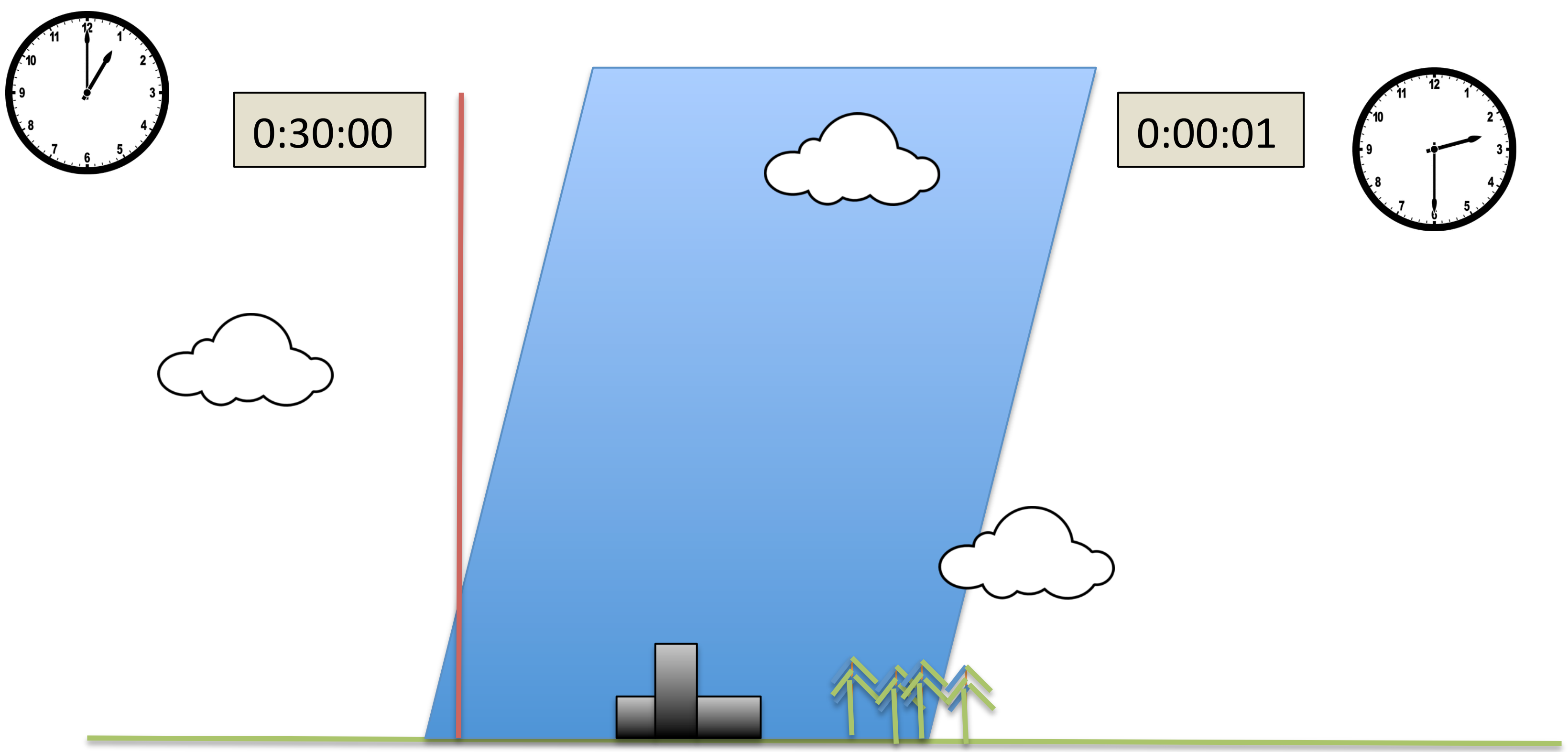
Co-location uncertainties



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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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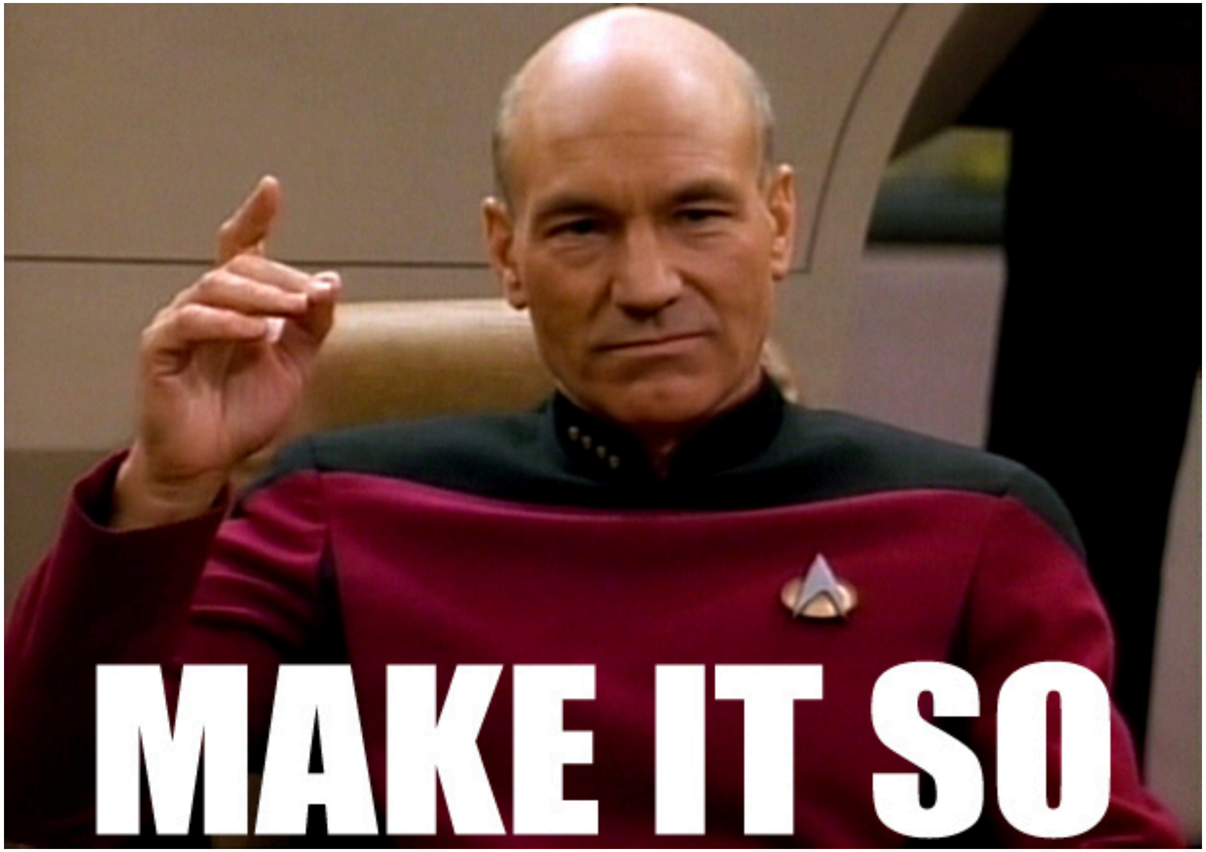
From theory to practice



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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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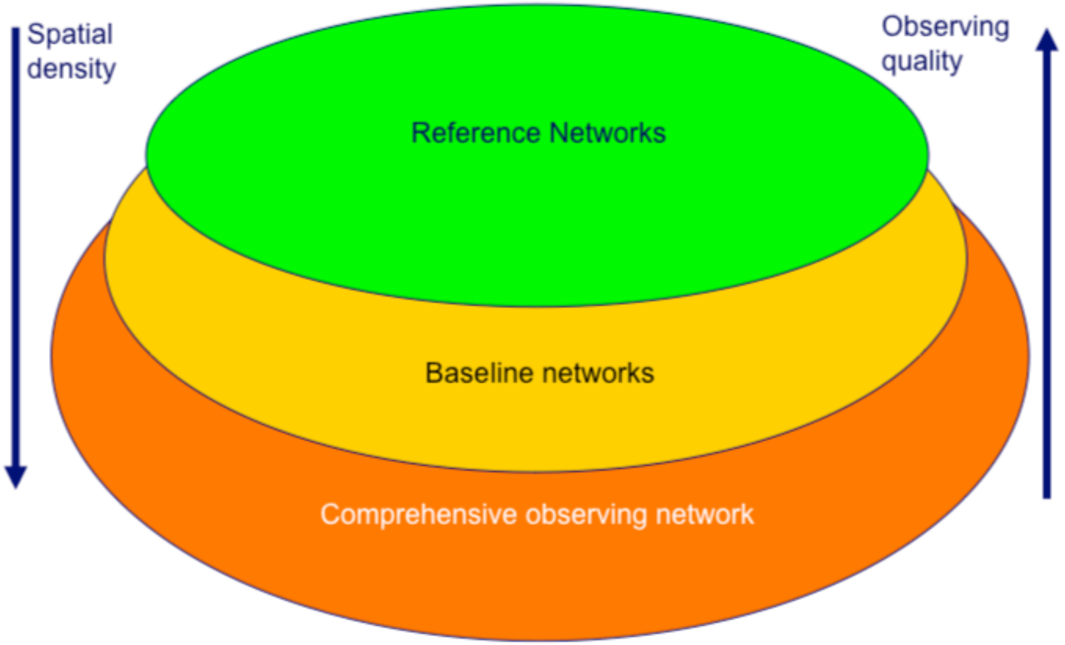
A tiered system of systems approach



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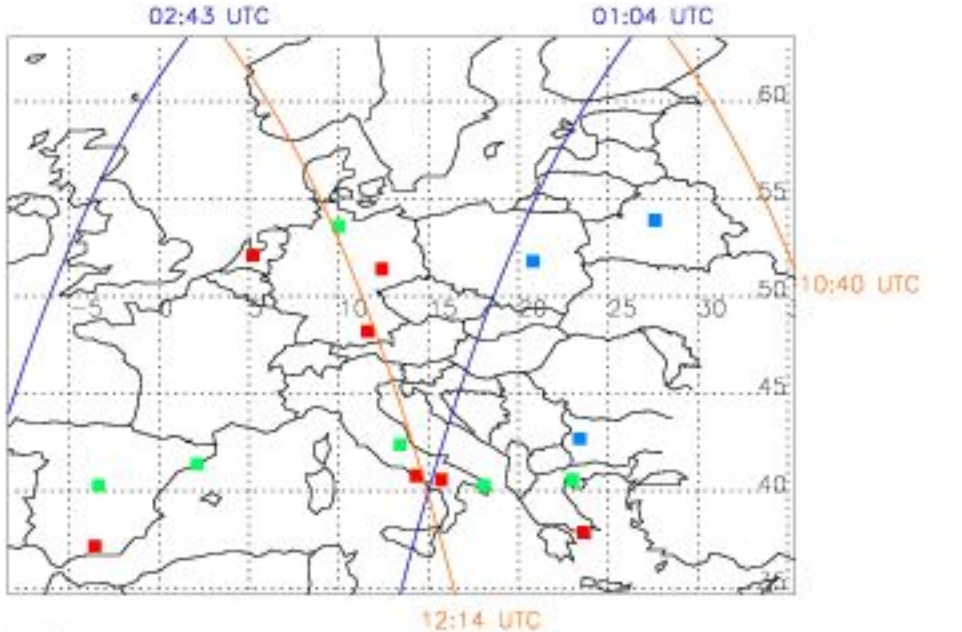
Visualize observational capabilities



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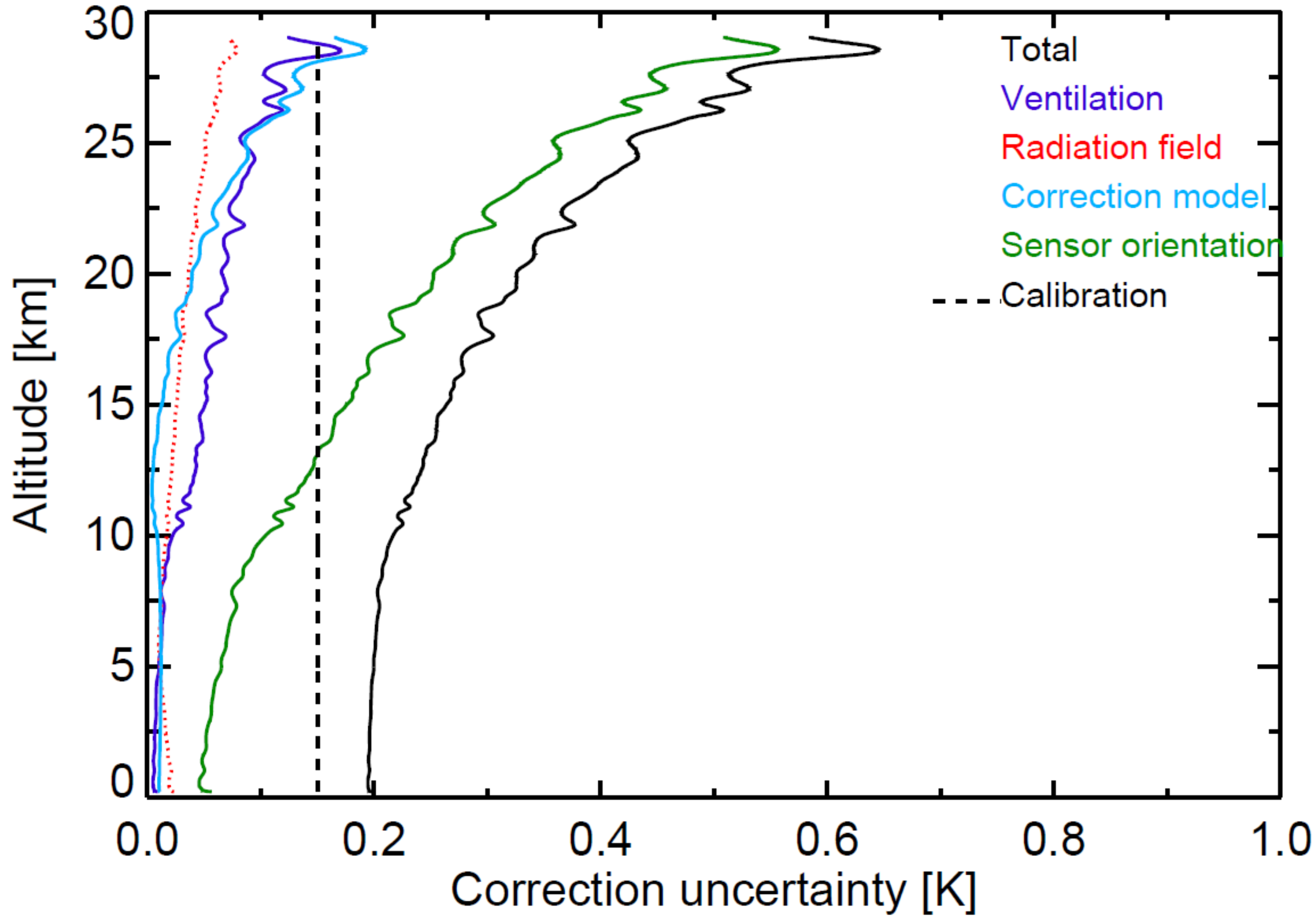
WP2: Quantifying measurement uncertainties



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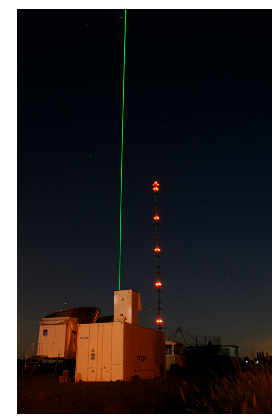
From the complete list of key ECVs targeted within this project (see table on previous slide), a subset of ECVs measured with techniques mature enough to be very likely candidates for data streams of reference quality has been selected:

- **Microwave Radiometers:**
  T and H_2O profiles

- **Fourier Transform Spectrometers:**
  CH_4, CO_2, O_3 and H_2O columns and profiles

- **LIDAR:**
  Aerosol, H_2O, O_3 and T profiles



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- **UV/visible spectroscopy:**
  O_3 total column

- **MAX-DOAS/PANDORA:**
  Tropospheric O_3

- **GNSS:**
  H_2O 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
  - Differences in horizontal geolocation
  - Differences in vertical registration
  - Differences in vertical smoothing
  - Differences in horizontal smoothing
  - Vicarious data issues such as cloud impacts if comparing to radiances in the IR spectrum.

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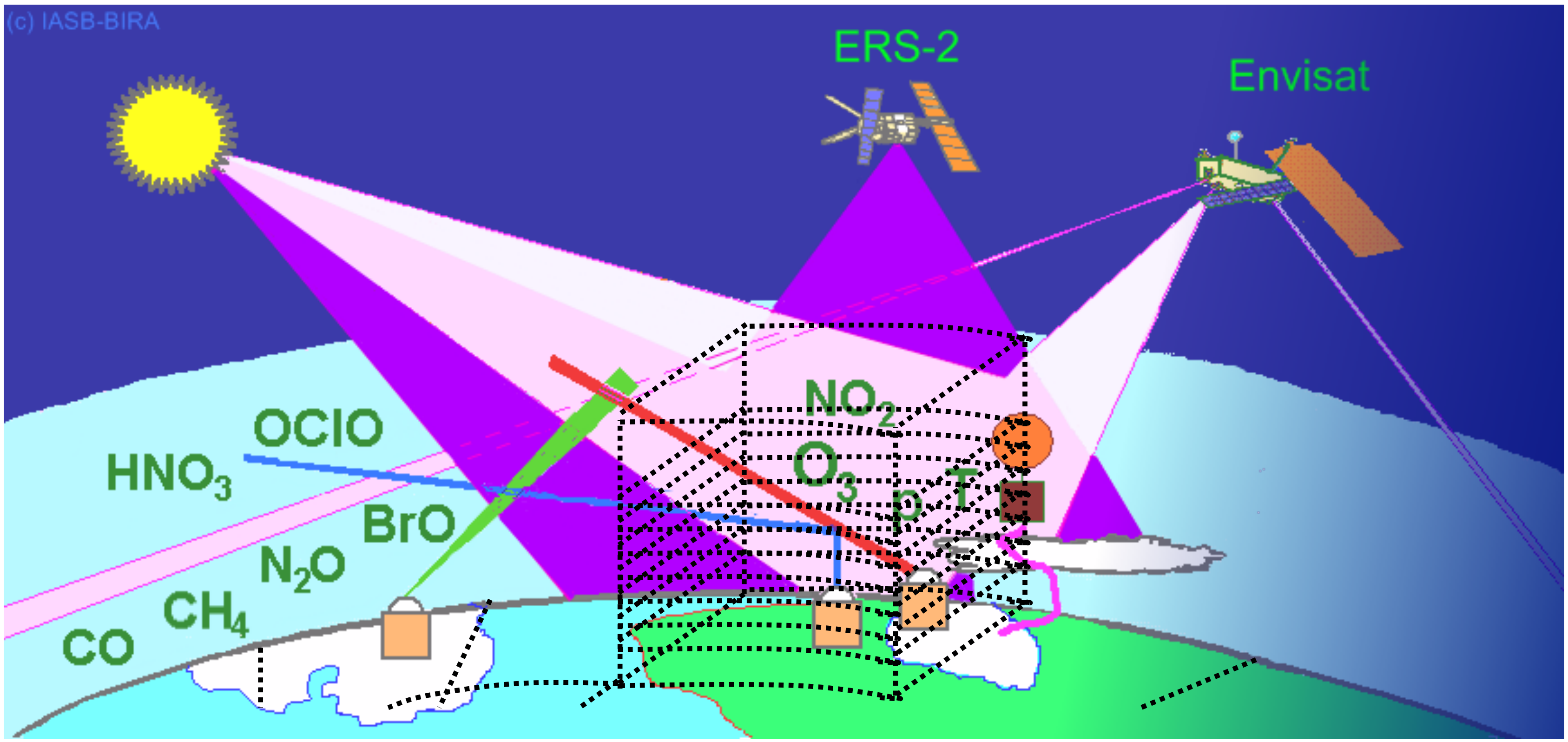
What is a co-location mismatch ?

Sampling (time, space) AND smoothing differences !



$$\varepsilon_{smoothing} = f\left((A_1 - A_2).S_{atmos.}.(A_1 - A_2)^T\right)$$

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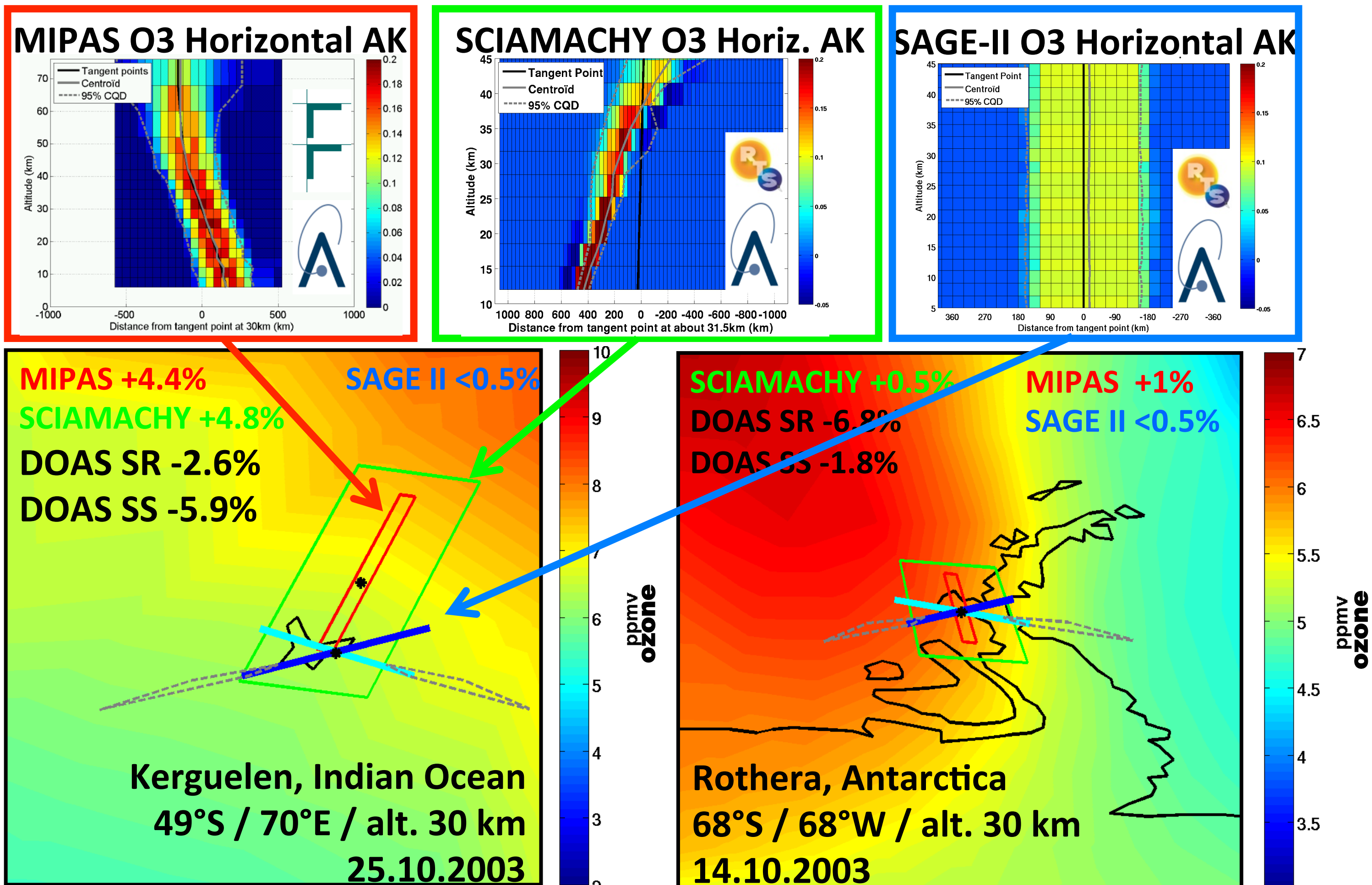
Horizontal smoothing examples



Vandenbussche et al., Lambert et al., GEOmon TNs, 2011

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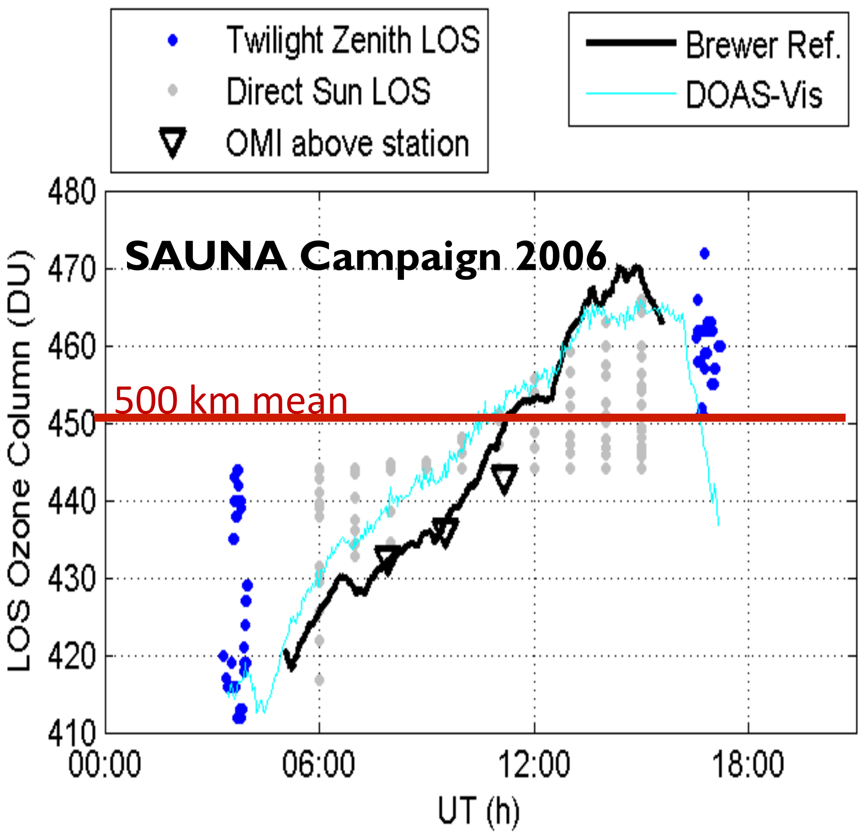
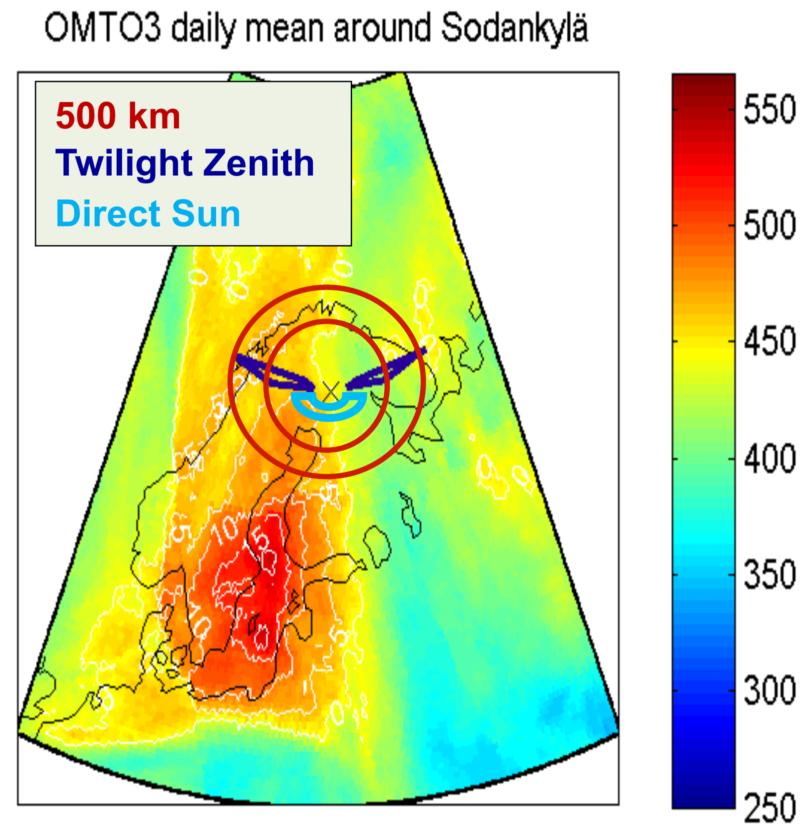
Optimization of co-location criteria
Diurnal change, smoothing difference or real bias?





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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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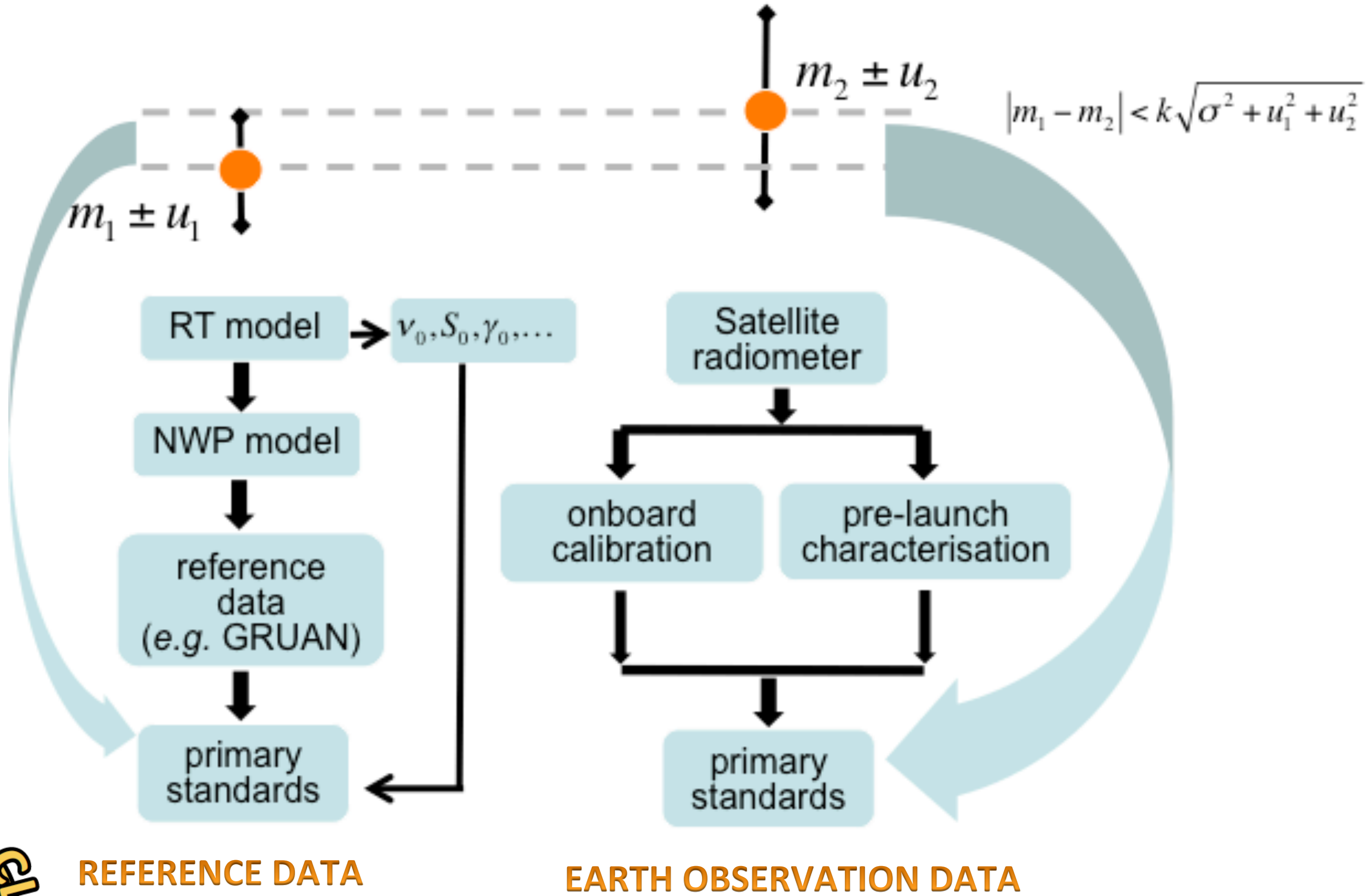
Validation of EO data: Idealised case 'observation space' validation



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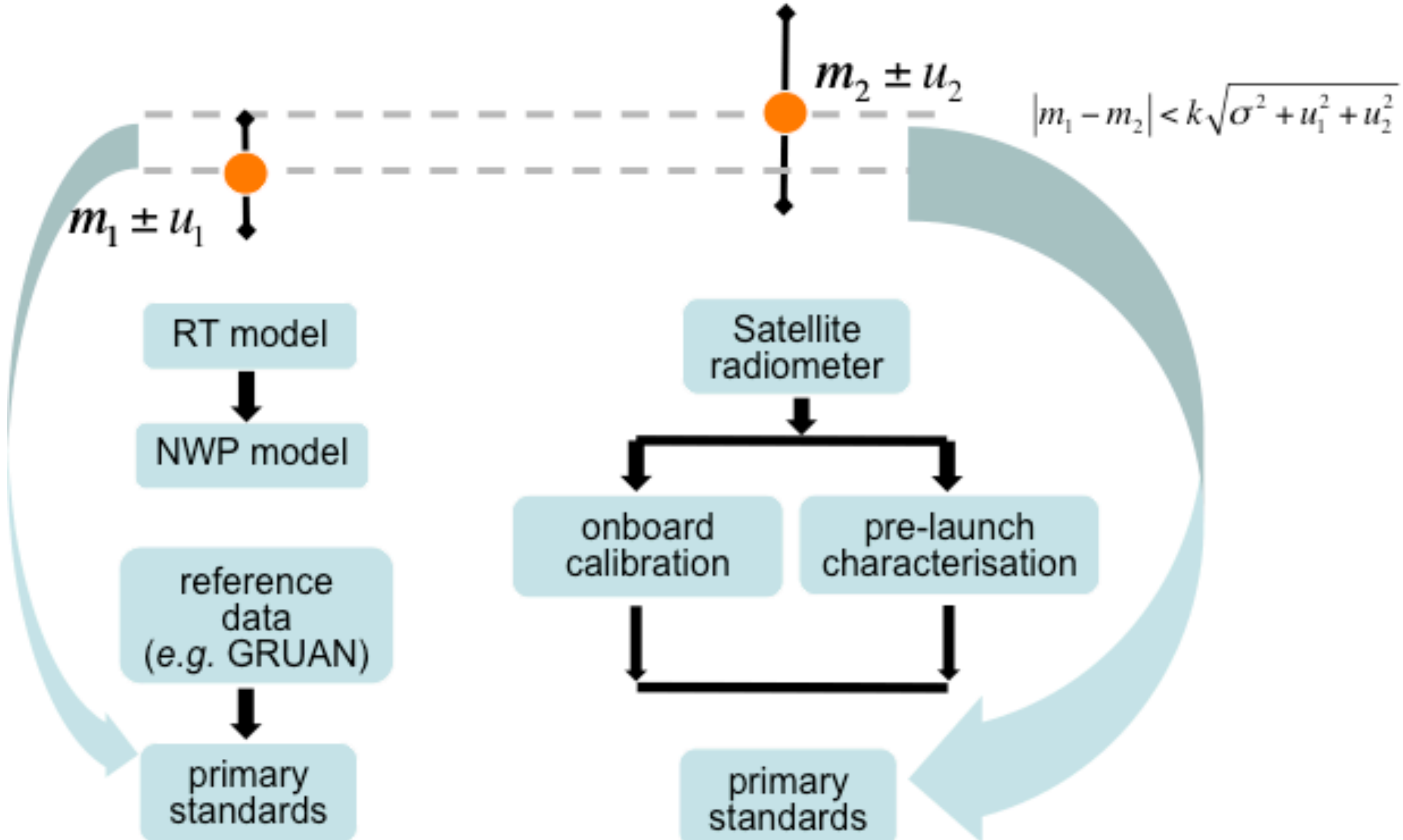
Validation of EO data: Current situation

‘observation space’ validation



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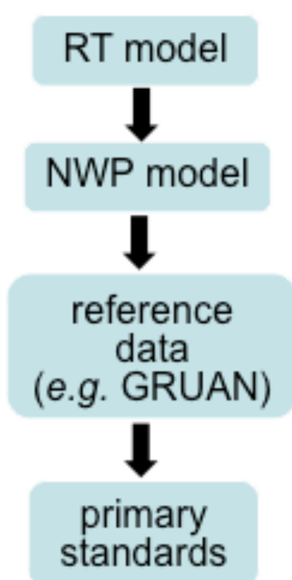
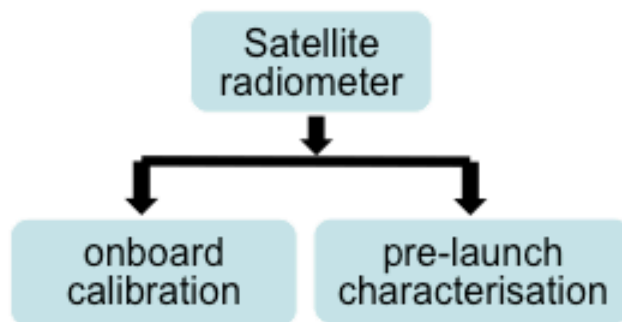
Validation of EO data: What can we achieve in GAIA-CLIM WP4 ?

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





- Establish uncertainties in radiances simulated from NWP
- Evaluate $|m_1 - m_2|$ for several key satellite instruments
- Establish uncertainties in satellite radiance measurements

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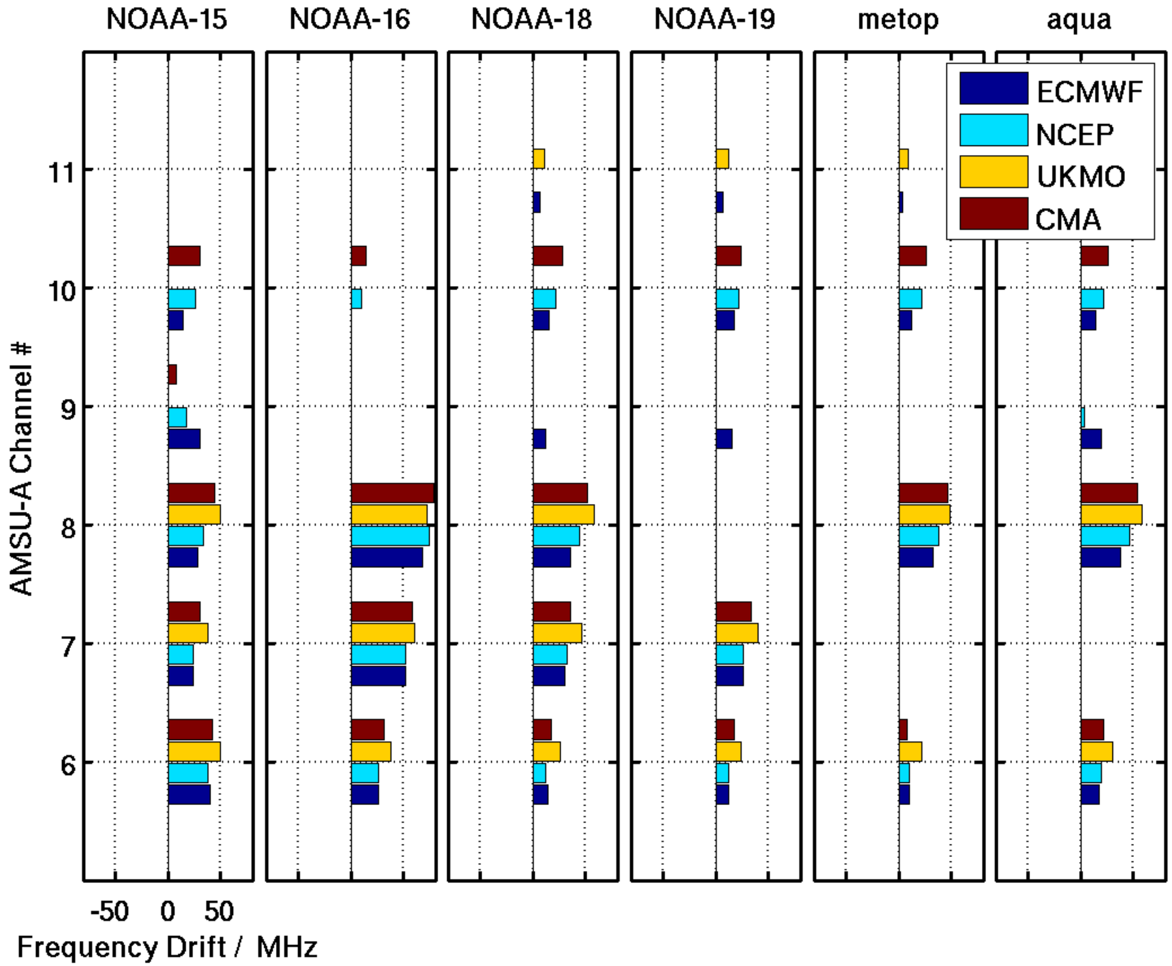
Analysed Frequency Shifts for AMSU-A: NWP Model Dependence

Similar results obtained From 4 NWP models (ECMWF, UKMO, NCEP, CMA)

Lu and Bell, JTECH, 2014



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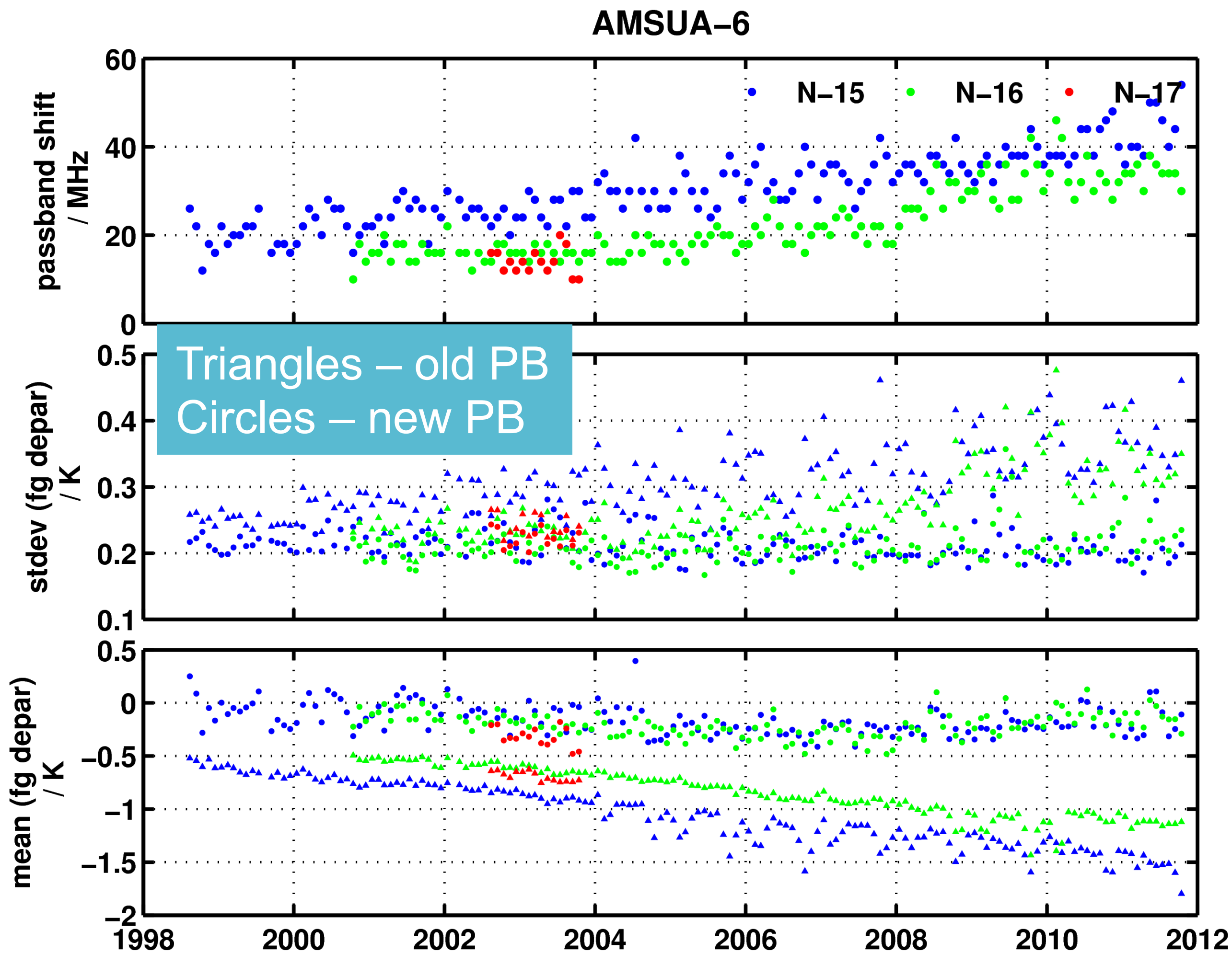
Frequency shifts with time *e.g.* AMSU-6

Uses ERA-Interim analysis fields

Reduced seasonal cycle in obs-model misfit

Reduced inter-satellite biases & obs-model biases



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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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Graphical Analytical User Interface

There is a lot to choose from but challenging to figure out what users need/want?

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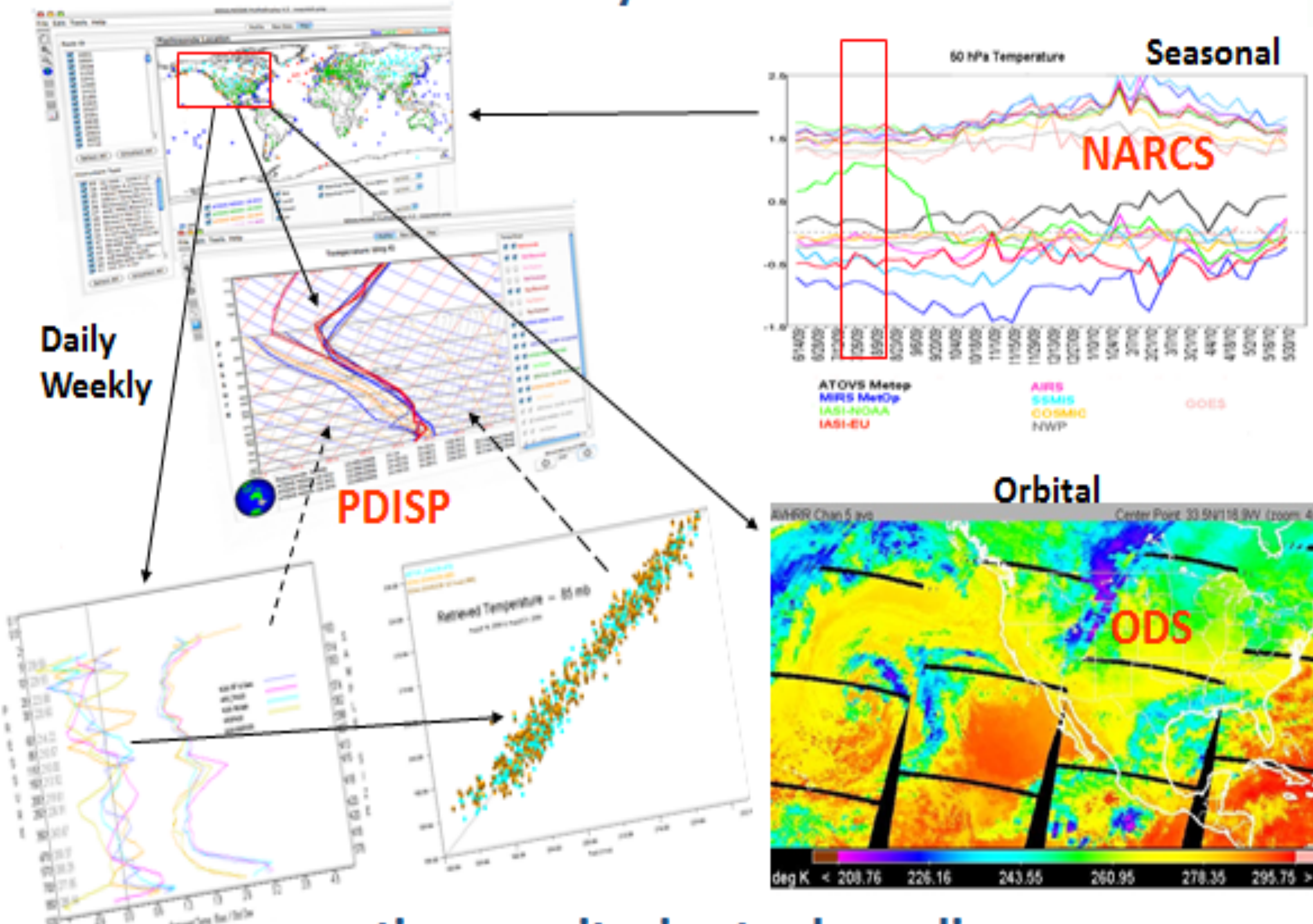
EDGE Analytical Interface ...



... routine monitoring to deep dive

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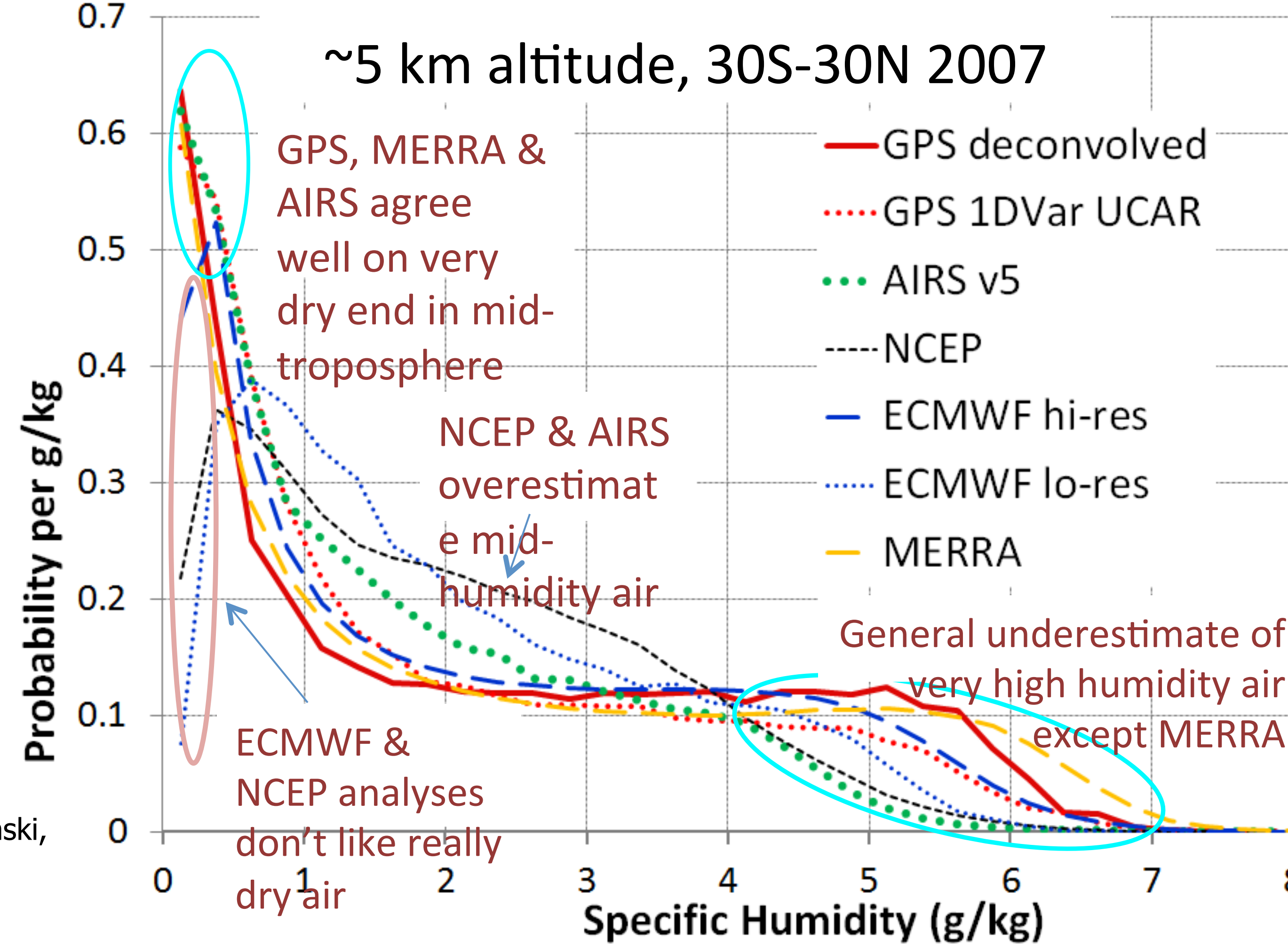
547 hPa Specific Humidity Comparisons



Courtesy Rob Kursinski, MOOG

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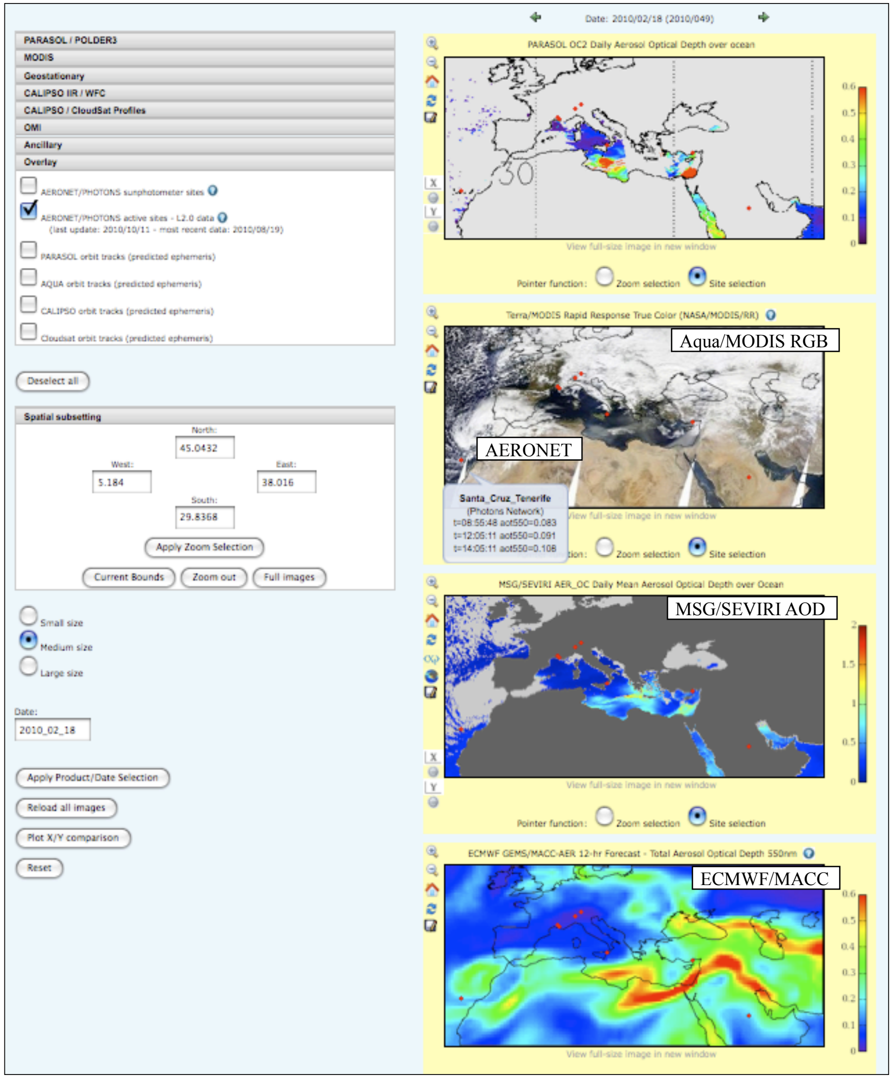
Global Gridded Products

Multi-sensor browse interface
http://www.icare.univ-lille1.fr/browse

- A user-friendly interface where multiple products can be displayed over the user-defined region of interest
- Top-down selection (Product>Date>Region) coupled with transverse selection (i.e., modify date or product or region selection)
- Orbit tracks overlay available
- X/Y comparison plot available
- Link to AERONET sunphotometer database
- Some models and analyses are available (e.g., MACC aerosol forecast)



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Full report with traceability and download options

Currently viewing

REPORT PROPERTIES	
Intercomparison	O3-fnyp-MWR
Period	MONTHS
Start	01 Jul 2014
End	31 Jul 2014
Location	[ALL]
Affiliation	[ALL]
Generated	04 Oct 2014, 05:31h

Report actions

DOWNLOAD ACTIONS

- Download report as PDF file
- Download report and data files as zip archive

Related reports

PERIODS

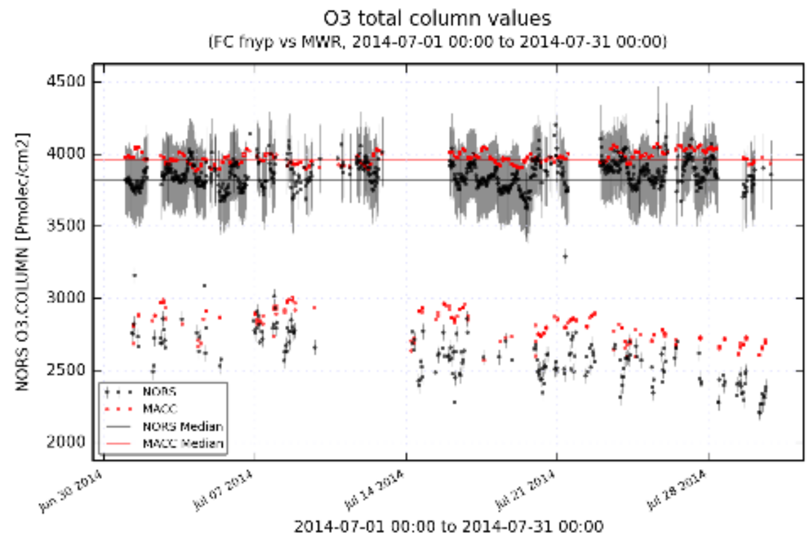
- previous month
- next month

Intercomparison Report

NORS Report: MACC fnyp vs NORS MWR - O3

MACC vs NORS O3 - Intercomparison Statistics

f (predicted variable)	MACC O3.COLUMN [Pmolec/cm2]
o (observed variable)	NORS O3.COLUMN [Pmolec/cm2]
# measurements	1035
median bias	137.581
B (mean bias)	138.883
RMSE (root mean square error)	115.996
MNMB (modified normalized mean bias)	0.0405263
FGE (fractional gross error)	0.0439414
R (correlation coefficient)	0.975414
RS (Spearman rank correlation coefficient)	0.486943



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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.
- Prioritisation of potential gap remedies and improvements in capabilities

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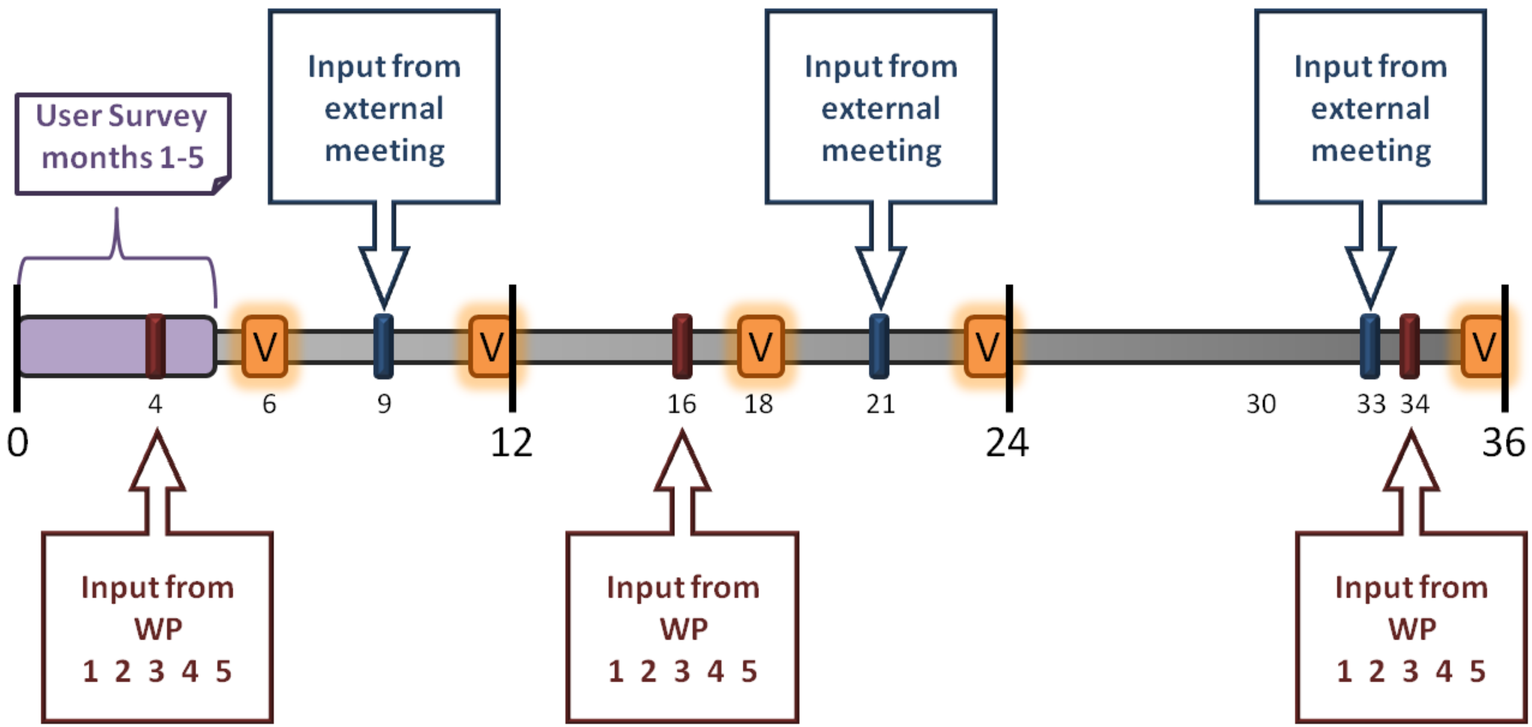
Gap assessment is iterative with community



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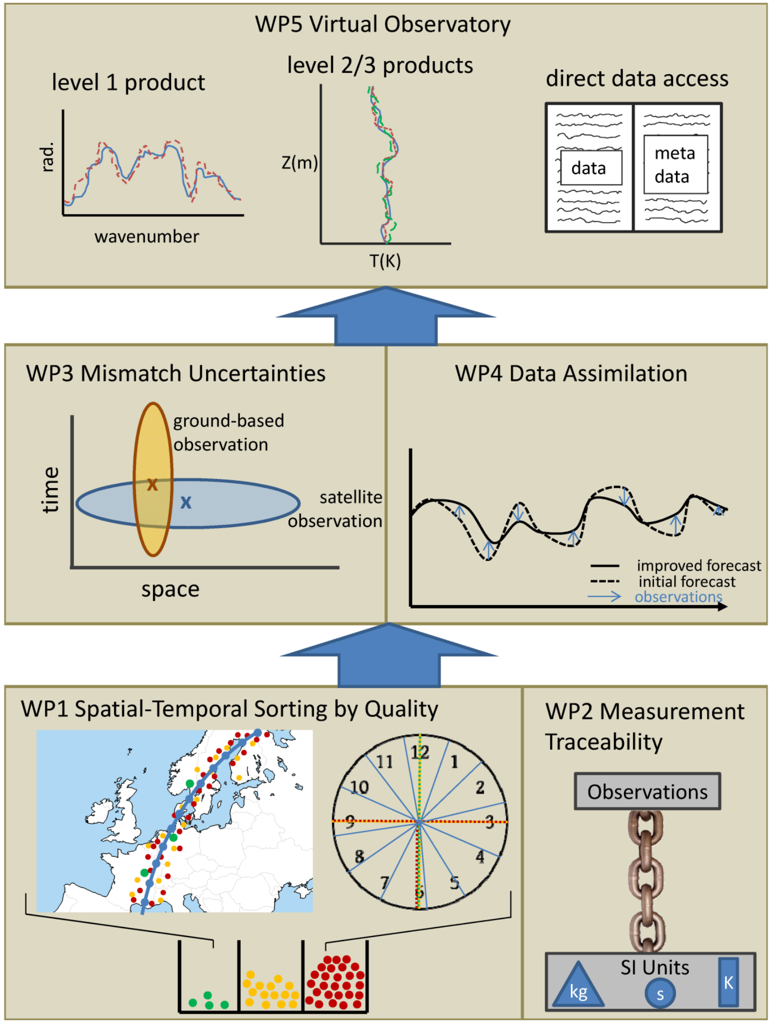

- Define data quality attributes and map by capabilities
- Improve metrological quantification of in-situ ground-based and sub-orbital measurements
- Robustly quantify the impacts of inevitable measurement mismatches
- Use Data Assimilation to improve the usefulness of high quality measurements
- Provide 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 15th !*

- only 10' work and we need to hear from you, **the users**, so we build something you will a. use and b. find useful

- 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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