GAIA-CLIM H2020 project

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

Peter Thorne, January 15th 2015

With thanks to WP leads: Fabio Madonna, Karin Kreher, Jean-Christopher Lambert, Bill Bell, Joerg Schulz, Martine de Maziere

A new project starting in March

- NERSC (coordinator)
- NUIM (Science coordinator)
- BIRA (WP lead)
- CNR (WP lead)
- MO (WP lead)
- BKS (WP lead)
- EUMETSAT (WP lead)
- ECMWF
- KNMI
- FMI
- MPG
- Bremen University
- Tallinn University of Technology
- NPL
- Helsinki University
- Bergamo University
- Lille University
- KIT
- Plus NOAA, NASA (no cost)

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.

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

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.

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 (agreement within stated design specification tolerance)

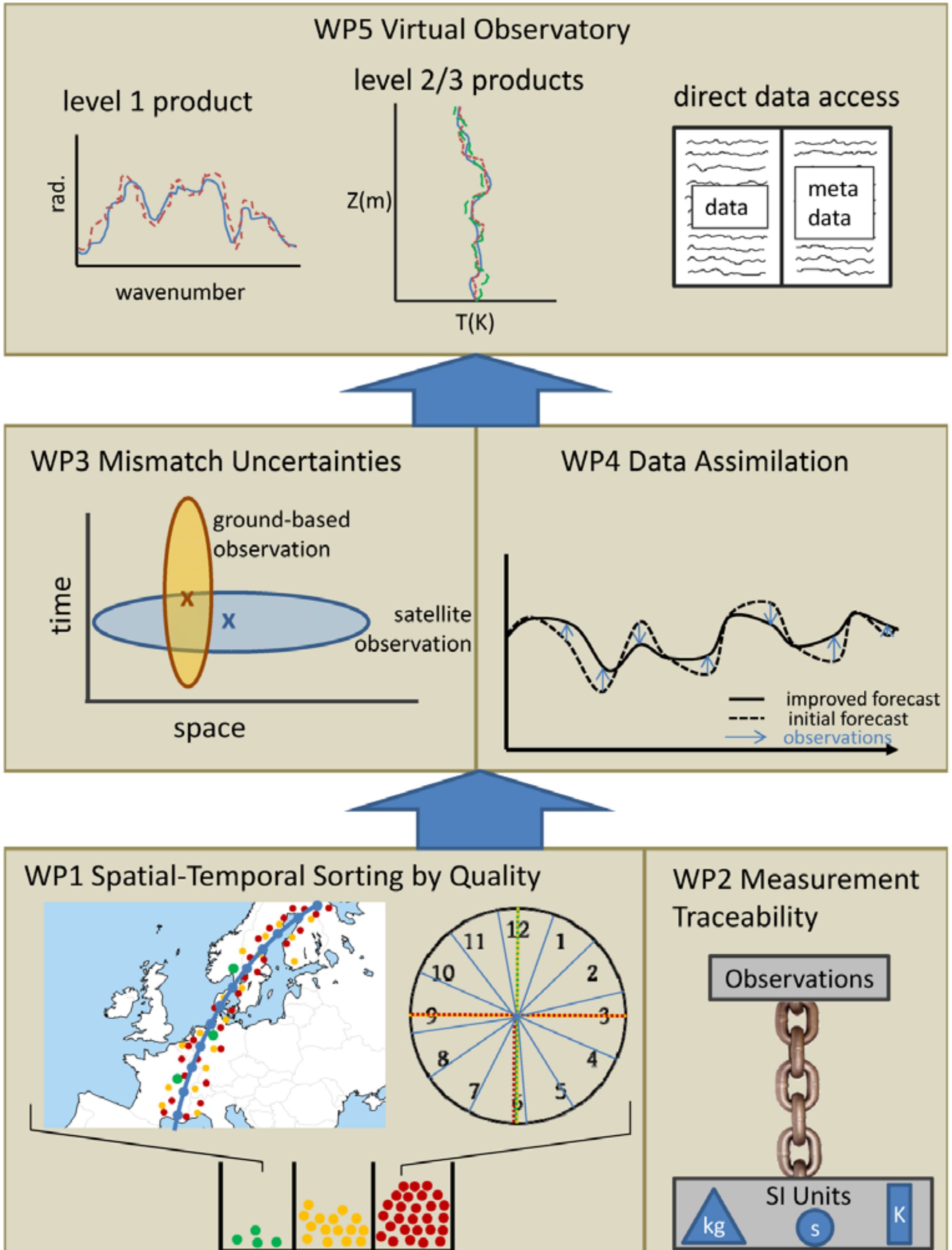
$\lvert m_1 - m_2\rvert < k\sqrt{u_1^2 + u_2^2}$	TRUE	FALSE	significance level
k=1	consistent	suspicious	32%
k=2	in agreement	significantly different	4.5%
k=3	-	inconsistent	0.27%

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

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

✓ This test is only meaningful, i.e. observations are co-located or co-incident if: $\sigma < \sqrt{u_1^2 + u_2^2}$

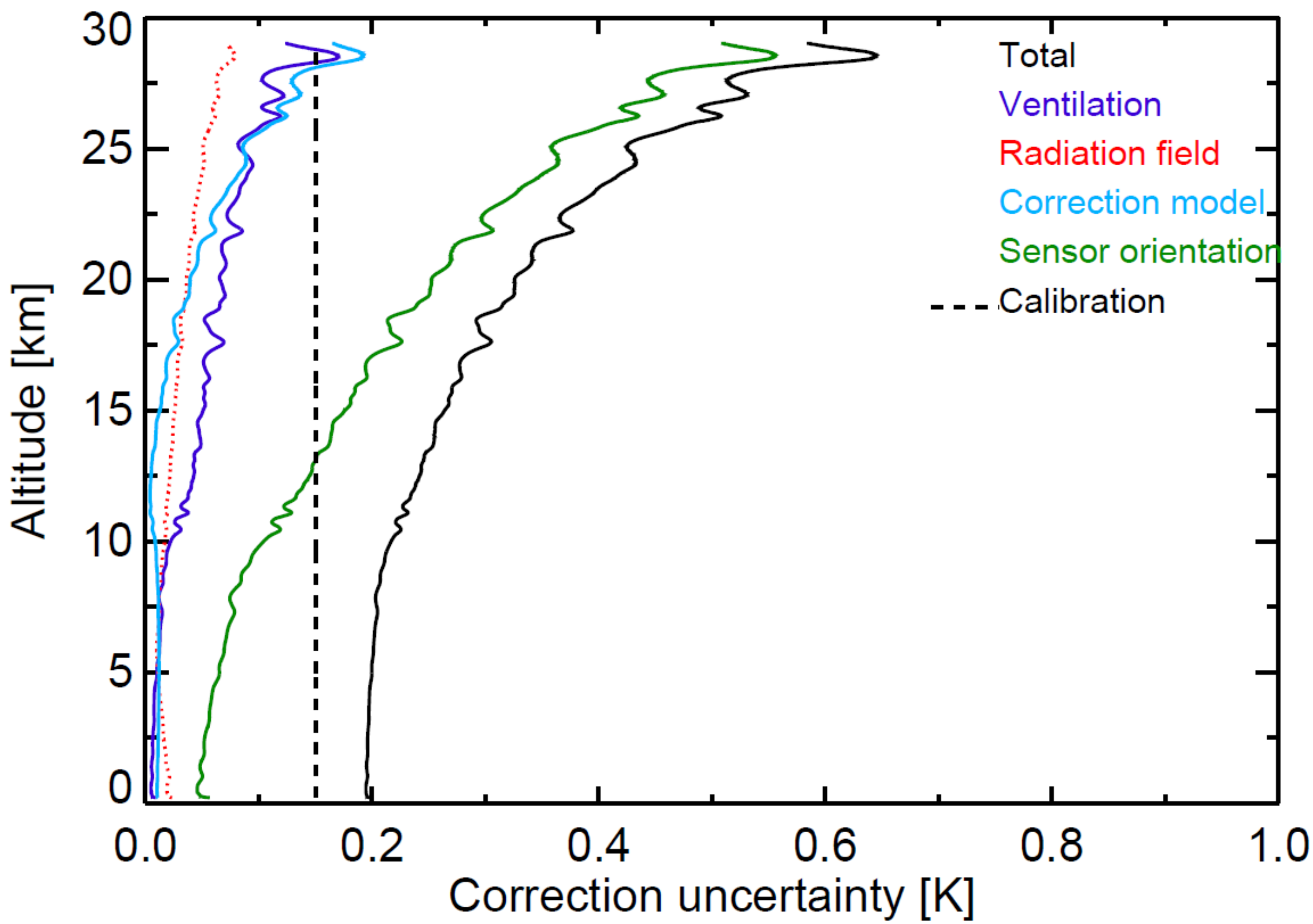


- Define data quality attributes and map by capabilities
- Improve metrological quantification of in-situ ground-based and sub-orbital measurements
- Robustly quantify the impacts of inevitable measurement mismatches
- Use Data Assimilation to improve the usefulness of high quality measurements
- Provide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

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

WP2: Quantifying measurement uncertainties

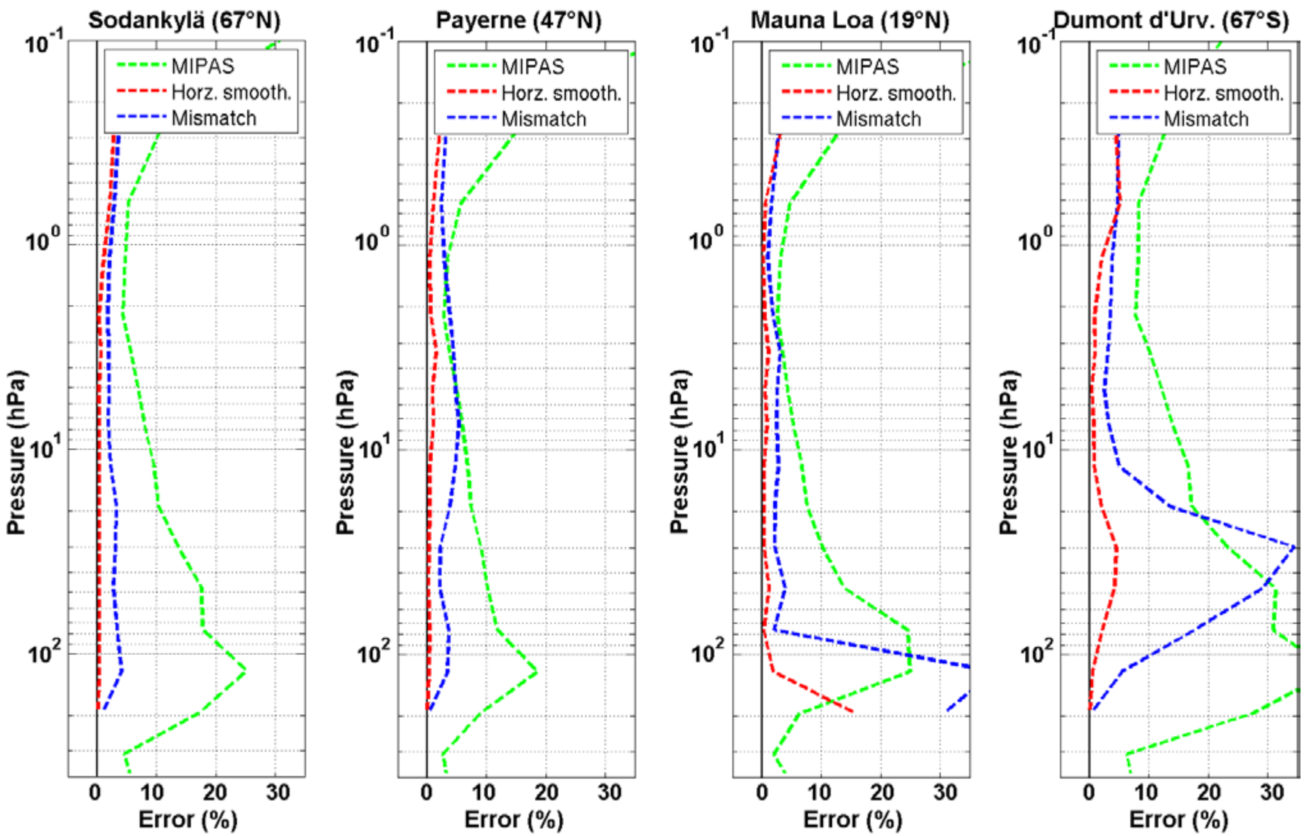


Instruments / programme	T	q	CO_2	CH_4	O_3	Aerosols	CO	HCHO	NO_2
Pre-existing / already in process on GAIA-CLIM timescales									
Radiosondes (RS92 and various others)	■	■							
Frostpoint hygrometer sondes		■							
Ozonesondes					■				
QA4ECV project (various instruments)							■	■	■
Planned in GAIA-CLIM									
Lidars	■	■			■	■			
Microwave radiometers	■	■							
FTIR / FTS		■	■	■	■				
UV/visible spectroscopy					■				
MAX-DOAS/Pandora					■				
GNSS-PW		■							

WP3: Measurement mismatch uncertainties

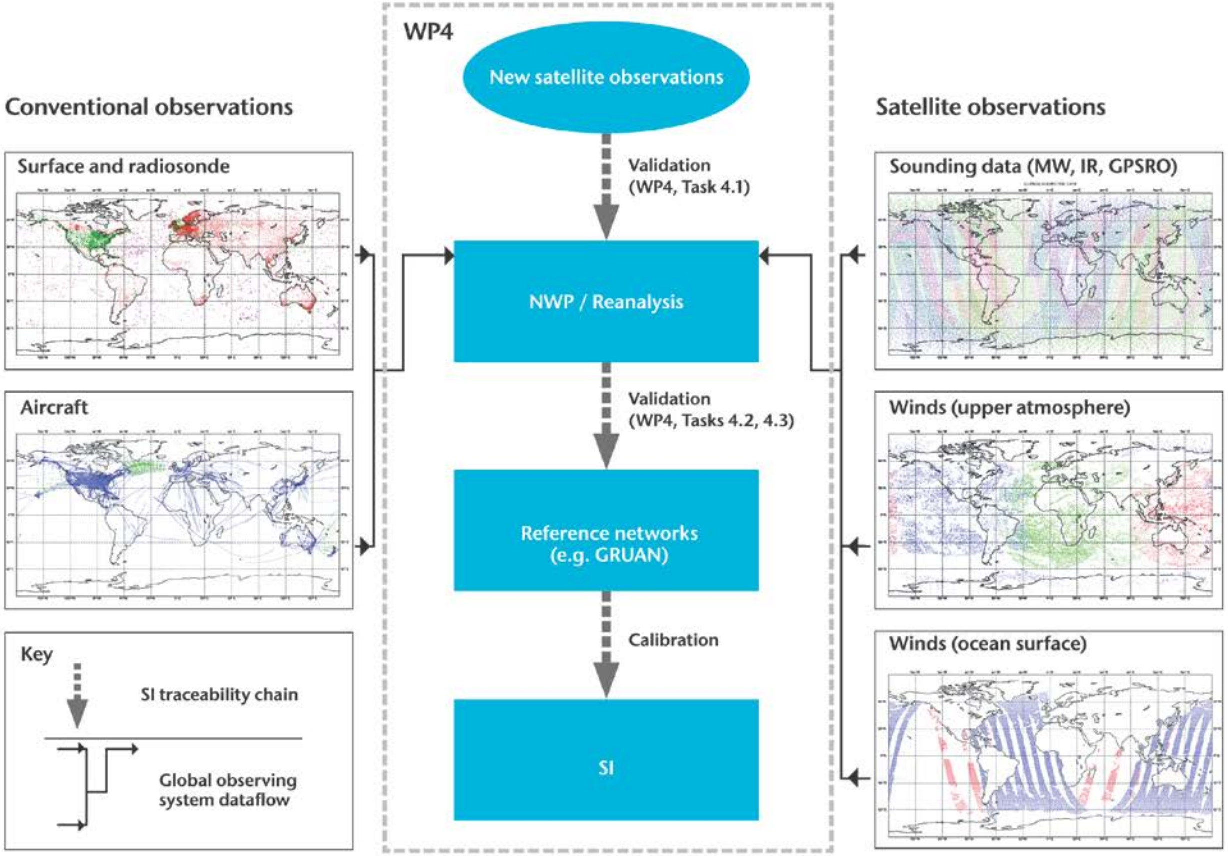
- Satellites and other measures will never measure the exact same volume over the exact same interval.
  - Differences in time of observation (including measurement time integral mismatch and diurnal cycle effects)
  - Differences in horizontal geolocation, including such time-varying effects as drift 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.

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



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

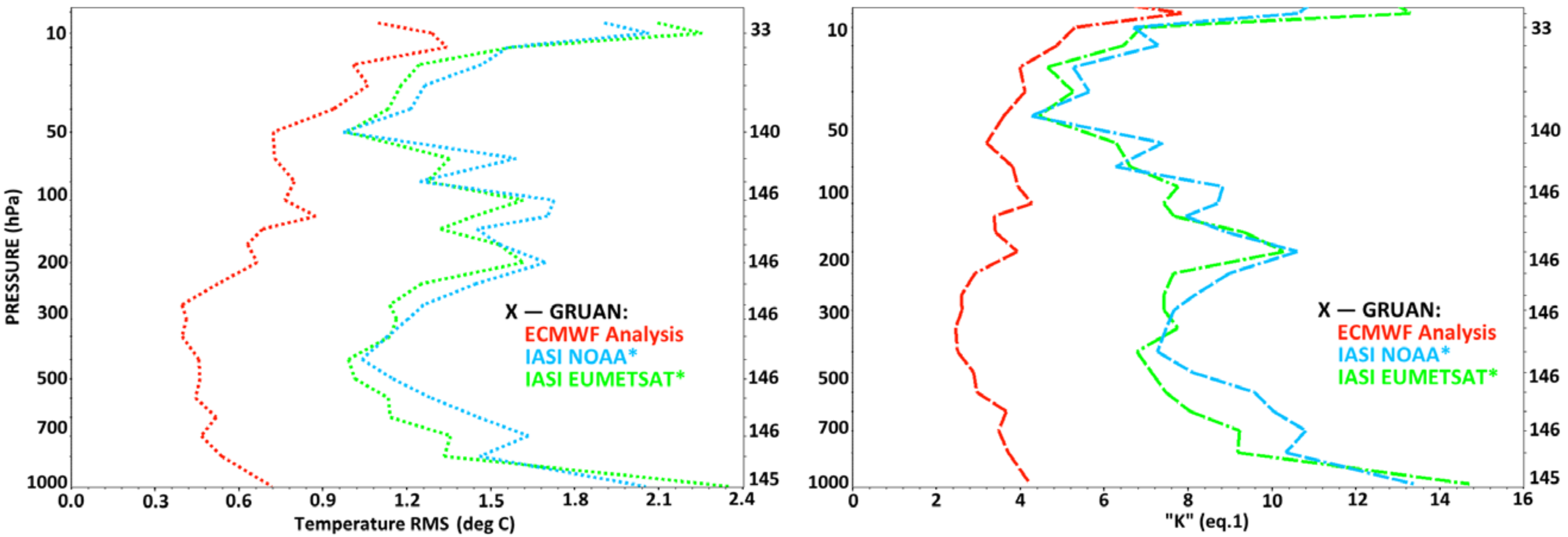

WP4
New satellite observations
Conventional observations
Satellite observations
Surface and radiosonde
Sounding data (MW, IR, GPSRO)
Validation
(WP4, Task 4.1)
NWP / Reanalysis
Aircraft
Winds (upper atmosphere)
Validation
(WP4, Tasks 4.2, 4.3)
Reference networks
(e.g. GRUAN)
Calibration
Winds (ocean surface)
Key
SI traceability chain
Global observing
system dataflow
SI

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

NPROVS+

14 July 2013 — 19 January 2014

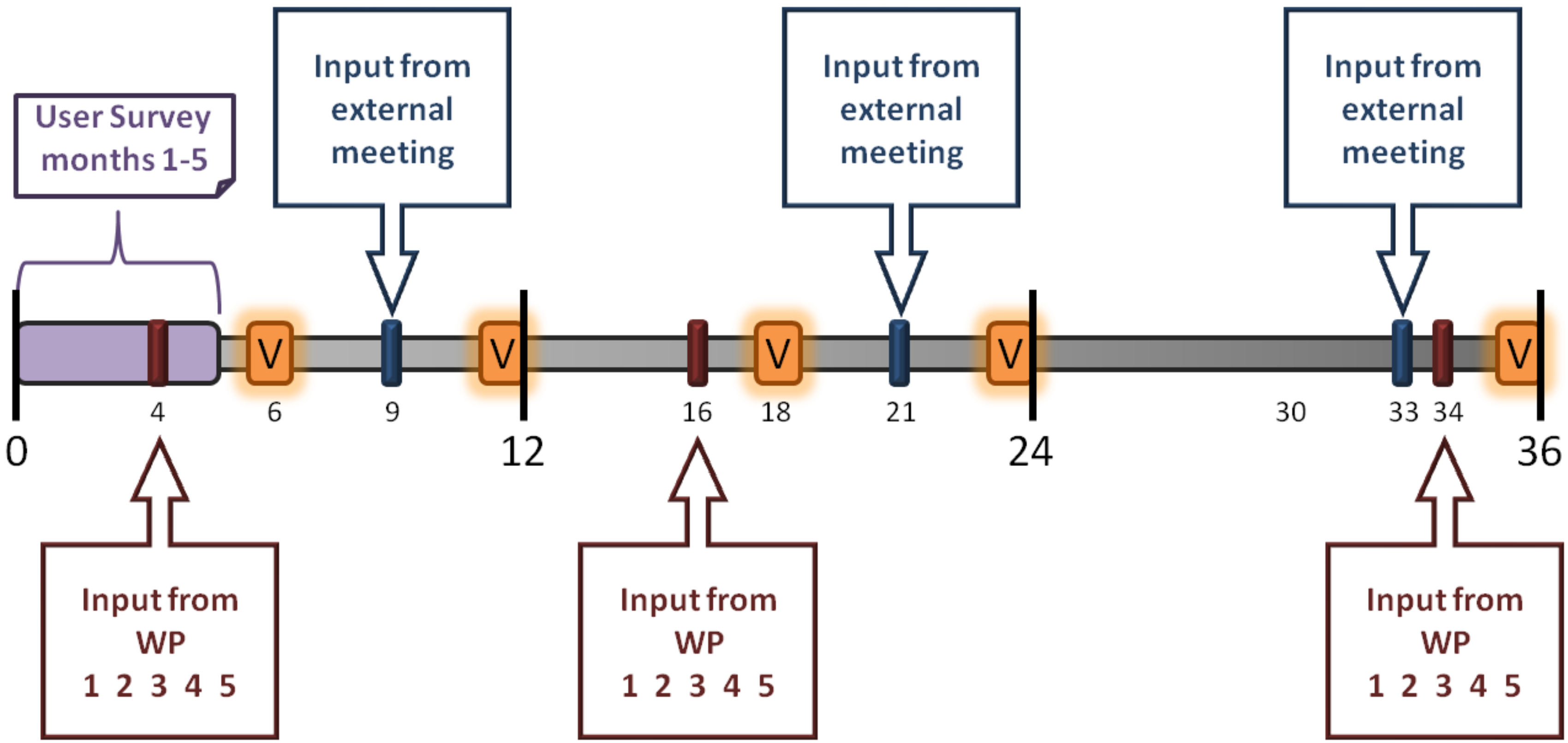


* IR + MW, passed QC

WP6: Outreach and gaps assessment

- Gaps in geographical coverage and their impacts arising from the geographical mapping exercise
- Gaps in knowledge of measurement properties and uncertainties for both specific instrument types and on an ECV basis.
- Gaps in understanding of the impact of measurement mismatches arising from inadequacies in knowledge of how to deal with measurement mismatch issues.
- 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.

Gap assessment is iterative with community



Potential inter-project synergies

- **QA4ECV** – ensured complementary not duplicative
- **FIDUCEO** – UT wv and aerosols work would provide metrological uncertainty on the satellite measurements (u_2 in earlier equations robustly quantified so do we match? X-check)
- **ERA-CLIM2 / UERRA** - potential synergies with GAIA-CLIM WP on data assimilation.
- **CORE-CLIMAX** - extension of data product maturity matrix concept to measurement system maturity aspects.

Summary

- GAIA-CLIM will:
  - concentrate upon building SI traceability and physical mismatch uncertainty into in-situ-satellite comparisons using several techniques incl. data assimilation
  - produce a toolset for satellite characterization / validation through a virtual observatory hosted by EUMETSAT
  - produce an assessment of gaps in conjunction with the broader community
  - be fun (I hope …)
- We start with a Kick-off meeting on March 2nd in Matera, Italy