ESA's ADM-Aeolus Wind Lidar Mission

Getting Ready for Launch

Anne Grete Straume, Anders Elfving, Denny Wernham, Frank de Bruin, Thomas Kanitz, Dirk Schuettemeyer, Jonas von Bismarck, Fabio Buscaglione

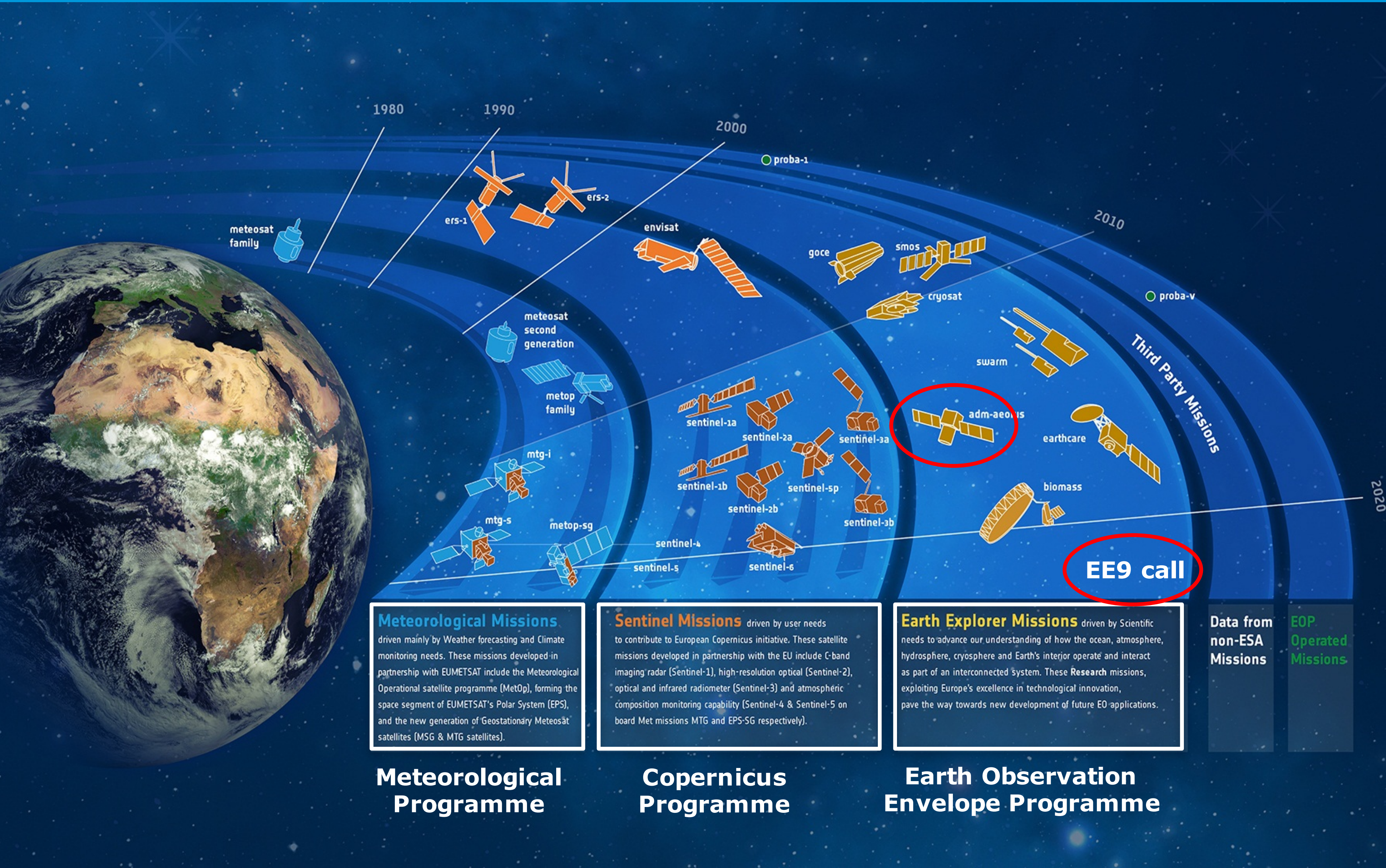
European Space Agency

International Winds Workshop 13, Monterey 26 June-01 July 2016

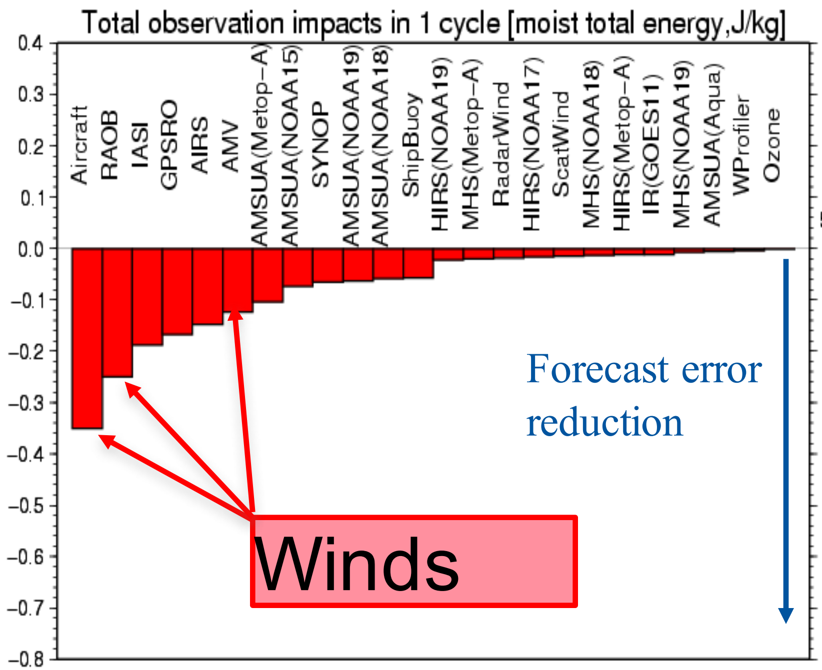
ADM-Aeolus teams

- ADM-Aeolus Project team
- Mission science and campaigns team
- PDGS and data quality teams
- Flight Operations Team
- Airbus Defence and Space & partners
- Aeolus Mission Advisory Group
- L1 and L2 algorithm development teams (DLR, DoRIT, ECMWF, KNMI, MeteoFrance)
- Campaign and CAL/VAL teams
- …

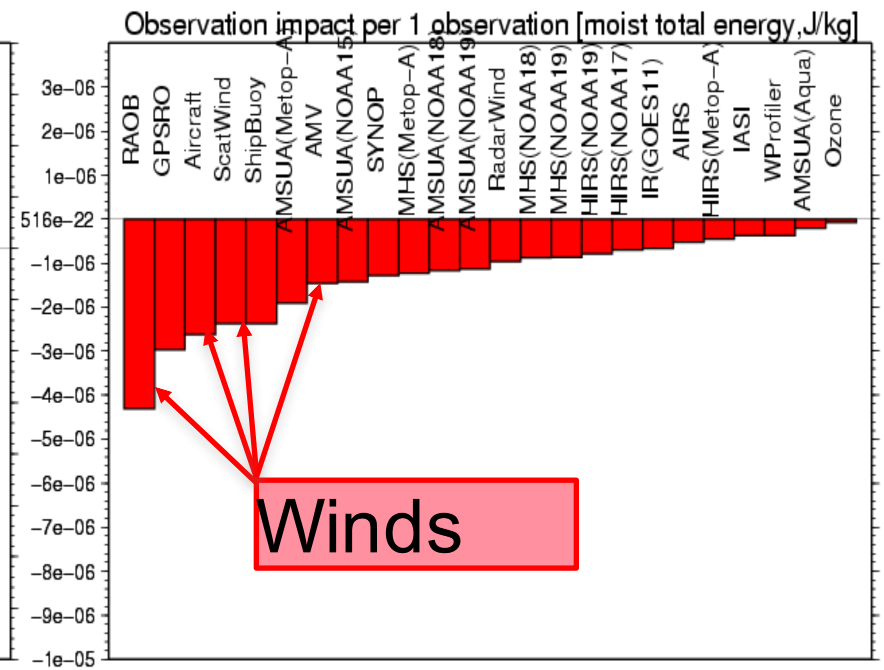
ESA’s Earth Observation Programme



WMO Workshop Sedona, May 2012
Assessment Global Observing System Impact



Total impact



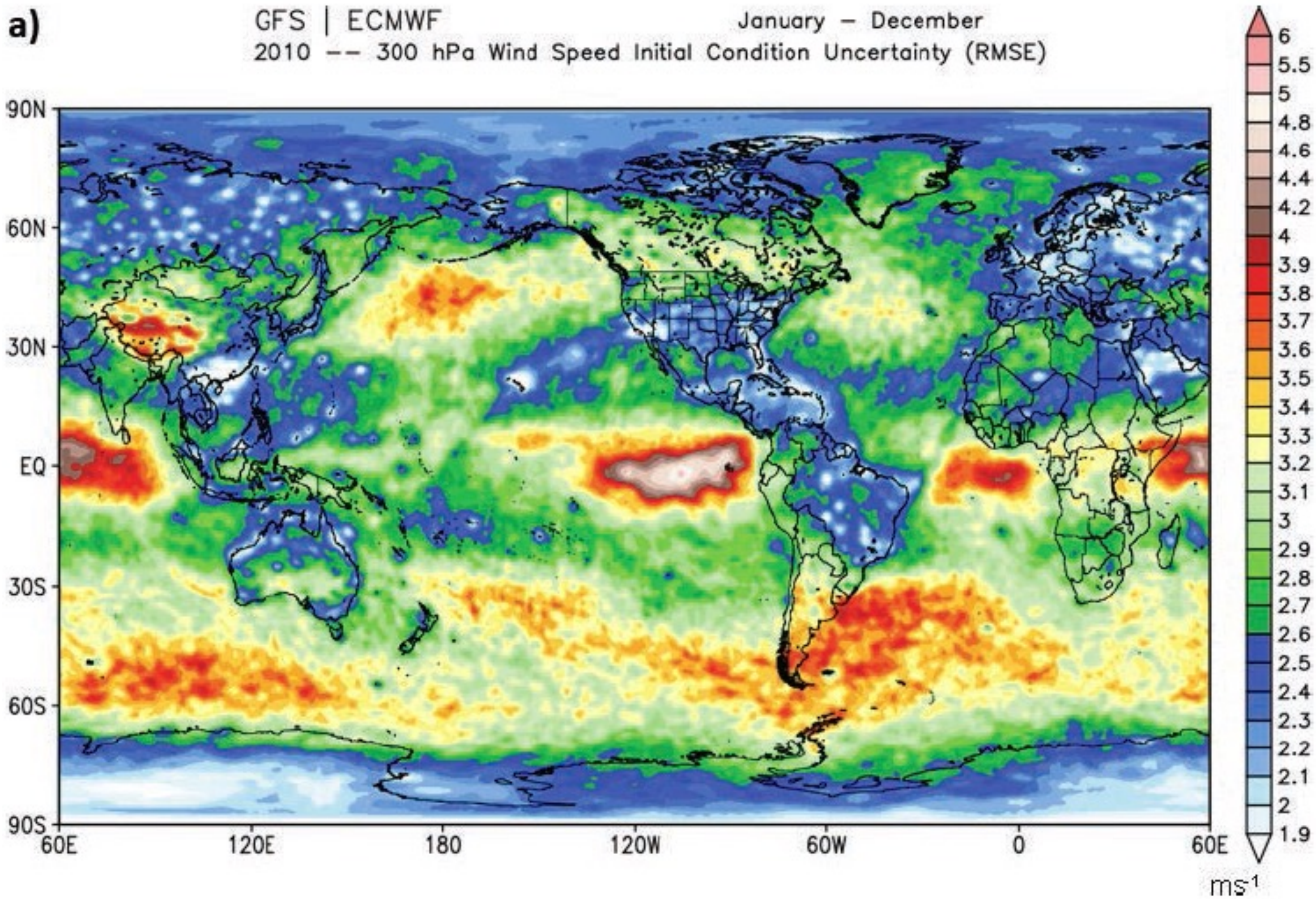
Impact per observation

Courtesy L.P. Riishojgaard

All observation types have positive **forecast impact** on average

Total impact: 1) aircraft, 2) AMSU-A, 3) radiosonde, 4) IASI, 5) GPSRO
Impact per observation: 1) radiosonde, 2) GPSRO, 3) aircraft, 4) scatterometer wind, 5) marine surface observation

Differences in forecast reanalysis data



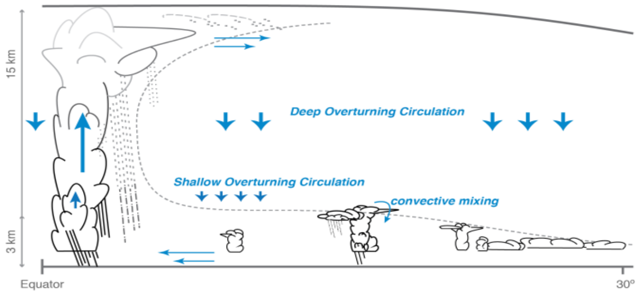
W. Baker et al., BAMS 2014

Examples - Importance of winds for climate

1. Atmospheric reanalyses for **climate model verification** need more wind observations

2. **Grand Challenges of World Climate Research Programme** are

   a. Understanding the role of dynamically driven cloud circulation interactions for **climate sensitivity**



Courtesy S. Bony, B. Stevens

   b. Understanding coupling of Tropospheric and Stratospheric dynamics and its impact on **climate variability**

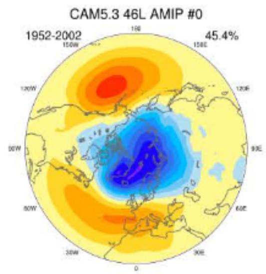
3. Meridional transport of **ozone** is strongly impacted by tropical dynamics (e.g. convection -> gravity waves, planetary waves)

Importance for winds for climate applications

– Understanding coupling Troposphere and Stratosphere dynamics and its impact on climate variability

Northern Annular Mode (EOF1 DJF SLP 20-90°N, 1952-2002)

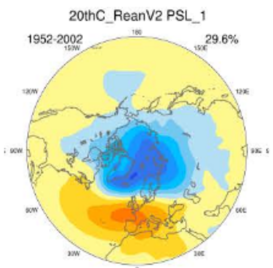
46L CAM5



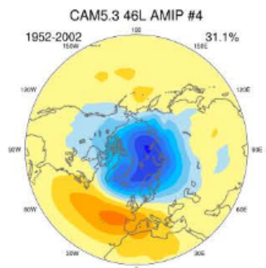
Run 1
45%

Courtesy C. Desler, NCAR

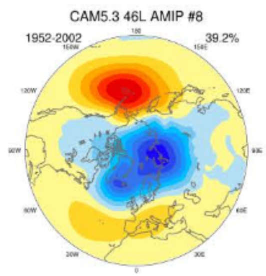
Observations (20CR)



30%



Run 4
31%



Run 8
39%

Related to
North Atlantic Oscillation

ADM-Aeolus Mission Objectives

Scientific objectives

- To improve the quality of weather forecasts;
- To advance our understanding of atmospheric dynamics and climate processes;

Explorer objectives

- Demonstrate space-based Doppler Wind LIDARs potential for operational use.

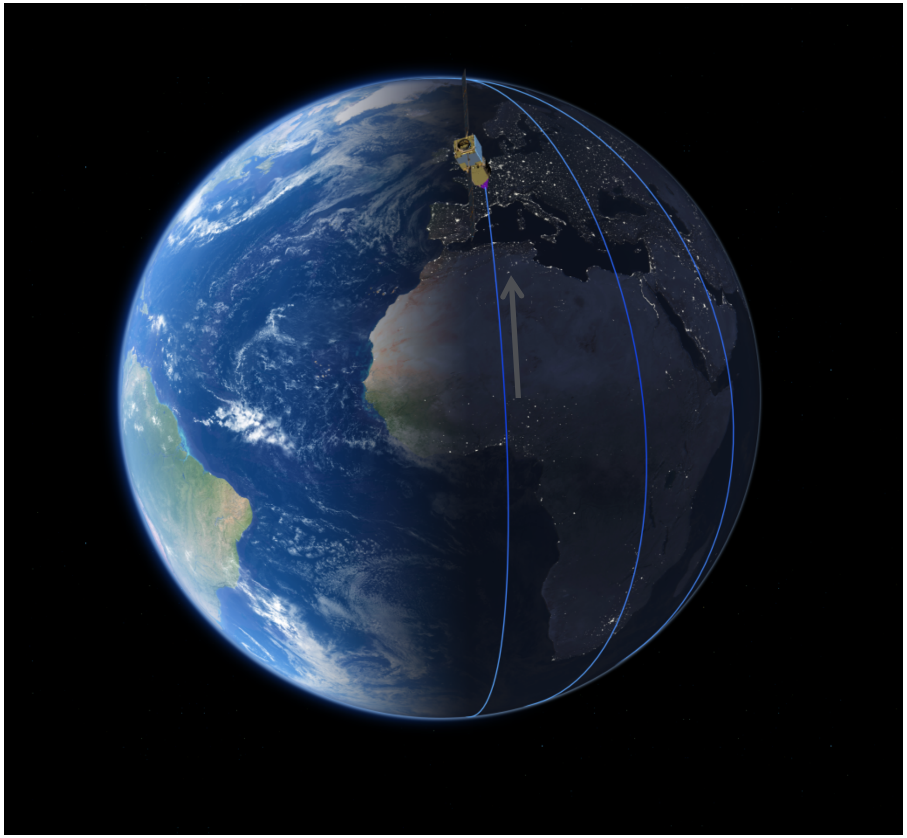
Observation means:

- Provide global measurements of horizontal wind profiles in the troposphere and lower stratosphere

Payload

- ALADIN: Atmospheric LAser Doppler INstrument

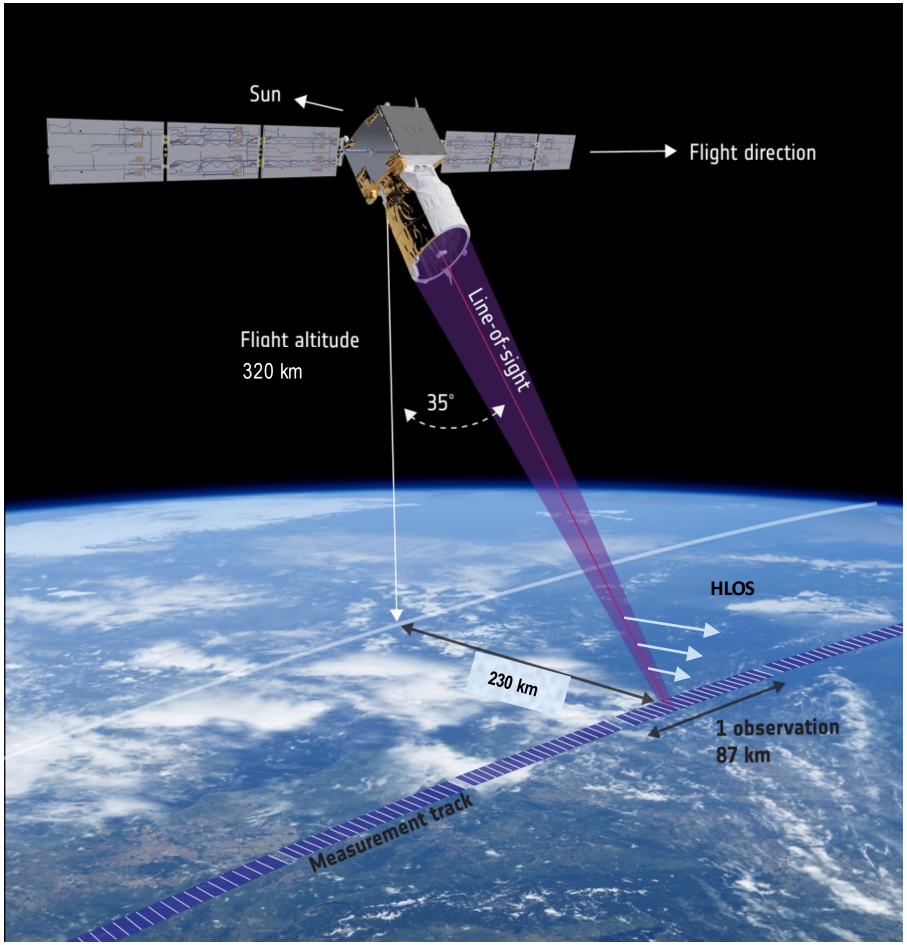
Mission characteristics



Mission Parameters

- Orbit: sun-synchronous
- Mean altitude: ~320 km
- Local time: 18:00 ascending node
- Inclination: 96.97°
- Repeat cycle: 7 days / 111 orbits
- Orbits per day: ~16

ADM-Aeolus Measurement Principle (1/2)

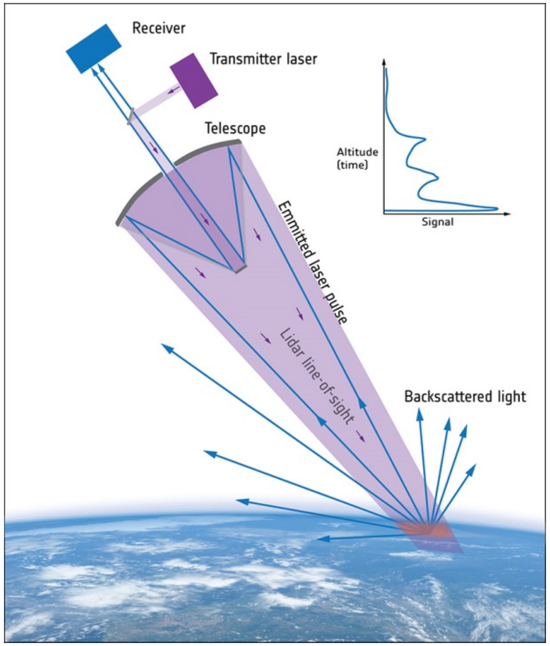


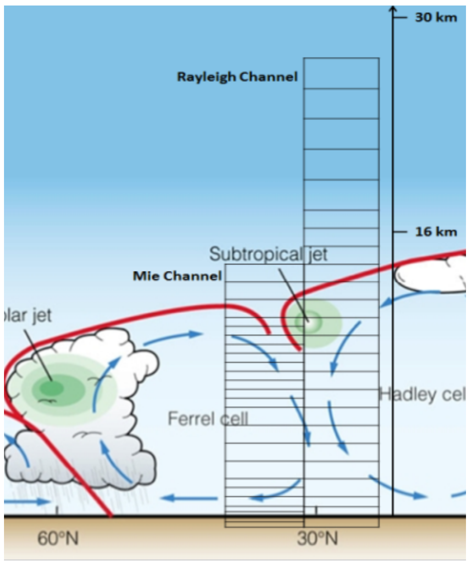
- UV Doppler wind Lidar operating at 355 nm and 50 Hz PRF in continuous mode, with 2 receiver channels (HSRL):
  - Mie receiver (aerosol & cloud backscatter)
  - Rayleigh receiver (molecular backscatter)
- The line-of-sight is pointing 35° from nadir to derive horizontal wind component
- The line-of-sight is pointing orthogonal to the ground track velocity vector to avoid contribution from the satellite velocity
- Spacecraft regularly pointed to nadir for calibration

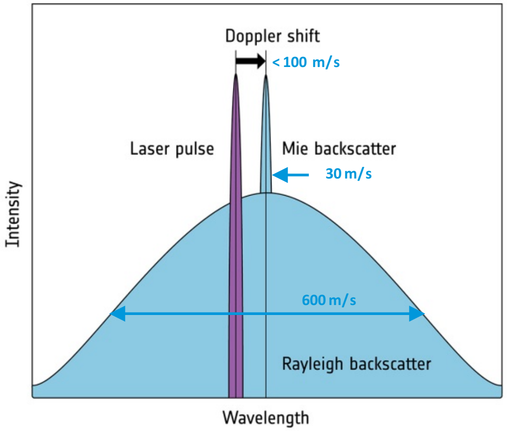
Measurement Principle (2/2)

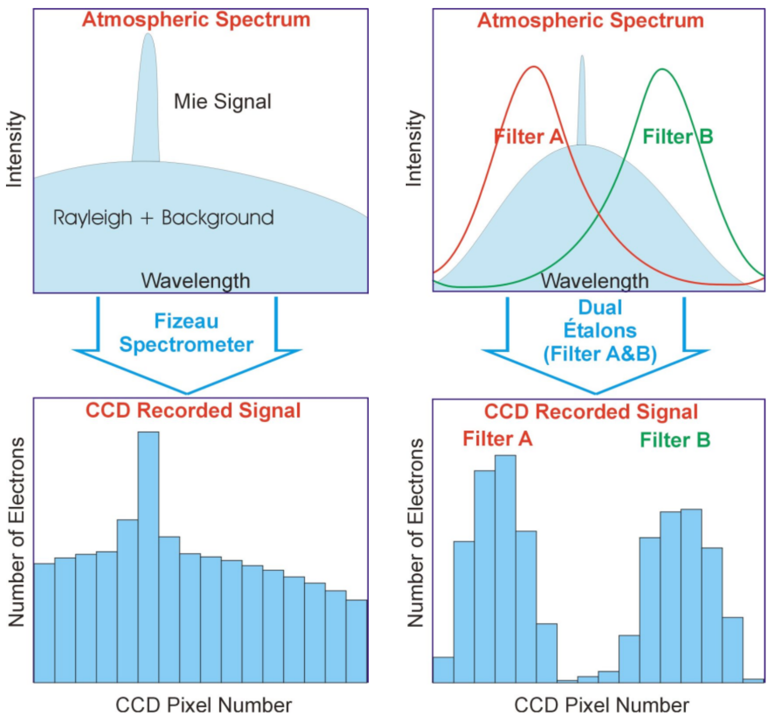
Mie channel:
- Aerosol/cloud backscatter
- Imaging technique

Rayleigh channel:
- Molecular backscatter
- Double-edge technique



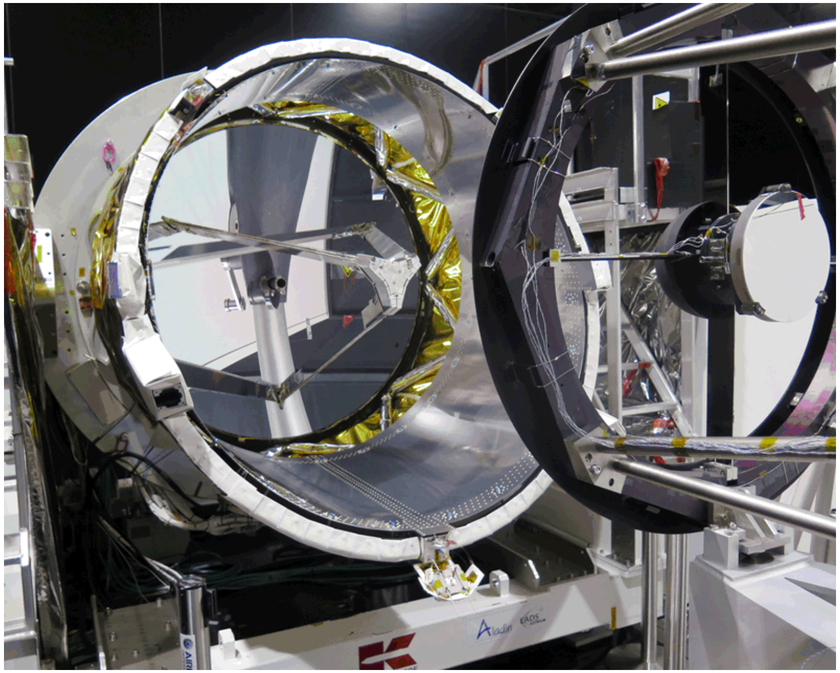






Instrument Status

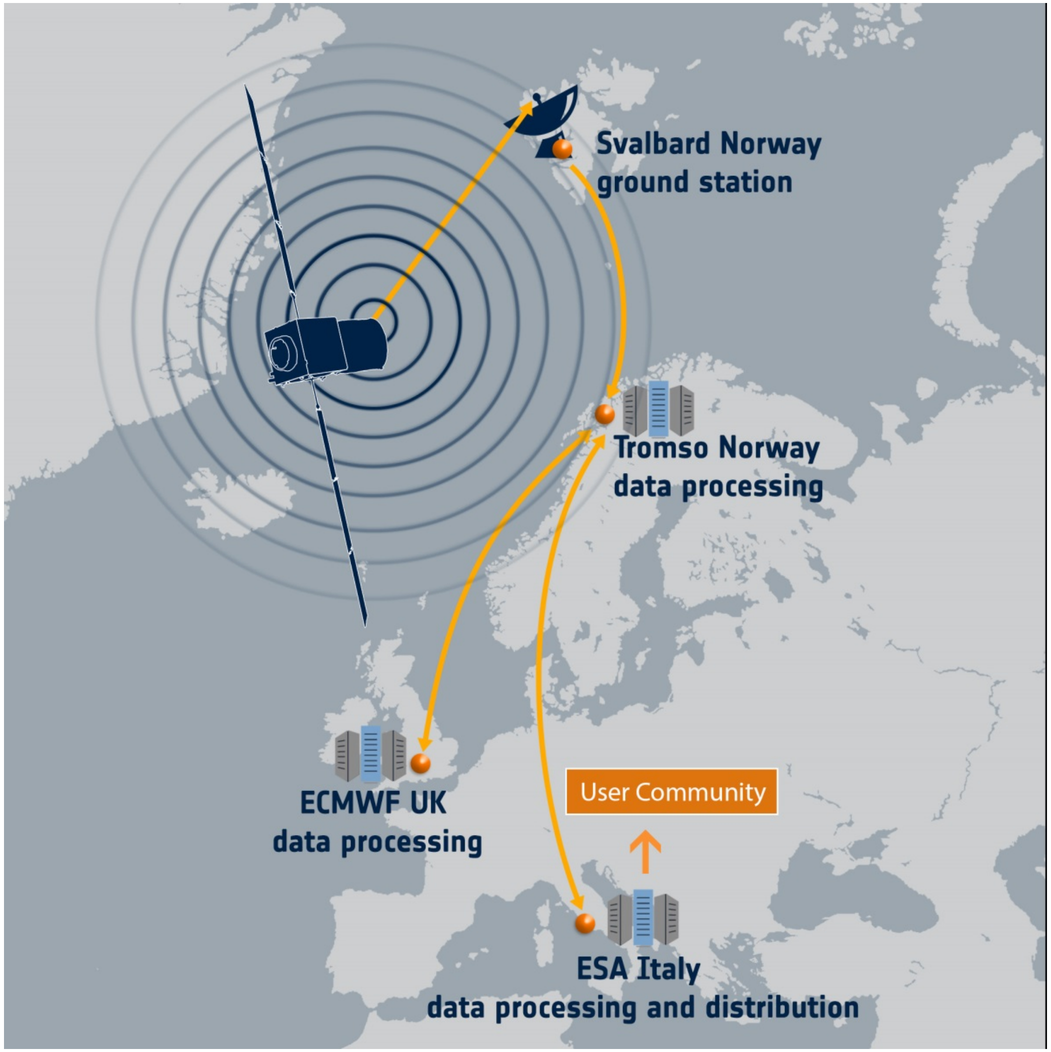
1. Instrument Full Functional Performance Test (IFP) April 2016
    a. End-to-end testing in ambient conditions
    b. Analysis on-going, preliminary results:
        - Random errors extrapolated from tests within 5% of expectations
        - detailed correlation analysis needed to confirm this (e.g. OGSE limitations)
        - Analysis of bias looks good
2. Instrument delivery: July 2016



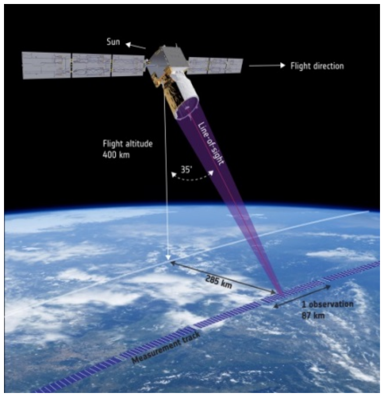
Mission status

1. Satellite platform ready for instrument integration
2. Instrument integration on platform: autumn 2016
3. Testing of instrument on platform: April 2017
4. **Satellite launch readiness: October 2017**
5. Launch: at the earliest 6 weeks thereafter
6. Commissioning phase: L – L+3 months
7. **Operational Phase: L+3 months – 3 years**

Data processing and distribution



Data Processing



?

Wind Velocity

AIS P → L0 → L1A → L1B → L2B v_{HLOS} → ECMWF, Met Centres, Science

CAL Suite

L1B → L2A β, σ → Air quality, Forecasts, Science

Data preparation

Mission products

1. Primary product (L2b):

Horizontally projected LOS (HLOS) wind profiles

- Approximately zonal at dawn/dusk (6 am/pm)
- ~85 km observation from 3 km subsamples – scene classified
- From surface to ~30 km in 24 vertical layers
- Random errors: 1-2(PBL), 2(Trop), 3-5 (Strat) m/s
- Bias requirements: 0.7 m/s
- **L2c product**: assimilated

Aeolus L1b product available NRT + L2b processor from ECMWF
Data format L1b: ESA EE binary format. L2b BUFR convertor

Aeolus L2a product available NRT

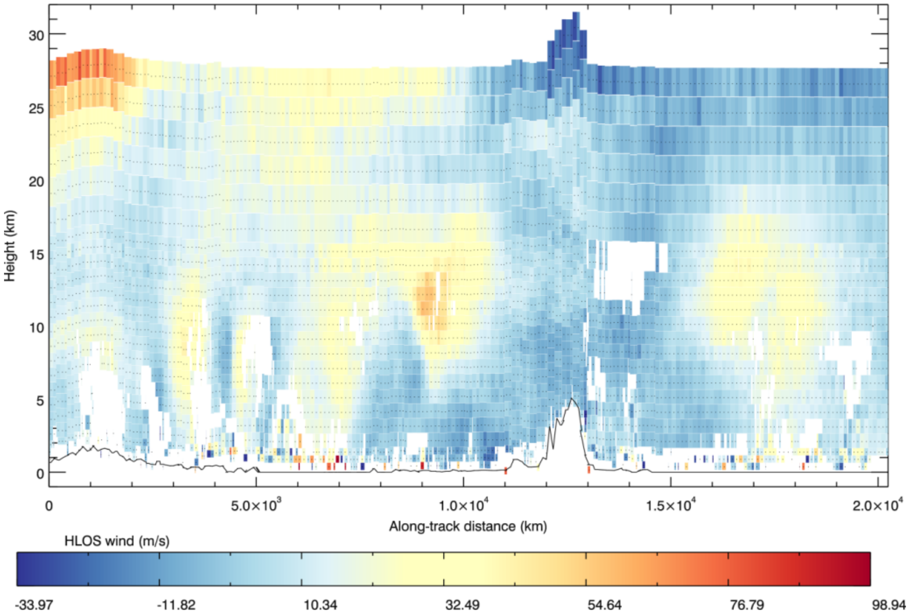
2. Spin-off

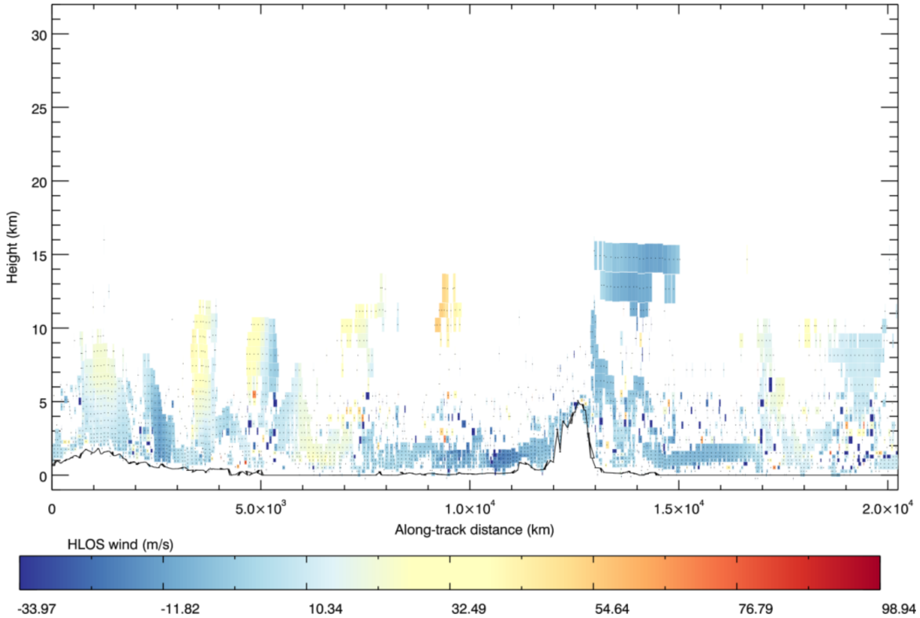
...ion averages from 3 km subsamples

...s one can deduce:

- Cloud/aerosol cover/stratification
- Cloud/aerosol top heights
- Cloud/aerosol base height (optically thin)

Simulated Aeolus Rayleigh (left) and Mie (right) winds

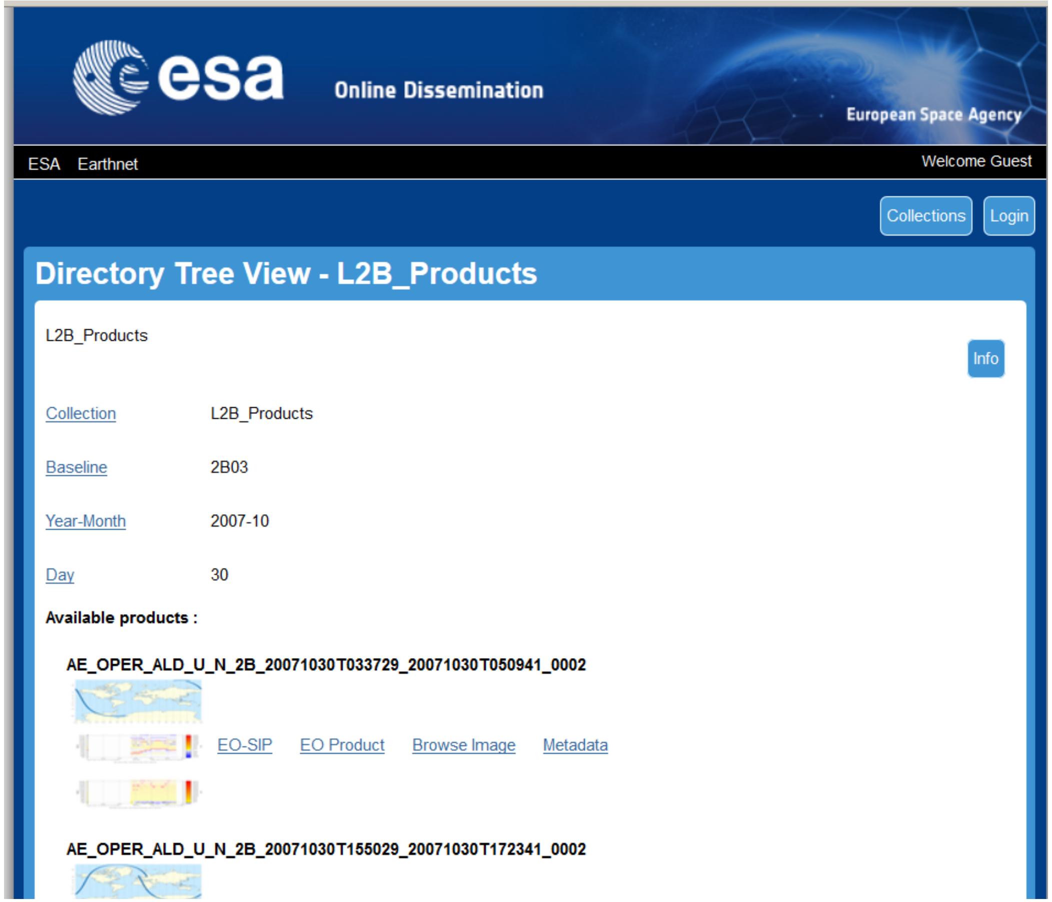




Courtesy Michael Rennie, ECMWF

(L2B processor development: KNMI & ECMWF)

Data access portal



http://aeolus-ref-addf.eo.esa.int/addf/

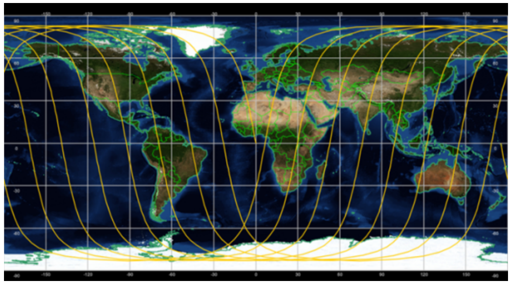
ADM-Aeolus: Observational Requirements

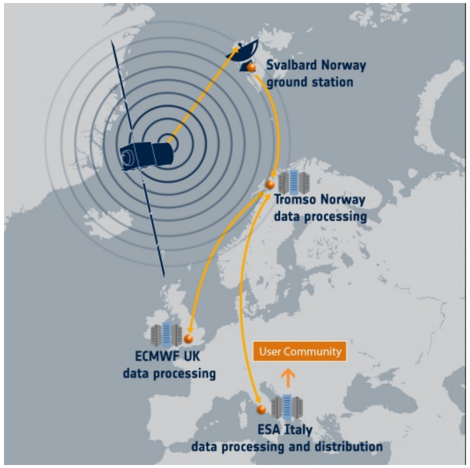
Requirement ID			Observation Requirements		
			PBL	Troposphere	Stratosphere
MR-85	Vertical Domain	[km]	0-2	2-16	16-20 (30)*
MR-60	Vertical Resolution	[km]	0.5	1.0	2.0
MR-80	Horizontal Domain		Global		
MR-70	Number of Profiles (sampling)	[hour^{-1}]	>100		
MR-150	Minimum horizontal track data availability	[%]	95		
MR-75	Temporal sampling	[hour]	12		
MR-50	Horizontal observation size	[km]	15 (goal) – 100 (threshold)		
MR-50	Horizontal measurement size	[km]	3 km		
MR-110	Precision (HLOS Component)	[m/s]	1	2.5	3 (3-5)*
MR-100	Systematic error (HLOS component)	[m/s]	0.7		
MR-90&95	Dynamic Range, HLOS	[m/s]	±100 (150)**		
MR-120	Error Correlation (per 100 km and between adjacent vertical bins)		< 0.1		
MR-130	Probability of Gross Error	[%]	5		
MR-140	Timeliness	[hour]	3		
MR-160	Length of Observation Dataset	[yr]	3		

***: Not required but feasible**

Examples of product error sources

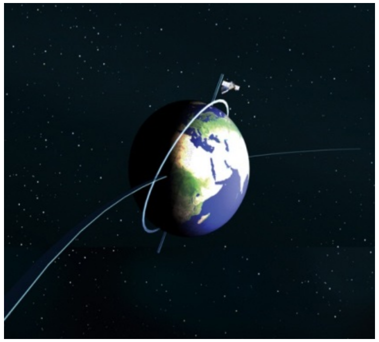
Examples of ADM-Aeolus error sources

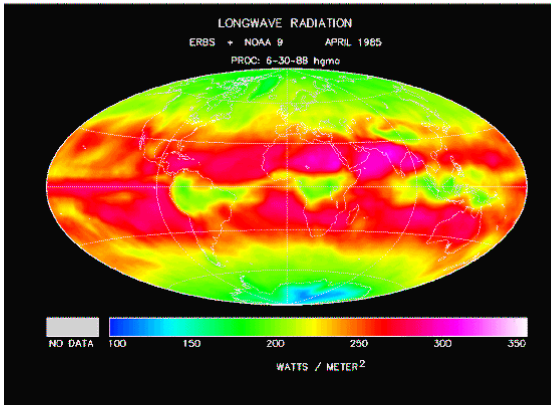


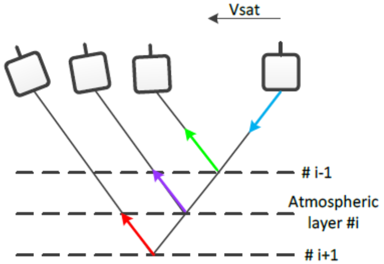


1. **Instrument errors**
   a. Instrument alignment and transmission
   b. Spectrometer imperfections
   c. Instrument degradation and laser stability, …
2. **Satellite / orbit related errors**
   a. Harmonic biases from thermal variability
   b. Range dependent biases
   c. Pointing stability, …
3. **L1 (and lower) processing errors**
   a. Calibration
   b. Signal processing and QC
   c. EQ, …
4. **L2 processing errors**
   a. *A-priori* T and p (ECMWF)
   b. Calibration, signal processing and QC …
   c. EQ, …

Examples of spatially varying error sources







1. **Harmonic** variations in instrument alignment over an orbit lead to **wind biases**:
   a. **Thermo-elastic** effects from changes in the solar aspect angle
   b. **Thermo-elastic** effects from changes in shortwave and thermal fluxes from Earth
   c. Satellite altitude varies through orbit (harmonic **range-dependent** biases)

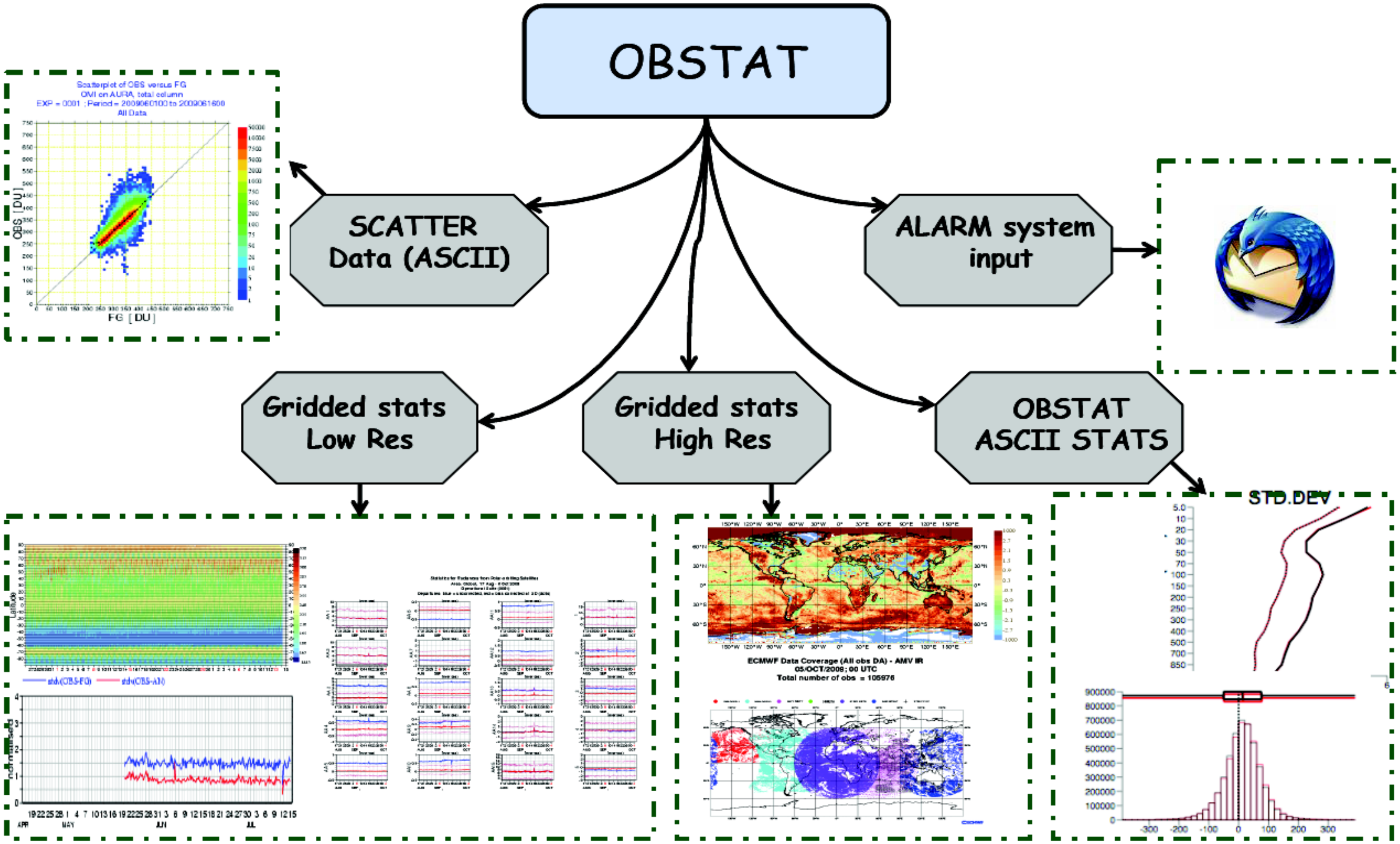
   Bias correction implemented using ground returns and error fitting through harmonic functions
2. Satellite movement along circular orbit cause variable backscatter angle on telescope as function of range (time)
   - **Range Dependent wind bias correction scheme implemented**
3. Regional T and p accuracy variations

ADM-Aeolus CAL/VAL needs

1. Characterization, calibration and validation needed on instrument, satellite and product levels to **verify Mission Requirements**
    a. Industry, ESA, algorithm core teams, CAL/VAL teams

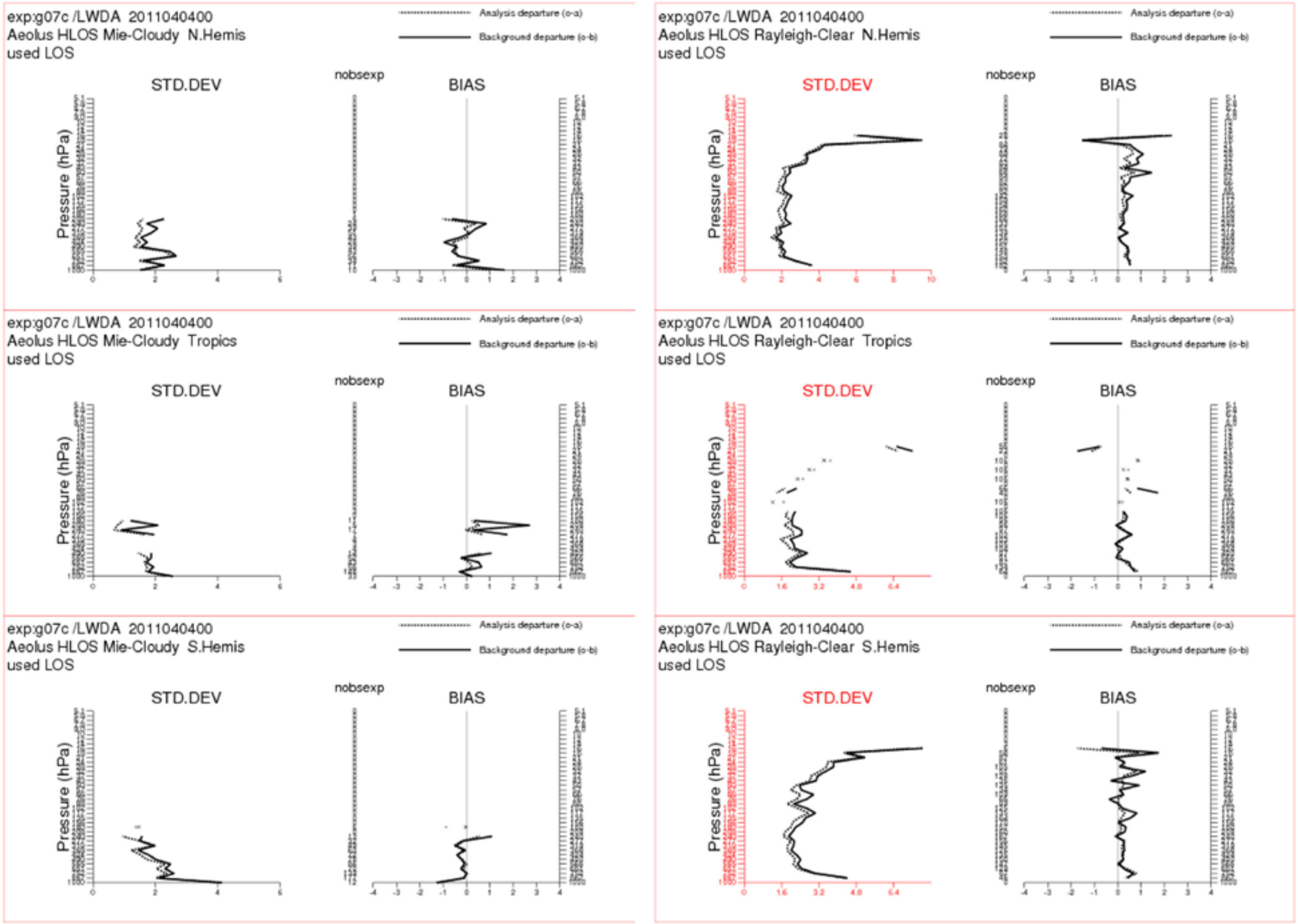
2. Verification and validation needs addressed by **CAL/VAL teams**:
    a. Verification and validation on **several product levels** (L0, L1b, calibration files, L2a, L2b, L2c) looking at selected scenes
    b. **NWP monitoring** (i.e. comp. L2 HLOS and NWP model wind)
    c. Validation by comparison to **collocated observations** with similar and different instrumentation
        – **Airborne** (short-term, well collocated), **ground-based** (long-term, less frequent collocations)
    d. **Short and long term** calibration and validation (minutes, hours, days, weeks, seasons, lifetime)
    e. Appropriate **geographical coverage**
    f. Comparison with **independent retrieval algorithms**

Example of planned NWP monitoring of Aeolus at ECMWF (1/2)



Some examples of OBSTAT output
Courtesy Mohamed Dahoui (ECMWF)

Example of planned NWP monitoring of Aeolus at ECMWF (2/2)



Example OBSTAT plots for assimilated Aeolus L2B winds. Mie-cloudy on the left, Rayleigh-clear on the right. Courtesy Mike Rennie (ECMWF)

ADM-Aeolus (delta-) AO CAL/VAL Call 2014 -

responses

17 ADM-Aeolus CAL/VAL Proposals – all selected after review

Activity Schedule

ID	PI Name and institute location	Topic	Method	Pre-Launch	Phase 1	Phase E2	Remarks
5156	DABAS Alain, FR	W, A	RO, AC, GC				
5166	Apituley Arnoud, NL	W, A, C	GC				
5177	Hardesty Robert Michael, US	W, A, C	RO, AC, GC, M, S				
5186	Baumgarten Gerd, DE	W, A	RO, GC, M				
5188	Apituley Arnoud, NL	W, A, C	RO, GC				
5190	Stoffelen Ad, NL	W, A	M, A				
5192	Schyberg Harald, NO	W, A, C	RO, M				linked to 5186
26989	Gausa Michael, NO	W, A, C	AC, GC				
27329	Reitebuch Oliver, DE	W, A	AC, GC				
27389	Stebel Kerstin, NO	W, A	RO, GC, S				
27409	Amiridis Vassilis, GR	A, C	RO, GC				
27411	Wu Songhua, CHI	W, A, C	GC				
27449	Zagar Nedjeljka, SLO	W	M				
27529	Forsythe Mary, UK	W, A	AC, M, S				
27589	Ishii Shoken, JA	W	GC				
27590	Joe Paul, CA	W, A, C	RO, GC, M, S				
28295	Kushner Paul, CA	W	M				

W = Wind
A = Aerosol
C = Clouds

RO = Routine Operations
AC = Airborne Campaigns
GC = Ground Based Campaigns
M = Model Studies
S = Other satellite obs

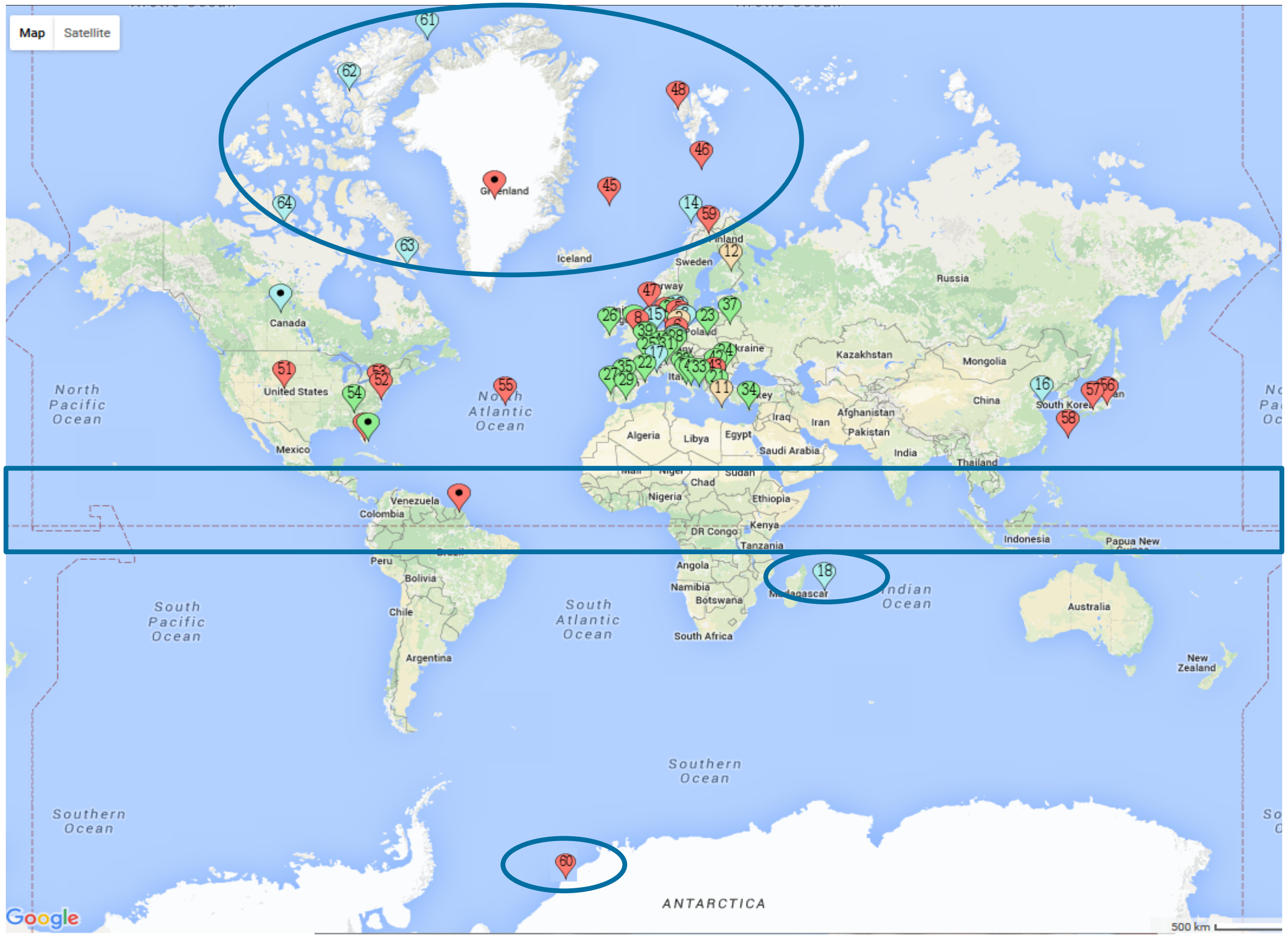
A = Alternative L2 products

funding secured
funding partly secured
no secured funding
unknown

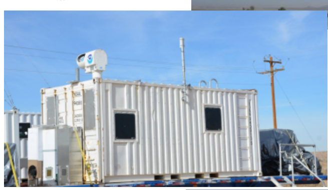
Coordinated national effort

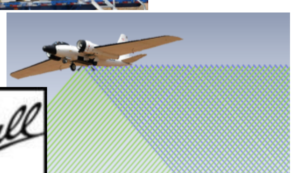
Multinational effort

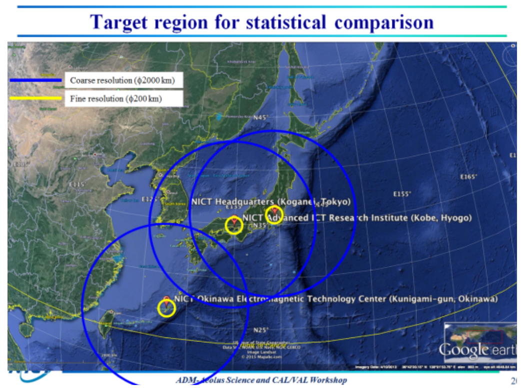
Geographical coverage CAL/VAL proposals

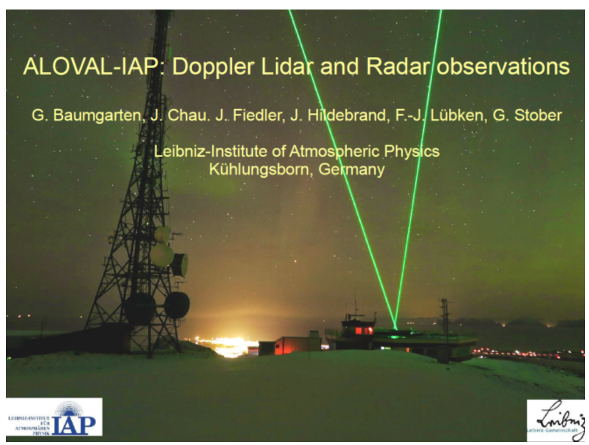


Examples proposed Aeolus CAL/VAL Activities

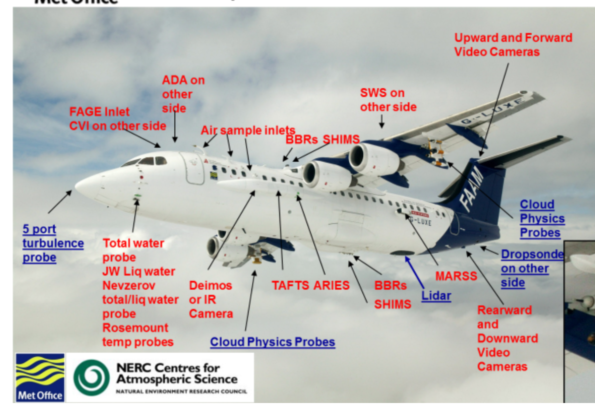


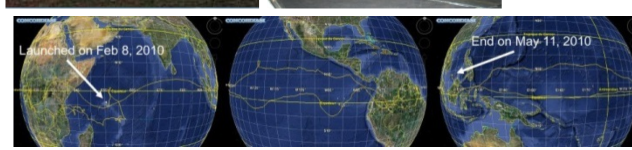




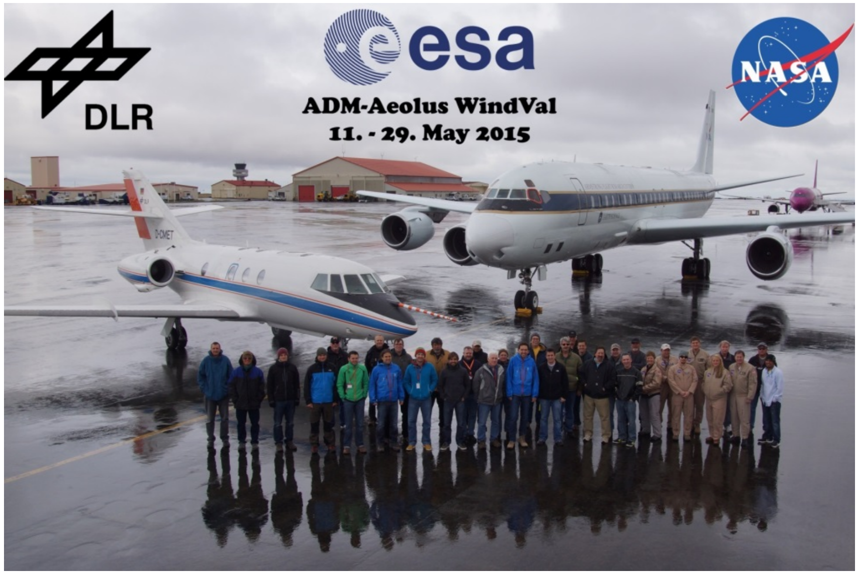


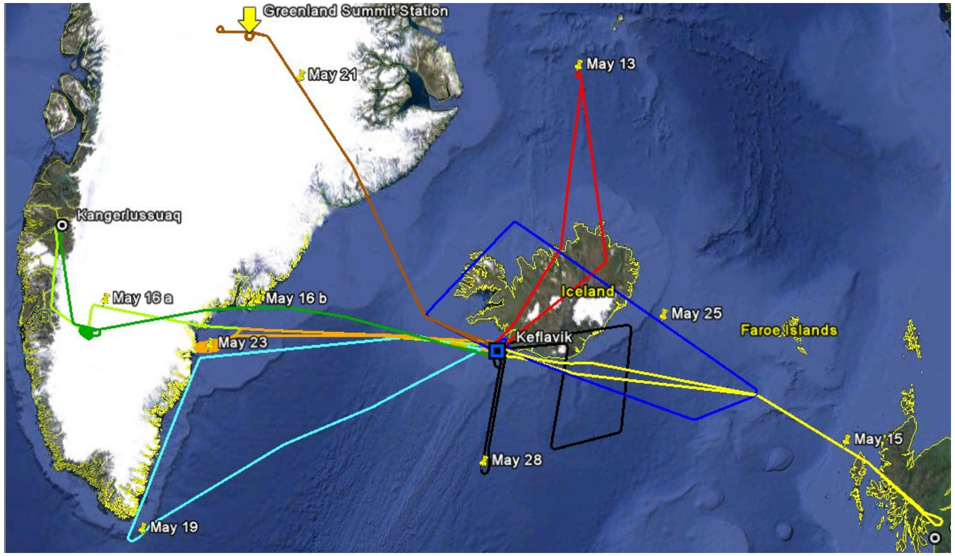
FAAM BAe–146–301
Atmospheric Research Aircraft

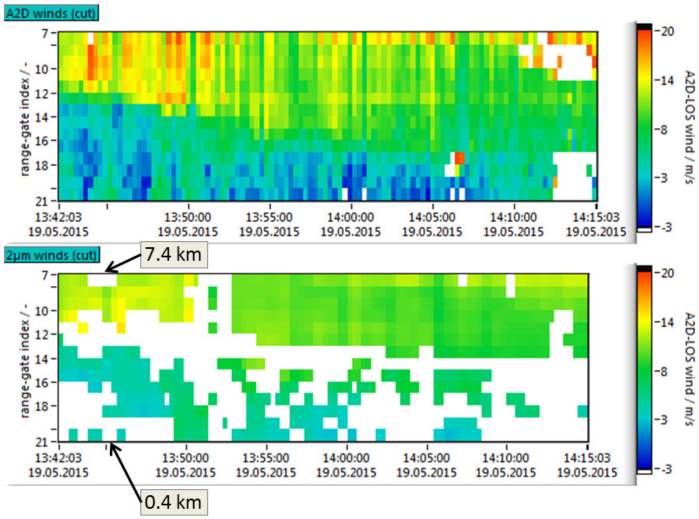




WindVal pre-launch campaign – May 2015

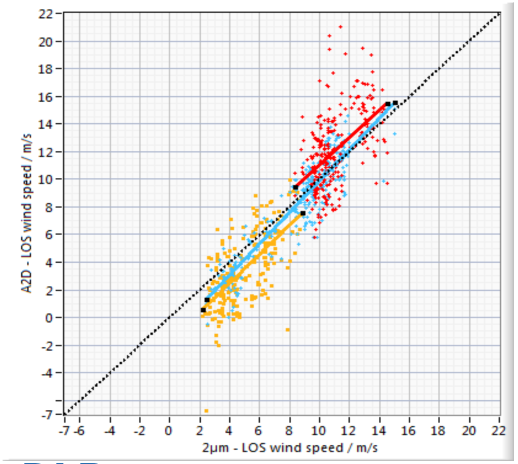






Statistical Results

corr. coeff. r = 0.89
N points = 765
slope = 1.28
std. dev. = 2.2 m/s
avg. bias = -0.17 m/s



Credits U. Marksteiner, DLR

ADM-Aeolus CAL/VAL Schedule

1. ADM-Aeolus Science and CAL/VAL Workshop held in February 2015
    - Instrument, processing, science and CAL/VAL Plans presented
2. Draft CAL/VAL Implementation Plan reviewed by PIs and being updated
3. CAL/VAL Coordination & Rehearsal Workshop planned for Q1 2017
4. ADM-Aeolus launch readiness 4th QRT 2017
5. Phase E1 CAL/VAL Workshop at L+3 months
6. Regular workshops throughout phase E2

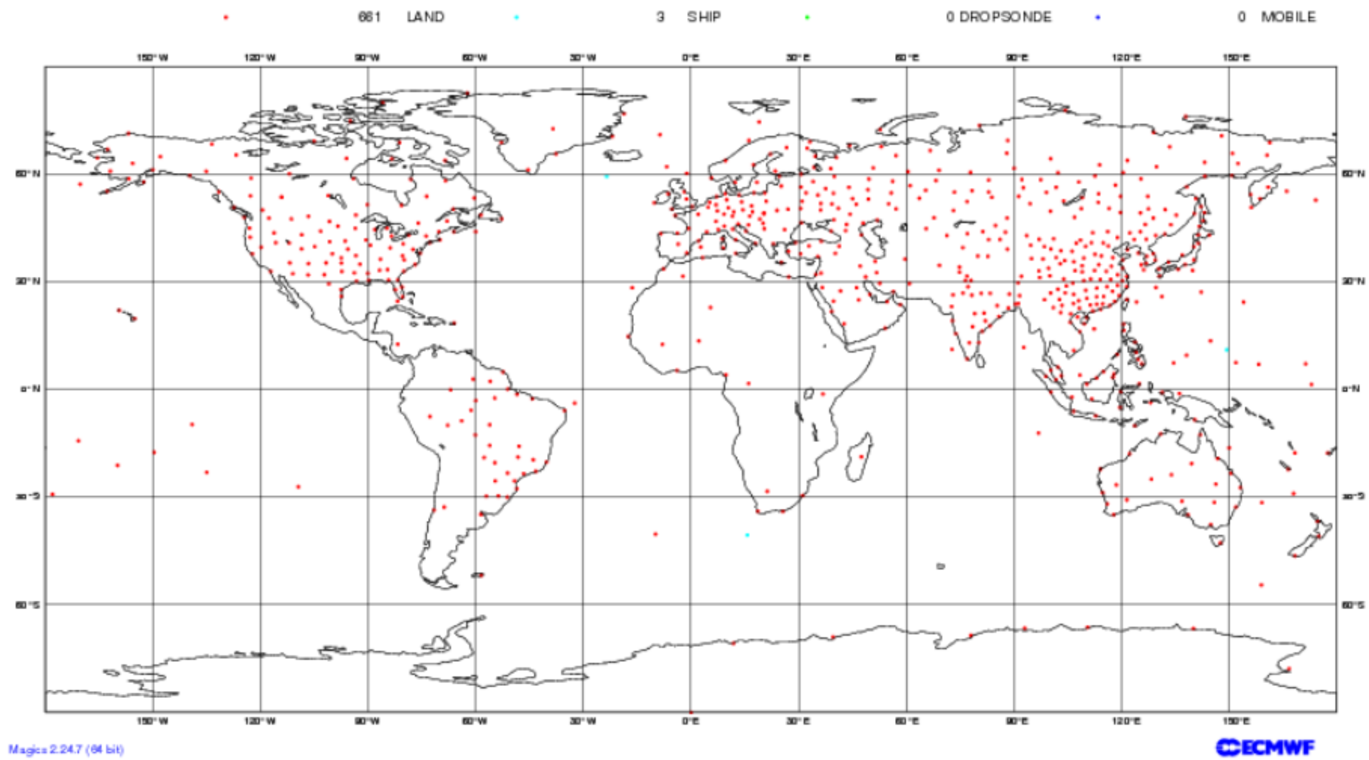
Concluding remarks

1. ADM-Aeolus selected in response to identified deficiency in the Global Observing System w.r.t. global coverage of direct wind profile observations
2. ADM-Aeolus will serve Numerical Weather Prediction and Air Quality Forecasting and support Climate Modelling (improved parameterization)
3. 17 (inter-) national CAL/VAL teams are getting ready to validate and exploit ADM-Aeolus data
4. CAL/VAL Implementation Plan drafted and reviewed
    - Coordination and further expansion of activities on-going
    - National funding confirmation sought by end 2016
    - Pre-launch campaigns -> Key for rehearsal and lessons learnt
5. ADM-Aeolus launch readiness: 4th quarter 2017
6. ADM-Aeolus L1 and L2 data availability to science community expected 3-5 months after launch

Backup

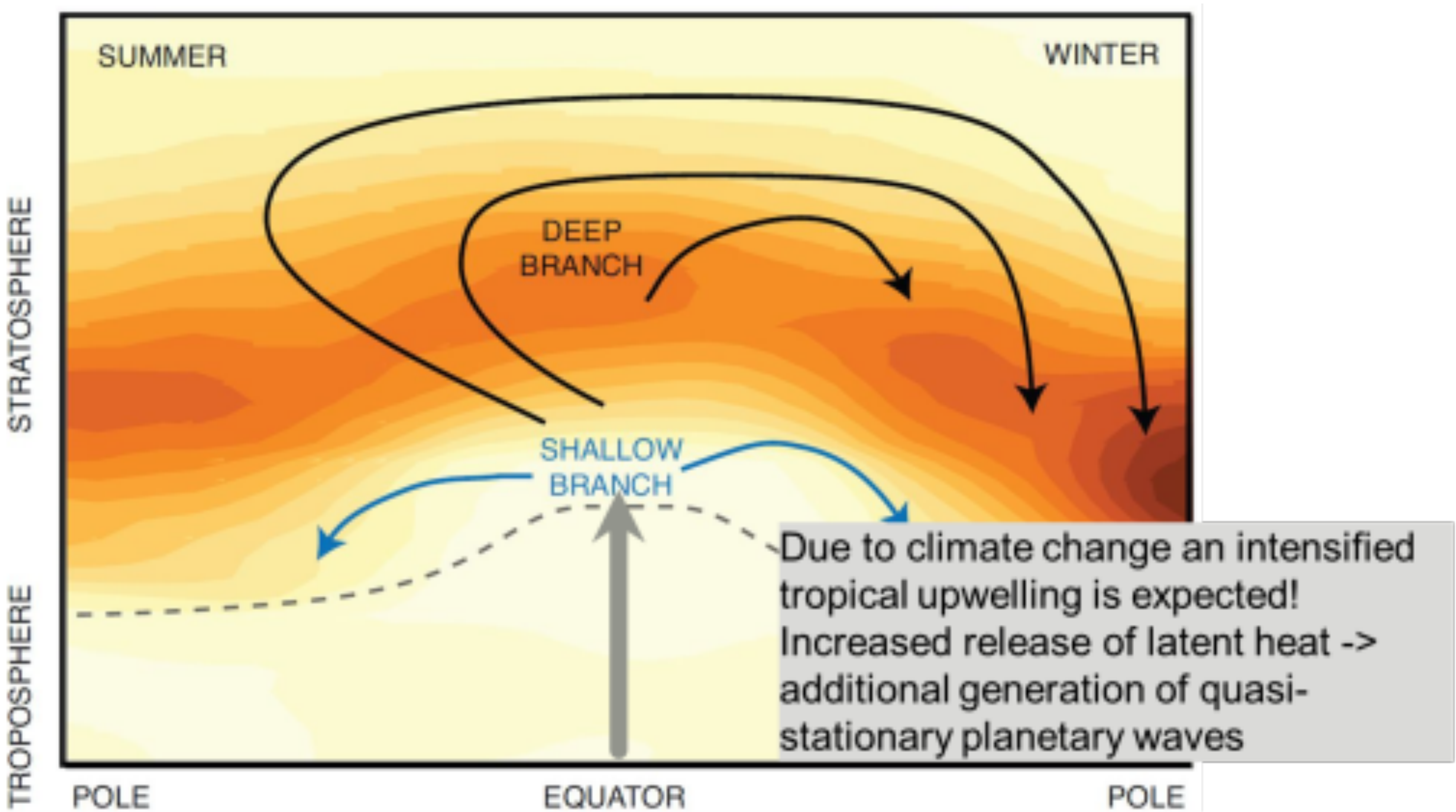
Radiosonde network

ECMWF Data Coverage (All obs DA) - Temp
10/Feb/2016; 00 UTC
Total number of obs = 664



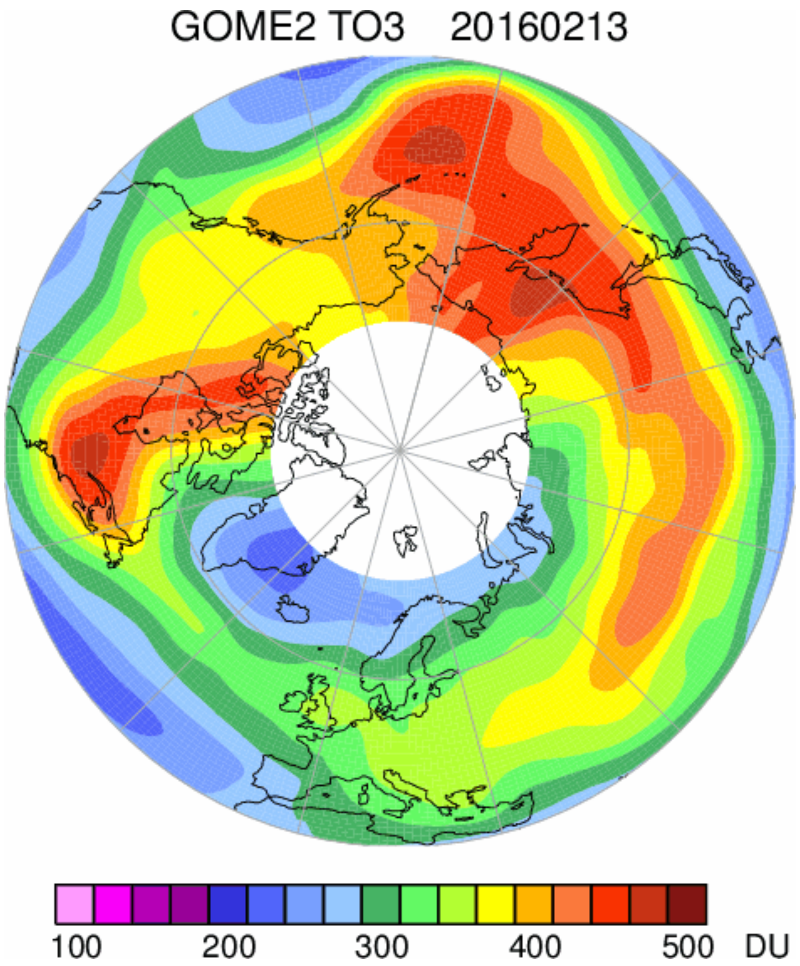
Importance for winds for climate applications

- Tropical ozone strongly impacted by UTLS dynamics (e.g. convection, gravity waves, planetary waves)



Courtesy: M. Dameris, DLR

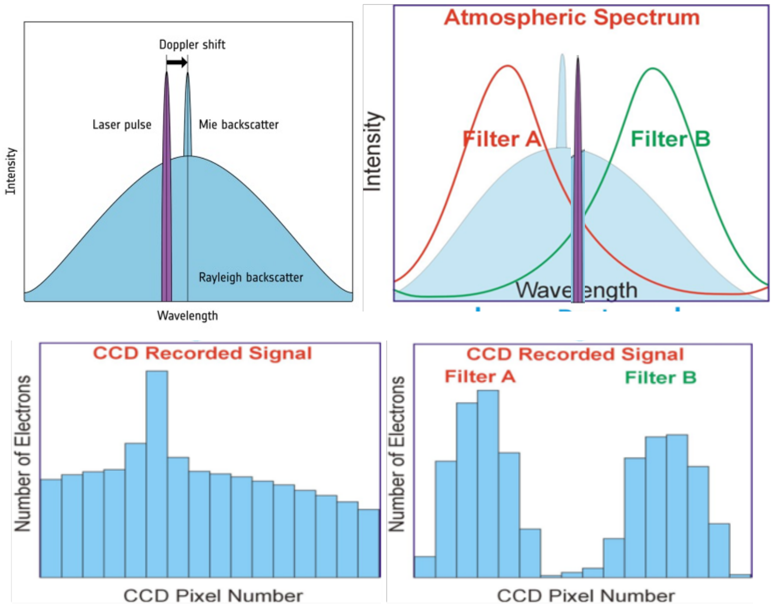
Ozone hole event NH 2016



Courtesy, M. Weber, J. Burrows and colleagues, IUP Bremen

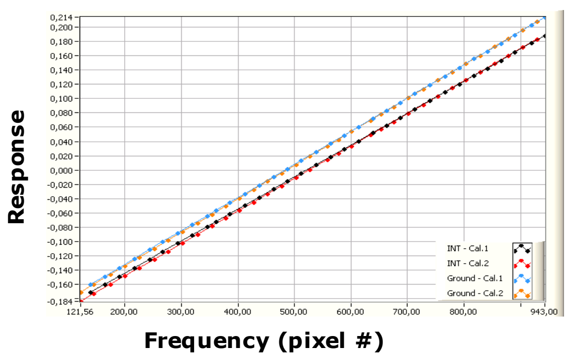
WFDOAS Algorithm Weber IUP University Bremen

Examples of time varying error sources



Mie receiver: fringe imaging Fizeau spectrometer

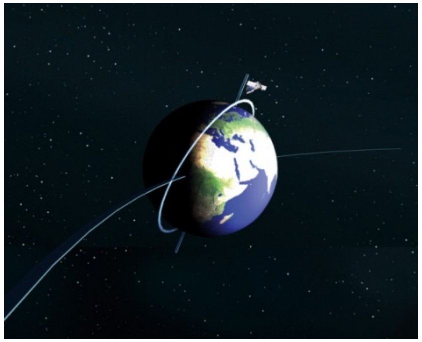
Rayleigh receiver: double edge Fabry-Pérot etalon



1. Regular detector **response calibrations** (weekly) to detect and correct short-term instrument (alignment) drifts

2. **Laser** emit frequency and pulse energy **monitoring**

3. **Seasonal instrument alignment** variability



Temporal coverage CAL/VAL Proposals

1. Most proposals foresee CAL/VAL **throughout phases E1 and E2**

2. Most have **limited resources**, hence **campaigns are limited in number and time-span**

3. Manpower and hardware maintenance for **long-term ground-based monitoring needs attention**

4. Iterations with teams to look for **possibilities to expand and coordinate activities**
    - Piggy-backing on campaigns for other missions (e.g. S5p, S1, S2, S3, …)
    - Year of Polar Prediction (YOPP, 2018 -2019)
    - Tropical campaigns
    - …

ADM-Aeolus CAL/VAL Implementation Plan

esa

Table of contents: