Aeolus
ESA's Wind Mission

T. Parrinello, A.G. Straume, J. von Bismarck, S. Bley, V. D. Tran, P. Fischer, T. Kanitz, D. Wernham, T. Fehr, E. Alvarez, I. Krisch, O. Reitebuch, M. Rennie and L. Isaksen

Paper EGU2020-4091. Session AS1.35 – Aeolus data and its application

A successful Track-Record

ESA-Developed Earth Observation Missions

esa

Satellites

15 in operation

25 under development

12 in preparation

2010

ERS-1

ERS-2

Envisat

Proba-1

SMOS

GOCE

CryoSat

2015

Meteosat 10 (MSG)

MetOp-B

Meteosat 11 (MSG)

Sentinel-1A

Sentinel-2A

Proba-V

Sentinel-1B

Sentinel-2B

Swarm

Sentinel-3A

Sentinel-3B

Sentinel-5P

Aeolus

Seosat

Sentinel-6A

Sentinel-2C

Sentinel-1C

EarthCARE

Sentinel-3C

Biomass

Sentinel-1D

Sentinel-2D

Sentinel-3D

FLEX

Sentinel-6B

2020

MetOp-C

MetOp-SG-B1

Sentinel-5A MetOp-SG-A1

MTG-I

Sentinel-4A MTG-S1

2025

MTG-I2

Sentinel-5B MetOp-SG-A2

MTG-I3

MetOp-SG-B2

2030

Sentinel-4B MTG-S2

Science

Copernicus

Meteorology

EUMETSAT

Aeolus: European Space Agency's Wind Mission

- **Launched**: 22 August 2018, Kourou
- **Launcher**: Vega
- **Main Payload**: ALADIN - DWL @355 nm
- **Orbit**: Altitude of 320 km, inclination 97°, sun-synchronous, 7-day repeat cycle, MLT 6pm
- **Mission Control**: ESA/ESOC (DE)
- **Ground Station**: Kiruna (SWE), Svalbard (NOR) and Troll (Antarctica)
- **Data Processing**: Tromsø, (NOR), ECMWF (Reading, UK), ESA/ESRIN (IT)
- **Mission Management:** ESA/ESRIN (ITA)
- **Mission Life**: 3 years

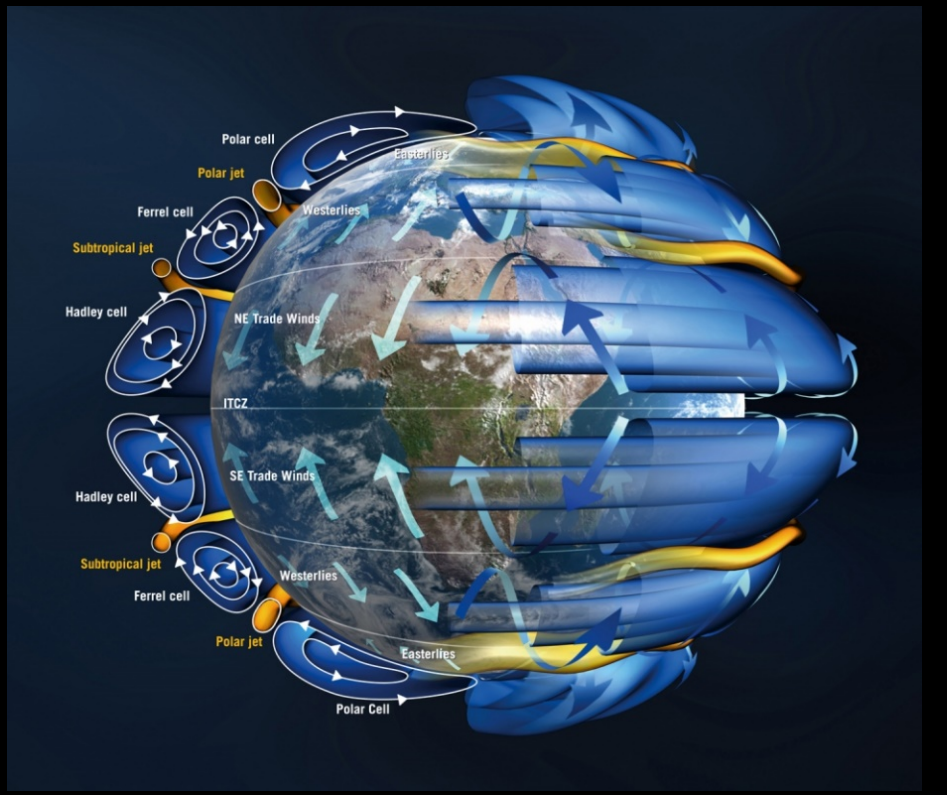
Aeolus: European Space Agency's Wind Mission

Mission Objectives

1. To improve the quality of weather forecasts by providing global measurements of horizontal wind profiles in the troposphere and lower stratosphere
2. To advance our understanding of atmospheric dynamics and climate processes

Long-term goal

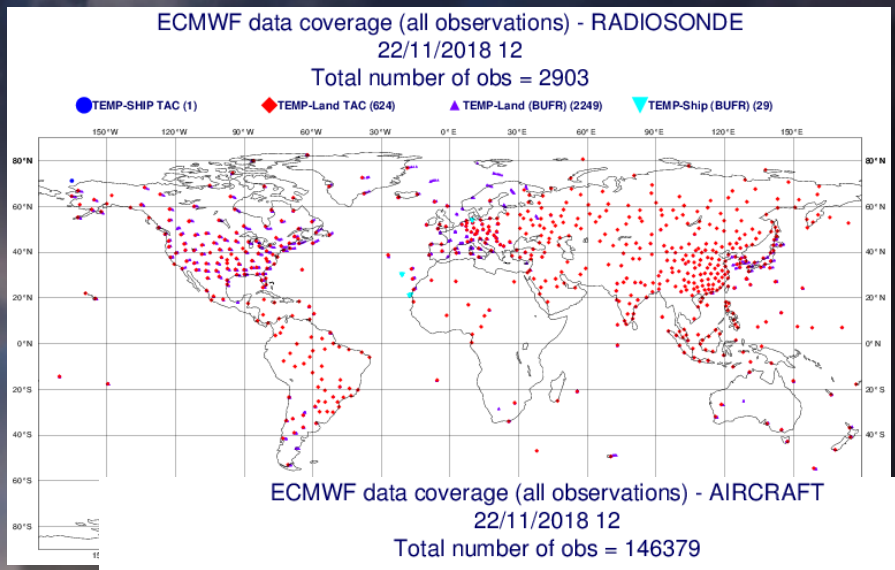
- Demonstrate space-based Doppler Wind LIDARs capability for operational use

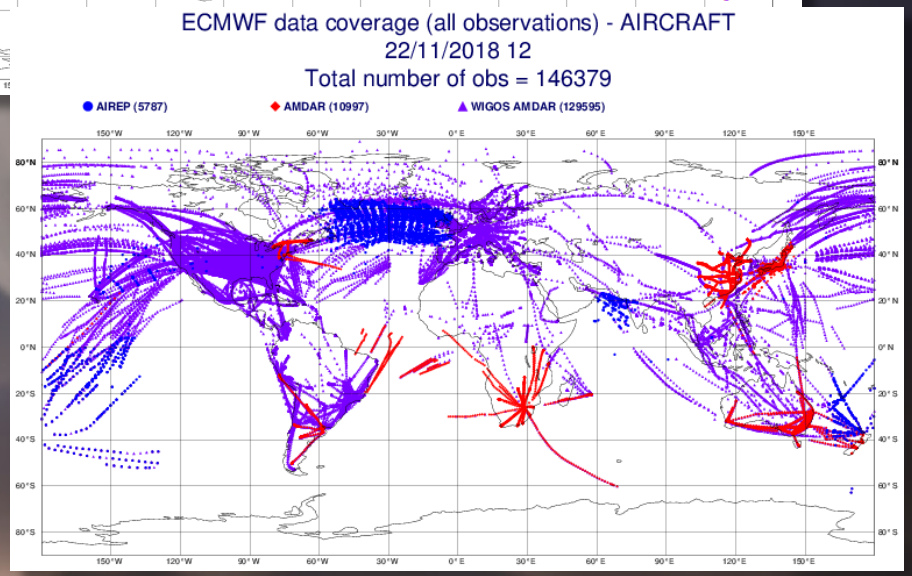


Aeolus: European Space Agency's Wind Mission

Motivation

"Wind observations are scarce in the present Global Observation Systems which limit our ability to predict weather especially in the tropics where atmospheric motions on all scales are dominated by the wind field" and furthermore "expect to obtain information on aerosol and cloud properties"
(extracted from Aeolus Science Report)

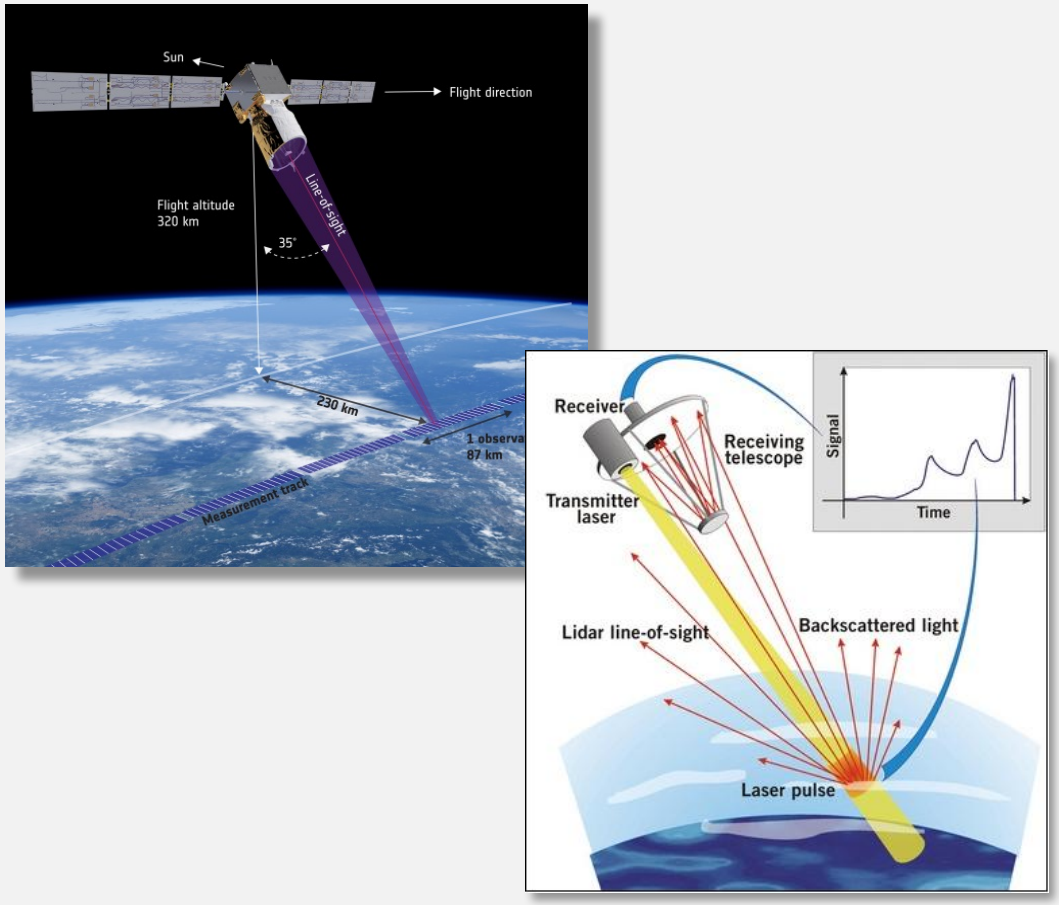




Example of Direct wind observations in the GOS: radiosondes, surface (conventional, scatterometers), airplanes, AMVs

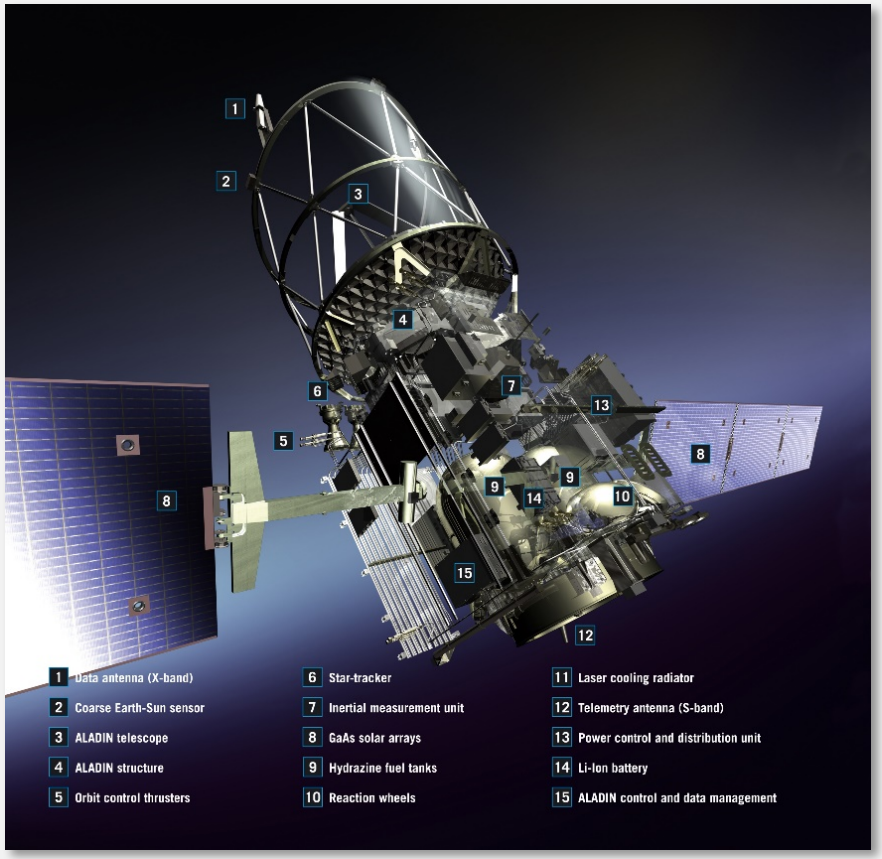
Measurement Principle

- The line-of-sight (LOS) points 35° from nadir to capture profiles of single component horizontal wind (projected to HLOS)
- Direct detection UV Doppler Wind Lidar (355 nm) on two receiver channels: **Rayleigh** to determine winds from molecular backscatter and **Mie** to determine winds from aerosol & cloud backscatter
- Vertical wind resolution: 24 vertical bins per channel, 250m-2km. Configuration of bins are programmable.
- Horizontal wind resolution: 87 km for Rayleigh, 10 km for Mie
- Several on-ground and in-orbit calibrations are periodical performed to characterise instrument performance and improve data output

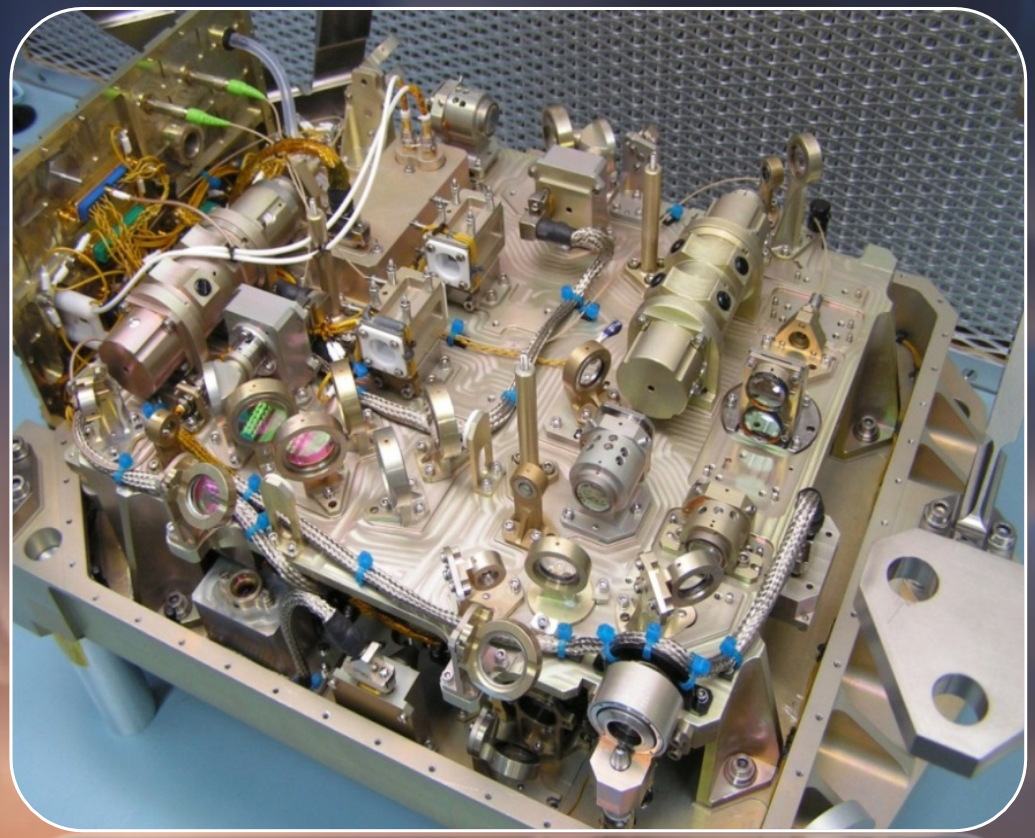


Satellite Platform

- 3 years designed lifetime
- Platform based on heritage from Rosetta, CryoSat and Mars Express.
- 1300 kg (450kg payload) – 1.4 kW average required
- Three-axis stabilised using thrusters, reaction wheels and magnetorquers as actuators and magnetometers, Coarse Earth Earth Sun Sensors, Inertial and Rate measurements units, Star Trackers and GPS as sensors
- Orbit is maintained by 5N thrusters
- Highly autonomous system - only one contact required every 7 days



ALADIN: A Technological Challenge



- One of the most sophisticated instruments ever to be put in orbit
- High-power ultraviolet (UV) laser transmitter containing ~80 optical functions and different wavelength conversion
- Extreme backscatter sensitivity via 1.5m telescope, 80 microns field stop and etalon spectrometers
- **Doppler Wind Lidar** principle
  - $\Delta f = 2*f_o*V_{LOS}/C$
  - V_{LOS}=1 m/s
    - Δf = 5.64 MHz
    - $\Delta f / f_o = 6.7\ 10^{-9}$
    - $\Delta\lambda = 2.4\ 10^{-15}$ m ($H^+ \approx 1.7\ 10^{-15}$ m)

Aeolus Payload Data Ground Segment

X-Band TM

Acquisition Service

Svalvard

Troll

Downlink Plan

VC0/1/2 Files

KSAT NW

Processing Facility (APF)
Tromsoe

L2/MET Processing Facility
Reading

L1/2 products
Aux Files
Monitoring Files

L0/1/2 products
Aux Files
Monitoring Files

Calibration & Monitoring Facility (ACMF)

Mission Management and Planning Facility (MMPF)

Surveillance Facility (APSF/Horus)

L0/1/2 products
Aux Files
Monitoring Files

EO NW

Internet

L1/2 products

Users

L0?/1/2 products
Monitoring Files

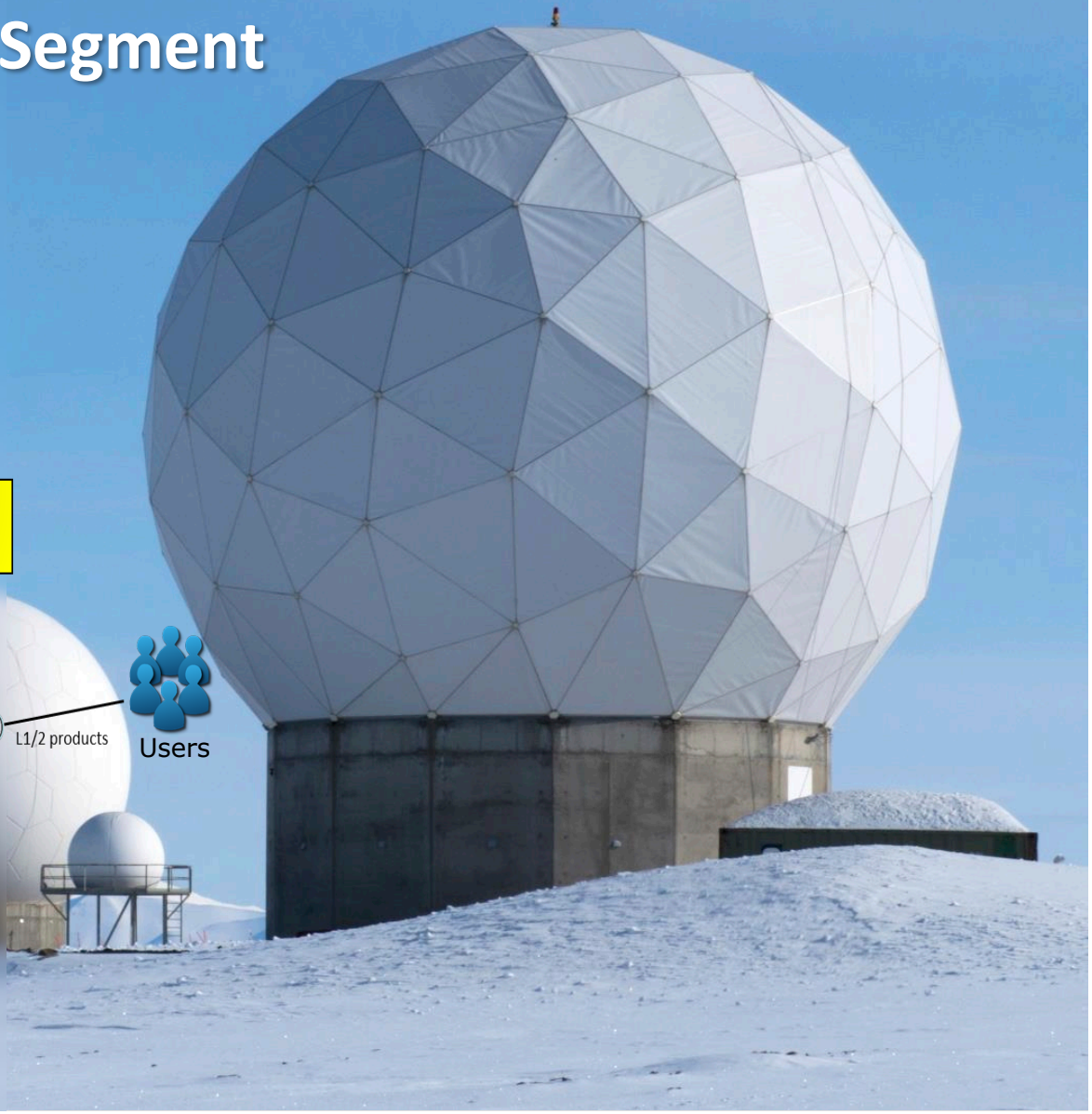
Back-up Archive

Reference Archive (DAS)
Luxembourg, Nice

Preservation Element

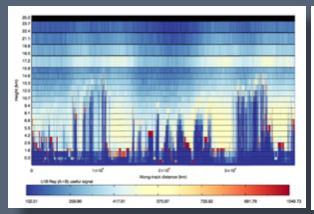
Dissemination Facility (ADDF)
Amsterdam

ESRIN - Frascati

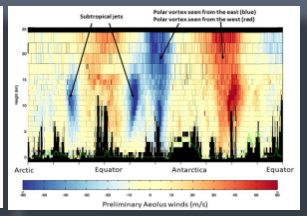


In-Orbit Timeline

Launch
22/8/2018



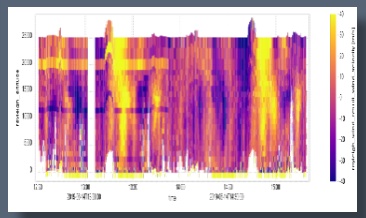
First Aeolus returns
(L+14d)



First Aeolus winds
(L+21d)

CALVAL workshop
(March 2019)

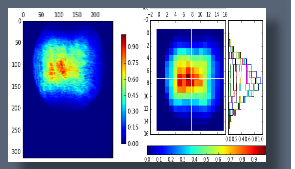
GPS reboot anomaly
(13/01/2019)
one month downtime



First dynamic bias
correction June 2019

Wind measurements
with FM-B since
28/06/2019

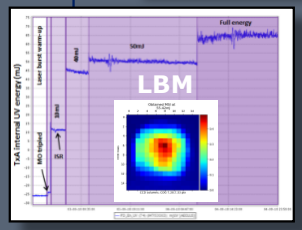
Working meeting NWP
centers, ESOC - 12
September 2019
confirmed impact on
weather forecast



Lesson Learnt

FM-A: 9 months in operations ≈ 1 Billion shots

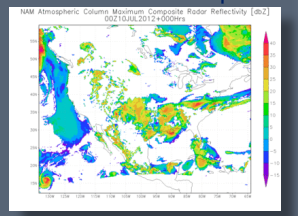
FM-B ≈ 1.2 B million shots so far



FM-A switch-on to
full energy (L+11d)

IOCR 30/01/2019

Switch to FM-B (17/06/2019)
Procedures benefits from LL &
FM-A experience

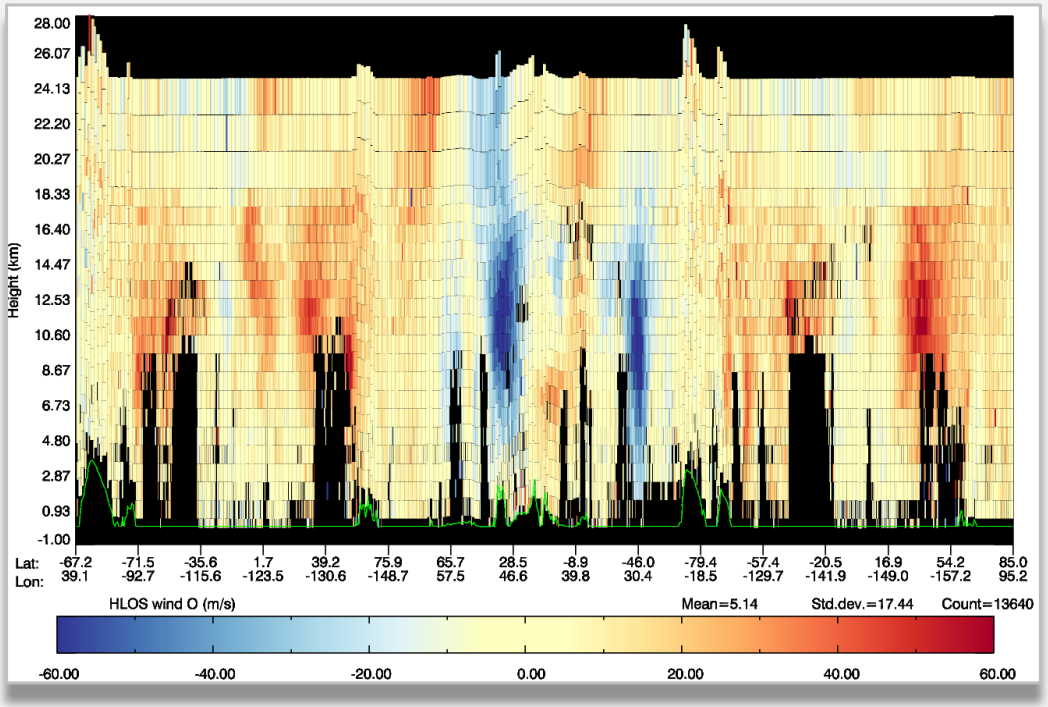


ECWMF Assimilates Aeolus Data
09/01/2020

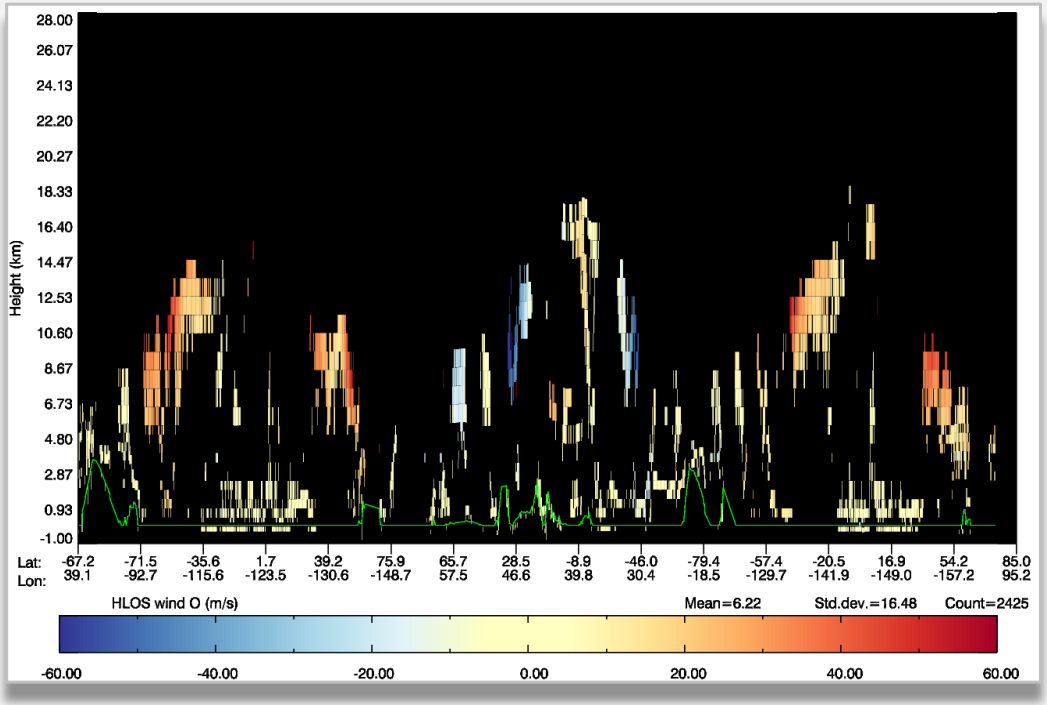
European Space Agency

Aeolus Products: HLOS Wind

Aeolus L2B Wind



Vertical winds profiles from molecular backscatter (L2B Rayleigh clear)

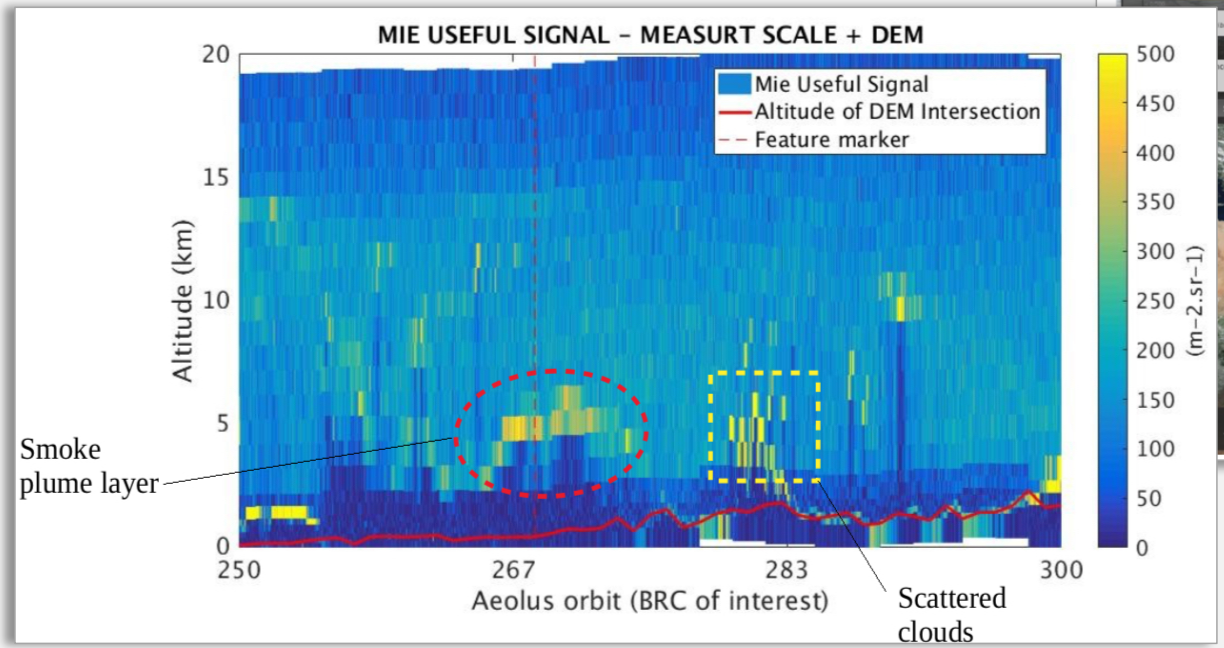


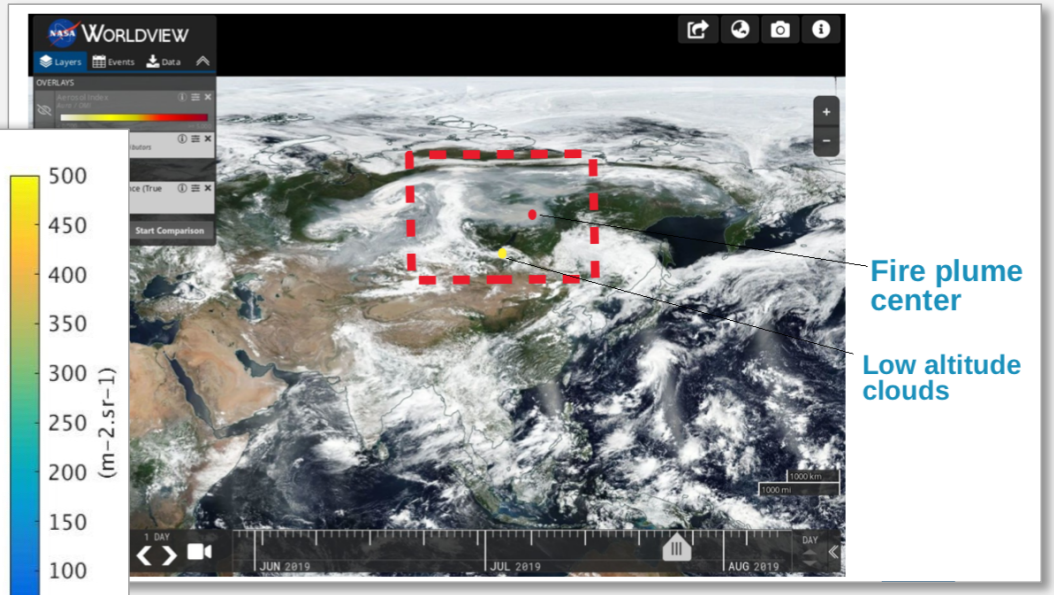
Vertical winds profiles from particle/cloud backscatter (L2B Mie cloudy)

Images courtesy Michael Rennie (ECMWF)

Aeolus Products: Aerosol and Clouds

Aeolus L2A Aerosol



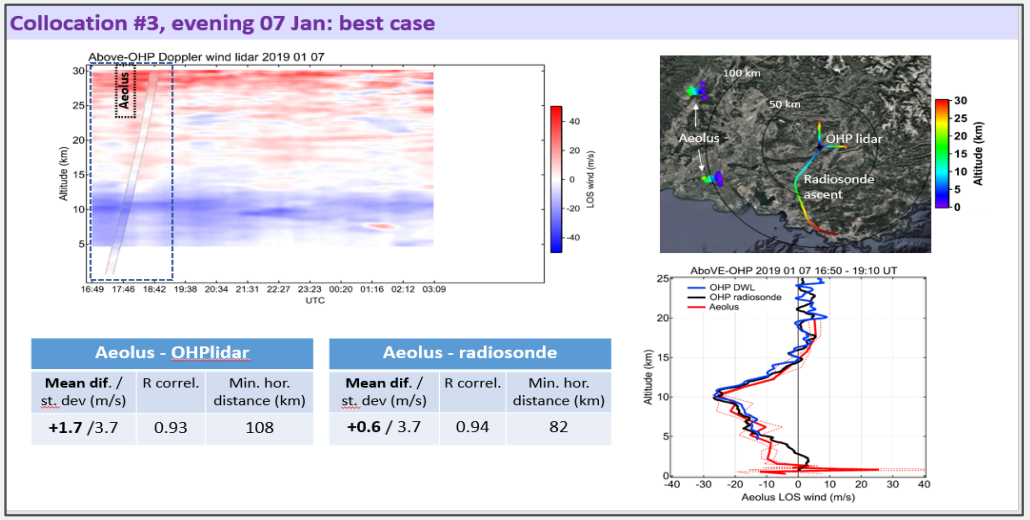


Courtesy:Dimitri Trapon – MeteoFrance

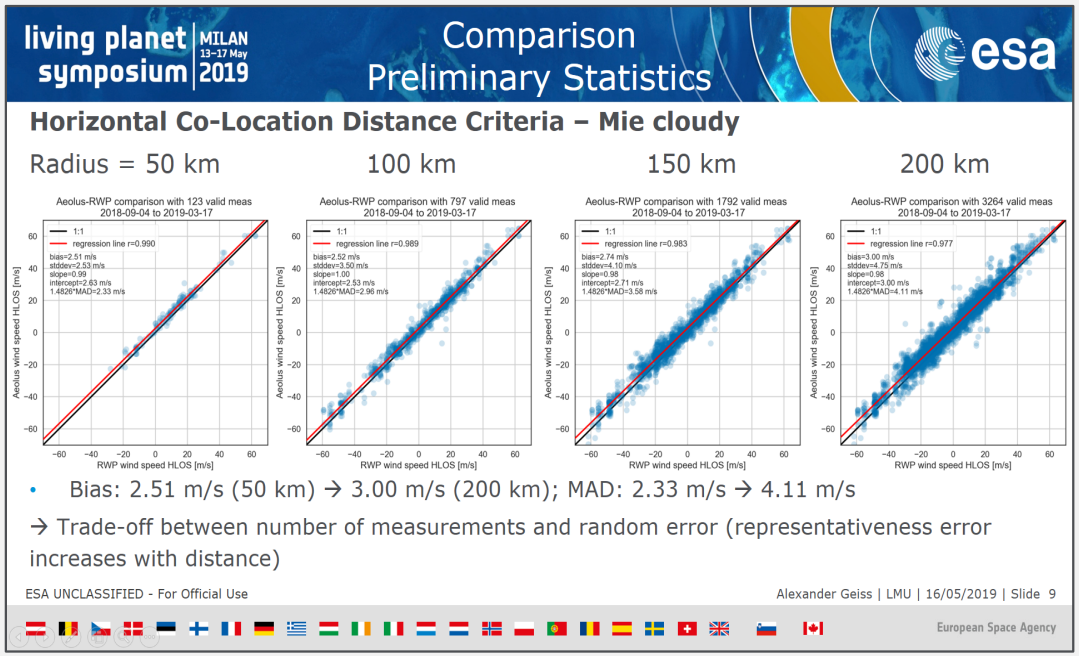
Mie signal: features are clearly visible for smoke plume and low altitude cumulus.

The Importance of Cal/Val

Aeolus L2B wind quality constantly checked by CAL/VAL teams



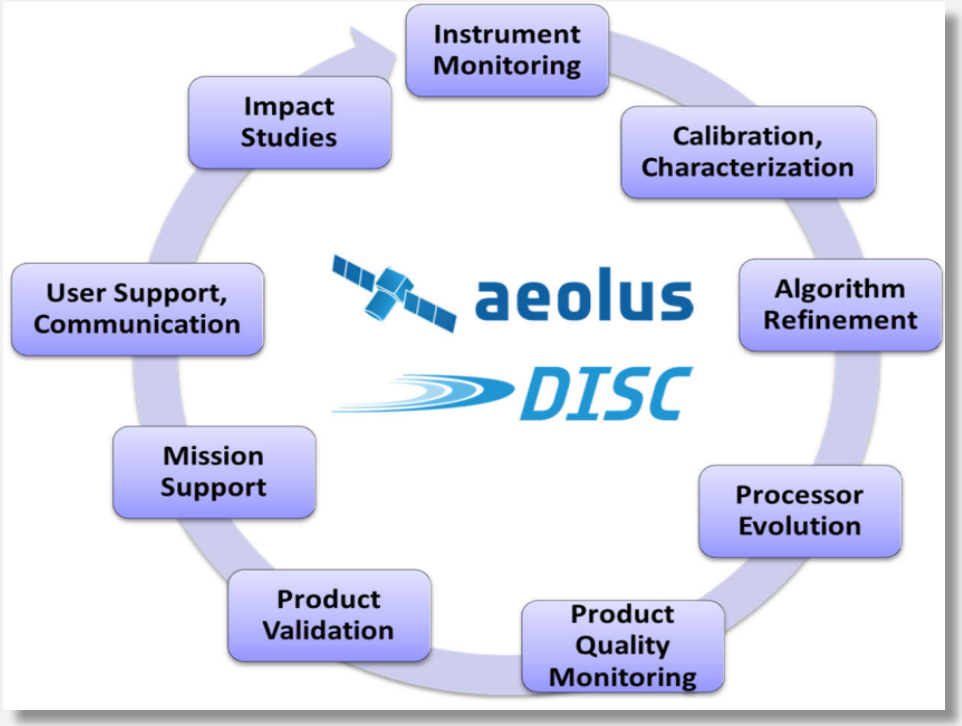
Comparison of Aeolus Rayleigh winds with radiosonde and Rayleigh lidar at Observatoire de Haute Provence, France. Courtesy S. Khavkin et al



Comparison of Aeolus Mie winds with radar wind profiler at Lindenberg, Germany. Courtesy A. Geiss et al.

Quality and Data evolution

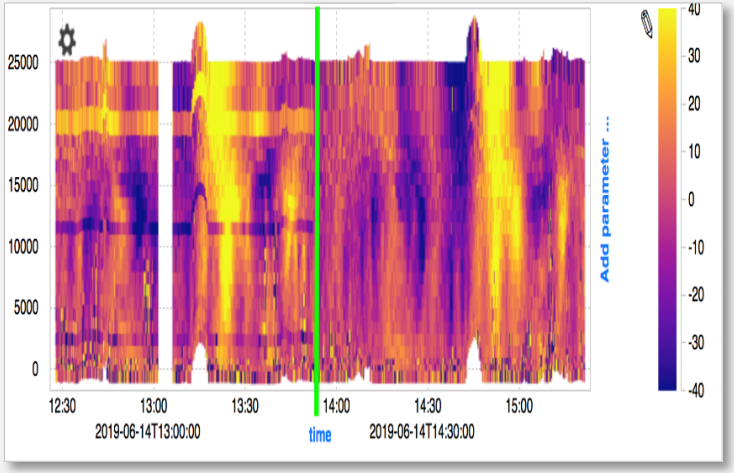
Aeolus Data Innovation & Science Cluster (DISC)

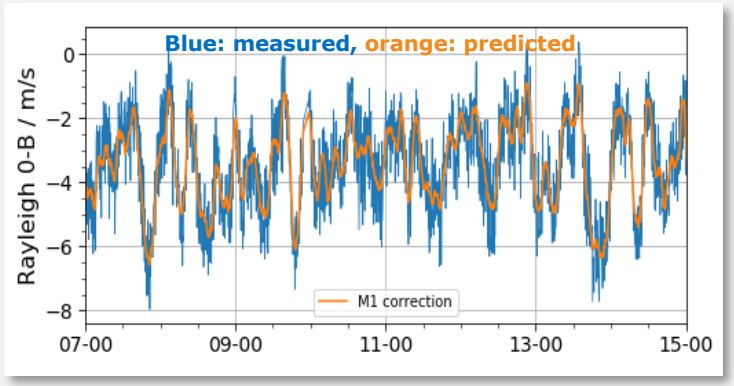


DLR
DoRIT
ECMWF
METEO FRANCE
Toujours un temps d'avance
ABB
Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu
serco
s[&]t
esa
Physics Solutions
OLA
IB Reissig

Quality and Data Evolution

- Constant NWP monitoring of Aeolus data quality (random and systematic errors) allows quick reaction to performance issues.
- Rapid 6-month processor update cycles of ground processors allowed swift adaption to lessons learnt and operational/scientific needs.
- Correction found for two major systematic errors:
  1. Major patch for Hot Pixel correction deployed June 2019
  2. M1 Telescope temperature bias correction discovered in Fall 2019 and will be applied to the baseline which will be public released. It is expected to reduce bias below MRD thresholds
- Random errors are affected by reduced return atmospheric signal and lower UV emitted energy

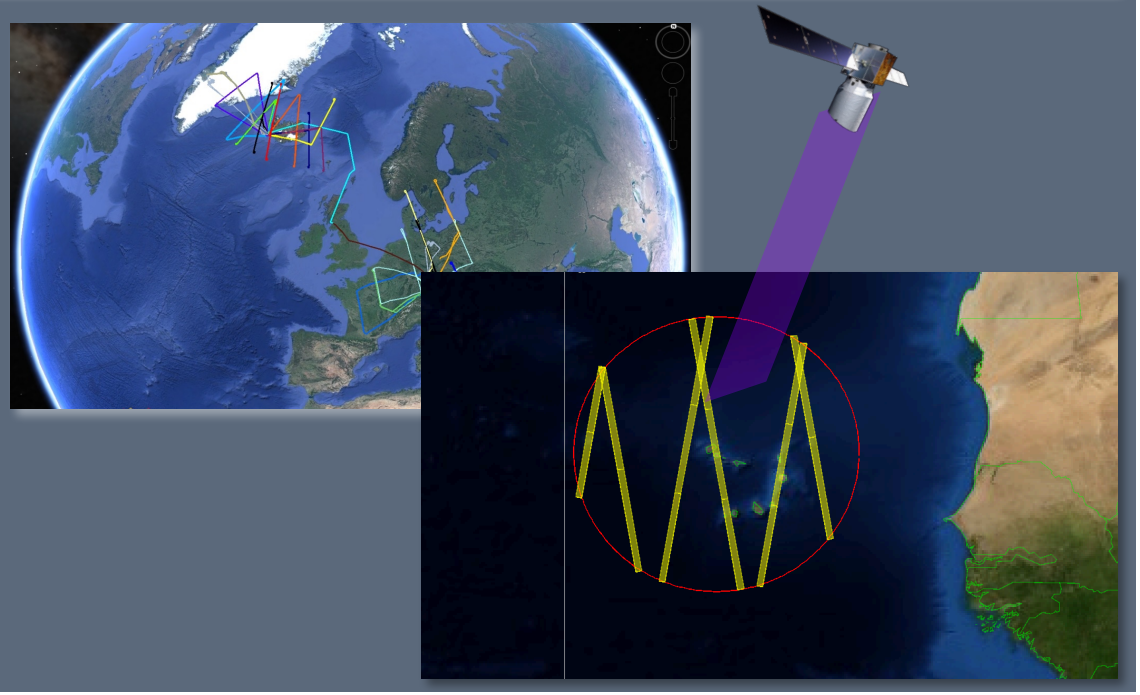


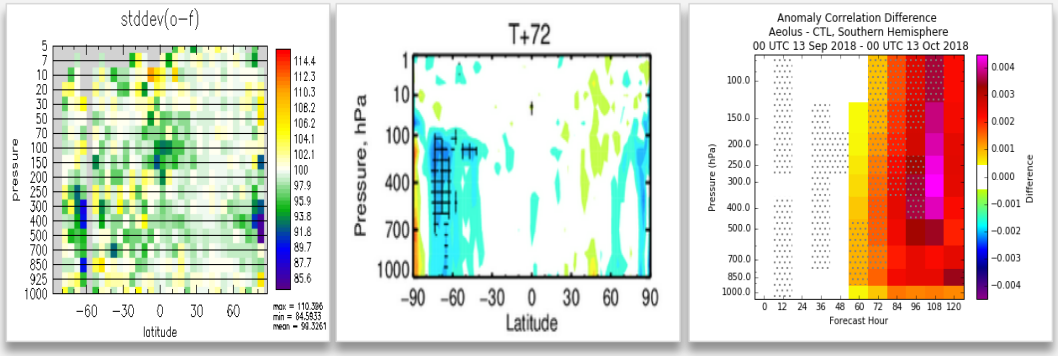


Images courtesy of DISC

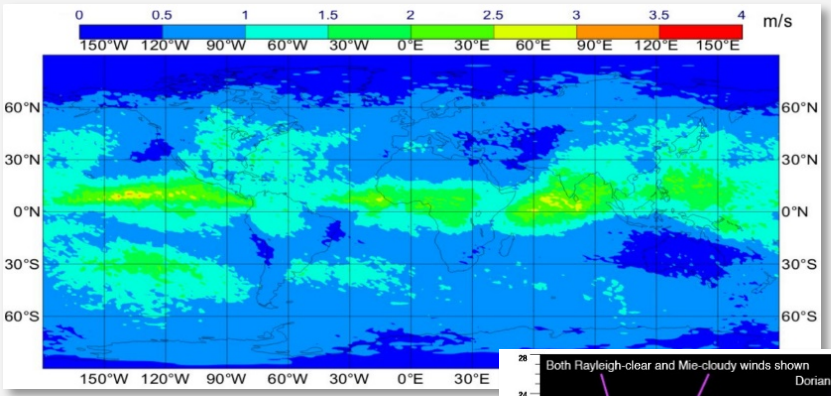
Aeolus Airborne Campaigns (2018-2021)

- **WindVal III** (Central Europe, Nov 2018)
  Successfully completed
- **AVATARE** (Central Europe, May 2019)
  Successfully completed
- **AVATARI** (Iceland Arctic, September 2019)
  Successfully completed
- **STRATEOLE2** (Seychelles, Nov. 2019 - Feb. 2020)
  Successfully completed
- **TROPICAL** (Cape Verde/Tropics, Summer 2020)
  Re-planned for Summer 2021 due to Covid-19

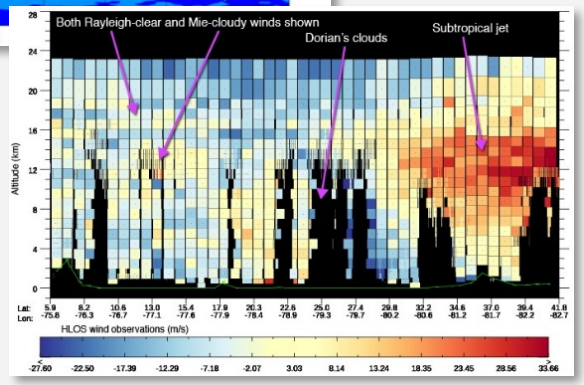




Presented @NWP Workshop - *Courtesy: DWD, ECMWF and* NASA GMAO



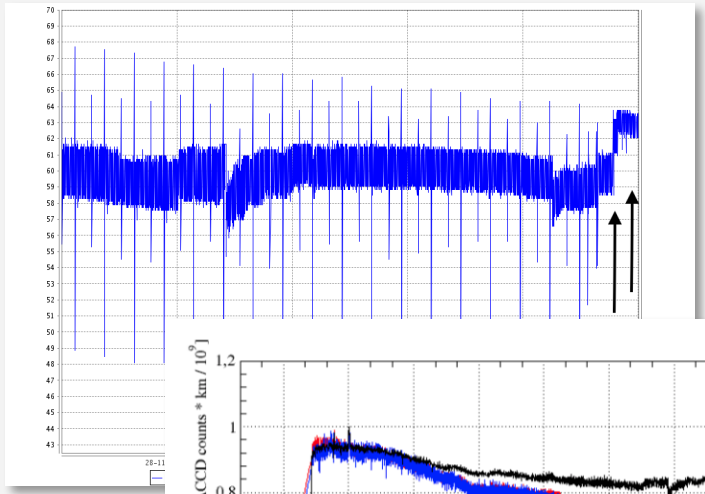
Changes in the u-wind at 250 hPa - Assimilation Aeolus data Aug – Oct 2019
Courtesy: DISC, ECMWF

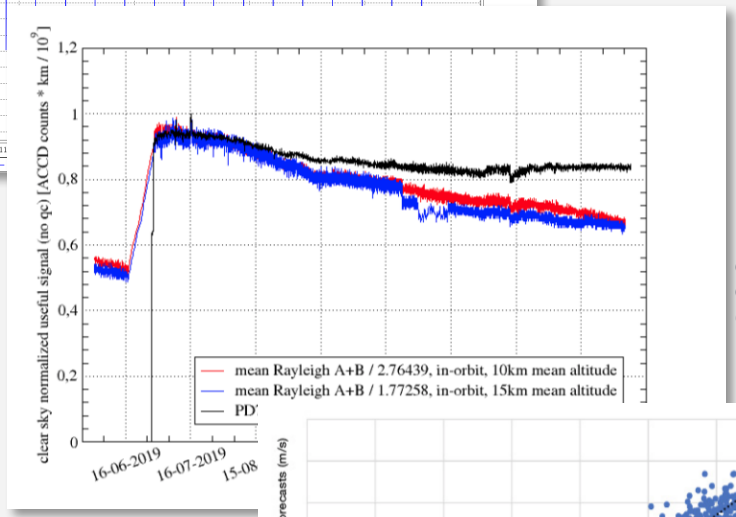


Hurricane Dorian at 1805 UTC on 1 Sep 2019.
Courtesy: M. Rennie, ECMWF

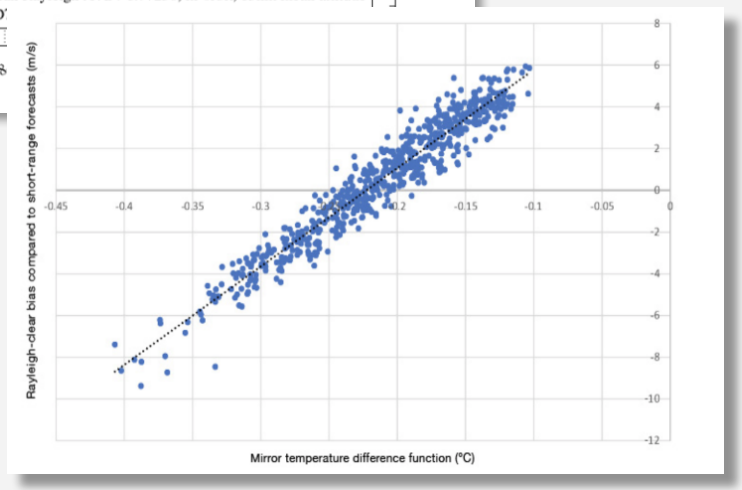
Main Achievements

- **NWP centers presented positive impact @ESOC workshop Sep 2019**
- **Global Cal/Val teams results in general agreement with monitoring results**
- **Early Dissemination of Aeolus data through EUMETCAST Nov 2019**
- **ECMWF starts assimilation of Aeolus data into their operational systems Jan 2020**
- **Establishment of Aeolus Science Advisory Group**
- **Published Aeolus+ Innovation study ITTs**
- **10 publications since launch**





Normalized atmospheric path Rayleigh signal evolution and laser energy.
Courtesy: O. Reitebuch

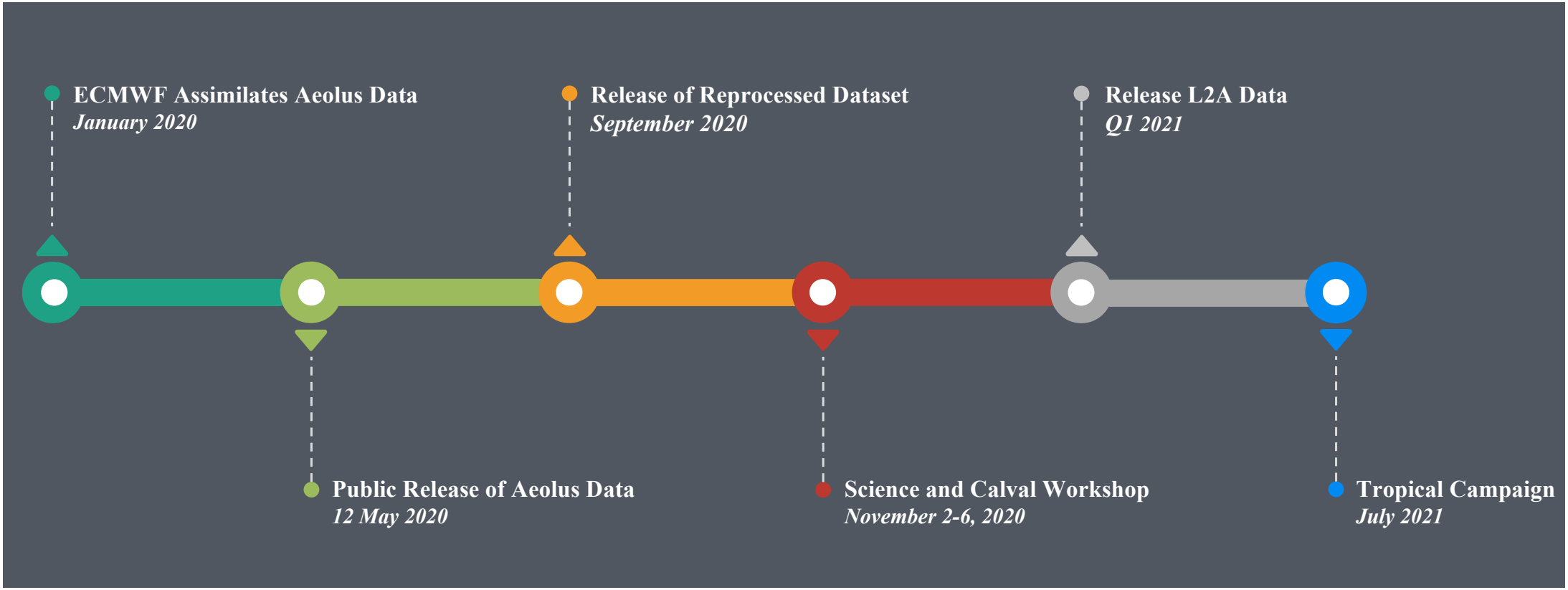


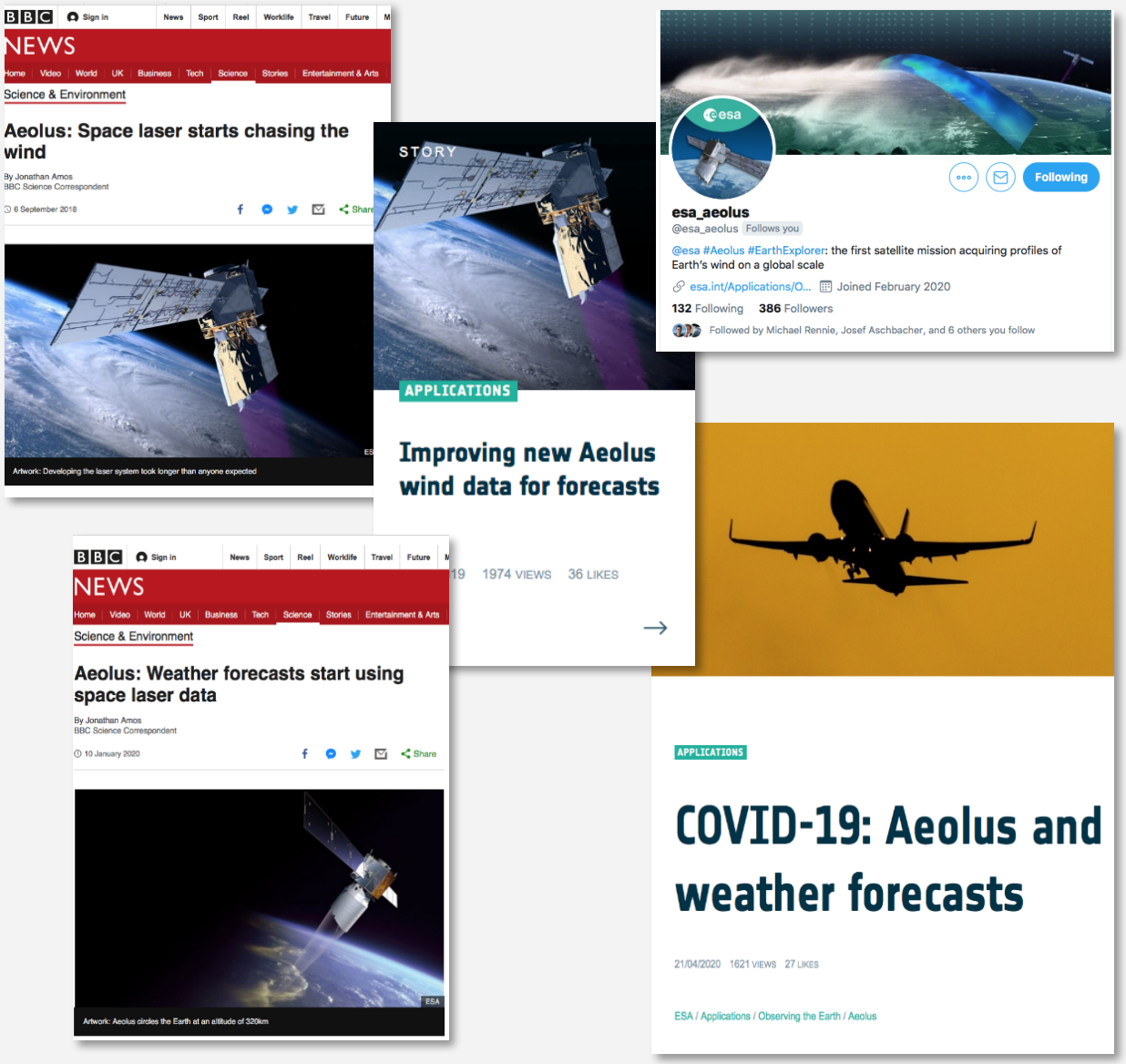
Courtesy: M. Rennie, ECMWF

Main Challenges

1. **Stabilize Output Energy and Laser Performance**
2. **Reduce Loss of signal of Atmospheric Receive Path**
3. **Biases vs. Telescope M1 (gradient) Temperatures**
4. **Minor Pending Platform issues**

Project Schedule – 18 months Outlook

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Aeolus: Space laser starts chasing the wind
By Jonathan Amos
BBC Science Correspondent
6 September 2016
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Improving new Aeolus wind data for forecasts
19
1974 VIEWS
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esa.int/Applications/O...
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ESA / Applications / Observing the Earth / Aeolus

In the News

Summary

- The overall performance of the mission is satisfactory. After the switch to FM-B, a number of issues remain challenging but are not currently undermining the expected instrument life-time.
- Aeolus has been providing global measurements of horizontal wind profiles for almost 18 months (≈2B shots). Main bias variations are understood and it is on the right track to meet its top level mission requirements
- Preliminary NWP impact results are quite positive, particularly in the tropics and southern hemisphere
- ECMWF has started to assimilate Aeolus data into their operational forecast system already, paving the way to public releases planned for **12 May 2020**
- Aeolus has successfully demonstrated positive value of space-based Doppler Wind Lidars technology for operational use and there is a lot of interest to start programmatic steps for planning an operational follow-on