ESA's wind mission Aeolus
Mission status and scientific highlights

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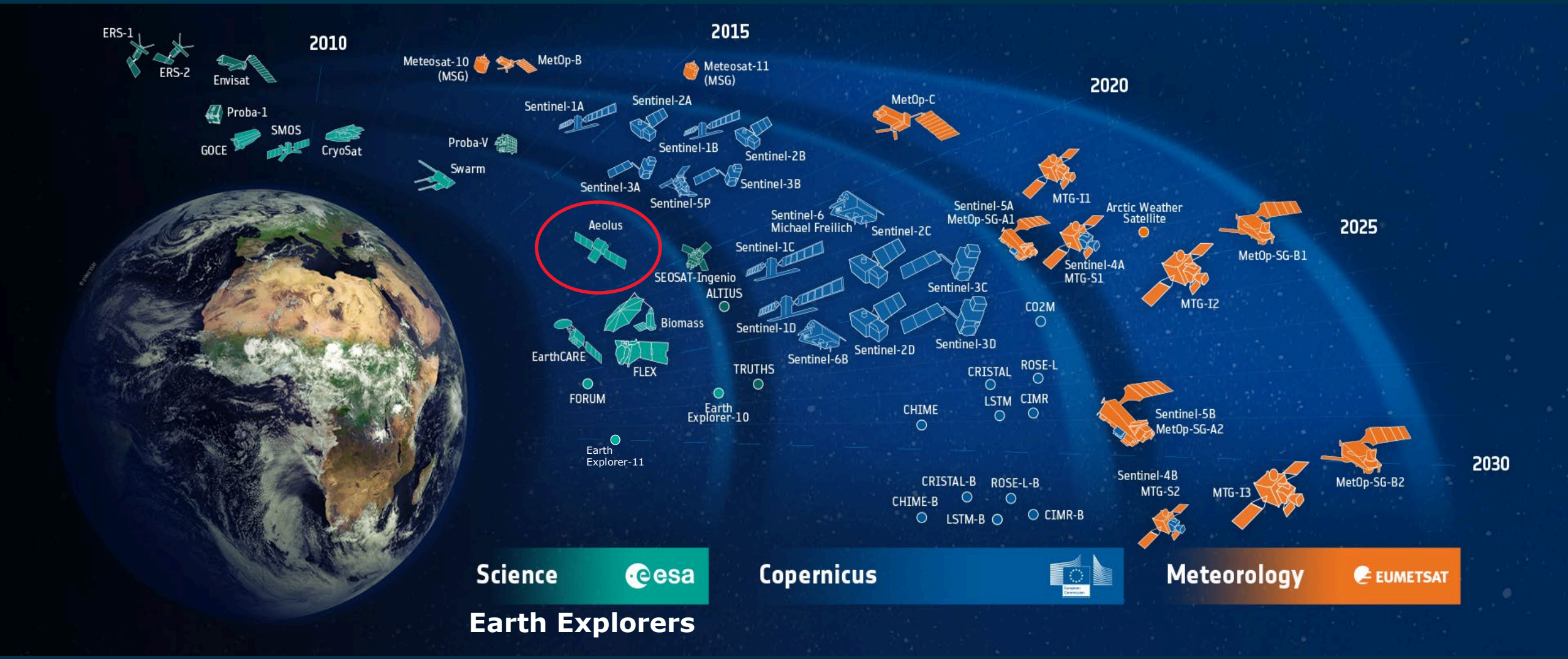
[1]European Space Agency, 2: European Space Agency, Aeolus DISC, Aeolus CAL/VAL and science community, ADS and subcontractors

ATMOS Conference, 22-26 November 2021

Aeolus, an ESA Earth Explorer



Aeolus Science and mission objectives

Scientific objectives

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

Explorer objective

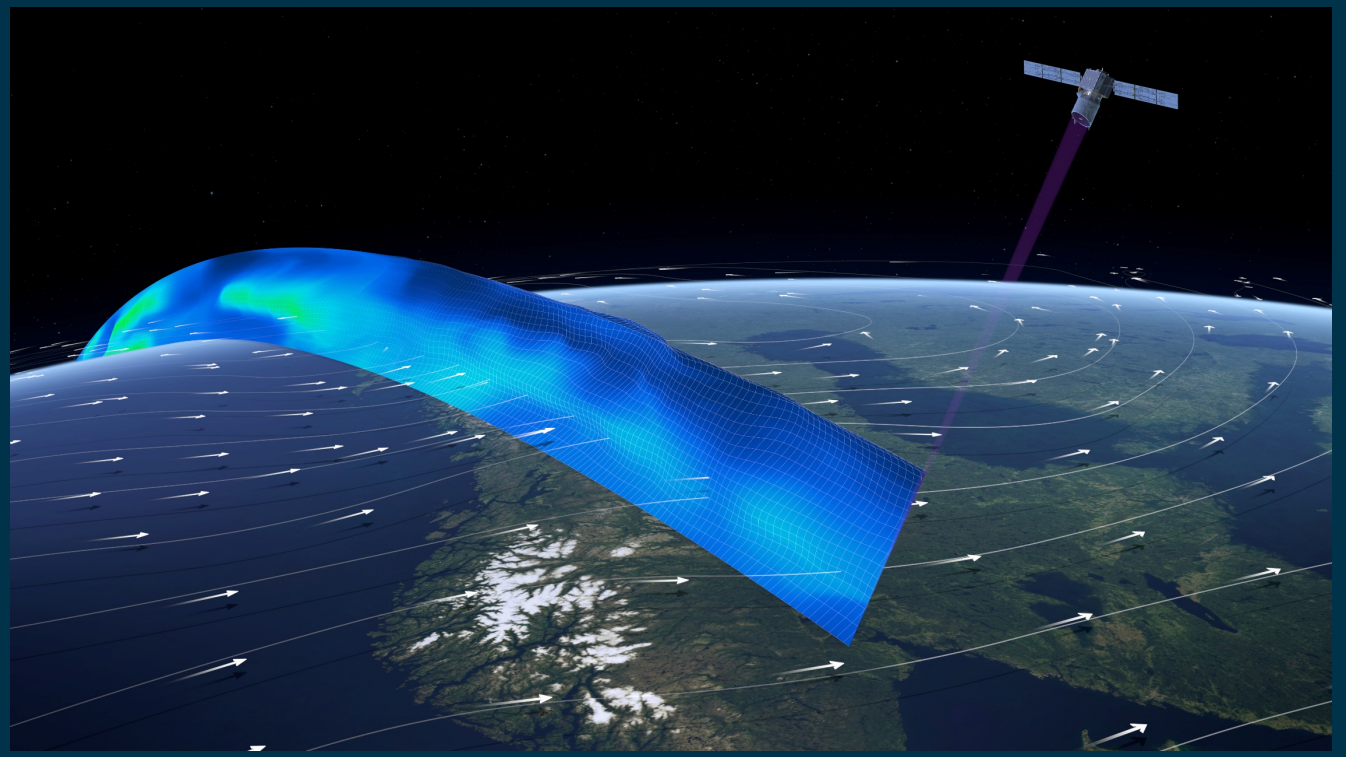
- Demonstrate space-based Doppler Wind LIDARs potential for operational use

Mission objectives

- Globally distributed profiles of horizontally projected line-of-sight winds in troposphere and low stratosphere
- Spin-off products are atmospheric extinction and backscatter coefficients and lidar ratio profiles

Payload

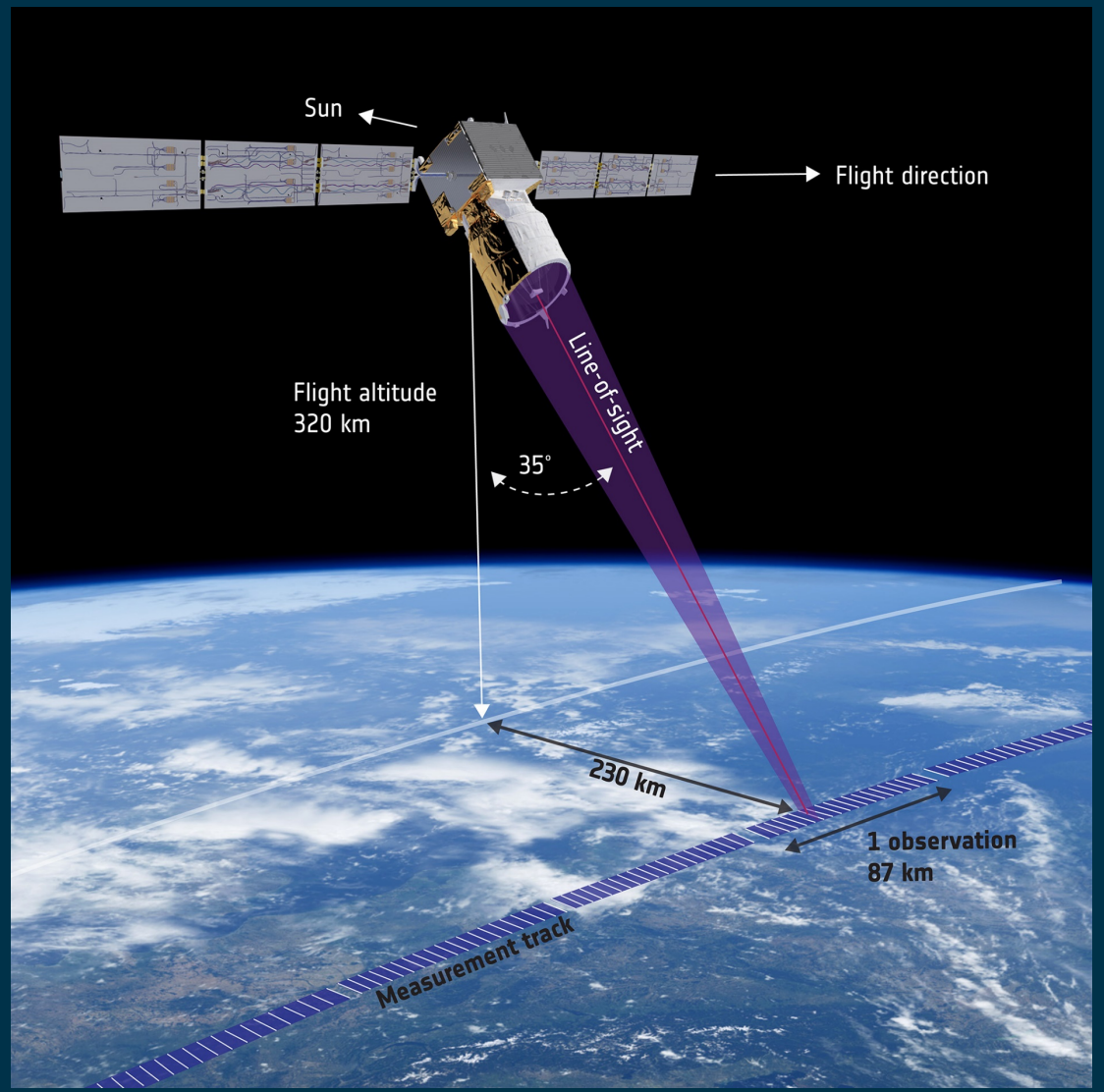
- ALADIN: Atmospheric LAser Doppler INstrument



Aeolus mission and measurements concept

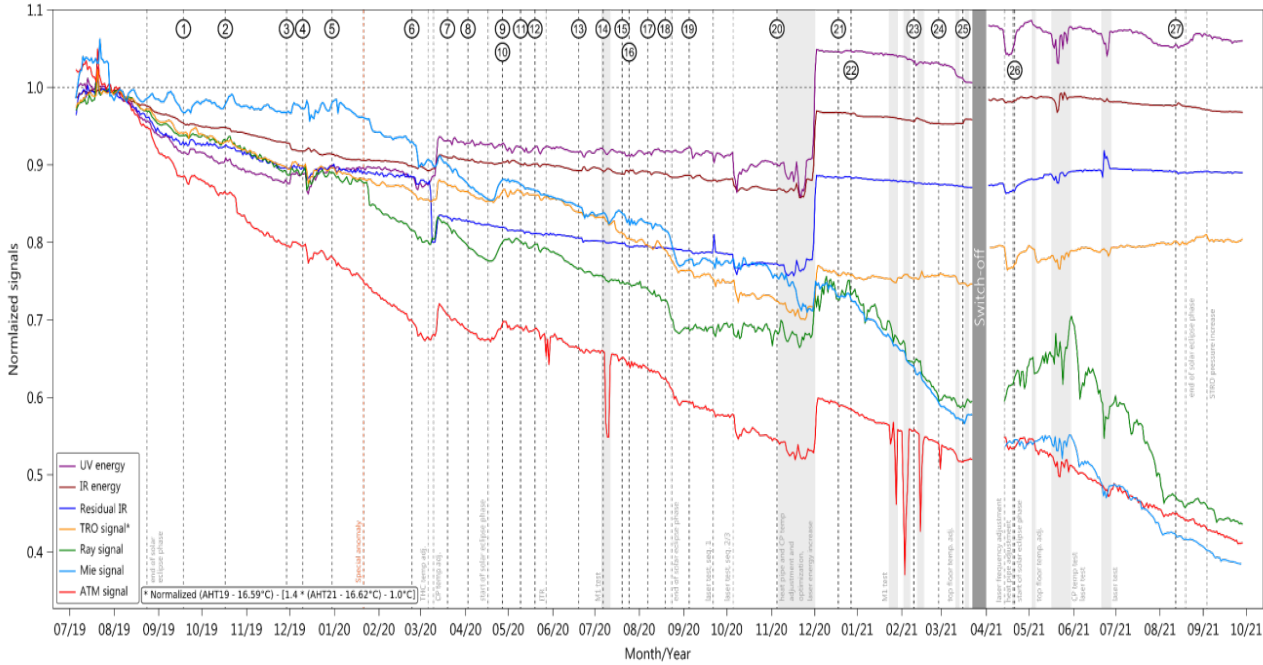
- Launched on 22 August 2018, 3 months commissioning + 3 years lifetime
- Satellite at 320 km sun-synchronous orbit, dawn/dusk

- Aladin instrument:
  - Direct detection UV Doppler Wind Lidar (355 nm), ~70 mJ laser output*, 50 Hz PRF, 2 receiver channels
    - Mie receiver to determine winds from aerosol & hydrometeor backscatter (Fizeau)
    - Rayleigh receiver to determine winds from molecular backscatter (Double edge Fabry-Perrot)
  - The line-of-sight (LOS) points 35º from nadir to capture profiles of single component horizontal wind
  - Ground return used for attitude correction and instrument calibration



Aeolus performance in-flight

- Satellite performs well and within specifications. Number of special operations tasks relatively high
- Data acquisition > 98% and NRT timeliness > 98%
- Redundant flight laser (FM-B)
  - UV energy stable, currently ~70 mJ
  - Recent software issue forced instrument switch to Survival Mode (22 October 2021)
  - Probably caused by single event upset, and instrument back to full power on 20 October, back to operations 2 November
- Remaining challenge
  - Continuous decrease internal and atmospheric return signal → slowly increasing wind random errors (see next slide)
  - Investigations (ESA, industry and external expert teams) on-going, roadmap to mitigate loss established and kept up-to-date
  - Full signal recovery not expected
  - More radical options include possible orbit lowering and/or switch-back to main laser transmitter



Evolution of the Aeolus Aladin instrument internal and external signal levels, June 2019 until October 2021, courtesy O. Lux (DLR and Aeolus DISC)

Mission extended to end of 2022

QUALITY AND DATA EVOLUTION

- Constant monitoring and improving of Aeolus data quality (random and systematic errors) allowing for quick reaction to performance issues.
- Random errors slowly decreasing: algorithm improvements lower random errors, but are counteracted by decreasing atmospheric return signal and lower UV emit energy.
- Biases improved through algorithm and calibration improvements, almost compliant with MRD

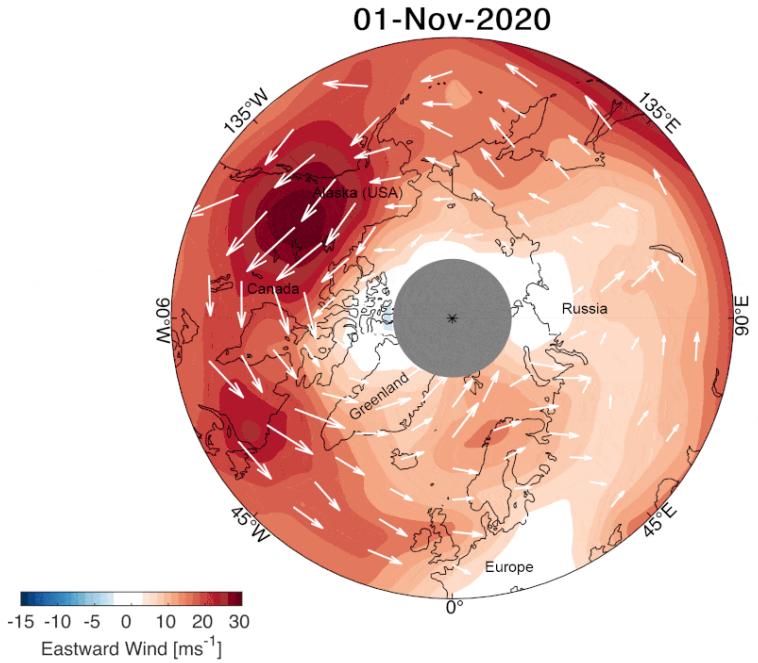
	PBL [0-2 km]		Troposphere [2-16 km]		Stratosphere [16-30km]	
HLOS Wind	**Requirement**	**Measured**	**Requirement**	**Measured**	**Requirement**	**Measured**
Bias Systematic	**0.7 m/s**	M: 0.5 m/s	**0.7 m/s**	M: 0.5 m/s R: 1.0 m/s	**0.7 m/s**	R: 1.0 m/s
Random Error	**1.0 m/s**	M: 2.8 m/s	**2.5 m/s**	M: 3.5 m/s R: 6.0 m/s	**3.0 m/s** ***(3-5 m/s)***	R: 7.2 m/s

Mission Requirements versus measurements: July – October 2021

- L2B wind product released in May 2020. L2A product becoming mature and released in summer 2021. Latest algorithm Baseline 12: May 2021.
- Second reprocessing campaign based on B11 and covering June 28 2019 – October 10 2020: released October 11 2021.
- Any new evolution is taking into consideration the outcome of the ongoing investigations (Aeolus DISC, and CAL/VAL following CAL/VAL Implementation Plan), output of scientific studies (following Aeolus Science Plan) and synergies with other missions (e.g. EarthCARE)

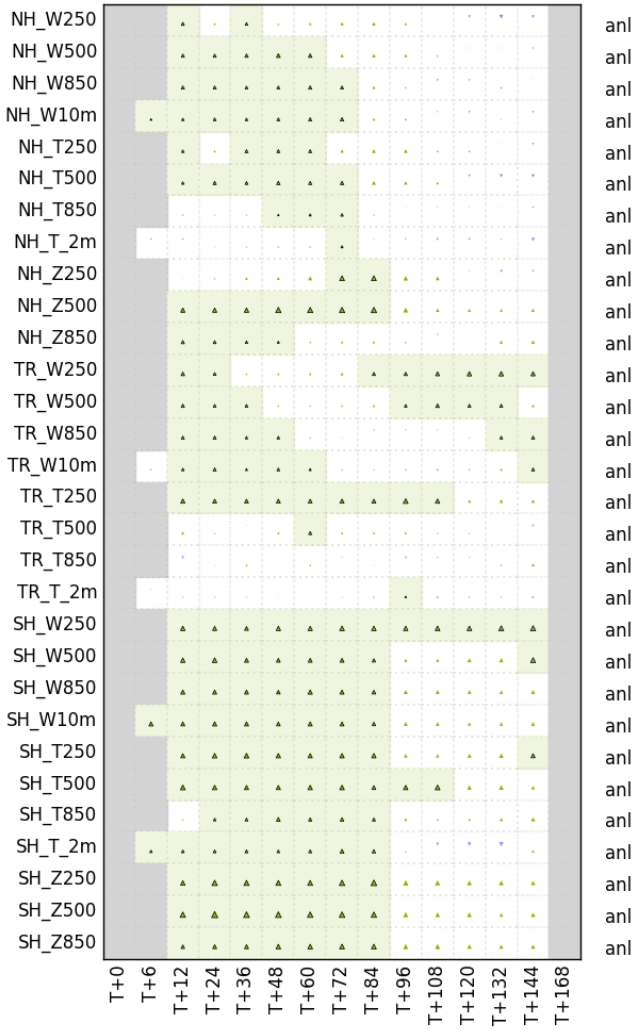
SCIENCE

- Status of achieving Mission Objectives is good. A full report will be presented at the end of 2022
- ECMWF, DWD, Météo-France, UK MetOffice and recently the Indian NCMRWF are now assimilating Aeolus data. KMA and JMA possibly by the end of 2021
- Aeolus CAL/VAL and science community teams investigating mechanisms driving atmospheric dynamics and dynamics change using Aeolus data
- Six Aeolus+ Innovation studies are on-going investigating new mission spin-off products and/or applications, including air quality modelling, sea surface and sub-surface products. Other Aeolus scientific studies (i.e. prediction on extreme weather events and regional NWP impact) are ongoing according or being KO soon
- Aeolus Tropical Campaign took place between July and end September 2022
- New scientific papers have been published. Deadline for the Aeolus special issue extended to March 2022 https://amt.copernicus.org/articles/special_issue1131.html
- Aeolus is present at international conferences (e.g. CGMS-IWWG, EGU, IGARSS, EUMETSAT, ATMOS, LPS 2022, etc.)



Dynamical and Surface Impacts of the January 2021 Sudden Stratospheric Warming in Novel Aeolus Wind Observations, MLS and ERA5. Courtesy Corwin J. Wright et al.

Aeolus scientific highlights

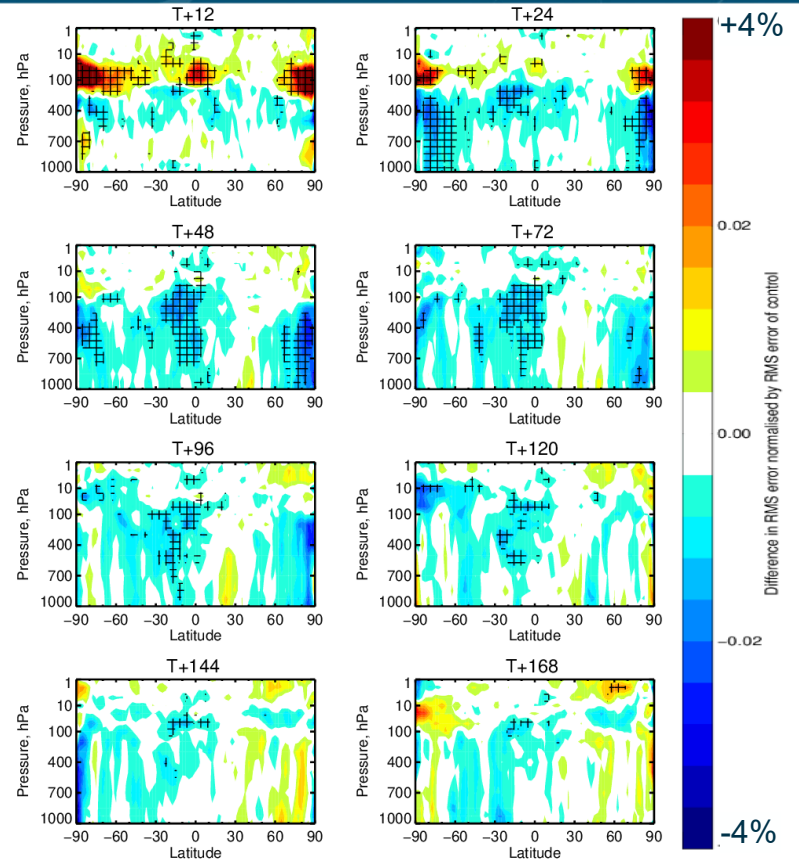


Statistically significant positive impact seen by ECMWF and MetOffice in their weather forecasts

ECMWF started operational assimilation 9 January 2020

UK MetOffice started in December 2020

Courtesy ©G. Halloran (UK MetOffice)
Example of UKMO model score card. Green (large triangles) indicate positive (significant) impact of Aeolus Mie winds on forecast of wind, temperature, and geopotential at different heights and geographical regions



Courtesy ©M. Rennie (ECMWF)
Example of ECMWF model forecast improvements at different forecast lengths (T hours) when assimilating Aeolus winds.
Blue colours: positive impact.
Hashed: statistically significant impact.

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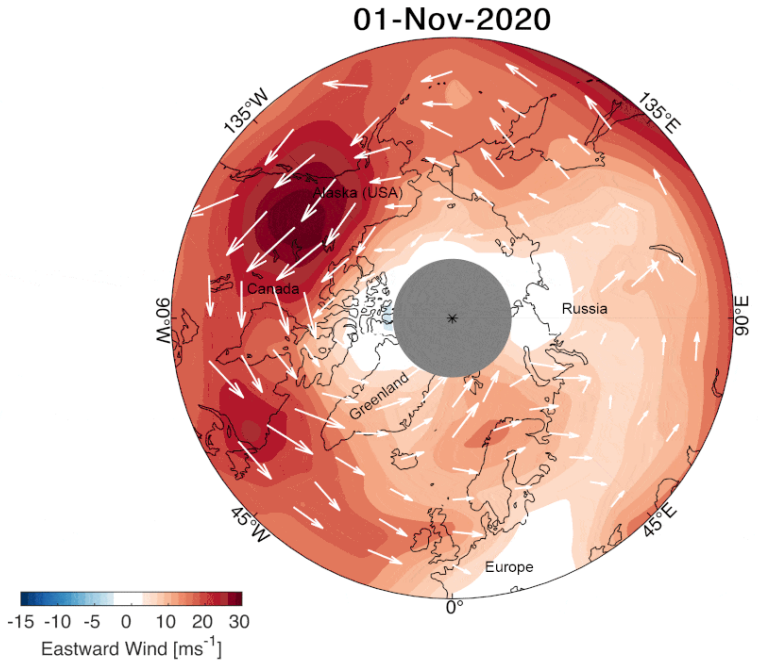


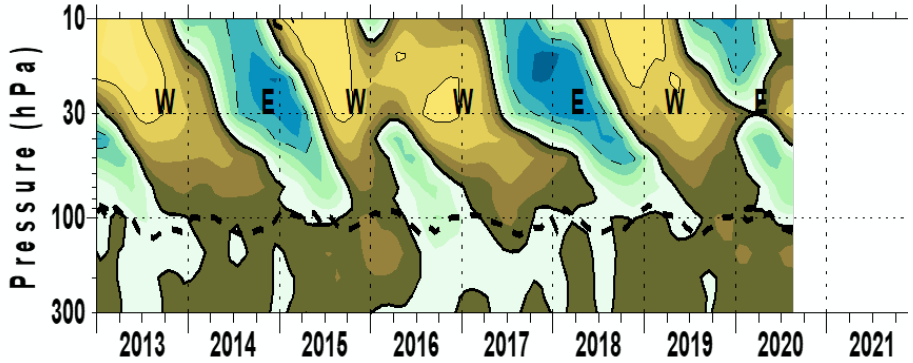
Aeolus observing stratospheric polar vortex split in winter 2020/2021, courtesy C. Wright, U. Bath

Aeolus data to study possible effects of climate change

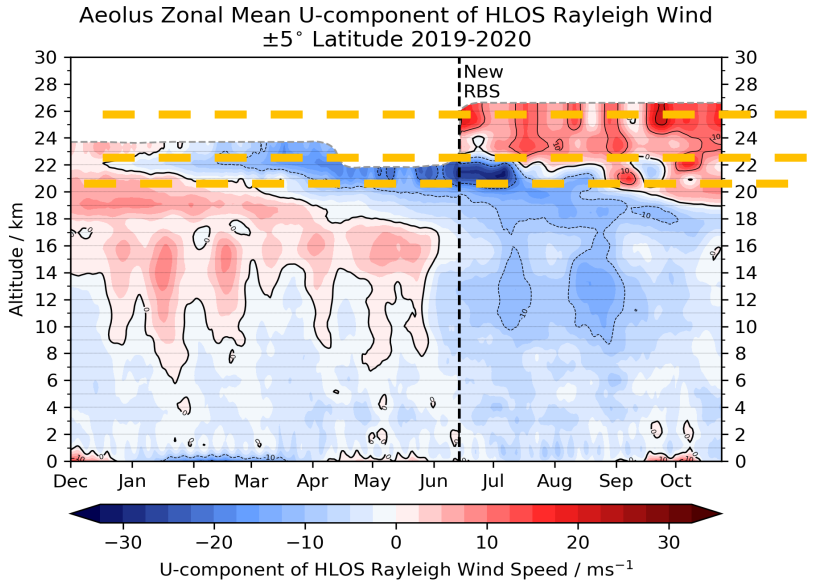
- Climate change cause changes to Earth's large-scale circulation and their natural variability such as the QBO, Monsoon, MJO, El Niño, tropospheric and stratospheric jet streams, etc.

- Stratospheric Quasi-Biannual Oscillation (QBO) circulation disruption appeared for the first time in 2016, and reoccurred in 2019/2020
  - https://www.essoar.org/doi/10.1002/essoar.10503358.2
  - QBO disruption observed by Aeolus (lower right panel)

- Scientific investigations on-going using Aeolus data addressing the mechanism behind the circulation change



Paul A. Newman, Larry Coy, Leslie R. Lait, Eric R. Nash (NASA/GSFC) Wed Sep 2 16:20:14 2020

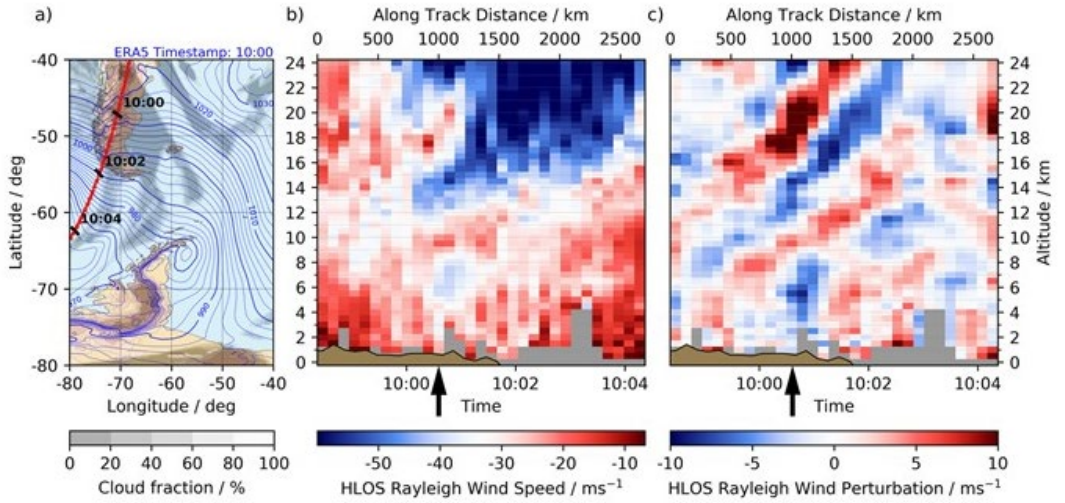


Courtesy ©T. Banyard (University of Bath) and S. Osprey (University of Oxford) et al.

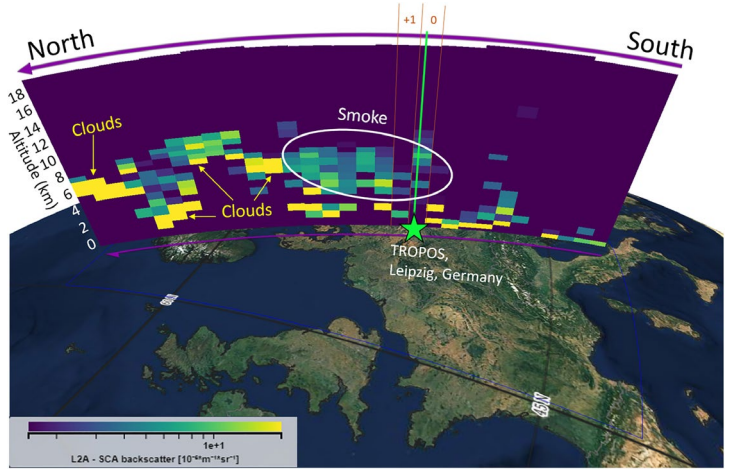
Aeolus observing gravity waves and BBA

- Aeolus observes atmospheric gravity waves triggered by the Andes mountains:

  Banyard *et al.*, GRL 2021, https://doi.org/10.1029/2021GL092756



- Long-range transport of aerosols from strong forest fires in California in 2020: Baars *et al.* GRL 2021, https://doi.org/10.1029/2020GL092194



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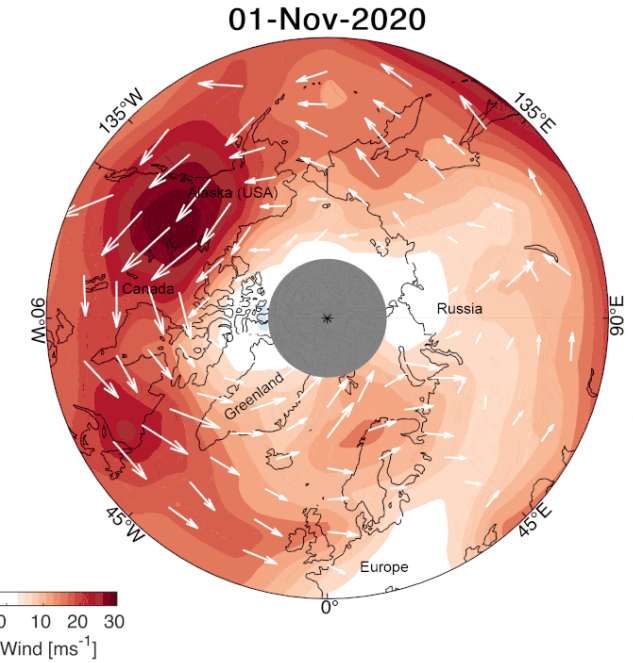
More on Aeolus session Thursday 9:00 - 12:15



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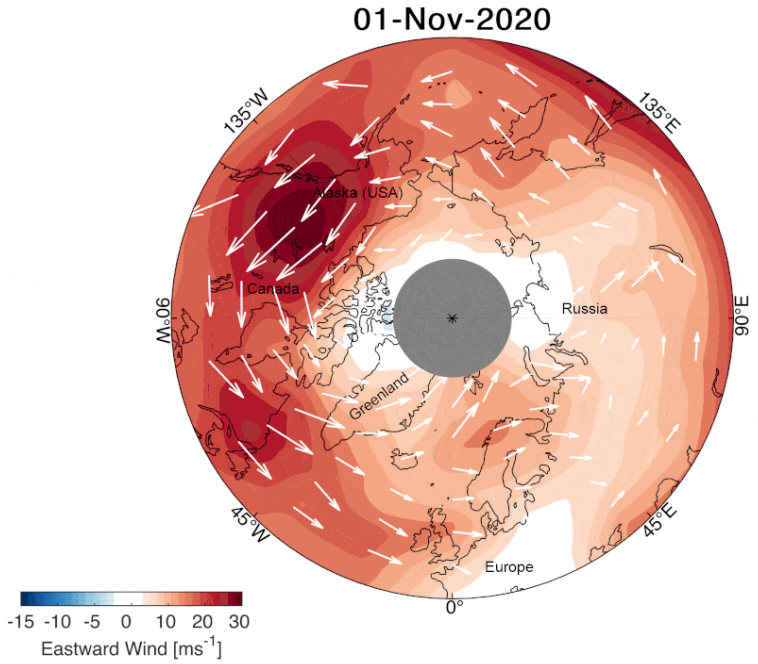

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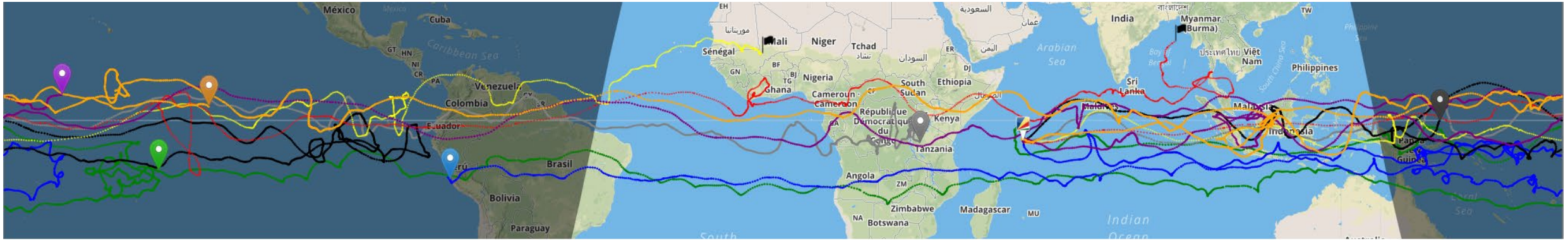
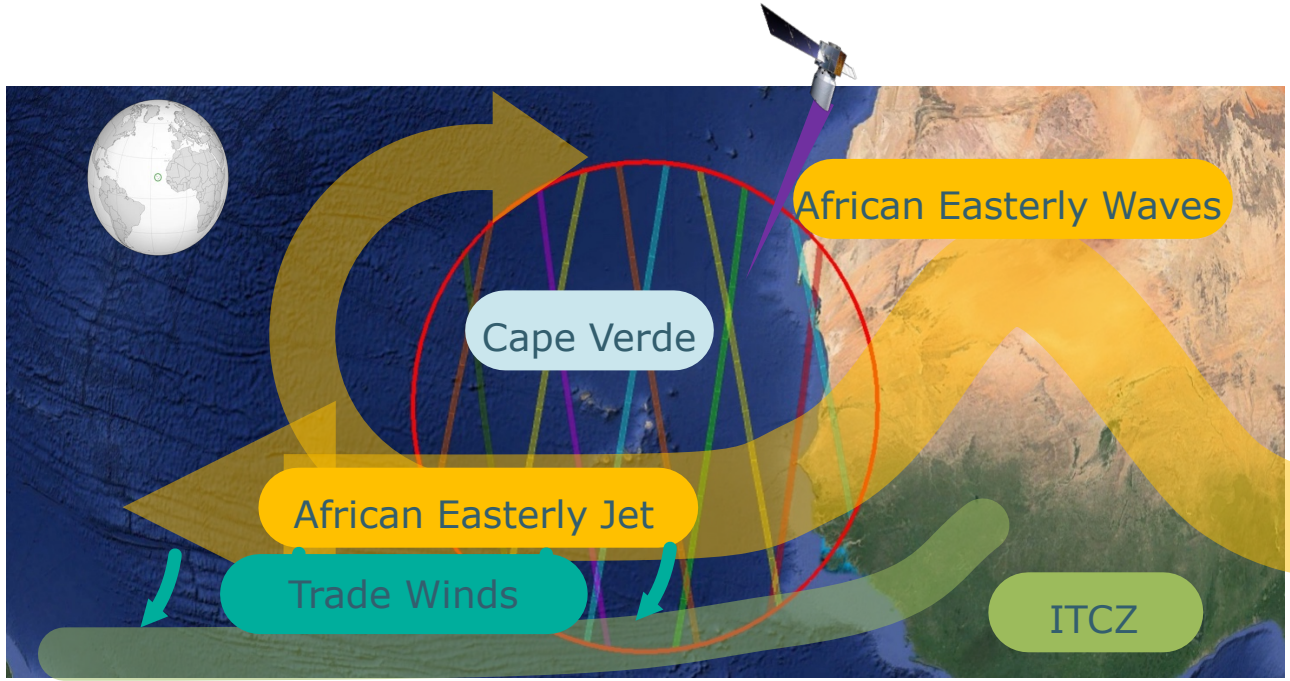
Aeolus campaigns



- Early airborne Aeolus (proof of concept) campaigns started in 1980s
- Aladin Airborne Demonstrator (A2D) used on-ground and in aircraft since 2006 (DLR under ESA contract), more than 100 lessons learnt!
- Multiple campaigns ESA, DLR, LATMOS, NASA before launch
  - Three campaigns by DLR with A2D and reference lidar system since launch
- CNES Stratospheric Balloon experiment Strateole-2 / TAPAPA also in support of Aeolus CAL/VAL
- International Tropical campaign for Aeolus wind and aerosol product CAL/VAL and science in July - September 2021, Cape Verde. International consortium under ESA contract/ lead/cooperation



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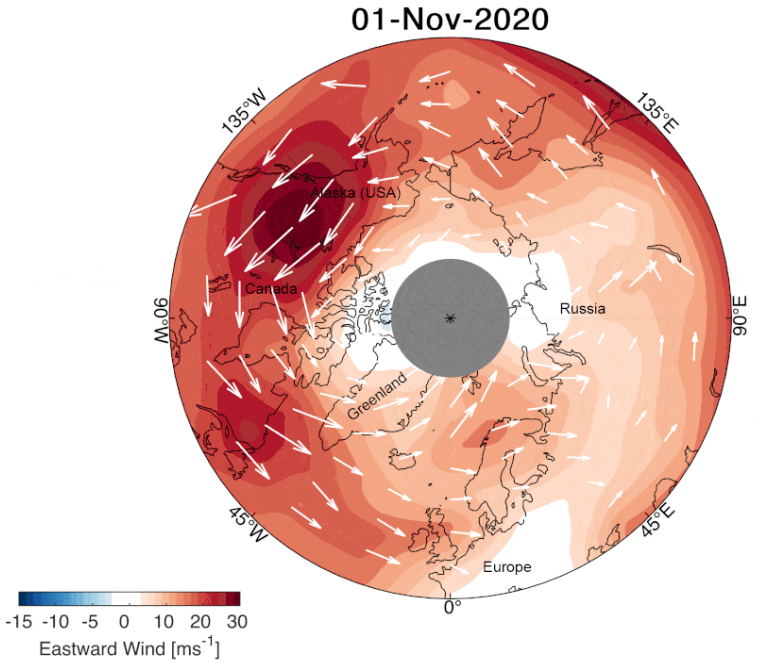

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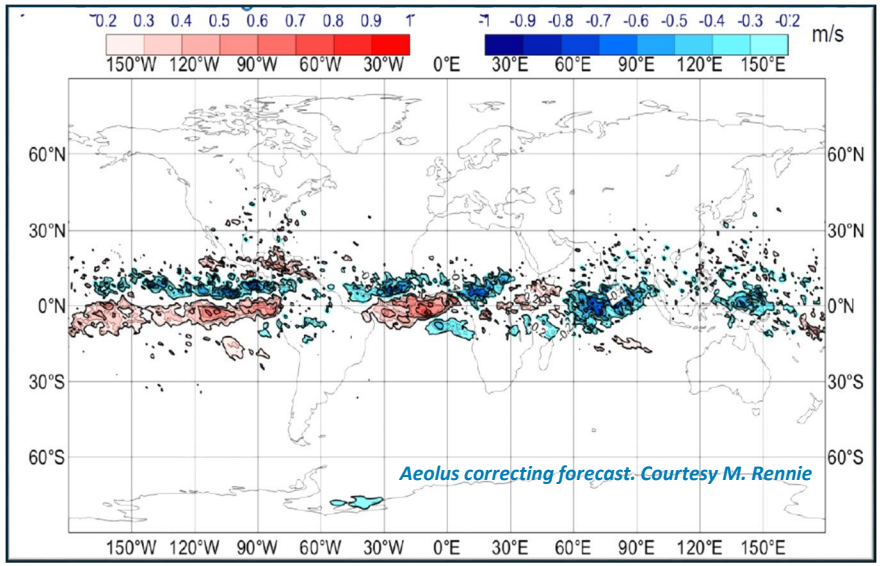
STRATEGIC MISSION GOALS [2021-2022]

Goal #1: Support the Tropical Campaign in summer 2021 with best possible performance with Laser B to support both the validation and the science aspect of the campaign

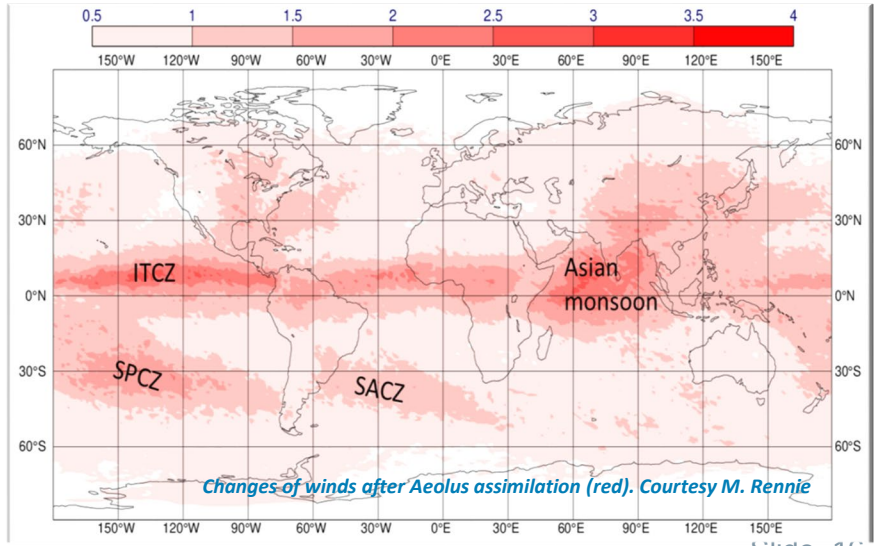
Goal #2: Achieve the designed end of life-time (Dec 2021) with best possible performance on both channels RAY and MIE to complete the prime mission objectives

Goal #3: Achieve within the extended life-time (2022) the best possible performance on both channels or at least on one (e.g. Mie)

Goal #4: Perform technological and science demonstration to support the Aeolus Follow on



Aeolus correcting forecast. Courtesy M. Rennie



Changes of winds after Aeolus assimilation (red). Courtesy M. Rennie

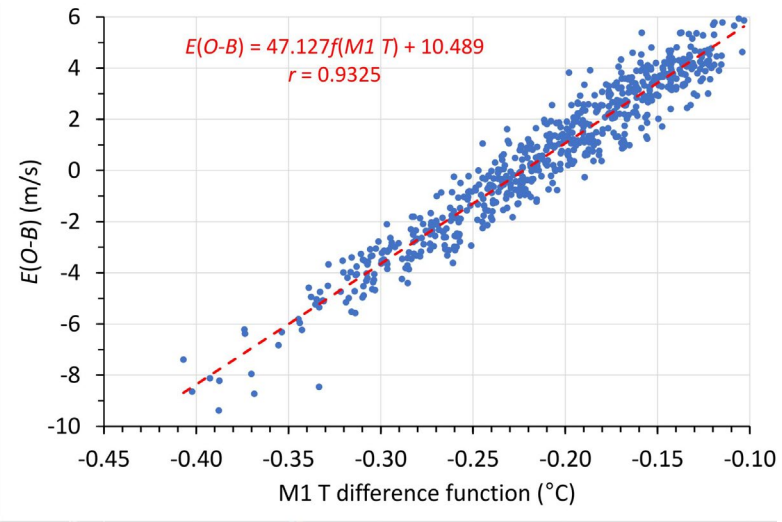
SUMMARY

- The overall performance of the mission is good. Aeolus has been providing global measurements of horizontal wind profiles f bias variations have been corrected. Improver emains challenging
- A roadmap to recover the ent has been defined and adopted by the Miss **main goals** until end of 2022.
- The beneficial impact of A bal NWP models and contribution to atmosphe waves, improved air quality modelling, etc.), h odelling emerging.
- Tropical Campaign succe nerging
- Overall the achievement of Aeolus as a scientific and technological demonstrator is very good and making it a worldwide acknowledged **pathfinder** of future operational DWL missions (e.g. as demonstrated during 7th WMO NWP impact workshop and at 15th CGMS-IWWG)

Spares

Wind biases caused by telescope temperature variability

- The Aladin M1 telescope (1.5 m Ø) known to be temperature sensitive (Top of Atmosphere (TOA) radiance variability), and active thermal control implemented in mission design
- Ground returns (zero Doppler shift) intended to correct potential residual wind speed errors in L2 wind product
  - Hampered by surface albedo variability and lower than expected in-flight performance → fewer valid ground returns
- Aeolus DISC team found root-cause for Aeolus wind bias variability along orbits using [Observation (O) - Forecast model background (B)] statistics
  - Telescope thermistor readings following TOA radiance variability, differences temperatures center versus edge impact alignment
  - Telescope thermal control hence less effective than expected
- Aeolus DISC and ESA developed effective on-ground processing correction scheme (implemented since 20 April 2020)
- Further optimization of M1 telescope thermal control under investigation by industry



Mission Timeline [2021-2022]