DEMONSTRATED AEOLUS BENEFITS IN ATMOSPHERIC SCIENCES

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ABSTRACT

We highlight some of the scientific benefits of the Aeolus Doppler Wind Lidar mission since its launch in August 2018. Its scientific objectives are to improve weather forecasts and to advance the understanding of atmospheric dynamics and its interaction with the atmospheric energy and water cycle. A number of meteorological and science institutes across the world are starting to demonstrate that the Aeolus mission objectives are being met. Its wind product is being operationally assimilated by four Numerical Weather Prediction (NWP) centres, thanks to demonstrated useful positive impact on NWP analyses and forecasts. Applications of its atmospheric optical properties product have been found, e.g., in the detection and tracking of smoke from the extreme Australian wildfires of 2020 and in atmospheric composition data assimilation. The winds are finding novel applications in atmospheric dynamics research, such as tropical phenomena (Quasi-Biennial Oscillation disruption events), detection of atmospheric gravity waves, and in the smoke generated vortex associated with the Australian wildfires. It has been applied in the assessment of other types of satellite derived wind information such as atmospheric motions vectors. Aeolus is already successful with hopefully more to come.

Index Terms— Aeolus, winds, optical properties, NWP, atmospheric dynamics, DWL

1. INTRODUCTION

The European Space Agency's (ESA) Aeolus satellite mission is the world's first spaceborne Doppler Wind Lidar (DWL), providing profiles of Horizontal Line-Of-Sight (HLOS) wind retrievals and UV (Ultra-Violet) optical properties profiles [1]; [2]; [3]. Aeolus partially fills a gap in the global observing system for global direct wind profile measurements [4]; [5]. It has already successfully demonstrated the suitability of space-based Doppler Wind lidar technology for operational Numerical Weather Prediction (NWP), and there is an increasing list of benefits for atmospheric sciences being confirmed and further discovered. The good data quality that has been achieved to allow these benefits is in a great part due to the efforts of the thorough pre-launch preparations of the Aeolus on-ground data processing and monitoring and the in-flight instrument and data analysis and data processing improvements by the Aeolus Data Innovation and Science Cluster (DISC) in collaboration with ESA. This work has also been supported by further invaluable contributions from the Aeolus CAL/VAL and science teams in Europe and across the world. This paper briefly reviews some of the important benefits found.

2. AEOLUS WINDS IN NUMERICAL WEATHER PREDICTION

The main objective of the Aeolus mission is to provide profiles of Horizontal Line-Of-Sight (HLOS) wind for data assimilation in NWP models to improve the weather forecasts and for atmospheric dynamics research. The main Aeolus wind types, Rayleigh-clear and Mie-cloudy, typically have HLOS wind random error statistics of 4-6 m/s and 3 m/s respectively (one standard deviation). The benefits of the assimilation of Aeolus Level-2B (L2B) HLOS wind profiles have been demonstrated by several NWP centres (as presented at the Aeolus Science and CAL/VAL Workshop in November 2020 and at the WMO's 7th Workshop on the Impact of Various Observing Systems on NWP). In particular, positive impact has been demonstrated by, inter alia, ECMWF [6], DWD, Météo-France, Met Office, NOAA, NASA, Indian NCMRWF. So far four centres have started to operationally assimilate Aeolus (ECMWF, DWD, Météo-France and the Met Office), which is an unusual achievement for a short satellite demonstration mission, such as Aeolus, and highlights the usefulness of the data.

An example of the positive impact of Aeolus winds in ECMWF's global forecasting system is shown in Figure 1. Aeolus is typically found to provide the largest positive impacts in the tropical upper troposphere and lower stratosphere (UTLS) with the lower stratospheric impact extending well into the medium range. Positive impacts are also found in polar regions, again particularly in the UTLS. Aeolus causes the largest changes to the wind analysis in the intertropical convergence zone (ITCZ) and more generally in the convergence zones around the world.

An indirect benefit is to use Aeolus as a reference for the verification of other changes to the NWP system, such as adding other satellite data, or changing model physical or dynamical parameterizations in otherwise under-constrained areas.

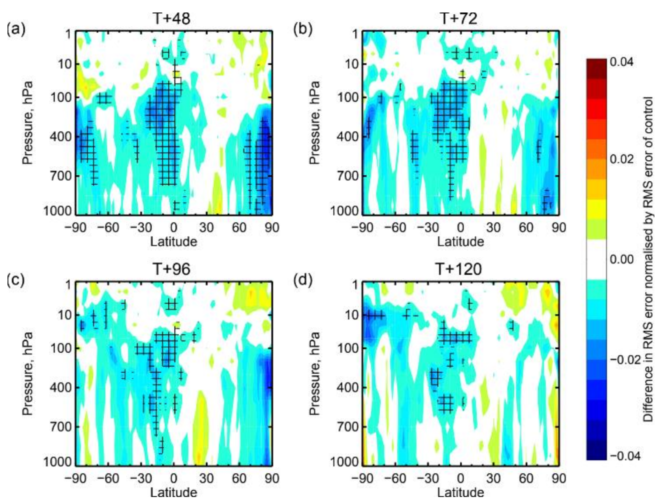

Figure 1. Zonal average normalised change in vector wind root mean square error for forecast range of a) 48, b) 72 c) 96 and d) 120 hours for period 2 August to 31 December 2019, due to assimilating Aeolus winds. Negative values (blue areas) indicate Aeolus wind data is improving the forecasts; see [6] for further details.

3. AEOLUS OPTICAL PROPERTIES

The retrieved optical properties from Aeolus (the Level-2A product) i.e. backscatter and extinction coefficient profiles and lidar ratios indicating aerosol and cloud layers are recently showing a positive impact in atmospheric composition models e.g. the ECMWF CAMS model (assimilation of quality-controlled backscatter coefficient profiles). The optical properties algorithms are being continuously improved, with the current emphasis to successfully detect and distinguish aerosol and clouds layers. Comparisons of the Aeolus optical properties to ground-based lidar measurements by CAL/VAL teams are very encouraging. This product will no doubt become even more useful with future reprocessing.

4. AEOLUS WINDS FOR ATMOSPHERIC DYNAMICS RESEARCH

Aeolus winds have found applications for monitoring the temporal trends in the Quasi-Biennial Oscillation (QBO) zonal wind component in the tropical lower stratosphere. By pointing ~10 degrees off the zonal direction in the tropics, Aeolus has a strong sensitivity to the zonal wind component in which the QBO is evident. 2019-2020 was a very unusual year for the QBO, in that a westerly disruption of the nominal easterly phase occurred (a similar event occurred only once before in 2016). This event was well captured with Aeolus L2B HLOS winds [7]; see Figure 2; the westerlies (red) appear > 22 km. Such dynamical events may be associated with climate change, and by observing them Aeolus can help improving our understanding of how they are triggered and will evolve in the coming decades. This demonstrates further scientific and societal benefits of Aeolus.

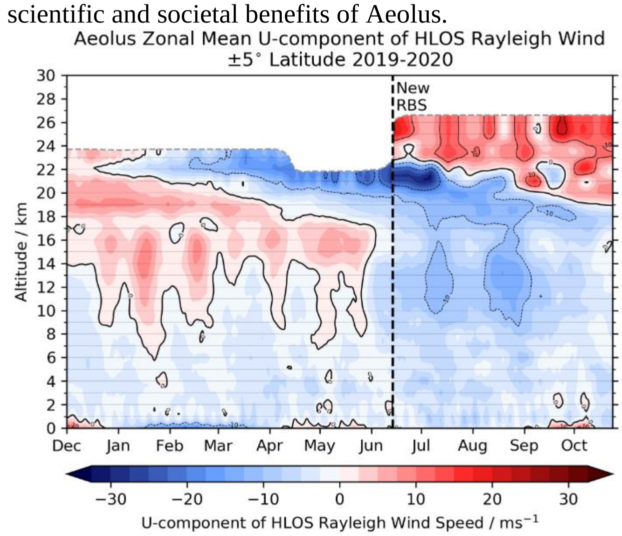

Figure 2. The temporal evolution of the zonal average zonal wind component within the ±5° latitude band from L2B Rayleigh-clear winds for the period December 2019 to October 2020. Courtesy of S. Osprey; see [7].

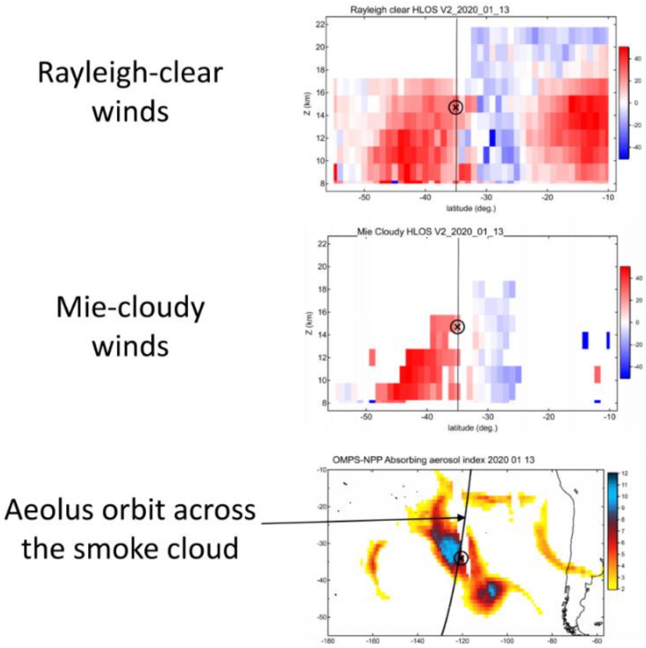

Figure 3. The top two plots show L2B HLOS wind observations (cross-sections) of the smoke generated vortex on 13 January 2020. The bottom map shows the location of the smoke aerosol and the corresponding Aeolus orbit. Courtesy of S. Khaykin; see [9].

Aeolus winds also proved to be a unique observational source in measuring winds associated with a highly unusual 1000 km-scale stratospheric vortex generated by the solar heating of the smoke plume resulting from the extreme early 2020 Australian wildfires ([8] and [9]); as illustrated in Figure 3.

By investigating the NWP analyses and forecasts with and without Aeolus assimilation, it is possible to learn about model systematic wind errors in the tropics. Such investigations are being carried out by several research teams. Initial findings suggest Aeolus observations have a strong positive effect on the prediction of the African Easterly Jet and Tropical Easterly Jet.

Aeolus can also resolve larger amplitude gravity waves, which due to Aeolus' global coverage will surely find application in future research. Another area, only recently being explored, is research of the fast-changing dynamics of the wintertime stratospheric polar vortex, which Aeolus captures well. For example, Figure 4 shows the dramatic shift from westerly (red) to easterly (blue) winds above ~70 hPa in early January 2021, due to an exceptionally strong and early sudden stratospheric warming event.

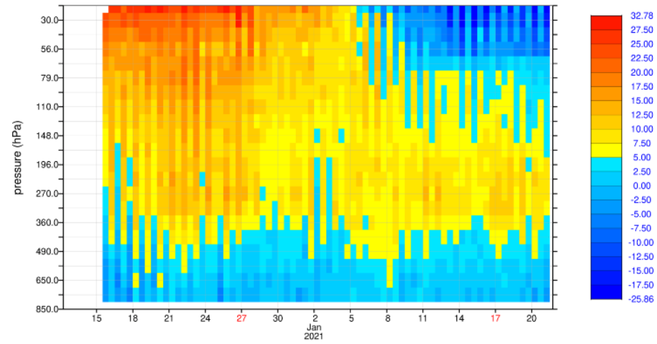

Figure 4. Ascending orbit 12-hourly mean L2B Rayleigh-clear HLOS winds (m/s) for latitude band50-75°N as a function of time and pressure from 15 December 2020 until 21 January 2021.

5. COMPARISONS TO ATMOSPHERIC MOTION VECTORS AND NEW DATA PRODUCTS

Several studies comparing Aeolus HLOS winds to atmospheric motion vectors (AMVs, typically geostationary satellite feature tracked winds) are being carried out by research teams around the world. Some of this work aims at verifying the quality of Aeolus winds for CAL/VAL, and some to study the complex error characteristics for AMVs in poorly observed areas such as the tropics, where AMVs are thought to suffer from situation dependent biases. Another application is comparing AIRS hyperspectral infrared sounder wind retrievals to Aeolus data and finding a high correlation and complementarity [10]. Finally, a series of new studies are just starting to look into the possibility to retrieve ocean and land surface properties information from Aeolus. First results from these are expected in early 2023.

6. CONCLUSION

Aeolus winds are being exploited in operational NWP by several NWP centres. Aeolus winds and optical properties retrievals are finding beneficial application in many areas of atmospheric science, as was highlighted in the many talks at the 2020 Aeolus Science and CAL/VAL workshop. Some exciting new applications of the data beyond the main aim of the mission (which is to improve global NWP forecasts and the understanding of atmospheric dynamics and its interaction with the atmospheric energy and water cycle) were explored, such as the monitoring of unusual atmospheric phenomena, which are expected to become more common as a result of climate change. This surely provides strong evidence of the need for an operational follow-on mission of this unique observation type.

7. REFERENCES

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