Meeting report | Aviation and turbulence in the free atmosphere

The Royal Meteorological Society special interest group on Aviation Meteorology originated this meeting at Imperial College. The organiser, Bob Lunnon, introduced the importance of being able to forecast turbulence for both safety reasons and to reduce the operational delays and costs incurred from such events.

The afternoon's first talk was from *Bob Sharman* of the National Center for Atmospheric Research. He identified three main areas for improvement in future turbulence forecasting: the provision of observations; better nowcasting and forecasting capabilities; enhanced understanding of the underlying mechanisms for turbulence in all its forms. His work on the Graphical Turbulence Guidance (GTG) system hopes to aide this by combining an ensemble of clear air turbulence (CAT) predictors into a single product and has been used over the USA and more recently globally. The diagnostics used are converted to eddy dissipation rate (EDR), an International Civil Aviation Organization standard for turbulence monitoring that is aircraft independent. Verification using PIREPS (Pilot Reports) and aircraft automatic observations shows that the GTG consistently performs better than any individual diagnostic.

In understanding the nature of CAT, parametrisation is used because we do not yet have the capability of sub aircraft scale modelling, as a consequence, EDR is not calculated directly from a model but instead from the parametrised diagnostics. A demonstration of cirrus banding from the outflow of convective weather systems showed that with the assistance of satellite imagery, areas that may be conducive to turbulence due to the shear and gravity waves associated with the outflow of these storms can be identified.

Paul Williams from the University of Reading referred back to classical fluid dynamics in the first part of his talk to describe turbulence and how it manifests itself. In laboratory testing it was shown that even in a neutrally stratified atmosphere (where the Richardson number is >1/4) it is possible for Kelvin–Helmholtz instability to form in a region and cause turbulence where it may not have otherwise formed. The source of turbulent events often is many hundreds of miles from where turbulence is experienced, demonstrating that gravity wave propagation is a feature requiring further research.

In the second part of his talk Dr Williams explored the theory that projected changes in our climate resulting from a doubled CO_2 atmosphere may alter the number and severity of CAT cases, particularly in relation to North Atlantic air traffic. He noted that historical datasets may indicate that there has already been an increase in turbulence, other factors such as the way the observations are made and how the data is reanalysed could have an impact. The Phase 3 Coupled Model Intercomparison Project (CMIP3) climate model data were used for his study because it is known to represent upper-air winds well. His analysis of a range of different CAT diagnostics showed that, in every case, there was an increase of the median turbulence value by 10–40% and the extremes by 40–170%.

From modelling and laboratory testing the talks moved to the European funded Demonstration of LIdar based Clear Air Turbulence project. *Patrick Vrancken* from the German Aerospace Centre (DLR) described the project and its aim of using an aircraft mounted LIDAR to identify CAT 15–30km ahead of the aircraft. *Jacek Kopeć*, from the University of Warsaw, is part of the meteorological component working on generating a climatology of CAT over Europe which found that the winter months show a greater likelihood of encountering CAT than summer months.

The results of the project are still being finalised but the major conclusions show that there is some correlation with the root-mean-square error of LIDAR data and that of the direct observations. During the talk the many obstacles that needed to be over come were highlighted, such as obtaining approval for a forward facing LIDAR on the aircraft, the cooling system requirements and the complexity of taking observations from an aircraft in flight.

On the future of turbulence forecasting in the UK, the Met Office's *Piers Buchanan* presented work he and *Phil Gill* have done on the use of ensembles in verification of turbulence. The Met Office has access to observations from Boeing 747-400 aircraft and from these observations, turbulence climatologies are formed. The Met Office Ensemble Prediction System has been used in a trial and is expected to be used by WAFC (World Area Forecast Centre) forecasters to forecast turbulence in the near future. Similar to the GTG, a number of CAT diagnostics are used along with an ensemble of models with slightly different initial conditions. The output offers uncertainty estimates of the CAT likelihood rather than categorisation of CAT strength. The advantage of using multiple predictors from ensembles and the climatology of CAT generated better statistical skill scores than individual predictors, which will have a positive economic impact.

Finally, identifying turbulence through satellite monitoring was investigated in a talk by *Peter Francis* of the Met Office. His work primarily looked at overshooting tops in deep convective storms and the associated gravity waves and wind shear associated with such events, which can propagate many hundreds of miles from the source. The satellite used for the identification of the convective tops was Meteosat Second Generation, which was able to make use of all available wavelengths to identify the physical shape and structure of the convection, and also the temperature at the top of the cloud mass.

Case studies using two different methods to identify overshooting tops had varying success. The method using water vapour and infrared (IR) tended to identify larger areas of potential overshooting tops than actually exist, but areas that would have been of importance due to their convective activity. The other method, using just IR at 10.8µm, would identify areas of interest below 215K such as newly developed cloud tops. The second method did not identify as many areas but this could be because of the update rate and resolution of the images compared with the short life cycle of the overshooting tops.

In the future, the Meteosat Third Generation satellite will have a significantly higher refresh rate and resolution that will enable the transient nature of overshooting tops to be tracked by satellite technology. Animations demonstrated the benefits of the new generation, where the gravity waves propagated out from a storm cell over several hundred miles, thus signifying the impact gravity waves can have on aviation.

The closing remarks concluded that there is a wide range of research investigating all types of turbulence that affect airline operations. Ensembles and multiuse predictors pave the way to future turbulent predicting methods for forecasting a few minutes ahead out to several days, which will benefit all aviation activities.

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