

A prediction scheme for aircraft turbulence at tropopause folds using satellite imagery and EDR data

Anthony Wimmers, Wayne Feltz

CIMSS, University of Wisconsin – Madison, 1225 W. Dayton St., Madison, WI 53706, USA

Abstract

Previous work has established the association between GOES water vapor gradients and tropopause folds. Tropopause folds are layers of stratospheric air that penetrate into the troposphere near a front and frequently exhibit dynamical instability below the jet stream. Aircraft traveling in the upper troposphere often experience clear air turbulence (CAT) when they encounter these areas of instability. In this study, a new turbulence metric (eddy diffusion rate – EDR) collected in-situ from commercial aircraft for over a year is used to parameterize a tropopause folding model to predict turbulence associated with tropopause folds in three dimensions. The unprecedented quantity of objective data provided by this dataset allows us to determine the conditions that favor turbulence with much greater accuracy than was ever possible with manual pilot reports. The accuracy of this prediction scheme is due to a consideration of several factors, including direction of the fold; angle of incidence between the aircraft and the fold; and location with respect to the fold.

INTRODUCTION

The GOES Layer Average Specific Humidity (GLASH) product is a derived product image based on the GOES water vapor channel, depicting specific humidity at a fixed layer in the upper troposphere (250-500 hPa) (Wimmers and Moody, 2001). Recent investigation has found that strong gradients in the image-derived specific humidity correspond closely with tropopause folding (Wimmers and Moody, 2004a, 2004b), described as an event in which the boundary between the stratosphere and the troposphere folds into the troposphere, frequently leading to dynamical instability (enhanced aircraft turbulence) (Shapiro, 1980) and chemical mixing between the two regions.

This paper describes an empirical model of tropopause folding based on the GLASH product that we use to predict areas of clear air turbulence. The validation of this tropopause folding product uses automated commercial aircraft records of high-resolution eddy dissipation rate (EDR) (Cornman et al., 2004) obtained from the National Center for Atmospheric Research (NCAR).

DATA

The following data were used in this study:

- GLASH images created from GOES-East Water vapor channel and RUC-2 temperature fields.
- RUC-2 hourly analysis fields: temperature, pressure heights and tropopause temperature. This establishes the height of the modeled tropopause folds.
- Automated Eddy Dissipation Rate (EDR) measured from inertial disturbances on (unnamed) commercial aircraft in 3-minute time segments. Light or Greater (“LOG”): 0.10; Moderate or Greater (“MOG”): 0.30; Serious or Greater (“SOG”): 0.60. The domain is the eastern United States (away from mountain wave turbulence), ~360 days from May 1 2004 to April 30 2006, at elevations above 20 000 feet (6100 meters).

RESULTS AND DISCUSSION

Although the tropopause folding product has already been validated for detecting stratospheric tracers, the EDR dataset proves that turbulence occurs in only a subset of conditions. Consequently, five new criteria were added to the detection scheme, indicated by the shaded areas in Figures 1 and 2.

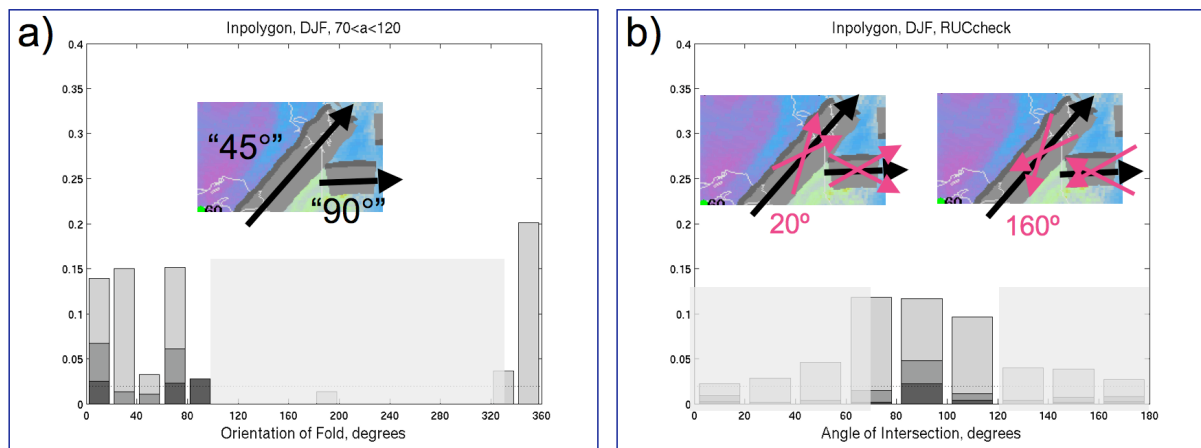


Figure 1: a) Probability of detecting turbulence based on orientation of the tropopause fold; inset: an example of tropopause fold orientation assignment; Light grey bar segments: LOG turbulence, medium grey bar segments: MOG turbulence, dark grey bar segments: SOG turbulence; semitransparent shaded area: range of values subsequently omitted as a condition of turbulence detection. b) Probability of detecting turbulence based on the angle of intersection between the tropopause fold and the aircraft path; Inset: two examples of angle of intersection assignments wherein the flight directions are shown as magenta arrows; bar chart elements are the same as (a).

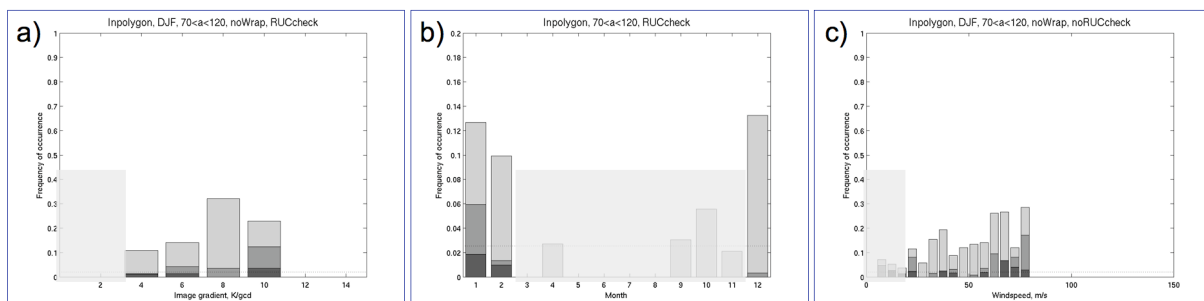


Figure 2: a) Probability of detecting turbulence based on the image gradient associated with the tropopause fold, b) Probability of detecting turbulence based on month, c) Probability of detecting turbulence based on RUC-2 derived wind speed. Bar chart elements are the same as Figure 1.

Figure 1a shows that the most turbulent tropopause folds are the ones that are most likely to be aligned with the jet, pointing between approximately 0 and 90 degrees on the compass. Figure 1b shows that after the condition from Figure 1a is met, the most turbulent encounters with tropopause folds occur when the flight path is nearly orthogonal to the tropopause fold, rather than in the direction (usually with the wind) or in the opposite direction (usually *against* the wind) of the tropopause fold. This supports the theory that mixing around the tropopause fold is dominated by eddies that rotate on an axis parallel to the wind (Shapiro, 1980), which are the only possible mechanism of mixing that could affect aircraft crossings but not aircraft travelling against the wind.

Figure 2a confirms that turbulence increases with the intensity of the associated gradient in the geostationary water vapor imagery; thus it is appropriate to use only gradients above a certain threshold (3.2K/gcd). According to Figure 2b, tropopause fold turbulence is much more prevalent in the winter months (Dec, Jan and Feb) than the rest of the year, so the prediction scheme is only

applied to these months. Finally, Figure 2c shows that the tropopause fold area must be associated with a RUC model-derived wind speed of 20 m/s or greater.

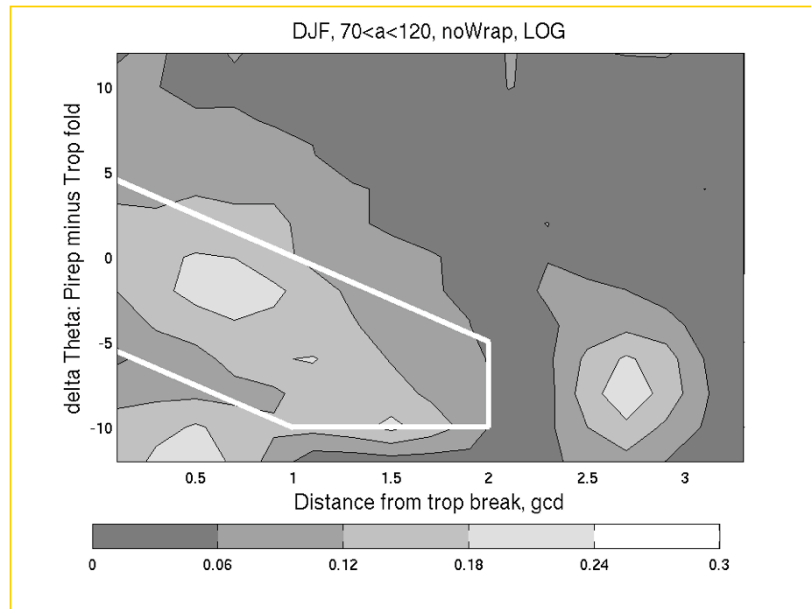


Figure 3: Cross-section of the probability of detecting LOG turbulence after all of the conditions from Figures 1 and 2 are applied. The x-axis is in units of great circle degrees (111km per gcd) and the y-axis is the difference in potential temperature between the tropopause (at the inflection point, or opening, of the tropopause) and the observation; the white line marks the expected perimeter of a tropopause fold.

Taken together, the conditions of Figures 1 and 2 produce the probability of detection shown in Figure 3. The distribution of turbulence detection in Figure 3 takes a very similar shape as the expected perimeter of the tropopause fold, which is a strong confirmation of the design of this prediction scheme.

CONCLUSIONS

- Turbulence is common to a subset of tropopause folding events limited especially by the time of year, orientation of the fold, and the relative angle of the flight track.
- These results confirm the turbulent effects of eddies that rotate on an axis parallel to the wind direction. These would have the strongest effect on aircraft crossing the jet stream perpendicularly.
- The vertical domain of the turbulence is difficult to constrain because of RUC model uncertainties in the dynamic tropopause height and the large variety in tropopause fold morphology.

ACKNOWLEDGEMENTS

This research was supported by the NASA LaRC Subcontract #4400071484 and by the NOAA GOES-R Algorithm Working Group. More information can be found at <http://cimss.ssec.wisc.edu/snaap/>.

REFERENCES

- Browell, E.V. et al., (2003) Ozone, aerosol, potential vorticity, and trace gas trends observed at high-latitudes over North America from February to May 2000, *J. Geophys. Res.*, **108**(D4).
- Cornman, L. B., P. Schaffner, C. A. Grainger, R. T. Neece, T. S. Daniels and J. J. Murray, (2004) Eddy dissipation rate performance of the Tropospheric Airborne Meteorological Data Reporting (TAMDAR) sensor during the 2003 Atlantic THORPEX regional campaign, 11th conference on aviation, range and aerospace, American Meteorological Society, 4-9 October 2004.
- Shapiro, M.A., (1980) Turbulent mixing within tropopause folds as a mechanism for the exchange of chemical constituents between the stratosphere and troposphere, *J. Atmos. Sci.*, **37**, pp 994-1004.
- Wimmers, A.J., and J.L. Moody, (2001) A fixed-layer estimation of upper tropospheric specific humidity from the GOES water vapor channel: Parameterization and validation of the altered brightness temperature product, *J. Geophys. Res.*, **106** (D15), pp 17115-17132.
- Wimmers, A. J., and J. L. Moody (2004a), Tropopause folding at satellite-observed spatial gradients: 1. Verification of an empirical relationship, *J. Geophys. Res.*, **109**, D19306, doi:10.1029/2003JD004145.
- Wimmers, A. J., and J. L. Moody (2004b), Tropopause folding at satellite-observed spatial gradients: 2. Development of an empirical model, *J. Geophys. Res.*, **109**, D19307, doi:10.1029/2003JD004146.