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

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1. Objective

To resolve areas of clear air turbulence in near-real time over the United States using a GOES derived product that predicts tropopause folding at air mass boundaries.

2. Introduction

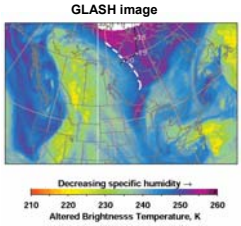
The GOES Layer Average Specific Humidity (GLASH) product is a derived product image based on the GOES water vapor channel, depicting specific humidity at a fixed layer in the upper troposphere (250-500 hPa) (Wimmers and Moody, 2001). Recent investigation has found that strong gradients in the image-derived 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 turbulence) (Shapiro, 1980) and chemical mixing between the two regions.

This poster 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 (TFP) 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).

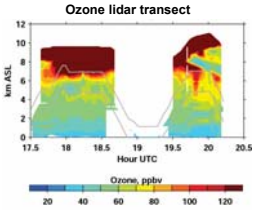
The current scanning schedule of GOES only allows for a rapid update of aircraft turbulence over the continental U.S. However, with the the next generation GOES-R ABI, a full-disk turbulence product will be possible.

3. Horizontal humidity gradients and tropopause folds

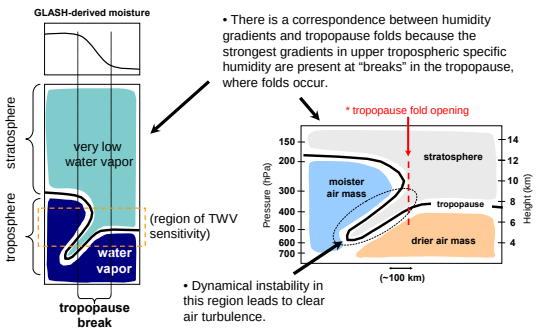
• In-flight ozone lidar transects from the TOPSE (Tropospheric Ozone Production about the Spring Equinox) campaign (Browell et al., 2001) that found tropopause folds have been matched with features in corresponding GLASH images. The folds were found to occur at humidity gradients that distinguish upper-level air mass boundaries:



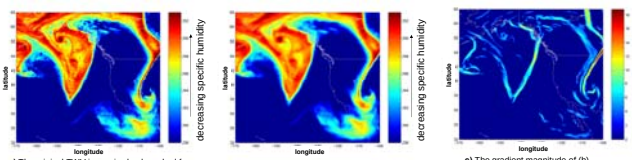
(Above) The flight track (black line) crosses a major gradient in specific humidity (white dashed line) at approximately 1945 UTC.



(Above) A tropopause fold opening* (white dashed line) is observed at approximately 1945 UTC.



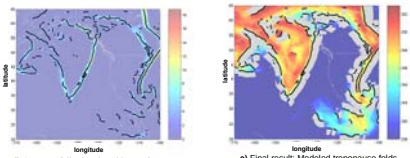
4. Construction of the Tropopause Folding Product



a) The original TWV image is cloud-masked for ABT< 238 K. (Colorscale is Altered Brightness Temperature (ABT) in degrees K.)

b) Image (a) is "smoothed" with a Gaussian filter, at a filter width of ~66 km.

c) The gradient magnitude of (b) resolves air mass boundaries above the threshold of 4.4 (units: degrees K per standard geographic degree).



d) Contours following the "ridges" of maximum gradient in (c) delineate the modeled tropopause fold openings*.

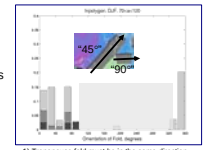
e) Final result: Modeled tropopause folds reach out from the modeled openings* at a uniform width of 234 km.

5. Data

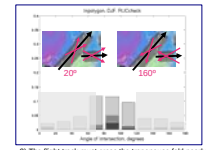
- GLASH images created from GOES-East Water vapor channel and RUC-2 temperature fields
- RUC-2 hourly analysis fields: temperature, pressure heights, tropopause temperature - this establishes the height of the modeled tropopause folds
- Automated Eddy Dissipation Rate (EDR) measured from inertial disturbances on (unnamed) commercial aircraft in 3-minute time segments. Light or Greater ("LOG") turbulence is assigned to EDR values above 0.10; Moderate or Greater ("MOG"): 0.30; Serious or Greater ("SOG"): 0.60.
- Domain: 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).

6. Results and Discussion

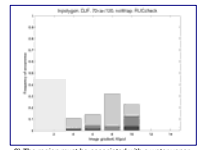
Detection criteria: Although the tropopause folding product has already been validated for detecting stratospheric tracers, the EDR dataset proves that turbulence occurs in only a subset of conditions. Consequently, five new criteria were added to the detection scheme, indicated by the shadowed areas in these five charts.



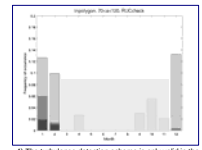
1) Tropopause fold must be in the same direction as a likely jet streak



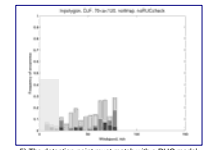
2) The flight track must cross the tropopause fold nearly perpendicularly



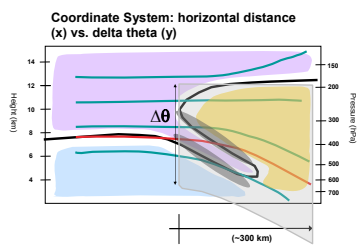
3) The region must be associated with a water vapor channel gradient of 3.2K/gcd or greater



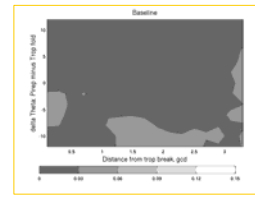
4) The turbulence detection scheme is only valid in the winter months: December, January and February



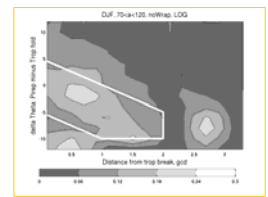
5) The detection point must match with a RUC model-determined windspeed of 20 m/s or greater



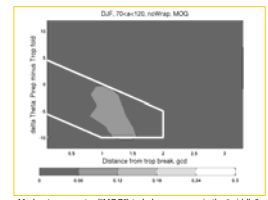
Assigning tropopause fold heights: Dynamic instability is most common at the upper and lower boundaries of the tropopause fold (gray shaded regions). Normally these areas decrease in potential temperature with distance from the tropopause "break," or the opening of the fold. To find the height of the satellite-detected fold, we use the potential temperature of the tropopause fold on the side of the cold air mass (red line) and follow this surface toward the direction of the fold. This surface delineates the zero value of a new y-axis. The fold is then confined to a region within this coordinate system defined by the white polygon on the three cross-sections to the right.



Without the additional criteria ("baseline" case), turbulence is not a common event in tropopause folds



After applying the selection criteria, we measure a frequency of Light or greater ("LOG") turbulence of around 20%



Moderate or greater ("MOG") turbulence occurs in the "middle" of the tropopause fold with a frequency of around 10%

7. 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 20-km scale 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.

Acknowledgments

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