The GOES-R Tropopause Folding Turbulence Product: Finding clear-air turbulence in GOES water vapor imagery

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1. Objective

To validate an operational product for the GOES-R Proving Ground that predicts regions prone to clear air turbulence by using the water vapor channel to identify tropopause folding at air mass boundaries.

2. Introduction

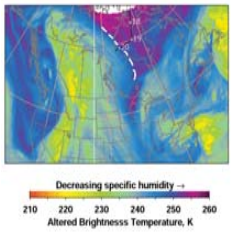
The GOES Layer Average Specific Humidity (GLASH) product is a derived product image, based on the GOES water vapor channel, depicting specific humidity at a fixed layer in the upper troposphere (250-500 hPa) (Wimmers and Moody, 2001). Previous investigation has found that strong gradients in the image-derived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

Aircraft traveling in the mid- and upper-troposphere often experience clear air turbulence (CAT) when they encounter these areas of instability. Here we present examples and validation of an operational tropopause fold nowcasting scheme developed for the GOES-R Algorithm Working Group. The algorithm has been implemented in the GEOCAT programming environment for easy transition to operations. The wealth of automated observational data from commercial aircraft (eddy diffusion rate – EDR) (Cornman et al., 2004) allows the tropopause folding product to show sensitivity to several factors, such as the direction of the fold; angle of incidence between the aircraft and the fold; and location with respect to the fold.

3. Horizontal humidity gradients and tropopause folds

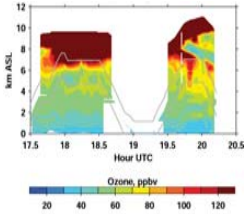
• In-flight ozone lidar transects from the TOPSE (Tropospheric Ozone Production about the Spring Equinox) campaign (Browell et al., 2003) that found tropopause folds have been matched with features in corresponding GLASH images. The folds were found to occur at humidity gradients that distinguish upper-level air mass boundaries:

GLASH image

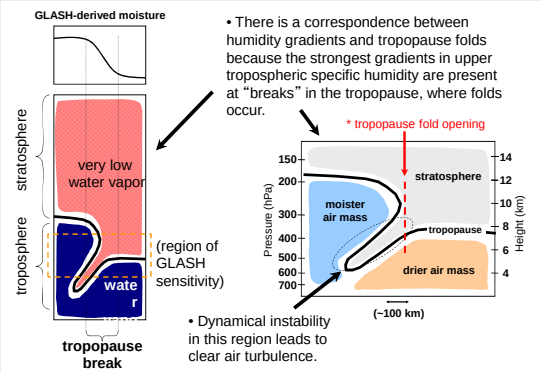


(Above) The flight track (black line) crosses a major gradient in specific humidity (white dashed line) at approximately 1945 UTC.

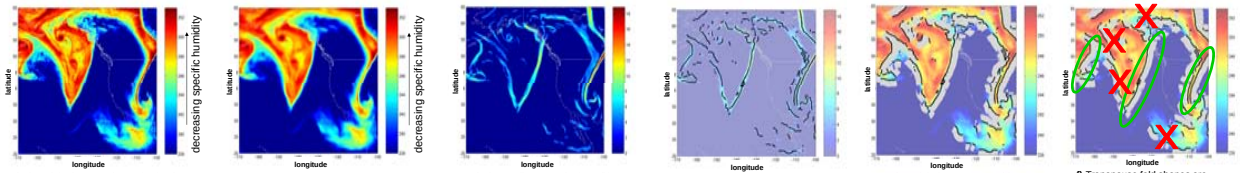
Ozone lidar transect



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



4. Calculation of the Tropopause Folding Turbulence Prediction Product



a) The original GLASH 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) Modeled tropopause folds reach out from the modeled openings* at a uniform width of 234 km.

f) Tropopause fold shapes are filtered down to a subset of regions that fit a set of empirical criteria…

… Those criteria include:

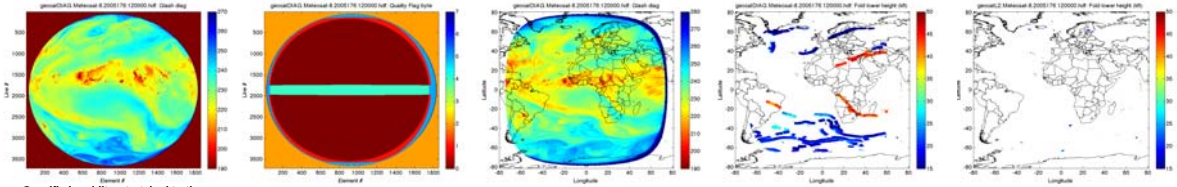
i) Keep only the tropopause folds that are 333km long or more.

ii) Keep only the tropopause folds that are oriented between NNW and due East.

iii) Filter by additional requirements identified in the product cal/val (Section 5).

5. Verification

- Satellite data: GOES-12 Nov 2005 – Dec 2007, 1445, 1745, 2045 and 2345 UTC over the continental U.S.
- Turbulence validation data: Automated aircraft EDR within one hour of image.
- Product requirement is 50% accuracy at detecting flight passages with Moderate or Greater (MOG) turbulence. Validation achieved 53% accuracy.
- The leading edge of a strong baroclinic trough is the most significantly turbulent. The algorithm must filter for only these cases.



Specific humidity, stretched to the scale of the water vapor channel, original METEOSAT projection

Quality flag byte, original METEOSAT projection

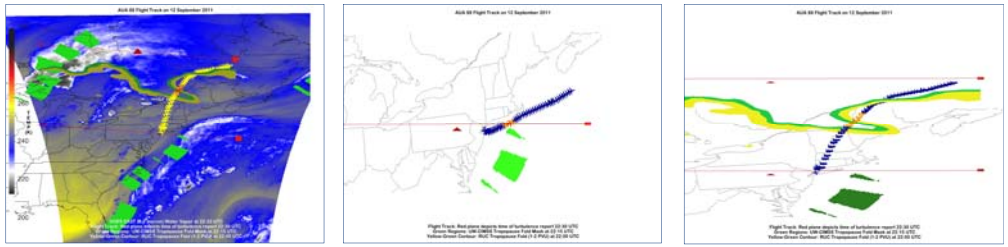
Specific humidity, stretched to the scale of the water vapor channel, rectangular projection

Tropopause folds (all), rectangular projection

Tropopause folds (filtered for MOG turbulence), rectangular projection

6. Case study

- On 12 Sept 2011, Australian Airlines Flight 88 experienced severe turbulence shortly after takeoff from New York
- The turbulence product confirmed that this occurred at a major tropopause fold
- The following images (right) show this flight segment in McIDAS-V depicted with GOES-East water vapor imagery, RUC-2 potential vorticity, and the Tropopause Folding product.



7. Summary

• Tropopause folds can be resolved from gradients in the GLASH product, which is built from the GOES-12/GOES-R satellite upper-tropospheric water vapor channels.

• The available data shows that the TFTP model demonstrates meets the product requirement of 50% for predicting MOG turbulence for resolved tropopause fold.

• Accuracy at predicting turbulence is highly dependent on image gradient magnitude at the tropopause fold, the orientation of the tropopause fold, tropopause height information from an NWP model and absolute height.

Acknowledgements

This research was supported by the NOAA GOES-R Algorithm Working Group. More information can be found at http://cimss.ssec.wisc.edu/snaap/.

References

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