GOES-R AWG Aviation Team: Tropopause Folding Turbulence Prediction (TFTP)

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Outline

- Executive Summary (1 slide)
- Requirements and Product Qualifiers (2)
- Algorithm Description (9 fast slides)
- Examples of Product Output (3 slides)
- Validation Approach (5 slides)
- Validation Results (2 slides)
- Steps to Reach 100% (1 slide)
- Summary (1 slide)

Executive Summary

- The Tropopause Folding Turbulence Prediction (TFTP) algorithm generates four Option 2 products
- Software Version 3 was delivered in March. ATBD (80%) and test datasets were delivered in May 2010
- Algorithm performs edge detection in the upper tropospheric water vapor channel to identify turbulent tropopause folding signatures
- Validation dataset: Compared to co-located, in-situ observations of eddy disturbance from commercial aircraft (737s and 757s)
- Validation studies indicate 80% spec compliance, with improvements on schedule to meet the 100% deadline in October 2010.

Requirements and Product Qualifiers

Name	User & Priority	Geographic Coverage (G, H, C, M)	Vertical Resolution	Horizontal Resolution	Mapping Accuracy	Measurement Range	Measurement Accuracy	Product Refresh Rate/Coverage Time (Mode 3)	Product Refresh Rate/Coverage Time (Mode 4)	Vendor Allocated Ground Latency	Product Measurement Precision
Tropopause Folding Turbulence Prediction	GOES-R	FD	SFC – 100 mb	2 km	1 km	Binary yes/no detection above boundary layer for moderate or greater condition	50% correct detection of Moderate or Greater turbulence	15 min	5 min	159 sec	N/A
Tropopause Folding Turbulence Prediction	GOES-R	M	SFC – 100 mb	2 km	1 km	Binary yes/no detection above boundary layer for moderate or greater condition	50% correct detection of Moderate or Greater turbulence	5 min		159 sec	N/A

M – Mesoscale **FD – Full Disk**

Requirements and Product Qualifiers

Name	User & Priority	Geographic Coverage (G, H, C, M)	Temporal Coverage Qualifiers	Product Extent Qualifier	Cloud Cover Conditions Qualifier	Product Statistics Qualifier
Tropopause Folding Turbulence Prediction	GOES-R	FD, M	Day and night	Quantitative out to at least 70 degrees LZA and qualitative at larger LZA	Clear conditions down to feature of interest associated with threshold accuracy	Over the lengths of separate flight transects through the region of positive prediction

FD – CONUS **M** - Mesoscale

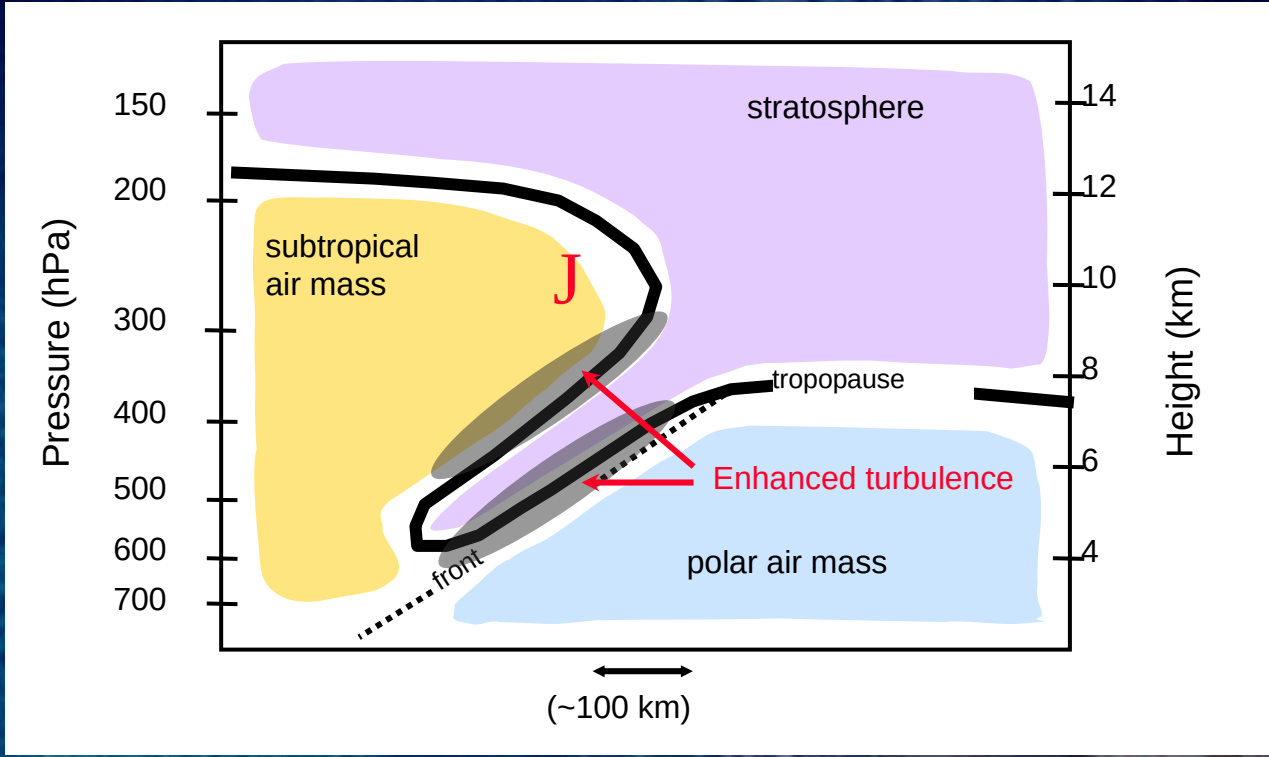
Algorithm Description

What Is a Tropopause Fold?

- Tropopause folding describes an event at the tropopause break in which the tropopause folds into the troposphere due to ageostrophic flow around the jet stream.

- This frequently leads to dynamical instability (enhanced turbulence) because of high levels of vertical shear across the boundary of the tropopause fold, which contains elevated potential vorticity.

Upper-air front

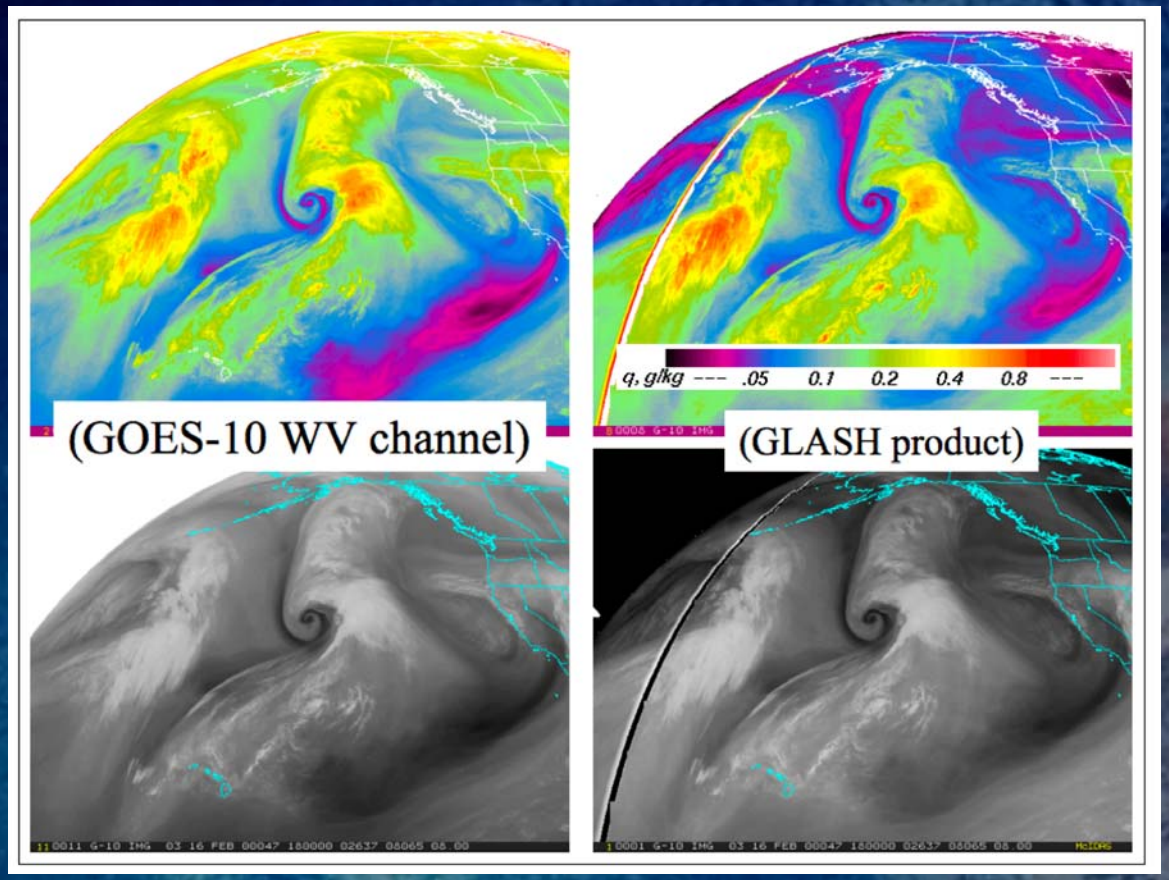


Algorithm Summary

- Input Datasets: Proxy Channel 8 ABI data (upper tropospheric water vapor) are generated from GOES-12 channel-3 water vapor data. NWP analysis fields are used to adjust water vapor channel brightness temperatures and to locate the tropopause fold features vertically (pressure, height, temperature, tropopause height)
- Adjust the water vapor image to vary with specific humidity and compute image gradients
- Contour the gradient image to delineate the location of tropopause breaks
- Draw polygons out from the contours to define the horizontal coverage of the tropopause folds
- Filter the number of tropopause fold objects to select only turbulent areas
- Use ancillary model fields to assign height ranges to the tropopause folds
- Identify the directions of flight through the folds that are the most hazardous for aircraft

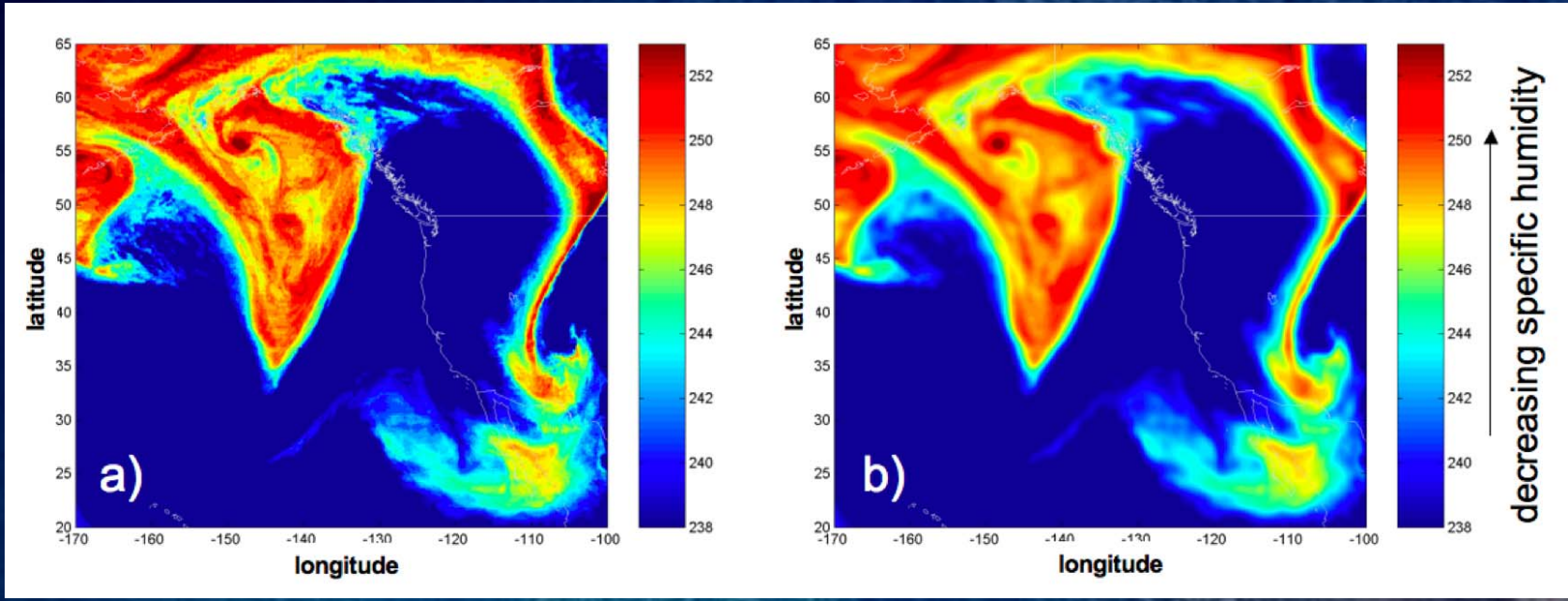
Tropopause Fold Turbulence Detection Processing Schematic (1 of 7)

INPUT: BT_9 and NWP grids → **Create GLASH product (GOES Layer Average Specific Humidity)**



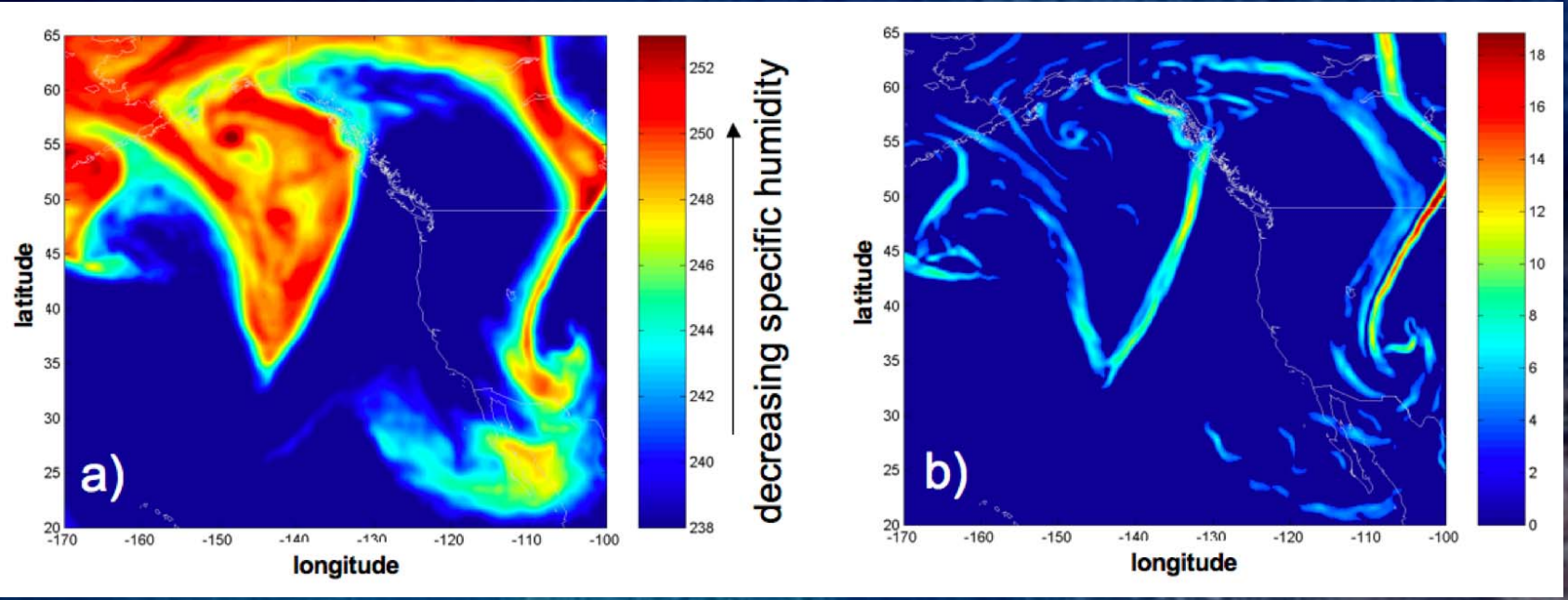
Tropopause Fold Turbulence Detection Processing Schematic (2 of 7)

Create GLASH product (GOES Layer Average Specific Humidity) → Smooth GLASH image to keep only synoptic-scale contours



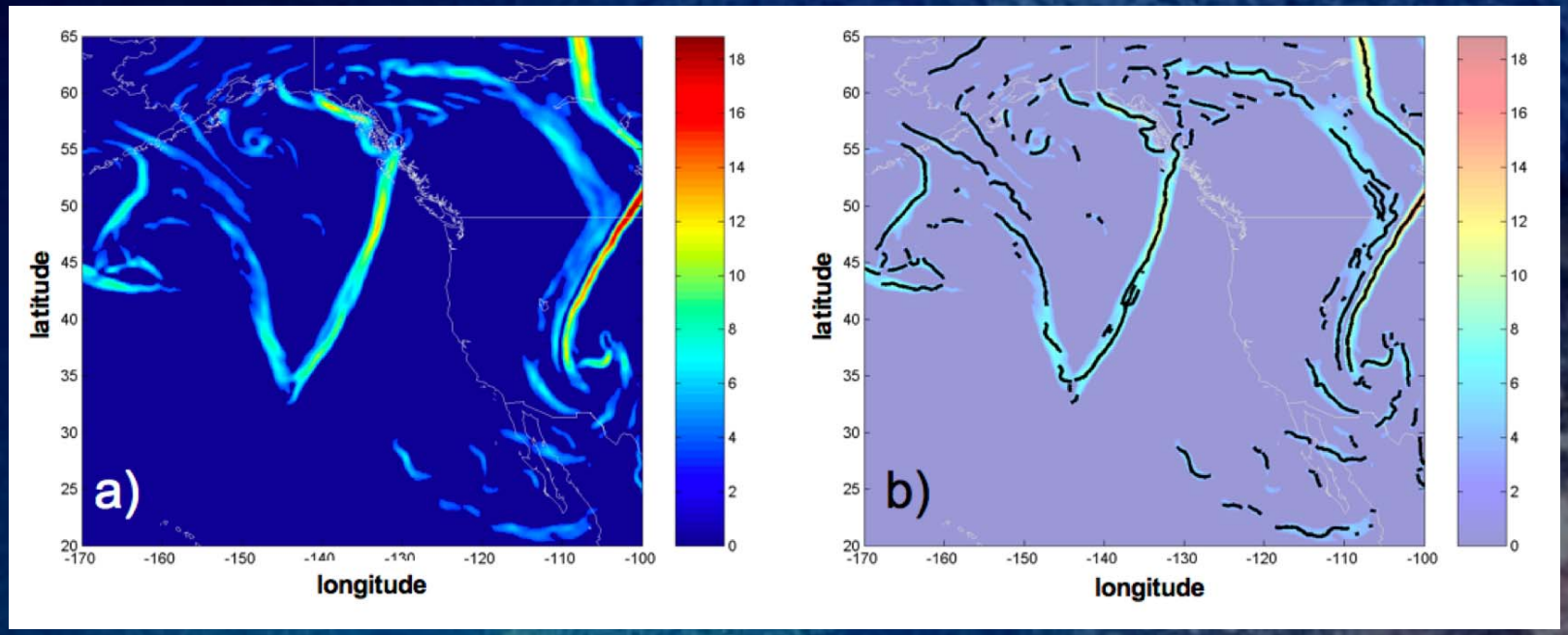
Tropopause Fold Turbulence Detection Processing Schematic (3 of 7)

Smooth GLASH image to keep only synoptic-scale contours → Compute gradient to resolve the major boundaries



Tropopause Fold Turbulence Detection Processing Schematic (4 of 7)

Compute gradient to resolve the major boundaries → Compute contours along the gradient image

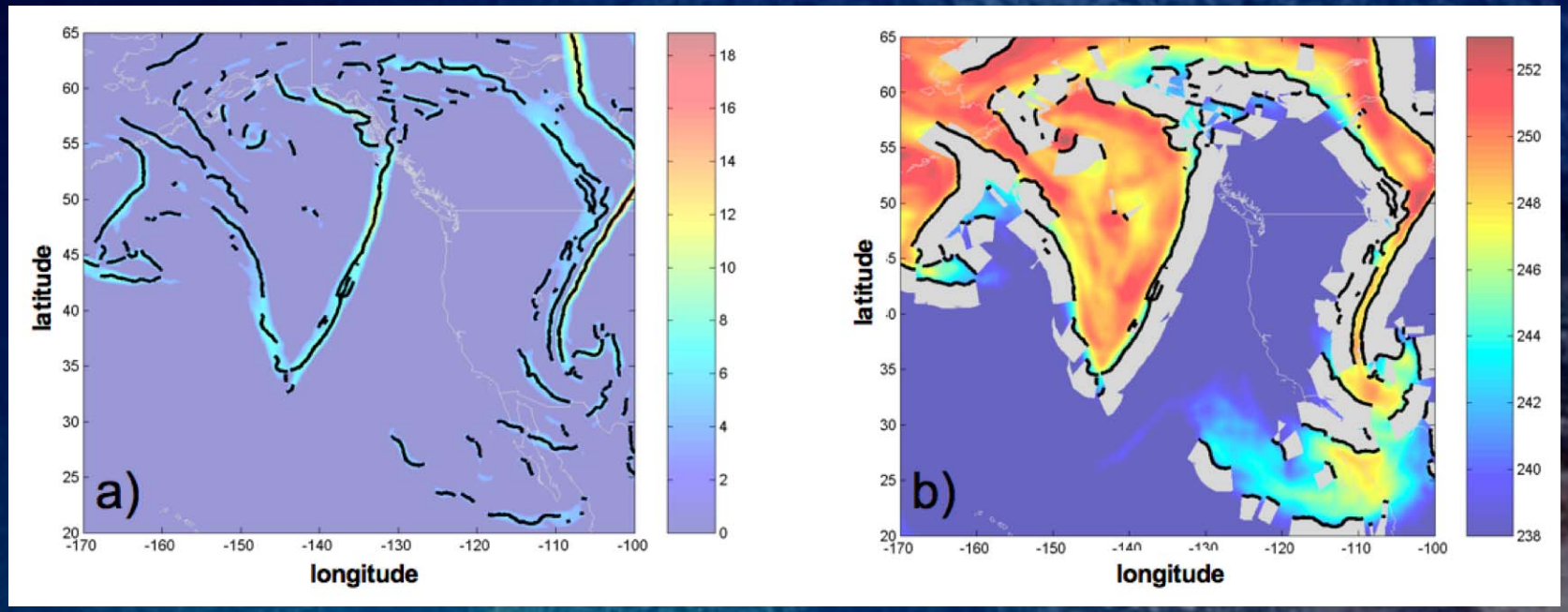


Tropopause Fold Turbulence Detection Processing Schematic (5 of 7)

Compute contours along the gradient image

→

Generate tropopause fold objects as polygons that reach out from the contoured boundaries

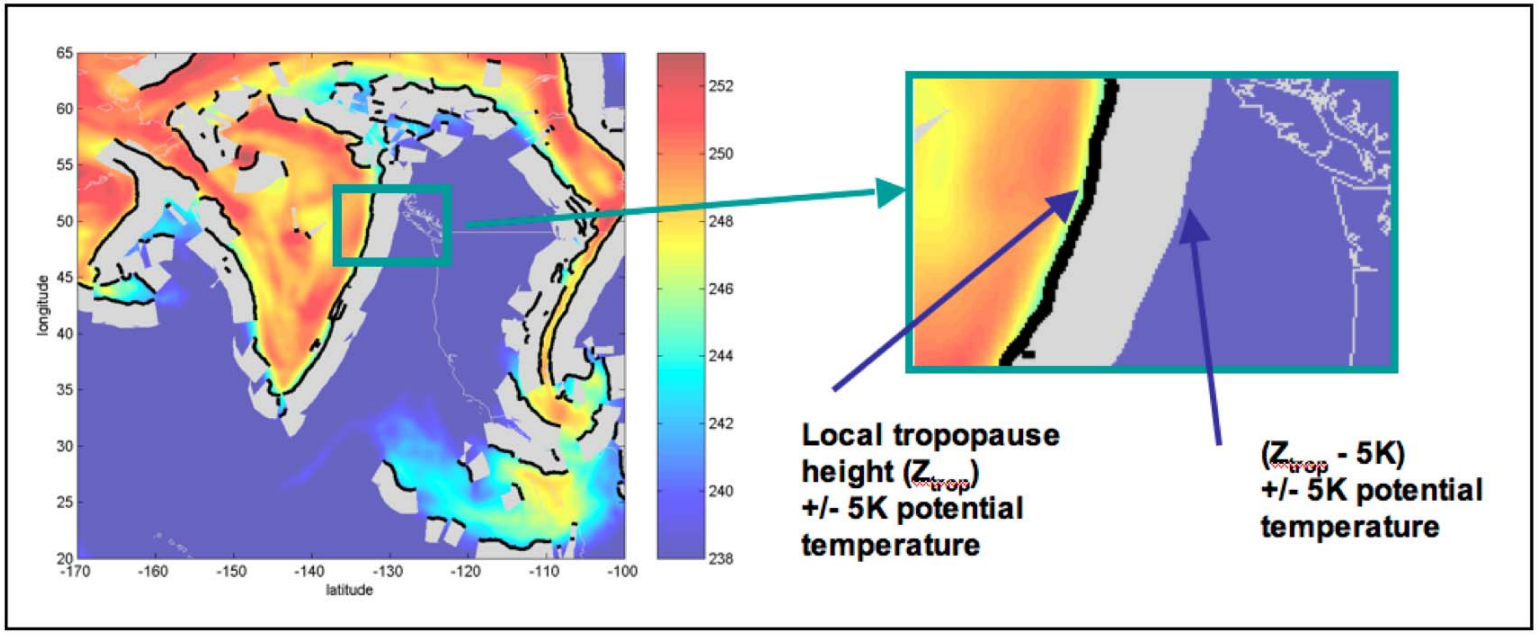


Tropopause Fold Turbulence Detection Processing Schematic (6 of 7)

Generate tropopause fold objects as polygons that reach out from the contoured boundaries

→

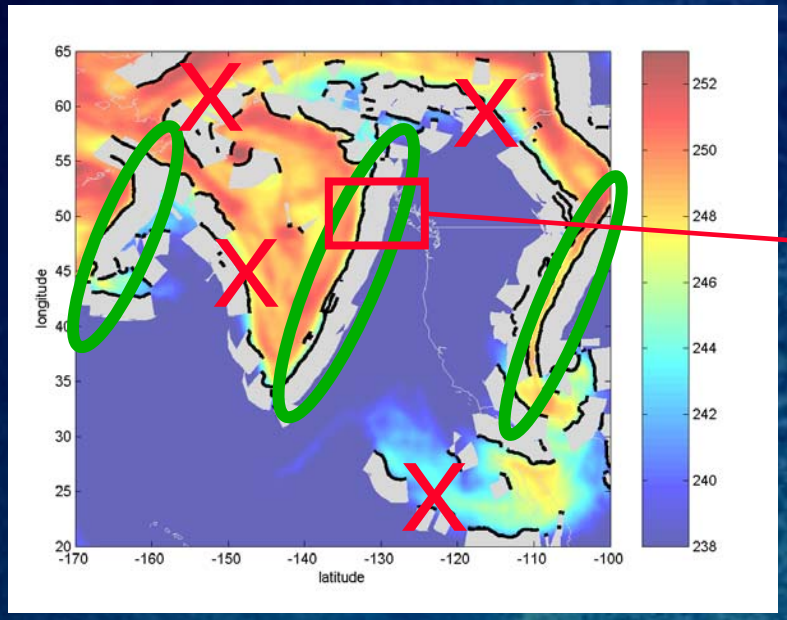
Assign heights to the tropopause fold objects relative to the corresponding tropopause height

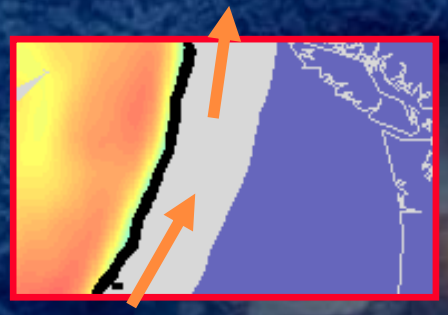


Tropopause Fold Turbulence Detection Processing Schematic (7 of 7)

Generate tropopause fold objects as polygons that reach out from the contoured boundaries

1) Assign trop. fold object orientation (compass direction), 2) Filter for direction and 3) Output the corresponding directions that are hazardous to flights



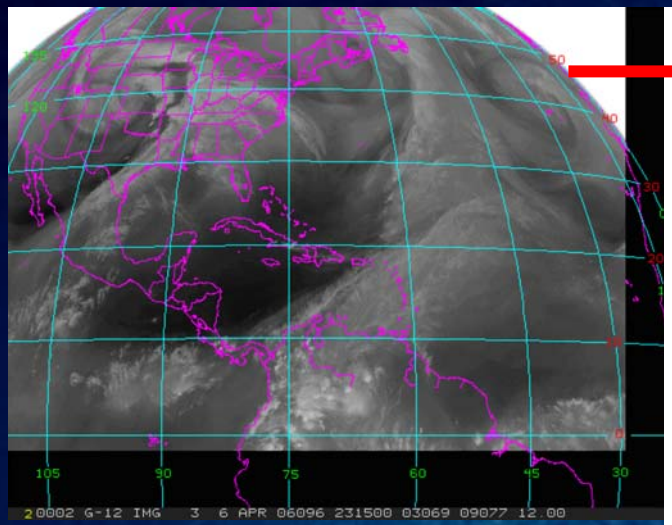


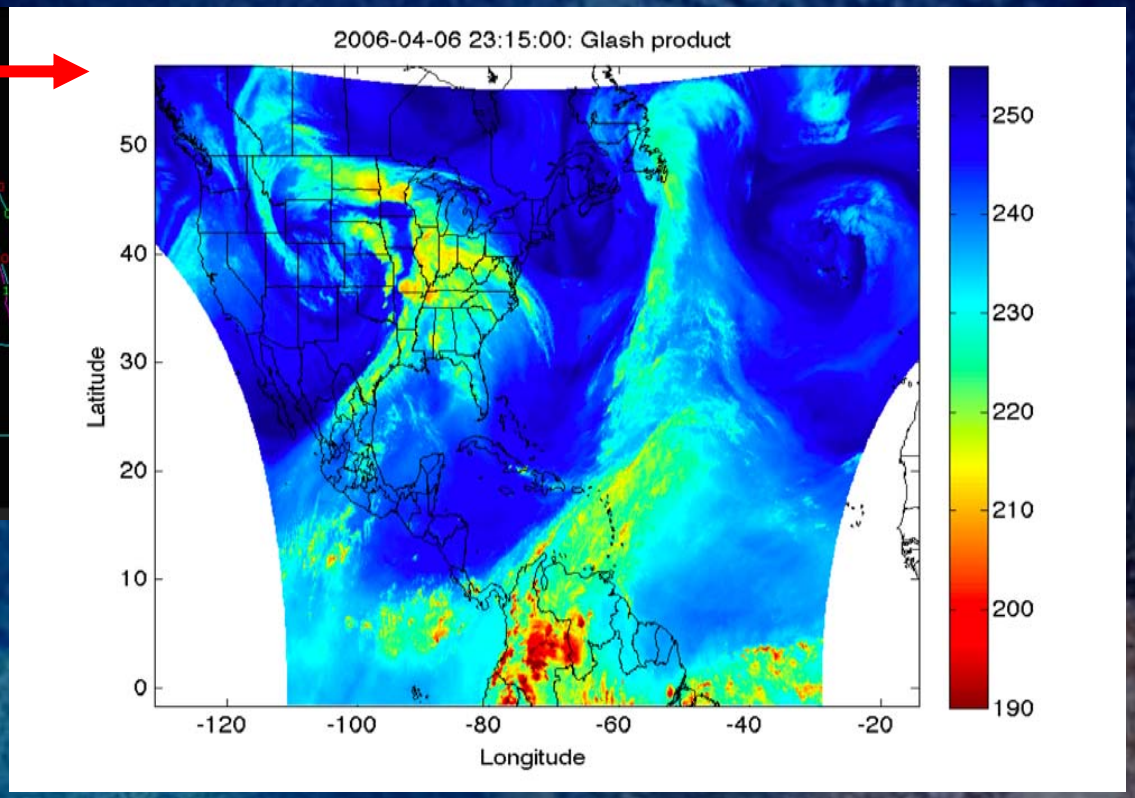
10 to 30 degrees (√)

Examples of Product Output

TFTP Product (intermediate GLASH image)

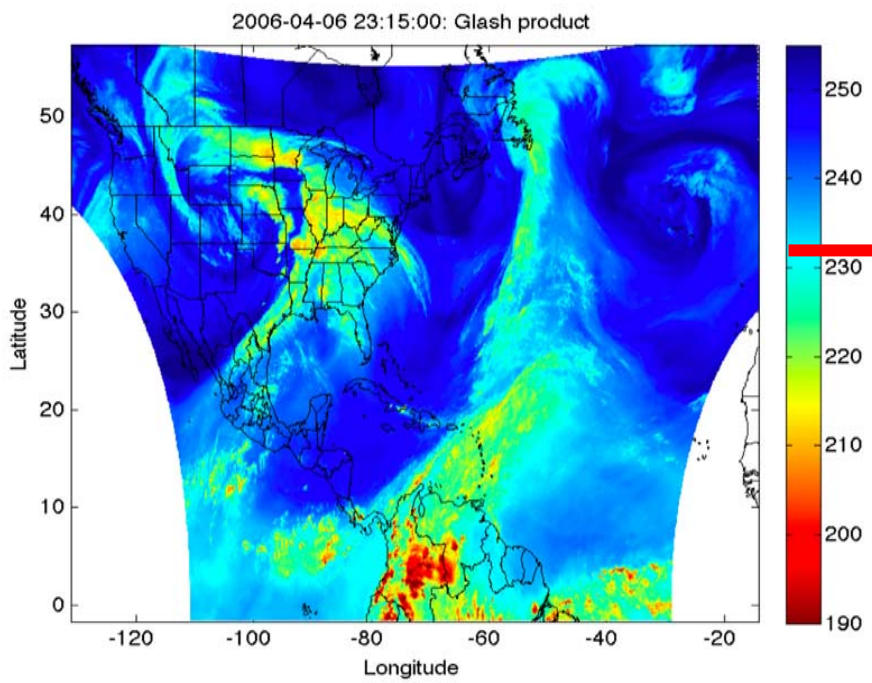
Input: GOES-12 water vapor brightness temperature



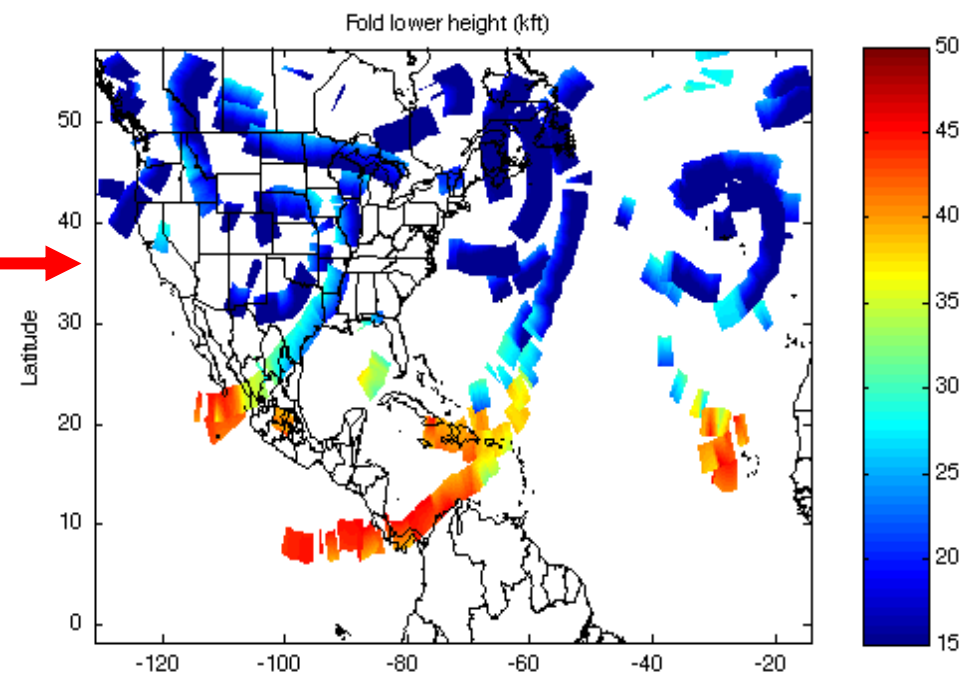


GLASH image (varies with upper trop specific humidity)

TFTP Product
Tropopause fold distribution

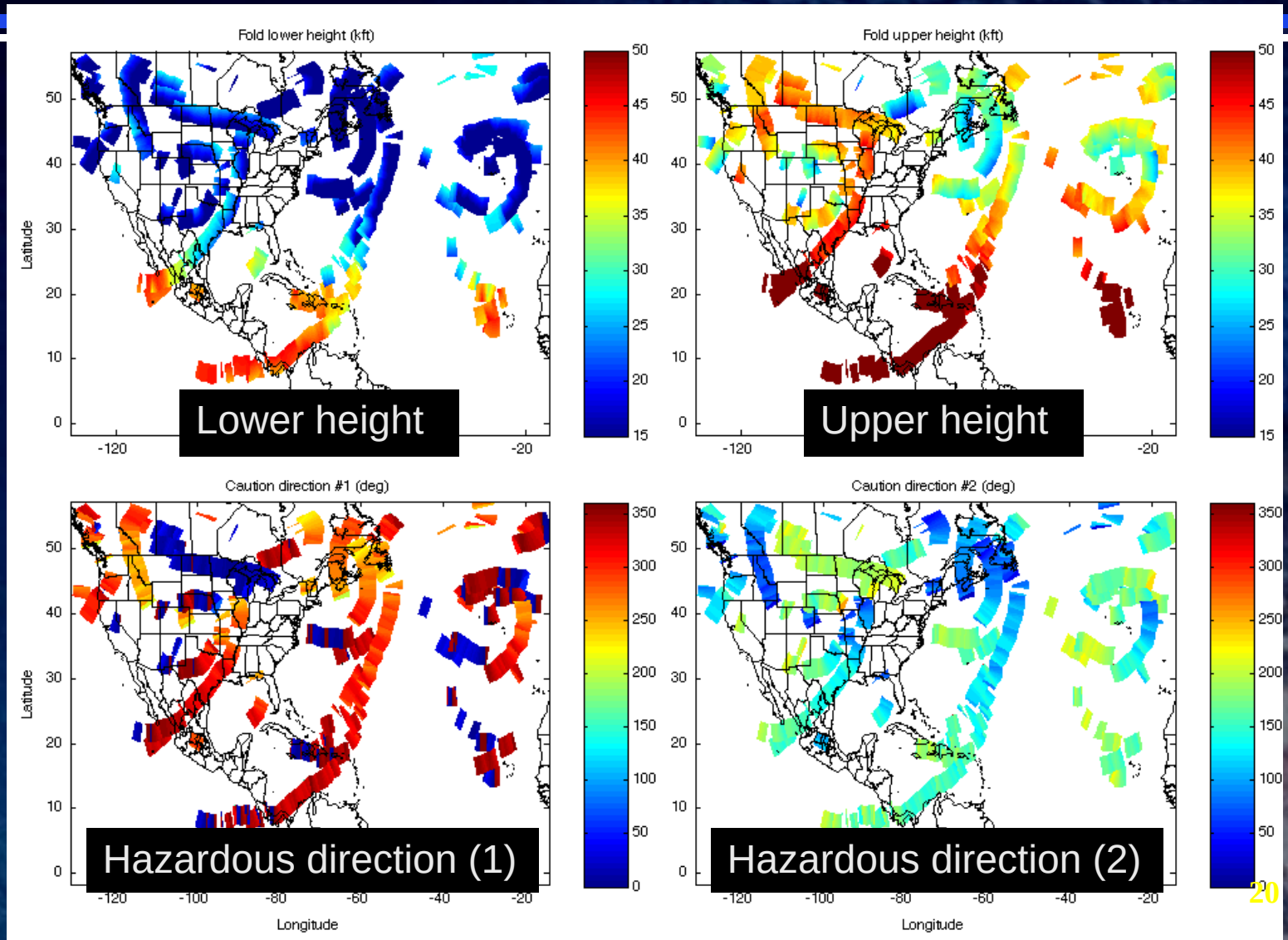


GLASH image (varies with upper trop specific humidity)



Tropopause fold object distribution

TFTP Product
4 output fields



Validation Approach

Trop Folding Turbulence Approach – Offline Validation: Data, Methods

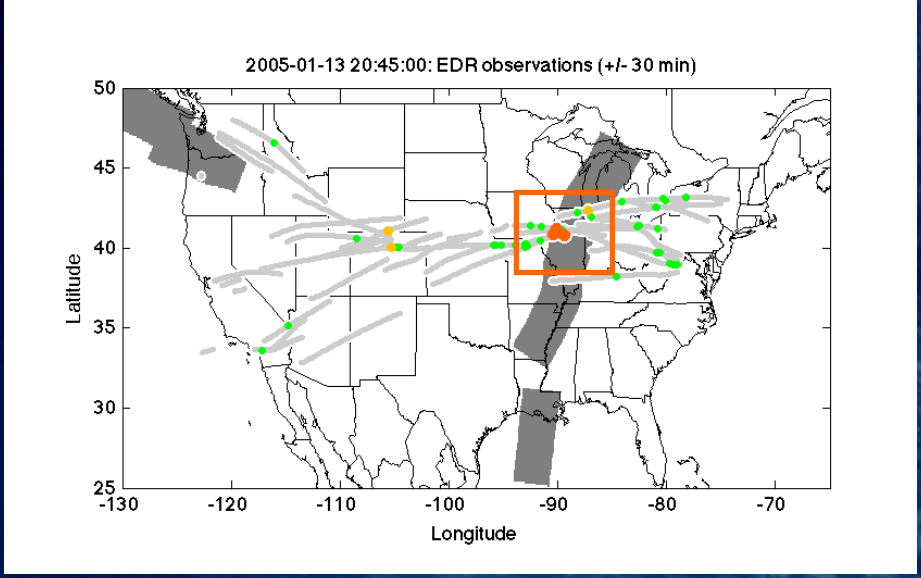
- Test data
  - » GOES-12 Northern Hemisphere (domain of validation data)
  - » Corresponding ancillary NWP files: GFS 12 hour forecasts covering observation times

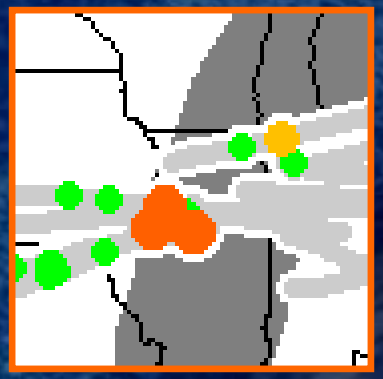
Trop Folding Turbulence Approach – Offline Validation: Data, Methods

- Truth data
  - » Automated in-situ observations of eddy disturbance from commercial aircraft (737s and 757s)
  - » Generally limited to the airspace of the continental U.S.
  - » Turbulence metric is “EDR” (Eddy Dissipation Rate)

Trop Folding Turbulence Approach – Offline Validation: Data, Methods

- Method: Compare Tropopause Fold product with collocated EDR observations



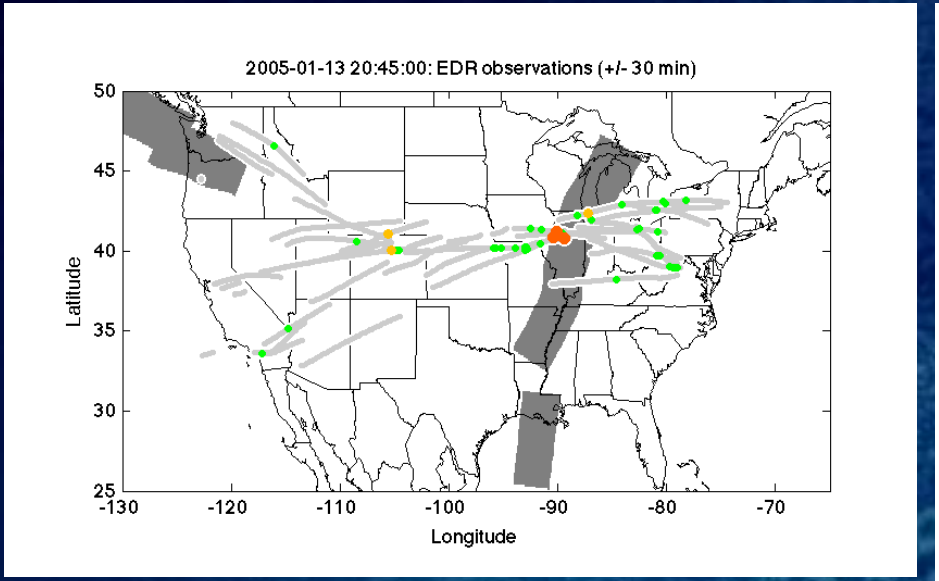


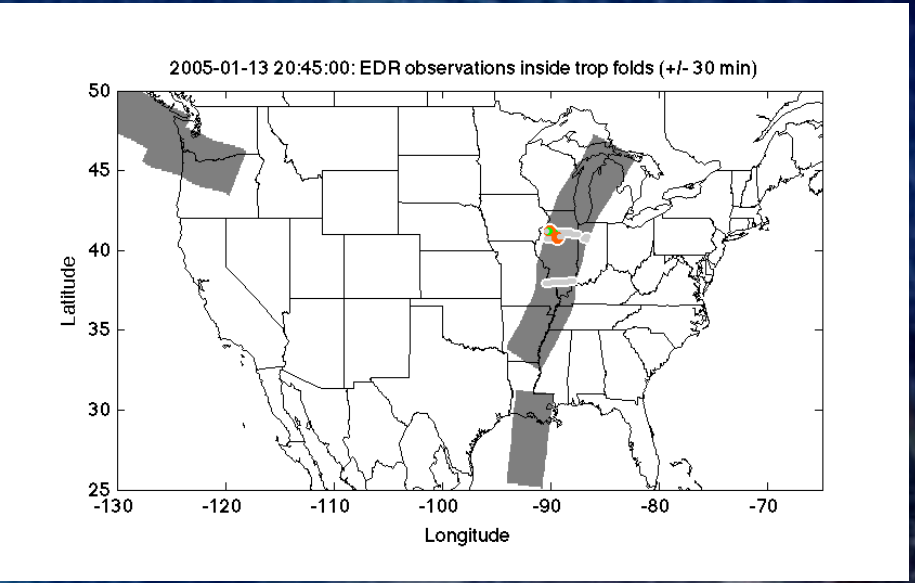
- Moderate turbulence is yellow/orange.
- (Light is green)

All EDR observations +/- 30 minutes from the image time

Trop Folding Turbulence Approach – Offline Validation: Data, Methods

- Method: Compare Tropopause Fold product with collocated EDR observations



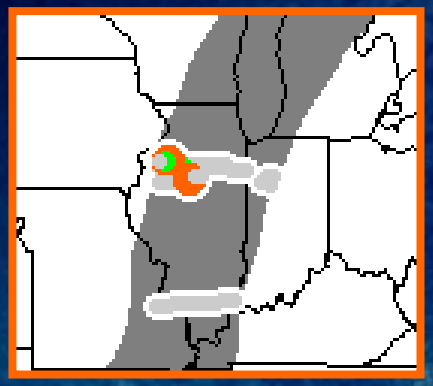


All EDR observations +/- 30 minutes from the image time

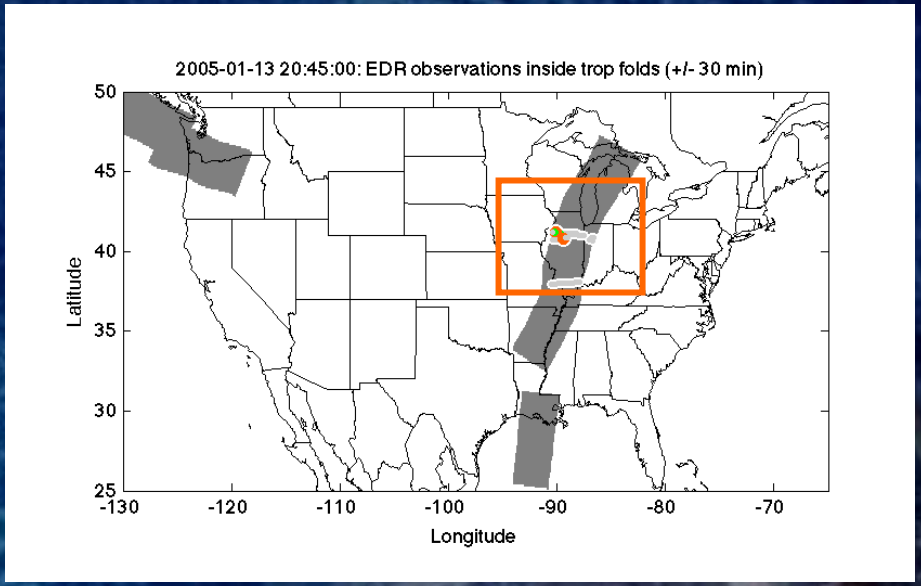
EDR observations collocated with Tropopause Fold product (with vertical and directional constraints).

Trop Folding Turbulence Approach – Offline Validation: Data, Methods

- Method: Compare Tropopause Fold product with collocated EDR observations



(Sub-sampled to the volume of the tropopause fold)



EDR observations collocated with Tropopause Fold product (with vertical and directional constraints).

Validation Results

Validation Results: Status

- The 2009 change in the Product Requirements requires a new validation
  - » The new validation began this year and is on schedule (due October 2010), with preliminary results from 10 cases presented here
- The full validation will consist of 1132 images from November 2005 to February 2007

Validation Results (preliminary)

Times of the sample images for initial validation	
1. 2005 Dec 22 1715 UTC	6. 2007 Jan 04 2315
2. 2005 Dec 22 2015	7. 2007 Mar 29 2015
3. 2006 Apr 06 2315	8. 2007 Mar 29 2315
4. 2006 Apr 15 2315	9. 2007 Jun 06 2315
5. 2006 Sep 21 1715	10. 2007 Dec 03 2015

# Total measurements in trop. folds	# MOG events	Probability of MOG at the spatial scale of trop. folds	Product requirement
2364	88	46%	50%

Steps to reach 100%

- Perform validation on full 1132 image dataset
- Finalize error flag outputs
- Optimize output to meet 50% accuracy requirement (currently at 40%)

Summary

- The Tropopause Folding Turbulence Prediction product uses gradients in the ABI water vapor channel imagery to estimate areas of clear air turbulence at upper-tropospheric air mass boundaries
- The product is uniquely validated with a new, automated, in-situ dataset of eddy disturbances to aircraft.
- Algorithm meets latency requirements and is at 80% accuracy performance
- The complete validation, with additional performance improvements, is planned for October 2010

Extras

Trop Folding Turbulence Approach – Offline Validation: Data, Methods

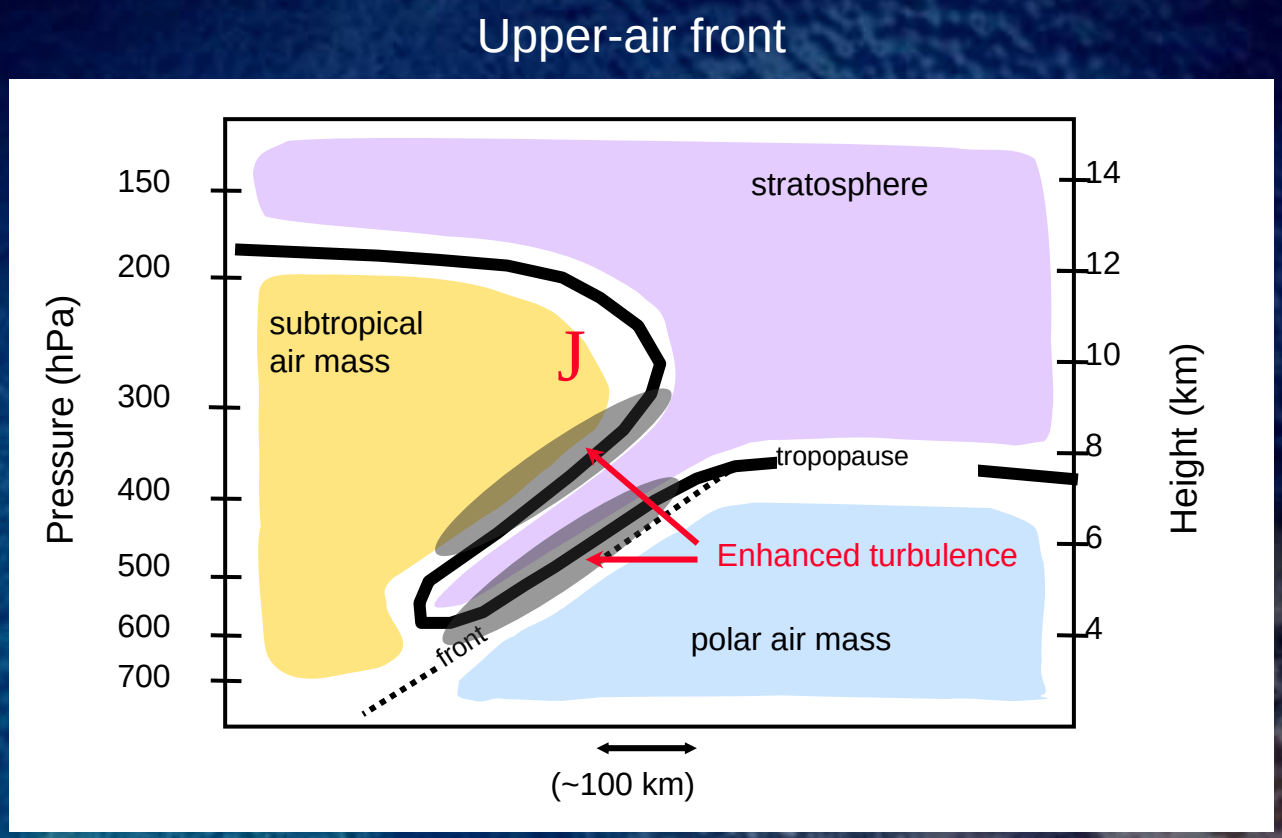
- Method:
  - » Evaluate the probability of occurrence of moderate-or-greater turbulence during aircraft transects through the product's tropopause folds.
  - » The product requirement is 50% accuracy, which is validated as the likelihood of experiencing moderate-or-greater turbulence at least once per aircraft transect through a tropopause fold
  - » The average transect is 16 minutes, so this equates to one "hit" per 16 observations, quantified as

$$1 - (1 - FAR_{1min})^{16}$$

What Is a Tropopause Fold?

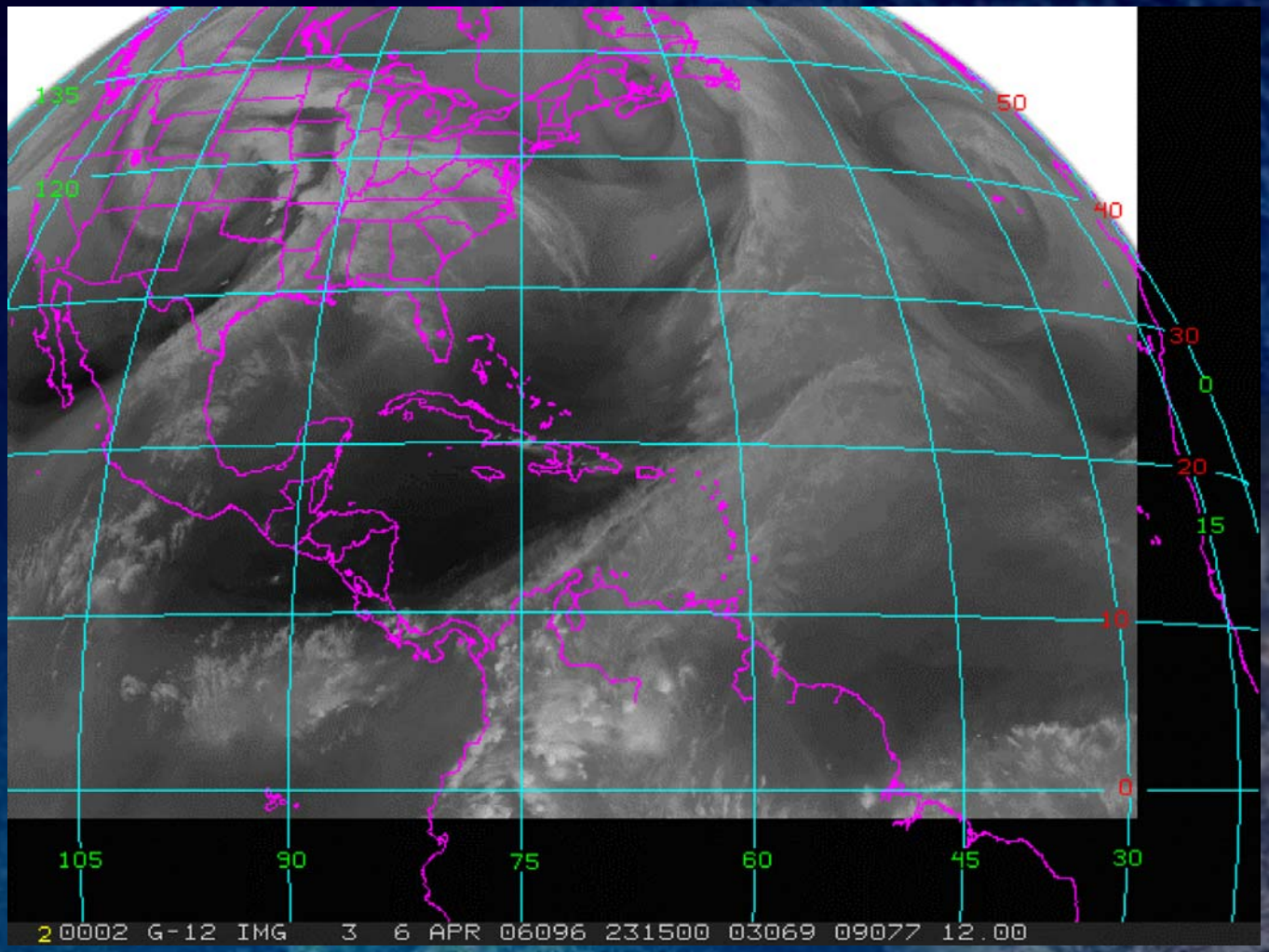
- Shapiro (1980) observed vertical winds (due to turbulent eddies) in this region

- This dynamical instability was confirmed by Shapiro through signatures of chemical mixing at the top and bottom of the tropopause fold



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.

TFTP Product input: 6 April 2006 2345 UTC



GOES-12 water vapor brightness temperature