



National Transportation Safety Board

**Office of Aviation Safety
Washington, D.C. 20594-2000
April 19, 2017**

**ATTACHMENT 3 to the METEOROLOGY GROUP FACTUAL REPORT
DCA16LA214**

United Airlines recurrent training, Fall 2015, turbulence avoidance.

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NTSB, AS-30*

Turbulence Avoidance

Fall Recurrent 2015
October 2015

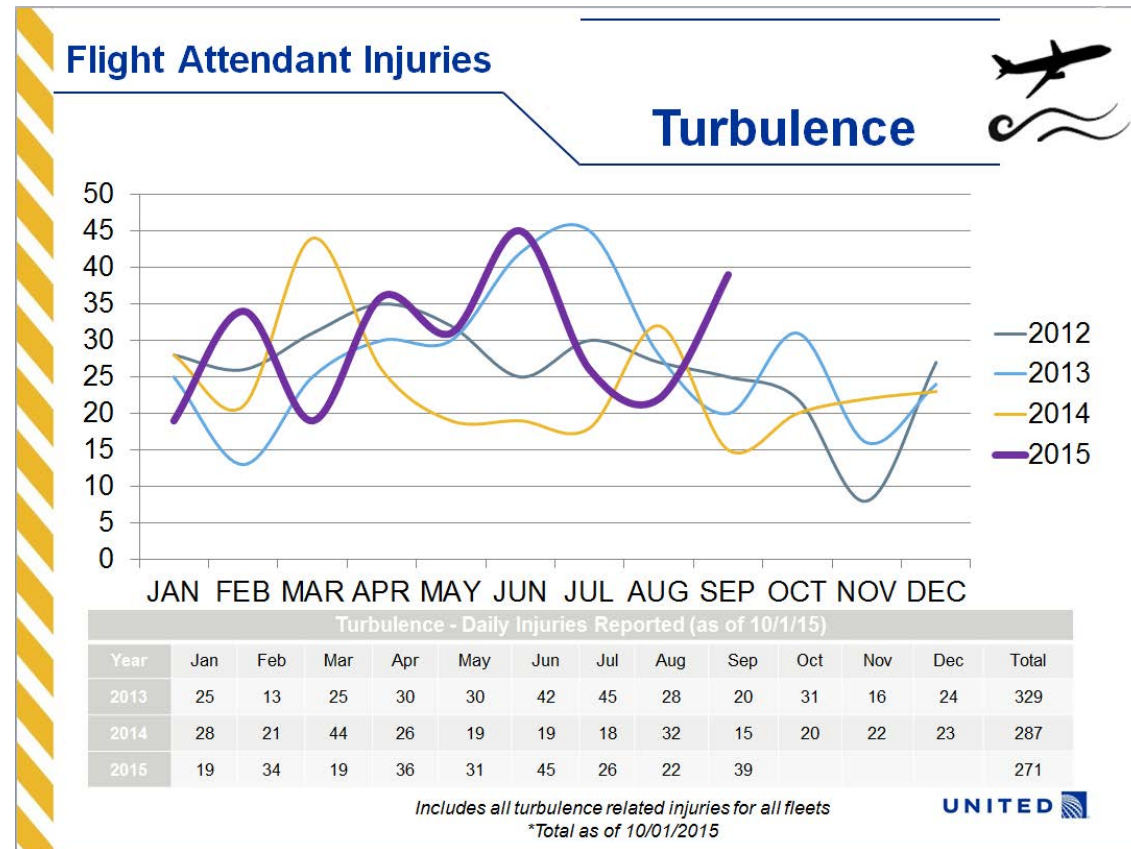


A STAR ALLIANCE MEMBER 

UNITED 

Introduction

- **71%** of weather-related accidents attributed to turbulence (NTSB data)
- Hundreds of FAs injured per year; costs in the \$\$ millions
- In this lesson we will discuss:
 - Using satellite imagery to identify turbulence signatures
 - Flight Explorer recommendations
 - Review of new WSI TAPS and GTG products





Introduction

- Turbulence is leading cause of injuries in commercial aviation
- Turbulence costs the industry **>\$150 million** per year (injuries, ops inefficiency, maintenance)
- Two-thirds of turbulence-related accidents occur above FL300
- Injury-causing events on average are less than 10 seconds in duration and occur with very little or no warning





Turbulence Prediction Difficulties

- Difficult to precisely predict timing, altitude, and severity of turbulence encounters (*"it came outta nowhere!"*)
- Encounters are short-lived, often occurring great distance from areas of strong radar reflectivity
- Industry-wide data shows that in strong turbulence encounters, flights preceding and following the incident aircraft did not experience same magnitude of turbulence or injuries.



Turbulence Mitigation

- Tools available to Dispatch:



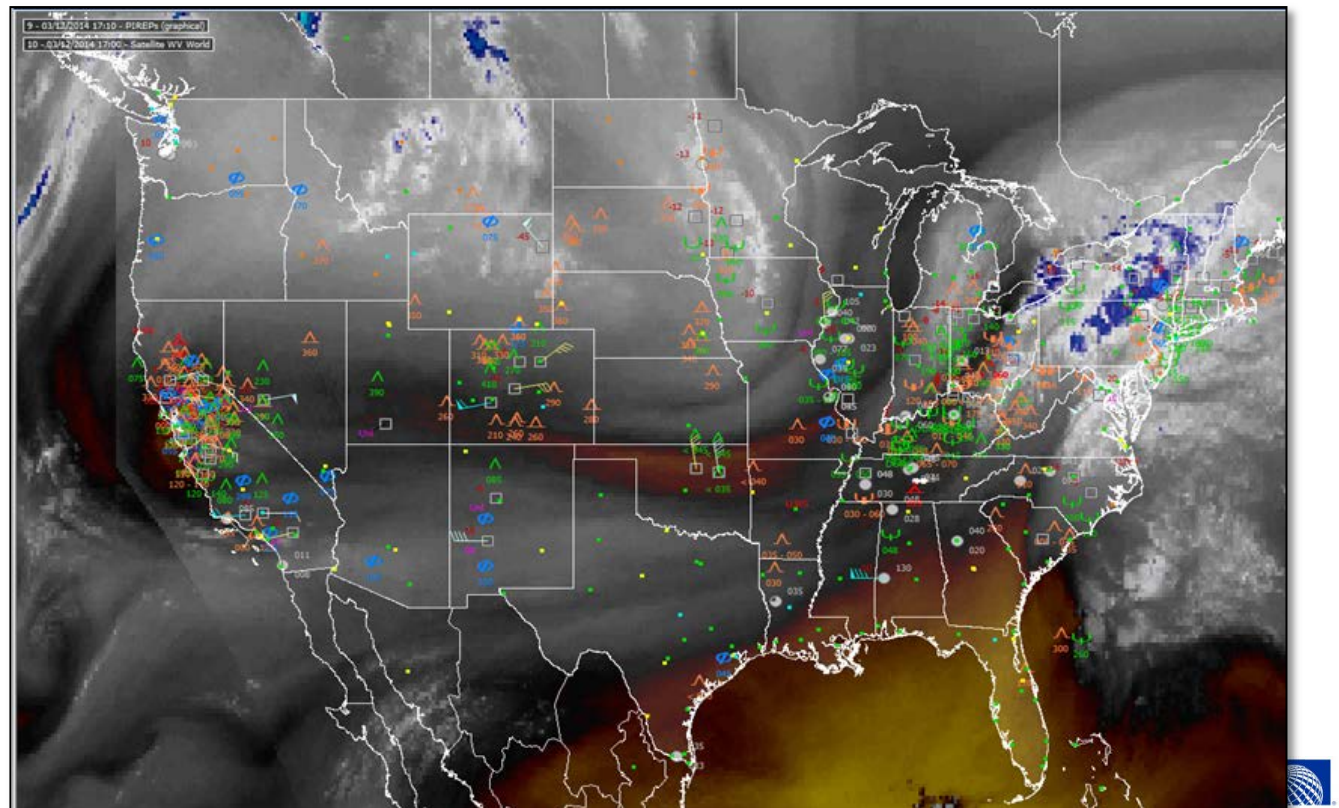
- Traditional PIREPs
- Satellite imagery
- WSI FPGs/SIGMETs
- WSI Graphical Turbulence Guidance (GTG)
- WSI TAPS
- Government SIGMETs



Satellite Turbulence Recognition

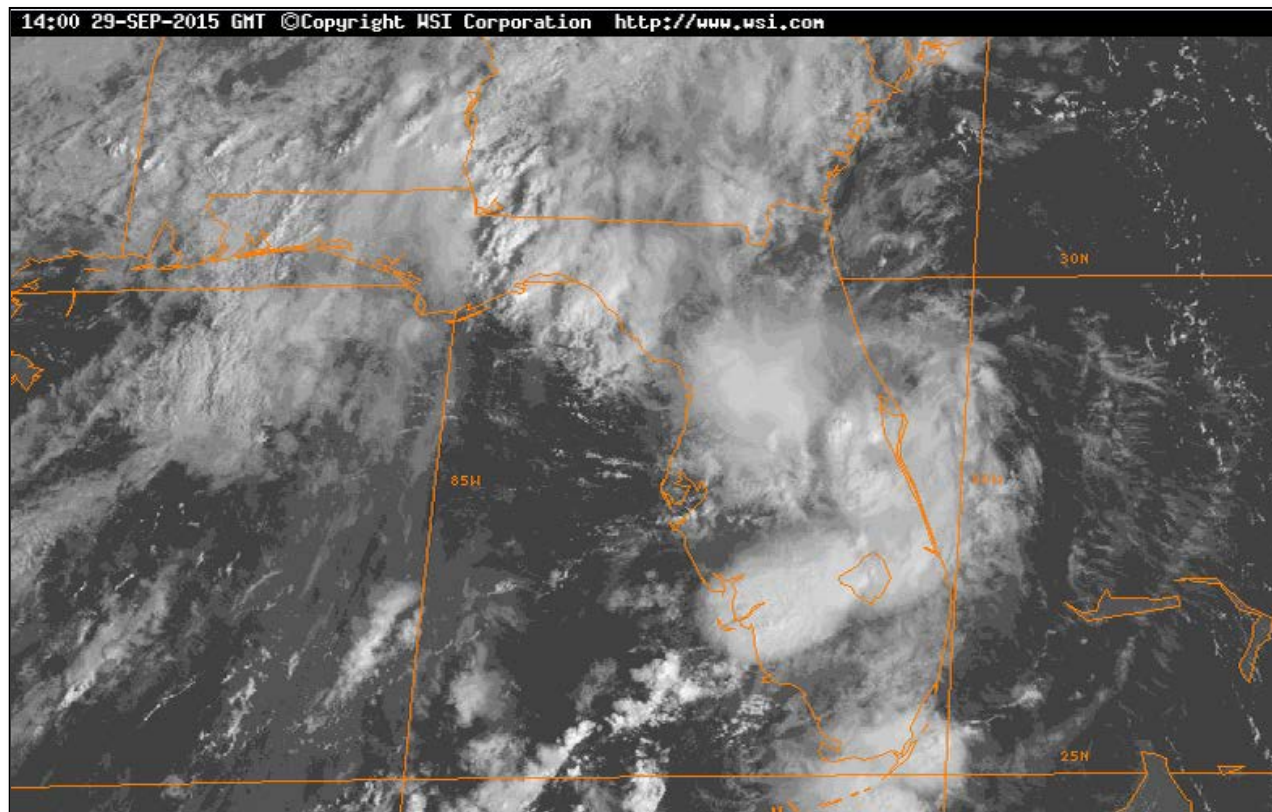
Satellite Imagery Interpretation

- Identify jet streams and other significant upper air features important to flight planning process.
- Suggests presence of shear & turbulence, but does not identify altitude.
- Available as overlays in Flight Explorer or WSI Optima.
- Three distinct channels each providing different information:
 - Visible
 - Infrared
 - Water Vapor



Visible Satellite Imagery

- Sensor detects percentage of visible light energy reflected by the earth's surface or atmosphere ("albedo"). Imagery shaded with gray color scale based on amount of reflection
 - **Bright white = more reflected light (*thick clouds*)**
 - **Dark gray = less reflected light (*clear skies*)**



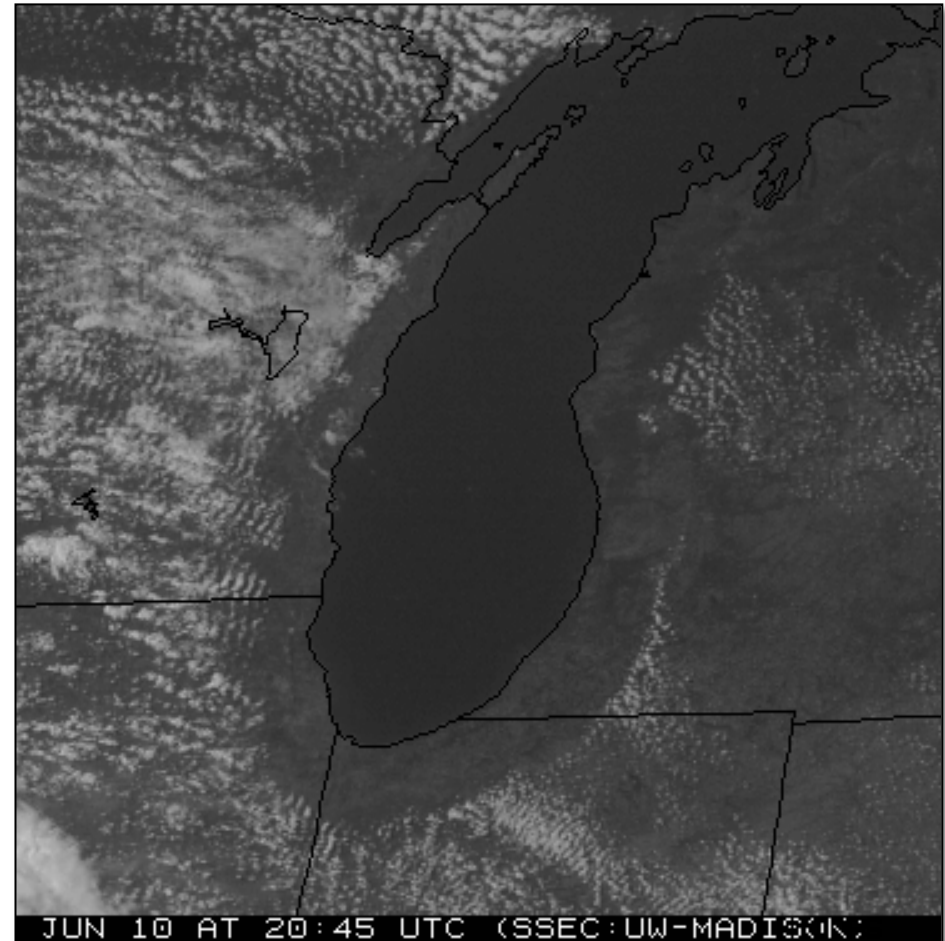
Using Visible Satellite Imagery

Strengths

- Higher resolution than other channels
- Identify small-scale features
 - Thunderstorms with overshooting tops
 - Fog
 - Frontal zones (e.g. sea breeze)

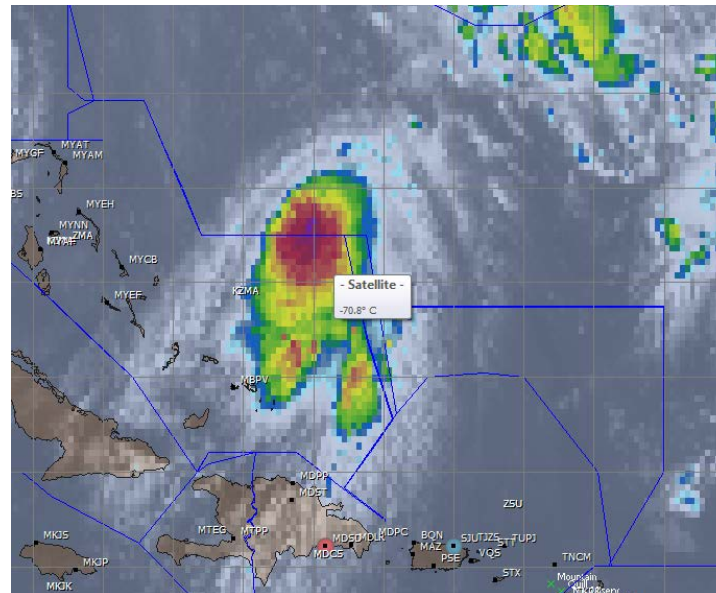
Weaknesses

- Useless at night
- High-resolution imagery limited to US
- Difficult to distinguish clouds at various altitudes



Infrared Satellite Imagery

- Infrared (IR) sensors detect the amount of heat energy (infrared radiation) being emitted by an object (cloud/surface). The intensity of the IR radiation reaching the satellite depends on the warmth of the object emitting that radiation.
 - The brighter the object displayed, the colder the temperature of the object.
 - The dimmer the object displayed, the warmer the temperature of the object.



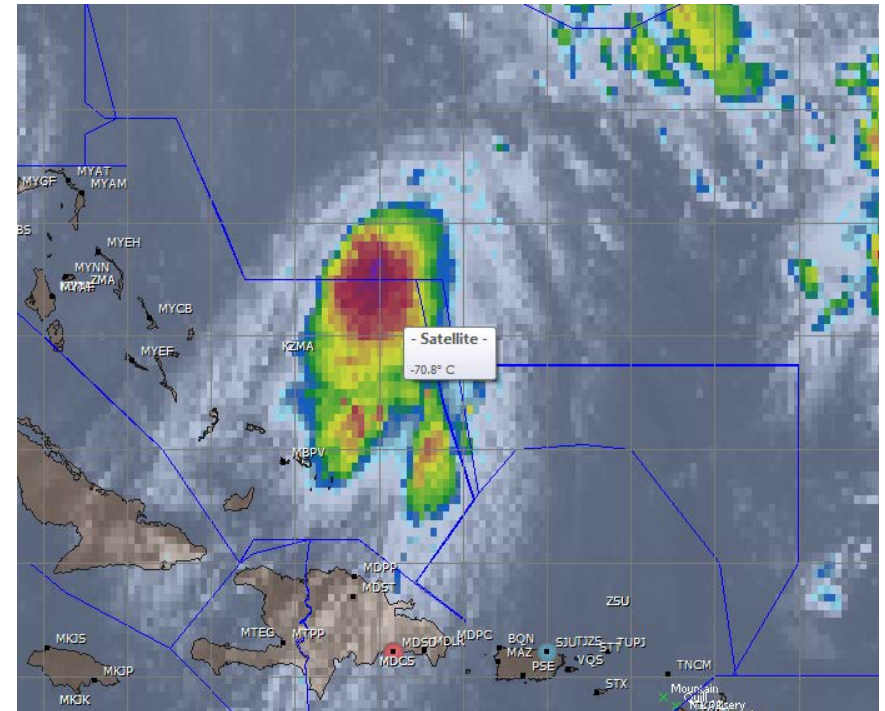
Using Infrared Satellite Imagery

Strengths

- Available 24/7/365
- Color enhancement possible for distinguishing features.
- Ability to distinguish developing or dissipating system prior to changes via radar.

Weaknesses

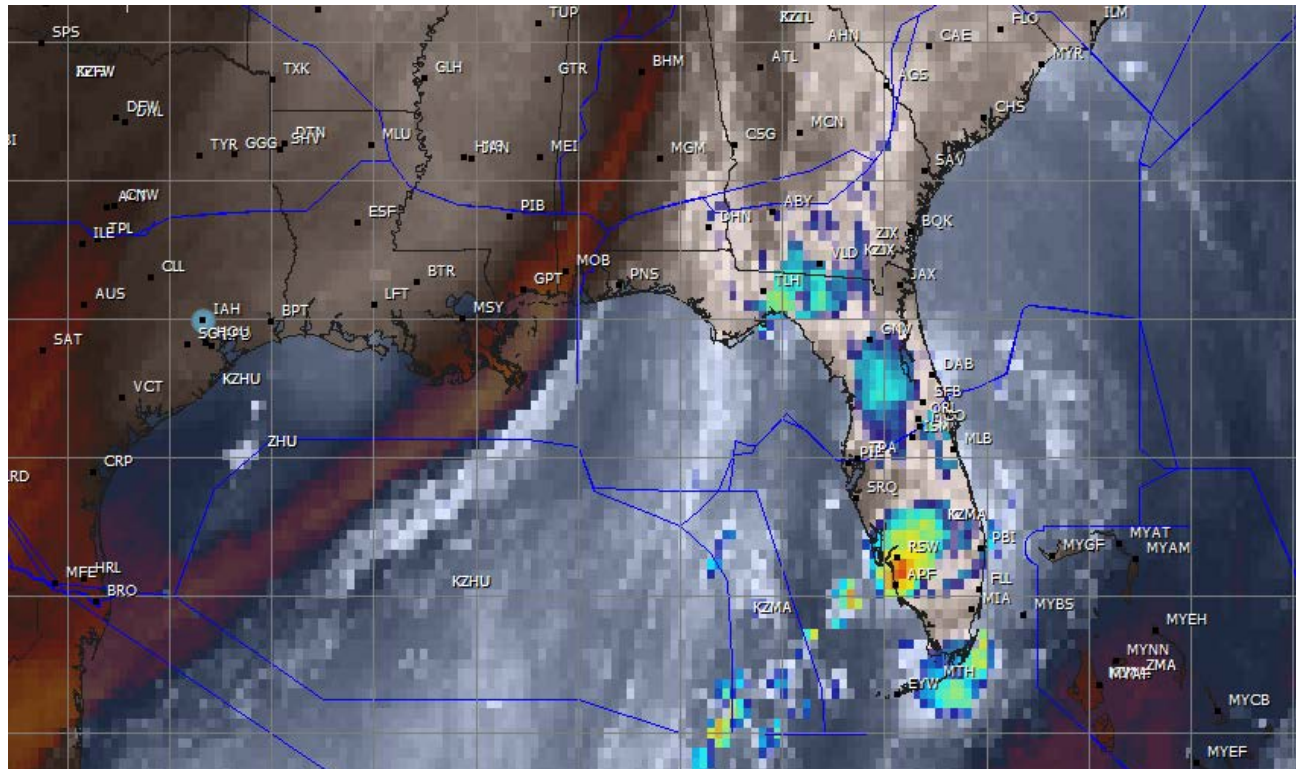
- Course resolution compared to visible imagery.
- Effectivity reduced closer to polar regions due to lack of changes in temperature.



Water Vapor Satellite

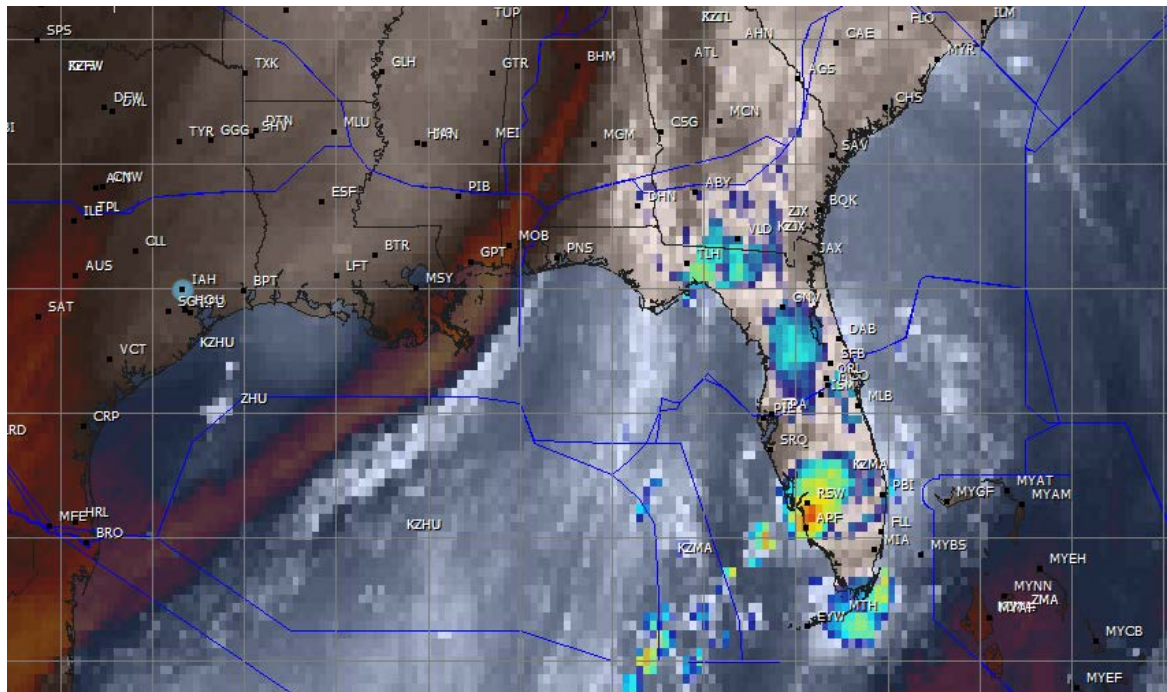
Water vapor (WV) imagery is a measure the amount of radiation emitted by water vapor contained in the mid to upper levels of the troposphere at a specific wavelength. Water vapor, similar to IR imagery, displays the amount of water vapor in a parcel of air based on a grey scale or can be color enhanced for specific features.

- The more saturated a parcel of air, the brighter the imagery will be displayed.
- The drier a parcel of air, the darker the imagery will be displayed.



Water Vapor Satellite

- Water Vapor strengths:
 - Available 24/7/365
 - Ability to discern vertical movement of air (rising/sinking) when animated.
 - Displays synoptic features such as troughs, ridges, and jet stream
- Water Vapor weakness:
 - Cannot discern low altitude features
 - Course resolution



Satellite Synopsis

The table below summarizes the three satellite sensors and their distinct capabilities:

- Visible satellite imagery senses reflected solar radiation.
- Infrared sensors measures the amount of radiation energy re-emitted as heat.
- Water Vapor imagery displays the strong emission (or absorption) of water vapor in the upper troposphere

Channel	Wavelength	Name	Use
Channel 1 (VIS)	0.55-0.75 μm	Visible	▪ Daytime only ▪ Morning fog, ice and snow cover, pollution and haze ▪ Detect convectively-induced turbulence signatures (CIT) (e.g. overshooting tops) ▪ Locate sea breeze fronts and outflow boundaries
Channel 2 (IR2)	3.8-4.0 μm	Infrared	▪ Day/night cloud cover ▪ Mid-latitude cyclones ▪ Thunderstorm growth/decay via enhanced color imagery of cloud-top temperatures ▪ Turbulence signatures (e.g. transverse banding, CIT)
Channel 3 (WV)	6.5-7.0 μm	Water Vapor	▪ Mid to upper-level moisture content and movement ▪ Detect clear-air turbulence (e.g. mountain waves) ▪ Infer rising/sinking motion and turbulence associated with upper-level fronts and troughs ▪ Identify shortwave troughs embedded in jet stream

Satellite Signatures

- Six satellite signatures can be easily identified in satellite imagery:
 1. Moisture Channel Darkening
 2. Transverse Banding
 3. Deformation
 4. Baroclinic Leaf Cloud Pattern
 5. Mountain Wave
 6. Overshooting Tops/Rapid Vertical Expansion



Moisture Channel Darkening

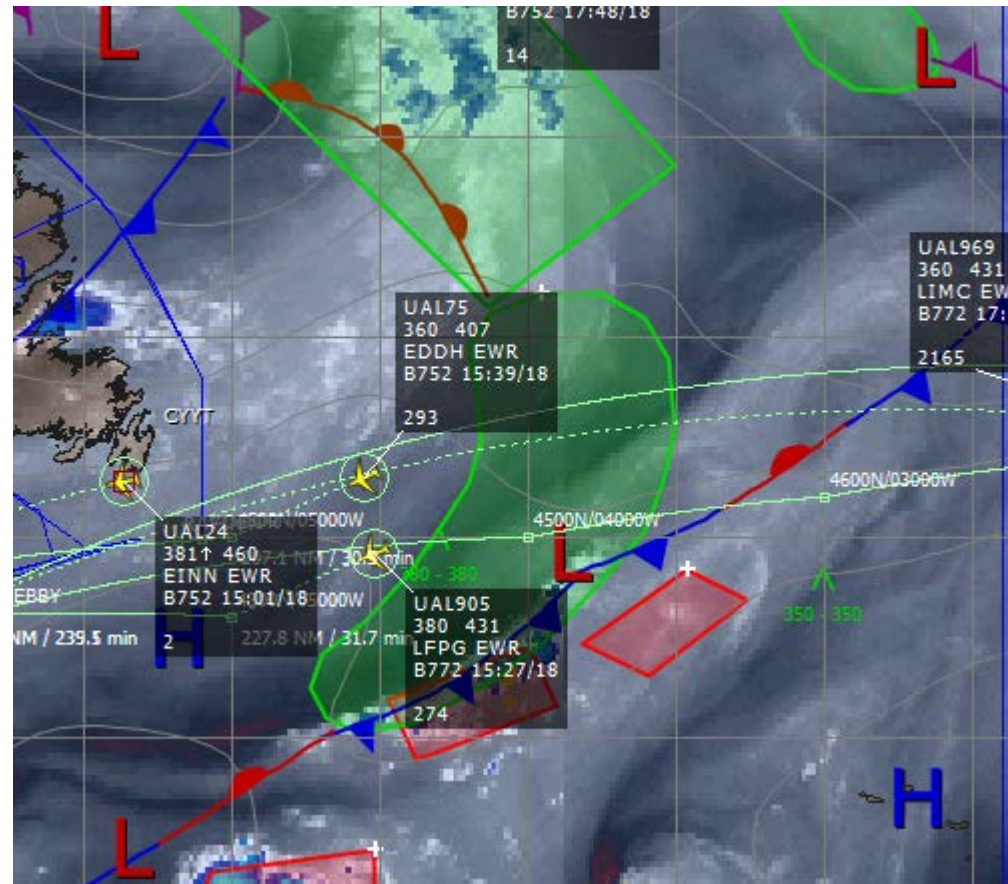
Water Vapor imagery interpretation aids in the identification of turbulence by displaying areas of upper level convergence and areas of deep sinking air.

In areas where these two features occur within relative proximity along a shear zone (e.g., upper level trough or along curved jet stream curves) clear air turbulence is most likely to form.

Moisture channel darkening is best seen when imagery is placed into a loop.

Easiest turbulence satellite signature to locate on Flight Explorer/WSI Optima.

Moisture channel darkening is not an official term, but is used in NASA reports discussing turbulence related incidents.



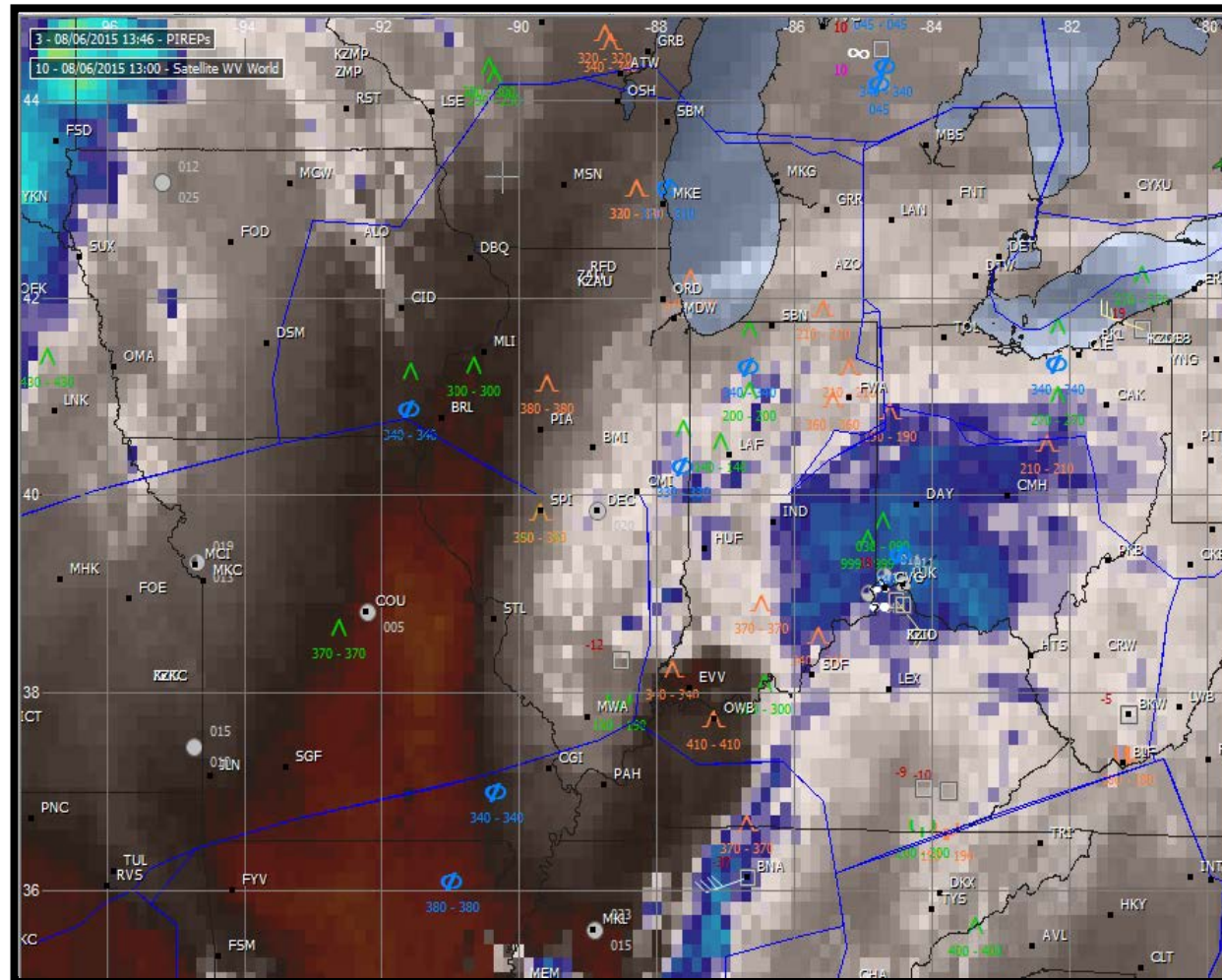
Moisture Channel Darkening Example

The following are the steps in the identification of potential moisture channel darkening

Identify the area where you have rising air associated with upper level convergence

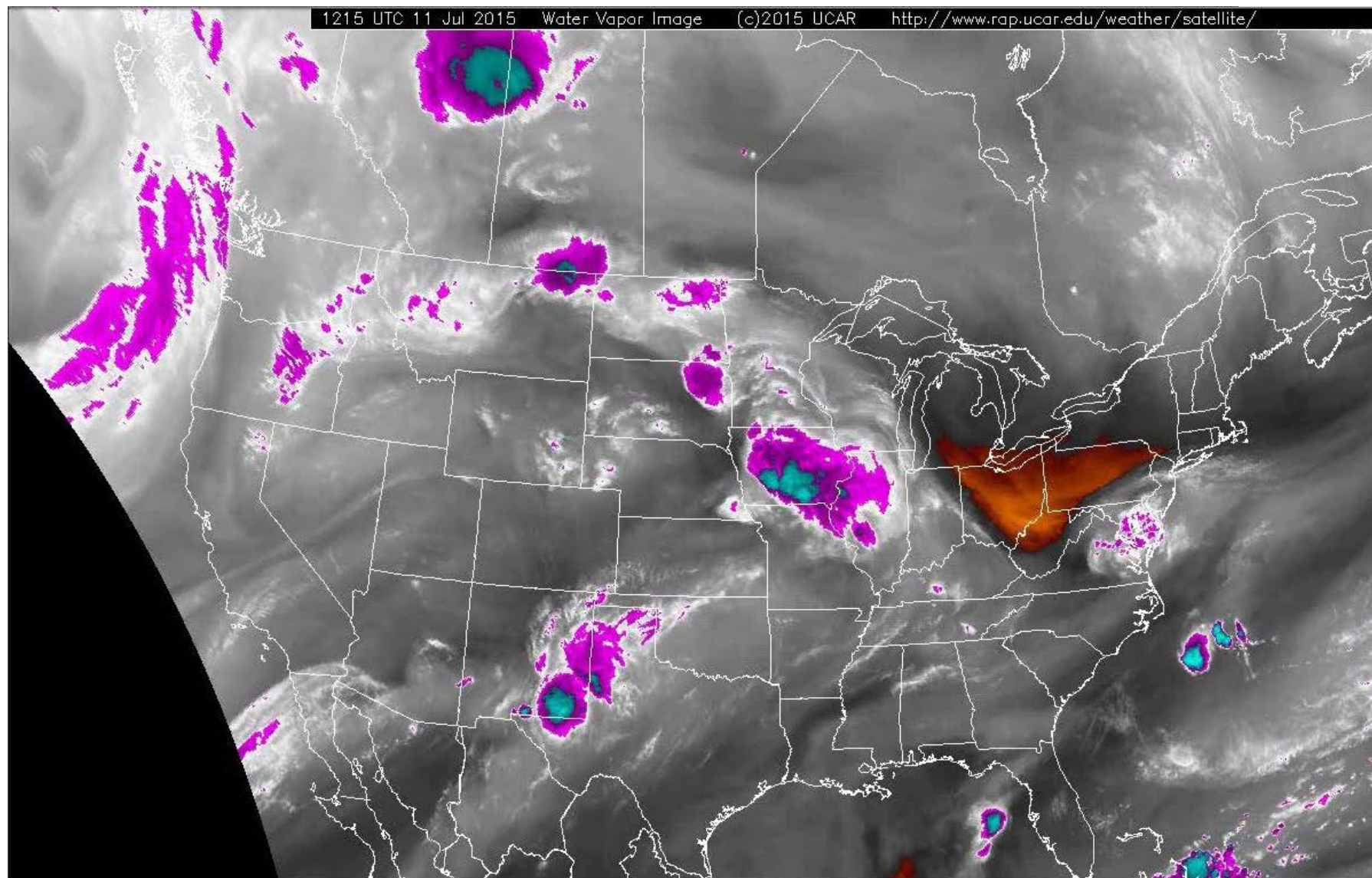
Locate the area where you have air that is drying, therefore sinking.

Along the border of these two air masses, especially when sharply defined as shown to the right, will be the most likely location for turbulence.





Moisture Channel Darkening Example



Transverse Banding

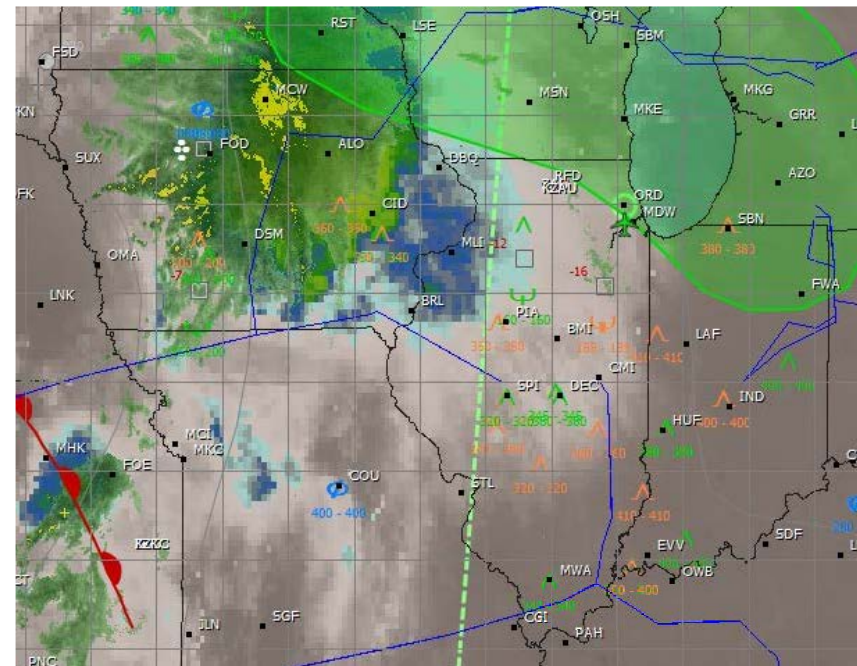
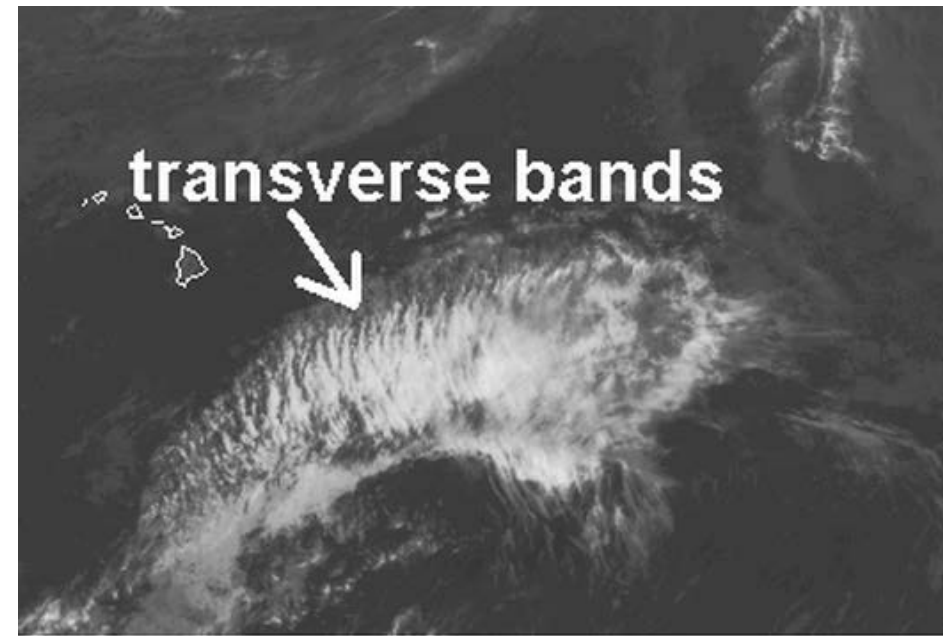
Transverse banding are parallel bands of clouds that form a jet stream, perpendicular to (transverse or across) the jet flow. These bands are best associated with upper tropospheric turbulence.

Banding features are best identified in infrared imagery, but can be identified in visible or WV imagery.

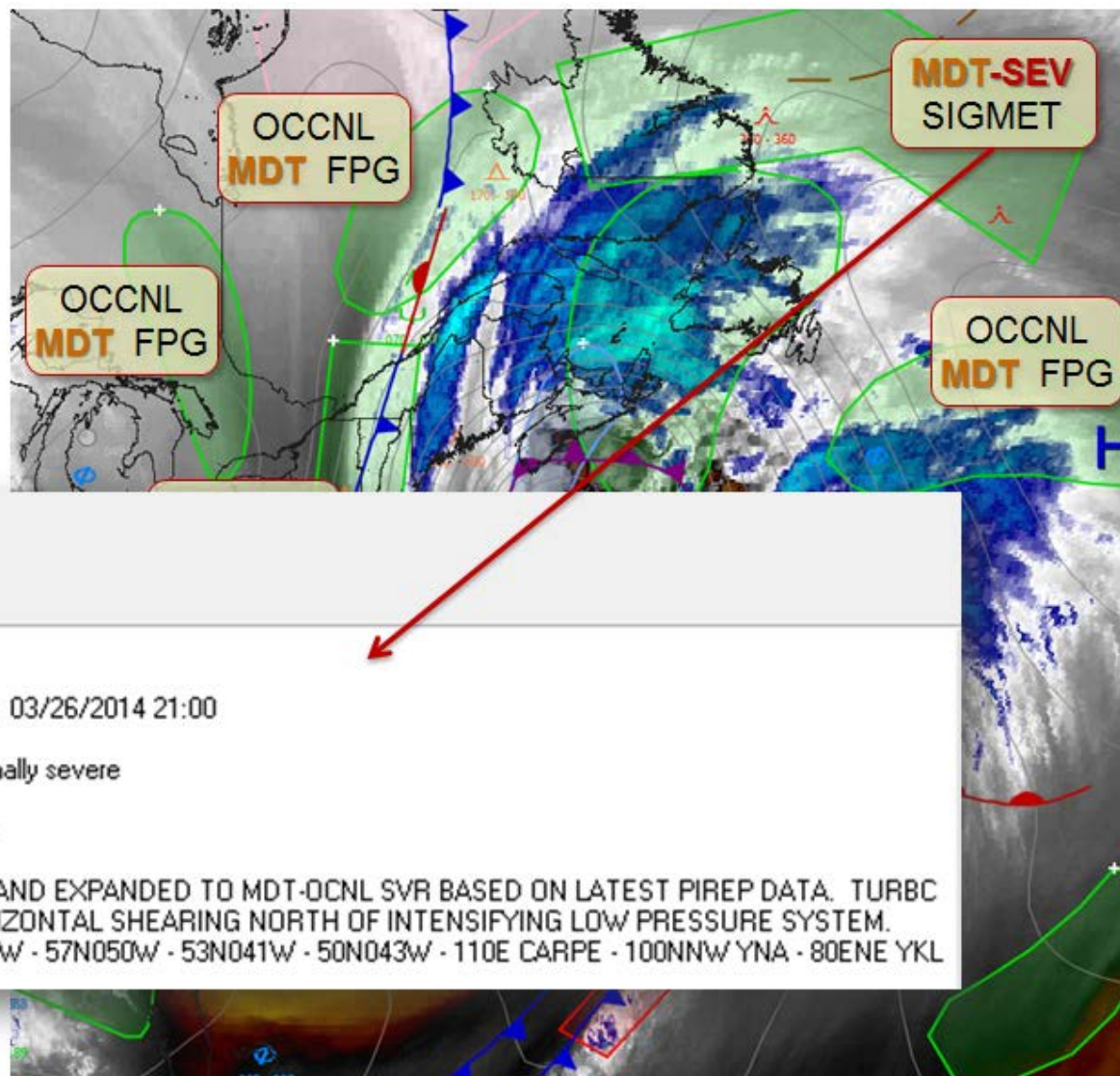
Similar to mountain waves, but have uneven spacing between bands and the shape does not repeat downstream.

Transverse banding will move with the jet stream and can take hours before dissipating.

WSI will identify well-defined transverse banding in their FPGs and Sigmets.



Transverse Banding



Sigmet label: TURB 03599

Details

ID: TURB 03599

Issued: 03/25/2014 22:50

Valid: 03/26/2014 17:45 to 03/26/2014 21:00

Type: Normal

Severity: Moderate, occasionally severe

Altitude: FL320 to FL380

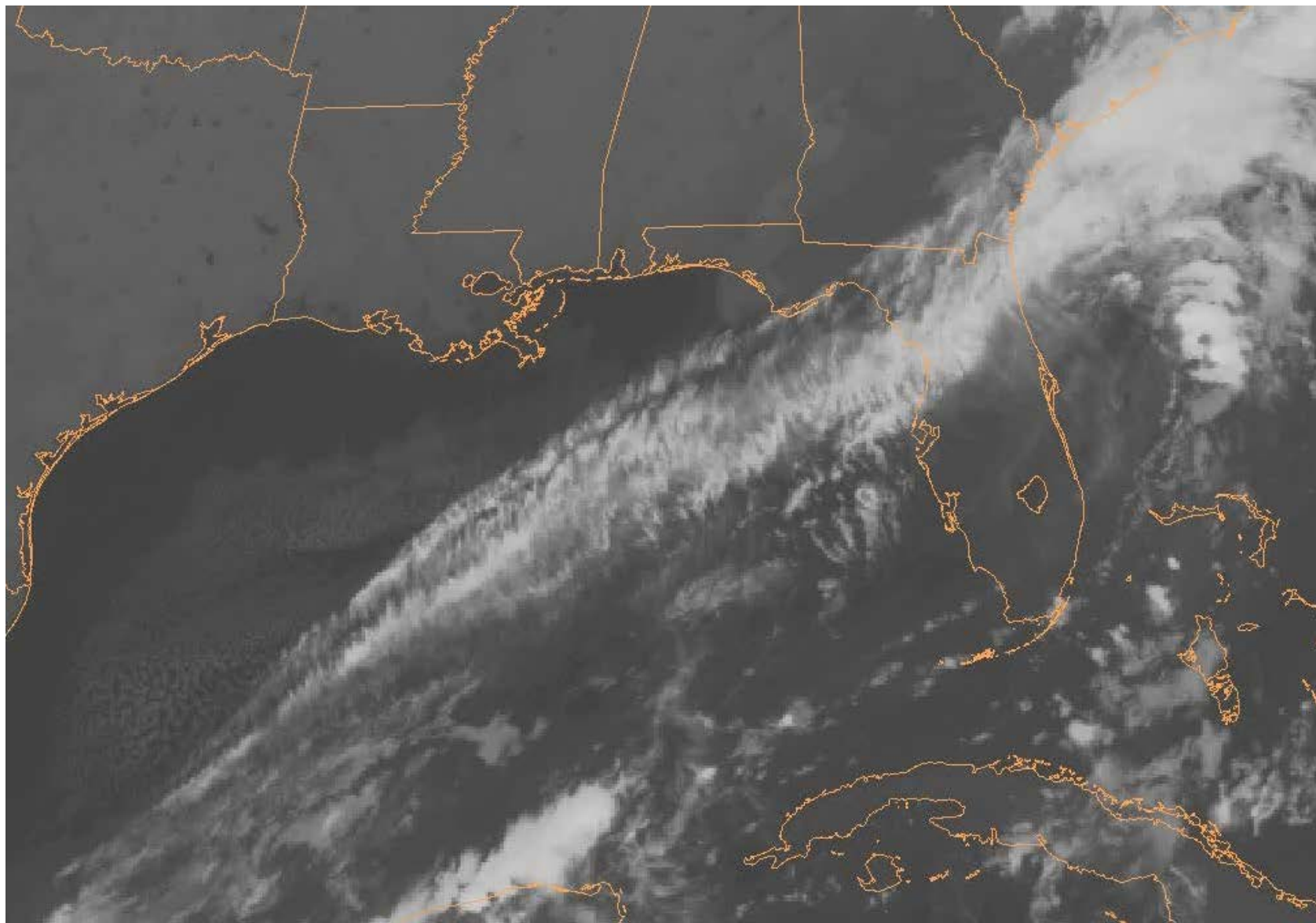
Movement: NNE at 20 knots

Outlook: No change

Description: ** UPGRADED AND EXPANDED TO MDT-OCNL SVR BASED ON LATEST PIREP DATA. TURBC ASSOC WITH SHARP HORIZONTAL SHEARING NORTH OF INTENSIFYING LOW PRESSURE SYSTEM. AREA 80ENE YKL - 57N051W - 57N050W - 53N041W - 50N043W - 110E CARPE - 100NNW YNA - 80ENE YKL



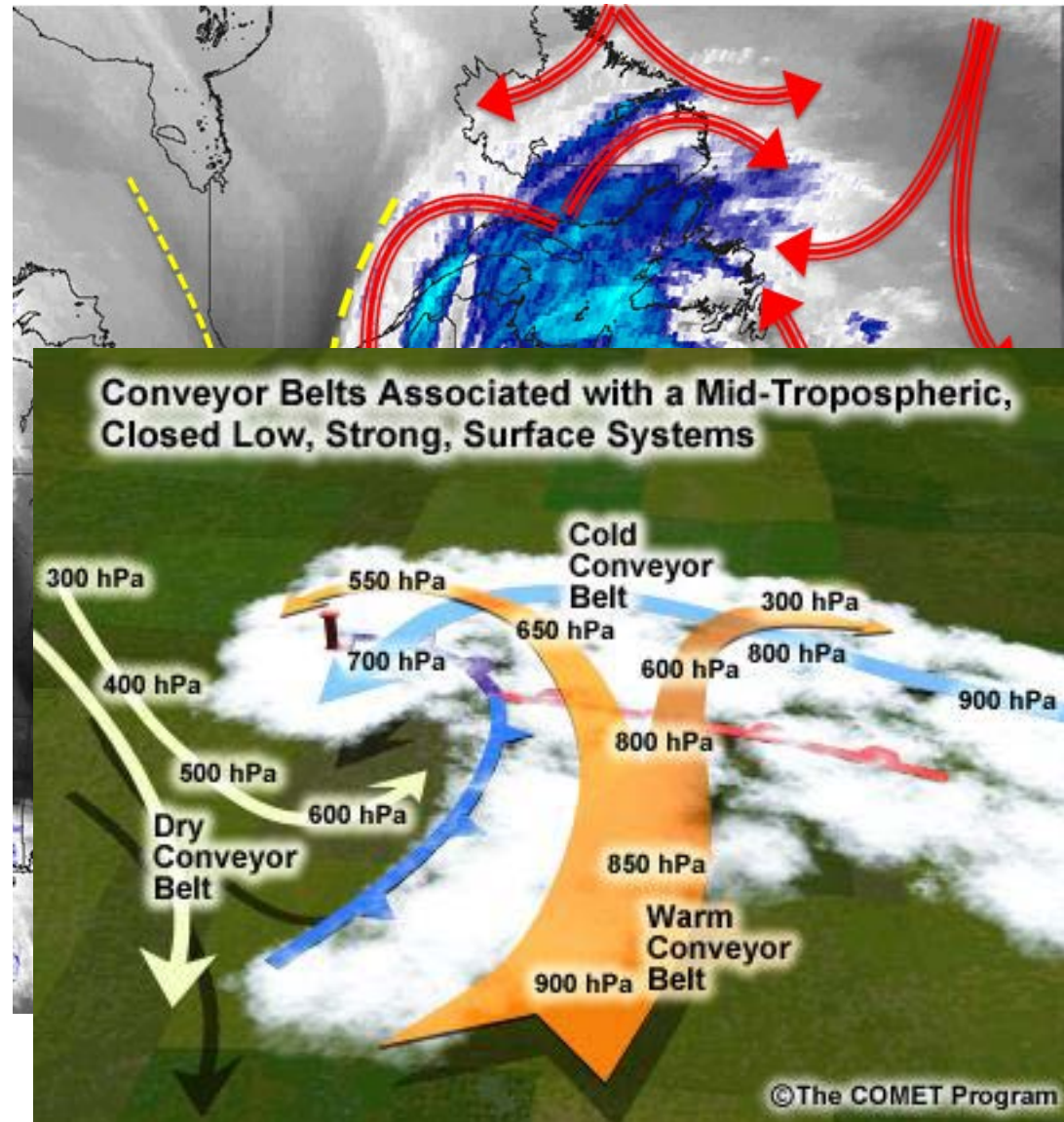
Transverse Banding



Deformation

Deformation is a region in which:

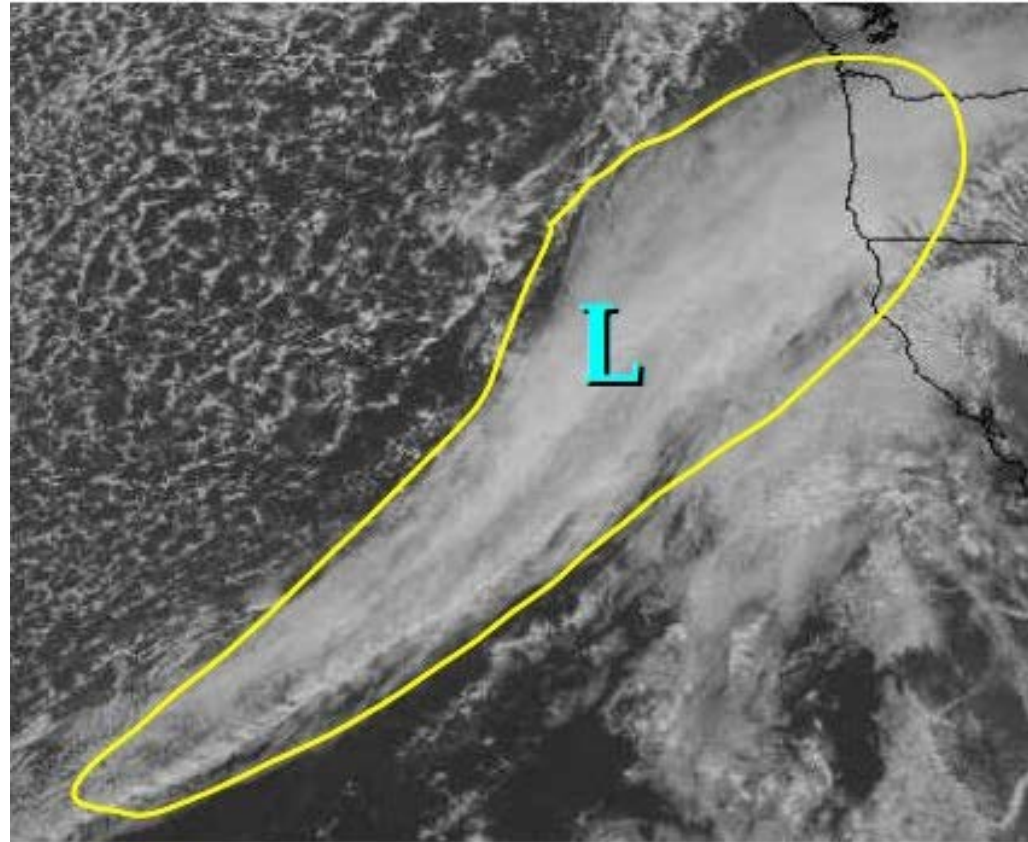
- The atmosphere becomes elongated and sheared in a direction perpendicular to jet stream flow along the northern edge of a mature surface low.
- Stretching is caused by airstreams flowing toward each other and then fanning out.
- Development/decay of frontal systems occurs



Baroclinic Leaf Cloud Pattern

A baroclinic leaf cloud pattern:

- Develops due to a cloud mass sheared by a curved jet stream core
- Typically develops along the northeast side of a developing surface low pressure system.
- Most likely area for turbulence with these system is along the northern edge of the developing surface low.
- Typically associated with clear air turbulence.

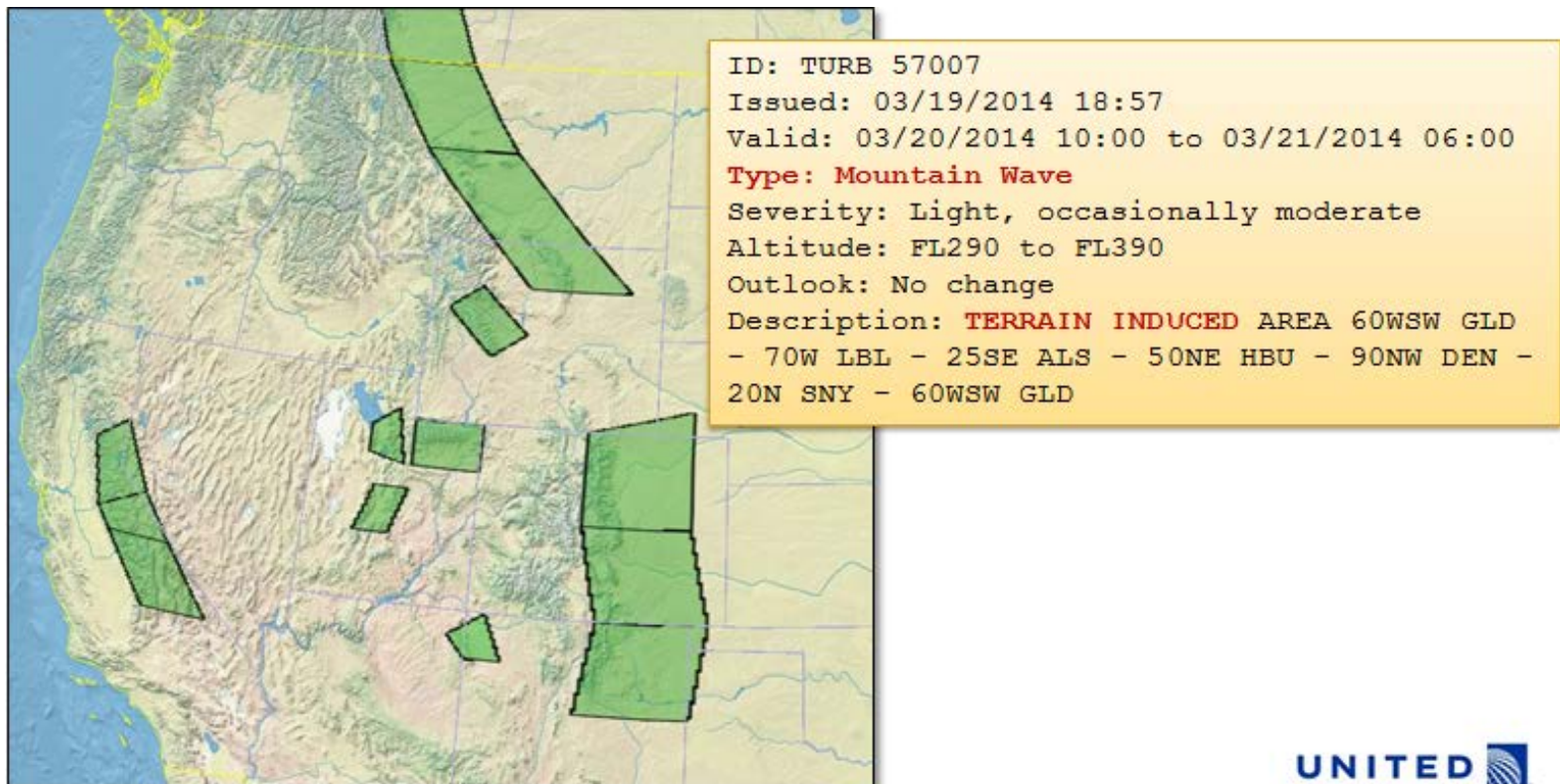




Mountain Waves

Mountain waves form when upper level winds are greater than 30-40 knots flowing perpendicular to mountain surfaces. Severity increases as winds exceed 50 kts at the mountain top.

- Waves can reach to 60,000 feet and stretch 150 miles downstream
- Strongest during winter months and nighttime hours in stable air
- Will display as quasi-stationary banding at normal intervals parallel to the ridge axis. Animated satellite imagery is extremely helpful in identifying these features.

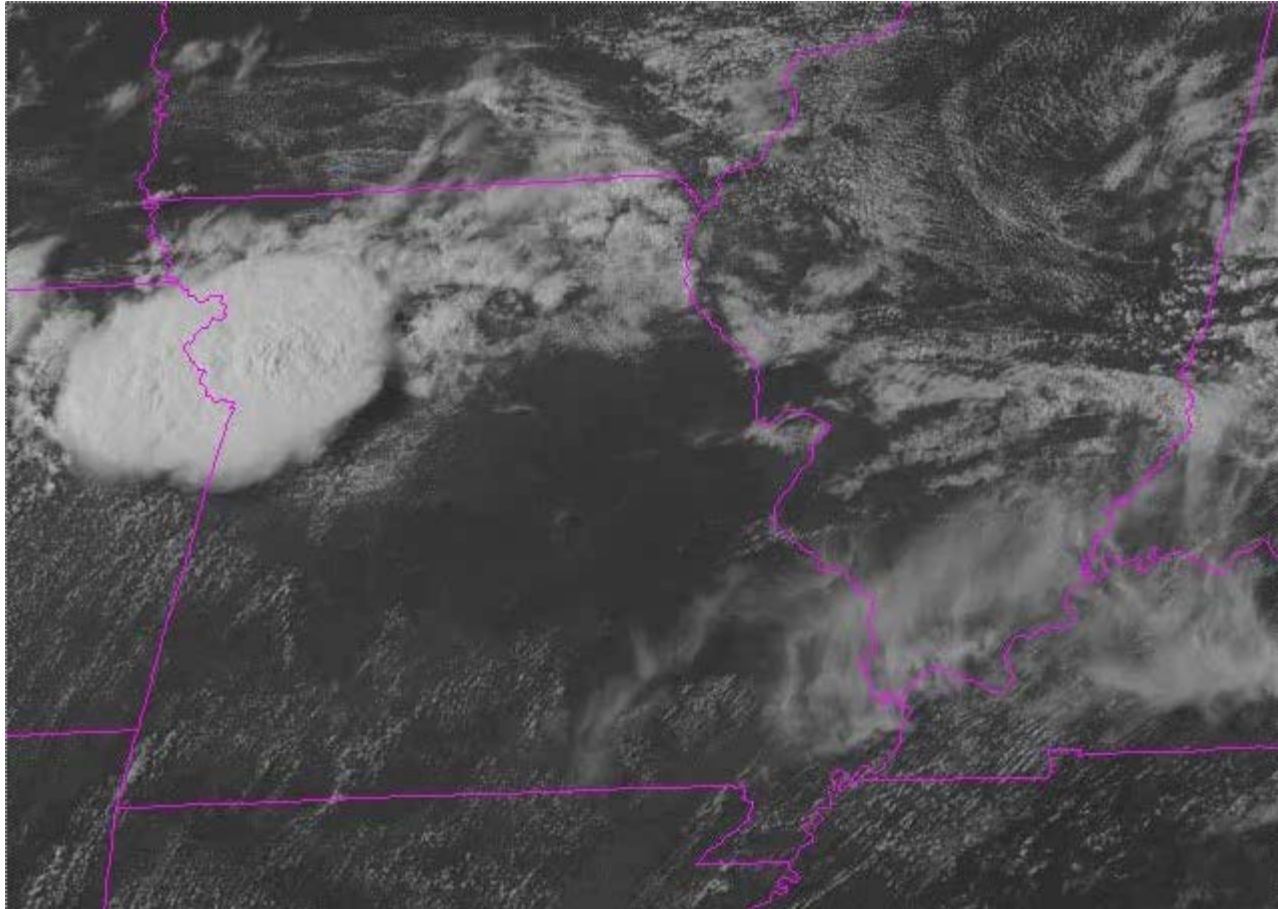




Convectively Induced Turbulence (CIT)

Rapid Anvil Expansion, overshooting tops, and enhanced-V signatures are indicative of an air mass capable of producing turbulence

- Commonly associated with CIT which produces 75% of injuries.
- Typically a spring/summer fall type pattern.
- Flight deviations are typically based on radar reflectivity which in no way ensure avoidance of turbulence.





Flight Explorer Recommendations for Turbulence Situational Awareness

Flight Explorer Set-Up

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Current View

- Planes
 - Plane filters
 - Plane icons/rings
 - Plane tags/3D
 - Weather**
 - Animation & alerts
 - Product properties
 - Product properties 2
- Airports
 - Airport rings/zoom
- Airspace boundaries
- Airways
- Background images
- Cities
- Communication facilities
- Drawing objects
- Fixes
- Flex modules
- Flight service stations
- Geography/Map
- Holding patterns
- Latitude/longitude
- NAVAIDs
- Password / Misc. / 3D
- RADAR
- Road (Interstate)
- Sectors
- Shape files

Weather

☒ Show Weather overlays

	Layer	Enable	Animate	Product	Objects	Labels
(top)	1	☒	☒	Lightning (global)*	☐	☒
	2	☒	☐	PIREPs	☐	☒
	3	☒	☒	Surface Analysis (current)*	☐	☒
	4	☒	☒	GTG (FL340)*	☐	☒
	5	☒	☒	FPG (global; enroute hazards)*	☐	☒
	6	☒	☐	Sigmets (global; enroute hazards)	☐	☐
	7	☒	☐	Sigmets (government)	☐	☒
	8	☒	☒	SATRad Europe*	☐	☒
	9	☒	☒	Radar North America 1km WxType*	☐	☒
(btm)	10	☒	☒	Satellite WV World*	☐	☒

To animate a product it must be animatable (shown with an asterisk), it's layer's 'Animate' check box checked and animation enabled on the 'Animation & alerts' dialog box.
Label and graphic object settings are only valid for certain products.

Objects Labels

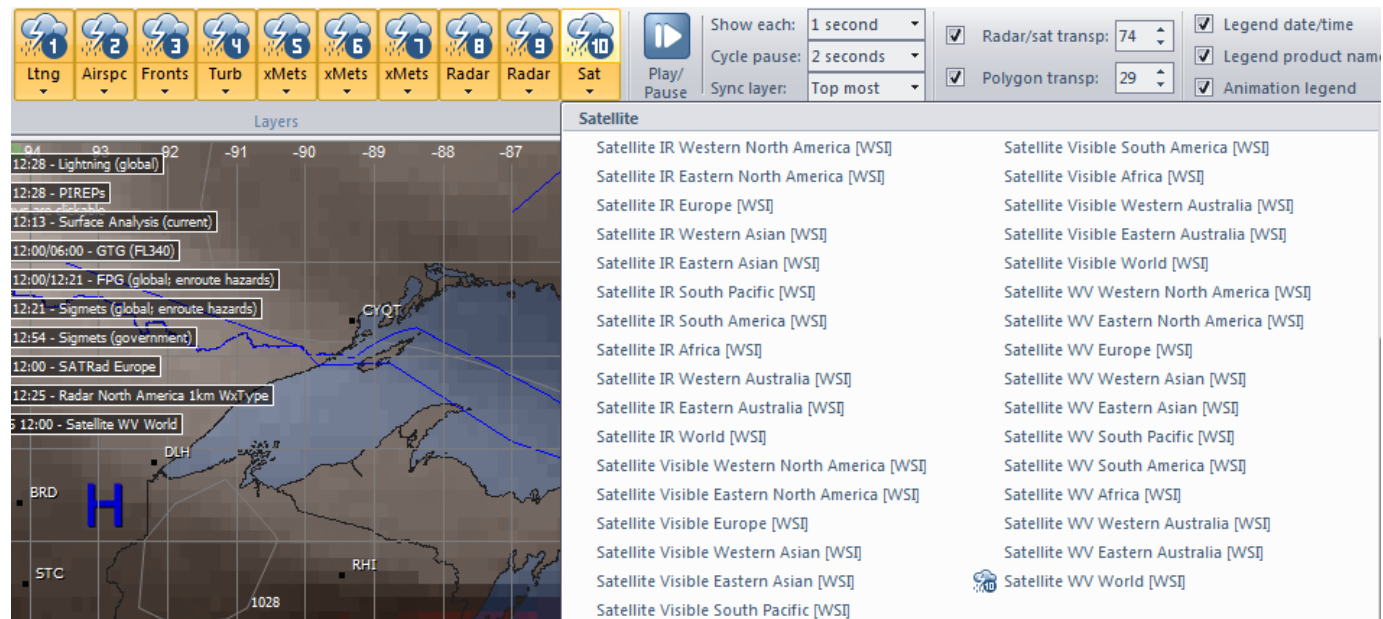
☐	☒	☐
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layer's 'Animate' dialog box.
ducts.



Satellite imagery Flight Explorer

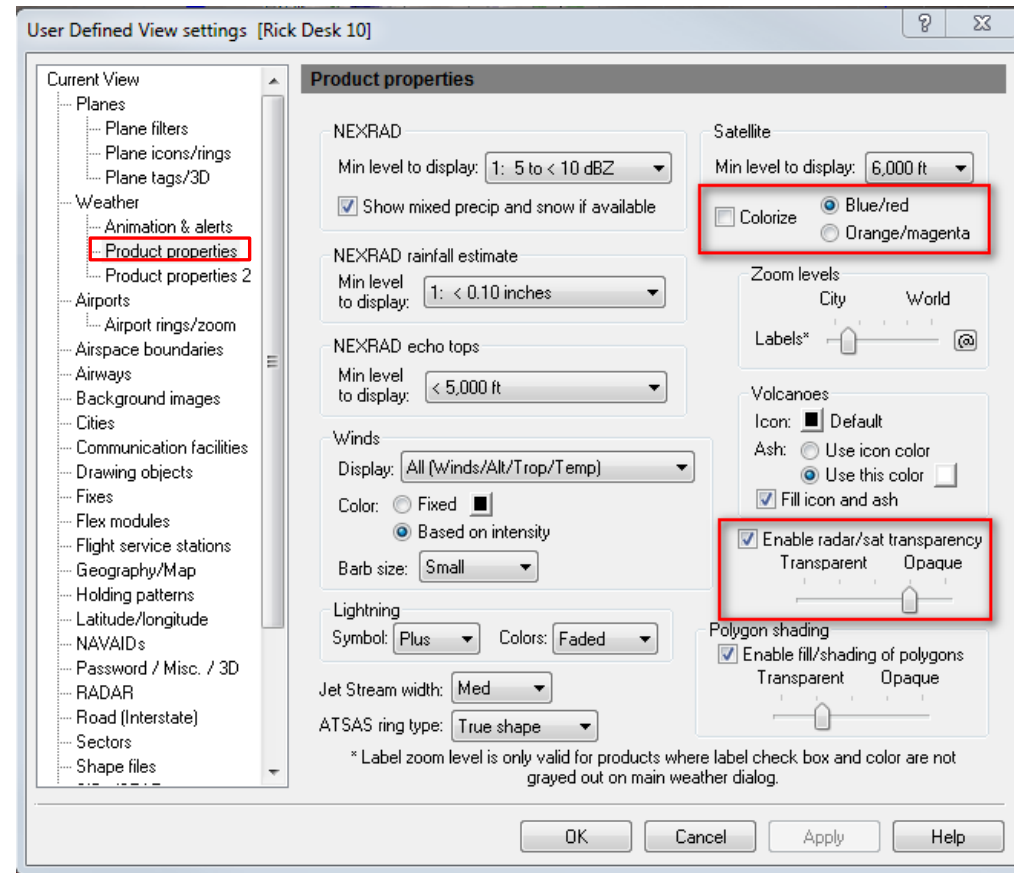
- Selection of the satellite sensor in Flight Explorer can be accomplished using the Weather “Product” dropdown list of all products. An alternative method is through use of the Weather ribbon.
- The weather ribbon allows the dispatcher to select each individual layer which can be grouped by product type or vendor.
- The Satellite grouping includes selection for infrared, water vapor, and visible imagery.
- Each satellite sensor allows for a worldwide setting or regionalized view which have slightly better resolution.



Flight Explorer Color Enhancement

Enhancements of satellite imagery can be set in Flight Explorer with the following settings:

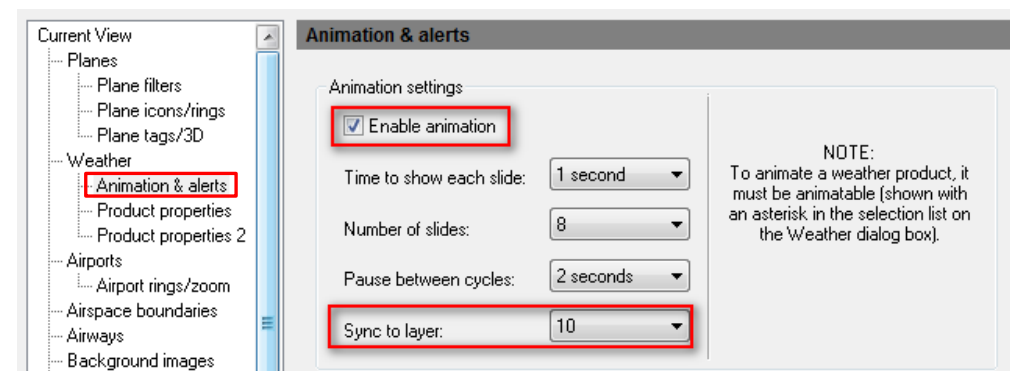
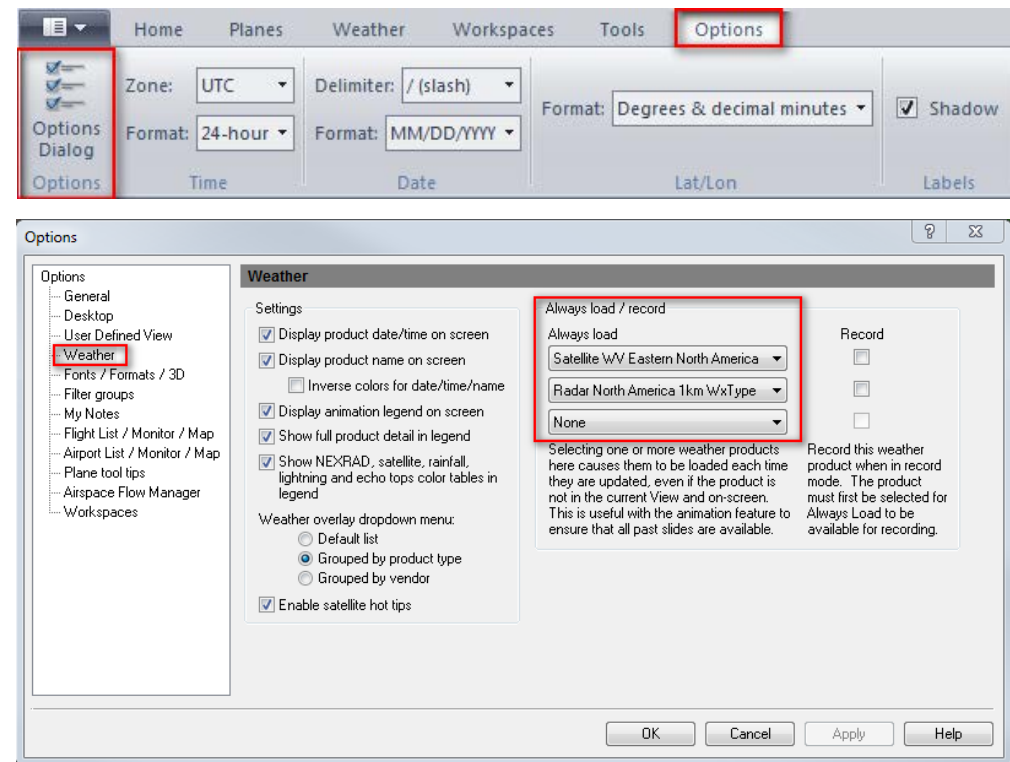
- Adjustment of the radar/satellite transparency by one of two methods:
 - “Enable radar/sat transparency” checkbox and slider from the Weather Product Properties menu
 - “Radar/sat transparency” checkbox and selection box/arrows from the Weather ribbon
- Optional colorization schemes (blue/red or orange/magenta) to coldest pixel temperatures from the Weather Product Properties menu



Flight Explorer Animation Settings

Turbulence monitoring via Flight Explorer for the best results requires animation.

- Weather settings must be set to automatically load images for pre-loading. Weather can be automatically loaded using an “Always load” setting.
 - Located on the Options ribbon by opening the Options Dialog box.
 - Selection of the “Weather” options will allow for three weather products to be auto loaded.
- Sync settings are normally suggested to be a layer that updates frequently, but for turbulence monitoring layers such as radar/satellite are more advantageous to get animation over longer period of time.



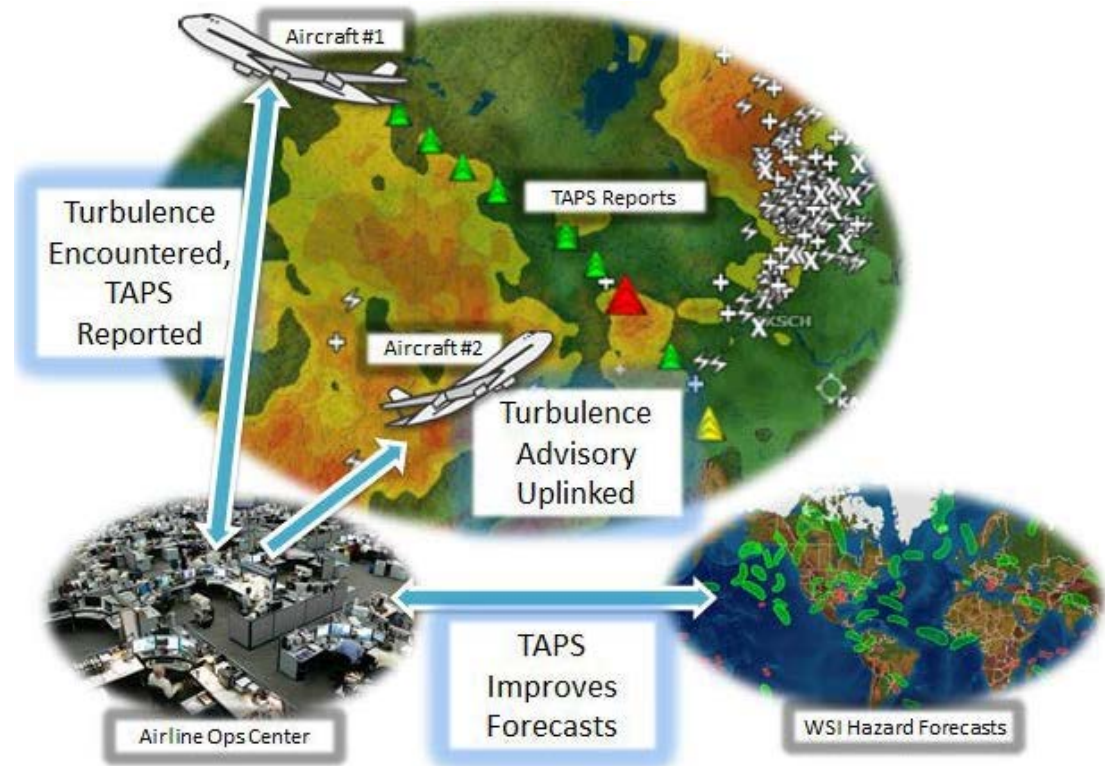
**Turbulence Auto-Pirep System
(TAPS)
Graphical Turbulence Guidance
(GTG)
Review**

TAPS/GTG

Satellite identification of potential turbulence is one step in mitigating turbulence injuries.

WSI TAPS/GTG products introduced in Spring Recurrent 2015 are now available to dispatchers in WSI Optima and Flight Explorer with the latest upgrade.

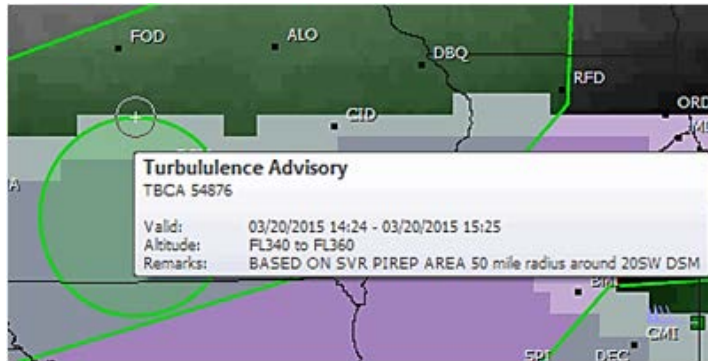
TAPS/GTG when overlayed on Flight Explorer with the route and other familiar weather products (satellite, pireps, FPGs) can validate (disprove) where turbulence is expected to occur.





Flight Explorer TAPS

- Flight Explorer 14.1.0 turbulence weather product capabilities now include the ability to view:
 - Turbulence Advisories
 - Advisory of significant turbulence based on TAPS event(s) or PIREP outside of or worse than existing SIGMETs and/or FPGs



- TAPS (public) – TAPS events for all equipped aircraft from all airlines
- TAPS (private-United) – TAPS events for United Airlines equipped aircraft

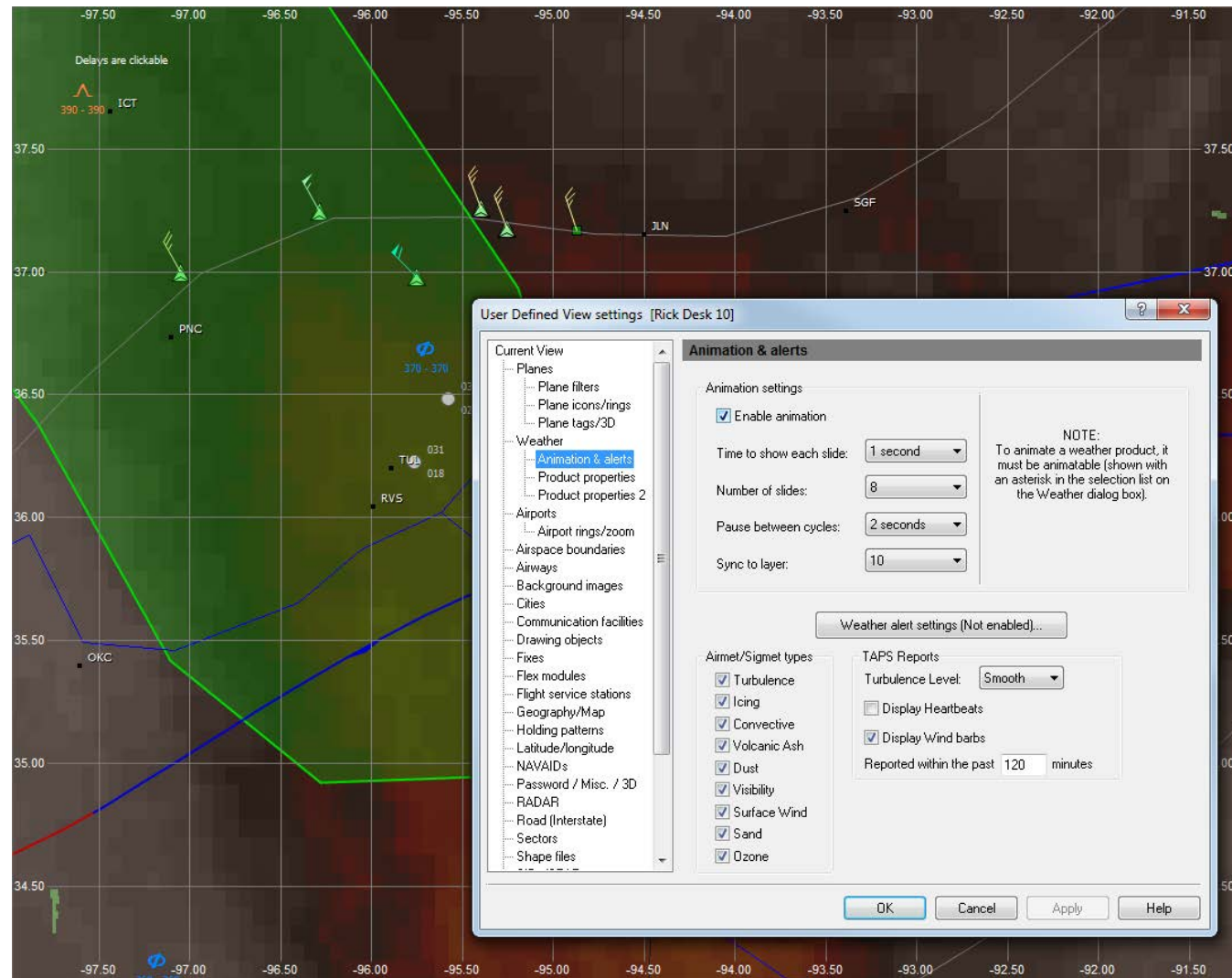
Turbulence	
Turbulence Advisories (global) [WSI]	GTG (FL240) [WSI]
 TAPS (public) [WSI]	GTG (FL270) [WSI]
TAPS (private-United) [WSI]	GTG (FL300) [WSI]
GTG (FL110) [WSI]	 GTG (FL340) [WSI]
GTG (FL130) [WSI]	GTG (FL390) [WSI]
GTG (FL150) [WSI]	GTG (FL430) [WSI]
GTG (FL180) [WSI]	GTG (composite) [WSI]
GTG (FL210) [WSI]	



Flight Explorer TAPS

Setting in Flight Explorer allow dispatchers to be:

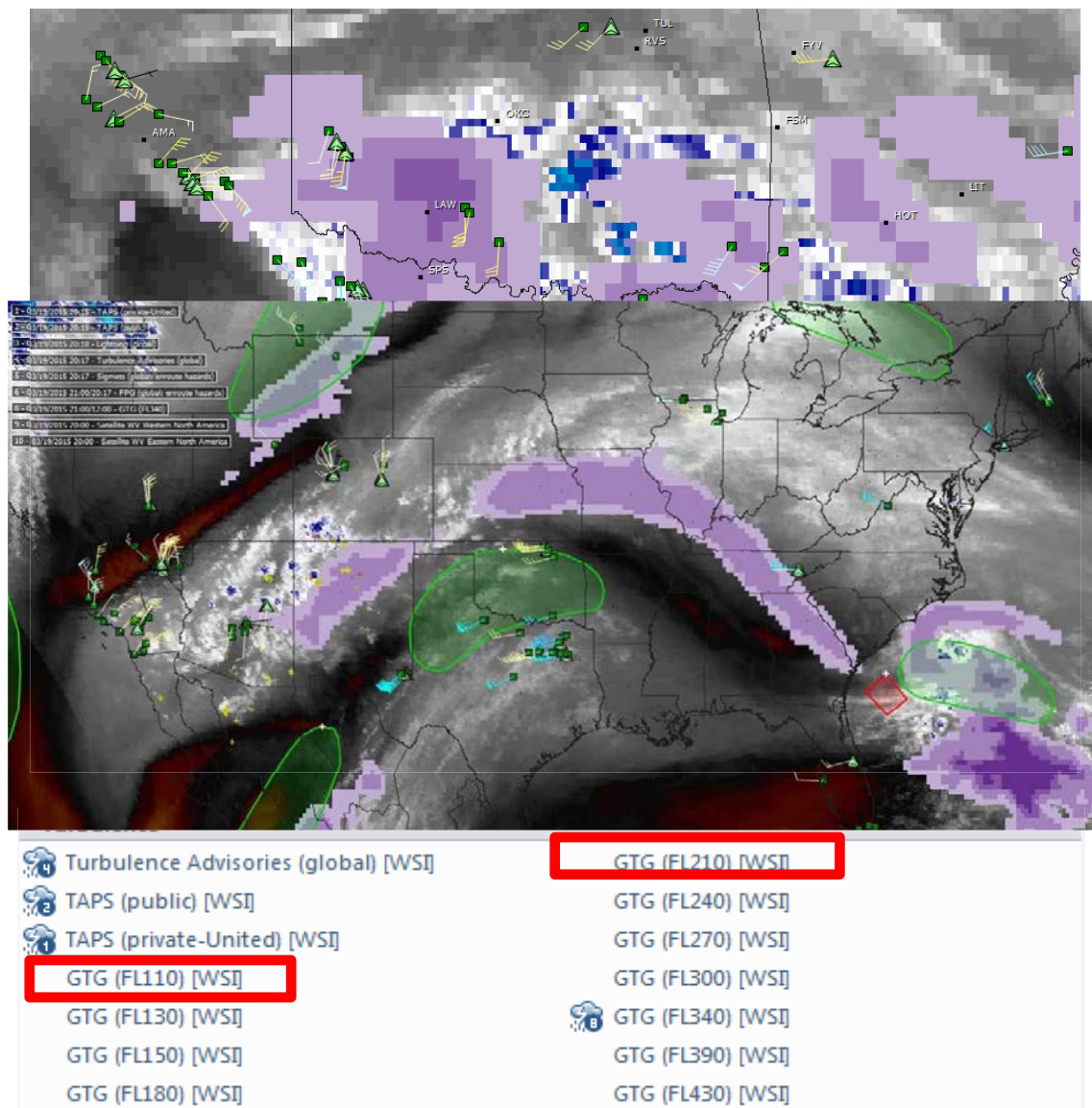
- Able to view last 3 hrs of TAPS reports but animation not enabled.
- Display heartbeat reports.
- Display wind barbs that will be color-coded based on strength of winds.
- Adjust Intensity filter available in the Animation & alerts settings.





WSI GTG

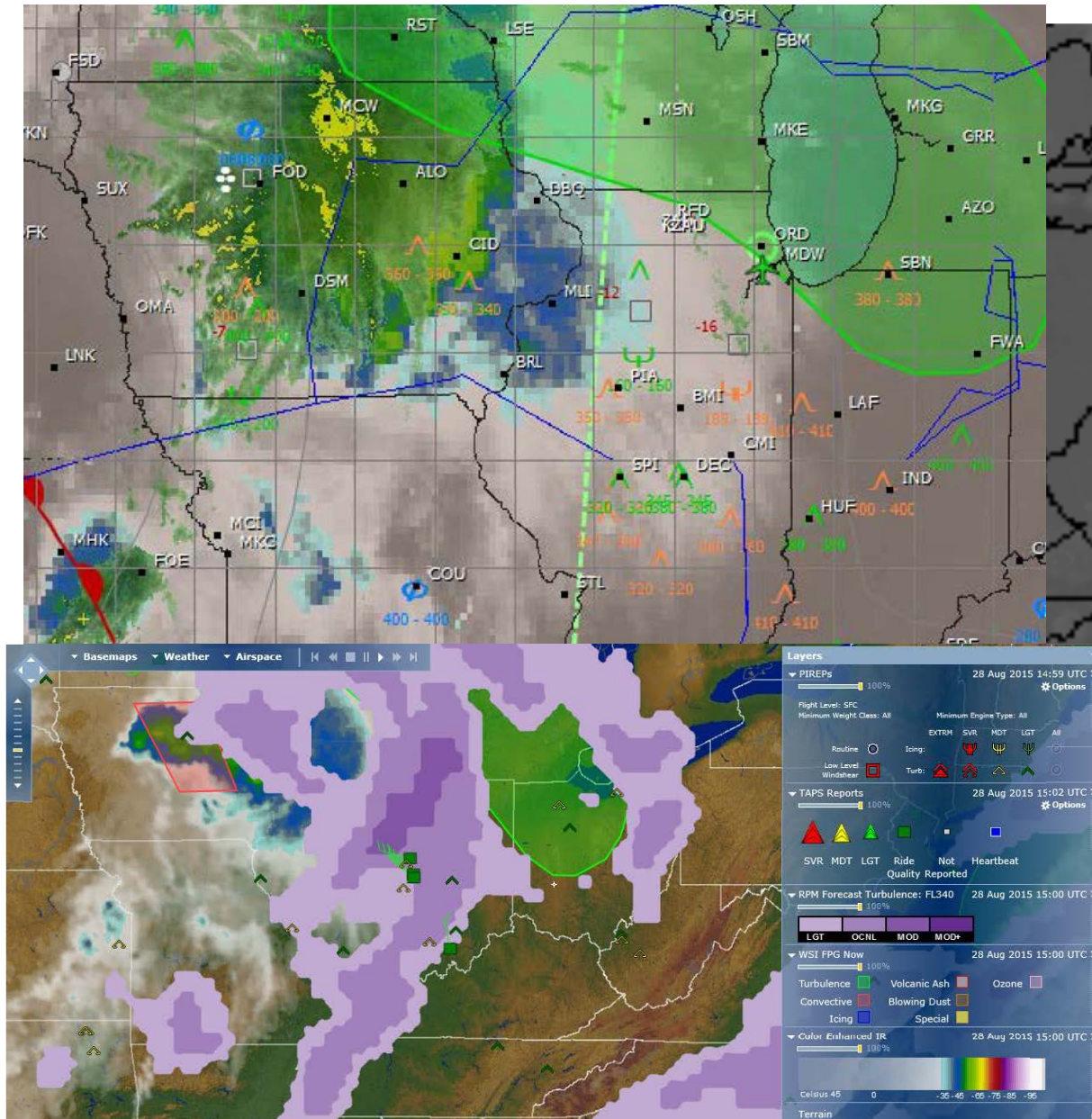
- The WSI GTG product is now available in the Flight Explorer product with the upgrade to Flight Explorer 14.1.0
- The GTG product can be displayed in the same manner as the TAPS reports using the group by Product Types.
- GTG can be analyzed for different altitudes for a pseudo-three dimensional view.
- GTG can be animated to determine the trend going into the future.



GTG Validation Example

The image to the right displays the infrared image from a recent September day:

- Locate the most likely area of turbulence?
- What is the cause of this turbulence?
- The image to the right is what the view from Flight Explorer looked like with pireps attached.
- The last image was overlaid with the GTG at FL340 to validate/reject the transverse banding signature.





Final Simulated Example

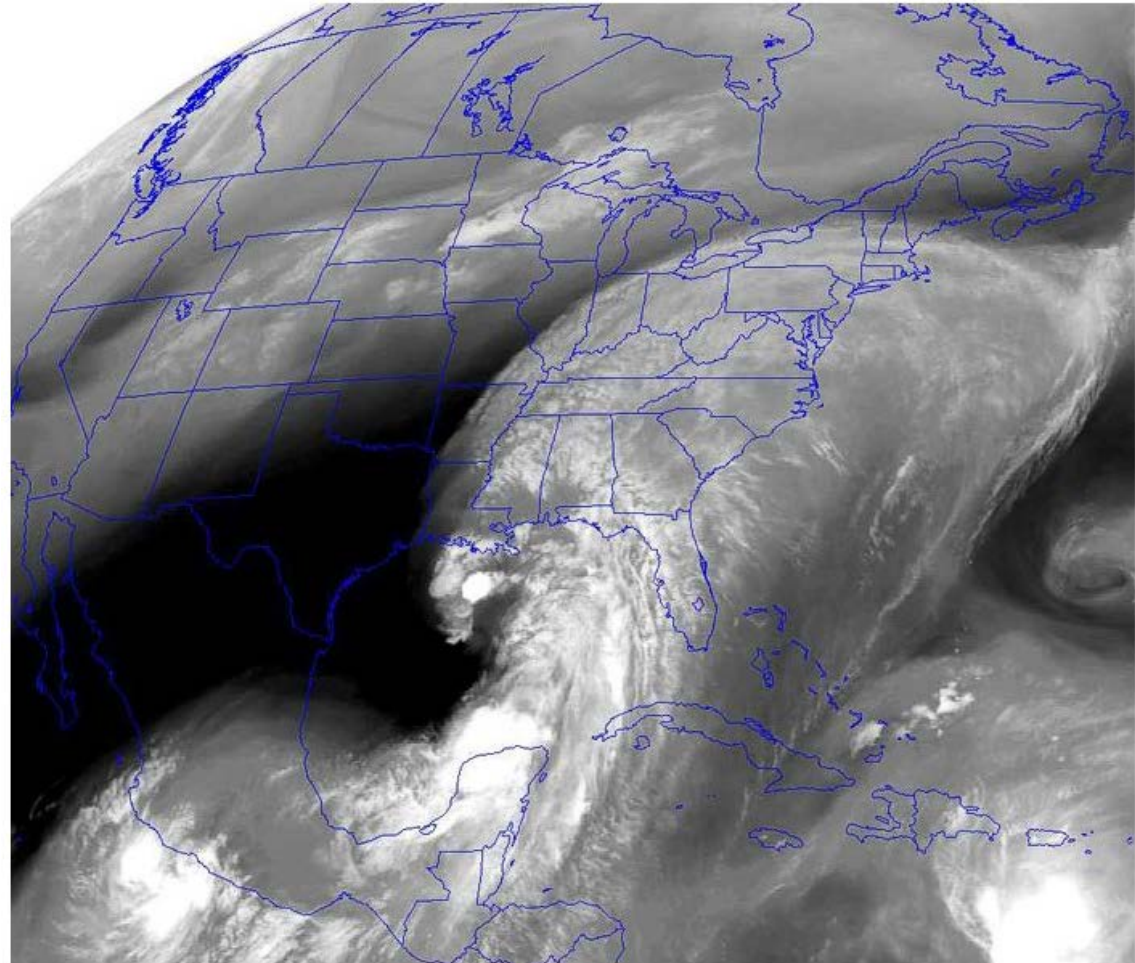
Locate the most likely existence of potential turbulence in the image to the right.

What are the likely causes of this potential turbulence?

What sources can we use to validate/reject our suspicions?

- Pireps
- TAPS
- GTG

Water Vapor Satellite Image



Try predicting turbulence live during class

As a class example the instructor will now pull up the latest Flight Explorer image:

Students should:

- Sign into Flight Explorer.
- Overlay the various satellite sensors.
- Identify potential areas of turbulence to the instructor.
- Discuss with the instructor the likely causes and how can your suspicion be validated.



Recommended Websites

Flight Explorer imagery can be very grainy and the resolution poor. Alternate commercial and government providers using EWINS authority can provide better resolution.

The disadvantage is overlay of routes and other weather data may not be available from these providers. Repacking of these products may use alternate color schemes. Be cautious when using these sites for interpretation.

NASA Satellite Images:

<http://www.ghcc.msfc.nasa.gov/GOES/>

NOAA Geostationary Satellite Server :

<http://www.goes.noaa.gov/>

SSEC Geostationary Satellite Images:

<http://www.ssec.wisc.edu/data/geo/>

NCAR RAP Real-Time Weather Data:

<http://weather.rap.ucar.edu/satellite/>

Weather Channel:

<http://www.weather.com/weather/radar/interactive/I/USIL0425:1:US?layers=ussat&zoom=6>

WeatherTAP:

<http://www.weathertap.com/satellite>

Intellicast:

<http://www.intellicast.com/Local/WxMap.aspx>

Accuweather:

<http://www.accuweather.com/en/us/national/satellite>

Weather Underground:

<http://www.wunderground.com/wundermap/>

MeteoStar:

http://wxweb.meteostar.com/models/noaaport_loop.php?PATH=/var/www/leads_images/satellite/SYS/COMP/

Conclusion

Turbulence recognition using satellite technology

- Requires practice to become efficient
- Increases your situational awareness
- Takes a few seconds to identify potential signatures
- Required as part of flight monitoring requirements
- Improves flight planning skills and reduces inefficient planning

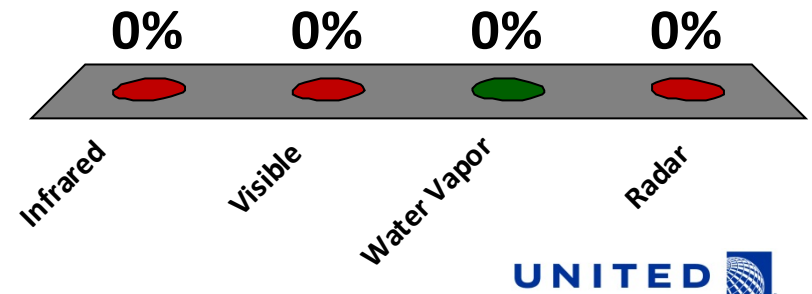
Turbulence recognition is not a perfect science and predictions will sometimes be wrong, but practice will increase crew confidence that monitoring is occurring. Communication with your flight crews is essential.

Most importantly, it improves the chance of keeping our fellow co-workers and the flying public safe!!!!



Which satellite best identifies areas of possible turbulence along sharply defined borders of upper level convergence and deep sinking air?

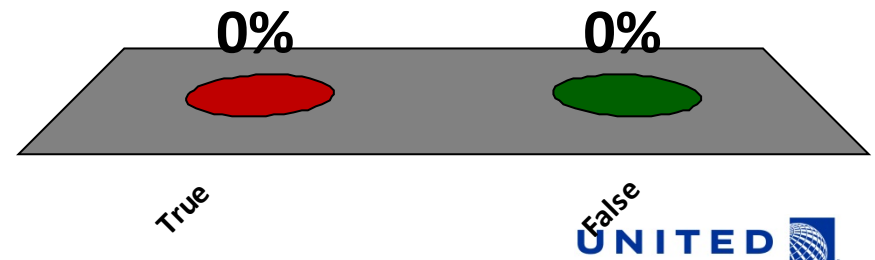
- A. Infrared**
- B. Visible**
- C. Water Vapor**
- D. Radar**



Mountain wave activity can form up to 60,000 feet and stretch 150 miles downstream. Waves form in uneven spacing between bands and move with the jetstream.

A. True

B. False



TAPS/GTG when overlayed on Flight Explorer with the route and other familiar weather products (satellite, pireps, FPGs) can be used to help validate (disprove) where turbulence is expected to occur.

A. True

B. False

