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Turbulencia y Engelamiento

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Axiom for WPC International Desks/NWS/NOAA

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02 Tipos de Turbulencia

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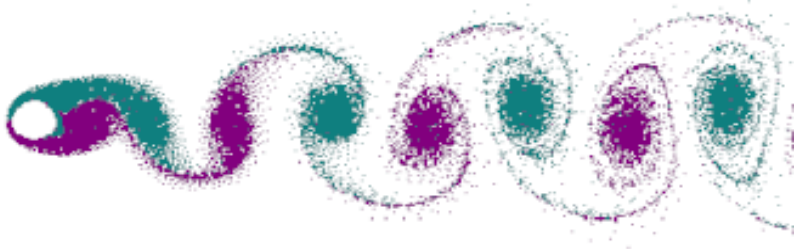
04 Casos Estudio

01

Introducción a Turbulencia

Qué es turbulencia?

- Cambios súbitos y caóticos en el movimiento de un fluído. En la atmósfera, resulta en cambios de velocidades verticals violentos que pueden afectar a la aviación.
- Es la manera en la que un fluído disipa energía.
- Es función de la velocidad del viento, densidad y viscosidad del fluído; y se representa con el Número de Reynolds (Re).



$$Re = \frac{\rho u L}{\mu}$$

Número de Reynolds (*Re*), función de densidad (ρ), velocidad (u), distancia (L) y viscosidad (μ)

Número de Reynolds (Re)

- Se relaciona a la velocidad del fluído, su densidad, viscosidad y la distancia recorrida.
- Representa la razón entre fuerzas inerciales y viscosas.
- Mayor = Más Turbulencia. Valores:

4×10^6	Persona nadando
4×10^8	Ballena azul
5×10^9	Barco grande
1×10^{12}	Ciclón Tropical

$$Re = \frac{\rho u L}{\mu}$$

Número de Reynolds (*Re*), función de densidad (ρ), velocidad (u), distancia (L) y viscosidad (μ)

Turbulento (Re alto)	-Flujo rápido -Mayor distancia -Fluído denso -Poca viscosidad
Laminar (Re bajo)	-Flujo lento -Distancias cortas -Flujo ligero -Fluído viscoso

Importancia de pronosticar turbulencia

- Riesgo para la aviación: Salud y estructuras de la aeronave.
- Pronosticar Turbulencia es una competencia de la OMM que debe ser cumplida por pronosticadores aeronáuticos::
  - Las alertas deben ser emitidas con anticipación. Pueden ser actualizadas o canceladas siguiendo criterios documentados.
  - Si se pronostica Turbulencia moderada o severa, require indicar: Tiempo de inicio, duracnón, intensidad, cobertura especial y tipo (**orográfica**, **convectiva** o de **aire claro**).

Categorías de Turbulencia para la aviación

Establecidas en función a impactos a aeronaves, particularmente fluctuaciones de velocidad y sus rachas:

	Fluctuaciones en velocidad de la aeronave(m/s)	Rachas (m/s)	Impacto en pasajeros
Ligera	2.6 – 8	1.5 – 6	Se require el uso de cinturones de seguridad, pero objetos no asegurados permanecen en reposo.
Moderada	8 - 13	6 - 11	Los pasajeros requieren cinturones y son ocasionalmente empujados unos a otros. Los objetos no asegurados se mueven. Es difícil caminar en la aeronave por los movimientos.
Severa	>13	11 - 30	La aeronave puede perder el control momentáneo y es difícil mantener altitude de vuelo. Los pasajeros y objetos se mueven y golpean a pesar de los cinturones.

Source: UK Met Office Handbook of Aviation Meteorology

02

Tipos de Turbulencia

Tipos de Turbulencia para la Aviación

1) Orográfica

- Inducida por terreno (ondas de montaña, gradientes de velocidad del viento)

2) Convectiva (termal)

- Inducida por convección (húmeda y termales secos en la capa límite. Para aviación se da Importancia a la generada por convección húmeda.

3) Turbulencia de Aire Claro (TAC)

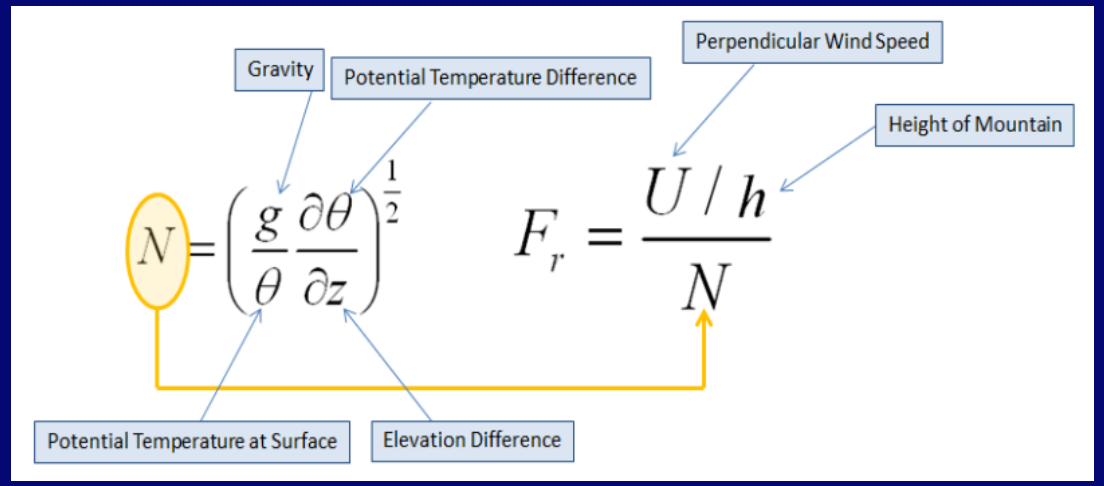
- Producida por cizalla vertical y/u horizontal del viento en condiciones de ausencia de nubosidad.
- “Aire claro” significa que es invisible para los pilotos.

1) Turbulencia Orográfica

Se desarrolla cuando flujo rápido interacciona con estructuras en el terreno y tiende a persistir flujo abajo especialmente cuando se propaga en una capa estable.

Rol del flujo y de la estabilidad:

- **Flujo rápido:** Mayor potencial de pasar de laminar a turbulento.
- **Estabilidad Estática:** Capas estables sirven de medio de Propagación. Preservan las ondas inducidas sobre una distancia extensa. Capas inestables disipan la energía y las ondas decaen rápidamente con la distancia.



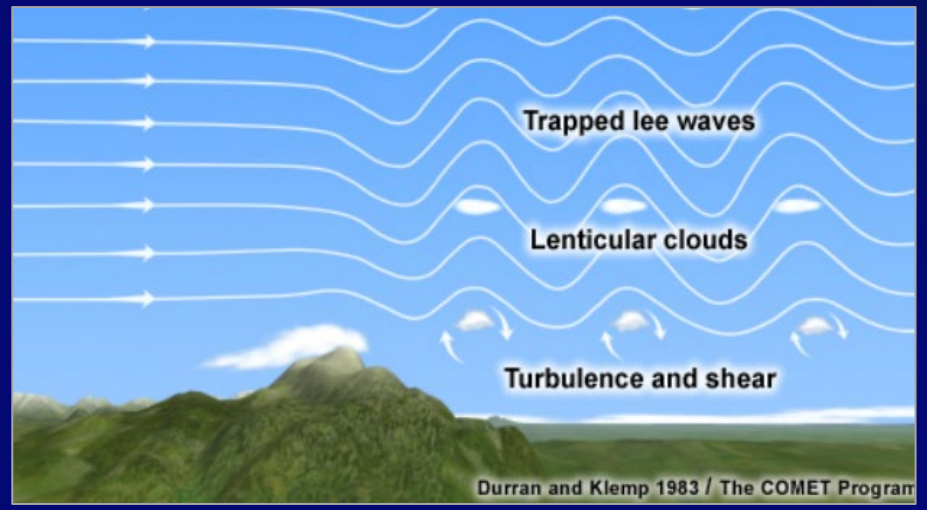
Número de Froude (Fr)

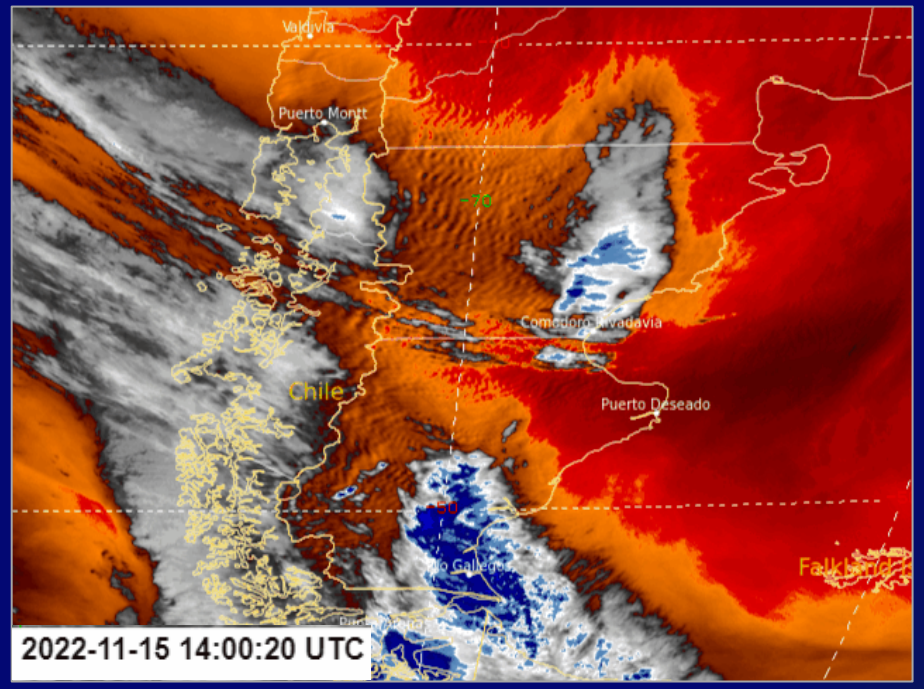
Ondas de montaña

- Ocurren cuando flujo acelerado interacciona con una cadena de montañas lo que desarrolla ondas y turbulencia flujo abajo.

- La turbulencia tiende a ser más extrema cerca a las montañas pero puede extenderse cientos de km flujo abajo.

- Cadenas de montaña tienen efectos muchos mayores que picos aislados. La Turbulencia se maximiza bajo flujos perpendiculares al eje de la cadena.





Ondas de Montaña al este de los Andes en Sudamérica, en imágenes del vanal de 3.3um o “vapor de agua de nivel bajo” del GOES-16 (Fuente: CIRA Slider).

Tipos de Onda de Montaña

- Se forman a sotavento de una cadena de montañas, cuando hay flujo perpendicular.

- Tipos:

  a) Atrapadas: Cuando existe una capa inestable por encima de la capa de las ondas y/o la velocidad del viento se incrementa con la altura.

  b) De Propagación Vertical: Cuando la capa entera es estable. Pueden llegar hasta el tope de la atmósfera.

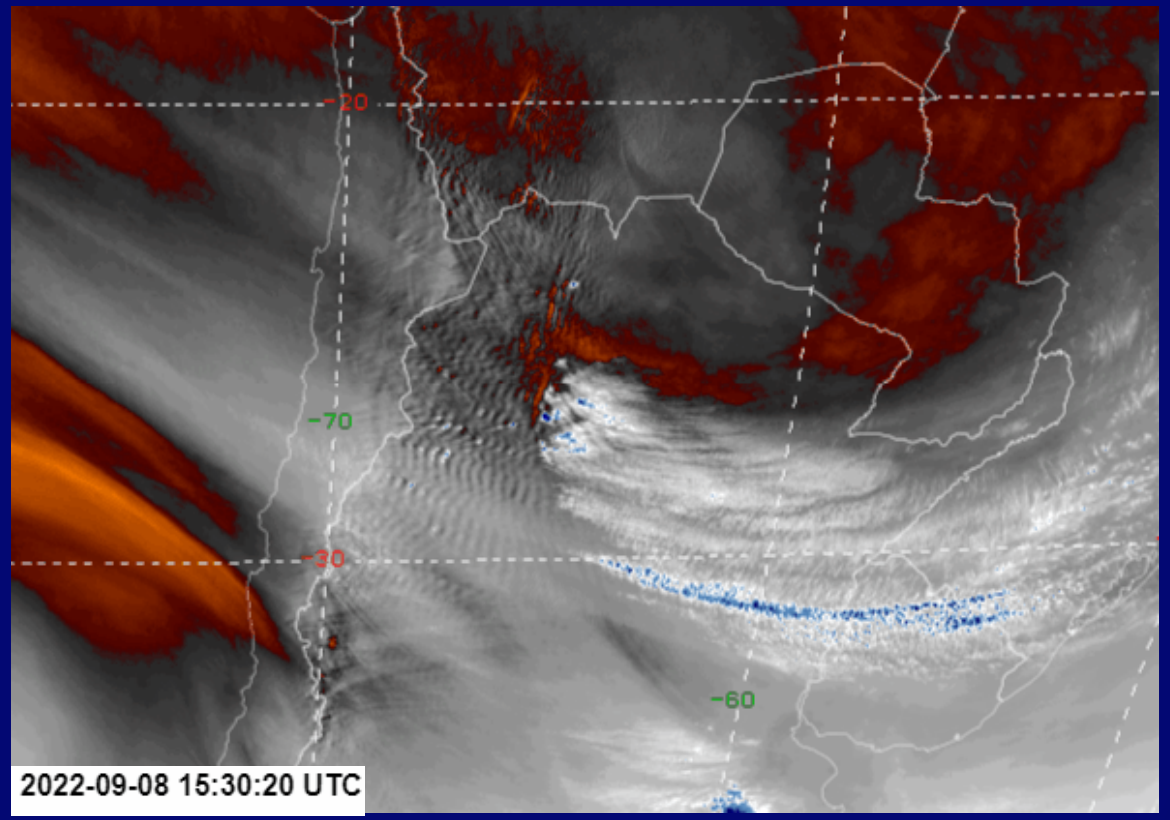


Ejemplo de ondas propagándose en la vertical.

Turbulencia de Montaña en Productos de Satélite

- Las imágenes de capor de agua son las mejores herramientas para encontrar ondas de montaña.
- Permite encontrarlas en ambiantes de aire claro.
- La paleta de colores importa, para ayudar a la visualización.
- Las más intensas ocurren cerca a la cadena de montaña pero pueden extenderse cientos de km flujo abajo.

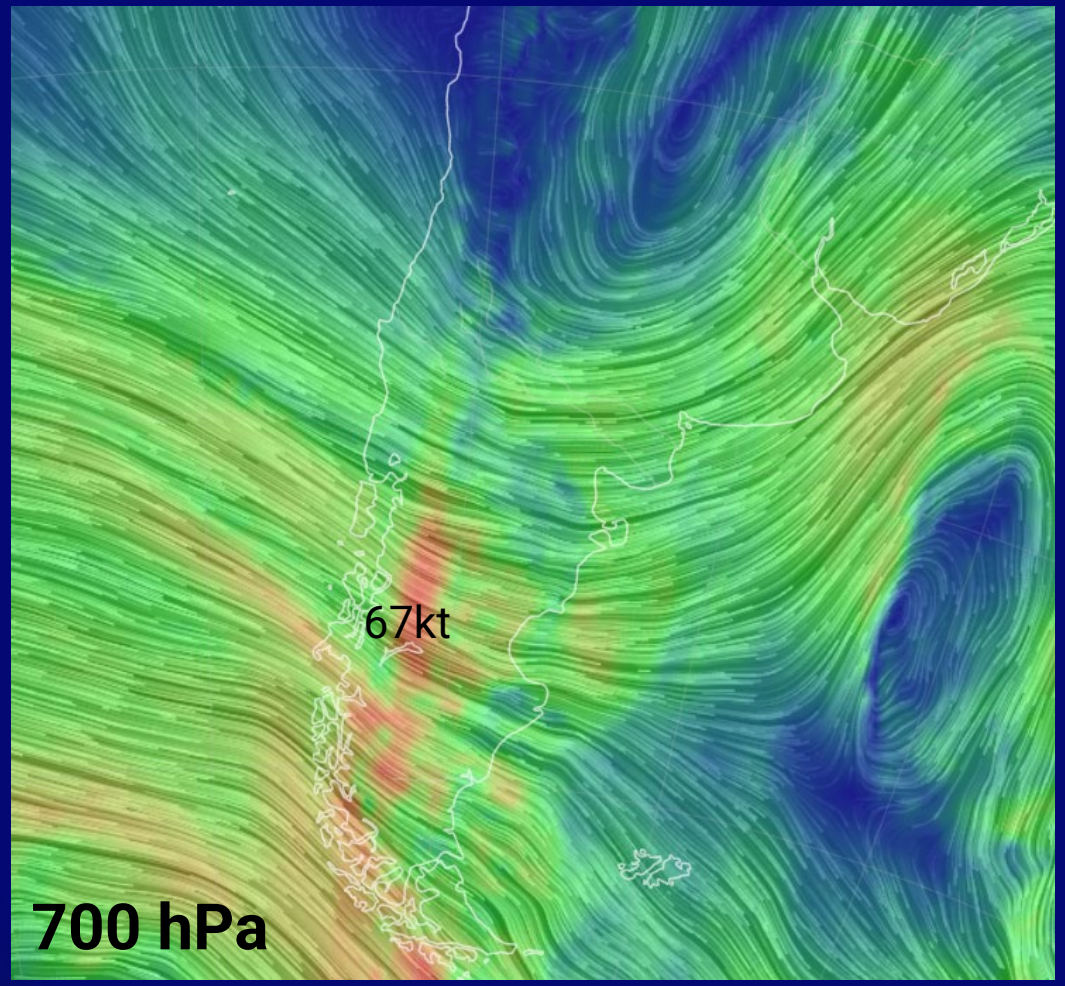
Vapor de Agua de Nivel Alto (6.2um)



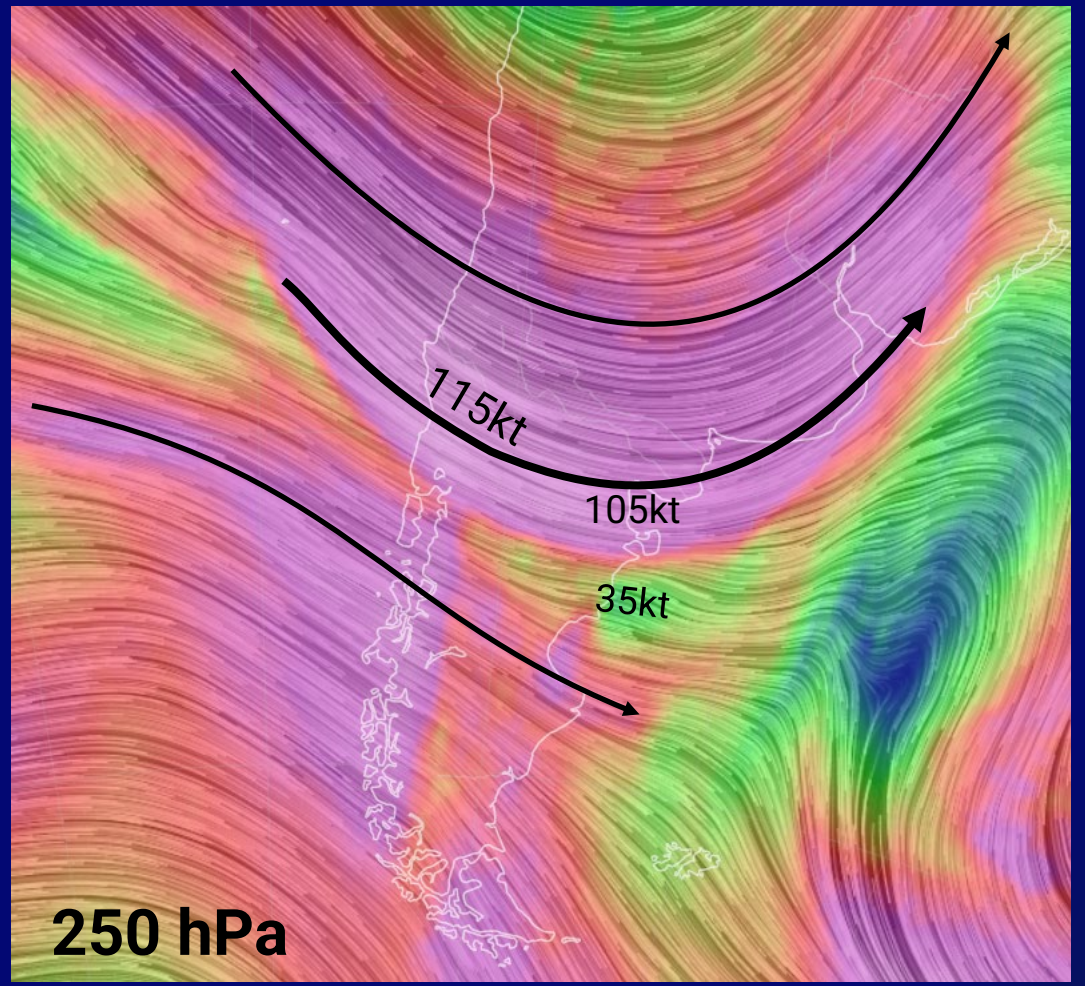
Fuente: CIRA Slider

Ondas de Montaña y Flujo

15-Nov-2022 18UTC



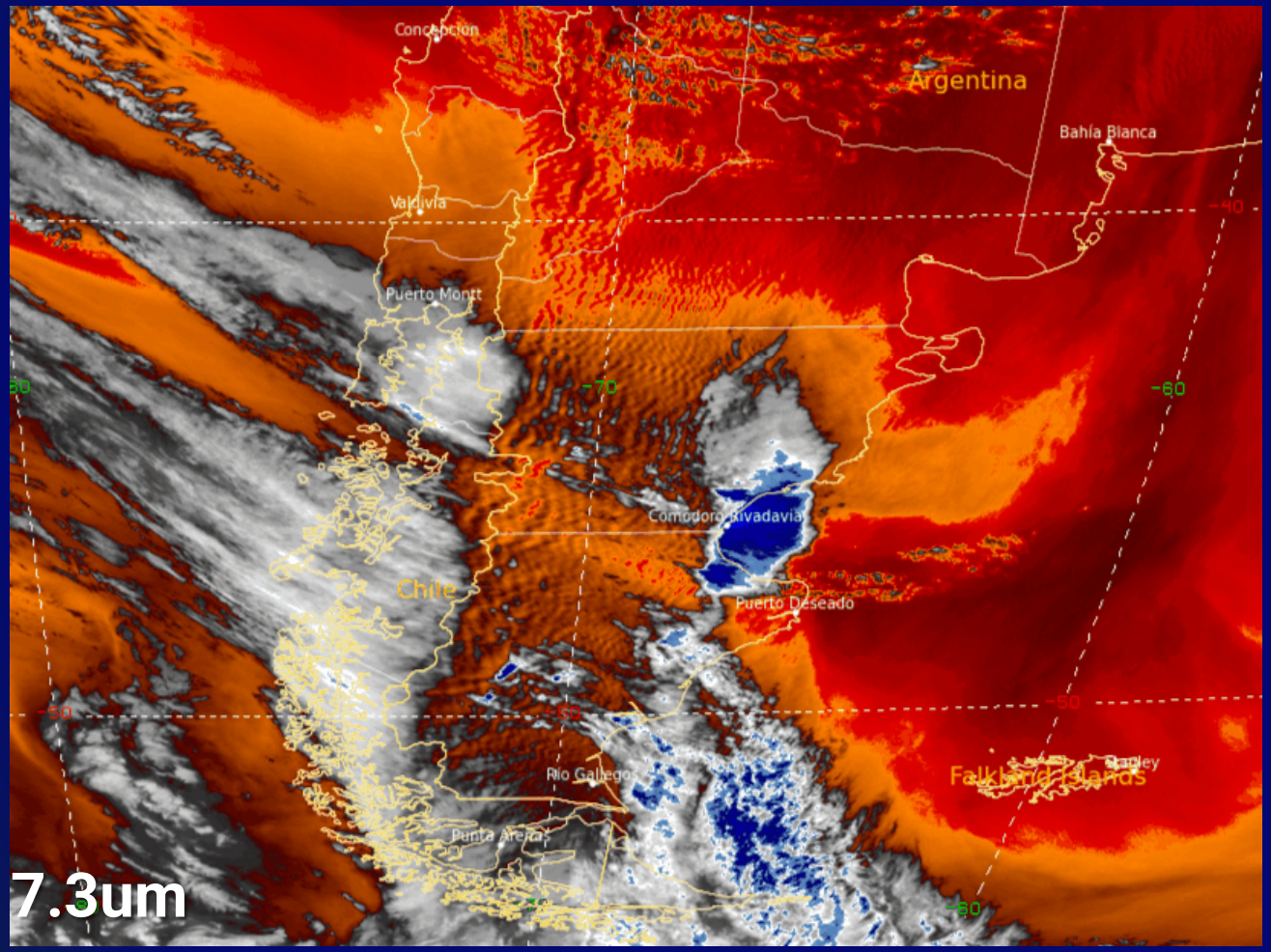
Fuente: Earthnullschool



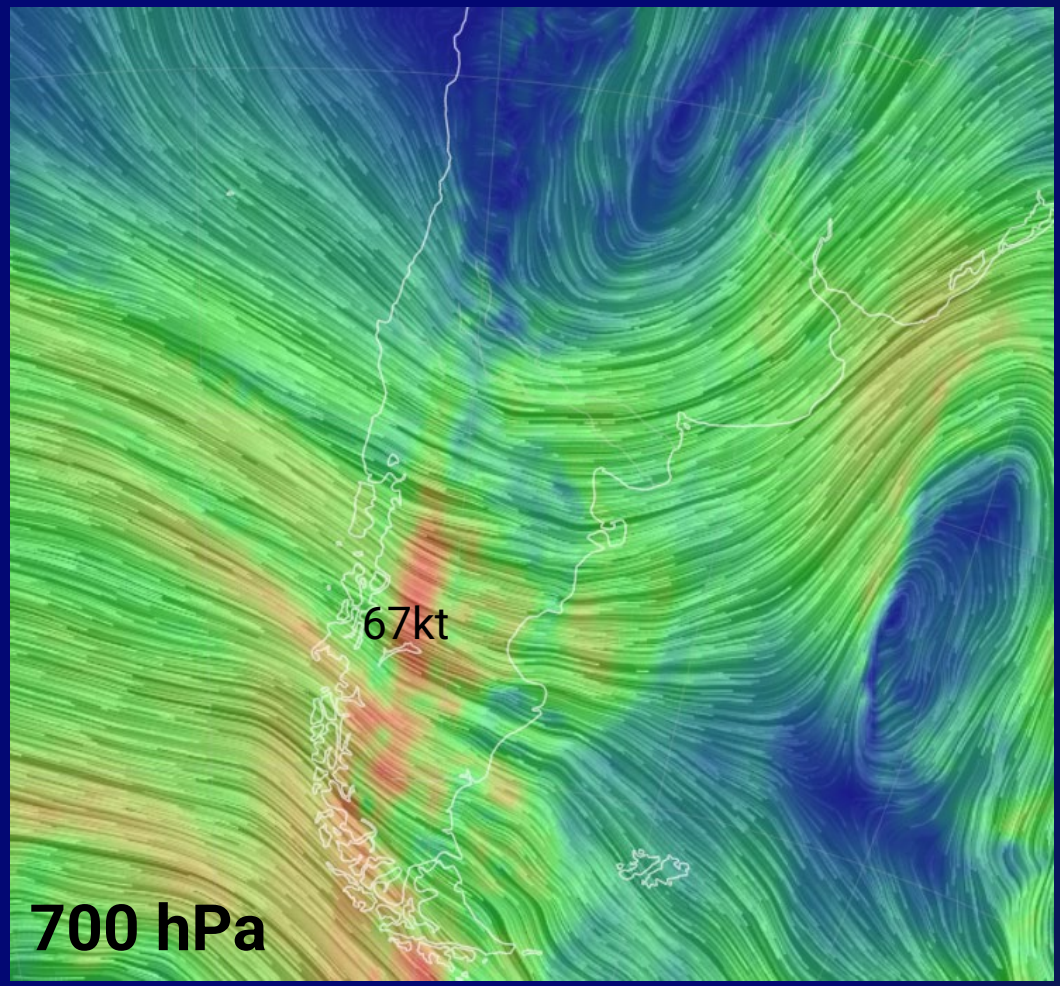
Fuente: Earthnullschool

Ondas de Montaña y Flujo

15-Nov-2022 18UTC



Fuente: CIRA Slider

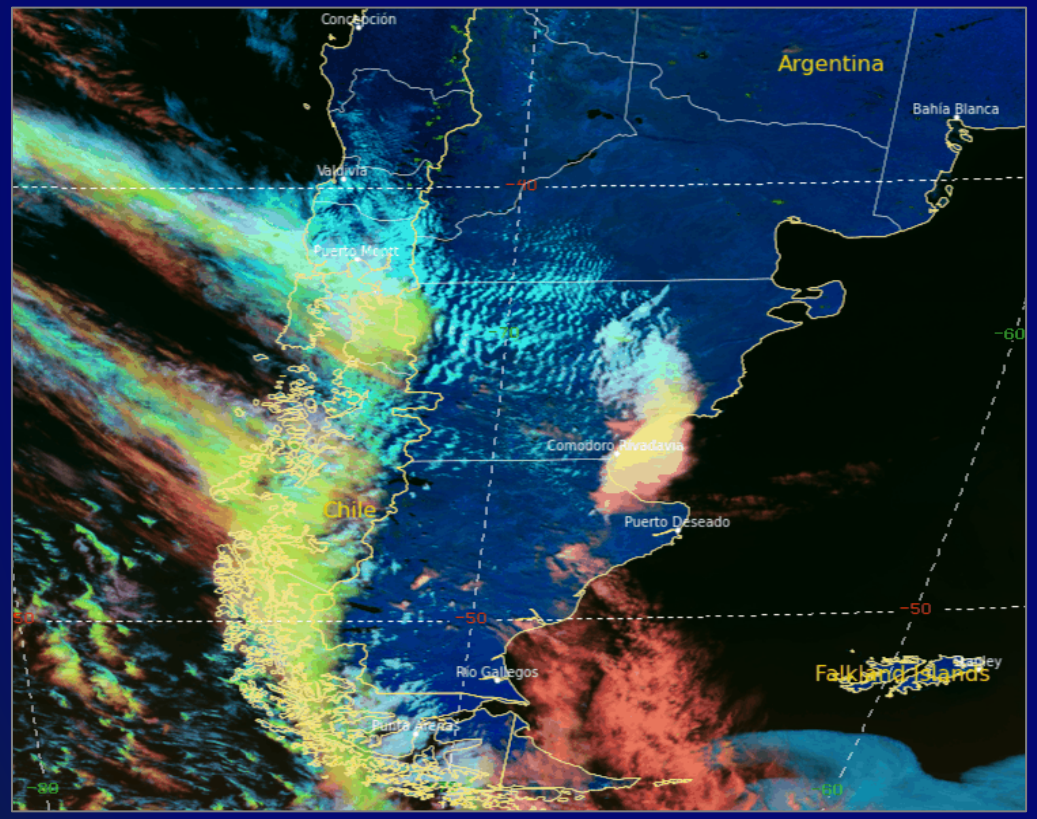


Fuente: Earthnullschool

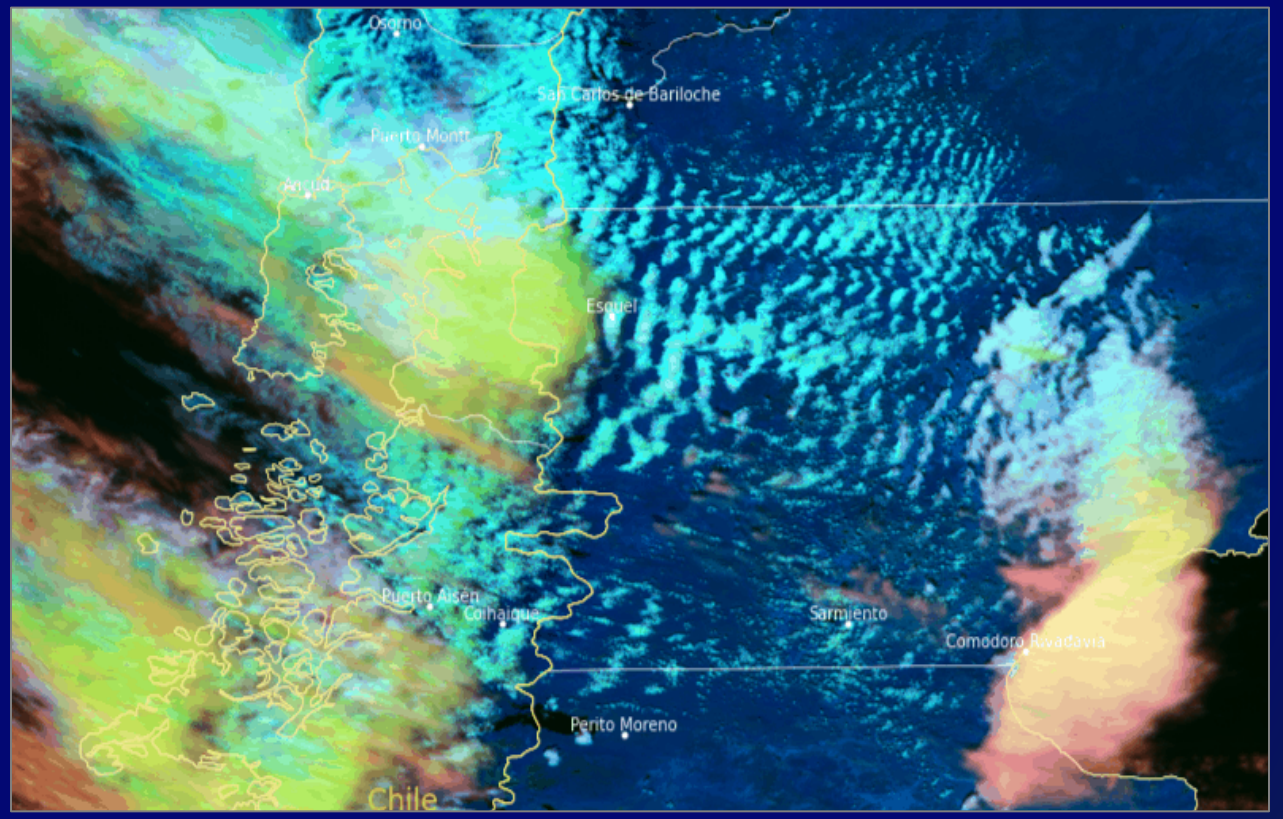
Ondas de Montaña y Flujo

15-Nov-2022 18UTC

El product de distinción de fase de nube de día ayuda a encontrar onlas de montaña SOLAMENTE cuando existen nubes asociadas. Se pueden identificar como estructuras lineales quasiestacionarias, paralelas a la cadena de montaña y flujo abajo de ella.



Fuente: CIRA Slider

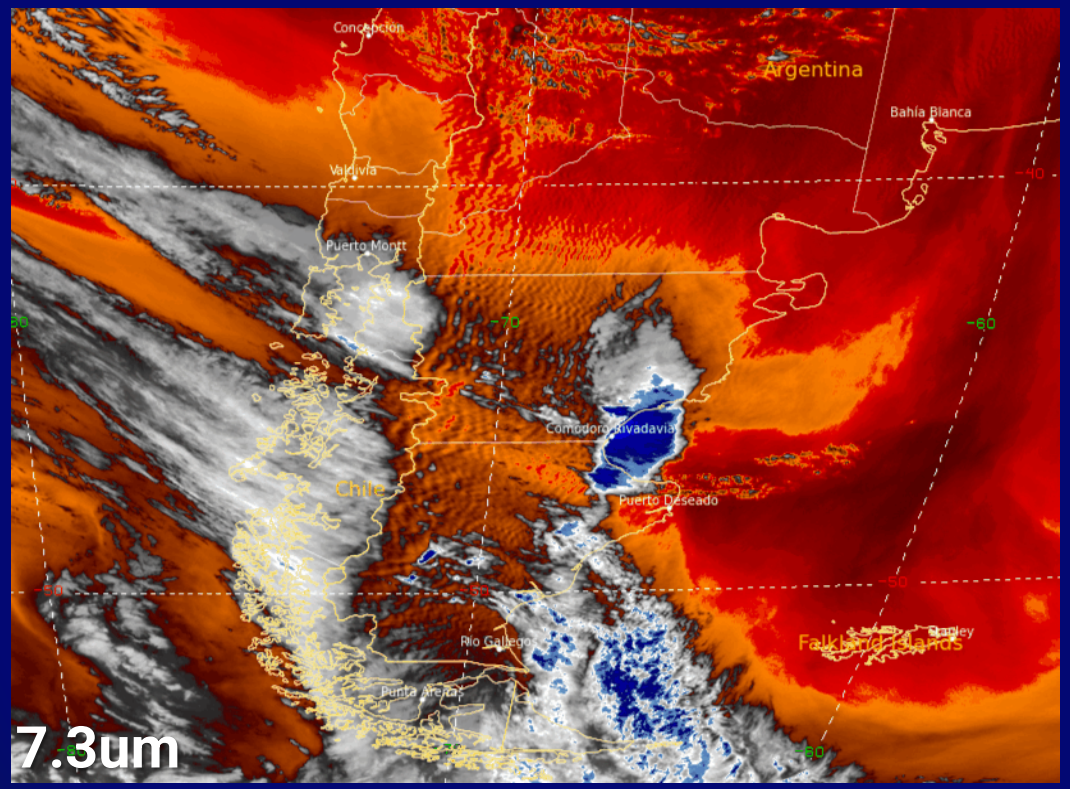


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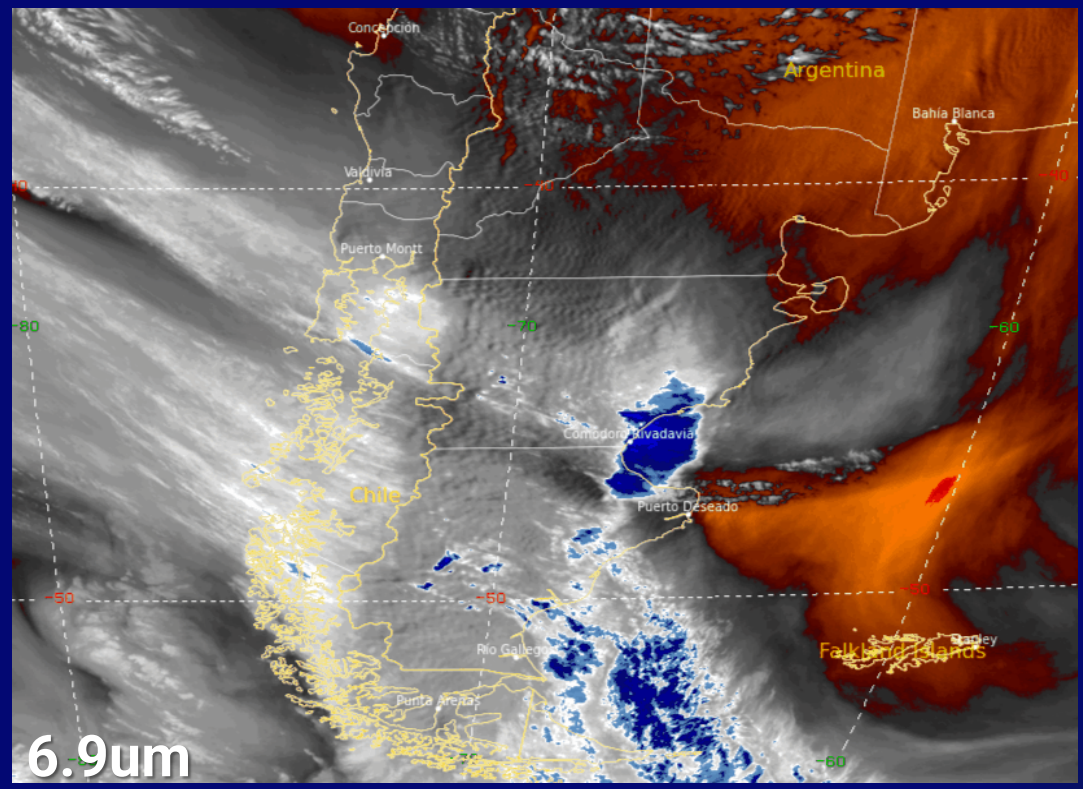
Ondas de Montaña y Flujo

15-Nov-2022 18UTC

Imágenes de vapor de agua de nivel bajo (banda 7.3um) ayudan a la detección de ondas cuando el terreno es más bajo (e.g. 1500-2000 m). En Patagonia, las imágenes muestran nubes desapareciendo al cruzar los andes, por compression adiabática. En cambio, se generan ondas de montaña que se propagan cientos de k, flujo abajo.



Fuente: CIRA Slider

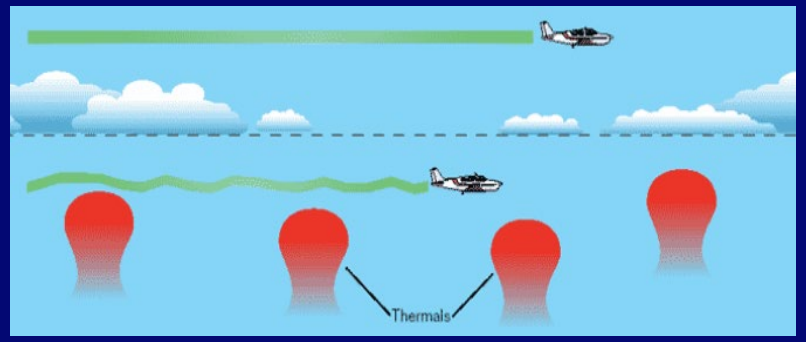


Fuente: CIRA Slider

Turbulencia Convectiva

2) Turbulencia Convectiva (Termal)

- Generada por movimientos verticales inducidos por inestabilidad.
- Tipos:
    a) Capa Limite: El calentamiento solar desestabiliza los niveles bajos e induce la formación de termales ascendientes.
    b) Convección húmeda: Cumulus y cumulonimbus se asocian a Corrientes ascendientes intensas y pueden generar ondas de gravedad al alcanzar capas estables.



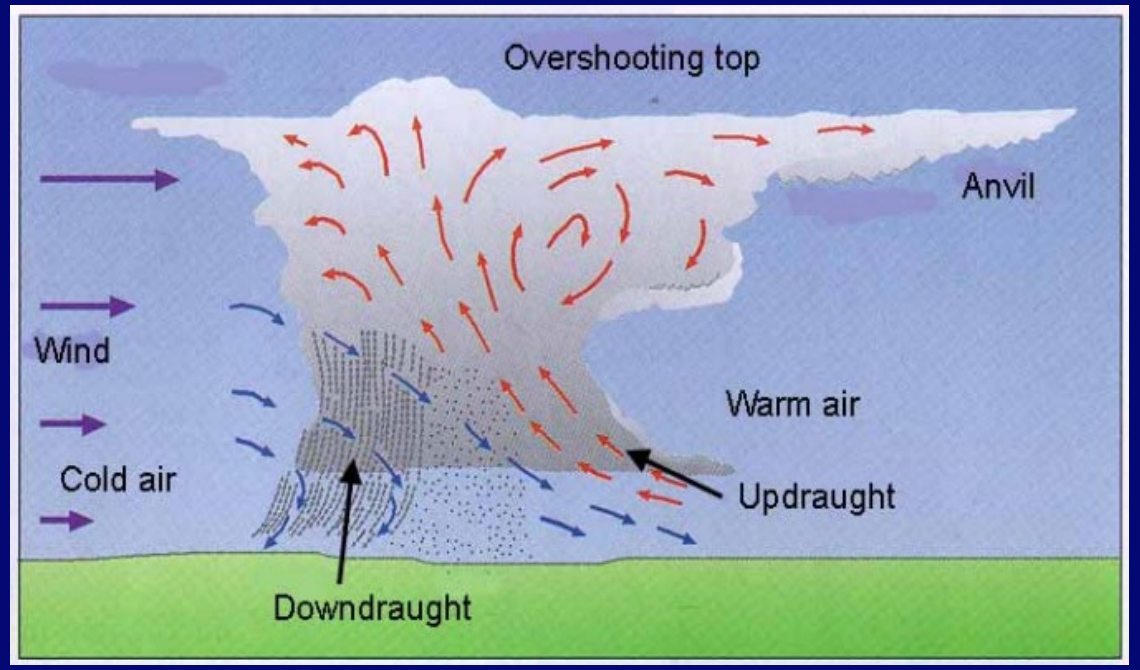
Capa límite


Convección profunda

Turbulencia por convección húmeda

Generada por:

- Corrientes ascendentes intensas dentro y cerca del Cb.
- La mayor Turbulencia ocurre si un piloto ingresa al Cb.
- Pero ondas de gravedad y Turbulencia también ocurren en capas estables circundantes cuando la corriente ascendente llega a ellas (Ejemplo: Nivel de equilibrio y/o la tropopausa, entre otros).



Topes que rebasan la tropopausa

Son nubes más frías que el yunque de un Cb, formadas por corrientes ascendentes tan intensas que rebasan la tropopausa y penetran a la estratósfera..

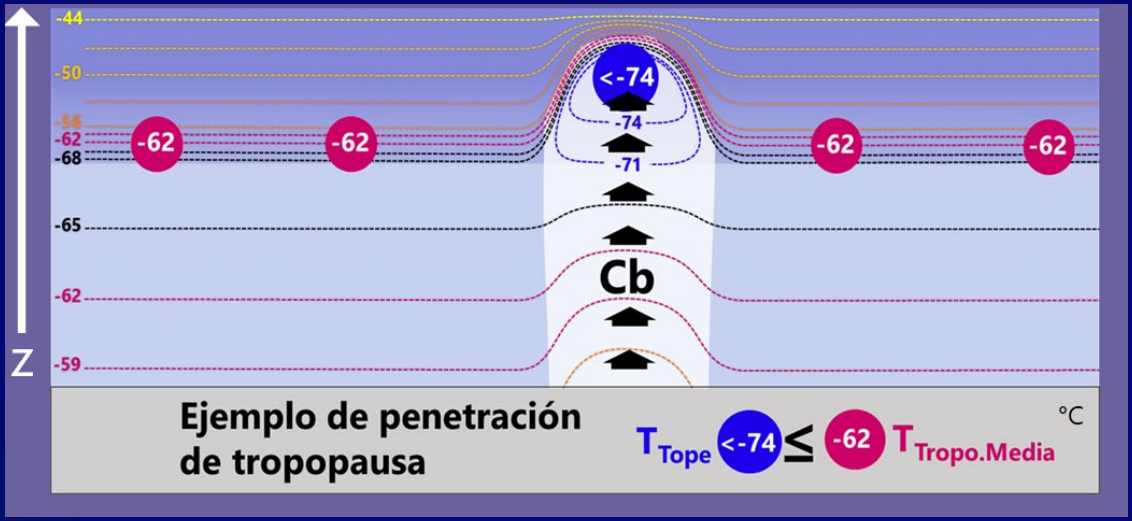
- Sugieren ascendentes extremas y un alto potencial de turbulencia moderada o severa dentro y cerca de un Cb.

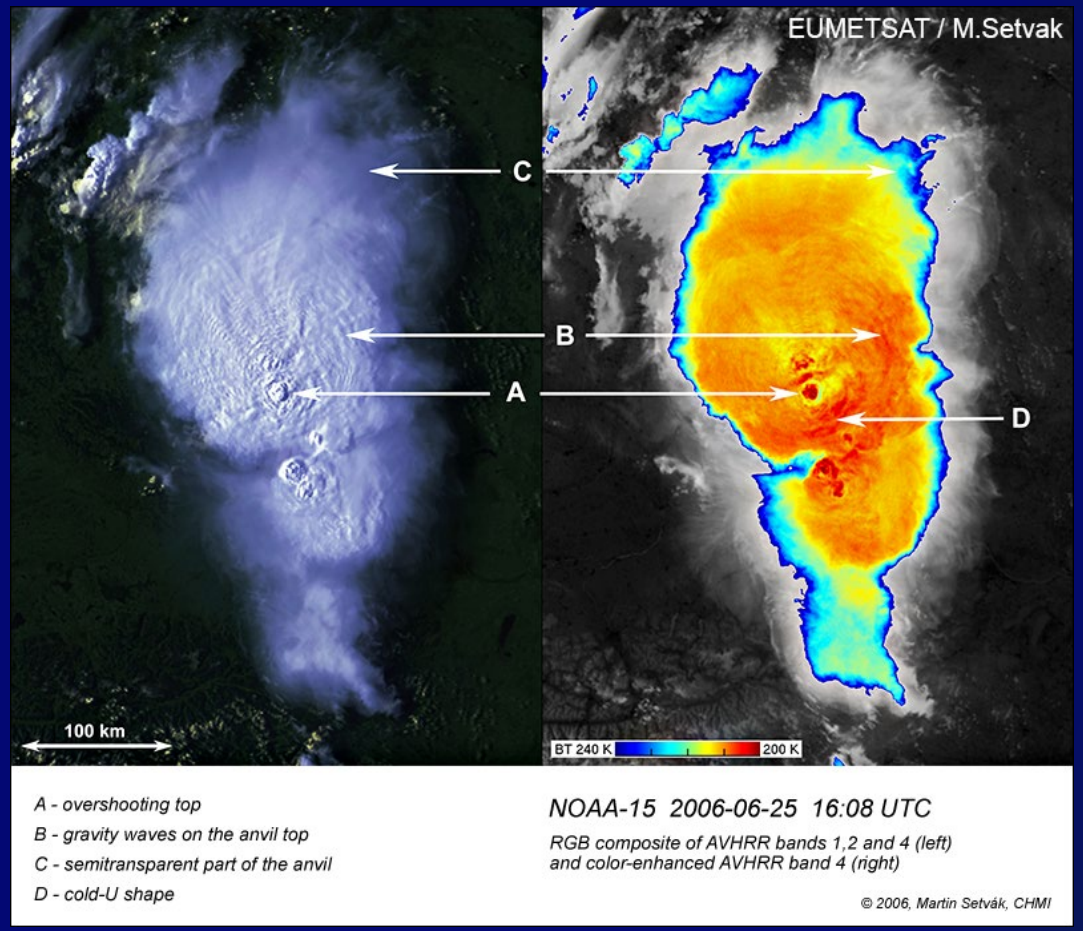


Source: INUMET, Taller de Tiempo Severo de 2019

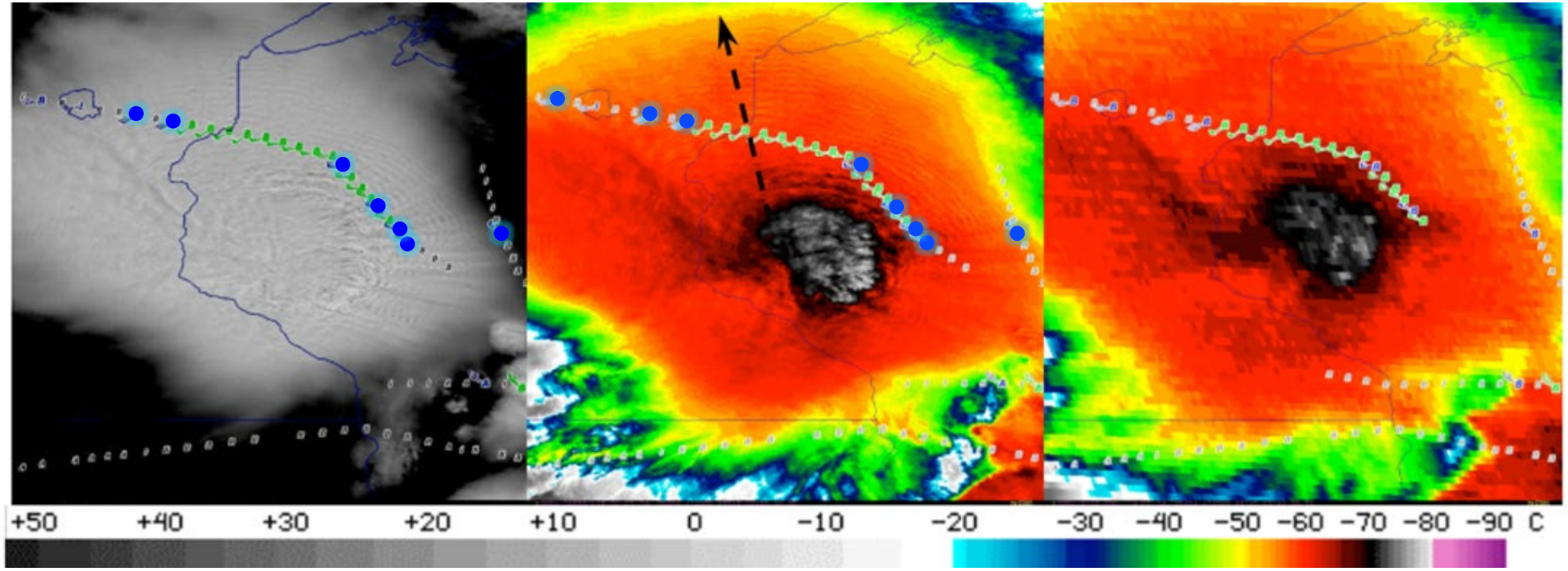
Topes rebasantes desde el satélite

- Estructuras circulares embebidas dentro de un yunque o área extensa estratiforme.
- Las temperaturas son menores que en el resto del yunque.
- Ondas de gravedad tienden a irradiar desde los topes rebasantes.





Turbulencia convectiva cerca al yunque de un Cb



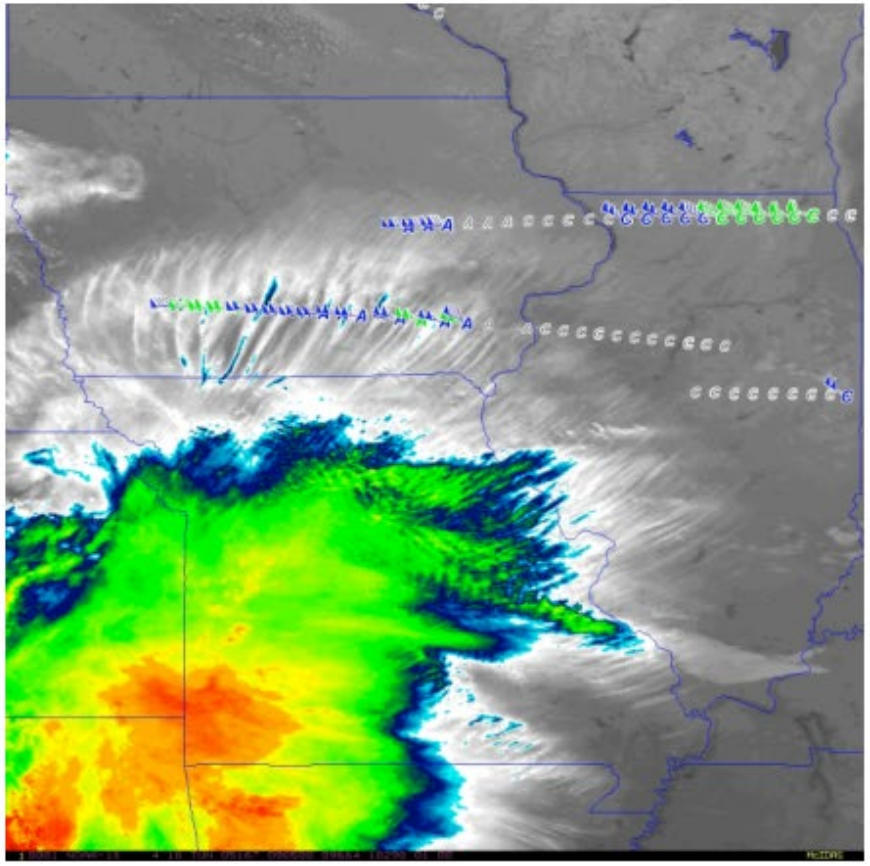
Turbulencia Severa

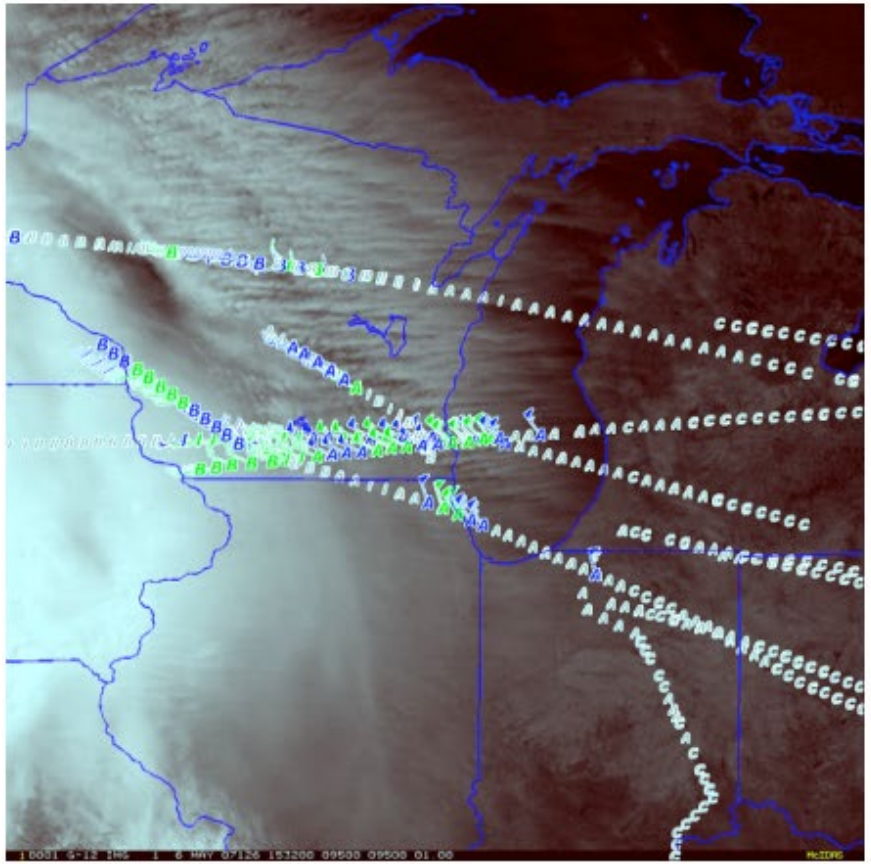
Moderada

Ligera

Figure 3: Turbulence associated with wave signatures initiated by overshooting convective tops. (left) Contrast-enhanced Terra MODIS 1 km visible channel imagery (middle) Terra MODIS 1 km 10.7 micron infrared window imagery (right) GOES-12 4 km 10.7 micron infrared window imagery at 1725 UTC on 23 July 2005. The letters plotted upon the imagery represent the relationship between the aircraft-observed and IR window brightness temperatures. "A" indicates aircraft temperature colder than satellite, suggesting flight above cloud top. "I" indicates aircraft temperature within 2 K of satellite, suggesting flight within cloud top. "B" indicates aircraft temperature warmer than satellite, suggesting flight below cloud top. "C" indicates aircraft temperature significantly colder than satellite, suggesting flight in clear sky. The color of symbols indicates severity of turbulence as estimated by EDR with blue being light, green being moderate, and red being severe. Grey indicates no turbulence. EDR observations within +/- 30 mins from the image timestamp are shown.

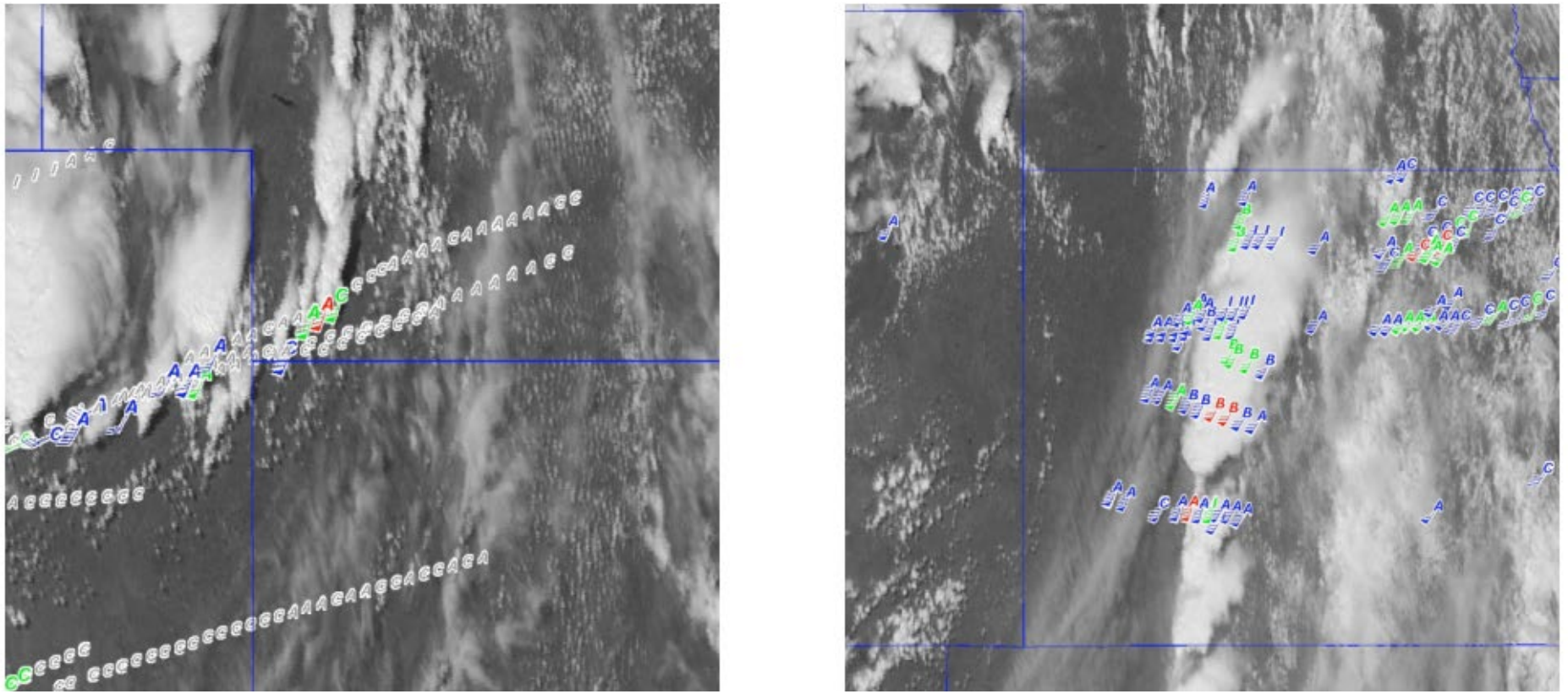
Turbulencia convectiva cerca al yunque de un Cb





Turbulencia asociada a salidas a bandas producidas por un yunque (“bandas transversales”) mostrando tubulencia moderada.

Turbulencia convectiva cerca al yunque de un Cb



Turbulencia asociada a cumulus en desarrollo (izquierda) y a cúmulos maduro en imágenes visibles del GOES 12, a las 1945 UTC del 7 de mayo de 2005 y a las 1815 UTC del 5 de mayo de 2007.

Turbulencia de Aire Claro

Turbulencia de Aire Claro (TAC)

Definición: Turbulencia generada en aire claro, donde no hay nubes; y que es invisible al piloto. Tiende a aparecer de manera súbita.

- La detección visual es un reto. Ocasionalmente, algunas estructuras nubosas pueden sugerir que CAT puede estar presente en regiones vecinas.
- TAC se asocia a valores altos de cozalla del viento, deformación horizontal y Convergencia, en una region con deficit de Saturación (sin humedad suficiente para permitir la formación de nubes).
- La mejor manera de indentificar TAC es guiándose con soluciones de modelos numéricos e imágenes de satélite de forma conjunta.

Estimando TAC a partir de valores de cizalla

TAC es causada primariamente por cozalla/cortante de viento (cambio en la dirección y/o velocidad del viento en una distancia):

- Causas principales: Cizalla vertical e horizontal.
- Flujo desacelerándose.
- Cizalla direccional cerca a un gradiente termal.

	TAC Moderada Fluctuaciones de la velocidad de aeronave: 8 - 13 m/s	**TAC Severa** Fluctuaciones de la velocidad de aeronave >13 m/s
Cizalla vertical	>6kt / 1000ft	>9kt / 1000ft
Cizalla horizontal	>20kt / 100 km	>30 kt / 100 km
Cizalla por flujo desacelerándose	>40kt / 1000 km	>125kt / 1000 km
Cizalla direccional	Giro de 75° cerca a un gradiente termal	

Source: COMET Modules

Patrones de flujo que favorecen TAC

Todas las situaciones que desarrollen gradientes de viento importantes en la horizontal y/o vertical; y regions de velocidades verticales importantes cambiando en distancias cortas.

Ejemplos de patrones

- **Chorros:** Se asocian a gradients de viento y cizalla extremos; y a regions de movimientos verticales importantes.
- **Periferia de vaguadas y dorsales de altura:** Cizalla resaltada por gradients horizontals de viento.
- **Ciclogénesis:** Movimientos verticales importantes.
- **Plegamiento de la Tropopausa:** Asociado a chorros y ciclogénesis.

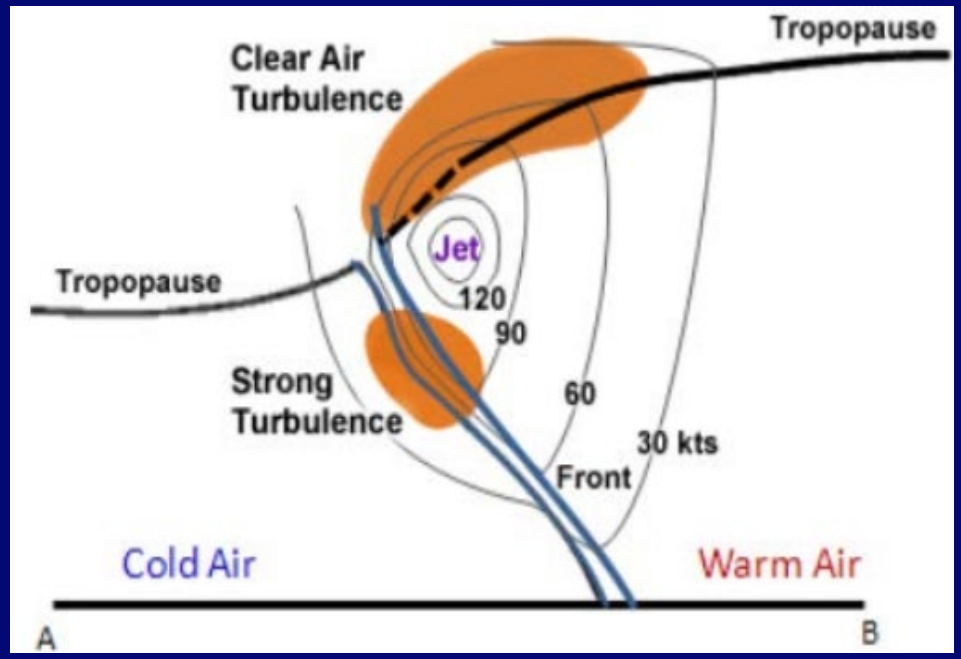
Chorros de Altura y TAC

Los chorros de altura son la fuente principal de TAC en la alta tropósfera:

- Ocurre principalmente por cizalla, pues los chorros tienen regions de cambios rápidos en la velocidad del viento con la distancia.
- Existen otros procesos como:

  - Interacciones de chorros con vaguada

  - Velocidades verticals infucidas por los chorros.

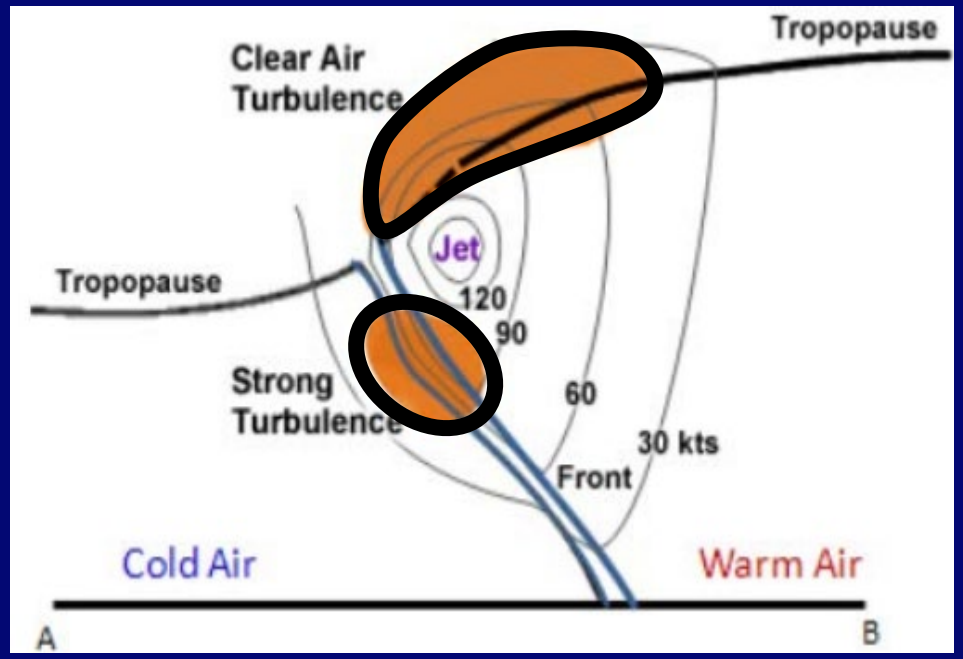


Cross section of turbulence with upper jets

Chorros de Altura y TAC

Briggs (1961), analizó los lugares de ocurrencia de TAC en base a 73 casos:

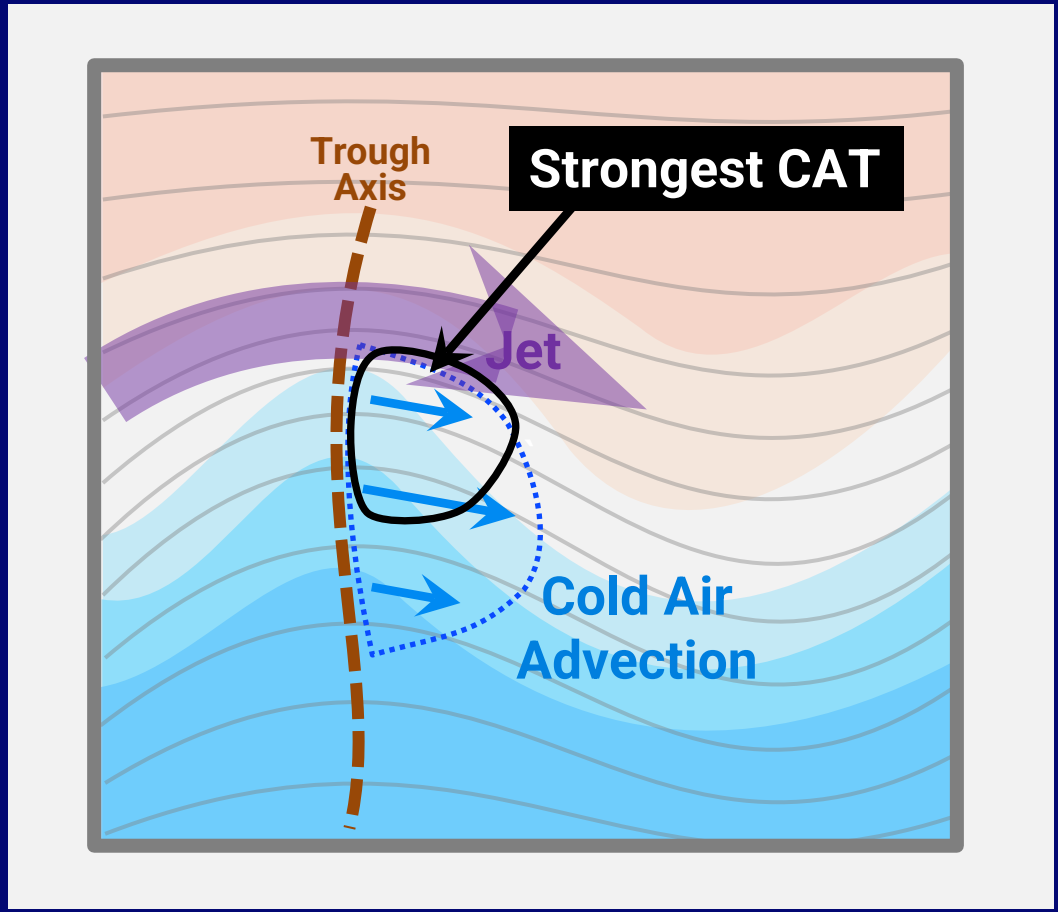
- La mayoría ocurría con vaguadas de altura debajo de ejes de chorro en altura.
- TAC era favorecida a menos de 200km del máximo del chorro y de 1.5-4.5 km bajo la tropopausa.
- Asimismo, TAC ocurría sobre el eje de los chorros donde los vientos dismimuyen rápidamente con la altura en una capa estable.



Cross section of turbulence with upper jets

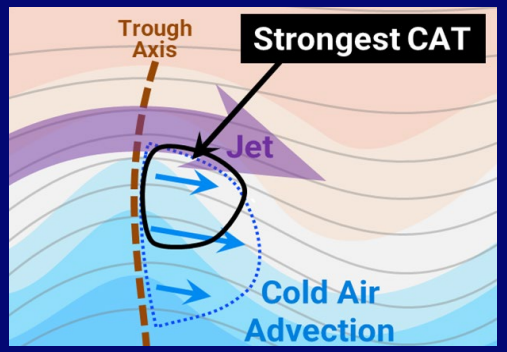
TAC y Advección Fría en Altura

- Turbulencia es favorecida flujo abajo de un eje de vaguada y cerca al chorro.
- Mayor si el chorro se ubica en el lado cálido de la vaguada.
- Mayor si coincide con la salida fría de un máximo de chorro (jet streak), pues esta region se asocial a ascensos dinámicos inducidos importantes.

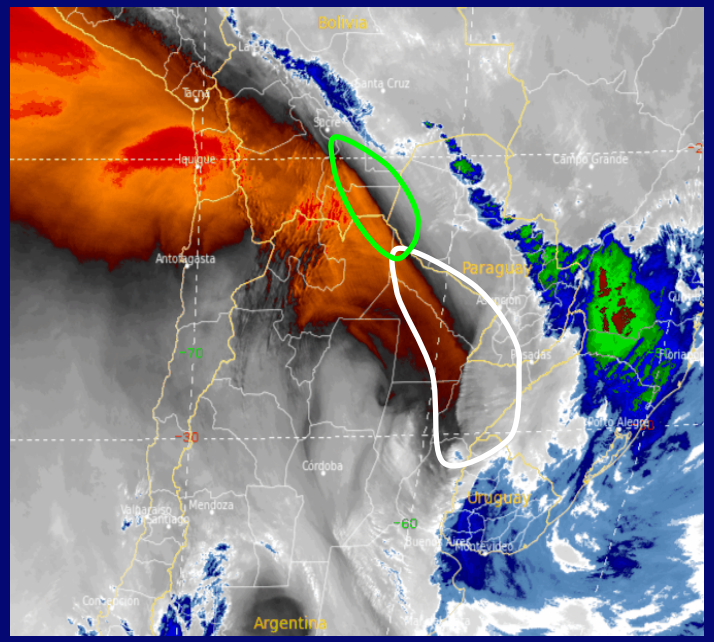


Ejemplo de TAC, 06 Oct 2022

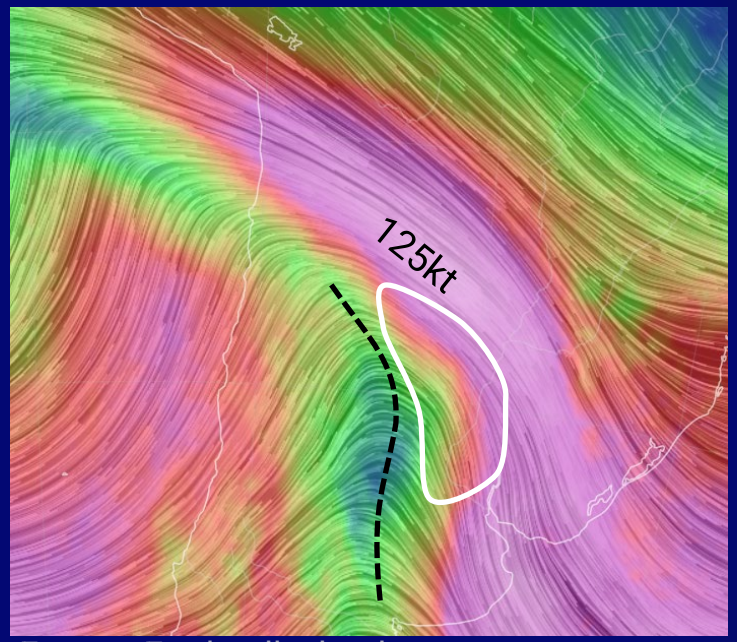
- TAC ocurre flujo abajo de la vaguada de altura, en el lado frío de un chorro de altura.
- Existe advección fría cerca al chorro y a su salida fría (ascensos).



- Imagen: Los gradientes de humedad que se vuelven más marcados en el borde Paraguay-Bolivia-Argentina sufieren potencial TAC (por incremento de la cizalla)



Fuente: CIRA Slider

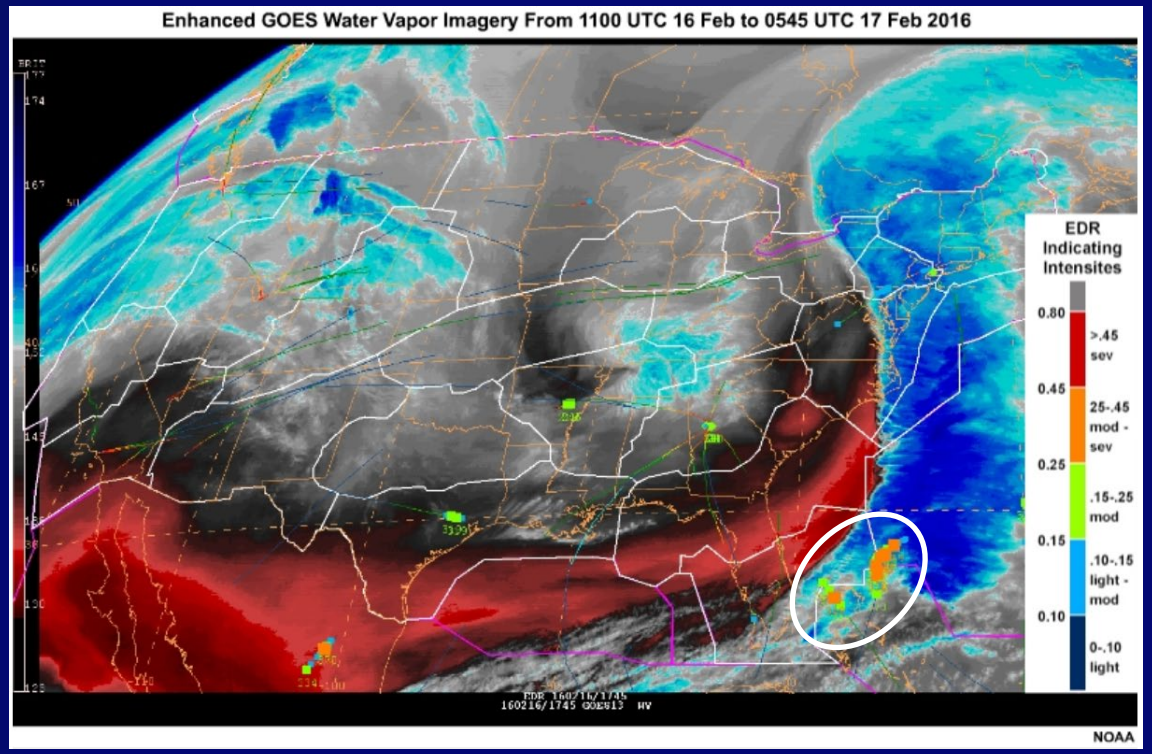


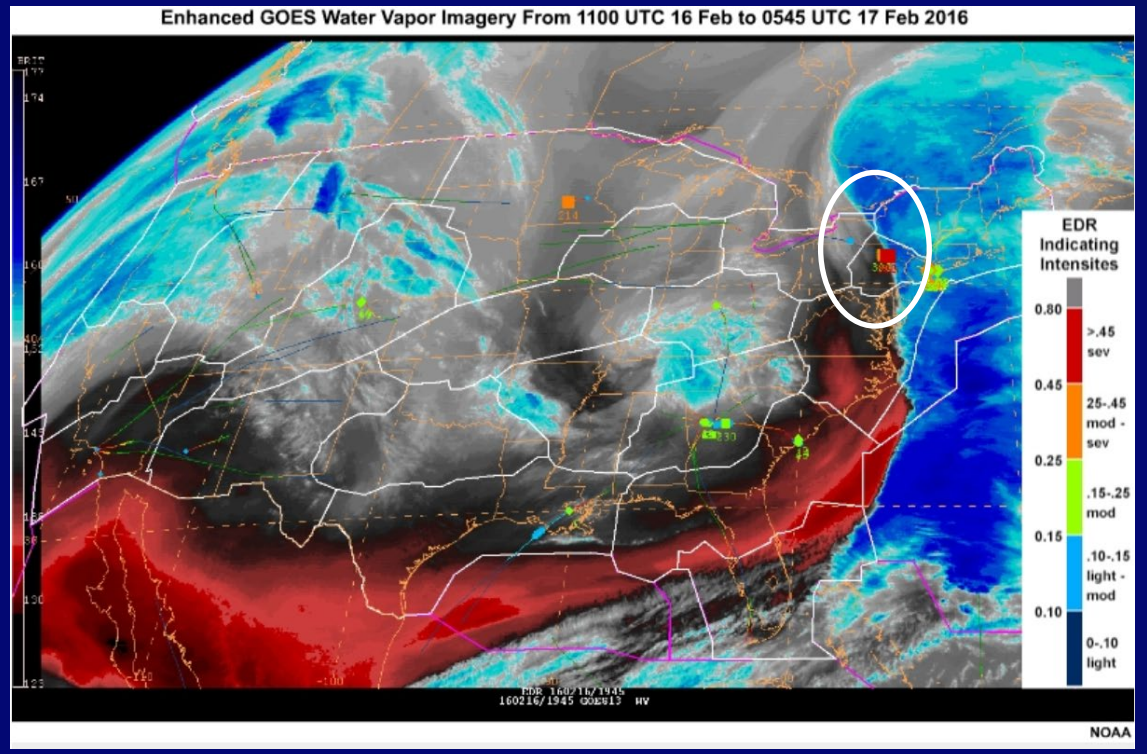
Fuente: Earthnullschool

Gradientes de velocidad para TAC severa: >30 kt / 1° de latitud

Caso estudio: USA, 2016

TAC en Imágenes: Caso Estudio USA





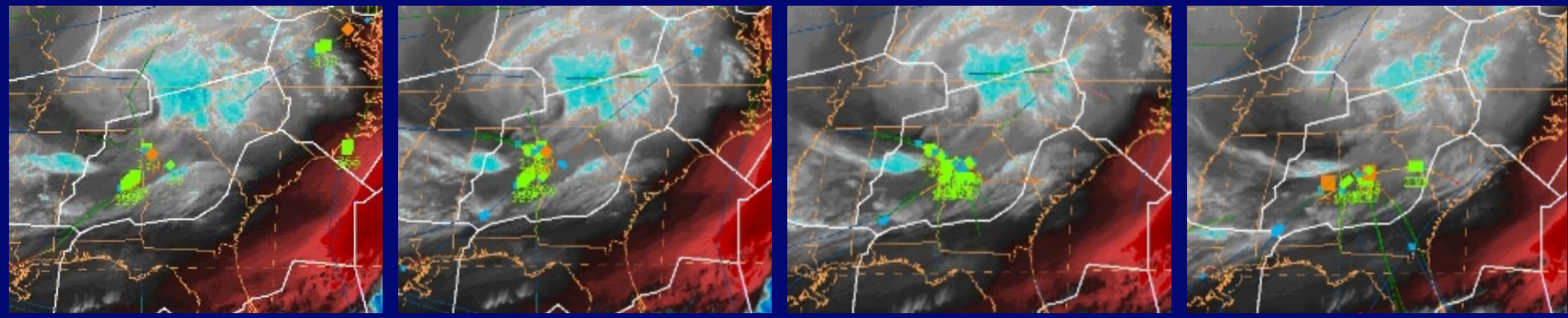
- Se puede ver en regiones de gradientes de humedad abruptos en la periferia de vaguadas de altura y cerca a chorros (Nueva York, imagen derecha).
- En las Bahamas (imagen izquierda), la turbulencia se asocial al patron de ondas de gravedad en los cirrus. Muestra la presencia de un chorro. El gradiente abrupto de humedad puede ubicarse debajo de los cirrus, pero no es totalmente evidente en las imágenes.

TAC en imágenes de vapor de agua

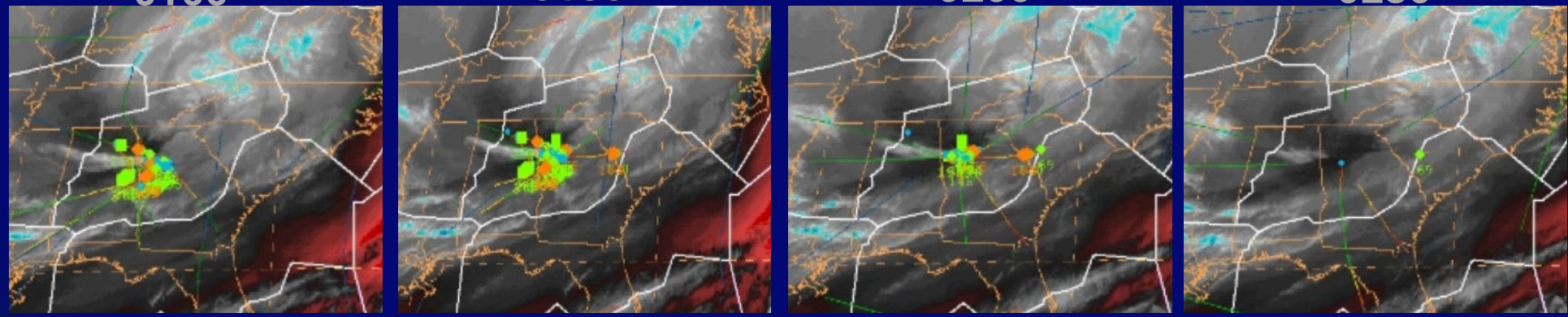
Turbulencia moderada a severa en Atlanta con vaguada de altura.

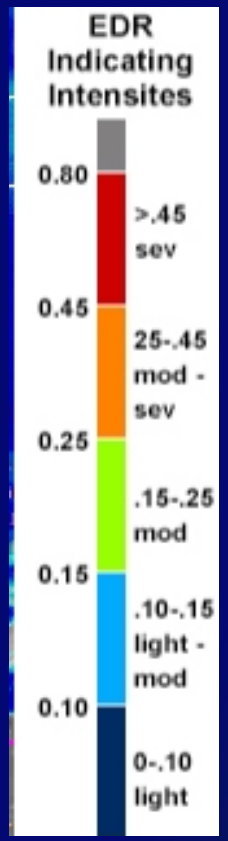
16-17 Feb 2016

2300 2330 0000 0030



0100 0130 0200 0230

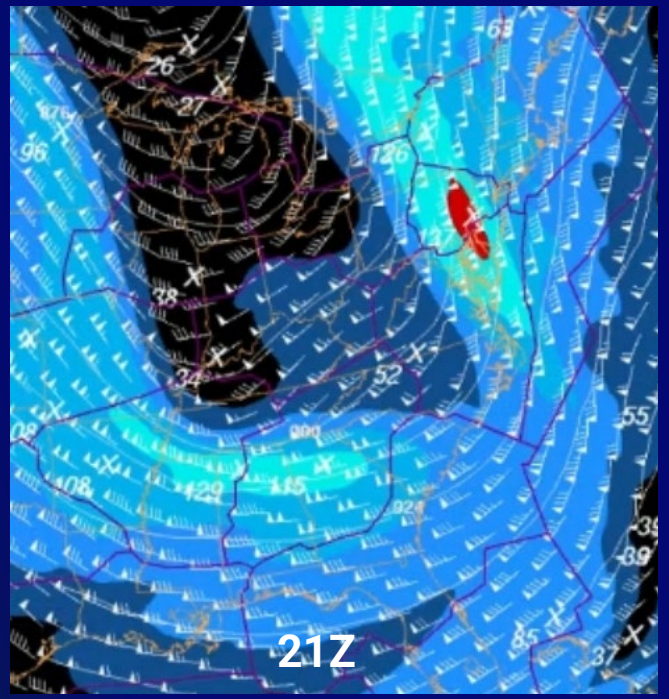




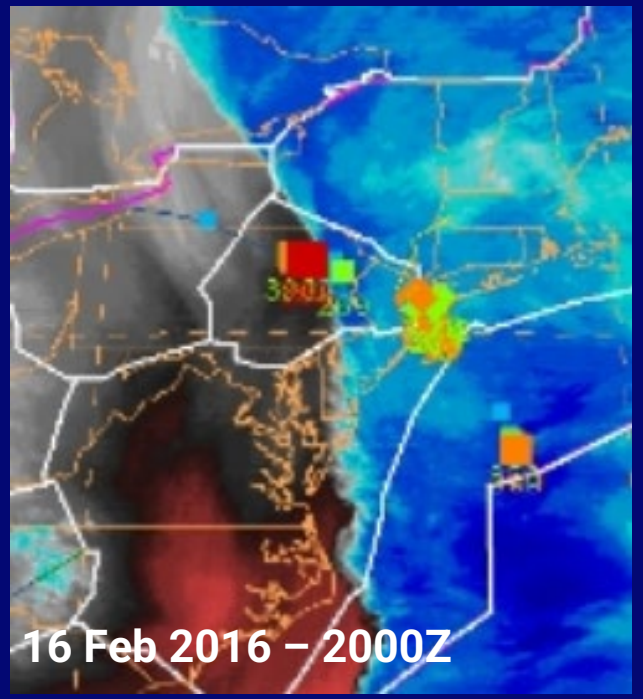
TAC en imágenes de vapor de agua

Turbulencia moderada a severa en Nueva York con chorro y plegamiento de la Tropopausa

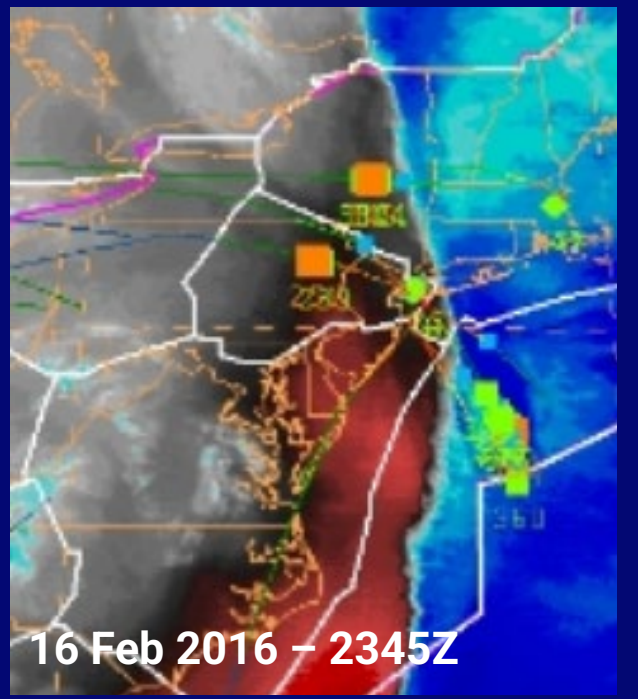
Viento en 300 hPa

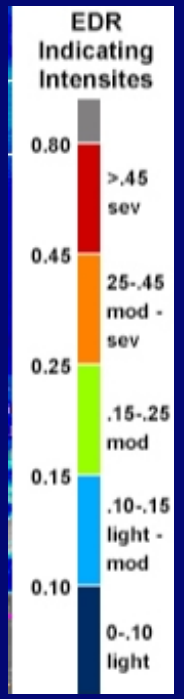


WV



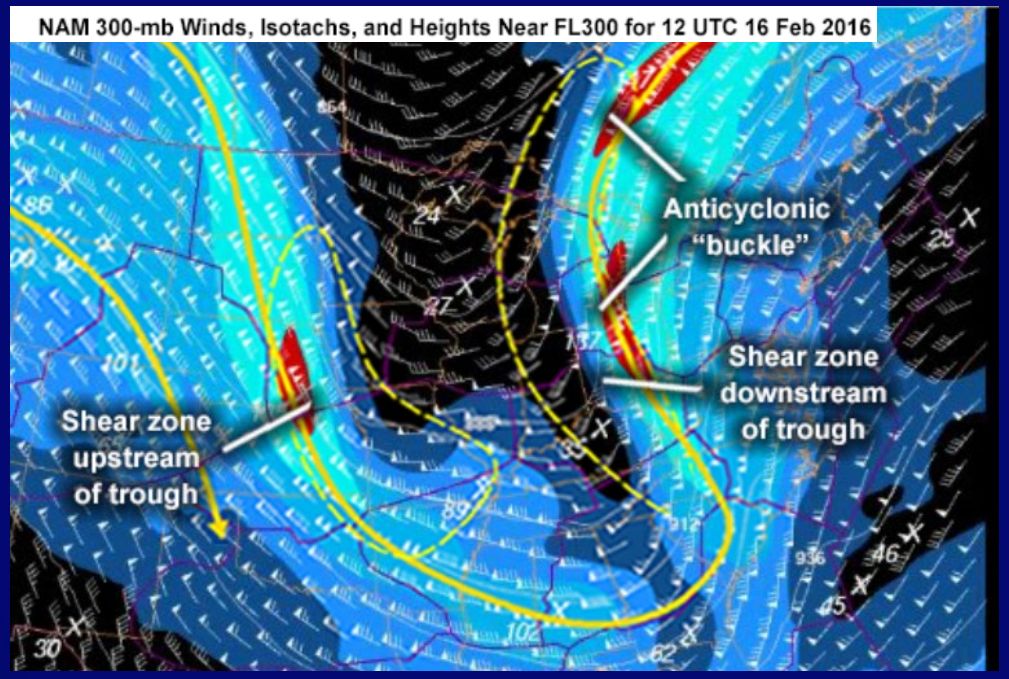
WV

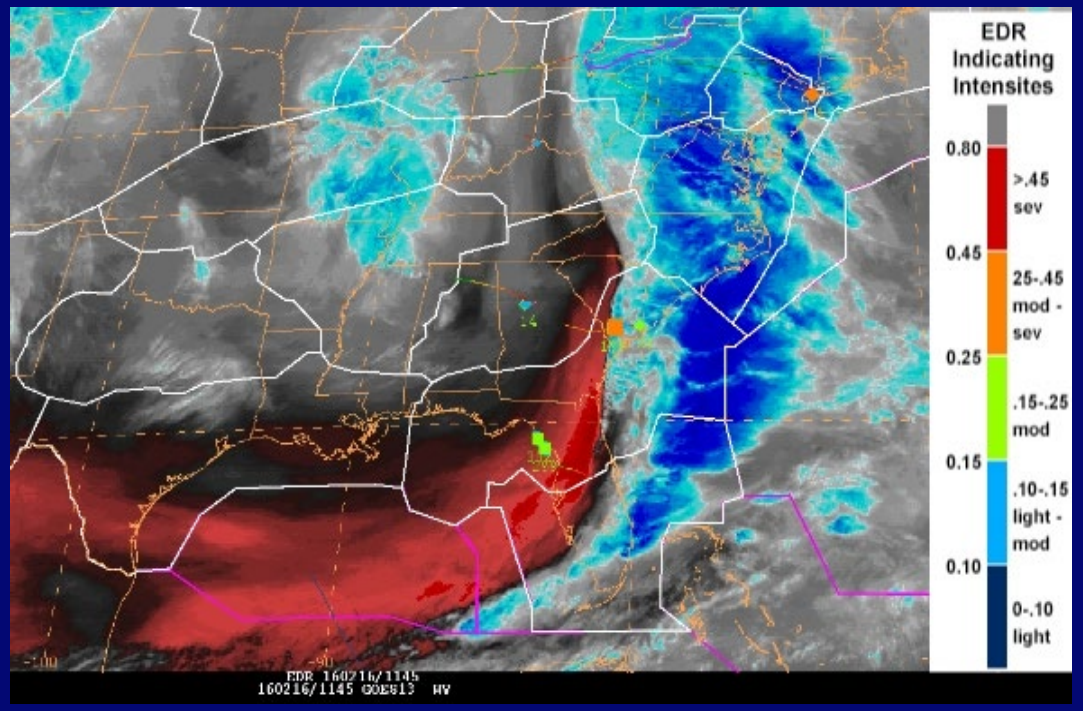




TAC en imágenes de vapor de agua

Turbulencia moderada a severa en Nueva York con chorro y plegamiento de la Tropopausa



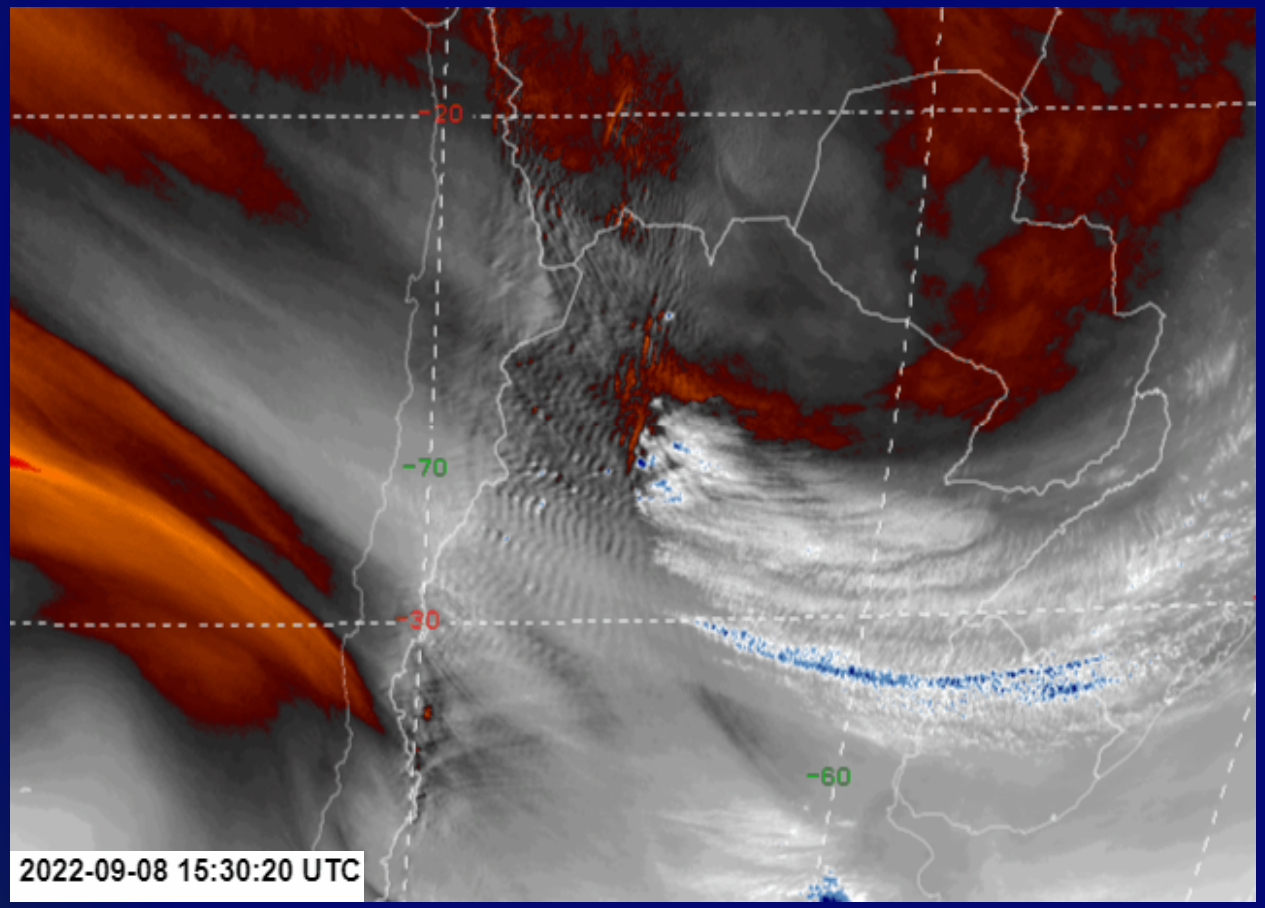


Señales de TAC en imágenes

- Notar que, de todas formas, se recomienda analizar lo visto en imágenes con datos de modelos numéricos.
- Que buscar en imágenes. Principalmente usando imágenes de vapor de agua, infrarrojas y el producto RGB de Masa de Aire:

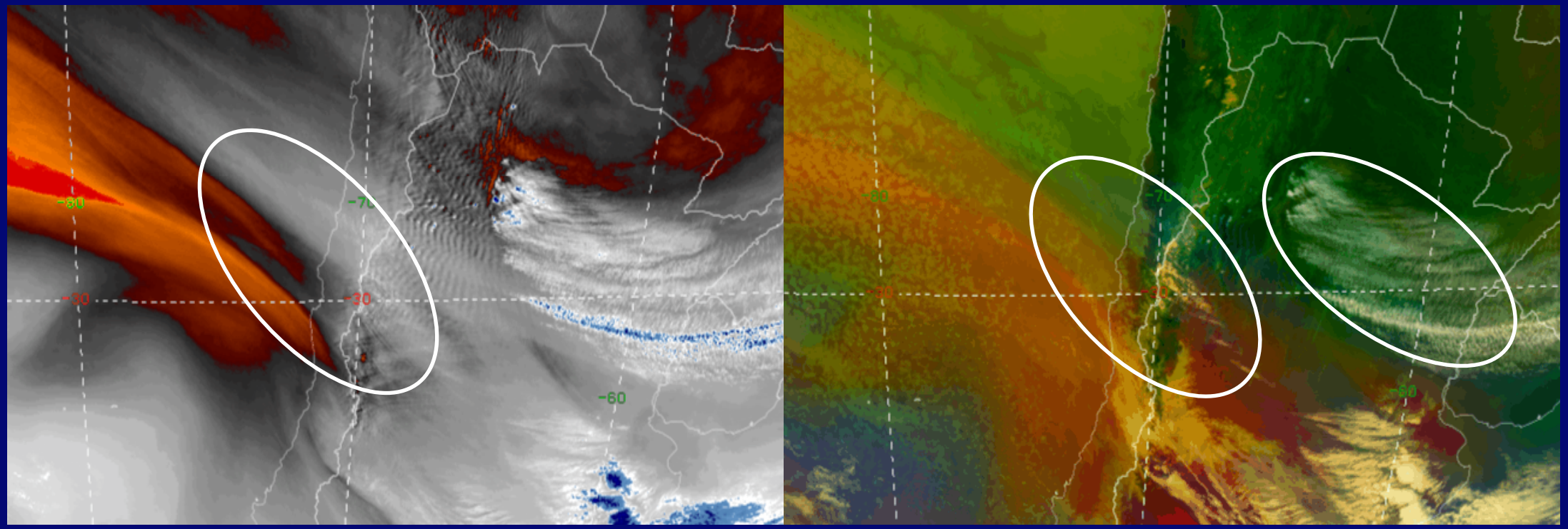
1. Flujo rápido y bandas transversales (chorros).
2. Gradientes de humedad a lo largo de chorros de altura, especialmente si una vaguada existe en el lado frío del chorro.
3. Plegamiento de la tropopause e intrusiones de ozono (rojo intenso en el product RGB de Masa de Aire, junto a gradientes intensos de color.
4. Ondas de gravedad (estructuras lineares semiestacionarias)

Otros ejemplos de TAC en imágenes



- Ondas de gravedad definidas sobre y flujo abajo de los Andes.
- Gradientes de humedad abruptos en forma de línea flujo abajo de la cordillera.
- Presencia de chorros, evidentes en bandas transversales en nubes Ci.
- Los gradientes extremos de humedad en el Pacífico pueden asociarse a TAC, pues se asocian a chorros en aire claro y a una Vaguada aproximándose desde el suroeste.

Vapor de agua nivel alto vs RGB Masa de Aire

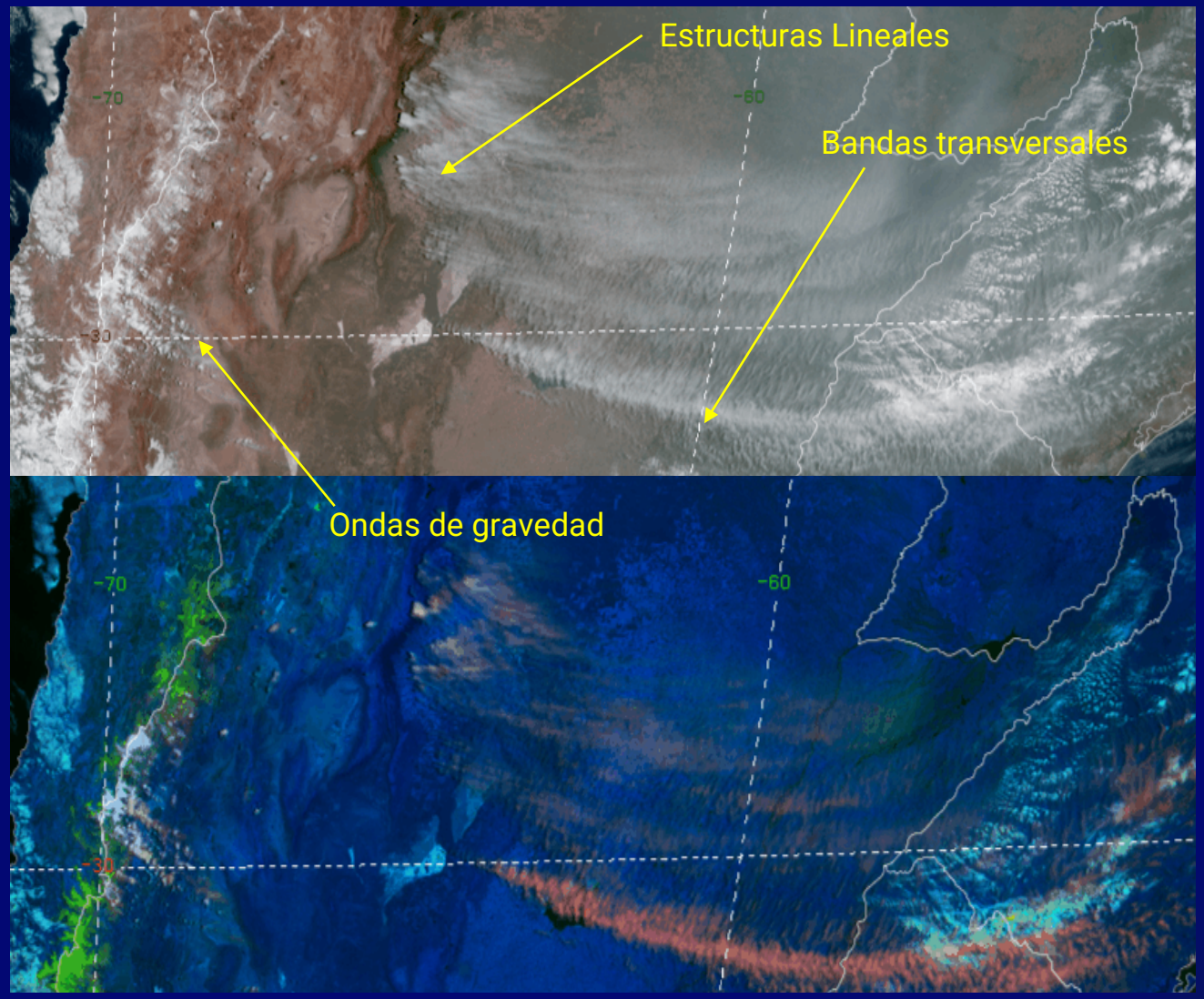


- En el Geocolor no se ven claramente las ondas de gravedad, pero los gradients de coloración sugieren una vaguada intense con potencial plegamiento de la tropopausa. El centro de Chile y regions flujo abajo se ven preocupantes.

Color	Band / Band Diff. (µm)	Min – Max Gamma	Physically Relates to…
Red	6.2 – 7.3	-26.2 to 0.6 C 1	Vertical water vapor difference
Green	9.6 – 10.3	-43.2 to 6.7 C 1	Tropopause height based on ozone
Blue	6.2 (inverted)	-29.25 to -64.65 C 1	Water vapor ~200-500 mb

Geocolor vs Distinción de Fase de Nube de Día

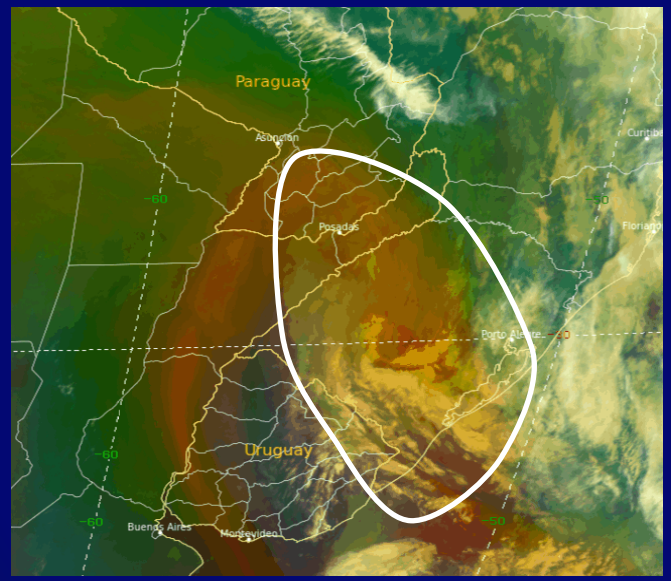
- Sólo se puede diagnosticar potencial de TAC donde existe nubosidad.
- Buscar bandas transversales y estructuras lineales a sotavento.
- Nubes en forma de ondas.
- RGB de Distinción de Fase de día muestra nubes cirrus en coloración rosa, Geocolor solo muestra la textura.

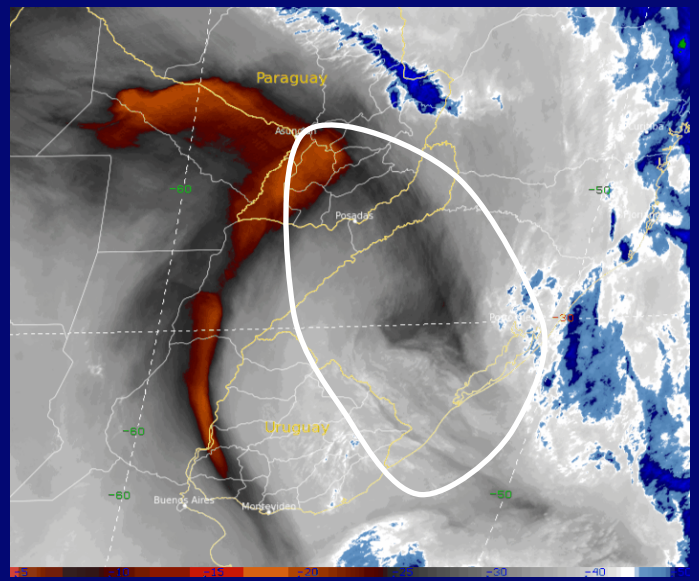


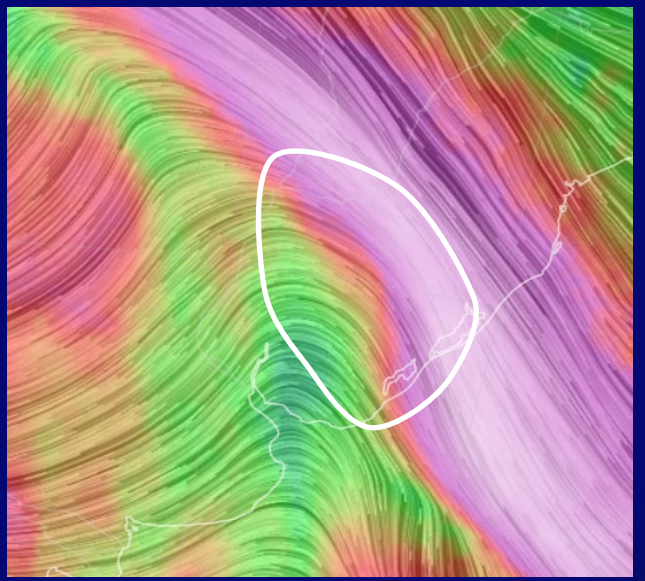
TAC y ciclogénesis

7-Oct-2022 07Z

- La ciclogénesis se asocial a TAC.
- Buscar vaguada en el lado frío de un chorro con gradientes de viento y humedad.
- Buscar rotación en las imágenes de vapor de agua.
- Buscar intrusión de ozono estratosférico (rojo) en RGB de Masas de Aire.





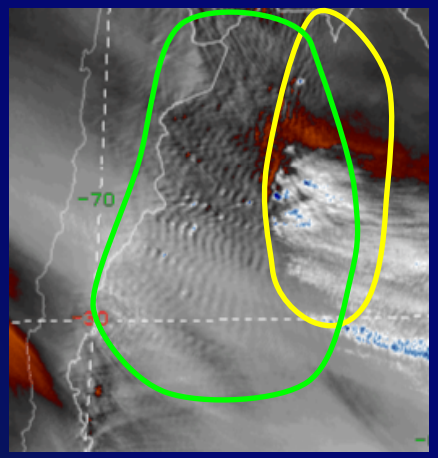


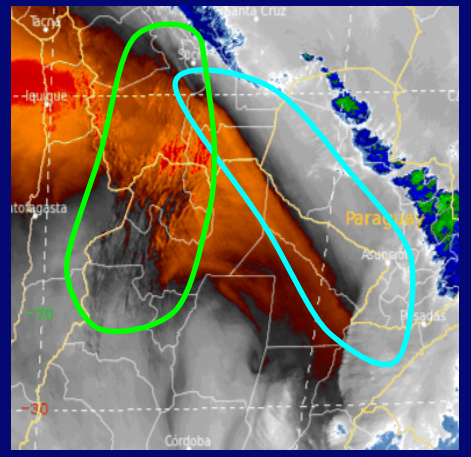
Resumen: Identificación de TAC

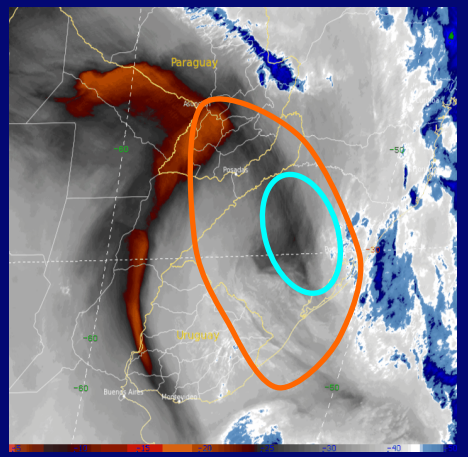
Identificar TAC en imágenes

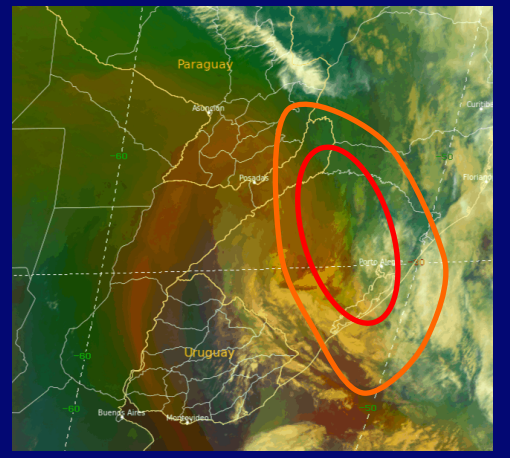
Vapor de Agua, Airmass RGB y otras

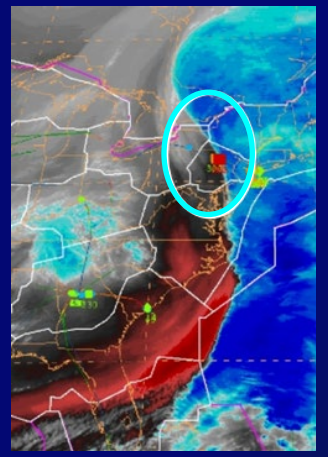
- Chorro cruzando cadena de montañas, especialmente con secamiento a sotavento (Fiehn/Zonda?) y ondas de gravedad de diferentes escalas.
- Estructuras lineales (ondas de gravedad).
- Gradientes de humedad a lo largo de chorros, intensificándose.
- Vaguadas de altura de inclinación negativa.
- Chorro de altura con vaguada en su lado frío, flujo abajo de la vaguada y en la salida fría del chorro.
- Periferia de chorros anticiclónicos.
- Ciclogénesis
- Plegamiento de la tropopausa











Arbol de decisiones para la identifación de TAC

1. Evaluar imágenes y datos de modelos numéricos:

   A) Encontrar ejes de los chorros.

   B) Encontrar ondas de gravedad. Especialmente si hay de varias dimensiones.

   C) Identificar regions de cizalla horizontal (intensificación de gradientes de humedad, áreas flujo abajo de vaguadas de altura en el lado frío de chorros, etc).

   D) Evaluar cizalla vertical con secciones transversales y en la horizontal.

2. Solidificar el modelo mental de lugares, periodos y altura de TAC.

3. Identificar intersecciones de rutas aéreas con las regiones de TAC. Emitir productos según los reglamentos.

04

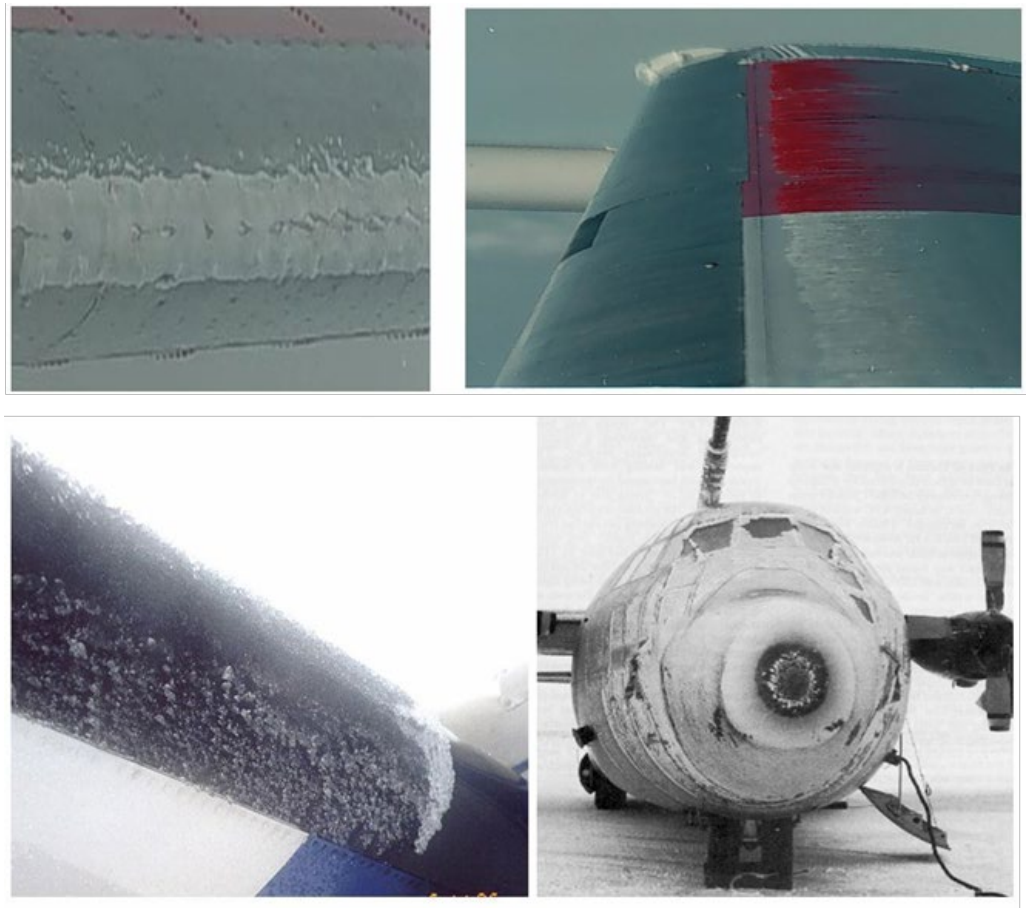
Engelamiento

Engelamiento en la Aviación

Definición: Es la formación de hielo en la aeronave debiro a la acumulación de agua sobreenfriada que se congela inmediatamente al adherirse a una superficie.

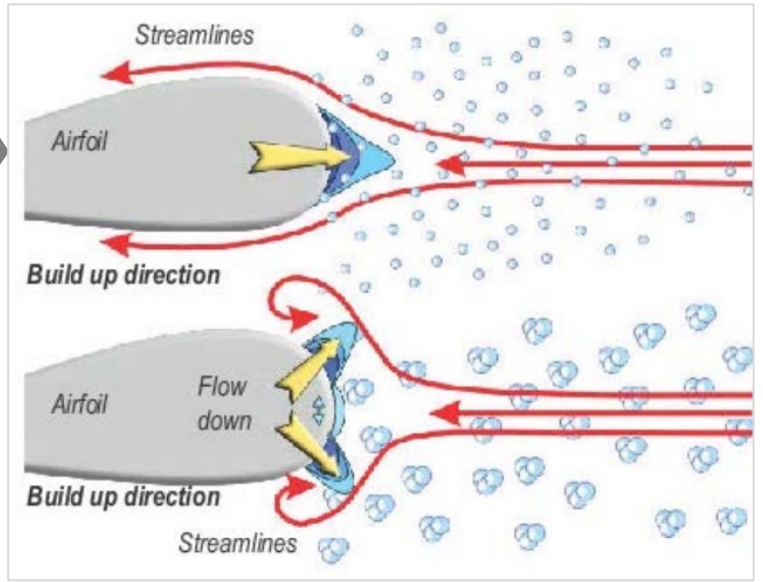
Puede interferir con las operaciones de la aeronave afectando la flotación, el control y las comunicaciones.

Se forma en ambientes donde existe alto contenido de agua líquida sobreenfriada y/o Precipitación; y a temperaturas entre 0 y -20°C.



Impacto en Aeronaves

1. **Flotación:**
   - Hace más pesada a la aeronave.
   - Afecta la dinámica de flujo que estimula ascenso en las alas, reduciéndo la capacidad de ascender en un 30-50%.



2. **Control de la aeronave**
   - Acumulación en las helices genera disbalance.
   - Blocks or limits the control of the wheel and other moving parts of the wing.

3. **Visibilidad:** Acumulación en el parabrisas.

4. **Comunicaciones:**
   - Hielo en las antenas interfiere con las comunicaciones.

Ambientes favorables para Engelamiento

1) Temperatura de 0 a -20°C

- Por la existencia de agua sobreenfriada. Rango ideal = -4 to -10°C.

2) Nubes con alto contenido de agua líquida

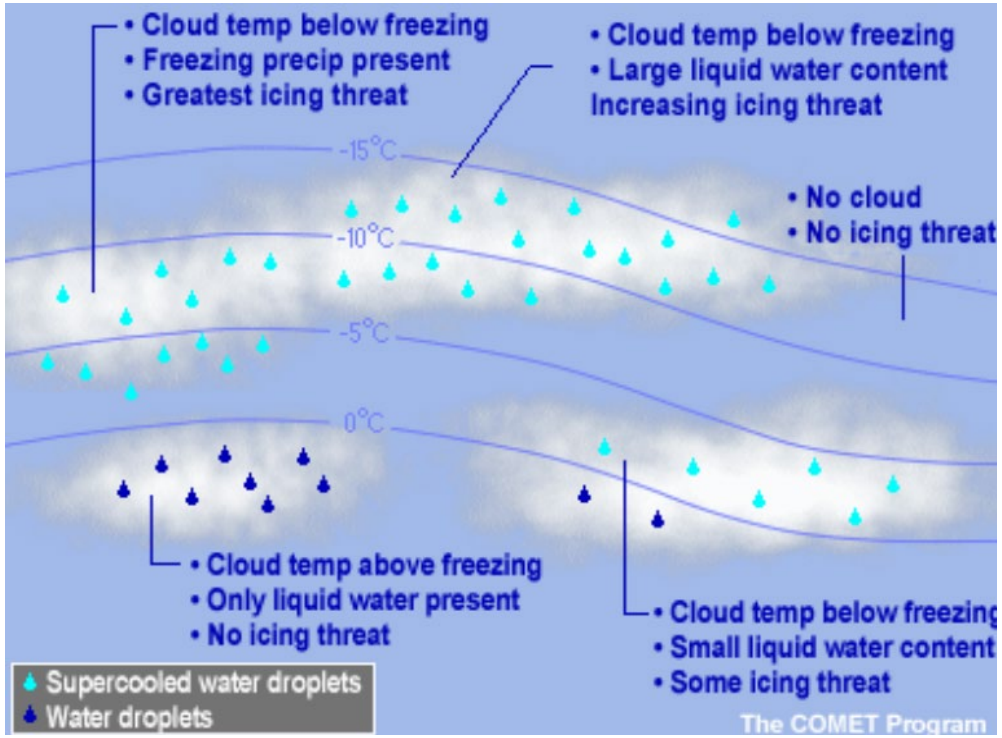
- Valores alto de razon de mezcla de agua líquida en una nube (CWMR). Implica mayor densidad de gotas de agua sobreenfriada.
- Mayor riesgo si está precipitando.

3) Humedad relativa >80%

- Favorece alto contenido de agua líquida al limitar la evaporación.

4) Ascenso

- Favorece condensación continua por incremento contínuo de la saturación, ayudando a que las gotas crezcan.



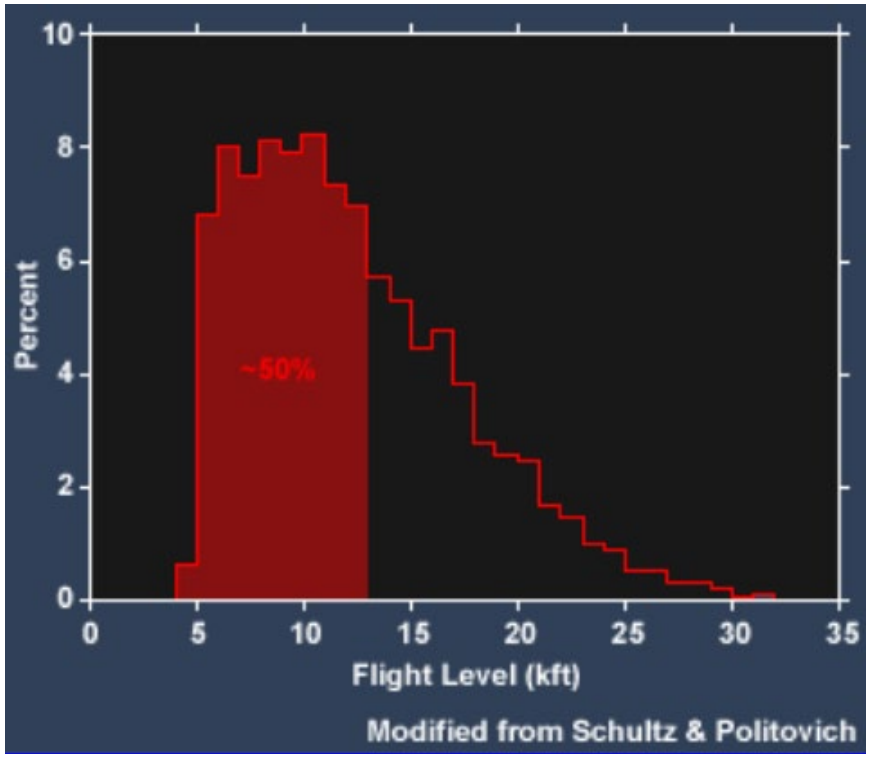
Niveles de vuelo más suceptibles

Extratrópicos:

- Mayoría de reportes: 5000-13000 ft (FL050 – FL130) o ~850 – 600 hPa.
- Más común que en los trópicos por mayor frecuencia de regiones extensas de nimbostratus con alto contenido de humedad y temperaturas de 0 a -20°C.

Trópico y subtrópico:

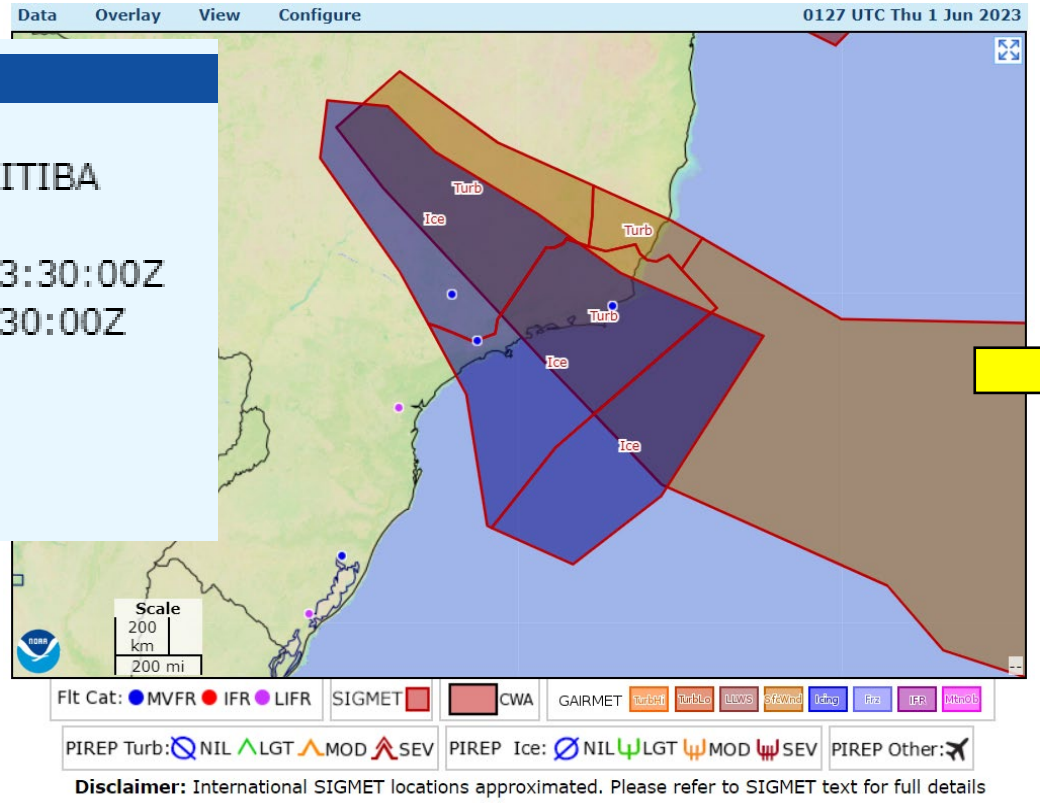
- Mayoría de reports: 13000-24000 ft (FL130 – FL240) o 600-400hPa. Ocurre a alturas mayores (el nivel de Engelamiento es más elevado
- Menos frecuente por áreas menores engelantes, que son más fáciles de esquivar.



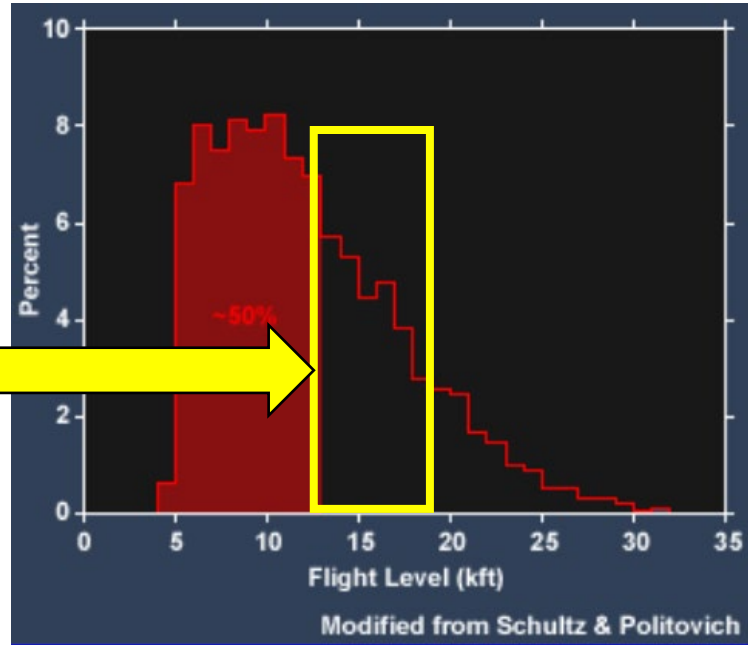
SIGMET por Engelamiento en Brasil, 1-Jun-2023

SIGMET para 13000 – 19000 ft (600-500 hPa)

ICE SIGMET
FIR Id: SBCW
FIR Name: SBCW CURITIBA
Hazard: ICE - SEV
Begins: 2023-05-31T23:30:00Z
Ends: 2023-06-01T03:30:00Z
Top: 19000 ft
Base: 13000 ft
Move: stationary
Change: NC



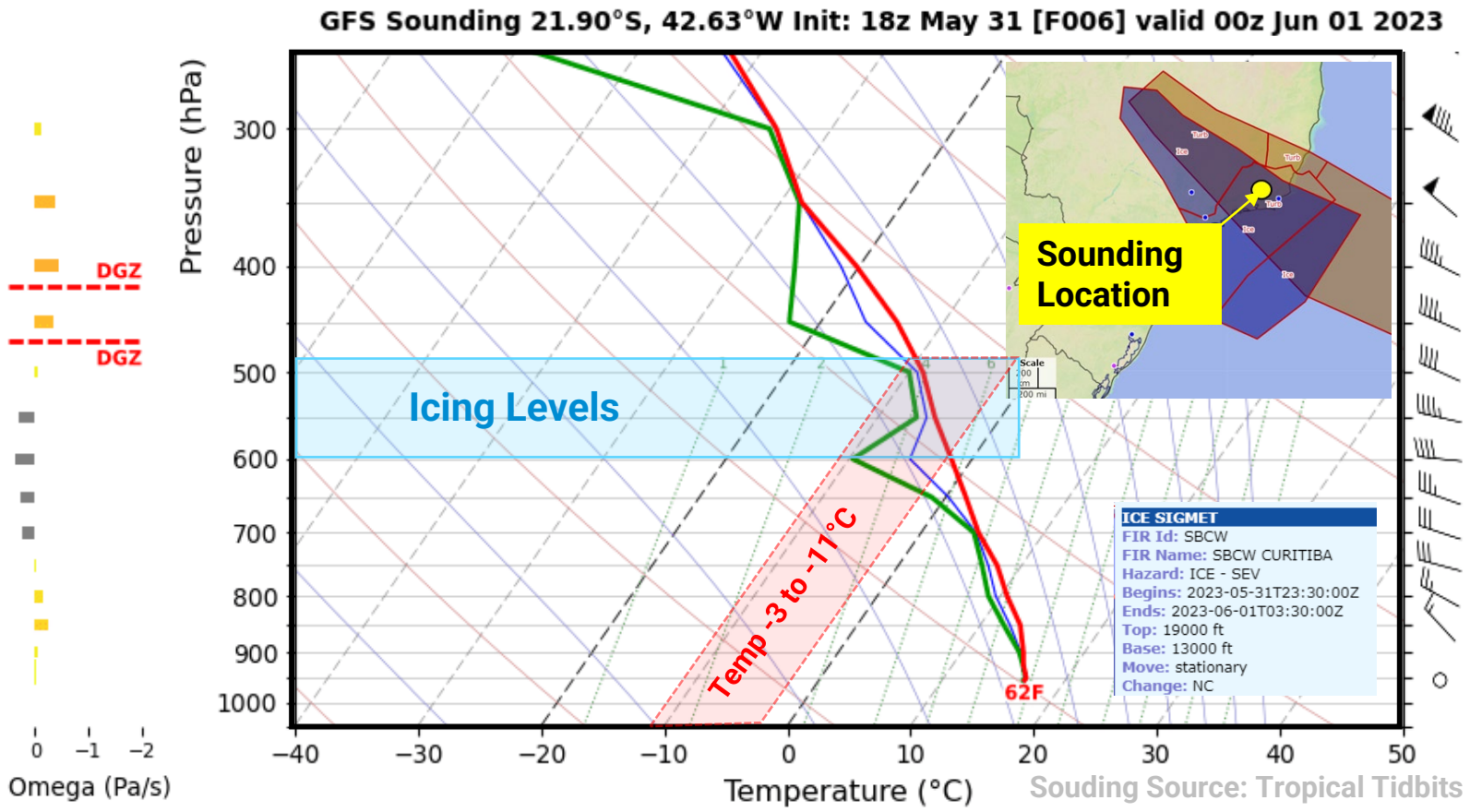
Disclaimer: International SIGMET locations approximated. Please refer to SIGMET text for full details



SIGMET por Engelamiento en Brasil, 1-Jun-2023

Puntos clave en el sondeo:

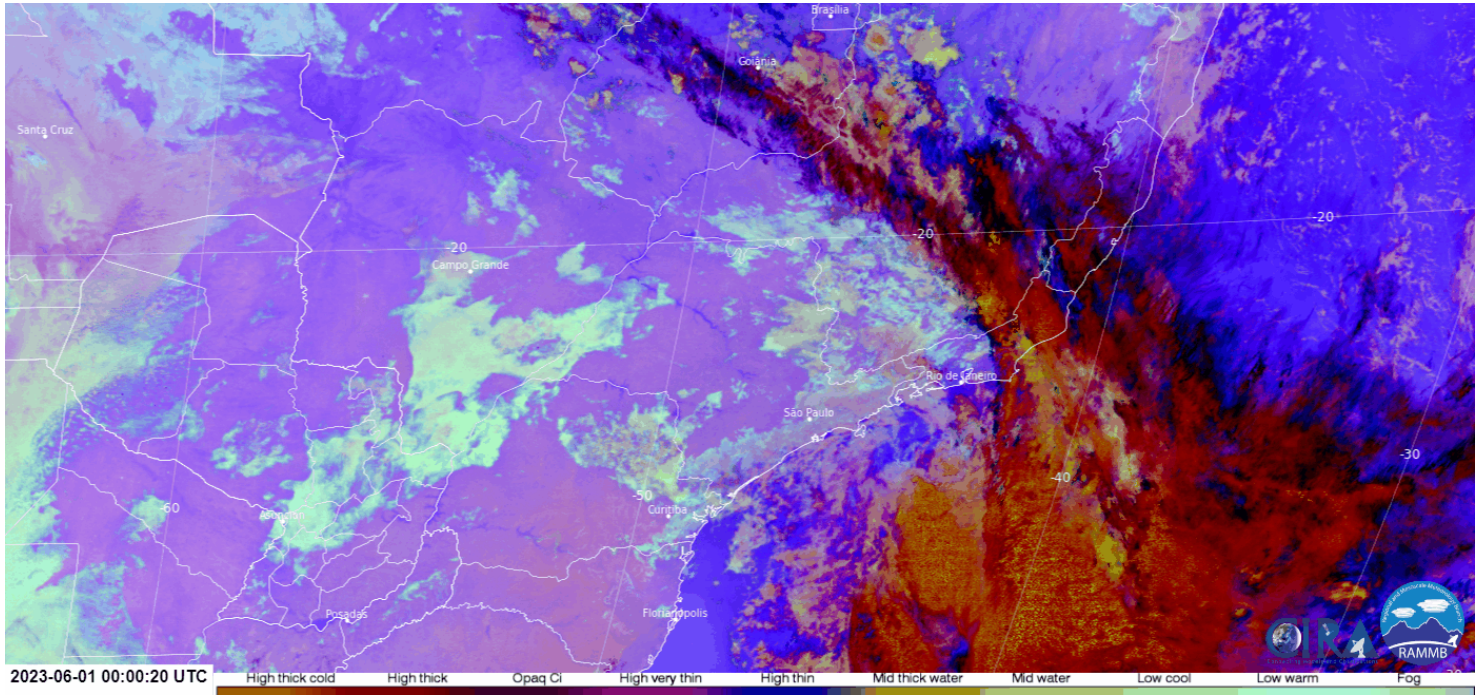
- Temperatura de -11 a -1°C, (agua sobreenfriada).
- Humedad relativa alta, 83-99% (cerca a la saturación)
- Ascenso (omegas negativos), Pero en este caso el modelo (en este punto y para este tiempo) sugiere que solo sobre la region de Engelamiento.



SIGMET por Engelamiento en Brasil, 1-Jun-2023

Situación sinóptica

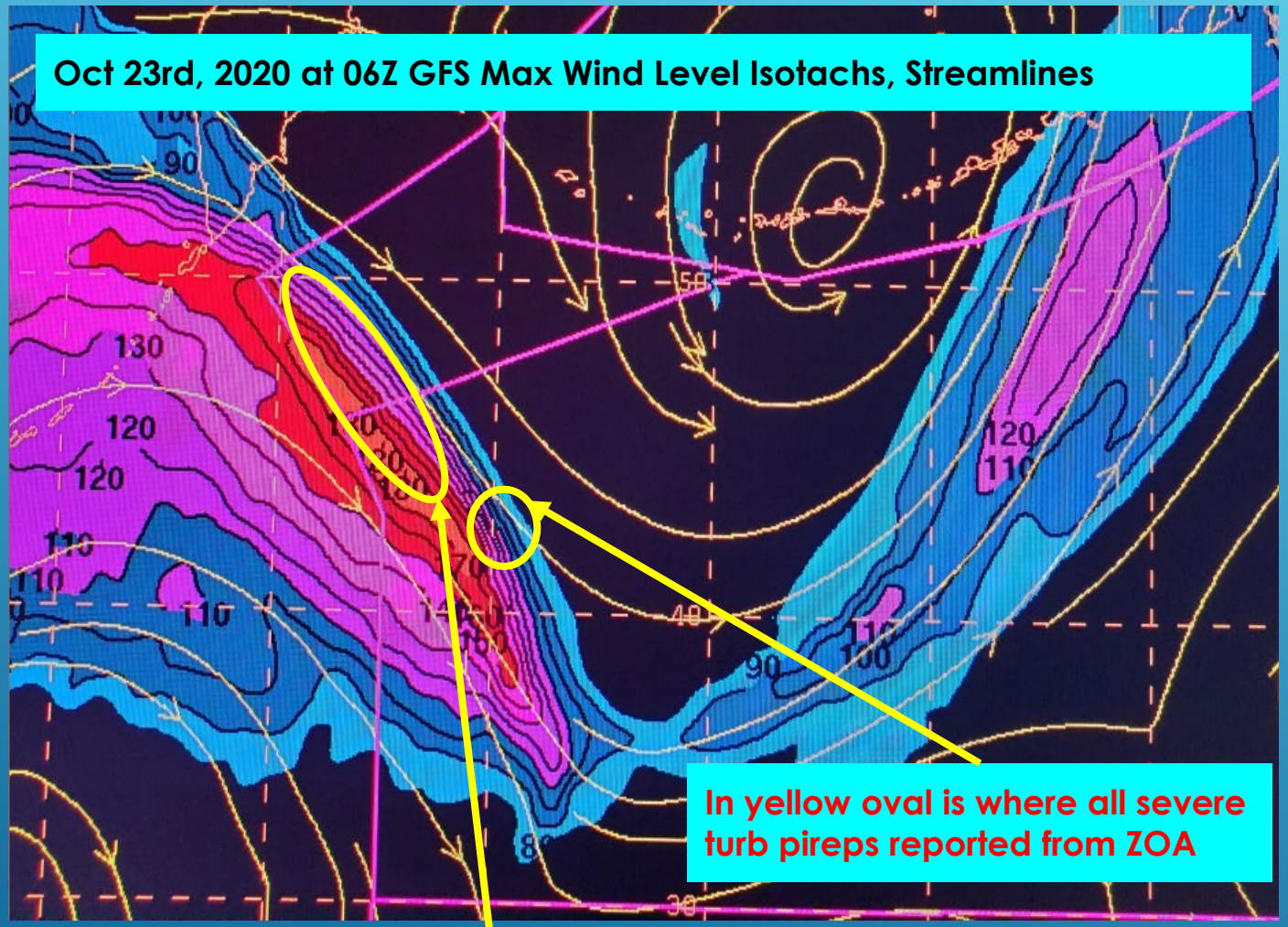
- Animación de imágenes de microfísica nocturna.
- Nubes con hielo se ven rojas /anaranjadas y amarillas.
- Se ve pasaje de vaguada de altura (rotación ciclónica) con un chorro de altura asociado (bandas transversales) .
- Nubes rojas sobre Rio de Janeiro indican nubes gruesas con contenido de hielo (nimbostratus).

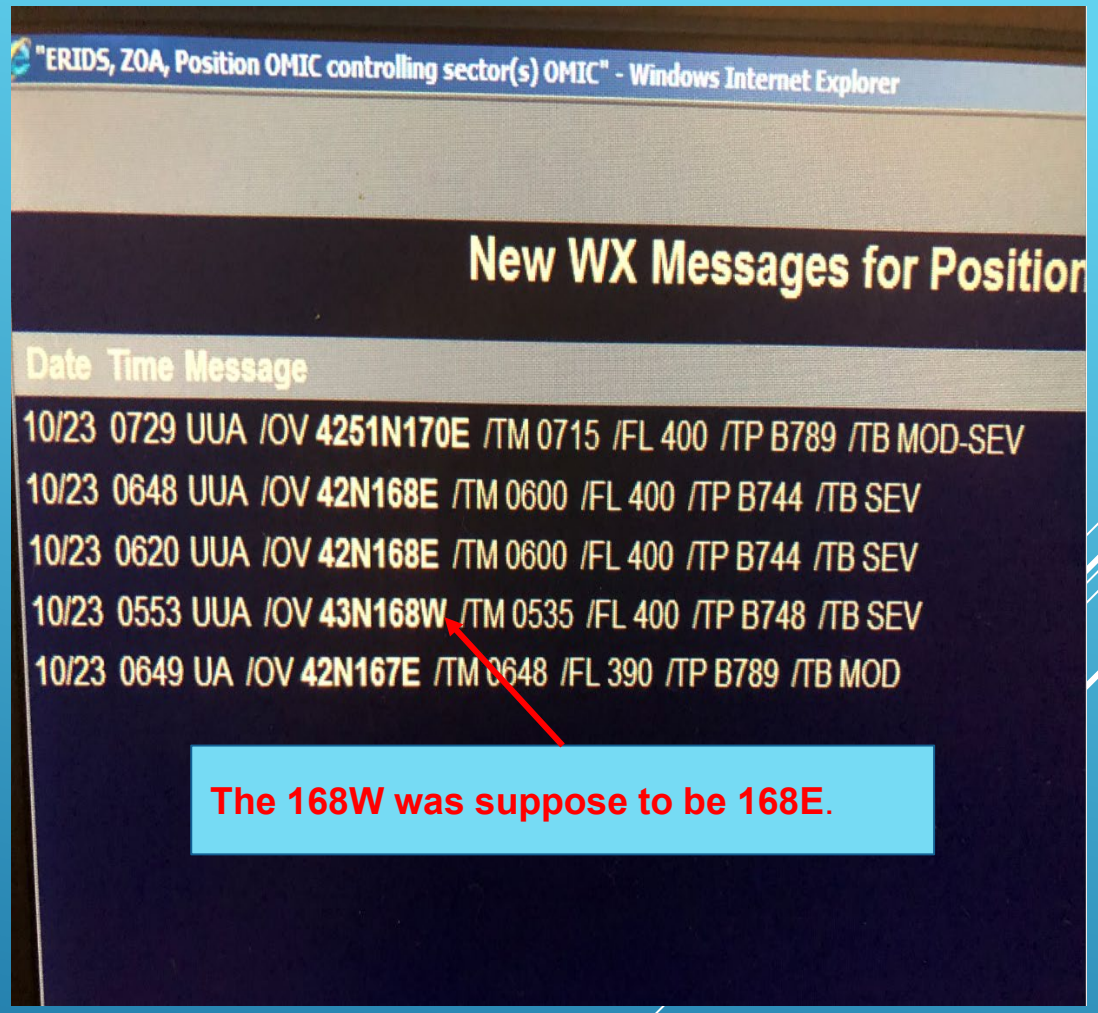


04

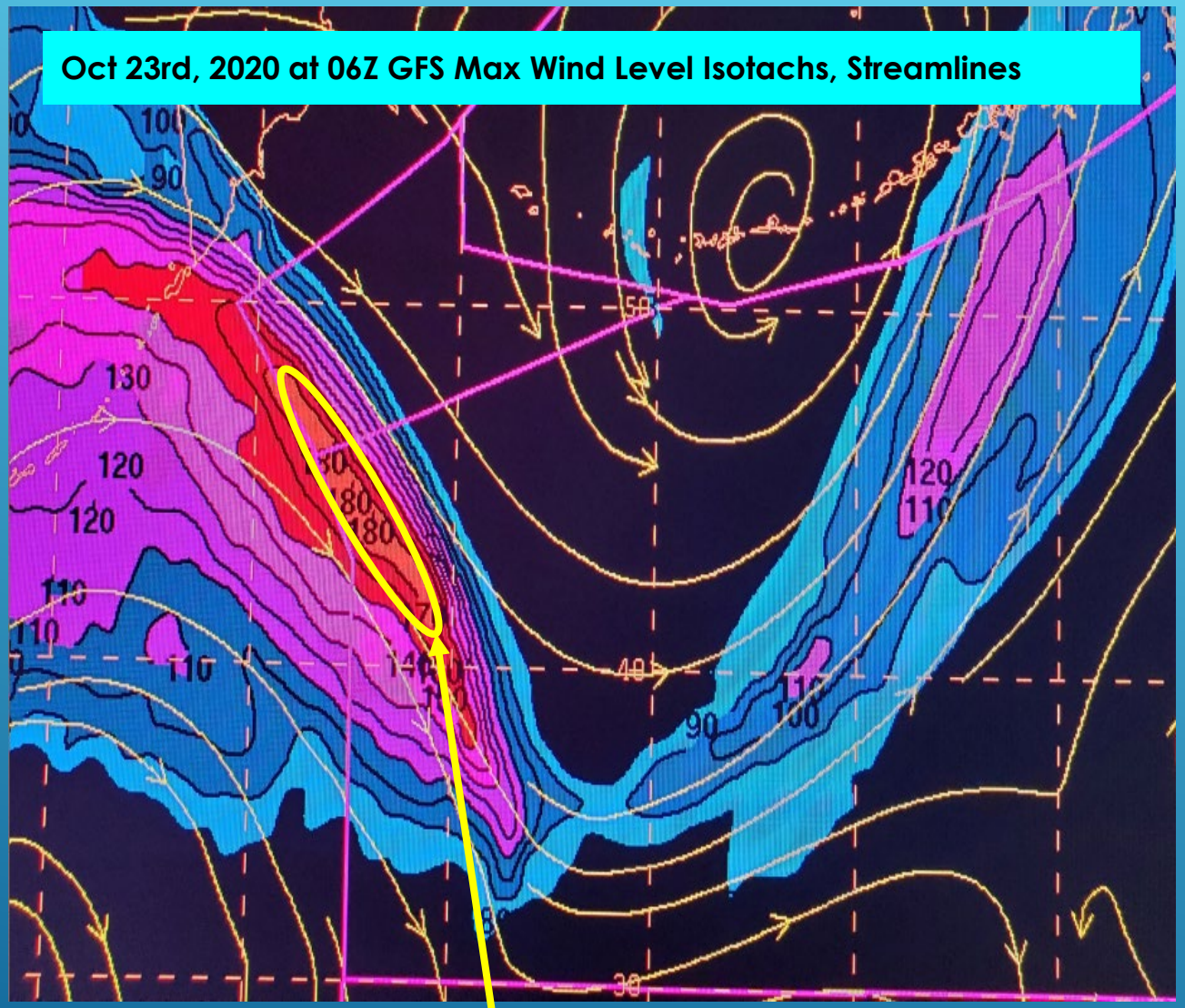
Casos Estudio

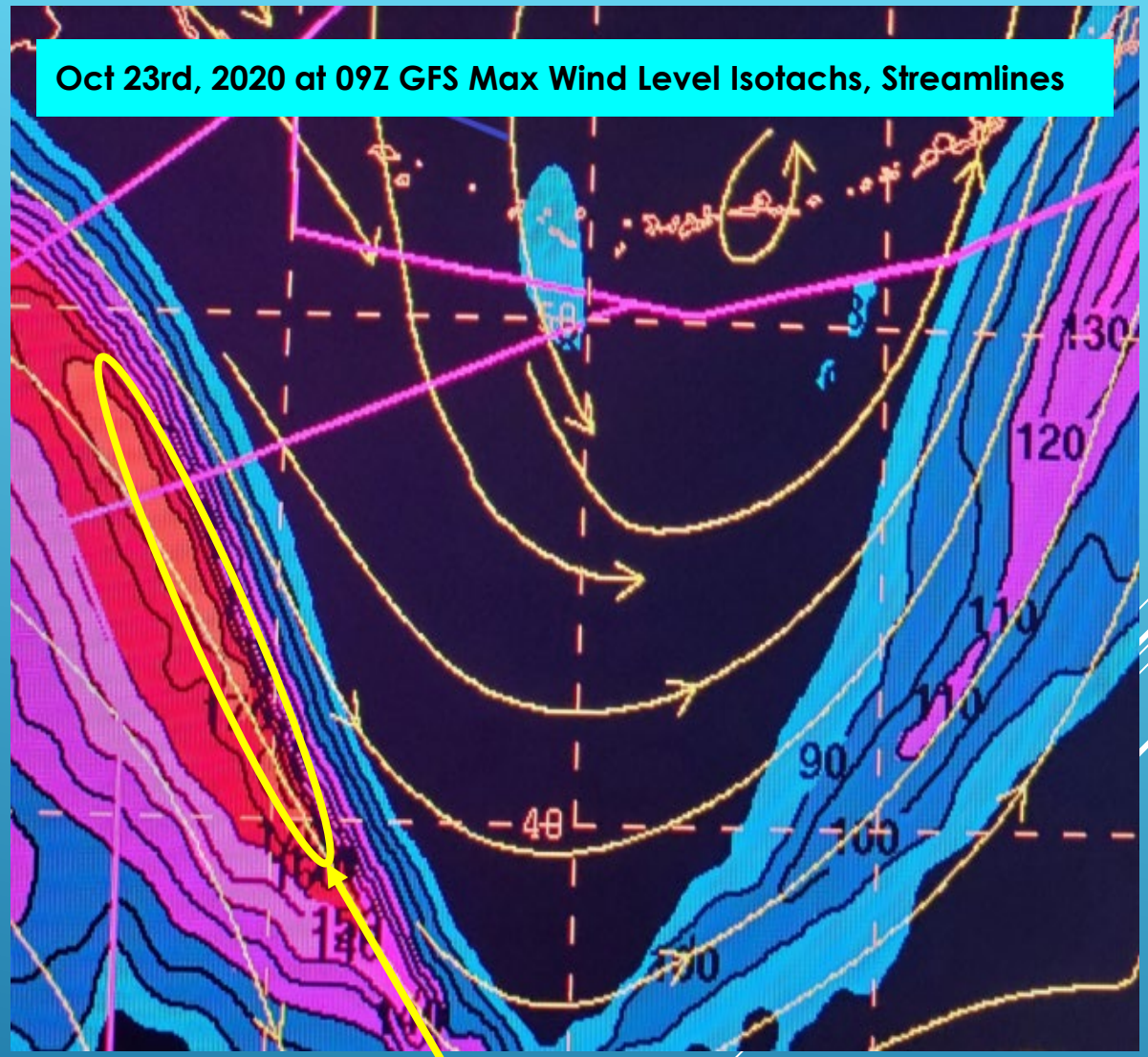
Oct 23rd, 2020 SEVERE TURBULENCE EVENT BETWEEN THE AAWU'S OCEANIC ANCHORAGE & OAKLAND OCEANIC FIRS by Perry Dehne





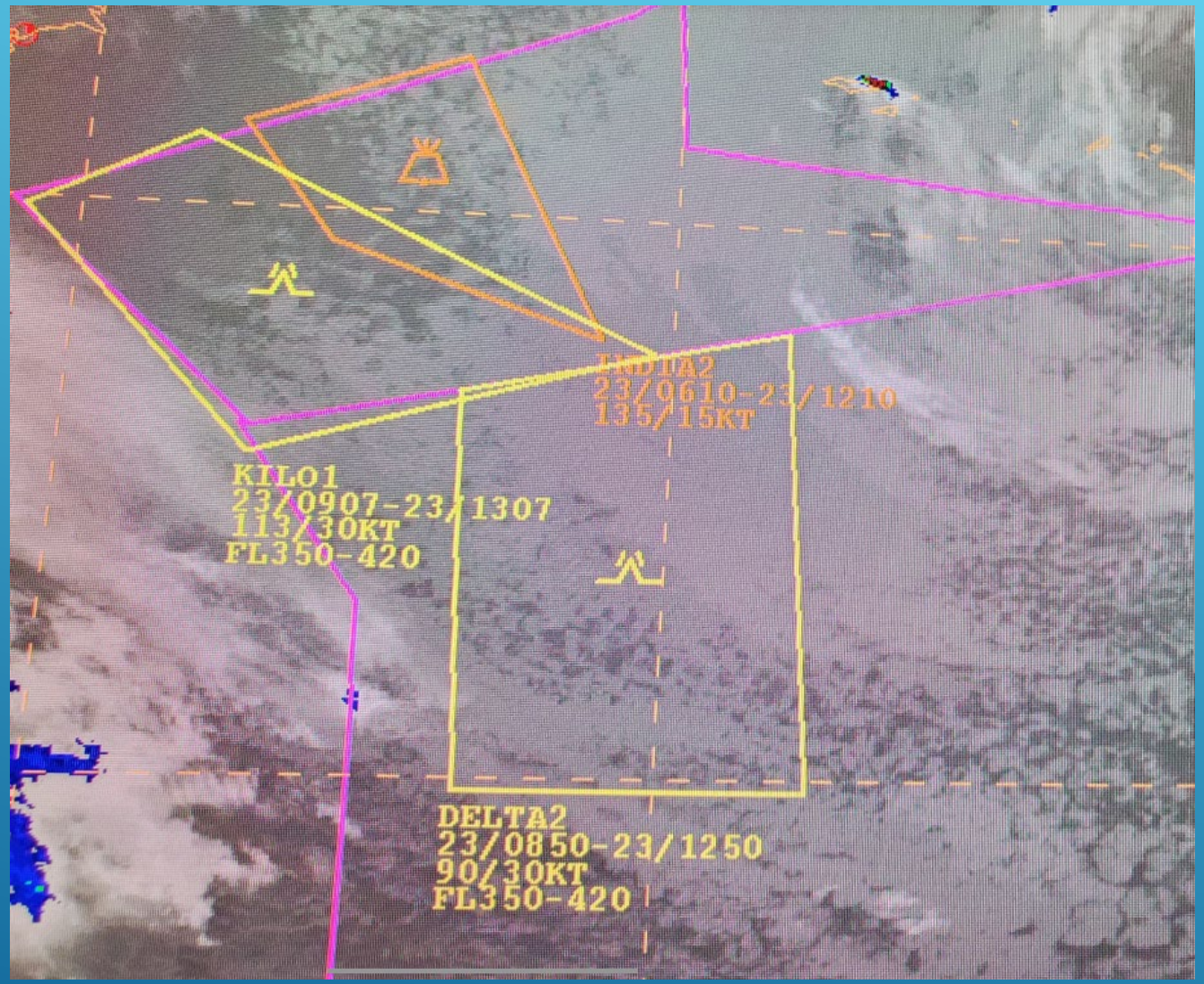
There was a strong northwest 180 knot jetstreak digging into the base of the trough. Oct 23rd, 2020 around 0730Z Oakland FAA called and reported severe turb pirep at FL400 at 42.51N 170E. I then received email with the next severe turb pireps and issued DELTA#1 SEVERE TURB SIGMET. The earliest severe turb pirep was almost 2 hrs old. ZOA had said they had trouble getting pireps into the system.

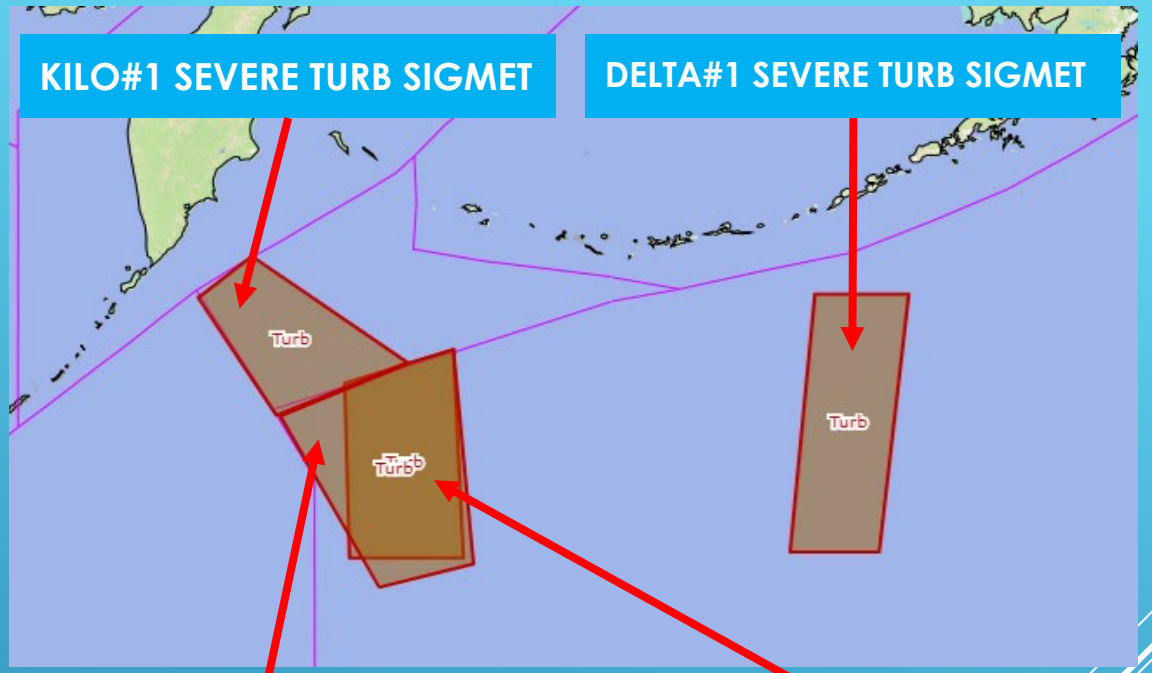




Oct 23rd/06Z, 2020 Jetstreak & Streamlines with strong northwest jetstreak as it continues around the anti-cyclonic flow around the amplified ridge axis.

Oct 23rd/09Z, 2020 Jetsreak & Streamlines with jetstreak becoming more elongated as it digs into the base of the trough.



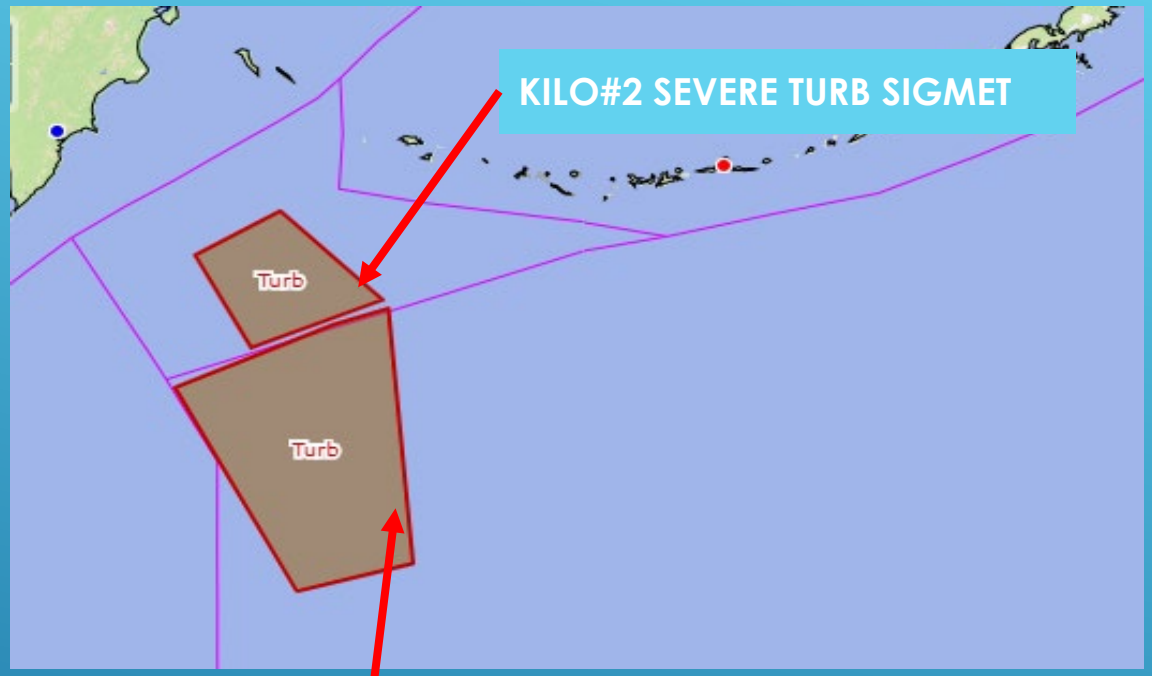


DELTA#3 SEVERE TURB SIGMET. I reissued to better match with AAWU KILO#1 sigmet.

TURB SIGMET
FIR Id: PAZA
FIR Name: OAKLAND OCEANIC FIR ANCHORAGE
Hazard: TURB - SEV
Begins: 2020-10-23T08:50:00Z
Ends: 2020-10-23T12:50:00Z
Top: 42000 ft
Base: 35000 ft
Move: E
Speed: 30 kt
Change: NC

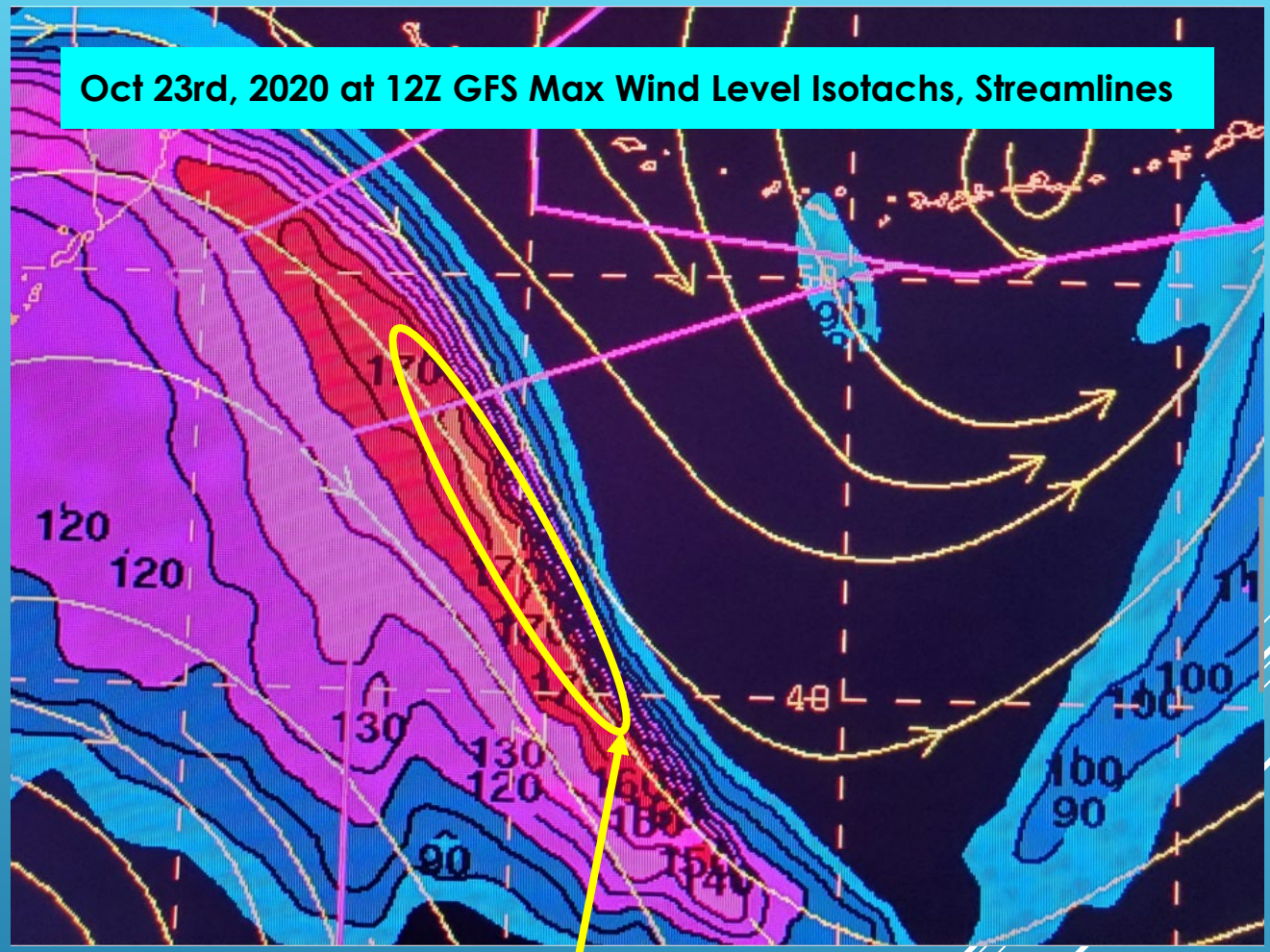
WSPN04 KKCI 230850
SIGP0D
KZAK PAZA SIGMET DELTA 2 VALID 230850/231250 KKCI-
OAKLAND OCEANIC FIR ANCHORAGE FIR SEV TURB FCST WI N4800 E17200 -
N3945 E17230 - N3945 E16645 - N4645 E16630 - N4800 E17200.
FL350/420. MOV E 30KT. NC.

I issued DELTA#1 SEVERE TURB SIGMET and updated with DELTA#2 SIGMET due to plotting the wrong longitude using 170W instead of 170E longitude. Thankfully I had notified AAWU when I had issued DELTA#1 due to habit of always keeping communication open with their office. The AAWU Lead noticed my mistake and notified ASAP. I updated again with DELTA#3 for better alignment between sigmets.



TURB SIGMET
FIR Id: KZAK
FIR Name: OAKLAND OCEANIC
Hazard: TURB - SEV
Begins: 2020-10-23T11:15:00Z
Ends: 2020-10-23T15:15:00Z
Top: 42000 ft
Base: 35000 ft
Move: E
Speed: 30 kt
Change: INTSF

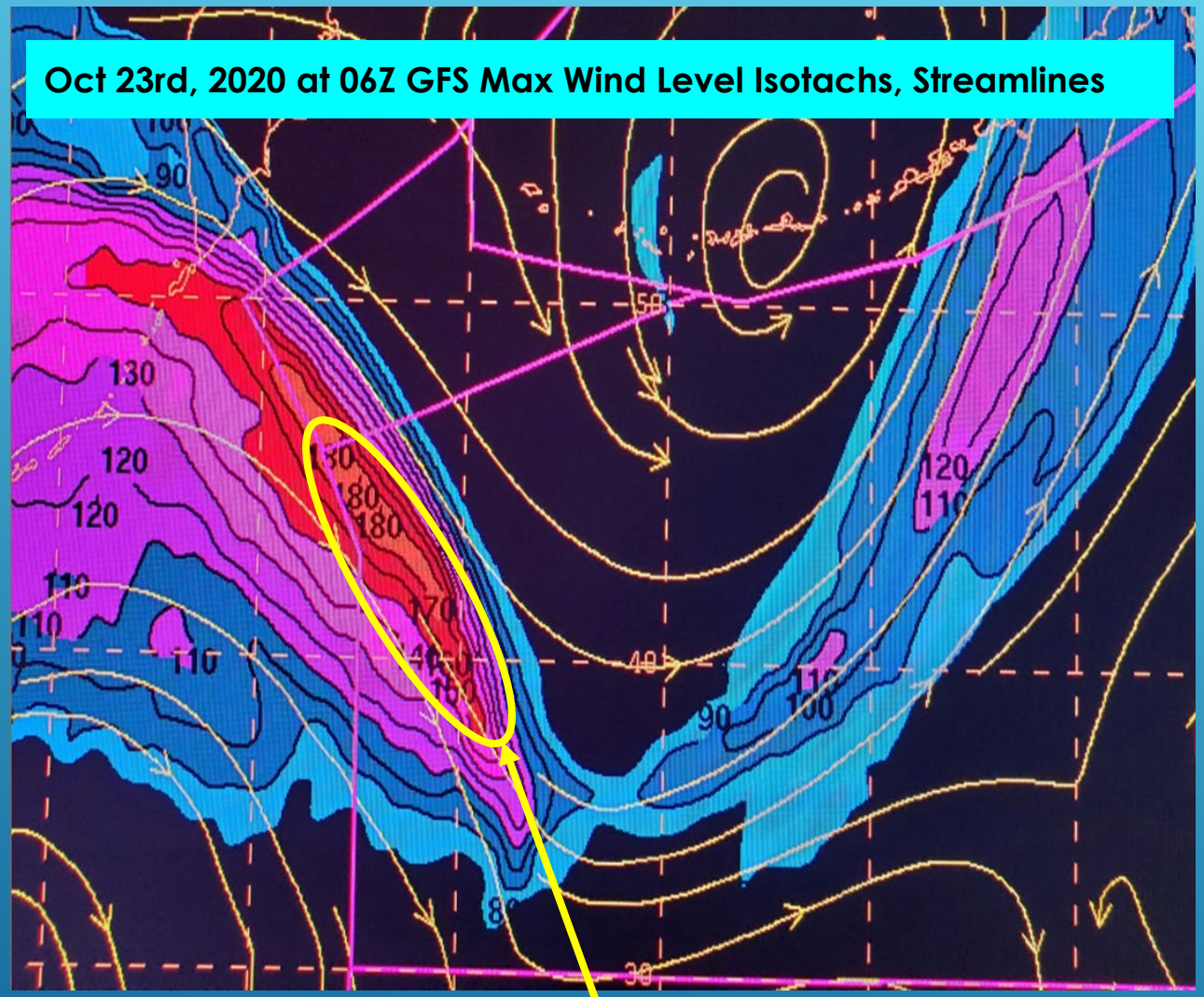
WSPN04 KKCI 231115
SIGP0D
KZAK SIGMET DELTA 3 VALID 231115/231515 KKCI-
OAKLAND OCEANIC FIR SEV TURB FCST WI N4800 E17200 - N3930 E17300
- N3830 E16815 - N4530 E16315 - N4730 E16945 - N4800 E17200.
FL350/420. MOV E 30KT. INTSF.



Oct 23rd/12Z, 2020 Jetstreak MaxWnds & Streamlines

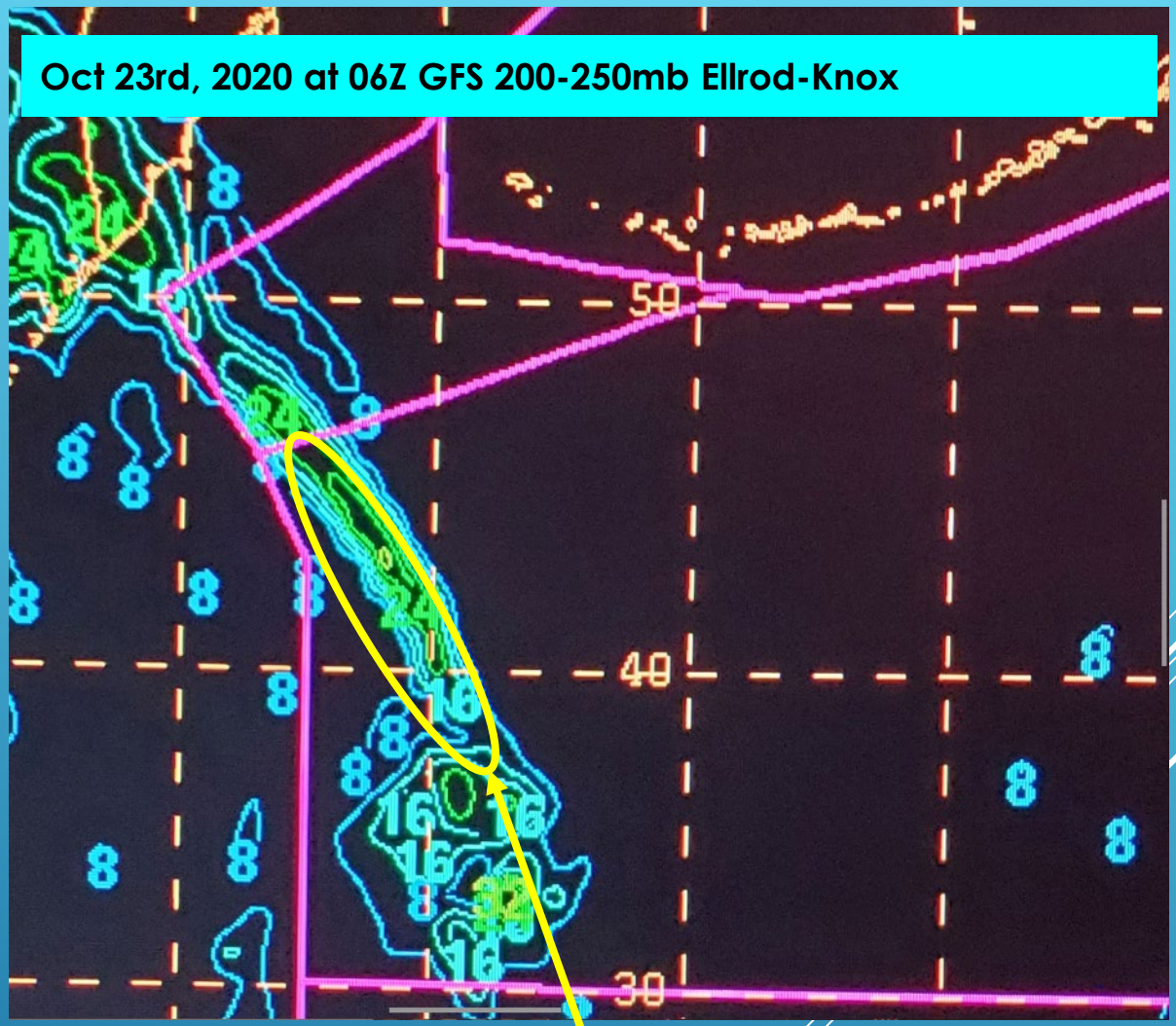
This was the final update I had done before handing over the Tropical dayshift. The strong northwesterly jetstreak was looking to move farther southeast into the Pacific ocean. I had extended over to Tokyo FIR with a sigmet they had issued. The AAWU has problems sometimes with their software on the borders, but otherwise great teamwork between the AAWU and AWC offices!

Oct 23rd, 2020 at 06Z GFS Max Wind Level Isotachs, Streamlines



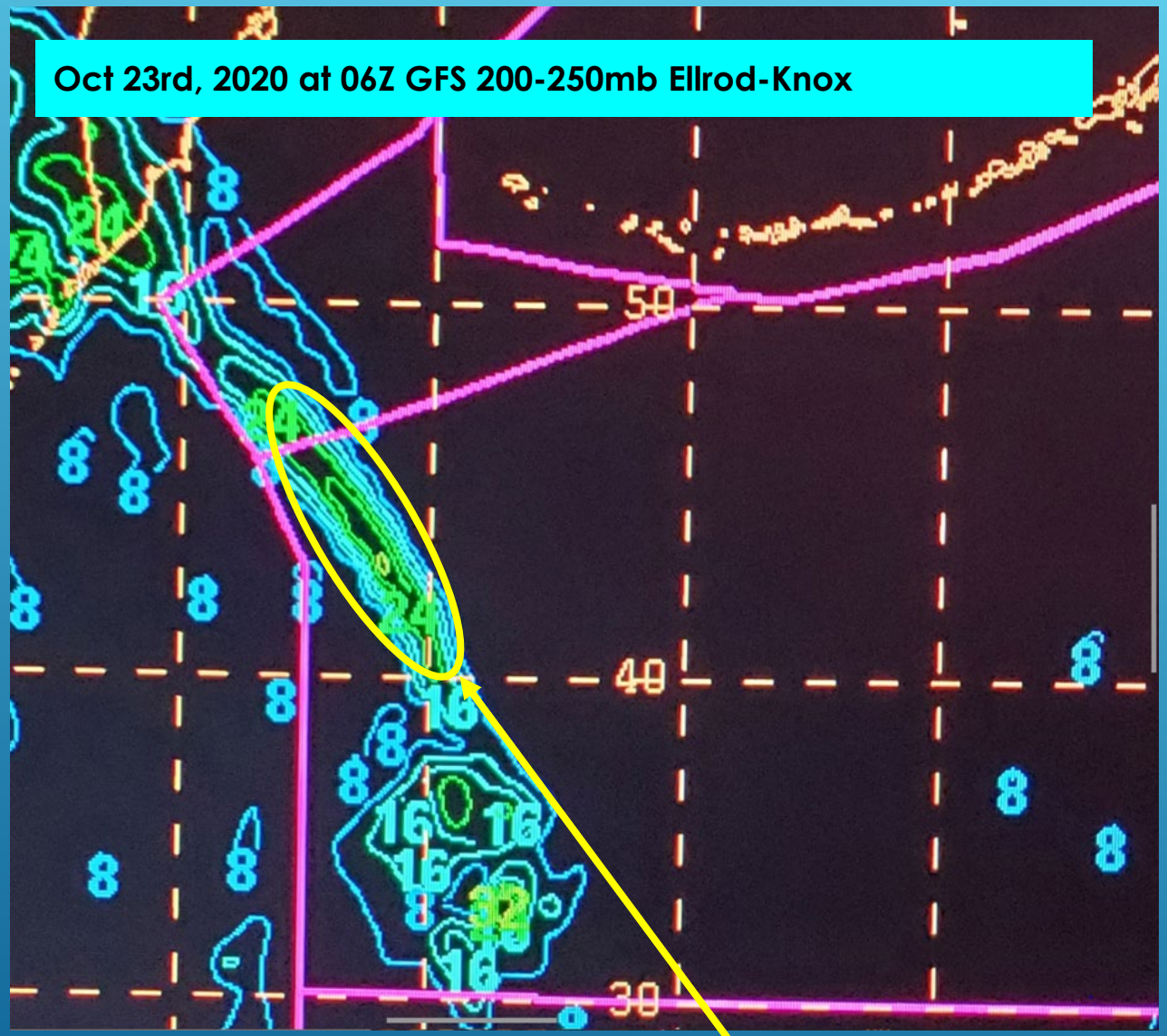
Oct 23rd, 2020 at 06Z with GFS **Jetstreak MaxWnds/Streamlines.** These are great dynamics for producing severe turb with a strong jetstreak coming over anti-cyclonic ridge and digging into base of the upstream trough.

Oct 23rd, 2020 at 06Z GFS 200-250mb Ellrod-Knox



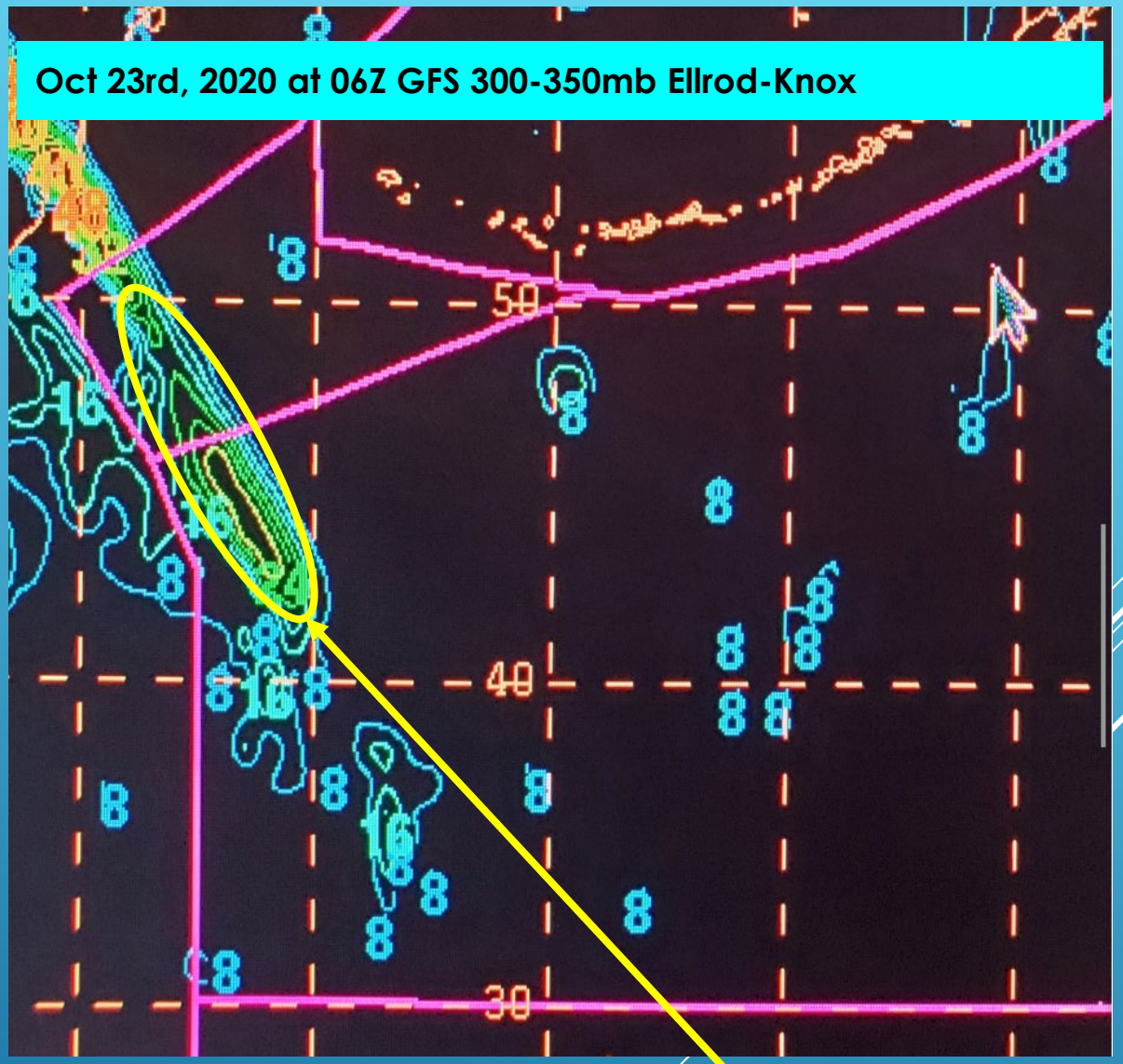
Oct 23rd, 2020 at 06Z with GFS **200-250mb Ellrod-Knox.** The Ellrod-Knox indices above look borderline moderate to severe turb potential but with the dynamics I can see why we received the severe turb pireps.

Oct 23rd, 2020 at 06Z GFS 200-250mb Ellrod-Knox

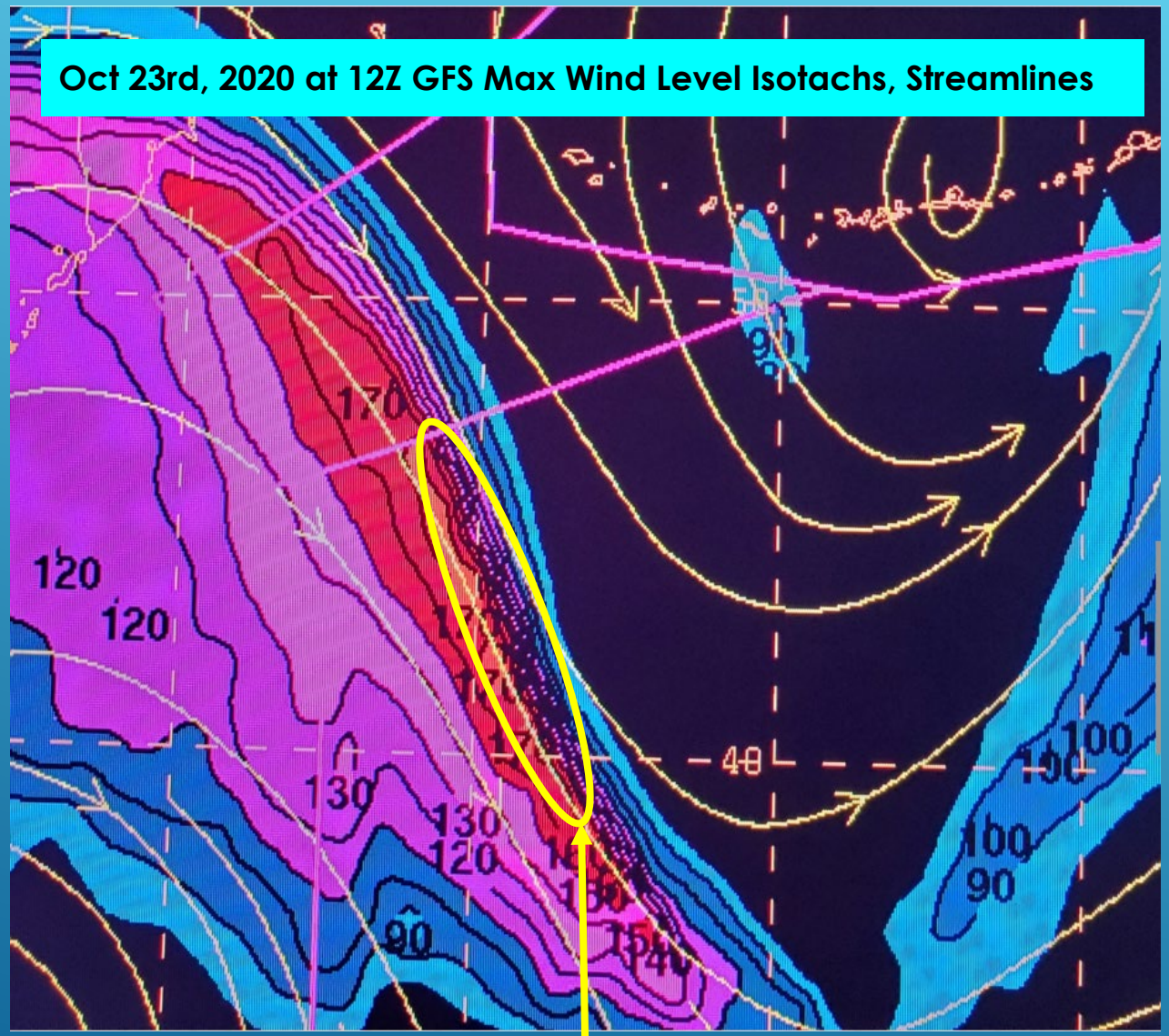


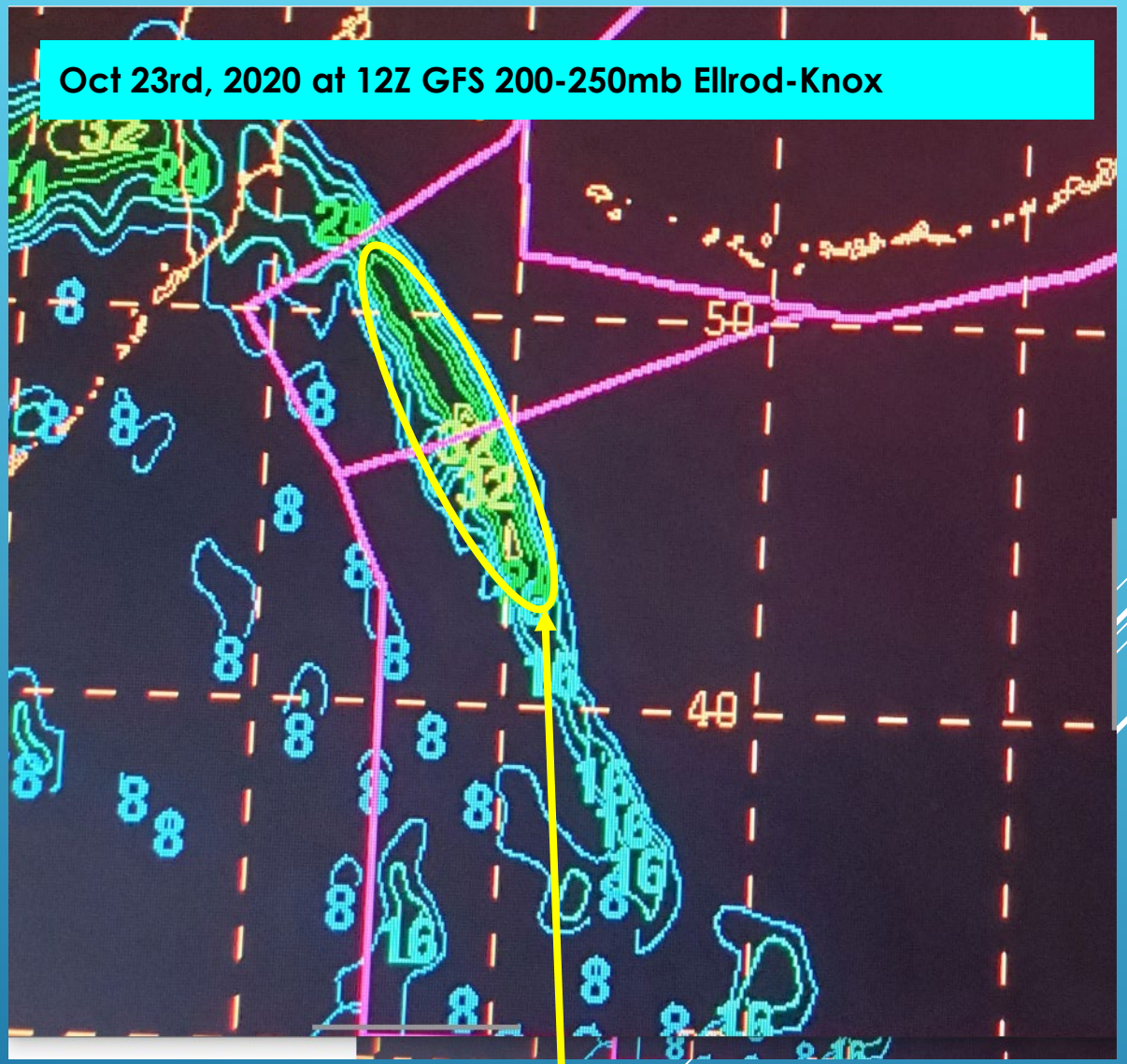
Oct 23rd, 2020 at 06Z with GFS 200-250mb Ellrod-Knox and the Ellrod-Knox indices at 300-350mb look pretty much the same for strength of possible shear turbulence.

Oct 23rd, 2020 at 06Z GFS 300-350mb Ellrod-Knox



Oct 23rd/06Z, 2020 GFS 300-350mb Ellrod-Knox and as mentioned previously the strength looks about the same as the other turbulence indices.

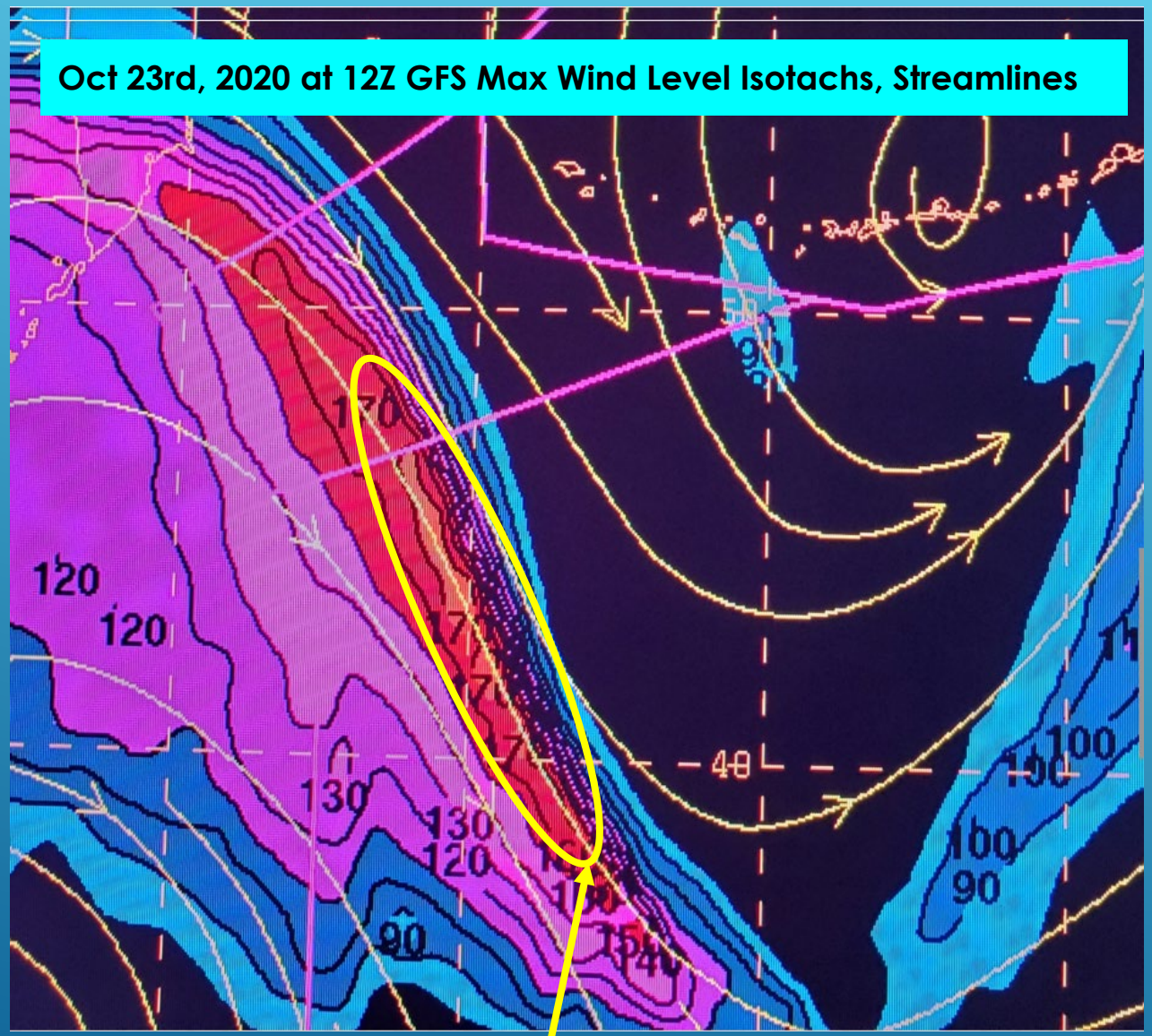




Oct 23rd, 2020 at 12Z with GFS Jetstreak MaxWnds & Streamlines continue to show the jetstreak diving farther southeast as it digs into the base of trough.

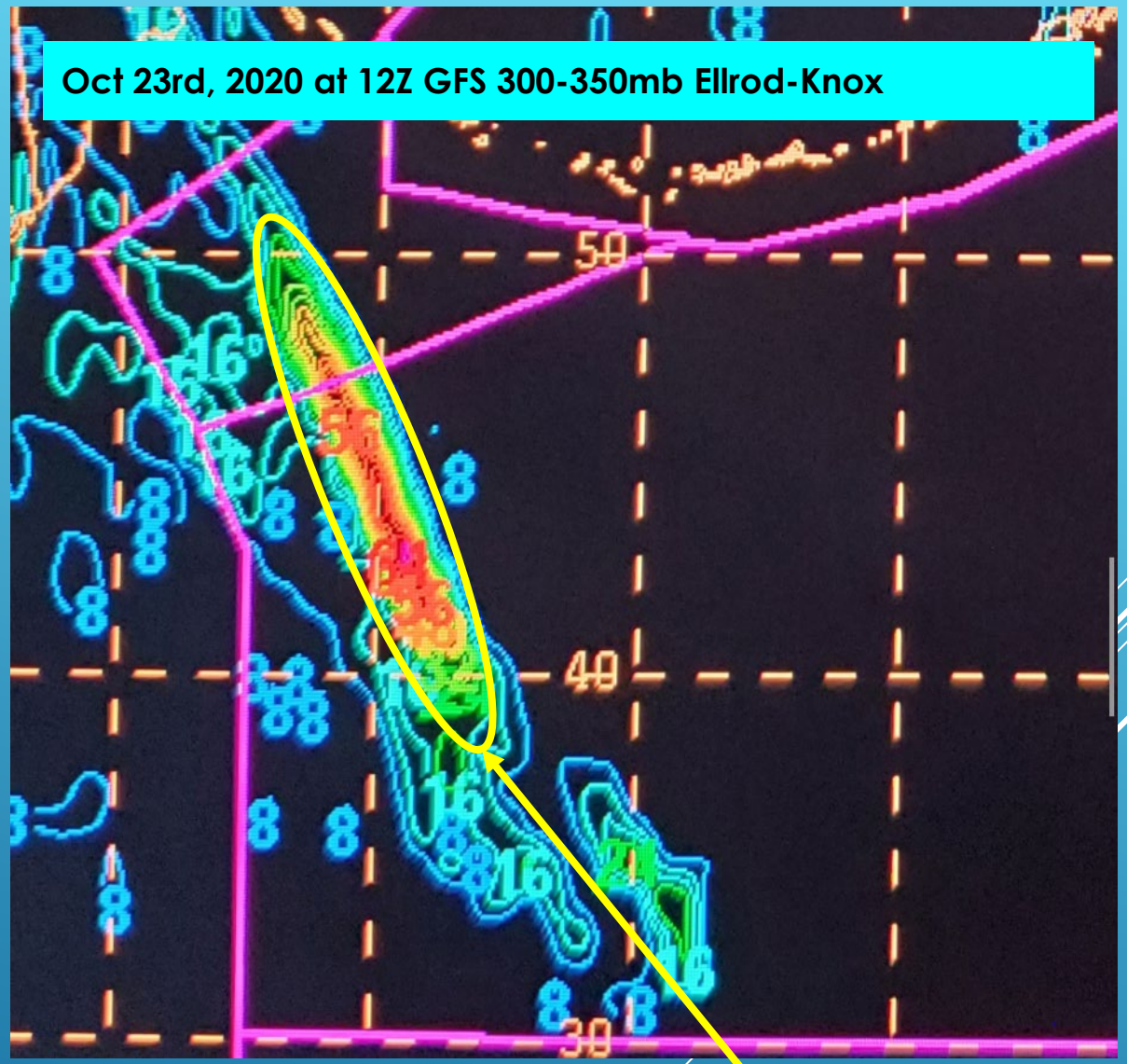
Oct 23rd, 2020 at 12Z with GFS 200-250mb Ellrod-Knox indices looks to be intensifying from the 200-250mb Ellrod-Knox at 23/06Z time-frame.

Oct 23rd, 2020 at 12Z GFS Max Wind Level Isotachs, Streamlines

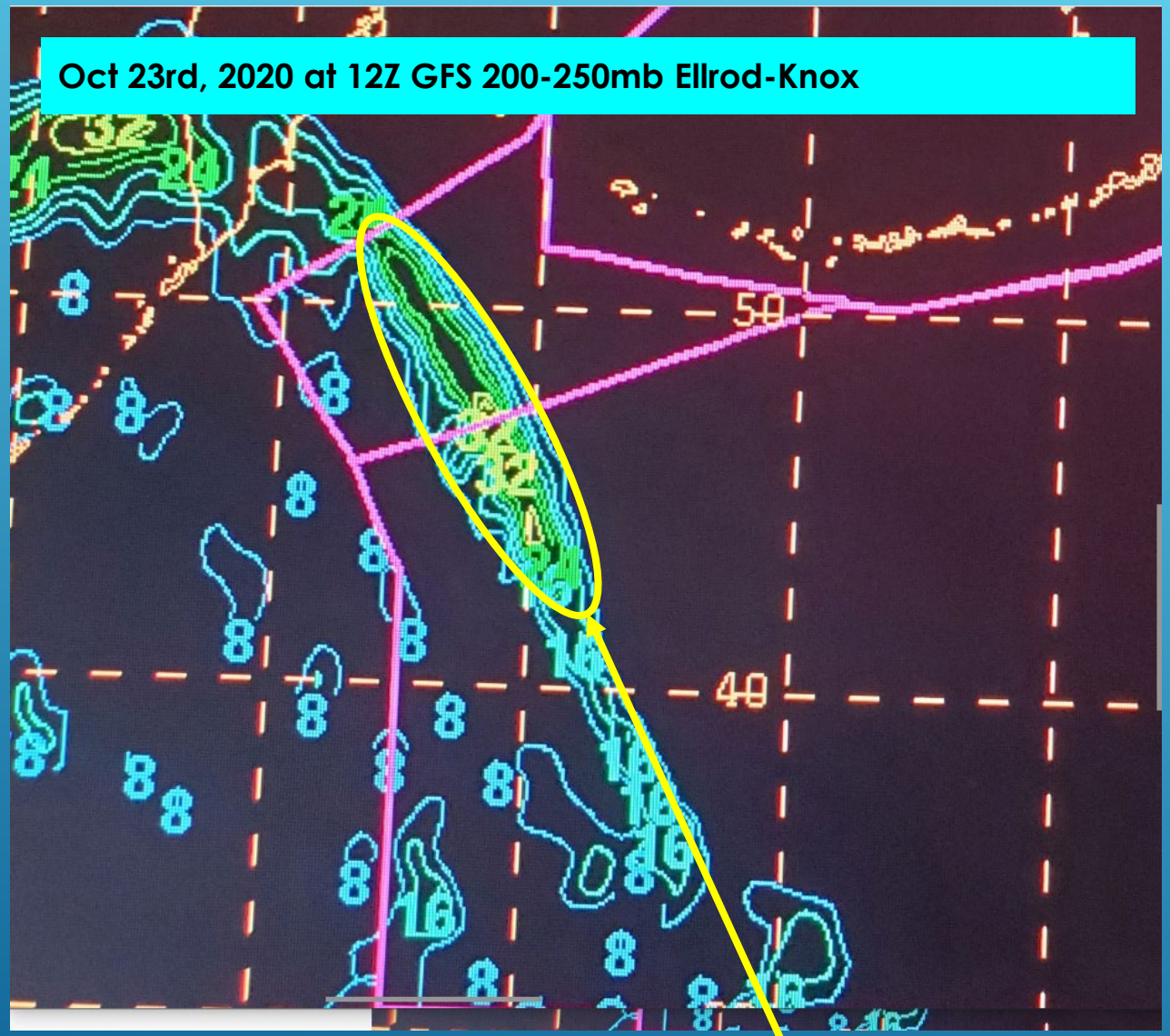


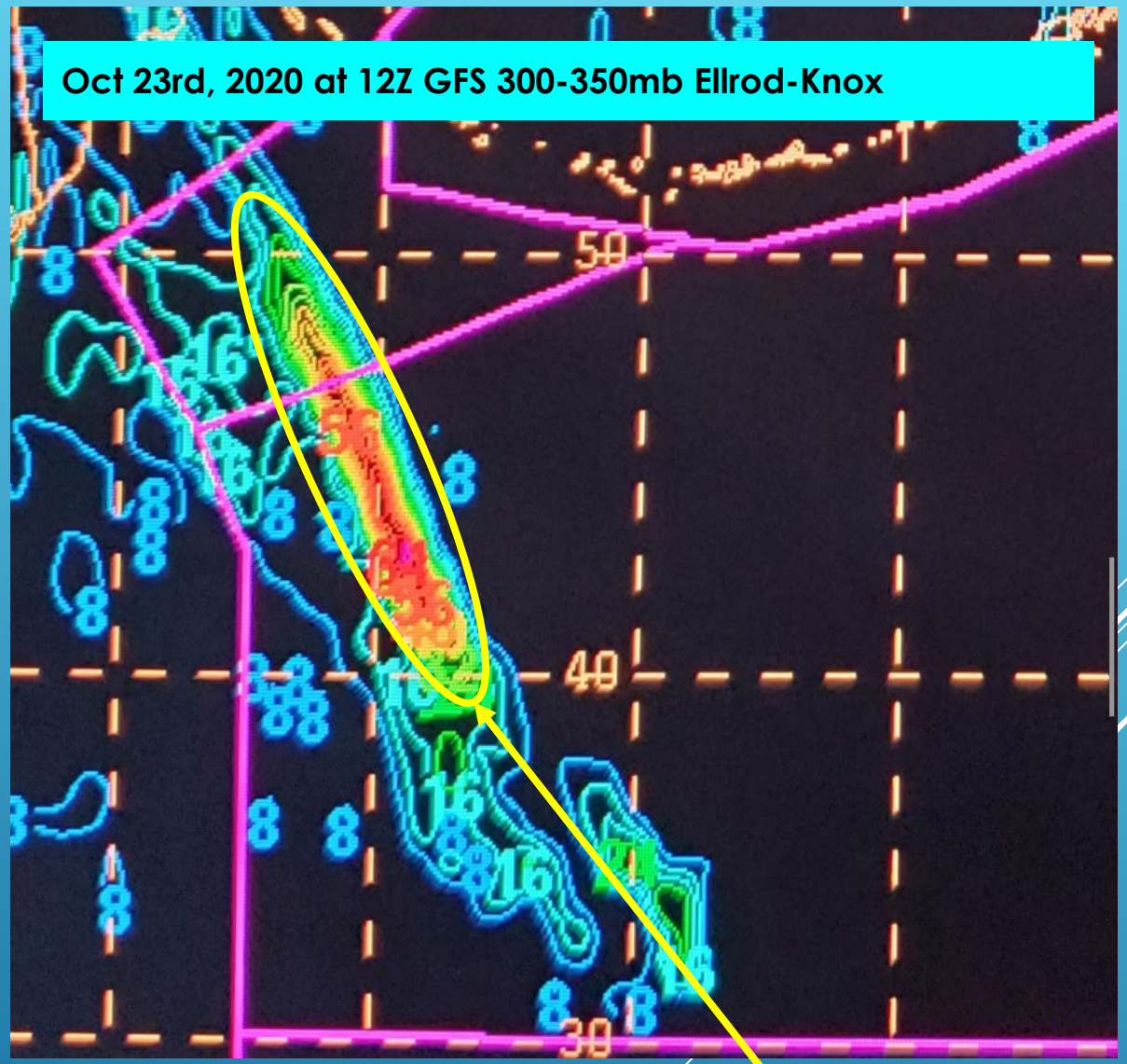
Oct 23rd, 2020 at 12Z with GFS Jetstreak MaxWnds & Streamlines remains with a strong northwest jetstreak as it moves toward the base of the upstream trough.

Oct 23rd, 2020 at 12Z GFS 300-350mb Ellrod-Knox



Oct 23rd, 2020 at 12Z with GFS 300-350mb Ellrod-Knox indices have greatly intensified and great justification for having severe turb sigmet in both FIRs.

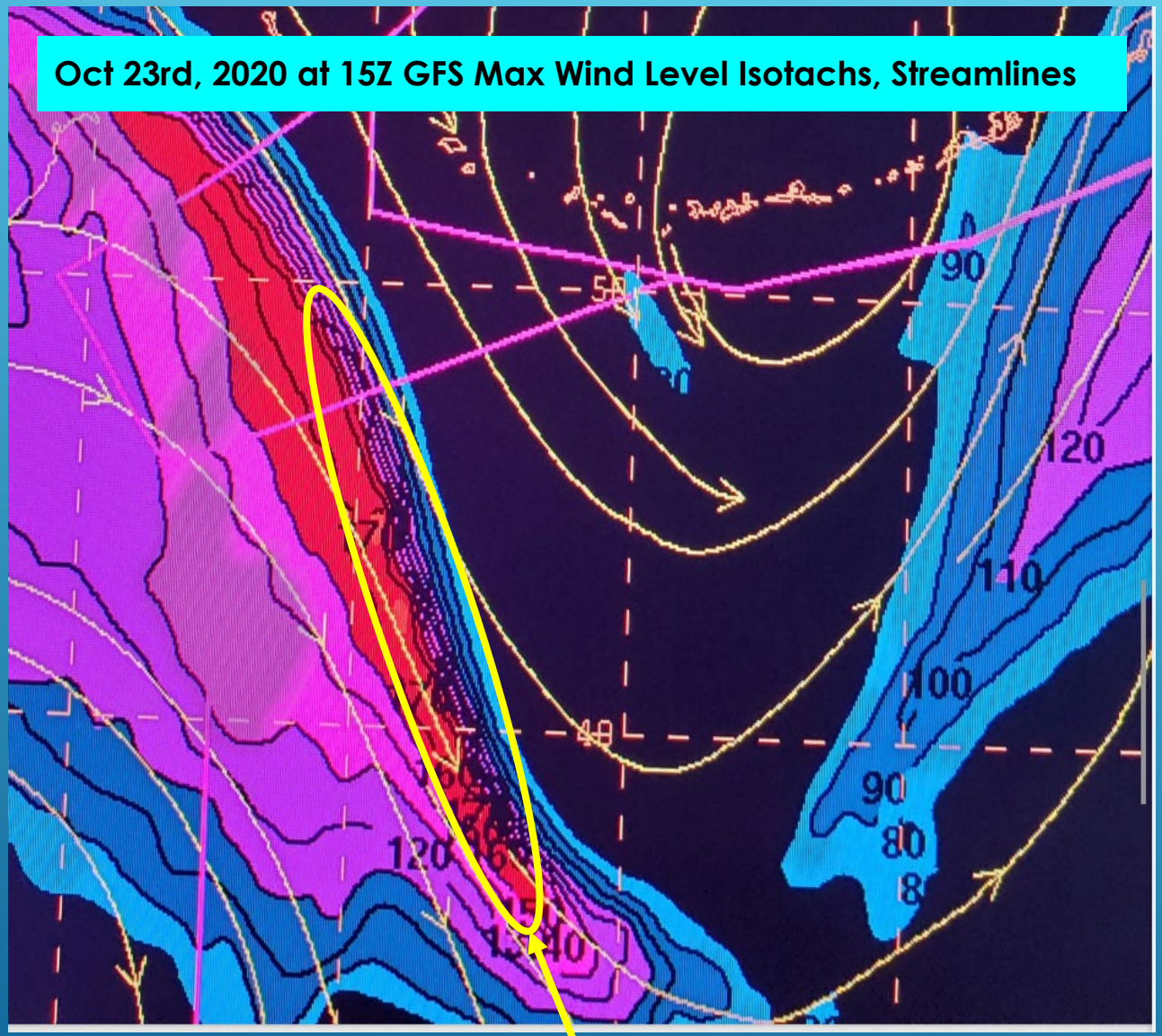




Oct 23rd, 2020 at 12Z with GFS 200-250mb Ellrod-Knox indices are good when combined with dynamics for possible severe turbulence.

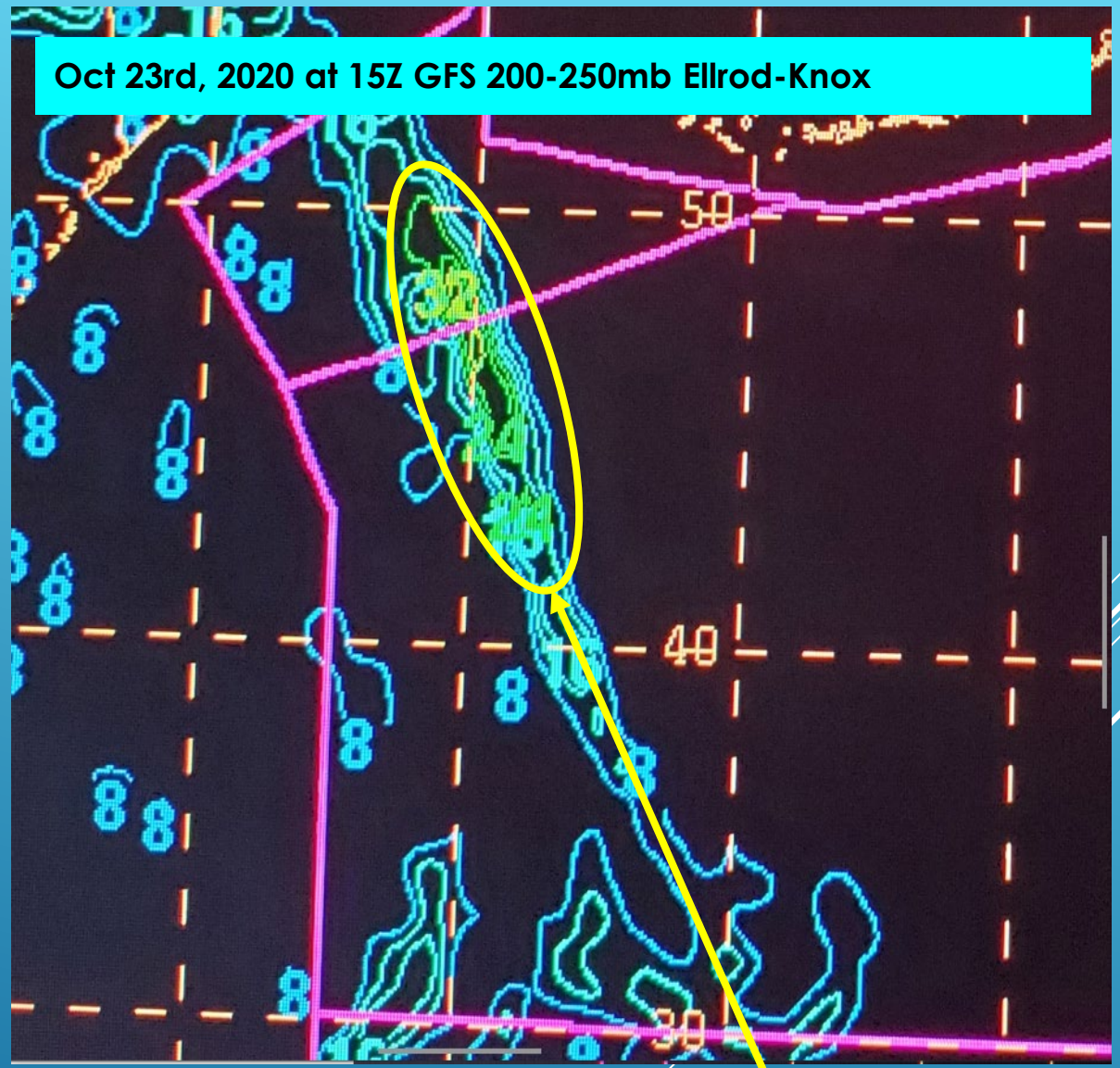
Oct 23rd, 2020 at 12Z with GFS 300-350mb Ellrod-Knox indices leave no doubt for severe turbulence coupled with strong northwest jetcore through this region.

Oct 23rd, 2020 at 15Z GFS Max Wind Level Isotachs, Streamlines



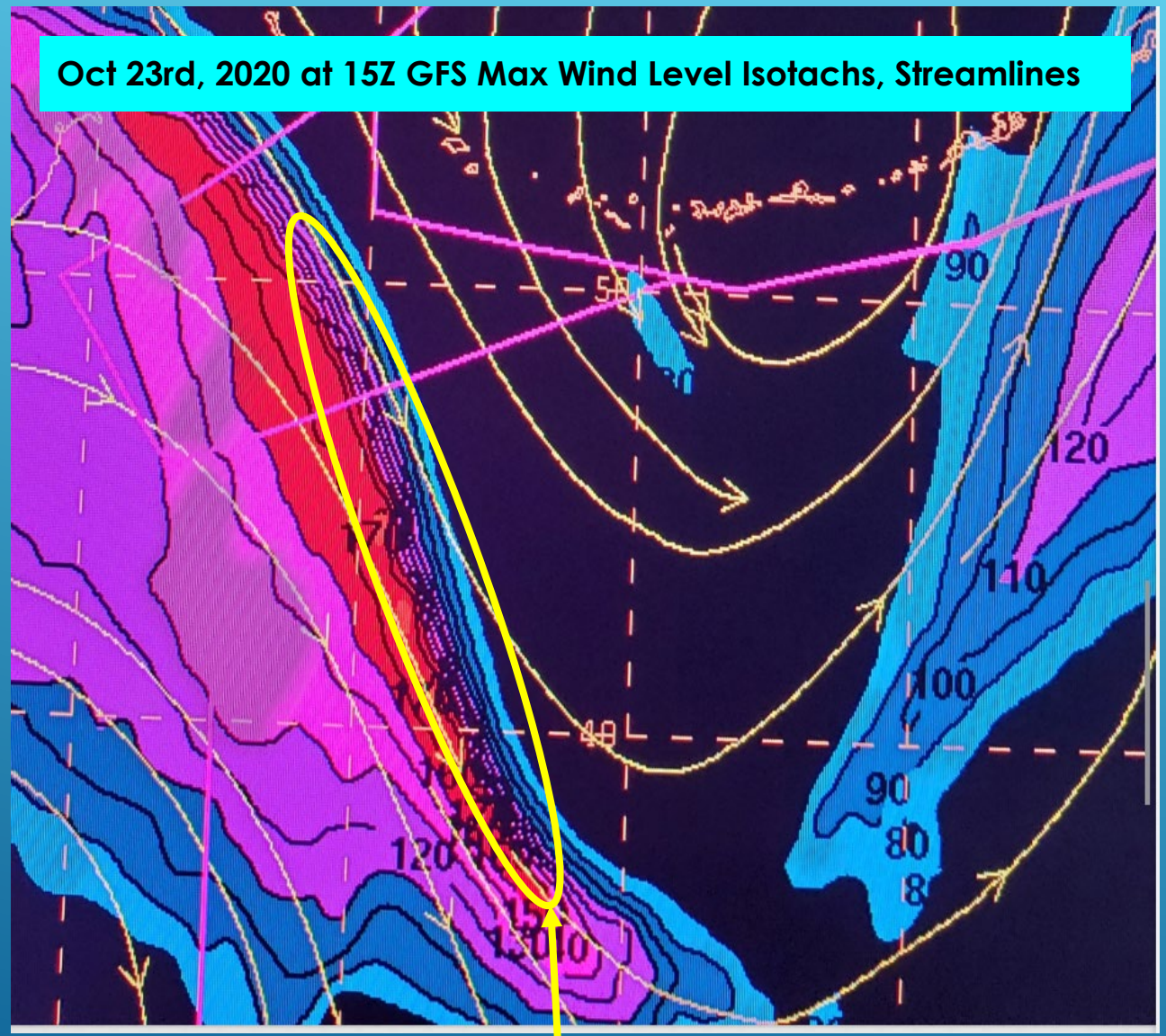
Oct 23rd, 2020 at 15Z with GFS Jetstreak MaxWnds & Streamlines continue to dive southeastward as it digs into the base of trough.

Oct 23rd, 2020 at 15Z GFS 200-250mb Ellrod-Knox



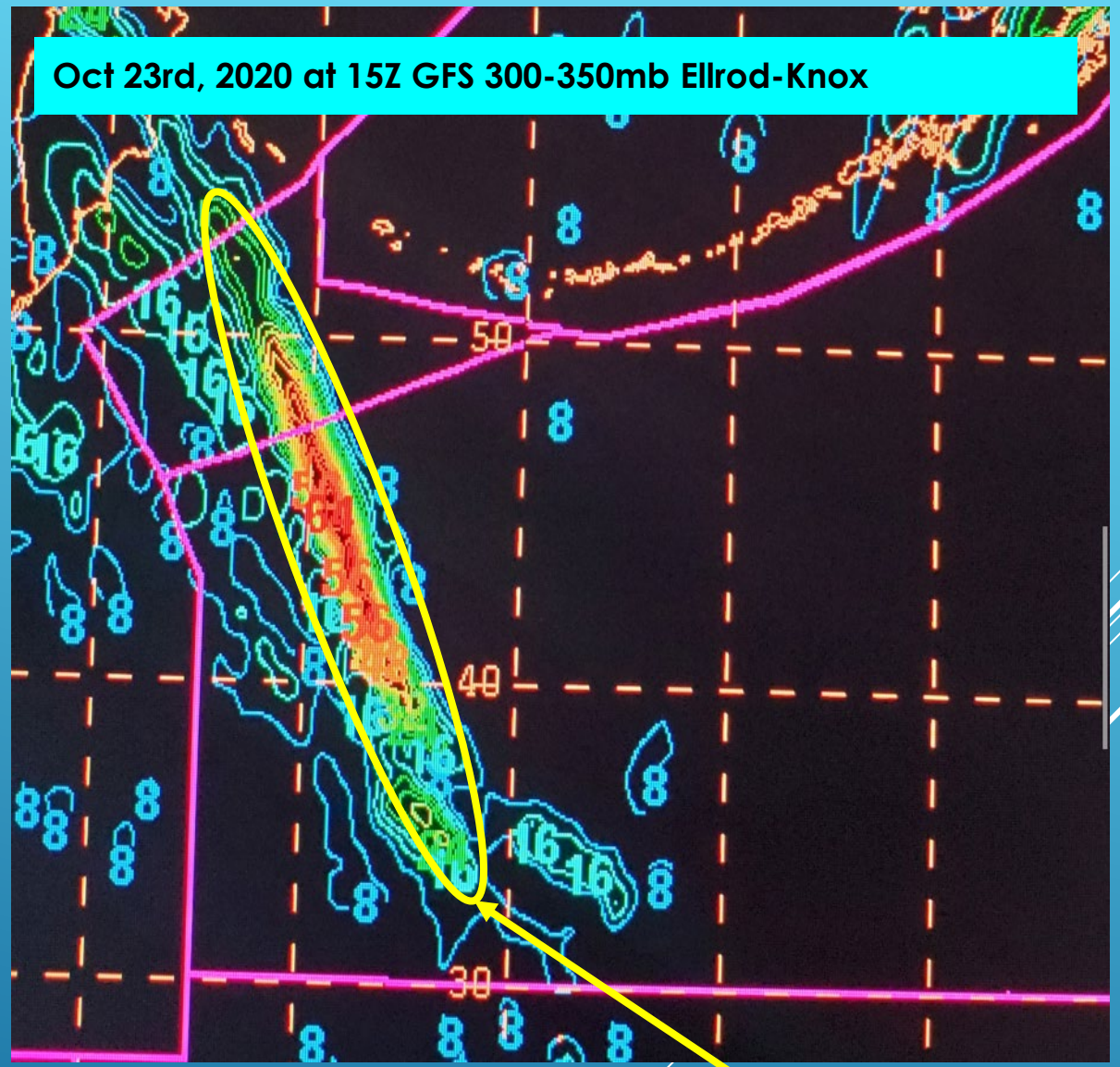
Oct 23rd, 2020 at 15Z with GFS 200-250mb Ellrod-Knox indices remained pretty close the same from the previous 200-250mb Ellrod-Knox indices from 23/12Z.

Oct 23rd, 2020 at 15Z GFS Max Wind Level Isotachs, Streamlines

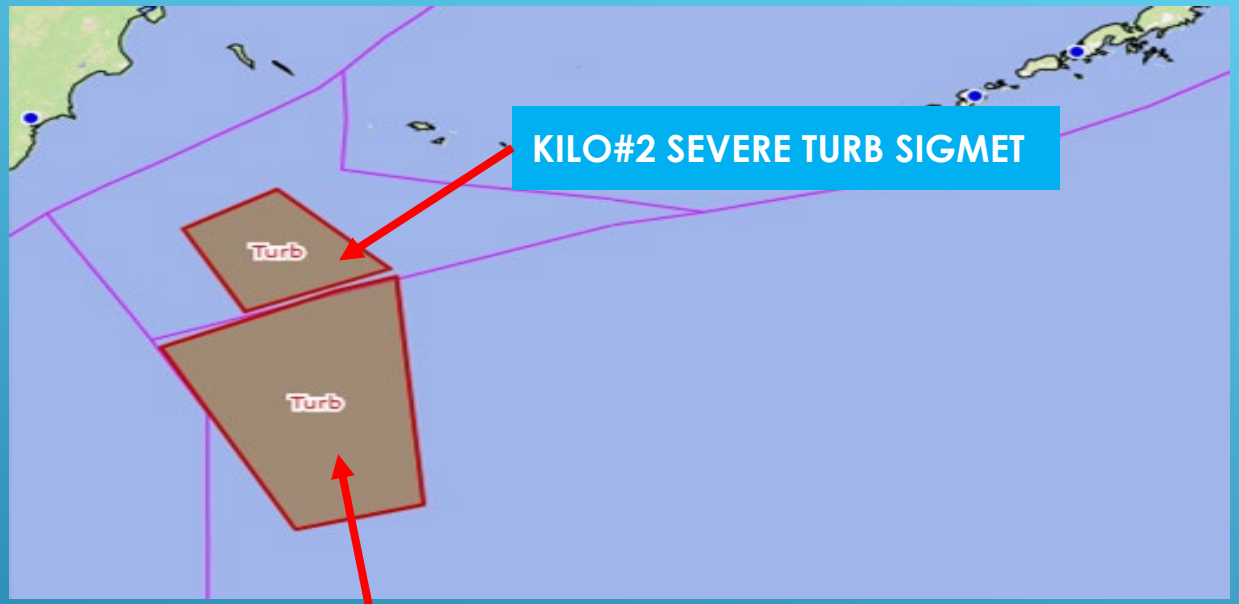


Oct 23rd, 2020 at 15Z with GFS Jetstreak MaxWnds & Streamlines continues to show great dynamics for producing possible severe turbulence.

Oct 23rd, 2020 at 15Z GFS 300-350mb Ellrod-Knox



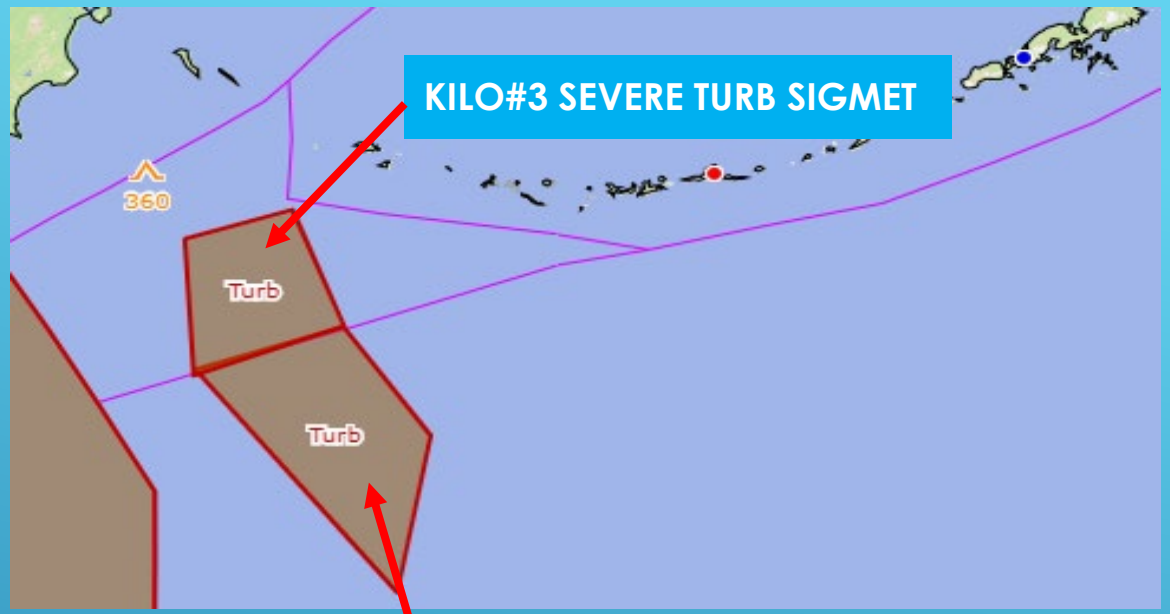
Oct 23rd, 2020 at 15Z with GFS 300-350mb Ellrod-Knox indices remain fantastic for potential severe turbulence and same as 300-350mb Ellrod-Knox from 23/12Z.



TURB SIGMET

FIR Id: KZAK
FIR Name: OAKLAND OCEANIC
Hazard: TURB - SEV
Begins: 2020-10-23T11:15:00Z
Ends: 2020-10-23T15:15:00Z
Top: 42000 ft
Base: 35000 ft
Move: E
Speed: 30 kt
Change: INTSF

WSPN04 KKCI 231115
SIGP0D
KZAK SIGMET DELTA 3 VALID 231115/231515 KKCI-
OAKLAND OCEANIC FIR SEV TURB FCST WI N4800 E17200 - N3930 E17300
- N3830 E16815 - N4530 E16315 - N4730 E16945 - N4800 E17200.
FL350/420. MOV E 30KT. INTSF.



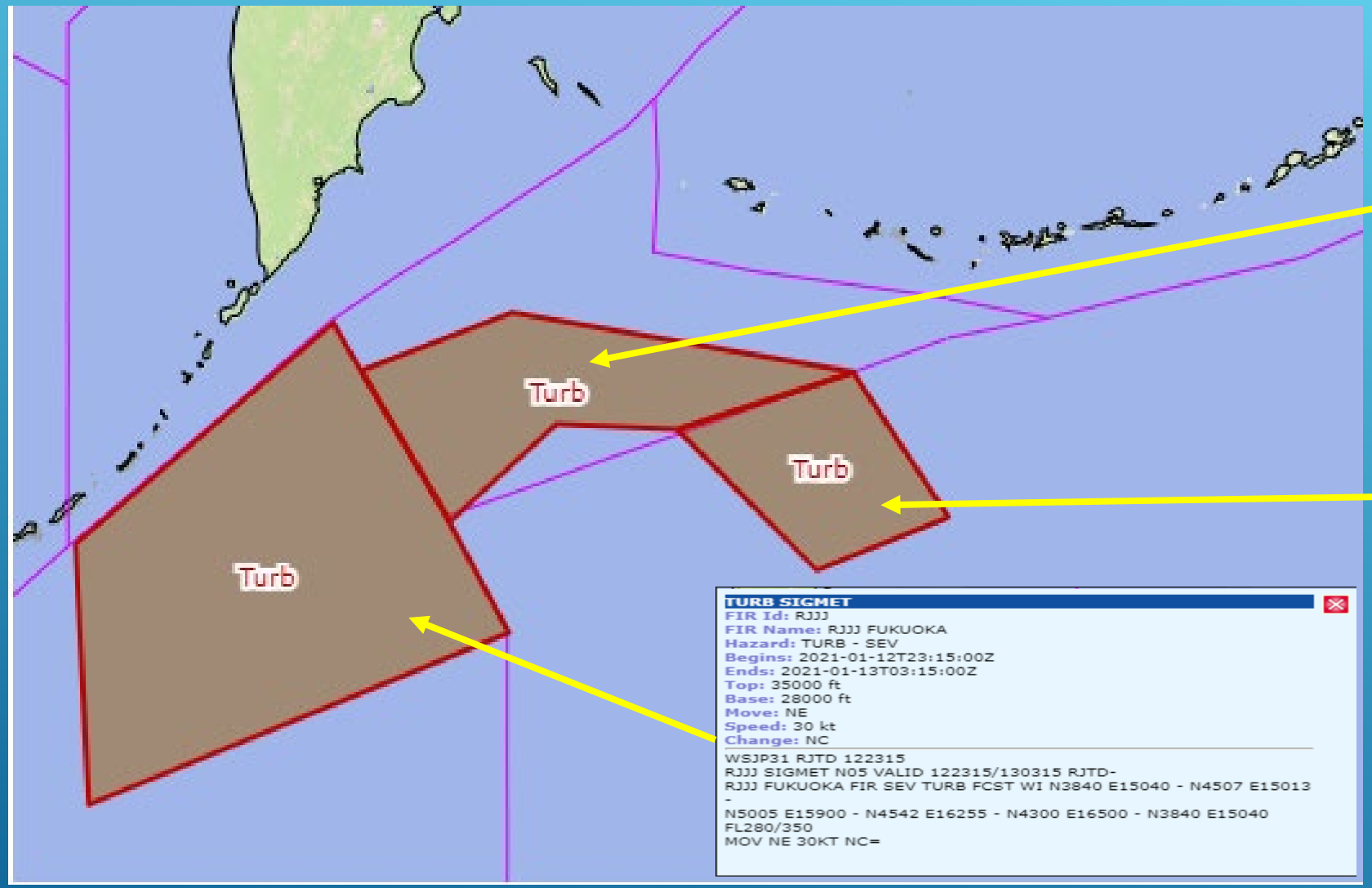
TURB SIGMET

FIR Id: PAZA
FIR Name: OAKLAND OCEANIC FIR ANCHORAGE
Hazard: TURB - SEV
Begins: 2020-10-23T15:10:00Z
Ends: 2020-10-23T19:10:00Z
Top: 40000 ft
Base: 25000 ft
Move: ENE
Speed: 30 kt
Change: NC

WSPN04 KKCI 231510
SIGP0D
KZAK PAZA SIGMET DELTA 4 VALID 231510/231910 KKCI-
OAKLAND OCEANIC FIR ANCHORAGE FIR SEV TURB FCST WI N4800 E17200 -
N4445 E17515 - N3945 E17400 - N4645 E16630 - N4800 E17200.
FL250/400. MOV ENE 30KT. NC.

The dayshift for Tropical desk did a great job coordinating with the AAWU office with the reissuance of the Delta#3 Severe Turbulence Sigmet to Delta#4.

SEVERE TURBULENCE EVENT ON JAN 13TH, 2021 THRU THE OCEANIC ANCHORAGE & OAKLAND & TOKOYO FIR'S



TURB SIGMET
FIR Id: PAZA
FIR Name: ANCHORAGE OCEANIC
Hazard: TURB - OCNL
Begins: 2021-01-13T02:00:00Z
Ends: 2021-01-13T06:00:00Z
Top: 35000 ft
Base: 25000 ft
Move: E
Speed: 40 kt
Change: INTSF

WSAK01 PAWU 130200
SIGAK1
ANCI WS 130200
PAZA SIGMET INDIA 1 VALID 130200/130600 PANC-
ANCHORAGE OCEANIC FIR OCNL SEV TURB FCST WI N5018 E16507 - N4901
E17645 - N4745 E17047 - N4752 E16637 - N4539 E16300 - N4903 E15958 -
N5018 E16507. FL250/FL350. MOV E 40KT. INTSF.
SEV TURB THREAT ASSOC W/STG SHEAR IN UPPER-RDG.

JAM JAN 2021 AAWU

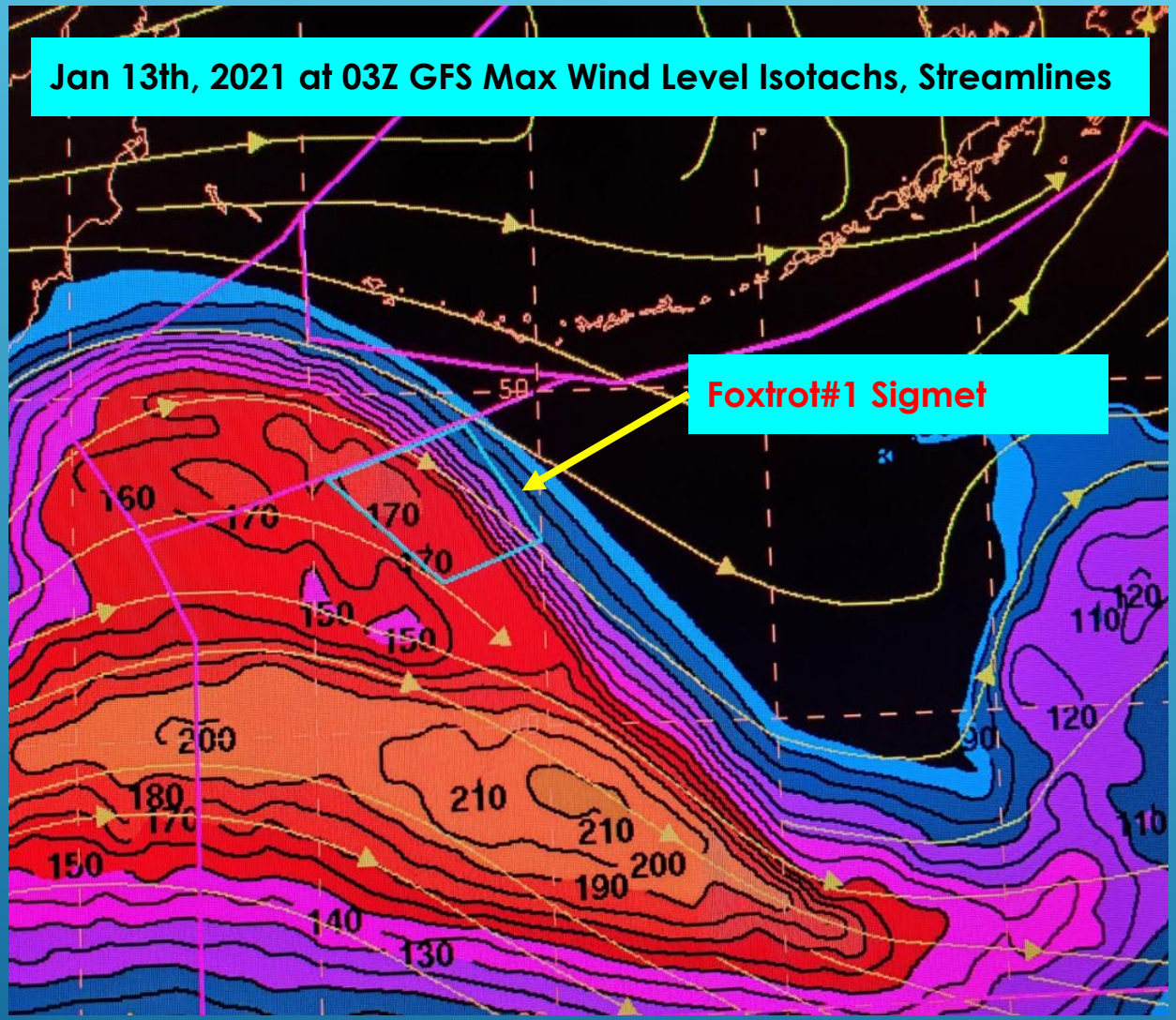
TURB SIGMET
FIR Id: RJJJ
FIR Name: RJJJ FUKUOKA
Hazard: TURB - SEV
Begins: 2021-01-12T23:15:00Z
Ends: 2021-01-13T03:15:00Z
Top: 35000 ft
Base: 28000 ft
Move: NE
Speed: 30 kt
Change: NC

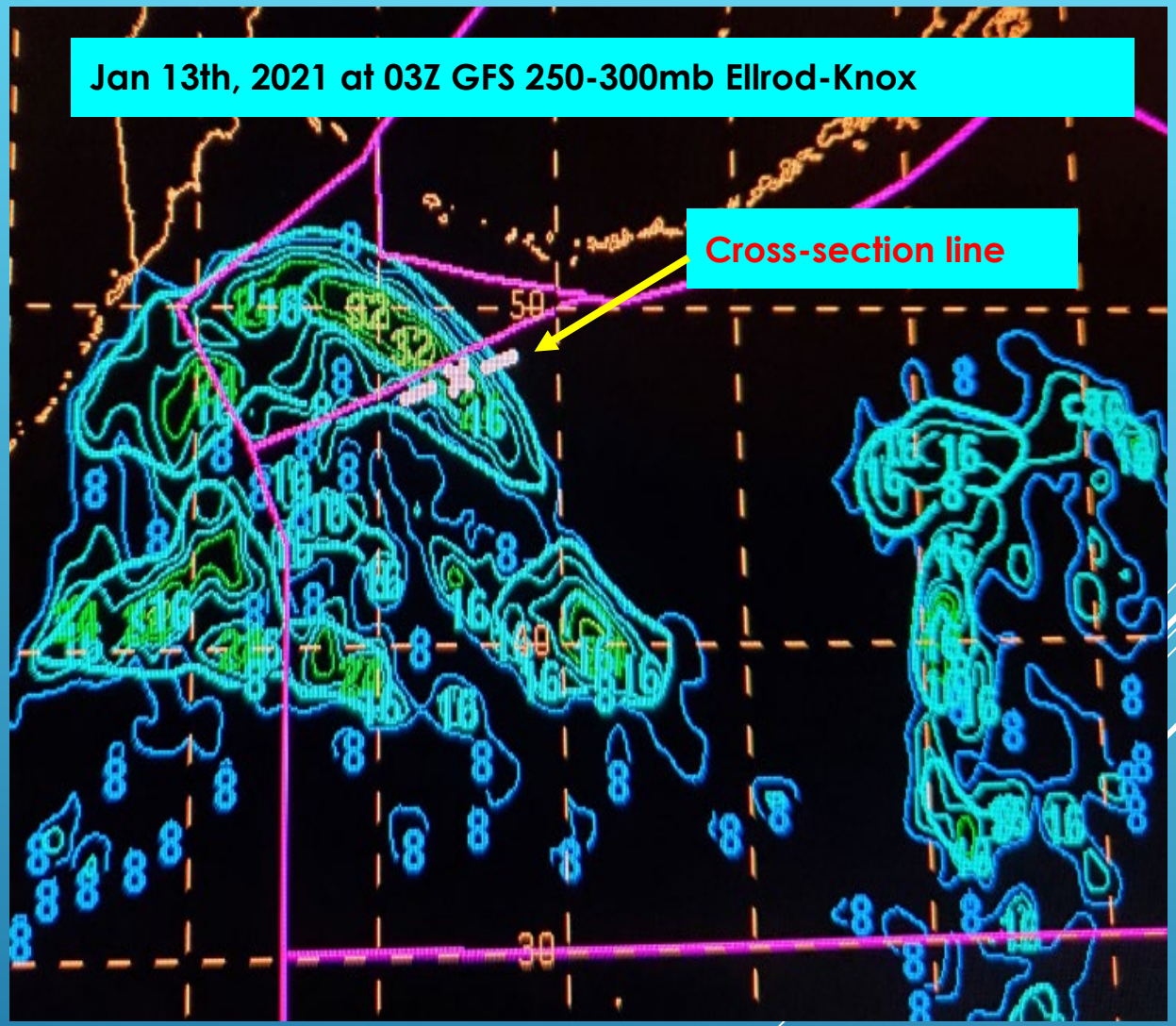
WSJP31 RJTD 122315
RJJJ SIGMET N05 VALID 122315/130315 RJTD-
RJJJ FUKUOKA FIR SEV TURB FCST WI N3840 E15040 - N4507 E15013 -
N5005 E15900 - N4542 E16255 - N4300 E16500 - N3840 E15040
FL280/350
MOV NE 30KT NC=

TURB SIGMET
FIR Id: KZAK
FIR Name: OAKLAND OCEANIC
Hazard: TURB - SEV
Begins: 2021-01-13T01:45:00Z
Ends: 2021-01-13T05:30:00Z
Top: 35000 ft
Base: 25000 ft
Move: ESE
Speed: 40 kt
Change: INTSF

WSPN06 KKCI 130145
SIGP0F
KZAK SIGMET FOXTROT 1 VALID 130145/130545 KKCI-
OAKLAND OCEANIC FIR SEV TURB FCST WI N4900 E17645 - N4545 W18000
- N4430 E17530 - N4745 E17045 - N4900 E17645. FL250/350. MOV ESE
40KT. INTSF.

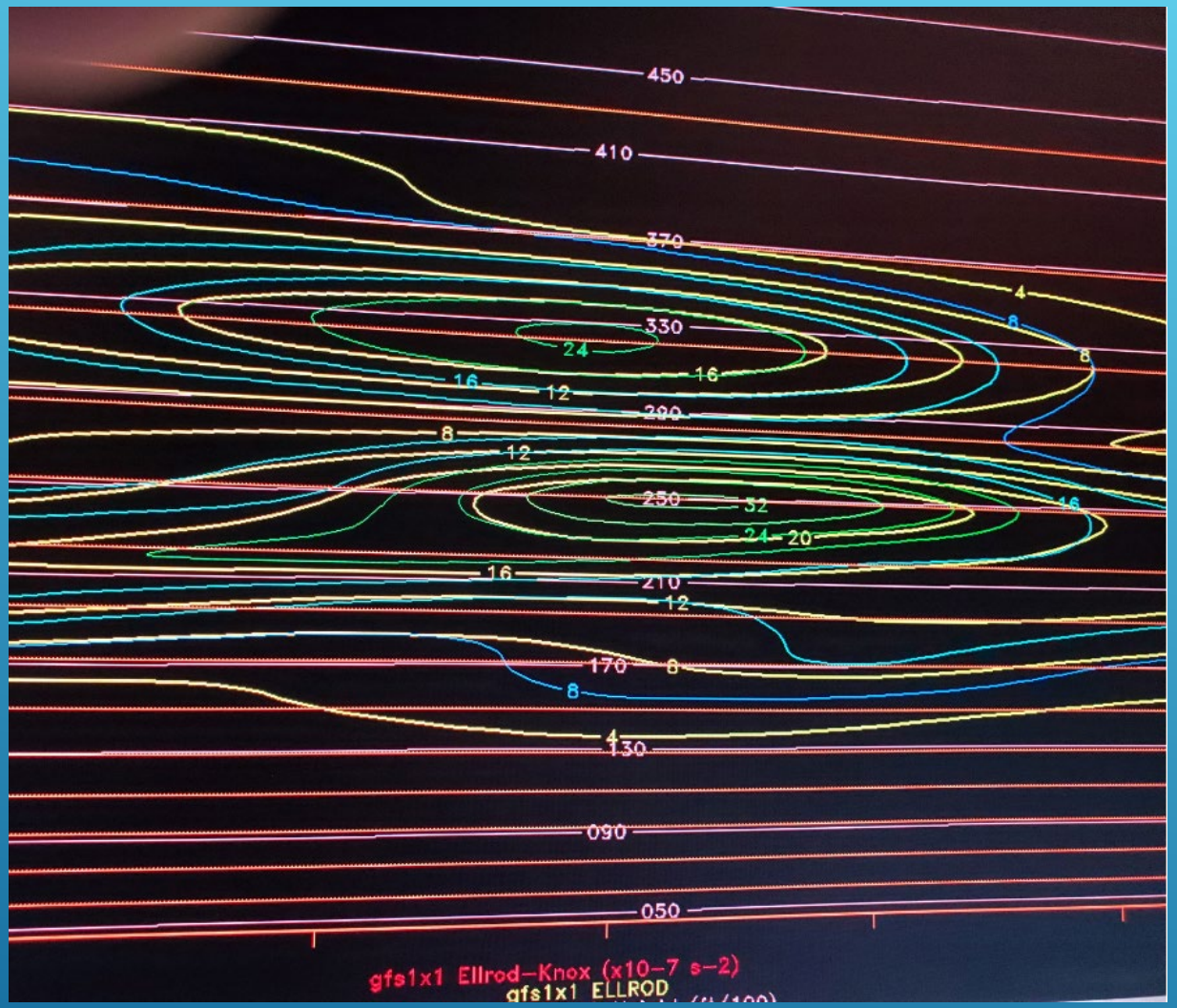
We had another strong northwesterly jet thru SW Oceanic Anchorage FIR moving through the northwest Oakland FIR. We never had any severe turb pireps for this event. We had great coordination between the AAWU and AWC offices during this event.



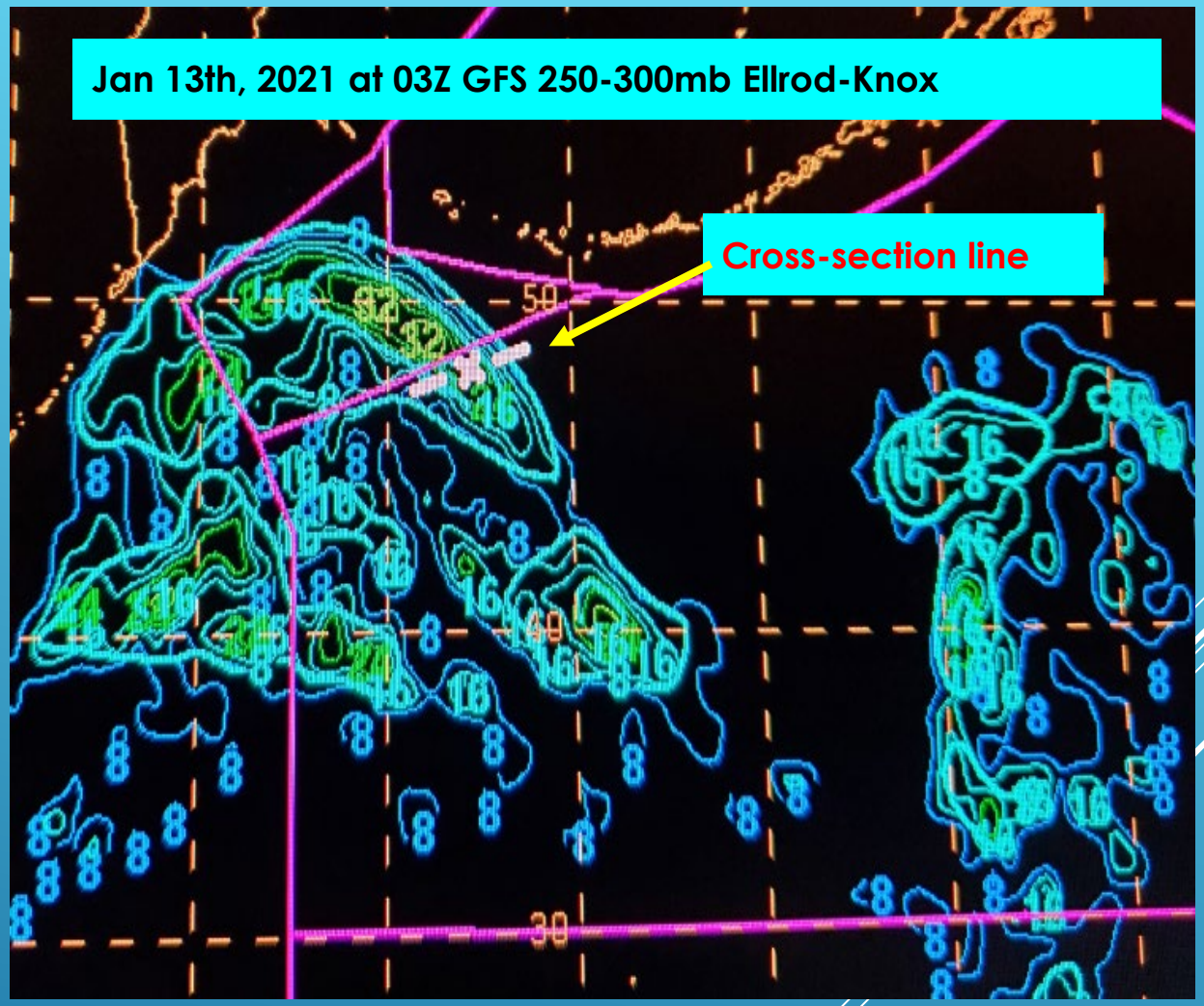


Jan 13rd, 2021 at 03Z with GFS Jetstreak MaxWnds & Streamlines strong northwesterly 170 knot jetstreak that is moving over the anticyclonic ridge.

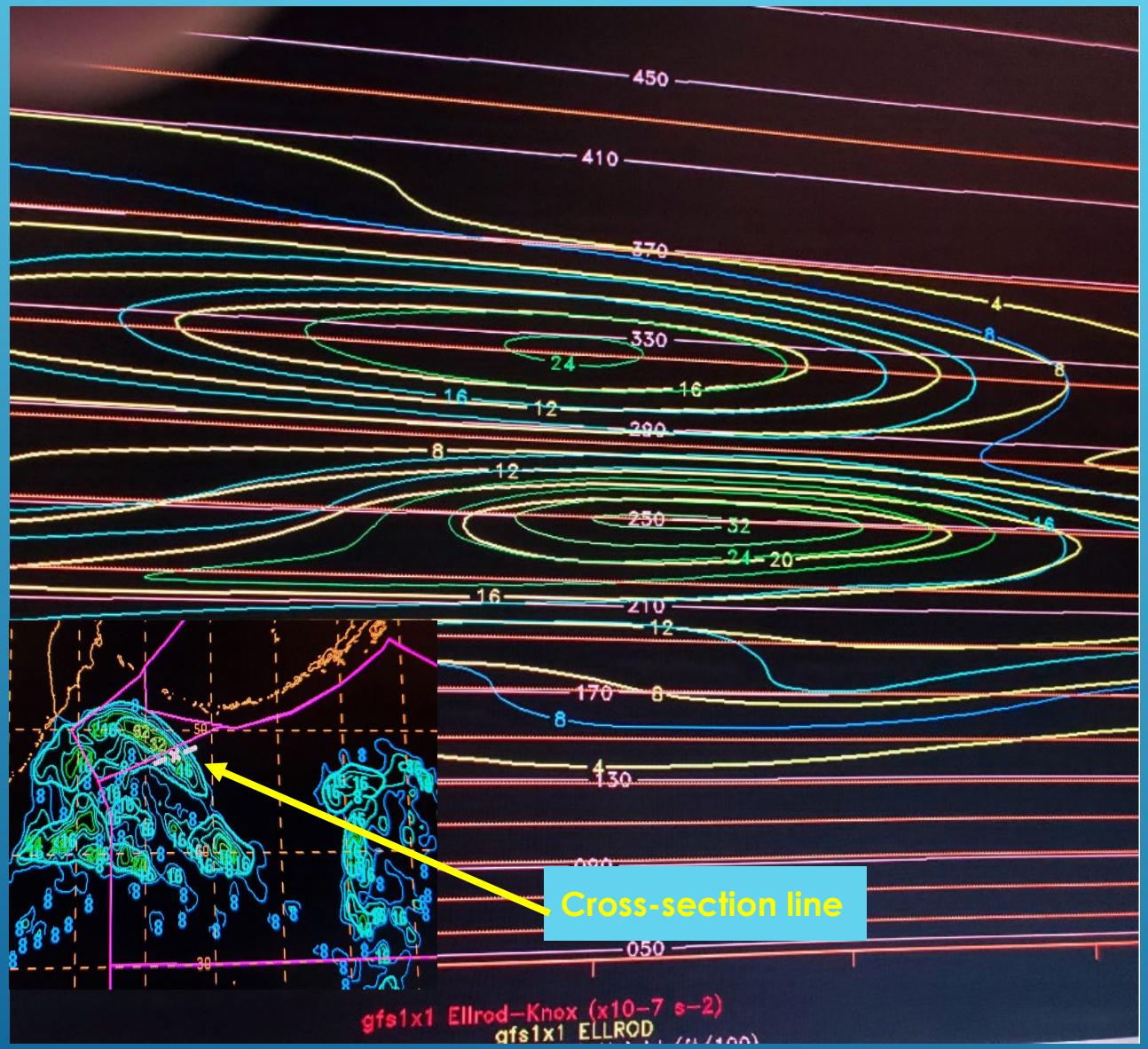
GFS ELLROD & ELLROD-KNOX 250-300mb on Jan13th, 2021 at 03Z indices were showing the potential for moderate to severe turbulence.



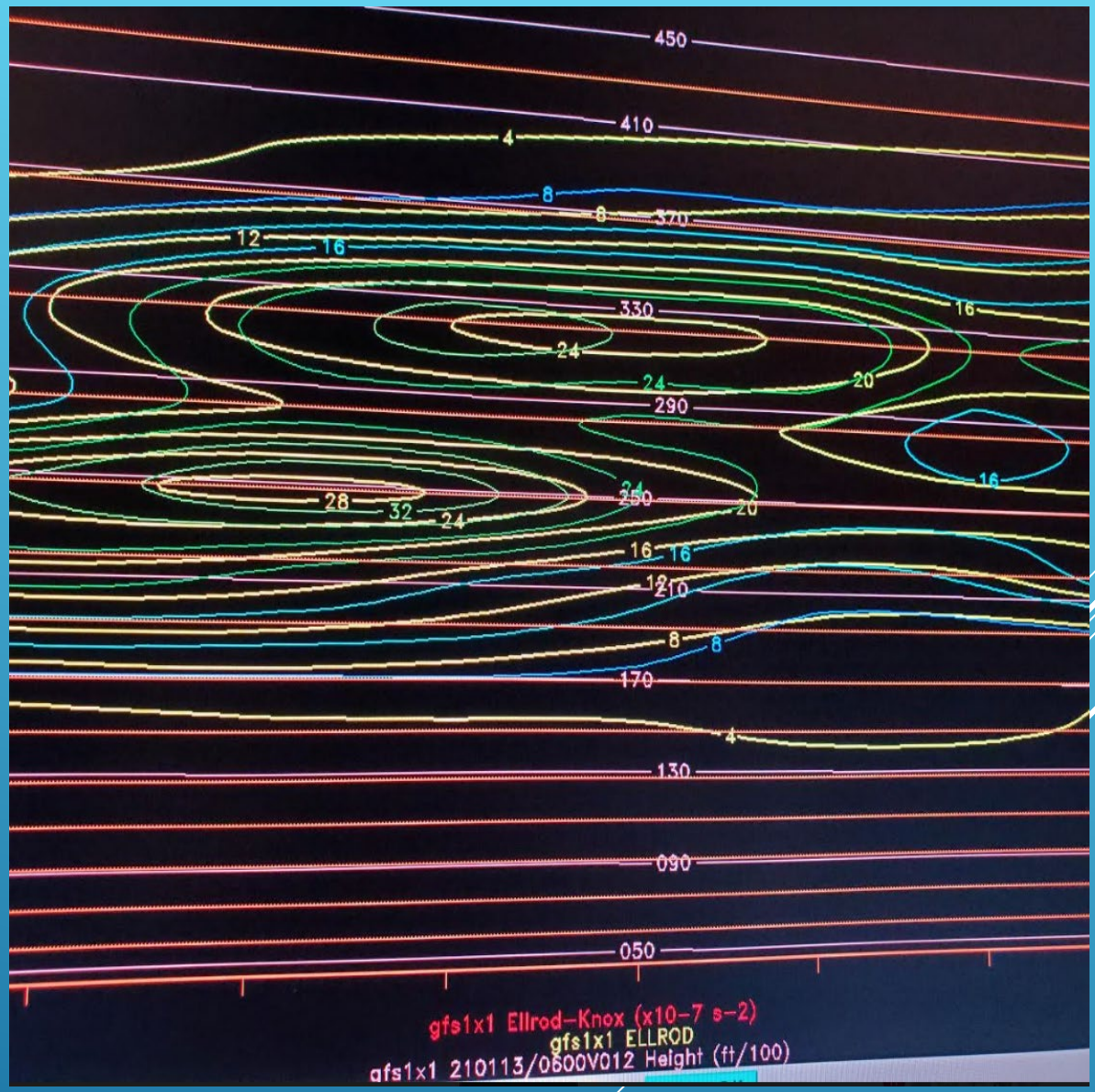
GFS ELLROD & ELLROD-KNOX cross-section for Jan 13rd/2021 at 03Z with the cross-section line shown where it was drawn on the right image.



GFS ELLROD & ELLROD-KNOX 250-300mb on Jan 13, 2021 at 03Z. The AAWU SW Oceanic Anchorage FIR had stronger turbulence indices but they will be moving into the Oakland FIR as the northwest jetstreak continues to move southeast into the Pacific Ocean.



GFS ELLROD & ELLROD-KNOX 250-300mb on Jan 13, 2021 at 03Z



GFS ELLROD & ELLROD-KNOX 250-300mb on Jan 13, 2021 at 06Z

CONCLUSION: SEVERE TURBULENCE ON OCT 23rd, 2020 -- SW OCEANIC ANCHORAGE and Northwest OAKLAND OCEANIC FIRS

- Strong northwesterly 180 knot jetstreak riding over an amplified anticyclonic ridge.
- The 180 knot jetstreak was beginning to dig into the base of the upstream trough.
- The GFS Ellrod and Ellrod-Knox indices at 300 to 350mb greatly intensified within a 6 hr time-frame as the jetstreak became more northwesterly coupled with the ridge becoming more amplified.
- There were 5 severe turb pireps reported in a 2 hr window in proximity of the 180 knot jetcore.
- Maintain strong relationships with fellow Aviation offices, which in this case study the Aviation Lead in the AAWU office caught my error in plotting of the Delta#1 Severe Turbulence Sigmet.

CONCLUSION: SEVERE TURBULENCE ON Jan 13th, 2021 -- SW OCEANIC ANCHORAGE and Northwest OAKLAND OCEANIC FIRS

- This case study had similar dynamics as the Oct 23rd, 2020 severe turbulence event through the same FIRs.
- Strong northwesterly 170 knot jetstreak riding over anticyclonic ridge. The ridge didn't get as amplified as previous case study.
- The GFS Ellrod and Ellrod-Knox indices at 300 to 350mb were not as strong but still potential for possible moderate to severe turbulence.
- There were no severe turbulence pireps reported in both the NW Oakland and SW Oceanic Anchorage FIRs during this event.

Severe Low Level Icing
Vicinity of ORD

Nov 30, 2020

Prepared by Robb Kaczmarek & Andrew Snyder

Specifics:

- Shallow cloud layer:
  - Bases: 2,500’ – 3,500’, Tops: 7,000’ – 8,000’
  - Thickest over Lake Michigan (lake effect)
  - Stratocumulus over/near Lake Michigan (steep 1000-850 lapse rates)

- Subtle wind changes an important factor:
  - Gusty NNW winds AM backed NW PM
  - West Flow config favored at ORD
  - Icing avoidance resulted in period of East Flow as winds allowed

- Minimal precipitation at ORD (spotty flurries, runways dry)

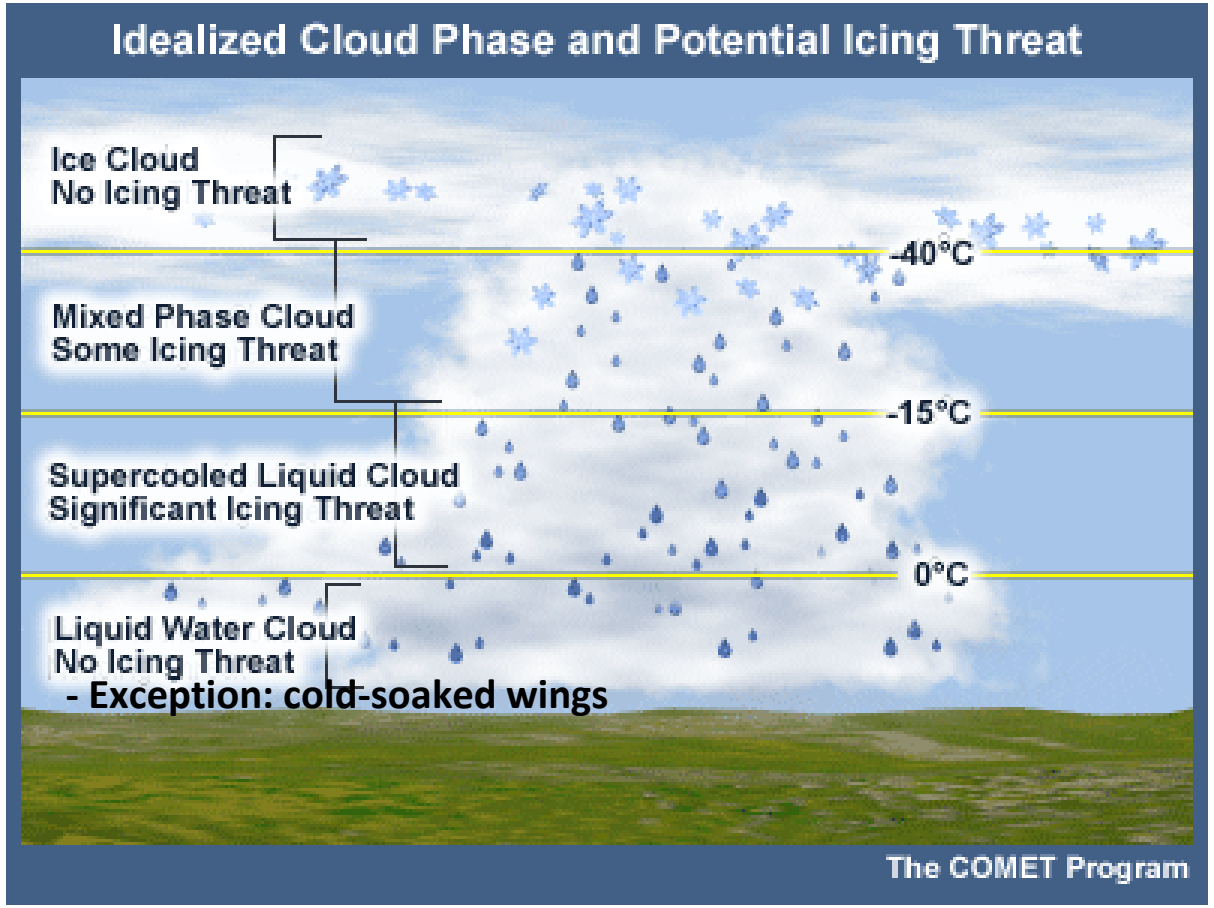
Specifics (cont):

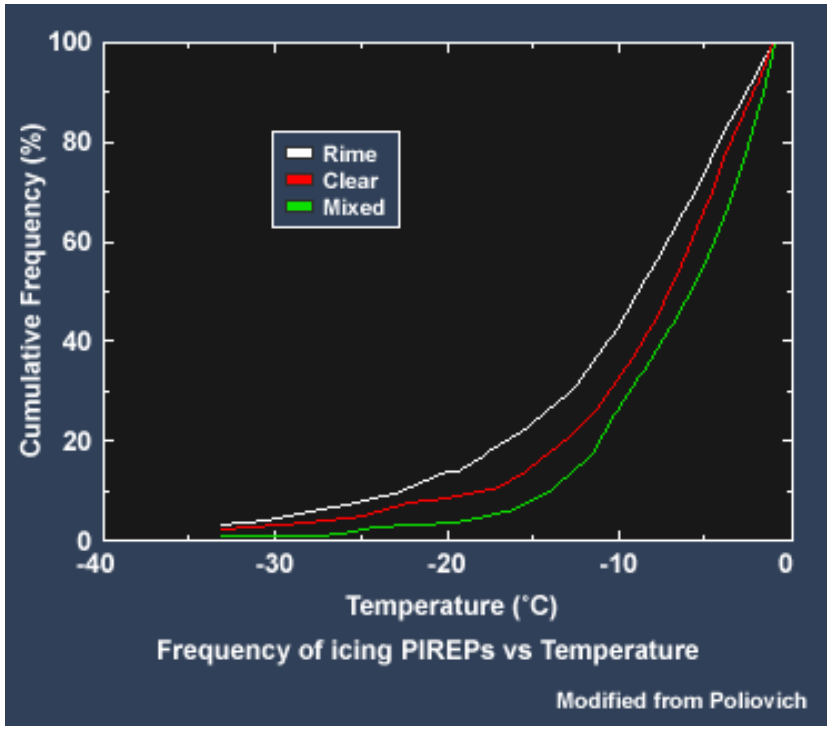
- Numerous/frequent MOD icing reports 3,000’ – 7,500’
  - Mostly rime or mixed ice, several clear
    - Phase mainly supercooled liquid, but some ice present
    - In-cloud temperatures -13.5°C or warmer

- Six SEV icing reports near ORD 3,500’ – 5,000’
  - Chicago TRACON (C90) avoidance helped mitigate risk
    - Revealed importance of timely PIREPs and forecast updates

- Surface temperatures at ORD fell below freezing → de-icing necessary
  - Significant operational impacts for UAL

Forecast Considerations
Cloud Microphysics and Icing Risk

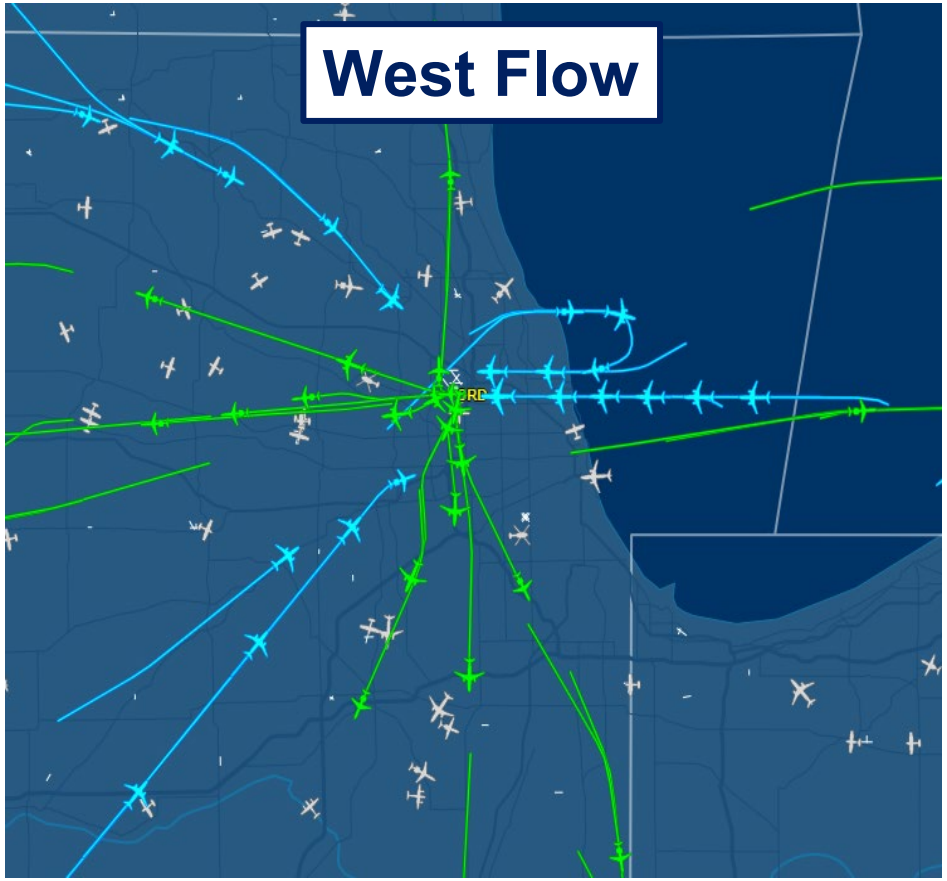


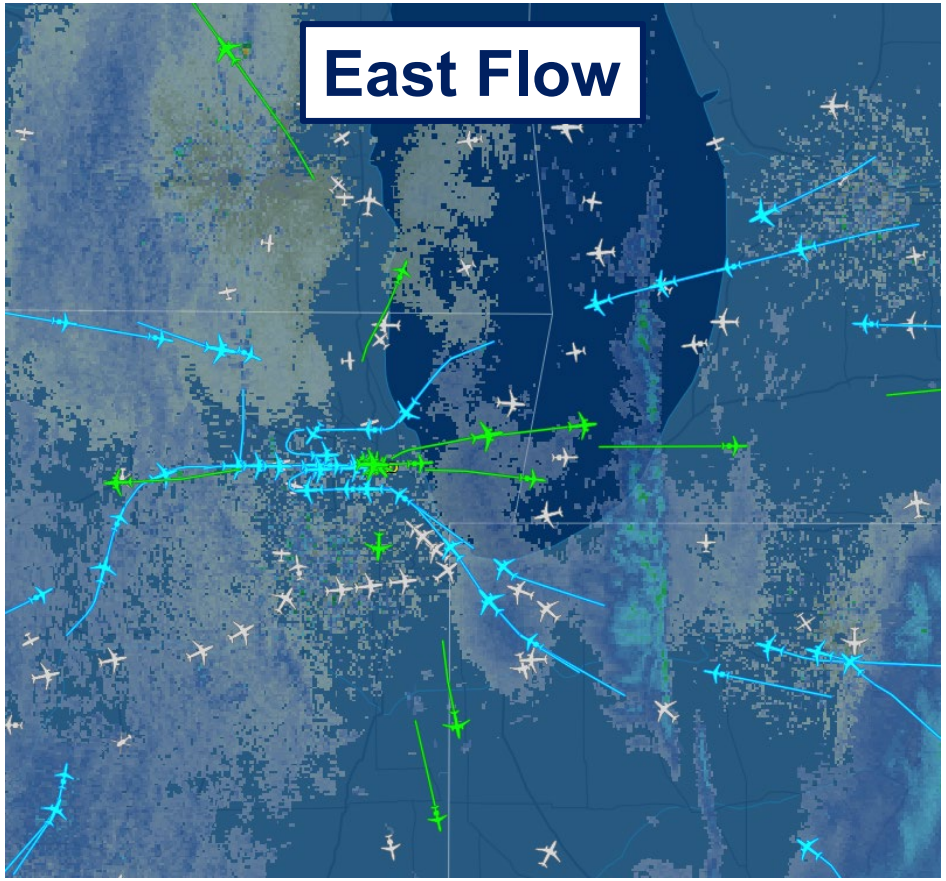


- **Relatively few icg PIREPs colder than -30°C**
- **Majority 0 to -15°C**

Images courtesy UCAR METED Program

Forecast Considerations - Airspace

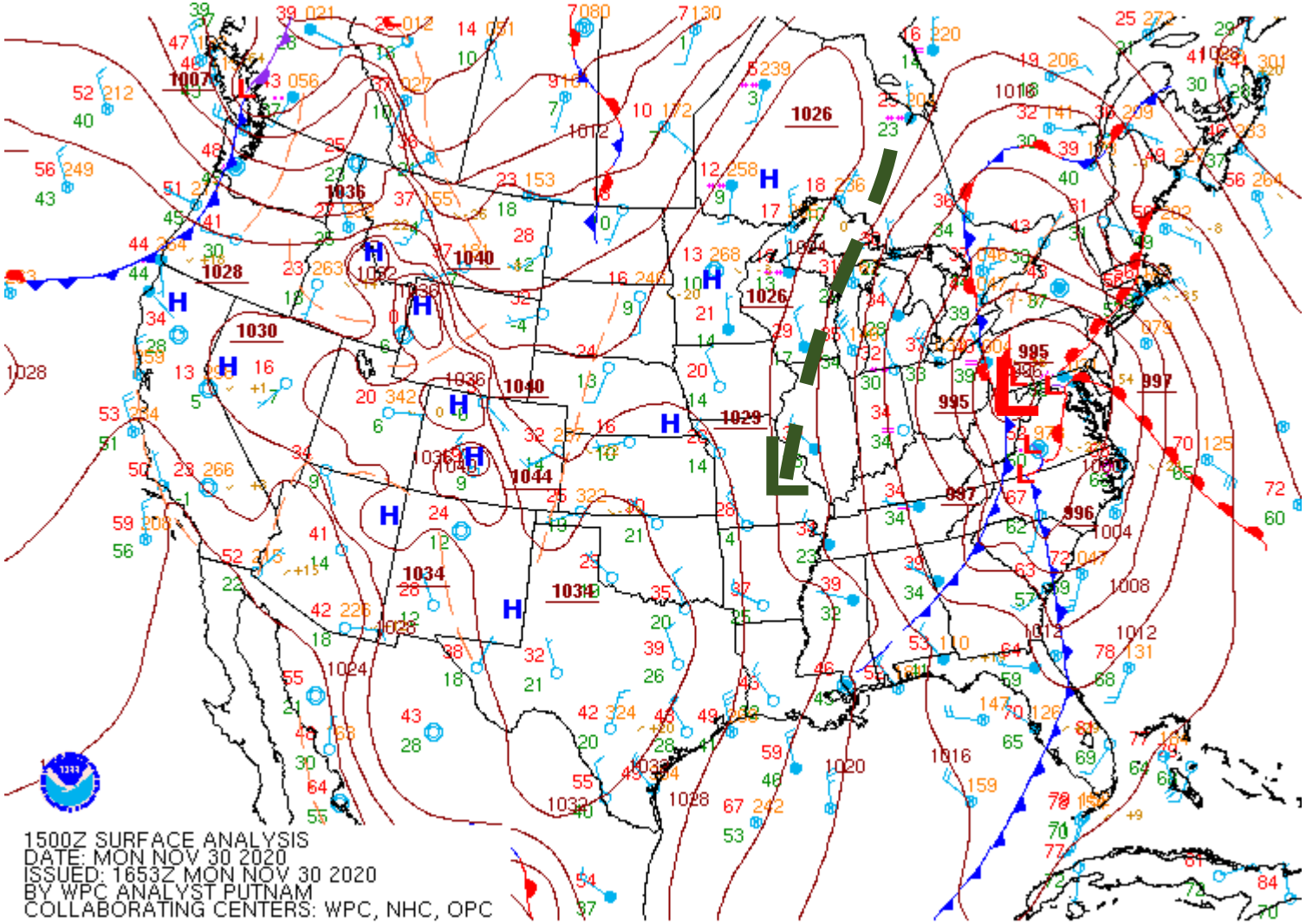




Images courtesy FlightAware

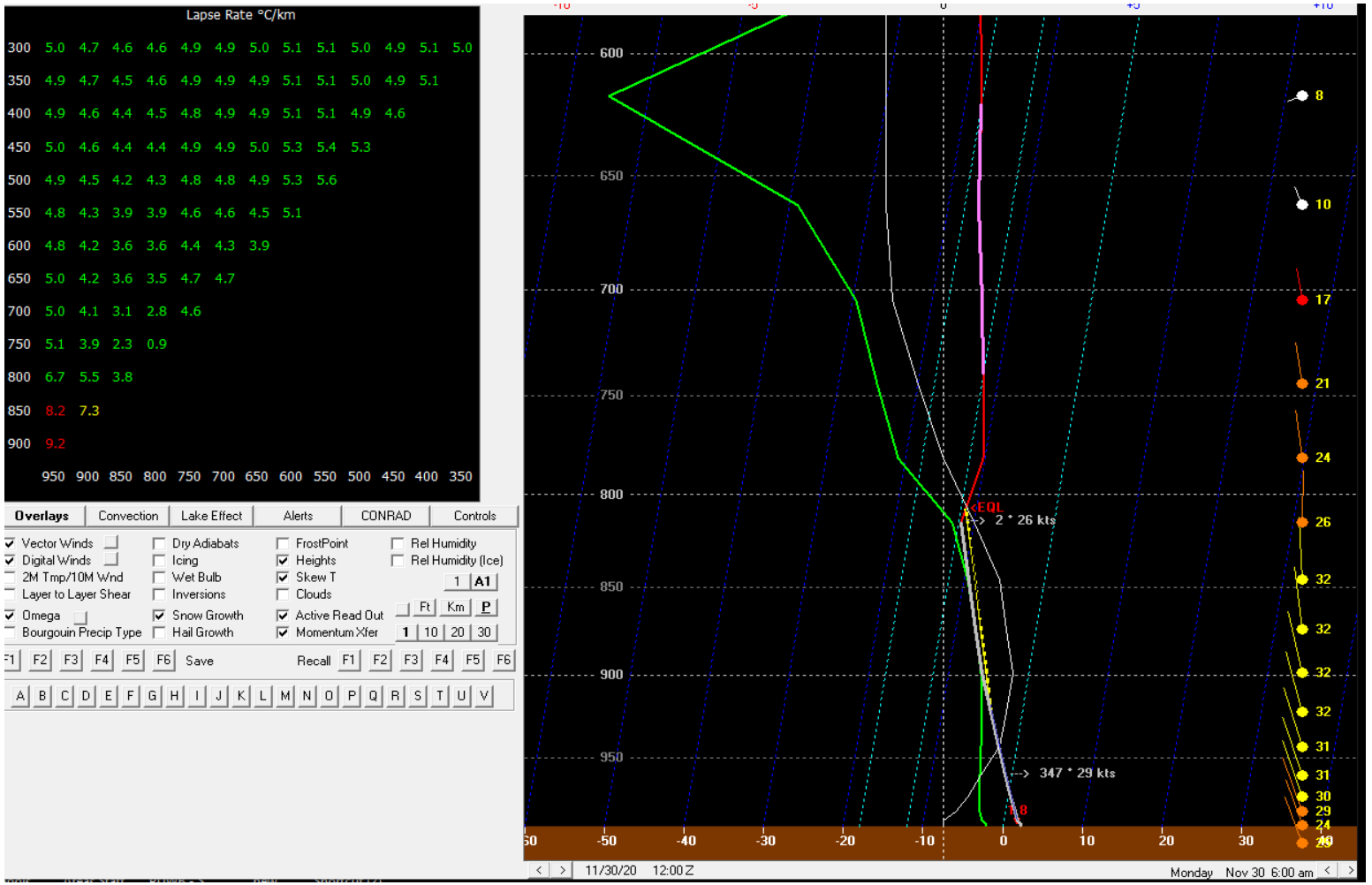
Synoptic Pattern

- Strengthening surface low in the East
- Surface high Ontario to Texas
- Persistent 500mb trough axis ~GRB to STL
- Continued low-level CAA through the day



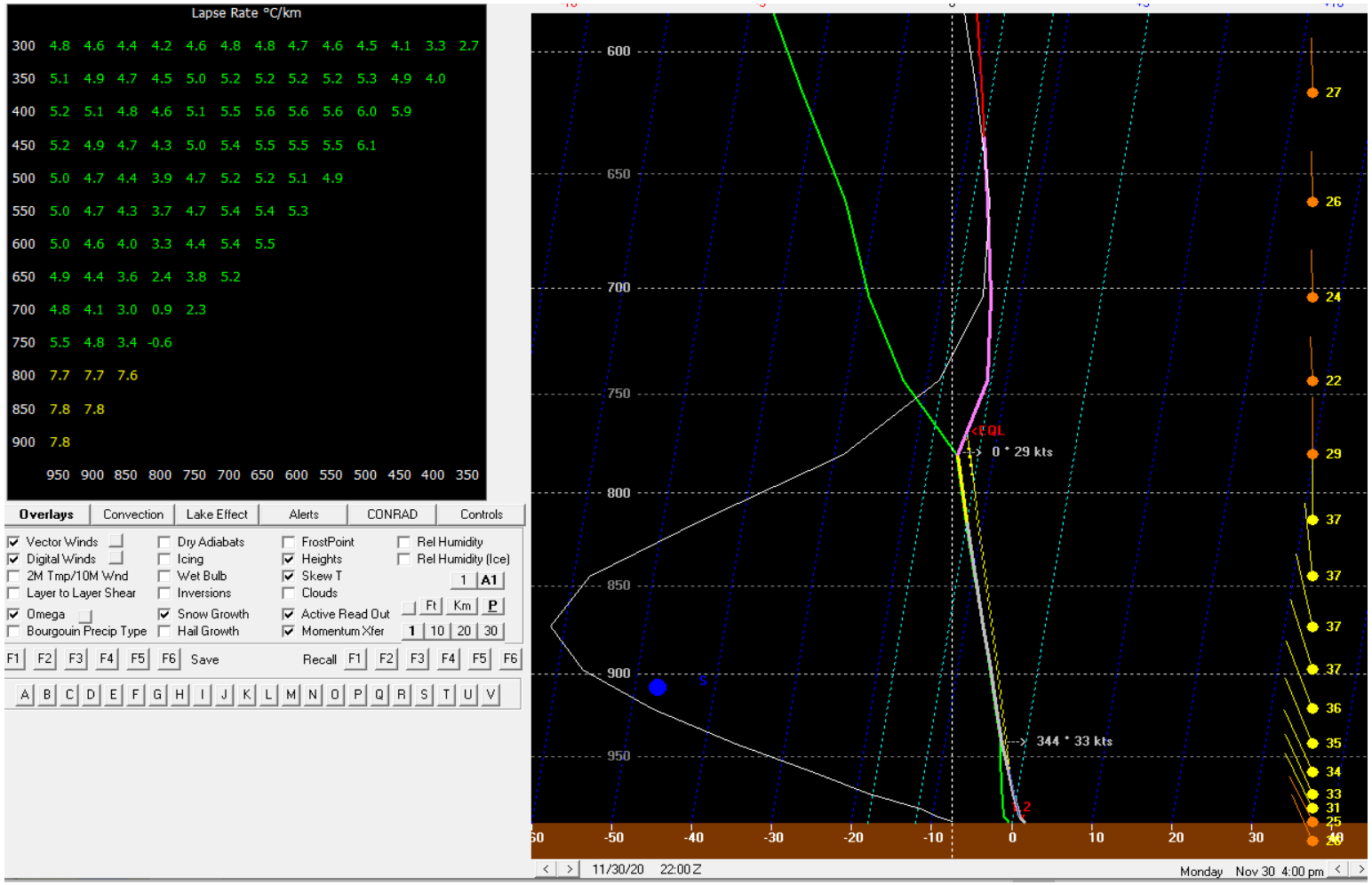
Forecast Sounding

- Forecast valid 12Z at LM2 (S Lk MI buoy)
- Steep Sfc-850hPa lapse rates
- Saturation -4° to -10°C



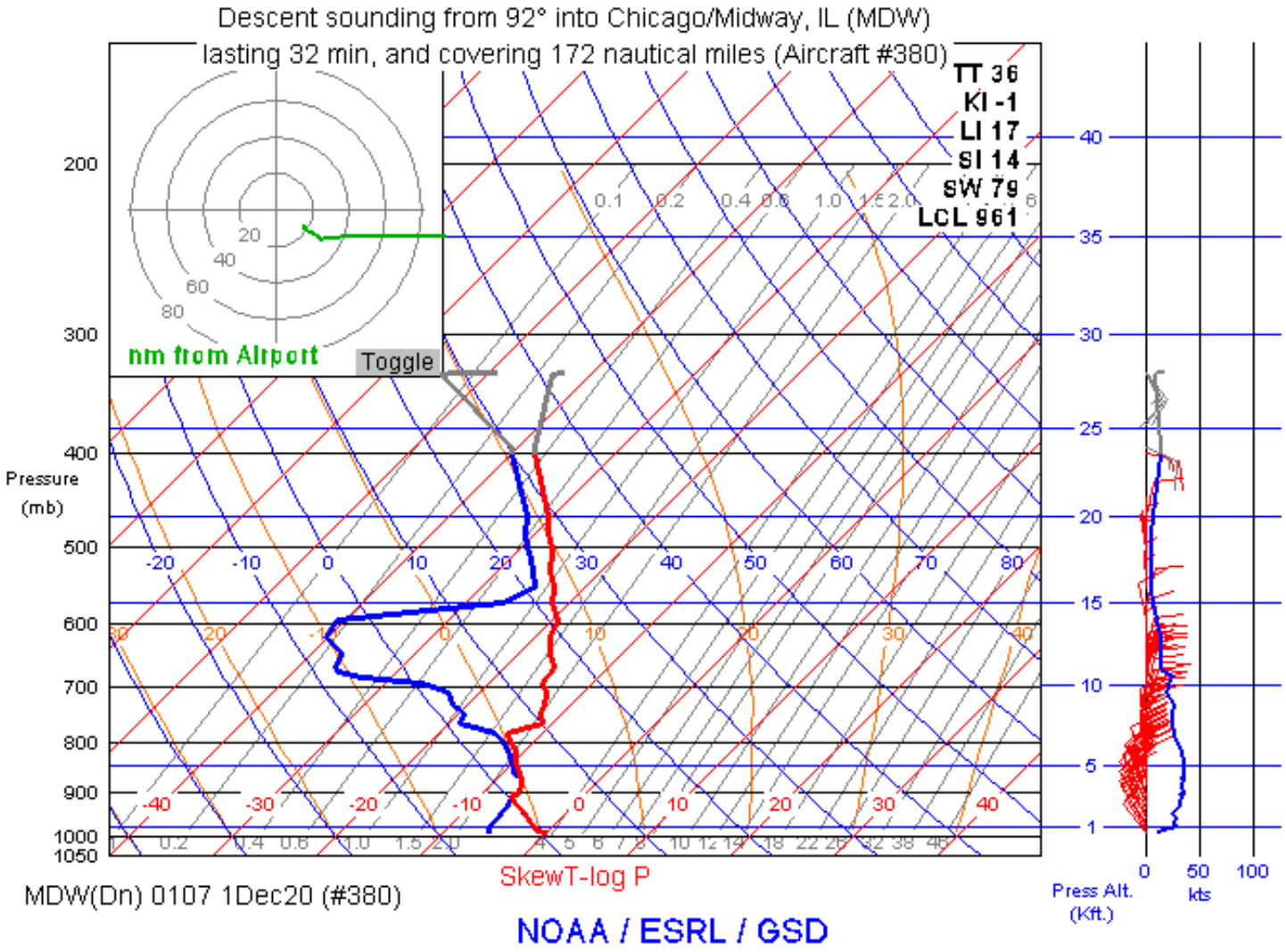
Forecast Sounding

- Forecast valid 22Z at LM2
- Sfc-850hPa lapse rates weaken slightly
- Saturation -5° to -12°C
- Max lift near 875hPa



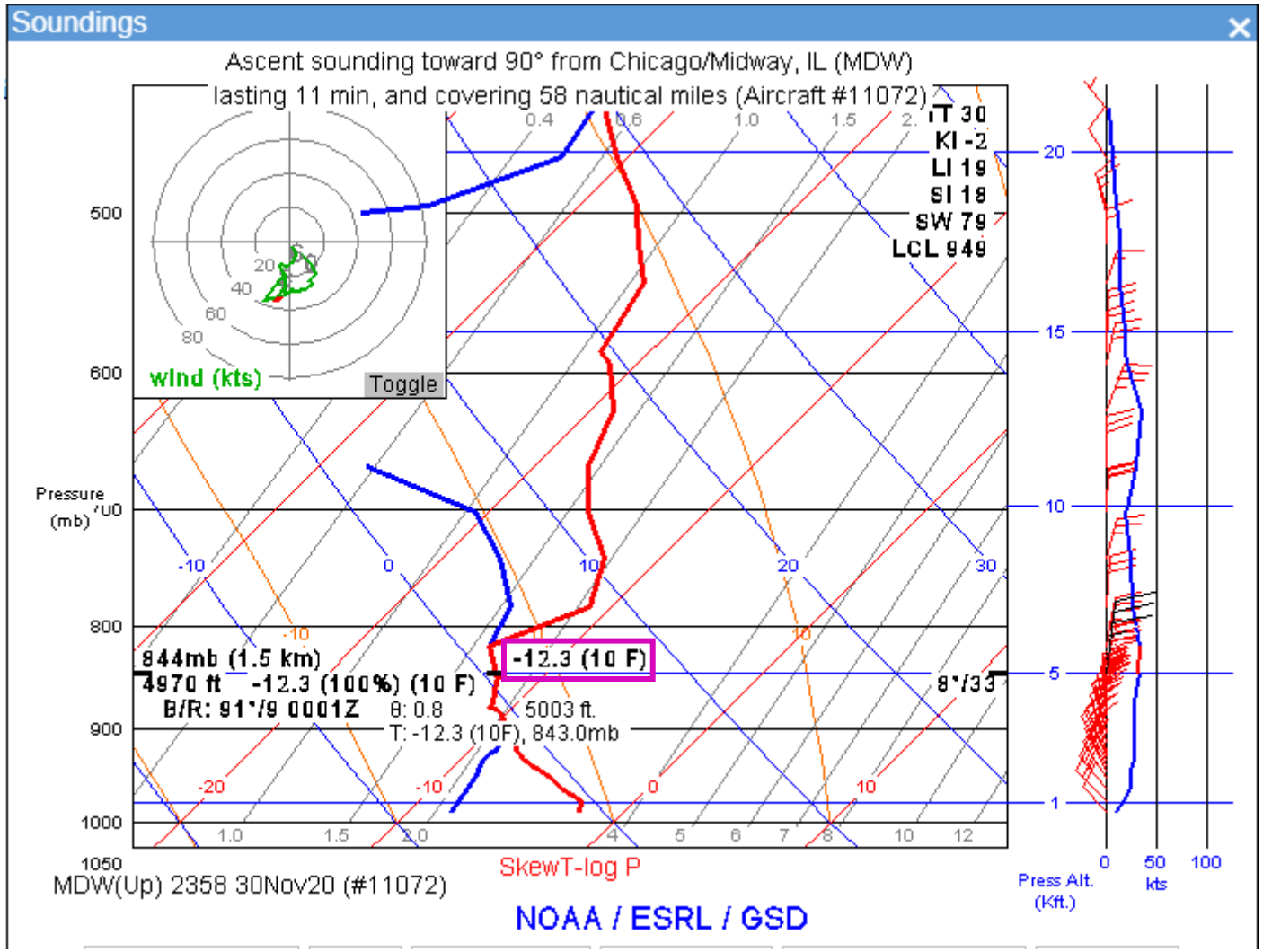
AMDAR MDW Arrival Sounding

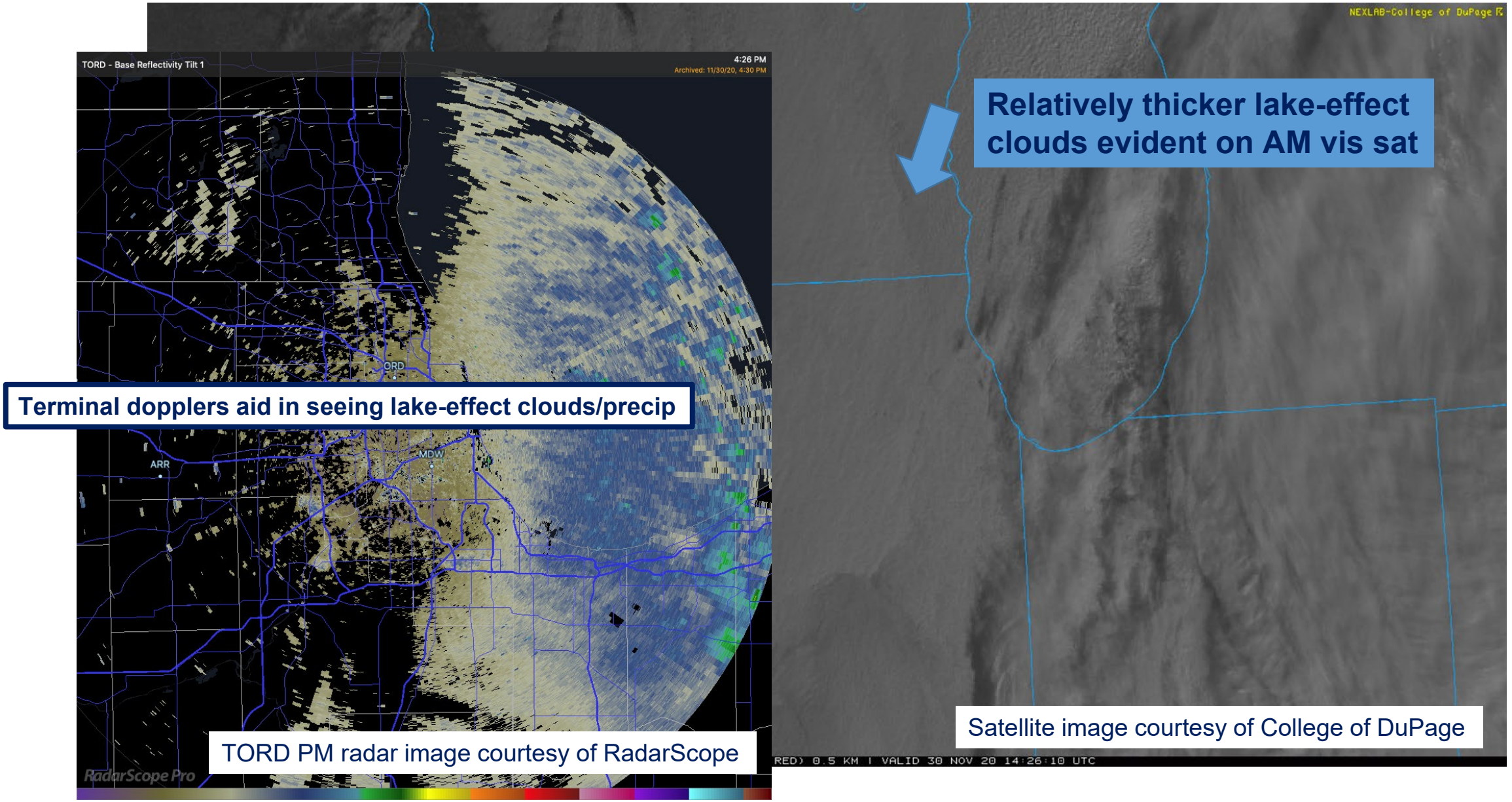
- MDW arrival traveled through lake-effect plume
- Saturation of a ~100hPa thick layer
- Unlikely that lake-effect precip being seeded by mid/high clouds (verified by radar)



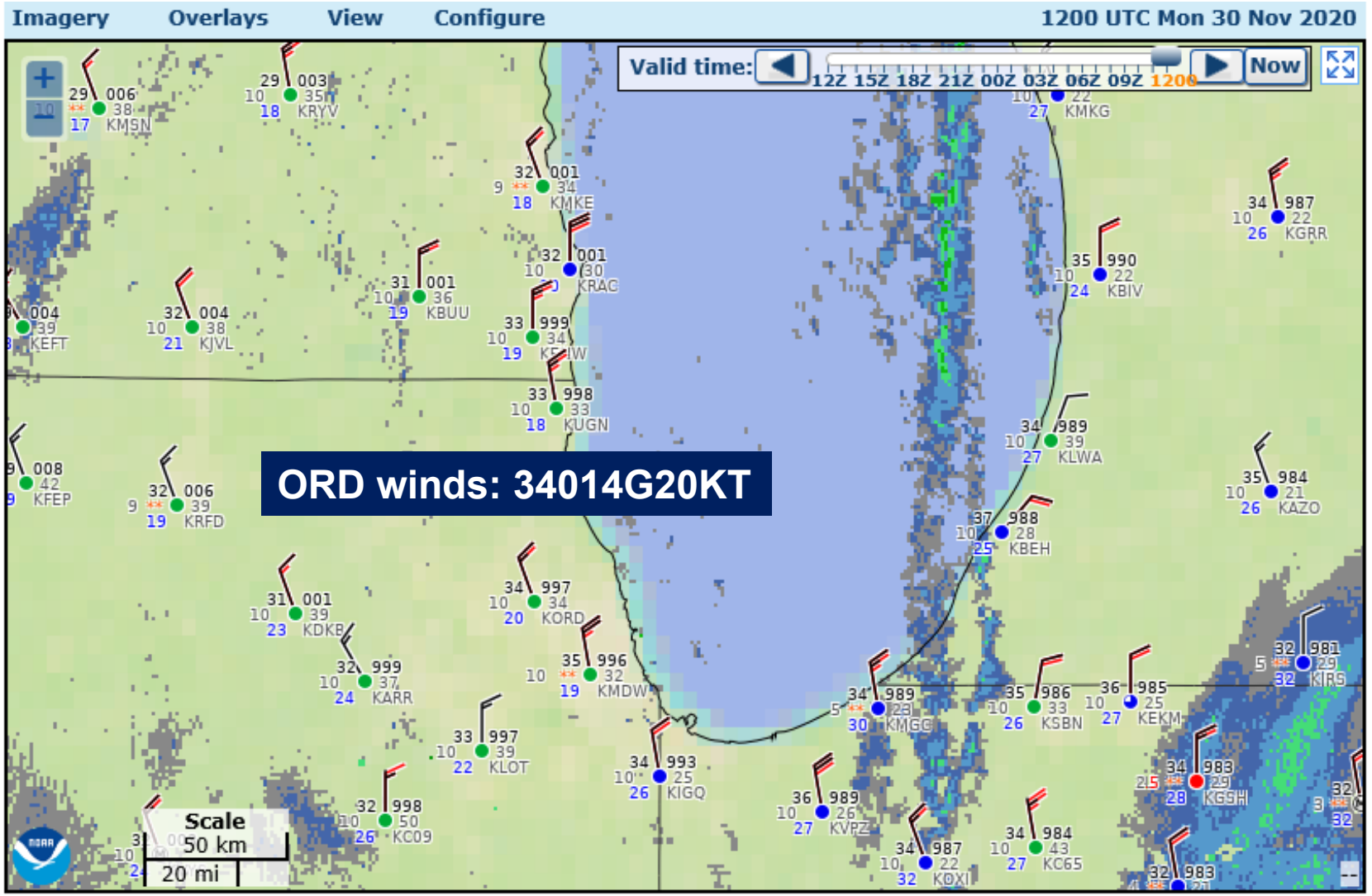
AMDAR MDW Departure Sounding

- Saturation of a ~100hPa thick layer, from ~ -8.0°C to -13.5°C
- NW winds in boundary layer
- N-NNE winds above
- Worst icing PIREPs 4,000 – 5,000’
  - Temperatures of -11° to -13°C

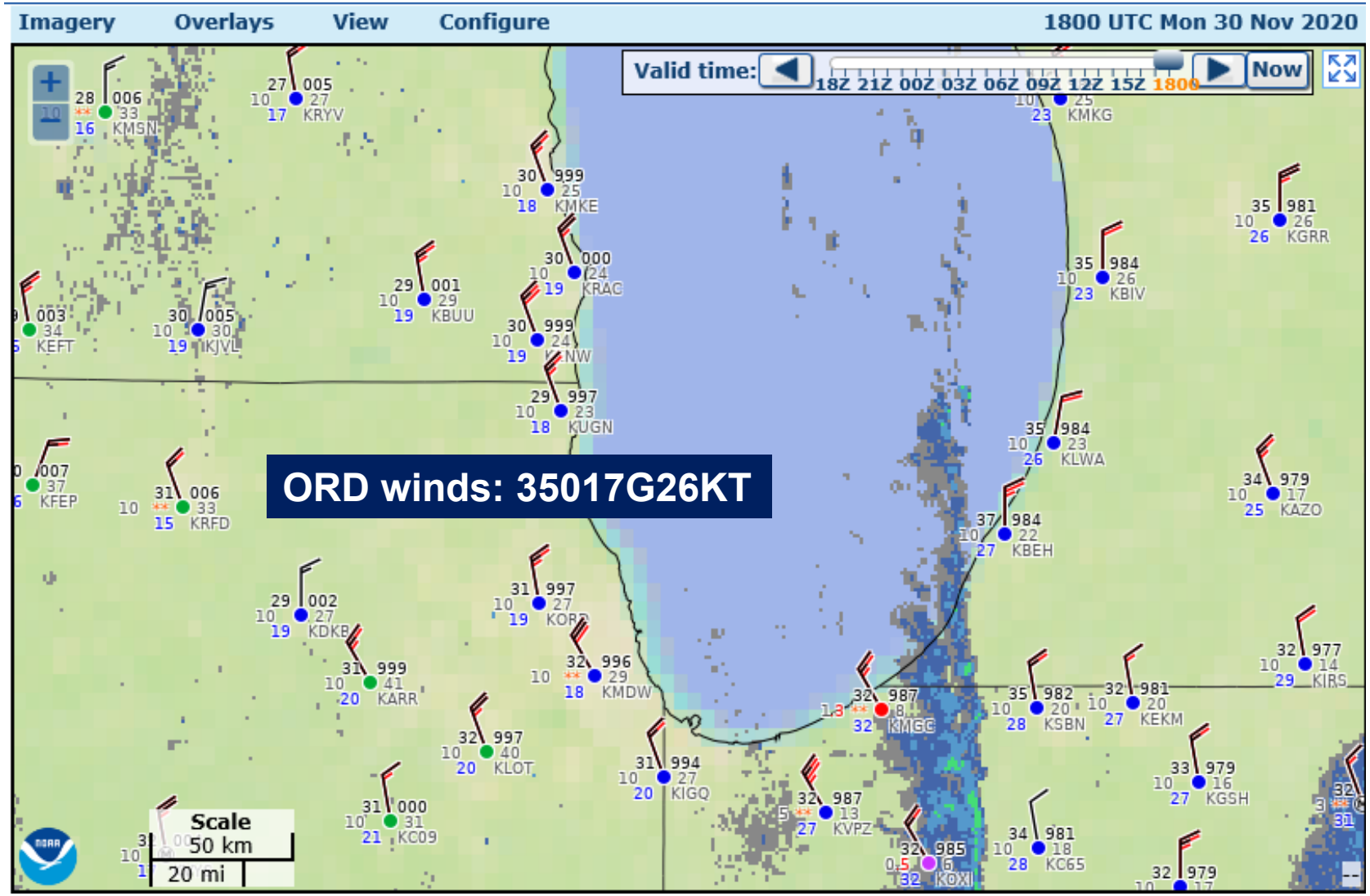



TORD - Base Reflectivity Tilt 1
4:26 PM
Archived: 11/30/20, 4:30 PM
ORD
MDW
ARR
RadarScope Pro
NEXLAB-College of DuPage
Relatively thicker lake-effect clouds evident on AM vis sat
Terminal dopplers aid in seeing lake-effect clouds/precip
TORD PM radar image courtesy of RadarScope
Satellite image courtesy of College of DuPage
RED) 0.5 KM | VALID 30 NOV 20 14:26:10 UTC

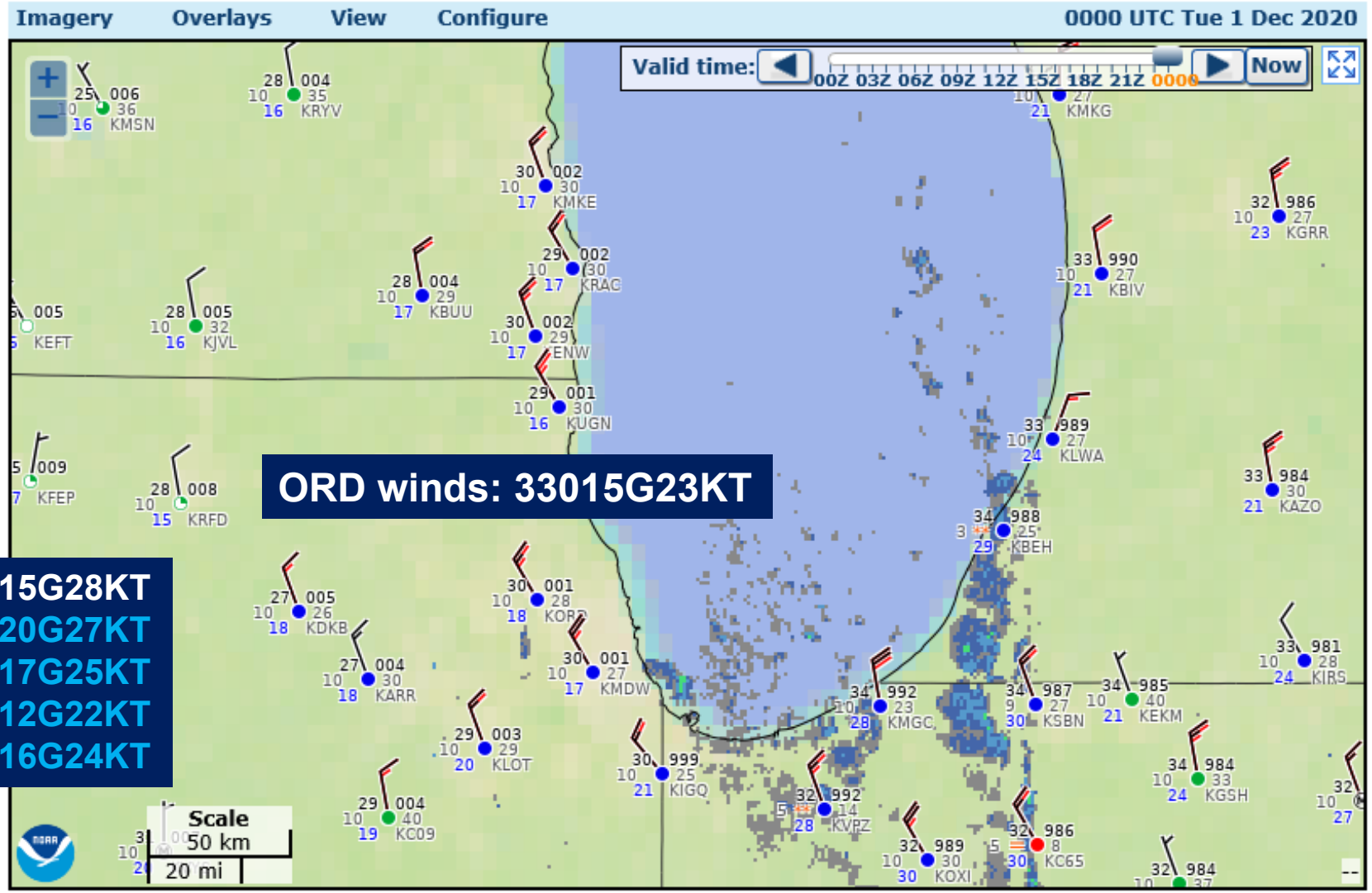
12Z Surface Map



18Z Surface Map



00Z Surface Map



19Z: 34015G28KT
20Z: 33020G27KT
21Z: 33017G25KT
22Z: 32012G22KT
23Z: 33016G24KT

Impacts to ORD, C90 and ZAU

ORD UA /OV ORD/TM 1253/FL036/TP A321/TA -6/IC MOD-SEVERE RIME ICING

ORD UA /OV OBK045020/TM 1952/FL050/TP C750/SK OVC038/TA M08/IC MOD-SEV RIME

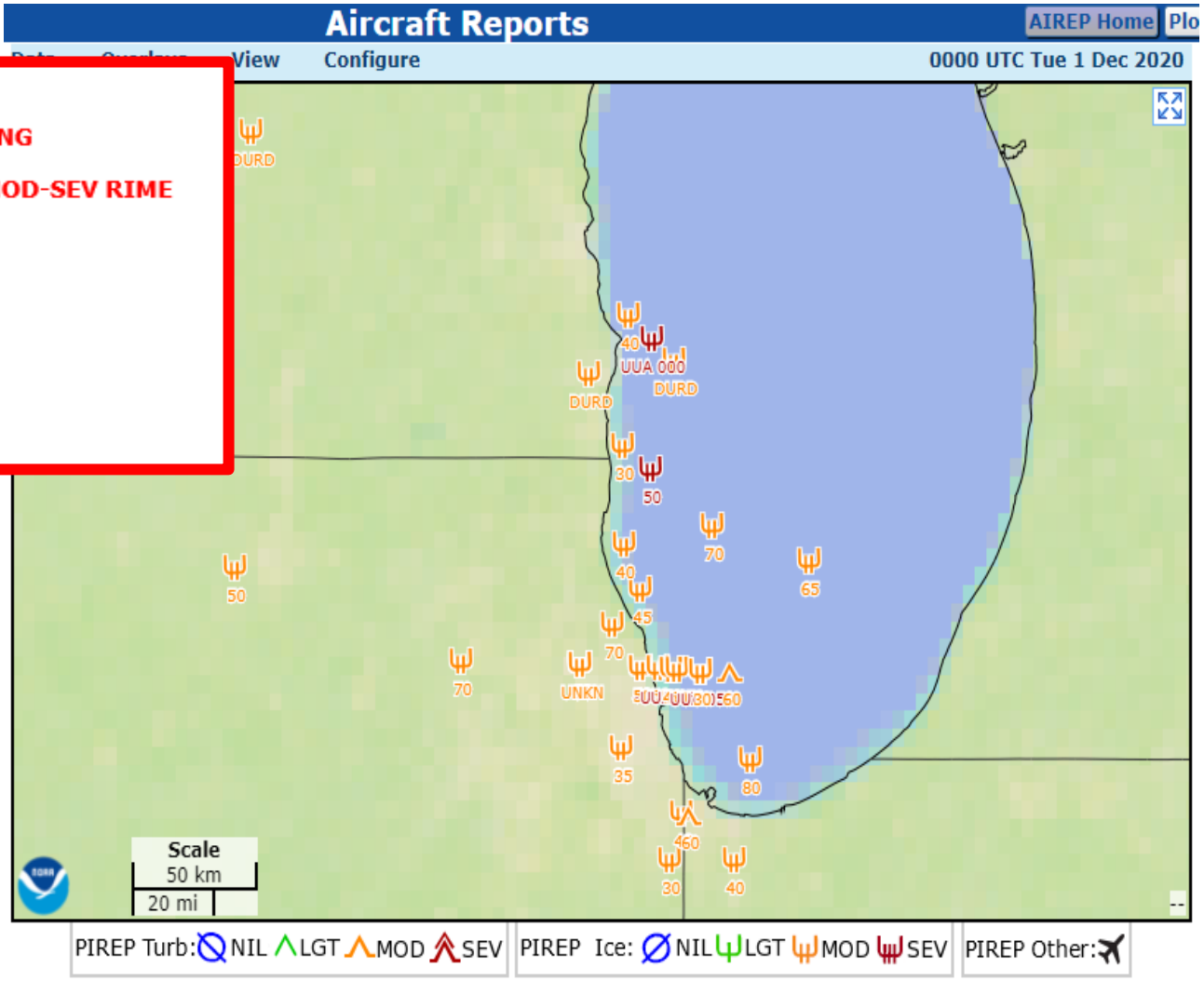
ORD UUA /OV 15 E ORD/TM 2250/FL050/TP B777/TA -10/IC SEVERE

ORD UA /OV 10 E ORD/TM 2252/FL040/TP A319/TA -10/IC MOD-HVY

ORD UA /OV 10E ORD/TM 2252/FL040/TP B772/TA -10/IC MOD TO SVR RM

ORD UUA /OV 20 E ORD/TM 2310/FL050/TP E145/IC SEVERE MIX

- 1253Z - first SEV icing PIREP
- 1305Z - ORD E flow (13Z METAR: 34016G23KT)
- CWA 101 issued for SEV ICG until 1530Z
- 1335Z, 1400Z, 1515Z: CWSU collab w/ AWC-Zulu desk for SEV icing SIGMET 3,000' – 7,000'
- 15Z – ZAU traffic management supervisor indicated ORD to stay on E flow ALAP for icing avoidance
- 17Z – CWSU PIREP solicitation charts updated for MOD-ISOL SEV icing 030-070



Impacts to ORD, C90 and ZAU

ORD UA /OV ORD/TM 1253/FL036/TP A321/TA -6/IC MOD-SEVERE RIME ICING

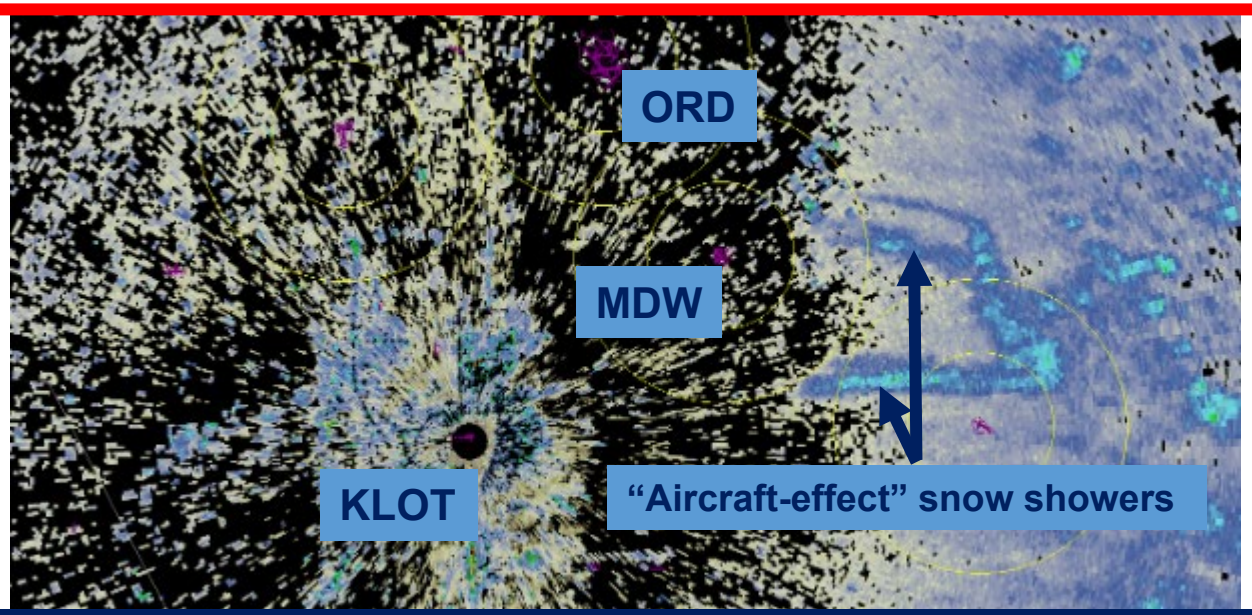
ORD UA /OV OBK045020/TM 1952/FL050/TP C750/SK OVC038/TA M08/IC MOD-SEV RIME

ORD UUA /OV 15 E ORD/TM 2250/FL050/TP B777/TA -10/IC SEVERE

ORD UA /OV 10 E ORD/TM 2252/FL040/TP A319/TA -10/IC MOD-HVY

ORD UA /OV 10E ORD/TM 2252/FL040/TP B772/TA -10/IC MOD TO SVR RM

ORD UUA /OV 20 E ORD/TM 2310/FL050/TP E145/IC SEVERE MIX



- 1835Z – LOT called to AMD ORD for MVFR cigs
- 1925Z – CWSU collab with AWC-Zulu for continuation of SEV icing SIGMET 030-070
- ~20Z – additional SEV icg report w/ update to adjust PIREP charts for ISOL SEV 025-080 based on reported cloud layers
- ~2030Z – C90 intends to go back to West Flow at ORD (33020G27KT) – too much tailwind to stay East
- 2046Z – Departures so far getting MOD icg reports east of ORD
- 21Z TAF update – extend MVFR cigs, adjust winds to 330°
- LiveATC utilized to hear near real-time PIREPs of additional SEV icing
- Winds forced C90 to maintain West Flow
- C90 mitigated icing risk by adjusting arrivals to quickly descend through cloud layer (no SEV, only MOD reports thereafter)

Impacts to United Airlines

Images and quotes courtesy of Mike Fox at UAL





“Despite the heavy Lake Effect snow remaining just east of ORD, 15-hour pitched battle with moderate and at times heavy RIME ice.”

Impacts to United Airlines - Deicing



“Average 145 – 160 gallon usage per aircraft between two and four times gallon levels generally experienced with RIME.”



“Impacted all aircraft types and surfaces from 1 to 1½ inches thick, nearly tripling removal times.”

Images and quotes courtesy of Mike Fox at UAL

Takeaways

- PIREPs!
  - Key observations for en route environment, but they are subjective
  - Their frequency may be dependent on air traffic
  - Often a delay from occurrence to reporting (sometimes as long as 10-15 min)
    - Use new/alternative tools, like LiveATC broadcast for real-time obs
  - Not always consistent (HVY vs SEV, many without severity/type qualifiers)

- Icing severity dependent on:
  - Depth and temperature of saturated layer (liquid or mixed phase)
    - Size of supercooled water droplets key to accretion
  - <u>For this case, duration of aircraft in the icing layer</u>
    - Spatial awareness - know how the airspace is designed and operates

- Forecast collaboration between CWSU, WFO and AWC as important as communicating the risks to the FAA

- Both ceiling and wind forecasts are crucial even when seeming trivial (few KT or 10°)

Low Level Stratus

SEVERE ICING

January 2023

By Shari Mutchler

A couple case studies of severe icing reported 30 November, 2020 near Chicago, then again near Buffalo 9 January 2023.

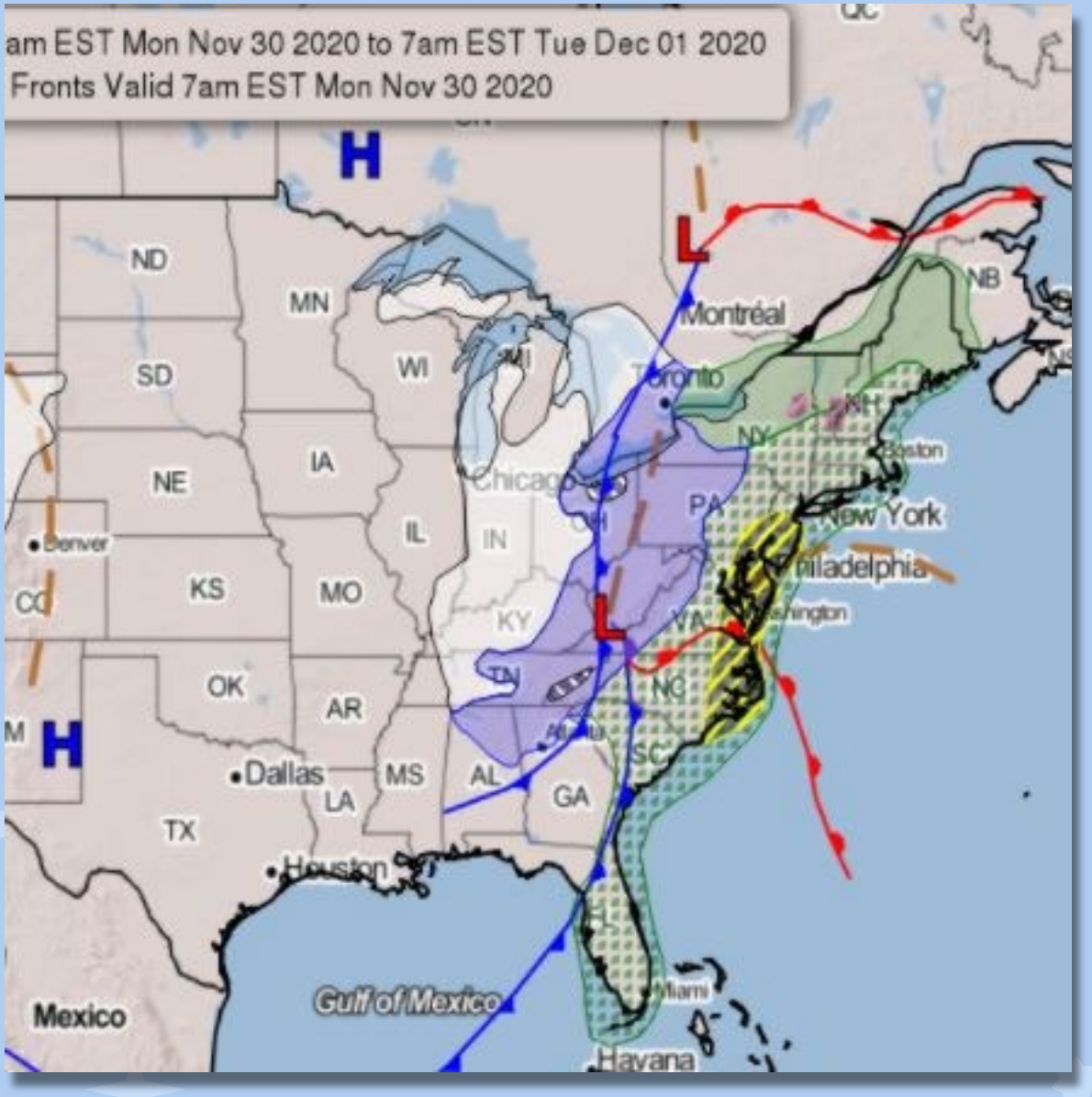
This is a very brief presentation to show a scenario in which low level stratus in the vicinity of Lake Michigan and Lake Erie made for severe icing conditions.

It is unusual to get severe icing reports, especially from larger aircraft out of a stratus layer.

The Weather scenario...

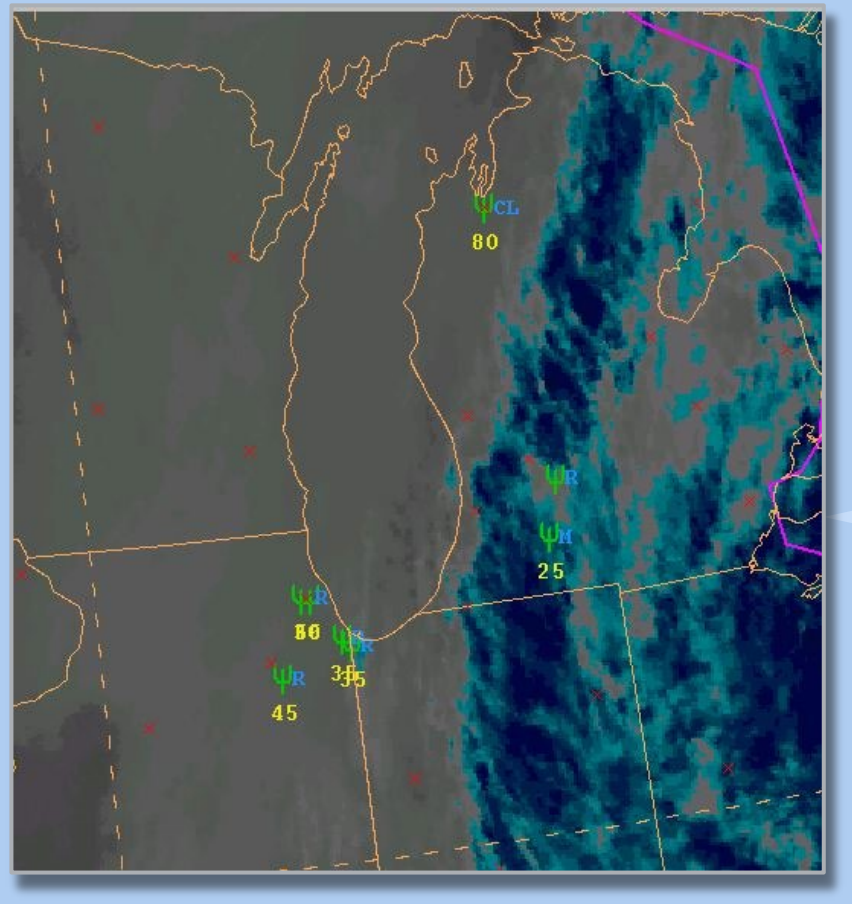
Elongated system moving northeastward towards eastern US with a variety of multiple freeze levels throughout.

Radar indicated low pressure center near southeast OH at the time a report of moderate to severe icing came in from an A320 near Chicago.

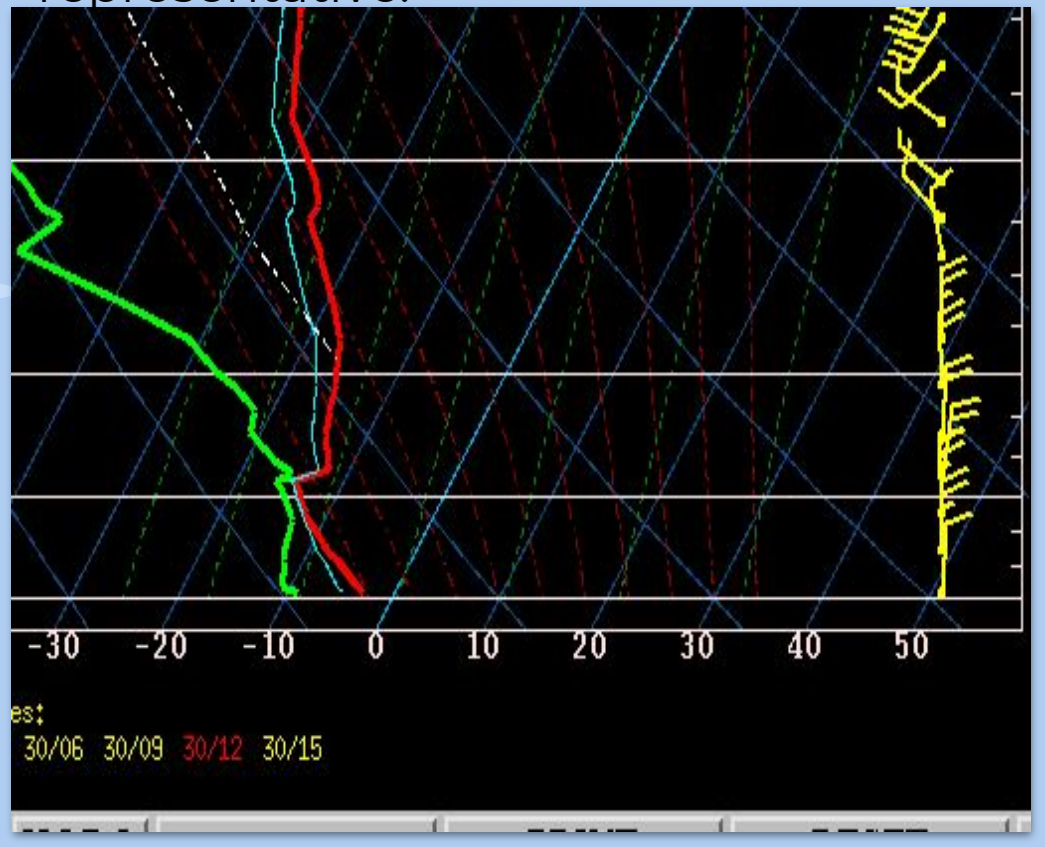


MOD-SEV icing was reported by an A320 aircraft around 7 AM CST Near Chicago.

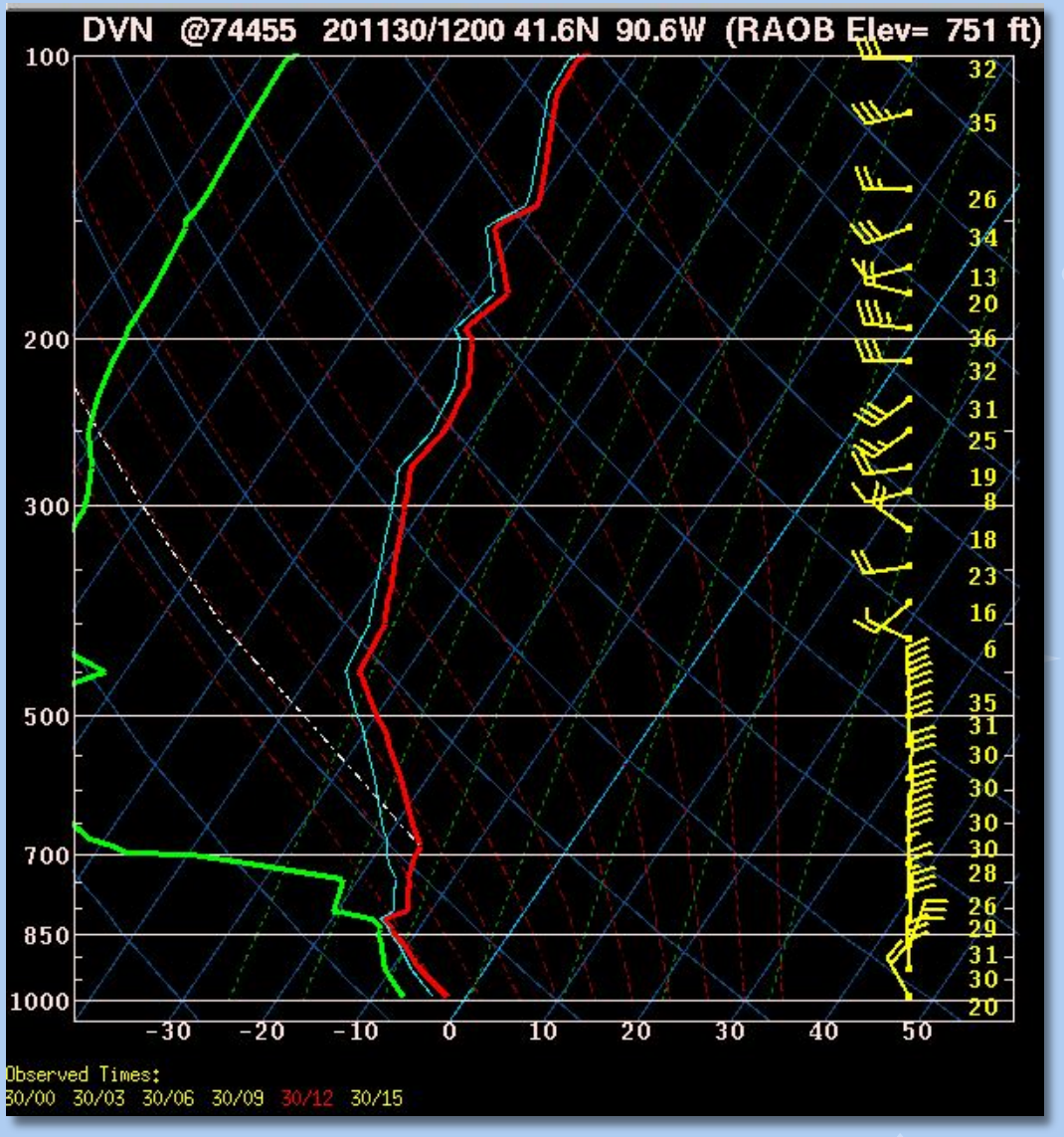
Mainly low level stratus layer was prevalent throughout Lake Michigan, WI and IL regions in the wake of an exiting weather system. The sigmet covered the route used by aircraft for take-off and landing at O’ Hare.



Even though the Green Bay sounding was “upwind” of the icing area, the Davenport sounding seemed to be more representative.



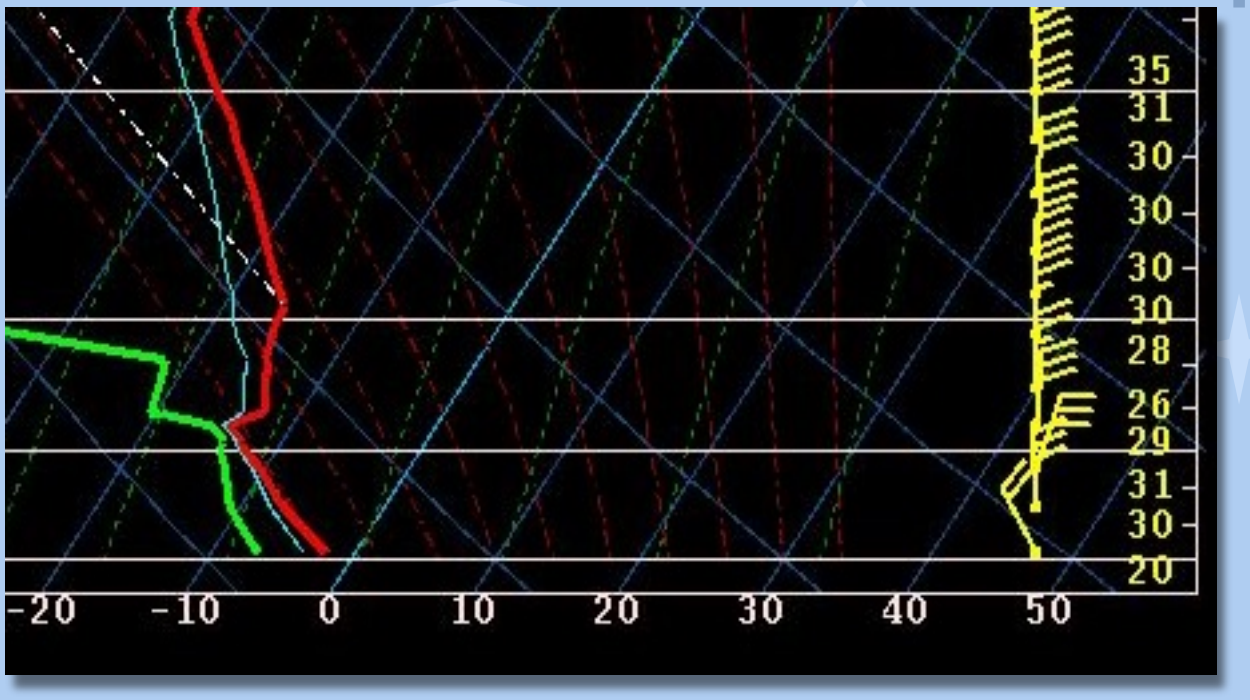
12Z Green Bay Sounding 11/30

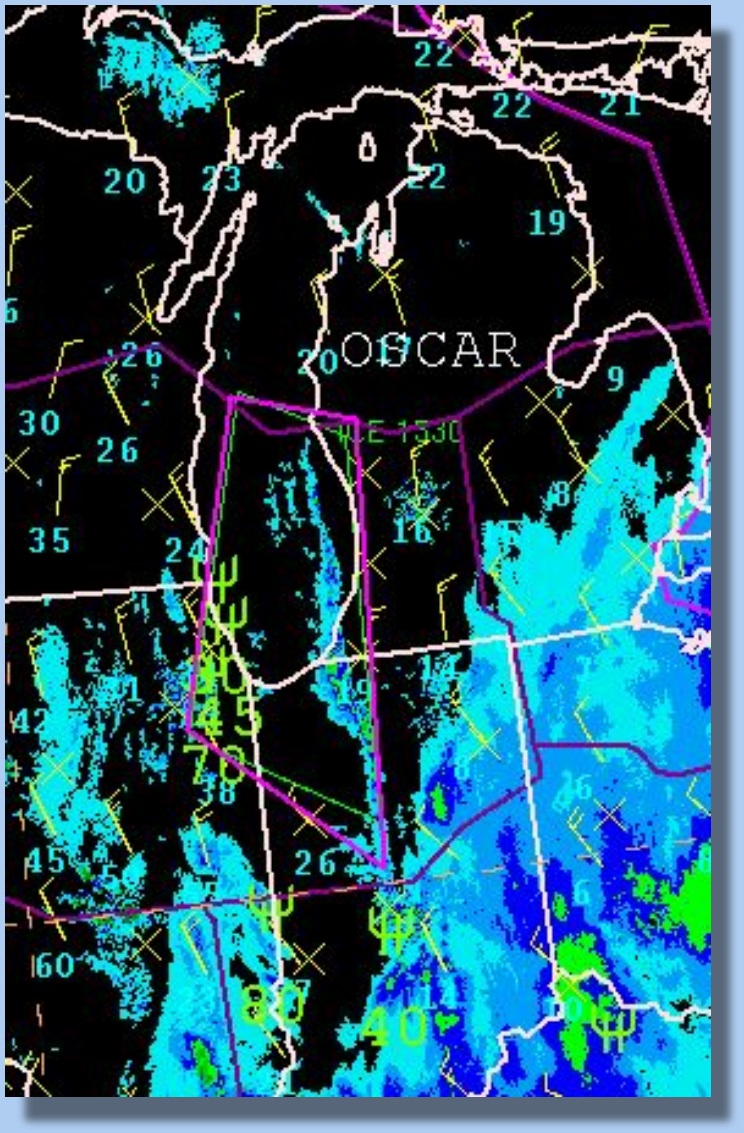


12Z Davenport Sounding 11/30

The DVN sounding shows the stratus layer in the low levels. Also to note that temperature is below freezing, with temperatures between 0C and -12C.
Winds from the north through the area created a long “fetch” over Lake Michigan leading to Chicago area. This contributed to the icing by adding more moisture to the lower levels.
The lapse rate below 850mb was steep as well, contributing to lift.

Close up of DVN sounding





Radar image showing “fetch” over Lake Michigan

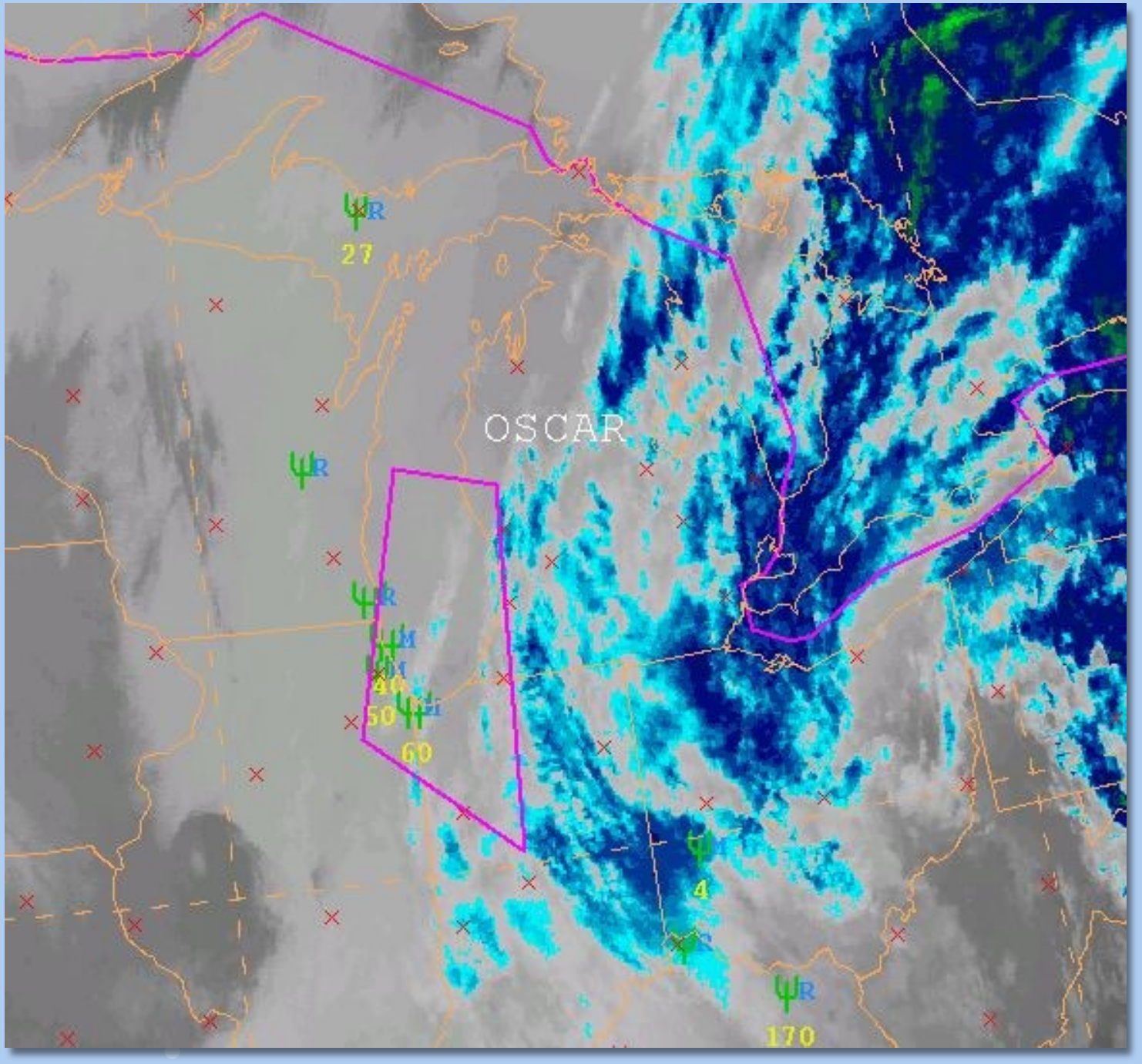
BREF Radar overlaid with wind and icing PIREPS show how moisture was transported from Lake Michigan onto shore. North wind provided the long fetch of air towards the Chicago region. Note the convective “rolls” parallel to the Michigan shore

Sigmet Oscar was issued for levels between 070 and 030 based on coordination with CWSU ZAU.

CWSU ZAU carried a CWA for the area for the first couple hours, after which we decided to run sigmet OSCAR.

It is unusual to get reports of severe icing from stratus clouds, unless aircraft are flying in the stratus for an extended period of time, such as during landing.

The A320 aircraft uses a “bleed air” system to keep the leading edge of the wings free from ice. A “bleed air” system routes hot air from the engines through small tubes through the wings, tail and engine inlets.

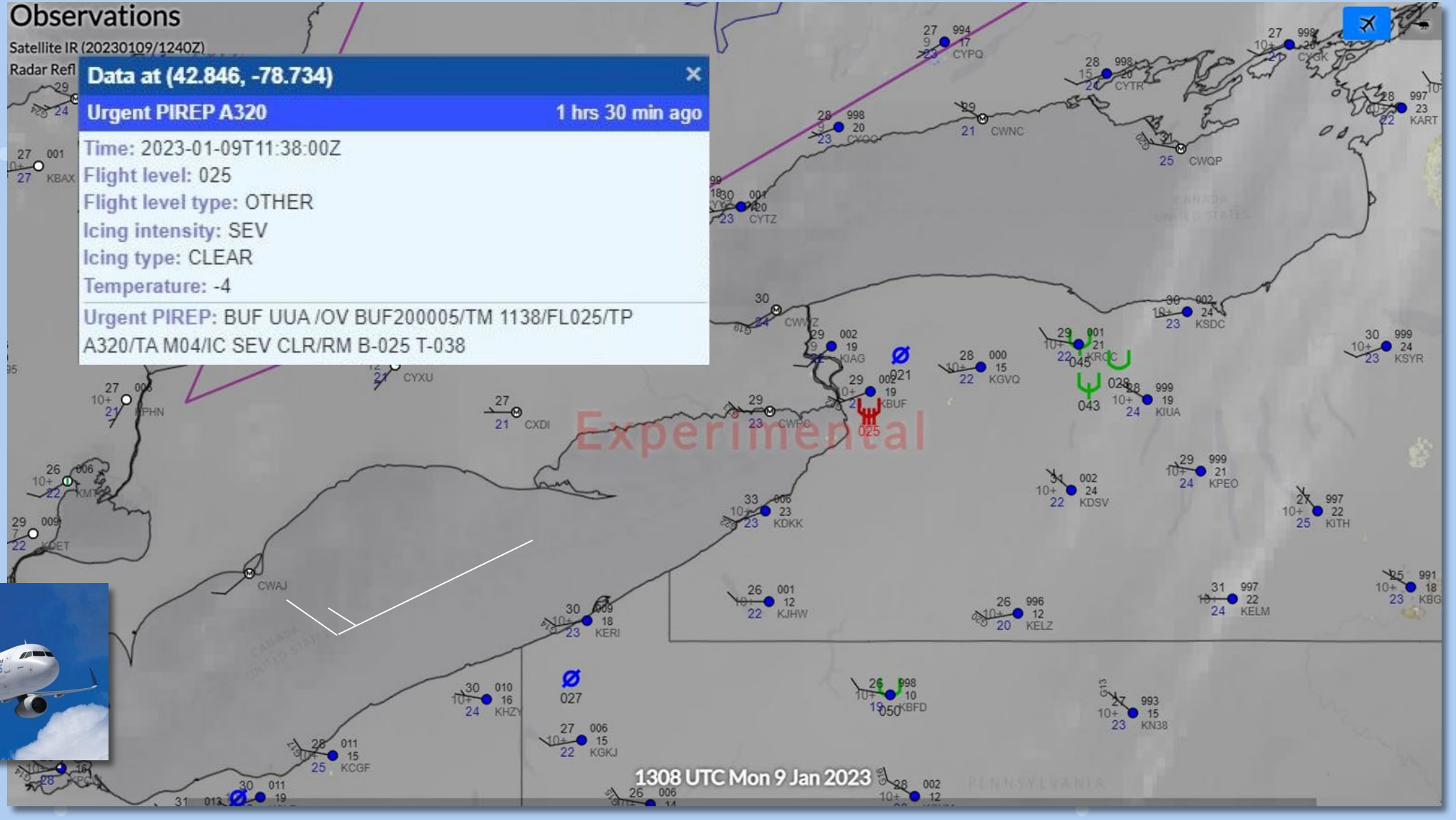


IR Satellite image shows extent of low clouds West of system exiting to the east.

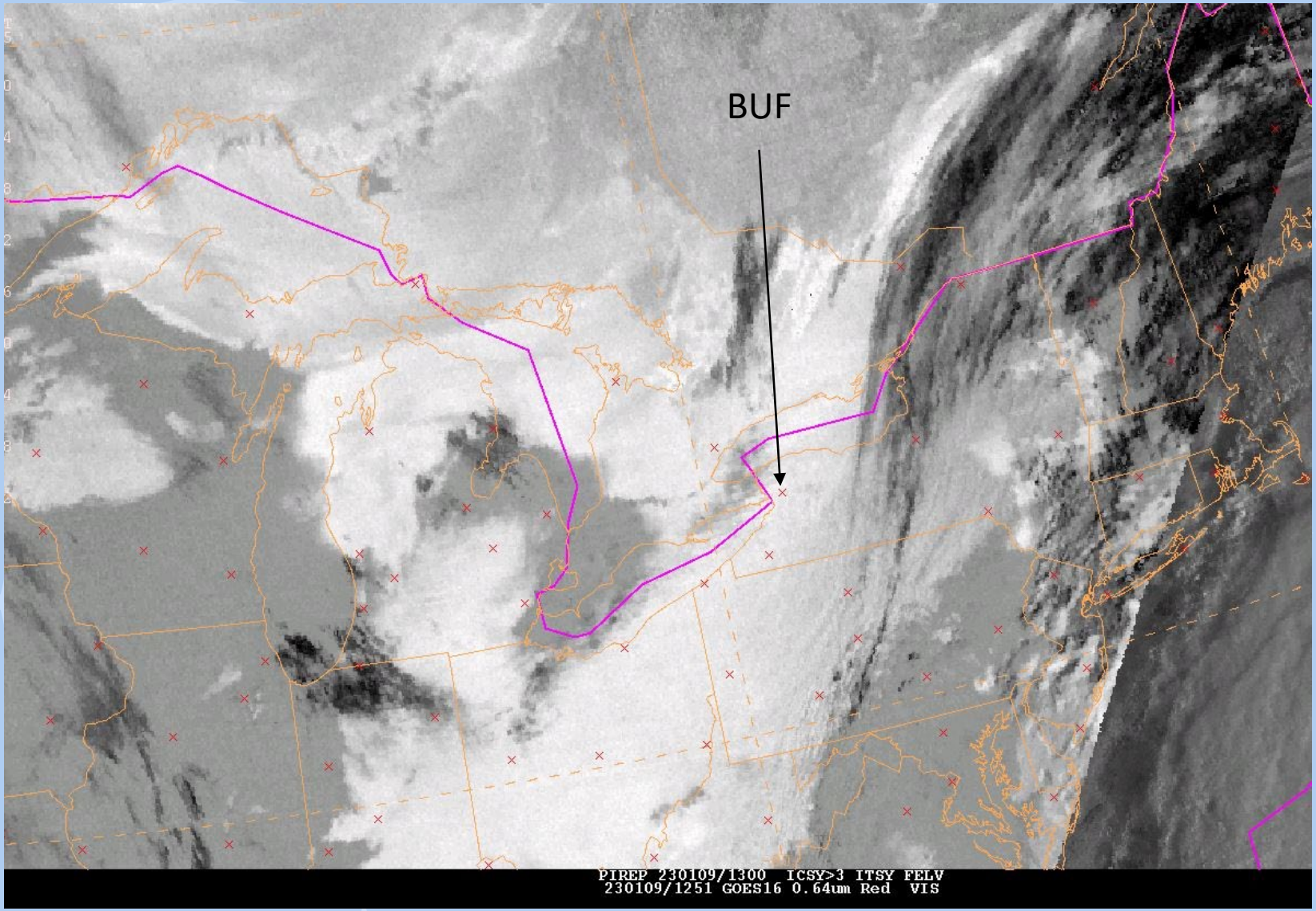
A similar case from 9 January 2023 near Buffalo, NY, an A320 reported severe clear icing.

Note that the wind direction is parallel to Lake Erie, producing a long “fetch” over the water leading up to Buffalo, NY

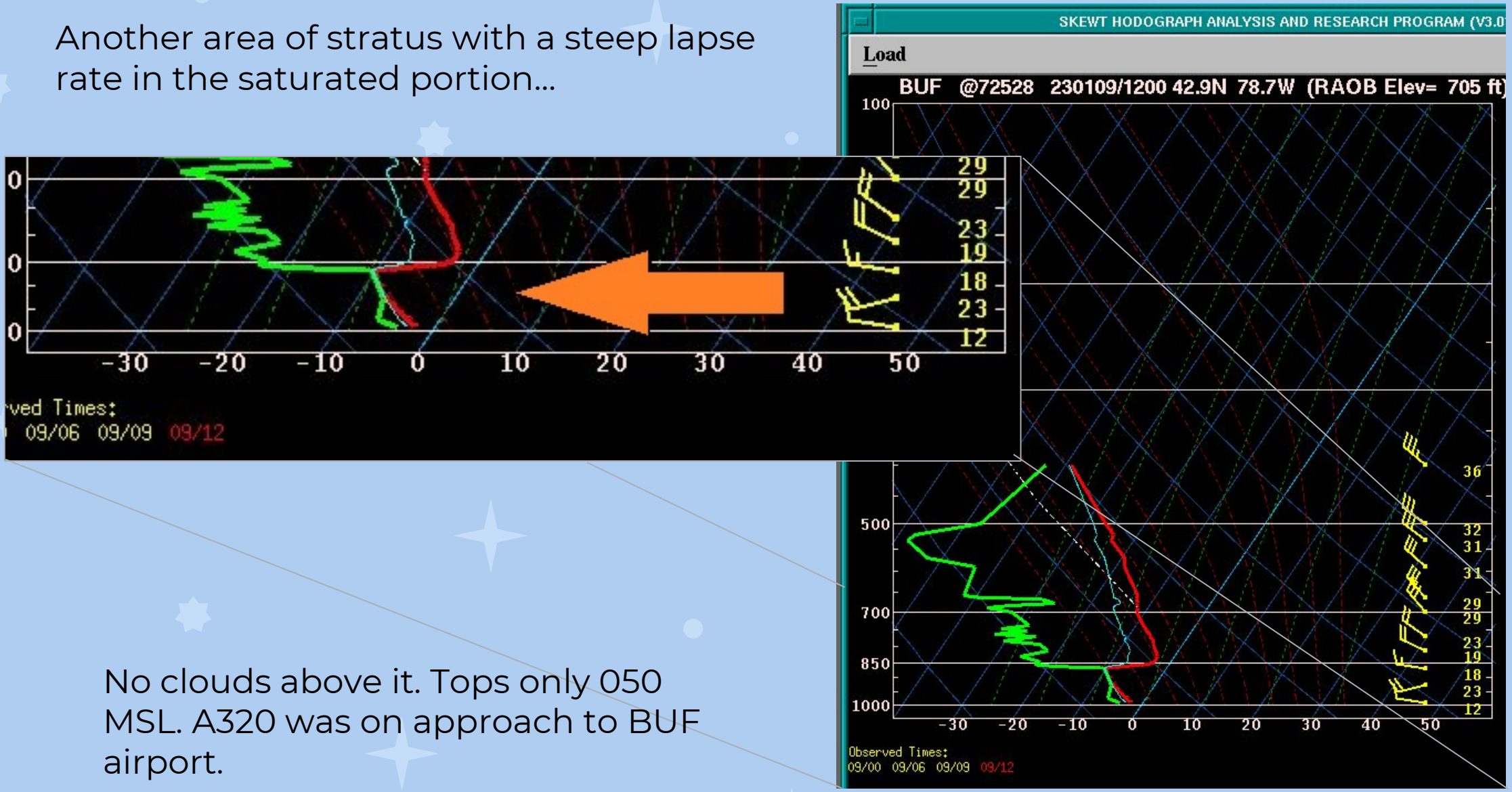




Satellite imagery showed an expansive area of stratus that extended from the northern Great Lakes region through the OH River Valley and into New England, but only Buffalo produced a severe icing report.
This stratus was on the western edge of an exiting low pressure system, similar to previous case.

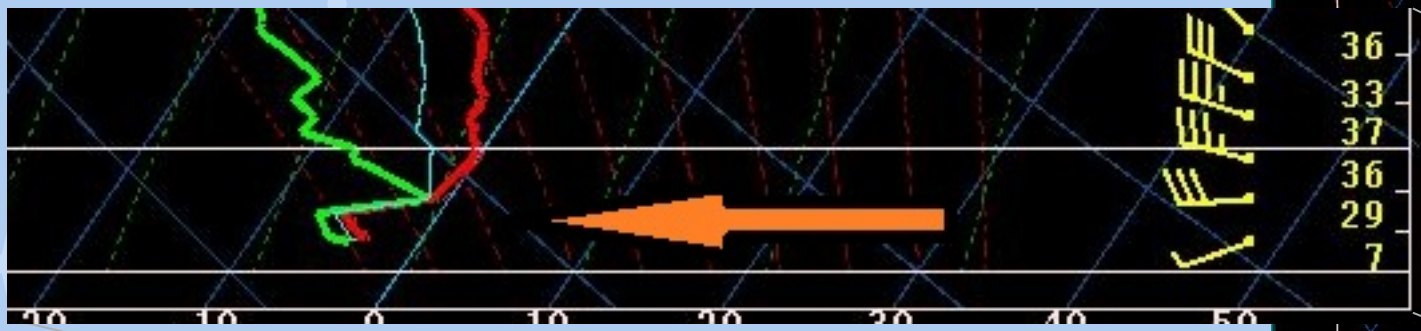


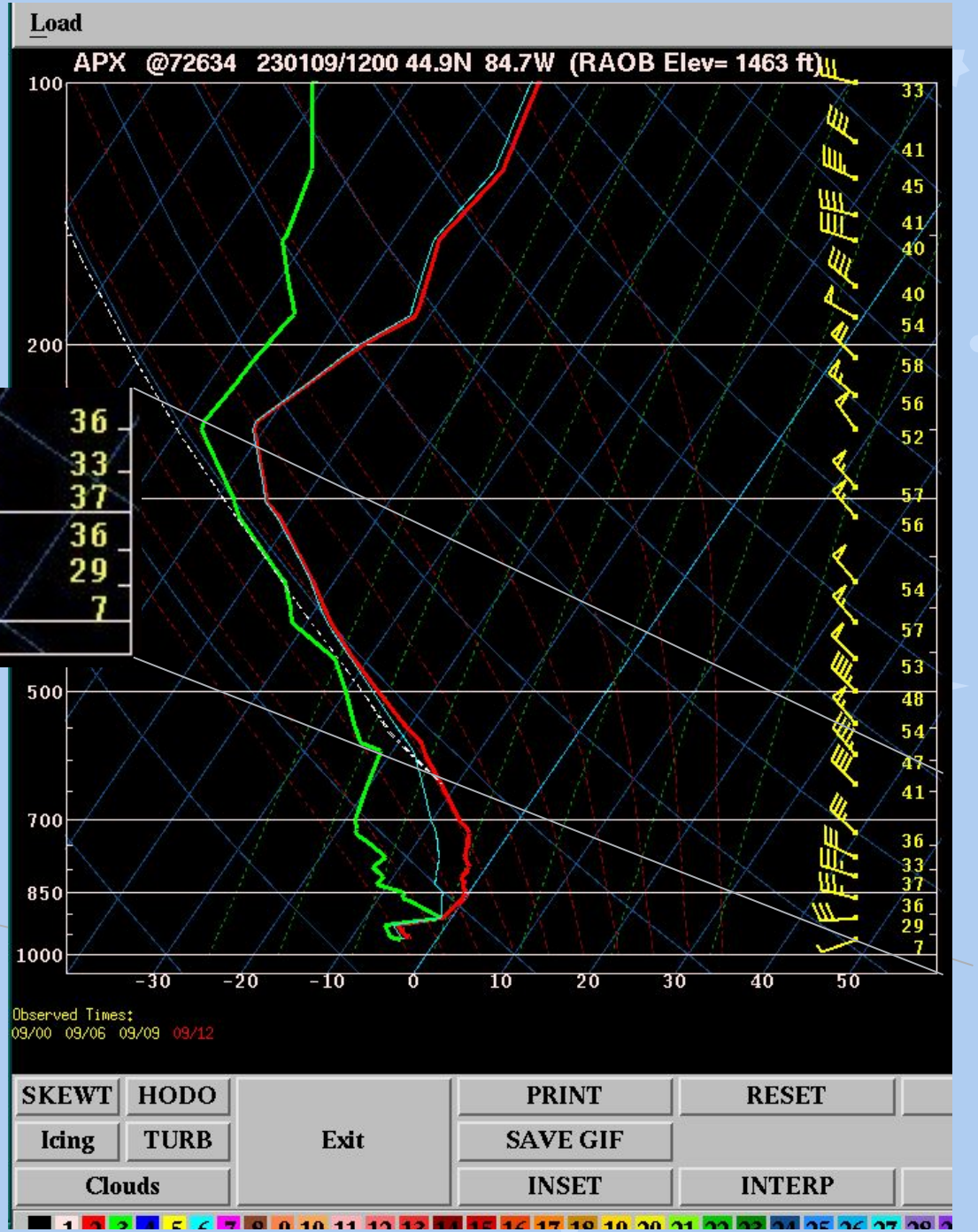
Another area of stratus with a steep lapse rate in the saturated portion…



No clouds above it. Tops only 050 MSL. A320 was on approach to BUF airport.

Compared to the Alpena, MI sounding, which was stable, and didn't produce anything other than reports of light ice.





The wind at Alpena Michigan was also off-shore (from the West,) not on-shore.

No sigmet was created for the Buffalo scenario since other aircraft reported no ice or just light ice. The report ended up being isolated.

“Fast aircraft with thin wing cross-sections are more susceptible to deteriorating aerodynamics, and hence are more susceptible to ice accretion.” WMO.(link)

OVERVIEW: **There were several great dynamics for this severe turbulence event:**

- A strong 980mb low pressure system moved just across Montana/Canadian border with cold front from the low pressure system moving through the western Montana and central Idaho before entering the Tetons towards Nov 5th, 2022 by 18Z. The winds prefrontal were strong westerly thru MT-ID-WY and tight postfrontal pressure gradient .

- The RAP 2000ft AGL winds showed strong westerly cross-barrier flow across the Tetons, Big Horn and Rocky mountains.

- The RAP 300mb winds showed the Right-front exit quadrant region jet-core over Tetons by Nov 5th, 2022 at 18Z through Nov 6th, 2022 at 00Z.

- The NAM cross-sections showed a vertically propagating wave punching through the Tropopause near 250mb.

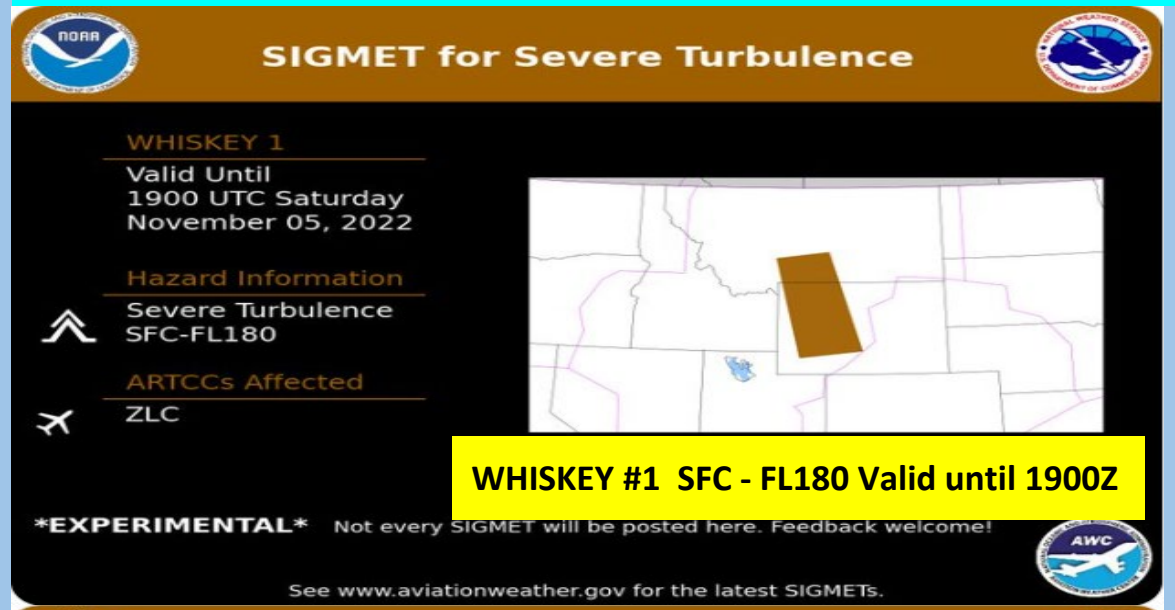
- The 700 to 500mb Lapse Rates values 5.5 C/km or less coincided in aiding in development of the vertically propagating couplets. There were severe mtn wave pilot reports over the Big Belt mountain in MT where the lapse rates were near 6.0 C/km.

- WRF showed a breaking mountain wave developed near Dubois, WY in time-frame from 11/05/12Z - 11/05/18Z.

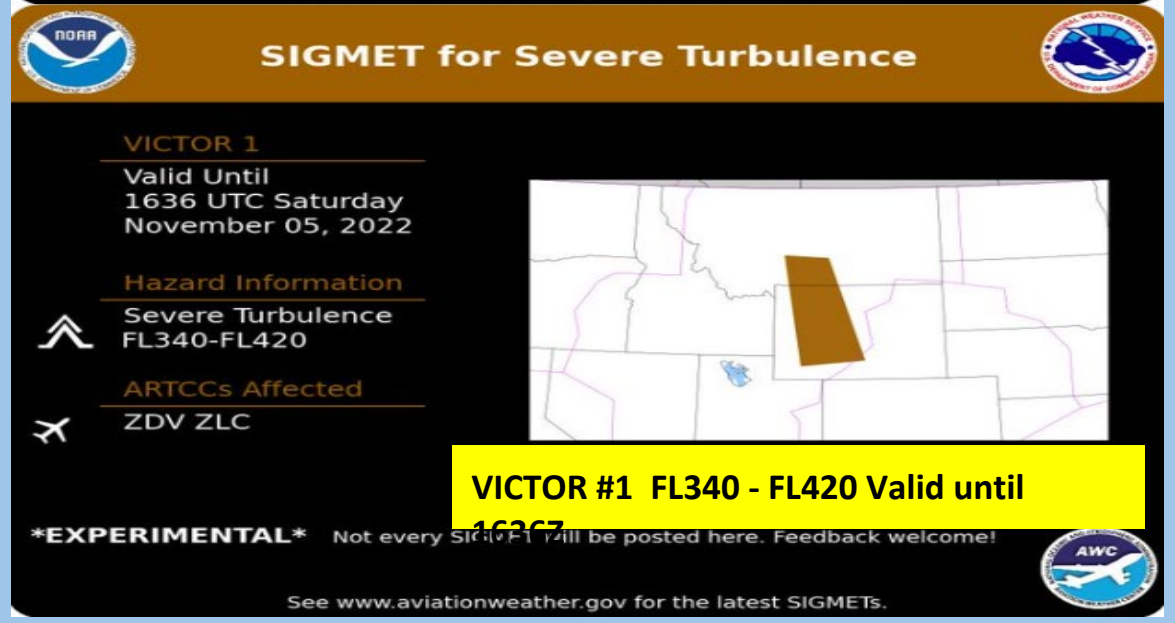
- The combination of these multiple indices and vertical shear, and strong RAPGTG Mtn wave composites resulted in SIGMETs for occasional severe turbulence below FL180 and between FL340 - FL420.

Nov 5-6th, 2022 Severe Mountain Wave Turbulence Event through Tetons & Big Horn & Northern Rockies

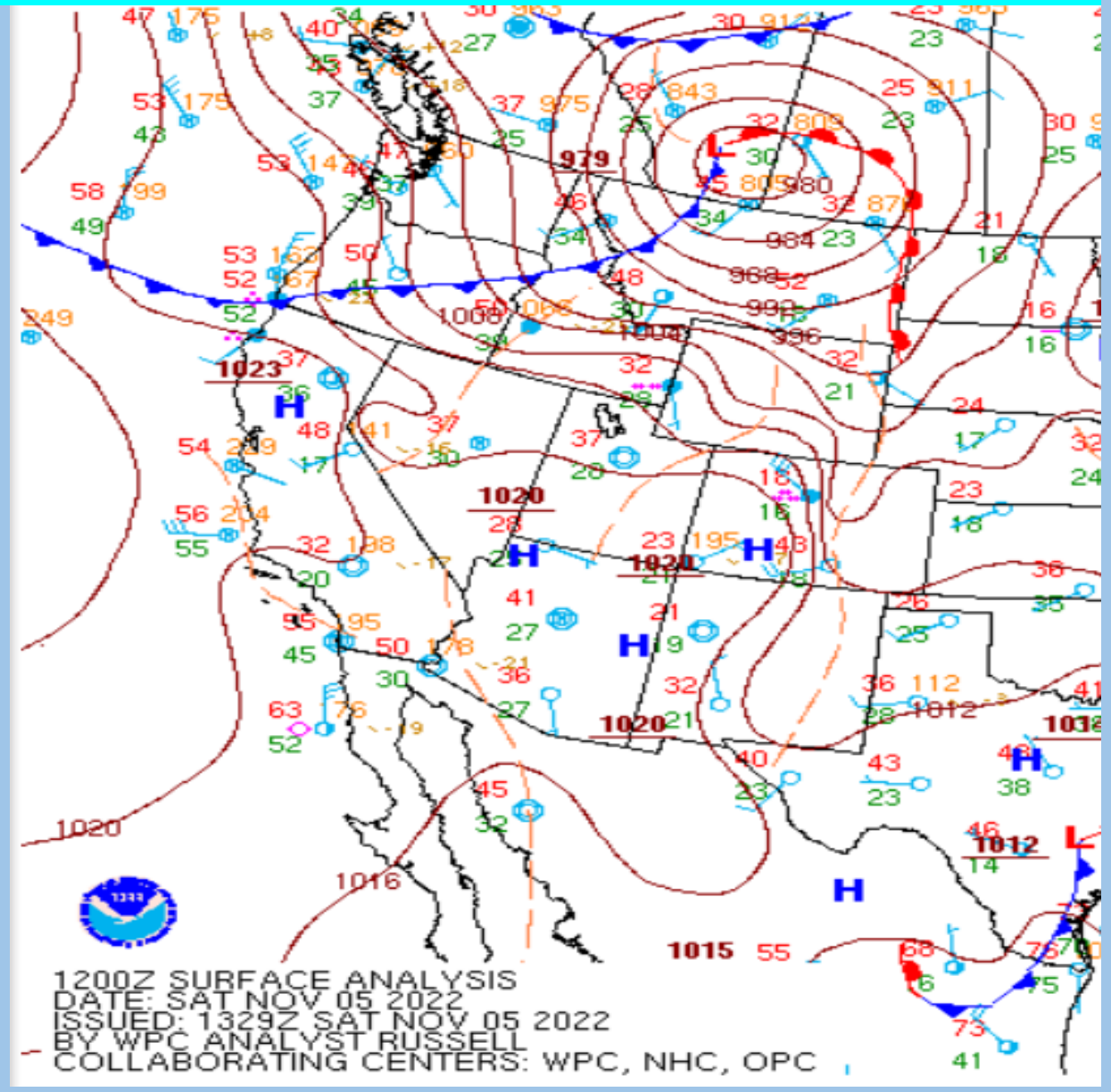
by Perry Dehne, Ryan Connelly & Emily Niebuhr



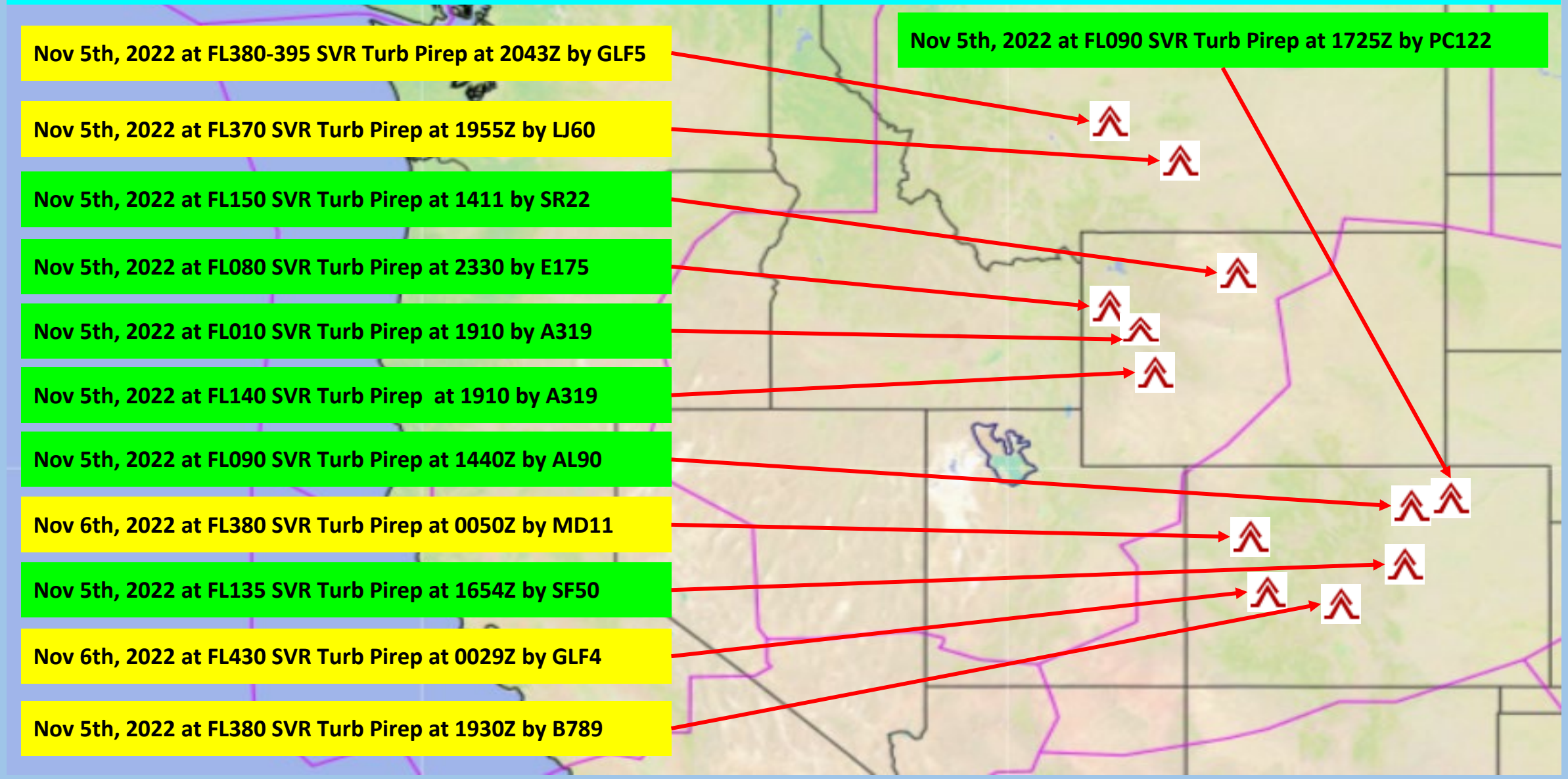
WHISKEY #1 SFC - FL180 Valid until 1900Z



VICTOR #1 FL340 - FL420 Valid until 1636Z



NOV 5th - 6th, 2022 SEVERE TURBULENCE PIREPS THROUGH THE TETONS AND THE ROCKY MOUNTAINS



MOUNTAIN WAVE INDUCED TURBULENCE DECISION TREE

Do you have perpendicular cross-barrier flow with surface wind speeds 35kts or greater? Do you have ridge top wind speeds 50kts or greater?

YES, keep going

NO, not likely

Does Satellite show Foehn gap or subsidence & any severe turbulence pilot reports?

YES, keep going

NO, not likely

Is there an inversion near the mountain tops?

(This allows for vertical propagating couplet to develop in stable region)

YES, keep going

NO, not likely

Do you have a sharp or tight strong updraft/downdraft couplet?

YES, keep going

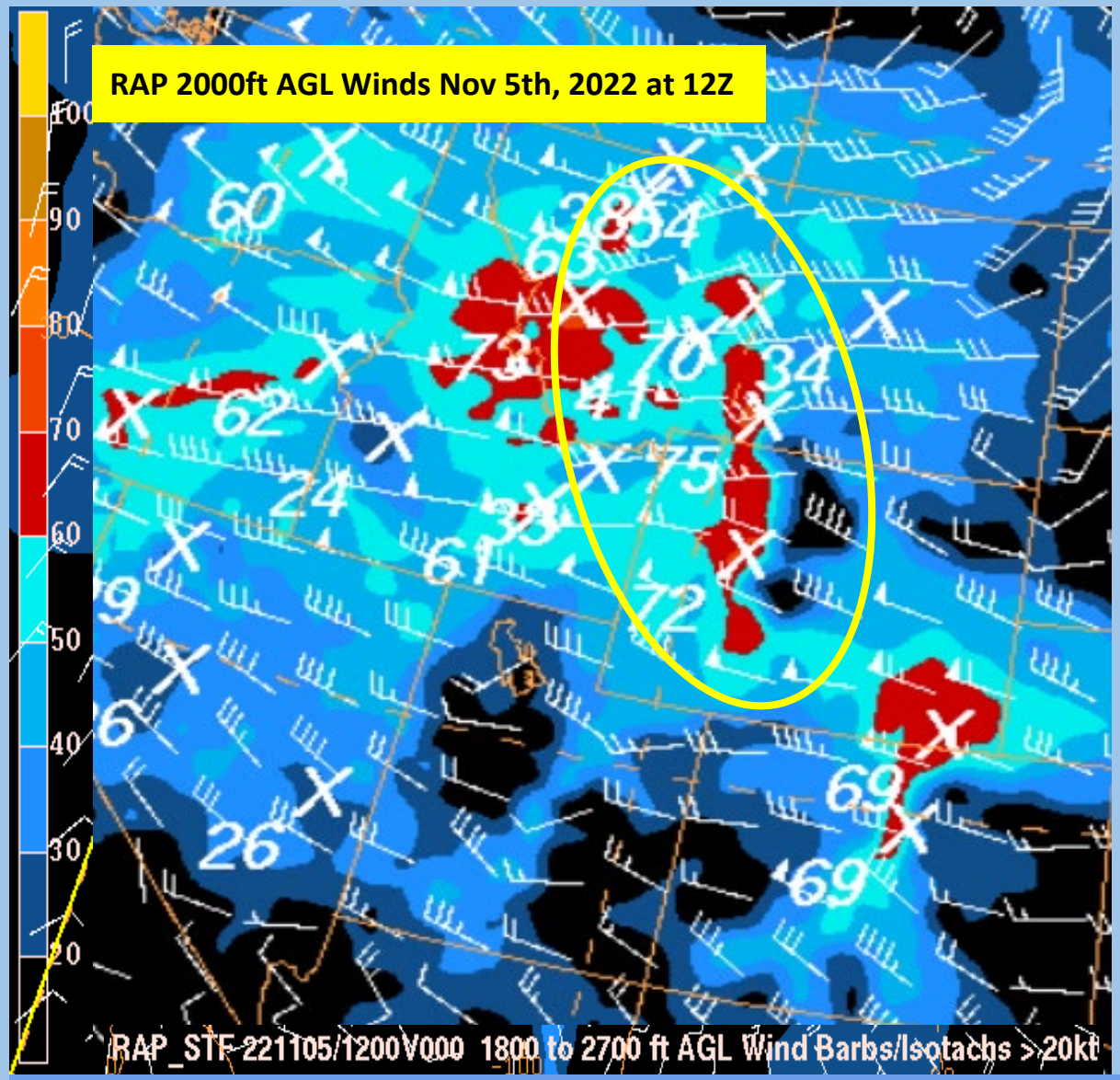
NO, monitor

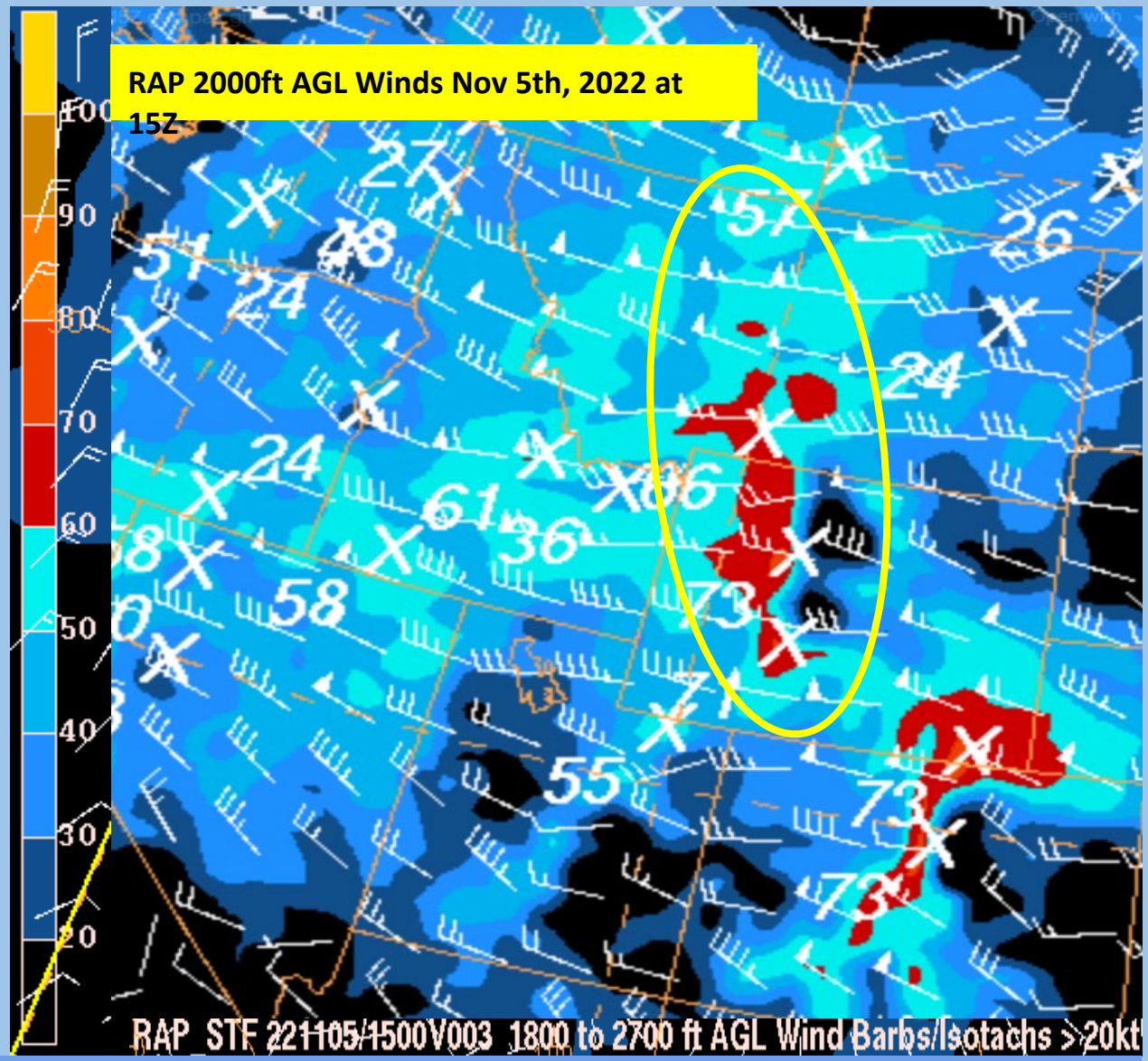
Does the strong vertical propagating motion or couplet punch through the tropopause?

YES, keep going

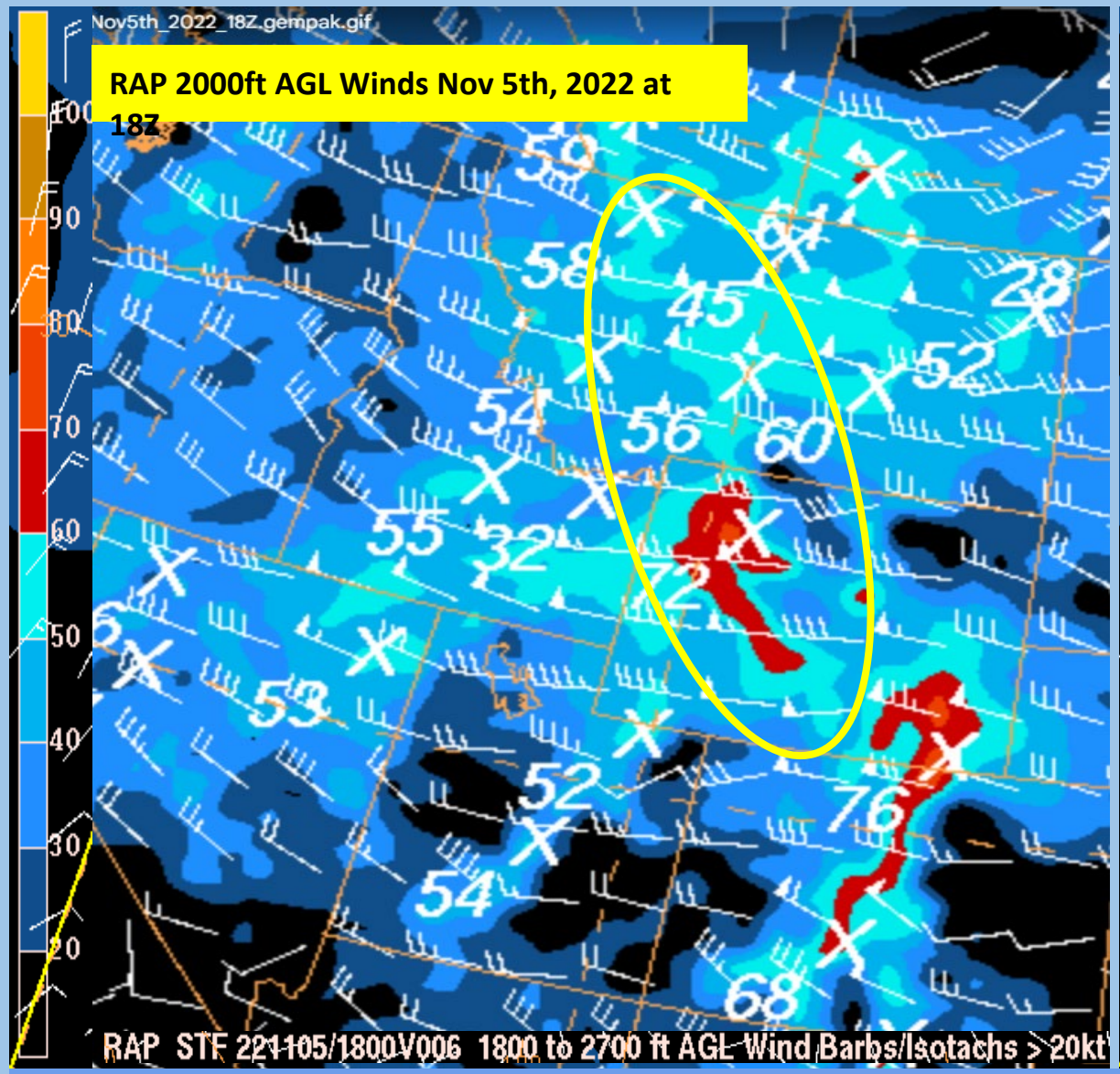
NO, monitor

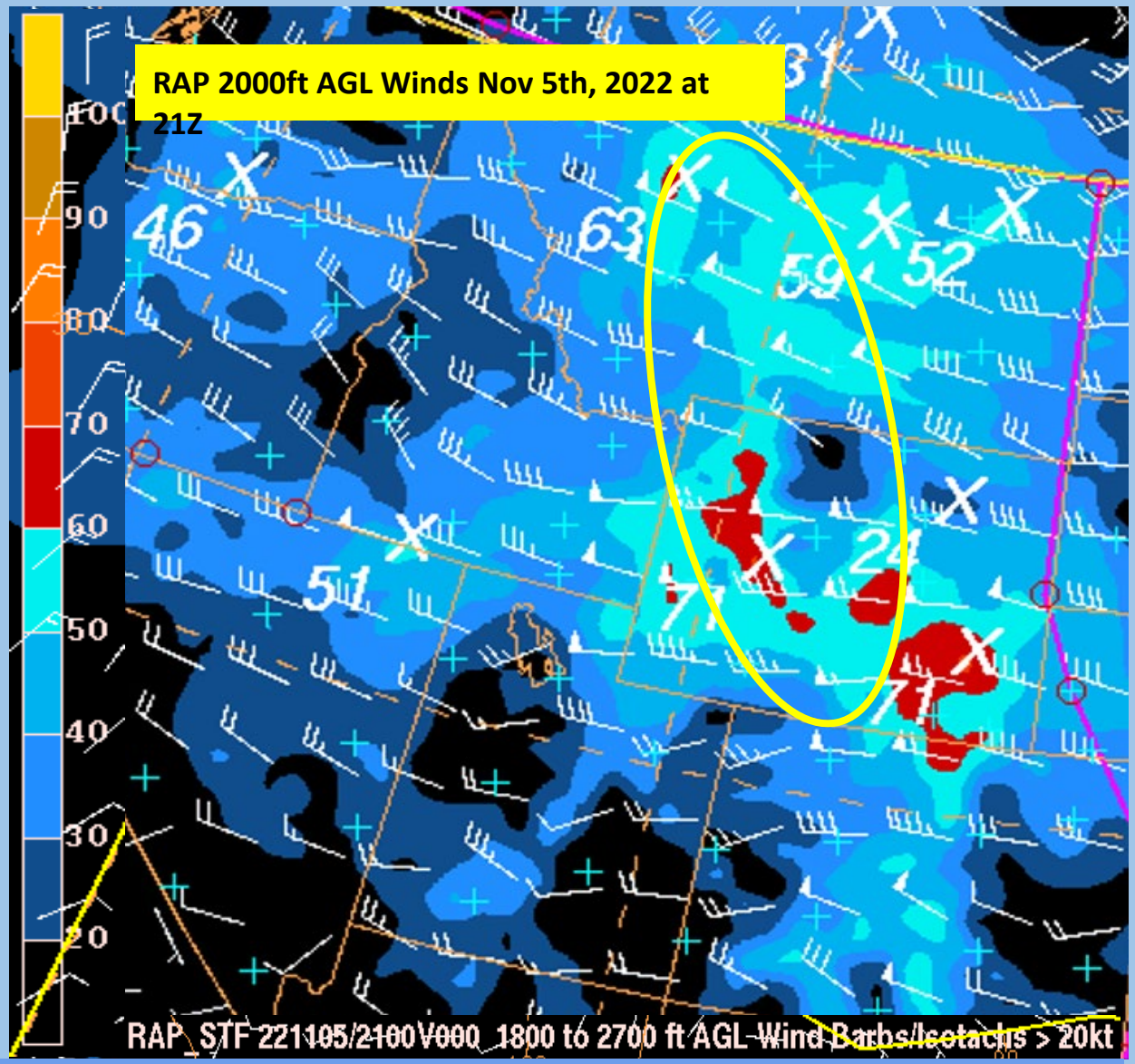
Issue the Low and/or High Severe Turbulence SIGMET



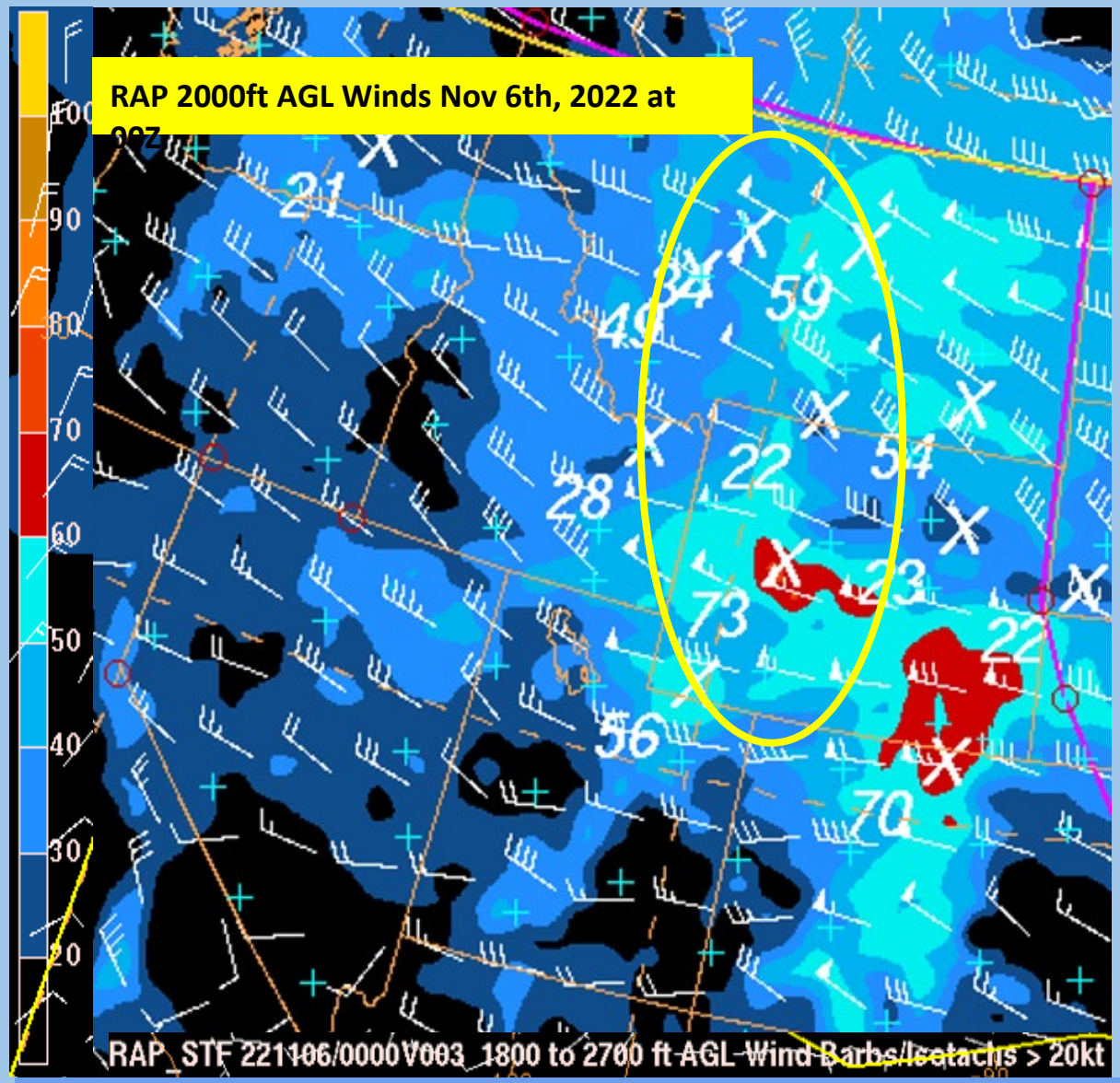


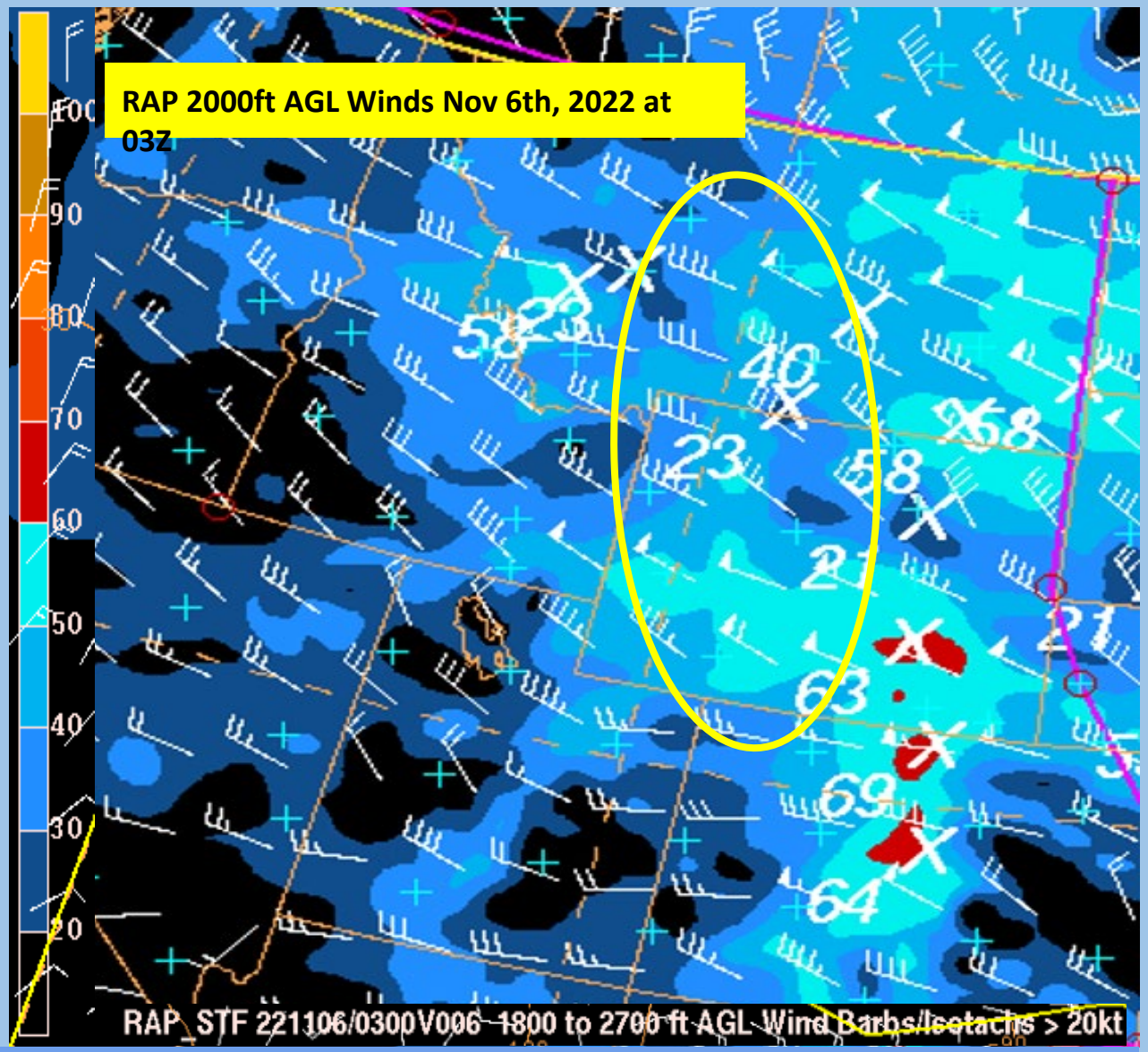
The RAP 2000 ft AGL winds in the yellow ovals were showing strong westerly cross barrier flow at 55-75 kts from 11/05/12Z - 11/05/15Z through the Tetons, Big Horn, Lewis Range and the Big Belt mountains.



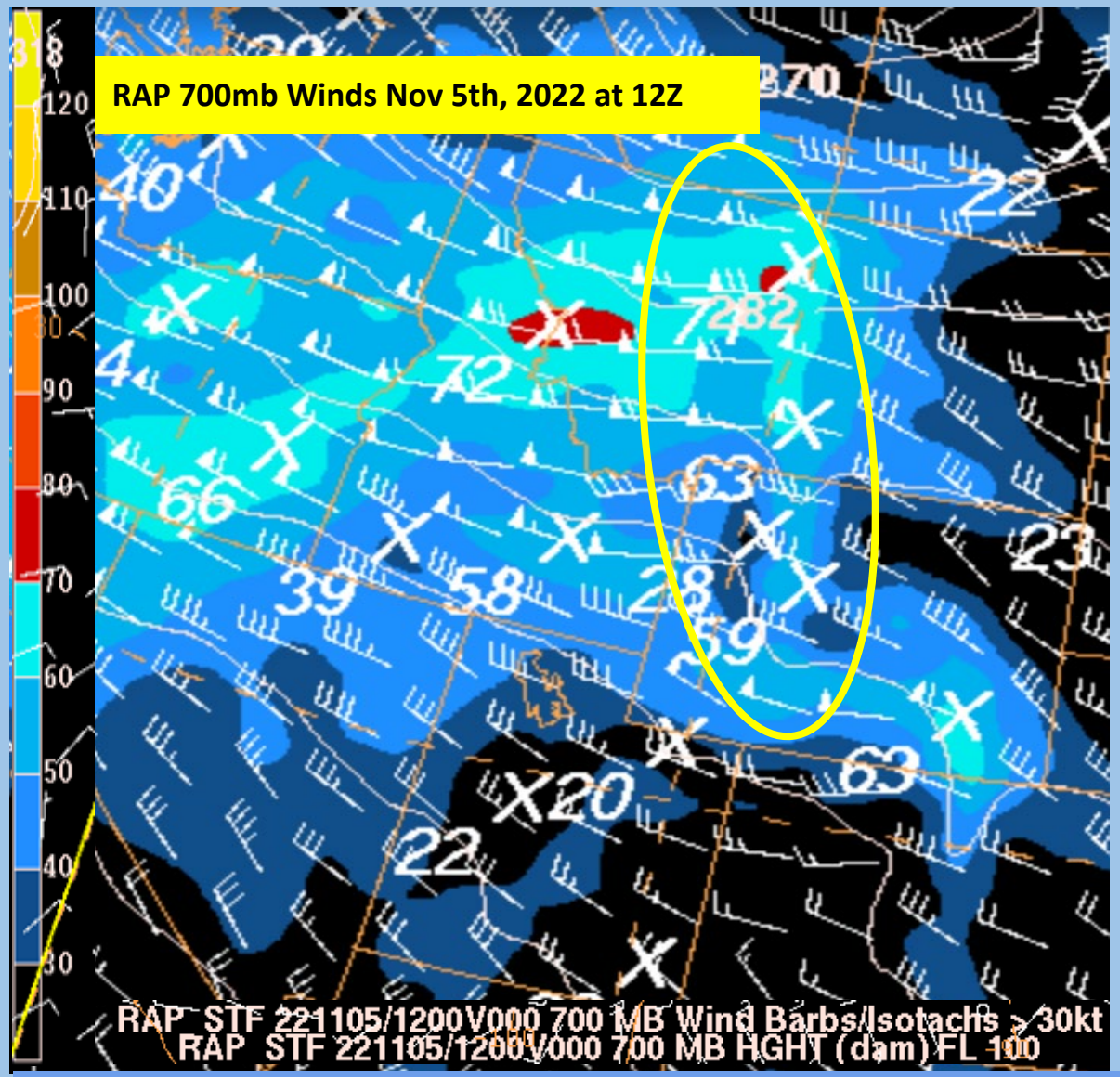


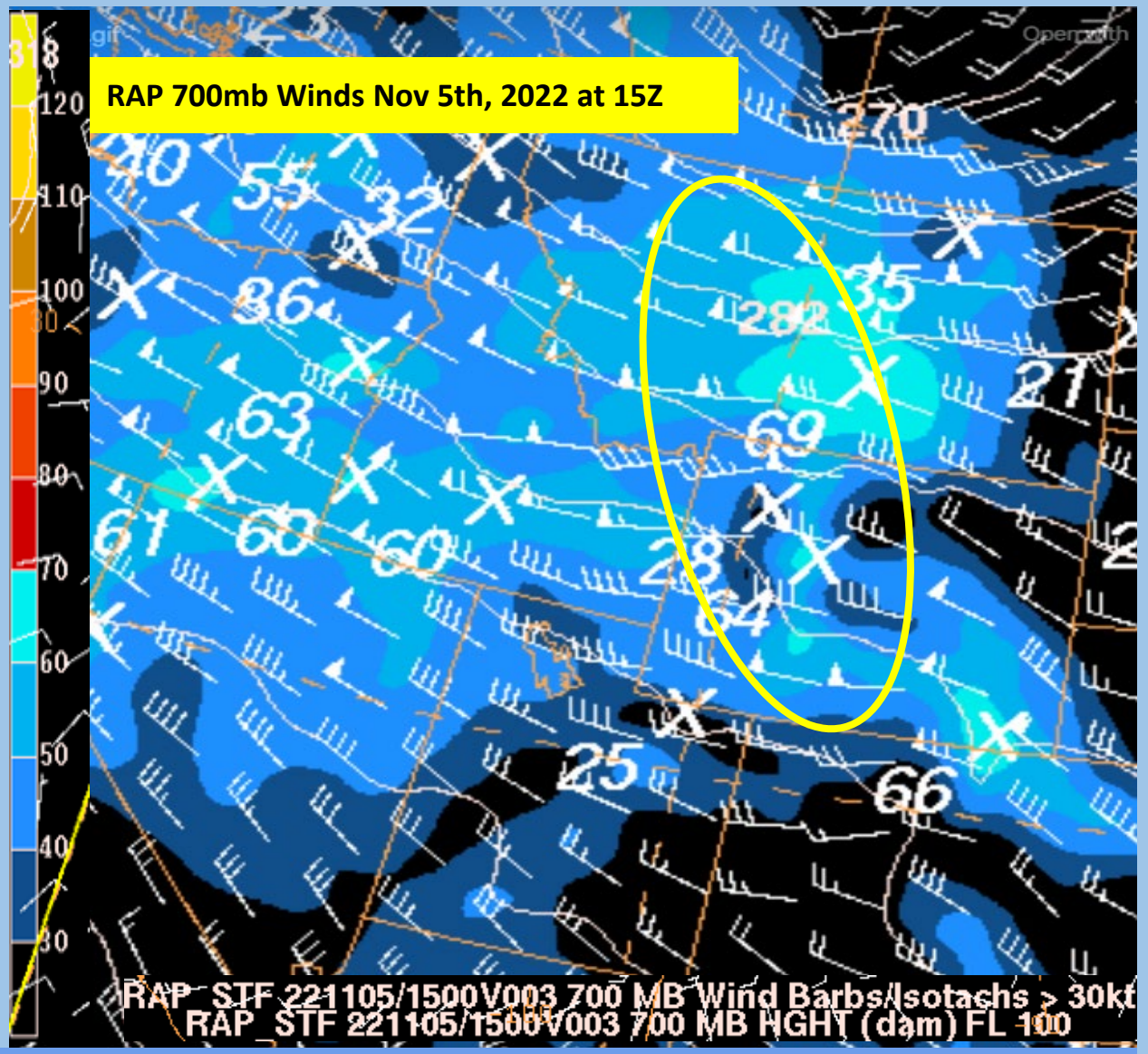
The RAP 2000 ft AGL winds in the yellow ovals remained very strong with westerly cross barrier flow at 55-75 kts through the Tetons, Big Horn, Lewis Range and the Big Belt mountains through 11/05/21Z.



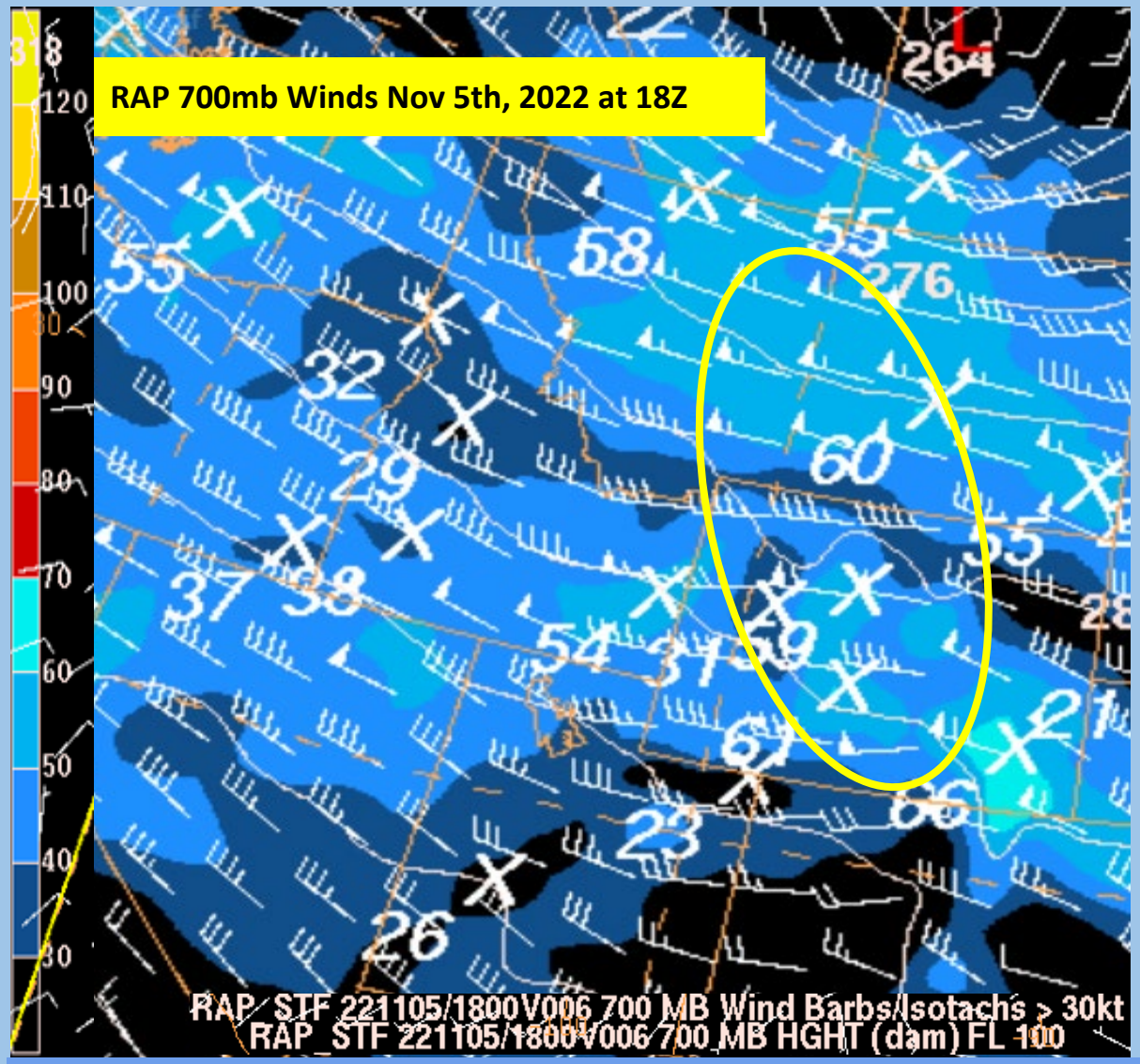


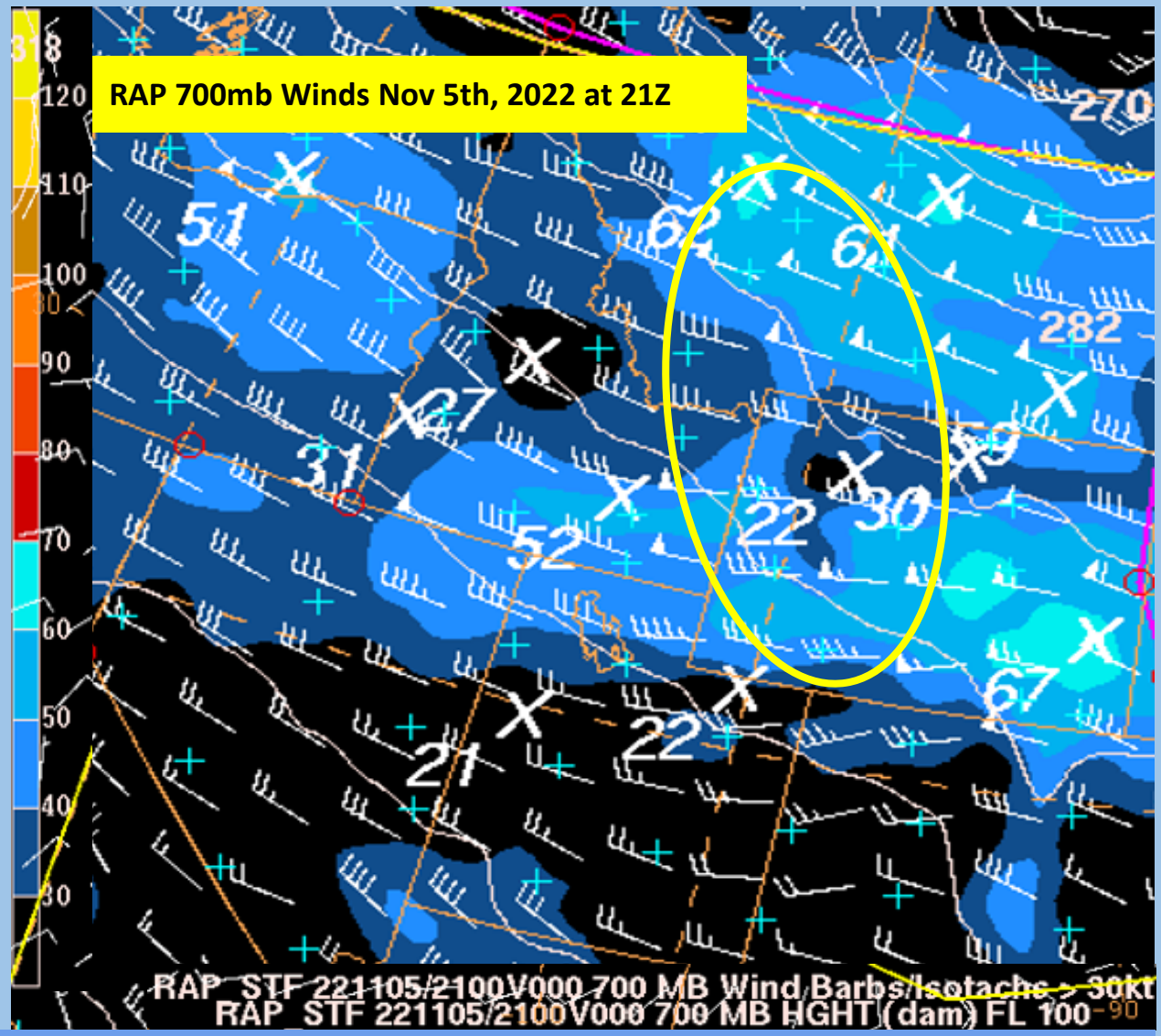
The RAP 2000 ft AGL winds in the yellow ovals continued with strong westerly cross barrier flow at 55-75 kts through the Tetons, Big Horn, Lewis Range and the Big Belt mountains through 11/06/00Z before beginning weakening by 11/06/03Z.



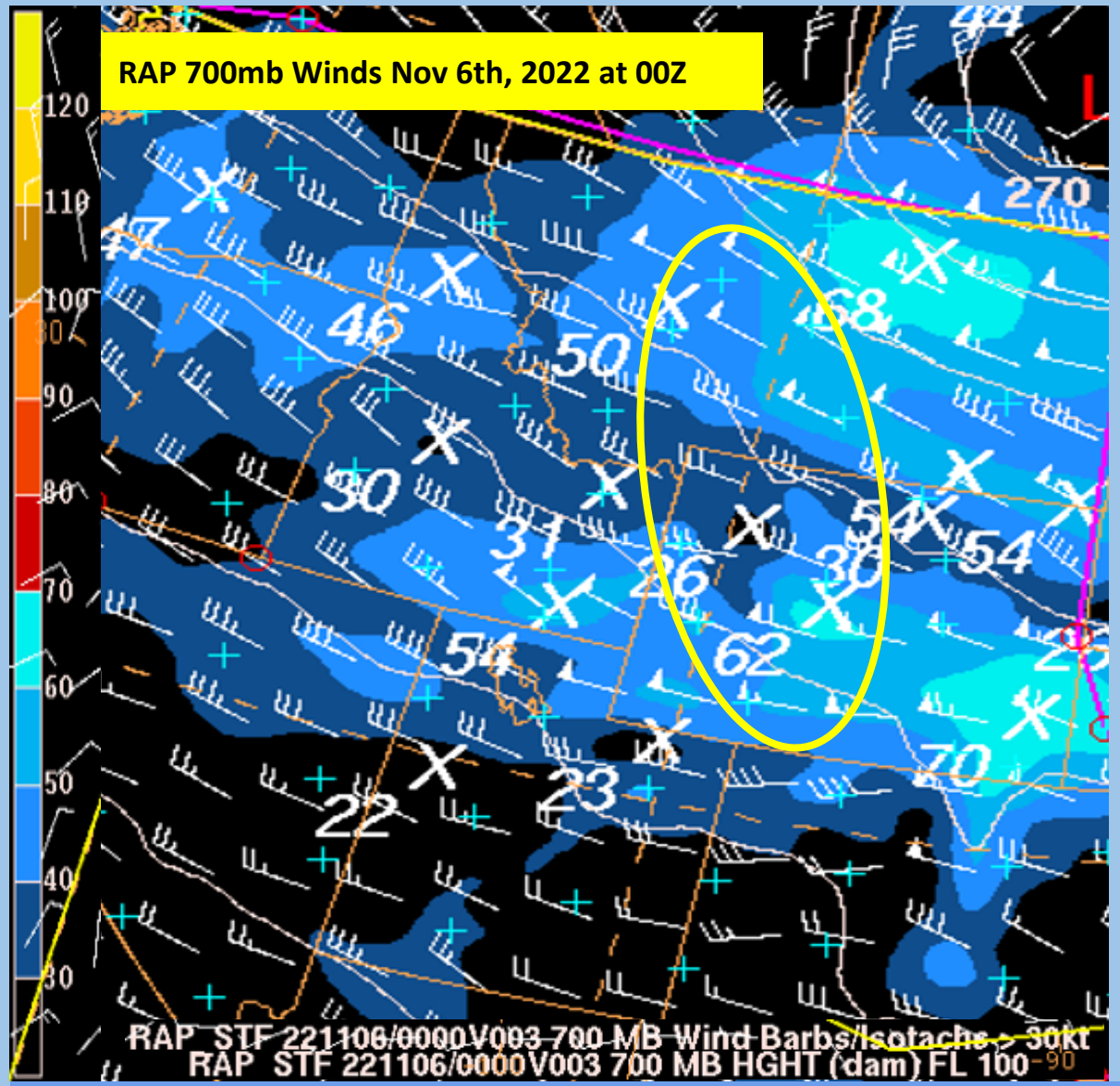


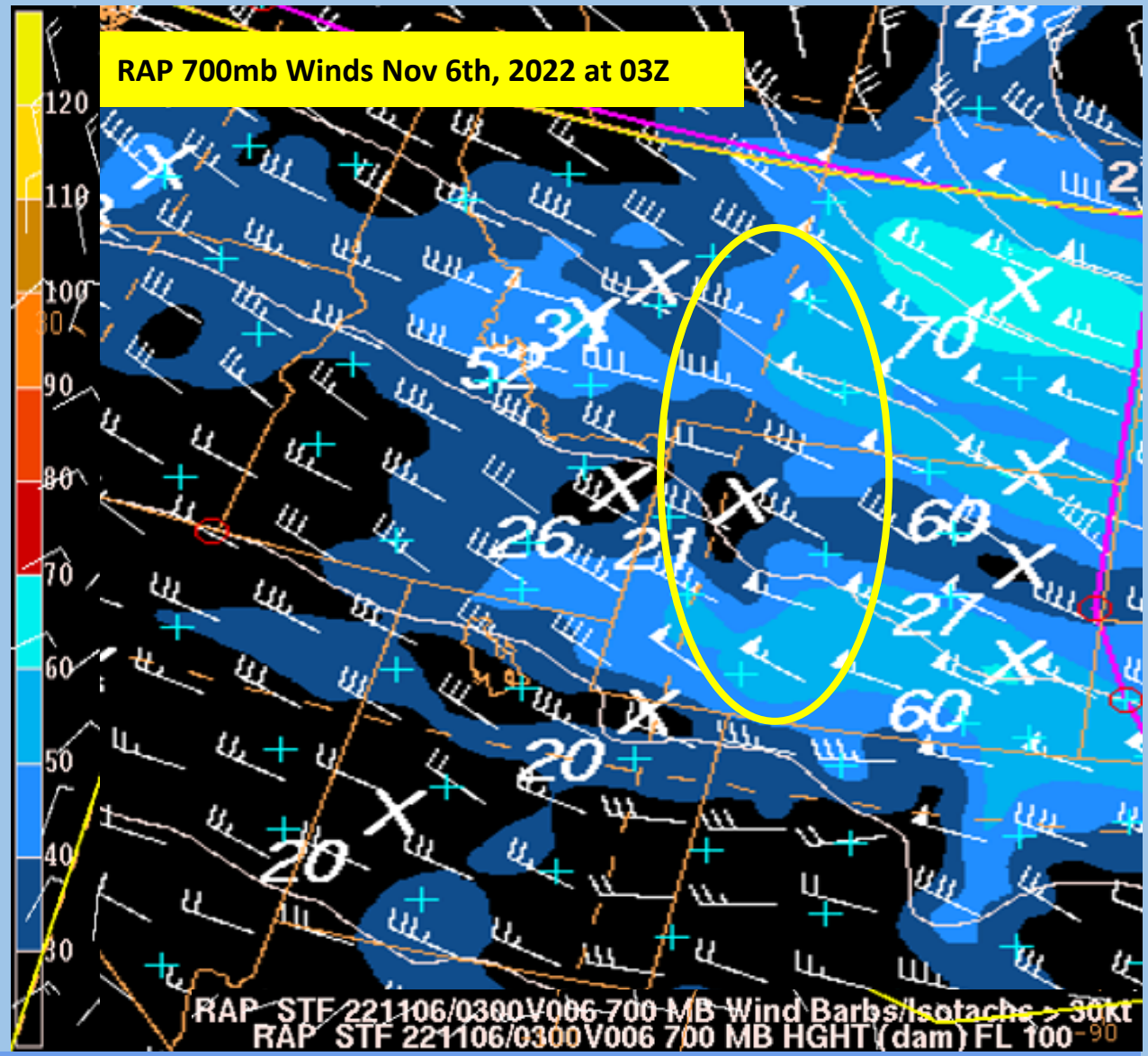
The RAP 700mb winds in the yellow ovals were showing strong westerly cross barrier flow at 60-70 kts from 11/05/12Z - 11/05/15Z through the Tetons, Big Horn, Lewis Range and the Big Belt mountains. I should of used 600mb winds for closer heights for more accurate height of ridge top winds.



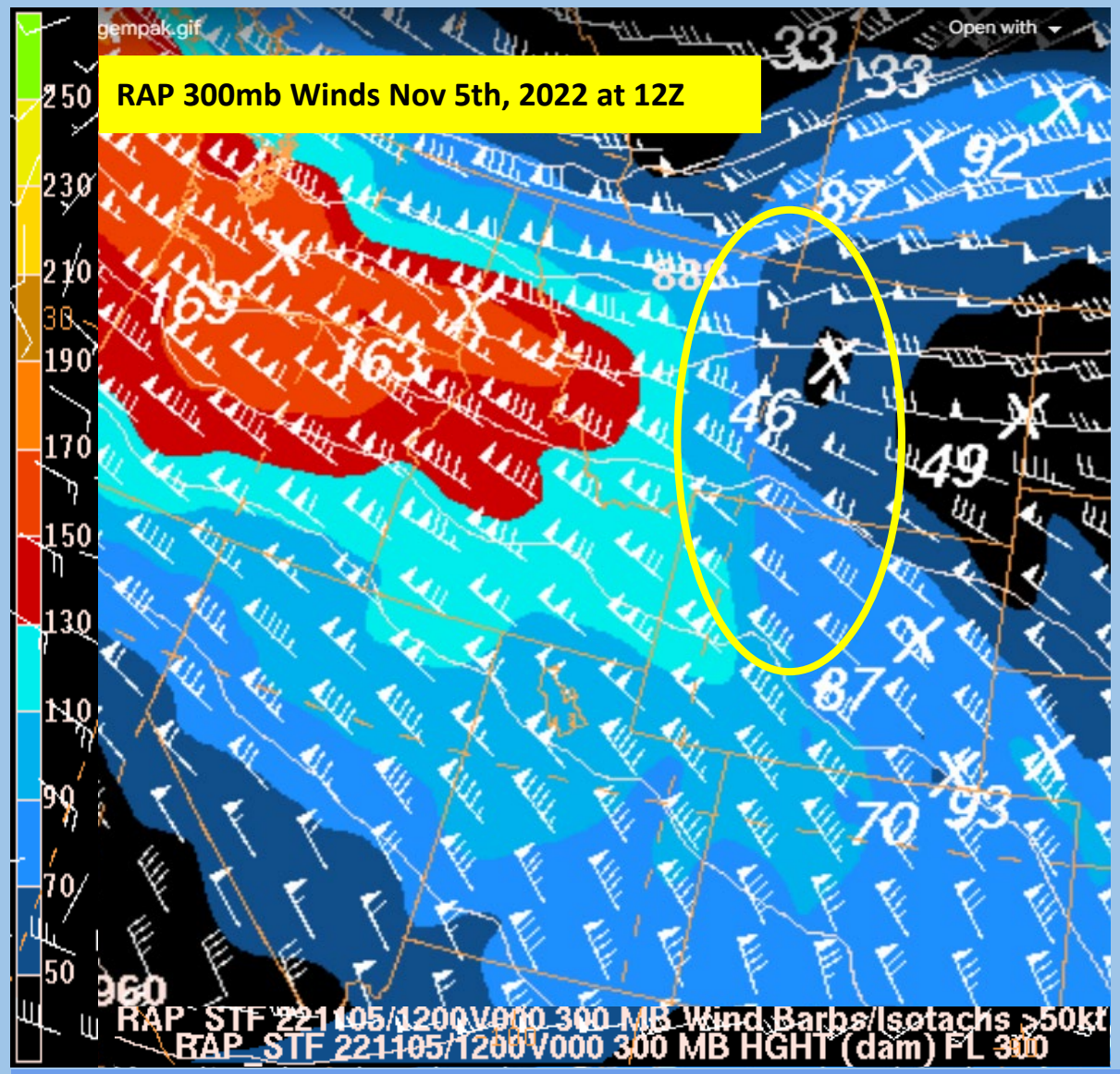


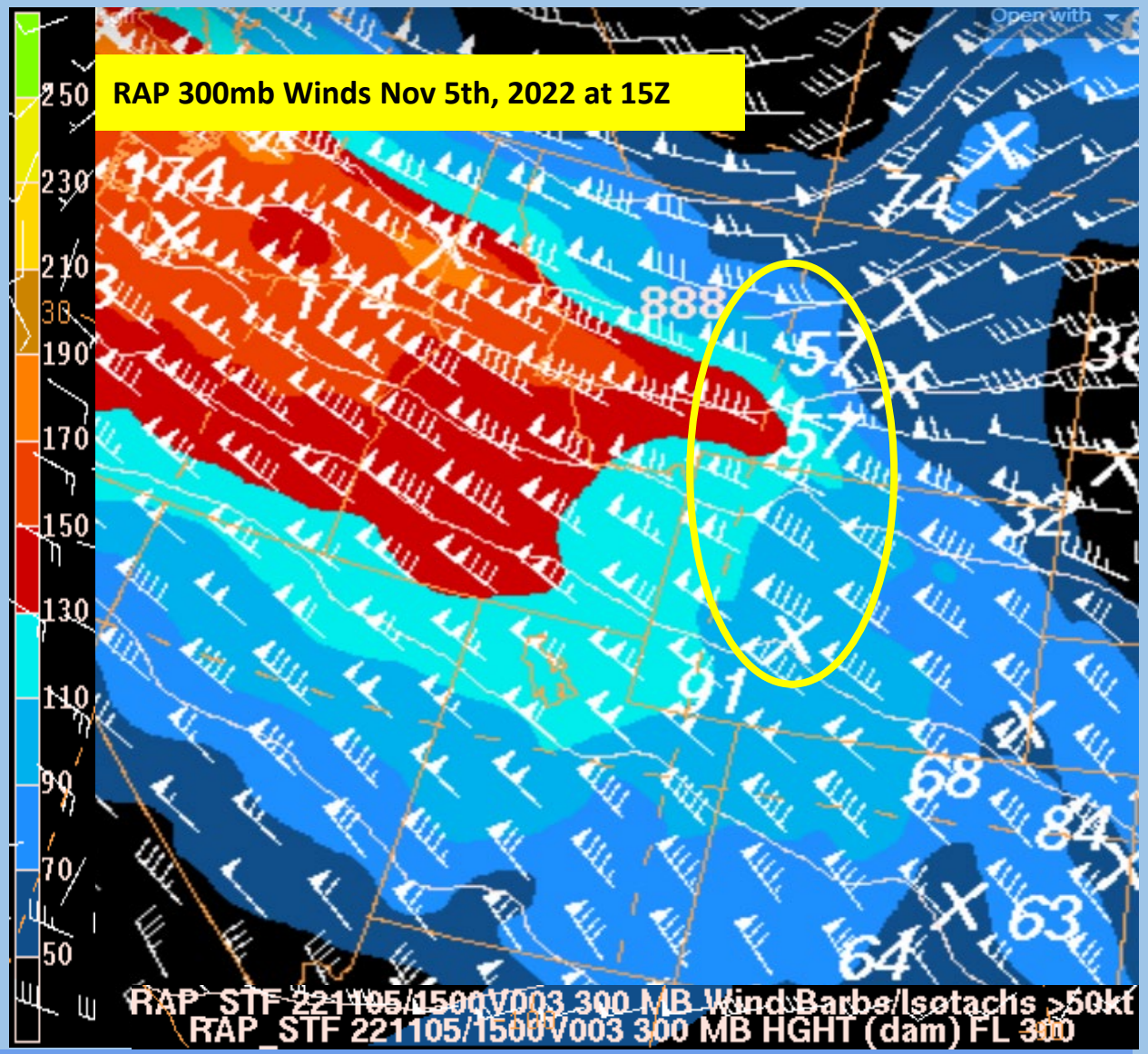
The RAP 700mb winds in the yellow ovals continued to show strong westerly cross barrier flow at 60-70 kts from 11/05/12Z - 11/05/15Z through the northern Rockies. While the northern Tetons the winds were diminishing but the southern Tetons and the Big Horn mountains remained with strong westerly cross barrier flow through 11/05/21Z.



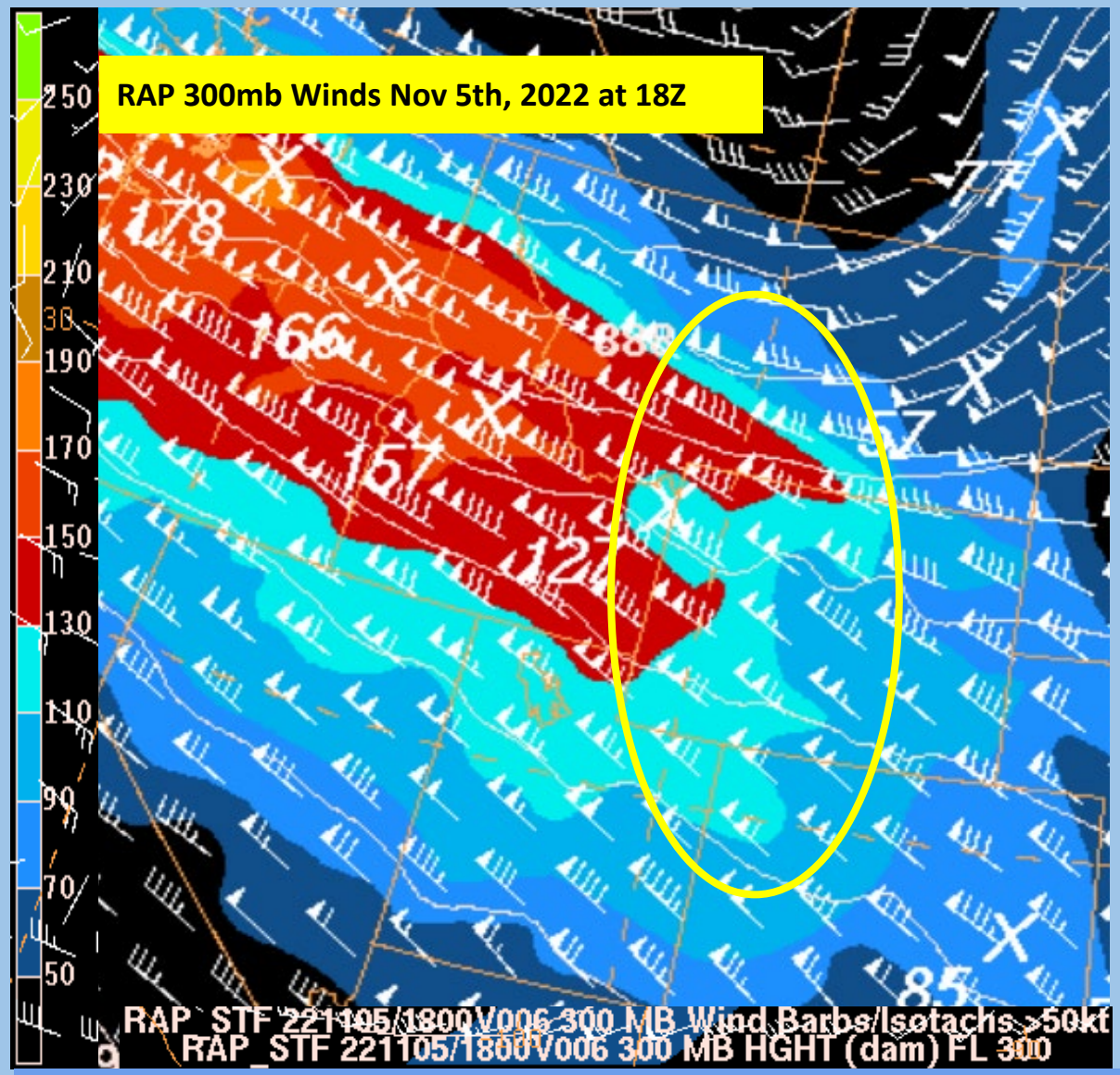


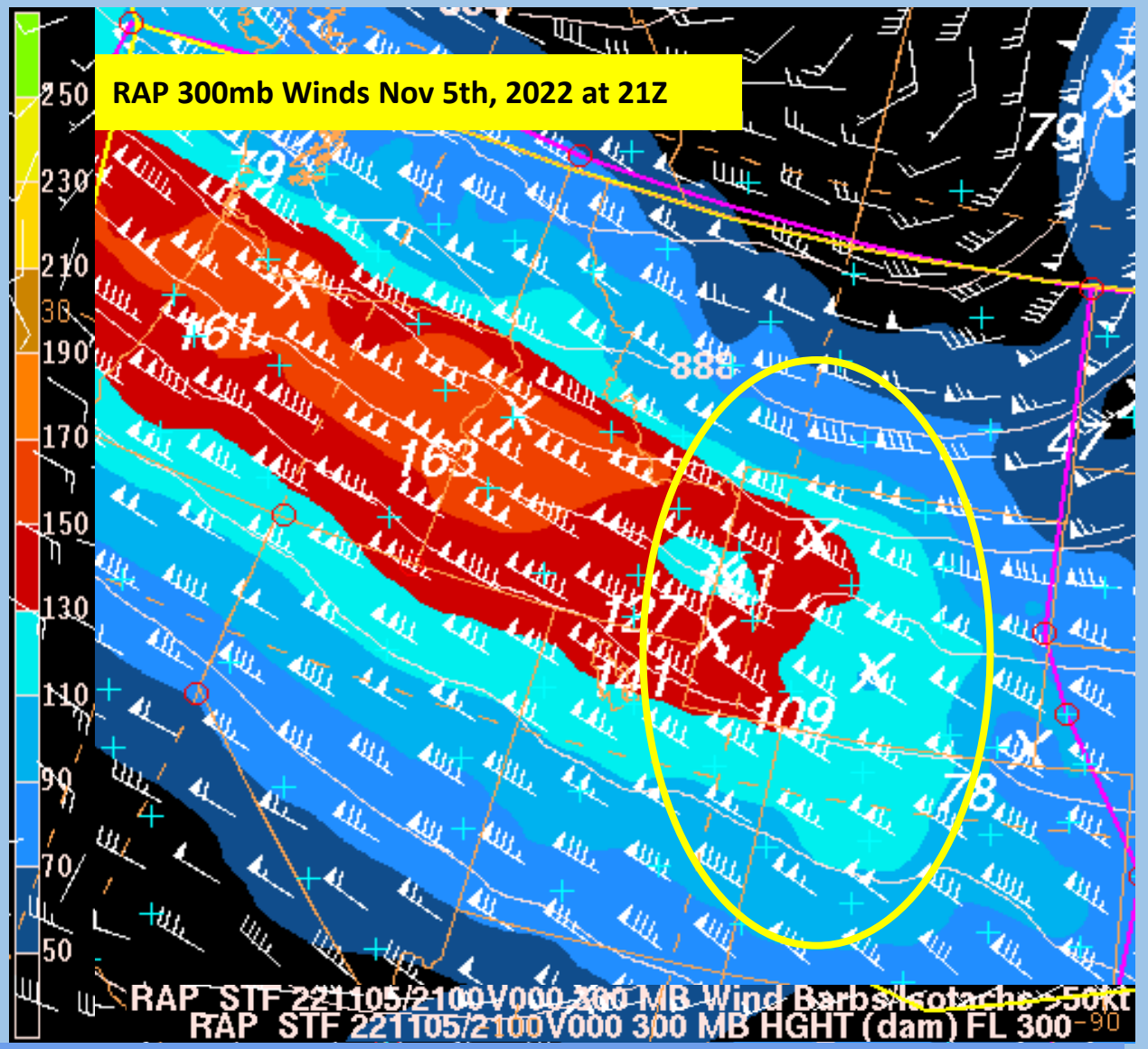
The RAP 700mb winds in the yellow ovals continued to show strong westerly cross barrier flow at 50-60 kts though 11/06/03Z through the northern Rockies. While the northern Tetons the winds continued to diminish but the southern Tetons and the Big Horn mountains remained with strong westerly cross barrier flow through 11/06/03Z.



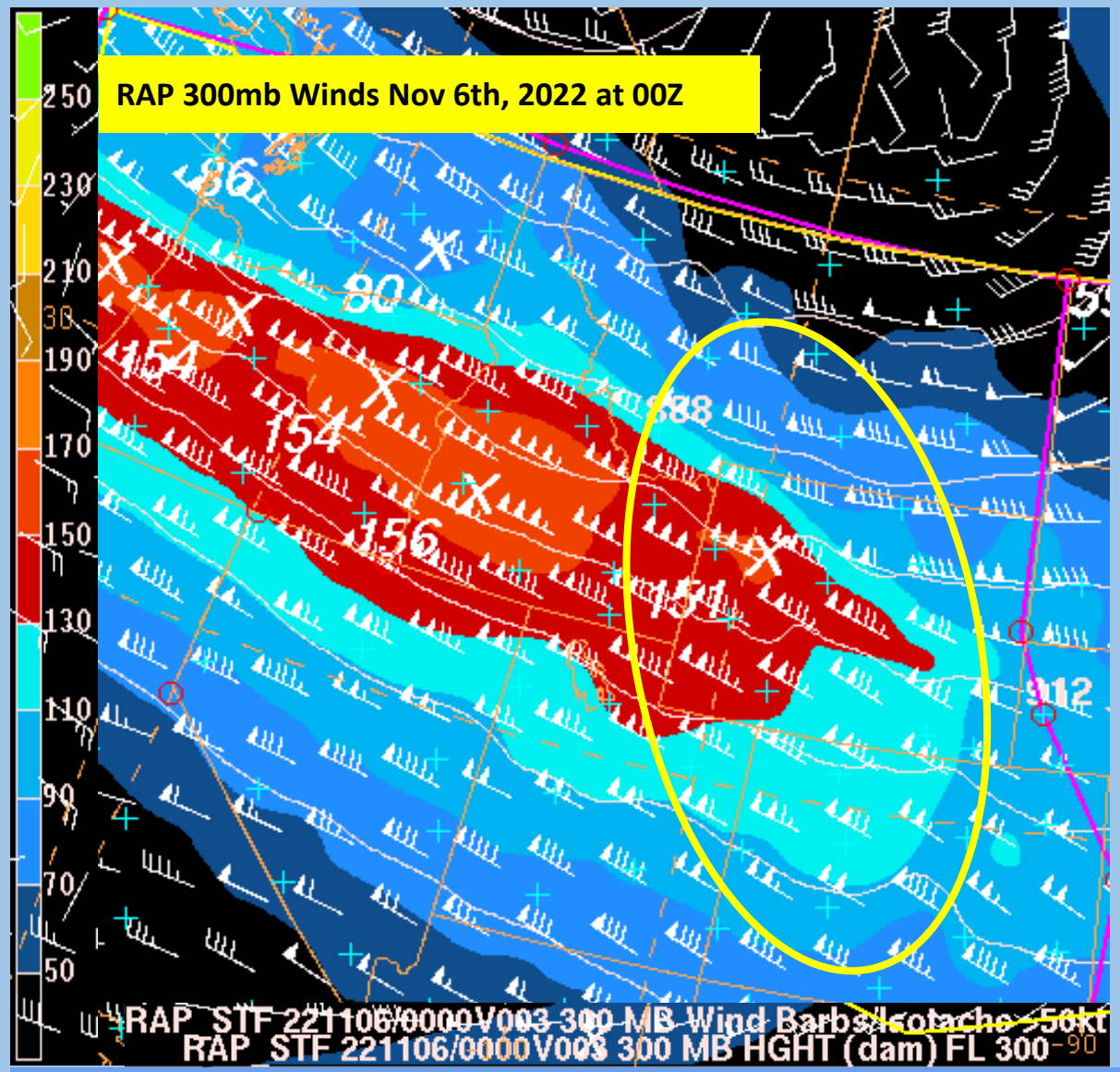


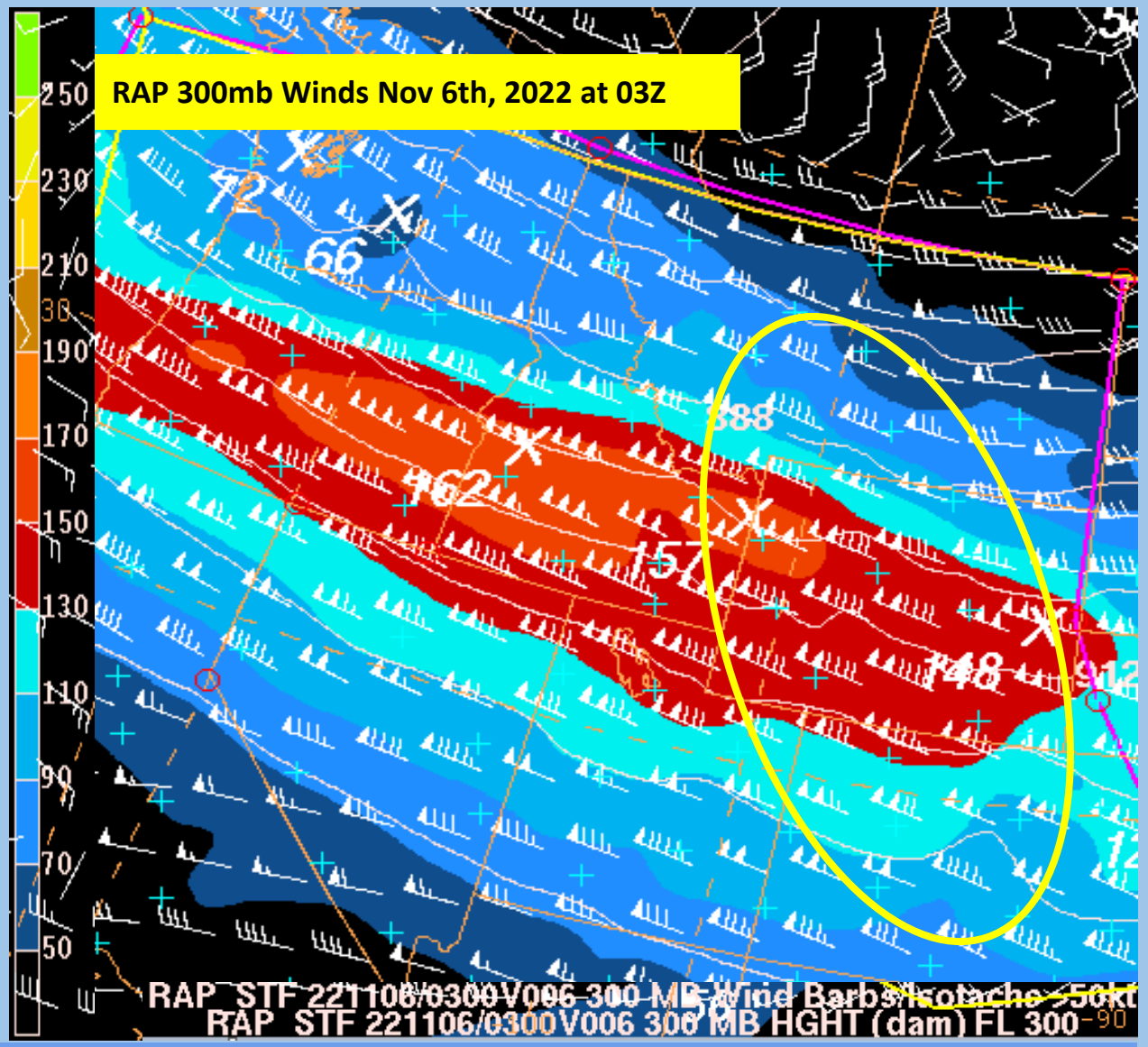
The yellow ovals were showing strong horizontal speed convergence intensifying by 15Z as the northwesterly to westerly nose of the jetcore entered the western to central MT region. While divergence occurred from central to eastern MT. These features were coupled with the left exit quadrant region of jetcore entering the central MT to northern WY region.



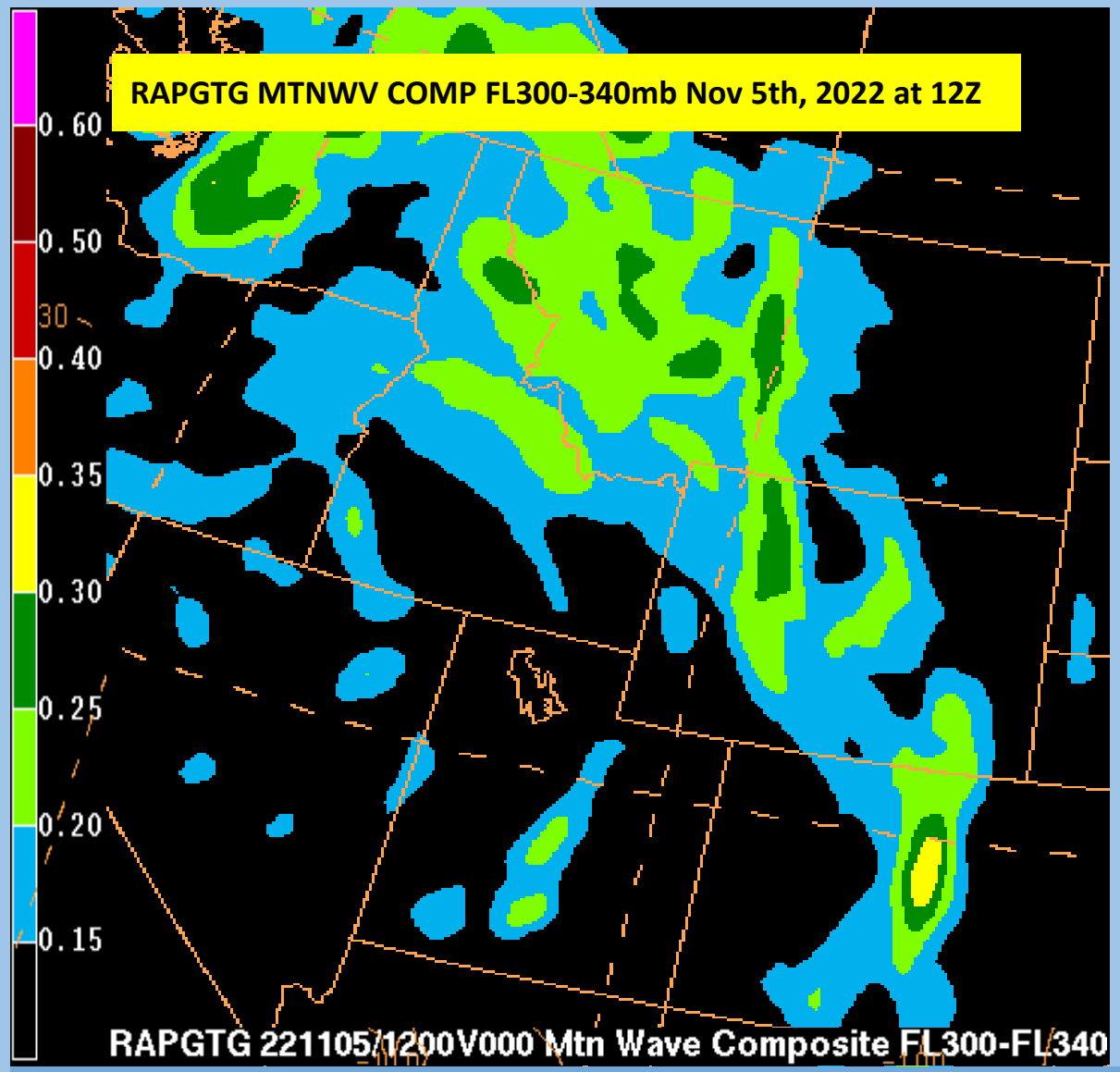


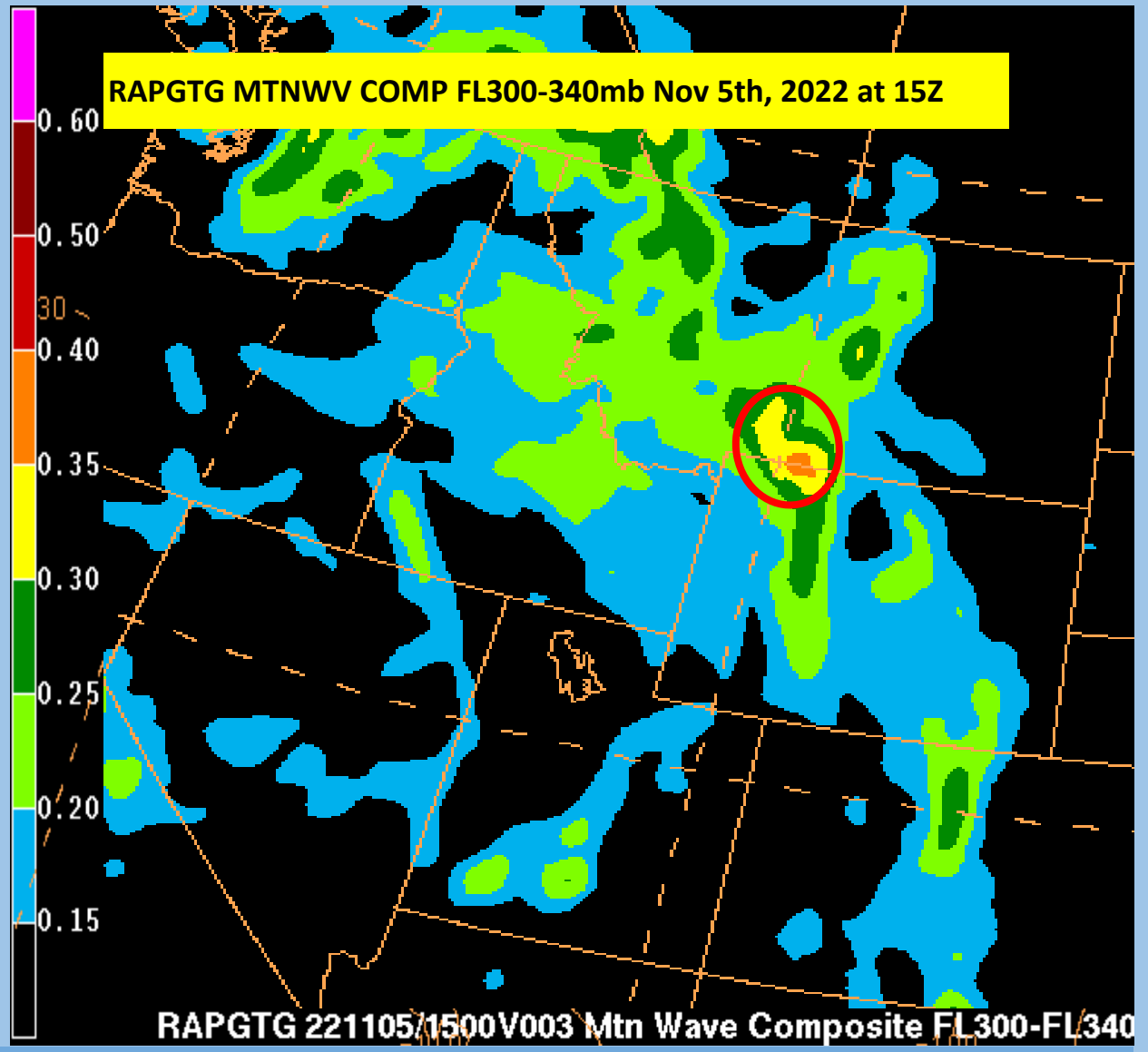
The yellow ovals show the northwesterly left front exit quadrant region of the 300mb jetcore as it continues to stream through the western to central MT & WY regions. While divergence has moved farther eastward into the ND/SD region.



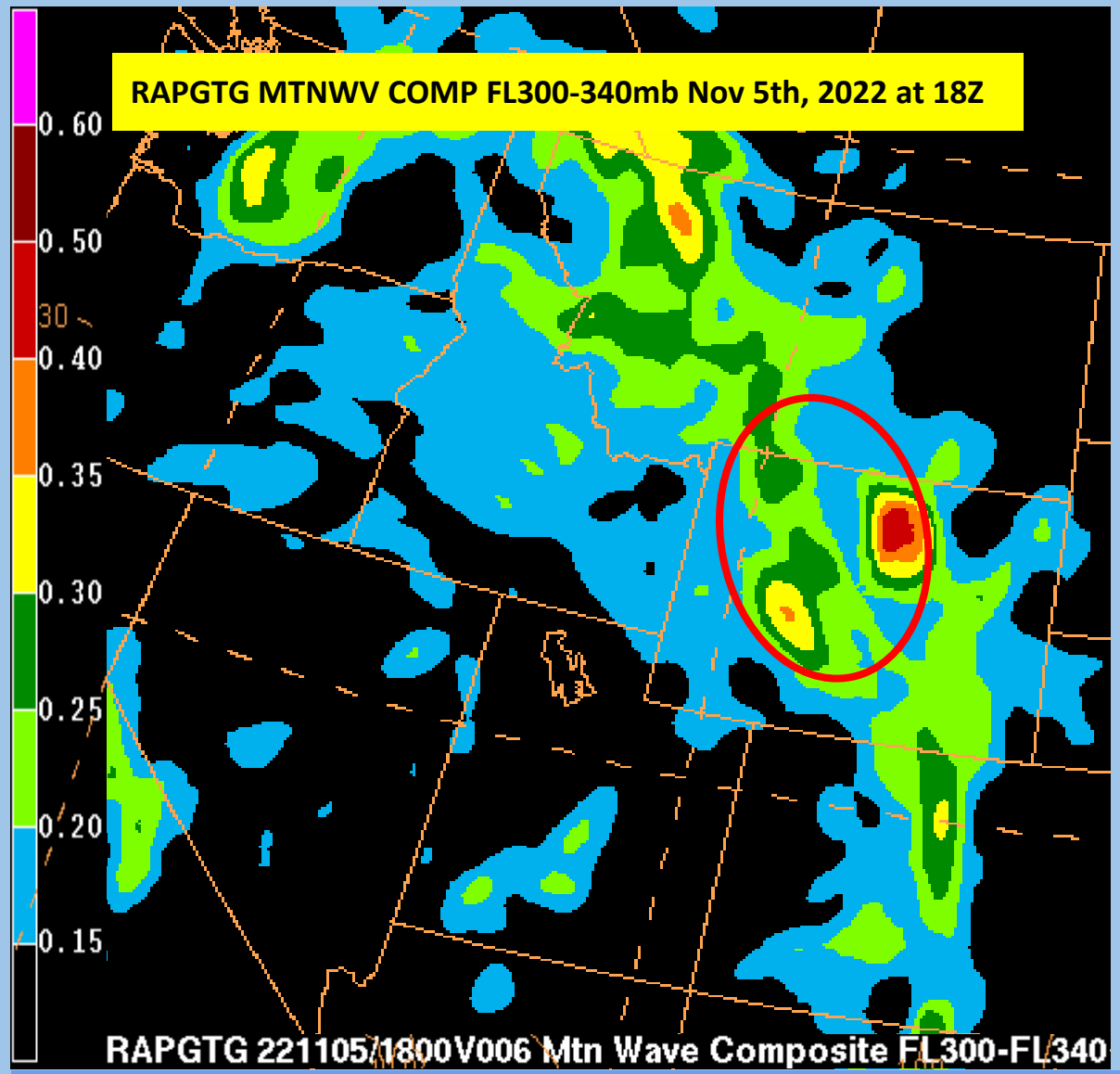


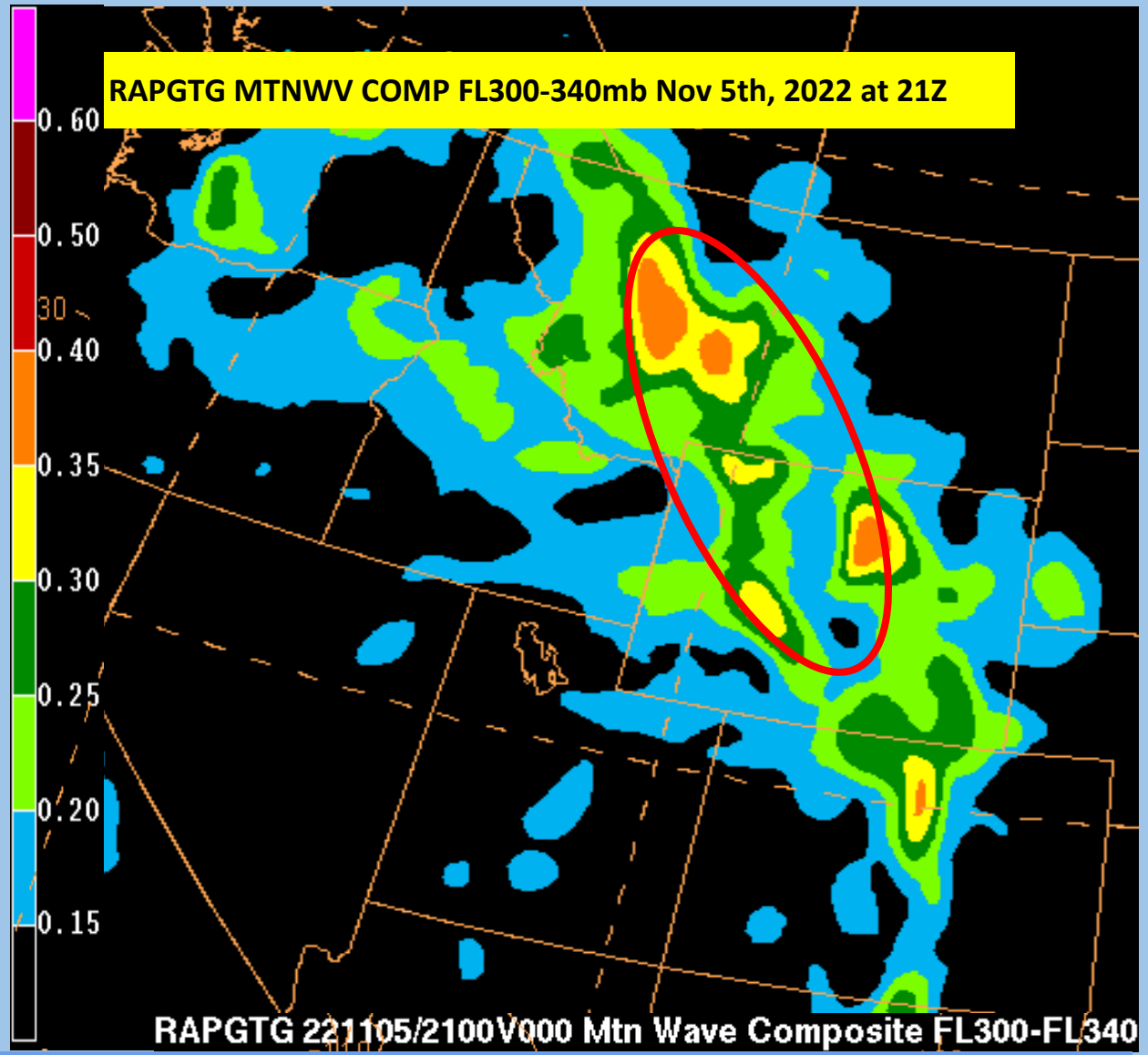
The yellow ovals show the continued northwesterly left front exit quadrant region of the 300mb jetcore as it streams through the western to central MT & WY regions through 11/06/03Z. While the right front exit quadrant region of the 300mb moves into the Denver region through 11/06/03Z.



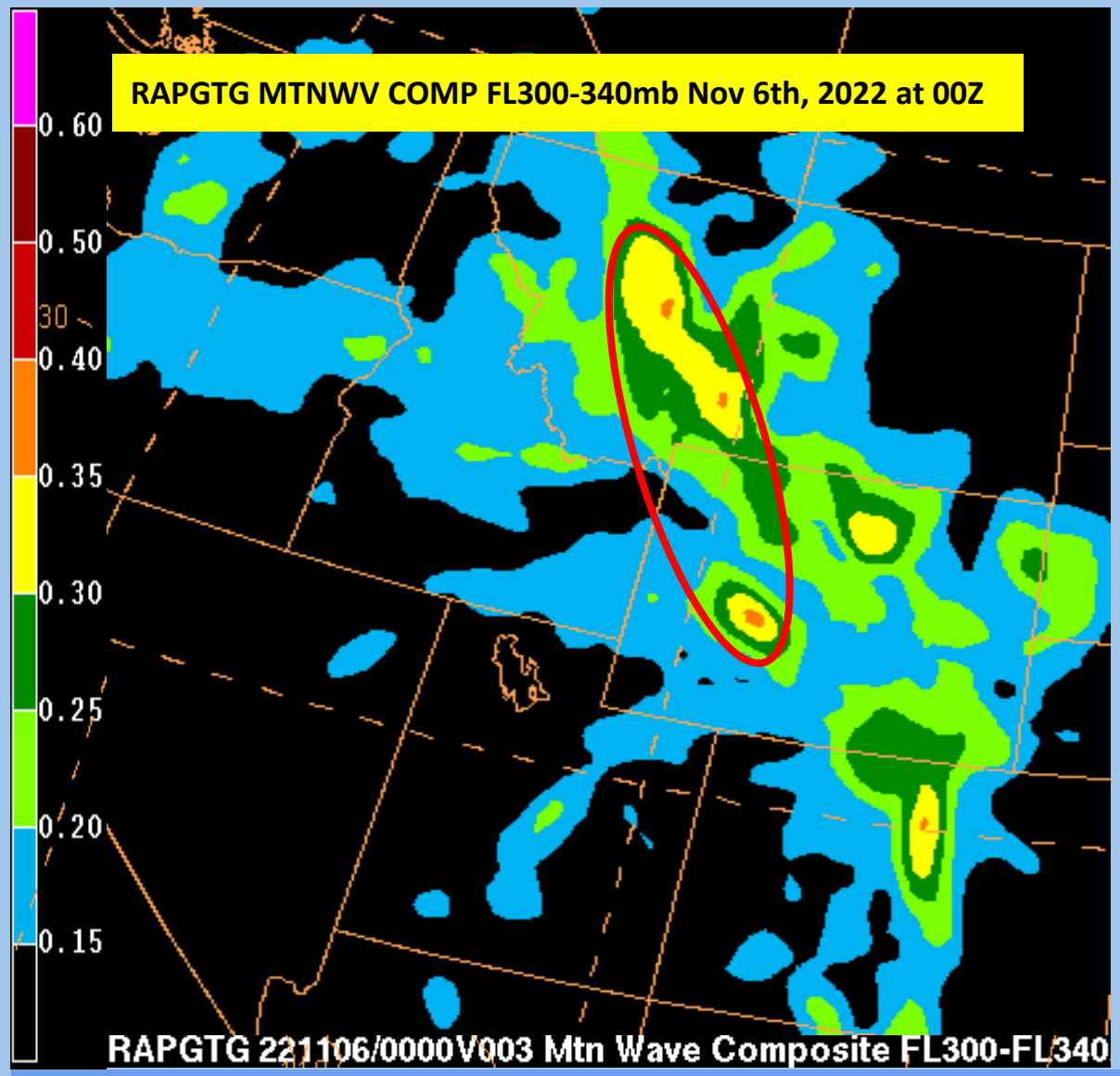


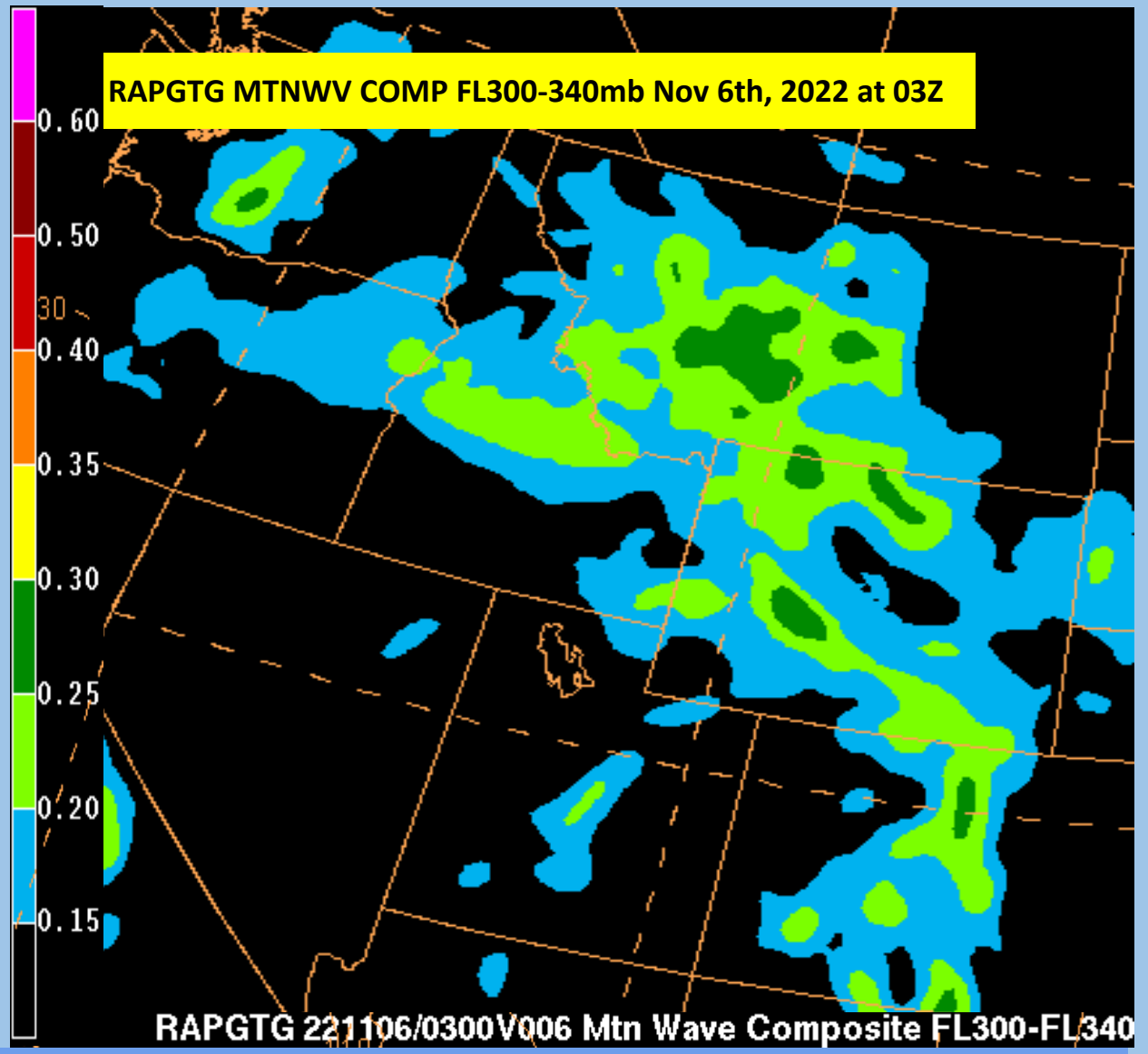
The RAPGTG Mountain Wave Composite shows possible moderate turbulence at FL300-340mb by 11/05/15Z through the lower southern Rockies or the Abasaroka mountains.



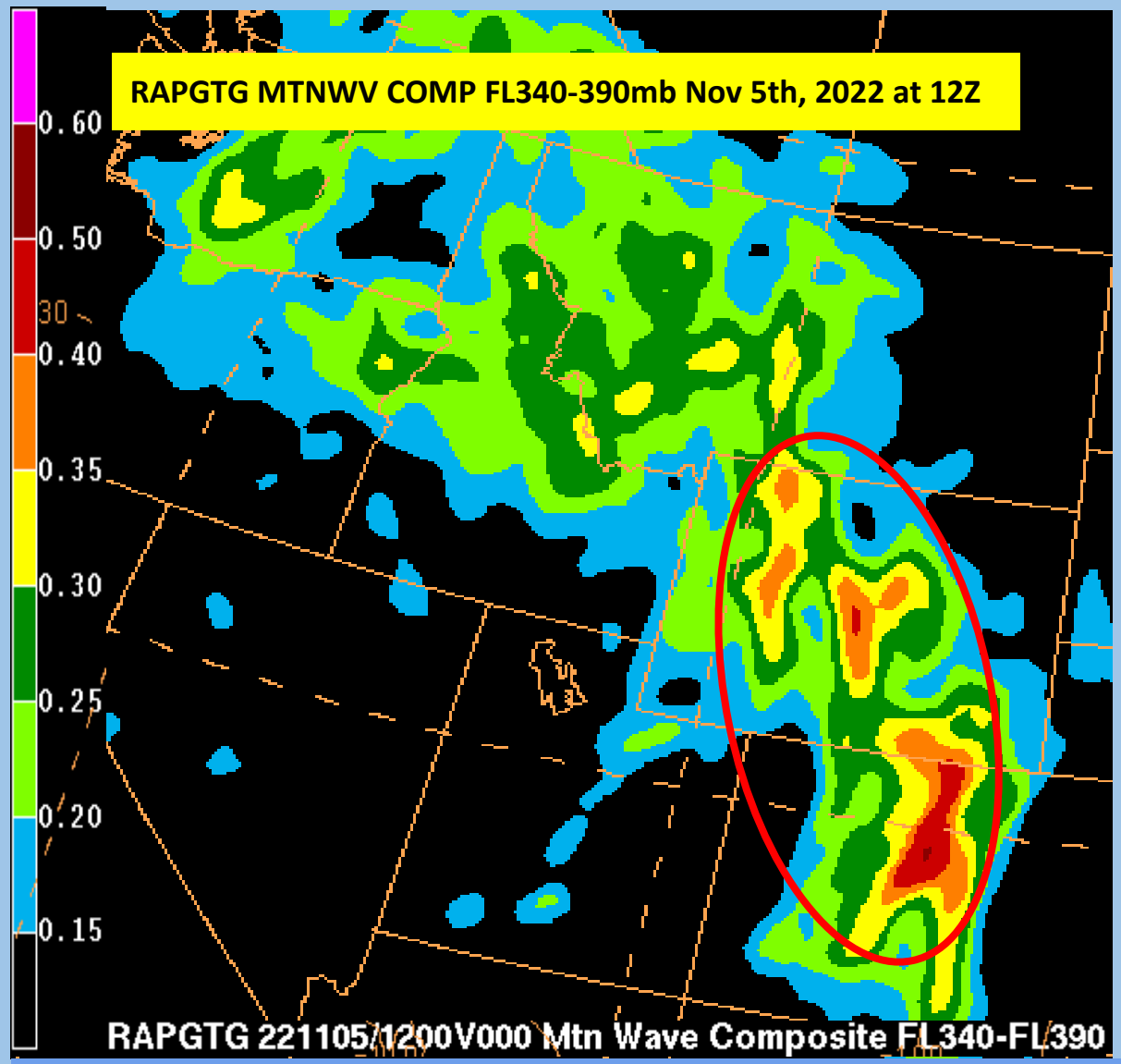


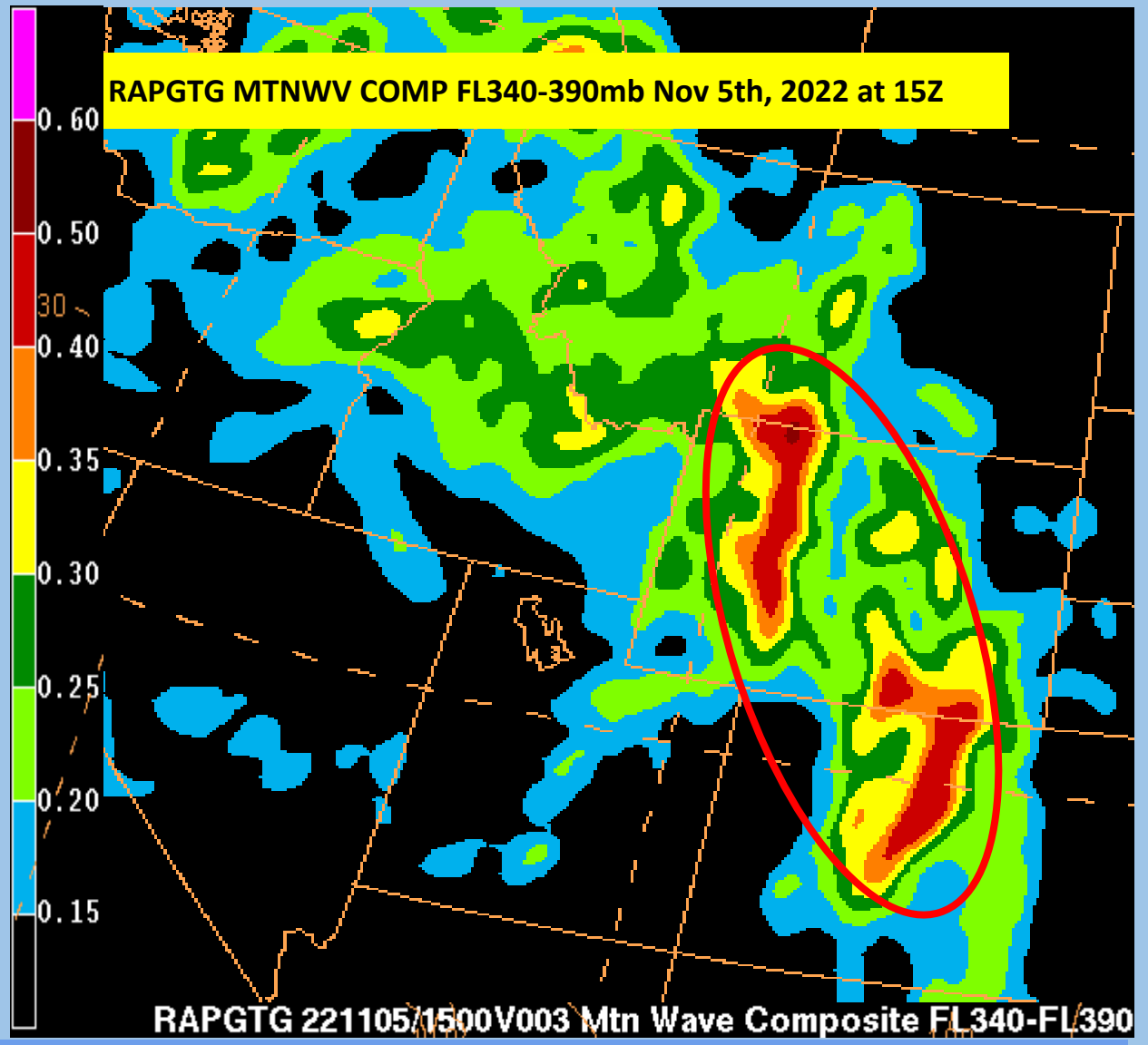
The RAPGTG Mountain Wave Composite at FL300-340mb starts to strengthen with stronger indices over the Big Belt mountains in MT and the Big Horn mountains in WY by 11/05/18Z.



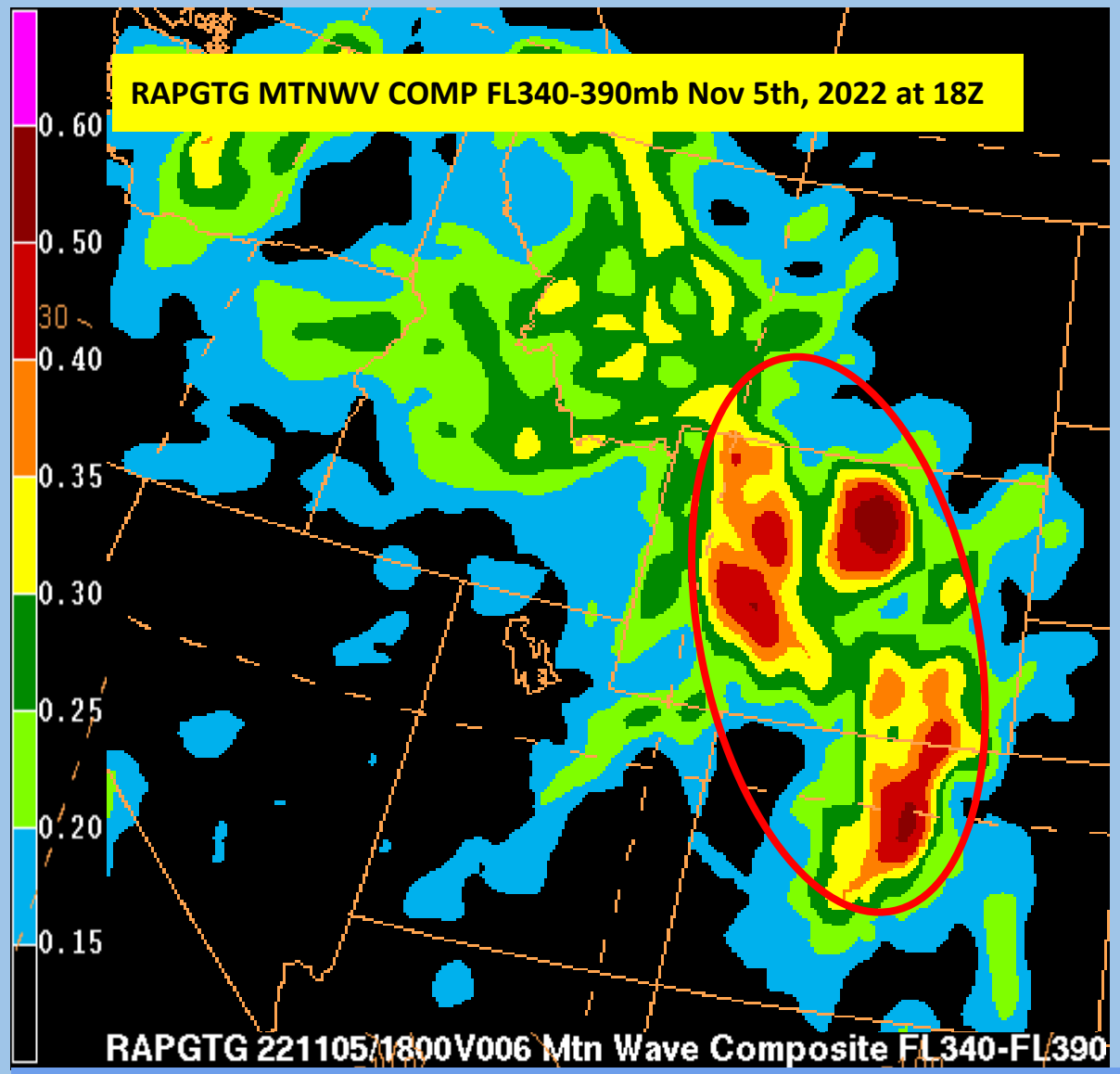


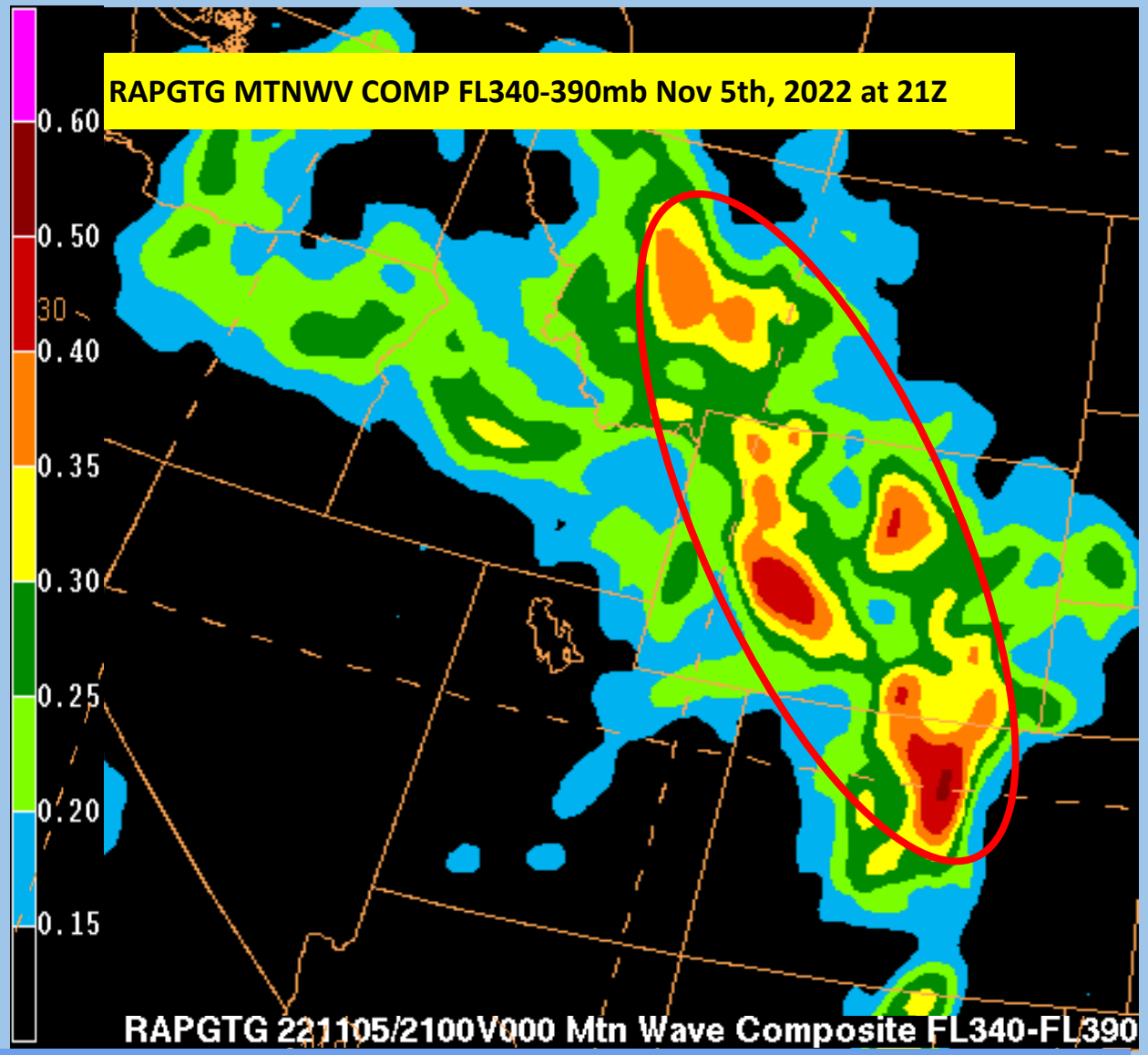
The RAPGTG Mountain Wave Composite at FL300-340mb has possible moderate turbulence during 11/06/00Z over the Tetons and northern Rockies. By 11/06/03Z the mountain wave indices totally diminishes for MT and WY regions.



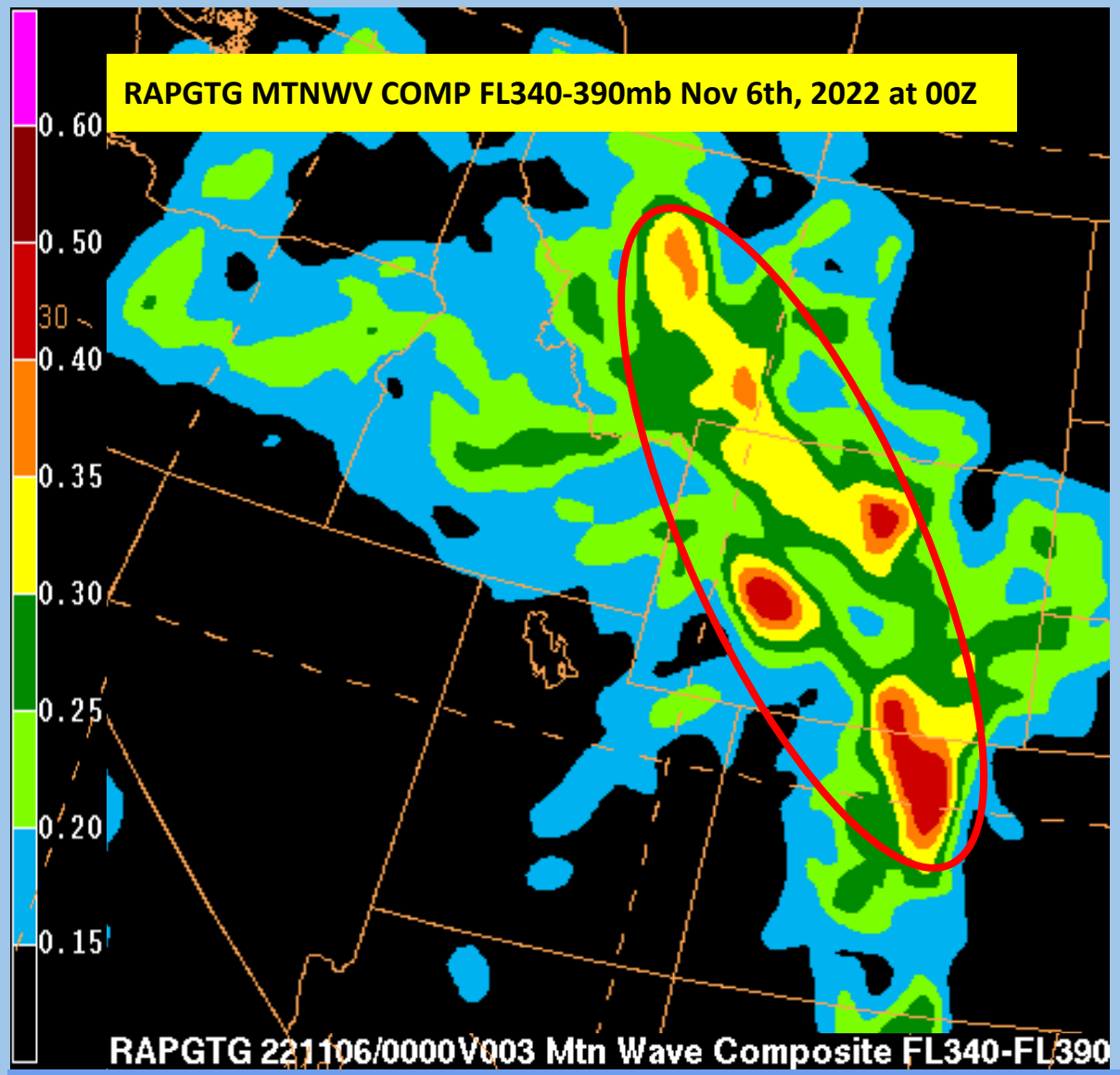


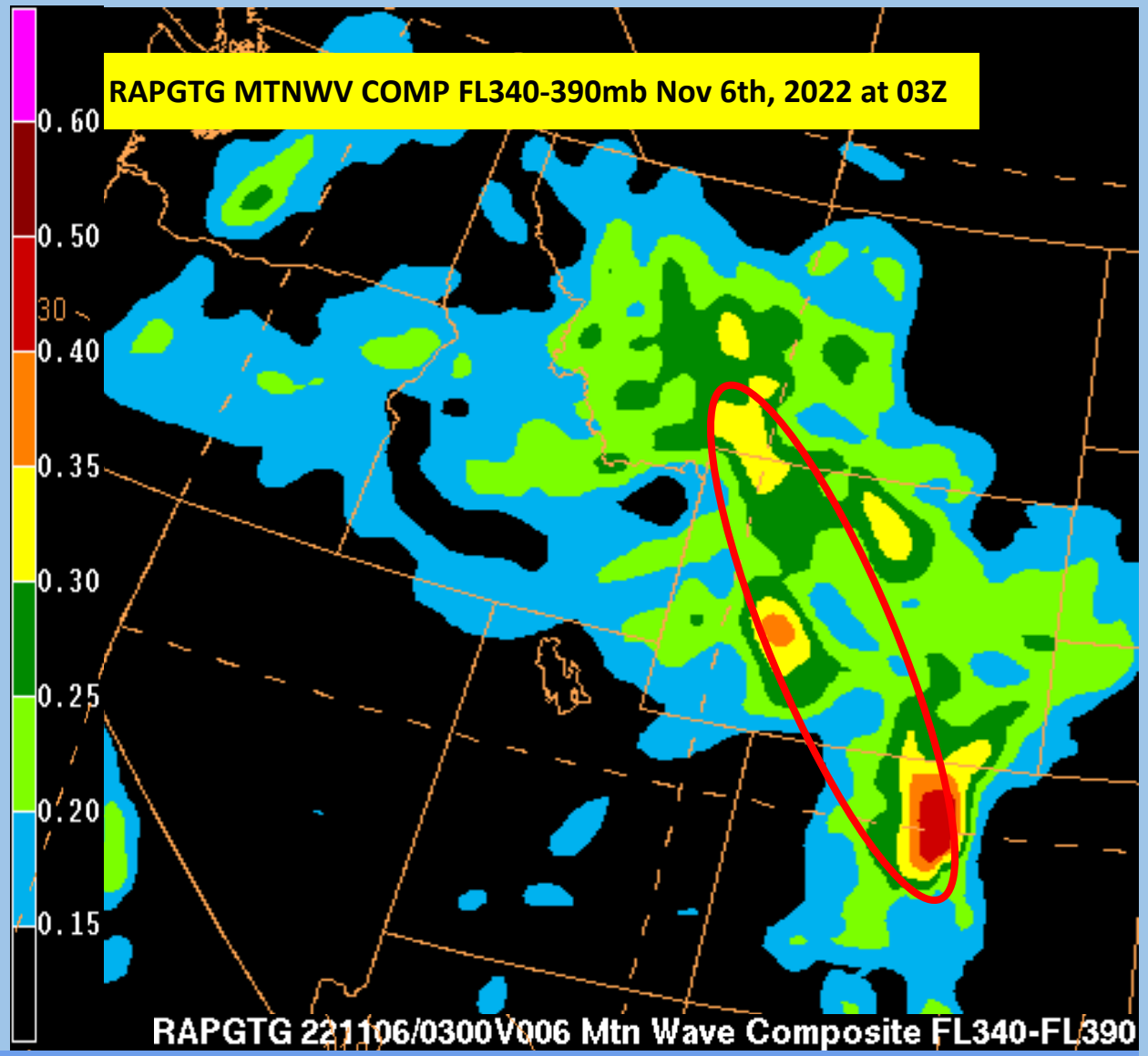
The RAPGTG Mountain Wave Composite at FL340-390mb has moderate to severe turbulence from 11/05/12Z over the Tetons and Big Horn and into the Rocky mountains in CO through 11/05/15Z.



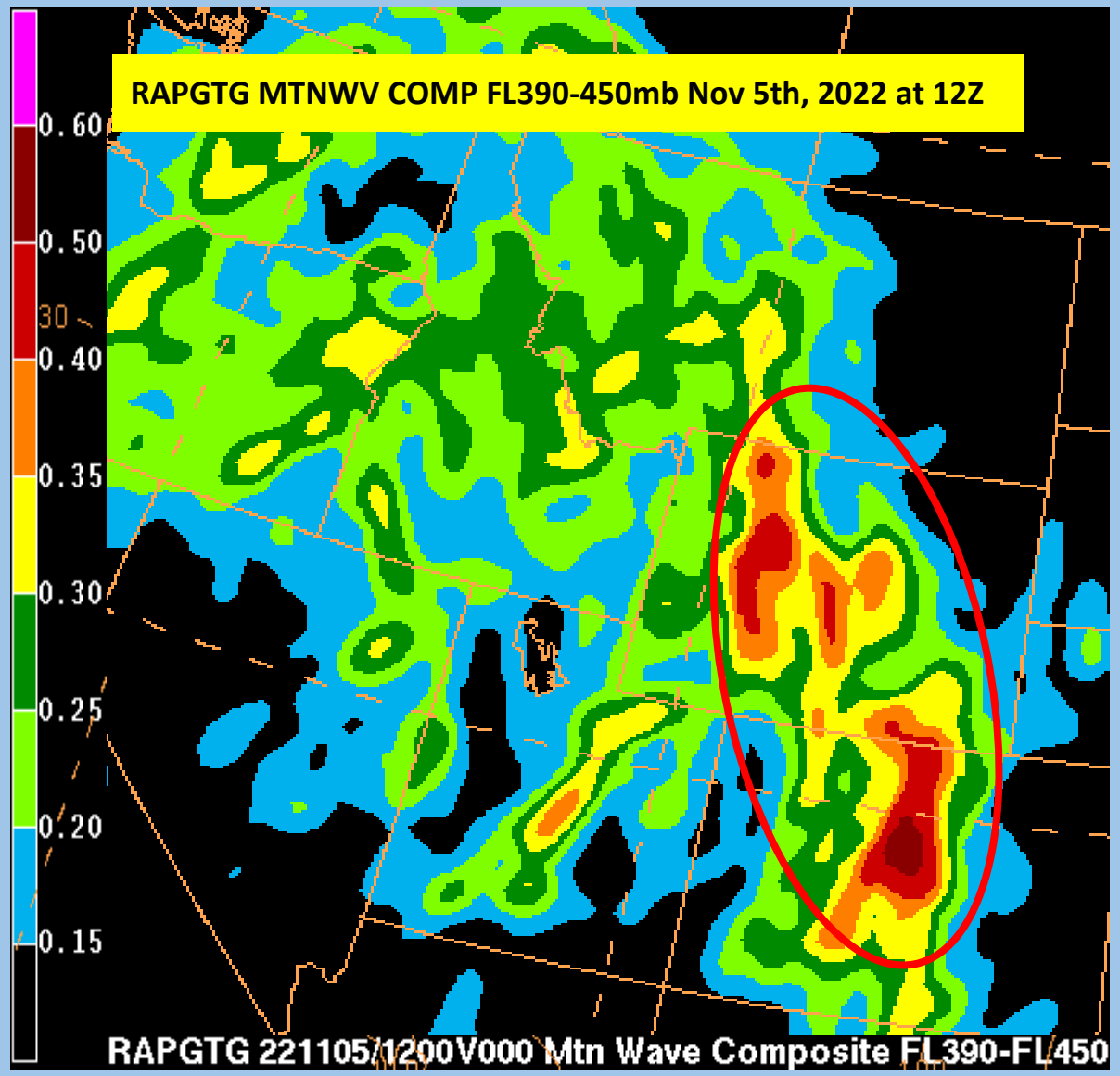


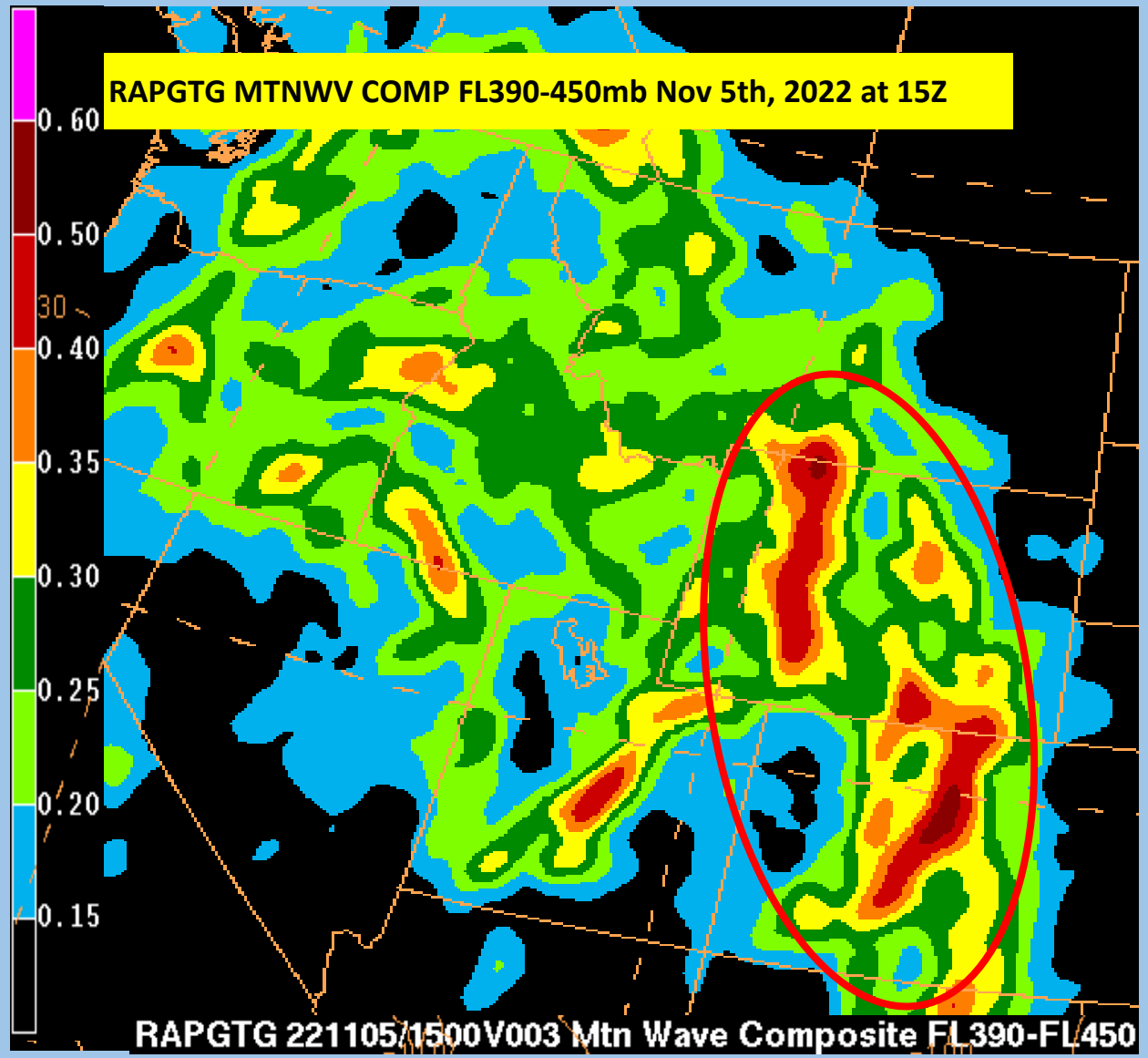
The RAPGTG Mountain Wave Composite at FL340-390mb continues showing potential for moderate to severe turbulence from 11/05/18Z over the Tetons and Big Horn and into the Rocky mountains in CO. The mountain wave indices stay strong through 11/05/21Z and spreads to northern Rockies or Big Belt mountains in MT.



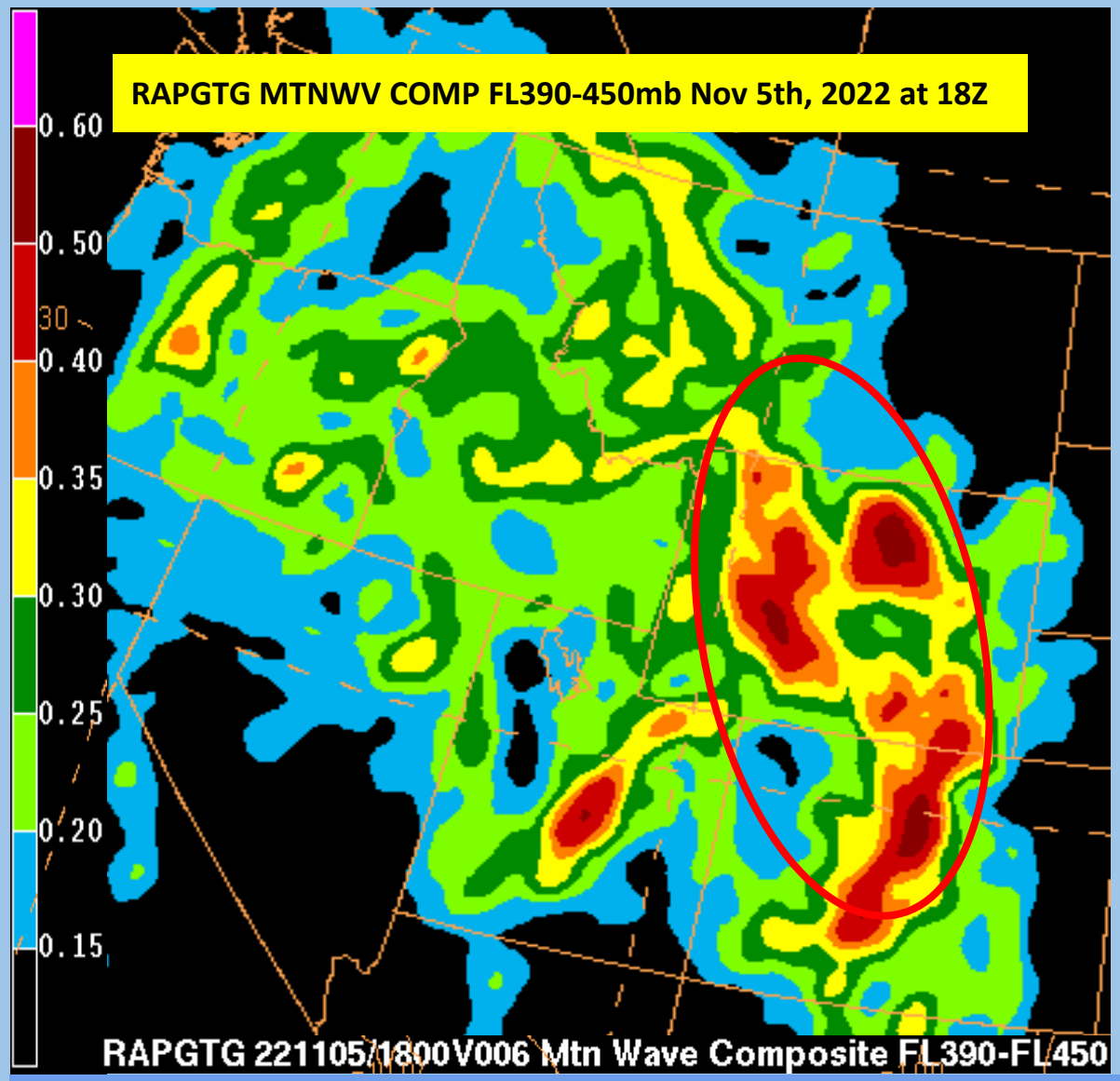


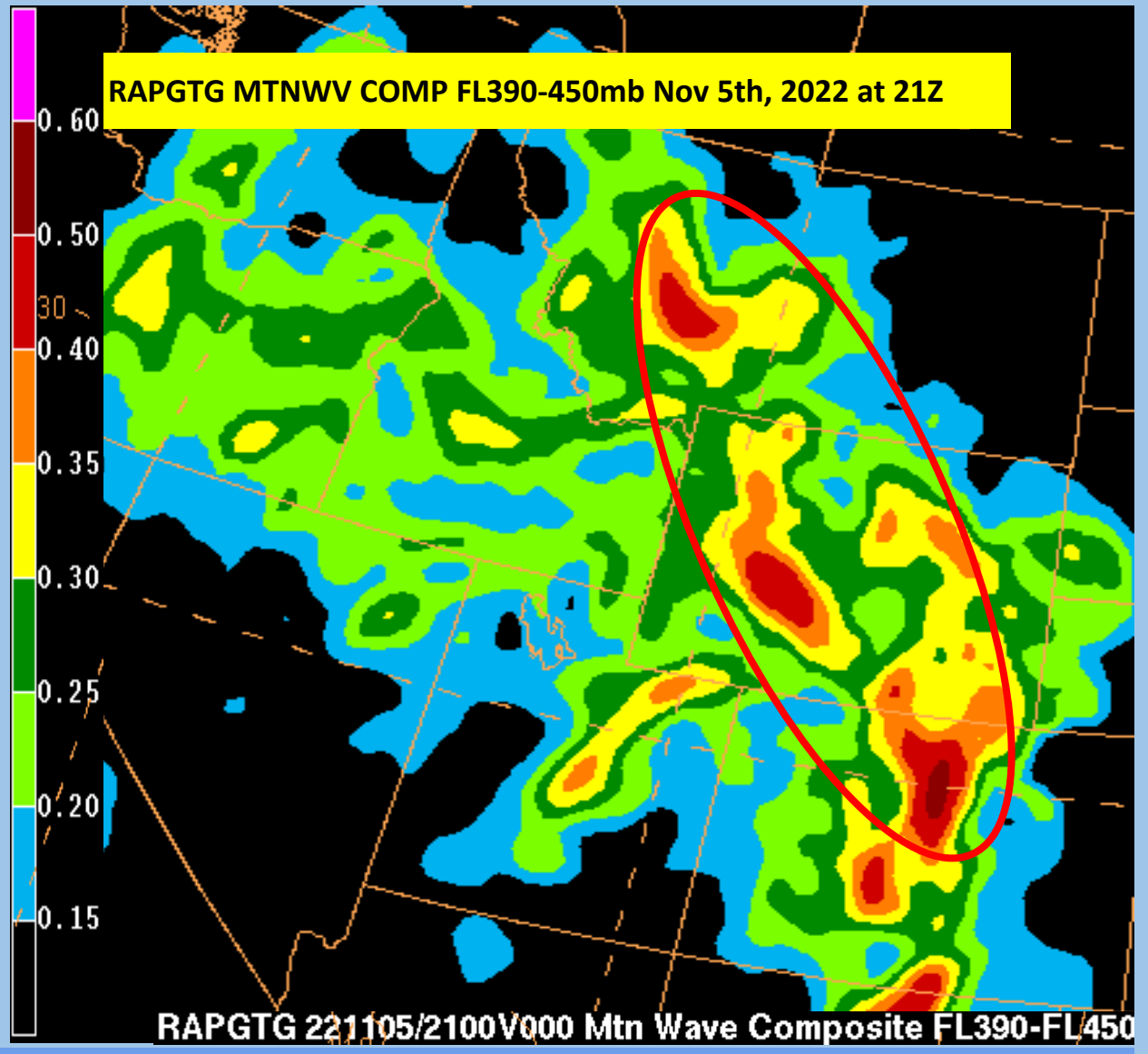
The RAPGTG Mountain Wave Composite at FL340-390mb continues showing potential for moderate to severe turbulence through 11/06/00Z over the Tetons and Big Horn and northern Rockies in MT. By 11/06/03Z the potential for moderate to severe turbulence is mainly over the Rocky mountains in CO.



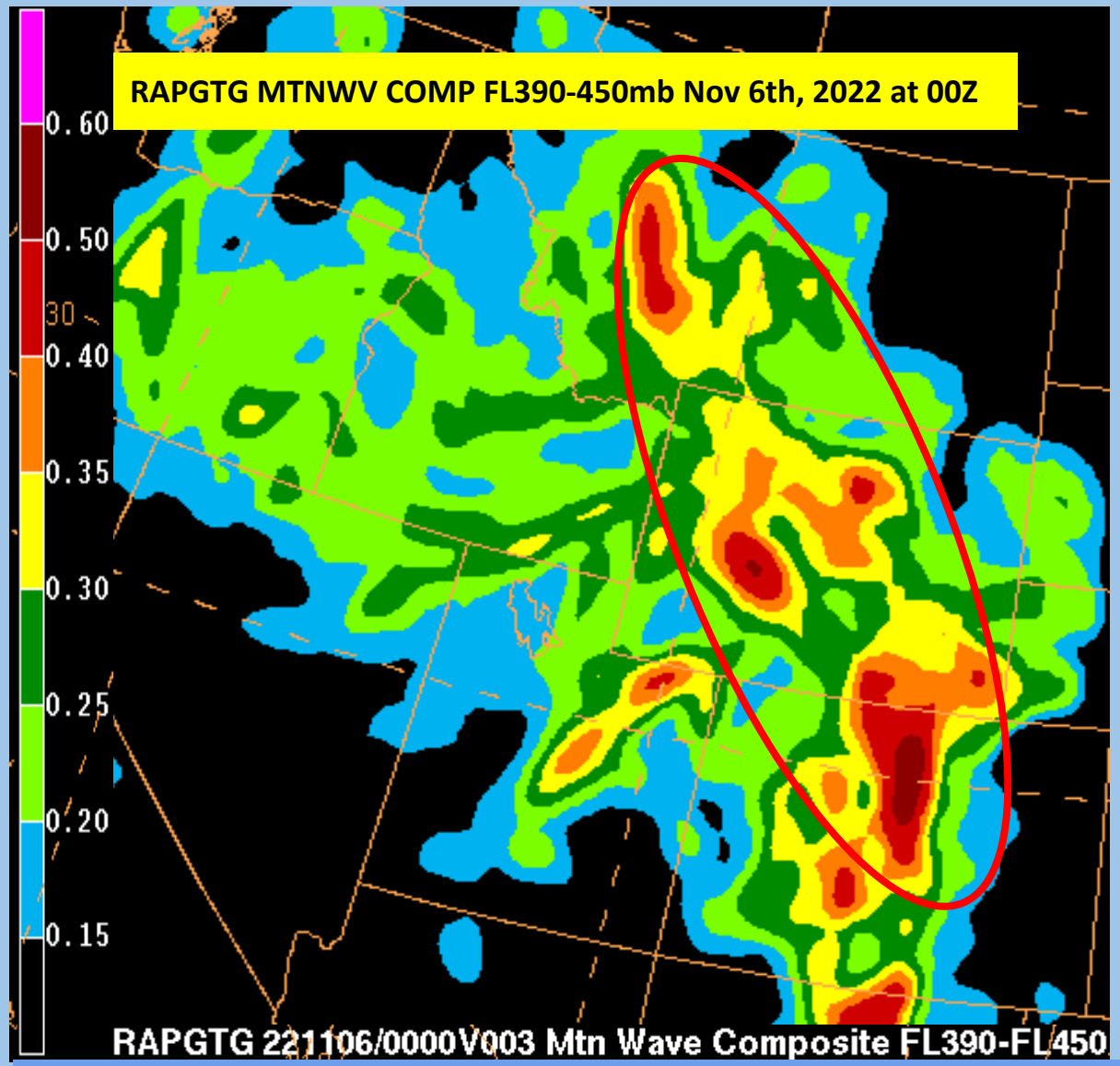


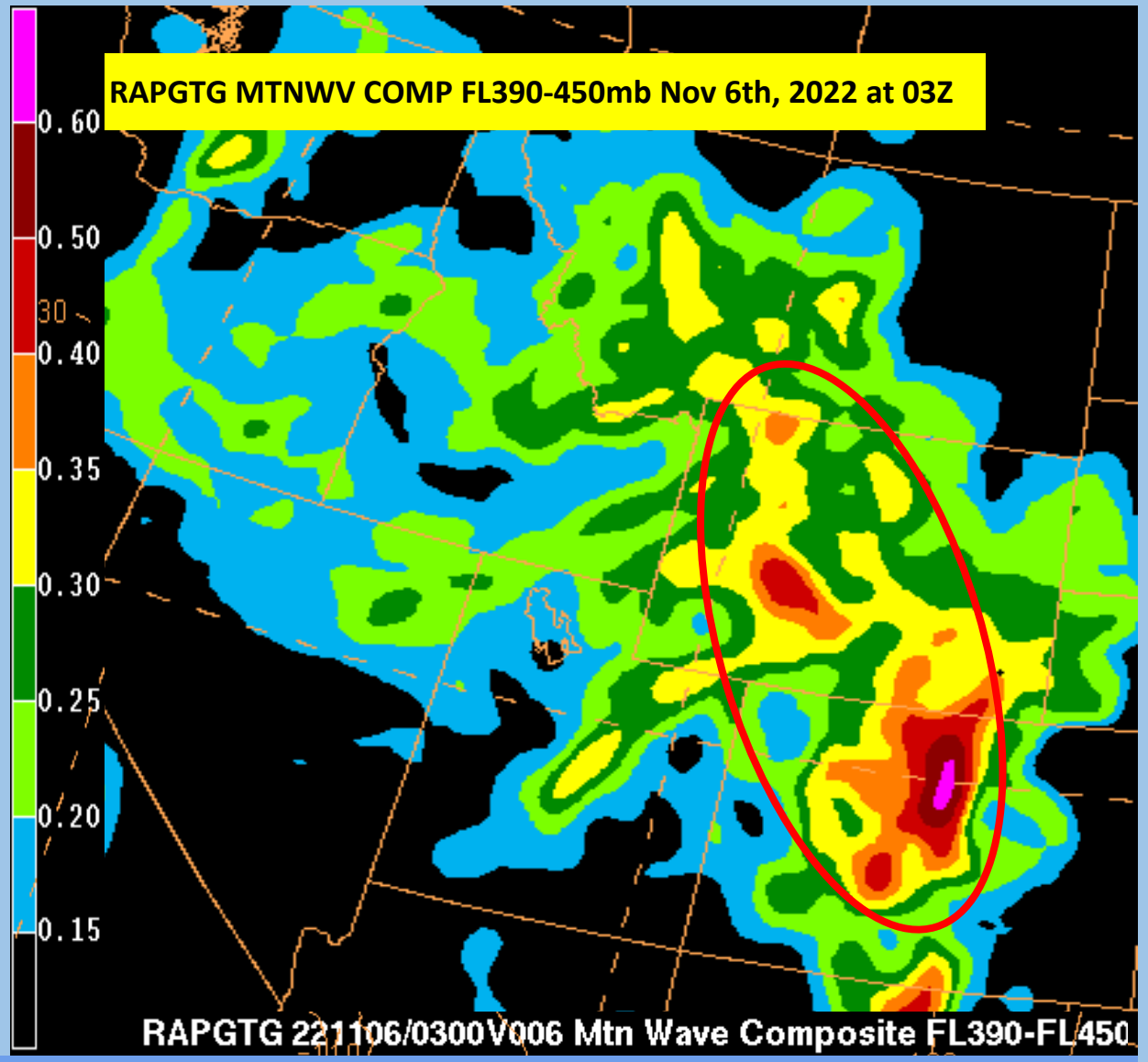
The RAPGTG Mountain Wave Composite at FL390-450mb showed good potential for moderate to severe turbulence from 11/05/12Z over the Tetons and Big Horn and southward into the Rocky mountains in CO. The mountain wave indices stayed strong through 11/05/15Z but there was only moderate turbulence pilot report in the CO region.





The RAPGTG Mountain Wave Composite at FL390-450mb continued to show good potential for moderate to severe turbulence from 11/05/18Z over the Tetons and Big Horn and southward into the Rocky mountains in CO. By 11/05/21Z the mountain wave indices intensified over the Big Belt mountains in MT region.





he RAPGTG Mountain Wave Composite at FL390-450mb continued to show good potential for moderate to severe turbulence from 11/06/00Z over the Tetons and Big Horn, Big Belt mountains and southward into the Rocky mountains in CO. By 11/06/03Z the strong mountain wave indices were mainly over the Tetons and the Rocky mountains in CO region.

MOUNTAIN WAVE INDUCED TURBULENCE DECISION TREE

Do you have perpendicular cross-barrier flow with surface wind speeds 35kts or greater? Do you have ridge top wind speeds 50kts or greater?

YES, keep going

NO, not likely

Does Satellite show Foehn gap or subsidence & any severe turbulence pilot reports?

YES, keep going

NO, not likely

Is there an inversion near the mountain tops?

(This allows for vertical propagating couplet to develop in stable region)

YES, keep going

NO, not likely

Do you have a sharp or tight strong updraft/downdraft couplet?

YES, keep going

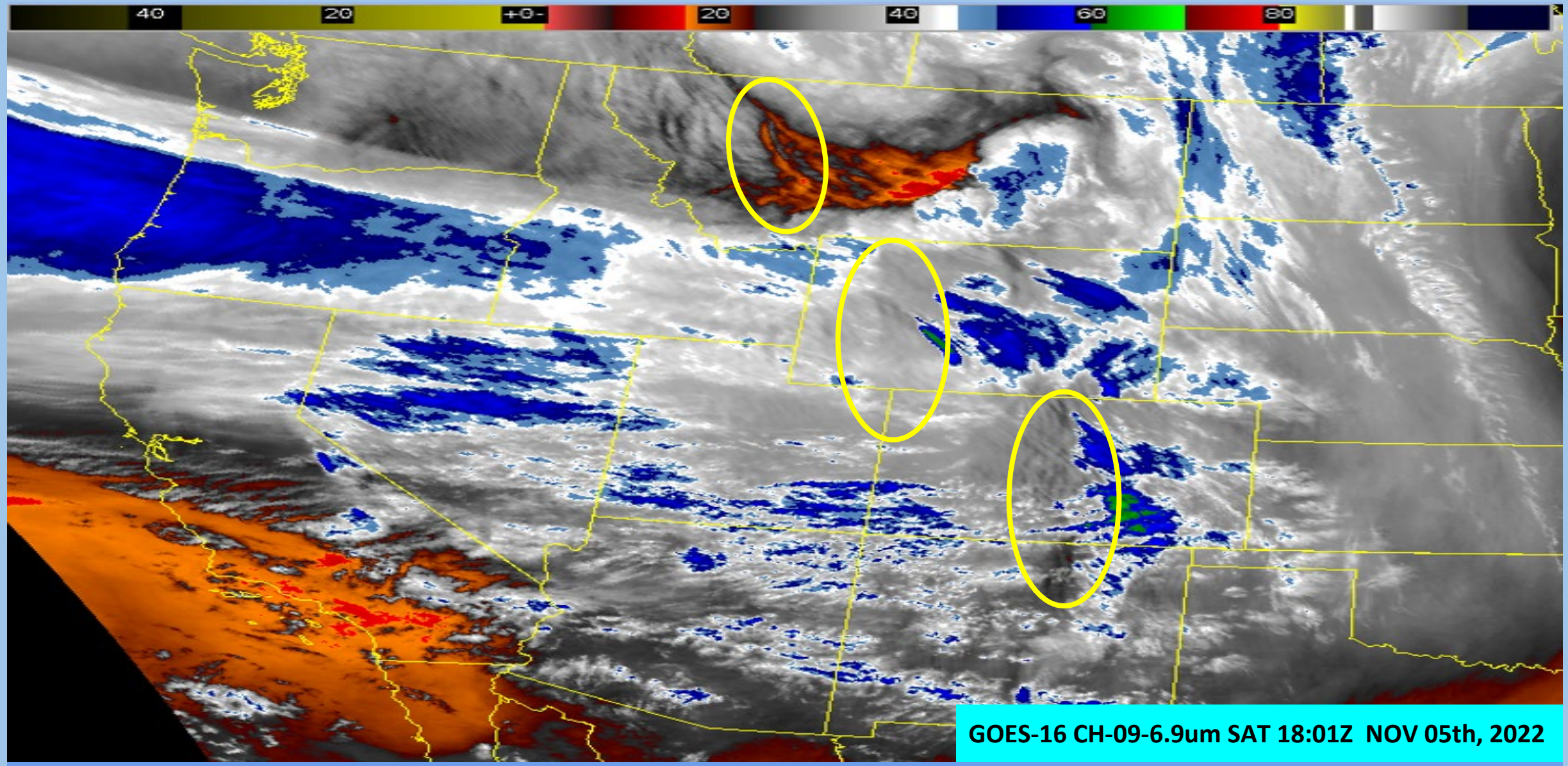
NO, monitor

Does the strong vertical propagating motion or couplet punch through the tropopause?

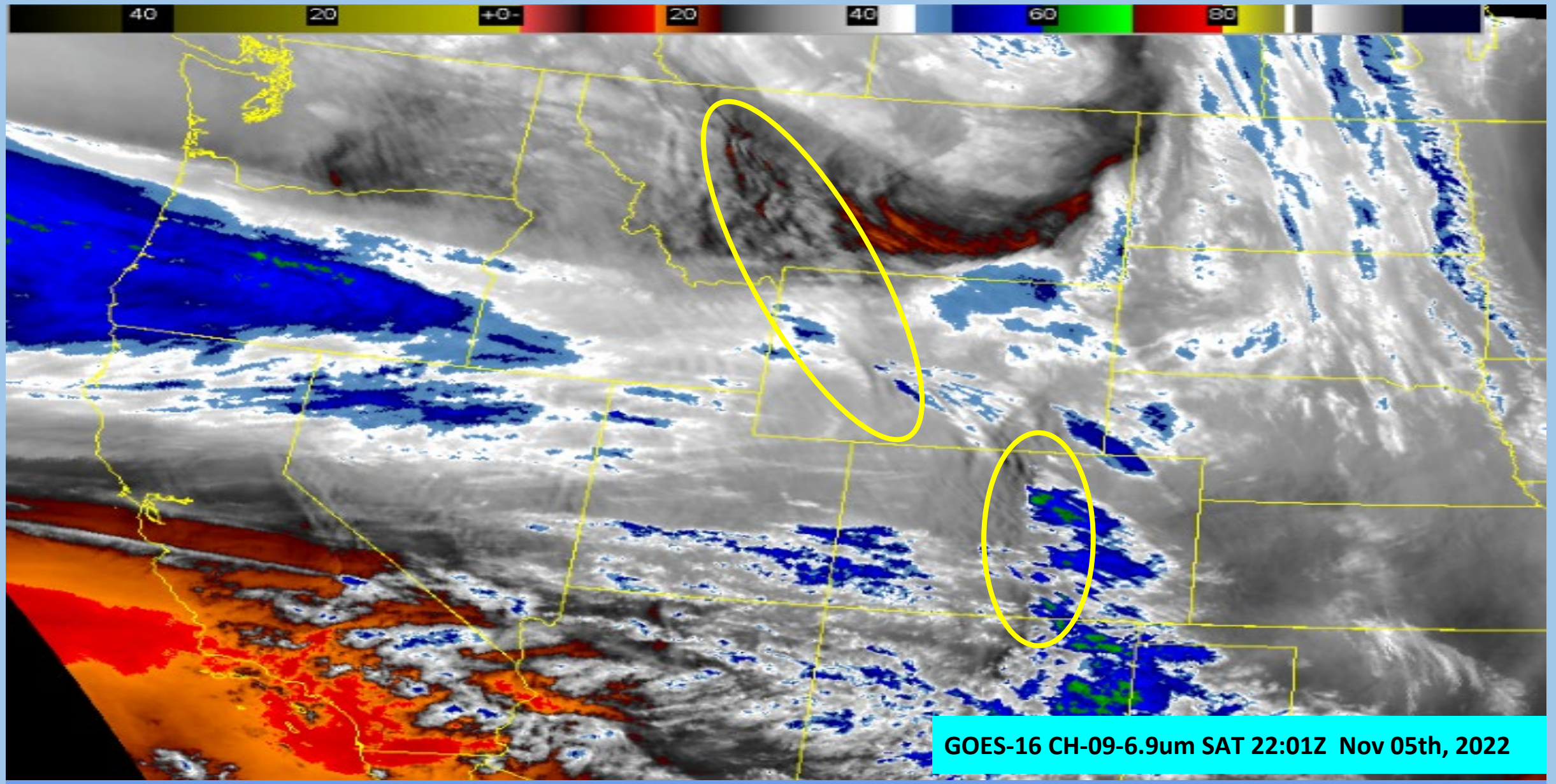
YES, keep going

NO, monitor

Issue the Low and/or High Severe Turbulence SIGMET



The yellow ovals showed the standing clouds and some had beginning of dry slots and MT region over northern Rockies had wide swath of subsidence and coupled with foehn gap.



The yellow ovals showed the standing clouds and transverse turbulence clouds. While WY had better developed dry slot through the Teton mountains.s

MOUNTAIN WAVE INDUCED TURBULENCE DECISION TREE

Do you have perpendicular cross-barrier flow with surface wind speeds 35kts or greater? Do you have ridge top wind speeds 50kts or greater?

YES, keep going

NO, not likely

Does Satellite show Foehn gap or subsidence & any severe turbulence pilot reports?

YES, keep going

NO, not likely

Is there an inversion near the mountain tops?

(This allows for vertical propagating couplet to develop in stable region)

YES, keep going

NO, not likely

Do you have a sharp or tight strong updraft/downdraft couplet?

YES, keep going

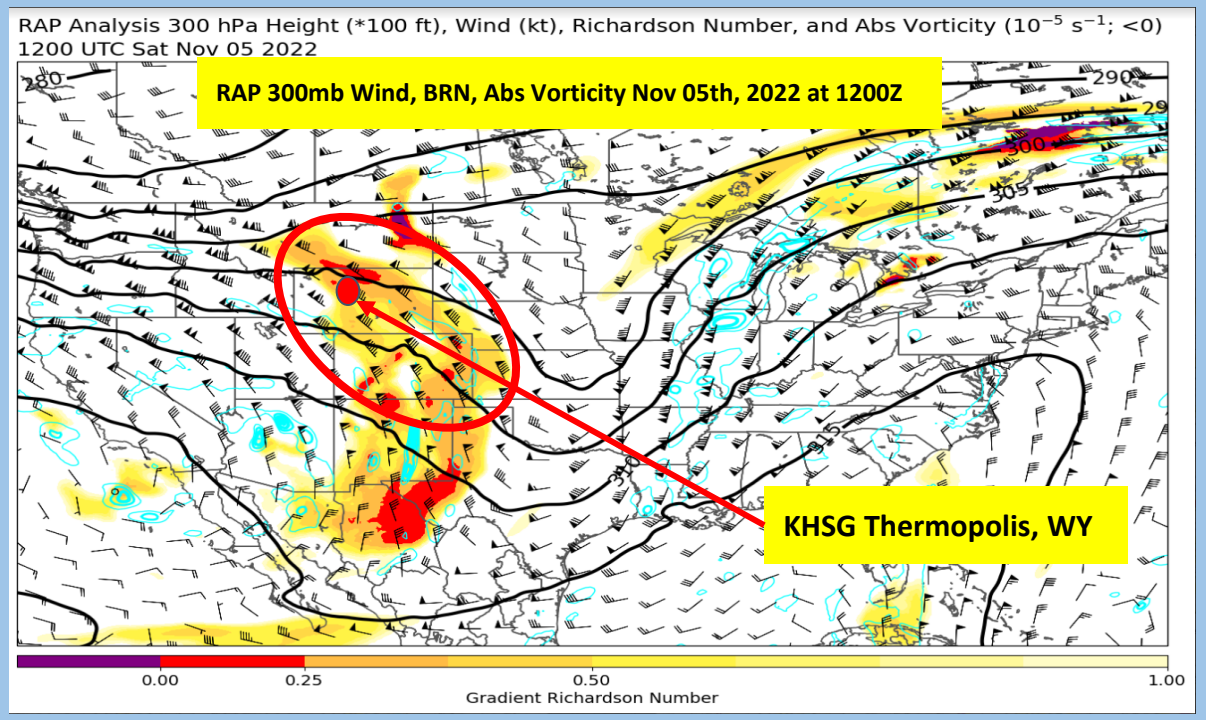
NO, monitor

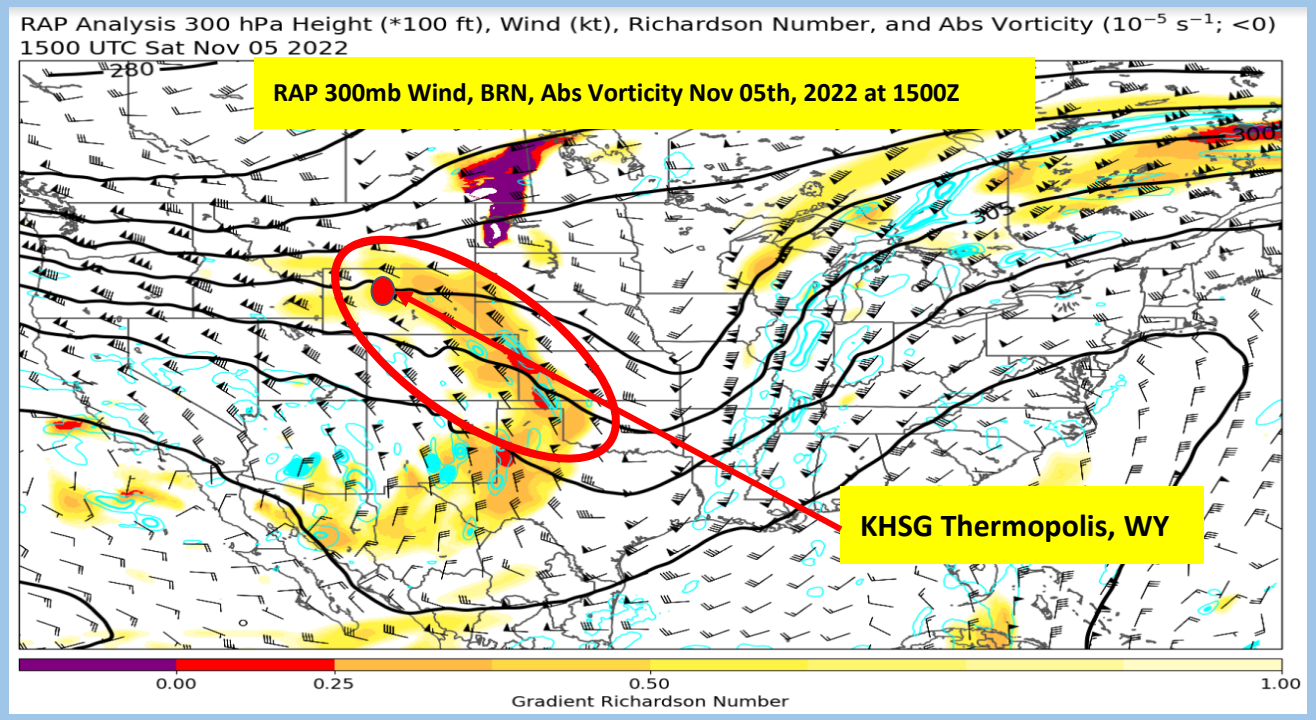
Does the strong vertical propagating motion or couplet punch through the tropopause?

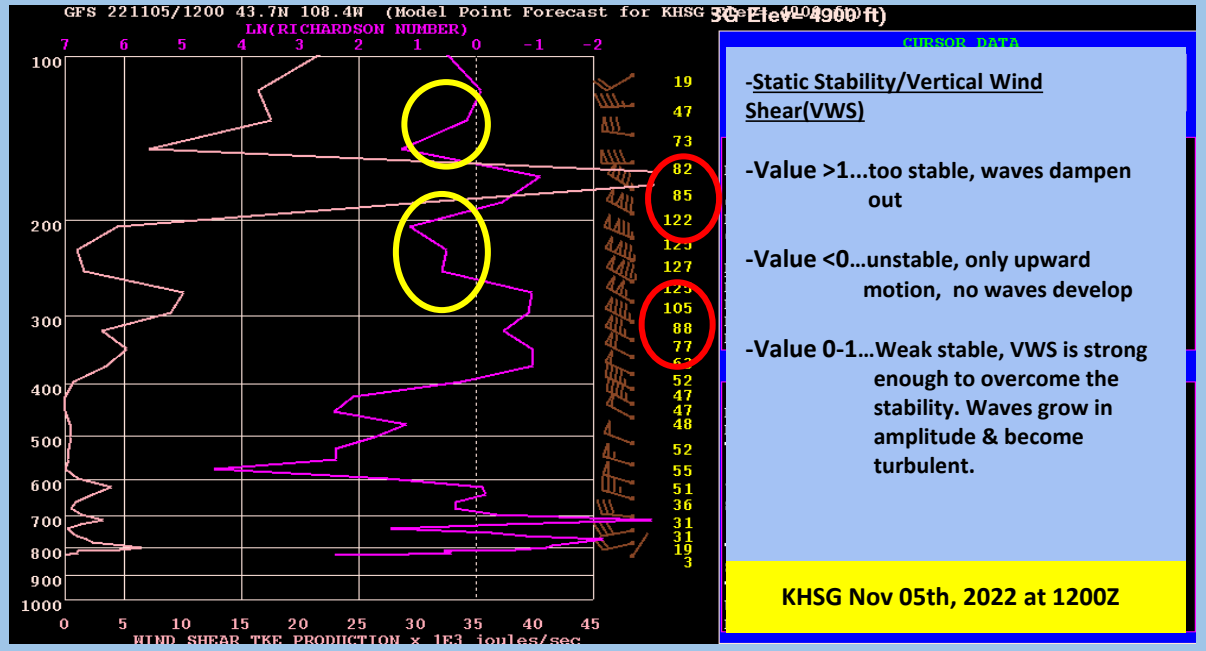
YES, keep going

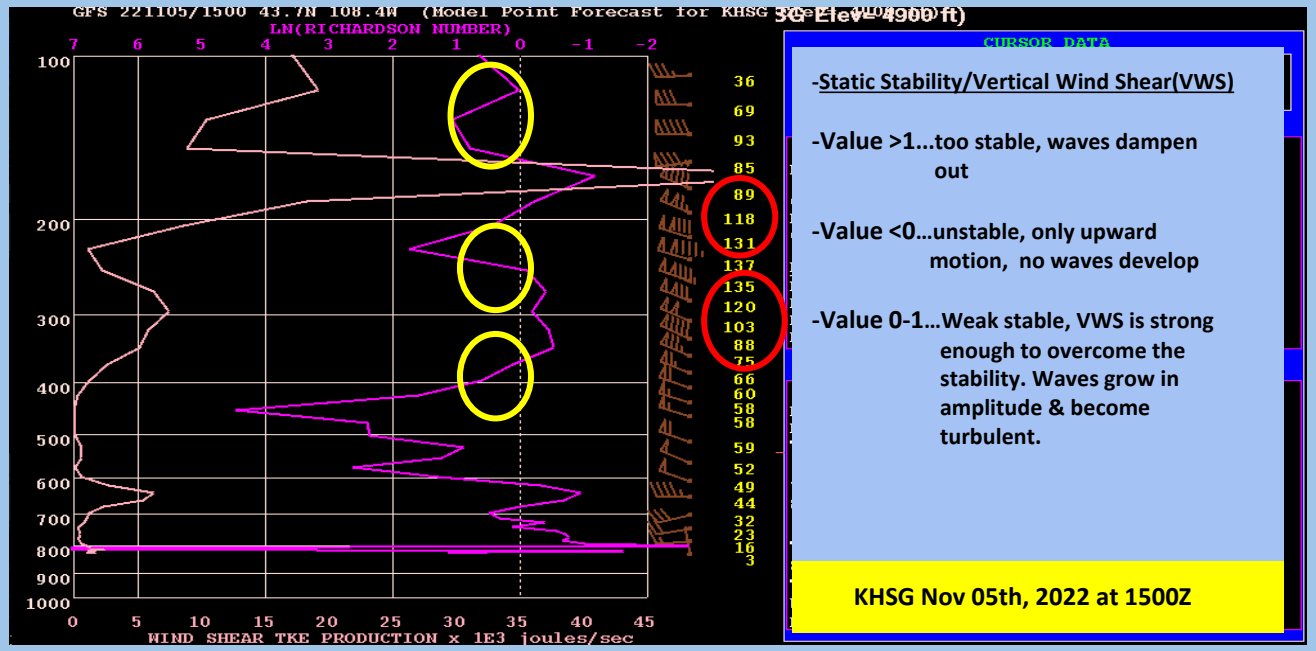
NO, monitor

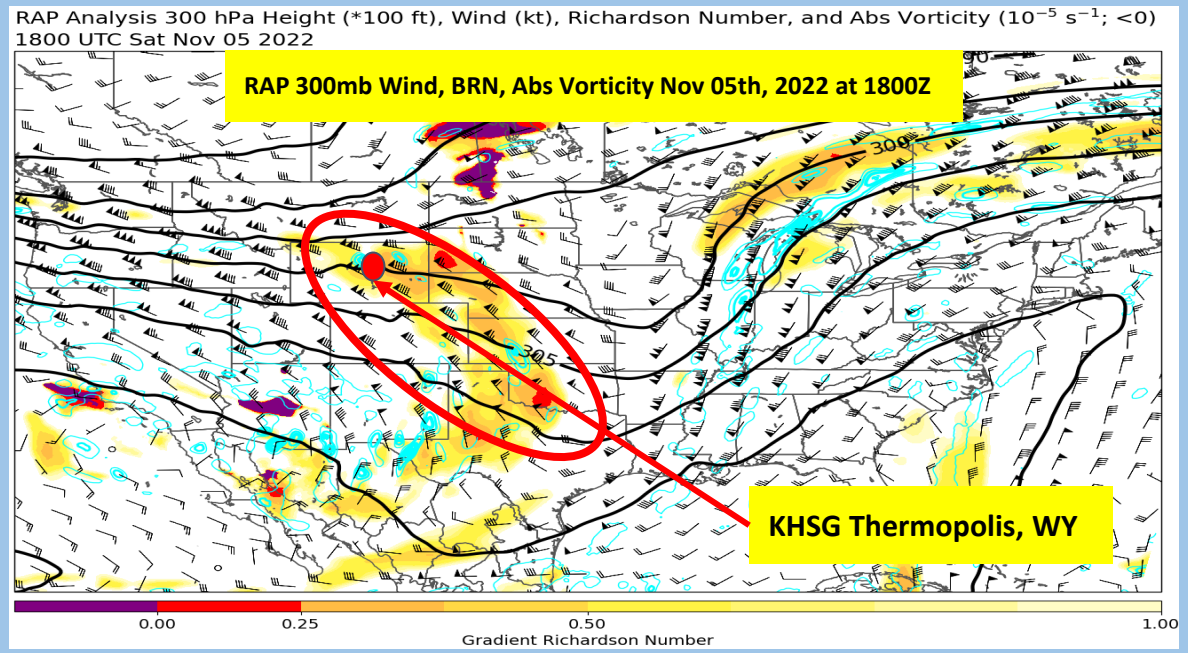
Issue the Low and/or High Severe Turbulence SIGMET

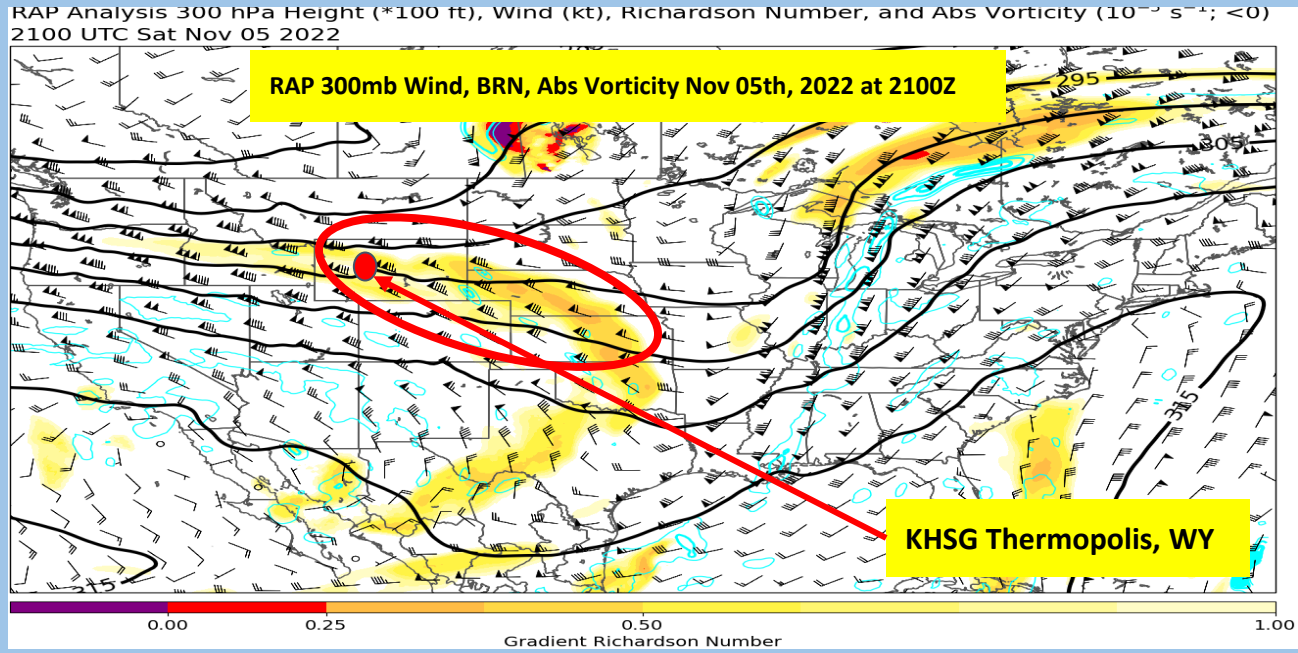

RAP Analysis 300 hPa Height (*100 ft), Wind (kt), Richardson Number, and Abs Vorticity (10^{-5} s^{-1}; <0)
1200 UTC Sat Nov 05 2022
RAP 300mb Wind, BRN, Abs Vorticity Nov 05th, 2022 at 1200Z
KHSG Thermopolis, WY
0.00
0.25
0.50
1.00
Gradient Richardson Number

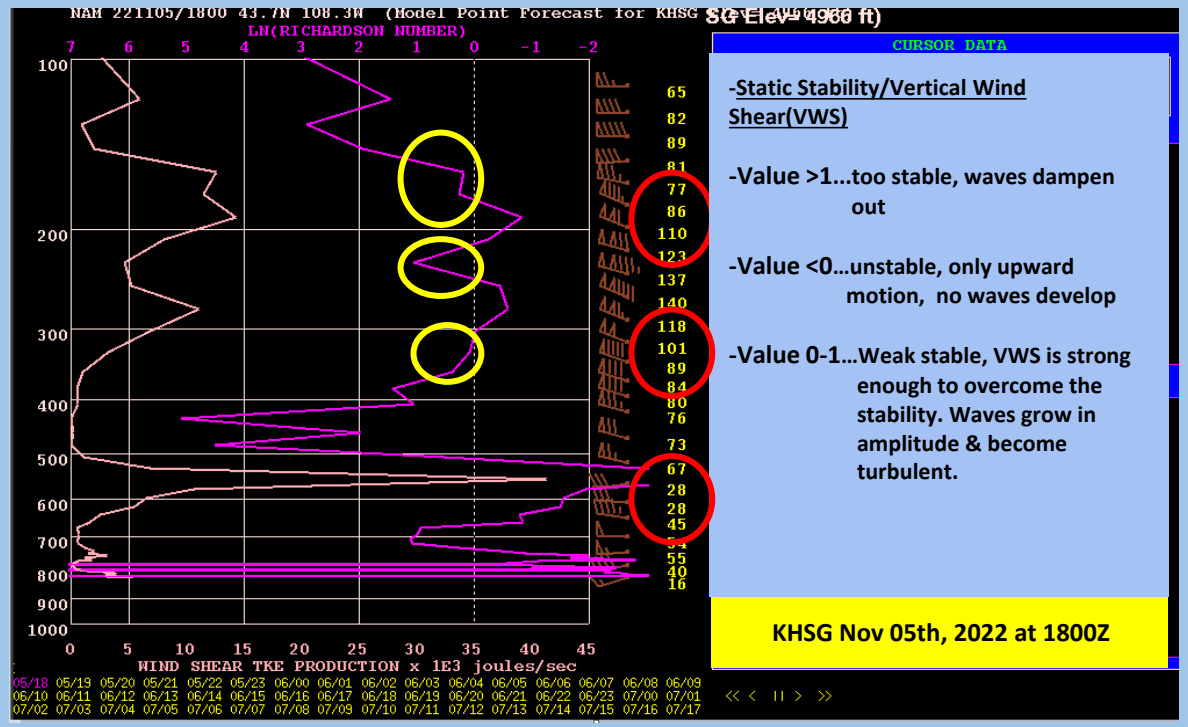

RAP Analysis 300 hPa Height (*100 ft), Wind (kt), Richardson Number, and Abs Vorticity (10^{-5} s^{-1}; <0)
1500 UTC Sat Nov 05 2022
RAP 300mb Wind, BRN, Abs Vorticity Nov 05th, 2022 at 1500Z
KHSG Thermopolis, WY
0.00
0.25
0.50
1.00
Gradient Richardson Number

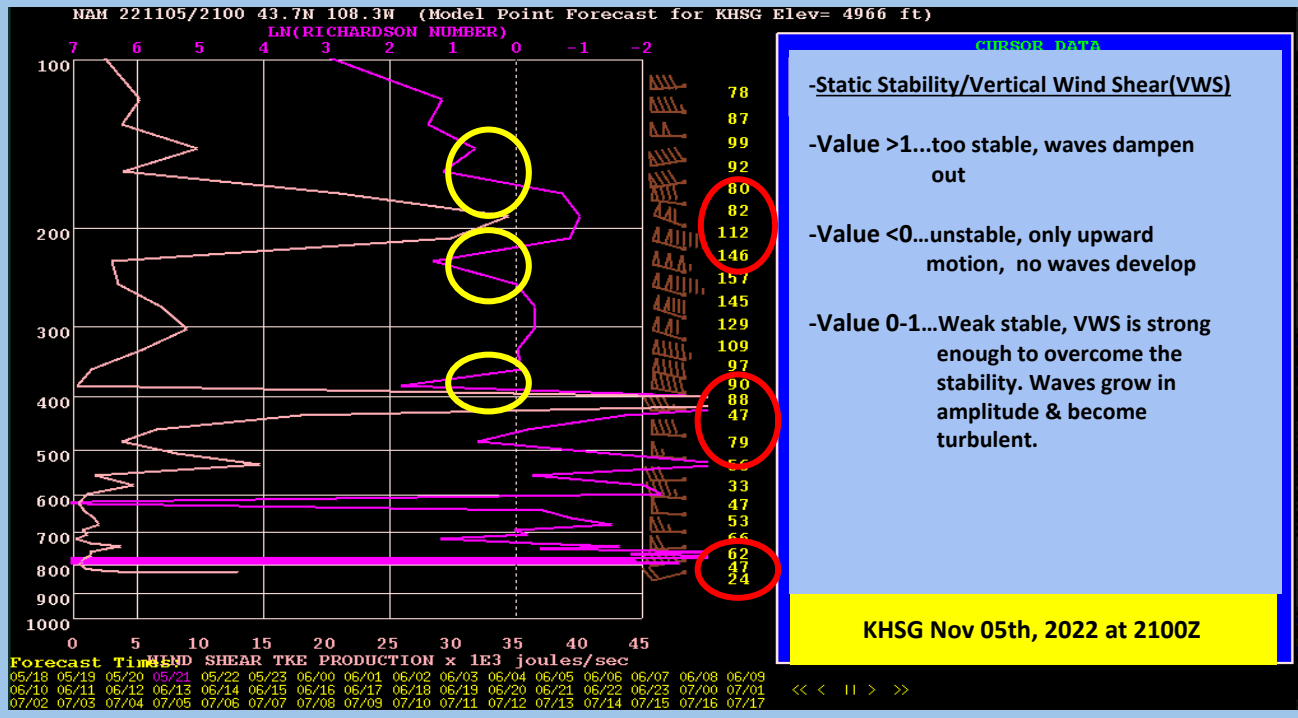

GFS 221105/1200 43.7N 108.4W (Model Point Forecast for KHSG 3G Elev=4900 ft)
LN(RICHARDSON NUMBER)
WIND SHEAR TKE PRODUCTION x 1E3 joules/sec
CURSOR DATA
-Static Stability/Vertical Wind Shear(VWS)
-Value >1...too stable, waves dampen out
-Value <0...unstable, only upward motion, no waves develop
-Value 0-1...Weak stable, VWS is strong enough to overcome the stability. Waves grow in amplitude & become turbulent.
KHSG Nov 05th, 2022 at 1200Z

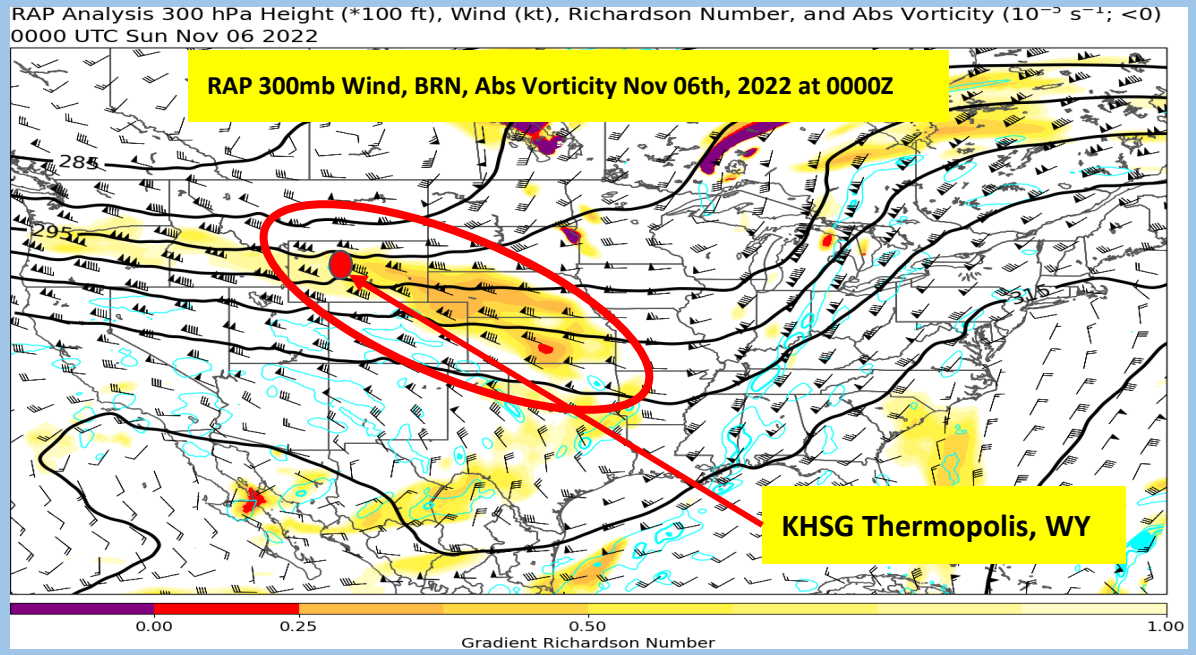

GFS 221105/1500 43.7N 108.4W (Model Point Forecast for KHSG 3G Elev=4900 ft)
LN(RICHARDSON NUMBER)
WIND SHEAR TKE PRODUCTION x 1E3 joules/sec
CURSOR DATA
-Static Stability/Vertical Wind Shear(VWS)
-Value >1...too stable, waves dampen out
-Value <0...unstable, only upward motion, no waves develop
-Value 0-1...Weak stable, VWS is strong enough to overcome the stability. Waves grow in amplitude & become turbulent.
KHSG Nov 05th, 2022 at 1500Z

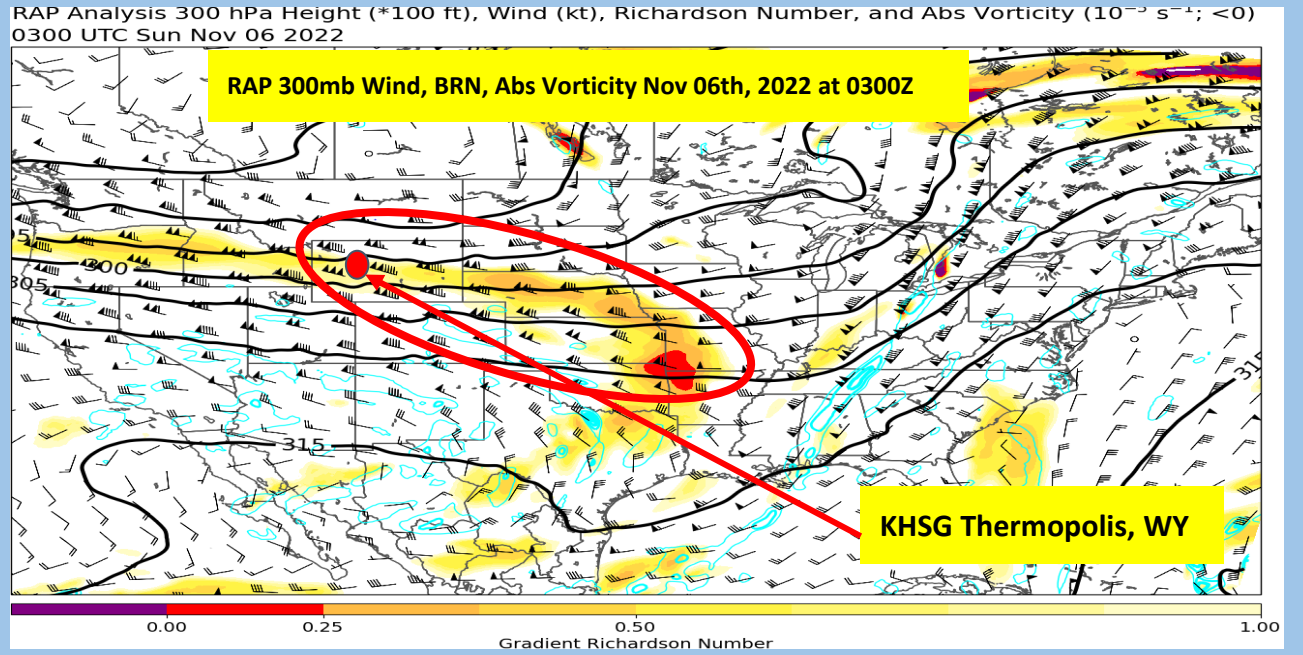

RAP Analysis 300 hPa Height (*100 ft), Wind (kt), Richardson Number, and Abs Vorticity (10^{-5} s^{-1}; <0)
1800 UTC Sat Nov 05 2022
RAP 300mb Wind, BRN, Abs Vorticity Nov 05th, 2022 at 1800Z
KHSG Thermopolis, WY
0.00
0.25
0.50
1.00
Gradient Richardson Number

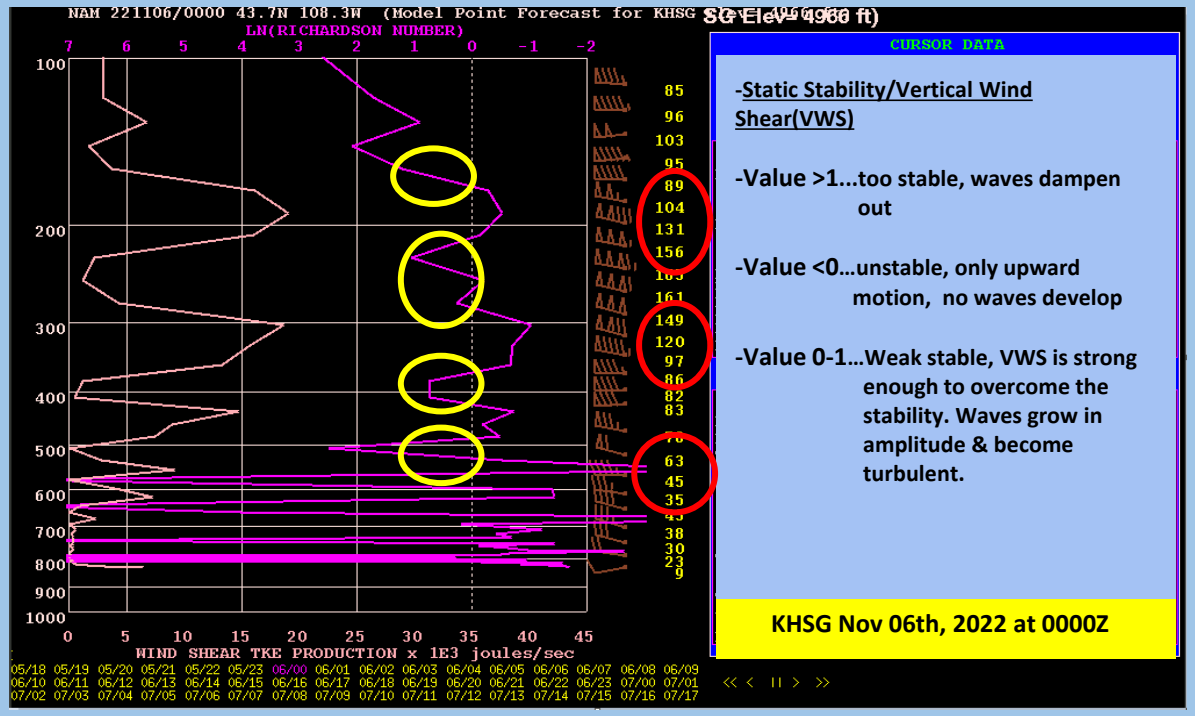

RAP Analysis 300 hPa Height (*100 ft), Wind (kt), Richardson Number, and Abs Vorticity (10^{-5} s^{-1}; <0)
2100 UTC Sat Nov 05 2022
RAP 300mb Wind, BRN, Abs Vorticity Nov 05th, 2022 at 2100Z
KHSG Thermopolis, WY
0.00
0.25
0.50
1.00
Gradient Richardson Number

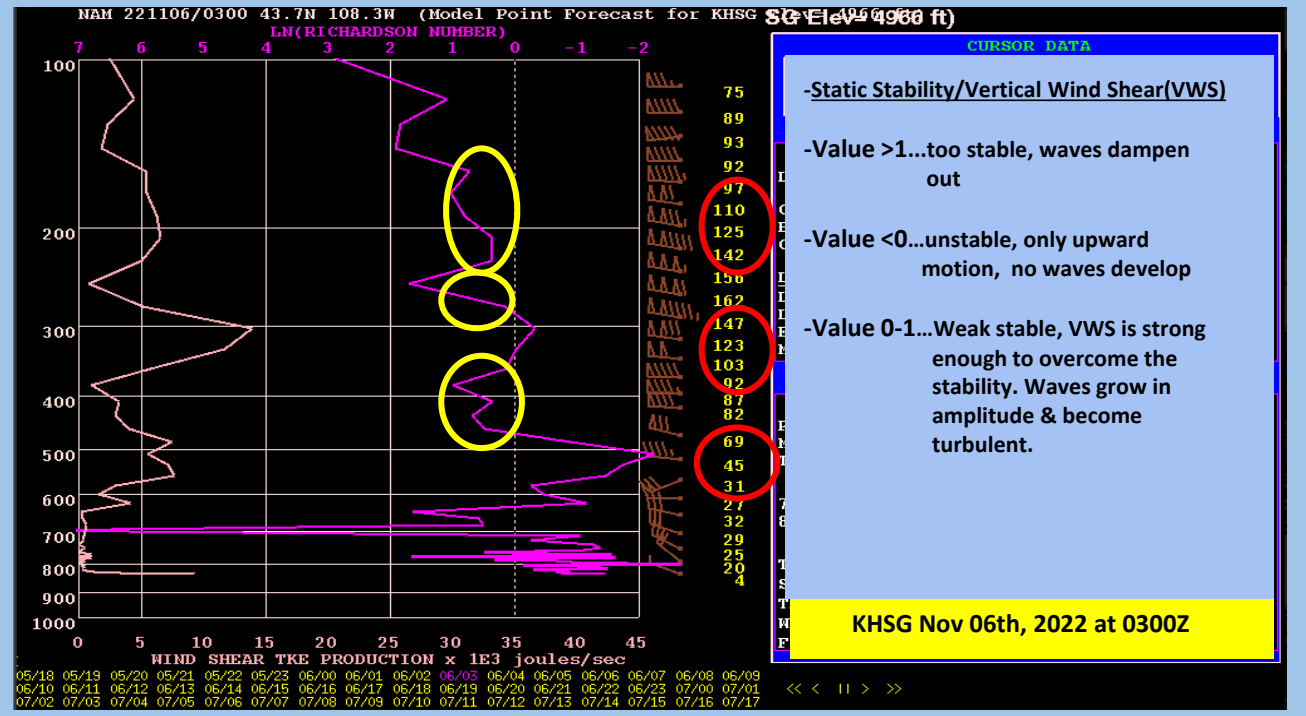

NAM 221105/1800 43.7N 108.3W (Model Point Forecast for KHSG Elev= 4966 ft)
LN(RICHARDSON NUMBER)
WIND SHEAR TKE PRODUCTION x 1E3 joules/sec
CURSOR DATA
-Static Stability/Vertical Wind Shear(VWS)
-Value >1...too stable, waves dampen out
-Value <0...unstable, only upward motion, no waves develop
-Value 0-1...Weak stable, VWS is strong enough to overcome the stability. Waves grow in amplitude & become turbulent.
KHSG Nov 05th, 2022 at 1800Z

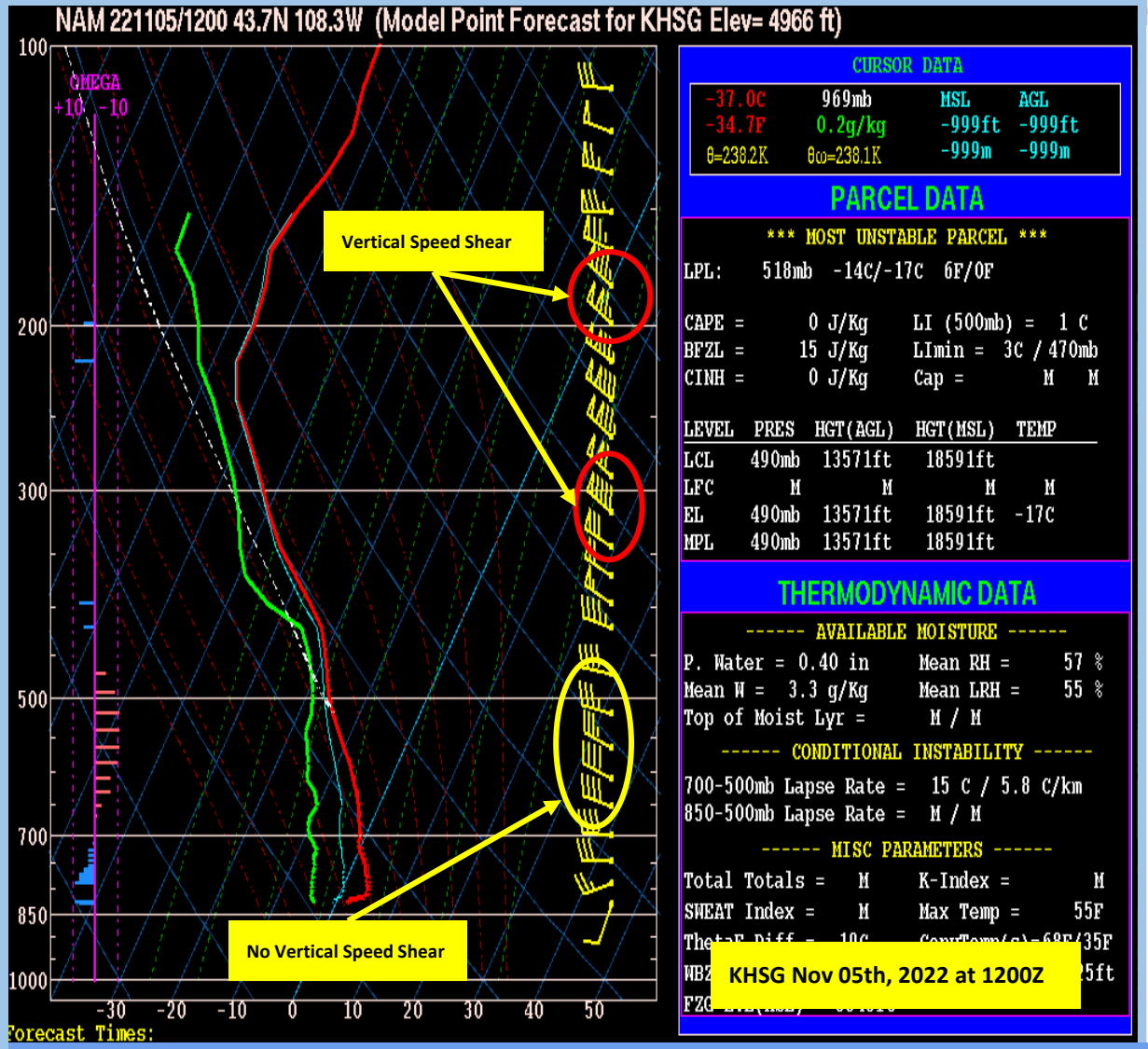

NAM 221105/2100 43.7N 108.3W (Model Point Forecast for KHSG Elev= 4966 ft)
LN(RICHARDSON NUMBER)
WIND SHEAR TKE PRODUCTION x 1E3 joules/sec
Forecast Time
CURSOR DATA
-Static Stability/Vertical Wind Shear(VWS)
-Value >1...too stable, waves dampen out
-Value <0...unstable, only upward motion, no waves develop
-Value 0-1...Weak stable, VWS is strong enough to overcome the stability. Waves grow in amplitude & become turbulent.
KHSG Nov 05th, 2022 at 2100Z

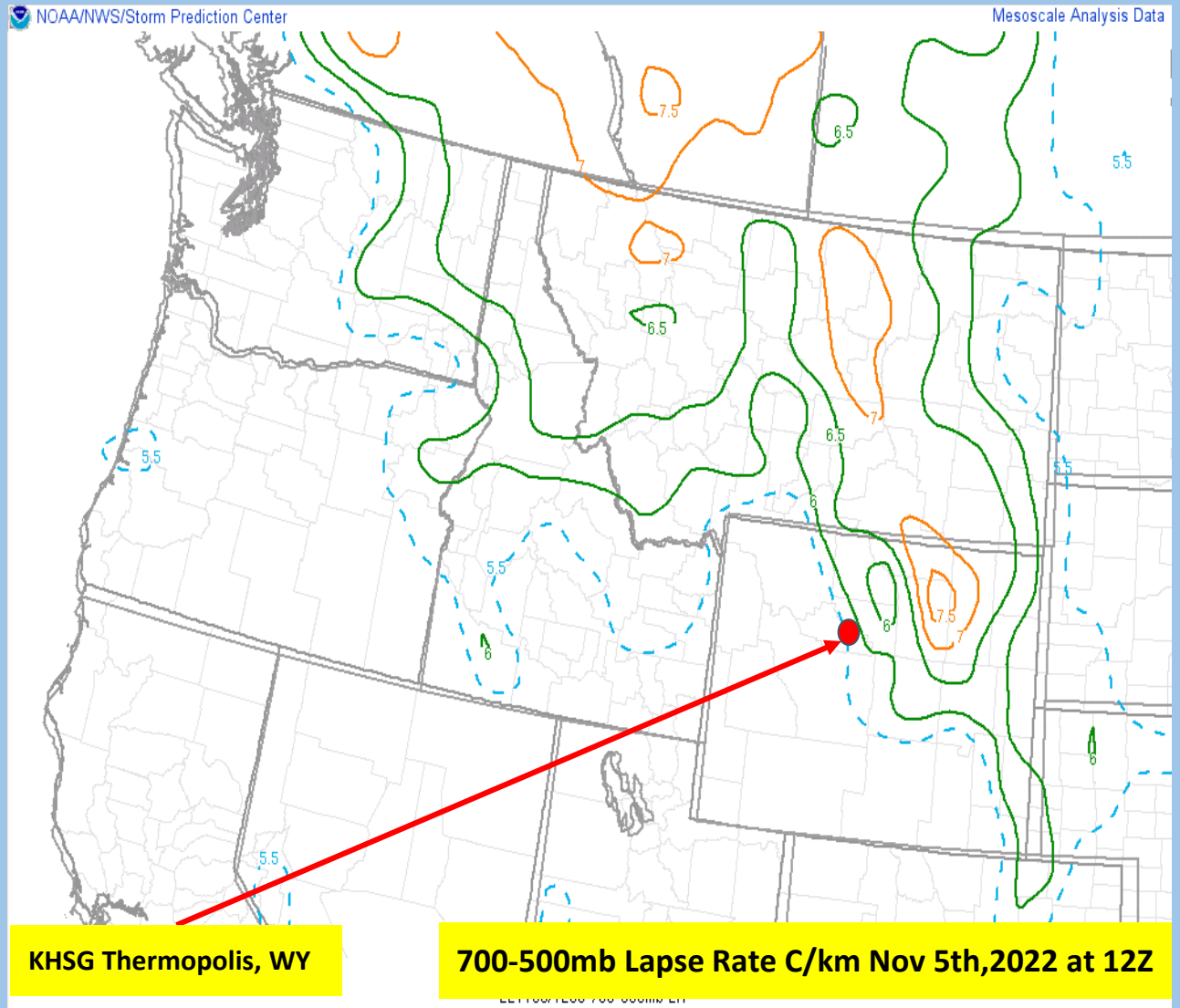

RAP Analysis 300 hPa Height (*100 ft), Wind (kt), Richardson Number, and Abs Vorticity (10⁻⁵ s⁻¹; <0)
0000 UTC Sun Nov 06 2022
RAP 300mb Wind, BRN, Abs Vorticity Nov 06th, 2022 at 0000Z
KHSG Thermopolis, WY
0.00
0.25
0.50
1.00
Gradient Richardson Number


RAP Analysis 300 hPa Height (*100 ft), Wind (kt), Richardson Number, and Abs Vorticity (10⁻⁵ s⁻¹; <0)
0300 UTC Sun Nov 06 2022
RAP 300mb Wind, BRN, Abs Vorticity Nov 06th, 2022 at 0300Z
KHSG Thermopolis, WY
0.00
0.25
0.50
1.00
Gradient Richardson Number

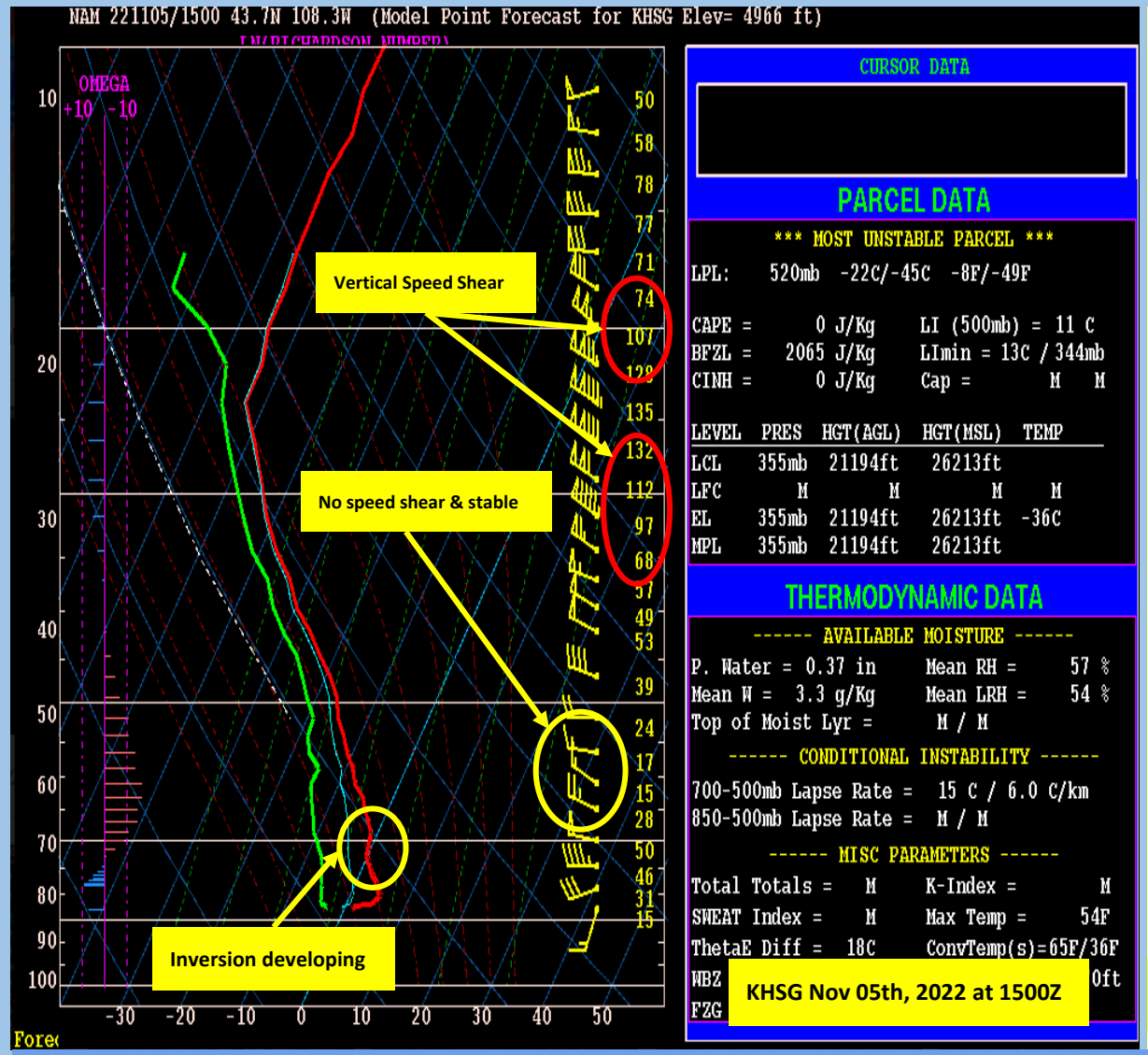

NAM 221106/0000 43.7N 108.3W (Model Point Forecast for KHSG
SG Elev= 4960 ft)
LN(RICHARDSON NUMBER)
WIND SHEAR TKE PRODUCTION x 1E3 joules/sec
CURSOR DATA
-Static Stability/Vertical Wind Shear(VWS)
-Value >1...too stable, waves dampen out
-Value <0...unstable, only upward motion, no waves develop
-Value 0-1...Weak stable, VWS is strong enough to overcome the stability. Waves grow in amplitude & become turbulent.
KHSG Nov 06th, 2022 at 0000Z

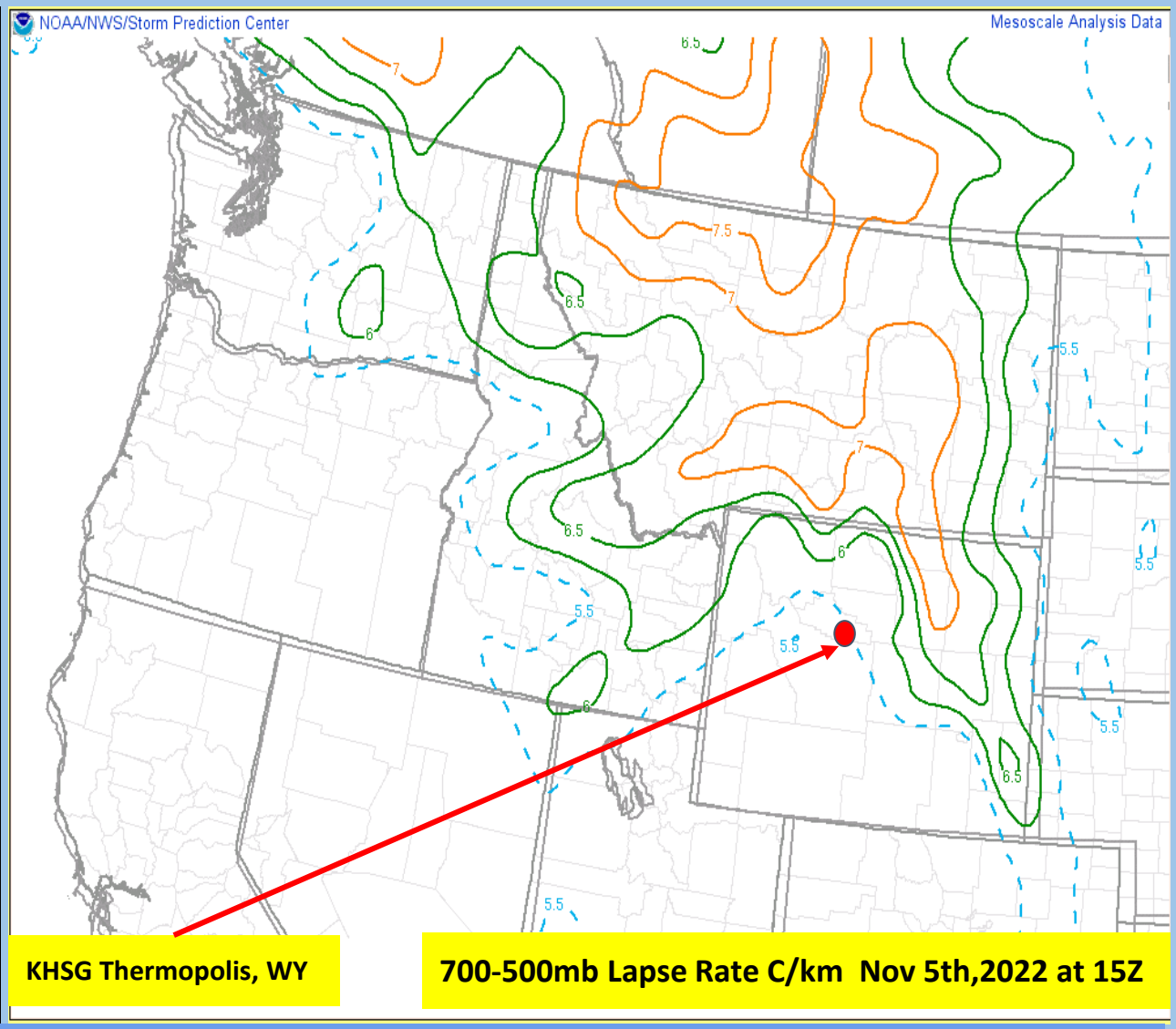

NAM 221106/0300 43.7N 108.3W (Model Point Forecast for KHSG
SG Elev= 4960 ft)
LN(RICHARDSON NUMBER)
WIND SHEAR TKE PRODUCTION x 1E3 joules/sec
CURSOR DATA
-Static Stability/Vertical Wind Shear(VWS)
-Value >1...too stable, waves dampen out
-Value <0...unstable, only upward motion, no waves develop
-Value 0-1...Weak stable, VWS is strong enough to overcome the stability. Waves grow in amplitude & become turbulent.
KHSG Nov 06th, 2022 at 0300Z



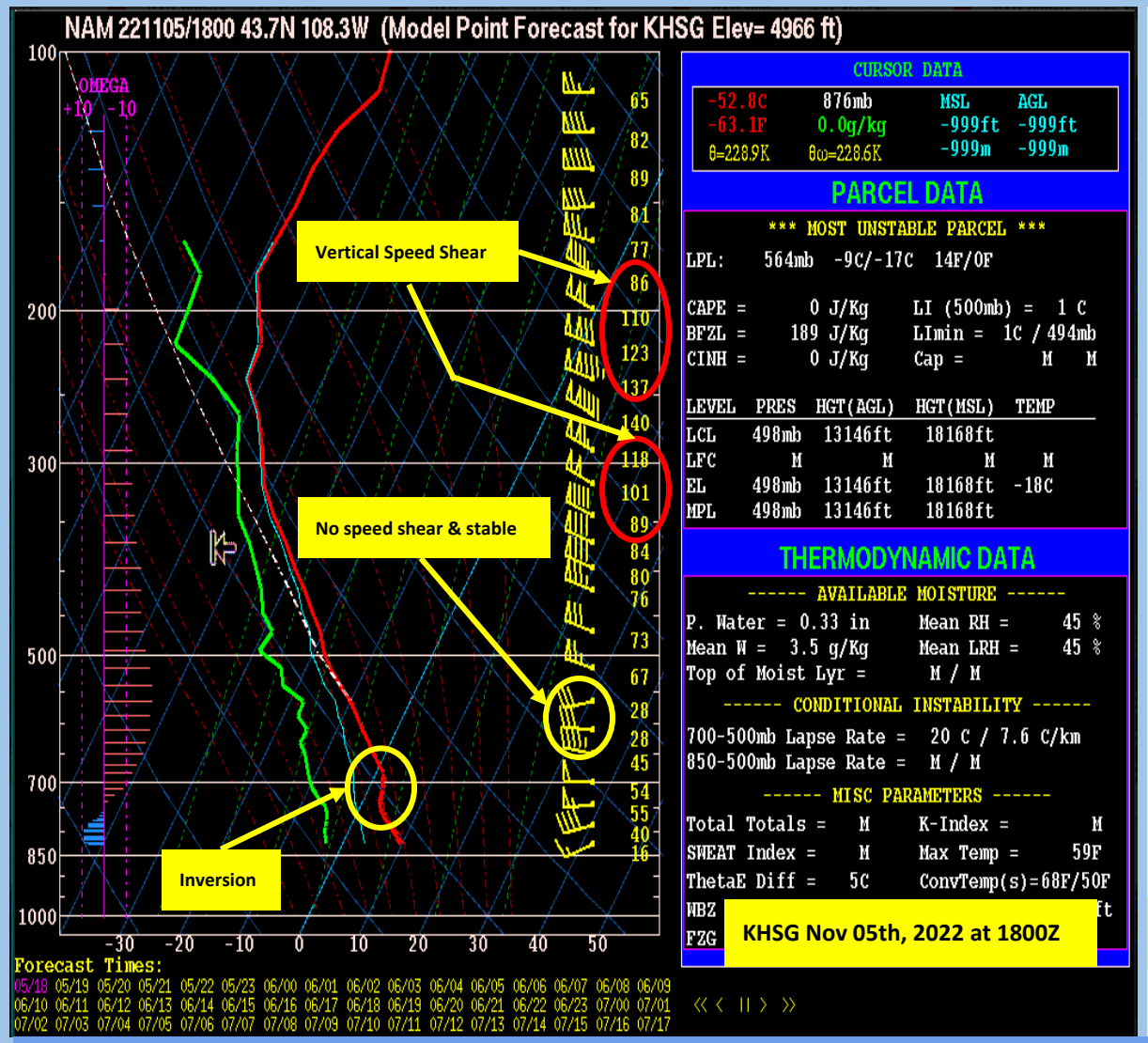


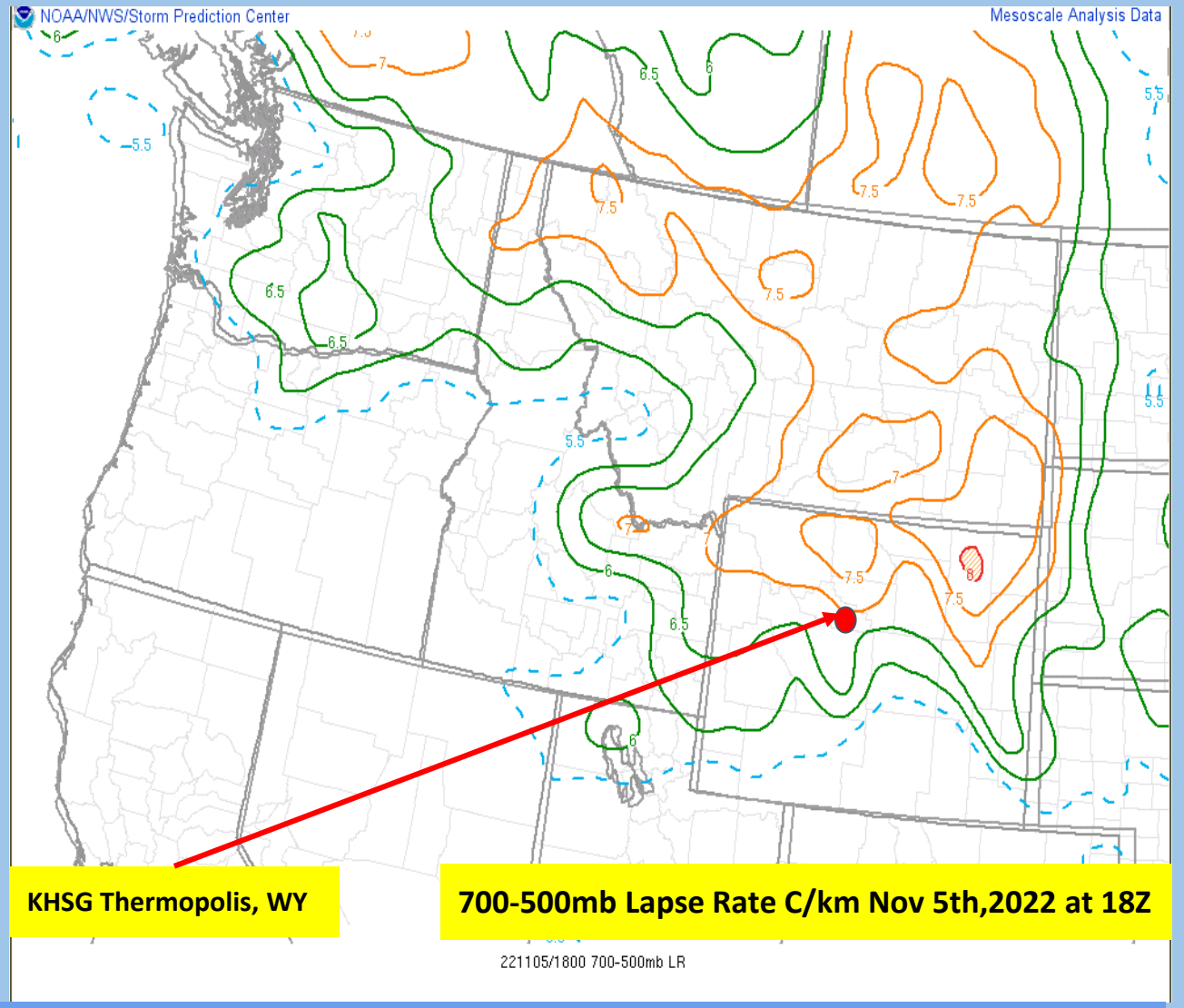
The KHSG skew-t at 12Z was showing forward wind shear profile. There looked to be vertical speed shear around 300mb and 200mb depicted with the red ovals. Looking at the Storm Prediction Center's 700-500mb lapse rates the Tetons and portions of the Big Horn mountains had stable conditions in the layer above the ridge tops. This feature as well extends to northern Rockies covering the Big Belt and the Abasaroka mountains. The importance of having stable lapse rate for 100-200mb above inversion or ridge tops it allows the possible development of couplet on lee side of mountains for hydraulic jump.



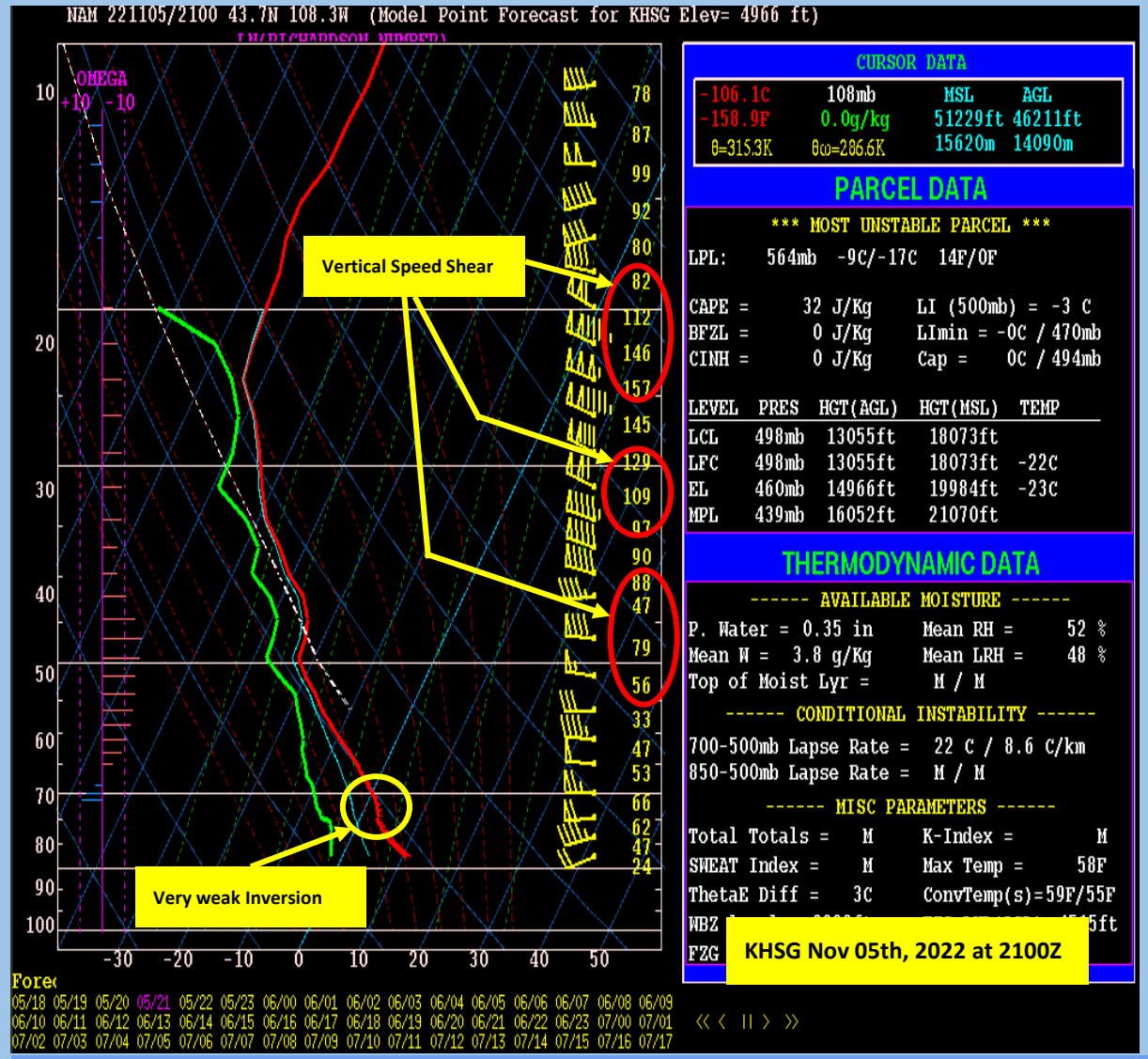


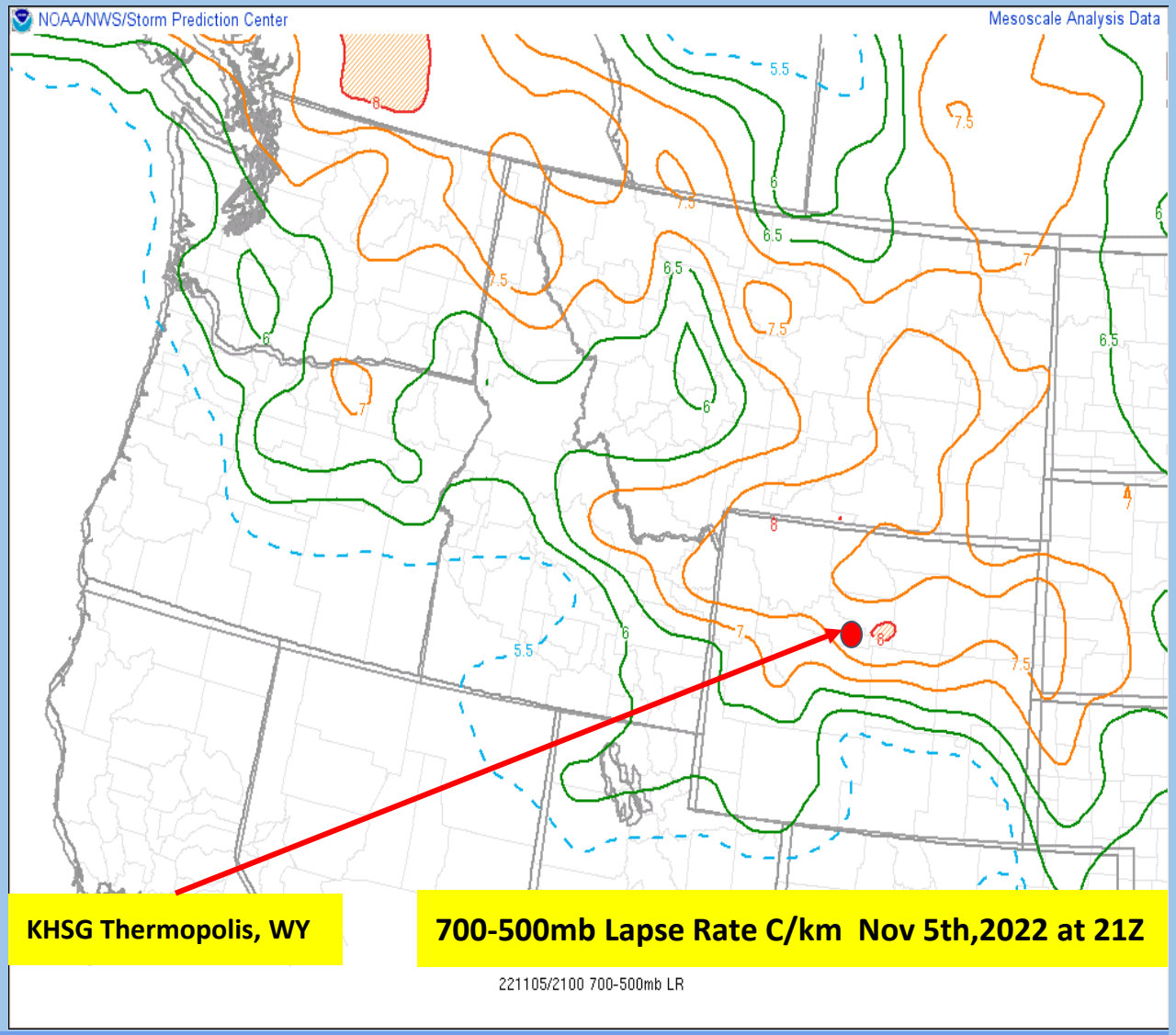
The KHSG skew-t at 15Z was showing a key feature with the development of inversion near the mountain ridge top. The 100-200mb layer above the inversion is then stable and the 700-500mb lapse rate over KHSG has a 5.5 C/Km which is another indicator of a stable layer near the mountain ridge top and will allow the development of a possible couplet on the lees side of the mountain. the upcoming cross-section slide (36) will show a strong upward vertical motion couplet that is shown easily punching through the tropopause. There looks to be vertical speed shear around 300mb and 200mb depicted with the red ovals.



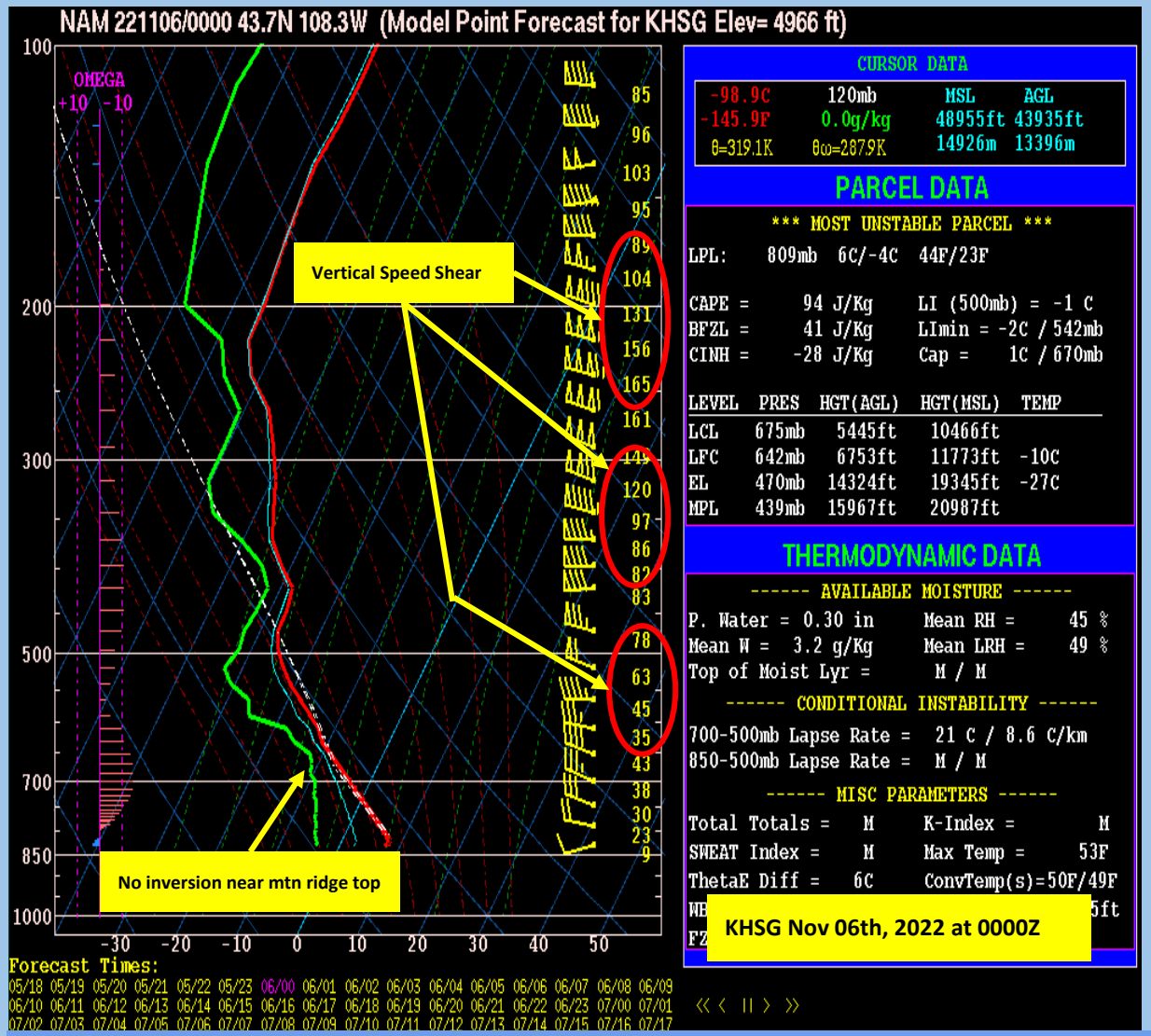


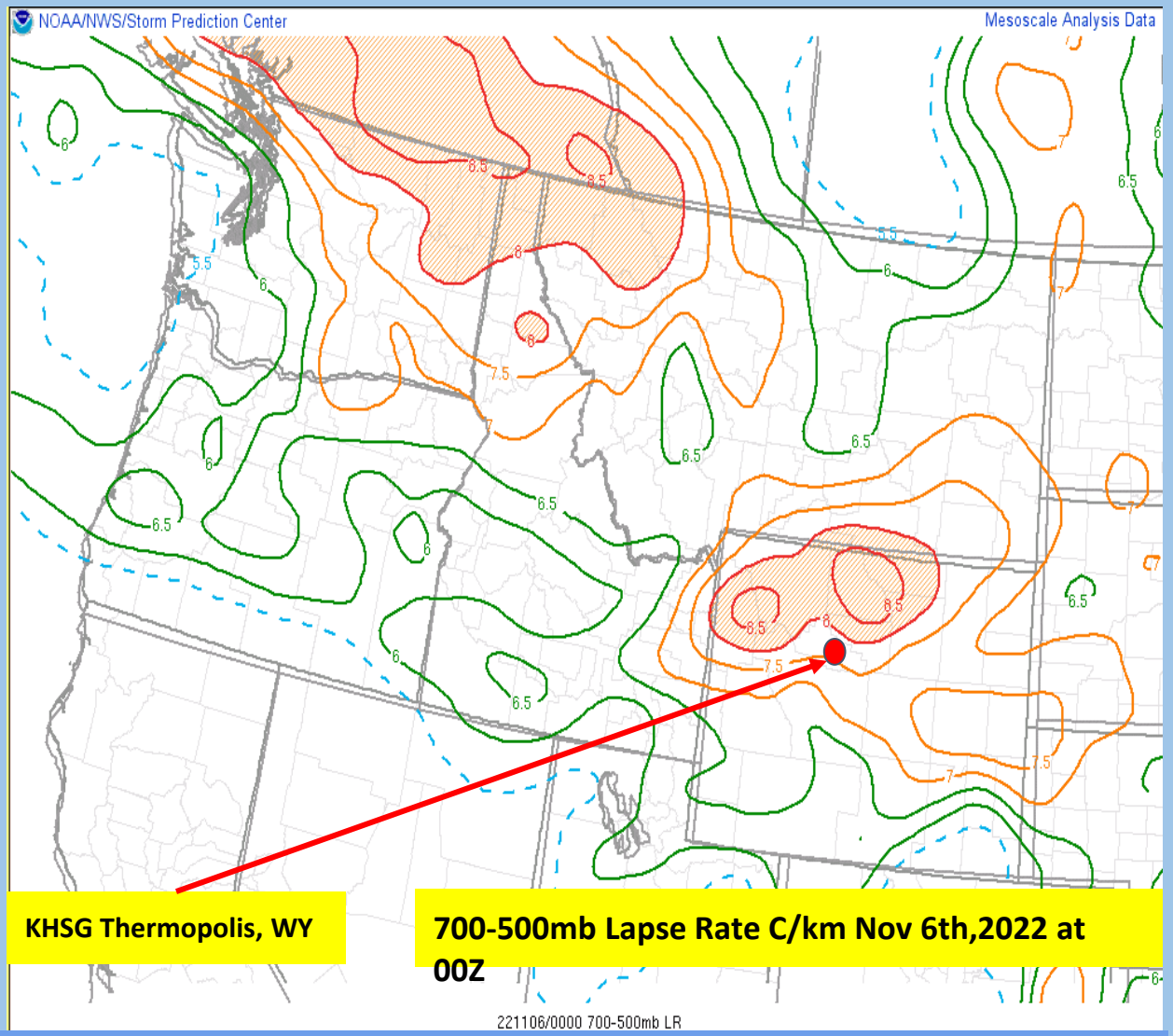
The KHSG skew-t at 18Z continues to show an inversion near the mountain ridge top near 680mb. The 100-200mb layer above the inversion still depicts stable conditions but had a higher 700-500mb lapse rate over KHSG around 6.8 C/Km. The cross-section on slide (36) shows a very strong upward vertical motion couplet propagating wave and punched through the tropopause. There looks to be vertical speed shear around 300mb and 200mb depicted with the red ovals. There were no severe mtn-wave pilot reports over the Tetons during this timeframe and not sure if it was due to the higher lapse rates.



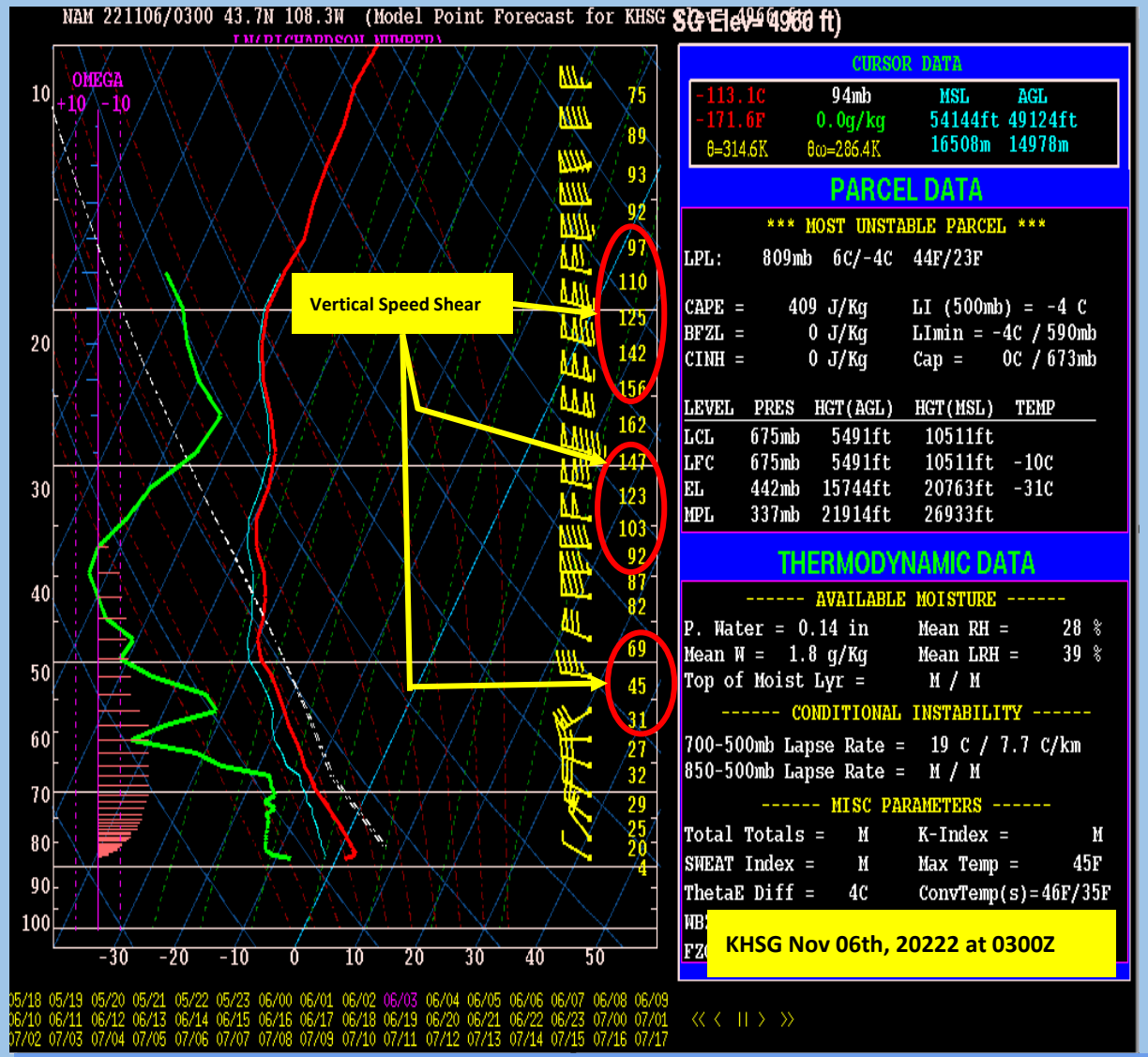


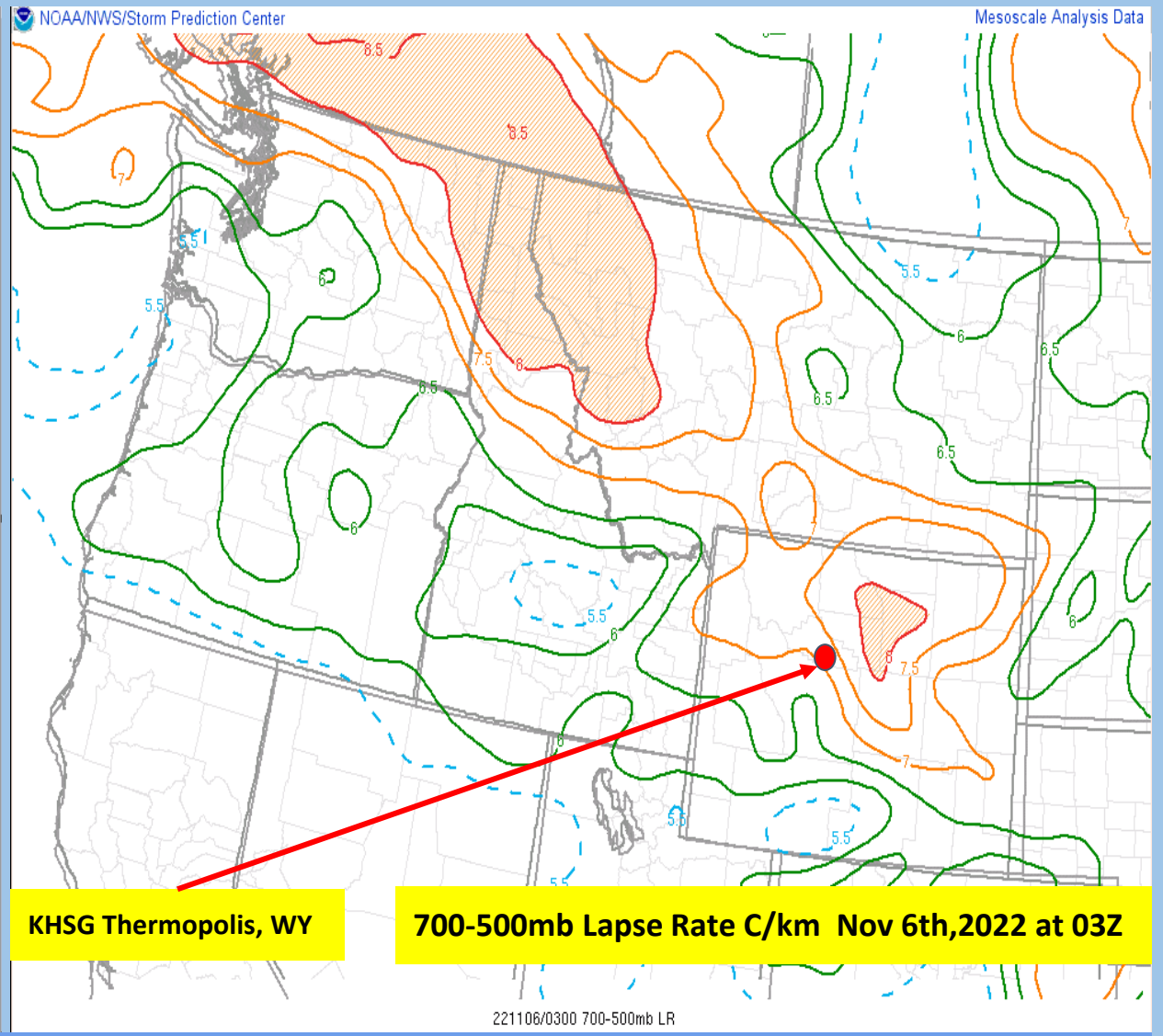
The KHSG skew-t at 21Z looks like the inversion has weakened and the 100-200mb layer above has stronger vertical speed shear. This coincides with the 700-500mb lapse rates near 8.0 C/km. Which inhibits mountain wave development but slide (37) shows the 11/05/21Z cross-section over KHSG still depicts a strong upward vertical motion couplet propagating wave and punching through the tropopause. There looks to be vertical speed shear around 300mb, 200mb, and 400mb depicted with the red ovals. There were only low level severe turbulence pilot reports over the Tetons during this timeframe.





The KHSG skew-t at 06/00Z shows no inversion near the mountain ridge top and the 100-200mb layer above has stronger vertical speed shear. This coincides with the 700-500mb lapse rates near 8.0 C/km. Which inhibits mountain wave development but slide (38) shows the 11/06/00Z cross-section over KHSG still has a strong upward vertical motion couplet propagating wave and punching through the tropopause. There looks to be vertical speed shear around 300mb, 200mb, and 500mb depicted with the red ovals. There were only low level severe turbulence pilot reports over the Tetons during this timeframe.





The KHSG skew-t at 06/03Z still shows no inversion near the mountain ridge top and the 100-200mb layer above has stronger vertical speed shear. This coincides with the 700-500mb lapse rates near 7.0 C/km. Which inhibits mountain wave development but slide (39) shows the 11/06/00Z cross-section over KHSG a slightly weaker upward vertical motion couplet propagating wave as it punches through the tropopause. There looks to be vertical speed shear around 300mb, 200mb, and 500mb depicted with the red ovals. There were only low level severe turbulence pilot reports over the Tetons during this timeframe.

MOUNTAIN WAVE INDUCED TURBULENCE DECISION TREE

Do you have perpendicular cross-barrier flow with surface wind speeds 35kts or greater? Do you have ridge top wind speeds 50kts or greater?

YES, keep going

NO, not likely

Does Satellite show Foehn gap or subsidence & any severe turbulence pilot reports?

YES, keep going

NO, not likely

Is there an inversion near the mountain tops?

(This allows for vertical propagating couplet to develop in stable region)

YES, keep going

NO, not likely

Do you have a sharp or tight strong updraft/downdraft couplet?

YES, keep going

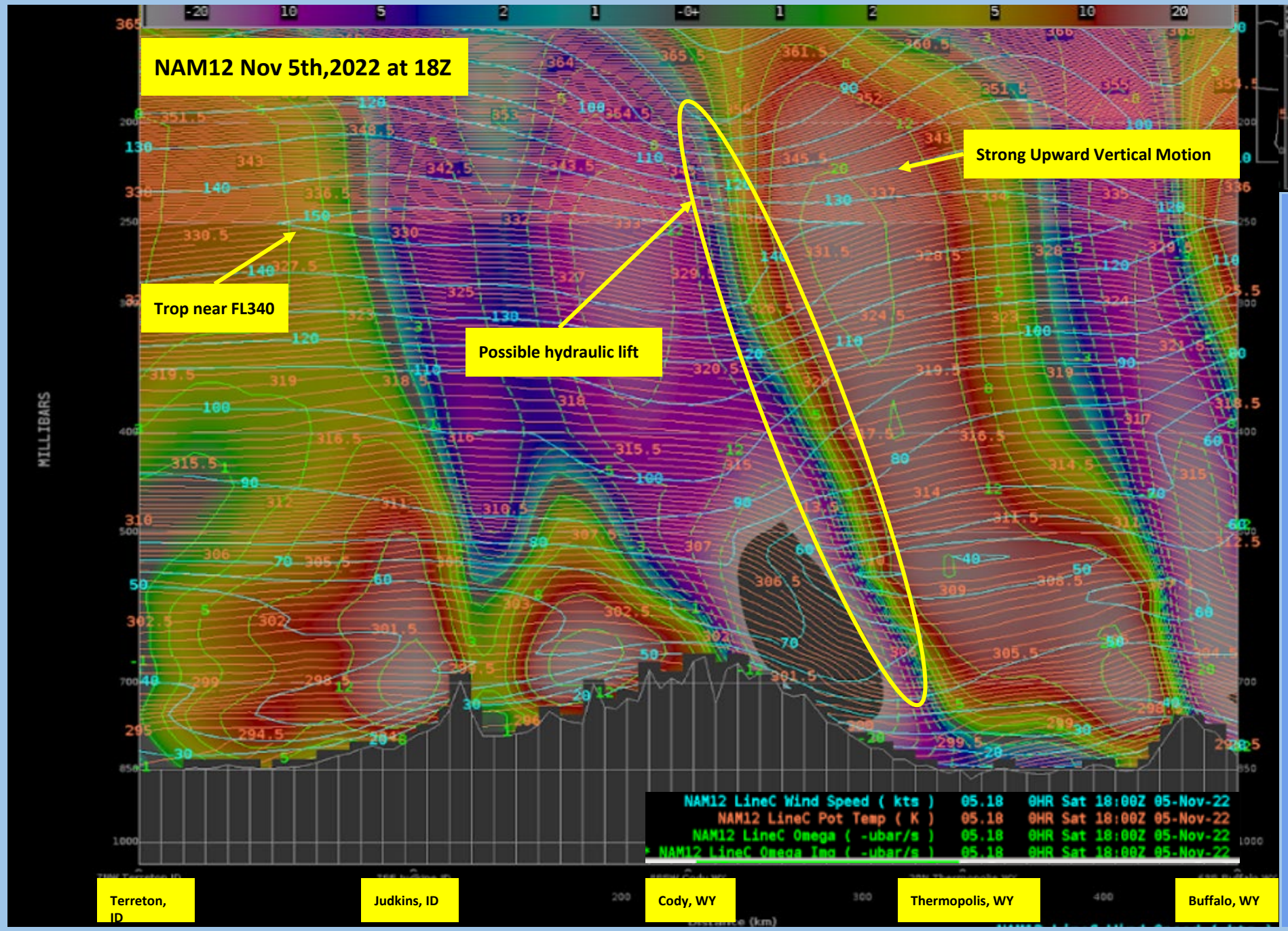
NO, monitor

Does the strong vertical propagating motion or couplet punch through the tropopause?

YES, keep going

NO, monitor

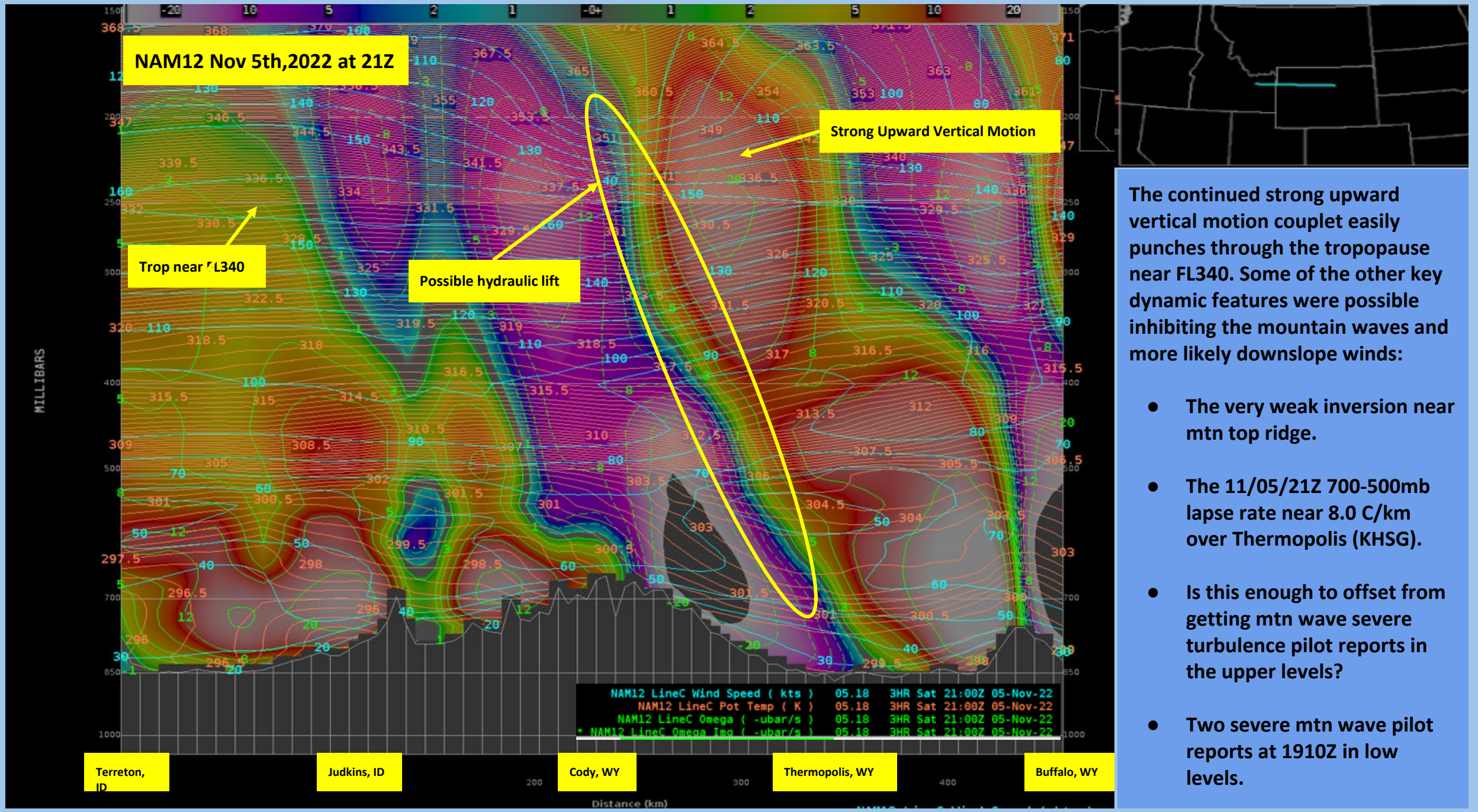
Issue the Low and/or High Severe Turbulence SIGMET





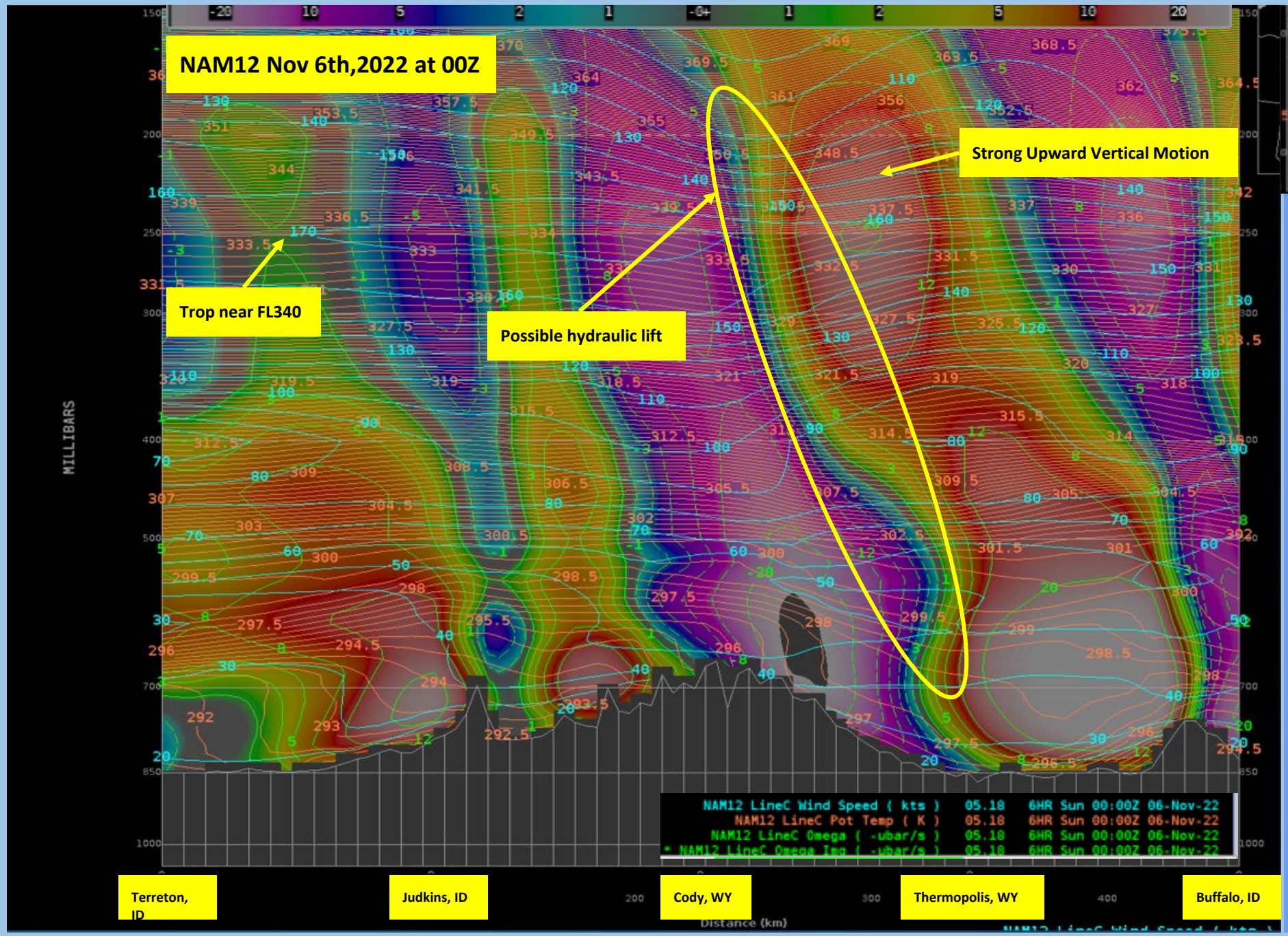
The strong upward vertical motion couplet easily punches through the tropopause near FL340. There were alot of other key dynamic features that aided in producing the potential for mountain waves:

- The RAPGTG Mtn wave composites from FL340 thru FL450 had strong bullseye indices over the Tetons.
- The 300mb nose of jetstreak over the Tetons.
- The RAP 2,000ft AGL had strong westerly 70kts winds.
- The 11/05/15Z 700-500mb lapse rate of 5.8 C/km over Thermopolis (KHSG).



The continued strong upward vertical motion couplet easily punches through the tropopause near FL340. Some of the other key dynamic features were possible inhibiting the mountain waves and more likely downslope winds:

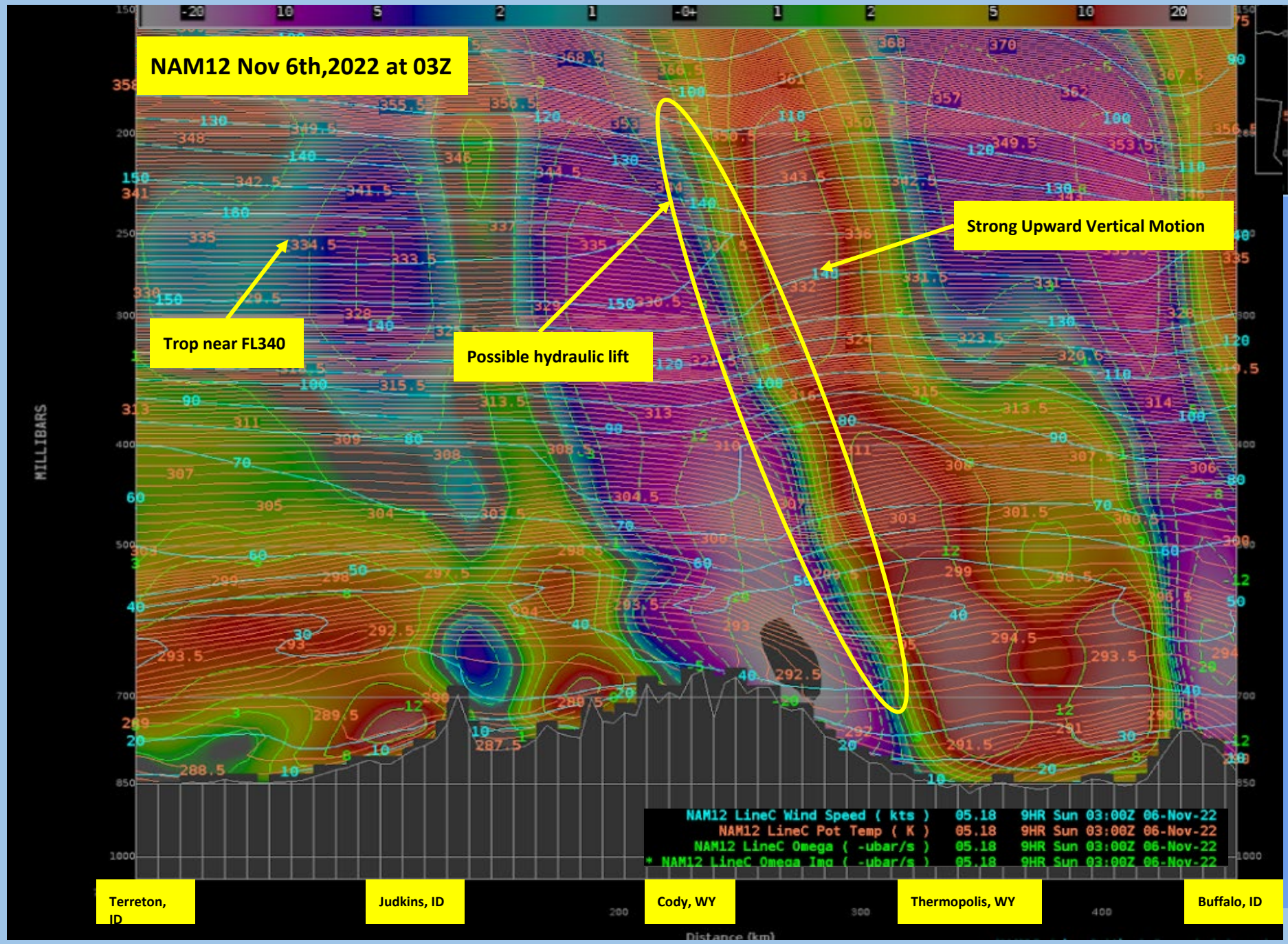
- The very weak inversion near mtn top ridge.
- The 11/05/21Z 700-500mb lapse rate near 8.0 C/km over Thermopolis (KHSG).
- Is this enough to offset from getting mtn wave severe turbulence pilot reports in the upper levels?
- Two severe mtn wave pilot reports at 1910Z in low levels.





The continued strong upward vertical motion couplet easily punches through the tropopause near FL340. Some of the other key dynamic features were possible inhibiting the mountain waves and more likely downslope winds:

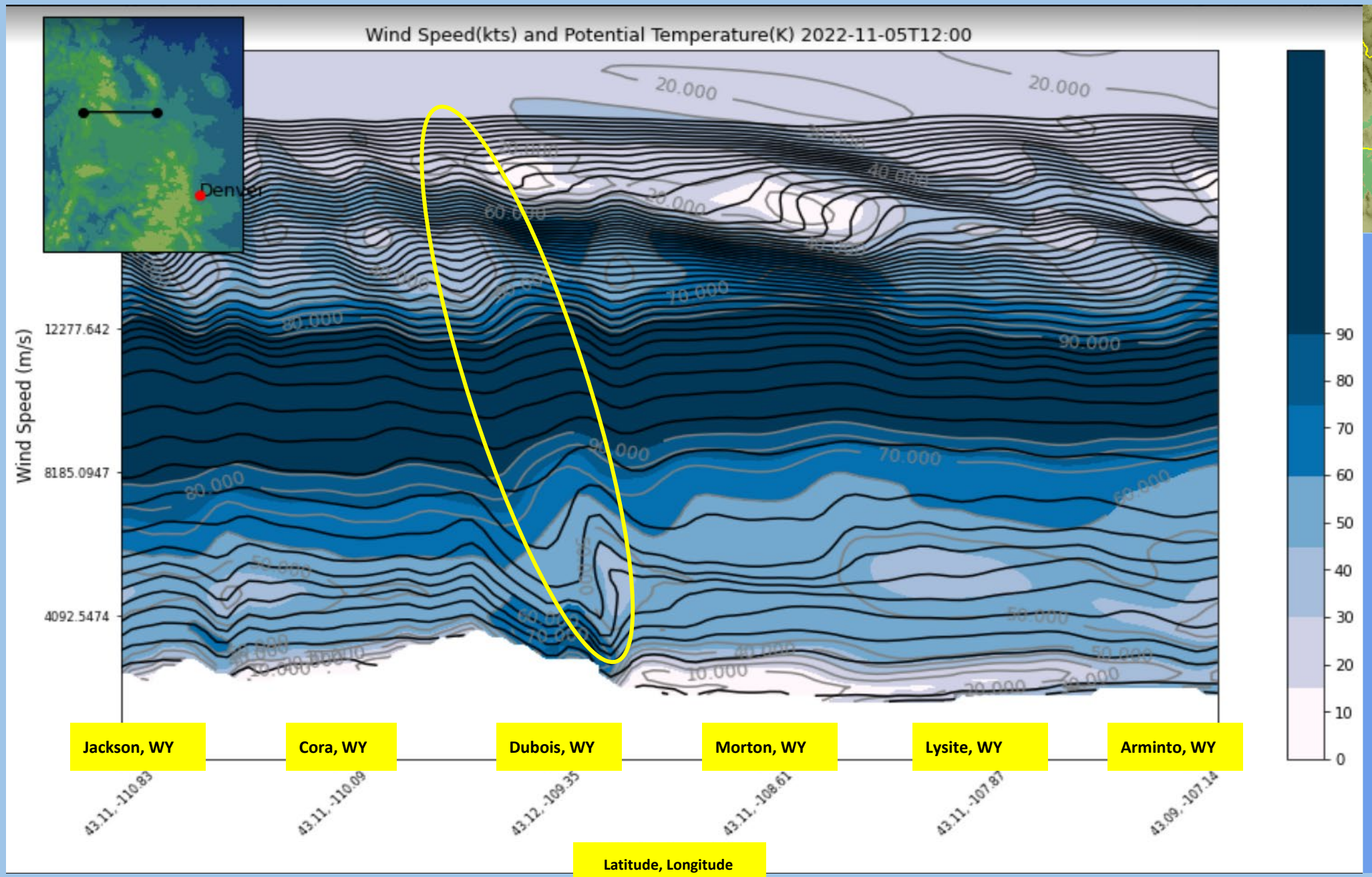
- No inversion near mtn top ridge.
- The 11/06/00Z 700-500mb lapse rate near 8.0 C/km over Thermopolis (KHSG).
- Is this enough to offset from getting mtn wave severe turbulence pilot reports in the upper levels?
- One severe mtn wave pilot reports at 2330Z in low levels.

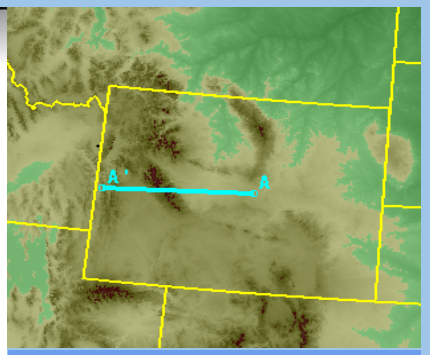




The continued strong upward vertical motion couplet easily punches through the tropopause near FL340. Some of the other key dynamic features were possible inhibiting the mountain waves and more likely downslope winds:

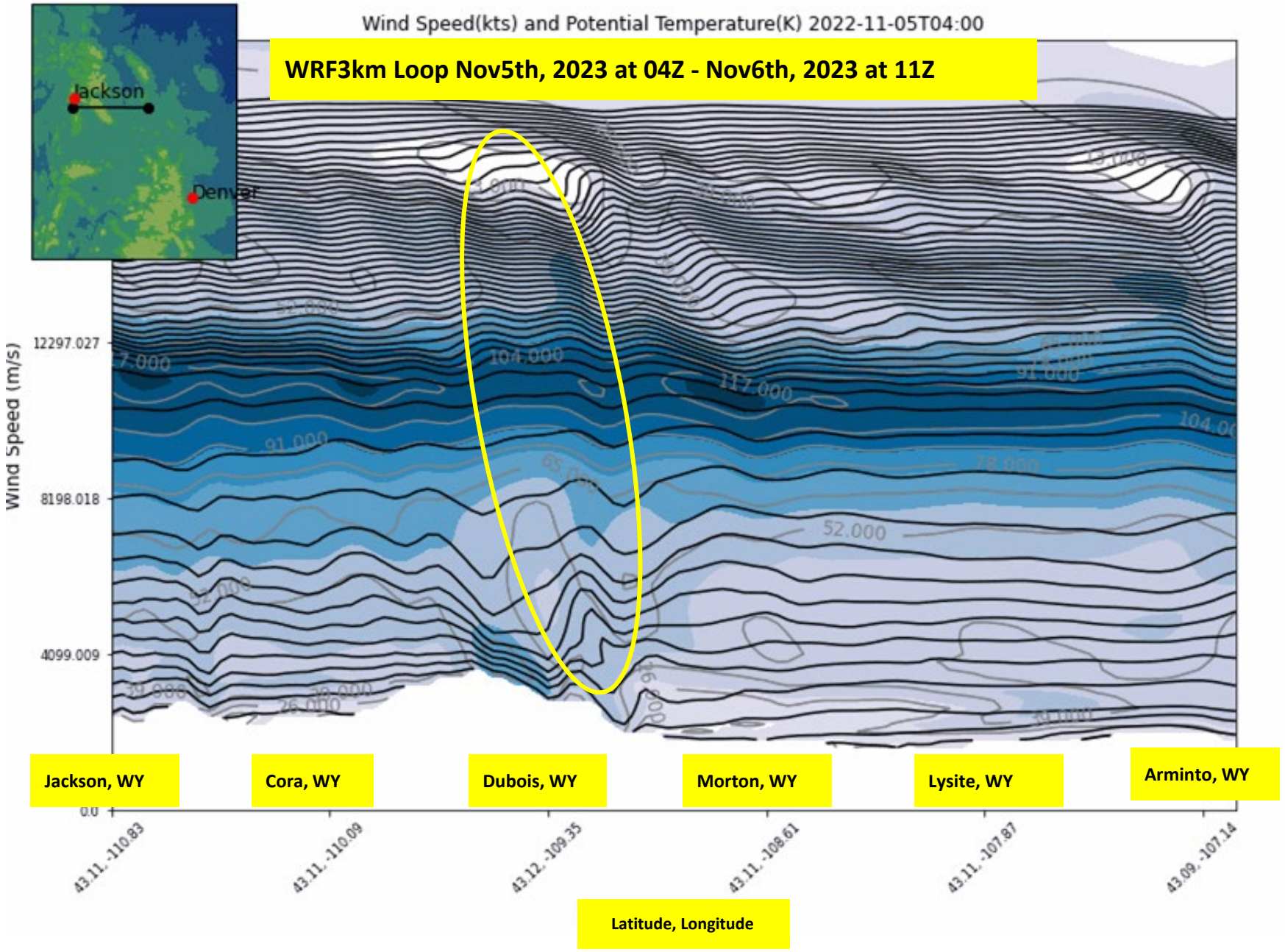
- No inversion near mtn top ridge.
- The 11/06/00Z 700-500mb lapse rate near 7.0 C/km over Thermopolis (KHSG).
- Is this enough to offset from getting mtn wave severe turbulence pilot reports in the upper levels?
- No severe mtn wave pilot reports.

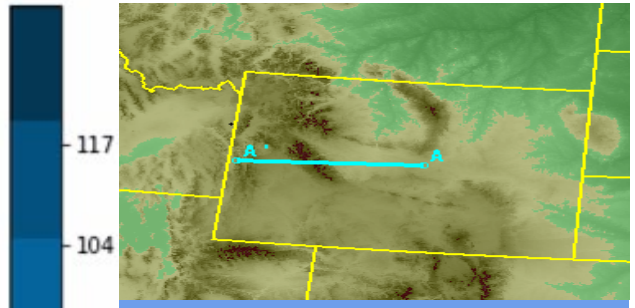




The yellow oval on the WRF-3km shows a breaking wave over the Dubois, WY area during the timeframe on Nov 5th, 2022 at 12Z. This disturbance coincides with:

- Nose of the 300mb jet streak entering the western WY region.
- The RAP 2,000 ft AGL wind were at 70-75kts with excellent cross barrier flow through the Teton mountains.





The yellow oval on the WRF-3km shows a breaking wave over the Dubois, WY area during the Nov 5th, 2022 occurring from 12Z - 18Z time-frame. This coincides with:

- Nose of the 300mb jet streak entering the western WY region.
- The RAP 2,000 ft AGL westerly wind were at 70-75kts with excellent cross barrier flow through the Teton mountains.
- RAPGTG Mtn Wave Composite having strong bullseye indices from FL340 to FL450.
- Strong upward vertical motion couplet punching through the tropopause.

CONCLUSION: There were several great dynamics for this severe turbulence event:

- Strong westerly cross-barrier flow across the Tetons, Big Horn and Rocky mountains.
- Right-front exit quadrant region jet-core over Tetons, but lapse rates too high and resulted in more downslope severe low turbulence.
- The 300mb RAP winds showed a strong northwesterly to westerly jet-core intensified by 11/05/18Z as the right-front exit quadrant region entered the western to central MT region. The 300mb speed convergence intensified with strong horizontal speed shear from 90kts at 11/05/12Z to 145kts by 11/05/15z.
- The NAM cross-sections thru western ID westward into the Tetons showed a vertically propagating wave punching through the Tropopause near 250mb. The WRF 3km showed a breaking mtn wave developed near Dubois, WY in the time-frame of 11/05/12Z to 11/05/18Z.
- The 700 to 500mb Lapse Rates values 5.5 - 6.5 C/km or less coincided in aiding in development of the vertically propagating couplets. There were severe mtn wave pilot reports over the Big Belt mountain in MT where the lapse rates were near 6.0 C/km. The left-rear entrance quadrant of jet was entering MT during those pilot reports.
- As this system moved into Denver later midday timeframe they had all the desired indices and resulted in several severe mtn wave turbulence pireps.

Future Goals:

- How to better analyze or understand cross-sections of propagating waves and incorporating the 600-500mb lapse rates and the 600-500mb QG forcing.



Thank You!

ICAO