Flight Operations in Mountain Wave

Kurt Kleiner–CFII   2020

Mountain Wave briefing topics

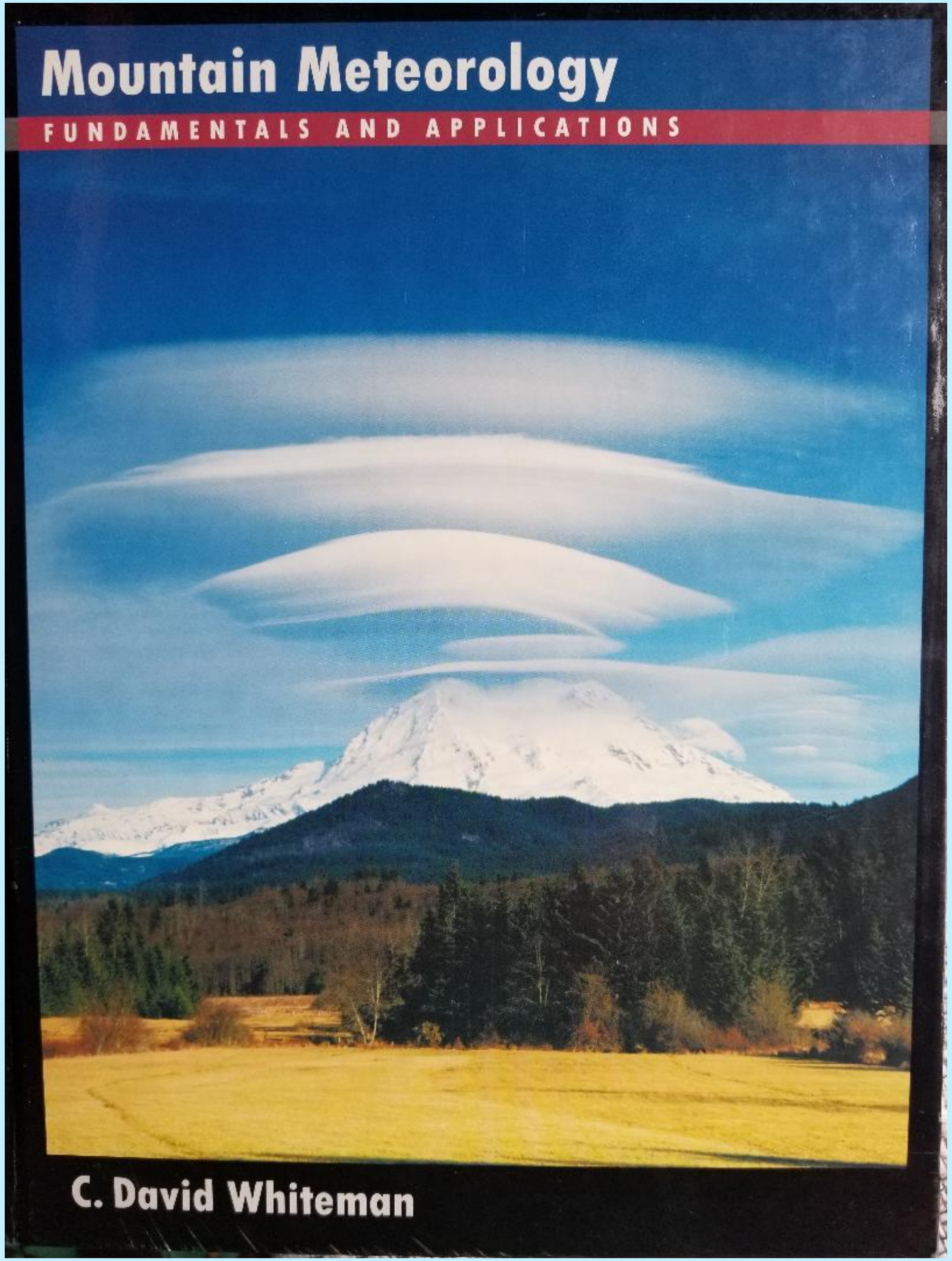
- Conditions needed for wave formation
- Structure of mountain waves
- Three types of wave
- How to forecast or predict wave
- Hazards to Aviators
- Wave soaring techniques and records

Information sources

FAA Advisory Circular **AC 00-57** (1997) “*Hazardous Mountain Winds and Their Visual Indicators*”

Soaring Society of America, glider clubs, and soaring weather sites.

Various online research papers, scientific sites; UCAR Met Ed, UNLV, NOAA-National Weather Service, NASA, etc.



Three necessary conditions for wave

- WIND: greater than 20 kts. at mountaintop level with winds aloft in same general direction (without a shear layer)

- TOPOGRAPHY: a block or barrier with wind direction perpendicular to the orientation of a mountain range, or within 30 degrees of perpendicular (or a prominent lone peak or volcano)

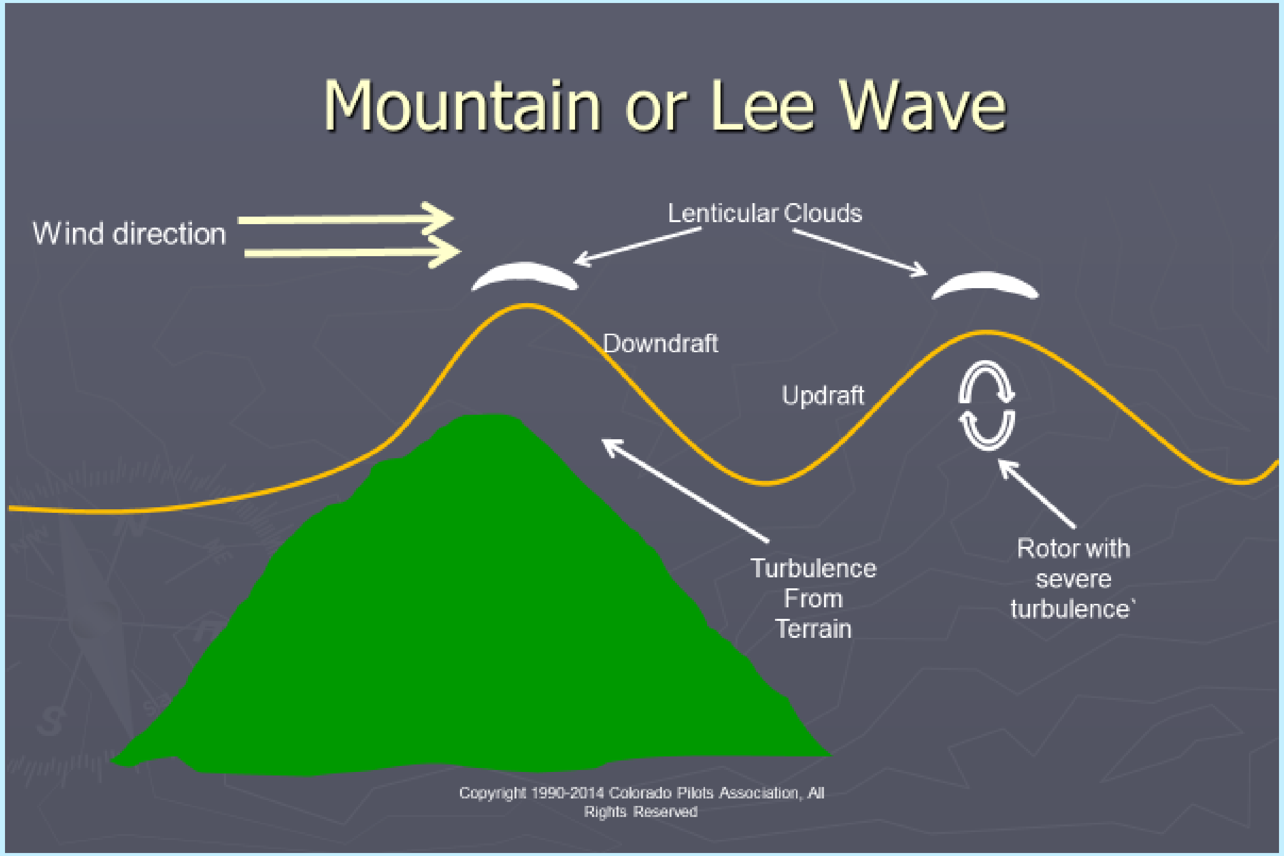
- ATMOSPHERIC STABILITY: must be stable, resistant to convection.

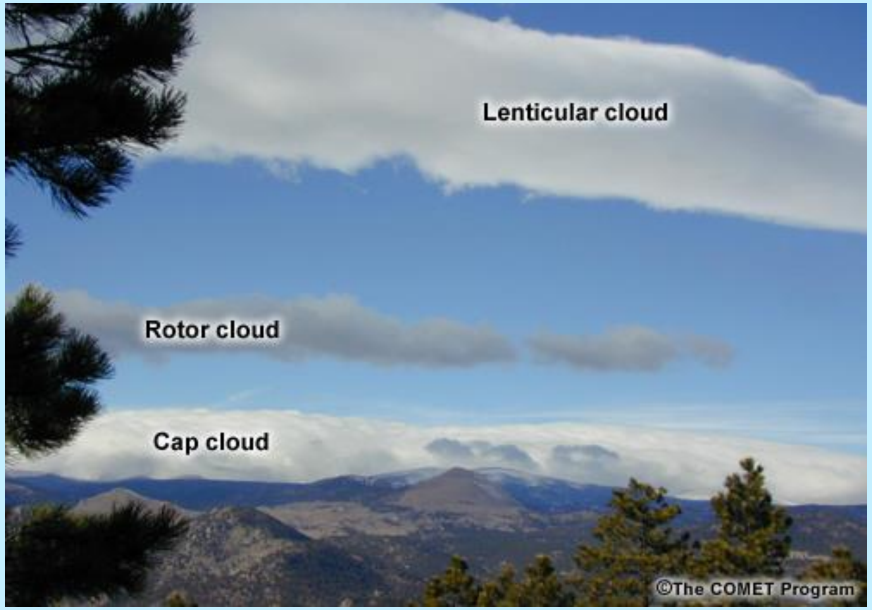
***How it works*….**

Strong flow of stable air blocked by terrain is compressed, pushed up and over the top, rushes down the lee side, rebounds off the stable air layer below, and then deflected back up/down in multiple oscillations.


Altocumulus Lenticularis (Standing Lenticular)

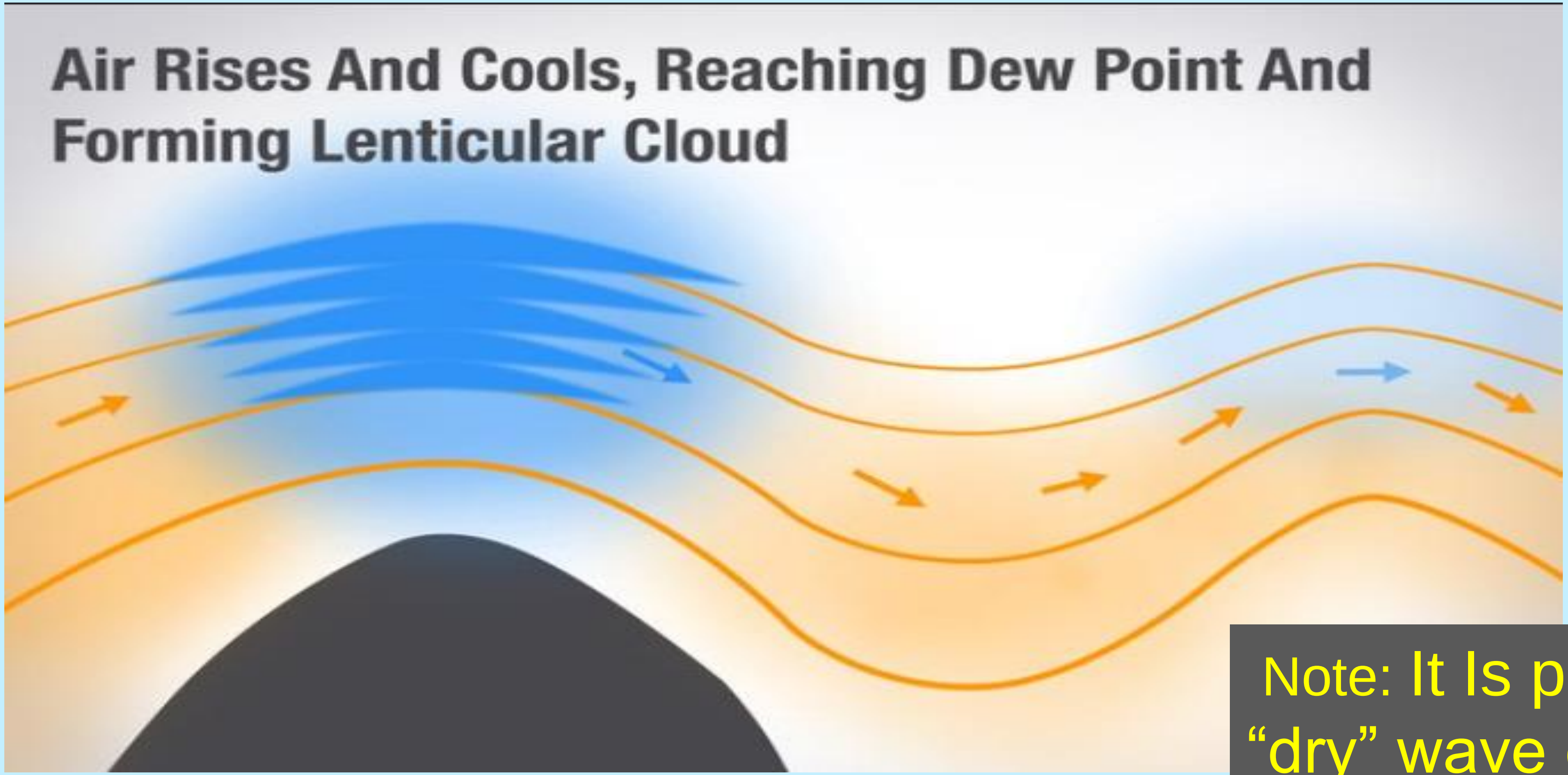
Wave structure and visual indicators





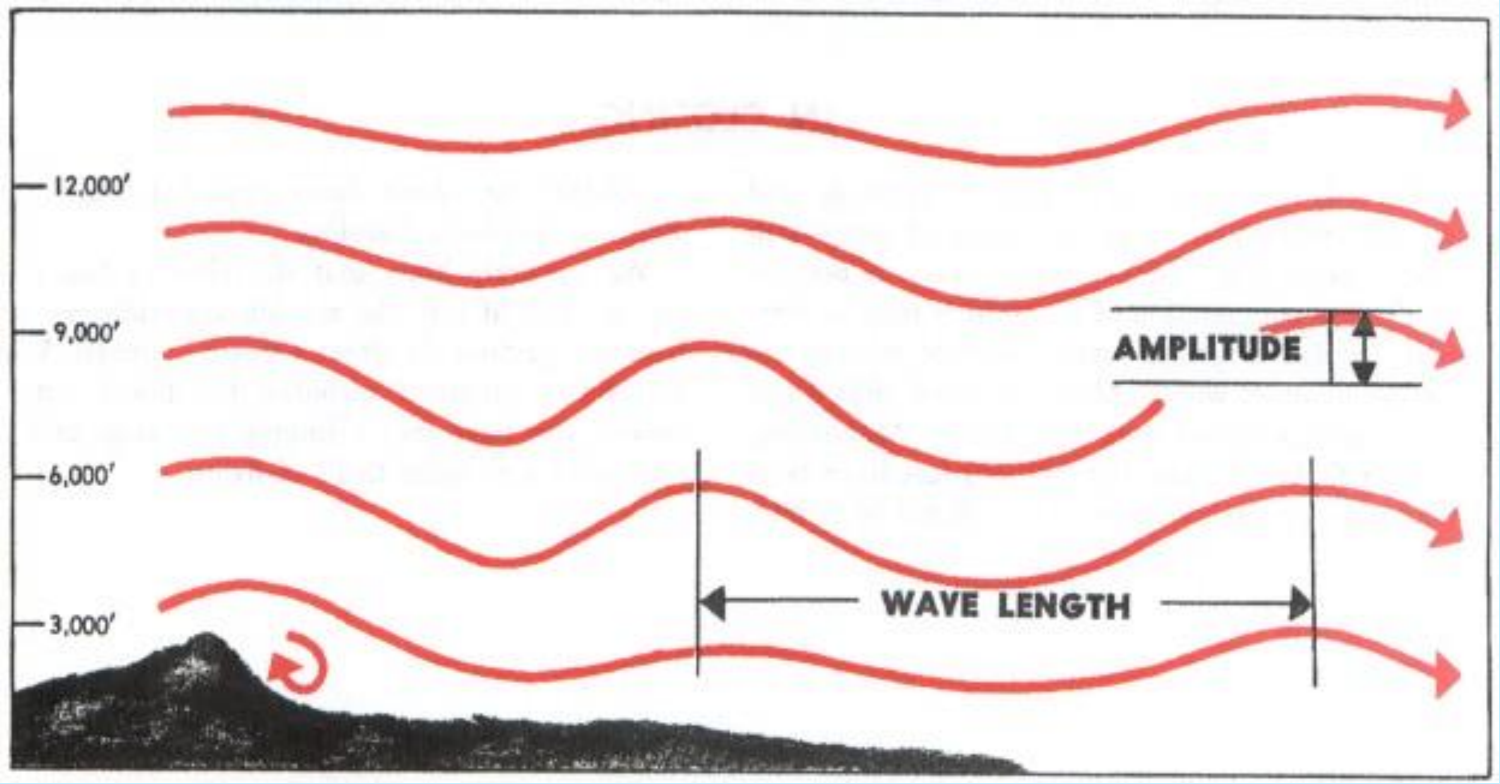
The “Rotor” is the primary hazard to small GA aircraft.

Lenticular clouds appear to be "standing still"



Note: It Is possible to have "dry" wave conditions if there is insufficient moisture for clouds to form!

Wave Terminology: Amplitude & Wave Length



- **Wave length** is the horizontal distance between crests of multiple waves.
- **Amplitude:** is half the altitude difference between the trough and crest.

Wave length is determined by:

- The direction and strength of the wind striking a mountain. ***Stronger winds produce longer wave lengths with less amplitude.***

- The slope angle and height of the mountain's lee side. ***Shallow lee-side slopes = longer wave lengths with less amplitude.***

- The distance between wave crests may be 2 to 25 miles apart. (8-10 miles is "typical").

Amplitude is determined by:

- Terrain: Mountain ranges with a very steep slope and large vertical drop on the lee side produce the greatest amplitude.

Tetons, Colorado Front Range, & Sierra Nevada have a steep 7,000 to 10,000 ft. vertical drop on east side from summits to valley floor.

Lower, more rounded mountains like the Appalachians produce lower amplitude waves. Long wave lengths downwind are still possible.

- Atmospheric stability: Stable air on the lee side that resists convection and thermal activity produces stronger wave.

- Amplitude can be “re-energized” by terrain downwind.

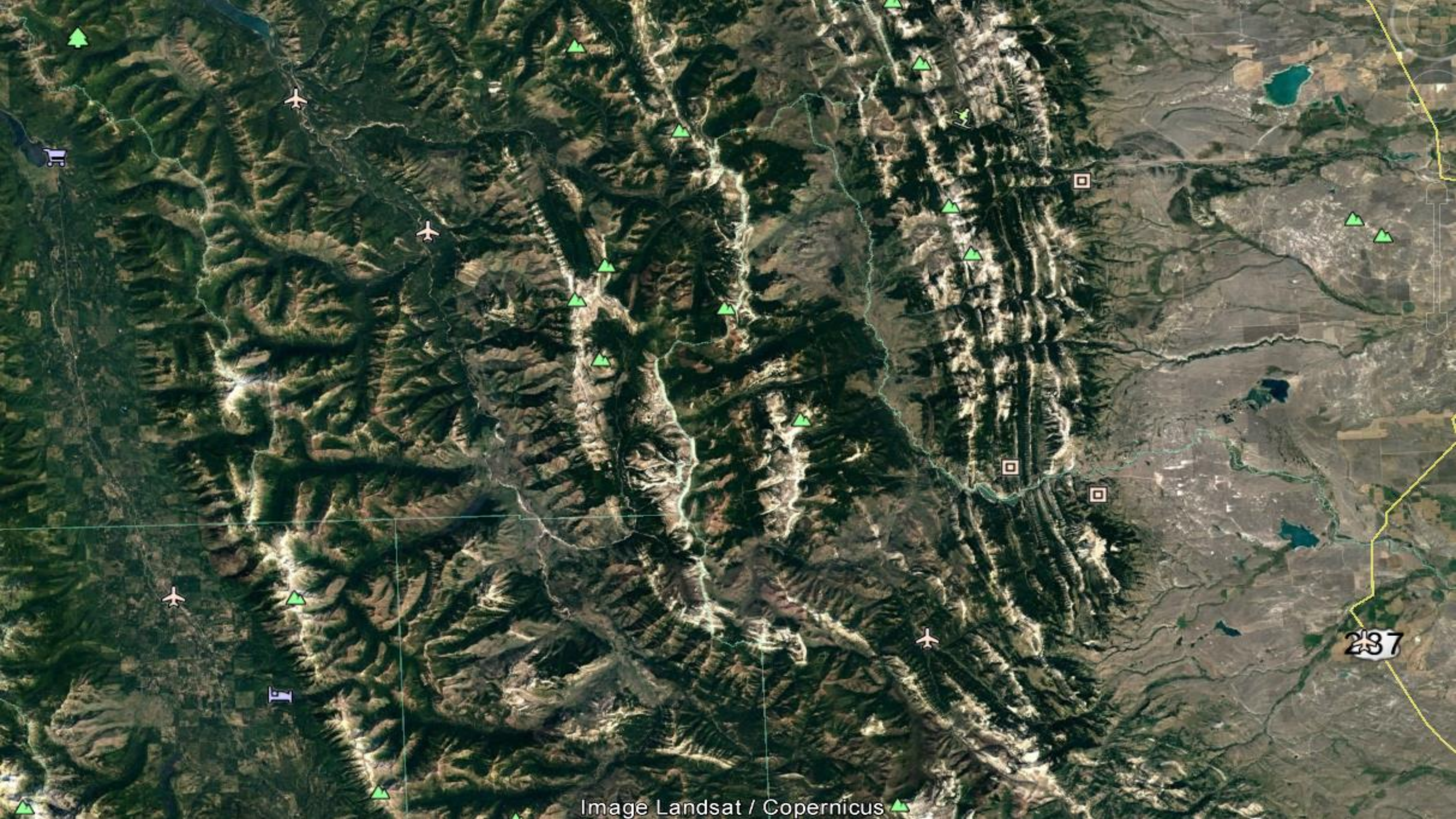

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Image Landsat / Copernicus

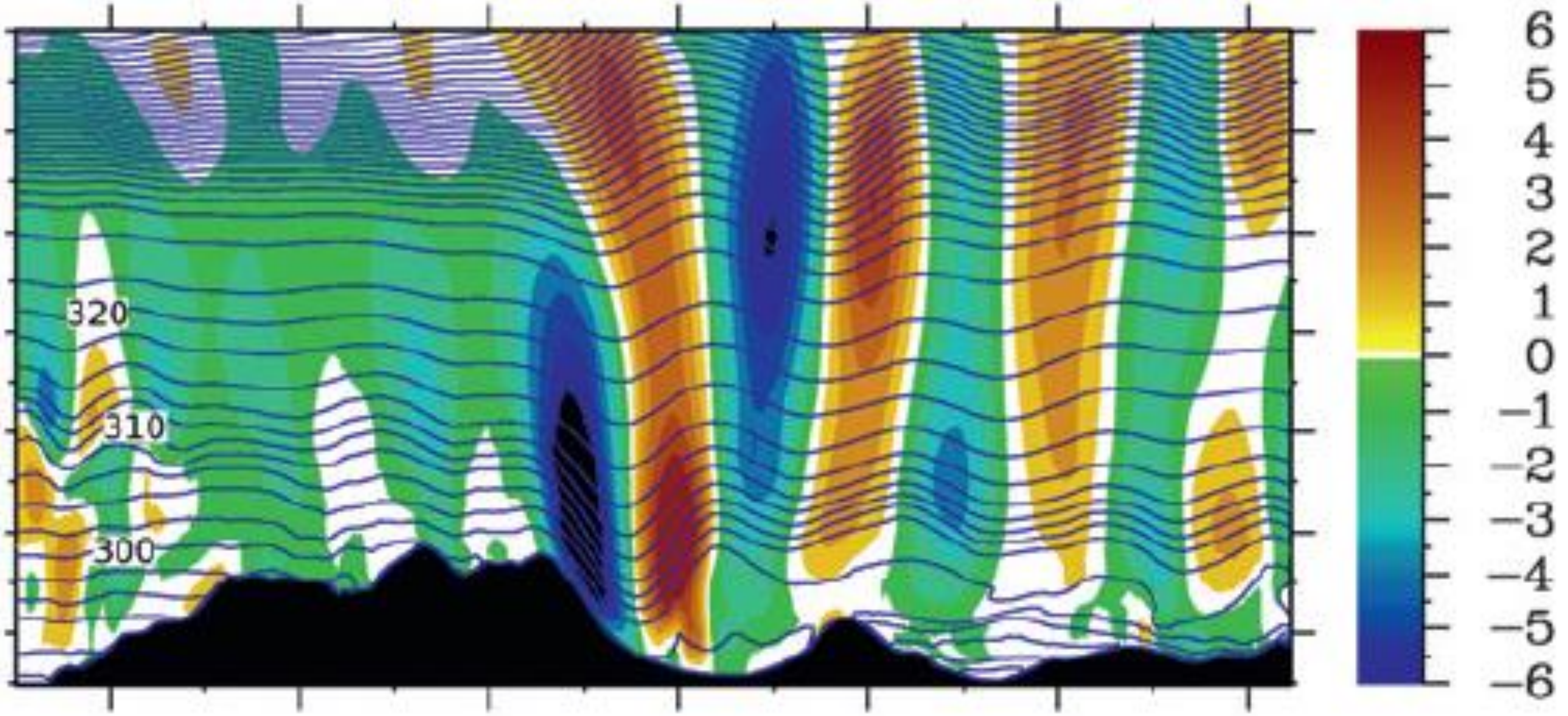
Amplitude characteristics:

- The greatest amplitude is normally found 3,000 to 6,000 feet above mountain top level, downwind of the lee slope.

- Large amplitudes waves tend to have shorter wave lengths and more severe rotors underneath.

Owens Valley, CA on east side of the Sierra Nevada range

Sierra Nevada-Owens Valley slope and wave profile (m/s)



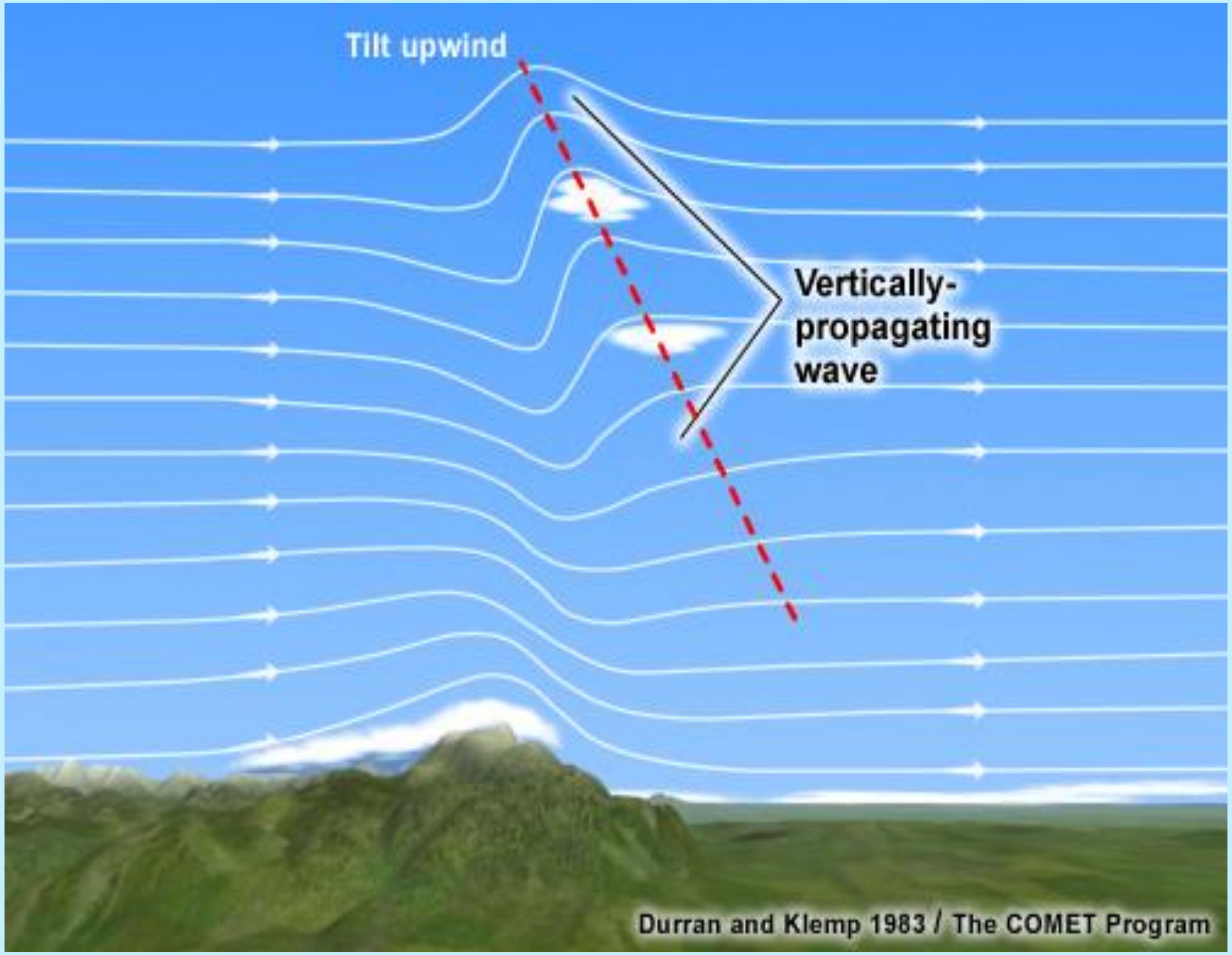
High-Resolution Simulations of Lee Waves and Downslope Winds over the Sierra Nevada during T-REX IOP 6

PETER SHERIDAN AND SIMON VOSPER

Three Types of Mountain Wave

- Vertically Propagating Wave
- Breaking Wave
- Trapped Lee Wave

1.) Vertically Propagating Wave



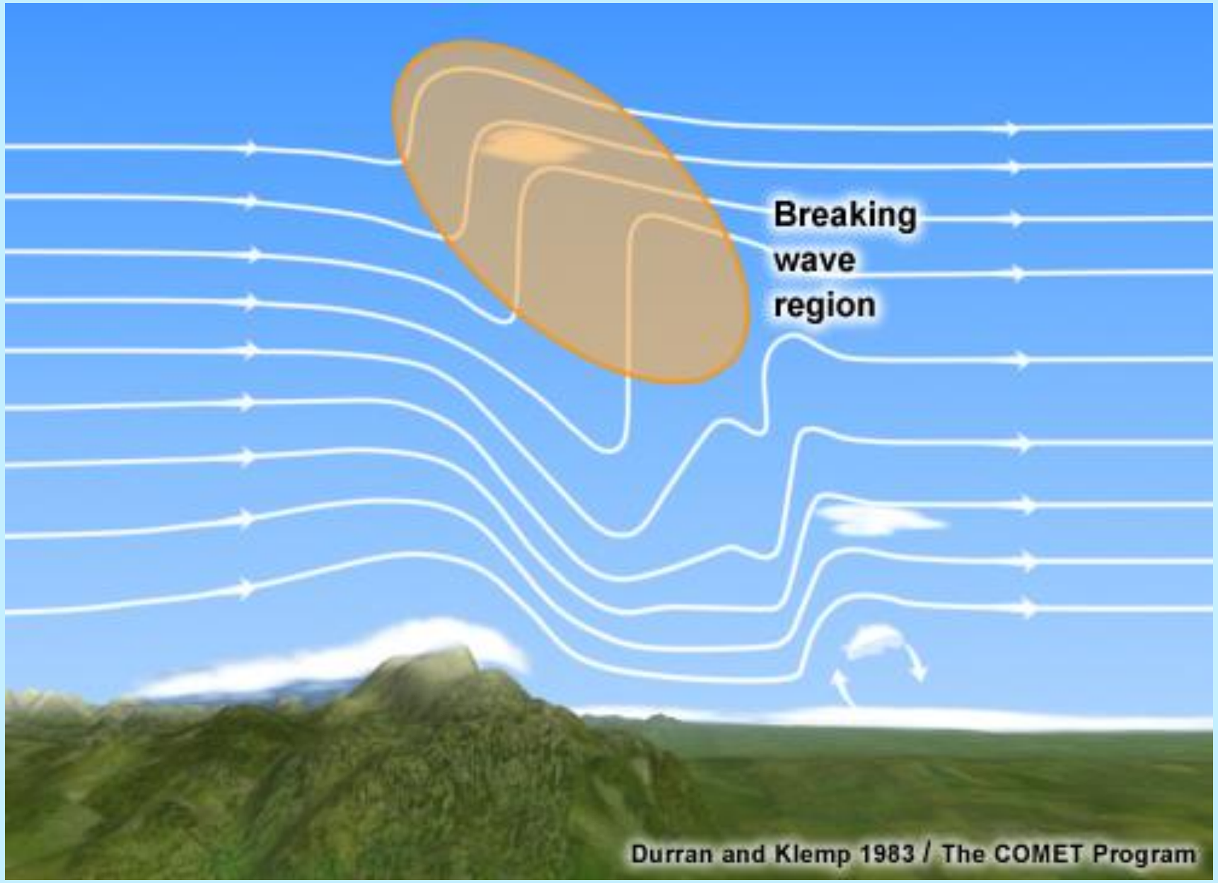
Strong lift and Clear Air Turbulence may extend up to 100,000 ft.

2.) Breaking Wave

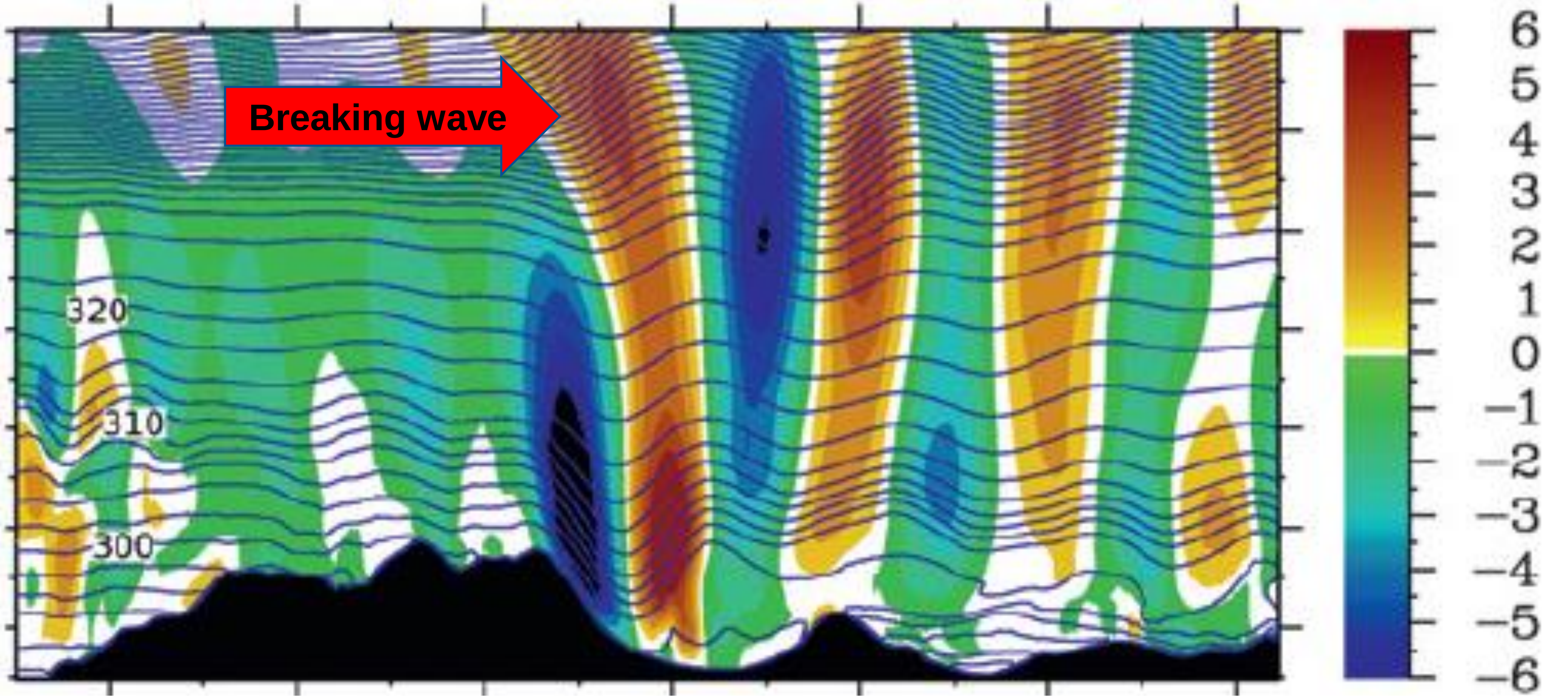
Vertically-propagating waves with sufficient amplitude may **break**, and result in severe Clear Air Turbulence between 20,000 and 40,000 feet.

If the wave does not break, the main turbulence hazard is the low level rotor area.

Expect strong but smooth lift and sink elsewhere.



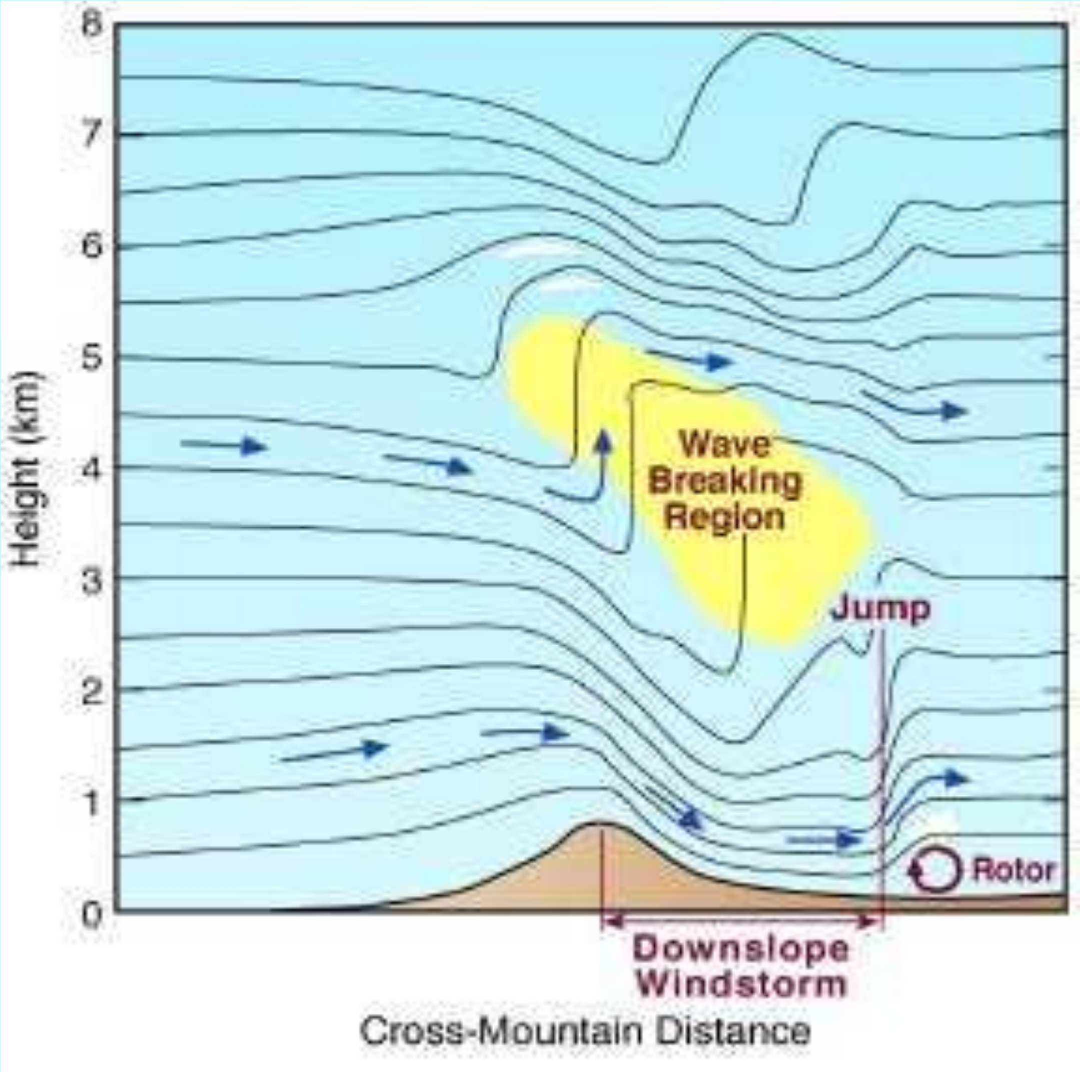
Sierra Nevada-Owens Valley slope and wave profile (m/s)



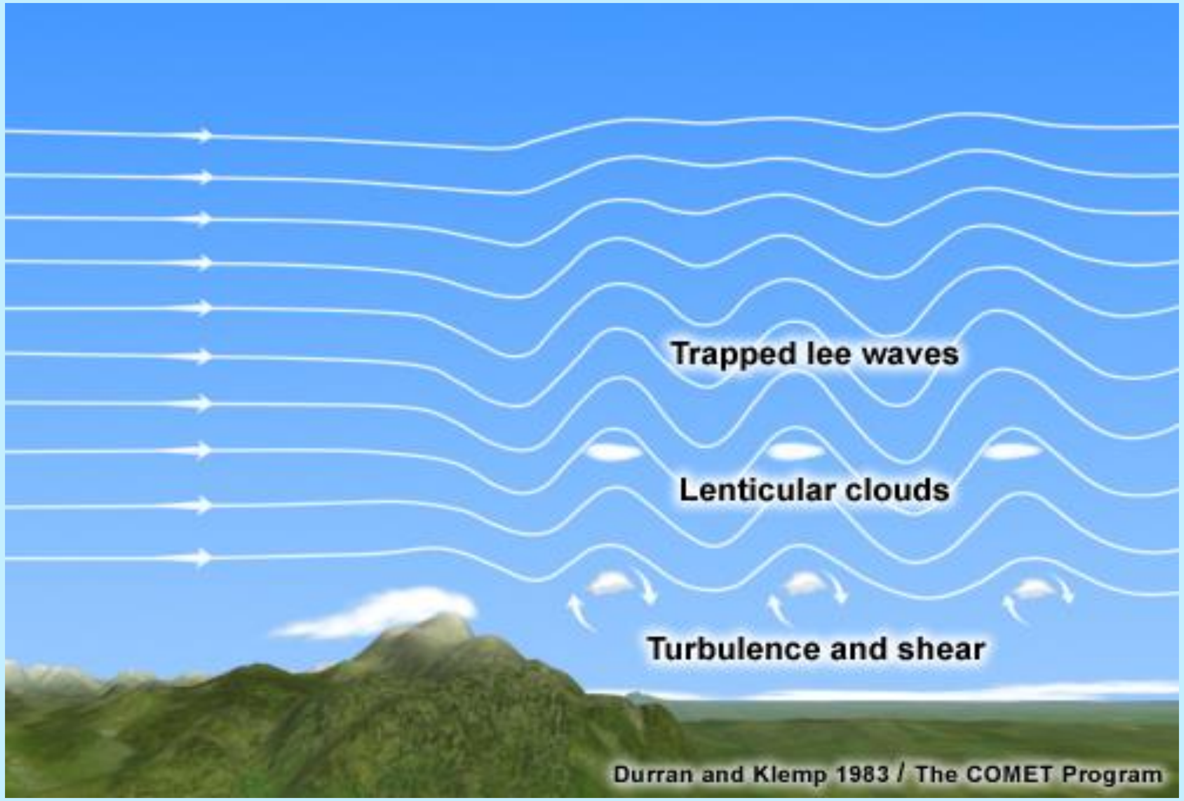
High-Resolution Simulations of Lee Waves and Downslope Winds over the Sierra Nevada during T-REX IOP 6

PETER SHERIDAN AND SIMON VOSPER

Remember…
Air has fluid properties



3.) Trapped Lee Wave



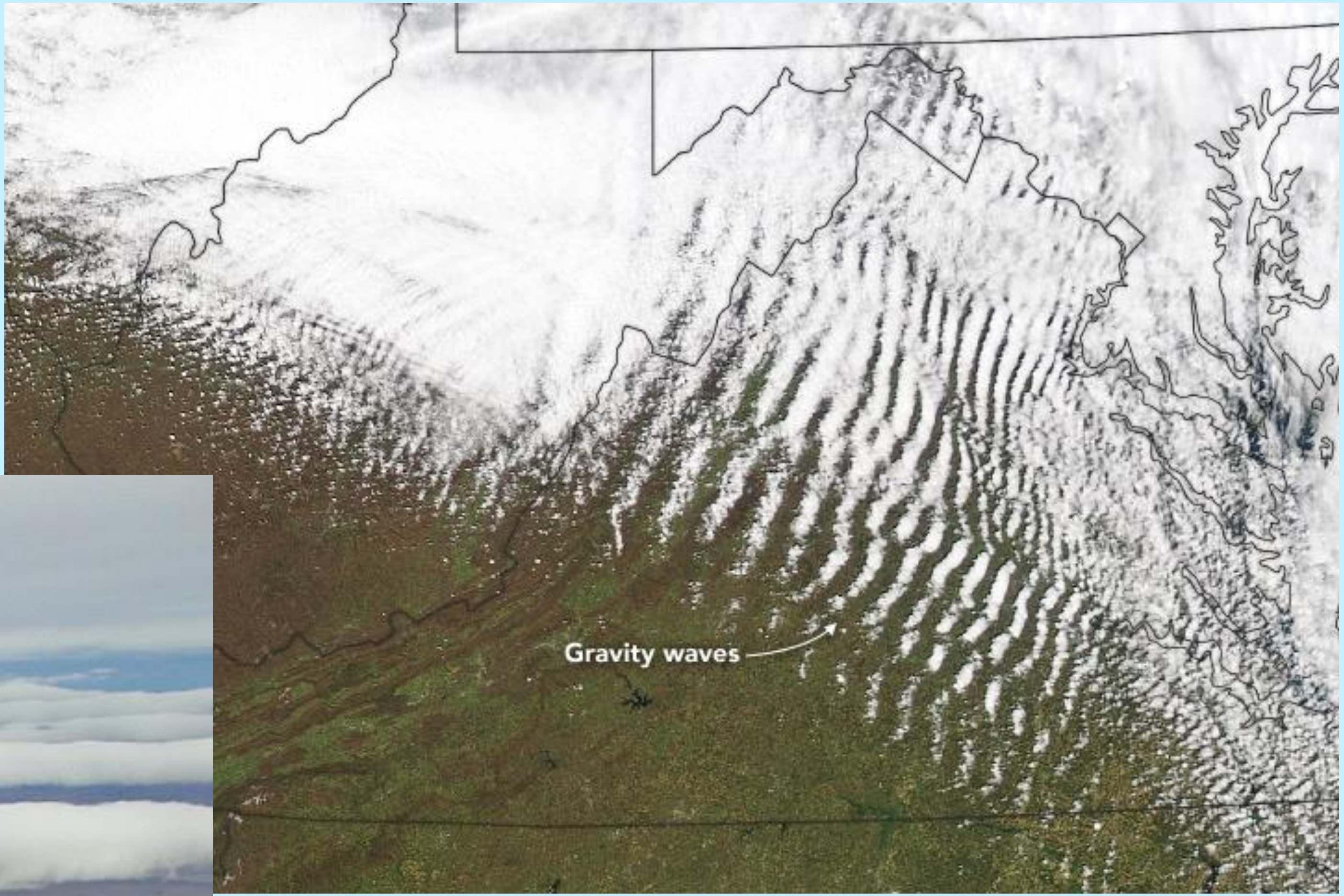
Energy does not propagate vertically due to strong wind shear or unstable conditions above.

Wave amplitude is limited to lower altitudes and said to be "*trapped.*"

Rotors below trapped lee wave crests are typically weak and less severe than rotors found beneath high amplitude (vertically propagating) waves.

Trapped lee waves can extend for hundreds of miles downwind.
Glider pilots who are new to wave soaring will prefer this type of wave.

The sequence of trapped lee waves is referred to as Primary, Secondary, Tertiary, etc.



Strength of lift and sink gradually decreases on each successive wave. Series can extend over 500 miles downwind.

How can I predict or forecast wave?

The transfer of mechanical energy from larger to smaller turbulent structures can be expressed by….

$$\varepsilon' = \zeta^2 \left(12 \frac{u'}{L'} \cdot u''^2 + 15 \cdot \nu \left(\frac{u'}{L'} \right)^2 \right)$$

$$\zeta^2\, 12 \frac{u'}{L'} u''^2 = \zeta^2 \left(12 \frac{u''}{L''} \cdot u'''^2 + 15 \cdot \nu \left(\frac{u''}{L''} \right)^2 \right).$$

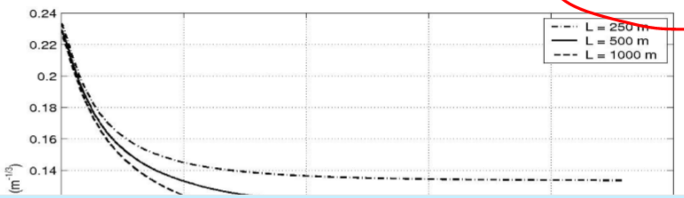
turbulence energy balance for the 2nd structure level

Spectrum width EDR computation

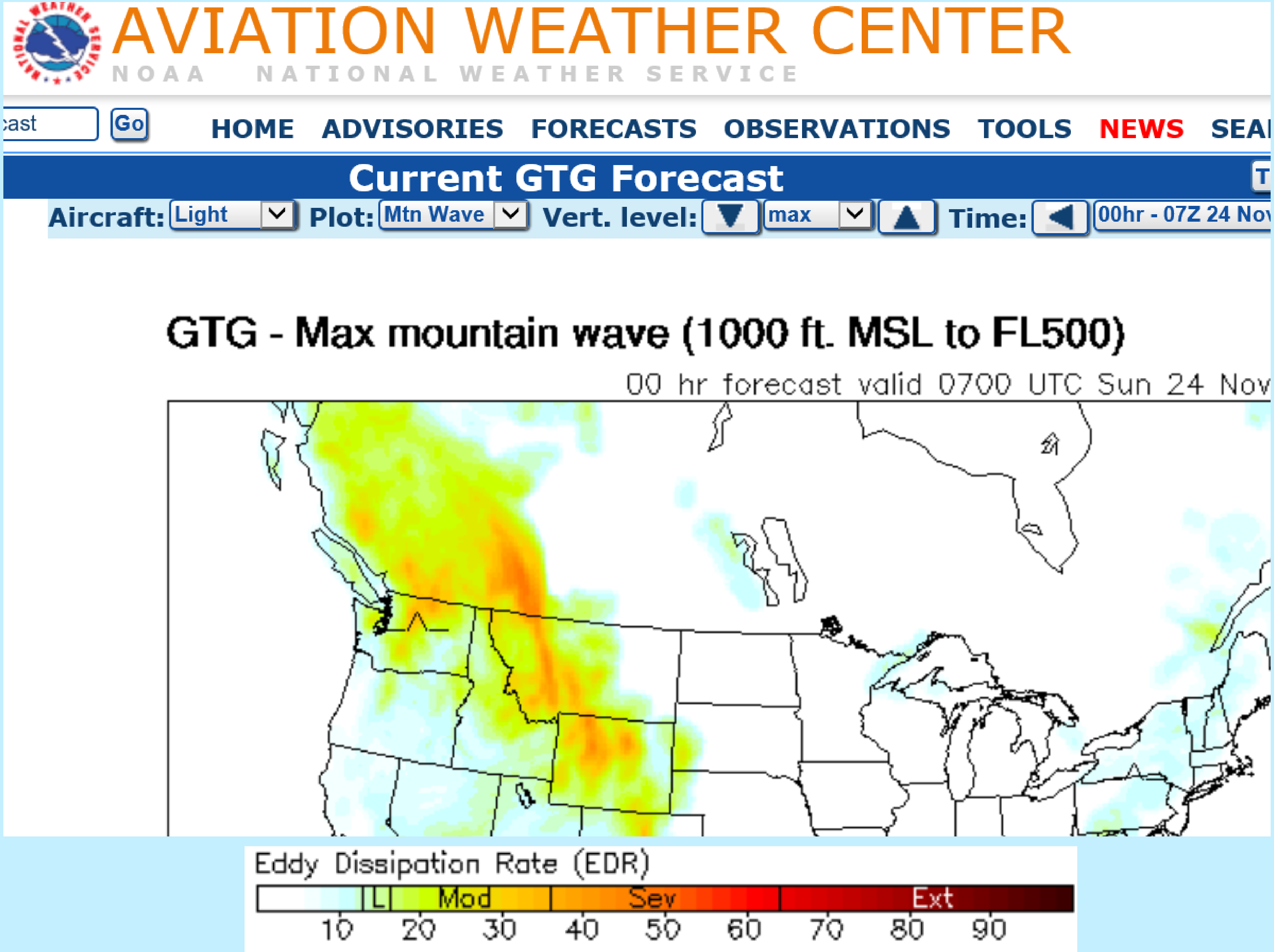
- Let $\varepsilon_i^{1/3} = s_i\, f(r_i)$

raw EDR "estimate" — measured spectrum width — "scale" factor for range r_i computed by assuming von Karman turbulence with $L_0 = 500$ m

- At a given range and azimuth, EDR is $\varepsilon^{1/3} = \dfrac{\Sigma_{i \in \mathrm{disc}}\, c_i\, \varepsilon_i^{1/3}}{\Sigma_{i \in \mathrm{disc}}\, c_i}$



Eddy Dissipation Rate


AVIATION WEATHER CENTER
NOAA NATIONAL WEATHER SERVICE
HOME ADVISORIES FORECASTS OBSERVATIONS TOOLS NEWS SEA
Current GTG Forecast
Aircraft: Light Plot: Mtn Wave Vert. level: max Time: 00hr - 07Z 24 Nov
GTG - Max mountain wave (1000 ft. MSL to FL500)
00 hr forecast valid 0700 UTC Sun 24 Nov
Eddy Dissipation Rate (EDR)
L Mod Sev Ext
10 20 30 40 50 60 70 80 90

Winds Aloft forecast

Winds/Temps Dat

Level: ◉ Low ○ High | 14Z-21Z ▾ | Rocky Mounta

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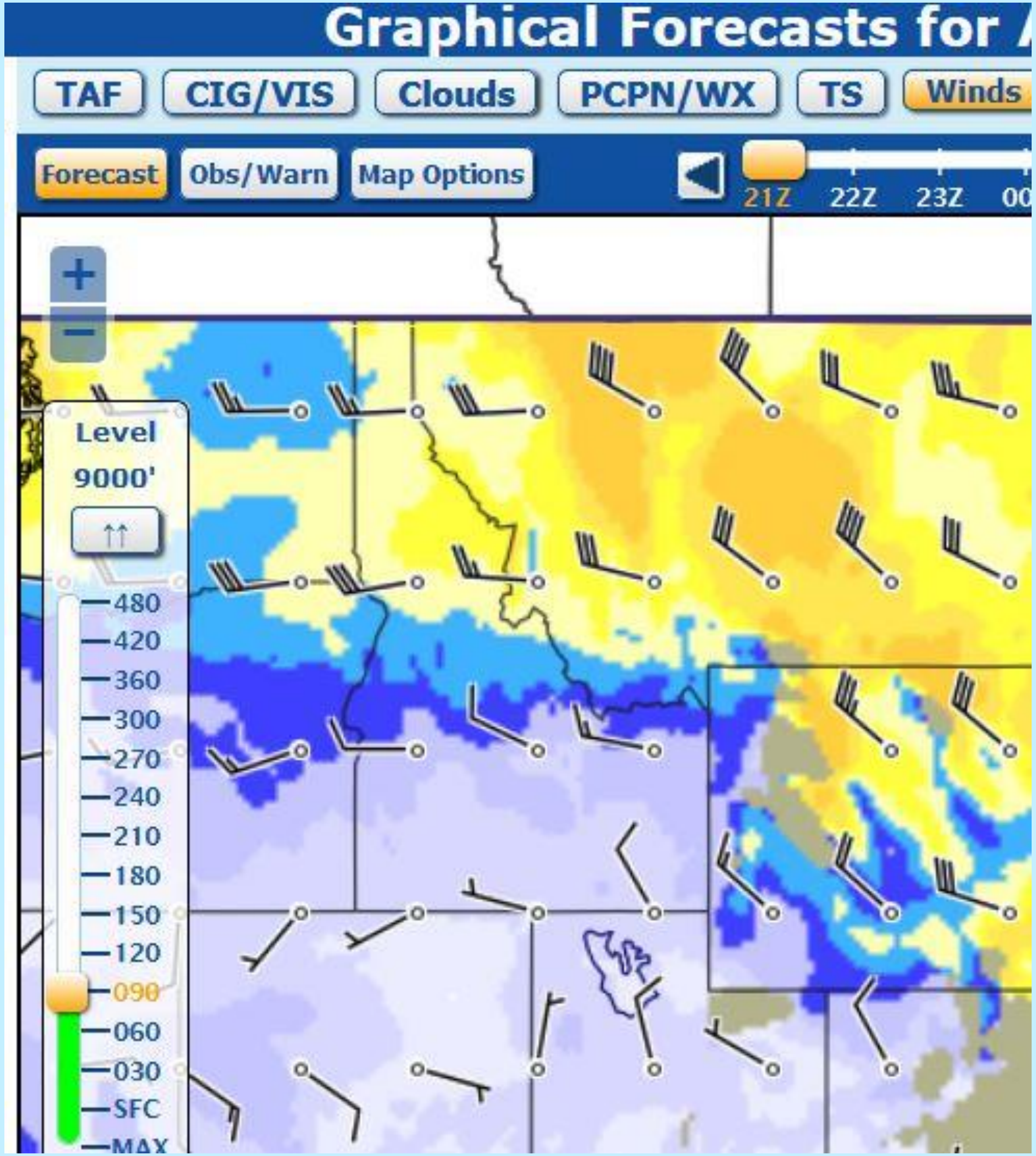
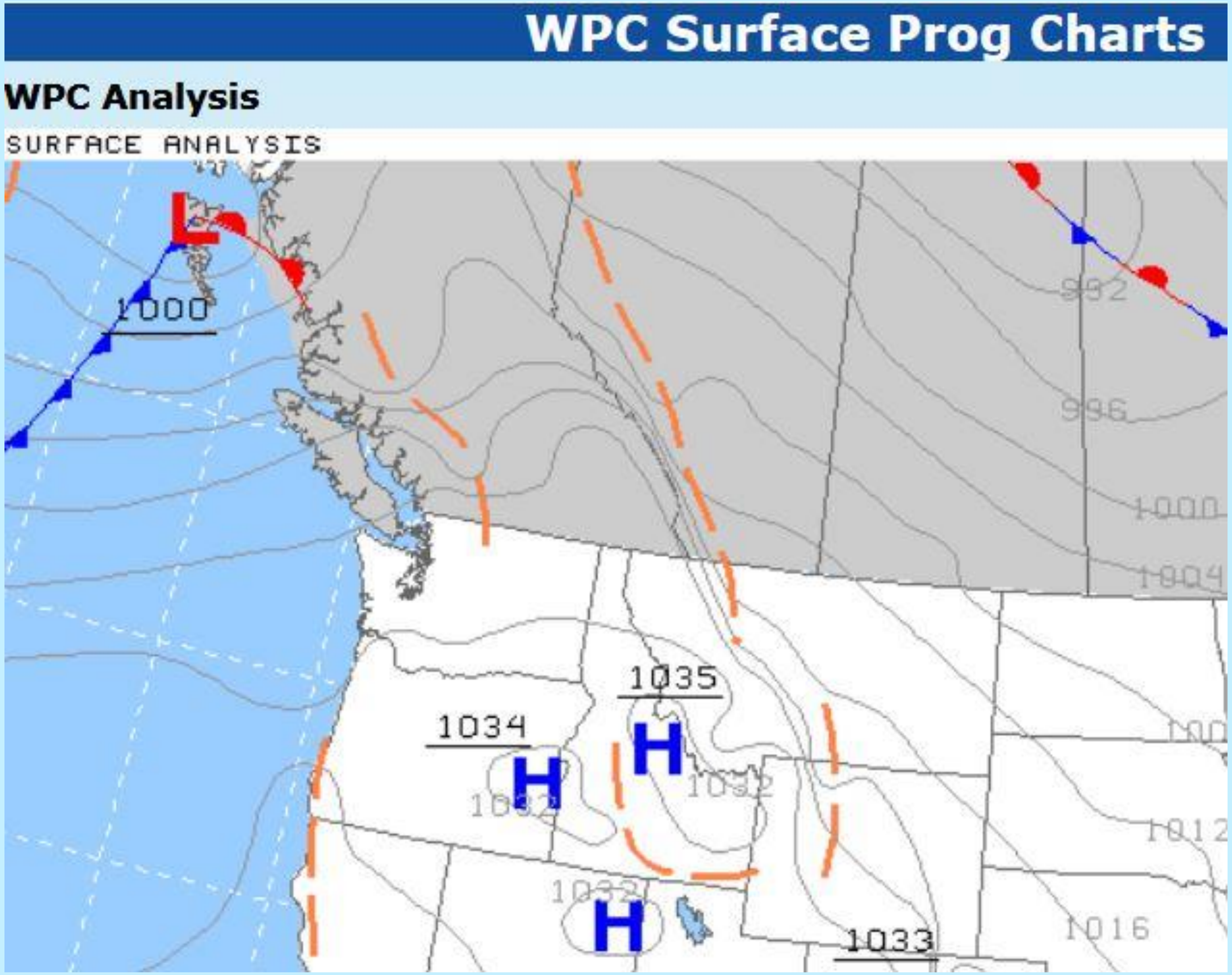
 (Extracted from FBUS31 KWNO 231354)
FD1US1
DATA BASED ON 231200Z
VALID 231800Z    FOR USE 1400-2100Z. TEMPS
```

FT	3000	6000	9000	12000	18000
PHX	0816	0809+08	1006+05	2305+00	2627-14
PRC			9900+04	9900-02	2722-15
TUS		1213+10	9900+07	2514+02	2524-14
ALS				3409-01	9900-16
DEN			2908+04	3319-01	3118-17
GJT			9900-02	0309-02	1009-17
PUB			3311+03	3415-01	3211-17
BOI		2605+01	2911+02	3006-01	2813-17
LWS	9900	2520+03	2721+01	2824-04	2929-17
PIH		2210	2815+01	3218-01	3017-17
BIL		2952	3232+01	3031-05	3045-17
DLN			3028+01	3133-04	2947-19
GGW		2913+07	3308+00	3023-07	3154-18
GPI		2420-03	2937-02	2947-06	2942-17
GTF		2942	2920+01	3029-06	3141-17
MLS		3133+03	2935+01	3037-05	2949-17
BAM			1408+02	1007-02	0913-17

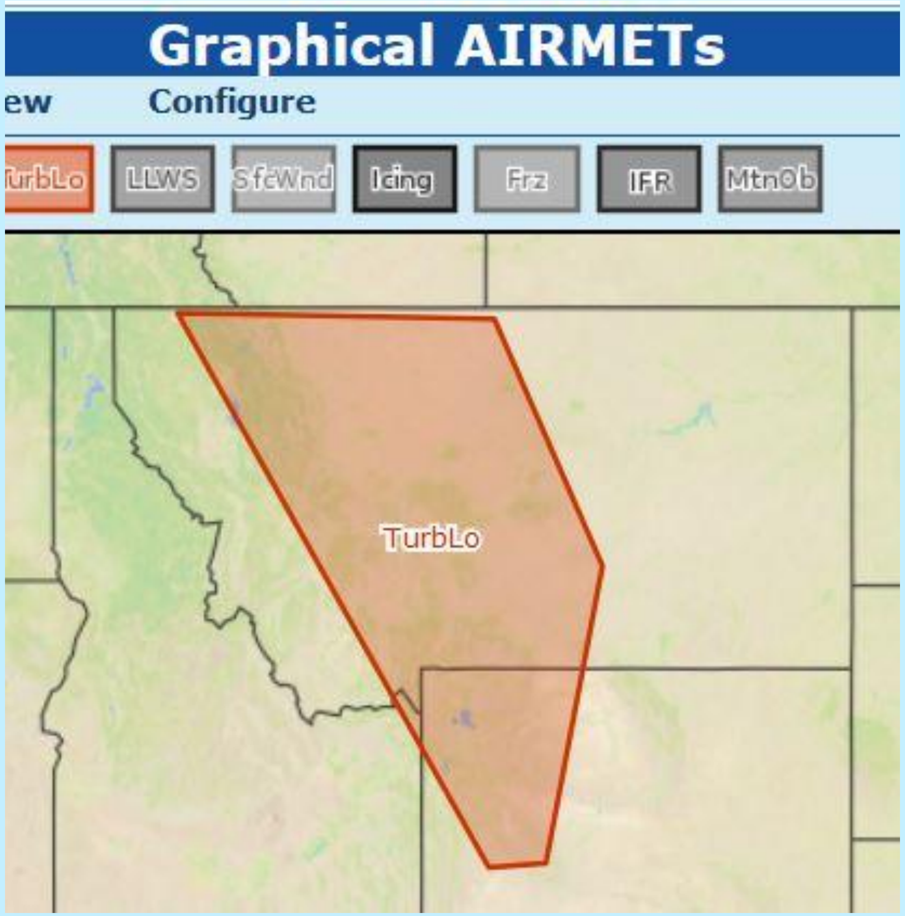


What about Stability?

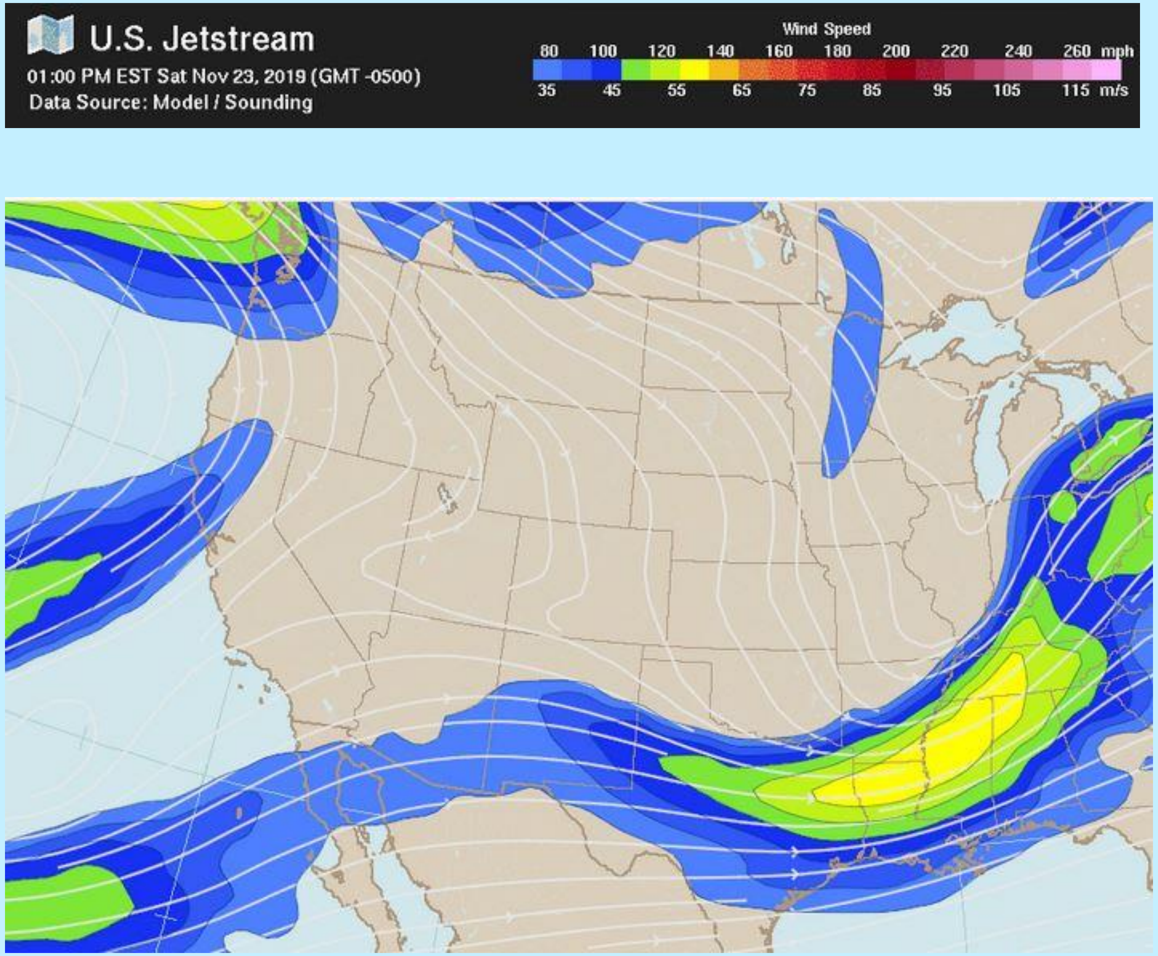


Note location and concentration of High pressure centers, and the compressed isobars (pressure gradient) just east of the Continental Divide

AIRMETs



Low Level Turbulence G-AIRMET
Valid: 2019-11-23T21:00:00Z
Issued: 2019-11-23T14:45:00Z
Severity: MOD
Top: 16000 ft
Base: Surface



SIGMETs

TURB SIGMET
Center: KSFO
Begins: 2020-02-09T19:58:00Z
Ends: 2020-02-09T23:58:00Z
Top: 33000 ft
Base: 24000 ft

WSUS06 KKCI 091958
SFOV WS 091958
SIGMET VICTOR 2 VALID UNTIL 092358
SIGMET
CA AND CSTL WTRS
FROM 40SSW FMG TO 50WNW BTY TO 60SSE SNS TO PYE TO 40SSW FMG
OCNL SEV TURB BTN FL240 AND FL330. DUE TO MTN WV ACT. RPTD BY
ACFT. CONDS CONTG BYD 2358Z.

High Level

TURB SIGMET
Center: KSFO
Begins: 2020-02-09T22:27:00Z
Ends: 2020-02-10T02:27:00Z
Top: 12000 ft
Base: 0 ft

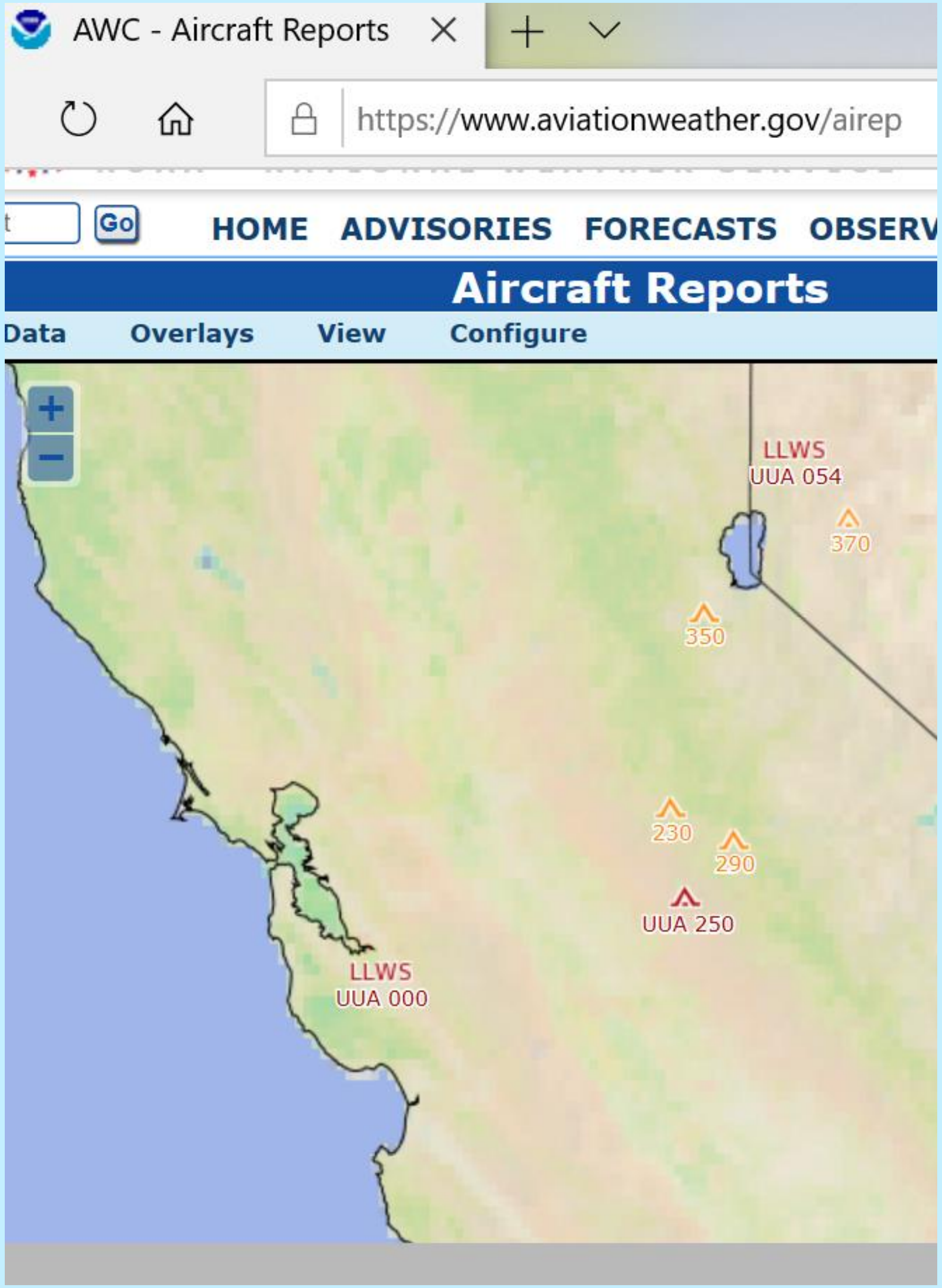
WSUS06 KKCI 092227
SFOX WS 092227
SIGMET XRAY 1 VALID UNTIL 100227
SIGMET
CA
FROM 40WNW FMG TO 50SSW FMG TO 50SSW OAL TO 30SSW CZQ TO 20NNW
SAC TO 40WNW FMG
OCNL SEV TURB BLW 120. DUE TO STG LOW LVL WNDS AND WNDSHR ASSOCD
WITH JTST AND STG UDDFS AND LLWS. RPTD BY B737 AC90. CONDS CONTG
BYD 0227Z.

Low Level

PIREPs

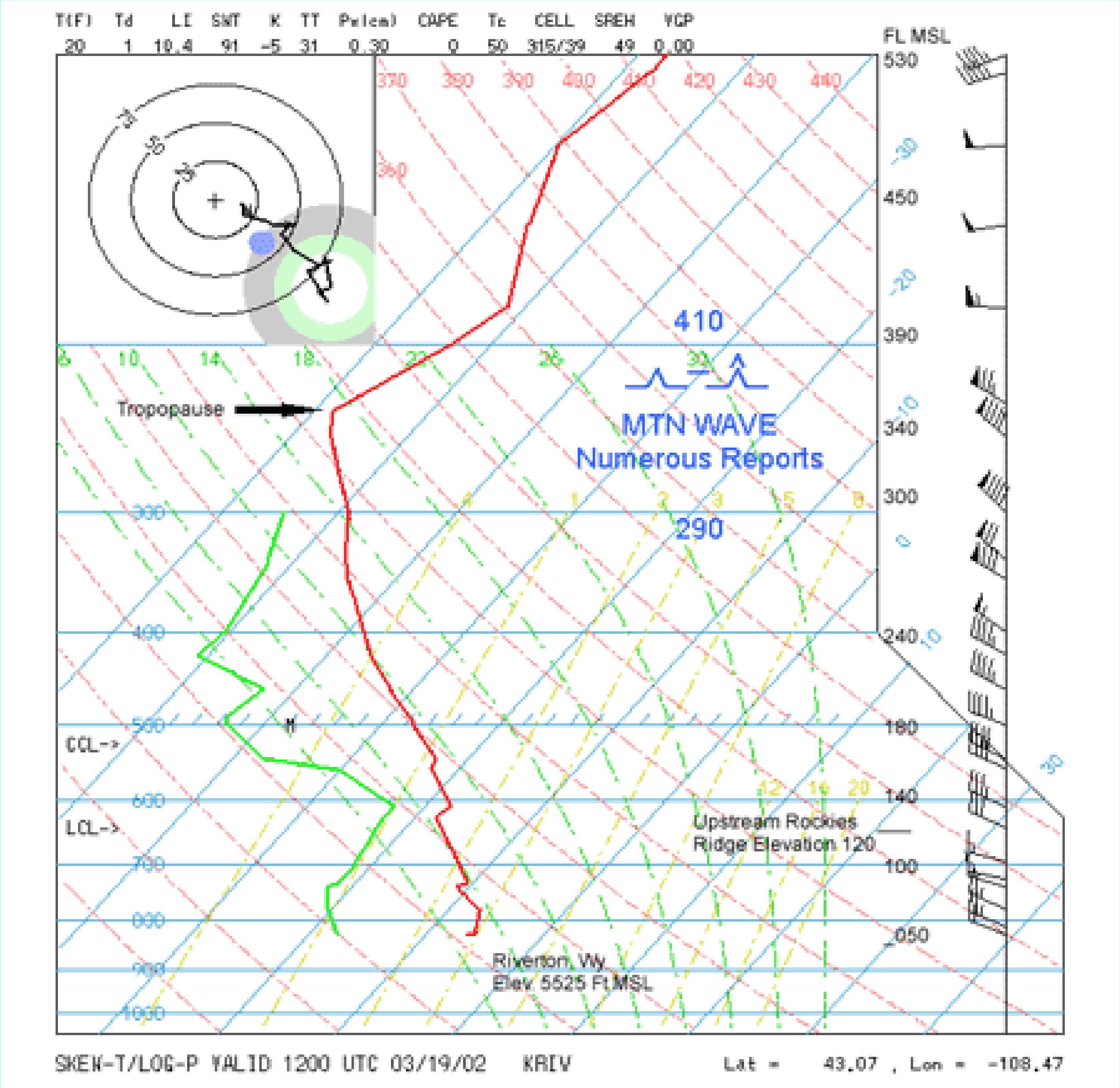
Urgent PIREP B737
Obs Time: 2020-02-09T23:33:00Z
Turb intensity: MOD-SEV
Flight level: 250

Urgent PIREP: MOD UUA /OV MOD068030/TM 2333/FL250/TP B737/TB MOD OCNL SEV 250/RM FL250-FL350 MOD OCNL SEV WEST BOUND /ZOA CWSU AWC-WEB/

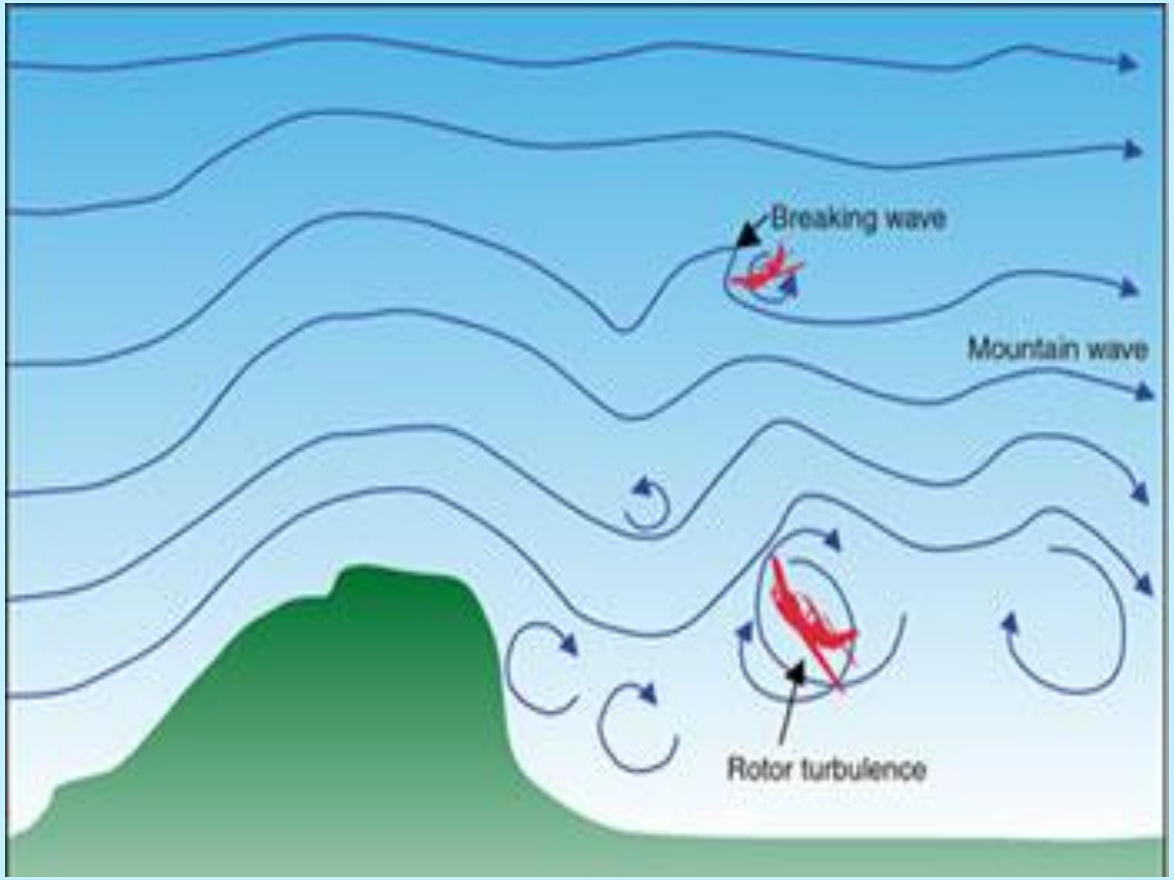


The Skew-T / Log-P chart offers a wealth of information.

- Wind speed and direction at all altitudes
- Layers of stable vs. unstable air, inversions, etc.
- Altitude of cloud base
- Lapse rate and height of any instability
- Potential for thunderstorms, mountain wave, etc.



Hazards to Aircraft



Aircraft Accidents related to Mountain Wave

- 1966 – in-flight break up; Boeing 707 - Mt. Fuji, Japan
- 1992 – DC-8 lost one engine and part of it's wing
- 1993 – Evergreen B-747: Anchorage, AK

  NTSB Report # DCA93MA033*: Number 2 engine separated from the aircraft shortly after takeoff. Probable cause; excessive multi-axis lateral loading of the #2 engine pylon during an encounter with severe or extreme turbulence associated with mountain wave.*

From Advisory Circular AC 00-57

Event	Date	Location	Comments
Accident	31 Mar 93	Anchorage, AK	B-747 turbulence. Loss of engine.
Accident	22 Dec 92	West of Denver, CO	Loss of wing section and tail assembly (two-engine cargo plane). Lee waves present.
Accident	09 Dec 92	West of Denver, CO	DC-8 cargo plane. Loss of engine and wing tip. Lee waves present.
Unknown Cause; Accident	03 Mar 91	Colorado Springs, CO	B-737 crash.
Accident	12 Apr 90	Vacroy Island, Norway	DC-6 crash.
Severe Turbulence	24 Mar 88	Cimarron, NM	B-767 + 1.7 G. Mountain wave.
Severe Turbulence	22 Jan 85	Over Greenland	B-747 + 2.7G.
Severe Turbulence	24 Jan 84	West of Boulder, CO	Sabreliner, ~+0.4G, -0.4G.
Severe Turbulence	16 Jul 82	Norton, WY	DC-10, +1.6G, -0.6G.
Severe Turbulence	03 Nov 75	Calgary, Canada	DC-10, +1.6G.
Accident	02 Dec 68	Pedro Bay, AK	Fairchild F27B. Wind rotor suspected.
Accident	06 Aug 66	Falls City, NB	BAC 111. Wind rotor suspected.
Accident	05 Mar 66	Near Mt. Fuji, Japan	B-707. Wind rotor suspected.
Accident	01 Mar 64	Near Lake Tahoe, NV	Constellation. Strong lee wave.

How is wave turbulence severity defined?

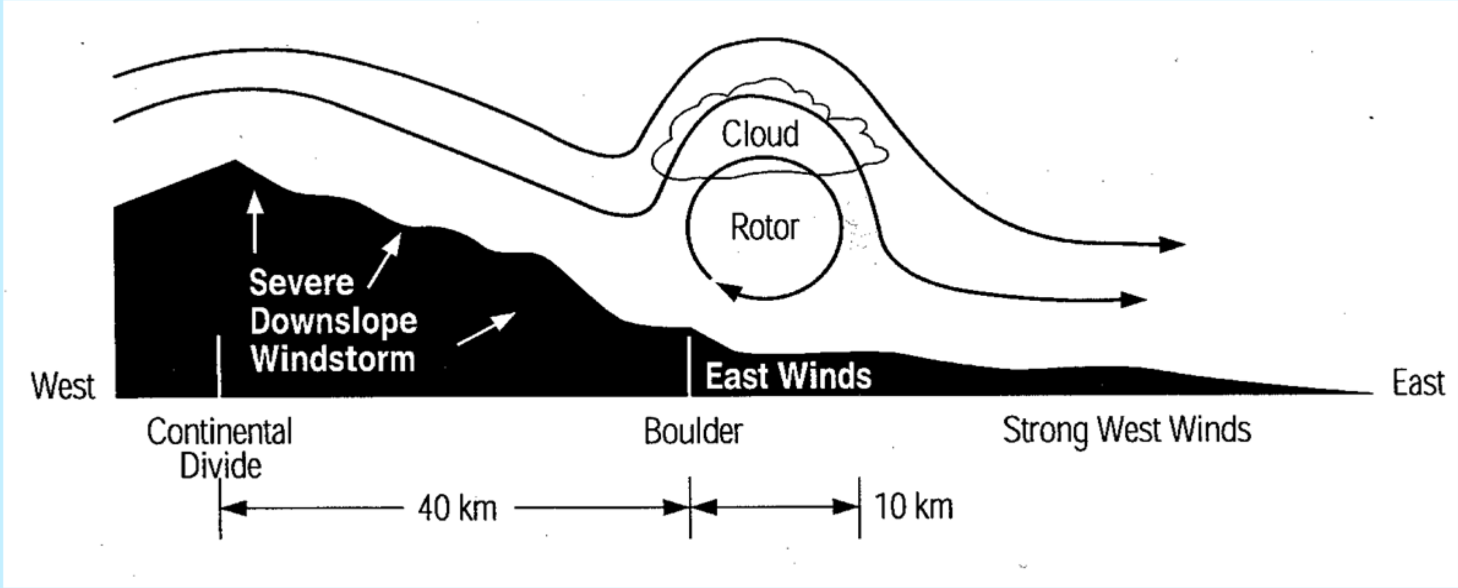
- No official ICAO criteria for severity!!

Wave Intensity	Up & Down Drafts	Speed Change	Net Altitude Change
Moderate	350-599 ft/min	+/- 15-24 KT	500-999 ft
Severe	>=600 ft/min	>= +/- 25 KT	>1000 ft

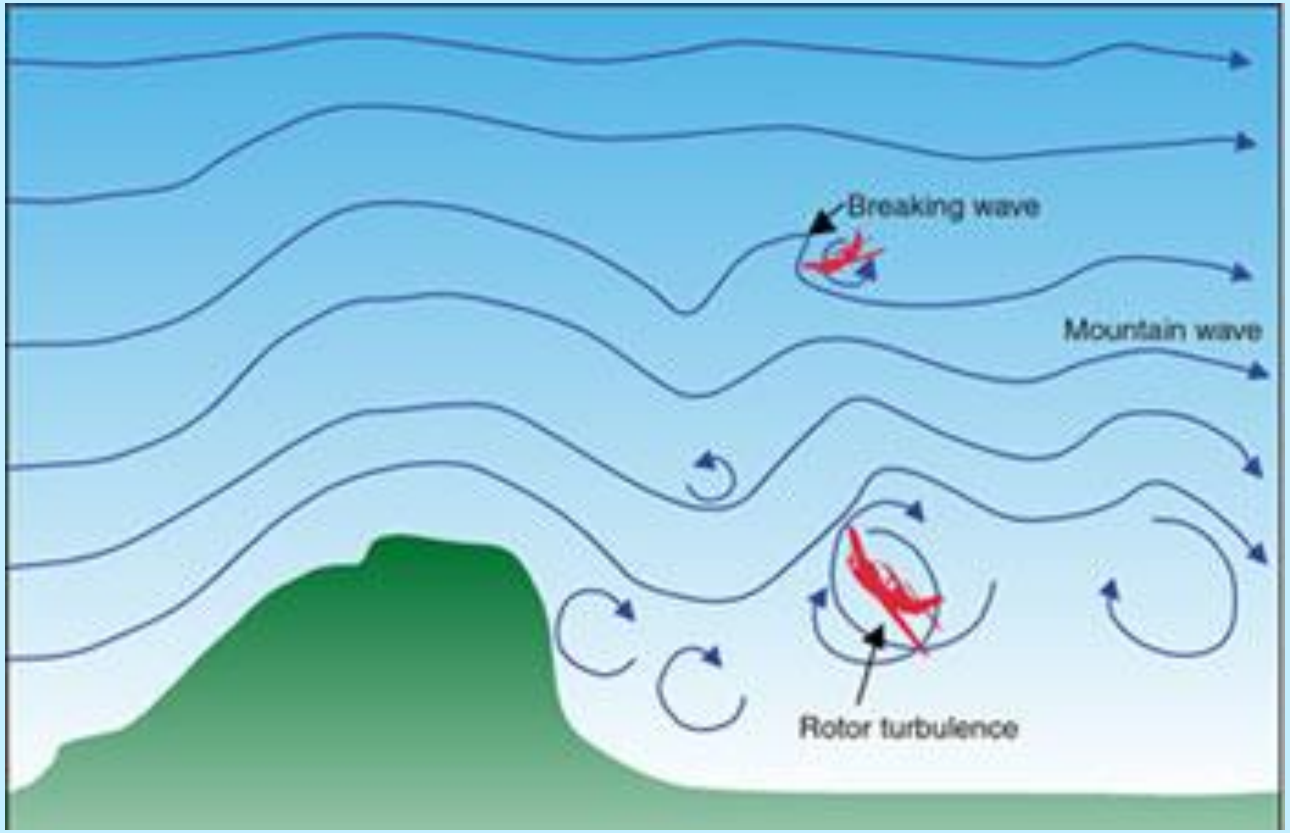
- General criteria developed to create a more consistent forecast/product.
- PIREPs with DETAILS are key in providing quality data to pilots!!

Figure 1: *USAF B-52H Stratofortress flight that encountered mountain wave turbulence and lost its vertical tail, Jan. 10, 1964. Photo courtesy of White Eagle Aerospace History Blog.*

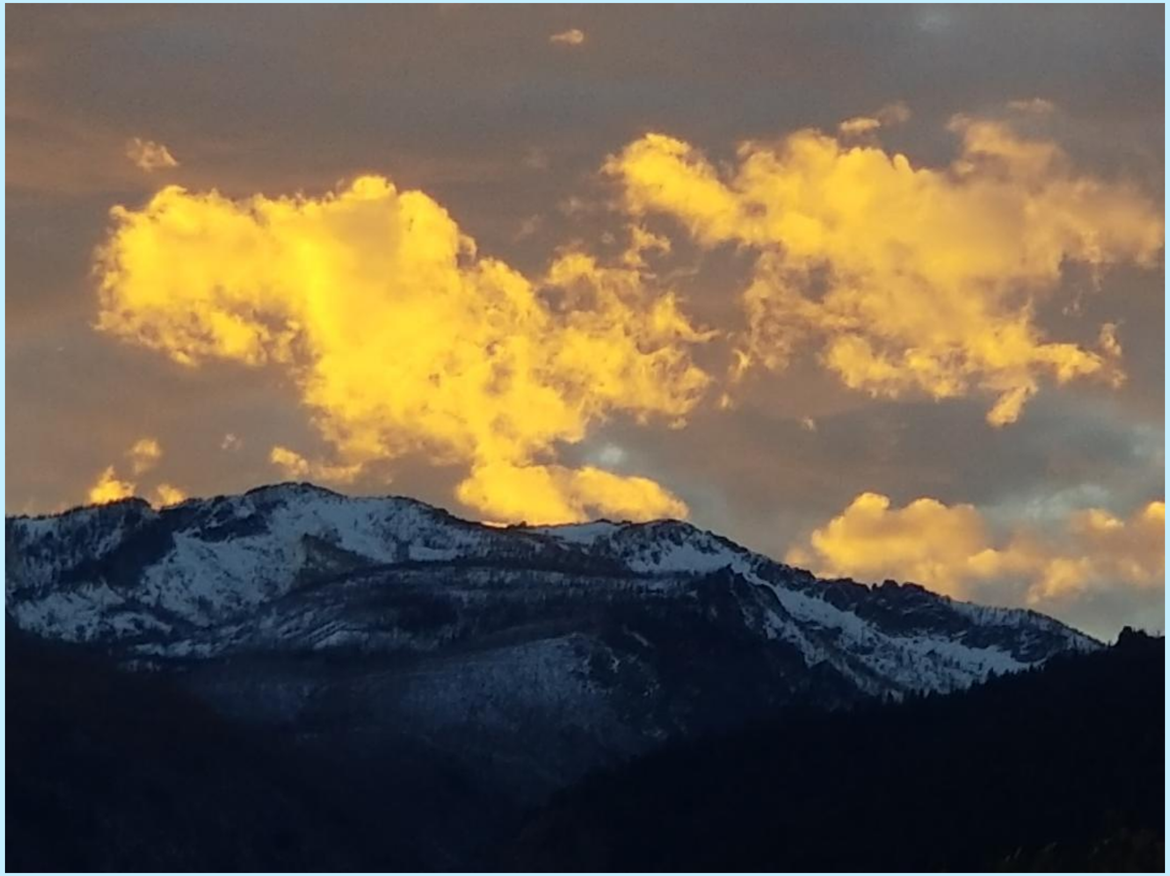
Rotor clouds (or roll clouds) have the innocent appearance of small cumulus clouds that form beneath a Lenticular cloud. Strong to extreme turbulence may be found in the rotor.



Hazardous wave rotors



Learn to recognize and avoid rotors and downdraft areas.



Tips for flying light aircraft (VFR) near mountain wave:

- Set personal minimums: i.e. Avoid flying lower than 1,000 AGL over mountains if winds aloft are more than 20 kts. (Stay away from lee side rotors and stay out of canyons.)
- Seek additional knowledge and mountain flying training.

To fly over mountains in high wind, fly <u>above the top</u> of peaks, by <u>at least one half the height</u> of the peak (from its base to top).

*i.e. base is 7,000 ft., summit is 11,000 ft., Peak is **4,000 ft**. high. Cross over at least **2,000 ft**. above the top (at 13,000' MSL)*

If you encounter strong sink, pitch down, fly through it quickly toward lower terrain. It is better to sacrifice altitude to minimize time spent in sink. Remain VFR.

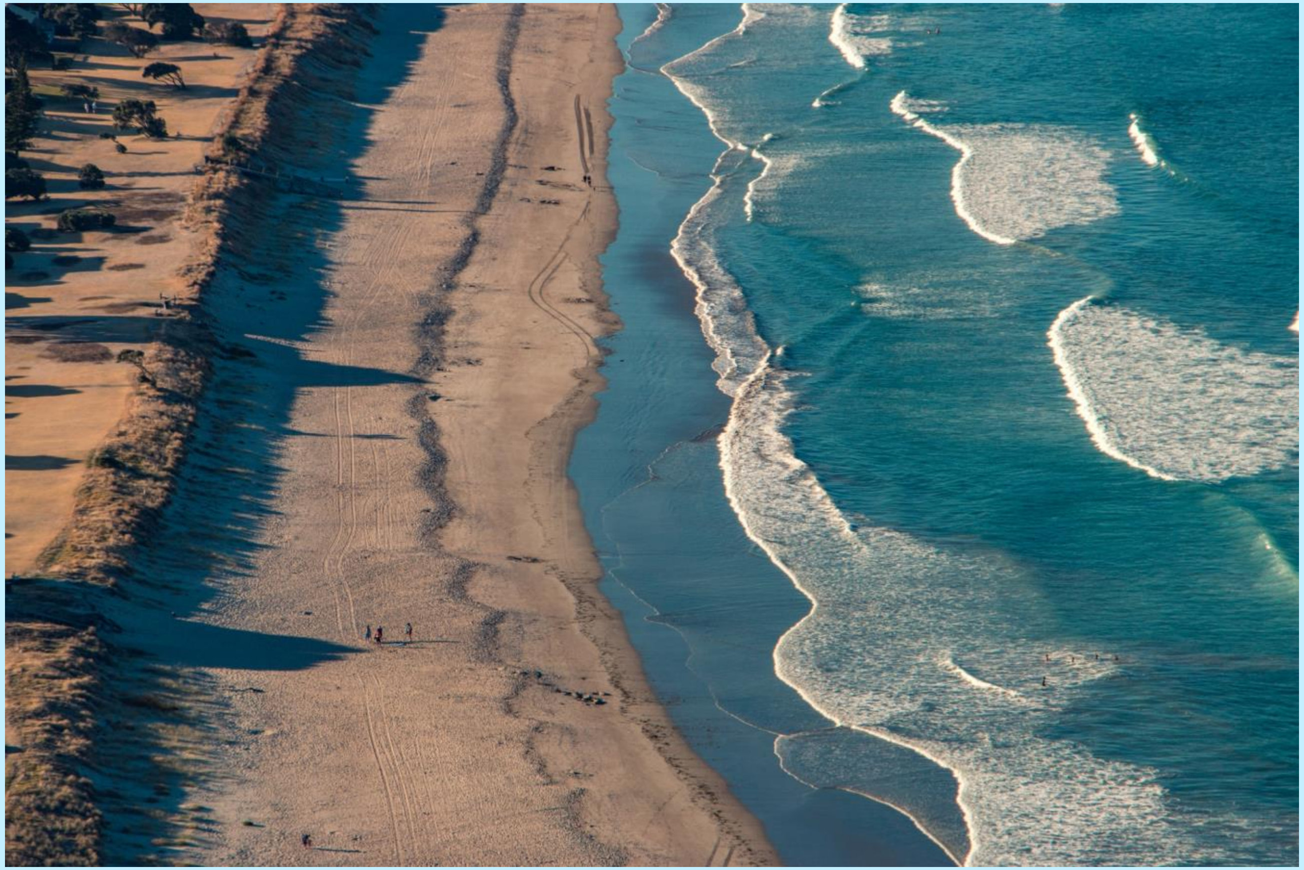
- *Do **not** attempt to fly at Vy with full power to out-climb sink.*
- *Remain at or below Va (maneuvering speed) in turbulence.*

The wave is my playground!

What conditions are best for wave soaring?

- Moderate winds aloft (30-50 kts.)
- Vertically Propagating Waves offer
  - the strongest lift
  - highest possible altitude gains
- “Trapped lee-side waves” offer
  - easier access, less effort
  - option to stay over open flats
  - rotors usually less severe

Wave lift shifts and pulses much like waves on a beach



Some challenges for sailplane pilots

- Long tows to higher than normal altitudes to find wave lift.
- Getting “drilled” in sink you cannot escape, landing out.
- Bucking a headwind to get home. (*Never let yourself get too far downwind of a safe LZ. Always have a “way out*.”)
- XC flight in wave is difficult (much easier in thermals)
- Numerous other unusual hazards with severe consequences.

Hazards of wave soaring

"What can possibly go wrong?"

- O2 system malfunction
- Canopy icing up inside
- Hypothermia/frostbite
- Traffic in the Airspace
- Rotors and extreme sink, resulting in forced landing

Always have a way out !

"Plan B" and "Plan C"

ADM – “*It looks so inviting. Can I reach it? Can I make it back? Where can I land if I don’t make it back? Are my retrieval logistics in place (cell coverage w/ driver, vehicle and trailer ready with keys, glider disassembly tools, etc.)? Alternate plan?*”

Hazards of wave soaring (continued)

- Increased wind speed aloft may prevent you from staying ahead of the wave leading edge. You could be backing into the wave cloud behind you.

- Inadvertent VMC flight into IMC leading to spatial disorientation and loss of control.

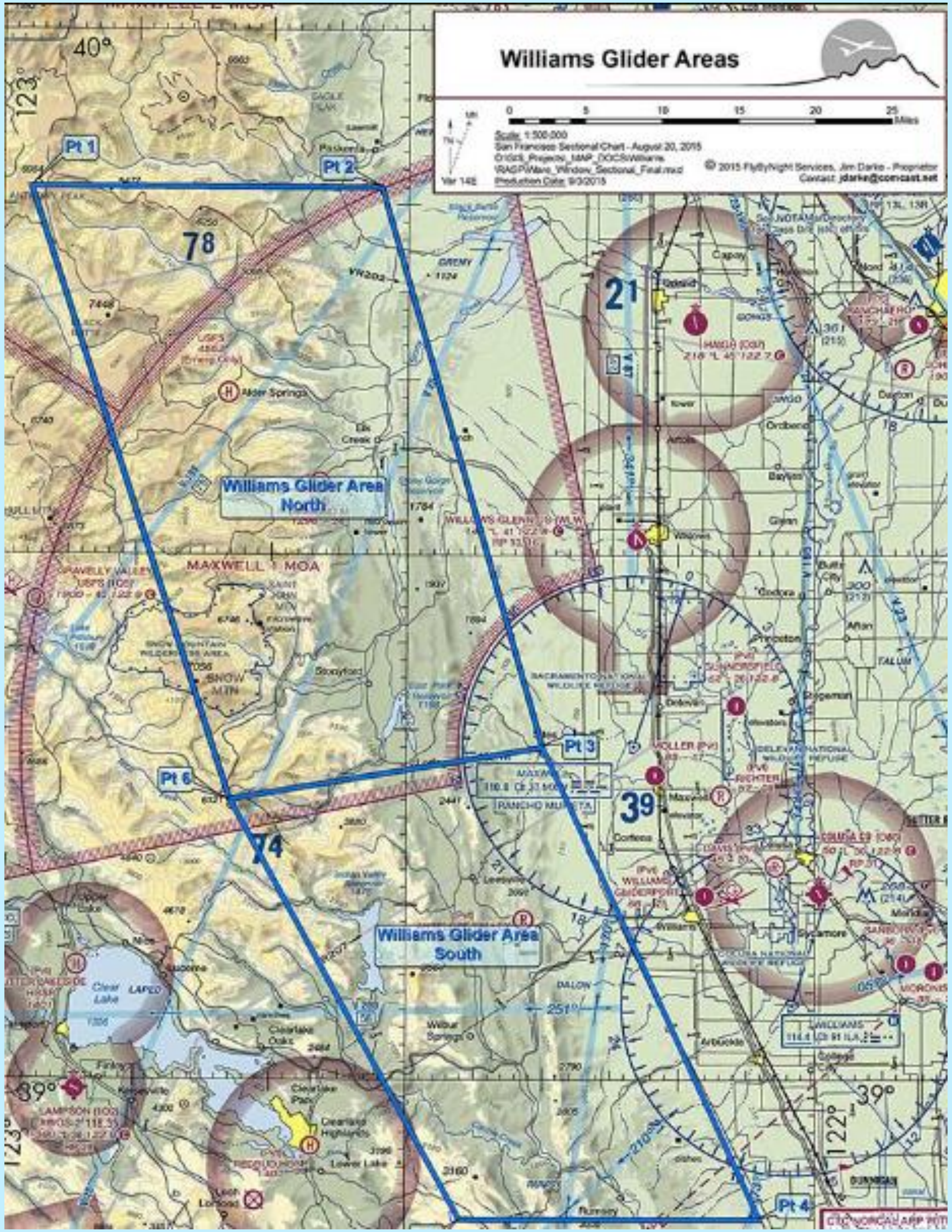
- Exceeding (TAS) V_{ne} and load factor limits.


ON
GO

ADM – “*It looks so inviting. Can I reach it? Can I make it back? Where can I land if I don’t make it back? Are my retrieval logistics in place (cell coverage w/ driver, vehicle and trailer ready with keys, glider disassembly tools, etc.)? Alternate plan?*”

Soaring in Class A airspace requires adherence to established FAA ARTCC authorizations and waivers, local protocols, and prior notification with ATC.

There are several established “wave windows” for soaring in Class A airspace in western states.



SSA and FAI Altitude Records for Gliders

Montana State Record: **35,000 ft.**

6/26/1973 Nelson Funston (location unknown)

US National Record: **49,009** ft.

2/17/1986 Robert Harris Owens Valley, CA

and the World Record is……. (*drum roll please….*)

Perlan Project

CURRENT WORLD RECORD **<u>76,124</u> ft.**

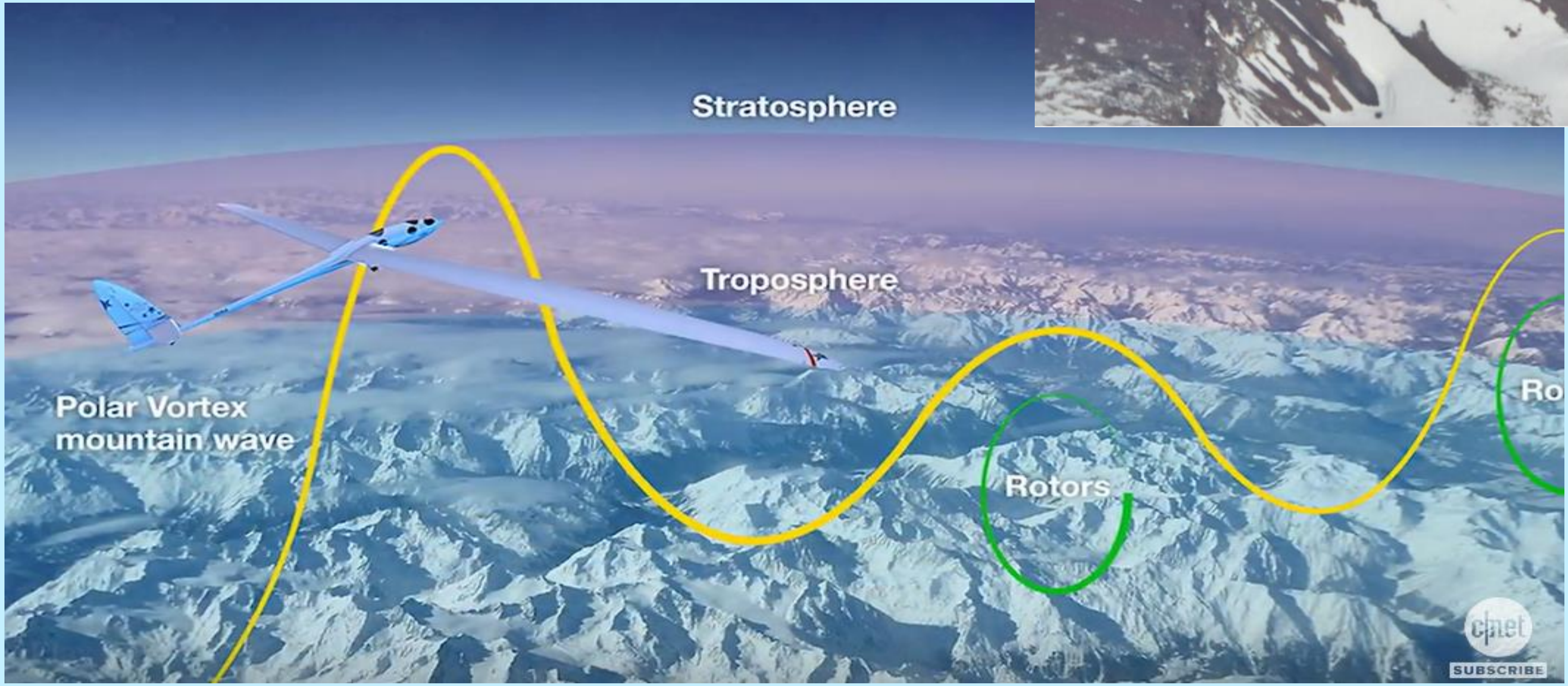
Sept. 2, 2018 Jim Payne and Tim Gardner

El Calafate, Argentina (Patagonian Andes)

The Perlan Project goal is to reach 90,000 ft.

higher than 98% of the earth's atmosphere.

https://www.youtube.com/watch?v=KE792Y9hyww


Stratosphere
Troposphere
Polar Vortex
mountain wave
Rotors
SUBSCRIBE

Final recommendation…..

Earn your glider rating and start soaring!

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rock2sky@yahoo.com