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Orographically-Inverted Snow in the Wasatch Front of Utah



JULY 15th, 2020

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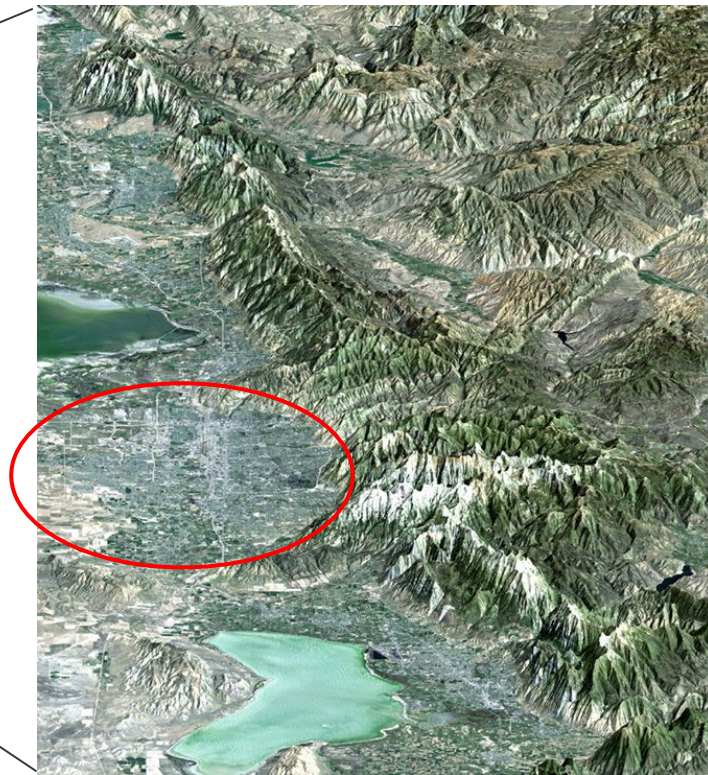
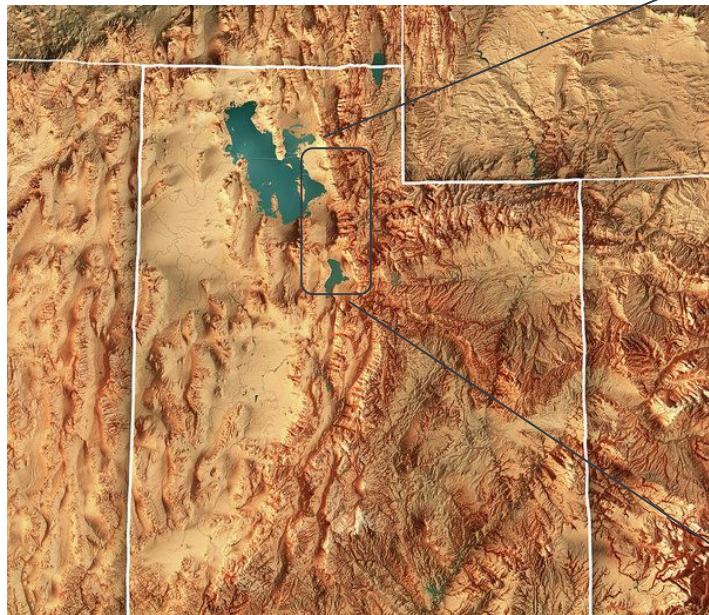
Collaborators: Glen Merrill - Forecaster WFO SLC, Mike Seaman - Senior Forecaster WFO SLC

Outline

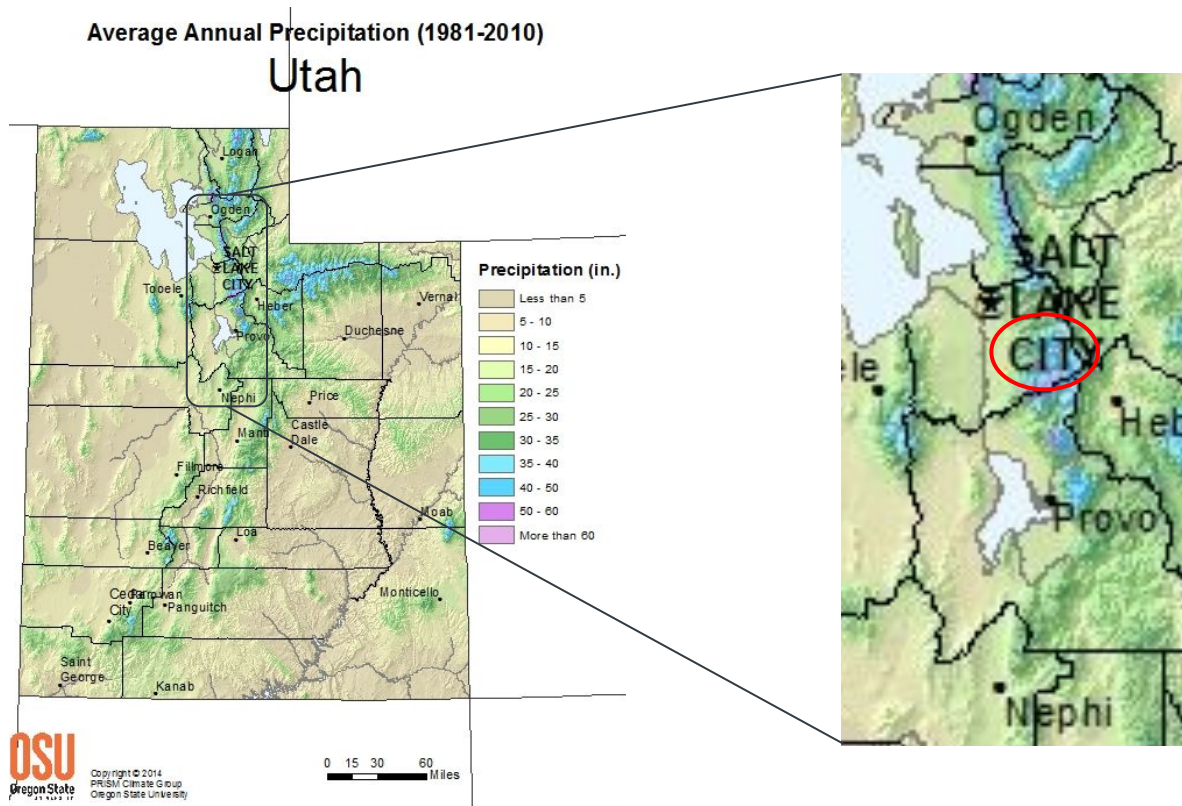
- Explanation of orographically inverted events and their impacts.
- Work to diagnose events using Froude Number.
- Ingredients-based forecast methodology.



What is “Orographically-Inverted” Snow?



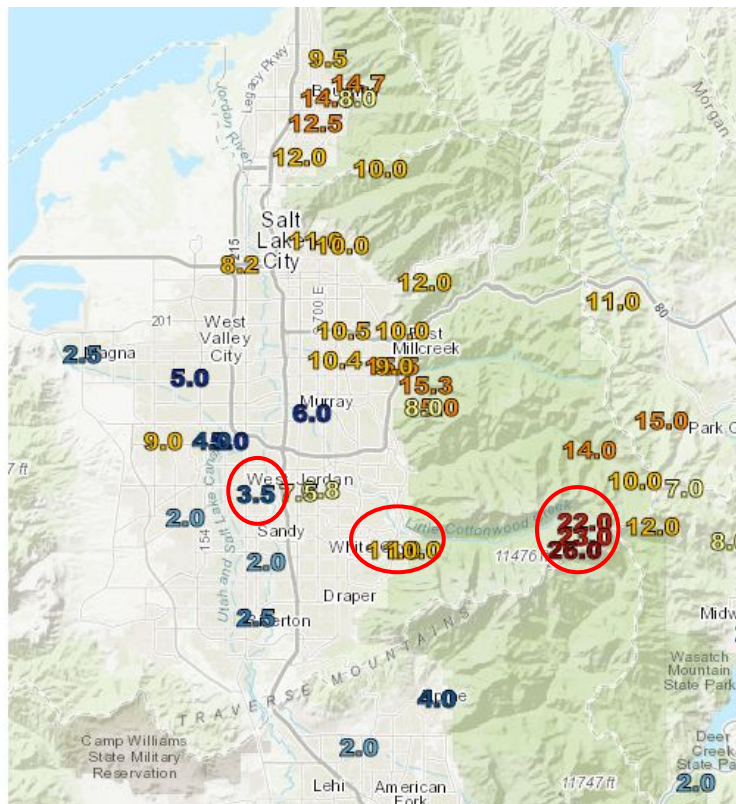
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What is “Orographically-Inverted” Snow?

Standard orographic
ratio case: 3/4/18

Most common
snowfall distribution
observed along the
Wasatch Front



Wasatch Mountain Valleys		
Woodland	8 AM Sun	3.0"
Midway	8 AM Sun	2.0"
Deer Creek Dam - 5270 ft	5 AM Sun	2.0"
Heber City - 5768 ft	9 AM Sun	1.5"
Morgan - 5090 ft	5 PM Sun	1.0"
Wasatch Mountains North of I-80		
Emigration Canyon	7 AM Sun	12.0"
Summit Park - 7000 ft	11 AM Sun	11.0"
Snowbasin-mid. Bowl - 7402 ft	5 PM Sun	10.0"
City Creek Water Plant - 5330 ft	5 PM Sun	10.0"
Powder Mountain	4 PM Sun	8.0"
Laketown - 5980 ft	5 PM Sun	1.5"
Wasatch Mountains South of I-80		
Snowbird - 8100 ft	3 PM Sun	26.0"
Alta Collins - 9662 ft	4 PM Sun	23.0"
Alta Udot - 8799 ft	4 PM Sun	22.0"
Canyons Village at Park City - 8800 ft	3 PM Sun	15.0"
Big Cottonwood Spruces - 7402 ft	4 PM Sun	14.0"
Brighton Crest - 9500 ft	4 PM Sun	12.0"
Solitude - 8200 ft	4 PM Sun	10.0"
5 S Park City	12 PM Sun	8.0"
Park City Mountain - 9300 ft	5 PM Sun	7.0"
3 E Provo	7 AM Sun	5.0"
Provo Canyon - 6100 ft	6 AM Sun	5.0"
Western Uinta Mountains		
Heber City 10 ESE - 8305 ft	8 AM Sun	4.0"
Sanpete/Sevier Valleys		
Scipio - 5315 ft	5 PM Sun	4.0"
Nibley	9 AM Sat	2.0"
West Central Utah		
Fillmore - 5120 ft	5 PM Sun	13.0"
Oak City - 5135 ft	7 AM Sun	8.8"
Delta	11 AM Sun	6.0"



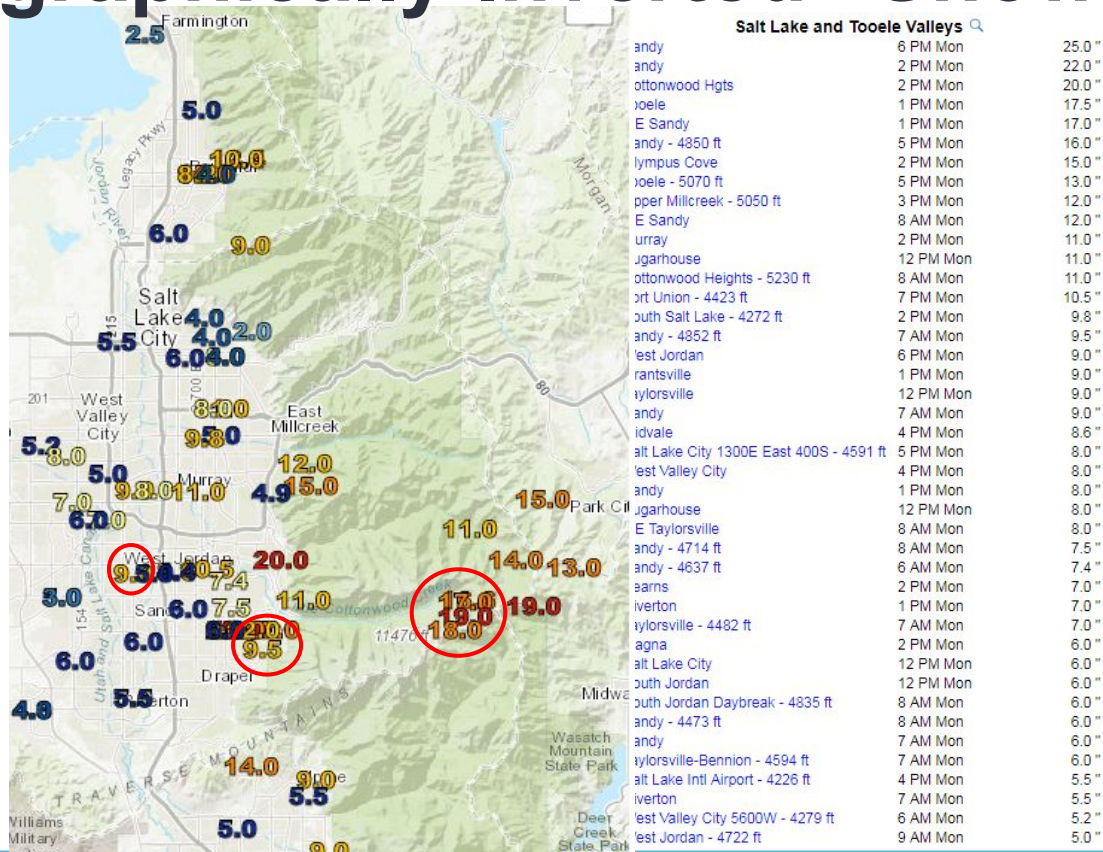
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What is “Orographically-Inverted” Snow?

Reduced orographic ratio
case: 2/19/18

Most common with slow
moving/stalled baroclinic
zones.

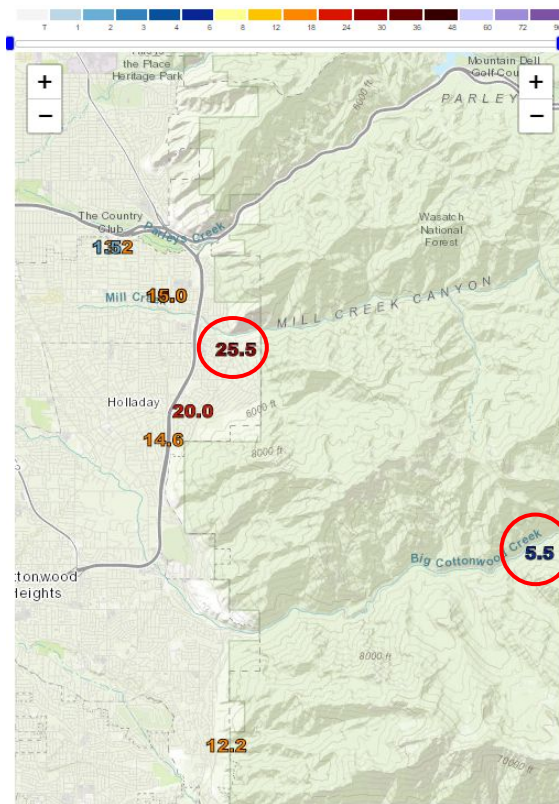


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What is “Orographically-Inverted” Snow?

Full orographic inversion
case: 1/10/13



Northern Wasatch Front

2 E Bountiful	5 PM Fri	34.0"
Woods Cross	5 PM Fri	21.0"
2 E Bountiful	5 PM Fri	21.0"
Centerville - 4445 ft	2 PM Fri	20.0"
Hill Air Force Base - 4787 ft	5 PM Fri	18.0"
Clearfield	5 PM Fri	18.0"
North Salt Lake	10 AM Fri	18.0"
East Layton	8 AM Fri	18.0"
East Layton	8 AM Fri	18.0"
Centerville - 4346 ft	7 AM Fri	18.0"
1 W Layton	5 PM Fri	16.0"
Bountiful - 5085 ft	8 AM Fri	15.3"
Bountiful	5 PM Fri	15.0"
Farmington - 4239 ft	6 AM Fri	14.5"
South Ogden - 4780 ft	9 PM Fri	14.0"
Farmington	5 PM Fri	13.0"
Layton - 4460 ft	5 PM Fri	13.0"
Bountiful	8 AM Fri	13.0"
Clinton	5 PM Fri	12.0"
Roy	5 PM Fri	12.0"
Fruit Heights	11 AM Fri	12.0"
West Pt	8 AM Fri	12.0"
Northeast Ogden Bench - 4560 ft	8 AM Fri	11.5"
Perry - 4491 ft	6 AM Fri	11.5"
Syracuse	8 AM Fri	9.0"
West Haven - 4239 ft	7 AM Fri	8.0"
Centerville	8 PM Thu	8.0"
North Ogden - 4392 ft	7 AM Fri	7.0"
West Weber - 4248 ft	7 AM Fri	6.5"
Brigham City	9 PM Thu	6.0"

Salt Lake and Tooele Valleys

Upper Millcreek - 5050 ft	3 PM Fri	25.5"
Olympus Hills - Msi - 4960 ft	5 PM Fri	20.0"
East Millcreek	9 AM Fri	19.0"
Upper Avenues - 5000 ft	5 PM Fri	16.0"
Salt Lake City	2 PM Fri	15.0"
East Millcreek	6 AM Fri	15.0"
East Millcreek	12 AM Fri	15.0"

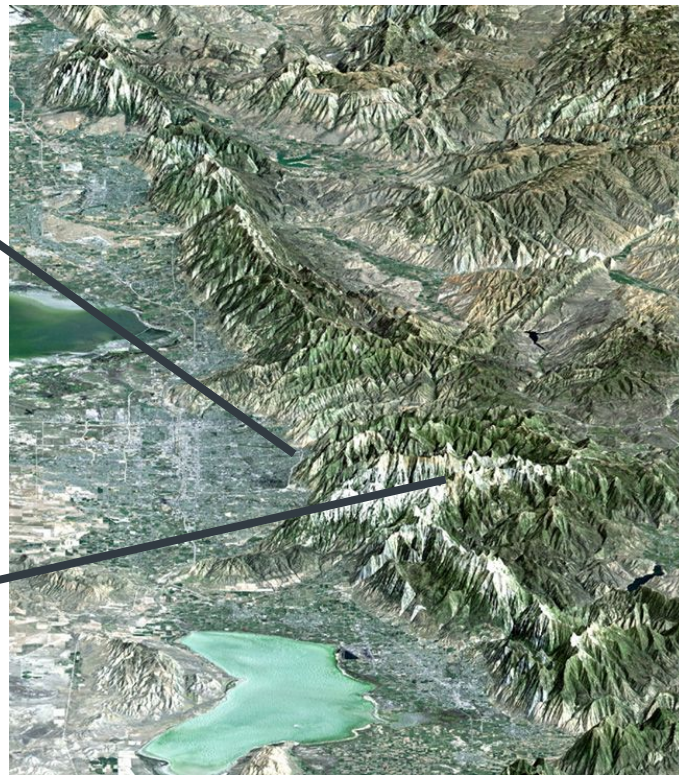
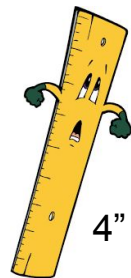


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What is “Orographically-Inverted” Snow?



Full orographic inversion
case: 1/10/13



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Impacts of Orographically-Inverted Snow Events

- Transportation (mitigation and planning implications for UDOT).
- Ski enthusiast surprise.



Using Froude Number

$$N = \left(\frac{g}{\theta} \frac{\partial \theta}{\partial z} \right)^{\frac{1}{2}}$$

Gravity

Potential Temperature Difference

Potential Temperature at Surface

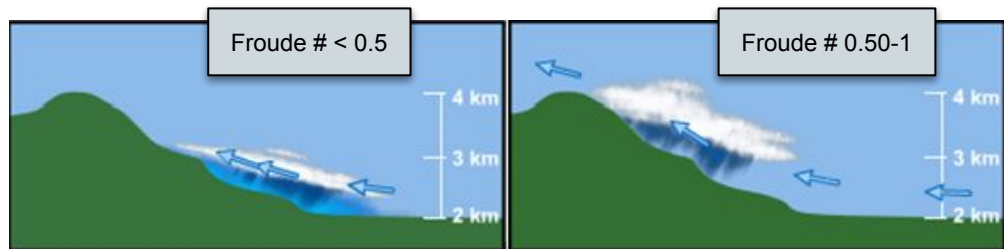
Elevation Difference

$$F_r = \frac{U / h}{N}$$

Perpendicular Wind Speed

Height of Mountain

For blocked flow, would expect high N (stability), low U (wind component normal to barrier) and/or higher h (taller barrier). Thus, **the lower the Froude the more blocking expected.**



Froude Number (Frd#):

Frd# < 0.5 Flow is subcritical and blocked

- Upslope clouds/precip backed farther upwind of and up to mtn crest.
- Inverted orographic enhancement (precip maxima displaced upstream of barrier)
- Gap winds possible.

Frd# 0.5-1 Flow is subcritical/slow moving/blocked

- Upslope clouds/precip falls immediately upwind of mtn crest.
- Standard orographic enhancement.
- Gap winds possible.

Frd# 1-2 Flow is critical

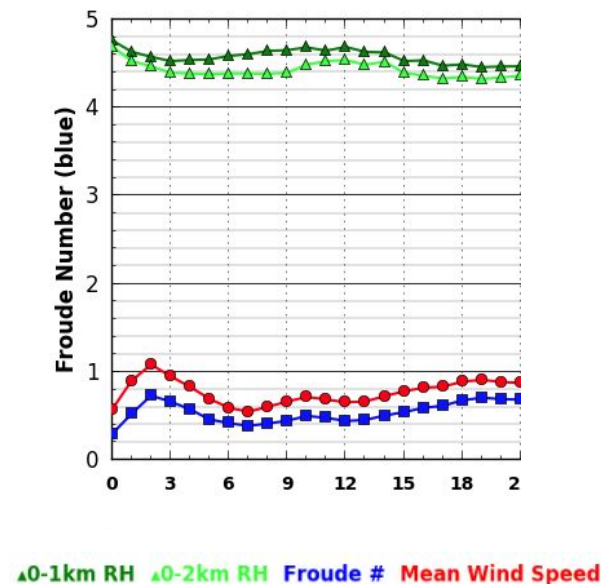
- Precip falls close to mountain ridge crests and on lee side.
- Lessened orographic enhancement.
- With strong winds, Mountain waves/downslope winds possible.

Froude > 2 Flow is supercritical/unblocked(rapid flow)

- Air flows freely over terrain.
- No orographic enhancement, persistent upslope precip not favored.

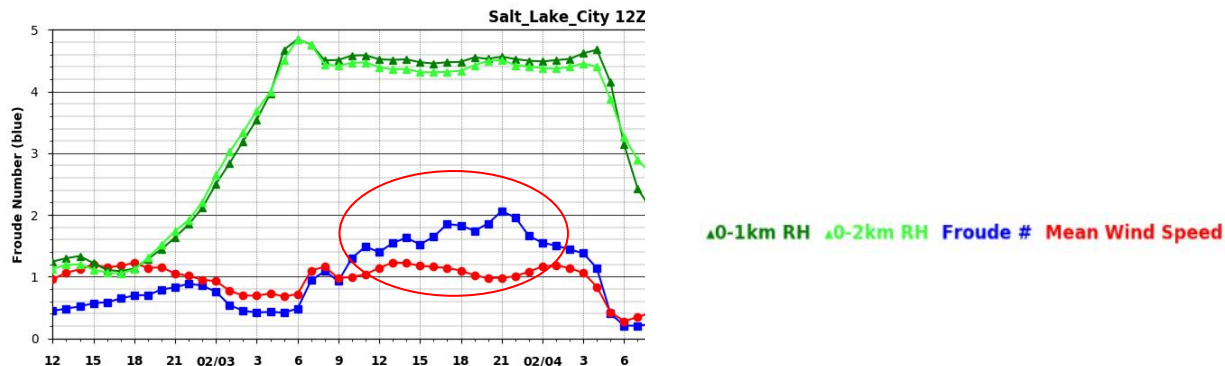
Using Froude Number

- Period of interest must be sufficiently saturated to support precip.
- Need perpendicular flow to the barrier (or close to it).
- Froude number below 0.5 to indicates strong blocking. Extreme cases could approach 0.25.



Problems With Froude Number

- Many assumptions which become increasingly unrealistic with increased barrier height
- Froude # was not successful for some cases.



Alternative Methods to Diagnose

- Forecaster experience has shown model soundings to be helpful in diagnosing blocked flow. BUFKIT works well.
- Multiple ingredients noticed in past cases.
- CAMs can resolve.



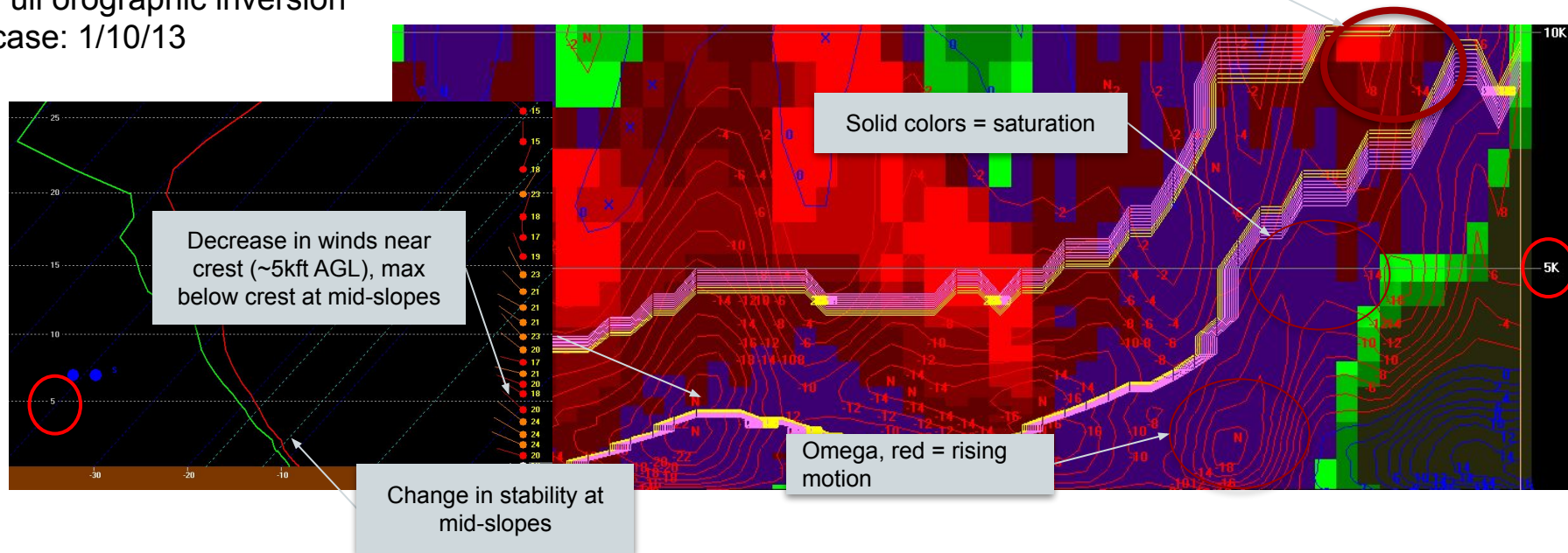
Ingredients Noted in Past Cases

- Past cases of “full orographic inversion”:
1/10/13, 12/15/15, 2/19/18, 2/3/20
- Unusually cold, long period of moist post-frontal NW flow (but lighter winds than most NW flow cases)
- Typical signatures in BUFRKIT for KSLC:
 - Best dendritic growth below 5kft AGL
 - Capping inversion around 5kft AGL
 - Wind profile change above 5kft AGL



Using BUFKIT as a Diagnostic Tool

Full orographic inversion
case: 1/10/13



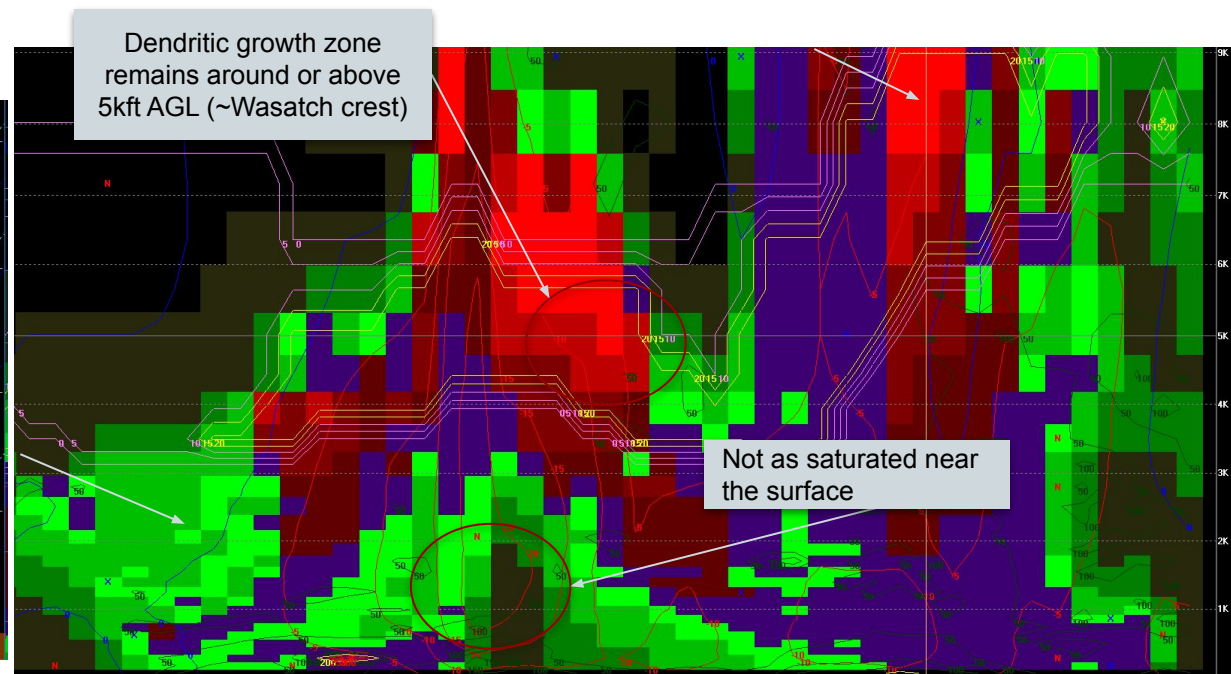
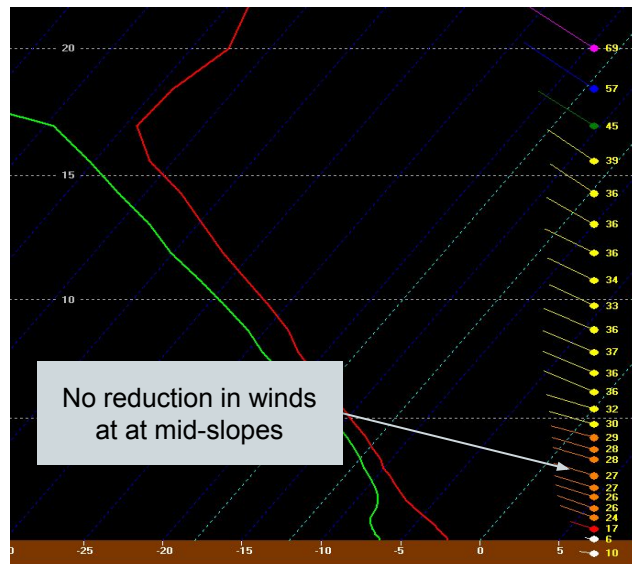
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Using BUFKIT as a Diagnostic Tool

Standard orographic
ratio case: 3/4/18



Orographically-Inverted Snow Forecast Funnel

- 3+ days out: recognize and have sufficient confidence in synoptic pattern
- 2-3 days out: recognize BUFKIT signatures
- 1-2 days out: recognize patterns in CAM QPF
 - Build enough confidence to change our messaging, both for the public and core partners (e.g. UDOT and snow safety community)



Future Work

- Explore Froude number in different layers and depths.
- Collect additional cases.
- Derive orographic ratios and classify cases (e.g. regular orographics, reduced orographic ratio, inverted orographic ratio), then composite synoptic features for the various classifications.



Questions?

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