Lake Effect Snow

Adventures from the Wasatch Mountains to the Tug Hill Plateau

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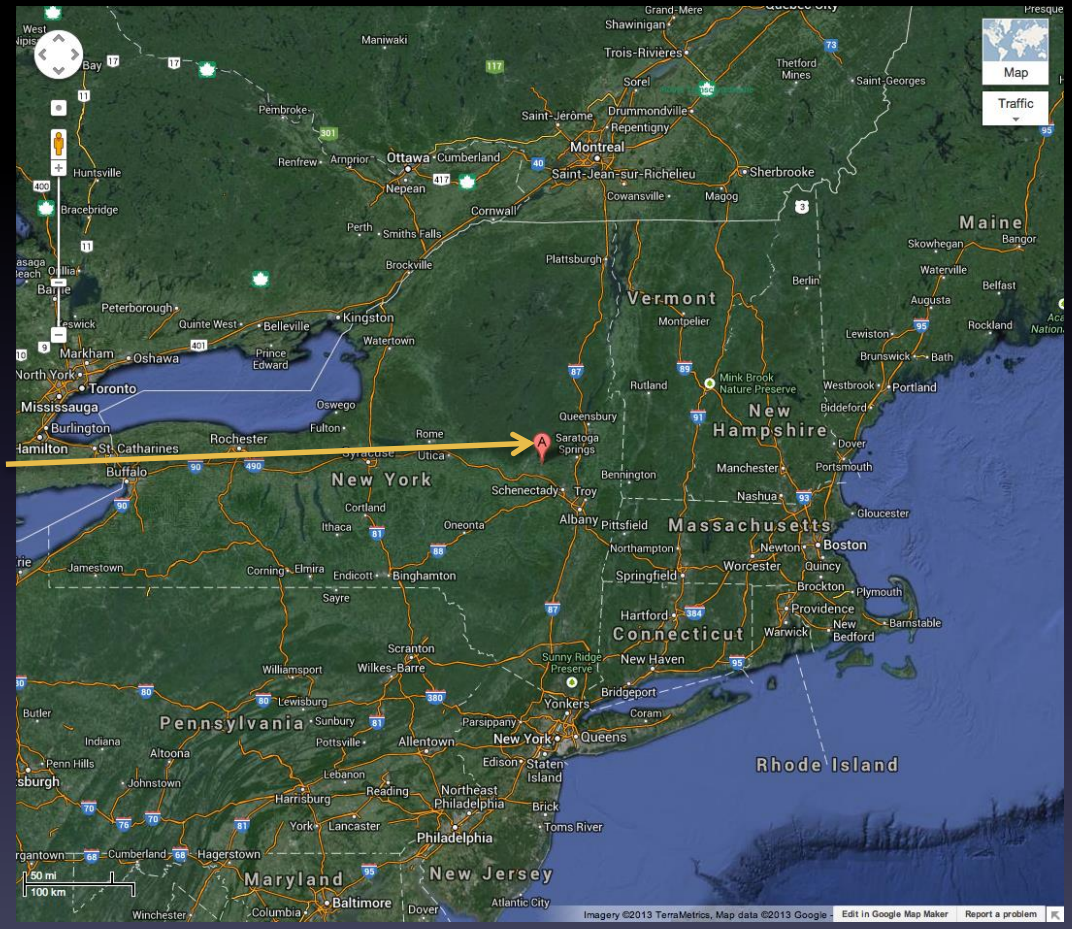
Special thanks to Leah Campbell, Peter Veals, Melissa Maestis, Sarah Bang, Trey Alvey, Zhuocan Xu, Tyler West, Derek Jensen, Justin Minder, Ted Letcher, and all the OWLeS participants

Photo: Trevor Alcott

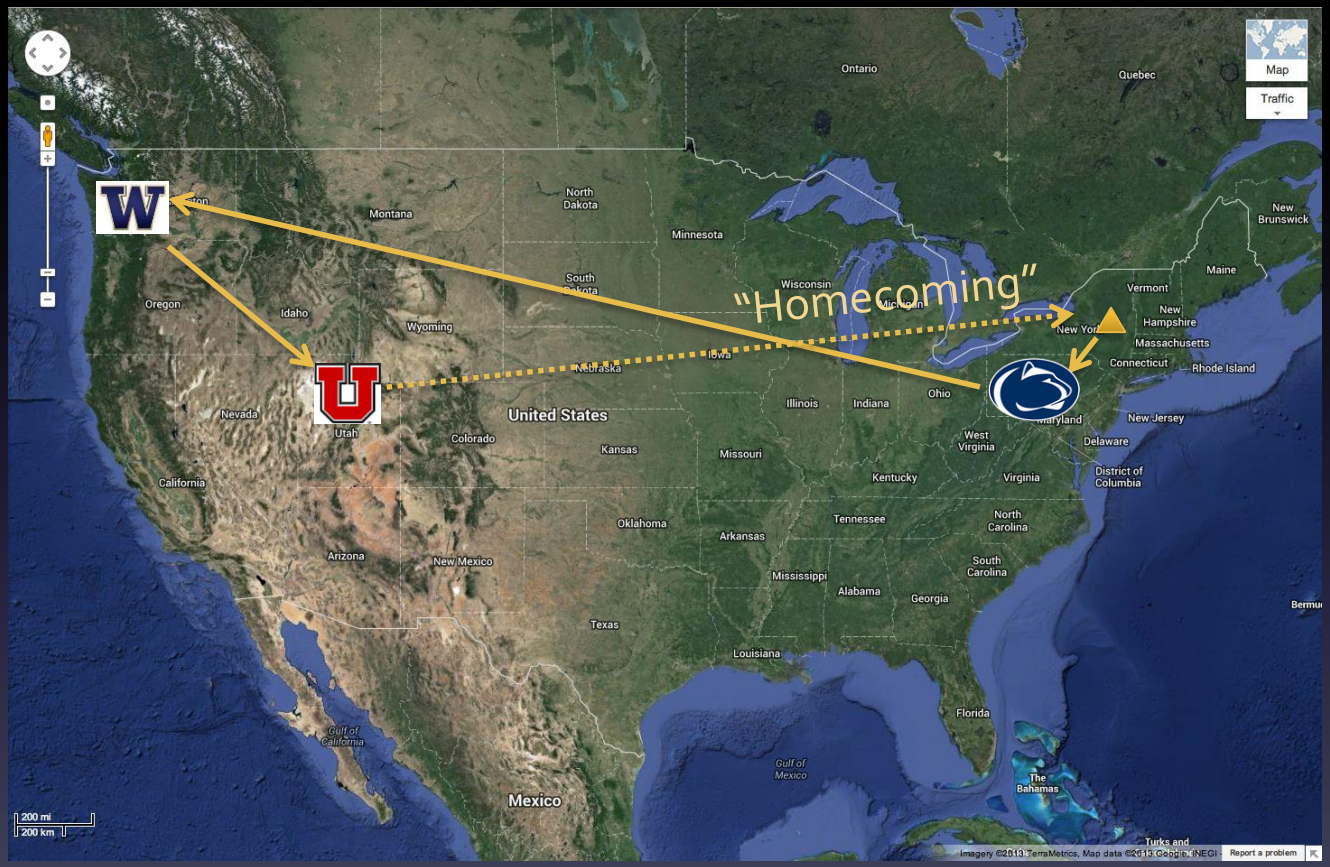
Who I Am

1985 graduate of Perth Central School
Rural K-12 district

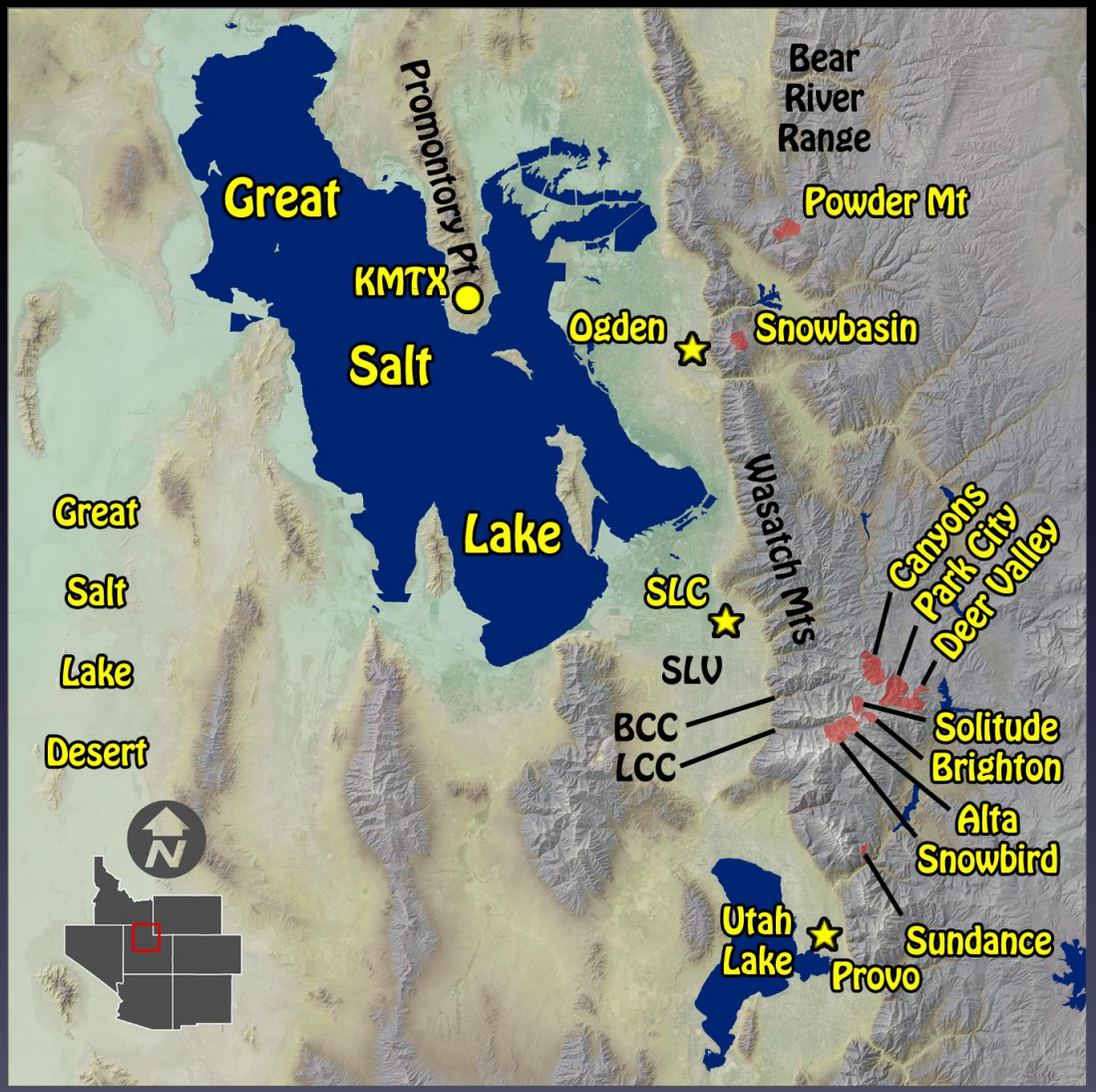
Interests: Skiing, Hiking, Snow…



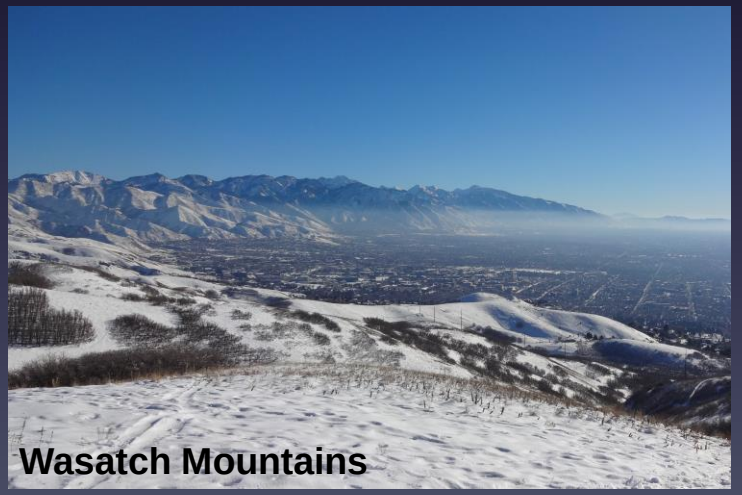
Who I Am


"Homecoming"
United States
Mexico
Ontario
Quebec
Montana
North Dakota
Minnesota
Wisconsin
Oregon
Idaho
Wyoming
Nebraska
Iowa
Illinois
Indiana
Ohio
Nevada
Utah
Colorado
Kansas
Missouri
West Virginia
Kentucky
Virginia
California
Oklahoma
Tennessee
Arkansas
North Carolina
Arizona
New Mexico
Mississippi
Alabama
Georgia
South Carolina
Texas
Louisiana
Florida
New Brunswick
Maine
Vermont
New Hampshire
Massachusetts
Connecticut
Rhode Island
New Jersey
Delaware
District of Columbia
Gulf of California
Gulf of Mexico
The Bahamas
Map
Traffic
200 mi
200 km

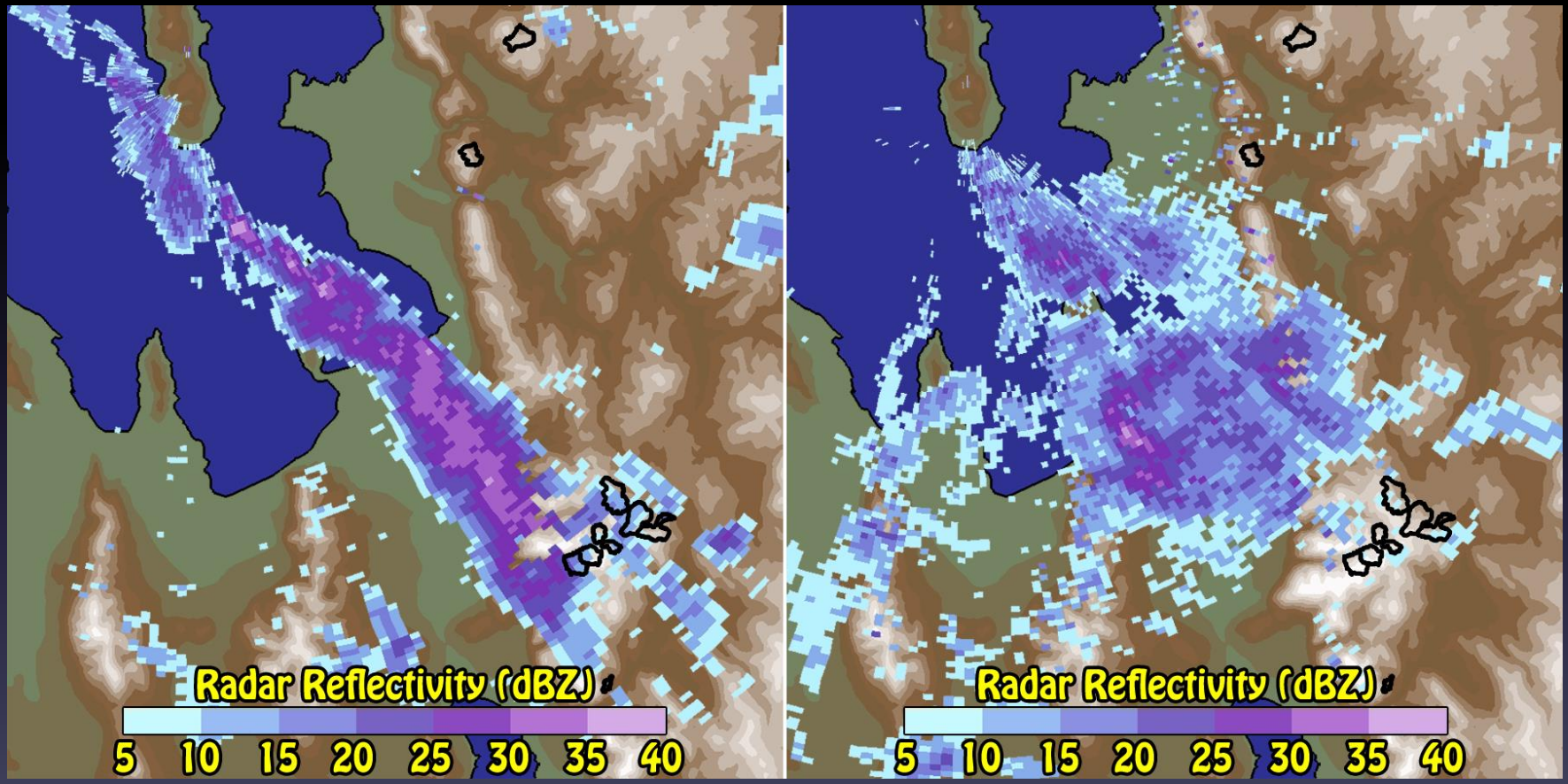
Northern Utah




Great Salt Lake


Wasatch Mountains

Yes, We Get Lake Effect



Steenburgh (2014)

Yes, We Are Also Snow Snobs


Photo: Tyler Cruickshank


Photo: Brett Kobernik

- Average annual snowfall > 500" in some parts of Wasatch Mountains
- Most reliable snow climate in contiguous U.S.
- Probably the best powder skiing in North America if not the world
- Snowmobiling too – especially in surrounding ranges

Yes, We Are Also Snow Snobs

Tug

Utah

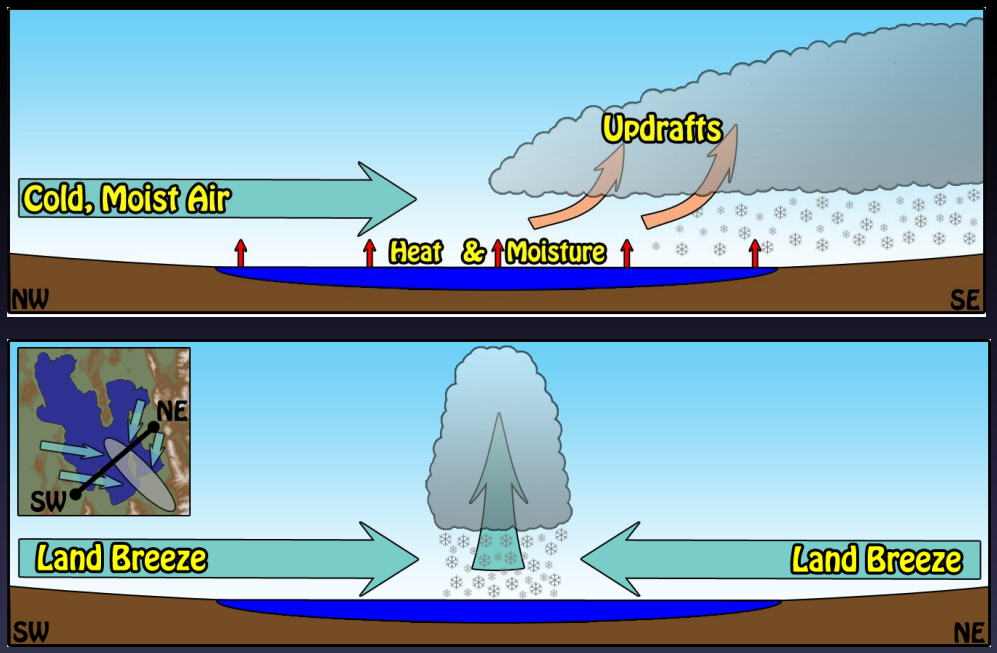
What Brings Me to the Tug?

- Reunite with my "high-school sweetheart"
  - First deep powder ski day @ Snow Ridge circa 1984
- Great place to study how terrain affects lake-effect storms
- Opportunity to observe some of the most intense snowstorms in the world
- Participate in the Ontario Winter Lake-effect Storms (OWLeS) Project (owles.org)
  - Trying to understand and better forecast lake-effect storms in your area

What Is Lake-Effect?

- Precipitation (snow or rain) generated by the interaction of the atmosphere with a relatively warm body of water (lake, sea, or ocean)

- Contributing ingredients
  - Heat and moisture fluxes
  - Lake shape
  - Thermally driven flows (land breezes)
  - Coastline shape (convex or concave) and roughness
  - Hills, plateaus, and mountains



Lake Ontario and Tug very well configured for intense storms

Steenburgh (2014)

Storm Intensity

"Snow rates during some events are the greatest ever measured on record from anywhere in the world"
– Christopher Burt

12 inches in 1 h, Copenhagen, NY
2 Dec 1966

17.5 inches in 2 h, Oswego, NY
26 Jan 1972

51 inches in 16 hours, Bennetts Bridge, NY
17-18 Jan 1958

77 inches in 24 hours, Montague, NY
11-12 Jan 1997

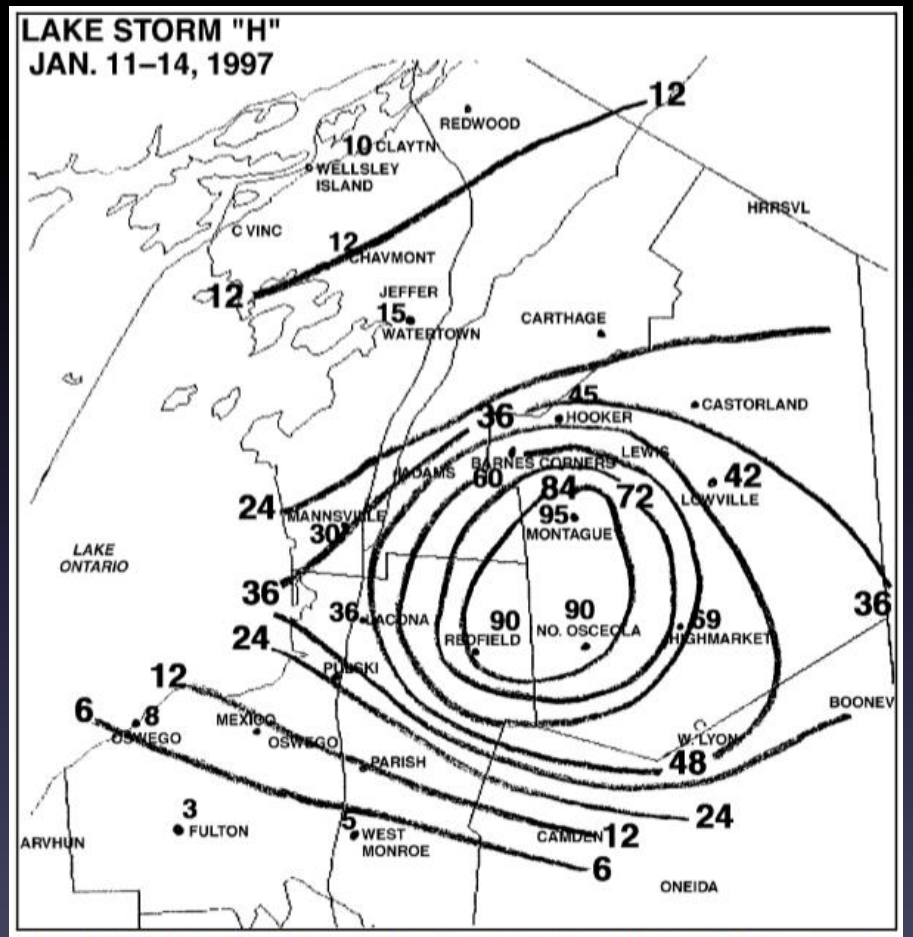


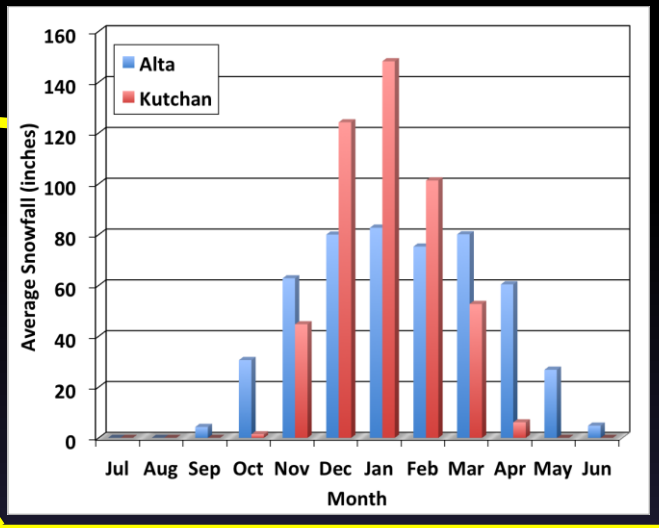
Figure 2: WSFO BUF Internet Snowfall Map for January 10-14, 1997 Tug Hill Snowstorm (date shown in upper left corner of Internet map is incorrect).

Burt (2010), NOAA (1997), WSFO Buffalo

Other Lake-Effect Regions

Slide: Trevor Alcott

Biggest Seasonal Lake Effect



Kutchan
180 m MSL
480 in (1220 cm)

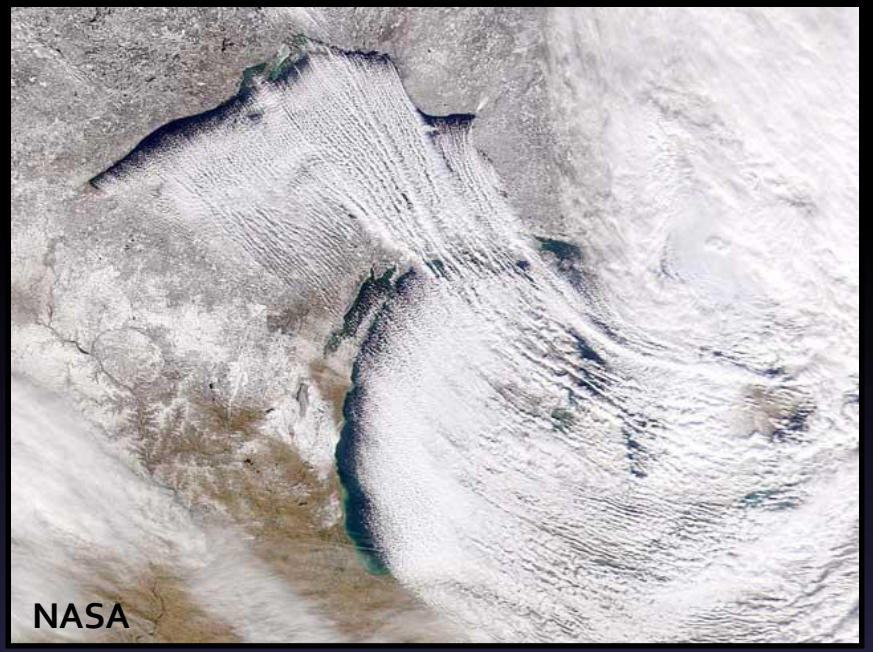
Alta
2600 m MSL
510 in (1295 cm)

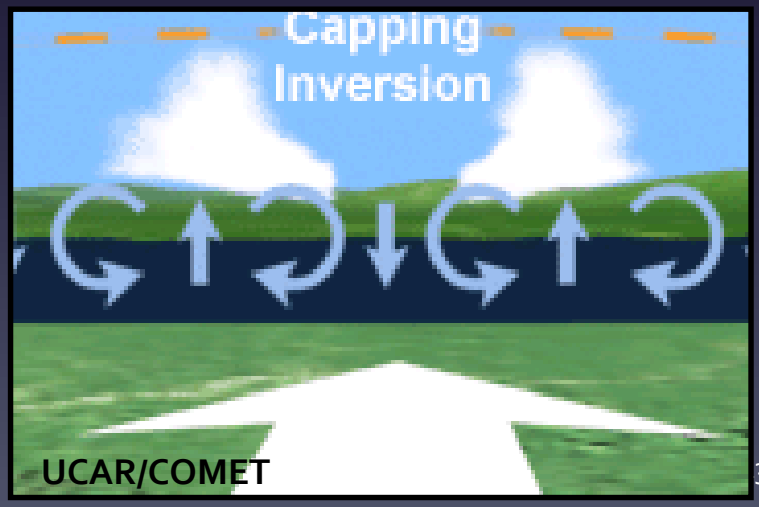
Aomori
Population 300,000; Elevation 200 m; Snowfall 305 in/775 cm

Steenburgh (2014), JMA, Wikipedia User Uryah

Lake-Effect Types

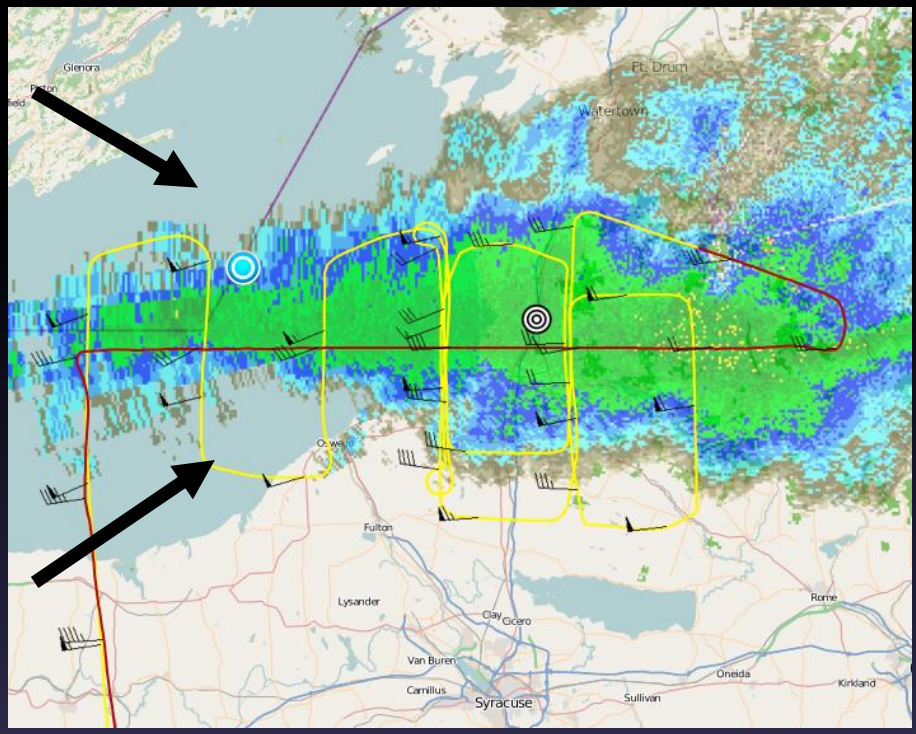
- Short-Fetch = Wide-area coverage
  - Wind parallel bands (a.k.a. cloud streets)
  - Typically occurs when the flow is across the long-lake axis
  - Snowfall widespread, but not typically intense

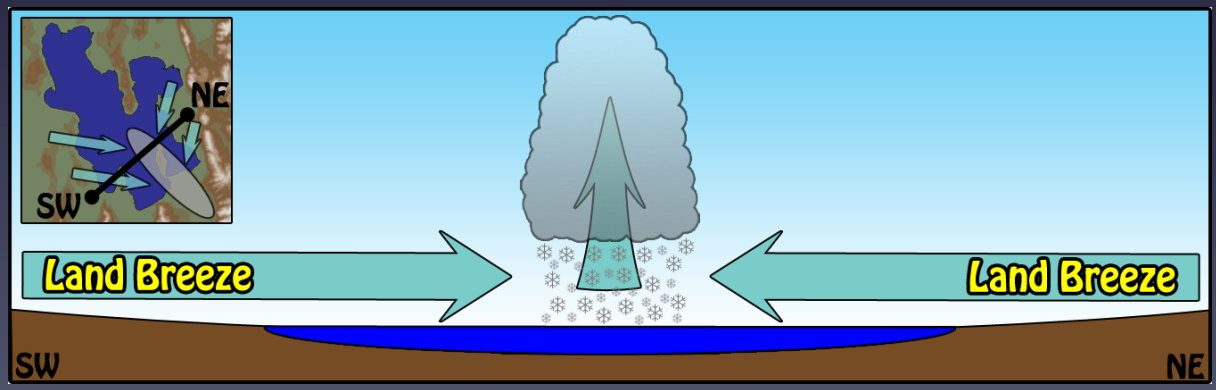




Lake-Effect Types

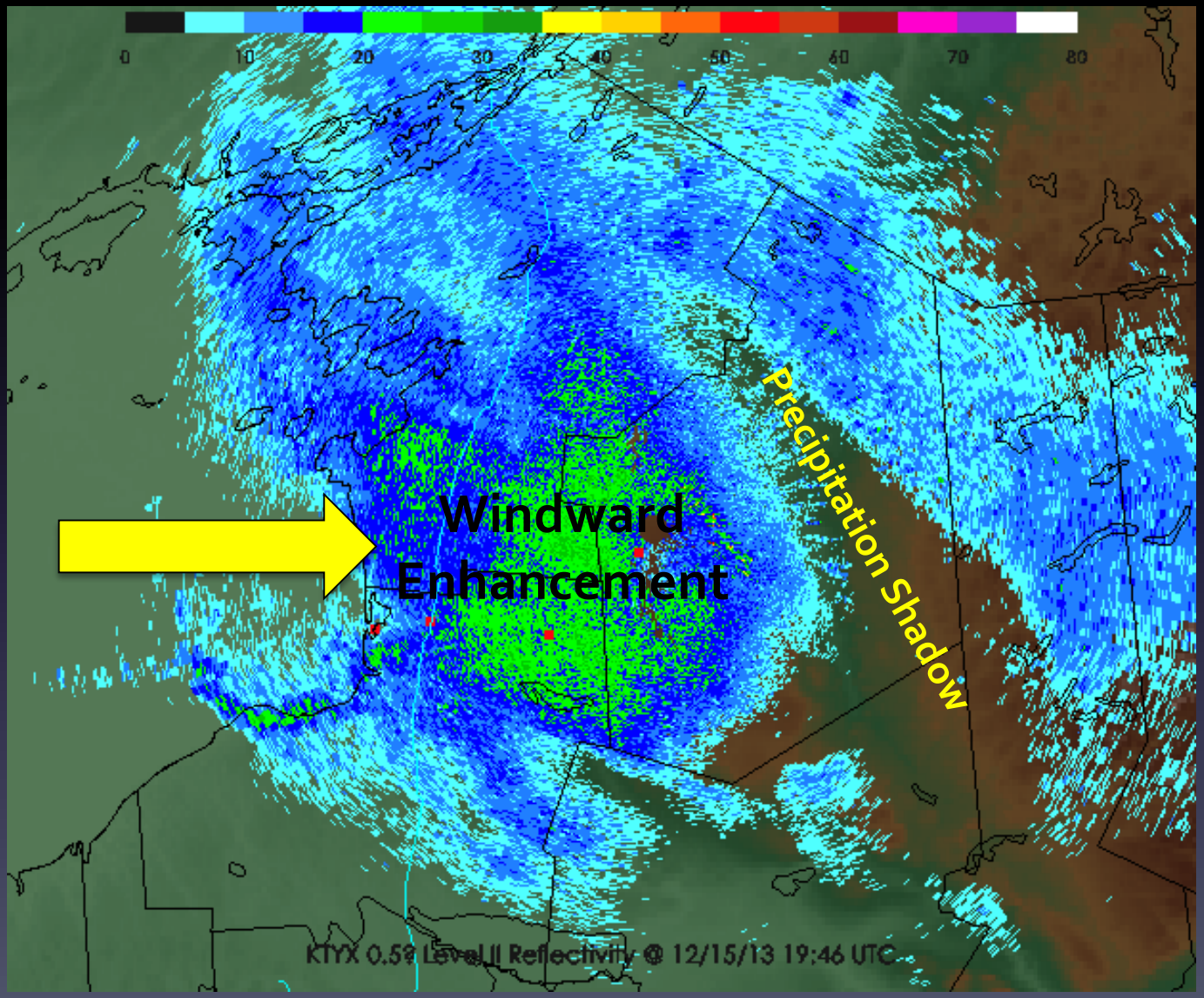
- Long Fetch = "LLAP Bands"
  - Occur when flow parallels long-lake axis
  - Land-breezes from opposing shorelines organize bands
  - Most intense type of lake effect
  - Common on Tug



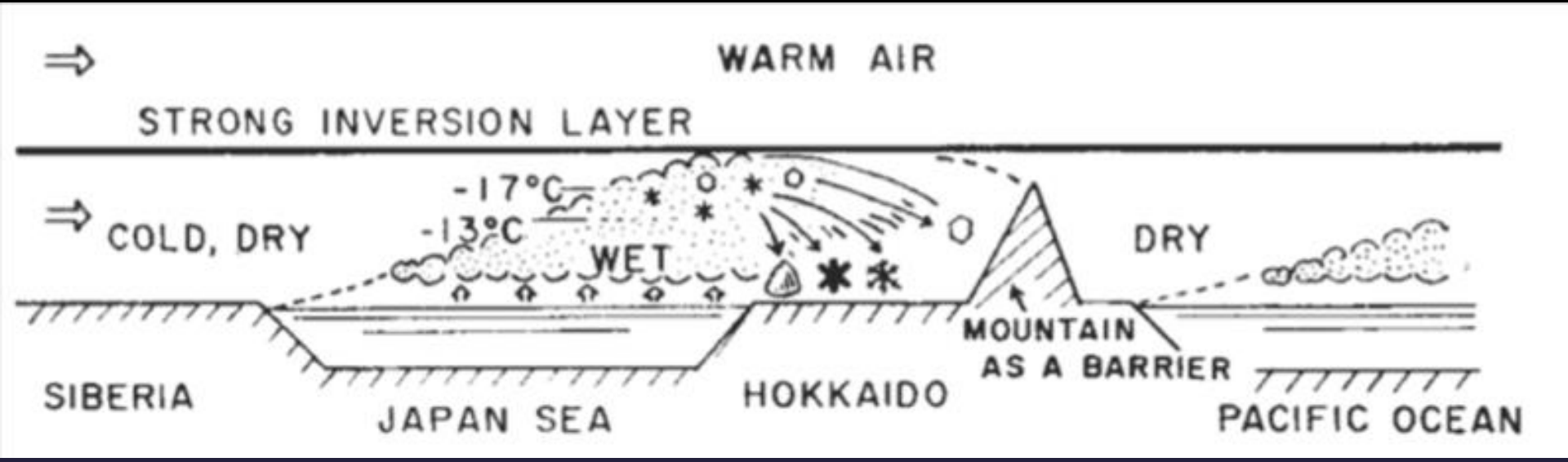


Steenburgh (2014)

Plateau Effects



Big Mountain Effects



Schematic of Satoyuki Storm

Satoyuki (lowland snowfall) – Heavier snow in lowland areas

Yamayuki (mountain snowfall) – Heavier snow in mountain areas

Storm type depends on height of capping inversion layer

Magono et al. (1966)

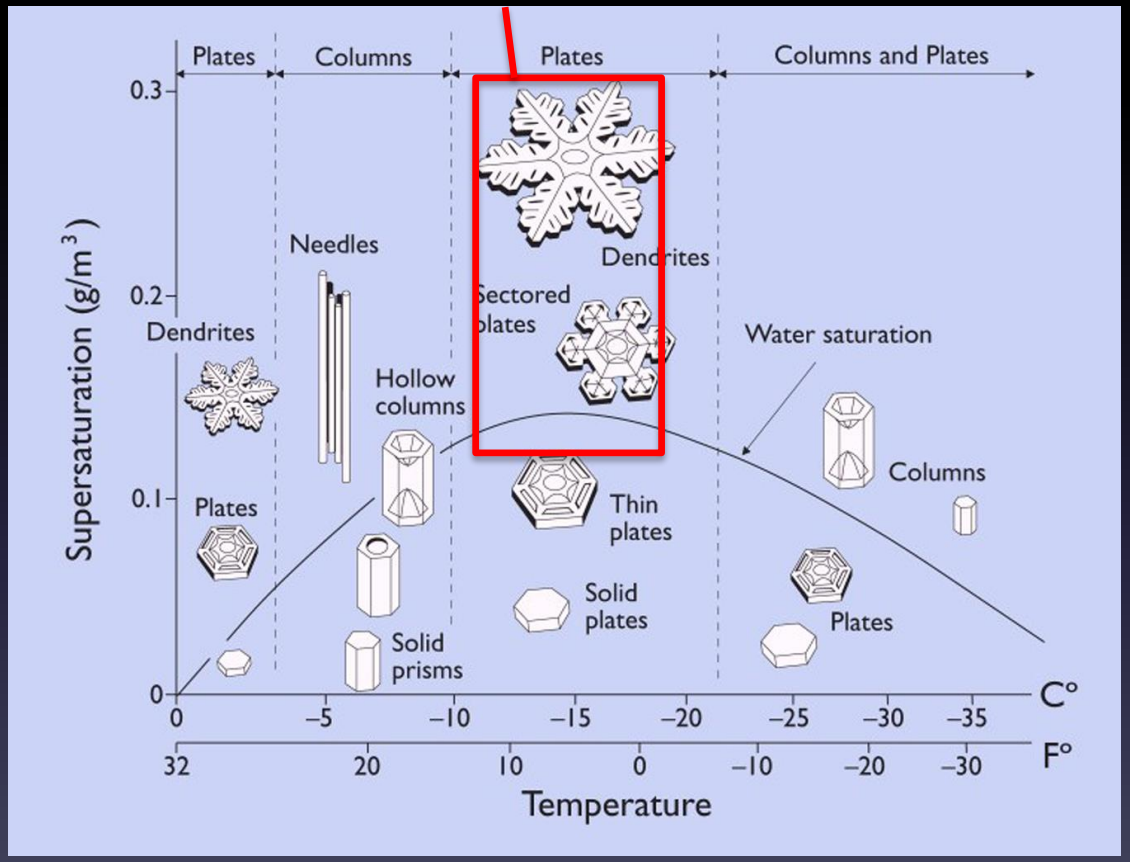
No Two Snowflakes Are Alike?

- Worldwide, a million billion snowflakes reach the ground every second
- Snowflakes can look similar, but it is extremely unlikely that any two are *exactly* alike
- The types of snow crystals that fall during a storm determine the water content and snow-to-liquid ratio of the snow
  - Is the snow light and fluffy or heavy and dense?

Photo: University of Utah

Snowy Details

Dendritic Growth Region (-18 to -12°C/0°F to 10°F)



Columns and Needles

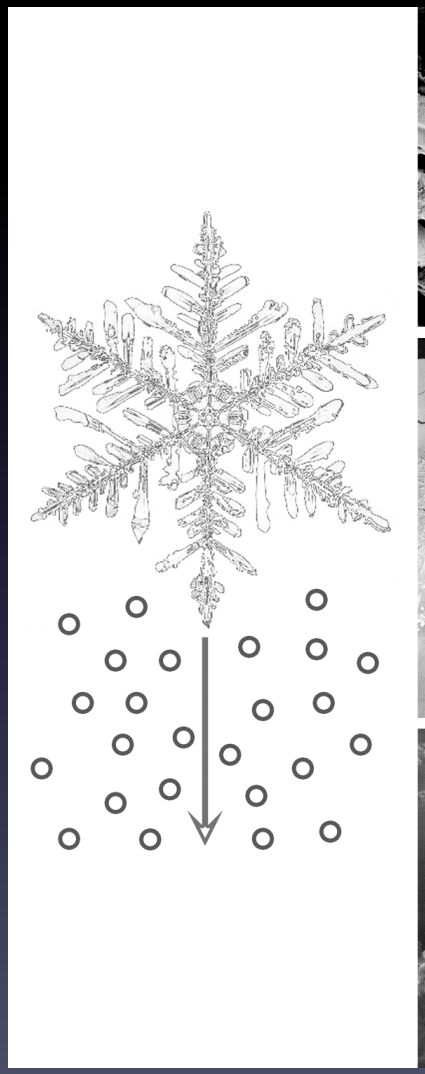
Stellar and Sector Plates

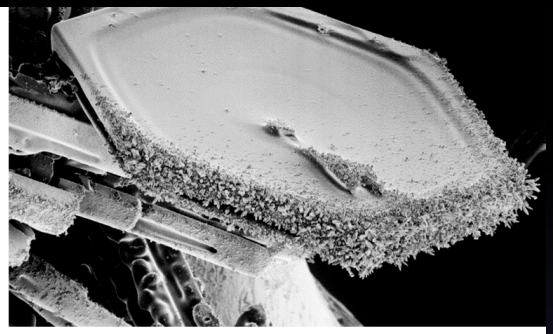
Dendrites

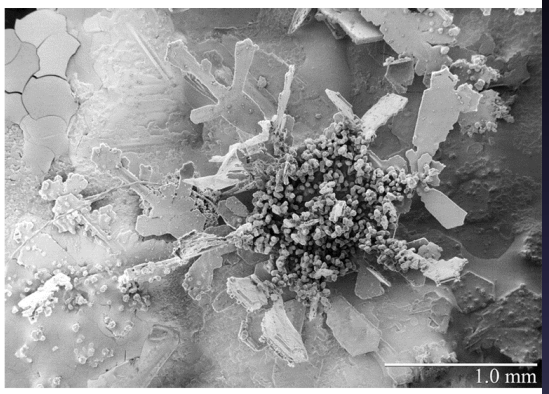
Type of snow flake depends partly on the temperature and humidity in the cloud

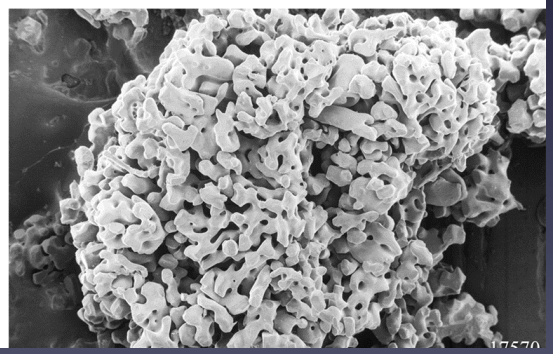
Images/photos: snowcrystals.com

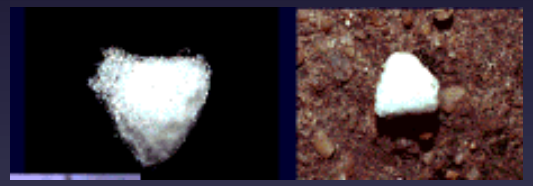
Complications: Riming











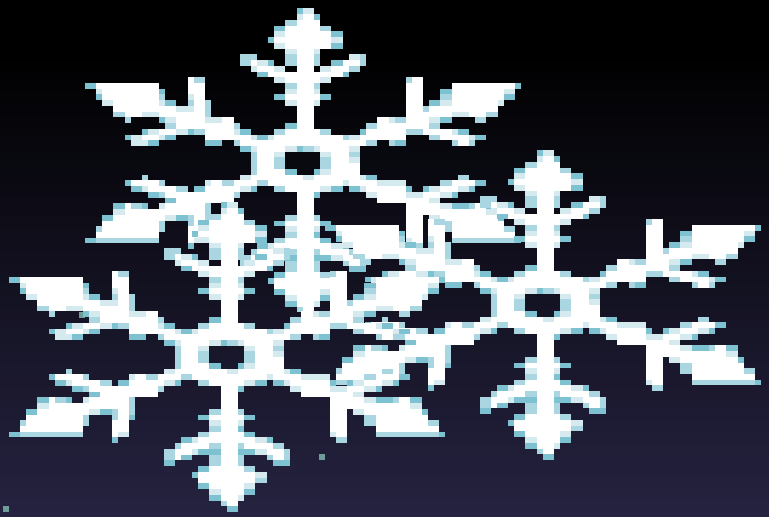
Hexagonal

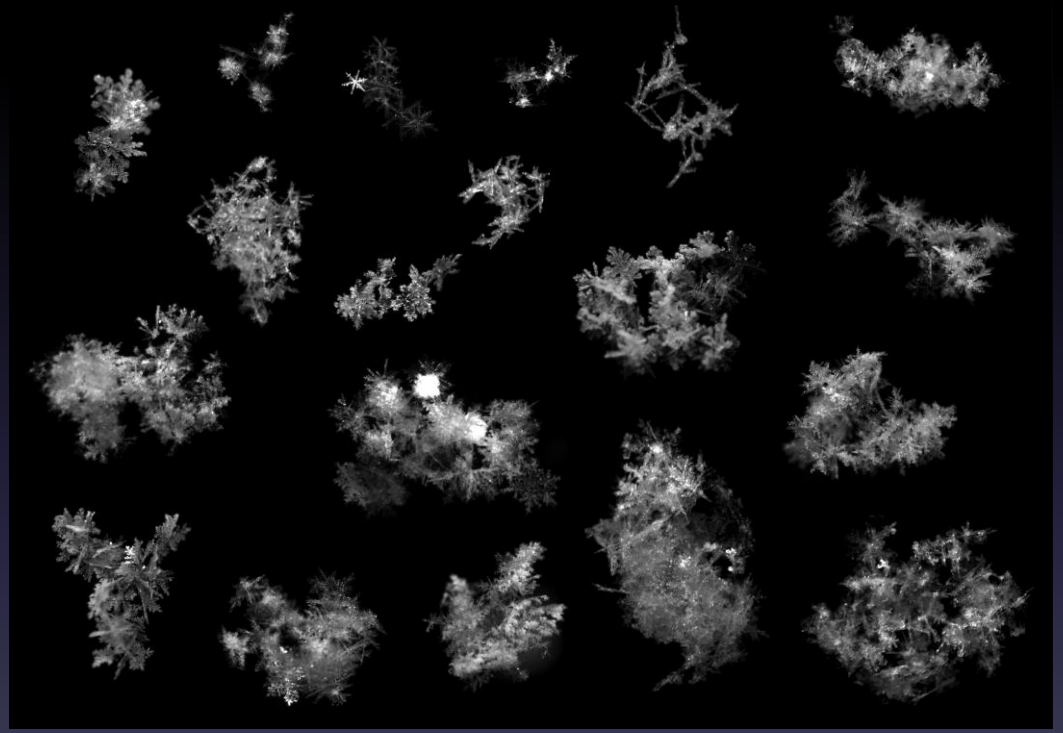
Lump Graupel

Cone

Steenburgh (2014), Casey Lenhart/MSI, UCLA, Magono and Lee (1966)

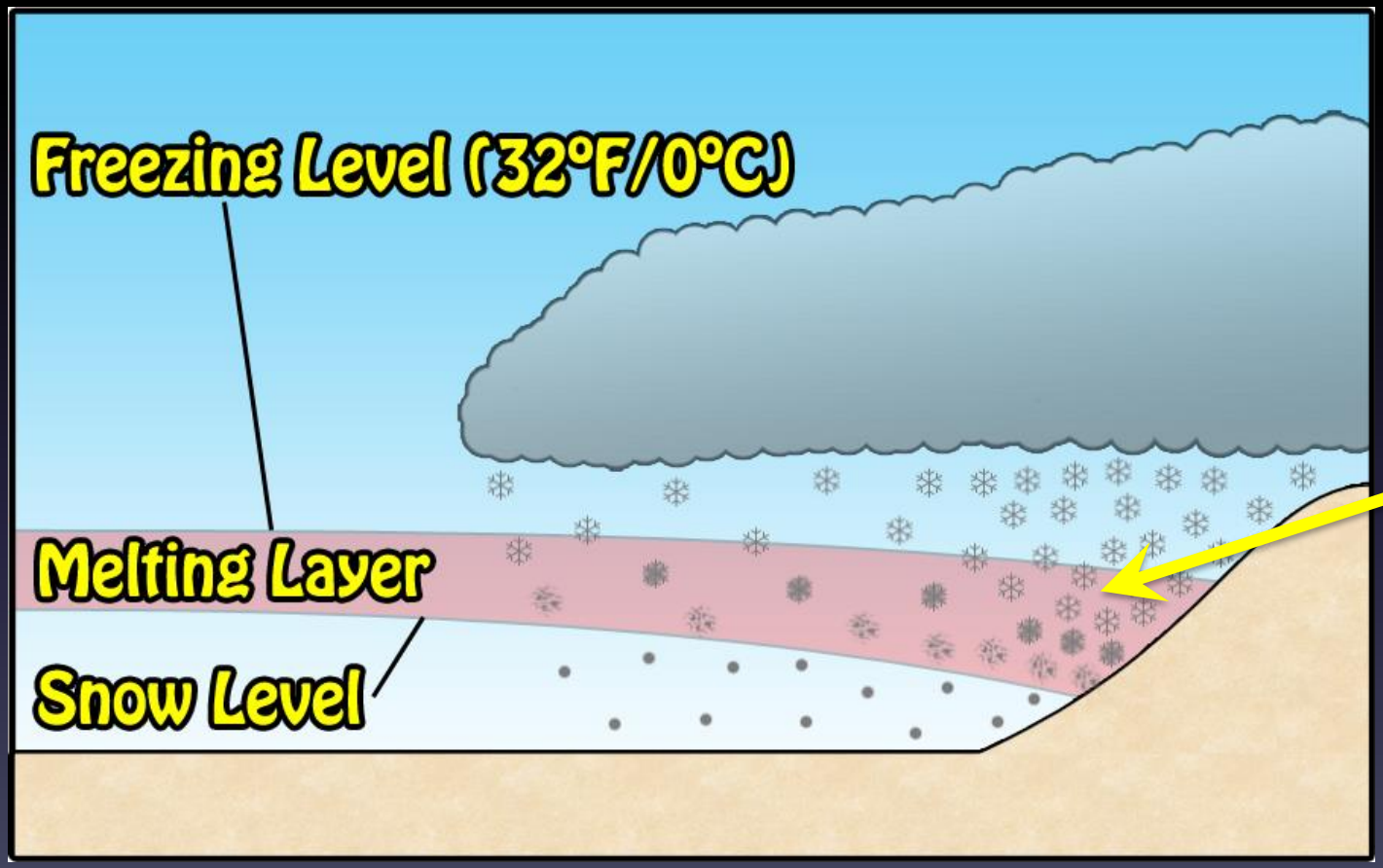
Complications: Aggregation





Crystal Images: Tim Garrett

Complications: Melting

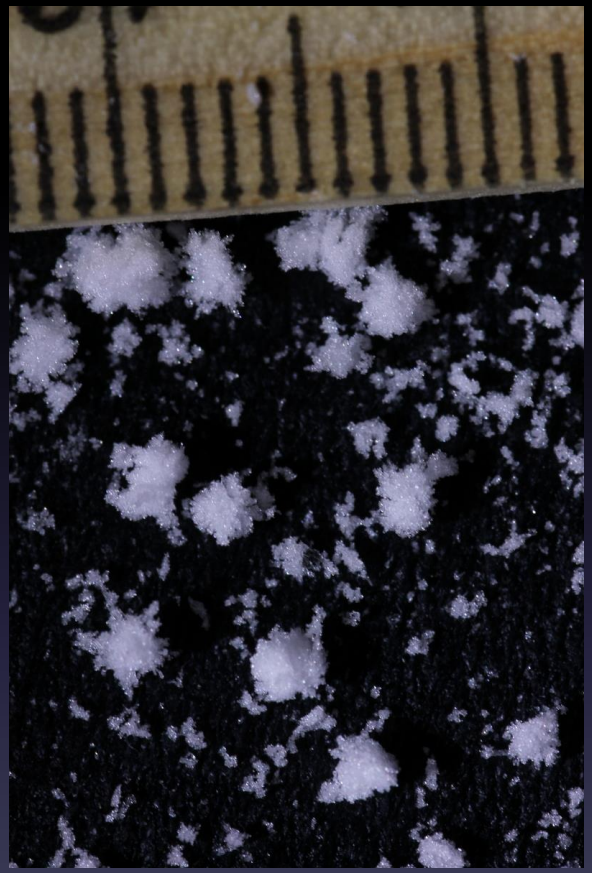


Aggregation
&
Melting
"Densifies"
Flakes

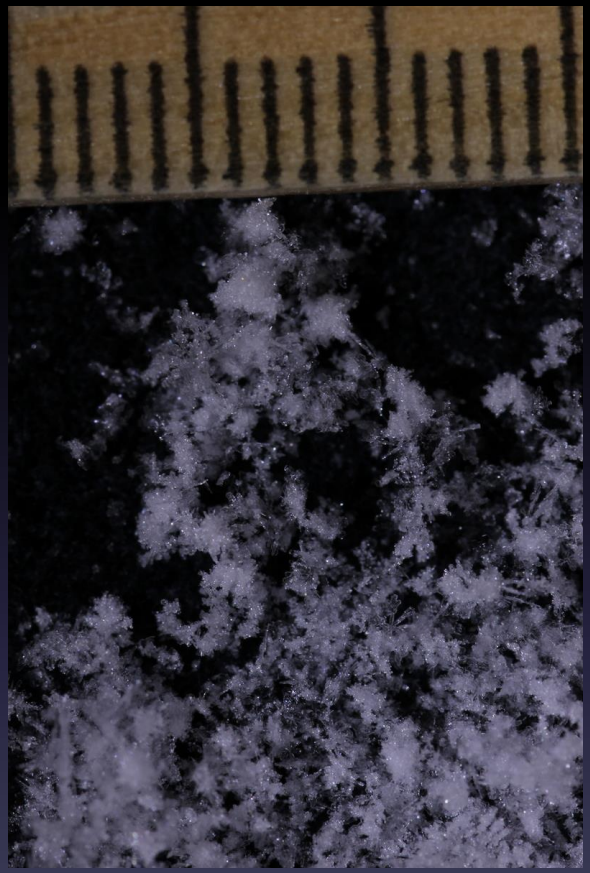
Steenburgh (2014)

Snowflakes Have a Tough Life

5:36 PM
Broken and Aggregated Dendrites



6:59 PM
Rimed Crystals/Small Graupel



7:08 PM
"Stuff"

Most Snowflakes Are "Defective" and Irregular in Shape
Lots of Changes in Snowflake Types during Many Storms

Crystal Images: University of Utah

Storm Extremes

<u>Dendrite Dominated</u>
Very little riming
Lots of dendrites and dendritic aggregates
Fluffy, low water content snow
Very large hourly and daily accumulations
The biggest Tug events

<u>Riming Dominated</u>
Heavy Riming
Lots of graupel or rimed crystals
Dense, high water content snow
Lower snowfall rates but
Lots of water (good for base)

Snow Water Content

- Snow Water Content = Fraction of snow that is water or ice
  - Light/dry snow < 7% water content
  - Average snow 7–11% water content
  - Heavy/wet snow > 11%

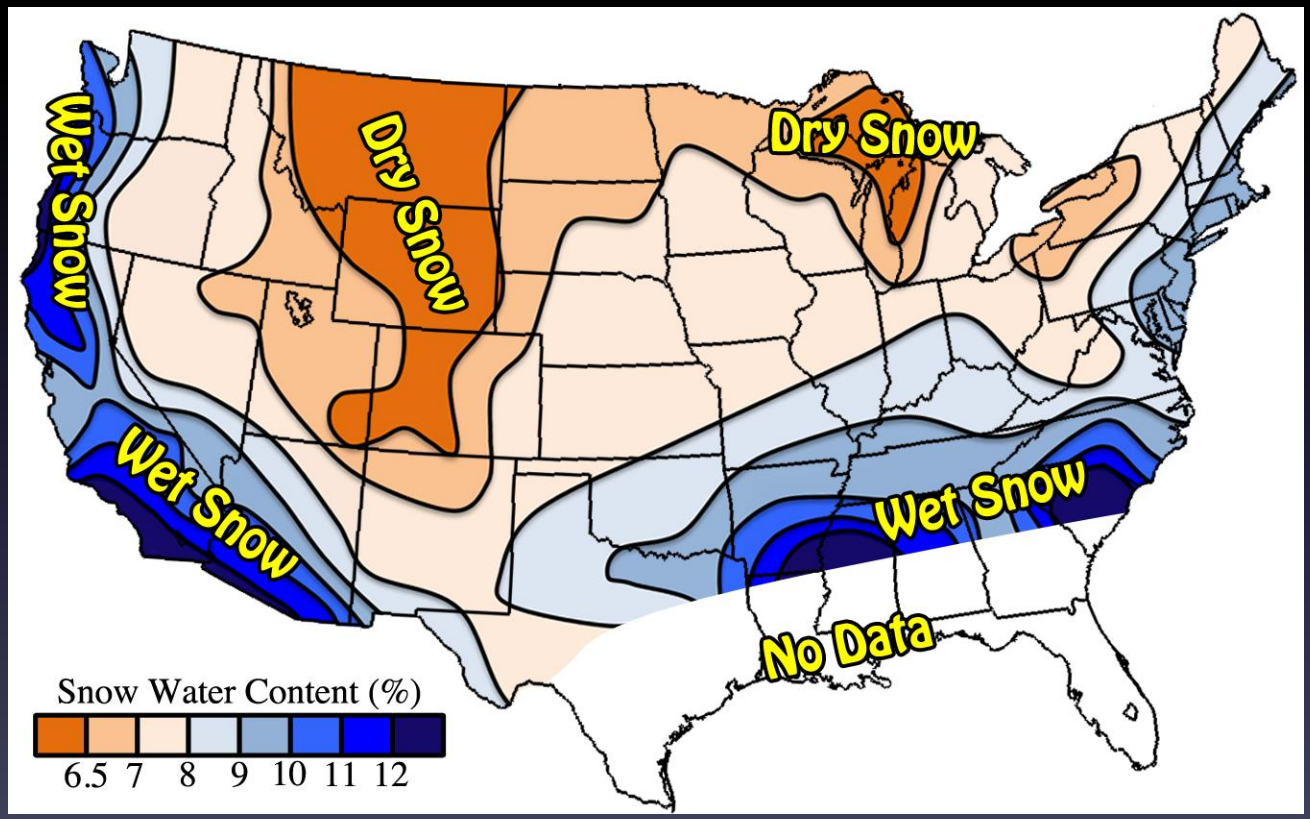
- The water content of snow on the ground increases as it settles and reaches ~50% by spring


Light/Dry Snow


Heavy/Wet Snow

Photos: Steenburgh (2014), Top courtesy Howie Garber

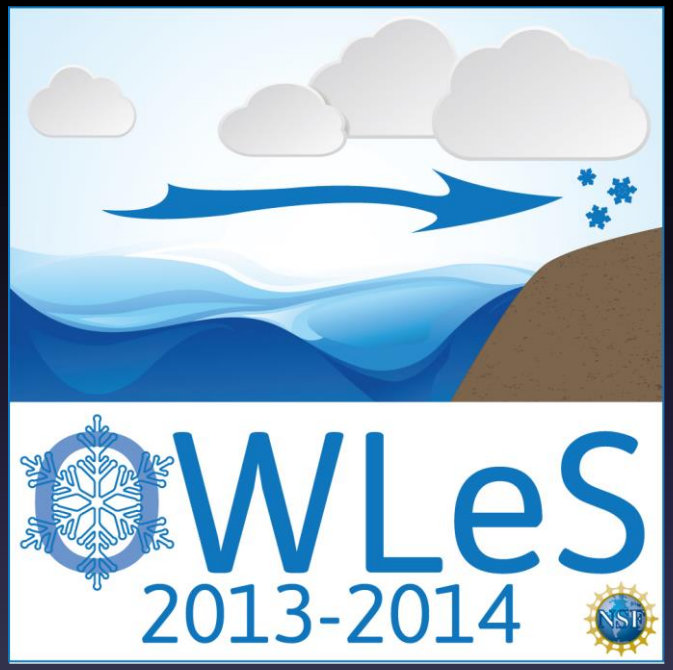
Tug Snow on Average Is as Dry as the "Greatest Snow on Earth"



Average water content of 99 inches of lake effect in Dec 2013: 5.8%
Average @ Alta, UT: 8.4%; Steamboat Springs, CO: 7.2%

Photos: Steenburgh (2014), Based on Baxter et al. (2005)

What Is OWLeS?



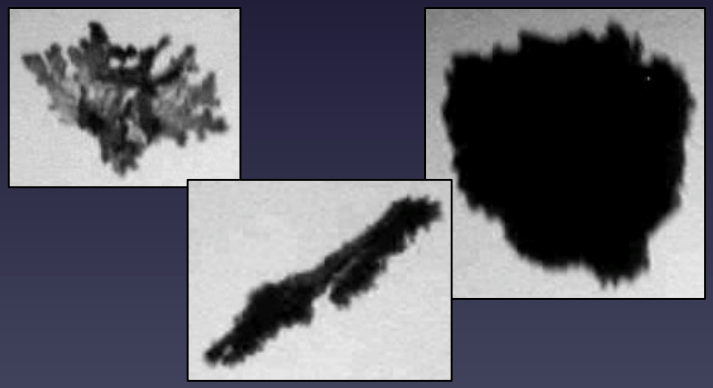
- Ontario Winter Lake-effect Systems (OWLeS)
- Supported by the National Science Foundation
- Long-axis, short-axis, and orographic components
- University of Wyoming, University of Illinois, University of Utah, SUNY Oswego, Hobart and William Smith Colleges, Millersville University, Penn State University, University of Alabama in Huntsville, SUNY Albany, and the Center for Severe Weather Research

Observing Systems

University of Wyoming King Air

CSWR Doppler on Wheels (DOW)

Weather Balloons



Meisei Inc. HYVIS Snowflake Camera

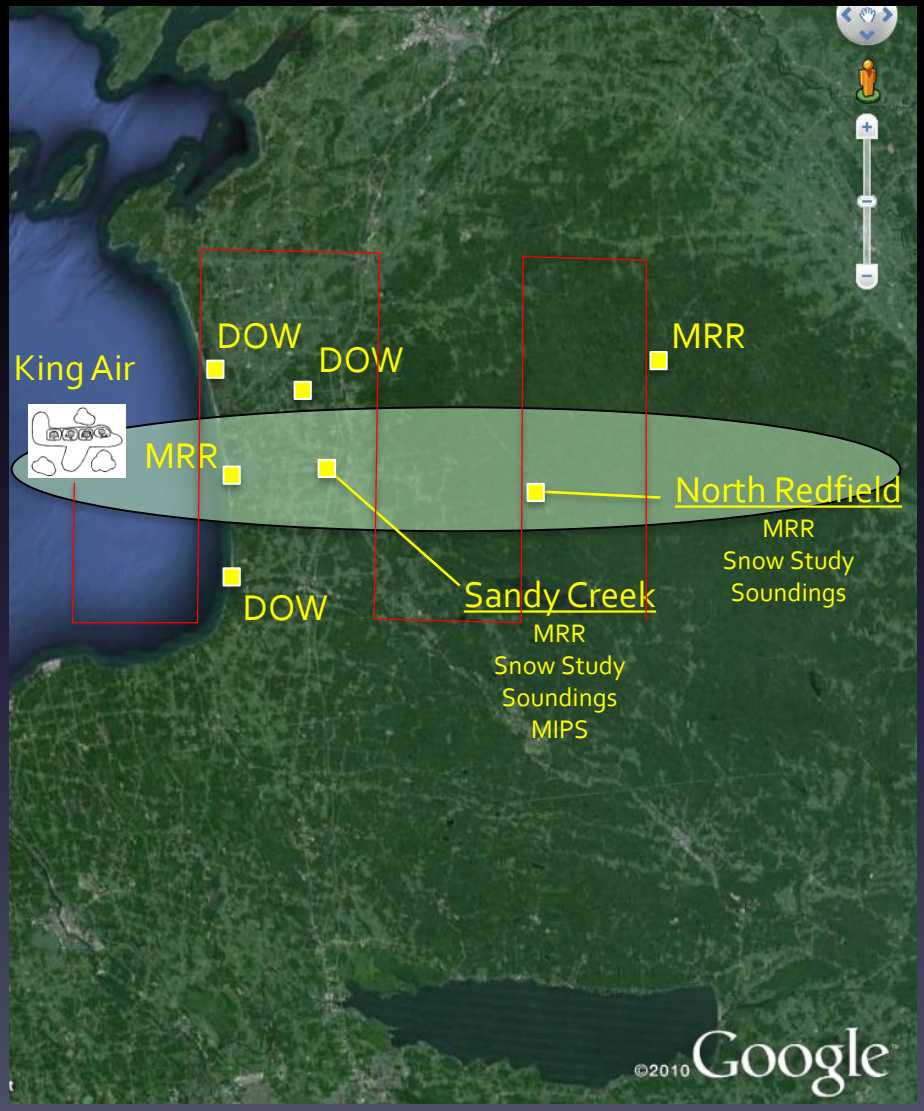
MRR Doppler Radars

Plus Many Other Toys

Weather and Snow Study Stations

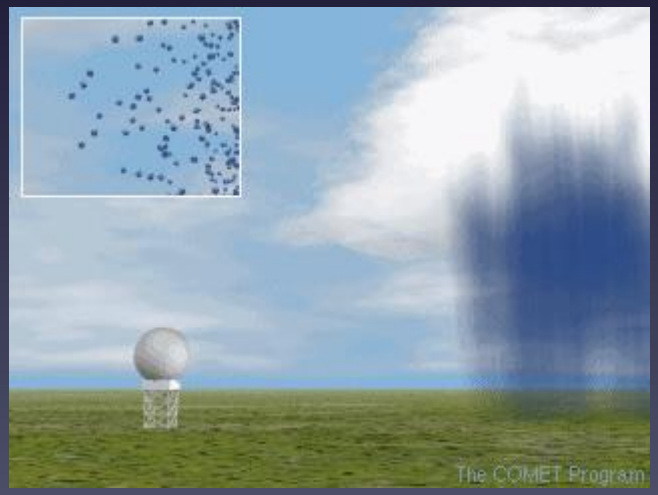
Photos: Vanda Grubisic, Trevor Alcott, University of Utah

Adventuring during Tug Storms



- University of Wyoming King Air flying "lawnmower" tracks through bands
- Three Doppler on Wheels (DOW) radars – 2 on coast, one scanning from coast to Tug
- Four MRR radars from coast to plateau
- Snow study stations @ Sandy Creek and North Redfield
- Balloon soundings @ Sandy Creek, North Redfield, and 3 mobile sites
- Other toys and goodies

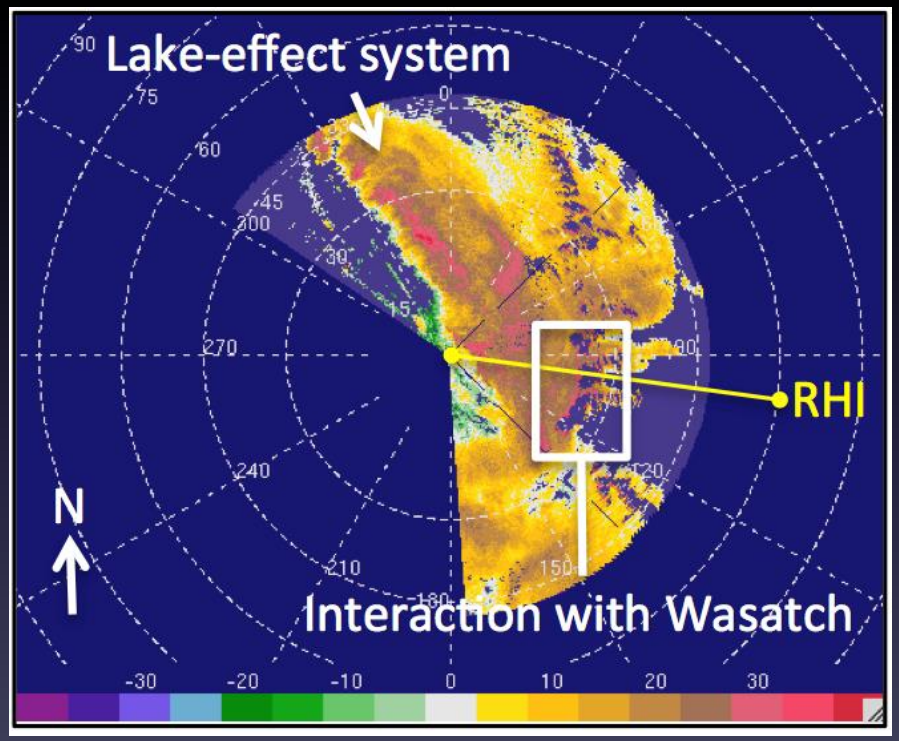
Doppler on Wheels (DOW)

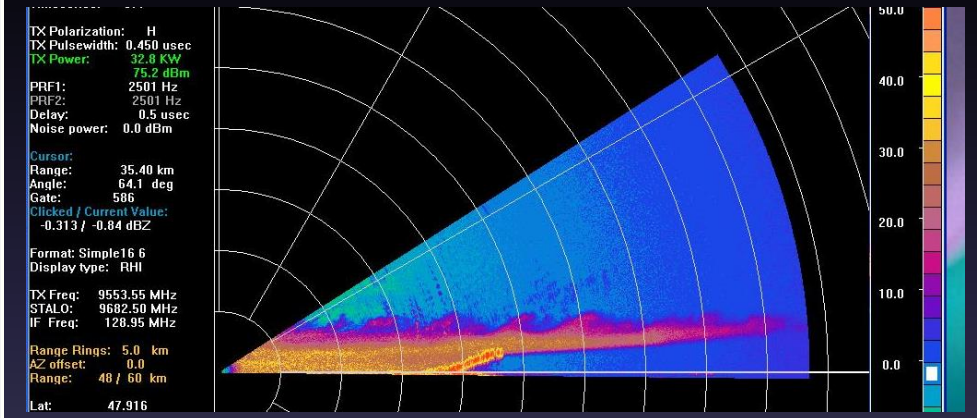


- Advantages of DOW
  - Mobile: Can be placed in a location to optimally survey storms
  - Can be configured to rapidly scan only area of interest
  - Far more detailed, especially in the vertical, than NWS radars
- Disadvantages
  - Shorter range

Photo: Karen Kosiba; Animation: The COMET Program

Meteorological Cat Scans

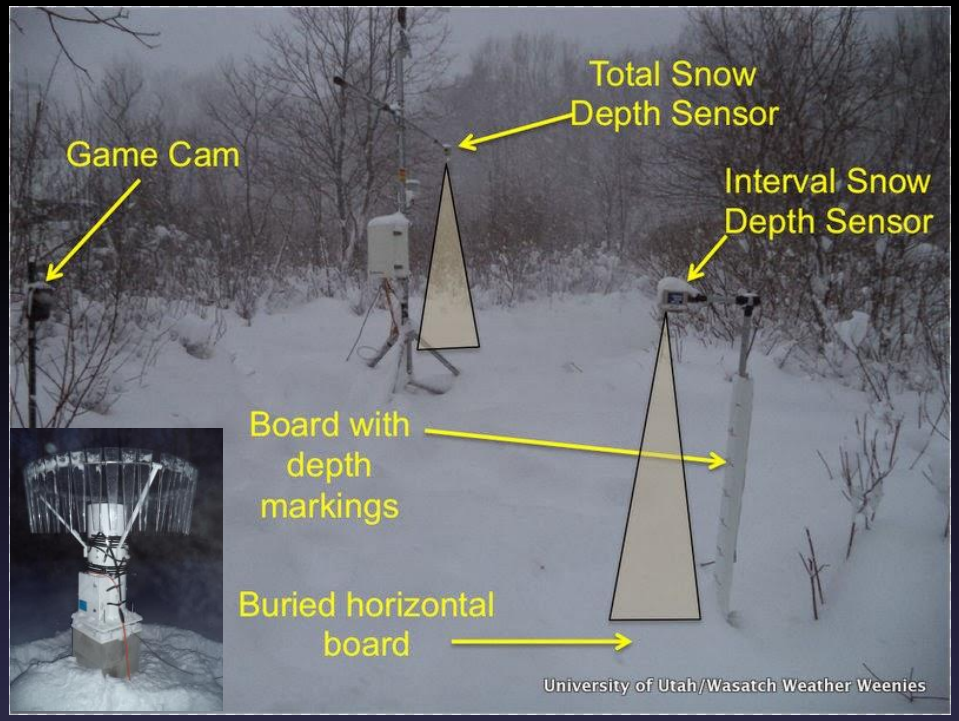


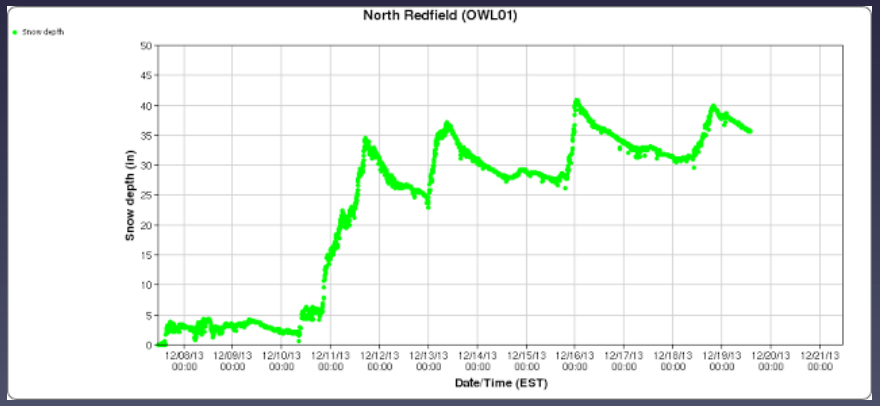


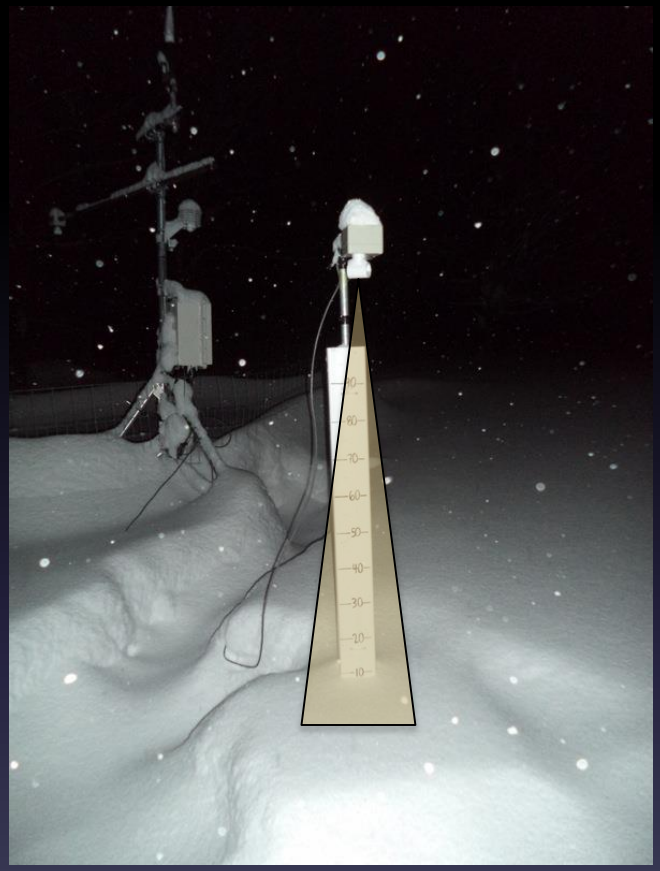
Science for Kids

Pulaski High School, Jan 2010, 2014 (Photos: University of Utah)

Measuring Snow







New snow depth (every 6 h)
Total snow depth
Snow water equivalent (SWE)
Water Content (e.g., 5.8%)

Photos: University of Utah

Measuring Snow






http://www.snowmetrics.com/store/basic-12-kit-p-205.html

Improved weather monitoring : A priority for New York

*"First we want to start by **installing the nation's most advanced weather detection system** here in the state of New York because early detection will literally save lives and we haven't been getting the correct information early enough "*

-Gov. Andrew Cuomo, 2014 State of the State Address

Schoharie Creek during Irene

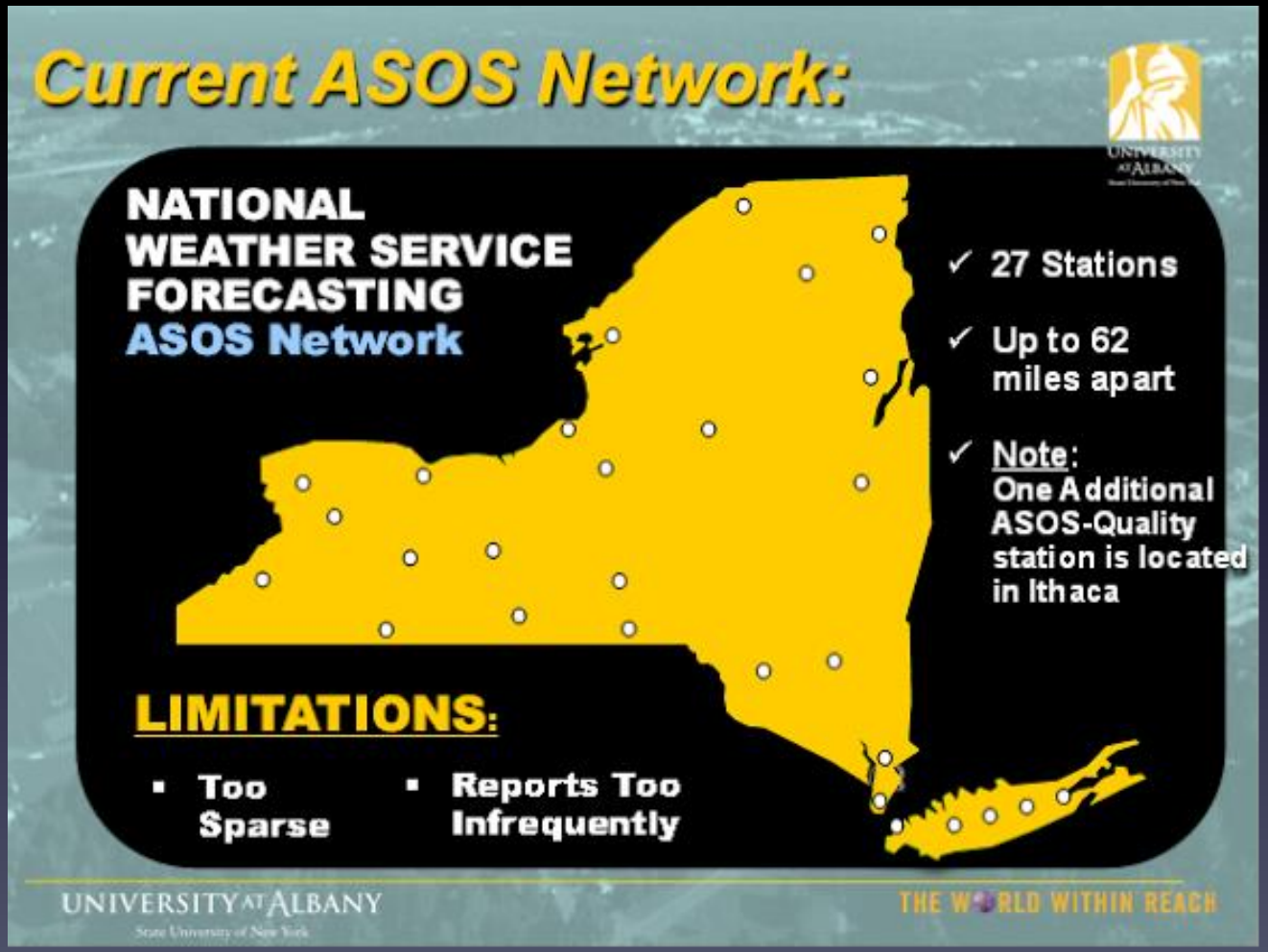
http://blogs.villagevoice.com/forkintheroad/2011/08/will_the_nyc_gr.php

Jan 1998 Ice Storm

National Weather Service Burlington,Vermont

The current network of high-quality, frequently reporting, weather stations is insufficient to capture:

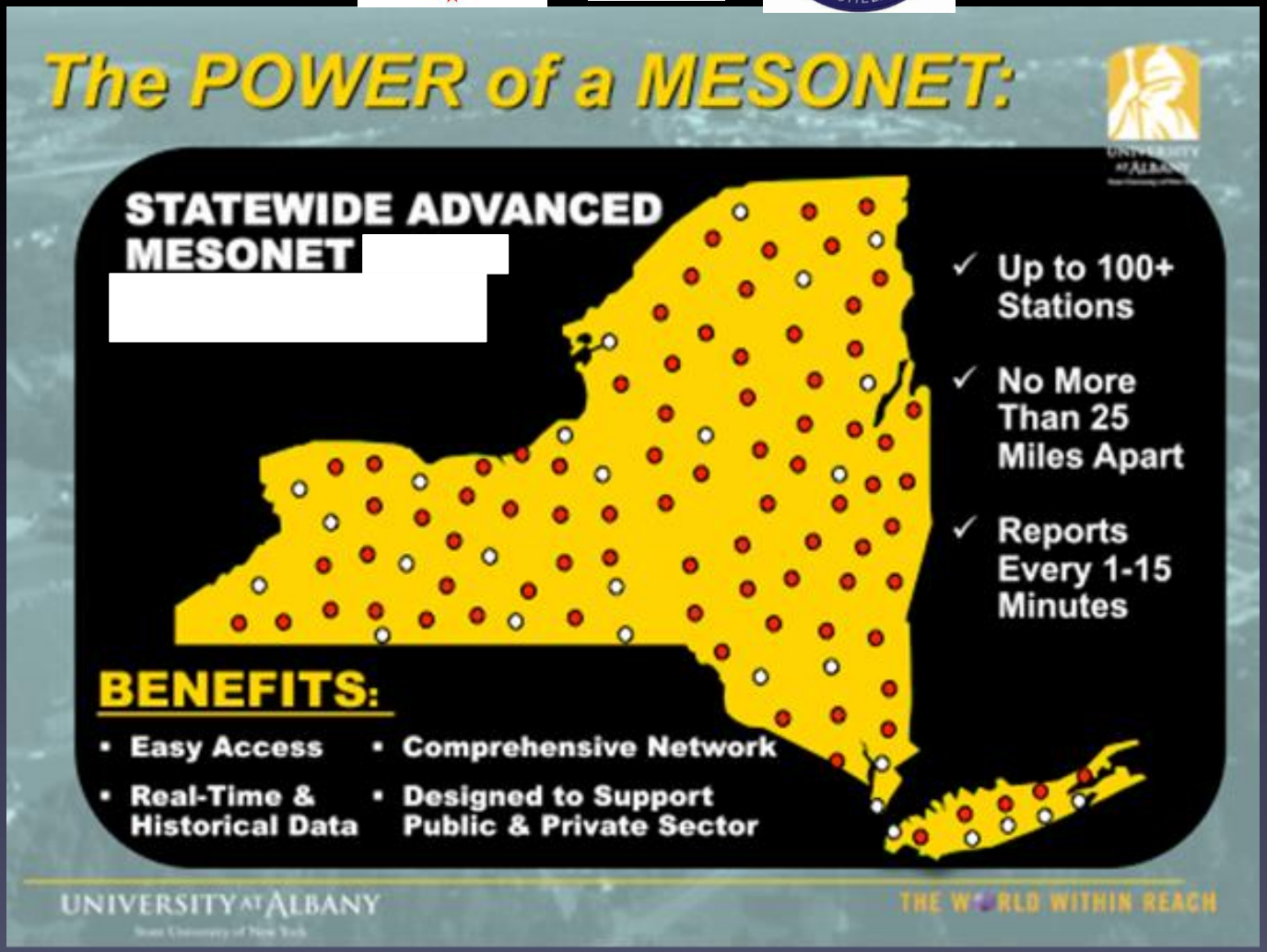
- *Local weather*
- *Extreme events*
- *Impacts on recreation, travel, energy, agriculture, …*



A dense "Mesonet" of high-quality stations is being developed for NY

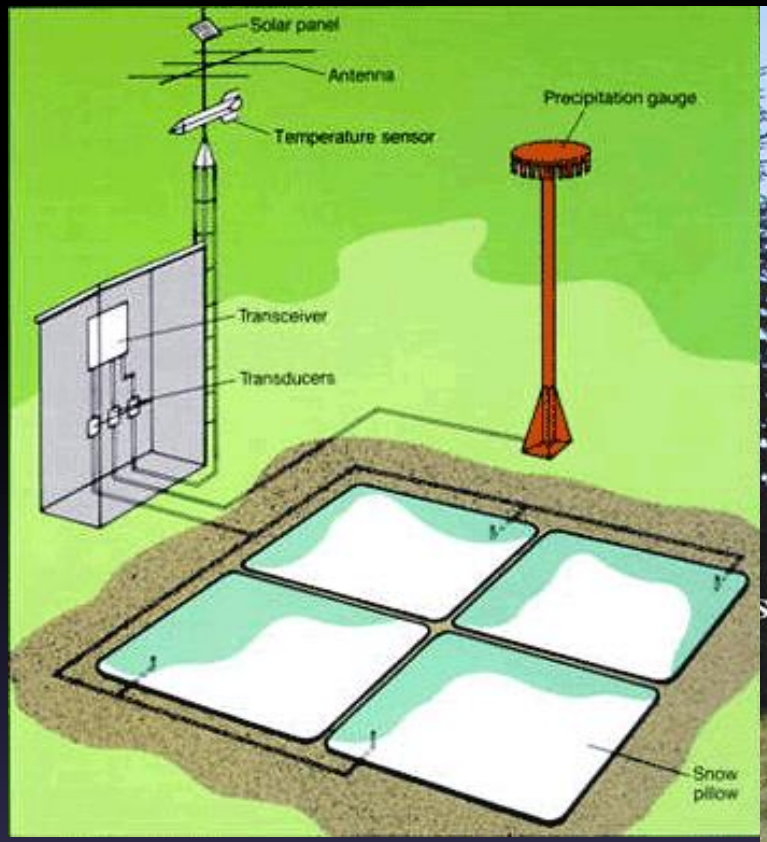
A partnership that includes:

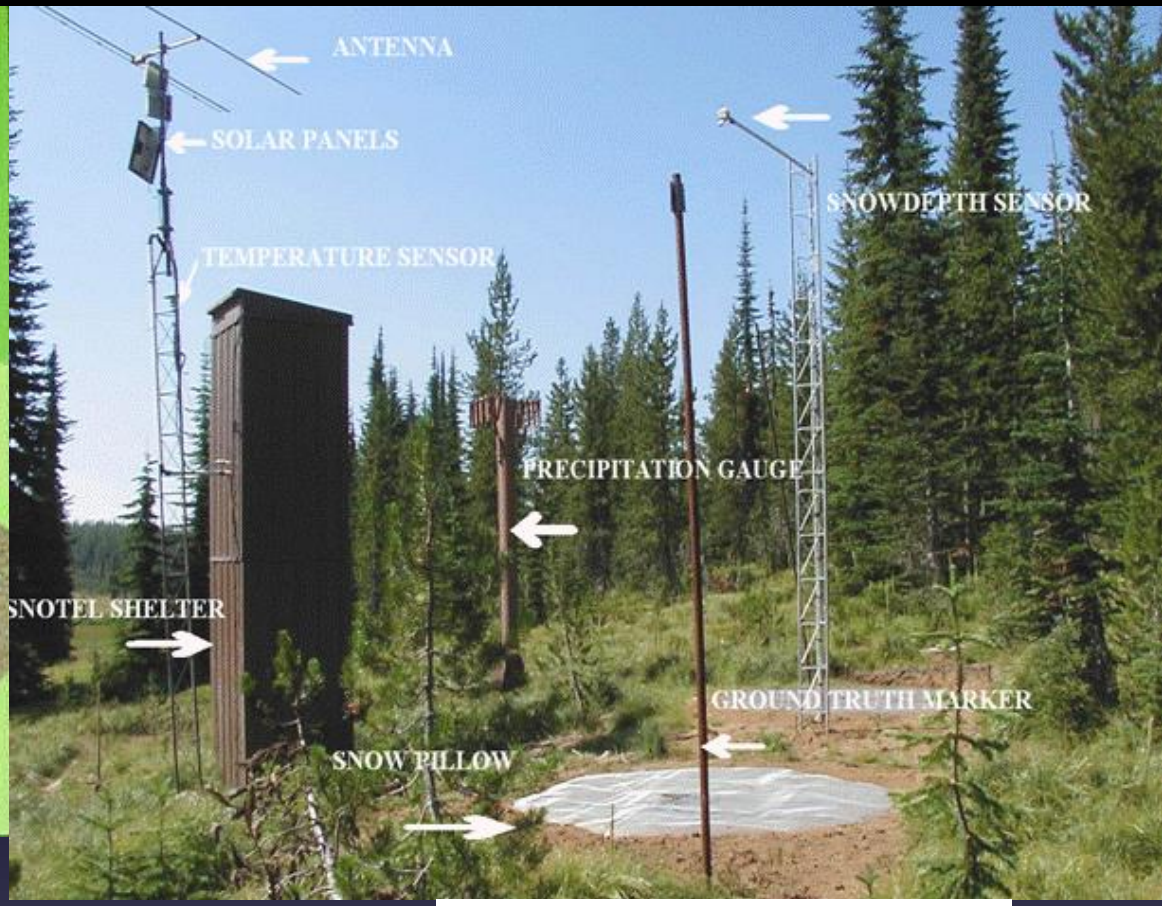
- *NYS homeland security*
- *University at Albany*
- *National Weather Service*



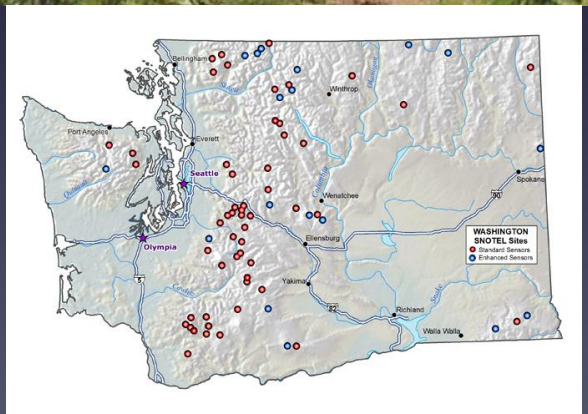
Schematic of network design (true network design is underway)

The Mesonet will also contain 10-20 "snow-stations"





- Modeled after Western US *SNOTEL* network
- Measures precip, snow water, and basic meteorology
- Can operate remotely & transmit data
- Valuable for water resources, flood forecasting



Improving Monitoring & Forecasts

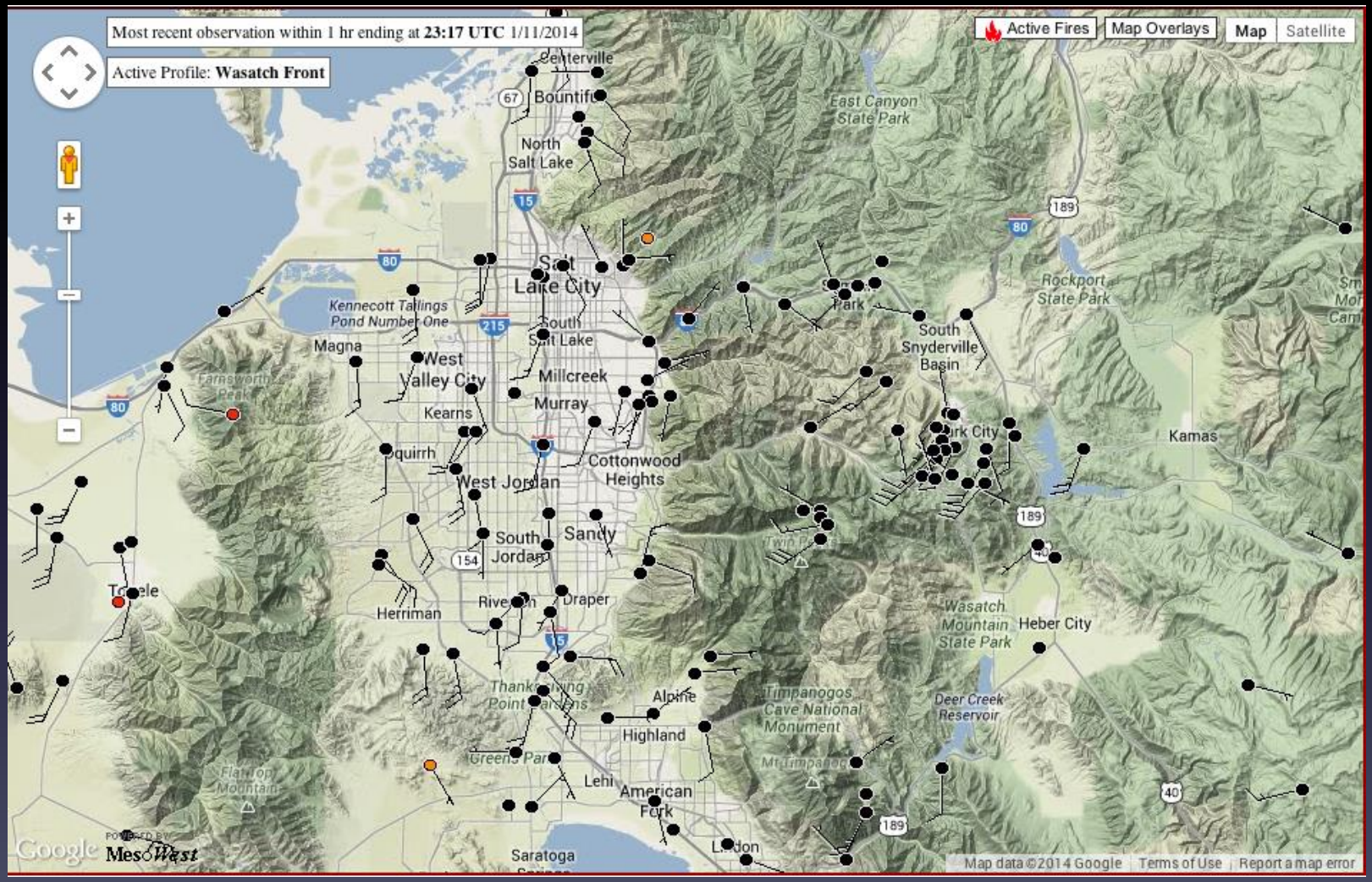
Basic Met, Modem,
2 snow depth
Sensors ~$6,000

Snow board & coring tube
$200 or less
www.cocorahs.org
&
http://www.erh.noaa.gov/buf/CoCoRaHSwebsite.html

NWS Buffalo Twitter Feed

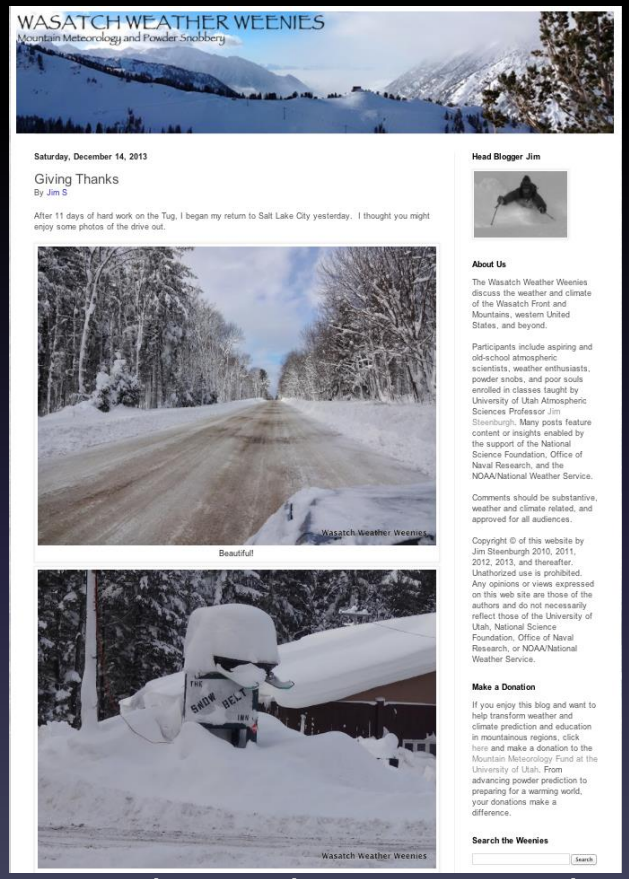
Photos: NRCS, University of Utah

MesoWest/MADIS



Thank You!

For More Info See

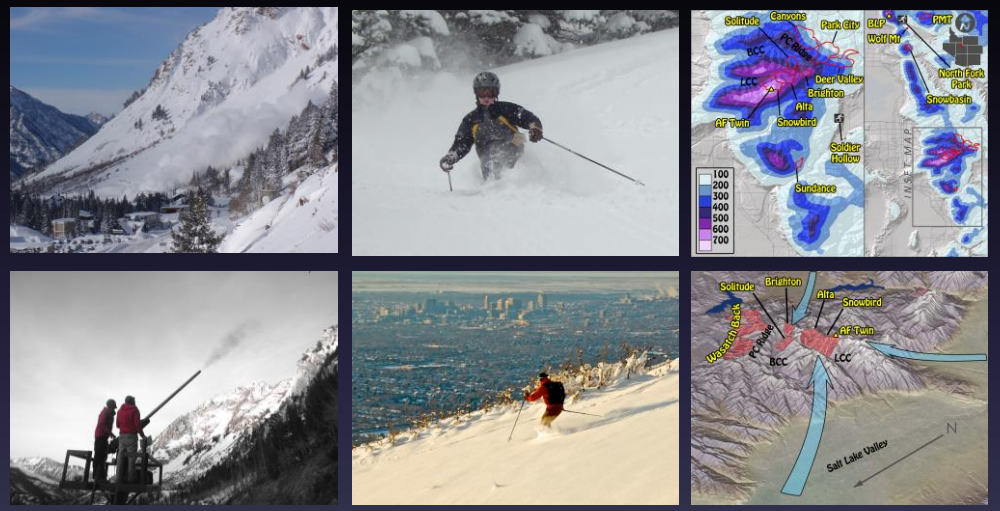


Wasatch Weather Weenies Blog

wasatchweatherweeenies.blogspot.com

Secrets of the Greatest Snow on Earth

Mountain Weather, Avalanches, and Finding Powder
in the Wasatch Mountains and around the World

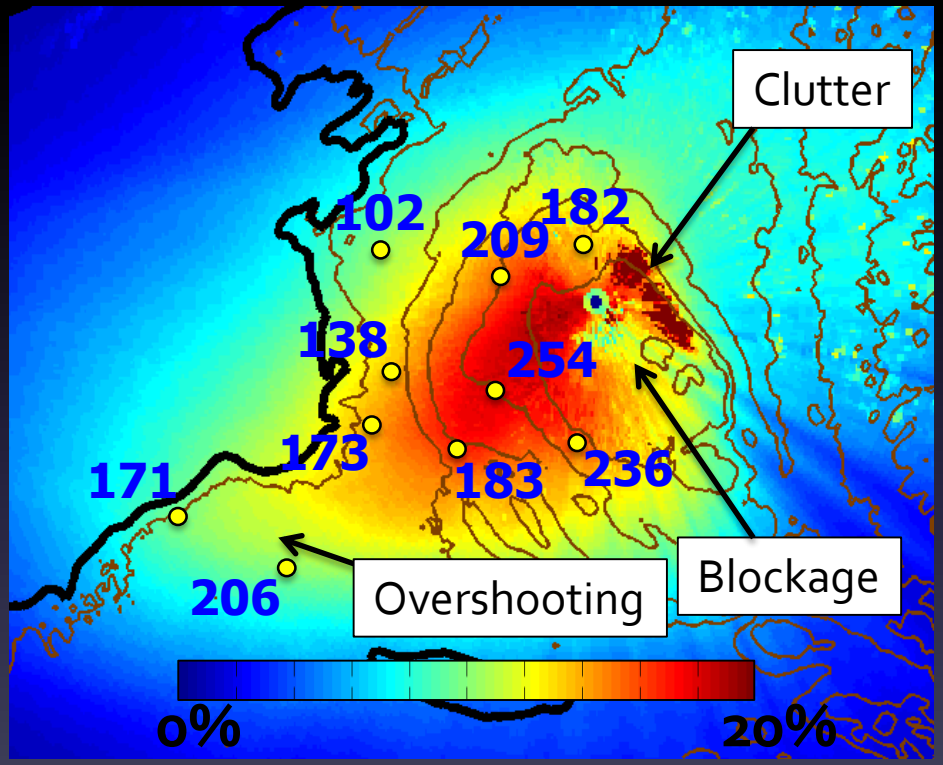


University Press of Colorado/Utah State University Press
September 2014

Mesonet Contact: justinminder@gmail.com

Monitoring Lake Effect/Snow

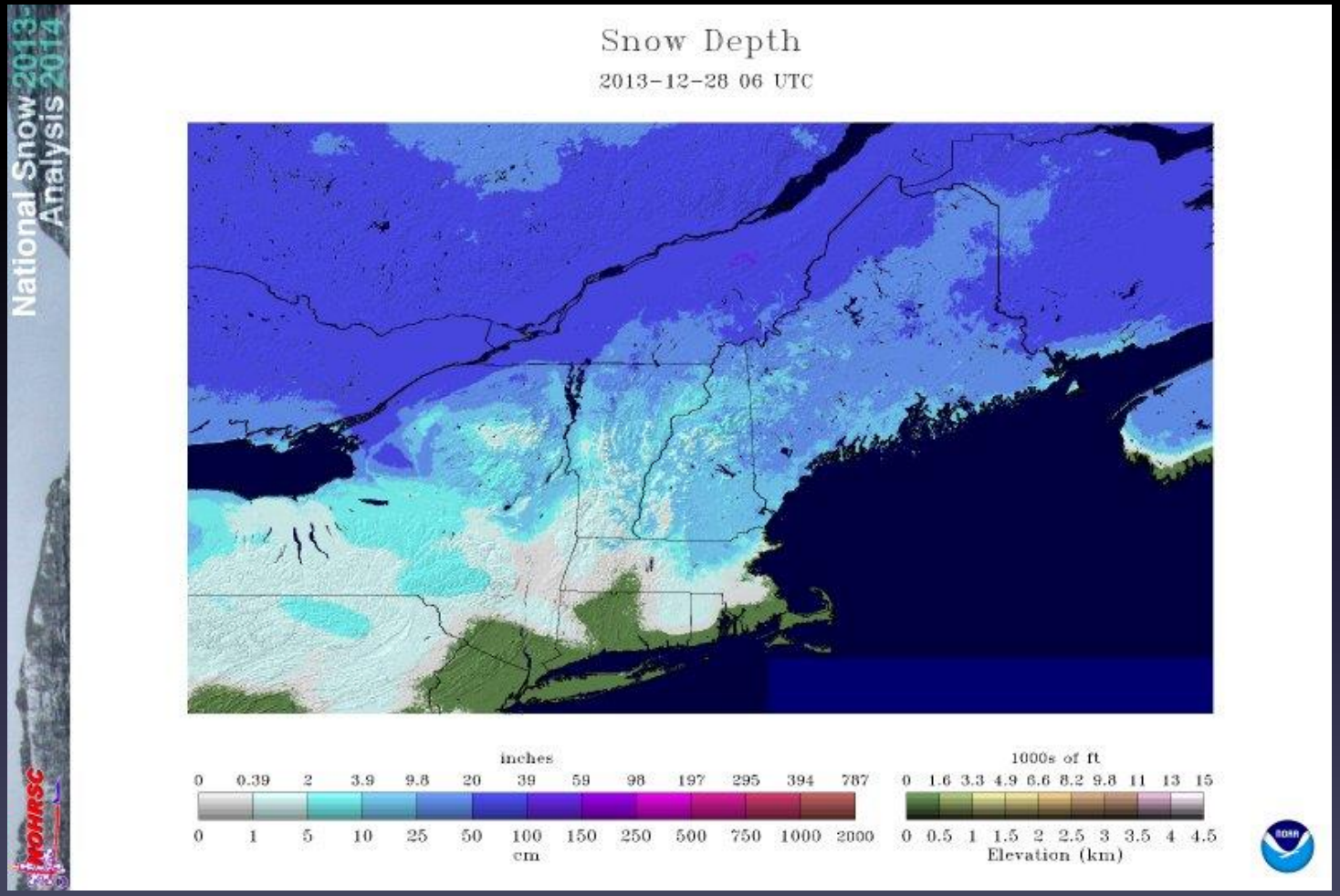
- KTYX/Montague NWS Radar
  - Generally good coverage
  - Beware of
    - Partial or full blockage
    - Clutter from wind farm
    - Overshooting
- Northern Chateau Cams



Frequency of 20 dBZ during Lake-Effect Periods (11 yrs)
Mean Snowfall (Inches) 2003/04–2005/06

Radar image courtesy Peter Veals

Monitoring Lake Effect/Snow



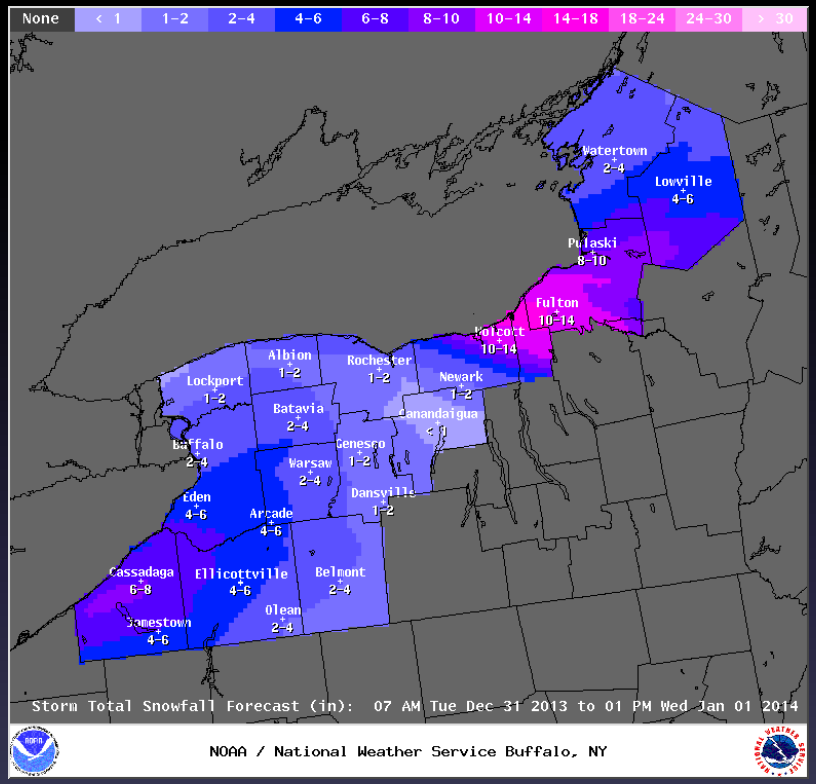
National Snow Analyses
http://www.nohrsc.noaa.gov/nsa/

Finding Forecasts

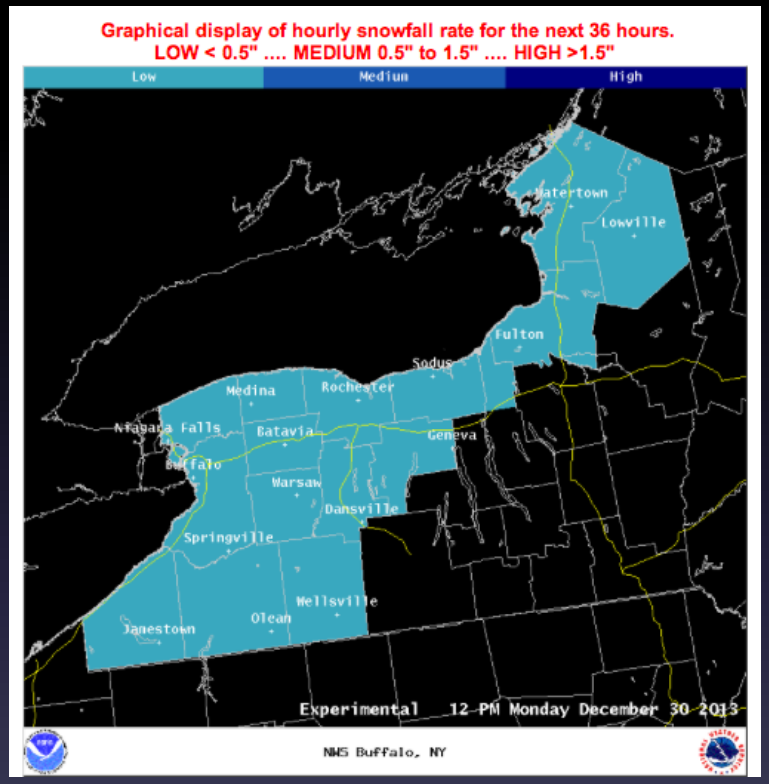
National Weather Service (NWS): http://www.weather.gov
Buffalo NWS Office (Oswego, Jefferson, Lewis): http://www.erh.noaa.gov/buf/
Binghamton NWS Office (Oneida): http://www.erh.noaa.gov/bgm/
Albany NWS Office (Herkimer, Hamilton): http://www.erh.noaa.gov/aly/
Burlington NWS Office (St. Lawrence): http://www.erh.noaa.gov/btv/

Image: Northeast Regional Climate Center

Special NWS-Buffalo Products



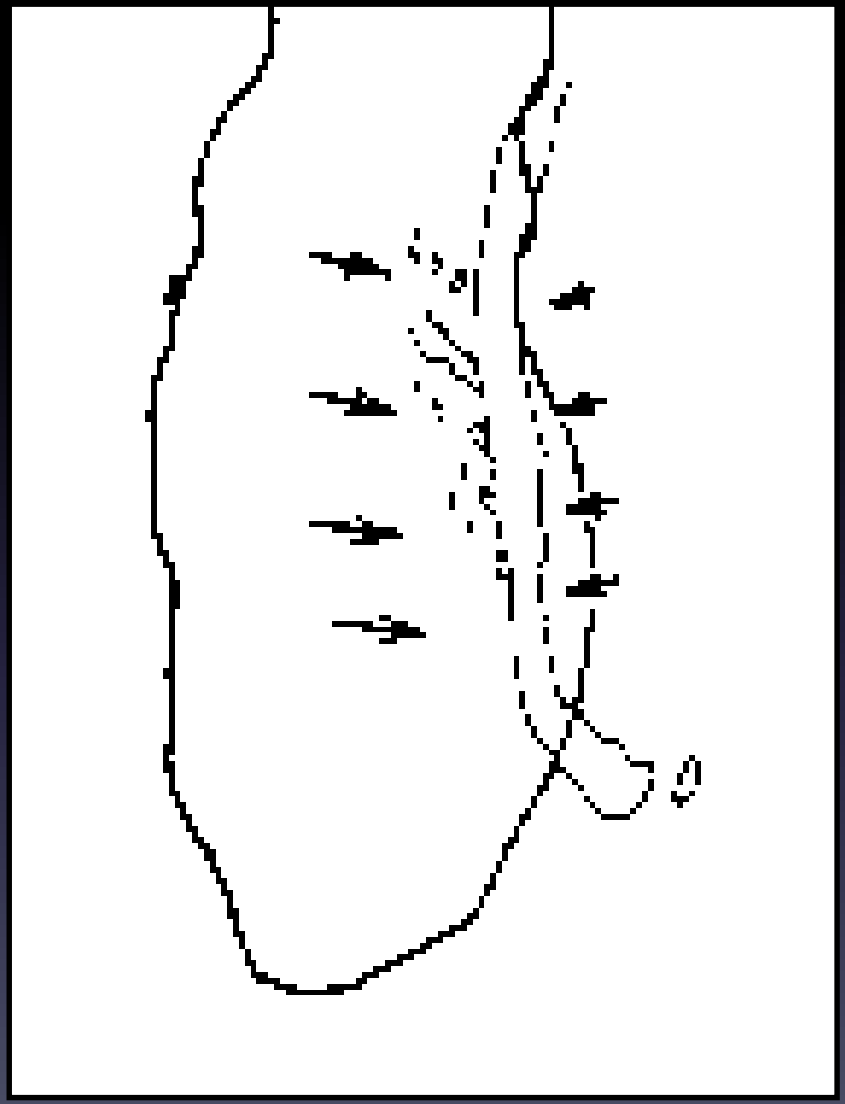
Storm Total Snowfall Forecast
http://www.erh.noaa.gov/buf/gfemaps/StormTotalSnow.shtml



Snowfall Rate Graphics
http://www.weather.gov/buf/Snow_Threat

Lake-Effect Types

- Shore-parallel bands
  - Form near lee shore
  - Land breeze opposes large-scale flow



Hjelmfelt (1990)

Lake-Effect Types

- The Lake-Effect Vortex
  - Comma or spiral-shaped feature
  - Can have an eye
  - Very cool, but rare