Contribution of Lake-Effect Snowfall to the Catskill Mountains Snowpack

Dorothy K. Hall[1,2]
Allan P. Frei[3]
and
Nicolo E. DiGirolamo[4,2]

[1]Earth System Science Interdisciplinary Center (ESSIC) / University of Maryland, College Park, Md.
[2]Cryospheric Sciences Laboratory, NASA / Goddard Space Flight Center, Greenbelt, Md.
[3]Hunter College, City University of New York, NY, New York
[4]SSAI, Lanham, Md.

dorothy.k.hall@nasa.gov

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Objective

To determine if lake-effect snowfall is a significant contributor to the snowpack in the Catskill/Delaware Watershed

- To identify and quantify the number of lake-effect snowstorms that deposited snow in the Catskill/Delaware Watershed during a 13-year study period from 2004 – 2017

Relevance and Background

- Meltwater from snow that falls in the Catskills contributes to the reservoirs that supply drinking water to ~9 million people in New York City
- Snowfall comprises 20 – 30% of the total annual precipitation in the Catskill/Delaware Basin (Frei et al., 2002)
- Is there a significant contribution of snowfall from lake-effect storms?
- Projected changes in the frequency of lake-effect storms may affect the snowpack and reservoirs in the Catskills

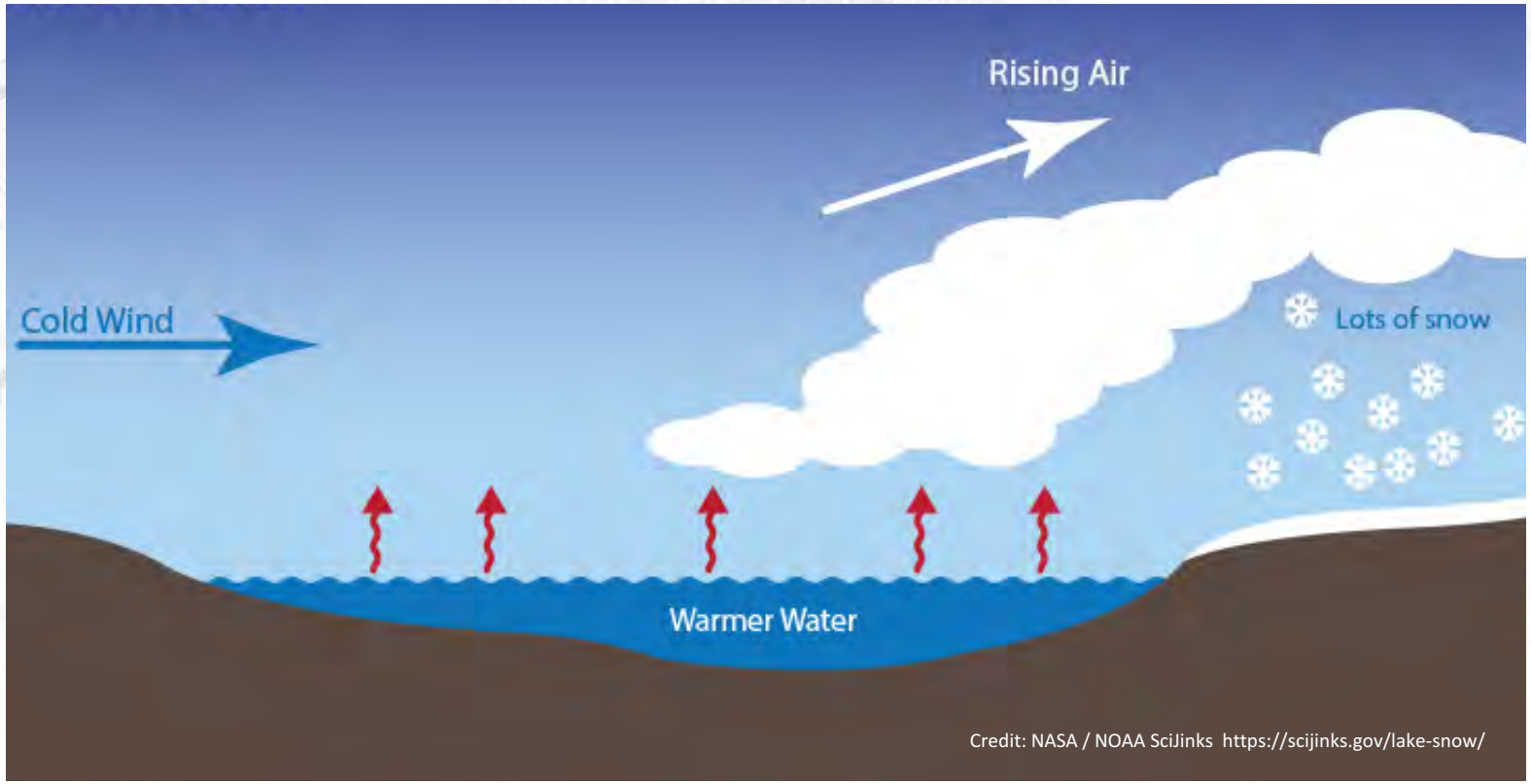
What is Lake-Effect Snow?

- LE snow forms when cold air passes over the warmer waters of a lake causing lake water to evaporate. This warmer, wetter air rises and cools as it moves away from the lake.

- There must be a large contrast (at least 13°C) between the surface water temperature (SWT) and the air temperature at 850 mb over the lake.

- The lake should be ice-free or have a small amount of ice on it.

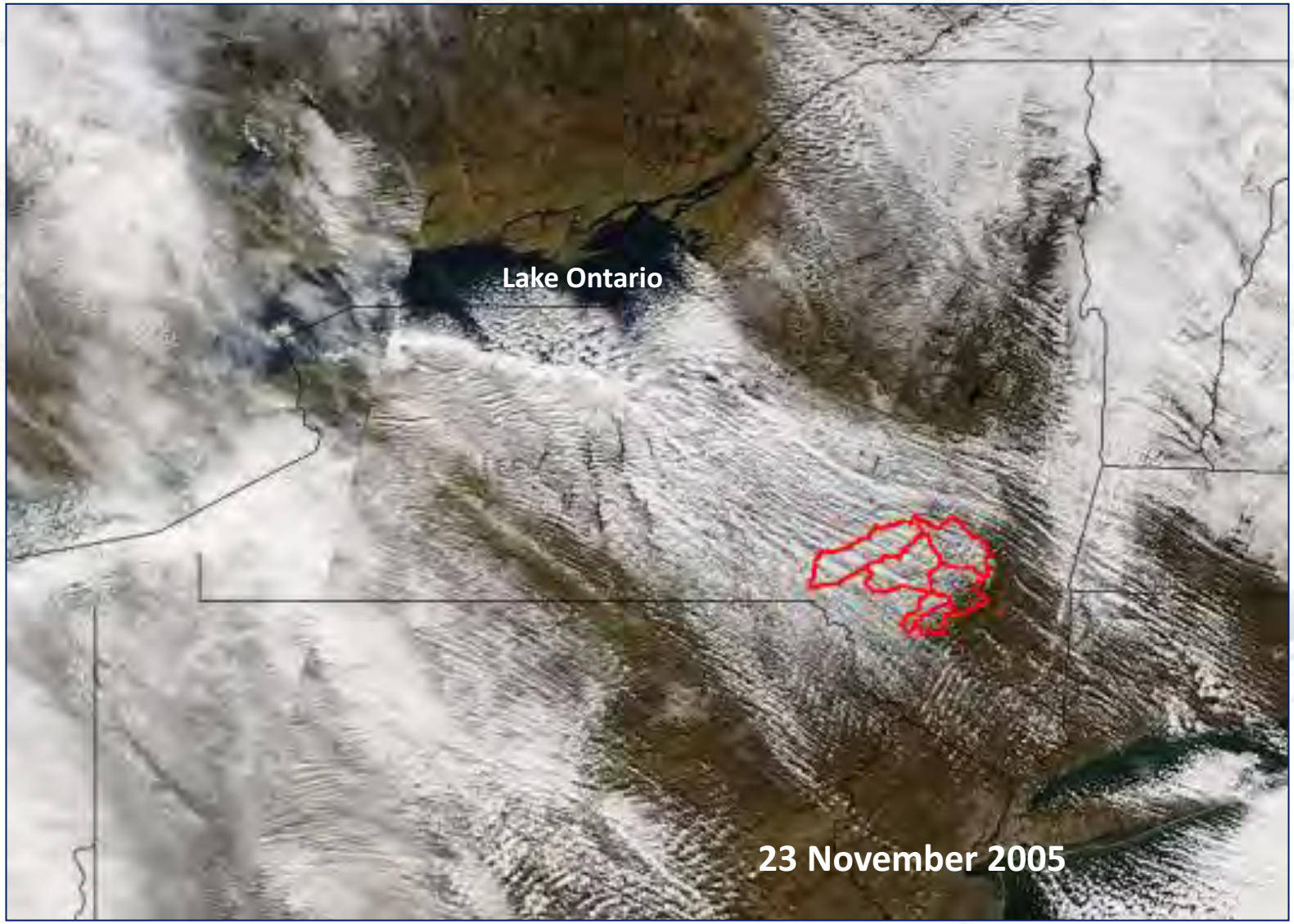
- There should be a long fetch.



Background cont’d.

Inspection of MODerate-resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS) snow maps and images revealed many lake-effect snowstorms that seemed to extend far enough inland to reach the Catskill Mountains.

MODIS true-color image of lake-effect snow emanating from Lake Ontario



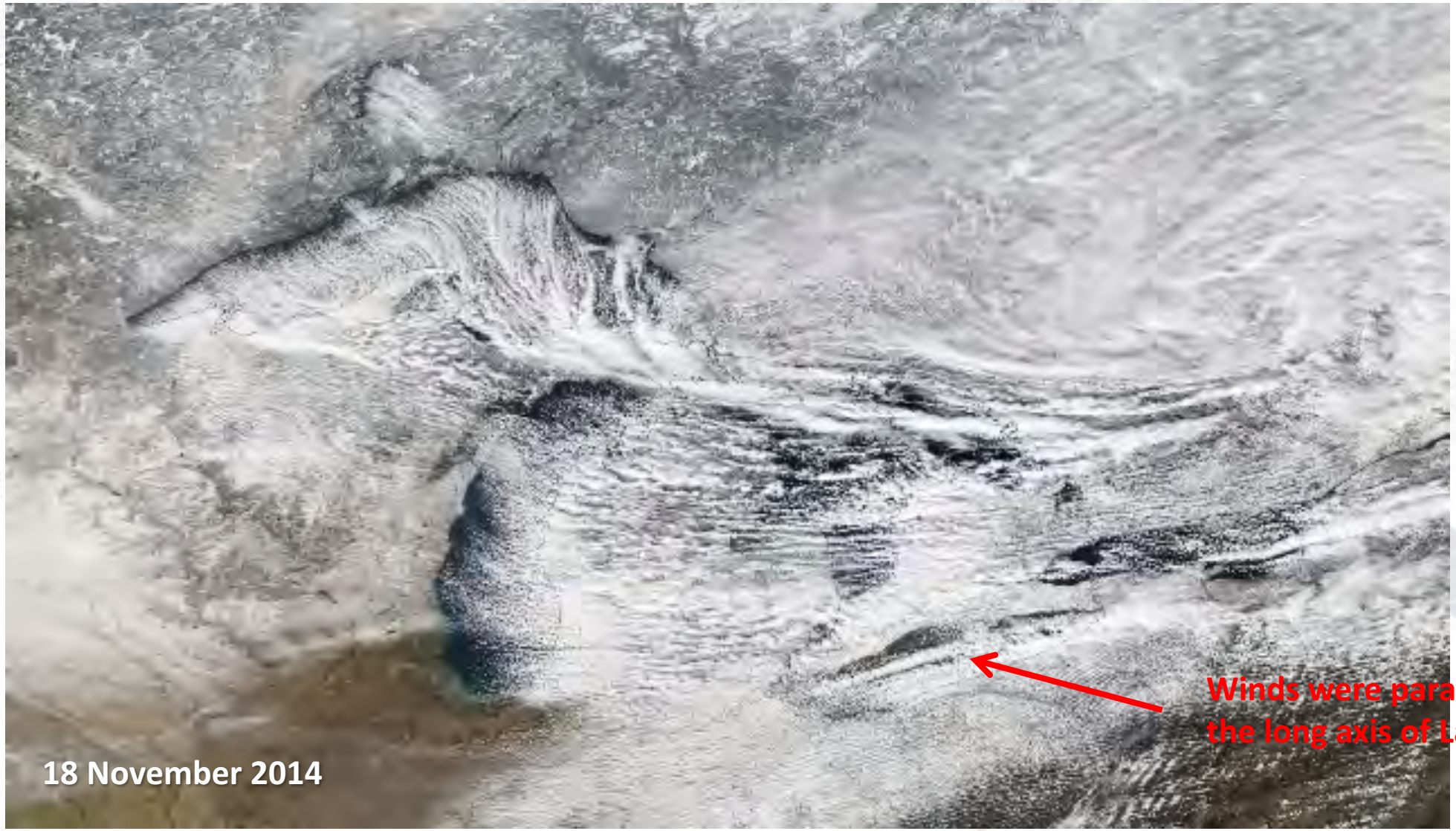
Cloud streets form when cold air blows over warmer water to produce thin parallel bands of cumulus clouds.

The six basins of the Catskill/Delaware Watershed are outlined in red.

Image obtained from Land, Atmosphere Near real-time Capability for EOS (LANCE)

Suomi-NPP VIIRS image showing narrow, elongated snow bands over Lake Superior and Lake Michigan / Huron

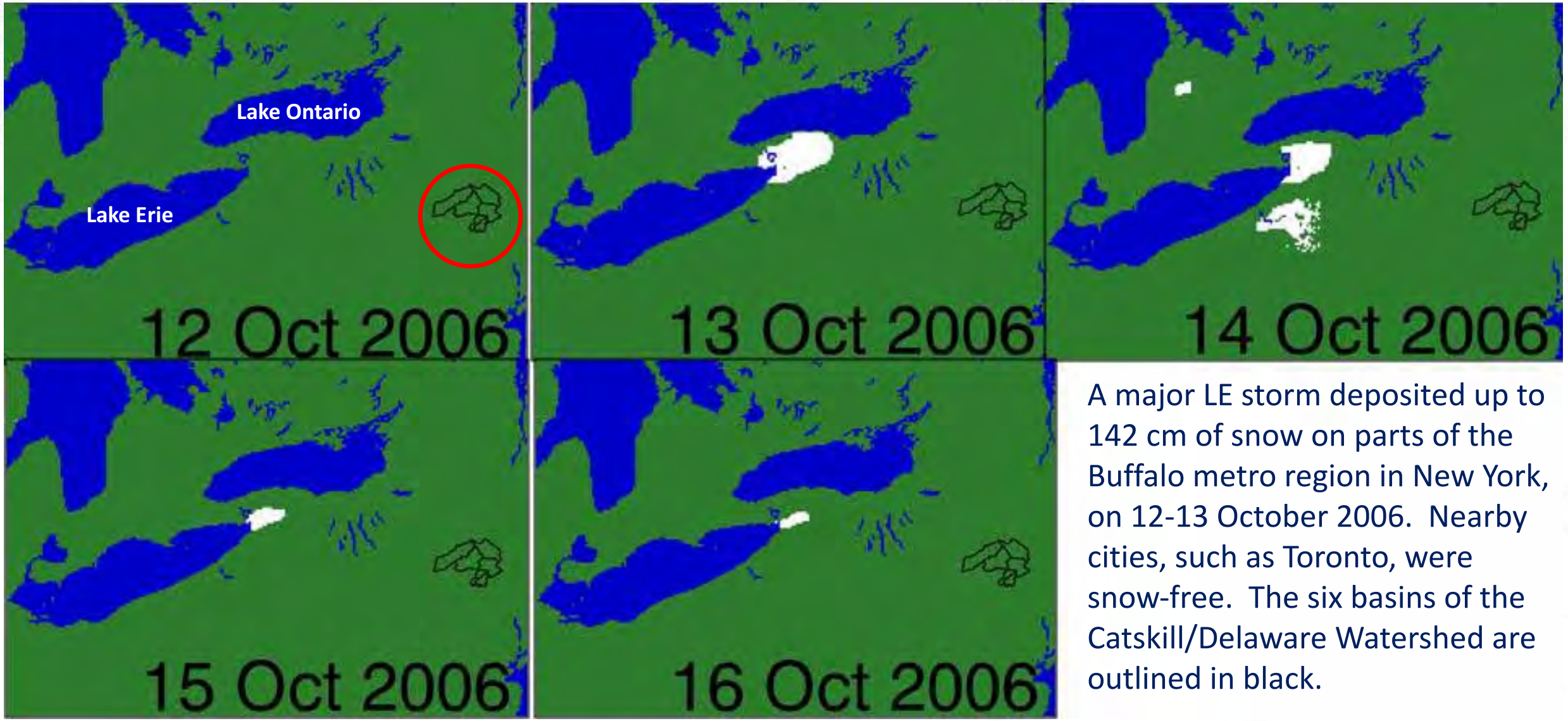
Cold arctic air with temperatures in the range of about -7 to -4°C flowed across the warm waters (~8-10°C) of Lake Erie and Lake Ontario, causing a major LE snowfall on 18 November 2014



Credit: CIMSS & NASA Earth Observatory

Cloud-free snow maps are needed to identify and track lake-effect storms

Time series of NOAA IMS* 4km resolution snow maps



A major LE storm deposited up to 142 cm of snow on parts of the Buffalo metro region in New York, on 12-13 October 2006. Nearby cities, such as Toronto, were snow-free. The six basins of the Catskill/Delaware Watershed are outlined in black.

*Interactive Multisensor Snow and Ice Mapping System

Does Lake-Effect Snow from Lake Ontario and Lake Erie reach the Catskills? If so, what is the contribution of LE snow to total snowfall in the Catskills?

The Cannonsville Basin is located ~170 km from the shoreline of Lake Ontario and ~300 km from the shoreline of Lake Erie

Storms can reach far inland when the wind is parallel with the long axis of the lake creating a long fetch, especially when there is a big difference between the SWT and the 850 mb air temperature

Data Used for this Work

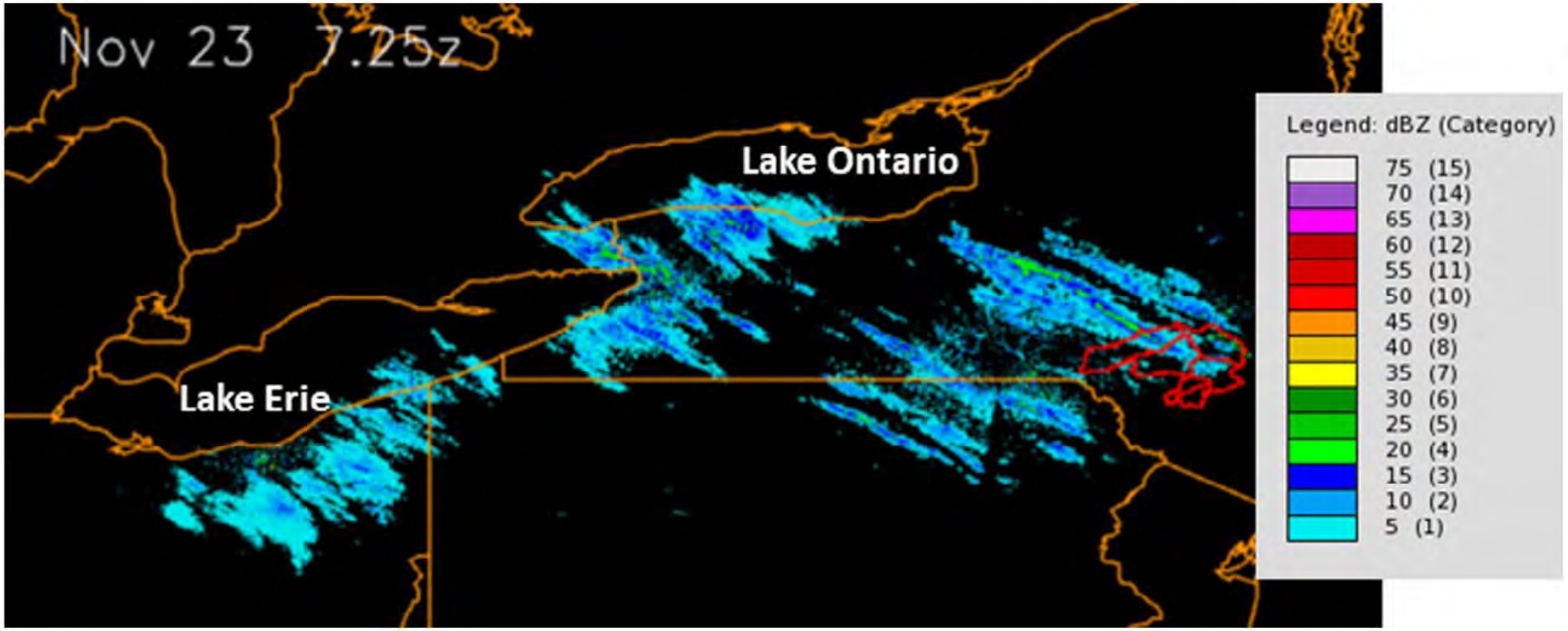
Satellite data:

NOAA National Ice Center Interactive Multisensor Snow and Ice Mapping System (IMS) 4km snow-cover extent (SCE) maps;
MODerate-resolution Imaging Spectroradiometer (MODIS) 500-m resolution standard snow-cover maps and surface reflectance images;
Landsat Enhanced Thematic Mapper Plus (ETM+)-derived snow maps.

Other data:

Meteorological station data from Oswego, NY;
NEXRAD Level III base reflectivity radar data from: Albany, Binghamton, Buffalo and Cleveland
Modern-Era Retrospective analysis for Research and Applications - 2 (MERRA-2) temperature data;
NOAA Great Lakes Environmental Research Lab (GLERL) CoastWatch data (percent ice cover and other data).

NWS NEXRAD Radar Data



Cloud and precipitation “banding” emanating from Lake Erie and Lake Ontario on 23 November 2005; echo intensity, in dBZ, from radar is shown in the blue and green colors

Difference between air temperature and surface water temperature

Date	Temp difference
21 Nov 2005	2.4
22 Nov 2005	3.9
23 Nov 2005	19.8*
24 Nov 2005	--

*From MERRA-2

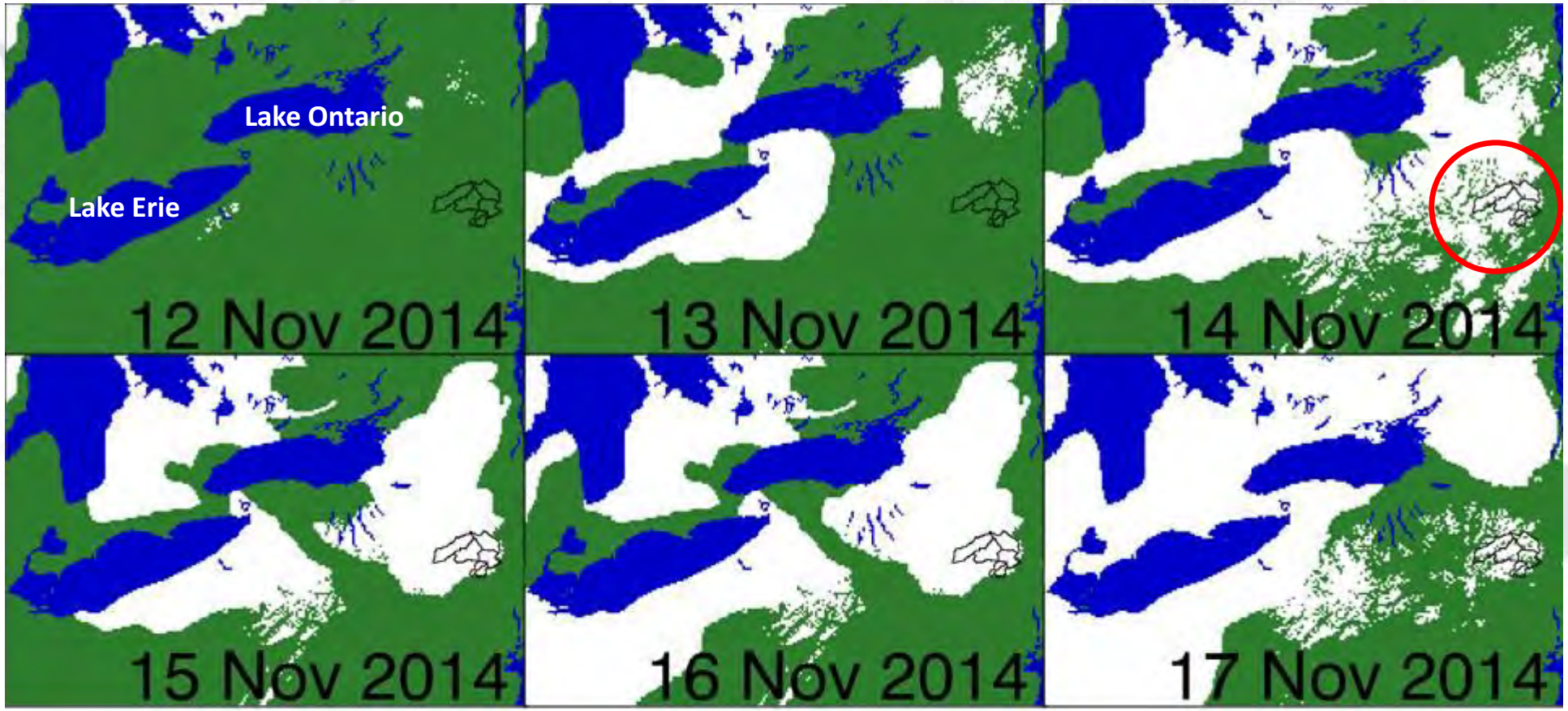
Percent ice coverage was zero for all dates according to the NOAA GLERL CoastWatch website.

Time series of IMS 4km snow maps showing the progression of a lake-effect storm that deposited snow in the Catskills

22 – 24 November 2005

Time series of IMS 4km snow maps showing the progression of the LE storm that deposited snow in the Catskills

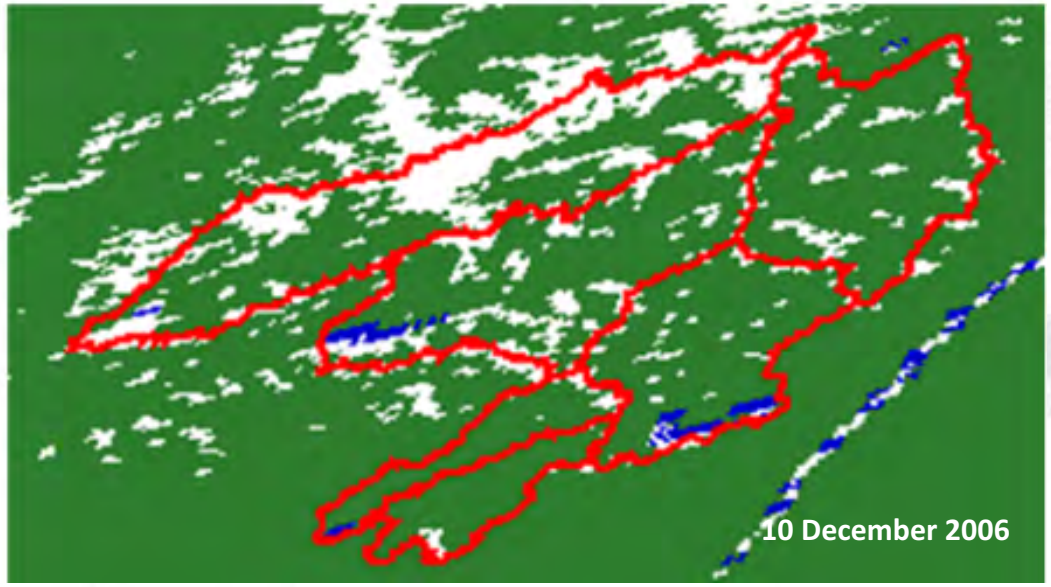
12 – 17 November 2014



The snow that fell on the Catskills originated from a LE storm that probably started over Lake Ontario.

Hall et al., 2018

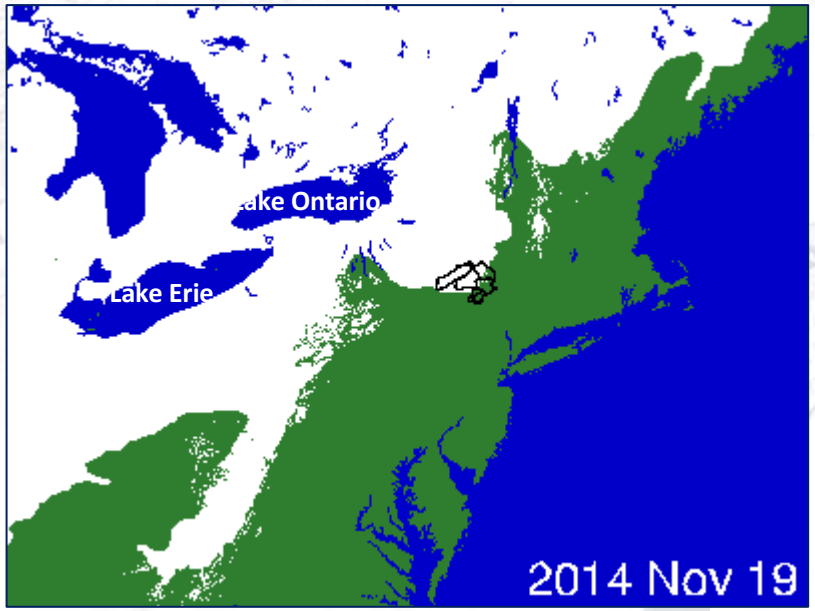
MODIS Snow Maps are useful for mapping snow cover in clear-sky conditions

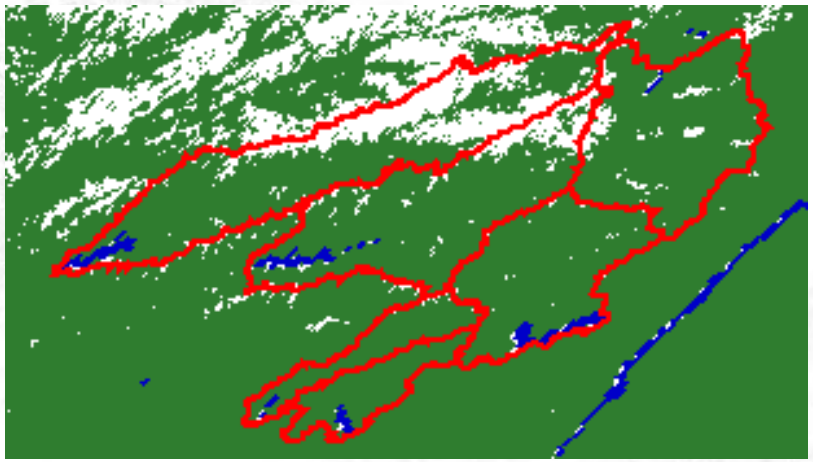


Left - Terra MODIS 250-m “true-color” image; Right - MODIS-derived snow-cover map

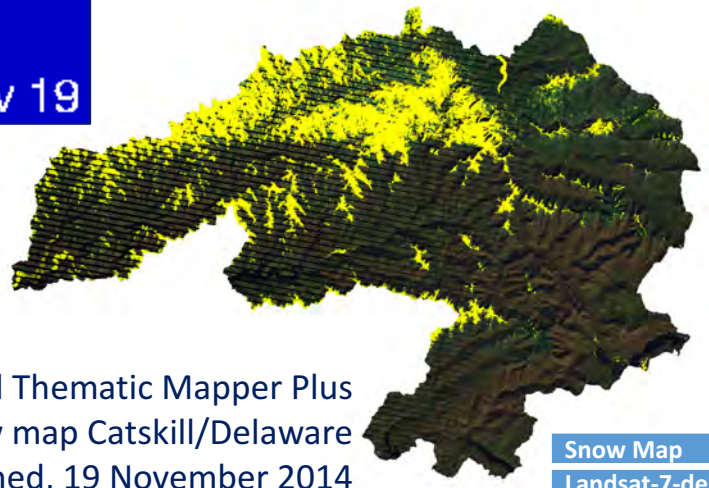
IMS 4km, MODIS and Landsat Snow Maps

19 November 2014





MOD10A1 C6 NDSI snow map of the Catskill/Delaware Watershed, 19 November 2014



Landsat-7 Enhanced Thematic Mapper Plus (ETM+) – derived snow map Catskill/Delaware Watershed, 19 November 2014

19 Nov 2014

Snow Map	Percent Snow Cover in Watershed	Area of Snow Cover in km^2
Landsat-7-derived snow map	15.7	647
MODIS MOD10A1 snow map	15.7	664
IMS 4km snow map	65.5	3292

Measurement of snow-cover extent (SCE) in the Catskill/Delaware Watershed using Landsat-7 Enhanced Thematic Mapper Plus (ETM+), Terra MODIS and IMS 4km SCE maps, 19 November 2014.

Dates and day of year (DOY) of 32 lake-effect (LE) storms from which snow reached the Catskill Mountains

Date	DOY	Lake
03 Dec 2004	338	Erie
13 Dec 2004	348	Erie then Ontario
05 Jan 2005	005	Both
23 Nov 2005*	327	Ontario
04 Dec 2005	338	Both
19 Jan 2006	019	Ontario
02 Feb 2006	033	Ontario
16 Mar 2006	075	Ontario
EO says 7-8 Dec 05 Dec 2006*	339	Ontario
10 Jan 2007	010	Ontario
17 Jan 2007	017	Ontario
18 Apr 2007	108	Erie
17 Nov 2007	321	Ontario
01 Dec 2007	335	Both?
19-22 Nov 2008	324-327	Both
27 Nov 2010	331	Erie
04 Dec 2010	338	Ontario?
02 Apr 2013*	092	Ontario?
14-15 Nov 2014*	318-319	Ontario?
01 Jan 2015	001	Both?
21 Dec 2015	355	Erie
05 Jan 2016	005	Both
12 Jan 2016	012	Ontario, then Erie
25 Feb 2016	056	Erie
04 Apr 2016	095	Ontario
21 Nov 2016	326	Ontario
29 Nov 2016	334	Ontario
08 Dec 2016	343	Erie
27 Dec 2016	362	Ontario
25 Jan 2017	025	Ontario
28 Feb 2017	059	Ontario
03-05 Mar 2017	062-064	Ontario, then Erie

Hall et al., 2018

A snowstorm cannot be tracked over snow-covered terrain using IMS snow maps

Frequency of Lake-Effect Storms

- Lake-effect storms from Lake Erie and Lake Ontario had been increasing between about 1950 and 1990.
- Models show that the frequency of LE storms will decrease in the future as regional temperatures continue to warm (Suriano and Leathers, 2016 & 2017).
- This is likely to impact the amount of snow falling in the Catskill Mountains.

Summary and Future Work

- Using a time series of NOAA IMS 4km snow maps, along with ancillary information, 32 LE storms were identified that deposited snow in the Catskill/Delaware Watershed during the 13-year study period; many others occurred but were not measureable from satellite data
- LE storms can travel quite far inland if conditions are right
- MODIS, VIIRS and Landsat allow accurate mapping of snow in the watershed under clear skies
- Changes in the frequency of LE snow would have the most impact in the Cannonsville basin; it is also the basin with the second largest reservoir feeding NYC
- In follow-on work, we will focus on methods to quantify the amount of lake-effect snowfall reaching the Catskill Mountains through modeling

Backup

As a surrogate for air temperature over Lake Ontario, both mean daily air temperatures from Oswego, NY, and from MERRA-2 (M2) were used; MODIS land-surface temperature (LST) was used to obtain a surface water temperature (SWT). Temperatures are in °C.

Date	Avg LST	Avg Tair Oswego	Tskin M2	Tair 2m M2	Tair 10m M2
21 Nov 2005	4.8	7.2	--	--	--
22 Nov 2005	5.0	1.1	6.8	3.1	2.8
23 Nov 2005	5.2	-5.6	6.0	-1.4	-2.0
24 Nov 2005	--	-3.9	5.7	-0.4	-1.0

Difference between air temperature from Oswego and SWT from MODIS LST

Date	Temp difference
21 Nov 2005	2.4
22 Nov 2005	3.9
23 Nov 2005	19.8*
24 Nov 2005	--

*From MERRA-2

Percent ice coverage was zero for all dates according to the NOAA GLERL CoastWatch website.