

NOTES AND CORRESPONDENCE

A Unique Satellite Perspective of the 13–14 January 2004 Record Cold Outbreak in the Northeast

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ABSTRACT

A cold, dry arctic air mass occupied southeastern Canada and the northeastern United States on 13–14 January 2004. This air mass was quite dry—total column precipitable water values at Pickle Lake, Ontario, Canada, and The Pas, Manitoba, Canada, were as low as 0.02 in. (0.5 mm)—allowing significant amounts of radiation originating from the surface to be detected using *Geostationary Operational Environmental Satellite (GOES) 6.5- μ m* “water vapor channel” imagery. On this day the strong thermal gradient between the very cold snow-covered land surface in southern Canada and the warmer, unfrozen, cloud-free water along the northern portion of the Great Lakes was quite evident in *GOES-12* imager water vapor channel data. Several hours later, as the cold dry air mass moved eastward, the coast of Maine, Cape Cod, and the Saint Lawrence River were also apparent in the water vapor channel imagery.

1. Introduction

On 13 January 2004 a cold arctic air mass moved over southeastern Canada and the Great Lakes region, resulting in minimum temperatures as low as -49°F (-45°C) in south-central Ontario and -59°F (-51°C) at La Grande IV in Quebec. This cold air mass was also quite dry, with dewpoint temperatures around the northern Great Lakes region as low as -20°F (-29°C). The following day, several minimum temperature records were broken in the New England region of the northeastern United States. On 14 January, Bangor, Maine, had a daily maximum temperature of only -6°F (-21°C), which was its lowest daily maximum temperature ever for the month of January. Many northeastern U.S. locations reported their lowest minimum temperatures in nearly a decade during this cold air outbreak. How cold and dry was this particular air mass?

2. Satellite observations

Satellite observations provided a unique perspective on the unusually cold and dry conditions associated with this arctic air. Most meteorological satellite pay-

loads include a radiometer that measures longwave infrared energy between 10 and 12 μm , since this spectral region is in the “infrared window” allowing very minimal absorption of outgoing radiation by the atmospheric gases. This wavelength is often used to estimate the temperature of the surface and cloud tops. Figure 1 is an image from the Moderate Resolution Imaging Spectroradiometer (MODIS) 11- μm IR channel (King et al. 1992), which on 13 January measured brightness temperatures of approximately 0°C in the clear waters of northern Lake Superior. Adjacent to the Great Lakes, brightness temperatures were between -20° and -30°C , with brightness temperatures farther north in southern Ontario colder than -40°C . Multiple lake-effect snow (LES) bands were apparent in the image as the cold air mass moved over the warmer Lake Superior waters.

Figure 2 shows the *Geostationary Operational Environmental Satellite-12 (GOES-12) 6.5- μm* channel image on 13 January 2004 at 1600 UTC, which displays a more dramatic (and perhaps unexpected) signature of the low temperature and humidity characteristics of this air mass. The low total column water vapor content and the strong contrast in surface temperature between the unfrozen northern Great Lakes and the surrounding snow-covered land surface in Canada allow surface features (the northern coastline of the Great Lakes) to be detected in this “water vapor channel” imagery; even hints of the boundary layer LES cloud bands over Lake Huron are discernible in animations of the images

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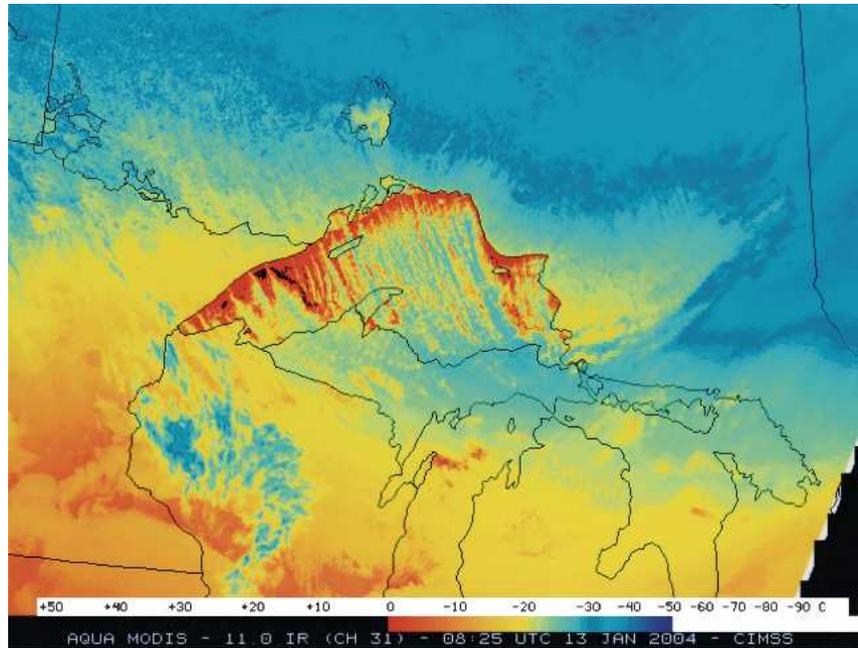


FIG. 1. The 11- μm IR image of the upper Great Lakes as measured by the MODIS instrument on the NASA *Aqua* satellite on 13 Jan 2004 at approximately 0825 UTC.

(available online at <http://cimss.ssec.wisc.edu/goes/misc/040113/040113.html>).

Satellite observations at wavelengths between 5.8 and 7.3 μm are referred to as water vapor channel im-

agery, because water vapor is very effective at absorbing and reemitting upwelling terrestrial radiation at these wavelengths (Schmit et al. 2001; Menzel and Purdom 1994; Weldon and Holmes 1991; Morel et al.

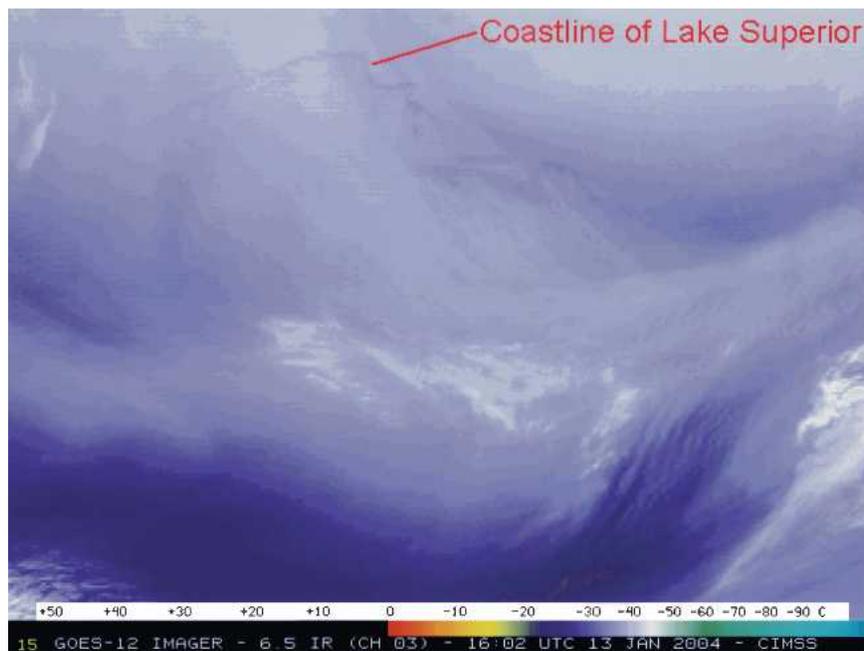


FIG. 2. The *GOES-12* water vapor channel image at approximately 1600 UTC on 13 Jan 2004. The northern coastlines of the Great Lakes are apparent in this image. Mountain waves are also seen to the lee of the Appalachian Mountains (in the southeast portion of this image). The brighter white areas are clouds.

1978). Meteorologists make extensive use of water vapor channel satellite imagery because time series animations (or satellite loops) often reveal important atmospheric circulations within the middle and upper troposphere. For clear-sky conditions, the observed brightness temperature in this spectral region depends on the temperature of the atmosphere, and also on the amount and vertical distribution of water vapor. Under typical midlatitude conditions, absorption/emission by water vapor is strong enough to block surface emitted infrared energy at this wavelength from reaching the satellite detector. Yet absorption is weak enough so that energy emitted from the midlevels of the troposphere does reach the satellite, because of the low concentrations of water vapor above the tropopause.

The water vapor weighting function profile provides valuable information about the level(s) of the atmosphere that contribute to the satellite measurement (Menzel and Purdom 1994). The weighting function is determined by the absorption properties of the gas (in this case water vapor), the gas concentration, the vertical distribution of the gas, and the temperature profile. The brightness temperature measured by the satellite is a strong function of the height of the weighting function peak. Thus, in displays of water vapor channel imagery, dry cloud-free air masses typically exhibit relatively warm brightness temperatures since the weighting function peaks in the lower portion of the troposphere, while humid air masses often exhibit colder brightness temperatures because much of the atmospheric emission originates from the higher and colder upper troposphere. Calculation of the weighting function profile for typical midlatitude temperature and moisture conditions indicates that the surface-emitted radiation does not contribute to the satellite measurement, and the radiation sensed by this channel generally originates from the 300–600-hPa layer (Weldon and Holmes 1991).

Figure 3 shows the *GOES-12* water vapor channel weighting functions calculated using the Pickle Lake, Ontario, rawinsonde data at 0000 and 1200 UTC on 13 January 2004. At 0000 UTC the air mass over Pickle Lake was quite dry, with a total precipitable water of only 0.07 in. (1.8 mm) and a mean boundary layer mixing ratio of 0.5 g kg^{-1} . The weighting function showed that the layer of the atmosphere contributing most to the observed radiant energy was centered at approximately 600 hPa. The weighting function is very small at the surface, indicating that the satellite is sensing very little energy emitted from the surface. However, at 1200 UTC on 13 January the water vapor content of the atmosphere over Pickle Lake fell even farther, as rawinsonde data indicated a total column precipitable water of only 0.02 in. (0.5 mm) and a mean boundary layer mixing ratio of less than 0.2 g kg^{-1} . With such low total column water vapor amounts the water vapor weighting function profile peaked at an abnormally low altitude

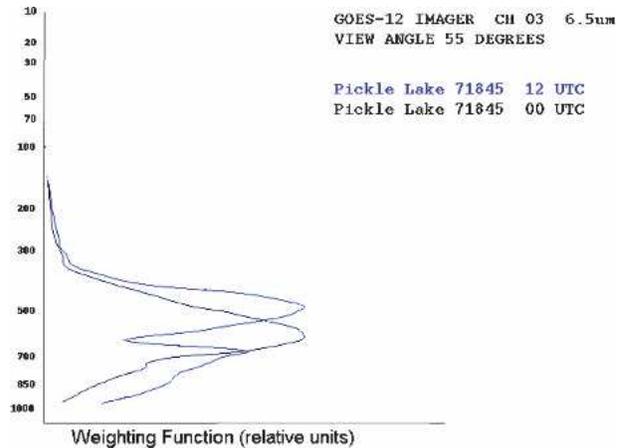


FIG. 3. Water vapor weighting functions calculated using the Pickle Lake, Ontario, temperature and moisture profiles measured at 0000 UTC (black curve) and 1200 UTC (blue curve) on 13 Jan 2004. The 1200 UTC weighting function indicates a significant contribution of radiation from the surface.

(secondary peak near 700 hPa), and showed a significant contribution from the surface to the total measured radiance at the satellite. While the peak contribution at 1200 UTC is near the 500-hPa level, the surface and lower-tropospheric contribution was much larger than it was 12 h earlier.

Several hours later, as the cold dry air mass moved southeastward on 14 January, the coasts of Maine, Cape Cod, and the Saint Lawrence River were apparent in the *GOES-12* water vapor imagery (Fig. 4). The Albany, New York, rawinsonde at 0000 UTC on 14 January measured a total column precipitable water value of only 0.8 in. (2.0 cm), with a mean boundary layer mixing ratio of 0.8 g kg^{-1} . The water vapor weighting function profile calculated for these atmospheric conditions peaked at a relatively low level of 650 hPa, and also indicated a contribution from the surface.

3. Summary

Under typical atmospheric conditions, the water vapor channel imagery generally displays the temperature of the water vapor contained within the atmospheric layer between approximately 300 and 600 hPa, and these satellite data are often used to track middle- and upper-tropospheric circulation patterns. When utilizing the water vapor channel imagery for weather analysis and forecasting, it is important to keep in mind the potential three-dimensional variability of the water vapor weighting function, since this has an important effect on the vertical location of the atmospheric features being displayed. If an air mass is unusually cold and dry, the features that are detected on the water vapor channel may be located at much lower levels than the “normal” 300–600-hPa layer. The cold arctic air outbreak of

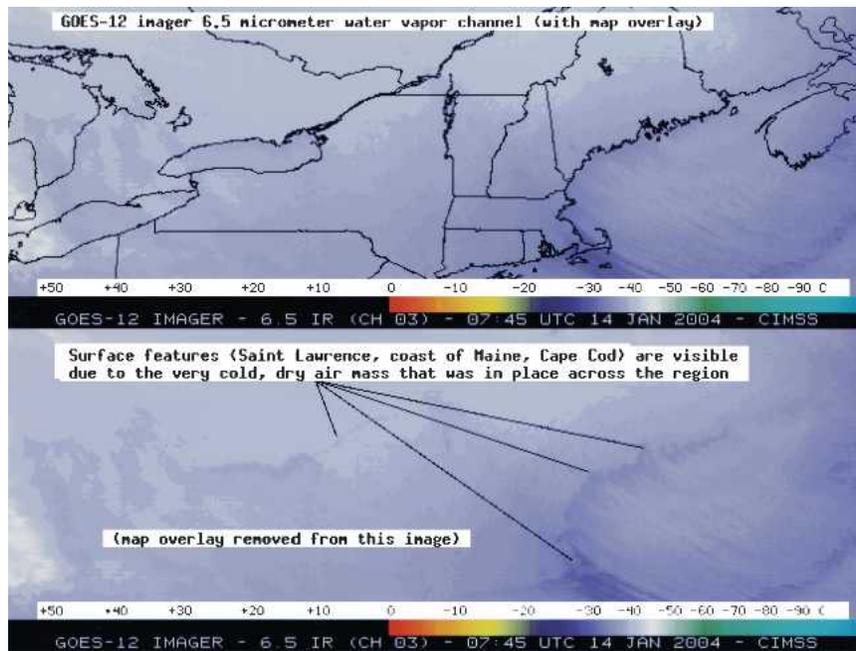


FIG. 4. The *GOES-12* water vapor image at 0745 UTC on 14 Jan 2004. (top) The water vapor channel data with a map overlay. (bottom) As in the top panel but with the map removed to show that surface features (the coastline of ME, Cape Cod, and the Saint Lawrence River) were clearly visible.

13–14 January 2004 provided an unusual example of the ability to detect surface-based features (in this case, coastlines) using the GOES water vapor channel imagery.

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