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ERTS-1 VIEWS THE GREAT LAKES

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ABSTRACT

The meteorological content of ERTS images, particularly mesoscale effects of the Great Lakes and air pollution dispersion is summarized. Summertime lake breeze frontal clouds and various winter lake-effect convection patterns and snow squalls are revealed in great detail. A clear-cut spiral vortex over southern Lake Michigan is related to a record early snow storm in the Chicago area. Marked cloud changes induced by orographic and frictional effects on Lake Michigan's lee shore snow squalls are seen. The most important finding, however, is a clear-cut example of alterations in cumulus convection by anthropogenic condensation and/or ice nuclei from northern Indiana steel mills during a snow squall situation. Jet aircraft condensation trails are also found with surprising frequency.

1. INTRODUCTION

With the launching of TIROS I in April, 1961, meteorologists gained a valuable tool for the study of synoptic scale weather systems. The inherent resolution characteristics of the imaging systems used, however, made it difficult to define the details of synoptic systems and failed even to detect many mesoscale processes. Atmospheric motion system peak in the mesoscale (1-100 km wavelengths). The meteorological effects induced by the Great Lakes, both upon cloud systems and air pollution dispersion, could in most cases be classified as mesoscale. ERTS-1, with its extremely high resolution as well as multispectral monitoring capability, promised to be the first satellite ideally suited to the needs of mesometeorologists, cloud physicists, and air pollution meteorologists. It appears to have more than lived up to its initial promise in this first summer and winter of monitoring the various distinctive interactions between the Lakes and the atmosphere.

2. GREAT LAKES IN SUMMER

Great Lakes surface water temperatures during spring and summer months often are as much as 30°C colder than advecting air masses. This results, under certain circumstances, in extreme supression of cumulus and thunderstorm convection over the Lakes. Moreover, lake breezes frequently push onshore, further altering convective cloud distributions.

These mesoscale cold fronts may penetrate inland from one to fifty km, typically are 500 m in depth, and have peak values of vertical motion at the leading edge of 100 to 200 cm/sec. Depending upon synoptic scale wind patterns, convective clouds near the front may either be dissipating or experiencing rapid growth (occasionally to severe thunderstorm stages). In either case, a well defined cloud line marks the inland penetration of the lake air. On 20 August 1972, conditions for a lake breeze over the lower Great Lakes were ideal. Figure 1 clearly shows the lake breeze frontal cloud band along the south shore of Lake Ontario and around both shores of Lake Erie. It is apparent that the front closely parallels the shoreline indentations, an assumption made in numerical models. The inland penetration does not seem to be affected by the presumed heat sources of major cities (Rochester and Buffalo), as is sometimes suggested. Each and every cumulus cell is easily identified. Future such images will be of great value in studying mesoscale cloud-lake interactions, and in evaluating the physical processes involved in summer precipitation deficits suspected present over the Lakes.

3. GREAT LAKES IN WINTER

During fall and winter arctic air masses, sometimes more than 30°C colder than the underlying water, move across the Lakes resulting in intense lake-effect snow squalls, dumping massive amounts of snow on lee shores. Numerous ERTS views of such events have shown the full range of patterns expected, including Bénard-like cellular patterns during weak convection, the more intense linear longitudinal bands roughly paralleling the low level winds, and the massive single-band snow squalls of the type which afflict Lakes Erie and Ontario during periods of cold, unstable southwesterly flow. Certain indications have suggested however that during situations conducive to even more intense convection than in the single-band case, a series of small mesoscale lows may propagate with the winds. Microbarograph networks at the eastern end of Lake Ontario have indicated such travelling depressions. During an intense snow burst in Chicago on 23 February 1967 (7 inches in one hour), radar revealed a spiral band echo pattern over southern Lake Michigan resembling a miniature hurricane. On 19 October 1972, a cold arctic high centered in Iowa advected air with near-freezing surface temperatures across lakes some 20°F warmer. Northeasterly flow across Lake Huron generated a multi-striated snow squall band which travelled across lower Michigan and then over Lake Michigan. The ERTS images show that the band regenerated and developed an obvious spiral cloud pattern (Fig. 2a) northeast of Chicago. Preceeding snow squalls (and perhaps mesolows) had already deposited 3-5 inches of snow over northwestern Indiana in the prior 9-12 hours, easily visible especially in the 0.5-0.6 micrometer band and in CIR composits. Snow approaching moderate intensity was falling along the Chicago shoreline at the time of ERTS overflight, and surface wind reports certainly suggest a mesoscale cyclonic circulation approaching the shore (Fig. 2b).

On 11 December 1972, cold west-southwesterly flow across southern Lake Michigan was resulting in the expected cumulus convection over the water. What is most intriguing about the cloud patterns on the lee shoreline (Fig. 3) is the abrupt transition from scattered to nearly overcast cloud cover, the sudden formation of longitudinal bands, and a change in cloud appearance suggesting glaciation. Steep-faced 100 m high dunes at the shorelines apparently caused significant orographic lift, and combined with onshore frictional convergence within the boundary layer, the sudden increase in vertical motions produced marked changes in cloud structure, and presumably snowfall potential.

4. INADVERTANT WEATHER MODIFICATION

On 24 November 1972, cold southwesterly flow again traversed Lake Michigan. An inspection of the cumulus patterns (Fig. 4) show particulate plumes from at least seven steel mills and power plants feeding directly into the clouds. The bands emerging from these plumes, which almost certainly contain vast amounts of anthropogenic condensation and ice nuclei, form closer to the shoreline and become more intensely developed. Pollution in this area has long been suggested as the cause of the La Porte, Indiana precipitation anomaly, and this obvious incidence of inadvertant weather modification strengthens such a contention.

Man-made cirrus clouds from jet aircraft are also being considered as a potential modifying factor in the global energy balance. Figure 5a shows a broken layer of cirriform cloudiness over southeastern Wisconsin, and intermingled are contrails in various stages of diffusion, some having expanded to at least 11 km in width. In the 0.8 - 1.1 micrometer band (Fig. 5b), two things are notable: the considerable transparency of both natural and man-made cirrus in the near infrared, and the easily recognizable shadows of the jet contrails.

5. SUMMARY

As both ERTS images and supporting meteorological data become available, it is obvious that many major projects of meteorological significance should evolve. Particulate plumes visually tracked for over 50 nm from steel mills proves graphically how adjacent Air Quality Control Regions (Chicago and Southeast Wisconsin) can share common airsheds. UWM's Cessna 336 aircraft, equipped to measure total suspended particulates, will attempt to find relationships between ERTS image brightness levels and total atmospheric mass loading. Aircraft and ground all-sky time-lapse photography simultaneous with ERTS overflights will allow further investigation of ERTS resolution, cloud morphology and dynamics. A continued search for inadvertant weather modification events will be of increasing significance as large-scale cloud seeding of the Great Lakes to regulate water levels approaches operational status.

6. ACKNOWLEDGMENTS

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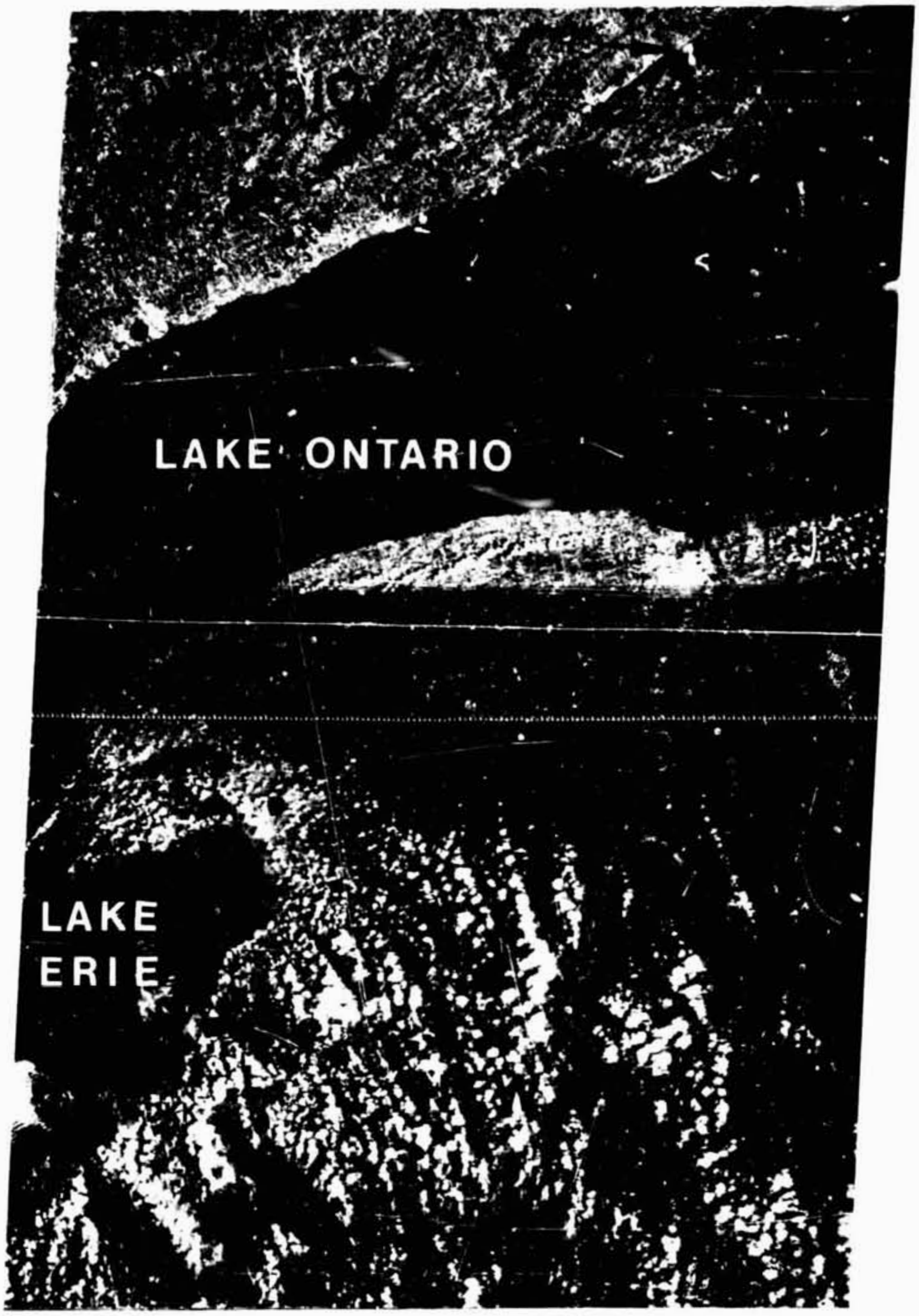

Figure 1: ERTS-1 MSS band 5 view of lower Great Lakes, 20 August 1972 showing lake breeze front cumulus clouds. Cirrus over Lake Ontario became invisible in band 7. Arrow points to apparent smoke plume. Cities noted include Toronto (YYZ), Rochester (ROC), Buffalo (BUF) and Dunkirk, N.Y. (DKK).

Figure 2(a): ERTS-1 MSS band 4 showing snow cover over Chicago-northwest Indiana and cyclonic cloud swirl, 19 October 1972, (b) band 7, with 1000 LST surface data and wind streamlines. One full wind barb equals 5 kts in all figures.

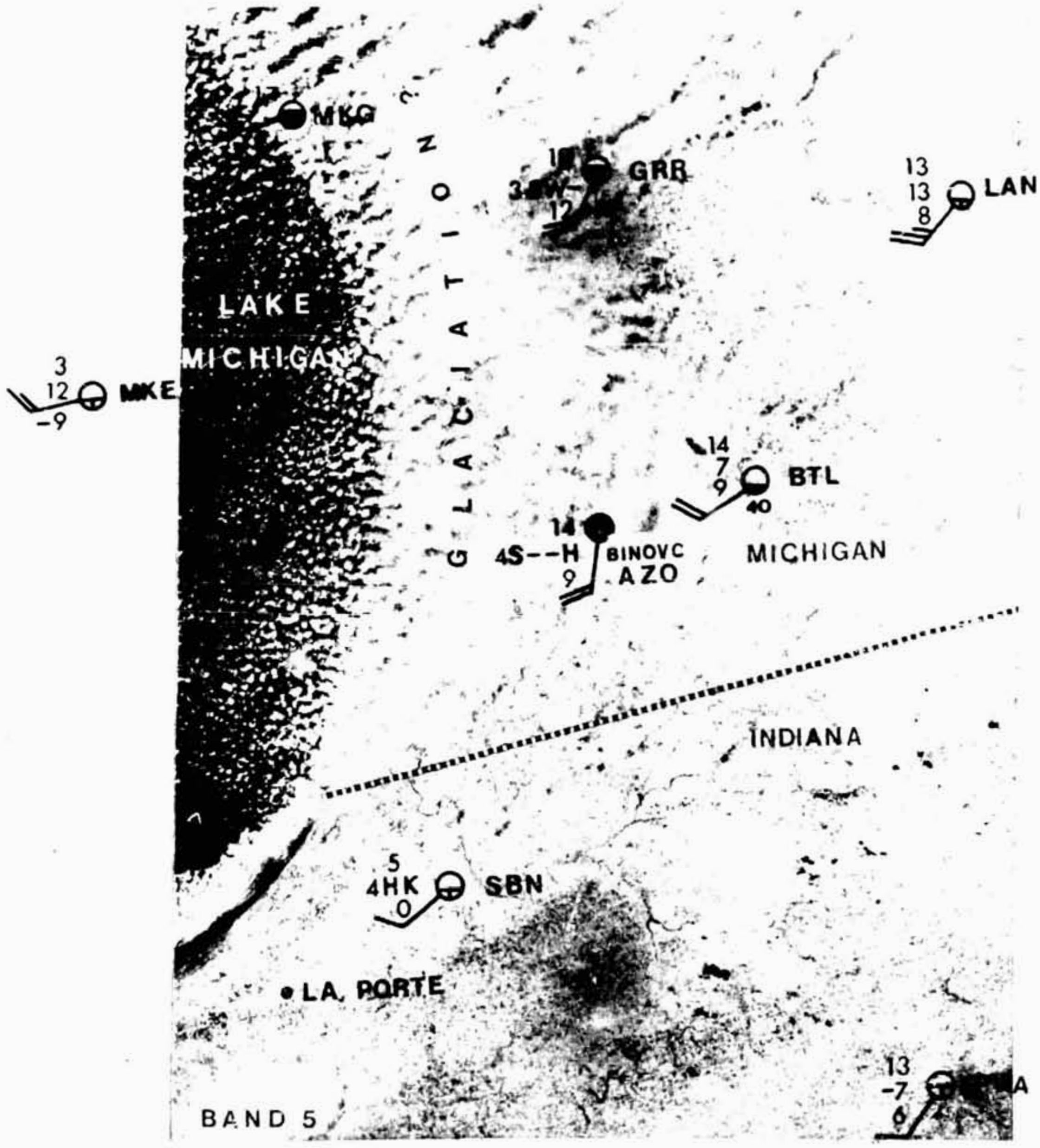

Figure 3: ERTS-1 MSS band 5 view of southeastern shore areas of Lake Michigan, 11 December 1972. Scattered and mostly random shallow cumulus convection suddenly thickens to broken to overcast as it moves inland. Orographic lift from shoreline dunes and frictional convergence, especially near Muskegon (MKG), appear likely causes. The clouds appear to rapidly glaciate about 20 nm inland. Note snow flurries at Grand Rapids (GRR) and Kalamazoo (AZO). The surface air temperatures increased from 3 to 17°F while crossing the lake.

Figure 4: ERTS-1 MSS band 6 view of southern Lake Michigan, 24 November 1972. Southwesterly flow of near freezing air over warmer lake results in cumulus convection. Plumes of suspended particulates from seven identified shoreline power plants and steel mills are causing notable effects in the shallow convective clouds. When viewing transparencies, the clouds forming out of the plumes begin noticeably closer to the shoreline and become denser and more well developed, a clear cut case of inadvertant weather modification.

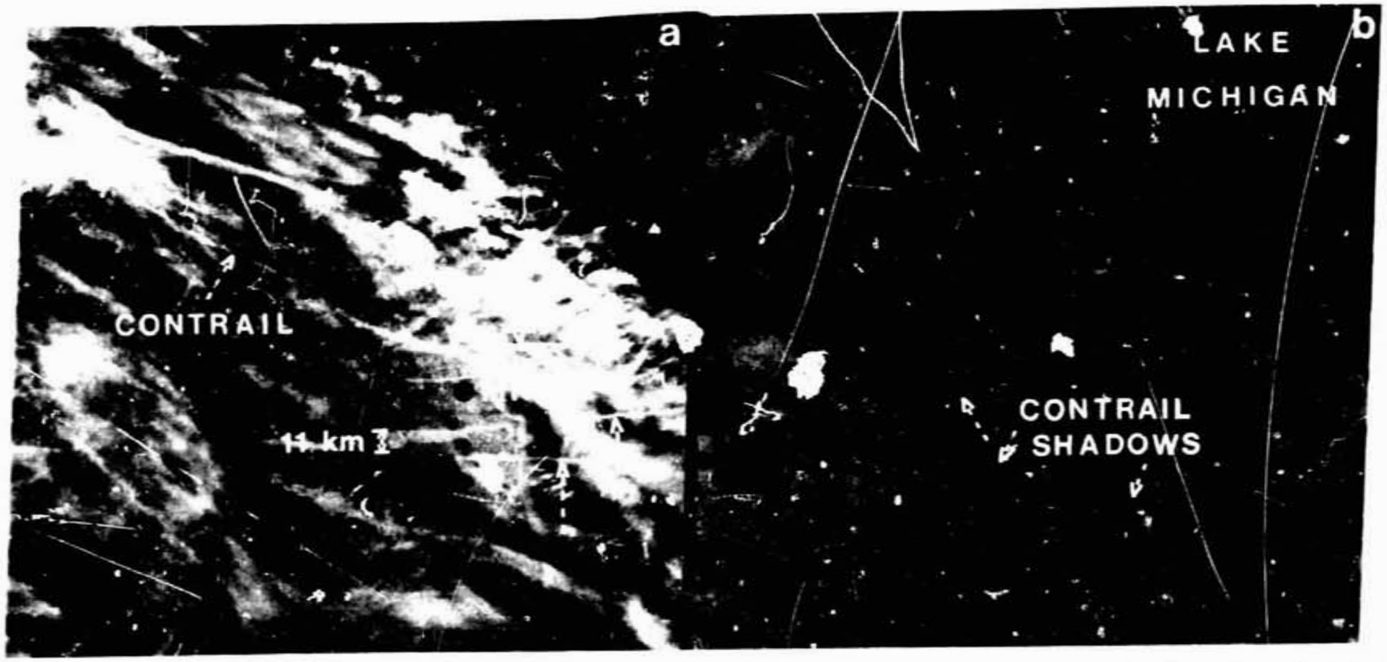

Figure 5(a): ERTS-1 MSS band 4 view of southeastern Wisconsin, 20 October 1972. The dot labled MKE is the Milwaukee National Weather Service station, reporting cirrus cloud cover at 25,000 feet. The clouds are oriented roughly with the wind at that level (310°, 60 kts). Superimposed on the natural cirrus, however, are jet condensation trails (contrails), some of which are indicated by arrows. In the moist environment at that level, some have spread to widths of at least 11 km. (b) Band 7 reveals the surprising degree of transparency of cirriform (ice) clouds in the near infrared, as well as distinct cloud contrail shadows. The spectral variations of cirrus albedo may well lend themselves to automatic detection by pattern recognition techniques.