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Cloud Spatial Structure During the FIRE MS IFO

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EXTENDED ABSTRACT

This abstract summarizes work being done at the Goddard Laboratory for Atmospheres on the fractal properties of clouds observed during the FIRE Marine Stratocumulus Intensive Field Observations (MS IFO) and their effects on the large-scale radiative properties of the atmosphere. This involves three stages: (a) analysis of LANDSAT Thematic Mapper (TM) cloud data to determine the scaling properties associated with various cloud types; (b) simulation of fractal clouds with realistic scaling properties; (c) computation of mean radiative properties of fractal clouds as a function of their scaling properties. The focus here is on the empirical work, which is being done with the assistance of Mark Nestler of Science Applications Research.

Thirty-three LANDSAT scenes were acquired As part of the FIRE Marine Stratocumulus IFO in July 1987. They exhibit a wide variety of stratocumulus structures. Analysis has so far focused upon the July 7 scene, in which the NASA ER-2, the BMO C130 and the NCAR Electra repeatedly gathered data across a stratocumulus-fair weather cumulus transition.

Before discussing our conclusions about cloud structure based upon observations of cloud reflectivity, we should first note that what we really wish to know is how the cloud liquid water is distributed, since the reflectivity is computable from the distribution of liquid water, traditionally by specifying microscopic properties like drop sizes, and macroscopic properties like optical depth, etc.. The radiation field provides a kind of low-pass spatial filter, so that there may be small-scale variations of liquid water to which the LANDSAT data is completely insensitive. However, the LANDSAT data does reveal considerable small-scale structure not included in our usual plane-parallel assumptions. Interpretation of this structure in terms of the three-dimensional distribution of liquid water will be an important result of coordinating the satellite and aircraft data analysis.

brightness histograms

The LANDSAT TM has 3 visible reflected bands, 3 near-infrared bands and the thermal water vapor window band. The July 7 stratocumulus clouds have a maximum reflectance of about 0.5, which saturates two of the visible and one of the near-infrared TM bands. Table 1 shows the typical maximum reflectance required to saturate each band. Bands 1, 3 and 5 are all saturated at a reflectance of less then 0.5, and thus are saturated by the July 7 stratocumulus. Band 2 (0.52-0.60) is saturated at 0.5, so that only the few brightest pixels are saturated. Bands 4 and 7 are well below saturation.

Band	Wavelength(μ)	Rsat	saturated?
1	0.45-0.52	0.22	√
2	0.52-0.60	0.50	
3	0.63-0.69	0.46	√
4	0.76-0.90	0.63	
5	1.55-1.75	0.41	√
7	2.08-2.35	0.60	

The histogram of the thermal band (Band 6, 10.4-12.5 microns) for July 7 shows two narrow peaks separated by about 8^{o}C, which corresponds to a cloud top at about 800 meters if we assume a dry adiabatic lapse rate.

Plots of temperature versus brightness (band 6 vs band 7, for example) show the usual scatter of points extending up from the warm dark surface cluster to the cold bright cloud cluster. At 1 km resolution the points are all concentrated at the two extremes, but as the resolution is refined to 120 m, narrowing the field-of-view to keep the number of pixels the same, the points spread out uniformly between the cloudy and clear clusters. This is due to the fact that the field-of-view is focusing in on the stratocumulus boundary, where a high percentage of partially cloudy pixels occur.

spatial distributions

The wavenumber spectra and cloud size distributions are approximately power-law, but the stratocumulus clouds conform to a single power more closely than do the fair weather cumulus, which exhibit a clear change in the fractal dimension at a diameter of about 0.4 km. The fractal dimension also changes with the reflectivity threshold. As the threshold is raised from cloud base to cloud top, the perimeter fractal dimension increases, perhaps indicative of the increased turbulence at cloud top. The aircraft and island data from FIRE will allow us to relate the spatial structure of the LANDSAT brightnesses to that of the liquid water, drop sizes, vertical motion and entrainment rate.

The fact that the larger clouds are less probable and more irregular in shape suggests a random coincidence hypothesis. That is, the smaller clouds are generated by a scaling fractal process up to some maximum cell size of about 0.5 kilometers, and larger clouds occur only as accidental coincidences of the smaller ones. One test of this picture is to see if the smaller cloud areas have a simpler distribution of cloud brightnesses within each cloud area. Visual inspection of a few cases seems to bear this out, since we observe that the smaller cloud areas have a single brightness maximum, while larger ones invariably have multiple brightness maxima.

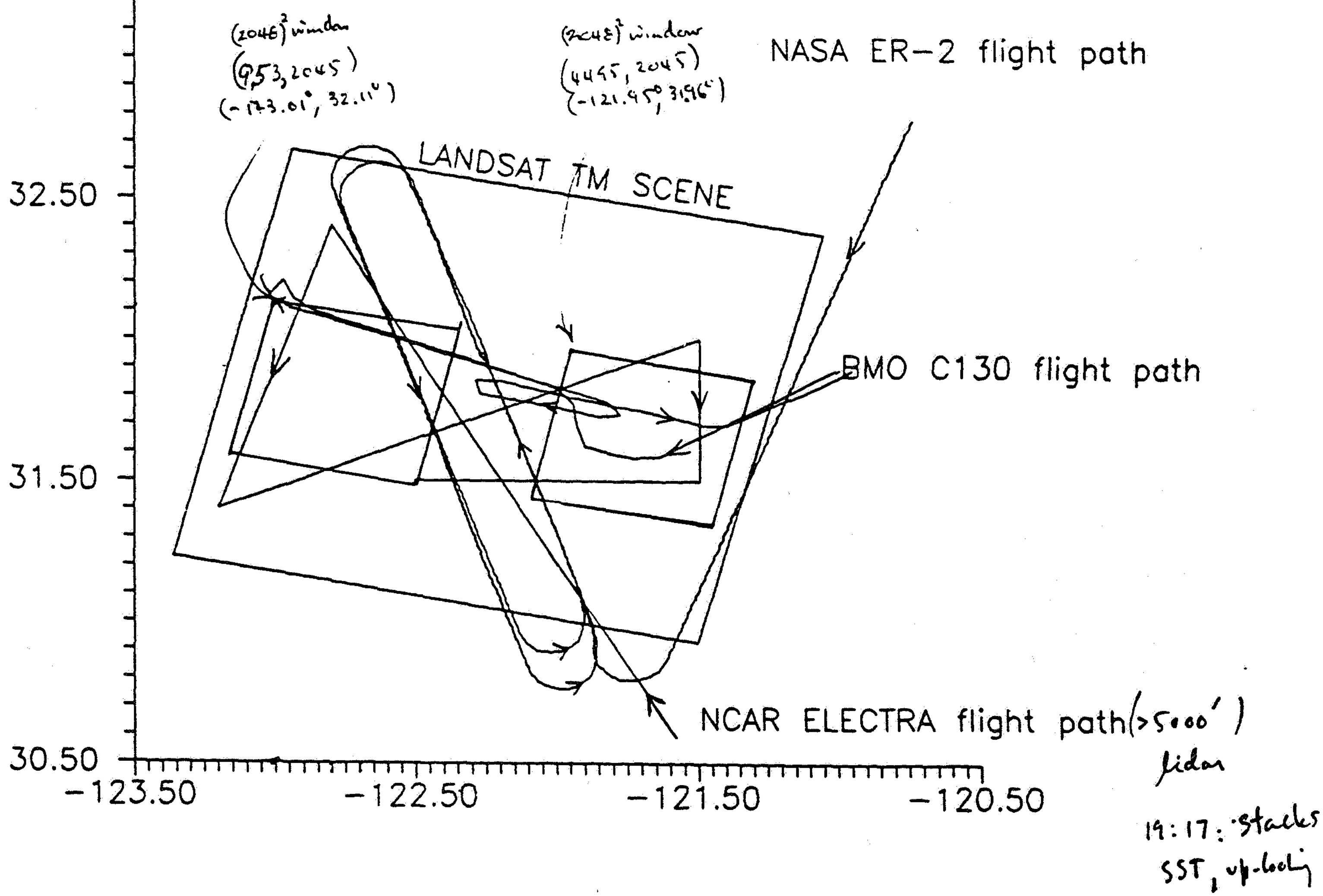
Raising the threshold to a high level allows the determination of the fractal dimensions of the bright regions. The brighter regions were found to have higher perimeter dimensions for both fair weather cumulus and stratocumulus. In the case of fair weather cumulus it may be that the thicker, and therefore brighter, cloud regions are more irregular because they arise from the random coindidence of the smaller cells. On the other hand, in the case of stratocumulus this may be associated with increased turbulence at the cloud top, where the convection is driven by radiative cooling. Note that there is a limit to the increase of the perimeter dimension with threshold, since the brighter regions cover a successively smaller area as the threshold is raised.

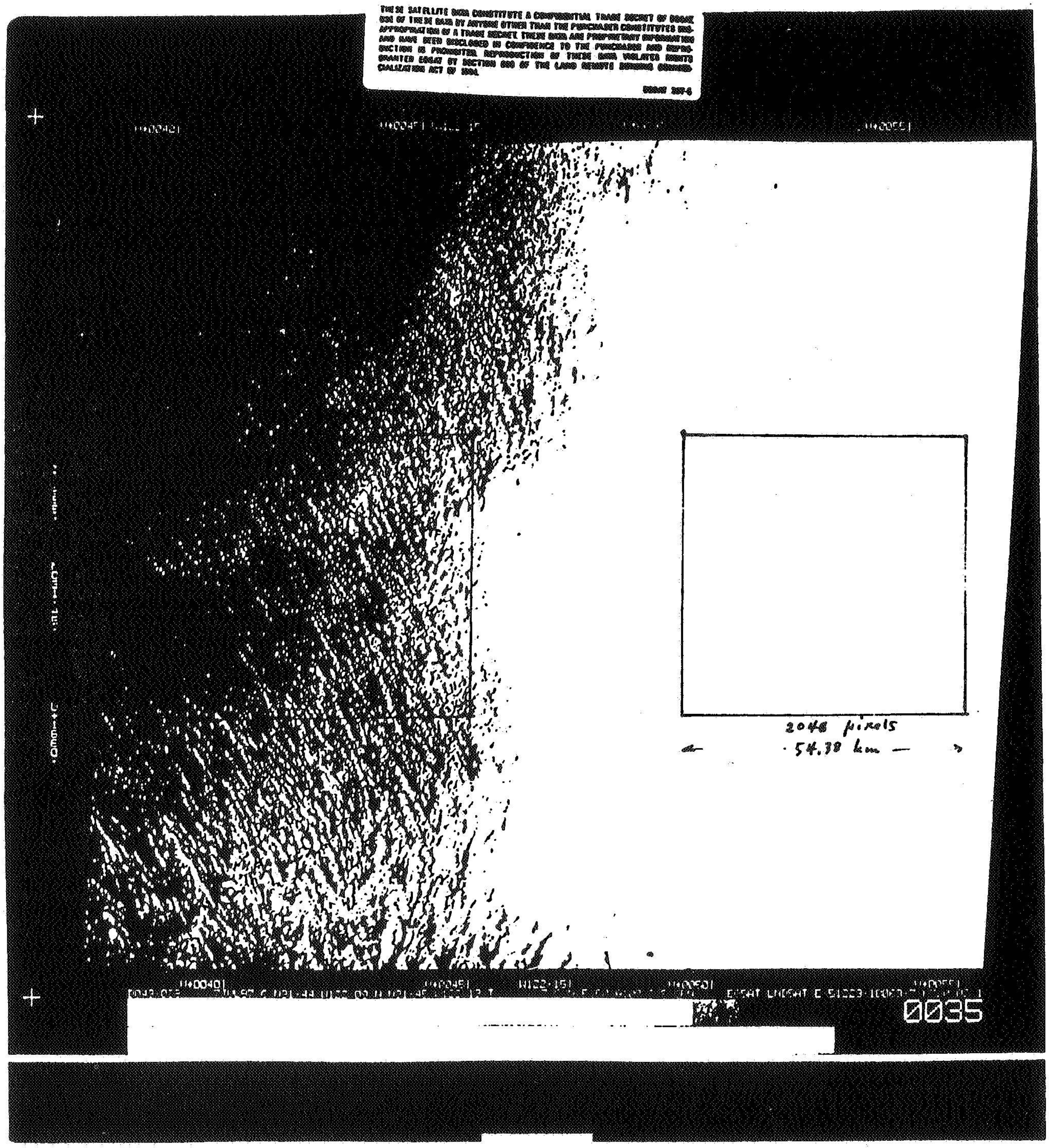
Stratocumulus dimensions are intermediate between the smaller and larger fair weather cumulus, and the break in slope is less pronounced. Since stratocumulus convection is driven by cooling at the cloud top, rather than heating from below as in fair weather cumulus, the stratocumulus downdraft regions are of more interest. These take the form of long, irregular leads, not unlike those observed in sea ice.

Simulations of fair weather cumulus and stratocumulus clouds have been developed which take these properties into account. The simulations depend upon two scaling parameters which determine the distributions of cloud sizes and spacings, respectively, and also upon a maximum characteristic cell size. The fair weather cumulus simulations begin with an initially cloud free scene and add liquid water associated with updraft regions, while the stratocumulus simulations begin with a uniform liquid water distribution and remove liquid water in downdraft regions. The simulations may be run until a given total liquid water is generated, or each updraft and downdraft may be assigned a "lifetime" from some probability distribution, and the resulting time-dependent simulation run to a steady state.

The initial Monte Carlo radiative transfer computations have been carried out with a highly simplified model in which liquid water is redistributed in an initially plane-parallel cloud while cloud height and mean optical depth are held fixed at each step. Redistribution decreases the mean albedo from the plane parallel case, since the albedo of optically thick regions saturates as optical depth is increased. The albedo of each homogeneous region may be computed from the thickness of each region independently only when the horizontal optical depth is large compared to the photon mean free path. The albedo of a region comparable in horizontal optical depth to the photon mean free path depends upon radiation from the sides. The mean albedo is insensitive to variations in optical depth on horizontal scales much smaller than the photon mean free path. These concepts have been illustrated with a simple one-parameter fractal model.

JULY 7, 1987 NAVIGATION
for FIRE marine statocumulus
intensive field observations





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