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APPLICATION OF NIMBUS-6 MICROWAVE DATA TO PROBLEMS IN PRECIPITATION PREDICTION FOR THE PACIFIC WEST COAST

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1. INTRODUCTION

Reliable predictions of the rapid augmentation of mountain snowpack or of runoff in the Pacific Northwest westward of the Cascades depend largely on the extent to which pertinent percursor meteorological conditions can be diagnosed over the northeastern Pacific Ocean, where little or no conventional weather data exist. Although interpretations from satellite cloud-image data are increasingly used in weather forecast preparation, it is difficult to identify in advance those storm systems that produce surges of heavy precipitation over land, especially between October and April.

At present, the regional Limited-Area Fine-Mesh Model (LFM) of the National Meteorological Center (NMC) predicts precipitation for the West Coast. However, as pointed out by Fawcett (1977), the absence of observations over the eastern Pacific and the failure to model correctly atmospheric convection and complicated terrain effects on the atmosphere make the model less accurate over the western United States than for other geographic areas. Weather forecasters, therefore, must still depend on personal insight and experience in conjunction with numerical guidance when forecasting precipitation. The output of the numerical prediction models is currently complemented by objective precipitation forecasts from the Model Output Statistics (MOS) technique and the map-type PoPs (Klein and Glahn, 1974; Rasch and MacDonald, 1975); however, precipitation in moderate and heavy amounts remains one of the most difficult weather variables to predict.

Passive microwave sensors carried on satellite platforms provide measurements inside extensive storm cloud systems that the visible and infrared radiometers cannot obtain. For example, the electrically scanning microwave radiometer (ESMR) and scanning microwave spectrometer (SCAMS) instruments on the NIMBUS 5 and 6 satellites have provided data directly related to precipitable water, cloud liquid water, and rainfall over the ocean. This information should be exploited in research related to the precipitation prediction problems and the hydrology of the Pacific West Coast States, since conditions antecedent to significant precipitation and those with which numerical prediction models must be initialized develop over the ocean.

This paper reports on the preliminary results of a research study that emphasizes the analysis and interpretation of data related to total precipitable water and nonprecipitating cloud liquid water obtained from NIMBUS–6 SCAMS.

Sixteen cyclonic storm situations in the northeastern Pacific Ocean that resulted in significant rainfall along the west coast of the United States during the winter season October 1975 through February 1976 are analyzed in terms of their distributions and amounts of total water vapor and liquid water, as obtained from SCAMS data. The water-substance analyses for each storm case are related to the distribution and amount of coastal precipitation observed during the subsequent time period when the storm system crosses the coastline. Concomitant precipitation predictions from the LFM are incorporated into the study also. The overall objective of the research is to explore techniques by which satellite microwave data over the ocean can be used to improve precipitation prediction for the Pacific West Coast states.

2. DATA ANALYSIS AND INTERPRETATION TECHNIQUE

Table 1 lists the 16 three-day periods for which storm cases over the northeastern Pacific Ocean were selected for analysis. In each case, the selected storm system moved eastward toward the West Coast.

The NIMBUS-6 SCAMS digital data tapes of vertically integrated water vapor and nonprecipitating cloud liquid water are used in the analyses. Two time periods of SCAMS data coverage (ascending and descending node) at intervals of 10 to 13 hours are available for each storm day.

Daily precipitation records were examined in conjunction with sequences of SMS-2 cloud images to determine the time period during which each selected storm system affected rainfall along the West Coast. For this time period (usually two to three successive days), rainfall observations at 27 coastal stations extending from Washington (48°N) to central California (34°N) were analyzed in terms of the latitude variation or distribution of coastal precipitation. This observed variation was then related to antecedent conditions of the storm's liquid water content over the ocean, as obtained from SCAMS.

The computer program used in analysis of the NIMBUS-6 SCAMS digital data and the coastal rainfall data has three major subroutines. One subroutine prints the satellite scan spot values for a given time period on a Mercator map extending from 30°N to 54°N latitude and 120°W to 168°W longitude. The second subroutine averages these data on a 1° mesh grid-point array (25 rows, 27 columns). For each time period, the third subroutine characterizes the storm (on the basis of the SCAMS data) in terms of the distribution of water vapor and liquid water as a function of latitude from north to south across the storm area.

Figures 1 and 2 illustrate the technique. Figure 1 shows the conditions of cloud liquid water associated with a major storm system over the ocean at 1045 GMT 7 Oct. 1975, and about 24 hours later, at 0915GMT 8 Oct. 1975. These

Table 1
Storm Cases in Northeastern Pacific Ocean Selected for Analysis

Case No.	Dates (PST)	Case No.	Dates (PST)
1	7 - 9 Oct 75	9	10 - 12 Dec 75
2	15 - 17 Oct 75	10	19 - 21 Dec 75
3	24 - 26 Oct 75	11	23 - 25 Dec 75
4	27 - 29 Oct 75	12	6 - 8 Jan 76
5	3 - 5 Nov 75	13	12 - 14 Jan 76
6	12 - 14 Nov 75	14	11 - 13 Feb 76
7	17 - 19 Nov 75	15	23 - 25 Feb 76
8	3 - 5 Dec 75	16	26 - 28 Feb 76

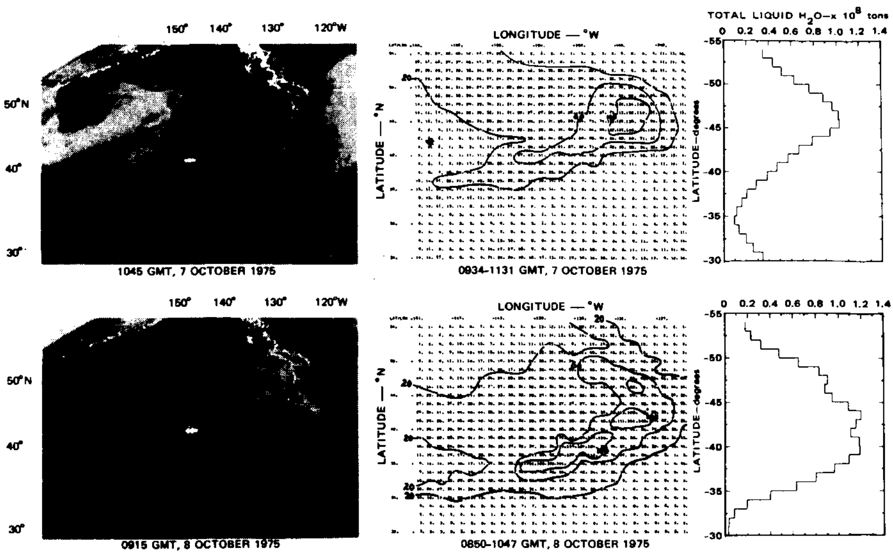

Fig. 1–SMS–2 infrared cloud image (left frame) and analysis of Nimbus–6 SCAMS cloud liquid water content (middle frame, units of mg/cm^2) for storm system at 1045GMT, 7 October 1975, and 24 hours later at 0915GMT, 8 October. Characteristic profiles of liquid water (right frames) are used to extract information on coastal rainfall distribution.

conditions are antecedent to the coastal rainfall shown in Figure 2, which indicates the observed distribution of 24-hour coastal rainfall for 8-10 Oct., and the 72-hour cumulative total for the three days. In Figure 1, the digital data of SCAMS liquid water (middle frames) are analyzed on the 1° mesh grid-point array. Each printed number represents the vertically integrated (columnar) liquid water, averaged over the grid square, expressed in units of 10^{-2} mm (mg/cm^2). The characteristic profiles of total liquid water (1° zonal strips across the grid-point area), expressed in units of 10^8 tons, are shown on the right side. Figure 1 shows that the SCAMS data:

- Have adequate quality for further analysis and interpretation.
- Reproduce the characteristic shape of the SMS–2 storm–cloud system.
- Reveal meaningful information on the space and time variations of cloud liquid water content not apparent in the image data.

Comparing the data of Figures 1 and 2 shows that the distribution of SCAMS cloud liquid water at about 0915GMT 8 Oct. has a maximum (>0.9 x 10^8 tons for 1° latitude intervals) between latitude 45°N and 37°N where coastal rainfall has a maximum on 9 Oct. and also in the three-day cumulative total. Thus, in this particular case, the distribution of the cloud liquid water content obtained from the NIMBUS–6 SCAMS contains information related to the distribution of coastal precipitation observed at a later time.

Analyses such as presented in Figures 1 and 2 were made for all 16 cases. Results of the research study are summarized below on the basis of representative case studies.

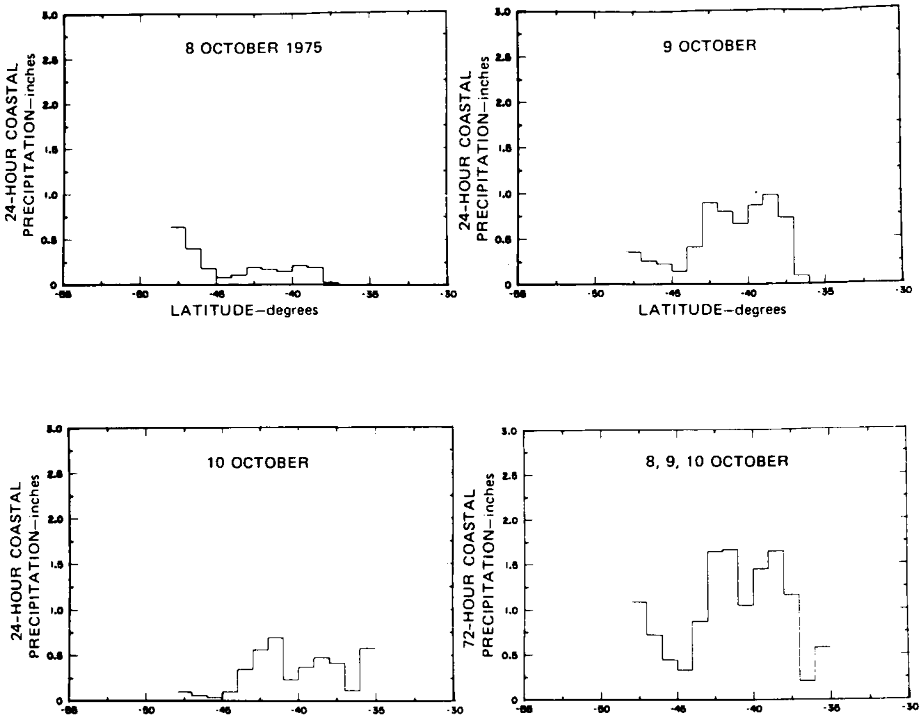

Fig. 2–Observed coastal rainfall distribution from Washington (48°N) to central California (34°N) during 3-day period in which storm system of Figure 1 affected weather conditions.

3. PRELIMINARY RESULTS

3.1 Discussion of Case Studies for December 1975

Table 2 summarizes the results for Cases 8 through 11 of Table 1. Two consecutive days of SCAMS data coverage are listed for each case. During these two days, the storm system moved eastward from about 145°W onto the West Coast. On each day, the area chosen for analysis is covered by SCAMS data from two consecutive descending-node (near local midnight) and two consecutive ascending-node (near local noon) NIMBUS–6 orbital passes. Each storm system is associated with approximately three consecutive days of coastal rainfall. At each listed time period t_0, the latitude (north to south) variation of SCAMS liquid water across the storm area is correlated with the distribution of the three-day (72-hour) cumulative coastal rainfall. The highest positive linear correlation coefficients are boxed: For these cases, the north-to-south distribution of storm-cloud liquid water at t_0 is quite similar to the distribution of the three-day total precipitation observed along the coast from Washington to central California at later time $t_0 + \Delta t$. The positive correlation increases when the two stations in Washington (Quillayute and Hoquiam), where rainfall is significantly affected by orography, are eliminated from the data sample.

Table 2
Linear Correlation Between SCAMS Liquid Water Distribution Over the Ocean at t_0 and Coastal 72-Hour Total Rainfall Distribution at $t_0 + \Delta t$

SCAMS Liquid Water Distribution			72-Hour Coastal Rainfall Distribution			
Case No.	Dates (Dec 75)	Time Period, t_0 (PST)	Δt (Hours)	Correlation Coefficient: With Washington: 48° - 34°N	Correlation Coefficient: Without Washington:* 46° - 34°N	Coastal Rainfall Dates (Dec 75)
8	3	0114–0312	96	+0.89	+0.88	4,5,6
		1130–1330	84	+0.90	$\boxed{+0.92}$	
	4	0033–0230	72	+0.69	+0.63	
		1047–1247	60	+0.28	+0.17	
9	10	0139–0333	96	+0.23	+0.27	11,12,13
		1201–1348	84	+0.39	+0.45	
	11	0052–0250	72	+0.63	$\boxed{+0.71}$	
		1107–1305	60	+0.47	+0.70	
10	20	0135–0332	72	-0.02	+0.15	20,21,22
		1151–1348	60	+0.34	+0.37	
	21	0051–0249	48	+0.62	$\boxed{+0.71}$	
		1107–1305	36	-0.54	-0.56	
11	24	0032–0228	96	+0.48	+0.03	25,26,27
		1233–1429	84	-0.41	-0.74	
	25	2347–0146	72	-0.61	-0.62	
		1150–1200	60	-0.10	$\boxed{+0.53}$	

*Boxed numbers indicate highest positive correlations, discussed in the text.

Figure 3 shows the information sets of the SCAMS cloud liquid water distribution over the ocean and the coastal precipitation distribution without the stations in Washington (46°N to 34°N) that correspond to the boxed correlations of Table 2. Table 2 shows that antecedent time periods (Δt) associated with the maximum (boxed) data correlations differ for each case, being 84 hours for Case 8 and 48 hours for Case 10. The reason is the difference in atmospheric circulation and storm movement.

The results for the storm cases examined in October and November 1975 showed that the distribution of the 72-hour cumulative coastal rainfall was highly correlated (linear correlation coefficients $>$ 0.75) with the distribution of storm liquid water content over the ocean at a time period exclusively 60 to 72 hours earlier. The January and February cases showed results similar to those of Table 2, with variable antecedent time periods. The analyses results are straightforward when storms systems move from west to east, and our grid area (25° latitude x 26° longitude) encloses only one system at a time as was the case in October and November (see Figure 1). For December, January, and February, however, two frontal-wave systems were frequently present within the area of analysis, and a certain degree of discrimination must be exercised to separate the liquid water distributions.

3.2 Discussion of the LFM Data

We requested and received forecasts (printouts) of the amount of LFM precipitation corresponding to Cases 1 and 3 (October 1975) and Cases 5 and 7 (November 1975). Forecast periods up to 36 hours are available. Forecasts for longer time periods

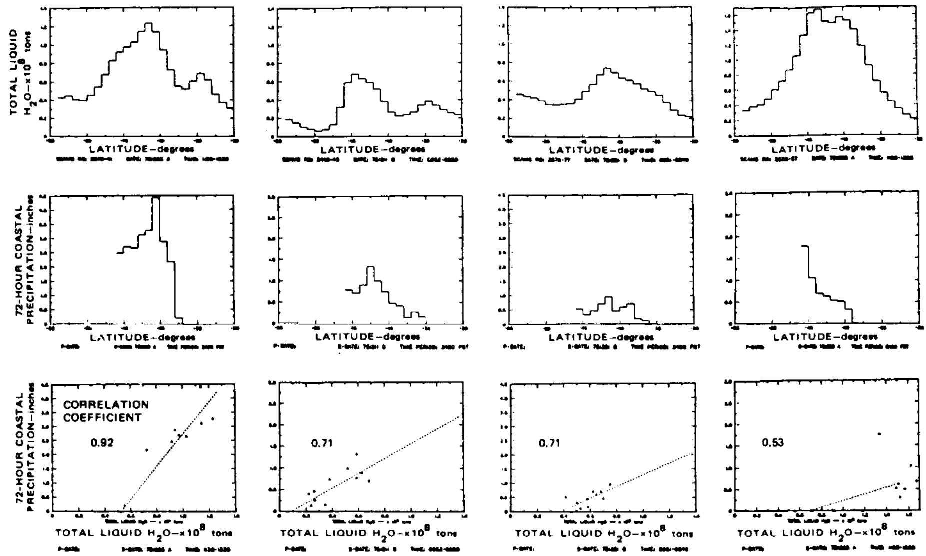

Fig. 3–Data sets of observed 72–hour coastal rainfall between 46°N and 34°N latitude, and of antecedent distribution of SCAMS liquid water over the ocean, that correspond to the high positive correlation coefficients of Table 2.

would have been preferable for comparison with the results of our October and November case studies, which showed high positive correlation between coastal rainfall distributions and the 60- to 72-hour antecedent SCAMS liquid water distributions over the ocean. From the available data, the LFM 24–hour precipitation predictions were selected for further analysis and interpretation in the following manner:

- The case studies for which LFM data are available were re–examined for high positive correlation between the distributions of observed coastal rainfall and of SCAMS data over the ocean at antecedent time periods less than the 60 to 96 hours considered previously (see Δt values in Table 2).
- For these "short-term" periods, our computer program analyzed the corresponding data sets of observed rainfall over land and antecedent total vapor and liquid water abundance over the ocean in a similar fashion, as shown in Figures 2 and 3. However, the coastal distributions of LFM 24-hour precipitation prediction closest in validation time to the time of observed precipitation (2400 PST) were included in the correlation.
- Values of LFM rainfall prediction at each location of the 27 coastal stations used in the study were obtained from the printouts by linear interpolation. These values provided the input to our computer program for correlation with the microwave sensor data.

An analysis sample is summarized in Figure 4 for Case 3 (25-27 Oct. 75). Available LFM 24-hour precipitation predictions, valid 1545 PST 25 Oct. and 0345 PST 26 Oct., are related to observed rainfall based on a midnight (2400 PST) observation time. In general, the distributions of SCAMS liquid water show a more

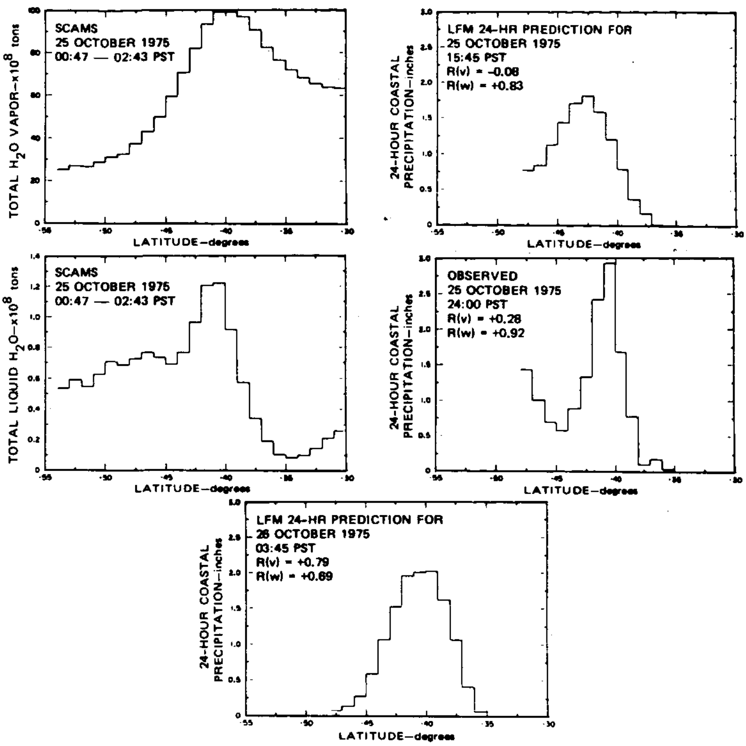

Fig. 4–Comparison between latitude variation of SCAMS-analyzed total vapor and liquid water abundance over the ocean, and the observed and LFM-predicted 24-hour cumulative coastal rainfall about 24 hours later. Degree of linear correlation of the latitude variation between the precipitation data sets and the SCAMS data is indicated by R(v) and R(w) for total vapor and liquid water, respectively (data refer to Case 3).

obvious relation than do the distributions of total vapor to observed and LFM-predicted rainfall at a later time. Most likely, total vapor would relate better if a background component of atmospheric water vapor, which results from the general increase in atmospheric temperature with decreasing latitude, were subtracted.

In Figure 4, the SCAMS liquid water distributions of 0047-0243 PST 25 Oct. 1975, shows a high positive correlation [R(w) = +0.92] with the distribution of coastal rainfall observed 24 hours later, and a somewhat lower positive correlation with the distributions of LFM-predicted rainfall about 15 hours later [R(w) = +0.83] and 27 hours later [R(w) = +0.69].

Analyses similar to those of Figure 4 were made for Cases 1, 5, and 7, and will be continued for other cases to explore the input of passive microwave remote sensor measurements of cloud liquid water to numerical prediction models.

4. CONCLUSIONS

Comparison and interpretation of information sets obtained from NIMBUS–6 passive microwave sensor data over the ocean and from precipitation records over land indicate that rainfall along the coast of Oregon and California is related to antecedent conditions of remotely sensed storm-cloud liquid water content over the northeastern Pacific Ocean. Specifically, for each case examined, the distribution of SCAMS cloud liquid water across the storm system over the ocean foreshadows the relative distribution of coastal rainfall at a later time. Also, the antecedent SCAMS liquid water distributions over the ocean generally show a somewhat higher positive correlation with the observed coastal rainfall distributions than with the LFM-predicted distributions. This may indicate that the passive microwave remote sensor measurements contain information that can enhance the LFM predictions of coastal rainfall distribution.

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