J1.2 **RADAR APPLICATIONS TO WINTER-SEASON WEST COAST RESEARCH AND FORECASTING IN THE CALJET AND PACJET EXPERIMENTS**

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1. Introduction

The California Land-falling Jets Experiment (CALJET) was conducted in the winter of 1997/98 based on the need to improve observations, understanding, and prediction of land-falling winter storms that strike the U. S. West Coast. Because of the importance of the low-level jet (LLJ) within the cyclone warm sectors in terms of air-sea exchange, orographic precipitation and flood forecasting, the LLJ was selected as a focus for study. Based on the CALJET experience it was recommended that a follow-on effort be mounted to address not only storms along the California coast, but also along the Oregon and Washington coasts. The joint scientific, forecaster and forecast-user workshops following CALJET refined this recommendation and led to the creation of the Pacific Land-falling Jets Experiment (PACJET). In addition to the geographical expansion, the planning process recommended a move from the traditional episodic "field experiment" mode (which served the scientists well, but left forecasters and users without the real-time data they had found useful during the field phase), into an ongoing "testbed" approach that could best serve the science, forecasting, and forecast-user communities. PACJET's field efforts have now been conducted in the winters of 2000/01, 2001/02 and 2002/03.

The goals and priorities of CALJET were motivated partly by the U. S. Weather Research Program's (USWRP) goals for improved quantitative precipitation forecasting (QPF) and a recognition of the vulnerability of the U. S. West Coast to these destructive storms. Both scientific and forecasting objectives were to be addressed and observing system capabilities and limitations quantified. This presentation will briefly highlight those efforts and results within CALJET and PACJET that have involved the development, deployment and/or evaluation of radar-based observations in the coastal zone. This summary is organized around radar types: boundary layer wind profilers (BLWP), the "S-Prof" extended-dynamic-range vertically pointing S-band radar, and scanning radars (NEXRAD, P-3 tail radar, and the X-band "Hydro" radar). Both the field work and analysis efforts have been accomplished through collaborations involving NOAA, Navy, and university researchers and forecasters, as well as forecast users from the marine, emergency management, flood control, energy and other communities. (Please see http://www.etl.noaa.gov/programs/2003/pacjet/ for lists of key participants, science and forecast applications efforts, and other background information, as well as links to the CALJET and earlier PACJET summaries).

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2. Boundary Layer Wind Profilers

Partly due to the importance of processes focused in the lowest 2 km of the atmosphere, i.e., orographic blocking, the LLJ, and air-sea interaction, a major element of CALJET and PACJET has involved the use of existing BLWPs and the deployment of up to 12 additional BLWPs from NOAA's Environmental Technology Laboratory. These sensors have proven useful for both research and nowcasting. Selected results from these data include:

- Documentation of the statistical relationship between upslope flow and rain in coastal California mountains. Analysis of a full winter season at three coastal locations showed that up to 50% of the hour-to-hour variability in coastal mountain rain rates was explained by hour-to-hour variability in the upslope wind speed near the altitude of the LLJ. It also showed that the orographic precipitation efficiency increased by 50% when a LLJ was present and that blocking increased rainfall at the coast. (Neiman et al. 2002a, 2002b).
- In addition to the importance of wind speed, the role of wind direction in the LLJ was highlighted in a study of local variations in flood severity during an extreme storm that caused record flooding on a lightly populated watershed. It was found that a lesser flood occurred on an adjacent watershed that was heavily populated, and that this watershed had been protected by a rain shadow within the cyclone warm sector. A slight (10°) shift in wind direction of the LLJ was shown to control the position of a dividing streamline emanating from the lateral location of a key mountain range in this highly complex terrain (Ralph et al. 2003). Similar magnitude changes in mean LLJ wind direction using

reanalysis data were found to be correlated with the phase of the El Niño-Southern Oscillation (ENSO) during major floods on this and nearby watersheds. An analysis of flood frequency on these and other coastal California watersheds as a function of ENSO revealed a similar relationship, with verification using wind profiler data from the entire 1997/98 winter season (Andrews et al. 2003). An even greater sensitivity to low-level wind direction was found by Nuss and Miller (2001) in an idealized modeling study, where 1° changes in large-scale wind direction caused key changes in mountain waves.

- Comparisons between island-mounted BLWPs and those on the coast documented the occurrence and vertical structure of blocking by the coastal mountains. A detailed case study also revealed that this blocked flow remained in place while a leading cold front moved overhead, thus creating a coastal frontal occlusion until the secondary cold front with colder postfrontal conditions swept out the blocked flow. (Neiman et al. 2003).
- Based on local forecasters' request for snow-level monitoring, an algorithm was developed to automatically diagnose the bright-band snow level (BBSL) using radial velocity and signal-to-noise ratio data from the vertically pointing beam of each of ETL's BLWPs. The technique was tested against rawinsondes in PACJET-2001 and was later evaluated by forecasters using prototype web-based real-time products (White et al. 2002). The response of the National Weather Service (NWS) Weather Forecast Offices (WFO) and River Forecast Centers (RFC) has been very positive. In fact, feedback gathered during these deployments indicated these observations were positively impacting the NWS Watch -Warning program. For example, the prototype product revealed a significant error in the predicted 4000 ft snow level for a land-falling storm on 7 February 2002. As the storm reached the coast, the BLWP at Newport, Oregon showed the BBSL was at 2000 ft, well below the major mountain passes. Based on these coastal observations, the forecast from the Portland, OR NWS WFO was upgraded from a "Snow Advisory" to a "Winter Storm Warning" that later verified. (Nance et al., to be presented at this conference). Based on the success of this test in the west, a similar demonstration study was conducted in New England during the winter of 2002/03, where detecting the transition from snow to freezing rain was a focus.

3. The S-Prof vertically pointing S-band radar with extended dynamic range

The first deployment of the S-Prof radar, which was developed at NOAA/ETL, was for CALJET in December 1997. Its purpose was to study the shallow precipitation process that was confounding the ability of NEXRAD to adequately detect numerous critical storms that appeared to have little or no echo at mid tropospheric altitudes. To make the radar even more effective for this purpose, a novel approach was developed that reduced receiver saturation in moderate to heavy precipitation (White et al. 2000). This allowed for an extended dynamic range of 96 dB, which has been used to document the shallow rain process and to quantify the capabilities and limitations of NEXRAD with respect to this process. Selected results from these data include:

- The first demonstration of the new "extended dynamic range" vertically pointing S-Prof radar (White et al. 2000) was accomplished during CALJET. This included the use of a "coupler" to introduce 30 dB of attenuation during one of 3 modes of operation, and use of pulse coding in another mode. A 96 dB dynamic range was achieved with vertical resolutions from 45-420 m, and max heights of ~10 km. The radar operated successfully unattended for several months, thereby keeping down the deployment cost.
- Data were collected from the entire winter deployment of 1997/98 at Cazadero, CA, a coastal mountain site at 500 m MSL. White et al. (2003) developed an algorithm to distinguish periods of rainfall characterized by the presence or absence of a radar bright band. It was found that non-bright-band rain (NBB rain) could cause rain rates in excess of 15 mm/h, and accounted for roughly 25% of the entire season's 1841 mm of rain at that site. NBB rain was shown to have much weaker reflectivities and fall velocities compared to bright band rain, for the same rain rates.
- The ten largest rain-producing storms observed at Cazadero during the 1997/98 winter were examined to determine the variability of precipitation characteristics as a function of synoptic regime. How these characteristics differed in the lee of the coastal mountains was also studied. S-Prof, BLWPs, NEXRAD, balloon soundings and surface meteorological data were used. At Cazadero, the warm frontal regimes of landfalling storm systems produced the largest amount and longest duration of precipitation, with an average rate of 6.7 mm/hr. The most intense precipitation occurred during cold frontal

regimes, with an average rate of 11.3 mm/hr. The two levels of most rapid precipitation growth occurred around the -15 C level and just above the melting level. Comparison with the well known Marshall-Palmer Z-R relationship suggested the presence of larger numbers of smaller raindrops, especially during the warm frontal and warm sector regimes when a large amount of precipitation was associated with growth below the melting level, suggestive of a collision-coalesence process. In the lee of the coastal mountains, near Sacramento, there was on average only one-sixth the amount of precipitation that fell in the coastal mountains to the west. Weaker echoes and a somewhat lower bright-band were found in the lee, as well as a closer match to the Marshall-Palmer relation.(Kingsmill et al., to be presented at this conference).

- Following the successful deployment of S-Prof for CALJET, it was then deployed again for PACJET 2000/01, 2001/02, and 2002/03, as well as for the IMPROVE-II experiment in late 2001. These deployments have revealed that the NBB rain process also occurred at sites on the west slopes of the Sierra Nevada and Cascade Mountain ranges.
- A key characteristic of NBB rain is its shallow nature. The season-long composite from Cazadero showed very little echo above 3.5 km MSL. This was shown to present a fundamental detection problem for NEXRAD due to either blockage of the radar beam for sites located in valleys, or due to overshooting of the radar beam from mountain sites at ranges exceeding roughly 50 km (White et al. 2003).

4. Scanning radar studies

Although much was gained from the vertically pointing radars described above, much was also accomplished through use of scanning radars, both the operational NEXRAD radars and research radars. CALJET and PACJET utilized both the tail Doppler and belly radars on the NOAA P-3 research aircraft in 1997/98, 2000/01 and 2001/02, as well as a ground-based polarimetric scanning radar (NOAA/ETL's "Hydro radar") in 2002/03. The following lists selected results from scanning radar studies.

- A study (Ralph et al. 2003) of a severe flood revealed that the quantitative precipitation estimates (QPE) were misleading in the positioning of a critical area of heavy orographic rainfall. The stream gauges and rain gauges clearly showed that the major rain fell in the Pescadero Creek watershed, while NEXRAD QPE showed it in the adjacent, heavily populated, San Lorenzo Creek watershed. It was determined that strong winds (>25 m/s) and likely small fall velocities led to the advection of the hydrometeors by about 5 km to a position just over the crest of the ridge separating the two watersheds. Thus it was concluded that accurate QPE in these important storms must account for hydrometeor drift between the radar beam's altitude and the ground.
- A key challenge in coastal storm prediction is the lack of significant offshore radar coverage by NEXRAD. Although the radars do scan offshore in places, the radar beams are usually well above the region of active weather important for nowcasting. For example, the LLJ and narrow cold frontal rainbands (NCFRs) are both usually located below 2 km MSL, while the radar beams are much higher than this. Interactions with forecasters led to the development of a strategy to use the P-3 tail Doppler and belly radars to target areas of potentially severe weather outside the range of coastal NEXRAD radars. This idea was tested successfully on 25 January 2001 during PACJET, after a major upgrade to the satellite data transmission capabilities of the P-3 and the creation of an NWS-manned operations center on the ground. A severe NCFR approaching the coast was detected by the P-3 based on numerical model and satellite guidance. The severity of the storm was documented through the tail radar detection of severe storm structure, the measurement of hurricane force LLJ winds, and other indications. These data were communicated to the PACJET operations center where forecasters used this information as a basis for issuing a severe thunderstorm watch for San Francisco. This forecast provided an unprecedented 4-h lead time before the storm shut down SFO airport. Emergency managers and others in the region credited this lead time with helping them prepare for the power outages, traffic problems etc. that ensued, and thus successfully demonstrated the "NEXRAD-in-the-Sky" coastal storm surveillance concept.
- Studies of the dynamical processes modulating the gap-core structure of NCFRs was carried out by Jorgensen et al. (2003) using P-3 tail radar data and in situ data to diagnose the fine-scale kinematic structure of NCFR gaps and cores. These data showed a link between the systematic structural variations of the NCFR gaps and cores and the vorticity balances that modulate the upright versus slanted orientation of the convection. These results will present

forecasters with a dynamically based conceptual model with which to anticipate structural variations of convection along the NCFR.

- Based on several results from the previous years, PACJET-2003 focused on deployment of a coastal X-band scanning radar with polarimetric capabilities. The deployment, which was on the coast near the mouth of the flood-prone Russian River, was aimed at both research and testing the use for a future operational forecasting objective. The polarimetric capability was combined with soundings, S-Prof data from 2 sites and 2 disdrometers to study the microphysical properties of the NBB rain described earlier. Several developments were tested that are required for a future test of its capability to fill a key gap in NEXRAD radar coastal coverage.

5. Summary

This report was intended as a brief summary of selected results to date from the use of radars in studies of coastal meteorology conducted during the CALJET and PACJET experiments. The full research papers that are summarized here are listed below. These papers represent a spectrum of studies addressing physical processes, evaluation of observing system capabilities and limitations, and forecast technique development. Analysis of data collected to date is ongoing, and planning for future PACJET deployments are underway. The data are available to any parties interested in their use, and input is welcome in terms of planning for future field efforts.

<u>References (formal publications from CALJET/PACJET that involve use of radar in coastal studies or prediction, and are in print or in review as of 1 June 2003)</u>:

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