Improving the Understanding and Prediction of Heavy Rain in Land-falling Pacific Winter Storms: The CALJET and PACJET Experiments

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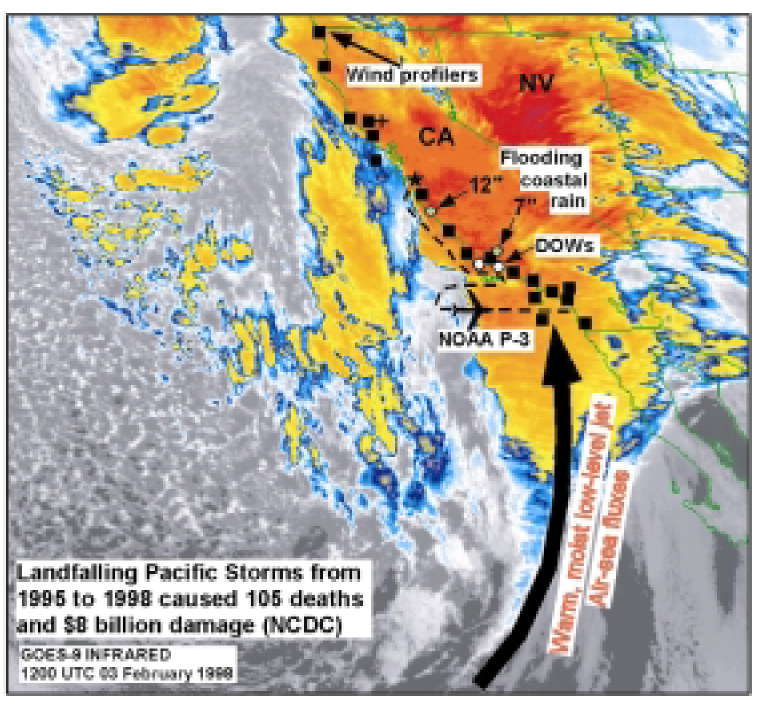
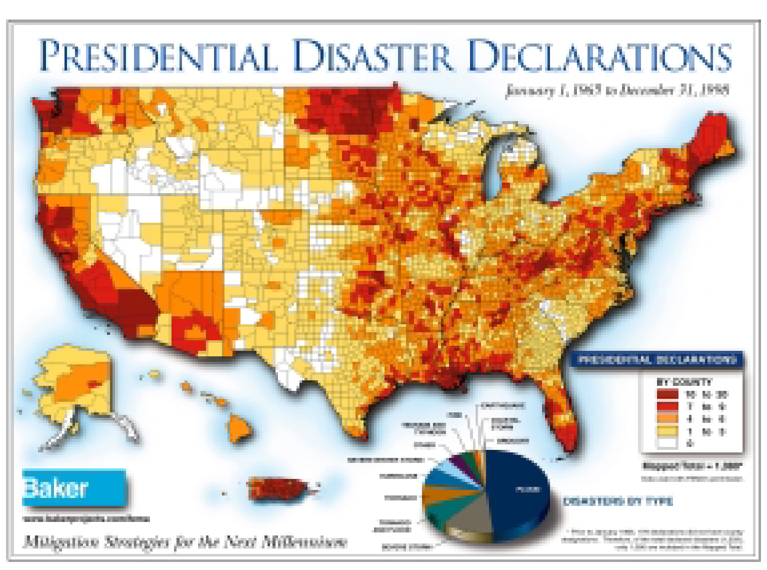
I. THE CHALLENGE OF WEST-COAST WINTER STORMS

- **Major storms strike the West Coast each winter with hurricane force winds and flooding rains and, yet, are difficult to predict partially due to their origin over the expansive data-sparse Pacific Ocean. The low-level jet within these storms plays a key role and, yet, is poorly observed offshore and along the coast.**
- **Flooding is the most frequent problem faced by emergency managers in the region.**
- **Accurate mesoscale quantitative precipitation forecasts (QPF) are needed to improve numerous decisions affecting emergency response, reservoir management and water supply in the semi-arid West.**



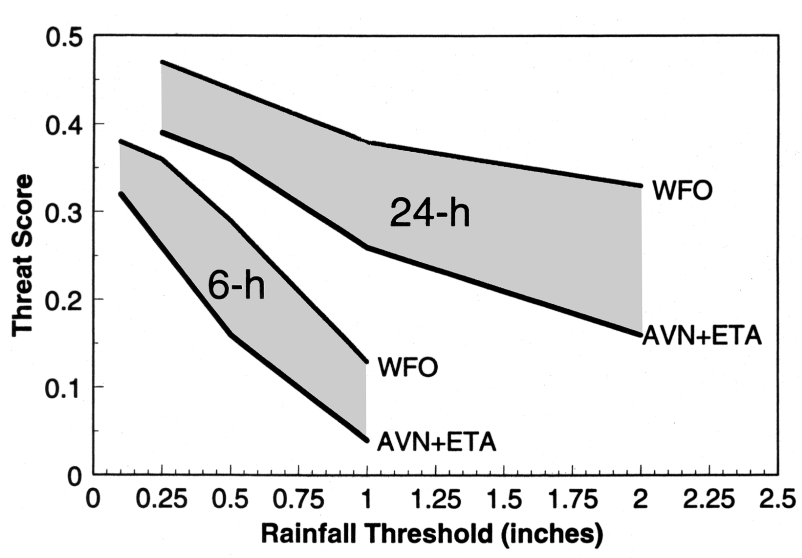
Selected characteristics of land-falling Pacific winter storms

- **Hurricane force winds**
- **Over 12 inches of rain in 24 hours**
- **Over 40 inches in 7 days**
- **Complex structure (e.g., multiple fronts, mesoscale rainbands)**
- **The figure shows a major land-falling storm during CALJET in 1998 with 100 mph surface winds and 12 inches of rain in 24 hours (up to 19 inches in 48 hours). The low-level jet, the NOAA P-3 aircraft, and coastal wind profilers are highlighted.**



Examples of the impacts of West Coast storms

- **The West Coast is an area that has received many presidential disaster declarations.**
- **Storms cause loss of life and property in the West Coast states at an annually averaged rate comparable to the impacts of earthquakes in this earthquake prone region (roughly 10 lives lost and $1 billion damage annually).**

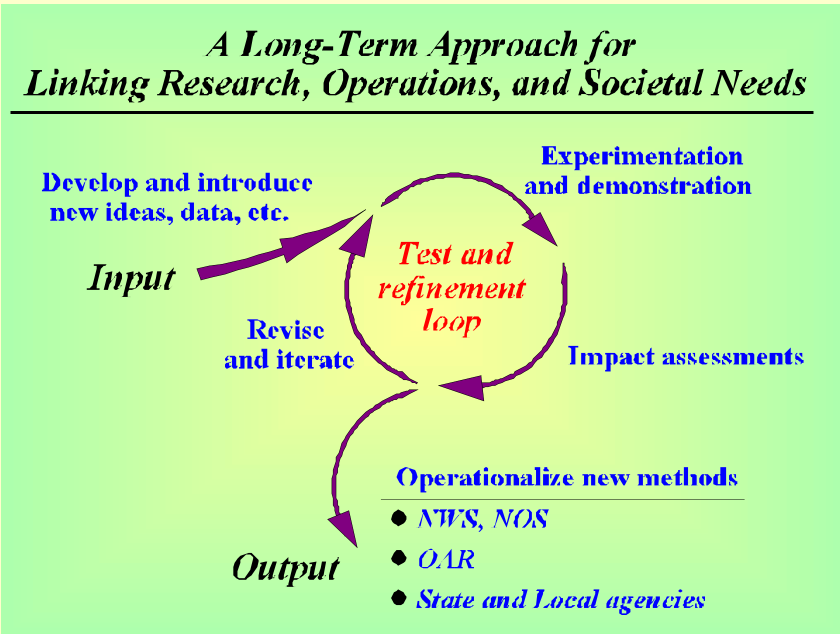


Assessment of model-based and human quantitative precipitation forecasts during the 1998-99 winter season at the California-Nevada River Forecast Center (from NWS report on the QPF process)

- **QPF produced by humans consistently scores above model QPF.**
- **Accuracy decreases for higher (and more important) rain rates.**
- **QPF for 6-hour accumulation is much less accurate than for 24-hour accumulation, largely due to timing errors and, yet, the NWS operational stream-flow model requires 6-hour QPF.**
- **Improvements in QPF will require a long-term, sustained effort.**

II. LINKING RESEARCH, OPERATIONS & FORECAST USERS TO ADDRESS WEST-COAST WINTER STORMS

A. A Philosophy for Bridging Research and Operations



An illustration of key components of CALJET and PACJET's approach to developing new applications of observing systems, models, and physical understanding, and generally for development of new forecasting techniques. At the core is a feedback loop that tests and refines new ideas in the crucible of real-world situations. It integrates basic and applied research approaches with forecasting experience to tackle key problems in sectors of society where weather predictions influence decisions involving risk management or resource management.

B. The CALJET Experience in 1997-98

- In 1996 interactions between NOAA Research and Operations identified short-term flood forecasting in land-falling winter storms as a key West-Coast forecast problem.
- The 1997-98 CALJET experiment was conducted to explore the optimal observing system for West Coast flood forecasting and to study the physical processes involved.
- CALJET influenced not only numerical weather prediction forecasts through assimilation of new data, but also explored how data could aid forecasters directly.
- Support for CALJET grew when the strong El Niño of that year raised the threat of major flooding in California, where CALJET was planning operations.
- Real-time data was successfully incorporated into the Monterey Weather Forecast Office and into the AVN operational numerical model.
- A critical flash flood forecast was issued with 6-hour lead time due largely to P-3 aircraft observations of a low-level jet of 80 knots in an approaching storm.
- The addition of dropsonde data into the AVN model based on targeted areas provided by NCEP improved 24-hour forecast accuracy in 5 out of 5 cases.
- CALJET was extended by one month based on requests from the state and local emergency managers who felt that CALJET data helped them save lives and property.

C. Building on CALJET

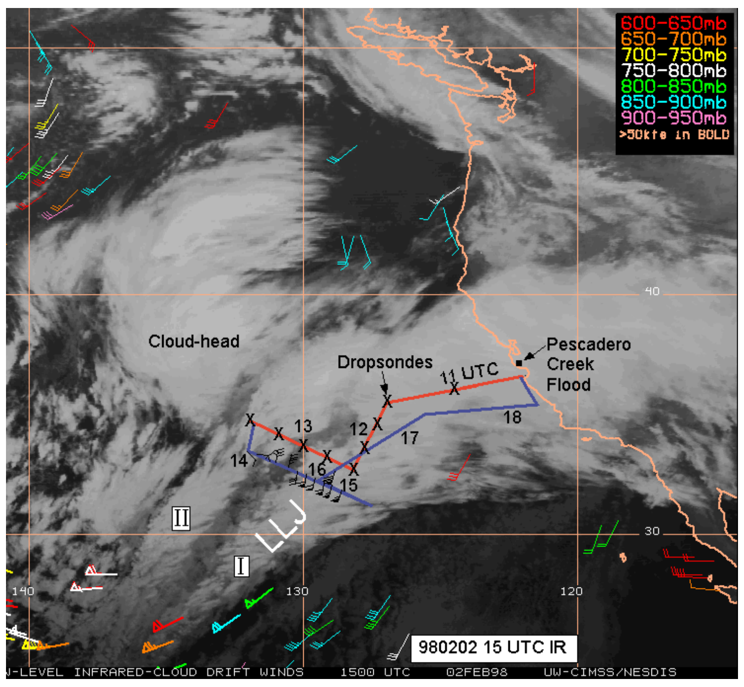
- A workshop was conducted in September 1999 at the Naval Postgraduate School in Monterey, CA that brought together 40 people from the research, operational and forecast user communities to discuss lessons from CALJET and possibilities for future efforts. A summary report is available.
- Groups who participated in the PACJET Planning Workshop of September 1999:
  - <u>Forecast community</u>
    - NOAA/NWS/National Centers for Environmental Prediction (HPC, EMC, MPC)
    - NOAA/NWS/Western Region (7 Weather Forecast Offices and a River Forecast Center)
    - Navy (San Diego)
    - Television Broadcasting
  - <u>Forecast user community</u>
    - Flood Control-Water Supply (CA Department of Water Resources, Army Corps of Engineers)
    - Emergency Management (CA Governor's Office of Emergency Services, San Mateo County Sheriff)
    - Commercial Fishing (Pacific Coast Federation of Fishermen's Associations)
  - <u>Research community</u>
    - NOAA Research (Environmental Technology Lab., National Sever Storms Lab., Forecast Systems Lab., Aircraft Operations Center)
    - NOAA/NESDIS (CIMMS-University of Wisconsin, CIRA-Colorado State University)
    - Navy (Naval Postgraduate School, Naval Research Lab.)
    - Universities (University of California, University of Colorado, University of Nevada)
- Recommendations from the 1999 PACJET Planning Workshop:
  - improve short-term (0-24 hour) mesoscale weather prediction and warnings; QPF emphasis
  - develop and use new data for both nowcasting and NWP
  - test prototype measurement strategies more thoroughly and explore new observing platforms
  - extend domain to include the Pacific Northwest
  - focus on key aspects of storms
  - coordinate with other observational enhancements in the Pacific
  - assess data impact in near-real time
  - explore forecast failures
  - explore the use of mesoscale ensembles
  - disseminate experimental data to operational community and to key forecast users
  - train key personnel on new types of data and on PACJET operations
  - develop modules to facilitate data use by emergency managers
  - establish a process to infuse the most useful new technologies into operations

D. Research-Operations Interactions in PACJET-2001

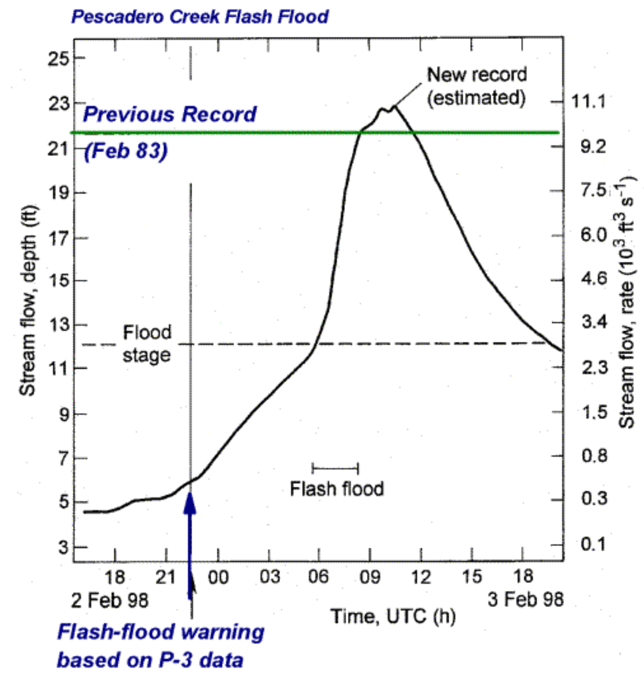
- Prototype observations introduced into operations on an experimental basis during PACJET 2001:
  - P-3 airborne radar data, flight-level data and dropsonde data from NOAA/Aircraft Operations Center
  - coastal and inland profilers from NOAA/ETL, including real-time melting-level detection
  - 4 GPS integrated precipitable water vapor sites from NOAA/FSL
  - a new GOES rapid scan technique for improving GOES winds coverage from CIMSS
  - AMSU satellite-derived height and wind fields from CIRA
- NOAA/FSL ran and disseminated a West Coast version of the RUC model that extended far offshore.
  - impacts of assimilating the new data into the RUC model will be assessed using parallel runs without the new data
- Forecaster reactions to the new data and modeling were gathered.
- Each day, two or three NWS forecasters, representing 9 NWS Forecast Offices and NCEP/HPC, participated in PACJET operations by presenting detailed forecasts and by providing feedback on new ideas, data, etc. in real time.

III. SELECTED LESSONS FROM THE 1997-98 CALIFORNIA LAND-FALLING JETS EXPERIMENT (CALJET)

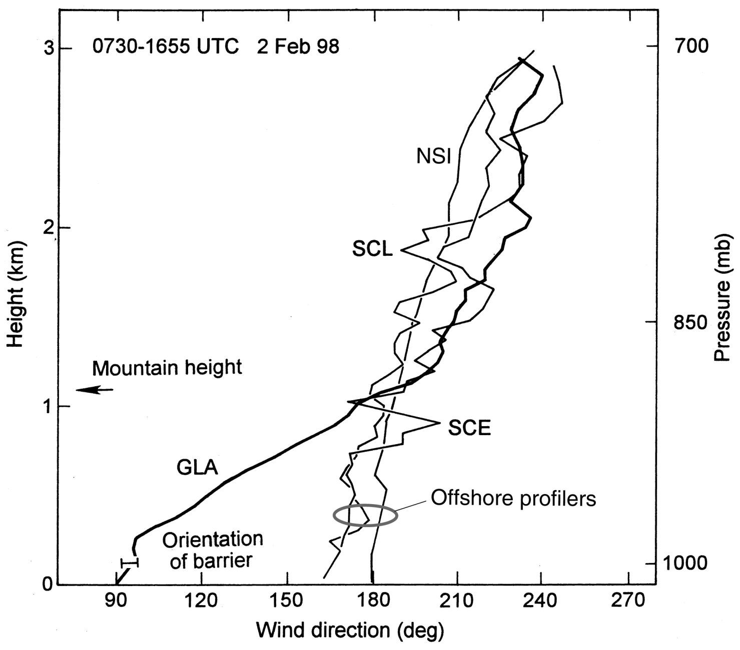
A. Direct forecaster use of offshore aircraft data can aid in issuance of flood warnings.



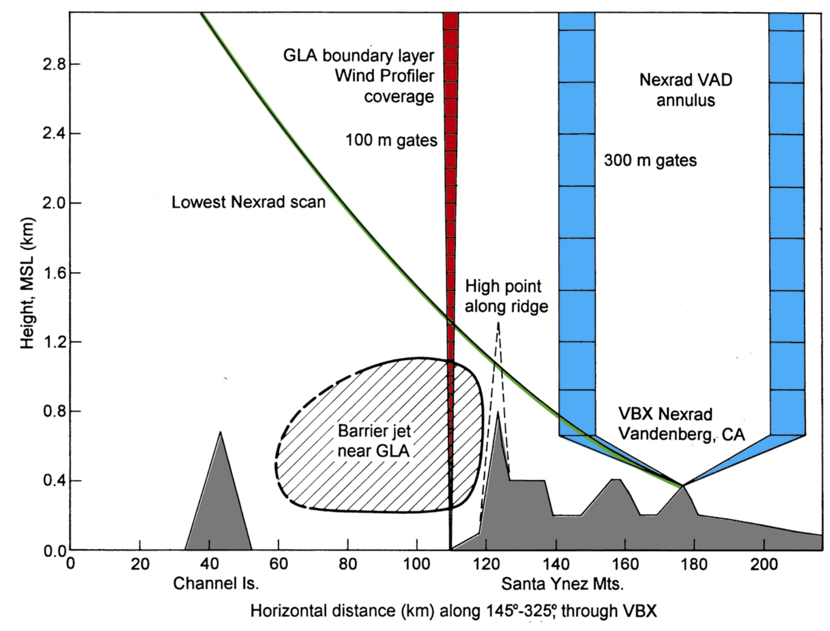
During CALJET, NOAA's P-3 research aircraft provided the operational forecast community with offshore data to assist in short-term forecasting. The infrared satellite image (left) shows the complex cloud structure associated with a developing storm on 2 Feb 98 that created major flooding when it reached the coast. The P-3 observed hurricane-force winds within the moist low-level jet. This measurement was reported to the National Weather Service Forecast Office in Monterey, CA, which then issued a flash flood warning that gave a 6-hour lead time for a record-breaking flash flood on Pescadero Creek (right). PACJET is designed partly to determine the representativeness of this powerful anecdote.



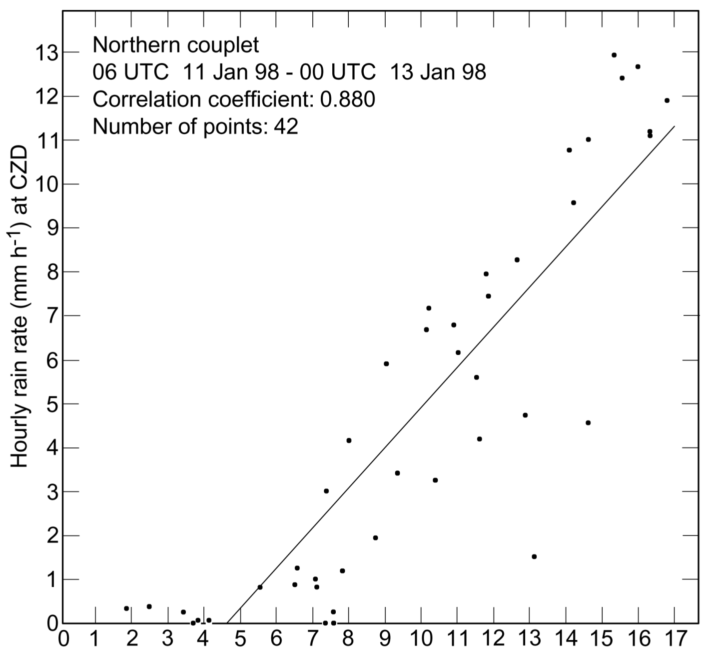
B. Coastal wind profilers can fill gap between surface and NEXRAD data.



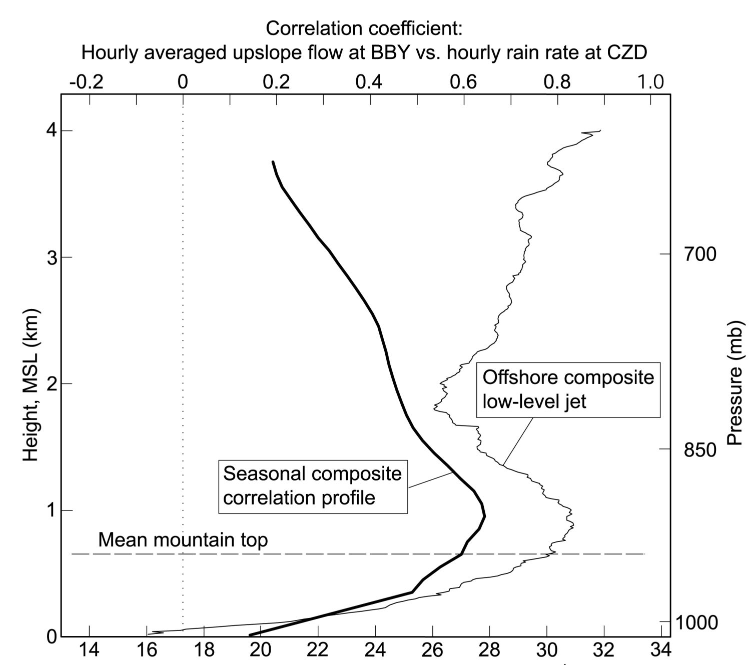
The barrier jet is an important terrain-induced wind phenomenon that affects weather-sensitive activities in California's coastal zone where many people live, international airports reside, and much commerce takes place. This shallow jet is directed roughly parallel to the mountain barrier that generates it. The operational NEXRAD radars often scan over the top of this jet and surface instruments are typically beneath it, but this gap can be filled by well-placed coastal wind profilers (left and right). This NEXRAD-wind profiler hybrid observing system takes advantage of the strengths of each radar system.



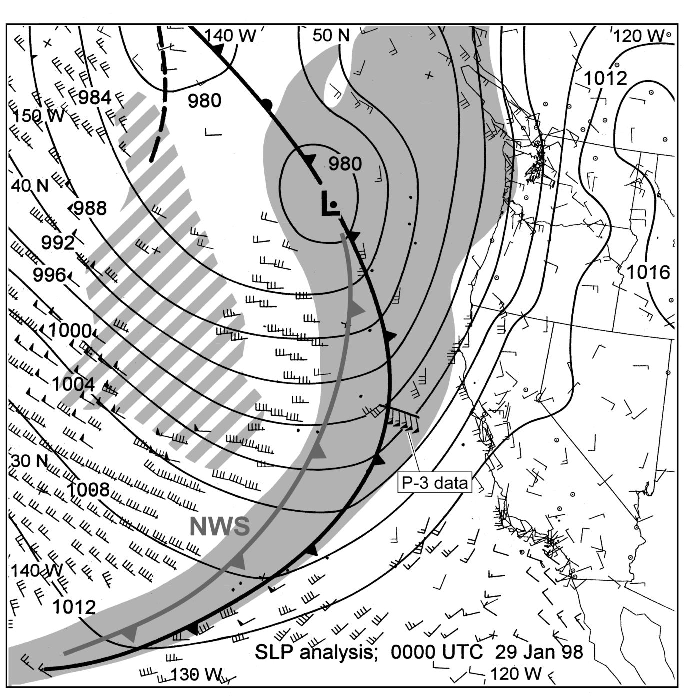
C. Coastal rain rates are strongly controlled by the low-level jet.



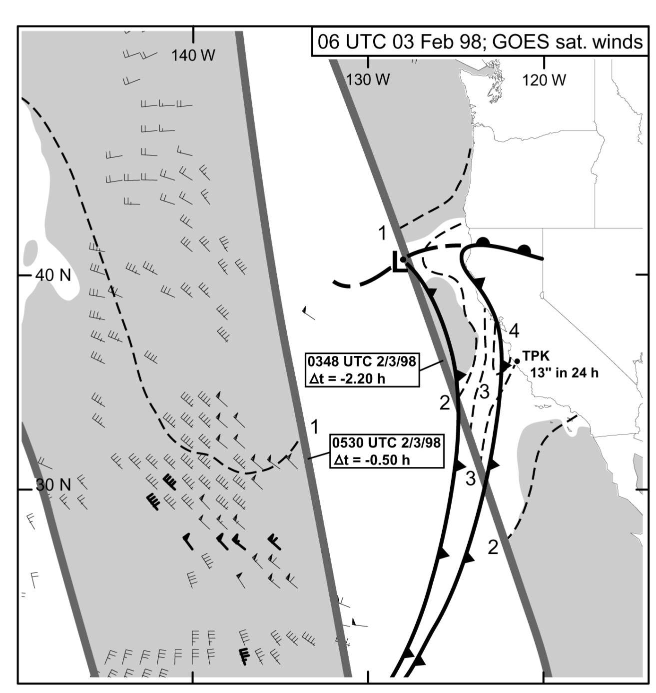
A direct relationship was documented between the magnitude of the upslope flow measured by coastal wind profilers and the magnitude of the rain rate in the coastal mountains (left). The layer of upslope flow that optimally controls orographic rainfall is situated near mountain top (right). NOAA's P-3 aircraft allowed us to explore the connection between the low-level jet (LLJ) over the open ocean and orographic rainfall in the coastal mountains. It was found that the strength and direction of flow in the LLJ significantly impact the orographic rainfall in the coastal mountains. A composite wind-speed profile over the ocean contains a LLJ at the height of the winter-season correlation maximum (right).



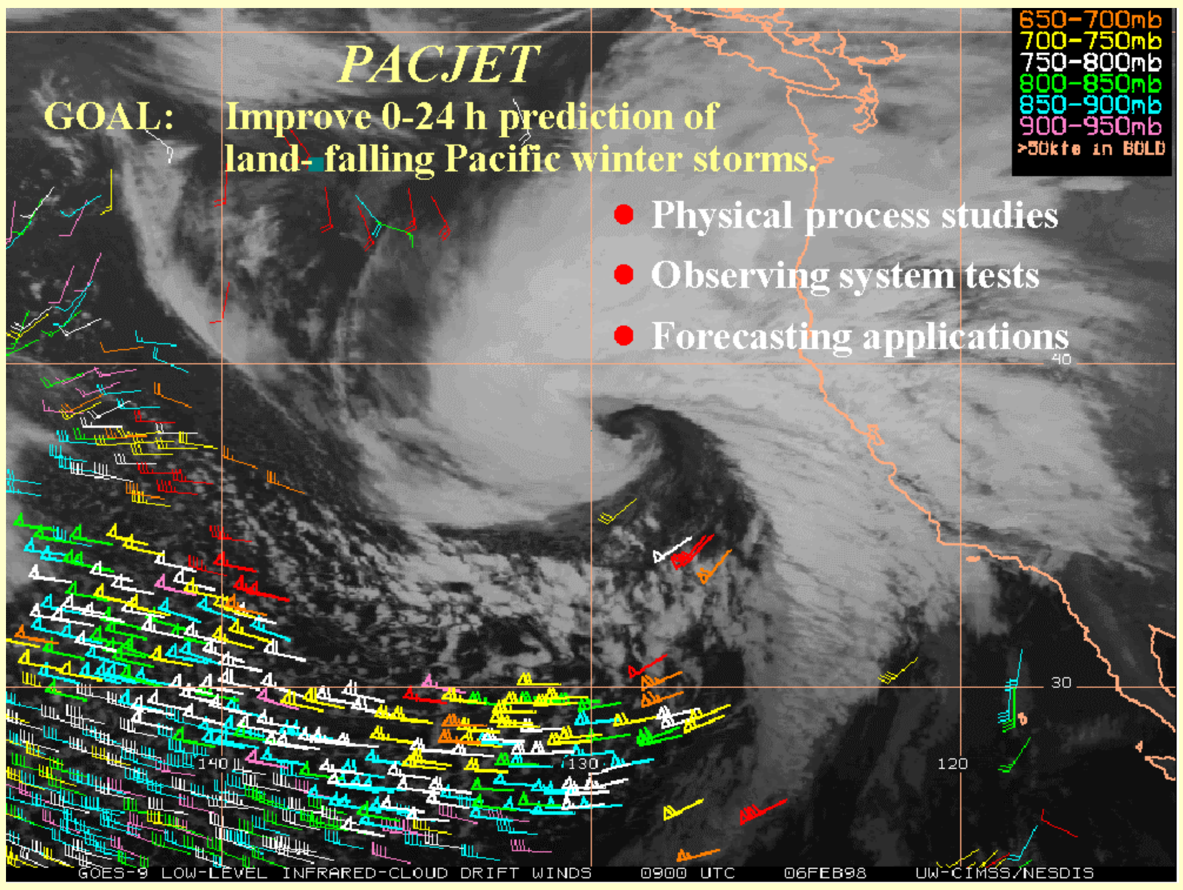
D. New satellites and satellite techniques help fill gaps, but key limitations still remain.



The GOES and POES satellites each offer unique attributes in their observing capabilities. Limitations do exist, however. For example, the GOES imagery is often unable to provide low-level, cloud-track winds near the front or pinpoint the location of the cold front at low levels due to the presence of the comma tail's broad high-cloud coverage (left; solid gray shading). The POES SSM/I provides surface wind-speed measurements over the open ocean but surface wind speed cannot be retrieved in regions of large cloud liquid water (right; gray shading indicates where SSM/I surface winds are available from SSM/I overpasses within ± 3 h of 06 UTC 3 Feb 98, dashed contours are SSM/I integrated precipatable water vapor in cm, wind barbs are from GOES).



IV. THE PACIFIC LAND-FALLING JETS EXPERIMENT (PACJET) - 2001 AND BEYOND
(see www.etl.noaa.gov/programs/pacjet for data examples and further background information)



__Overarching goal:__ *To develop and test methods to improve short-term (0-24 hour) forecasts of damaging weather on the U. S. West Coast in land-falling winter storms emerging from the data sparse Pacific Ocean.* **PACJET is designed to be a next step toward attaining this goal. It is envisioned as part of a long-term effort that combines a series of focused field experiments, analysis, development of new products and tools for operational forecasting, and exploration of physical processes that contribute to the linkage between seasonal-to-interannual climate variability (e.g., ENSO) and extreme coastal weather events.**

WHY? **Impacts of land-falling Pacific winter storms on an annual average are comparable to those of earthquakes. Yet, their prediction is hindered by the fact they develop over the data-sparse ocean. The human and economic costs of these storms have increased dramatically in recent years.**

WHEN? **Phase I: January to March 2001. Phase II: January to March 2002.**

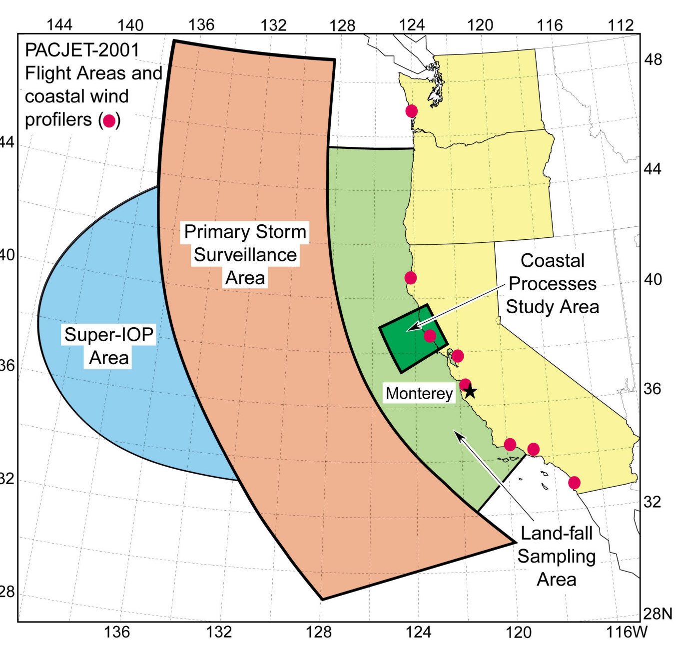
WHERE? **From 300 km inland to 1500 km offshore of the United States West Coast, from Southern California to Washington State.**

HOW? **Testing new ways to observe approaching storms; exploring better ways to use existing data; improving understanding of key physical processes; exploring linkages between climate variability and extreme weather; and working with forecasters to develop new forecasting tools.**

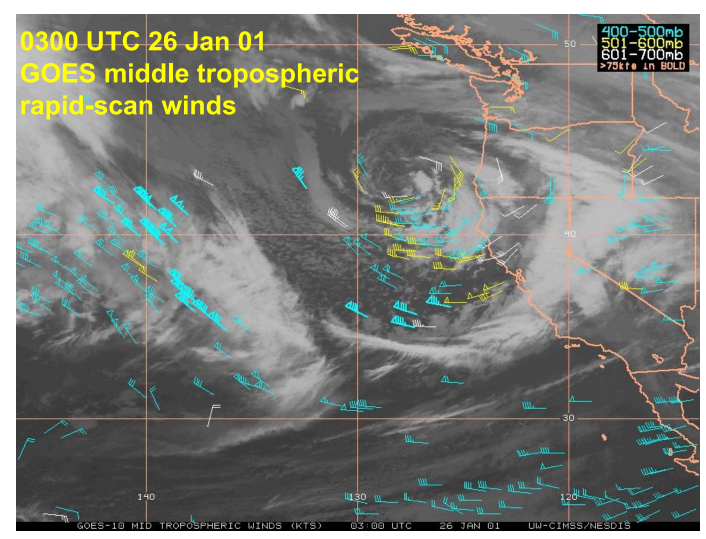
TOOLS? **NOAA P-3 research aircraft; NOAA research vessel Ronald H. Brown (Phase II); specialized satellite products and validation; coastal and inland wind profiler network; coastal processes study site (microphysics and fluxes); assimilation of data into operational forecast models; and expanded RUC domain extending 1000 km offshore.**

WHO? **NOAA Research (ETL, NSSL, FSL, CDC); NOAA Office of Marine and Aviation Operations (AOC, MOC); NOAA NESDIS (ORA, CIMSS, CIRA); NOAA NWS (NCEP, Western Region WFOs, CNRFC); U. S. Navy (NPS); University/Joint Institutes (SCRIPPS, CIRES, CIRA, CIASTA, Penn State, JIMO).**

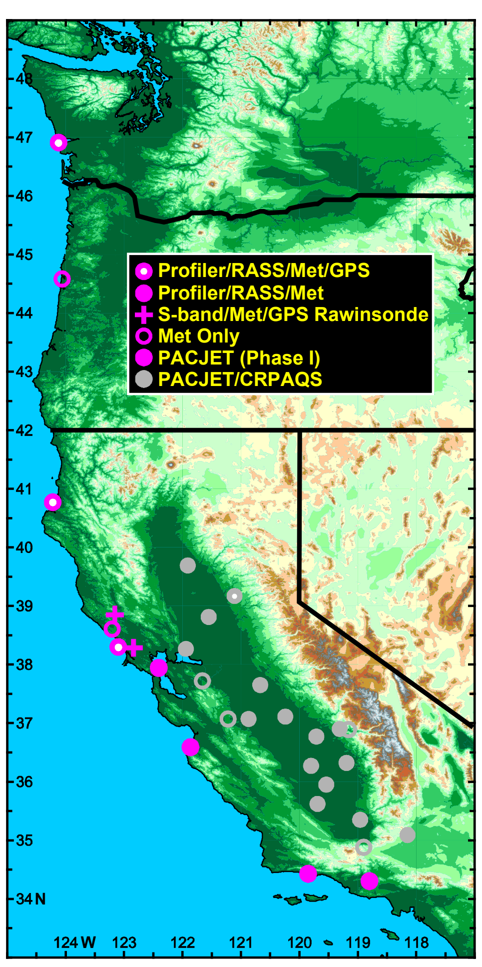
SPONSORS? **NOAA Research, NWS, NESDIS, USWRP.**



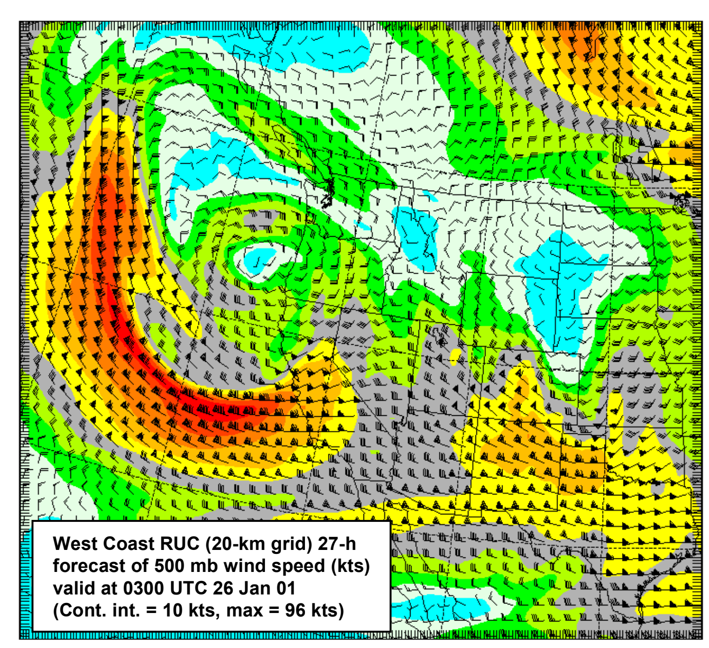
Left: ***Aircraft Observations: A NOAA P-3 research aircraft is being used to observe storms offshore and as they make landfall. Several flight strategies are used to fill gaps in the operational observing network by measuring offshore rainbands, low-level jet characteristics, etc., and to carry out physical process studies (air-sea fluxes, microphysics, etc.).***



Right: ***A new GOES rapid scan experiment (GWINDEX) is being carried out to increase the temporal (1 hour) and areal coverage of GOES winds, partly to aid PACJET. Similarly, new products derived from AMSU on a polar orbiting satellite are being tested. This GOES image was taken at the forecast verification time for the numerical model output shown below.***

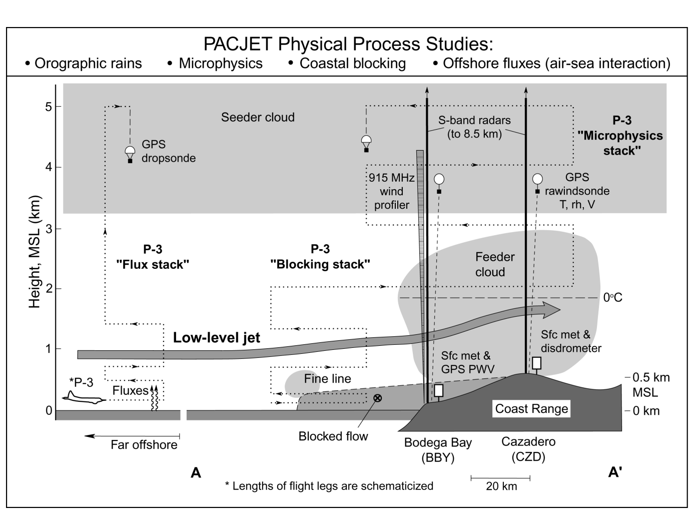


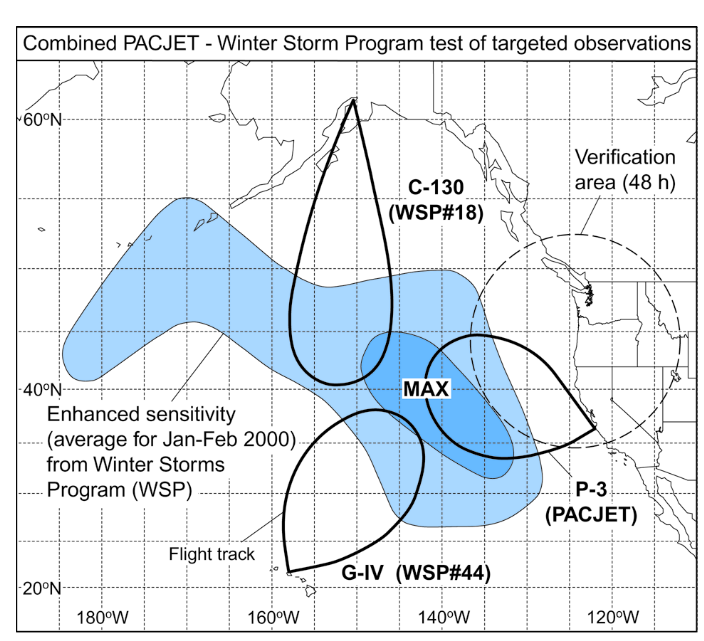
Left: ***An extensive array of wind profilers, GPS receivers for integrated precipitable water vapor, vertically pointing S-band radars, a disdrometer, special balloon launches, surface fluxes, and more were deployed from CA to WA, with the greatest density in CA, where many of these instruments were deployed as part of an air quality study (CRPAQS) during Phase I.***



Right: ***NOAA/FSL created a West-Coast version of the operational RUC model at 20 km grid size that was disseminated to forecasters around the West. A limited number of parallel runs without the experimental satellite, profiler, and aircraft observations were obtained during Phase I. More sensitivity studies are planned for the future. The MM5 model was run in real time at NPS and, in a different configuration, at NOAA/ETL to provide additional guidance during PACJET.***

Right: ***The P-3 conducted one PACJET flight in direct coordination with NCEP's Winter Storm Program's (WSP) flights in the central Pacific to cover a larger area of the targets NCEP identified using the ensemble transform approach. This allowed tests of the importance of areal coverage of a target on a larger scale than was possible using WSP's two aircraft.***





Left: ***The underlying theme of PACJET's coastal processes research was to better understand key processes that contribute to coastal orographic rain in land-falling storms. The schematic cross section illustrates the strategies used to study the phenomena. Aircraft sampling of air chemistry allowed studies of the role of mesoscale flow features in determining air pollution distributions.***