UNIDATA COMMUNITY EQUIPMENT AWARD PROPOSAL

Submitted to

Unidata Program Center
ATTN: Community Equipment Awards
c/o Joanne Graham
1850 Table Mesa Drive
Boulder, CO 80305

TITLE: **VisionLab 2005**

EFFECTIVE DATES: 6/1/2005-5/31/2006
REQUESTED AMOUNT: $25,000; UH Cost Match $25,000

Signature _____

Principal Investigator: Professor Steven Businger
University of Hawaii at Manoa
Department of Meteorology
2525 Correa Rd.
Honolulu, HI 96822
Phone (808) 956-2569
Fax (808) 956-2877
Email businger@hawaii.edu

Meteorology Department Chair: _____
Kevin Hamilton
(808) 956-8327
kph@hawaii.edu

_____
Klaus Keil, Interim Dean
SOEST
1000 Pope Road
Honolulu, HI 96822
(808) 956-8612
keil@hawaii.edu

_____
Kevin Hanaoka
Interim Director of Research Services
2530 Dole St., Sakamaki D-200
Honolulu, HI 96822
(808) 956-7800
hanaokak@hawaii.edu

1. Project Summary

This proposal seeks resources to update and expand the University of Hawaii (UH) VisionLab to maintain state-of-the-art workstation technology in the UH School of Ocean and Earth, Science and Technology (SOEST). VisionLab utilizes operational data streams from Unidata and NOAA NWS, and custom data from UH research programs to bring real-time and archived weather observations and products to UH students and staff. In addition VisionLab weather servers provide access to a broad range of operational and custom products via the Internet. Staff responsible for construction and maintenance of VisionLab will interact with Unidata's support environment to develop new software capabilities and data resources for the central North Pacific Region. The goals of this proposal are to acquire necessary hardware resources to

(i) Enhance the Internet Data Delivery (IDD) system at UH and the NOAAport data exchange with the Honolulu National Weather Service Forecast Office, which is collocated in our building on the UH campus. The added capacity will allow UH Meteorology to become a relay node in the IDD for other users in the Pacific region.

(ii) Expand an historical archive capability that facilitates automated remote access to custom and operational Pacific data sets for research and education, and

(iii) Keep pace with the demand on computational resources of an increasing data stream and increasing numbers of students vying for workstation access.

2. Project Description

VisionLab is housed in the Meteorology Department and takes advantage of the Unidata program's data stream and other data resources from NOAA and NASA via the Internet and NOAAport to bring real-time weather data to UH. VisionLab was developed in two phases with support from NSF equipment grants (ATM-9419433 received in 1995, and ATM-9815959 received in 1998). During the course of the VisionLab project, ongoing interaction has taken place with Unidata's support environment to develop new software capabilities directed at the tropical Pacific Region. Dr. Steven Chiswell led the initial execution of the project, which led to a job offer from Unidata where he continues to work small miracles. The VisionLab project represents a core resource for the Meteorology Program at UH and marks the successful beginning of an ongoing process to upgrade out-dated equipment and maintain state-of-the-art facilities in the UH Meteorology program. It is utilized to varying degrees in most academic courses offered. The greatest academic impact of VisionLab has been in the lower division courses and upper-division synoptic lab classes. In introductory courses access to real time data via the World Wide Web and VHS video projection systems has formed a powerful combination to bring the beauty of science to the lecture hall. In the upper division courses, the ability to manipulate real time data sets as part of a forecasting class is a critical capability.

Given Hawaii's remote location and historical problems with data delivery across the Internet, requested hardware resources will allow UH to more fully contribute to and participate in Unidata activities. VisionLab 2005 will increase community access to a broad range of operational and custom data products available at UH Meteorology via our weather servers. A goal of this proposal is to develop a dynamic archive of our data streams to make it available for educational and research purposes to the Unidata community and society in general via the Internet. Our current online data archive is limited by storage capacity to

historical gif images. The requested expandable storage will allow gridded data in NetCDF format to be archived and served via the Internet.

Since 1999, SOEST has experienced a significant increase in the number of undergraduate majors. This increase is seen in all disciplines in SOEST: meteorology from 25 to 40, geology/geophysics majors from 35 to 65, but especially in oceanography where majors in a new global environmental science program have increased from 10 to 70. Consequently, overcrowding and inadequate computing resources characterize our programs, particularly in the meteorology classrooms where a significant number of introductory labs and upper division courses that utilize VisionLab are taught. Slow workstations and file servers, and hard-disk failures in the current Meteorology VisionLab are frustrating student and faculty attempts to analyze and display weather data.

2.1 Details of the Equipment Request

Equipment Request and Rationale

In order to remain a vibrant contributor to the Unidata community, we propose to upgrade our existing facilities. The proposed upgrades will enable the Meteorology Department to: (i) serve as a relay node for new sites in the Pacific Region, (ii) expand our suite of retained custom and IDD products, (iii) act as an archiving site of IDD products and custom non-IDD products, and (iv) incorporate continuous improvements in the curriculum and augment our transition to a more web-based learning environment. The requested equipment will be integrated with our existing equipment and will serve many purposes that benefit UH and the broader community.

(1) The PowerEdge SC1420 LDM workstation will help alleviate delays in the current synoptic lab, particularly during Met 412 and Met 416 classes. No monitor is requested for this machine to minimize its use outside of LDM datastream processing. However, specified 320 GB hard disk space is greater than that specified for the lab workstations to be able to store a longer period of the LDM datastream. The current LDM datastream represents ~23-25 GB of space per day, with 15 GB of that supporting operational models at UH. At 15 GB/day, we will be able to keep ~2 weeks most recent data quickly available to the community upon request.

2) The requested Dell Precision 670n workstations, will replace our oldest workstations, and will provide the computing power to fully utilize current versions Unidata software applications. It will also ensure that a sufficient number of seats are available for the synoptic labs, homework assignments, and research projects. Enrollment in these key courses has more than doubled during the past 5 years. Twenty-one students in Met 412 during spring semester 2004 had to share 8 workstation seats in VisionLab, and the expectation of larger classes in future, highlight the need for additional workstation access.

3) Upgrade archive system to a Dell PowerVault Storage Array Tower will enable VisionLab to serve an expanding archive function. The present tape archive is becoming cumbersome and outdated. We propose to substantially upgrade our archive system to allow expanding data storage on a storage system that allows remote access. A quick inspection of the Unidata "needdata" email list reveals that the majority of messages involve requests for data less than

one year old. Our proposed strategy is to provide online access to digital imagery and data files in NetCDF format for a growing suite of operational and custom sources. One tower will be devoted to the growing satellite datastream (NASA and NOAA). The second tower will be devoted to custom analysis and model output data in NetCDF format (LAPS, RSM, MSM, MM5, etc.). Empty drives docks will be filled in future at a cost of $1k for drive (cost may decrease with time), and at a rate of 2-4 drives per year.

SOEST's computer network provides high-speed connections and data transfer capabilities. It connects to the UH Manoa campus FDDI campus backbone network, and through that to PACOM wide-area network services, which link Hawaii directly with the Far East and the US mainland. Network switches in the Hawaii Institute for Geophysics Building (HIG) that houses VisionLab have recently been upgraded to one GB capacity. The proposed hardware will allow us to take advantage of the enhanced SOEST network bandwidth.

VisionLab comprises ~1200 square feet of space, which contains five Ethernet outlets and 27 electrical outlets. Sufficient space is available in VisionLab for the proposed computing resources. Once the hardware arrives, SOEST research computing facility (RCF) staff will work with the PI to construct and maintain VisionLab. Appropriate software for the project is currently available for transfer through a limited area network to the workstations. Existing full-time technical personnel that are currently employed in SOEST will maintain hardware purchased for VisionLab. Ongoing network support for data delivery from Unidata via Internet will be provided through departmental resources.

2.2 Benefits to Research, Education, and Unidata Community at Large

A primary research objective of VisionLab and this proposal is to mitigate the impact of natural hazards on society and industry through improvements in our ability to observe and predict the evolution of these events over the central and eastern North Pacific Ocean. Hardware requested in this proposal will allow a number of data streams and products not routinely available through Unidata to be accessed and archived for research and educational purposes. A sample of these multidisciplinary data sets for the central and eastern Pacific region is listed in Table 1, and select visual examples are shown in Figs. 1 and 2. Publications in the reference section represent a partial list of research that directly benefited from VisionLab. The research objectives outlined in this section will greatly benefit from enhanced access to real-time and archived gridded data made possible by this proposal.

In the data-sparse central Pacific, remote-sensed data sets are of critical importance for numerical weather prediction (NWP) and development of operational tools to assist forecasters (Businger et al. 2001). Improvements in the prediction of local weather events have been achieved through a combination of i) synthesis of custom and operational data sets (see Table 1) using the Local Analysis and Prediction System (LAPS) adapted to the central Pacific, ii) operational application of mesoscale primitive equation models for NWP with initial conditions from LAPS, iii) case studies of outstanding events that result in the formulation and/or refinement of conceptual models (e.g., Businger *et al,* 1998; Morrison and Businger 2001), and iv) development and testing of forecast tools with special attention to remote-sensed sources (e.g., Mazany et al. 2002). The data storage and staging capabilities that an enhanced VisionLab will bring to the Meteorology Department and SOEST will significantly facilitate our continued research progress, and will provide an expanded

resource for the Honolulu Forecast Office of the NWS and the Joint Typhoon Warning Center (also located in Honolulu).

Table 1 Data Streams for the Central and Eastern North Pacific. Note the cross-disciplinary nature of a number of the data streams. This is not a comprehensive list.

Project Name	Data Stream	Project URL
1. PacNet	Long-range lightning data	http://imina.soest.hawaii.edu/MET/Faculty/businger/projects/pacnet/
2. Skynet	GPS precipitable water	http://imina.soest.hawaii.edu/pgf/public/SkyNet/
3. GroundWinds	UV lidar wind profiles	http://lumahai.soest.hawaii.edu/Groundwinds/index.html
4. UH LAPS	Objective Analyses	http://weather.hawaii.edu/
5. UH MM5	Custom NWP Output	http://weather.hawaii.edu/
6. GOES Satellite	GOES/GMS for Pacific	http://weather.hawaii.edu/
7. UH Earth Observing Station (downlink site for NASA satellite data over the Pacific)		
	NASA & NOAA data	http://www.eos.hawaii.edu/
8. UH Infrasound Lab		
	Infrasound data	http://www.isla.hawaii.edu/
9. UH Sea-level Center		
	Sea-level data	http://ilikai.soest.hawaii.edu/uhslc/data.html
10. UH SWAN	Wave model output	http://www.soest.hawaii.edu/~buoy/model.html#oahu_uh
11. Hawaii Center for Volcanism		
	Volcanic emissions	http://www.soest.hawaii.edu/GG/hcv.html

VisionLab has facilitated a number of cross-disciplinary research efforts. A prime example is the Mauna Kea Weather Center (MKWC), which provides custom forecast support for the astronomical observatories at Mauna Kea (Businger et al., 2001). The MKWC staff undertakes research in data assimilation and modeling of turbulence and seeing above the summit of Mauna Kea. In particular, assimilation of CIMMS atmospheric motion vectors and long-range lightning data has enhanced regional objective analyses and improved mesoscale model predictive skill (Cherubini, et al. 2004). The Infrasound Lab monitors the source regions of infrasound signals in the atmosphere. Research shows that these low-frequency sound waves are generated through interference of storm generated ocean swell trains, which may provide a novel means to remotely track tropical cyclones (Willis et al. 2004). An effort to model the dispersion of volcanic smog (vog) emanating from the Kilauea volcano complex (Hollingshead et al. 2003) has led to the development of an operational vog dispersion forecast system[1]. The ensemble dispersion model helps mitigate the adverse impacts of vog on general aviation and health. GPS data from Skynet show that Mauna Loa's flanks are swelling (Brooks et al. 2004), leading to predictions of an imminent eruption of the summit caldera, and increasing the value of the vog forecast capability.

Requests to UH Meteorology weather server pages (http://weather.hawaii.edu and http://mkwc.ifa.hawaii.edu) are exceeding 35,000 hits per day. During the hurricane season (Jun-Nov) requests sometimes reach 80,000 per day, especially when there are tropical

[1] See http://www.arl.noaa.gov/data/ensemble/

cyclones in the Atlantic, Eastern Pacific or Central Pacific regions. Tropical storm-centered GOES10 satellite images and combined GMS/GOES10 images overlaid with plots synoptic observations or model output are especially popular web addresses in our tropical weather section (e.g., Fig. 1). Roughly 20% of the requests are from sites that make 75 or more requests per week. The high level of requests is straining current server resources.

Results from our research initiatives are currently utilized in VisionLab to train meteorology students. However, due to growth in the SOEST student body and in the size of the data stream (25+ GB/day combined IDD and NOAAport), additional hardware resources are proposed to ensure adequate workstation access and sufficiently fast response times to student and faculty commands. The proposed resources will also allow utilization of greater bandwidth made available in our building through the installation of faster (1 GB) switches.

It is important for today's undergraduate and graduate students to be educated in the use of UNIX-based analysis and displays systems. Equipment purchased with previous cost-matching grants has been successfully incorporated into VisionLab and the Meteorology curriculum and laboratories during the past decade. The analysis and display of real-time data distributed by the IDD is now a daily activity in UH Synoptic Meteorology and Weather Analysis and Forecasting courses. Enrollment in these key courses has more than doubled during the past 5 years; 21 Students in Met 412 during spring semester 2004 had to share 8 workstation seats in VisionLab, highlighting the need for additional computer resources for our lab classes. Significant use of Unidata products also occurs in the general-education (100-200 level) courses and the dynamics courses. As the suite of IDD and custom products expands and our generation of graphical products becomes more automated and interactive, we envision increased usage of Unidata products in additional SOEST courses.

Given Unidata's implementation of JAVA-based applications, software developers at UH are able to efficiently create a graphical user-friendly interface for the educational applications on UH VisionLab. Applications are being developed with the aid of a large body of existing public domain software, including educational applications developed by Dr. Businger's group, that have been adapted to VisionLab. The development of four-dimensional visualization software at Unidata (IDV) has opened special educational possibilities given the robust nature of the data stream available to VisionLab (Table 1). During the next five years in our VisionLab program, we will incorporate continuous improvements in the meteorology curriculum and augment our transition to a multidisciplinary web-based learning environment. These capabilities open new possibilities in teaching the fundamentals of science, while enhancing the ability for users to explore previously intractable combinations of data display and manipulation.

There is a continuing need for the development of training and education curricula for the modernized NWS, for both current and future employees. This need is particularly acute for the Pacific Region since it encompasses such a vast geographic area and includes tropical mesoscale weather regimes that have had significantly less scientific attention than their midlatitude counter parts in the past. Forecast problems specific to the Pacific Region, some of which are touched on in this proposal, will be the focus of a NWS-UH Collaborative Workshop in Tropical Meteorology to be held on the UH campus in 2006. Results of climatological and case study investigations, and numerical model simulations developed on VisionLab will be incorporated in the Workshop curriculum. Data from numerous research projects (Table 1) will also be utilized on VisionLab to provide participants with computer driven case studies and exercises. The faculty at UH and the staff at the WSFO HNL are

enthusiastic about working together in developing the curriculum for the Tropical Meteorology Workshop, which is tentatively scheduled for the winter of 2006. The Workshop organizers will work with COMET (with Tim Spangler's direction) to explore the possibility of transitioning appropriate tropical case studies to COMET for distribution to the broader community.

The UH Meteorology Department has been an active participant in the Unidata program. The PI's long-standing experience and interaction with the Unidata program played a role in his selection to serve as chairman of the review panel for Unidata's NSF proposal for a 5-year renewal in 1998. During the course of the VisionLab project ongoing interaction has taken place with Unidata's support environment to develop new software capabilities directed at the tropical Pacific region. We aspire to contribute more to the Unidata community in future. We are interested in improving our online archival site, supporting and promoting other sites in the Pacific, and participating in testing of future data transfer and archiving technologies (e.g., Unidata LEAD program).

2.3 Relationship of Requested to Current Computer Resources

The proposed additions to VisionLab fulfill the projected hardware needs in the area of data access, synoptic instruction, and geosciences data display for the next 5 years. The UH SOEST and the Meteorology Department are committed to strengthening such mutually beneficial activities. Our commitment to maintaining a state-of-the-art research and instructional facility is readily documented. Excluding salaries for support staff, the UH and SOEST have collectively contributed more than $100K in real dollars over the past ten years through grant-matching funds, software, maintenance, and hardware upgrades. Given the growth in the data streams available through research, Unidata and the NWSFO, the hardware requested in this proposal will allow the UH/SOEST to contribute to and participate fully in Unidata's future efforts.

a) Current Departmental Computing Resources (since 1990)

Acquired 1990: Sun SPARCStation 1 (with upgraded SPARC SS5/85mhz clone cpu)
Acquired 1992: Sun SPARCStation 2 (with upgraded SPARC SS5/85mhz clone cpu)
Acquired 1993: Sun SPARCStation 2 (40mhz)
Acquired 1994: Sun SS10 Model 514 with 4 40mhz cpus,
HP 9000 Model 712 with 80mhz cpu,
HP 9000 Model 735 with 99mhz cpu
Acquired 1995: DEC AlphaServer 2100 4/275 upgraded to 5/375 in 1997
Acquired 1996: Sun Ultra 1 Model 170 with 167mhz cpu
Acquired 1997: HP 9000 Model C180 with 180mhz cpu
Acquired 1998: Sun Ultra 1 Model 170E with 167mhz cpu
Sun Ultra 1 Model 170 with 167mhz cpu
Sun Ultra 1 Model 200E with 200mhz cpu
Acquired 2000: DecAlpha ES40 with 4 667mhz cpus
Acquired 2002: DecAlpha XP1000 with 667mhz cpu
Acquired 2003: DELL 12-node PC cluster with 2.4GHz dual Xeon processors

School-wide SOEST has ~100 Unix RISC workstations and servers. In addition to departmental computer resources, faculty utilize computer resources off campus, including

supercomputer facilities at the Subaru center in Hilo, the Maui High-Performance Computing Center, NCAR, and the Earth Simulator in Japan.

b) Current Computing Resources in VisionLab

Dr. Businger received awards from NSF in 1994 and 1998 to build UH VisionLab. The following is a summary of the equipment and facilities currently available for UH VisionLab.

Acquired 3/94: Sun SPARCStation 10 Model 512, 50mhz workstation with two cpu, 128 MB memory, 8bit TurboGX graphics buffer, 9GB + 4GB + 2GBinternal disk drive, EXABYTE 8505XL 8mm tape drive.

Acquired 8/95: Four Sun SPARCStation 5, 100mhz workstations, 32 MB memory, 8bit TurboGX graphics buffer, QIC-150 Tape drive, Hewlett-Packard: LJ III printer, Tektronics Phaser 200 Printer.

Acquired 7/98: Sun Ultra 60 with dual 300mhz CPU; 256MB Memory; 4.2GB Internal, Disk Drive; Internal CD-ROM Drive; 3D Graphics System,
Four Sun Ultix10 workstation consoles.
RAID disk system with 288 GB/disc capacity.

3. Description of the Budget for VisionLab2005

Please refer to Section 2.1 for a detailed justification of the hardware listed in this section.

	Number	Cost per	Total
1) LDM Workstation without monitor: PowerEdge SC1420, 2.8 Intel Xeon processor w/ 1MB 800 MHz Cache 2 GB RAM, Red Hat Enterprise Linux WS V.3 2 - 160GB, 7.2K RPM Serial ATA Hard Drives	1	2,600	2,600
2)VisionLab Workstations: Dell Precision 670n, 2.8 Intel Xeon processor w/ 1MB L2 Cache, 2 GB RAM Red Hat Enterprise Linux WS V.3 17 inch Ultrasharp Flat Panel Monitor 40 GB of Space	14	2,600	36,400
3) Archive Center: Dell PowerVault 220S/221S SCSI Storage Array Tower 4 drives with 300 GB 10 RPM Ultra 320 SCSI Hard Drive provides 10 Empty docks for expansion	2	5,500	11,000
Total			$50,000
UH Cost Match			-$25,000
Total Request to Unidata Community Equipment Program			**$25,000**

Cost-Sharing

UH will provide 50% matching funds on the requested hardware, along with providing all software, installation, warranty, and maintenance services needed to operate the equipment. The P.I., Dr. Businger will oversee purchase, installation, and networking of the equipment and SOEST RCF staff will install software, software updates, and maintain the lab.

4. Project Milestones

Since the physical space and networking for VisionLab and the personnel involved with maintaining VisionLab are already in place, we foresee no contingency to delay the timetable below.

Timetable for VisionLab 2005

Summer 2005 – Equipment will be purchased and installed so that the updated VisionLab facility will be fully functional for fall 2005 classes that start at the end of August.

Fall 2005 – Data and imagery will be added to the new archive facility and additional products will be made available on UH weather servers. Case studies from recent research by UH Meteorology faculty will be selected for further development on VisionLab for the winter Workshop in Tropical Meteorology.

Winter - Spring 2006 – Added archive capacity will be functional as an on-line resource for imagery and data in NetCDF format.
Winter Workshop in Tropical Meteorology will be held at UH.

Summer 2006 onward – A fully implemented VisionLab facility will provide enhanced research and educational opportunities for students, researchers, the Unidata community and the broader community.

5. References

The following is a partial list of publications that directly benefited from the development of VisionLab and the increased interaction between the WSFO-HNL and the UH Department of Meteorology.

Brooks, B.A., Foster, J., Cherubini, T., Businger, S., Miklius, A., Mouginis-Mark, P., 2004: Mitigation of Atmospheric Errors in Differential InSAR Data Using a High-Resolution Weather Model, Mauna Loa and Kilauea volcanoes, Hawaii. Fall AGU meeting, San Fransisco, CA, December 2004.

Businger, S., R. McLaren, R. Ogasawara, D. Simons, and R.J. Wainscoat, 2001: Starcasting. *Bull. Amer. Met. Soc.*, **83**, 858–871.

Businger, S., T. Birchard, Jr., K.R. Kodama, P.A. Jendrowski, and J-J Wang, 1998: A bow echo and severe weather associated with a Kona Low in Hawaii. *Wea. and Forecasting,* **13**, 576-591.

Businger, S., S.R. Chiswell, M. Bevis, J. Duan, R. Anthes, C. Rocken, R. Ware, M. Exner, T. VanHove, F. Solheim, 1996: The promise of GPS in atmospheric monitoring. Bull. Amer. Met. Soc., 77, 5-18.

Cherubini, T., S. Businger, C. Velden, and R. Ogasawara, 2004: Assimilation of satellite derived winds in mesoscale forecasts over Hawaii, 7-9 June 2004, Helsinki, Finland.

Chiswell, S.R., Businger, S., Bevis, M., Rocken, R., Solheim, F., and R. Ware, 1993: Improved Retrieval of Integrated Water Vapor from Water Vapor Radiometer

Measurements using Numerical Weather Prediction Models. J. of Atmos. and Ocean. Tech., 11, 1253 - 1261.

Foster, J., M. Bevis, S. Businger, Y-L Chen, and Y. Zhang, 2004: The Kau storm (Nov 2000): Imaging precipitable water using GPS. J. Geophys. Res., 108(D18), 4585, doi:10.1029/2003JD003413, 2003.

Foster, J., M.G. Bevis, T. Schroeder, S. Businger, M. Merrifield, S. Dorn, S. Marcus, J. Dickey, Y. Bar-Sever, 2000: El Nino, water vapor, and the Global Positioning System. Geophy. Res. Letters, **27**, 2697-2700.

Hollingshead, A., S. Businger, R. Draxler, J. Porter, and D. Stevens, 2003: Dispersion modeling of the Kilauea plume. *Bound.-Layer Meteor.*, 108, 121-144.

Kodama, K.R. and S. Businger, 1998: A Brief Overview of Weather and Forecasting in the Pacific Region of the National Weather Service. *Wea. and Forecasting,* **13**, 523-546.

Morrison, I. and S. Businger, 2001: The synoptic structure and evolution of a kona low. *Wea. and Forecasting*, **16**, 81-98.

Morrison, I., S. Businger, F. Marks, P. Dodge, and J.A. Businger, 2005: An observational case for the prevalence of roll vortices in the hurricane boundary layer. *J. Atmos. Sci.*., In press.

Motell, C., J.N. Porter, J. Foster, M. Bevis, and S. Businger, 2002: Comparisons of Water Vapor Derived from GPS, Sounding and the Split Window Technique, *Int. J. of Remote Sensing*, **23**, 11, 2335-2339.

Wang, J.-J., H.-M. Juang, S. Businger, K. Kodama, Y.-L. Chen, and J. Partain, 1998: Application of the NCEP regional spectral model to improve mesoscale weather forecasts in Hawaii. *Wea. and Forecasting,* **13**, 560-575.

Willis, M., M. Garces, C. Hetzer, S. Businger, 2004: Infrasonic observations of open ocean swells in the Pacific: Deciphering the song of the sea. Geophys. Res. Lett., Vol. 31, No. 19, L19303.

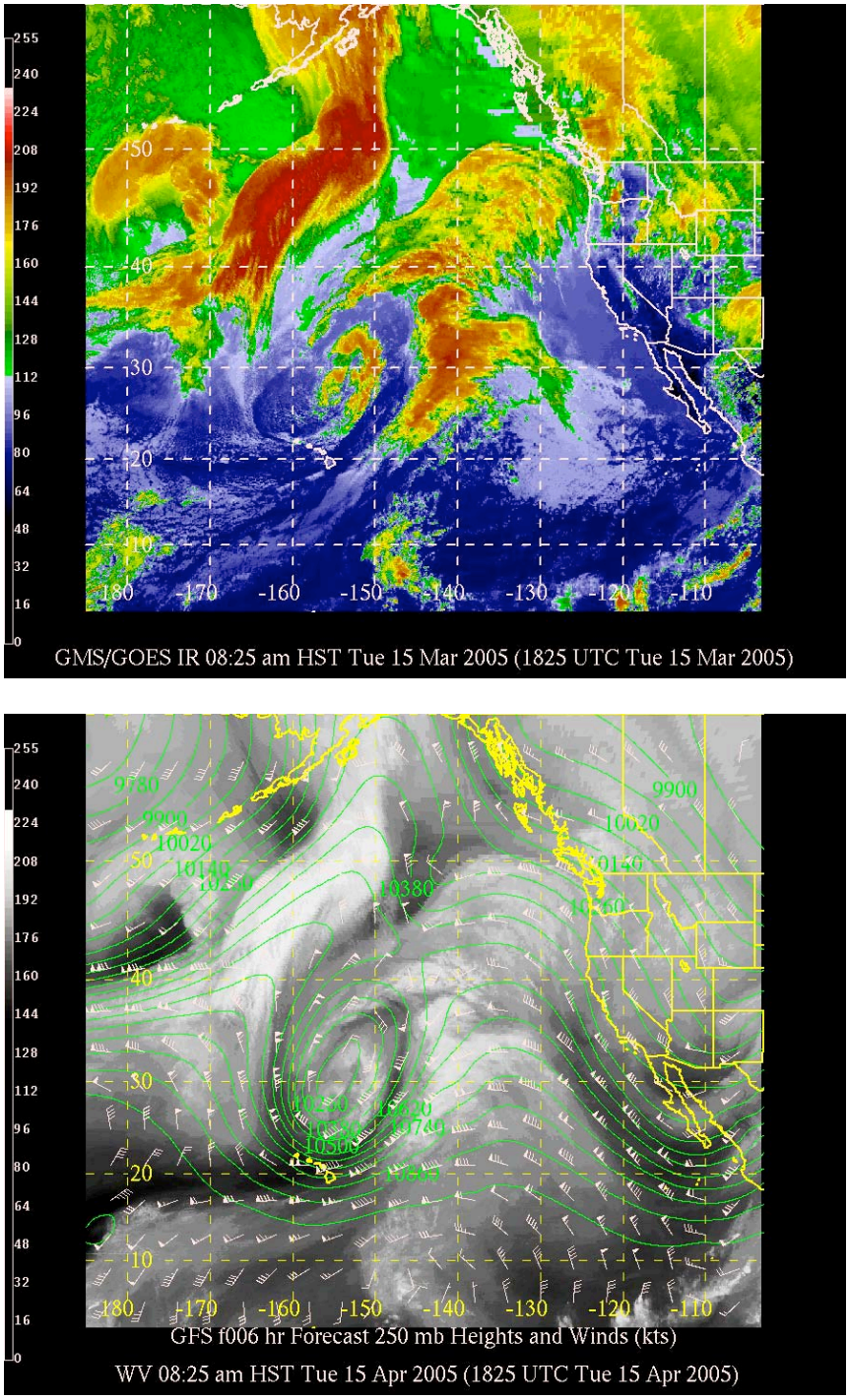


Fig. 1 GOES/GMS composites at 1825 UTC on 15 March 2005 of infrared (top) and water vapor images with 250 mb GFS overlay of geopotential height and winds (bottom).

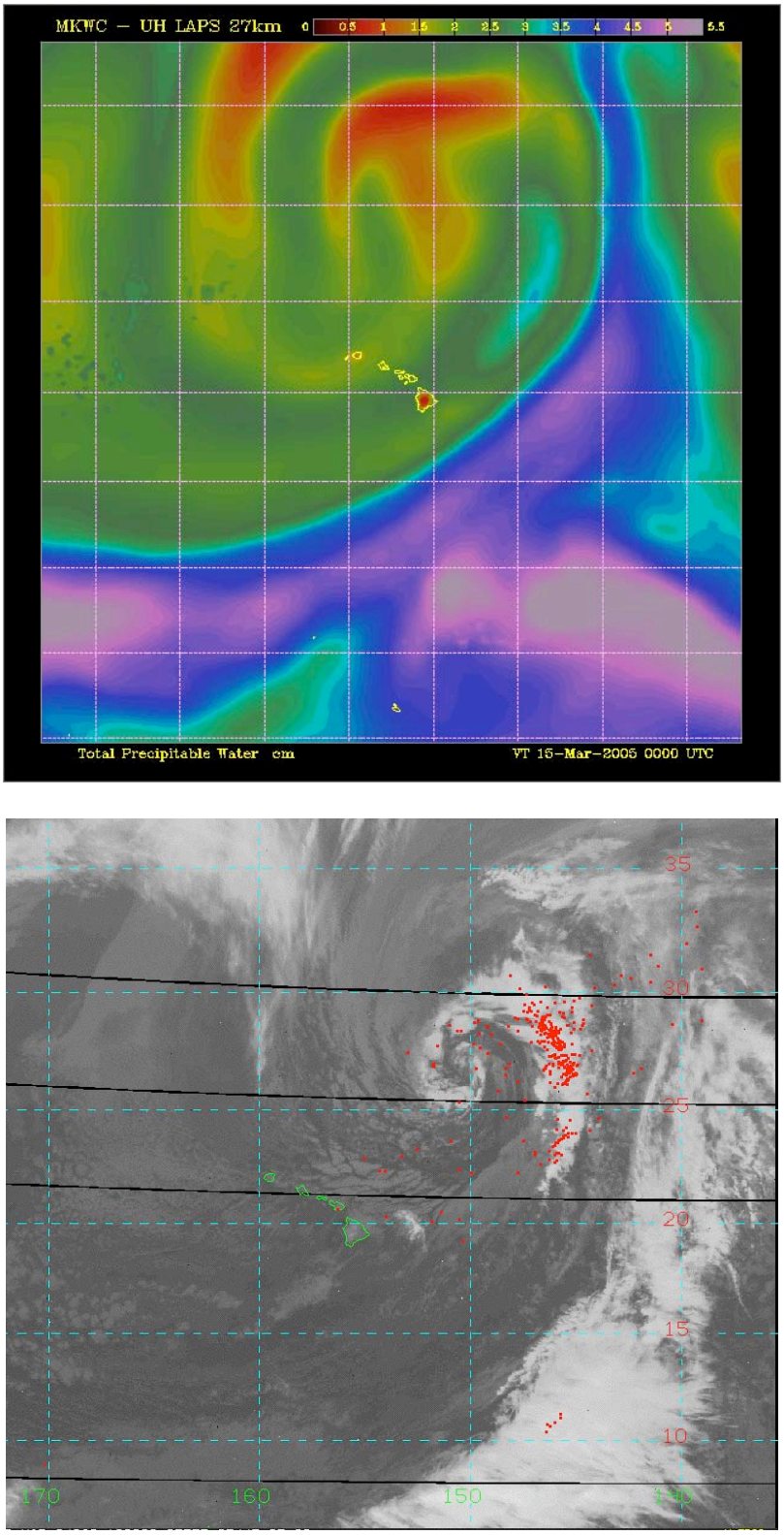


Fig. 2 LAPS analysis of precipitable water at 0000 UTC on 15 March 2005 (top). Sferics from lightning measured by PacNet (red) on 9 March 2004 at 1500 UTC. The sferics distributions were binned into three-hour intervals and overlaid on GOES 10 infrared imagery (bottom).