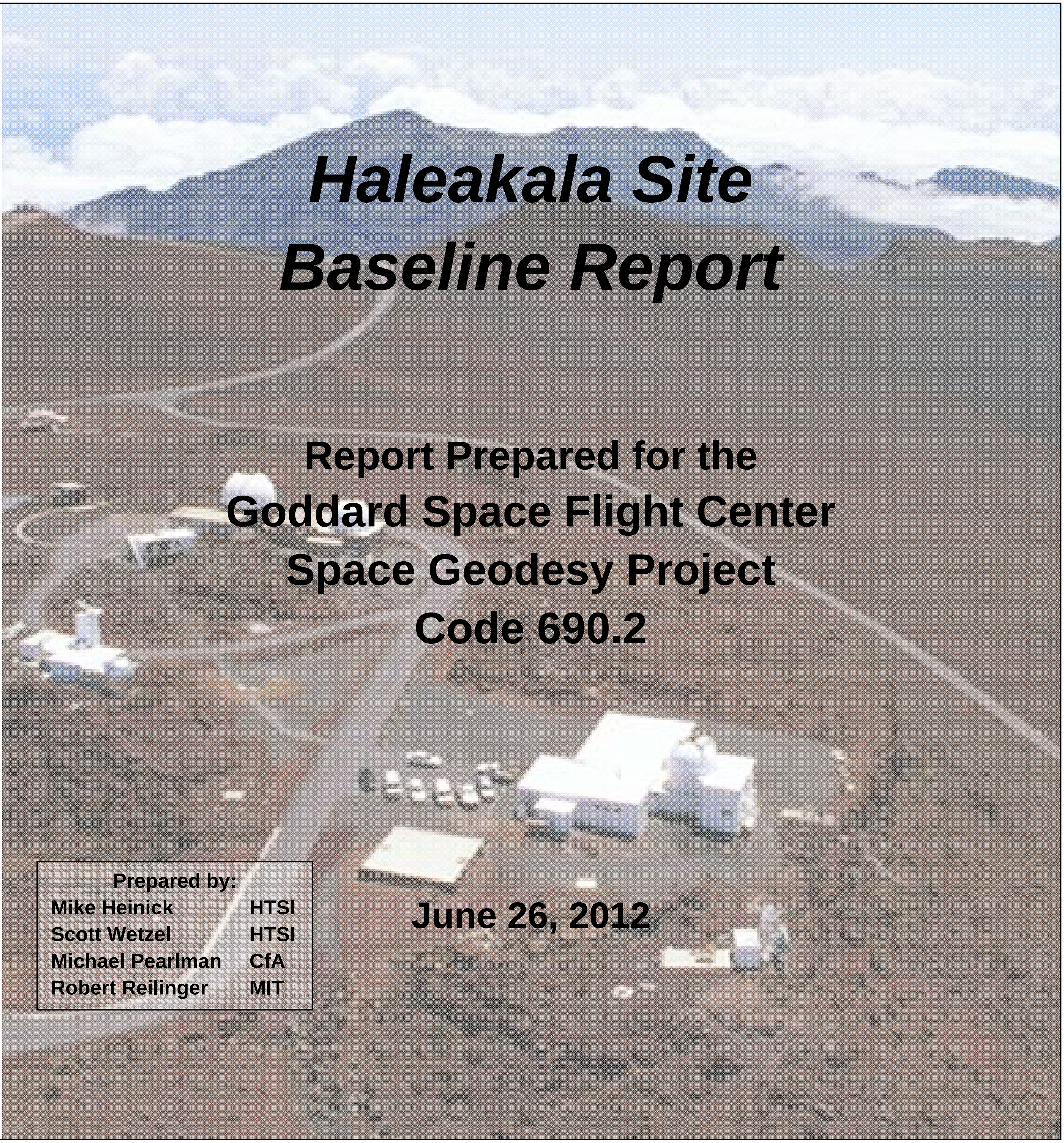

Haleakala Site Baseline Report

Report Prepared for the Goddard Space Flight Center Space Geodesy Project Code 690.2

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June 26, 2012

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1.0 Acknowledgements

The authors would like to thank the following people for their extensive knowledge and information that contributed to the writing of this report. They include: Julie Horvath from Honeywell Technology Solutions Inc., Michael Floyd and Robert King from MIT, and Dan O'Gara from the University of Hawaii.

One component that is necessary for the success of NASA's Space Geodesy Project is the identification of key locations to populate the next generation space geodesy techniques to form a Fundamental Station. As part of the process, a baseline of each occupied NASA SLR and VLBI site and a few key GPS sites will be compared with the site criteria to determine viability for a Fundamental Station. This baseline information will then be used to evaluate other potential sites. With significant help from the above referenced people we were able to accumulate much of this information into a report that will help determine the next NASA Space Geodesy Network.

2.0 Executive Summary

One of the tasks under the NASA Space Geodesy Project (SGP) is to identify candidate locations for the new Fundamental Stations. A Fundamental station is one that ideally consists of the following space geodesy techniques, a next generation satellite laser ranging (NGSLR) ground system, a next generation very long baseline Interferometry (VLBI-2010) system, and an updated Global Navigation Satellite System (GNSS) ground system that has the capability to receive data from all GNSS satellite constellations. If a Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) system is also included, it would be an advantage. The requirements for this Fundamental Station can be found in the document, "*Site Requirements for GGOS Fundamental Stations*, 2011":
(http://cddis.gsfc.nasa.gov/docs/GGOS_SiteReqDoc.pdf)

The initial requirement of this project is to baseline the current NASA SLR, VLBI, and select GNSS sites to the requirements stated in the site requirement document. As NASA has a rich history of sites with 1 to all 4 techniques collocated, a baseline of each NASA site will allow for a better understanding of what existing and new sites will meet with the SGP requirements.

The SLR site located on Maui, at the summit of the Haleakala volcano, currently the location of the Transportable Laser Ranging System number 4 (TLRS-4), is the second site to be baselined. The significance of looking at Haleakala second is to be able to compare the Haleakala site with that of the KPGO site on Kauai for co-locating SLR, VLBI, GNSS and DORIS systems. As KPGO has a long standing VLBI presence, the Haleakala site has long standing SLR time series. The Lure Observatory, also known as the Hollas SLR site, was one of the first laser ranging systems to perform lunar laser ranging (LLR) in 1974. It was also a key SLR site by virtue of its location in the Pacific Ocean and by it's altitude, ~10,000 feet. The Lure Observatory operated as an SLR system from 1981 to 2004. It was dismantled and the site was then taken over by the PAN-STARRS system. SLR again occurred on Haleakala with the deployment of the TLRS-4 system, beginning SLR in October 2006.

TLRS-4 and the IGS GNSS receiver (*MAUI*) are located on property held by the University of Hawaii, Institute for Astronomy (UofH Ifa). TLRS-4 is co-located at the facility with a number of other observatories supporting numerous scientific endeavors. Coexistence between the diverse experiments are managed through a Haleakala Users Group that meets regularly.

In support of the SGP, there is adequate infrastructure including power, excellent high speed communications (through the USAF), road access, site safety and security, and operations facilities exist at the Haleakala summit. Local commitment is in place with the UofH IfA coordinating activities on the summit and a good working relationship with the USAF.

There exists a SLR technical team of 2.5 dedicated members that support SLR, GNSS, and site maintenance and/or operations. There are also part time casual labors that support mount observation during SLR operations and a reach back to others at the UofH that can support machine shop, facilities and other needs, if necessary. The site is geologically stable with no earthquakes noted greater than 3.5 in the past decade.

Areas of concern for this facility include an issue with site size, utilization and potential. No existing location for a VLBI2010 system is also at issue; both for actual facility location and potential significant RFI due to FAA and television antennas in direct line of site to the UofH compound or located on the compound. More work on RFI will be required to identify and quantify this and other potential RFI sources.

The main issue with the Haleakala facility is the lack of location for a VLBI antenna, and potential RFI that would limit VLBI operations. Also, construction on this site, while certainly possible, is difficult due to restrictions on land use, permitting and adherence to local building regulations.

As stated in the KPGO report, the Haleakala site is an excellent site for SLR with outstanding seeing and about 80% tracking sky, contrasting to the approximately 40% clear sky at the KPGO site on Kauai. Conversely, the KPGO site is an excellent site for VLBI due to the long term data series, local facilities and infrastructure.

Utilizing the solutions set in the KPGO report may be the best solutions as VLBI would be difficult to locate on Haleakala. Below are the potential solutions from the KPGO report.

Possible ways to mitigate the high amount of unusable SLR tracking weather on Kauai and RFI and space / constructions issue on Maui are:

1. NGSLR only on Kauai
   a. Locate an NGSLR system within the "D" Parcel at KPGO
   b. Only limited tracking would be possible with the significant cloud cover
   c. Significant reduction in SLR would occur.
2. NGSLR only on Maui
   a. Do not locate an NGSLR system at KPGO but only on Haleakala on Maui
   b. Utilize a network of high performance GNSS antennas in key positions on both Maui and KPGO to use in a precise tie between the two islands.
3. NGSLR on Kauai and Maui
   a. Locate an NGSLR system in the "D" Parcel at KPGO and concentrate on geodetic satellites only
   b. Locate an NGSLR system on Haleakala, Maui
   c. Utilize a network of high performance GNSS antennas in key positions on both Maui and KPGO to use in a precise tie between the two islands.

In summary, the Haleakala facility has a long time series for NGSLR and GNSS. It is a key facility in the ILRS and IGS its location in the Northern Pacific. While there is ample infrasctrure with access, power, communications and local commitment, there are issues with placing a VLBI at this site. It is an excellent choice for at least NGSLR and GNSS and could be key if a solution is found to tie the KPGO and the Haleakala sites using SLR and GNSS.

3.0 Introduction - Haleakala Site Conditions for GGOS

This report describes the current conditions at Haleakala that will determine the suitability of the site as a Fundamental Station for geodesy as described in the paper *Site Requirements for GGOS Fundamental Stations*, 2011. The information provided below will also provide a basis for comparison with other candidate sites during the site selection process.

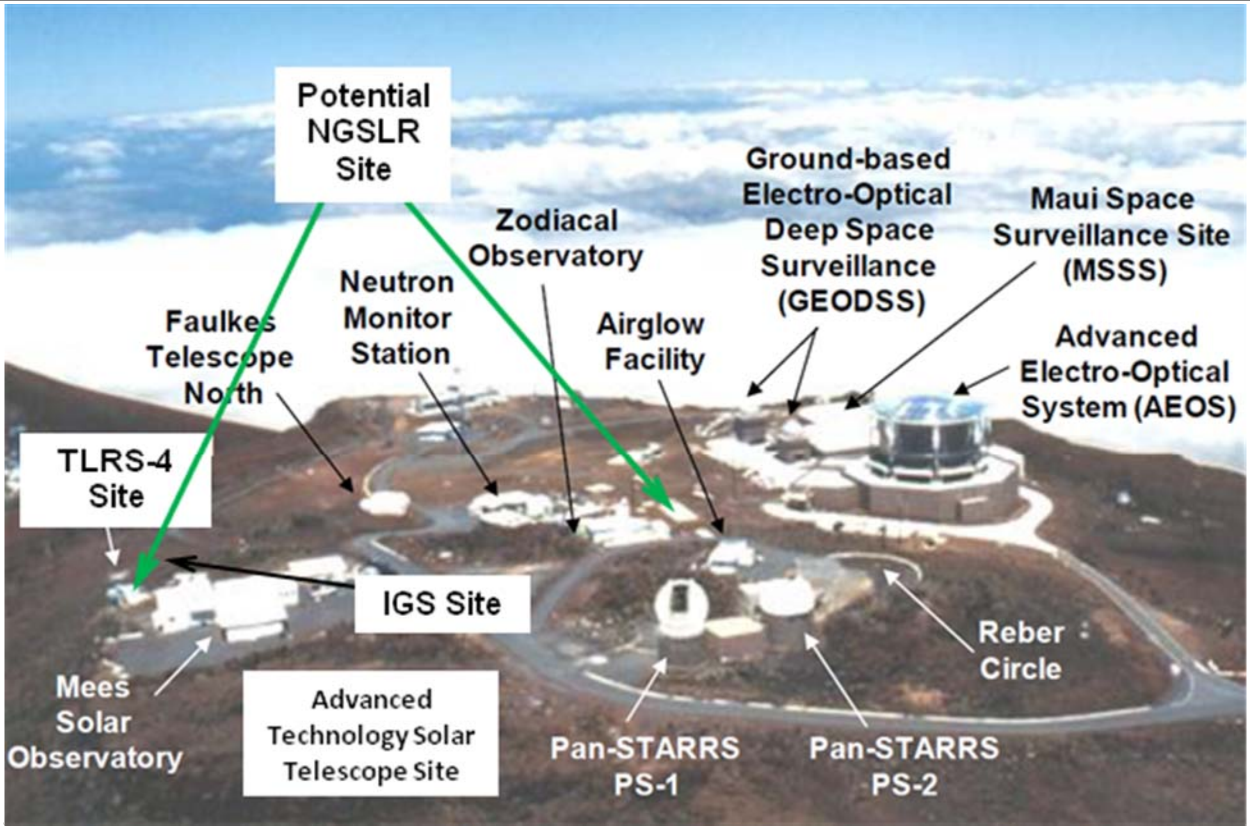
The key elements that make up a Fundamental Station include a Next Generation Satellite Laser Ranging (NGSLR) system, a broadband capable Very Long Baseline Interferometry (VLBI2010) system and a Global Navigation Satellite System (GNSS) capable system. A DORIS system is desirable to the success of the Fundamental Station but is subject to the plan of the DORIS network.

The following sections will examine all of the components of the Site Requirements for a Fundamental Station and will provide a summary of this examination. While NASA has occupied these initial locations by either SLR, VLBI, GNSS or combination of 2 or all three techniques, no site is to be considered as an exact candidate for a Fundamental Station. Also, it is understood that none of the existing sites is an exact match to the requirements. Ideally, the requirements within the *Site Requirements for GGOS Fundamental Stations* would make the best site; however, there is probably not an existing NASA occupied site that meets all of the criteria. This report just provides a baseline of the existing sites and allows for an informed decision by the Space Geodesy Project (SGP) to make the next choices for a Fundamental Station.

4.0 Existing Techniques

Techniques currently active on Haleakala include SLR and GPS.

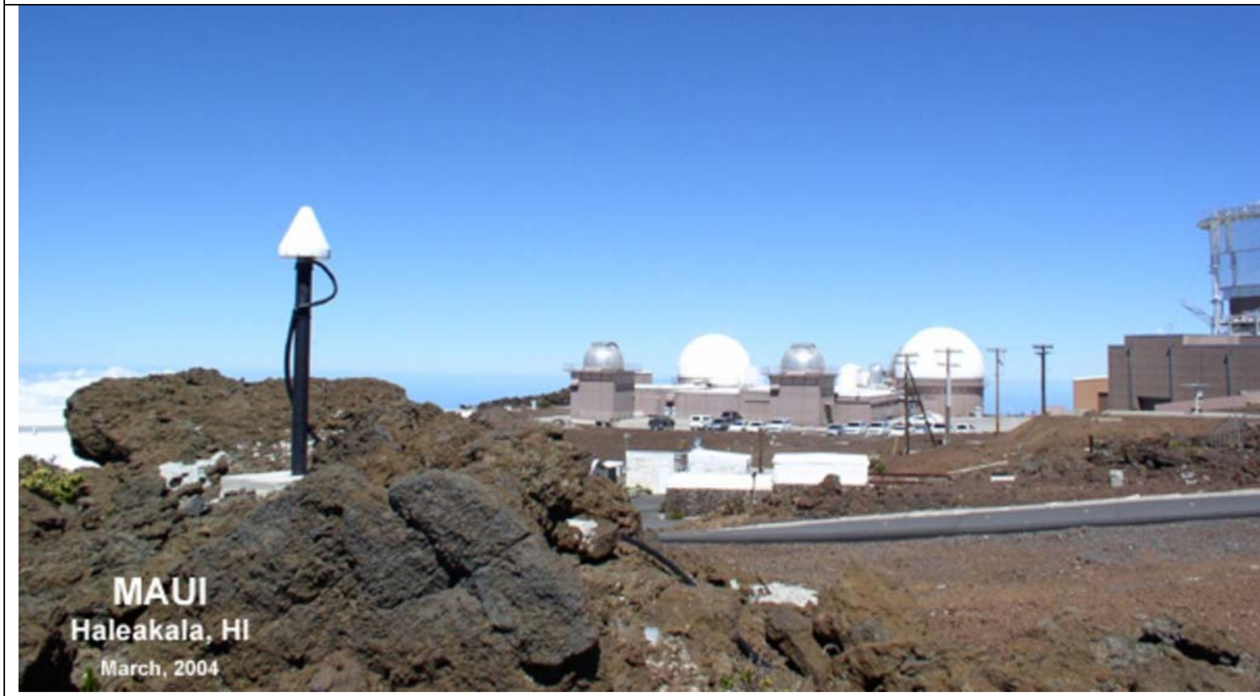
Aerial View of Haleakala



Source: Haleakala High Altitude Observatory Site Management Plan (Updated)

VLBI – VLBI is not currently on site.

GNSS - A GPS antenna was installed in 1996 at IGS station MAUI.

IGS Station MAUI

Source: http://igscb.jpl.nasa.gov/network/site/maui.html Domes: 40445S008 PID: AJ8470 Code: MAUI

DORIS –.DORIS is not currently on site.

SLR – The Hollas LURE Observatory began laser ranging of the Moon in 1974 and satellite laser ranging (SLR) to artificial satellites in 1981. At the beginning of 2004, the Hollas LURE observatory closed and was replaced with TLRS-4 in 2006. SLR data acquired at the mid-Pacific Haleakala site over the decades has proven to be critical for maintaining the precise orbit determination required for various scientific investigations.

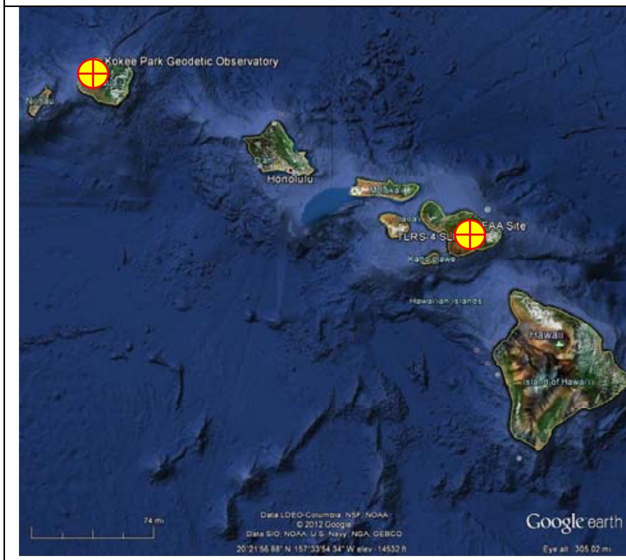
Hollas SLR at the LURE Observatory

TLRS-4


5.0 Global Consideration for the Location

The Haleakala site is located near the middle of the North Pacific Ocean. The MAUI GPS station at the Haleakala site is located at latitude 20 42’ 23.94705” N and longitude 203 44’ 34.73062” E (156 15’ 25.26938” W).

Haleakala in Hawaii	
SGP Sites in Hawaii	Haleakala Site on Maui



5.1 Geometrical Distribution

A GGOS site in Hawaii is critical due to the very limited number of possible locations in the North Pacific. The only site selection consideration is how the location of the Haleakala site compares with other Hawaii sites, such as KPGO on Kauai. Due to the close proximity between the two islands, other requirements will be a more determining factor for the items of this section.

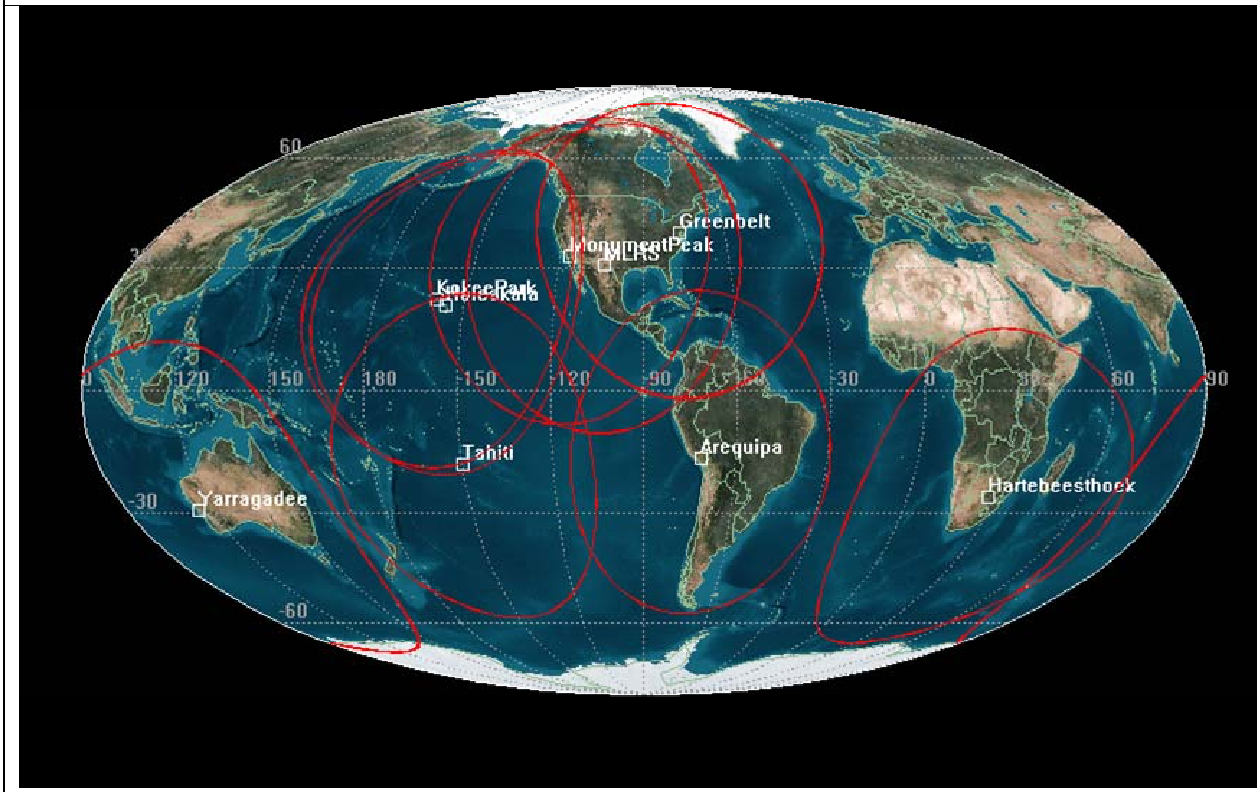
5.2 Technical Distribution

A GGOS site in Hawaii is critical due to the very limited number of possible locations in the North Pacific.

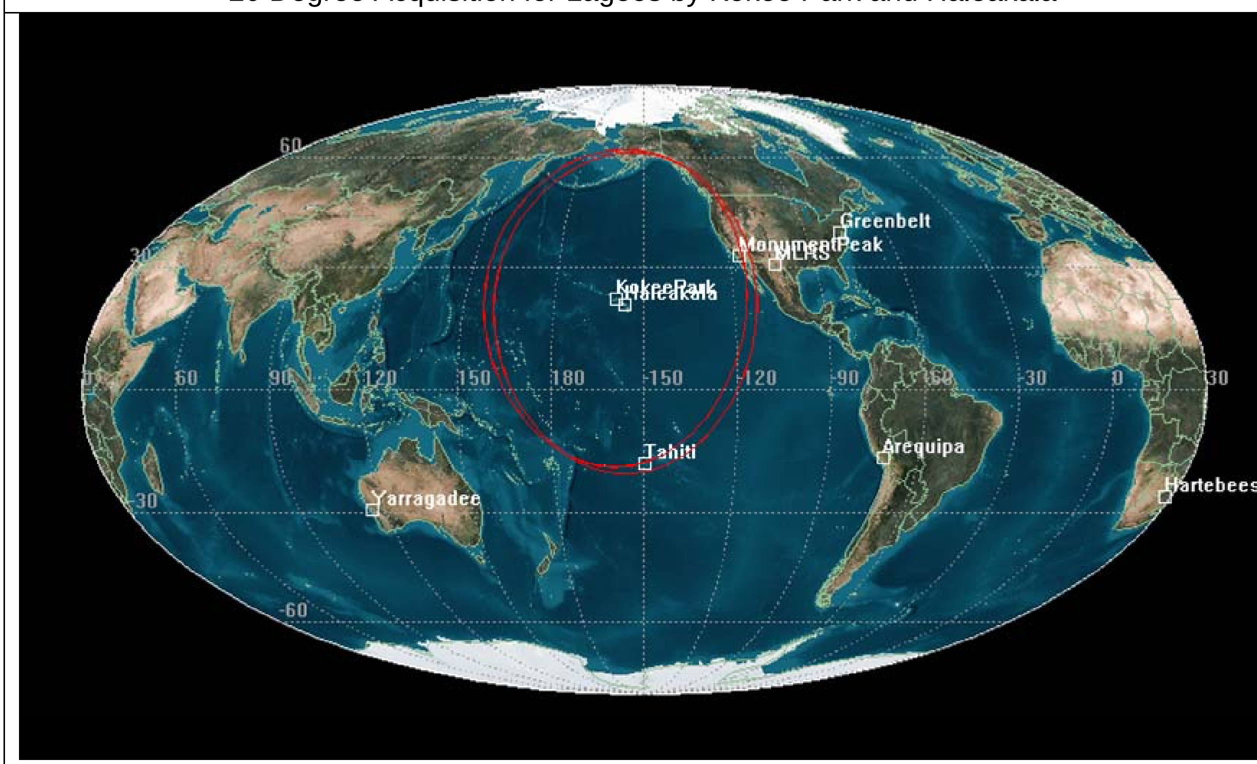
5.3 Technique Dependent Distribution

A GGOS site in Hawaii is critical due to the very limited number of possible locations in the North Pacific. The following plots display the tracking coverage down to 20 degrees elevation for LAGEOS by the NASA SLR sites. VLBI success is not impacted by the physical location of the VLBI on Kauai or Maui. Other factors will dictate the success of this determination.

20 Degree Acquisition for Lageos by NASA Sites

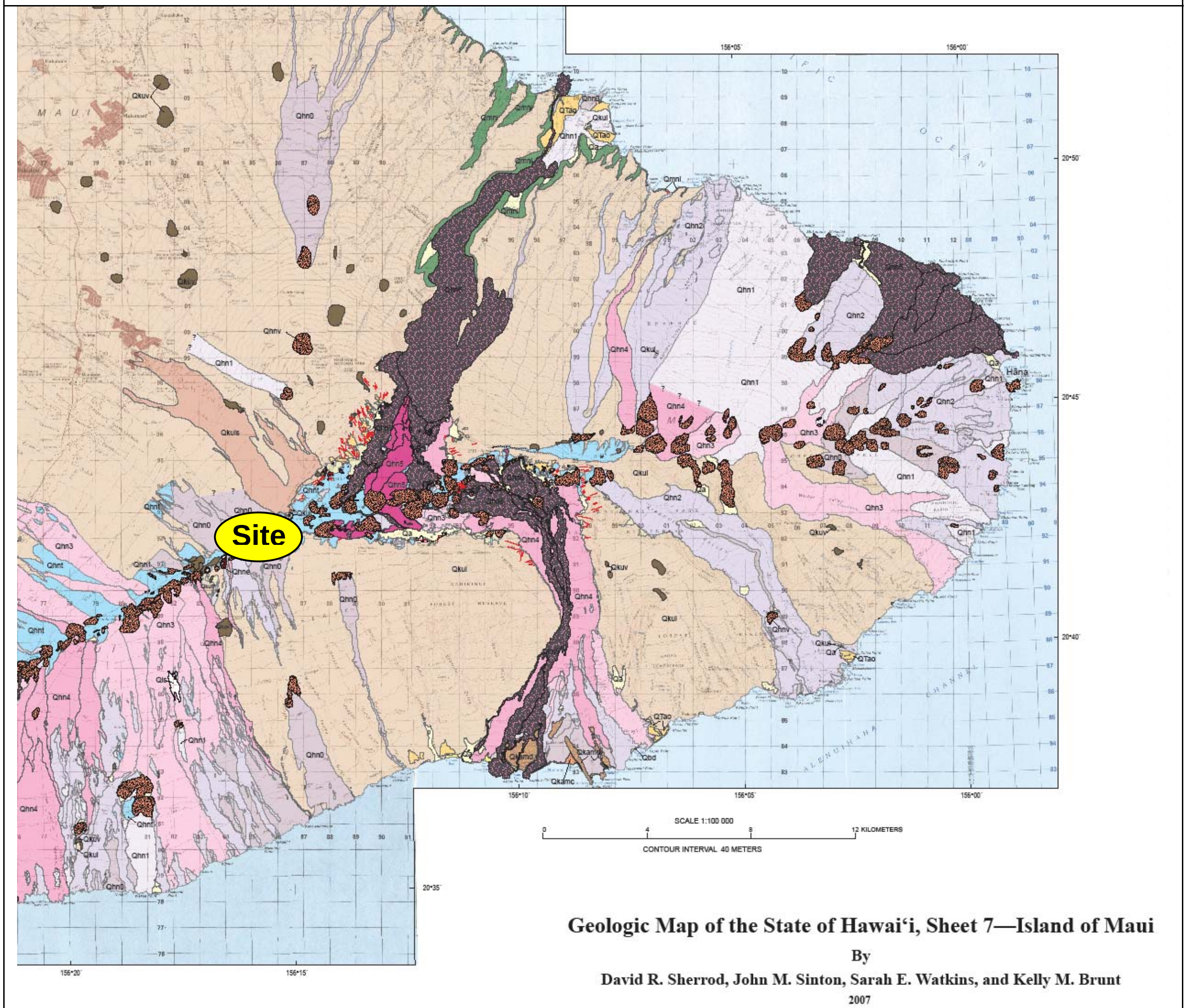


20 Degree Acquisition for Lageos by Kokee Park and Haleakala



6.0 Geology

Excerpt from Geologic Map of the State of Hawai'i, Sheet 7 – Island of Maui



6.1 Substrate

A geological survey of Haleakala Observatory site can be found at: http://www.ifa.hawaii.edu/haleakalanew/LRDP/images/AppendixA.pdf . This report by S. Bhattacharji mentions recent volcanism taking place on the Southwest Rift Zone between 1750 and 1790. It also states that "volcanoes on the Southwest Rift Zone can only be considered active volcanoes which can erupt again in the near future".

Bedrock – Volcanic lava flows 50,000 – 140,000 years old. (from the map)

See Bhattacharji, S., Geological Survey of the University of Hawaii Haleakala Observatories at Haleakala Summit Region, East Maui, Hawaii, (references Sinton in 2002)

See Patterson, Sam H., (1963), Halloysitic Underclay and Amorphous Inorganic Matter in Hawaii, U.S.G.S., Twelfth National Conference on Clays and Clay Minerals

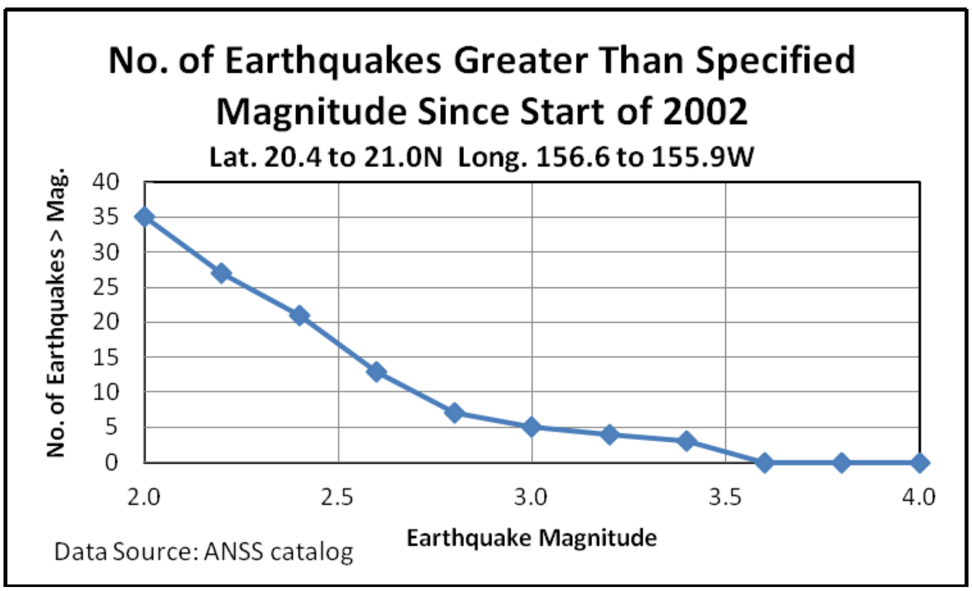
Geologic Map of the State of Hawai'i, Sheet 7—Island of Maui, David R. Sherrod, John M. Sinton, Sarah E. Watkins, and Kelly M. Brunt, 2007

http://ngmdb.usgs.gov/ngm-bin/ILView.pl?sid=81276_2.sid&vtype=b

Local structure – See the Geologic Map of the State of Hawai'i, Sheet 7, and the report by Bhattacharji.

6.2 Tectonic Stability

A search of the Advanced National Seismic System (ANSS) catalog for earthquakes with magnitudes greater than 2.0 in an area bounded by latitudes 20.4N and 21.0N and longitudes 155.9W and 156.6W from 2002 to the present yielded 35 events, 5 of which were greater than magnitude 3.0. (Source: http://quake.geo.berkeley.edu/cnss/catalog-search.html, accessed 6/07/2012)



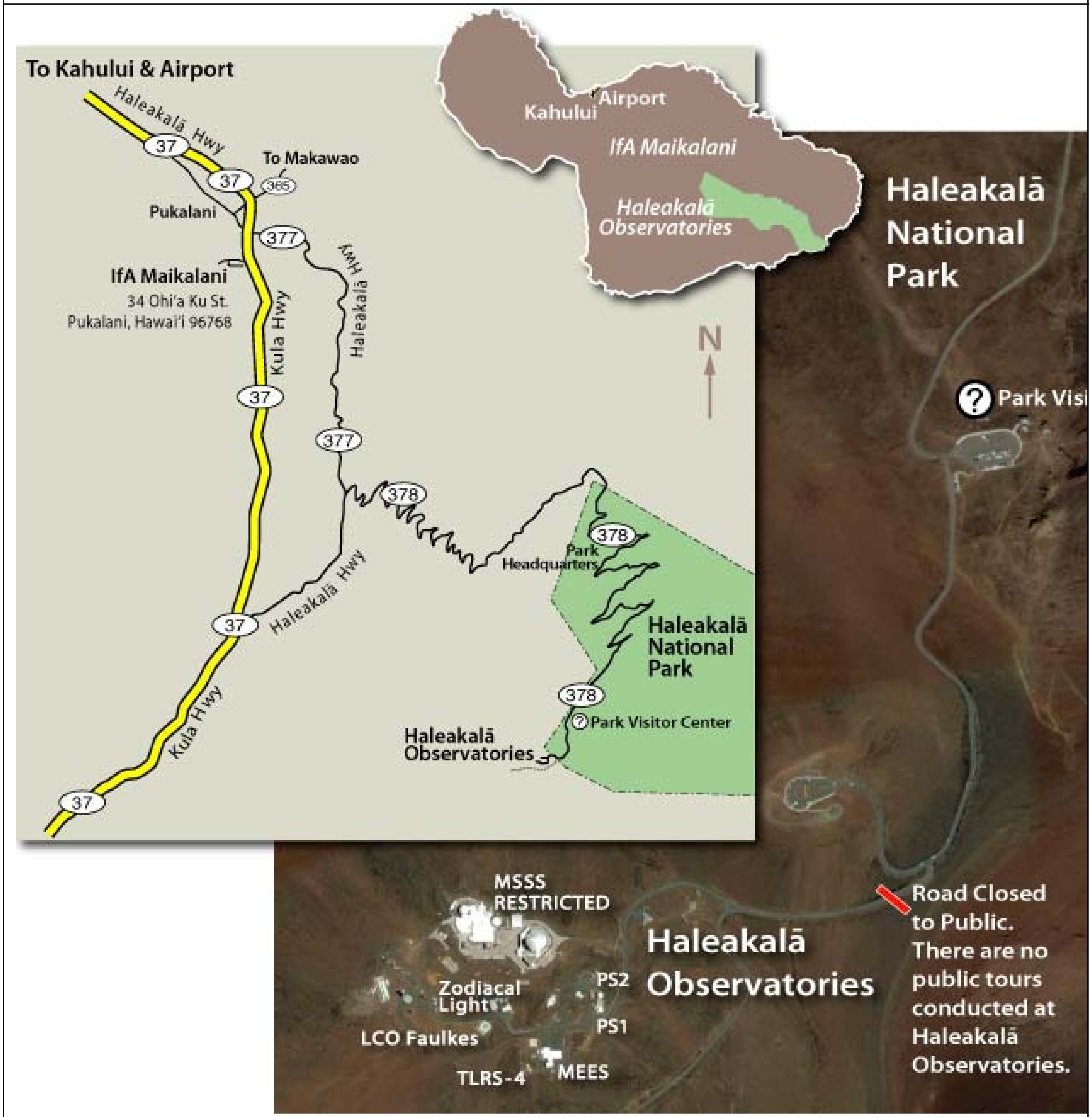
A team from MIT will investigate the stability of the Haleakala site and will issue a draft report which is to be included at the end of this document. .

7.0 Site Area

Maui, Hawaii, is a bilobed island trending northwest to southeast consisting of two main volcanic peaks separated by roughly 40km and connected by a land bridge. The larger part of the island to the southeast is roughly triangular in shape, about 40-50km on a side. The site is located in the southeastern part of the island on top of the Southwest Rift Zone of Haleakala at a height of approximately 3050 meters.

A key reference for information about the site, its local environment, usage, and regulations is the *Haleakala High Altitude Observatory Site Management Plan* prepared by KC Environmental, Inc., in 2010 (Link: http://www.ifa.hawaii.edu/haleakalanew/LRDP/index.htm)..

Haleakala Observatories on Maui



Source: http://www.ifa.hawaii.edu/haleakalanew/summitMap.shtml

7.1 Local Size

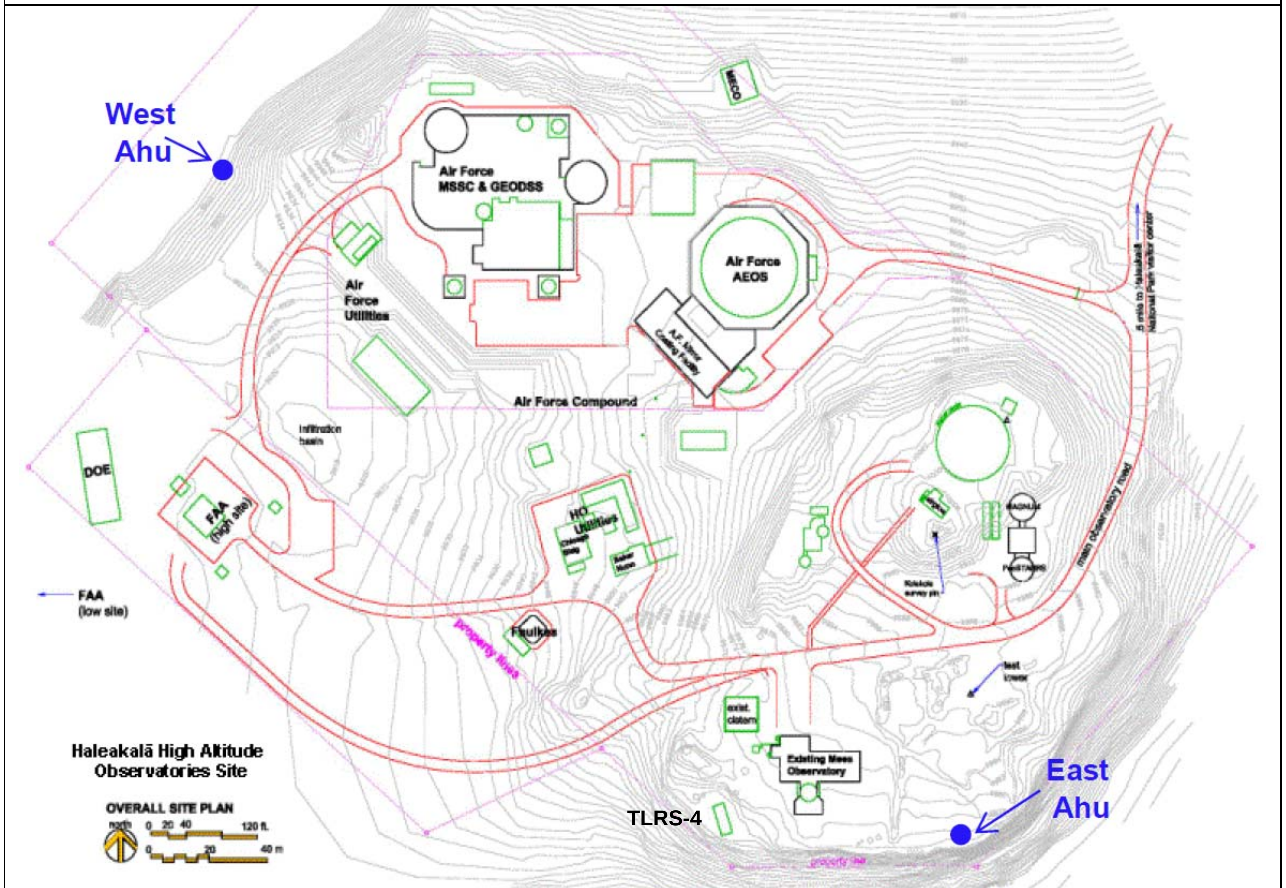
The existing site contains several observatories, including Mees Observatory, PAN-STARRS PS1 and PS2, LCO Faulkes Observatory, Zodiacal Light Observatory, the Advanced Electro-

Optical System (AEOS) of the Air Force, the Maui Space Surveillance Site (MSSS) operated by the Air Force, and theTLRS-4 satellite laser ranging system. The large Advanced Technology Solar Telescope (ATST) will be built next to the Mees Observatory in the near future. These facilities are located within a roughly rectangular area of 7.35 hectares. Within the 7.35 hectare site, the MSSS is provided 1.82 hectares. There are several archeological locations within the site where development is not permitted. Local cultural and environmental considerations may make future development and expansion of the area difficult.

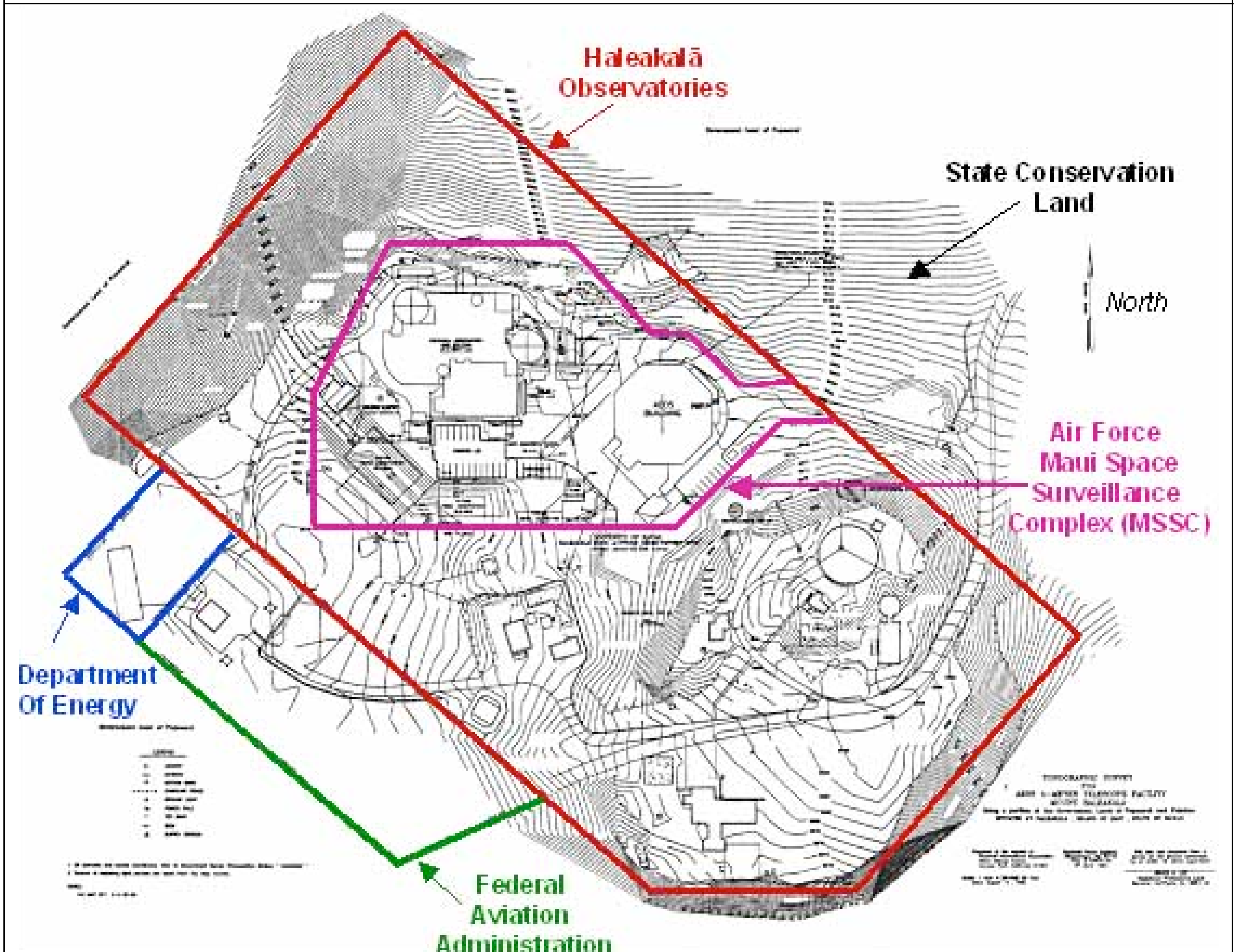
Haleakala Site Layout

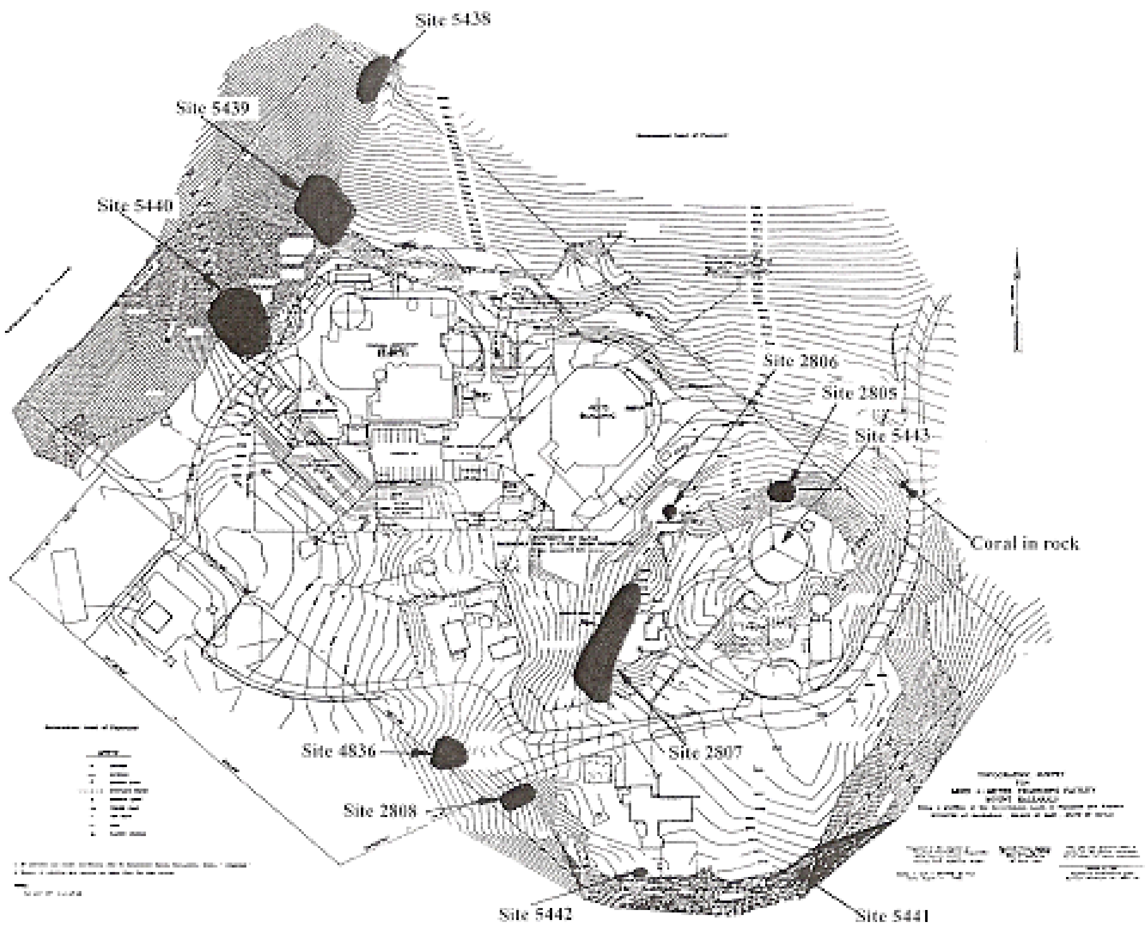
Source: http://www.ifa.hawaii.edu/haleakalanew/summitMap.shtml

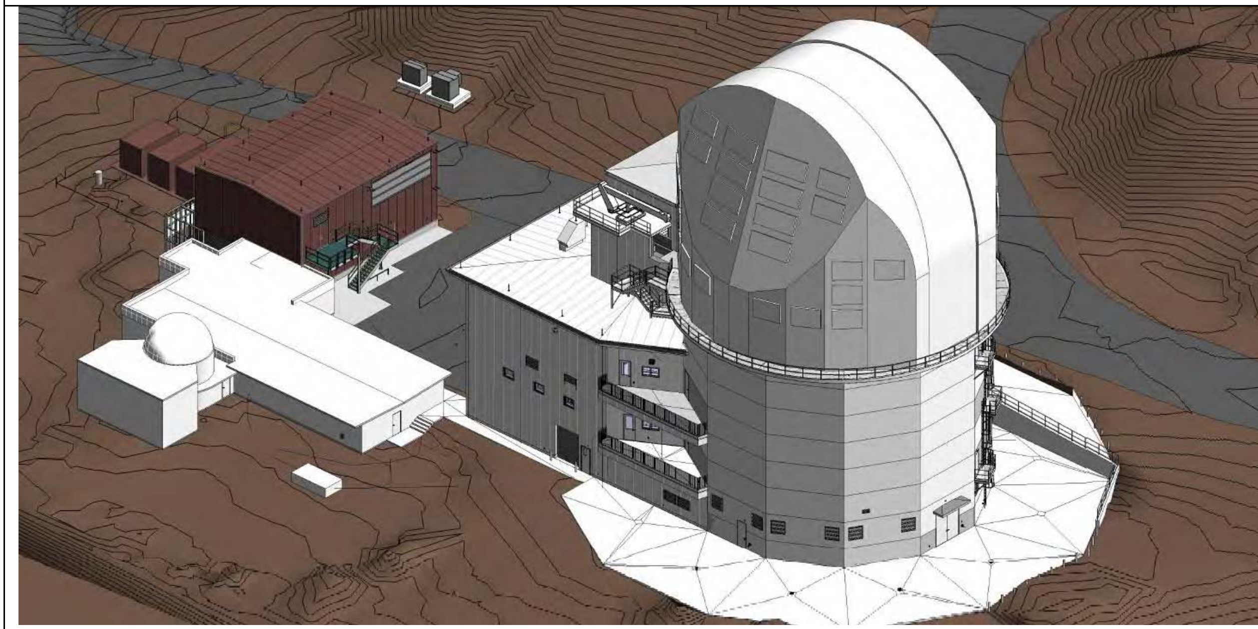
Haleakala Observatory Site Plan



Source: Haleakala High Altitude Observatory Site Management Plan

Haleakala Observatory Site and Adjacent Properties

Source: Haleakala High Altitude Observatory Long Range Development Plan

Archeological Sites at Haleakala Observatory Site

Source: Haleakala High Altitude Observatory Site Management Plan

ATST to be Constructed Next to Mees Observatory

Source: NSO Newsletter, Vol.2, No. 1: March 2012, pg. 7 Link: http://www.nso.edu/sites/www.nso.edu/files/files/press/NSO_NL02.pdf

7.2 Weather & Sky Conditions

7.2.1 Climate

The climate at Haleakala is tropical, although the site is above much of the tropical weather at the 3050 meter altitude of the summit. The Haleakala National Park Weather Page at http://www.haleakala.national-park.com/weather.htm provides the following description
:
"The weather at the summit of Haleakala is unpredictable. Temperatures commonly range between 40 deg F and 65 deg F, but can be below freezing at anytime of year with the wind chill factor. Weather changes rapidly at high elevations on Haleakala. Intense sunlight, thick clouds, heavy rain and high winds are possible daily." Also, "At 10,000 feet and no permanent living areas on the summit, it can be difficult to work due to the extreme elevation changes that can cause altitude sickness."

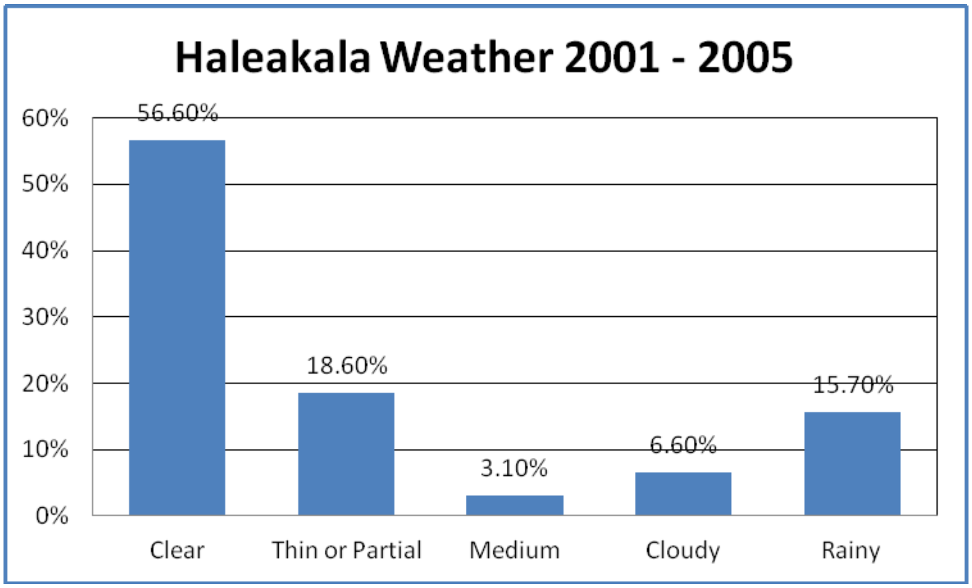
Haleakala National Park Weather Stats

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg High - ï¿½F	59.8	59.0	59.4	60.6	62.3	65.7	65.5	66.1	65.0	64.3	62.8	60.7	62.6
Avg Low - ï¿½F	41.9	41.4	41.6	42.6	43.9	46.5	47.2	47.5	46.3	46.0	45.3	43.4	44.5
Avg Precip (in)	8.85	6.78	7.15	4.92	2.10	1.20	2.42	2.79	1.87	2.72	5.67	7.32	

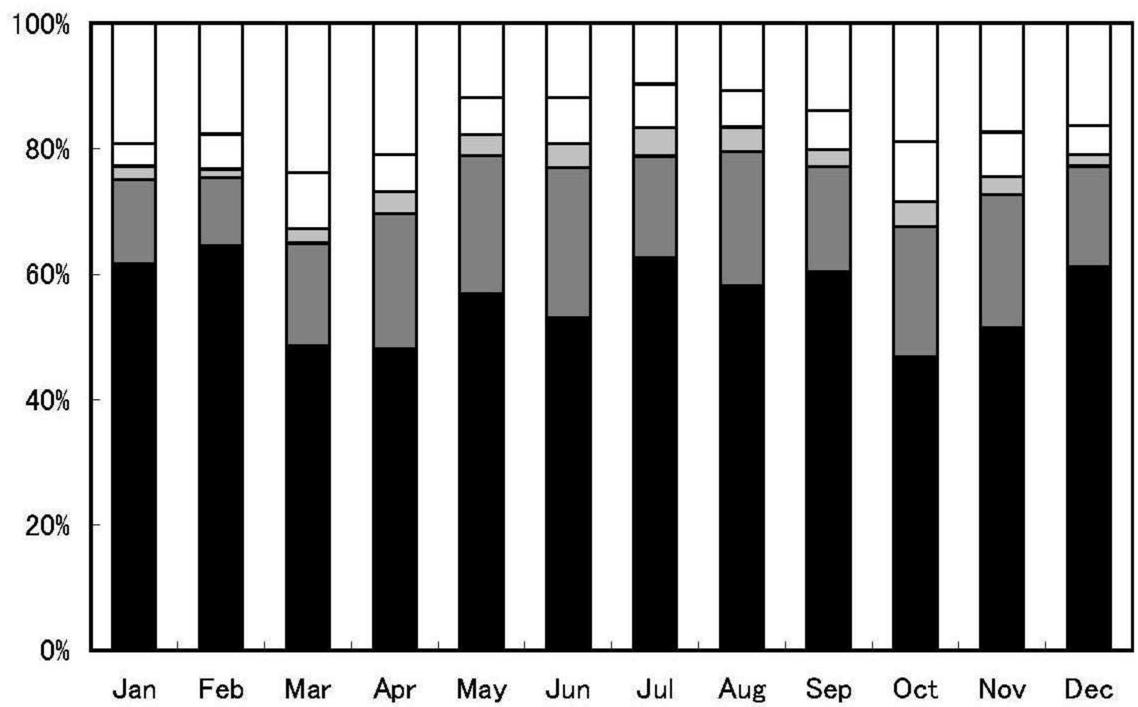
See the following link for a different general description of the climate of Hawaii:
http://www.wrcc.dri.edu/narratives/HAWAII.htm

7.2.2 Sky Conditions

A plot of sky conditions for Haleakala for the period 2001 through 2005 is displayed below. If the clear, thin or partial, and half of the medium categories indicate trackable weather by SLR, that leaves untrackable weather only 23% of the time. The data is from the paper The Infrared Cloud Monitor for the Magnum Robotic Telescope at Haleakala. That is only 23% untrackable weather by SLR on Haleakala compared to ~60% untrackable weather at Kokee Park on Kauai.



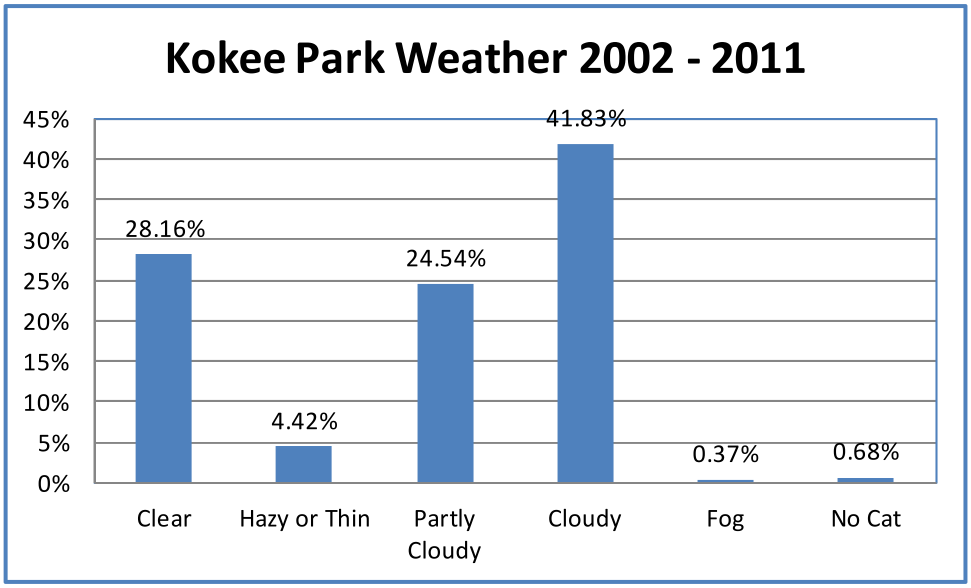
Monthly Distribution of Sky Conditions

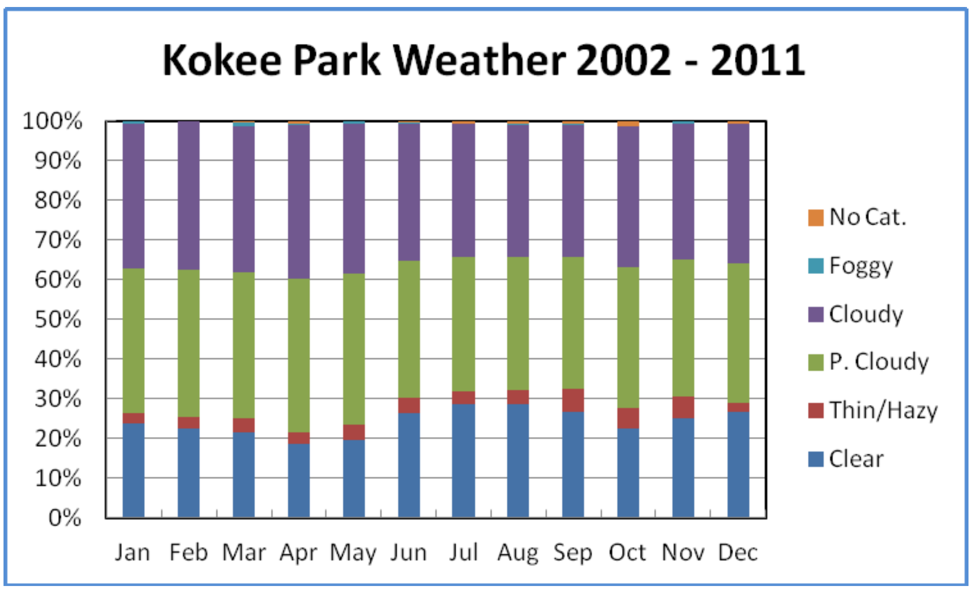


Mean monthly distribution of whole-sky cloud conditions at the Haleakala site over five years, from 2001 to 2005. From the bottom to top, "CLEAR" (black), "THINor-PARTIAL" (gray), "MEDIUM" (light gray), "CLOUDY" (white), and "RAINY" (white).

Excerpted from Suganuma, M., et al, 2007, The Infrared Cloud Monitor for the Magnum Robotic Telescope at Haleakala

For comparison, plots of KPGO sky conditions are provided below. KPGO's location within the microclimates of Kauai makes recorded visual onsite observations the only meaningful ground based data on sky conditions. The following plots are based on hourly comments by the operators at KPGO during operations, usually 2-3 days per week. The data indicate untrackable weather for SLR approximately 60% of the time.





7.3 RF and Optical Interference

7.3.1 RF Interference

While the Haleakala facility is supposed to be an RF quiet facility, there exists a number of RF generators in the form of FAA microwave transmitters or repeaters and television transmitters, located very near the University of Hawaii site location. These sources are in direct line of site and in close proximity to any potential VLBI pad and therefore could pose significant damage concerns for the VLBI receiver. Detailed analysis remains to be completed if this site would be considered for a VLBI system as is listed as an outstanding action.

SLR LHRS systems cannot currently be located or used a this facility, so no RFI from the SLR LHRS system would be an issue.

7.3.2 Optical Interference

Haleakala is one of the premier astronomical observing sites in the world. There are existing procedures at the site to limit interference among the various facilities on the site. There are also lighting restrictions in the region to limit the impact of night lighting on endangered night flying birds. For systems on the site transmitting laser beams, there is a Laser Traffic Control System (LTCS) currently under development to resolve conflicts between optical systems to ensure that reflected laser transmissions do not enter the fields of view of other telescopes on site.

7.3.3. Other Possible Interference

Other than possible sources of interference (cell phones? laser pointers?) that may be carried by tourists to the park and native Hawaiians visiting the site, the remoteness and very high altitude of the site greatly minimizes the possible sources of manmade interference that are not under the control of the site.

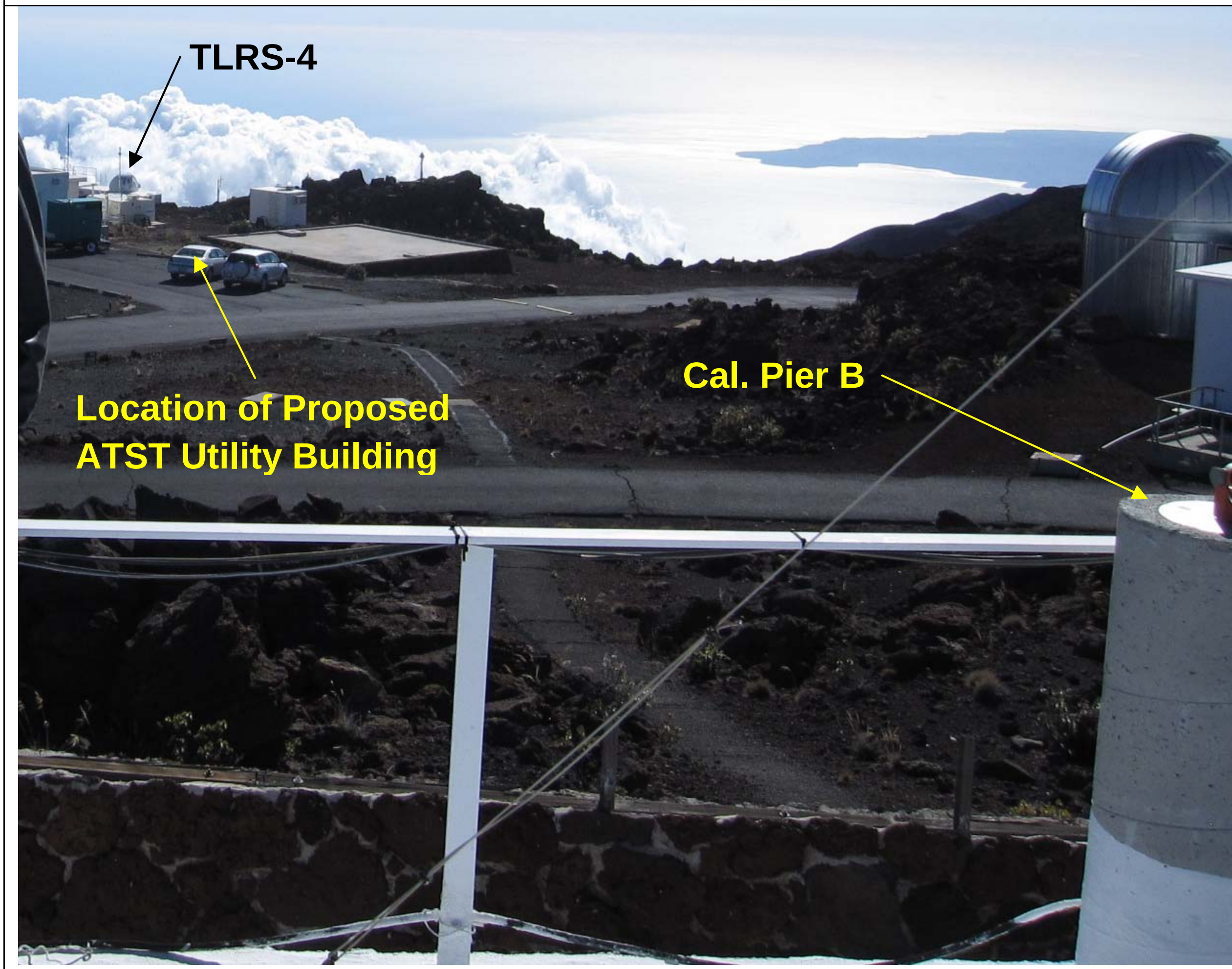
7.4 Horizon Conditions

The *Site Requirements for GGOS Fundamental Stations* document states that, ideally, stations should have an obstruction free view down to 5 degrees elevation over 95% of the horizon.

At Haleakala, as with any site, horizon conditions for each technique will vary depending on the location and height of each technique on the site. For SLR, the radar of the Laser Hazard Reduction System (LHRS) used for aircraft protection works best with a clear horizon within 400 meters free of trees, buildings, towers, and other tall objects that would contribute to ground clutter. There are no trees and minimal vegetation at the Haleakala site. The rocky topography and manmade structures define the horizon.

A utility building for the soon to be built ATST is understood to probably block the optical path between TLRS-4 and Calibration Target A. Consequently, new calibration piers are being planned for installation but locations have not yet been finalized.

View From Calibration Pier B Toward TLRS-4



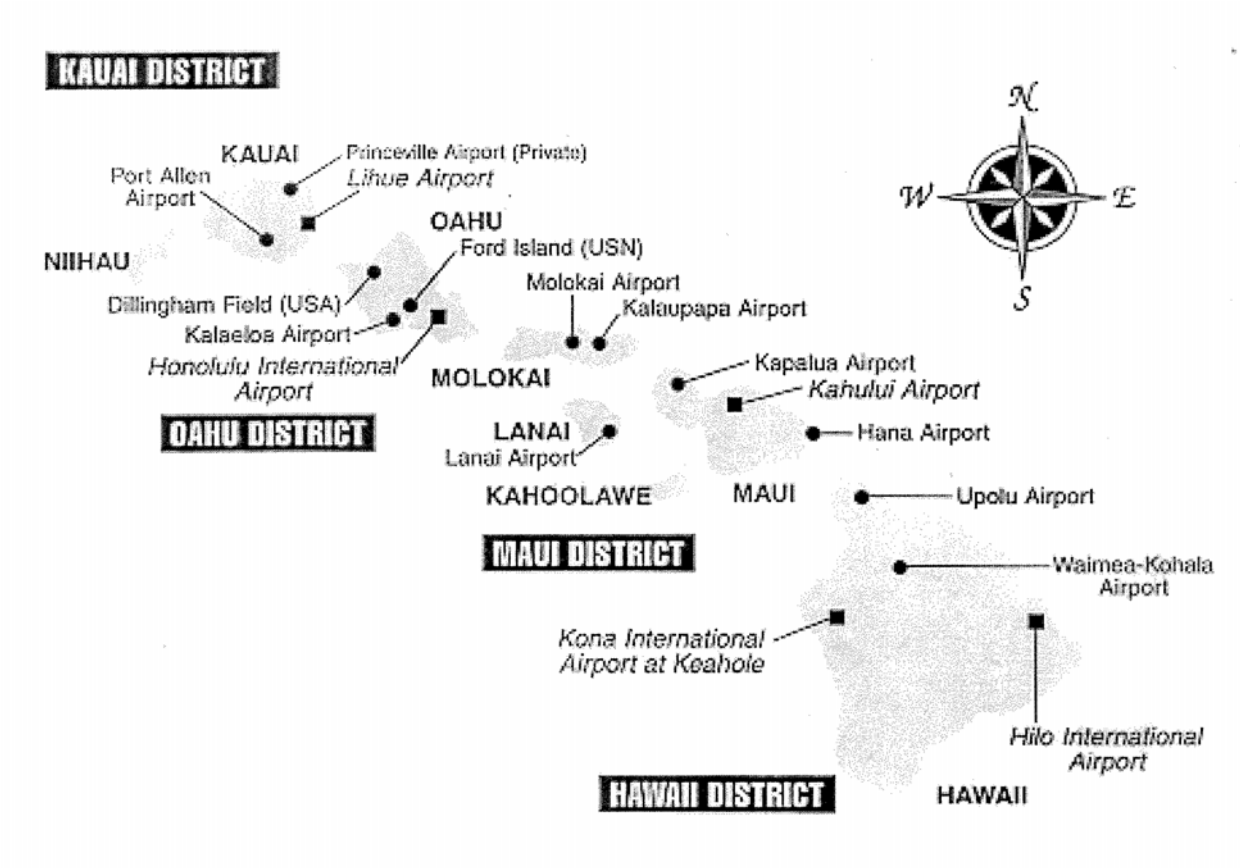
Haleakala Horizon From Roof of TLRS-4

Haleakala Horizon From Proposed NGSLR Pad

Haleakala Horizon From Airglow Building

7.5 Air Traffic

Hawaiian Airports



Source: The State of Hawaii Airport Activity Statistics by Calendar Year, 2011, State of Hawaii, Department of Transportation, Airports Division

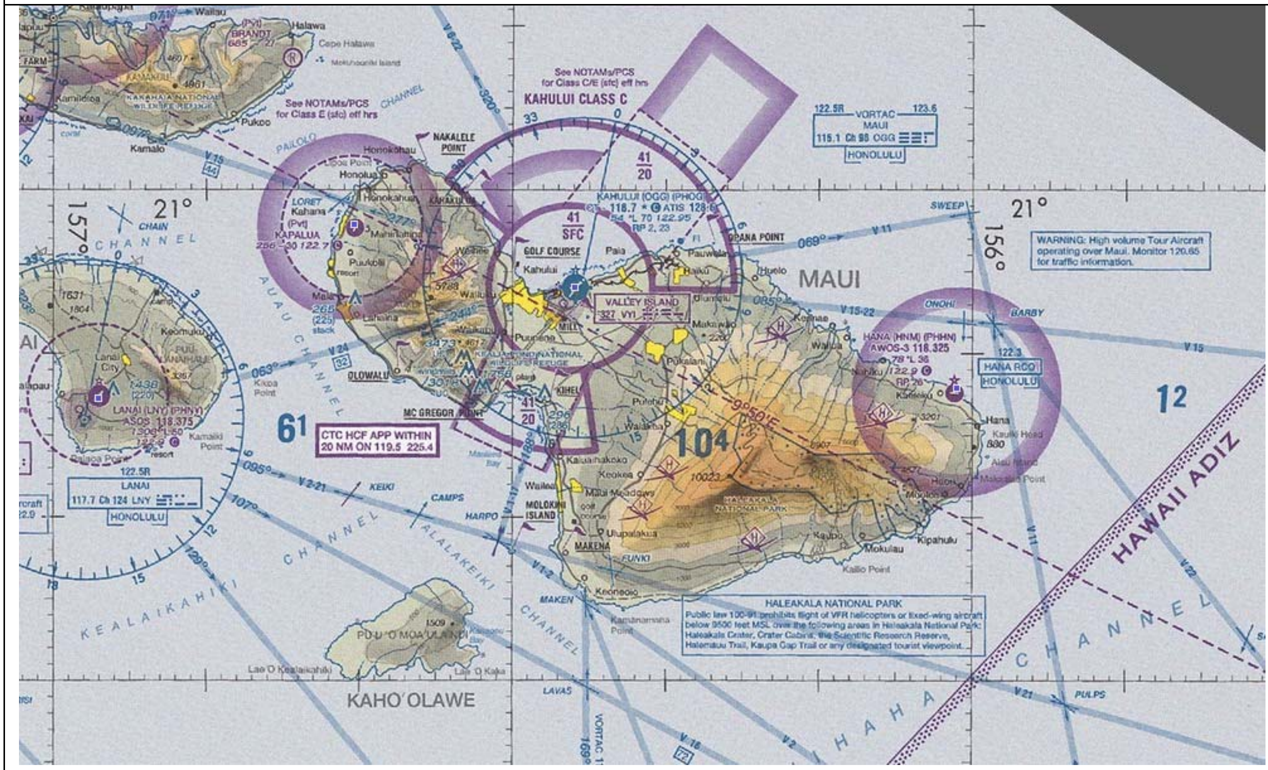
Airports and Airfields on Maui

Hana Airport Hana, Hawaii Facility Usage: Public	Hawaii State Airports Div 400 Rodgers Blvd, Suite 700 Honolulu, HI 96819 (808) 838-8701
Kahului Airport - OGG Kahului, Hawaii Facility Usage: Public	Hawaii State Airports Div Honolulu Intl Arpt Honolulu, HI 96819 (808) 838-8600
Kawela Farm Heliport - 99HI Kaunakakai, Hawaii Facility Usage: Private	Corboy Ltd Partnership 95-717 Kipapa Drive 23 Mililani, HI 96789 (808) 627-0824
Molokai Airport - MKK Kaunakakai, Hawaii Facility Usage: Public	Hawaii State Airports Div Honolulu Intl Arpt Honolulu, HI 96819 (808) 836-6432
Panda Airport - HI49 Kaunakakai, Hawaii Facility Usage: Private	John Hutton Corp 2005 Kalia Rd Honolulu, HI 96815 (808) 941-1566
Hyatt Regency Maui Hotel Heliport - HI50 Lahaina, Hawaii Facility Usage: Private	Km Hawaii Inc. 900 Fort St Mall, Suite 1350 Honolulu, HI 96813 (808) 521-9404
Kapalua Airport - JHM Lahaina, Hawaii Facility Usage: Private	State Of Hawaii Airports Division Honolulu Intl Airport Honolulu, HI 96819 (808) 838-8701
Lanai Airport - LNY Lanai City, Hawaii Facility Usage: Public	Hawaii St Arpts Div Honolulu Intl Arpt Honolulu, HI 96819 (808) 836-6432
Source: http://www.tollfreeairline.com/hawaii/maui.htm	

Statistics of air traffic

http://hawaii.gov/dot/airports/library/publications-and-statistics/annual-air-traffic-statistics.pdf

Airport	Passengers	Cargo (U.S. Tons)	Mail (U.S. Tons)	Aircraft Operations (takeoffs + landings)
Honolulu International	18,443,873	369,360	116,029	263,440
Kahului - Maui	5,346,694	25,482	14,533	118,896
Kona International	2,649,493	19,688	8,822	124,889
Lihue	2,416,812	14,386	0	106,815
Hilo International	1,279,342	25,245	3,218	78,663
Molokai	169,233	816	0	26,491
Kapalua	80,627	873	0	5,846
Lanai	90,567	572	0	8,094
Kalaupapa	1,795	160	0	2,472
Hana	664	27	0	1,776
Waimea-Kohala	54	0	0	1,418
Kalaeloa	-	-	-	112,830
Dillingham Airfield	-	-	-	17,338
Port Allen	-	-	-	3,368
Upolu	-	-	-	0
Source: The State of Hawaii Airport Activity Statistics by Calendar Year State of Hawaii, Department of Transportation, Airports Division Note: Nearby Barking Sands PMRF is not included.				

Flight Navigation Chart For Maui

Source: http://vfrmap.com/?type=vfrc&lat=20.796&lon=-156.014&zoom=10

7.6 Aircraft Protection

Restrictions on RF transmissions at the site do not permit the use of radar with the Laser Hazard Reduction System (LHRS). Currently, mount observers deactivate the laser transmission whenever a plane approaches the beam. Work is in progress to get an FAA feed from the Air Force, and it may also be possible to use something like the transponder solution that is utilized at the Apache Point station. This is possible only because of the altitude of the Haleakala site is over 10,000 feet, the base threshold of the FAA requirement for any aircraft flying over 10,000 feet to have an operational transponder at all times. There is also a FAA feed utilized by the USAF at the MSSS that may be utilized to support aircraft safety.

Trailer Used by Mount Observer for aircraft protection

7.7 Communications

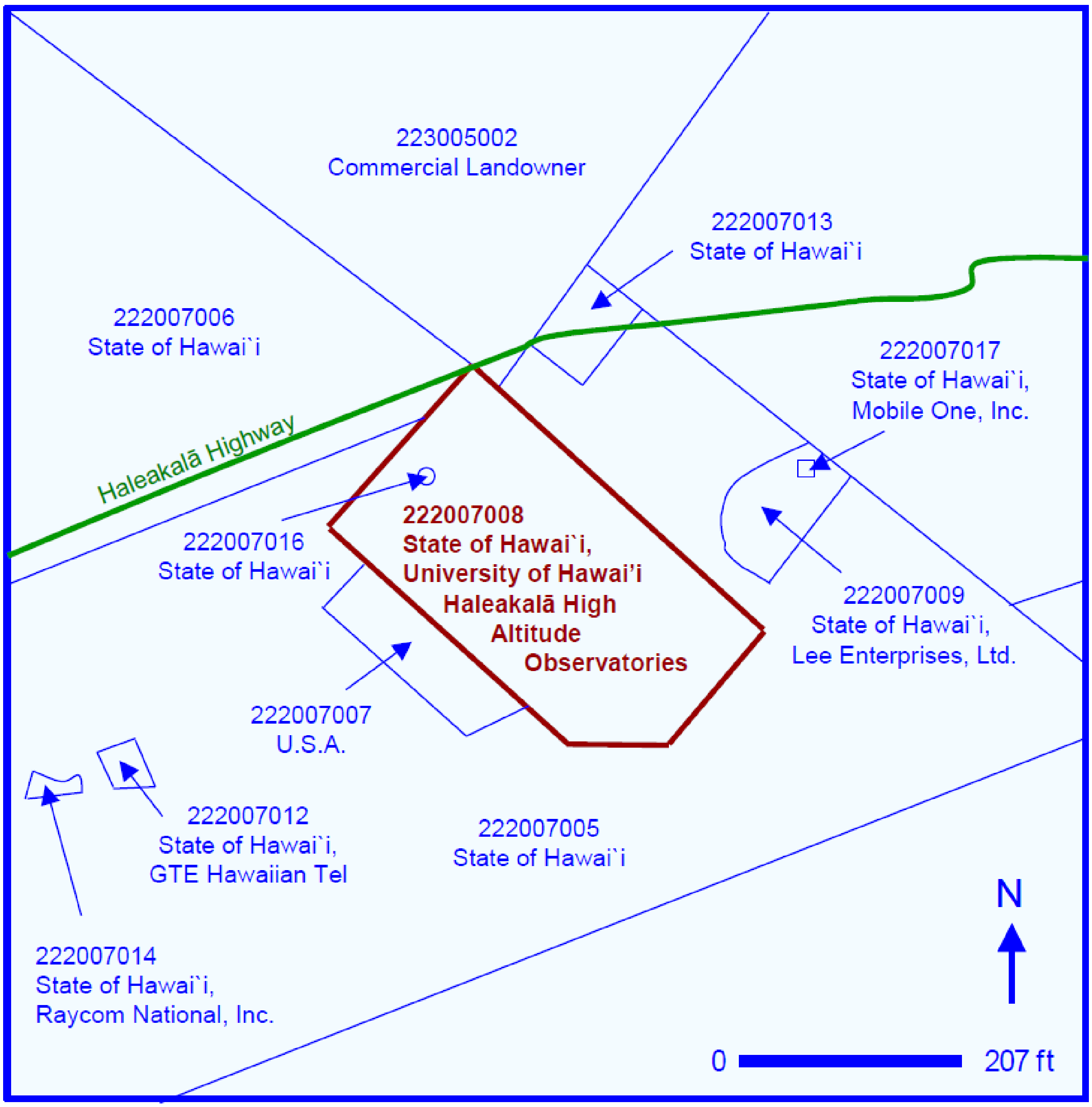
The SLR station, TLRS-4, currently shares a CO3 comm line provided by the U. S. Air Force. The PAN-STARRS project has a dedicated high speed line provided by Verizon. A gigabit connection for the site is expected in the near future. This could be used to support e-VLBI transmission.

7.8 Land Ownership

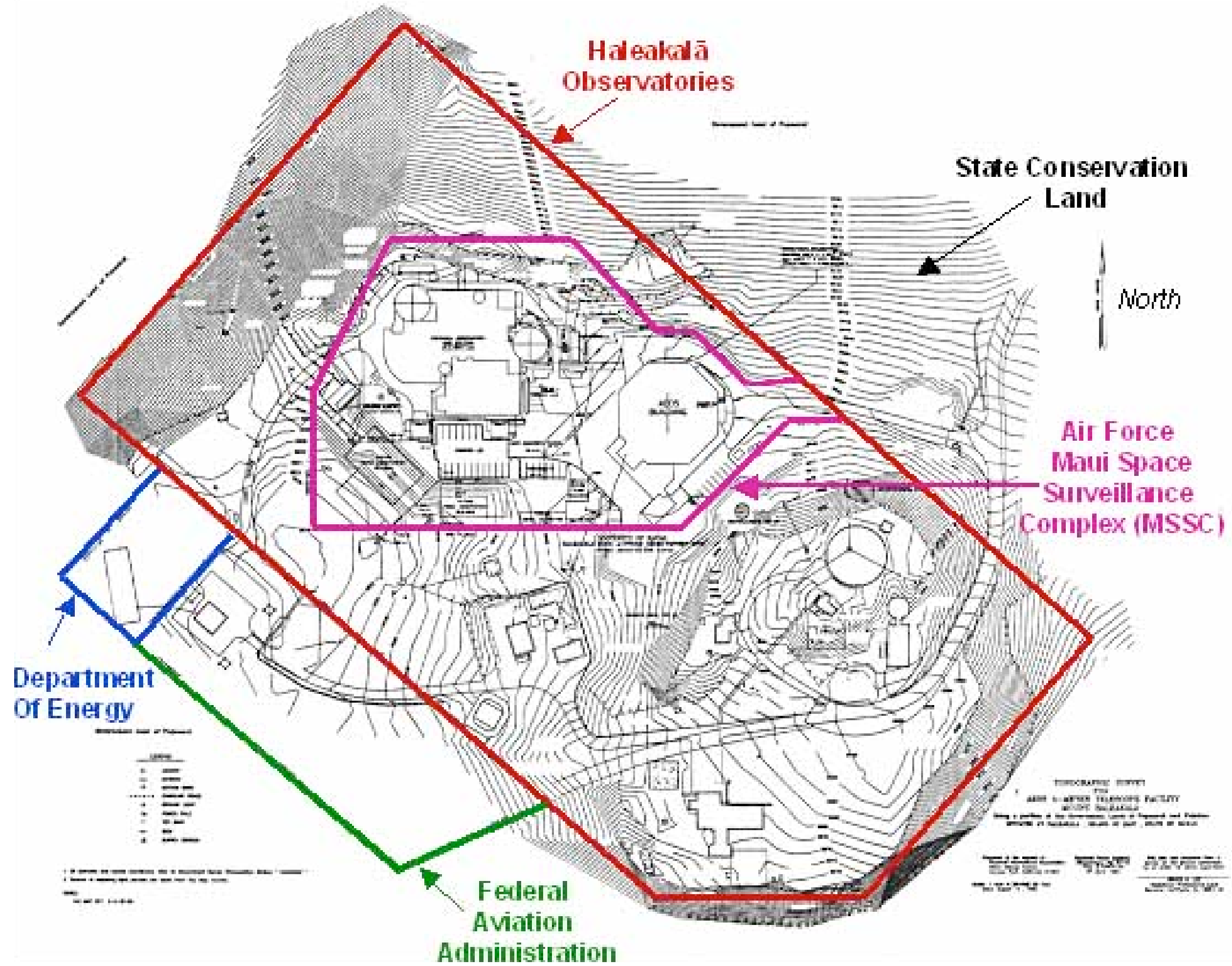
The University of Hawaii owns the site by Governor's Executive Order 1987 issued in 1961. There is no expiration date. An excellent reference describing the site, its history, usage, and restrictions is the *Haleakala High Altitude Observatory Site Management Plan.*

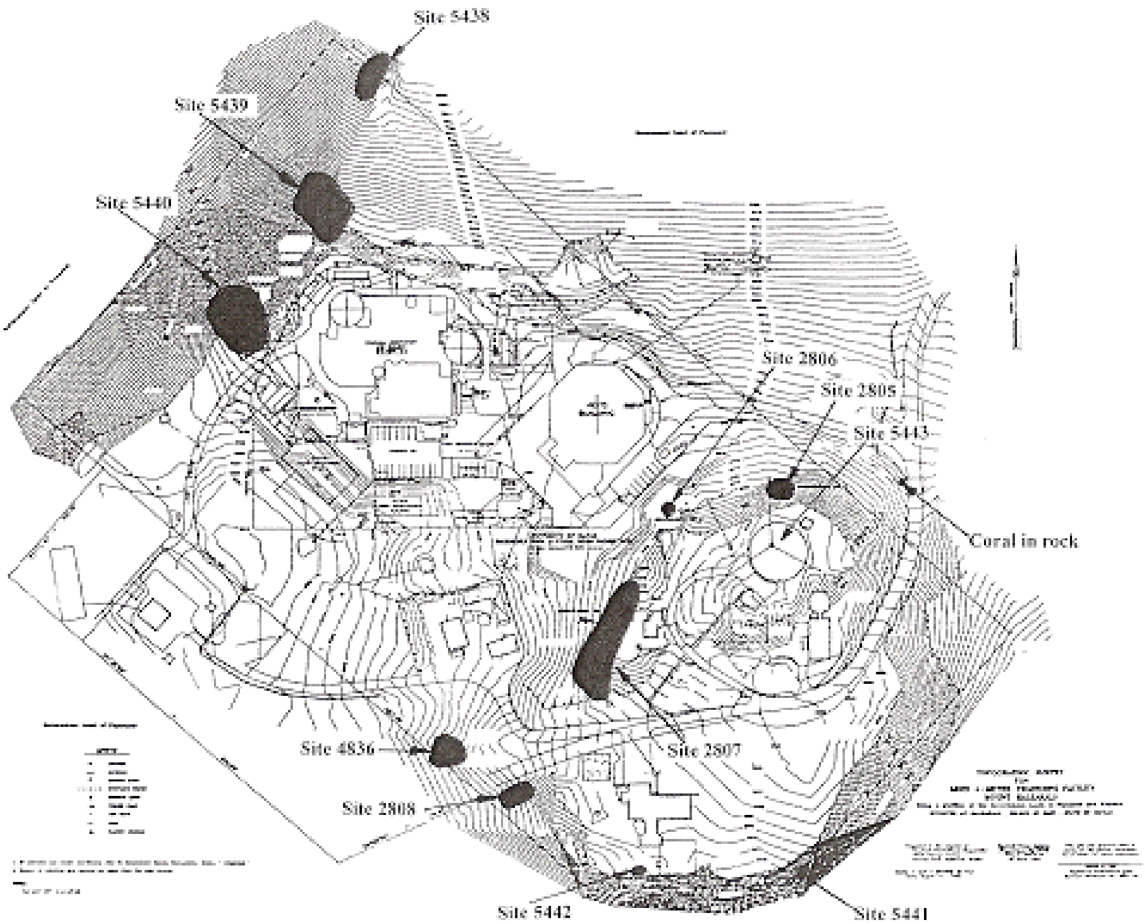
Improvements to the Haleakala facility are significantly more difficult than at KPGO on Kauai, largely due to restrictions addressing environmental and cultural concerns. With the lease of the KPGO site to NASA, NASA is permitted to make changes within code without the cultural and environmental clearances required at Haleakala.

Haleakala Observatory Site and Adjacent Properties



Source: Haleakala High Altitude Observatory Site Management Plan
Note: The Haleakala Highway is not positioned correctly on the map.

Haleakala Observatory Site and Adjacent Properties

Source: Haleakala High Altitude Observatory Long Range Development Plan

Archeological Sites at Haleakala Observatory Site

Source: Haleakala High Altitude Observatory Site Management Plan

7.9 Local Ground Geodetic Networks

7.9.1 Local Station Network

Periodic surveys of the Haleakala site have been performed in 1980, 1981, 1984, 1986, 1989, 1993, 1996, 2002, 2005, and 2006. The KOLEKOLE Reset 1950 survey marker has been used as the primary survey control monument. A GPS CORS station was installed at geodetic reference marker MAUI, PID AJ8470, in 1996.

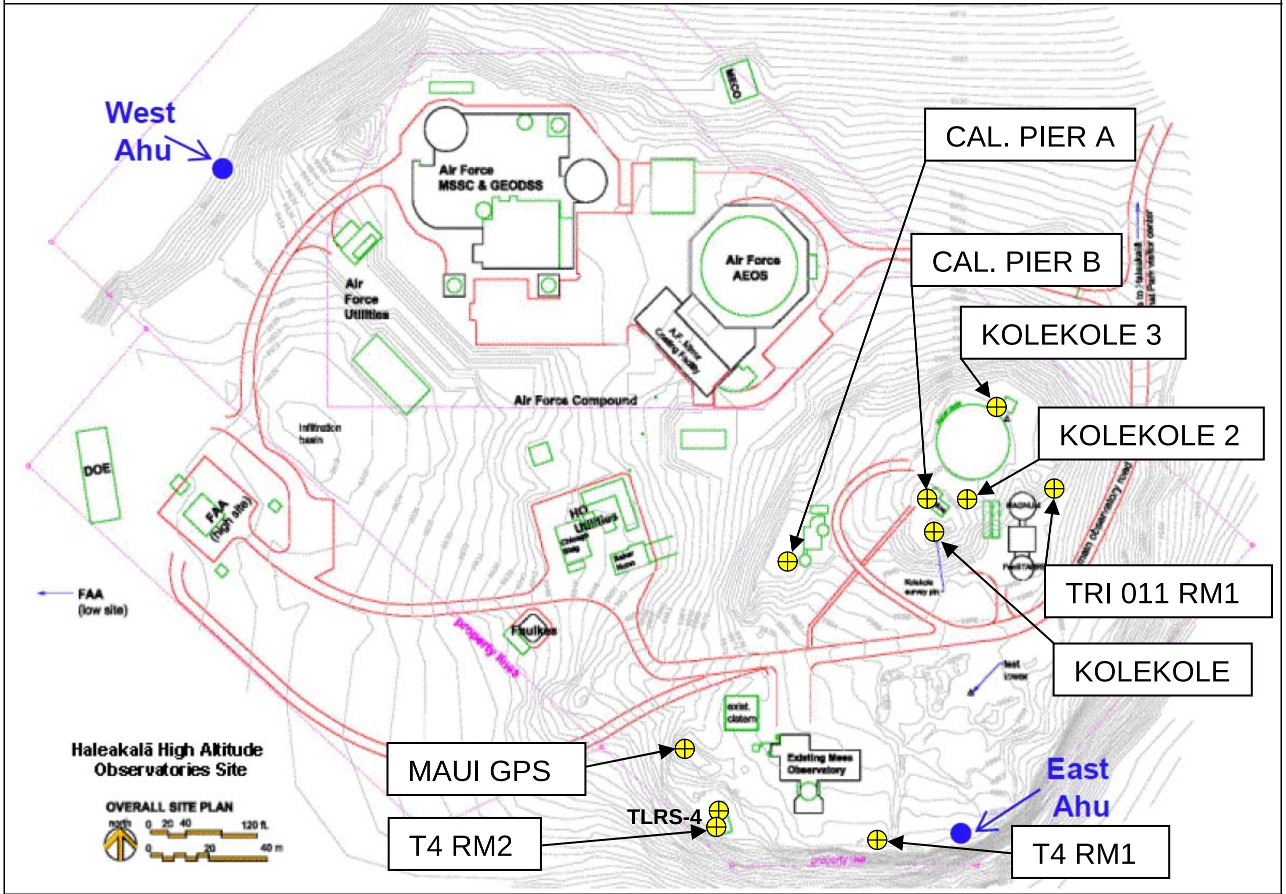
Markers and items with DOMES numbers are listed in the following table.

DOMES No.	Description	Code
40445M001	HOLLAS fixed carriage bolt (PID TU3486, Destroyed in 2005)	7210
40445M002	MOBLAS 7120 (1980) (PID TU3485)	7120
40445M004	Marker under SLR telescope. Local number 71191401	7119
40445S005	LLR Haleakala transmitter (Destroyed in 2005)	7210
40445S008	AshtechDorne-Margolin chokering antenna SN:12610 (PID AJ8470)	MAUI
40445S009	Permanent SLR Instrument – Intersection of axes	7119
Source: ITRF website http://itrf.ign.fr//site_info_and_select/site.php		

Markers Used in 2006 Survey:

a. KOLEKOLE Reset 1950 USC&GS (PID TU2862)
b. KOLEKOLE Offset DMA 1986
c. GPS Pier (1993) NASA
d. UH HIG
e. MOBLAS 7120 NASA
f. GPS Pier MAUI
g. Calibration Pier A (TLRS4)
h. Calibration Pier B (TLRS4)
i. T4 RM1
j. T4 RM2
k. T4 RM3
l. T4 Disk
m. TLRS4
n. Calibration Pier 1

Sampling of Geodetic Markers



Source of Map: Haleakala High Altitude Observatory Site Management Plan
Source of Marker Positions: TLRS-4 Survey Report, 2007

<table>
<tr><td colspan="2">TLRS-4 Geodetic Markers</td></tr>
<tr><td>
T4 RM1</td><td>
T4 RM2</td></tr>
<tr><td>
T4 RM3</td><td>
T4 2006</td></tr>
</table>

Calibration Pier A (2006)

Calibration Pier B (2006)

The calibration piers noted above will need to be replaced for TLRS-4's use as the ATST facility construction will block direct line of sight to TLRS-4. As of now, the new locations have not been provided at the time of this report.

If an NGSLR system were to be installed at the TLRS-4 site, visibility to at least two calibration piers would need to be planned and installed. This would also be required if one of the other two possible sites were to be used, either the Airglow or the lower vacant pad. Look angles and minimum ranges would need to be considered during a second review for the new system installation as part of the site preparation activity.

Differential Coordinates (DN, DE, DU) (Meters)

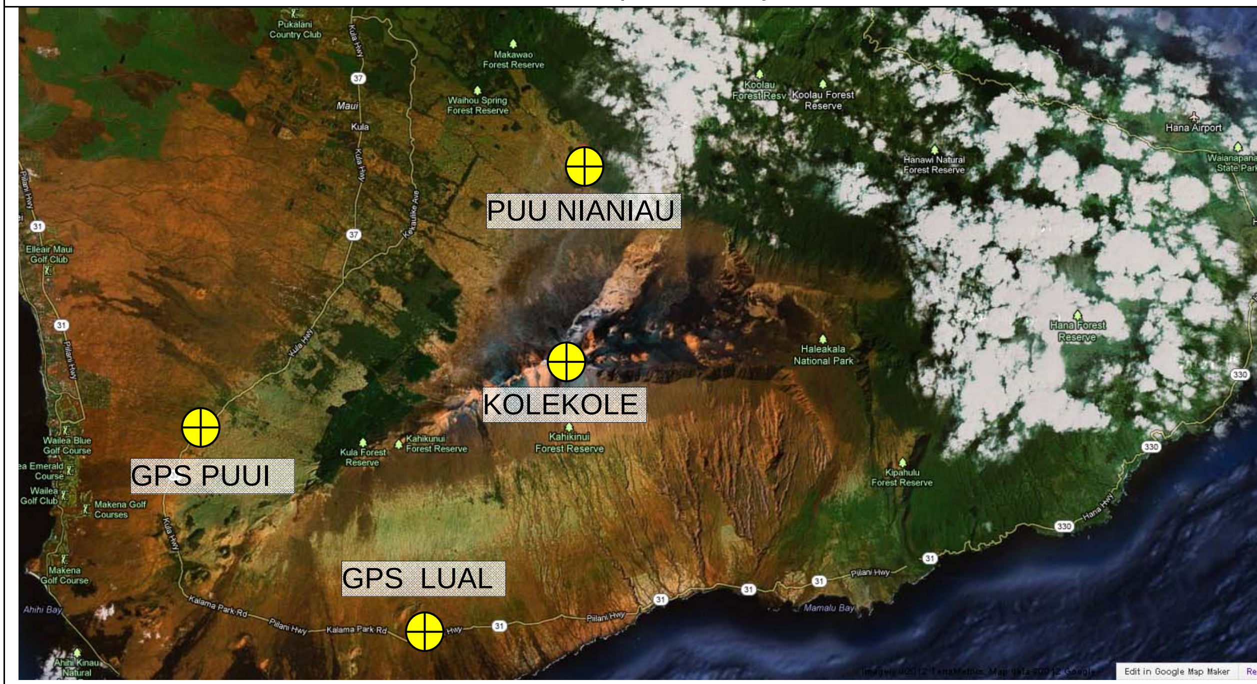
FROM STATION	TO STATION	∆N	∆E	∆U
T4 DISK	MAUI (40445S008)	+18.330	-10.755	+5.829
T4 DISK	7210 (40445M001)	+81.043	+104.755	+11.245
T4 DISK	MOBLAS 7120 (40445M002)	+124.750	+90.255	+11.551
MAUI (40445S008)	7210 (40445M001)	+62.713	+115.511	+5.416
T4 DISK	T4 RM1	-10.759	+53.199	+2.731
T4 DISK	T4 RM2	-3.650	-3.988	-0.210
T4 DISK	T4 RM3	+4.504	-11.299	+0.223

(DOMES information: - *http://itrf.ign.fr//site_info_and_select/site.php*

7.9.2 Regional Network

Footprint observations were carried out in 1993, 1996, and 2002. Included in the surveys were markers Kolekole Reset 1950 and Puu Nianiau 1950. Also included were two newly installed NASA survey control monuments, PUUI and LUAL. Puu Nianiau 1950 is approximately 7.4km from Kolekole Reset 1950. LUAL is approximately 12km away and PUUI is approximately 13.6km away from Kolekole.

Locations of Footprint Survey Markers



Some regional geodetic points, including a few on Kauai, are listed in the following table.

Domes No.	Description	Code
49896S006	Kokole Point, Kauai	KOK6
49896S005	Kokole Point, Kauai	KOK5
49980S001	Lihue, Kauai	LHUE
49970S001	Honolulu Tide Gauge	HNLC
40445S008	Ashtech Dorne-Margolin chokering antenna, Haleakala	MAUI
40445M001	Maui HOLLAS fixed carriage bolt (Destroyed)	7210
40445M004	Marker under TLRS-4	7119
40445S009	TLRS-4 telescope intersection of axes	7119
Source: ITRF website http://itrf.ensg.ign.fr/GIS/index.php		

7.10 Site Accessibility

Route 378, the main road through Haleakala National Park, provides access to the site. The site is at the end of the road in an area not open to the public. Native Hawaiians are, however, welcome to enter for cultural and traditional practices at any time..Access is gained through the National Park. This access is controlled in the event of severe weather or other need, determined by the National Park Service. In the past, immediate need for the UofH staff to the site is granted by the the National Park Service. There are other gates that can limit access to the summit, however, they are normally left open.

7.11 Local Infrastructure and Accommodations

The Haleakala site currently has the office space and facilities to support personnel onsite along with office, storage, and laboratory space to support a Fundamental Station facility. Offices supporting the site are located at a lower elevation in Pukalani. Pukalani is 26 miles from the observatory site, a drive that takes approximately 50 minutes to an hour.

Typical drive time from the closest accommodations is 50 minutes, but can vary considerably. Slow moving sightseeing tourists can make the trip take longer. Current members of the crew generally have drive times of 60 to 90 minutes.

7.12 Electrical Power

TLRS-4 currently shares power from a 400 amp transformer with the Las Cumbres Observatory Global Telescope Network (LCOGTN) (Faulkes) telescope facility.

Source of power -.Maui Electric Company (MECO); Substation on site. Single phase and three phase power are available.

Available capacity –. Dependent on MECO to make upgrades to its equipment at the site to support future requirements to meet power needs.

Reliability – Backup generators can be utilized on site as many of the other observatories use them. Proper location to limit contamination to sensitive optical components would need to be planned, depending on the final location determination for any SLR or VLBI system.

7.13 Technical and Personnel Support

Onsite operators and technical support are provided by the University of Hawaii Institute for Astronomy. Currently, the number of personnel working at TLRS-4 is 2 full time and 1 half time, plus 2-3 part time mount observers to support aircraft safety. There is a considerable reach back availability by the University of Hawaii technical personnel to support critical need and facilities support.

The level of support suggested by the *Site Requirements for GGOS Core Sites* document is that the site will require a senior technician, eight shift technicians (2 per shift), a logistics and administrative officer, and a custodian.

Any new construction or modifications to the University of Hawaii facility does require interaction with the University and with local organizations. Cultural awareness is very important to the locals, especially when it comes to activity on Haleakala. When site modifications or other work is performed at the site, all working on the project must take cultural awareness training. This training is provided, at cost, to sensitize those working on the island as to the cultural and religious aspects of working on Maui. In some cases, a local religious person must be retained to oversee work performed on the site.

Actual work performed at the summit requires that all work equipment, trucks, excavators, etc. be steam cleaned prior to traveling to the site. It is important that no foreign dirt/fill not from the summit be used at summit.

7.14 Site Security

Site security is controlled by the University of Hawaii. The site is not gated; there is only an "Authorized Entry Only" sign on the road entering the site. Native Hawaiians are welcome to enter for cultural and traditional practices.

Entrance to the Haleakala Observatory Site

Sign at Site Entrance

Source: Haleakala High Altitude Observatory Site Management Plan

7.15 Site Safety

At the Haleakala observatory site, the National Park Service provides the emergency medical service. An ambulance is stationed 10 miles, about 25 minutes, away at the park headquarters. In the case of a fire, the nearest fire station is about 45 minutes away.

7.16 Local Commitment

Since the University of Hawaii was granted control of the site at the summit of Haleakala by governor's executive order in 1961, several significant astronomical observatories have been located at the site. There are well known sources of infrastructure support on the island and neighboring islands.

8.0 Concluding Remarks

The critical mid-Pacific location and natural setting of the Haleakala Observatory site at high altitude are very desirable factors for a GGOS Fundamental Station site. The site has supported Satellite Laser Ranging for over three decades with HOLLAS and TLRS-4. Compared to KPGO on Kauai, Haleakala is a much better site for SLR, primarily due to much better sky conditions. Several astronomical observatories currently occupy the site, and the very large Advanced Technology Solar Telescope is to be built there soon. Locating and building a VLBI system at the site may prove difficult and time consuming due to potential significant RFI issues and with the lack of remaining space and environmental and cultural restrictions on construction at the site.

9.0 Work to be completed

Additional work that needs to be completed for this assessment, include the following:

1. Completion of an RFI Study for broadband.
2. Local hydrology (well levels, aquifer characteristics) and relationship to apparent vertical site stability.
3. Network analysis of multiple stations (i.e., differencing station positions may help separate site stability from instrumental/wave propagation effects). We are not aware of any evidence for landslide activity, but this should be checked in more detail.
4. Inclusion of a local and regional tie maps.
5. Identification of a possible locations for VLBI and DORIS.
6. Improved cloud coverage data.

10.0 References

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Appendix A: GGOS Site Stability Investigation From MIT

TBP -

Appendix B: List of Acronyms

AEOS	Advanced Electro-Optical System
ANSS	Advanced National Seismic System
ATST	Advanced Technology Solar Telescope
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
FAA	Federal Aviation Administration
GGOS	Global Geodetic Observing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning Satellite
HTSI	Honeywell Technology Solutions Inc.
IAG	International Association of Geodesy
IDS	International DORIS Service
IfA	Institute for Astronomy
IGS	International GNSS Service
ILRS	International Laser Ranging Service
IVS	International VLBI Service for Geodesy and Astrometry
KPGO	Kokee Park Geodetic Observatory
LAGEOS	Laser Geodynamic Satellite
LCO	Las Cumbres Observatory
LCOGTN	Las Cumbres Observatory Global Telescope Network
LLR	Lunar Laser Ranging
MECO	Maui Electric Company
MIT	Massachusetts Institute of Technology
MOBLAS	MOBile Laser System
MSSS	Maui Space Surveillance Site
NASA	National Aeronautics and Space Administration
NGSLR	Next Generation Satellite Laser Ranging
SGP	Space Geodesy Project
SLR	Satellite Laser Ranging
TLRS-4	Transportable Laser Ranging System – 4
UoH	University of Hawaii
VLBI	Very Long Baseline Interferometry