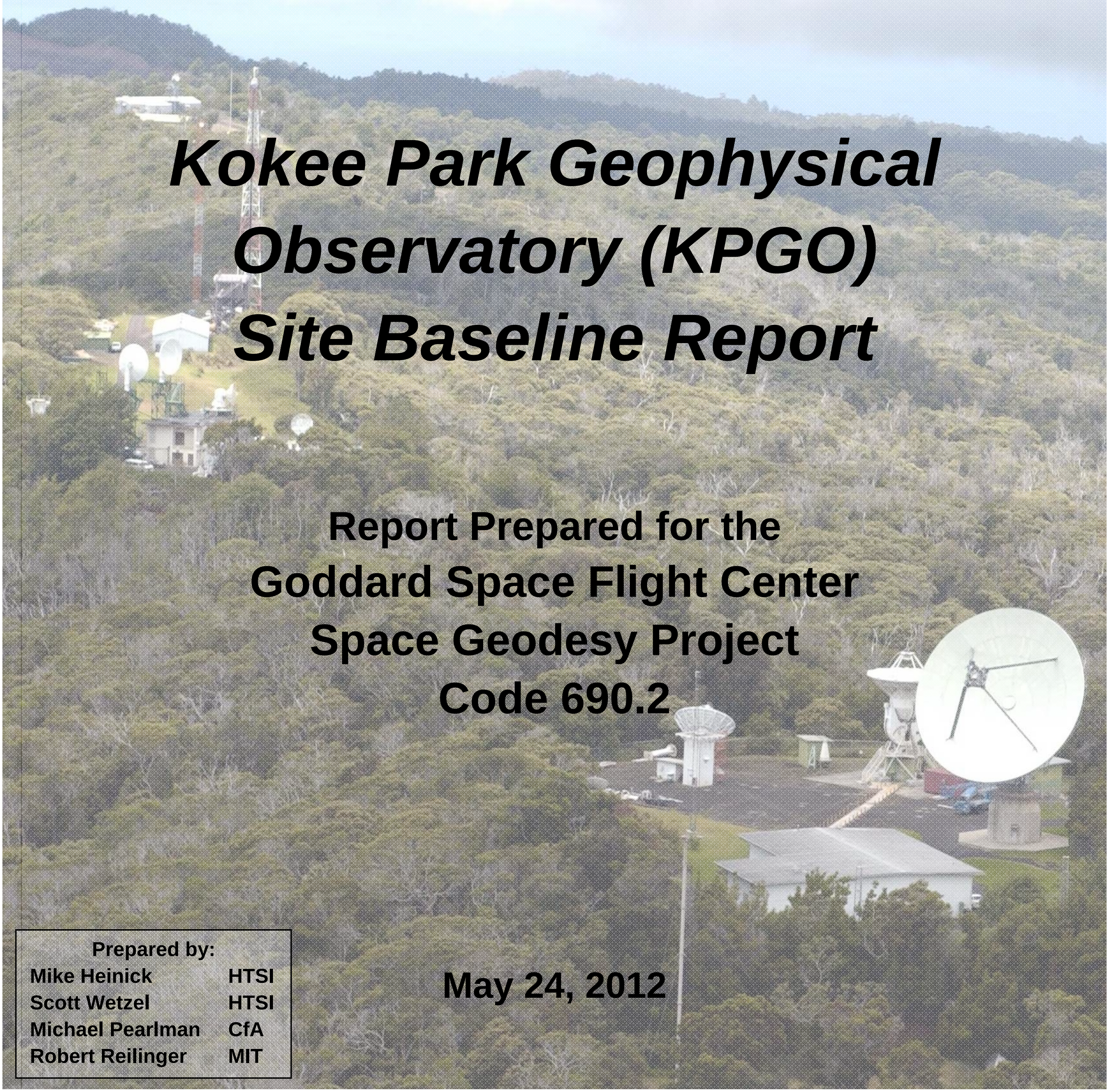

Kokee Park Geophysical Observatory (KPGO) Site Baseline Report

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

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May 24, 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: Chopo Ma from NASA Goddard Space Flight Center, Mark Evangelista and Julie Horvath from Honeywell Technology Solutions Inc., Michael Floyd and Robert King from MIT, Ron Curtis from ITT Exelis, 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 Fundamental Station requirements.

The Kokee Park Geodetic Observatory (KPGO) site is the first site to be baselined. This site has had long occupations with VLBI (1984, 1993), GNSS (1990) and DORIS (2002). The facility is located on the island of Kauai on property leased to NASA from the State of Hawaii. The KPGO facility consists of two parcels separated by approximately 350 meters. In the upper "E" parcel, VLBI and GNSS are collocated. In the lower "D" parcel, the DORIS antenna and a once planned SLR pad exist. The SLR pad has since been occupied by the US Navy, so another site nearby would need to be selected for an NGSLR.

Adequate infrastructure including power, excellent high speed communications (DREN), road access, site safety and security, and operations facilities exist at the KPGO. Local commitment is in place with a good working relationship with the US Naval Pacific Missile Range Facility (PMRF), who provide facilities maintenance and site security functions as part of the NASA / US Navy agreement. There exists a VLBI technical team of 7 members that support VLBI, GNSS, and DORIS site maintenance and/or operations. There is also good space available at the "E" parcel for the inclusion of a new 12 meter VLBI2010 antenna with the planned removal of the old Apollo 9 meter antenna. The site is geologically stable as Kauai is the oldest of the Hawaiian Islands, and the islands provide a key Northern Pacific location for all geodetic techniques.

Areas of concern for this facility include an issue with the two parcels. That these parcels are separated by approximately 350 meters and have no direct line of site between the compounds makes the site ties not ideal. No existing location for an NGSLR system is also at issue. However, there are several candidate areas within the D parcel that may be suitable for an

NGSLR system. A positive of the two parcels is that both the DORIS and SLR systems are somewhat removed from the VLBI2010 receiver which improves potential RFI issues. While the Navy has other antennas in the area, additional research into RFI from those antennas needs to be studied.

The main issue with the KPGO facility is the high levels of clouds and rain in the area. The KPGO site is usable for SLR only about 40% of the time due to clouds and rain. This is compared to over 75% useable sky at the nearby Haleakala observatory on the island of Maui.

Possible ways to mitigate the high amount of unusable SLR tracking weather on Kauai 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.

The resulting costs for option 3 would be greater with two NGSLR systems, however, a stronger tie may result from this.

In summary, the KPGO facility has a long time series for VLBI, GNSS, and DORIS. It is a key facility in the IVS, IGS, and IDS by its location in the Northern Pacific. There is ample infrastructure to support a Fundamental Station and strong local commitment. At issue is poor sky for strong SLR support and a compound that consists of two separate parcels that are farther separated than ideal. It is an excellent choice for at least VLBI2010, GNSS and DORIS.

3.0 Introduction - Kokee Park Site Conditions for GGOS

This report describes the current conditions at the Kokee Park Geodetic Observatory (KPGO) 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.

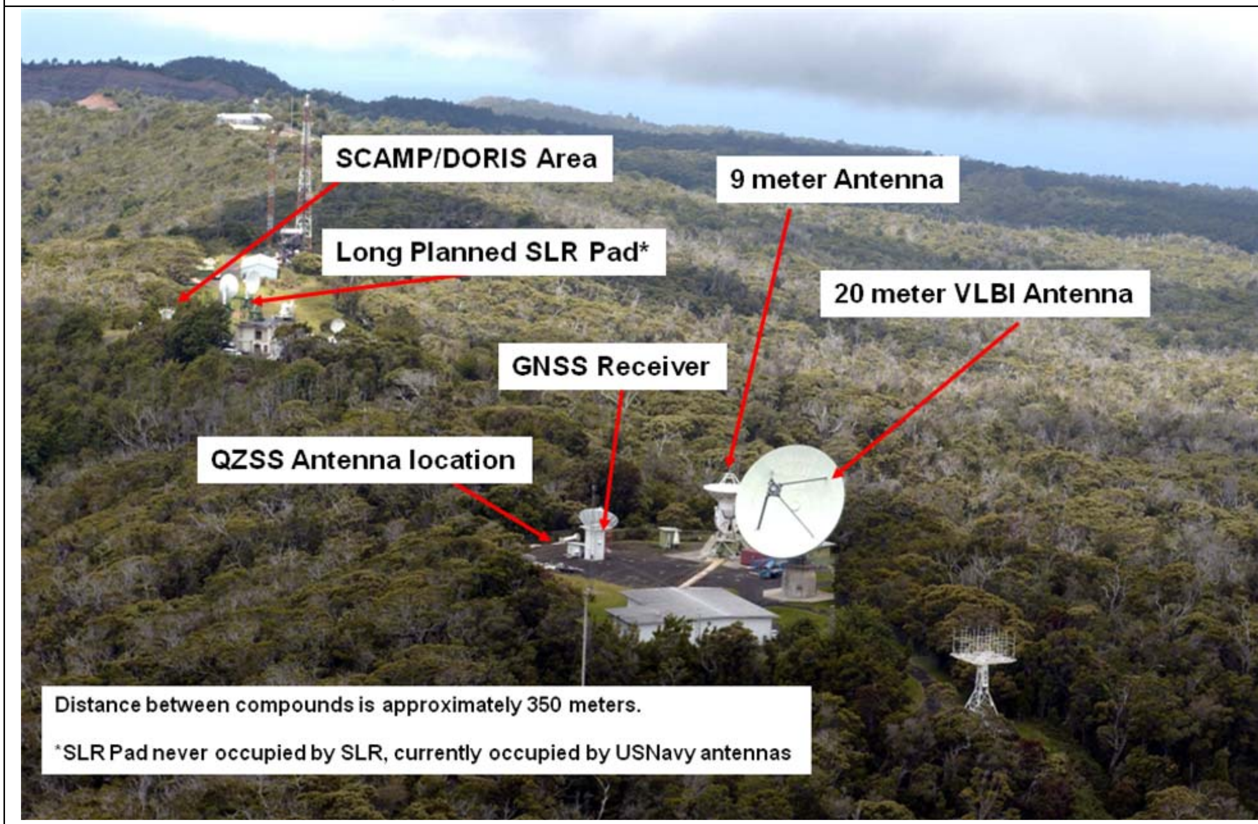
KPGO is the first of the existing NASA sites to be examined for suitability for all techniques to be considered for a Fundamental Station. The key elements that make up a Fundamental Station include a Next Generation Satellite Laser Ranging (NGSLR) system, a broadband capable Very Long Baseline Interferometry (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 sites, 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

Operations at Kokee Park began in 1961 as part of the NASA Manned Space Flight Network (see Carpenter, Troy D, March 4, 2008, *Kauai, Hawaii Kokee Park Geophysical Observatory (KPGO) VLBI Geodetic Survey Report*). Since that time the site has continued operations as part of various NASA networks and projects.

Aerial View of KPGO Looking to the Southwest



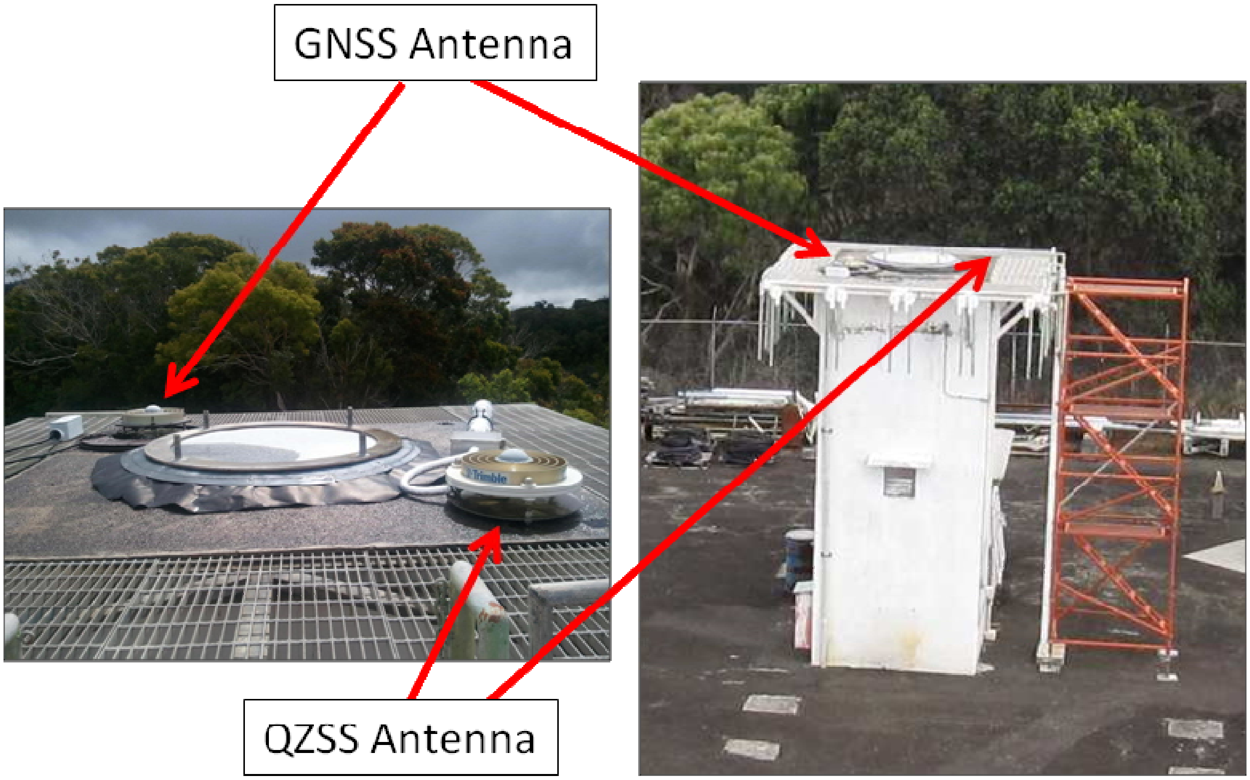
VLBI – In 1984 a 9-meter S-band antenna was modified to support the VLBI Great Alaska Pacific Experiment and began continuous VLBI operations in 1986. A 20 meter antenna was completed and began VLBI operations in 1993, and the 9-meter VLBI operations were discontinued. Kokee Park is scheduled to participate in 104 24-hour sessions in the observing year 2012. This is the fifth highest number, only trailing by a small margin Wettzell, Ny Alesund, Fortaleza, and TIGO, and followed by Tsukuba and Westford. The subsequent stations contribute half or less station days. Kokee Park and Wettzell form the baseline for the weekday Intensive sessions (1-hour sessions) for the determination of dUT1, i.e., 260 sessions in 2012. While Tsukuba operations supporting Intensive observations are impacted in the aftermath of the Tohoku earthquake of March, 2011, Kokee Park serves as backup station for the Tsukuba Intensives.

20 Meter VLBI Antenna and Ops Building

GNSS - The 3028-S geodetic marker was installed in 1987. A GPS antenna was installed on that marker in late 1990.

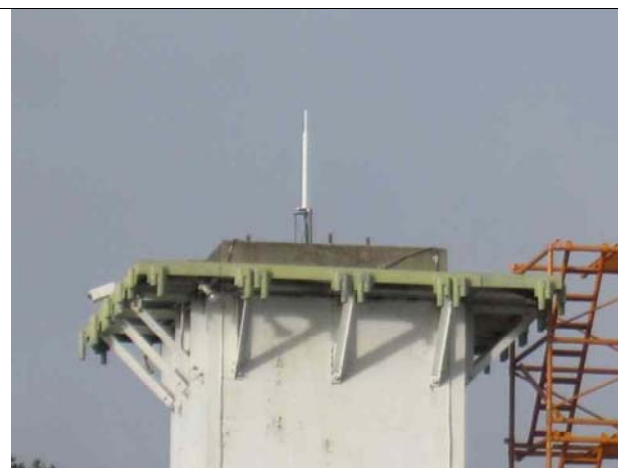
QZSS – The Quasi-Zenith Satellite System (QZSS) antenna was installed in 2010 as part of a JAXA initiative to have a QZSS ground system in the Hawaii region. It consists of a Trimble choke ring antenna, capable of tracking all GNSS satellites. It's current use, either just for QZSS or most/all GNSS is being determined.

JPL GPS 3028-S KOKB, QZSS Antennas



DORIS – The DORIS KOKA station Alcatel antenna was installed in September, 1990. It was replaced with the DORIS KOLB station Starec 52291 type antenna located in the southern compound in November, 2002, to move the RFI source away from VLBI.

Doris Antenna KOLB



SLR – No SLR at this site. A pad was constructed, but has never been surveyed or occupied by a SLR system. The pad is currently occupied by USN antennas.

5.0 Global Consideration for the Location

Kokee Park Geophysical Observatory (KPGO) is located near the middle of the North Pacific Ocean. The KOKB GPS station at the KPGO site is located at latitude 22 07’ 34.53703” N and longitude 200 20’ 6.27697” E (159 39’ 53.72303” W).

KPGO in Hawaii	
SGP Sites in Hawaii	KPGO on Kauai
	

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 KPGO site compares with other Hawaii sites, such as Haleakala. Due to the close proximity between the two islands, other requirements will be a more determining factor for the items of this section.

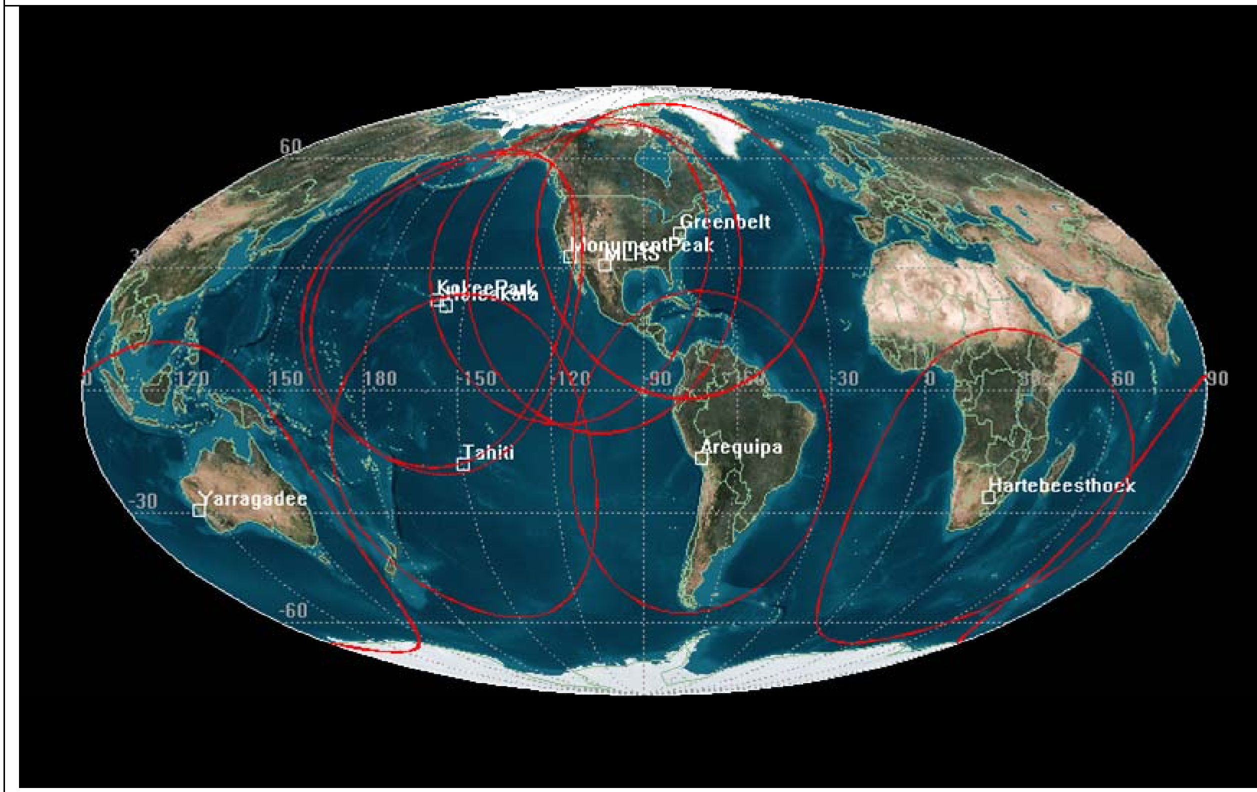
5.2 Technical Distribution

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

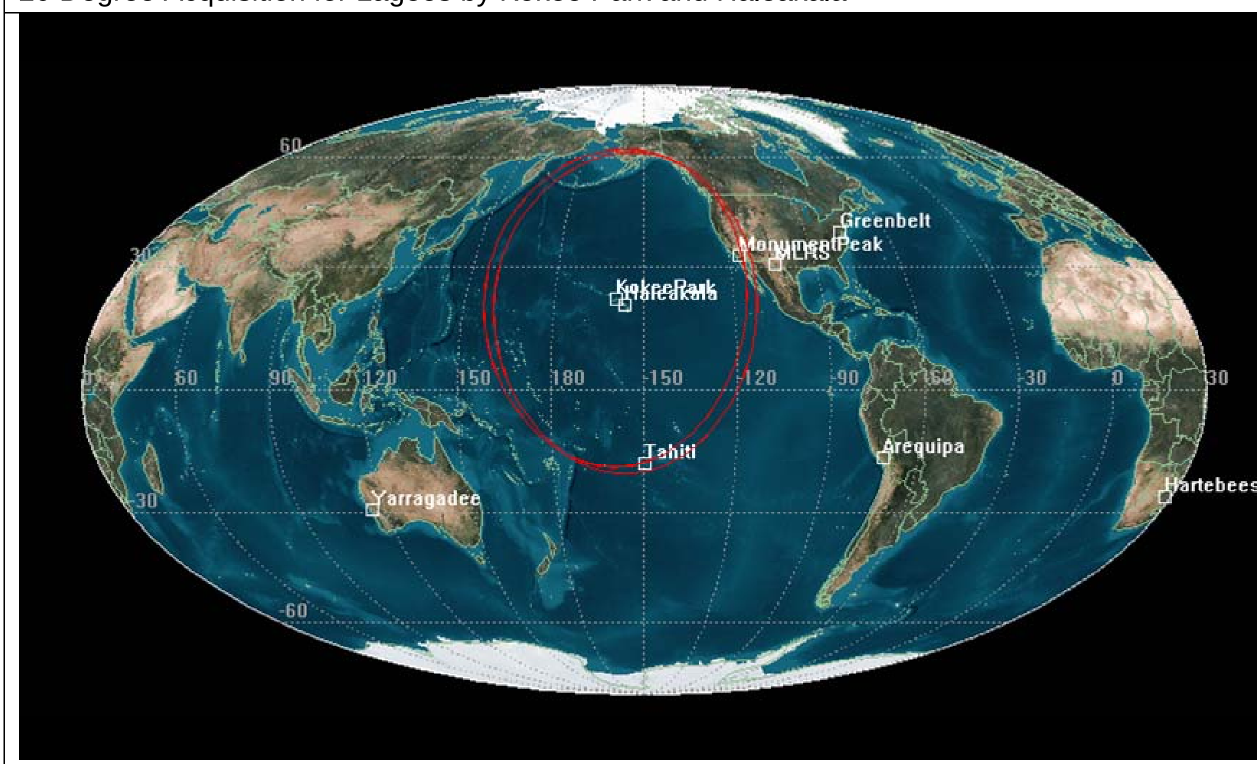
5.3 Technique Dependent Distribution

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 and LARETS 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.

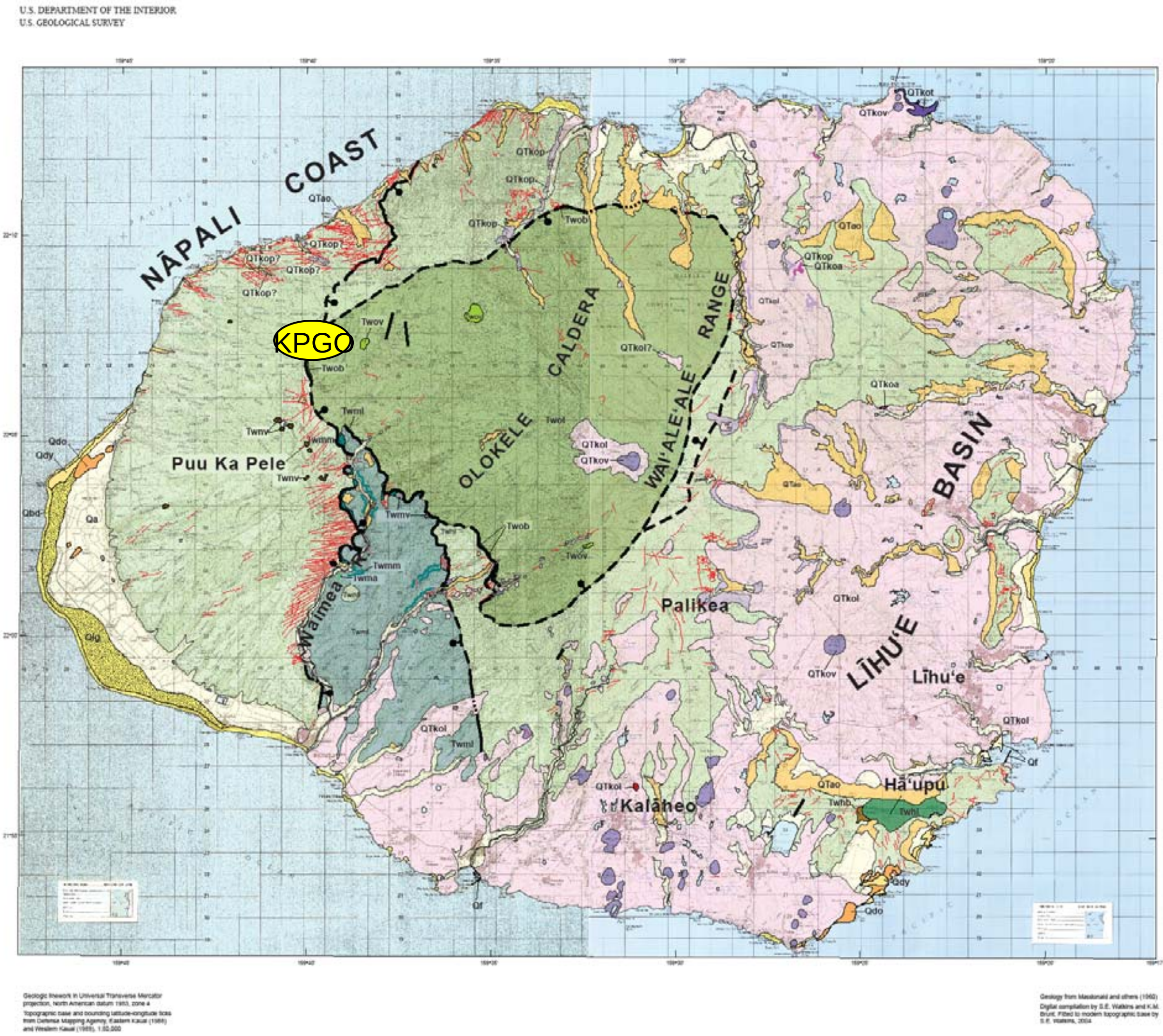
20 Degree Acquisition for Lageos by NASA Sites



20 Degree Acquisition for Lageos by Kokee Park and Haleakala



6.0 Geology



6.1 Substrate

Bedrock – Volcanic basalt http://www.teok.com/Maps/Geologymap.html
The Waimea Canyon Basalt is almost all olivine basalt making up thin, highly vesicular flows. 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

From SSWB – Waimea Canyon Basalt, Napali member lava flow (see map) of the Pliocene and Miocene.

Geologic Map of the State of Hawai'I, Sheet 2—Island of Kaua'I, 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

http://www.hawaii.edu/environment/ainakumuwai/html/ainakumuwaiislandformation.htm

Local structure – The site is located on the northwest rim of the Olokele Caldera on the upside of a nearby fault (see the map)

6.2 Tectonic Stability

Nearby faults include the Olokele Caldera rim fault and the Kalalau fault

A search of the Advanced National Seismic System (ANSS) catalog for earthquakes with magnitudes greater than 2.0 in an area bounded by latitudes 21N and 23N and longitudes 158W and 161W from 2002 to the present yielded a single event of magnitude 3.0 that occurred on August 13, 2008, at latitude 21.53N and longitude 158.49W. That location is to the southeast, just off of the northwest coast of Oahu. (Source: http://quake.geo.berkeley.edu/cnss/catalog-search.html, accessed 5/16/2012)

A team from MIT has begun investigating the stability of the KPGO site and has issued a draft report which is included at the end of this document. The initial investigation has focused primarily on the analysis of the GPS time series from Kokee Park. Magnitudes of the annual and semi-annual terms range from 0.1 to 0.7 mm in horizontal and from 0.4 to 1.6 mm in vertical. These values include a number of unmodeled factors that will require a much more detailed analysis of the GPS data and other relevant data before a more definitive statement on site stability can be provided. They conclude that, within the Hawaiian Islands, Kokee Park is among the most stable in regard to tectonic or volcanic deformation. The main issues are unmodeled loading due to tides and excessive rainfall. These should be monitored and modeled to achieve the 0.1 mm/yr velocity and 1 mm positioning specified for GGOS.

7.0 Site Area

Kauai, Hawaii, is an island ~40-50km across. KPGO is located at a height of approximately 1165 meters on the northwestern side of the island on the ancient caldera rim above the Napali coast. The site consists of two compounds separated by approximately 350 meters on a line running just east of north to just west of south.

7.1 Local Size

The northern compound, or Parcel E, covers an area of approximately 1.4 hectares. The VLBI 20m and 9m antennas, KPGO VLBI Operations building, PEACSat 7.2m antenna, and the KOKB GPS station, are located there.

The southern compound, or Parcel D, covers an area of approximately 0.7 hectares, and contains the DORIS KOLB station and numerous other US Navy antennas. The DORIS antenna was located in the southern compound to avoid RFI interference to the VLBI antennas in the northern compound.

Layout of KPGO

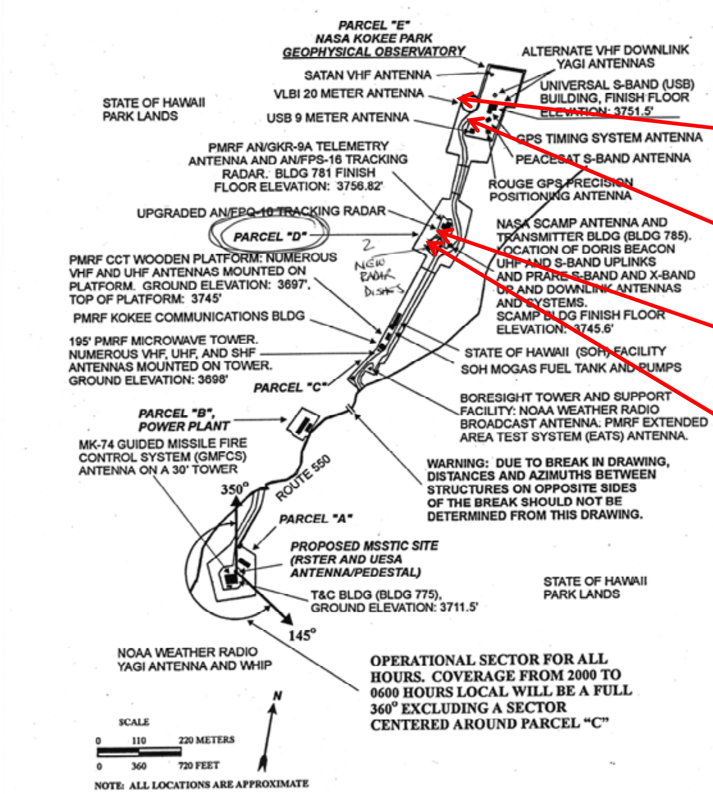


Figure 3. Map of the NASA Kokee Tracking Station (NKTS, Also Known as PMRF Kokee) Showing the RF Systems at Parcels "A" through "E"

5

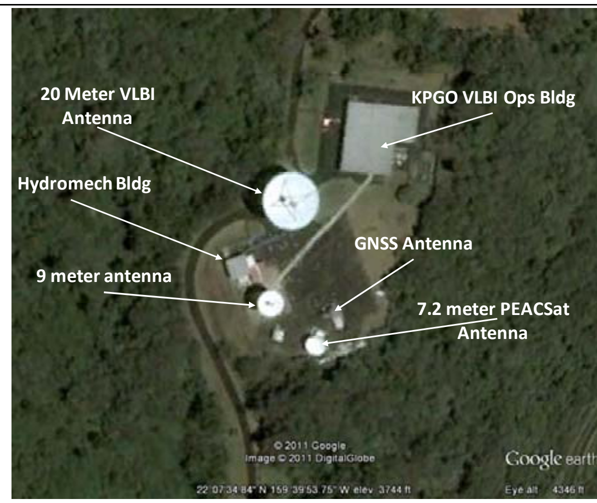
KPGO Site Description

- 20 meter VLBI Antenna
  - Elevation – 3751 feet
  - Taken from site building
- GNSS antenna
  - Elevation -3751 feet
  - Taken from site building
- DORIS Antenna
  - Elevation – 3745 feet
  - Taken from SCAMP building floor
- Planned SLR Pad
  - No SLR system ever occupied
  - Currently occupied by other antenna

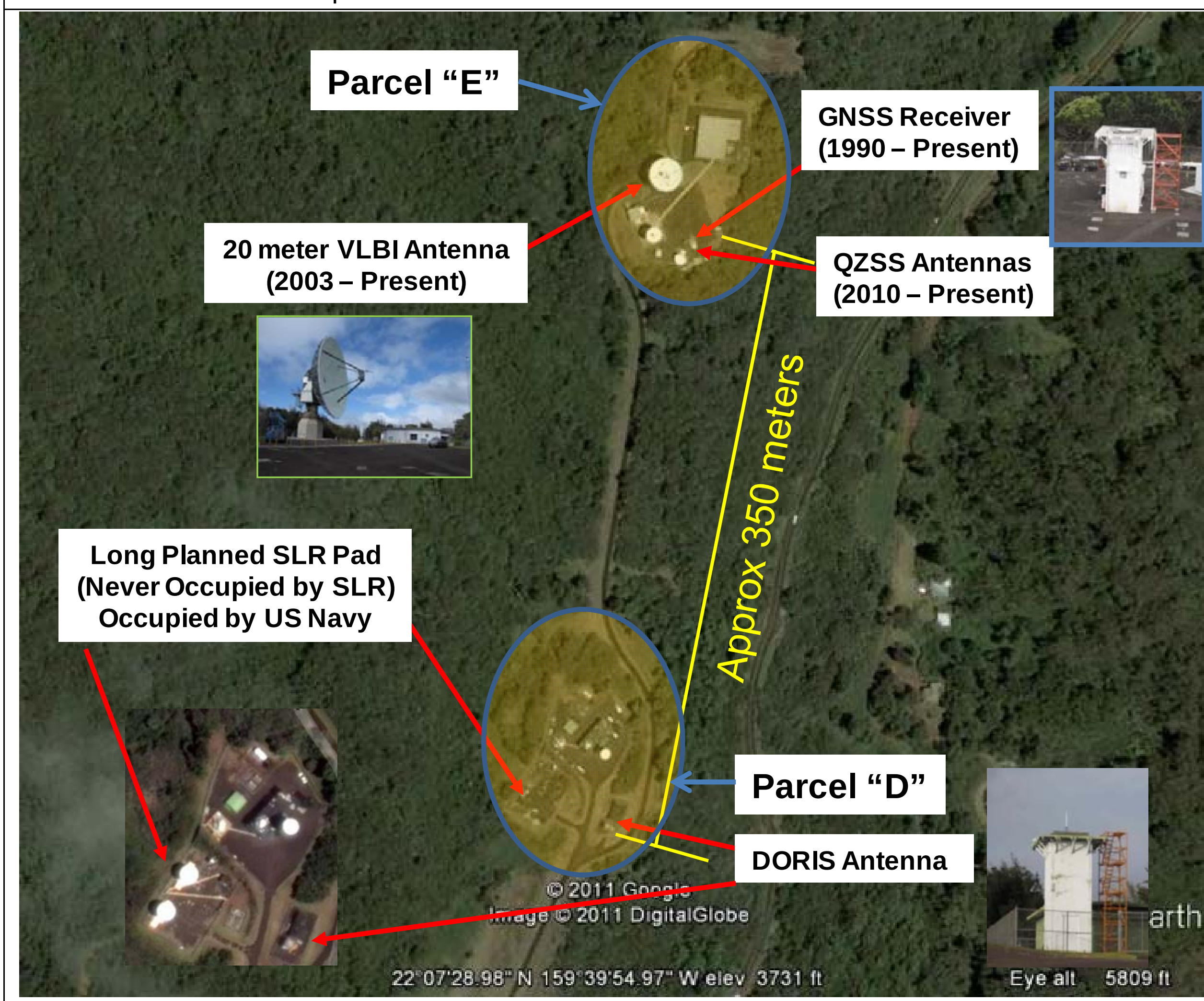
The KPGO Site

Parcel D (South) Compound with DORIS

Parcel E (North) Compound with VLBI



View of Both KPGO Compounds



7.2 Weather & Sky Conditions

7.2.1 Climate

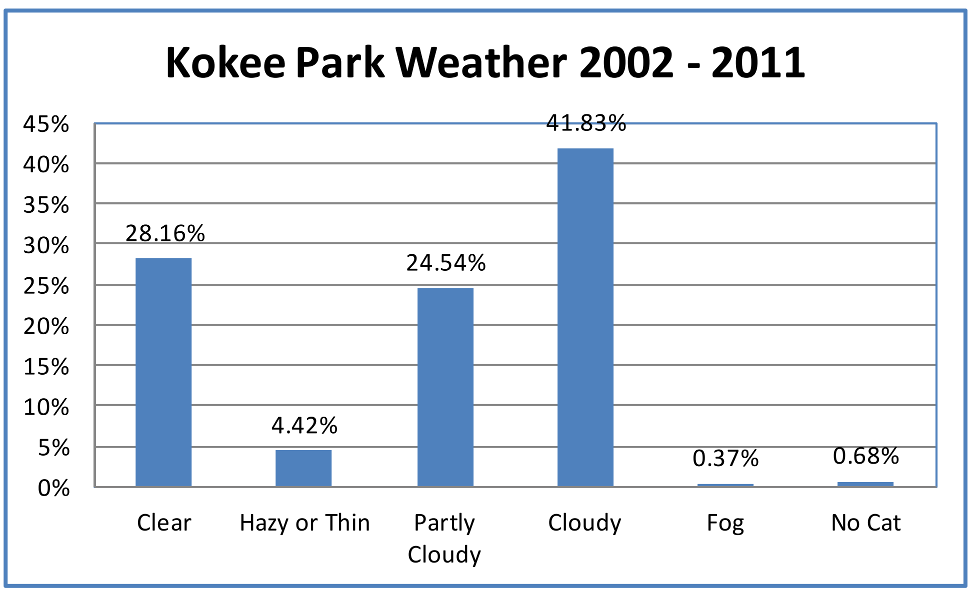
The climate at KPGO is tropical. KPGO is located close to the boundary between the drier northwest side of Kauai and the wetter southeast side. Kokee Park, surrounding KPGO, contains rain forests. Nearby Mt. Waialeale is claimed to be the wettest place on Earth.

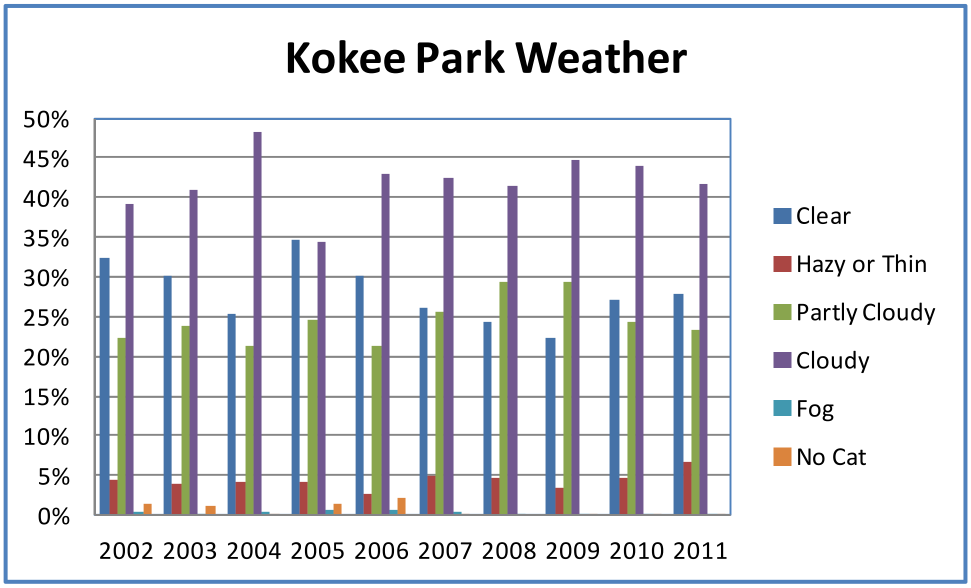
See the following link for a general description of the climate of Hawaii:
http://www.wrcc.dri.edu/narratives/HAWAII.htm

The air at the site is corrosive due to salt in the air from the ocean. This is evident based on the required 20m antenna and Hi-Ranger lift truck maintenance, and the condition of the Hi-Ranger.

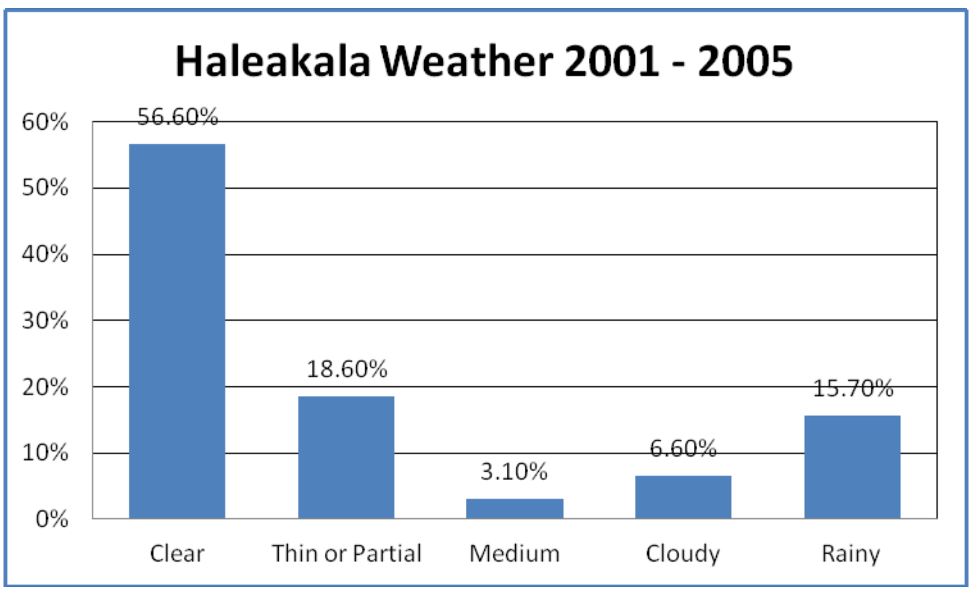
7.2.2 Sky Conditions

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.





For comparison, a similar plot 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, 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 ~60% untrackable weather at KPGO compared to only ~23% untrackable weather at Haleakala.



7.3 RF and Optical Interference

7.3.1 RF Interference

Currently, there are no significant RFI issues with the S/X system at the 20 meter antenna. Other than the potential RFI issues of the existing DORIS system at the parcel D compound and a possible LHRS source near that, an RFI study would need to be performed for the potential VLBI2010 broadband system. There are a number of US Navy Antennas at KPGO and nearby are the Air National Guard antennas. This RFI study should be performed during the next phase of site selection if KPGO is listed as a Fundamental Station site.

7.3.2 Optical Interference

Night skies at KPGO are dark. The Kokee Park site is remote. Most of the population of Kauai, less than 67,000 in 2010, lives on the opposite side of the island, so the impact from lights on the night sky is minimal. Also, there are efforts to control night lighting on Kauai to protect night flying sea birds from becoming confused by artificial lighting. Wooded surroundings block direct illumination from nearby offsite light sources.

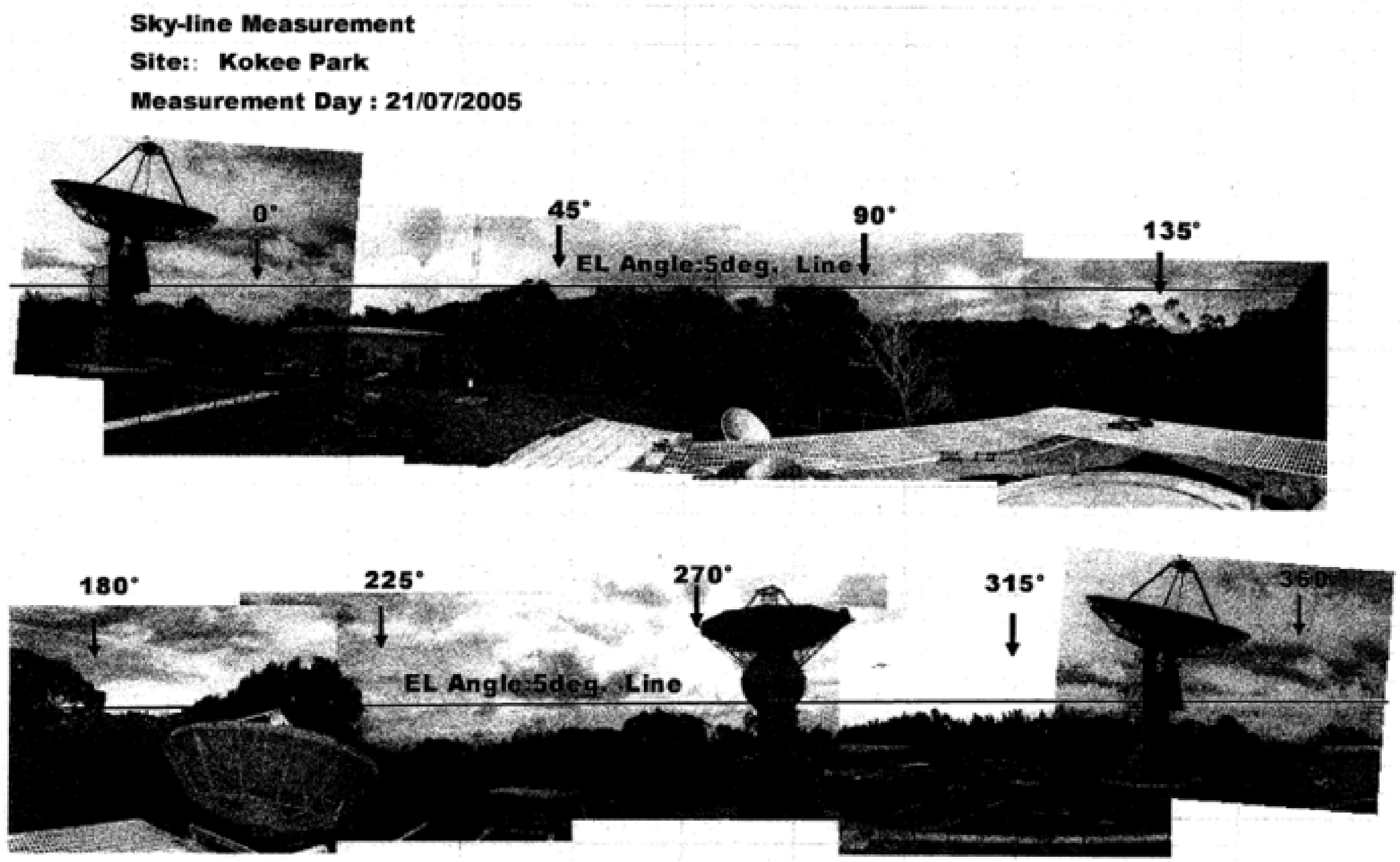
7.3.3. Other Possible Interference

KPGO is located 100-200 meters from route 550, the main road into Kokee Park. Tourist vehicles make up the bulk of the traffic.

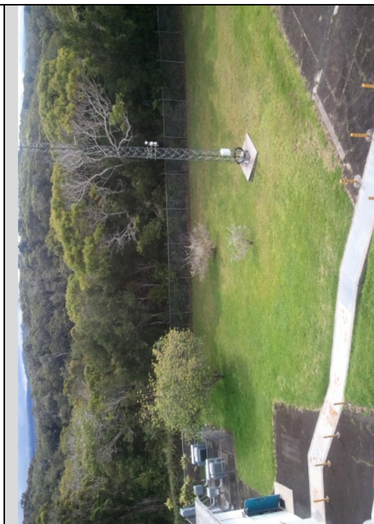
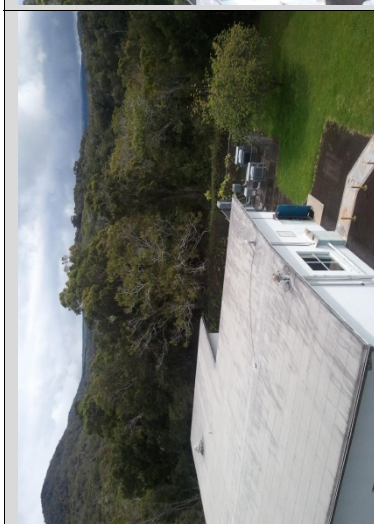
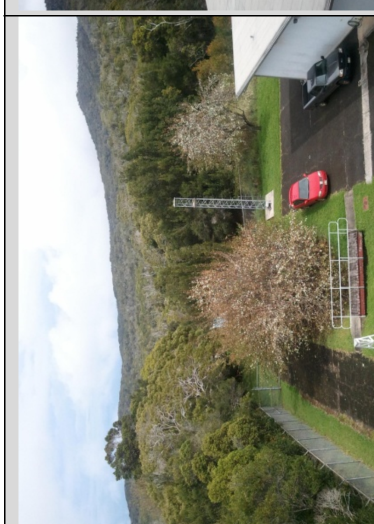
7.4 Horizon Conditions

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 KPGO, as with any site, horizon conditions for each technique will vary depending on the location and height of each technique on the site. The bottom edge of the 20 meter VLBI antenna at 0 degrees elevation and the GPS and Doris antennas are currently all mounted more than 4 meters above ground level. There are several structures and antennas supporting various projects in both compounds at KPGO. For possible future 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.

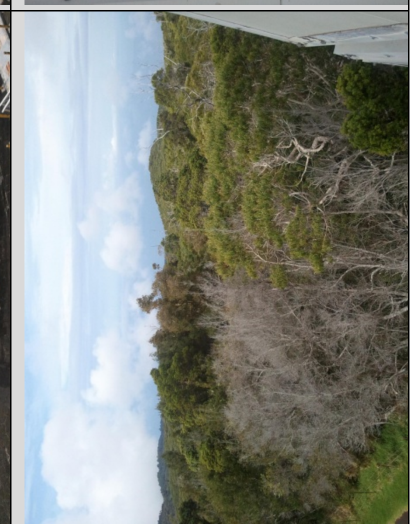
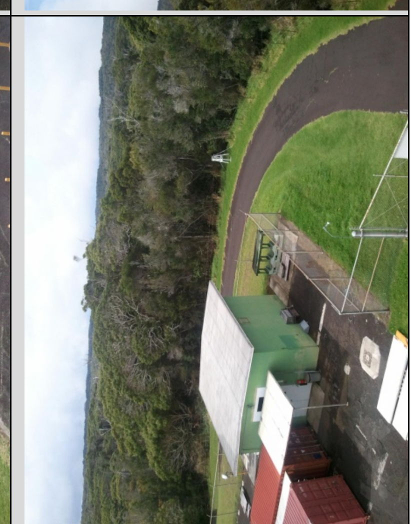
Horizon From Tower Occupied by GPS and QZSS Antennas



Views of North Compound From the 20 meter Pedestal

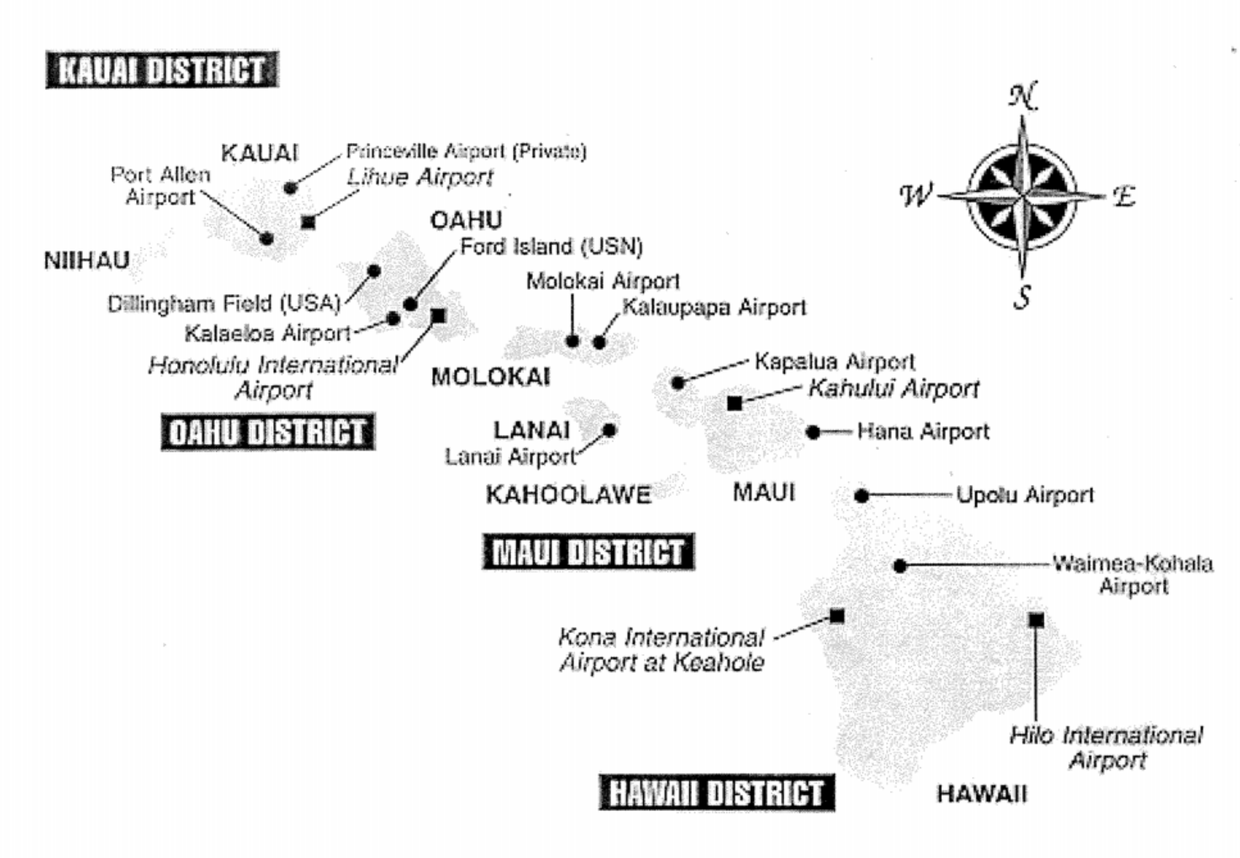


Views of South Compound From the Scamp Tower

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 Kauai

Kalalau Beach Heliport - HI53 Haena, Hawaii Facility Usage: Private	State Of Hawaii
Princeville Airport - HI01 Hanalei, Hawaii Facility Usage: Private	Princeville Mauka Village, Llc P.O. Box 223040 Princeville, HI 96722 (808) 826-3040
Hanamaulu Airstrip Airport - HI03 Hanamaulu, Hawaii Facility Usage: Private	Lihue Plantation Co Ltd 2970 Kele Street Lihue, HI 96766 (808) 245-7325
Port Allen Airport - PAK Hanapepe, Hawaii Facility Usage: Public	Hawaii St Arpts Div 400 Rodgers Blvd, Suite 700 Honolulu, HI 96819 (808) 838-8701
Barking Sands Pmrf Airport - BKH Kekaha,Kauai, Hawaii Facility Usage: Private	Us Navy Oceanographic Ofc - Code 3142 Washington, DC 20373
Lihue Airport - LIH Lihue, Hawaii Facility Usage: Public	Hawaii St Arpts Div Honolulu Intl Arpt Honolulu, HI 96819 (808) 838-8600
Haiku Airstrip Airport - HI33 Puhi, Hawaii Facility Usage: Private	Grove Farm Co. P.O. Box 662069 Linhue, HI 96766 (808) 245-3678
Hi 23 Airstrip Airport - HI46 Puhi, Hawaii Facility Usage: Private	The Lihue Plantation Co Ltd 2970 Kele Street Lihue, HI 96766 (808) 245-7325
Source: http://www.tollfreeairline.com/hawaii/kauai.htm	

Eight airports and airfields on Kauai are listed. Haiku Airstrip, Hi 23 Airstrip, and Hanamaulu Airstrip are all in the vicinity of Lihue Airport on the ESE side of the island. Port Allen Airport is on the south side of the island. Princeville airport is on the NNE side of the island. Barking Sands and the Kalalau Beach Heliport are closest to Kokee Park.

Kalalau Beach Heliport:
http://www.airnav.com/airport/HI53
http://vfrmap.com/?type=vfrc&lat=22.175&lon=-159.656&zoom=10

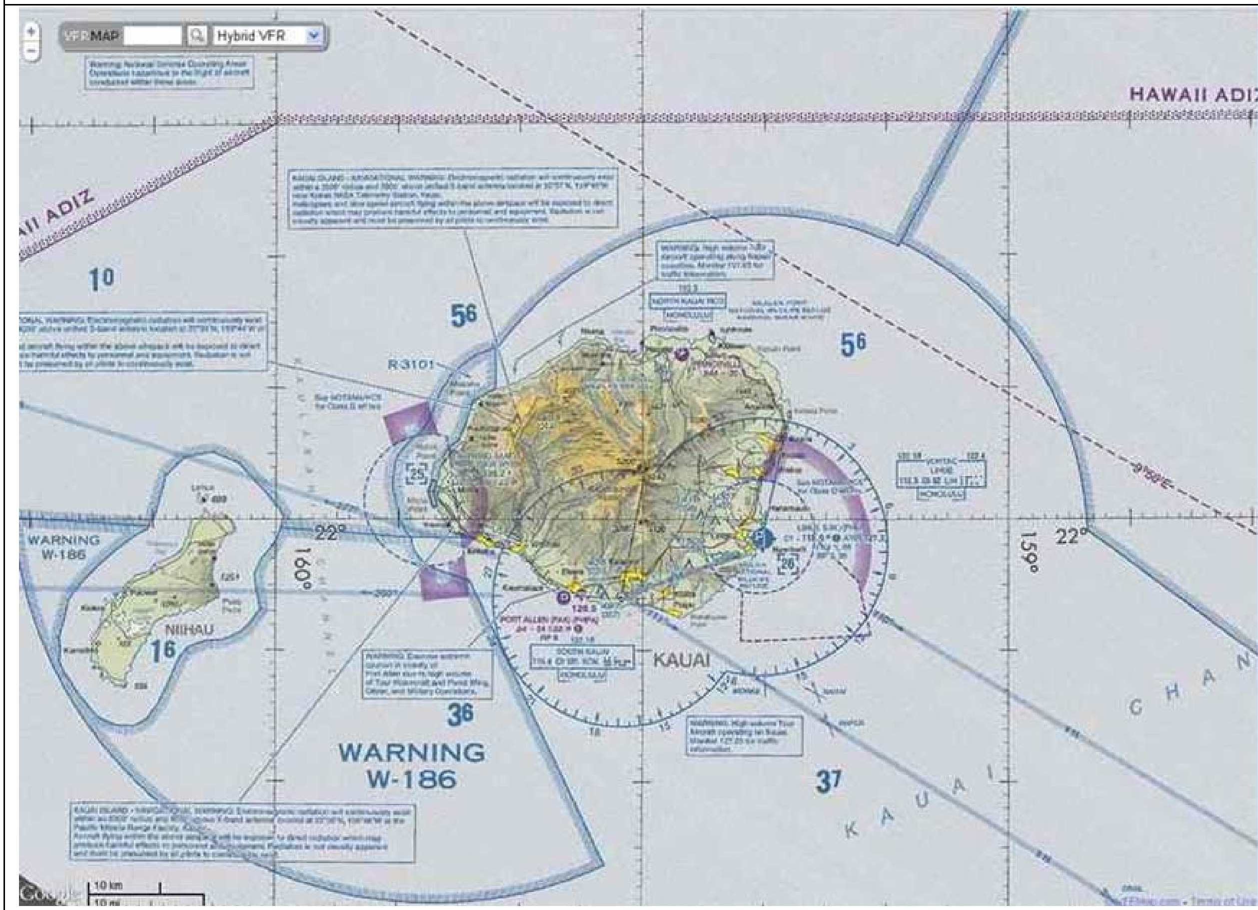
Port Allen Airport information:
http://hawaii.gov/lih/airport-information/port-allen-airport-pak

Helicopter tour with landing:
http://www.safarihelicopters.com/kauai/refuge-eco-tour/

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	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 Kauai



7.6 Aircraft Protection

For SLR, a Laser Hazard Reduction System (LHRS) will automatically detect aircraft and block the laser beam. With the potential SLR located at or near the DORIS parcel, it may be possible to position the LHRS in a manner to minimize RFI to the VLBI2010 antenna and the 20 meter. The LHRS is currently the best possible solution for aircraft detection for SLR systems located below 10,000 feet. The ability of the LHRS to detect aircraft from very low to high altitudes is the strength of the system. Other potential detection systems have limitations that make operations not acceptable to NASA and to the FAA.

7.7 Communications

Voice communications are handled by copper wire pairs and one Vonage connection.

High Bandwidth (DREN-type) connection – OC12 microwave connection to DREN foundry at PMRF. The DREN is not utilized yet, but will provide communications for e-VLBI once established and will be able to handle the data bandwidth of a VLBI2010 system. Use of this system will be expensive and exact costs are still being determined.

Lower Bandwidth (T1) – The University of Hawaii managed T1 connection with Hawaiian Telcom as the local carrier which is acceptable bandwidth for SLR, GNSS, DORIS to support operations.

7.8 Land Ownership

NASA controls the KPGO property on a long term lease from the State of Hawaii. Work is in progress on the Memorandum of Agreement (MOA) with the USN to clarify and update property usage. The last signed MOA was in 2007. The current MOA is in review at NASA. NASA funds KPGO for facilities support, site power, and other support on an annual basis.

Improvements to the KPGO facility are significantly easier than at Haleakala on Maui. With the lease to NASA, NASA is permitted to make changes within code. The QZSS installation is a recent example. One downside is that the labor force on Kauai is limited, and labor coming from other islands can face issues with local labor and suppliers.

7.9 Local Ground Geodetic Networks

7.9.1 Local Station Network

The primary geodetic reference marker at KPGO is the JPL GPS marker 3028-S, code KOKB. Currently, there are no clear lines of sight that will allow direct survey measurements between markers on the north and south compounds. Surveyors have used several temporary points during surveys to measure the required ties.

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

Domes No.	Description	Code
40424M004	VERLOT radar building, JPL GPS marker 3028-S	KOKB
40424S001	9m VLBI reference point	1311
40424S007	20m VLBI antenna	7298
40424S008	DORIS antenna (Alcatel type)	KOKA
40424S009	DORIS antenna(Stares type)	KOLB
Others Without Code		
40424M005	CIGNET GPS marker	
40424M006	JPL GPS temporary mark	
40424S002	T14100/L1—86-	
40424S003	T14100 FRPA-2/L1 02-JUL-90	
40424S004	Trimble 4000SST/L1 02-JUL-90 17-MAR-92	
Source: ITRF website http://itrf.ign.fr//site_info_and_select/site.php?SelecSite=404024		

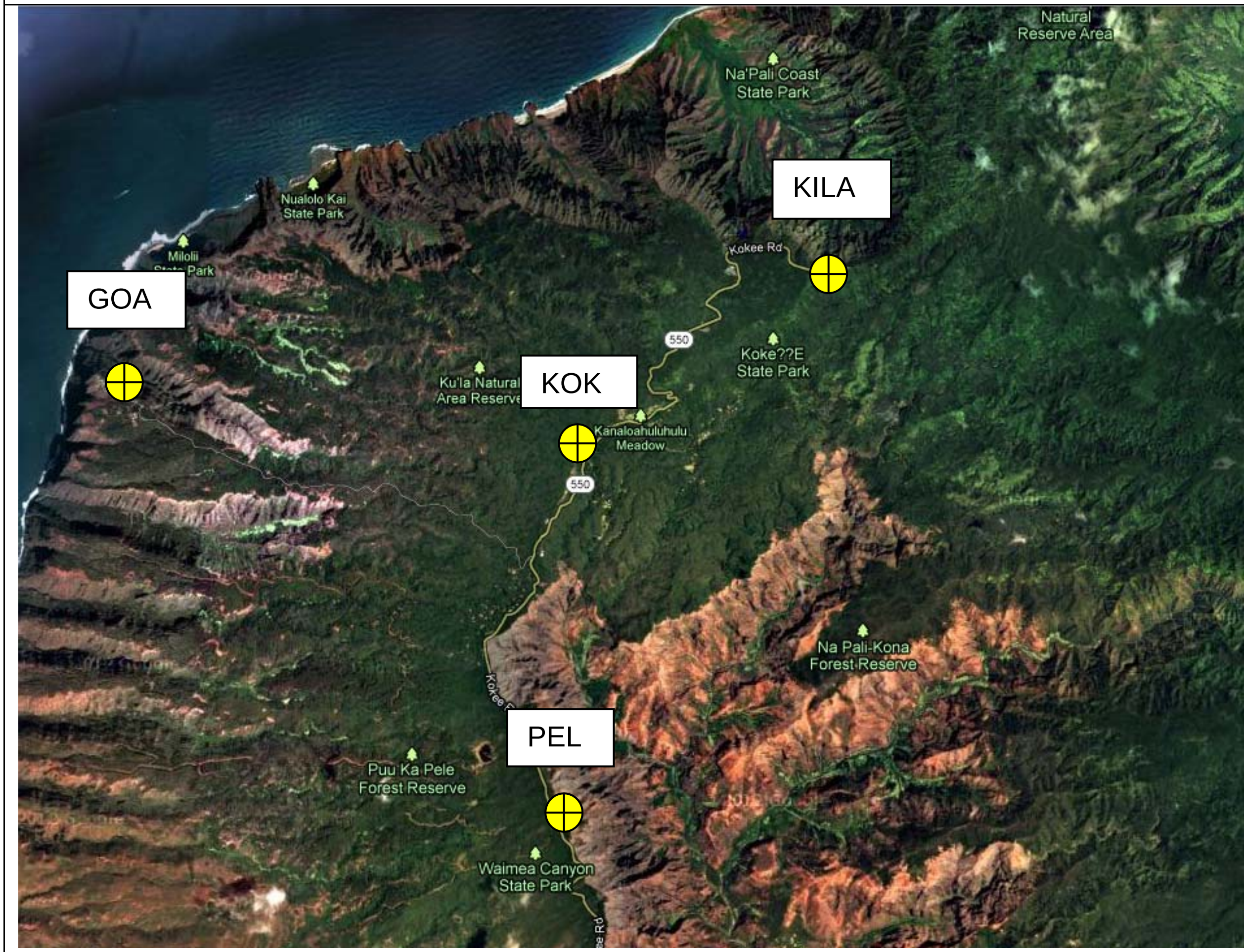
Kauai Local Ties, KPGO, GeoLab3 Results, 1996+2002 Survey						
From	To		Delta X(m)	Delta Y(m)	Delta Z(m)	Distance (m)
GPS 3028-S KOKB	VLBI 1311		-7.9406	23.6153	4.4066	25.3013
		ITRF 2005	-7.9335	23.6156	4.4044	25.2989
		Diff.	0.0071	0.0003	-0.0022	
GPS 3028-S KOKB	VLBI 7298		0.5007	19.4010	42.2334	46.4791
		ITRF 2005	0.5037	19.4023	42.2335	46.4798
		Diff.	0.0030	0.0013	0.0001	
GPS 3028-S KOKB	DORIS KOKA		-136.5266	-2.6648	-321.5320	349.3271
		ITRF 2005	-136.5269	-2.6687	-321.5313	349.3266
		Diff.	-0.0003	-0.0039	0.0007	
GPS 3028-S KOKB	DORIS KOKA		-143.1535	2.6012	-328.9694	358.7765
		ITRF 2005	-143.1546	2.5970	-328.9677	358.7753
		Diff.	-0.0011	-0.0042	0.0017	

(Doris antenna information: - http://ids-doris.org/network/sitelogs/station.html?code=KOKA)
(DOMES information: - http://itrf.ign.fr//site_info_and_select/site.php & http://itrf.ign.fr//site_info_and_select/site.php?SelecSite=404024)

7.9.2 Regional Network

GPS Footprint surveys were carried out in 1993, 1996, and 2002. Included in those surveys were offsite markers PELE 1926 (PID TU1999), GOAT 1964 (PID TU0822) (note that the NGS datasheet says that this marker is GOAT 1967), and KILA GPS (PID AA3588). PELE is approximately 5km distant from KOKB, GOAT is approximately 6.1km distant from KOKB, and KILA is approximately 4.2km distant from KOKB.

Locations of the PELE 1926, GOAT 1967, and KILA Survey Markers for Regional Ties to KOKB



The Kauai island coast line is only 4-8km distant to the northwest, preventing the distribution of regional 10-30km ties in that direction. Some regional geodetic points, including a few on Maui, 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	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

Kokee Road (Route 550), the main road from the base of Waimea Canyon into Kokee Park, and gated Faye Road provide good access to the site. These roads have accommodated an 80 ton crane in the past. PMRF and NASA control site access to KPGO.

7.11 Local Infrastructure and Accommodations

KPGO currently has the office space and facilities to support personnel onsite along with office, storage and laboratory space to support a Fundamental Station facility.

The small size of Kauai limits the distances between the site and residential areas. Roads are generally routed around the perimeter of the island. Typical drive time from the closest accommodations is 45 minutes, but can vary considerably. Slow moving sightseeing tourists can make the trip take longer. Current members of the crew generally live farther away with drive times of 60 to 90 minutes.

7.12 Electrical Power

Source - Site power originates from PMRF. The main site powerhouse is located in Parcel B which is south of Parcel D, the southern compound. There are two sub-stations in each compound, one for tech power, and the other for utility power. Power conditioners have been added for protection.

Available capacity – Adequate power is available for both the VLBI2010 system and a SLR system. More power will be available after the planned removal of the 9-meter antenna and with the eventual closure of the PEACESat system.

7.13 Technical and Personnel Support

Currently, the number of personnel supporting KPGO is 7.

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.

7.14 Site Security

Site security is controlled by the United States Navy at the Pacific Missile Range Facility (PMRF) at Barking Sands following NASA specified security controls for physical access. Visits must be approved by the US Navy. There is a locked gate from the Kokee Park road, and another locked gate to the northern compound containing the 20 meter VLBI antenna and main operations building. The main gate is locked with locks for the State, PMRF, and KPGO.

Gate to VLBI/GPS/Main Office Compound	Locks on Main Gate (State, PMRF, KPGO)
	

7.15 Site Safety

As a current NASA site, NASA safety regulations and practices are already in place. Fire suppression response and emergency transport by road might be slow and are performed by PMRF. Helicopter transport is possible in an emergency with landing capability near the DORIS compound.

7.16 Local Commitment

NASA has occupied the site at Kokee Park for various projects since the beginning of manned spaceflight in the early 1960s. There is a good relationship with NASA and the US Navy and there are well known sources of infrastructure support on the island or neighboring islands.

8.0 Concluding Remarks

The KPGO facility is adequate for a GGOS Fundamental Station site. Communications, security, power, and local support are all good. However, at best, the KPGO offers only marginal, ~60% cloudy, sky conditions for SLR, but the site can accommodate a SLR system, if located near the DORIS antenna. A SLR system currently operates on Haleakala on Maui where conditions for SLR are much better. Between the two parcels at KPGO, the terrain and current vegetation block lines of sight to current geodetic markers that are used to develop and monitor strong ground survey ties between the geodetic techniques necessitating the use of temporary survey targets. Also, the two parcels are separated by approximately 350 meters and geodetic ties may be further separated depending on where an NGSLR system could be located.

The KPGO can be a Fundamental Station site with the addition of a SLR system and modifications to the site to accommodate survey lines of site required to maintain the geodetic ties between the techniques. SLR operations would be significantly compromised by cloudy skies.

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 SLR pad locations. Most likely within or near Parcel D.
6. Improved cloud coverage data.

10.0 References

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Appendix A: GGOS Site Stability Investigation From MIT

GGOS Site Stability Investigation

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Introduction:
Our principal objective is to investigate the level of stability for potential GGOS sites. GGOS requires site stability of 1 mm in 3-dimensions and long-term stability at the 0.1 mm/yr level. Determining whether specific sites meet GGOS stability requirements will require the most precise techniques available to monitor surface motion and very accurate estimates of short period motions due to tidal, loading, and local hydrologic effects as well as modeling systematic errors that can be difficult to distinguish from surface motions. Strain and tiltmeters (in boreholes or caves) and repeated precise leveling are the most precise ground deformation observation techniques on local scales. Leveling provides information only on vertical motions, is time consuming and is primarily useful for relatively local investigations. It also suffers from systematic errors in areas of high relief that need to be modeled. Strain and tilt meters are susceptible to very local conditions and are primarily useful for detecting short period "events" – determining actual ground deformation from strain measurements is non unique and non trivial. InSAR is not sufficiently precise to determine motions at this level of precision.

GPS offers the opportunity to investigate stability on local, regional, and global scales. GPS has demonstrated measurement precision as good as 0.2 mm horizontal and 1 mm vertical on short baselines and 0.5 mm horizontal and 1.5 mm vertical, and long-term stability at the level of 0.2 mm/yr horizontal and 0.5-1.0 mm/yr vertical on a global scale, in principal close to the precision needed to evaluate site stability at the level required by GGOS. To meet this level of precision requires accurate modeling of a range of factors that influence positioning estimates, including tectonic and magmatic deformation and other real surface movements over short time scales (e.g., tidal loading, hydrology) as well as apparent movements due to measurement errors (e.g., multipath changes, water vapor, monument stability).

Our initial investigation focuses on analysis of the GPS time series from Kokee Park.

GPS time series analysis:
We did noise analysis for each of the GPS stations operating on the island of Kauai, including the Kokee Park Observatory station (KOKB). The attached figures show de-trended time series from the MIT global analysis. KOKB and KOK1 have sufficient data to provide useful results. 1-sigma uncertainties on velocity for both stations (a rough measure of the long term stability) are of the order 0.1 – 0.2 mm/yr in horizontal and about a factor of 3 larger in the vertical (0.5 – 0.6 mm/yr) – the large uncertainty for the E position of KOKB is most likely due to instrument and/or

atmospheric influences and not ground motion. Daily scatter in position (RMS and WRMS) is on the order of 2-3 mm in horizontal and 5-7 mm in the vertical. The magnitudes of the annual and semi-annual terms are annotated on the figures and are in the range of 0.1 – 0.7 mm in horizontal and 0.4 – 1.6 mm in vertical.

These variations reflect un-modeled atmospheric, site [multipath, water table changes, monument stability], tidal [solid, ocean loading], water table variations, instrument/antenna effects, and reference frame instability as well as any possible tectonic motions. Much more detailed analysis of the GPS time series and other relevant data is necessary to estimate the contribution of these different factors before it will be possible to provide more definitive bounds on site stability.

Tectonics/Geology:
Kauai is the oldest of the Hawaiian Island chain having formed about 6-5 Myr BP. The small island (~50 km in diameter) has spectacular relief with elevations exceeding 1.5 km.

At present the island is inactive both volcanically and seismically (Harvard catalog). There is no evidence that we are aware of for active tectonics on the island.

Atmospheric:
The Island has an average annual rainfall reaching 12 m on its eastern side and substantially less on the west side (Kokee is located on the west side of Kauai) with the most rain during the winter-spring period. This is among the highest rainfall anywhere on Earth. Weather systems have extreme spatial and temporal variability.

Local hydrology: Needs further study of aquifers and water utilization.

Conclusions/Recommendation for Kokee Park GGOS site:

There is no evidence for local tectonic or volcanic deformation. This location should be among the most stable in this regard of potential Hawaiian Island sites. The main issues will be vertical ground motion on a potentially broad scale associated with unmodeled tidal loading. Secondly, loading due to the excessive rainfall could be substantial at the level of stability required for GGOS. These influences will need to be monitored and modeled to achieve stability at the 0.1 mm/yr velocity and 1 mm positioning levels. The small uncertainties on horizontal station velocities offer promise that stability at the 0.1 mm/yr level over periods of a few years are achievable.

To Do:
Local hydrology (well levels, aquifer characteristics) and relationship to apparent vertical site stability.
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.

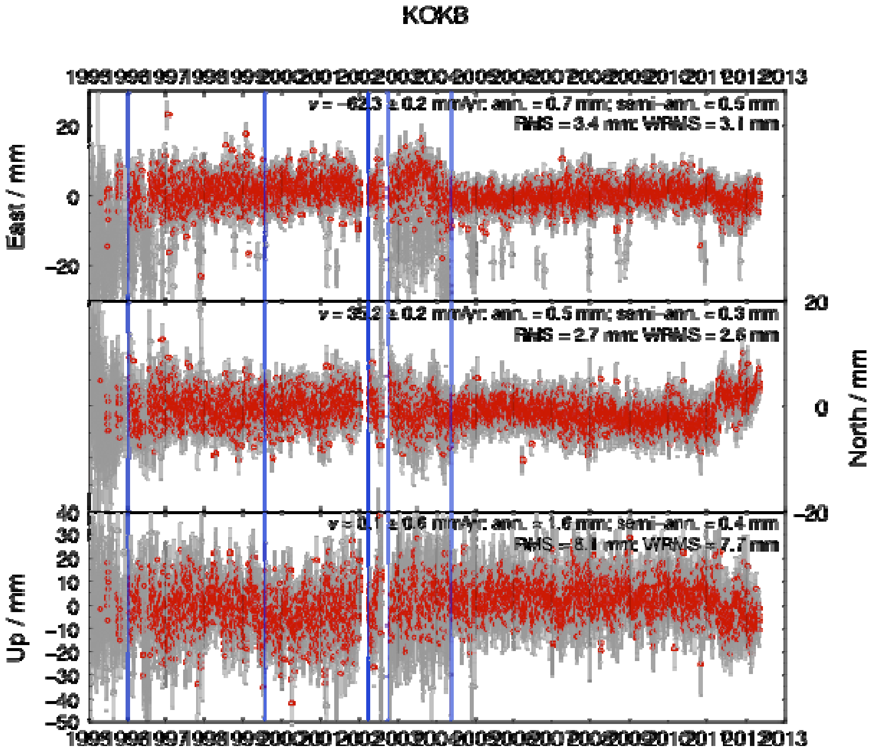

Figure 1 A. KOKB GPS time series. This station is located at the Observatory.

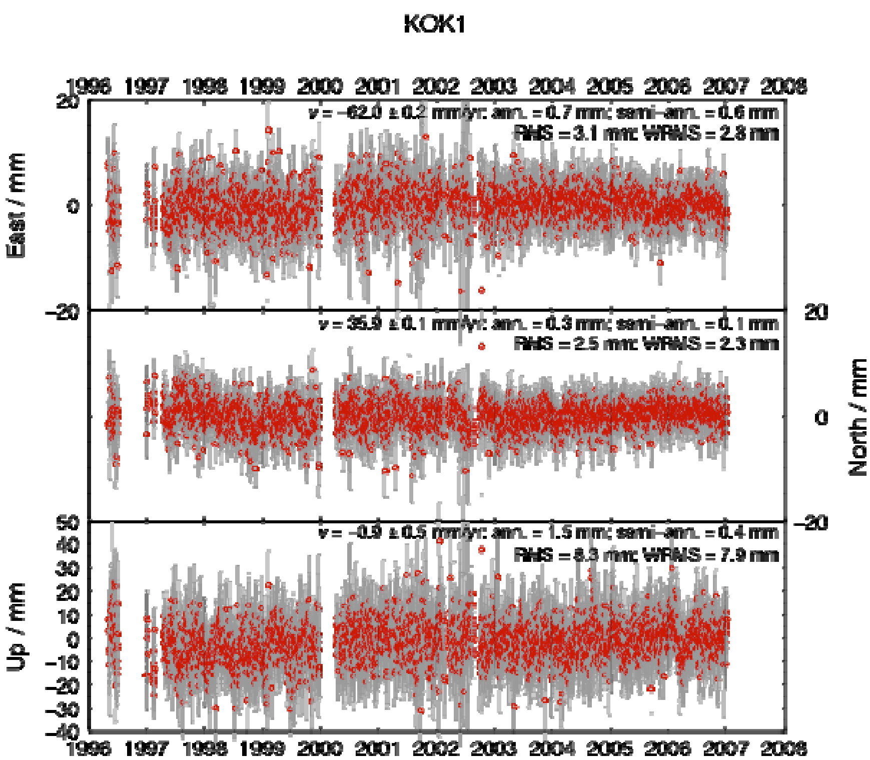

Figure 1B. KOK1 GPS time series.

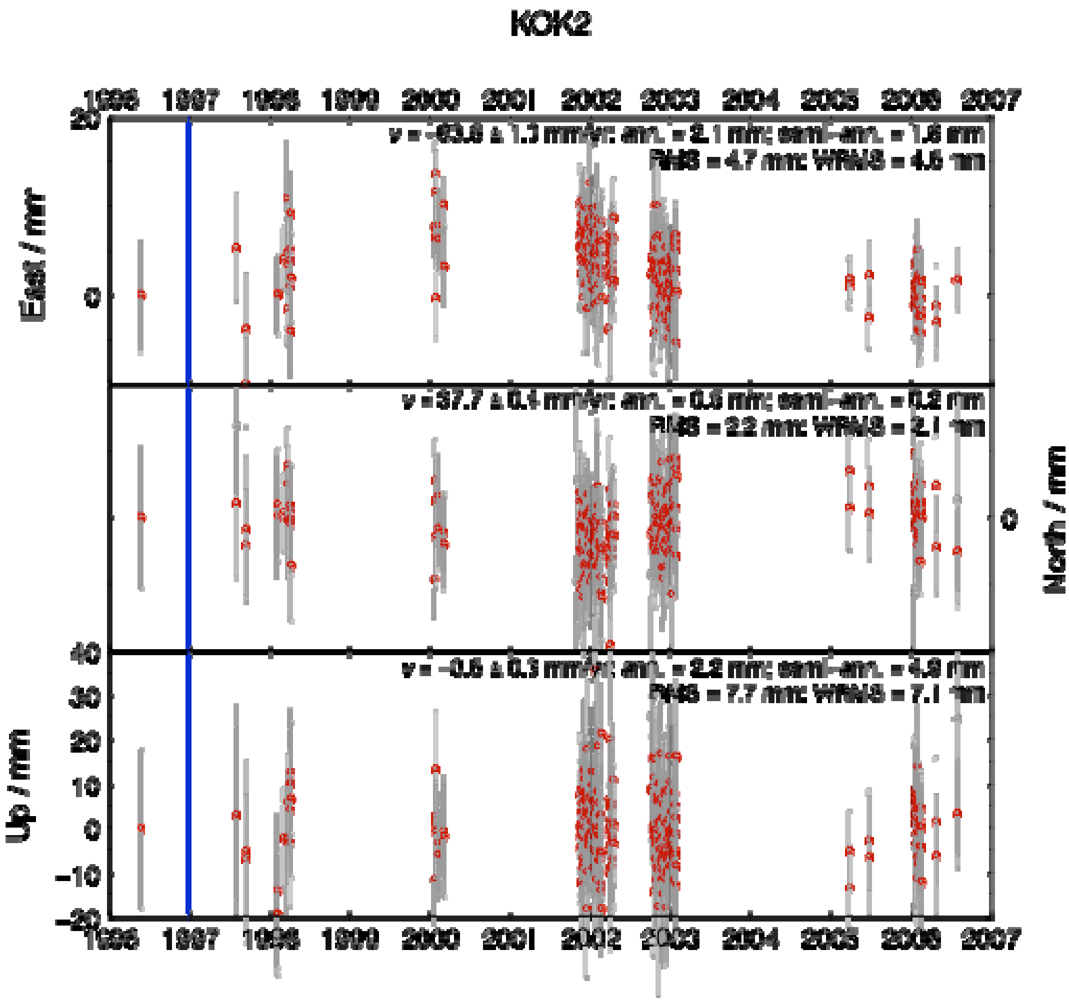

Figure 1C. KOK2 GPS tome series. Intermittent data allow only long-term velocity estimates.

Appendix B: List of Acronyms

DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DREN	Defense Research and Engineering Network
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
MIT	Massachusetts Institute of Technology
MOBLAS	MOBile Laser System
NASA	National Aeronautics and Space Administration
NGSLR	Next Generation Satellite Laser Ranging
PMRF	Pacific Missile Range Facility - US Navy
QZSS	Quasi-Zenith Satellite System
SGP	Space Geodesy Project
SLR	Satellite Laser Ranging
TLRS-4	Transportable Laser Ranging System – 4
UoH	University of Hawaii
VLBI	Very Long Baseline Interferometry