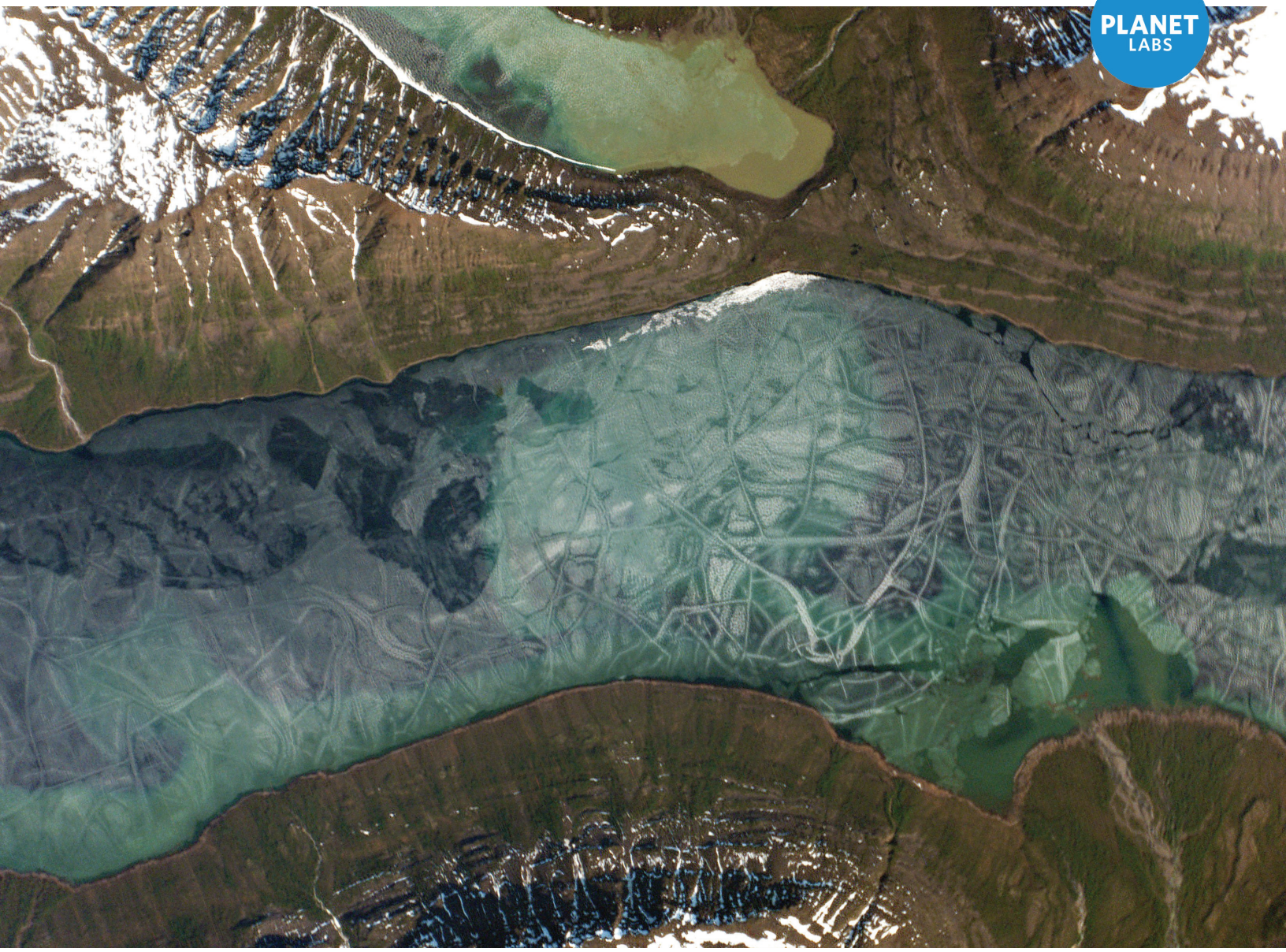

Planet Labs Specifications: Spacecraft Operations & Ground Systems

Version 1.0 | June 2015

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Disclaimer - This document is designed as a general guideline for customers interested in acquiring Planet Labs imagery products and services. Planet Labs takes an agile and iterative approach to its technology, and therefore may make changes to the product(s) described IN THIS DOCUMENT. This document is provided “as is” without warranty of any kind.

1. Introduction

1.1 Overview of this Document

This document describes Planet Labs' Spacecraft Operations & Ground Systems. It is intended for users of satellite imagery interested in working with Planet Labs' initial product offerings.

1.2 Company Overview

Planet Labs was founded in 2011 by three ex-NASA engineers to disrupt the traditional aerospace industry by using modern consumer electronics manufacturing techniques to build a large constellation of nanosatellites. Planet Labs uses an agile aerospace approach for the design of its satellites, mission control and operations systems; and the development of its web-based platform for imagery and information. It is the only fully integrated company that designs, builds, and actively operates satellites while also delivering data to customers via an internally developed web-based platform. Planet Labs employs an "always on" line-scanning image capturing method as opposed to the traditional tasking model used by most satellite companies today.

1.3 Space and Ground Systems Overview

Planet Labs designs, builds, and operates large constellations of nanosatellites. Each individual satellite is 3U form factor (10cm x 10cm x 30cm). The spacecraft payload is an optical system and camera, capable of capturing imagery at 3-5 meter Ground Sample Distance (GSD).

Planet Labs satellites are designed to be frequently updated and replaced; each satellite has an expected operational lifetime of 3 years. Planet Labs uses an "agile aerospace" approach to technology development, using rapid iterative design and frequent testing in space in order to continually deploy improved spacecraft and payloads. Planet Labs has launched three versions of its optical system, Planet Scope 0, Planet Scope 1, and Planet Scope 2.

Satellites are deployed into two types of orbit. International Space Station (ISS) orbits are at a 52 degree inclination at approximately 420km altitude. Sun Synchronous Orbits (SSO) are at 98 degrees inclination or higher at approximately 475km altitude. Large constellations of satellites will be operated in both orbit types.

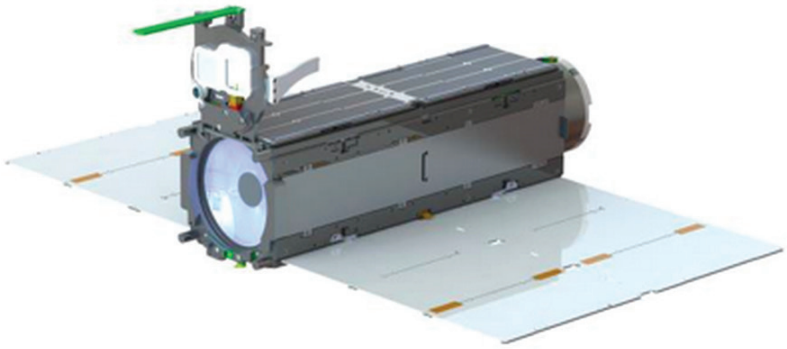
Planet Labs' satellite constellations operate in a constant monitoring mode. Individual satellites are not tasked, they remain nadir pointing and they continuously capture imagery of the sunlit portion of the earth's surface. Planet Labs has developed its own network of ground stations to ensure efficient satellite operations and successful downlink of imagery.

2. Spacecraft and Payload Design

2.1 The “Dove” Spacecraft

The Planet Labs Dove satellite design is based on the “3U” cubesat form factor (10cm x 10cm x 30cm). Planet Labs refers to a group of Doves deployed simultaneously into a single orbit as a flock.

Figure I: Planet Labs Dove Satellite in Operational Configuration with Solar Panels Deployed and Communications Antenna Flap Opened.



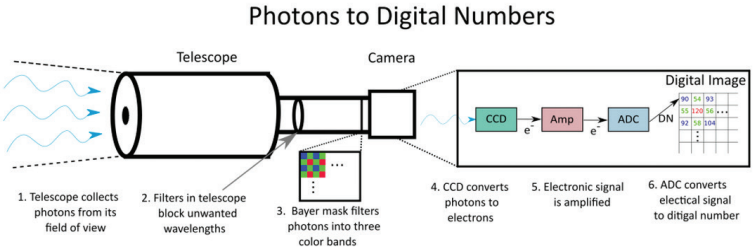
Planet Labs captures imagery using a telescope and camera combination which has been optimized for this form factor. The imaging system aboard each spacecraft captures red, blue and green (RGB) imagery. Planet Labs is currently developing Near Infrared (NIR) imaging capabilities.

2.2 Optical System, Camera and Capture Techniques

2.2.1 Payload Design

Planet Labs satellites each carry a telescope and a frame CCD camera equipped with Bayer-mask filter. The CCD sensor converts filtered photons into electrons, which are then amplified in order to produce a digital number corresponding to each pixel in each band.

Figure II: Planet Labs Optical System and Camera.



2.2.2 Instruments

Planet Labs has flown three generations of optical instruments: Planet Scope 0 (PS0), Planet Scope1 (PS1), and Planet Scope 2 (PS2). Images have different attributes depending on satellite altitude and instrument type.

Table B: Spectral Band and Field of View (FOV) Information for PS0, PS1 and PS2 Instruments Flown at Various Altitudes

Instrument	Spectral Bands (nm)	Field of View (FOV) and Ground Sampled Distance (GSD)		
		620km (Altitude of Planet Labs Flock 1c)	475km (Target altitude for future SSO Flocks)	420km (ISS Flocks altitude)
PS0 and PS1	Red = 630-714 Green = 515-610 Blue = 424-478	HFOV: 16.1km VFOV: 10.7km Area: 173 km sq GSD: 4m	NA (Instrument not flown at this altitude)	HFOV: 10.9km VFOV: 7.3km Area: 79 km sq GSD: 2.7m
PS2		NA (Instrument not flown at this altitude)	HFOV: 24.6km VFOV: 16.4km Area: 405 km sq GSD: 3.73m	HFOV: 21.8km VFOV: 14.5km Area: 316 km sq GSD: 3.3m

PS0 features a 2 element Maksutov Cassegrain optical system paired with an 11MP CCD detector. Optical elements are mounted relative to the structure of the spacecraft.

PS1 features the same optical system as PS0, aligned and mounted in an isolated carbon fiber/titanium telescope. This telescope is matched with an 11MP CCD detector.

PS2 features a five element optical system that provides a wider field of view and superior image quality. This optical system is paired with a 29MP CCD detector.

2.2.2.1 Spectral Characteristics:

PPS0 and PS1 optical systems are designed to collect data in the visible portion (red, blue and green) of the electromagnetic spectrum. The following figures show the expected RGB spectral characteristics of the PS0 and PS1 systems:

Figure III: RGB Spectral Bands for PS0/1

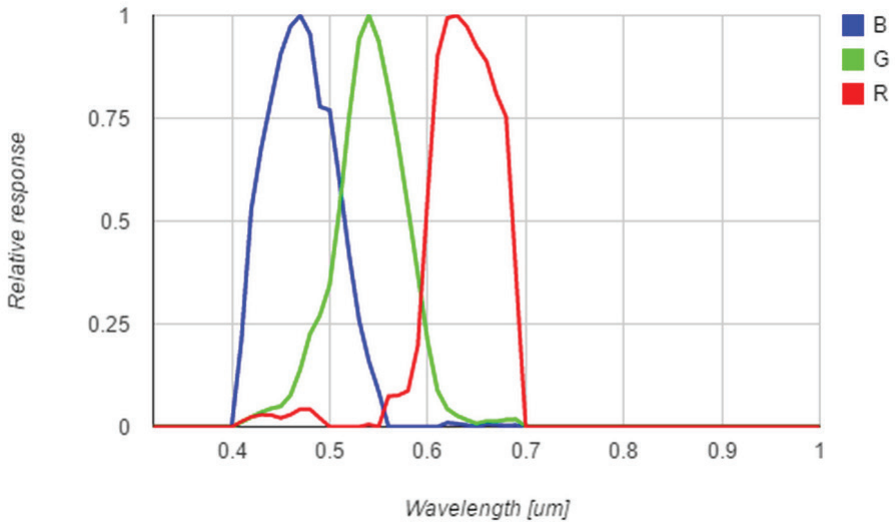
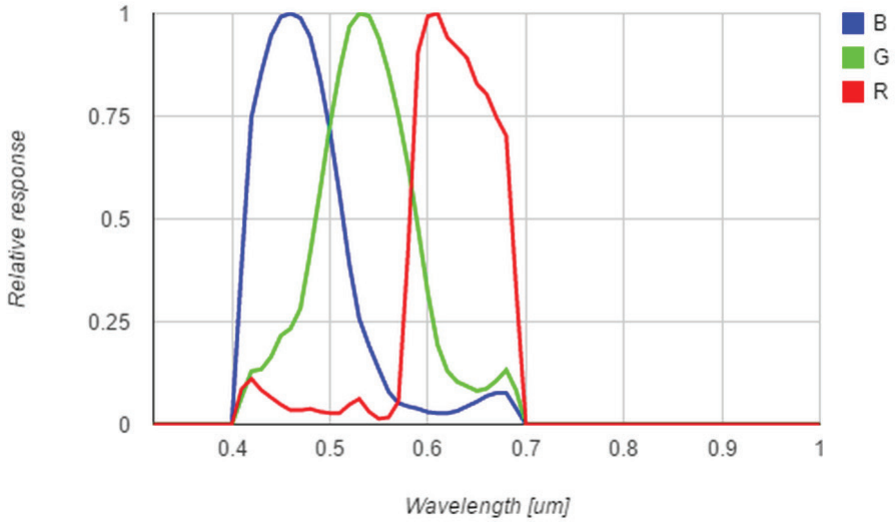


Figure IV: RGB Spectral Bands for PS2



2.2.2.2 Near-Infrared:

Planet Labs is currently testing a near-infrared (770-900nm) sensor.

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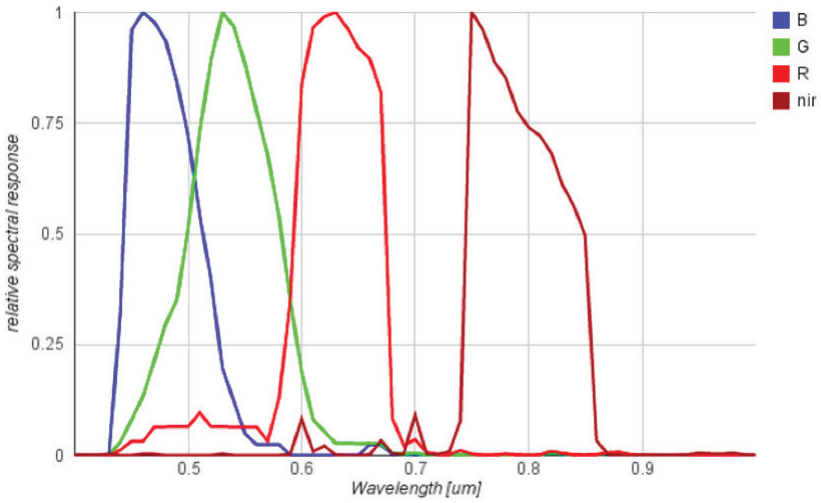
Figure V: Expected Spectral Response for PS2 (with NIR capability)



2.2.3 Image Quality Variations between PS0/1 and PS2

Images from PS0 and PS1 systems exhibit vignetting, or a decline in pixel usability towards the edges of the sensor. Planet Labs provides an alpha mask to discard pixels of unusable quality.

Images from PS2 systems exhibit uniformly high pixel quality and usability over the entire sensor.

3. Orbits, Operational Mode and Constellations

3.1 Monitoring Operational Mode

Planet Labs does not employ the traditional "tasking model" for space-based imagery collection. In the traditional model, imagery collections are prioritized and planned based on "targeted" collects with little or no imaging of non-prioritized areas. Planet Labs' satellites are designed to operate in concert to continuously collect imagery of the sunlit portion of the Earth's surface. At full constellation, Planet Labs' monitoring capability is expected to yield approximately one complete global image dataset every day.

Traditional Industry:
Tasking

Planet Labs:
Monitoring

Table B: Orbit, Constellation and Satellite Specifications

	International Space Station Orbit	Sun Synchronous Orbit
Inclination	52°	98°
Expected Lifetime	1 year per satellite; constellation is replenished over time	2-3 years per satellite; constellation is replenished over time
Orbital Insertion Altitude	420km	475km (target altitude for future SSO launches
Equator Crossing Time	Varies	9:30-11:30am local solar time
Sensor Type	Bayer-masked CCD camera	Bayer-masked CCD camera
Spectral Bands	Red: 610-700nm Green: 500-590nm Blue: 420-530nm	Red: 610-700nm Green: 500-590nm Blue: 420-530nm
Ground Sampling Distance (Nadir)	2.7m - 3.2m	3.7m - 4.9m
Mission Continuity	Maintain up to 55 satellite constellation (continually replenishing/upgrading satellites)	Maintain 100-150 satellite constellation (continually replenishing/upgrading satellites)

3.2 Constellation Development

Planet Labs has been collecting imagery since March 2014. Many of Planet Labs' early launches were to deploy test flocks, intended to validate certain aspects of the imaging and spacecraft operations systems. The normal operations cycle for a flock is launch, deployment, commissioning, operations, and decommissioning. A number of our early satellites have already been decommissioned, while at any given time a set of newer satellites are awaiting launch and deployment.

As of June 2015 Planet Labs' constellation consists of 19 operational satellites.

Table C: Planet Labs Inventory of all Launched Satellite Flocks.

Flock Name	Launch Date	Orbit	Quantity Launched	Quantity Operational As of July 2015
Flock 1a	1/9/2014	ISS	28	0
Flock 1c	6/19/2014	SSO (620km)	11	8
Flock 1b	7/13/2014	ISS	28	10
Flock 1d	10/24/2014	ISS	0 (Launch Failure)	0
Flock 1d'	1/10/2015	ISS	2	1

Currently targeted additional satellite launches are listed below. Note that these dates are estimates as launch dates can change or encounter other technical difficulties.

Table D: Planet Labs Expected Launch Manifest (H2 2015 and 2016)

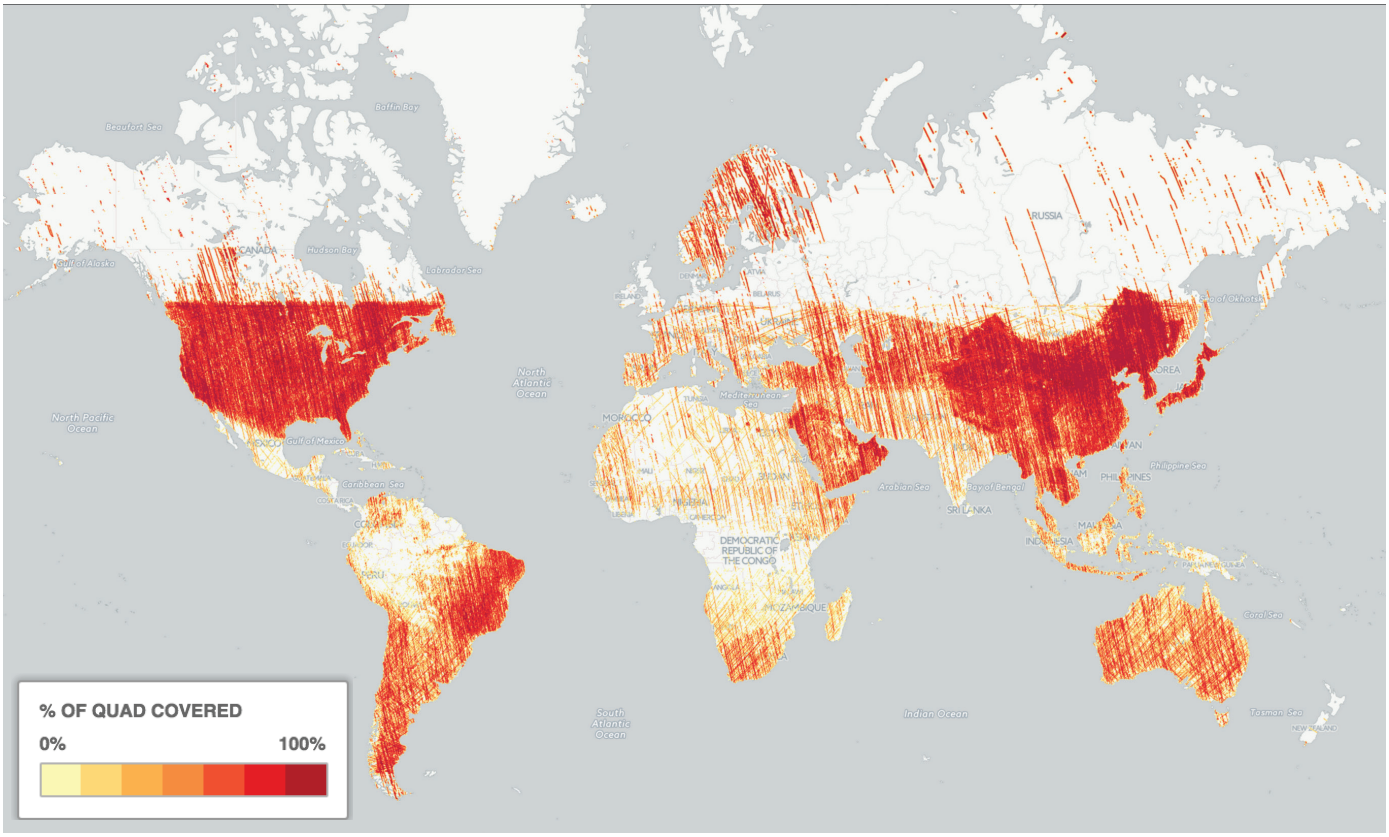
Flock Name	Expected # of Sats	Expected Deployment Date	Orbit
Flock 1e	14	Q2 2015	ISS
Flock 1f	8	Q3 2015	ISS
Flock 2b	14-22	Q4 2015	ISS
Flock 2d	8-16	Q4 2015	ISS
Flock 2c	56	Q1 2016	SSO
Flock 2k	48	Q1 2016	SSO
Flock 3	150	Q2 2016	SSO
Flock 2	36	Q4 2016	SSO

3.3 Coverage

3.3.1 Imagery Archive

Throughout 2014 and the first half of 2015, Planet Labs focused collection capacity on North America, Asia, and South America. Focusing on these areas allowed Planet Labs to establish initial imagery archive to develop and refine imagery processing, imagery quality, imagery mosaic, and API capabilities.

Figure VI: Heat Map as of June 2015, Showing Percent of Quad Tiles Covered by Planet Labs' Imagery



3.3.2 Constellation Growth and Future Coverage

Planet Labs measures area coverage capacity in units of Global Land Area (GLA), where one GLA is approximately 150 million square kilometers.

Planet Labs forecasts future coverage capacity based upon operational satellites in space and proven improvements in satellite payloads and operations. All forecasts are subject to change based upon launch.

Table E: Estimated Operational Satellites, Collection Capacity, and Days to Revisit Based on Northern Hemisphere Latitude

	Q3 2015	Q4 2015	Q1 2016	Q2 2016	Q3 2016
Estimated # Operational Satellites	20	25	30	50	150
Estimated Collection Capacity (Global Land Areas)	1.5	2	5	10	50
Latitude (Northern Hemisphere)	**Days to Revisit: Average (90% Certainty)**				
70°	60 (70)	70 (80)	50 (60)	3 (5)	1 (2)
60°	50 (60)	60 (70)	20 (36)	2 (4)	1 (2)
50°	22 (35)	14 (21)	8 (16)	1 (3)	1 (2)
40°	28 (38)	15 (25)	13 (19)	2 (3)	1 (2)
30°	30 (40)	17 (30)	15 (20)	2 (4)	1 (2)
20°	35 (46)	23 (33)	16 (22)	3 (4)	1 (2)

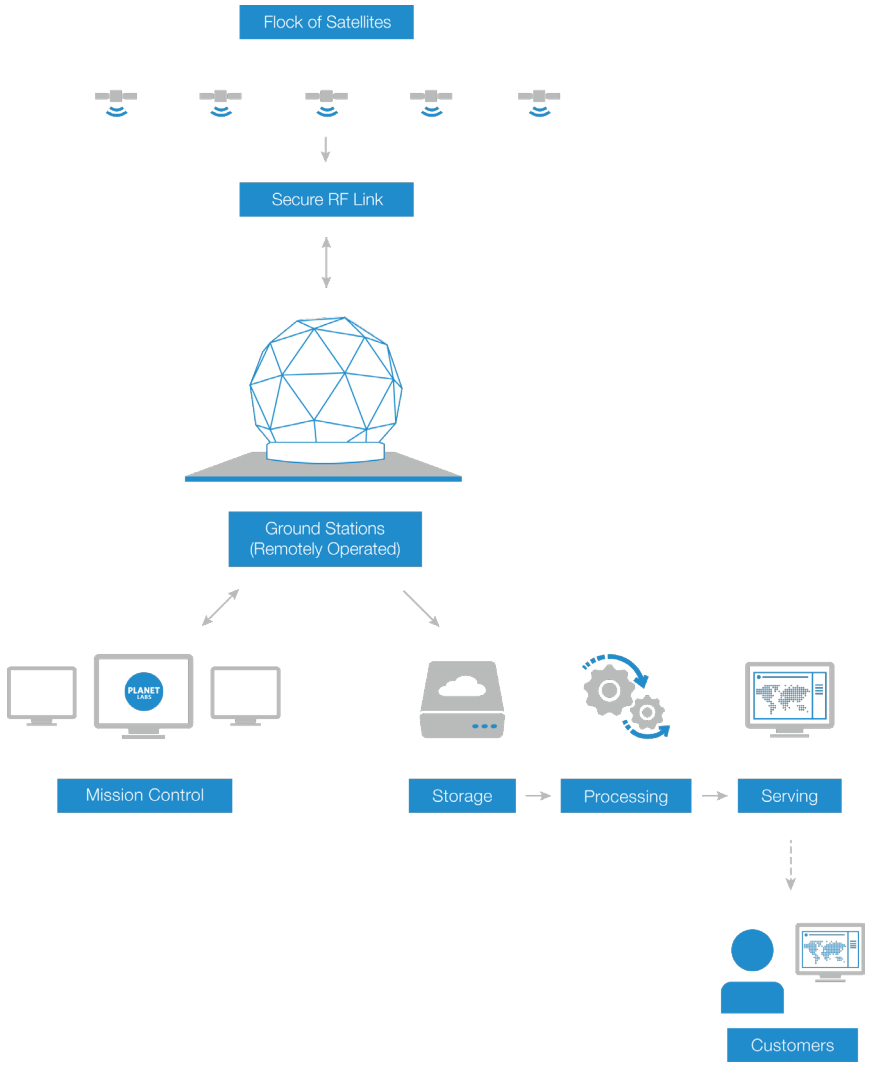
Planet Labs' forecasts are strongly driven by successful completion of launch. Launch manifests are subject to change. Collection capacity estimates include the effect of clouds (on average 45% of the Earth's surface is obscured by cloud cover) Revisit estimate are based on orbital parameters only, and do not include the effect of clouds.

4. Ground Stations and Network

4.1 Network Architecture

Planet Labs has developed its own global network of ground stations to support both spacecraft mission operations and image data downlink. Each ground station consists of an antenna and a Radio Frequency (RF) system, coupled with a local computer server, connected via secured VPN access to centralized services. Downlinked image files are transferred from local ground station servers to Amazon Web Service (AWS) for ingestion into Planet Labs' data processing and distribution pipeline.

Figure VII: Planet Labs End-to-End Data Flow



Planet Labs utilizes two low speed UHF systems for satellite operations and high speed X-band system for imagery download. Planet Labs currently operates six X-band ground stations and will increase this number to 28 at 10 separate locations, in order to meet the downlink capacity requirements for a planned constellation of over 200 satellites operating simultaneously.

4.2 Compression

Images are captured in 12 bit aboard the satellites and are then encoded to 8 bit for data transmission to the ground station. Several compression methods are used to maintain image quality, including:

- **Gamma Encoding:** Gamma is a non-linear encoding method that allocates more bits to low light areas of the image
- **Green Channel Compression (GCC):** Uses 2x2 downsampling in the green channel
- **JPEG compression:** Individual JPEG compression is used on each of the four color component images