National Aeronautics and Space Administration

Balloon-borne Venus gravity survey

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Program: Spontaneous Concept

Project Objective:

As part of a study of possible ***future Venus missions***, we have been examining opportunities for making a suite of geophysical measurements using a ***balloon floating in the Venus atmosphere*** as platform.

Rather detailed analyses were conducted in the 1980s of balloon-borne gravity surveys for Earth [Lazarewicz, 1985]. An advantage, compared to orbital platforms is that the sensors can be much closer to the source, which increases accuracy of the output field.

Recently, engineering sensors on the Curiosity rover were used to determine the gravity field in a traverse across Gale crater and to infer information about the structure of Mount Sharp [Lewis et al., 2019].

A Venus balloon, swept around the planet in the super-rotating flow would have the potential of determining the gravity field along a traverse of 1 million kilometers during the 90 day nominal lifetime of a Venus balloon mission.

A key challenge is that on-board accelerometer measurements will include both signal and noise, in terms of gravitational and non-gravitational accelerations. In order to recover the gravitational field component, we will need to have independent measurements of the non-gravitational effects, which will be dominated by the wind field. Earth-based range and range-rate measurements to the balloon will allow reconstruction of the line-of-sight component of acceleration. Simultaneous tracking from several, well separated ground stations (VLBI) or in-orbit assets will enable reconstruction of the acceleration field.

We will examine a range of measurement accuracies and configurations, in terms of on-board sensors, Venus-orbit-based and Earth-based tracking. Our objective is to obtain a broad-brush view of the Venus gravity field measurement accuracy attainable from various sensing configurations, and to compare those values with what is needed to resolve key questions concerning internal structure and dynamics. We will also look at synergies with other types of investigation possible with the same instrument suite including investigations of infrasound from Venus quakes and topographically generated gravity waves.

Significance of results:

Gravity measurments are a feasible and attractive component of a future balloon-borne Venus mission.

Current generation sensors are adequate for the task.

Approach:

The baseline on-board measurement suite will include a 3-axis gravimeter, and an externally mounted barometer and thermometer. The baseline Earth-based tracking would involve range and range-rate measurements from a single DSN station. Lazarewicz [1985] used first generation three-axis gyros, accelerometers and magnetometers to achieve signal precision at the 100 mGal level using an earlier generation of technologies from a balloon platform at stratospheric altitude of about 30 km. In contrast, accelerometers recently used by Lewis et al., [2019] achieved about 10 mGal sensitivity using the Curiosity platform on Mars to resolve gravity anomalies. Surface gravimetry is challenging on Venus due to high temperature and pressure and is likely still decades away.

We investigated sensitivities of high-end IMUs, very precise pressure sensors and VLBI tracking to achieve at least a factor of 10 improvement in resolving gravity anomalies down to the 10 mGal level or better from balloon platforms on Venus. Within each configuration, we simulated the accuracy of recovered gravity resulting from a range of measurement accuracy values and acquisition cadences. We also examined how the spatial coverage of the balloon-borne measurement values maps onto ability to resolve candidate internal density structures.

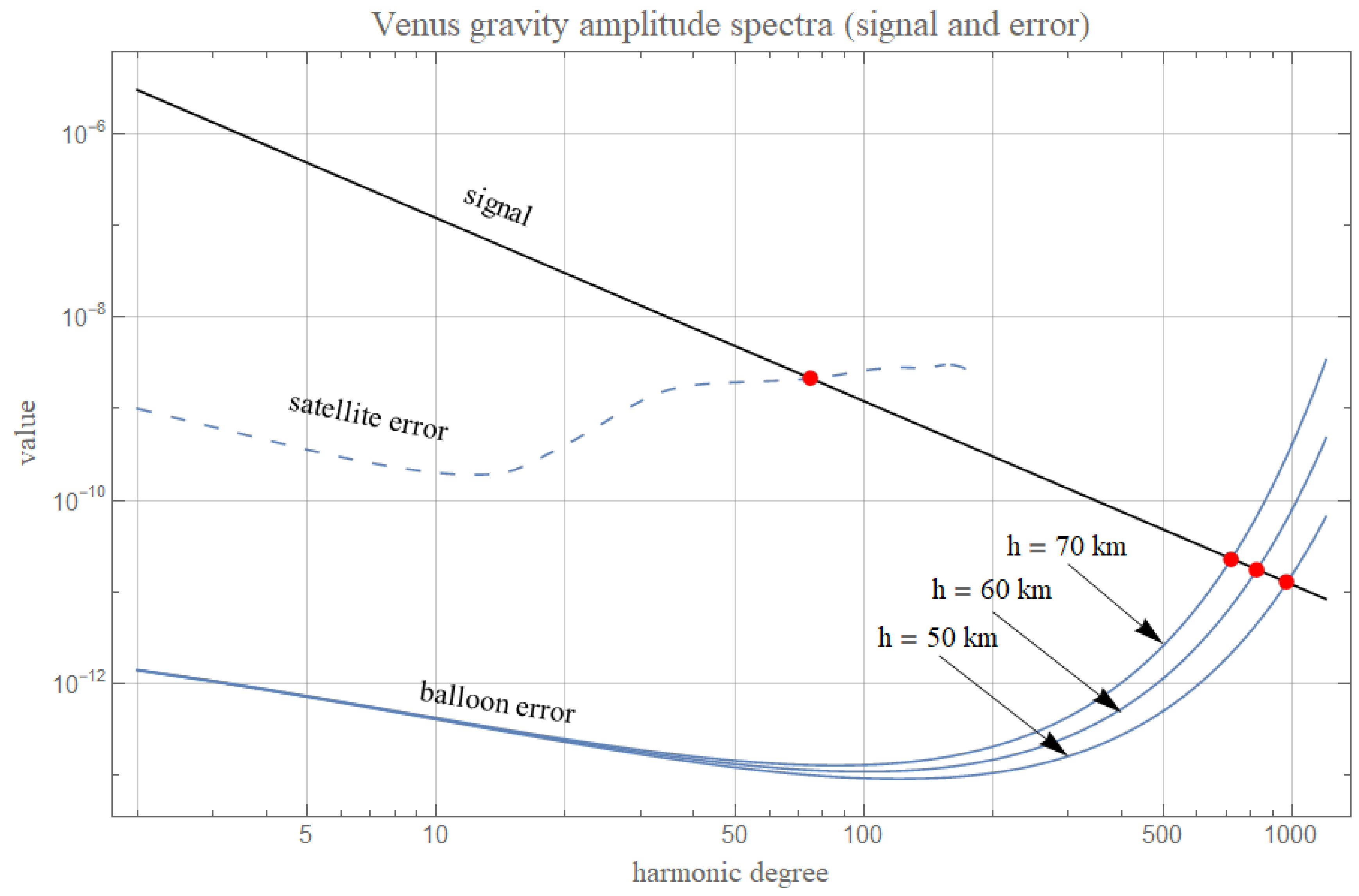
In order to minimize atmospheric turbulence as a noise source, it appears desireable to position the balloon in the 40-70 km altitude range. The lower altitudes present greater thermal challenges. We thus simulated performance at 50, 60, and 70 km altitudes. As a representative case, we assume motion of the balloon along an equatorial great circle.

FY18/19 Results:

The error in estimating a spherical harmonic coefficient of degree **n**, from **N** independent observations of the radial component of gravity, taken at radius **r**, with measurement error $\boldsymbol{\varepsilon}$, on a body with gravitational monopole moment $\boldsymbol{\mu}$, and mean radius **R** is

$$\sigma_n = \left(\frac{\varepsilon}{\sqrt{N}}\right)\left(\frac{1}{n+1}\right)\left(\frac{R^2}{\mu}\right)\left(\frac{r}{R}\right)^{n+2}$$

The figure below shows Fourier amplitude spectra for static gravity signal, current error (from Magellan mission measurments), and simulated error spectra from balloon measurements, for 90 days of observations, with 10 mGal error and 1 second sampling cadence, at altitudes of 50, 60, and 70 km.



The SNR (signal to noise ratio) is currently below 1 only out to degree 75. With the simulated balloon results, we would have an equatorial strip in which the SNR is below 1 out to degree 720 to 970, depending upon altitude. These results assume that balloon position knowledge and turbulence related noise suppression is sufficient that the direct gravity measurement error dominates.

The optimal combination of this high resolution strip, with a lower resolution global model, is a task for future work.

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