UNCERTAINTIES IN THE JPL PLANETARY EPHEMERIS

W.M. FOLKNER
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109
e-mail: william.m.folkner@jpl.nasa.gov

ABSTRACT. The numerically integrated planetary ephemerides by JPL, IMCCE, and IPA are largely based on the same observation set and dynamical models. The differences between ephemerides are expected to be consistent within uncertainties. Uncertainties in the orbits of the major planets and the dwarf planet Pluto based on recent analysis at JPL are described.

1. INTRODUCTION

Numerically integrated ephemerides of the planets have been used to support planetary spacecraft missions since the first missions to Mars in the 1960s [Peabody et al. 1964]. The accuracy of the ephemerides has improved dramatically over time, due to improvements in the definition of the celestial reference frame, advanced models for Earth's orientation, CCD images of planets and natural planetary satellites from observatories, laser ranging to retro-reflectors on the Moon and measurements of radio signals from spacecraft in proximity to planets. The accuracy of the ephemerides is an important factor for planetary spacecraft missions. Near-term missions with a need for accurate planetary ephemerides include the MESSENGER mission to Mercury, with orbit insertion in March 2011; the Mars Science Laboratory planned for launch in November 2011 and arrival at Mars in August 2012; and the New Horizons mission to Pluto with arrival in the summer of 2015.

The accuracy of the planetary ephemerides is generally assessed for each mission, which requires characterizing the observation accuracy and the possible systematic errors. Systematic errors may be assessed by comparing orbit estimates based on non-overlapping or partial data sets. In a recent accuracy analysis of JPL ephemerides for near-term planetary encounters, it has been found that scaling the formal uncertainty (sigma) by a factor of two gives a reasonable measure of the variation in estimated orbits based upon partial or non-overlapping data sets.

The observations in current planetary ephemerides are generally as described in Folkner et al. [2009]. Additional data used for the uncertainties given below are described for each planet. VLBI observations of spacecraft at Mars, Saturn, and Venus serve to align the planetary ephemeris with the International Celestial Reference Frame [Fey et al., 2009].

2. PLANETARY EPHEMERIS UNCERTAINTIES

Figures 1-8 show the uncertainty in right ascension, declination, and distance of the major planets and the dwarf planet Pluto with respect to Earth over the time period 1950 to 2050. For planets with natural satellites the uncertainty is for the system barycenter.

The Mercury orbit estimate is based on radar ranging to the planet's surface, range measurements from two encounters by the Mariner 10 spacecraft, and VLBI and range measurements for three encounters of the MESSENGER spacecraft. The uncertainty is dominated by an overall rotation uncertainty of $\sim 0.001''$, with a slow growth in uncertainty in right ascension and distance due to uncertainty in the semi-major axis. After the MESSENGER spacecraft goes in to orbit, radio range measurements are expected to improve the Mercury orbit accuracy by a factor of three.

The Venus orbit estimate is dominated by range measurements to the Venus Express spacecraft, as evidenced by the minimum in distance uncertainty over the observation period from 2006 to 2010. The Venus Express range data serve to indirectly tie the Venus orbit orientation to the ICRF through VLBI observations of spacecraft in orbit about Mars.

The Mars orbit estimate is based on range and VLBI observations of spacecraft in orbit about Mars and range measurements to the Viking landers. The uncertainty in the Mars orbit for a one-year prediction is about 300 m, as required for the Mars Science Laboratory mission, but grows rapidly for times before and after the spacecraft observation time span due to the influence of asteroids with orbits near that of Mars. The predicted orbit and uncertainty depend greatly on the asteroid model used. For the uncertainty given here, the mass parameters for the 67 asteroids with greatest influence on the orbit of Mars were estimated along with planetary orbital parameters [Konopliv et al. 2010].

The Jupiter orbit estimate is based on analysis of radio signals for spacecraft passing by Jupiter, by VLBI observations of the Galileo spacecraft in orbit about Jupiter, and by modern optical observations of the Galilean satellites. No range measurements were made to the Galileo spacecraft because the high-gain antenna failed to open. Significant improvement in the Jupiter ephemeris is expected from ranging measurements from the Juno mission, planned for launch in October 2011 and arrival at Jupiter in 2016.

The Saturn orbit estimate is dominated by range and VLBI observations of the Cassini spacecraft. The VLBI observations made using the Very Long Baseline Array [Jones et al. 2010] are the most accurate angular observations of planets available. The current data set covers the time period 2004 to 2010, less than one quarter of the orbital period, which results in the periodic signature seen in the uncertainty in right ascension and declination. Additional measurements should be available through 2017.

The orbits of Uranus, Neptune, and Pluto are dominated by astrometric observations, with only a small fraction of an orbit for each planet covered with modern observations made using ICRF-based star catalogs. Encounters by the Voyager 2 spacecraft with Uranus and Neptune are evident in the minima for the respective orbit uncertainties. The uncertainty in the distance to Pluto is an important factor for planning observations during the New Horizons mission encounter in 2015.

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3. REFERENCES

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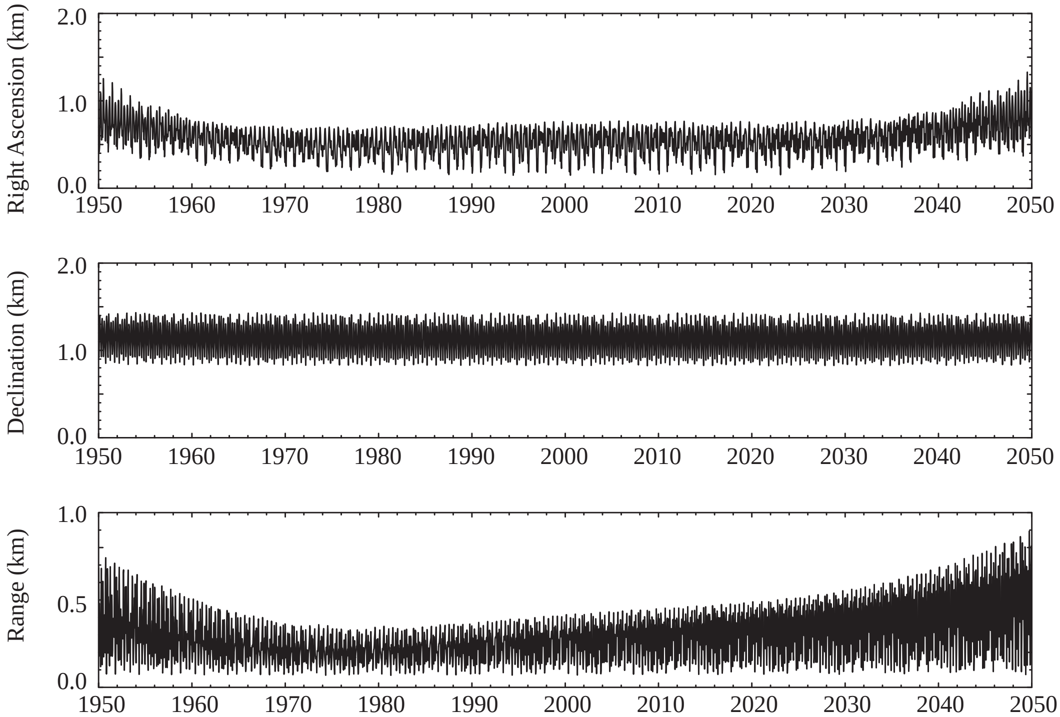

Figure 1: Mercury orbit uncertainty with respect to Earth

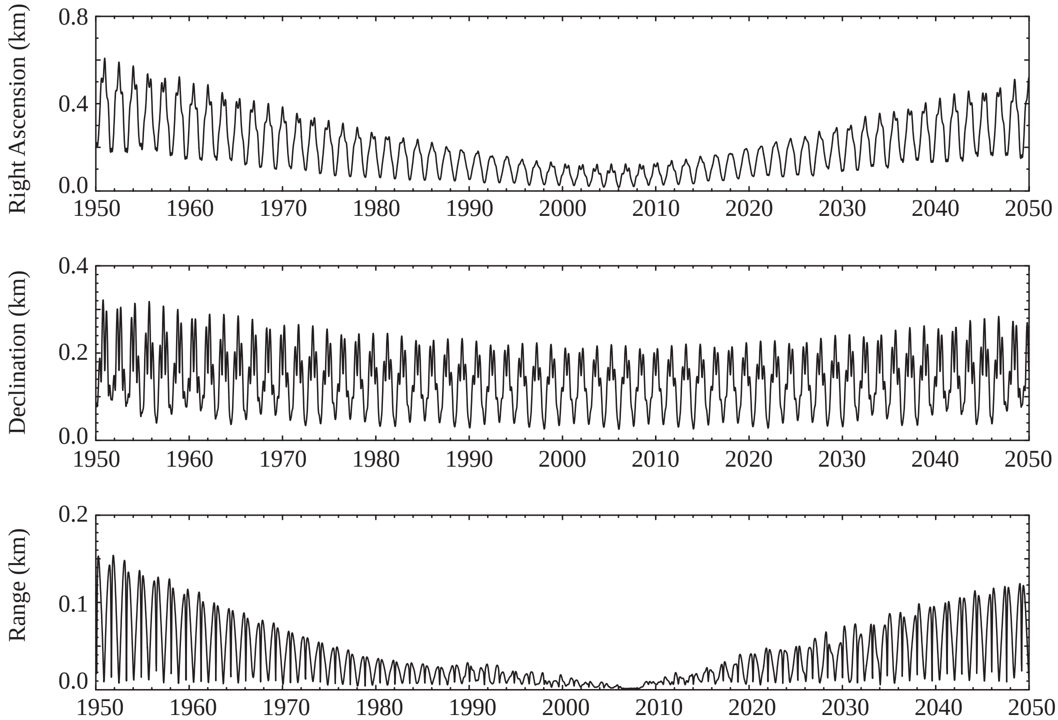

Figure 2: Venus orbit uncertainty with respect to Earth

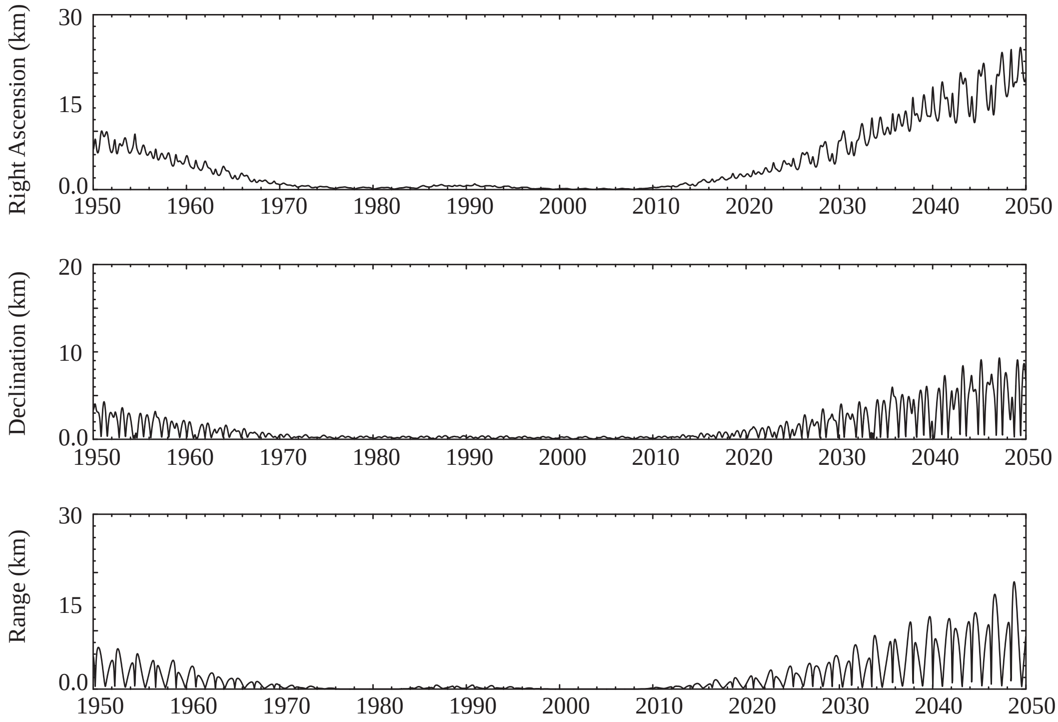

Figure 3: Mars orbit uncertainty with respect to Earth

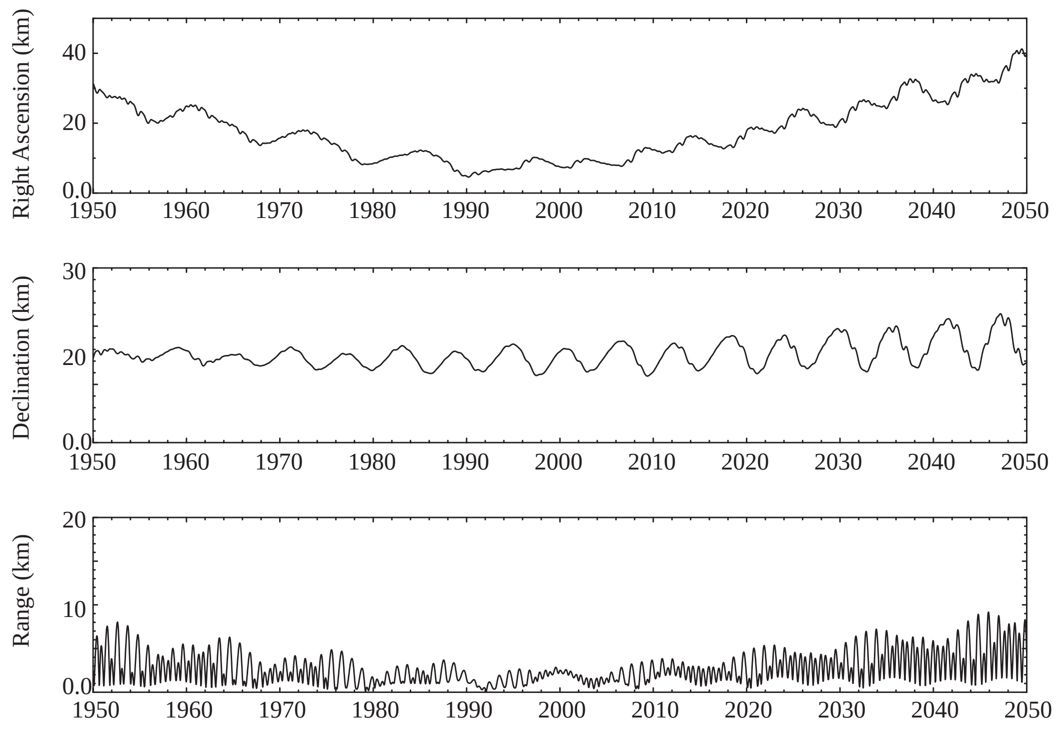

Figure 4: Jupiter orbit uncertainty with respect to Earth

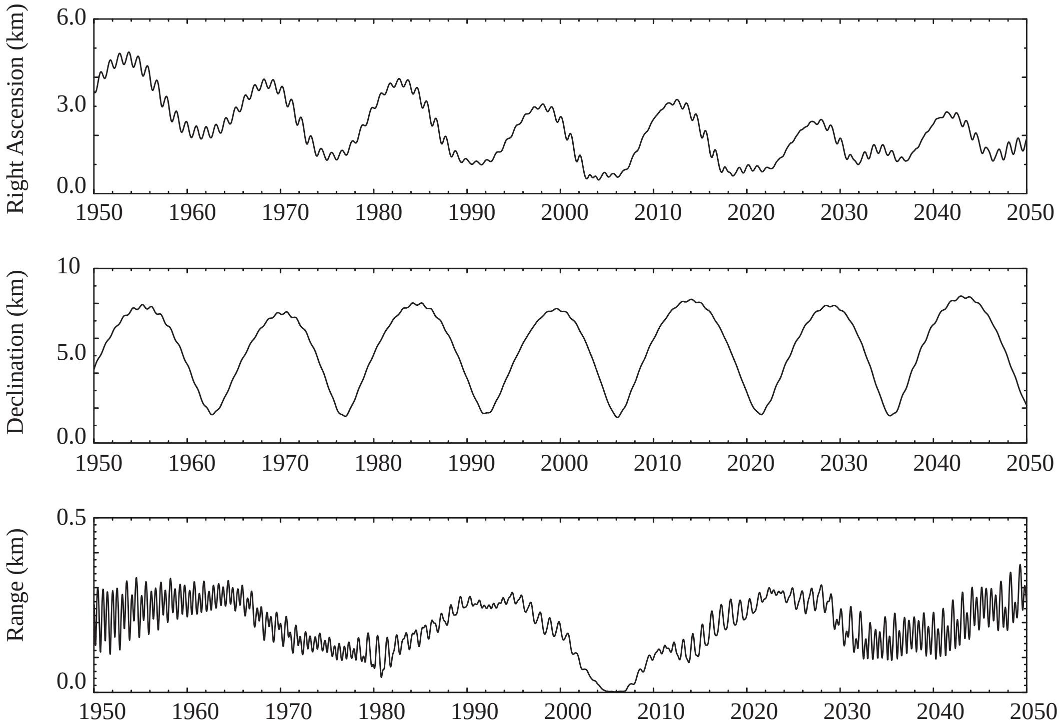

Figure 5: Saturn orbit uncertainty with respect to Earth

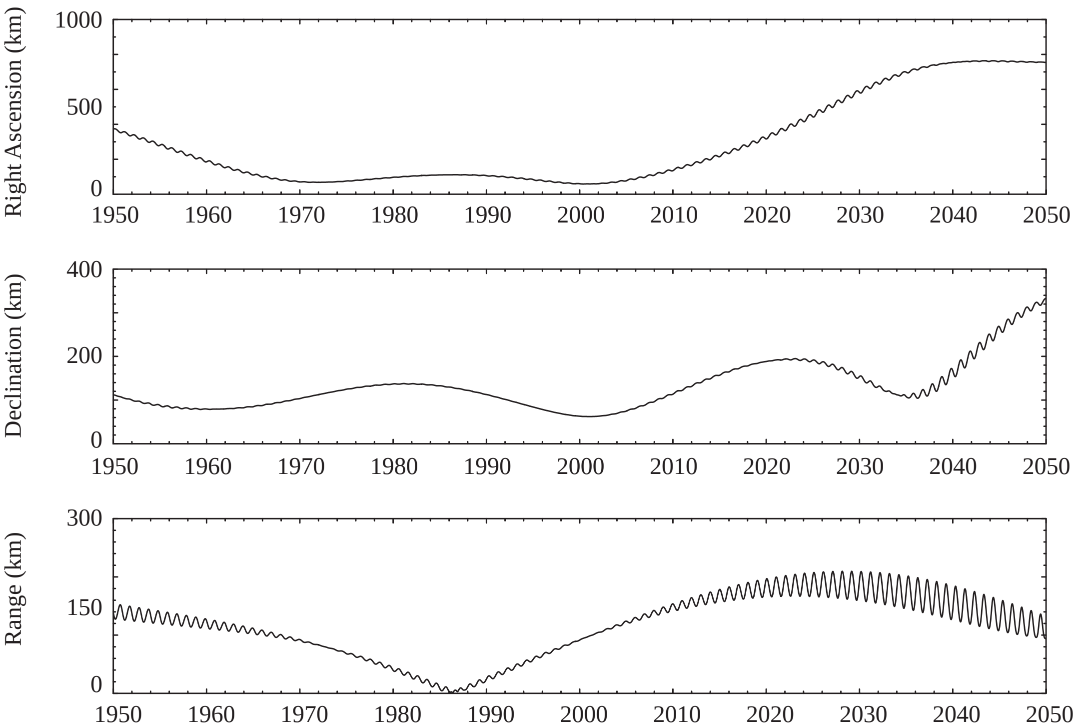

Figure 6: Uranus orbit uncertainty with respect to Earth

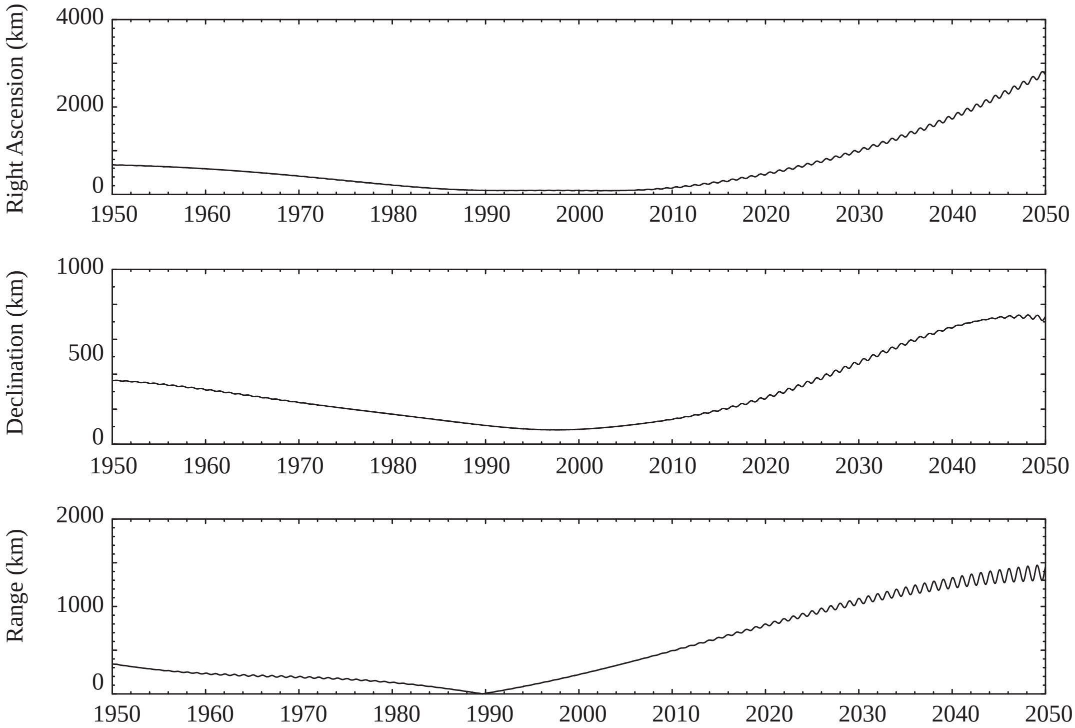

Figure 7: Neptune orbit uncertainty with respect to Earth

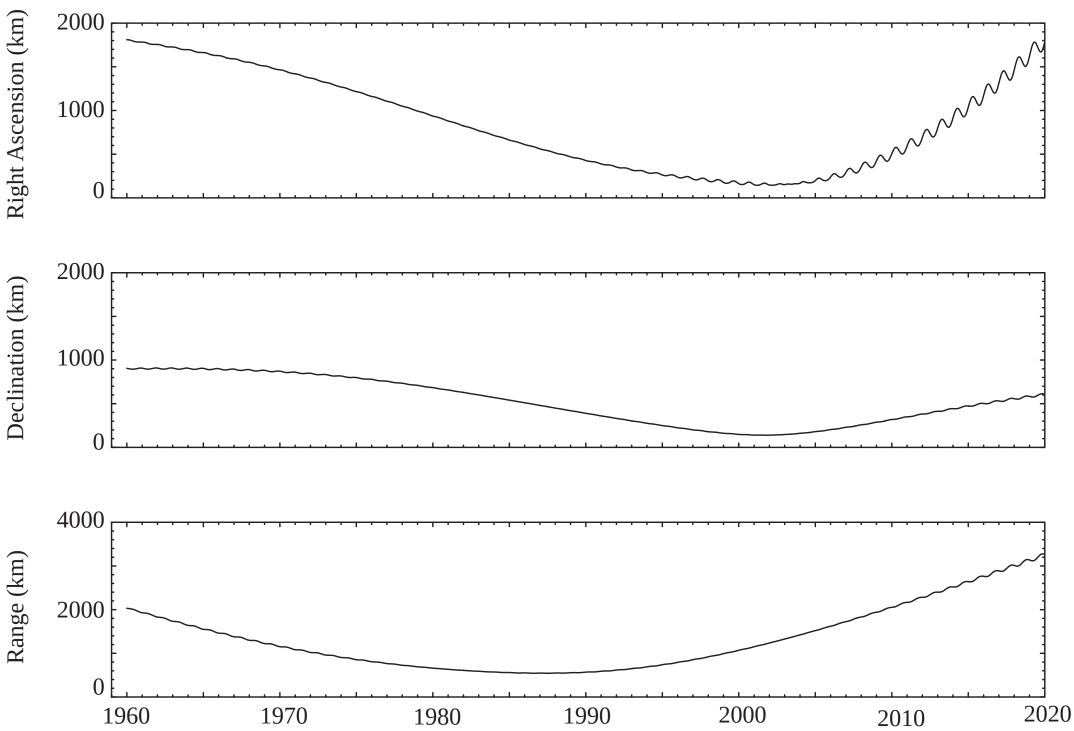

Figure 8: Pluto orbit uncertainty with respect to Earth