

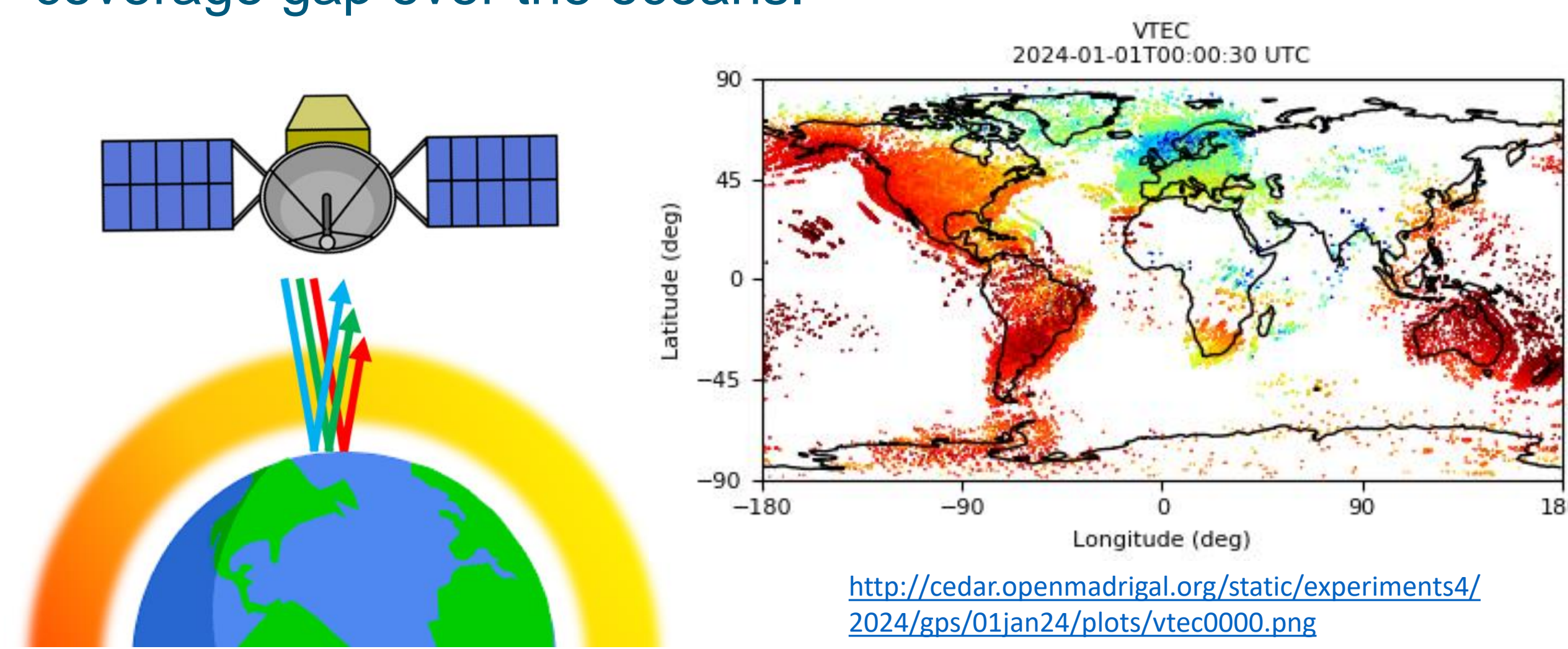
ReflecTEC: A Concept Satellite Sensor for Measuring Vertical Total Electron Content

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INTRODUCTION AND MOTIVATION

Characterizing global ionospheric electron density is critical for understanding and mitigating effects on, for example, radio communication and satellite navigation systems. Yet measurements of the ionosphere are often too sparse to specify electron density to the fidelity necessary. This is especially true over the open ocean because of the gap in ionosonde and ground GNSS receiver observations.

ReflecTEC is a concept for a novel spaceborne sensor that estimates vertical total electron content (TEC) of the ionosphere below the satellite altitude in LEO by transmitting VHF signals at multiple frequencies and measuring the differential delay of their reflections from the ocean surface. ReflecTEC can help fill the critical data coverage gap over the oceans.

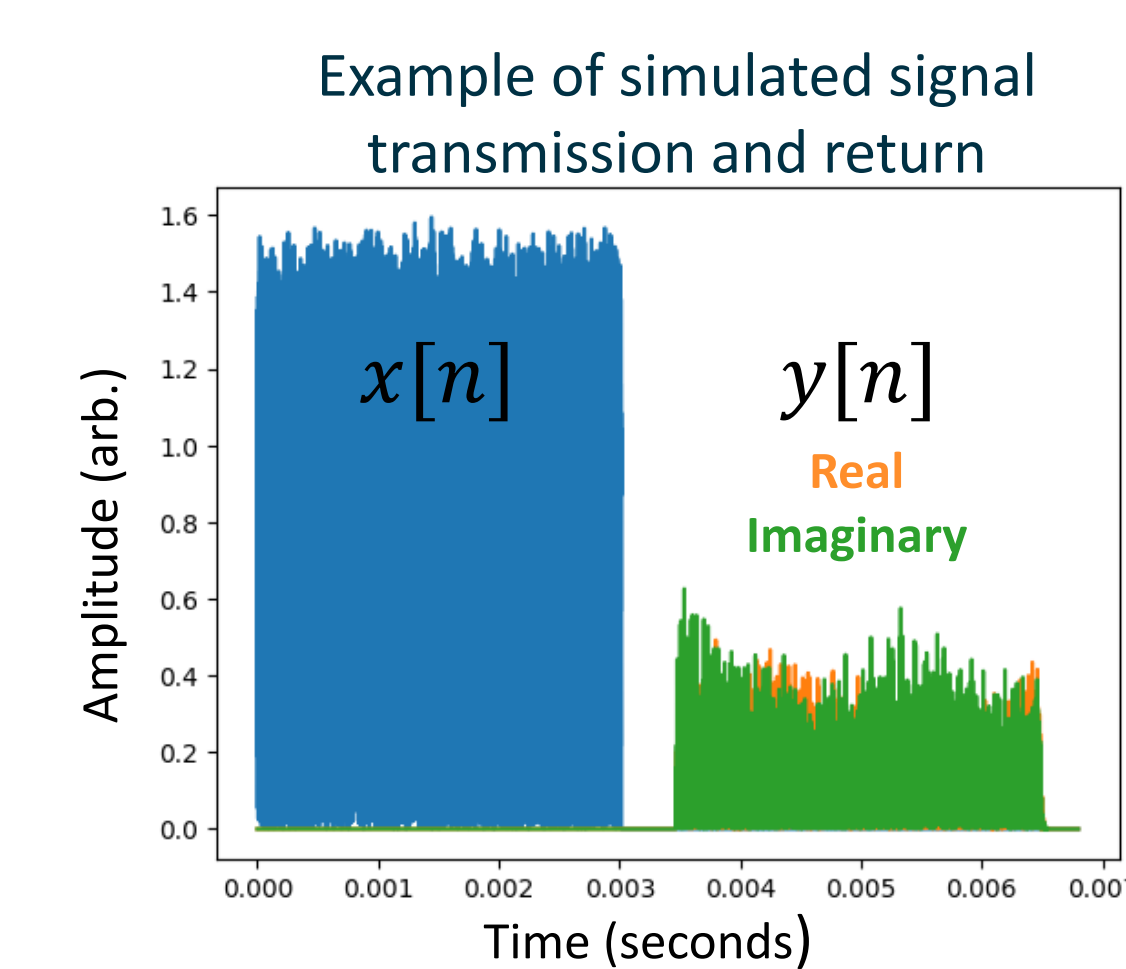
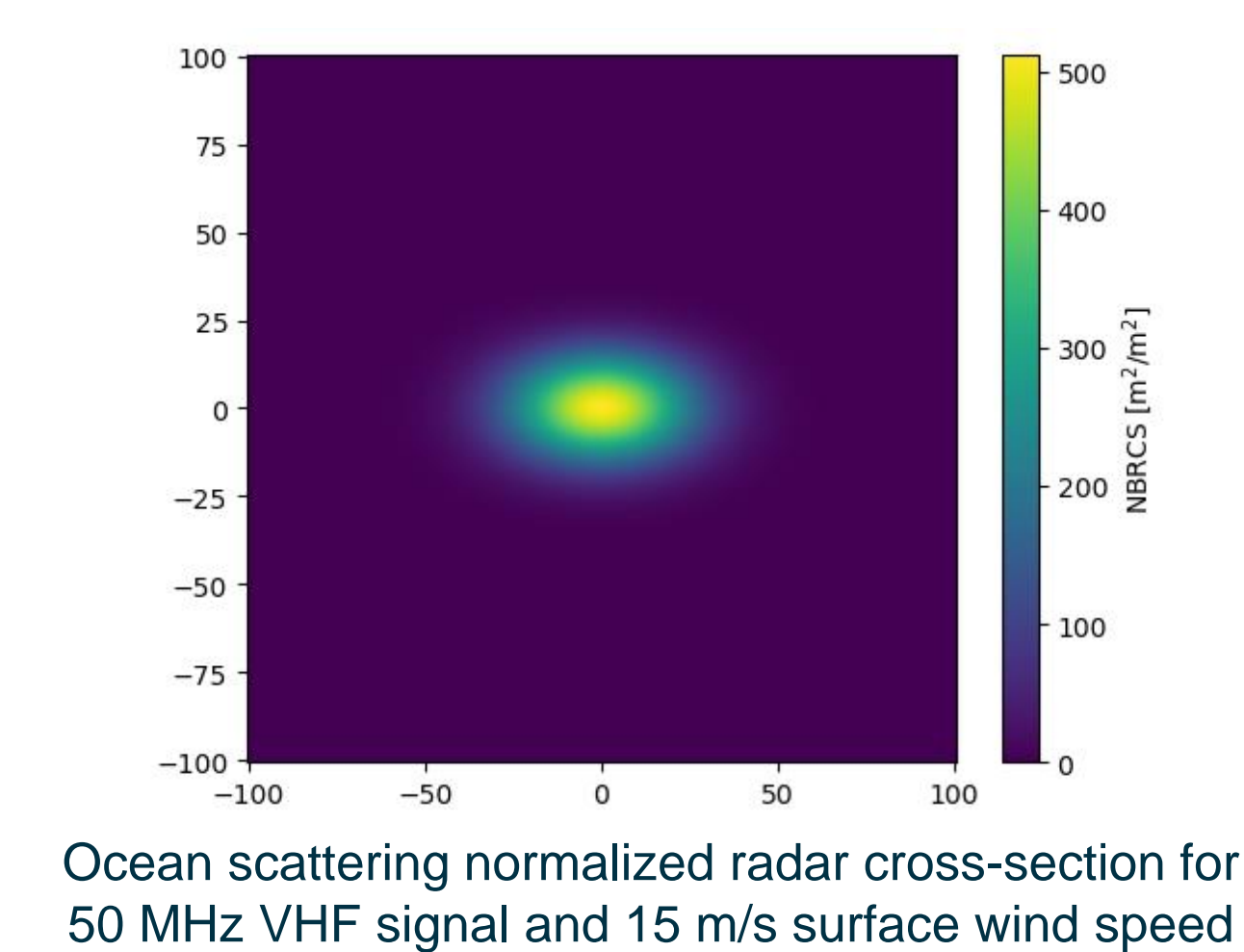
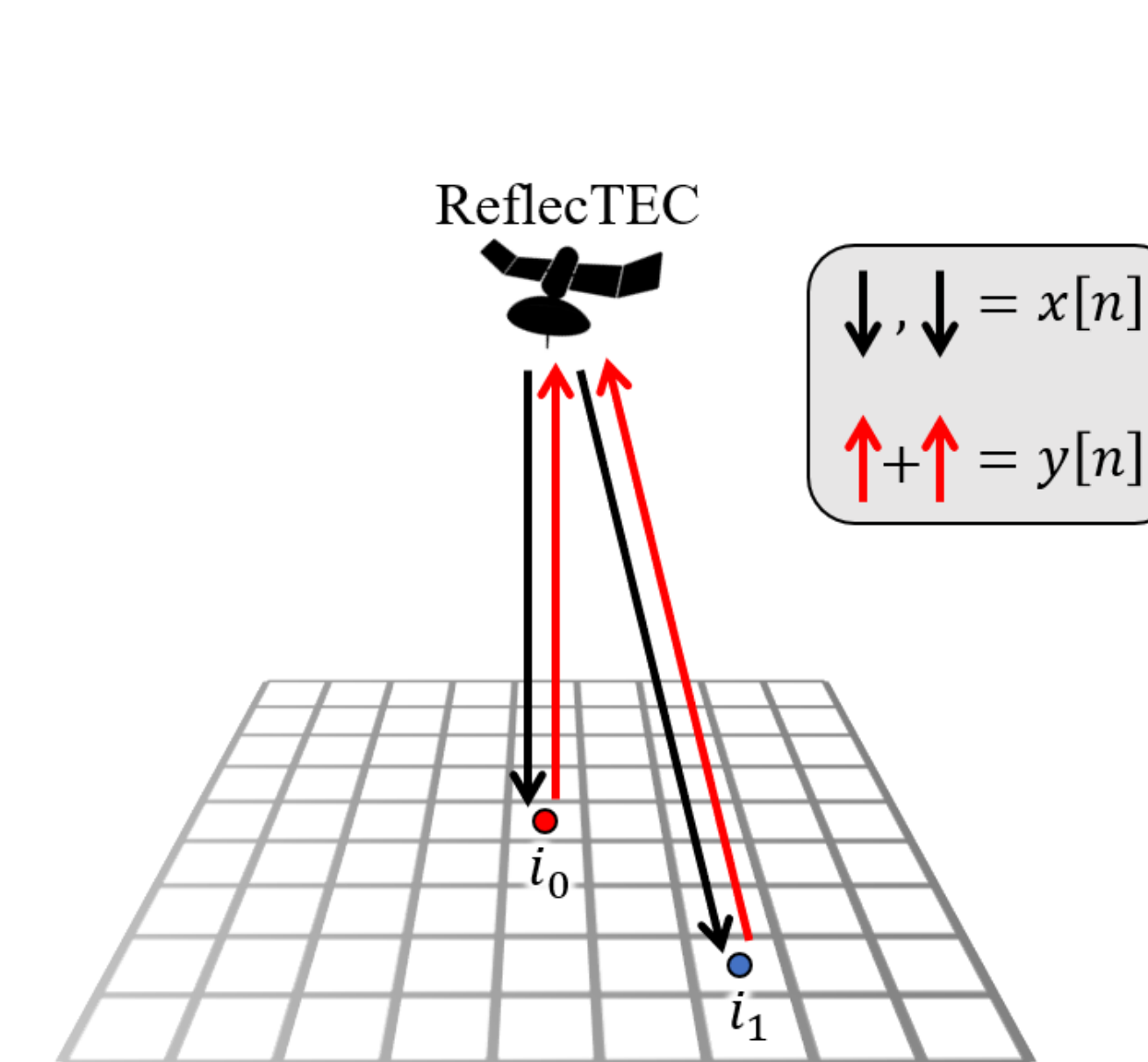


KEY ADVANTAGES

ReflecTEC will provide unique observations that are complementary to other measurements of ionospheric electron density and TEC (see concept figure). It has several key advantages:

- 1. Ionosphere Focused Geometry:** With a vertical raypath, no mapping from slant TEC to vertical TEC is necessary. Only the ionosphere up to the satellite altitude contributes to the TEC.
- 2. More Coherent Ocean Reflections:** At the lower end of VHF, ocean reflections will be coherent for typical ocean roughness conditions, reducing distortion in the reflected signal and enabling phase-based measurements.
- 3. Higher Sensitivity:** ReflecTEC uses lower frequencies and larger differences in frequency to achieve significantly higher sensitivity to TEC (for a given ranging error) compared to GNSS.
- 4. Accurate and Robust TEC:** Three or more transmitted frequencies allow for TEC to be better estimated using a least squares solution. If some measurements are unavailable, TEC can still be computed from two frequencies.

FEASIBILITY STUDY



Signal Simulation

To predict the TEC accuracy that can be attained by ReflecTEC under various operating conditions, we simulate the entire process from signal transmission, propagation and surface scattering effects, receiver matched-filter signal processing to obtain range measurements, and TEC estimation.

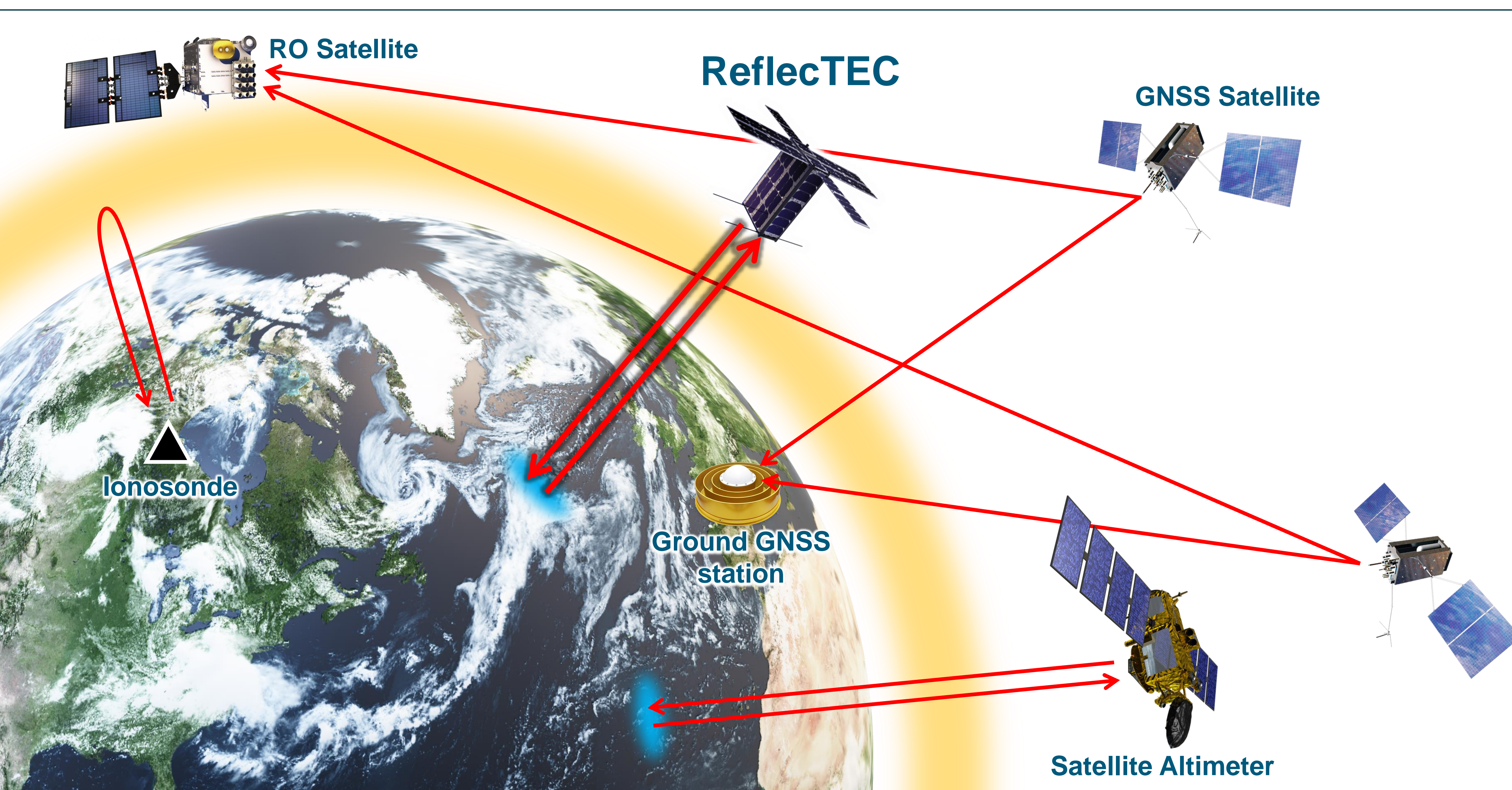
ReflecTEC transmits a signal $x[n]$. We tested a binary phase-shift key signal with the pulse length limited so that the pulse ends before the first sample of the signal return is received.

The received signal waveform $y[n]$ is the superposition of $x[n]$ with the following effects applied:

- Doppler response (varies with satellite line-of-sight velocity across the grid)
- Phase shifts due to ocean speckle noise
- Delay response (due to varying signal propagation distance and the ionosphere, including overall delay at center frequency and distortion across signal bandwidth)
- Amplitude response (includes computation of radar cross-section from ocean scattering)

Matched-filter signal processing is applied to $y[n]$ with a software defined radio designed in GNU Radio. TEC is estimated from pairs of frequencies using conventional methods or from 3+ frequencies with a least squares solution.

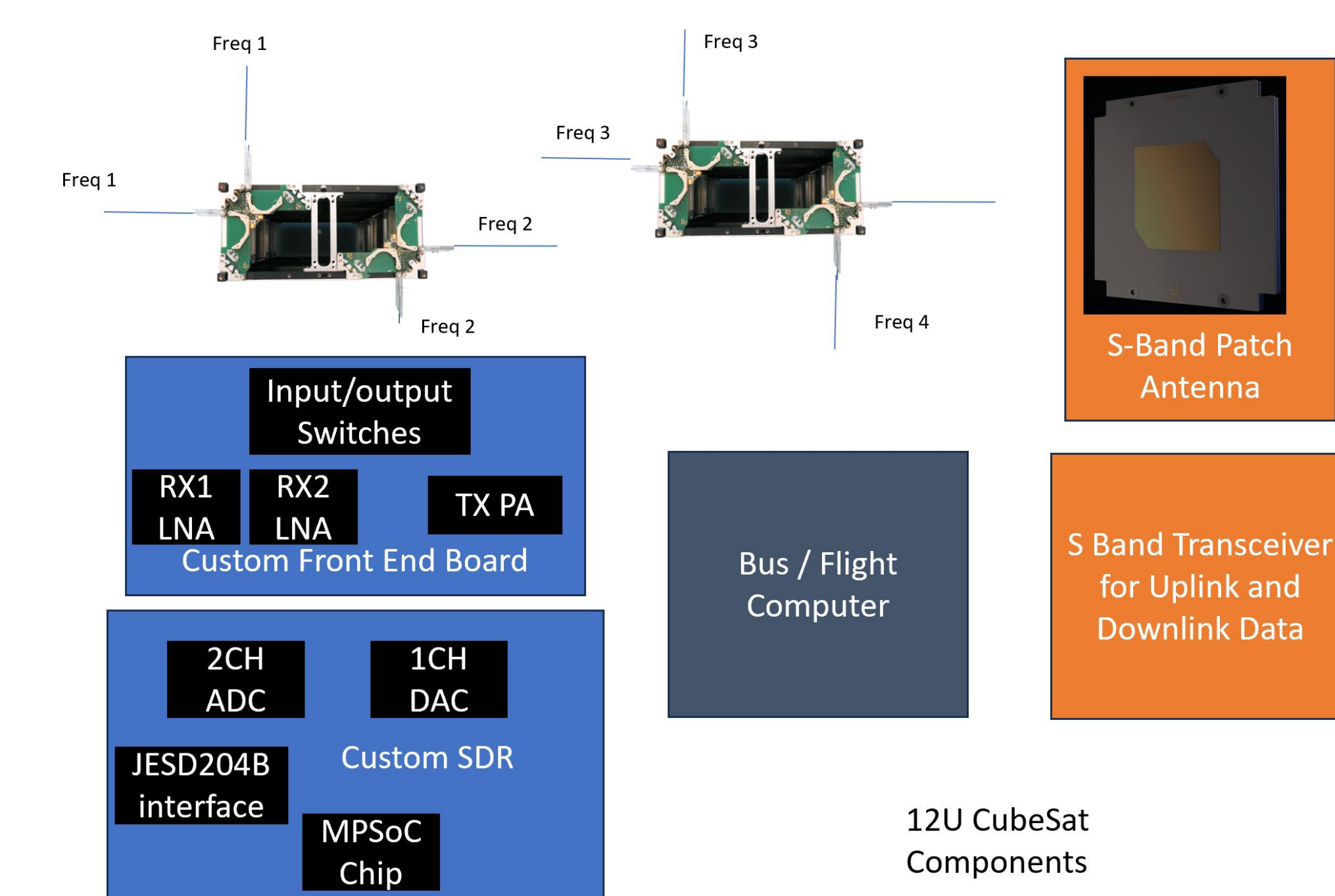
The feasibility study results show that ReflecTEC is likely to estimate TEC with <0.1 TECU uncertainty under many conditions.



NEXT STEPS

- Under a separate program, Orion Space Solutions is launching a satellite with an HF sounding payload that can transmit arbitrary waveforms. This may be an early opportunity to test the ReflecTEC concept.
- **We are pursuing opportunities to build and operate a dedicated prototype ReflecTEC satellite.**
- In the future, a constellation of relatively low-cost ReflecTEC satellites could significantly enhance ionospheric specification, such as through data assimilation.

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Notional payload design of ReflecTEC