esa

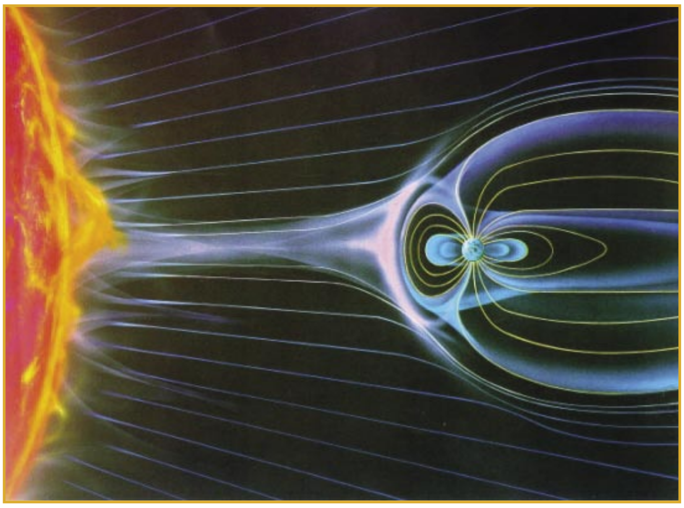
EGNOS FACT SHEET

2: THE IONOSPHERE EXPLAINED

EGNOS improves accuracy by broadcasting wide area differential (WAD) corrections to users. Unlike conventional DGPS corrections that provide one term for each satellite, the WAD corrections includes terms for each error component including an improved ionospheric model for single frequency GPS users.
This article outlines the effect of the ionosphere on GPS measurements, introduces the complex and variable nature of the ionosphere, and presents different mitigation strategies, before emphasising the benefits of EGNOS for all GPS users.

Why do we need an improved ionospheric model?
The effects of the ionosphere can be breathtakingly beautiful: the aurora borealis or northern lights are shimmering sheets of light that occur when charged particles enter the Earth's atmosphere at high latitudes.
The effects can also be devastating: solar storms can cause widespread power blackouts, disrupt navigation systems and radio communications, and destroy the payloads on commercial satellites.
GPS broadcasts timing codes and data on two frequencies, L1 and L2. The magnitude of the ionospheric effects on GPS measurements is dependent on the signal frequency and the level of ionospheric activity. The maximum vertical delay on GPS L1 measurements is about 15 m, but low elevation angles increase this by a factor of three. The ionosphere may also cause intermittent signal fading, in severe cases causing losses of availability.
We need a model to reduce these errors. The ionospheric model broadcast by GPS corrects for only 50% of the delay, and this is now the largest error source in a GPS error budget. This is why EGNOS is broadcasting an improved model for single frequency users.

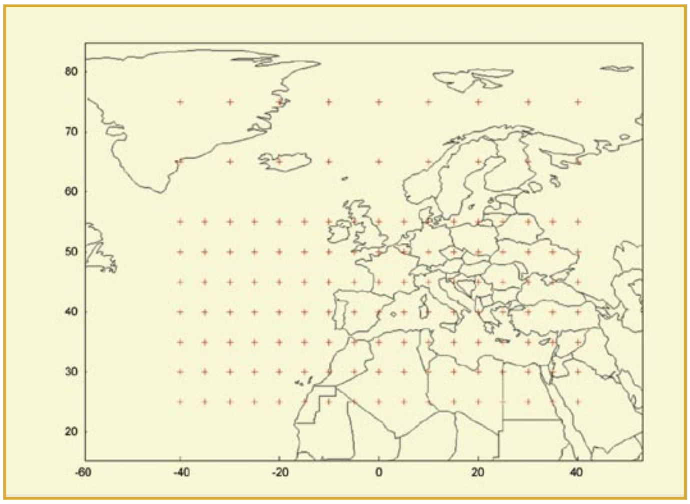
What is the ionosphere?
The ionosphere is the ionised part of the atmosphere that extends from an altitude of around 50 km to more than 1000 km. There are a significant number of free electrons and positive ions although it is electrically neutral. The level of ionospheric activity is generally described in terms of electron density. The interaction of solar radiation or charged particles with the Earth's atmosphere drives ionospheric behaviour.
The structure of the ionosphere is very complex. The vertical structure comprises four layers or regions (D, E, F1 and F2). The electron density of each layer varies



The Solar-Terrestial Environment

with time of day, and is a maximum in the F2 layer at an altitude of around 350 km.
The different ionospheric charging mechanisms allow us to predict the temporal and spatial variability of the electron density with some degree of confidence.
Predictable temporal variations include: an eleven-year solar cycle, the Earth year, the 27 day solar rotation, and the 24 hour Earth rotation. The Earth's magnetic field is the reference for spatial variability, and some effects are more prevalent in specific regions - for example, the fountain effect near the Equator and polar cap absorption at the poles.
However, it is the unpredictable variability that is critical for many users, especially those requiring high levels of performance. Sudden ionospheric disturbances raise the electron density and cause signal fading at some frequencies. Travelling ionospheric disturbances can move at speeds up to 1000 metres per second, causing sudden changes in the electron density. In addition, ionospheric scintillations, which manifest themselves as rapid variation of phase and amplitude of the received signal, can cause GPS receiver to loose lock, thereby interrupting the reception of one or more satellites.

How can we mitigate the effect of ionospheric propagation?
The most accurate and most expensive strategy is to combine carrier or pseudo-range data from dual frequency receivers to eliminate the ionospheric delay. The critical issue is decoding the encrypted Precise (P)



EGNOS Ionospheric Grid Model

code. Authorised users have keys for the encryption, and hence can use this approach. Some manufacturers have developed techniques that allow civil receivers to access both frequencies, but these receivers tend to be rather expensive. Later this decade, GPS will transmit a second civil code on L2, and that will make this approach more widely available. Nevertheless, we must stress that dual frequency users are subject to signal fading and L2 is not a protected frequency for safety-related application. In severe conditions their receivers may revert to single frequency, and they will need a model for the ionosphere. Single frequency receivers are less expensive but an ionospheric model is required, and there is a clear trade-off between accuracy and economies in terms of the number of parameters broadcast to users.
The GPS model users errs towards economy.
Each satellite transmits eight terms that represent the global ionosphere in terms of the amplitude of the vertical delay and the period of the model. They are updated at least once every six days, and provide at least a 50% reduction in the single-frequency user's error. This cannot hope to model the short-term regional ionospheric effects.
The EGNOS model optimises both accuracy and integrity by providing corrections for specific grid points in the European service area. Grid Ionospheric Vertical Delays (GIVDs) improve accuracy, and Grid Ionospheric Vertical Errors (GIVEs) guarantee integrity. The density of the grid points has been chosen to cope with expected spatial variations in the ionospheric vertical delay during periods of high solar activity. The parameters are updated at least every five minutes, and the residual grid point ionospheric vertical delays are expected to be less than 0.5m.

So what are the real benefits of the EGNOS ionospheric model?
If you are a user with an expensive dual frequency receiver, you can overcome nearly all the delay effects, but you are still subject to signal fading. This could reduce your functionality to single frequency with large errors resulting from the GPS broadcast model.
When you choose EGNOS, you will see significant improvements in position accuracy compared with dual frequency GPS, but at a similar price to low-cost single frequency GPS. The improved ionospheric model also enhances availability for dual frequency users when they suffer from signal fading. Finally, you will also see improvements in integrity for safety-related applications, and this is driving the long-term need for EGNOS.