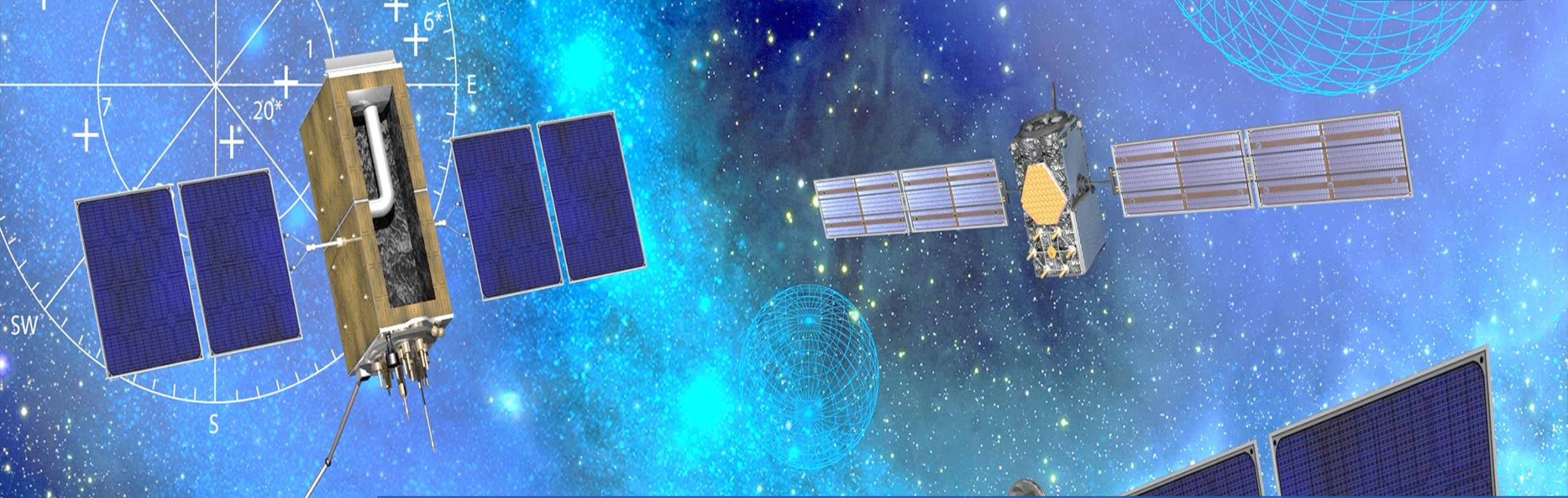


# Real-world ionospheric scintillation events in a Spirent Simulator

Cathryn Mitchell[1], Talini Pinto Jayawardena[1,2], Richard Boyle[2], Guy Buesnel[2], Biagio Forte[1], Robert Watson[1]

University of Bath[1] and Spirent Communications[2]

# Contents

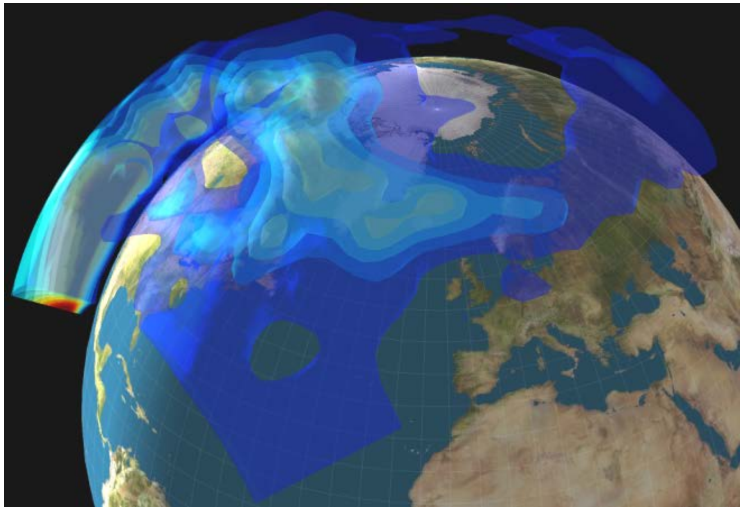
GNSS Systems affected by TEC and scintillations

- Ionospheric Scintillation

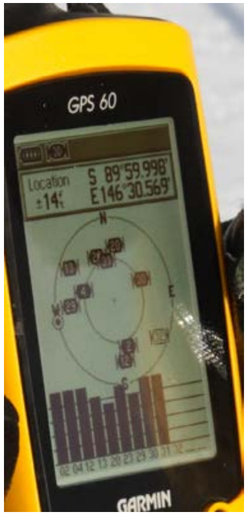
  Effect on Positioning and Timing

Scintillation Re-Creation

- Capability
- Challenges to simulate extreme events
- Possible ways ahead



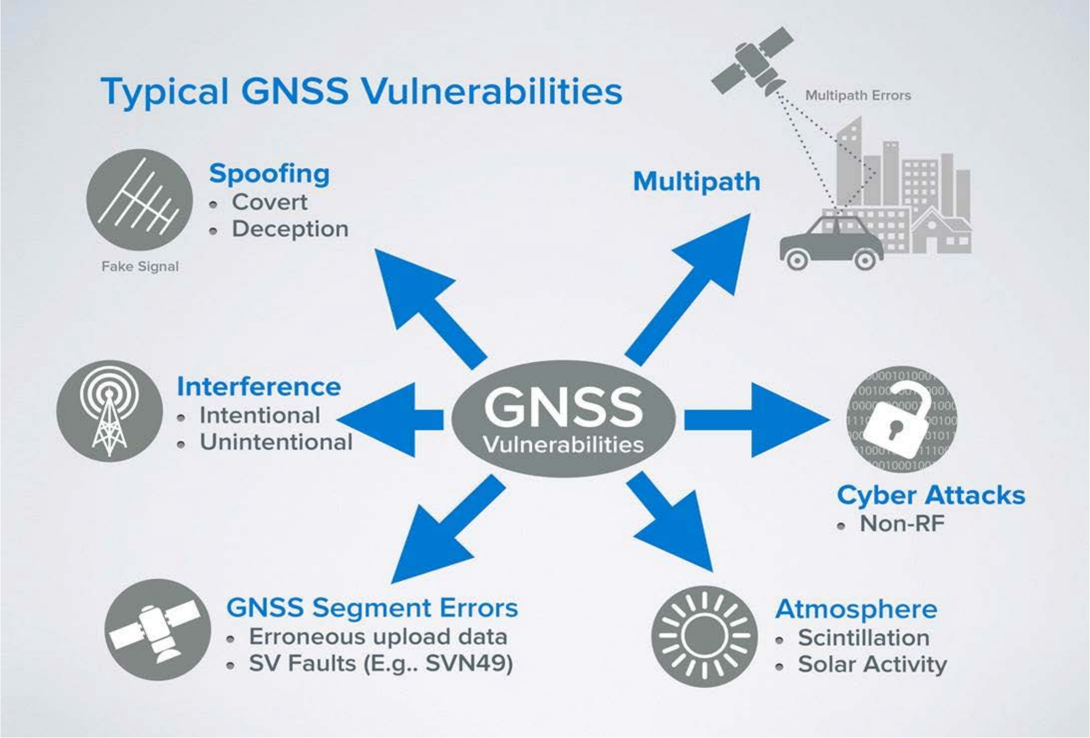
# Positioning and Timing reliant on GNSS




**"Many systems now are GNSS reliant but the knowledge of their vulnerability has been lost"**

# Current Test Frameworks

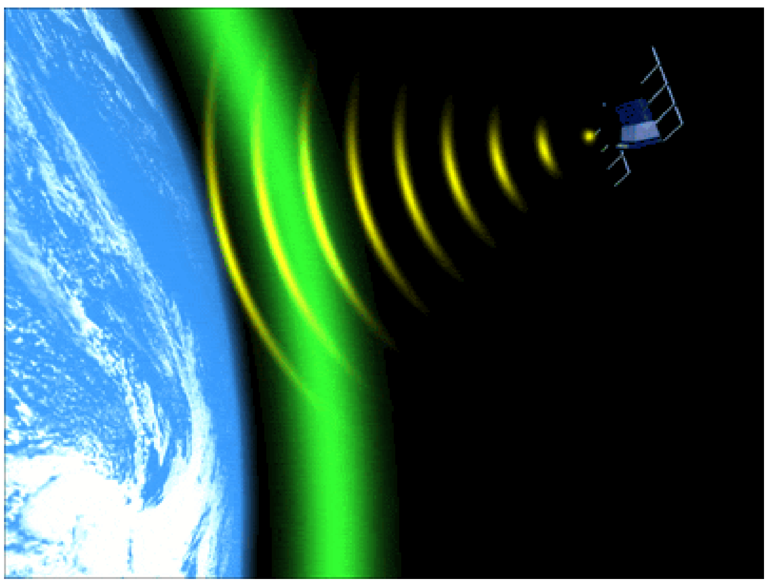
*The Need for Test Frameworks*




**Test frameworks and methodologies needed to assess and compare performance of systems under GNSS threat mechanisms**

# Ionospheric Scintillation

- Rapid fluctuation of amplitude/phase caused by signal refraction and diffraction when travelling through electron density irregularities in the ionosphere
- Dependent on time of day, year and geomagnetic location, and enhanced during magnetic storms



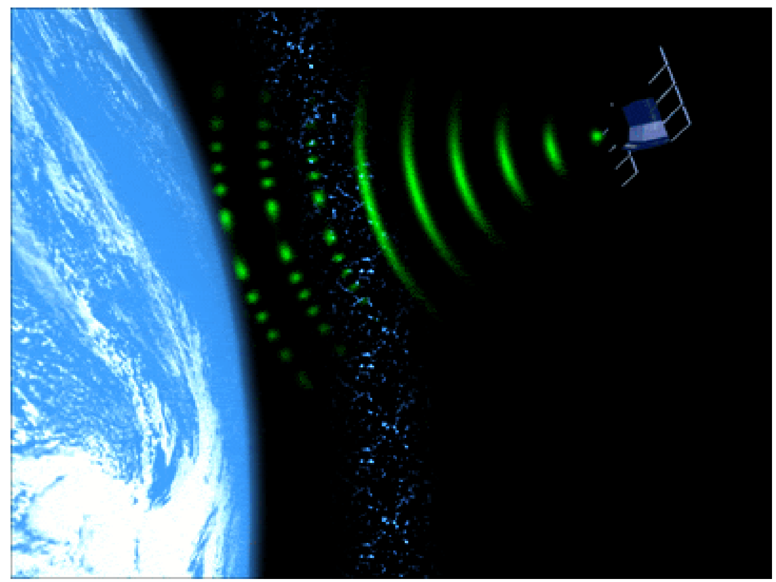


**Image credits: MIDAS, University of Bath**

# Current Test Frameworks

Scintillating GNSS signals disrupts tracking capability of receivers

- Leads to loss of signal lock causing degraded accuracy, precision and availability
- Growing concern for safety-critical applications (e.g. aviation)

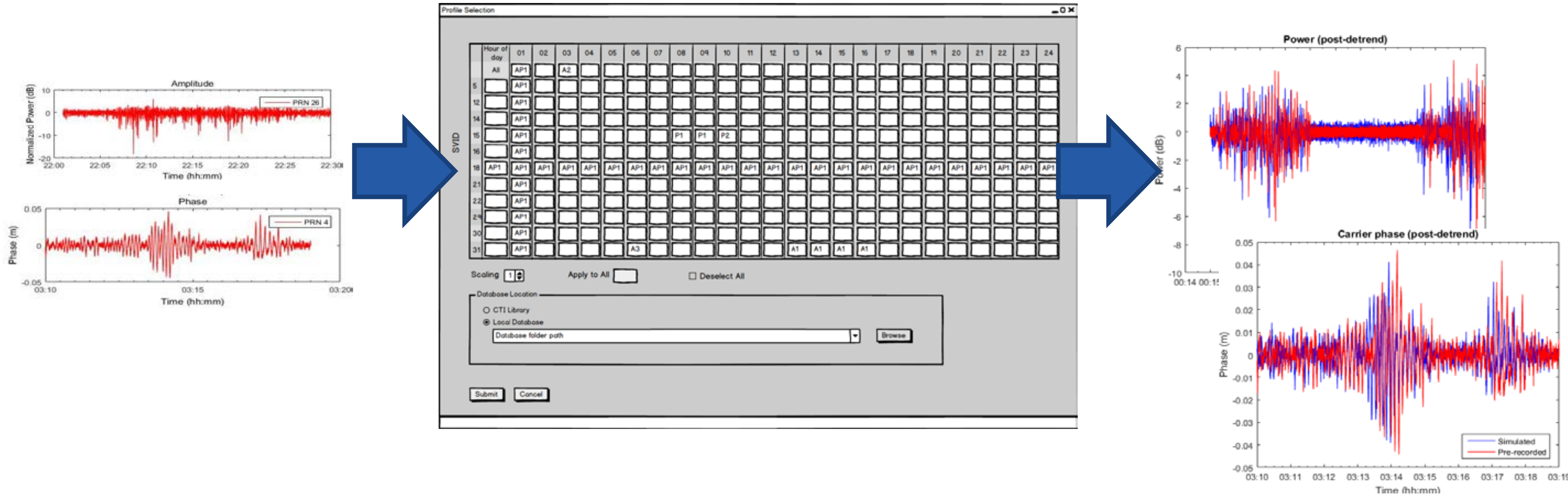
*Limitations of Ionospheric Scintillation Testing*

- Conventional methods for scintillation testing use statistical modelling and simulations

- Results in:
  - Underestimation of the rate of cycle slips
  - Assumption of linear operation – violated during strong scintillation conditions

# The Concept

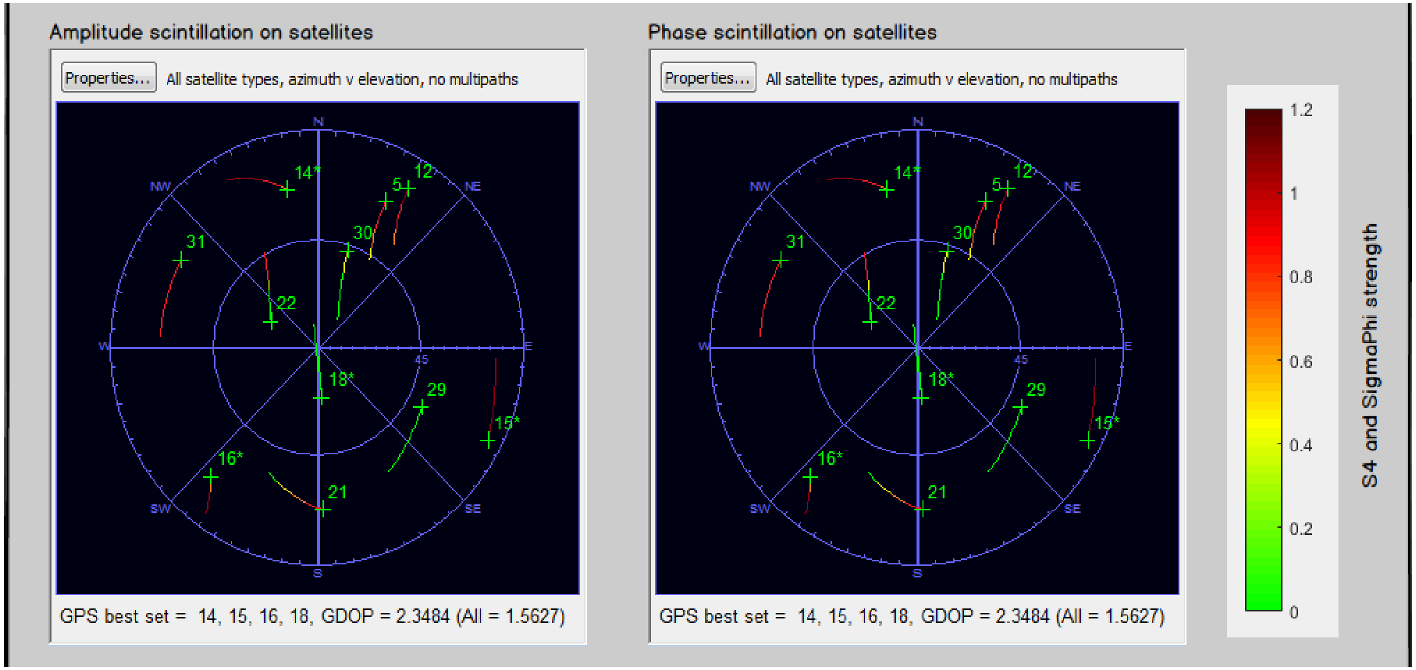
## *Scintillation Profile Application*




- A range of scintillation profiles extracted from pre-recorded data
- Profiles validated through verification of receiver responses to the live-sky (pre-recorded) and synthesized RF signals
- Full user flexibility to generate custom scenarios

# The Concept

## *Satellite-Specific Scintillation Modelling*




- Provided as a guidance to the user
- Scintillation strengths derived for each satellite-in-view based on the base grid and satellite elevation

Mechanistically this can and is being done – this is ‘engineering’ – we measured events and we can re-create them in a simulation to see how they affect different receivers or different operational activities

But it does not yet answer the question about extreme events – outcome of UK Gov’t exercise

## What about events we have never measured?

To quantify extreme events:

What physics do we know?

What tools to we have to apply this knowledge?

Are we right? Does it matter?

# Modelling the electron density in a storm

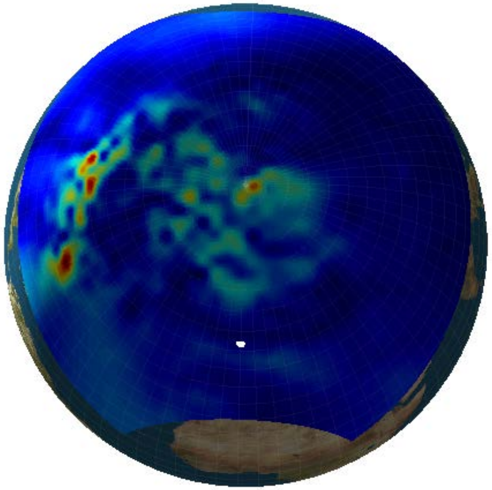
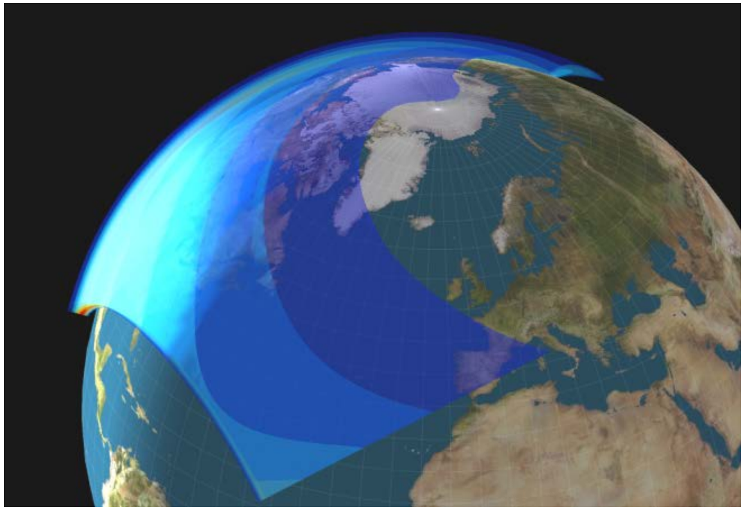


Image credits: MIDAS, University of Bath

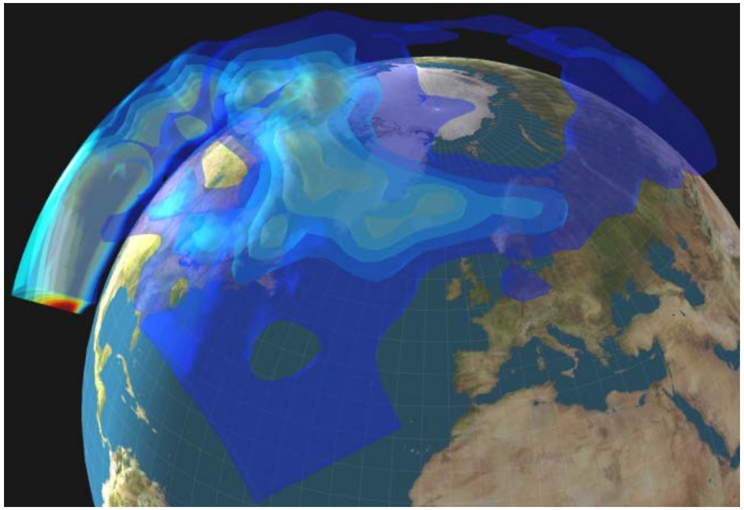
# How do we quantify an extreme storm?

- Electron density departs significantly from model

**IRI Statistical Model**



**MIDAS Image (from measurements)**



- MIDAS GPS movie – how do we scale up to an extreme event? We can assume the physics is the same and run models. But are we really able to do this properly ? We knew all the physics for the October 2003 event but it still surprised us, because although we *could* have modelled it before it happened we had not done so.

**Image credits: MIDAS, University of Bath**

UNIVERSITY OF BATH

# Modelling the electron density in an extreme storm

- Even the best ionospheric physicists were surprised at the high density and long lifetime of the plasma. They knew the physics but had not put it all together – what happens then you intensify and expand the electric field, and have sunlight and have composition changes and have neutral wind effects all at the same time. Pre-2003 some ionospheric models ruled out electric field effects at mid-latitiude. Most still rule out particle precipitation.
- This was all understood *after* the severe event.

What questions should we ask before we model a very extreme storm?

- For example, what would happen if equatorial physics and polar cap physics were happening in the same place?
- This is actually quite exciting when you think about it - the ionosphere may still surprise us!

**Image credits: MIDAS, University of Bath**

# What about scintillation?

- Current understanding of the underlying science is too primitive to make reasonable predictions from first principle models about the effect of scintillation on radio waves

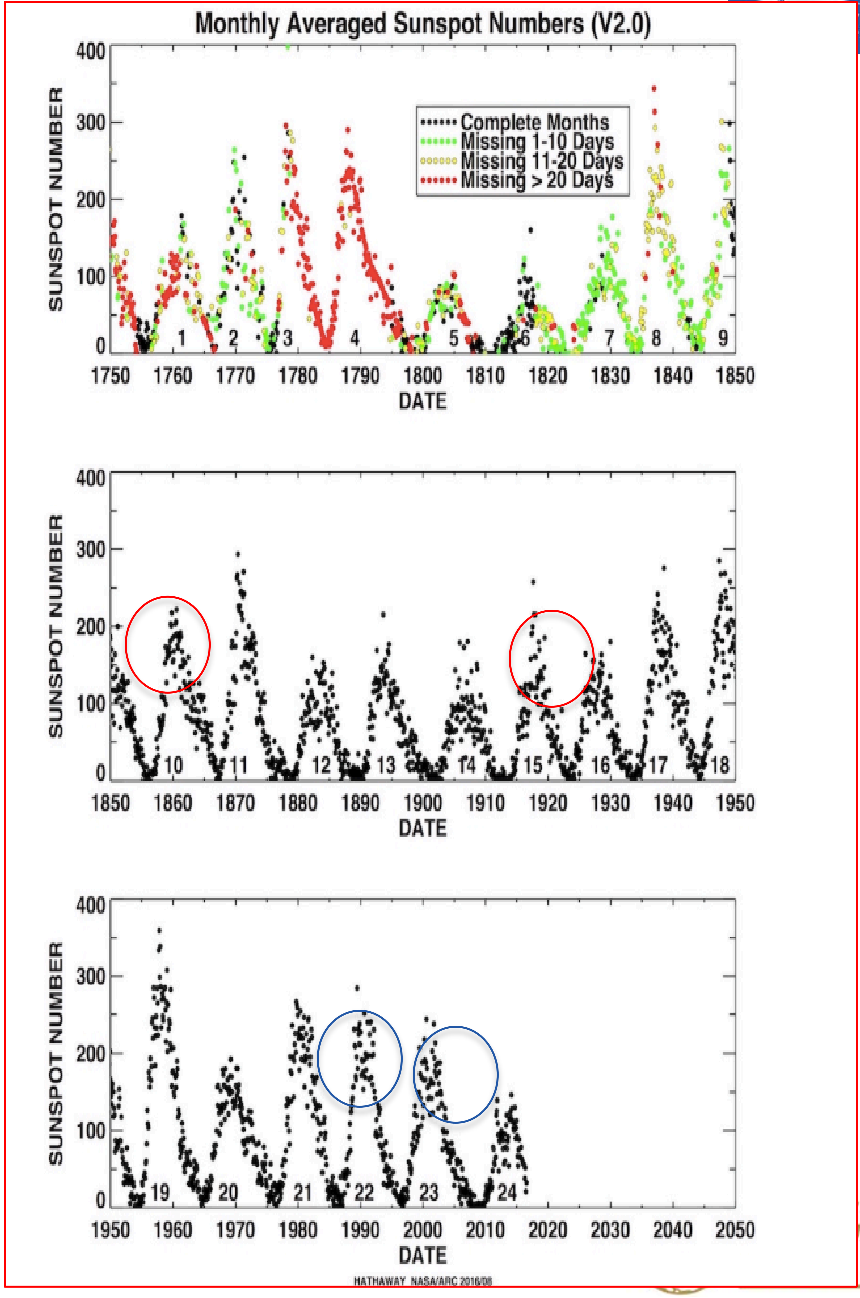
- The predictions needed are – how deep can the fade be and how long can this fade last, how quickly is it repeated and how long does it go on for – provide all worst case scenarios please!

- This seems hard.

# How often do we see solar super-storms?

Notable events that affected the Earth:

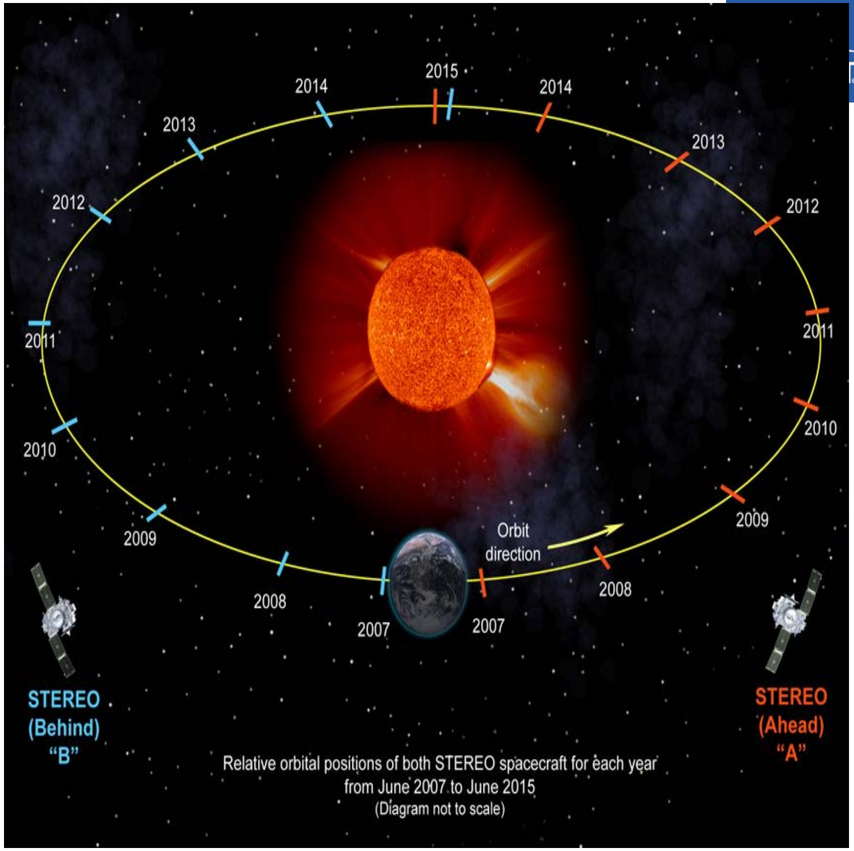
- 1859
- 1921
- March 1989
- Oct 2003

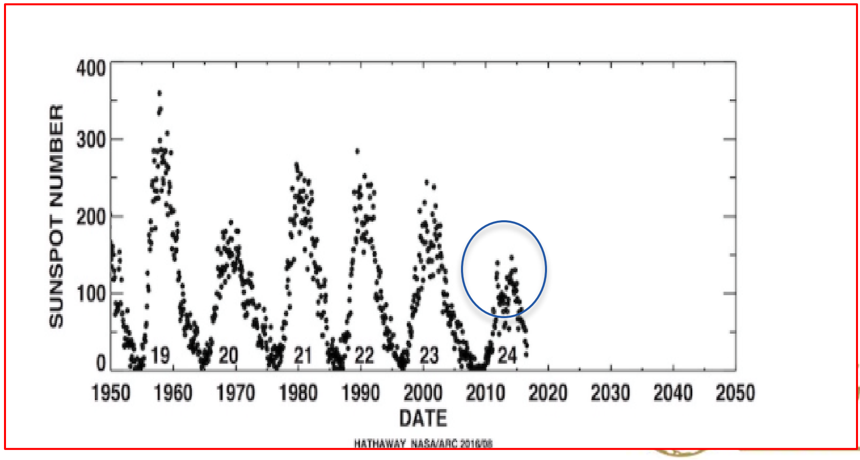


# How often do we see solar super-storms?

Notable events:

- 1859
- 1921
- March 1989
- Oct 2003
- **July 2012 - STEREO**



Often enough that it matters.

# Summary

- We can measure TEC and scintillation and there is enough data to re-create scenarios for a GNSS simulator

- This is useful to test the operation of GNSS-reliant equipment though most conditions in any location on the Earth

- We can make sensible estimates of the severity of extreme events but we don't have much granularity in there – many people still think the scale is Carrington-level or not

- Our *reluctance* to do anything is due to lack of knowledge about the likelihood of an event but our *ability* to test our systems for robustness is partly limited by gaps in the physics