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Dynamic Positioning Conference
October 17-18, 2000
Sensors

Space Weather and the Ionosphere

Grant Marshall
Trimble Navigation, Inc.

Note: Use the “Page Down” key to view this presentation correctly

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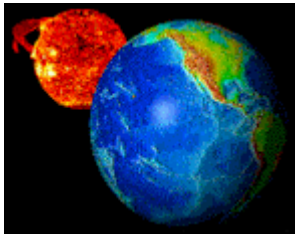

Space Weather and the Ionosphere

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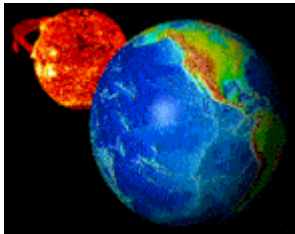

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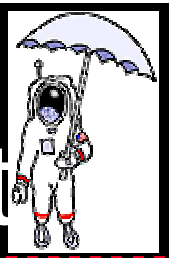

Space Weather - what is it?

The interaction of the solar wind with Earth's magnetic field and atmosphere

Space Weather - when and where

- Earth's Atmospheric Structure
- Sources of GPS signal delay
  - Troposphere
  - Ionosphere
- Ionosphere
  - Total Electron Content (TEC)
  - Scintillation
  - Geographic variations
- Solar Cycle
  - Daily variations
  - Solar seasons

Space Weather - what we can do

- Resources on the Internet
  - Space Weather alerts
  - Scintillation predictions
  - Total Electron Content maps
- What is Trimble doing?
  - Data collection and observations
  - Research and analysis
- What can you do?
  - Change the way you work

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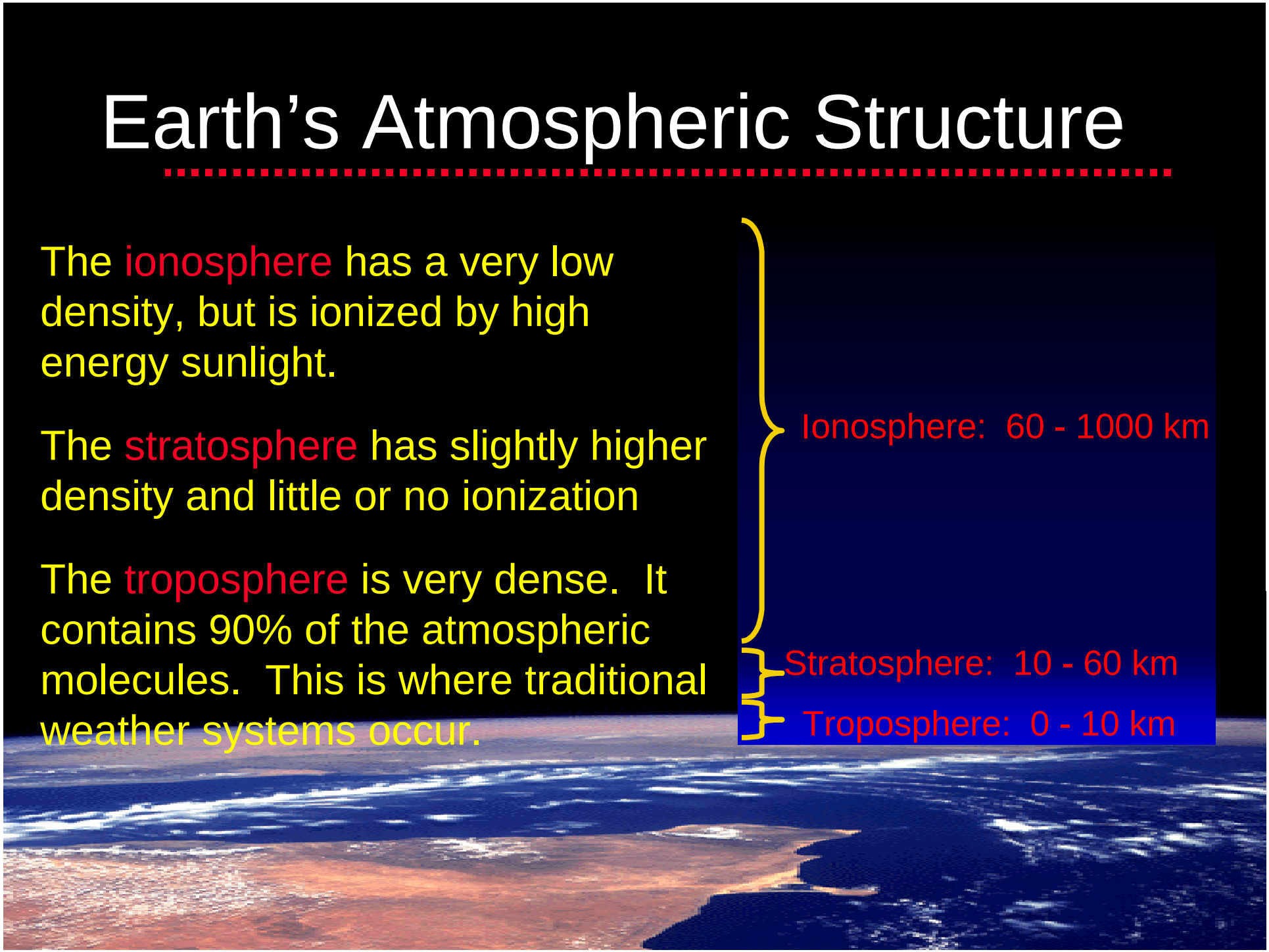
Earth's Atmospheric Structure

The ionosphere has a very low density, but is ionized by high energy sunlight.

The stratosphere has slightly higher density and little or no ionization

The troposphere is very dense. It contains 90% of the atmospheric molecules. This is where traditional weather systems occur.



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Troposphere - GPS signal delays

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- High density lower atmosphere causes refraction (bending) of GPS signals paths

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- High density lower atmosphere causes refraction (bending) of GPS signals paths
- Signal path range errors grow from ~3 meters overhead to ~20 meters near the horizon
- Troposphere signal delay models are used to remove most of the error

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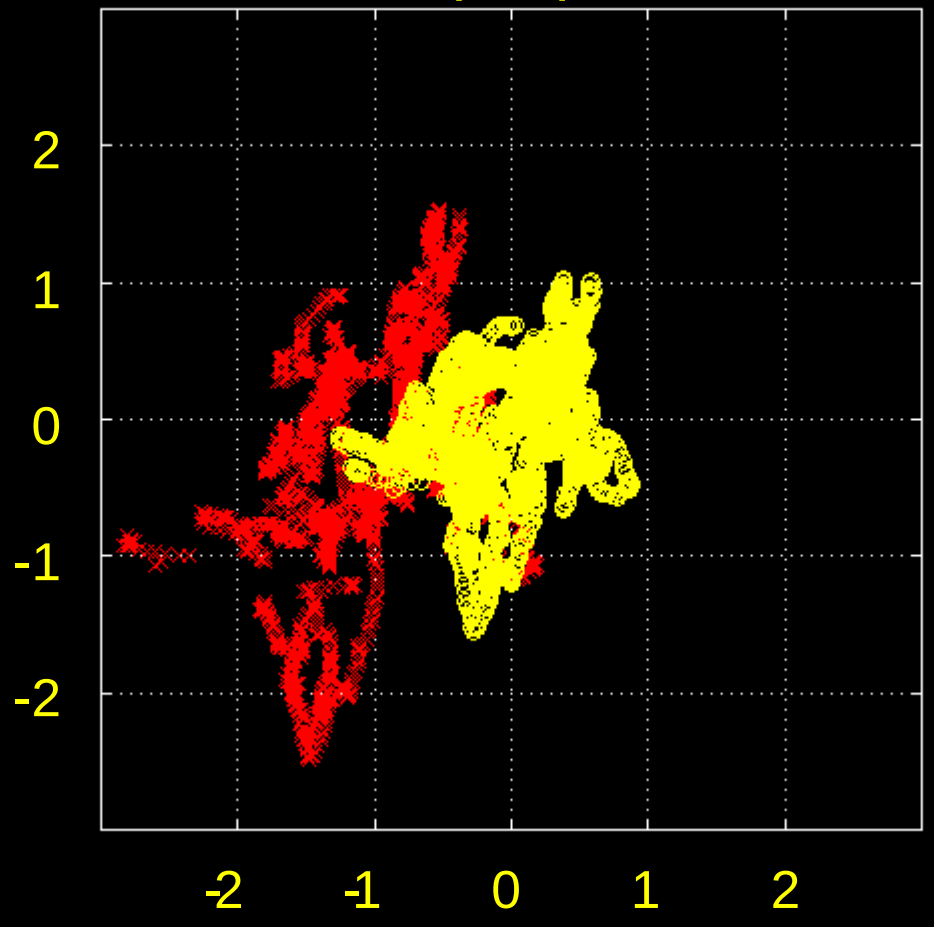
Troposphere - no model correction

Differential code at 1000 kilometers from the base with no troposphere correction

Red x's have no troposphere correction

Yellow circles, standard differential correction



Standard deviations

0.62 m

0.96 m

1 meter bias

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Ionosphere - composition

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Ionosphere - composition

- Composed of partially ionized gases (electrically charged particles)
- Positively-charged molecules and negatively-charged electrons
- Ionization is caused by ultraviolet sunlight which removes electrons from neutral molecules
- The charged particles interact with the Earth’s magnetic field and also affect GPS signals

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Ionosphere - GPS signal delays

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- Magnitude of the effect (delay) on GPS depends on the density of free electrons - Total Electron Content (TEC)

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Ionosphere - GPS signal delays

- Magnitude of the effect (delay) on GPS depends on the density of free electrons - Total Electron Content (TEC)
- Signal path range errors grow from near zero overhead to ~15 meters near the horizon
- Ionosphere signal delay models are used to remove most of the error (the broadcast model)

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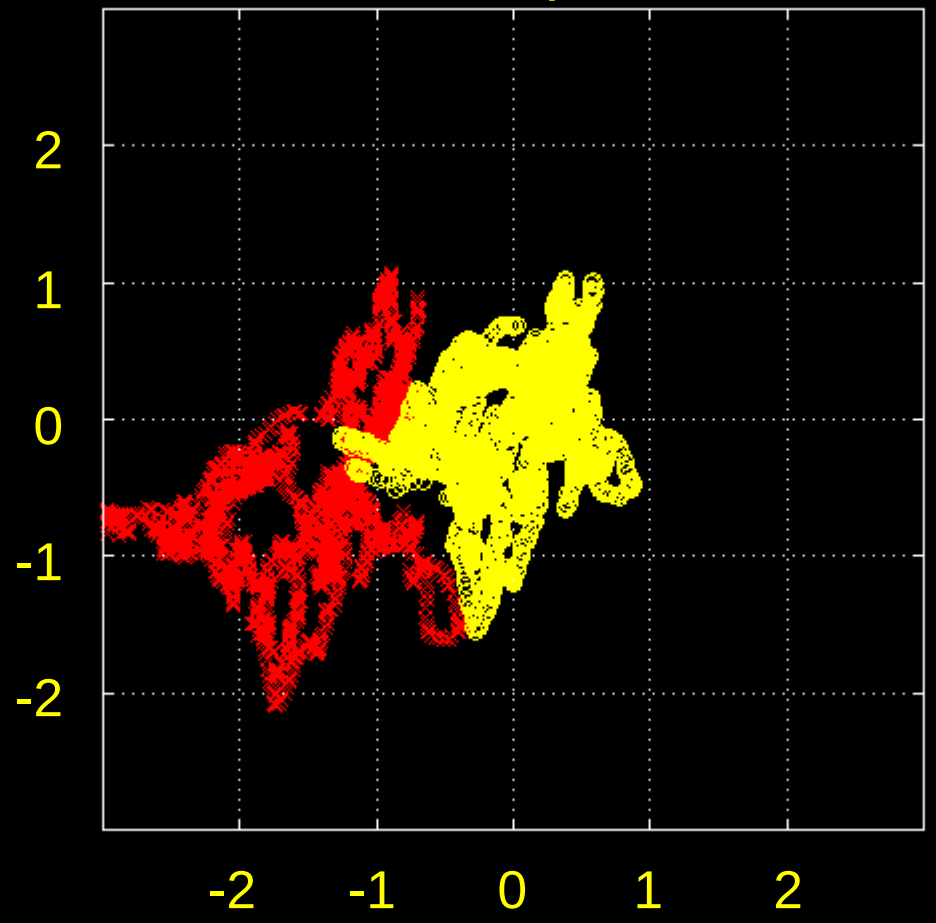
Ionosphere - no model correction

Differential code at 1000 kilometers from the base with no ionosphere correction

Red x's have no ionosphere correction

Yellow circles, standard differential correction



Standard deviations

0.62 m

0.85 m

1.54 meter bias

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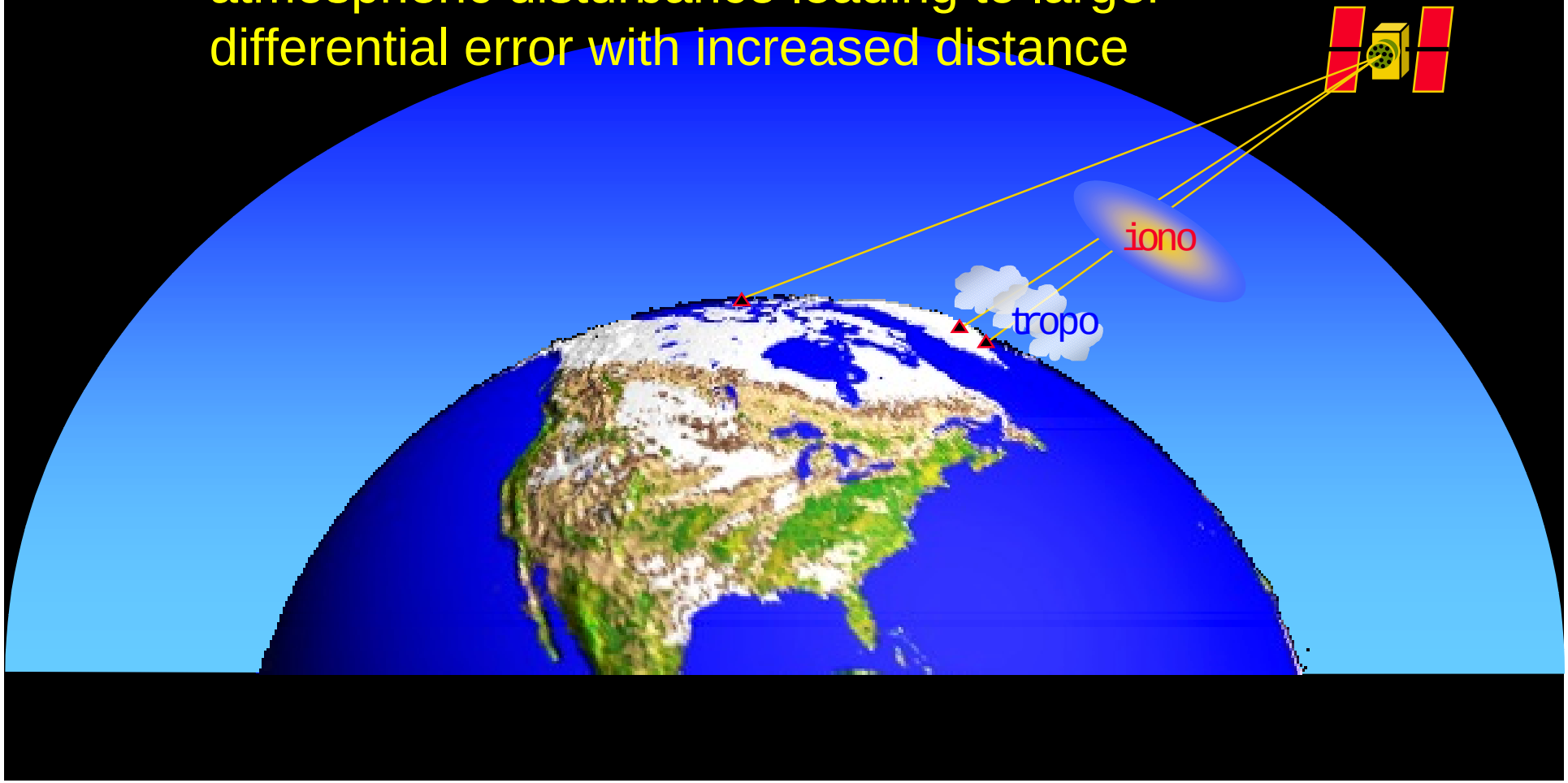
Distance from Base to Rover

Significantly different paths through the atmosphere may have different amounts of atmospheric disturbance leading to larger differential error with increased distance



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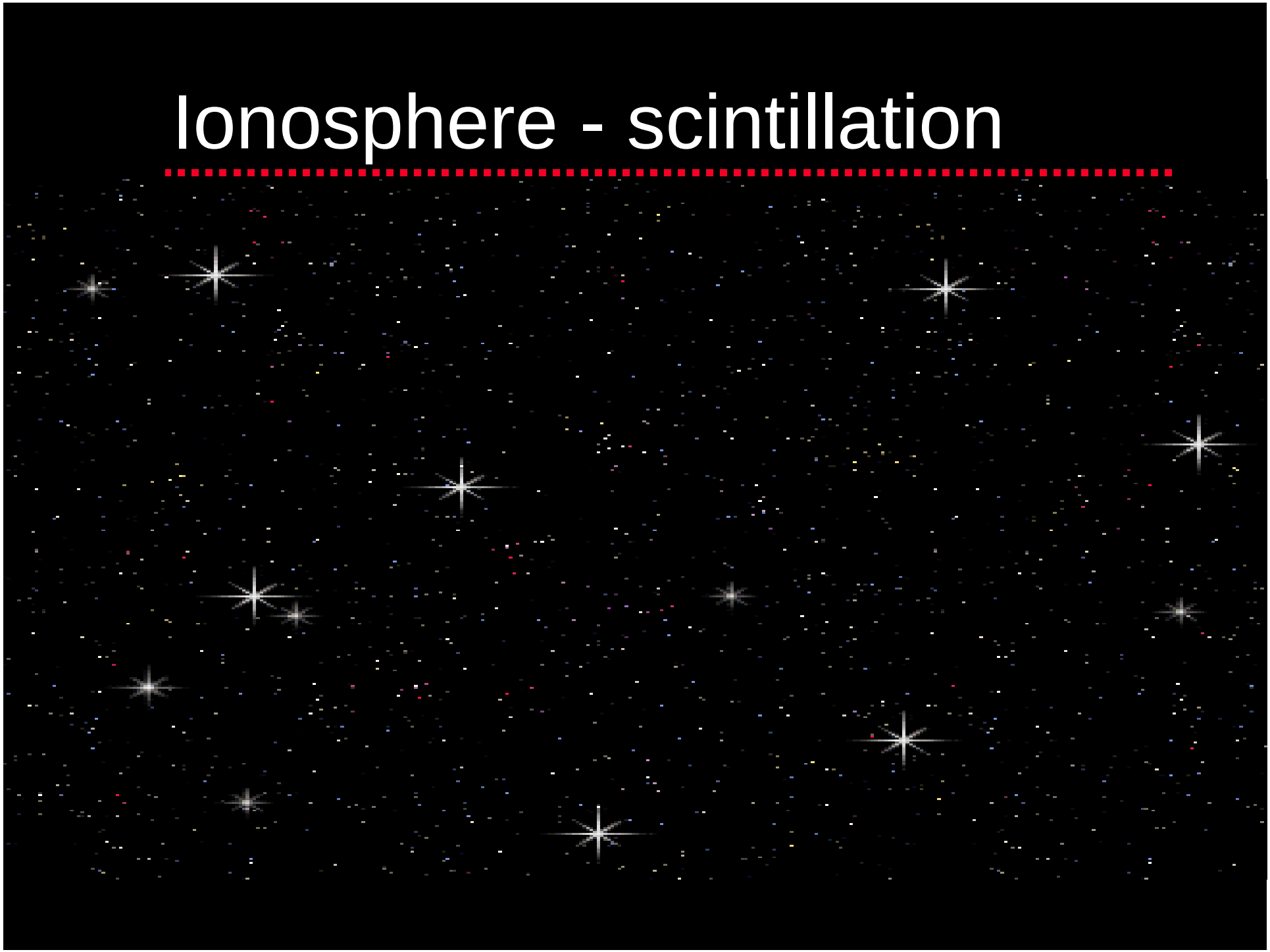
Ionosphere - scintillation



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Ionosphere - scintillation

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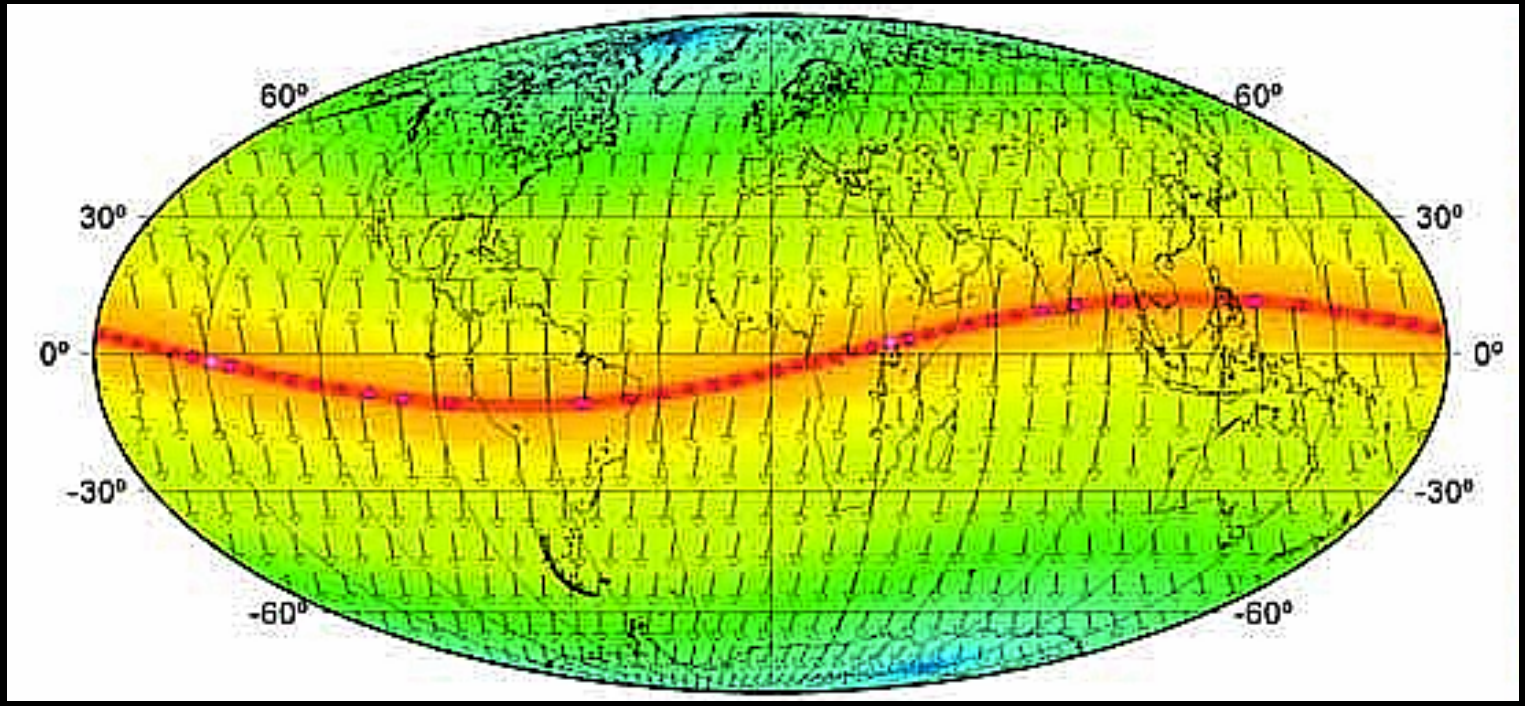
Ionosphere - scintillation

- Rapid, random, turbulent motions of the ionosphere cause scintillation
- Causes rapid fluctuations of the amplitude and phase of GPS signals
- Reduces signal-to-noise ratios
- May cause loss of tracking
- Affects all satellite to ground communications, not just GPS

Ionosphere - geographic distribution

Ionosphere TEC and scintillation occur near the magnetic poles and along the magnetic equator



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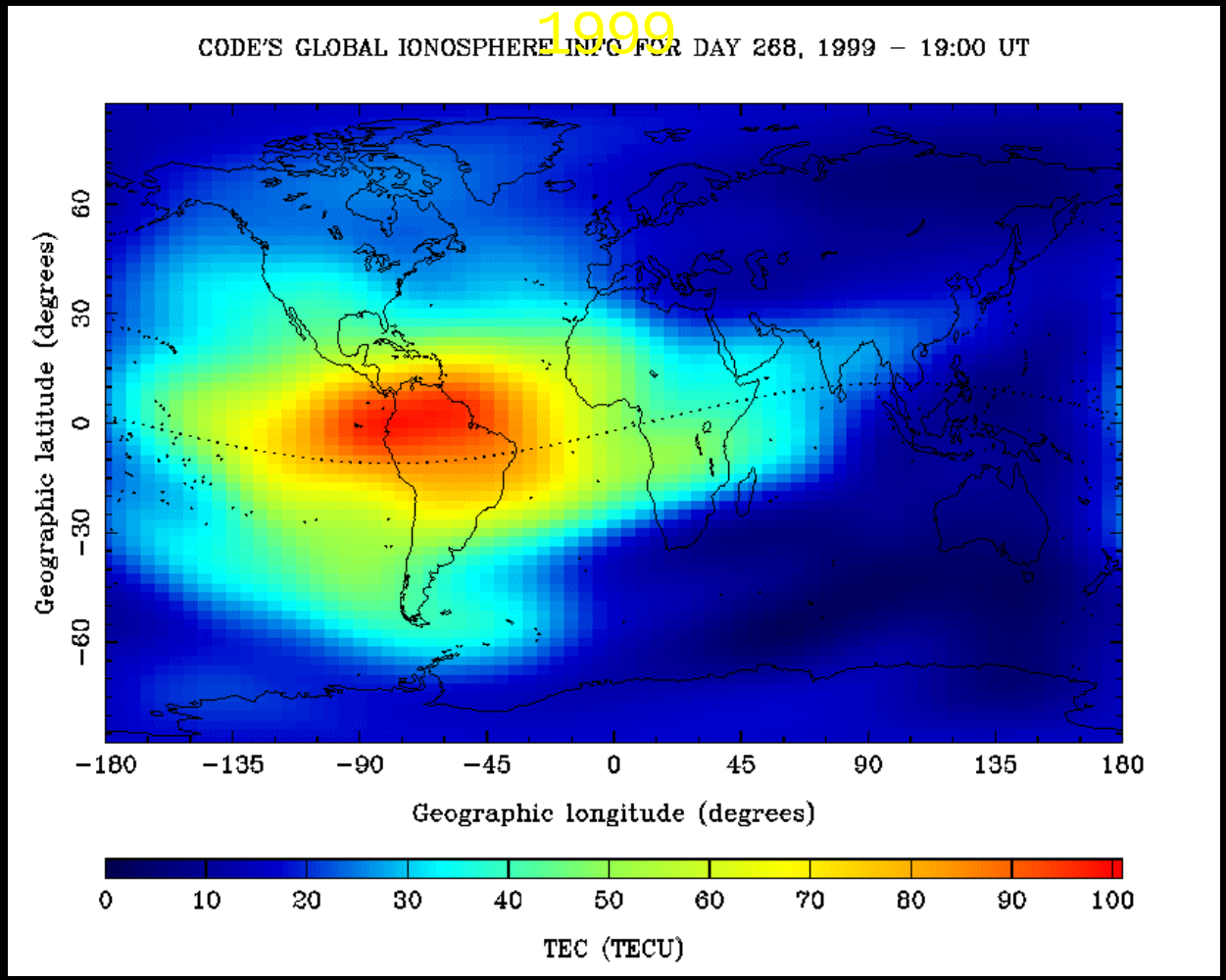
Ionosphere - TEC distribution

Global TEC distribution - September 25, 1999



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The Solar Cycle - daily variations

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The Solar Cycle - daily variations

- TEC depends on sunlight and is greatest in the middle of the day and lowest at night
- Scintillation usually occurs after sunset when the TEC is transitioning back to nighttime values.
- Scintillation may occur at any time in the polar regions

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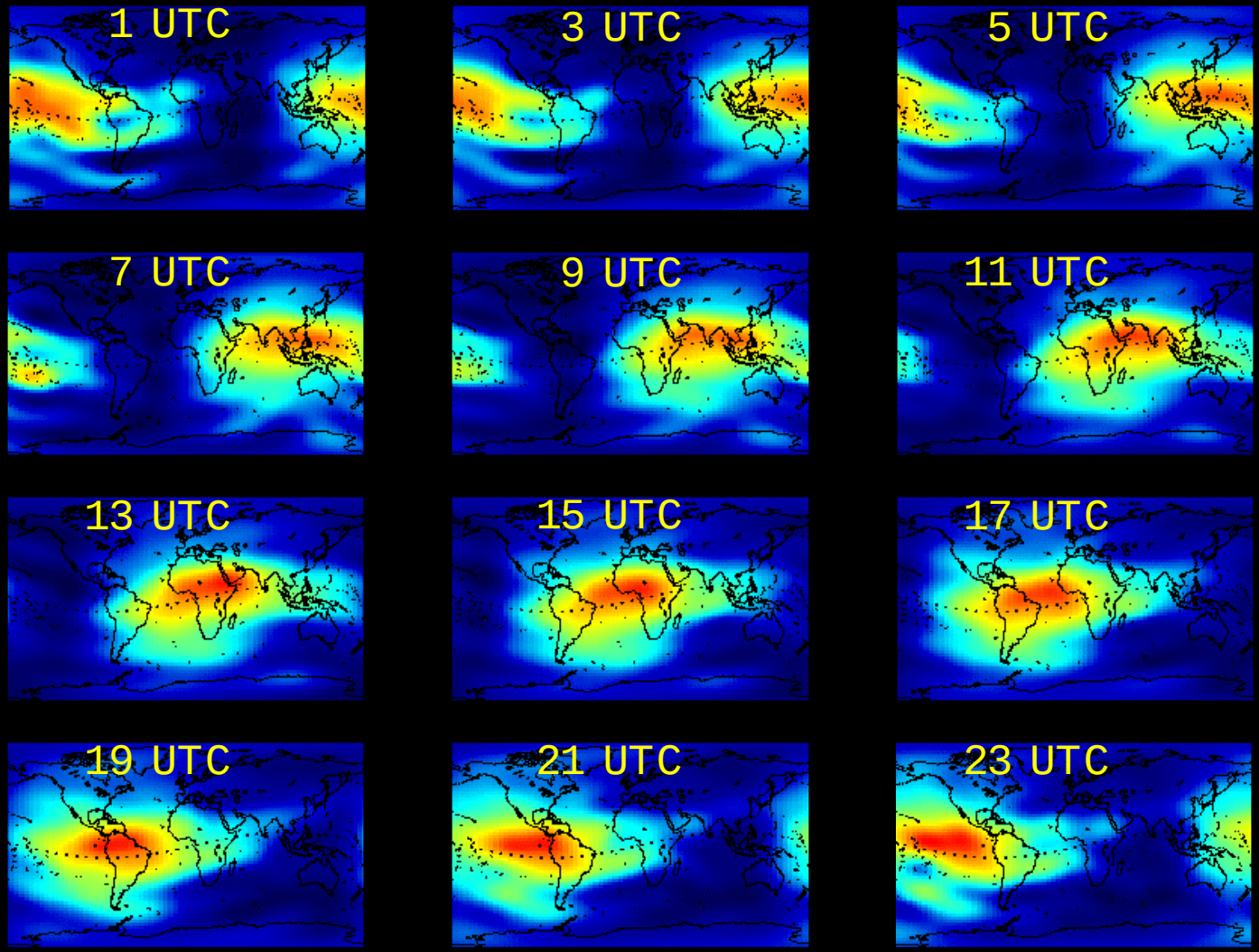
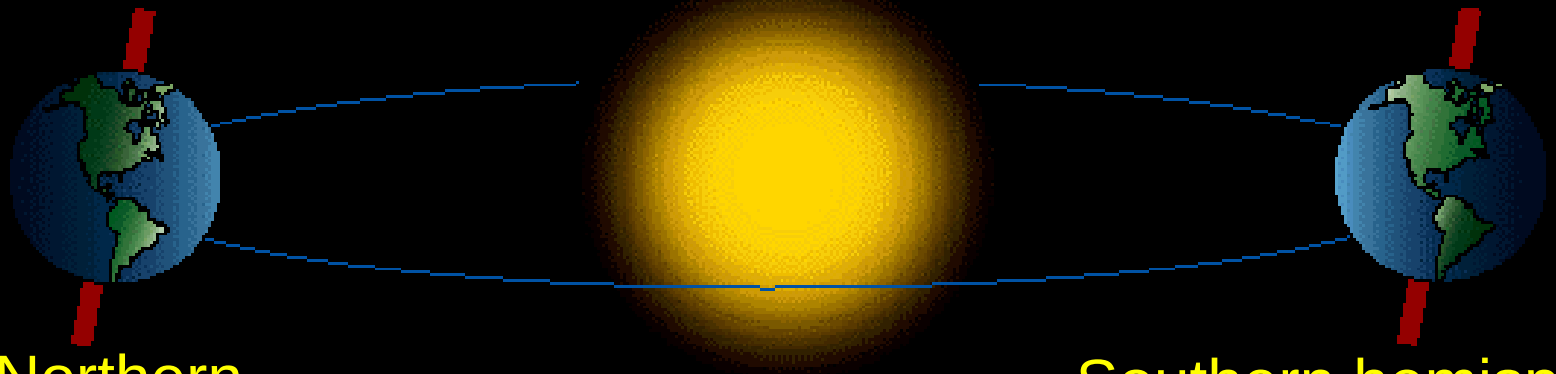
TEC - daily variations



The Solar Cycle - seasonal variations

Earth's tilted rotation axis leads to seasonal variations in ionosphere activity



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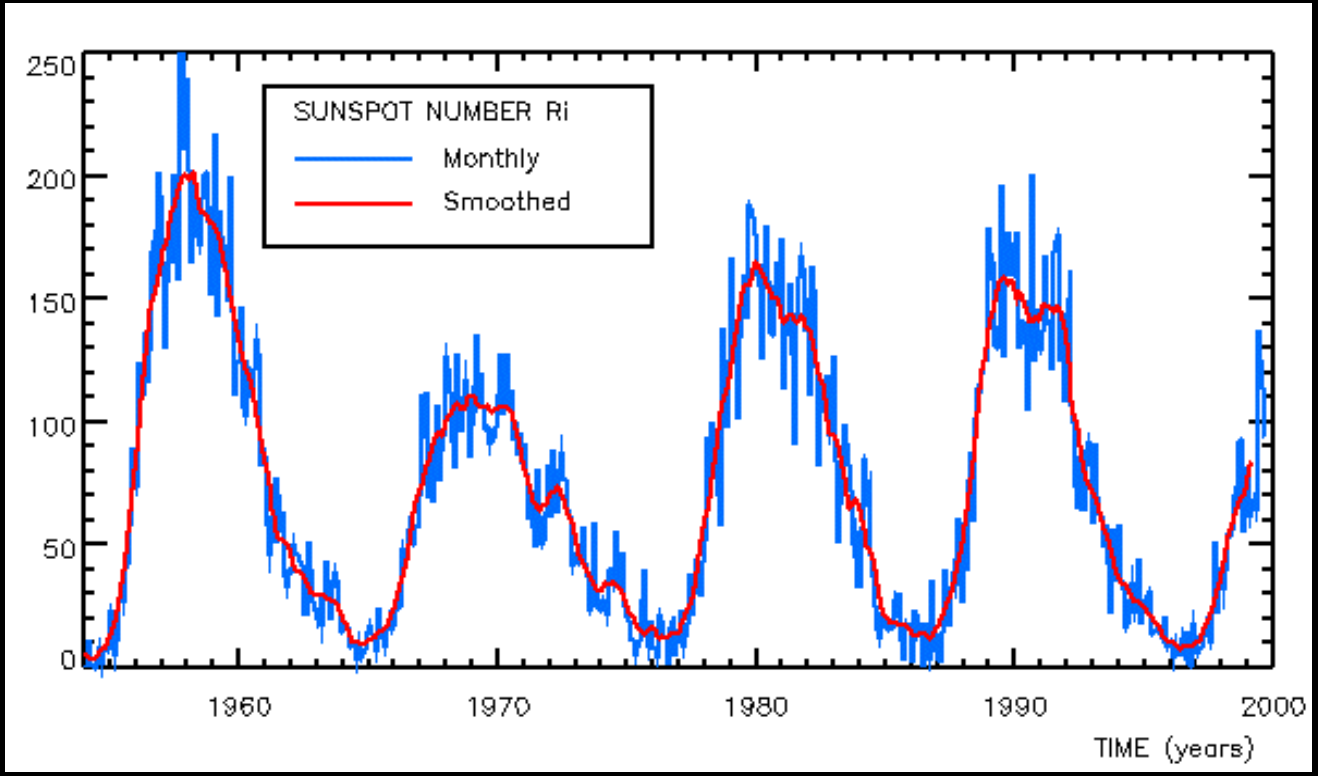
The Solar Cycle - 11-year variations

- Sunspots indicate high solar activity
- Solar activity cycles over an 11 year period
- Modern GPS receivers have been used mostly during a Solar minimum period



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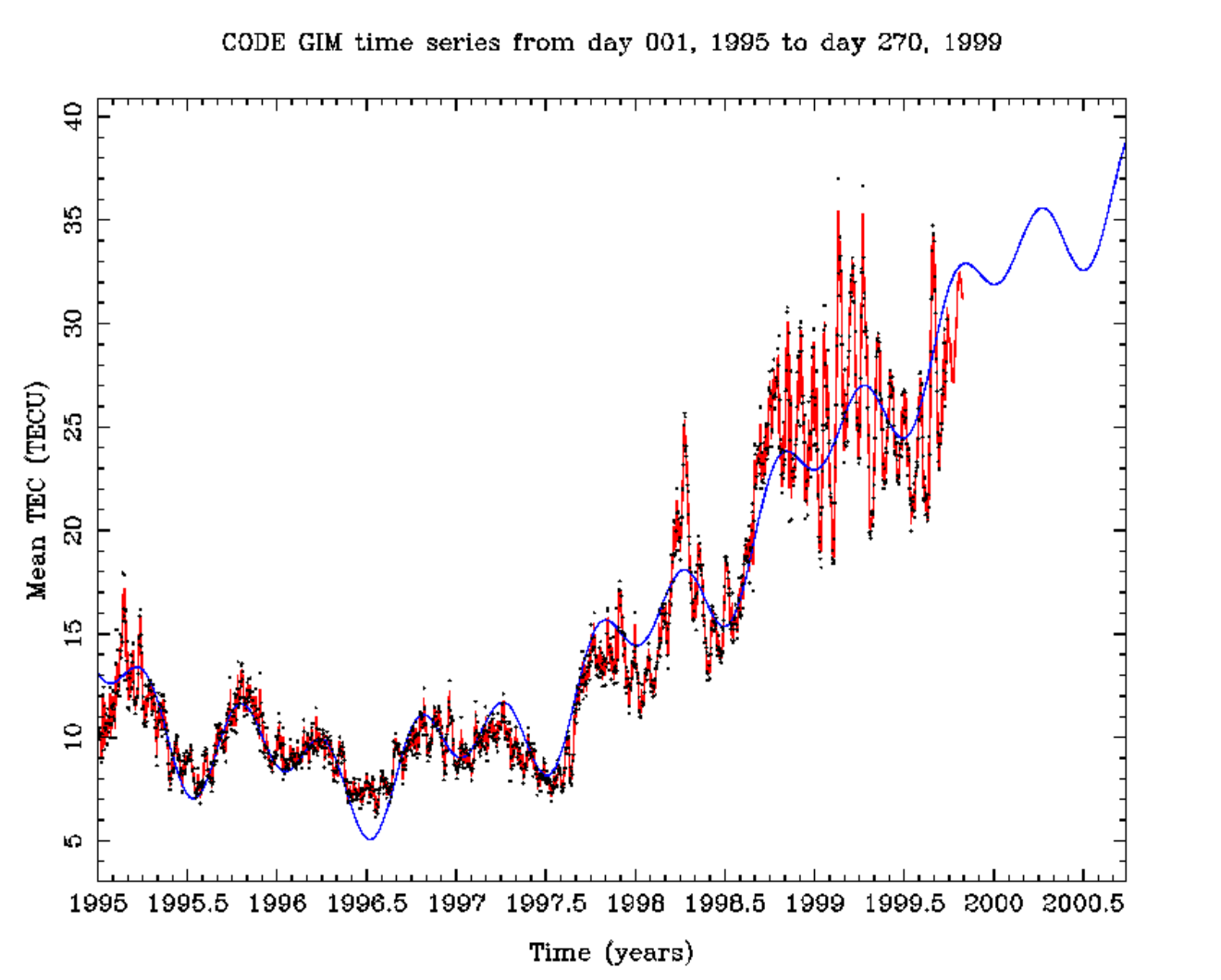
The Solar Cycle - Mean TEC variations



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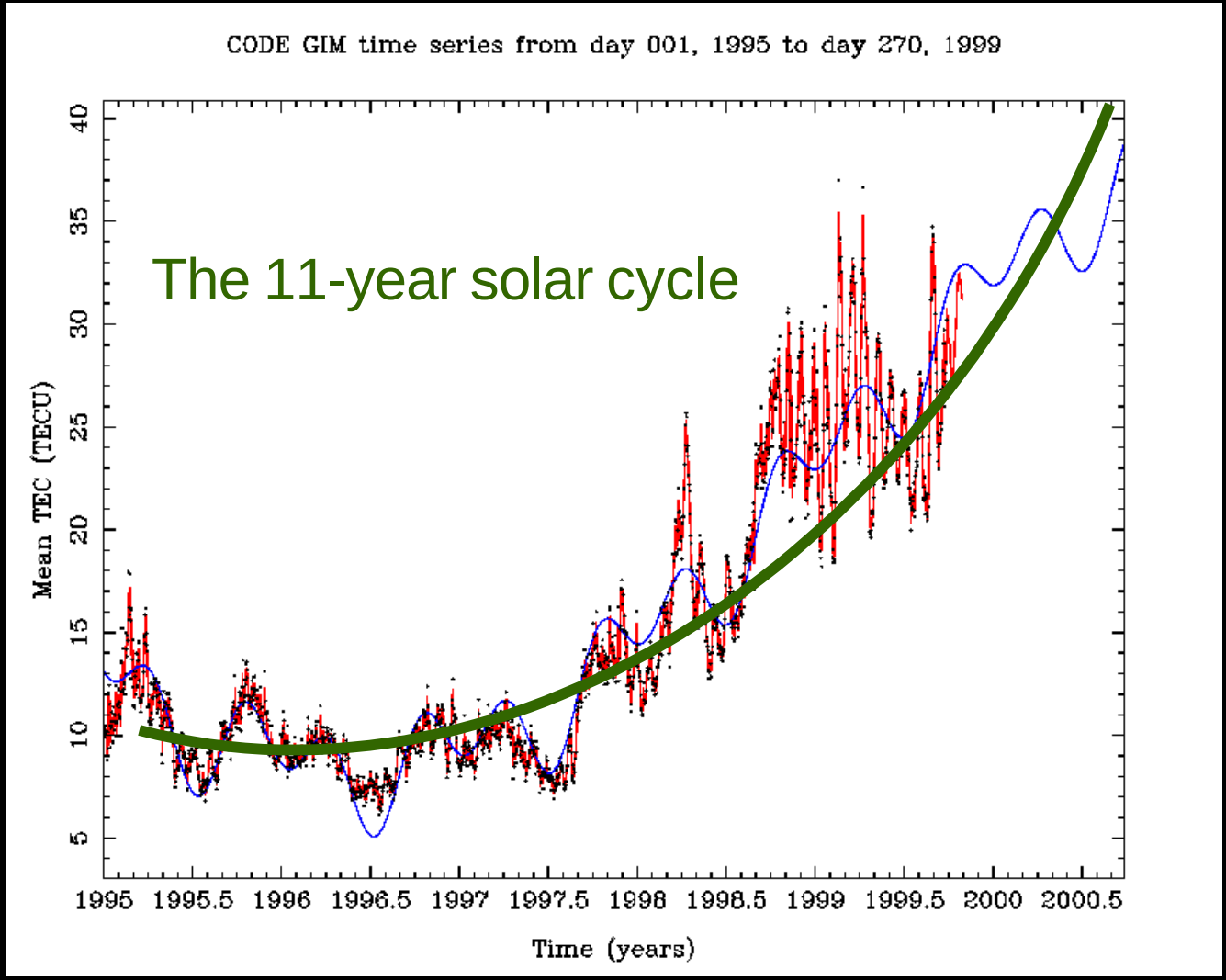

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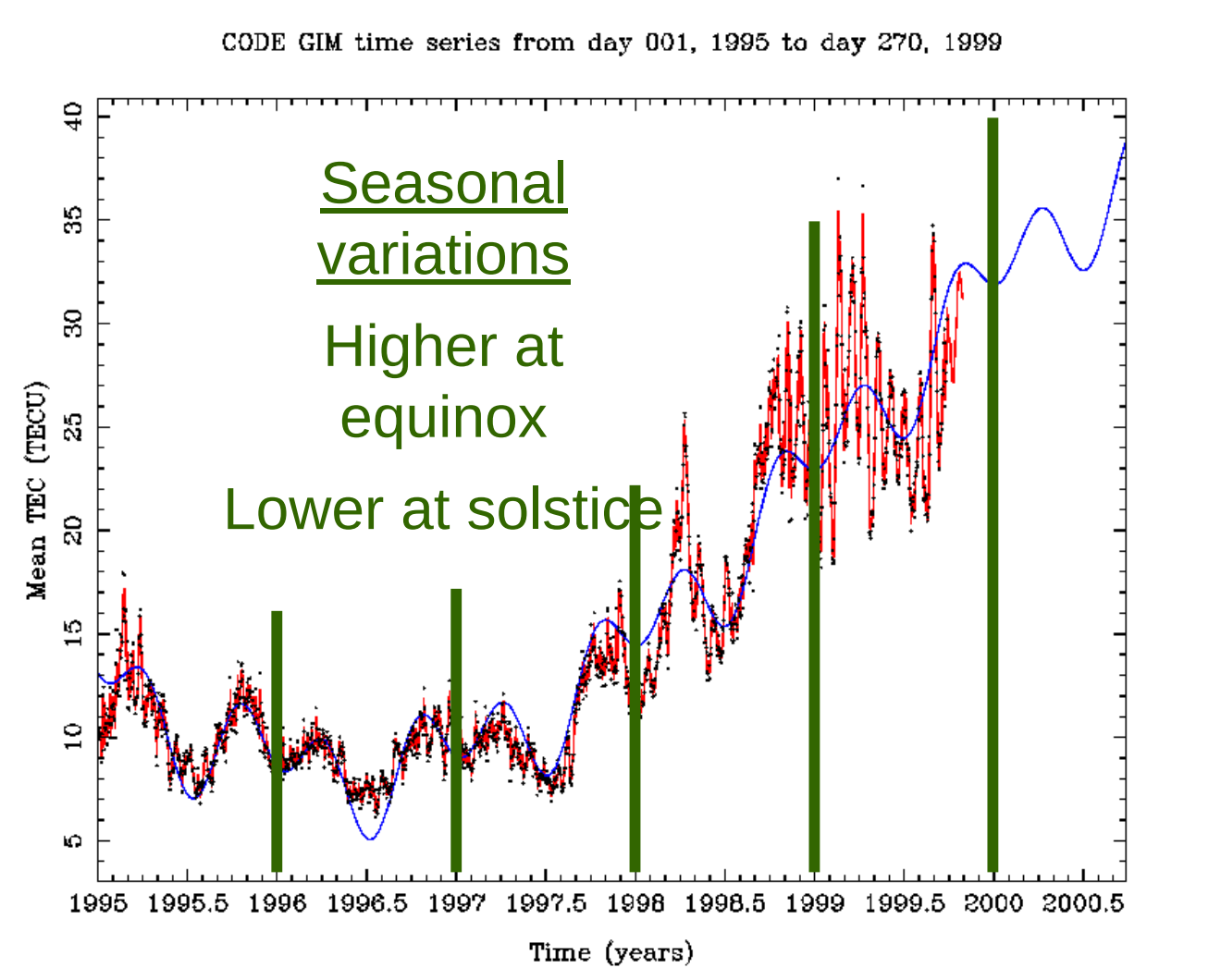

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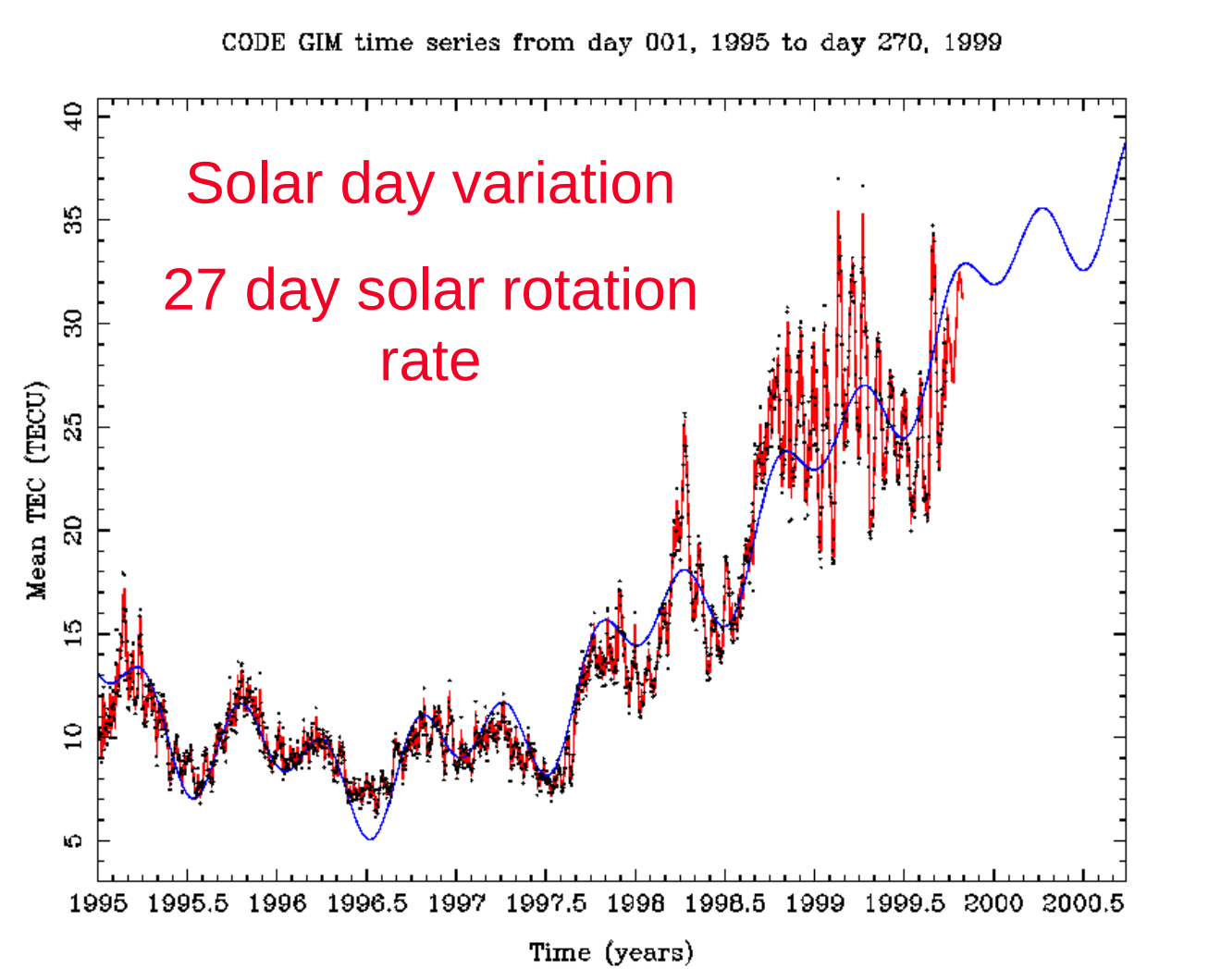

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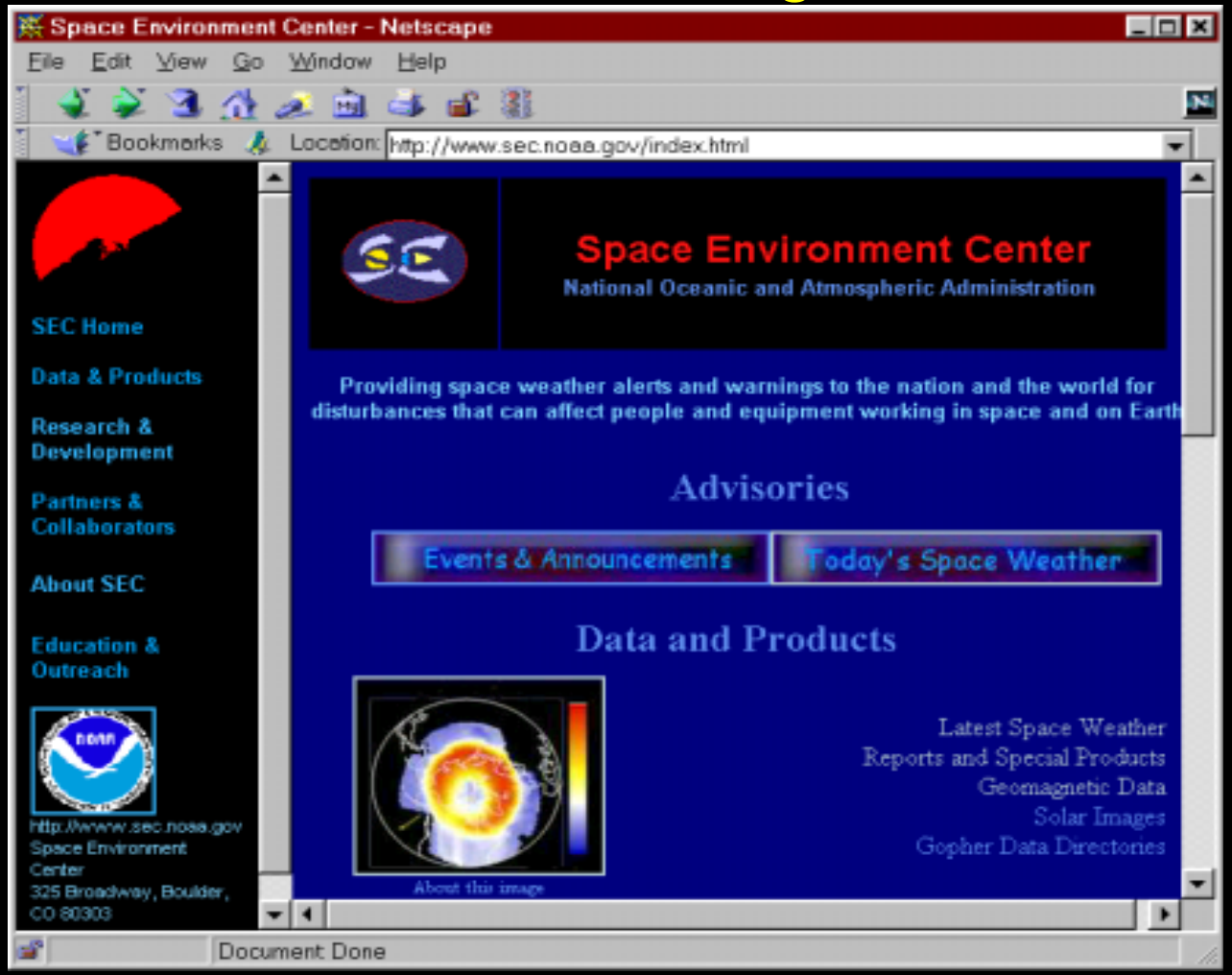
Internet Resources

www.sec.noaa.gov



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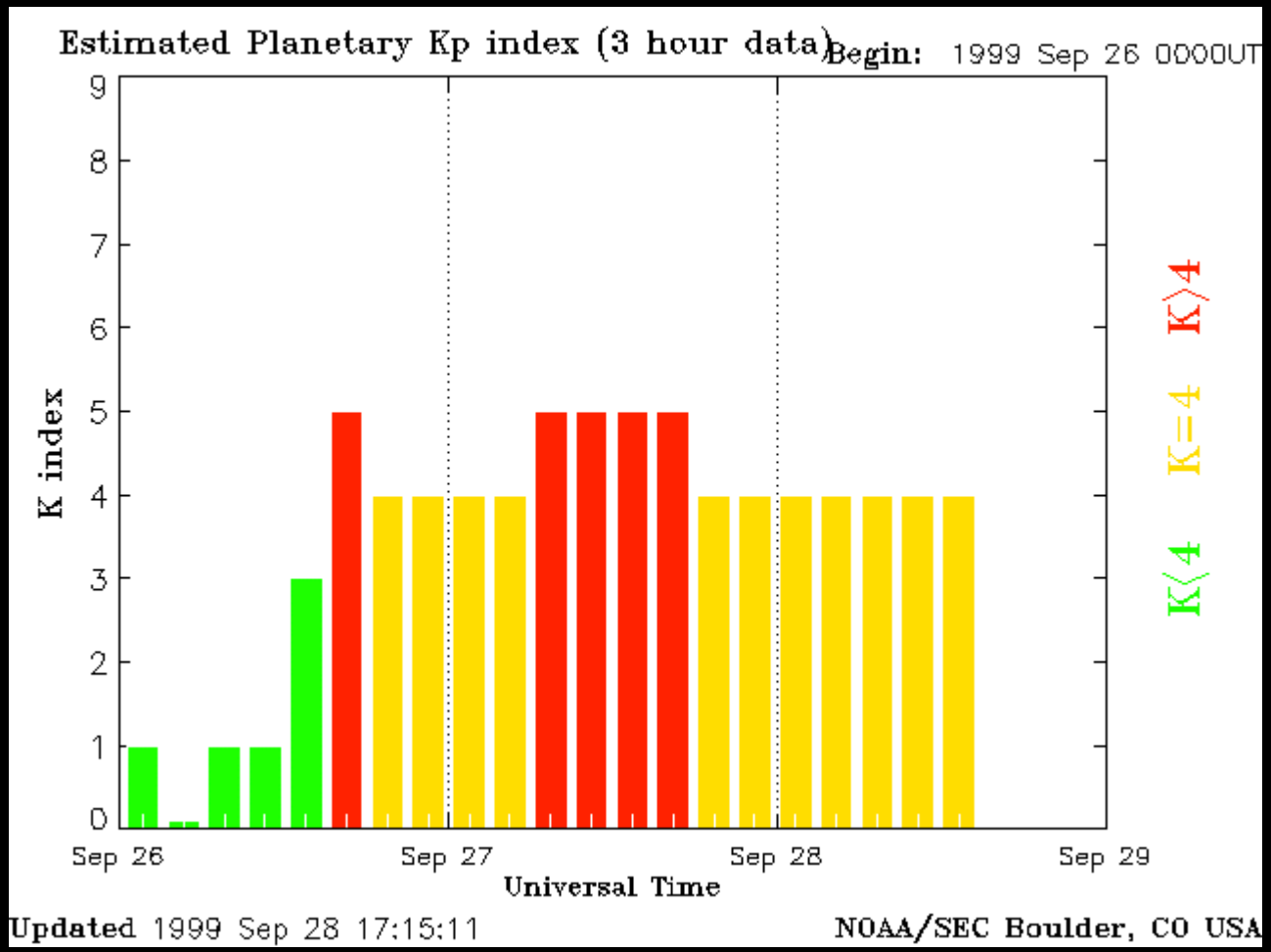

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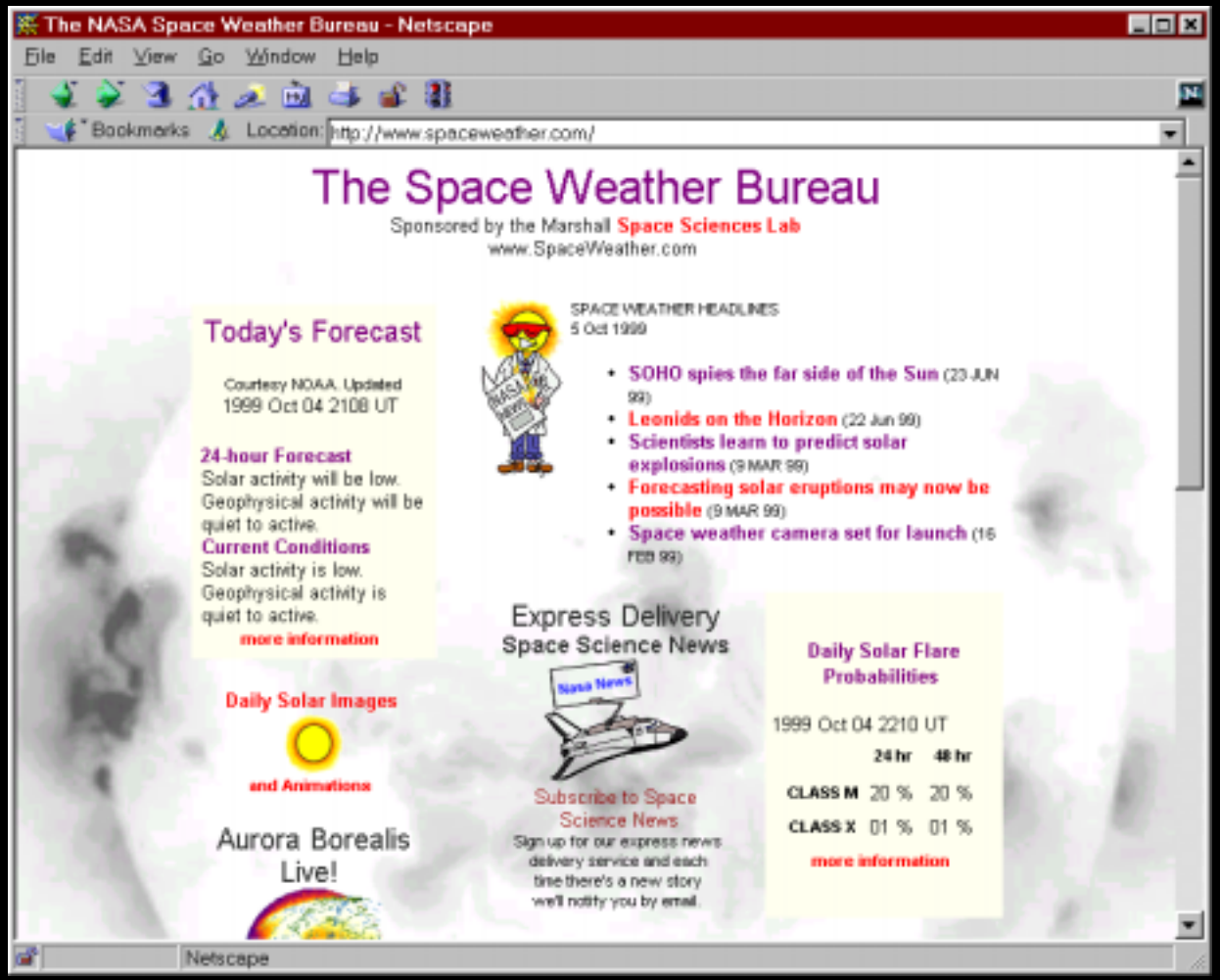
Internet Resources

www.spaceweather.com



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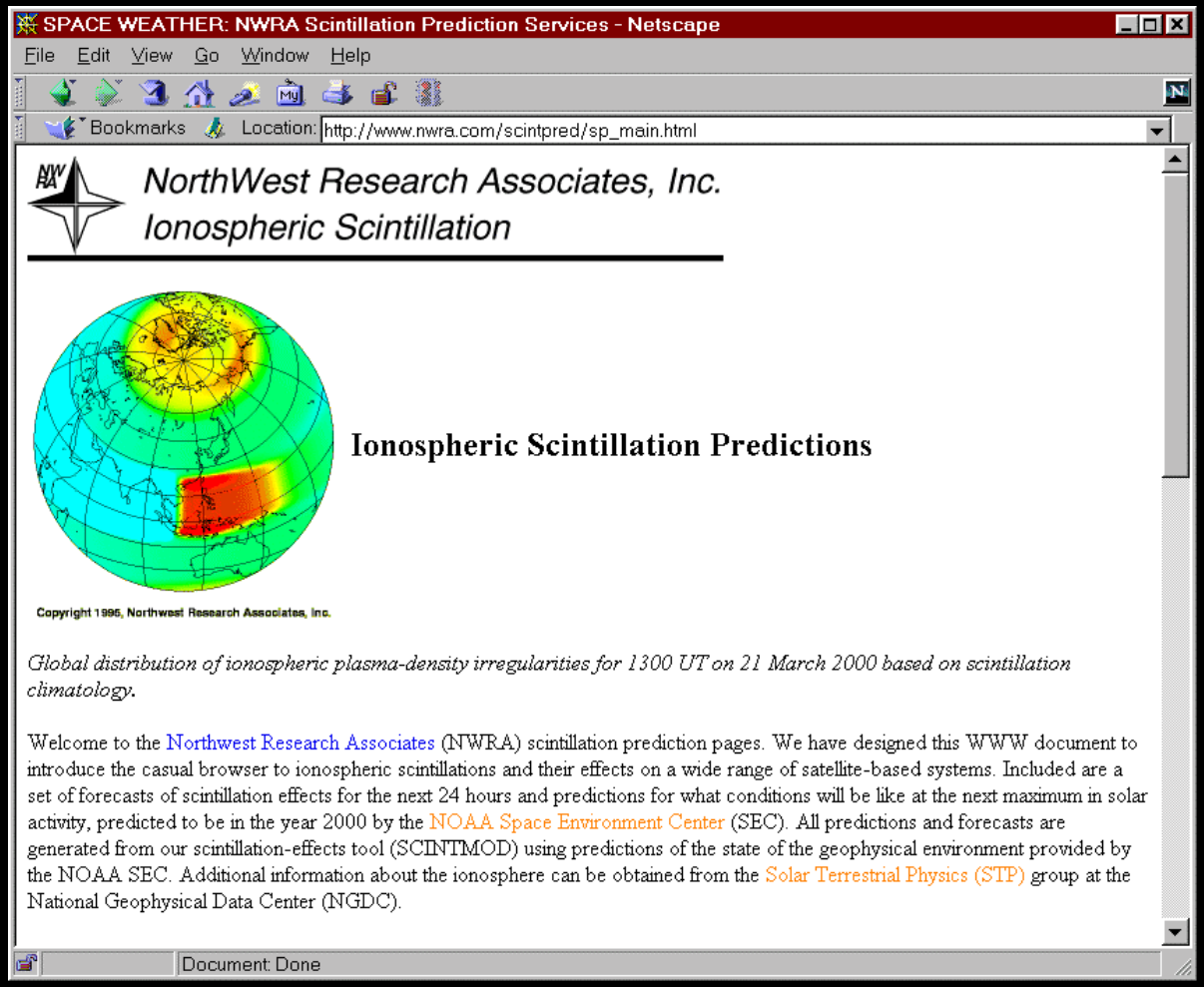
Internet Resources

www.nwra.com/nwra/scintpred/sp_main.html



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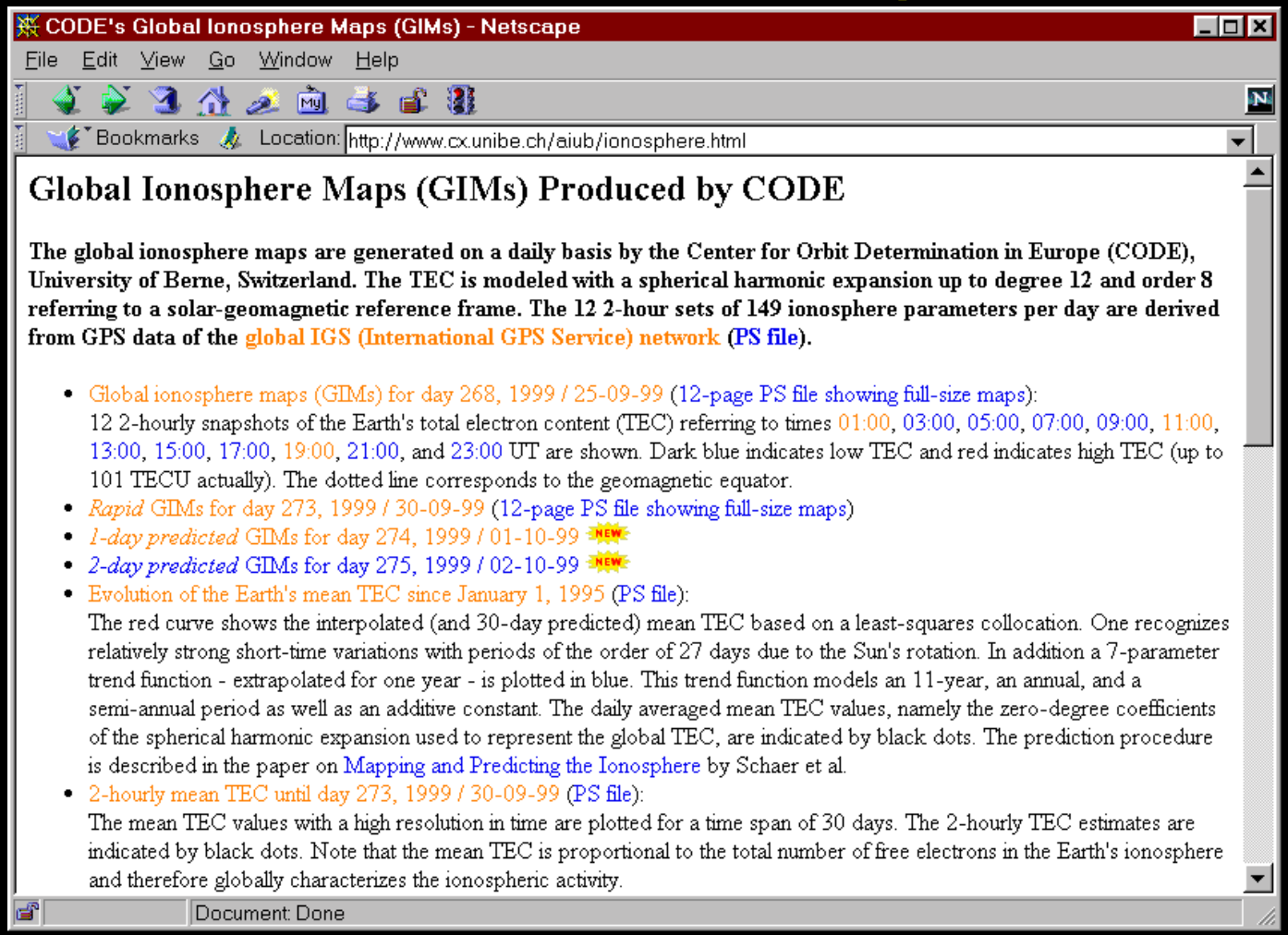
Internet Resources

www.cx.unibe.ch/aiub/ionosphere.html



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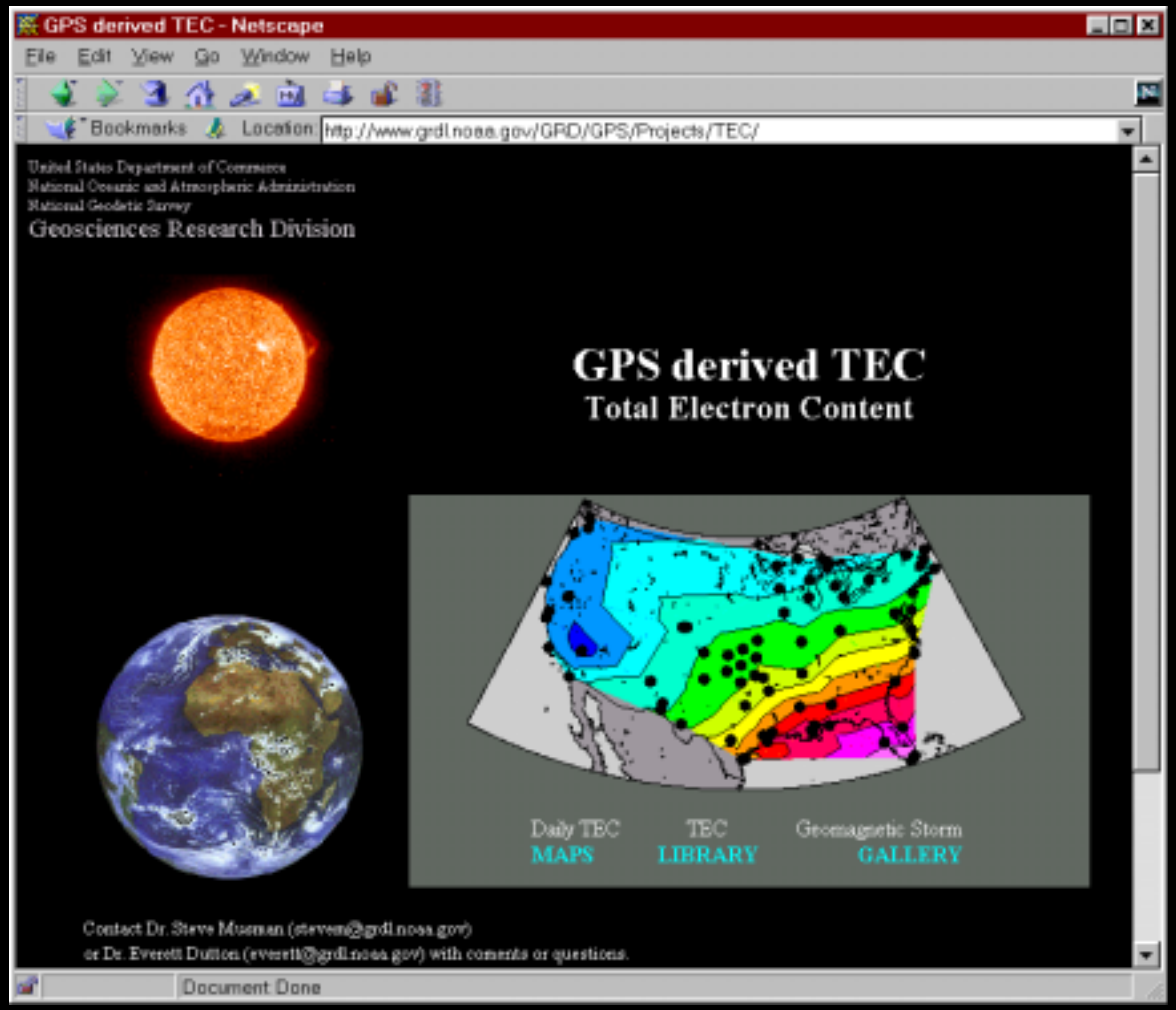
Internet Resources

www.grdl.noaa.gov/GRD/GPS/Projects/TEC



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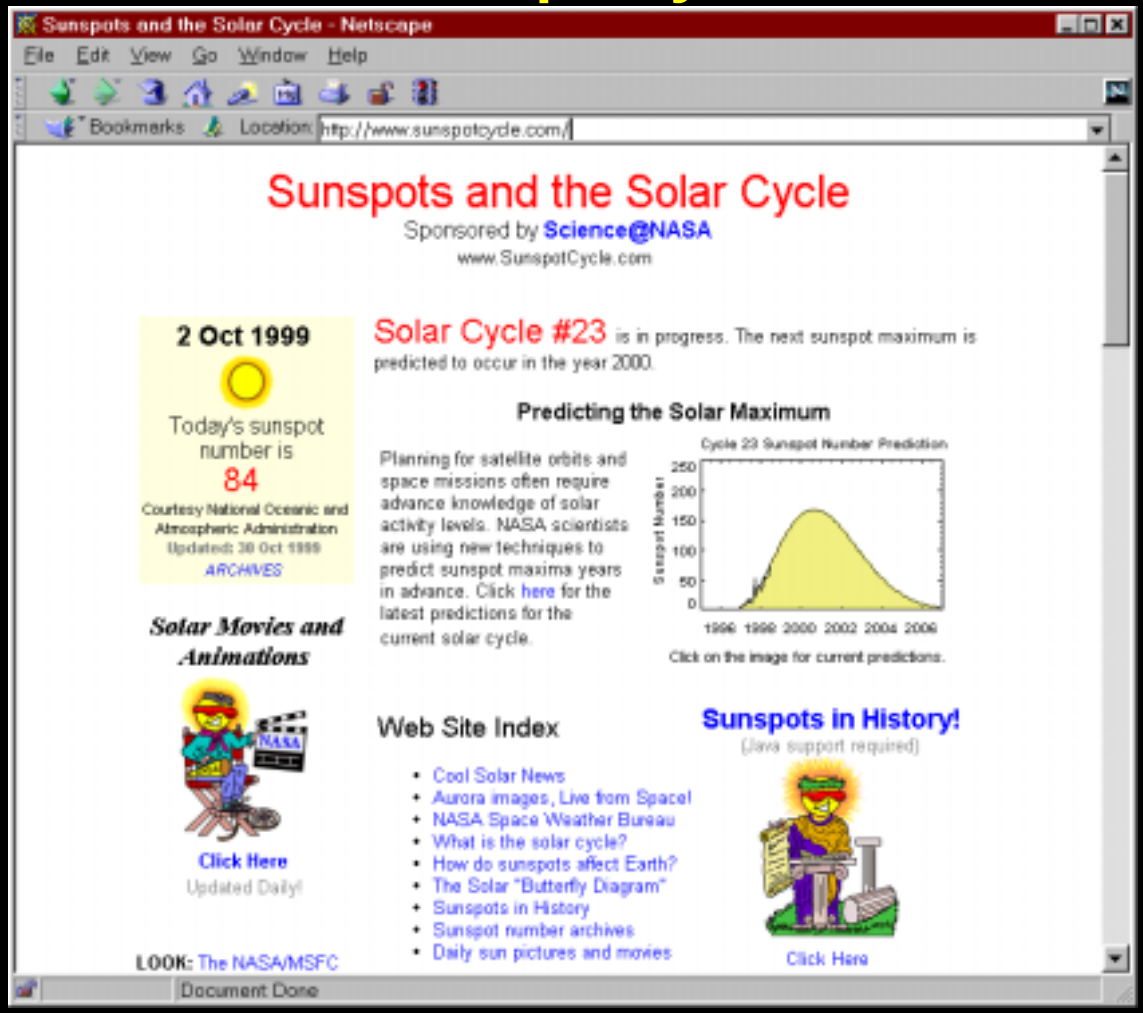
Internet Resources

www.sunspotcycle.com



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What is Trimble doing?

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- We are developing data collection tools to capture scintillation contaminated GPS signals for study

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- We are researching hardware and firmware enhancements to handle scintillation events

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What is Trimble doing?

- We are developing data collection tools to capture scintillation contaminated GPS signals for study
- We are researching hardware and firmware enhancements to handle scintillation events
- We are studying how scintillation affects tracking, post-processing, RTK surveying, and mapping DGPS

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Summary

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- Space weather is the interaction of the sun’s radiation with the earth’s atmosphere and magnetic field

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- Increases in solar activity cause increased disturbances in the earth's ionosphere
- The solar cycle has daily, monthly, seasonal, and 11-year variations
- Ionospheric disturbances are concentrated near the equator and the poles

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Summary

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- Ionosphere scintillation occurs mostly after sunset in the equatorial regions, but may occur anytime near the poles

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- Models and dual frequency observations help to remove atmospheric delays

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Summary

- Ionosphere scintillation occurs mostly after sunset in the equatorial regions, but may occur anytime near the poles
- Models and dual frequency observations help to remove atmospheric delays
- The Internet is a valuable source of information about the solar cycle, ionosphere, and space weather

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What can YOU do?

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What can YOU do?

- Change the way you work, by...

What can YOU do?

- Change the way you work, by...
- Maintaining an awareness of the solar cycle

What can YOU do?

- Change the way you work, by...
- Maintaining an awareness of the solar cycle
- Knowing when and where you may encounter increased noise or scintillation

What can YOU do?

- Change the way you work, by...
- Maintaining an awareness of the solar cycle
- Knowing when and where you may encounter increased noise or scintillation
- Using the forecast Kp index as a mission planning tool

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Thank You

Questions?