

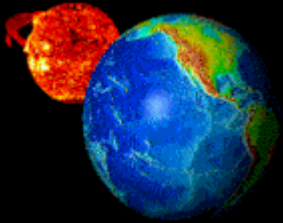
Dynamic Positioning Conference
October 17-18, 2000

Sensors

Space Weather and the Ionosphere

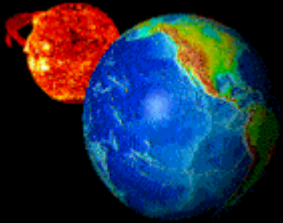
Grant Marshall
Trimble Navigation, Inc.

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



Space Weather and the Ionosphere

Grant Marshall

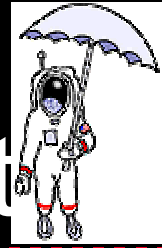


Space Weather and the Ionosphere

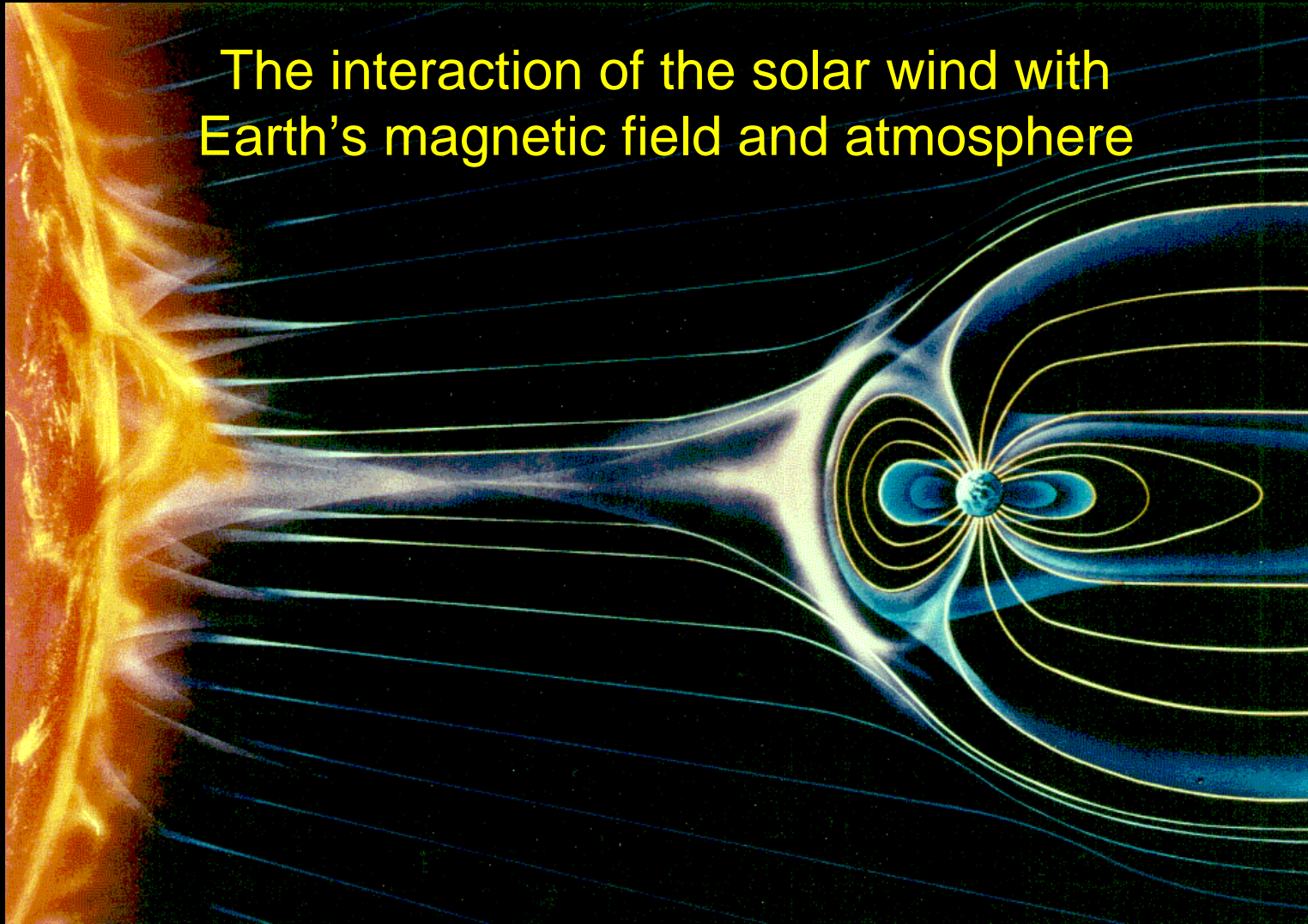


Grant Marshall

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

Earth's Atmospheric Structure

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

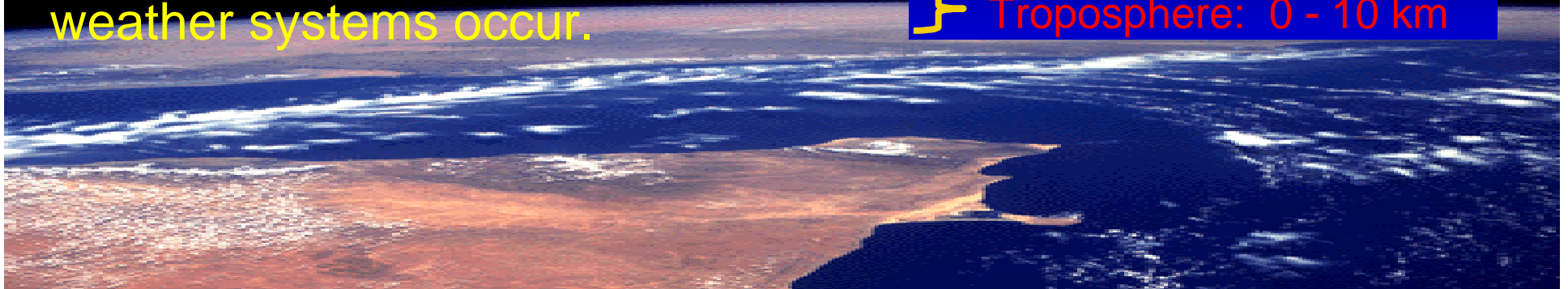
The **stratosphere** has slightly higher density and little or no ionization

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

Ionosphere: 60 - 1000 km

Stratosphere: 10 - 60 km

Troposphere: 0 - 10 km



Troposphere - GPS signal delays

Troposphere - GPS signal delays

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

Troposphere - GPS signal delays

- 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 - GPS signal delays

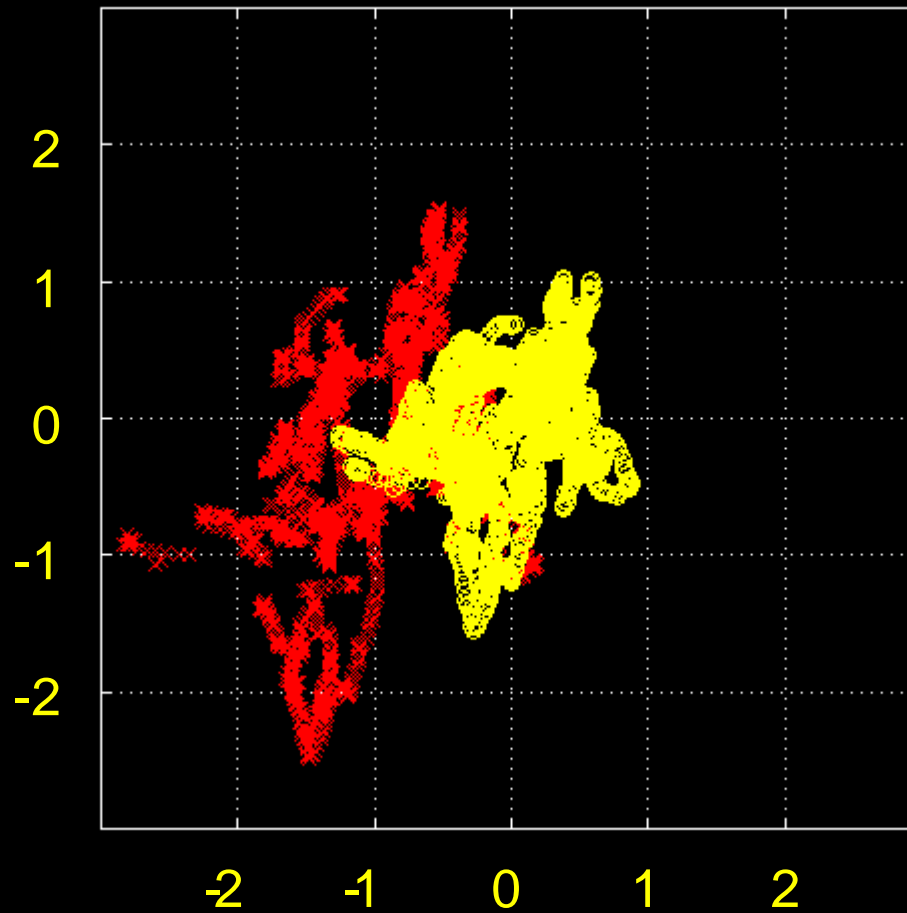
- High density lower atmosphere causes refraction (bending) of GPS signals paths
- Signal path range errors grow from ~3 meters overhead to ~20 meters near the horizon
- Troposphere signal delay models are used to remove most of the error

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

Ionosphere - composition

Ionosphere - composition

- Composed of partially ionized gases (electrically charged particles)

Ionosphere - composition

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- **Positively-charged molecules and negatively-charged electrons**

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**

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**

Ionosphere - GPS signal delays

Ionosphere - GPS signal delays

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

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 - GPS signal delays

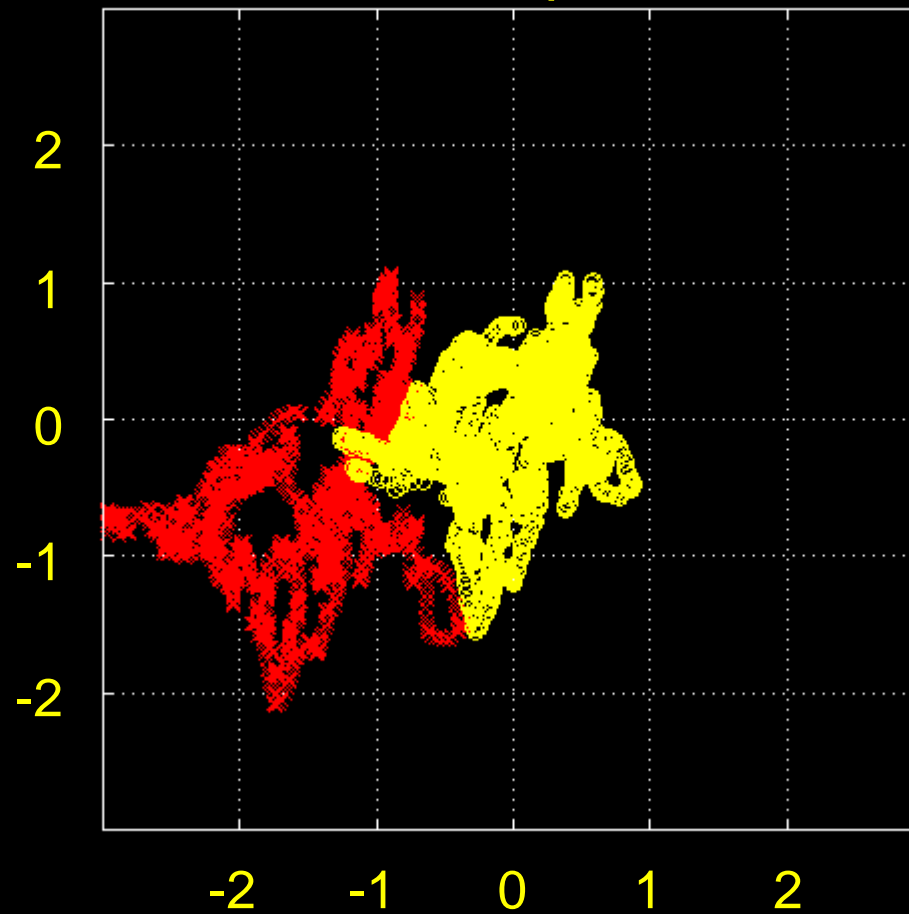
- Magnitude of the effect (delay) on GPS depends on the density of free electrons - Total Electron Content (TEC)
- Signal path range errors grow from near zero overhead to ~15 meters near the horizon
- **Ionosphere signal delay models are used to remove most of the error (the broadcast model)**

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

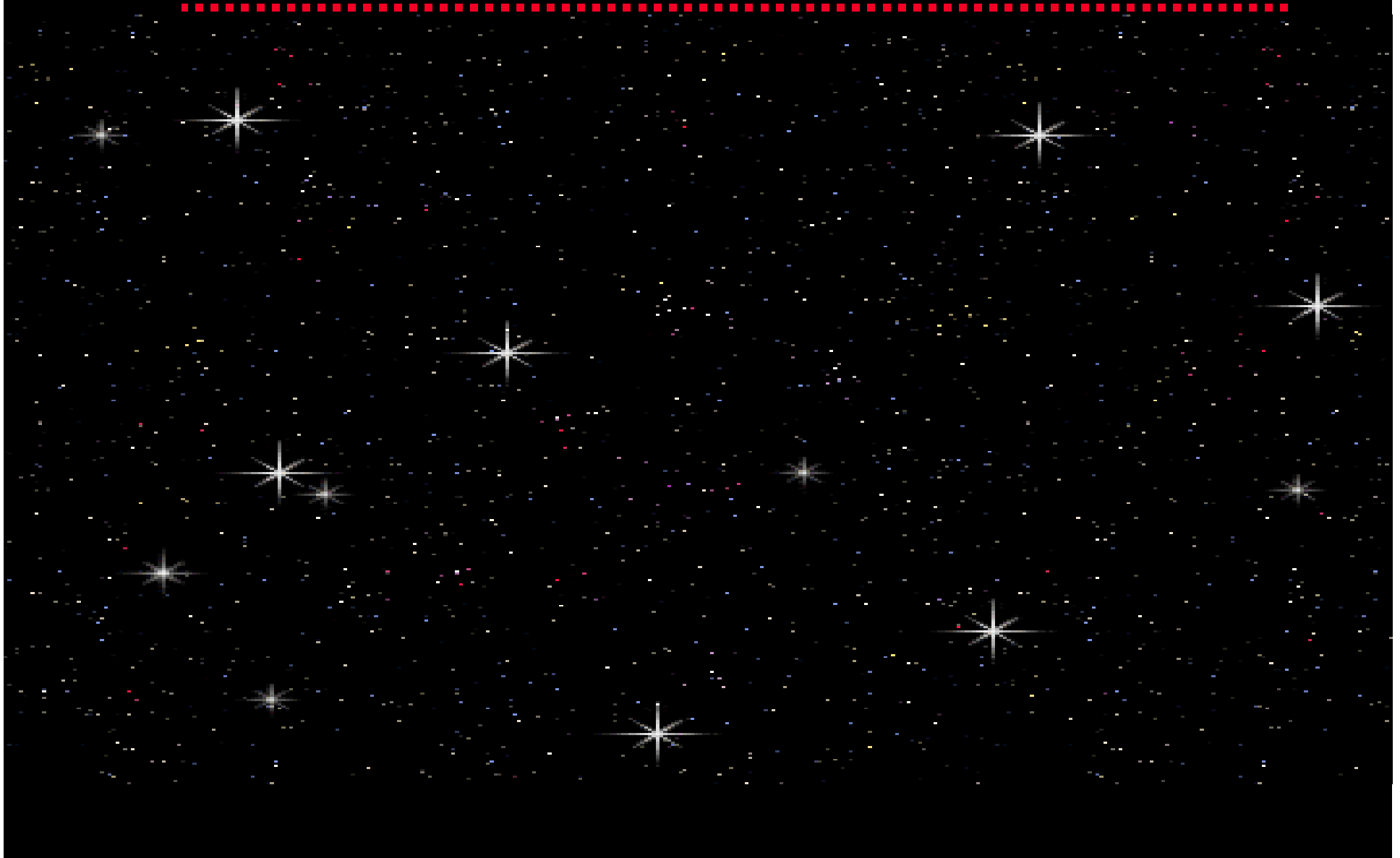
1.54 meter bias

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



Ionosphere - scintillation



Ionosphere - scintillation

- Rapid, random, turbulent motions of the ionosphere cause scintillation

Ionosphere - scintillation

- Rapid, random, turbulent motions of the ionosphere cause scintillation
- Causes rapid fluctuations of the amplitude and phase of GPS signals

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**

Ionosphere - scintillation

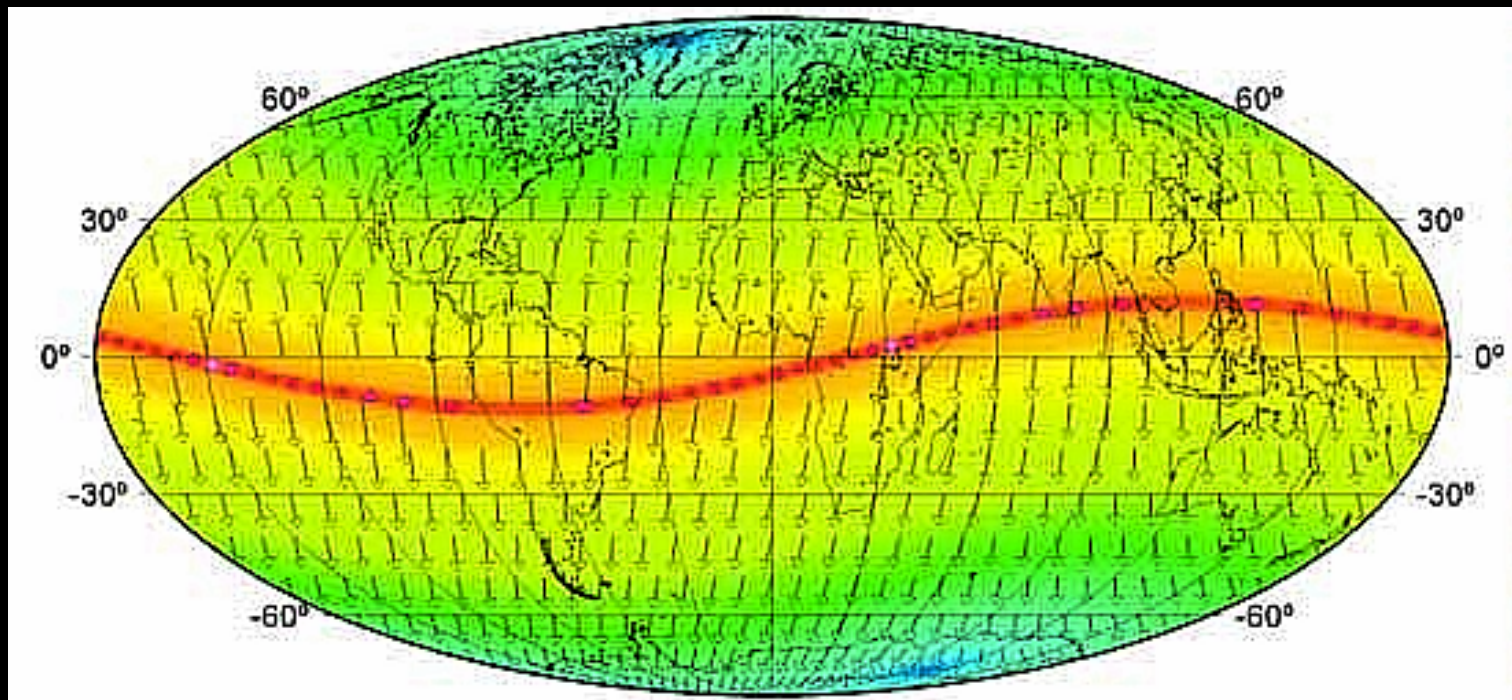
- Rapid, random, turbulent motions of the ionosphere cause scintillation
- Causes rapid fluctuations of the amplitude and phase of GPS signals
- Reduces signal-to-noise ratios
- **May cause loss of tracking**

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

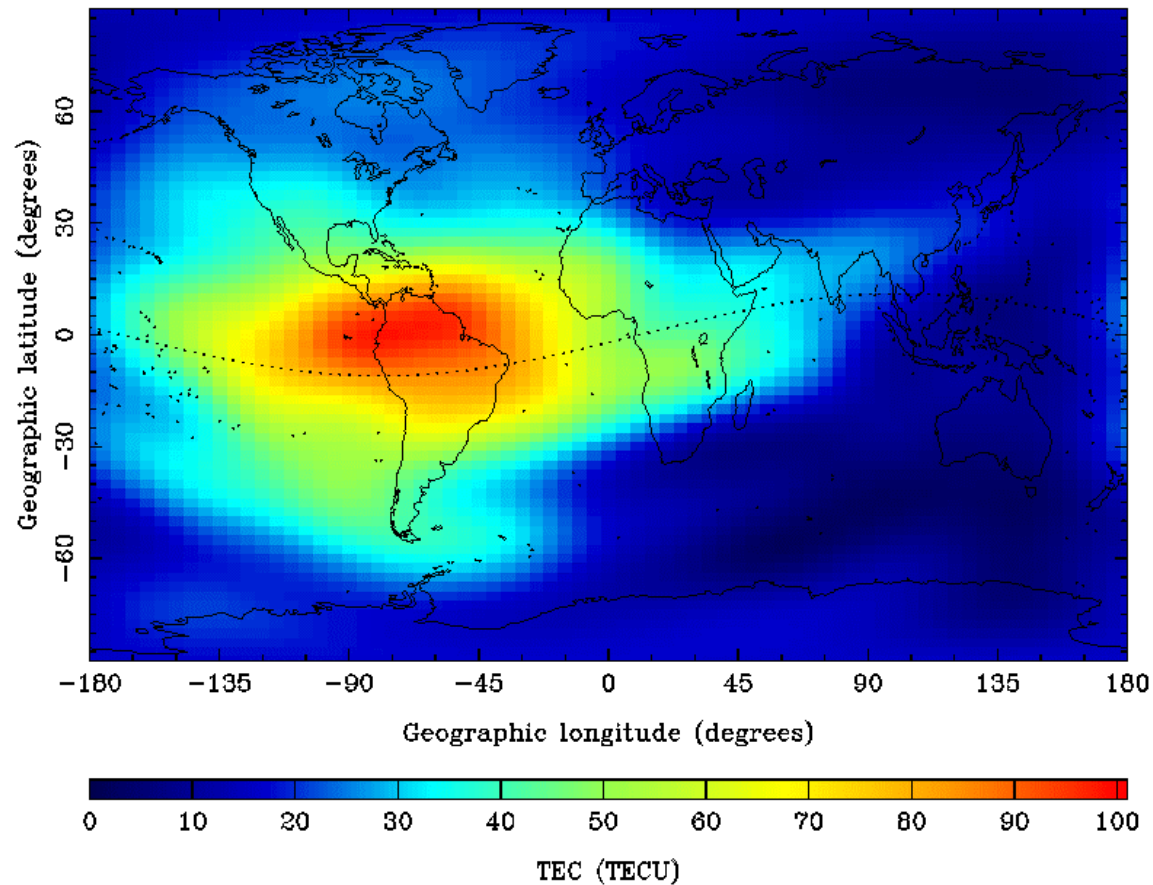


Ionosphere - TEC distribution

Global TEC distribution - September 25,

1999

CODE'S GLOBAL IONOSPHERE INFO FOR DAY 288, 1999 - 19:00 UT



The Solar Cycle - daily variations

The Solar Cycle - daily variations

- TEC depends on sunlight and is greatest in the middle of the day and lowest at night

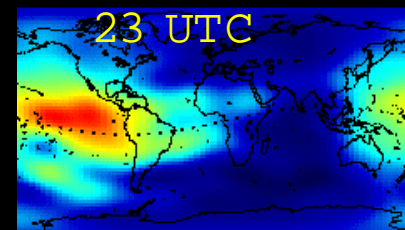
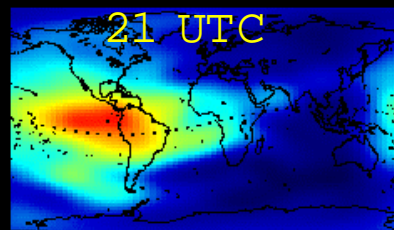
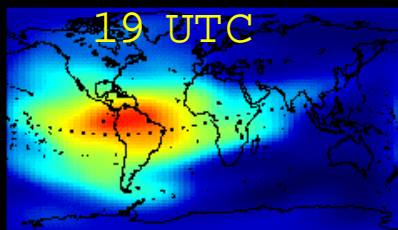
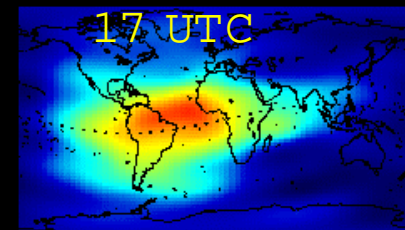
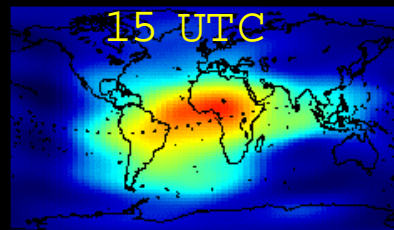
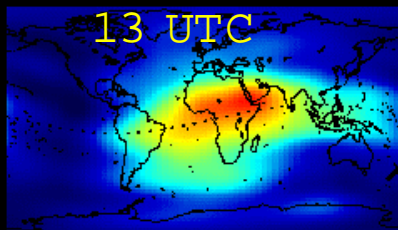
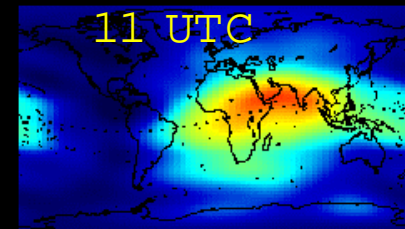
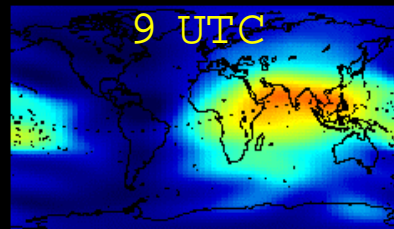
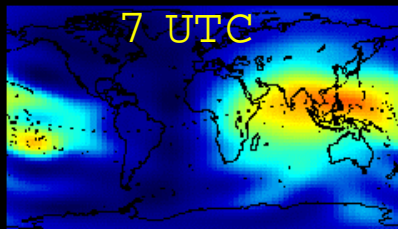
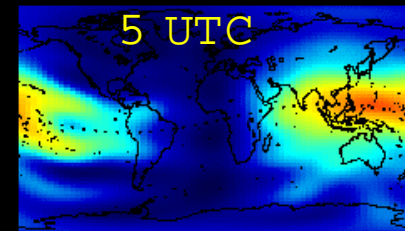
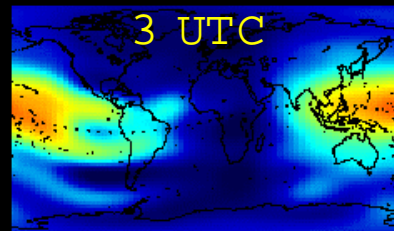
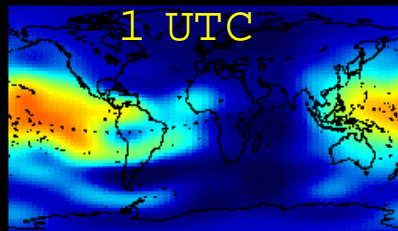
The Solar Cycle - daily variations

- 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.

The Solar Cycle - daily variations

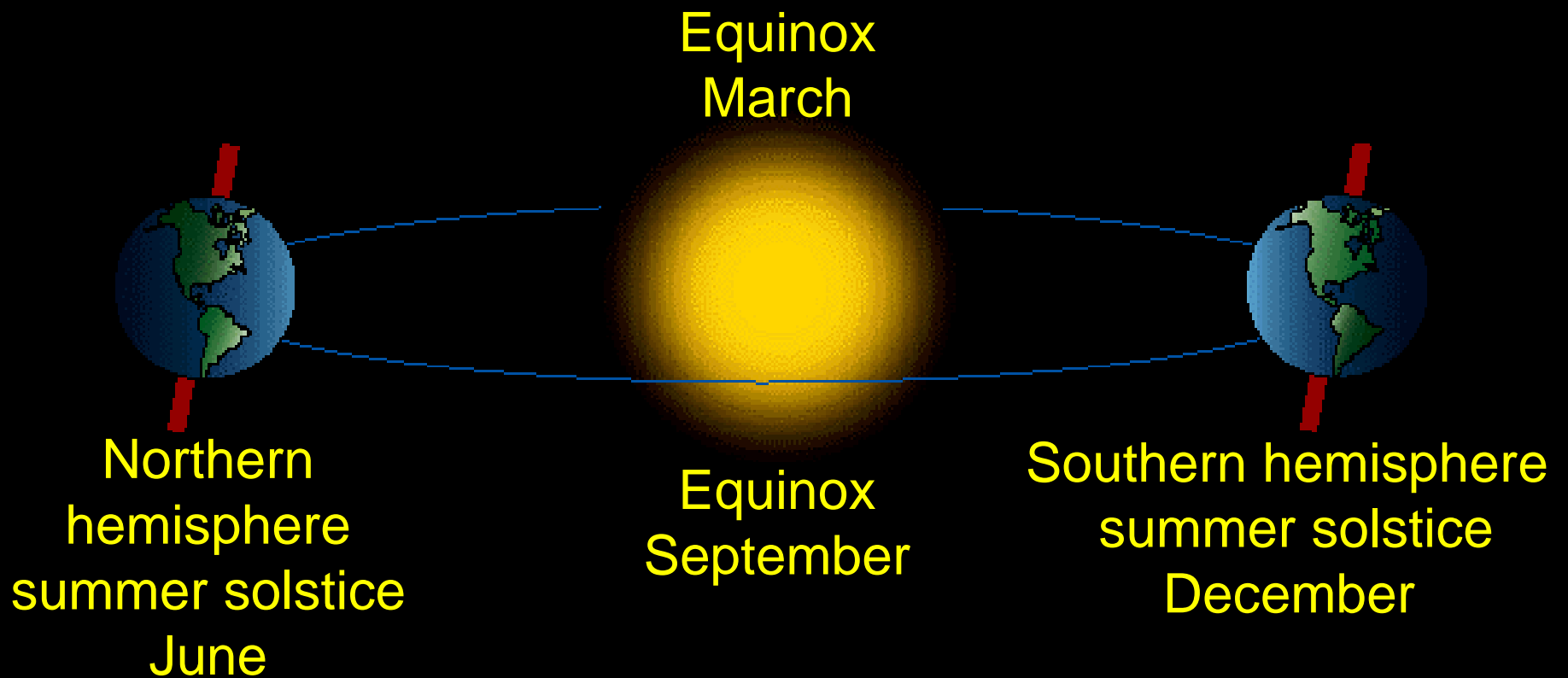
- TEC depends on sunlight and is greatest in the middle of the day and lowest at night
- Scintillation usually occurs after sunset when the TEC is transitioning back to nighttime values.
- Scintillation may occur at any time in the polar regions

TEC - daily variations



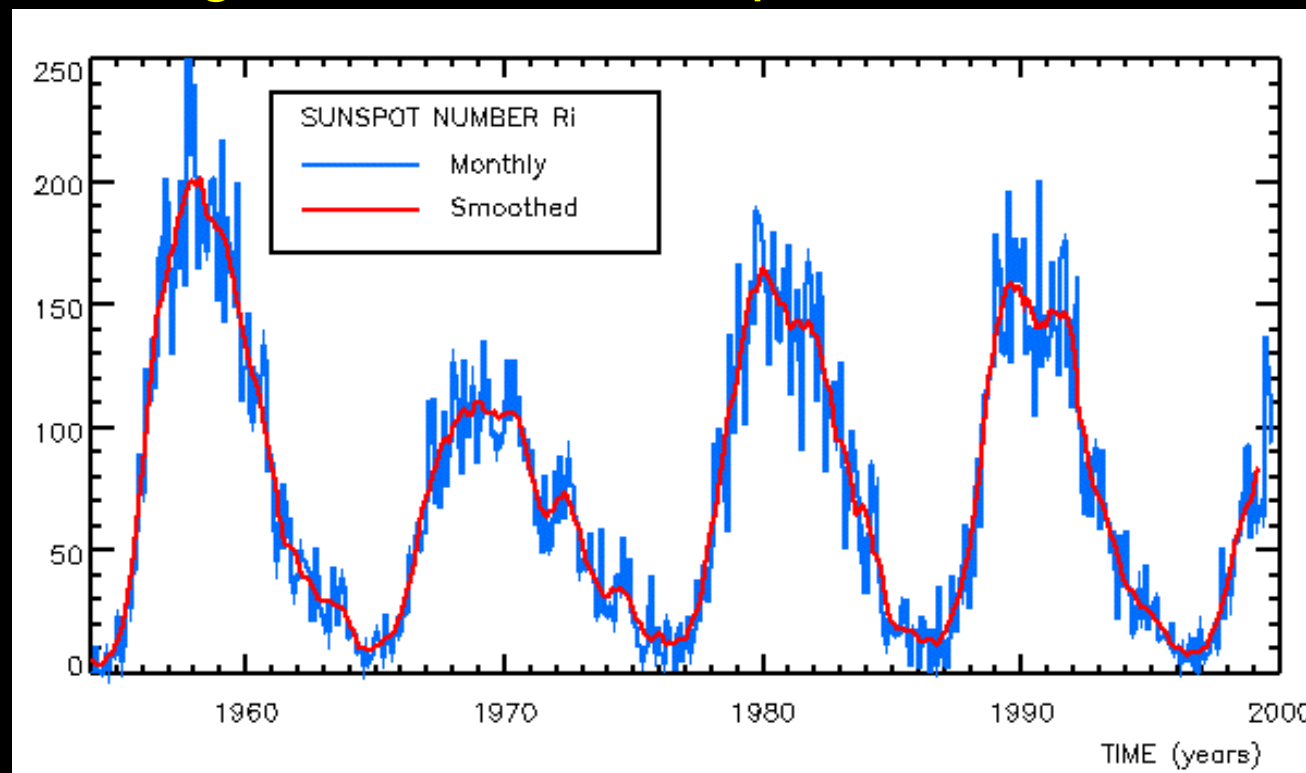
The Solar Cycle - seasonal variations

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

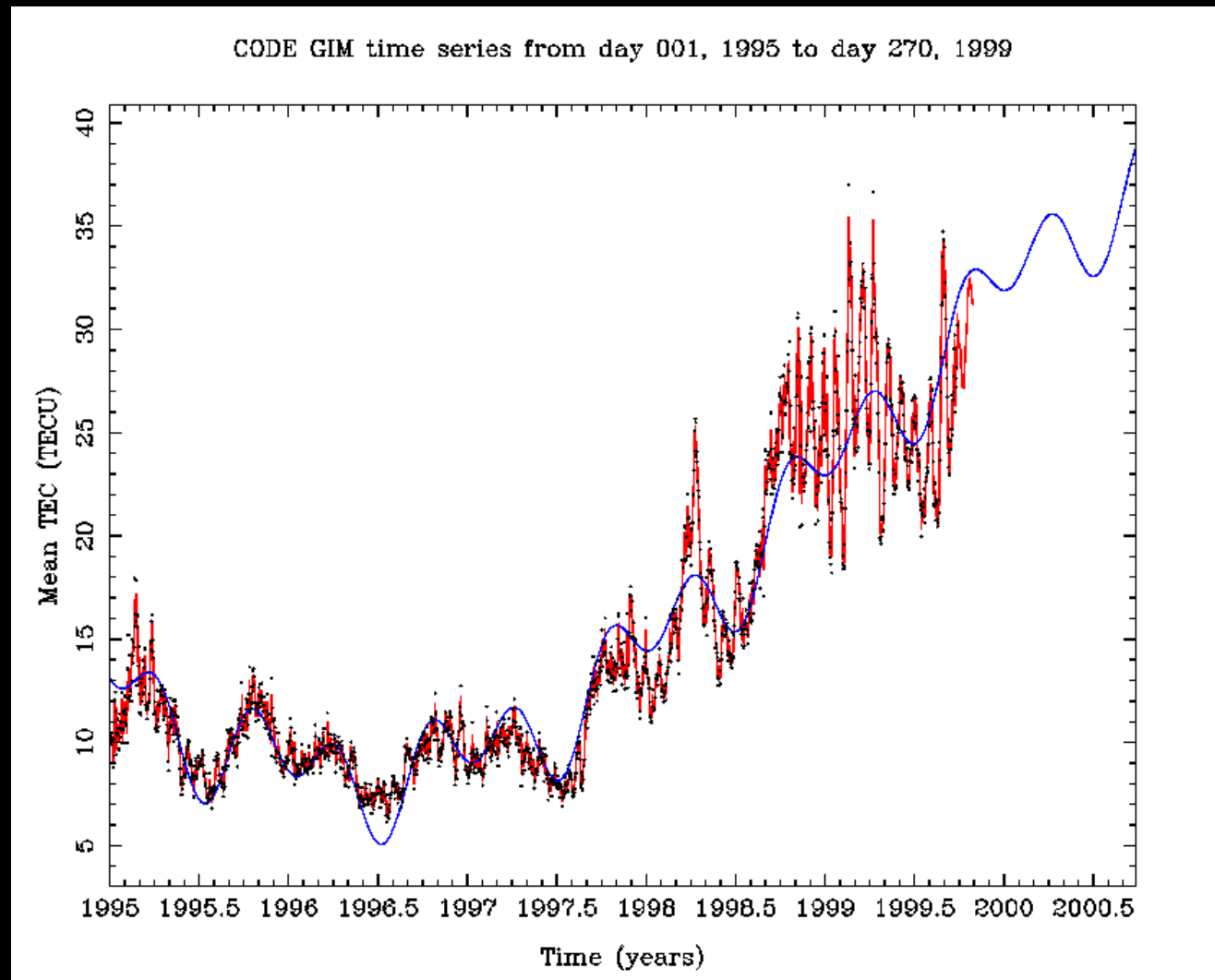


The Solar Cycle - 11-year variations

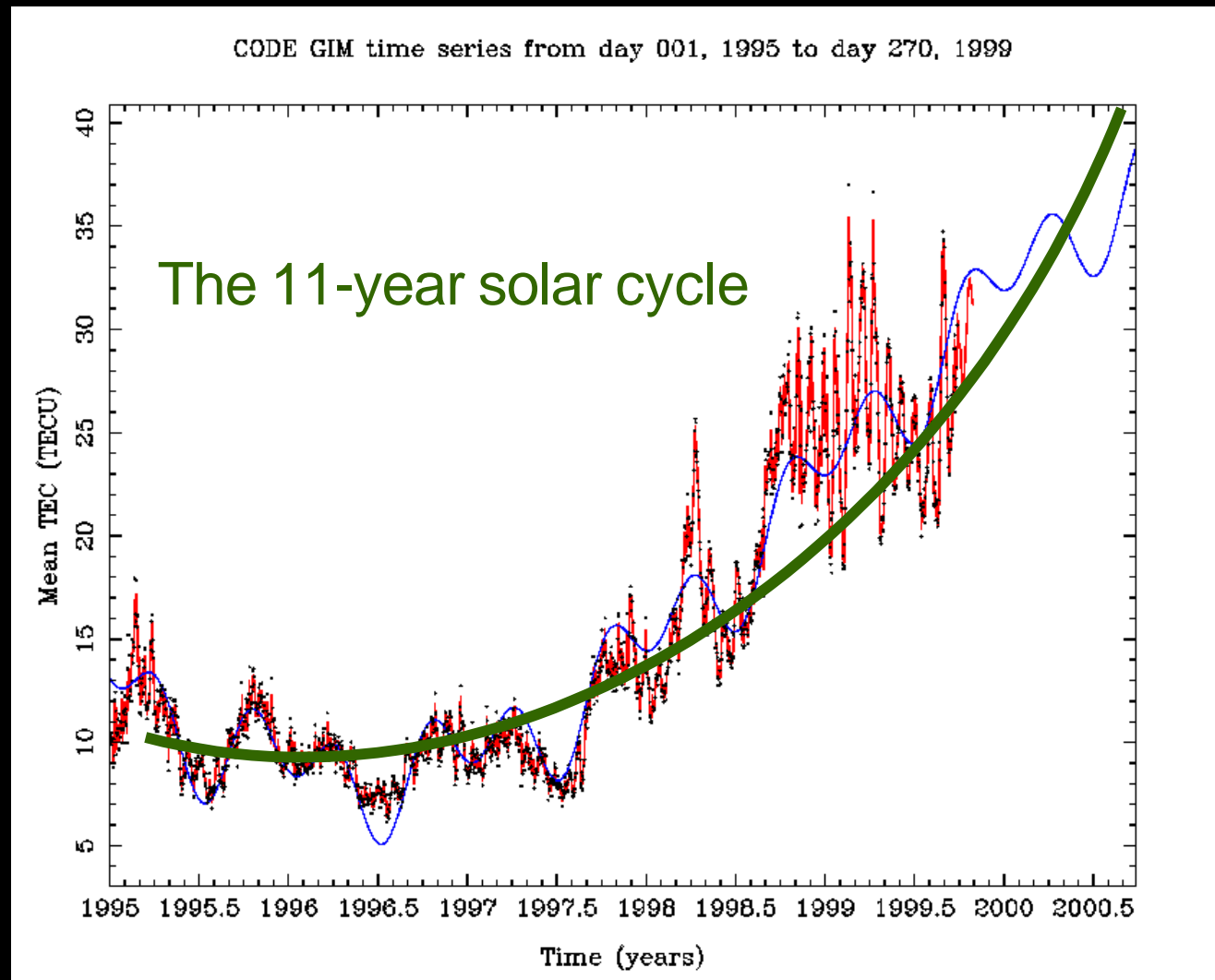
- Sunspots indicate high solar activity
- Solar activity cycles over an 11 year period
- Modern GPS receivers have been used mostly during a Solar minimum period



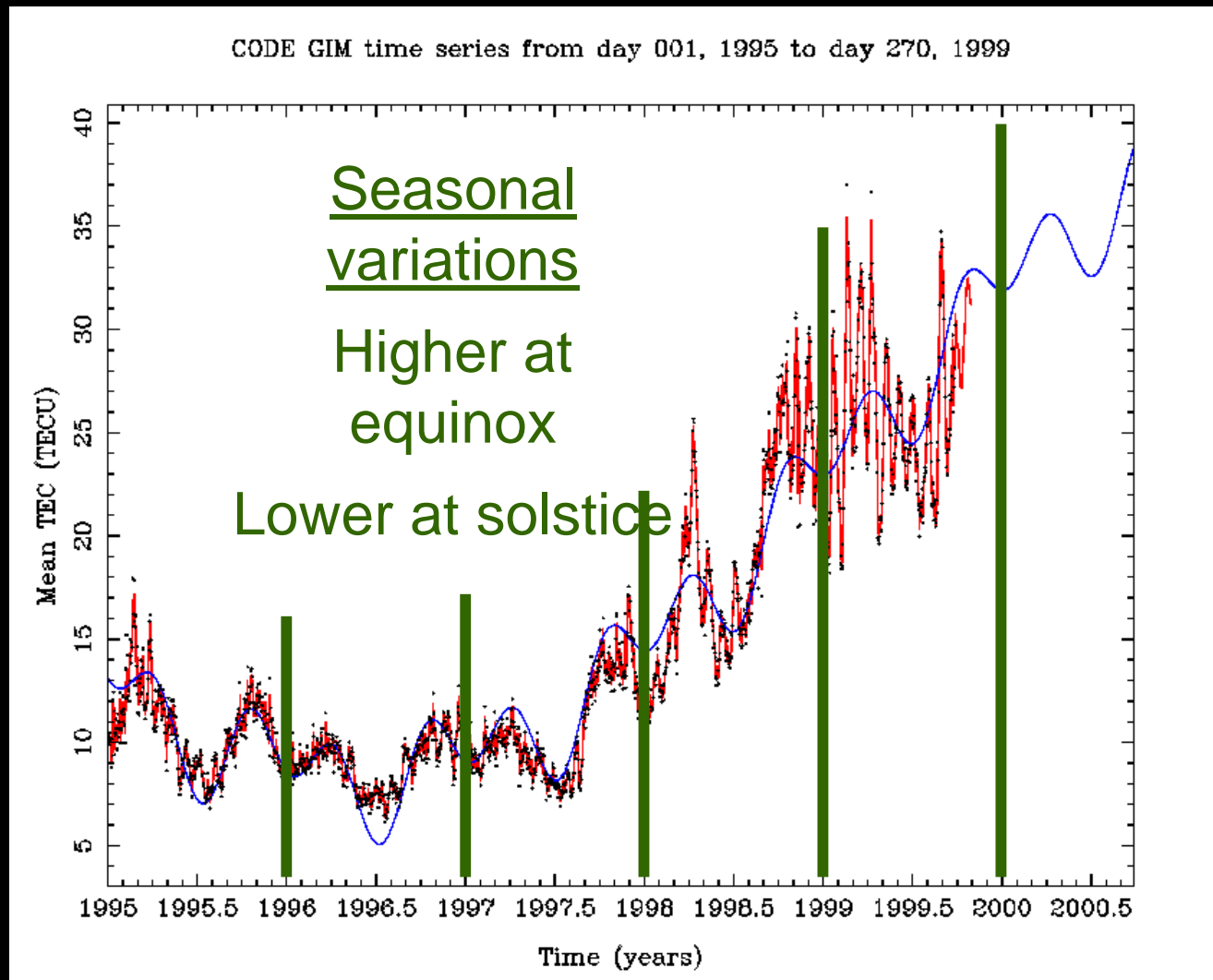
The Solar Cycle - Mean TEC variations



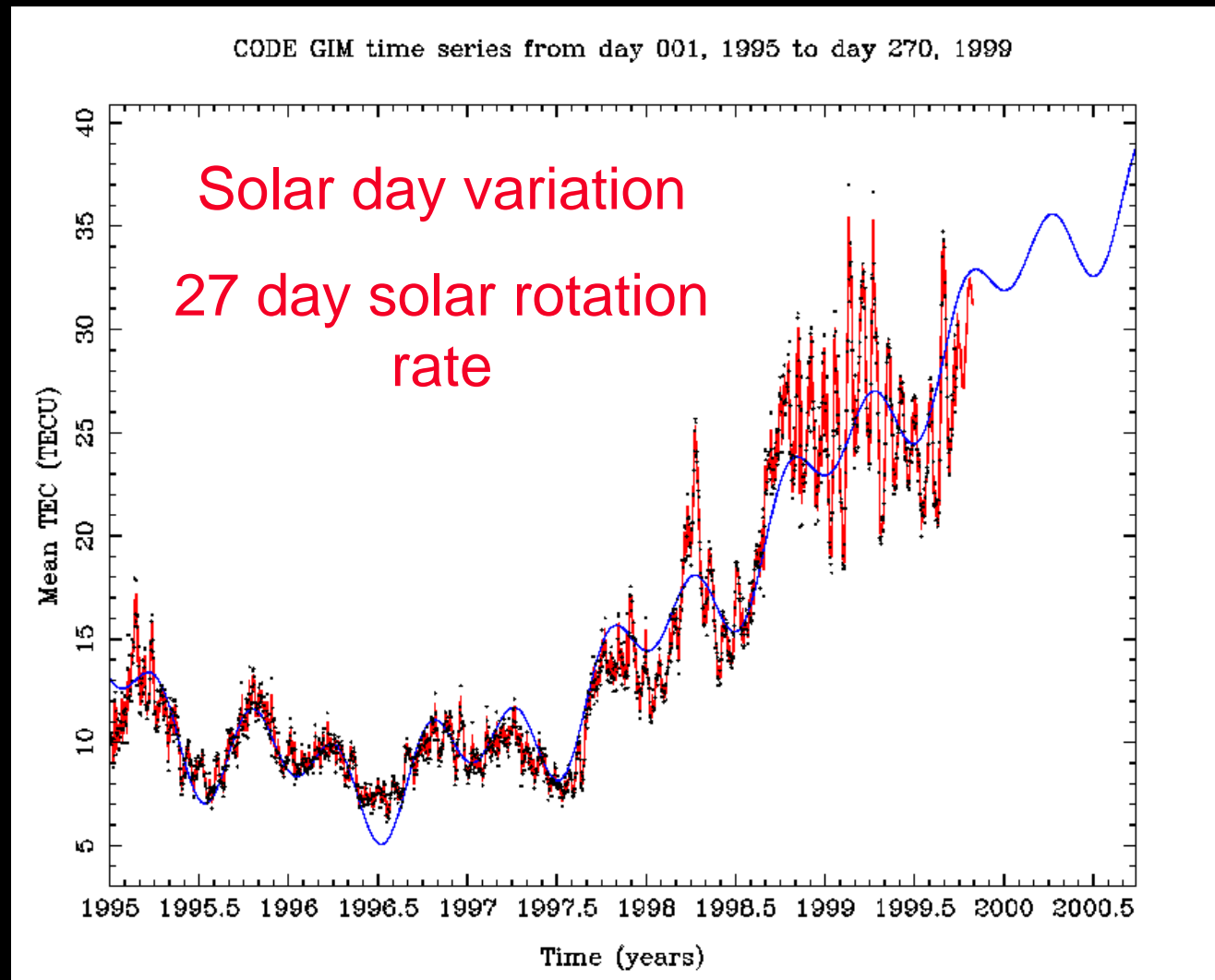
The Solar Cycle - Mean TEC variations



The Solar Cycle - Mean TEC variations



The Solar Cycle - Mean TEC variations



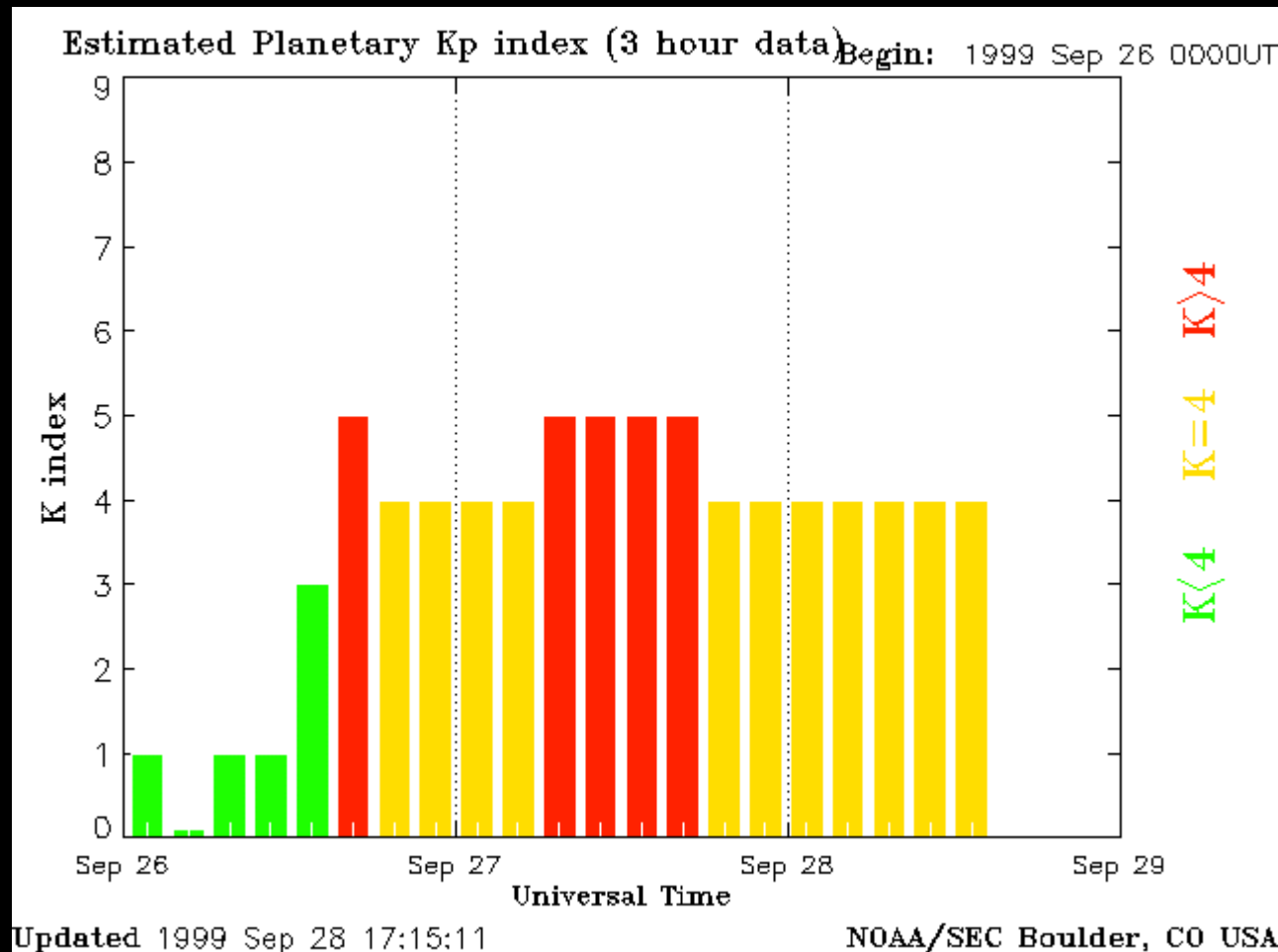
Internet Resources

www.sec.noaa.gov

The screenshot shows a Netscape browser window displaying the Space Environment Center website. The browser's title bar reads "Space Environment Center - Netscape". The address bar shows the URL "http://www.sec.noaa.gov/index.html". The website has a dark blue background with white and red text. On the left side, there is a vertical navigation menu with the following links: "SEC Home", "Data & Products", "Research & Development", "Partners & Collaborators", "About SEC", and "Education & Outreach". Below the menu is the NOAA logo and the text "http://www.sec.noaa.gov", "Space Environment Center", and "325 Broadway, Boulder, CO 80303". The main content area features the "Space Environment Center" logo and name, followed by the text "National Oceanic and Atmospheric Administration". Below this is a paragraph: "Providing space weather alerts and warnings to the nation and the world for disturbances that can affect people and equipment working in space and on Earth". The "Advisories" section contains two buttons: "Events & Announcements" and "Today's Space Weather". The "Data and Products" section includes a solar image with a color scale and a list of links: "Latest Space Weather Reports and Special Products", "Geomagnetic Data", "Solar Images", and "Gopher Data Directories". A small link "About this image" is located below the solar image. The browser's status bar at the bottom indicates "Document Done".

Internet Resources




www.sec.noaa.gov



Internet Resources

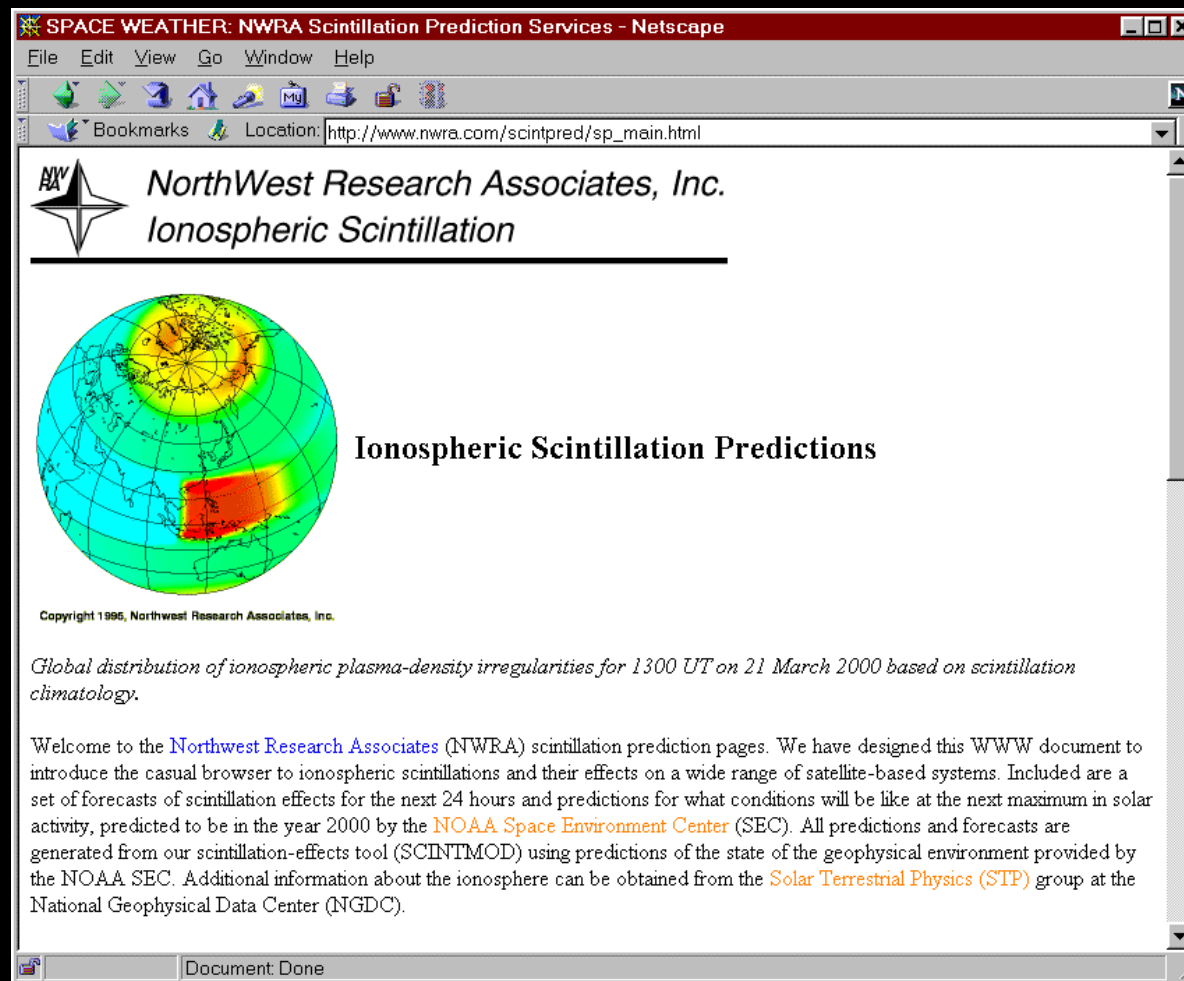
www.spaceweather.com

The screenshot shows a Netscape browser window titled "The NASA Space Weather Bureau - Netscape". The address bar shows the URL "http://www.spaceweather.com/". The main content area features the following sections:

- The Space Weather Bureau**
Sponsored by the Marshall **Space Sciences Lab**
www.SpaceWeather.com
- Today's Forecast**
Courtesy NOAA. Updated 1999 Oct 04 2108 UT
24-hour Forecast
Solar activity will be low. Geophysical activity will be quiet to active.
Current Conditions
Solar activity is low. Geophysical activity is quiet to active.
[more information](#)
- SPACE WEATHER HEADLINES**
5 Oct 1999
 - **SOHO spies the far side of the Sun** (20 JUN 99)
 - **Leonids on the Horizon** (22 Jun 99)
 - **Scientists learn to predict solar explosions** (9 MAR 99)
 - **Forecasting solar eruptions may now be possible** (9 MAR 99)
 - **Space weather camera set for launch** (16 FEB 99)
- Daily Solar Images and Animations**

Aurora Borealis Live!

- Express Delivery Space Science News**

Subscribe to Space Science News
Sign up for our express news delivery service and each time there's a new story we'll notify you by email.
- Daily Solar Flare Probabilities**
1999 Oct 04 2210 UT
24 hr 48 hr
CLASS M 20 % 20 %
CLASS X 01 % 01 %
[more information](#)

Internet Resources


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

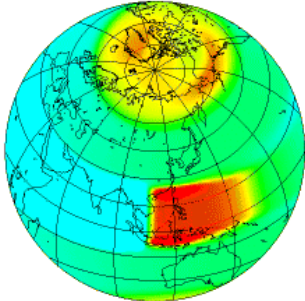


SPACE WEATHER: NWRA Scintillation Prediction Services - Netscape

File Edit View Go Window Help

Bookmarks Location: http://www.nwra.com/scintpred/sp_main.html

 **NorthWest Research Associates, Inc.**
Ionospheric Scintillation

 **Ionospheric Scintillation Predictions**

Copyright 1995, Northwest Research Associates, Inc.

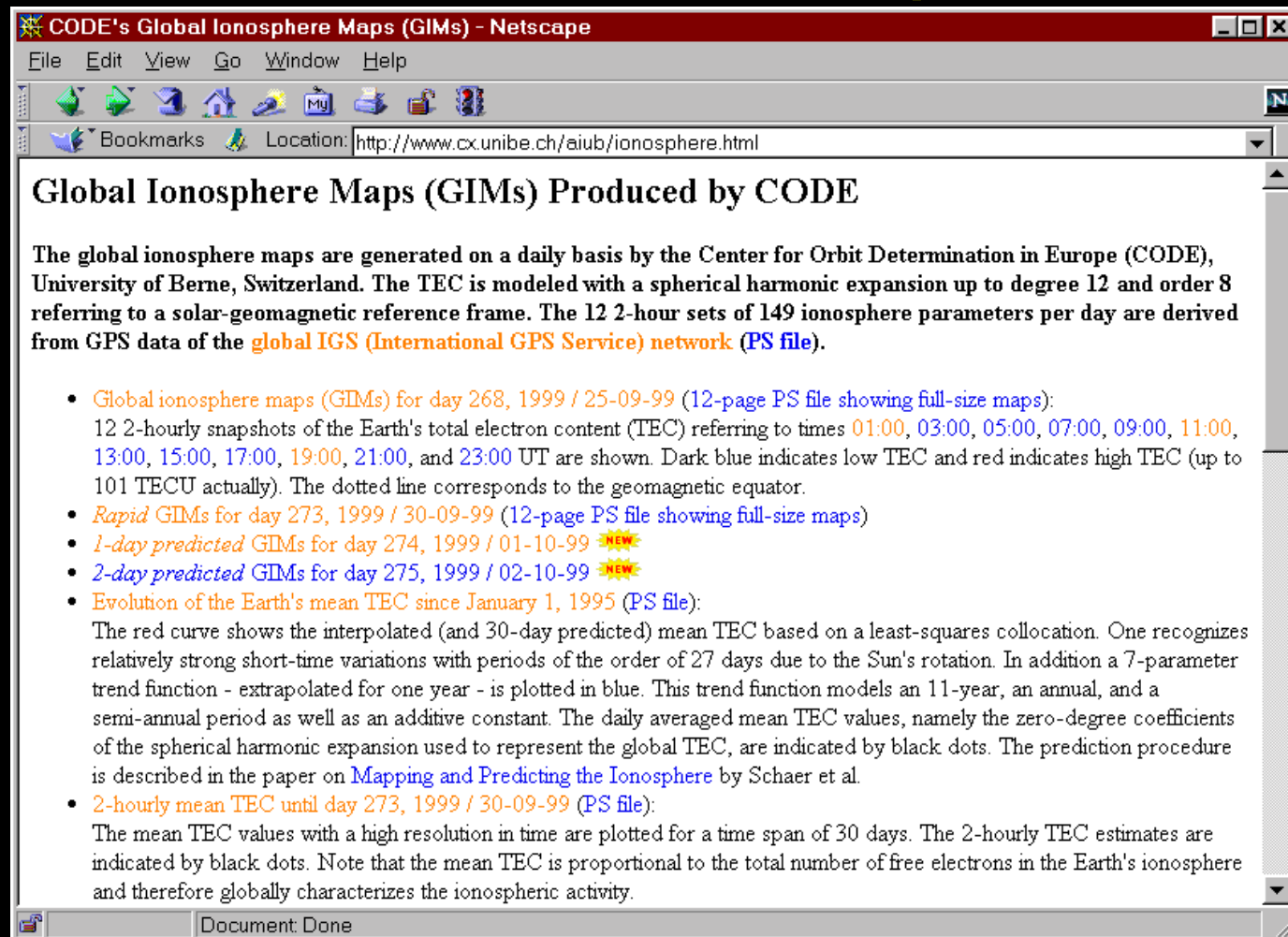
Global distribution of ionospheric plasma-density irregularities for 1300 UT on 21 March 2000 based on scintillation climatology.

Welcome to the [Northwest Research Associates](#) (NWRA) scintillation prediction pages. We have designed this WWW document to introduce the casual browser to ionospheric scintillations and their effects on a wide range of satellite-based systems. Included are a set of forecasts of scintillation effects for the next 24 hours and predictions for what conditions will be like at the next maximum in solar activity, predicted to be in the year 2000 by the [NOAA Space Environment Center](#) (SEC). All predictions and forecasts are generated from our scintillation-effects tool (SCINTMOD) using predictions of the state of the geophysical environment provided by the NOAA SEC. Additional information about the ionosphere can be obtained from the [Solar Terrestrial Physics](#) (STP) group at the National Geophysical Data Center (NGDC).

Document Done

Internet Resources

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



CODE's Global Ionosphere Maps (GIMs) - Netscape

File Edit View Go Window Help

Location: <http://www.cx.unibe.ch/aiub/ionosphere.html>

Global Ionosphere Maps (GIMs) Produced by CODE

The global ionosphere maps are generated on a daily basis by the Center for Orbit Determination in Europe (CODE), University of Berne, Switzerland. The TEC is modeled with a spherical harmonic expansion up to degree 12 and order 8 referring to a solar-geomagnetic reference frame. The 12 2-hour sets of 149 ionosphere parameters per day are derived from GPS data of the [global IGS \(International GPS Service\) network \(PS file\)](#).

- [Global ionosphere maps \(GIMs\) for day 268, 1999 / 25-09-99 \(12-page PS file showing full-size maps\)](#):
12 2-hourly snapshots of the Earth's total electron content (TEC) referring to times 01:00, 03:00, 05:00, 07:00, 09:00, 11:00, 13:00, 15:00, 17:00, 19:00, 21:00, and 23:00 UT are shown. Dark blue indicates low TEC and red indicates high TEC (up to 101 TECU actually). The dotted line corresponds to the geomagnetic equator.
- [Rapid GIMs for day 273, 1999 / 30-09-99 \(12-page PS file showing full-size maps\)](#)
- [1-day predicted GIMs for day 274, 1999 / 01-10-99](#) **NEW**
- [2-day predicted GIMs for day 275, 1999 / 02-10-99](#) **NEW**
- [Evolution of the Earth's mean TEC since January 1, 1995 \(PS file\)](#):
The red curve shows the interpolated (and 30-day predicted) mean TEC based on a least-squares collocation. One recognizes relatively strong short-time variations with periods of the order of 27 days due to the Sun's rotation. In addition a 7-parameter trend function - extrapolated for one year - is plotted in blue. This trend function models an 11-year, an annual, and a semi-annual period as well as an additive constant. The daily averaged mean TEC values, namely the zero-degree coefficients of the spherical harmonic expansion used to represent the global TEC, are indicated by black dots. The prediction procedure is described in the paper on [Mapping and Predicting the Ionosphere](#) by Schaer et al.
- [2-hourly mean TEC until day 273, 1999 / 30-09-99 \(PS file\)](#):
The mean TEC values with a high resolution in time are plotted for a time span of 30 days. The 2-hourly TEC estimates are indicated by black dots. Note that the mean TEC is proportional to the total number of free electrons in the Earth's ionosphere and therefore globally characterizes the ionospheric activity.

Document Done

Internet Resources

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

The screenshot shows a Netscape browser window titled "GPS derived TEC - Netscape". The address bar displays the URL <http://www.grdl.noaa.gov/GRD/GPS/Projects/TEC/>. The page content includes the following elements:


- United States Department of Commerce
National Oceanic and Atmospheric Administration
National Geodetic Survey
Geosciences Research Division
- An image of the Sun.
- An image of the Earth.
- A large map of the United States showing Total Electron Content (TEC) data, with a color scale ranging from blue (low) to red (high).
- Navigation links: [Daily TEC MAPS](#), [TEC LIBRARY](#), and [Geomagnetic Storm GALLERY](#).
- Contact information: Contact Dr. Steve Musman (smusman@grdl.noaa.gov) or Dr. Everett Dutton (everett@grdl.noaa.gov) with comments or questions.

Document Done

Internet Resources

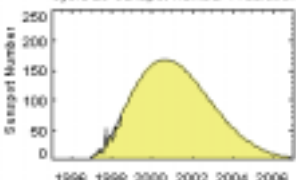
www.sunspotcycle.com


Sunsports and the Solar Cycle
Sponsored by Science@NASA
www.SunspotCycle.com

2 Oct 1999

Today's sunspot number is **84**
Courtesy National Oceanic and Atmospheric Administration
Updated: 30 Oct 1999
[ARCHIVES](#)

Solar Cycle #23 is in progress. The next sunspot maximum is predicted to occur in the year 2000.


Predicting the Solar Maximum
Planning for satellite orbits and space missions often require advance knowledge of solar activity levels. NASA scientists are using new techniques to predict sunspot maxima years in advance. [Click here](#) for the latest predictions for the current solar cycle.

Cycle 23 Sunspot Number Prediction

Click on the image for current predictions.

Solar Movies and Animations

[Click Here](#)
Updated Daily!

Web Site Index

- [Cool Solar News](#)
- [Aurora images, Live from Spacel](#)
- [NASA Space Weather Bureau](#)
- [What is the solar cycle?](#)
- [How do sunspots affect Earth?](#)
- [The Solar "Butterfly Diagram"](#)
- [Sunspots in History](#)
- [Sunspot number archives](#)
- [Daily sun pictures and movies](#)

Sunspots in History!
(Java support required)

[Click Here](#)

LOOK: [The NASA/MSFC](#)

What is Trimble doing?

What is Trimble doing?

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

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**

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**

Summary

Summary

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

Summary

- Space weather is the interaction of the sun's radiation with the earth's atmosphere and magnetic field
- **Increases in solar activity cause increased disturbances in the earth's ionosphere**

Summary

- Space weather is the interaction of the sun's radiation with the earth's atmosphere and magnetic field
- Increases in solar activity cause increased disturbances in the earth's ionosphere
- **The solar cycle has daily, monthly, seasonal, and 11-year variations**

Summary

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

Summary

Summary

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

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**

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**

What can YOU do?

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

Thank You

Questions?