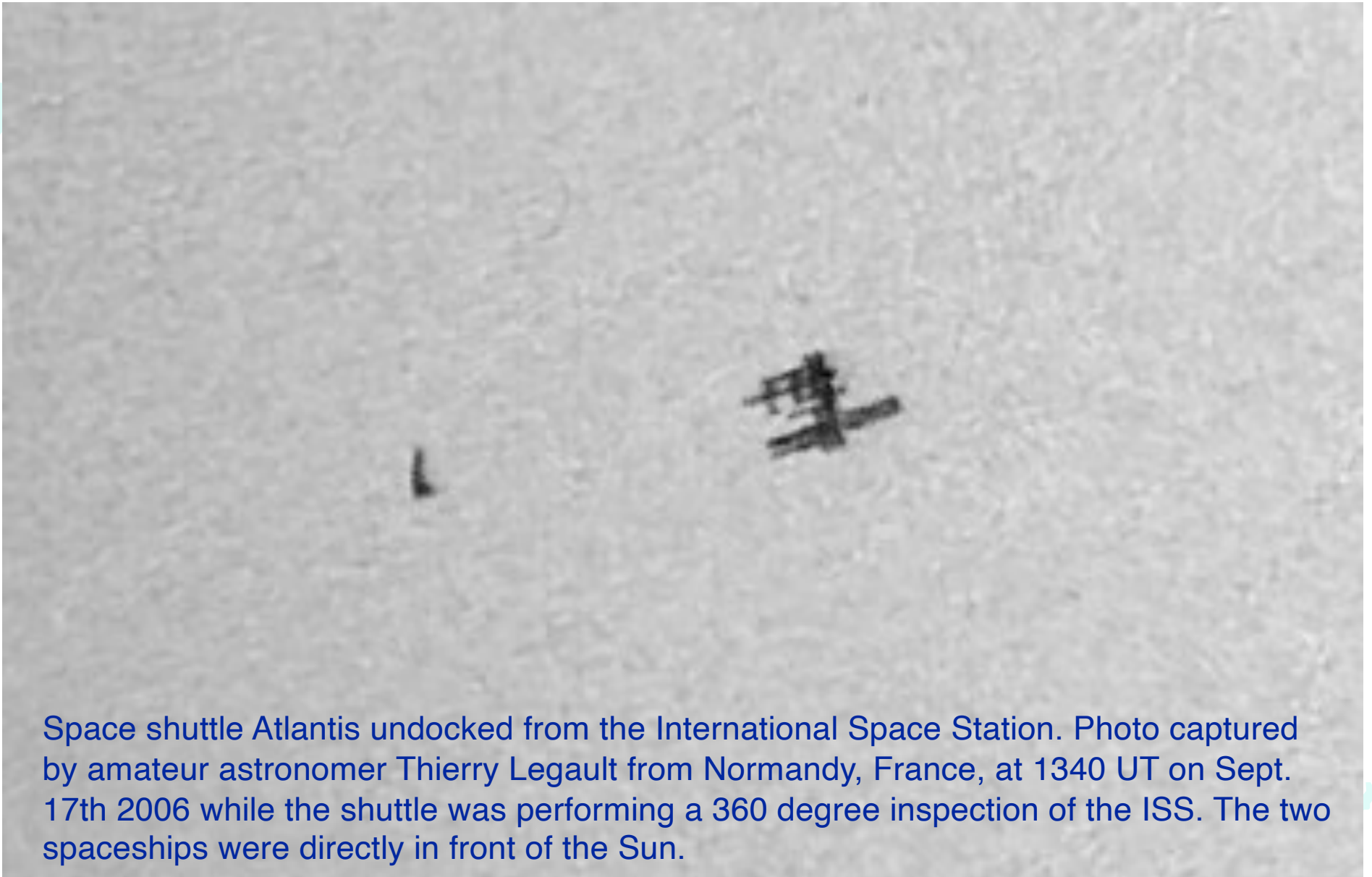


Environmental effects - I (neutral atmosphere)

Lecture 5

W.K. Tobiska

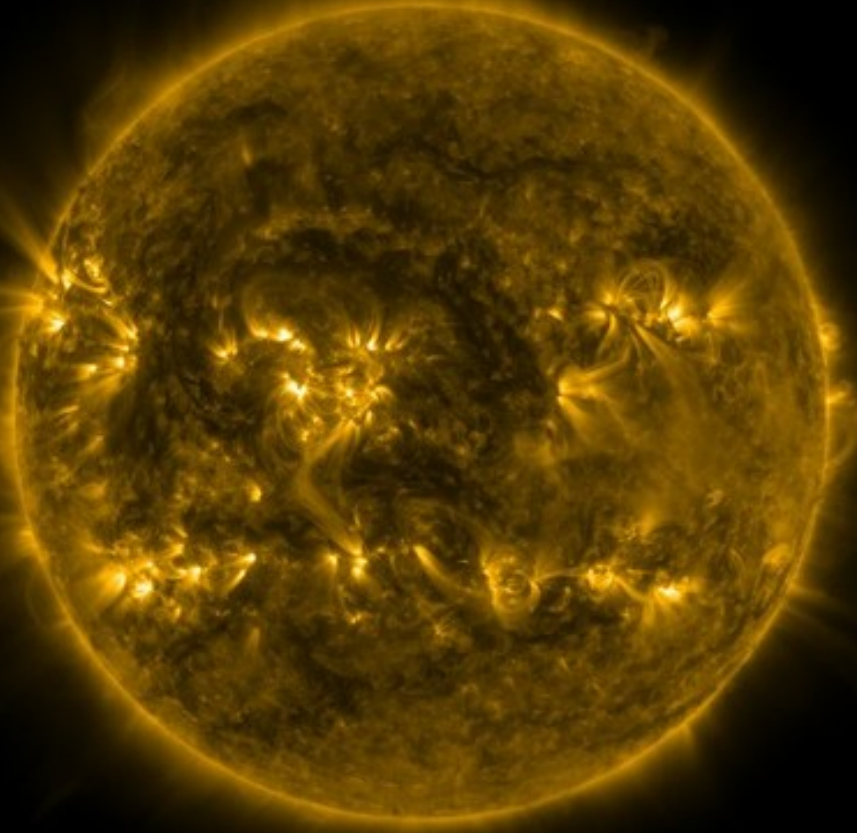
Space Environment Technologies



Space shuttle Atlantis undocked from the International Space Station. Photo captured by amateur astronomer Thierry Legault from Normandy, France, at 1340 UT on Sept. 17th 2006 while the shuttle was performing a 360 degree inspection of the ISS. The two spaceships were directly in front of the Sun.

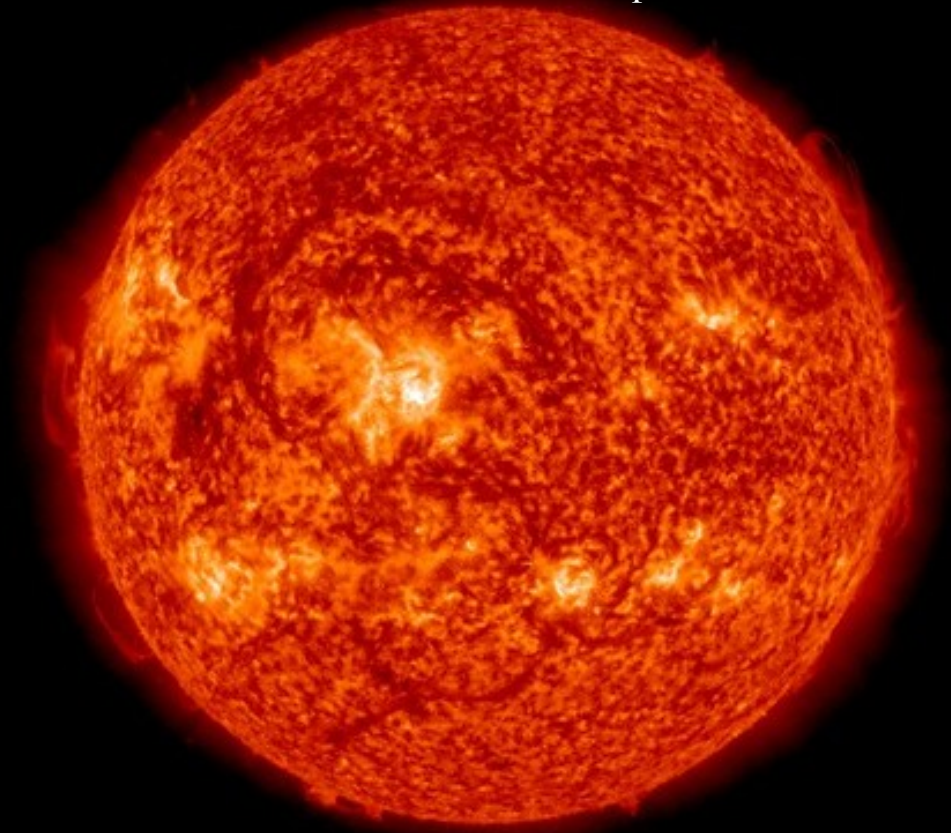
Low latitude regions - Sep 24, 2013

17.1 nm corona



SDO/AIA 171 2013-09-24 23:29:24 UT

30.4 nm chromosphere



SDO/AIA 304 2013-09-24 23:29:20 UT

Contributions

Current solar active regions at Vern

Raben's site with maps that helps visualize the second problem on Homework #2:

<http://www.raben.com/maps/>

Two asteroids pass close to Earth

<http://news.blogs.cnn.com/2010/09/07/two-asteroids-to-pass-close-to-earth-on-wednesday/?hpt=C1>

Sep 6 2010 flare eruption picture and YouTube movie

<http://www.physorg.com/news203336267.html>

Contributions

Real time position of over 13,000 satellites orbiting the Earth using Google Earth (also available from <http://spacewx.com> Innovations link, visualizing space weather with KML). <http://www.gearthblog.com/satellites.html>

Possible declining solar magnetic field

http://news.sciencemag.org/sciencenow/2010/09/say-goodbye-to-sunspots.html?sms_ss=email

Solar wind as a means of propulsion

<http://www.universetoday.com/74000/fleet-of-solar-sail-spacecraft-envisioned-for-future/>

National geographic picture of aurora and solar flare

http://news.nationalgeographic.com/news/2010/09/photogalleries/100915-aurora-moon-sun-science-best-space-pictures-111/#/space111-solar-prominence-sun_26068_600x450.jpg

Aurora link <http://antwarp.gsfc.nasa.gov/apod/astropix.html>

Solar Flare and CME difference

https://www.youtube.com/watch?feature=player_embedded&v=TWjtYSRIOUI



Space Water Concept

SET is working on Space Water concept

<http://spacewx.com> Innovations:Space Water menu link

Space Water objective: Enable space assets to help solve 21st Century problems. Use space resources (solar power satellites) to augment energy needs of seawater desalination on re-commissioned offshore oil platforms to produce urban and agricultural fresh water.

Tasks in a multi-discipline, multi-decade project:

2009-15: present topic to professional and policy communities

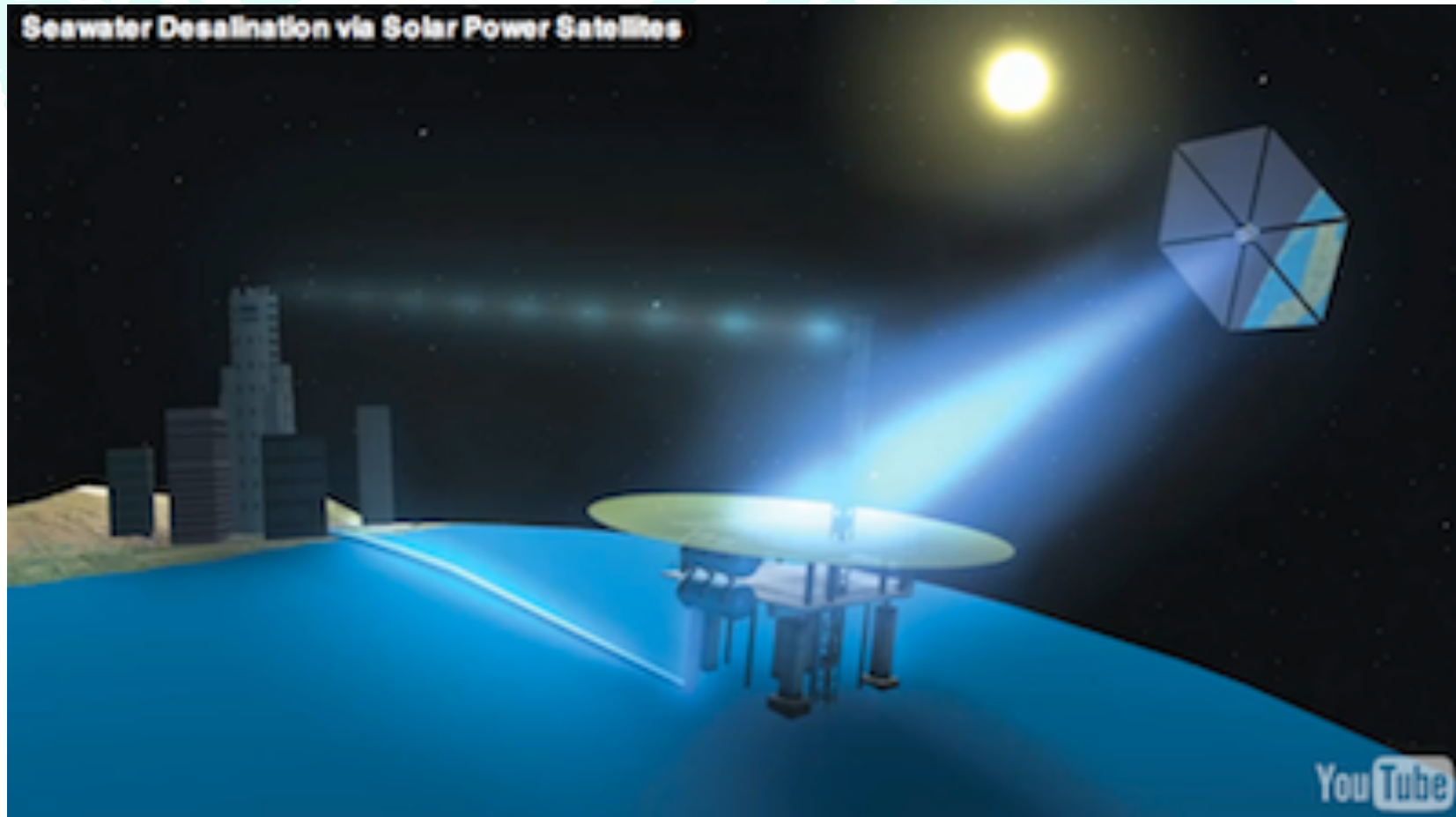
2016: hold international Space Water Workshop

2016-18: refine science, engineering, policy, financial issues

2019-: begin infrastructure development

SET seeks interested volunteers to help with organizing this activity – no funding available at this time but bright ideas and energetic work are needed to **develop this concept for solving 21st Century global fresh water challenges** – contact Prof. Tobiska if interested

Space Water Concept



<http://sunsat.gridlab.ohio.edu/>

Lecture Overview

Environmental effects (neutral atmosphere)

Kinetic energy

Atmospheric drag, attitude perturbations, sputtering

Chemical energy

Atomic oxygen erosion, UV degradation, spacecraft glow

Thermal

Temperature control

Particulate

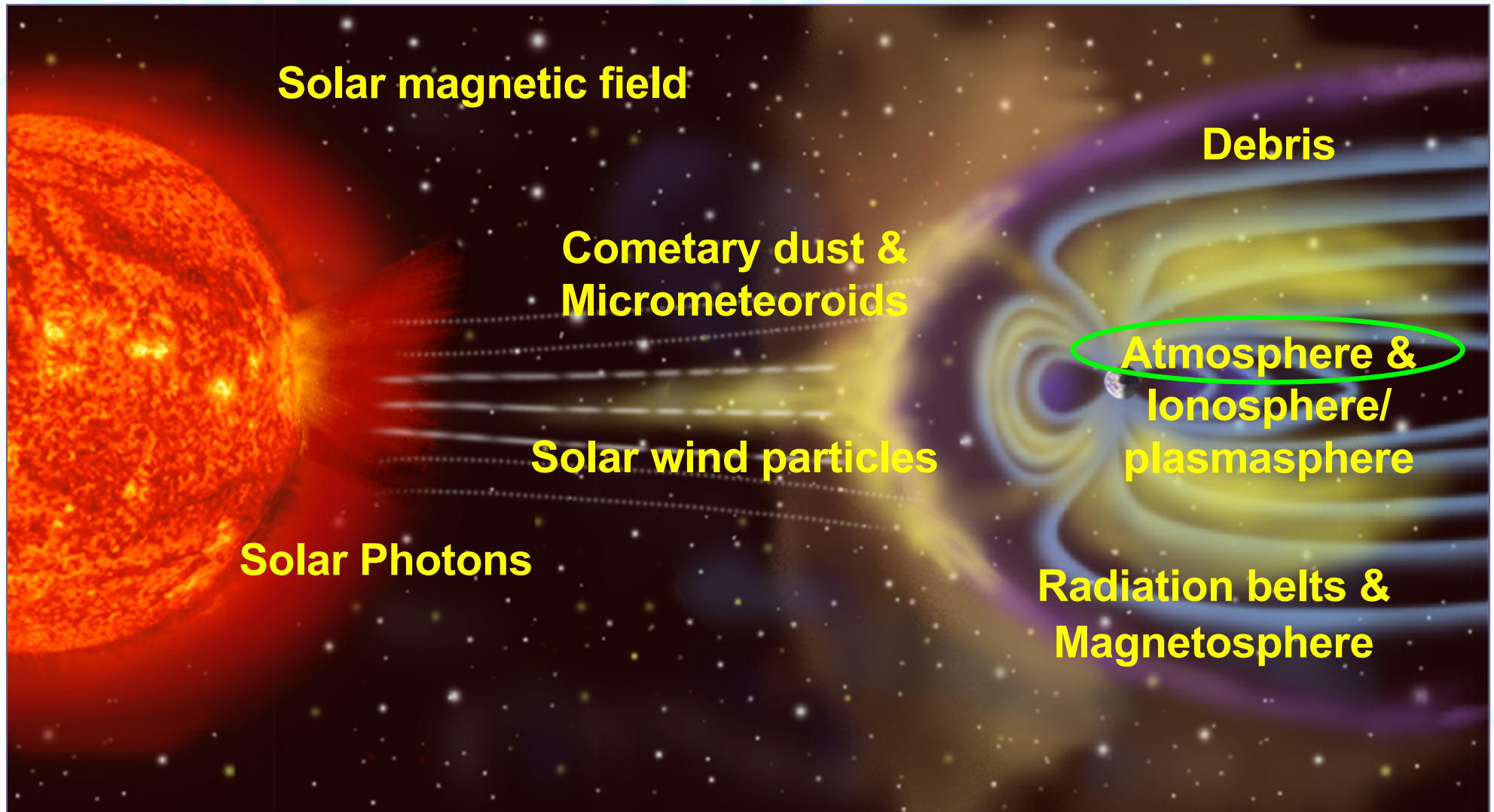
Contamination

Standards and guidelines

Models

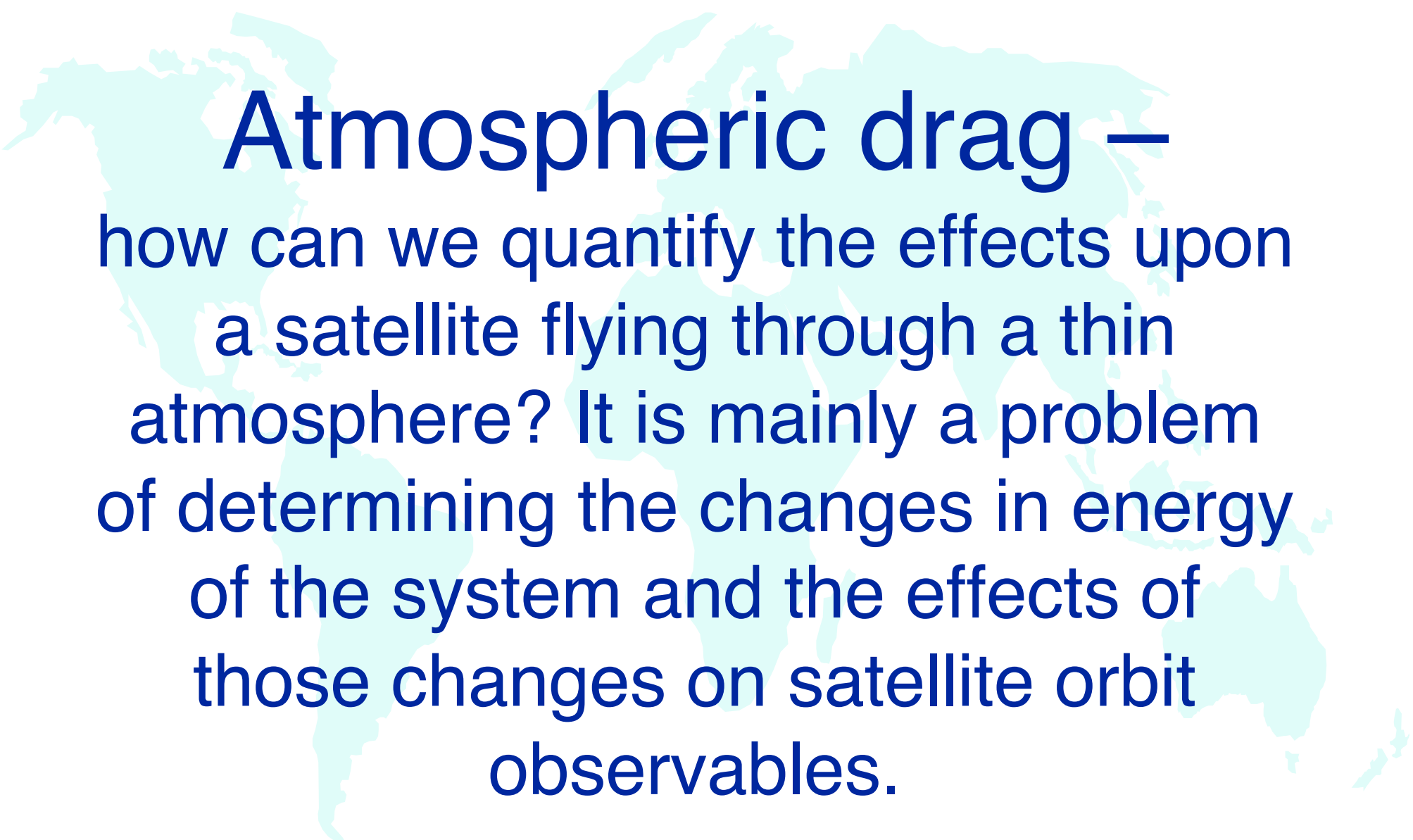
Homework

The space environment



A light blue silhouette of a world map is centered in the background of the slide.

Kinetic energy



Atmospheric drag –

how can we quantify the effects upon a satellite flying through a thin atmosphere? It is mainly a problem of determining the changes in energy of the system and the effects of those changes on satellite orbit observables.

Credit: Tobiska

Atmospheric drag

Elements of the atmospheric drag problem

Energy in an orbit

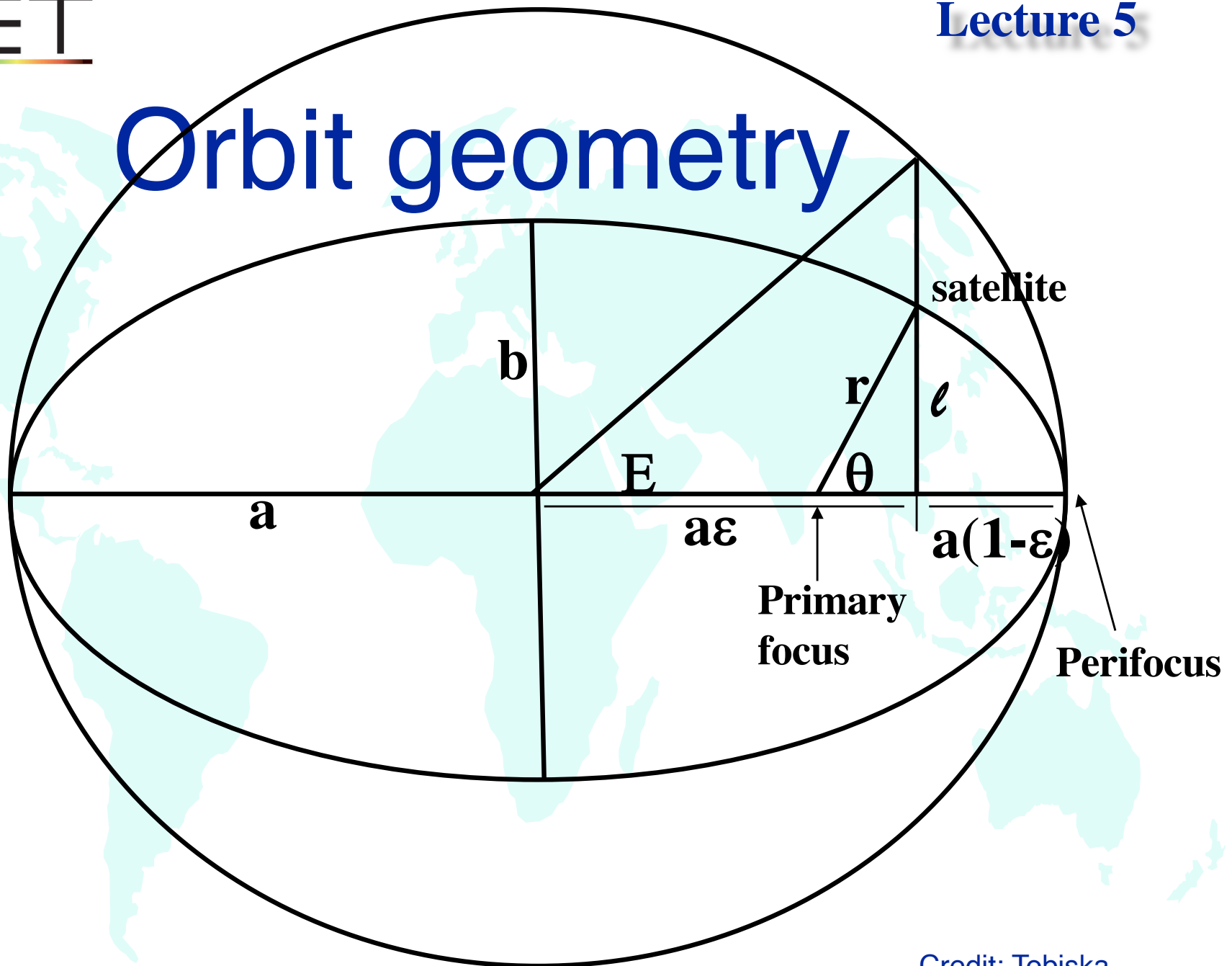
Orbit geometry

Drag force

Derivation of density from satellite observation

Example calculation

Orbit geometry



Credit: Tobiska

Energy in an orbit

Newton's 2nd Law & n-body problem

Let

$$\mu' = G(M_{\text{earth}} + m_{\text{satellite}}) \rightarrow \mu' \cong GM \quad (5-1)$$

Note that the definition of μ' used here is slightly different than that presented in Lecture 3 for a reduced mass.

Newton's 2nd Law: radial, transverse forces

$$F_r = ma_r = m(\ddot{r} - r\dot{\theta}^2) \quad (5-2)$$

$$F_\theta = ma_\theta = m(r\ddot{\theta} + 2\dot{r}\dot{\theta}) \quad (5-3)$$

Credit: Tobiska

Energy in an orbit

Law of Gravitation

and, where r is the distance from the center of the Earth

$$F_r = -\frac{GMm}{r^2} \quad (5-4)$$

Under gravitational attraction, there is no transverse force so angular momentum, h , per unit mass is conserved if

$$\frac{F_r}{m} = -\frac{\mu'}{r^2} \quad (5-5)$$

Energy in an orbit

and radial force per unit mass is written in terms of acceleration components (eq 5-2)

$$\frac{F_r}{m} = \ddot{r} - r\dot{\theta}^2 \quad (5-6)$$

therefore, by substitution with eq. 5-5

$$\ddot{r} - r\dot{\theta}^2 = -\frac{\mu'}{r^2} \quad (5-7)$$

and with no transverse force

$$F_\theta = m(r\ddot{\theta} + 2\dot{r}\dot{\theta}) = 0 \quad (5-8)$$

Energy in an orbit

then the acceleration term = 0

$$r\ddot{\theta} + 2\dot{r}\dot{\theta} = 0 \quad (5-9)$$

which can be rewritten as

$$\frac{d}{dt}(r^2\dot{\theta}) = 0 \quad (5-10)$$

and we see that

$$\int \frac{d}{dt}(r^2\dot{\theta}) = r^2\dot{\theta} = h = \text{constant} \quad (5-11)$$

where angular momentum per unit mass, h , is conserved

Credit: Tobiska

Energy in an orbit

Solving for r as a function of energy

let's arbitrarily define

$$r = \frac{1}{u} \quad (5-12)$$

and the rate change of the true anomaly

$$\dot{\theta} = hu^2 \quad (5-13)$$

with the radial velocity written as

$$\dot{r} = -\frac{1}{u^2} \frac{du}{dt} = -h \frac{du}{d\theta} \quad (5-14)$$

Credit: Tobiska

Energy in an orbit

Our objective is to combine geometry (r) and energy (h) into a solvable equation so we continue the substitutions ...

the radial acceleration is written as

$$\ddot{r} = -h \frac{d^2 u}{d\theta^2} \frac{d\theta}{dt} = -h^2 u^2 \frac{d^2 u}{d\theta^2} \quad (5-15)$$

By several substitutions we arrive at

$$\frac{d^2 u}{d\theta^2} + u = \frac{\mu'}{h^2} \quad (5-16)$$

Credit: Tobiska

Energy in an orbit

Eq. 5-16 is a 2nd order differential equation and is similar to an undamped mass-spring system with a constant forcing term, C

$$m\ddot{x} + kx = C \quad (5-17a)$$

The solution is well-known and, in our formulation, is given by

$$u = \frac{\mu'}{h^2} + C \cos(\theta - \theta_0) \quad (5-17b)$$

Credit: Tobiska

Energy in an orbit

The next task is to derive an orbit equation in which the radius is written in terms of the energy of the system

We first note that the total energy per unit mass, e , is **kinetic energy** + **potential energy** of the satellite

$$e = \frac{1}{2} v^2 - \frac{\mu'}{r} \quad (5-18)$$

Credit: Tobiska

Energy in an orbit

By substitution, energy is rewritten

$$e = \frac{1}{2} h^2 u^2 - \mu' u \quad (5-19)$$

where velocity is

$$v = r \dot{\theta} \quad (5-20)$$

and total energy per unit mass is

$$e = \frac{1}{2} h^2 C^2 - \frac{1}{2} \frac{\mu'^2}{h^2} \quad (5-21)$$

Credit: Tobiska

Energy in an orbit

C is solved in terms of energy – we let θ_0 be some constant and thus, the solution for C is

$$C = \sqrt{\frac{2e}{h^2} + \frac{\mu'^2}{h^4}} \quad (5-22)$$

If $\theta_0 = 0$ then

$$u = \frac{\mu'}{h^2} \left(1 + \sqrt{1 + \frac{2eh^2}{\mu'^2}} \cos \theta \right) \quad (5-23)$$

Credit: Tobiska

Energy in an orbit

Or by rewriting u again in terms of the radius, r , we arrive at an equation for an orbital radius in terms of total energy per unit mass

$$r = \frac{h^2 / \mu'}{1 + \sqrt{1 + \frac{2eh^2}{\mu'^2} \cos \theta}} \quad (5-24)$$

Orbit geometry

We use conic sections to get velocity

Using the properties of an ellipse

$$r = \frac{\ell}{1 + \varepsilon \cos \theta} \quad (5-25)$$

where ℓ is the semilatus rectum and ε is the eccentricity, we note for the true anomaly $\theta = 0$ and $\theta = \pi$ the equation (5-25) for periapsis and apoapsis is rewritten as

$$r_p = \frac{\ell}{1 + \varepsilon} = a(1 - \varepsilon) \quad (5-26a)$$

$$r_a = \frac{\ell}{1 - \varepsilon} = a(1 + \varepsilon) \quad (5-26b)$$

Credit: Tobiska

Orbit geometry

We also note that the semimajor axis, a , is

$$a = \frac{r_p + r_a}{2} \quad (5-27)$$

and the eccentricity, ε , and semilatus rectum are

$$\varepsilon = \frac{r_a - r_p}{r_a + r_p} = \frac{r_a - r_p}{2a} \quad (5-28)$$

$$\ell = a(1 - \varepsilon^2) \quad (5-29)$$

for

$$r = \frac{a(1 - \varepsilon^2)}{1 + \varepsilon \cos \theta} \quad (5-30)$$

Credit: Tobiska

Orbit geometry + energy

We now combine geometry and energy and write the geometrical terms (eccentricity, semilatus rectum, and semimajor axis) in terms of energy and angular momentum per unit mass

$$\varepsilon = \sqrt{1 + \frac{2eh^2}{\mu'^2}} \quad (5-31)$$

$$\ell = \frac{h^2}{\mu'} \quad (5-32)$$

$$a = \frac{\ell}{(1 - \varepsilon^2)} = \pm \frac{h^2}{\mu'(1 - \varepsilon^2)} = \mp \frac{\mu'}{2e} \quad (5-33)$$

Credit: Tobiska

Orbit geometry + energy

By substitutions in the above equations, we can finally write the orbit parameters as a function of energy if we substitute using equation (5-19)

$$e = \mp \frac{\mu'}{2a} = \frac{1}{2} v^2 - \frac{\mu'}{r} \quad (5-34)$$

$$\mp \frac{\mu'}{2a} = \frac{1}{2} v^2 - \frac{\mu'}{r} \quad (5-35)$$

... to obtain the Vis-viva integral for velocity

$$v^2 = \mu' \left(\frac{2}{r} \mp \frac{1}{a} \right) \quad (5-36)$$

Credit: Tobiska

Drag force

We now have created several tools to determine the relationship between a satellite's *orbit location* and the *energy of its motion*

We next want to know how atmospheric density changes the orbit by acting as a **resistive** force

We derive aerodynamic drag first

Credit: Tobiska

Drag force

Aerodynamic drag is defined as

$$F_D = \frac{1}{2} C_D A \rho v^2 \quad (5-37)$$

where C_D is the drag coefficient, A is the effective area of the spacecraft, ρ is the mass density of the atmosphere, and v is the velocity of the spacecraft. The acceleration due to drag for the satellite mass, m , is then

$$a_D = \frac{1}{2} C_D \frac{A}{m} \rho v^2 \quad (5-38)$$

Credit: Tobiska

Derivation of density

Using expressions for work and the rate change of work, we can write the work done **by** the atmosphere **against** the satellite

$$W = - \int_1^2 F ds \quad (5-39)$$

$$\dot{W} = -F\dot{s} = -Fv \quad (5-40)$$

$$\dot{W} = -\frac{1}{2} C_D A \rho v^3 \quad (5-41)$$

Credit: Tobiska

Derivation of density

The total energy of the system is kinetic + potential

$$E = T + V \quad (5-42)$$

and for the case of a satellite in a near circular orbit,
 $a \approx r$; if we ignore slight deviations from a circular
 orbit we can write

$$e = -\frac{\mu'}{2a} = -\frac{\mu'}{2r} \quad (5-43)$$

where the time derivative for rate change of total
 energy is

$$\frac{de}{dt} = \dot{e} = \frac{\mu' \dot{r}}{2r^2} \quad (5-44)$$

Credit: Tobiska

Derivation of density

Likewise, recalling eq. 5-5 the rate change of total energy can be written

$$\dot{E} = \frac{\mu' m \dot{r}}{2r^2} \quad (5-45)$$

and if we assume that the total change in energy of the orbit over time is equal to the work done on it by the atmospheric drag over the same time interval, then

$$\dot{W} = \dot{E} \quad (5-46)$$

Credit: Tobiska

Derivation of density

Therefore, from equation (5-46) we can derive radial velocity by assuming that work done by drag force equals the change in orbital energy

$$\dot{W} = -\frac{1}{2} C_D A \rho v^3 \quad (5-47)$$

$$\dot{E} = \frac{\mu' m \dot{r}}{2r^2} \quad (5-48)$$

to achieve

$$\dot{r} = -\frac{C_D A \rho v^3 2r^2}{2\mu' m} \quad (5-49)$$

Credit: Tobiska

Derivation of density

From Kepler's Third Law (eq 3-2) we know that the period, P , of an orbit is

$$P = \frac{2\pi r^{3/2}}{\mu'^{1/2}} \quad (5-50)$$

so the rate change of the period is just the first time derivative

$$\frac{dP}{dt} = \dot{P} = \frac{2\pi}{\mu'^{1/2}} \frac{3}{2} r^{1/2} \dot{r} \quad (5-51)$$

and simplifying for P using substitution

$$\frac{\dot{P}}{P} = \frac{3}{2} \frac{\dot{r}}{r} = -\frac{3}{2} \frac{A}{m} C_D \rho v^3 \frac{r}{\mu'} \quad (5-52)$$

Credit: Tobiska

Derivation of density

Now we eliminate terms, still assuming a circular orbit where $v_c = (\mu'/r)^{1/2}$

$$\frac{\dot{P}}{P} = -\frac{3}{2} \frac{A}{m} C_D \rho v_c \quad (5-53)$$

to get the **rate change of the period as a function of atmospheric density**

$$\dot{P} = -3\pi r \frac{A}{m} C_D \rho \quad (5-54)$$

Credit: Tobiska

Derivation of density

Alternatively, we can obtain the **density as a function of observed rate change of the orbit period**

$$\rho = - \frac{1}{3\pi r \frac{A}{m} C_D} \dot{P} \quad (5-55)$$

or get the **radius as a function of density and period change**

$$r = - \frac{1}{3\pi \rho \frac{A}{m} C_D} \dot{P} \quad (5-56)$$

Credit: Tobiska

Example calculation using this useful tool

You are tracking a high asset target by radar and must confirm target acquisition a week from today.

There have been several large active regions on the Sun and, over the next week, the Sun is expected to continue to be active at high solar EUV irradiance levels, thus causing added drag.

Given the number of targets you are tracking and the possibility of confusing them when they appear on your radar, you want to know when to expect that your target will appear.

Credit: Tobiska

Example calculation

The current altitude of the target is 400 km in a nearly circular orbit and the ballistic coefficient, β , which is often used if the satellite mass, area, and drag coefficient are not individually known, has been observationally determined to be $\beta = 16.67$ where

$$\beta = \frac{m}{C_D A} \quad (5-57)$$

We expect high solar activity and, at 400 km, atomic oxygen is the dominant species so we use only that constituent to simplify the problem.

Credit: Tobiska

Example calculation

We know that solar EUV heats atomic oxygen and its densities will increase; this will lead to a change in the orbit altitude and period by the atmosphere's work against the satellite. Increased density creates more “work” for satellite (removes energy) so $\Delta P = P_2 - P_1$ will be negative and a smaller (shorter) period will lead to a lower satellite altitude.

We can use the rate change of the period (dP/dt from equation 5-54) to find the time delay induced by atmospheric drag between today and a week from today.

$$\dot{P} = -3\pi r \frac{A}{m} C_D \rho$$

Credit: Tobiska

Example calculation

Solving for the rate change of period, we want to find ρ and recall that $\rho = nm$. For high solar activity, $n_{[O]} \approx 4E8 \text{ atoms cm}^{-3}$ from Lecture 4. Therefore,

$$\rho = nm = (4 \times 10^8) \times (2.65685 \times 10^{-26}) = 1.06274 \times 10^{-17}$$

in units of kg cm^{-3} or $1.06274E-11 \text{ kg m}^{-3}$.

We can now calculate $\Delta P/\Delta t$.

Credit: Tobiska

Example calculation

Since $1/\beta = C_D(A/m)$ then we obtain by substitution the following result

$$\begin{aligned}\dot{P} &= \frac{\Delta P}{\Delta t} = -3\pi((6378.14 + 400) \times 10^3) \times \\ &\quad \frac{1}{16.67} \times (1.06274 \times 10^{-11}) \\ &= -40.73 \times 10^{-6} (\text{dimensionless})\end{aligned}$$

$$\Delta P = -40.73 \times 10^{-6} \Delta t$$

Credit: Tobiska

Example calculation

We can now determine the **decrease** in the orbit period (shorter period) a week from today and it is

$$\Delta P = -40.73 \times 10^{-6} \left(86400 \frac{\text{seconds}}{\text{day}} \right) \left(7 \frac{\text{days}}{\text{week}} \right)$$

$$\Delta P = -24.63\text{s where } \Delta P = P_2 - P_1$$

Therefore, we expect about a ~25 second **earlier** observation of the target a week from today due to atmospheric drag driven by solar activity which lowers the orbit and **decreases** the period (makes it shorter). We note that P_2 is less than P_1 which gives a negative ΔP while t_2 is greater than t_1 for a positive Δt .

Orbit propagators will give a more accurate solution if they use a good atmosphere but this first order solution works for short time intervals or long-term averages in nearly circular orbits.

Credit: Tobiska

e-folding

- ◆ e-folding distance is the distance of one scale height where density falls-off by e^{-1}
- ◆ It is a quick method of calculating atmospheric densities that are in nearby altitude layers (within a few e-folding distances); simply multiply the reference altitude density by its proper e-folding distance
- ◆ Example: $h_2 = 500$ km, $h_{\text{ref}} = 400$ km, $\Delta h = 100$ km; if scale height H at the h_{ref} altitude = 35 km then $100/35 = 2.86$ scale heights difference at h_2 . If density at ref altitude (400 km) = $7\text{E-}12$ kg m⁻³ then density at 500 km would be approximately $(7\text{E-}12) \cdot e^{-2.86} = 4\text{E-}13$ kg m⁻³

Credit: Tobiska

A light blue silhouette of a world map is centered in the background of the slide.

BREAK

A light blue world map is centered in the background of the slide, showing the outlines of the continents.

Attitude perturbations

Perturbing forces

Perturbing forces on a spacecraft are important for missions requiring high precision pointing and accurate attitude knowledge

Solar radiation pressure - large area, light mass spacecraft are especially susceptible

Relativistic effects - become noticeable when precision of 1 part in 10^8 or greater are important

Planetary resonances - the solar system is full of orbital resonances

Credit: Tobiska

Solar radiation pressure

Electromagnetic radiation can induce energy, momentum, and angular momentum changes

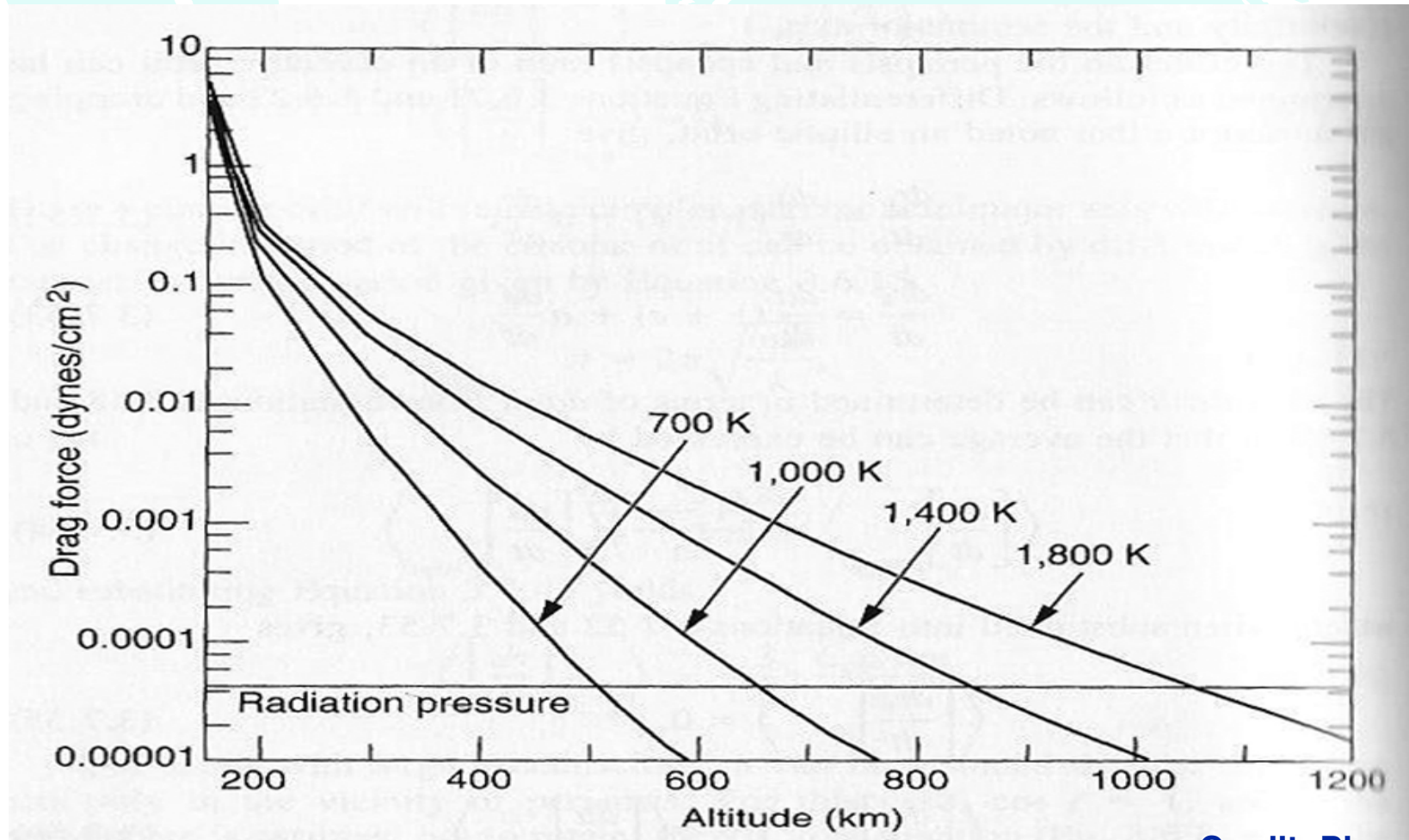
Eclipses are noticeable for Solar Radiation Pressure (SRP) changes

Daily to long-term changes in solar irradiance cause changes in pressure

Torques are induced on a spacecraft due to SRP

SRP becomes dominant force over atmospheric drag starting above 1000 km

Solar radiation pressure



Credit: Pisacane

Other space environment effects

Kinetic energy

Sputtering

Chemical energy

Atomic oxygen erosion, UV degradation, spacecraft glow

Thermal

Temperature control

Particulate

Contamination

Sputtering

Neutral molecules and atoms impact the spacecraft surfaces

Chemical bonds are severed with surface atoms and their neighbors

Chemical bond energy must be less than impact energy

Atomic oxygen erosion

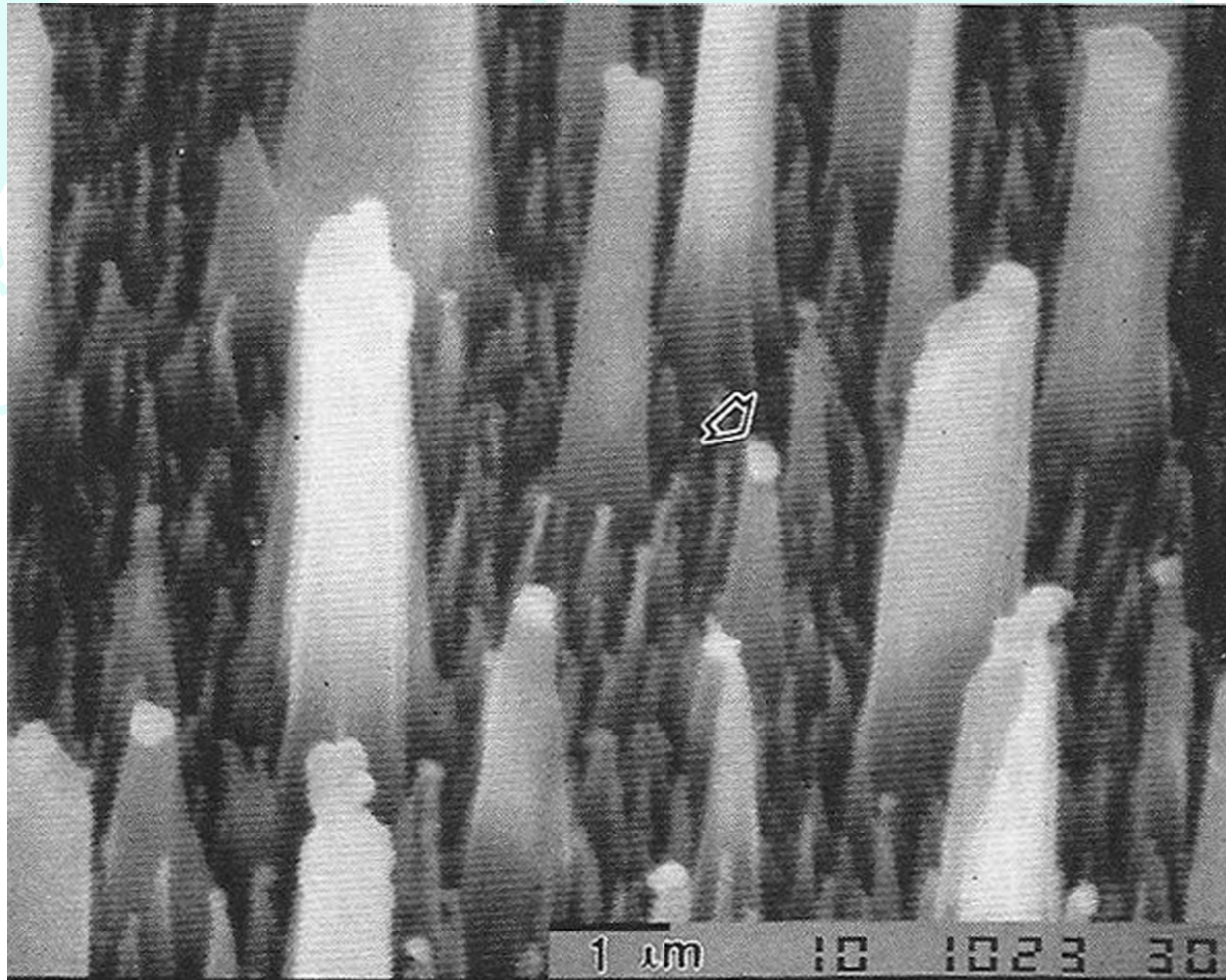
Atomic oxygen, AO, is highly reactive

Causes oxidation (oxide formation)
or erosion

Materials must be considered for
their reaction efficiency

Different materials oxidize at different
rates

Atomic oxygen erosion



UV degradation

UV degradation is the photodissociation of molecular bonds by solar UV and EUV irradiances

Many materials degrade when exposed to UV irradiances and the visual effect is a darkening of the material

Sometimes materials “recover” when exposed to oxygen under high pressure (e.g., beta cloth when it is returned to the ground)

Credit: Tobiska

Spacecraft glow

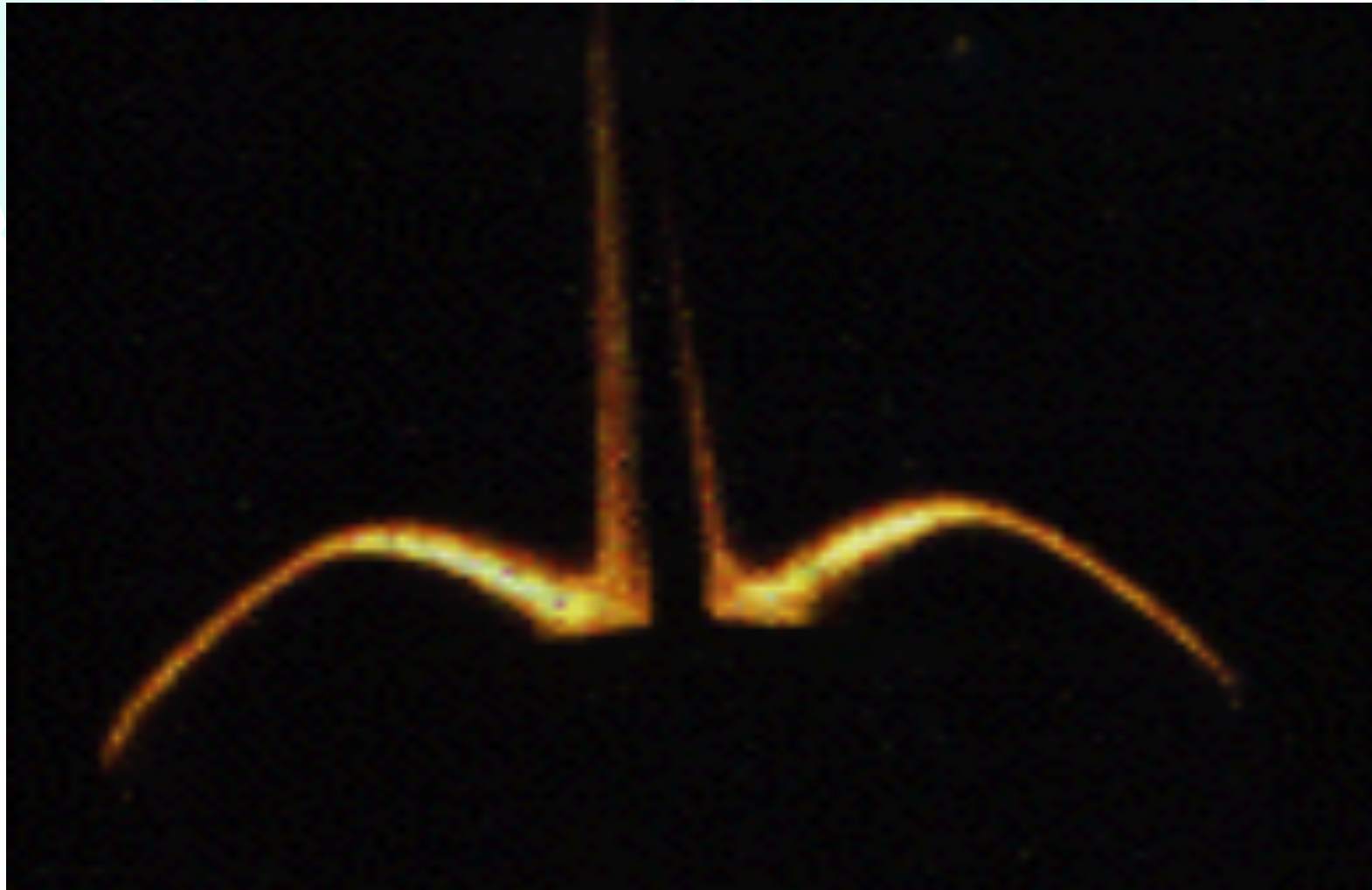
Spacecraft glow is present on or near most LEO satellites

The ambient gas atoms and molecules may be excited to higher electronic, vibrational or rotational energy states and re-emit photons of light

Excitation processes include at least kinetic (ram) and chemical (thruster exhaust)

Credit: Tobiska

Spacecraft glow



Temperature control

Most spacecraft components work best near room temperature (0-25° C)

All materials either absorb or reflect heat, including in the form of solar photons

Internal spacecraft components are another heat source - must be dissipated

Where possible, photons that cause heating are *reflected* and internal heat buildup is *radiated*

Credit: Tobiska

Particulate contamination

A material's ability to absorb solar heat will affect its contamination probability by enabling surface molecules to bind with outgassed contaminants

Particles, either from the space environment or from pre-launch, can adhere to surfaces, absorb or reflect light, and are a contaminant source

A light blue world map is centered in the background of the slide.

Standards, Guidelines, and Models

Atmospheric density

**AIAA G-003C-2010 (see <http://spacewx.com>
Standards link for most recent edition)**

Title: Guide to Reference and Standard Atmosphere
Models

Similar to ISO 11225

Status: AIAA/ANSI published

Descriptions of models including

- Model content

- Model uncertainties and limitations

- Basis of the model

- Publication references

- Dates of development, authors and sponsors

- Model codes and sources

Credit: Tobiska

Atmospheric density

AIAA G-003C-2010 models (partial list)

Global models: CIRA 1986; ISO 1982; GRAM-99; US Standard Atm 1976; IRI 2007 (ISO 16457)

Regional models: Int'l Tropical Ref.; So. Hemisphere middle atmosphere; China Nat'l Standard Atm

Middle Atmosphere models: AFGL constituent profiles & extreme climates; CIRA 1993 ext.

Thermosphere models: Jacchia 70, 71, 77; NRLMSISE-00; HWM; HASDM; MET 2007; JB2006; JB2008; DDCM (Russia); DTM-2000 (France)

Range models: Range Ref Atm 2001

Planetary models: Mars, Neptune, Titan GRAM; VIRA 1986, Mars Climate Database

Credit: Tobiska

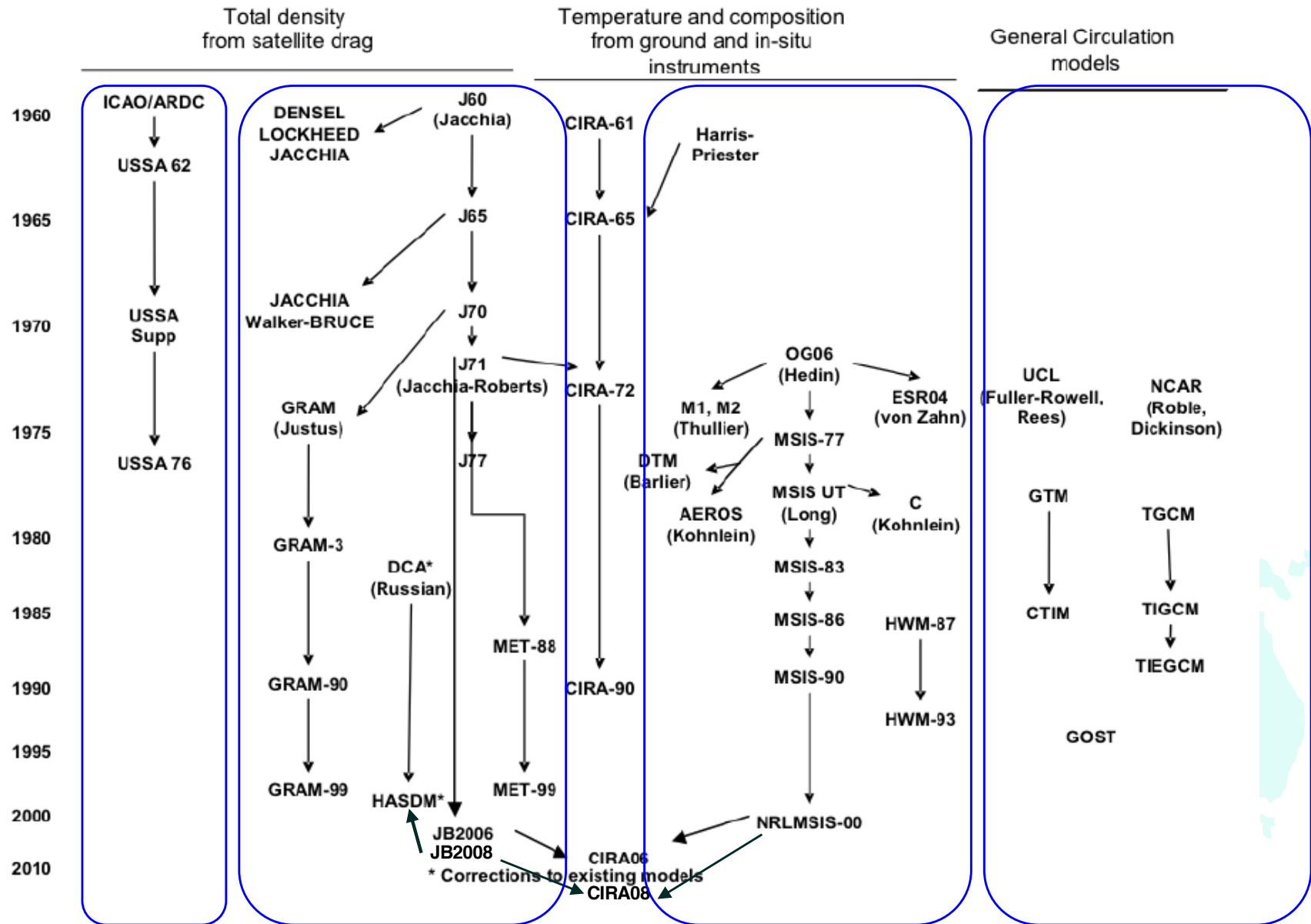
Atmospheric density

ISO 14222 Earth atmosphere density (based on CIRA08)

Status: published by ISO TC20/SC14/WG4, coincident with CIRA

- 3 primary density/composition models: JB2008, NRLMSISE-00, and GRAM-2010 developed by AFSPC, NRL, and MSFC, respectively,
- a wind Model based on the new HWM07;
- indices describing energy and momentum inputs to the atmosphere from solar, geomagnetic, dynamic and advective sources;
- a model of the minor (metal) species distribution in the mesosphere and lower thermosphere;
- a summary of physics-based and data assimilative models;
- error analysis, model guidelines and limitations;
- appendices including data output examples and reference atmospheres;
- In CIRA (<http://spaceweather.usu.edu/htm/cira>) there will be additional chapter devoted to issues in-progress including
 - drag coefficients,
 - trends such as thermospheric cooling

Credit: Tobiska



Jacchia 1971 (CIRA 1972)

Basis for MET v2, HASDM, JB2006, JB2008

All 4 have been modified from the original Jacchia version

Provides modeled densities

Between 25-75 km

Between 75-120 km

Above 120 km

Mean reference atmosphere

Computer source code available

Jacchia 1971 (CIRA 1972)

Main elements of Jacchia model

Thermospheric and exospheric temperatures are

$$T(z) = T_{\infty} - (T_{\infty} - T_0)e^{-\sigma(z-z_0)} \quad (4-29)$$

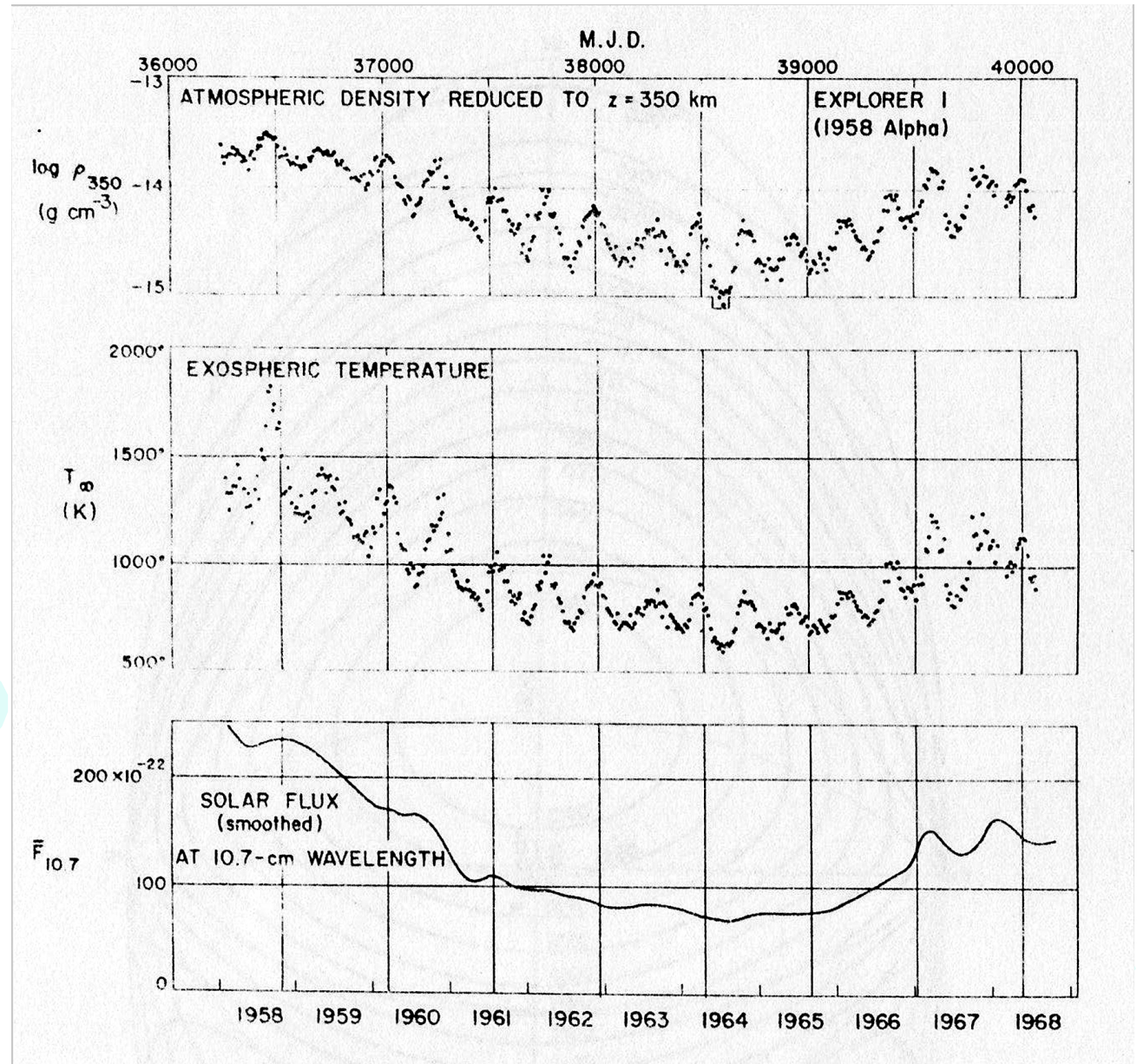
$$T_{\infty} = 379 + 3.24\overline{F_{10.7}} + 1.3(\overline{F_{10.7}} - \overline{F_{10.7}}) \quad (4-31)$$

Diffusive equilibrium composition (N_2 , O, O_2 , Ar, He)

Variations (solar cycle, diurnal, geomagnetic, semi-annual, seasonal latitudinal in lower thermosphere, seasonal latitudinal with He, gravity waves)

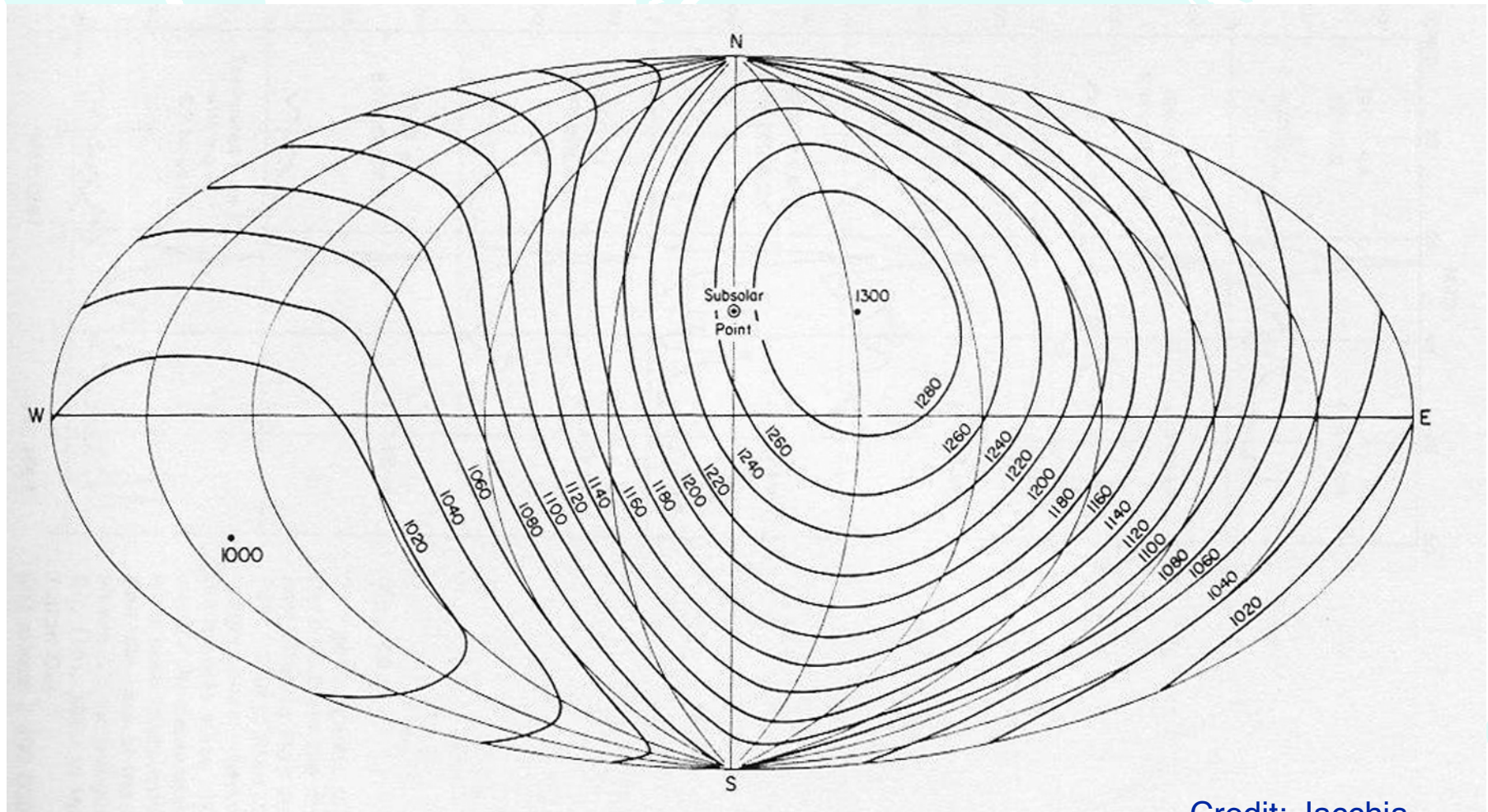
Credit: Tobiska

Jacchia 1971 (CIRA 1972)



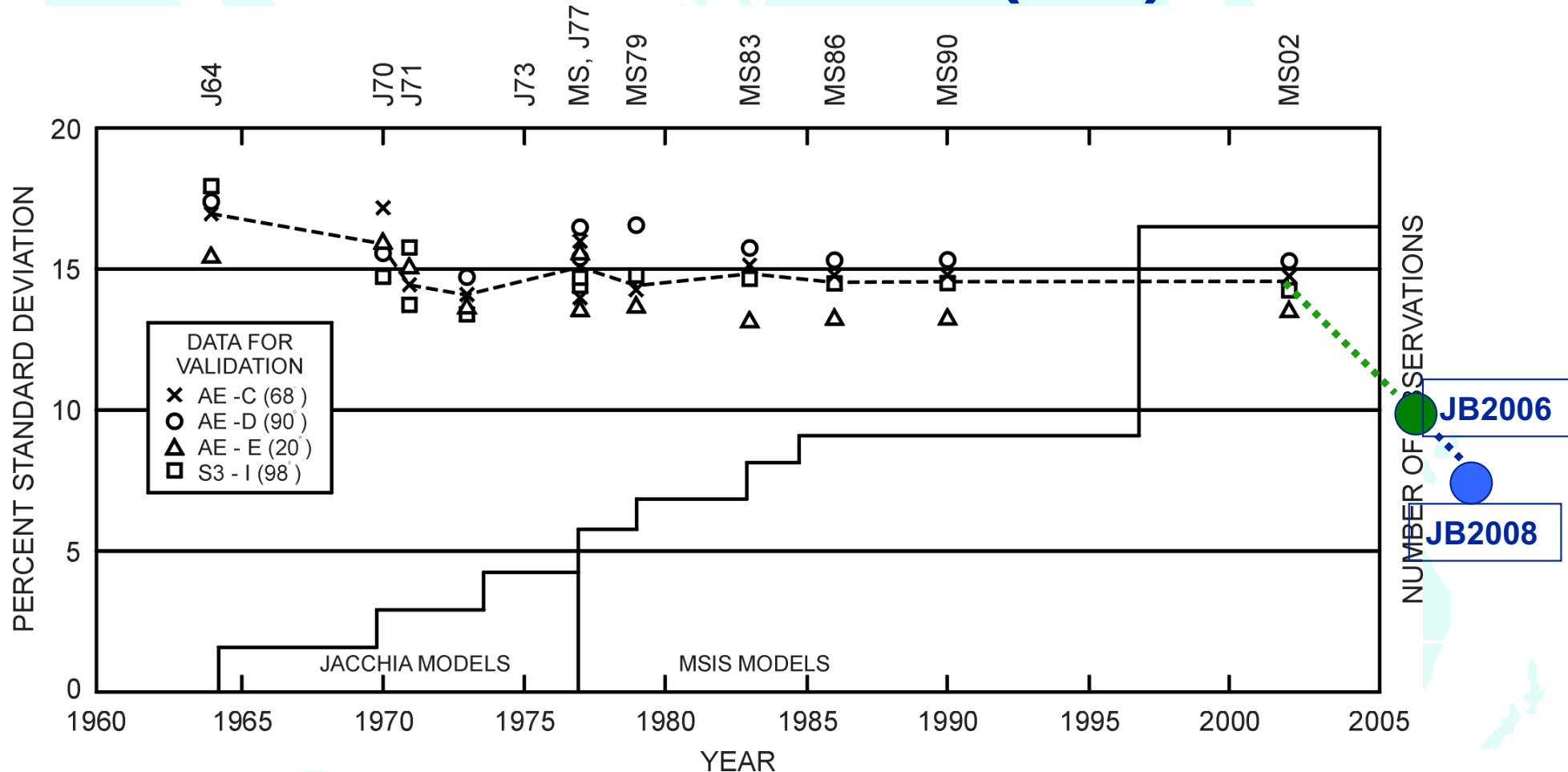
Credit: Jacchia

Jacchia 1971 (CIRA 1972)



Credit: Jacchia

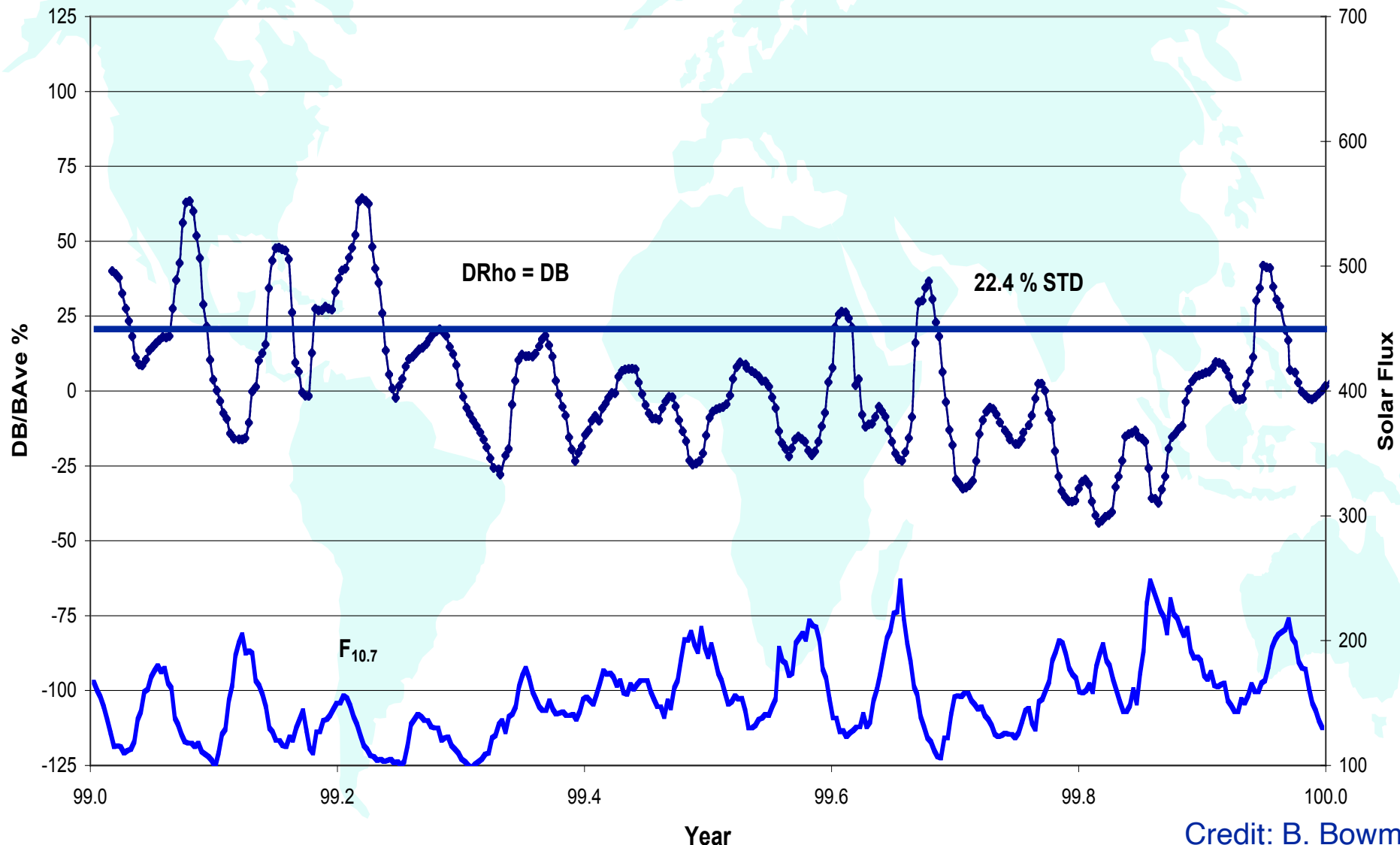
Historical Density Model Errors at 350 km ($1-\sigma$)



Credit: F. Marcos

J71 1999 Unmodeled ρ Error

00011 Vanguard 2 Sphere - DB/Bave Values - 560 km



Jacchia-Bowman 2008 thermospheric density model

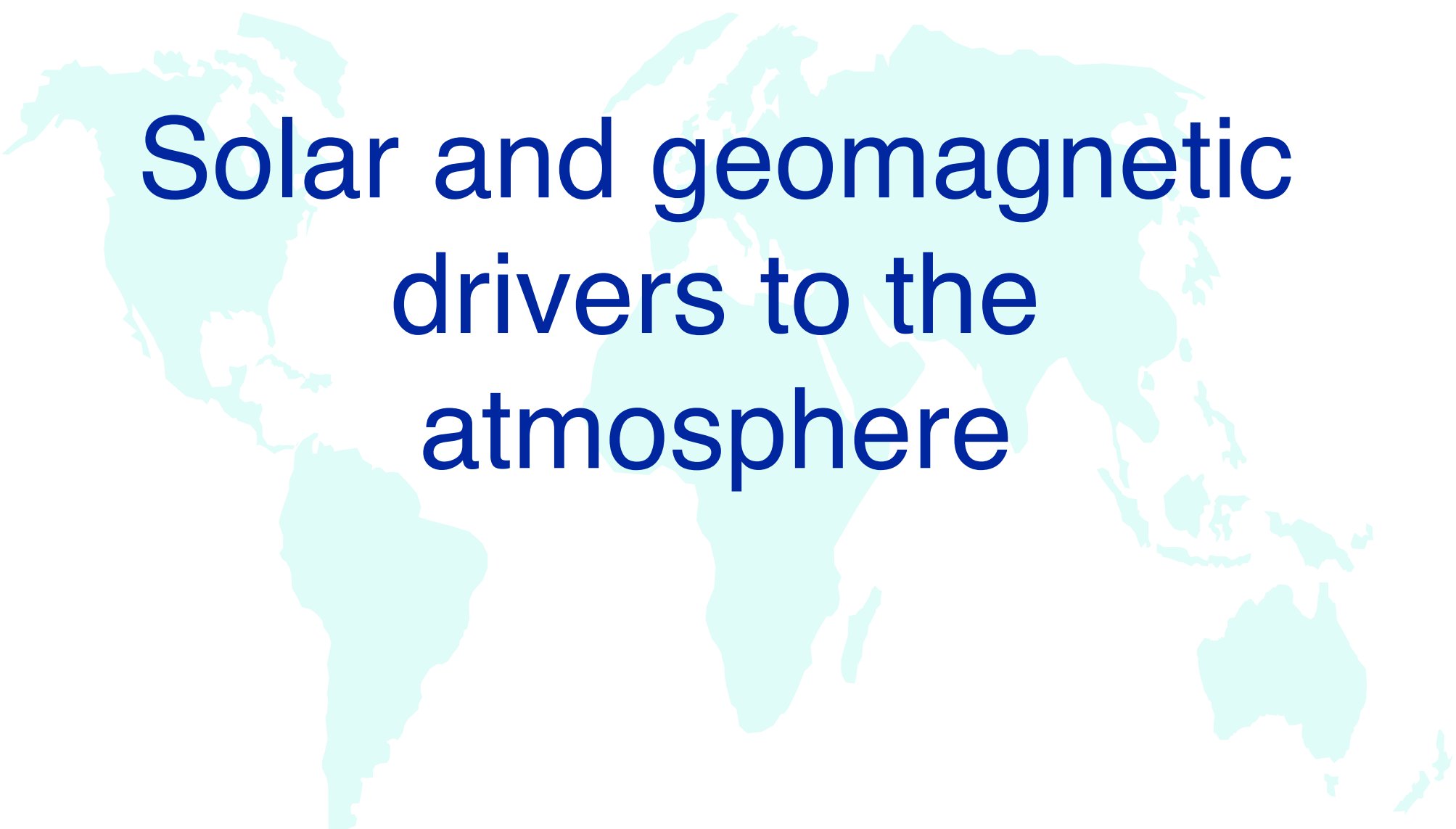
- Motivation: significantly reduce 1- σ error
- Improvements
 - 1) uses the CIRA72 (Jacchia 71) model diffusion equations
 - 2) new solar indices in the extreme and far ultraviolet wavelengths
 - 3) new exospheric temperature and semiannual density equations
 - 4) temperature correction equations for diurnal and latitudinal effects
 - 5) density correction factors at high altitude (1500- 4000 km)
 - 6) Dst index used for high latitude heating modeling
- Bowman *et al.*, AIAA-2008-6438_JB2008_Model.pdf (see JB2008 link <http://sol.spacenvironment.net/~JB2008/>)

Credit: Tobiska

Jacchia-Bowman 2008

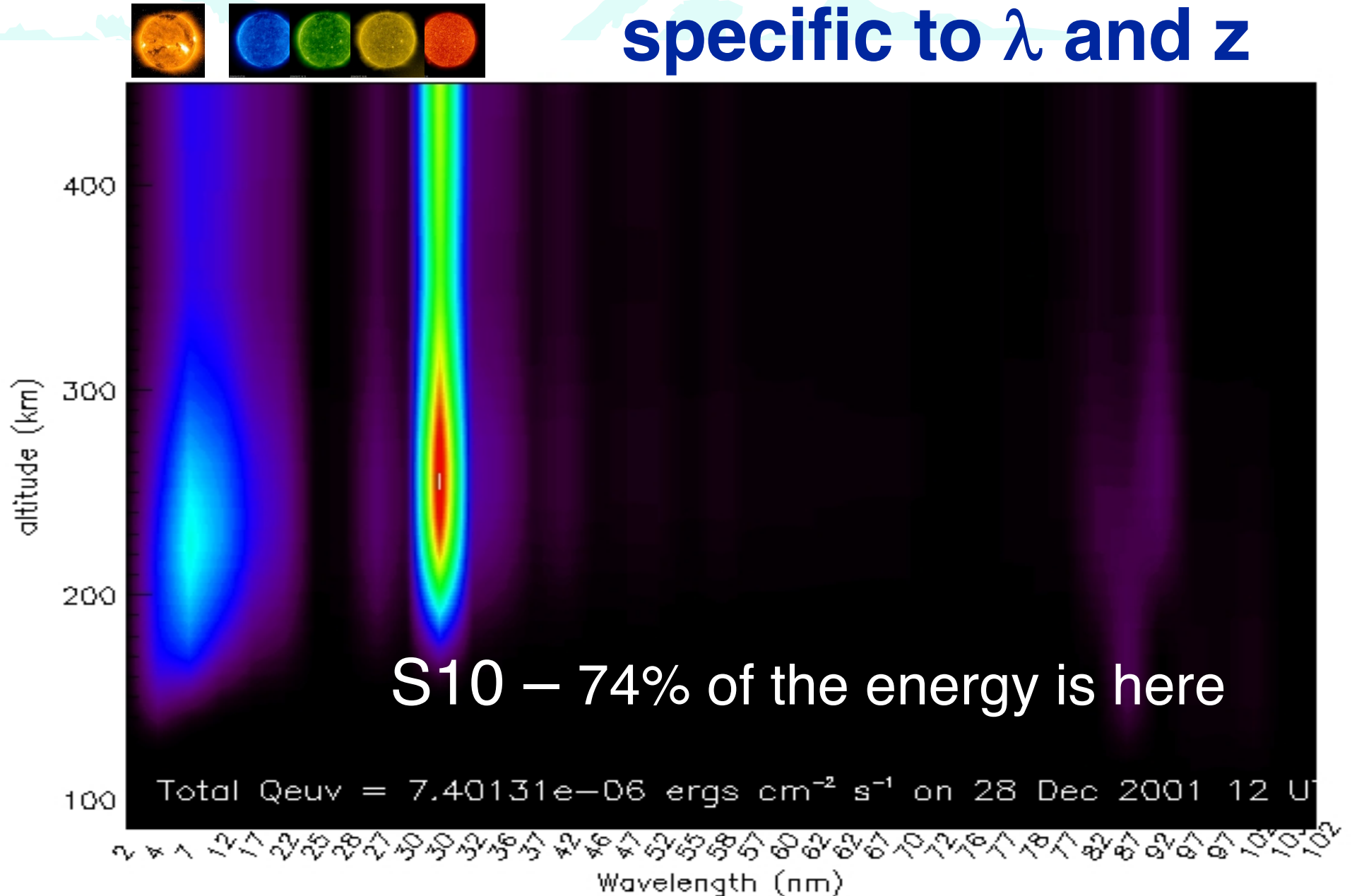
- JB2008 is validated through comparisons of accurate daily density drag data that are previously computed for numerous satellites
- For the 400 km altitude, the Jacchia 1971 18% standard deviation is reduced to 12% during periods of low geomagnetic storm activity

Credit: Tobiska

A light blue silhouette of a world map serves as the background for the title text.

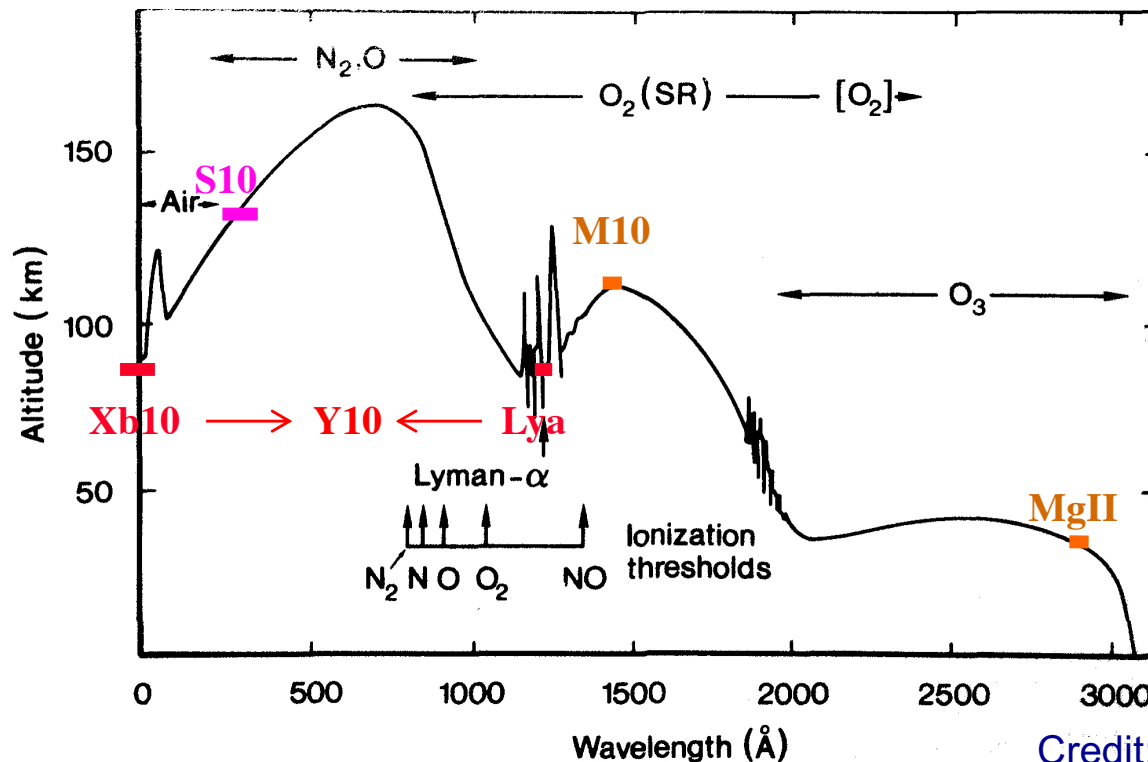
Solar and geomagnetic drivers to the atmosphere

Solar EUV heating is specific to λ and z



Motivation for solar indices ... capture photoabsorption, including SRC in FUV, for observation-based indices

Altitude of unit optical depth for photoabsorption



Credit: M.H. Rees

JB2008 Thermosphere Overview – Ops

Daily operational indices selected

- JB2008 additionally uses 81-day center smoothed indices

Index or proxy	Observing facility	Instrument	Observation time frame	Measurement cadence	Measurement latency	Operational availability
F _{10.7}	Penticton ground observatory	Radio telescope	1947-2013	3 times/day	Up to 24 hours	yes
S _{10.7}	SOHO, GOES	SEM, EUVS	1996-2013	15 seconds	Up to 24 hours	(a)
M _{10.7}	NOAA-16, 17, 18, SORCE, ERS-2	SBUV, SOLSTICE, GOME	1991-2013	2 times/day	Up to 24 hours	yes (c)
Y _{10.7}	GOES-12, UARS, SORCE, TIMED	XRS, SOLSTICE (2), SEE	1991-2013	1 minute, 16 times/day	Up to 10 minutes, up to 48 hours	(b)

(a) SOHO/SEM is a NASA research instrument but provides daily irradiances on an operational cadence; GOES 13 EUVS B channel makes measurements in the same bandpass as SOHO SEM.

(b) GOES XRS is a NOAA operational instrument whereas TIMED/SEE and SORCE/SOLSTICE are NASA research instruments providing daily irradiances on an operational measurement cadence.

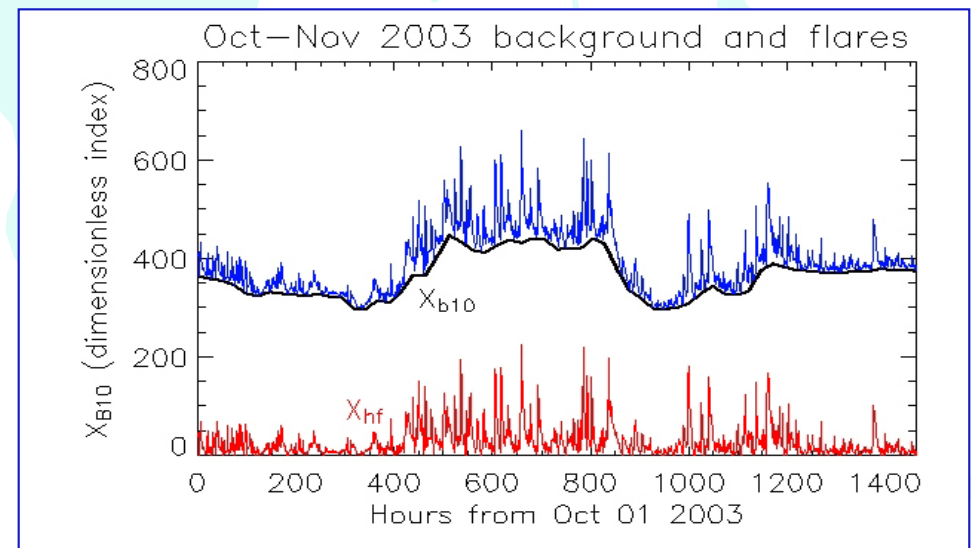
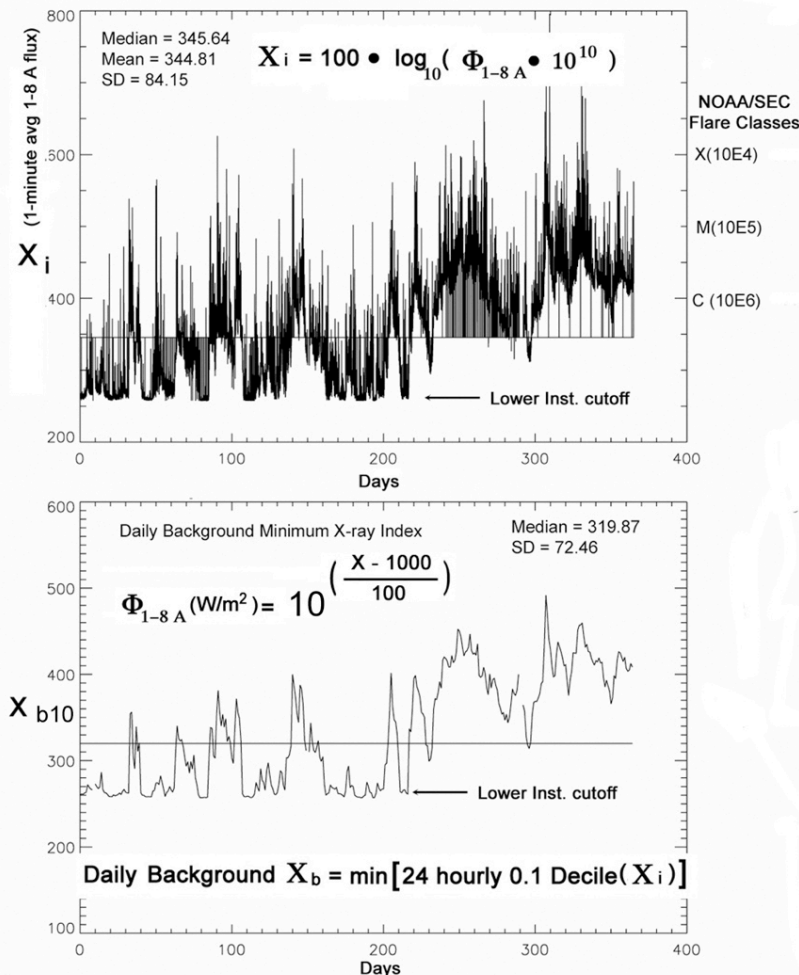
(c) UARS/SOLSTICE stopped in 2005; SORCE/SOLSTICE intends to provide data for several years. Credit: ISO 14222



X-ray background (X_{b10}) and flare (X_{hf}) indices

Lecture 5

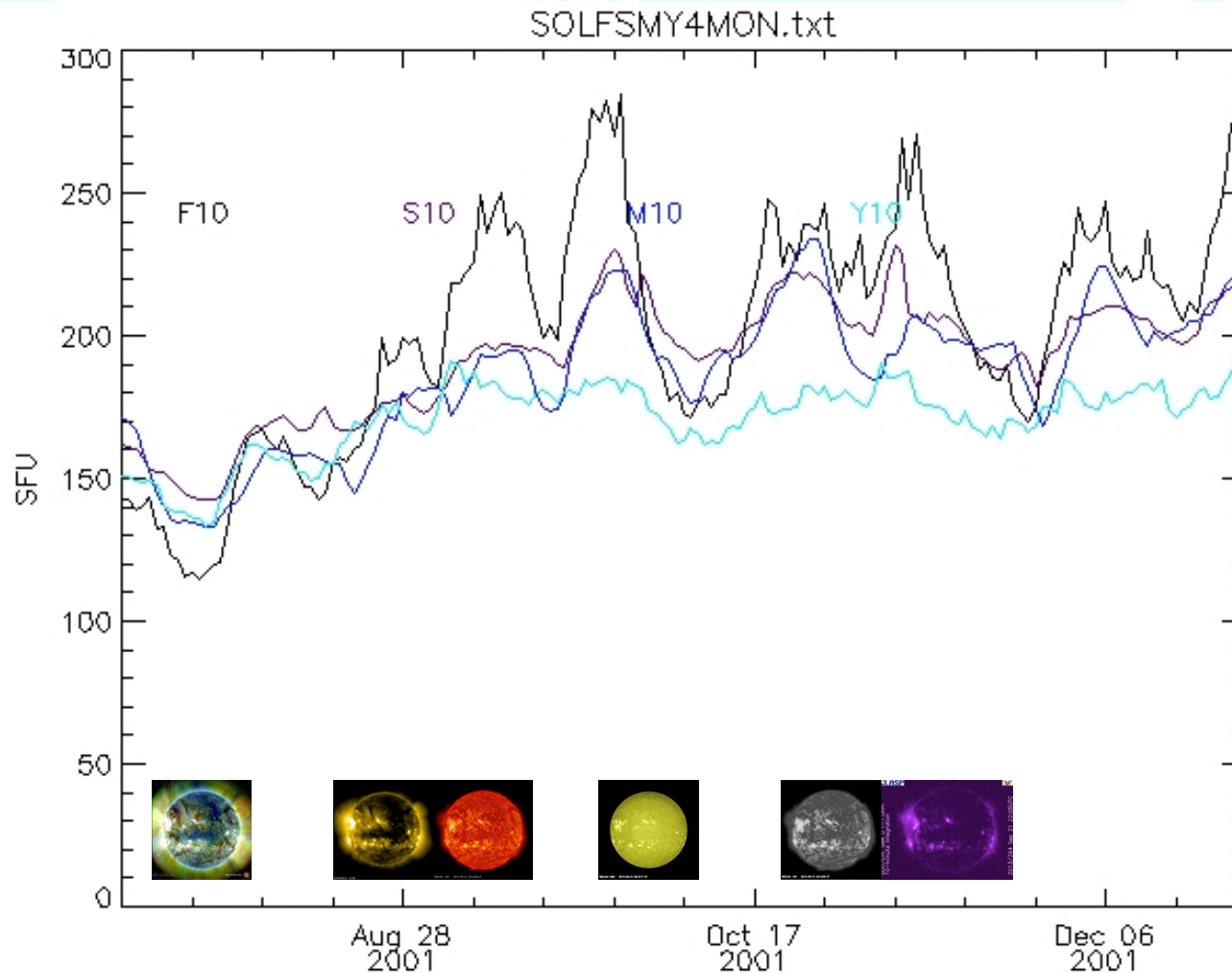
- X_{b10} is an index to the daily background X-ray flux, based on the minimum hourly value for that day (which is calculated from the lower decile of the 1-minute X-Ray flux in that hour)
- X_{hf} is the median flux within an hour above X_{b10}
- X_{b10} is used along with Lyman- α in creating the Y10 index while X_{hf} is used in the Anemomilos Dst algorithm to create the derived velocity of solar ejecta



X_{b10} and X_{hf} shown for October-November 2003.

JB2008 Solar Indices/Proxies example

Daily operational indices selection criteria



Solar models and data

IS 21348:2007

Title: Process for determining solar irradiances

Heritage: developed by ISO TC20/SC14/WG4

Provides process to determining solar irradiances

Product type definition - measurements, reference spectra, empirical models, physics-based models, proxies

Solar spectral categories - TSI and gamma rays through radio wavelengths

Compliance criteria - reporting, documenting, publishing, archiving, certification

Models (e.g. SIP) and data provided separately

Credit: Tobiska

Solar EUV models & data

Solar measurements

rockets, AE-E, SOHO, TIMED*, SDO*

Solar models

SERF1 (EUV81), Nusinov, SERF2, EUV91,
EUV97, NRLEUV, HEUVAC, SRPM,
SIP*(SOLAR2000/SOLARFLARE/VUV2002)

Solar proxies

F10.7*, E10.7*, S10.7*, M10.7*, Y10.7*, Rz

*IS 21348:2007 compliant

Geomagnetic proxies

Ap / Kp

Kp is the planetary index for geomagnetic activity

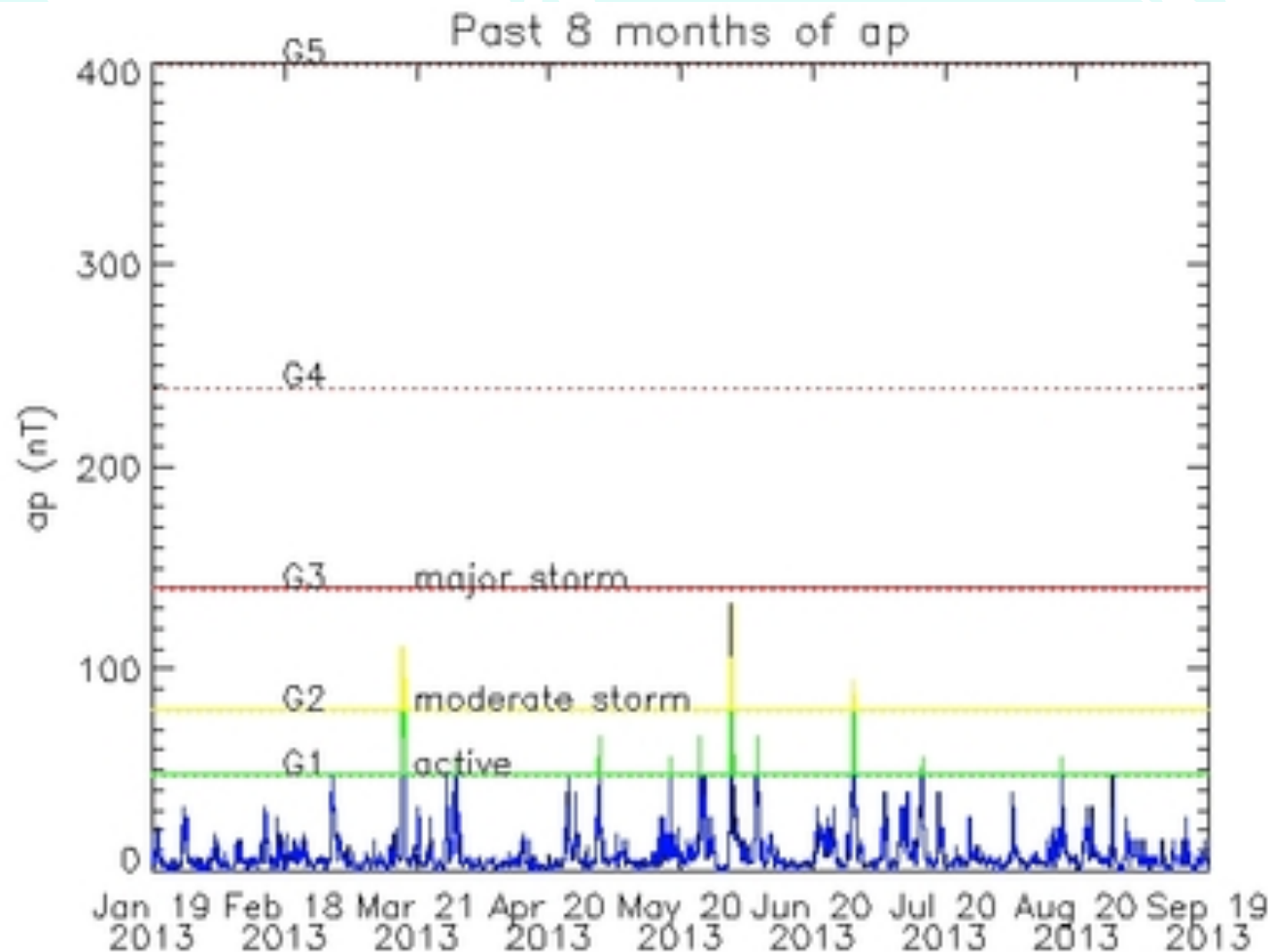
Calculated as a weighted average of K-indices from a network of geomagnetic observatories

Observatories do not report their data in real-time, necessary for an operations center to make the best estimate of this index based on available data

Ap invented to create daily average values from eight 3-hourly ranges

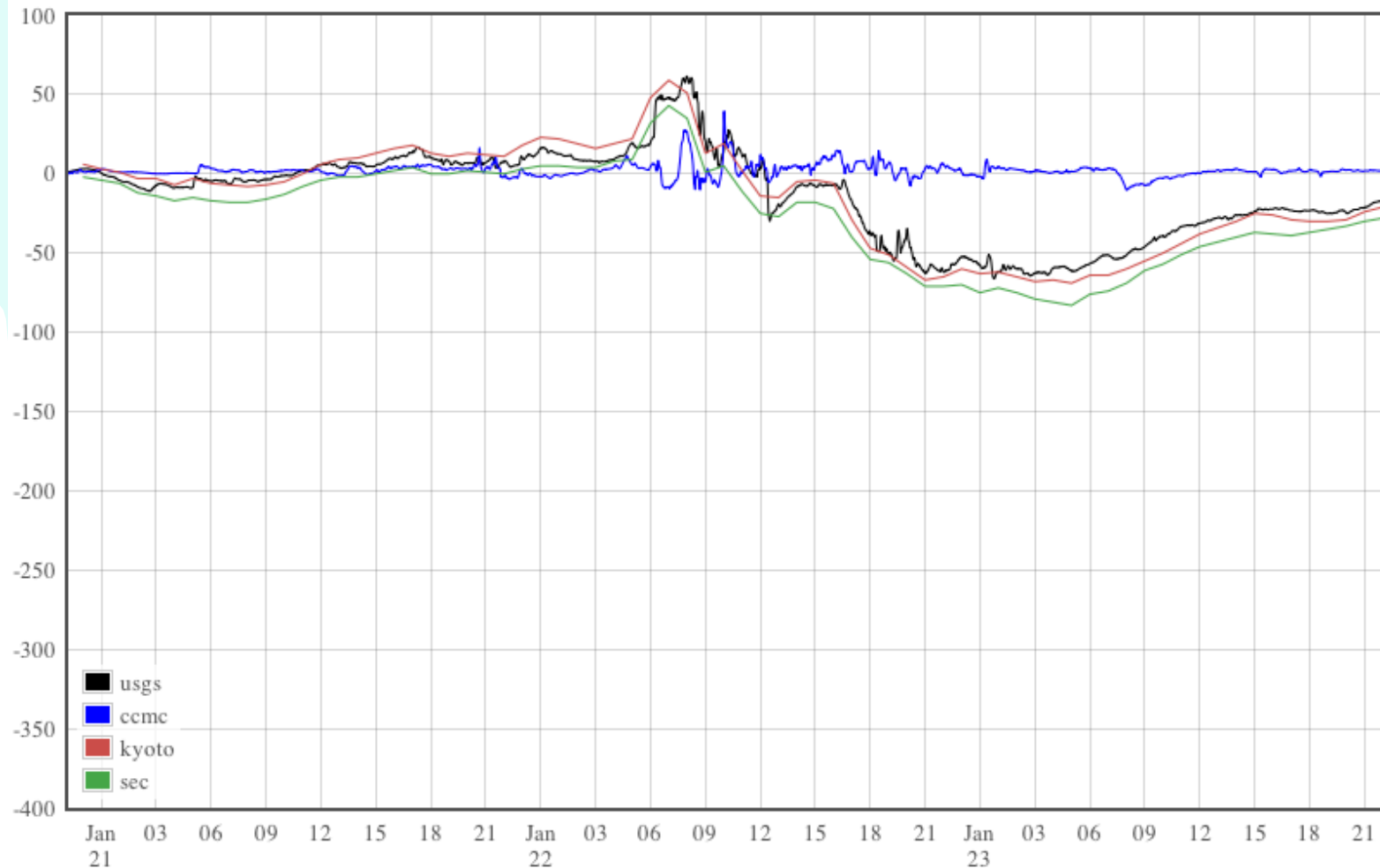
K	A	NOAA G
0	0	
1	3	
2	7	
3	15	
4	27	
5	48	G1
6	80	G2
7	140	G3
8	240	G4
9	400	G5

Geomagnetic proxies



Credit: SET

Real-time Dst used by SET

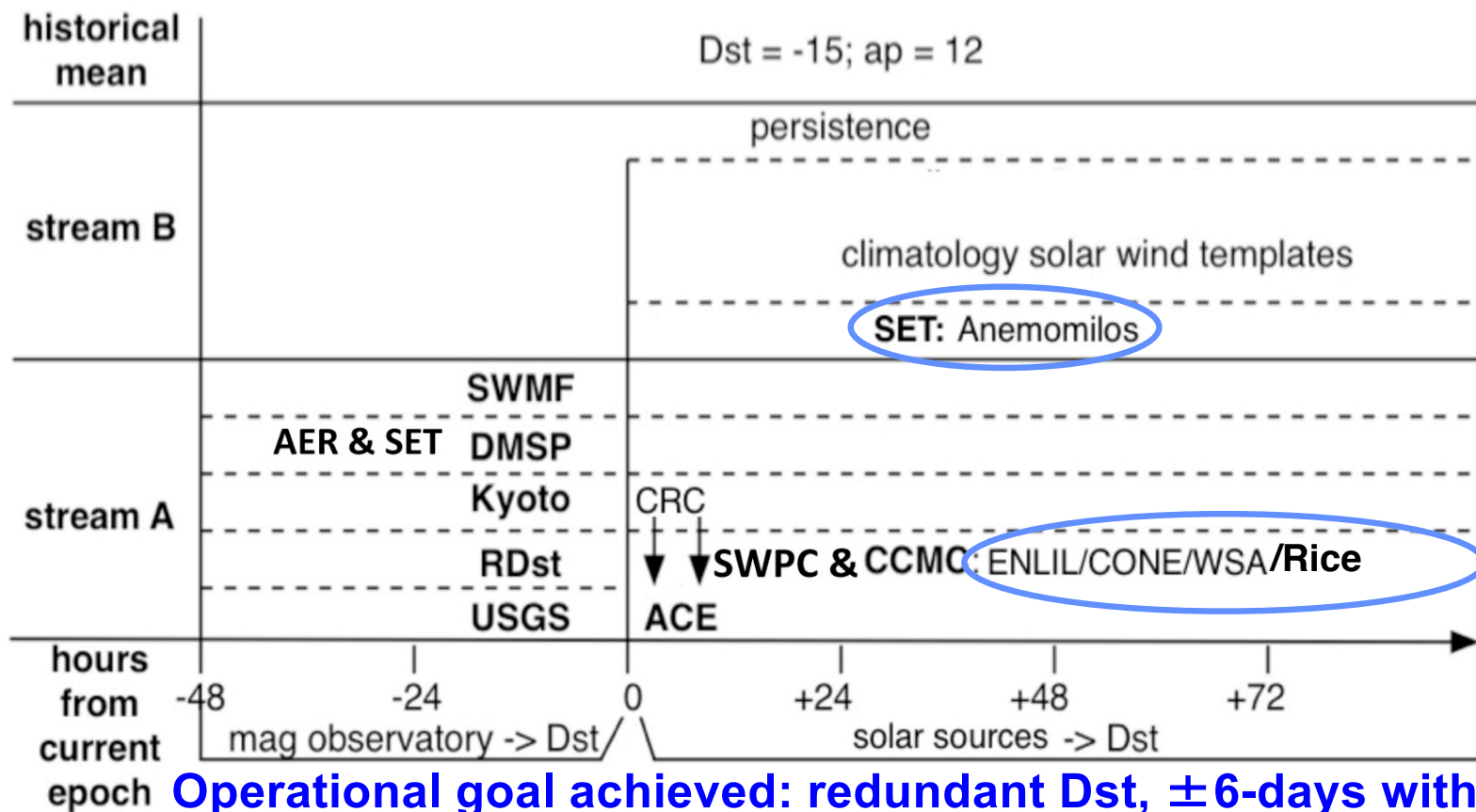


<< Date: Fri, 20 Jan 2012 22:12 >>

Credit: SET

JB2008 Thermosphere – Geomagnetic Storm Drivers

Hierarchy of definitive, real-time, and forecast Dst redundancy

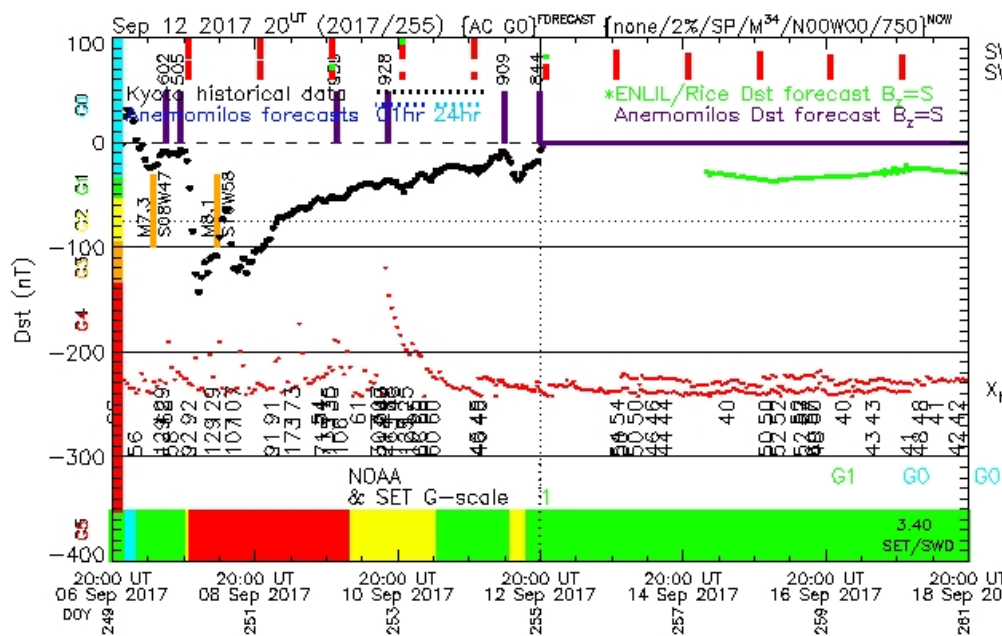


Operational goal achieved: redundant Dst, ± 6 -days with 1-hour granularity and 1-hour latency

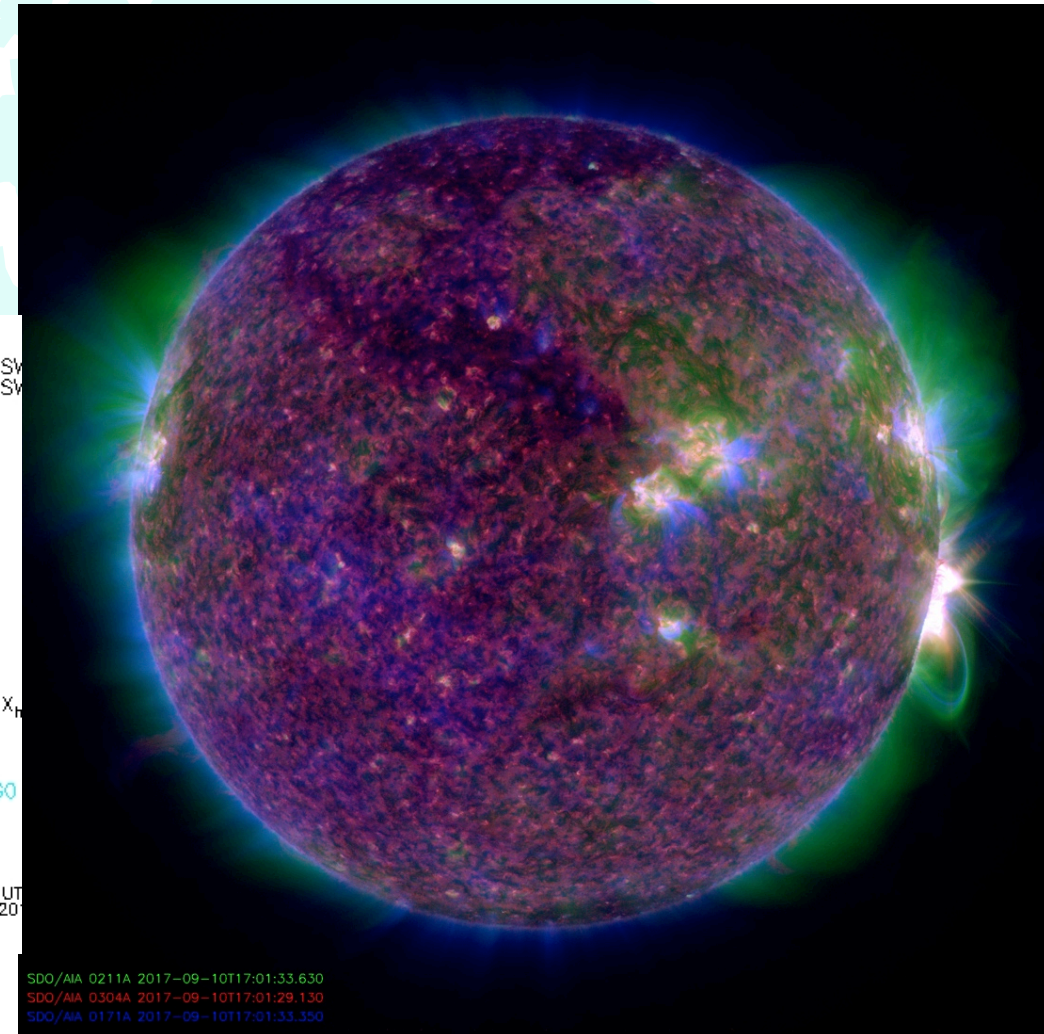
Credit: SET

Geomagnetic storms during solar cycle decline

- ◆ Sep 10, 2017 large CME misses Earth



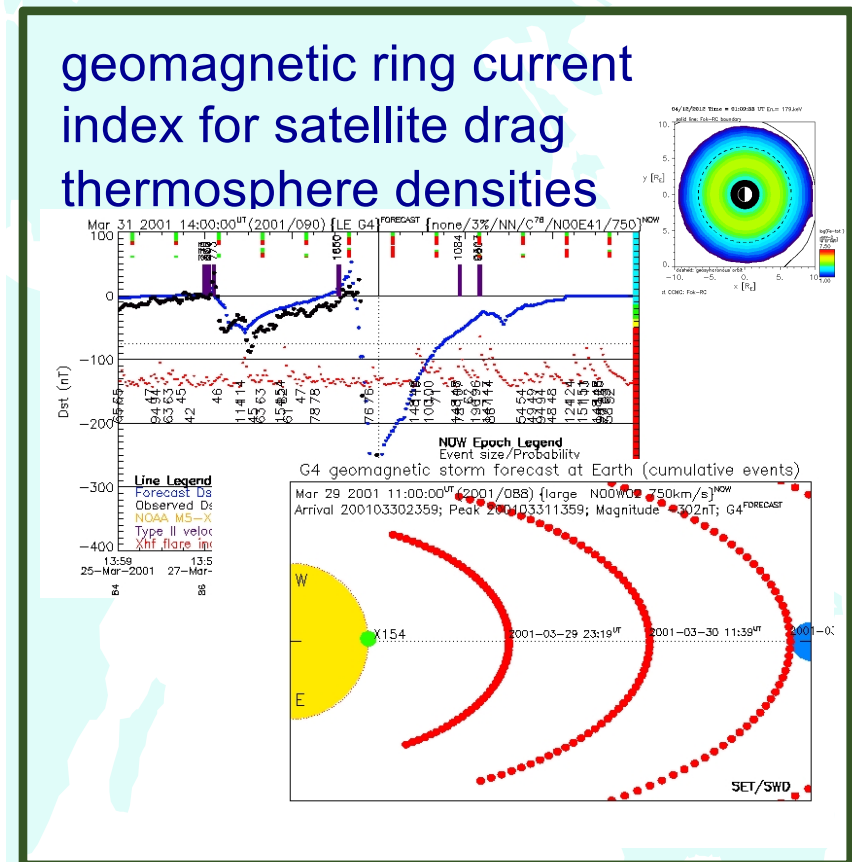
http://sol.spacenvironment.net/~sam_ops/index.html?



Anemomilos Forecast Dst

Anemomilos

- The Greek word for “windmill”
- 6-day forecast of hourly Dst with 1-hour latency
- It is a data-driven deterministic algorithm using solar observables to identify geoeffective events

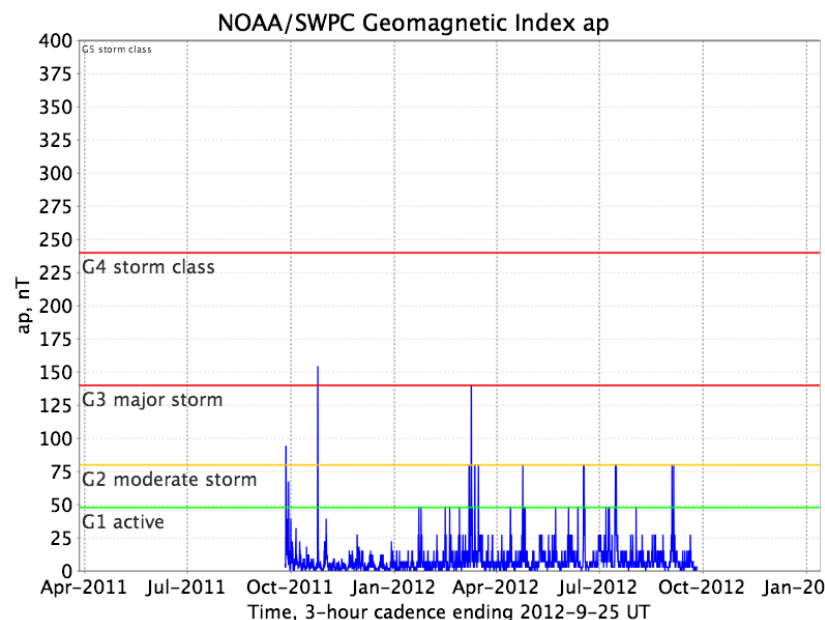


Credit: Tobiska

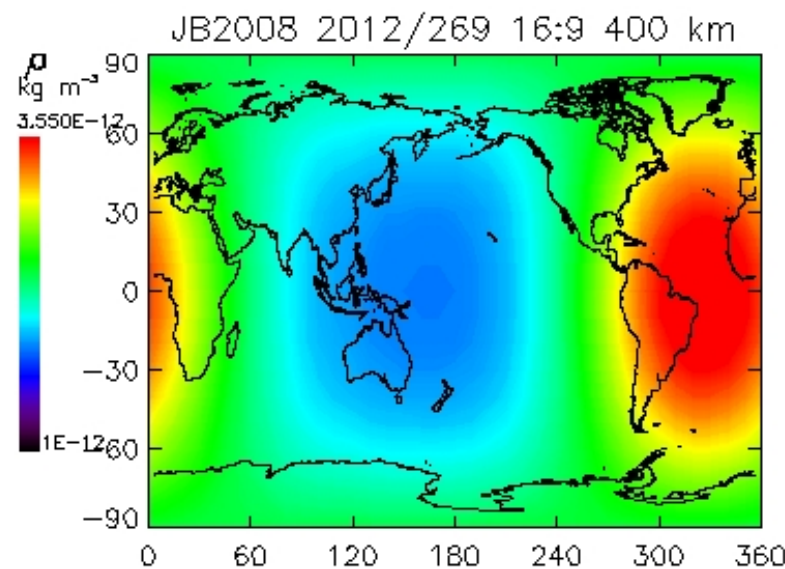
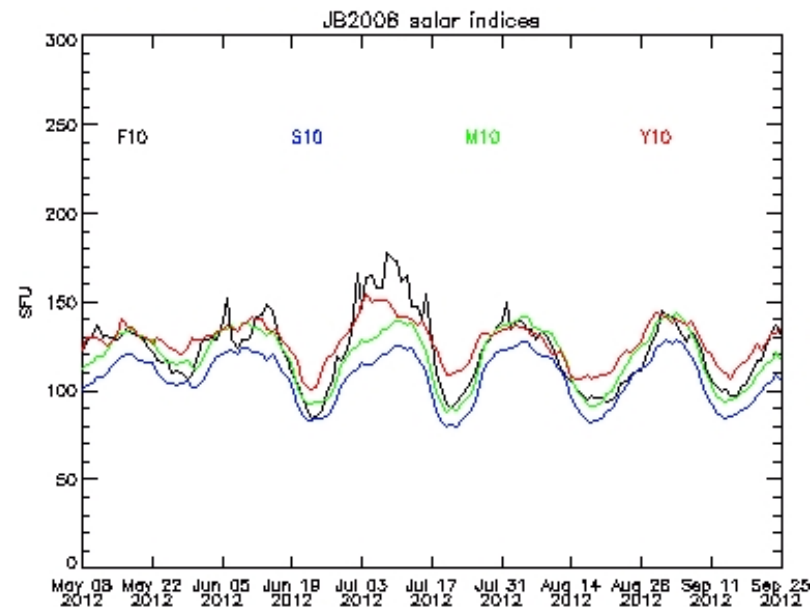
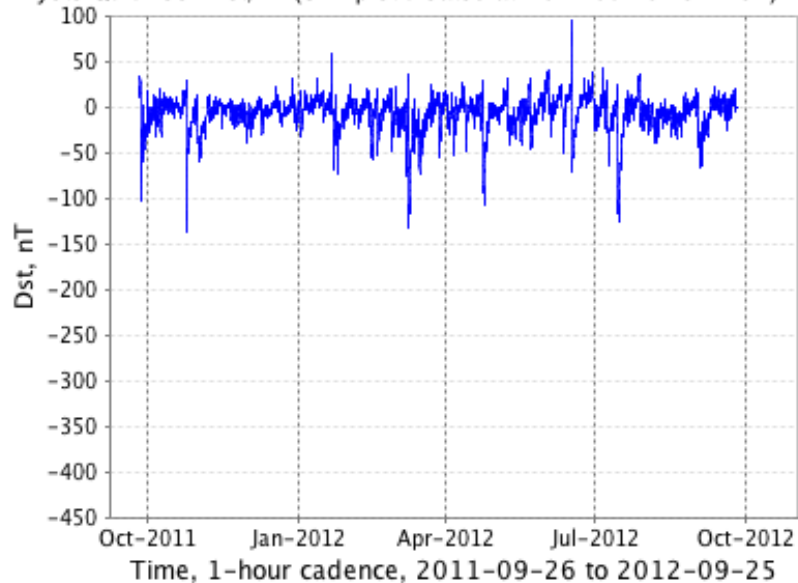


JB2008 Indices

Lecture 5

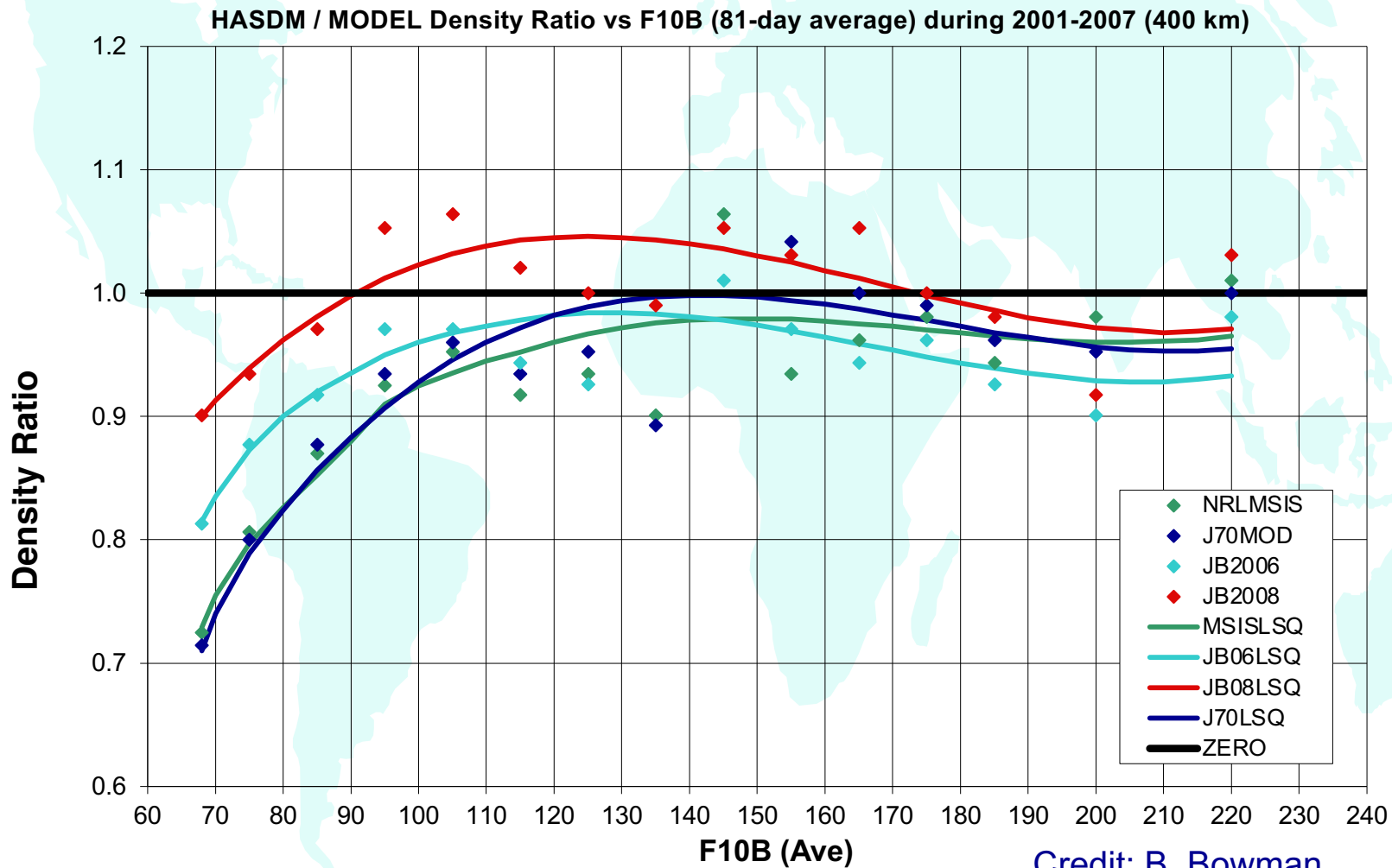


Kyoto Quicklook Dst, nT (SET plot created at: 2012-09-25 16:17 UT)



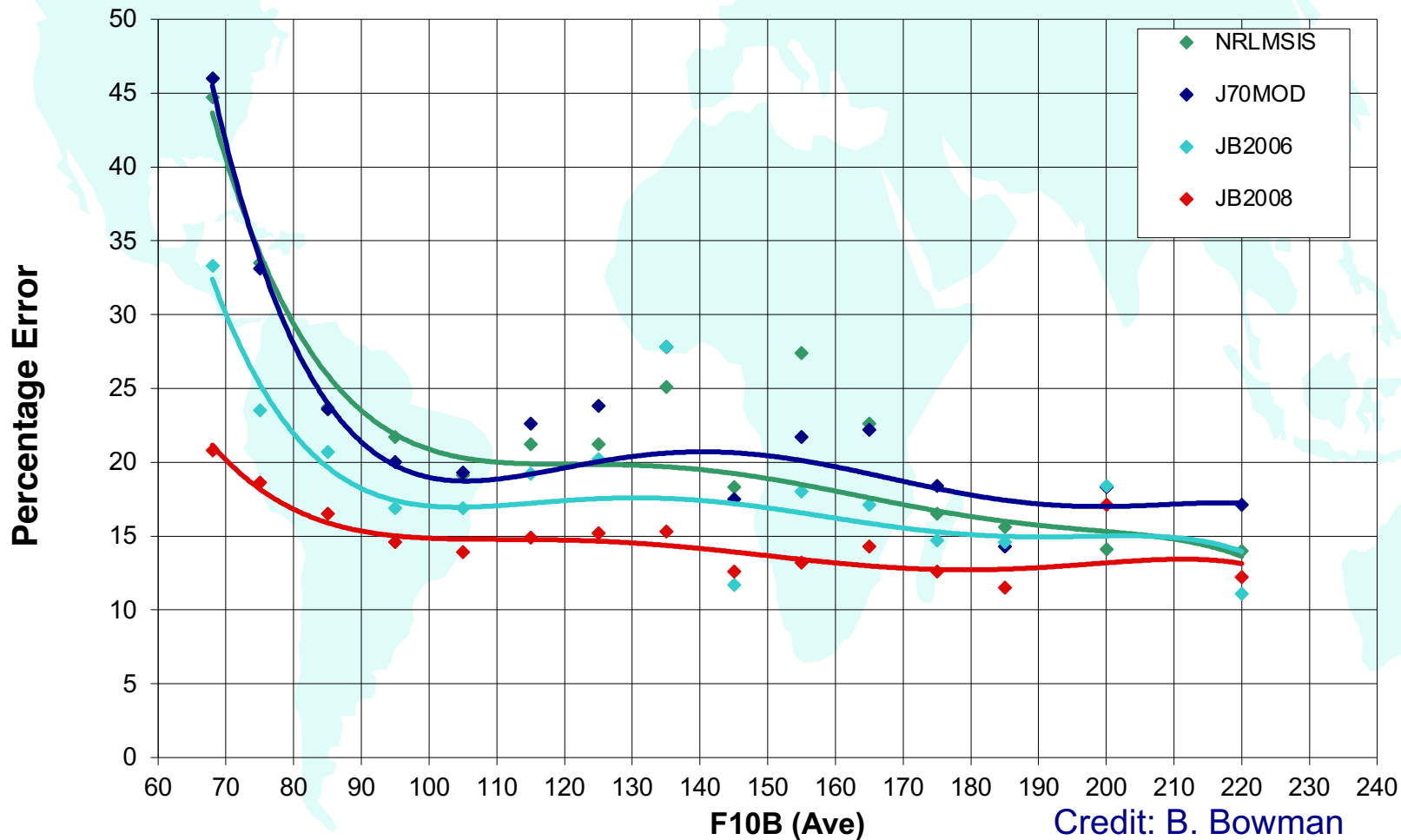
Credit: Tobiska

HASDM-Model density ratio



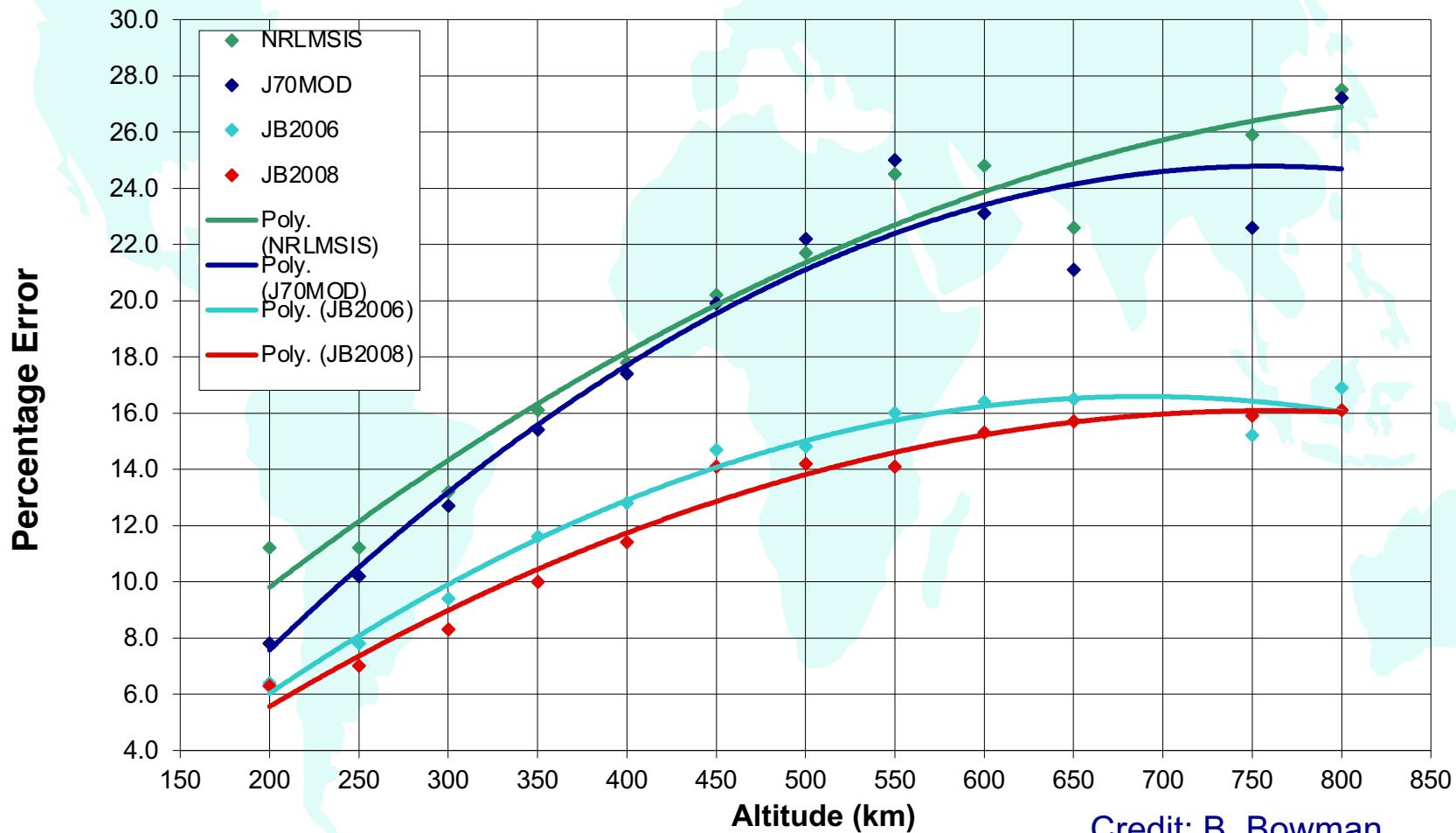
Standard deviation comparison

Density STD vs F10B During 2001-2007 (400 km)



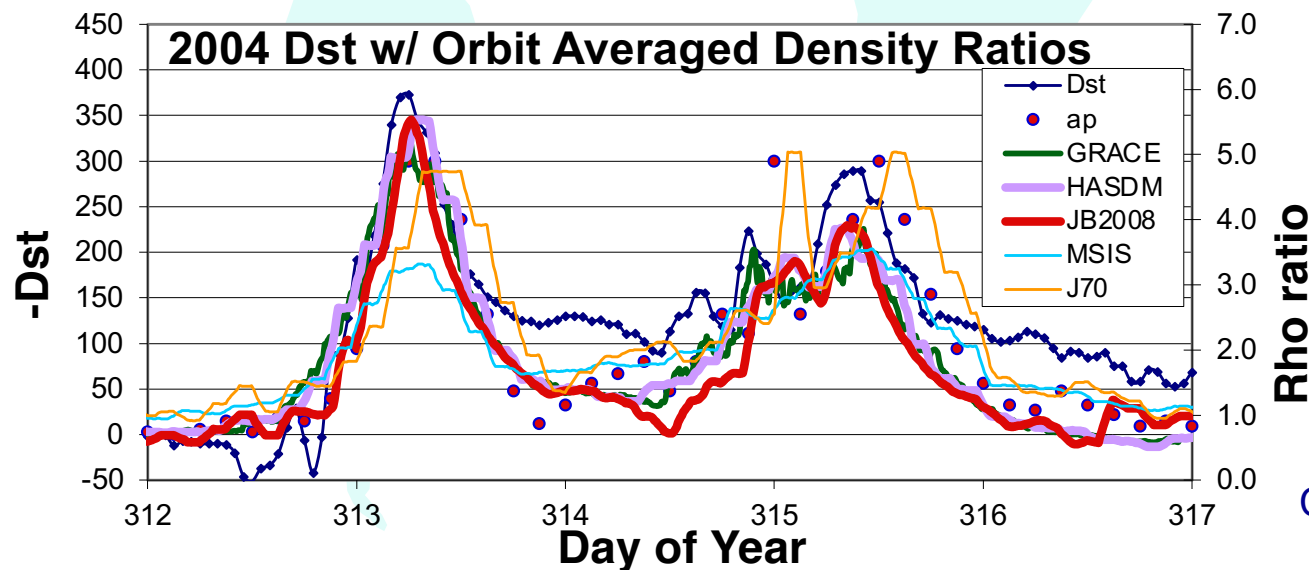
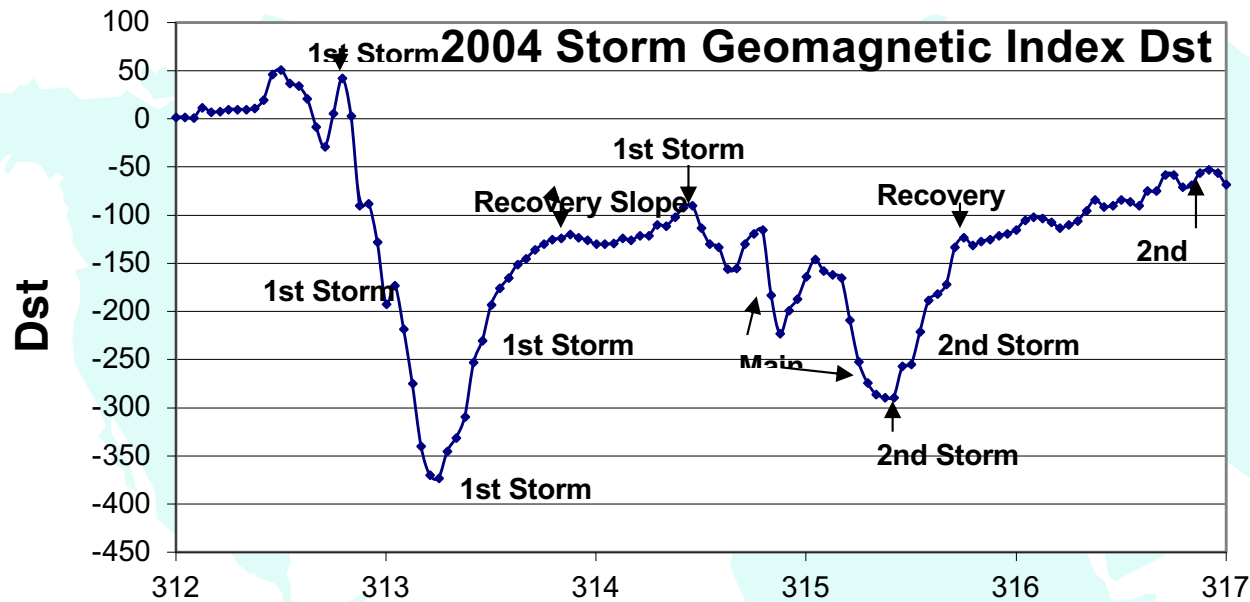
Average Daily Density Error

Average Daily Density Error versus Altitude During 1997-2007



Credit: B. Bowman

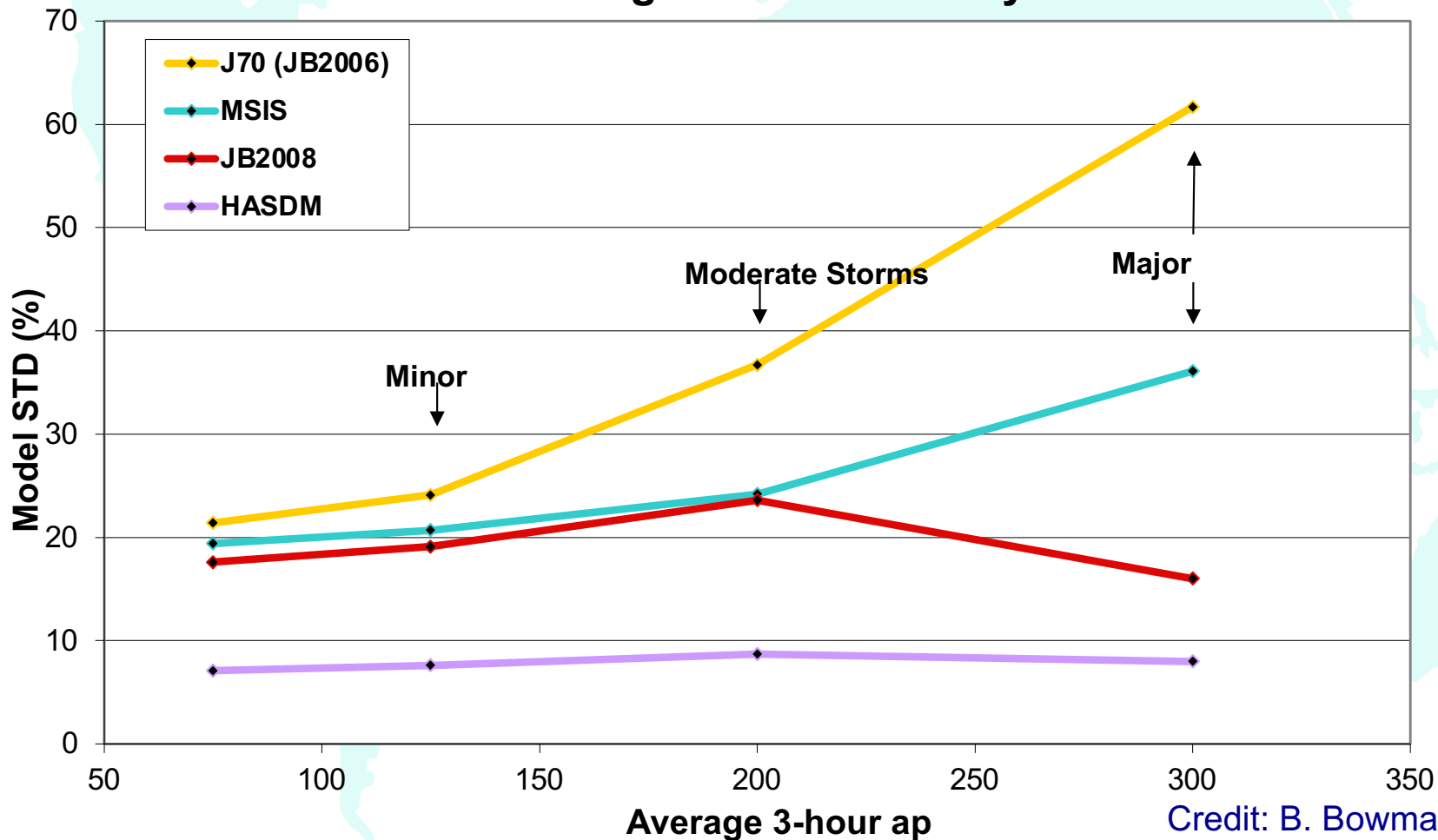
Storm-time Density Error compari sons



Credit: B. Bowman

Orbit Average Density Error

Orbit Averaged Model Density Errors



JB2008 (code, indices, docts)

JB2008

The Jacchia-Bowman 2008 Empirical Thermospheric Density Model



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Dear Colleague,

Welcome to the JB2008 empirical thermospheric density model website. Please provide your [name and email address](#) if you desire to be notified about updates to the JB2008 model, and the availability of forecasts.

[\[click here to register for updates\]](#) *

Please note that cookies must be enabled in your Browsers Preferences to register. Your local installation may have firewall implementations that prevent cookies or Java servlet protocols, in which case you should email spacenvironment@spacenvironment.net with "JB2008" in the subject line to receive updates.

Thank you,

Space Environment Technologies

Notice: Beginning 6 Oct 2012, JB2008 operations have been upgraded, and the JB2008 indices are now updated regularly at this website (note that most of these data released for public use will have an approximately 40-day lag from the current date). A number of significant improvements have been made to the JB2008 indices, which have been validated with 2001 and 2005 solar/geomagnetic data. For more information, contact spacenvironment@spacenvironment.net with "JB2008" in the subject line.

Last Website Update: 6 Oct 2012

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<http://sol.spacenvironment.net/~JB2008/index.html>

Credit: SET

<https://SpaceWx.com>

W. Kent Tobiska <ktobiska@spacewx.com>

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High Accuracy Satellite Drag Model (HASDM)

HASDM is a system run at USAF Space Command CSpOC (VAFB)

HASDM V1 – 2001 to 2011 used J71 with F10 and Ap for -48 hours to +72 hours

HASDM V2 – 2012 to present uses JB2008 with S10, M10, Y10, F10, Ap, and Dst (provided by SET) for -48 hours to +144 hours

3 conceptual modules in HASDM

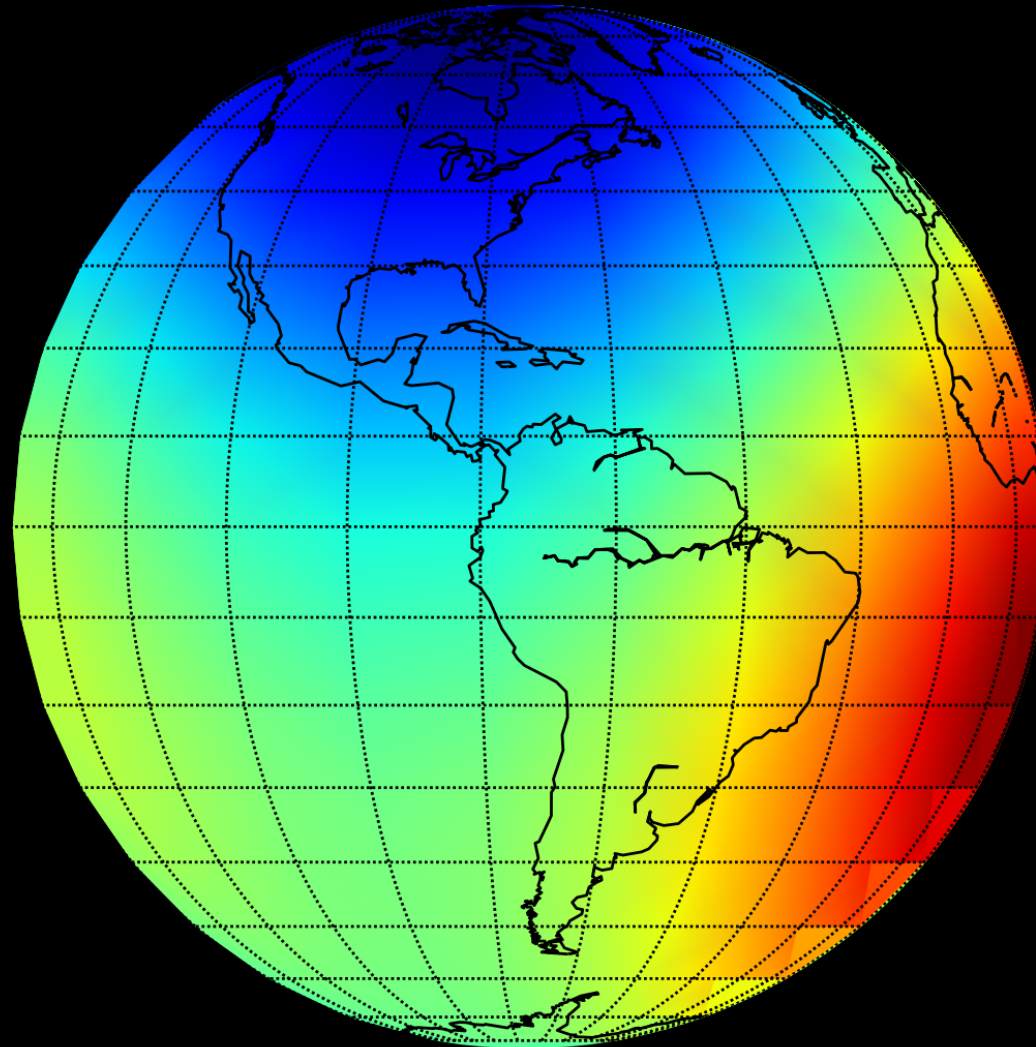
- **JB2008** core (called JBH09) providing current epoch and forecasts to 72 hours
- **Space Surveillance Network (SSN)** observations of ~60 calibration satellites
- **Dynamic Calibration of the Atmosphere (DCA)** code acting as a data assimilation Kalman filtering method to incorporate derived densities from observations into modeled background

HASDM provides thermospheric densities used for creating NORAD TLE catalog and for assessing debris/active satellite conjunctions

Credit: Tobiska

HASDM DataCube

Oct. 30 2003 00:00 UT at 400 km



1.2

1.3

1.4

1.5

1.6

Atmospheric Density (kg/m^3)

$1\text{e}-11$

Credit: Tobiska

Resources

- ◆ IS 15390:2004 - Galactic Cosmic Rays
- ◆ IS 21348:2007 - Solar irradiances
- ◆ IS 16457:2009 - Earth's ionosphere
- ◆ IS 14222:2013 – Earth atmosphere density
- ◆ AIAA G-003C-2010
- ◆ CIRA 1972 code
- ◆ JB2008 code
- ◆ NIST references
 - <http://physics.nist.gov/PhysRefData/contents.html>
- ◆ NSWP

Summary

- ✓ **Environmental effects (neutral atmosphere)**
 - ✓ Kinetic energy
 - ✓ Atmospheric drag, attitude perturbations, sputtering
 - ✓ Chemical energy
 - ✓ Atomic oxygen erosion, UV degradation, spacecraft glow
 - ✓ Thermal
 - ✓ Temperature control
 - ✓ Particulate
 - ✓ Contamination
 - ✓ Standards and guidelines
 - ✓ Models