Pilot Service for Improving Satellite Re-entry Predictions and Orbital Decay Modeling

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Purpose of the Work Proposed

The aim of the work proposed is to

- Study
- Test
- Evaluate

→ the **satellite orbital decay modeling**
[possible applications:
- orbit determination
- orbit propagation]

A space weather service for improving:

→ the **accuracy of re-entry predictions**
[possible application:
- Re-entry of risky space objects]

Companies Involved

- **The *Space Flight Dynamics Laboratory* of the Istituto di Scienza e Tecnologie dell'Informazione "Alessandro Faedo" [ISTI] – formerly CNUCE – of the Italian National Research Council [CNR] located in Pisa, ITALY**
- **The Space Environment Technologies' [SET] SpaceWx Division located in Los Angeles, CA, USA**

Background Experience [1]

- Since 1979, the ***Space Flight Dynamics Laboratory*** has been responsible for reentry predictions of potentially risky space objects for the Italian civil defense authorities
- In 1994, consolidating the leading role played in the field, a **Space Object Monitoring Service [SMOS]** was activated, on the behalf of the Italian Space Agency [ASI], to provide the national agencies and the government with advice and support on space debris and reentry technical topics
- In 1998, the Italian Space Agency joined the **Inter-Agency Space Debris Co-ordination Committee [IADC]** and ISTI was involved, as the National Technical Contact Point, in the IADC reentry test campaigns

Background Experience [2]

The *Space Environment Technologies' SpaceWx Division* **developed the world's first commercial operational solar irradiance specification system that provides historical, nowcast, forecast solar irradiances from the SOLAR2000 model.**

The overarching scientific goal of SOLAR2000 is to understand how the Sun varies spectrally and through time from X-ray to infrared wavelengths.

SOLAR2000 irradiance product major customers include:

- **The NOAA Space Environment Center [SEC]**
- **The USAF ISC2/HASDM project administered by Lockheed Martin**

ISTI Models and Assumptions

- **Sources of Orbital Data**
  - **NORAD Two-Line Elements [TLE] from the NASA/GSFC Orbital Information Group [OIG]**
- **Orbital Predictor**
  - **SATRAP [SATellite Re-entry Analysis Program]**
- **Atmospheric Density Models**
  - **Jacchia-Roberts 1971 [JR-71]**
  - **Mass Spectrometer Incoherent Scatter model 1986 [MSIS-86]**
  - **Mass Spectrometer Incoherent Scatter Extended model 1990 [MSISE-90]**
  - ***Thermospheric Density Model 1988 [TD-88]***
- **Current Sources of Environmental Data**
  - **Daily observed $F_{10.7}$ cm radio flux and A_P (or K_P) geomagnetic index. Their past values are obtained from the NOAA National Geophysical Data Center [NGDC], while their current and forecast values are acquired from the NOAA Space Environment Center [SEC], both located in Boulder, Colorado, USA.**

SET Roles and Services

SET could act as a service provider to ISTI providing

data services:

- In the form of daily historical, nowcast and forecast values of the parameter $\mathbf{E_{10.7}}$ from the SOLAR2000 model:
  - $\mathbf{E_{10.7}}$ is a solar flux proxy based on a full spectrum model of EUV solar emissions. The new parameter, $\mathbf{E_{10.7}}$, is reported in units of the 10.7 cm solar radio flux ($\mathbf{F_{10.7}}$) and it is designed to substitute $\mathbf{F_{10.7}}$ in all models that use the latter proxy

consultancies and assistance:

- In revising the nighttime minimum exospheric temperature, T_c, formulation for use in the JR-71 model
- In comparing the new and traditional T_c formulations for JR-71 in "a posteriori" analysis

$E_{10.7}$ Availability and Applications [1]

Why $E_{10.7}$?

It is directly correlated to the sun's ultraviolet irradiance

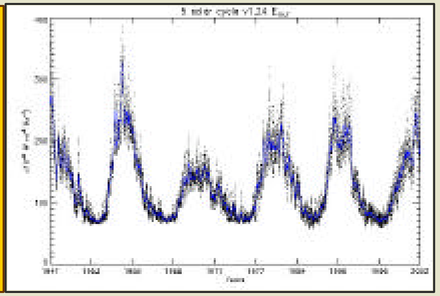
It improves the solar component of atmospheric heating when compared with $F_{10.7}$

<u>HISTORICAL VALUES</u>

From Feb. 14, 1947 to a few weeks prior to current epoch [July 31, 2002 for v1.24]

POST ANALYSIS

"A posteriori" analysis of the satellite' orbital decay



$E_{10.7}$ Availability and Applications [2]

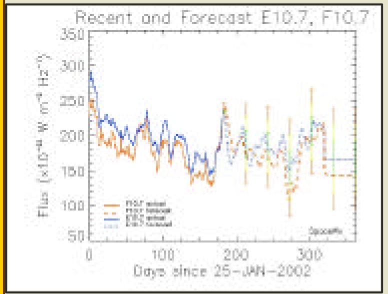
NOWCAST VALUES
24-hours ago to current time

REAL-TIME OPERATIONS
Space Objects Re-entry

FORECAST VALUES
From the current epoch to 5 solar cycles

SCHEDULING/PLANNING

Orbit Prediction
Orbit Determination
Lifetime Estimation



Logic of the Envisaged Work [1]

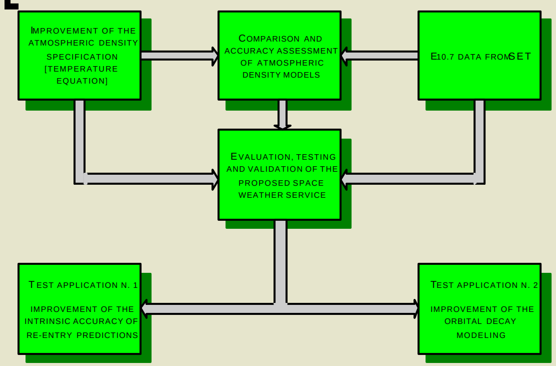
The aim of the work will be to study, test and evaluate a space weather service for improving

- The satellite orbital decay modeling
- The accuracy of re-entry predictions

The limitations of the currently used atmospheric density models and solar flux proxies will be investigated in quantitative detail and compared with the potential advantages of using a new temperature equation in the JR-71 model and the $E_{10.7}$ parameter to represent the solar flux.

ISTI will be the user and SET will be the service provider of $E_{10.7}$ data.

Logic of the Envisaged Work [2]



Technical Description

A lengthy comparison and assessment of the accuracy of the SATRAP's atmospheric density models will be carried out by analyzing the orbital decay of a sample of space objects:

- in the 150-1500 km altitude range
- in a wide range of orbital inclinations
- over a full solar activity cycle
- with two different solar activity proxies ($F_{10.7}$ and $E_{10.7}$)

The work will consist of **four different activities** aimed at:

1) Assessing the accuracy of density models through an "a posterior orbital decay of a set of space objects
2) Improving the atmospheric density specifications with the inclusion of the reformulated exospheric temperature equation in the JR-71 model
3) Assessing the confidence levels of the re-entry predictions
4) Improving the modeling of the satellite orbital decay

Technical Goals

Activity 1

To emphasize the discrepancies of some of the most widely used air density models and solar flux proxies ($E_{10.7}$, $F_{10.7}$)

Activity 2

To improve the performances of the JR-71 model

Activity 3

To test the validity of the nowcast and short-term forecast values of $E_{10.7}$

To improve the intrinsic accuracy of re-entry predictions using $E_{10.7}$ and the modified JR-71 model

Activity 4

To improve the modeling of satellite orbital decay due to air drag, using $E_{10.7}$ and the updated version of JR-71

Possible Applications

To demonstrate the advantage of the new model and solar proxy to potential astrodynamics users in the field of orbit determination and prediction

To improve the modeling of satellite orbital decay due to air drag

Such an improvement might be advantageous both for orbit determination [improvement of the solution; reduction of residuals] and trajectory prediction [improvement of the accuracy]

To improve the intrinsic accuracy of re-entry predictions

The results of the proposed service might helpfully provide the scientific community with information and instructions to reduce the overall uncertainty of the re-entry prediction process

They might also assist the scientists of the Inter-Agency Space Debris Co-ordination Committee [IADC] during their re-entry campaigns

Strategy for Further Developments [1]

Air Density Modeling

Further developments in the field of air density modeling have recently led to the formulation of the new empirical atmospheric model **NRLMSISE-00**. When compared to the respective types of data on which the MSIS-86/90 and JR-71 models are based, it incorporates the strengths of each data set.

- We are planning in the future to implement this model in SATRAP, with $E_{10.7}$ to represent the solar flux
- We also intend to include the Russian **GOST** model in our software. This model was constructed empirically from observations of the orbital motion of Russian Cosmos satellites and can be envisaged as an independent source of information on the structure and properties of the upper atmosphere.

Strategy for Further Developments [2]

Aerodynamic Drag Modeling

To really improve the models used in astrodynamics to compute the aerodynamic drag, in a wide range of altitudes and environmental conditions, a lot of work has still to be done. A significant step in that direction might be represented by

- the launch of dedicated spherical satellites, at different altitudes and inclinations, with geometrical, physical and surface characteristics – drag coefficient included – determined with accurate laboratory measurements