



# TIDAL SYNCHRONOUS ORBITS

Christopher Lowe, Malcolm MacDonald

Dept. Mechanical and Aerospace Engineering - [www.strath.ac.uk/space](http://www.strath.ac.uk/space)

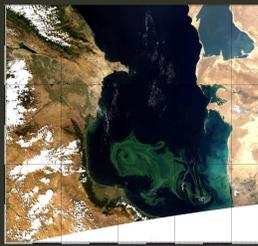
## FROM ALGAL BLOOMS TO OIL SLICKS:

Tides affect almost all of the world's oceans to an extent, whether moving oil/debris/organic matter, limiting access to busy shipping ports or defining patterns in wildlife migration.

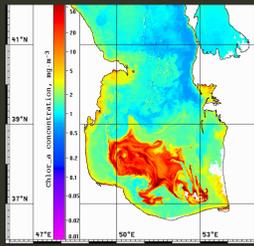
We could gain a better understanding of how such things as ocean colour patterns evolve and develop by analysing them with reference to the tidal sequence. This is perhaps most important in coastal regions, where the tide often has a greater influence over movement of the water and where human impact is most apparent.



Start of Algal Bloom in the Caspian Sea: 17 Aug 2005



Developed Algal Bloom: 01 Sep 2005



Chlorophyll-a image: 01 Sep 2005

## WHAT IS TIDAL SYNCHRONISM?

Tidal-synchronous orbits are a new family of orbits in which the 'sub-satellite point' (SSP) is *repeated* after an exact *integer* number of *Tidal Lunar Days (TLD)* ( $\tau_T = 24.84$  hours, time it takes for the Earth to spin  $360^\circ$  with respect to the Earth—Moons vector). This is analogous to the repeat characteristics required by Sun-synchronous orbits, where a repeat in the SSP occurs after an integer number of Earth days (24 hours). The orbit period of a spacecraft (S/C) ( $\tau_{S/C}$ ) in a tidal-synchronous orbit is defined by:

$$\tau_{S/C} = \frac{m\tau_T}{n}$$

Where;

$m$  = integer number of TLDs

$n$  = number of S/C orbits in time ' $m\tau_T$ '

By meeting this simple repeat requirement we can directly compare ocean properties at specific locations in an identical tidal state, thus increasing our knowledge of the relationship between such things as ocean colour patterns and tidal streams. Until now, oceanic monitoring has been conducted exclusively from *Sun-synchronous* or *Geo-stationary* orbits, which either bear no relation to the tidal sequence, or have limited coverage and resolution properties.

## HOW DO WE OBTAIN TIDAL SYNCHRONISM?

In order to match up the sub-satellite point with specific tidal states after an integer number ( $m$ ) of TLDs ( $\tau_T$ ), the *orbit plane of a satellite must rotate* about the polar axis by a specific amount,  $\varphi$ . This enables the orbit to be over the location of interest at, for example High tide, after each ' $m\tau_T$ ' period. The amount of *orbit plane rotation per orbit* is defined by:

$$\Delta\varphi = \frac{2\pi\tau}{\tau_T} \left( \frac{\zeta}{m} - \frac{\tau_T}{\tau_E} \right) \text{rads / orbit}$$

Where;

$\tau_E$  = Sidereal day (23hrs 56 minutes)

$\zeta$  = Nearest number of complete sidereal days before repeat SSP

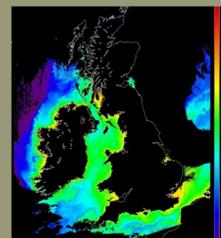
The orbit period and rate of plane rotation can then be used to define the orbit shaping parameters; semi-major axis ( $a$ ) and inclination ( $i$ ):

$$a = \left[ \mu \left( \frac{\tau}{2\pi} \right)^2 \right]^{1/3} \quad i = \arccos \left[ \frac{-\Delta\varphi a^2 (1 - e^2)^2}{3\pi J_2 R_E^2} \right]$$

Definition of 'tidal-synchronism' can be further restricted through application of two additional parameters, which limit the *number of Earth rotations between SSP repeats* ( $p$ ) and *number of satellite orbits between SSP repeats* ( $q$ ), where:

$$n = \frac{q\zeta}{p} \in \mathbb{Z}$$

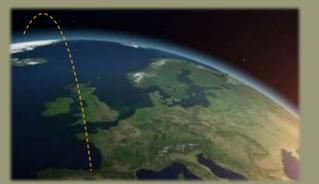
This condition benefits applications where both the *number of S/C* and *area of region to be covered* are limited. E.g. by setting  $q = 1$  and  $p = 14, 15$  or  $16$ , one can ensure a *repeat of the SSP each day*, with only a *single satellite*, while maintaining tidal-synchronism.



MODIS prediction of Bristol channel region Chlorophyll



Landsat-7 actual Bristol channel region ocean colour



Tidal Synchronous orbit trajectory to monitor Bristol channel colour properties

## SPECIAL CASE AND CONSTELLATIONS

$m = 57$

An almost '*sun & tidal-synchronous*' orbit exists when the condition  $m = 57$  is defined. Since 57 TLDs equates to 58.998 Earth days, the rotation of the satellite orbit plane ( $\varphi$ ) is  **$355.2^\circ/\text{year}$** , just  $4.8^\circ$  less than that of a Sun-synchronous orbit ( $360^\circ/\text{year}$ ). Maintaining the  $m = 57$  condition therefore provides the benefits of both tidal-synchronism and Sun-synchronism.

Global & Regional Coverage

An analytical solution for the number of S/C required to provide complete tidal-synchronous coverage (above latitude ' $L$ ') in a 'string of pearls' configuration is given by:

$$N_{S/C} = \frac{2\pi \cos L \sqrt{\frac{R_E^2}{1 + \sin L \left[ \frac{1}{(1-f)^2} - 1 \right]} \sin \left( \frac{\pi}{2} - \sin^{-1} \left( \frac{\cos i}{\cos L} \right) \right)}}{w \left[ \frac{n\tau_E}{m\tau_T} - \cos \left( \frac{\pi}{2} - \sin^{-1} \left( \frac{\cos i}{\cos L} \right) \right) \right]}$$

Where;

$w$  = Swath width

$f$  = Earth flattening parameter

