Heliophysics
Integrated
Observatory

Project No.: 238969
Call: FP7-INFRA-2008-2

Coordinate Systems

Version 1.0

Title:	**Coordinate Systems**
Document No.:	HELIO-UCL=N3-003-TN
Date:	22 March 2010
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Distribution:	Project

CAPACITIES

e-infrastructure

Revision History

Version	Date	Released by	Detail
Draft	2010-02-16	R.D. Bentley	First cut of how HELIO should handle coordinates
0.1	2010-03-01	R.D. Bentley	Revised following comments from Hapgood and Thompson
1.0	2010-03-22	R.D. Bentley	Rewrote the introduction. Revisions following comments from Hapgood and King

Note: This document will continue to undergo revisions during the implementation phase of HELIO to incorporate changes and improvements.

Introduction

In the HELIO project we need to facilitate the interpretation a variety of data and models in order to be able to understand how the Sun affects the Solar System. This means that we need to have a coherent way of relating a number of quantities from several different communities. While this is the subject of the effort related to the HELIO Data Model[1] and the Semantic VO (WP JRA1), spatial coordinates are sufficiently complex that we need to look at them separately – this is the purpose of this document.

The observations are from communities that have worked independently and not necessarily in an interoperable way. In addition, within each community, the analysis of observations by different researchers has resulted in the definition of similar (but not quite the same) coordinate systems. For HELIO we need to decide which of the many options we should use in each part of the system: i) to be able to track and model things moving through the solar system; ii) to be able to interpret remote-sensed and in-situ observations so that they can be used as boundary conditions in models, etc.

This is important for the specification of the Coordinate Transformation Service (CTS; see the HELIO Concepts Document). In addition, it will allow us to unambiguously identify the meaning of spatial coordinates in various event and features tables hosted by or maintained by HELIO. This is particularly necessary when we are distributing information in the form of a ***VOTable***[2] where the definition of the FIELDs need to be appropriately annotated so that the file can be used in other parts of the system (and by other users) without confusion – see HELIO Data Model.

We must therefore decide on coordinate systems:

1. To describe the location of solar features (and events) based on remote-sensed observations, as seen from a number of vantage points
   - Features on or near the solar surface
   - Features moving outwards from (but close to) the Sun

   The remote-sensed observations comprise images at various wavelengths taken from Earth or near the Sun-Earth line (including spacecraft in Earth orbit and at L1), and from more remote missions (like STEREO and Solar Orbiter). There are many types of general solar imagers; more specialized instruments are used to study features moving way from the solar surface include coronagraphs (on Earth and missions like SOHO, STEREO, etc.) and heliospheric imagers (HI on STEREO, SWAN on SOHO, and SMEI).

2. To describe the location of various objects in the heliosphere:
   - The planets in orbit around the Sun and numerous spacecraft moving in well-defined trajectories
   - Phenomena propagating through the heliosphere – e.g. CMEs

3. To identify the location where in-situ observations were made (and their relation to relevant bodies)

[1] Document in preparation
[2] The VOTable format, defined by the IVOA, is used to transfer information between different parts of the HELIO system

- On spacecraft moving within the heliosphere
- In the environs of various planets

We will look at these in turn in the following sections.

Remote-sensed observations related to the Sun

Features on (or near) the surface of the Sun

We need to be able to study the relationship between features and events on or near the surface of the Sun made at different times and from various vantage points. It is therefore essential that we choose a coordinate system in which their locations are related[3] to the *rotating* solar sphere.

We therefore propose to use the ***Heliographic Coordinates*** (HGC[4]) system (Franz and Harper, 2002). In this system, the heliographic latitude is measured from the solar equator positive towards North and the heliographic longitude is defined westward (i.e. in the direction of planetary motion) from the solar prime meridian which passed through the ascending node on the ecliptic of date on 1854 Jan 1, noon (JD 239 8220.0).

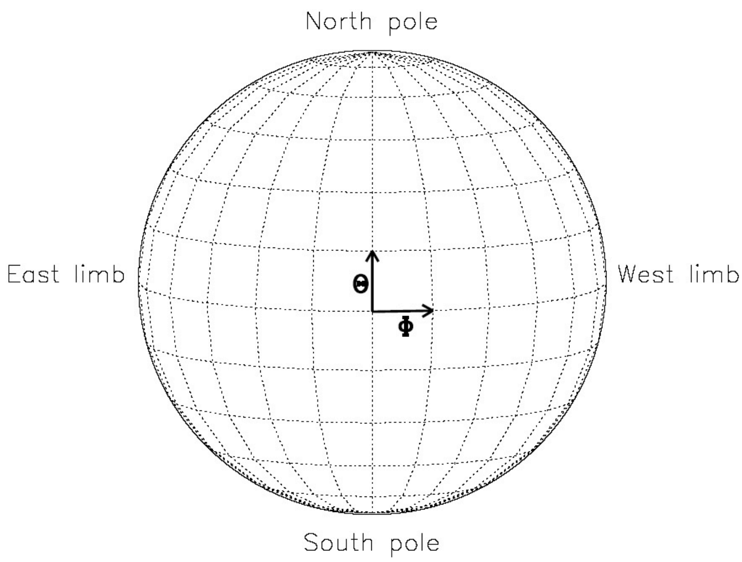

Figure 1 Heliographic Coordinates appear the same as Stonyhurst Heliographic Coordinates but are defined with respect to a reference longitude (Thompson, 2006a).

Because of the angular separation of the STEREO spacecraft from the Sun-Earth line, the imagers are seeing around the solar limb (from an Earth-based perspective). Heliographic Coordinates allow us to combine and compare these observations but it is important that we

[3] The Stonyhurst Heliographic coordinate system is often used to define features on the Sun, as seen from Earth; this system has the same latitude as the HGC system, but the longitude is defined with respect to the sub-Earth point. Some instruments, e.g. RHESSI, define the location of flares in helioprojective Cartesian coordinates; these take no account of the curve of the solar sphere or the tilt cause by the inclination of the ecliptic to the Sun's axis of rotation. If observations are to be compared, they need to be converted to Heliographic Coordinates.
[4] The HCG coordinate system is identical to the Carrington Heliographic coordinate system described in Thompson 2006a.

know the longitude of the sub-observatory point to know whether events or features seen by one observatory should or should not be visible from another.

Features moving outward from the Sun

Features observed by remote-sensed imaging systems, while the structures they represent are relatively close to the Sun, should be described in terms of ***helioprojective-radial coordinates*** (Thompson, 2006a).

However, since observatories away from the Sun-Earth line – such as STEREO, and in future Solar Orbiter – see a very different projected plane-of-sky image, it is important that the heliographic longitude and latitude of the sub-observatory point, as well as the heliocentric distance, are known for each image (and easily accessible).

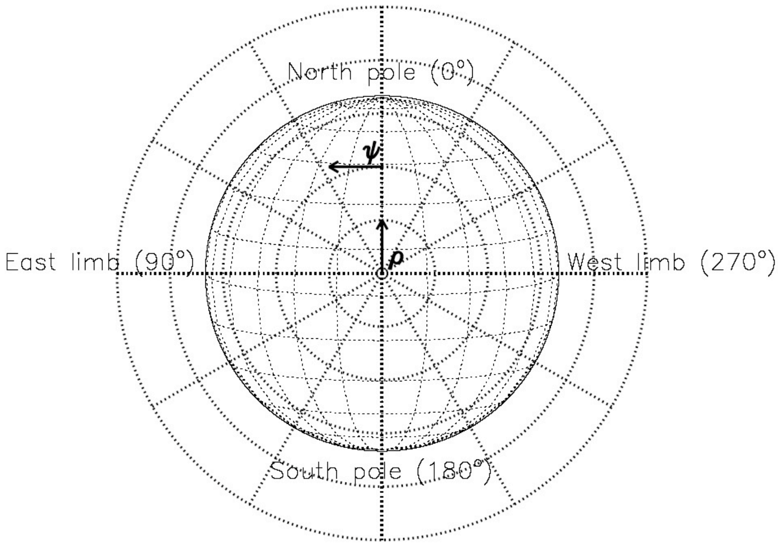

Figure 2 Helio-projective radial coordinates (Thompson, 2006a).

Coordinates for the location of objects in the heliosphere

There seem to be two options for coordinate systems:

- ***Heliocentric Inertial*** (HCI) system
- ***Heliocentric Aries Ecliptic*** (HAE) system

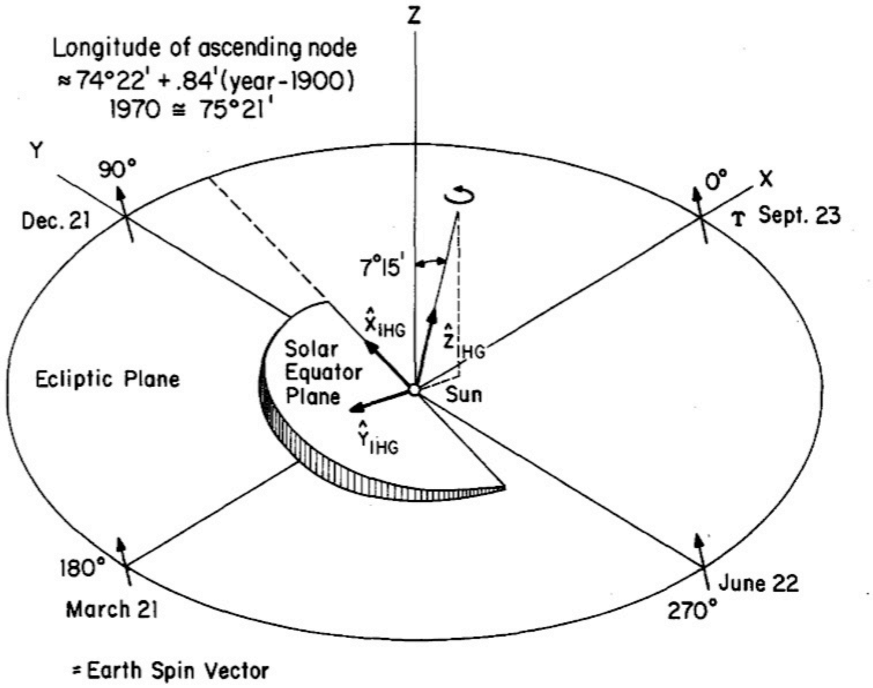

Figure 3 Inertial Heliographic (IHG) coordinates defined by Burlaga (1984); Heliocentric Inertial (HCI) coordinates are defined in the same way but based on an epoch of J2000. The plane of the Heliocentric Aries Ecliptic (HAE) system is shown; the first point in Aries in on/around March 21.

The basic difference between these is which plane is defined:

- The HCI system (previously called the HGI or IHG; Burlaga, 1984) defines everything with respect to the plane with solar equator; the reference longitude is the ascending node for epoch J2000.
- The HAE system defines everything with respect to the Ecliptic; the reference longitude is the first point in Aries.

The question is whether it is appropriate to choose the plane of the Earth's orbit around the Sun as a reference for the whole Solar System or whether we should use the rotation axis of the Sun as the reference frame. Burlaga argues that the Sun is the source of interplanetary plasma and magnetic fields and it is natural to put the origin of the coordinate system at the centre of the Sun; also, the sense of rotation of the Sun gives a natural rotation axis

For HELIO, we should probably also use the HCI system to describe the location of planetary and other bodies, and for heliospheric spacecraft[5].

[5] Including spacecraft following a trajectory and planetary missions during their cruise phase.

In-situ observations of the local environment

It is common to choose an axis system for *in-situ* observations that depends on the position of the spacecraft; the ***Heliocentric Radial-Tangent-Normal*** System (HGRTN/RTN[6]) is used to define the velocity and field direction of the plasma environment that the spacecraft finds itself in. The HGRTN system is used by the Ulysses mission (Franz and Harper, 2002) and by the STEREO mission (Thompson, 2006b).

We also need to understand where the spacecraft is located in the bigger picture:

Within the heliosphere

Use the Heliocentric Inertial (HCI) system described above.

Far region of a planetary environment

In the far regions the environment is dominated by the solar wind, e.g. the bow shock, magneto-tail and perhaps magnetopause.

A critical issue to consider is aberration – that the bow shock of a planet is rotated in the plane of the planet's orbit by angle $V_{planet} / V_{solar\_wind}$, where V_{planet} is the velocity of the planet in its orbit and V_{solar_wind} is the solar wind speed. The sense of rotation is such the bow shock lags its un-rotated location on the anti-sunward side of the planet. This is the +Y direction for a planetocentric solar ecliptic system (X to sun, and Z perpendicular to the planet's orbit, positive north) such as GSE at the Earth. Strictly speaking V_{planet} should be the component perpendicular to the solar wind. For the Earth under normal solar wind conditions (v ~400 km s^{-1}) the angle of aberration is 4 degrees, which is highly significant for determining magnetopause and bow shock locations.

Given this aberration, far aspects at the Earth should be handled using the Geocentric Solar Wind coordinates (GSW[7]) first defined Hones et al. (1986) – see Figure 4.

Near region of a planetary environment

In the near region, the environment is dominated by the properties of the planet, most importantly its magnetic field. In this region we need coordinate systems linked closely to the planet.

Looking at the near aspects, one needs to consider at least three systems: (a) one linked to the planet's global magnetic field if it has one, (b) one linked to the solar time on the planet, and (c) one fixed relative to the solid surface of the planet (if it has one). These would allow examination of phenomena linked respectively to the magnetic field, to solar illumination and to surface/sub-surface features such as topography and magnetic anomalies.

The latter pair is fairly straightforward: (c) requires a standard latitude/longitude system tied to the rotation axis and you just need to distinguish between geocentric and geodetic

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[6] Note: The HGRTN system is basically the same as the heliocentric-Cartesian coordinate system, except for differences in nomenclature

[7] Support for Geocentric Solar Ecliptic (GSE) and Geocentric Solar Magnetospheric (GSM) coordinates should also be included because: (a) they are intermediate steps in the calculation of GSW; (b) they are useful for import and export from databases.

systems; (b) would use the same latitude system but convert longitude to local solar time. However, (a) is more difficult unless you really have dipole magnetic field (so you can define latitude and local magnetic time based on the axis of that dipole). A solution for Earth takes us into non-Cartesian systems such as corrected geomagnetic latitude and the McIlwain L parameter.

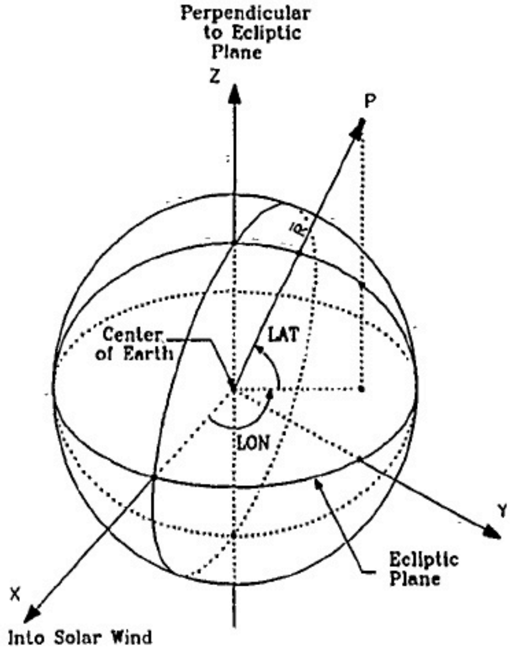

Figure 4 Geocentric Solar Wind (GSW) coordinates (Bhavnani & Vancour, 1991)

Naming convention for planetary coordinate systems

Many of the planetary coordinate systems are defined in the same fashion as those for the Earth, but different names have been used in the literature. Currently, Franz and Harper (2002) is the reference most commonly used for the coordinate system definitions and they are adapted to each planet.

The preferred naming convention for each planetary coordinate system is to replace the "G" in the Geographic coordinate system names with a letter corresponding to the planet. The letter map is:

Sun	H	Jupiter	J
Mercury	M	Saturn	K
Venus	V?	Uranus	U
Earth	G	Neptune	N
Mars	A		

and to replace the "E" for Ecliptic with "O" for orbital since the ecliptic is uniquely defined by the Earth.

So, Geocentric Solar Ecliptic (GSE) at the Earth becomes Jovian-centric Solar Orbital (JSO) at Jupiter. Likewise, GSM becomes JSM.

Questions:

1. How accurately do we need to know the location of the spacecraft in the remote and near regions?

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