



Navigation and Ancillary Information Facility

“High Accuracy” Orientation and Body-fixed Frames for the Moon and Earth

October 2007



Topics

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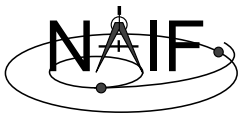
- **Introduction**
- **High accuracy rotation models**
- **Earth binary PCKs**
- **Lunar binary PCKs**
- **Information applicable to both Earth and lunar binary PCKs**
- **Lunar Frames Kernel**
 - Frame specifications
 - Frame alias names
- **Earth and Lunar Association Frames Kernels**
- **Kernel usage summary**
- **Backup**
 - Plots comparing Earth and lunar orientation as given in “high accuracy” binary PCKs with orientation provided by IAU models



Introduction

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- Now that you are an expert in “standard” PCKs and FKs you may want to learn about several “special” PCKs and FKs dealing with the Earth and the Moon.
- While it is ultimately up to you, in most cases you should use the kernels described here when working with the Moon or the Earth.



“High Accuracy” Rotation Models

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- **SPICE “high accuracy” rotation model data are available only for the Earth and Moon**
 - More accurate than the IAU rotation models
 - » More so for the Earth than the Moon. See plot in backup charts comparing orientation of the ITRF93 frame to that of the IAU_EARTH frame.
 - For the Earth, the highest accuracy is obtainable only for past epochs
 - » Unpredictable variations of UT1-TAI and polar motion limits accuracy of predicted Earth orientation
 - For the Moon, prediction accuracy of the IAU analytic model is not nearly as poor as for the Earth.
 - » See the plot in the backup charts comparing the IAU lunar rotation model to the integrated DE-403 model
 - Note that the IAU_MOON model was developed in 2000, published in 2002 (see documentation in pck00008.tpc).



Data Sources for “High Accuracy” Models

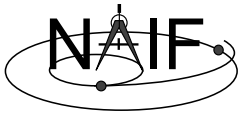
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- **Data for the Earth come from a JPL Earth Orientation Parameters file (EOP)**
 - Binary Earth PCKs represent the orientation of an Earth ITRFxx body-fixed reference frame relative to the ICRF*.
 - » ITRF* frames are defined by the International Earth Rotation Service (IERS)
 - » Currently only the ITRF93 frame is supported within SPICE
- **Data for the Moon come from JPL’s DExxx planet/lunar ephemeris (e.g. DE403)**
 - Binary lunar PCKs represent the orientation of the Moon’s “principal axis” reference frame (PA) relative to the ICRF*.

ICRF = International Celestial Reference Frame, often referred to in SPICE as the “J2000” frame, and also often referred to as the EME 2000 frame. An inertial frame.
ITRF = International Terrestrial Reference Frame

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5



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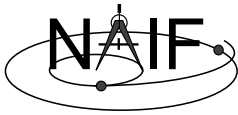
Earth Binary PCKs



Earth Rotation Model Effects

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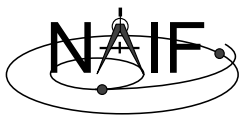
- **The ITRF93 high accuracy Earth rotation model takes into account:**
 - Precession: 1976 IAU model due to Lieske.
 - Nutation: 1980 IAU model, with IERS corrections due to Herring et al.
 - True sidereal time using accurate values of TAI-UT1
 - Polar motion



Earth PCK Production Scheme

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- **Three versions of the “high accuracy” binary Earth PCK are produced**
 - “The latest,” using each new release of a reconstructed EOP file by JPL
 - » Covers well into the past and approximately two months into the future beyond the production date
 - » Accuracy of the future data degrades rapidly past the production date
 - » Produced several times per week using an automatic script
 - Long term predict, for future uses not requiring high accuracy
 - » Produced infrequently
 - » Covers several years into the past and approximately 30 years into the future
 - » Accuracy at epochs in the future is low compared to that for past epochs, but any of it is far better than what is obtained from the IAU rotation model for the Earth provided in any text PCK
 - History file, containing only high accuracy historical data
- **All are in the pck directory under generic_kernels on the NAIF server: ftp://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/**
 - Read the “aareadme” file to see the file naming schema and more details



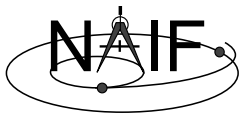
Accurate Earth Surface Locations

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- **High accuracy determination of surface locations relative to an inertial frame involves motions in addition to Earth rotation, including:**
 - tidal effects
 - ocean and atmospheric loading
 - tectonic plate motion
- **Tectonic plate motion is accounted for in NAIF's DSN and some non-DSN station SPK files.**
- **The other non-rotational effects affecting surface locations are NOT modeled by a PCK or any other SPICE component.**

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9



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Lunar Binary PCKs



Lunar Rotation Model Effects*

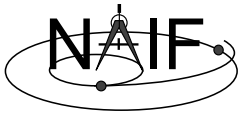
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- The DE-403 high accuracy lunar orientation model represents the result of a simultaneous numerical integration of lunar rotation and orbit, and of orbits of the planets.
 - The DE-403 integration model includes:
 - » A “solid Moon”
 - » Torques on Moon from the static gravity field of degree 2-4. Torque is due to Earth, Sun, Venus, and Jupiter.
 - » Torques on Moon and moments of inertia due to (degree 2) tides raised by Earth
 - » Dissipation effects on torques and moments due to tides on the Moon.
 - » Torques due to Earth J2 interacting with Moon degree 2 (J2 and C22).
 - Lunar quantities fit for DE403 include
 - » Initial conditions for lunar orbit and rotation of body
 - » Moment of inertia difference (C-A)/B and (B-A)/C
 - » Third-degree gravity field coefficients
 - » Tidal Love numbers and dissipation
 - » Locations of four laser retroreflector arrays

*Description provided by James G. Williams (JPL)

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11



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Information Applicable to Earth and Lunar Binary PCKs



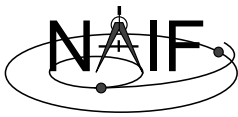
Binary PCK Format

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- **SPICE binary PCK files are used to accommodate these “high accuracy” rotation models.**
 - Just as for SPKs and CKs, the data are held in SPICE Double Precision Array files (DAF)
 - Multiple types are supported
 - » **Type 2: Chebyshev polynomials are used to represent Euler angles giving orientation as a function of time. Rates are obtained by differentiating polynomials. Coverage intervals have fixed length.**
 - Used for the Earth and the Moon
 - » **Type 3: Separate sets of Chebyshev polynomials are used to represent Euler angles and their rates. Coverage intervals have variable length.**
 - Not currently used for Earth or Moon
 - **Binary PCKs include a “comment area” for storing descriptive metadata**
 - » **Access the comment area using the Toolkit’s *commnt* utility program**
 - **Binary PCKs support high-speed direct access**
 - » **Cheby polynomials are fit to source Euler angles; these evaluate very quickly**

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13



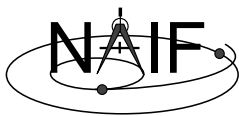
Precedence Rules for Text and Binary PCKs

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- **If two (or more) binary PCKs with functionally equivalent data are loaded, a later loaded file takes precedence.**
- **Loading one text PCK that supersedes another can lead to errors if data from the “old” PCK remain in the kernel pool.**
 - It’s essential to unload the old PCK before loading the new one.
 - » Use UNLOAD or KCLEAR to unload the old text PCK.
 - This problem doesn’t apply to binary PCKs.
- **If both a binary and a text PCK provide orientation for the same frame, data available from the binary PCK always take precedence over data available from the text PCK.**
 - This is independent of file loading order
 - **Note: this situation does NOT occur with the binary PCKs discussed in this tutorial.**

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14



Tools for use with Binary PCKs

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- Use the *commnt* utility to access a binary PCK comment area
 - Read, extract or insert metadata
- Use the *brief* or *spacit* utility to summarize a binary PCK
 - *brief* is easier to use; *spacit* provides more information
- Non-native binary PCKs can be read without first being converted to the native binary form
 - If you need to write to a non-native binary PCK you must first convert it to native binary form using *bingo* or the pair of *toxfr* and *tobin* from the NAIF Toolkit
 - Converting a non-native binary PCK to native form will also speed up data access somewhat



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Lunar Frames Kernel



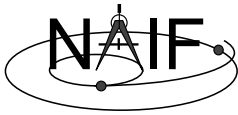
Lunar Frames Kernel

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- **A lunar frames kernel is maintained and available from NAIF. It has four functions.**
 - **Make the names of two lunar frames—Principal Axes (PA) and Mean Earth (ME)—known to the SPICE system.**
 - » **Note: the PA and ME frames are unique to a particular JPL-produced lunar and planetary ephemeris (DE/LExxx).**
 - **Connect the name PA frame to the high accuracy lunar orientation PCK that implements the PA orientation (relative to ICRF).**
 - **Provide specifications, in the SPICE context, for implementing the rotation between the PA frame and the ME frame**
 - **Provide generic frame names, aliased to the ME and PA frame names, that need not be changed when the ME or PA frame name changes due to use of new defining data**
 - » **The frames to which these aliases “point” will be updated whenever a new binary lunar orientation PCK is produced.**
- **To access the PA or ME frame you must load the lunar FK into your program in addition to the lunar binary PCK that implements the lunar PA frame orientation**

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17



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Association Frames Kernels for the Earth and the Moon



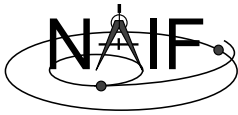
Introduction

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- In most SPICE modules that deal with one or more reference frames the name(s) of that/those frame(s) must be provided as input argument(s), for example:
 - `CALL SPKEZR (target,time, ref_frame, observer, correction, state, lighttime)`
- NAIF's SPICE developers assumed there would usually be only one body-fixed reference frame associated with each natural body during a program run.
 - Thus a specific body-fixed frame name would rarely be needed as an input to modules dealing with body-fixed frames
 - Instead, SPICE could use the body-fixed frame associated with a given body simply by knowing the body name or ID
 - » For most bodies SPICE associates the body with a frame named `IAU_<body name>` (example: `IAU_MOON`)
 - » This is known as the default body-fixed frame
- **Bad assumption... at least for the Earth and the Moon!**
 - Multiple body-fixed frames exist for the Moon and Earth
 - The default body-fixed frame for the Moon and the Earth, for which the defining data are provided in a generic text PCK (taken from an IAU report) are very inaccurate representations of the actual orientations of these bodies

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19



Better Choice for the Default

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- For the Earth and the Moon there are other choices for body-fixed frame that are almost certainly better than the default body-fixed frame conjured up by SPICE

<u>Body</u>	<u>SPICE Default Body-fixed Frame</u>	<u>Better choices</u>
Earth	IAU_Earth	ITRF93 ITRFxx (in the future)
Moon	IAU_Moon	Moon_PA Moon_ME

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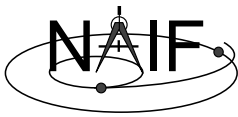
20



The Problem

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- The SPICE modules that make use of the default body-fixed reference frame are:
 - ET2LST, ILLUM, SRFXP, SUBPT, SUBSOL (and their C, Icy and Mice equivalents)
 - any indirect use of the above modules resulting from use of a parameterized dynamic frame
- NAIF rules regarding stability of our software offerings prevent us from changing the designs of those modules
 - So we must provide you means to change the default body-fixed frame associated with any solar system body of interest to you



Changing the Default Body-Fixed Frame Name

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- All bodies for which a body_fixed frame is defined by the IAU, and where the defining data are found in a SPICE text PCK file, have an associated default body-fixed frame name within SPICE:
 - The name style is: IAU_<body name>
 - Examples: IAU_MARS, IAU_MOON, IAU_EARTH
- A different default body-fixed frame name can be assigned at run time by placing the following assignment in any text kernel that is loaded into your program:

```
OBJECT_<body name>_FRAME = '<new default frame name>'
```

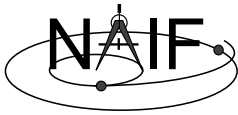
 - Example: OBJECT_MOON_FRAME = 'MOON_ME'



Using “Association” FKs to Change the Default

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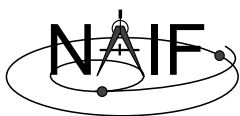
- For the Earth and the Moon changing the default body-fixed frame name as described on the previous page can be accomplished by loading the appropriate “association” frame kernel provided by NAIF. The association kernels available are shown below
 - For the Earth:
 - » `earth_assoc_itrf93.tf`
 - For the Moon:
 - » `moon_assoc_me.tf`
 - » `moon_assoc_pa.tf`
- These kernels are available on the NAIF server
 - For the Earth:
 - » `ftp://naif.jpl.nasa.gov/pub/naif/generic_kernels/fk/planets/`
 - For the Moon:
 - » `ftp://naif.jpl.nasa.gov/pub/naif/generic_kernels/fk/satellites/`



Kernel Usage Summary

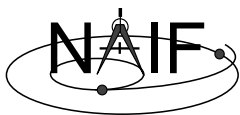
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- To use high accuracy Earth orientation data
 - Load one or more binary Earth PCKs
 - » If a long-term predict is used, load this kernel *before* loading any kernel containing reconstructed data.
 - If your application uses the default Earth body-fixed frame (pg. 21), load an Earth frame association kernel making ITRF93 the default earth body-fixed frame.
- To use high accuracy Moon orientation data
 - Load the current binary lunar PCK.
 - Load the current lunar FK.
 - If your application uses the default Moon body-fixed frame (pg. 21), load a Moon frame association kernel making either MOON_ME or MOON_PA the default.
 - » If necessary, your application can unload one of these kernels and load the other as many times as required.
 - Use UNLOAD to unload a currently loaded frame association kernel



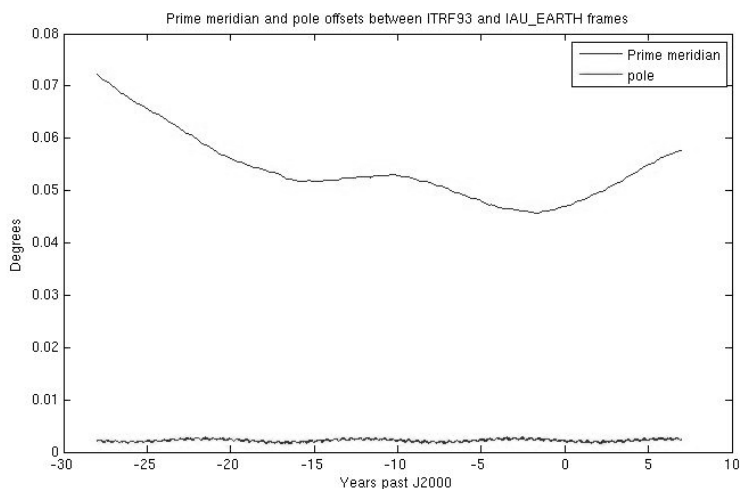
Backup

Earth and Lunar Frame Comparison Plots



IAU_EARTH vs ITRF93 Comparison Plot

Difference between the IAU_Earth frame and the ITRF93 frame

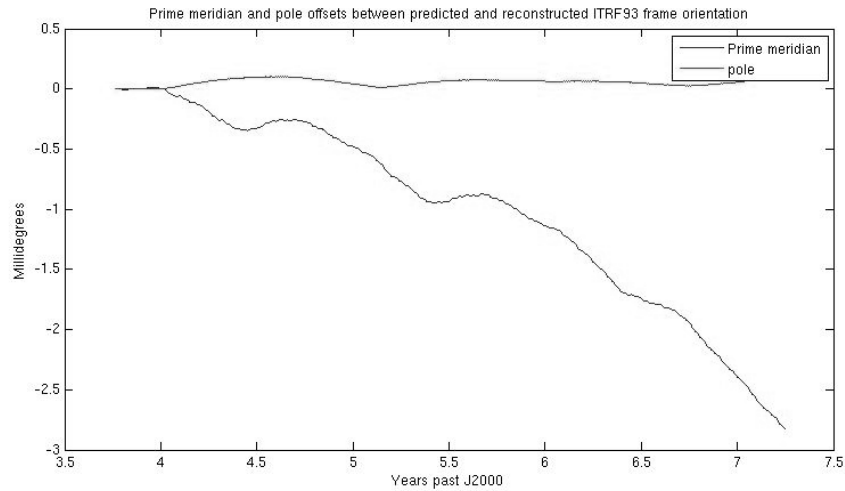




Earth Predicted vs Reconstructed ITRF93 Plot

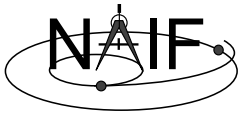
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Difference between predicted and reconstructed orientation of ITRF93 frame



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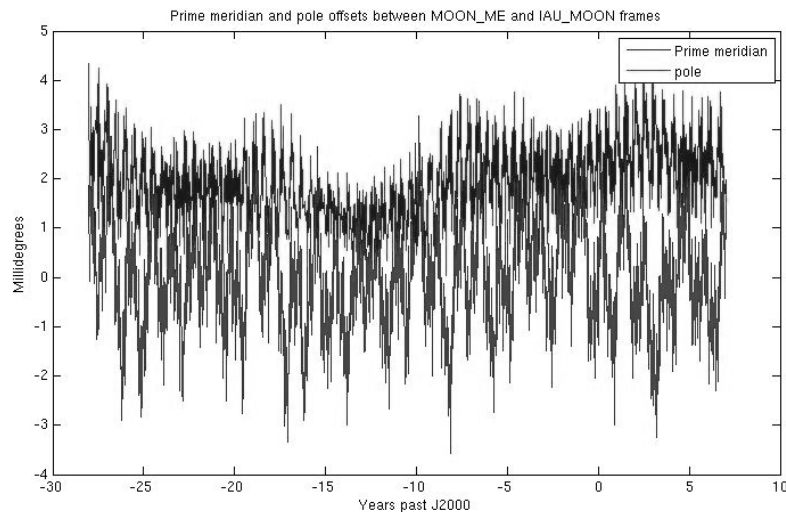
27



IAU_Moon vs MOON_ME Comparison Plot

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Difference between the IAU_Moon frame and the Moon_ME frame (equivalent to the Moon_ME_DE403 frame)



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28