Cross-Calibration Procedures in AE9/AP9/SPM

25 April 2016

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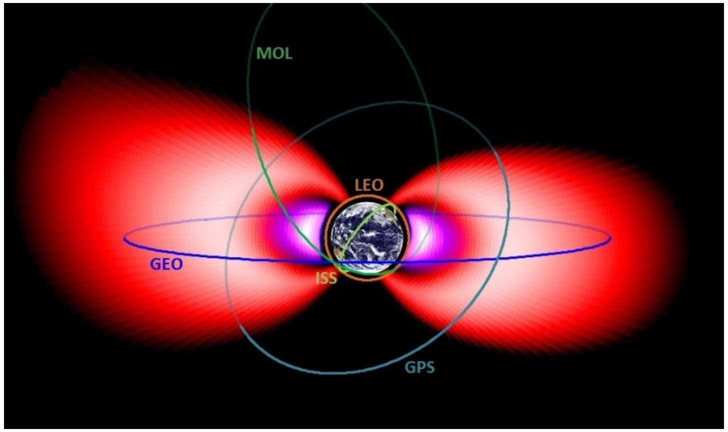
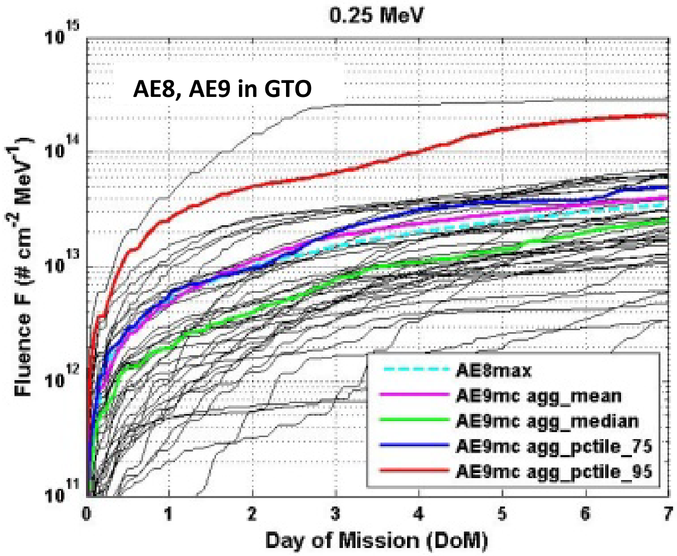
Integrity ★ Service ★ Excellence

AE9/AP9/SPM

- AE9/AP9/SPM specifies the natural <u>trapped</u> radiation environment for satellite design and mission planning
- It improves on legacy models to meet modern design community needs:
  - Uses 37 long duration, high quality data sets (many covering a full solar cycle)
  - Full energy and spatial coverage—plasma added
  - Introduces data-based uncertainties and statistics for design margins (e.g., 95th percentile)
  - Dynamic Monte Carlo scenarios provide worst case estimates for hazards (e.g., SEEs)
  - Architecture supports routine updates, maintainability, third party applications
- Version 1.00 released in Sep 2012
- Version 1.20 released in Feb 2015
- Version 1.30 released in Feb 2016





Cross-Calibration Objectives

- For AE9/AP9/SPM, on-orbit intercalibration of instruments is required in order to—
  - Determine systematic offsets between data sets (bias)
  - Determine measurement uncertainty (random error)
- Data sets are corrected for bias relative to an instrument nominally identified as a "gold" standard
  - Proton standard: GOES 8/SEM
  - Electron standard: CRRES/MEA+HEEF
- Random error is an input into development of flux maps
- Applications of standardized cross-cal for the models:
  - Supports "turn-key" ingestion of new, large data sets
  - Minimizes discontinuities at edges of data set coverage

AFRL

General Procedures (1)

- Use lowest level of data possible
  - For example, dosimeter channel results rather than results from inversions
- Construct comparable channels
  - Interpolate from standard channel energies to energies of target instrument
  - Integrate from standard differential channels to compare to target integral channels
- Typically use omnidirectional averaged data
- If available, use multiple pair-wise cross-cals
  - Whether average or best of multiple cross-cals is adopted depends on available statistics
- Bias and error estimates are produced independently for each channel where comparisons are possible
  - For target channels with no overlap, values from the channel closest in energy are used

General Procedures (2)

- Cross-cal uses cleaned data
  - Remove backgrounds, contaminated data, etc.
- Statistics based on linear fit to log data
  - Typically require slope=1 (i.e., same bias offset is used at all flux levels)

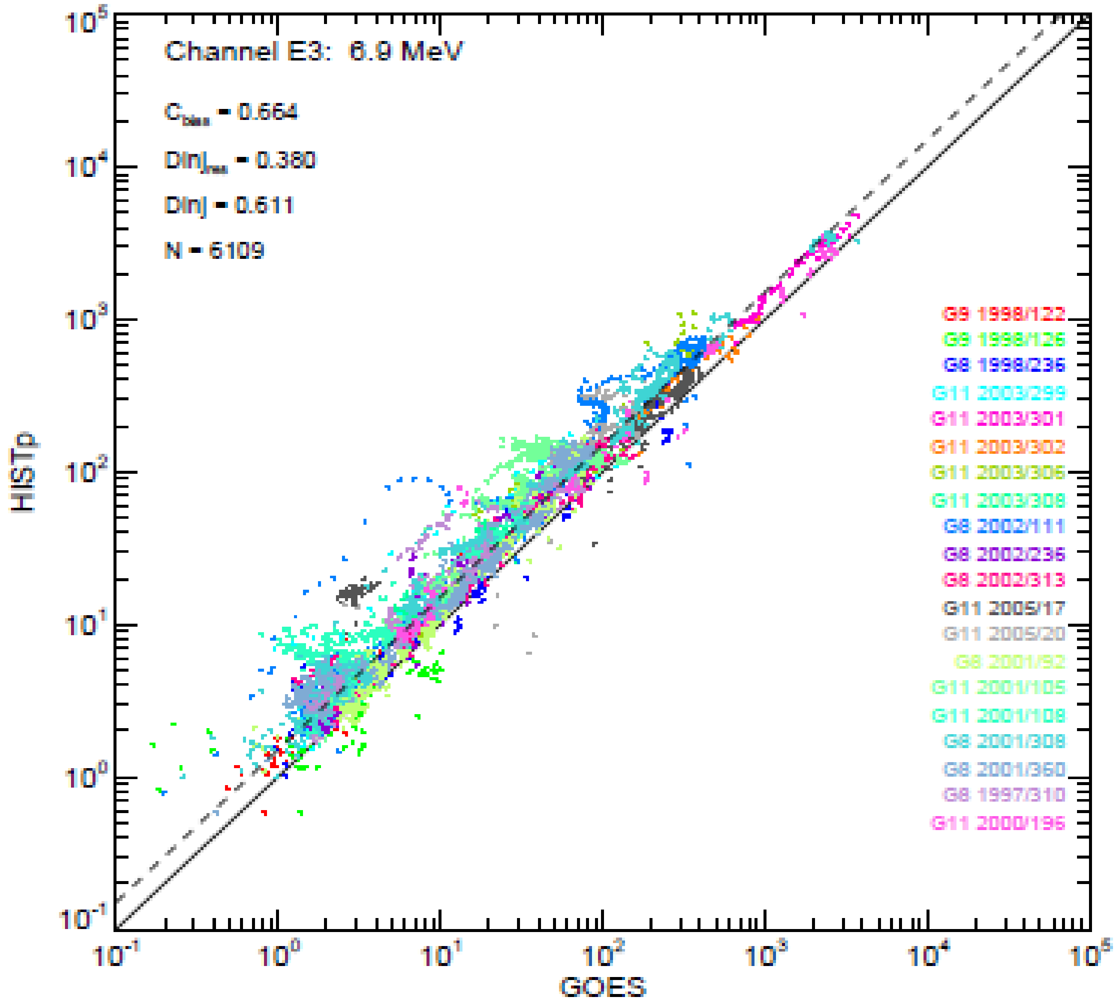


Figure shows SPE observations, Polar/HISTp vs. GOES/SPM, 6.9 MeV channel

Definition of Statistics

The principal intercalibration statistics needed for incorporating data sets are referred to as *cbias* and *dlnj.*

- Take $\mathbf{J}_A$ and $\mathbf{J}_B$, series of joint flux observations by satellites A and B, respectively (A=standard, B=target), for a single energy channel.
- Find median ratio

  $R = \mathrm{median}(\mathbf{J}_B / \mathbf{J}_A)$.
- The bias of $\mathbf{J}_B$ relative to $\mathbf{J}_A$ is described by

  $cbias = R$.
- The satellite B series is adjusted

  $\mathbf{J'}_B = \mathbf{J}_B / R$,

  so that the series $\mathbf{J}_A$ and $\mathbf{J'}_B$ have the same medians.
- The residual error is

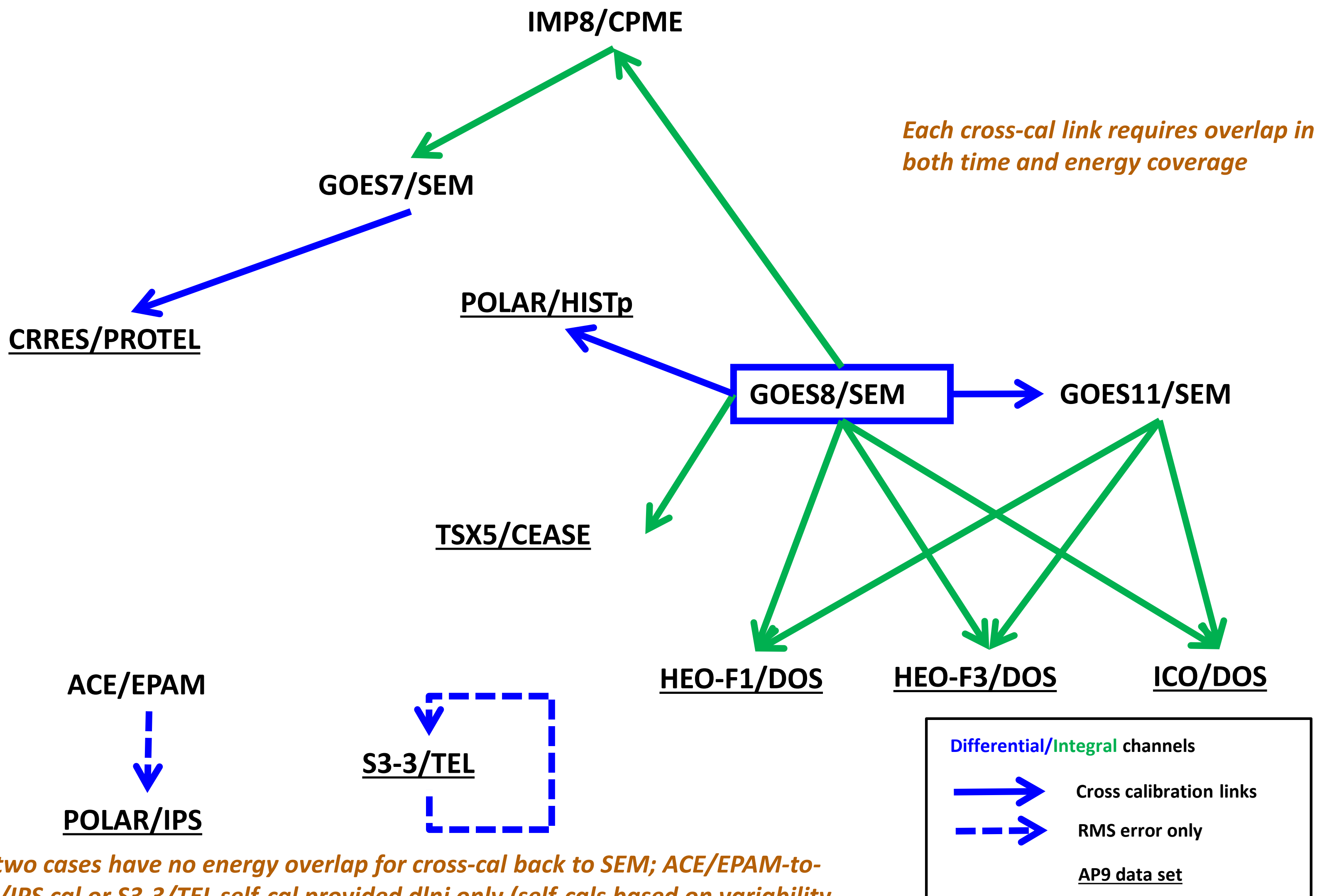
  $\mathbf{RE} = \ln(\mathbf{J'}_B / \mathbf{J}_A)$.
- The random error of series $\mathbf{J}_B$ is

  $dlnj = [(1/n)(\Sigma\, \mathbf{RE}^2)]^{0.5}$.

Procedure for Protons

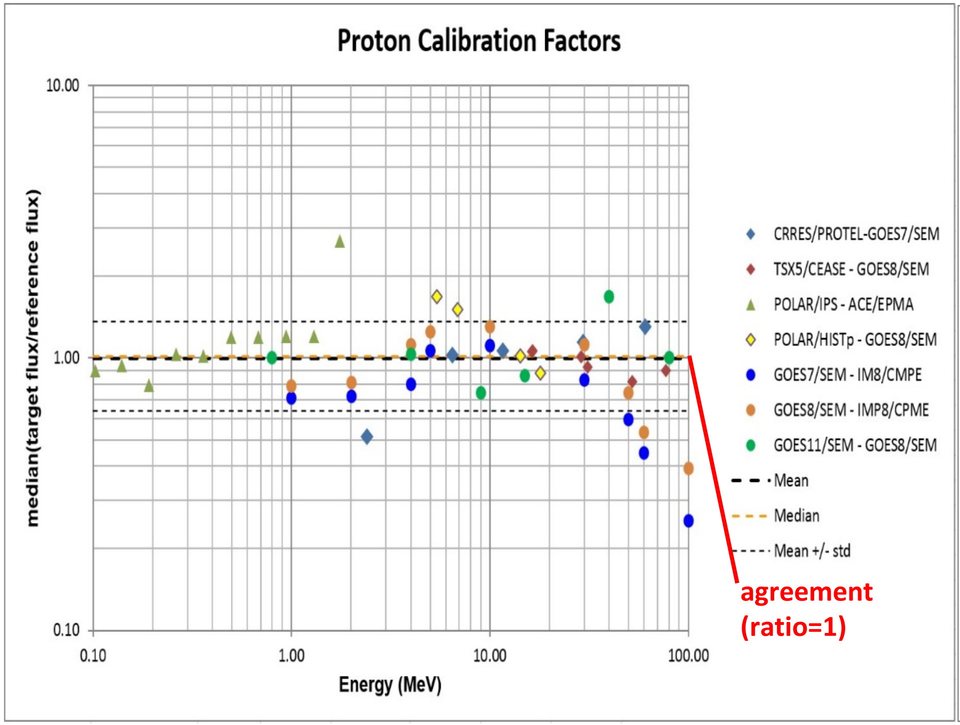
- GOES SEM used as "gold" standard
- Correction made to differential energy values for published channel values
  - Better accounts for monotonically decreasing spectra across channels (Ginet et al., IEEE TNS, 57:3135)
- Use SPE observations for conjunctions
  - Time periods from NGDC SPE list
  - Require >3 pfu in SEM channel (>10, >30, >60, >100 MeV)
  - Require spacecraft L_m>5.5

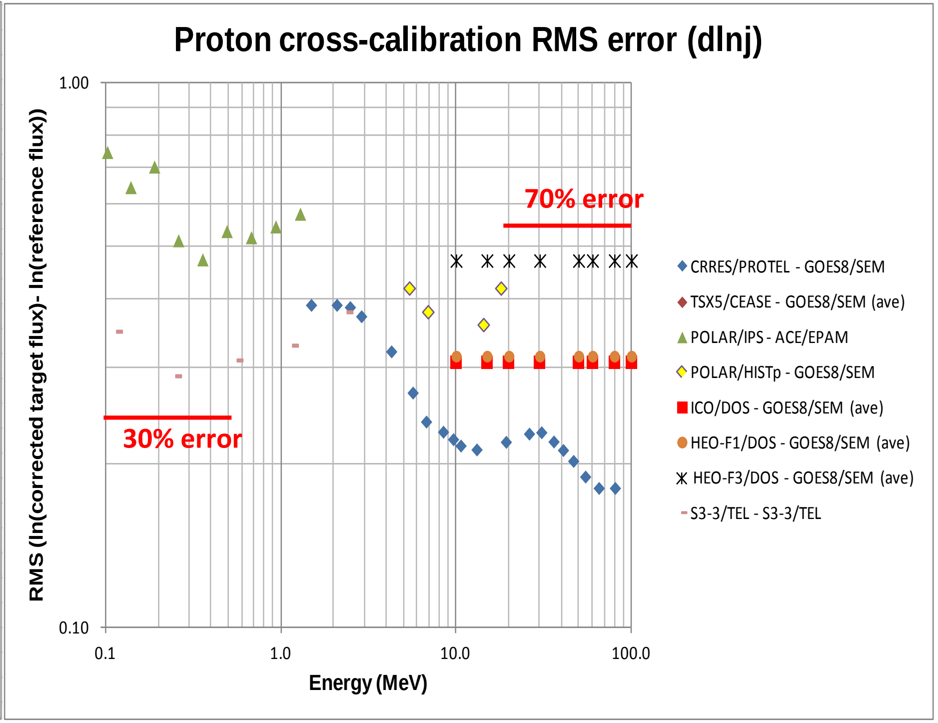
Proton CrossCal Tree



These two cases have no energy overlap for cross-cal back to SEM; ACE/EPAM-to-POLAR/IPS cal or S3-3/TEL self-cal provided dlnj only (self-cals based on variability within the data set from uniform locations/time periods)

Proton Results



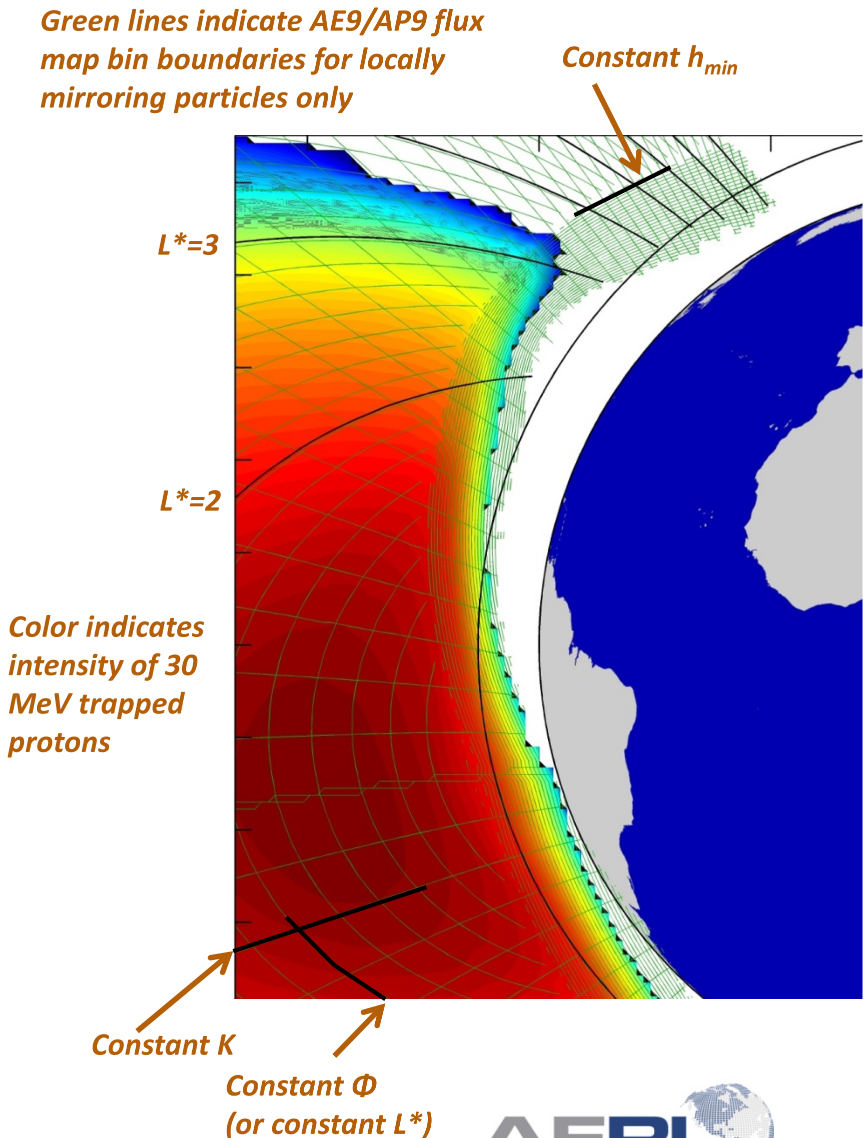


Some results above were averaged across channels for use in model development; assumed values for ICO and HEO are not shown

- Typical cbias values correspond to agreement within 10-20%
- Typical dlnj values correspond to 30-70% error

Magnetic Coordinates

- For electrons, SPE-like “standard candles” aren’t available, so magnetic conjunctions are used for cross-cal
  - Same is true for protons if SPEs aren’t useable, if:
    - Too few SPEs for statistics (like now?)
    - Low inclination LEO satellites
    - Can use trapped protons for cross-cal in these cases
- Option (1): use conjunctions in L and B/B_0
  - Used as native grid in legacy AE8/AP8 flux maps
  - Generally used for AE9/AP9 cross-cal to date
- Option (2): use conjunctions in AE9/AP9’s native flux map grid:
  - High altitude grid uses magnetic invariants K (related to equatorial pitch angle) and Φ (related to L*)
  - Low altitude grid uses K and h_{min} (=minimum altitude encountered on a drift path)
  - Grid parameters and bin sizes were selected to minimize trapped particle variation within bins
  - Limited use in AE9/AP9 cross-cals to date, but expected to be used more going forward



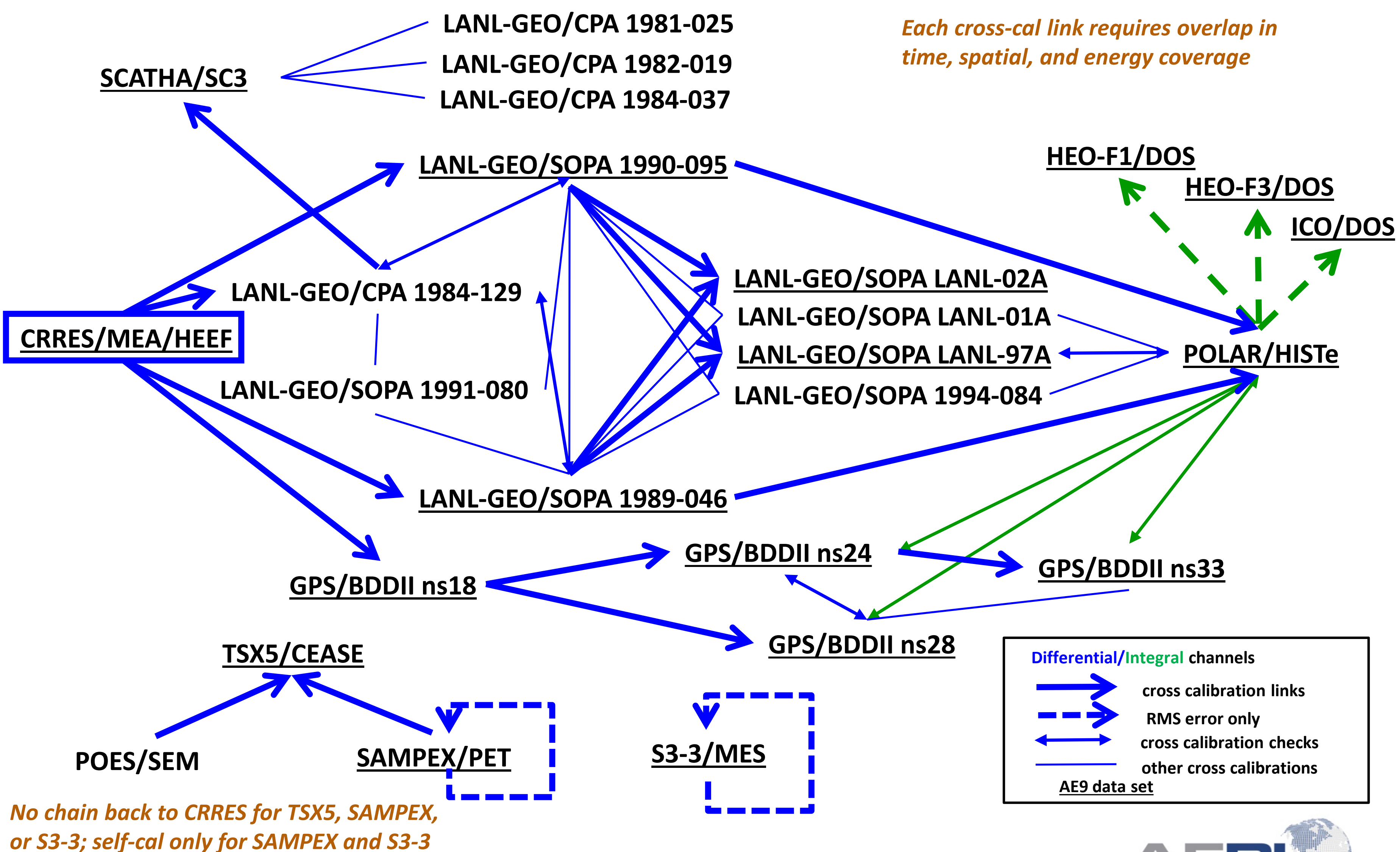
Procedure for Electrons

- CRRES MEA+HEEF used as "gold" standard
- Specifically, used data set version based on MEA+HEEF intercalibration (Johnston et al., 2014, AFRL-RV-PS-TR-2014-0016)
- Use magnetic conjunctions (option 1)
  - Eliminate active times and SPE periods
  - High altitudes: magnetic conjunction criteria based on Friedel et al. (2005, *Sp. Weather*, 3:S09B04)
  - Match L*, B/B_0, and UT
  - Assume little MLT variation
  - Adjust constraints for necessary statistics
  - Low altitudes: too much variation across L* and B/B_0 ranges, so add geographic constraints (e.g., GLON) or use model invariant coordinates (e.g., $K\text{-}h_{min}$)

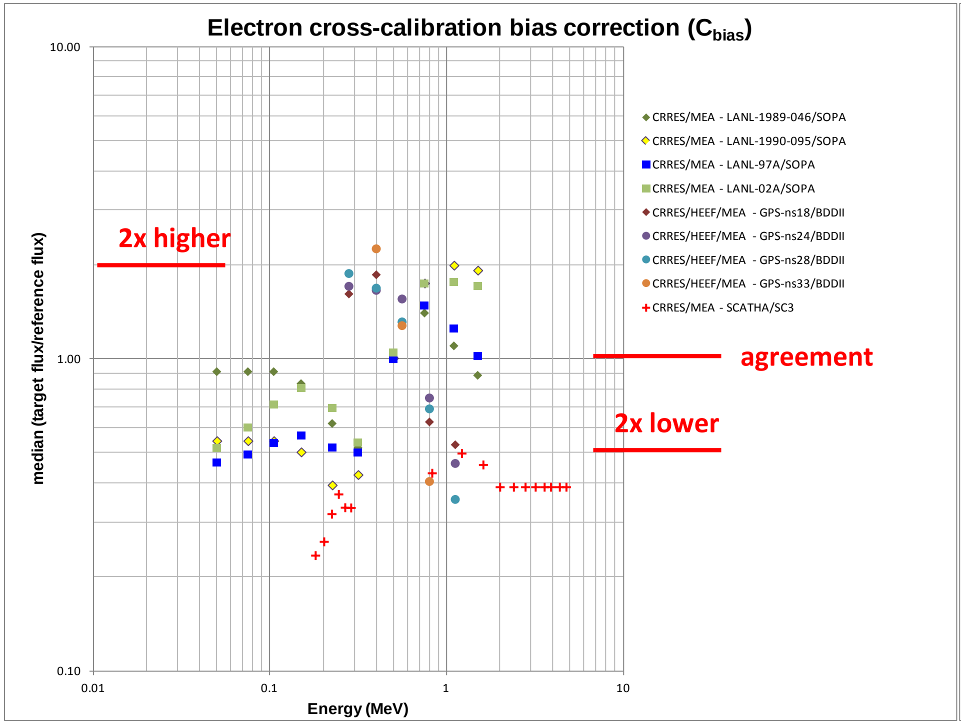
Criterion	AE9 CRRES—GEO	Friedel et al.
L*	<6.5	<6.0
ΔL*	<0.1	<0.1
Δ(B/Bo)	<0.1	<0.1
ΔUT	<3-4 hr	<3 hr
MLT	4-8 or 16-20	4-8 or 16-20
ΔMLT	N/A or <2 hr	<2 hr
Kp	<3 last 48 hr	<2 last 48 hr

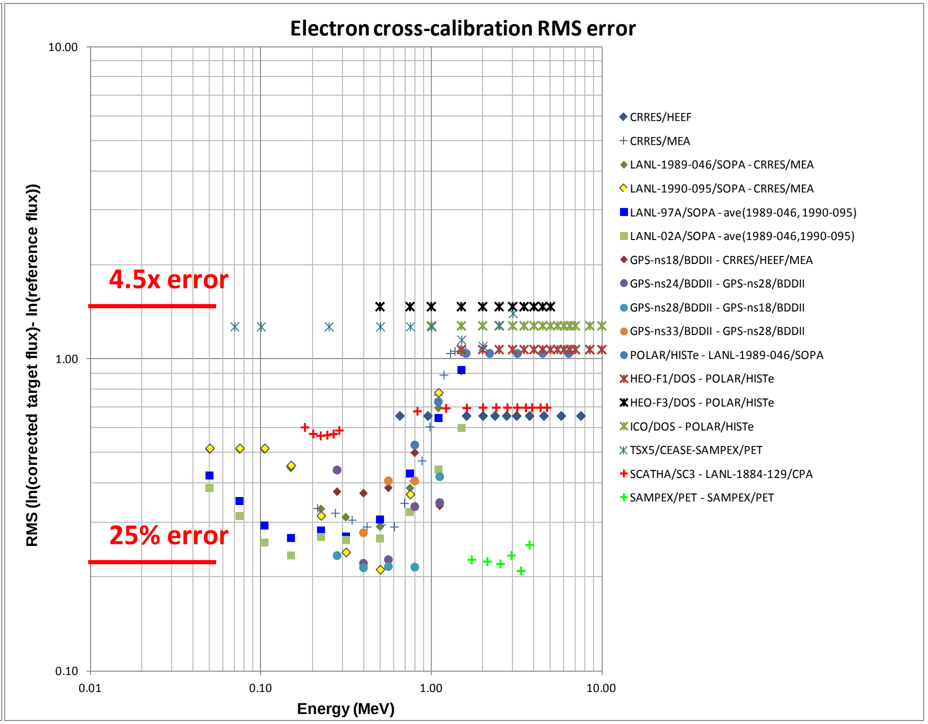
Criterion	AE9 TSX-5--SAMPEX
L*	2.5<L*<6.5
ΔL*	<(lesser of 0.1 and 5%)
Δ(B/Bo)	<0.1
ΔUT	<4 hr
ΔGLON	<60 deg
GLAT	same hemisphere

Electron CrossCal Tree



Electron Results





- Larger cbias differences (factor of 1.5-2.5) than protons
- Larger dlnj values (25%-factor of 4 error) than protons
- Reflects greater challenges for electron measurements plus weaker intercomparisons (conjunctions not matching environment)

Further Information

- More details are in the AE9/AP9/SPM technical documentation (some now complete, some forthcoming), such as
  - Descriptions of cross-calibration and data cleaning procedures
  - Reports on cross-calibrations for individual data sets
- Documents which are currently available are on our model distribution website:
  - https://www.vdl.afrl.af.mil/programs/ae9ap9/