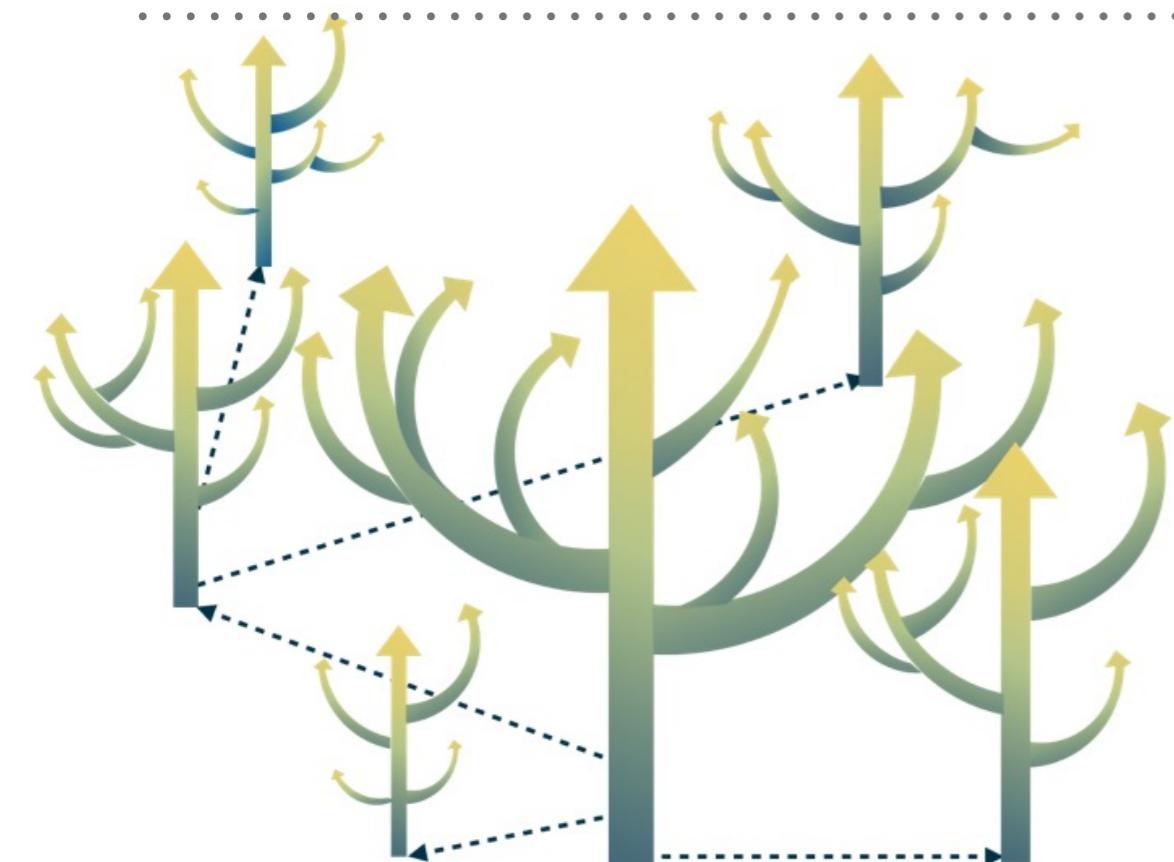


# DEVELOPING THE LDI AND LCI GEOMAGNETIC INDICES: AN EXAMPLE OF THE AUL FRAMEWORK.



*A. Halford, C. Cid,  
A. Guerrero,  
E. Saiz, and A. Kellerman*

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Article Number	A34
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Published online	26 September 2019

J. Space Weather Space Clim. 2019, 9, A34

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SPACE SCIENCE & SPACE PHYSICS

Editors' Highlights



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# Highlighting the Path from Space Weather Science to Applications

The transition of space weather science from research to operations needs a framework with both good science and a good dialogue with end users.

SOURCE: *Space Weather*

Establishment of end users and their requirements



Initial integration and verification



Complete Validation

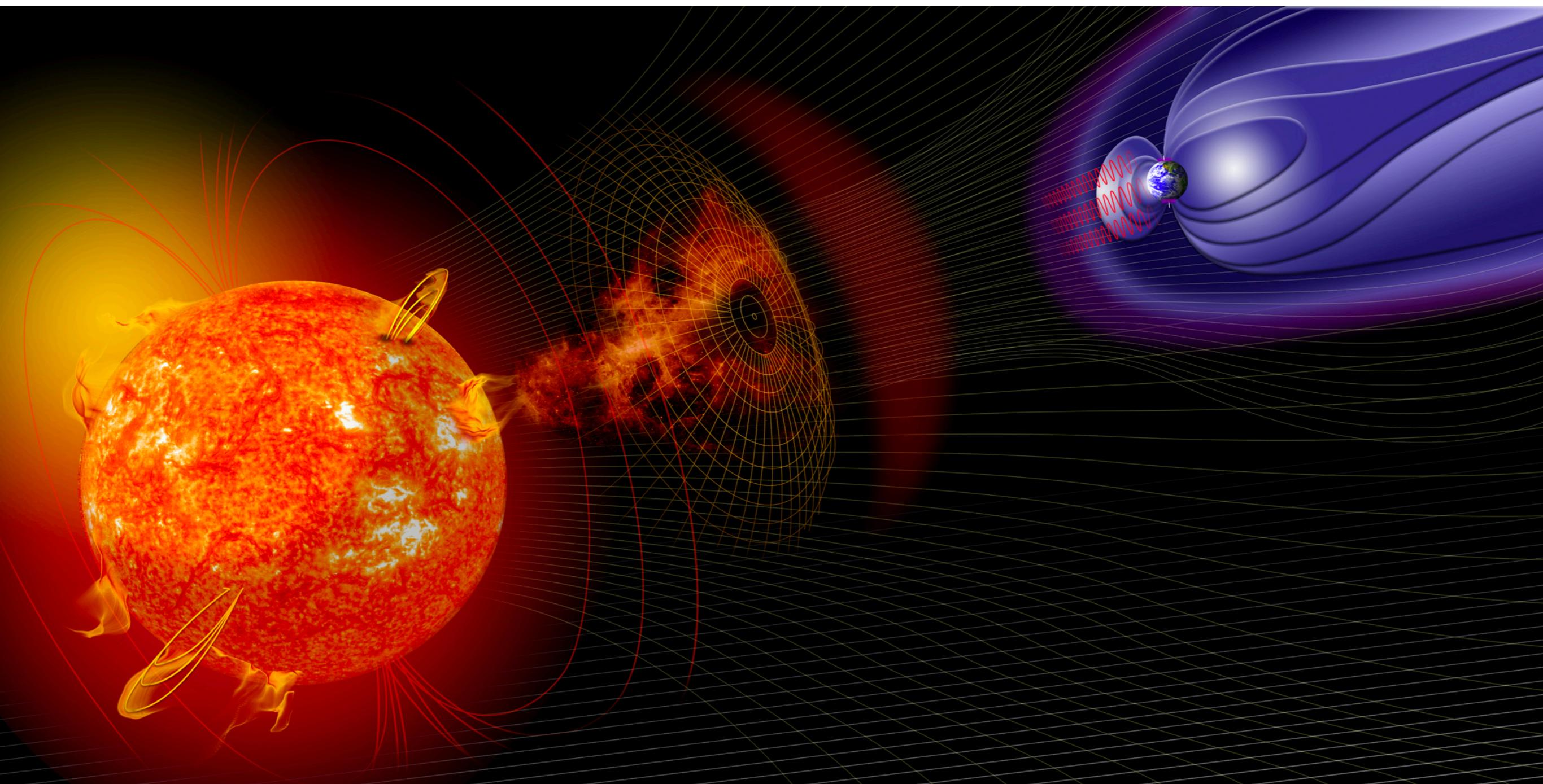


Validation in "real world" environment



# Space Weather:

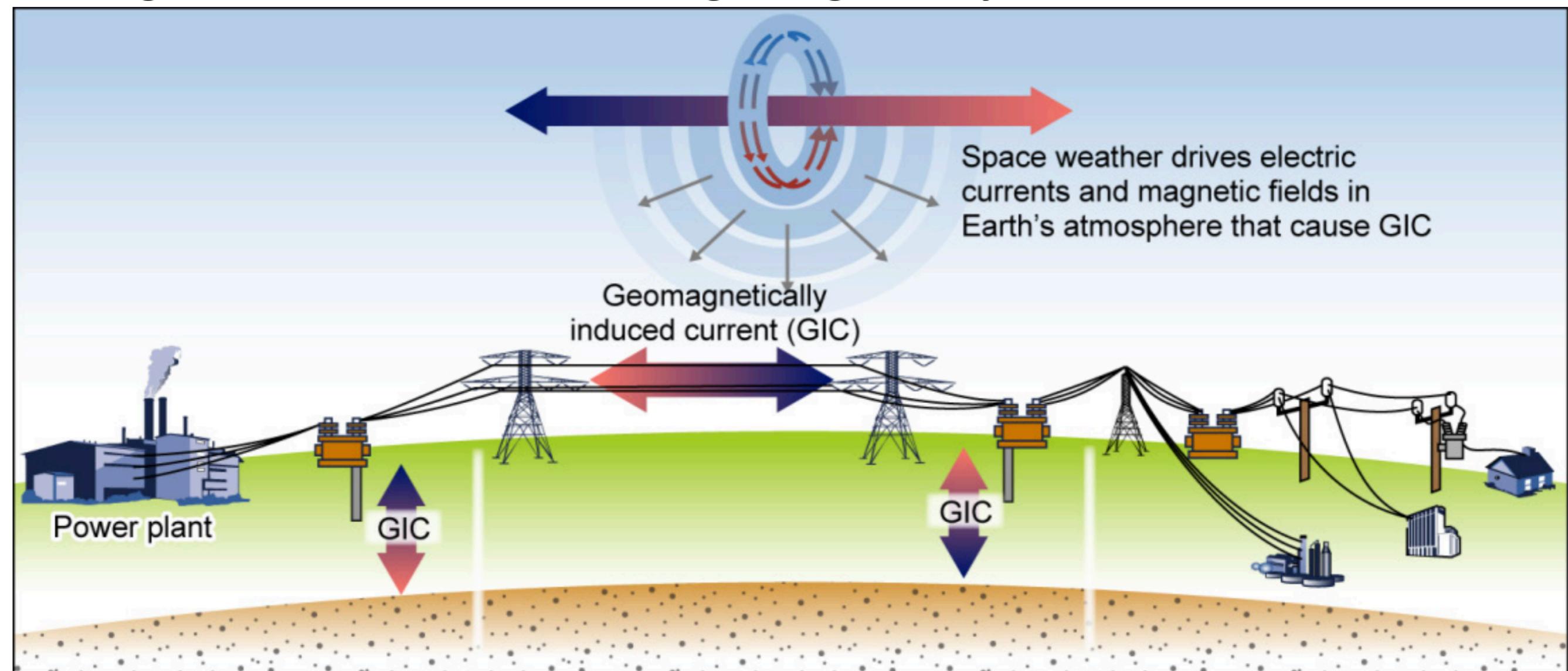
The study of how dynamics on the Sun and in the Earth -Space environment affect technology and humans.



# Geomagnetically Induced Currents:

A space weather impact that affects electrically conducting infrastructure

**Geomagnetic disturbances can lead to geomagnetically induced current.**



# Geomagnetically Induced Currents:

A space weather impact that affects electrically conducting infrastructure

NATIONAL AERONAUTICS  
AND SPACE ADMINISTRATION

**Space Plasma Physics**  
Marshall Space Flight Center  
Huntsville, AL

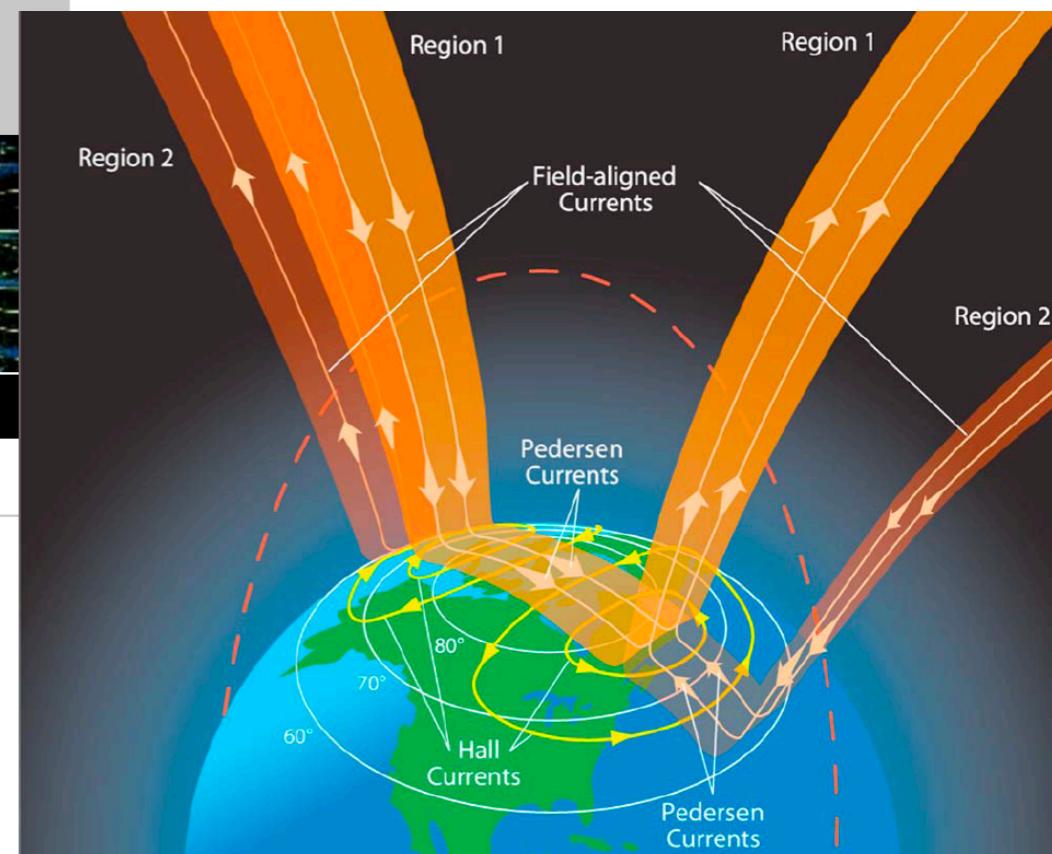
MSFC NSSTC Science@NASA Space Weather Plasmasphere

Home Projects News Science Education Resources Space Physics

**Who cares? Anyone living on Earth!**

PJM Public Service Step Up Transformer  
Severe internal damage caused by the space storm of 13 March, 1989.

The screenshot shows the homepage of the NASA Space Plasma Physics website. It features the NASA logo and the text "NATIONAL AERONAUTICS AND SPACE ADMINISTRATION". Below this, it says "Space Plasma Physics" and "Marshall Space Flight Center Huntsville, AL". There is a navigation bar with links for MSFC, NSSTC, Science@NASA, Space Weather, and Plasmasphere. On the left, there is a vertical menu with links for Home, Projects, News, Science, Education, Resources, and Space Physics. The "Space Physics" link is highlighted with a black background. In the center, there is a banner with the text "Who cares? Anyone living on Earth!" and an image of a transformer. To the right, there is a diagram of Earth showing field-aligned currents and Pedersen currents. At the bottom, there are two images: one of a transformer with scaffolding around it, and another of a destroyed building.



Le, G., J. A. Slavin, and R.  
J. Strangeway

# *Geomagnetically Induced Currents:*

A space weather impact that affects electrically conducting infrastructure

## Space Weather

Research Letter |  Free Access |

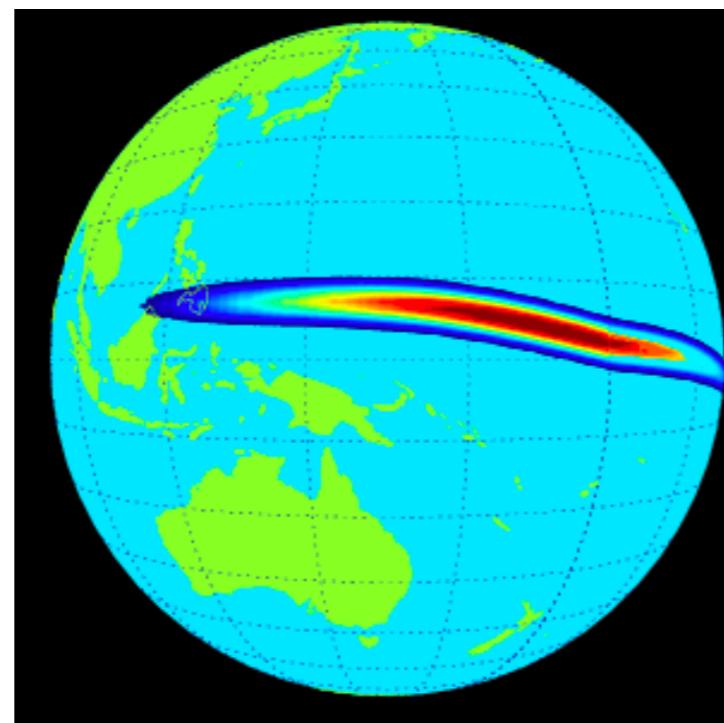
### Interplanetary shocks and the resulting geomagnetically induced currents at the equator

B. A. Carter , E. Yizengaw, R. Pradipta, A. J. Halford, R. Norman, K. Zhang

First published: 06 August 2015 | <https://doi.org/10.1002/2015GL065060> | Citations: 42



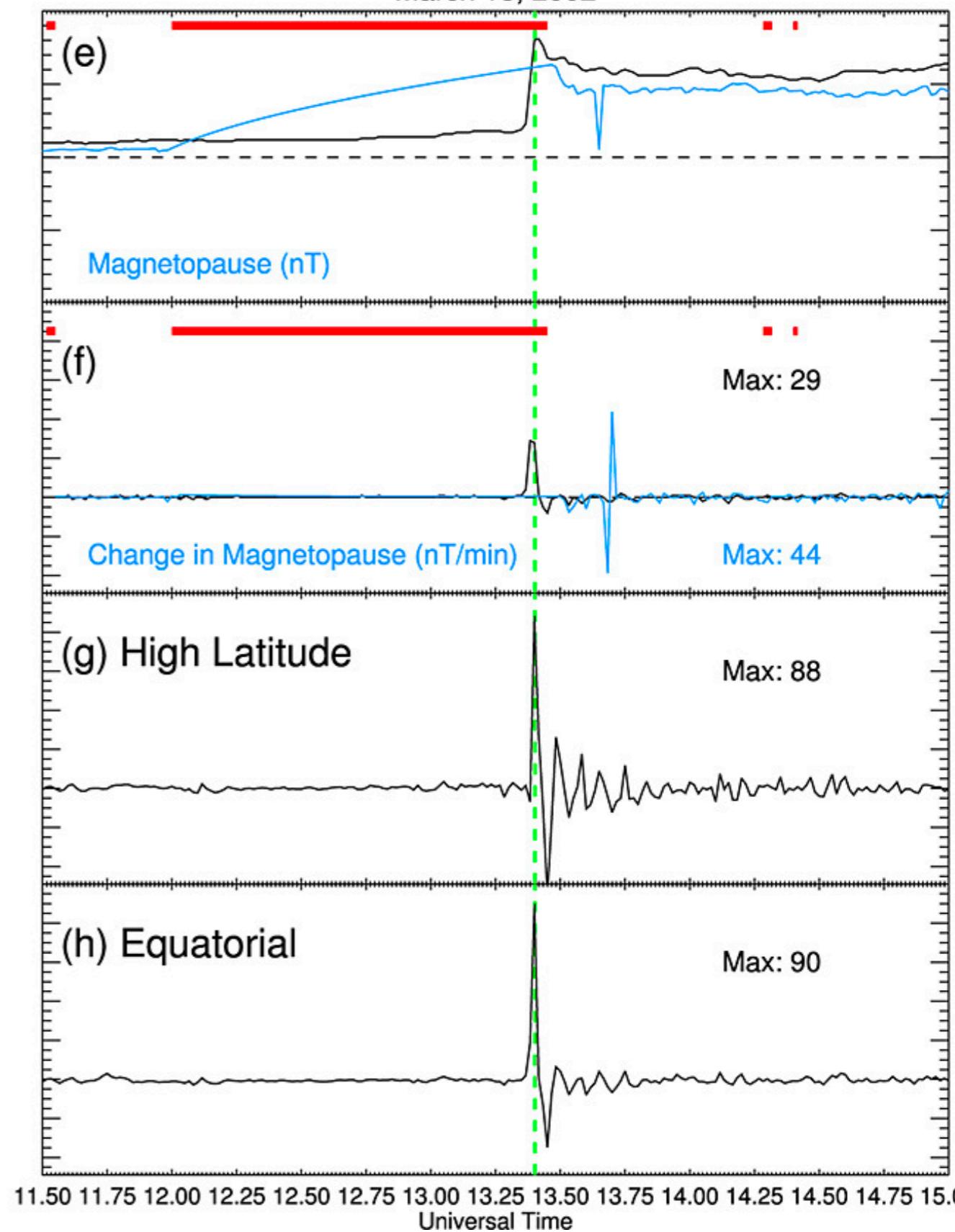
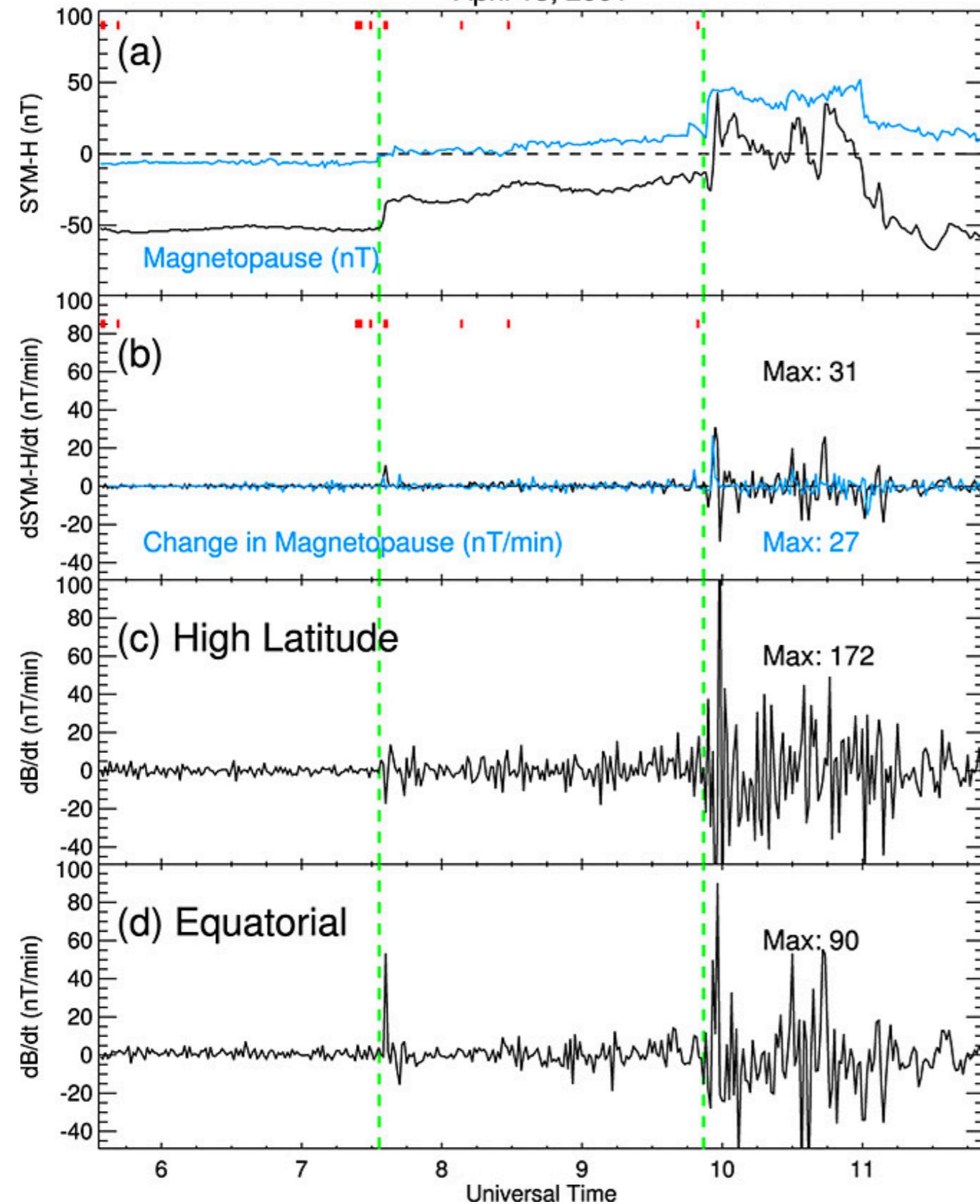
     
Figures References Related Information



# *Geomagnetically Induced Currents:*

April 13, 2001

March 18, 2002



# *A Transdisciplinary endeavor :*

*Researchers & industry partners working to create applications for immediate use.*



Fig 6: Failure in HV winding of Lethabo #6

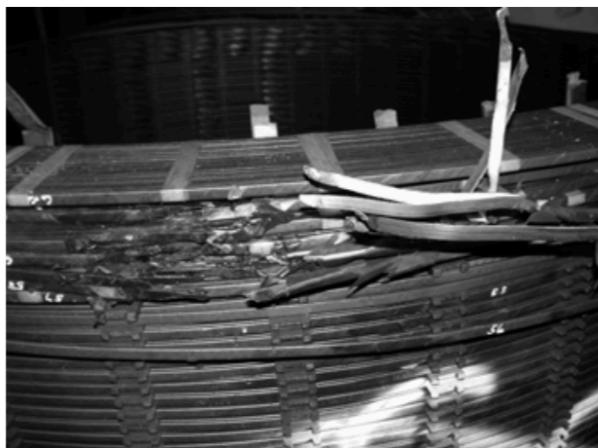
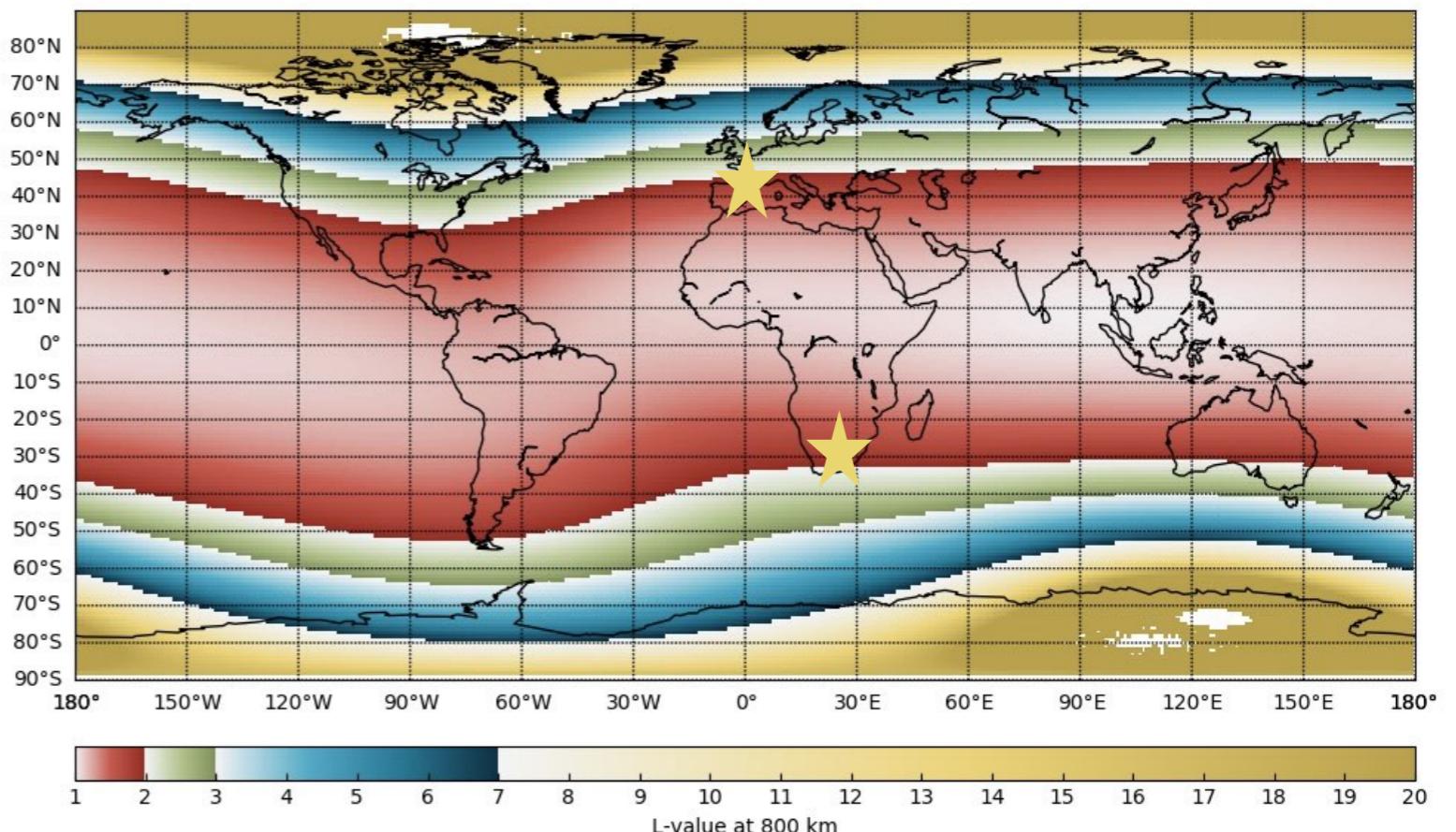


Fig 7: Failure in HV winding of Matimba #4



Fig 8: Overheating of LV terminals of Tutuka #1

*Gaunt and Coetze 2007*

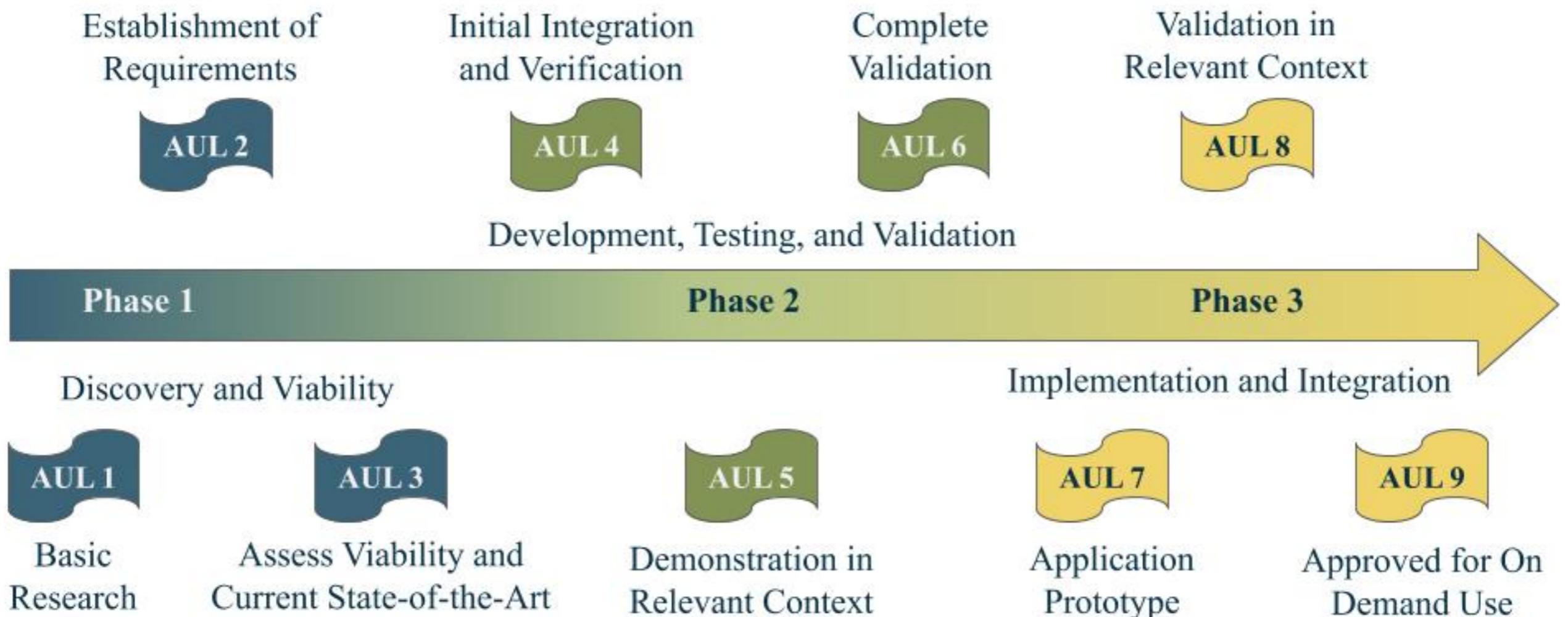


# *The Valley of Death: Research to Operations*



# *A Transdisciplinary endeavor:*

*Researchers & industry partners working to create applications for immediate use.*



# *A Transdisciplinary endeavor:*

## **AUL 1: basic research**

### *Phase 1: Identify Application, User, and Discovery and Viability*

*Milestones:*

- a. Basic research is documented and disseminated for the project, so that the usability may be assessed by way of the AUL method.
- b. Ideas for how the project output(s) may enhance decision making or be applied to an end user application are generated.
- c. Potential interested users are identified, but not necessarily contacted. This could occur, for example, through a literature search, conference attendance, or workshop participation.

## **AUL 2: establishment of users and their requirements for a specific application**

*Milestones:*

- a. Decide on the user(s), contact the user(s), and establish a reliable channel of communication that is used at a suitable frequency.
- b. Formalization of the application and project concept.
- c. Identification and formalization of the requirements and metrics necessary for successful application of the project for the user's needs.

## **AUL 3: assess viability of concept and current state of the art**

*Milestones:*

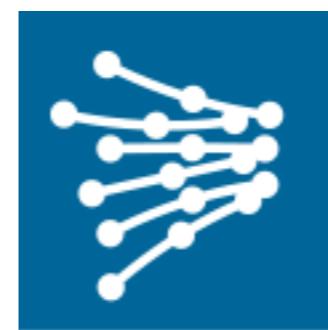
- a. Documentation and dissemination of the project's expected advancements from the current state-of-the-art used towards the identified application along with the proposed metrics for the specified application.
- b. Perform the initial analysis of the individual project components, to determine the viability and feasibility of the entire project.
- c. Complete a detailed characterization of the baseline performance and limitations with respect to the application.
- d. Determine the viability and feasibility of the proposed project towards improving upon the state of the art for the identified application. If the project is deemed not viable or feasible, the project is put on hold until the identified roadblocks are removed.

# *A Transdisciplinary endeavor:*

*Phase 1: Identify Application, User, and Discovery and Viability*



Universidad  
de Alcalá



**RED**  
**ELÉCTRICA**  
DE ESPAÑA



**esa**

**European Space Agency**

# *A Transdisciplinary endeavor:*

*Phase 1: Identify Application, User, and Discovery and Viability*

*Identification of a need for a localized set of indices to assess risk.*

*Identification of a need for indices which were not dependent on data not always reliable during extreme events.*

*Does the current state of the art (Dst) provide sufficient data for the needs of the users?*

*Have the users identified a need for this application?*

# *A Transdisciplinary endeavor:*

*Phase 1: Identify Application, User, and Discovery and Viability*

*Reaching out:*

*“This user was aware of space weather but had not been previously involved in any project on this issue. Moreover, they explained that they were aware of large solar flares, but they could not find any relationship between those large flares and the failures in their capacities. Initial conversations between UAH scientists and REE experts were very useful to show to REE that an increase of light coming from the Sun (i.e. the flare) cannot disturb by its own any power network, but mass ejections reaching the terrestrial environment (which sometimes are associated with flares) may well disturb it as had already occurred in Quebec or South Africa.”*

# *A Transdisciplinary endeavor:*

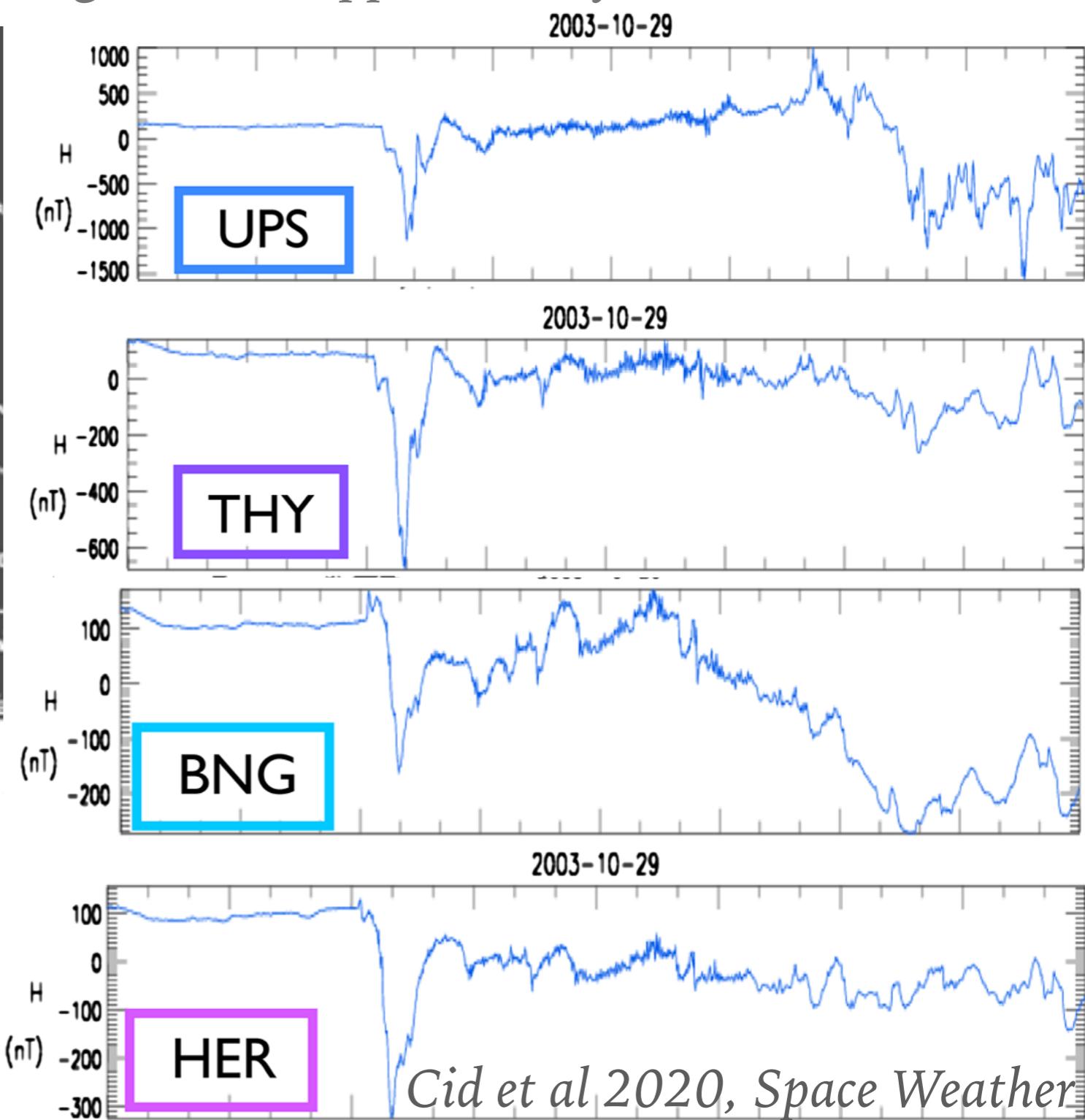
*Phase 1: Identify Application, User, and Discovery and Viability*

*Initial Study of Current State of the Art:*

*Geomagnetic indices commonly used by the scientific community like Kp or Dst, or even Sym-H, were considered - but no relationship was found. A fast conclusion to the study might be that the Spanish power grid is not affected by space weather.*

# *A Transdisciplinary endeavor:*

*Researchers & industry partners working to create applications for immediate use.*



# *A Transdisciplinary endeavor:*

*Phase 1: Identify Application, User, and Discovery and Viability*

*Initial Study of Current State of the Art:*

*Geomagnetic indices commonly used by the scientific community like Kp or Dst, or even Sym-H, were considered - but no relationship was found. A fast conclusion to the study might be that the Spanish power grid is not affected by space weather.*

*Local - not global - is key.*

# *A Transdisciplinary endeavor :*

*Phase 1: Identify Application, User, and Discovery and Viability*

*Initial Study of Current State of the Art: How the Dst/SymH is derived*

*“The baseline is expressed by a power series in time and the coefficients for terms up to the quadratic are determined by the method of least squares, using the annual means for the current year and the four preceding years”*

$$H_{base}(\tau) = A + Br + Cr^2$$

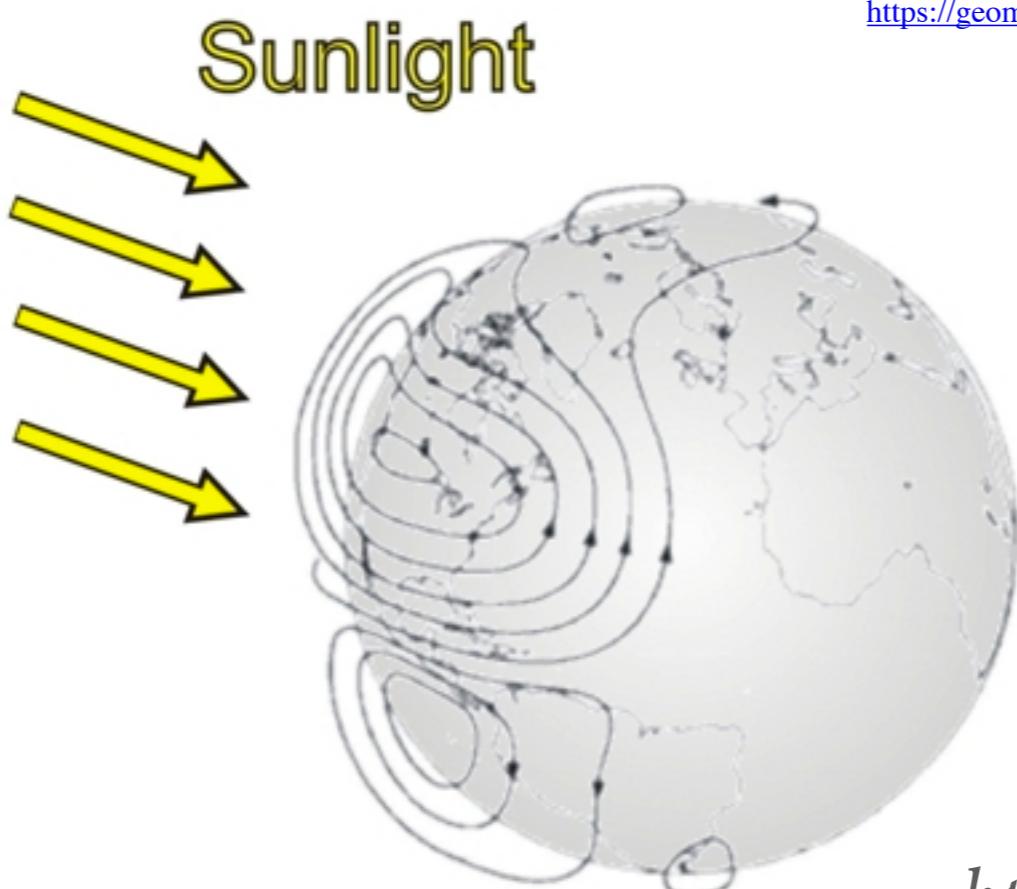
$$\Delta H(\tau) = H_{obs} - H_{base}(\tau)$$

# *A Transdisciplinary endeavor:*

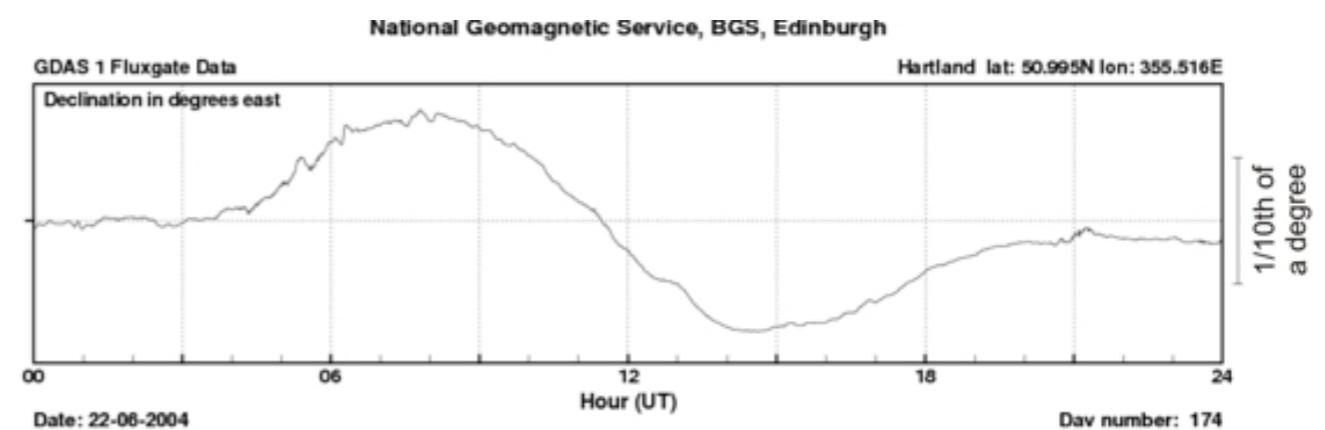
*Phase 1: Identify Application, User, and Discovery and Viability*

*Initial Study of Current State of the Art: How the Dst/SymH is derived*

$$S_q(t, s) = \sum_m \sum_n A_{mn} \cos(mt + a_m) \cos(ns + \beta_n)$$



<https://geomag.bgs.ac.uk/education/earthmag.html>



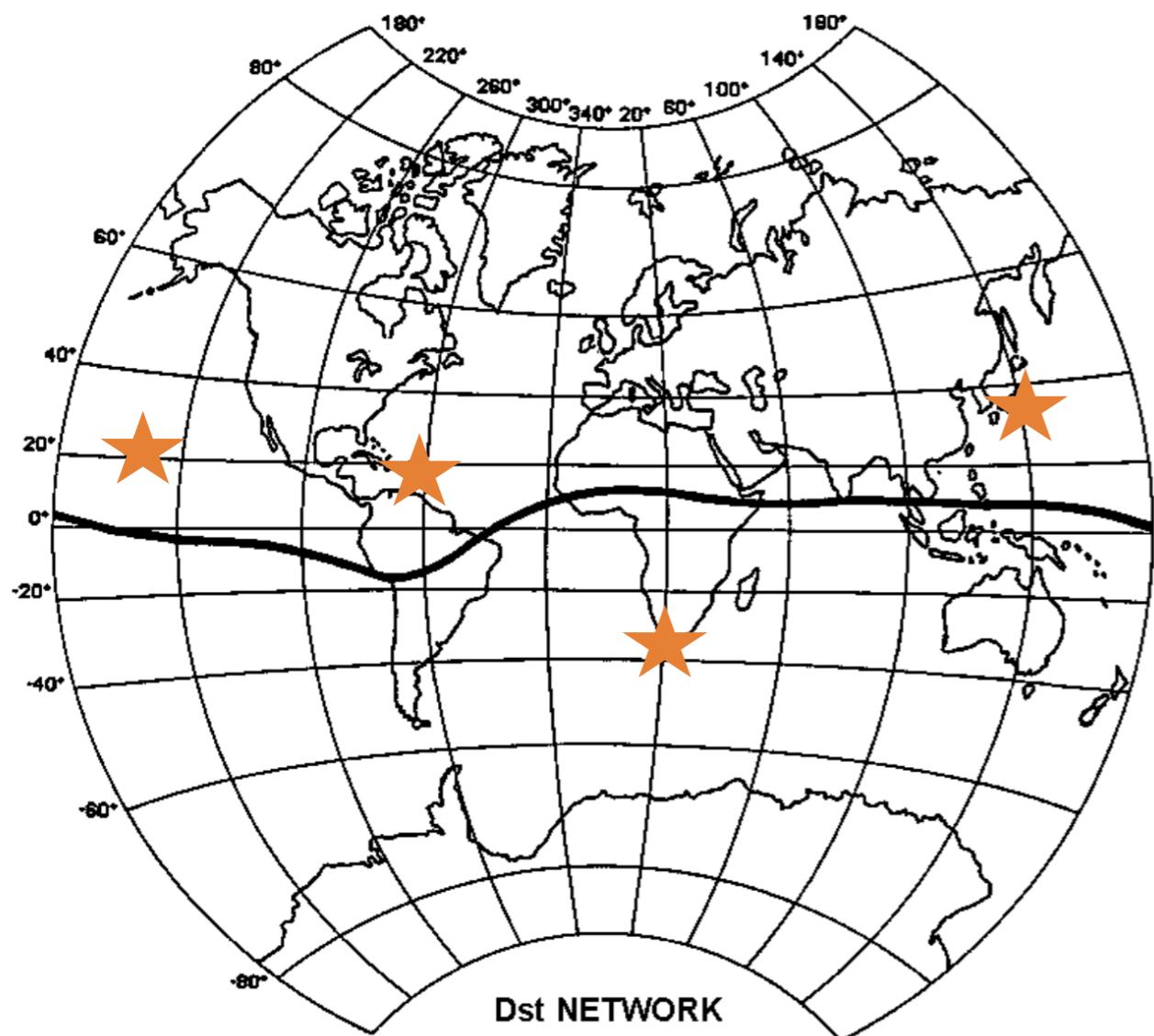
<https://geomag.bgs.ac.uk/education/earthmag.html>

<http://wdc.kugi.kyoto-u.ac.jp/dstdir/dst2/onDstindex.html>

# *A Transdisciplinary endeavor :*

*Phase 1: Identify Application, User, and Discovery and Viability*

*Initial Study of Current State of the Art: How the Dst/SymH is derived*



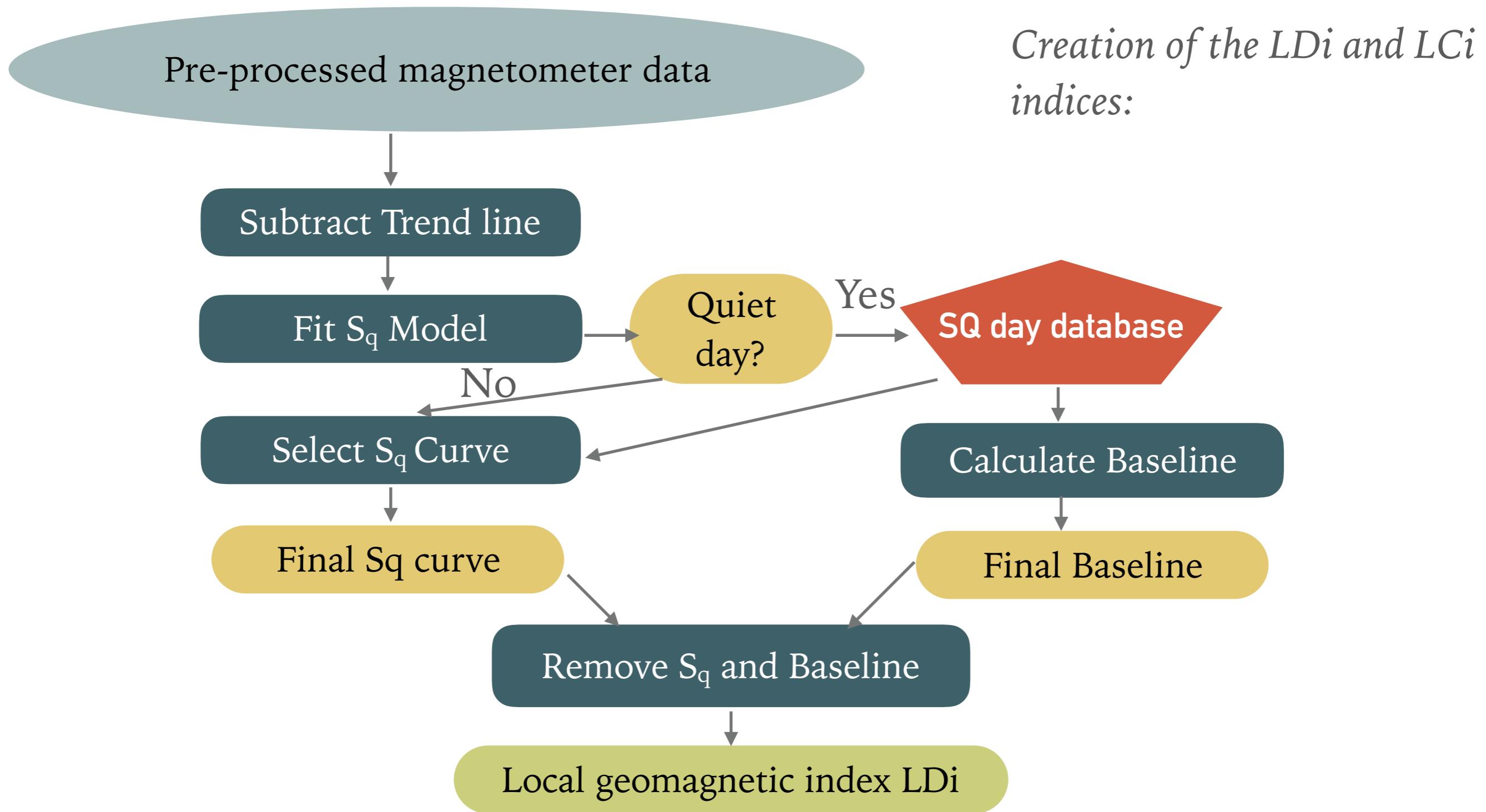
$$D(T) = \Delta H(T) - S_q(T)$$

Observatory	Geographic		Geomagnetic
	Longitude (E)	Latitude	Dipole latitude
Hermanus		19.22°	-34.40°
Kakioka		140.18°	36.23°
Honolulu	to April 1960	201.90°	21.30°
	after April 1960	201.98°	21.32°
San Juan	to January 1965	293.88°	18.38°
	after January 1965	293.88°	18.11°

$$Dst(T) = \frac{1}{n} \sum_n \frac{D_n(T)}{\cos \phi_n}$$

# *A Transdisciplinary endeavor:*

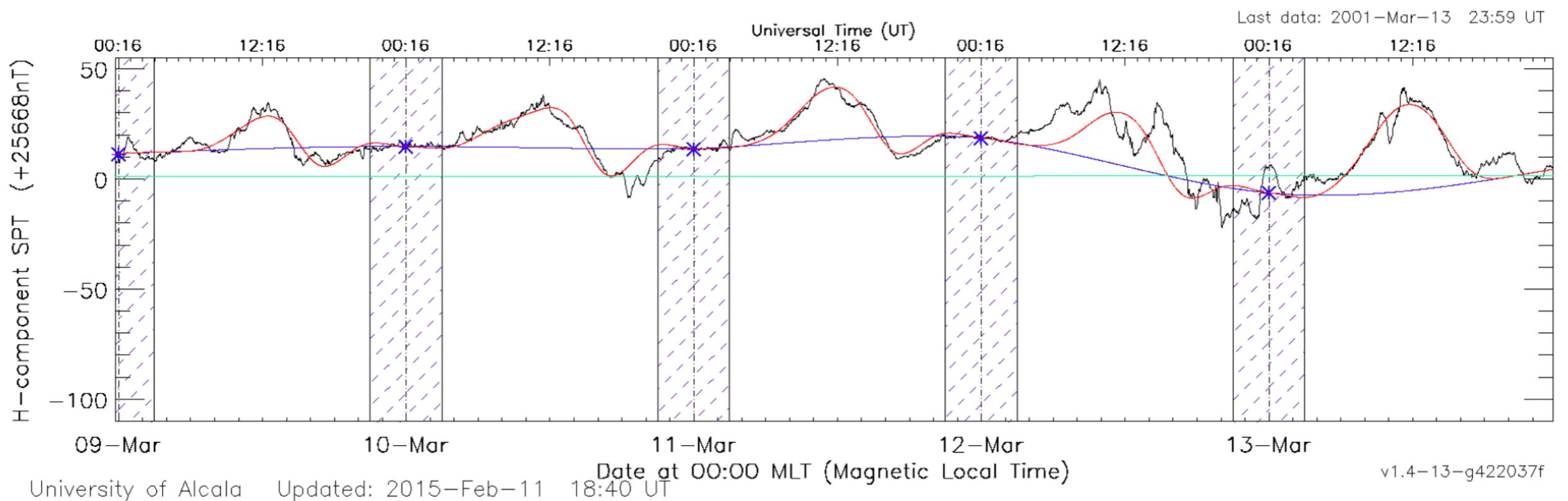
## *Phase 1: Identify Application, User, and Discovery and Viability*



# *A Transdisciplinary endeavor:*

*Phase 1: Identify Application, User, and Discovery and Viability*

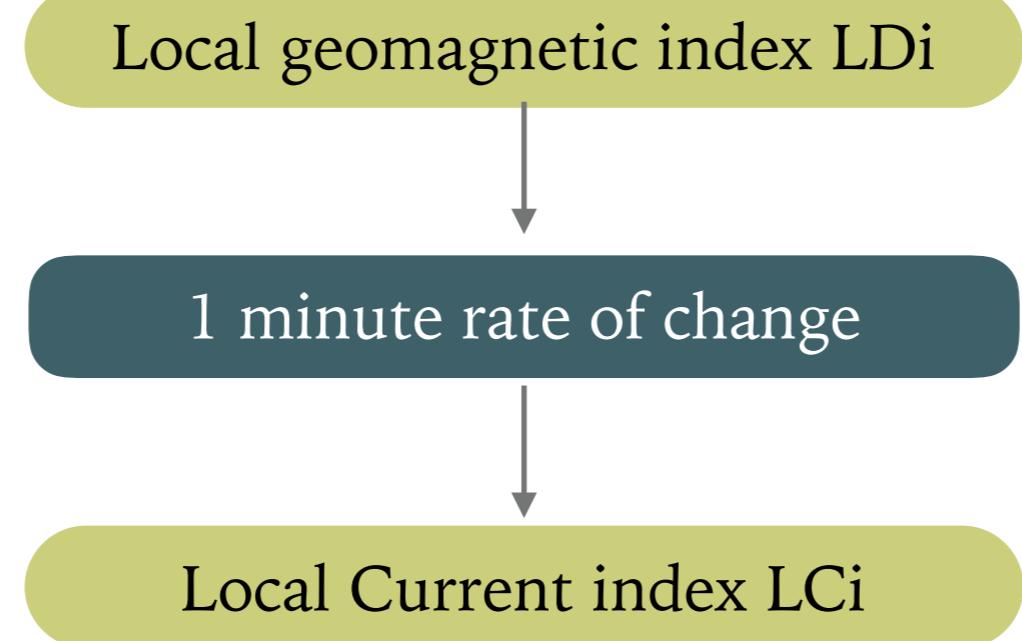
*Creation of the LDi and LCi indices:*



# *A Transdisciplinary endeavor:*

*Phase 1: Identify Application, User, and Discovery and Viability*

*Creation of the LDi and LCi indices:*



# *A Transdisciplinary endeavor:*

## *Phase 2: development testing and validation*

### **AUL 4: initial integration and verification**

*Milestones:*

- a. Integration of the individual components into the application.
- b. Organizational challenges and human process issues (if applicable) are identified and managed.

### **AUL 5: demonstration in the relevant context**

*Milestones:*

- a. The project team must articulate and disseminate the viability for the improvement upon the state of the art.
- b. Application components integrated into a functioning application system for use during the given relevant context parameters.

### **AUL 6: complete validation**

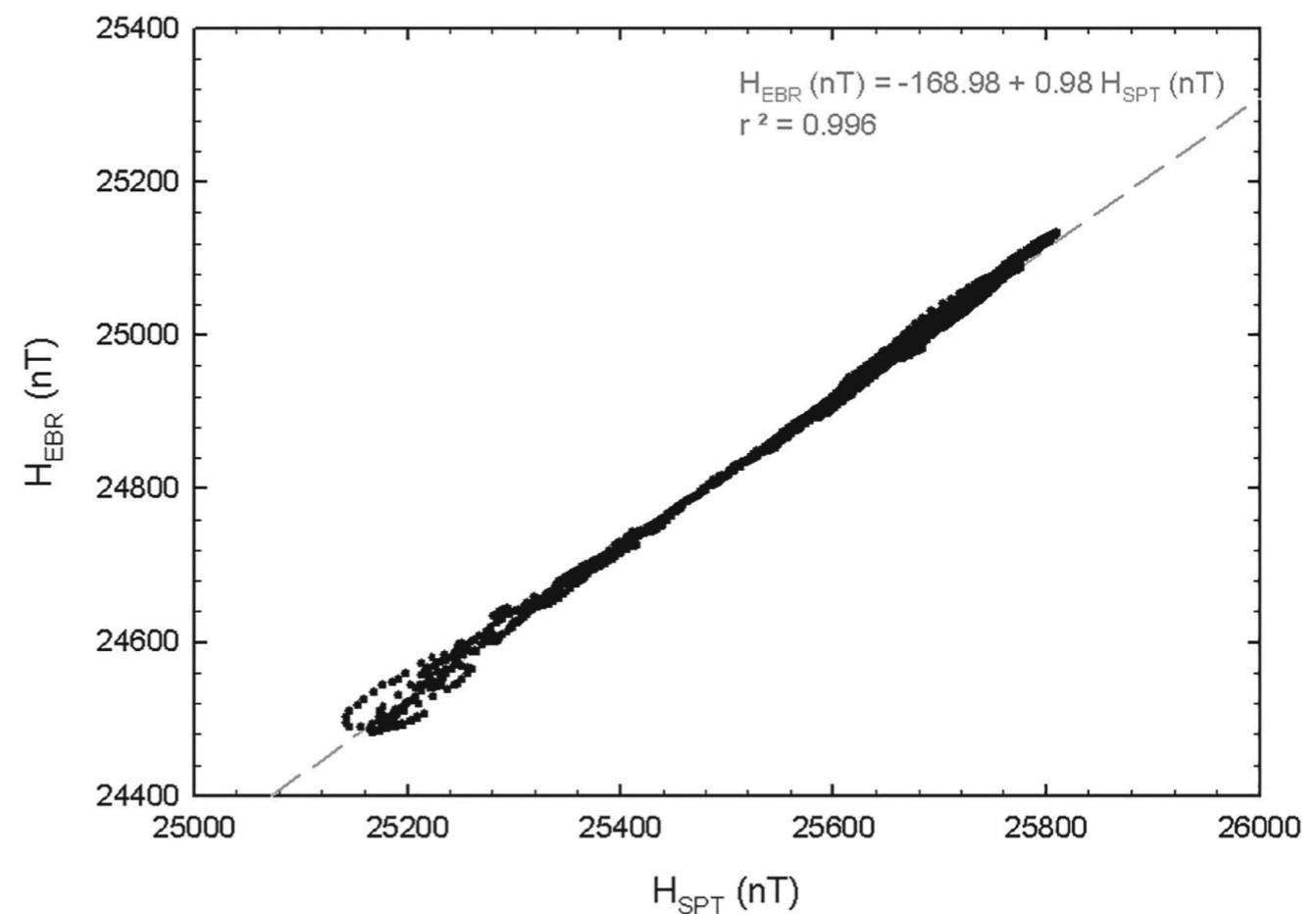
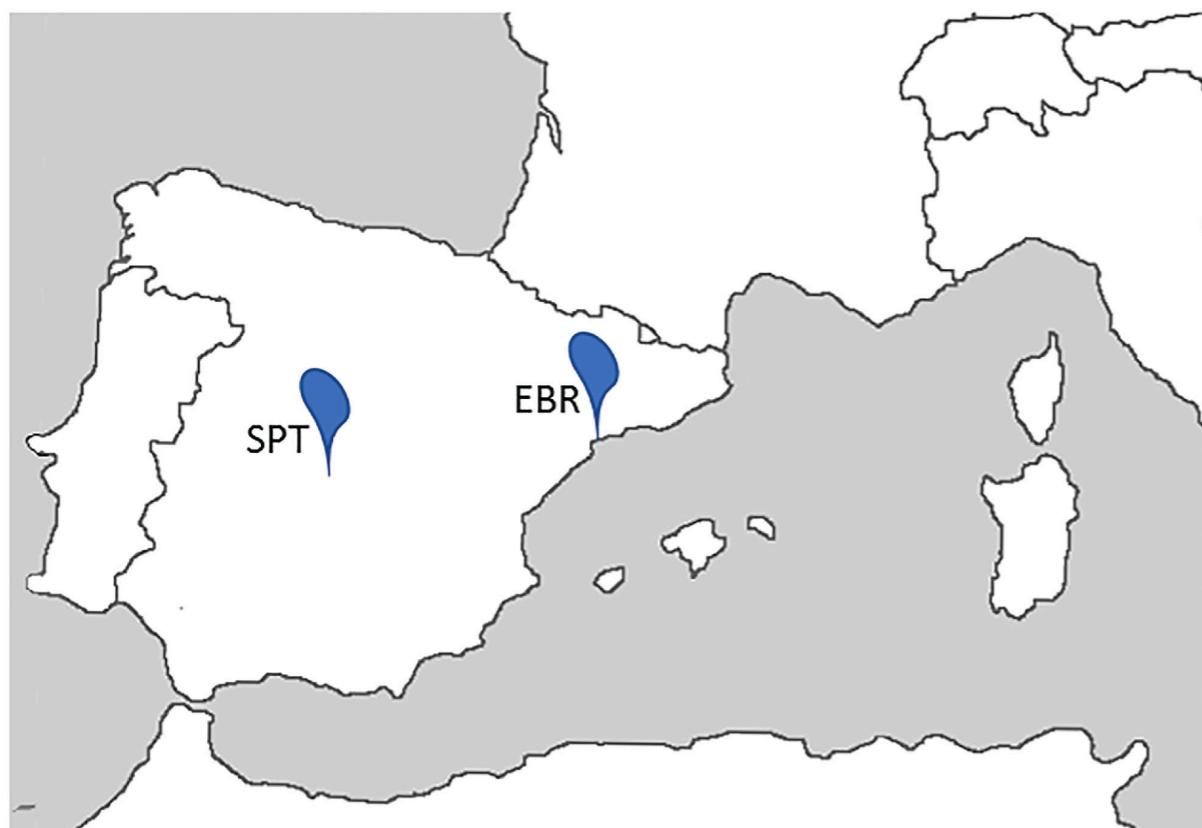
*Milestones:*

- a. Prototype application system beta-tested in a simulated operational environment.
- b. Projected improvements in performance of the state-of-the-art and/or decision making activity demonstrated in simulated operational environment.
- c. Documentation and dissemination of the specific application and associated metrics and the projects progress towards this application.

# *A Transdisciplinary endeavor:*

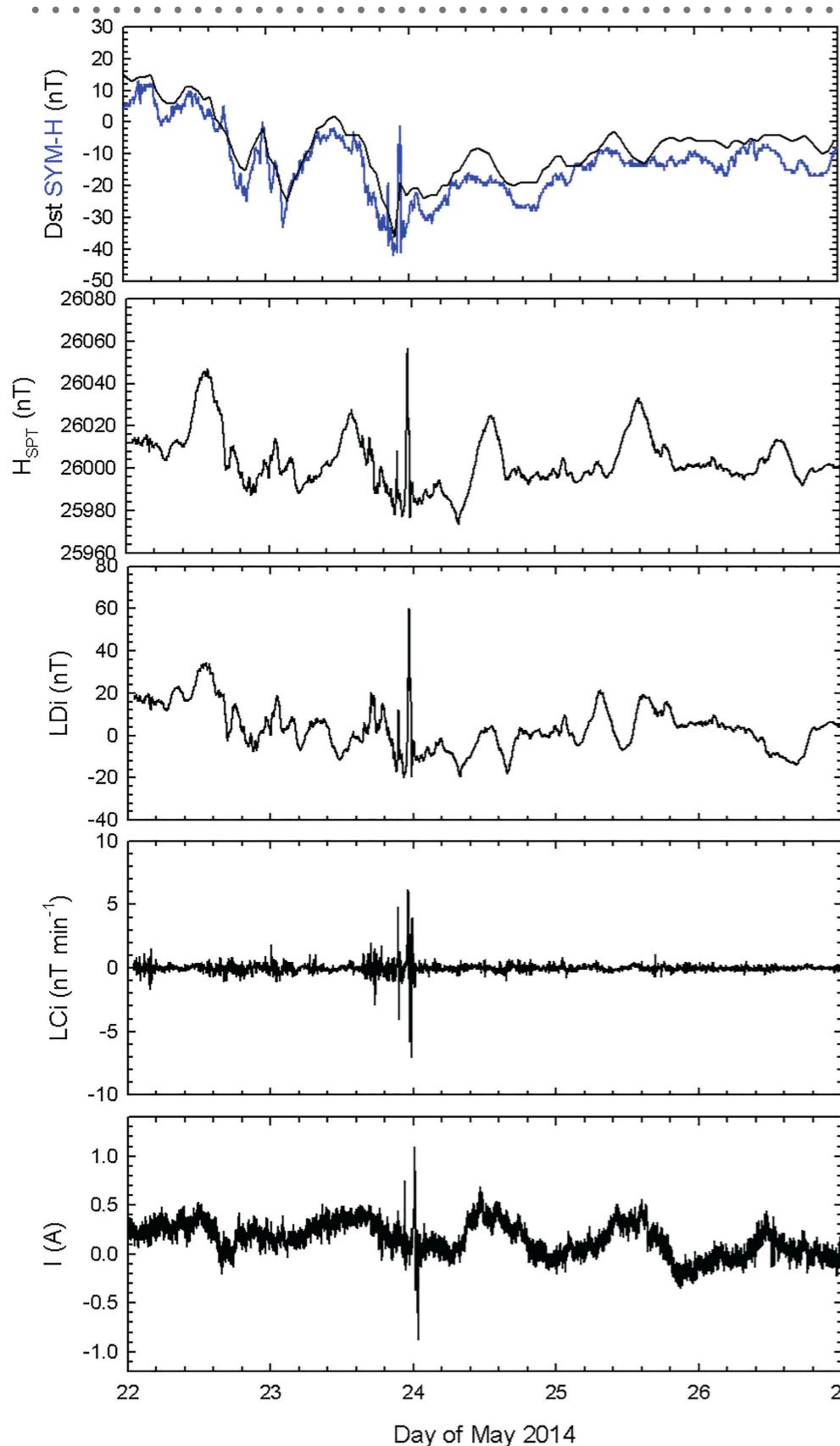
*Phase 2: development testing and validation*

*Only one index needed for Spain*



# *A Transdisciplinary endeavor :*

*Phase 2: development testing and validation*

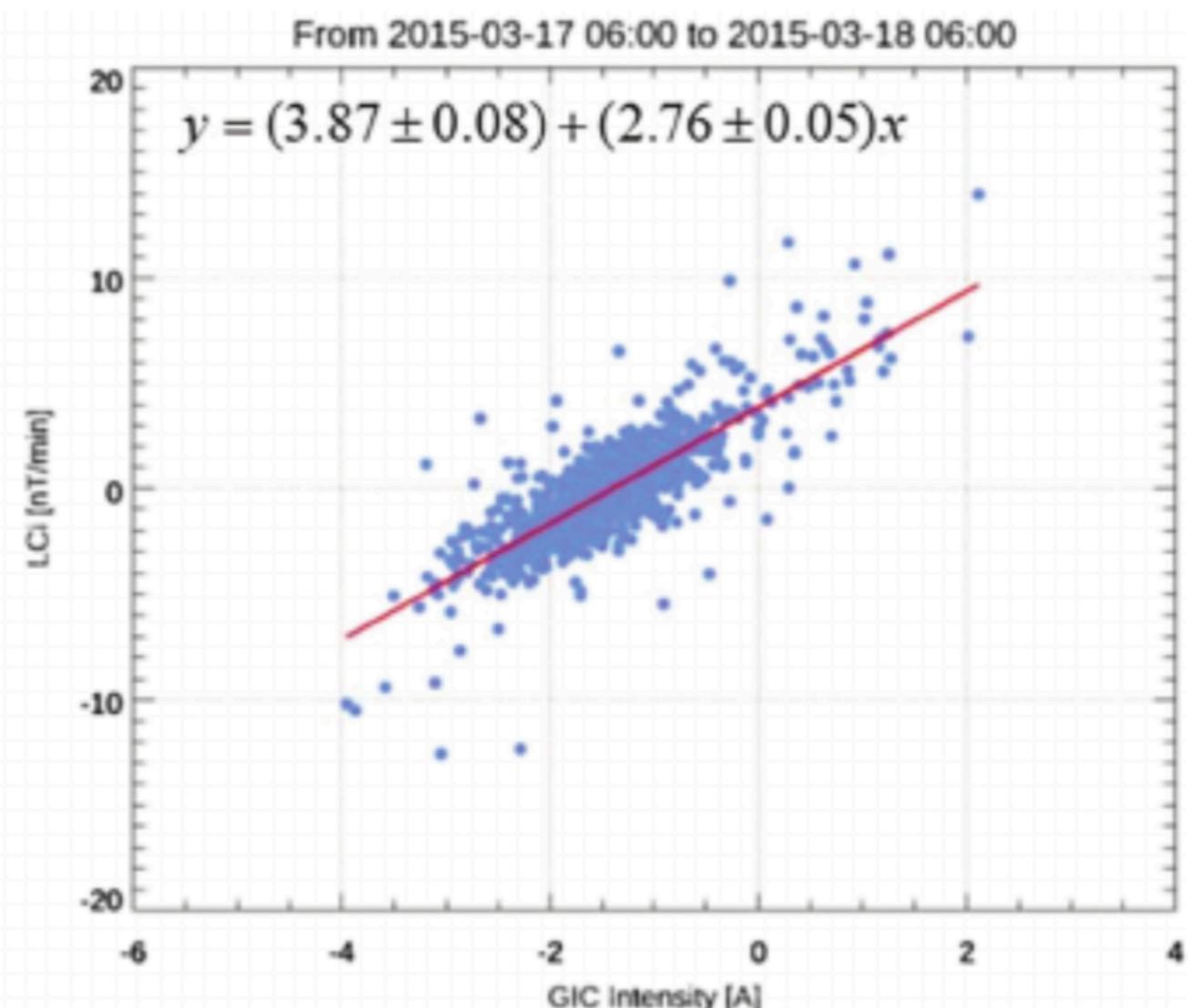
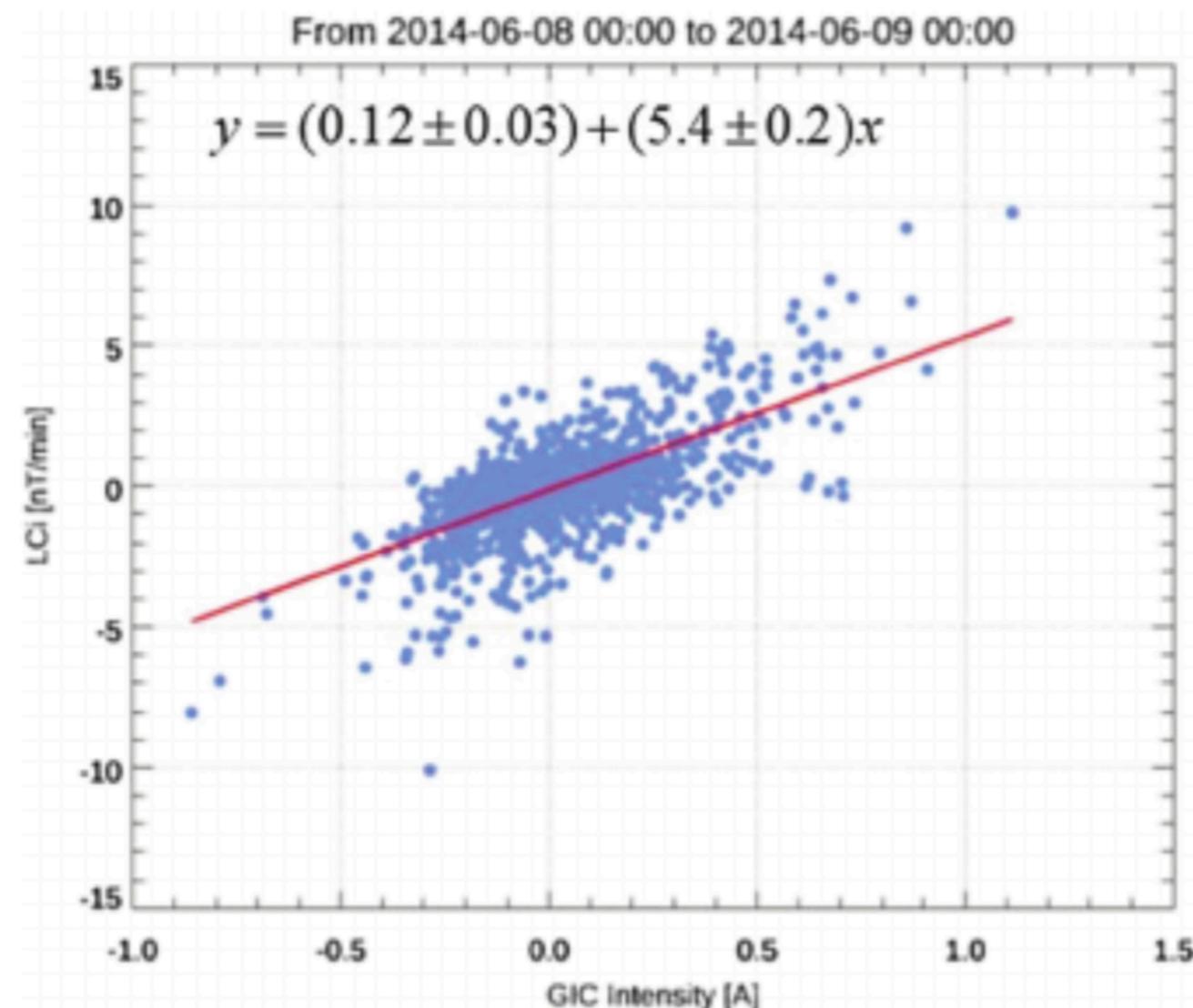


- *Disturbance seen in all 1 minute indices - but not Dst.*
- *Daily signal seen in the magnetometer and Sym-H but is not seen in LDi or LCi - proper removal was achieved.*
- *A daily signal was seen in the current corresponding to temperature variations within the instrument.*

# *A Transdisciplinary endeavor:*

*Phase 2: development testing and validation*

- *LCi shows a linear relationship to the GIC measurements*



# *A Transdisciplinary endeavor:*

## *Phase 3: Implementation and integration into operational status*

### ***AUL 7: application prototype***

*Milestones:*

- a. The system must be fully integrated into the operational environment specified by the user.
- b. The system's functionality is tested and demonstrated in the user's specified relevant context.
- c. Project team must demonstrate the functionality of the new system for the user's application and disseminate the results.

### ***AUL 8: validation in relevant "real world" environment***

*Milestones:*

- a. The user must approve the addition of the new project to their operational application system.
- b. Finalized application system tested, proven operational, and shown to operate within the specified requirements and metrics.
- c. Applications qualified and approved by the user.
- d. User documentation and training completed.

### ***AUL 9: approved for on-demand use towards stated application***

*Milestones:*

- a. Sustained and repeated use of the application by the specified users.
- b. The continued validation of the project in the operational environment.
- c. Dissemination of the validation efforts, metrics, and new state of the art project to the relevant community for the specific application.

# A Transdisciplinary endeavor:

*Phase 3: Implementation and integration into operational status*

The screenshot shows the homepage of the Spanish Space Weather Service (SeNMEs). The header features the SeNMEs logo and the text "Spanish Space Weather Service". Below the header are four menu items: "HOME", "REAL-TIME PRODUCTS", "NON-REAL-TIME PRODUCTS", and "WHAT SPACE WEATHER IS". On the right side of the header are links for "Home", "Contacto", and language selection (Spanish and English).

## Forecasting

- **Solar Heed** (Source: University of Alcala)
- **Solar Holdover** (Source: University of Alcala)
- **SYMHFor** (Source: University of Alcala)
- **DstFor** (Source: University of Alcala)
- **AhmF2** (Source: Ebro Observatory)

## Monitoring

- **LDiñ index** (Source: University of Alcala)

<p><b>LDiñ index</b> Local Disturbance Index (LD-SFS) - Last data: 2020-Apr-09 15:55 UT University of Alcala - Updated: 2020-Apr-09 15:55 UT SFS (San Fernando Observatory)</p>	<p><b>Description of the product:</b></p> <p>LDiñ (Local Disturbance index for Spain) is the result of the collaboration between University of Alcalá and Red Eléctrica de España in their aim to study the relationship between the space weather science and their effects on vulnerable technological infrastructures. It has been derived from research conducted by the Space Weather Group at University of Alcalá. The index quantifies the disturbance of the magnetic field for the Spanish territory. It makes use of the magnetic field registered at the station of the "Real Instituto y Observatorio de la Armada" in San Fernando (SFS) which is received with a maximum delay of 15 minutes and processed for removal of the daily variation. The LDiñ is a realtime index for monitoring, diagnostics, and forecasting purposes. The procedure to obtain the LDiñ is patented in Spain and patent-pending for Europe.</p> <p><b>Potential users:</b></p> <p>Potential users of this product include operators of any company involved in systems affected by geomagnetic disturbances.</p> <p><a href="#">Link to the product</a></p>
<b>Cadence:</b> One minute	<b>Data source:</b> The horizontal component of the geomagnetic field registered at San Fernando Observatory

Nowadays both indices are approved for autonomous use at the Spanish Space Weather Service (<http://www.senmes.es/>) and at the ESA Space Weather Portal (<http://swe.ssa.esa.int/>).

# *A Transdisciplinary endeavor:*

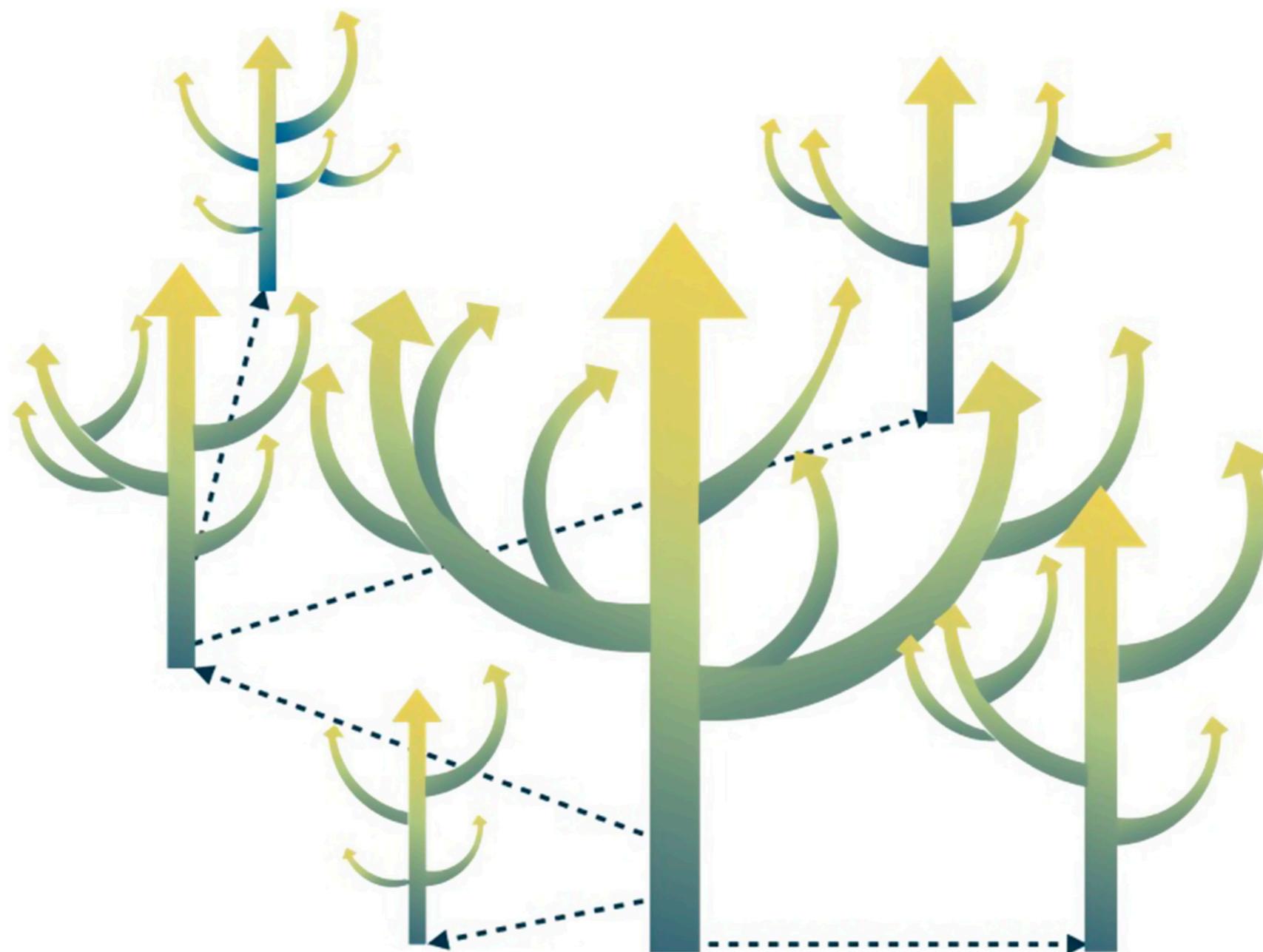
*Phase 3: Implementation and integration into operational status*

*Training and Use documents delivered:*

- *Technical note providing integration of products, reviewing ESA specifications and customer/system requirements of the product as well as validation approaches and results.*
- *The acceptance test plan, specification documents and acceptance test report*

# *A Transdisciplinary endeavor :*

*Phase 3: Not the end, only the beginning*



# OTHER AUL EXAMPLE PROJECTS -

.....

Example	Phase	AUL	Research Sub-field	Primary User	Longer example
4.1 Identifying a new application	1	1	Ionosphere	Research models	A.1
4.2 Application for another researcher	2	5	Ionosphere	The AMIE model	A.2
4.3 Branching applications	1,2	2,5	Magnetosphere	External Business	A.3
4.4 Transitioning a research model to a government user	2	6	Ionosphere	Australian Bureau of Meteorology	A.4
4.5 Validating in an operational environment	2	6	Magnetosphere	Industry/government	A.5
4.6 Identifying new transformative research by working with the user	3	8	Solar	Government/Air Force	A.6
4.7 Identifying new applications	1,3	1,9	GICs	Red Eléctrica de España, REE	
4.8 Funding applications through the three phases	3	9	Magnetosphere	British Antarctic Survey	A.7

- SamiPy - a python open source ionospheric code J. Klenzing in prep

Thank you

Questions?



# BACK UP SLIDES

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# Geomagnetically Induced Currents:

A space weather impact that affects electrically conducting infrastructure

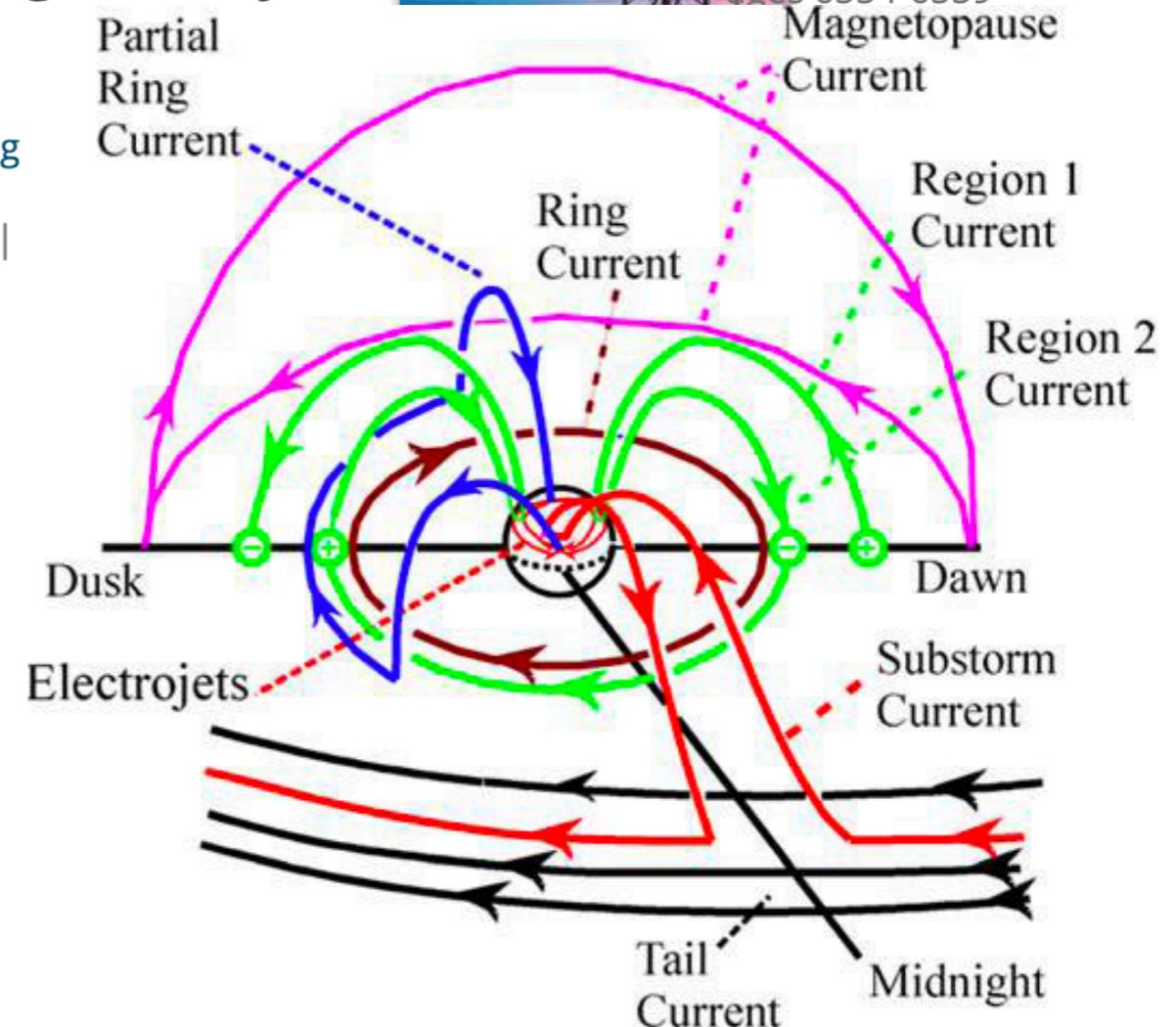
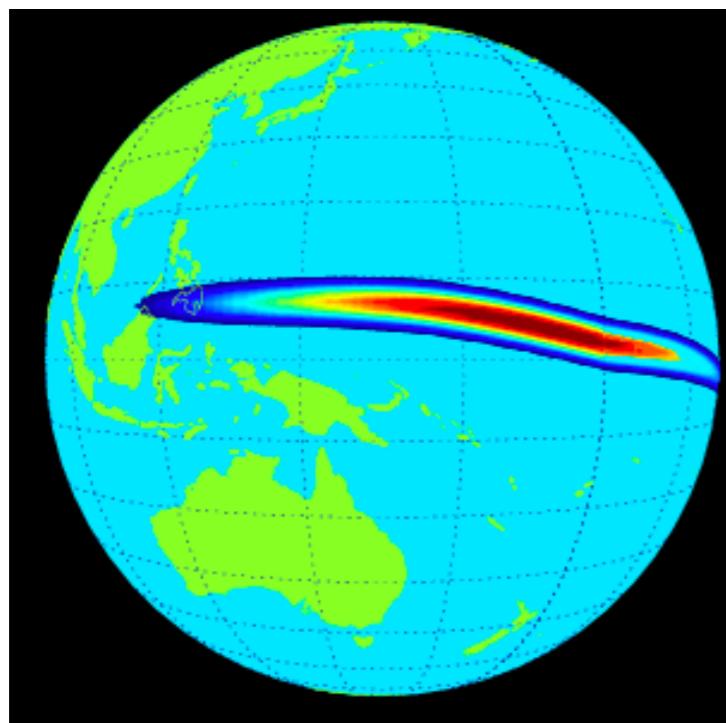
## Space Weather

Research Letter |  Free Access |

### Interplanetary shocks and the resulting geomagnetically induced currents at the equator

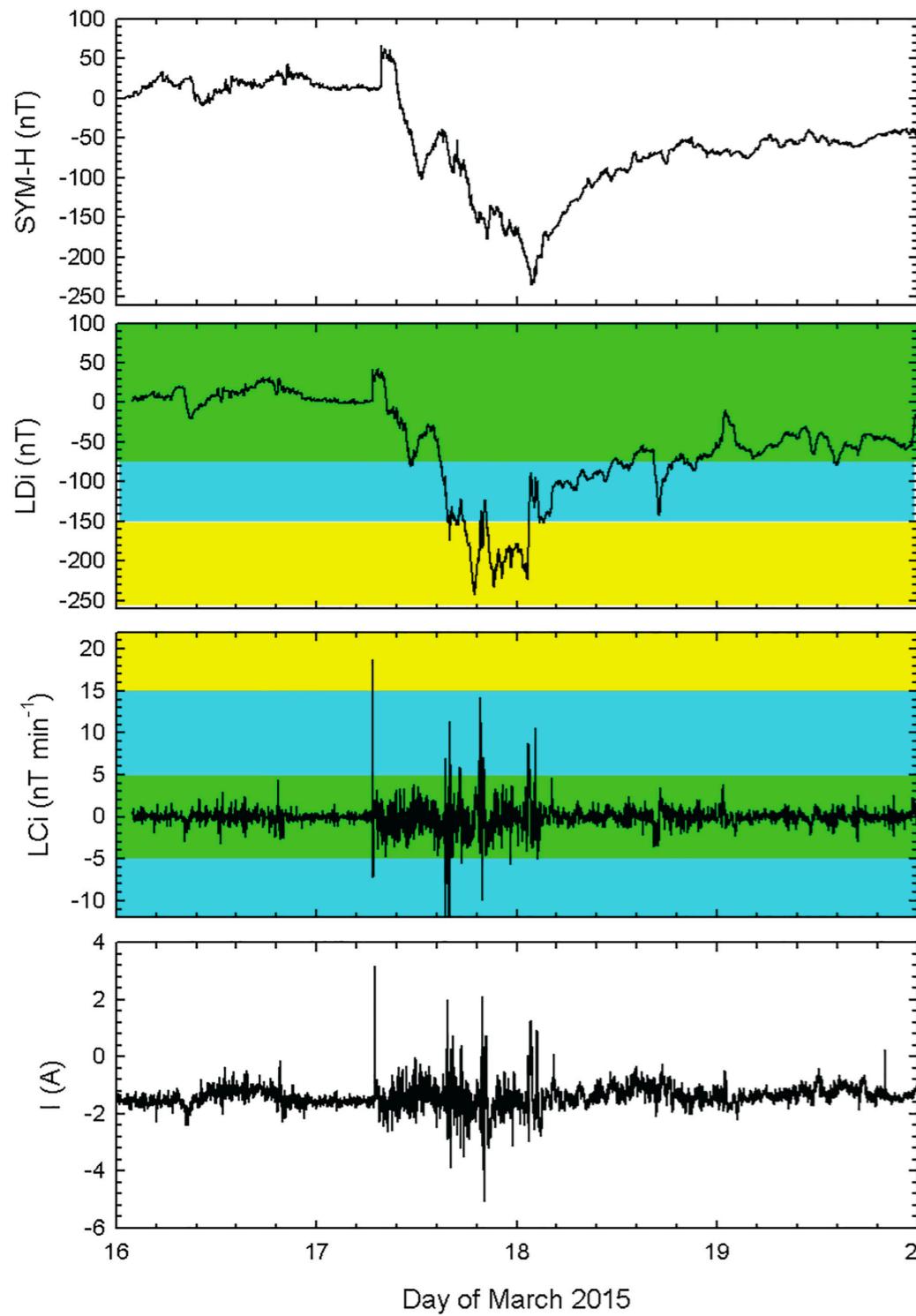
B. A. Carter , E. Yizengaw, R. Pradipta, A. J. Halford, R. Norman, K. Zhang

First published: 06 August 2015 | <https://doi.org/10.1002/2015GL065060> |



# *A Transdisciplinary endeavor:*

## *Phase 3: Implementation and integration into operational status*



*LCi reached the sever level prior to these levels being reached for Sym-H or LDi. NOAA classified this storm as a C2.1 with the following guidance: “Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid” - REE did not see any consequences.*

# *A Transdisciplinary endeavor:*

*Researchers & industry partners working to create applications for immediate use.*

Phase	Phase definition	AUL	Level description
Phase 1	Discovery and Viability	1	Basic Research
		2	Establishment of users and their requirements
		3	Assess viability and current state of the art
Phase 2	Development, Testing, and Validation	4	Initial integration and verification
		5	Demonstration in the relevant context
		6	Completed validation
Phase 3	Implementation and Integration in Operations	7	Application prototype
		8	Validation in relevant context
		9	Approved for on-demand use

# *Geomagnetically Induced Currents:*

*A space weather impact that affects electrically conducting infrastructure*

## **Cathodic protection system of the pipeline**

