The International Meridian Circles Program
A major opportunity for science, space weather monitoring and international collaboration

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On behalf of the IMCP international team

CEDAR Workshop 2023, San Diego, June 25-30, 2023

Main references on the IMCP project

Chinese Meridian Project (CMP)

Wang C, Xu J, Liu L, Xue X, Zhang Q, Hao Y, Chen G, Li H, Li G, Luo B, Zhu Y, Wang J. 2023. Contribution of the Chinese Meridian Project to space environment research: Highlights and perspectives. Science China Earth Sciences, 66, https://doi.org/10.1007/s11430-022-1043-3

International Meridian Circle Project (IMCP)

Liu W., M. Blanc, E. Donavan, J. Foster, M. Lester, H. Opgenoorth, L. Ren (2021), Science Objectives and Observation System for the International Meridian Circle, Science China, 2021. https://doi.org/10.1007/s11430-021-9841-8

Liu W., M. Blanc and 34 co-authors, Science Objectives and Observation System for the International Meridian Circle, Taikong #19, ISSI-Beijing, May 2020. http://www.issibj.ac.cn/Publications/Forum_Reports/201404/W020201105365405876299.pdf

Liu W., C. Wang, X. Shen, J. Wu J., M. Blanc, Y. Yan, S. Fu, X. Yue, J. Lei, W. Gong, S. Zhang., Q. Zhang, X. Wang, J. Yang, X. Zhang, J. Gao, J. Xu, G. Yang, H. Li, L. Ren, F. Yang, International Meridian Circle Program. Chin. J. Space Sci. (2020), 40(5): 723-725. DOI:10.11728/ cjss2020.05.723

I- FROM SCIENCE OBJECTIVES TO OBSERVATION SYSTEM

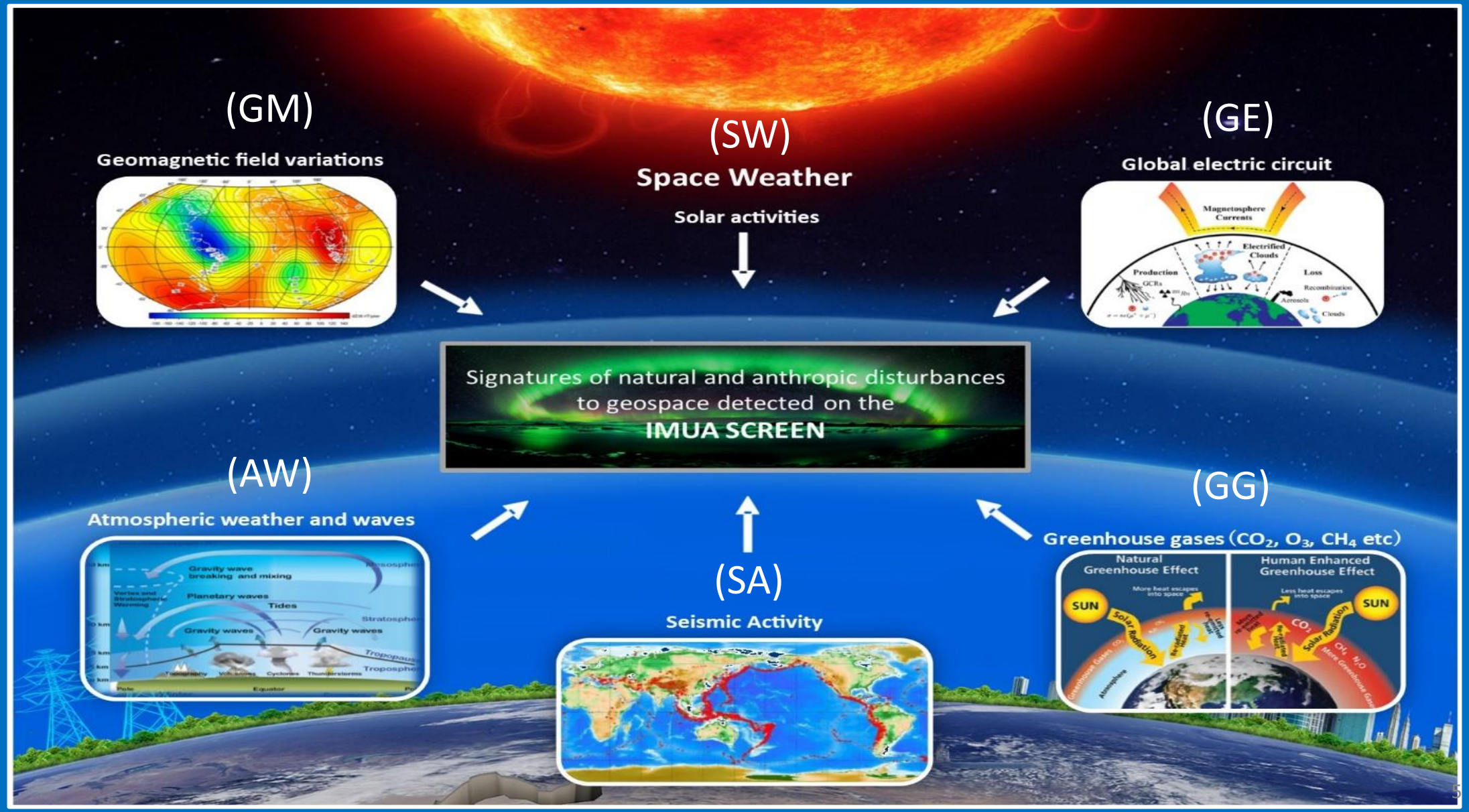
The Lower-Thermosphere & Ionosphere (LTI), or Ionosphere and Middle-Upper Atmosphere (IMUA), is the Boundary Layer separating Plasma Earth from Fluid Earth

Maximum deposition of energy from above and from below:
Vertical heat conduction
Photon, particle and Joule heating
Atmospheric waves breaking

LIT= Live "TV screen" detecting disturbances propagating from above and from below

IMCP OVERARCHING GOAL

BUILD A GLOBAL LTI SCREEN ON WHICH TO DETECT, STUDY AND MONITOR THE IMAGES OF THE DIFFERENT NATURAL AND ANTHROPIC DISTURBANCES



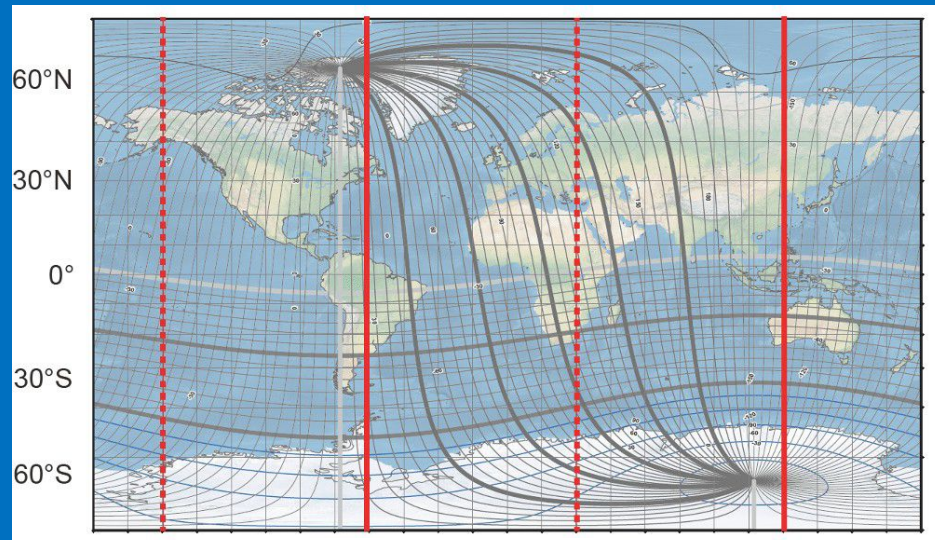
SOME KEY SCIENCE QUESTIONS THE IMCP CAN ADDRESS

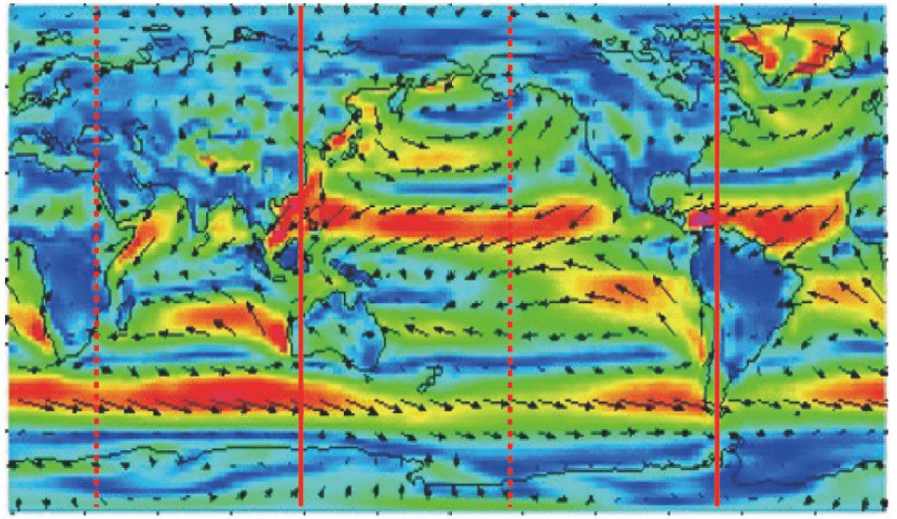
Characterize the "Screen": Lower thermosphere/ionosphere	**N, T, composition, winds, vertical gradients in lower thermosphere and ionosphere Momentun and energy deposition**
Coupling to Sun and Interplanetary Space	Key energy transfer processes (entry, storage and deposition regions)
Coupling to the dense atmosphere:	Atmospheric waves and interaction with mean flow:
	Global atmospheric circuit:
	Climate change in upper atmosphere:
Coupling to Solid Earth	Characterize geomagnetic field changes at the multi-decadal scale
	Effects of Earthquakes on upper atmosphere
	Effects of volcanic activity

DESIGNING AN "OPTIMIZED" GROUND-BASED OBSERVATION SYSTEM

(SW)

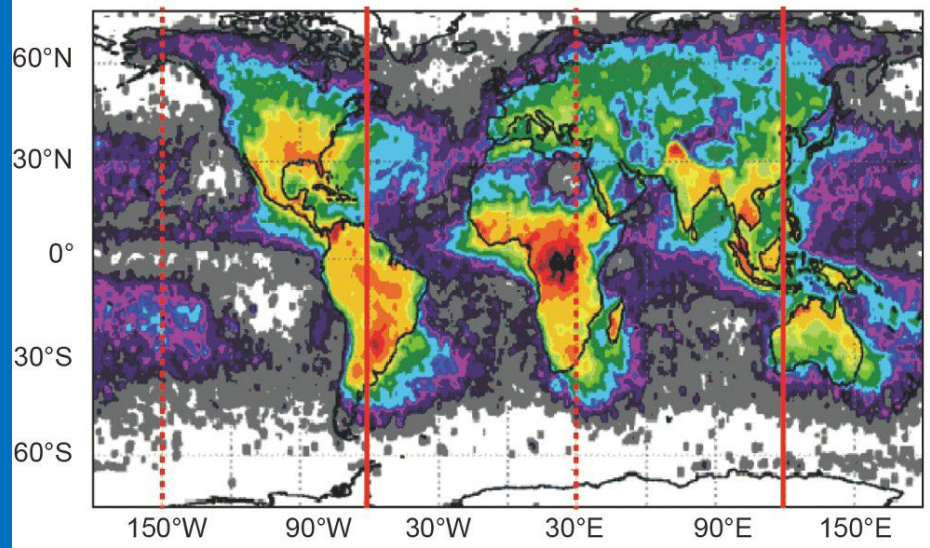
(GM)



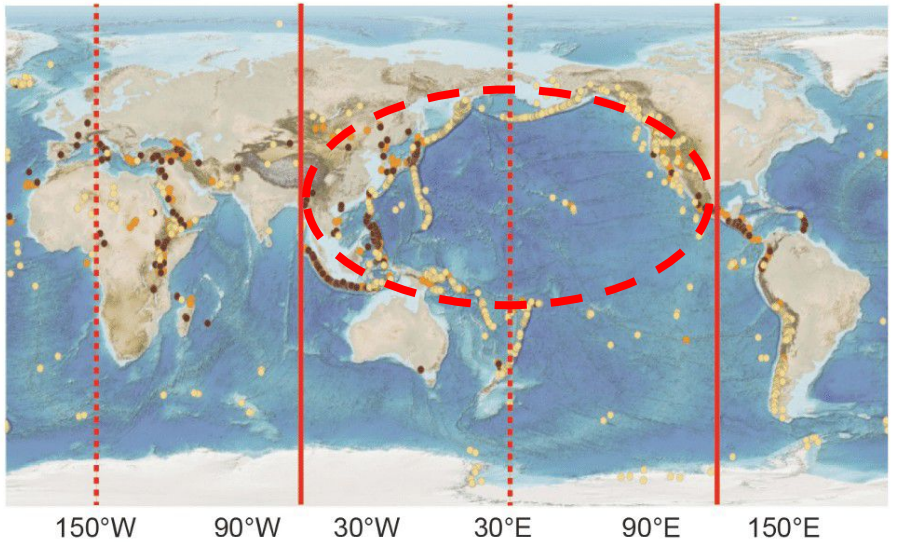


(GG)

(AW)



(GE)



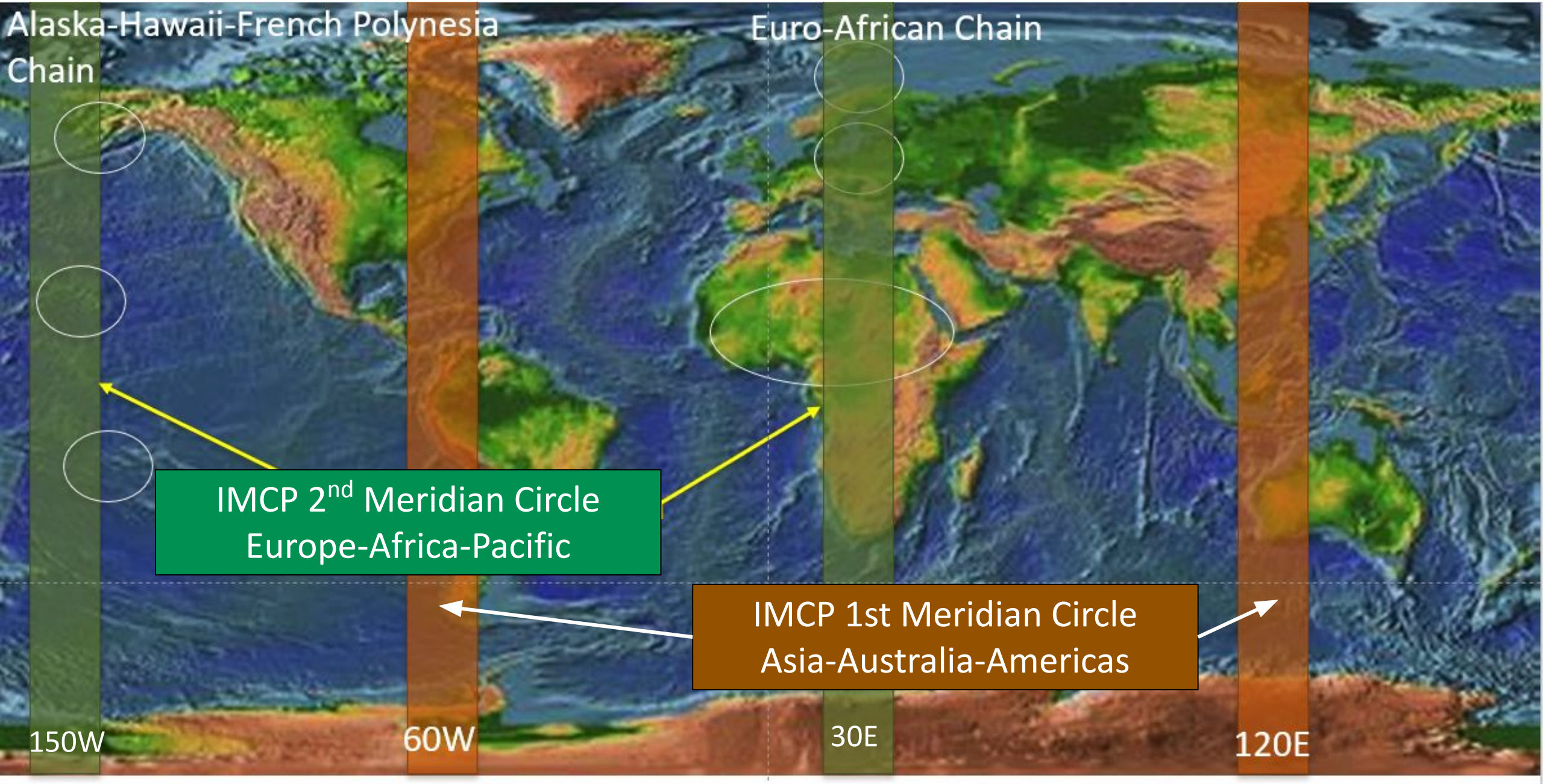
(SA)

Circum-Pacific firebelt

120° E - 60°W Meridian: ——————

30° E – 150° W: — · — · — · — · —

GEOGRAPHIC DEPLOYMENT



GEOGRAPHIC DEPLOYMENT

Alaska-Hawaii-French Polynesia Chain

IMCP 2nd Meridian C
Europe-Africa-Paci

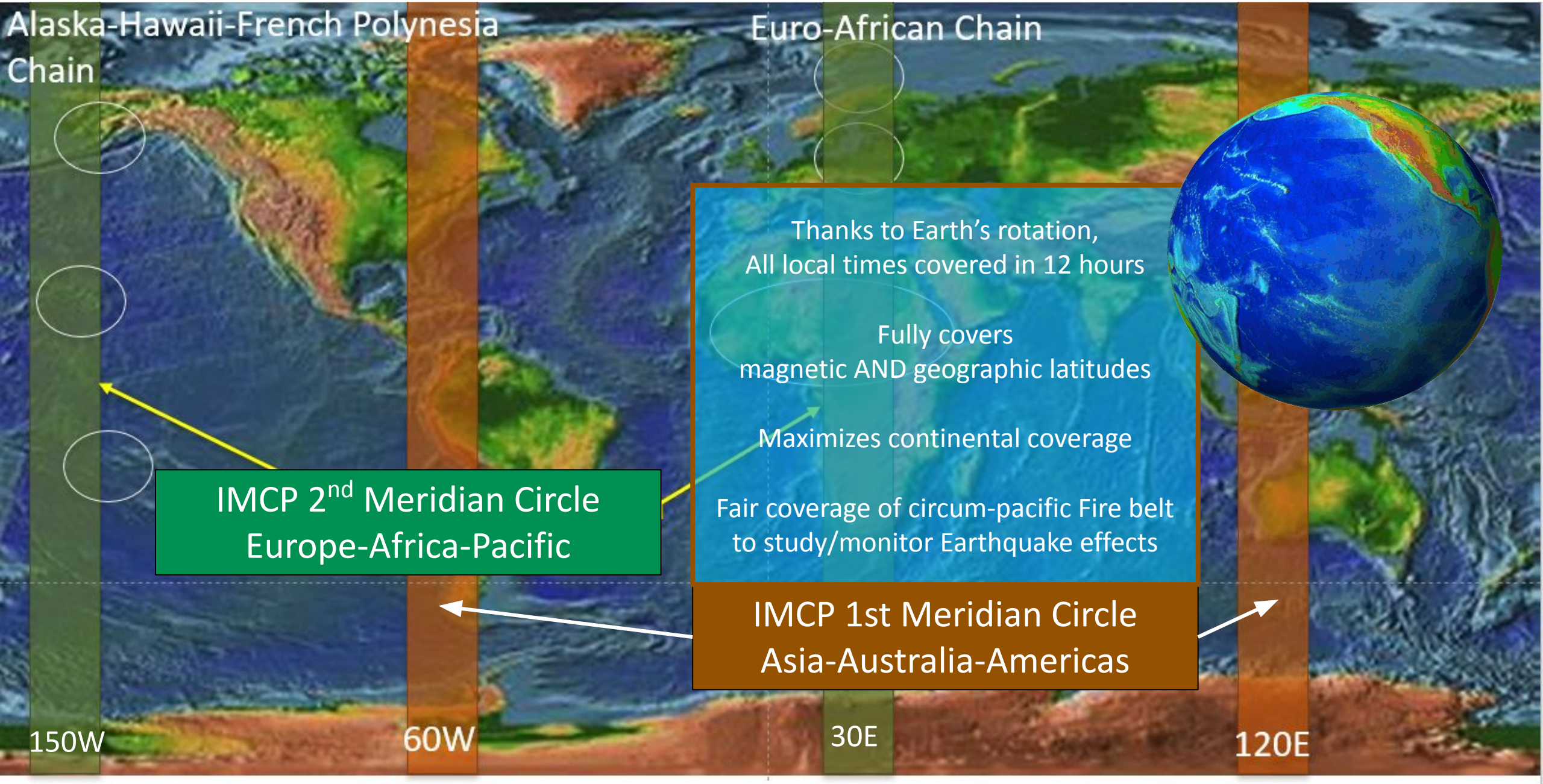
150W

60W

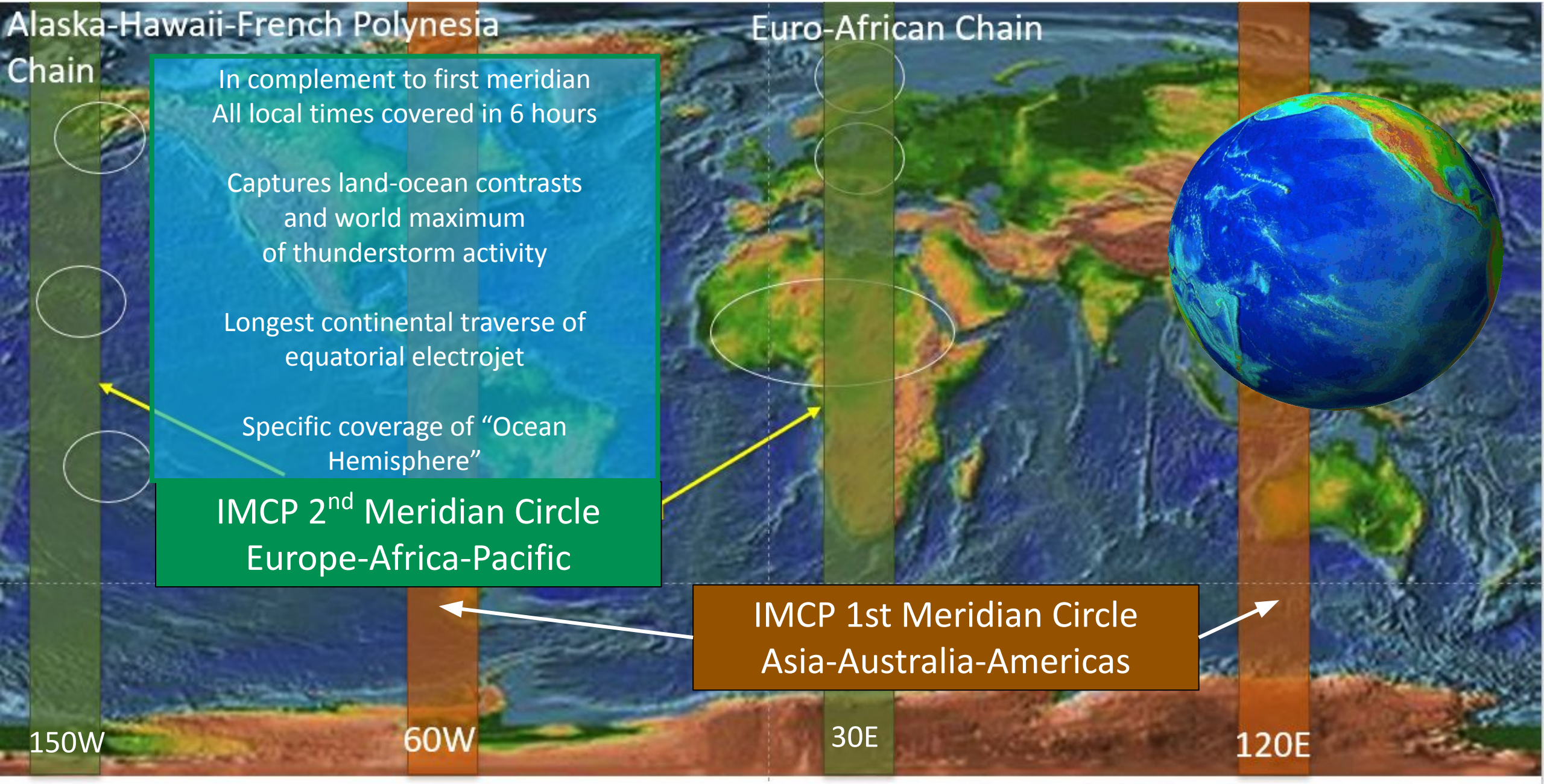
120E

Chinese Meridian Project

COVERAGE OF MONITORING OBJECTIVES



COVERAGE OF MONITORING OBJECTIVES

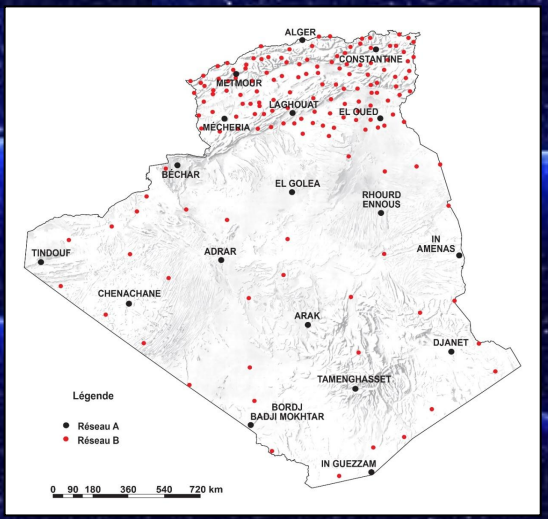


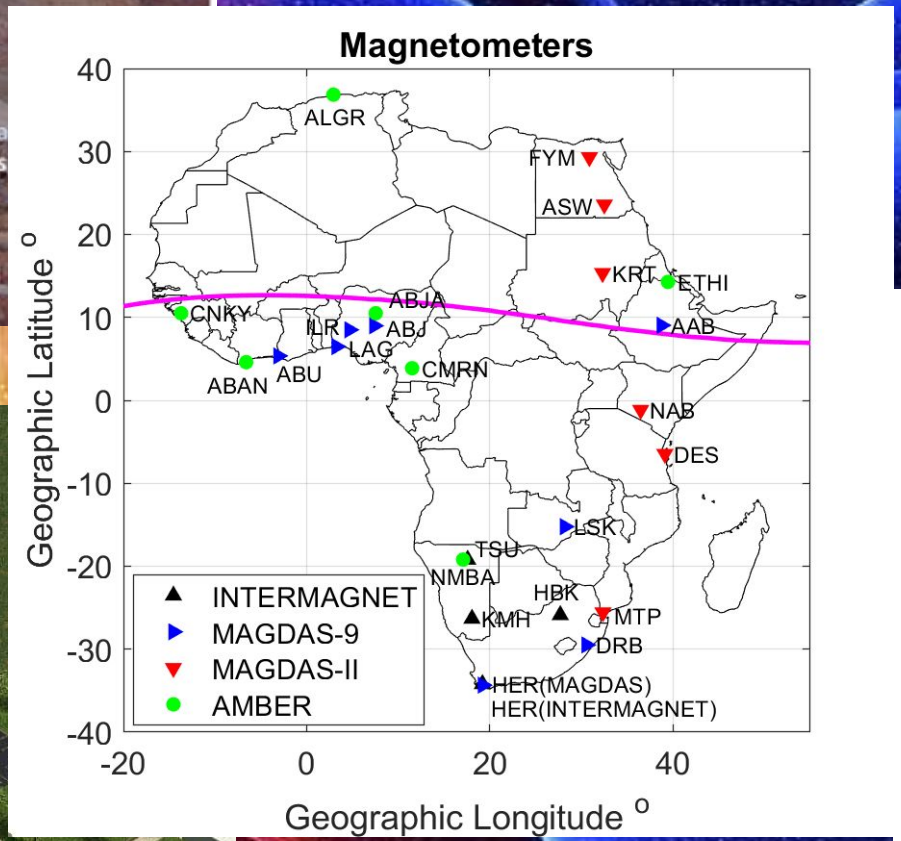
FOCUS ON THE UNIQUE POTENTIAL OF AFRICA

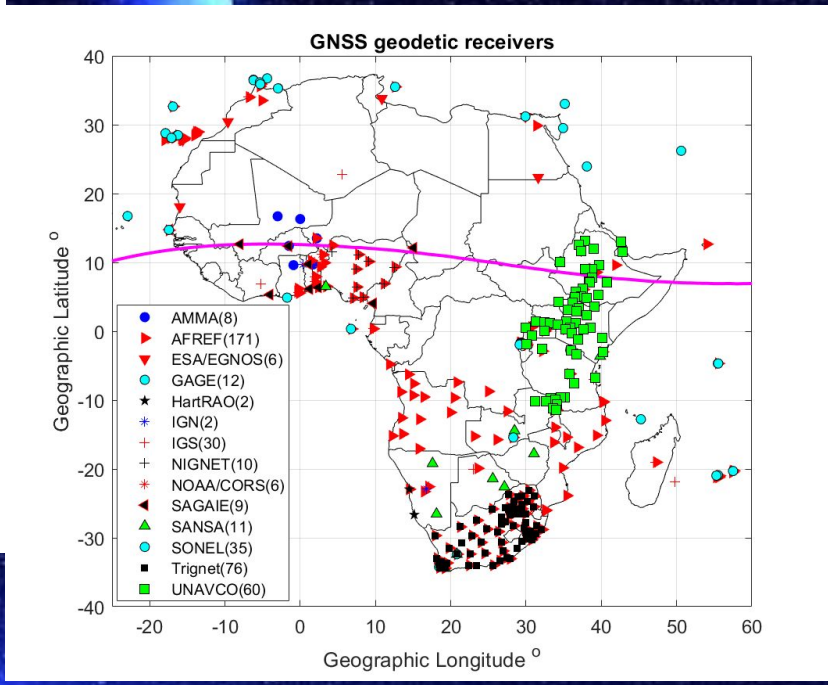
OUKAIMEDEN OBSERVATORY, MOROCCO

CRITICAL NEED TO MAINTAIN AND OPERATE EXISTING EQUIPMENTS, TO SHARE THEIR DATA…

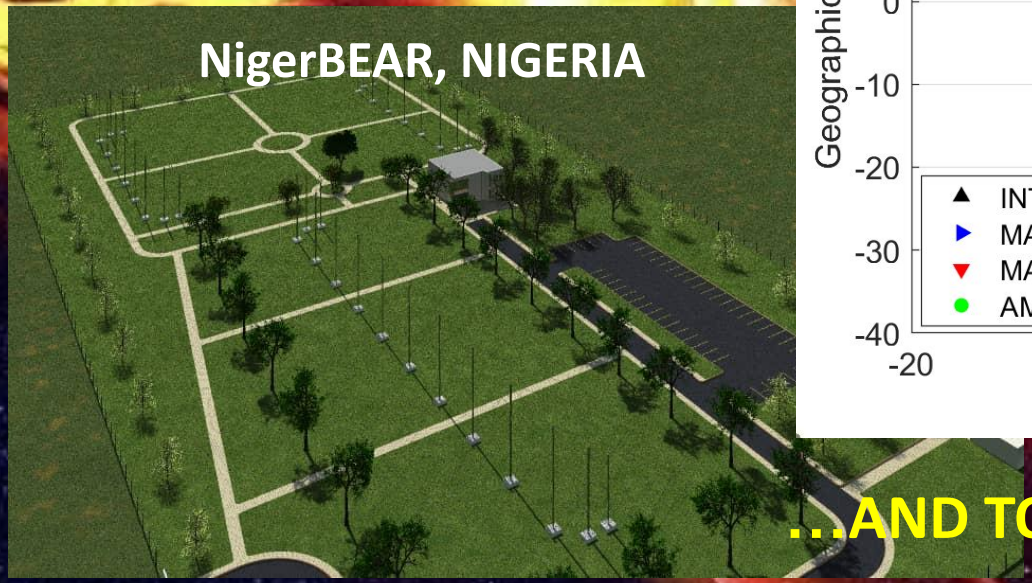
GNSS NETWORK, ALGERIA







NigerBEAR, NIGERIA



…AND TO DEVELOP NEW ONES!

See Baki et al., The Status of Space Weather infrastructure and Research in Africa, submitted to *Atmosphere*, June 2023)

ARCHITECTURE OF IMCP OBSERVATION SYSTEM

ON-SITE INSTRUMENTS

Large facilities

ISRs

LIDARs

Radioheliographs

…

Medium-scale

HF radars

Digisondes

FP spectrometers

Airglow imagers

…

Network instruments

Ionosondes

Magnetometers

GNSS stations

…

NETWORKS

Regional

Latitudinal

Longitudinal

World-wide

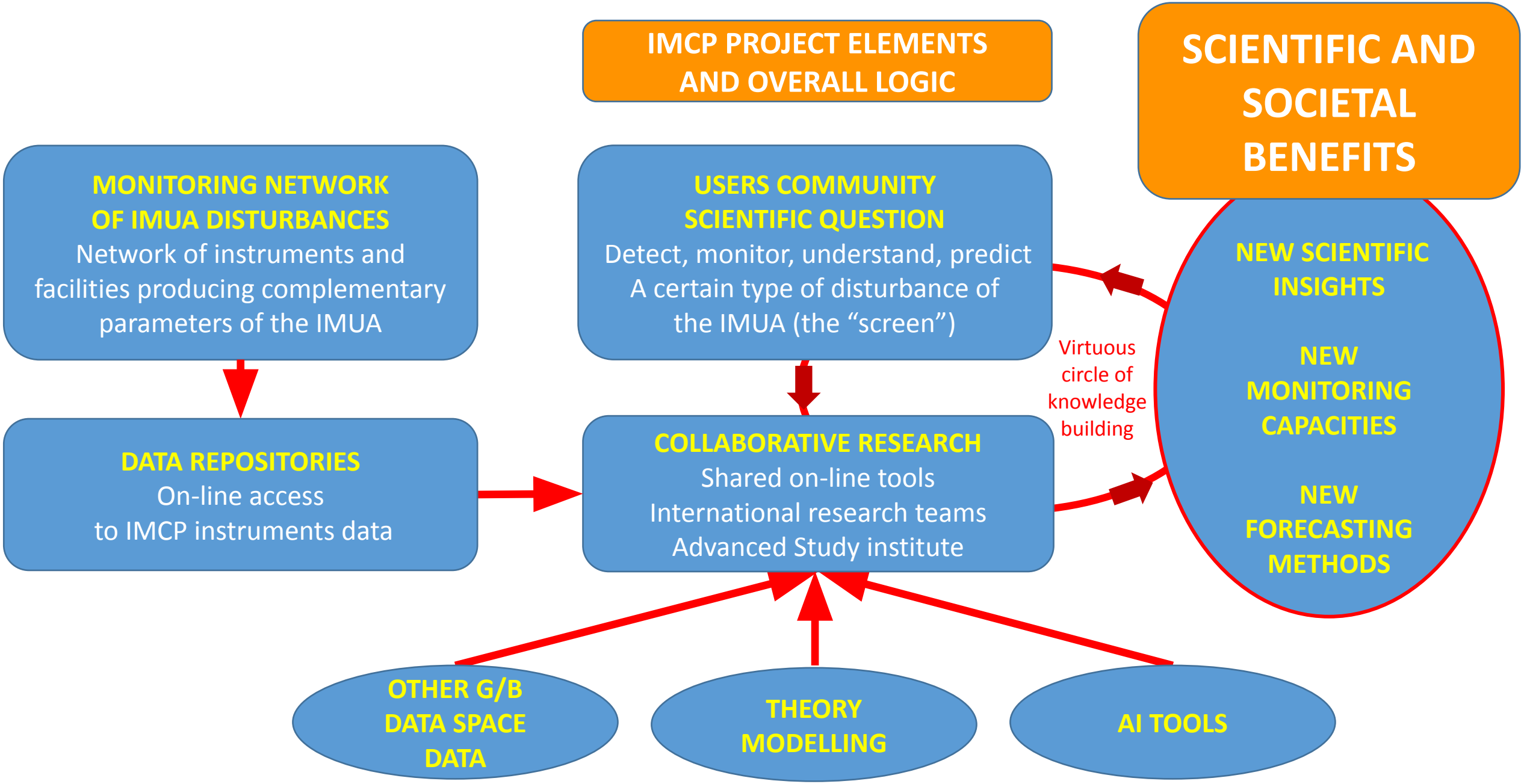
Each instrument brings a piece of the puzzle of upper atmosphere forcing from above and from below!

Each contribution welcome!

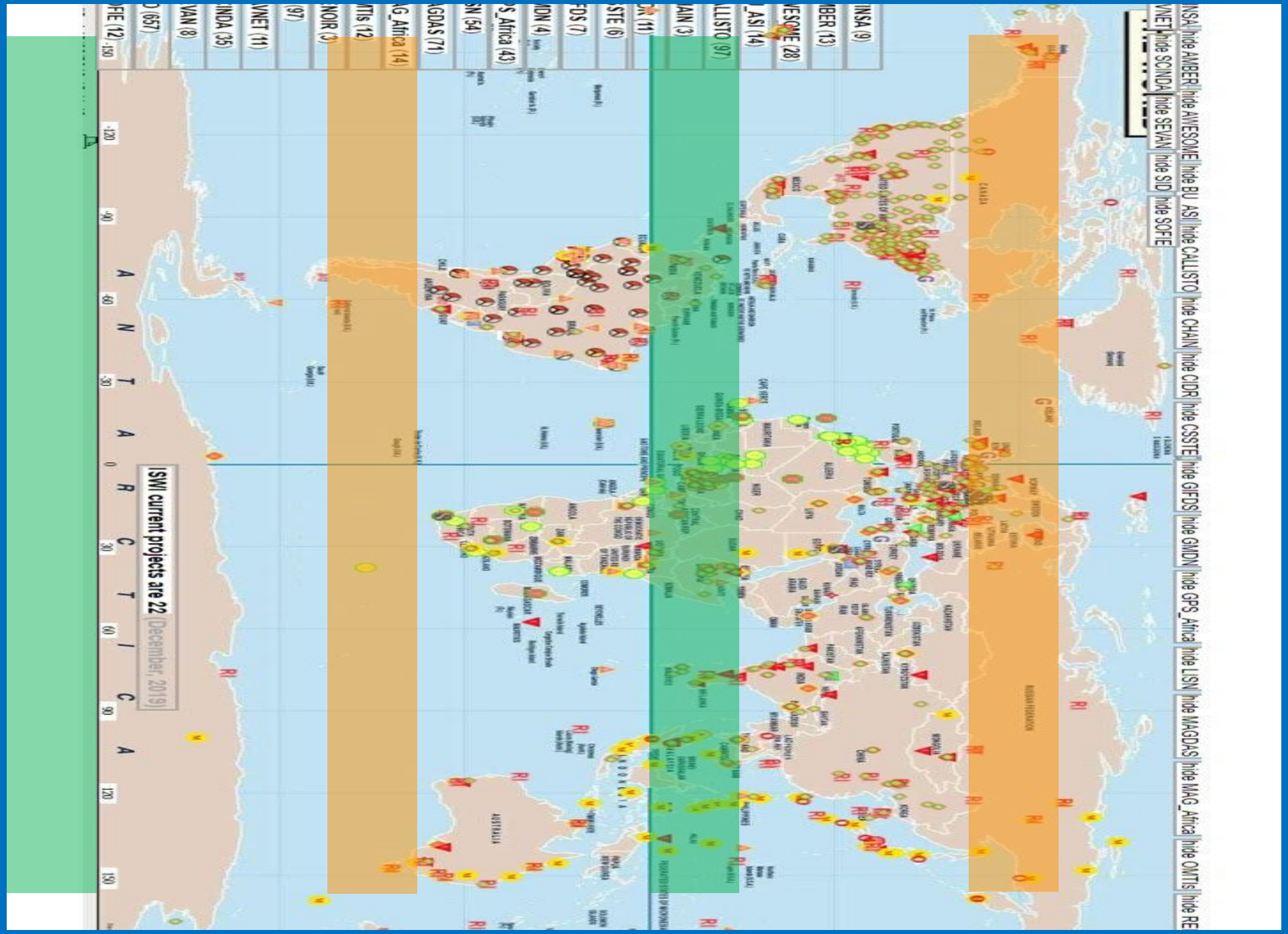
More effective monitoring of natural hazards achieved through data sharing and collaborative research

A collaboration between all nations that will benefit to all nations.

IMCP PROJECT ELEMENTS AND OVERALL LOGIC



International collaboration on the **IMCP project** under the umbrella of the **International Space Weather Initiative (ISWI),** a program of the **United Nations Office for Outer Space Affairs: UNOOSA**



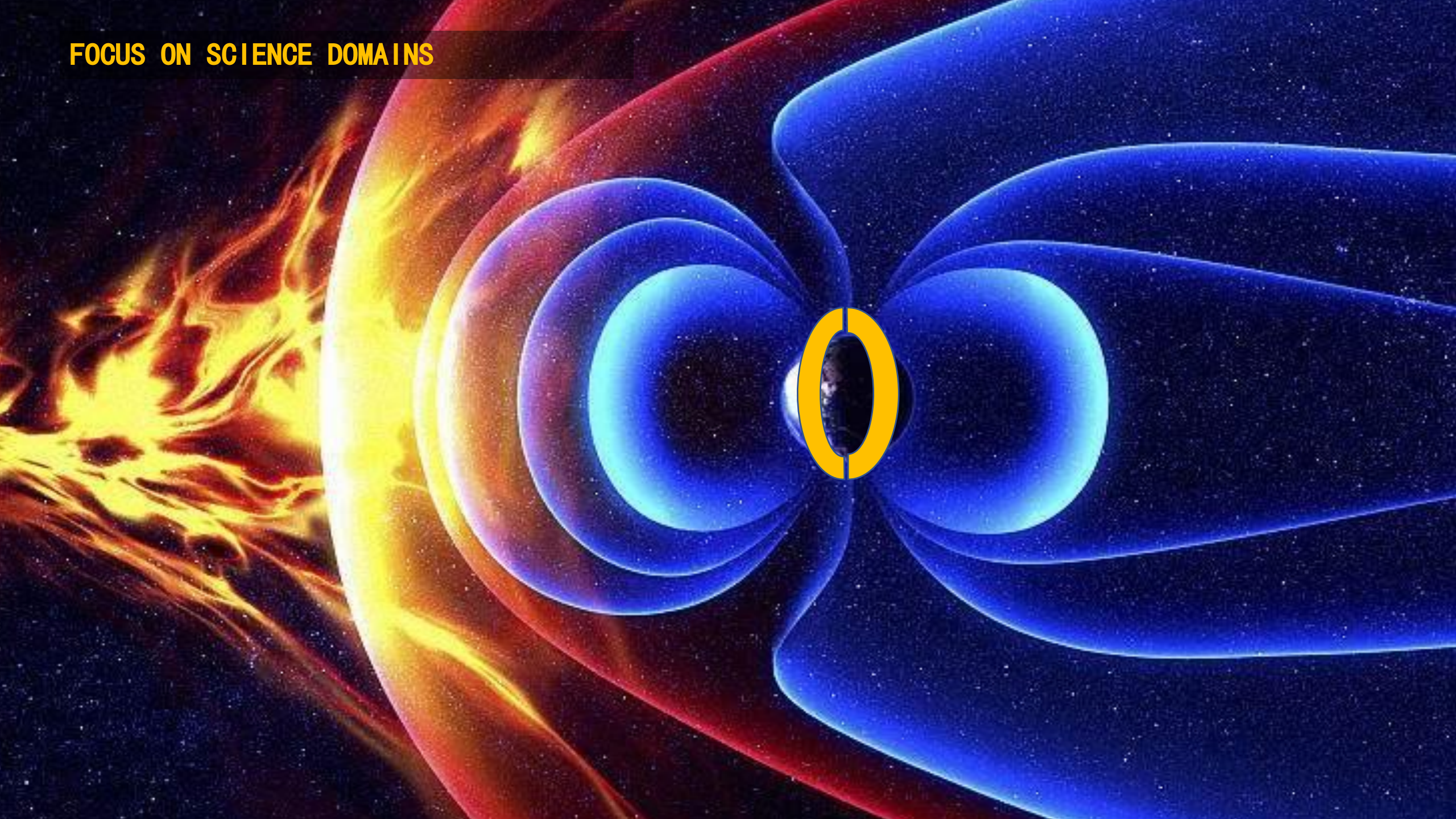
CEDAR COMMUNITY COLLABORATION WITH IMCP: A GAME CHANGER

- CEDAR community: ideal expertise to contribute to the 2 Great Circles
- Addtional collaboration opportunities offered with the second Great Circle:
  - African countries
  - EU funding schemes
- Several international meetings to come:
  - UNOOSA ISWI workshop, Vienna, this week – IMCP is being presented
  - IMCP forum and Summer School: Beijing, September 13-24
  - European Space Weather Week 2023, Toulouse, France, Nov. 20-24, 2023:

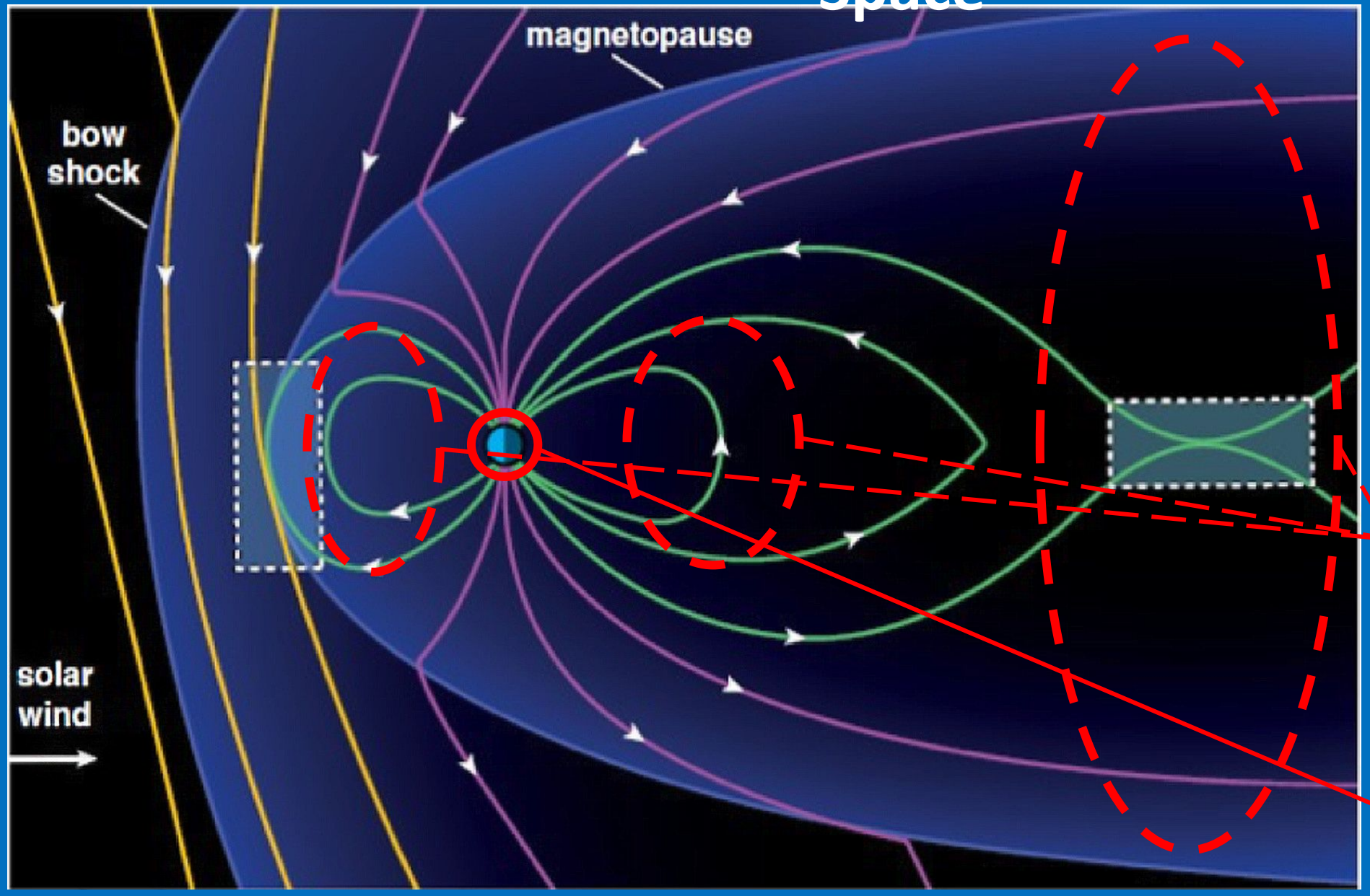
  https://esww2023.org
- IMCP Europe-Africa-Pacific Circle Workshop #1 in 2024 – likely Nigeria

Additional slides

FOCUS ON SCIENCE DOMAINS



(SW1) Geospace coupling to Solar wind and Interplanetary Space



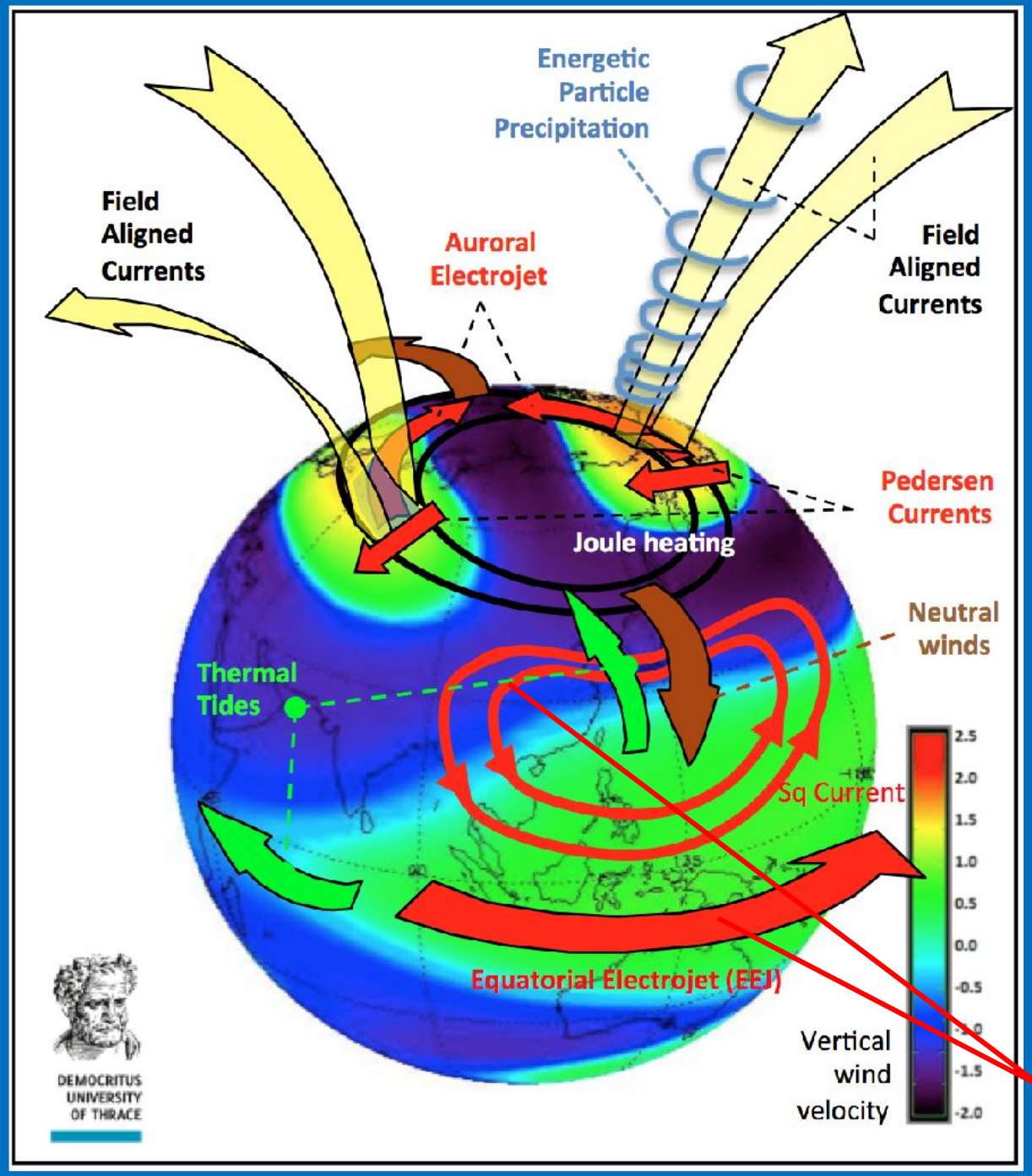
SOLAR WIND + ENERGETIC PARTICLES

ENERGY ENTRY AND TRANSFER

ENERGY STORAGE REGIONS: MAGNETOTAIL RING CURRENT

ENERGY DEPOSITION AND DISSIPATION REGIONS

(SW2) MIT and cross-latitude coupling processes



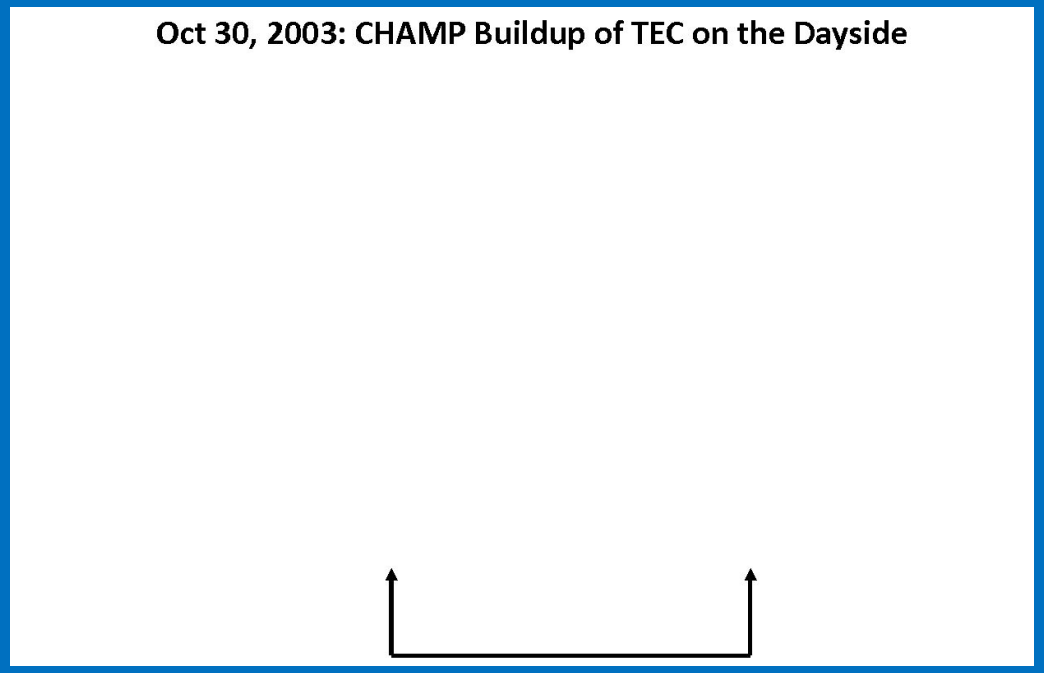
1. Penetration to middle and low latitudes of electric fields produced by the ionospheric closure of field-aligned currents

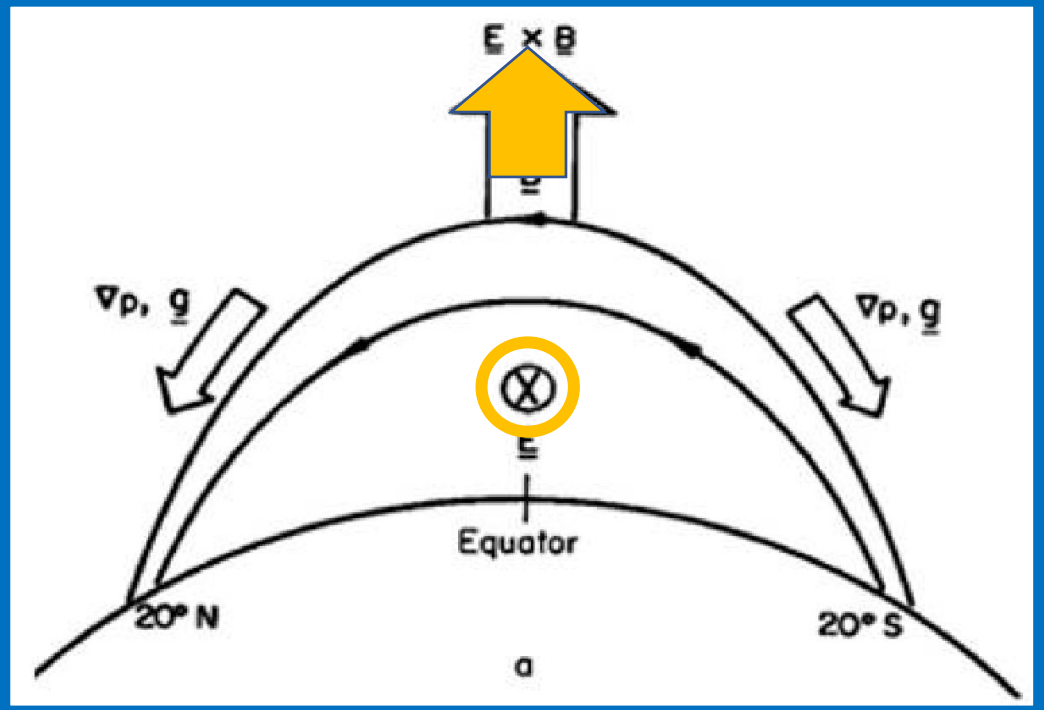
2. Partial and time-dependent shielding of these electric fields by the polarization of the inner edge of the ring current

3. Generation of latitudinal Hadley cells by auroral heating,latitude redistribution of angular momentum in thermosphere, production of westward flows in the middle latitude thermosphere

4. Transmission of these westward flows to the ionosphere and plasmasphere by the ”ionosphere disturbance dynamo” mechanism

“Red” : regular currents driven by tides (upward-propagating and in situ) generated via the Ionospheric Dynamo





(SW) LOW-LATITUDE PHENOMENA
Longest land traverse of equatorial electrojet in Africa

Equatorial electrojet and fountain are driven by :

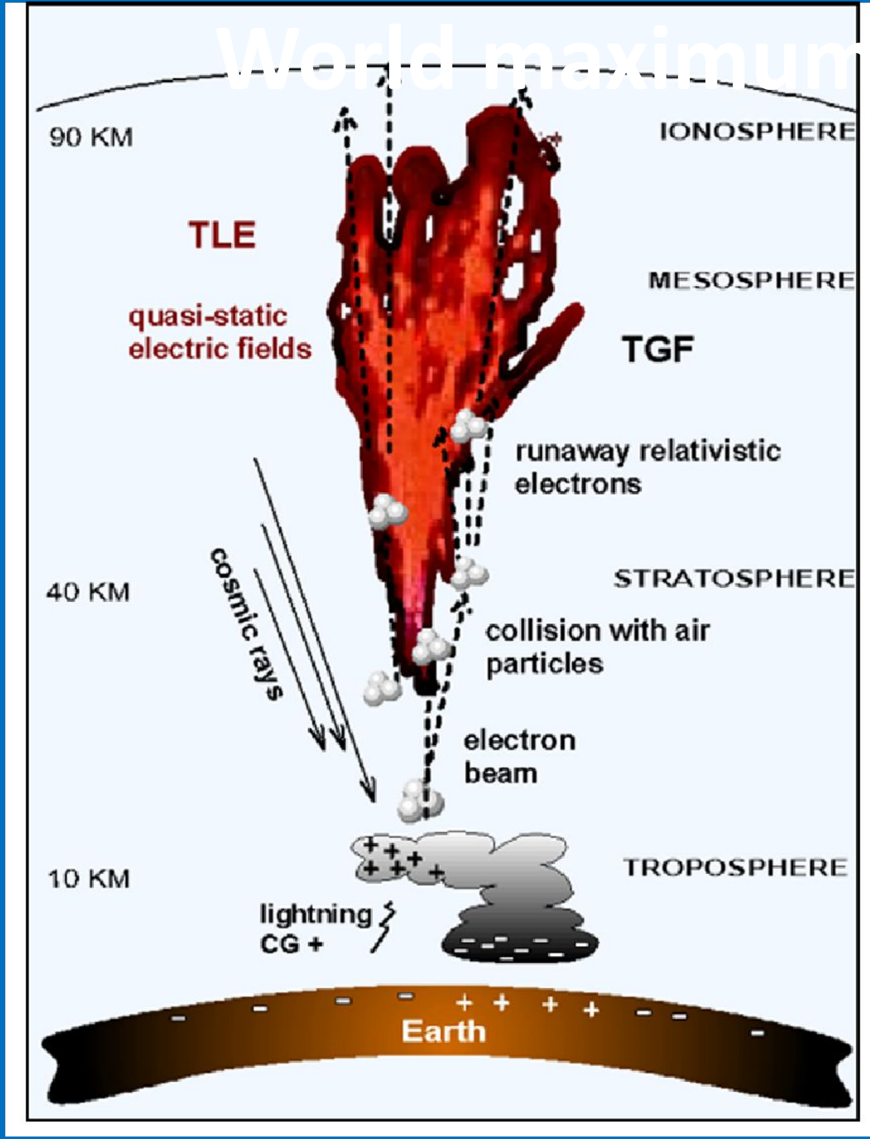
- Variations of the **zonal ionospheric electric field**
- Travelling atmospheric/ionospheric disturbances
- Cross-equatorial winds

Need to quantify the time response of:

- equatorial electrojet
- vertical plasma drifts
- sub-tropical crests
- equatorial irregularities
- spread-F

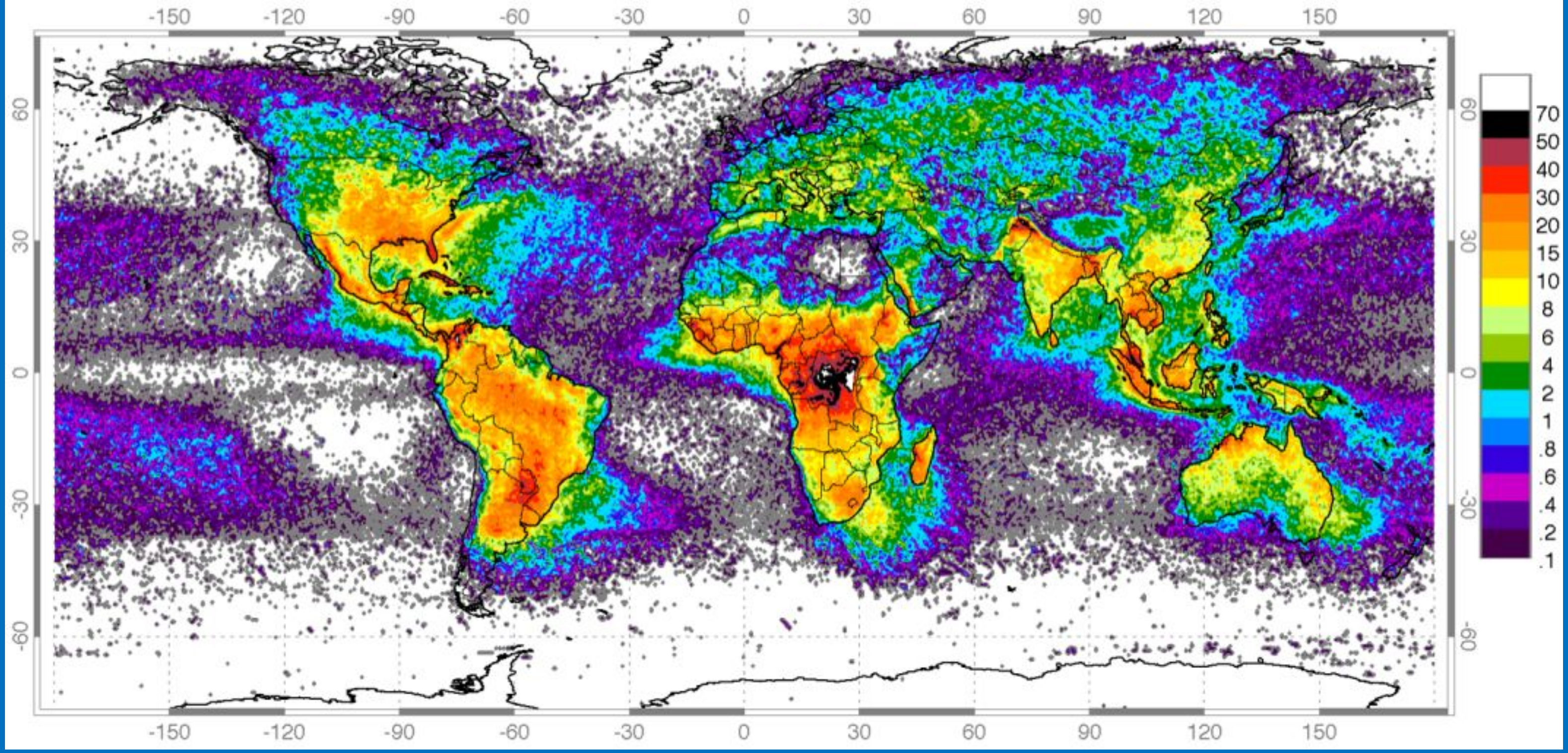
through the diversity of magnetic storms

(AW) + (GE) Vertical coupling in the atmosphere:
World maximum of thunderstorm activity in Africa

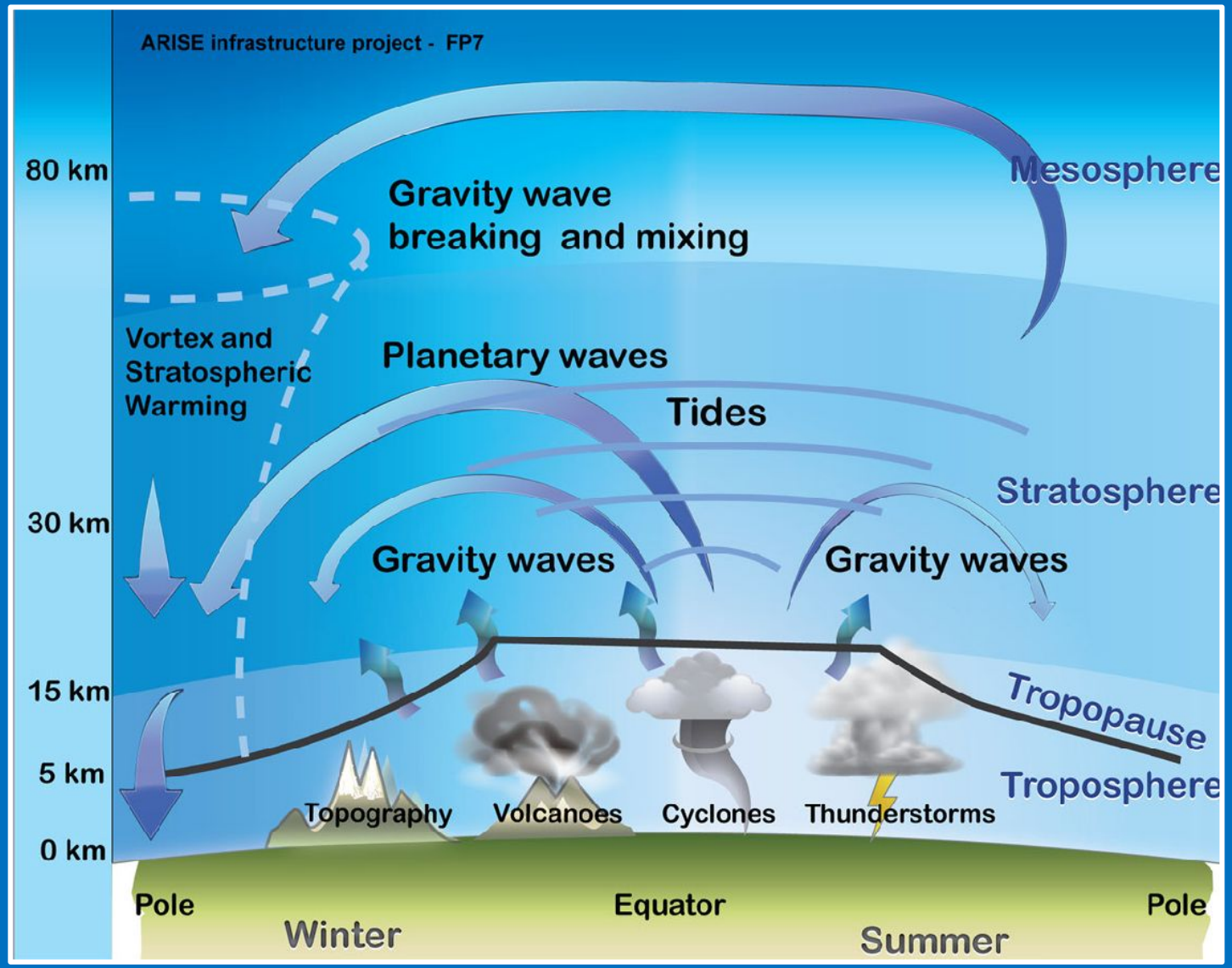


Upward electric discharges from top of clouds to ionosphere close the global ionospheric circuit

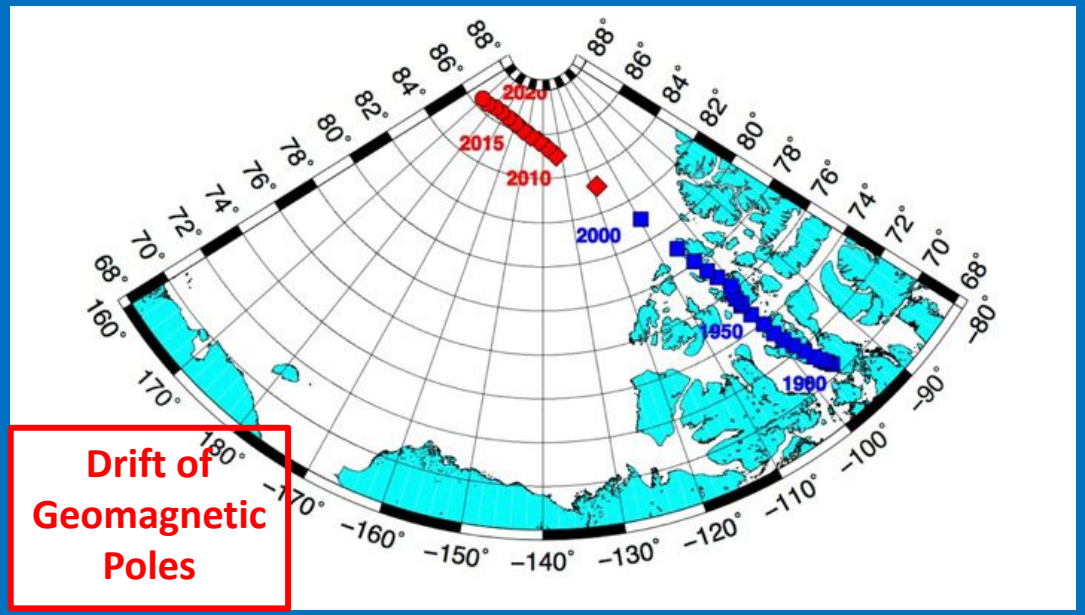
Identify how discharges are triggered, the host of EM and ES emissions they produce, their generation mechanisms and the charged particle acceleration mechanisms



(AW) Vertical coupling in the atmosphere:
Atmospheric waves

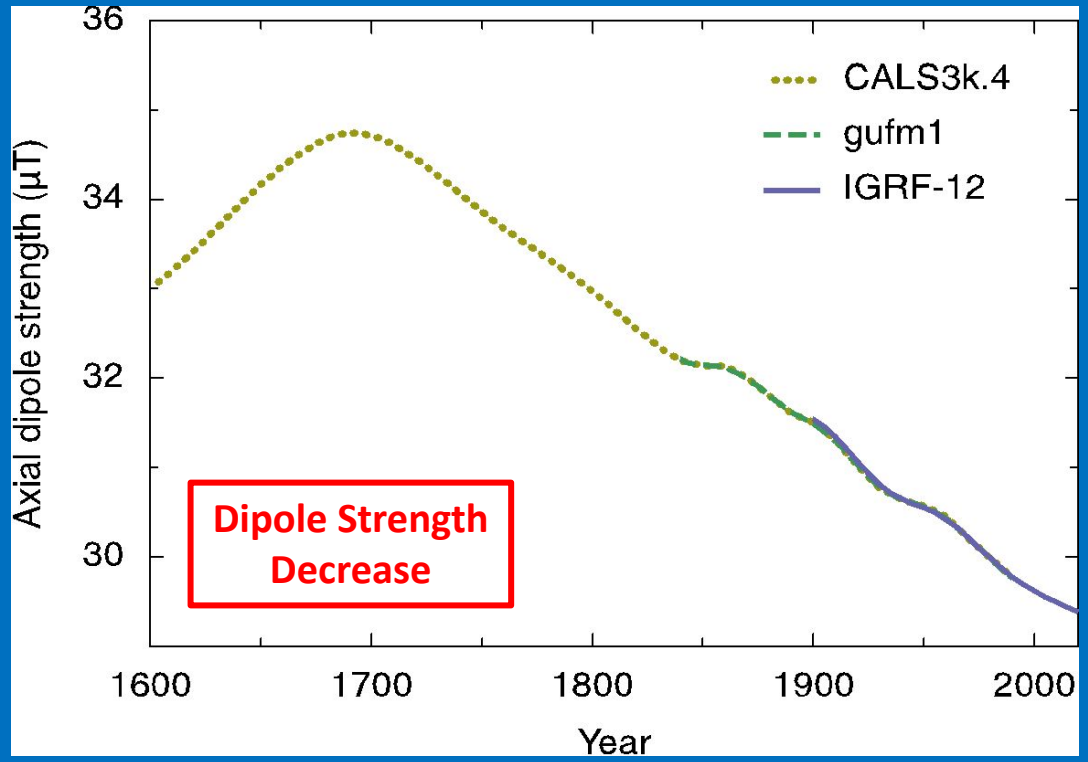


- A broad spectrum of atmospheric waves are generated by the latitudinal structure of general circulation, weather events, orography and land-ocean contrasts
- They propagate upwards through the stratosphere, mesosphere and into the lower atmosphere
- Reflection at critical levels, refraction, interactions with the mean wind, dissipation determine how much momentum and energy they transfer to the region of positive temperature gradient of the thermosphere

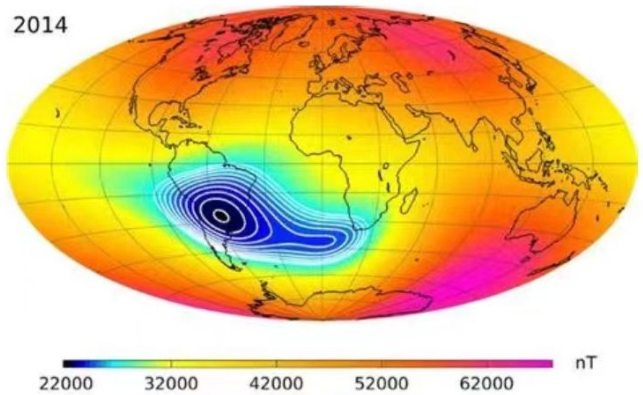


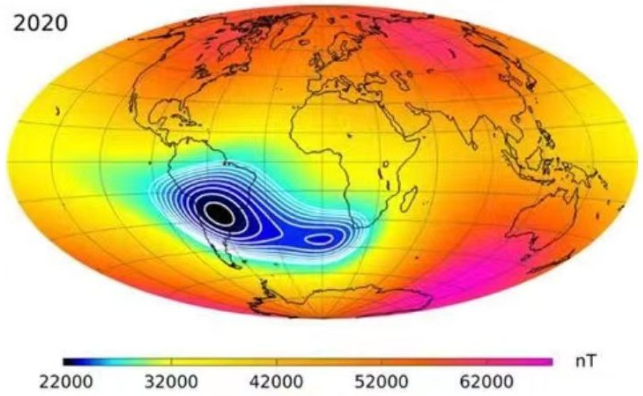
Drift of Geomagnetic Poles

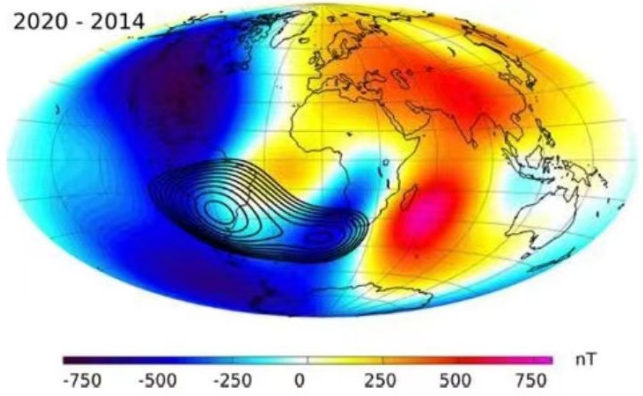
(GM) Secular variations of the geomagnetic field



Dipole Strength Decrease

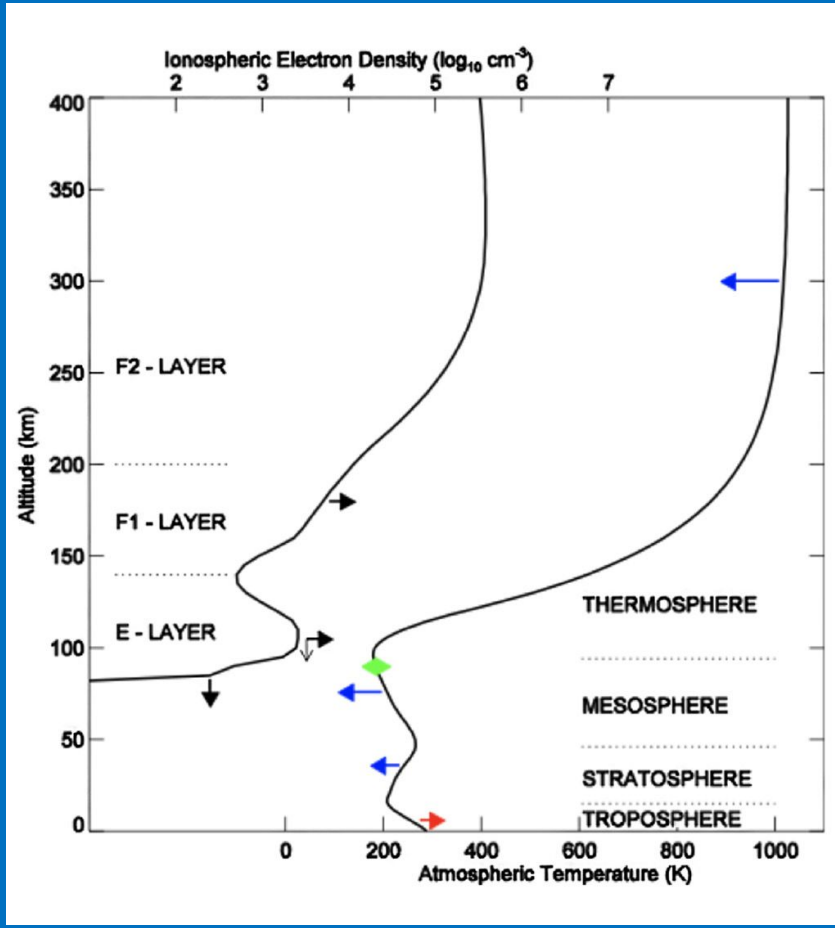




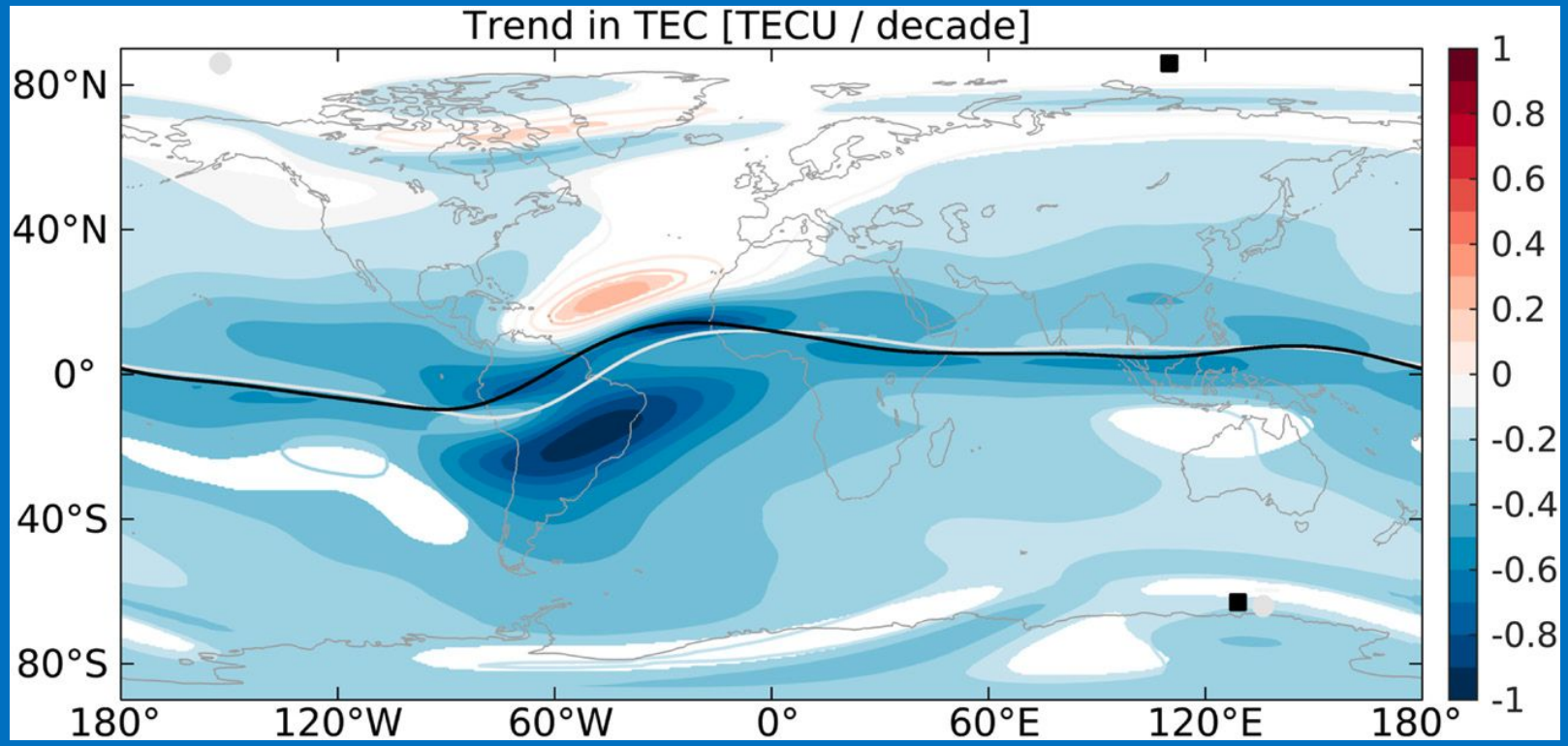


Drift and variations of regional anomalies

(GG + GM) Combined effects of climate change and geomagnetic field secular variations



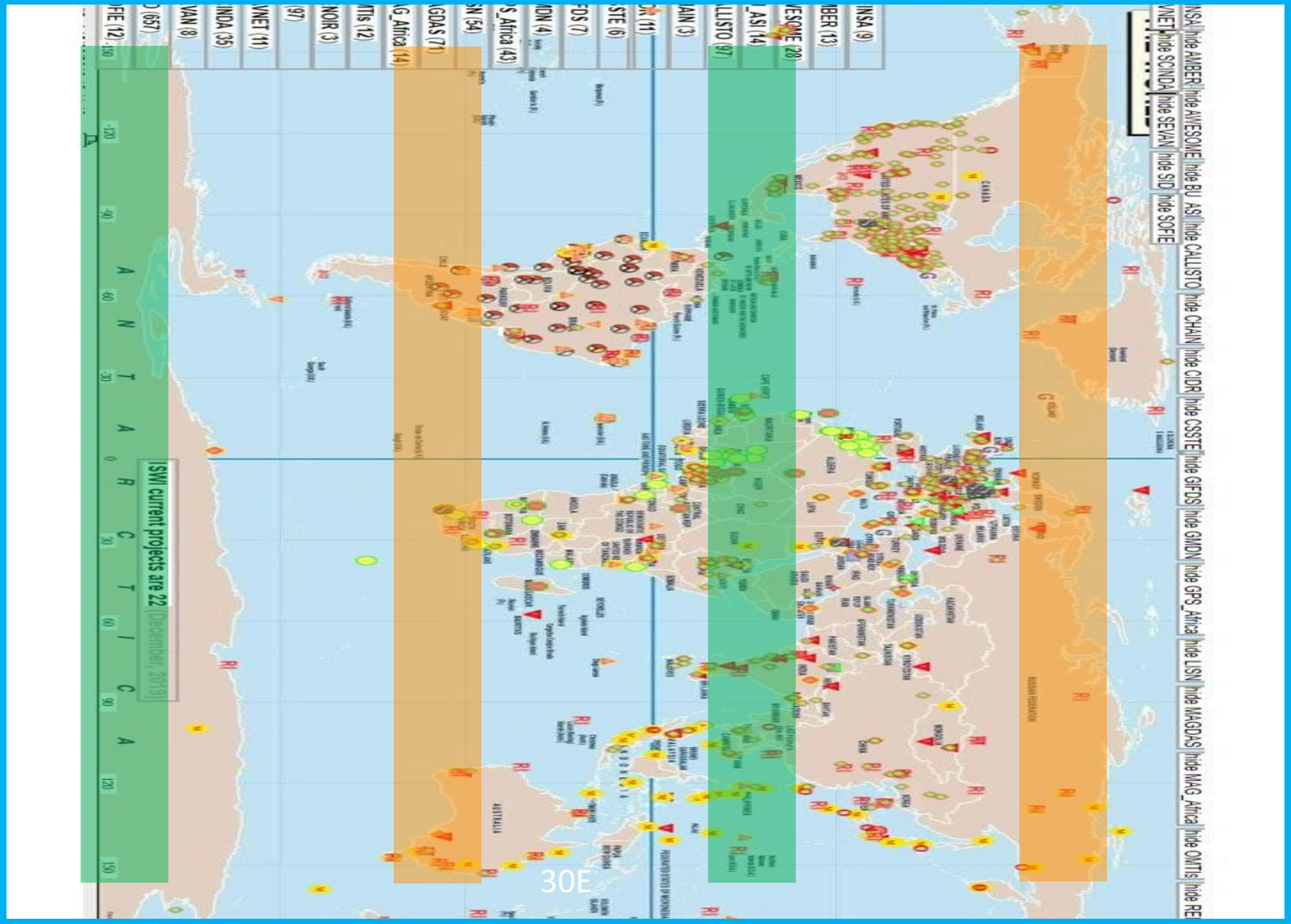
Emerging pattern of global change in the thermosphere and ionosphere, according to J. Lastocicka et al. (Ann. Geophys., 26, 1255-1268, 2008)



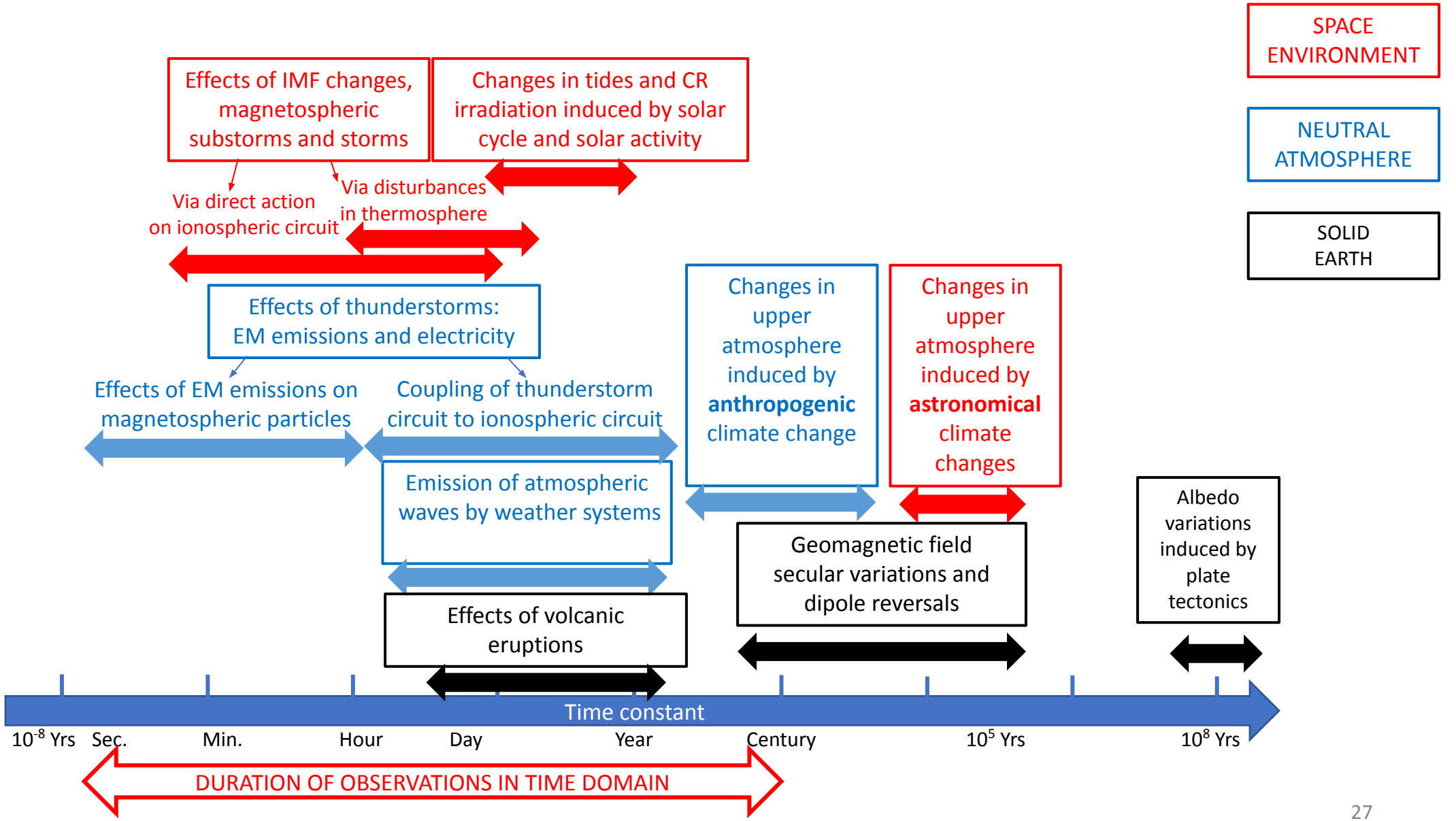
Model prediction of change in TEC between 2015 and 2070, according to the simulations of Cnussen (2022) GRL, 49, e2022GL100693. https://doi.org/10.1029/2022GL100693

IMCP within ISWI

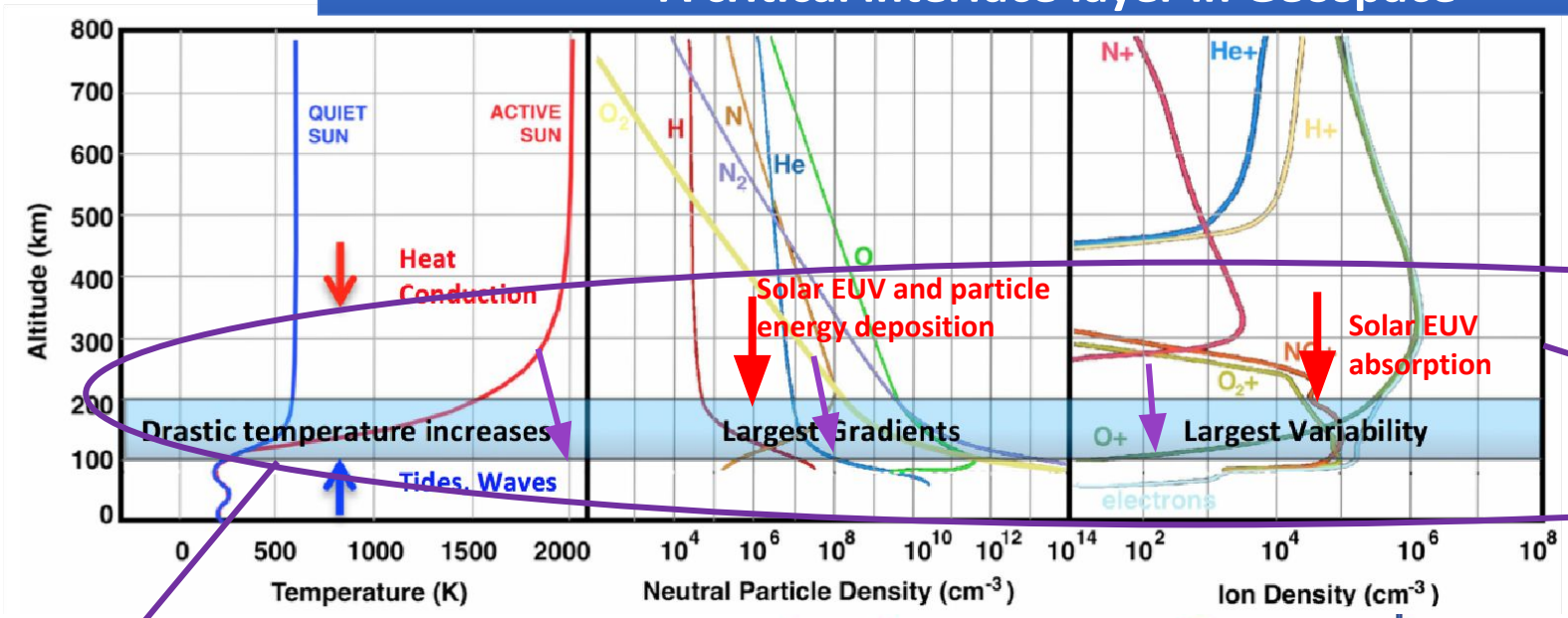
To facilitate cooperation between all interested countries, continuation of dialogue on the development of the IMCP project with its two Great Circles (and more…), continuation under the umbrella of ISWI and of UNOOSA will be particularly welcome

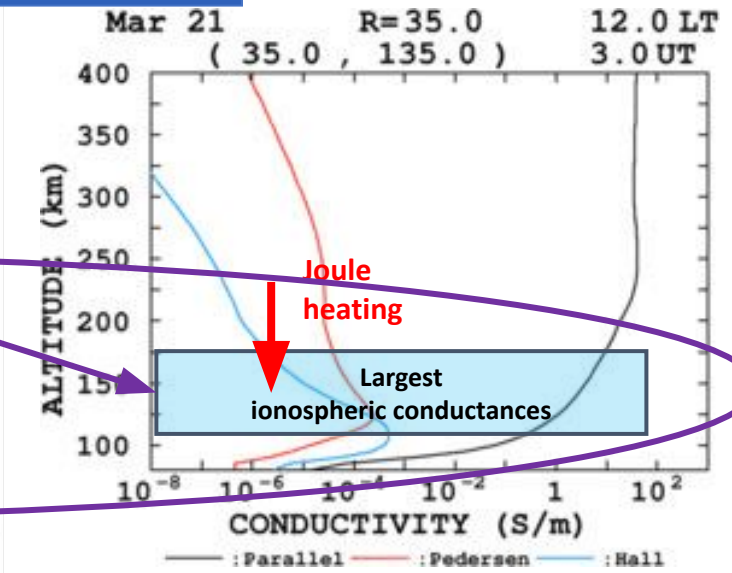


Timescales of the different sources



Ionosphere and Middle-Upper Atmosphere (IMUA)
A critical interface layer in Geospace





Need to identify a set of « Key Parameters » whose measurements can characterize the average state of this critical layer and the disturbances induced on it both from above and from below

1)