Disambiguating the detection of Rossby and Kelvin Wave Signatures in the Ionosphere

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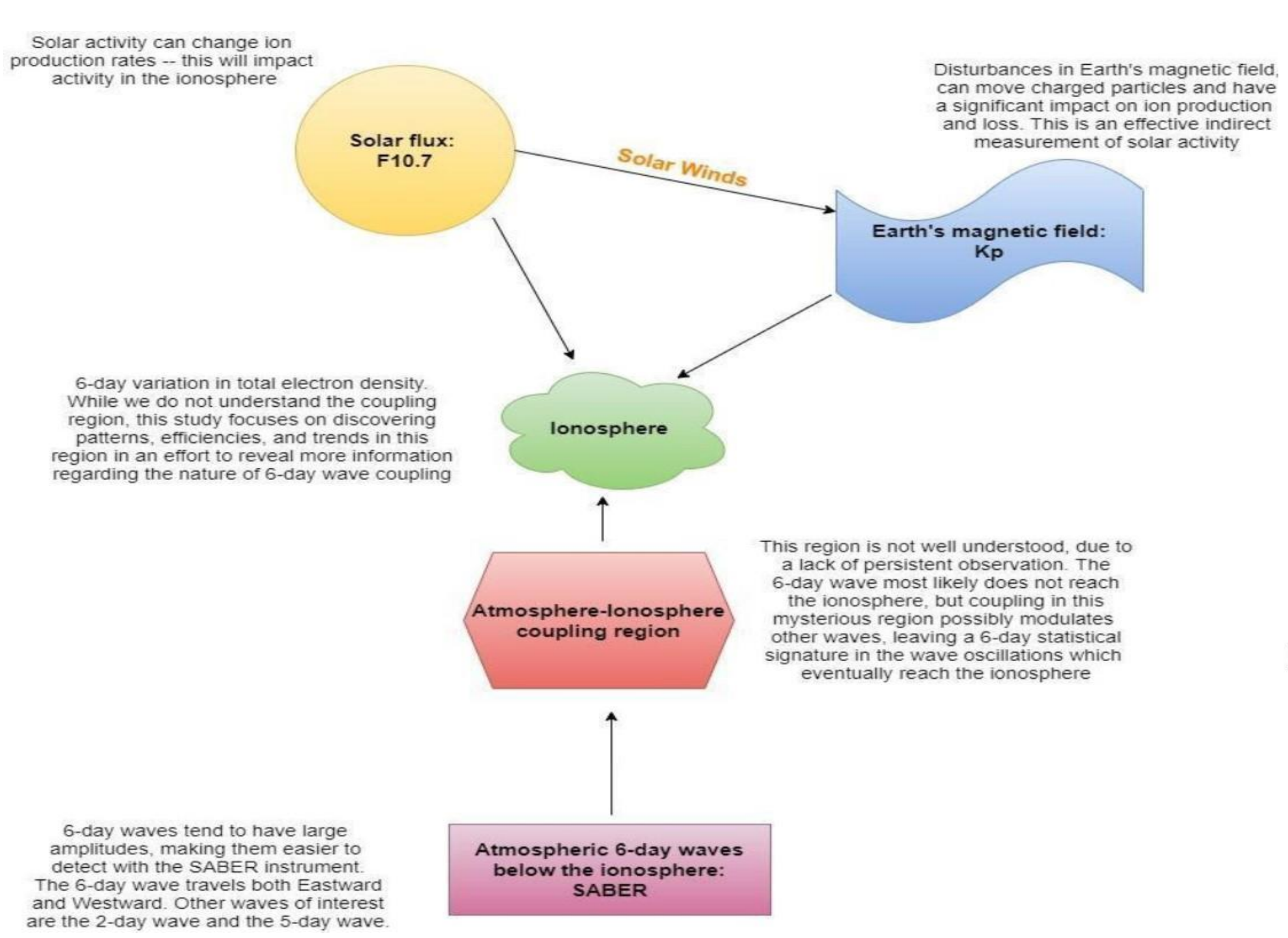
CEDAR Workshop 2023 COUP-13

ABSTRACT

Rossby and Kelvin waves play a critical role in shaping the interplay between the thermosphere and ionosphere. Both waves originate from the lower atmosphere and propagate upwardly by growing exponentially with height until they reach the ~ 90 – 100 km E-region altitude. At this altitude, they interact with ionized particles and upset the E-region dynamo, generating electric fields that subsequently modifies the F-region ionosphere at ~ 200 – 400 km altitude. The detection of the signatures of these waves in the ionosphere remains poorly understood due to challenges in identifying and quantifying them with episodic cases and short dataset. We disambiguate the detection of these waves by investigating all the cases of 2-, 3-, 5- and 6-day Rossby and Kelvin waves in the ionosphere and derive an efficiency for their detection and how these efficiencies may vary. For efficiency, the key thing is consistent long dataset. This study relies on global observations from NASA's TIMED/SABER temperature satellite measurements and global positioning satellite (GPS) total electron content (TEC) data from 2002 – 2022, covering solar cycle 23, 24 and 25. To prevent false signals in the detections, we exclude variations in solar flux and geomagnetic / magnetospheric disturbances. The outcome of this study offers insightful findings for both observational and modeling communities with the potential to initiate modeling efforts that will provide a refine understanding of the dynamics of planetary wave – ionosphere coupling mechanisms.

WHAT WE ARE DOING



- We are choosing to look at a lot of cases of planetary waves (PWs) in the ionosphere and look for patterns – to get an efficiency and how that might vary, rather than zeroing in on one case with plentiful observations.
- We want to make sure we don't have false signals when detecting PWs in the ionosphere – such as variation in solar flux, geomagnetic / magnetospheric impacts.

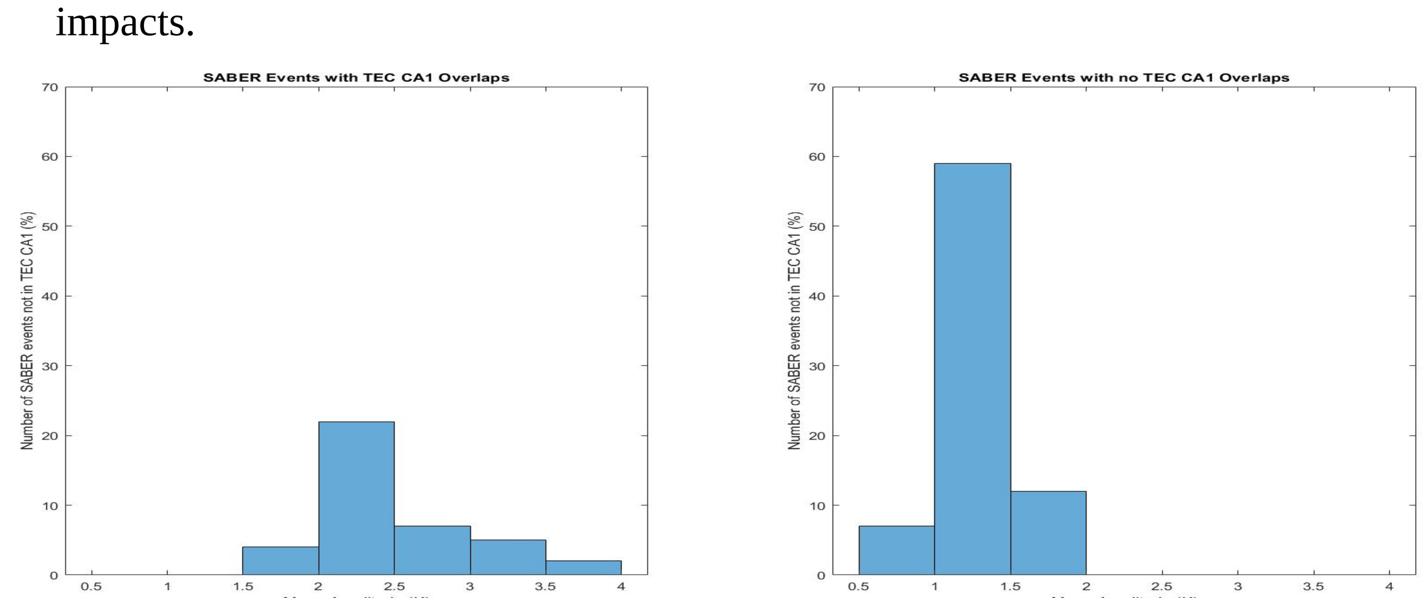


Figure 4. Results (Continued): One of our distribution of mean amplitude of the impact of 6-day wave amplitudes detected with SABER (right) manifestation in the ionosphere.(left) when SABER events did not induce a response in the ionosphere.

MOTIVATION

- Existing conjecture posits direct modulation of E and F region by 2-, 3-, 5- and 6-day waves. However, there are still open questions per the efficiencies of the detection of these waves in the ionosphere.

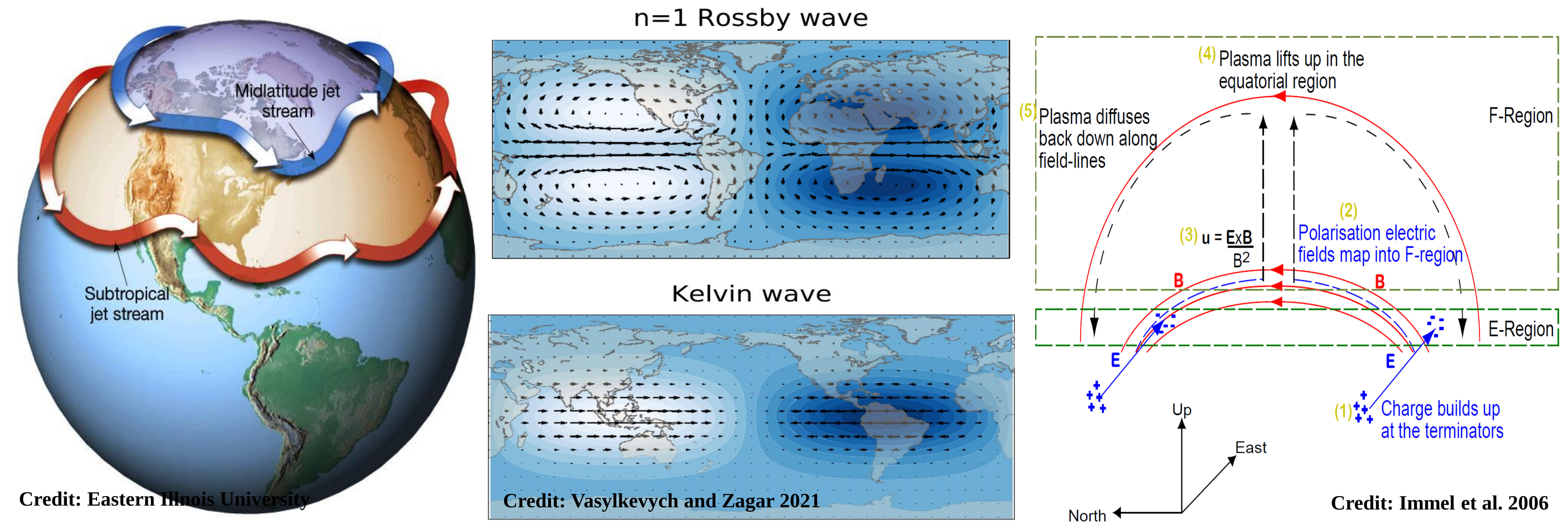
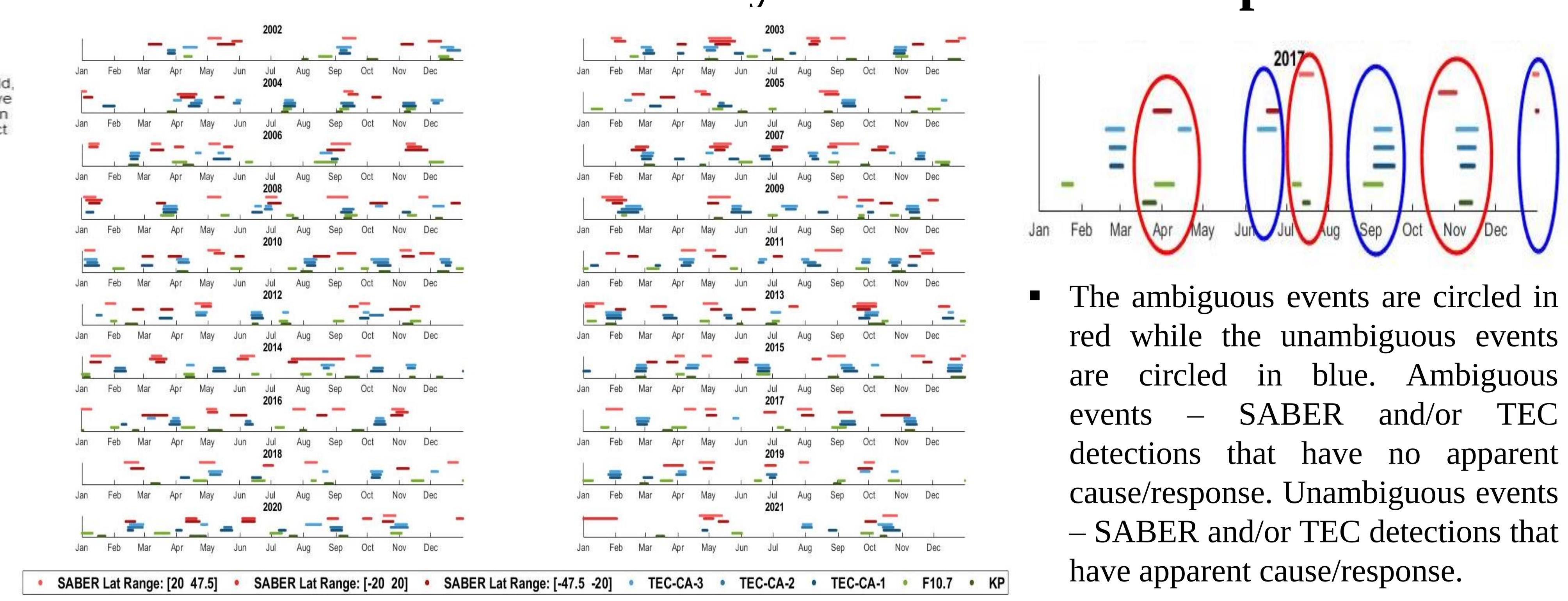


Figure 1. (left) Jet stream as an example of the driver of planetary waves. (center) Rossby waves (top) and Kelvin waves (bottom). Vectors depicts magnitudes while color gradient depicts relative temperatures. (right) Ionospheric Dynamo.

RESULTS: 6-Day Waves in the Ionosphere



- The ambiguous events are circled in red while the unambiguous events are circled in blue. Ambiguous events – SABER and/or TEC detections that have no apparent cause/response. Unambiguous events – SABER and/or TEC detections that have apparent cause/response.

Figure 3. 6-day wave signatures in SABER (westward rossby), TEC, F10.7 and Kp datasets for Central America (CA) with a standard deviation of 1.4.

Table 1 – (top) Efficiencies of Eastward Kelvin and Westward Rossby 6-day wave SABER detections that produce a TEC response in Central America (CA), Japan (JP), South America (SA) region. (bottom) Efficiencies of Eastward Kelvin and Westward Rossby 6-day wave SABER detections inducing a response in TEC with and without the false signals in the CA, JP and SA region (STD 1.4)

Regions	TEC CA 1	TEC CA 2	TEC CA 3	TEC JP 1	TEC JP 2	TEC JP 3	TEC SA 1	TEC SA 2	TEC SA 3	TEC SA 4	TEC SA 5
STD 1.2 (#, Percent)											
How many west only?	(23,23%)	(16,22%)	(15,19%)	(20,25%)	(24,29%)	(26,29%)	(21,25%)	(29,35%)	(28,28%)	(23,28%)	(21,30%)
How many east only?	(14,14%)	(13,15%)	(17,17%)	(20,22%)	(16,17%)	(15,16%)	(21,25%)	(20,24%)	(15,15%)	(12,15%)	(16,23%)
How many ambiguous?	(35,36%)	(32,37%)	(37,37%)	(29,31%)	(35,38%)	(26,29%)	(19,23%)	(20,24%)	(30,30%)	(26,32%)	(23,33%)
How many TEC response?	(72,73%)	(66,76%)	(77,77%)	(74,80%)	(75,81%)	(67,74%)	(61,73%)	(69,83%)	(73,73%)	(61,75%)	(60,86%)
TEC (#)	98	86	99	93	93	91	83	82	99	81	70
STD 1.3 (#, Percent)											
How many west only?	(19,22%)	(18,23%)	(19,22%)	(22,26%)	(23,26%)	(23,29%)	(18,24%)	(23,31%)	(24,28%)	(22,30%)	(22,29%)
How many east only?	(13,15%)	(10,13%)	(15,17%)	(19,22%)	(15,17%)	(11,14%)	(20,27%)	(18,24%)	(13,15%)	(12,16%)	(14,18%)
How many ambiguous?	(31,36%)	(30,38%)	(32,36%)	(27,31%)	(33,38%)	(22,28%)	(18,24%)	(20,27%)	(26,30%)	(23,31%)	(26,34%)
How many TEC response?	(63,73%)	(58,74%)	(66,75%)	(68,79%)	(71,81%)	(56,71%)	(56,75%)	(61,82%)	(63,73%)	(57,77%)	(62,81%)
TEC (#)	87	78	88	86	87	79	75	74	86	74	76
STD 1.4 (#, Percent)											
How many west only?	(20,24%)	(16,22%)	(15,19%)	(20,25%)	(24,29%)	(20,29%)	(19,28%)	(23,34%)	(21,28%)	(18,28%)	(21,30%)
How many east only?	(10,12%)	(10,14%)	(14,17%)	(17,22%)	(13,16%)	(8,12%)	(17,25%)	(17,25%)	(11,15%)	(12,18%)	(12,17%)
How many ambiguous?	(28,34%)	(27,38%)	(29,36%)	(27,34%)	(29,35%)	(18,26%)	(15,22%)	(17,25%)	(19,26%)	(20,31%)	(23,33%)
How many TEC response?	(58,70%)	(53,74%)	(58,72%)	(64,81%)	(66,80%)	(46,67%)	(51,75%)	(57,84%)	(51,69%)	(50,77%)	(56,80%)
TEC (#)	82	72	81	79	83	68	69	67	74	65	70

Regions	TEC CA 1	TEC CA 2	TEC CA 3	TEC JP 1	TEC JP 2	TEC JP 3	TEC SA 1	TEC SA 2	TEC SA 3	TEC SA 4	TEC SA 5
STD 1.4 (#, Percent)											
How many SABER only?	(32,39%)	(24,33%)	(22,27%)	(22,28%)	(23,28%)	(19,28%)	(20,29%)	(25,37%)	(25,34%)	(30,46%)	(29,41%)
How many F107 only?	(7, 9%)	(3, 4%)	(4, 5%)	(4, 5%)	(2, 2%)	(5, 7%)	(3, 4%)	(1, 1%)	(7, 9%)	(6, 9%)	(5, 7%)
How many KP only?	(5, 6%)	(6, 8%)	(6, 7%)	(4, 5%)	(7, 8%)	(6, 9%)	(4, 6%)	(2, 3%)	(1, 1%)	(3, 5%)	(3, 4%)
How many SABER & F107 only?	(10,12%)	(10,14%)	(13,16%)	(12,15%)	(15,18%)	(8,12%)	(8,12%)	(10,15%)	(9,12%)	(9,14%)	(9,13%)
How many SABER & KP only?	(12,15%)	(12,17%)	(16,20%)	(18,23%)	(19,23%)	(14,21%)	(13,19%)	(15,22%)	(12,16%)	(9,14%)	(14,20%)
How many SABER & F107 & KP?	(4, 5%)	(7,10%)	(7, 9%)	(12,15%)	(9,11%)	(5, 7%)	(10,14%)	(7,10%)	(5, 7%)	(2, 3%)	(14,20%)
How many TEC response?	(70,86%)	(62,86%)	(68,84%)	(72,91%)	(75,90%)	(57,84%)	(58,84%)	(60,88%)	(59,79%)	(59,91%)	(64,91%)
TEC (#)	82	72	81	79	83	68	69	67	74	65	70

DATA AND METHOD

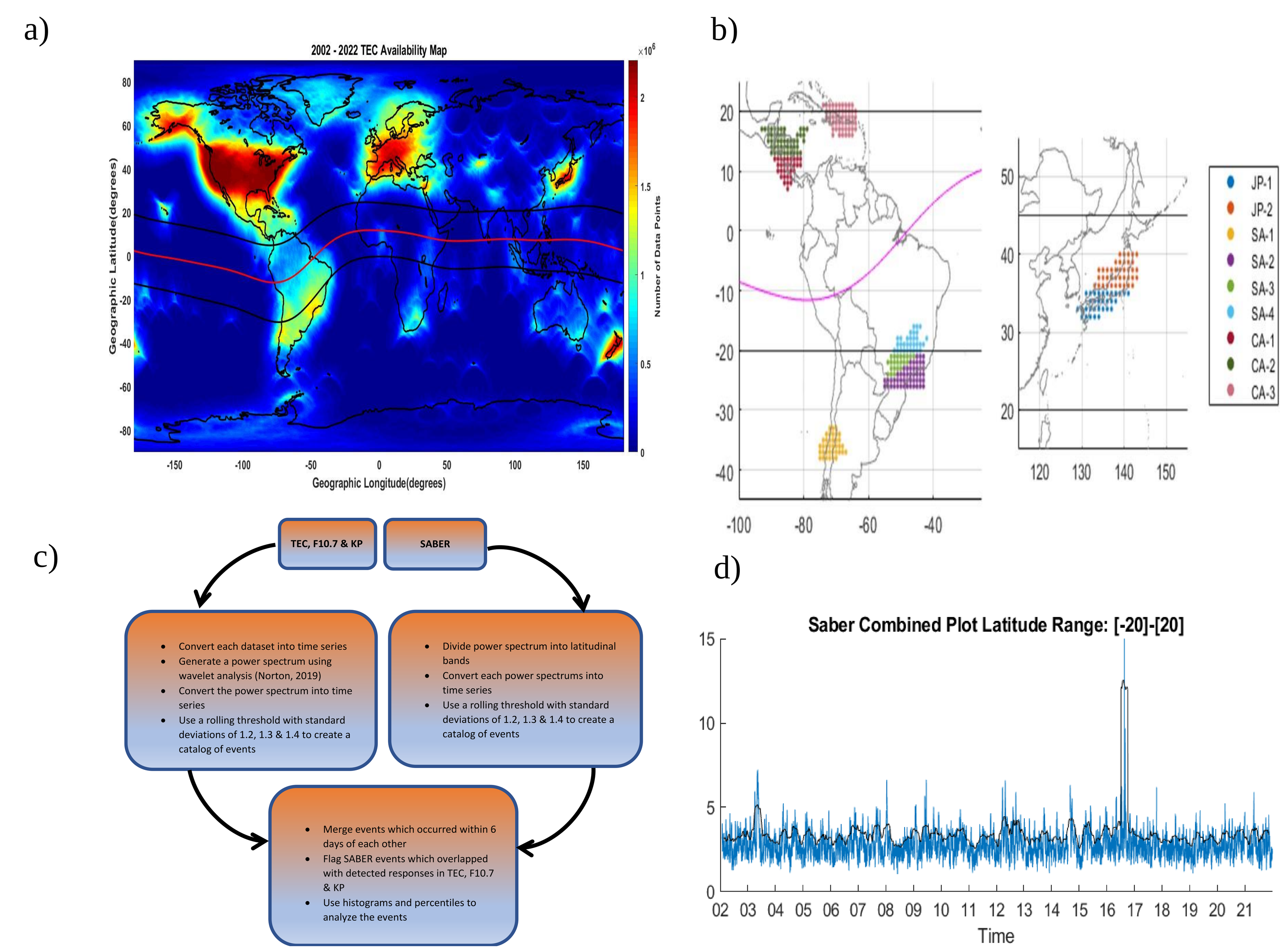


Figure 2. (a) Global total electron content (TEC) heat map from Madrigal GNSS network. (b) TEC data collection for regions under investigation. (c) Overview of steps utilized in this work. (d) 20-year continuous time series of SABER 6-day wave detection data, with an applied rolling amplitude threshold of standard deviation 1.4

CONCLUSIONS

- We created a catalog of planetary wave activities in the ionosphere that span two decades, covering the second half of solar cycle 23, the full solar cycle 24, and the ongoing phase of solar cycle 25.
- The algorithm we developed detected 336 6-day waves (189 Westward Rossby and 147 Eastward Kelvin 6-day waves) and 2689 TEC events (989, 890 and 810 TEC events for standard deviation (STD) 1.2, 1.3 and 1.4, respectively), as well as 75 F10.7 and 66 KP events. Of these TEC events, for STD 1.2, there are 283, 277 and 429 TEC events for Central America (CA), Japan (JP) and South America (SA) region, respectively. For STD 1.3, there are 253, 252 and 385 TEC events for CA, JP and SA region, respectively. While for STD 1.4, there are 235, 230 and 345 TEC events for CA, JP and SA region, respectively.
- The standard deviation had an inverse correlation with the number of TEC detections.
- The mean amplitude of the planetary waves seen by SABER is a reasonable proxy to detect Rossby and Kelvin waves signatures in the ionosphere.
- Of the 6-day waves signatures that showed up in the ionosphere ~ 79% - 91% produced a response in TEC, ~ 19% - 35% are Rossby waves, ~ 12% - 27% are Kelvin waves, ~ 27% - 46% produced an unambiguous response in TEC and ~ 22% - 38% produced an ambiguous response in TEC.
- The outcome of these PWs detections will be of great use to long term space weather simulations and modeling efforts.
- Future work is to examine other regions of the globe with more satellite observations.

REFERENCES

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