Weather & Six Meter 50 Mhz Es: A Citizen Science Investigation

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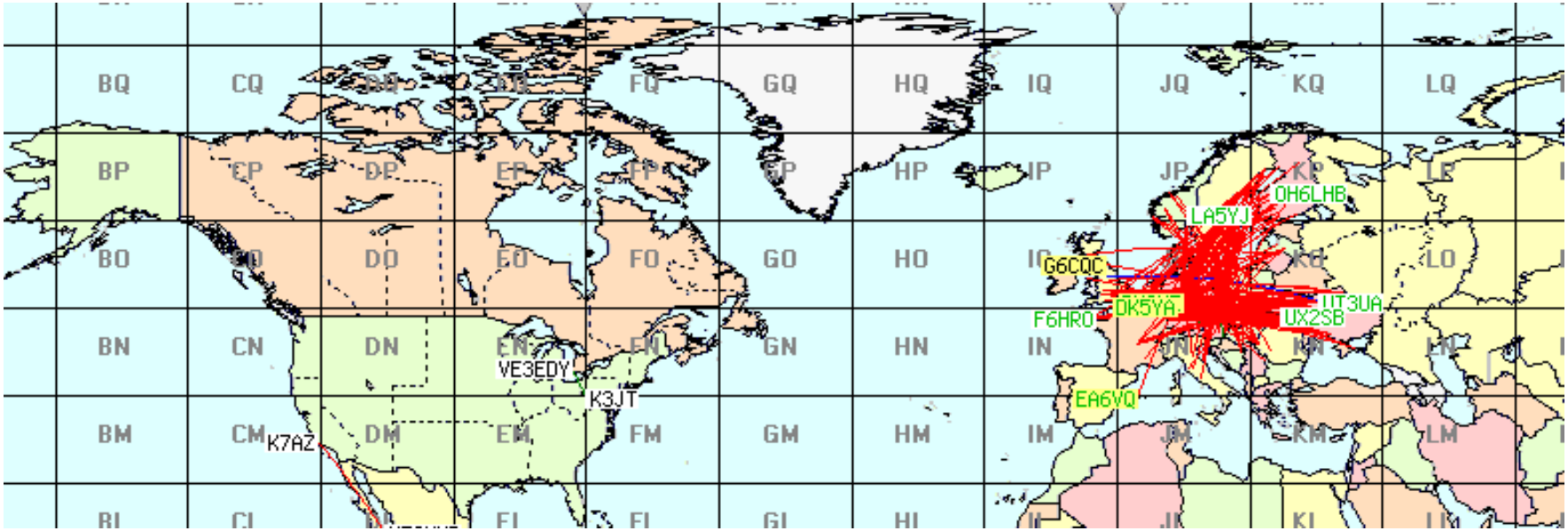
Outline

I. Introduction
II. What Started This Investigation?
III. Causes of Sporadic E (Es)
IV. Es and 6M Low Pressure Observations using Amateur Radio
V. Conclusions and Observations
VI. Updates: Winter Es

K1YOW

- Joe Dzekevich, FN42, Harvard, MA, USA
- Retired Reliability Engineering Fellow
- Licensed in 1962
- Station is modest: TS-950SG or IC-746-PRO, 100W, into a 7 band OCF dipole (added a VHF/UHF LP antenna late 2017)
- Interests: Propagation (Es, F2, Geomagnetic Storms, PCA, Tropo Ducts, Gray Line, Auroras), Astronomy, Science
- Used CRPL Predictions way back in the 60's.
- Email: K1YOW@ARRL.NET

What Started This Investigation?



Typical 6M Day for the Spring of 2016
European 6M Es, NA – Nothing!
What then are the causes of Es?

German Es Study using GPS

A Global Survey of Sporadic E Layers based on GPS Radio Occultations by CHAMP, GRACE and FORMOSAT–3 / COSMIC

Christina Arras

Scientific Technical Report STR10/09

ISSN 1610-0956

September 2010

A Landmark Paper!

- Excellent overview of radio wave propagation
- Chapters 2, 6, 7 and 8 are of the main interest to hams on Sporadic E (Es)
- It is 35 MB is size as a PDF file
- You may need a few mugs of coffee to get through the paper. It is long, but well written.
- It is up to date and not 60 yr old IGY data and uses modern GPS techniques.

Use GPS to Detect Global Es

- GPS satellites emit electromagnetic waves on L Band frequencies
- The signals are affected by strong electron density gradients at altitudes above approximately 80km and by atmospheric density, pressure and water vapor content in the troposphere and stratosphere

Ionization Layers

Layer	Altitude range	Prevalent ions	Typical electron density
Plasmasphere	400 km – 3 - 7 Earth's radii	H^+	$\sim 10^8\,m^{-3}$
F layer	170 – 1000 km	O^+	$\sim 10^{11} - 10^{12}\,m^{-3}$
E layer	90 – 170 km	O_2^+, NO^+	$\sim 10^{11}\,m^{-3}$
D layer	$\leq$90 km	H_3O^+, NO_3^-	$\sim 10^8 - 10^{11}\,m^{-3}$

Table 2.1: Main properties of the ionospheric layers.

Solar radiation is the major factor in ionization densities.

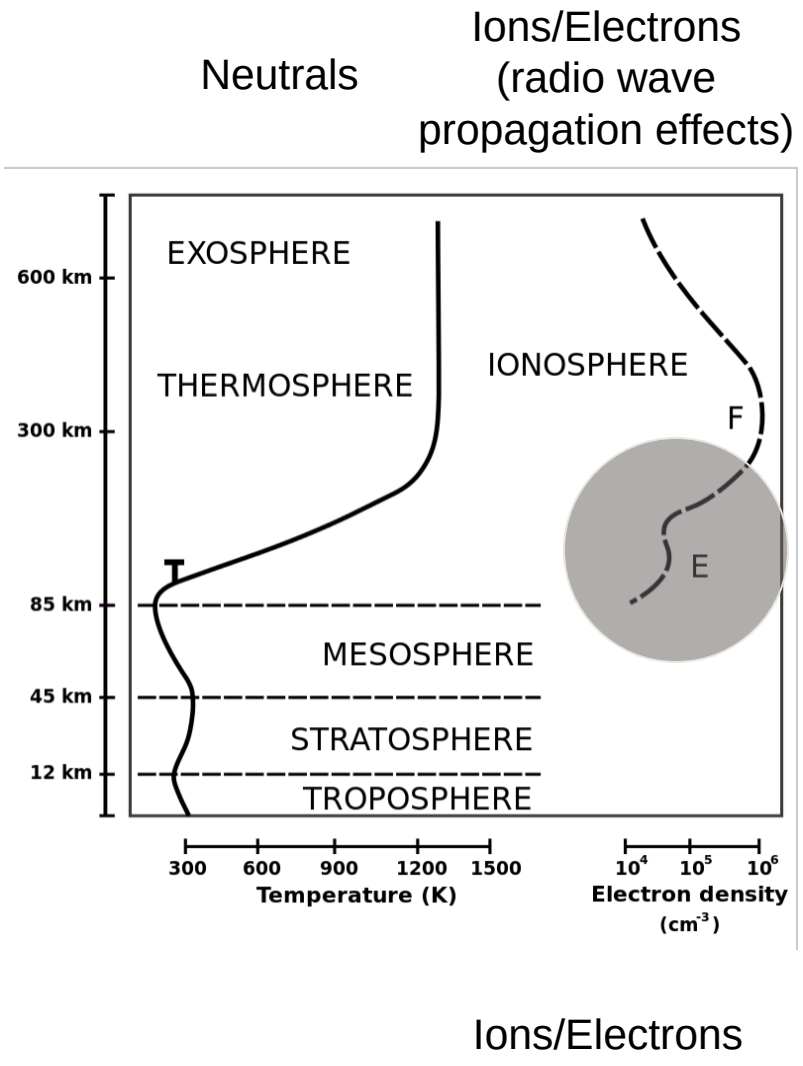
Generally, the electron content is on average higher at low latitudes compared to high latitudes.

The ionosphere varies on different time scales that follow daily, seasonal and solar sunspot cycle (11 years) changes.

Daily variations in the ionosphere are a result of the 24 hour rotation of the Earth around its axis

Sporadic E (Es)

- Sporadic E layers are phenomena of the ionospheric E region.
- The Es layers appear mainly at daytime in mid latitudes in the summer hemisphere.
- Sporadic E layers = enhanced electron density compared to the background ionization.
- They occur between 90 and 120 km altitude with a thickness of usually 0.5 – 5.0 km and a horizontal extent of 10 – 1000 km.



Radio Occulation

- This measurement method is termed “radio occultation” technique and it allows to receive a global picture of ionospheric and lower neutral atmospheric conditions.
- Visual astronomers use similar types of techniques when a planet edge (limb) passes in front of a star so that they can measure the planet’s atmospheric composition by measuring the star’s light changes.
- The German study focuses on the detection and analysis of sporadic E layers from GPS radio occultation measurements on a global scale.
- Previous data were from local Ionosonds, incoherent scatter radars (like Millstone) and 60 year old IGY data.

Radio Occulation

- Scientific satellites flying in low–Earth orbit receive the signals of the conversant GPS navigation satellites whenever they rise or set behind the Earth's limb.
- The GPS signals are modified when propagating through the different atmospheric layers due to their refractive index.
- These measurements contain information on atmospheric parameters like temperature, pressure, moisture and electron density as well as on their global distribution and spatial and temporal variations.

Radio Occulation

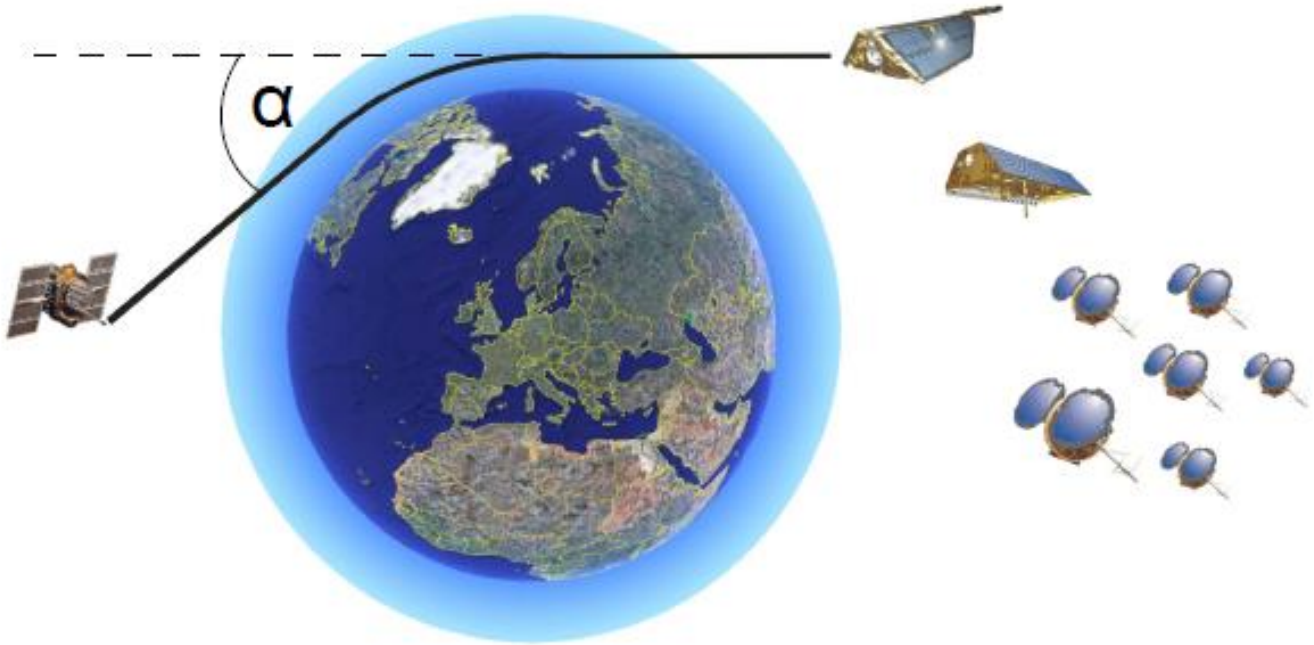


Figure 3.1: GPS Radio occultation principle. The LEO satellites CHAMP (top), GRACE (middle) and the COSMIC constellation (bottom) observe a rising or setting GPS satellite (left) behind Earth's limb. The key observable is the bending angle, α, which is induced by ionospheric and neutral atmospheric refraction.

Sporadic E

- Es is subject to coupling processes between the neutral atmosphere and ionosphere.
- Es occurrence is oriented along Earth's magnetic field
- Es altitudes are subject to tidal winds and that its annual cycle varies with meteor influx.

Mid Latitude Es Causes

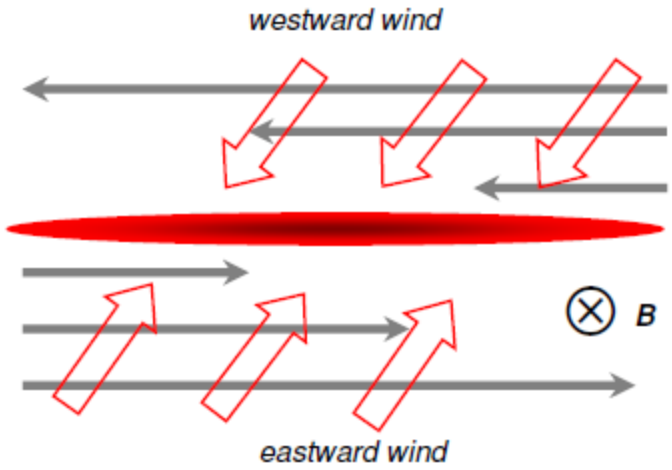
- Upper Level Vertical Wind Shear (Main Cause) from Solar Tides
- Meteor Inputs (long life metallic ions)
- Solar Inputs (Solar Tides in Upper Atmosphere from Heating Effect)
- Horizontal Magnetic Field Components (no Es: along the geomagnetic equator; geomagnetic field strength at the poles)

Solar Tides

- Solar tides are global scale oscillations that are present in the upper atmospheric wind, density, temperature, and pressure fields.
- The tidal waves in the upper atmosphere are thermally excited by solar radiation.
- The tidal wave is excited by absorption of solar UV radiation of the stratospheric ozone at altitudes between 30 and 60 km.
- Tidal structures are dominating the wind field in the upper mesosphere and lower thermosphere region.
- The tidal shears assist to compress ions into thin but compact sporadic E layers.

Mid Latitude Wind Shear

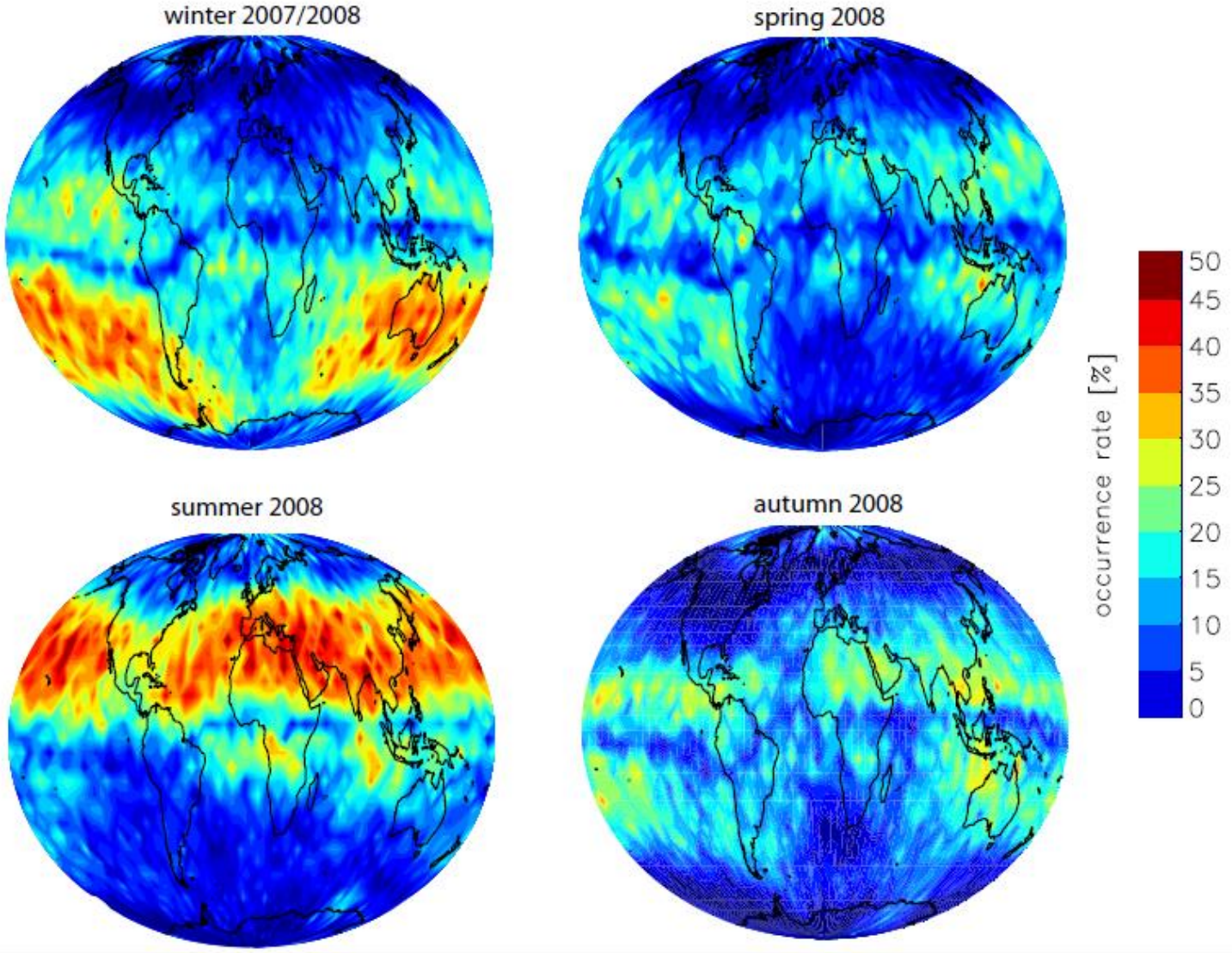
- Ionospheric plasma of large volume is swept together into a thin layer by the combined action of vertical wind shears, mainly produced by atmospheric tides, ion–neutral collision coupling and geomagnetic Lorentz forcing (somewhat like the right and left hand rule).
- The process works well in mid-latitudes at altitudes between 95 and 120 km.



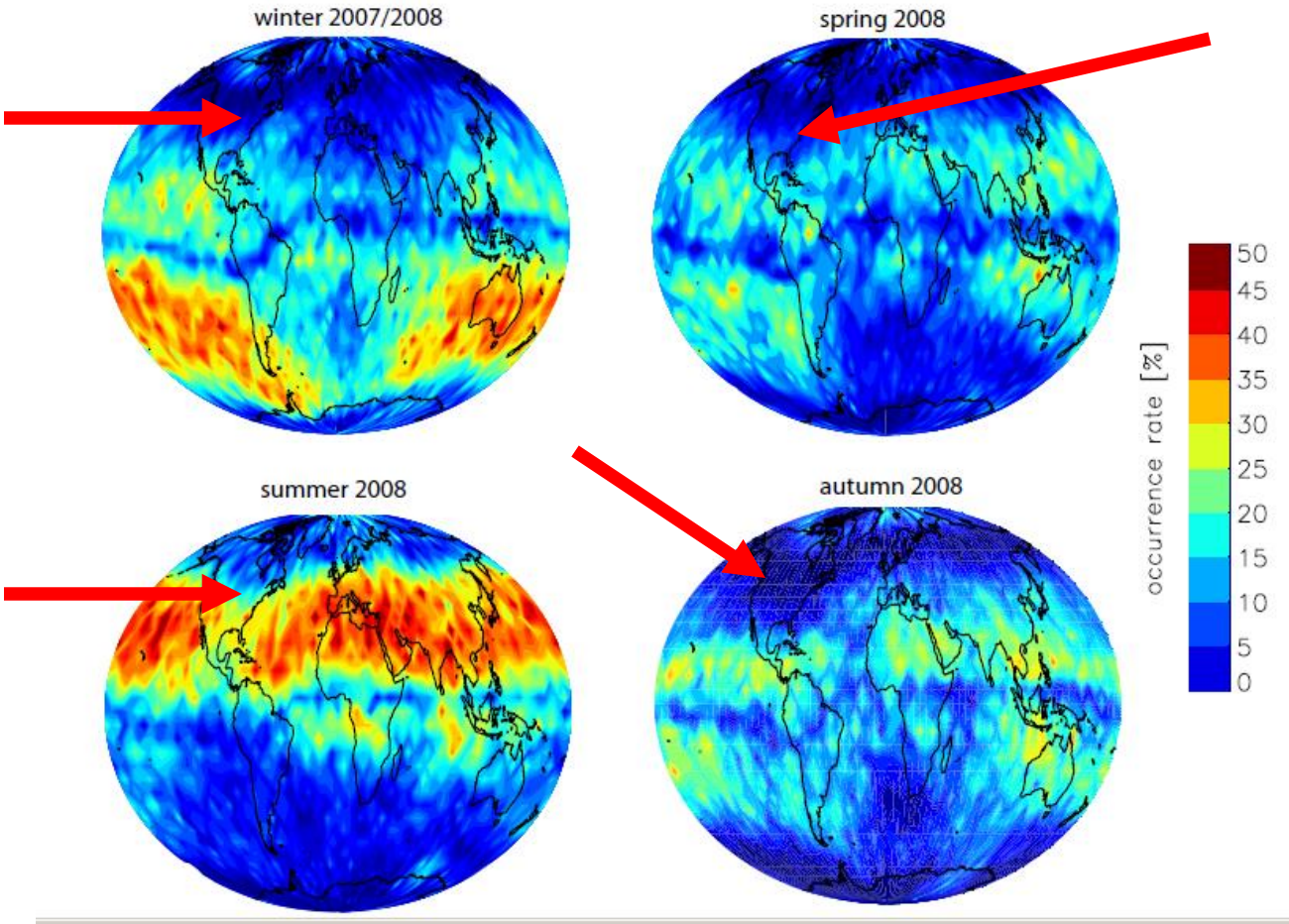
Mid Latitude Wind Shear

- The wind shear process works only in mid-latitudes.
- In polar and equatorial regions, electric fields become too strong for effective Es formation and cannot be neglected.
- Then why do we see some good propagation at the equator? More sun, better E and F2 MUFs, but stronger D absorption as well.

Global Es: Red/Yellow = Es Areas



North America is Not an Es Hot Spot!



What Else is Going On?

- If then North America is not an Es hot spot, then why do we see good Es at times?
- Amateurs over the years have also noticed that Es openings seem to happen near hurricanes and storms as well as the regular Es openings.

K1YOW's Hypothesis

- The hypothesis to be tested is: besides the normal random Es, Es openings are enhanced by strong storms like hurricanes and upper level low pressure systems for the mid latitudes.
- Are somehow lower atmosphere, low pressure systems, affecting upper level tidal wind shear?
- Can we see this using Amateur Radio?

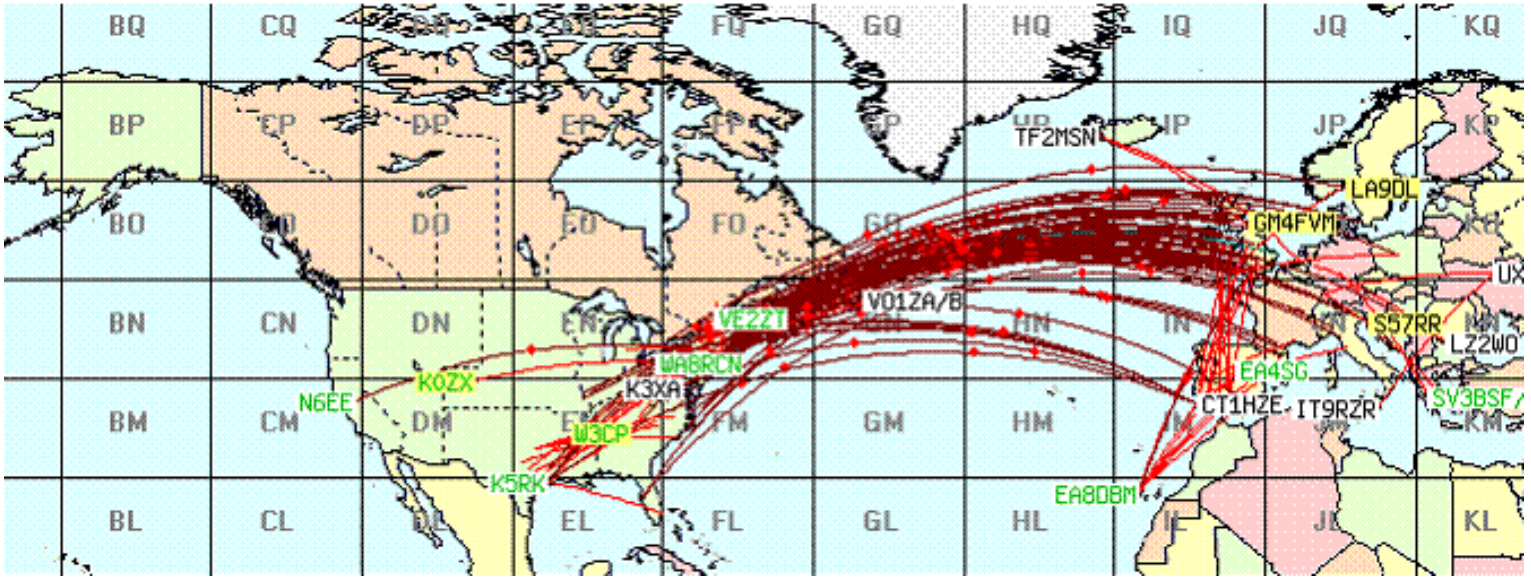
Low Pressure and T-Storms

- 2nd Paper Found: A statistical analysis on the relationship between thunderstorms and Sporadic E Layer over Rome V. BartaP1,2P, UC. ScottoUP3P, M. PietrellaUP3P, V. Sgrigna P4, G. SátoriP2P, L. Conti 5

Low Pressure and T-Storms

- Meteorological processes (cold fronts, mesoscale convective complexes, thunderstorms) in the lower atmosphere can affect the ionosphere mainly through two mechanisms: (i) electrical and electromagnetic phenomena (red sprites, blue jets etc.) and (ii) upward propagating waves in the neutral atmosphere.
- One type of these waves are the internal atmospheric gravity waves (AGWs) which can often be generated by thunderstorms in the troposphere but they are also generated by strong atmospheric fronts irrespective of lightning.
- The one-to-one correspondence between a meteorological phenomenon in the lower atmosphere and AGW in the mesopause is directly observable in the nighttime airglow images.
- They found no ionospheric response to low-pressure systems without **lightning**, consequently this localized intensification of the sporadic E layer can be attributed to lightning.

June 13, 2016 6 Meter Double Hop Trans Atlantic Es DX Map



The VHF Gods Were Smiling on us this Day!

K1YOW General Rules of Thumb for Radio Circuit Paths

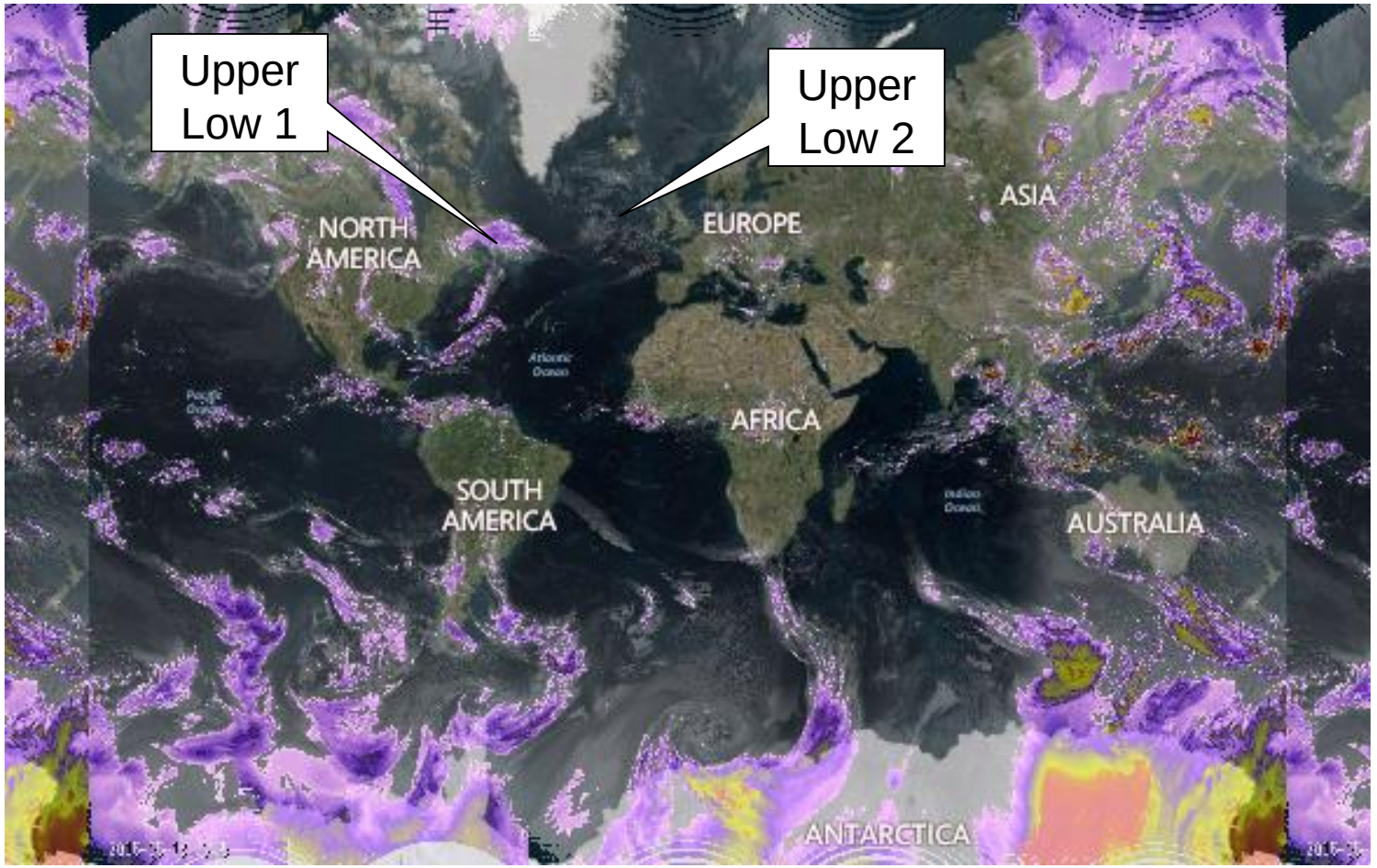
- 2000 Km path use .85 of the E layer MUF (80m, 40m, 30m, etc)
- 4000 Km path use .85 of the F2 layer MUF (20m, 17m, 15m or higher per conditions)
- 4000 Km path can also use E layer if multi hop
- Greater than 4000 Km path can use F2 layer multi hop BUT the MUF must be looked at 2000 Km from each circuit end point and at the middle of the path

June 13 2016

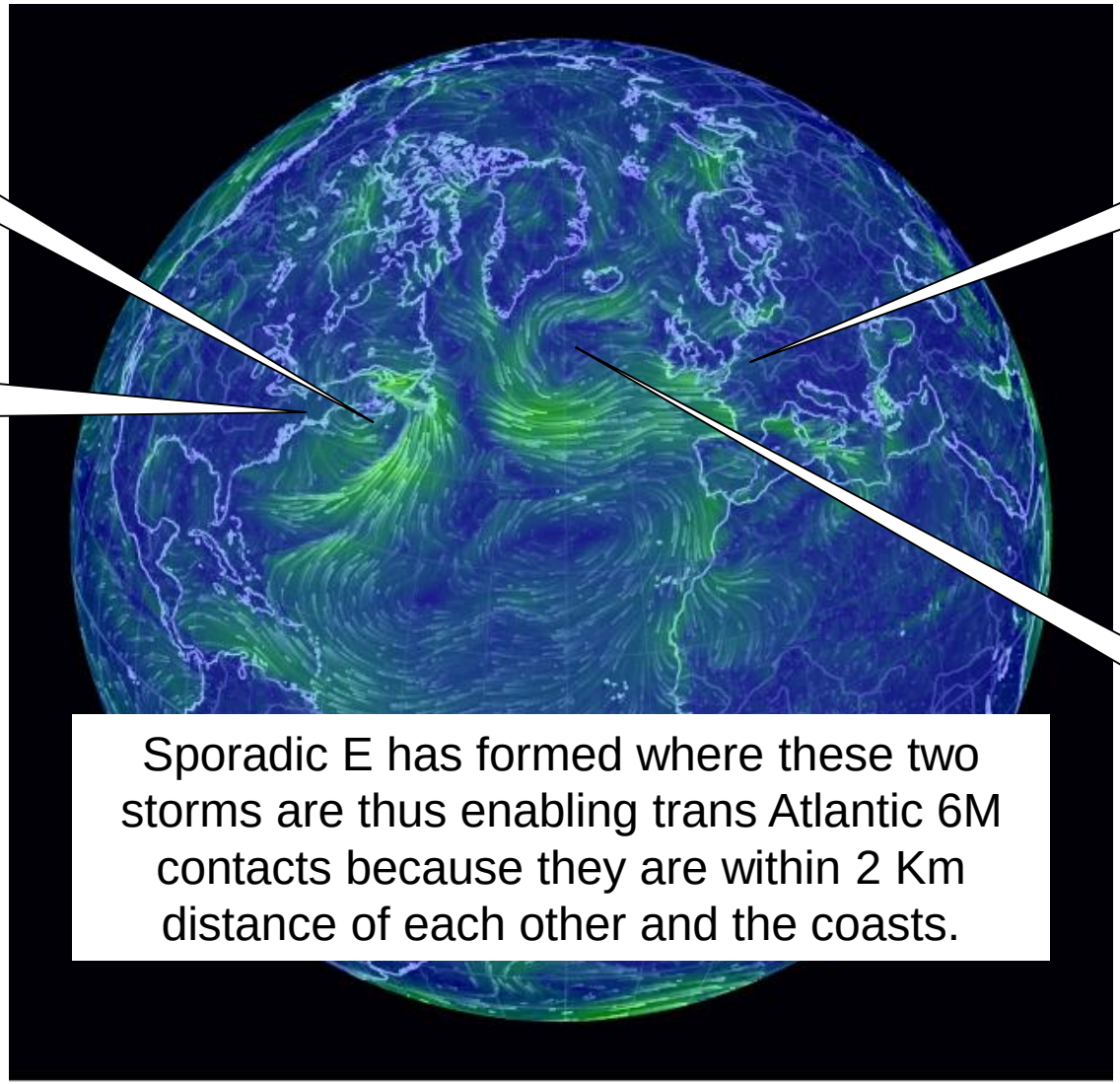
Two Upper Level Lows during 50 Mhz Trans-Atlantic Es Double Hop

Note: Views are surface level winds just to make things easier to see. Viewing high level winds make things very hard to see what is going on.

June 13, 2016 – Two Atlantic Storms



June 13, 2016 – Another View



K1YOW's Shack

135 ft Buckmaster OCF Dipole

Create 50 MHz to 1.3Ghz 21 el LP

Create 50 MHz to 1.3Ghz 21 el LP

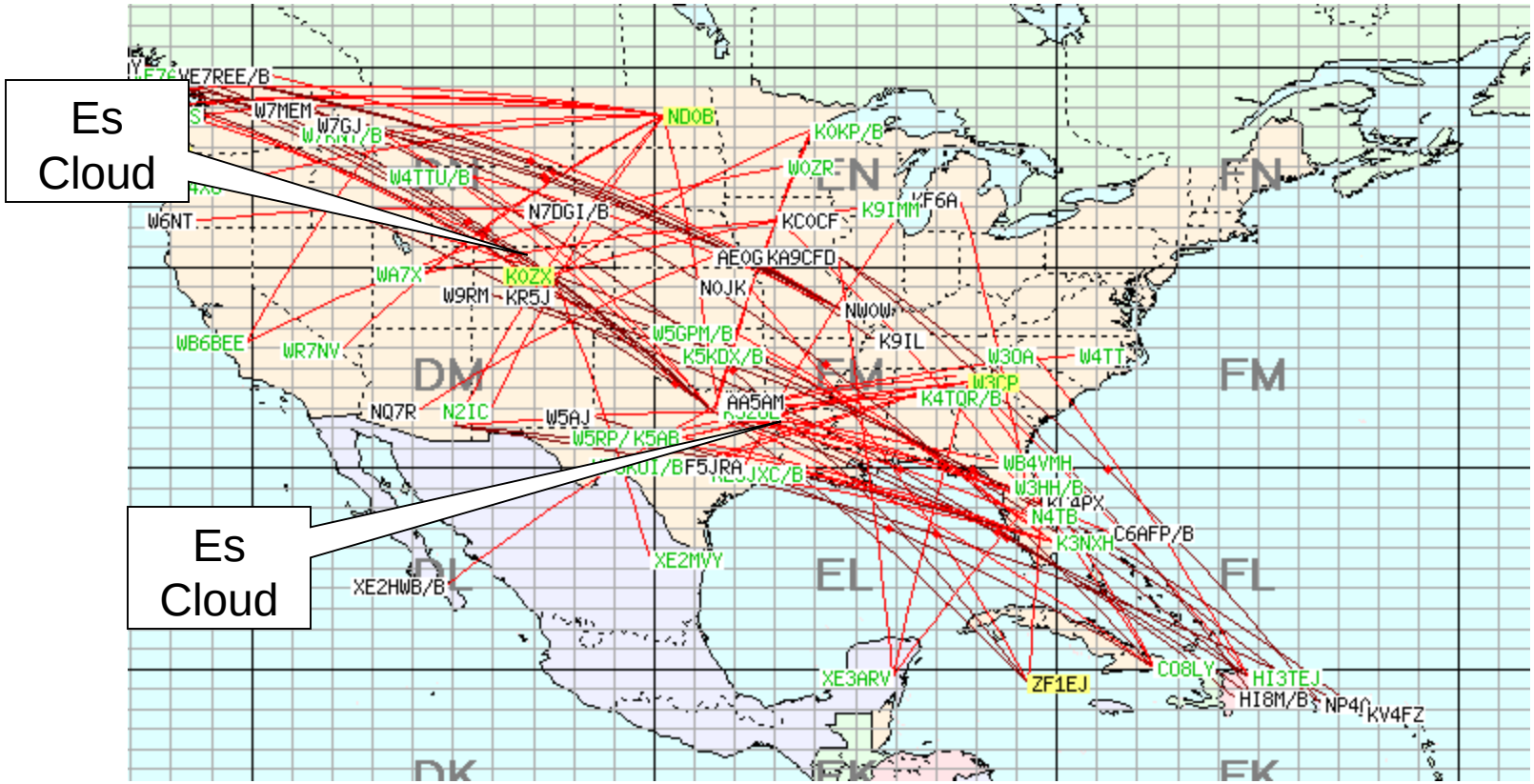
K1YOW on 6M in FN42 worked:

- EA7AH in IM67 on CW
- G4RRA in IO80 on CW
- EI4DQ in IO51 on CW
- One day earlier (VHF contest) I worked 35 stations in 2.5 hours in the 1,2,3,4,5,7,8,9 and 0 call districts on 6M. I did not call a single CQ.
- All using 100W and a 7 band Buckmaster OCF horizontal dipole strung in some white pines 1.5 stories up.
- So: We small guns do have a chance under good conditions

June 14 2016 17:55 GMT

- USA: Two Es 50 Mhz Clouds, one is along the wind shear line above East Texas and Louisiana and the other is over Colorado at another wind shear line.
- The June 13 upper level low in the North Atlantic has moved SE and gotten further apart from the Canadian Maritime upper level low, thus no European double hop Es like we had on the 13th.

June 14 2016 17:55 GMT



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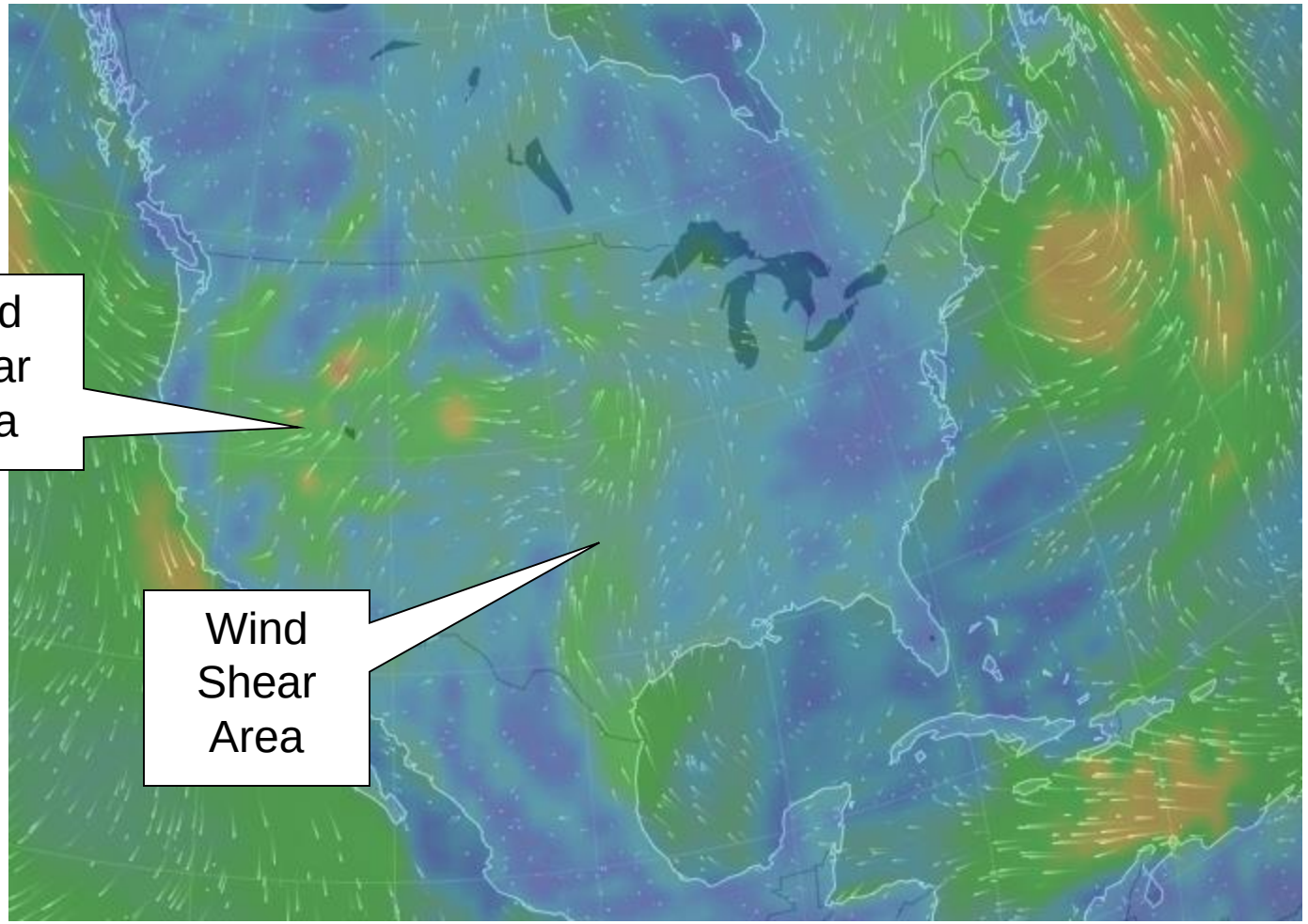
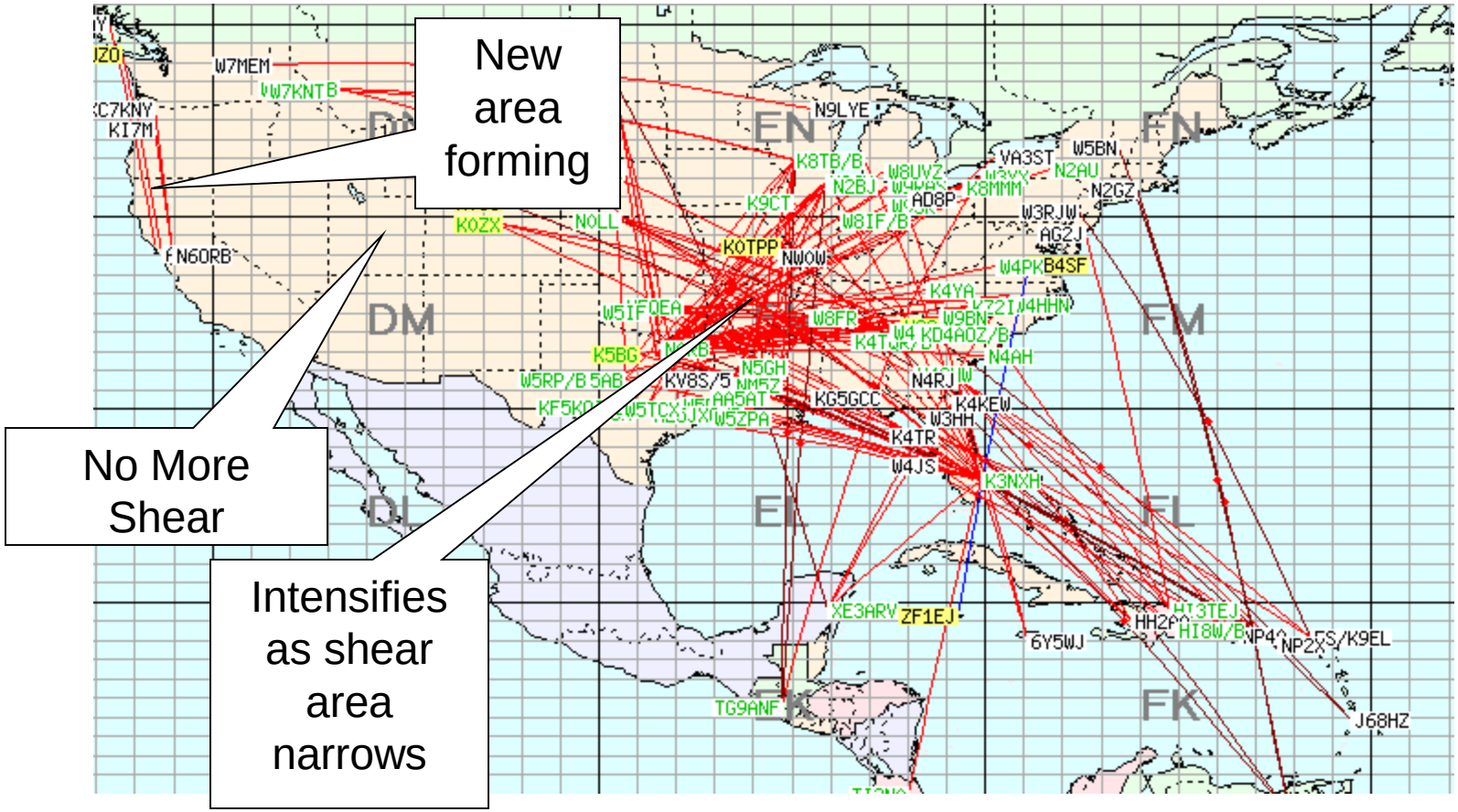
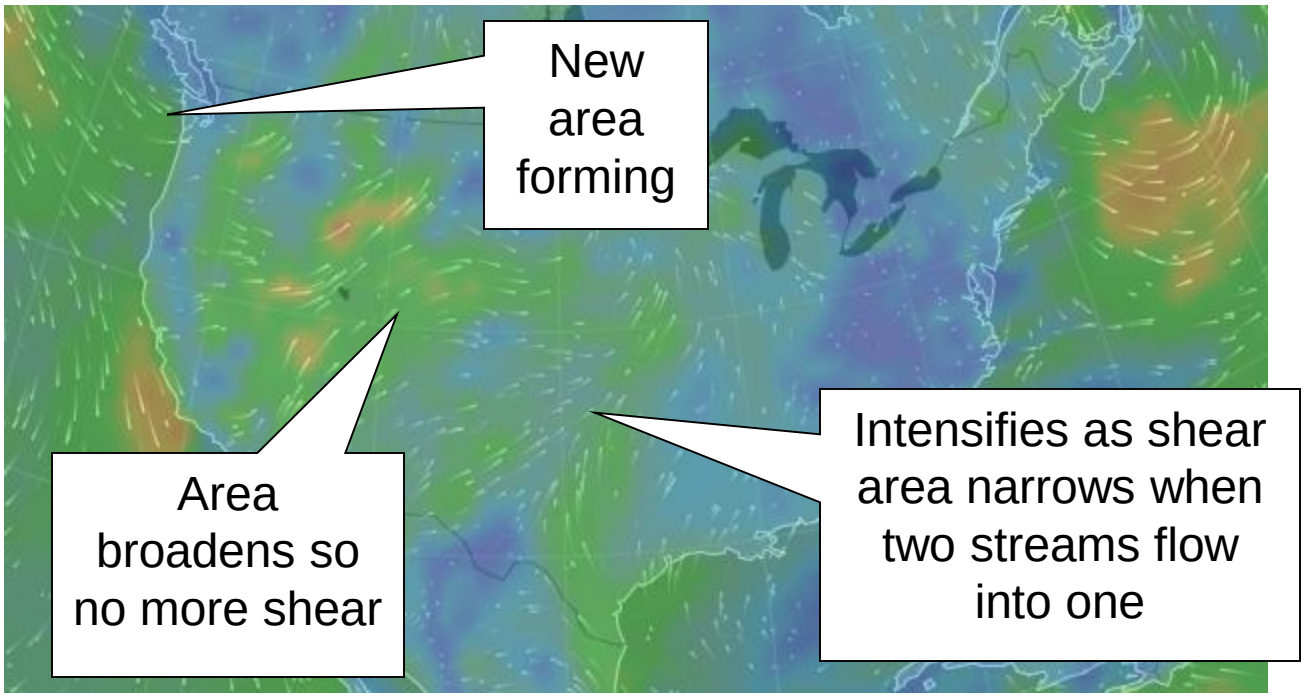


Later On 6/14/2016 in the Day

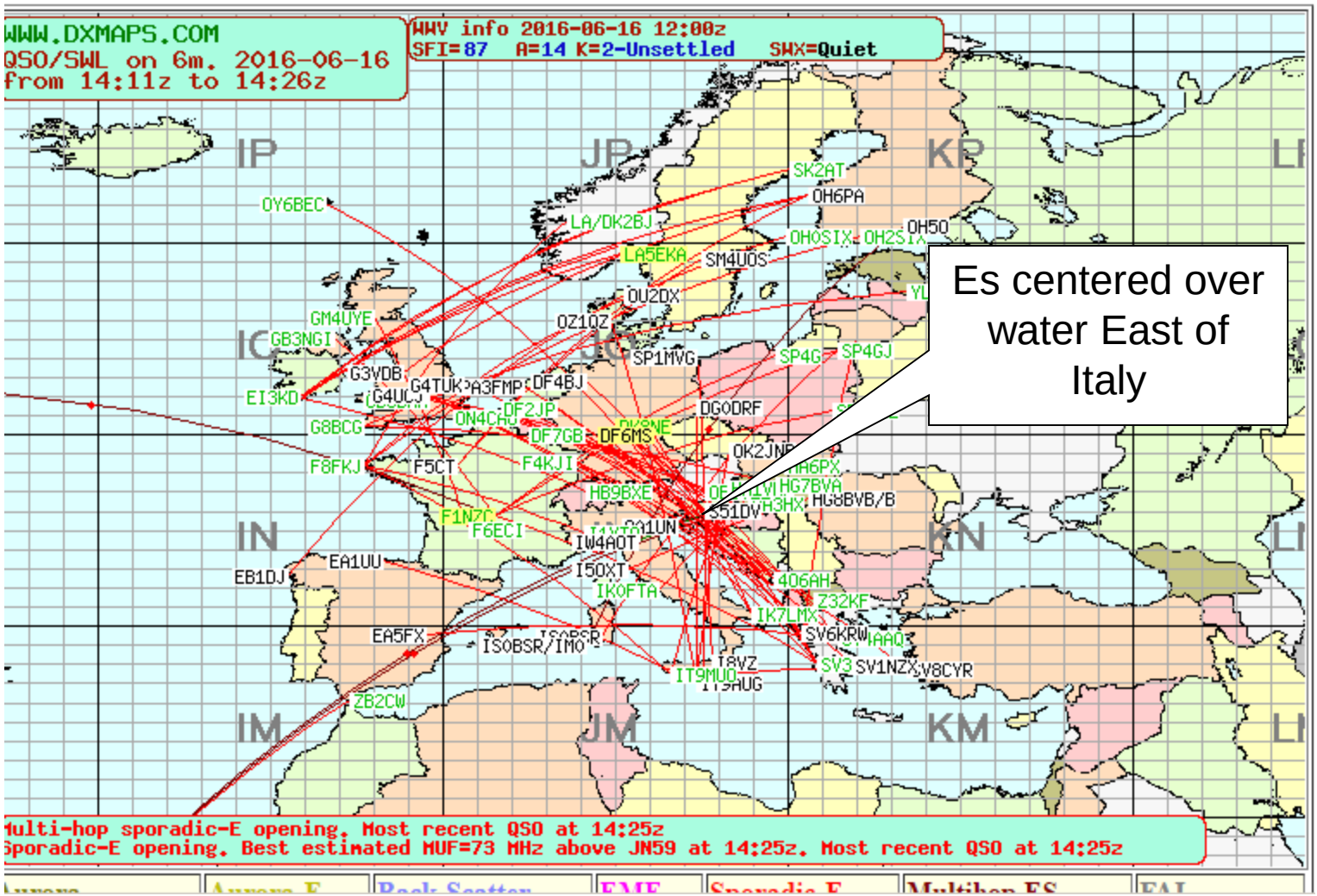


Later On 6/14/2016 Winds

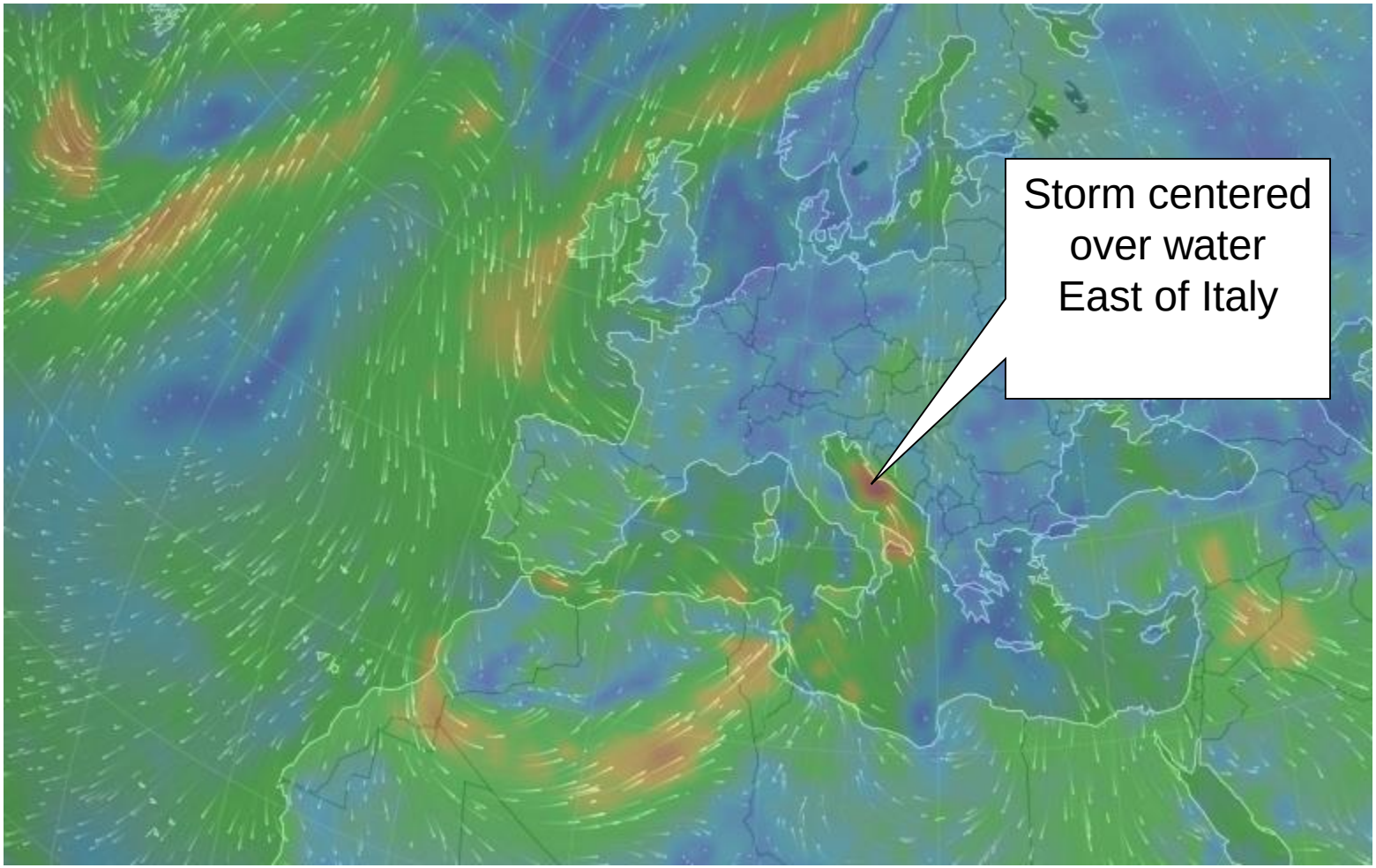


Colorado area broadens, so less to no shear, double hop area stops; Texas area narrows, more shear, more intense one hop, NW starts showing a shear area, new links going North to Alaska.

Europe 06/16/2016 14:30Z



Europe 06/16/2016 14:30Z



What About Hurricanes?

- Did Hurricane Matthew cause any Es?
- Don’t forget – these observations depend on Amateur Radio types being on the air.
- Hams won’t be on the air if they are being flooded and/or have no power (no backup batteries or generators) or if they sustain antenna damage from winds and fallen trees.

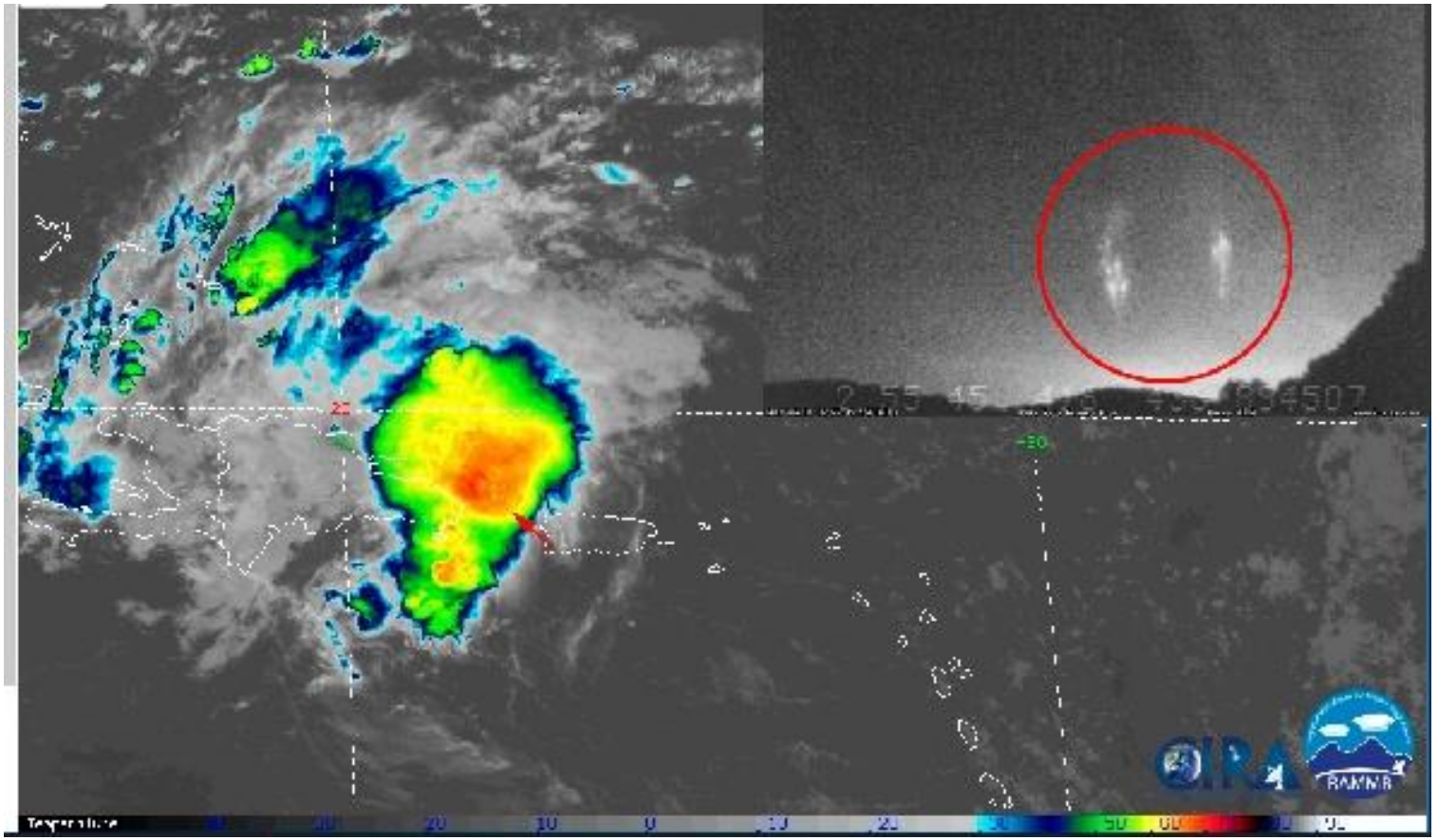
Lightning and Sprites

- Hurricanes spawn bands of thunderstorms.
- T-Storms spawn lightning and sprites.
- Italian paper: lightning can enhance Es and also probably sprites can enhance Es as well.

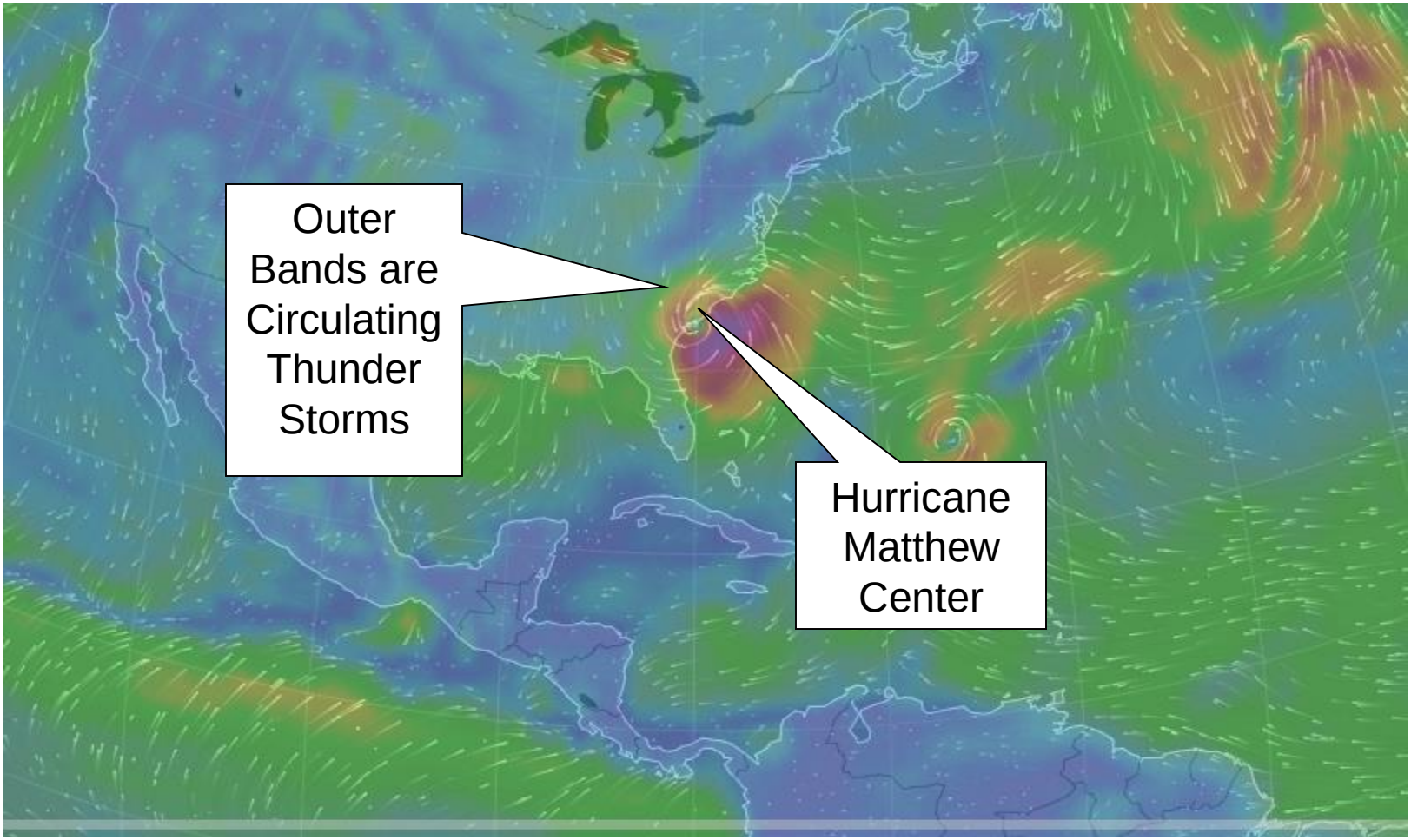
Hurricane Matthew Sprites from The Weather Channel

Hurricane Matthew Sprites from The Weather Channel

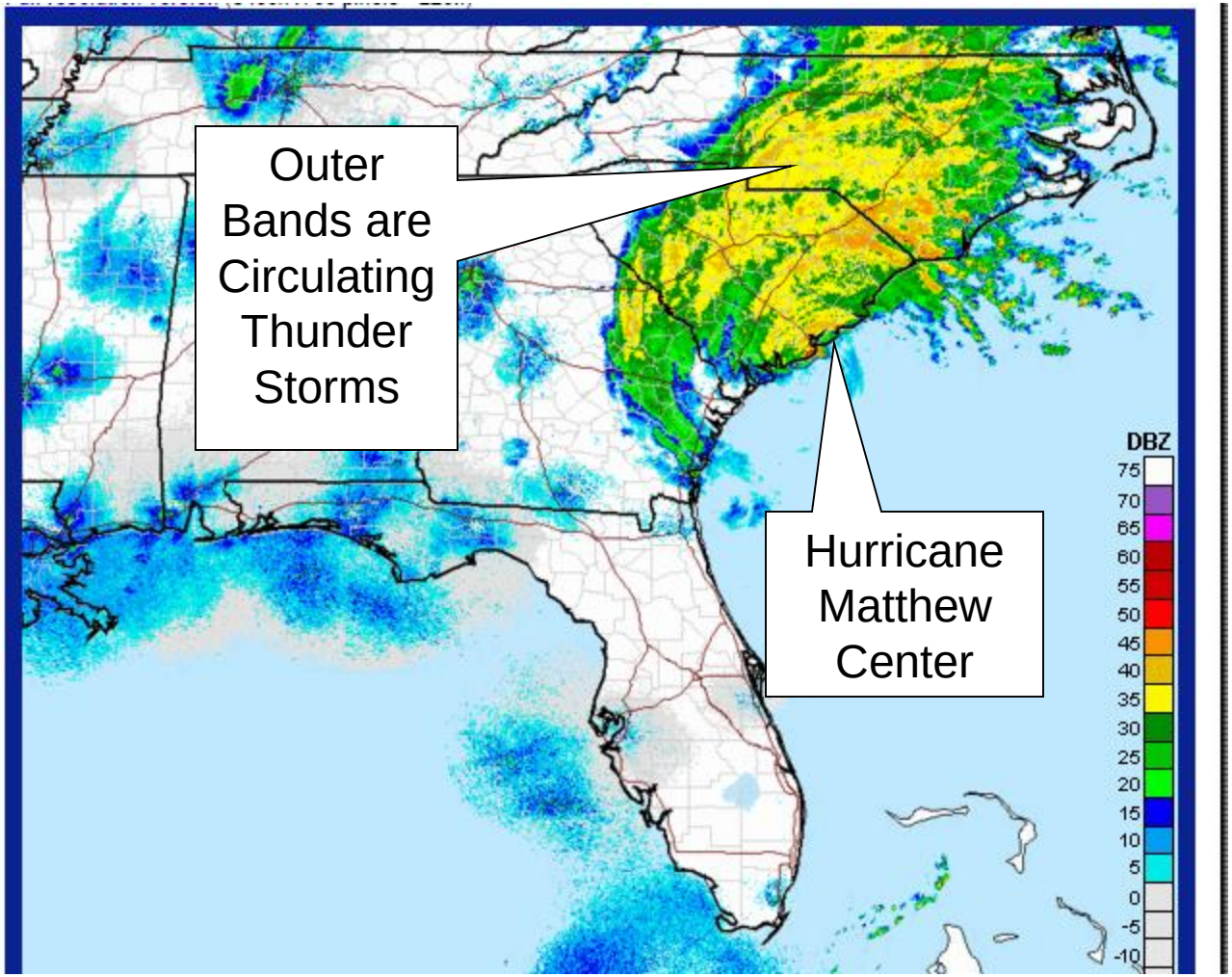
Sprites Before Gordon Became A Tropical Storm Sept 01 2018



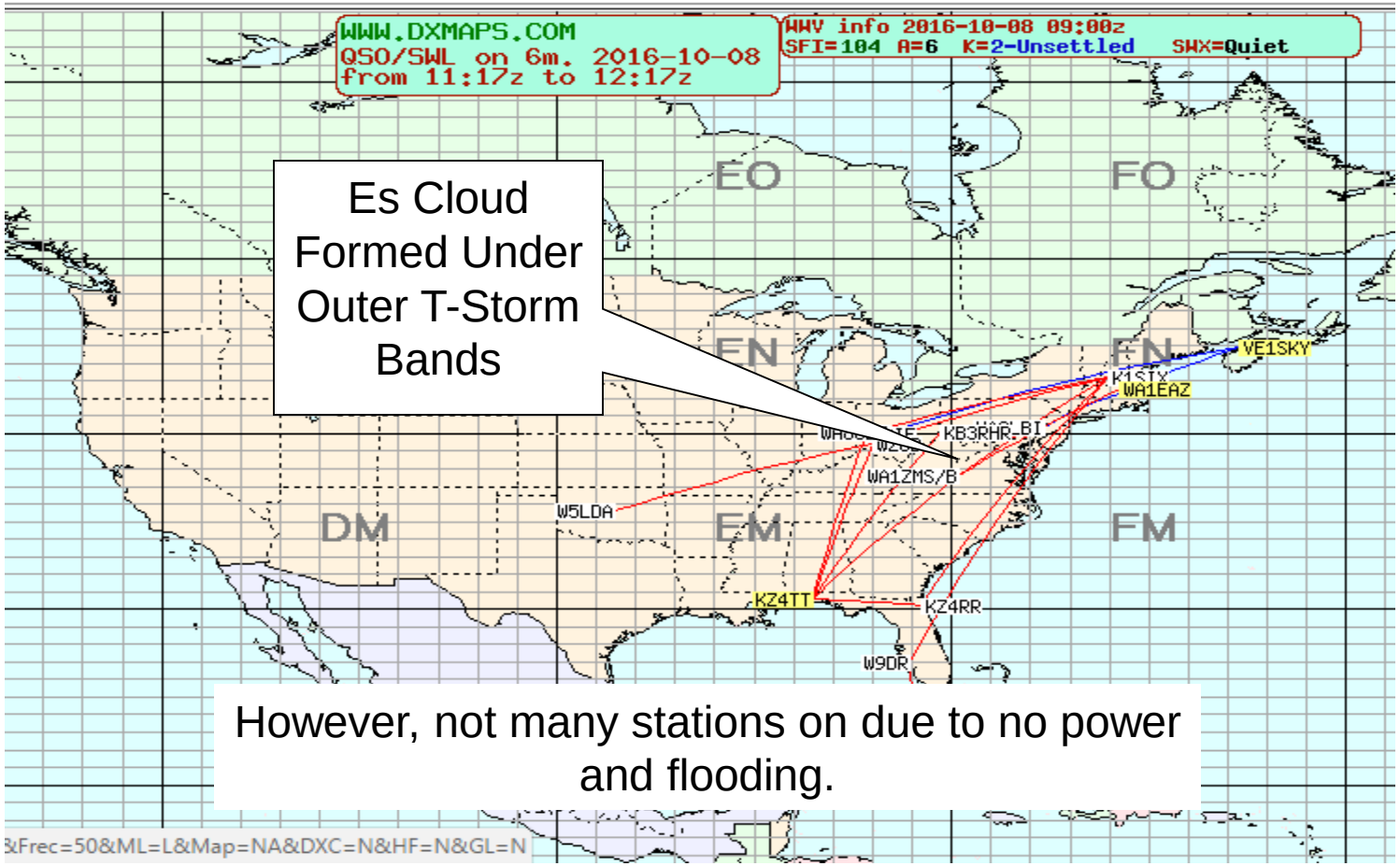
Hurricane Matthew 10/08/2016 12:20 GMT



Hurricane Matthew 10/08/2016 12:20 GMT



Hurricane Matthew 10/08/2016 12:20 GMT



No Polar or Equatorial Es?

- German paper: no Es in the polar or equatorial regions because things like and electric fields become more dominate factors.
- Yet we Hams do work some Es there – so it's not absolute that there is no Es from what we Hams can see.
- Maybe anything else going on?

Polar and Equatorial Electrojets

- Well, besides the Hz field differences, there are three electrojets: two Auroral (Polar and Antarctic) and one equatorial (Equator).
- Electrojets are current circuit paths that circumnavigate the Earth.
- We in NA are more familiar with the Northern Auroral Electrojet.
- We “see” it when the Auroral zone is enhanced due to things like geomagnetic storms caused by CMEs and flares and magnetic field snap-backs.

Northern Auroral Circle/Electrojet

G2

Moderate storm warning in effect: 13/1237 - 13/1800 UTC

PRIMARY AREA of IMPACTS

Poleward of 55 deg geomagnetic latitude

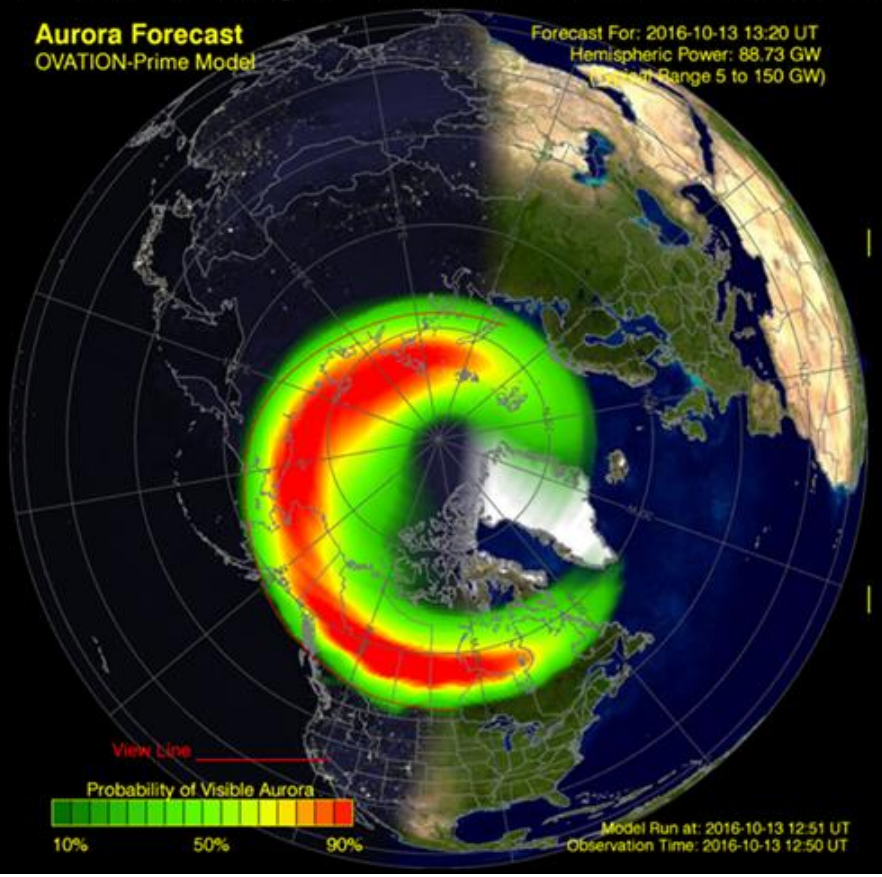
POSSIBLE EFFECTS

Power Systems: Power grid fluctuations; voltage alarms at higher latitudes

Spacecraft: Orientation irregularities; increased drag on low-Earth orbiters

Radio: high-latitude HF propagation fades

Other: Aurora may be visible as low as New York to Wisconsin to Washington state



Equatorial Electrojet Ion Fountains

- The sun shines the most time over the equator.
- More Ions are created due to more sunshine hours and more UV exposure.
- This forms ionic fountains that basically push ions towards the mid latitudes between 15 to 20 degrees North and 15 to 20 degrees South.
- Thus more Es forms in the mid latitude regions along with regular E and F propagation.

Equatorial Electrojet Fountain

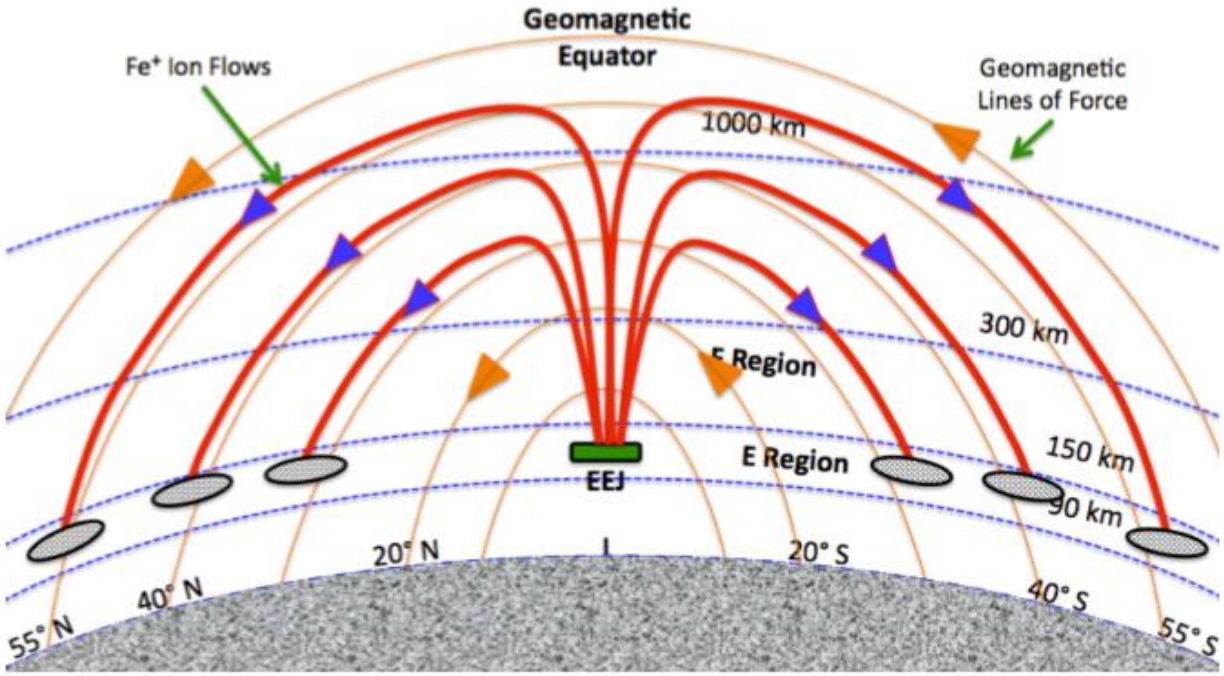
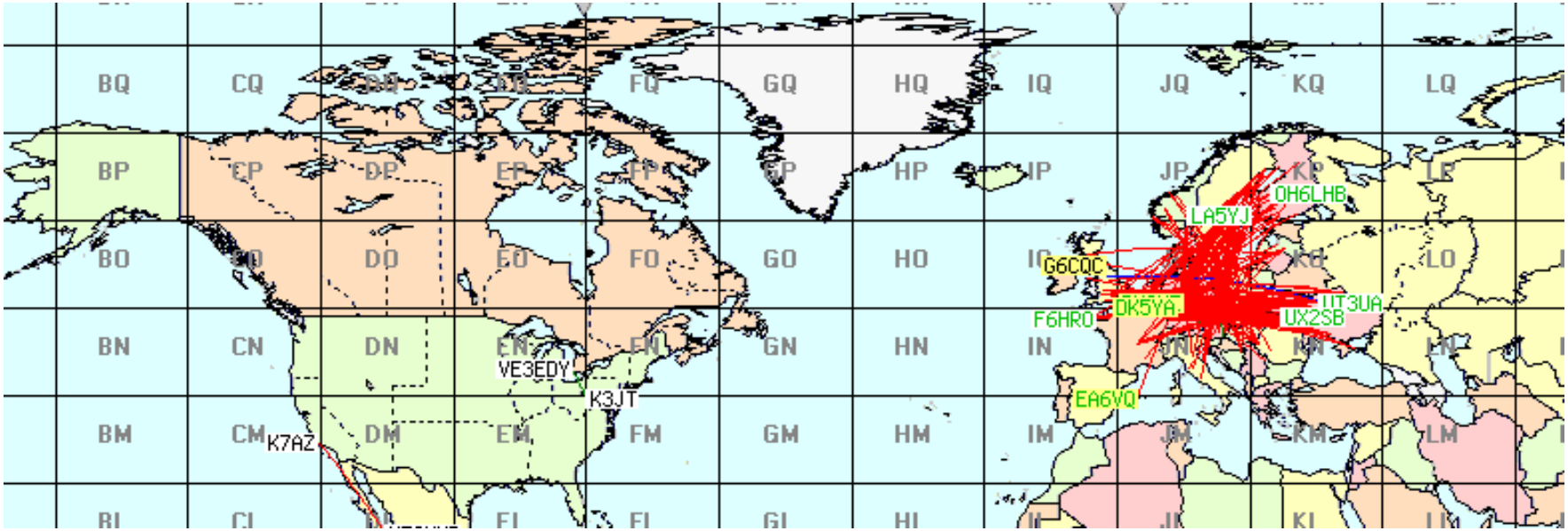


Figure 3: Looking eastward along the EEJ, the **ExB** effect causes both positive ions and free electrons to drift upward. The iron ions reach extreme F-region heights. Then, they fall downward along the Earth's magnetic field lines, until they reach the *midlatitude* E region. There they enhance the locally produced Fe^{+}, and add more free electrons, raising the Es MUF.

Figure Credit: Jim Kennedy, K6MIO/KH6

Typical 6M Day Spring 2016
This is what got me started on this!



June 17, 2016 19:30Z

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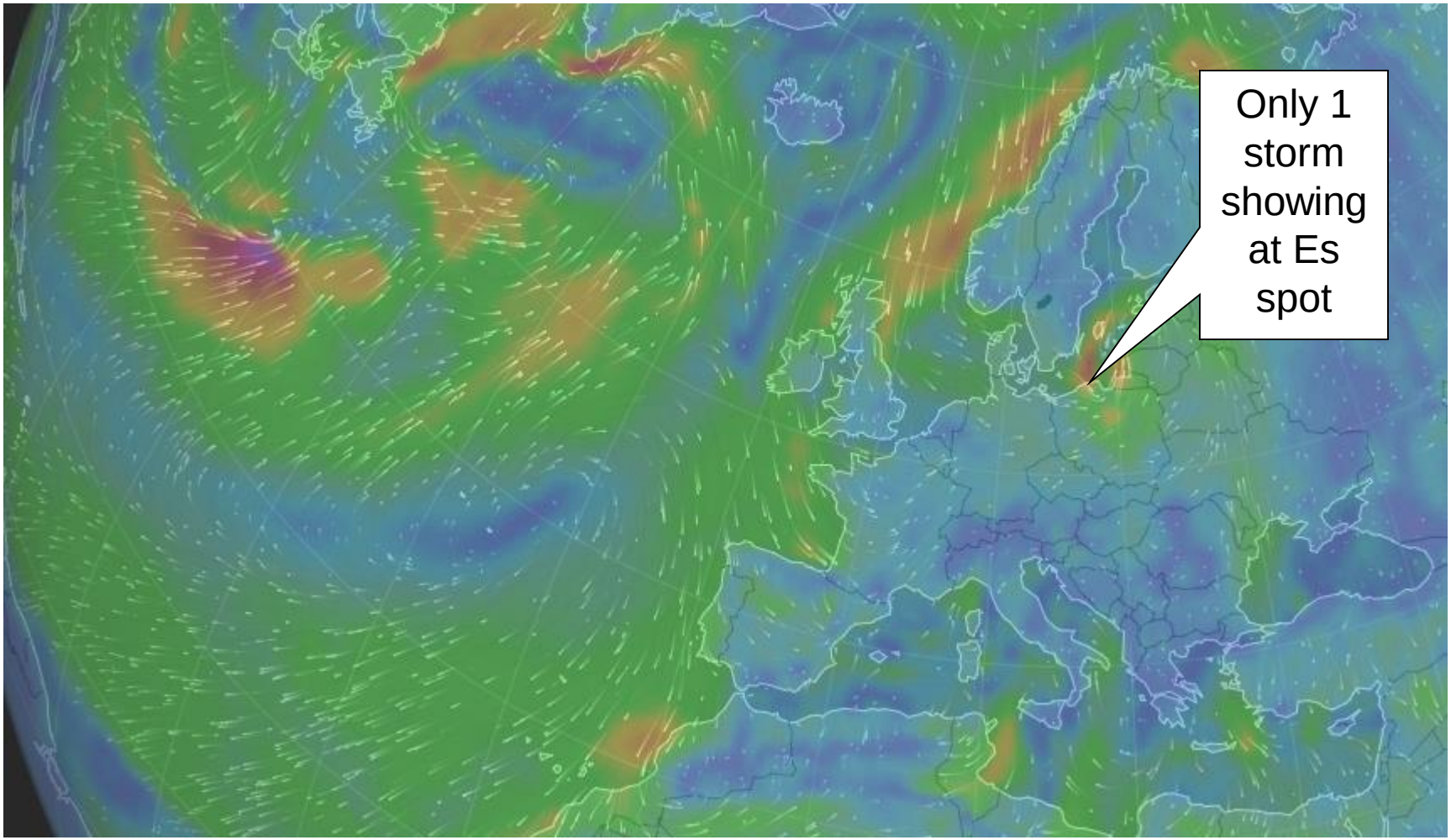
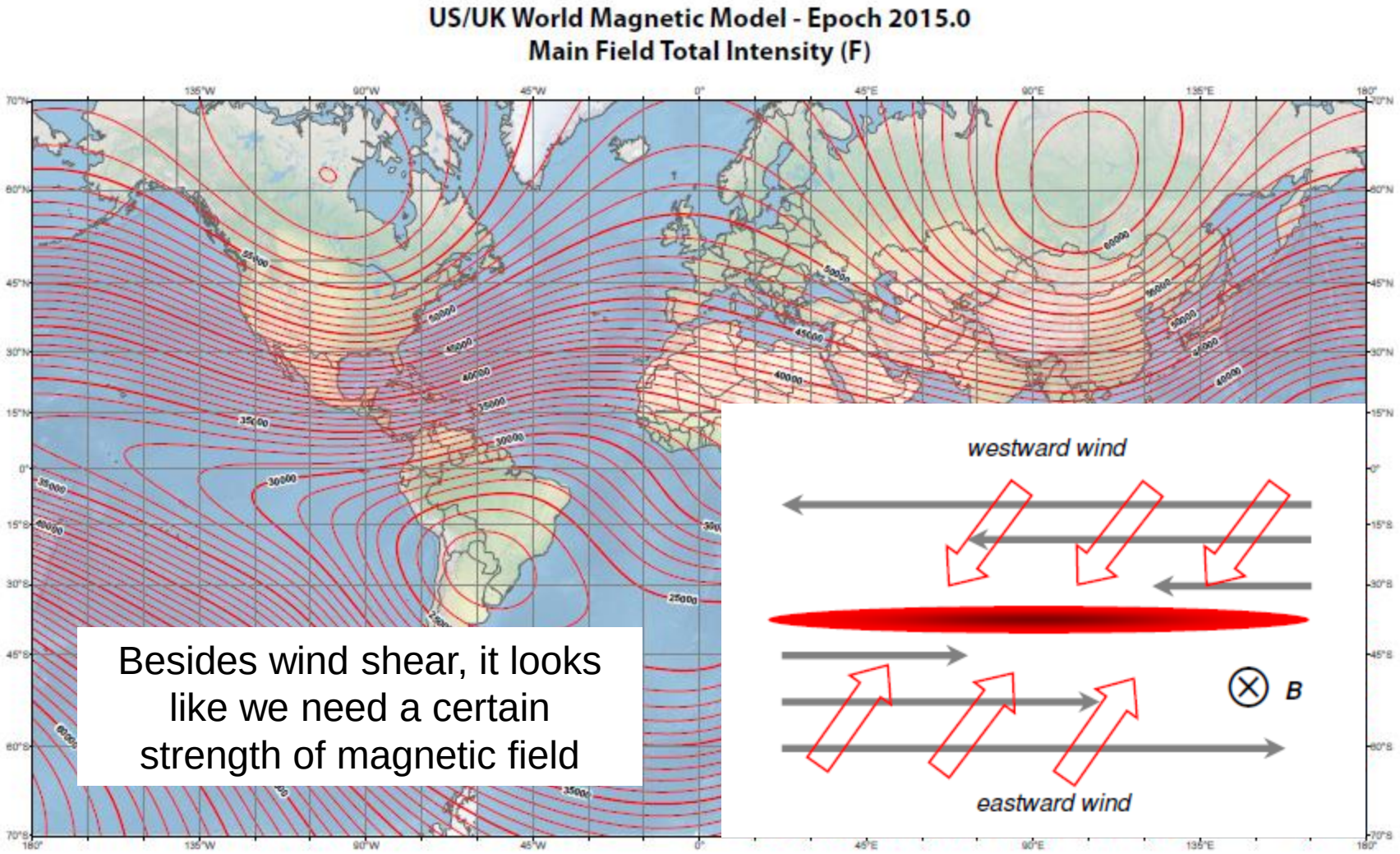


Daily European Es

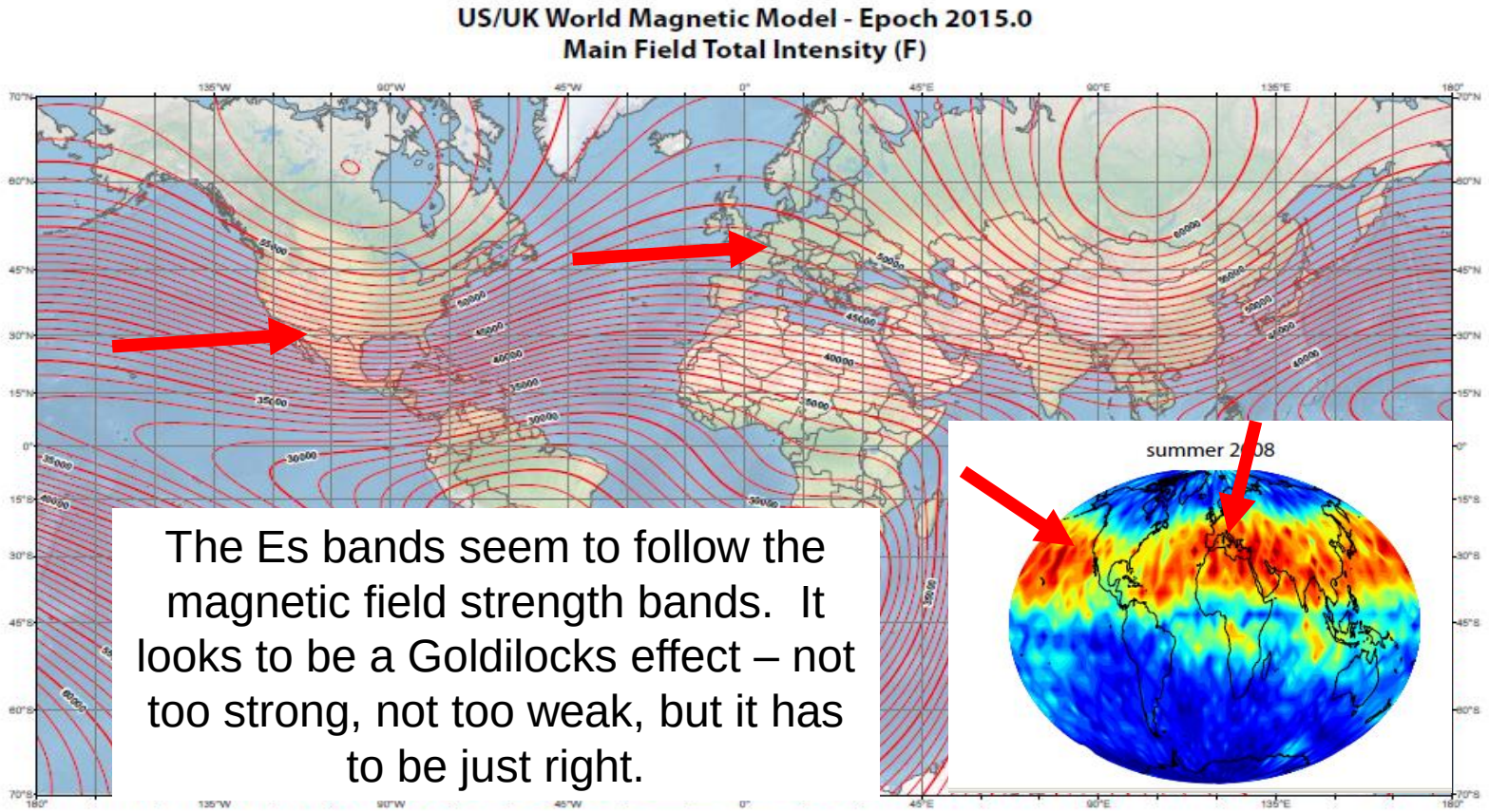
- For the last slide, we did see a storm under the Es spot.
- But, Europe was having Es almost every day, but they were not having storms every day.
- North America was very sparse for Es, yet North America had storms.
- Something else must be going on!
- Lightning and sprites look like they can enhance Es, but we need the Es to be there first, it seems.

World Magnetic Field



Besides wind shear, it looks like we need a certain strength of magnetic field

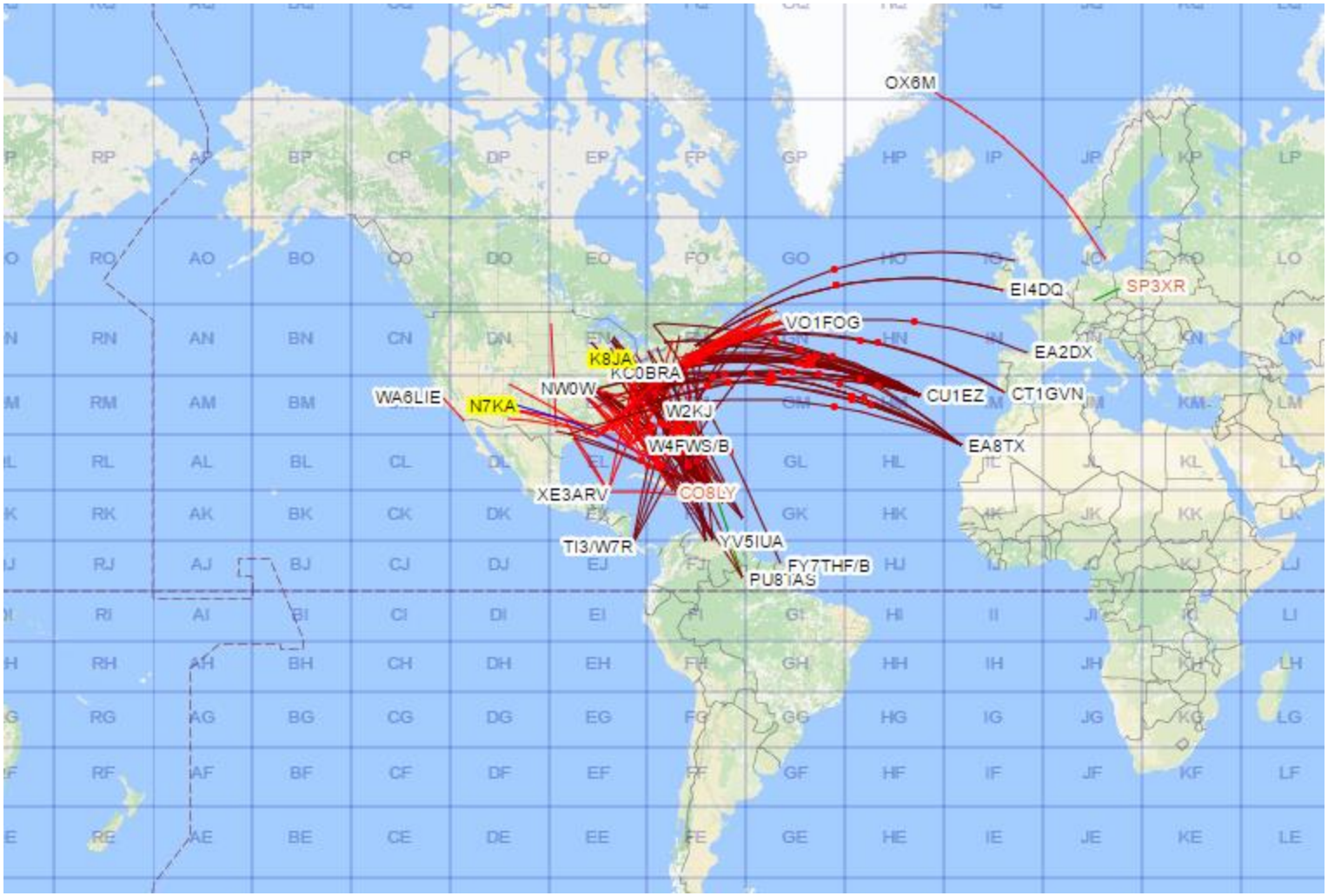
European and SW NA Mag Field Strengths the Same and Similar Es



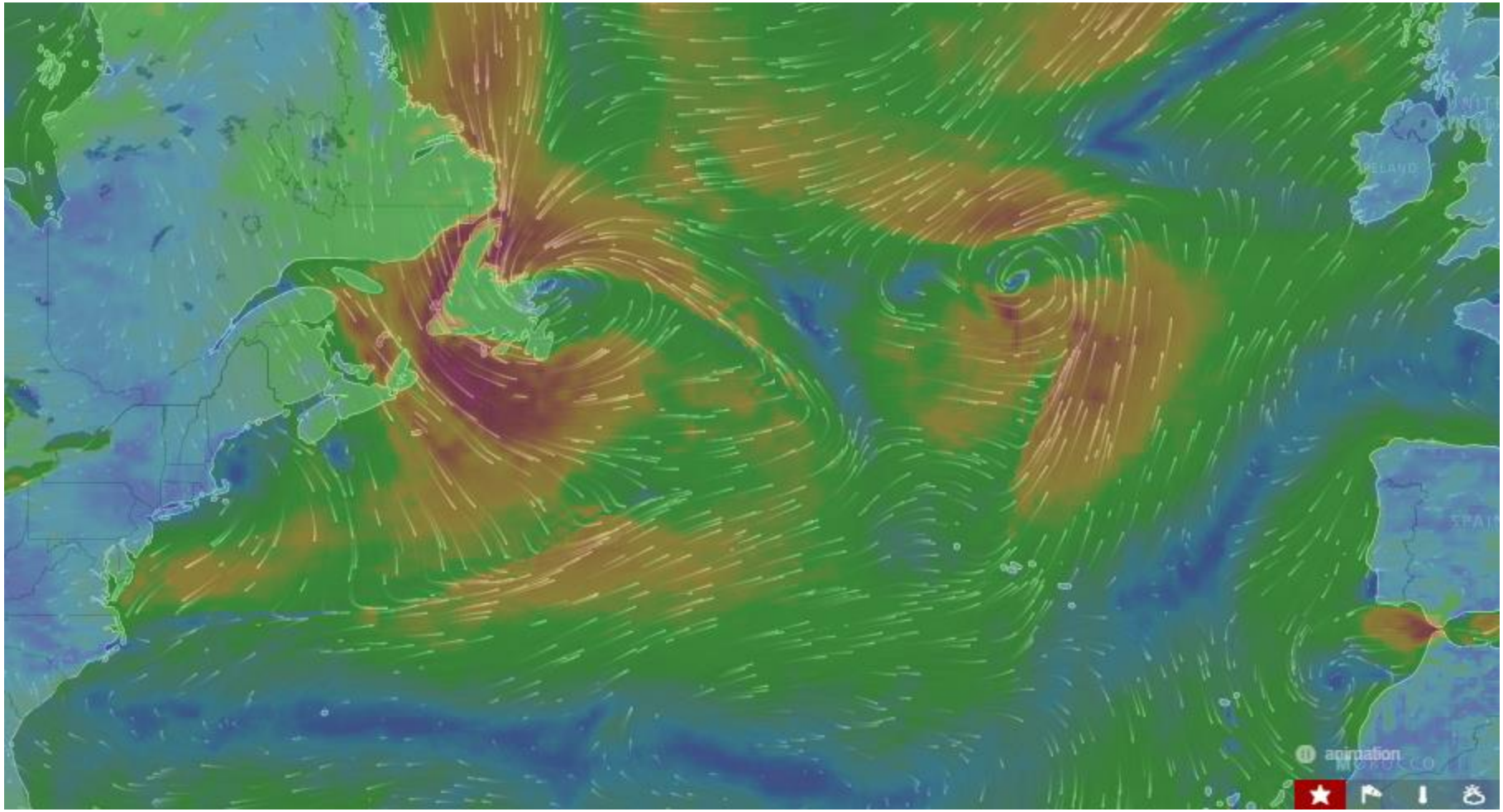
The Es bands seem to follow the magnetic field strength bands. It looks to be a Goldilocks effect – not too strong, not too weak, but it has to be just right.

What About 2017?

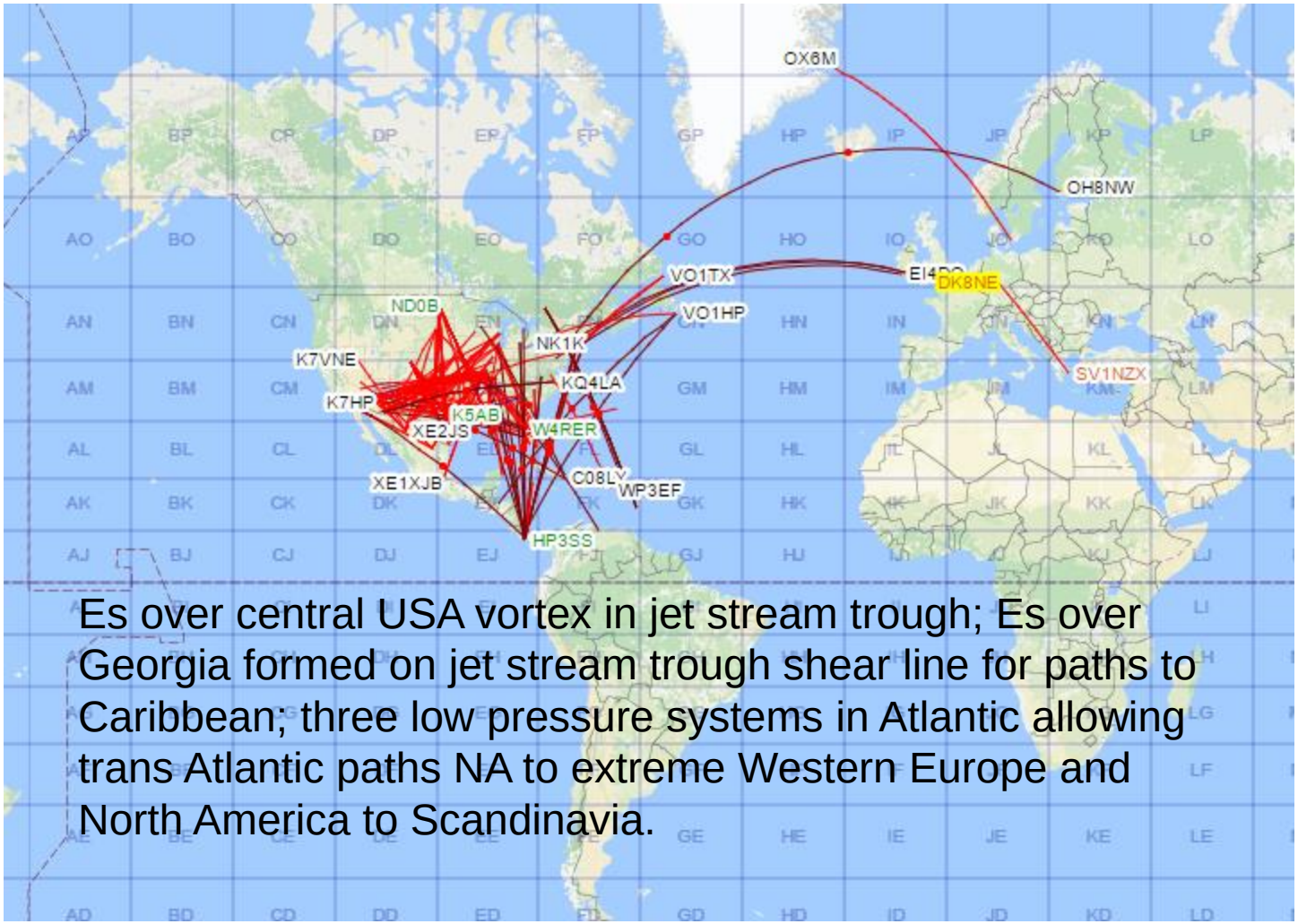
05/20/2017 22:25 GMT 6M



05/20/2017 22:25 GMT 6M

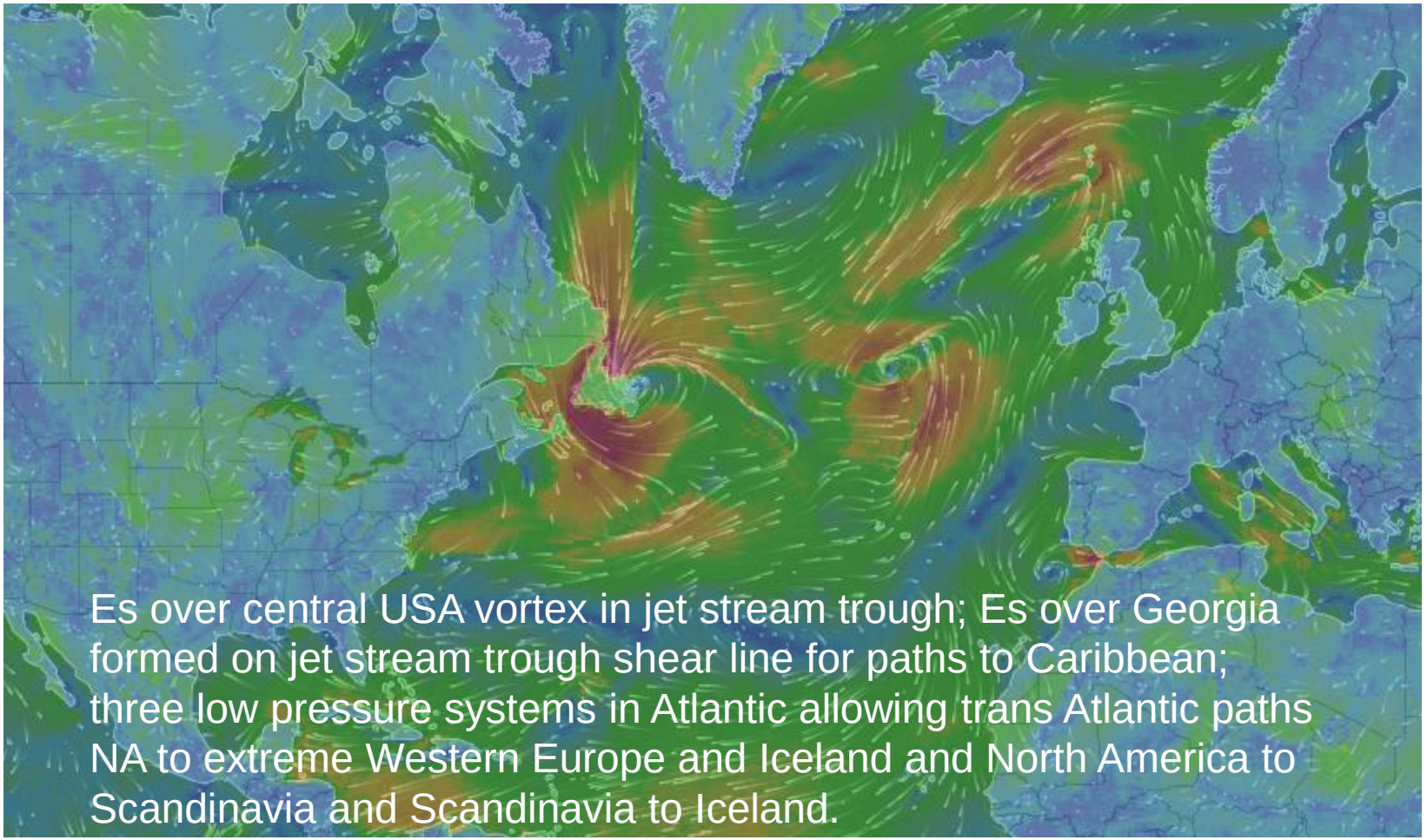


05/21/2017 00:05 GMT 6M



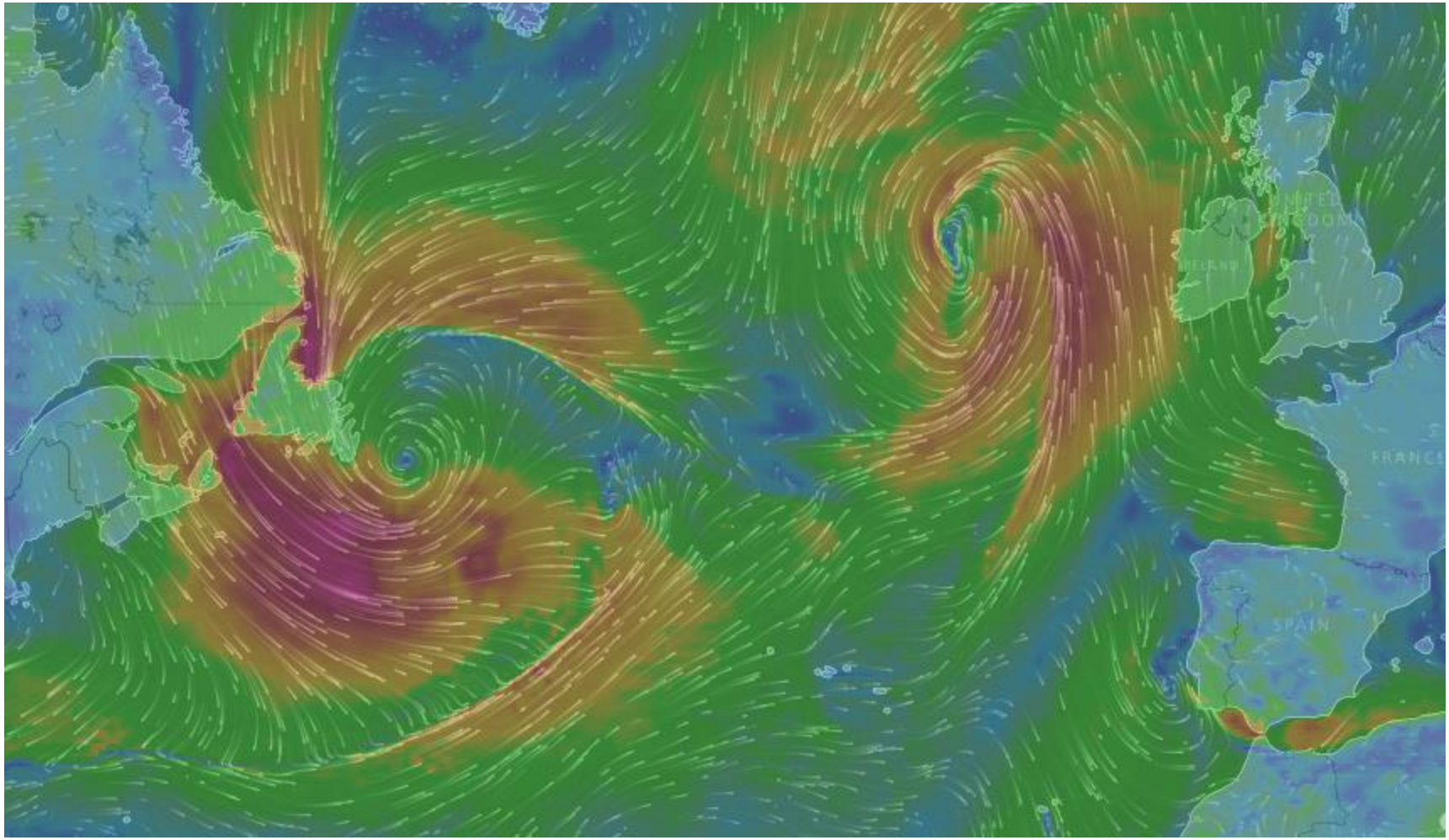
Es over central USA vortex in jet stream trough; Es over Georgia formed on jet stream trough shear line for paths to Caribbean; three low pressure systems in Atlantic allowing trans Atlantic paths NA to extreme Western Europe and North America to Scandinavia.

05/21/2017 00:05 GMT 6M



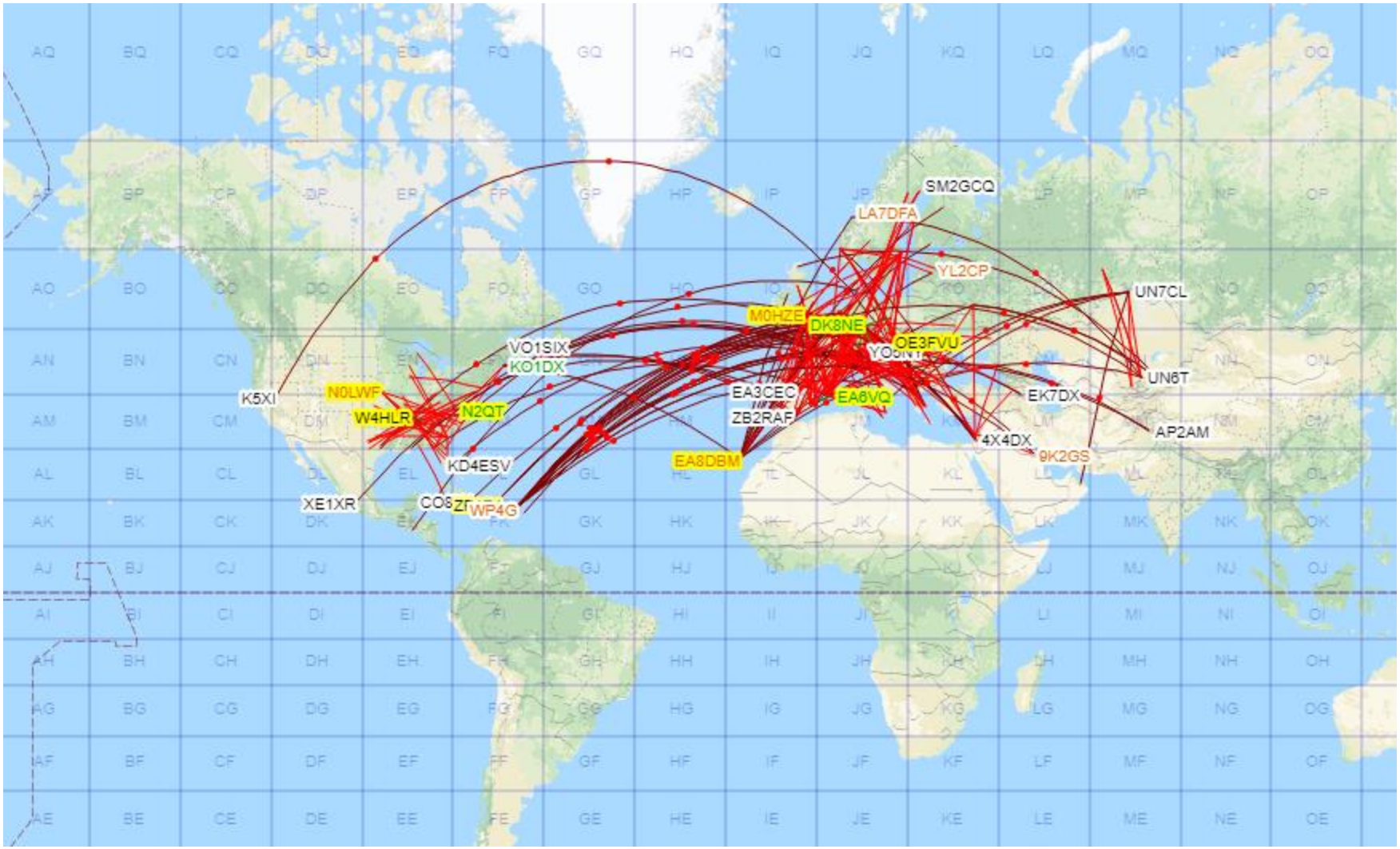
05/21/2017 12:40 GMT 6M

05/21/2017 12:40 GMT 6M

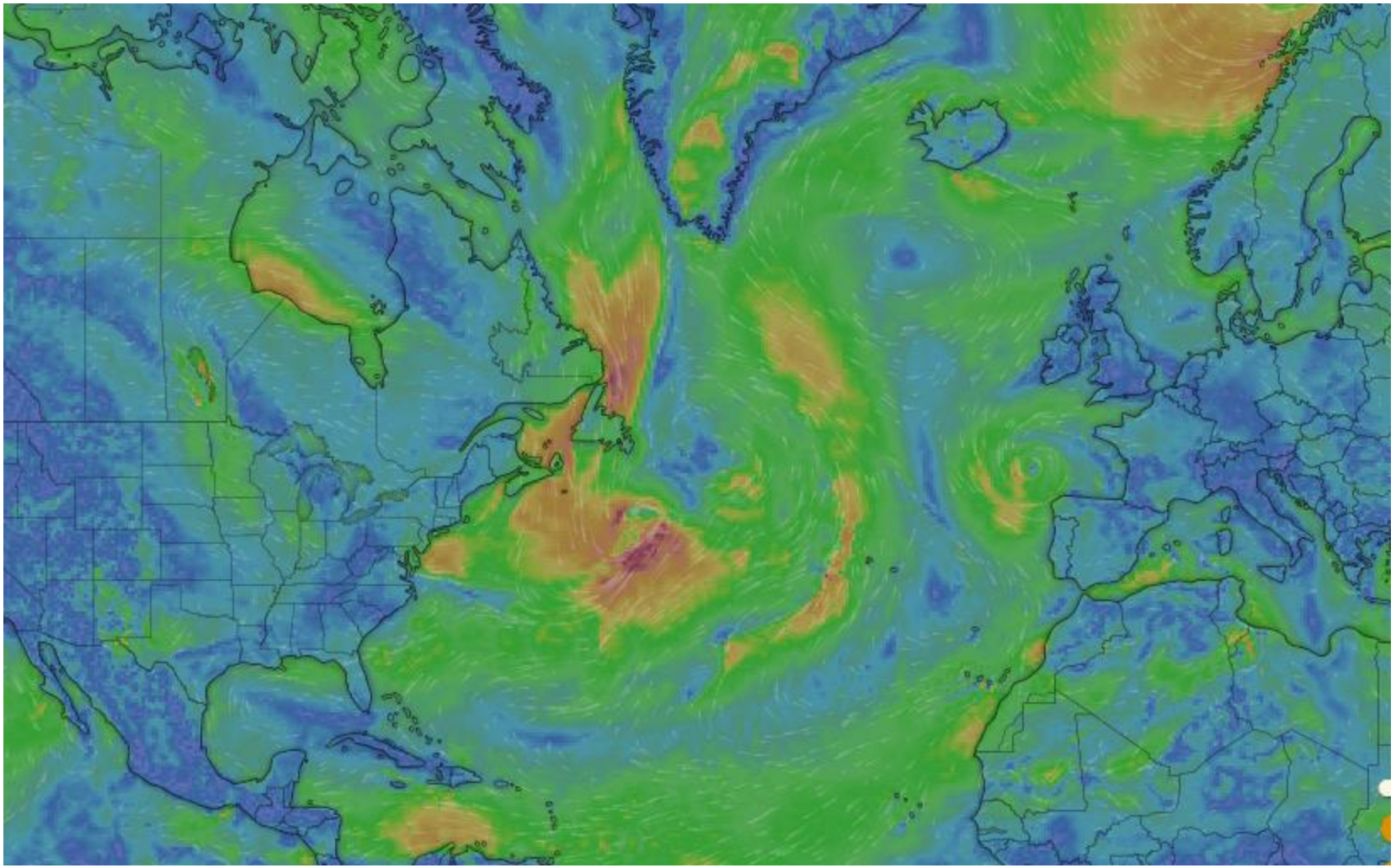


What About 2018?

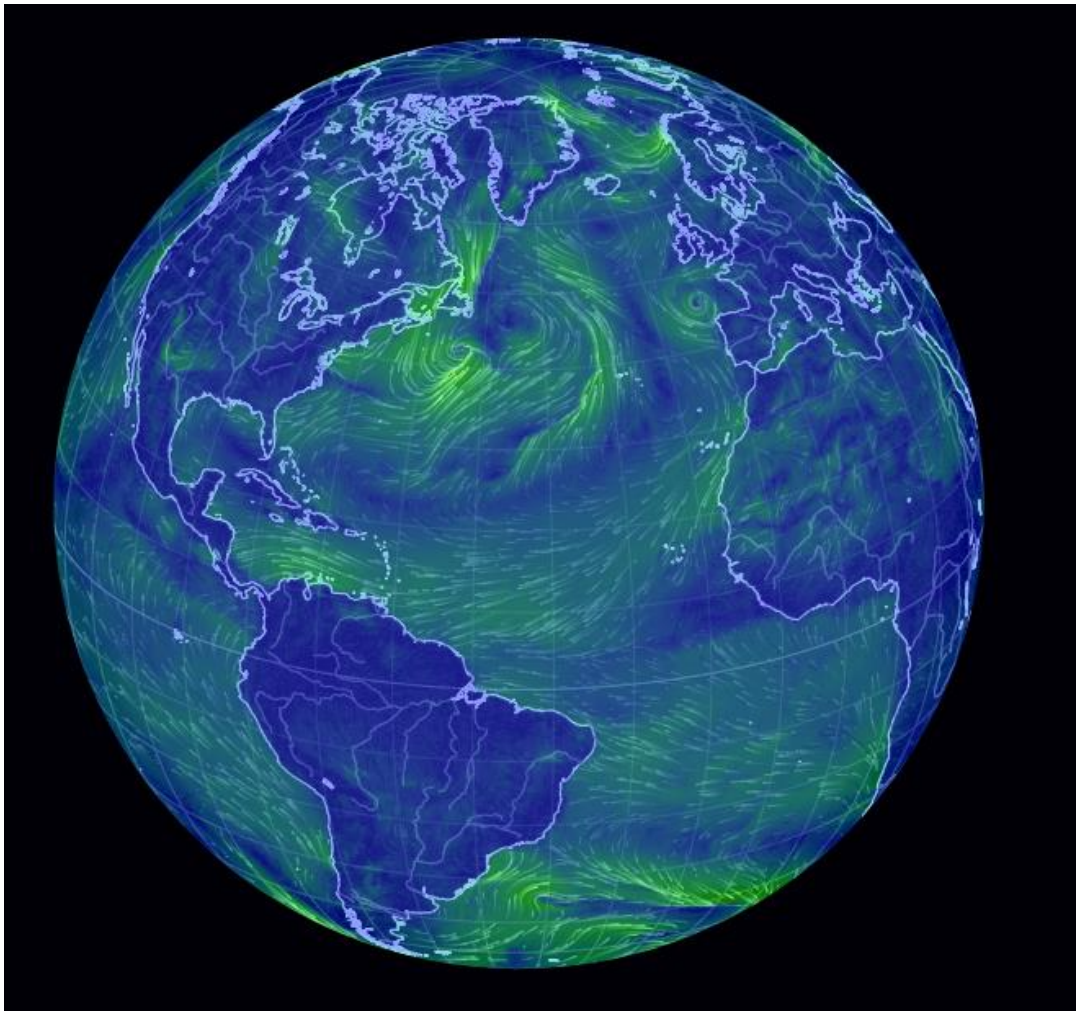
June 03 2018 6M 12:00 UTC



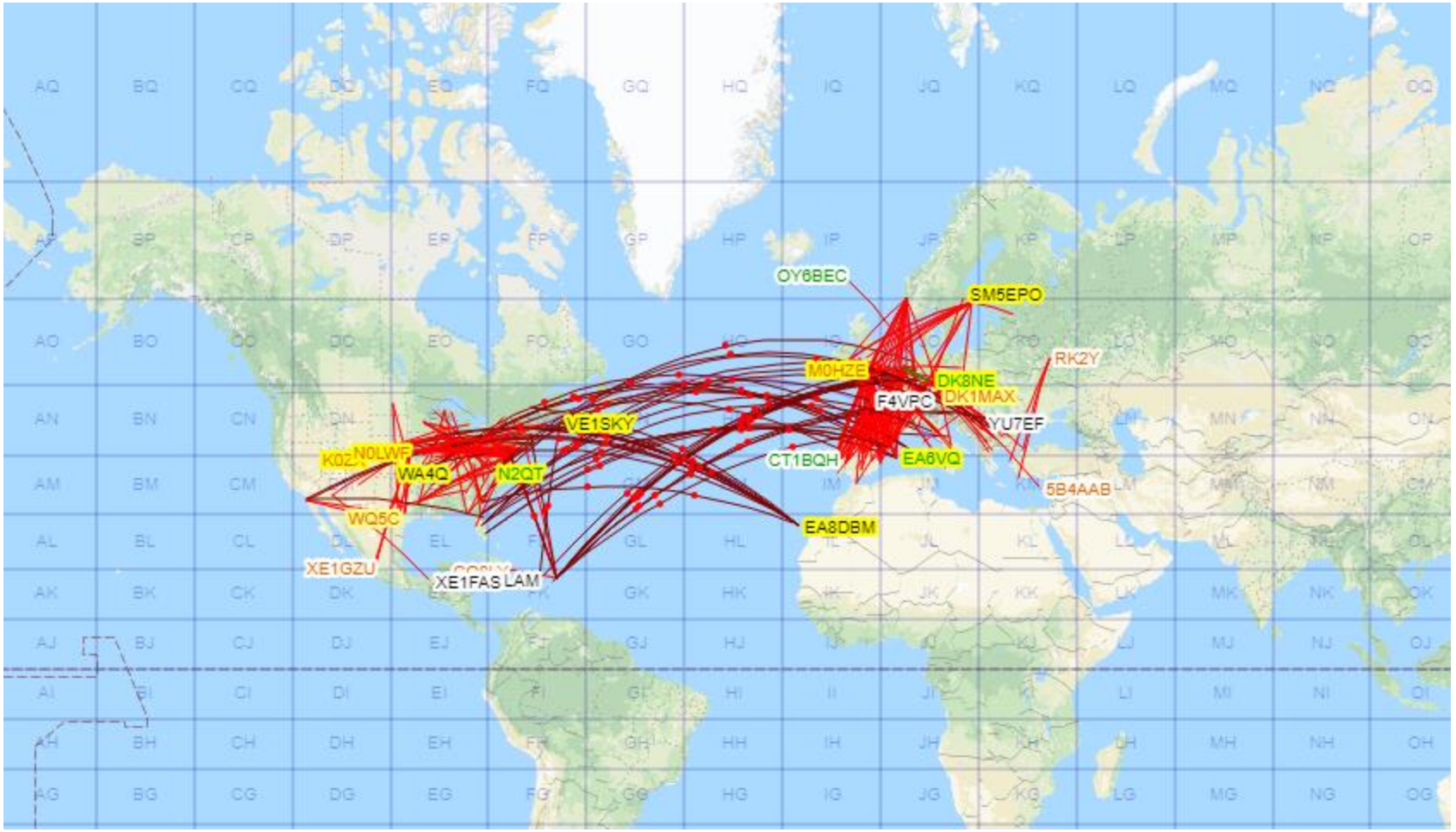
June 03 2018 6M 12:00 UTC



June 03 2018 6M 12:00 UTC



June 03 2018 6M 14:00 UTC



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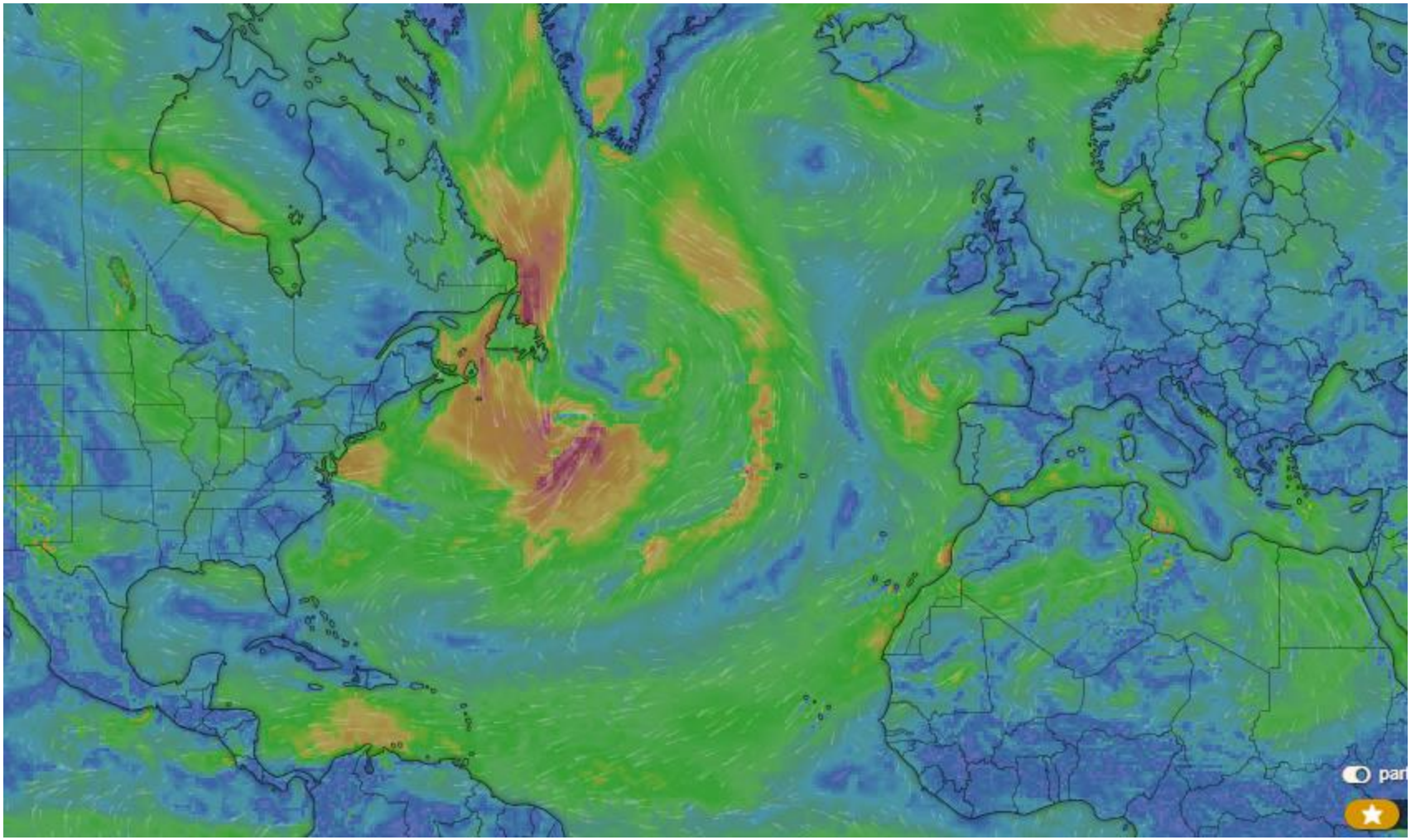

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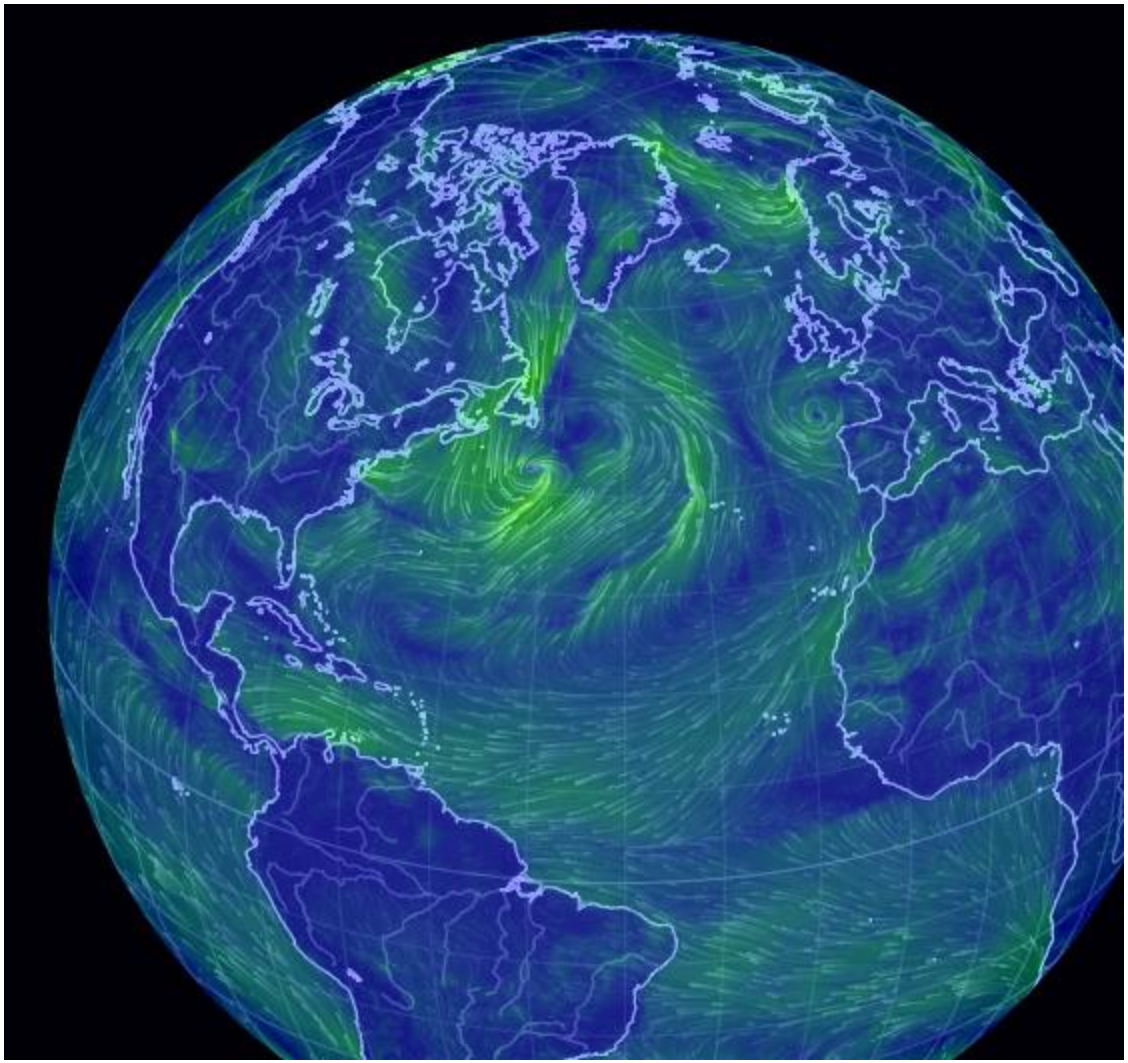

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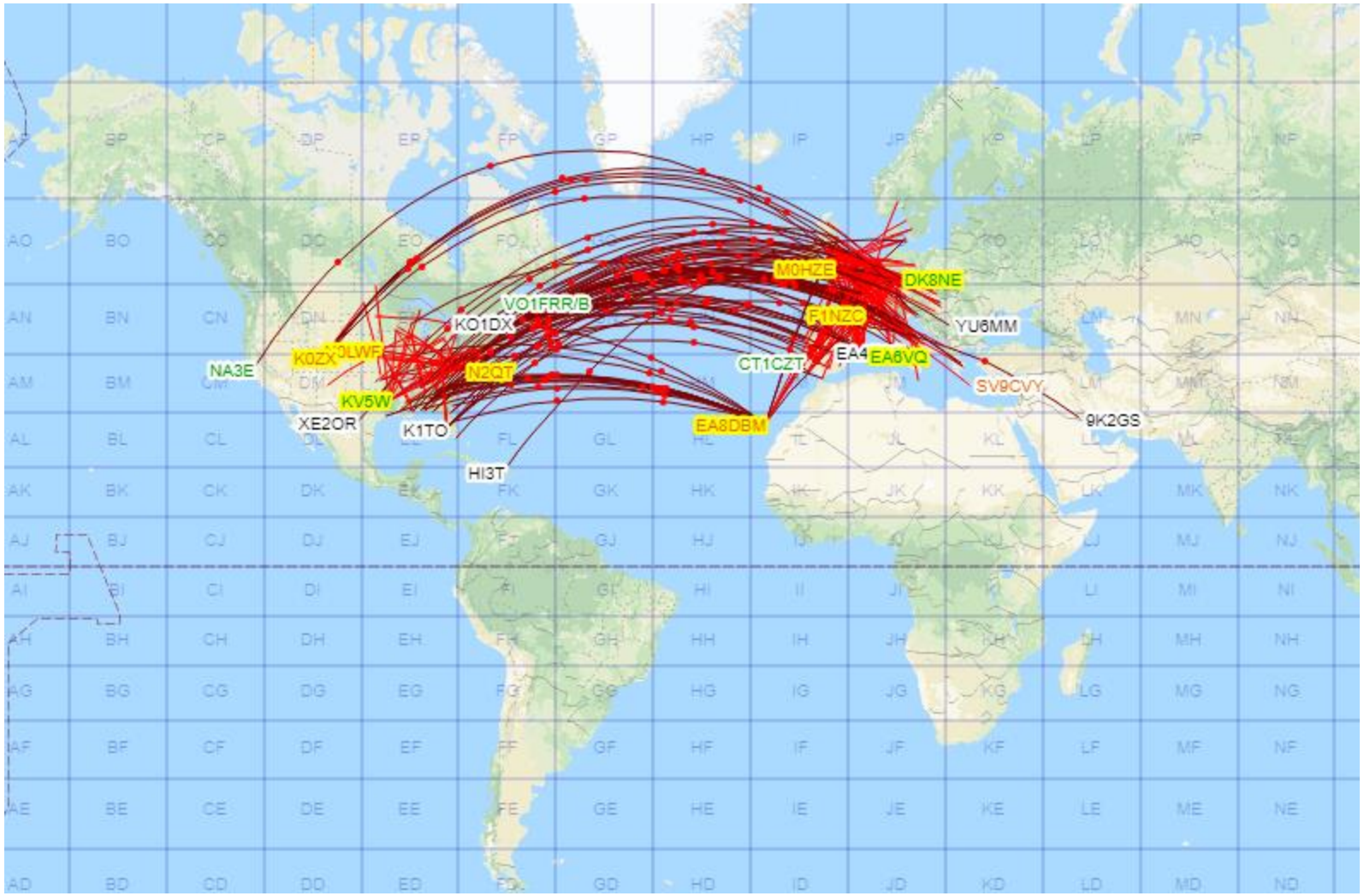

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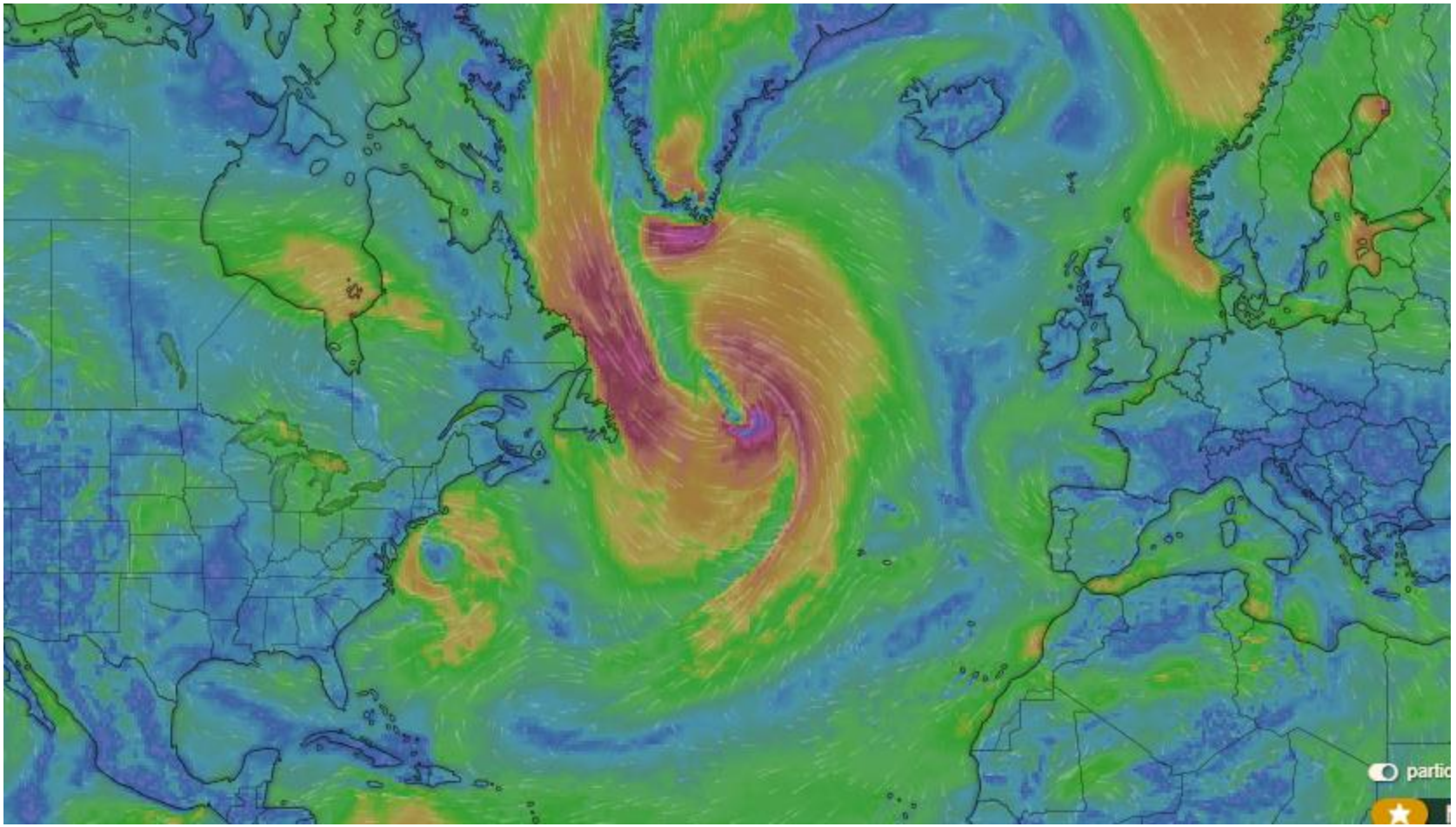

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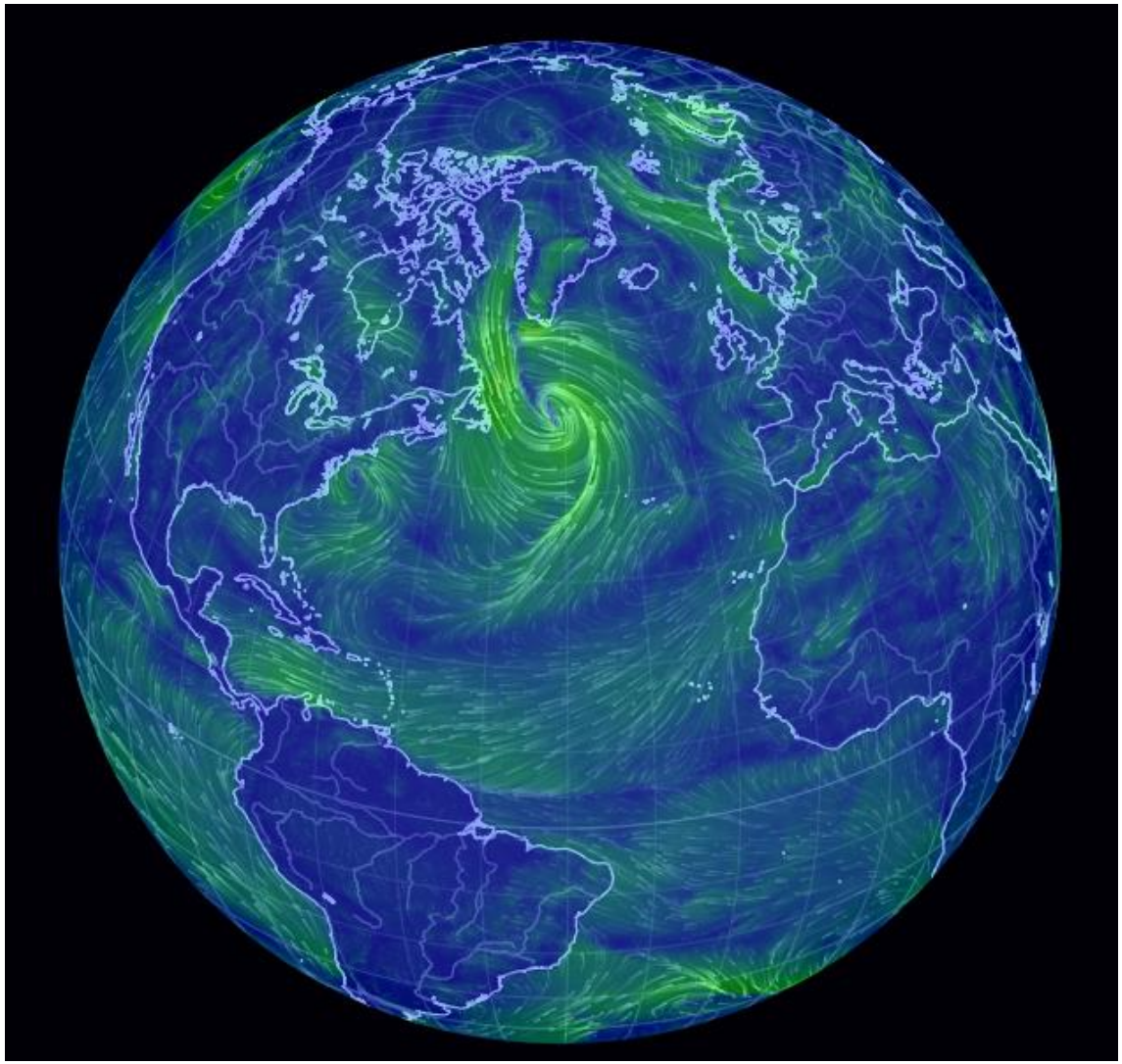


German Paper's Summary of Es

- We can now provocatively conclude that sporadic E layers do not appear sporadically.
- They follow distinct regularities and occur frequently under the convenient interaction of tidal winds, metallic ion concentration, and Earth's magnetic field.
- Es is a mid-latitude phenomenon.
- At this point we cannot say which parameter is most influencing Es formation.

K1YOW Ham Radio Conclusions

- Es is not random – just many variables – still can't predict it – yet!
- We hams make Es contacts in polar and equatorial regions even though the paper says no Es there.
- Upper level low pressure systems are affecting the high level tidal wind shear affects on Es via T-Storms, Hurricanes, Strong Fronts and especially Lightning.
- It is looking like we can use Amateur Radio to see and document these occurrences.
- North America is not the best Es spot in the world.
- Hams should not pray for hurricanes and storms just so they can work 6M DX!!!

Overall Summary – More to Come

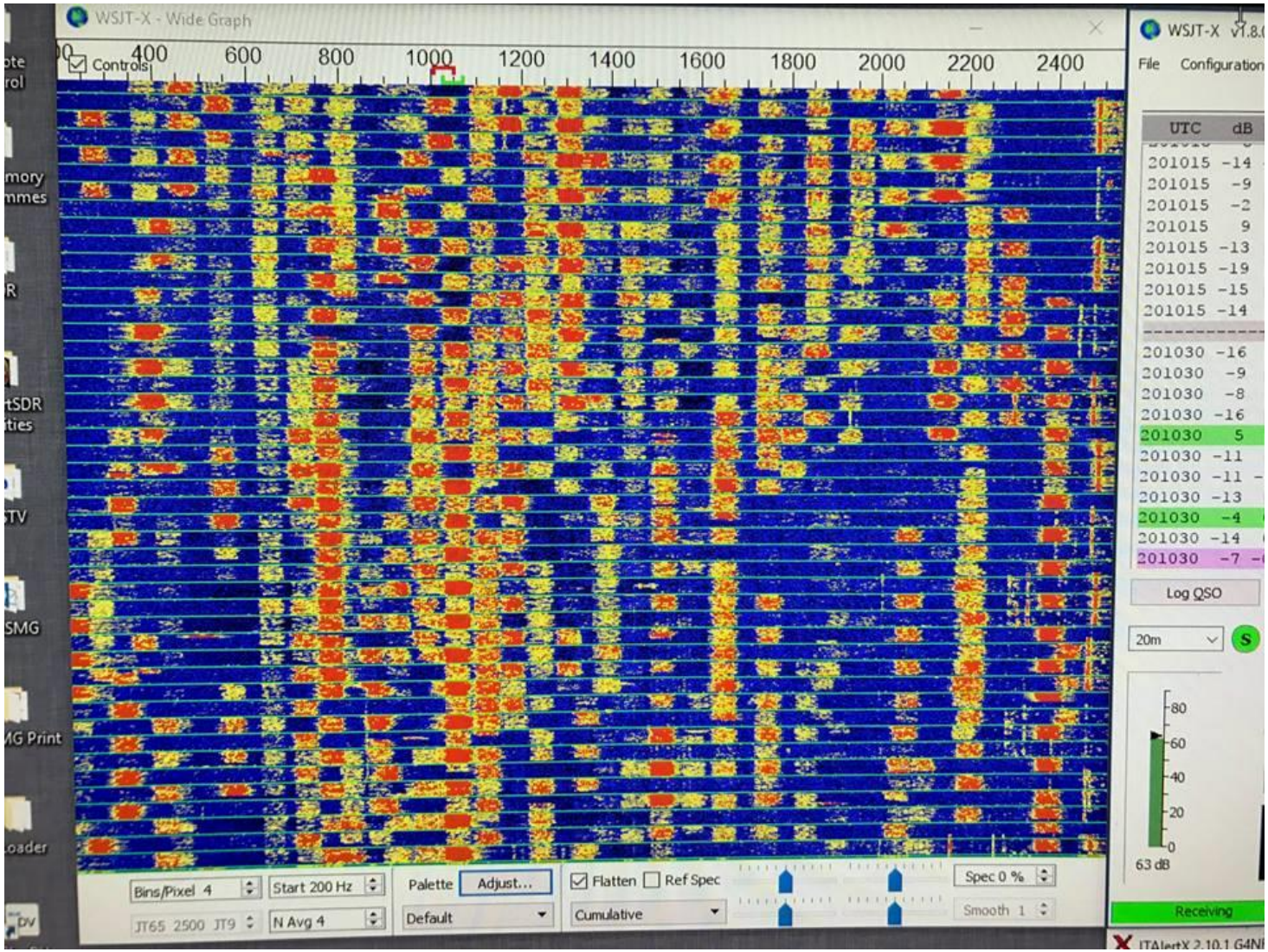
- So basically, it looks like the Es must be there formed by solar tidal wind shear in the E layer ionization field along with a horizontal Lorentz magnetic field component.
- Then, if there are also low pressure systems that generate lightning and sprites, they can ENHANCE the Es field up to 6 or 2 meter frequencies.
- In Europe, the magnetic field strength is the same as in Southern North America and we see more Es openings in S NA somewhat like we see more Es in EU. It looks to be a Goldilocks effect – must be not too strong nor too weak, but must be just right.
- It is like one big experiment with many variables.

More K1YOW Observations

- But, when seeing Northern So. America to Africa 6M Es, there are usually no storms present.
- Es can be seen over land, with or without storms
- I have noticed on 6M that I have not seen North Atlantic 6M Es unless there were storms also present.
- Some Es occurs after a geomagnetic storm, but usually not during a geomagnetic storm.
- The further South we go, the less dependence on storms so maybe Es is more dependent on magnetic field strengths and alignment, more increased ion fountain effect, more UV exposure, and maybe F2 and TE also confusing the pot.

06/05/2017 22:30 GMT 6M

New K1JT Mode – FT8 on 15S Cycles



K1JT Mode FT8 a Game Changer for 6 meters

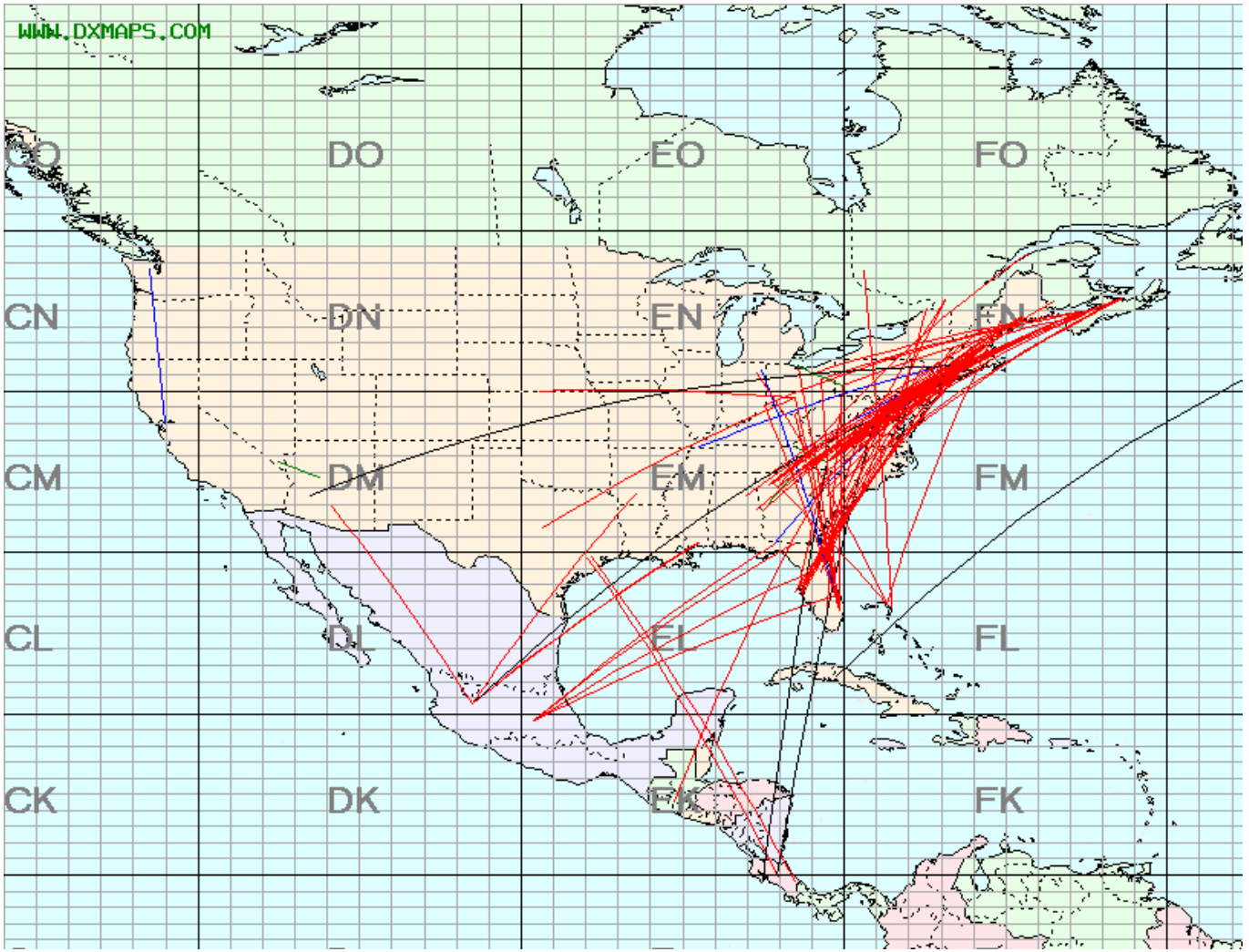
- JT65 with its good sensitivity but 1 minute cycle times was many times just too long for many Es conditions.
- FT8 has many of the JT65 attributes but its 15 second cycle times are a big win for shifting, fading and spotty Es conditions.
- The sensitivity of JT65, FT9 and now FT8 are allowing us to see and work conditions and paths previously impossible on CW and SSB.
- Leave rig on FT8 on 50.313 MHz and PSK Reporter and you will see Es on 6M every day!

	A	B	C	D	E	F	G	H	I	J
1	Date	Time UTC	Station	Sent	Rec'd	Grid	Freq	Mode	Country	Notes
2	6/5/2018	12:52	CT1ILT	-12.00	-14.00	IN50	50.313	FT8	Portugal	
3	6/6/2018	14:11	XE3N	-7.00	-12.00	EL60	50.313	FT8	Mexico	
4	6/15/2018	13:43	EA8AQV	-7.00	-1.00	IL28	50.313	FT8	Canary Is	
5	6/15/2018	13:55	EA8TL	3.00	-5.00	IL18	50.313	FT8	Canary Is	
6	6/15/2018	17:36	CT1GVN	5.00	-9.00	IM67	50.313	FT8	Portugal	
7	6/15/2018	17:42	SO1WS	-11.00	-14.00	IL46	50.313	FT8	Western Sahara	Copied IZ8
8	6/15/2018	21:24	IK7NXM	-1.00	-6.00	JN81	50.313	FT8	Italy	
9	6/15/2018	21:28	I8JIT	0.00	-18.00	JN71	50.313	FT8	Italy	
10	6/15/2018	21:53	EA6SX	-12.00	-14.00	JM19	50.313	FT8	Spain	
11	6/15/2018	22:23	EA6VQ	-6.00	-12.00	JM19	50.313	FT8	Spain	
12	6/16/2018	15:28	EA8AQV	2.00	4.00	IL28	50.313	FT8	Canary Is	
13	6/16/2018	15:34	CT3HF	-3.00	-8.00	IM12	50.313	FT8	Portugal	
14	6/16/2018	21:25	CT1ILT	-13.00	-14.00	IN50	50.313	FT8	Portugal	Copied SV9
15	6/16/2018	21:53	CT1HZE	-6.00	-11.00	IM57	50.313	FT8	Portugal	
16	6/17/2018	12:27	CU3AN	12.00	7.00	HM68	50.313	FT8	Azores Is	Copied 4X8LOS
17	6/18/2018	11:31	WP4AZT	13.00	-7.00	FK67	50.313	FT8	Puerto Rico	
18	6/18/2018	11:53	YV6IA	-3.00	-3.00	FJ78	50.313	FT8	Venezuela	
19	6/18/2018	12:30	HI3T	7.00	-6.00	FK49	50.313	FT8	Dominican Rep.	
20	6/18/2018	12:37	HI6JHV	-2.00	-9.00	FK48	50.313	FT8	Dominican Rep.	
21	6/16/2018	14:35	HI0RCD	-13.00	-14.00	FK58	50.313	FT8	Dominican Rep.	
22	6/18/2018	18:27	VP2ETE	-2.00	-14.00	FK88	50.313	FT8	Anguilla	
23	6/18/2018	18:36	KP4SX	-15.00	-17.00	FK78	50.313	FT8	Puerto Rico	
24	6/18/2018	18:44	PV8AJ	-5.00	-11.00	FJ92	50.313	FT8	Brazil	
25	6/19/2018	11:39	VP5DR	-3.00	-8.00	FL41	50.313	FT8	Turks Caicos Is	
26	6/19/2018	12:44	CO8LY	8.00	-13.00	FL20	50.313	FT8	Cuba	
27	6/19/2018	13:08	ZF1EJ	-4.00	-9.00	EK99	50.313	FT8	Cayman Is	Copied 4X4DK
28	6/19/2018	14:26	CT1HZE	-9.00	-12.00	IM57	50.313	FT8	Portugal	
29	6/19/2018	14:38	F5BZB	-2.00	-3.00	JN03	50.313	FT8	France	
30	6/19/2018	14:39	F6ECI	-14.00	-11.00	JN05	50.313	FT8	France	
31	6/19/2018	14:51	F6ITD	-7.00	-17.00	JN03	50.313	FT8	France	Copied 9K2GS
32										
33										

Winter 2017 into 2018

- In 2018 we had some nice winter Es openings
- What possibly could cause this?
- Low sun angles and exposure
- Cold temperatures
- Summer is usually the “hot” Es season

Dec 13 2017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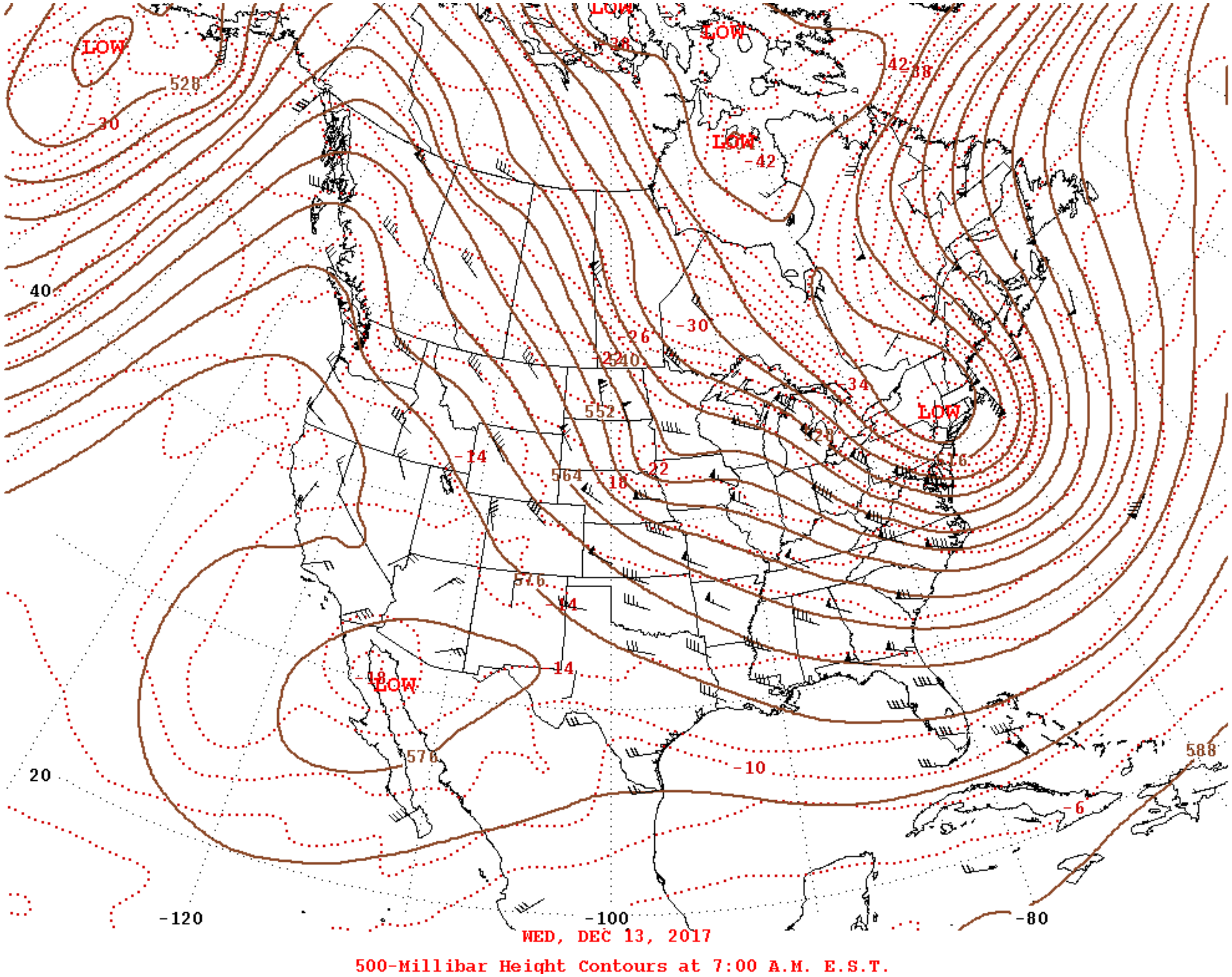
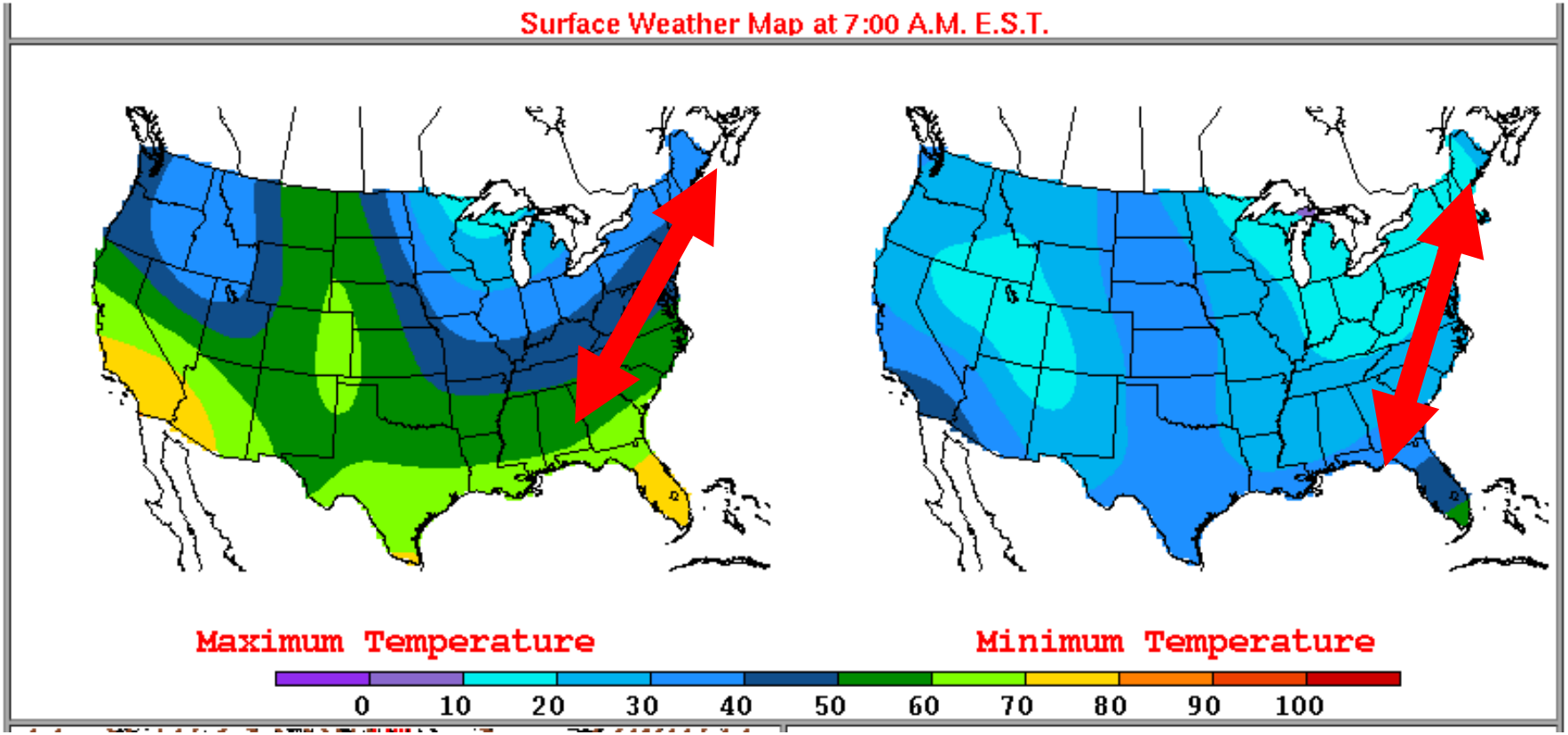
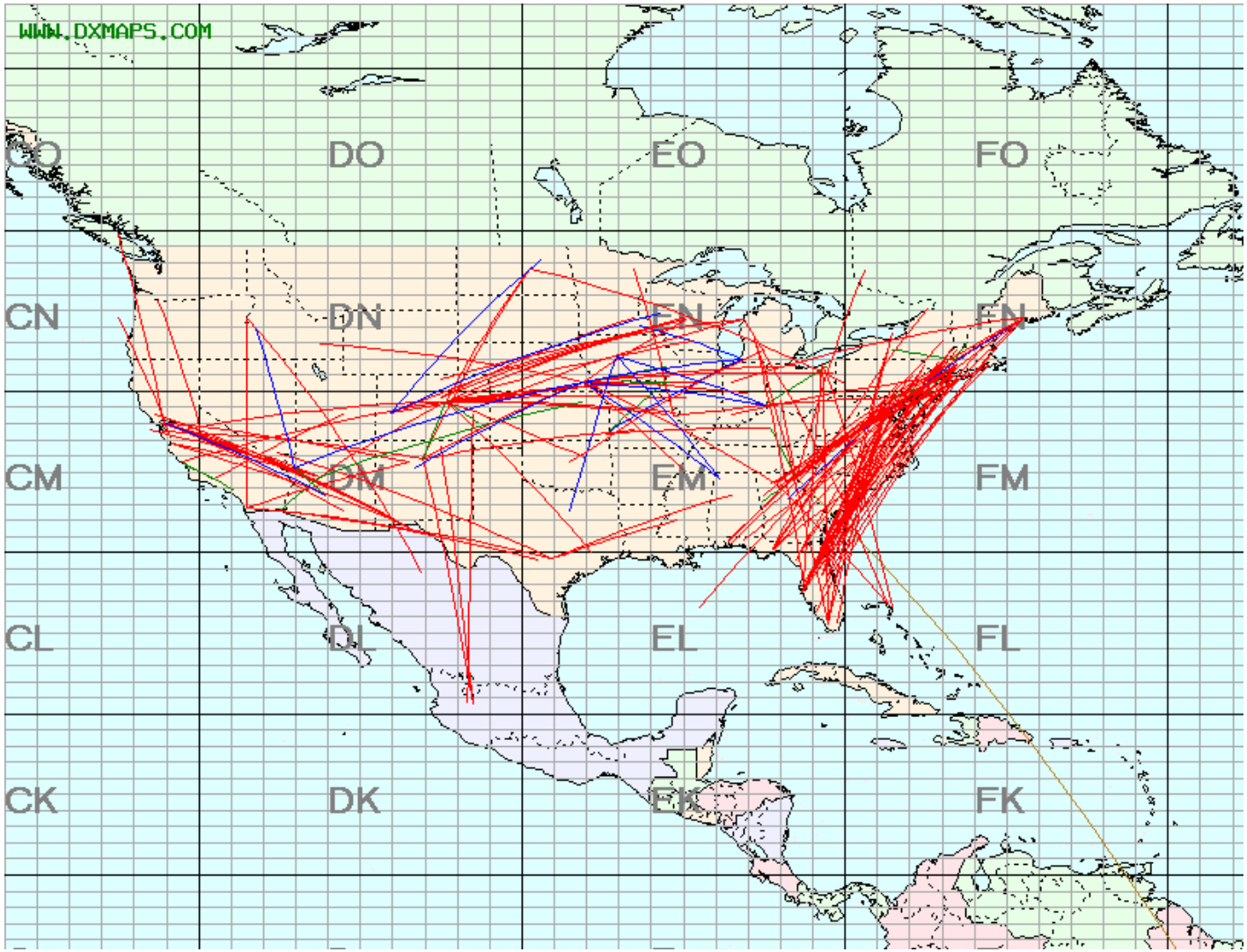
Dec 13 2017



Dec 13 2017 Es on Jet Stream Boundary



Dec 31 2017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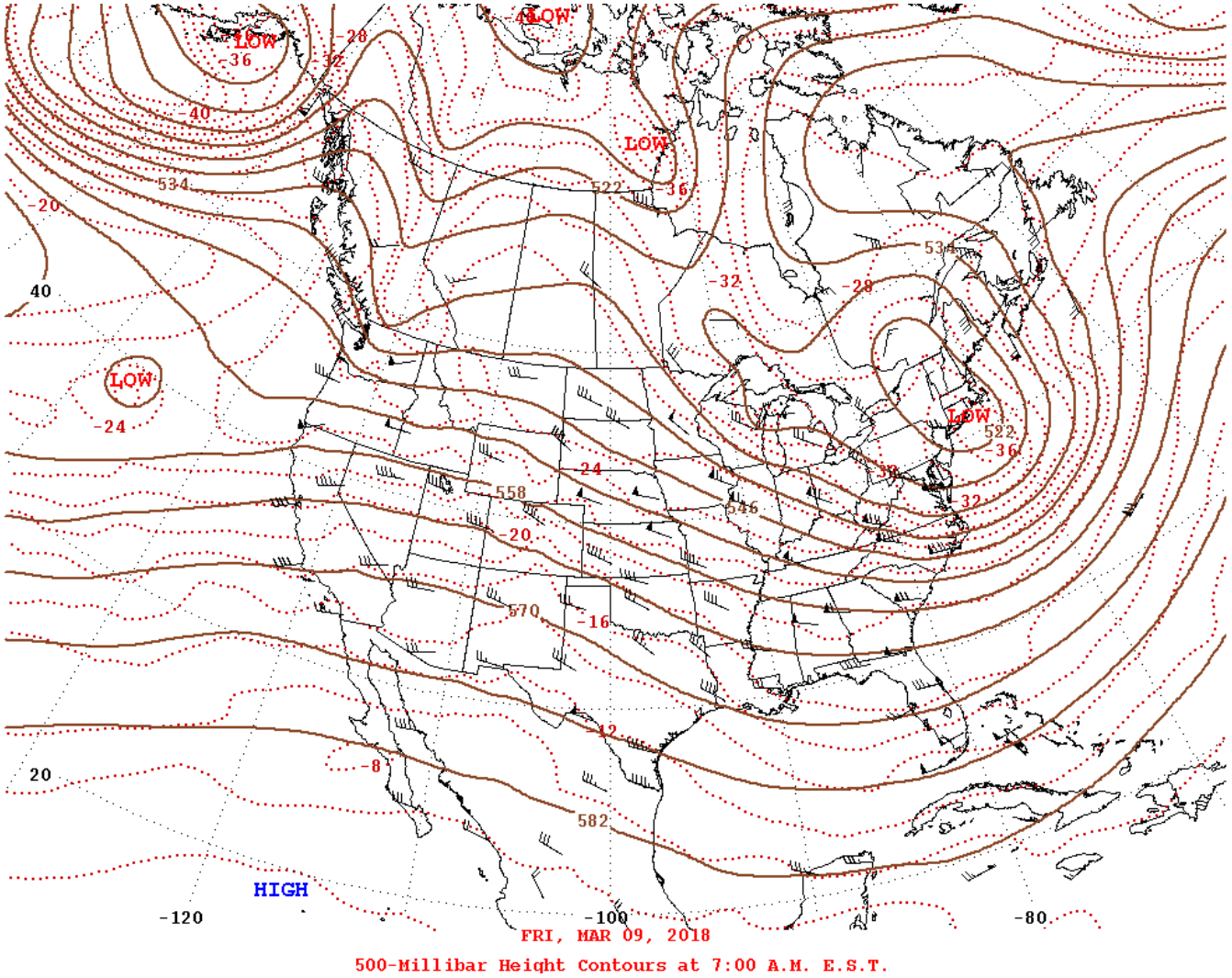
Dec 31 2017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-20
LOW
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-36
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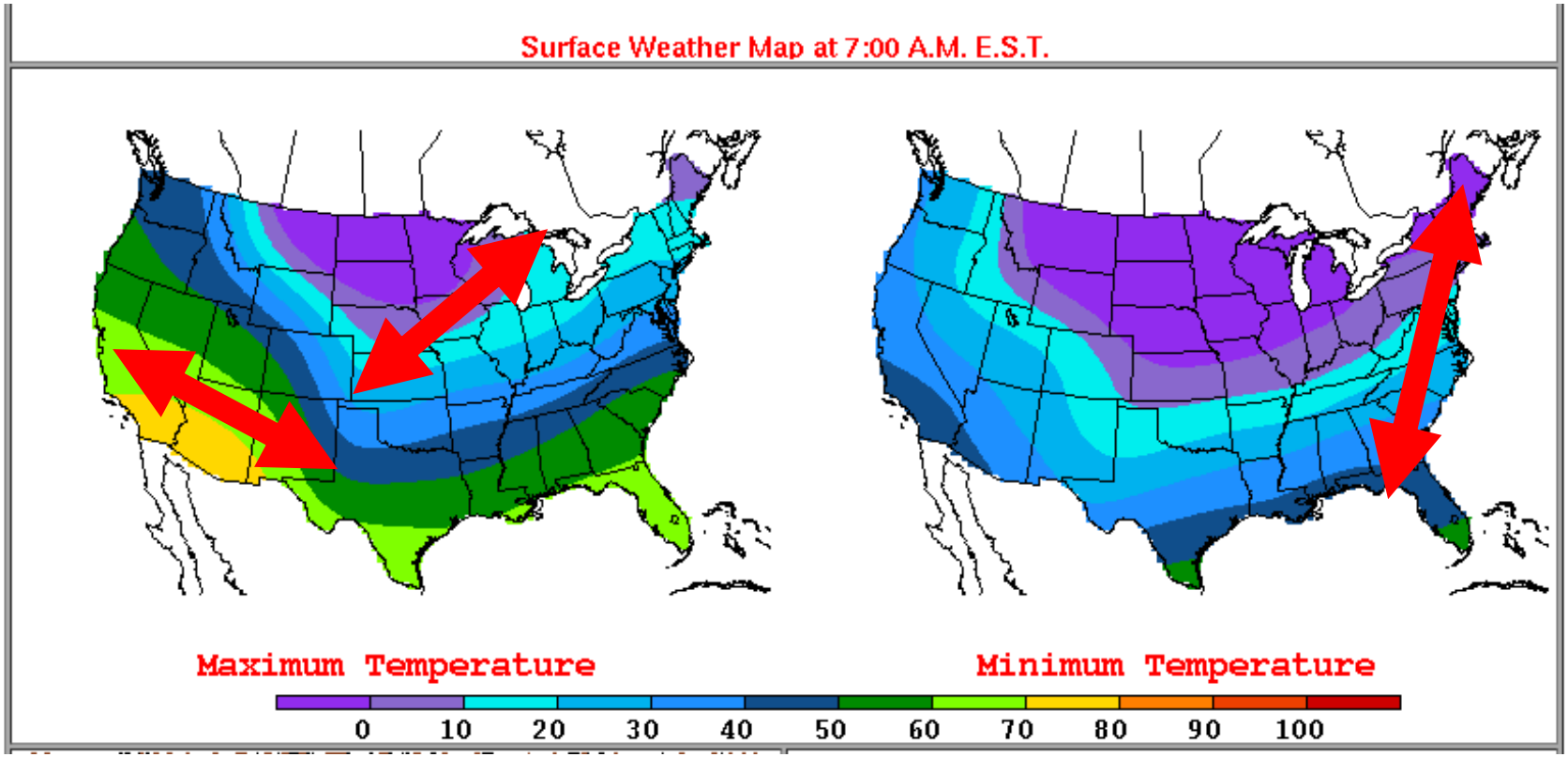
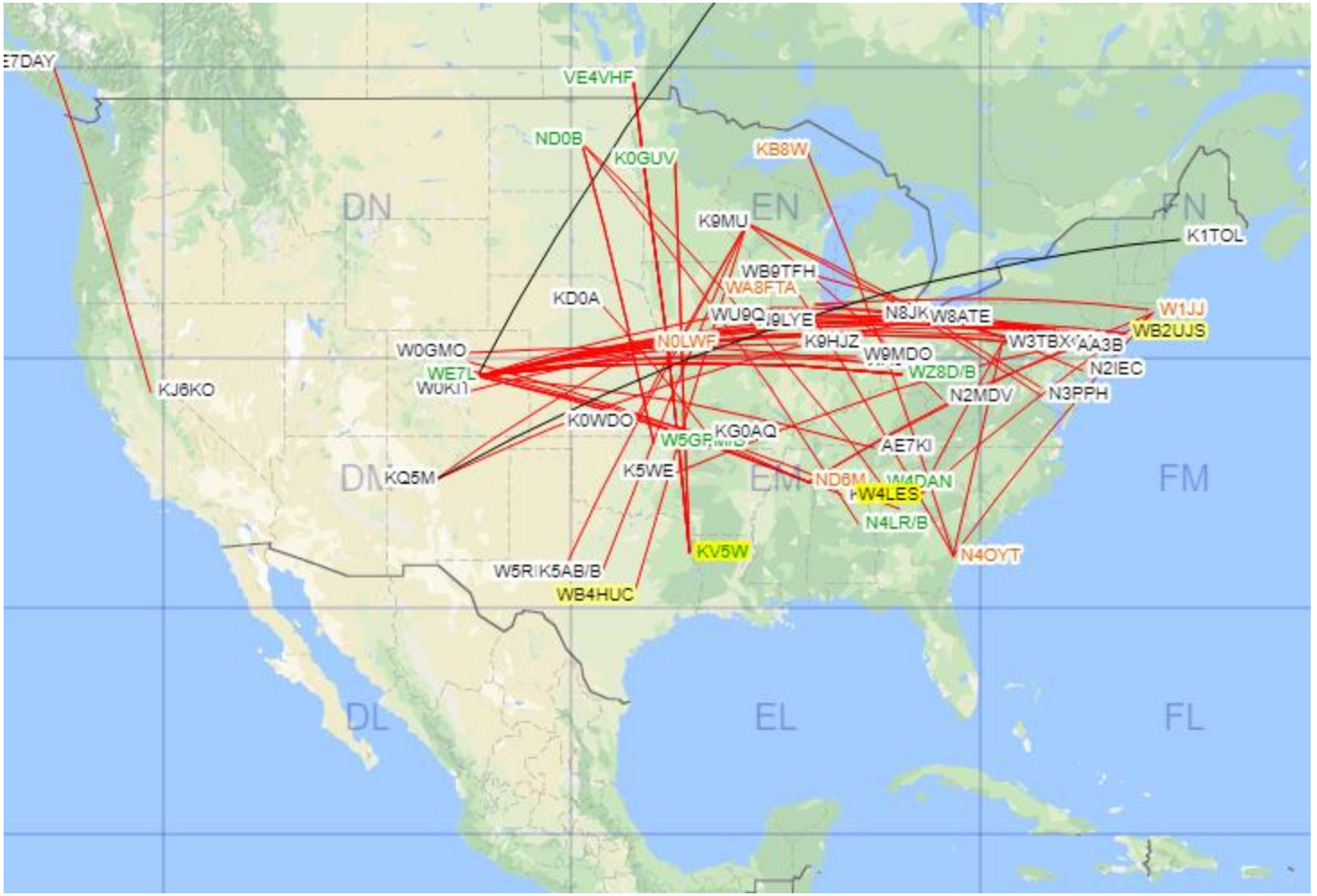
522
-36
-24
558
546
-20
570
-16
-12
-8
582
HIGH
-120
-100
-80
FRI, MAR 09, 2018
500-Millibar Height Contours at 7:00 A.M. E.S.T.

Dec 31 2017 Es on Jet Stream Boundaries



Jan 04 2018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WB2UJS
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AA3B
WE7L
WZ8D/B
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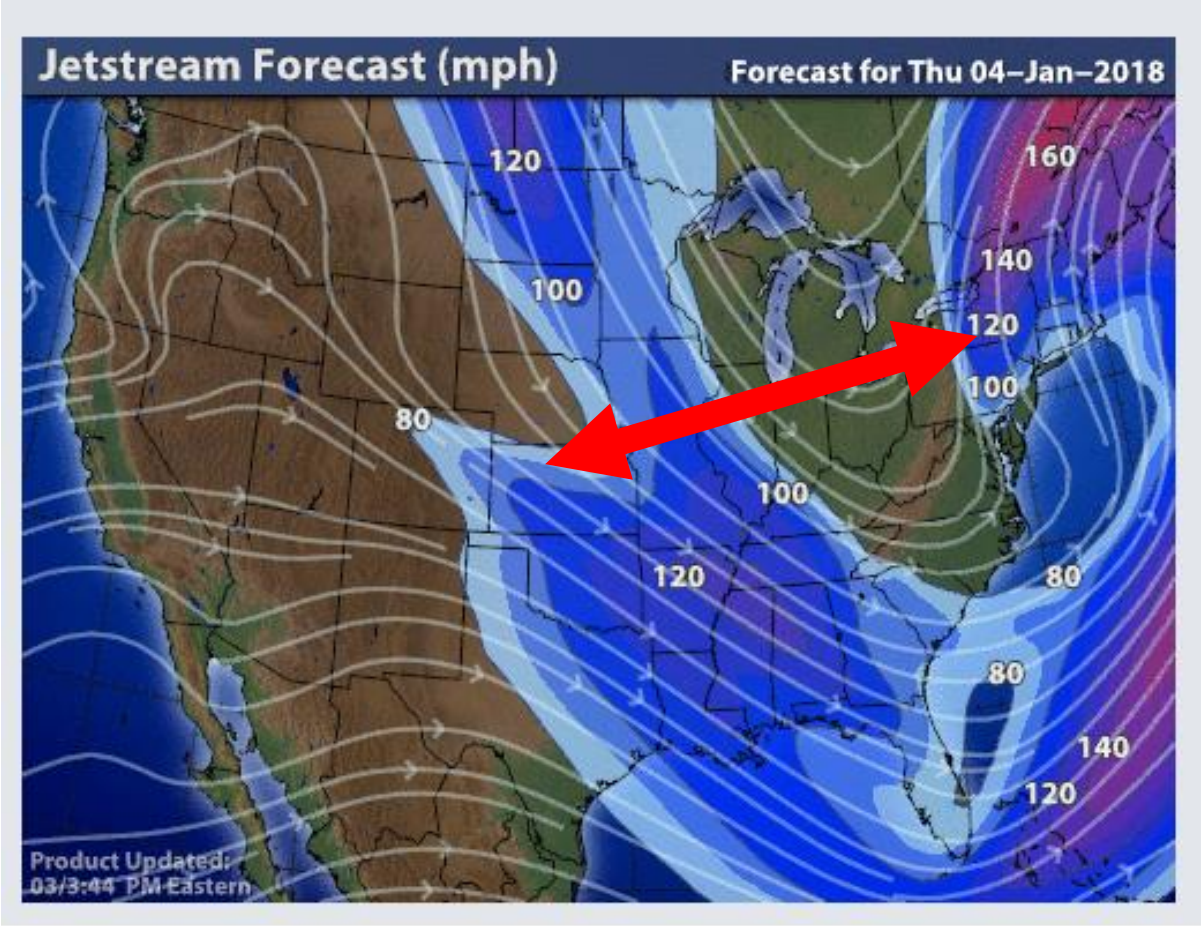
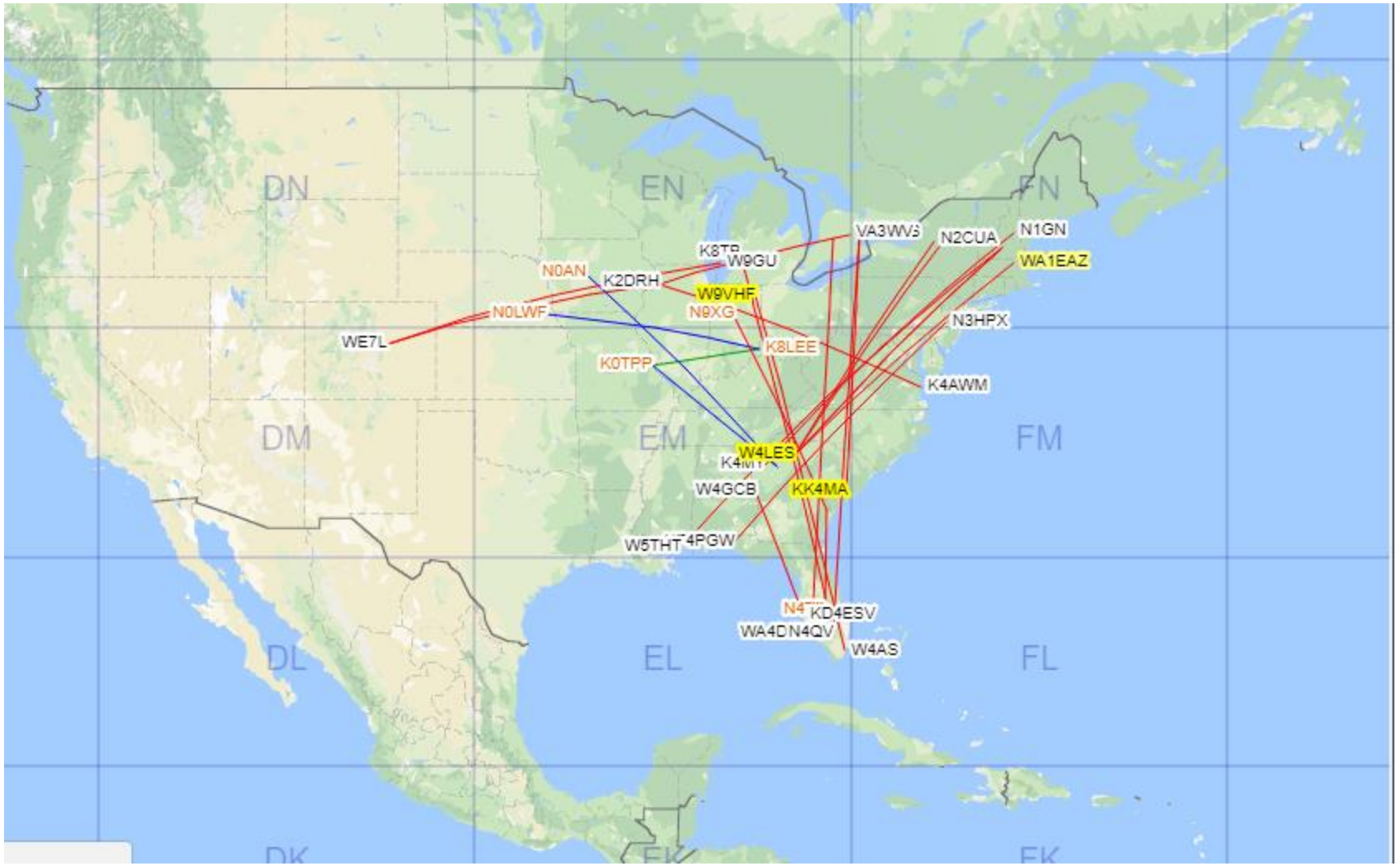
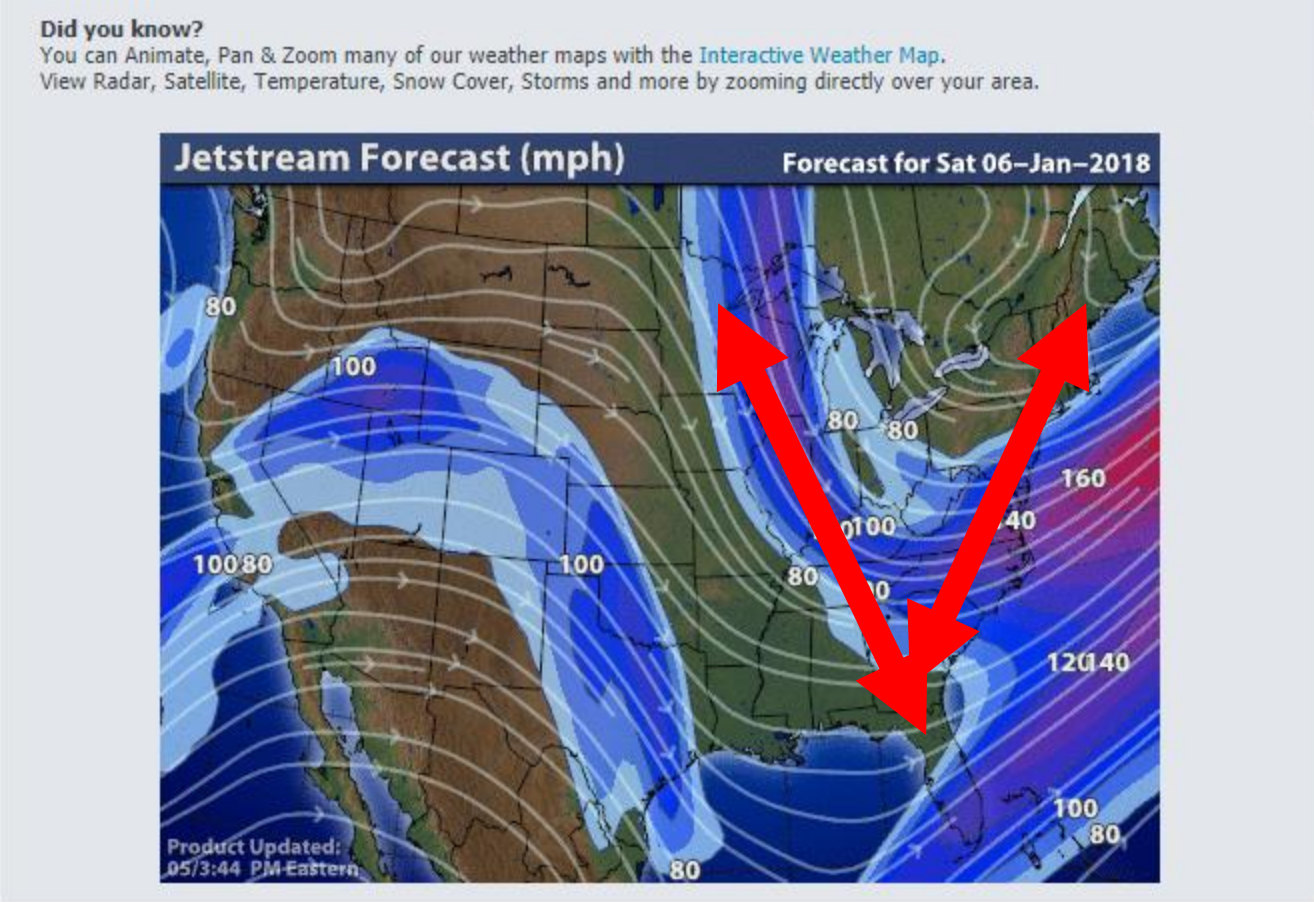
Jan 04 2018 Es Across Jet Stream Trough



Jan 06 2018 18:45 GMT



Jan 06 2018 18:45 GMT Es on Jet Stream Boundaries



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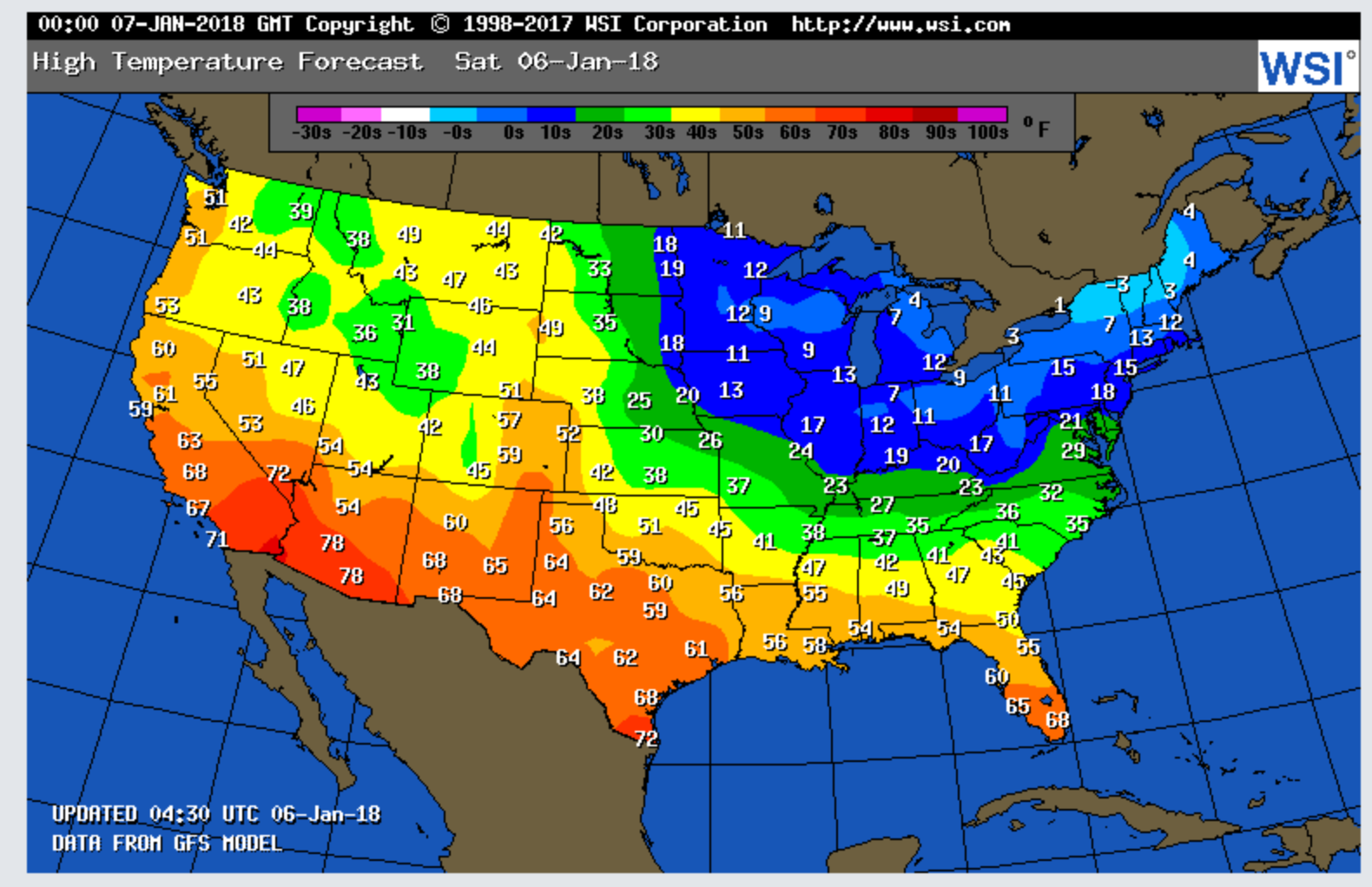


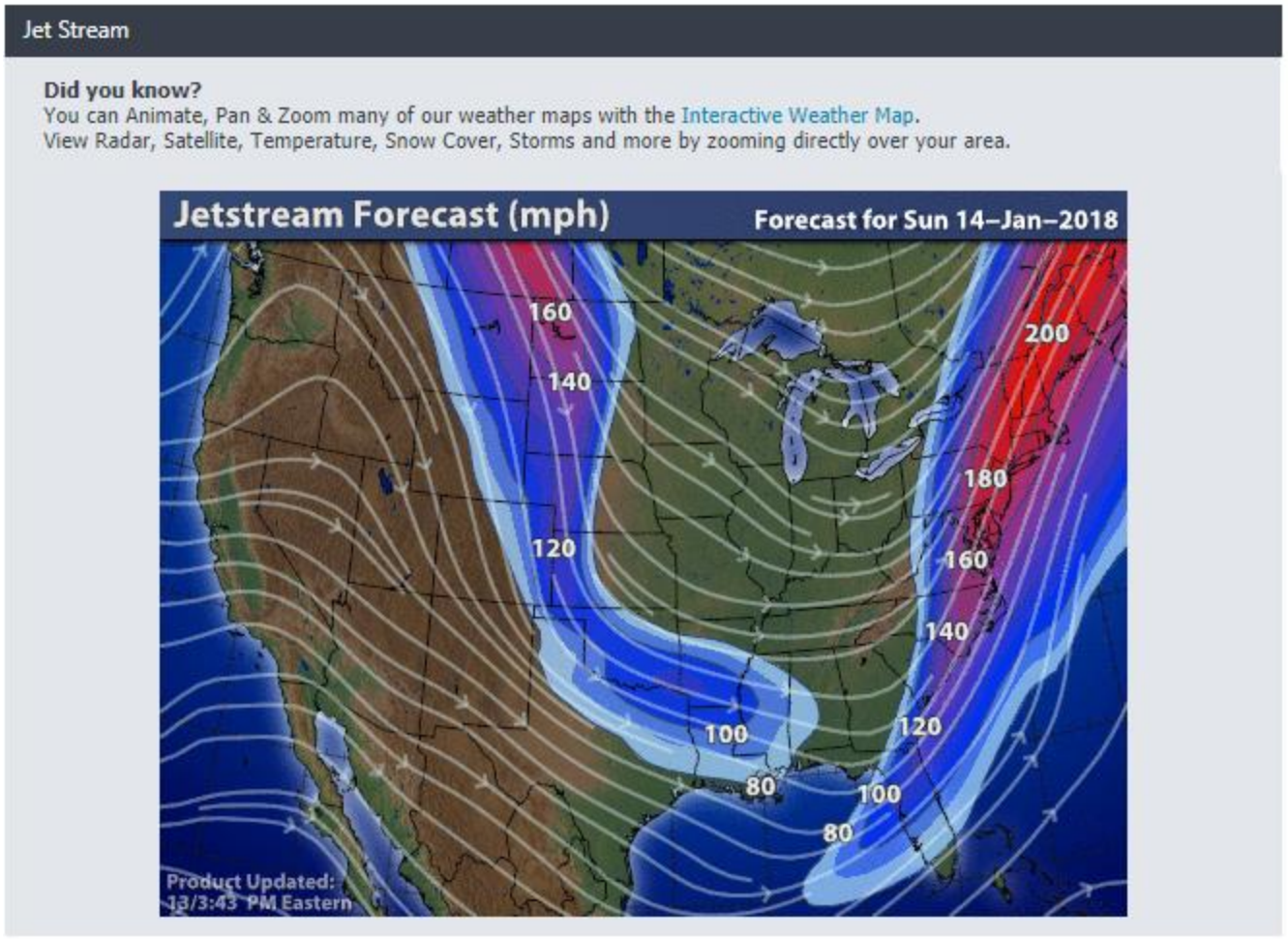
Notice the Trend?

- Es is forming on strong Jet Stream boundaries where there are strong wind shears and strong temperature gradients.
- It seems to form on the Eastern edge of either the Eastern or Western boundary of the Jet Stream trough.
- Es also can form across the trough dip but seems to form more often on the Eastern side of a boundary on the side where the air currents are heading – our NA Jet Stream flows West to East in the overall pattern.
- But…with Es there is ALWAYS a BUT:

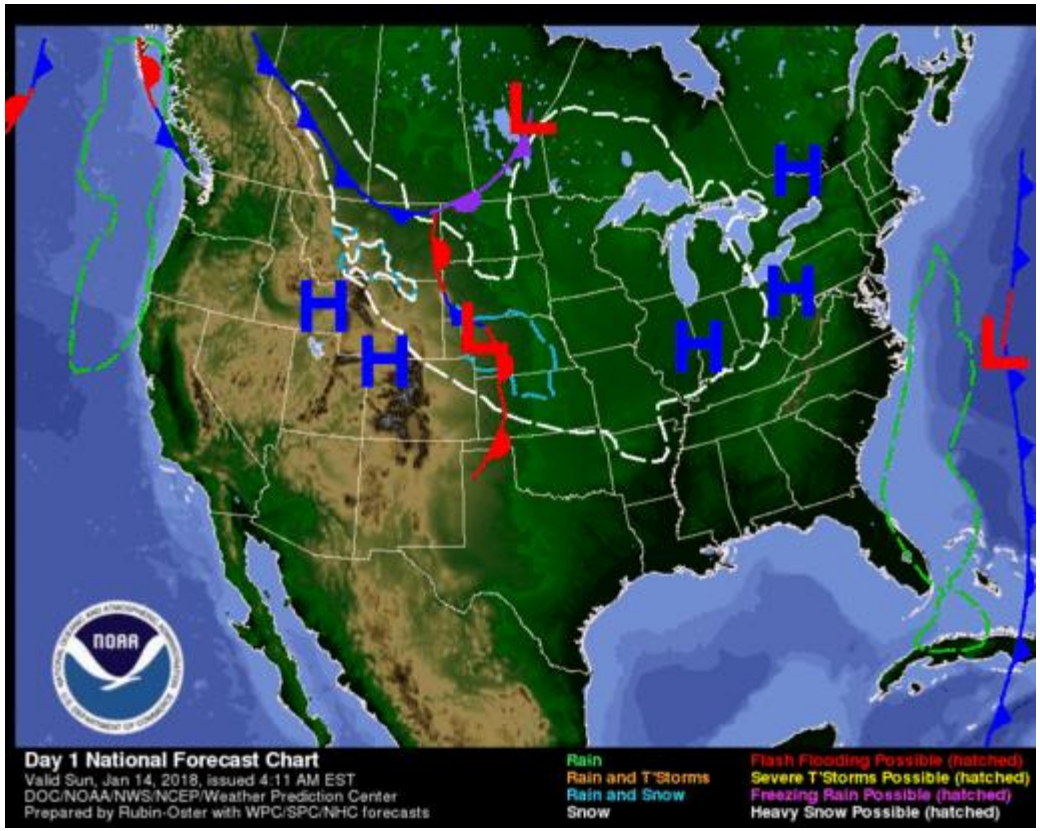
Jan 14 2018

Well, even with a similar Jet Stream this weekend (Jan 13/14, 2018) to the four past Es openings that happened over Jet Stream boundaries, it really didn't happen that way this time, which in itself, is a useful data point. This time, the sun did hiccup with a short G1 K5 storm, and there was Es in other parts of the world like in Australia, unlike the pervious winter North American openings in December and January. On Saturday there was some Es in NA but it was fairly scattered around and not the very strong SW to NE along the Jet Stream pattern that we saw with the previous openings. Also, many of the 6M hams were staying on meteor scatter as well and not moving to FT8.

Jan 14 2018 Strong Jet Stream but also G1/K5 Storm – No Es



Jan 14 2018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NOAA
Day 1 National Forecast Chart
Valid Sun, Jan 14, 2018, issued 4:11 AM EST
DOC/NOAA/NWS/NCEP/Weather Prediction Center
Prepared by Rubin-Oster with WPC/SPC/NHC forecasts
Rain
Rain and T'Storms
Rain and Snow
Snow
Flash Flooding Possible (hatched)
Severe T'Storms Possible (hatched)
Freezing Rain Possible (hatched)
Heavy Snow Possible (hatched)

No Jet Stream Es This Time

- Maybe the stream was not fast enough
- Maybe the temperature difference boundaries were not strong enough
- Maybe because the sun was quiet the last four times and this time we had a short G1/K5 set of conditions to negate the effect
- Maybe the frontal boundary pushed-off the eastern USA coast very fast and didn't linger per the previous four Jet Stream Es events
- Maybe, maybe, maybe, maybe…..

Es – Many Variables, Many Causes

- Like one big DOE (Design Of Experiment) with no variables under control
- Variables: Solar UV, magnetic fields (Goldilocks levels, anomalies, disturbances), upper neutral atmosphere shears and tides, solar storms (flares, CMEs, coronal hole particle streams), time of year, location on Earth, atmospheric weather (fronts, thunder storms, lightning, sprites, thermal boundaries)
- For me the surprise is: local weather has more Es effects than I would have thought – it is not just what the sun is doing at the moment

Reference Links

- http://www.dxmaps.com/spots/map.php
- http://www.accuweather.com/en/world/satellite
- https://earth.nullschool.net/
- https://www.windyty.com/?42.753,-71.584,4
- http://gfzpublic.gfz-potsdam.de/pubman/item/escidoc:23022:5/component/escidoc:23021/1009.pdf
- **A statistical analysis on the relationship between thunderstorms and Sporadic E Layer over Rome** V. BartaP1,2P, UC. ScottoUP3P, M. PietrellaUP3P, V. Sgrigna P4, G. SátoriP2P, L. Conti 5
- F-Region Propagation and the Equatorial Ionospheric Anaomaly, Jim Kennedy, K6MIO/KH6, QEX Issue No. 299 November/December 2016
- Thunderstorm connected with Sporadic E propagation, Flavio Egano, ik3xtv documento n. 128 del 5 Settembre 2008