Ray-trace Modeling of Diurnal Variation in Two-hop Sidescatter Propagation

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Abstract

Two-hop sidescatter is an off-great circle propagation mode enabling above-the-basic-MUF communications. It is identified by low SNR and high frequency spread. Observable at 7 MHz and above as a daytime mode it enables propagation from 10s km to 100s km. It may also appear before, and or after, great-circle one-hop propagation. We have devised a computationally efficient modelling approach for two-hop sidescatter using 3D PyLap ray tracing. The model suggests diurnal variations of sidescatter location and strength are particularly interesting for north-south path geometry: leading to morning scatter from the east, and evening from the west. We compare hourly model simulations with observations of signal level and circuit reliability to verify our ray-trace model approach.

Introduction

First observed in the mid-1920s sidescatter [1] has, among others, been investigated on trans-Pacific paths on 12 MHz, 18 MHz and 30 MHz [2] and across North America on 10 MHz [3]. Despite enabling daytime reception ranges up to 700 km on the upper HF bands sidescatter has received little recent attention compared with Near Vertical Incidence Skywave.

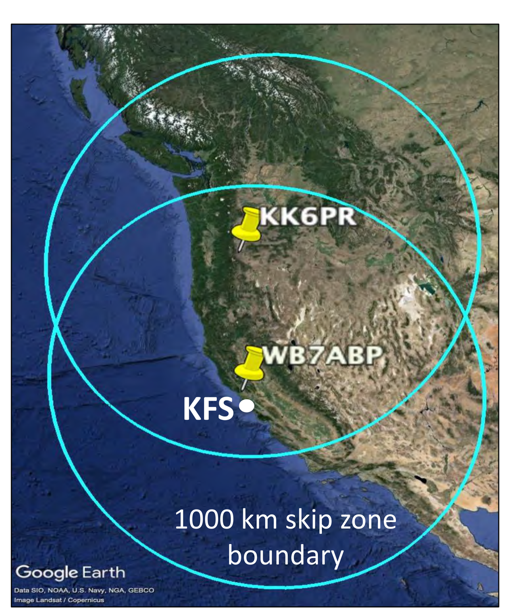

Fig. 1. Map showing transmitter and receiver locations. Circles show a 1000 km skip zone.

Consider a transmitter (WB7ABP) and receiver (KK6PR) on a north-south 680 km path, **Fig. 1**, on a band, here 14 MHz, and time when the skip zone extended to 1000 km. Direct one-hop propagation is not possible. However, **Fig. 1** shows intersections for the skip zones' outer boundaries: to the east and west. Part of the transmit power in signals impinging on land or sea near the intersections scatter in all directions. This sidescatter will result in signals at the receiver, albeit with lower amplitude than great circle one-hop. This poster explores, with ray-trace modelling and observations, how locations of two-hop sidescatter might vary throughout a day.

Methods: 3D Ray-trace modelling

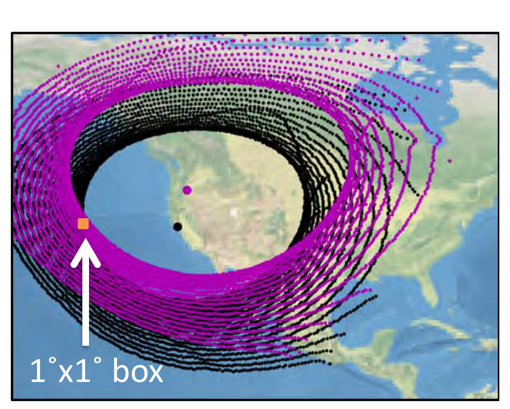

Fig. 2. PyLap ray landing spots at 04:00 UTC 18 April 2023 on 14 MHz. Maximum landing spot product in a 1˚x1˚ box was 441.

We used 3D PyLap ray tracing [4], which incorporates the International Reference Ionosphere, to map realistic likely sidescatter locations. Our approach assumes reciprocity. We calculate the product of ray landing spots from the transmitter (black) and a pseudo-transmitter at the receiver (magenta) in 1˚x1˚ boxes to give a metric of sidescatter, **Fig. 2**. Assuming reciprocity avoids the computationally intensive approach adopted by others of placing a transmitter at reach transmit ray landing spot [5].

Methods: Observations

Fig. 3. The 14 MHz Yagi at WB7ABP had enough directivity to discriminate great circle and sidescatter headings.

We verified the sidescatter location predictions with two experiments. The first used FST4W, a beacon-like mode within the WSJT-X package, transmitted by WB7ABP. The 5-element antenna, **Fig. 3**, was rotated in 10˚ steps as the signal level at KK6PR was recorded. The second experiment used FST4W transmissions from KK6PR and log periodic beam receive antennas at KFS directed to the SE (TCI527B) and SW (TCI532), **Fig. 1**.

Results

Fig. 4 shows scattering metric contours from the 3D ray-trace model. There is substantial diurnal variation in intensity and location of scattering. The thin-ring characteristic arises from focusing of high and low angle rays at the skip zone edge. Early morning (LT) has scatter distant and weak from the SE (**Fig. 4c**), reducing in range and increasing in strength as the MUF rises. By local noon (**Fig. 4d**) there is also scatter from the west, which becomes dominant in the evening, before fading. The rotating antenna experiment, **Fig. 4a**, showed highest signal level at transmit heading 320˚, 40˚ clockwise of the model's high scatter area and 50˚ anticlockwise of the direct path.

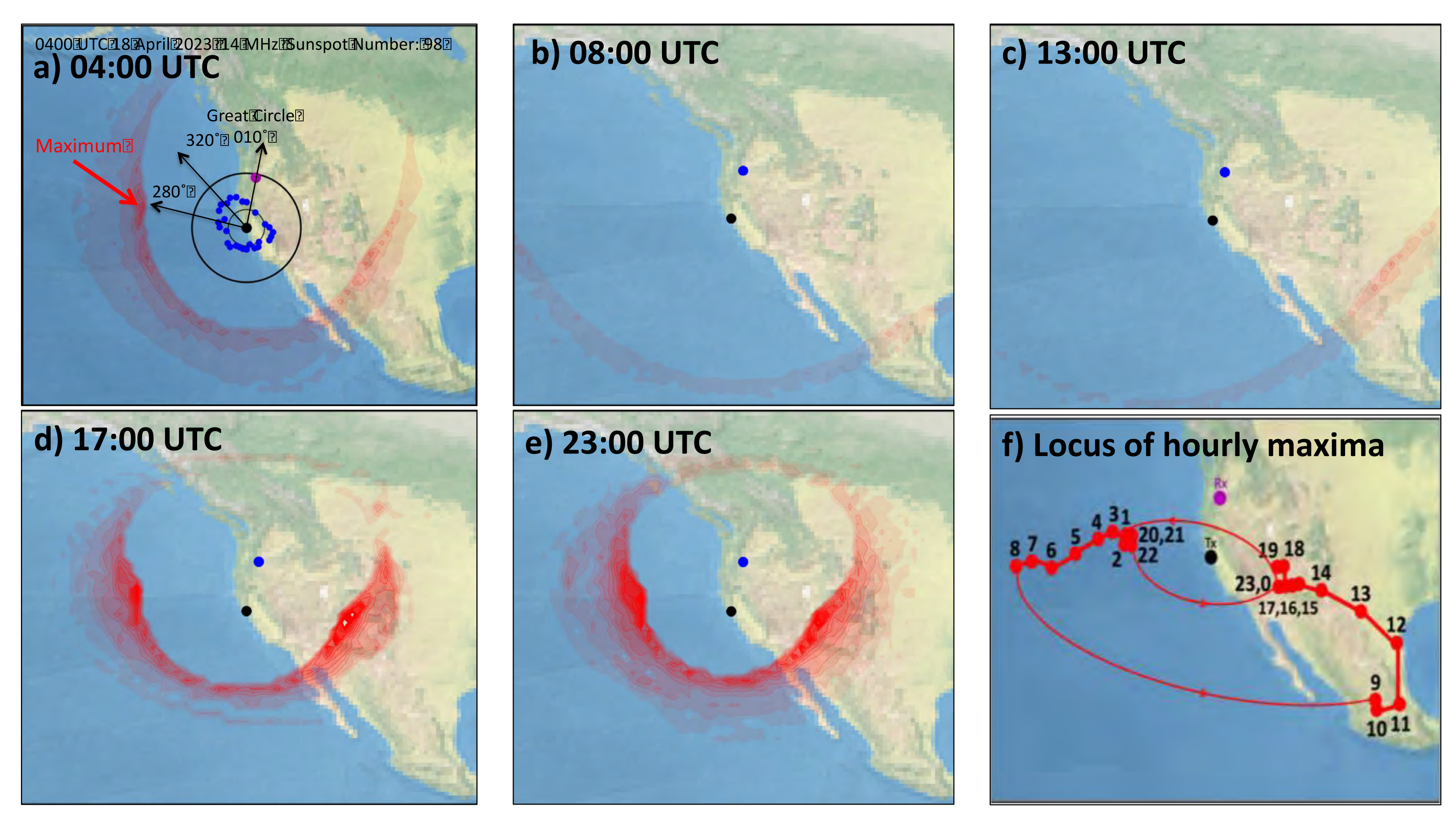

*Fig. 4 Contour plots of 3D ray-trace derived scattering metric showing diurnal variation in strength and location. **4a** superimposes the transmit antenna beam pattern as measured at KK6PR, showing peak response 50˚ CCW of the great circle path. **4f** shows how the location of the modelled maximum moves through a day.*

The broad patterns from the model were present in the diurnal variations of signal level and spot count in hourly intervals at KK6PR, **Fig.5**. However, there were differences of a few hours in timing. Lower signal levels were seen 09:00–14:00 UTC as the thin arc moved from west through south to east. Both measures then increased, but with a dip between 21:00 and 01:00 UTC. With the model showing high to east *and* west the resulting high frequency spread may have reduced decode probability.

Scan QR for 24-hr animation

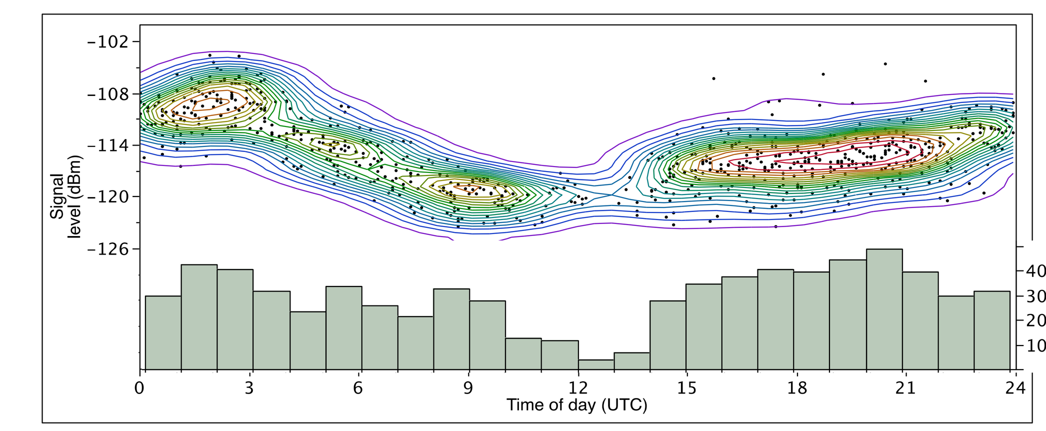

Fig. 5. Signal level and spot count in hourly intervals of 14 MHz WB7ABP transmissions at KK6PR.

The 18 MHz second experiment on 3-4 Feb. 2024 was from KK6PR to log-periodic beam antennas at KFS. As the band opened signals were *only* received from the SE, and, as the band closed, *only* from the SW, **Fig. 6**. At adjacent times signals were received on both antennas, likely via sidelobes, but probably *only* from SE and SW respectively. Signals *were* received during the gap, albeit with reduced circuit reliability, suggesting sidescatter was from SE *and* SW with increased frequency spread.

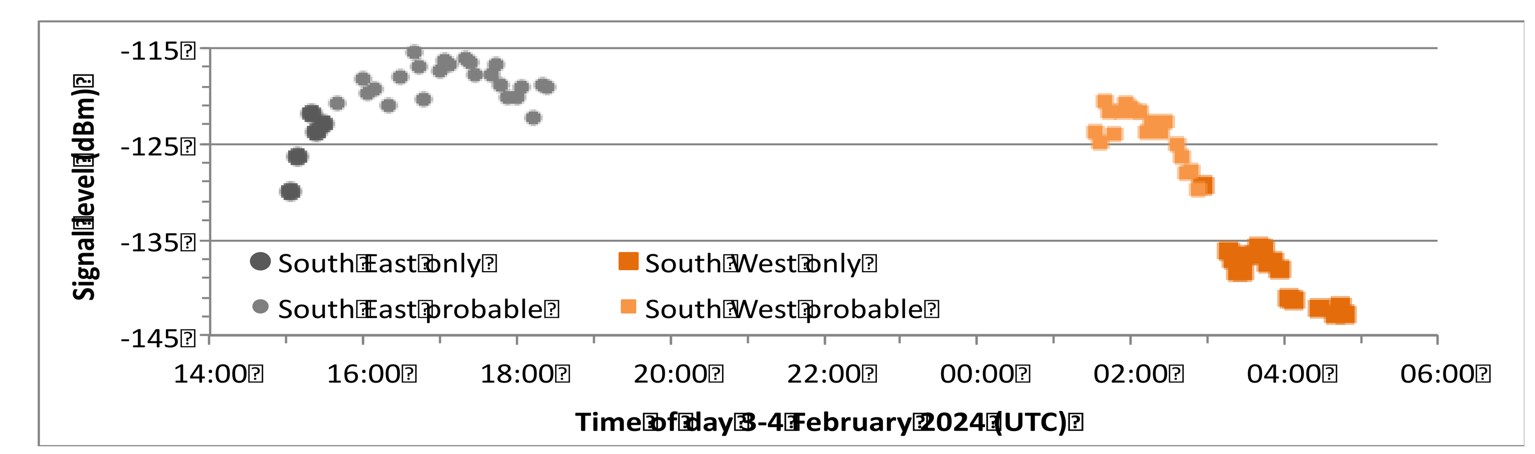

Fig. 6. KK6PR signal level at 18 MHz from beam antennas at KPH: SE (grey) and SW (orange) showing sidescatter from the SE in the morning and SW in the evening.

Conclusion

Sidescatter propagation is an everyday feature at HF enabling communications above the MUF. The simple approach of drawing circles for the skip zone gives an immediate guide to the radio amateur of likely scatter locations to aid antenna orientation. On north-south paths, where there will be east-west ambiguity, we have shown east to be favoured in the morning and west in the evening. When greater detail is needed a computationally efficient approach using PyLap 3D ray-tracing yields scattering likelihood contours. Experiments with rotating and fixed-beam antennas have verified the major trends seen in the ray-trace model. There is much scope for further investigations, e.g. land-sea differences, use of Direction Finding antennas.

References

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