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Near real-time predictions of the arrival at Earth, Mars and Venus of flare-related shocks during the minimum phase (December, 2006) of Solar Cycle 23 and their comparison with multi-spacecraft observations

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Active Region 930, which transited the east limb of the Sun on 5 December, 2006 (S06^o, E79^o), produced an X9 flare on that day, followed on 6 December by an X6, on 13 December by an X3.4/4B, on 14 December by an X1.5/2B and on 17 December by a C2 event. Although the disturbance associated with the X9 flare of 5 December 2006 and its accompanying CME were not expected to have a large impact at Earth, the CME activity associated with the X6 flare on 6 December was expected to cause major geomagnetic storm activity late on 8 December and on 9 December. As the active region continued to rotate across the disk, additional flaring gained an increasing potential to produce disturbances at the Earth. The event of 13 December produced strong radio blackouts (R3) and an associated moderate (S2) solar radiation storm. A large Earth-directed coronal mass ejection was associatively observed and its shock, which was predicted to arrive at L1 at 14.00 UT on 14 December, 2006 was observed at 13.56 UT on that day. Strong related geomagnetic storming and proton energetic bombardment occurred and endured until 16 December in association with the events of 13 and 14 December. As the active region transited the west limb, a slow moving CME which was released from above the SW limb on 17 December displayed similar timing to, and may have been associated with the C2 flare. The arrival times at Earth, Venus and Mars of flare-related shocks identified exiting the Sun (using metric radio drift data) were forecast in near-real time using the Hakamada-Akasofu-Fry Model (version-2/HAFv.2). These predictions are compared with available data showing the arrivals at L1, Mars and Venus of shocks recorded in plasma and magnetic data/complementary responses in other relevant data sets aboard the ACE, SOHO, Mars Express, Venus Express and GOES spacecraft. The utility of the three-dimensional multi-event capabilities of the HAFv.2 model are discussed in terms of the agreement obtained between the predicted and observed arrival times. Also, the influences exerted by prevailing interplanetary conditions, spatial locations and the interactions between shocks in determining the outcome at individual planetary targets are discussed having regard to the prevailing geometry.