Atmospheric Impacts on EDL Maneuver Targeting for the Insight Mission and Unguided Mars Landers

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Problem: Maneuver Design Sensitivity to Atmosphere Updates

- NSYT discovered that small updates in atmosphere knowledge, based on real-time MRO measurements, can cause large, unexpected fluctuations in the final trajectory correction maneuver (TCM)

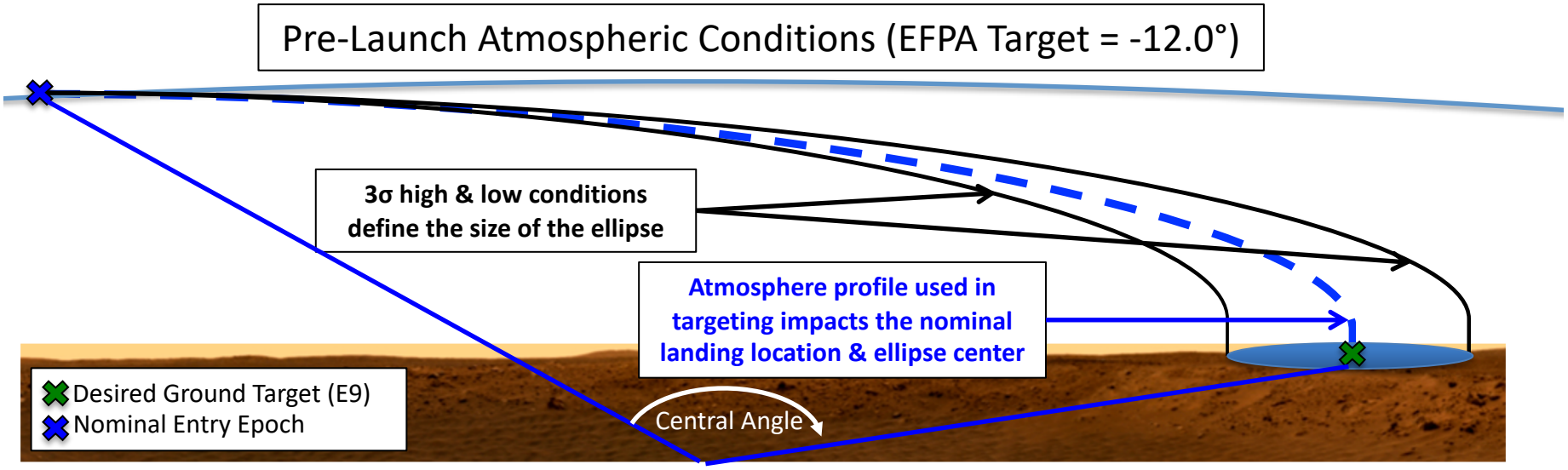
- Navigation uses an iterative targeting process to design TCMs
  - The process used ensures the landing location of the nominal EDL trajectory hits the desired ground target (latitude and longitude)

- The iterative process adjusts entry time but keeps both entry flight path angle (EFPA) target and ground target fixed

- Updates to the nominal atmosphere change the central angle of the nominal EDL trajectory
  - Changes to central angle result in large entry time deltas and very large TCMs at the final maneuver

Simplified Explanation of Maneuver Targeting Process

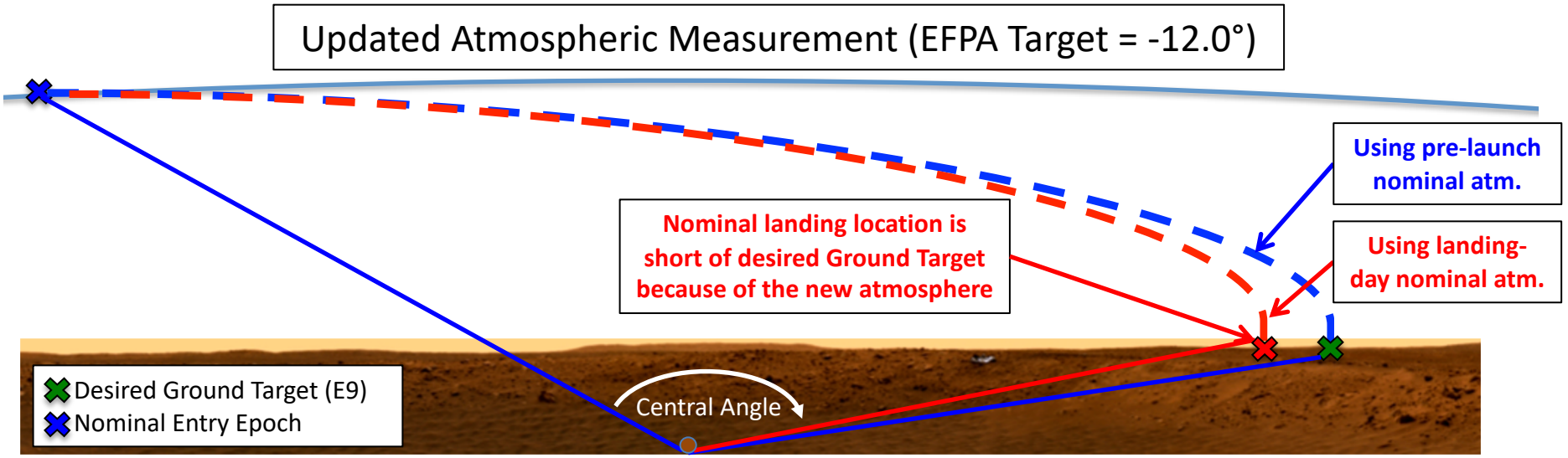
- Navigation designs a maneuver that targets the desired Ground Target with a specific Entry Flight Path Angle (EFPA) Target through an iterative process
  1. The nominal trajectory is integrated and the nominal landing location is compared to the desired Ground Target
  2. The entry epoch is adjusted so the nominal landing location of the nominal trajectory will hit the desired Ground Target
  3. Steps 1 & 2 are repeated until we hit the Ground Target at step 1



For a fixed EFPA, the arc flown through the atmosphere (central angle) is always the same

Impacts of Updating the Atmosphere

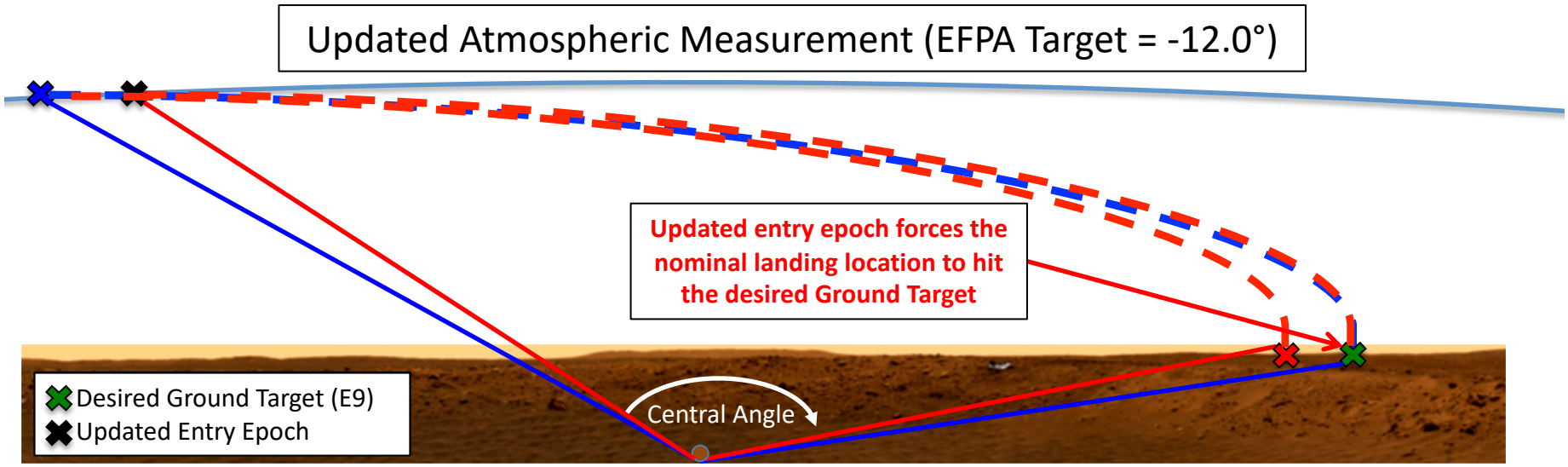
- Atmosphere measurements from MRO are used to update the atmosphere model prior to EDL
- Updating the atmosphere model changes the central angle of the nominal trajectory and *directly impacts the targeting scheme*
  - Changes to the nominal trajectory shifts the nominal landing location



Shift can easily be 10 km or more (in the case of a dust storm)

Option 1: Allow Entry Epoch to Vary

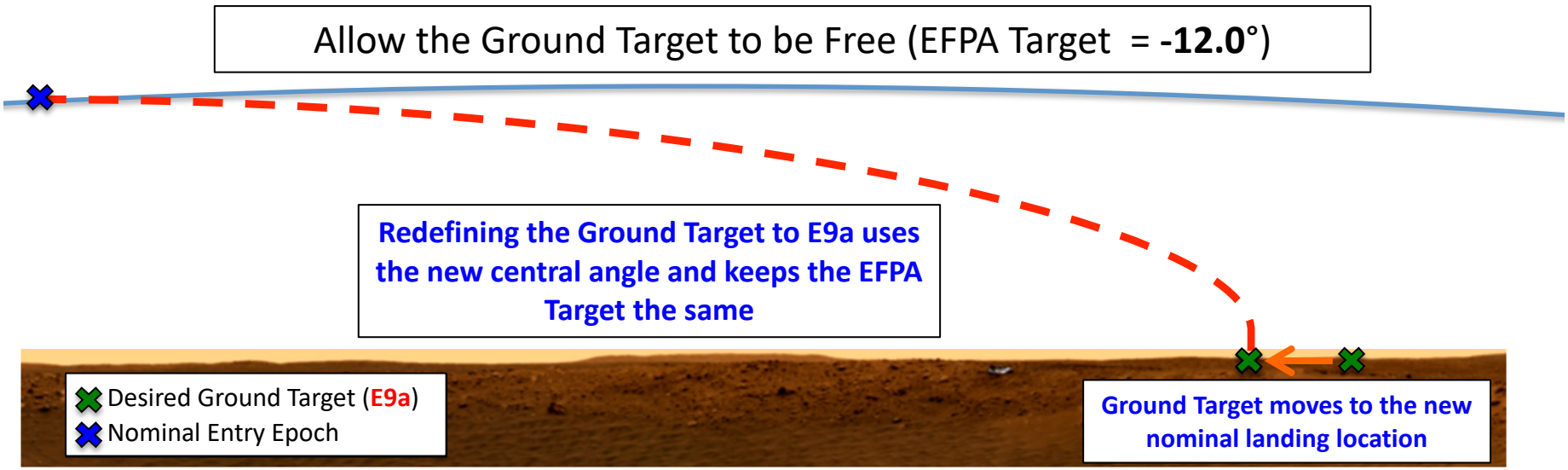
- Does not restore the central angle
- Changing the entry time at final TCM is expensive
  - Increases TCM-6 ΔV well beyond our current 99% (as much as 5-10 times larger)
  - The increase would result in a much larger landing ellipse than LSS had planned for
  - Entry time change is very sensitive to miss distance on the ground (bad for EDL Comm)



Option 2: Allow Ground Target to Move

Ground Target Tolerance

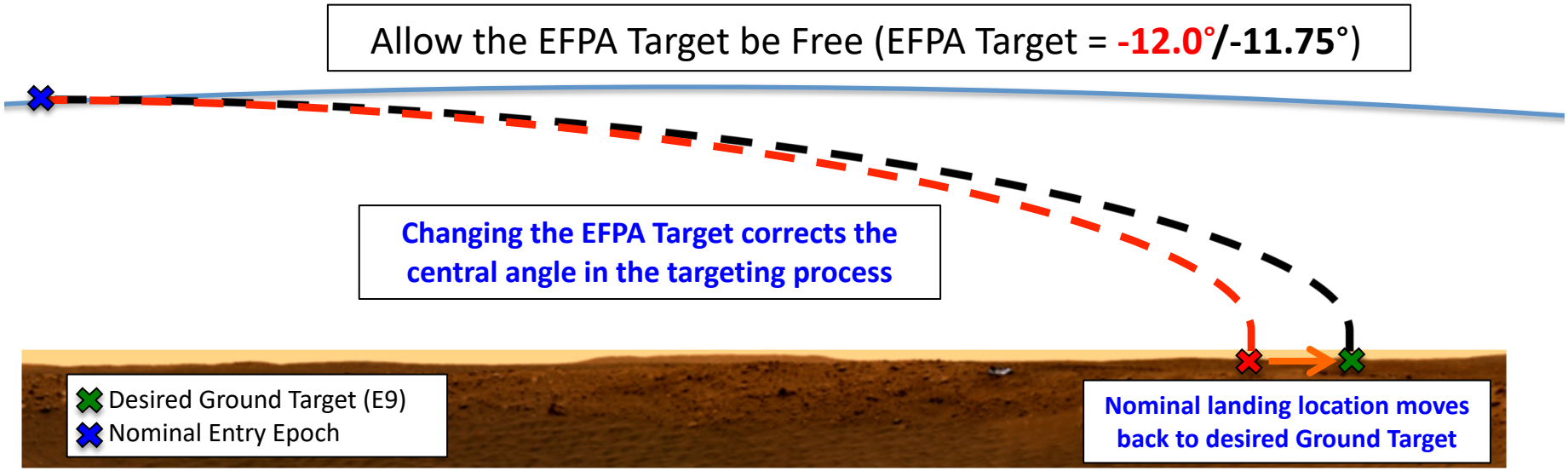
- Does not restore the central angle
- Zero ΔV cost
  - Essentially ignores the atmospheric update and allows the nominal trajectory land wherever the new atmosphere puts us on the ground
- Negative impacts to landing site selection (increases the required size of acceptable area)



Option 3: Allow Entry Epoch to Vary

EFPA Target Tolerance

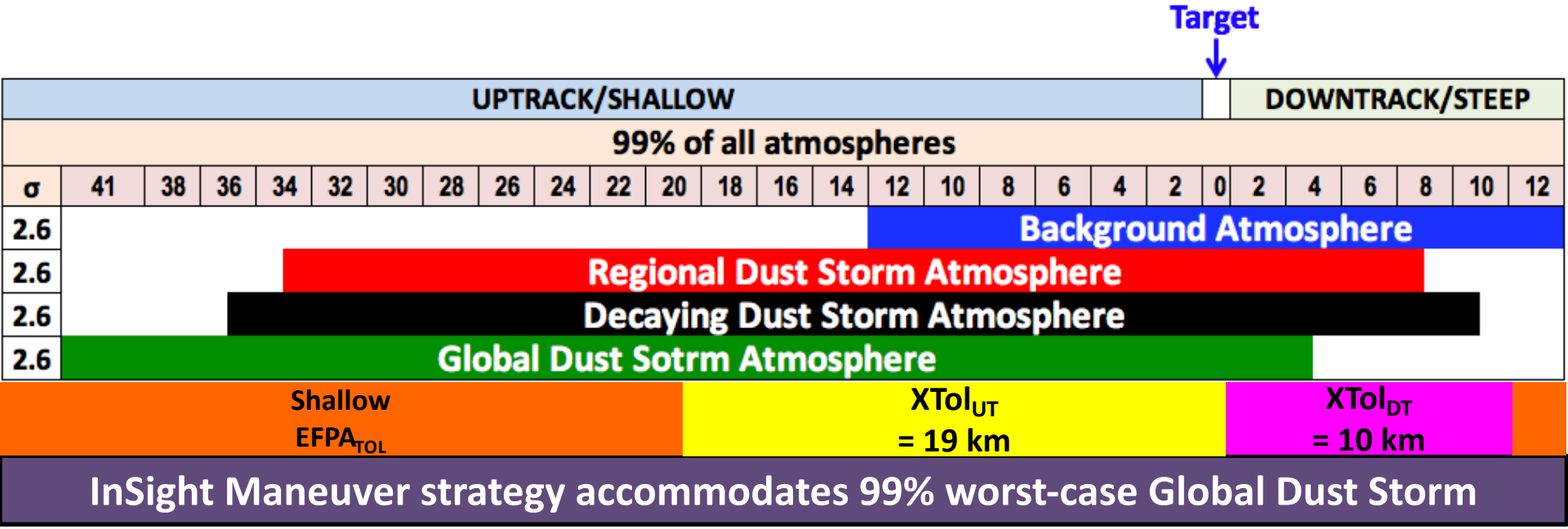
- *Does* restore the central angle (entry epoch *and* ground target unchanged)
- Very minimal ΔV impact (<5 cm/s at final TCM)
- Modifying the EFPA target changes the carefully-chosen balance of margins



InSight opted to used EFPA and ground target tolerance to minimize costly changes to the entry epoch

NSYT Targeting Strategy to Account for Atmospheric Updates

- InSight defined separate ground target tolerances in the downtrack/clear ($Xtol_{DT}$ = 10 km) and in the uptrack/dusty directions ($Xtol_{UT}$ = 19 km)
- The team also used an EFPA target tolerance ($EFPA_{TOL}$) of ±0.15° about the desired nominal EFPA (-12.0°)
- The EDL-Nav team assesses the new atmosphere and…
  - Uses the ground target tolerance first to define a new ground target
  - In extreme cases we will use both ground target and EFPA target tolerances (i.e. Nav would target an EFPA between -11.85° and -12.15°)

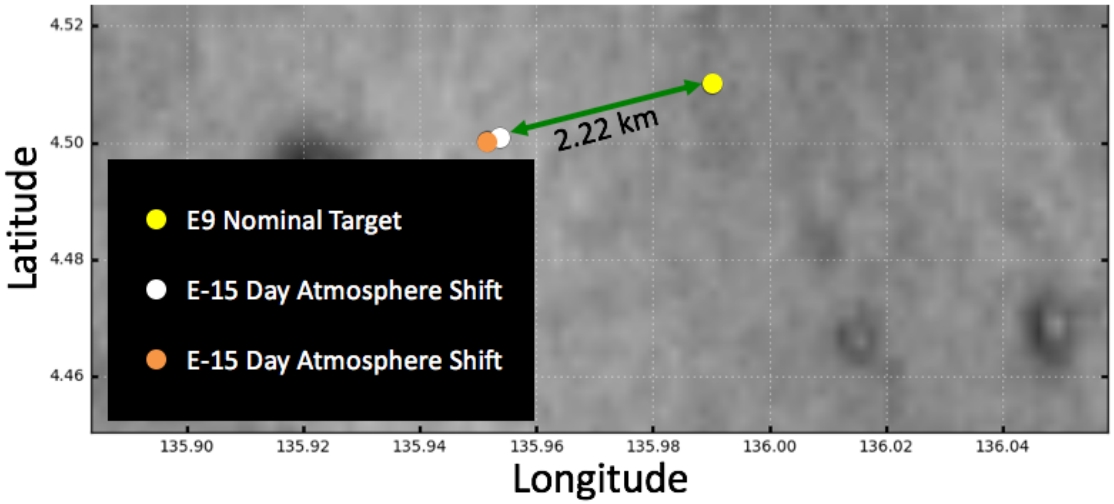


InSight Maneuver strategy accommodates 99% worst-case Global Dust Storm

InSight Operations

- Actual landing day measurements were pretty benign compared to worst-case scenarios
- Shifts were on the order of 2-3 km

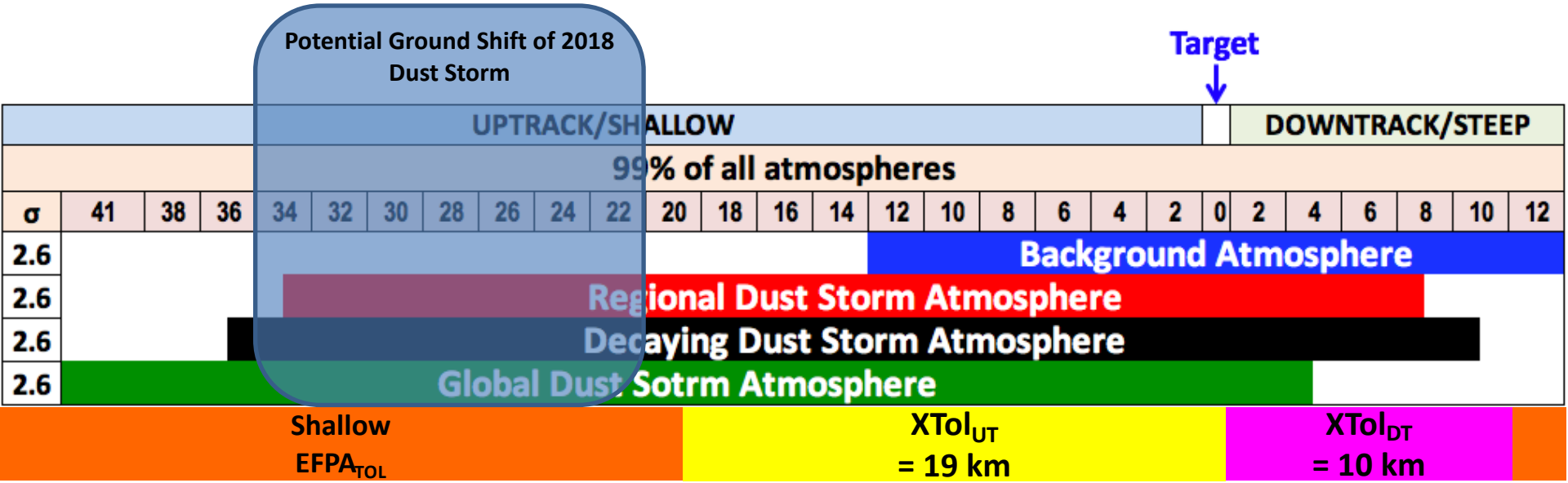
Atmosphere Model	Ground Shift Relative to E9 Landing Target	Shift Direction	Date Released
Background	0 km	N/A	Pre-Launch
E15	2.22 km	Uptrack	11/12/18
E7	2.35 km	Uptrack	11/20/18



But what if the 2018 Mars global dust storm occurred closer to our landing epoch???

2018 Martian Global Dust Storm

- A global dust storm began on Mars in June 2018 and subsided by October 2018 (1 month prior to EDL)
- Had the storm started a few months later, the plan for dealing with atmospheric changes would have had a much greater impact to operations
- Best guesses are the shift would have been in the 20-35 km range
  - Ground target would have shifted by 19 km and EFPA target would have been close to -11.95° To -11.9°.



Conclusions

- This is a real issue for any lander that updates their atmosphere based on real-time measurements, and which doesn't have guidance.
  - Even if you ignore it the affect in targeting, the bias will show up in the placement of the landing ellipse.

- EDL missions that plan to use real-time measurements to assess EDL performance should understand the influence to maneuver targeting and make sure requirements are written to accommodate these impacts.

- Without a plan to address this issue, the InSight project would have been taken by surprise had the 2018 global dust storm intersected with our arrival at Mars.