Quantifying the effect of CME removal on in-situ solar wind data assimilation

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Outline

Background

- ★ Solar wind
- ★ Data assimilation

Recent work

- ★ Using BRaVDA for solar wind forecasts
- ★ Removing CMEs

Future work

Conclusions

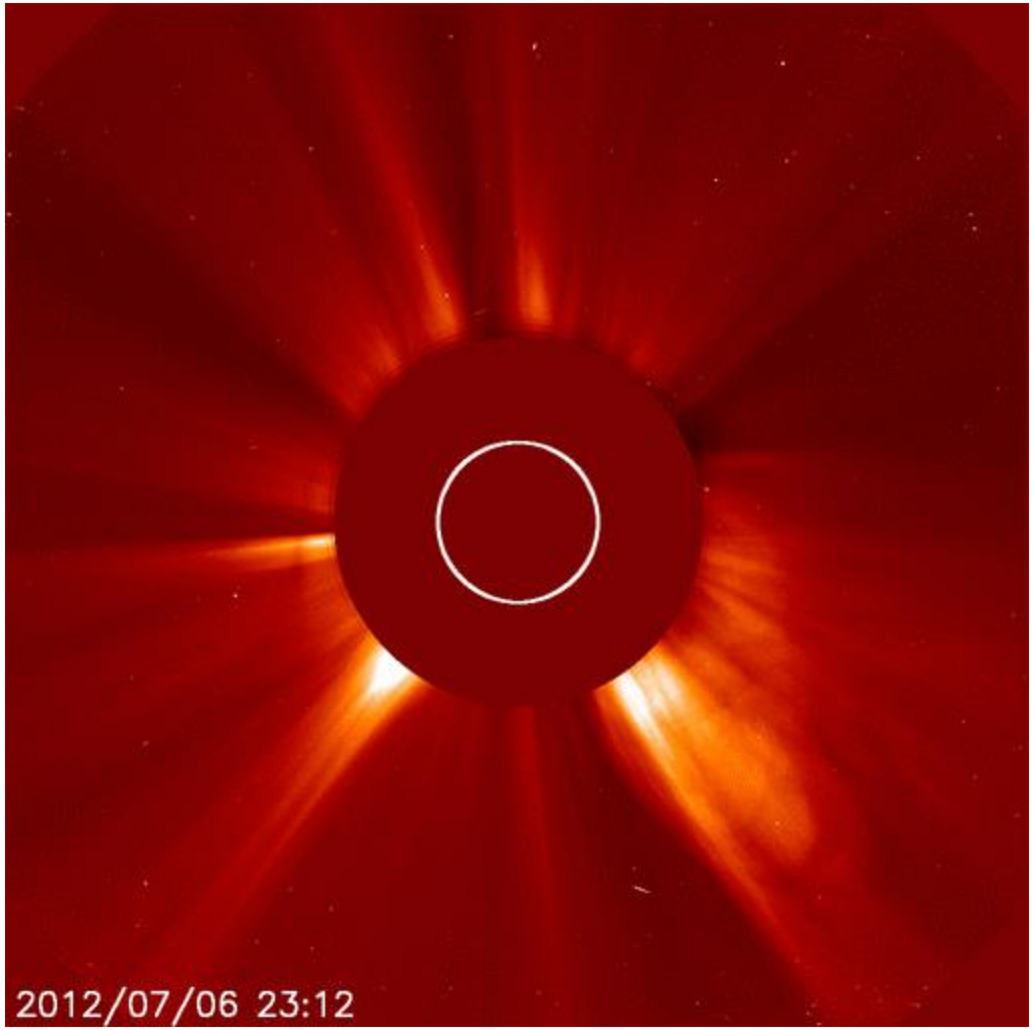
Background

The solar wind

- Continual emission of plasma from the Sun's surface
- Accelerates out into the solar system
- Comprised mostly of protons and electrons
- Solar activity varies over ~11 year cycle
  - Minimum and maximum phases

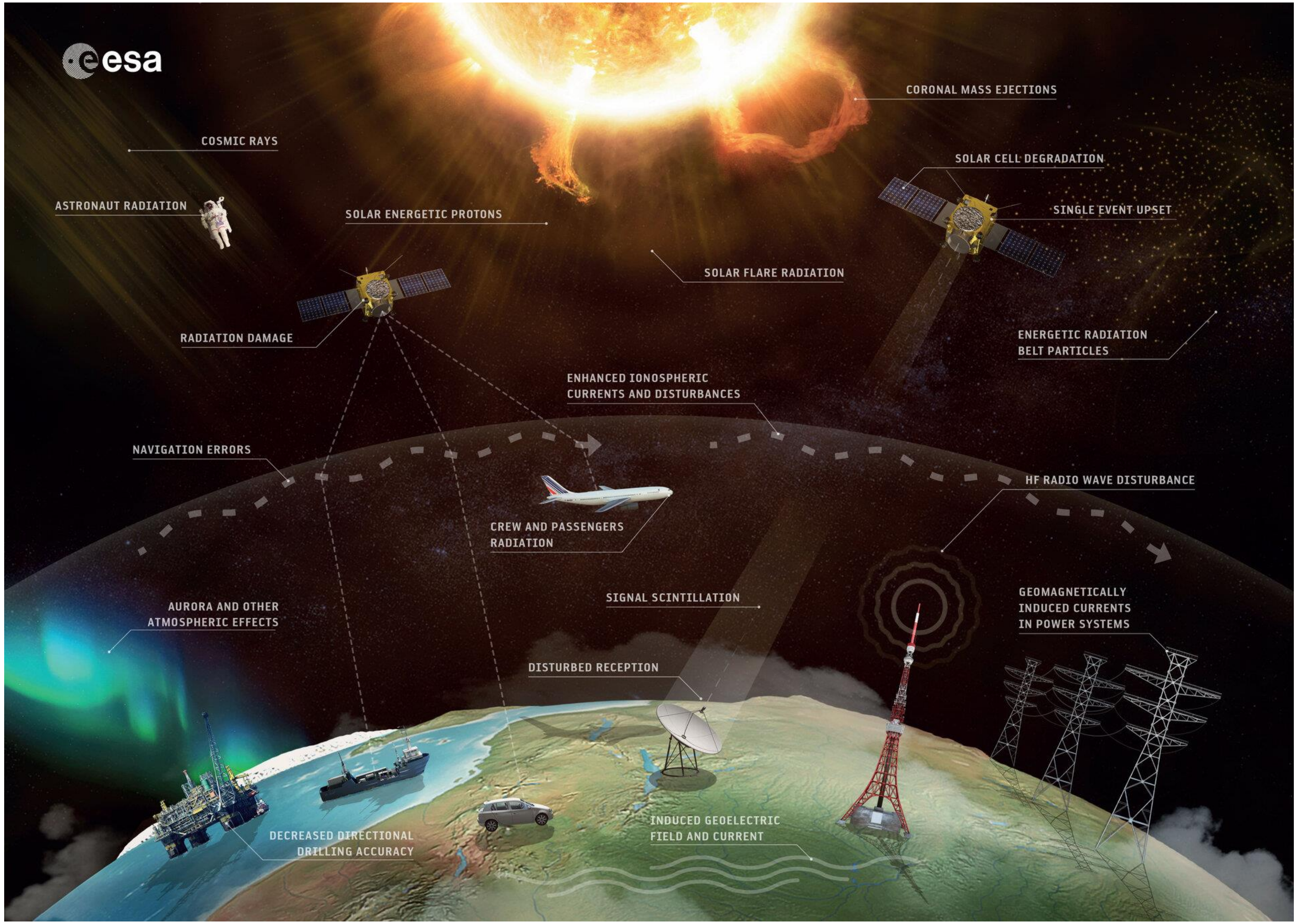
Coronal mass ejections (CMEs)

- Coronal mass ejections (CMEs) – eruption of material and radiation
  - Propagate through the solar wind
  - Need to know solar wind conditions to help mitigate CME impact
- Main driver of most severe space weather events



Source: NASA/ SOHO

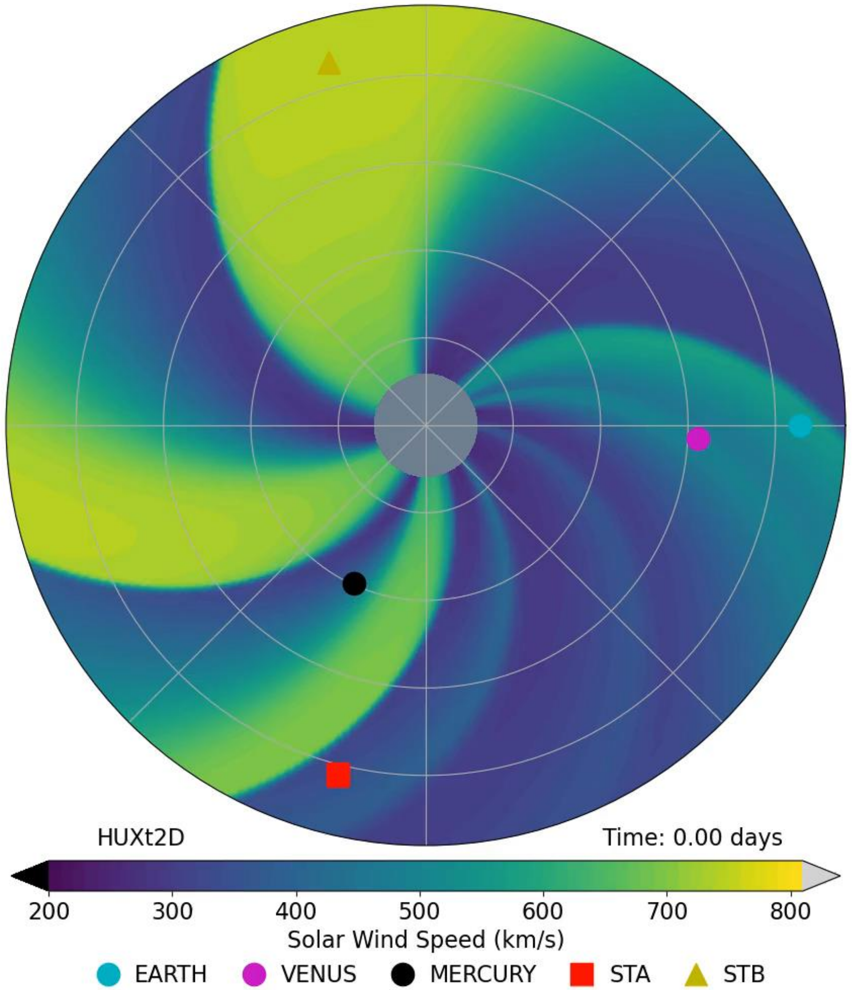
Space weather impacts



Source: ESA

Solar wind structure

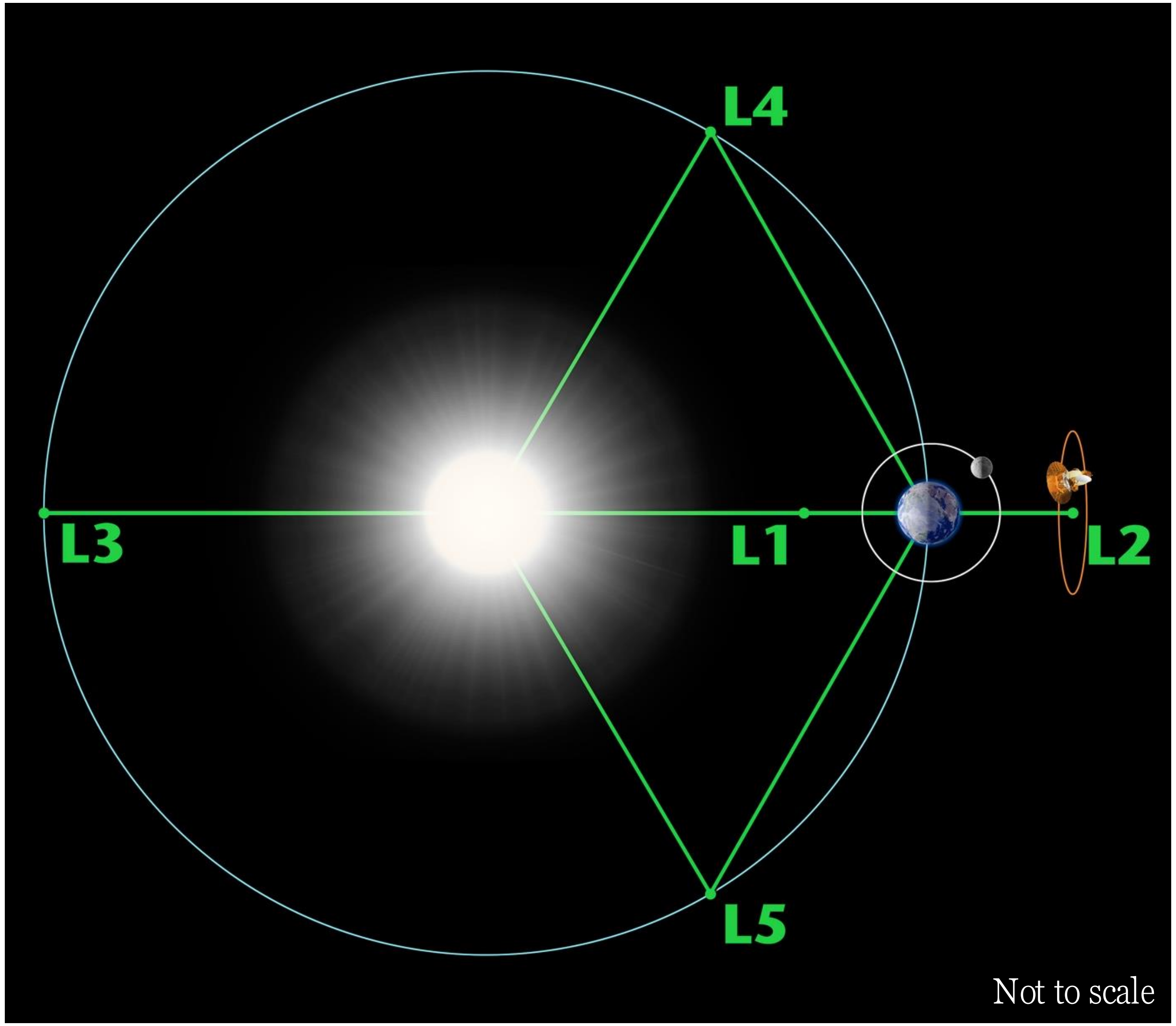
- Sun rotates in 27 days as viewed from Earth
- Bi-modal property – fast and slow wind
  - Fast wind greater than 600 km s^{-1}
  - Slow wind around 300 km s^{-1}
- The Sun's rotation pulls its magnetic field into an Archimedean spiral
- Solar wind flow is radial



Animation source: HUXt Solar wind model, Owens et al. (2020)

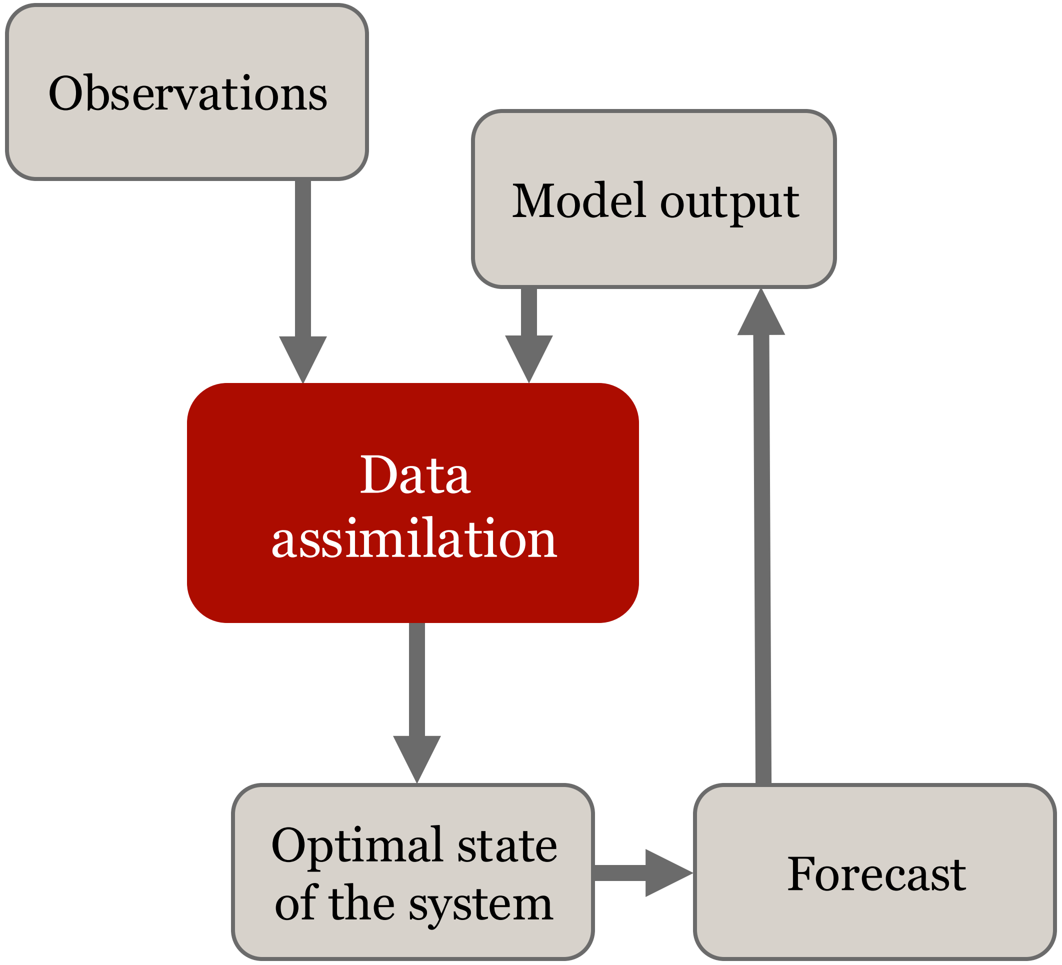
Current forecasting

- Coupled coronal and solar wind models
  - Coronal models based on empirical relations – Suns surface to 30 R_s
  - Magnetohydrodynamic (MHD) model – 30 R_s into the solar system
- Limited warning from L1 spacecraft
- Current forecasting has no observational constraints after 30 R_s



Data assimilation

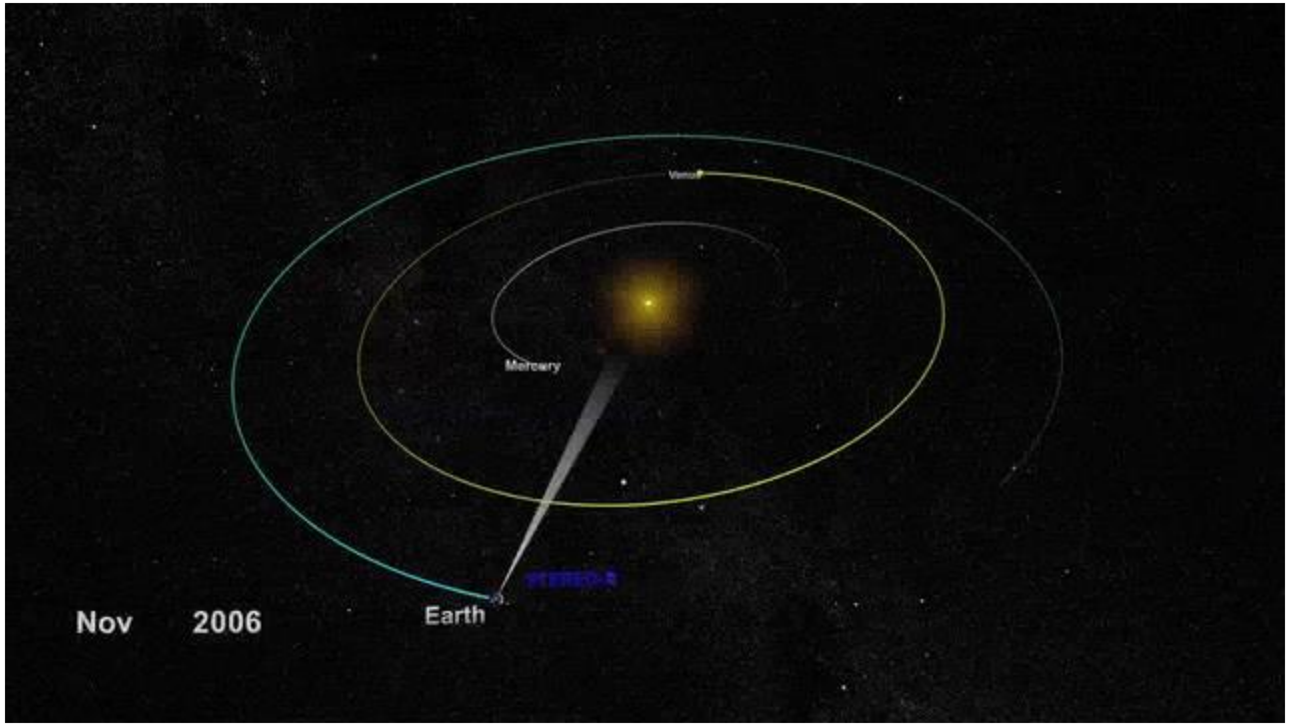
- Combining model output and observations to form an optimum estimation of reality
- Led to large improvements in terrestrial weather forecasting
- Under used in space weather forecasting



Recent work

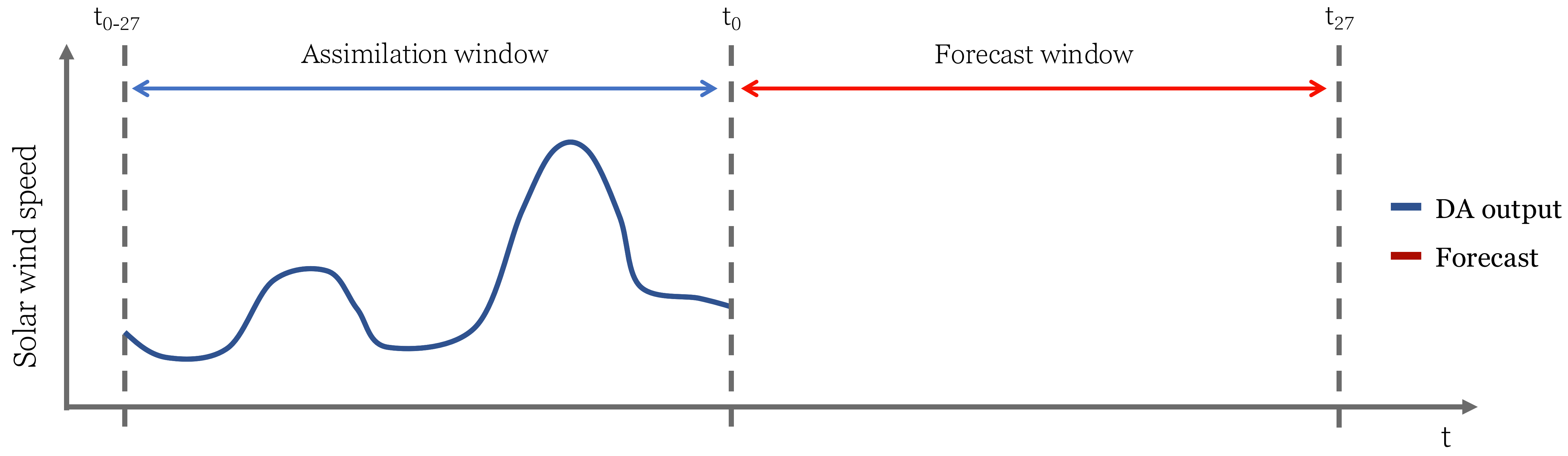
BRaVDA scheme

- Burger Radius Variational Data Assimilation scheme (Lang and Owens, 2019)
- Uses solar wind propagation model and observations from STEREO spacecraft and OMNI dataset
  - 3 sources of observations
  - Spacecraft observations can be assimilated together or individually
- Reconstructs solar wind in 27-day windows from 30 to 215 R_s

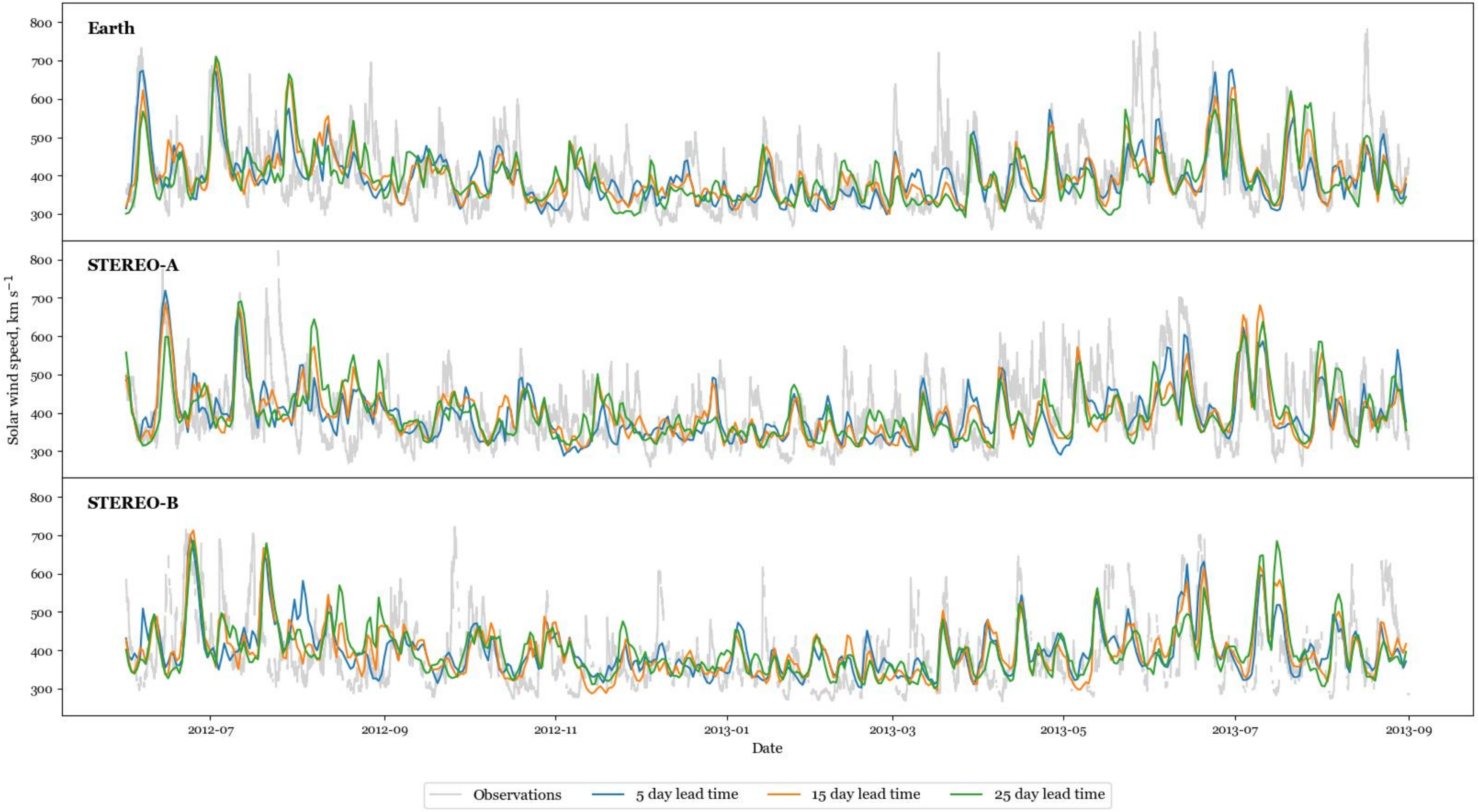


Solar wind forecasts from BRaVDA

- Using the 27-day reconstruction, this can be used to forecast the next 27 days
- Forecasts for Earth, STEREO-A and STEREO-B



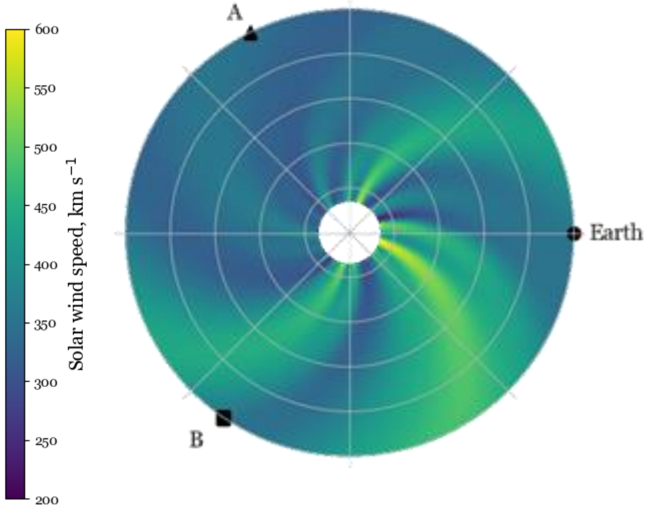
Forecast verification



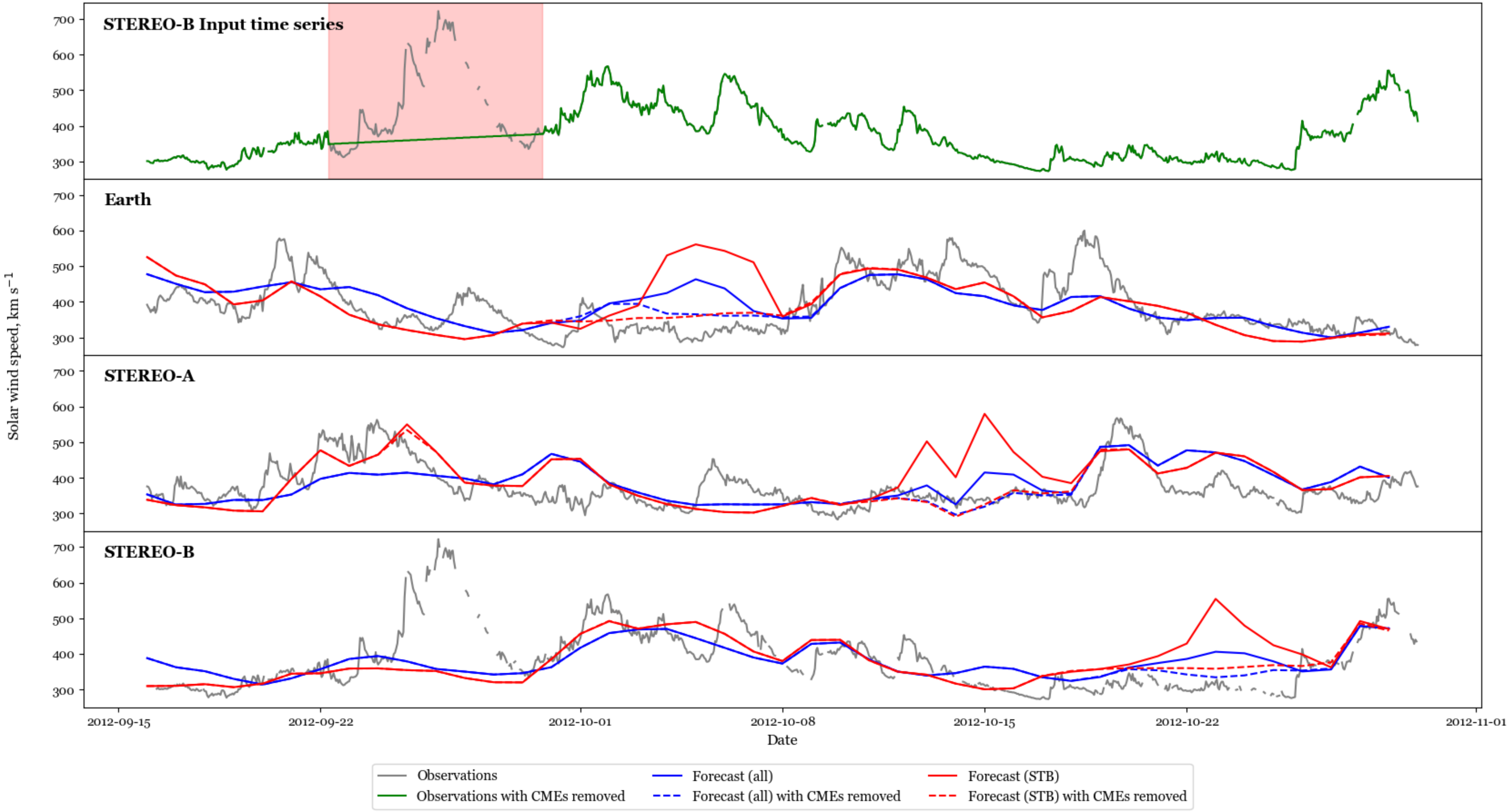
CME removal

- BRaVDA has no knowledge of CMEs, so observations are treated as the steady-state solar wind
- CMEs could produce false streams in the solar wind reconstruction or false alarms in the forecast
- Removed from the DA input time series and linearly interpolated over

CME removal



Solar wind speed, km s^{-1}
600
550
500
450
400
350
300
250
200
A
B
Earth



STEREO-B Input time series
Earth
STEREO-A
STEREO-B
Solar wind speed, km s^{-1}
700
600
500
400
300
2012-09-15
2012-09-22
2012-10-01
2012-10-08
2012-10-15
2012-10-22
2012-11-01
Date
Observations
Observations with CMEs removed
Forecast (all)
Forecast (all) with CMEs removed
Forecast (STB)
Forecast (STB) with CMEs removed

Future work

- Looking at the impact of observational age
- All experiments have been with science-level data
- Testing the performance of BRaVDA with real-time data
  - Required for operational deployment

Conclusions

- Solar wind forecasting required to mitigate impacts on Earth
- Data assimilation is in early development stages for space weather forecasting
  - Our implementation has improved solar wind forecasts
- Looking at 3 years of forecasts, removing CMEs improves forecast accuracy
- Better to assimilate multiple spacecraft observations rather than single spacecraft observations
- Moving towards using real-time data

Thank you

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References

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