A neural-network-based forward model to improve air quality estimation from spaceborne polarimeters

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***Client**: NASA Langley Research Center*

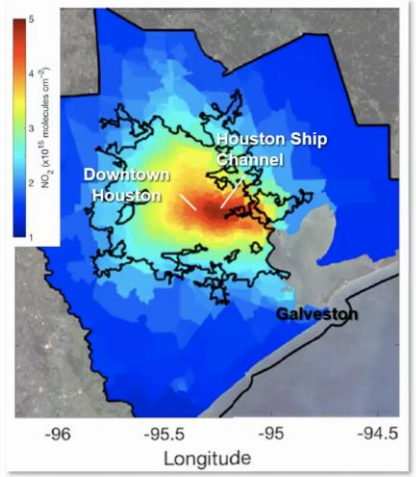
Introduction and Background

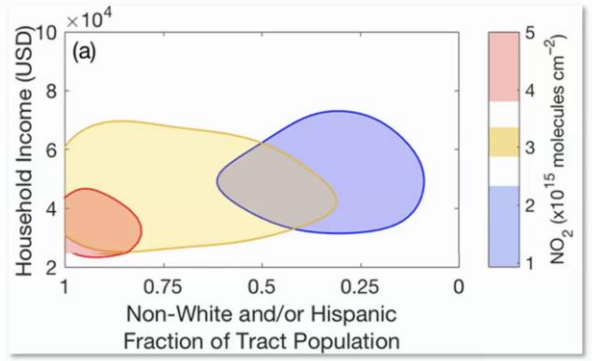
- Project goal: accurately and efficiently retrieve surface-level PM2.5 from satellite polarimeter and lidar measurements
  - PM2.5 is the mass-concentration of any particles in the air 2.5 microns or less in diameter (pollution & natural sources)

- The polarimeter satellite remote sensing retrieval problem is an *inverse problem*:
  - Optimal estimation inverts satellite polarimeter data (the output, or the measurements) into aerosol and ocean properties (the input, or the state vector)
  - Optimal estimation requires iteratively calling NASA's vector radiative transfer forward model (accurate but has a significant computational burden)

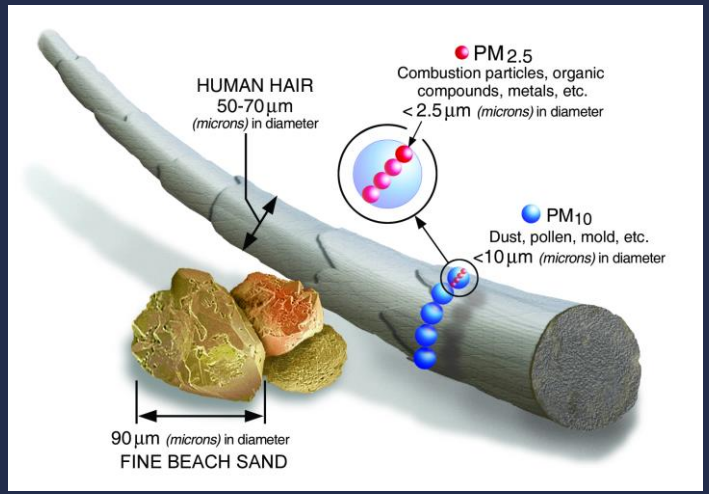
- Solution: Train an accurate and fast neural network to simulate PARASOL polarimeter measurements to replace the forward model and operationalize retrievals of aerosol properties and PM2.5

Pollution Disproportionately Impacts Low-Income, Non-White, and Hispanic Neighborhoods in Houston, TX





Demetillo**, M. A. G., Navarro, A., Knowles, K. K., Fields, K. P., Geddes, J. A., et al (2020). Observing nitrogen dioxide air pollution inequality using high-spatial-resolution remote sensing measurements in Houston, Texas. *Environmental Science & Technology, 54*(16), 9882–9895. https://doi.org/10.1021/acs.est.0c01864 **FINESST proposal



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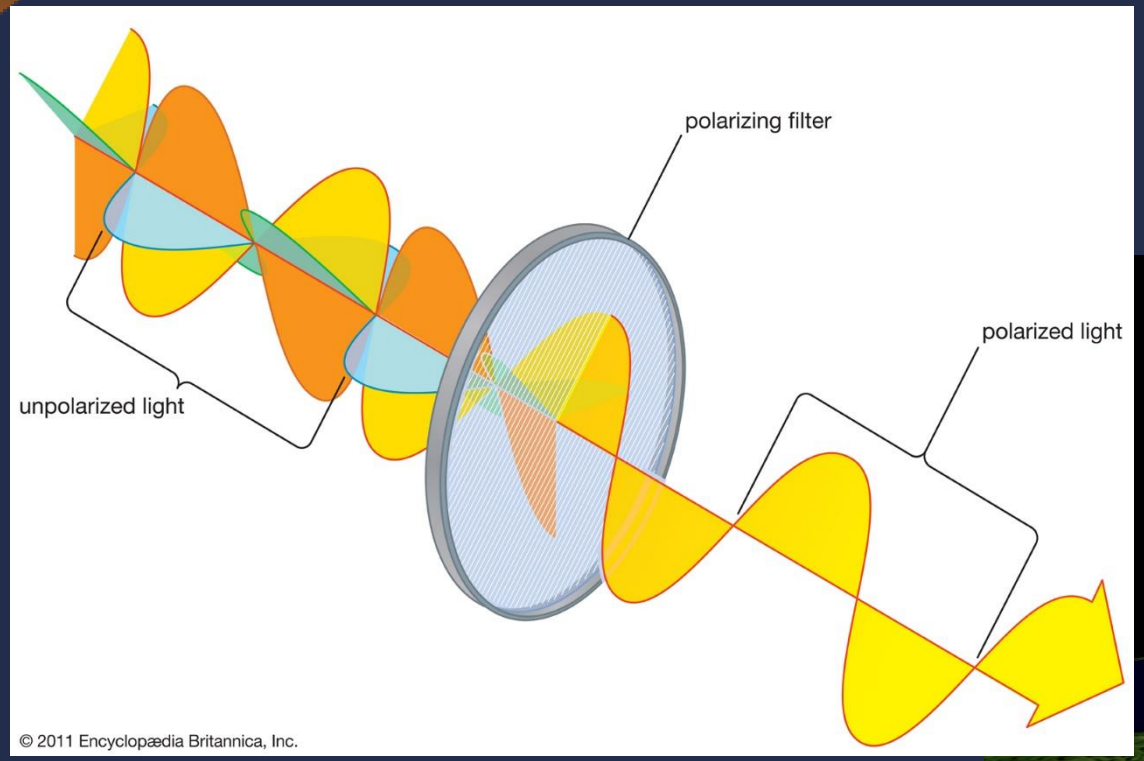
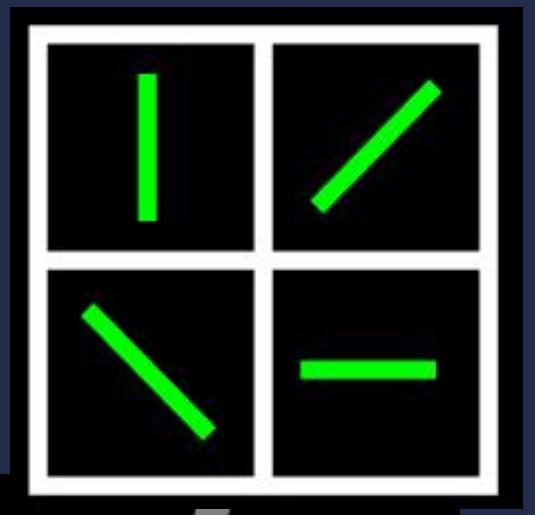
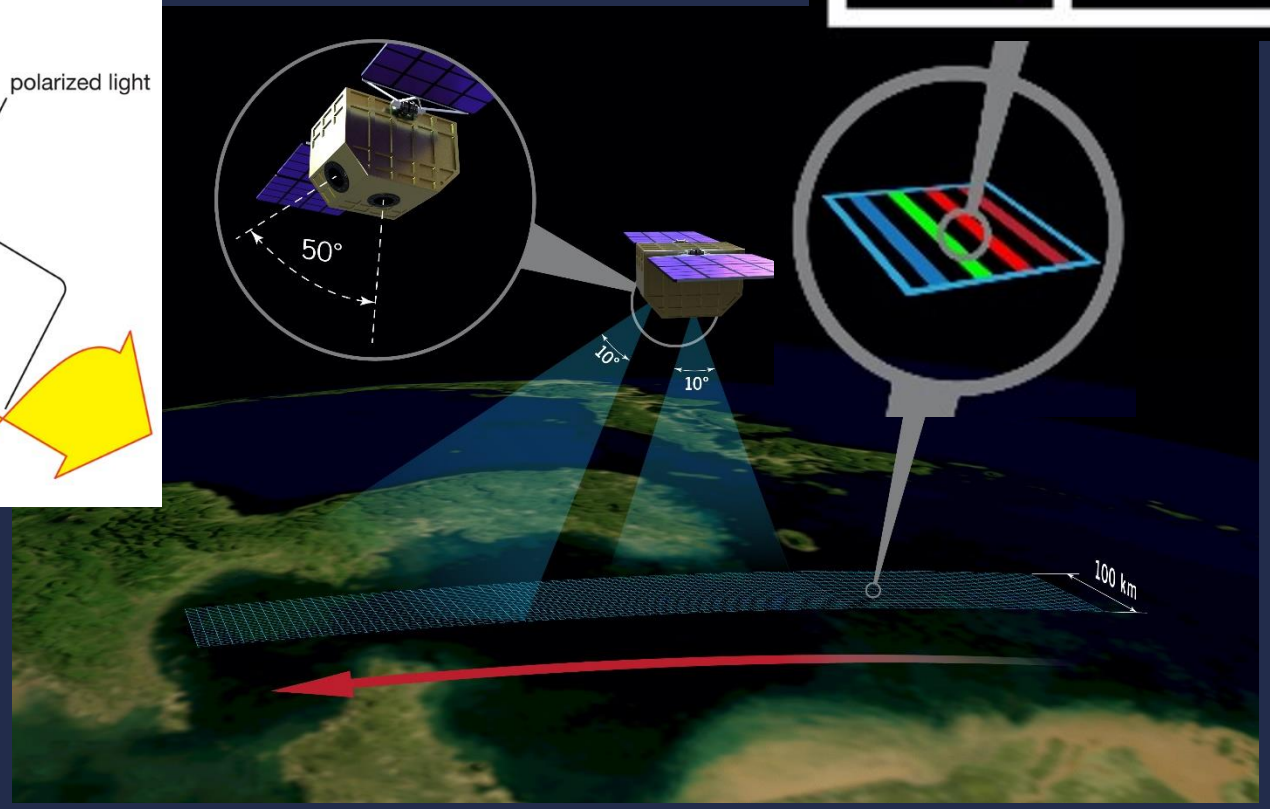
Satellite Polarimeters

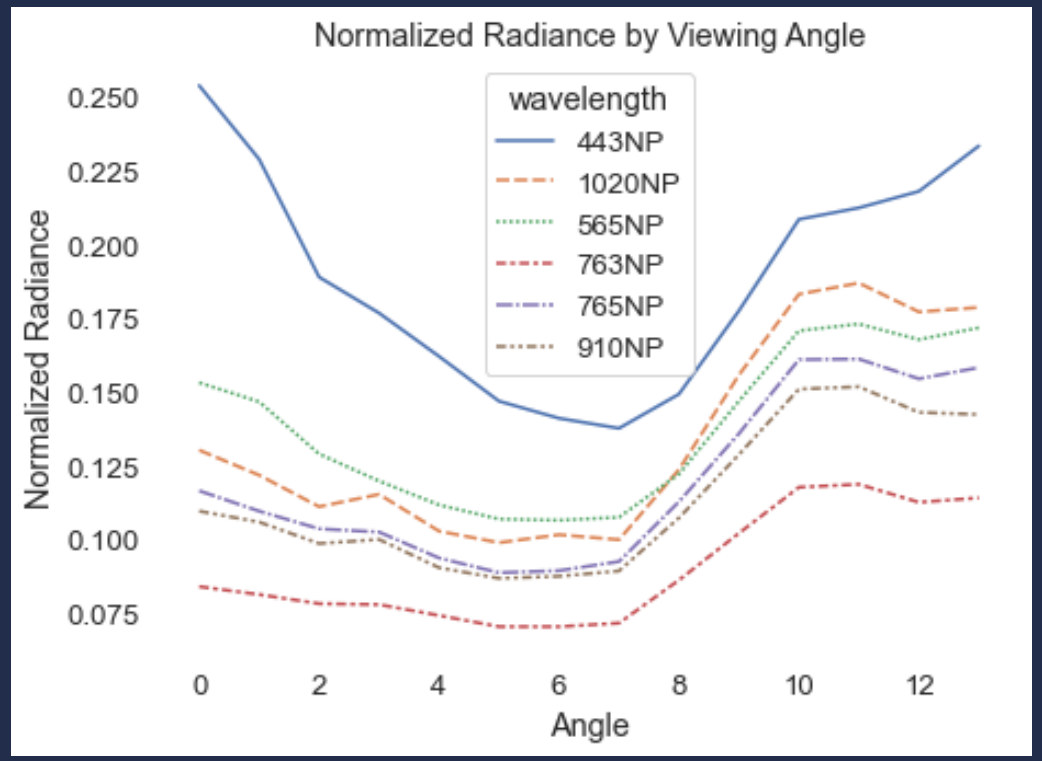


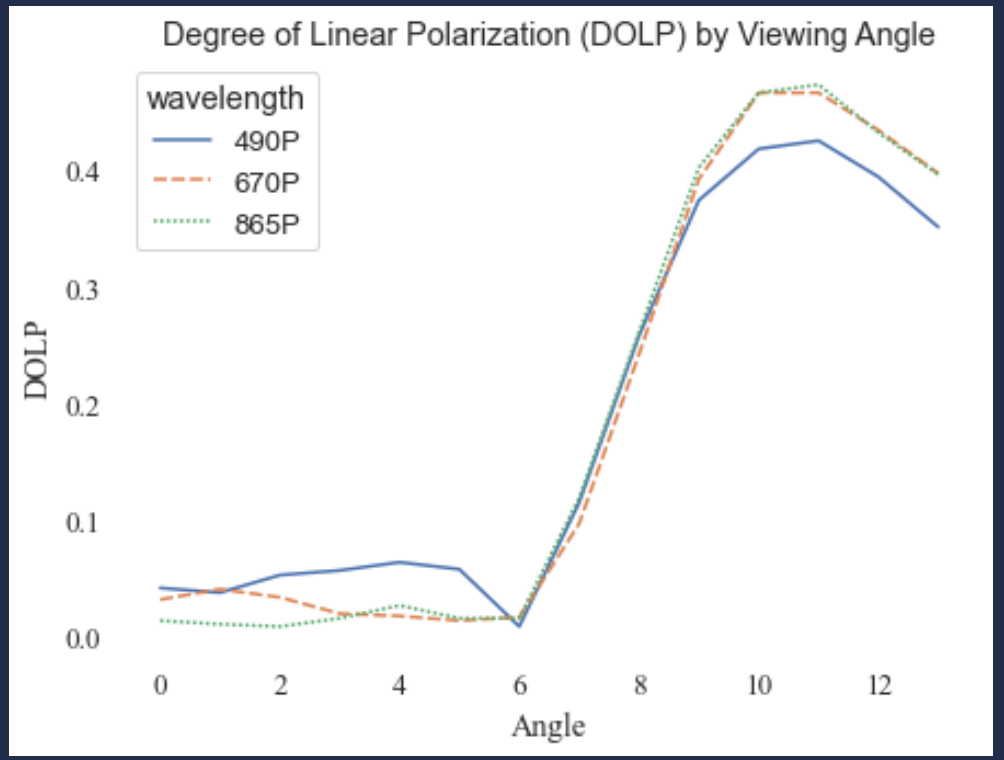




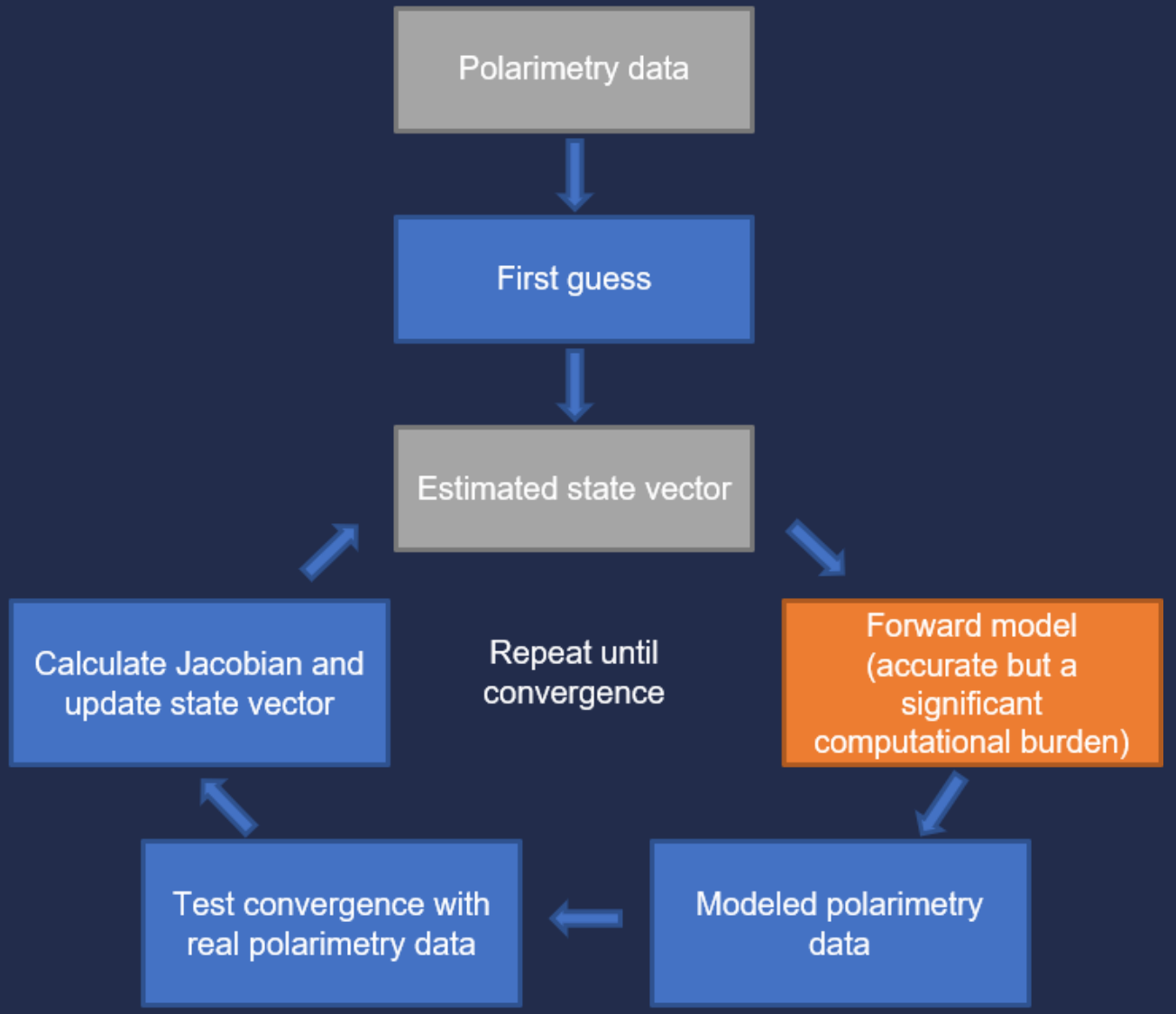
Data Description

- The University of Lille stores large volumes of satellite polarimeter data through ICARE
  - The data include spaceborne measurements at multiple wavelengths for a wide range latitude/longitude values and are stored in HDF files.

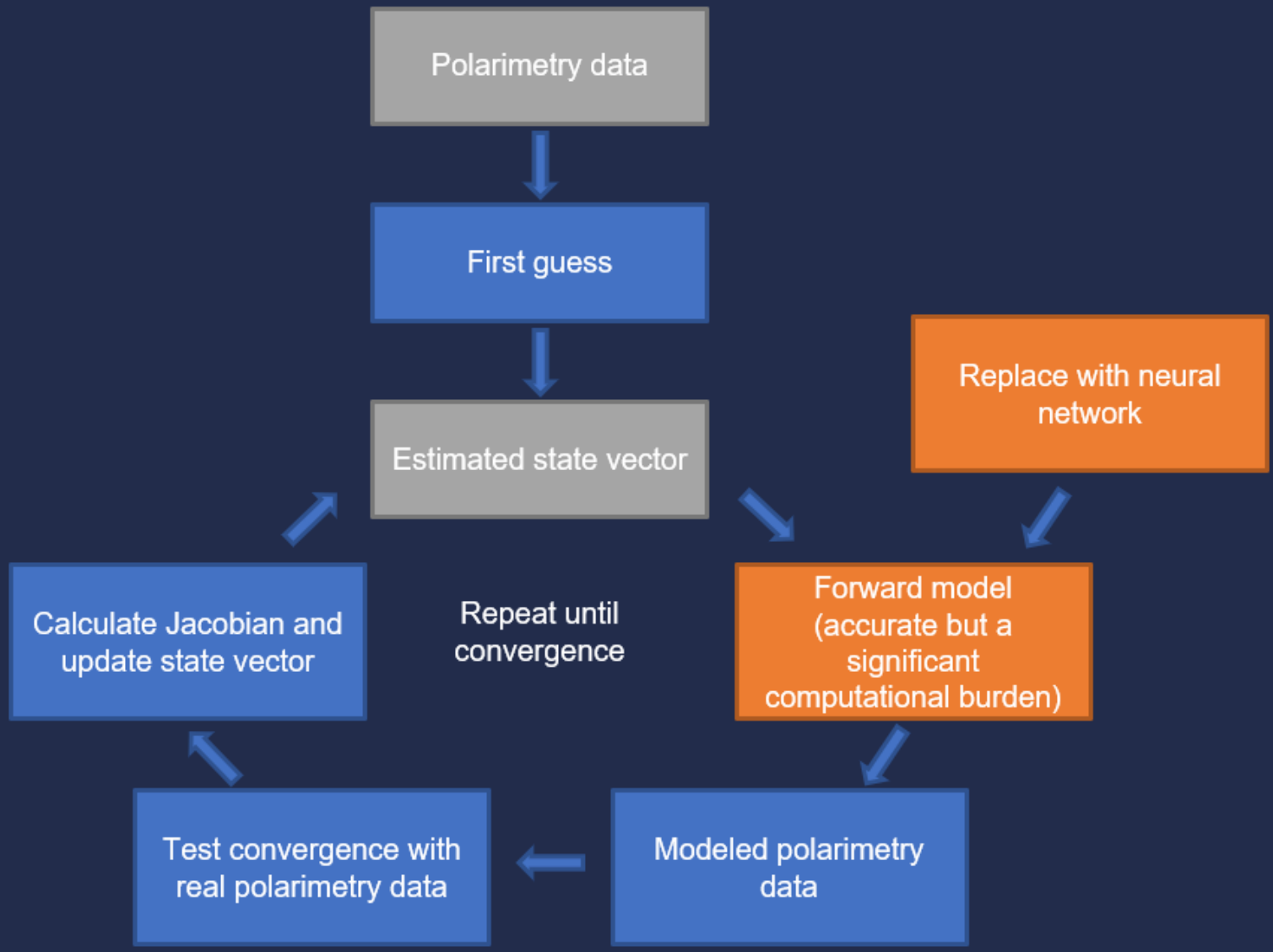




Retrieval Algorithm



Retrieval Algorithm



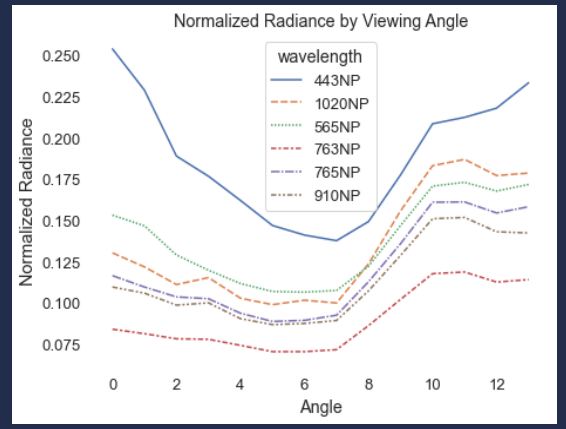
Methodology

- Simulating training dataset
  - Problem: Real data contain only measured polarized radiance, not state vectors
    - Retrieval of sufficient amount of state vectors with real data is prohibitively inefficient
    - Difficult to ensure sufficient state vector diversity
  - Solution: simulate data by sampling state vector values from physically representative distributions and then run the forward model to estimate spaceborne polarimetric measurements
- Neural network design and training
  - Sufficiently complex for accuracy but drastically reduces the computational resources required

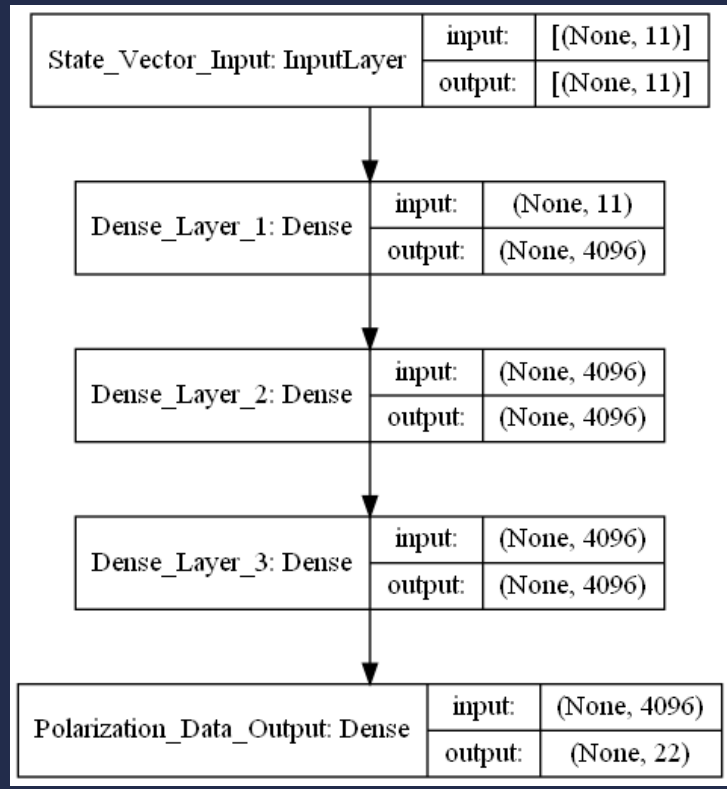
Input: aerosol and ocean input parameters (the state vector*)

$$\mathbf{x} = \langle\ \tau_{555f}\quad r_{nf}\quad \sigma_{gf}\quad n_{rf}\quad n_{if}\quad \tau_{555c}\quad r_{nc}\quad \sigma_{gc}\quad n_{rc}\quad n_{ic}\quad v\quad \mathrm{CHL}\quad z_c\quad z_f\ \rangle$$

Forward Model



Output: polarimeter measurements



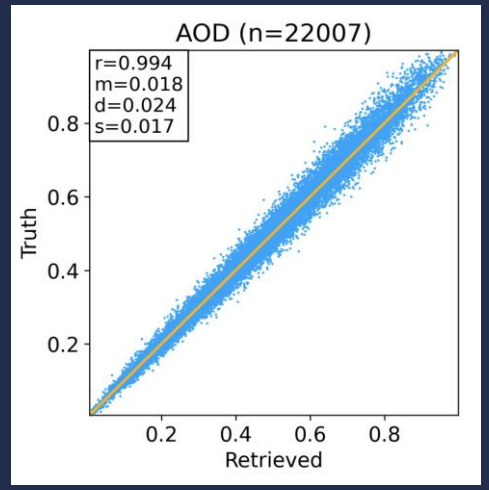
*State Vector Parameters
Bimodal (fine- and coarse-mode) aerosol optical depth (AOD) at 555 nm
Bimodal aerosol effective radius and variance
Aerosol complex refractive index
Ocean surface roughness
Ocean chlorophyll concentration

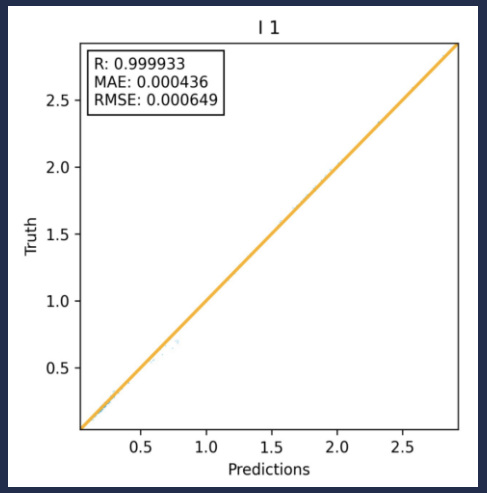
Results

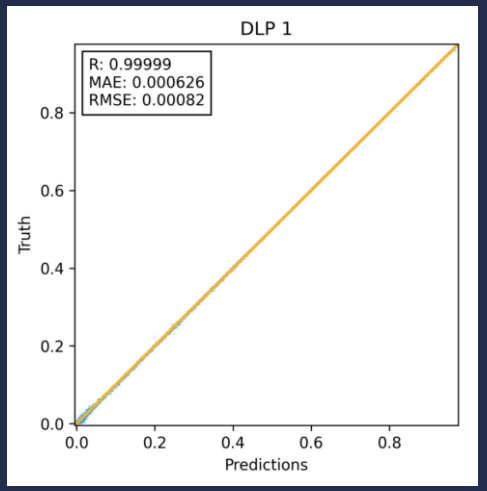
- The neural network model improves the speed of the forward model by a factor of 1000x without sacrificing appreciable accuracy
  - Overall satellite retrieval algorithm is likewise sped up

- Demonstrates that neural networks can effectively replace the vector radiative transfer forward model; this physics-based approach is an example of scientific machine learning, and thus preserves the depth and nuance of these data

- The speed enhancement of neural networks makes low-latency aerosol retrievals and PM2.5 products computationally feasible, and will allow for the development of pollution forecast models that require highly accurate/low latency data acquisition







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Future Work

- After this successful test using simulated data, the next step is to retrieve aerosol properties and PM2.5 from real satellite polarimeter data from PARASOL
  - Scripts have been created to interface with online data archives (ICARE) - download data files and process to L1C file format
- Collocation with Lidar measurements to model surface-level aerosol concentration and PM2.5
- Compare PM2.5 retrievals with those from GRASP, the algorithm for PARASOL polarimeter aerosol retrievals and PM2.5
- Create polarimeter-derived PM2.5 products for the future NASA Plankton, Aerosols, Clouds, Ecosystems (PACE) mission

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