A Deep Learning Approach to Estimate CERES Broadband Flux at 1km Resolution with MODIS Radiances

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Motivation

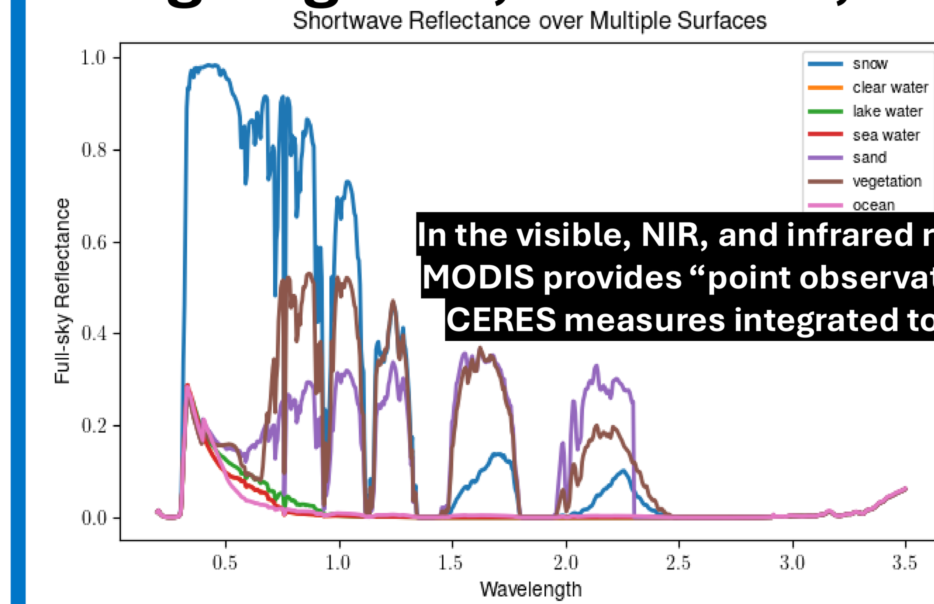
The CERES instrument on the Earth Observing System (EOS) Terra and Aqua polar-orbiting satellites measures the **total radiation leaving the surface** in the entire shortwave and longwave spectral ranges. It plays a pivotal role as a long-term direct observatory of Earth's energy budget (boasting a 25+ year data record), and provides a widely-recognized validation standard in land surface, atmospheric, and climate modeling. Nonetheless, its coarse resolution (~16x24km at NADIR) is a limiting factor.

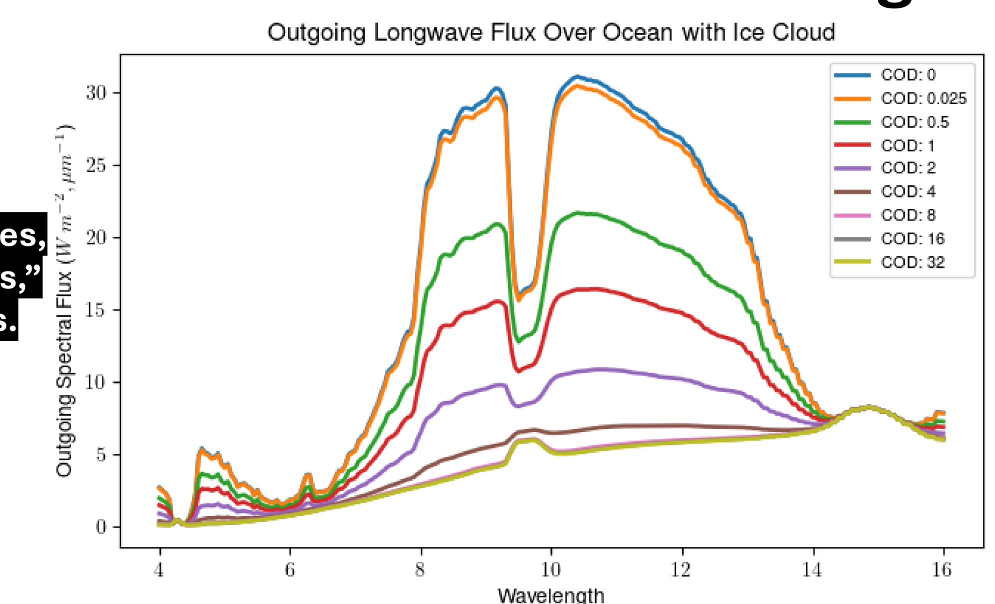
The MODIS instrument (also on the EOS platforms) is a radiometer with 36 narrow spectral bands in visible, near-infrared, and infrared ranges, at 1km resolution. Since their **observations are exactly coincident,** and should be strongly spectrally correlated, MODIS pixels can inform estimates of the full-sky fluxes from the CERES-SSF product.

In order to use the CERES observations as a prediction target, the weighted sum of model predictions must be calculated during training with the **point spread function** (PSF).

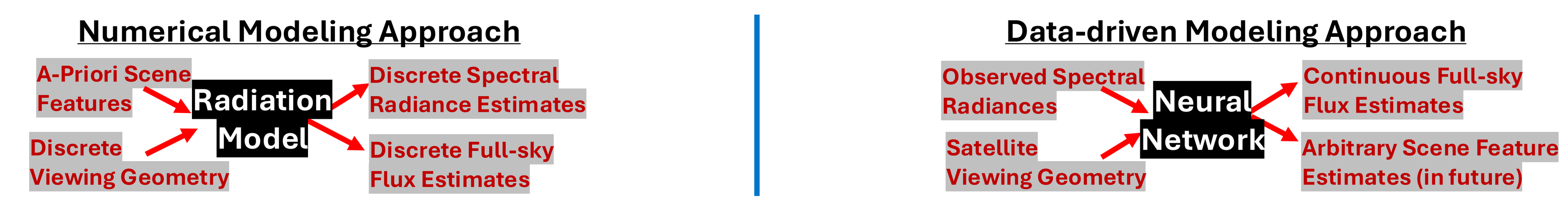
The subsequent model acts as a pixel-wise **data-driven radiative transfer model,** implicitly learning surface properties relevant to flux predictions. Predictions can be studied in isolation using bulk statistical techniques, or utilized to evaluate the flux from kilometer-scale features (cities, inland water bodies, mountain snow, and small clouds).

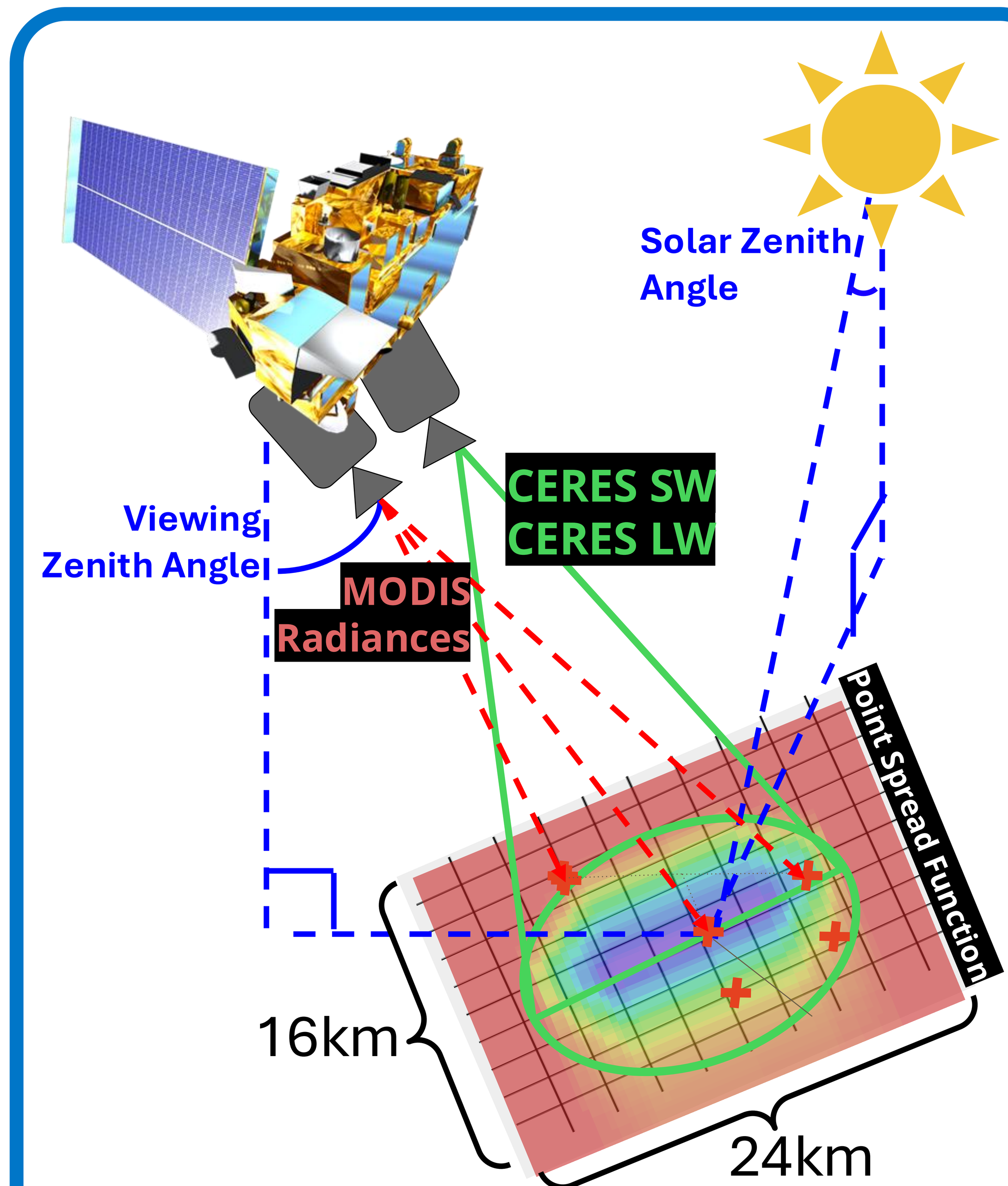
Outgoing Flux, Radiance, and Radiative Transfer Modeling





Model estimates of shortwave and longwave radiative flux over different surfaces (using SBDART). Typical radiative transfer model outputs are discrete, and based on a-priori assumptions about the surface characteristics. Narrow-band satellite observations provide information about surfaces' reflectivity, emissivity, and anisotropy, so in a data-driven model they are useful predictors for the full-sky flux.





Schematic diagram of the co-location of CERES and MODIS observations on EOS satellites Terra and Aqua.

Each CERES pixel directly overlaps ~400 MODIS pixels with contributions defined by point spread function

Objective

Given narrow band MODIS radiances and viewing geometry, train a simple deep learning model to estimate the total top-of-atmosphere outgoing shortwave and longwave radiative flux observed by CERES by making pixel-wise predictions at MODIS' 1km resolution, and applying the PSF to aggregate them during training.

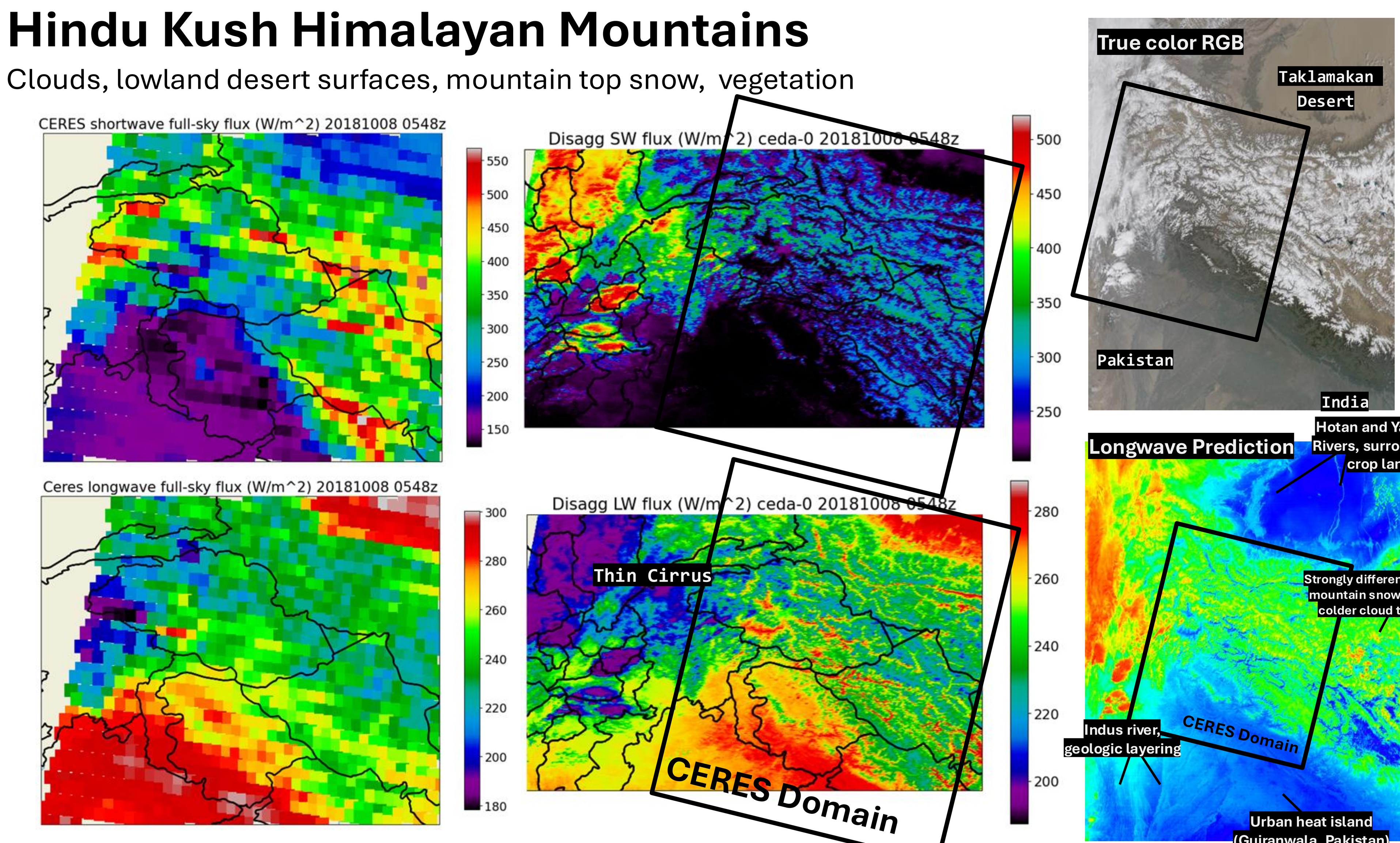
The model should **(1)** be lightweight enough to run on large MODIS granules with a CPU, **(2)** use the CERES point spread function to evaluate predictions during training, and **(3)** preserve locality (pixel-wise or close) so its radiative properties can be directly investigated in terms of a small number of incident MODIS pixels.

Methodology

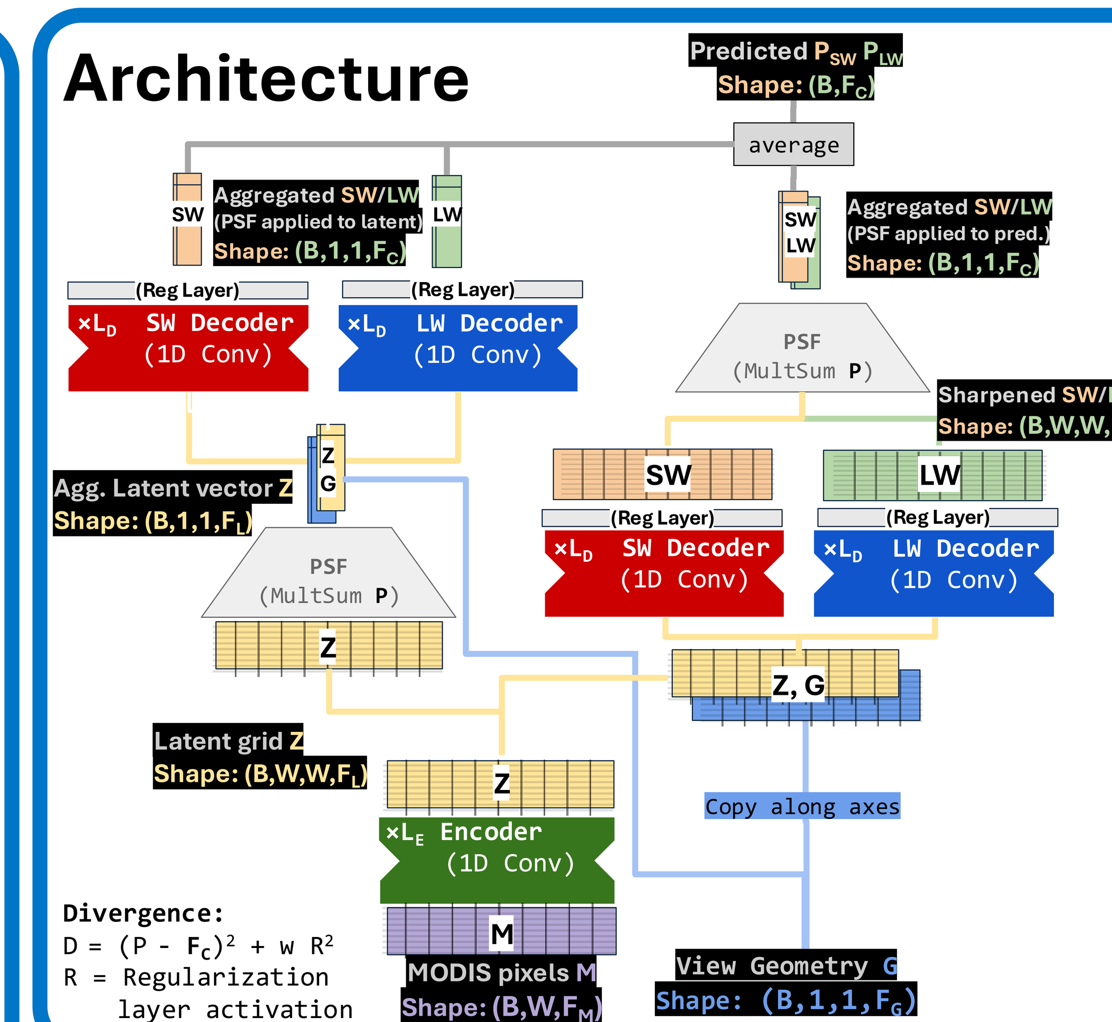
1. Acquire EOS-Aqua and EOS-Terra overpasses in 6 regions: NEUS, Alaska, Indonesia, SEUS, Himalayas, Amazon. (used more than 2,600 overpasses total).
2. Co-locate CERES footprints and simultaneous MODIS observations.
3. Use viewing geometry to calculate PSF for each overlapping CERES/MODIS tile.
4. Train a 1D CNN to make pixel-wise flux predictions, which are aggregated in the loss function using the calculated PSF.
5. Evaluate in a variety of scenes with the PSF set to 1 during inference.

Hindu Kush Himalayan Mountains

Clouds, lowland desert surfaces, mountain top snow, vegetation

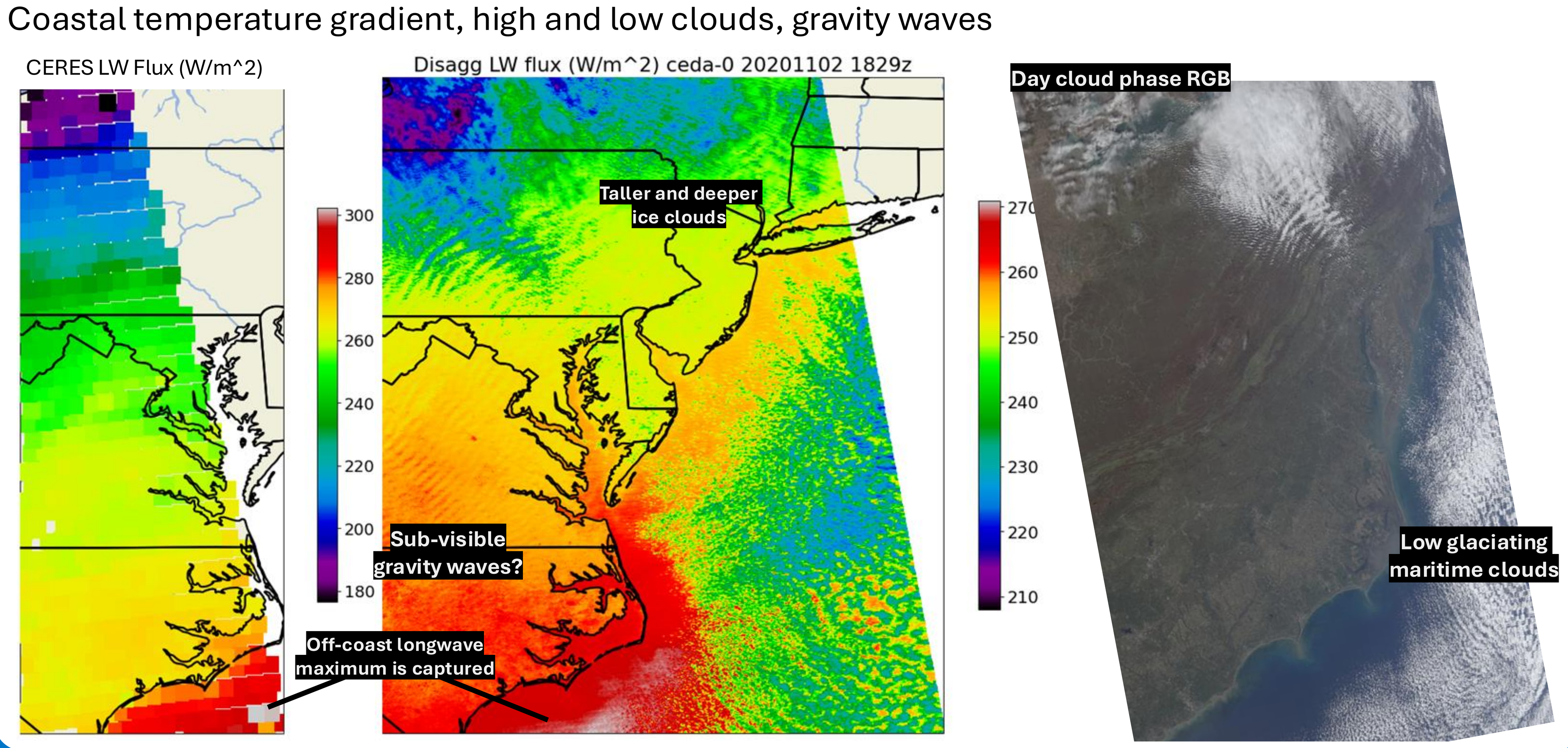


Architecture



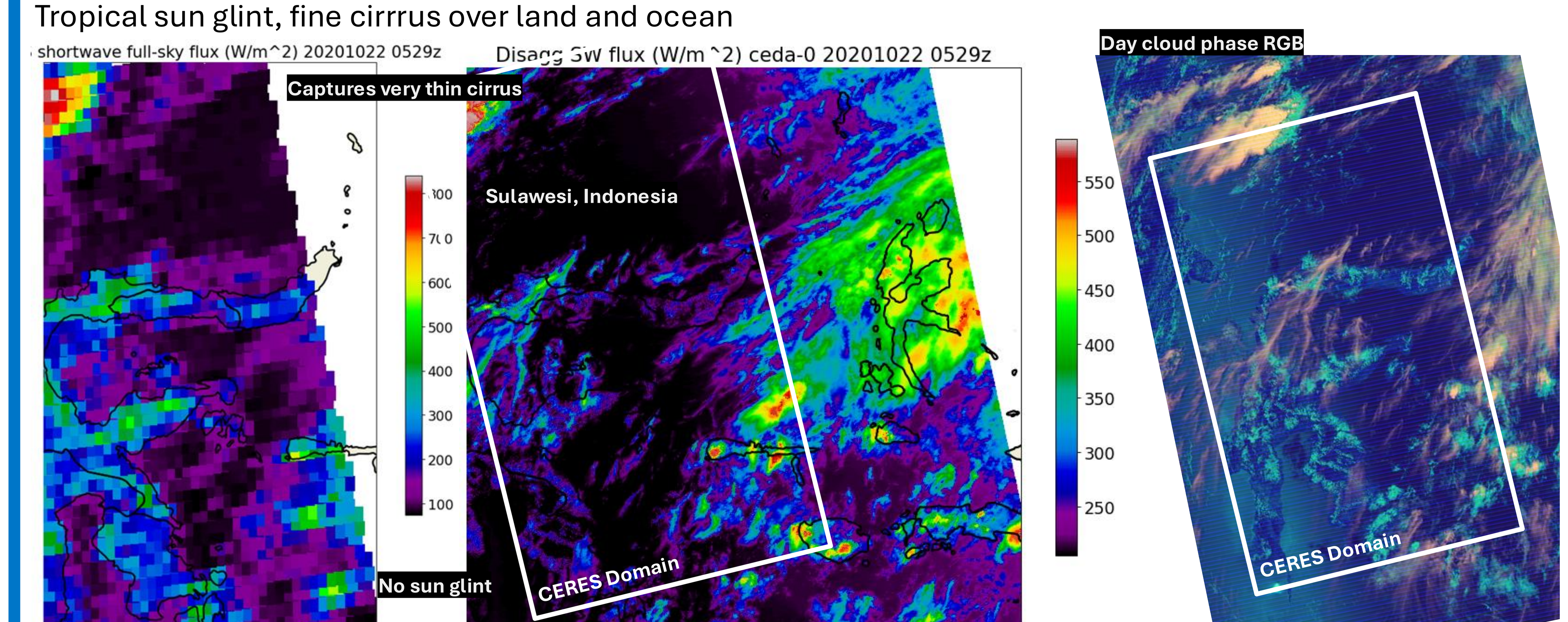
US East Coast

Coastal temperature gradient, high and low clouds, gravity waves



Southeast Asia / Oceania

Tropical sun glint, fine cirrrus over land and ocean



Future Work

1. Regional statistical analysis of predictions, and evaluation with respect to MODIS L2 products (aerosol/cloud optical depth, LST, etc).
2. Incorporate textural information by expanding first convolution layer to 3x3 and 5x5; investigate interpretability of activations.
3. Evaluate physical integrity of network by comparing flux outputs directly to RT models.
4. Improve geometric compactness of latent space outputs by using them to parameterize variational distributions before decoding.
5. Apply the same technique to the VIIRS instrument on Suomi-NPP and NOAA series satellites (which also have CERES instruments).
6. Adapt flux models to GOES geostationary data.