Exploring the Use of Artificial Intelligence (AI) to Optimize the Exploitation of Big Satellite Data in NWP and Nowcasting

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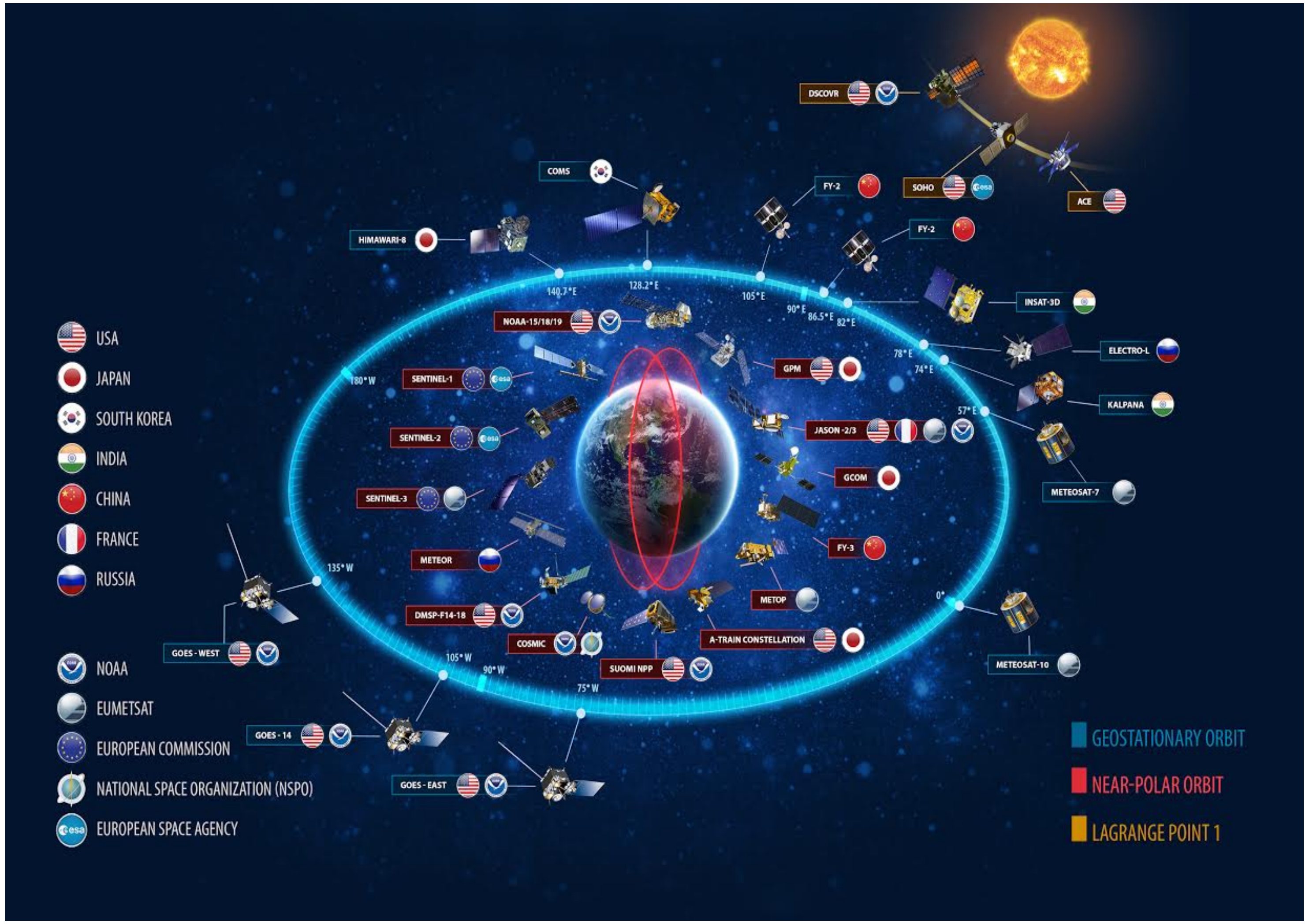
Agenda

1. **Why Artificial Intelligence (AI) ? Background and Motivations**
2. **Methodology & Description**
3. **AI for Remote Sensing and Data Assimilation/Fusion/NowCasting**
4. **Conclusions**

Trends in Global Earth Observation Systems

- **GOS Trends:**
  - New Players in GOS (international, commercial, etc)
  - New Sensors (higher resolutions, etc)
  - New technologies (small sats, etc)
  - Emergence of New GOS (IoT, etc)
  - **Significant Increase in volume and diversity of data**

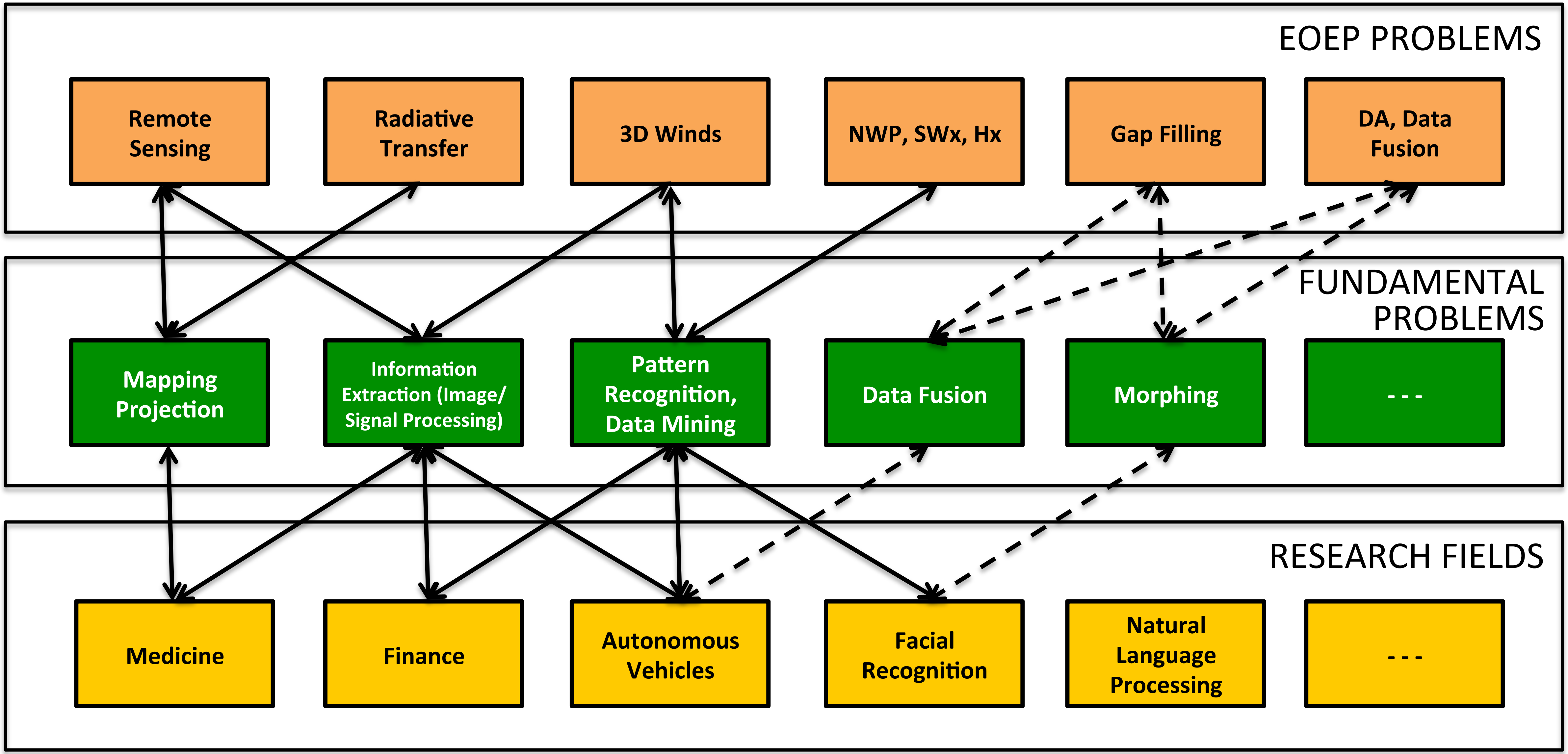
- **Parallel Trends**
  - Budget, HPC Constraints
  - Higher societal impact and expectations
  - Higher users expectations
  - Demand for Increase in quantity of data assimilated (5% currently assimilated)



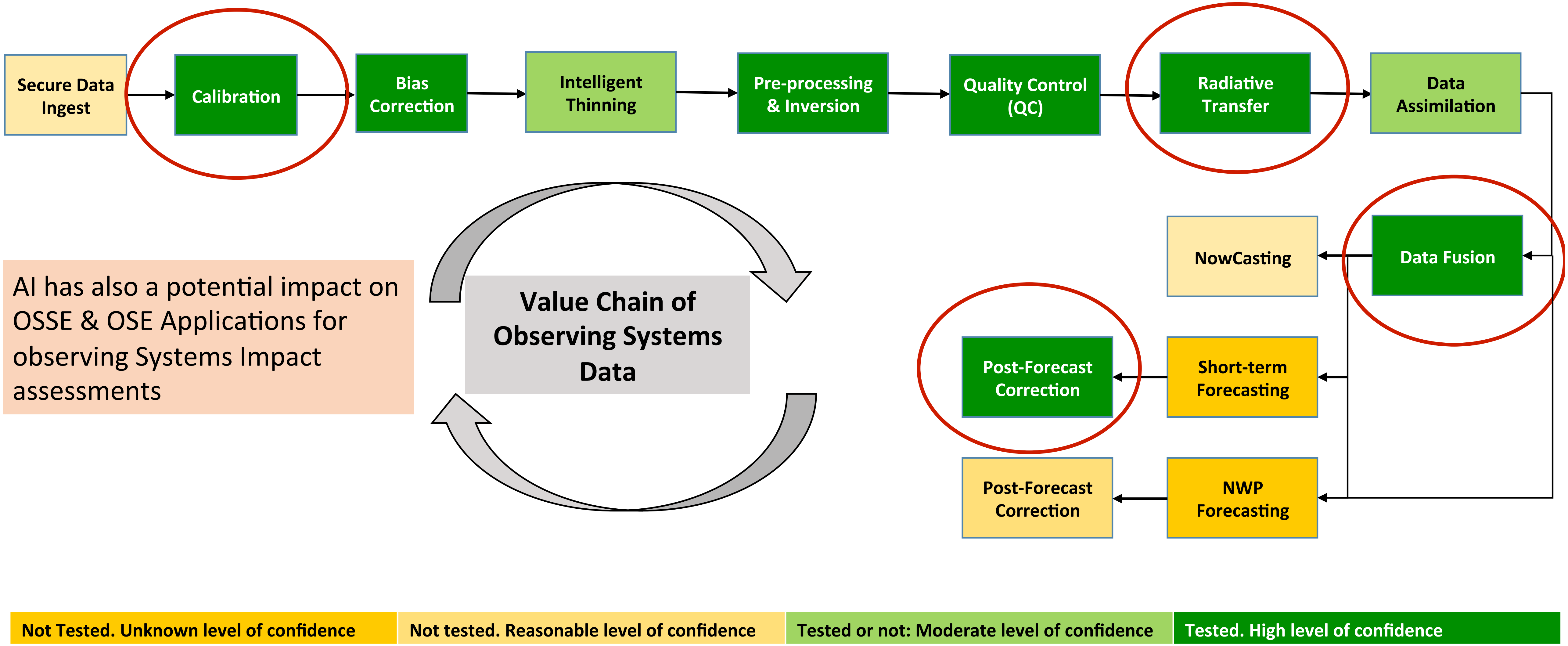
Why AI?

- **AI applied successfully in fields with similar traits as Environmental data & NWP/SA: (1) # obs. systems to analyze/assimilate/fuse and (2) predict behavior**
  - Medical field (Watson Project): Scan Image Analysis, Cancer detection, heart Sound analysis
  - In finance: Algorithmic Trading, market data analysis, portfolio management
  - In Music: Composing any style by learning from huge database & analyzing unique combinations.
  - Self-Driving Transportation Devices: Fusion of Multiple Observing Systems for situational awareness
  - …..
- **We believe Environmental data exploitation (remote sensing, data assimilation and perhaps forecasting), presents a viable candidate for AI application.**
- **This presentation is meant to present a few examples to convey that the potential is significant.**

Meta-Transfer Learning



Exploring AI for Remote Sensing, NWP & Situational Awareness (SA). Status



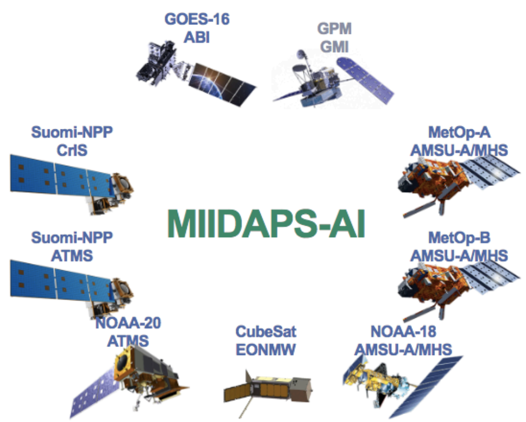
Methodology and Description
(baby steps)

- **Scope of the effort: Nowcasting/RS and Forecasting Adjustment**
  - focus on satellite-based analyses (RS), focusing on an enterprise algorithm used for inversion and assimilation pre-processing
  - but also assess capability of short term forecast correction
  - focus on atmosphere (T, Q, Wind) but highlight surface parameters and hydrometeors capability as well
- **Tools:** Google TensorFlow
- **Real data**
  - Focus on SNPP/ATMS and SNPP/CrIS

Training & Verification:

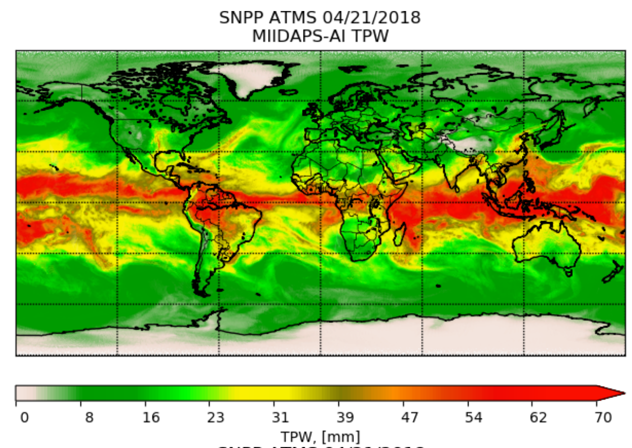
- Sets: ECMWF Analyses, G5NR fields, GDAS Analyses
- Noise addition: uncorrelated, Gaussian distributed noise with spread of (instrument noise*2) is added to simulations
- Sampling: Training data is randomly selected from a fixed set of ~5% of a days worth of data in each training epoch
- Simple training (sample over a day generally
- Independent sets used for verification, but still the same period

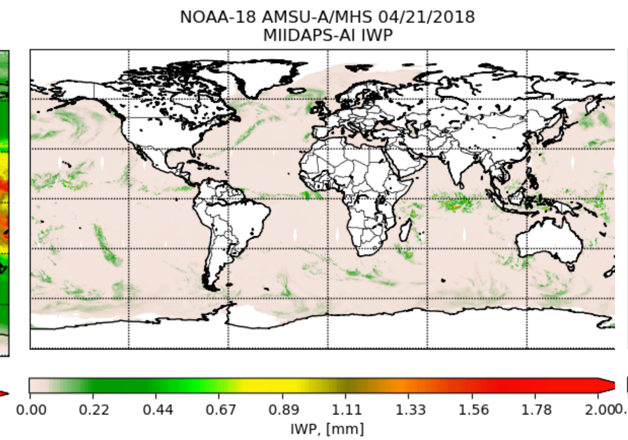
MIIDAPS-AI Product Examples – Real Polar Geo IR and MW Observations

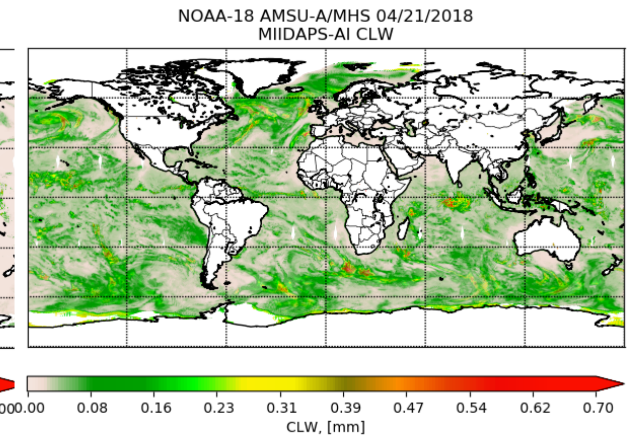


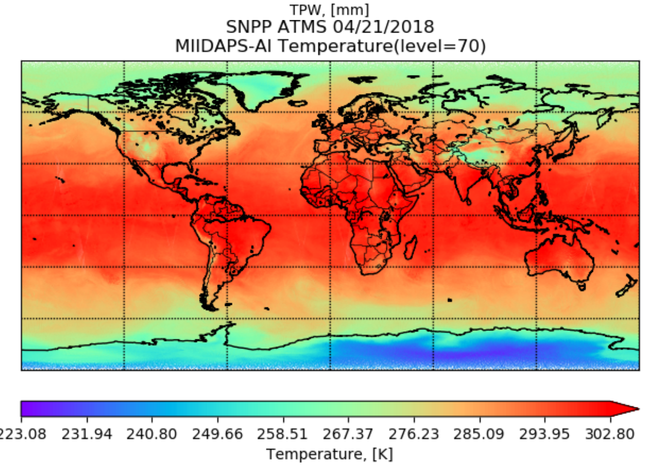
MIIDAPS-AI Remote Sounding Algorithm

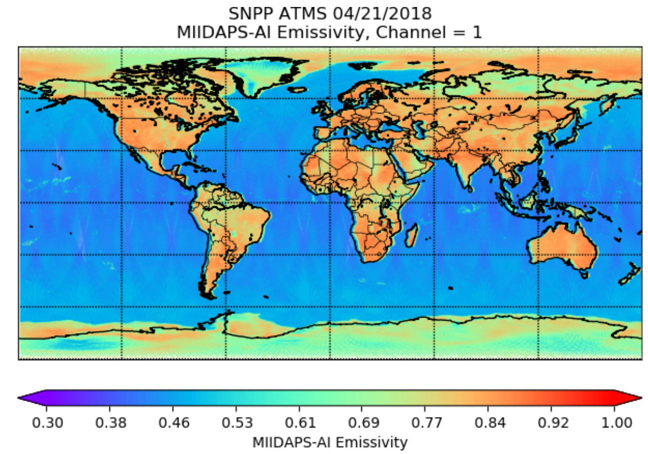
- *Algorithms are deep feed forward (and locally-connected) neural networks trained in simulation and applied to real observations*
- *Network architecture and hyper parameters are tested and optimized using Google TensorFlow™ and Keras*



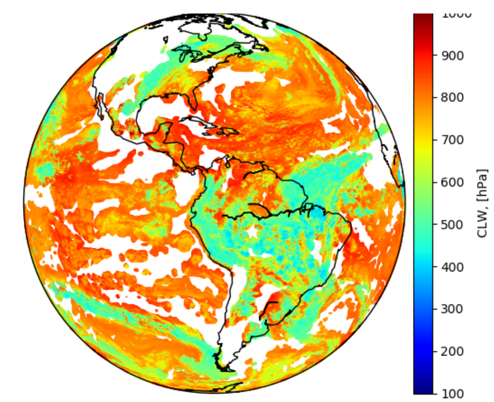








GOES-EAST ABI LIQUID CTP

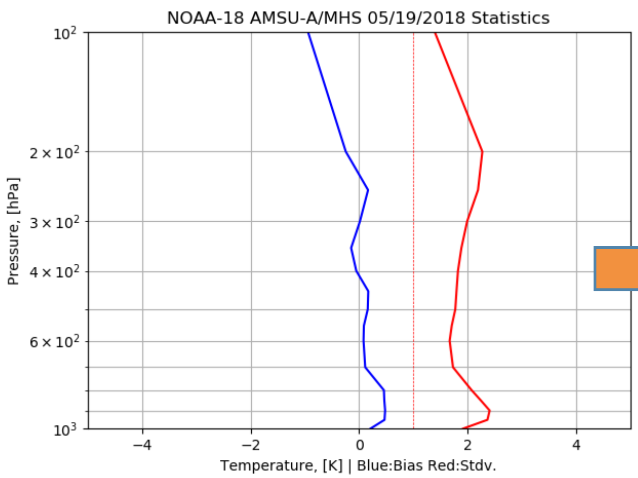


Can AI be used to perform bias correction of products/instrument observations?

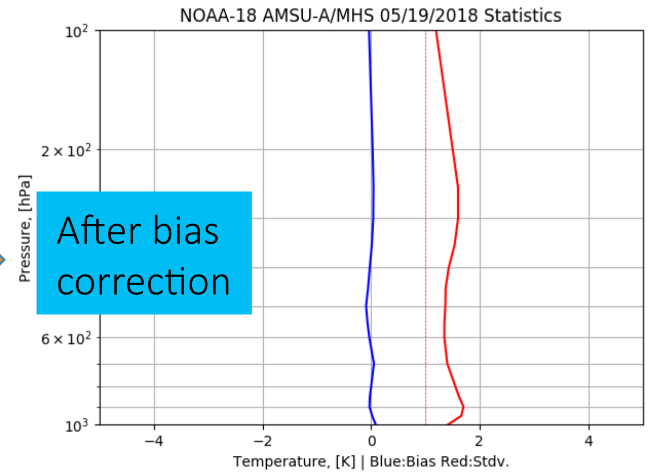
Predicted Temperature and Water Vapor profiles vs. ECMWF

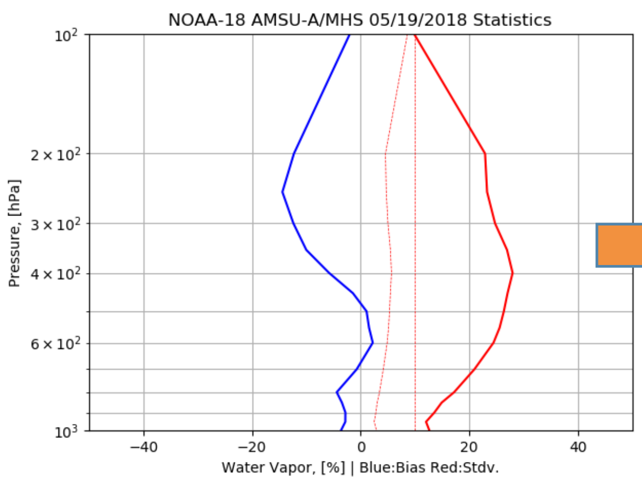
Inputs: AMSUA/MHS TB
Outputs: T, Tskin, Q

Inputs: AMSUA/MHS TB
Outputs: T, Tskin, Q, BC(TB_{sim}-Tb_{real})

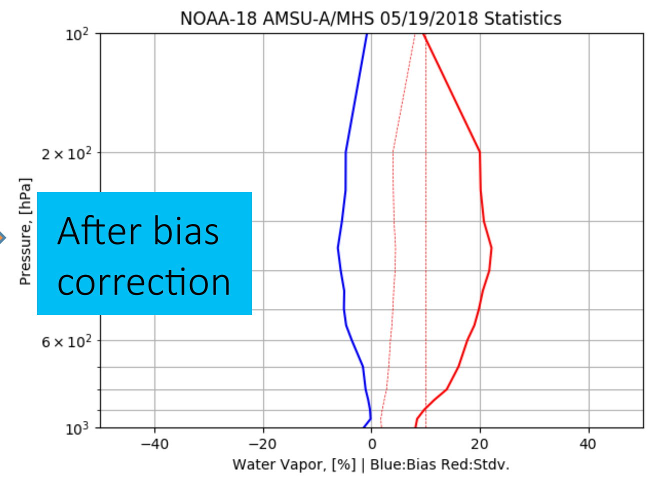


After bias correction



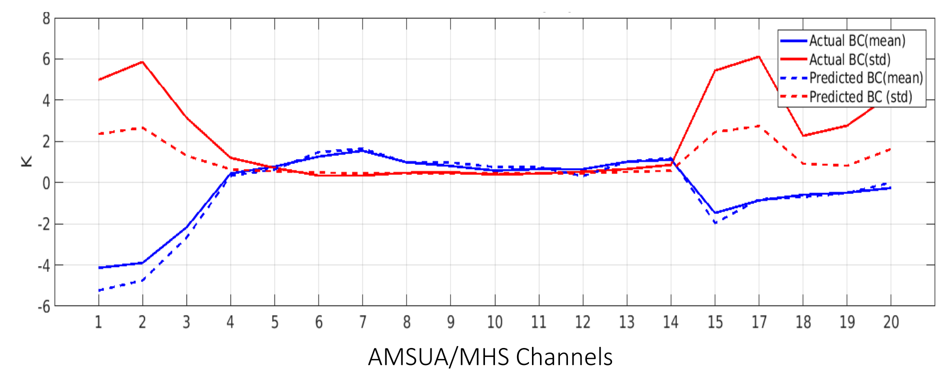


After bias correction



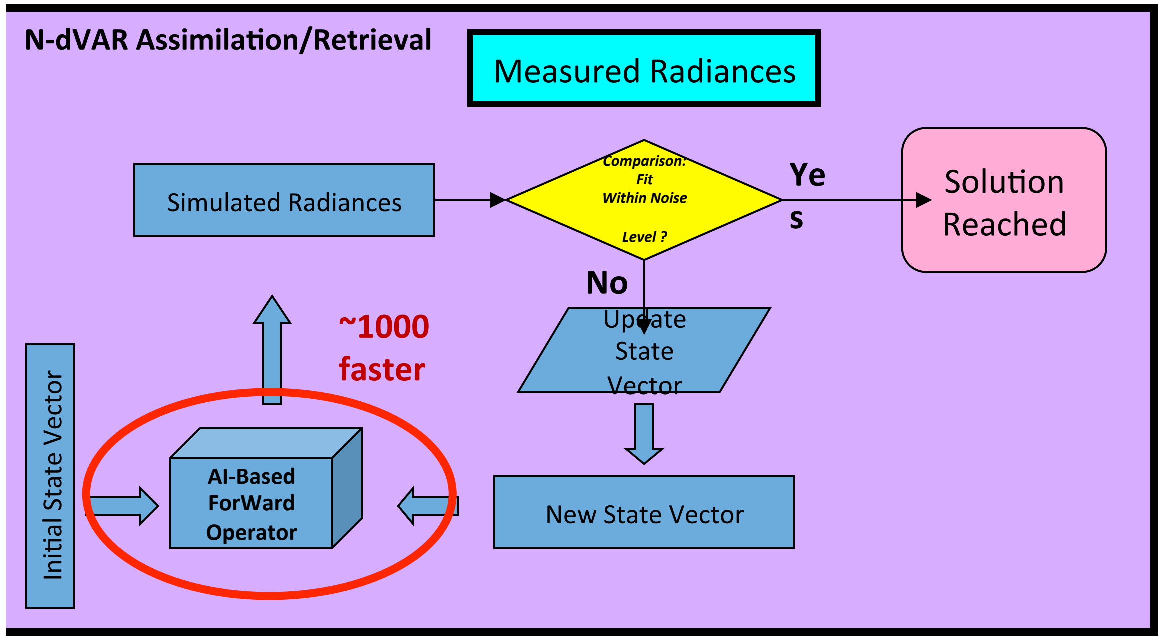
Adding ***BC*** into the training set improves the bias for both temperature and water vapor profiles

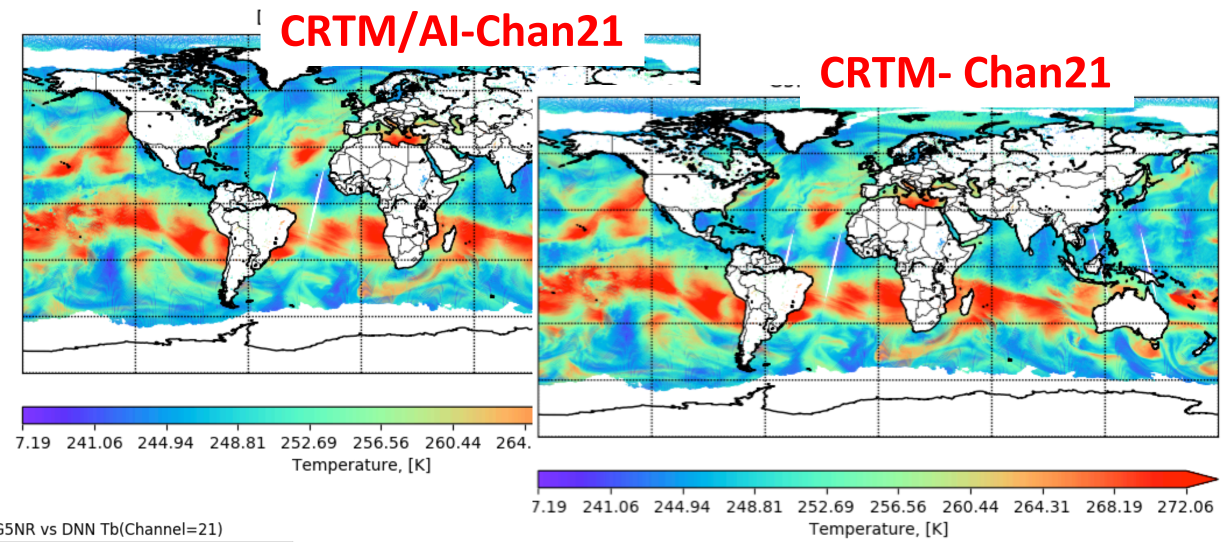
Predicted BC vs. Actual BC(TB_{sim}-Tb_{real})

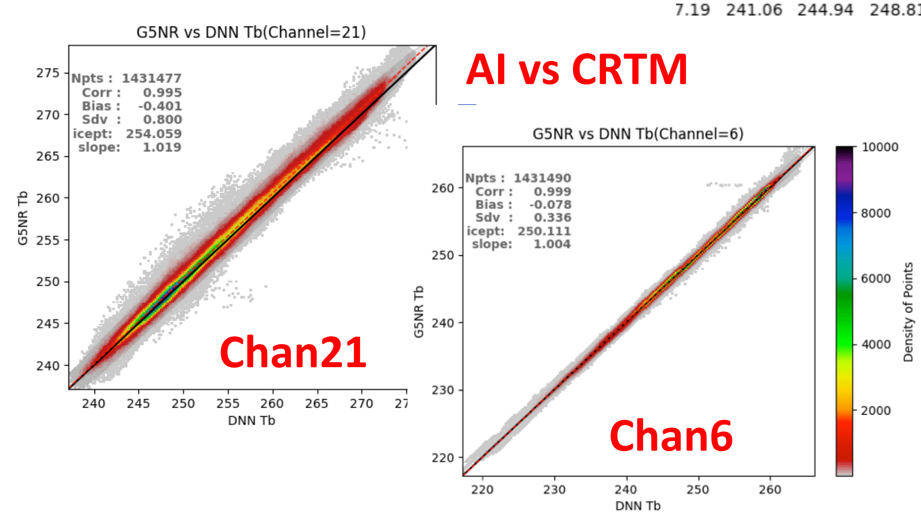


Can AI Be Used as Forward Operator?

Use of Deep Neural Network (DNN) for Radiative Transfer Modeling Purposes

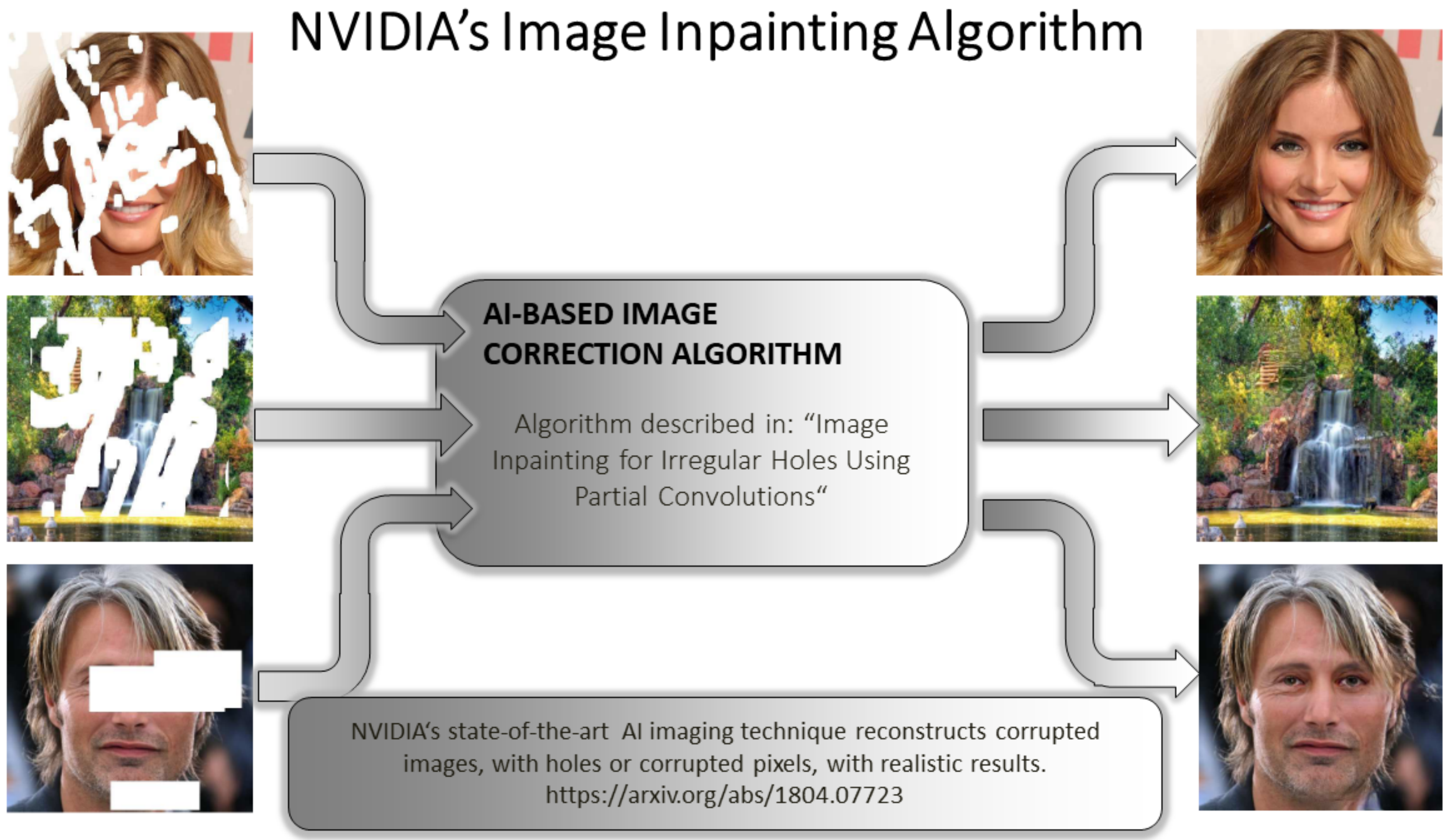






	CRTM-AI	CRTM
Processing Time for a full day data. A single sensor channel(ATMS). Excluding I/O	**<1 second**	**~ 1.3 hours**

Can AI be used to perform calibration correction for GOES-17 ABI thermal bands?



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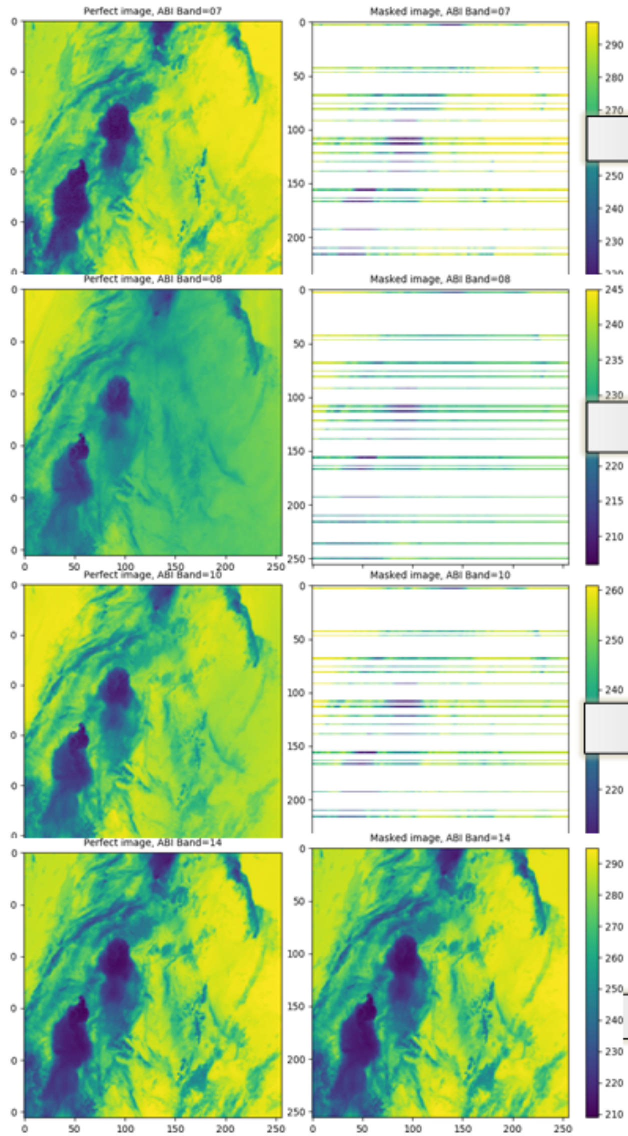


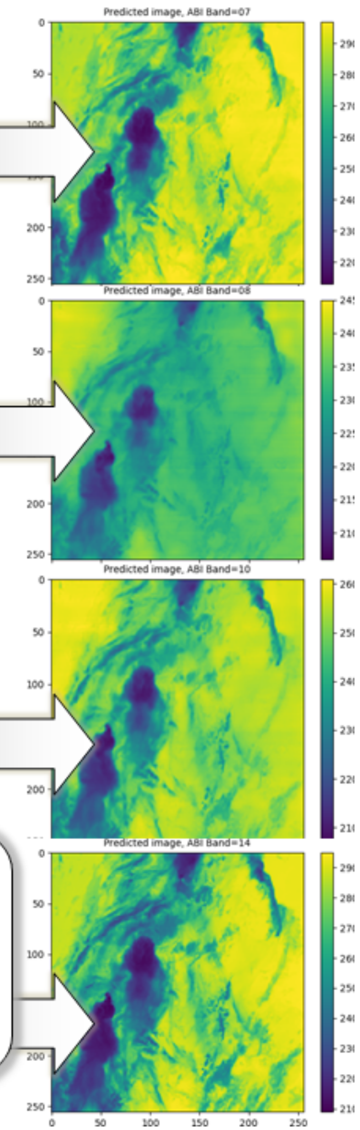
Proposed GOES-17 ABI Thermal Band Calibration Correction

AI-BASED IMAGE CORRECTION ALGORITHM

Correction based on NVIDIA's inpainting algorithm but applied for 256 x 256 pixel ABI thermal band images. Partial convolutions not implemented. Different loss fnc., architecture, hyperparams…all need tuned

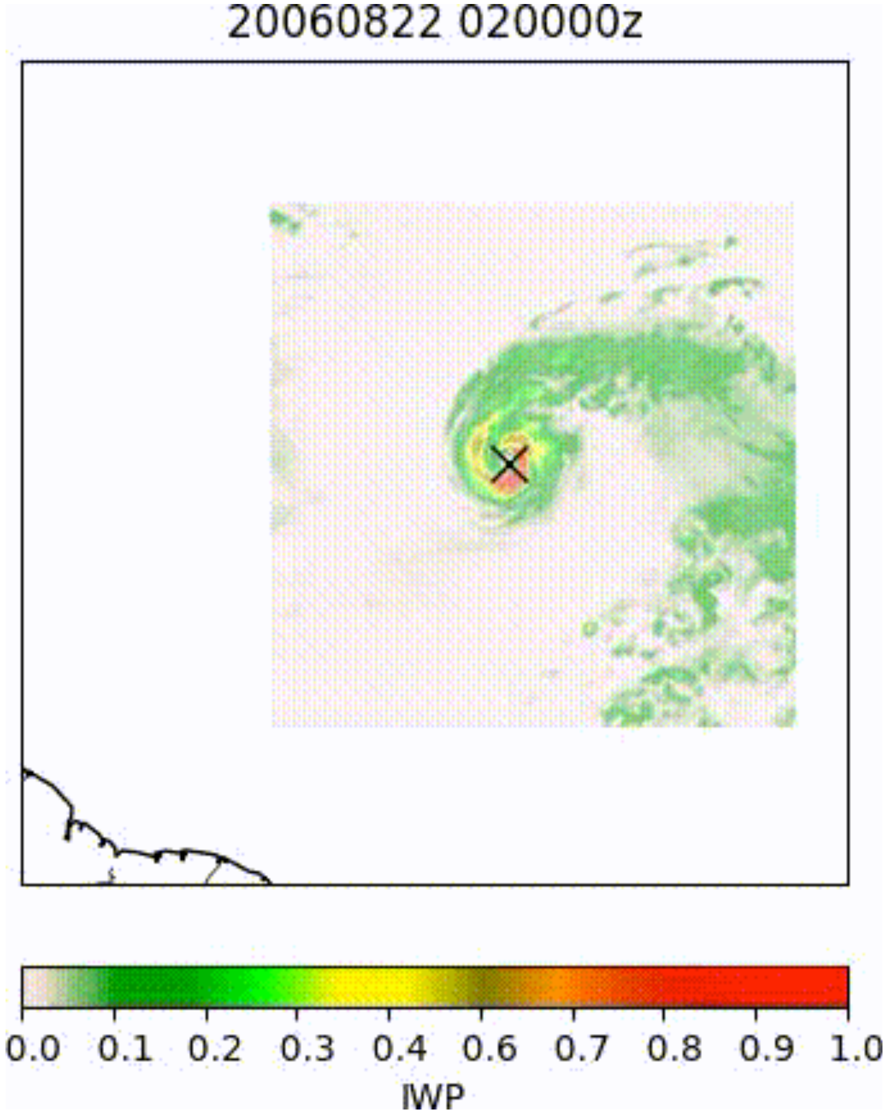
AI-based correction produces realistic images in corrupted bands.

Corrections can be applied when all thermal bands are corrupted or when only a subset of bands are corrupted. In the latter case, image reconstruction improved due to spatial/spectral redundancy.



Use of "morphing" AI Tool ("dogs" video morphing software) for Cloud/Precip morphing

Note the potential for morphing both the shape and color (i.e. equivalent of track and intensity)



- Used total integrated cloud ice from NASA GEOS-5 Nature Run (G5NR) "AL01" tropical cyclone at two time-steps (0200z and 0600z).
- Morphing software applied as a black box with some hand tuning of transformations between the two images.
  - Image at right sampled using 20 transformations between images

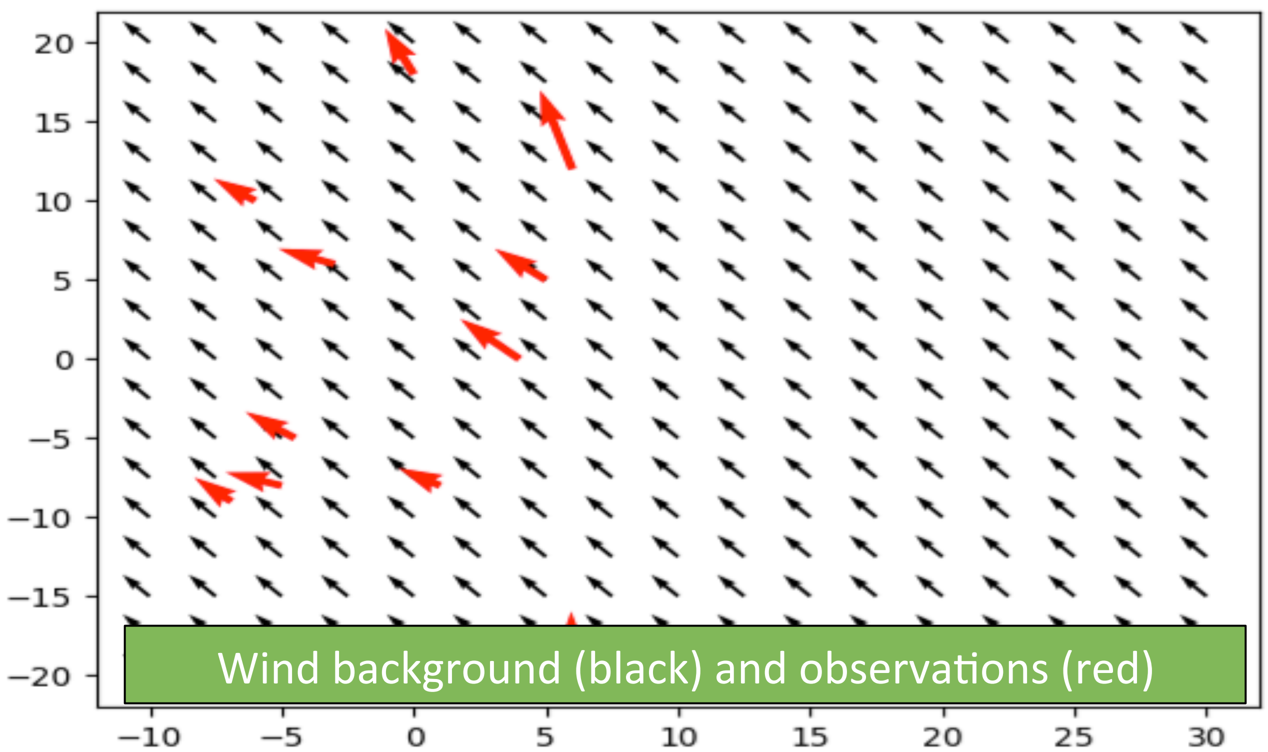
Credit: Example output and software from:
http://andrew.gibiansky.com/blog/image-processing/image-morphing/

Can AI Tools Be Used for Data Fusion & Data Assimilation?

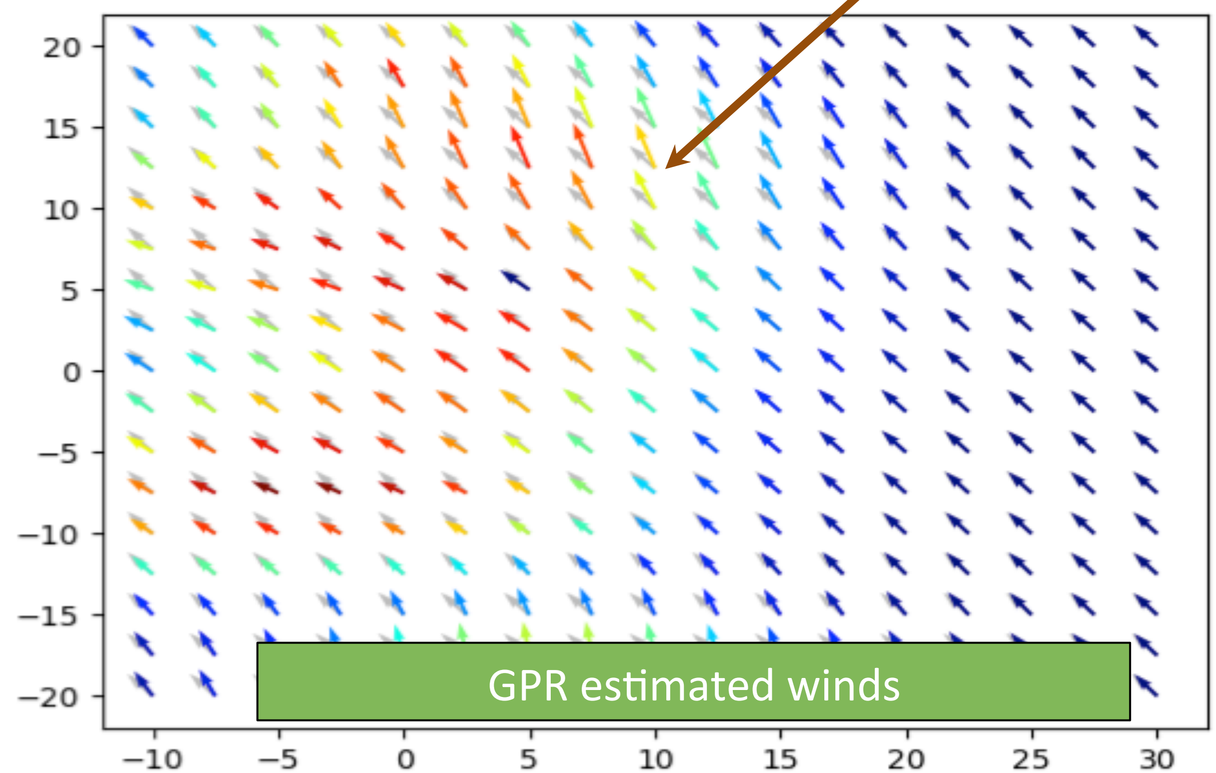
Use of GPR (Gaussian Process Regression) AI Model for Data Fusion/Assimilation (Case of AMV)

Color confidence/error estimates

Background and Measurements



GPR-Based Analysis

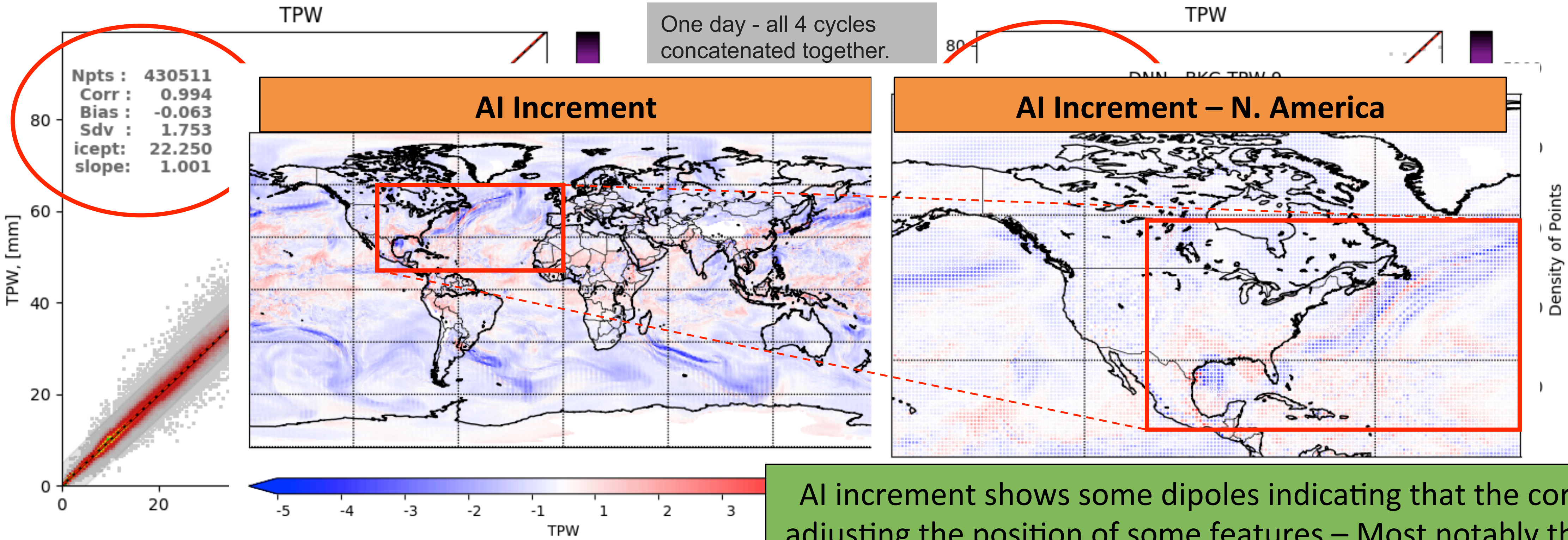


- Synthetic wind observations (red) are injected onto background (black) fields and GPR used to “fuse” the two.
- Color code corresponds GPR confidence – warmer colors reflect high confidence, while colder colors reflect low confidence estimates – and are consistent with observation locations.

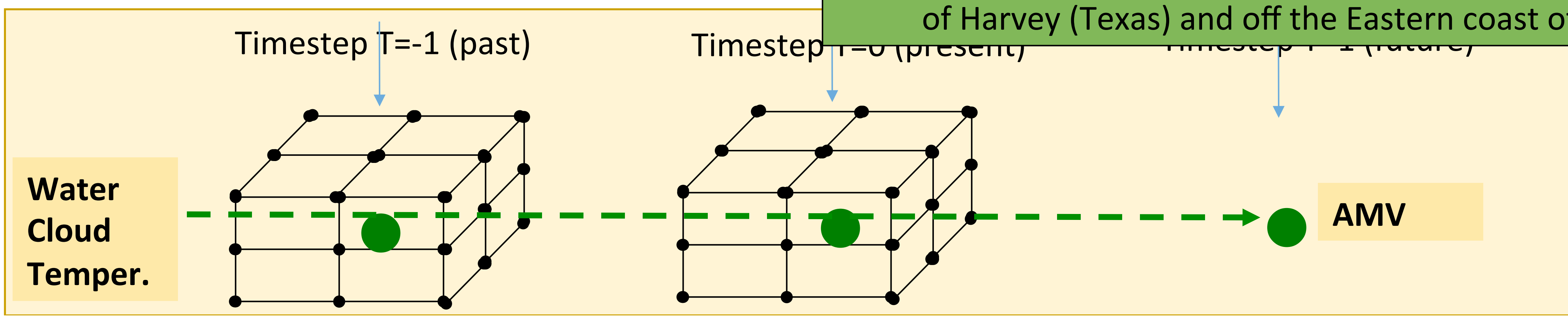
Correcting TPW Forecasting with AI?

ECMWF vs AI-corrected 6h fcst valid @ECMWF analysis time

ECMWF vs 6 hr frcst valid @ECMWF analysis time.



AI increment shows some dipoles indicating that the correction is adjusting the position of some features – Most notably the position of Harvey (Texas) and off the Eastern coast of N.America



Conclusions

- Increase in number, diversity and sources of global observing systems (GOS) including private sector. This presents unprecedented (and welcome) added resiliency and quality of the GOS. However this presents challenges: Cost and infrastructure to leverage/exploit them.

- Computing constraints, perhaps require us to explore new approaches for the future (not so distant). AI-Based Analyses (satellite-exlusive) are found to be radiometrically, spatially and geophysically consistent with traditional analyses.

- Goal of this study is not to show AI can do better, but that it can provide at least similar quality, much faster. It appears to be doing that.

- Different components can benefit from AI (Inversion, Data Assimilation, RT, QC, Data Fusion,..) for NWP and Situational Awareness SA.

- Encouraging results so far were found when assessing derivation of AMV using AI (not shown) and when assessing the feasibility of correcting GFS forecasts (using ECMWF as a target). Pointing to the potential for using AI for actual forecasting (at least short-term).

- Training is key for AI. Nature Run Datasets presents a good source for this.

- Pursuing AI applications, we believe, will allow us to :
  - (1) Reduce pressure on Infrastructure (ground systems), HPC and cost
  - (2) benefit from new environmental data (and face increased volume), including satellite data from all partners, including IoT
  - (3) Improve Latency
  - (4) Reduce cost of running legacy systems (remote sensing and data assimilation/fusion systems)
  - (5) Increase percentage of satellite data being assimilated (improved thinning, QC-ing, faster processing, etc)
  - (6) Reduce time to run OSE/OSSE and in general data assimilation/fusion systems, for decision making purposes
  - (7) <u>Perhaps</u> Improve forecast as a result of above and because AI can be exploited for forecast improvement