MERRA-2 ENERGY AND WATER CYCLES

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GMAO

Global Modeling and Assimilation Office

Overview

- Project Overview
- Climate Evaluation
- Recent Results
  - C-C Relationship
  - Land Water Storage
  - Arctic
  - Other
- Plans
  - Earth System Analysis
  - Ensemble 4DDA
  - CERES Support

MERRA-2 Motivation and Objectives

Produce an ongoing, intermediate reanalysis for the satellite era using a recent version of GEOS-5 to

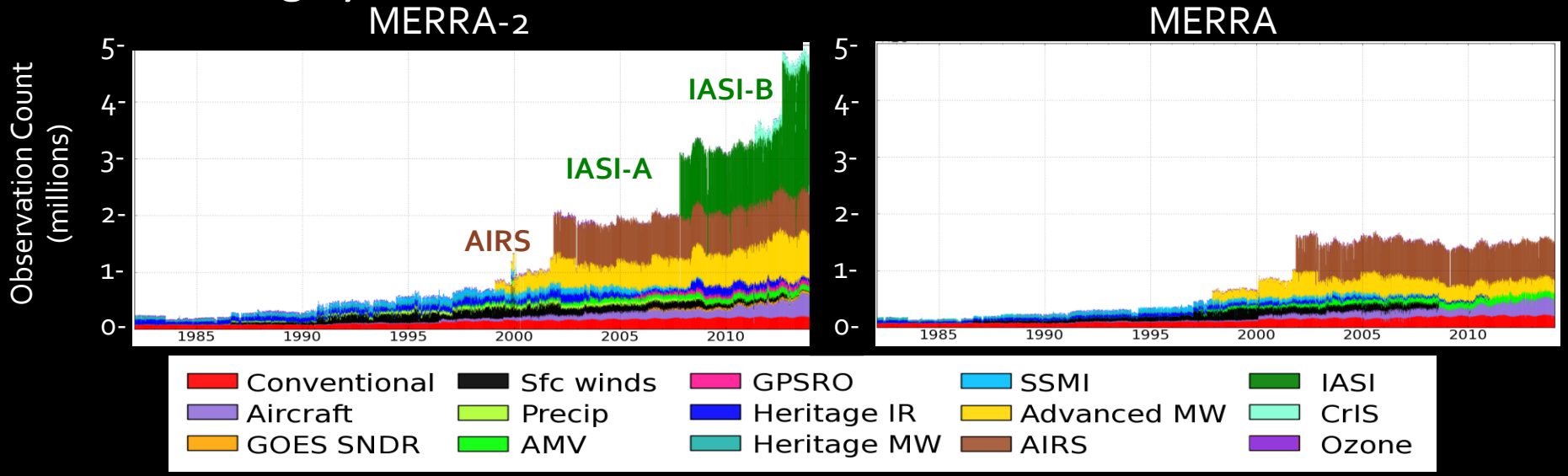
(1) address known limitations of MERRA (c. 2008), and

(2) a stepping stone to a *future coupled Earth system reanalysis.*

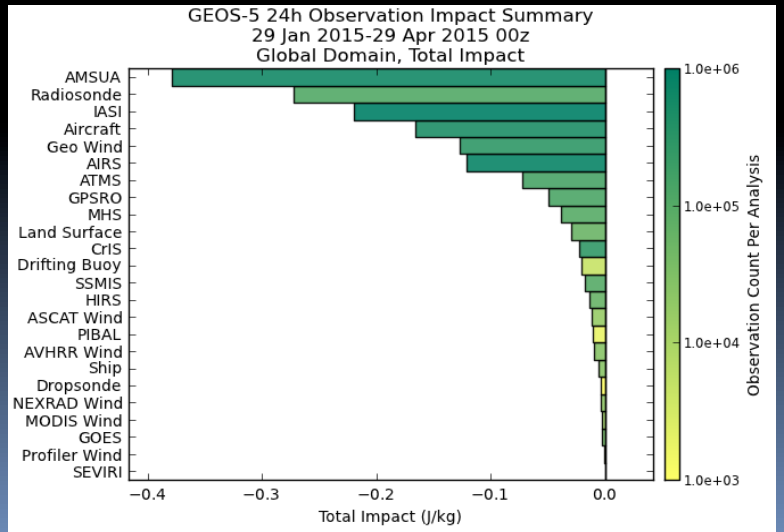
Specifics:

- Incorporate modern satellite observation types not available to MERRA
- Reduce spurious global trends and jumps related to changes in the observing system
- Reduce biases and imbalances in the water and energy cycles
- Test coupling GOES-5 meteorology with other Earth system components

Observing system time series for MERRA and MERRA-2



- Data counts increase as more hyper-spectral sensors become active
- No microwave radiance data after NOAA-18 in MERRA
- Data counts for MERRA could decrease rapidly, especially if AIRS data were no longer available
- In MERRA-2, current, AMSUA, IASI, and AIRS provide most global impact from radiances



The MERRA-2 data assimilation system

GEOS-5.12.4 AGCM/GSI 3D-Var 0.5° x 0.625° x 72 hybrid-eta levels to 0.01 hPa

- **Updates to the AGCM and GSI**

  AGCM

  - *Cubed-sphere dynamics; Updated physics: limited deep convection, re-evap of rain, snow sublimation (Molod et al, 2015)*
  - *Improved glacier model and cryosphere albedos*

  GSI

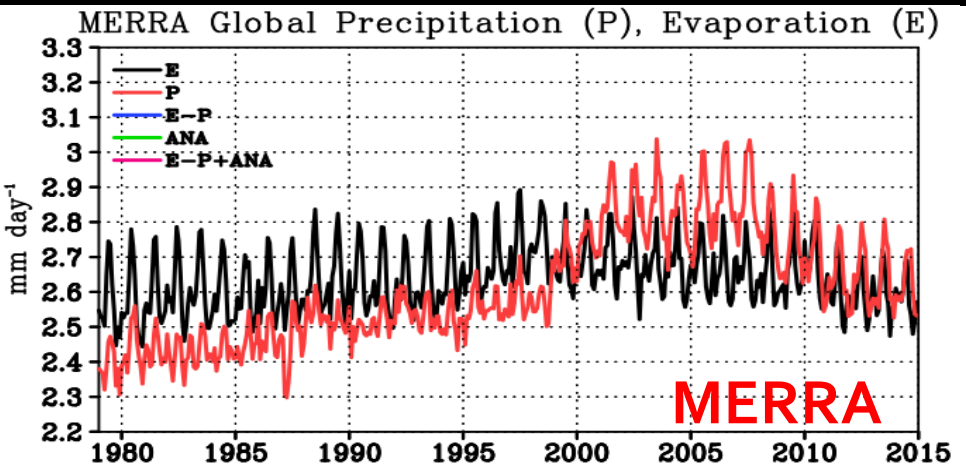
  - *Modern observations: GPSRO, NOAA-19, MetOp-A/B, S-NPP, SEVIRI, Aura OMI and MLS, capable for JPSS, MetOp-C* (McCarty et al. 2016)
  - *Updated moisture control variable and background errors*
  - *Bias correction for aircraft temperature observations*
  - *Balance constraint for noise*
  - *TC Relocation*
- **Aerosol assimilation with radiative direct effects (Randles et al. 2016)**
- **Constraints on dry mass and globally integrated water (Takacs et al. 2015)**
- **Corrected precipitation for land forcing, aerosol deposition (Reichle et al. 2015)**

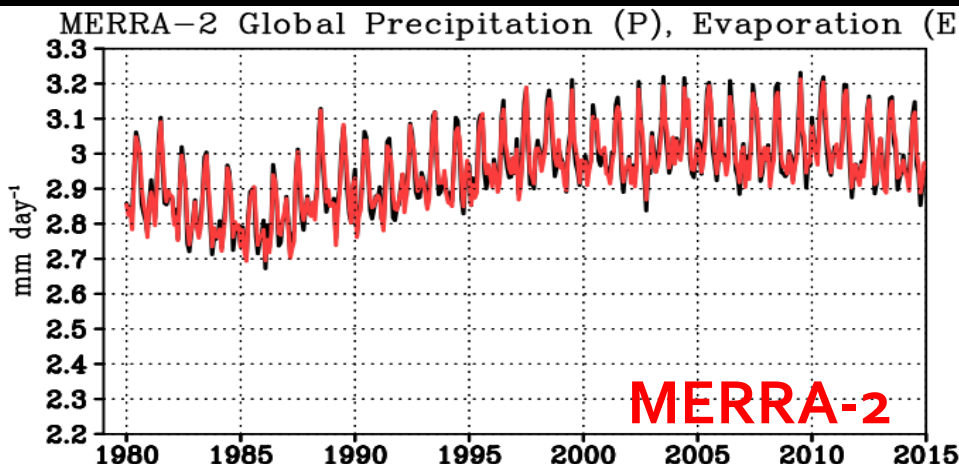
Water Cycle

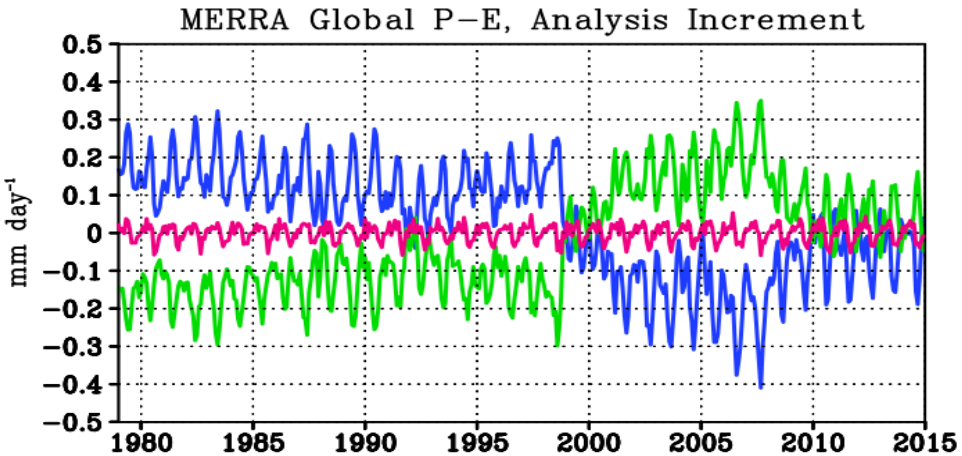
Globally precipitation, evaporation and analysis forcing

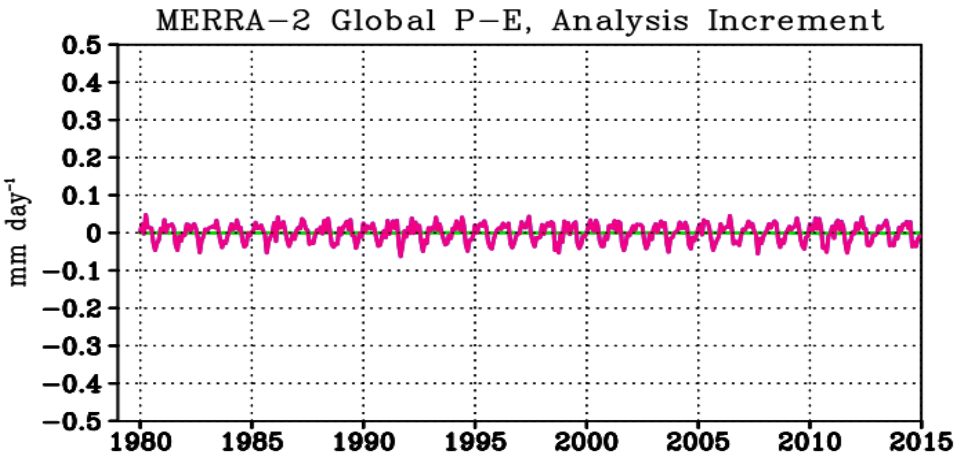
Surface pressure and water vapor analyses are penalized for global imbalances

(Takacs et al., *NASA GMAO Tech Memo, 2015; QJRMS 2016)*



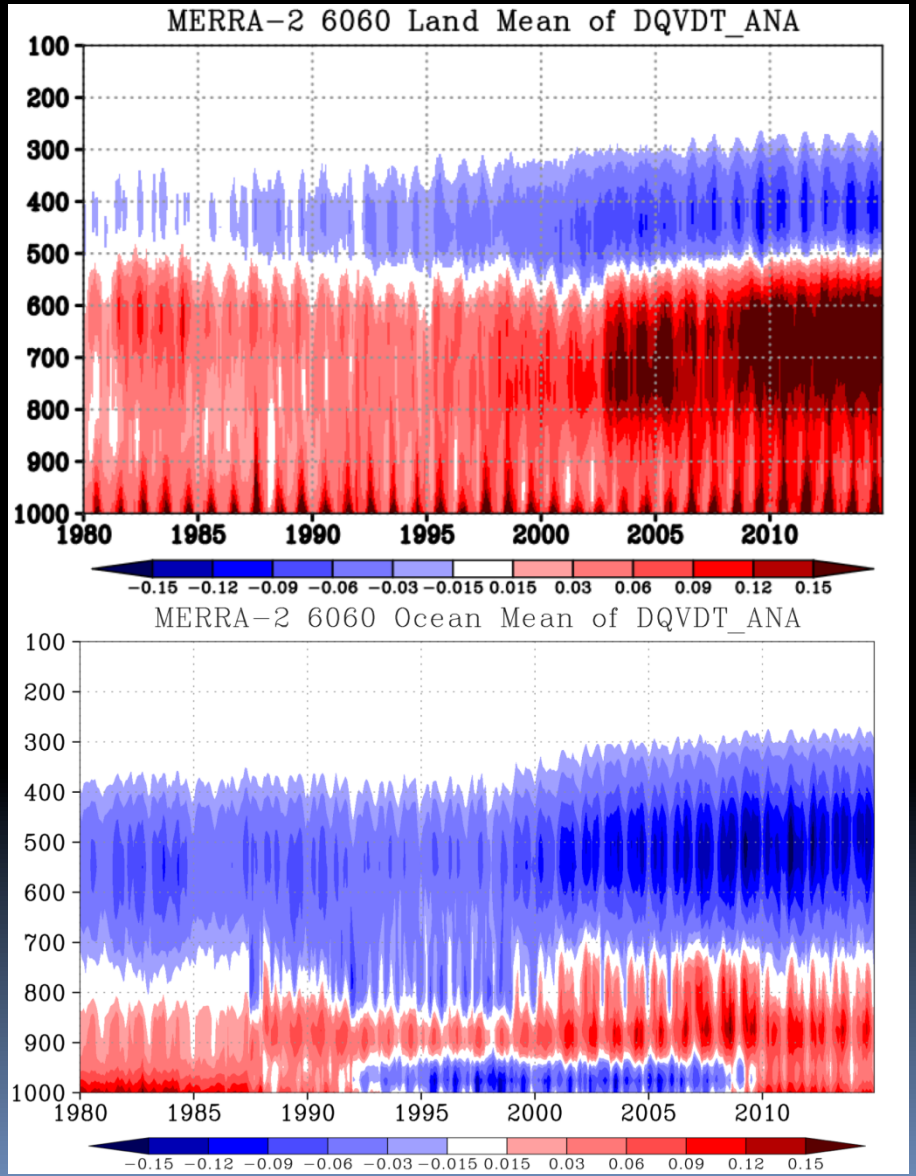






In MERRA, imbalances of P and E result from analysis adjustments, sensitive to changes in the observing system.

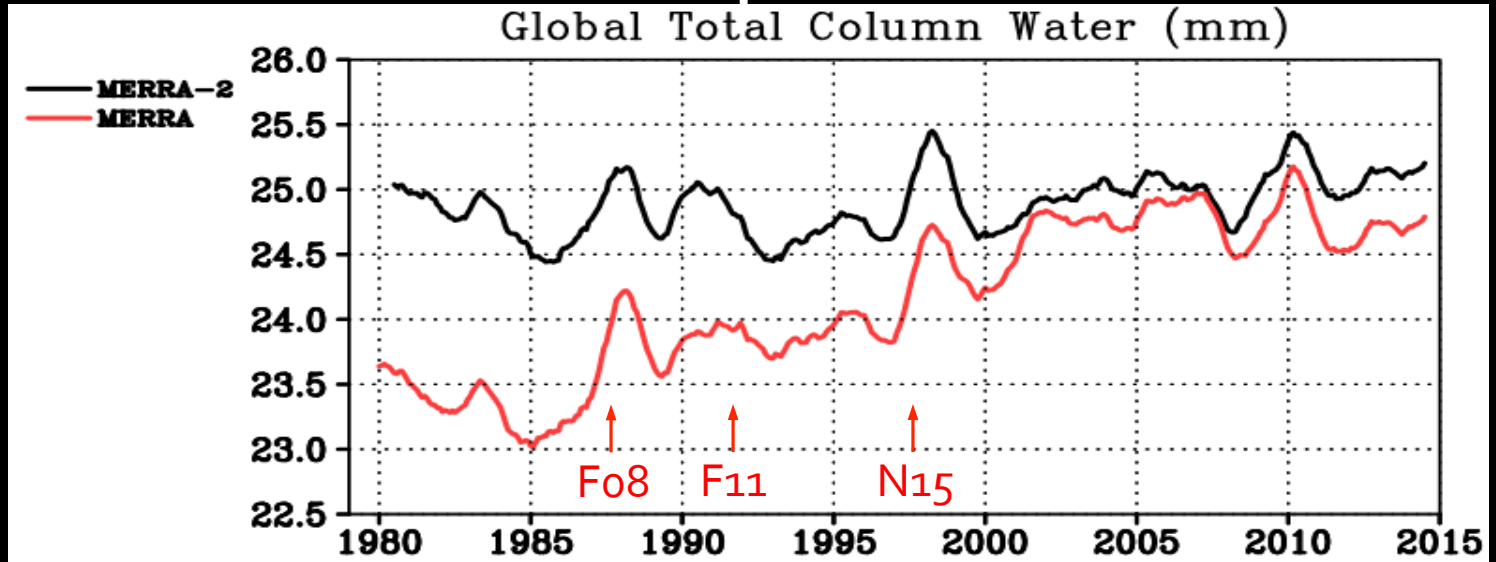
In MERRA-2, unphysical changes in total mass are ameliorated and global balance between P, E is maintained

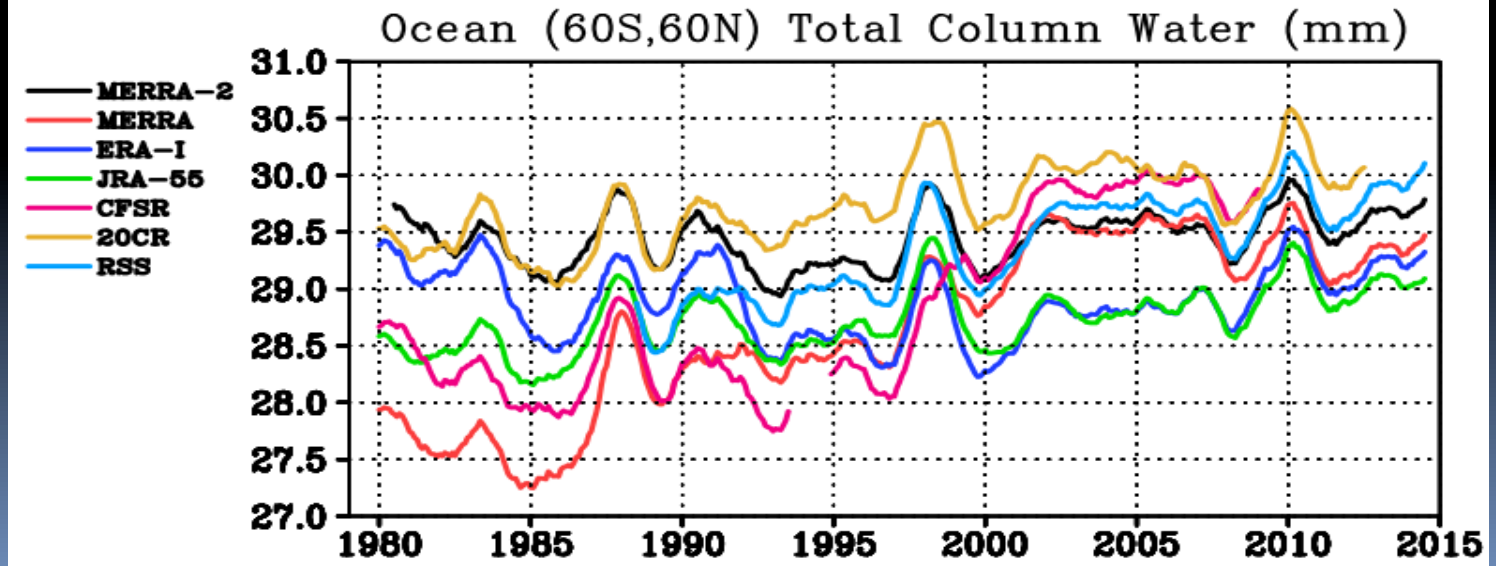


Distribution of Water Vapor Increments

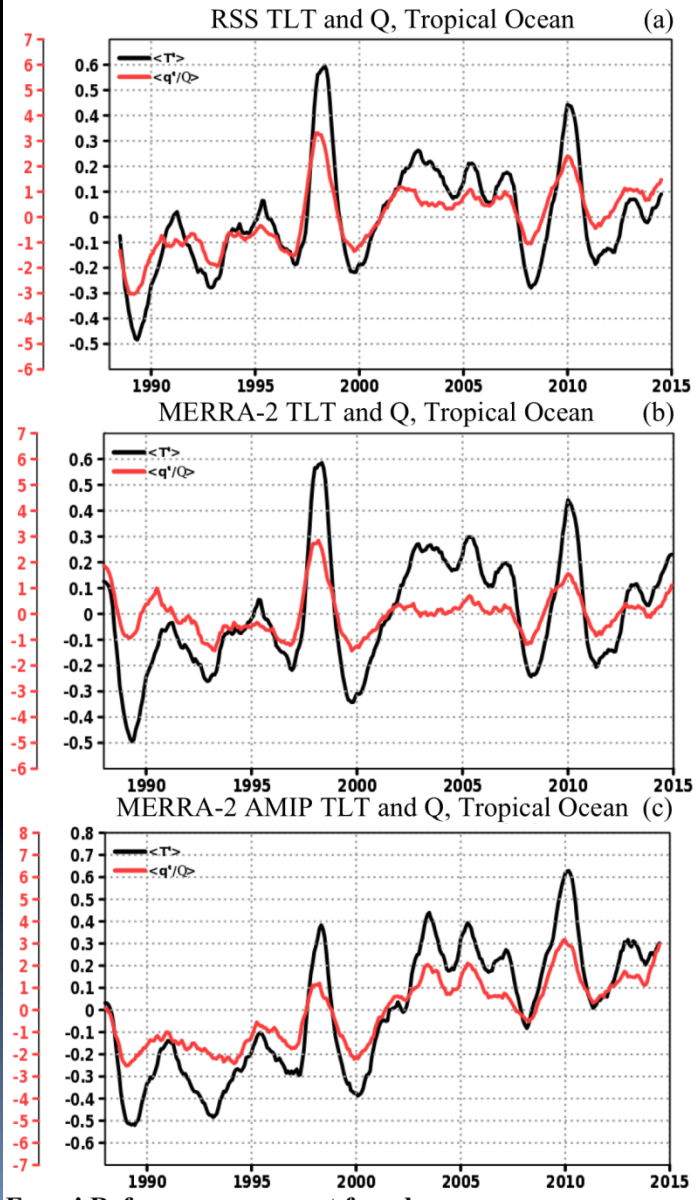
- Despite constraints, MERRA-2 corrects model error in space and time
- Distinctive observing system signatures are apparent

Time Series of Total Precipitable Water





MW data sources with large impact on MERRA have much less impact on MERRA-2 Global TPW



Testing Clausius – Clapeyron: Tropics

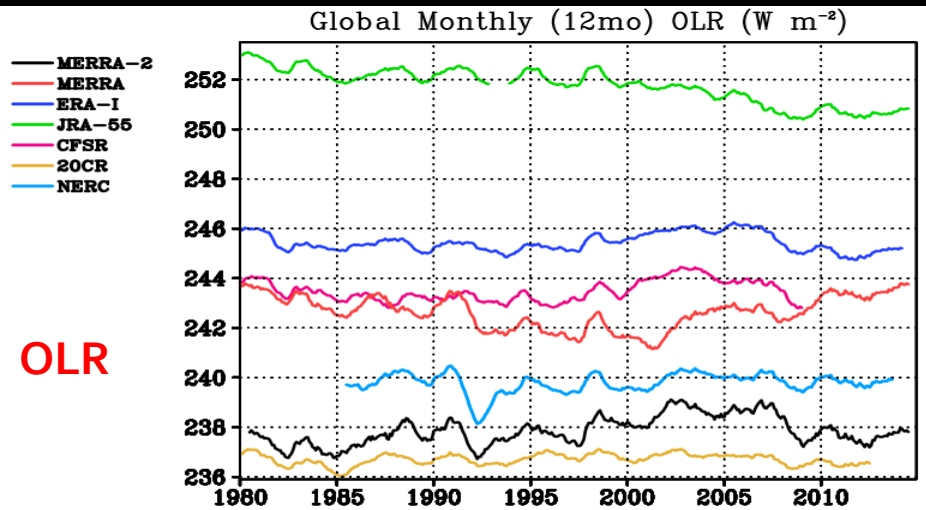
- Using TLT and TPW, MERRA-2 shows a weaker C-C relationship compared to RSS obs and AMIP simulation
- Analysis increment counters some local evaporative increases
- Other reanalyses also show a weak C-C relationship

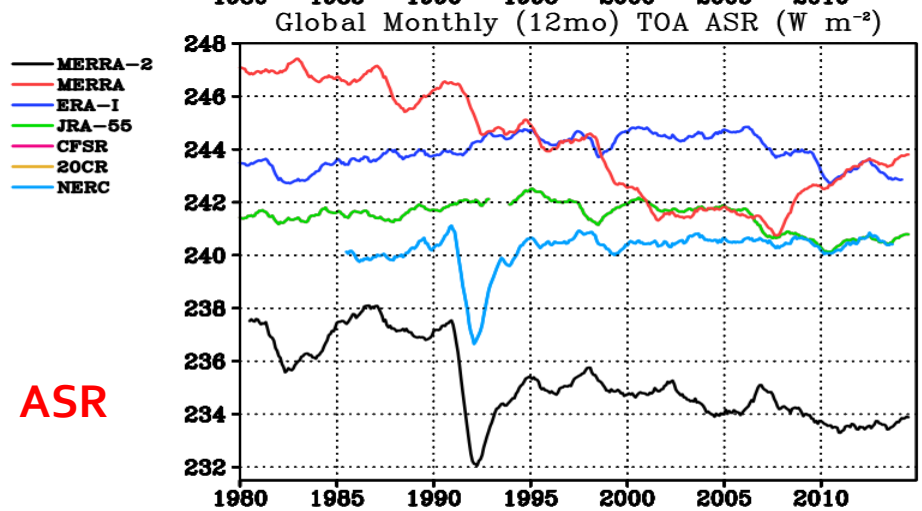
Bosilovich et al. (2016, under review)

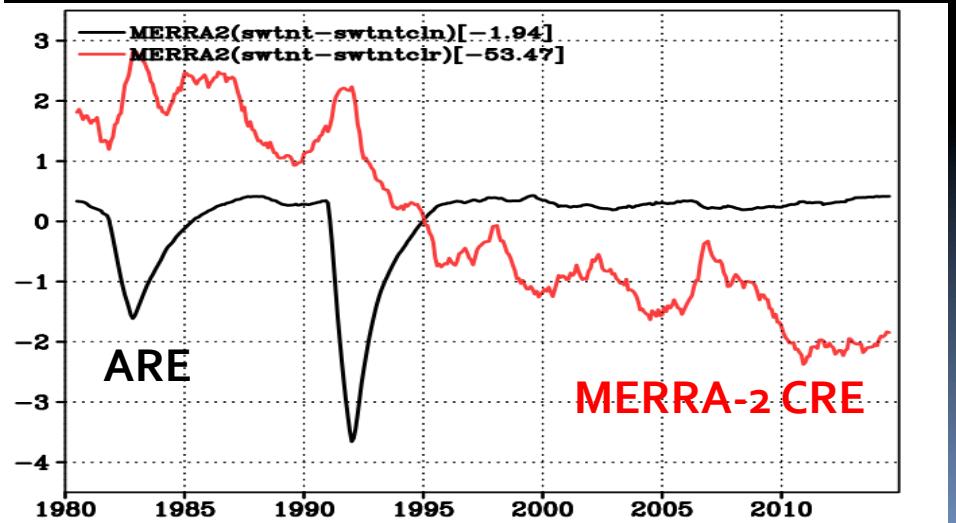
Energy Budget and Temperature

Clouds and Balance

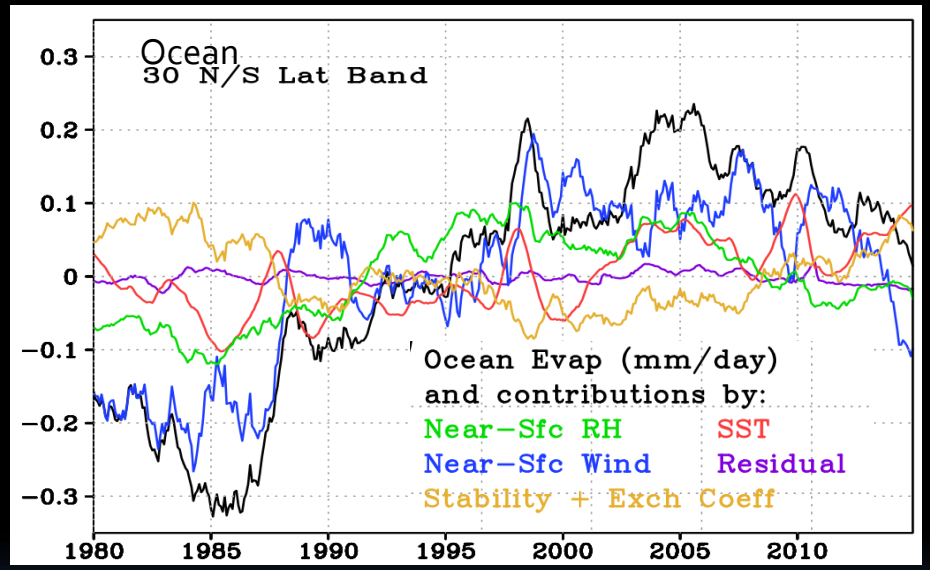
- OLR Compares well with CERES (Allan extension)
- ASR shows decreasing trend (and jumps with volcanic events)
- SW CRE shows the trend, related to clouds
- Regionality: DJF, Southern Ocean; MAM-JJA, E Pacific







Physical Influences on Evaporation

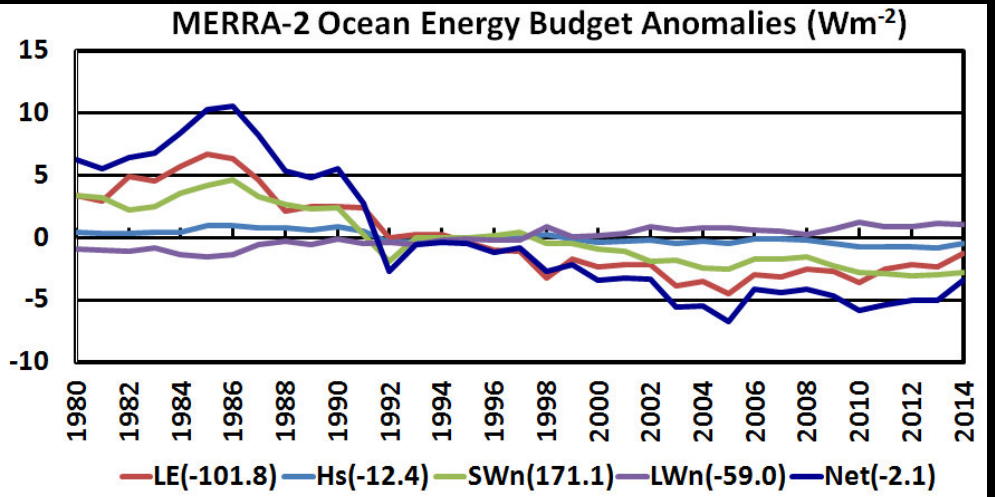


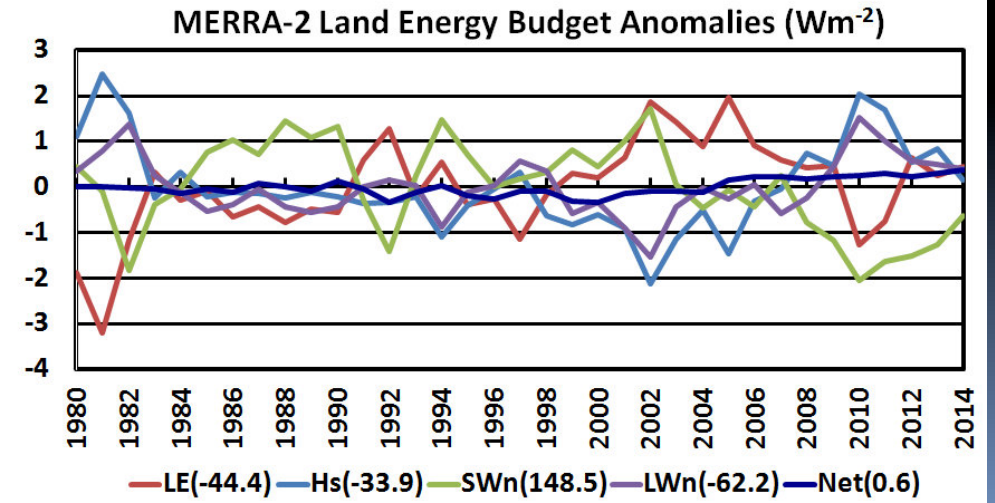
MERRA-2 Evaporation Taylor Series Expansion

$$\delta E = \frac{\partial E}{\partial SST}\delta SST + \frac{\partial E}{\partial U}\delta U + \frac{\partial E}{\partial RH}\delta RH + \frac{\partial E}{\partial S}\delta S + \frac{\partial E}{\partial C_E}\delta C_E + res$$

- Decomposition of the terms of evaporation:
  - Surface winds show strongest
  - SST shows ENSO and GW signals
  - Stability and water vapor influences compensate each other

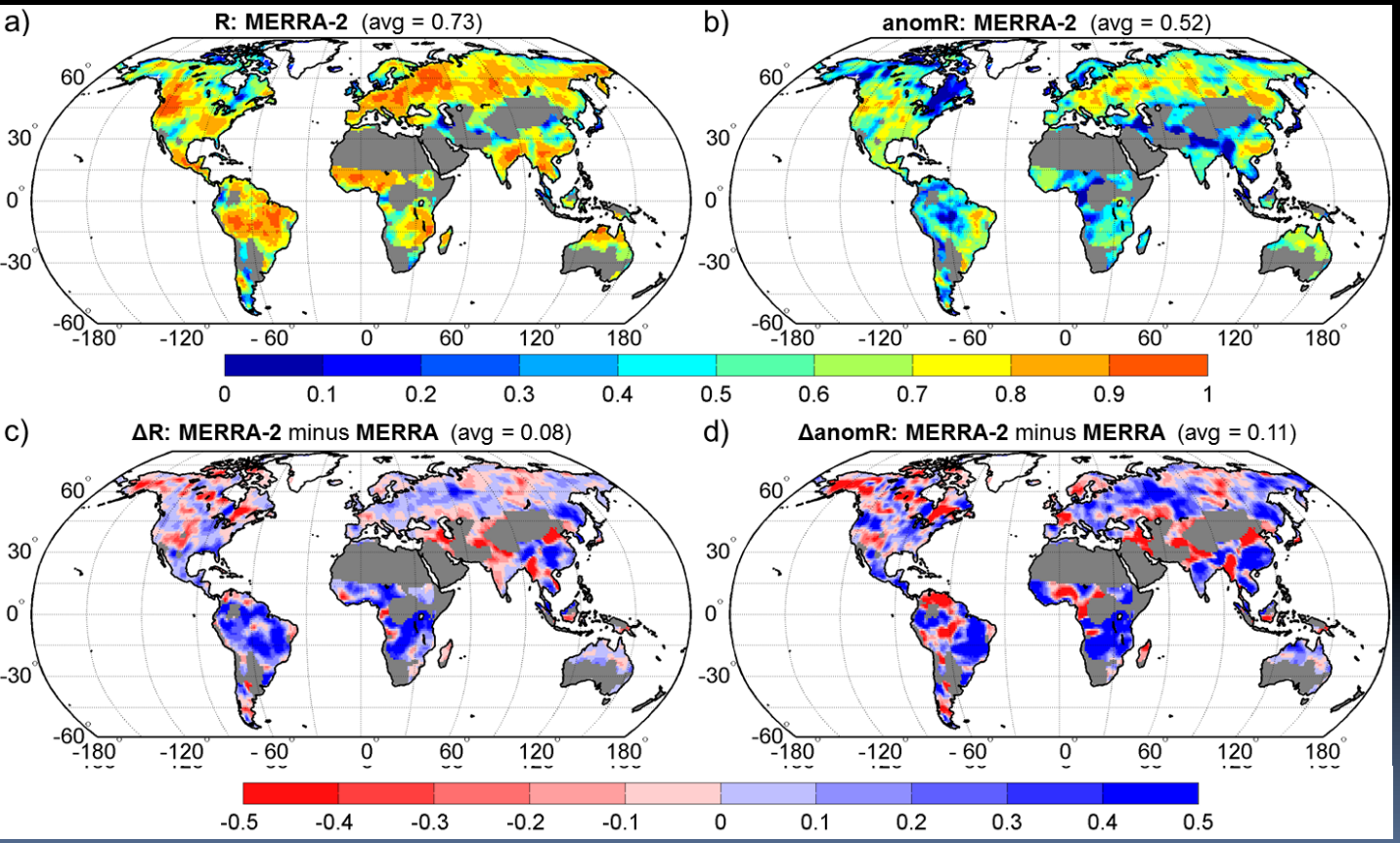
Surface Energy Budgets





- Ocean Surface
  - The evap affect clouds which changes sfc net SW, and Net Flux
- Land Surface
  - Net radiation is more stable over time
  - E, Hs often controlled by SM availability, while SW, LW controlled by cloudiness

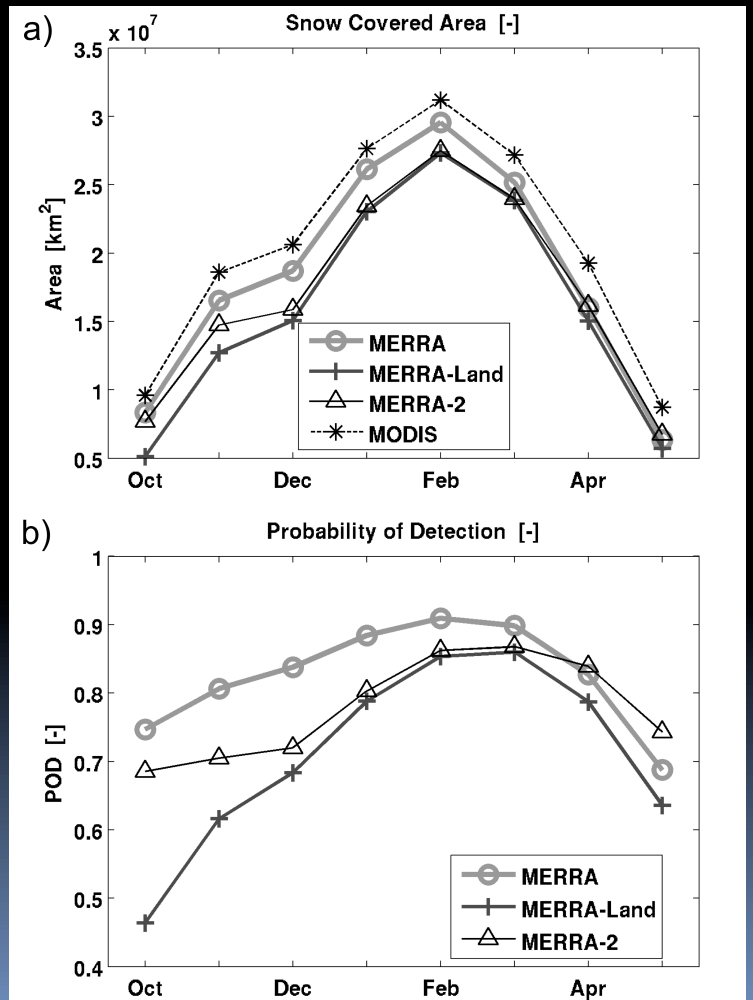
Terrestrial Water Storage



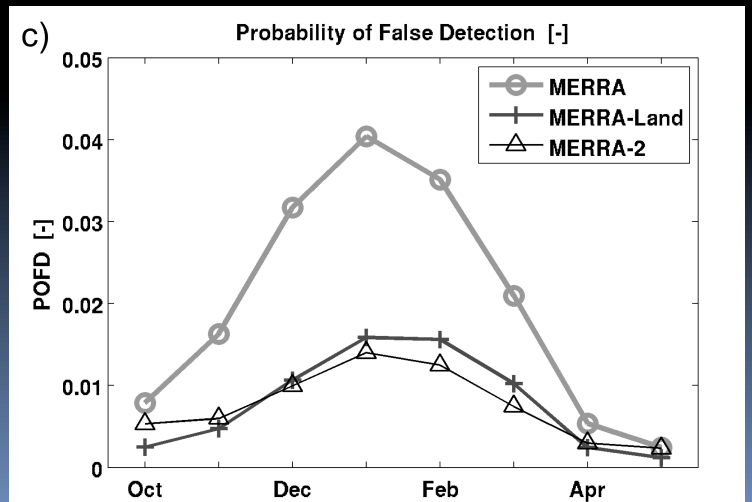
MERRA-2 Hydrology generally improved over MERRA, largely owing to observation corrected precipitation, but also model improvements.

Reichle et al. (2016, In Review)

Snow Cover and Detection



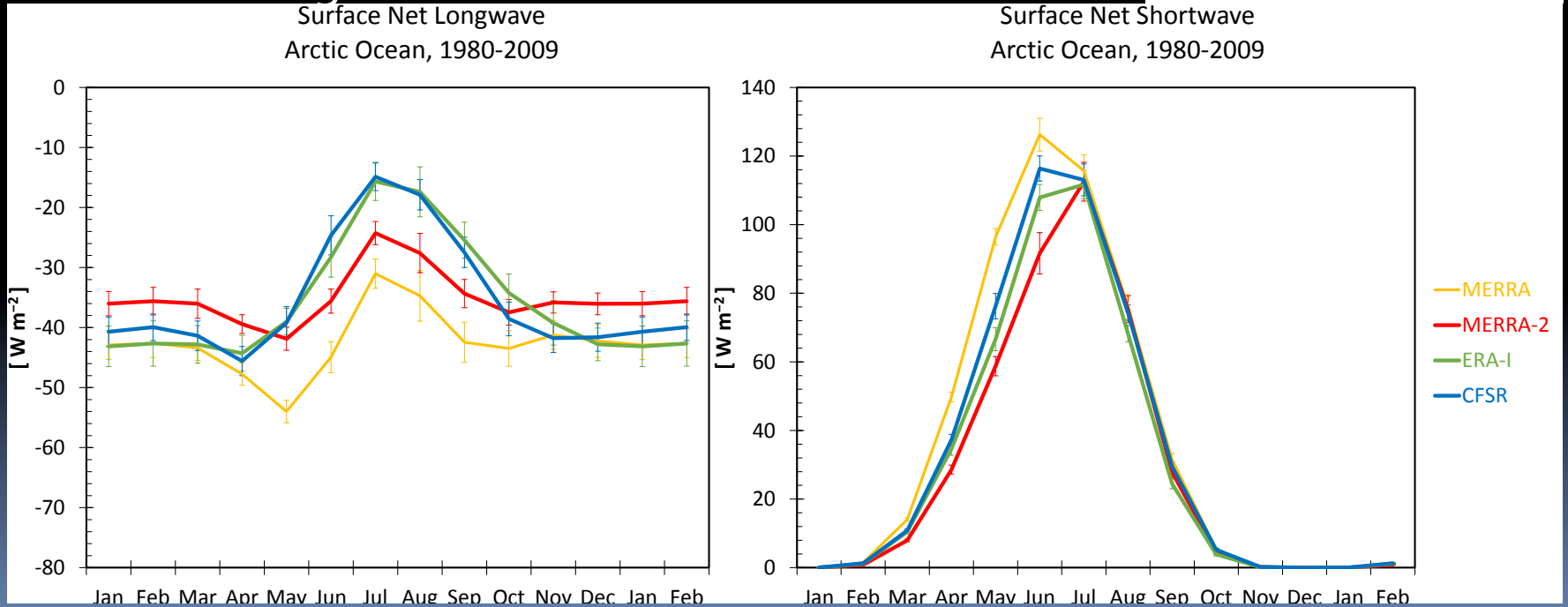
- Generally underestimate snow covered areas
- Probabilities of Detection and False Detection are improved in MERRA-2



Reichle et al. (2016, In Review)

Arctic Sfc Radiation

- Longwave, SHEBA shows MERRA-2 bias in winter months, summer is uncertain
- In Shortwave, diffs from ERAI are in the downwelling radiation



Courtesy Richard Cullather

MERRA-2 Products and Ancillary Applications

Completed 1980-present, now running as a continuing climate analysis with 2-3 week latency

Data available from the NASA Goddard Earth Sciences (GES) Data Information Services Center (DISC)

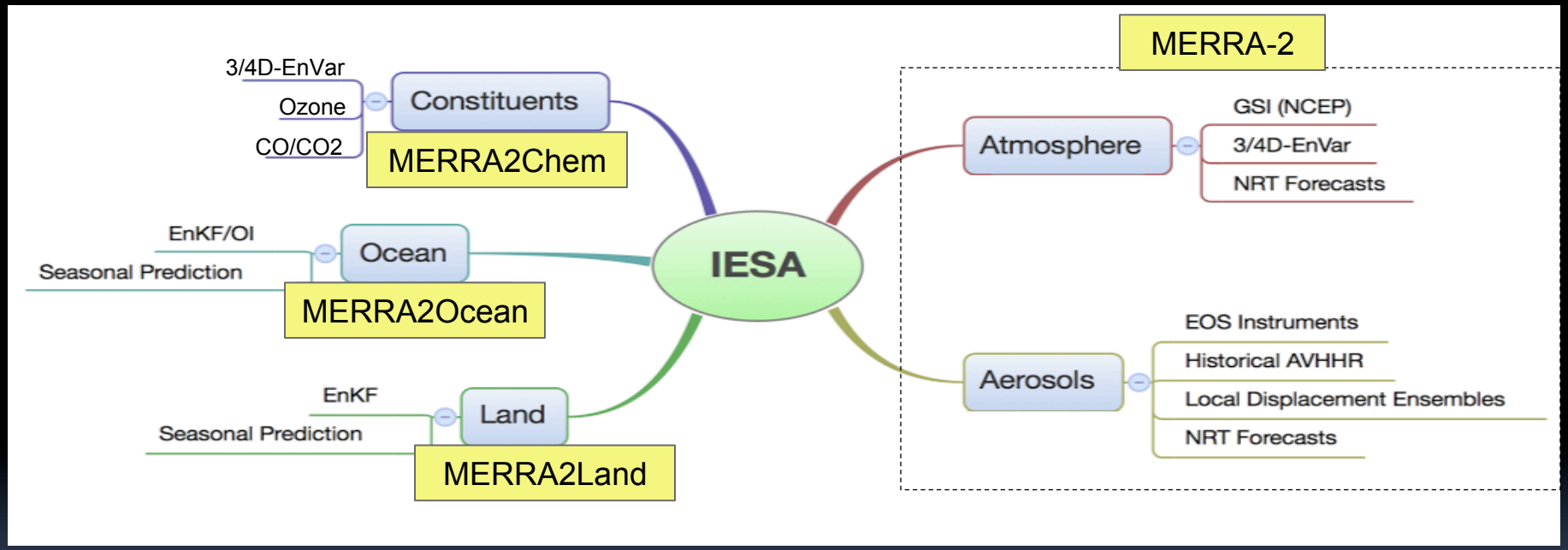
- 1-hourly surface/2D fields (and COSP MODIS/ISCCP), 3- and 6-hourly 3D fields
- Daily Products ~25 GB/day (9.1 TB/yr)
- Monthly Products ~34 GB/mo (408 GB/yr)

Gridded Innovations and Observations (6 hourly conventional - monthly radiances, still under a QC review and documentation)

Ensemble of 10 AMIP integrations using MERRA-2 model configuration

MERRA-2-driven analyses of ocean state (physics and biogeochemistry), atmospheric chemistry (EOS period), and carbon cycle (~Spring 2017)

Toward an Integrated Earth System Analysis



Coupled and MERRA2-driven component reanalyses

Reanalysis Progression

	MERRA	MERRA-2	Next Target
System vintage	2008	2014	------
Release	2009	mid 2015	------
Scope	Atmosphere	Atmosphere, including aerosols and land correction	Atmosphere-ocean-ice-land
Resolution	0.5°×0.66° L72	0.5°×0.625° L72 (C180 cubed sphere)	0.25°×0.3125° L137 (C360 cubed sphere) + 25-km ocean
Analysis	3D-Var atmos	3D-Var atmos	4D EnsVar atmos + EnKF land + EnOI ocean

GMAO

GMAO Reanalysis Support for CERES

- Add flexibility to CERES support, separate from MERRA project development path
- Build a set of evaluation criteria into the GMAO model development tracking
  - Identify/review each version of model/analysis in regards to these criteria
  - Use set case study periods (eliminates natural variations and other observing system perturbations)
- As CERES Reprocessing gets near we should have a complete understanding of the system regarding CERES needs
- Will require routine communication and regular review of the latest GEOS development experiments

Thanks!

https://gmao.gsfc.nasa.gov/reanalysis/

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