NASA ENERGY AND WATER CYCLE STUDY

Inter-annual to Inter-decadal Variability in Ocean / Land Moisture Transport: Estimates from Reanalyses, Satellites and Land Surface Models

Franklin R. Robertson[1] , Michael G. Bosilovich[2] and Jason B. Roberts[1]

[1]NASA / Marshall Space Flight Center, Earth Science Branch, 320 Sparkman Dr., Huntsville, AL 35805, USA [2]NASA / GSFC Global Modeling and Assimilation Office, 880 Greenbelt, Rd, Greenbelt, MD 20771

Issues & Challenge:

Vertically-integrated atmospheric transport of moisture between ocean and land is a fundamental component of the physical climate system linking the hydrologic and energy cycles of the planet as well as determining fresh water fluxes to the ocean, and water availability to the biosphere.

For land / ocean domains and monthly time scales, vertically-integrated moisture convergence $\int_m -\nabla\cdot q\boldsymbol{V}\,dm \sim$ P-E; thus, (i) direct estimates of this transport from reanalysis wind and moisture fields, (ii) E and P from satellite retrievals and, (iii) P and ET from observationally constrained land surface models yield largely independent estimates on land/ocean moisture exchange. *To what degree are variations in the fluxes mutually consistent?*

Atmospheric Moisture Budget and Complementary Data Sources

Atmospheric Reanalyses

- Atmospheric Reanalyses
- Passive Microwave Satellite (Ocean)
- Observationally Constrained Land Surface Models

Moisture Budget
$$\frac{\partial W}{\partial t} = \int_m -\nabla\cdot q\boldsymbol{V}\,dm + E - P$$

Flux Divergence Moisture Vanishes Globally
$$\int_{oc}\int_m \nabla\cdot q\boldsymbol{V}\,dm\,\delta a_{oc} = \int_{land}\int_m -\nabla\cdot q\boldsymbol{V}\,dm\,\delta a_{land}$$

Complementarity of Ocean and Land Area average Data
$$E_{OC} - P_{OC} = \int_{area} (P-ET)_{land}\,\delta a$$

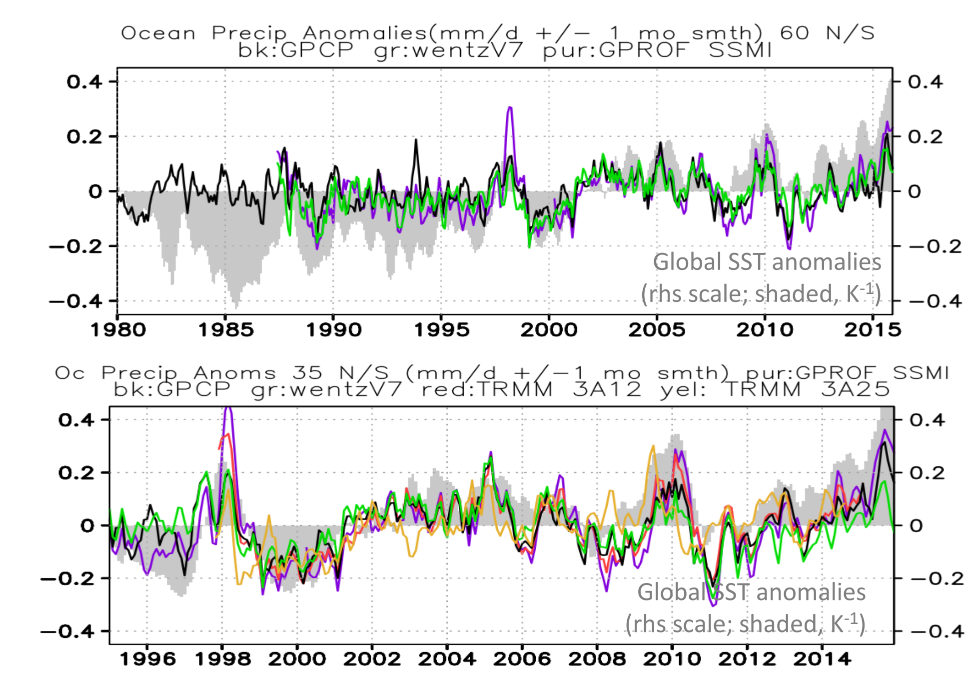
Satellite Evap	SeaFlux3, https://cclayson.whoi.edu/seaflux/ J-OFURO3, https://j-ofuro.scc.u-tokai.ac.jp/en/ FREMER4, https://wwz.ifremer.fr/oceanheatflux/ HOAPS4, https://wui.cmsaf.eu/
Reanalyses	JRA55C, http://jra.kishou.go.jp/JRA-55/index_en.html NOAA/ESRL 20CRv3,https://www.esrl.noaa.gov/psd/data/20thC_Rean/ CERA-20C, https://www.ecmwf.int ERA5,https://www.ecmwf.int
Precipitation	Remote Sensing Systems (RSS) http://www.remss.com/. P-ET from GPCP, https://precip.gsfc.nasa.gov/
Land Surface Models	http://www.watergap.de/ http://earth2observe.github.io/water-resource-reanalysis-v1/ https://www.gleam.eu/ (GLEAM 3.2 ET)
GMSL	https://sealevel.nasa.gov/
GRACE Reconst.	Humphrey et al, 2017 GRL

Time–Dependent Flux Variability over Ocean / Land Domains

Area-averaged monthly anomalies over 60°N/S Land and Ocean Regions
(units: kg m^{-2}, base climatology 1990/2010, running 3-month smoothing)

Global Ocean Precipitation (mm d^{-1})

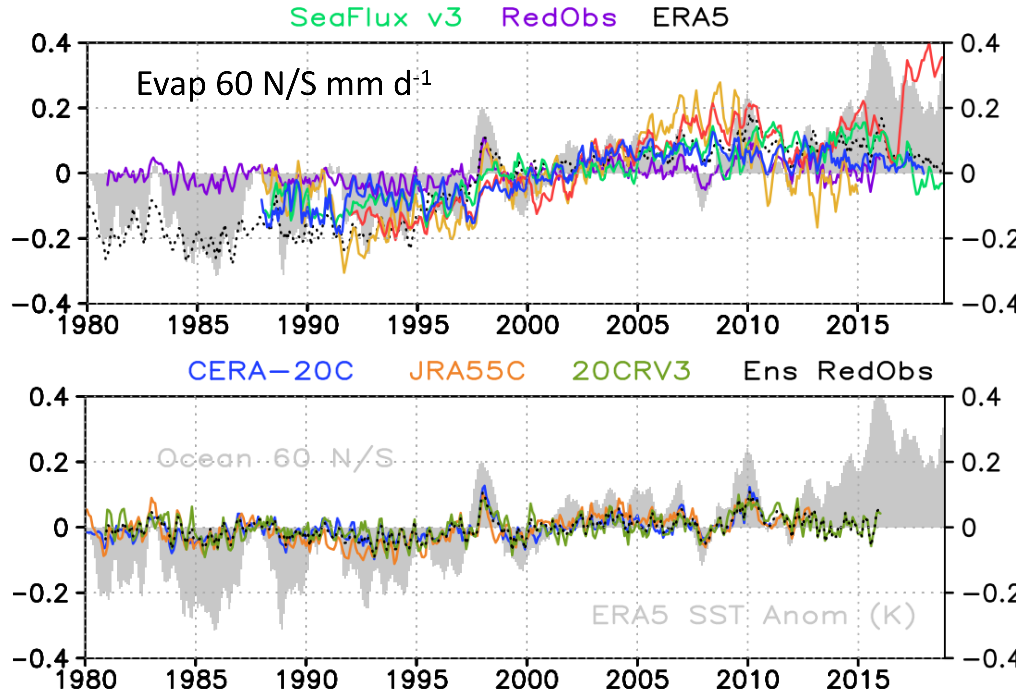
GPCP RSS V7 GPROF2010.2 TRMM GPROF TRMM 3A25



- Strong correlation between oceanic P and SST on ENSO time scales with more (less) P sequestered over oceans during warm (cold) events.
- PR 3A25 (Orbit boost & bias corrected) indicates GPROF biases related to stratiform / convective detection.

Global Ocean Evaporation (mm d^{-1})

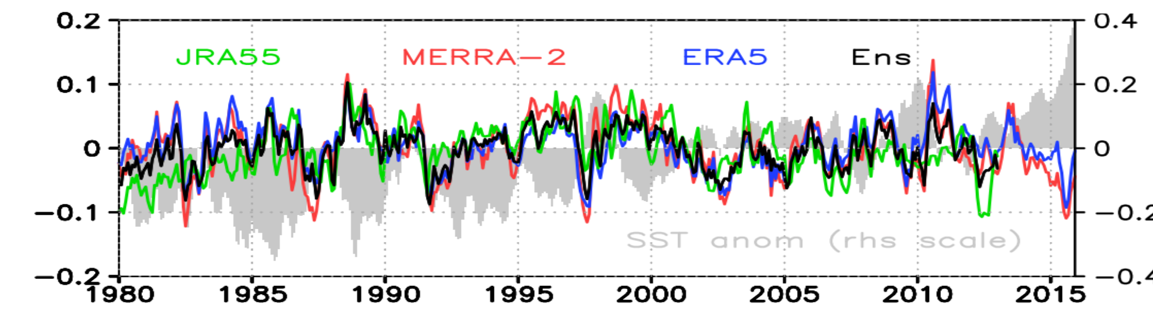
HOAPS4.1 IFREMER4.1 J–OFURO3 SeaFlux v3 RedObs ERA5



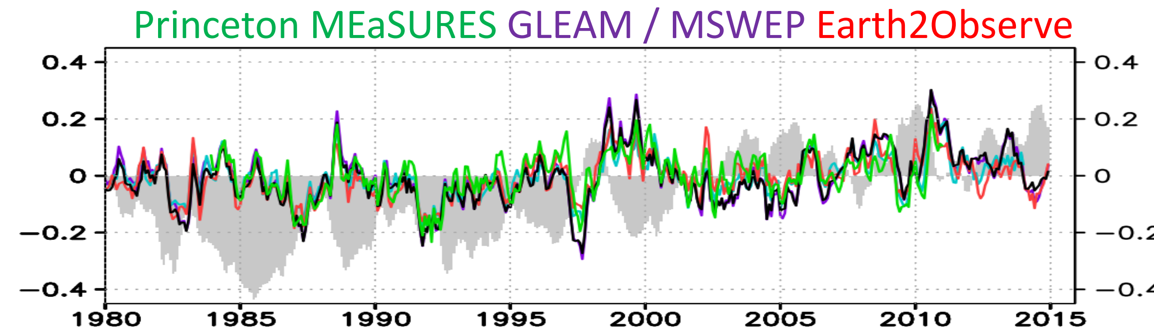
- Evaporation low-frequency behavior and trends are much greater and likely exaggerated in IFREMER4, HOAPS4 and ERA5 but JOFURO3 and SeaFlux v3 are generally closer to Reduced Observation Input Reanalyses (RedObs) which use no satellite inputs.
- Uncertainties in (1) SSMIS sensor wind speeds and (2) input qs(SST) are significant contributions to satellite retrievals.

Reanalysis Global Ocean $\int_m \nabla\cdot q\boldsymbol{V}\,dm$ and Land Surface Model P-ET (mm d^{-1})

MERRA-2 ERA5 JRA-55 (Adjusted for changes in satellites)

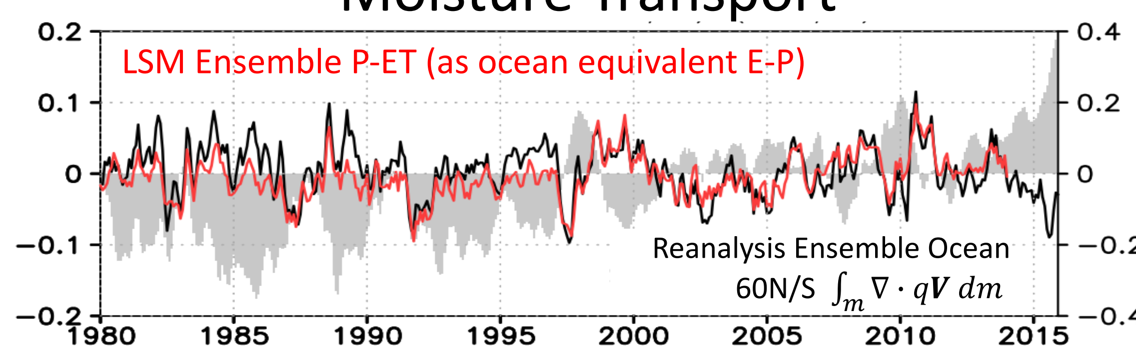


Land Surface Model P-ET WaterGAP (GPCC precip)
Princeton MEaSURES GLEAM / MSWEP Earth2Observe

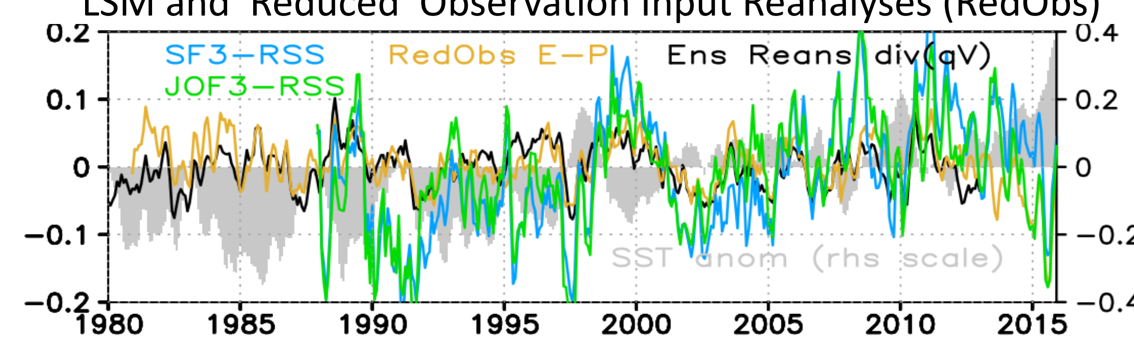


- Both reanalyses and LSMs show systematic anomalous export of moisture from ocean to land (land to ocean) during transition to ENSO cold (warm) events. Anomalous moisture export to land and P-ET decreases over land tend to lead global SST maxima.

Consistency Check: Atmospheric Moisture Transport



Reanalysis Ensemble $\int_m \nabla\cdot q\boldsymbol{V}\,dm$, E-P from Satellite, LSM and Reduced Observation Input Reanalyses (RedObs)

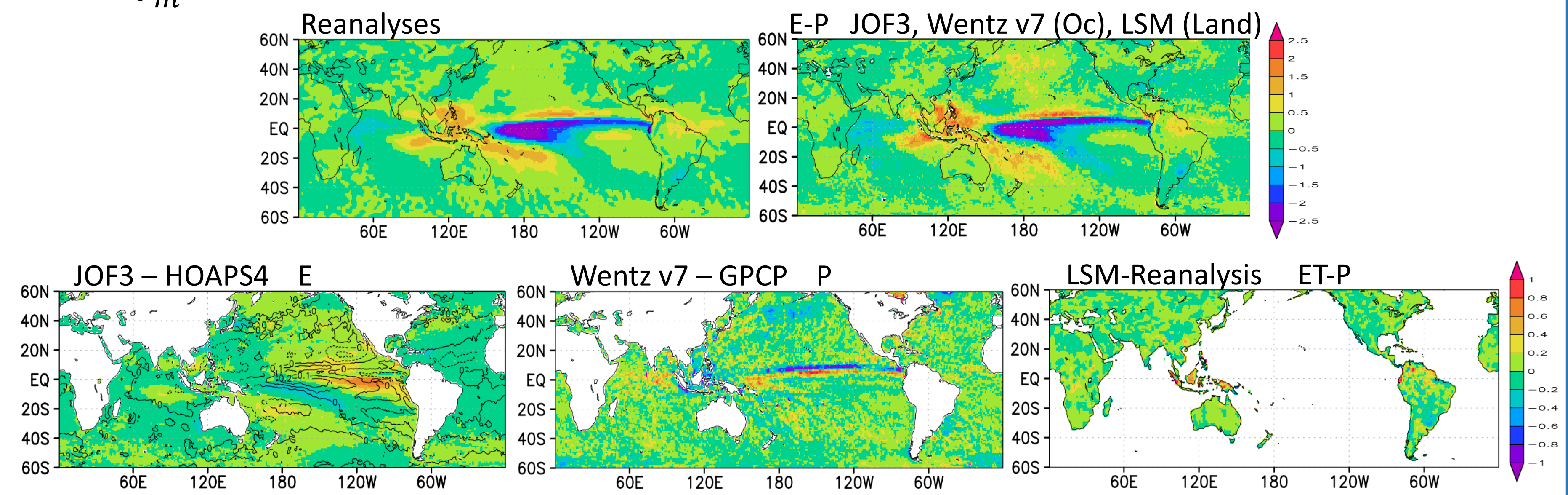


- Significant agreement exists between reanalysis export of moisture from ocean to land and land P-ET diagnosed from observationally-constrained Land Surface Models.
- Satellite retrievals of E-P over the global oceans, while sign-consistent in terms of interannual signals, exhibit greater amplitudes than reanalysis div(qV) or RedObs.

Summary Points:

(1) Reanalysis vertically-integrated moisture flux divergence variability shows strong consistency with quasi-independent, observationally driven LSM P-ET estimates.
(2) ENSO warm and cold SST events provide the primary interannual signal modulating land ocean moisture exchange.
(3) Satellite P - E estimates over ocean exhibit significantly stronger interannual signals and trends than either reanalyses or LSMs. Known retrieval issues with satellite evaporation (SSMIS calibration, input SST) drive trends. Satellite precipitation monthly variations are larger than reanalyses. → Satellite P-E differs from reanalyses and obs driven LSMs.
(4) Future work to optimally blend these and other water and energy cycle fluxes to minimize error depends on establishing error covariance structures of quantities and accounting for time and weather regime dependence of these errors.

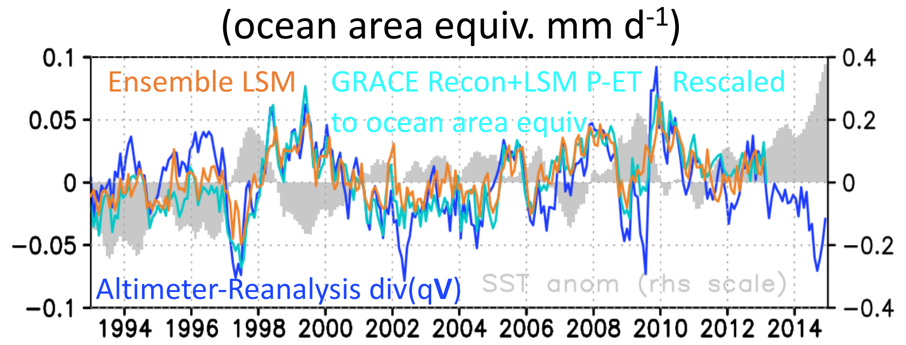
$\int_m \nabla\cdot q\boldsymbol{V}\,dm$ Zero-lag Regressions on Nino3.4 (mm d^{-1} K^{-1})



- Well-known regional patterns of moisture export / import in reanalyses are replicated by satellite retrievals and LSM syntheses of E-P.
- Satellite E retrieval differences have longitudinal variations, P differences are more meridional.

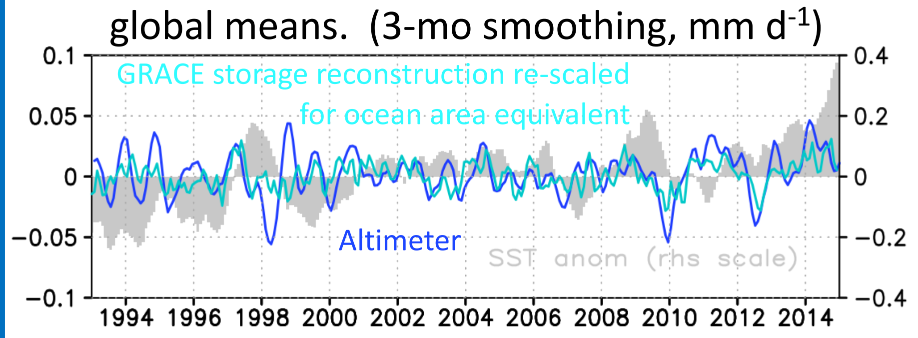
Consistency Check: Interannual Variability in Global Mean Sea Level

Discharge / Runoff (ocean area equiv. mm d^{-1})



Note: ALT/Rean estimate independent of LSMs

dGMSL/dt Anomalies from de-trended global means. (3-mo smoothing, mm d^{-1})



TOPEX/Poseidon / JASON & GRACE

- Atmospheric Reanalysis $-\int_m \nabla\cdot q\boldsymbol{V}\,dm$
- Satellite ocean P, E retrievals, LSM P, E

$$\frac{dGMSL}{dt} = P - E + \text{Discharge}$$

We update the Syed et al (2010) estimate of global land discharge variations solved as the residual of rate of GMSL change + either reanalysis $\int_m \nabla\cdot q\boldsymbol{V}\,dm$, or E-P anomalies from LSMs (scaled for land / ocean relative area coverage).

Tendencies of both TOPEX / Poseidon / JASON Altimeter (https://sealevel.nasa.gov/) and GRACE Reconstructed Storage data (Humphrey et al, 2017 GRL) are used to estimate GMSL rate of change.