Integrating Multi-Platform Satellite Soil Moisture and Evapotranspiration Retrievals to Constrain Water and Energy Balance Coupling

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MODIS Land Science Analysis
Motivation – Water and Energy Balance Coupling

Land-Atmosphere Interaction

- Outgoing Radiation
- Net Radiation
- Precipitation
- Latent Heat Flux
- Sensible Heat Flux
- Evaporation
- interception
- Infiltration

Physical Model

- Cross Validation
- In-situ
- Remote Sensing

Soil Moisture

Evapotranspiration

Energy Balance

Soil Heat Flux

Water Balance
Motivation – Multi-Platform Remote Sensing

- Meteorological Information
  - Solar insolation
  - Precipitation
  - Atmospheric temperature
  - Wind speed
  - Humidity
  ...

- Land Surface Characteristics
  - Soil moisture
  - Land surface temperature
  - Leaf area index
  - Landcover type
  ...

Multi-platform satellite soil moisture and evapotranspiration products
Here comes the question...

Are current land surface models accurate in characterizing the relation between soil moisture and evapotranspiration?

Key challenge:

Coupling estimates obtained from (relatively noisy) satellite retrievals are biased.

Our approach:

Obtain unbiased, observation-based global estimates of true coupling by integrating multi-platform soil moisture and evapotranspiration retrievals
Multi-Platform Land Products – Evapotranspiration

Atmosphere-Land Exchange Inverse

Energy balance:

\[ ET = (R_{NET} - G) - H \]

Blending height

ALEXI
(Atmosphere-Land Exchange Inverse model)

DATA FUSION: daily ET at field scale

[Anderson et al., 2011]
Multi-Platform Land Products – Evapotranspiration

- Global ALEXI ET product from MODIS LST

Radiation Fluxes
CFS-R CFSv2 [0.5°]

Lapse Rate Profile
CFS-R [0.5°]

Wind Speed
CFS-R [0.5°]

Landcover Type
UMD [0.01°]

Albedo
MODIS MOD43C [0.05°]

Land Surface Temperature
MODIS MYD11C1 [0.05°]

Leaf Area Index
MODIS MOD15A [0.01°]
Multi-Platform Land Products – Evapotranspiration

- MW-LST retrievals from Ka-band satellite sensors

[Holmes et al., 2015]
Cumulative - Clear Sky - Evapotranspiration (mm)
2004

[Holmes et al., 2018]
Multi-Platform Land Products – Soil Moisture

ESA CCI merged passive microwave soil moisture

MetOp-A/B ASCAT active microwave soil moisture

[Dorigo et al., 2017]
Multi-Platform Land Products – Soil Moisture

ESA CCI PASSIVE SM (2010/07/01)

Passive Microwave Soil Moisture \([m^3/m^3]\)

ESA CCI ACTIVE SM (2010/07/01)

Active Microwave Percent of Saturation [%]
A Unified Approach to Integrate Products

Triple collocation-based coupling strength metric

Soil Moisture Evapotranspiration


[Crow et al., 2015]
Discrepancy among Land Surface Models

Global Land Data Assimilation System

- Noah v3.3
- Community Land Model (CLM) v2.0
- Variable Infiltration Capacity (VIC)
- Catchment Land Surface Model (CLSM) F2.5

\[ R^2[SM_{LSM}ET_{LSM}] \]
Direct coupling from multi-platform and LSMs

Remote Sensing

$R^2 [SM_{RS} ET_{RS}]$

GLDAS LSMs

$R^2 [SM_{LSM} ET_{LSM}]$
Integrated multi-platform based coupling

Triple Collocation

$R^2[SM_{TC}ET_{TC}]$

GLDAS LSMs

$R^2[SM_{LSM}ET_{LSM}]$
Benchmarking Land Surface Models

Biases in LSMs with regard to triple collocation-based estimates

Maps showing biases in Noah, VIC, CLM, and CLSM models compared to triple collocation-based estimates.

Bar charts showing percentages of pixels for different regions (North America, South America, Europe, Africa, Asia, Australasia) for each model with indications of under-coupling, differences within 2-sigma, and over-coupling.
Benchmarking Land Surface Models

The diagram illustrates the mean of SM/LH coupling strength (Spearman $R^2$) across various Koppen-Geiger climate zones. The x-axis represents different climate zones, while the y-axis shows the mean of SM/LH coupling strength. The diagram includes several lines representing different models:

- $R^2[SM_{LSM}, ET_{LSM}]$ (Noah)
- $R^2[SM_{LSM}, ET_{LSM}]$ (CLM)
- $R^2[SM_{LSM}, ET_{LSM}]$ (VIC)
- $R^2[SM_{LSM}, ET_{LSM}]$ (CLSM)

The graph also indicates the number of land grid cells on the right y-axis. The climate zones are categorized as Hot, Humid, and Dry, with corresponding color coding for visual differentiation.
Here come the answers...

- Random errors in remote sensing products impede the direct comparison
- Large discrepancies exist among various land surface models
- Land surface models generally overestimate the soil moisture/evapotranspiration coupling strength along transitional climate regimes

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On-going Development

ALEXI

TIR-LST

VIIRS

MW-LST

FY-3B

CMIP5/6 LS3MIP

from offline to coupled

Land Surface Model

Noah-MP (modular)
Thank you!
Remote Sensing

$R^2[SM_{RS}ET_{RS}]$

GLDAS LSMs

$R^2[SM_{LSM}ET_{LSM}]$
Triple Collocation

$R^2[SM_{TC}ET_{TC}]$

GLDAS LSMs

$R^2[SM_{LSM}ET_{LSM}]$