National Aeronautics and
Space Administration

M21C Land Budgets, Part 2

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28 July 2024

Land Water and Energy Balance

National Aeronautics and Space Administration

Balance equations from the land ("lnd") perspective:

MERRA-2 File Specs (p. 71): **WCHANGE = PRECTOTLAND – EVLAND – RUNOFF – BASEFLOW + SPWATR**

MERRA-2 File Specs (p. 72): **ECHANGE = SWLAND + LWLAND – SHLAND – L_v EVLAND – L_f PRECSNOLAND – SPLAND – SPSNOW.**

Wrong!
(For M-2 and M21C.)

Correct balance equations (M-2 and M21C):

WCHANGE = PRECTOTLAND – EVLAND – RUNOFF – BASEFLOW – SPWATR

ECHANGE = SWLAND + LWLAND – SHLAND – EVPINTR – EVPSBLN – EVPSOIL – EVPTRNS
– Lf * PRECSNO – SPLAND – SPSNOW

For details and plots, see 11 Jun 2024 slides.

Land Energy Balance

Inconsistent output within "lnd" Collection (M-2 and M21C):

EVPINTR + EVPSBLN + EVPSOIL + EVPTRNS ≠ LHLAND !!!

In GCM mode, LHLAND adjusted in GEOS_CatchGridComp.F90:

```
if (CATCH_INTERNAL_STATE%CATCH_OFFLINE == 0) then

  !amm add correction term to latent heat diagnostics (HLATN is always allocated)
  !    this will impact the export LHLAND

  HLATN = HLATN - LHACC

  ! also add some portion of the correction term to evap from soil, int, veg and snow

  SUMEV = EVPICE+EVPSOI+EVPVEG+EVPINT

  where(SUMEV>0.)
    EVPICE = EVPICE - EVACC*EVPICE/SUMEV
    EVPSOI = EVPSOI - EVACC*EVPSOI/SUMEV
    EVPINT = EVPINT - EVACC*EVPINT/SUMEV
    EVPVEG = EVPVEG - EVACC*EVPVEG/SUMEV
  endwhere
endif
```

11 Jun 2024 slides:

→ LHLAND modified

EVACC~0 for SUMEV>0

→ EVP[*] essentially unchanged

For details and plots, see 11 Jun 2024 slides.

Connect Land Water and Energy Balances

National Aeronautics and Space Administration

Water [kg m-2 s-1]:

WCHANGE = PRECTOTLAND – EVLAND – RUNOFF – BASEFLOW – SPWATR

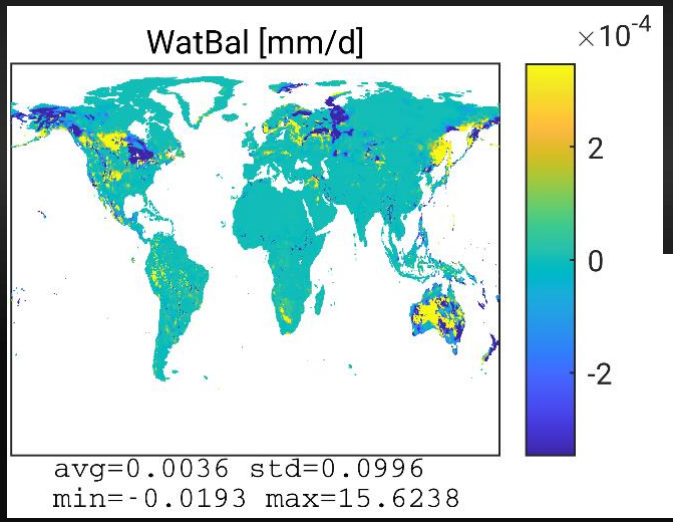
Energy [W m-2]:

ECHANGE = SWLAND + LWLAND – SHLAND – EVPINTR – EVPSBLN – EVPSOIL – EVPTRNS

– Lf * PRECSNO – SPLAND – SPSNOW

Consistent? No!

EVLAND ≠ (EVPINTR + EVPSOIL + EVPTRNS)/Lv + EVPSBLN/Ls




```
m21c_prod.lnd_tavg_2hr_glo_L1152x721_slv

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WatBal = evland
         -(evpintr+evpsoil+evptrns)/Lv -evpsbln/Ls;
```

Connect Land Water and Energy Balances

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Water [kg m-2 s-1]:

WCHANGE = PRECTOTLAND – EVLAND – RUNOFF – BASEFLOW – SPWATR

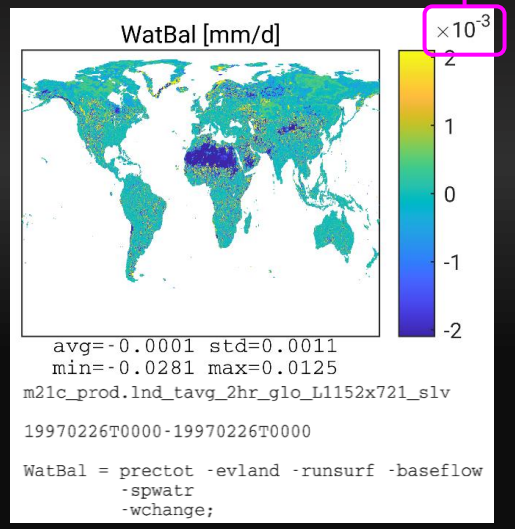
Energy [W m-2]:

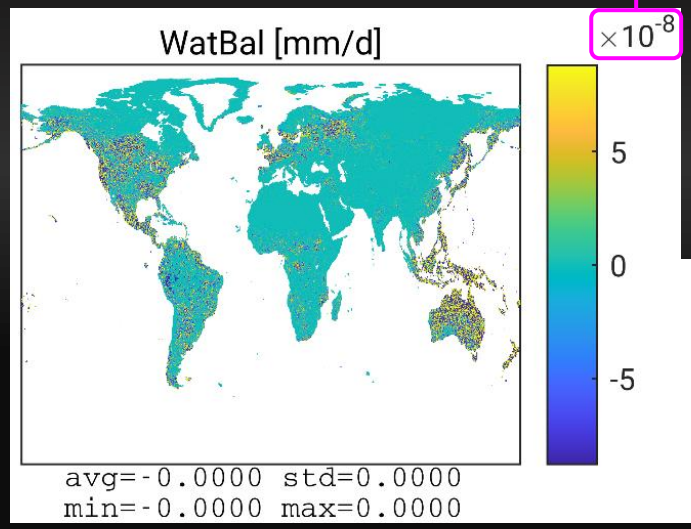
ECHANGE = SWLAND + LWLAND – SHLAND – EVPINTR – EVPSBLN – EVPSOIL – EVPTRNS

– Lf * PRECSNO – SPLAND – SPSNOW

Consistent when including SPWATR:

EVLAND + SPWATR = (EVPINTR + EVPSOIL + EVPTRNS)/Lv + EVPSBLN/Ls





Note: Residuals w/in roundoff.
Larger for full water balance.

```
m21c_prod.lnd_tavg_2hr_glo_L1152x721_slv

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WatBal = evland
         -(evpintr+evpsoil+evptrns)/Lv -evpsbln/Ls
         +spwatr;
```

Water Balance Across Land and Atmosphere

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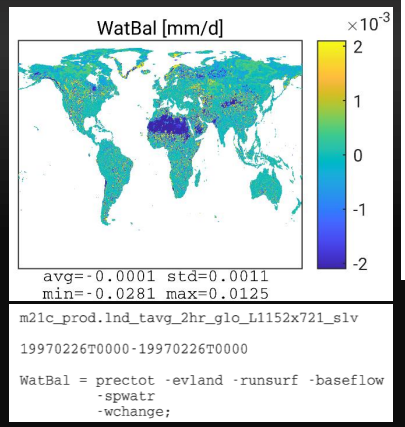
Land:

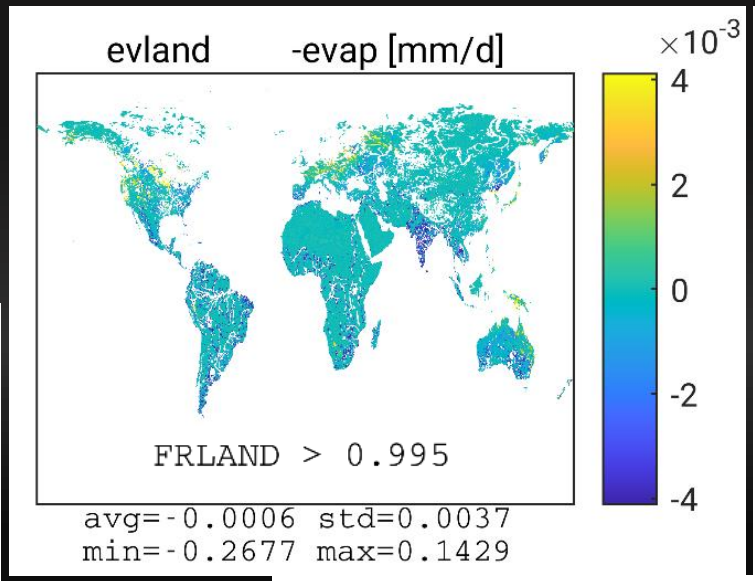
WCHANGE = PRECTOTLAND – EVLAND – RUNOFF – BASEFLOW – SPWATR

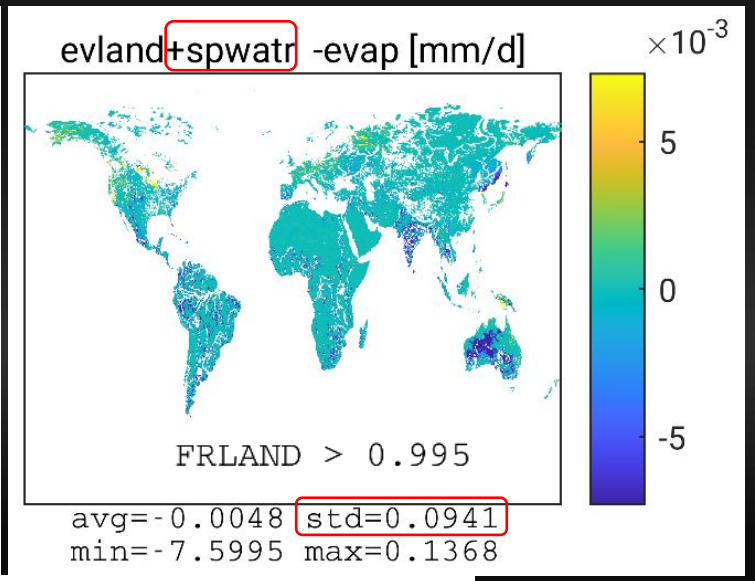
Atmosphere:

DQVDT_PHY + DQLDT_PHY + DQIDT_PHY = EVAP – PRECCU – PRECLS – PRECSN + QTFILL

For land-only grid cells: $EVLAND_{lnd} = EVAP_{flx}$







m21c_prod.lnd_tavg_2hr_glo_L1152x721_slv

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Energy Balance Across Land and Atmosphere

Land:

$$ECHANGE = SWLAND + LWLAND - SHLAND - \underbrace{(EVPINTR + EVPSBLN + EVPSOIL + EVPTRNS)}_{= SUMEVP} - Lf * PRECSNO - SPLAND - SPSNOW$$

Atmosphere: (Closure to be confirmed by Nathan.)

$$DHDT\_PHY + DKDT\_PHY + DQVDT\_PHY + DQIDT\_PHY =$$
$$(SWNETTOA - SWNETSRF) - (LWTNET + LWGNET) + HFLUX + \underbrace{Lv*EVAP}_{= EFLUX}$$
$$+ Lf*(FRZRN + SUBSN + SDMCI + COLCNVSN) + Lv*DQVDT\_CHM + Lv*DQVDT\_FIL - Lf*DQIDT\_FIL$$

For land-only grid cells:

$SWLAND_{lnd} =? SWNETSRF_{int}$

$LWLAND_{lnd} =? LWGNET_{int}$

$SHLAND_{lnd} =? HFLUX_{flx}$

$SUMEVP_{lnd} =? EFLUX_{flx}$

Energy Balance Across Land and Atmosphere

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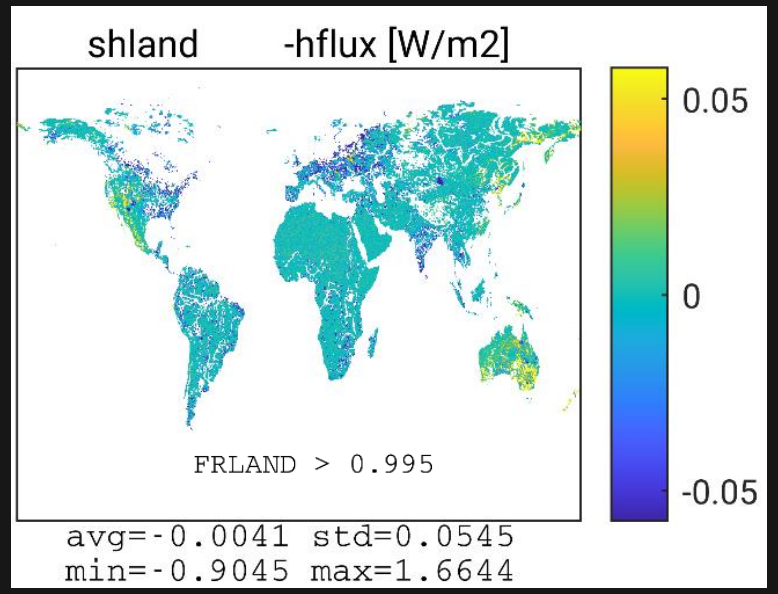
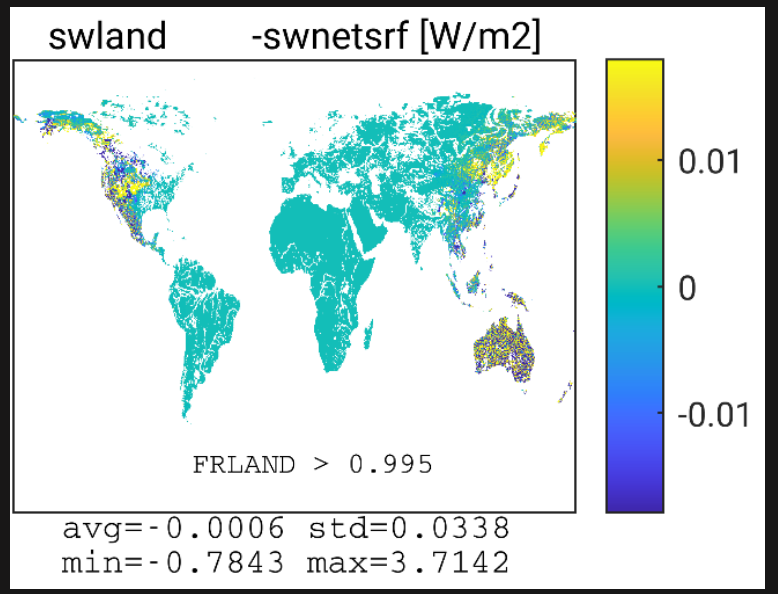
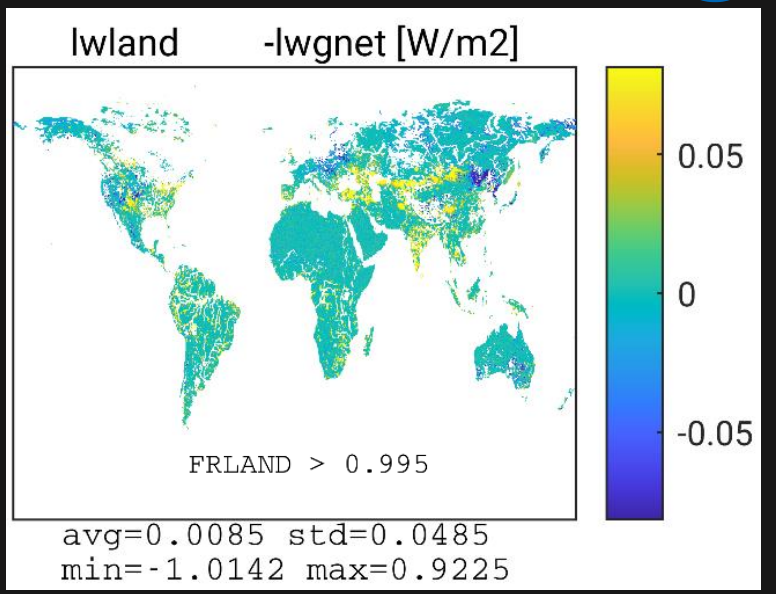






For land-only grid cells:

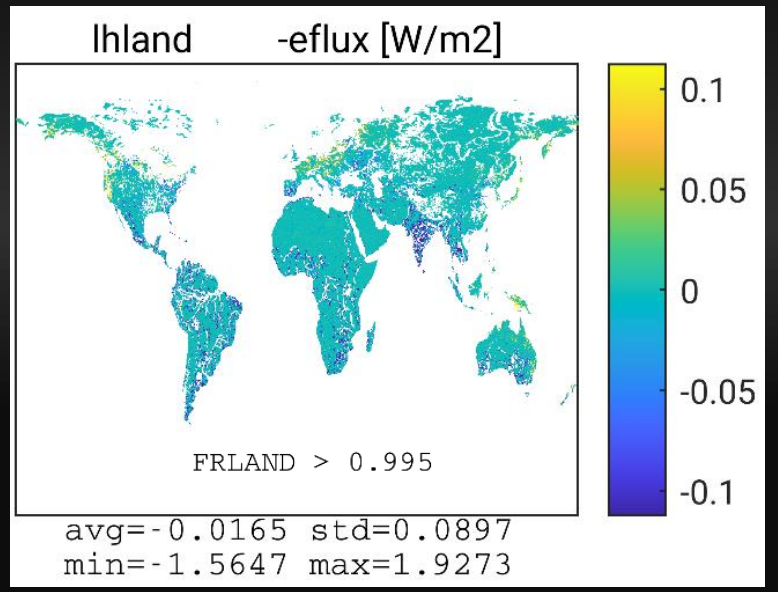
$SWLAND_{lnd} = SWNETSRF_{int}$

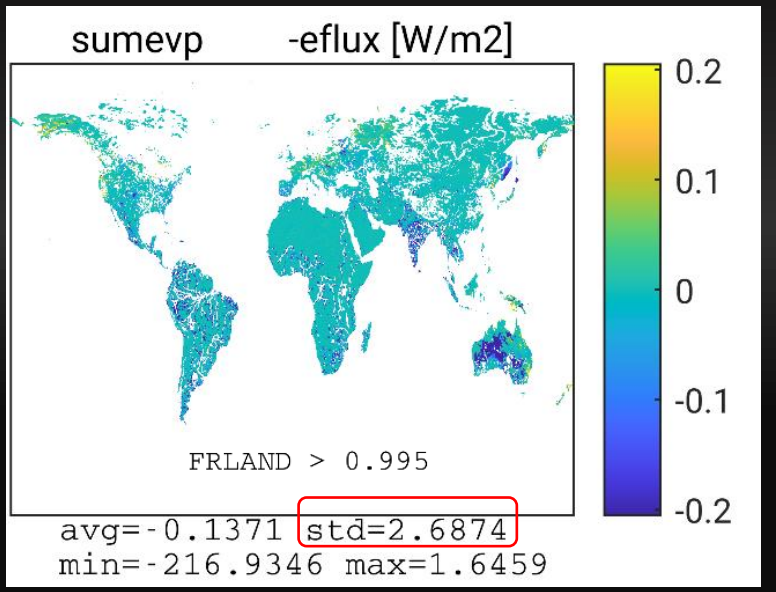
$LWLAND_{lnd} = LWGNET_{int}$

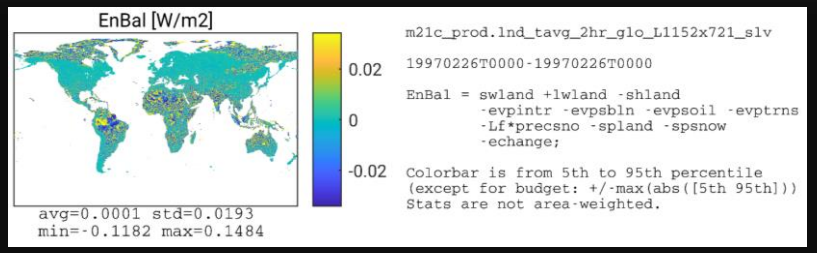
$SHLAND_{lnd} = HFLUX_{flx}$

~~$SUMEVP_{lnd} = EFLUX_{flx}$~~

$LHLAND_{lnd} = EFLUX_{flx}$







m21c_prod.lnd_tavg_2hr_glo_L1152x721_slv

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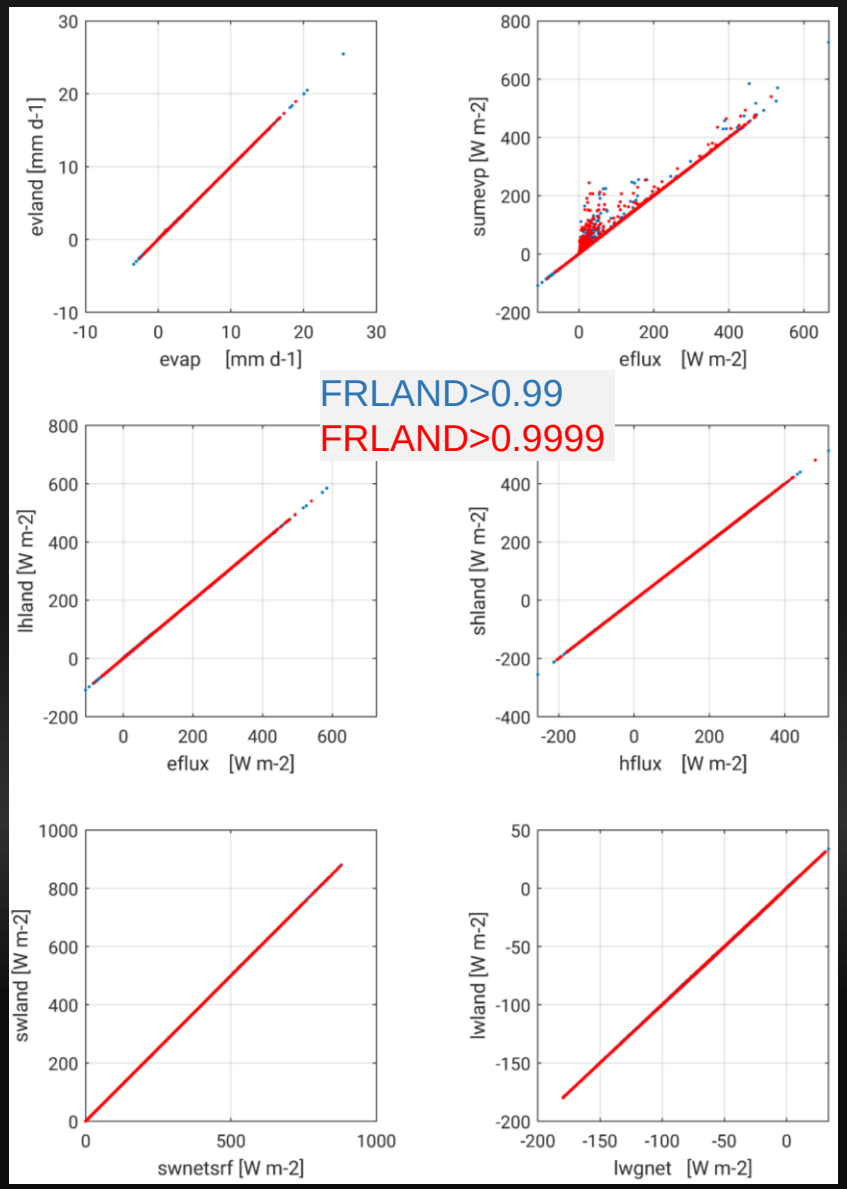
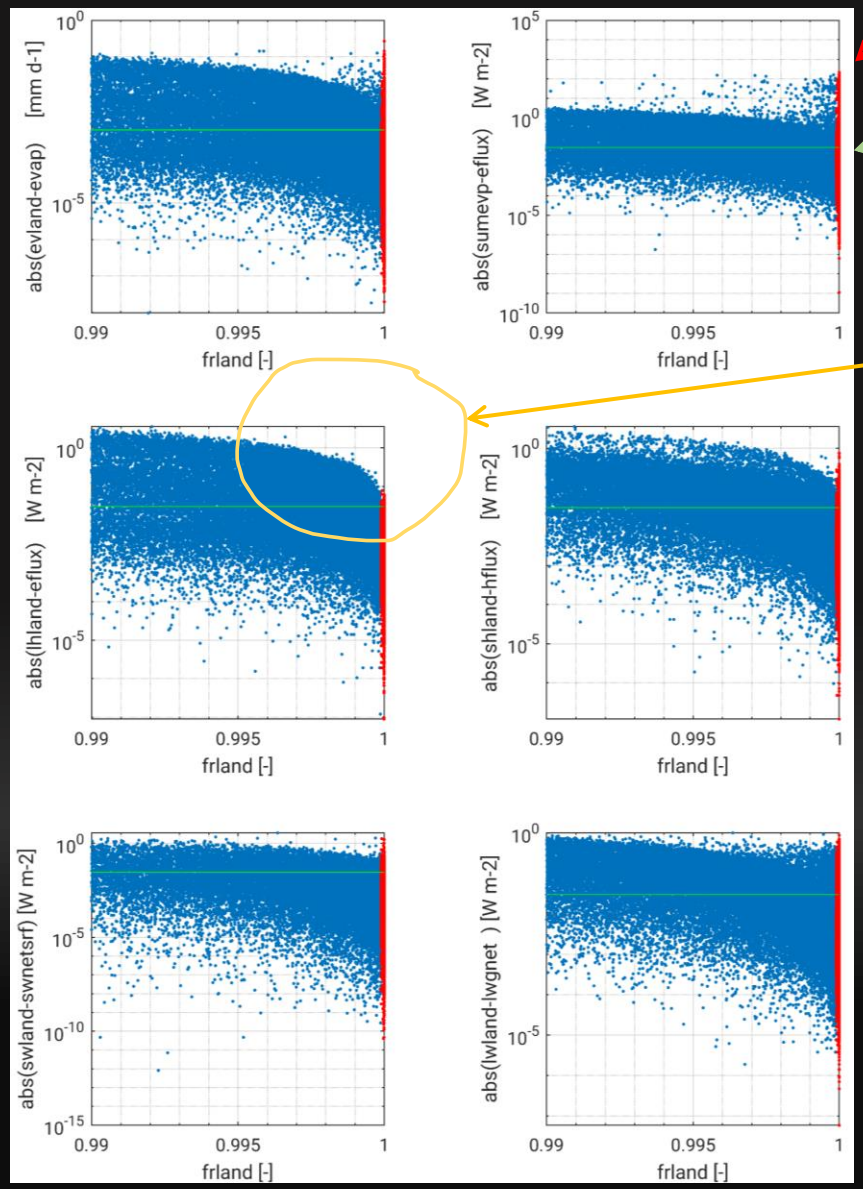
Energy Balance Across Land and Atmosphere





Red: FRLAND>0.9999

Horizontal lines at:
0.001 mm/d
0.030 W/m2

LHLAND and EFLUX match somewhat better than other terms, owing to explicit modification of LHLAND after catchment()?

Balance residuals are small but larger than roundoff.

m21c_prod.lnd_tavg_2hr_glo_L1152x721_slv

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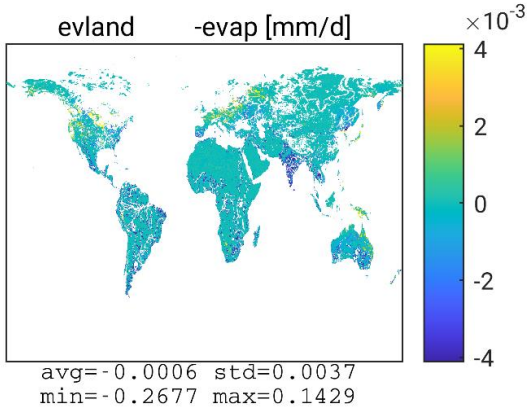
M21C vs MERRA-2



m21c_prod.lnd_tavg_2hr_glo_L1152x721_slv

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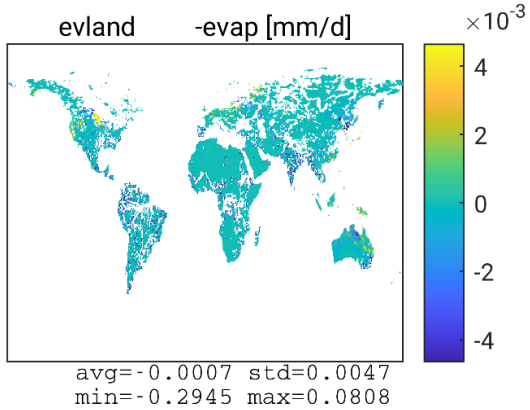
FRLAND > 0.995

Colorbar is +/-max(abs([5th 95th]))
Stats are not area-weighted.



MERRA2.tavg1_2d_lnd_Nx

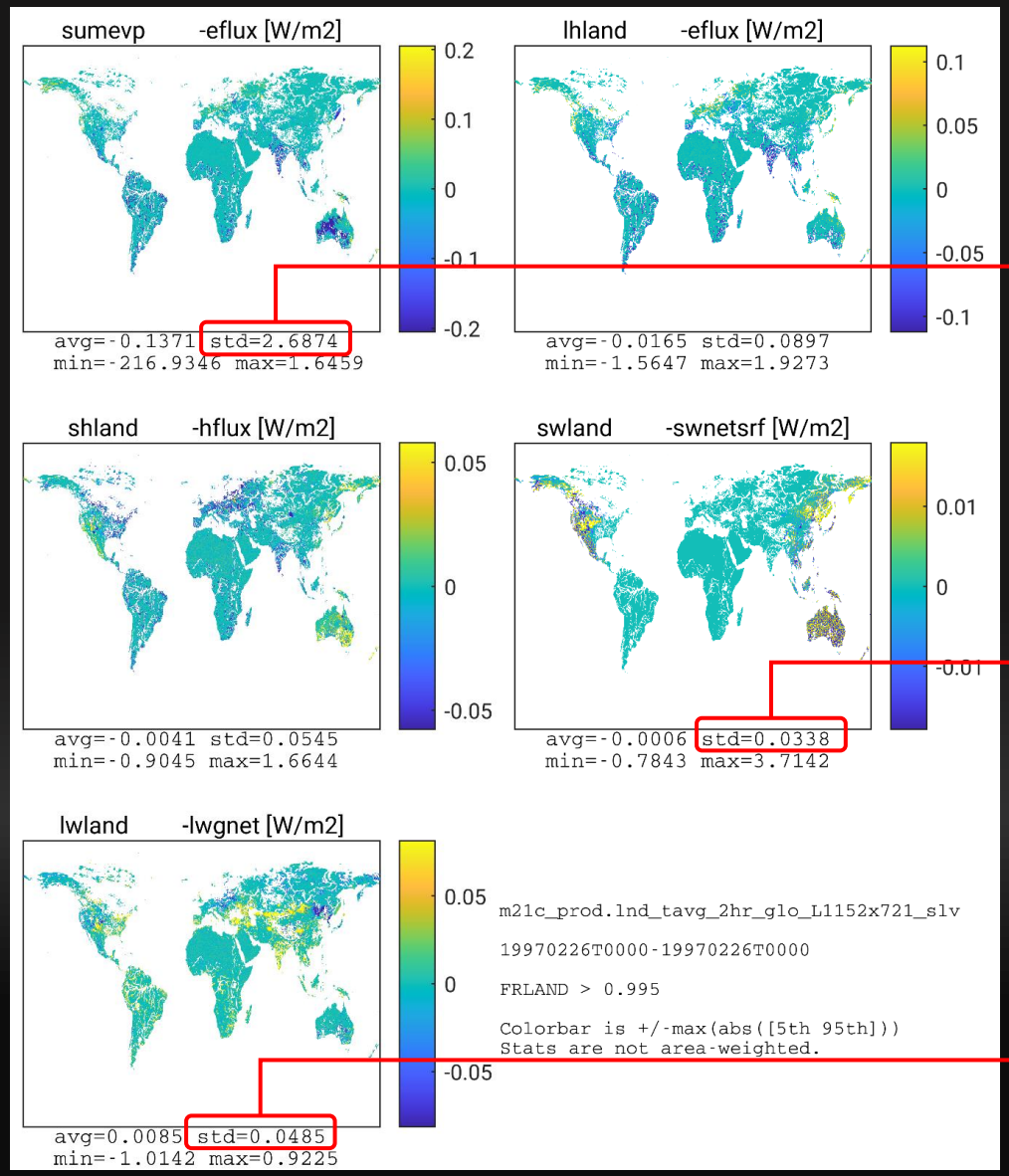
19970226T0030-19970226T0030

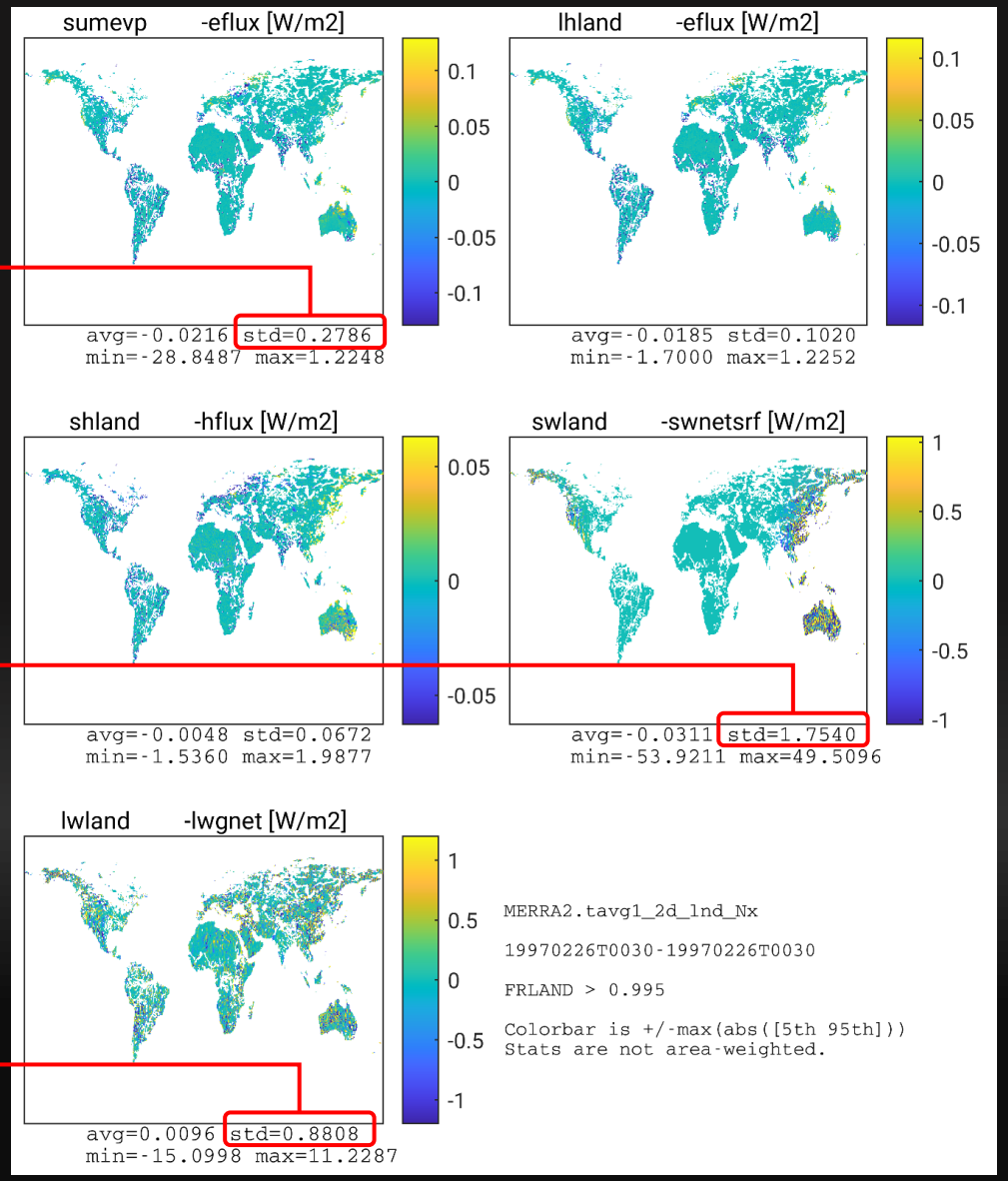
FRLAND > 0.995

Colorbar is +/-max(abs([5th 95th]))
Stats are not area-weighted.

Water balance terms across atmosphere and land equally consistent in M21C and M-2.

M21C vs MERRA-2





SUMEVP ≠ LHLAND
less severe in M-2, possibly because of land model change.

<u>In M-2, radiation inconsistent across atmosphere and land.</u>

Summary of Balance Equations

Land water:

$$WCHANGE = PRECTOTLAND - EVLAND - RUNOFF - BASEFLOW - SPWATR$$

Land energy:

$$ECHANGE = SWLAND + LWLAND - SHLAND - SUMEVP - Lf * PRECSNO - SPLAND - SPSNOW$$

where $SUMEVP = EVPINTR + EVPSBLN + EVPSOIL + EVPTRNS$

$LHLAND \neq SUMEVP$ ($\Delta \sim$LHACC, not in output!!!)

Land water and energy:

$$EVLAND + SPWATR = (EVPINTR + EVPSOIL + EVPTRNS)/Lv + EVPSBLN/Ls$$

Why SPWATR here but not in land-atmosphere eqn?

For land-only grid cells:

Land-atmosphere water: $EVLAND = EVAP_{flx}$

Land-atmosphere energy:

$SWLAND = SWNETSRF_{int}$

$LWLAND = LWGNET_{int}$

$SHLAND = HFLUX_{flx}$

$LHLAND = EFLUX_{flx}$

All variables from "lnd" collection unless subscript indicates otherwise.

Summary

- For brevity, variable names in this presentation were shortened from M21C names.
- Water and energy balance equations in M2 File Specs are wrong and need to be corrected!
- Corrected balance equations apply equally to M2 and M21C.
- While LHLAND matches EFLUX from turbulence, it is **not** equal to the sum of the EVP* component fluxes! (Equality holds in offline mode.)
  → Inconsistent across land and atmosphere balances.
- Spatial pattern of balance residuals is persistent, and residuals are larger than roundoff. Acceptable?
- A very minor and very rare residual energy balance error in M2 and M21C ("snow mass-limited sublimation from top snow layer") is addressed in GEOSgcm_GridComp PR#956.
- Radiation terms across land and atmosphere energy balances are more consistent in M21C than in M-2.

EXTRA SLIDES

Land Energy Budget

One-day AMIP simulations:

- "ctrl" : LH and evap output as in M21C.
- "exp1" : Without application of "accounting" terms.

Accounting terms:

- **`LHACC /= 0`**
- **`EVACC ~ 0 for SUMEV>0`**