Terrestrial evaporation: local warming vs. global cooling

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Land ≠ Ocean

Differences in:

- Capacity of the land to store water
- Heat capacity
- Topography
- Surface properties

*and more!*

The ocean effectively has unlimited water: evaporation is limited by the evaporative demand of the atmosphere
Land ≠ Ocean

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  *and more!*

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Terrestrial evaporation directly cools the land surface

\[ LW^\uparrow = \sigma T_s^4 \]

Still et al. 2019: Pinyon-Juniper woodland in southern California
land evaporation in models = warmer land (and ocean)

- Latent heat flux
- Evaporative cooling
- Surface temperature

Land is hotter if it can’t evaporatively cool

July surface temperature

Shukla & Mintz 1982
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Δ $T_s$ per 50 s/m ↑ in evaporative resistance

Warming can “drift” out over the ocean

Lagué et al. 2019

Shukla & Mintz 1982
land evaporation = warmer land (form surface energy budget)

• Direct result of repartitioning the the surface energy budget

• As such, we might not expect it to have anything to do with continental configuration...
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• Direct result of repartitioning the surface energy budget

• As such, we might not expect it to have anything to do with continental configuration...
Suppress evaporation in 6 different continental configurations
See what happens to surface temperatures
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See what happens to surface temperatures

Make the land “bucket” very tiny – near-zero terrestrial water storage... like a well drained paved parking lot

Isca idealized climate model
Idealized general circulation model, slab ocean
Simple land (Manabe bucket model)

Super easy to move continents around
1 experiment with normal bucket land
1 experiment with tiny bucket land
If all we care about is the surface energy budget, this should warm

Land evaporation = warmer land

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Super easy to move continents around
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Suppressing land evaporation warms (red) some places, in some continental configurations... otherwise large-scale cooling.
Subtropical deserts have no warming effect, just large-scale cooling.
Bigger continents have larger dry/desert areas, where evaporation is always zero... so making it harder to evaporate doesn’t lead to any local warming (zero to start, zero to end...)
Unlike the other continental configurations, Northland shows a huge cooling signal everywhere.
Why is Northland cooling when evaporation decreases?

If all we care about is the surface energy budget, less evap = warming.

Obviously not all we care about.

- Shortwave Radiation
- Longwave Radiation
- Sensible Heat
- Latent Heat

land evaporation = warmer land
Why is Northland cooling when evaporation decreases?

If all we care about is the surface energy budget, less evap = warming

BUT water vapour is also a fantastic greenhouse gas
Why is Northland cooling when evaporation decreases?

BUT water vapour is also a fantastic greenhouse gas

Little water vapour = cooler surface
Lots of water vapour = warmer surface

~ ½ of the modern greenhouse effect (Sherwood et al 2018)
Why is Northland cooling when evaporation decreases?

- In the present climate, there is plenty of ocean at every latitude, so it is hard to deplete the atmosphere of water vapour.

- In Northland, there is no infinite water source in the NH.

- Collapse the water vapour greenhouse = big cooling signal.
Balance of local warming vs global cooling from ↓ land evaporation depends on total land area, contiguous continent size, and location.
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Laguë et al. 2021
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Laguë et al. 2021

Colder air from ↓ water vapour = less LW ↓ over oceans

\[ \Delta T_s \text{ in response to suppressed terrestrial evaporation} \]

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Direct evaporative effect (warming)

Indirect water vapor effect (cooling)

↓ Latent cooling dominates

(i)

↓ Latent cooling and ↓ greenhouse warming

(ii)

↓ Greenhouse effect dominates

(iii)

Reduction of land surface evaporation

\[ +1.0 \, K \]

\[ +0.7 \, K \]

\[ +0.3 \, K \]

\[ -0.3 \, K \]

\[ -4.9 \, K \]

\[ +0.7 \, K \]

\[ +0.3 \, K \]

\[ -0.9 \, K \]

\[ -0.9 \, K \]

Global land fraction:

TwoPatchLand
NorthWestLand
ThreePatchLand
ThreeQuarterLand
NorthLand

-0.3
0.7
0.3
0.9
0.1
-1.4
0.9
-1.4

\[ \Delta T_s \text{ in response to suppressed terrestrial evaporation} \]

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Putting a big continent over a tropical ocean has a much bigger effect on atmospheric water vapour than putting a big continent over the poles.

Laguë et al. 2021

Direct evaporative effect (warming)

↓ Latent cooling dominates

(ii) Competition ↓ latent cooling ↓ greenhouse effect

↓ Greenhouse effect dominates (i)

Direct evaporative effect (warming)

Putting a big continent over a tropical ocean has a much bigger effect on atmospheric water vapour than putting a big continent over the poles.

Laguë et al. 2021

Reduction of land surface evaporation

Laguë et al. 2021
Real (modern) world sits somewhere to the left of this curve: plenty of ocean at every latitude keeps the atm from getting too depleted in water vapour.

Caveats:
- Clouds are invisible in this model, & land evaporation matters for clouds
- Pretty extreme evaporation changes
- No ocean warming that we see in more complex models
How important is this mechanism in the real world? Need to know (i) how much Δ water vapour is changing LW↓ (ii) what clouds do

Without the continental ↓ in water vapour, surface temperatures would be even warmer

Surface Latent Heat Flux (warms)

Water vapour over continents (cools)

Land warms from suppressing terrestrial evaporation (Isca)
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Use an atmospheric radiative kernel to determine how much $\Delta$LW↓ at the surface comes from $\Delta$ water vapour

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- Surface Latent Heat Flux (warms)
- Water vapour over continents (cools)

Both these processes impact clouds
And clouds impact surface temperatures

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Cloud-free model (Isca):

Air gets drier

Land gets warmer
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(i) how much $\Delta$ water vapour is changing LW↓
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Cloud-free model (Isca):
- Air gets drier
- Land gets warmer

Model with clouds (CESM):
- Air only gets drier some places (warmer air can hold more water)
- Land gets a lot warmer (cloud response helps warm, here)
Warm air can \textit{hold} more water, and total $\Delta$ water vapour from $\downarrow$ land evaporation depends on cloud cover! (Not as tidy a story as in the idealized model!)

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Even \textit{with} cloud feedbacks, would still expect giant continents (like Northland) to dry out the atmosphere.
In Summary...

Temperature response to ↓ land evaporation is a competition between:
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Temperature response to ↓ land evaporation is a competition between:

- **Local warming (surface energy budget)**
  - Land evaporation = warmer land
  - Shortwave Radiation → Land evaporation → Warmer land
  - Longwave Radiation → Sensible Heat → Warmer land
  - Latent Heat → Evaporation → Warmer land

- **Large-scale cooling (greenhouse effect)**
  - Dry atm = cool surface
  - Wet atm = warm surface
  - SW (Shortwave) → LW (Longwave) → Cool surface

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In Summary...

Temperature response to ↓ land evaporation is a competition between:

Local warming (surface energy budget)

- Land evaporation = warmer land

Large-scale cooling (greenhouse effect)

- SW Radiation
- LW Radiation

Where you sit on this curve depends on continental configuration, degree of change in evaporation, clouds, etc...