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Precipitation extremes in a changing climate
Results from high-resolution climate simulations

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The Experiment:

The ECMWF Integrated Forecast System (IFS) GCM version CY32r3 was integrated at resolution T1279 (16 km grid) with 91 vertical levels.

Both 20th and 21st century (20C and 21C) simulations are performed in "timeslice" mode with specified sea surface temperature (SST).

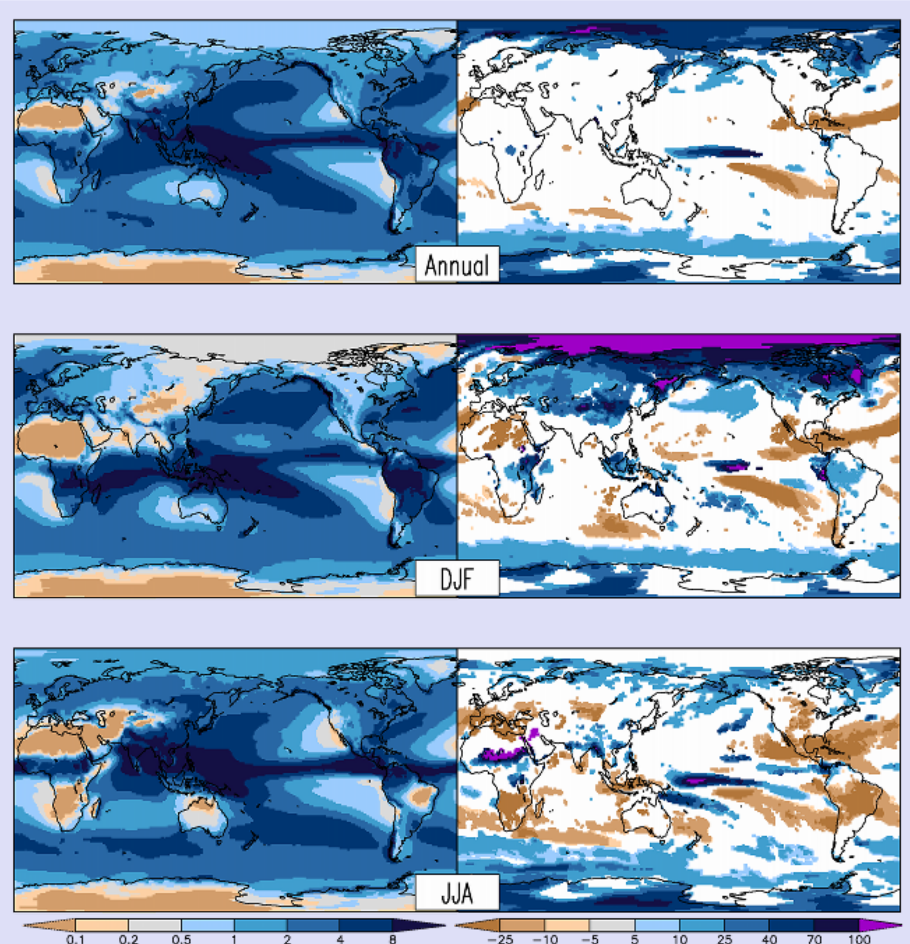
- The **20C simulation** begins at 0000UTC 1 January 1961 and continues for 47 years. Ocean boundary conditions are the same as used for the ERA-40 reanalysis:
  - 1961-1989: 1.125° monthly data interpolated linearly in time and space.
  - 1990-2001: 1.125° weekly data interpolated linearly in time and space.
  - 2002-2007: Daily SST from the ECMWF operational system.
- The **21C simulation** uses the same time series of SST, but scaled using the difference of mean climatologies (2065-2075 minus 1965-1975) from the coupled Community Climate System Model version 3 simulation from CMIP-3 under the A1B climate scenario. Greenhouse gases are also changed to the projected 2071 values.

These simulations were conducted as part of PROJECT ATHENA, which addresses the hypothesis that increasing climate model resolution to accurately resolve mesoscale phenomena can dramatically improve the fidelity of the models in simulating climate. (1)

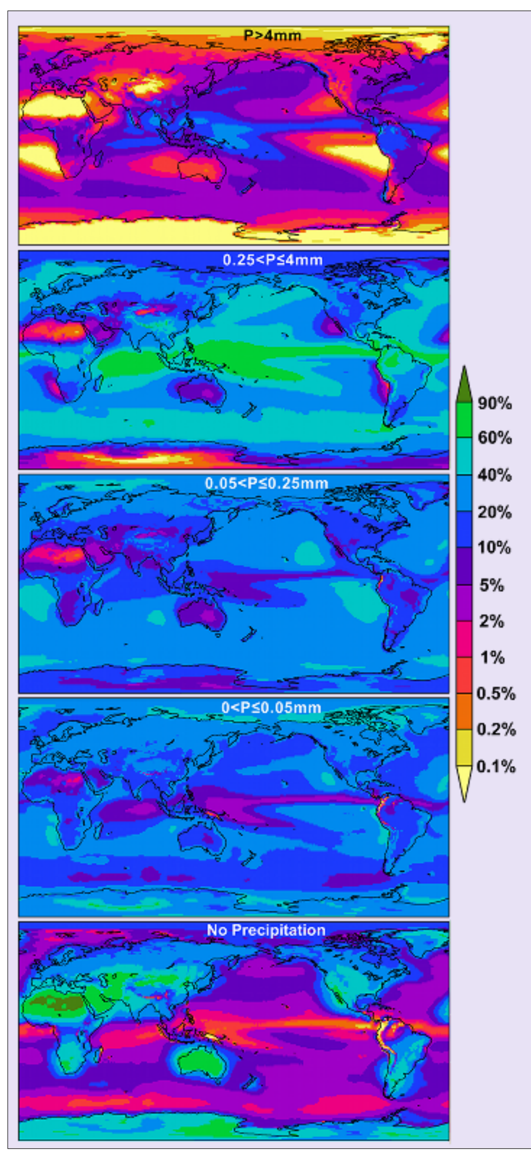
Characteristics of Precipitation

20C Precipitation Rate (left; mm/d) and Change (21C–20C; right; %)

- IFS has a good climatology of current precipitation.
- The climate change signal shows:
  - Increases over high latitudes in winter.
  - Drier during JJA over Mediterranean, Great Plains, much of S. Hemisphere.
  - Broad year-round drying over sub-tropical North Atlantic and Caribbean.
  - Most monsoon regions have more intense rainfall, except the North American monsoon, which becomes much weaker.

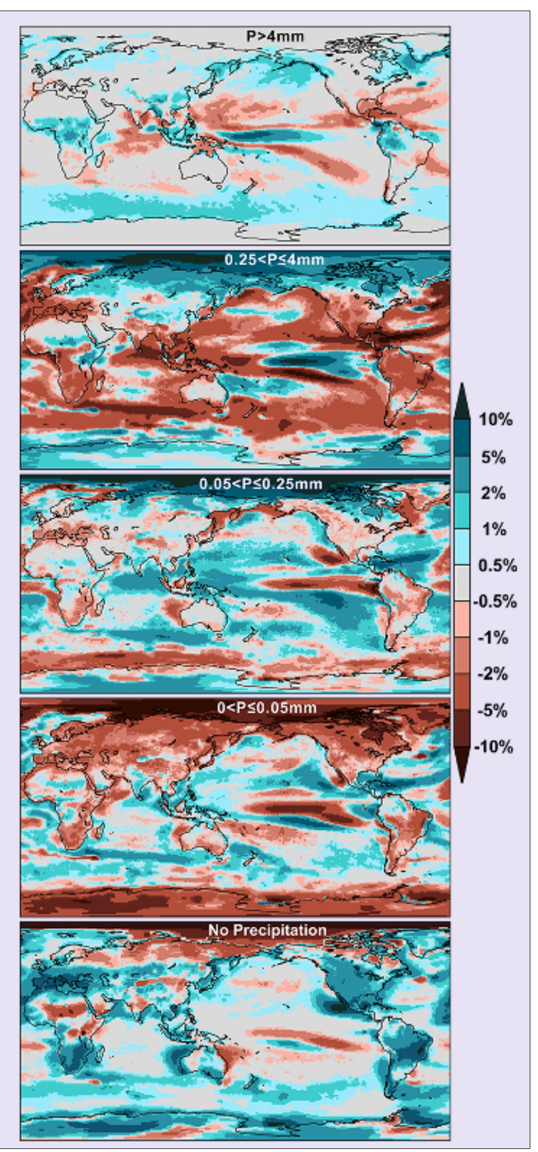


Changes significant at 95% confidence level are shaded.

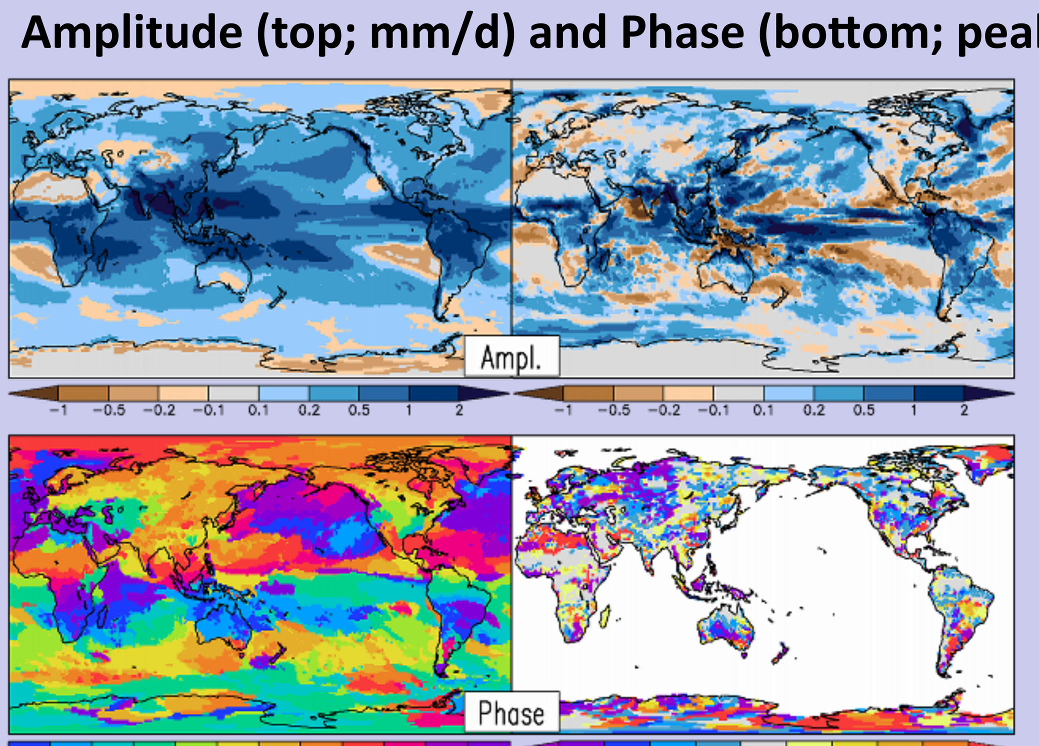


20C Categorical Precipitation Rates (left; % 6-hr intervals in each bin) and Change (21C–20C; right; %)

- Heavy precipitation days most common in tropics (ITCZ) and storm tracks, very rare over deserts, polar regions. Rain-free periods common over continents.
- Climate change brings increased frequency over land at both extremes; heavy events and rain-free.
- Big decrease in "nice" intermediate events, except at high latitudes.
- Heavy rains decrease over maritime subtropical regions, Indian Ocean, eastern Indonesia.
- The Sahel becomes rainier.



Annual Cycle of Precipitation (left: 20C; right: 21C–20C) Amplitude (top; mm/d) and Phase (bottom; peak month and shift in days)

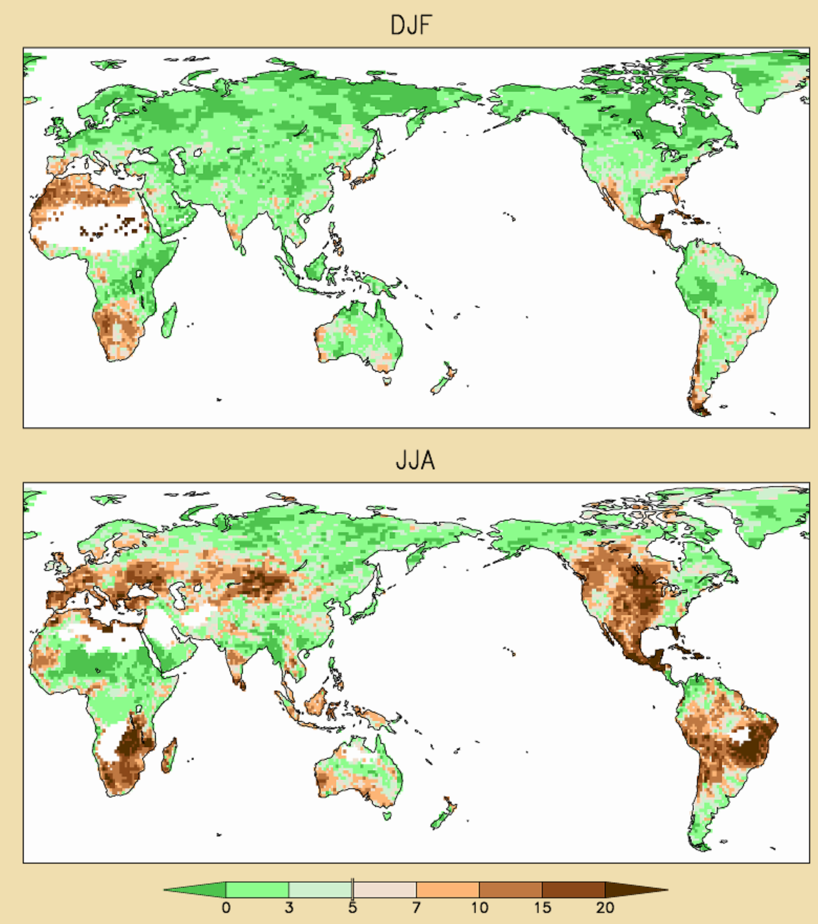


Amplitude and phase are calculated based on a best fit of the first annual harmonic.

- Most land areas show an increase in the amplitude of the annual cycle.
- Classical monsoon regions, except Mexico, have the strongest increases.
- The seasonal cycle over most land areas is either unchanged or shifts negative (earlier occurrence of rainy season peak).

Drought and Flood

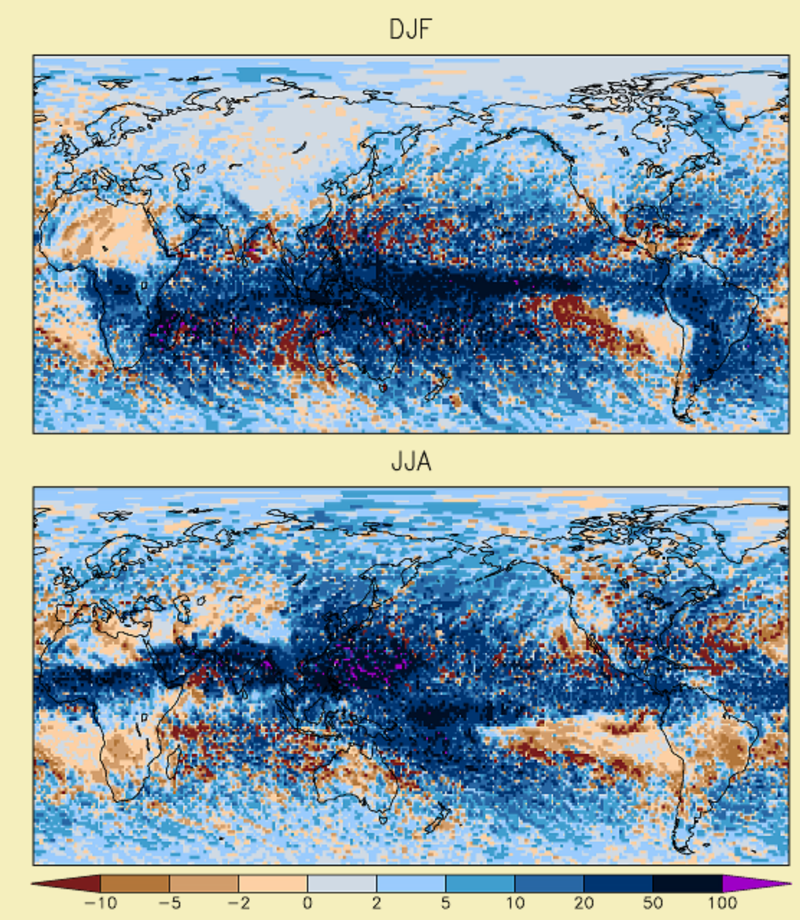
Change in Drought Occurrence



Number of years (out of 47) when seasonal precipitation during 21C is below the 5th driest year from the 20C simulation. 5 = no change, brown = more droughts, green = fewer.

- South Africa, the Mediterranean and Mexico have year-round increases of drought.
- Europe, Central Asia and North America have more frequent summer droughts.
- Dry-season droughts are more severe across much of the Southern Hemisphere.

Flash Flood Severity

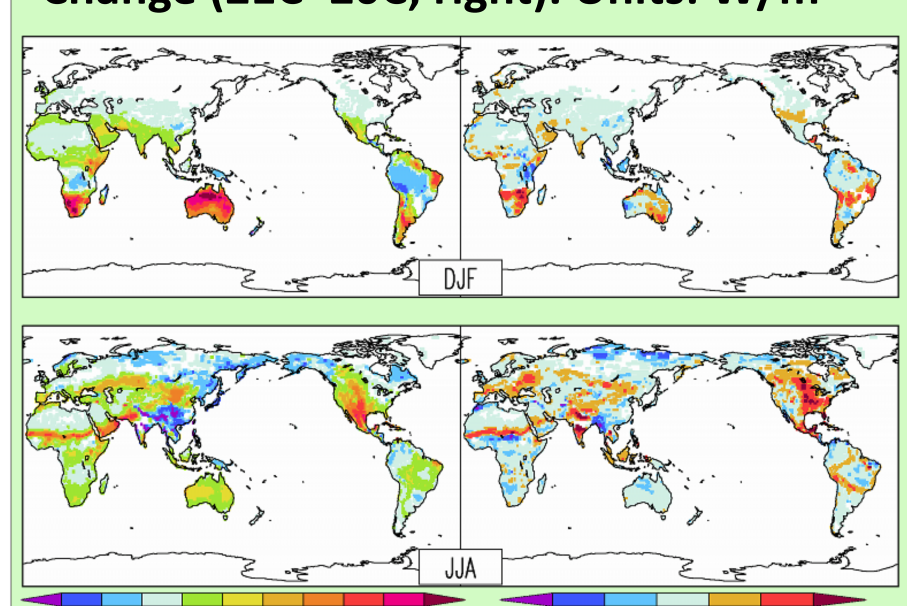


Change (21C–20C) in precipitation (mm/6hr) during the 5 wettest 6-hour intervals across 47-year simulations.

- Preponderance of blue indicates most locations experience more intense precipitation during extreme events.
- Tropics, monsoons, convective regimes show strongest increases.
- Many arid regions show decreased intensity of extreme flash flood events.

Land Feedbacks to the Hydrologic Cycle

20C Land Coupling Index I_{Land} (left) and Change (21C–20C; right). Units: W/m²



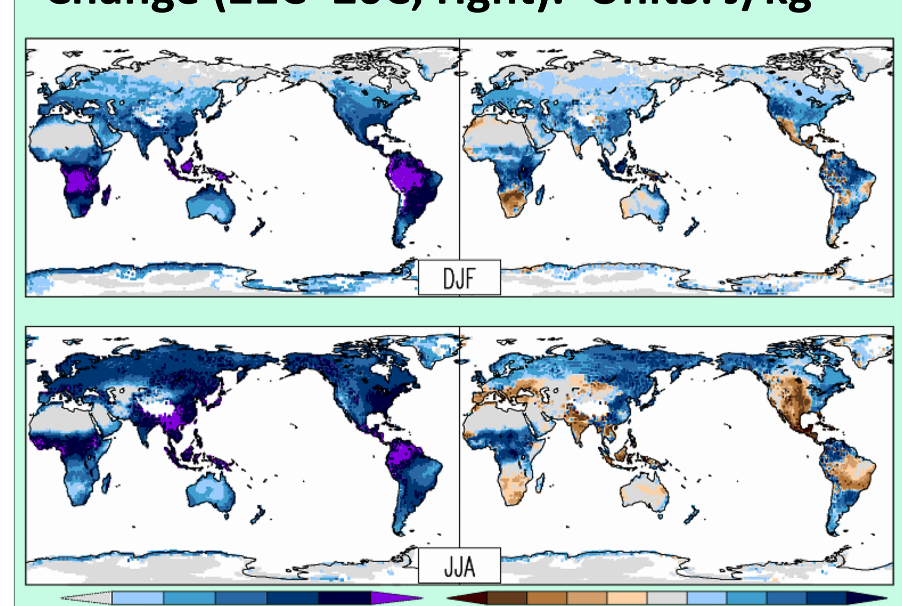
$$I_{Land} = \frac{\partial ET}{\partial SM}\sigma_{SM} = r(ET,SM)\sigma_{ET}$$ (2)

Correlations significant at 95% confidence level are shaded.

Red shades: soil moisture controls evaporation and variations are relatively large.

- Closely reflects "hot spots" of land-atmosphere coupling.
- Changes: Generally sensitive zones expand.

20C PBL Coupling Index I_{PBL} (left) and Change (21C–20C; right). Units: J/kg



Overbars: average during growth of PBL (0700-1900 LST) on rain-free days.

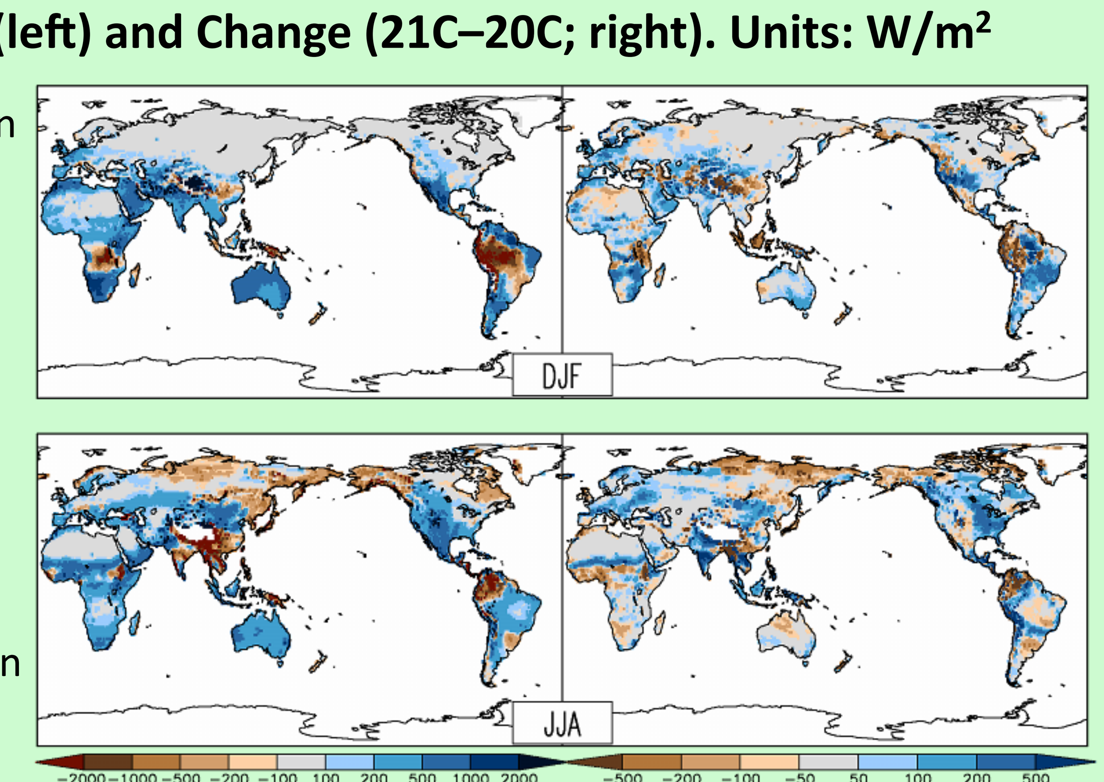
$$I_{PBL} = \frac{\overline{LH}\cdot\Delta t}{\rho_{PBL} H_{PBL}}$$ (3)

- Moistening tied to evaporation rate, PBL depth.
- Changes: Decreases are *mostly* due to deeper PBLs, increases *usually* caused by stronger evaporation rates.

20C Combined Coupling Index (left) and Change (21C–20C; right). Units: W/m²

Substitute I_{Land} for $\overline{LH}$ in the equation for I_{PBL} and we have a combined land-PBL coupling index.

- Blue = soil moisture control of surface fluxes + strong PBL impact.
- Brown/grey = soil moisture variations have no effect on PBL.
- Changes: More blue than brown. A greater role for land surface feedbacks on weather and climate in the future; hot spots expanding.



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