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A doubled increasing trend of evapotranspiration on the Tibetan Plateau (TP)

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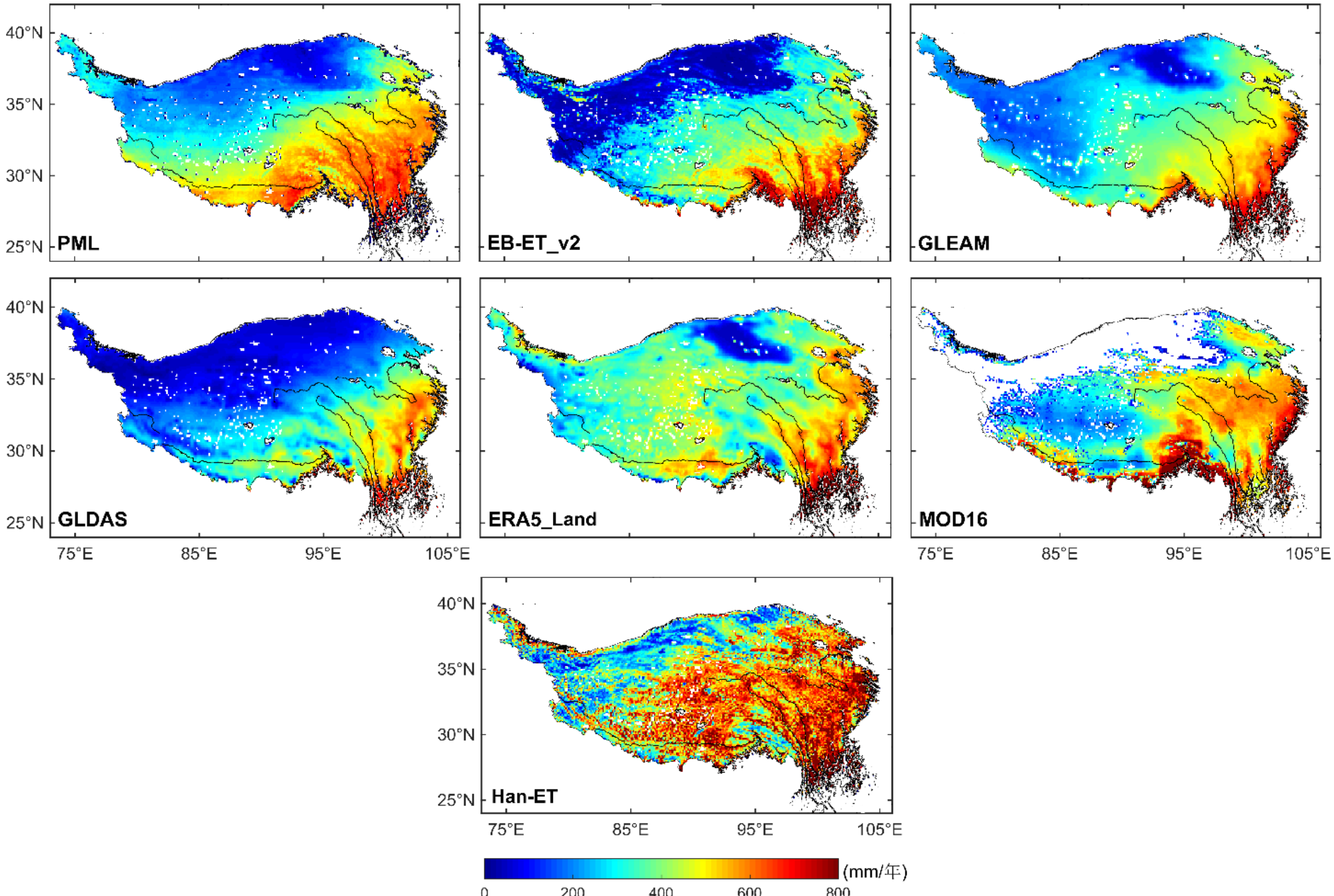
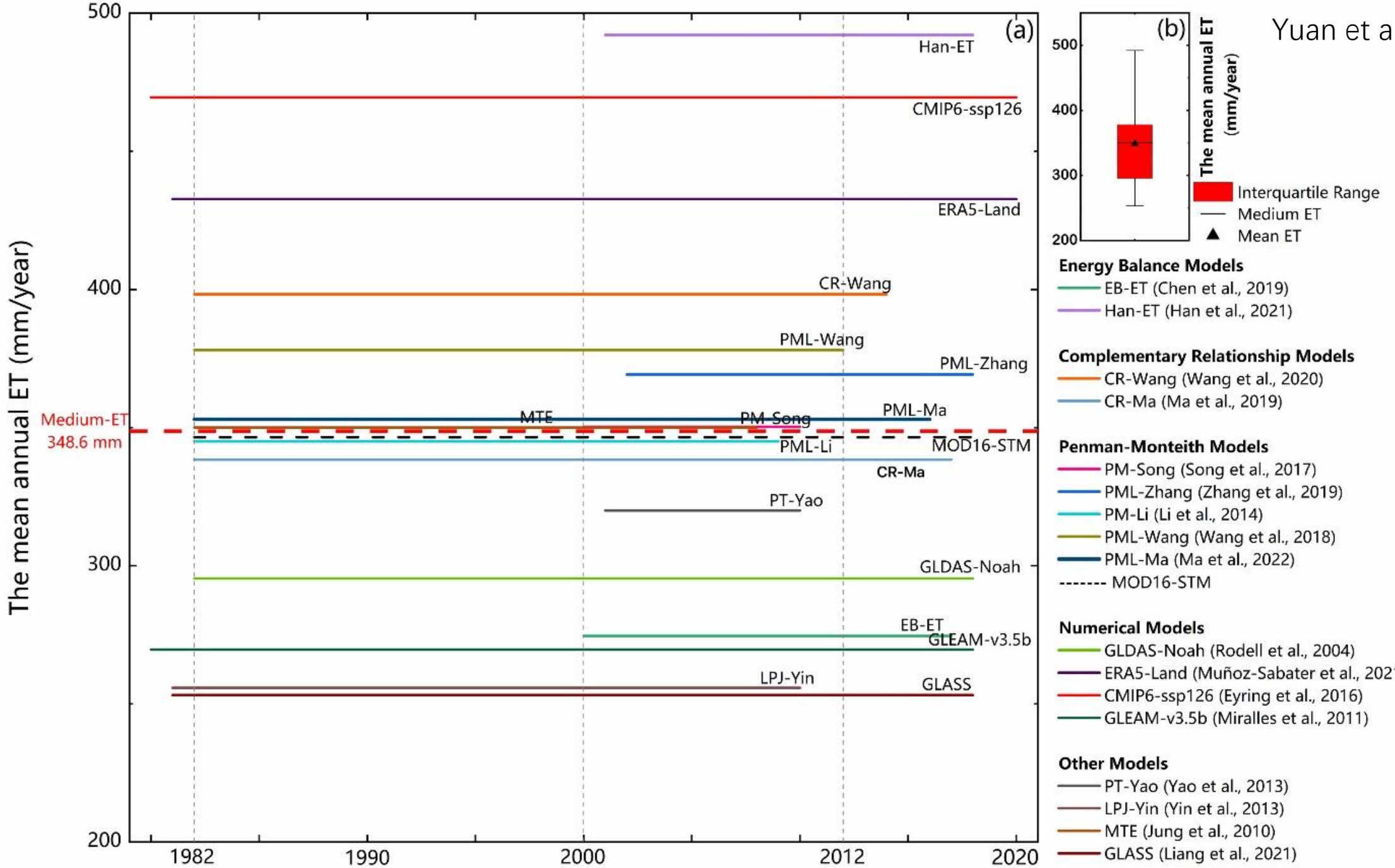
1. Evapotranspiration (ET) research progress on the TP





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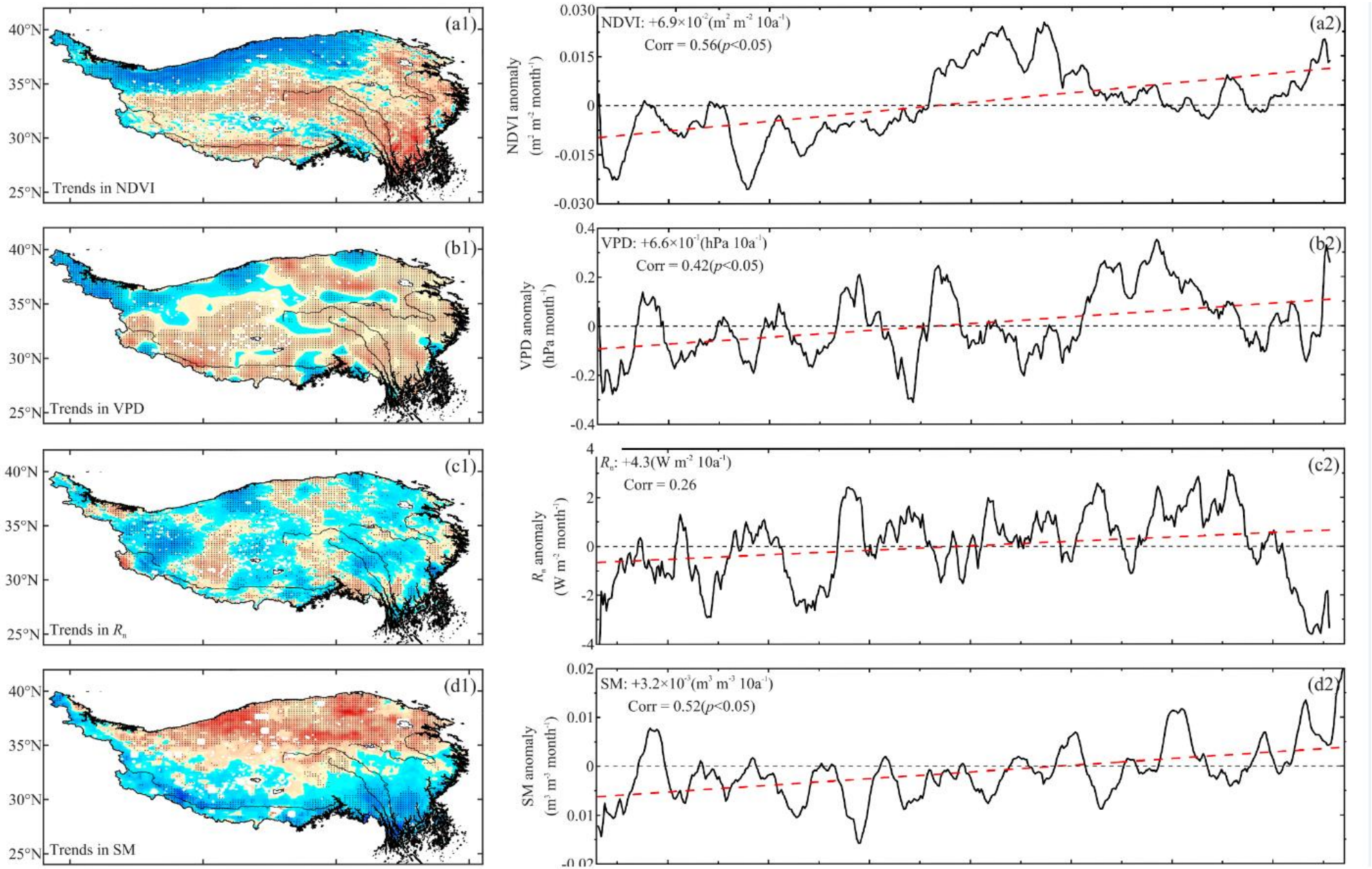
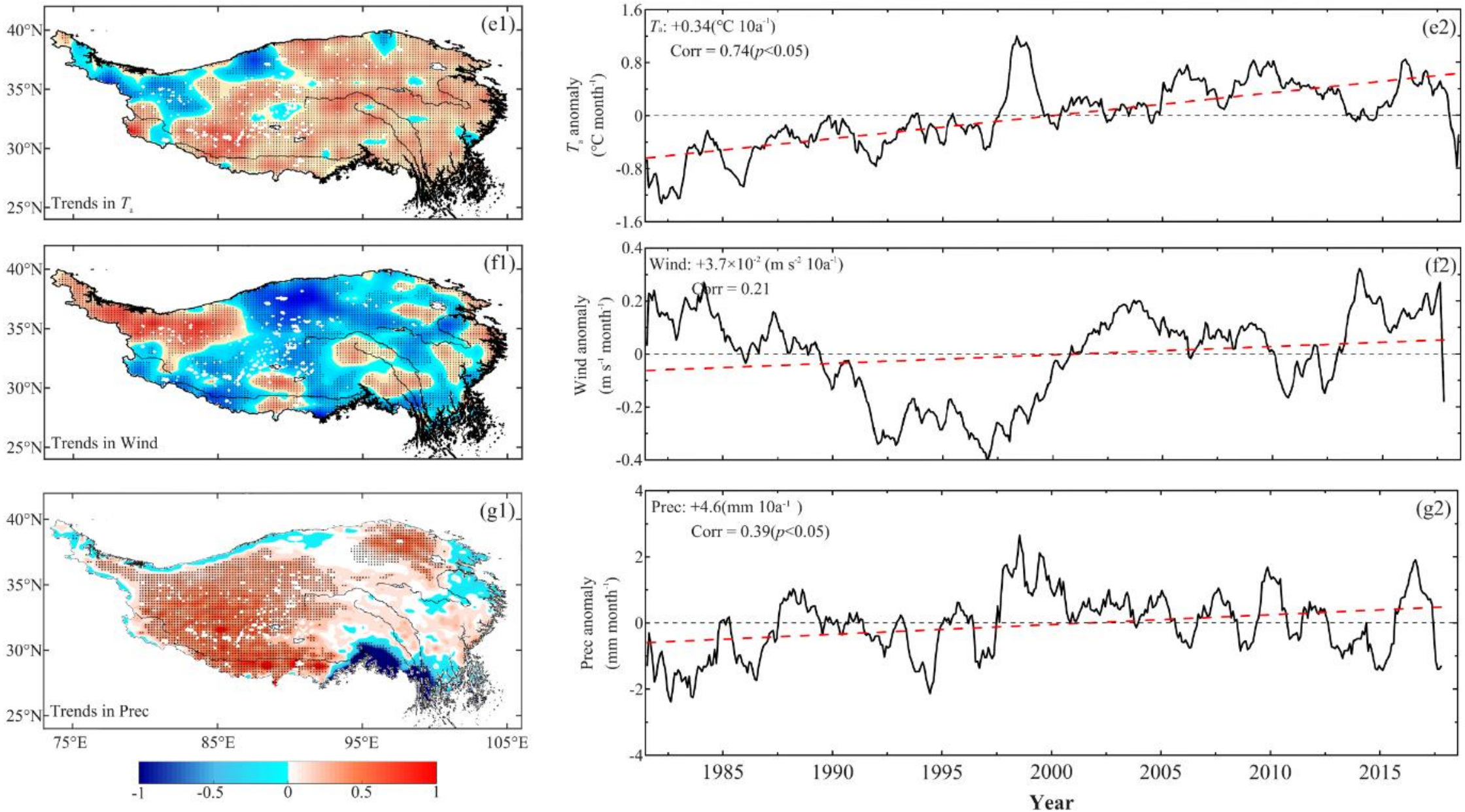
2. Scientific questions about the ET studies on the TP





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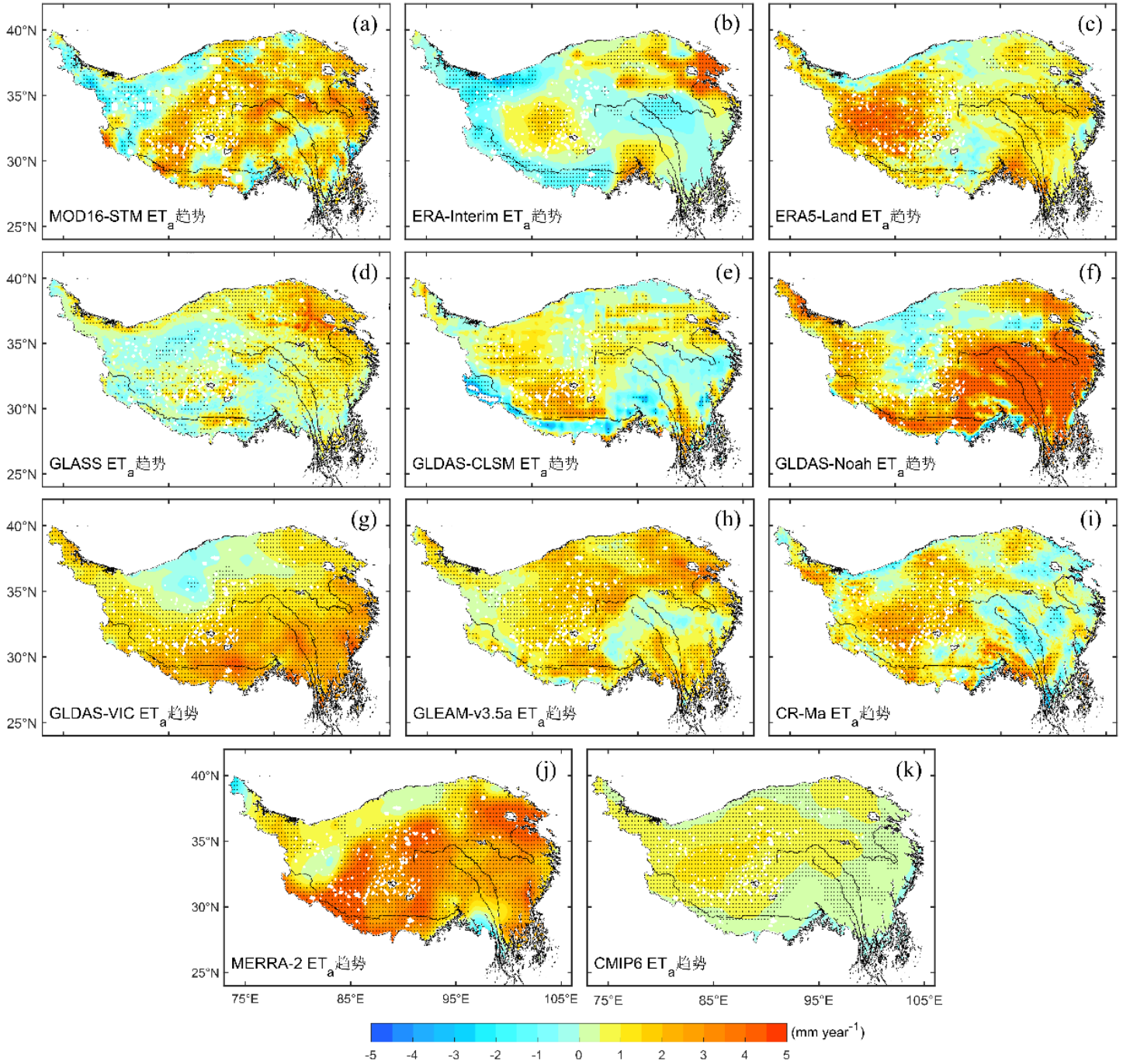

What are the changes in ET on the TP and what are the driving mechanisms behind them?

Num	Dataset	Method	Length (year)	Mean annual ET_a (mm $year^{-1}$)	ET_a trend (mm $decade^{-1}$)
1	PT-Yao[43]	Modified Priestley−Taylor model	10	320.0	−1.4
2	LPJ-Yin[44]	Lund-Potsdam-Jena dynamic vegetation model	30	255.8	0.8
3	MTE[16, 37]	Model Tree Ensembles	27	350.0	–
4	GLASS[40]	Empirical method	38	253.2	5.3
5	EB[45]	Energy balance model	18	274.6	−16.6
6	Han[14]	Energy balance model	18	492.1	−15.2
7	CR-Wang[12]	CR (complementary relationship) model	32	398.3	7.7
8	CR-Ma[11]	CR (complementary relationship) model	36	338.4	8.2
9	PM-Song[16]	Penman-Monteith method	11	350.3	−47.0
10	PM-Li[47]	Penman–Monteith model	28	345.0	–
11	PML-Zhang[43]	Penman–Monteith–Leuning model	17	369.2	50.1
12	PML-Wang[15]	Penman-Monteith-Leuning model	31	378.1	37.8
13	MOD16-STM[23]	Penman–Monteith method	37	347.9	9.6
14	GLDAS-Zhang[49]	Land surface data assimilation	38	295.4	11.0
15	GLEAM[39]	Microwave remote sensing data assimilation	39	269.7	9.4
16	ERA5-Land[41]	Reanalysis	40	432.7	6.8
17	CMIP6-ssp126[31]	Global climate model	37	469.5	5.6
		Median		347.9 (±70.4)	6.8 (±22.1)

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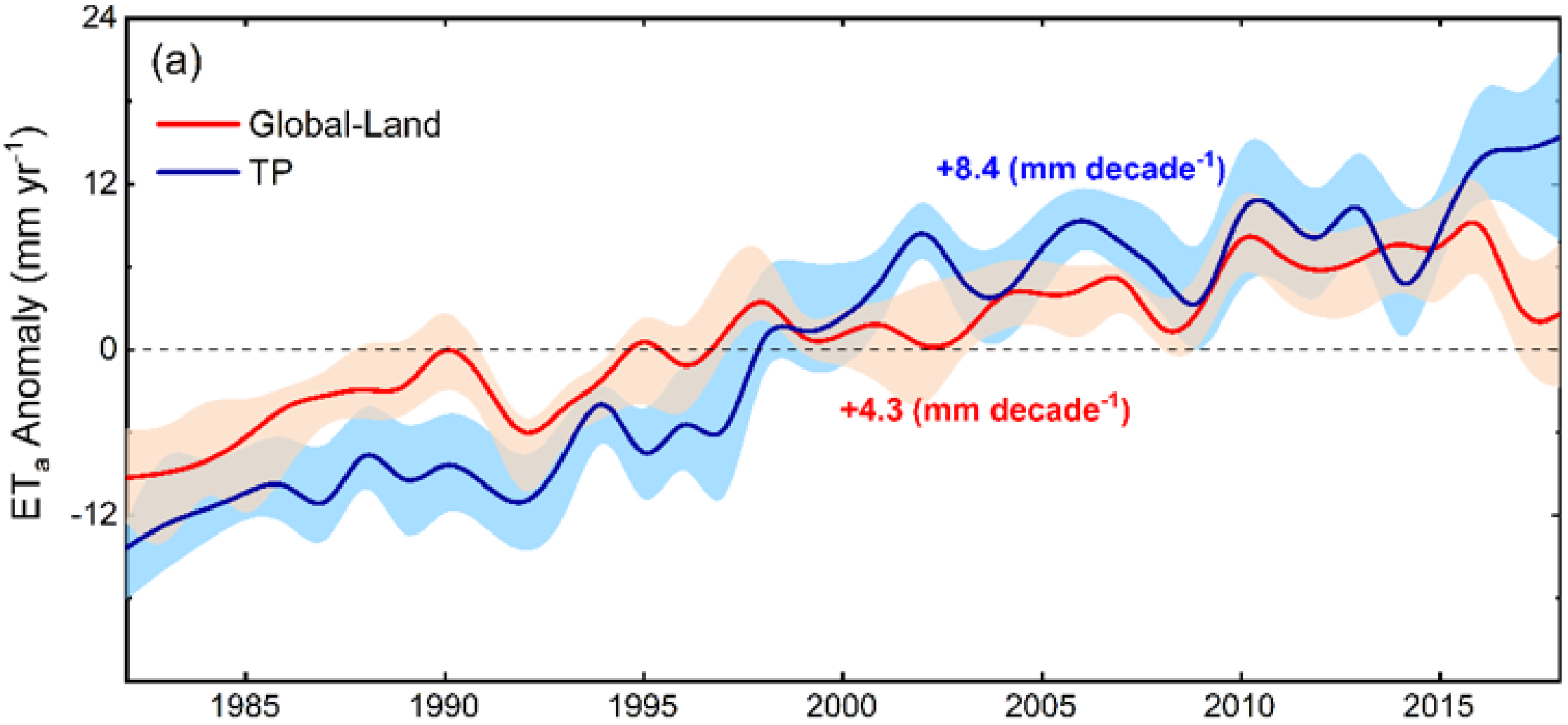
3. ET changes in the past forty years on the TP



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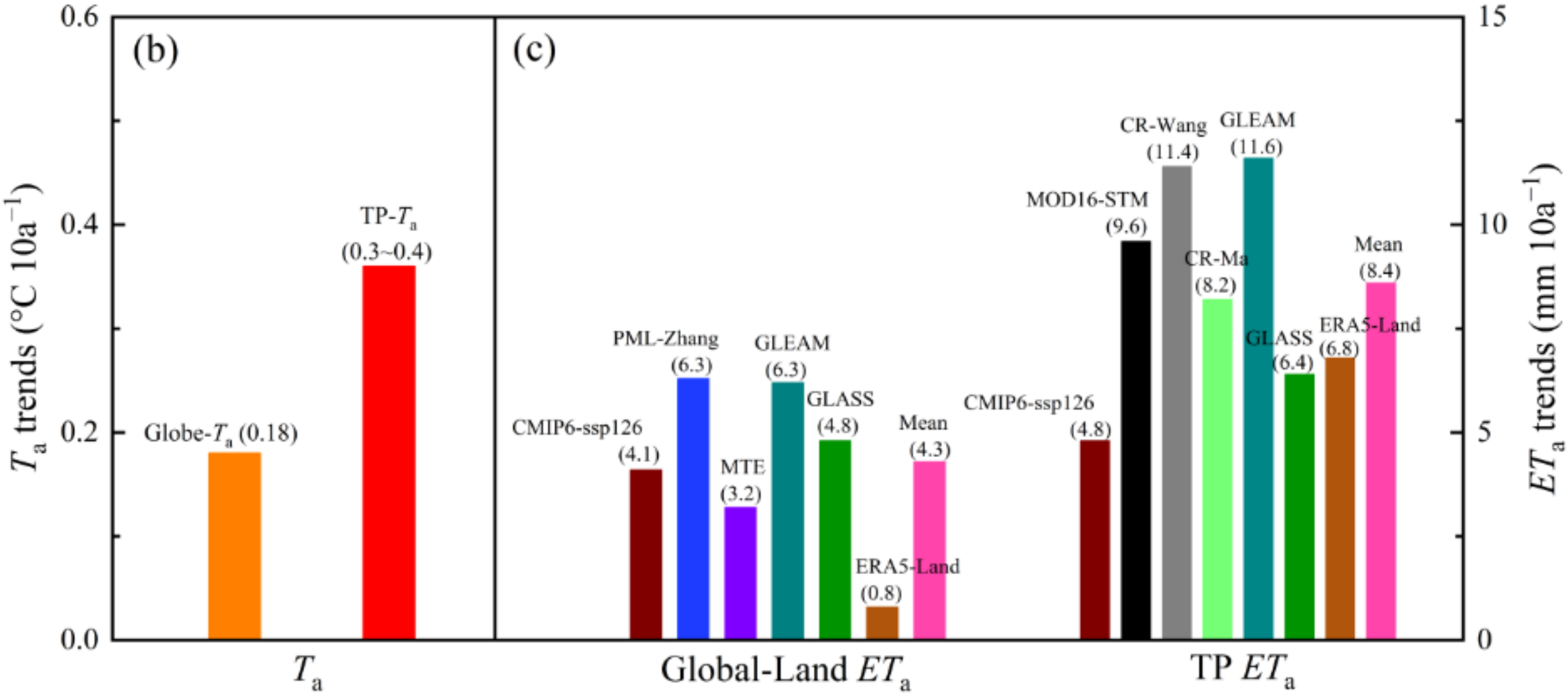

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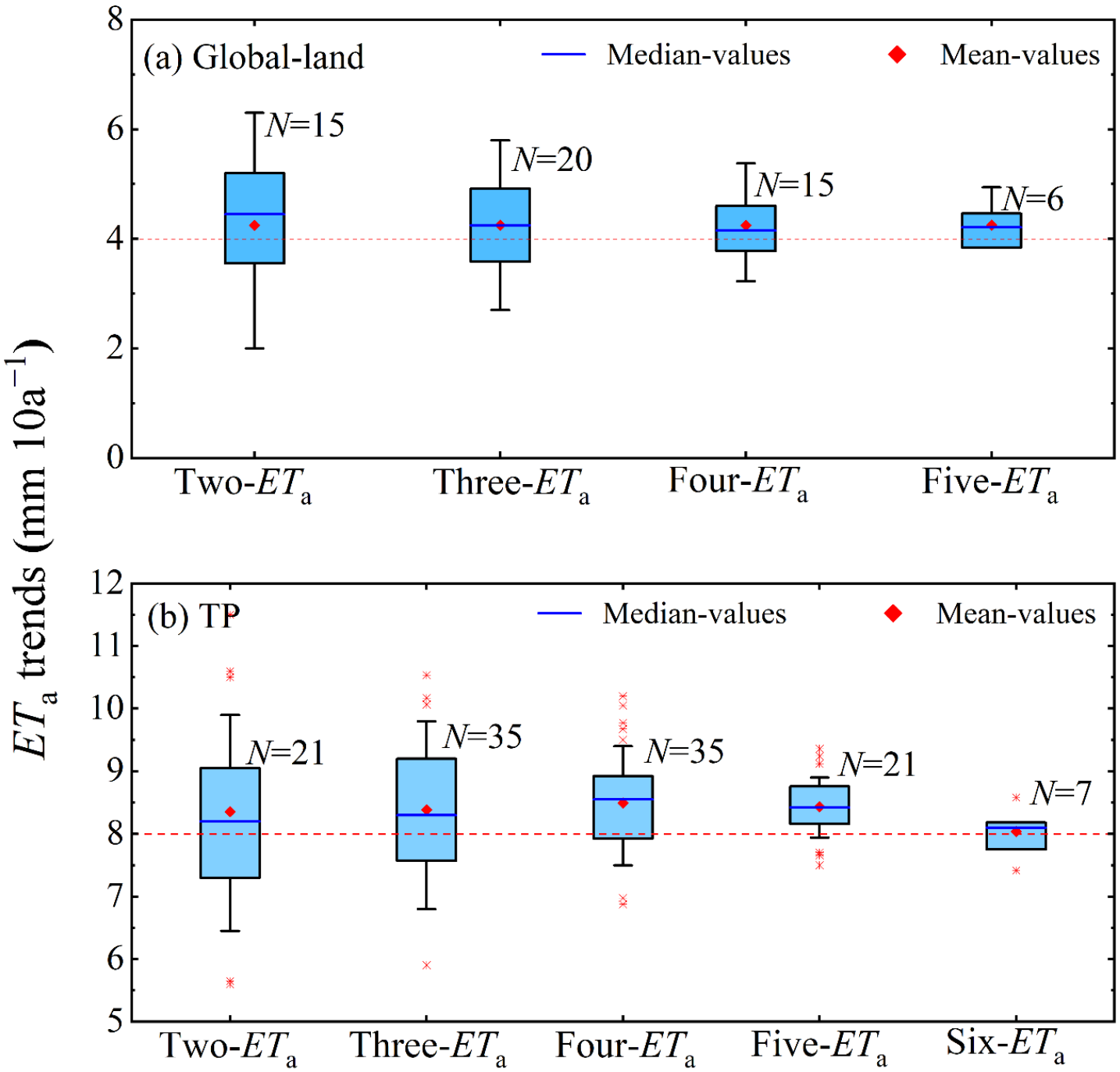

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4. The attribution of changes in ET on the TP

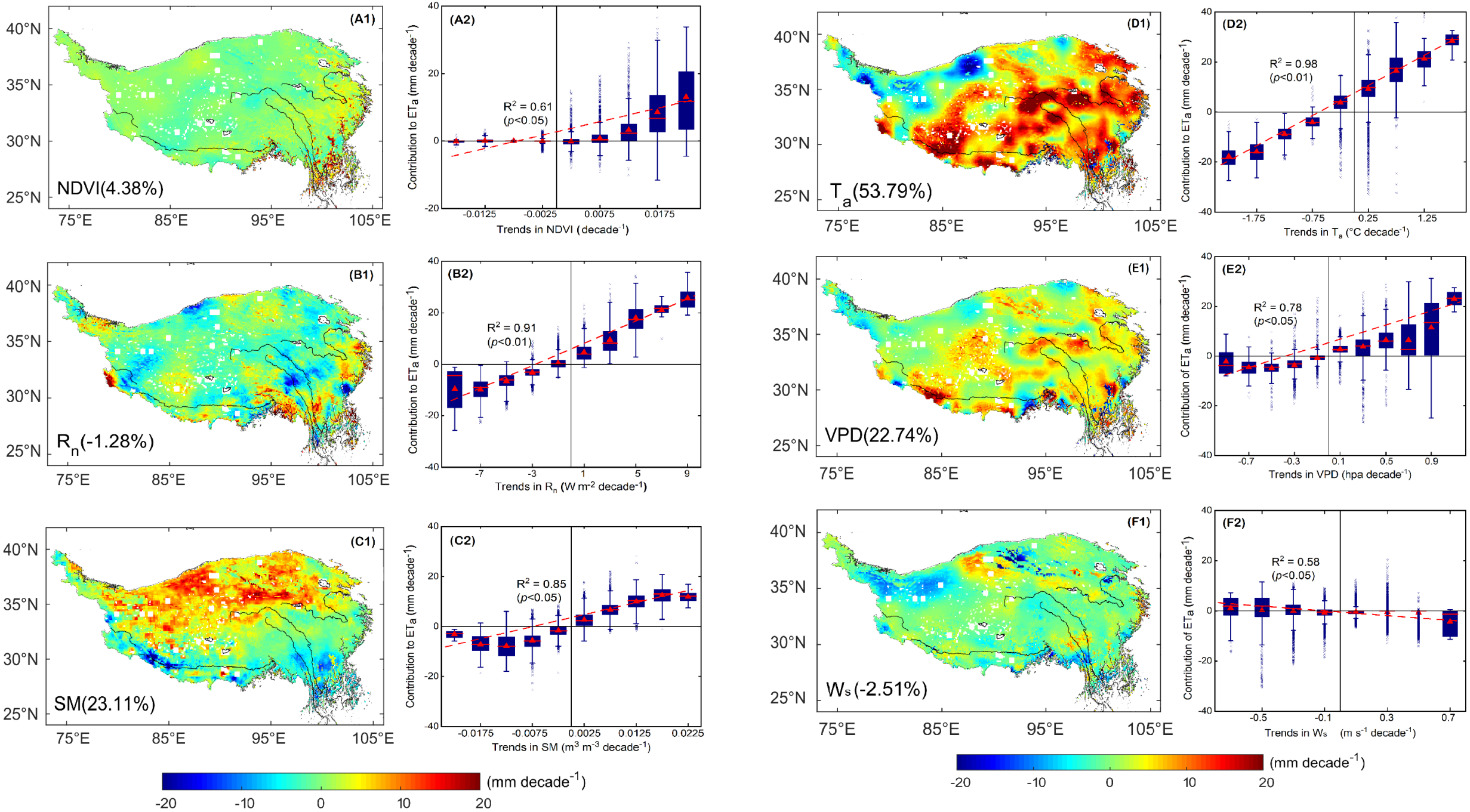
$$LE_c = \frac{(\Delta \times A_c + \rho_a \times C_p \times VPD \times f_c \times G_a) \times (1 - F_{wet})}{\Delta + \gamma \times (1 + \frac{G_a}{G_s})}$$

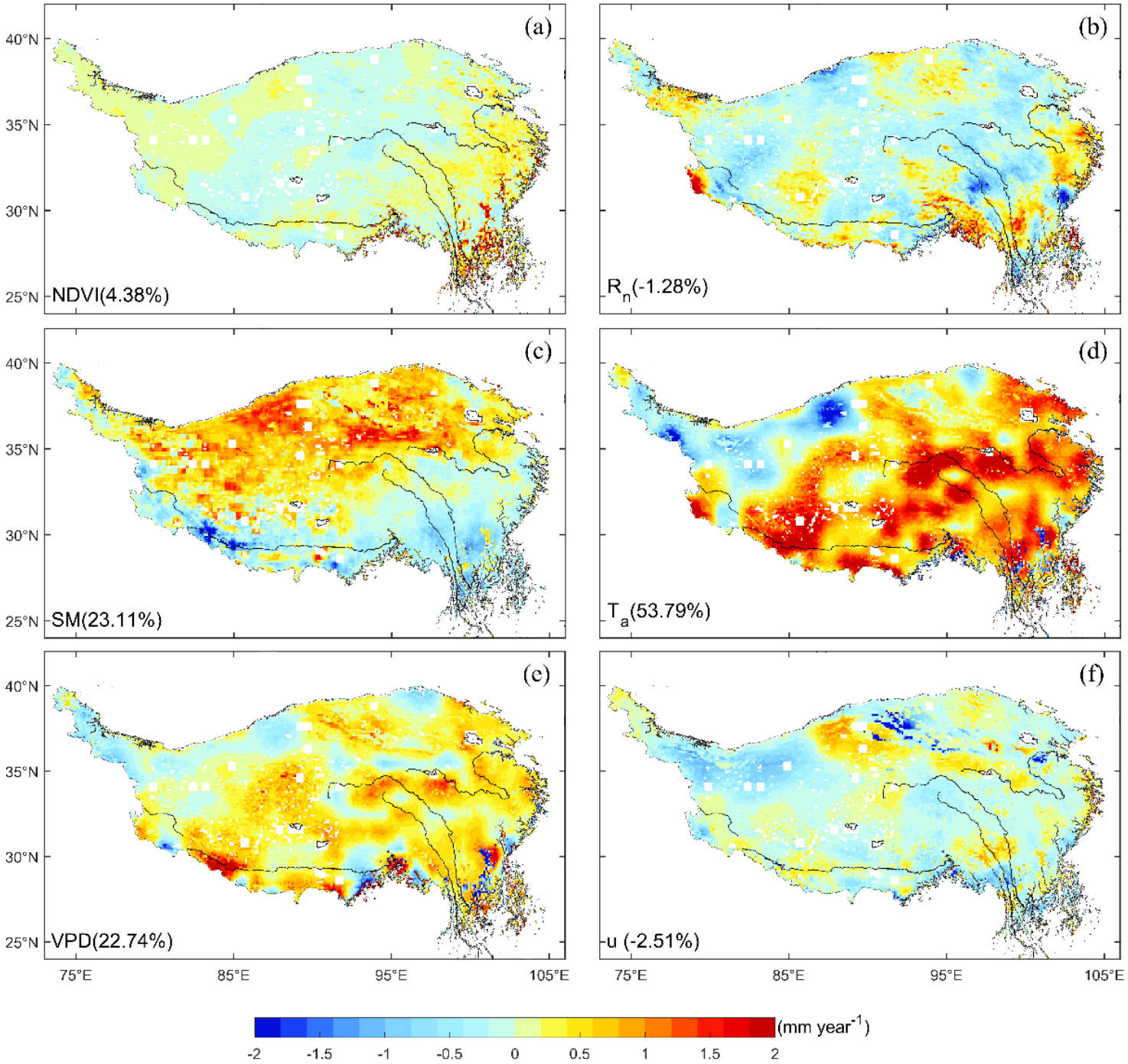
$$LE_s = \frac{(\Delta \times A_s + \rho_a \times C_p \times \frac{VPD}{r_a} \times (1 - f_c)) \times (1 - F_{wet}) \times F_s}{\Delta + \gamma \times (1 + \frac{r_s}{r_a})}$$

$$LE_{s\_wet} = \frac{(\Delta \times A_s + \rho_a \times C_p \times \frac{VPD}{r_a} \times (1 - f_c)) \times F_{wet}}{\Delta + \gamma \times (1 + \frac{r_s}{r_a})}$$

$$LE_{c\_wet} = \frac{(\Delta \times A_c + \rho_a \times C_p \times VPD \times fc \times G_a) \times F_{wet}}{\Delta + \gamma \times (1 + \frac{G_a}{G_s})}$$

MOD16-STM ET model
(Yuan et al. 2021 JGR)


(A1)
NDVI(4.38%)
(A2)
R² = 0.61
(p<0.05)
Contribution to ETa (mm decade⁻¹)
Trends in NDVI (decade⁻¹)
(B1)
Rn(-1.28%)
(B2)
R² = 0.91
(p<0.01)
Contribution to ETa (mm decade⁻¹)
Trends in Rn (W m⁻² decade⁻¹)
(C1)
SM(23.11%)
(C2)
R² = 0.85
(p<0.05)
Contribution to ETa (mm decade⁻¹)
Trends in SM (m³ m⁻³ decade⁻¹)
(D1)
Ta(53.79%)
(D2)
R² = 0.98
(p<0.01)
Contribution to ETa (mm decade⁻¹)
Trends in Ta (°C decade⁻¹)
(E1)
VPD(22.74%)
(E2)
R² = 0.78
(p<0.05)
Contribution of ETa (mm decade⁻¹)
Trends in VPD (hpa decade⁻¹)
(F1)
Ws(-2.51%)
(F2)
R² = 0.58
(p<0.05)
Contribution of ETa (mm decade⁻¹)
Trends in Ws (m s⁻¹ decade⁻¹)
(mm decade⁻¹)
-20 -10 0 10 20
(mm decade⁻¹)
-20 -10 0 10 20



- **The significant increase in the ET on the TP is largely driven by warming (>53%) and surface wetting (>23%).**

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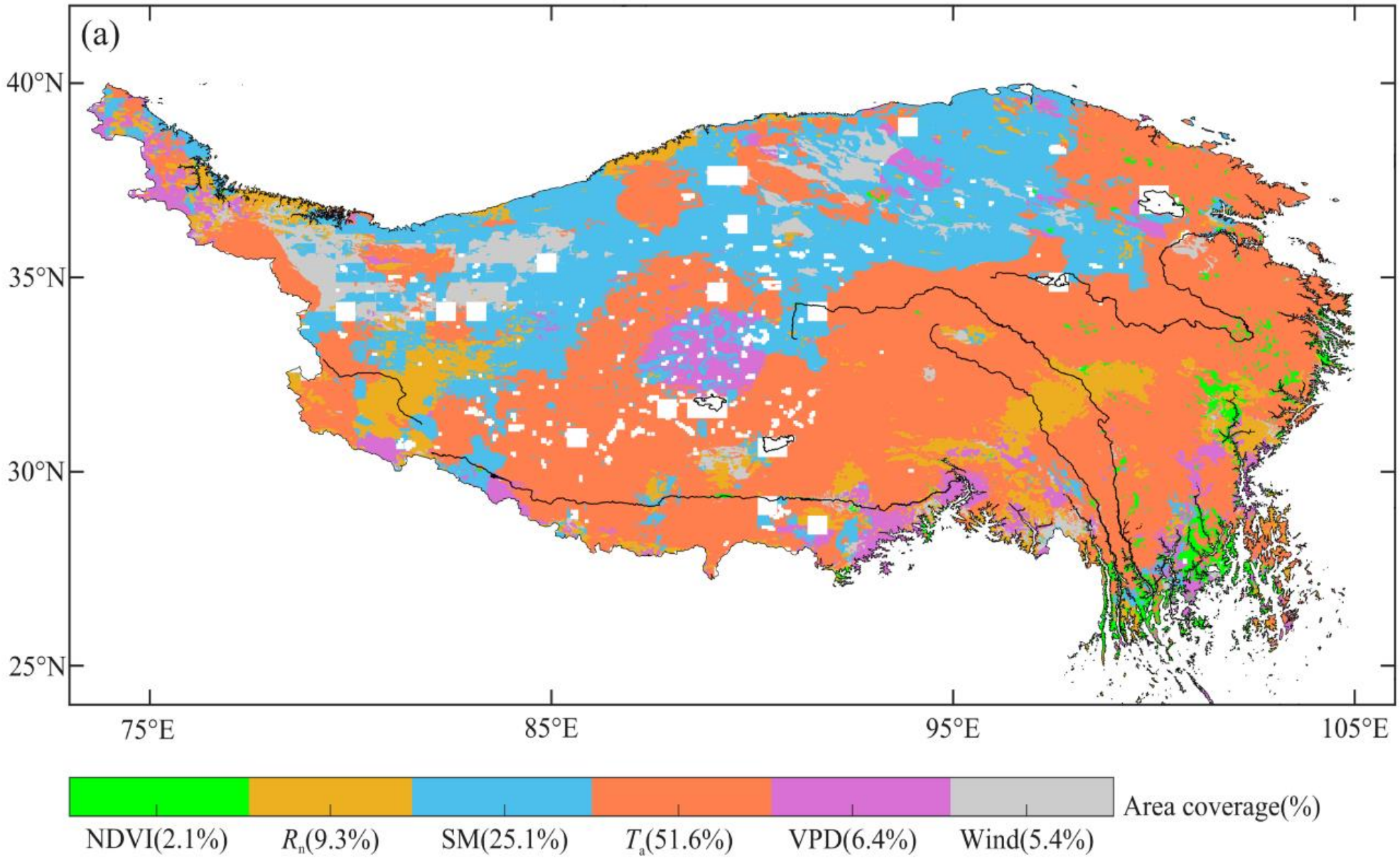

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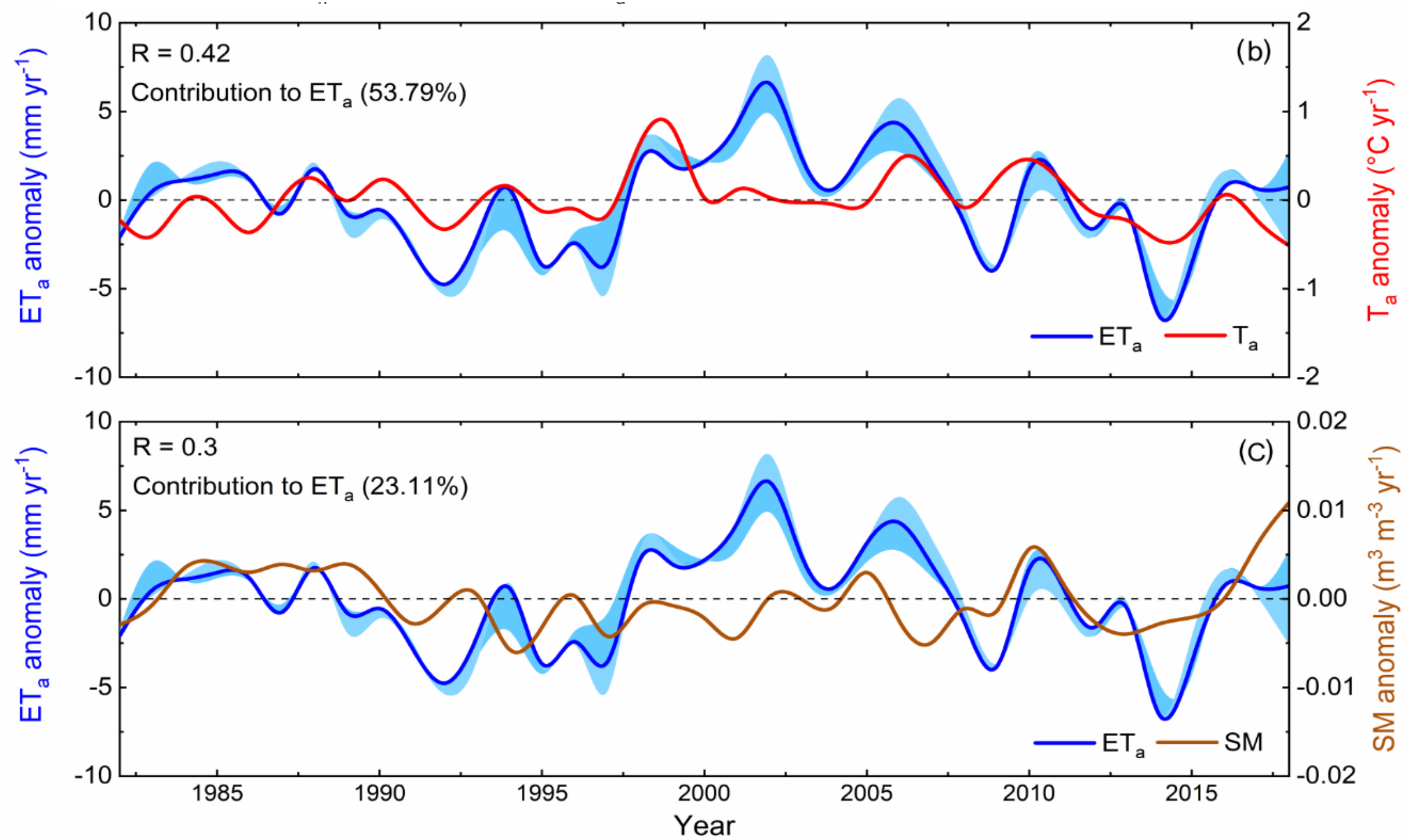
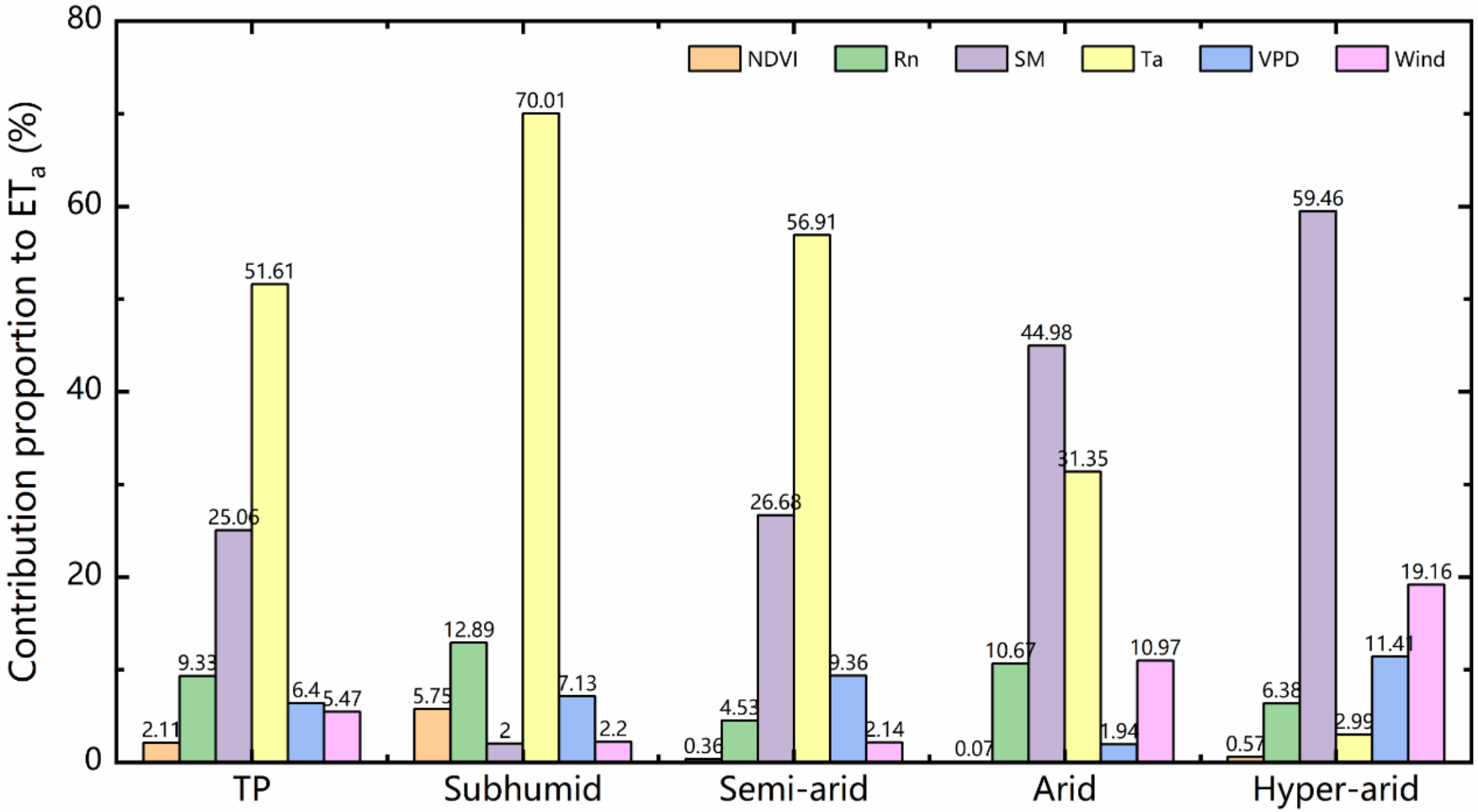
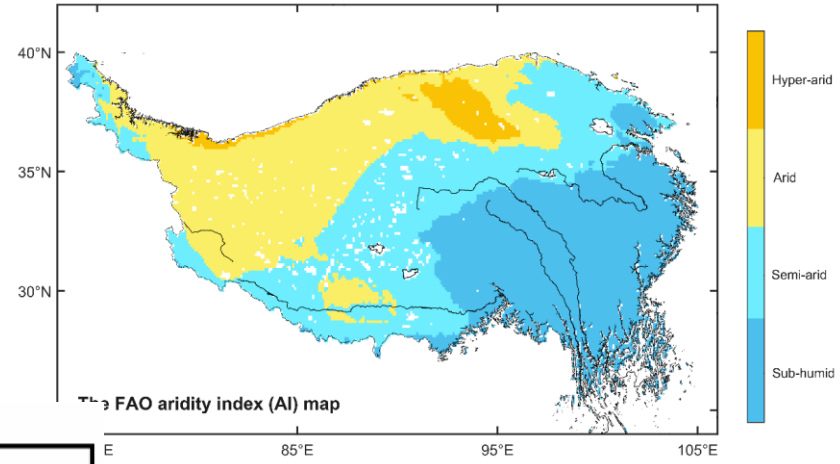

R = 0.42
Contribution to ETa (53.79%)
(b)
ETa anomaly (mm yr-1)
Ta anomaly (°C yr-1)
ETa
Ta
R = 0.3
Contribution to ETa (23.11%)
(C)
SM anomaly (m3 m-3 yr-1)
SM
10
5
0
-5
-10
2
1
0
-1
-2
0.02
0.01
0.00
-0.01
-0.02
1985
1990
1995
2000
2005
2010
2015
Year





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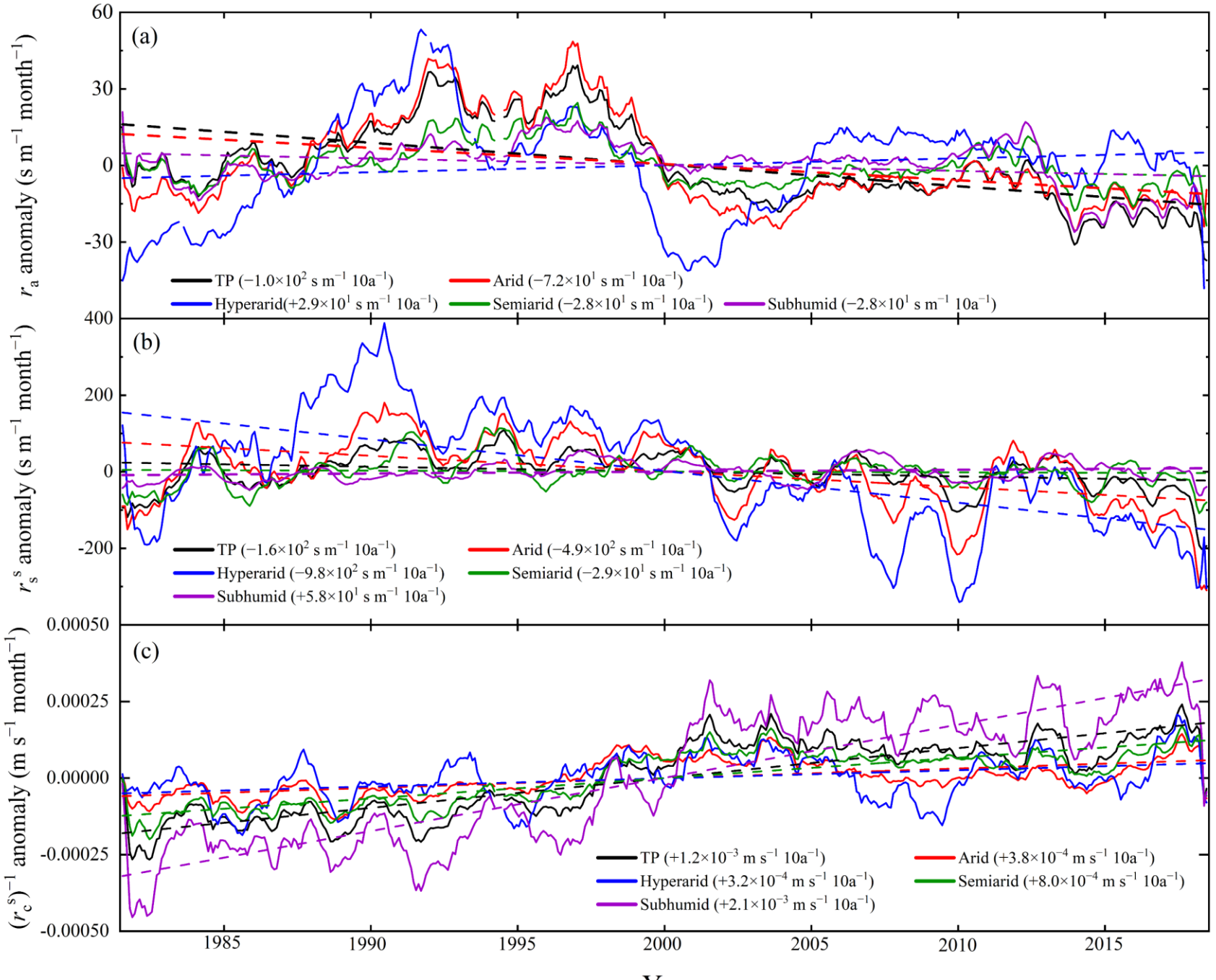

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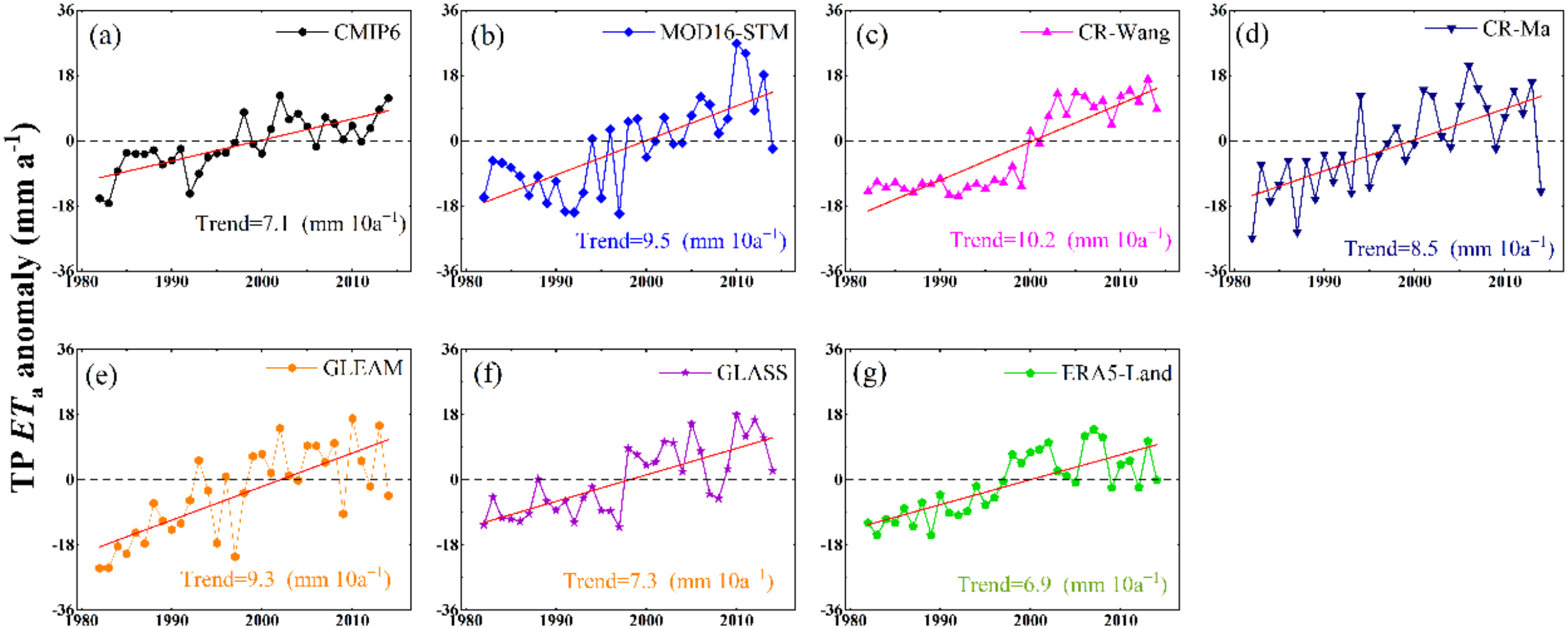

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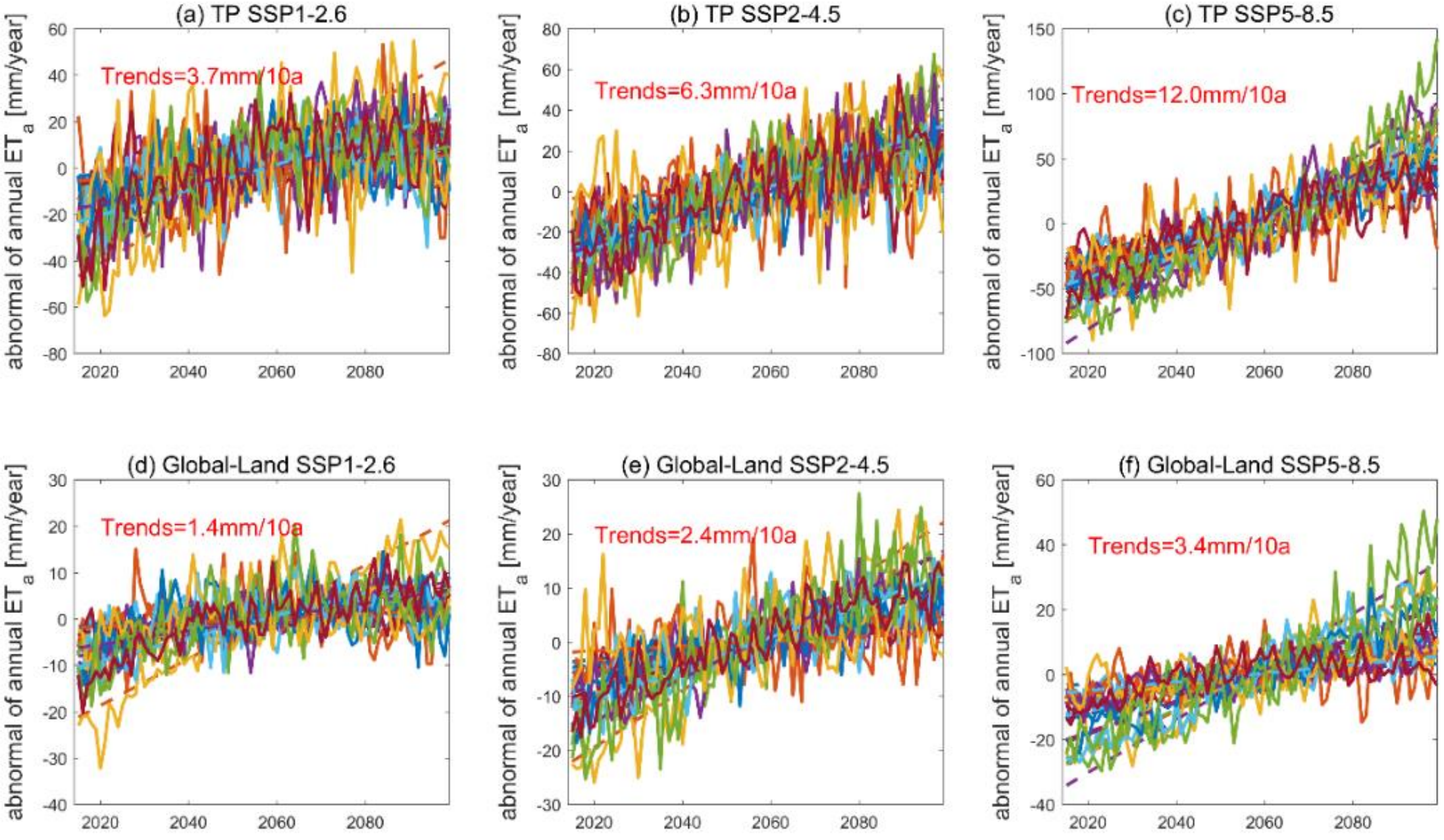
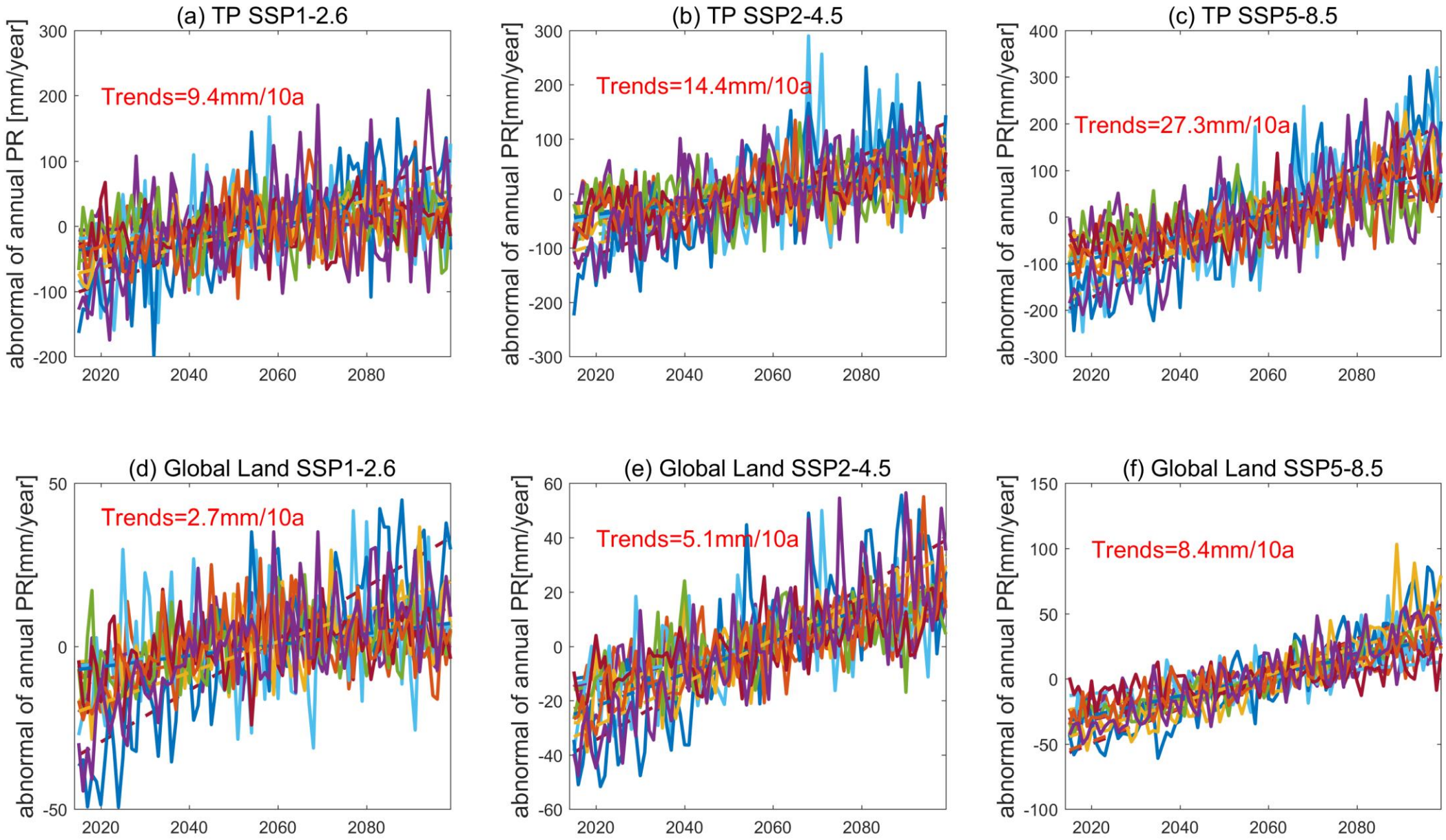


- **It is expected that ET on the TP will accelerating increased till 2100.**


(a) TP SSP1-2.6
Trends=9.4mm/10a
abnormal of annual PR [mm/year]
(b) TP SSP2-4.5
Trends=14.4mm/10a
abnormal of annual PR[mm/year]
(c) TP SSP5-8.5
Trends=27.3mm/10a
abnormal of annual PR[mm/year]
(d) Global Land SSP1-2.6
Trends=2.7mm/10a
abnormal of annual PR[mm/year]
(e) Global Land SSP2-4.5
Trends=5.1mm/10a
abnormal of annual PR[mm/year]
(f) Global Land SSP5-8.5
Trends=8.4mm/10a
abnormal of annual PR[mm/year]
2020
2040
2060
2080

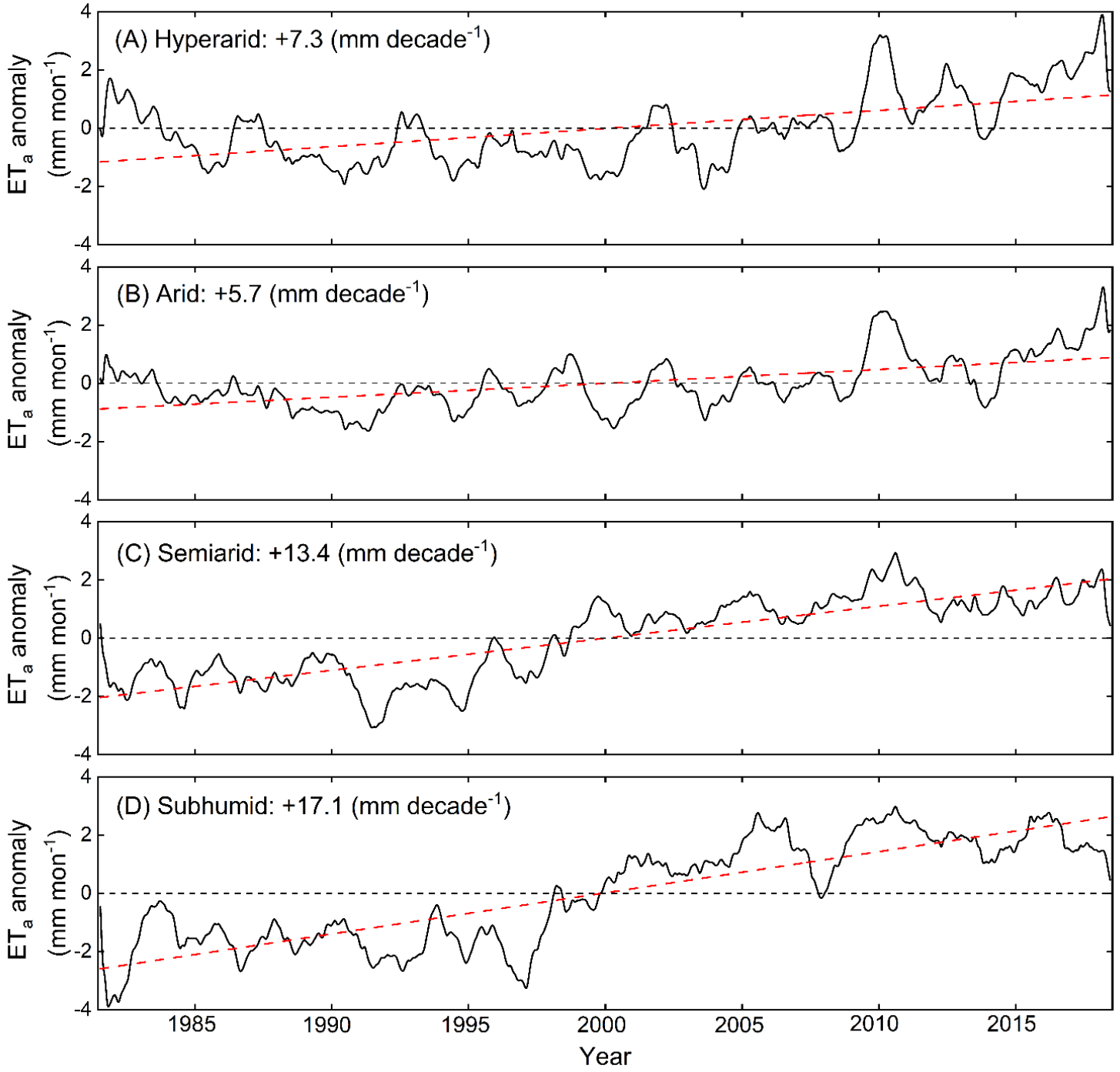
Summary

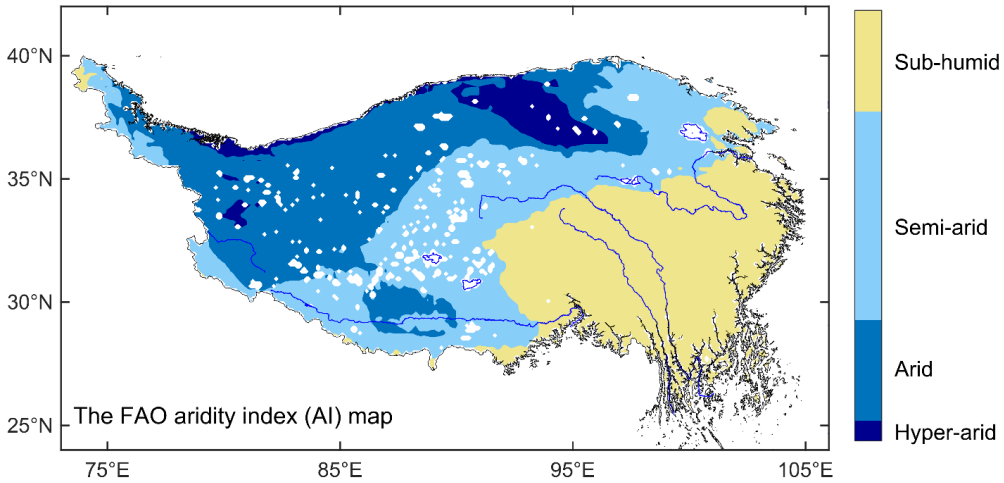
1. There are significant differences in various ET products on the TP, especially in the western TP where vegetation is sparse and evapotranspiration rates are low, leading to higher uncertainties.
2. Ensemble data confirms a continuous increase in ET, with a growth rate (0.84 mm/year) approximately twice that of the global land surface (0.41 mm/year).
3. CMIP6 projections suggest that ET on the TP will continue to increase, with the increasing rate becoming even faster by the end of this century.
4. The significant increase in ET on the TP is primarily driven by warming, followed by surface soil moisture.

References

- Yuan L., Ma Y.*, **Chen X.***, Wang, Y. An enhanced MOD16 evapotranspiration model for the Tibetan Plateau during the unfrozen season. Journal of Geophysical Research: Atmospheres，2021, 126(7): e2020JD032787
- Yuan, L.**, Chen X.***, Ma Y.*, et al., 2024. Long-term monthly 0.05° terrestrial evapotranspiration dataset (1982–2018) for the Tibetan Plateau. Earth Syst. Sci. Data, 16(2): 775-801.
- Chen, X. et al., 2024. A doubled increasing trend of evapotranspiration on the Tibetan Plateau. Science Bulletin.


Thank you!


(A) Hyperarid: +7.3 (mm decade-1)
(B) Arid: +5.7 (mm decade-1)
(C) Semiarid: +13.4 (mm decade-1)
(D) Subhumid: +17.1 (mm decade-1)
ETa anomaly (mm mon-1)
4
2
0
-2
-4
1985
1990
1995
2000
2005
2010
2015
Year


40°N
35°N
30°N
25°N
75°E
85°E
95°E
105°E
The FAO aridity index (AI) map
Sub-humid
Semi-arid
Arid
Hyper-arid