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Coupling of cloud base height and surface fluxes: a transferability study

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Introduction

- RCMs are useful tools for obtaining climate information at regional scales…
- and for understanding physical processes…
- There is a need to test regional climate models where they have not fully tuned their parameterizations (Gutowski et al, ictp, 2004).

Model intercomparison projects (MIPs)

ArcMIP, NAMAP, PIRCS, RMIP, BALTEX,PRUDENCE, NARCAPP, etc….

- Validate
- Evaluate/Assess
- Improve

Lessons learned from MIPS

- No model performs better than others in ALL situations
- Model ensemble realization usually more accurate than any single model realization

Transferability (a different approach)

Structured multi-domain studies

- Single model across multiple domains
  (transferability experiment)
- Multiple models across multiple domains
  (transferability intercomparison)

Aims and Objectives

- Reducing dependency on region specific tuning; improving our understanding and predictive capability of RCMs…
- Evaluate regional model simulations of climate processes of different climatic regions.
- Examine individual and ensemble performance between domains and on individual domains.

…in summary, identify model biases and probable causes

Requirements

- Coordinated RCM simulations
- High temporal resolution observations from different domains (e.g. CEOP)
- Centralized archival and retrieval systems for standardized output data

Simulations

Models

- Climate version of the Lokal Model (CLM) – Now known as COSMO
- Global Environmental Multiscale Limited Area Model (GEM-LAM)
- Canadian Regional Climate Model (CRCM)
- Rossby Centre Atmosphere Model, version 3 (RCA3)
- Regional Spectral Model (RSM)
- Regional Climate Model, version 3 (RegCM3)

Period

- July 1999 – December 2004

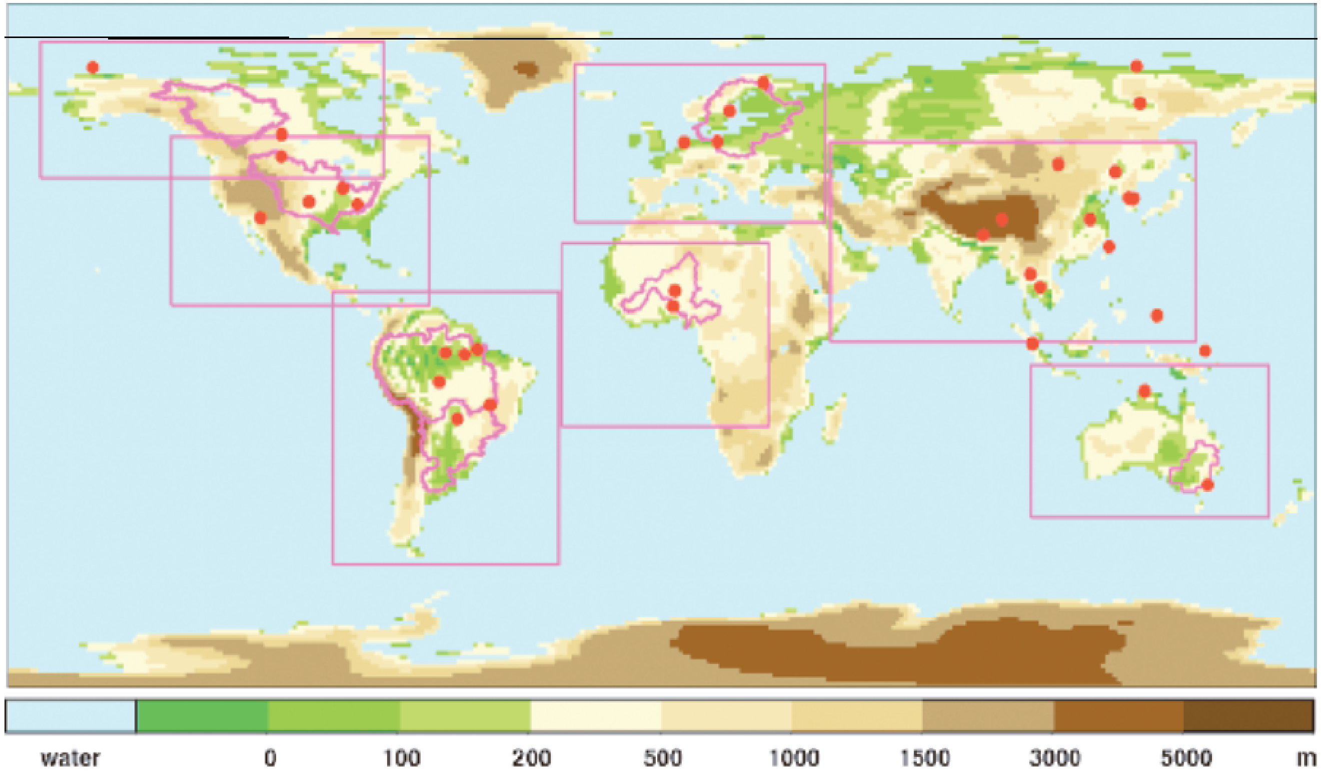
Resolution

- 0.5° x 0.5 °

Model overview

Model In	stitute	Dynamics	Lateral boundary	Radiation	Land surface	Turbulence	Microphysics	Convection	Large Scale Precipitation
CLM	GKSS, Germany	**non-hydrostatic** flow in a moist atmosphere without any scale approximations. (Steppeler et al. 2003)	Davies relaxation method (Davies, 1976)	SW and LW radiation. Two-stream radiation scheme (Ritter and Geleyn, 1992)	DWD soil model TERRA3D (Schrodin and Heise, 2001)	Mellor and Yamada hierarchy level 2.0 (Muller, 1981)	Kesler (1979), Lin et al. (1983)	Kain-Fritsch (1990) Mass flux scheme	Modified warm rain scheme, Kessler (1969)
GEMLAM	RPN/MSC and University of Quebec, Canada	**hydrostatic** primitive equations using implicit two time-level semi-Lagrangian scheme in time and 3D finite elements in space (Cote et al. 1998)	Davies relaxation method (Davies, 1976)	cccmarad radiative transfer scheme (Li and Barker ,2004)	Interactions between Soil-Biosphere-Atmosphere (ISBA) land surface scheme (Be´lair et al. 1998)	moist turbulent kinetic energy scheme, MoisTKE, (Mailhot et al., 2005)	Fully explicit micro-physical condensation scheme (Kong and Yau, 1997)	Kain-Fritsch (1990) Mass flux scheme	Consun condensation, Sundqvist et al. (1989)
MRCC	OURANOS, Canada	**non-hydrostatic,** fully elastic Euler equations (Laprise et al., 1997)	Davies (1976), refined by Yakimiw and Robert (1990)	SW radiation, Puckrin et al., (2004). LW radiation, Morcrette (1984)	Canadian LAnd Surface Scheme, (CLASS) Verseghy, 1991, Verseghy et al., 1993)	Vertical diffusion following Monin-Oboukhov, K-theory. Jiao (2006)	Relative humidity and stability dependant cloud formation (Lorant, 2002)	Kain-Fritsch (1990) Mass flux scheme	Modified cloud scheme (Lorant et al., 2002).
RCA3	Rossby Centre, SMHI, Sweden	**hydrostatic** grid point model (Kjellström et al. 2005)	Davies relaxation method (Davies, 1976)	SW radiation, Savijarvi (1990) LW radiation, Savijarvi(1990) Stephens (1984) Rogers(1977)	Modified HIRLAM land surface scheme. Kjellström *et al.* (2005) and Samuelsson *et al.* (2006)	prognostic turbulent kinetic energy combined with a diagnostic length scale (Cuxart et al. 2000)	Wyser et al. (1999) Jones and Sanchez (2002).	Kain-Fritsch (1993) Mass flux scheme	Rasch-Kristjánsson scheme. Rasch and Kristjánsson (1998).
RSM	Experimental Climate Prediction Center, USA	**hydrostatic** spectral model perturbed using primitive equations in sigma coordinates (Juang and Kanamitsu, 1994)	Explicit relaxation scheme after Juang et al. (1997).	SW radiation, Chou (1992). LW radiation, Chou and Suarez (1994).	Updated four-layer soil model Noah (Mitchell et al., 2004)	Non-local vertical diffusion package. Hong and Pan (1996)	Juang and Kanamitsu, 1994	Simplified Arakawa-Schubert formerly by Grell (1993), version from Pan and Wu (1995)	LRGSCL routine, calculates grid-scale precipitation for one leap- frog time-step. Hua-Lu Pan (1994)

Domains



domain	number of grid points including (relaxation zone ≈8 grid points)	lon/lat of the rotated North Pole
Africa	131 x 131	0. / 90.
Asia	201 x 147	–70. / 60.
Australia	127 x 127	135. / 65.
Europa	105 x 111	–170. / 32.5
North America 1	137 x 125	80. / 55.
North America 2	115 x 105	70. / 28.
South America	149 x 181	–60.0 / 68.0

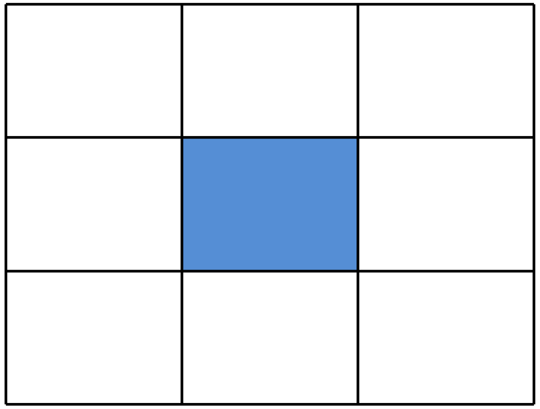
Data: Model & Observations

Surface energy fluxes and surface meteorological variables from the Coordinated Enhanced Observing Period (CEOP) Campaigns

> 35 Reference sites.

•October 2002 – December 2004

•3-hourly Model Location Time Series (MOLTS) data



Transferability Hypotheses

- Models show no superior performance on their domains of origin as evaluated by their accuracy in reproducing the diurnal cycles of key surface hydrometeorological variables.

- For all climatic regions and periods having convective precipitation during both day and night, alternative parameter settings in convective schemes at a specific resolution result in changes of intensity and diurnal phasing of precipitation that are correlated.

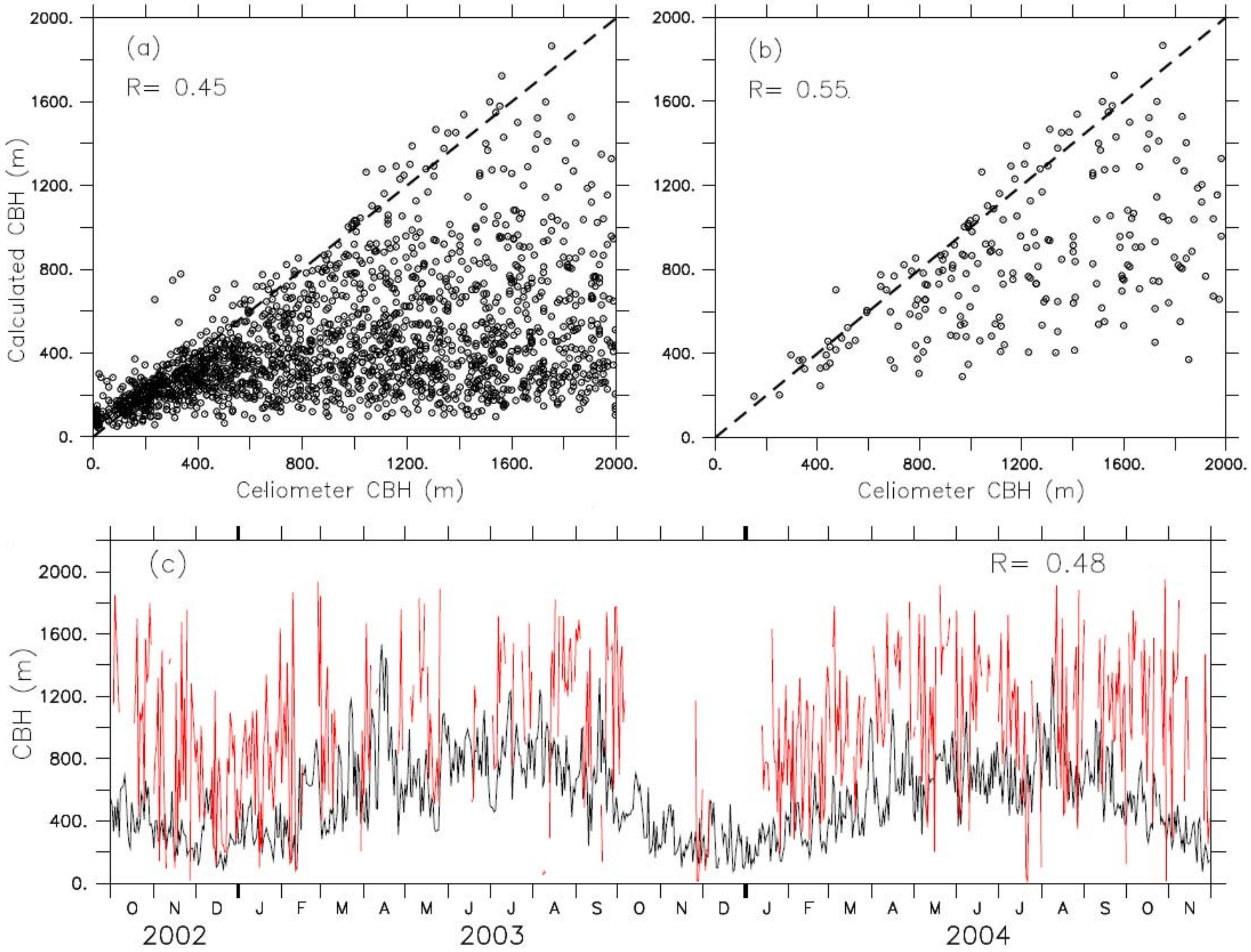
- No single domain provides climatic conditions for developing and tuning a regional climate model that result in measurably better regional climate model performance on all climate domains in the transferability domain ensemble. And;

- **For all nonmonsoon climatic regions experiencing weak large scale forcing, daytime surface fluxes are correlated with the height of cloud base.**

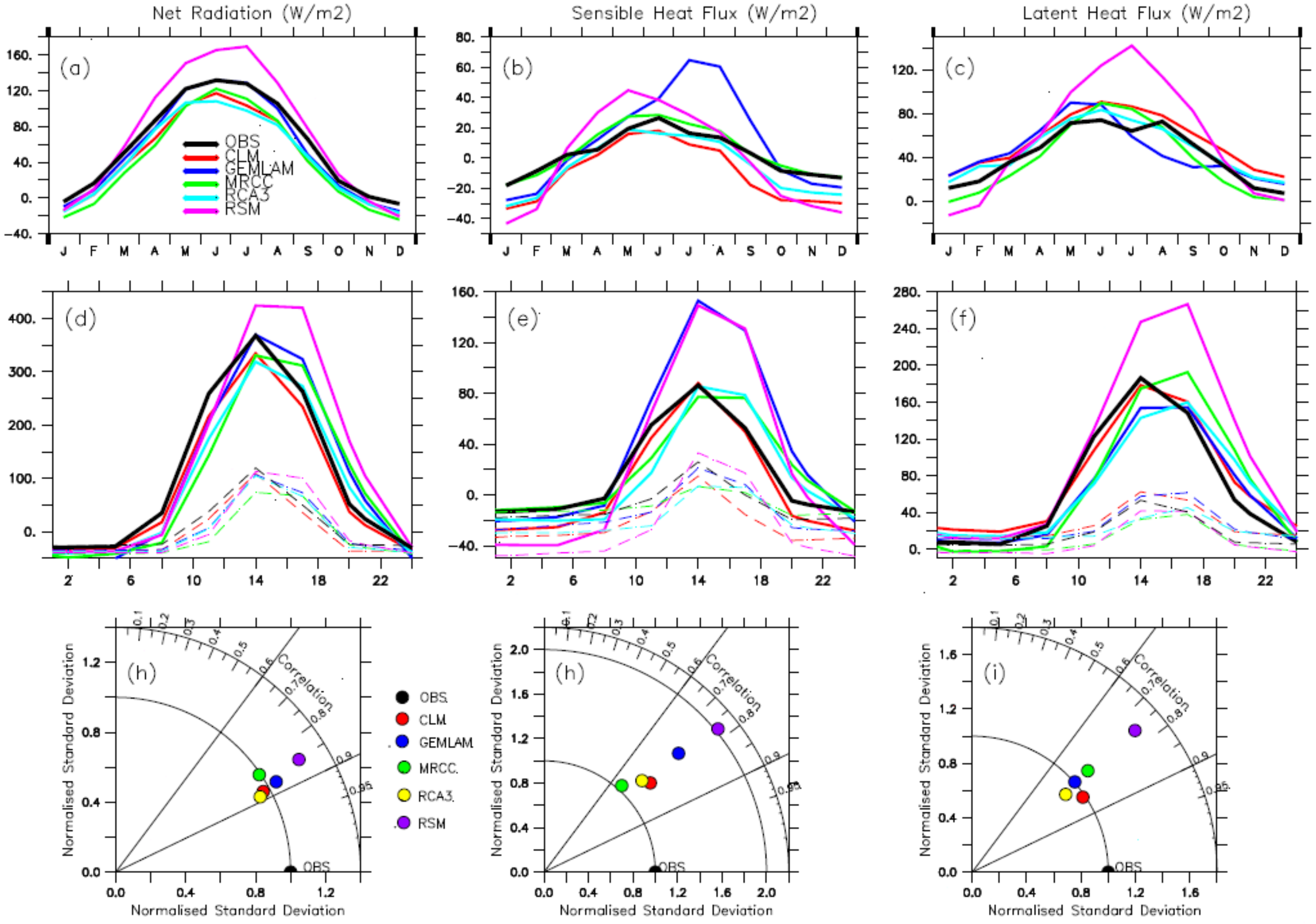
Takle, E. S., and Coauthors, 2007: Transferability intercomparison - An opportunity for new insight on the global water cycle and energy budget. *Bulletin of the American Meteorological Society*, 88, 375-384

Cabauw (51.970N, 4.930E) Test Bed

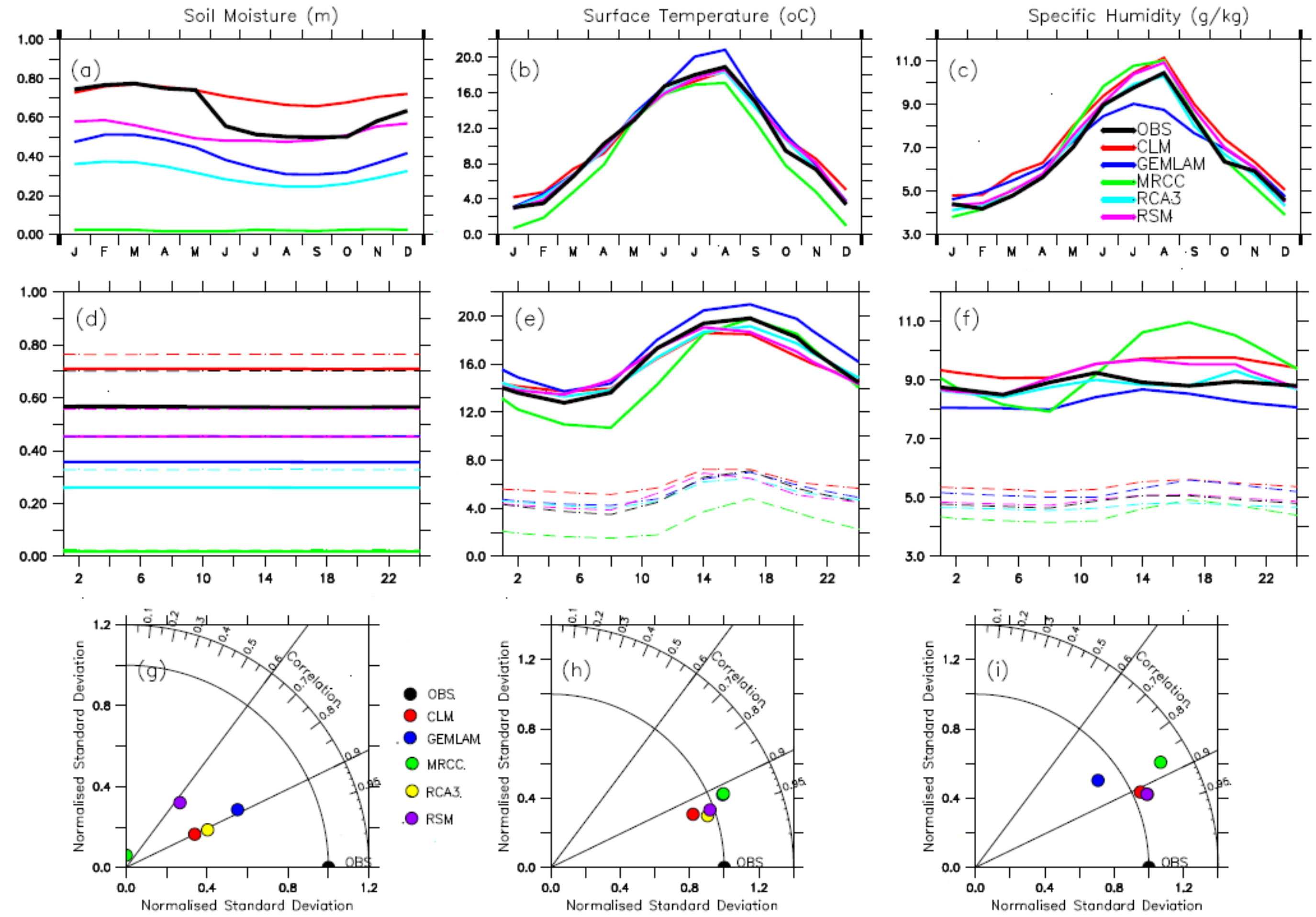
Cabauw cloud base height data



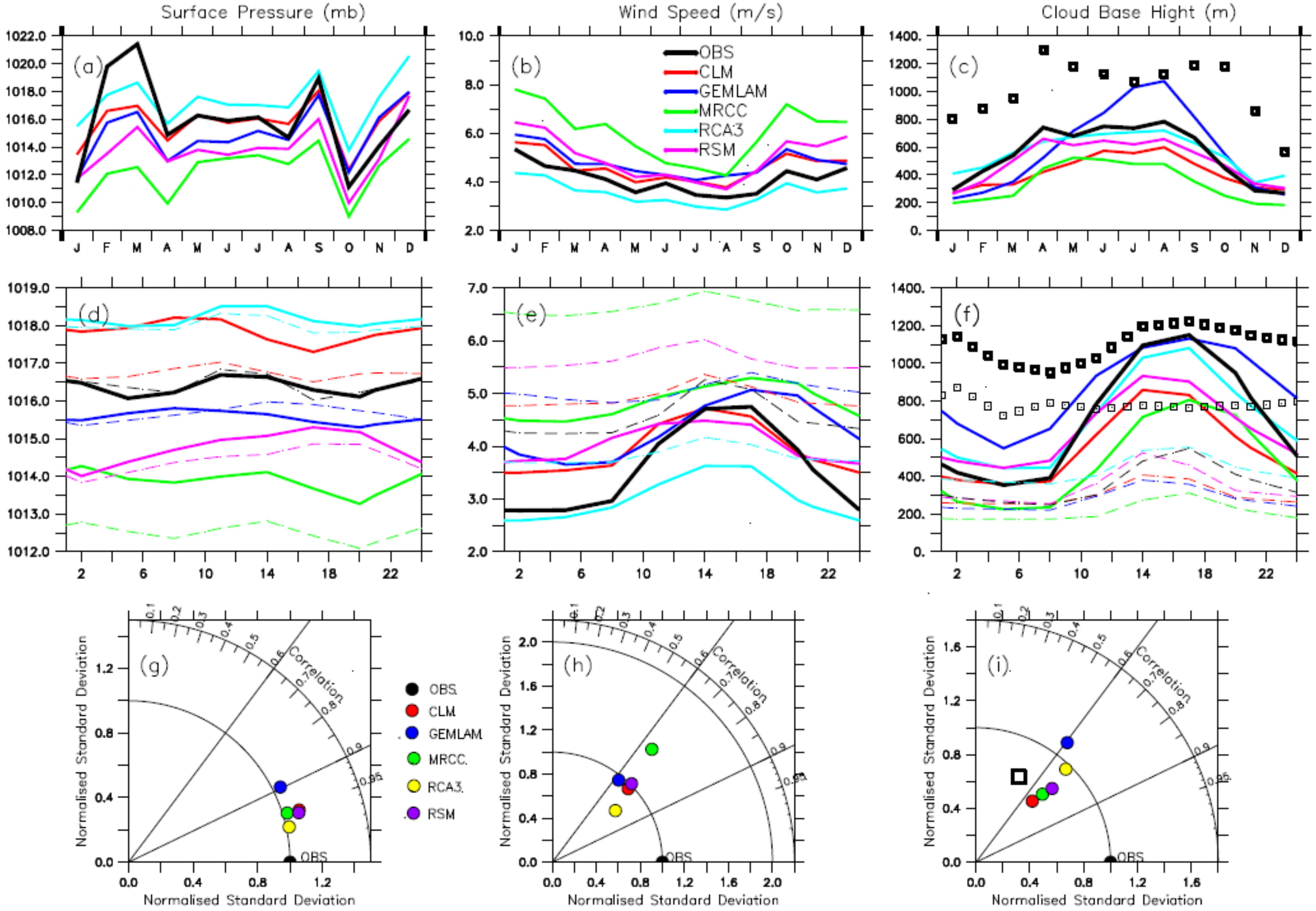
Surface energy fluxes



Surface variables



Surface variables

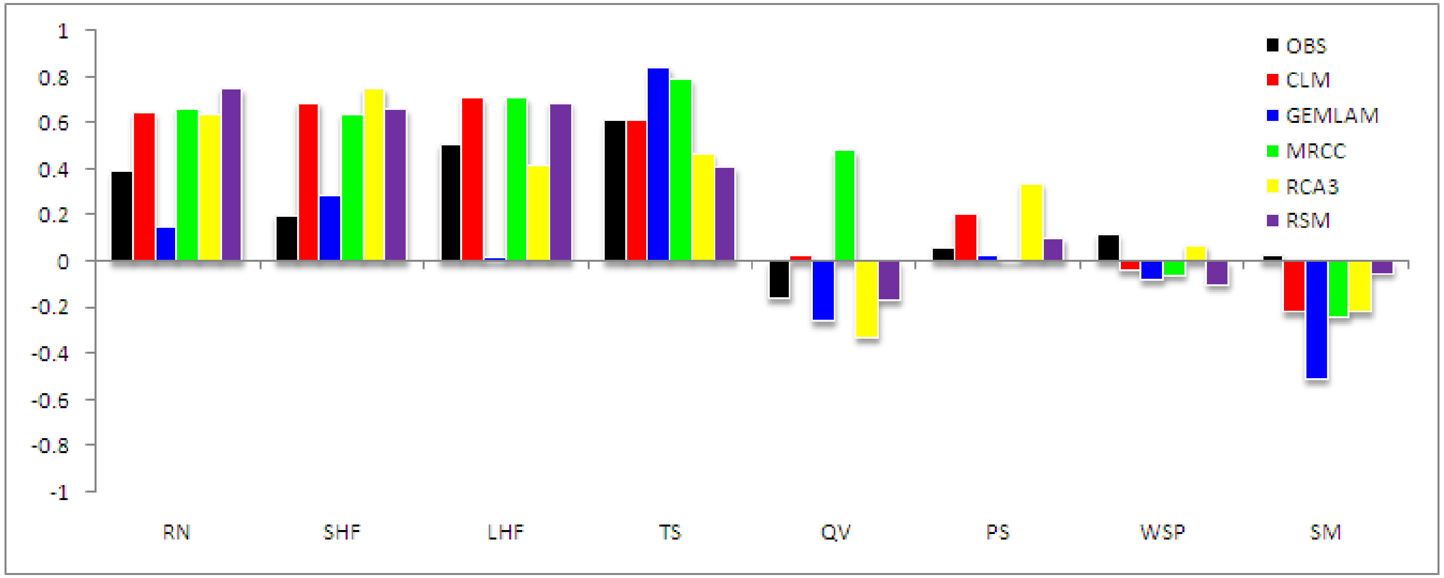


Cabauw: simulation errors in selected variables

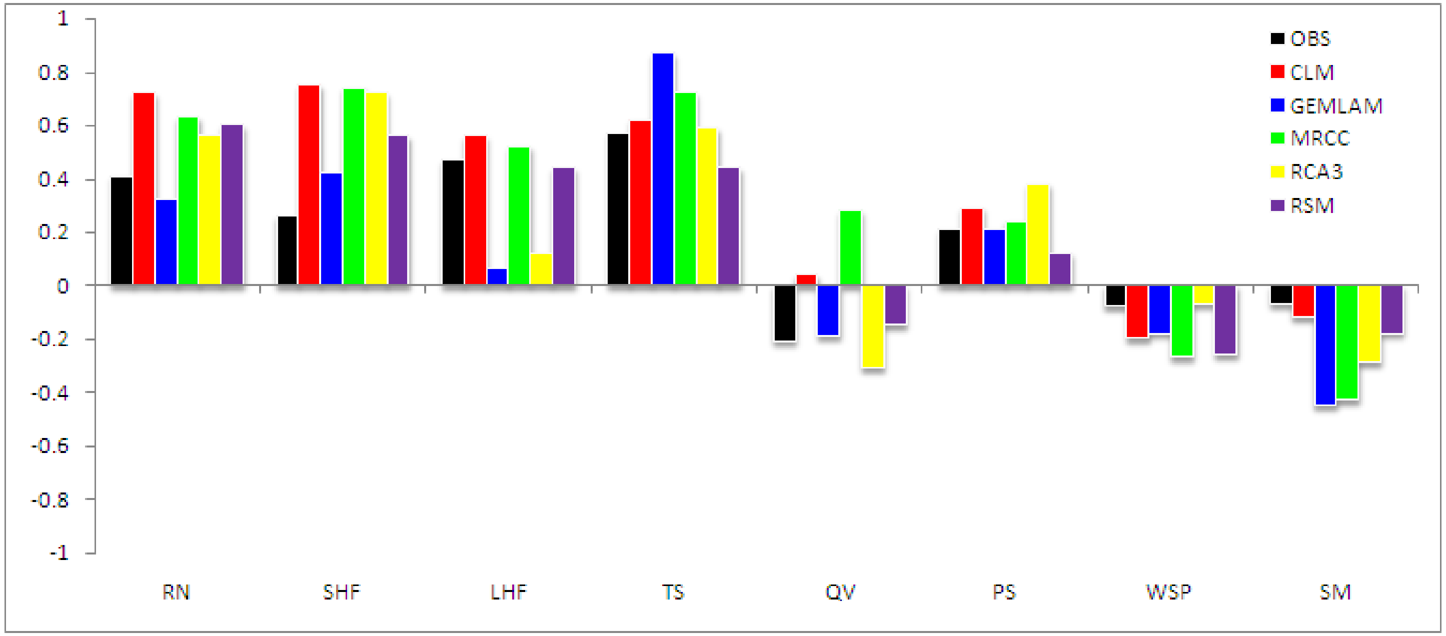
		Errors (simulated minus observed)				
Variables	**Observed**	**CLM**	**GEMLAM**	**MRCC**	**RCA3**	**RSM**
R_{net} (Wm^{-2})	56.5	-10.9	-1.2	-14.0	-11.0	**17.3**
SHF(Wm^{-2})	1.7	**-11.6**	10.0	3.4	-7.0	-1.6
LHF (Wm^{-2})	41.3	13.7	4.8	-3.5	6.2	**17.1**
SM (m)	0.6	0.1	-0.2	**-0.6**	-0.3	-0.1
Temp (°C)	10.2	0.7	1.1	**-1.4**	0.3	0.4
QV(Wm^{-2})	6.7	**0.8**	0.1	0.3	0.1	0.4
PS (mb)	1016.0	0.0	-0.8	**-3.5**	1.5	-2.0
WSP (ms^{-1})	4.1	0.5	0.7	**1.9**	-0.6	0.9
CBH (m)	536.8	-114.6	87.1	**-187.5**	51.6	-33.7
Albedo	0.22	-0.07	-0.03	-0.02	0.04	**-0.14**
Evaporation fraction*	0.70	0.00	**-0.18**	0.00	0.03	0.05

*summer daytime

Correlations between CBH and surface variables



Weak wind



Strong wind

Principal Component Analysis (summer daytime)

Weak wind

Variable	OBSERVED			CLM			GEMLAM			MRCC			RCA3			RSM		
	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3
NTR	**0.96**	-0.01	0.00	**0.96**	0.10	-0.03	**0.98**	0.03	0.00	**0.86**	0.39		**0.93**	-0.06	0.07	**0.97**	0.11	0.09
SHF	**0.86**	-0.07	-0.16	**0.94**	0.00	-0.02	**0.75**	0.34	-0.19	**0.72**	0.55		**0.91**	-0.17	-0.13	**0.88**	-0.16	0.13
LHF	**0.96**	-0.04	0.05	**0.92**	0.14	0.02	**0.82**	-0.24	0.26	**0.91**	0.19		**0.79**	0.21	0.39	**0.88**	0.30	0.05
CBH	**0.58**	0.24	0.22	**0.79**	0.17	0.30	0.16	**0.89**	-0.01	**0.85**	0.14		**0.80**	-0.07	-0.47	**0.87**	0.00	-0.04
T2M	0.35	**0.85**	0.26	0.48	**0.84**	0.08	0.28	**0.84**	0.37	**0.91**	-0.31		0.52	**0.80**	-0.15	0.39	**0.87**	0.11
QV	-0.10	**0.83**	0.14	0.03	**0.94**	-0.16	0.20	-0.06	**0.72**	**0.73**	-0.56		-0.12	**0.92**	0.24	-0.12	**0.96**	0.11
PS	0.18	-0.07	**-0.78**	0.19	-0.18	**0.79**	0.19	0.03	**-0.75**	0.00	0.60		0.16	-0.17	-0.69	0.12	-0.34	0.69
VABS	0.10	0.09	0.49	-0.02	-0.25	-0.06	0.04	-0.24	0.17	-0.03	-0.09		0.09	-0.44	0.06	0.00	-0.19	-0.49
SMI	0.15	-0.61	0.49	0.12	-0.40	**-0.77**	0.27	**-0.79**	0.30	-0.02	-0.58		0.17	-0.25	**0.80**	0.04	0.16	**0.72**
Tot. Var(%)	**34.83**	**20.57**	**13.91**	**39.53**	**21.19**	**14.88**	**27.29**	**26.28**	**16.06**	**46.17**	**18.06**		**36.70**	**20.45**	**17.72**	**38.11**	**22.05**	**14.19**

Strong wind

Variable	OBSERVED			CLM			GEMLAM				MRCC			RCA3			RSM			
	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF4	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF3	PF 4
NTR	**0.96**	0.02	0.02	**0.97**	0.01	0.06	0.28	**0.92**	0.15	0.07	**0.94**	0.20	0.09	**0.94**	0.04	0.14	**0.97**	0.04	0.04	0.03
SHF	**0.87**	-0.07	-0.05	**0.88**	-0.02	0.25	0.58	0.56	0.14	0.08	**0.88**	0.04	0.30	**0.90**	-0.04	-0.21	**0.83**	-0.17	0.33	-0.08
LHF	**0.92**	0.01	-0.09	**0.86**	-0.08	-0.21	-0.15	**0.91**	0.03	0.00	**0.85**	0.29	-0.05	0.60	0.05	0.61	**0.84**	0.28	-0.23	0.13
CBH	0.57	0.19	0.48	**0.81**	0.19	0.28	**0.88**	0.14	0.11	-0.24	**0.71**	0.22	0.42	**0.75**	0.10	-0.45	**0.71**	0.07	0.24	-0.33
T2M	0.31	**0.87**	0.25	0.51	**0.83**	0.13	**0.88**	0.16	0.13	0.25	0.54	**0.77**	0.14	0.49	**0.82**	-0.16	0.31	**0.91**	0.15	-0.11
QV	-0.13	**0.86**	-0.14	0.04	**0.91**	-0.07	0.06	0.05	0.02	**0.96**	0.23	**0.92**	-0.13	-0.18	**0.86**	0.28	-0.12	**0.96**	-0.01	0.07
PS	0.12	-0.27	**0.78**	0.20	-0.09	**0.79**	0.18	0.06	**0.77**	-0.26	0.12	0.07	0.69	0.35	-0.24	-0.67	0.13	-0.12	**0.75**	0.24
VABS	0.26	-0.18	**-0.76**	0.02	-0.22	**-0.79**	-0.04	-0.10	**-0.79**	-0.28	0.00	-0.56	-0.54	-0.02	-0.14	0.52	-0.04	-0.29	**-0.81**	0.17
SMI	0.03	-0.56	0.03	0.19	-0.64	-0.13	**-0.75**	0.47	-0.05	-0.09	-0.16	0.10	**-0.75**	0.01	-0.63	0.45	-0.06	0.00	0.07	**0.93**
Tot. Var(%)	**33.79**	**21.63**	**16.60**	**38.30**	**22.43**	**16.40**	**28.71**	**25.48**	**14.45**	**13.43**	**36.37**	**21.61**	**18.25**	**33.46**	**20.93**	**18.43**	**33.12**	**21.82**	**16.28**	**12.19**

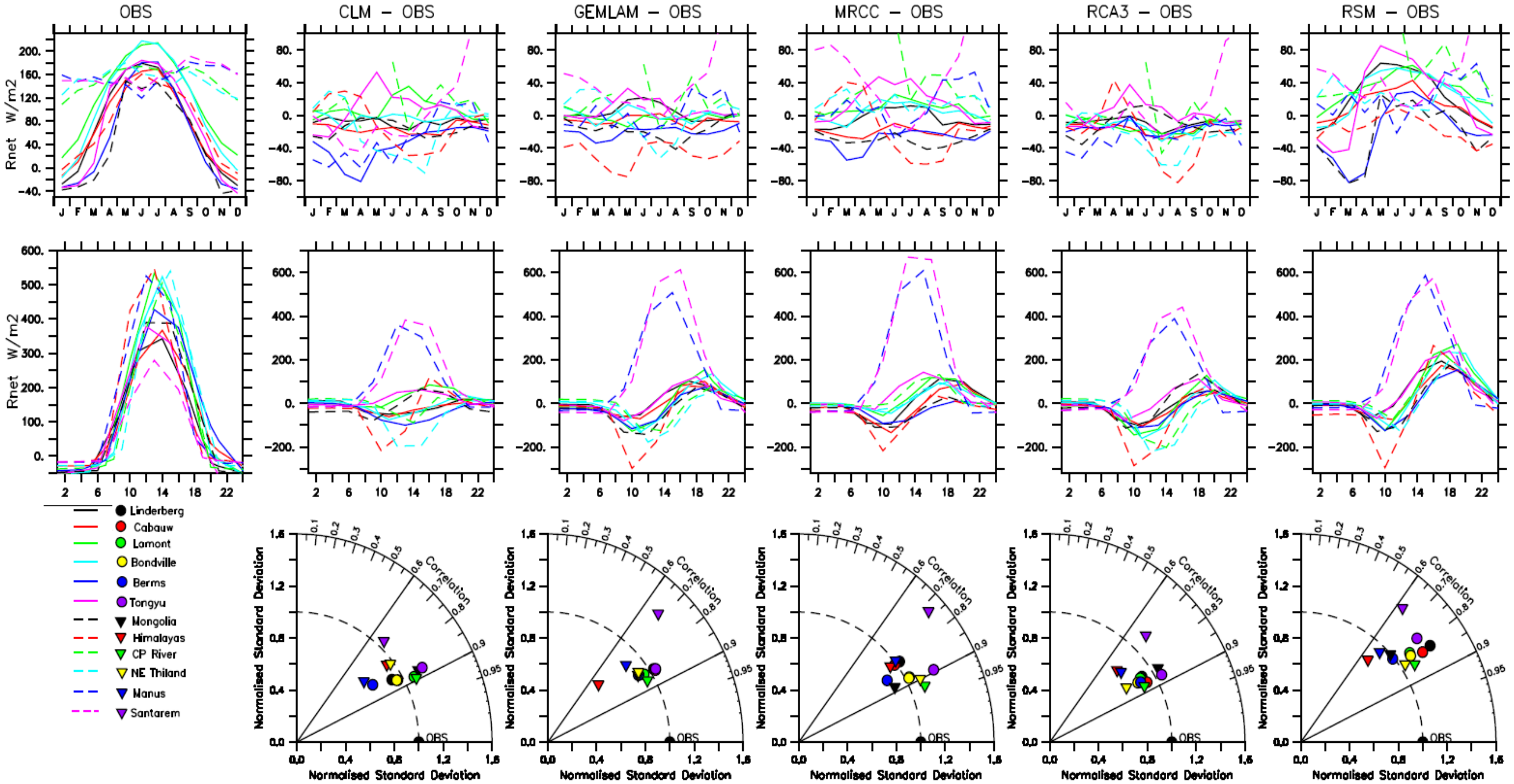
Transferability Intercomparison

- How do these couplings behave in other domains (i.e. how do they transfer?)

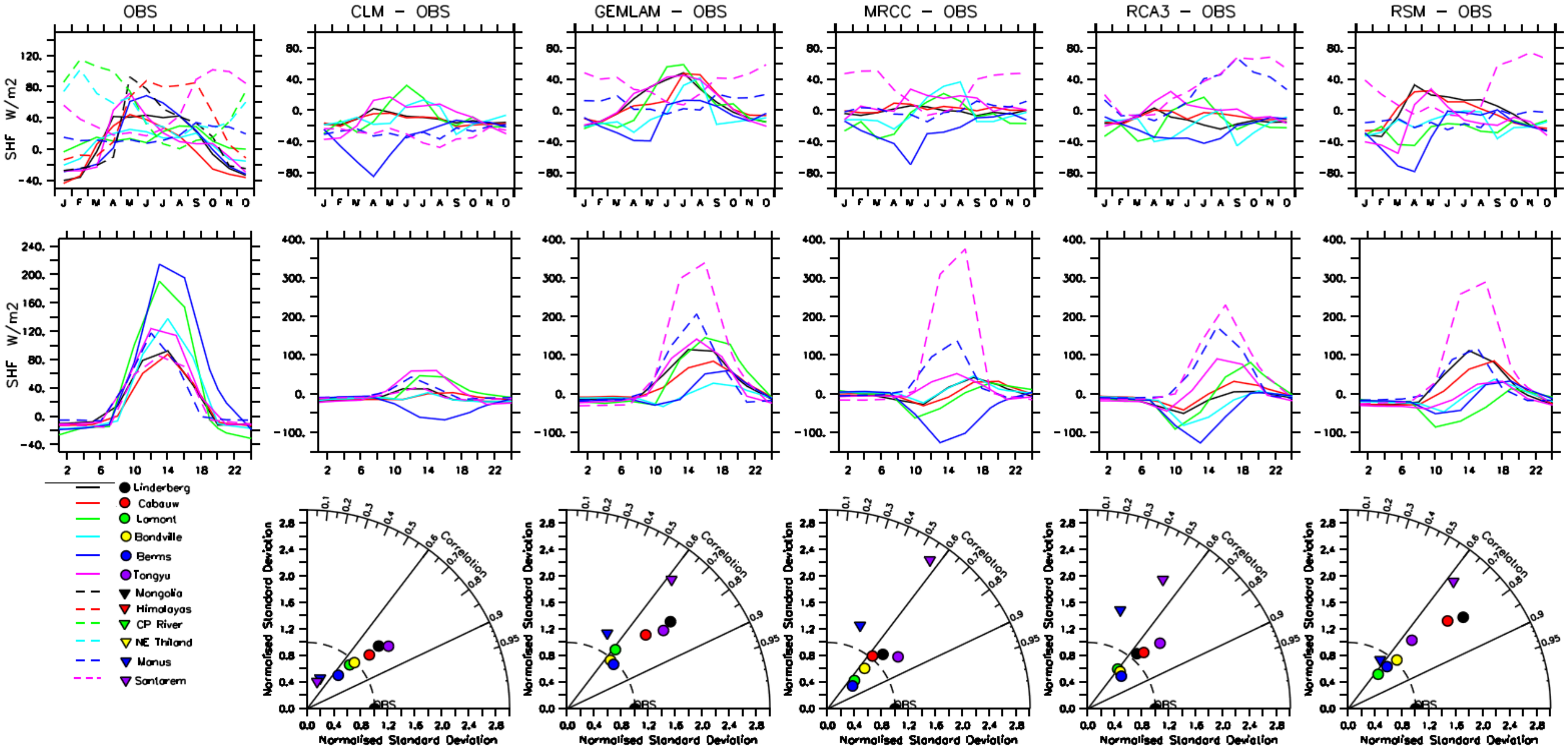
CEOP stations used in this study

S/No	Station	Latitude	Longitude	Country (Continent)	Climate	Station height (asl)	Short Description
1	**Lindenberg**	52.200N	14.120E	Germany (Europe)	mixed forest and grassland	101 m	Heterogeneous land use dominated by a mixture of forest (43%) and agricultural farmland (45%) with a number of small and medium-sized lakes (7%) (Beyrich and Adam 2004)
2	**Cabauw**	51.970N	4.930E	Netherlands (Europe)	grassland	4 m	Flat surroundings with meadows for grazing and for the production of hay. Vegetation cover is about to 100% all year (Beljaars and Bosveld 1997).
3	**Bondville**	40.010N	88.290W	USA (N. America)	temperate continental	216 m	Agricultural site. MODIS pixel shows mixture of corn and soybean.
4	**Lamont**	36.610N	97.490W	USA (N. America)	Southern Great Plains	314 m	Relatively homogeneous geography and wide variability of climate cloud type and surface flux properties. Large seasonal variation in temperature and specific humidity.
5	**BERMS (Old Black Spruce)**	54.000N	105.000W	Canada (N. America)	Cold mid-latitude	628 m	Vegetation is needle leaf forest
6	**Tongyu**	44.417N	122.867E	China (Asia)	semi-arid	184 m	A cropland station: corn and sunflower, which achieve a height of 2 m during the growing season. The ground is partly bare in the winter. Soils are described as sandy, salty alkaline, black humus, or meadow soil.
7	**Mongolia**	46.283N	107.298E	Mongolia (Asia)	grassland	1409 m	Mongolian plateau in the southern region of Ulaanbaatar. Seasonal land cover changes include greening from April to September and dead grassland from October to March.
8	**Himalayas**	27.959 N	86.813 E	India (Asia)	alpine	5050 m	Dominant land cover here is restricted to small areas of alpine meadow. The area is characterized by patches of low brushes dominated by rhododendron.
9	**Chao Praya River**	17.160 N	99.870 E	Thailand (Asia)	Tropical Monsoon	241 m	38 year old Teak plantation.
10	**North East Thailand**	14.466 N	102.379 E	Thailand (Asia)	Tropical Monsoon	311 m	Surrounded by cassava field. The height of the Cassava changes with the growing season, while the maximum height is around the 250cm; in dry season there is no vegetation. Soil Characteristics: Uniform acrisols up to 7m depth
11	**Manaus**	2.610 S	60.210 W	Brazil (South America)	Evergreen forest	130 m	Located within 100 km of the Manaus city in evergreen secondary and primary forest, pastures derived from primary forest conversion, logged forest, pastoral areas, and inundated areas. Soils are relatively nutrient-poor, sandy.
12	**Santarem**	3.020 S	54.970 W	Brazil (South America)	Para Forest	130 m	The site is located in the Tapajós National Forest (Flona Tapajós), which contains nearly 600,000 ha of protected old growth evergreen forest and is located 50 km south of Santarém. These soils are acidic, have a low base saturation and have high clay content.

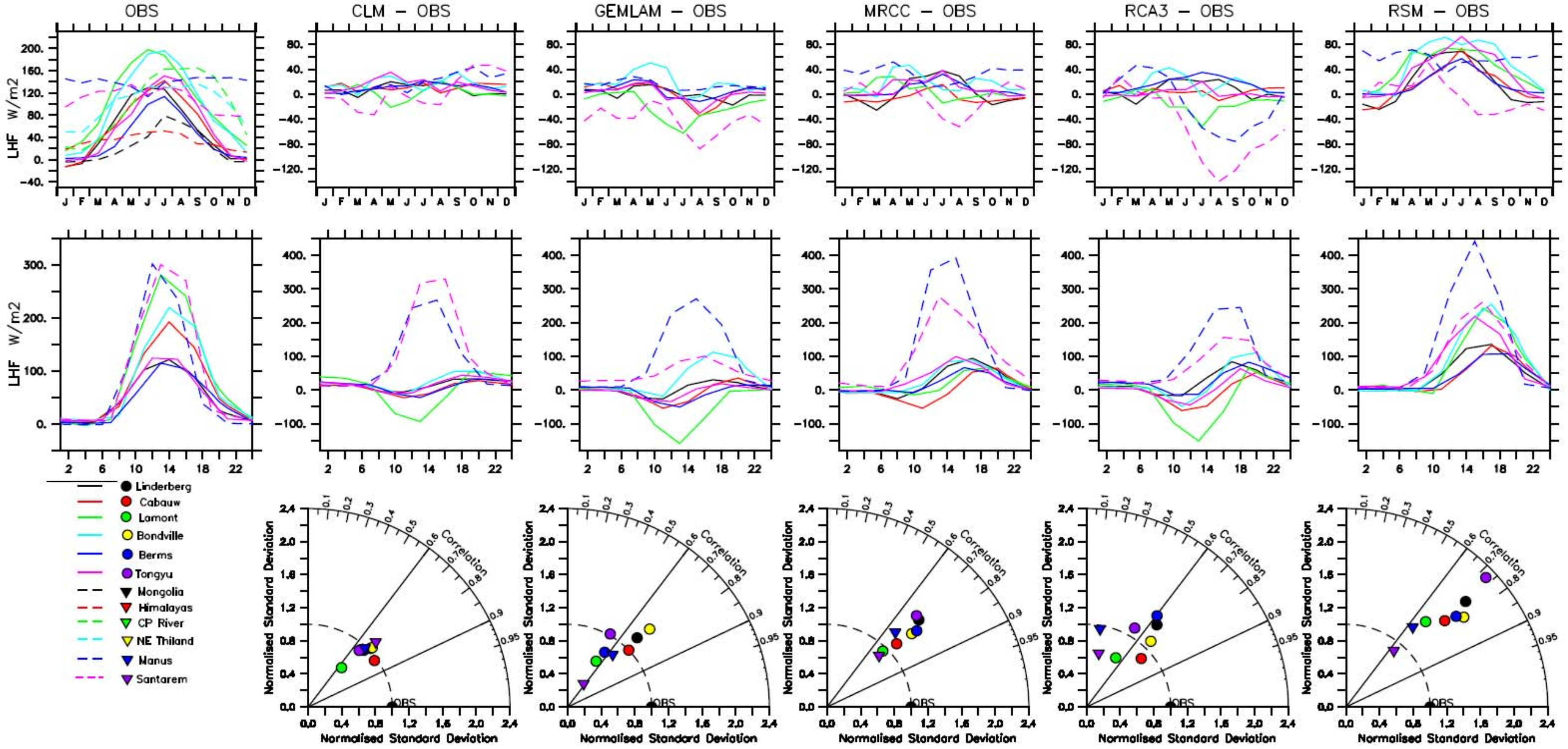
Net radiation



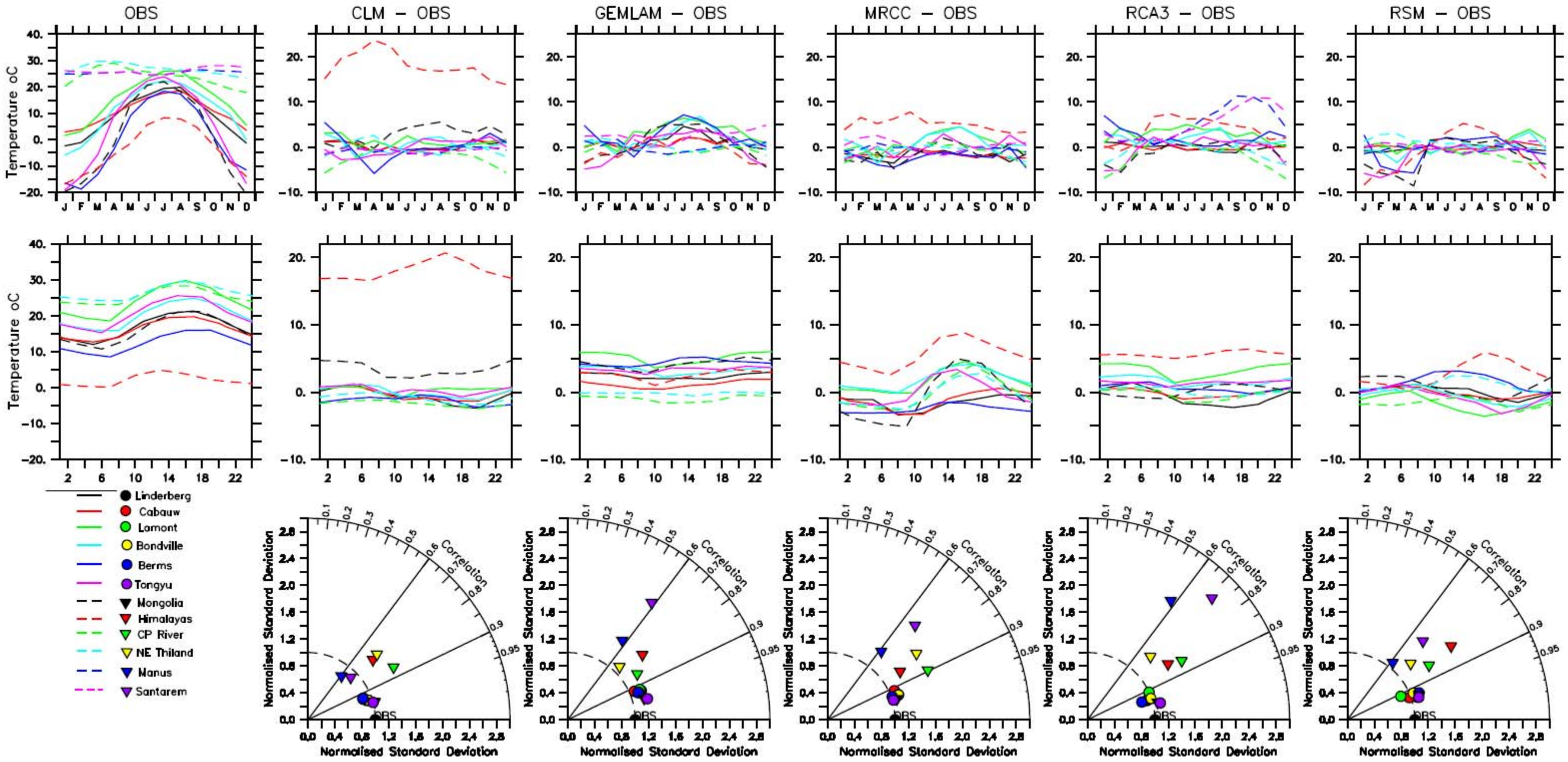
Sensible heat flux



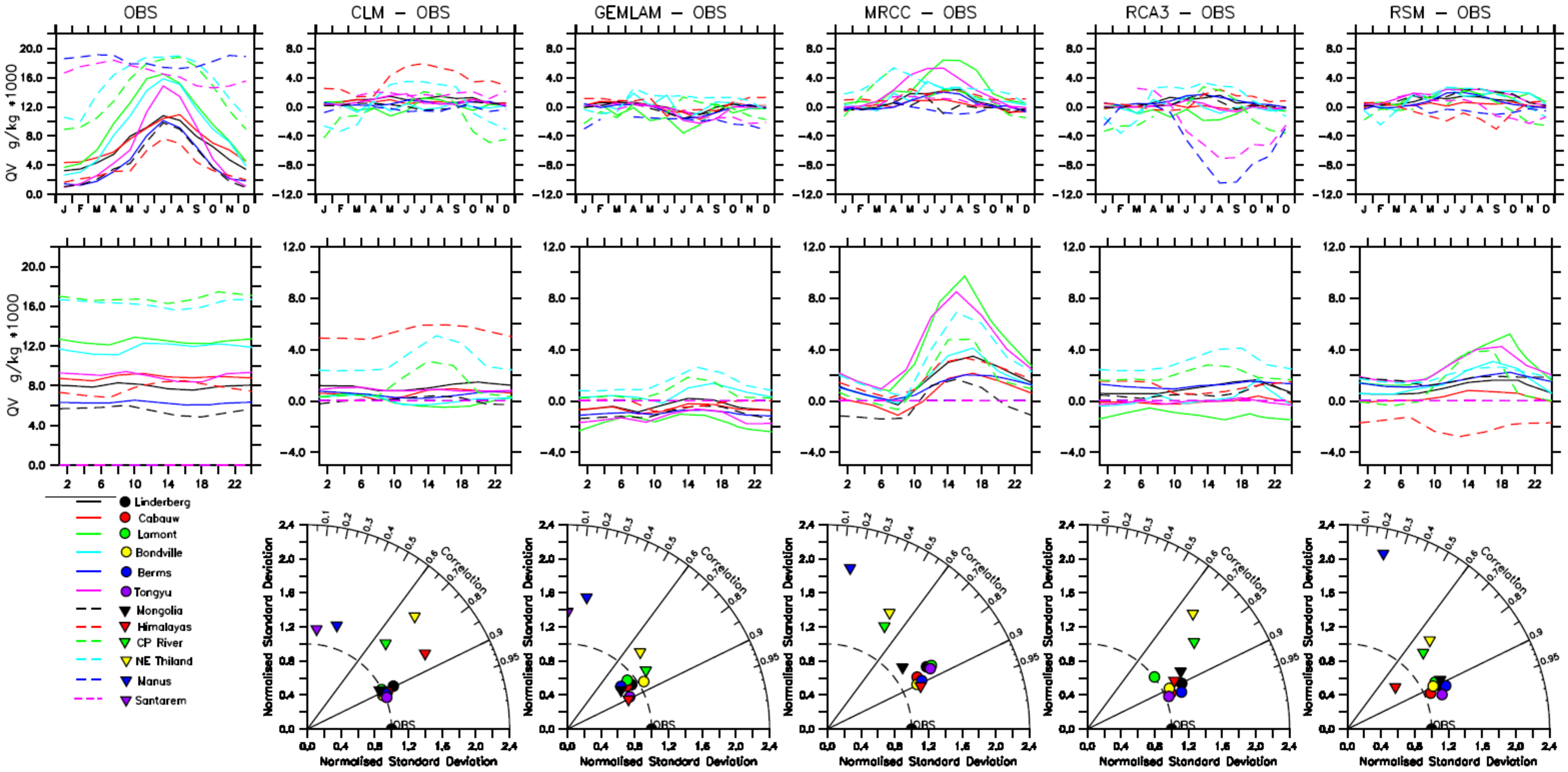
Latent heat flux



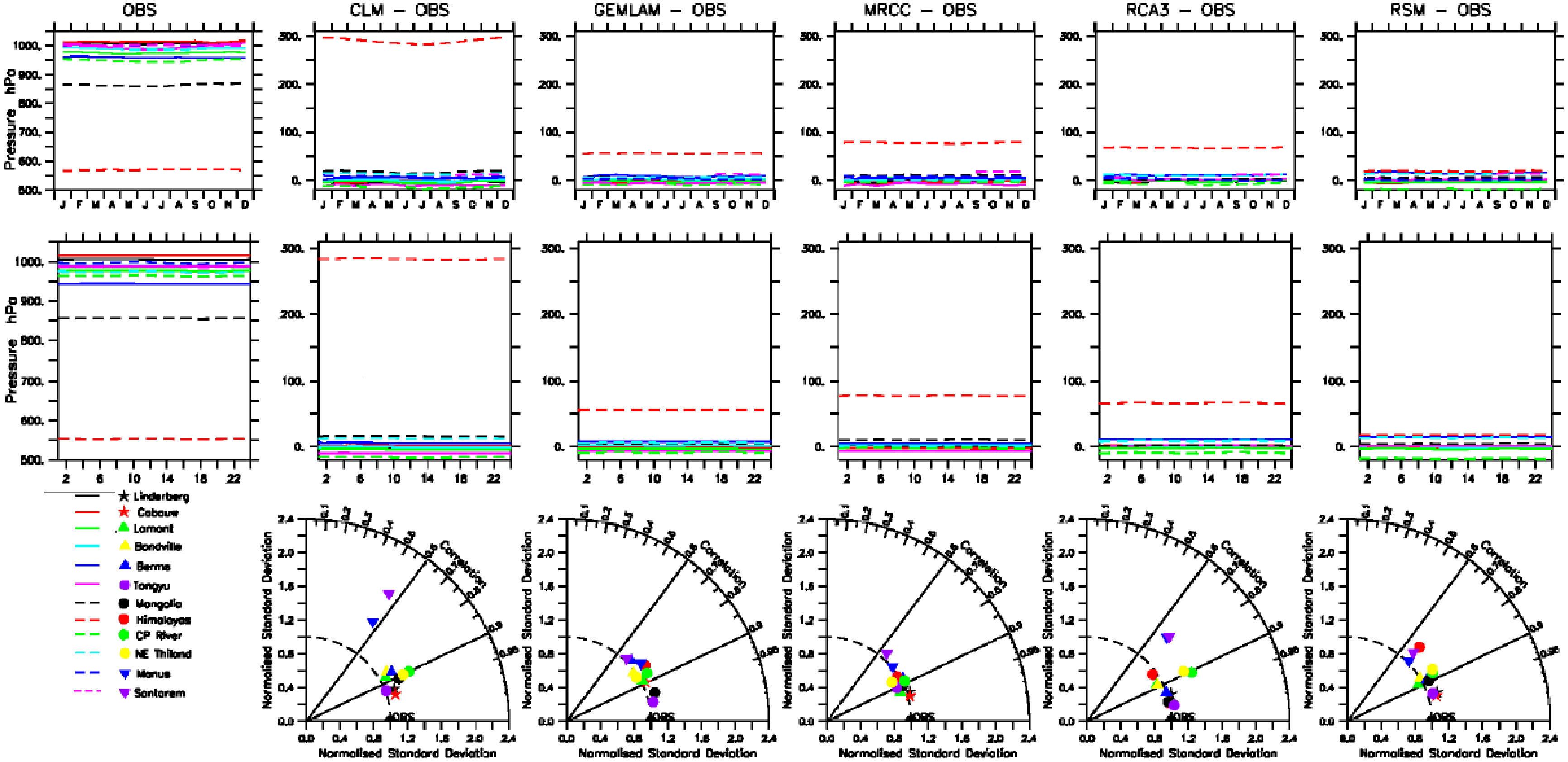
Temperature



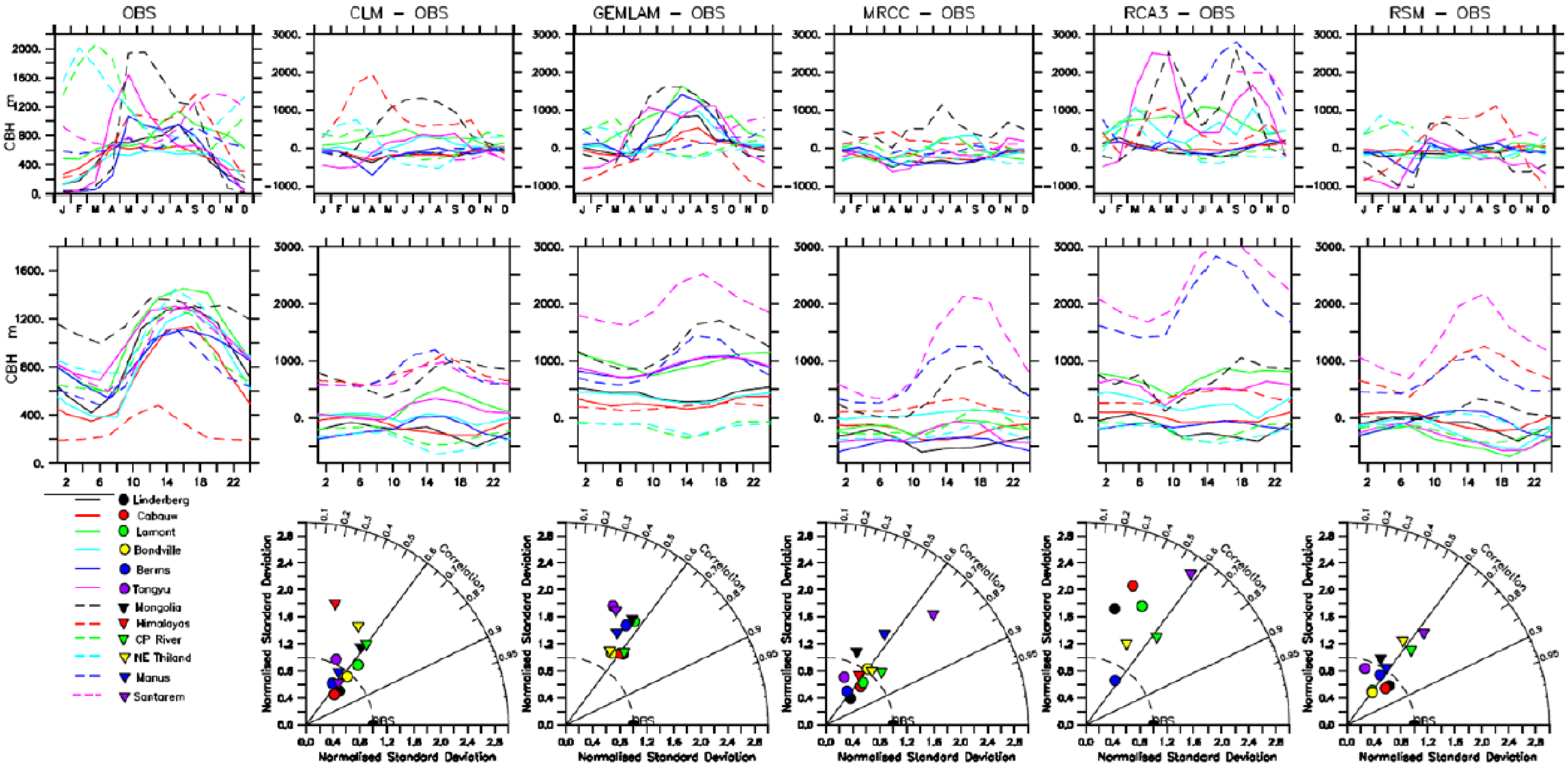
Specific moisture



Surface pressure



Cloud base height



Principal Component Analysis

(a) OBS

Variable	Lindenberg			Cabauw			Bondville			Lamont			Berms			Tongyu		
	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3
NTR	0.98	0.00	0.10	0.96	-0.01		0.95	0.14		0.95	0.13		0.95	0.08	-0.06	0.22	0.84	0.02
SHF	0.91	-0.13	0.13	0.87	-0.18		0.89	-0.07		0.72	-0.05		0.92	-0.08	0.01	0.04	0.72	-0.04
LHF	0.91	0.13	0.13	0.96	0.00		0.86	0.20		0.79	0.14		0.84	0.23	-0.09	0.11	0.90	0.01
CBH	0.16	-0.21	0.95	0.59	0.25		0.93	0.06		0.87	0.20		0.64	0.01	0.44	-0.22	0.12	0.92
T2M	0.19	0.60	0.76	0.34	0.87		0.64	0.72		0.60	0.73		0.37	0.85	0.20	0.78	0.19	0.50
QV	0.07	0.93	-0.02	-0.13	0.81		0.12	0.92		0.04	0.91		-0.04	0.94	-0.10	0.95	0.13	-0.11
PS	0.27	-0.55	0.11	0.17	-0.49		0.38	-0.61		0.10	-0.76		0.24	-0.41	0.56	-0.85	-0.15	0.00
WSP	0.09	-0.13	0.05	0.09	0.41		0.05	0.18		0.06	0.12		0.19	-0.16	-0.81	0.23	-0.14	0.42
Tot. Var(%)	34.64	20.43	19.20	38.91	23.89		48.34	22.83		39.41	25.50		38.81	23.47	15.29	29.84	26.65	16.22

(b) CLM

Variable	Lindenberg			Cabauw			Bondville			Lamont			Berms			Tongyu		
	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3
NTR	0.94	-0.10		0.94	0.12		0.98	0.02		0.98	0.10		0.97	-0.03		0.89	0.18	
SHF	0.89	-0.23		0.92	0.02		0.97	-0.03		0.97	0.05		0.95	-0.11		0.79	0.10	
LHF	0.80	0.13		0.91	0.16		0.94	-0.02		0.96	0.14		0.91	0.14		0.93	-0.11	
CBH	0.89	-0.10		0.84	0.11		0.92	0.11		0.94	0.07		0.96	0.03		0.69	-0.52	
T2M	0.74	0.54		0.51	0.82		0.64	0.71		0.70	0.67		0.56	0.77		0.63	0.58	
QV	-0.05	0.89		0.01	0.96		0.06	0.92		-0.02	0.91		0.02	0.94		0.01	0.96	
PS	0.12	-0.68		0.33	-0.31		0.02	-0.76		-0.08	-0.77		0.12	-0.59		-0.22	-0.77	
WSP	0.03	0.31		-0.03	-0.26		-0.13	0.14		-0.06	-0.01		0.00	0.18		-0.02	0.11	
Tot. Var(%)	46.04	21.48		45.21	22.56		50.76	24.36		52.67	23.86		49.07	23.76		39.95	27.15	

(c) GEMLAM

Variable	Lindenberg			Cabauw			Bondville			Lamont			Berms			Tongyu		
	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF3	PF1	PF 2	PF 3
NTR	0.98	0.07	0.03	0.98	0.08	0.00	0.94	0.06		0.98	0.03	0.08	0.97	-0.02	0.13	0.92	0.12	
SHF	0.85	0.24	0.17	0.77	0.29	-0.18	0.90	-0.09		0.90	-0.03	0.18	0.94	-0.07	0.10	0.84	0.02	
LHF	0.81	-0.13	-0.20	0.80	-0.10	0.24	0.78	0.14		0.82	0.11	-0.18	0.84	0.12	-0.01	0.77	0.13	
CBH	0.14	0.92	0.25	0.07	0.96	-0.15	0.80	-0.14		0.59	-0.02	0.72	0.34	0.13	0.86	0.70	-0.49	
T2M	0.23	0.95	-0.17	0.23	0.91	0.28	0.70	0.55		0.63	0.56	0.34	0.35	0.63	0.61	0.73	0.40	
QV	0.18	0.18	-0.81	0.25	-0.07	0.79	0.15	0.91		0.06	0.77	-0.55	0.10	0.87	-0.28	-0.08	0.95	
PS	0.14	0.08	0.77	0.21	-0.07	-0.73	0.18	-0.77		0.00	-0.80	-0.31	0.15	-0.80	-0.14	-0.23	-0.81	
WSP	0.10	-0.18	0.06	0.05	-0.21	0.18	0.29	0.01		-0.04	0.11	0.59	-0.11	-0.12	0.58	0.24	-0.14	
Tot. Var(%)	31.04	23.57	17.68	29.31	23.65	17.16	44.41	22.09		39.96	19.60	18.18	35.18	22.85	19.70	40.90	25.04	

(d) MRCC

Variable	Lindenberg			Cabauw			Bondville			Lamont			Berms			Tongyu		
	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3
NTR	0.94	-0.10		0.93	0.24		0.95	0.08		0.94	0.24		0.94	0.23		0.92	0.24	
SHF	0.86	-0.16		0.91	0.07		0.91	0.20		0.91	0.25		0.93	0.15		0.82	-0.05	
LHF	0.81	0.05		0.84	0.42		0.90	0.01		0.88	0.21		0.87	0.35		0.84	0.24	
CBH	0.71	0.32		0.66	0.55		0.83	0.33		0.90	0.13		0.91	0.28		0.87	0.18	
T2M	0.72	0.61		0.44	0.87		0.92	-0.17		0.94	-0.18		0.34	0.92		0.55	0.80	
QV	0.52	0.70		0.15	0.91		0.68	-0.58		0.86	-0.34		0.05	0.98		0.14	0.93	
PS	0.13	-0.71		0.46	-0.50		-0.04	0.85		-0.15	0.91		0.38	-0.21		0.13	-0.91	
WSP	-0.01	0.32		-0.01	-0.04		0.18	0.26		0.19	0.39		0.24	0.03		0.14	0.22	
Tot. Var(%)	44.82	19.94		40.70	29.76		57.32	16.29		62.41	16.40		45.90	26.62		41.91	31.40	

(e) RCA3

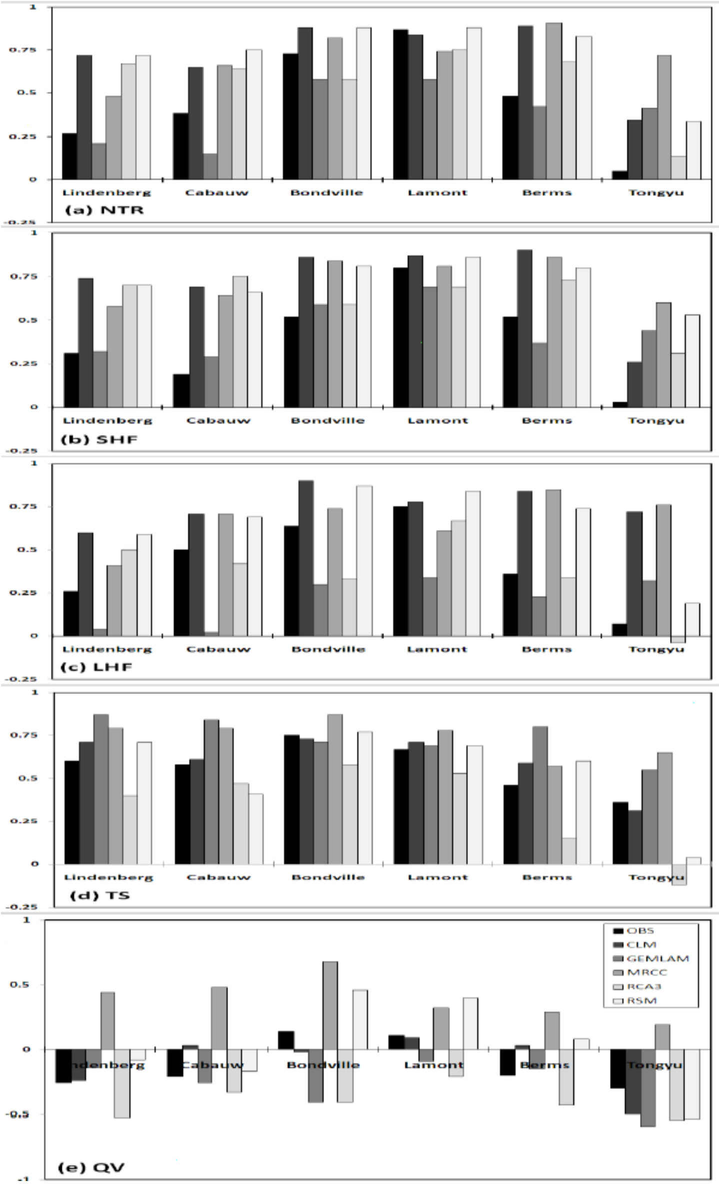
Variable	Lindenberg			Cabauw			Bondville			Lamont			Berms			Tongyu		
	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3
NTR	0.93	0.01	-0.03	0.92	-0.02	0.03	0.97	0.11		0.96	0.02	-0.03	0.96	-0.04		0.95	-0.03	-0.02
SHF	0.90	-0.19	0.01	0.91	-0.13	0.17	0.91	-0.02		0.92	-0.06	-0.05	0.87	-0.26		0.90	0.24	-0.13
LHF	0.80	0.33	-0.12	0.79	0.19	-0.36	0.91	0.19		0.77	0.20	-0.10	0.79	0.27		0.70	-0.21	0.14
CBH	0.84	-0.24	0.16	0.80	-0.04	0.40	0.87	-0.19		0.71	-0.30	0.47	0.75	-0.50		0.23	0.68	-0.39
T2M	0.49	0.74	0.21	0.53	0.77	-0.02	0.63	0.67		0.75	0.45	0.16	0.56	0.74		0.69	-0.50	0.03
QV	-0.29	0.91	0.06	-0.12	0.87	-0.36	0.02	0.93		0.04	0.87	-0.36	0.06	0.97		0.07	-0.92	-0.12
PS	0.16	-0.54	0.61	0.11	-0.01	0.87	0.16	-0.71		-0.07	-0.67	-0.41	0.16	-0.41		-0.21	0.75	0.05
WSP	0.09	-0.25	-0.82	0.16	-0.58	-0.29	-0.02	-0.14		-0.05	0.00	0.84	0.10	0.06		0.06	0.04	0.96
Tot. Var(%)	42.34	24.02	14.25	40.83	21.87	16.25	47.07	24.09		42.92	19.25	15.67	40.22	25.58		34.72	27.93	14.15

(f) RSM

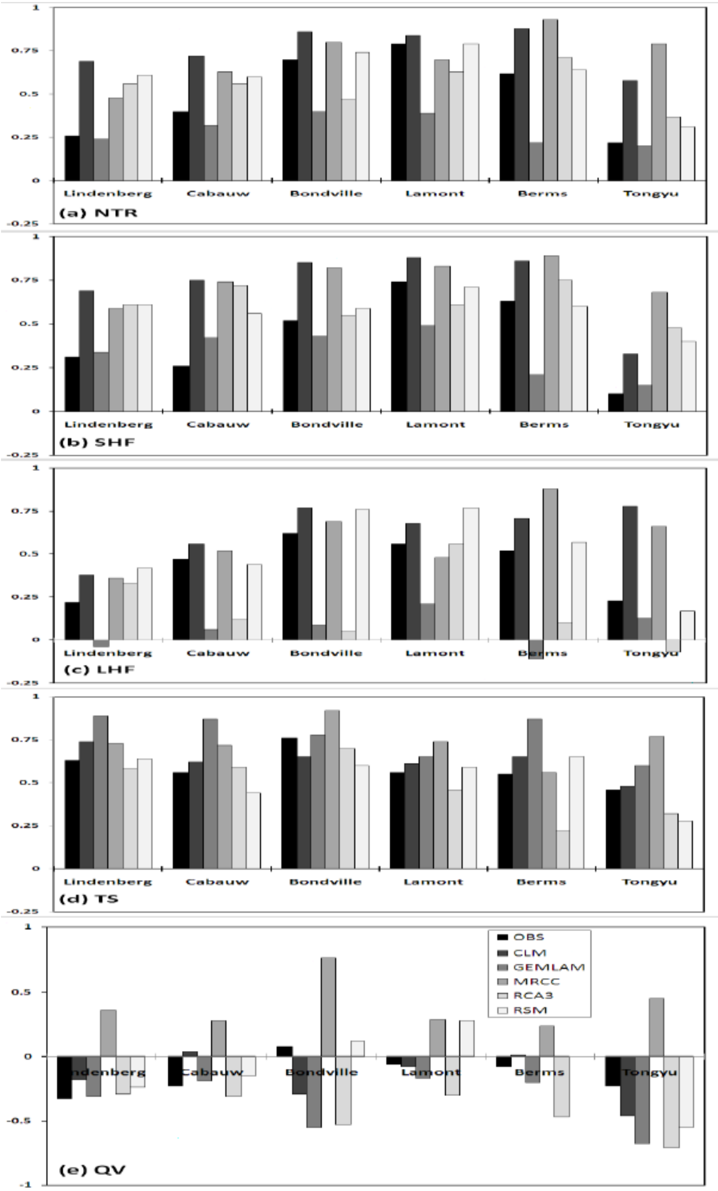
Variable	Lindenberg			Cabauw			Bondville			Lamont			Berms			Tongyu		
	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3	PF1	PF 2	PF 3
NTR	0.95	-0.14		0.97	0.11		0.96	0.22		0.97	0.15		0.98	0.01		0.94	0.22	0.00
SHF	0.85	-0.35		0.89	-0.16		0.96	0.01		0.96	-0.01		0.95	-0.11		0.87	-0.22	-0.09
LHF	0.86	0.10		0.88	0.28		0.91	0.28		0.95	0.20		0.93	0.10		0.81	0.34	0.02
CBH	0.86	-0.11		0.86	0.01		0.91	0.23		0.90	0.26		0.90	0.04		0.56	-0.63	0.37
T2M	0.74	0.57		0.40	0.89		0.52	0.79		0.62	0.72		0.58	0.76		0.49	0.73	0.28
QV	0.12	0.93		-0.11	0.96		0.23	0.91		0.30	0.87		0.13	0.93		0.06	0.98	0.07
PS	0.20	-0.50		0.20	-0.28		0.09	-0.72		0.05	-0.73		0.21	-0.62		-0.20	-0.20	-0.70
WSP	0.02	-0.24		-0.05	-0.26		-0.12	0.00		-0.05	-0.02		0.00	-0.17		-0.23	-0.08	0.72
Tot. Var(%)	46.61	20.79		43.27	24.66		48.18	26.88		50.72	24.28		49.08	23.43		36.98	26.89	15.48

Summer daytime CBH correlations with surface variables

Weak wind



Strong wind



Summary

- Models simulate the coupling of cloud base height with surface fluxes (poor at Lindenberg and Tongyu)
- Models show struggle with simulating the amplitudes of diurnal and seasonal temperature over tropical stations but give a good reproduction over the midlatitude stations
- Models reproduce sign of coupling
- Differences in coupling strengths in models (usually stronger than observed)
- Fair agreement in coupling strengths between regions (transferability)

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Finally, it’s coffee time….

Thank you!