Providing Climate Projection Datasets for War Games

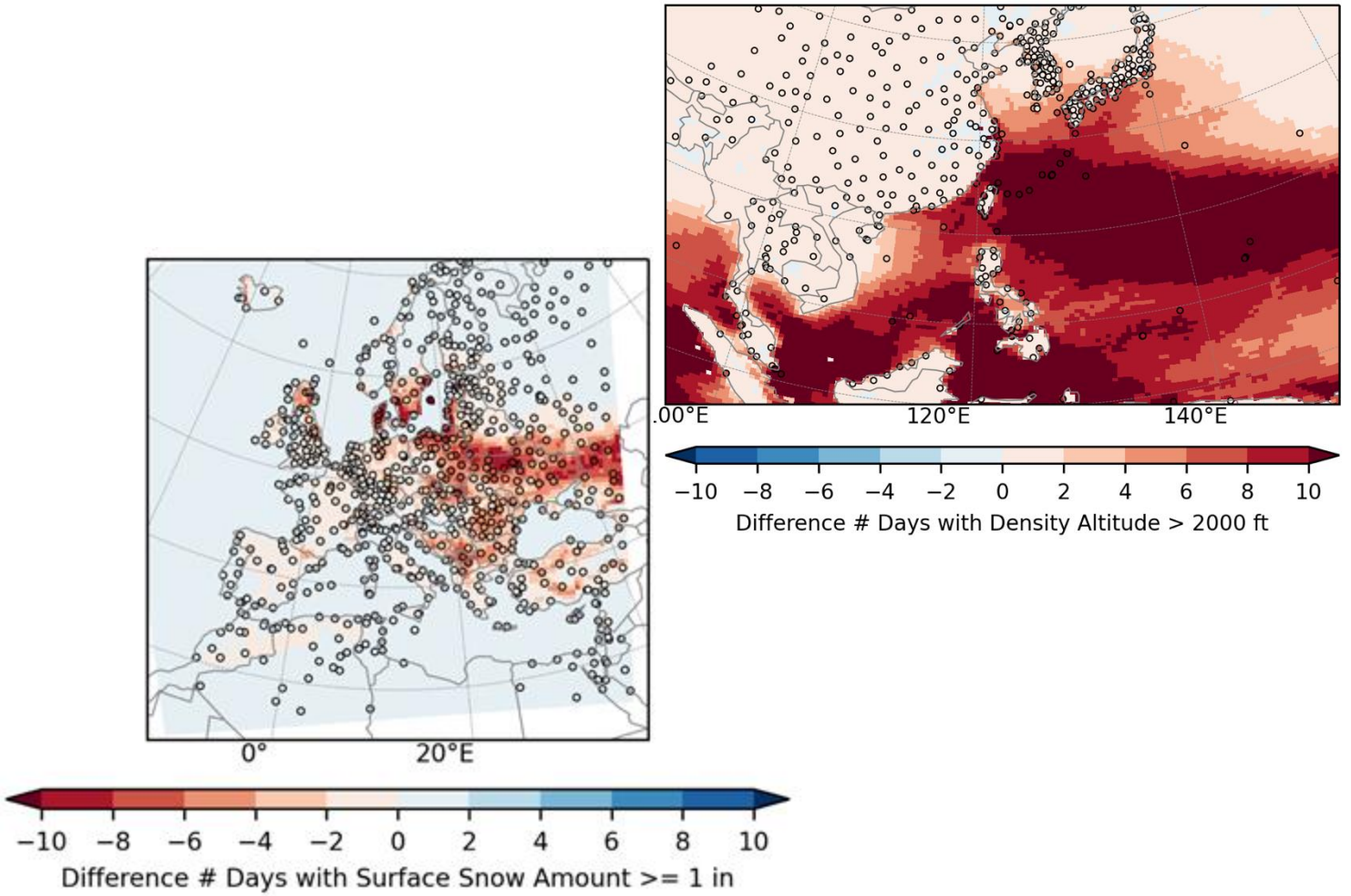
Carl Schreck

Kyle Wodzicki, John Uehling

NCSU/NCICS

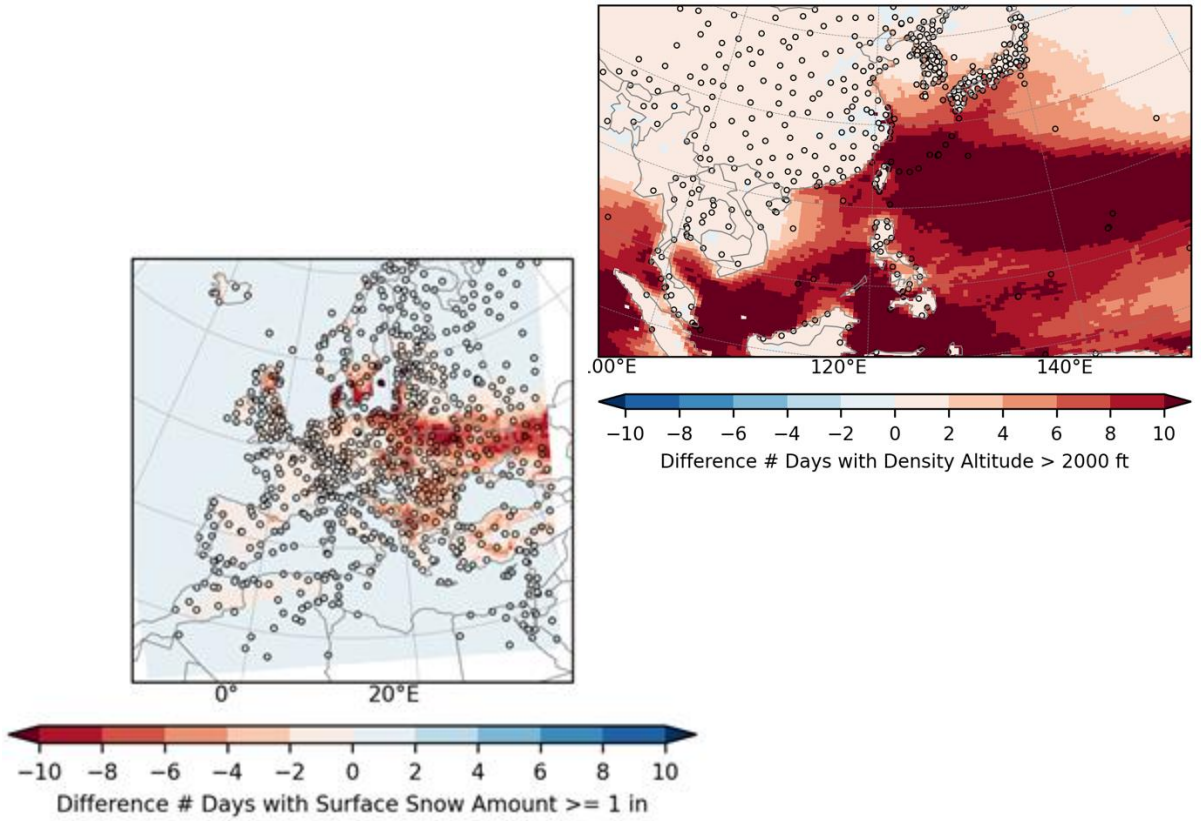
Jason Patla, Lt. Col. Benjamin Fulk

USAF/14WS



Mission

- U.S. Department of Defense is incorporating the effects of climate change into all threat assessments.
- Many Climate Change wargames use broad assessments of qualitative changes in risk.
- **How do we create projected climatological datasets for 2035 over Europe and East Asia?**



Climate and Warfighting

- The table on the right is based on existing military watch/warning criteria.
- Each threshold affects specific military operations.
- Wargame participants adapt to weather conditions provided by wargame planners.
- **The goal of this project is to provide a climatology of the future for those scenarios.**

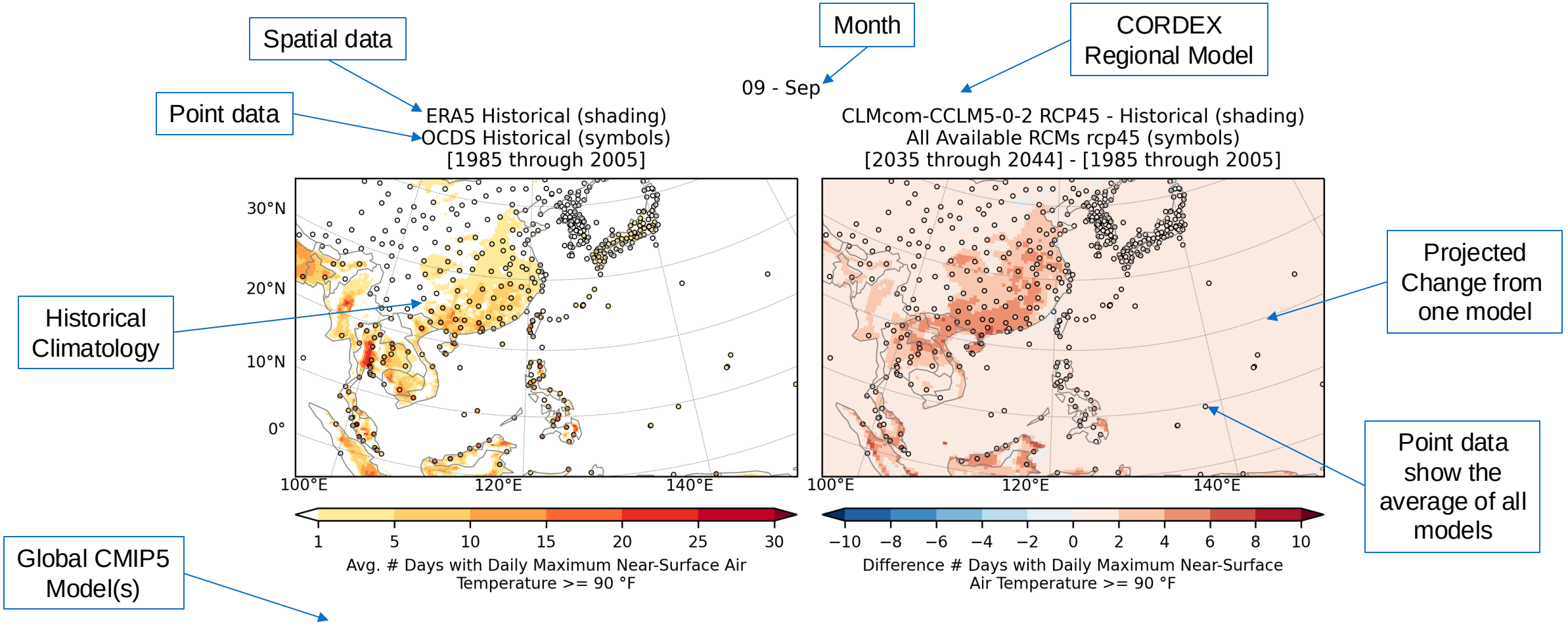
Parameter	Thresholds			Fixed Wing	Rotary Wing	ISR	Ground Ops
Temperature	≥90F	≤32F	≤0F	x	x	x	x
Precipitation	≥0 in	≥2 in		x	x	x	
Cloud Fraction	<20%	>80%		x	x	x	x
Visibility (Fog)	<1000 ft	<1500 ft	<2000 ft	x	x	x	x
Wind Sus and Gusts	≥25 kt	≥35 kt	≥50 kt	x	x	x	x
Snow Depth	≥1 in	≥6 in				x	x
Density Altitude	>2000 ft	>4000 ft	>6000 ft	x	x		
Freezing precipitation	Precip >0 in	AND	Temp ≤32F	x	x	x	x
Unfrozen Ground	Snow Depth <1 in	AND	Soil temp >32F				x

Datasets

- Historical station climatologies come from 14 WS's authoritative Operational Climate Data Summary (OCDS) dataset.
- The 557 WW's World Wide Merged Cloud Analysis (WWMCA) provides cloud fraction climatologies.
- ECMWF Model (ERA5) data are used for variables that are not available in OCDS or WWMCA.
- CORDEX regional climate models provide projected changes between their historical simulations of 1985–2004 and projections for 2035–2044.
- All processing done in AWS.

Parameter	Source
Temperature	OCDS
Precipitation	ERA5
Cloud Fraction	WWMCA
Visibility (Fog)	ERA5
Wind Sus and Gusts	OCDS
Snow Depth	ERA5
Density Altitude	ERA5
Freezing precipitation	ERA5
Unfrozen Ground	ERA5

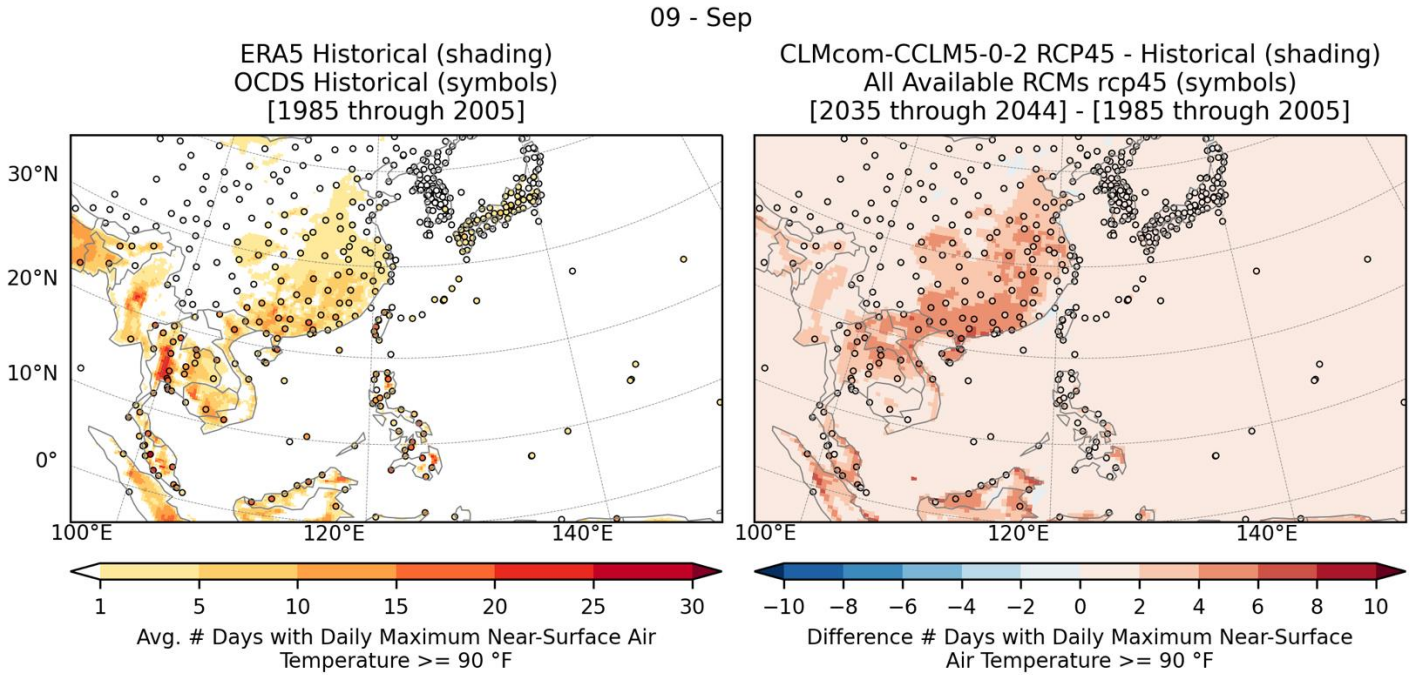
Map Explainer



Hot Days Over 32°C/90°F
Sep Asia: CCLM5

Historical Climatology

Difference (2035)



Models used: CNRM-CERFACS-CNRM-CM5, rcp45, r1i1p1; ICHEC-EC-EARTH, rcp45, r12i1p1; MPI-M-MPI-ESM-LR, rcp45, r1i1p1; MOHC-HadGEM2-ES, rcp45, r1i1p1

Assessment Highlights

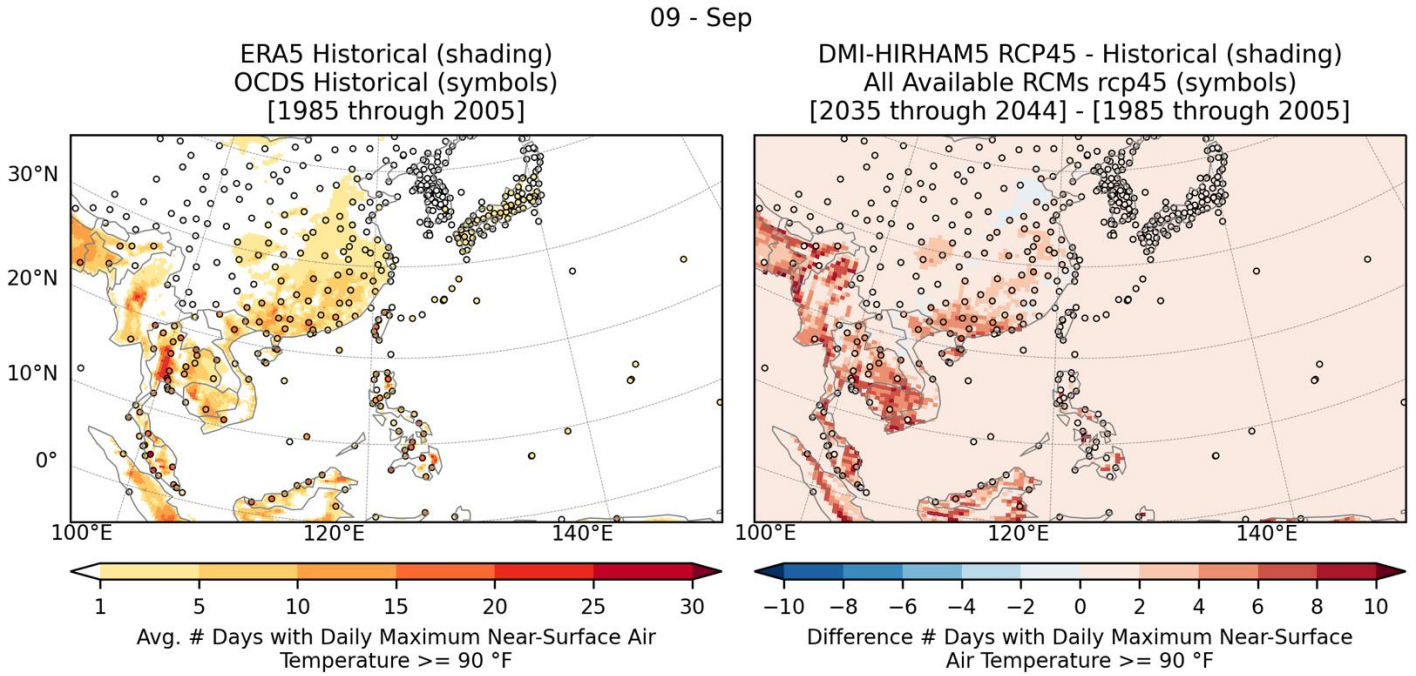
- The average September currently has 5–10 days over 90°F over southeastern China.
- The CCLM5 model projects about 5 more of these days per September in 2035–2045 relative to 1985–2005.

Operational Considerations: Ground Ops, Fixed Wing, Rotary Wing, ISR, Hydraulic Systems, Roadways & Logistics

Hot Days Over 32°C/90°F
Sep Asia: DMI-HIRHAM5

Historical Climatology

Difference (2035)



Models used: ICHEC-EC-EARTH,rcp45,r3i1p1

Assessment Highlights

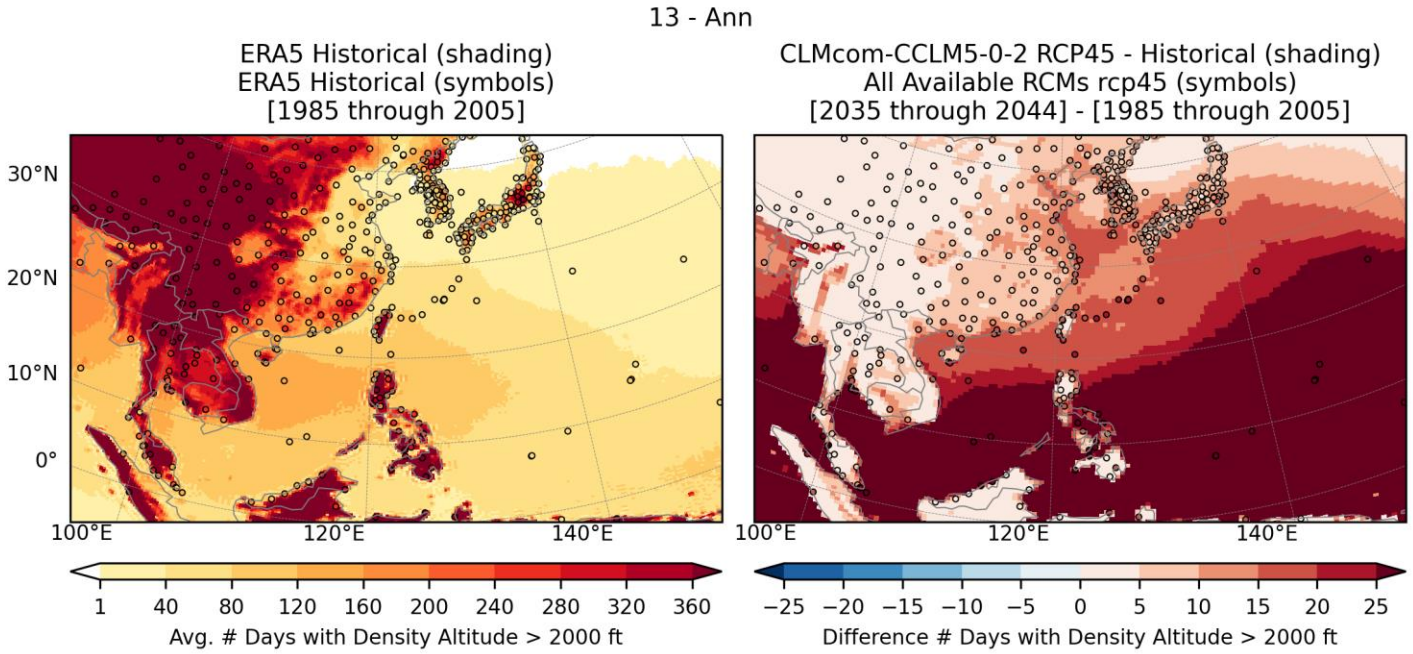
- The average September currently has 5–10 days over 90°F over southeastern China.
- The CCLM5 model projects about 5 more of these days per September in 2035–2045 relative to 1985–2005.
- The DMI-HIRHAM5 model has smaller increases for southeastern China but larger for Southeast Asia.
- Remaining slides will focus on CCLM5 for simplicity and because it uses multiple CMIP5 models.

Operational Considerations: Ground Ops, Fixed Wing, Rotary Wing, ISR, Hydraulic Systems, Roadways & Logistics

Density Altitude > 2000 ft Annual Asia

Historical Climatology

Difference (2035)



Models used: CNRM-CERFACS-CNRM-CM5, rcp45, r1i1p1; ICHEC-EC-EARTH, rcp45, r12i1p1; MPI-M-MPI-ESM-LR, rcp45, r1i1p1; MOHC-HadGEM2-ES, rcp45, r1i1p1

Assessment Highlights

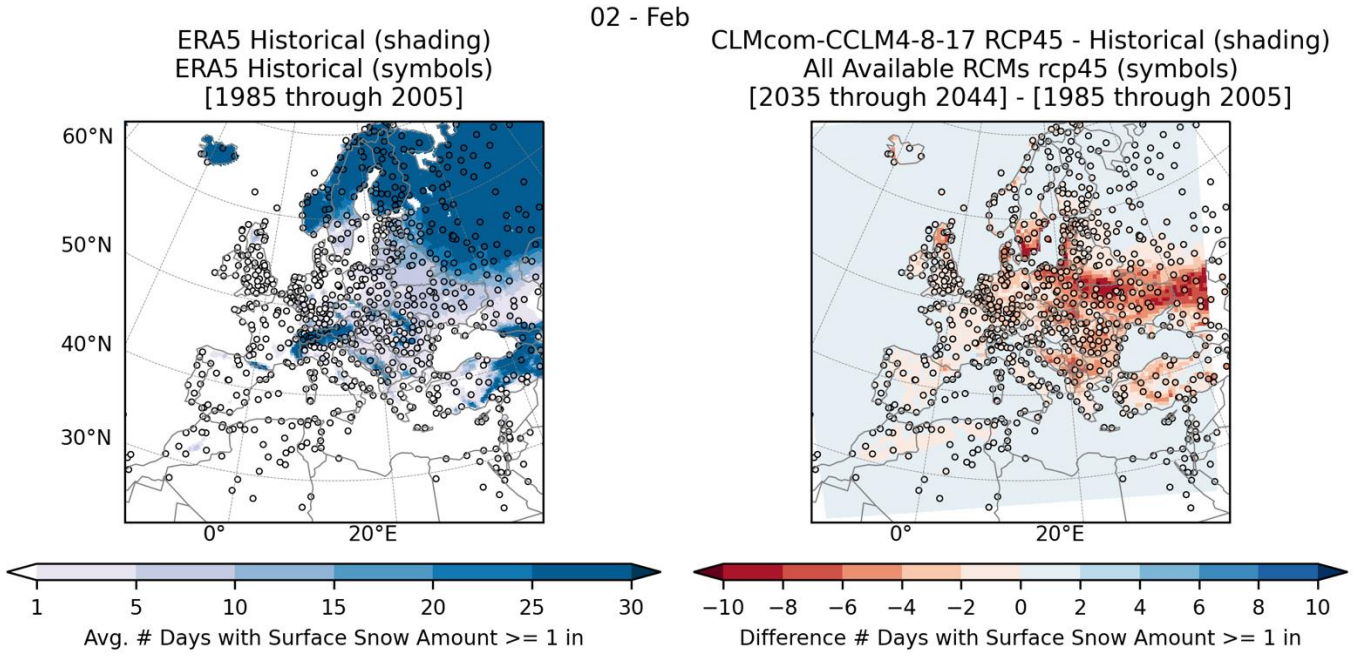
- Hot and humid temperatures can produce DA > 2000 ft even for low-elevation stations.
  - Examples include Southeast Asia, the Philippines, and eastern China.
- These days will increase by 5–10 days per year over most of eastern China, the Korean peninsula, and Japan.
- Those higher density altitudes will degrade aircraft performance (lower MTOW, range, runway length requirements, etc.).

Operational Considerations: Fixed Wing & Rotary Wing

Snowpack ≥ 1 inch February Europe

Historical Climatology

Difference (2035)



Models used: MPI-M-MPI-ESM-LR, rcp45, r1i1p1

Assessment Highlights

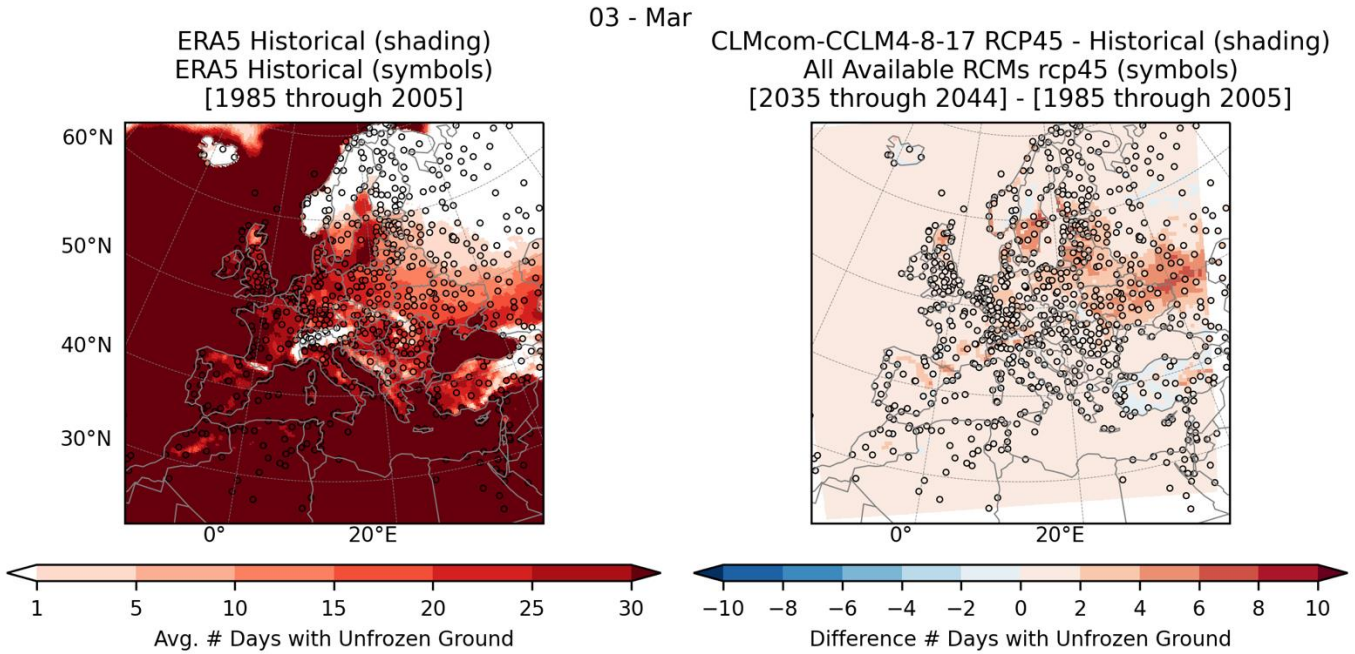
- Snow depth is currently >1” deep for 5–10 days per February over Eastern Europe with higher frequency at higher elevations and in Russia.
- The largest decreases in these days are projected to occur over Ukraine and the Baltics where there may be 6–10 fewer February days with snowpack in 2035.
- Less snowpack could mean increased mud and decreased trafficability.

Operational Considerations: Ground Ops & ISR

Unfrozen Ground March Europe

Historical Climatology

Difference (2035)



Models used: MPI-M-MPI-ESM-LR, rcp45, r1i1p1

Assessment Highlights

- Unfrozen ground is defined as soil temperature >32°F and snow depth <1 inch.
- The ground is typically unfrozen more than half the month in March over the Baltics and northern Ukraine.
- There are projected to be 4–8 fewer of these days per March in 2035 over both regions.
- Unfrozen ground is more susceptible to muddy conditions, which reduces trafficability.

Operational Considerations: Ground Ops

Spreadsheet: Each Month

Sources for historical data

Many more columns of variables

	% Frequency of Cloud Fraction < 20%		% Frequency of Cloud Fraction > 80%		% Frequency of Visibility < 3 mi		% Frequency of Wind > 25 kts		Clouds		Density Altitude	
	All Hours		All Hours		All Hours		All Hours		Average Cloud Cover (%)		Average # Days > 2 kft	
	WWMCA	Change	WWMCA	Change	OCDS	Change	OCDS	Change	OCDS	Change	ERA5	Change
station												
AFWA_382200	50	-0.7	40	1.8	41.5	-1.1	0.0	0.0	81.5	0.3	0.2	2.0
ICAO_AGGH	18	0.0	70	-1.9	0.6	0.7	0.0	0.1	70.1	-1.0	31.0	0.4
ICAO_AYPY	17	0.3	74	-0.9	0.7	7.8	0.2	0.0	74.8	-0.3	30.9	0.0
ICAO_OAIX	58	1.5	30	-2.2	8.4	-6.3	1.2	0.1	55.0	-1.9	31.0	0.0
ICAO_OAJL	60	0.8	31	-2.1	0.0	-4.2	0.0	0.0	49.0	-1.3	30.8	0.0
ICAO_OAKB	66	1.4	24	-1.6	35.1	-7.5	0.0	0.2	51.2	-1.6	31.0	0.0

Many more rows of stations

Historical climatological value

Ensemble mean projected change for 2035

Each month appears in a separate sheet plus one for the annual totals.

Spreadsheet: Each Station

Sources for historical data

Many more columns of variables

	% Frequency of Cloud Fraction < 20%		% Frequency of Cloud Fraction > 80%		% Frequency of Visibility < 3 mi		% Frequency of Wind > 25 kts		Clouds		Density Altitude	
	All Hours		All Hours		All Hours		All Hours		Average Cloud Cover		Average # Days > 2 kft	
	WWMCA	Change	WWMCA	Change	OCDS	Change	OCDS	Change	OCDS	Change	ERA5	Change
period												
01 - Jan	50	-0.7	40	1.8	41.5	-1.1	0.0	0.0	81.5	0.3	0.2	2.0
02 - Feb	44	-0.2	46	1.2	32.2	0.0	0.4	0.0	64.0	0.7	1.2	2.0
03 - Mar	40	1.6	51	0.2	11.4	0.4	0.9	0.0	68.5	-1.0	10.2	1.0
04 - Apr	43	1.2	48	1.6	6.4	2.1	1.1	0.0	69.5	0.4	24.7	0.4
05 - May	53	-2.6	36	-1.5	0.6	0.1	1.3	0.0	64.5	0.8	30.1	0.0
06 - Jun	55	0.9	33	0.8	1.0	0.1	1.2	0.0	53.5	-0.4	30.0	0.0
07 - Jul	65	0.9	24	-1.2	0.2	0.0	1.0	0.0	55.5	-0.8	31.0	0.0
08 - Aug	66	0.5	24	-1.4	1.1	0.0	0.9	0.0	51.5	-0.8	31.0	0.0
09 - Sep	63	3.9	26	0.1	0.0	0.1	0.2	0.0	38.5	-2.1	29.6	0.0
10 - Oct	54	0.1	38	0.8	5.8	-0.2	0.0	0.0	48.3	0.3	22.1	1.0
11 - Nov	47	1.1	43	0.0	22.5	-0.2	0.4	0.0	69.0	-1.3	8.5	0.8
12 - Dec	49	-1.1	41	0.3	42.4	0.4	0.0	0.0	63.0	1.3	1.3	2.8
13 - Ann	52	0.4	38	0.2	15.3	0.1	0.6	0.0	61.0	-0.2	219.9	10.1

Individual Months

Annual total

Historical climatological value

Projected change for 2035

Each station appears in a separate sheet and a GeoJSON file.

Limitations

- CORDEX only uses a small subset of the available CMIP models, so it can't capture the full range of possible climate sensitivities.
- Each model used slightly different grids, which precluded making multi-model mean maps.
- CORDEX provided soil moisture mass but not capacity or depth, so we could not calculate mud.

Future Work

- The existing cloud-based pipeline could easily be used to generate similar deliverables for other variables or CMIP5/6 models.
- Individual weather events could be identified in model projections for tactical wargames.
- Statistical downscaling can bias-correct CORDEX and CMIP projections using OCDS.
- The current output provides RCP-4.5 alongside RCP-8.5. These along with multi-model spread could be leveraged to give a range of outcomes.