Predicting Future Weather and Climate

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Warittha Panasawatwong
Ali Ramadhan
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Overview

- Introduction to Prediction; Why is Weather Unpredictable? Delving into Chaos Theory
- Weather Versus Climate: What Makes Them Different
- Future Projections of Climate

What is prediction?

Image: http://i1.wp.com/iotworm.com/wp-content/uploads/2016/02/weather-prediction.jpg?resize=668%2C363

What is prediction?

Prediction: extrapolation of knowledge of a sample to an entire population

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Forecasting: extrapolation of knowledge of the current or the past to the future; prediction in time

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What is prediction?

Prediction: extrapolation of knowledge of a sample to an entire population

Forecasting: extrapolation of knowledge of the current or the past to the future; prediction in time

We predict disease, stock markets, solar cycles, population dynamics...and weather and climate.

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How do we know if we're good at forecasting?

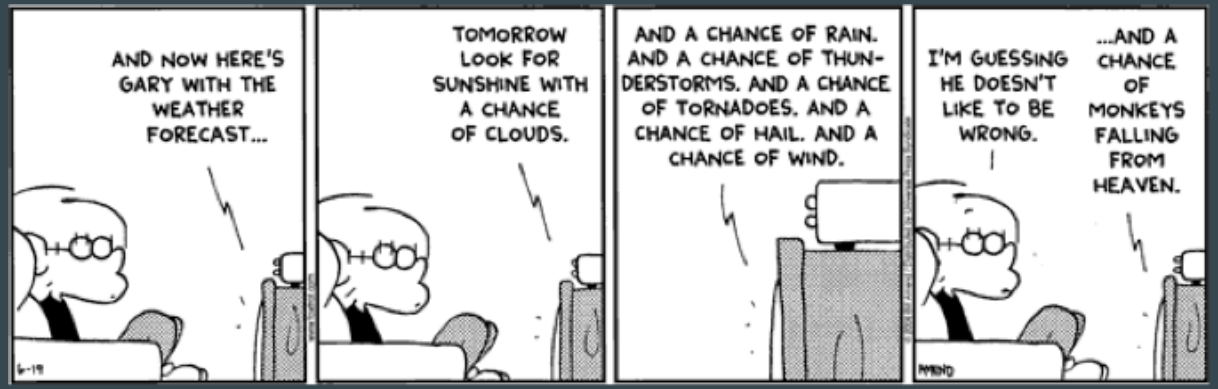

Image: http://www.greenskychaser.com/blog/wp-content/uploads/2010/03/foxtrot_wx_19June2006.gif

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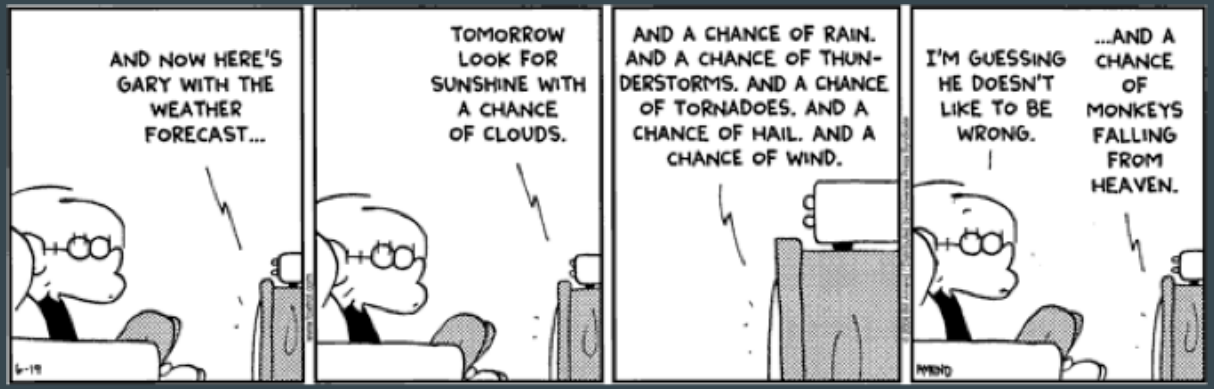

Forecast Skill: Quality of a forecast compared to observations

Image: http://www.greenskychaser.com/blog/wp-content/uploads/2010/03/foxtrot_wx_19June2006.gif
https://i.stack.imgur.com/iSWyZ.png

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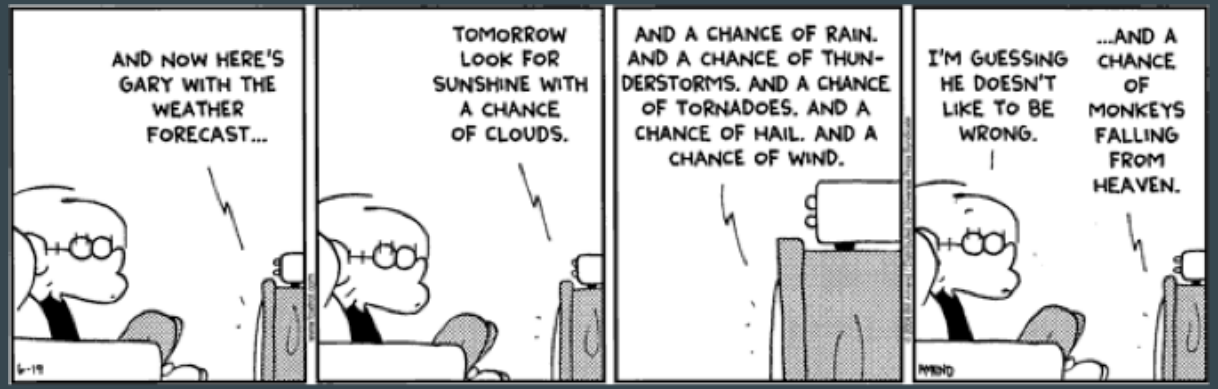

Forecast Skill: Quality of a forecast compared to observations

Methods of calculating forecast skill:
-Mean Squared Error Skill Score
-Ranked Probability Skill Score
-Logarithmic Skill Score

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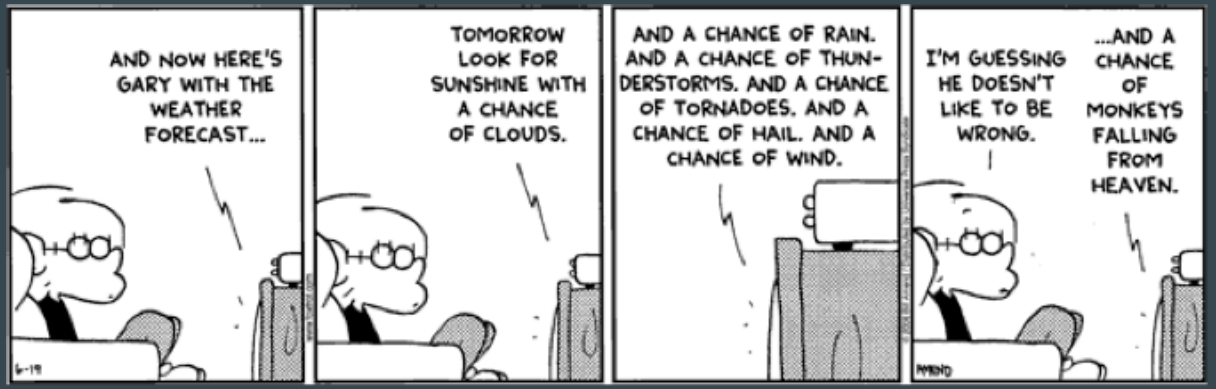

Methods of calculating forecast skill:
-Mean Squared Error Skill Score

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(\hat{Y}_i - Y_i)^2$$

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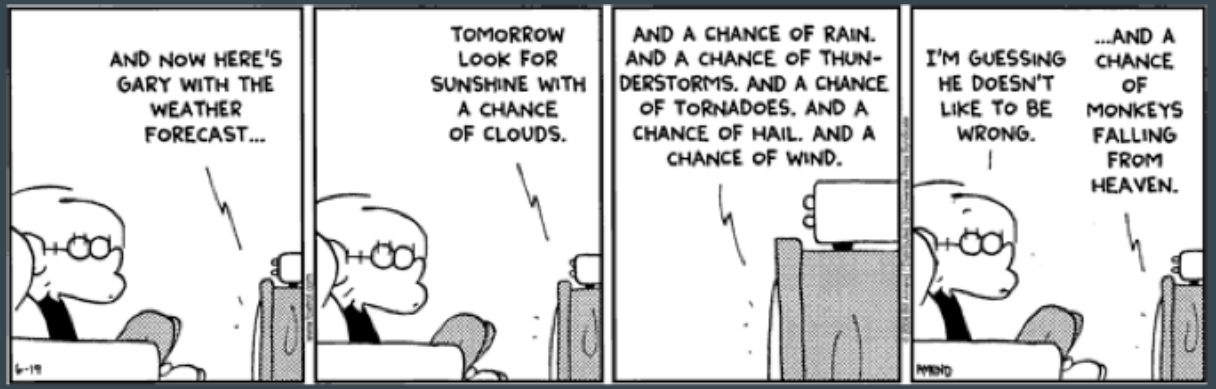


$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(\hat{Y}_i - Y_i)^2$$

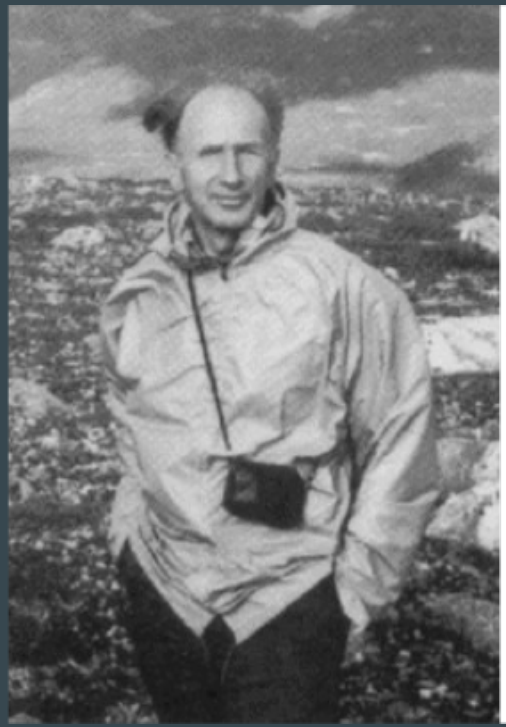
$$\mathrm{MSESS} = 1 - \frac{\mathrm{MSE}_{\mathrm{forecast}}}{\mathrm{MSE}_{\mathrm{ref}}}$$

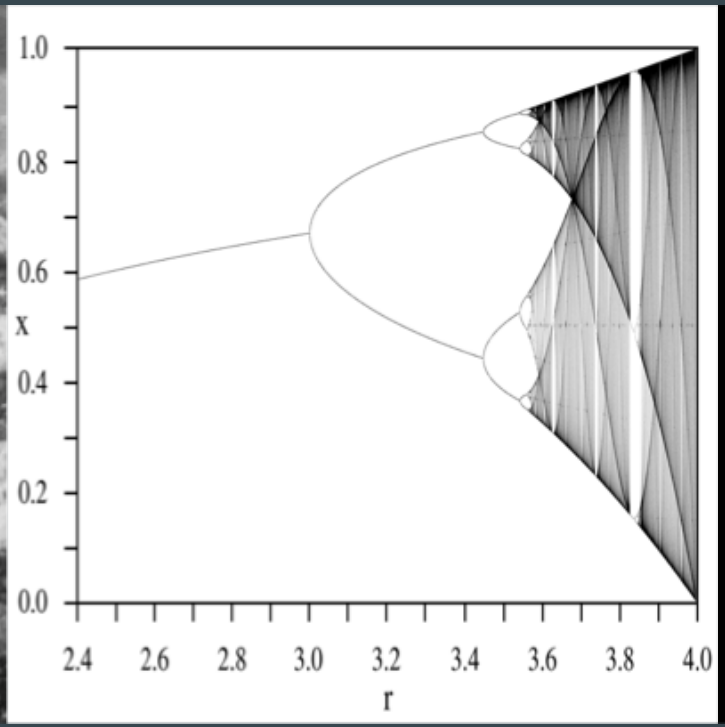
Image: http://www.greenskychaser.com/blog/wp-content/uploads/2010/03/foxtrot_wx_19June2006.gif
https://i.stack.imgur.com/iSWyZ.png

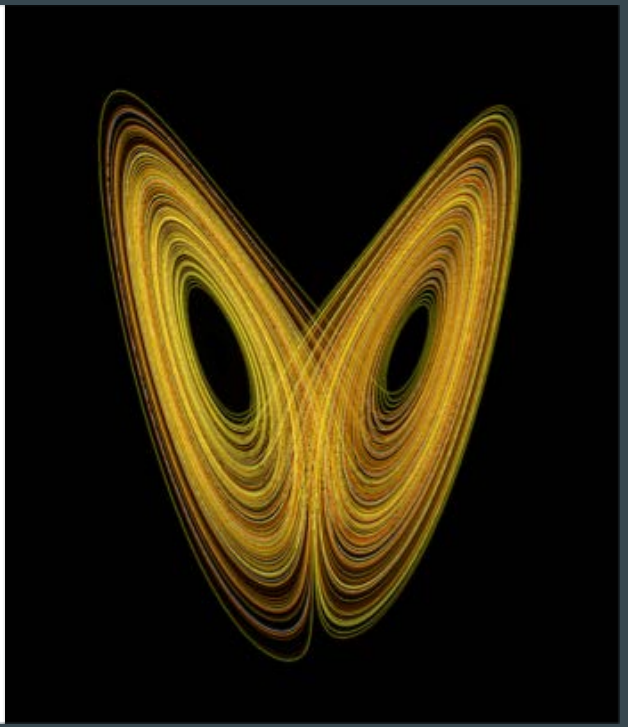
Why is weather so difficult to predict?

Image: http://www.tonygarza.com/wp-content/uploads/2016/01/iStock_000014861801_Large.jpg

A Bit of Math: Chaos Theory







Images: http://www.realclimate.org/images/lorenzHiking.jpg
http://s2.thingpic.com/images/7P/dMcPkcE43yRtYdAWSSdooZbH.png
http://www.biourbanism.org/wp-content/uploads/2013/03/LogisticMap_BifurcationDiagram.png

Properties of a Chaotic System

Chaos describes a dynamical system that has certain properties. These properties make these systems uniquely hard to predict...

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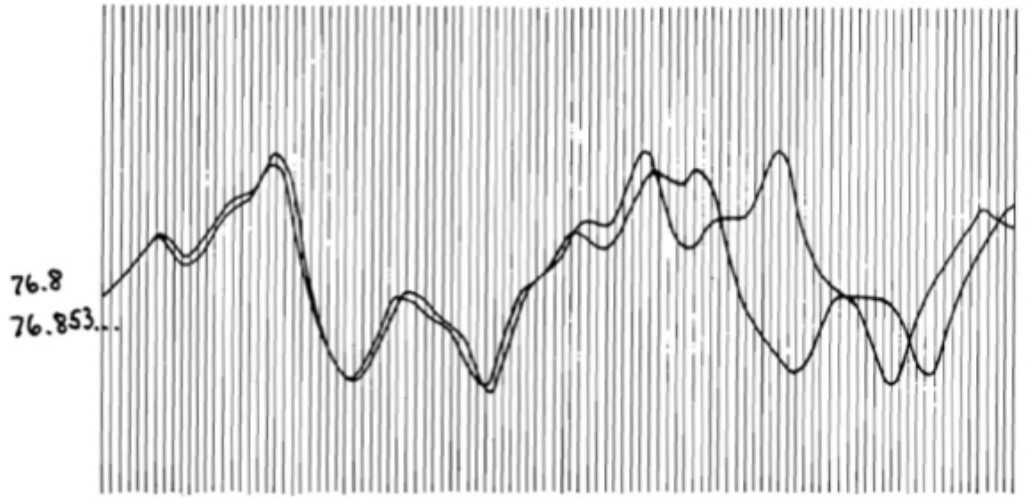
In the words of Edward Lorenz…

"When the present determines the future, but the approximate present does not approximately determine the future"

Source: http://mpe2013.org/2013/03/17/chaos-in-an-atmosphere-hanging-on-a-wall/

Properties of a Chaotic System

1. **Sensitivity to Initial Conditions**



HOW TWO WEATHER PATTERNS DIVERGE. From nearly the same starting point, Edward Lorenz saw his computer weather produce patterns that grew farther and farther apart until all resemblance disappeared. (From Lorenz's 1961 printouts.)

Image: http://www.syloslabini.info/online/wp-content/uploads/2014/07/LorenzPatterns.jpg

Properties of a Chaotic System

1. **Sensitivity to Initial Conditions**

2. **Topologically Mixing**

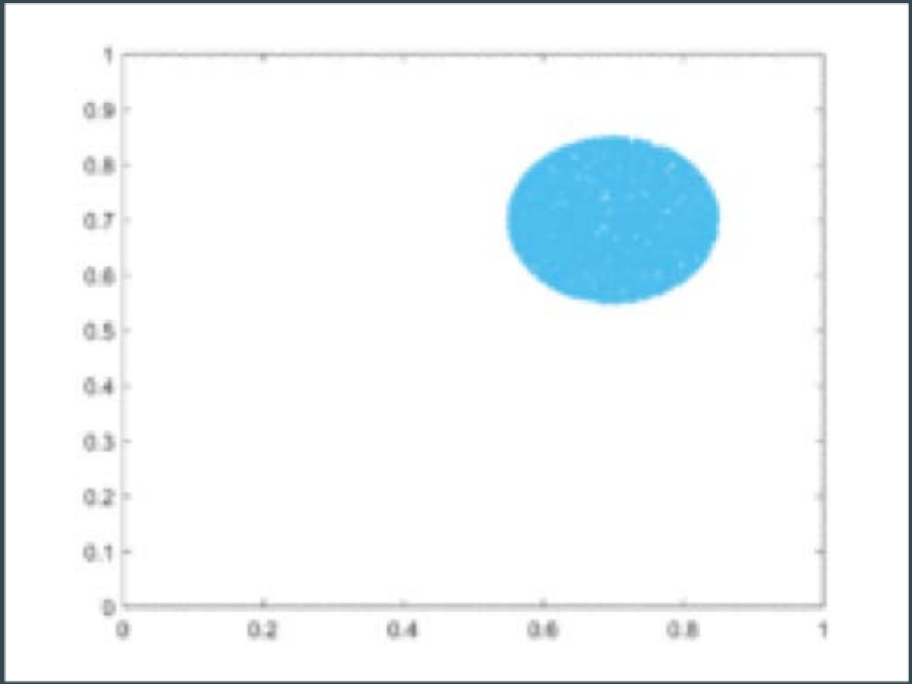


Image: https://upload.wikimedia.org/wikipedia/commons/thumb/6/6a/LogisticTopMixing1-6.gif/220px-LogisticTopMixing1-6.gif

Properties of a Chaotic System

1. **Sensitivity to Initial Conditions**
2. **Topologically Mixing**
3. **Dense Periodic Orbits**

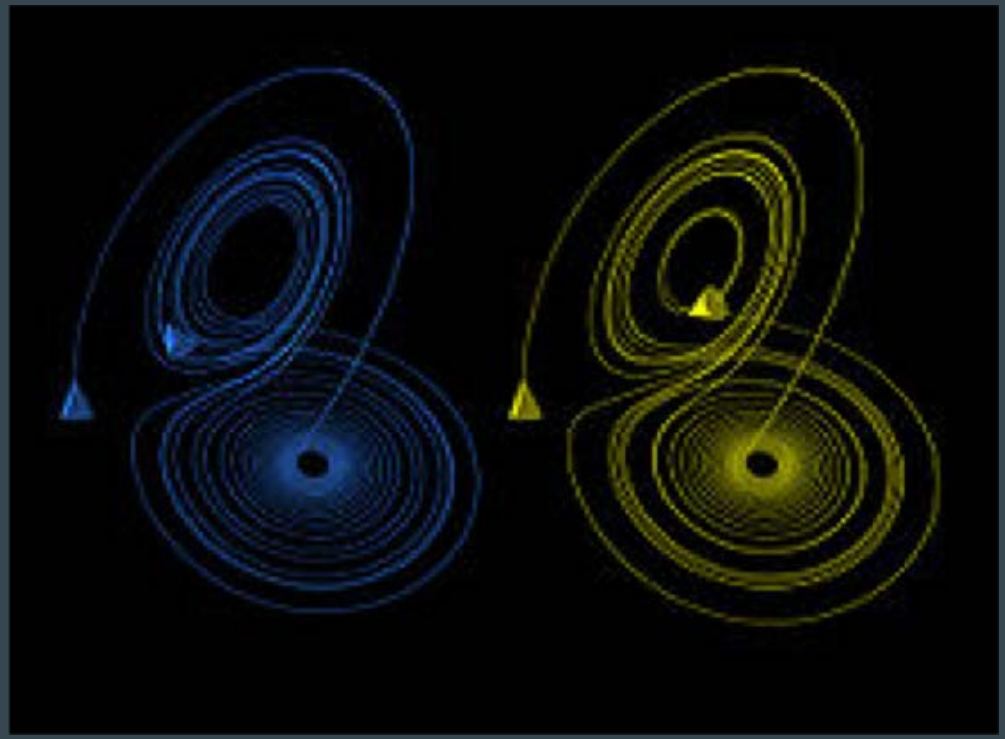


Image: https://upload.wikimedia.org/wikipedia/commons/thumb/4/44/TwoLorenzOrbits.jpg/220px-TwoLorenzOrbits.jpg

Properties of a Chaotic System

1. **Sensitivity to Initial Conditions**
2. **Topologically Mixing**
3. **Dense Periodic Orbits**
4. **Aperiodic**

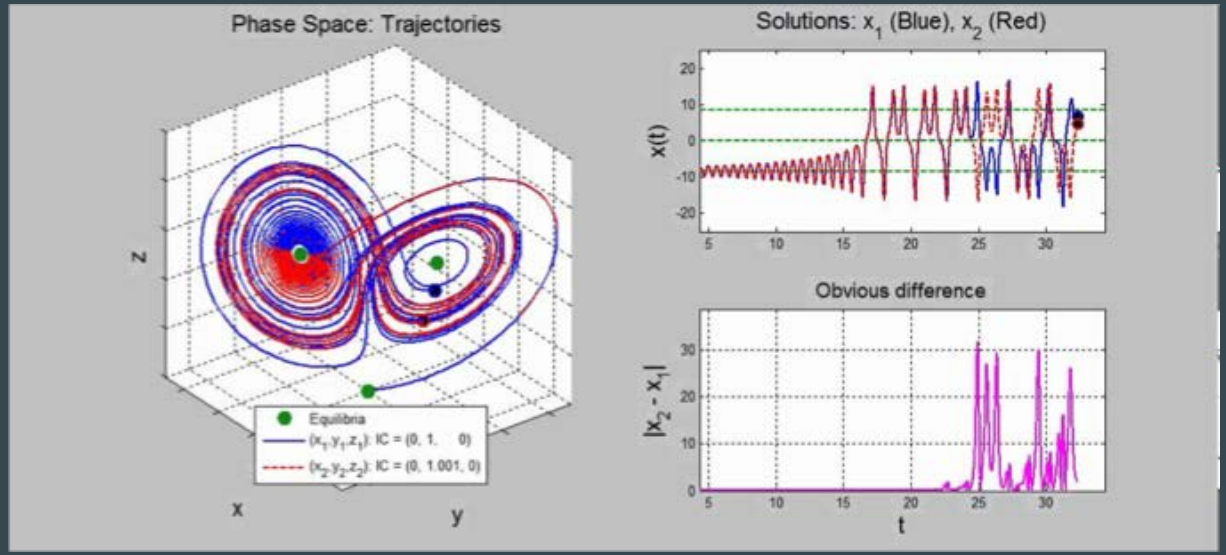


Image: https://i.ytimg.com/vi/8z_tSVeEFTA/maxresdefault.jpg

Properties of a Chaotic System - Summarized

As described by the Stanford Encyclopedia of Philosophy:

A dynamical system f is chaotic if, on a set M,

1. f has sensitivity dependence (weak) on set M
2. f is topologically transitive on M
3. Periodic orbits form a dense set on M
4. (Aperiodic)

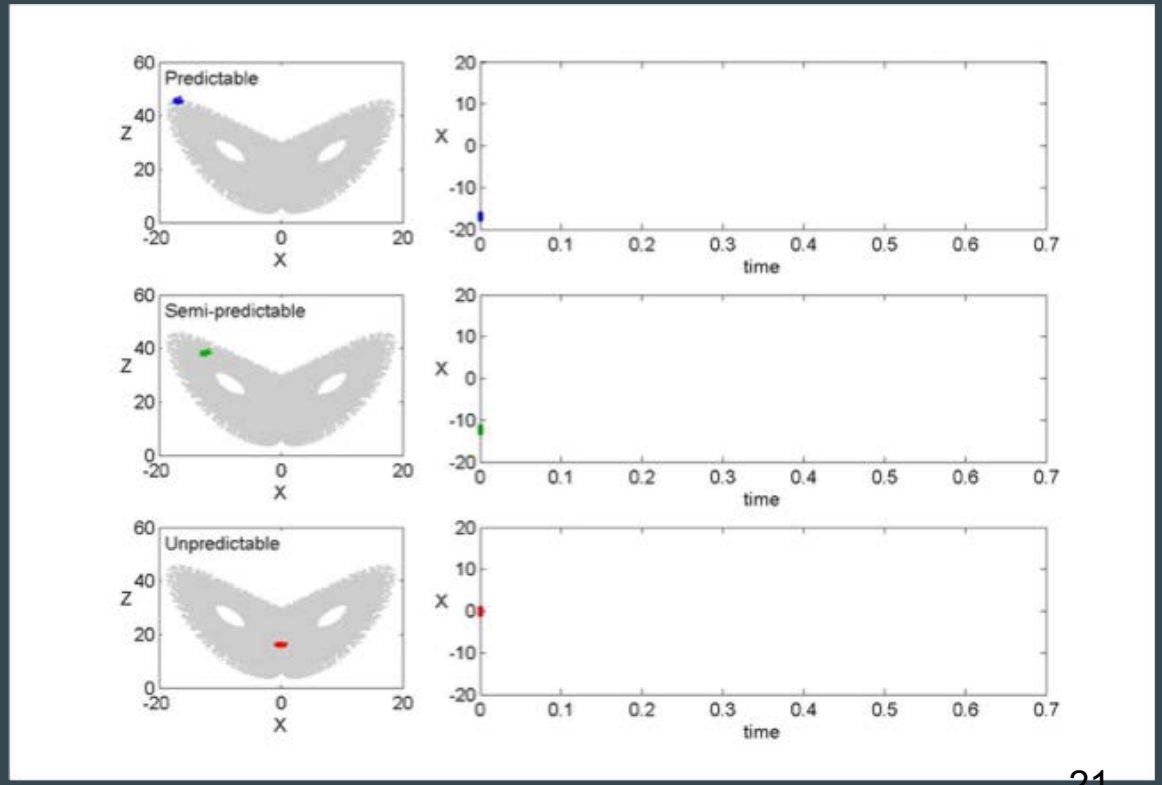
“When the present determines the future, but the approximate present does not approximately determine the future”

Source: https://plato.stanford.edu/entries/chaos/#DefCha

What Does This Have to Do With Weather?

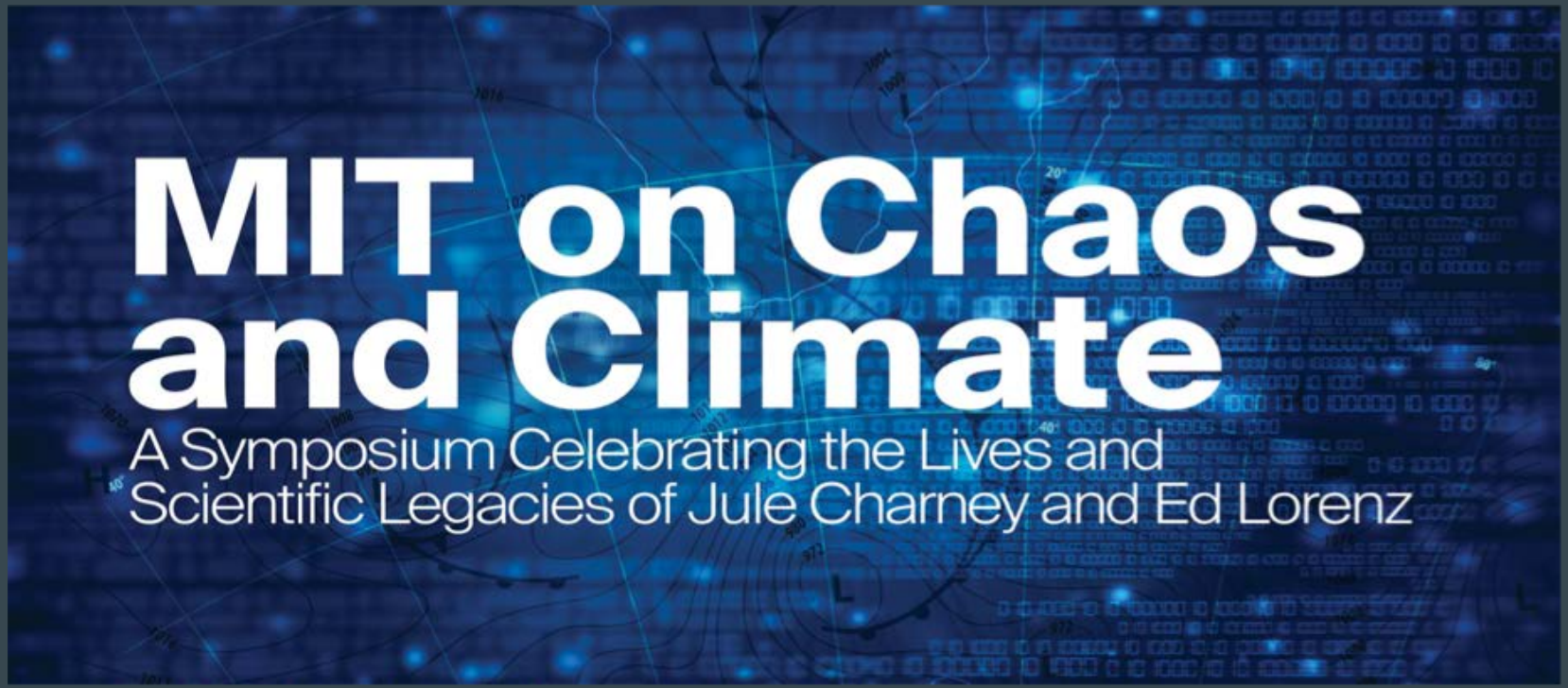
Chaos puts a limit on predictability...

$$\frac{dx}{dt} = -\sigma x + \sigma y;$$
$$\frac{dy}{dt} = rx - y + xz;$$
$$\frac{dz}{dt} = xy - bz.$$



Images: https://www2.physics.ox.ac.uk/sites/default/files/L63_web_movie_0.gif

If you want to know more...



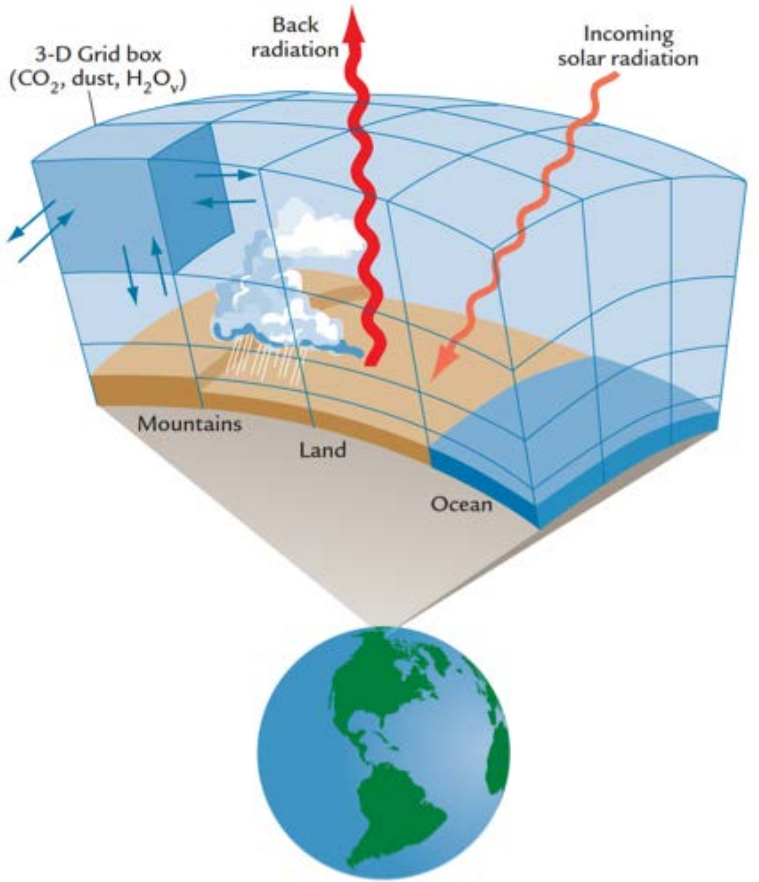
February 2nd, 8:30AM-5:30PM, MIT Wong Auditorium, E51-115

Climate Model Vs. Weather Model

- Grid system

- Physics and process

- A point is related to the next points



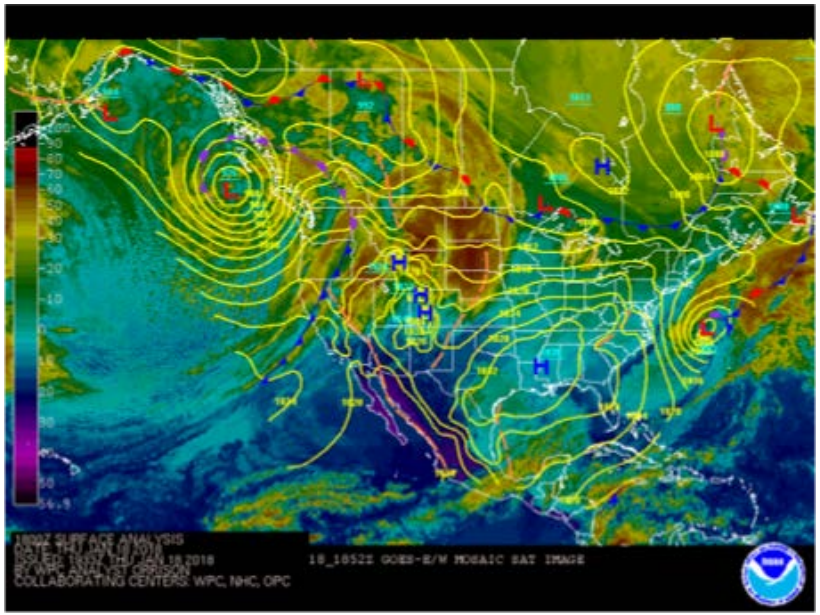
Weather Model

- Reliable observations -> checking if the model is correct

- Less variable to be concerned

- Shorter time scale: hourly - daily

DAY	DESCRIPTION	HIGH / LOW	PRECIP	WIND	HUMIDITY
TODAY JAN 18	Sunny	31°/22°	0%	NW 11 mph	61%
FRI JAN 19	Sunny	37°/28°	10%	WSW 8 mph	59%
SAT JAN 20	Partly Cloudy	49°/31°	0%	WSW 15 mph	51%
SUN JAN 21	Partly Cloudy	46°/31°	10%	W 7 mph	68%
MON JAN 22	PM Snow Showers	36°/34°	50%	ESE 10 mph	77%

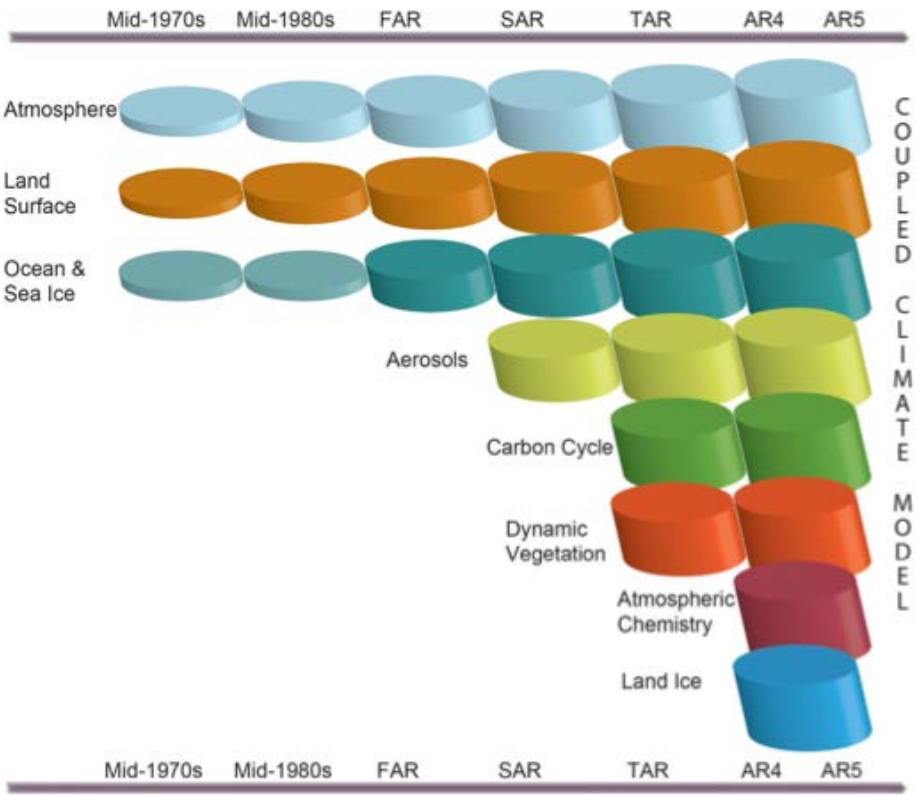


Climate Model

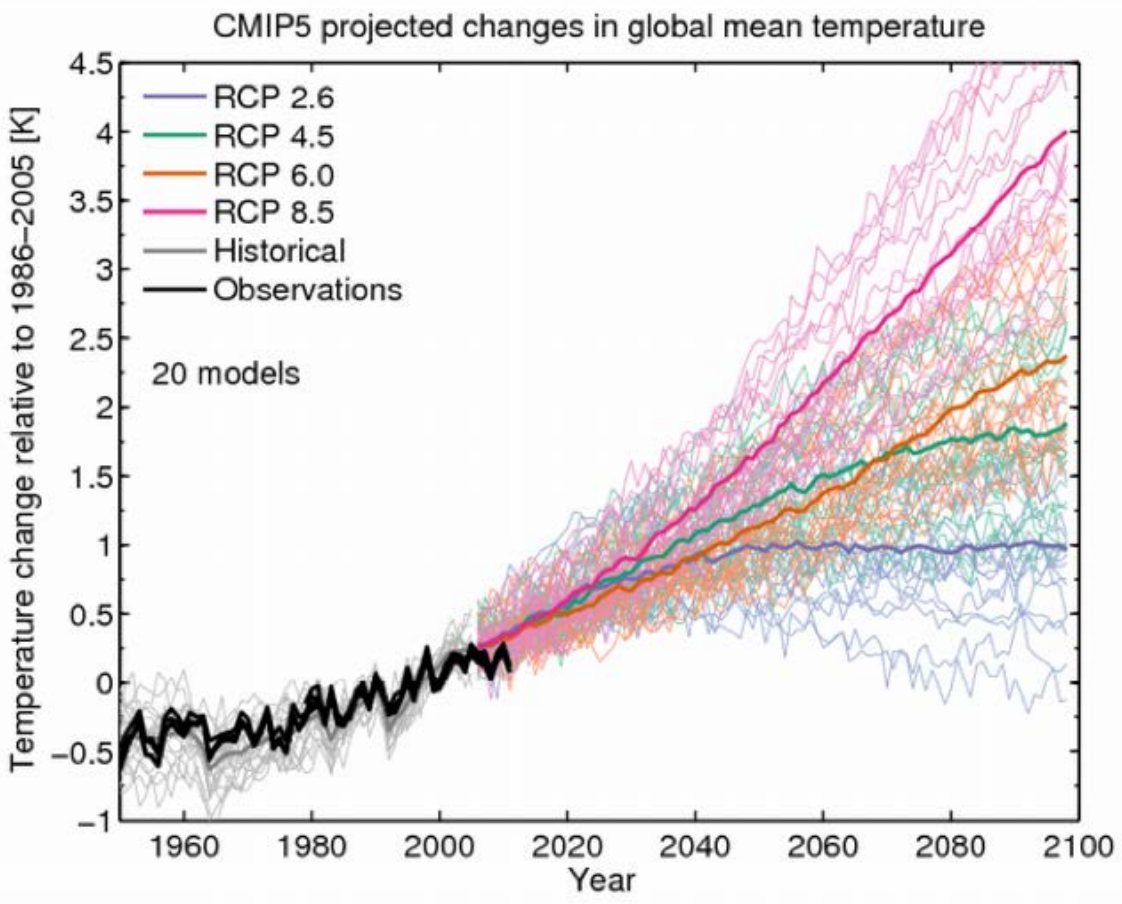
- ~ 50 years of reliable global data, thanks to satellite

- More processes to think about: ocean circulation, sea ice, vegetation, anthropogenic greenhouse gas

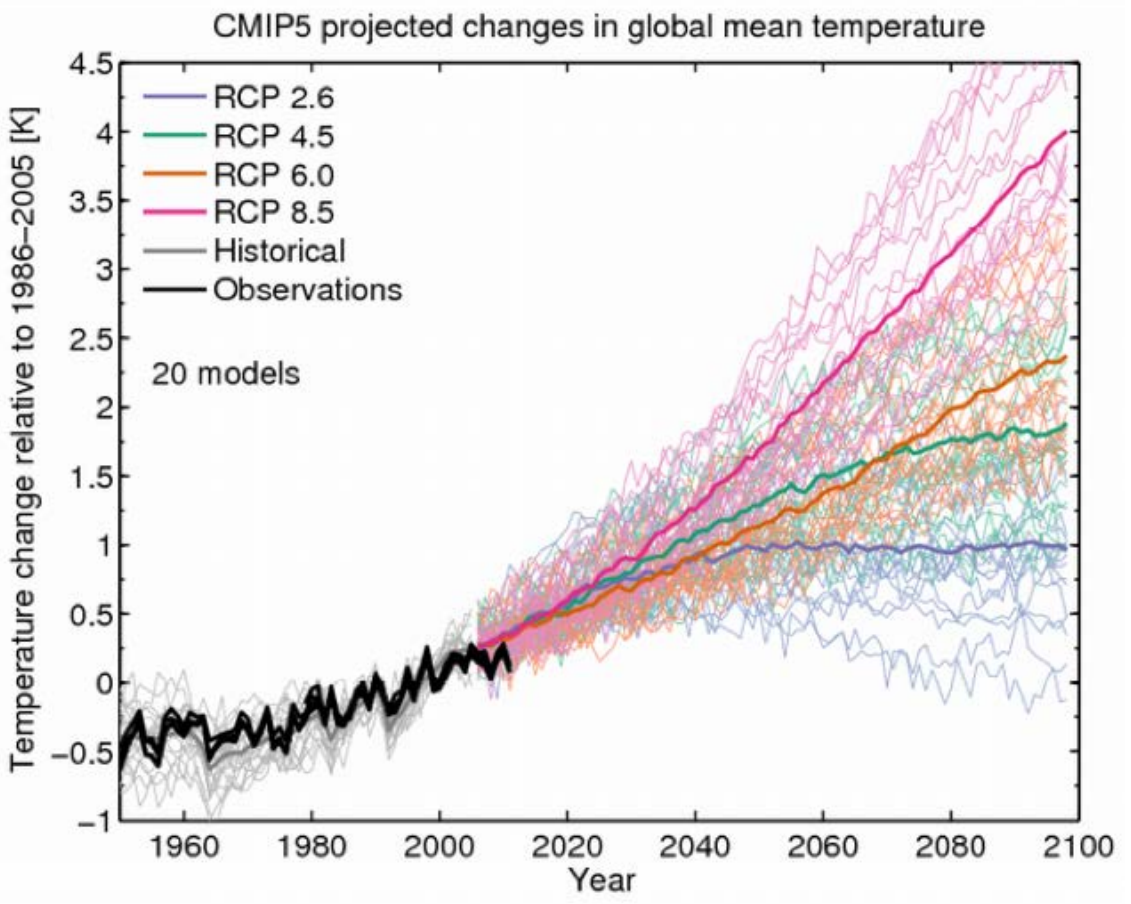
- longer timescale: monthly



Climate Model Evaluation



Climate Model Evaluation: Comparing between Models

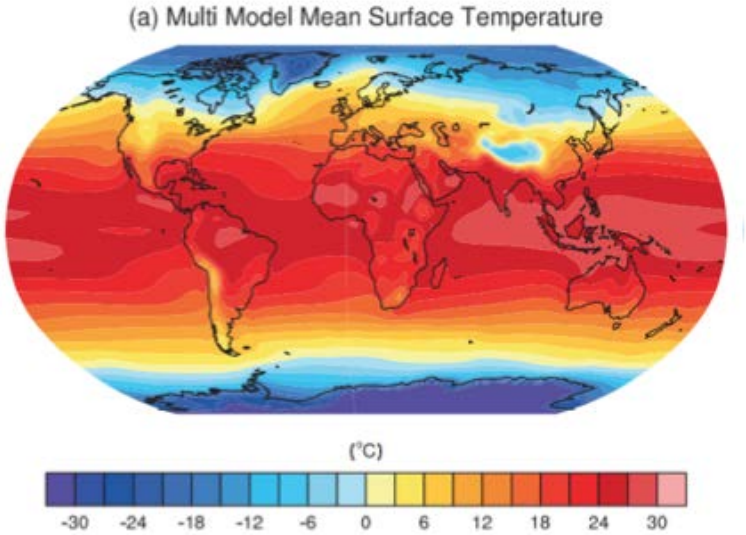


Model spread

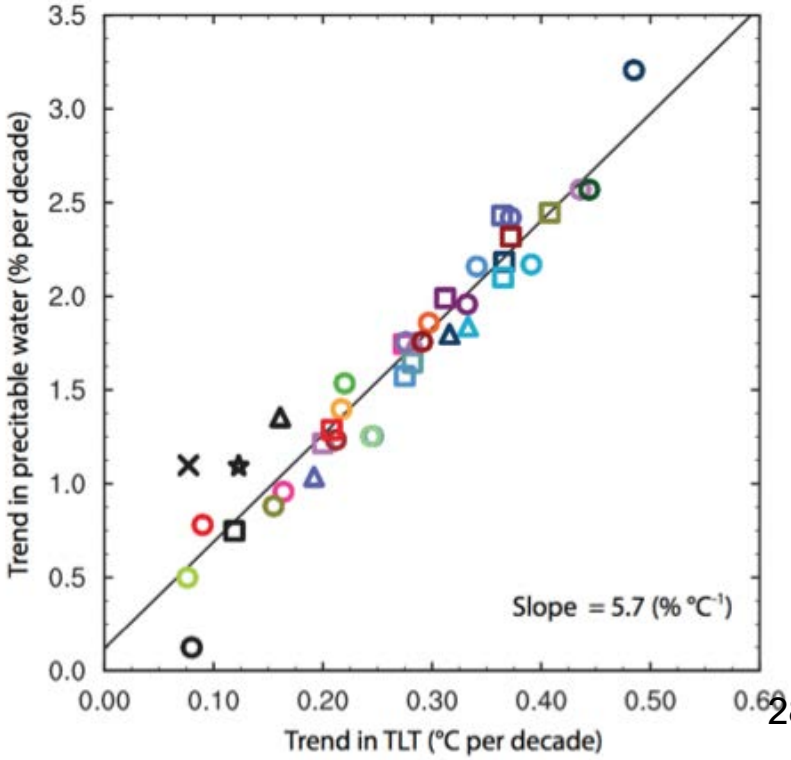
Climate Model Evaluation: Comparing between Models

- Set initial and boundary condition

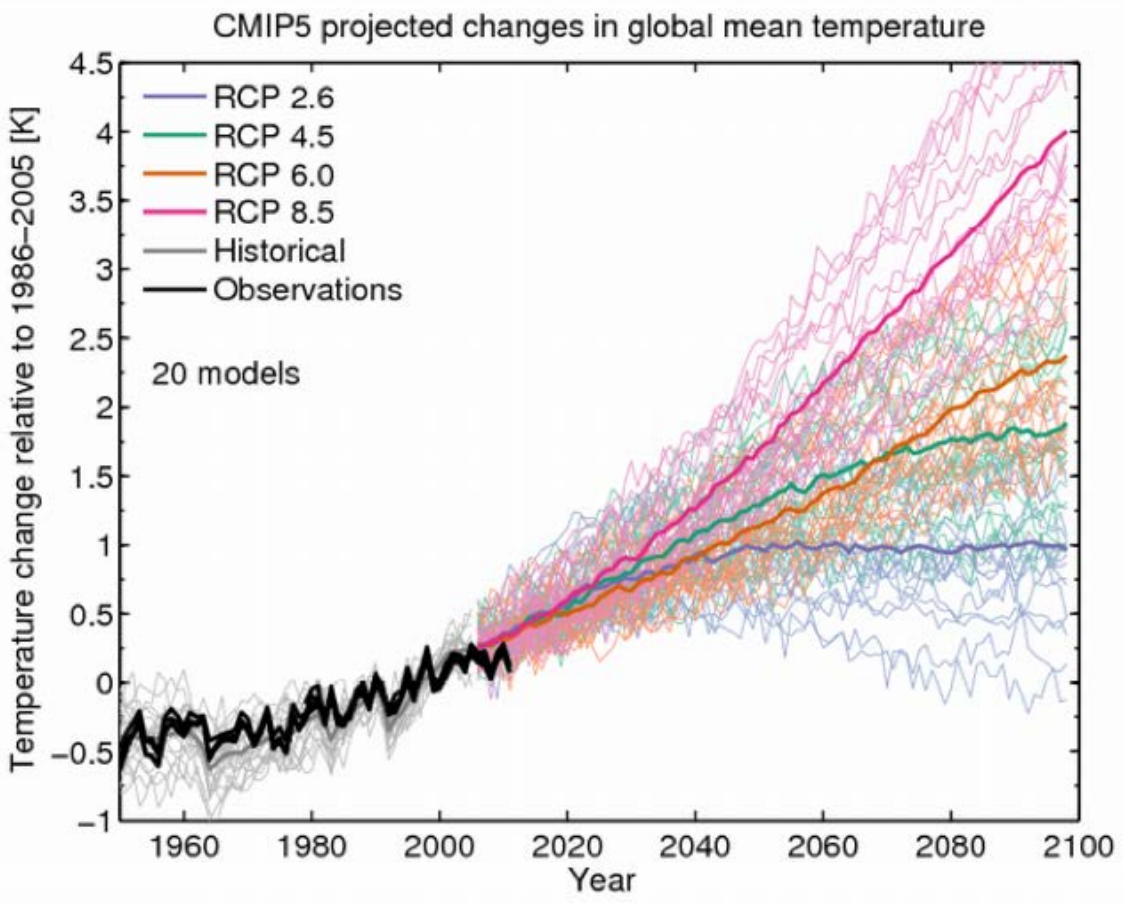
- Set scenarios for experiments



CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project



Climate Model Evaluation: Model Spin Up



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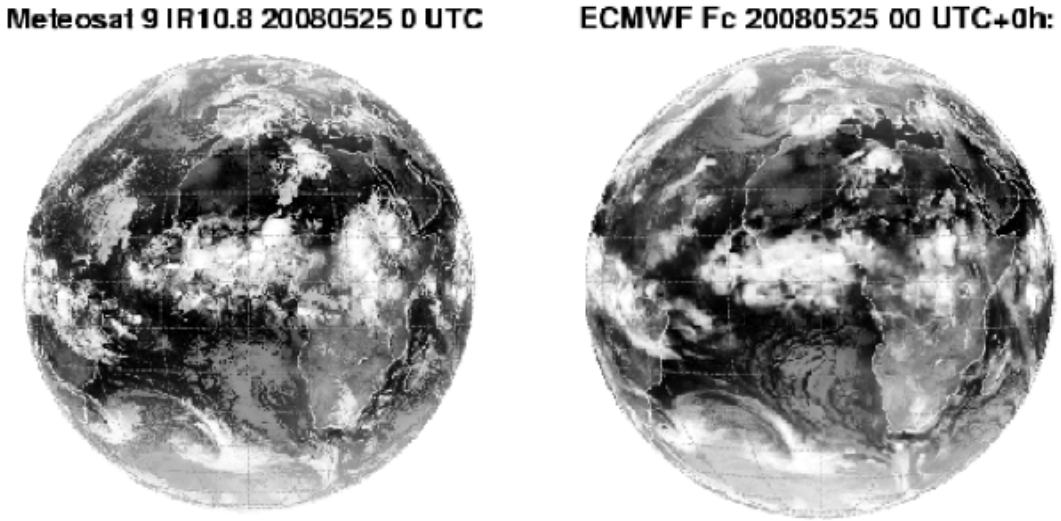
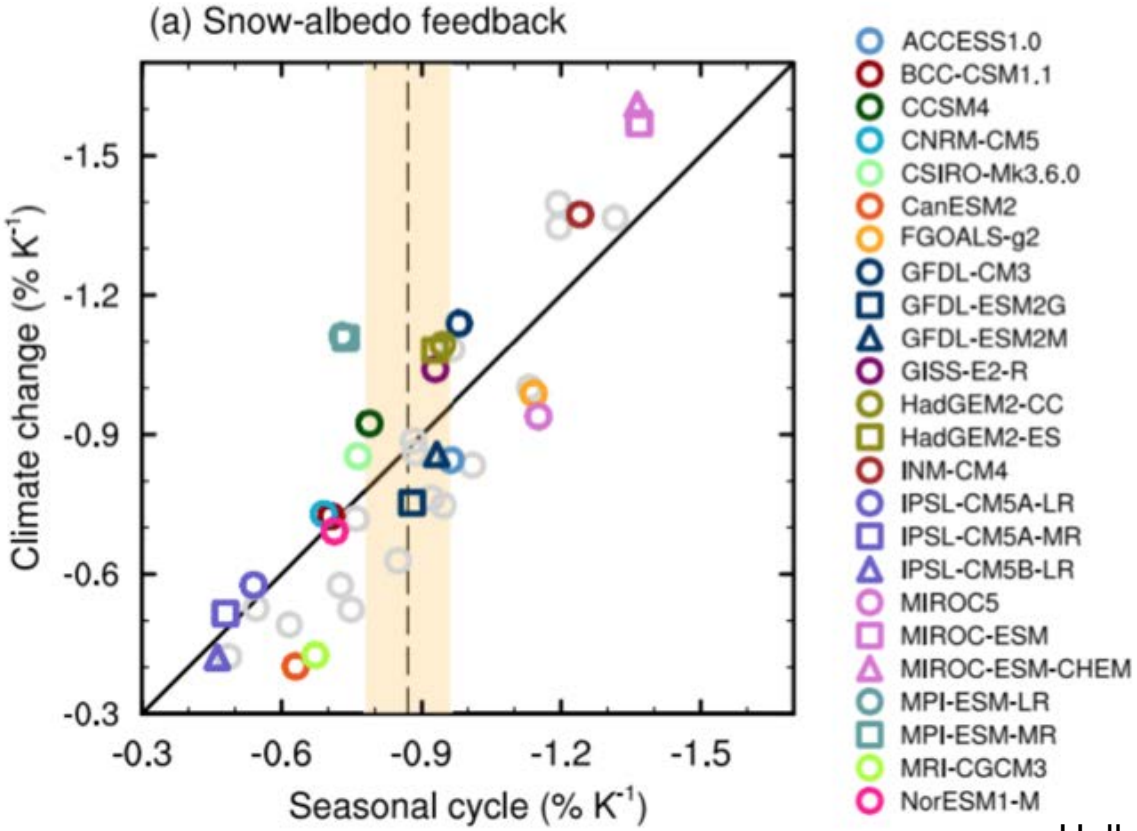


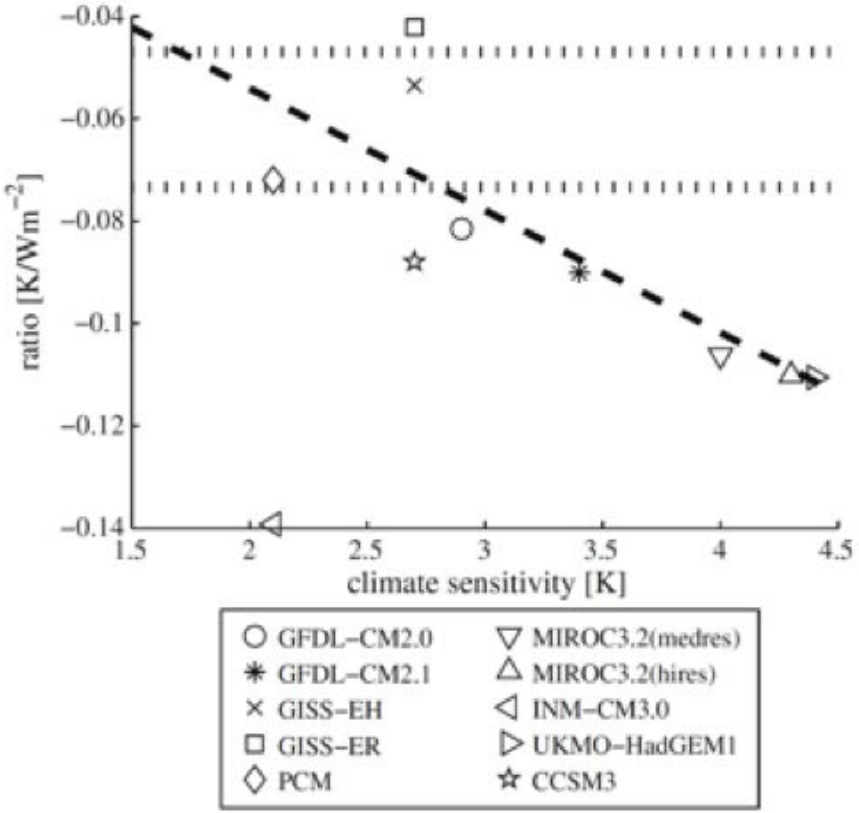
Meteostat satellite observations of clouds (left) are compared to climate model output from ECMWF (right)

Climate Model Evaluation: Emergent Constraint

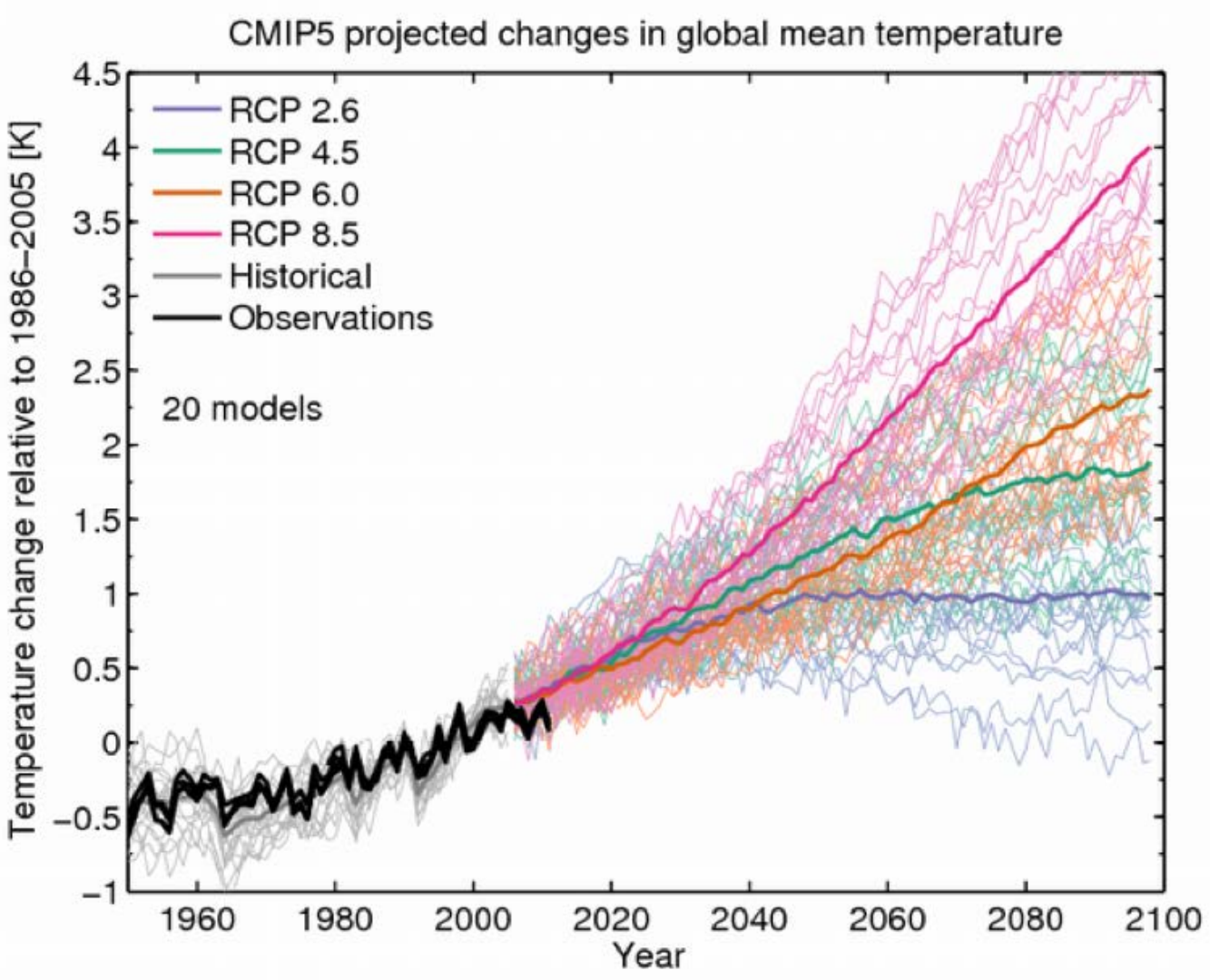


Hall and Qu (2016)

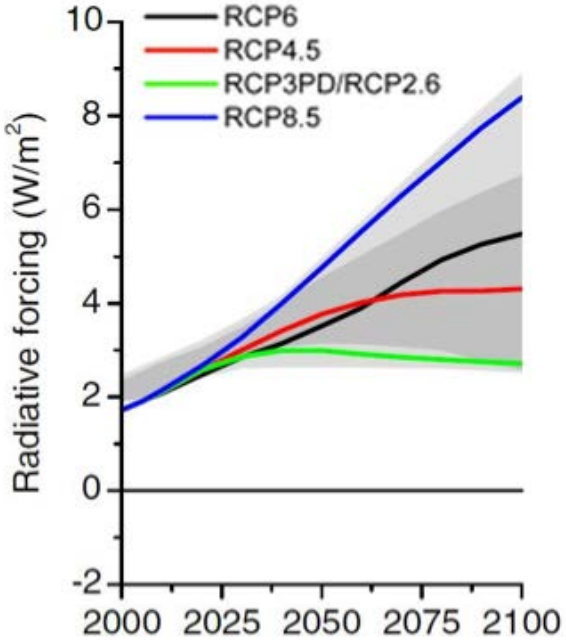
Climate Model Evaluation: Emergent Constraint

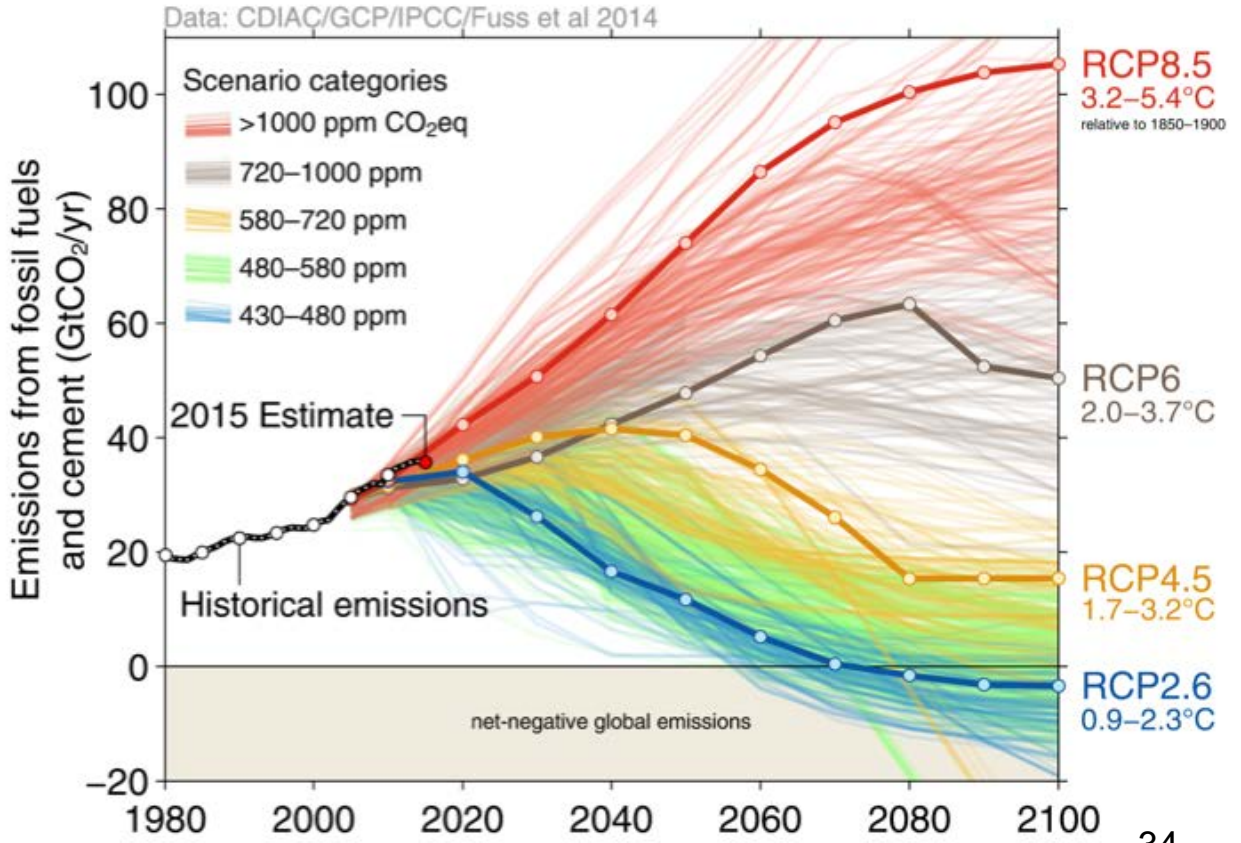


Bender, et al (2010)

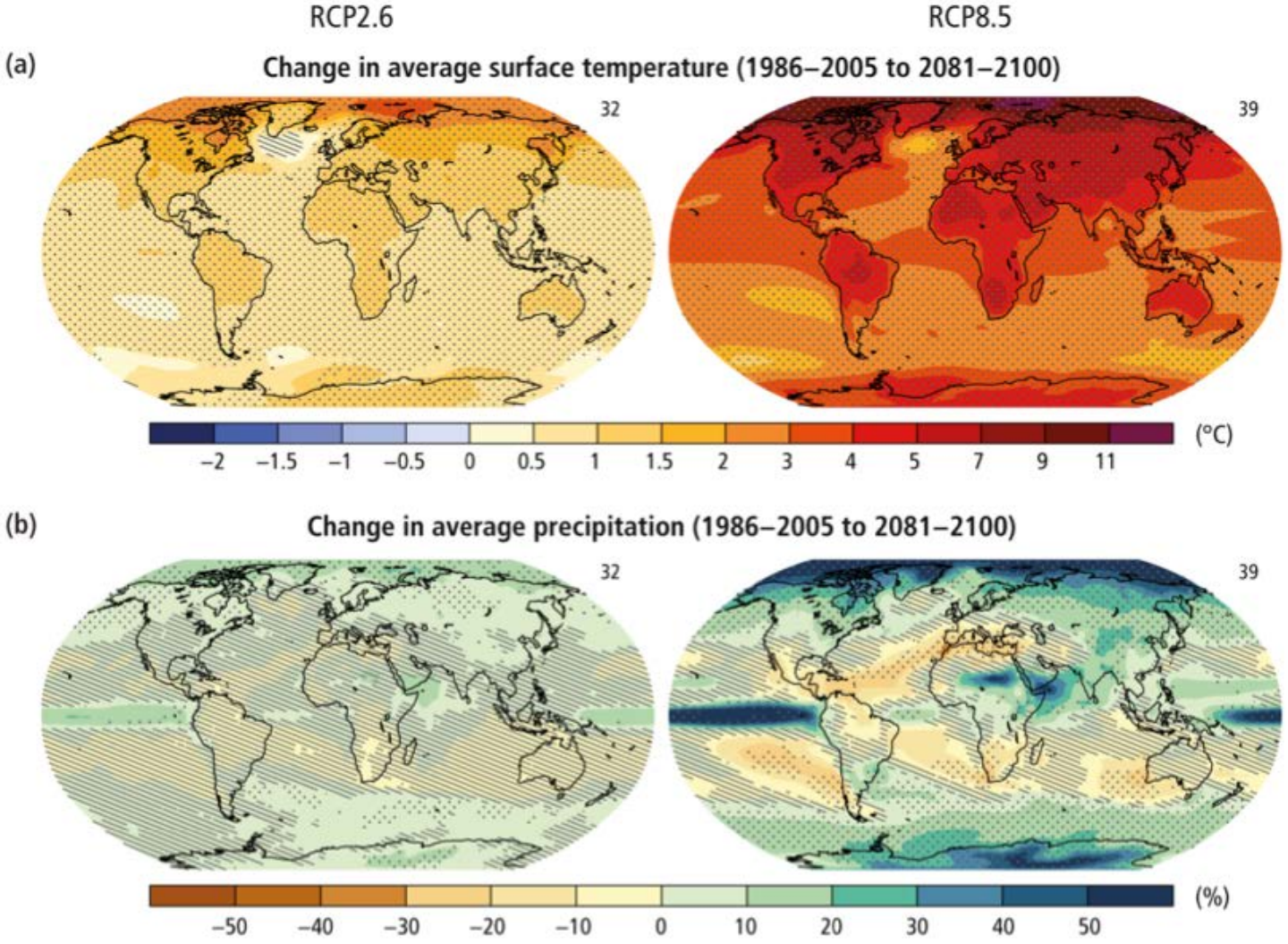

CMIP5 projected changes in global mean temperature
RCP 2.6
RCP 4.5
RCP 6.0
RCP 8.5
Historical
Observations
20 models
Temperature change relative to 1986–2005 [K]
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1
1960
1980
2000
2020
2040
2060
2080
2100
Year

What's up with all this RCP stuff?

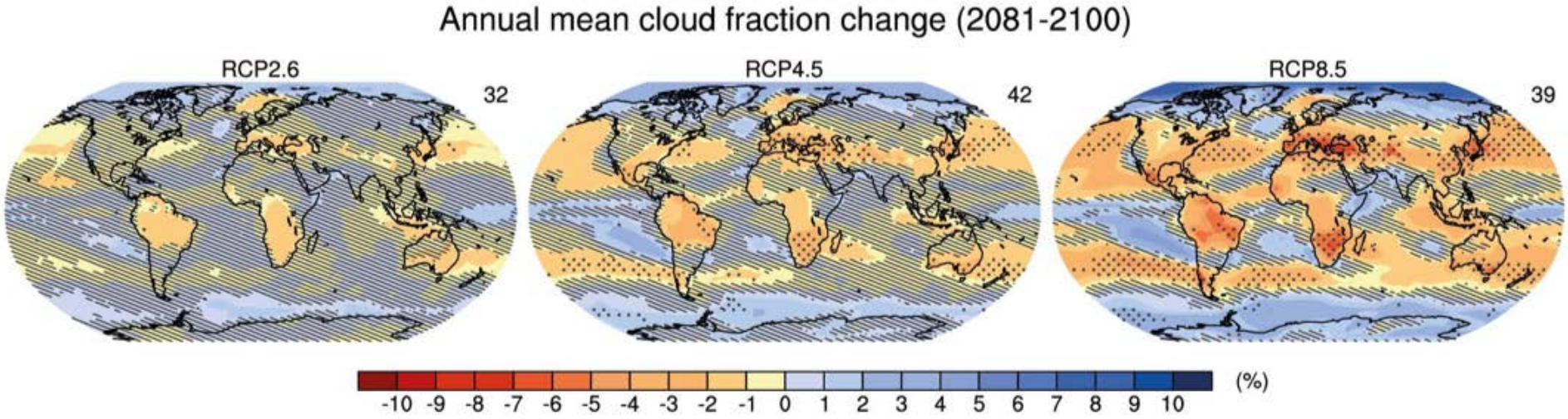




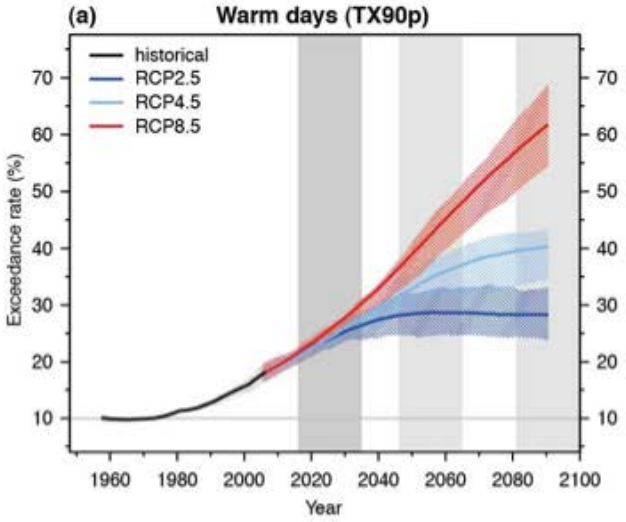
IPCC AR5

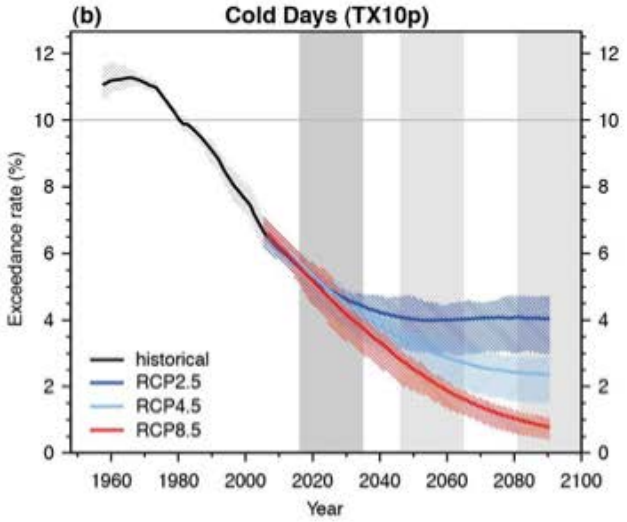

RCP2.6
RCP8.5
(a)
Change in average surface temperature (1986–2005 to 2081–2100)
32
39
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2 3 4 5 7 9 11
(°C)
(b)
Change in average precipitation (1986–2005 to 2081–2100)
32
39
−50 −40 −30 −20 −10 0 10 20 30 40 50
(%)

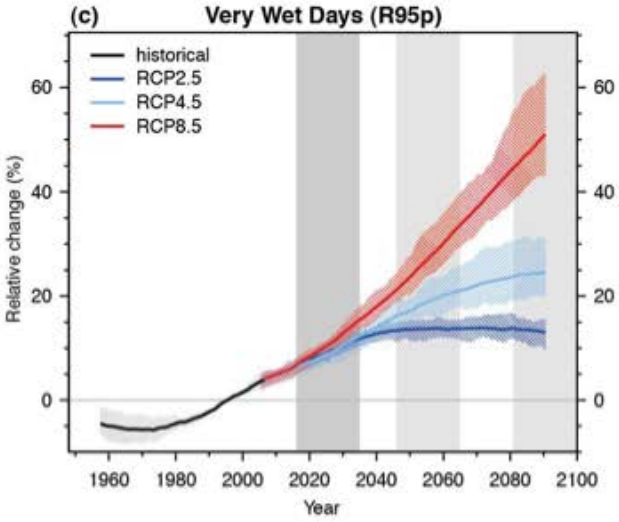
IPCC AR5


Annual mean cloud fraction change (2081-2100)
RCP2.6
32
RCP4.5
42
RCP8.5
39
-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10
(%)

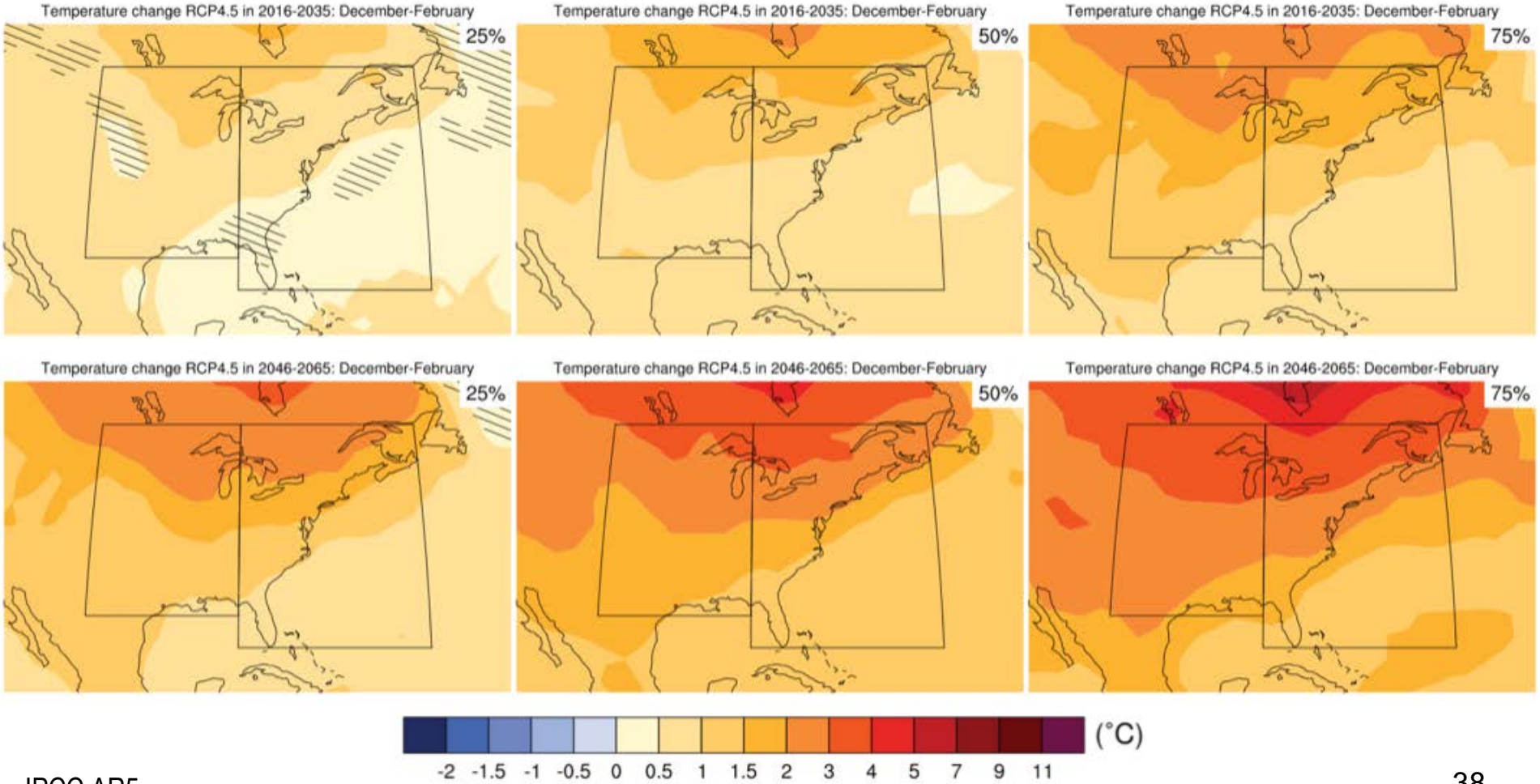
IPCC AR5


(a)
Warm days (TX90p)
historical
RCP2.5
RCP4.5
RCP8.5
Exceedance rate (%)
Year


(b)
Cold Days (TX10p)
historical
RCP2.5
RCP4.5
RCP8.5
Exceedance rate (%)
Year


(c)
Very Wet Days (R95p)
historical
RCP2.5
RCP4.5
RCP8.5
Relative change (%)
Year

IPCC AR5


Temperature change RCP4.5 in 2016-2035: December-February
25%
Temperature change RCP4.5 in 2016-2035: December-February
50%
Temperature change RCP4.5 in 2016-2035: December-February
75%
Temperature change RCP4.5 in 2046-2065: December-February
25%
Temperature change RCP4.5 in 2046-2065: December-February
50%
Temperature change RCP4.5 in 2046-2065: December-February
75%
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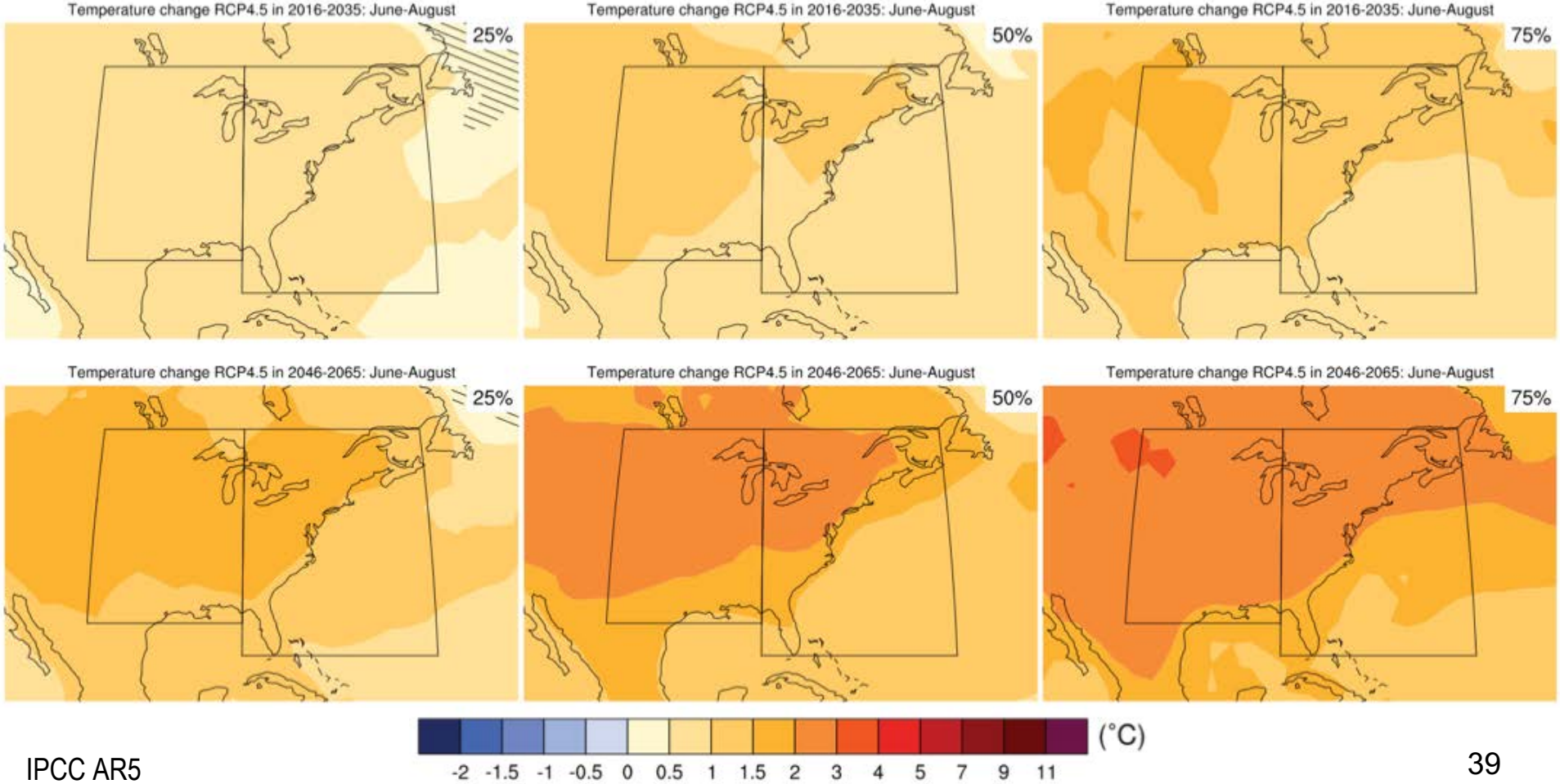
(°C)

IPCC AR5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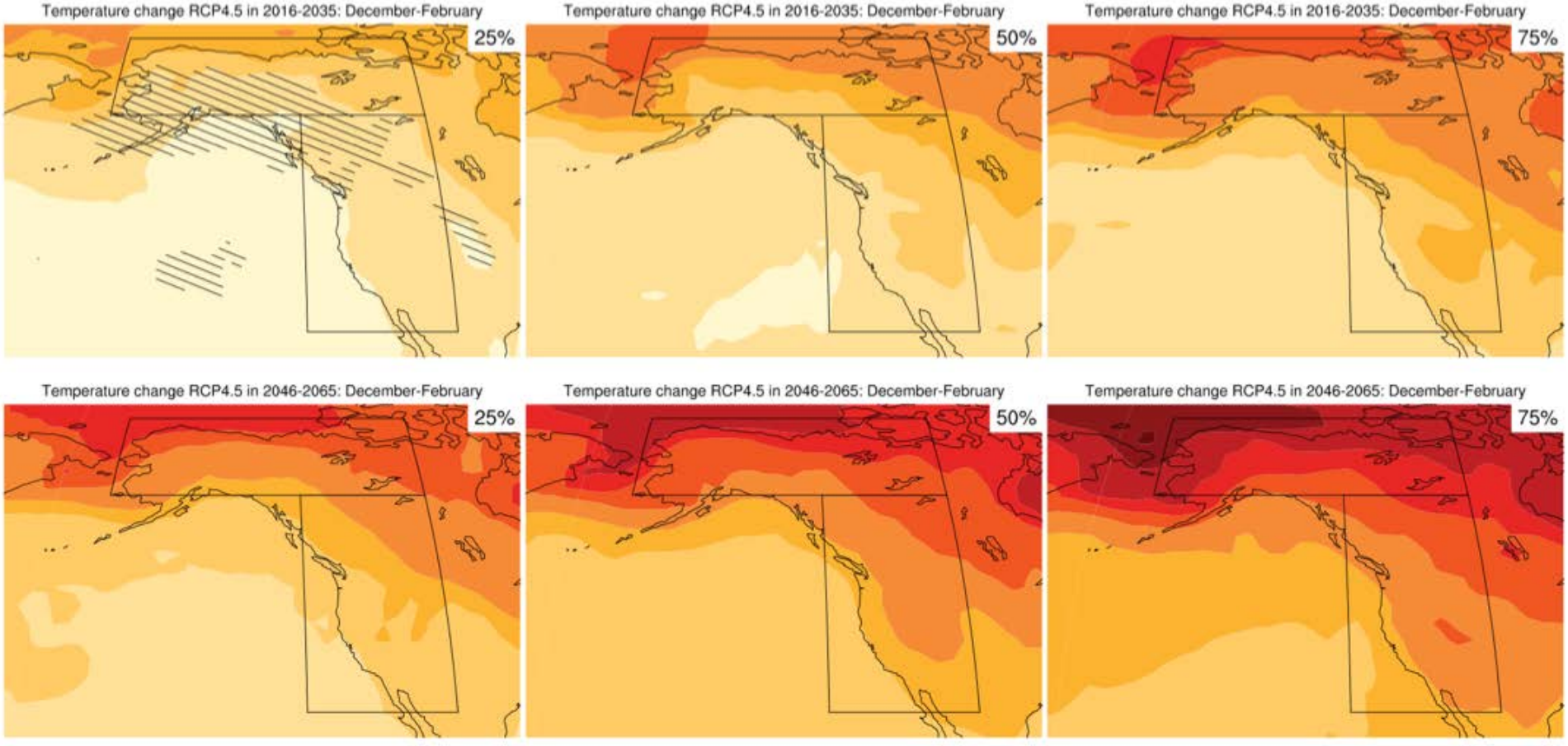
(°C)

IPCC AR5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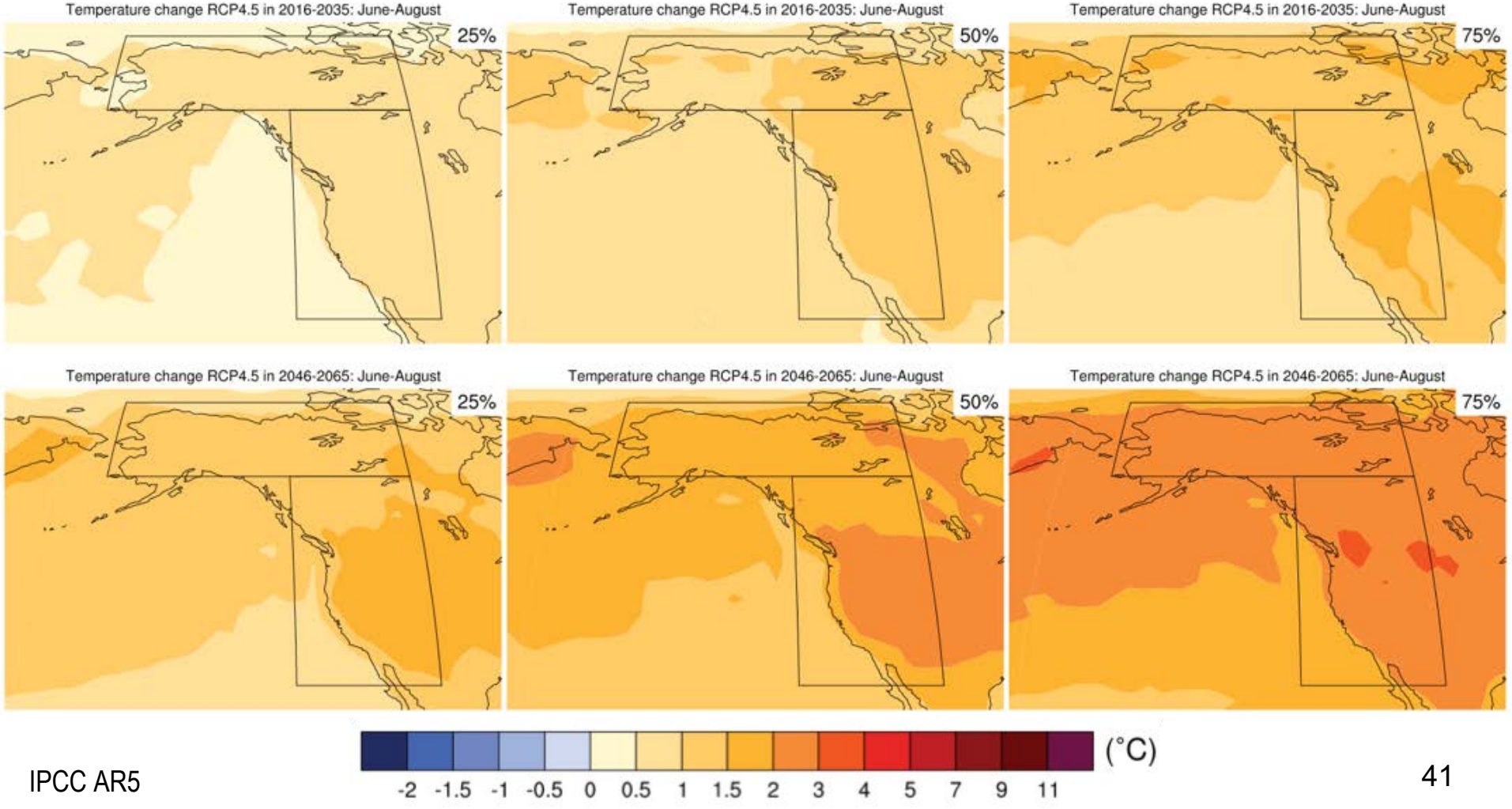
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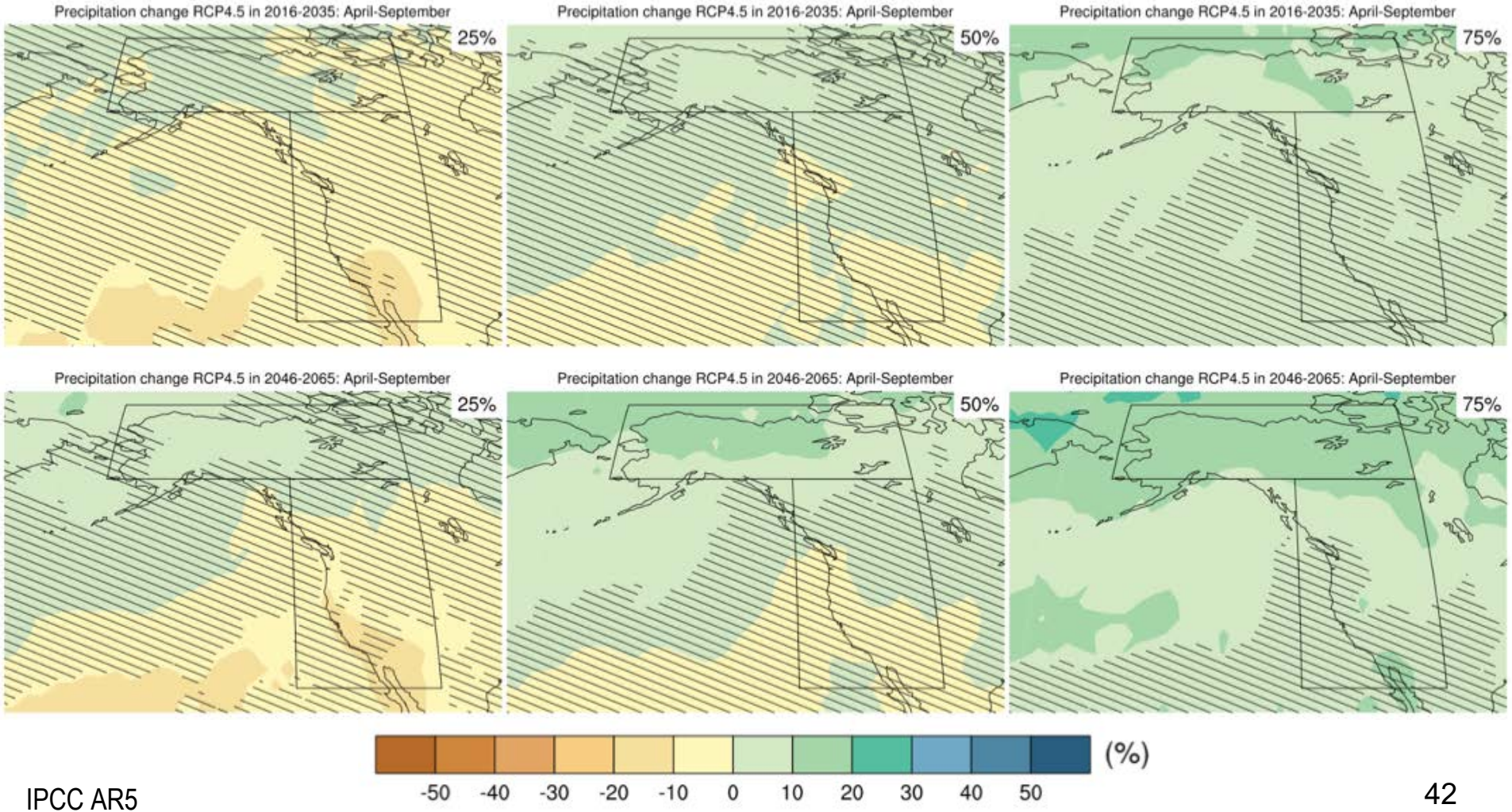
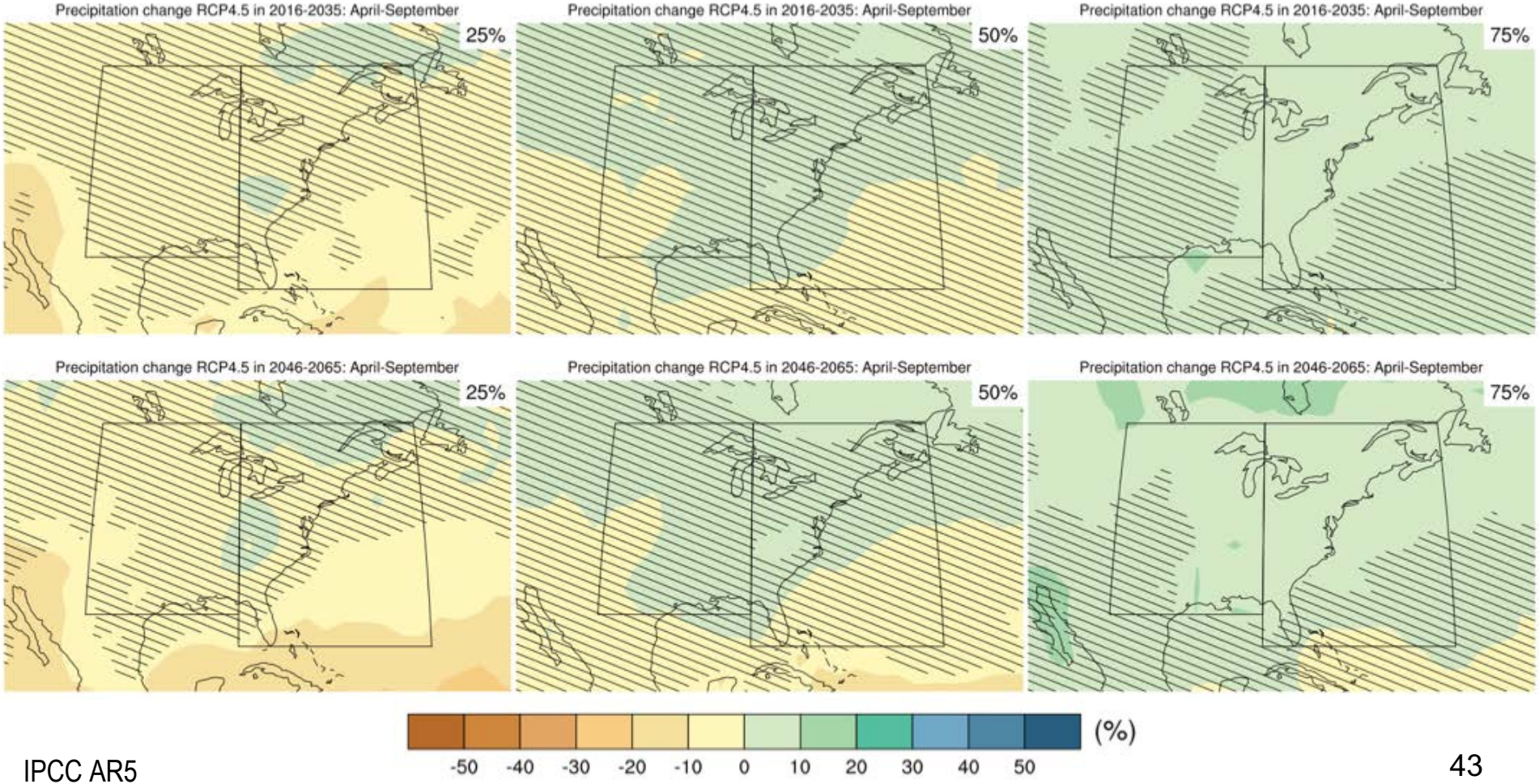
Temperature change RCP4.5 in 2046-2065: June-August
25%
Temperature change RCP4.5 in 2046-2065: June-August
50%
Temperature change RCP4.5 in 2046-2065: June-August
75%
-2 -1.5 -1 -0.5 0 0.5 1 1.5 2 3 4 5 7 9 11
(°C)

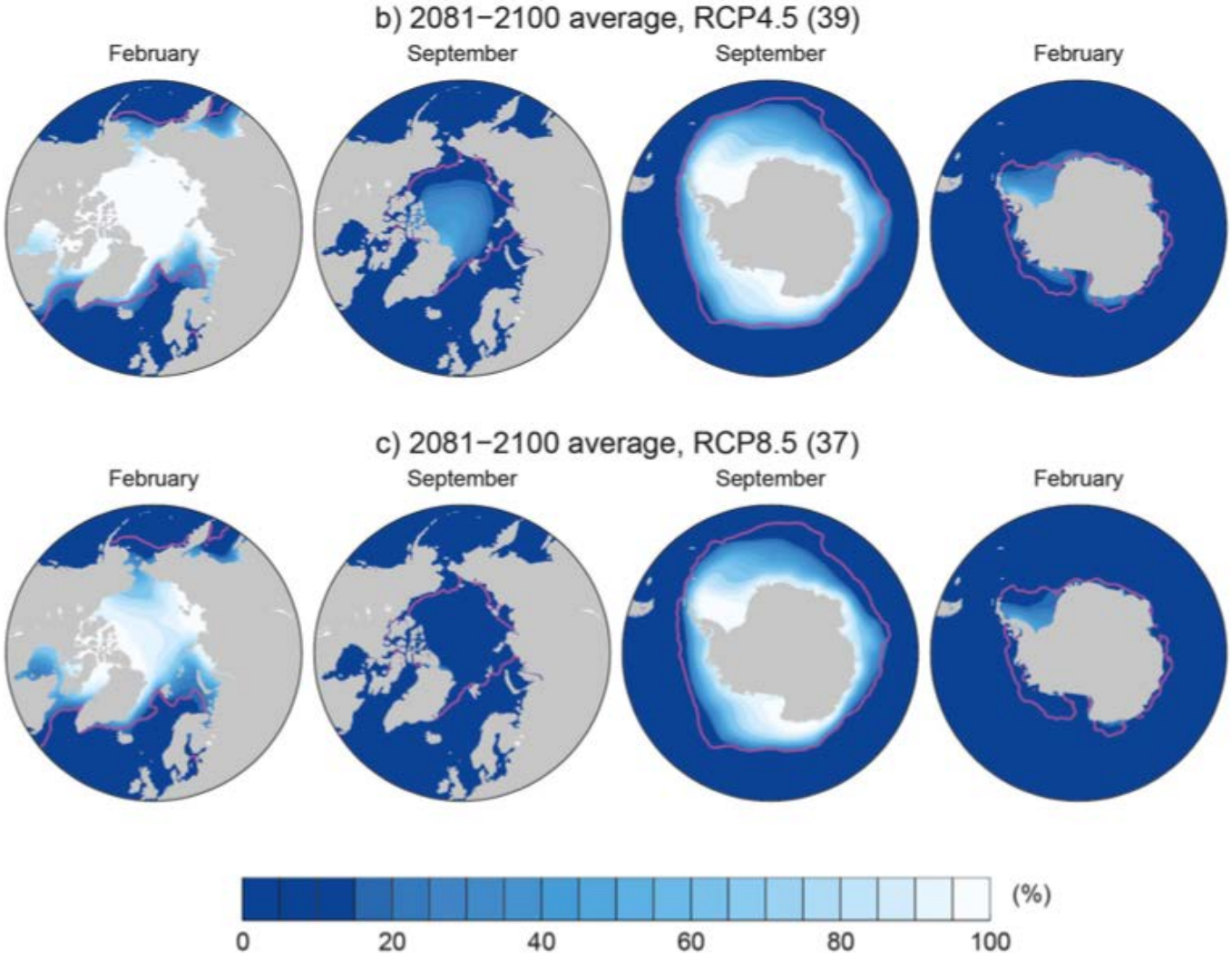
IPCC AR5


Precipitation change RCP4.5 in 2016-2035: April-September
25%
Precipitation change RCP4.5 in 2016-2035: April-September
50%
Precipitation change RCP4.5 in 2016-2035: April-September
75%
Precipitation change RCP4.5 in 2046-2065: April-September
25%
Precipitation change RCP4.5 in 2046-2065: April-September
50%
Precipitation change RCP4.5 in 2046-2065: April-September
75%
-50 -40 -30 -20 -10 0 10 20 30 40 50
(%)

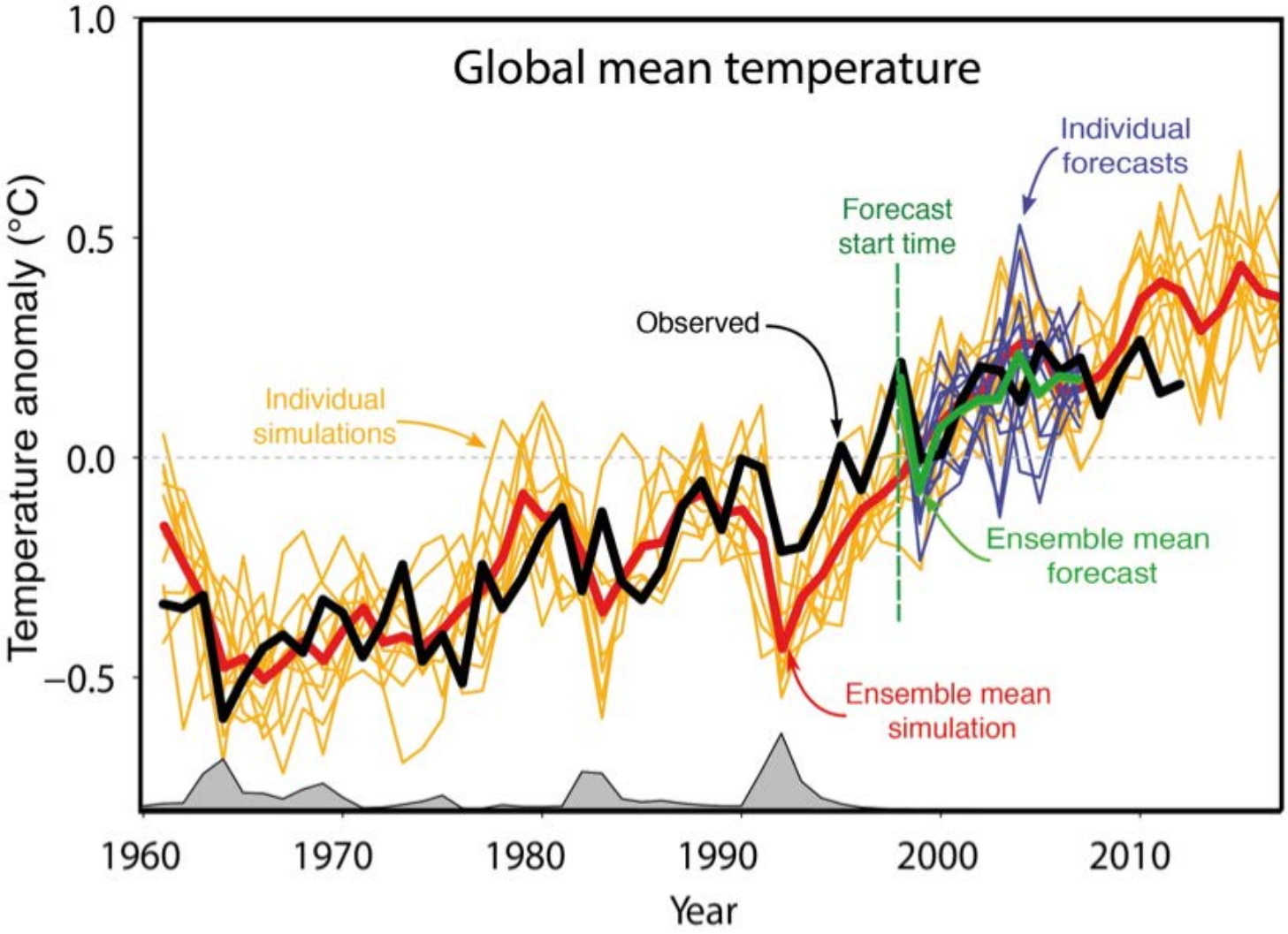
IPCC AR5

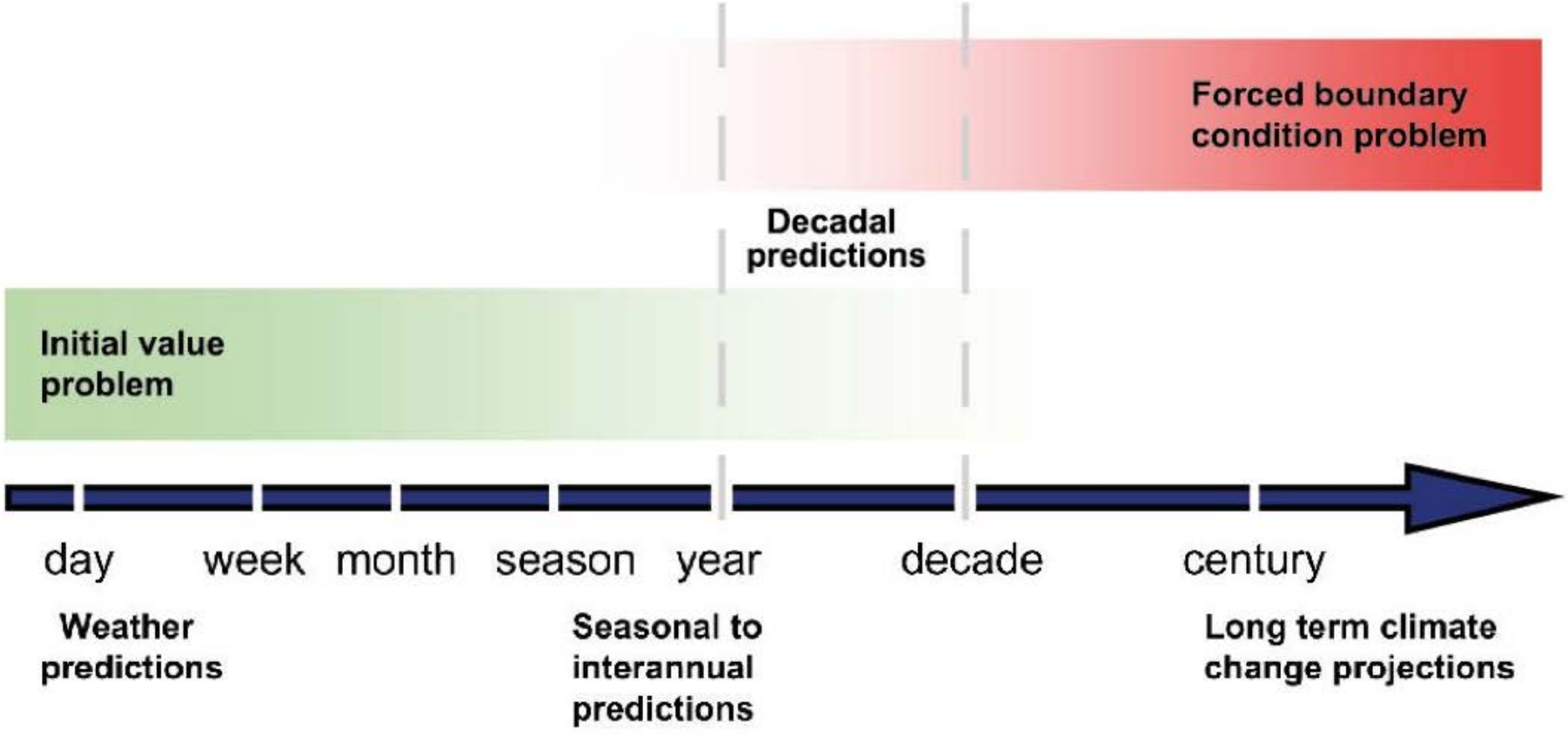

Precipitation change RCP4.5 in 2016-2035: April-September
25%
Precipitation change RCP4.5 in 2016-2035: April-September
50%
Precipitation change RCP4.5 in 2016-2035: April-September
75%
Precipitation change RCP4.5 in 2046-2065: April-September
25%
Precipitation change RCP4.5 in 2046-2065: April-September
50%
Precipitation change RCP4.5 in 2046-2065: April-September
75%
-50 -40 -30 -20 -10 0 10 20 30 40 50
(%)

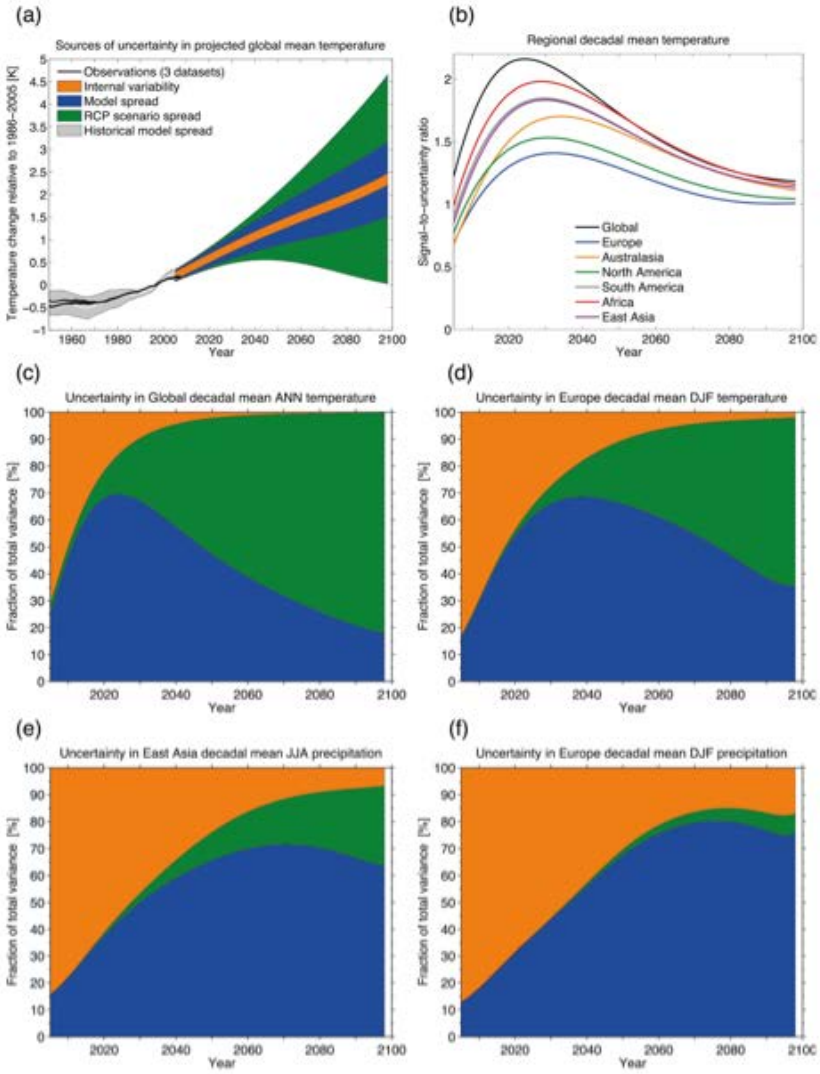
IPCC AR5


b) 2081–2100 average, RCP4.5 (39)
February
September
September
February
c) 2081–2100 average, RCP8.5 (37)
February
September
September
February
(%)
0
20
40
60
80
100

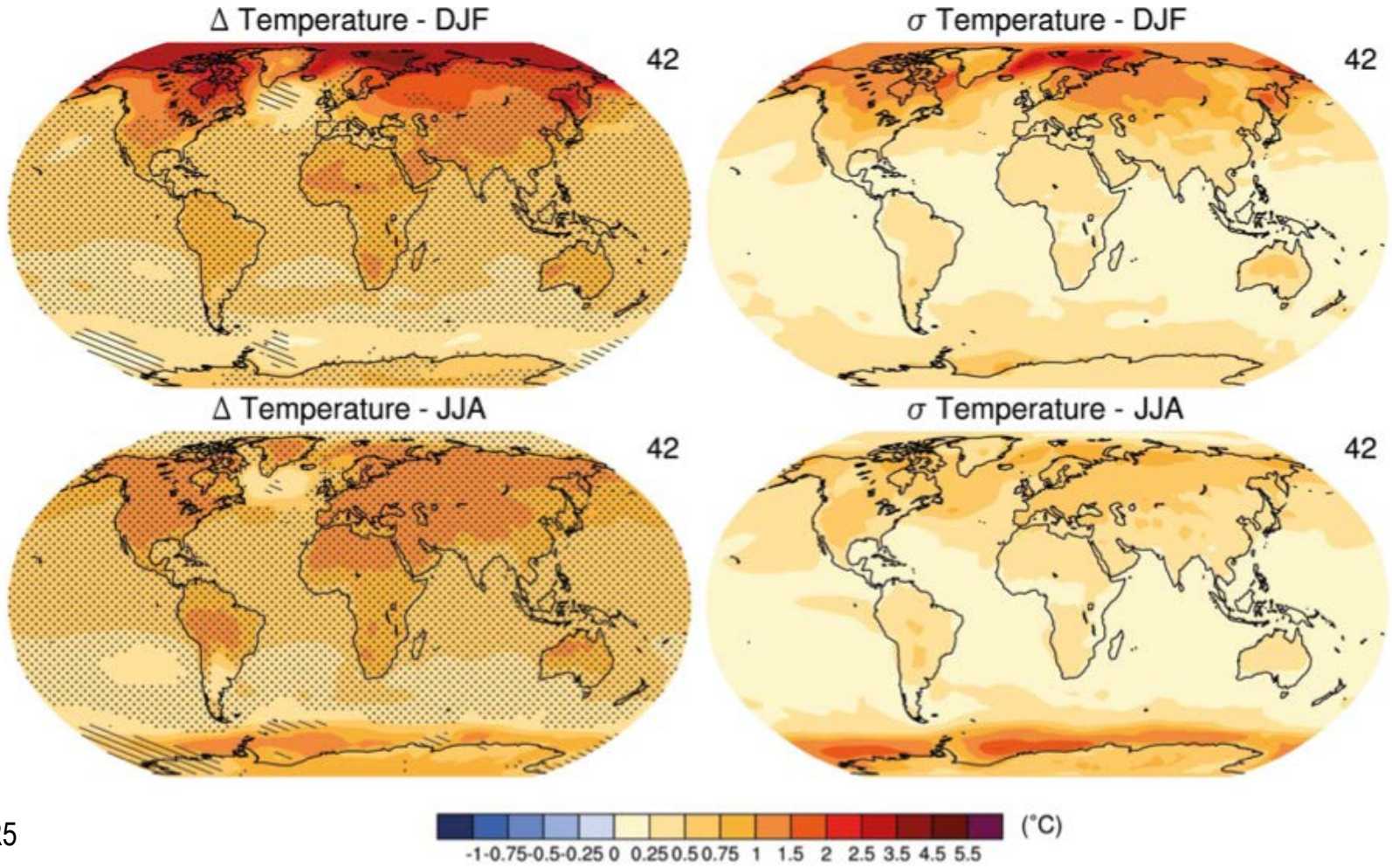
EXTRA SLIDES WE’RE NOT USING


Global mean temperature
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
1960
1970
1980
1990
2000
2010
Year
Individual forecasts
Forecast start time
Observed
Individual simulations
Ensemble mean forecast
Ensemble mean simulation


Forced boundary condition problem
Decadal predictions
Initial value problem
day
week
month
season
year
decade
century
Weather predictions
Seasonal to interannual predictions
Long term climate change projections


(a)
Sources of uncertainty in projected global mean temperature
Observations (3 datasets)
Internal variability
Model spread
RCP scenario spread
Historical model spread
Temperature change relative to 1986–2005 [K]
Year
(b)
Regional decadal mean temperature
Signal–to–uncertainty ratio
Global
Europe
Australasia
North America
South America
Africa
East Asia
Year
(c)
Uncertainty in Global decadal mean ANN temperature
Fraction of total variance [%]
Year
(d)
Uncertainty in Europe decadal mean DJF temperature
Fraction of total variance [%]
Year
(e)
Uncertainty in East Asia decadal mean JJA precipitation
Fraction of total variance [%]
Year
(f)
Uncertainty in Europe decadal mean DJF precipitation
Fraction of total variance [%]
Year

Seasonal mean air temperature change (RCP4.5: 2016-2035)



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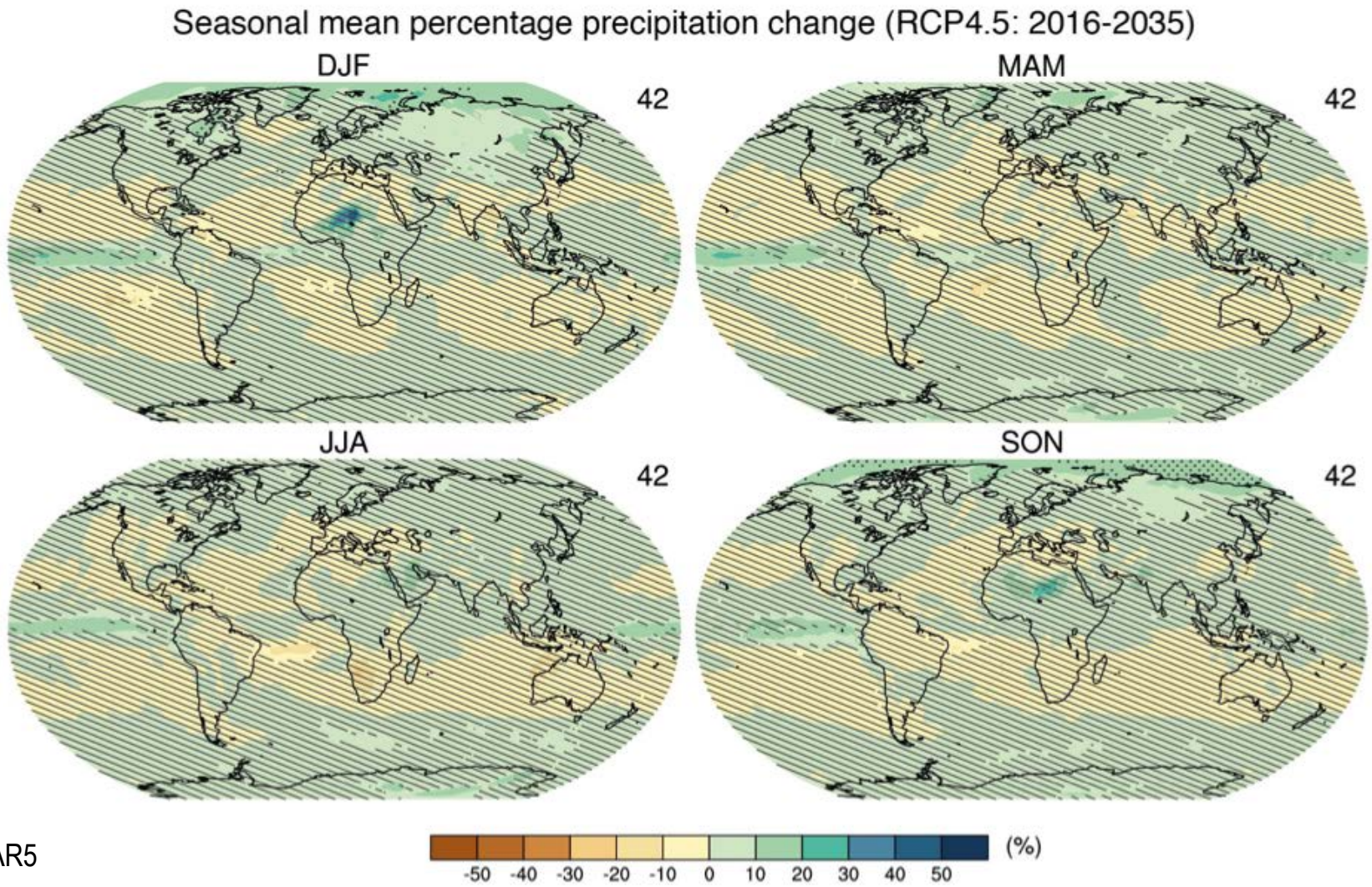

Seasonal mean percentage precipitation change (RCP4.5: 2016-2035)
DJF
MAM
JJA
SON
42
42
42
42
(%)
-50 -40 -30 -20 -10 0 10 20 30 40 50

IPCC AR5

So...how “good” are weather and climate predictions?

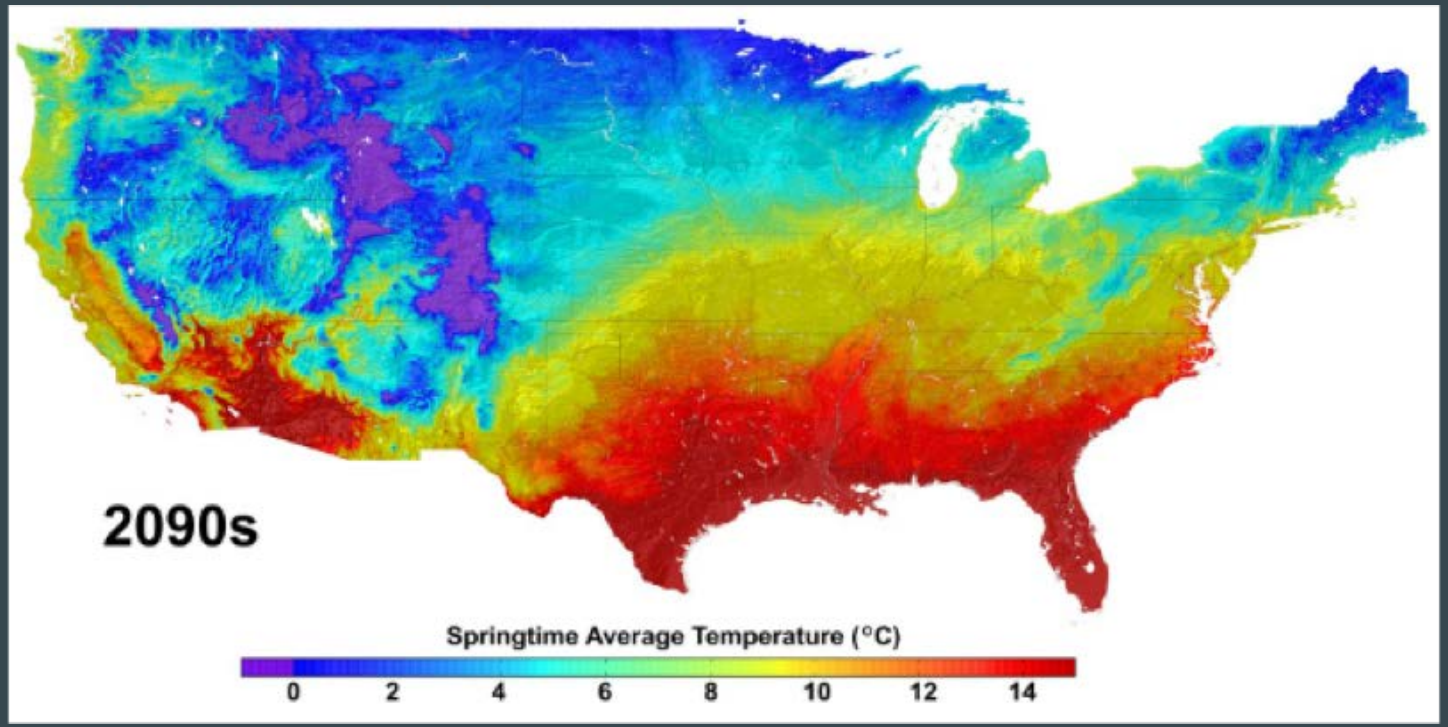
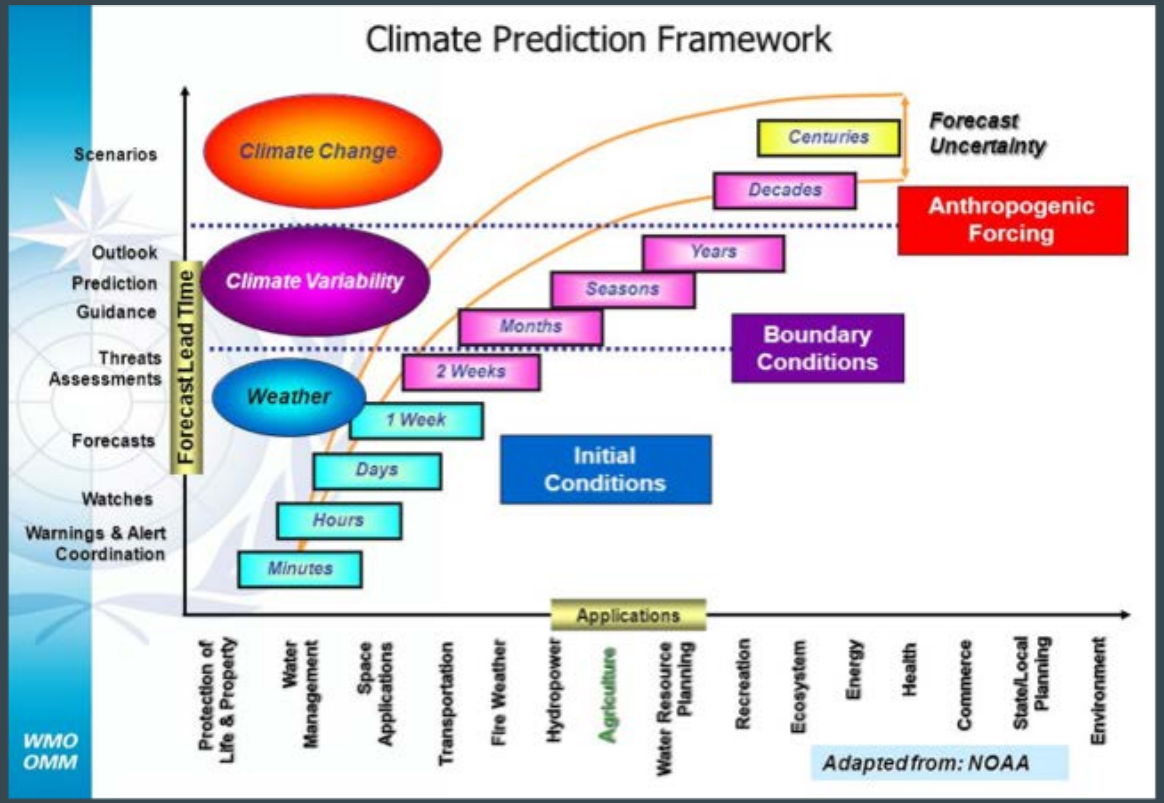


Image: https://www.nasa.gov/sites/default/files/images/NEXAmazonPR-600px.jpg

What About Climate?



Images:
http://slideplayer.com/slide/1447561/4/images/13/Climate+Prediction+Framework.jpg