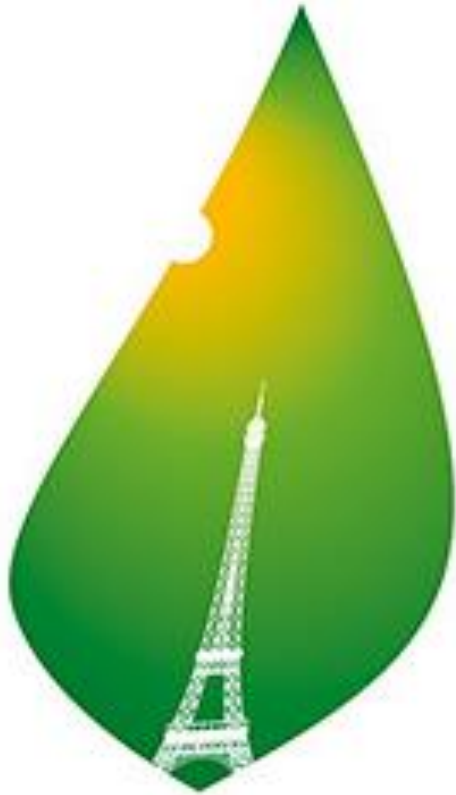


Kantelpunten in het klimaat: is twee graden te veel?



dr. Robbin Bastiaansen
Nationale Wiskunde Dagen (9 april 2022)



COP21 • CMP11

PARIS 2015

UN CLIMATE CHANGE CONFERENCE

Klimaatconferentie Parijs 2015

Akkoord van Parijs:

→ Beperk opwarming tot 2°C



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Klimaatconferentie Parijs 2015

Akkoord van Parijs:

→ Beperk opwarming tot **1.5°C**

A large glacier wall with a massive ice chunk falling into the water. The glacier is a deep blue color, and the water is dark blue. The ice chunk is falling from the center of the glacier wall, creating a large splash of white water. The text "INHOUD VOORDRACHT" is overlaid in the bottom right corner.

**INHOUD
VOORDRACHT**

Planning

1. Klimaatveranderingen – gevolgen
2. Klimaatmodellen – algemeen
3. Klimaatmodellen – simpele voorbeelden
4. Waarom is voorspellen zo moeilijk?

dr. Robbin Bastiaansen

tot 2019:

PhD @ Universiteit Leiden

Onderzoek naar verwoestijning en patroonvorming

Sinds 2020:

PostDoc @ Universiteit Utrecht

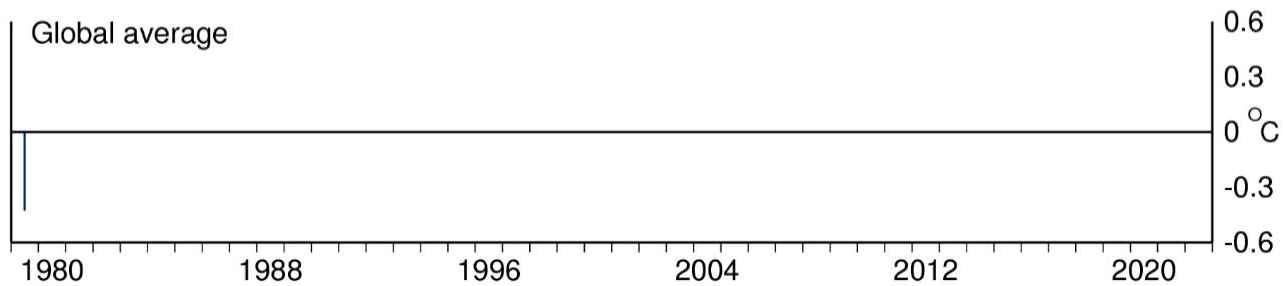
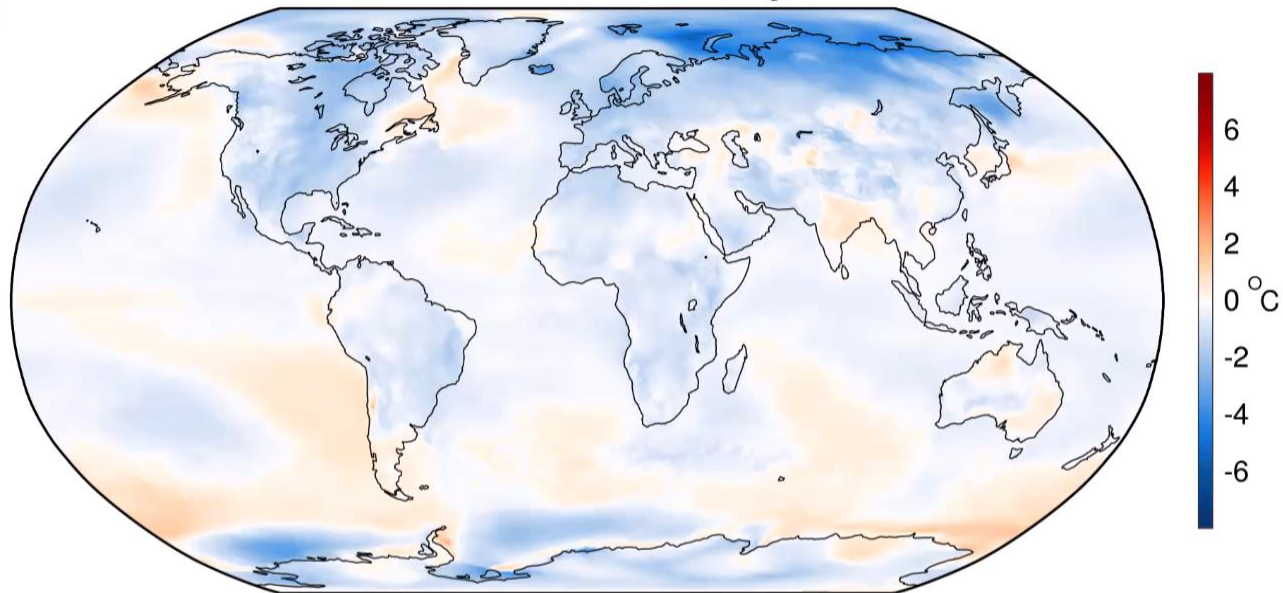
Onderzoek naar klimaatgevoeligheid



KLIMAATVERANDERING



Surface air temperature averaged from 197901 to 197912
relative to its 1991-2020 average



A firefighter in a dark uniform and a yellow helmet stands in a forest at night. The scene is filled with a dense shower of bright orange sparks falling from above, likely from a fire. The background shows silhouettes of trees and a utility pole. The overall atmosphere is one of intense heat and danger.

GEVOLGEN VAN KLIMAATVERANDERING

Extreme hagel in Spanje



Voorbeelden uit 2021

Extreme hitte Canada & VS



Bosbranden Zuid-Europa & Turkije



Overstromingen Limburg



Voorspellingen

- Meer zware neerslag
- Langere perioden van droogte
- Meer en intensere bosbranden
- Zeespiegelstijging
- Verzilting van water
- Meer stormen en orkanen
- Hogere landbouwopbrengsten

The Rodney & Otamatea Times

WAITEMATA & KAIPARA GAZETTE.

PRICE—10s per annum in advance

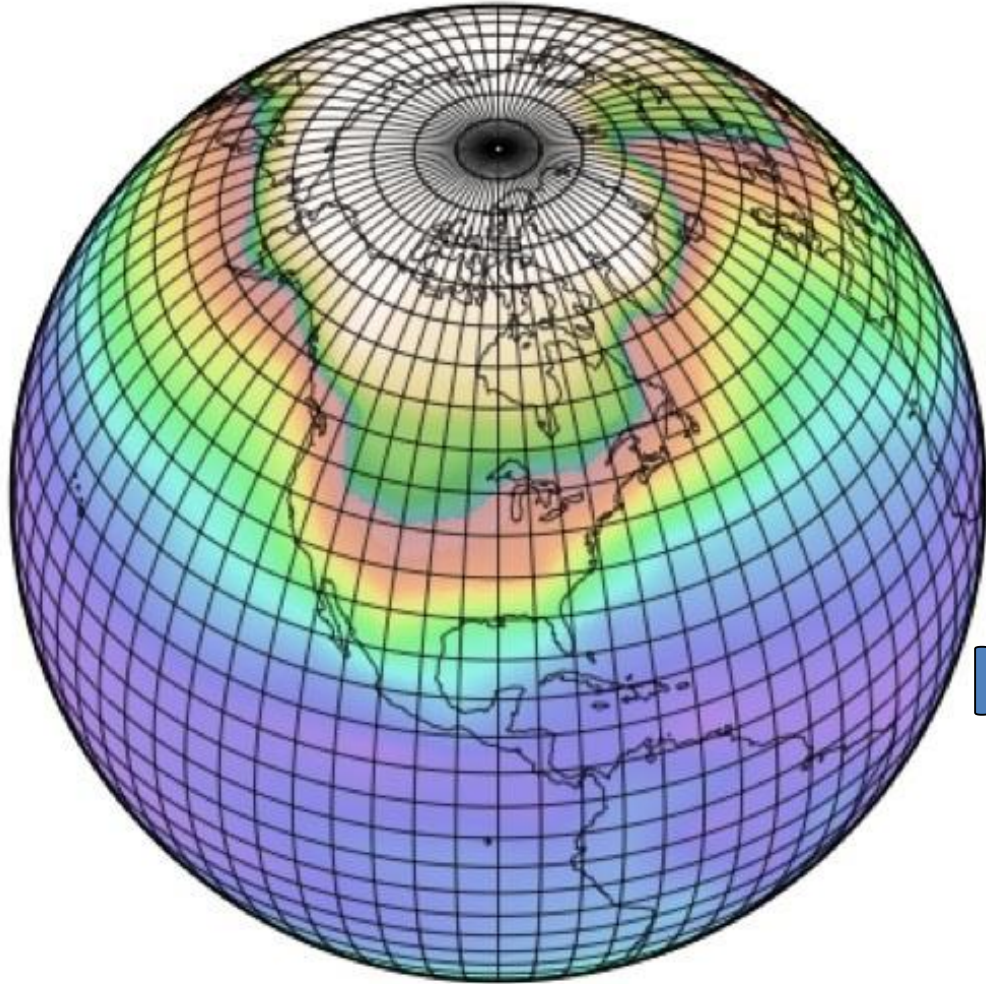
WARKWORTH, WEDNESDAY, AUGUST 14, 1912.

3d per Copy.

Science Notes and News.

COAL CONSUMPTION AFFECTING CLIMATE.

The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.



KLIMAATMODELLEN

Wiskundige modellen


\boldsymbol{x} : toestand van het systeem

Dynamisch systeem:

$$\frac{d\boldsymbol{x}(t)}{dt} = f(\boldsymbol{x}(t), t)$$

Type modellen

(beoogd)
niveau
van
realisme



GCMs (Global Climate Models)

- veel effecten
- kwantitatieve uitspraken
- moeilijk te doortasten

Conceptuele modellen

- alleen essentiële effecten
- kwalitatieve uitspraken
- (vaak) analytisch handelbaar
- geeft inzicht in essentie

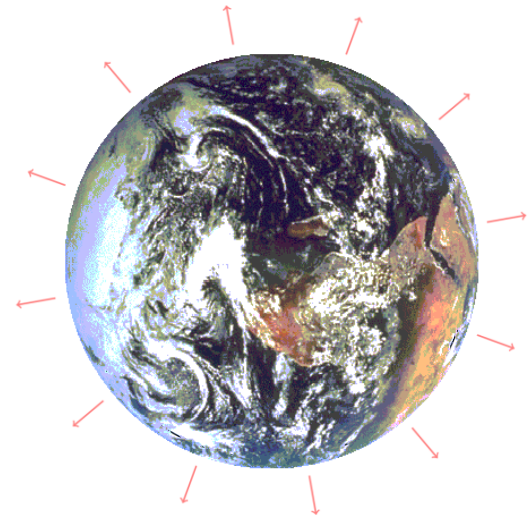
**KERN VAN DE
MOEILIKHEID**



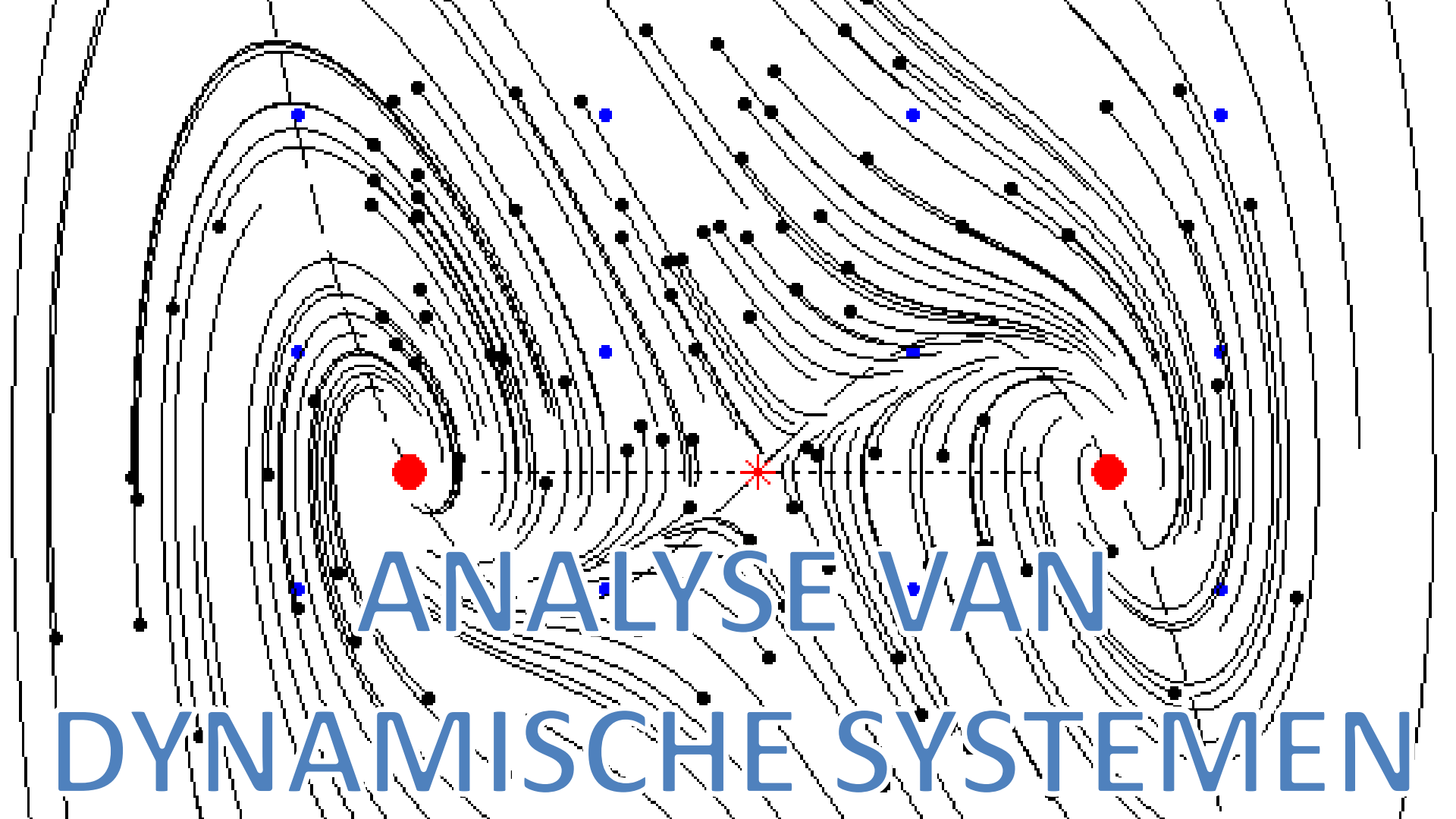
Niet-lineaire terugkoppeling



- veel ijs/sneeuw
- veel weerkaatsing zonlicht



- weinig ijs/sneeuw
- weinig weerkaatsing zonlicht



ANALYSE VAN

DYNAMISCHE SYSTEMEN

Dynamische systemen – de basis

$$x \in \mathbb{R}$$

$$\frac{dx}{dt} = f(x, t)$$

Dynamische systemen – de basis

$$x \in \mathbb{R}$$

$$\frac{dx}{dt} = f(x, t)$$

f alleen afhankelijk van *t*

$$\frac{dx}{dt} = f(t)$$

$$\int_{x(0)}^{x(t)} dx' = \int_0^t f(t') dt'$$

$$\rightarrow x(t) = x(0) + \int_0^t f(t') dt'$$

Dynamische systemen – de basis

$$x \in \mathbb{R}$$
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f alleen afhankelijk van *x*

$$\frac{dx}{dt} = f(t)$$
$$\int_{x(0)}^{x(t)} dx' = \int_0^t f(t') dt'$$
$$\rightarrow x(t) = x(0) + \int_0^t f(t') dt'$$

$$\frac{dx}{dt} = f(x)$$
$$\int_{x(0)}^{x(t)} \frac{dx'}{f(x')} = \int_0^t dt'$$
$$\rightarrow x(t) = \dots ?$$

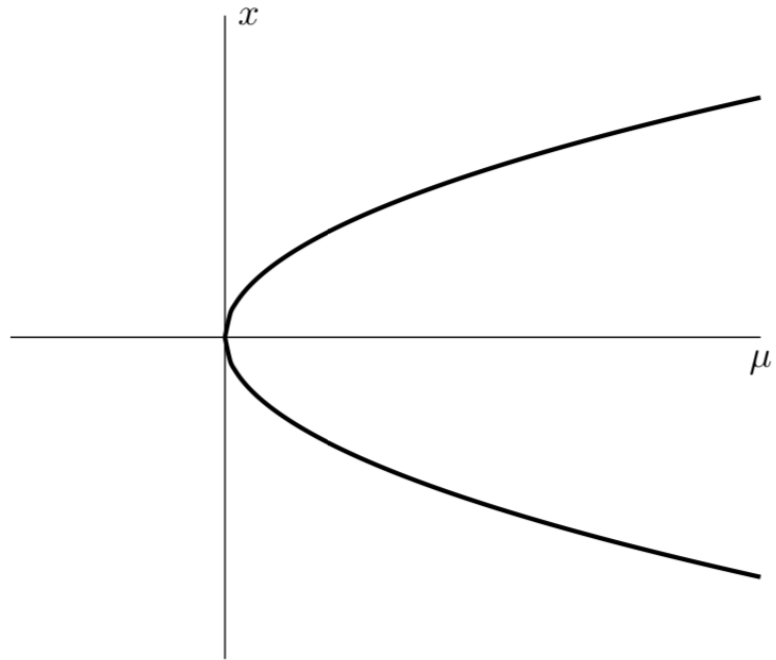
$$\frac{dx}{dt} = f(x) := \mu - x^2$$

$$\frac{dx}{dt} = f(x) := \mu - x^2$$

1. Vaste Punten

$$\frac{dx_*}{dt} = 0 = f(x_*) = \mu - x_*^2$$

$$\rightarrow x_* = \pm\sqrt{\mu}$$



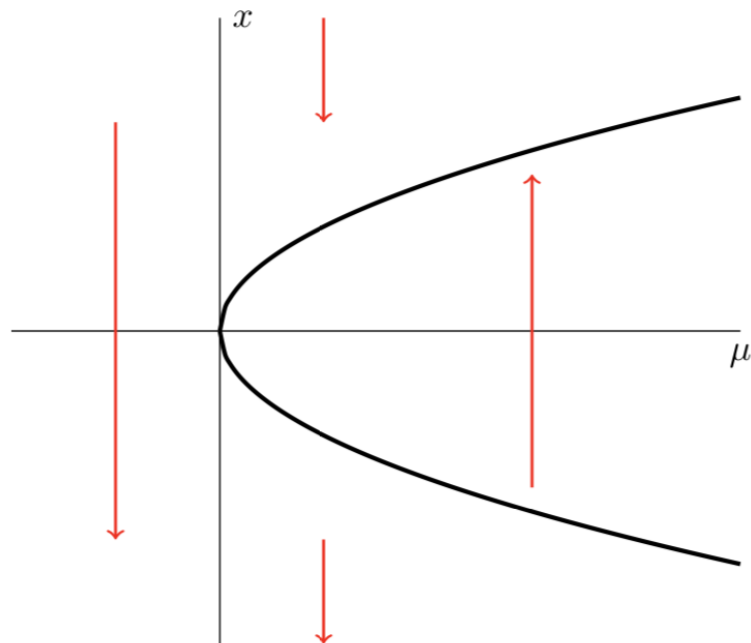
$$\frac{dx}{dt} = f(x) := \mu - x^2$$

1. Vaste Punten

$$\frac{dx_*}{dt} = 0 = f(x_*) = \mu - x_*^2$$

$$\rightarrow x_* = \pm\sqrt{\mu}$$

2. Stabiliteit



$$\frac{dx}{dt} = f(x) := \mu - x^2$$

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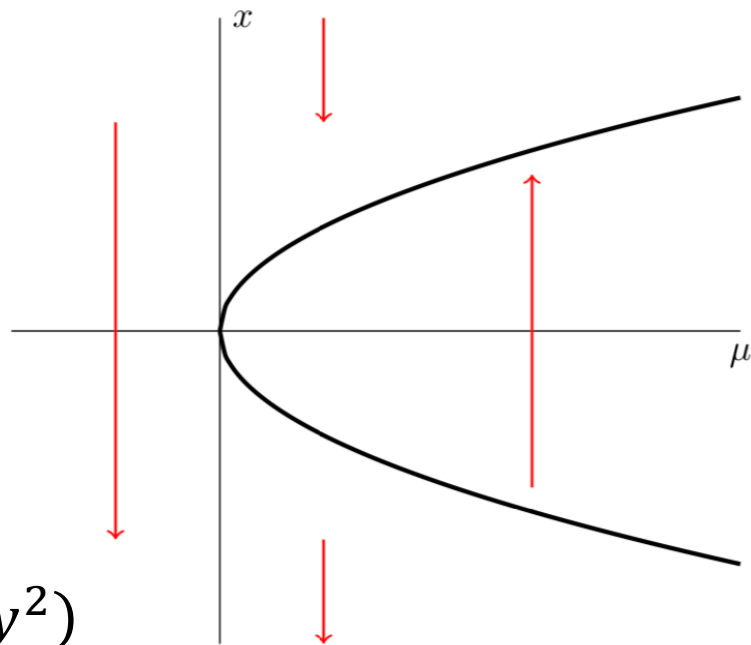
2. Stabiliteit

Kleine verstoring $x = x_* + y$

$$\rightarrow \frac{d(x_* + y)}{dt} = f(x_* + y)$$

$$\rightarrow \frac{dy}{dt} = f(x_*) + f'(x_*)y + \mathcal{O}(y^2)$$

$$\rightarrow \frac{dy}{dt} = f'(x_*)y$$



$$\frac{dx}{dt} = f(x) := \mu - x^2$$

1. Vaste Punten

$$\frac{dx_*}{dt} = 0 = f(x_*) = \mu - x_*^2$$

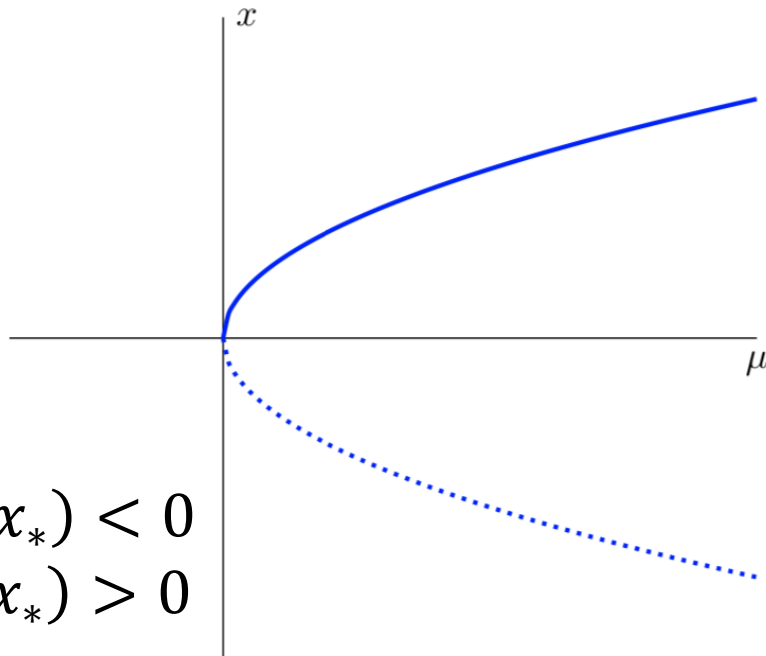
$$\rightarrow x_* = \pm\sqrt{\mu}$$

2. Stabiliteit

$$f'(x_*) = -2x_* = \mp 2\sqrt{\mu}$$

Stabiel (aantrekkend) $\Leftrightarrow \lambda := f'(x_*) < 0$

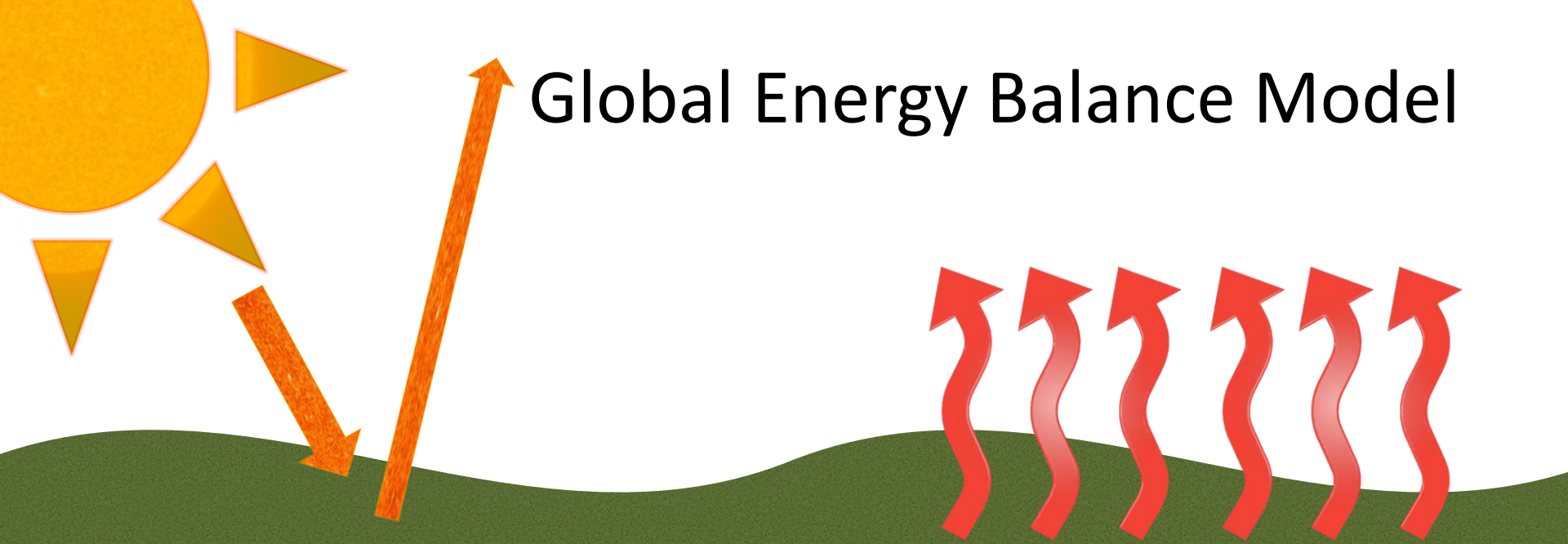
Instabiel (afstotend) $\Leftrightarrow \lambda := f'(x_*) > 0$





**VOORBEELD:
ICE-ALBEDO FEEDBACK**

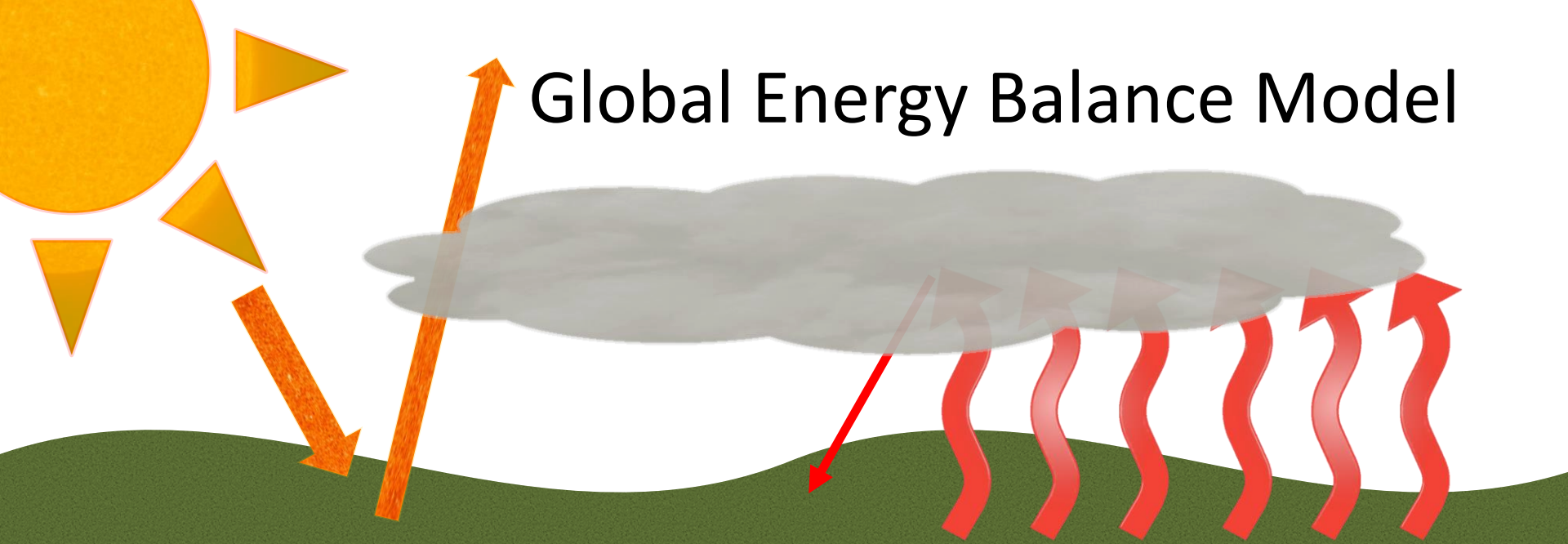
Global Energy Balance Model



opwarming = zonlicht - weerkaatst zonlicht - straling

$$\frac{dT}{dt} = 1 - \alpha(T) - T^4$$

Global Energy Balance Model

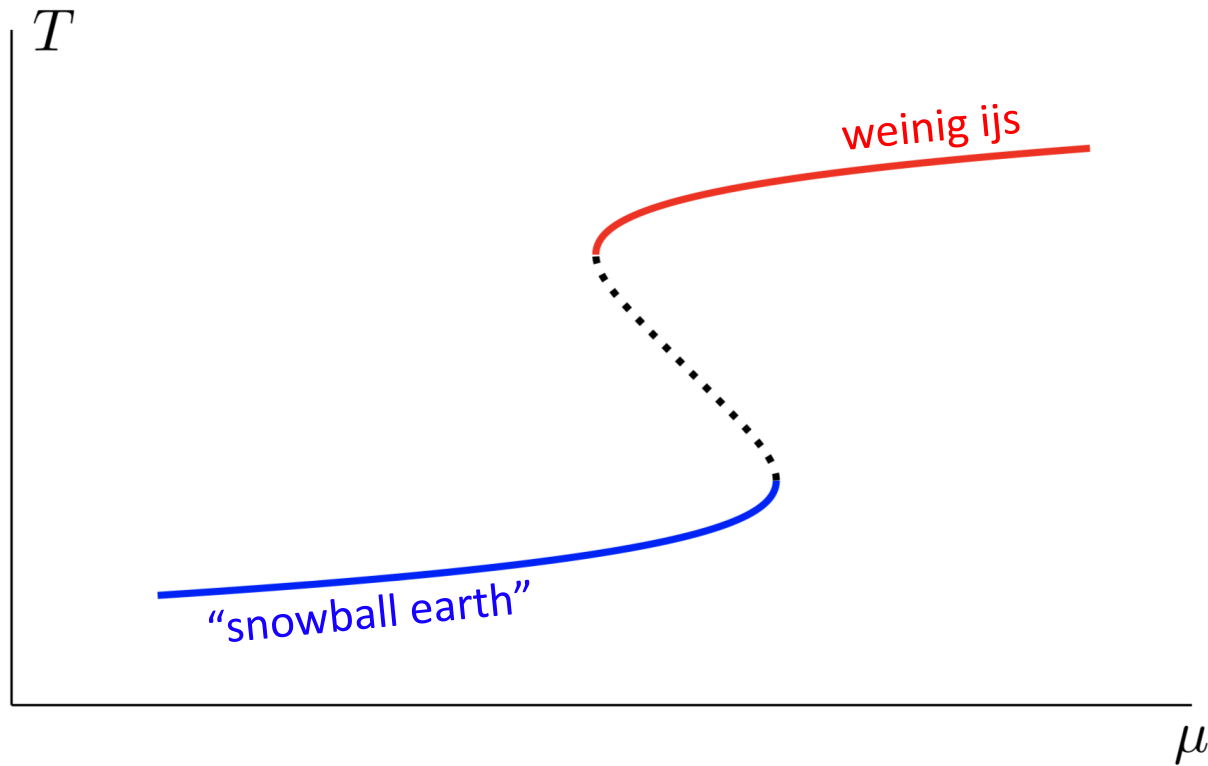


$$\frac{dT}{dt} = 1 - \alpha(T) - T^4 + \mu$$

$$\text{opwarming} = \frac{dT}{dt} = 1 - \alpha(T) - T^4 + \mu$$

Voor gegeven CO2 (μ)
Hoe warm wordt het?

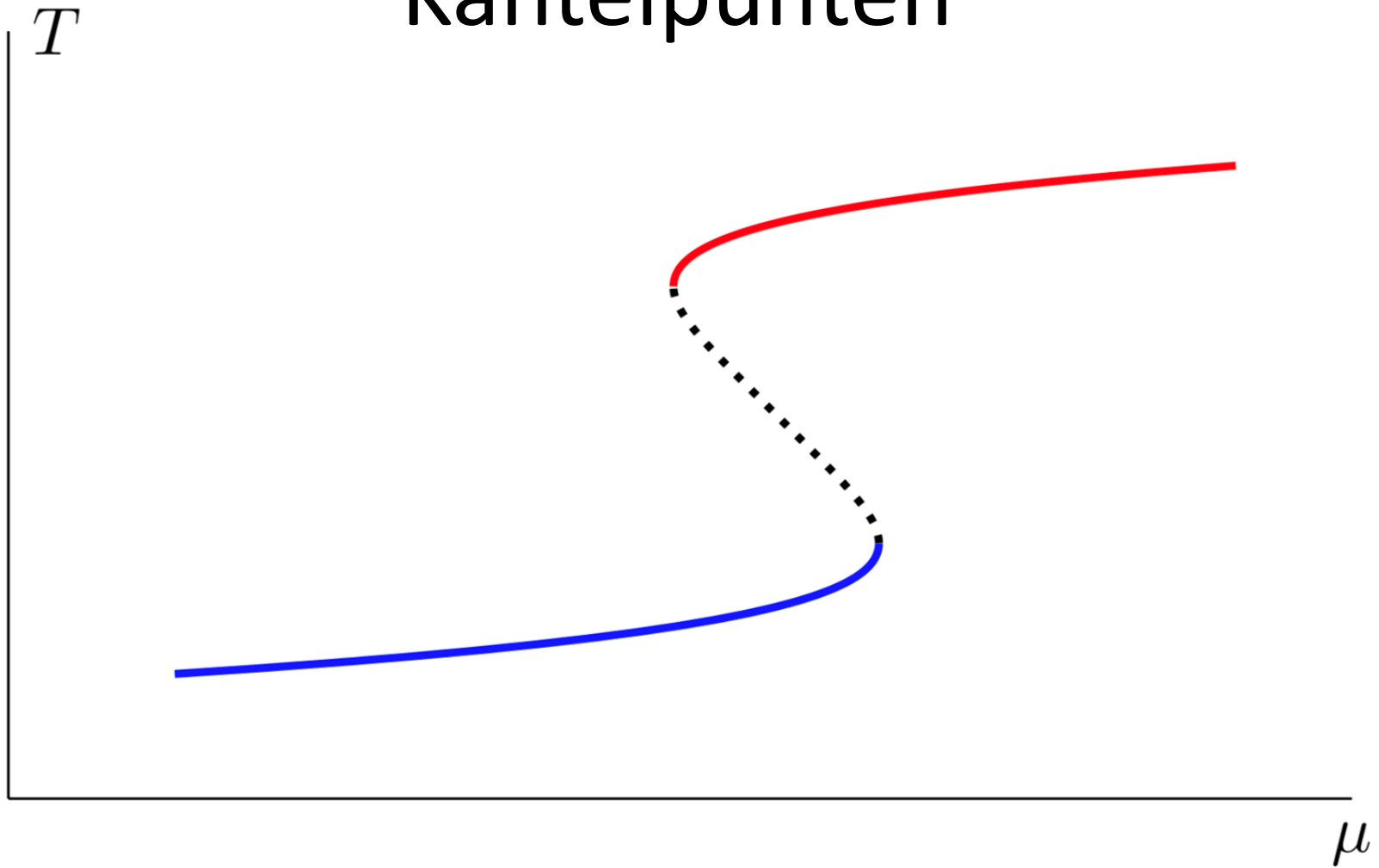
$$0 = 1 - \alpha(T) - T^4 + \mu$$



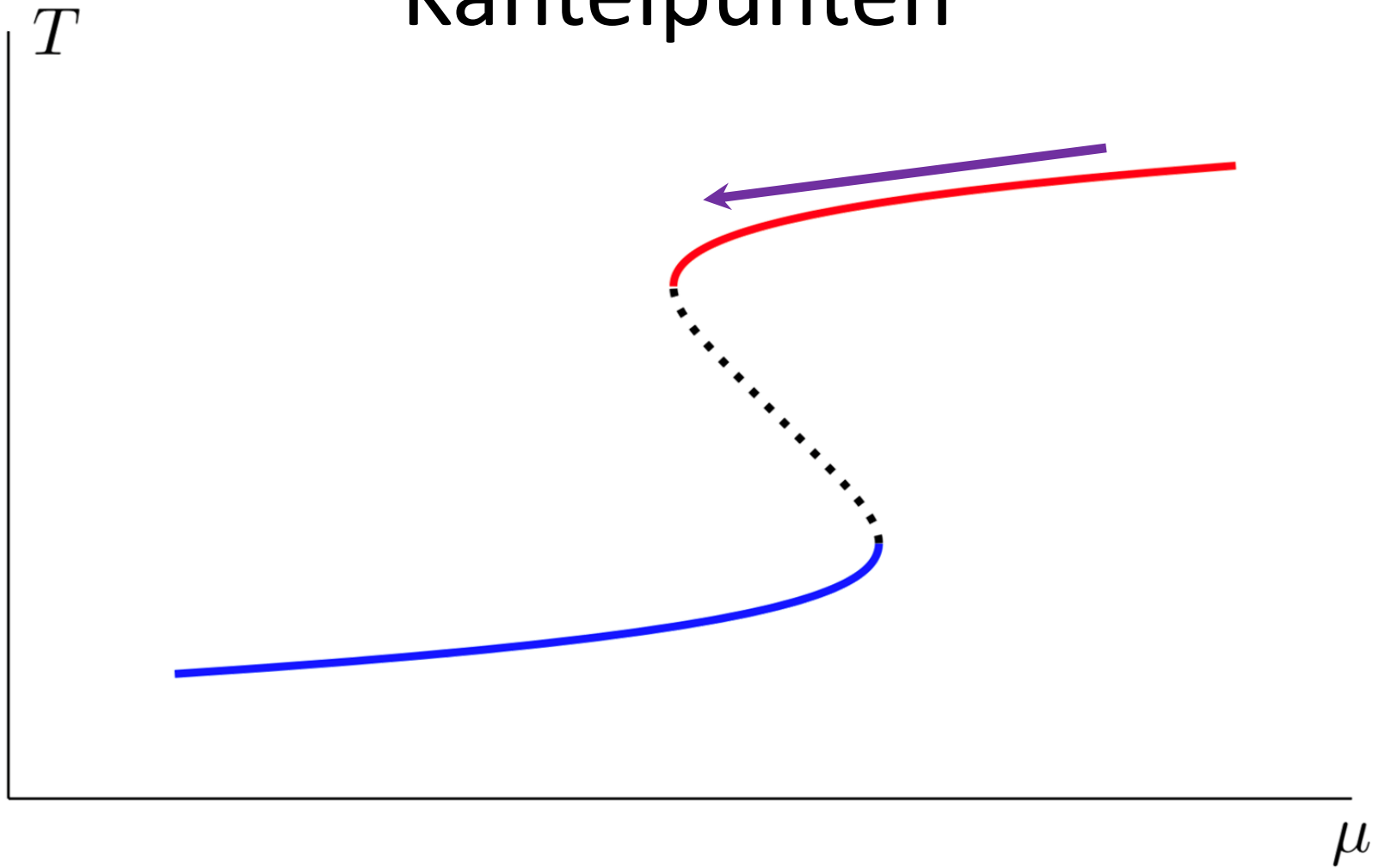
KANTELPUNTEN



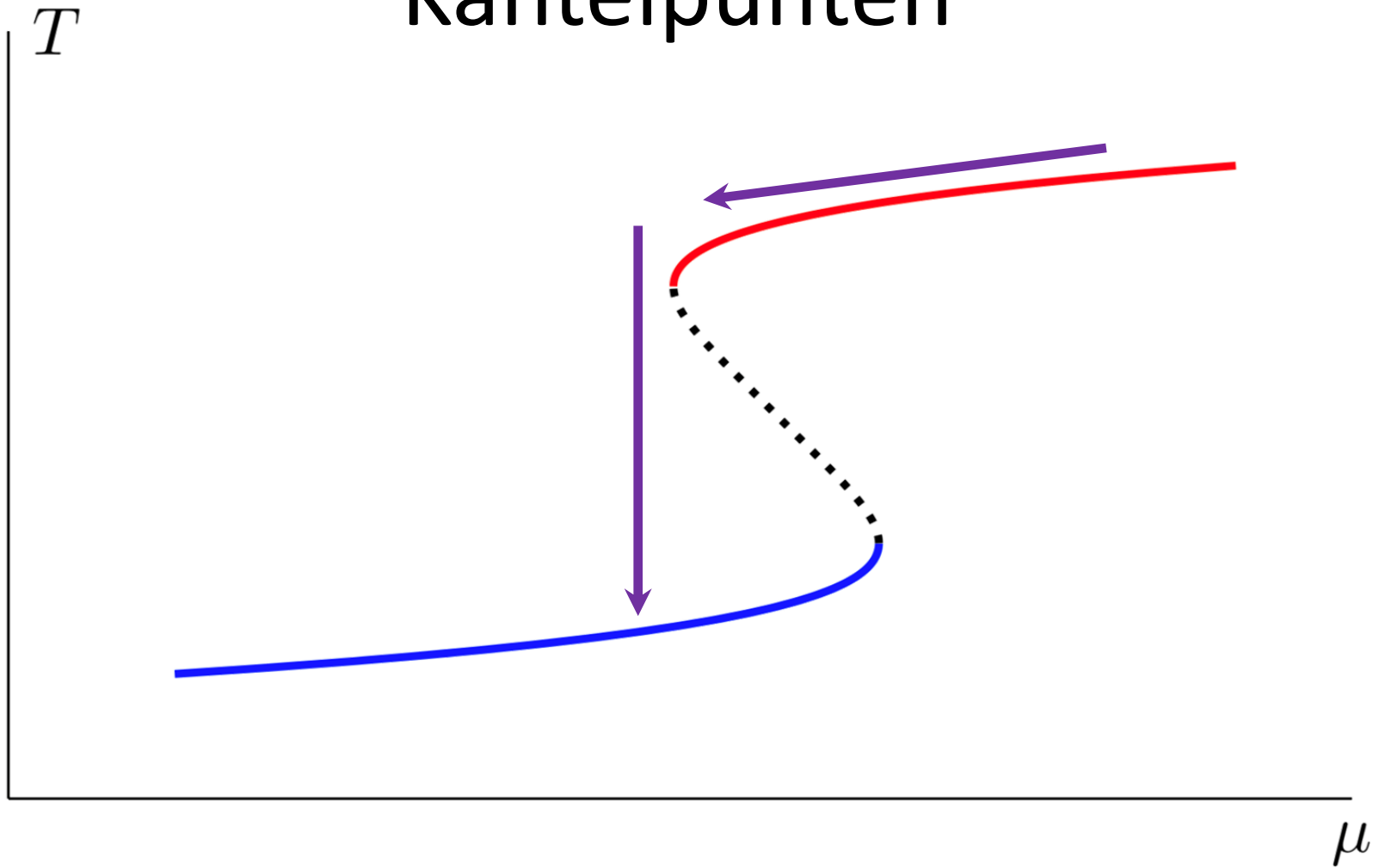
Kantelpunten



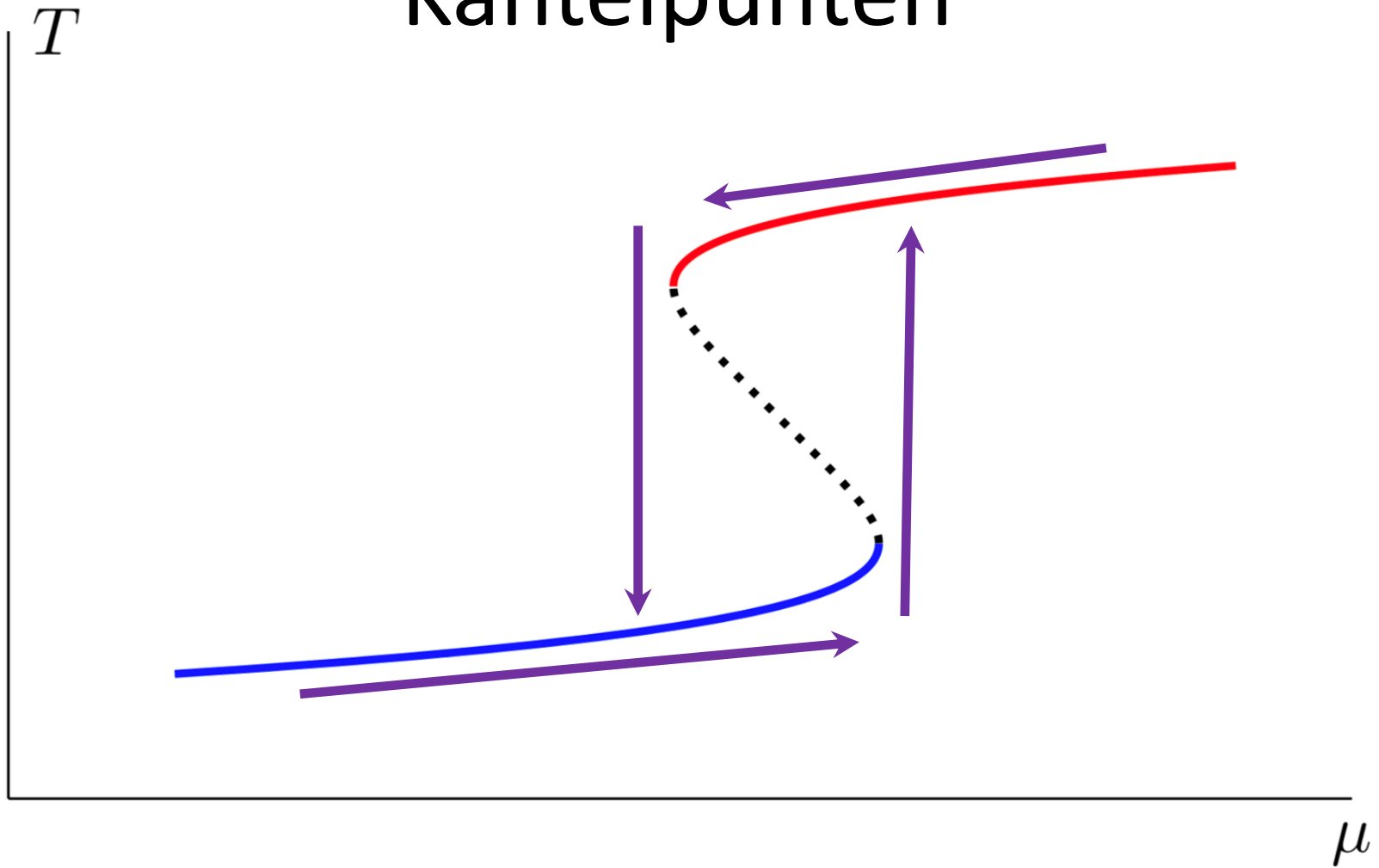
Kantelpunten



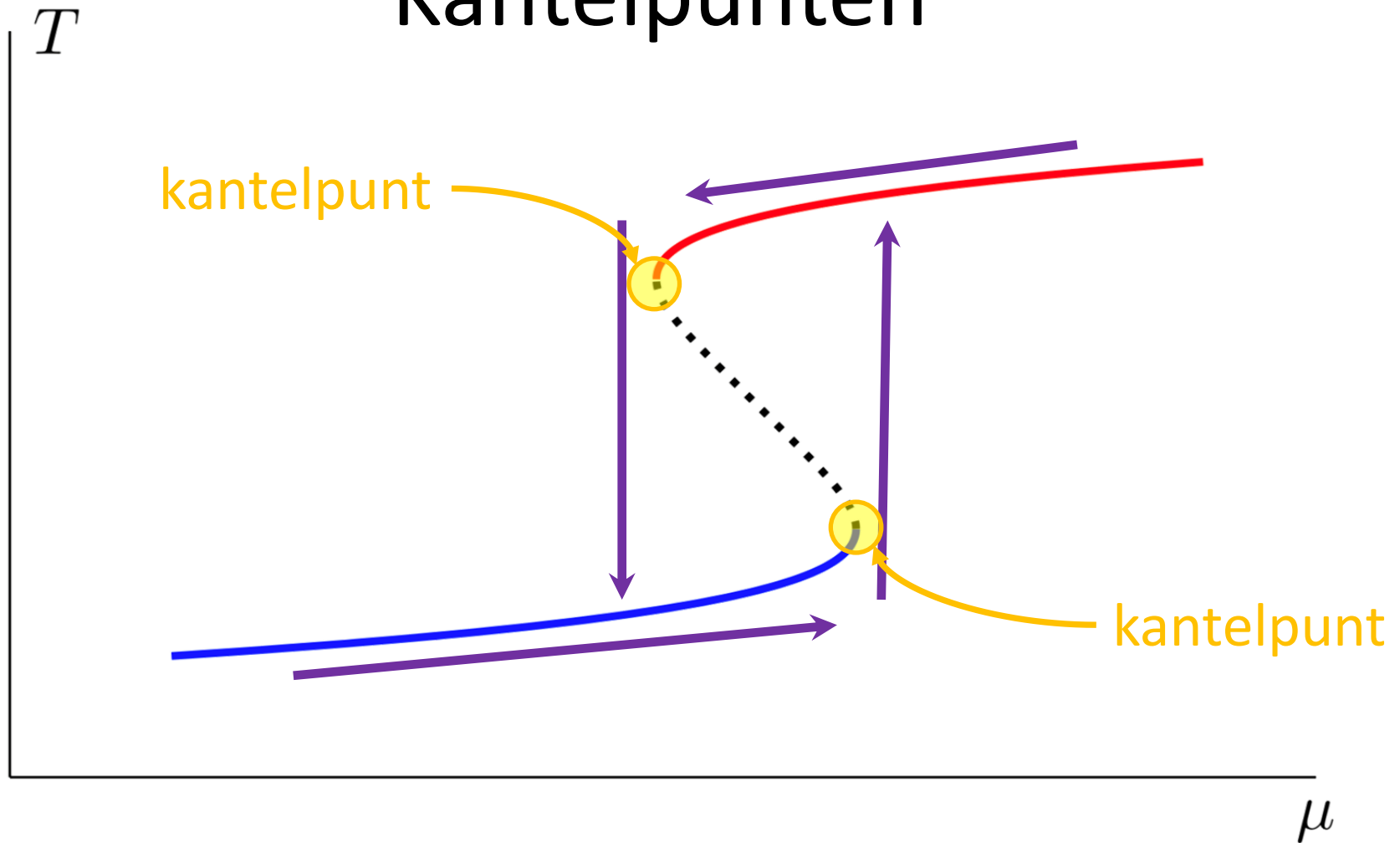
Kantelpunten

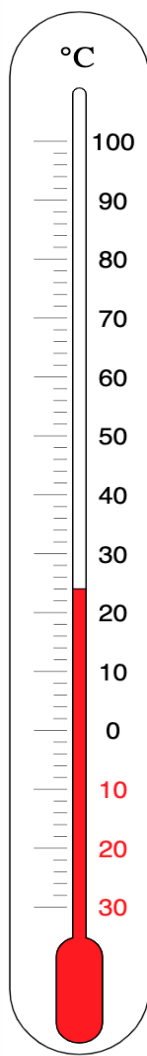


Kantelpunten



Kantelpunten





IS TWEE GRADEN
TE VEEL?

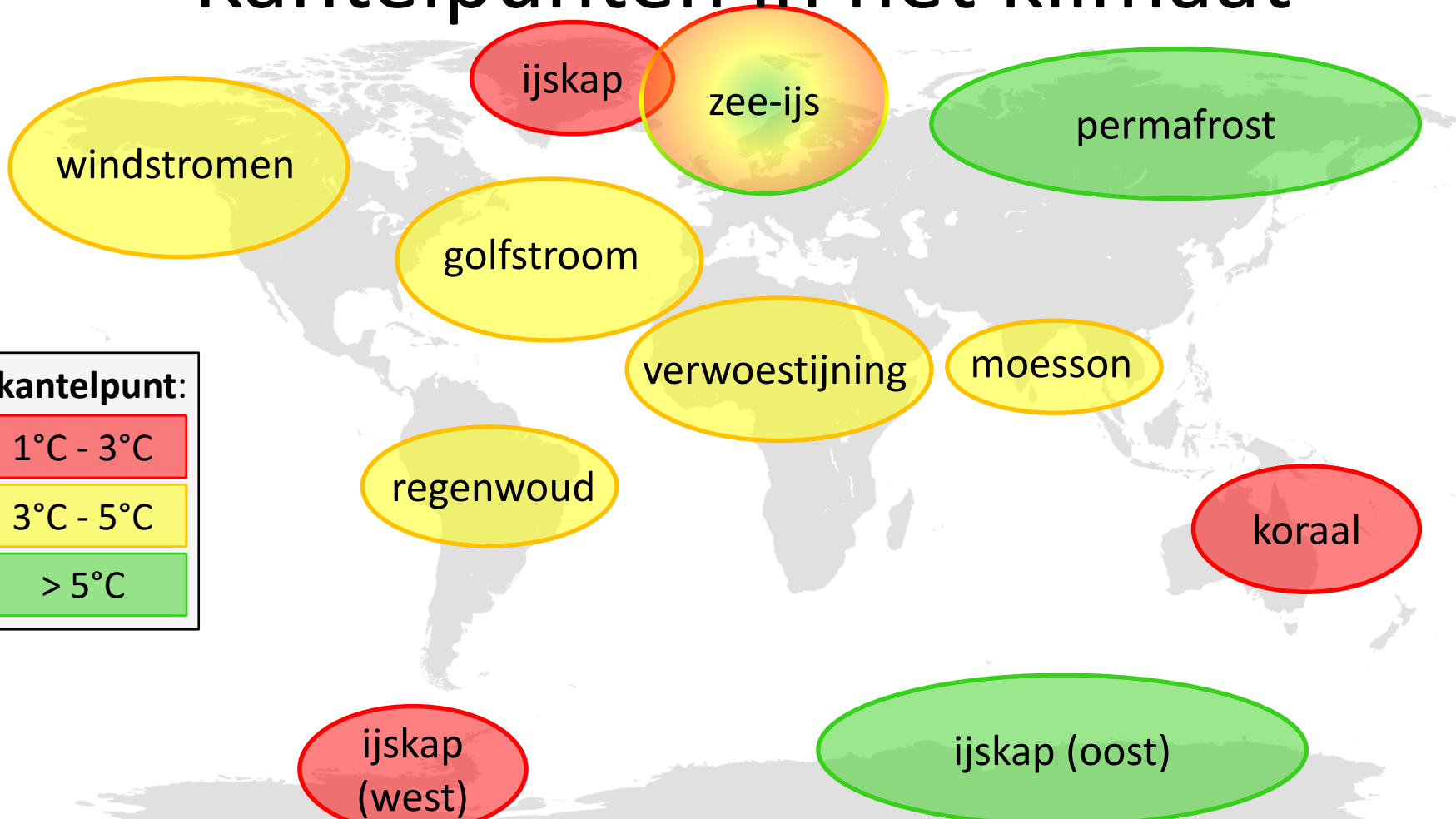
Two graden Celsius



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Klimaatconferentie Parijs 2015:
stijging 2°C: beperkte gevolgen

Kantelpunten in het klimaat



kantelpunt:

1°C - 3°C

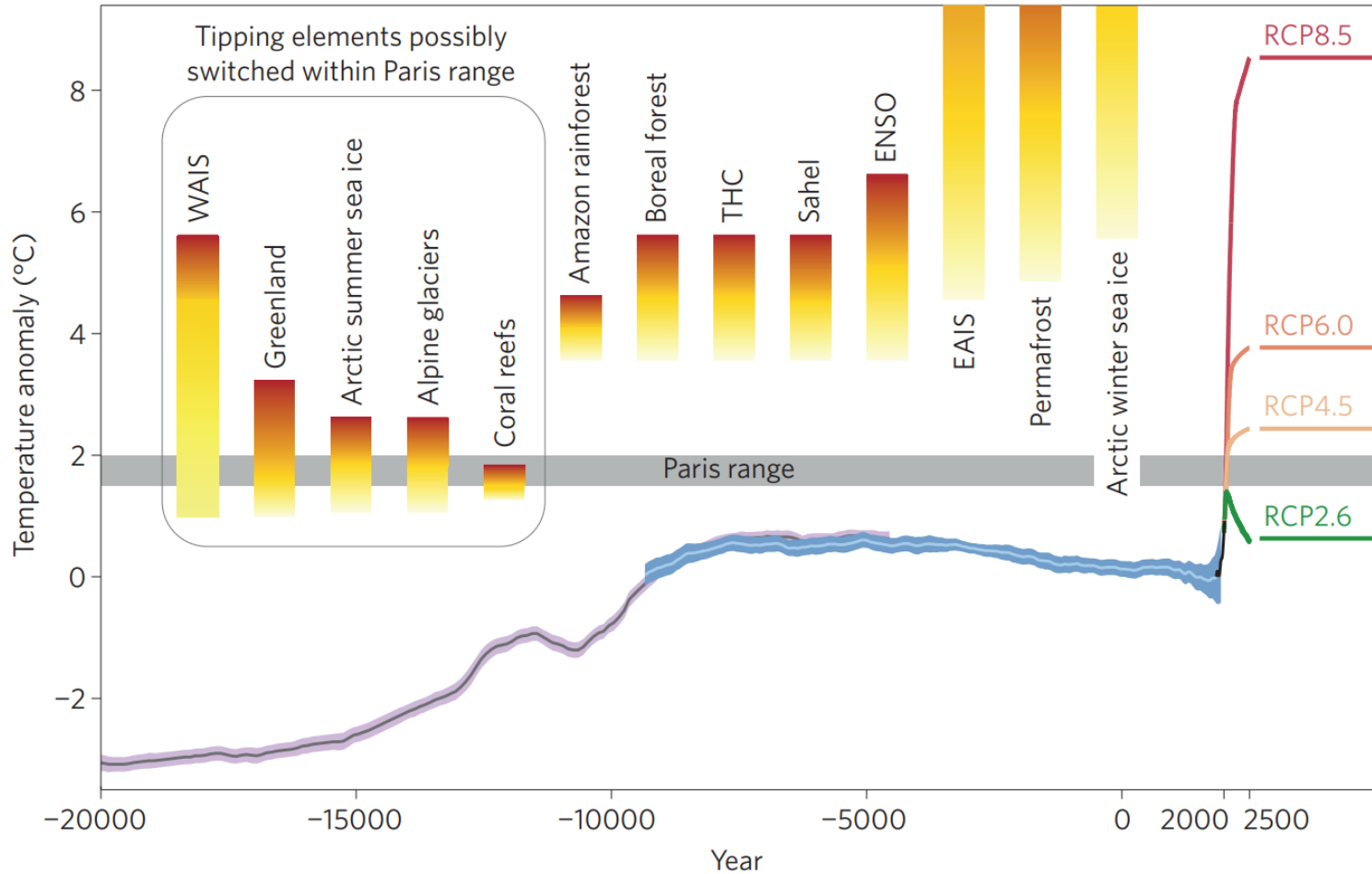
3°C - 5°C

> 5°C

Waarom zo moeilijke vraag?

- kantelpunten vaak pas achteraf duidelijk
- aarde is erg complex
 - veel processen
 - alle schalen van belang
- huidige situatie is uniek
 - snelle verandering

Kantelpunten & klimaatverandering



**Kantelpunten in het klimaat:
is twee graden te veel?**



**Kantelpunten in het klimaat:
is twee graden te veel?**

MISSCHIEN!

A large, rectangular iceberg floats in the center of the frame, its surface covered in snow. The water around it is a deep blue. In the background, there are more icebergs and a range of snow-capped mountains under a clear blue sky.