Using isotopes for understanding the water cycle

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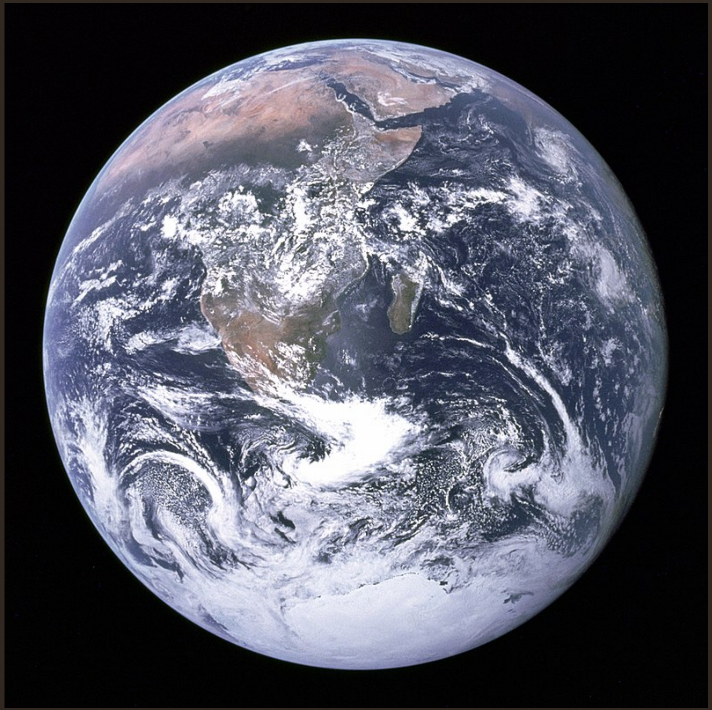

NASA / Apollo 17 crew
7 December 1972

NASA Atmospheric Composition and Modeling
Climate and Large-scale Dynamics
Atmospheric Chemistry
Paleo-perspectives on Climate Change
Climate Program Office

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Using isotopes…

Why bother?

How do it?

1990s (2000s)

Demonstration of sensitivity
“potential”

The forward problem

2020s and beyond

Implementing understanding
“new knowledge”

The inverse problem

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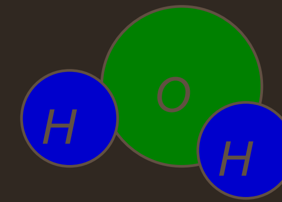
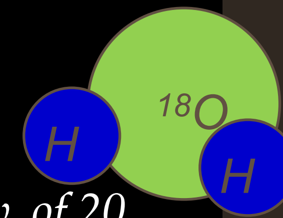
From atoms to planetary scales



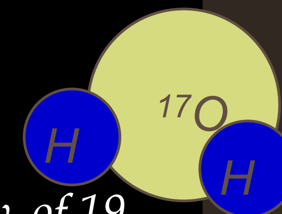
MGM 1937

Normal water, H_2O
(molecular weight of 18)



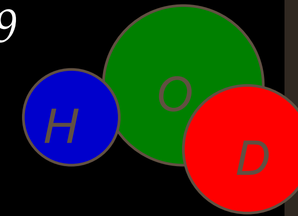
m.w. of 20

$H_2^{18}O$ (~0.2% of all water)
$H_2^{17}O$ (~0.04% of all water)
HDO (~0.031 % of all water)



m.w. of 19

m.w. of 19



Small natural variation in ratio because of the water cycle…

$$\delta = (R/R_{standard} - 1) \times 1000$$

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1913, Thomson (Nobel Prize for electron) and Aston discovers isotopes (Neon), using a new instrument. The mass spectrometer.

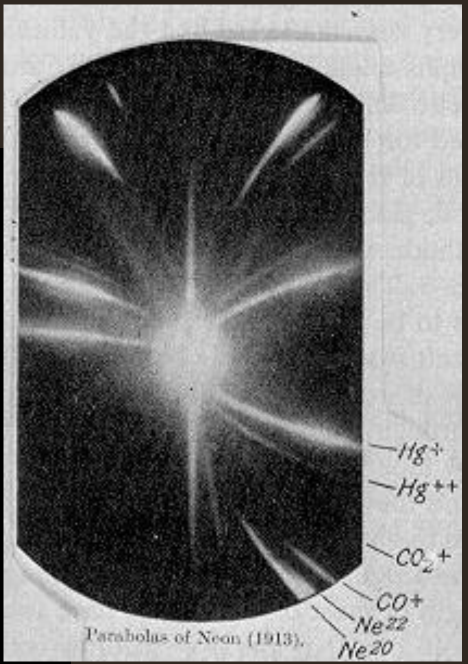
1931, Chadwick wins Nobel Prize for discovering the neutron, providing an explanation.

1934, Urey wins Nobel Prize for discovering "heavy hydrogen" based in part on his work with Bohr in Copenhagen.

WW2 years a lot of interest in "heavy water"

~1947, Neils Bohr Institute obtains a new more precise Isotope Ratio Mass Spectrometer...

… and an inspired student has an idea…



Danish Meteorological Institute Weather Forecast
COPENHAGEN: June 21, 1953. Expect rain.

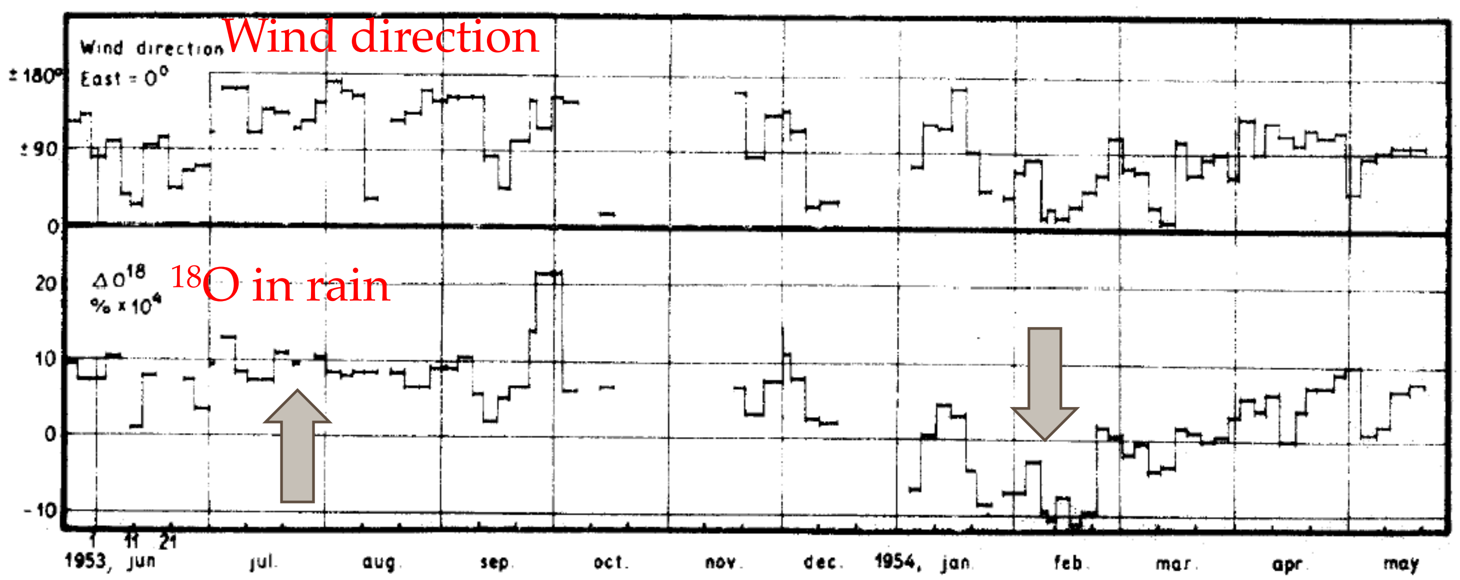


Fig. 2. In the lower part is shown deviations from the Danish standard of the O^{18}-abundance in samples of water vapour collected in 3 to 4 day periods. In the upper part for the same periods is shown the average deviation of the wind from the east point direction.

"…in all essentials …, offers the possibility by measurements of the … amount of the heavy oxygen isotope… *in layers of ice to determine climatic changes over a period of time of several hundred years of the past. "*

The forward problem, suggests the inverse.

Observations => [creative process] => *theory*

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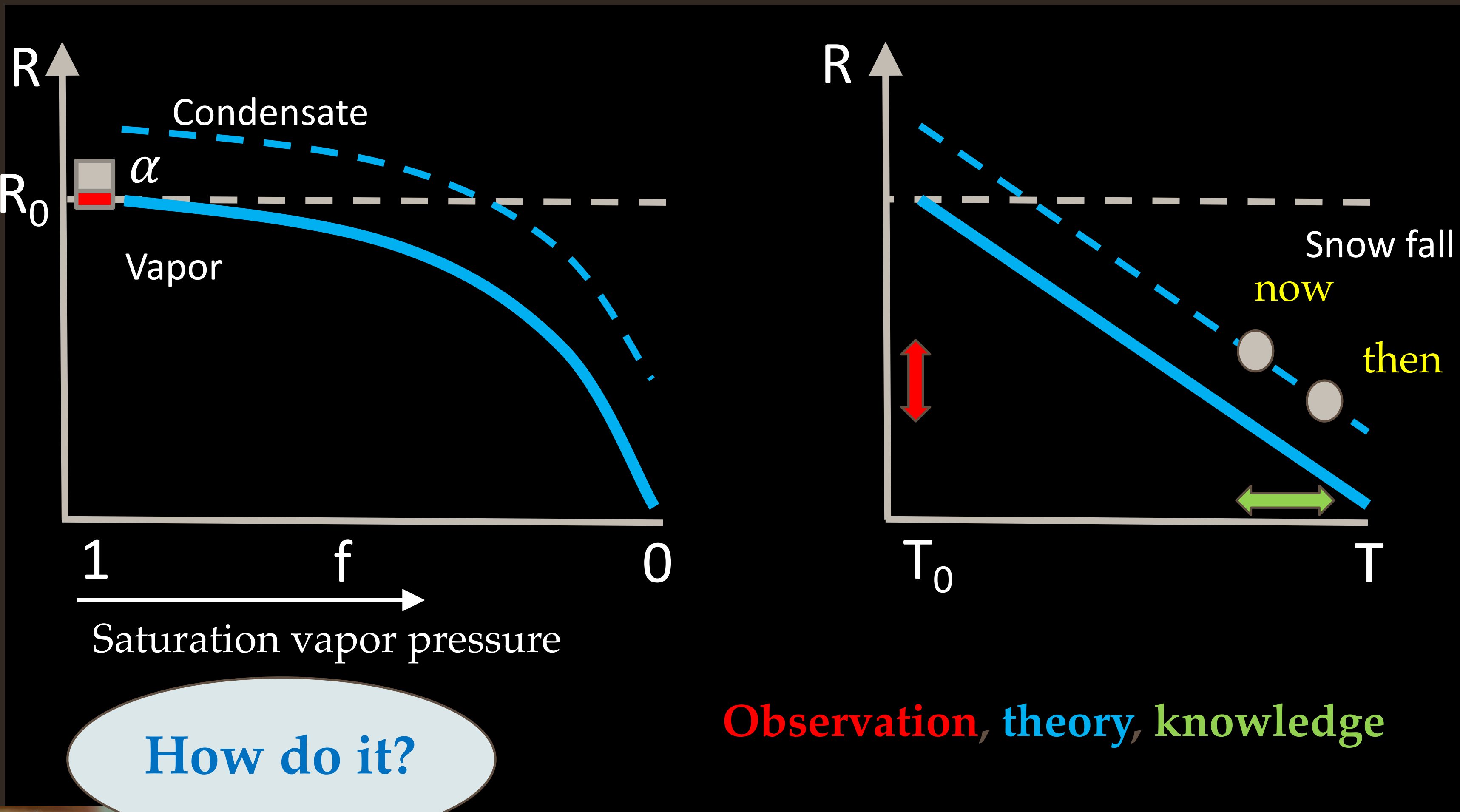
Dansgaard, 1954, 1964

The isotope recipe: e.g., The paleo-thermometer



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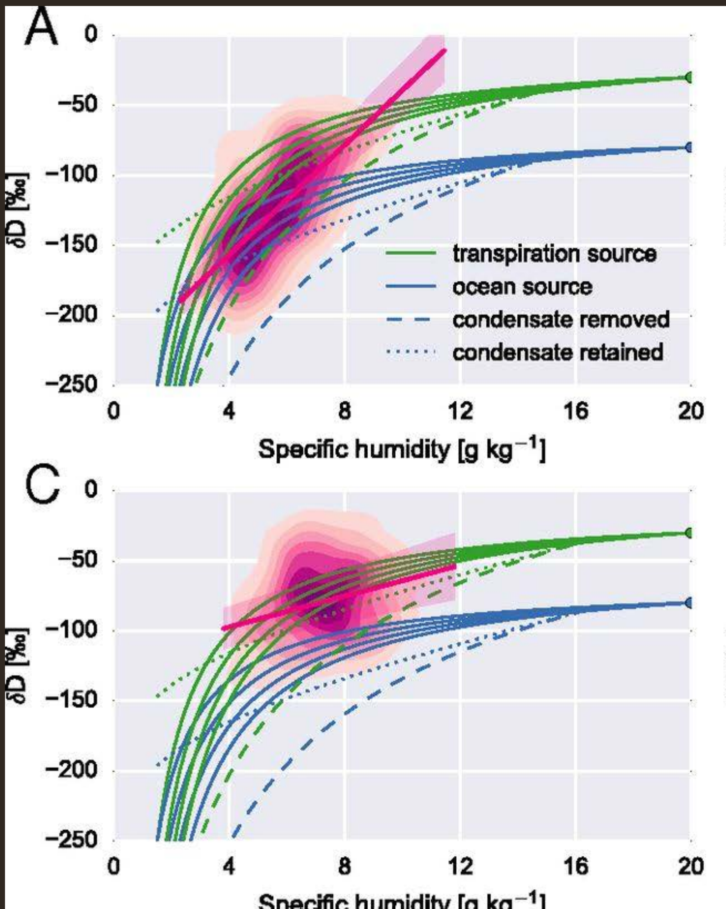
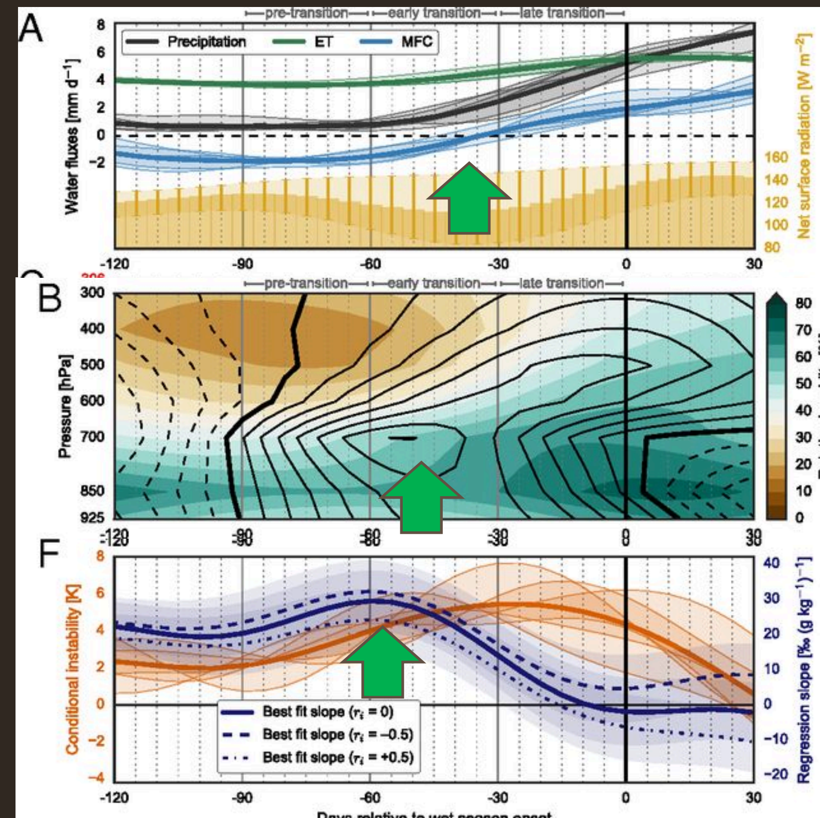
Does (how much) transpiration initiates rain?

Theoretical basis + observations



Application to new knowledge



Wright et al., 2017

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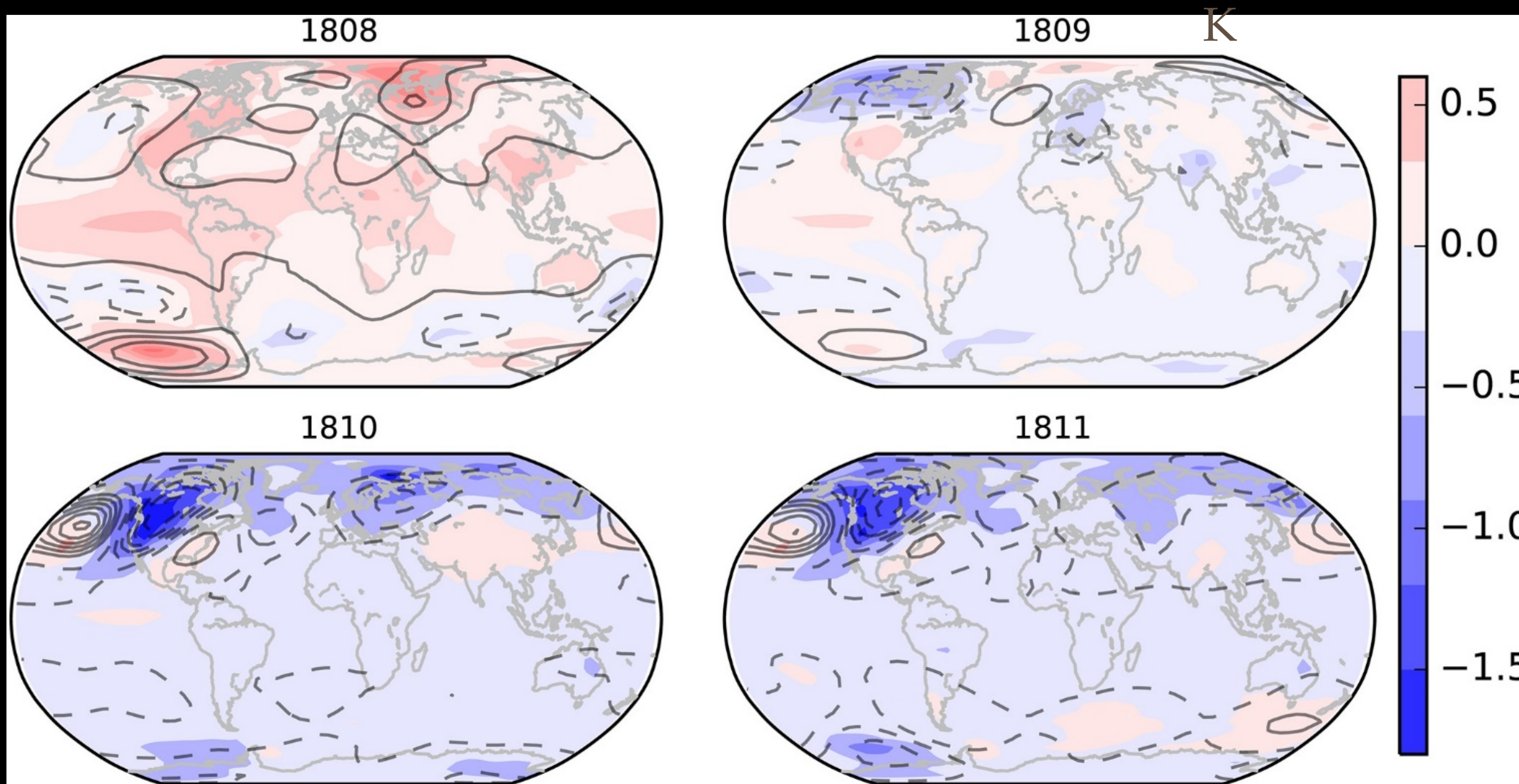
Patterns of past circulation from synthesis

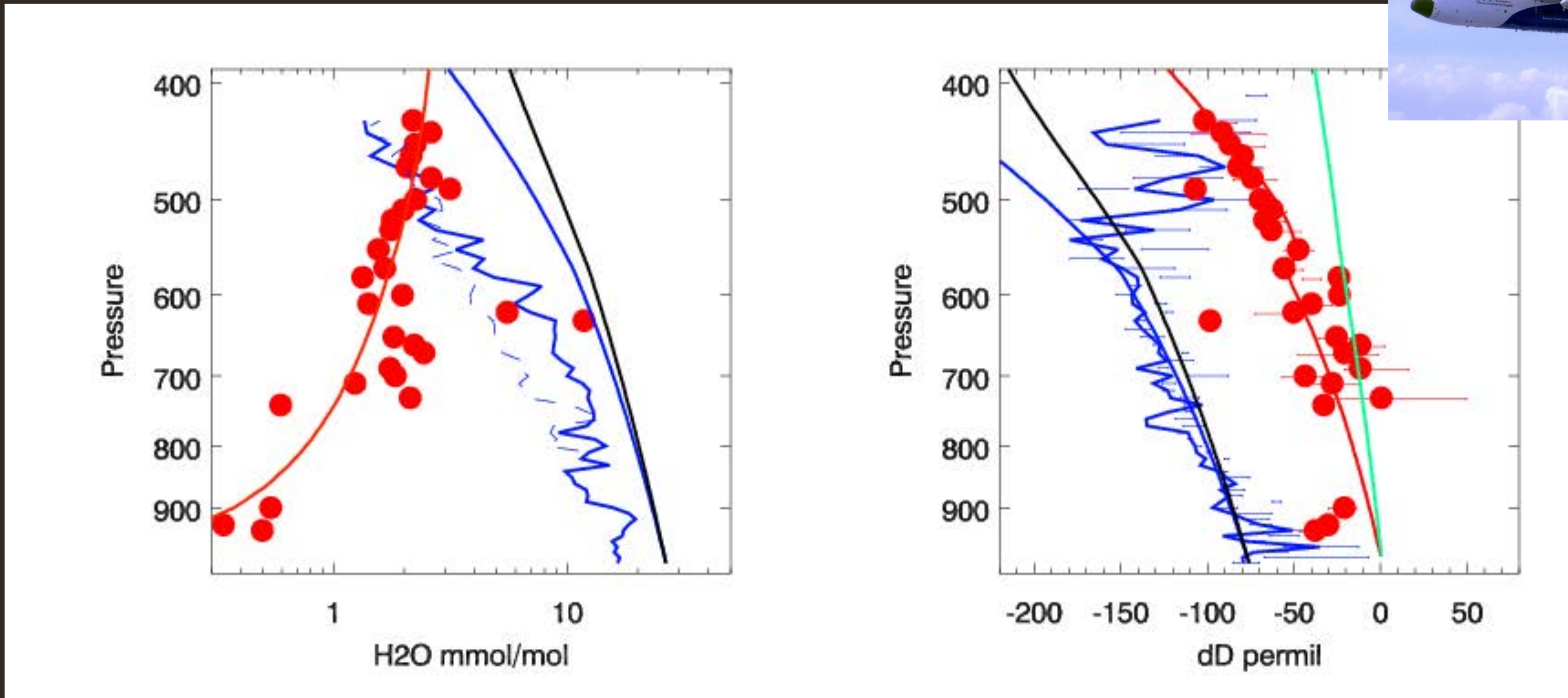
(*Isotope* + tree) proxies with CESM => **New knowledge of "mystery" volcano**



Temperature anomalies: shaded
500 hPa geopotential height: contours

Last Millennium Reanalysis: Paleoclimate Assimilation
Hakim et al 2017; also Horlick, 2018; Tardif et al., 2019.

How (much) do clouds moisten the troposphere?



Total water

Cloud vapor

Cloud condensate

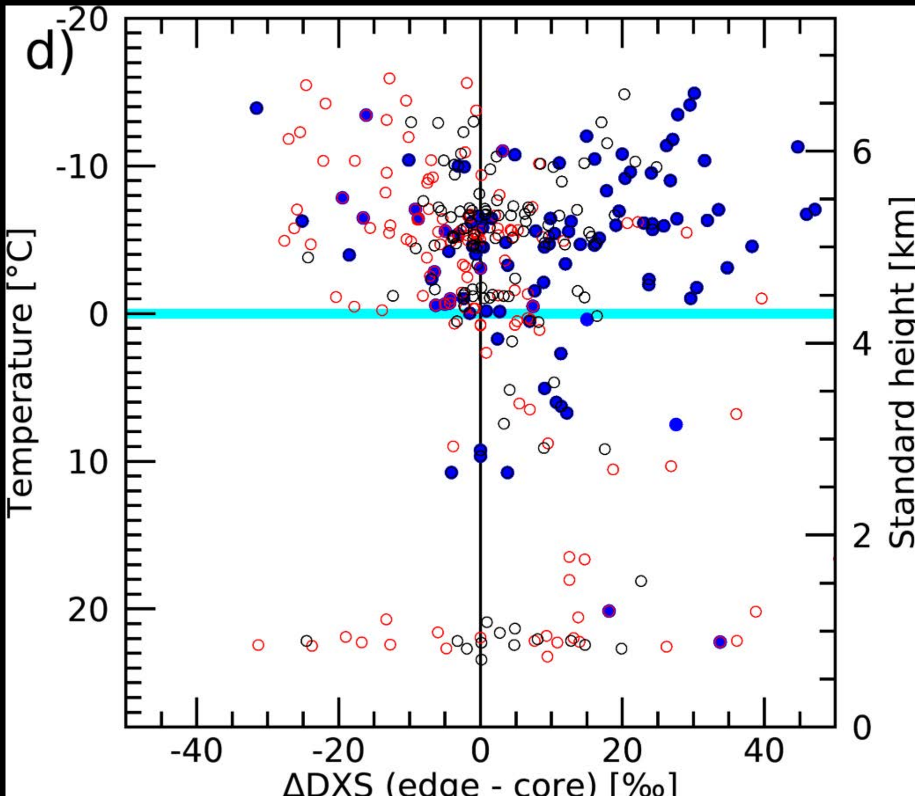
Detrainment/precip.

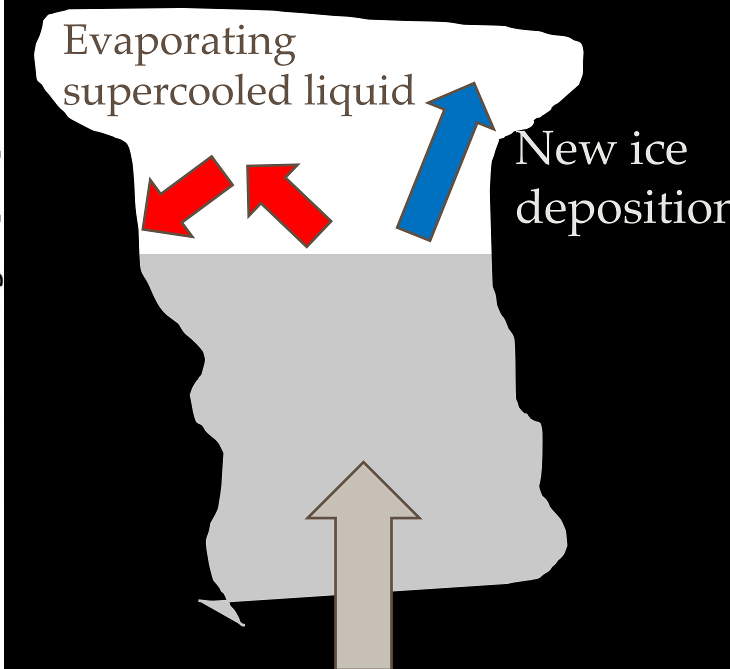
Observed cloud condensate

Not Rayleigh. 15% of water not condensed.

Detrainment/moistening above 550 hPa

What (proportion of) ice formation pathways?





Data categorized by updraft velocity.

Missing assessment and theory

How and when does water move?

(Continental recycling on land, entrainment in clouds)

What energy transformations occur?

(Entropy and energy constraints on circulation)

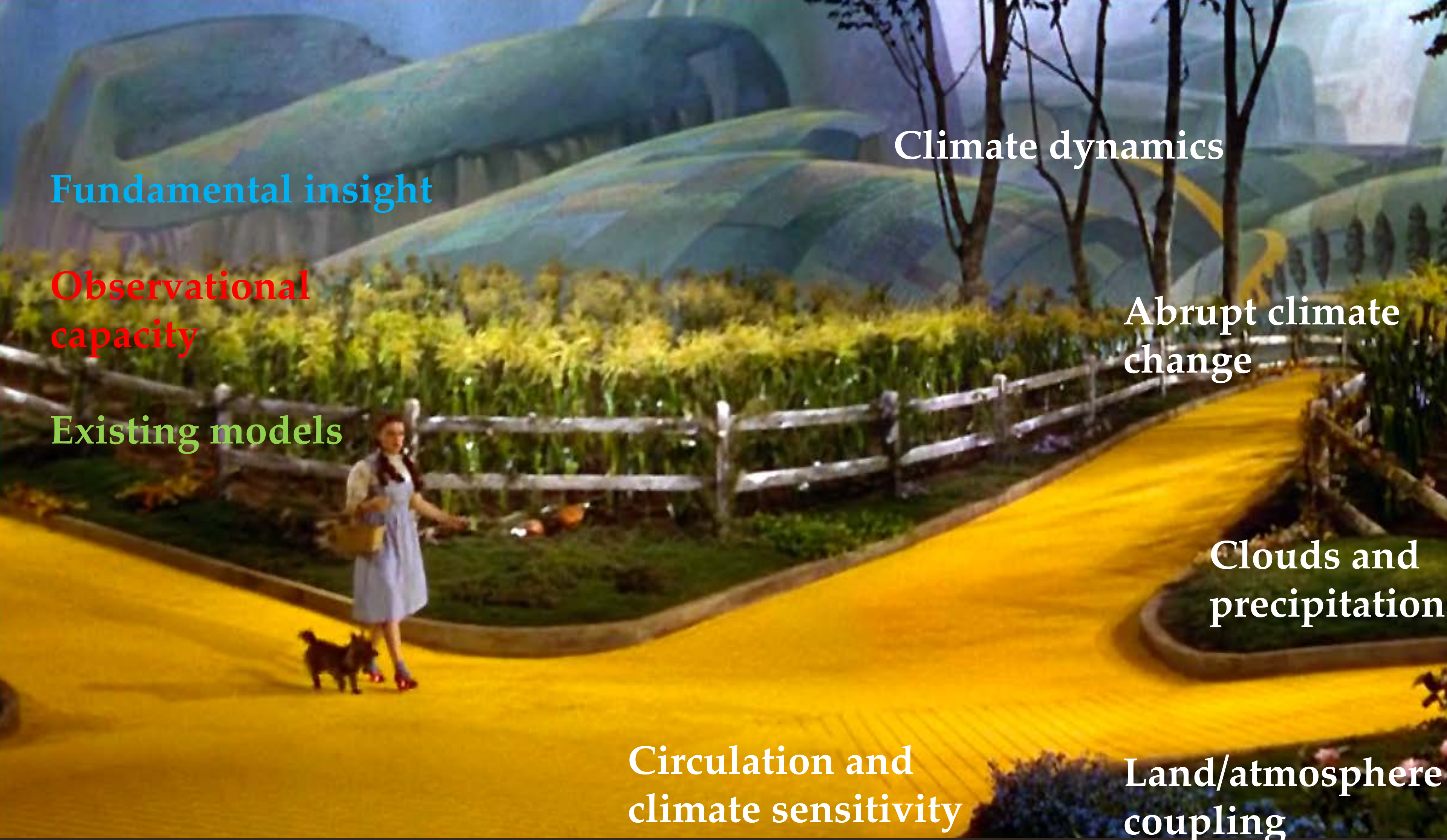
How are they changing:

Broad question of changes in hydrology:

"widening of the subtropics"

"acceleration of the hydrological cycle"
"frequency/magnitude of extremes"

1. ***Climate variability is not well observed*** *at time scales beyond a decade.*
2. ***Hydrological process not well observed*** *at the process level.*



Fundamental insight

Observational capacity

Existing models

Climate dynamics

Abrupt climate change

Clouds and precipitation

Circulation and climate sensitivity

Land/atmosphere coupling

What is needed to fully utilize isotopic information to crack open the grand challenge hydroclimate problems?

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