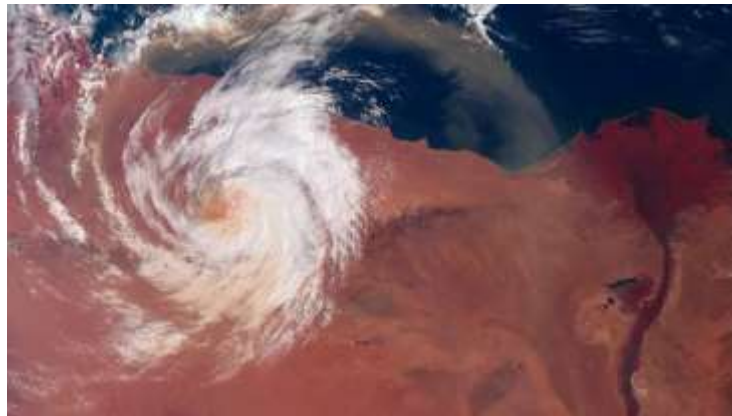
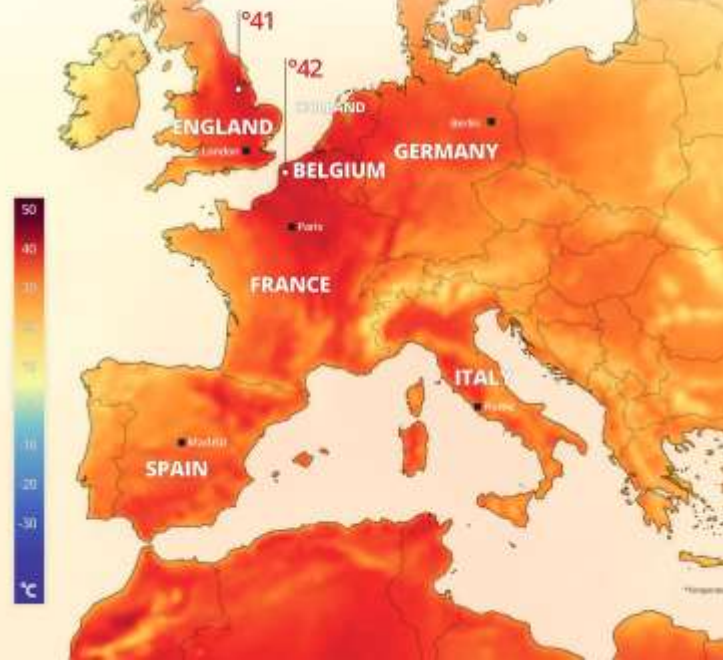


FUTURE CHALLENGES IN ENERGY & WATER CYCLE RESEARCH

Professor Richard Allan [@rpallanuk](#) r.p.allan@reading.ac.uk
John Harries Memorial, Imperial College, 22nd September 2023



Europe hit by scorching heatwave



ONGOING CLIMATE CHANGE



The Earth in space

Processes fluctuate naturally, molecules shoot around, chaotic limits apply, but basically nothing changes, until...

The only information and the only energy, that gets in or out is via electromagnetic radiation.....

This is the climate system
(physical + biological)

...Light and Heat

Energy arriving gives rise to myriad of processes between high frequency energy in and low frequency energy out (entropy!)

Precious little exchange of matter of any sort



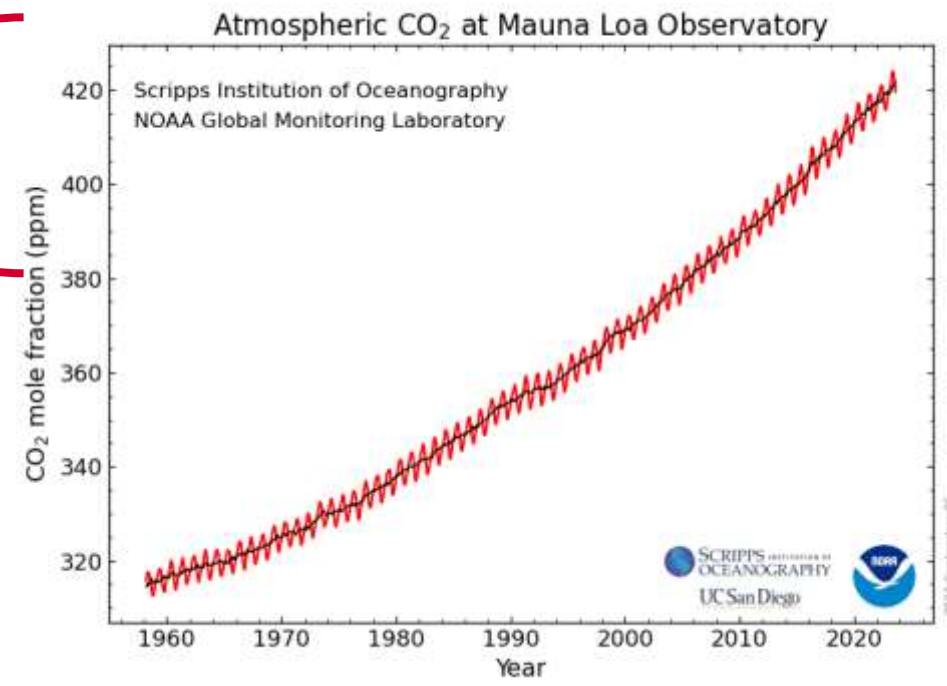
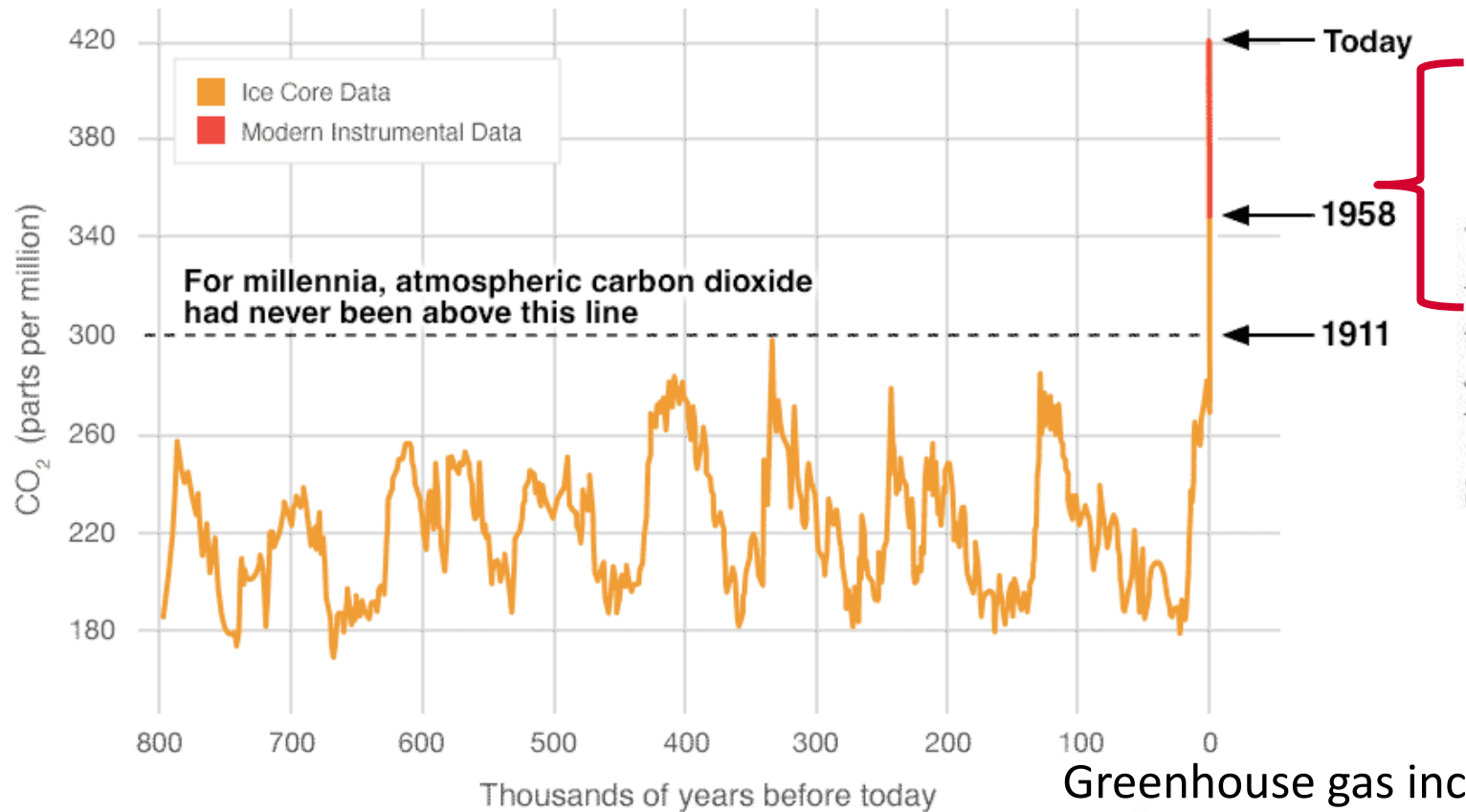
Some incoming light is reflected, by clouds, surface, ice

..until flux of energy/second/m² absorbed = emitted

Remainder absorbed, heats the planet

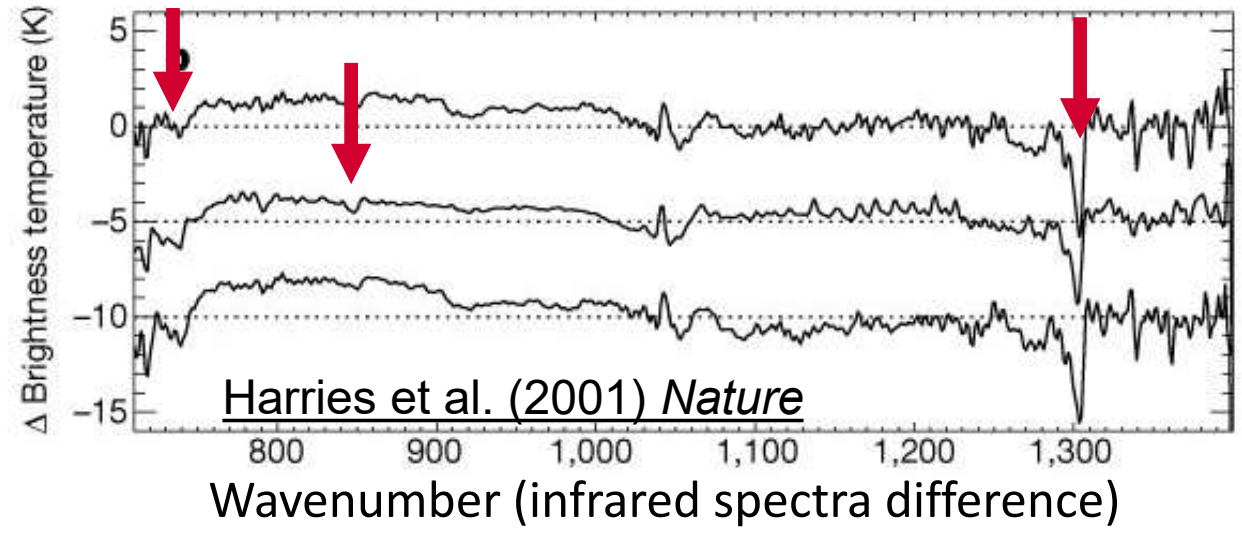
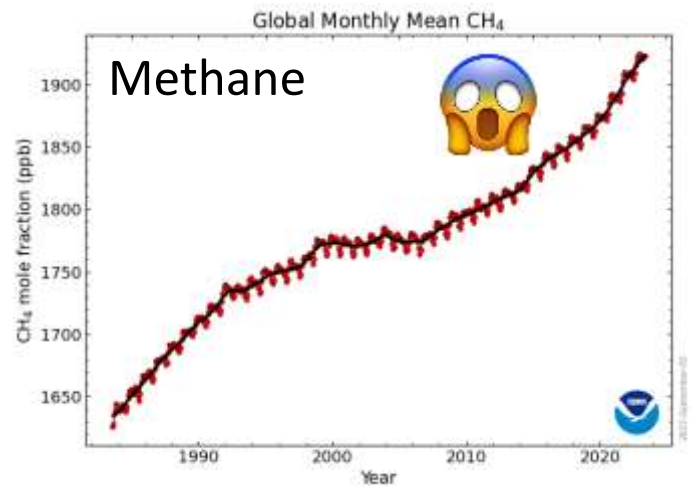
Planet goes on warming....

Temperature rises, IR emission back to space starts



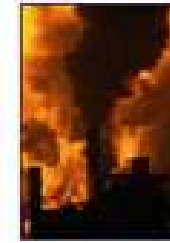
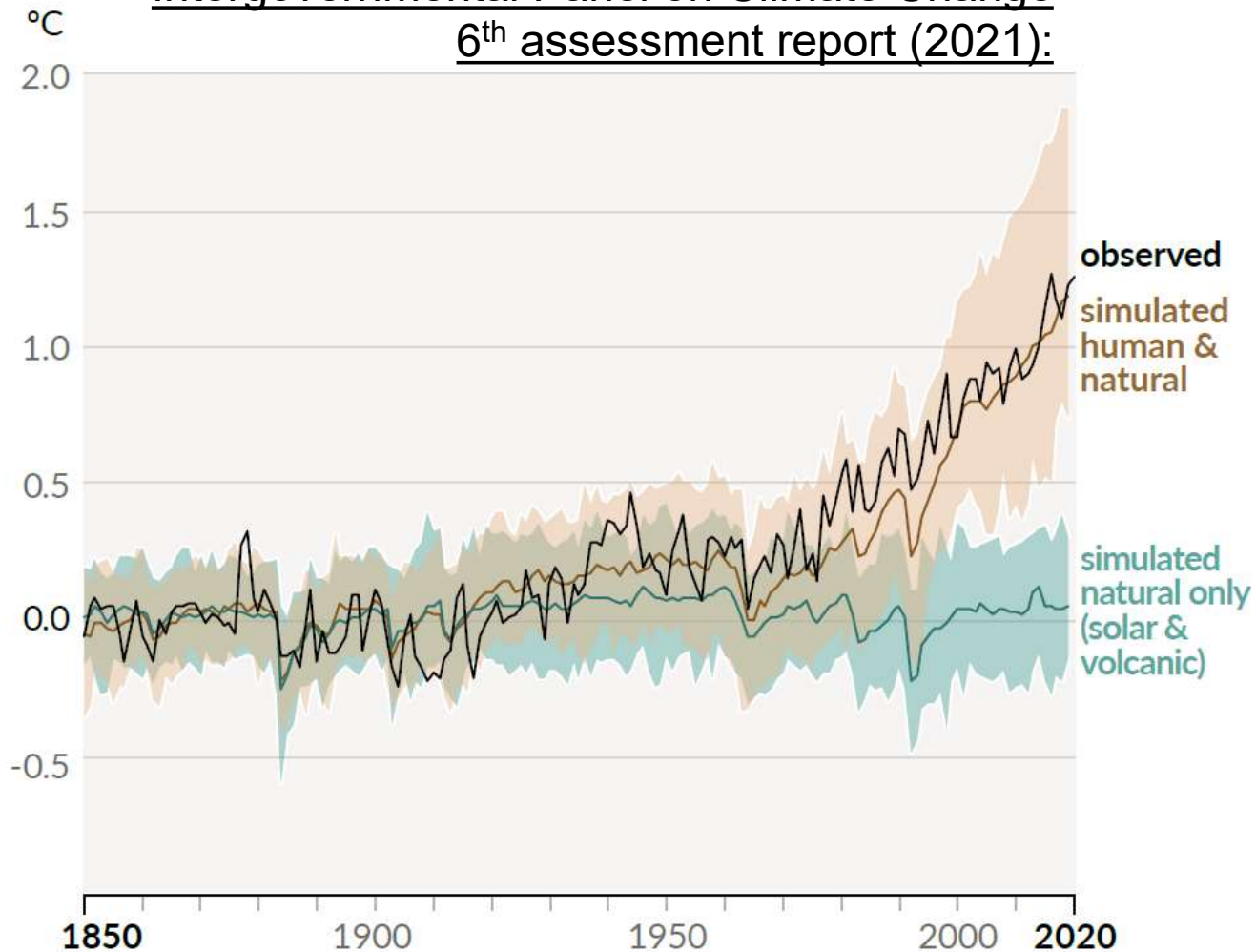
Greenhouse gas increases reduce outgoing infrared emission

Ouch!



It is indisputable that human activities are causing climate change

Intergovernmental Panel on Climate Change
6th assessment report (2021):



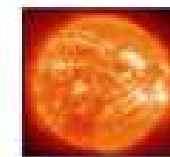
► Observed warming is driven by emissions from human activities



► Natural factors do not contribute to rapid warming over past 5 decades

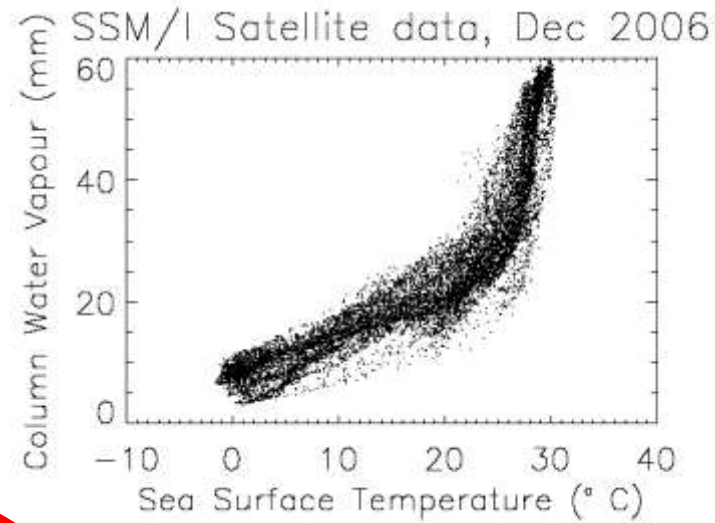
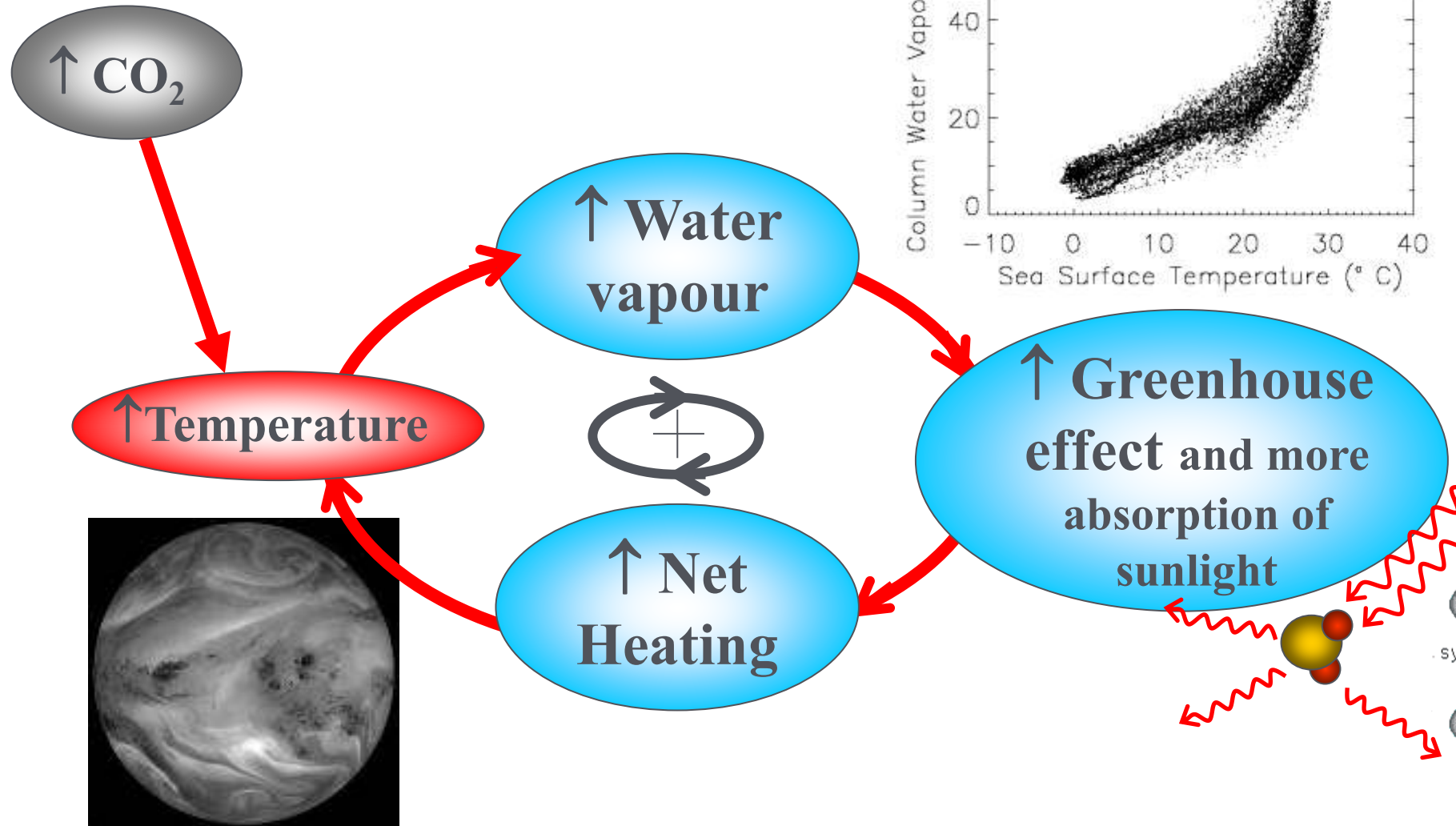


► Greenhouse gas warming has been partly masked by aerosol cooling



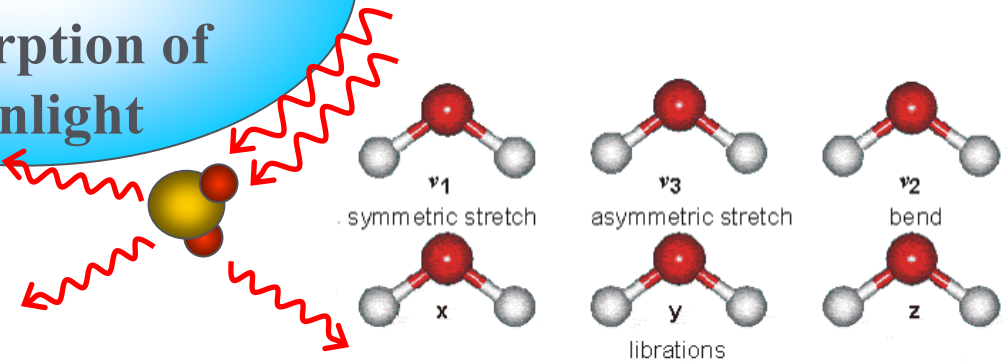
► Warming is amplified by feedback loops involving water vapour, ice & clouds

Feedback Loops Amplify Climate Change



Feedbacks:

- ice/snow (+)
- water vapour (++)
- clouds (++/-)
- temperature (- - -)





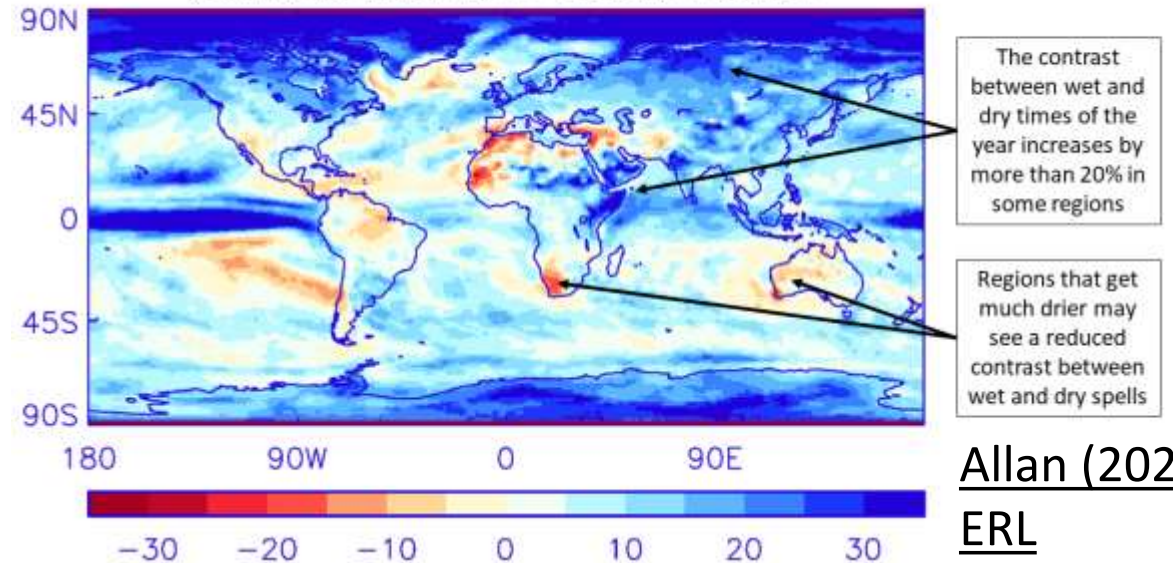
“

Increasing amounts of water vapour in the atmosphere are amplifying warming of climate and making extreme weather worse.

Water vapour is increasing

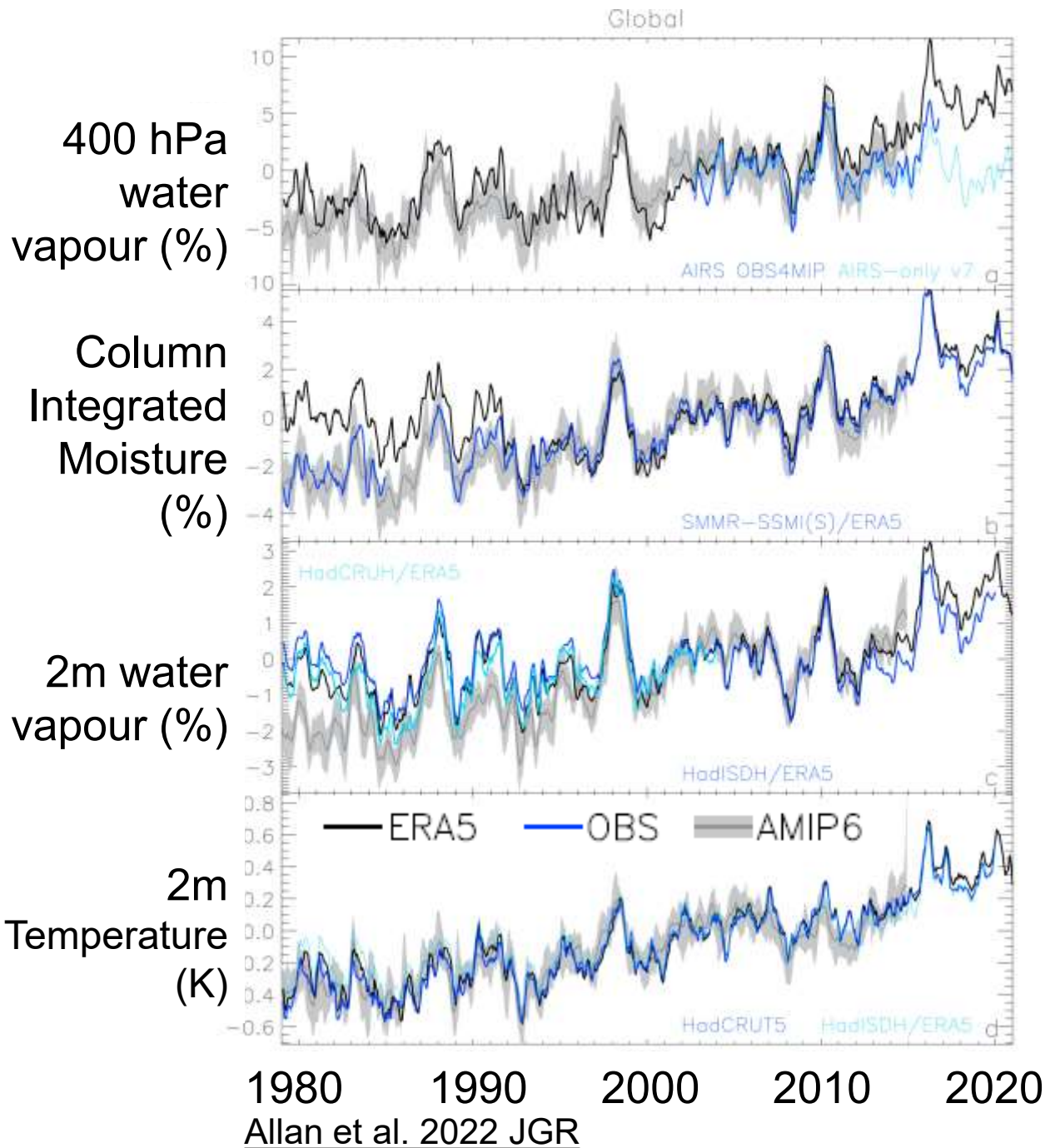
This is intensifying the water cycle: a thirstier atmosphere more effectively saps water from the surface and transports this extra moisture into storm systems, monsoons and polar regions

Increasing range between the wettest and driest time of year by the end of the 21st century in percent



Allan (2023)

ERL



How are moisture changes in the upper troposphere influencing climate change?

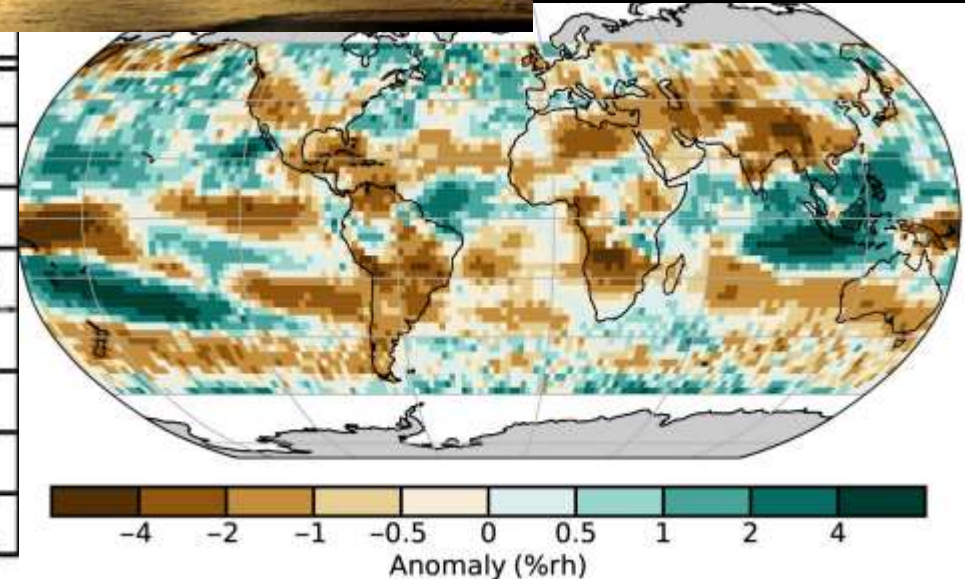
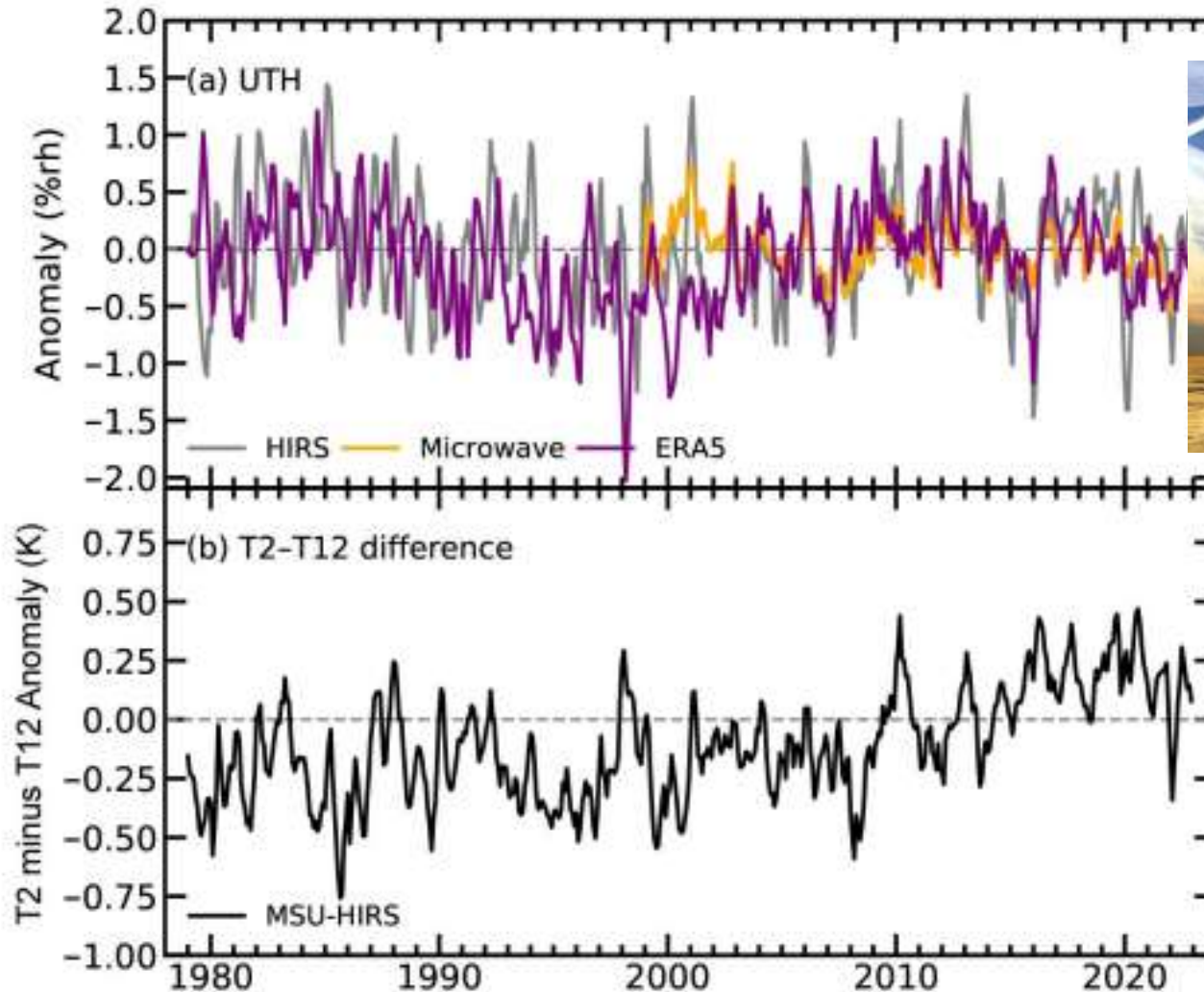
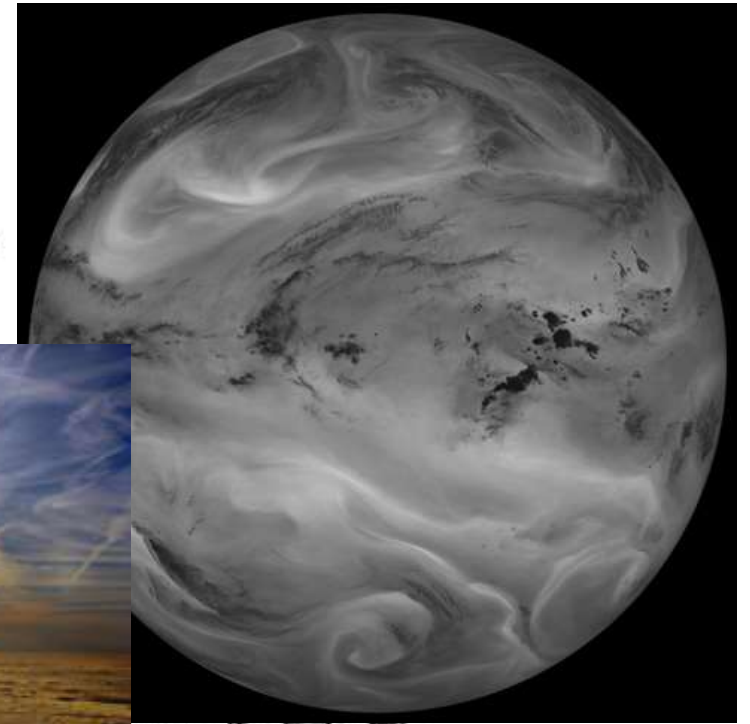
Q. J. R. Meteorol. Soc. (1996), **122**, pp. 799–818

The greenhouse Earth: A view from space

By J. E. HARRIES*

Imperial College, UK

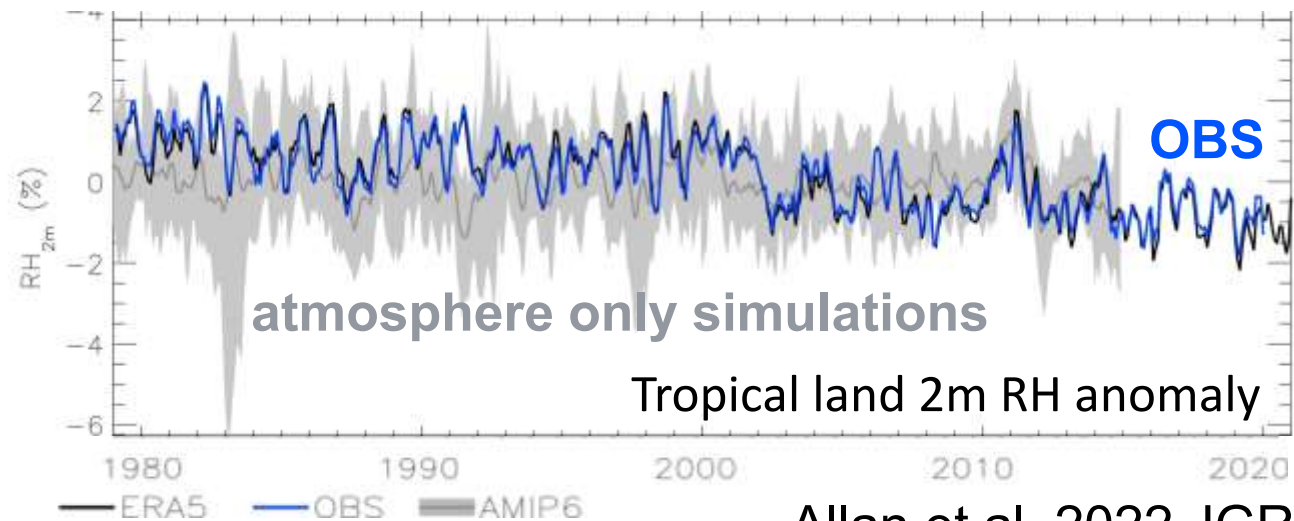
Presidential address, delivered 21 June 1995)



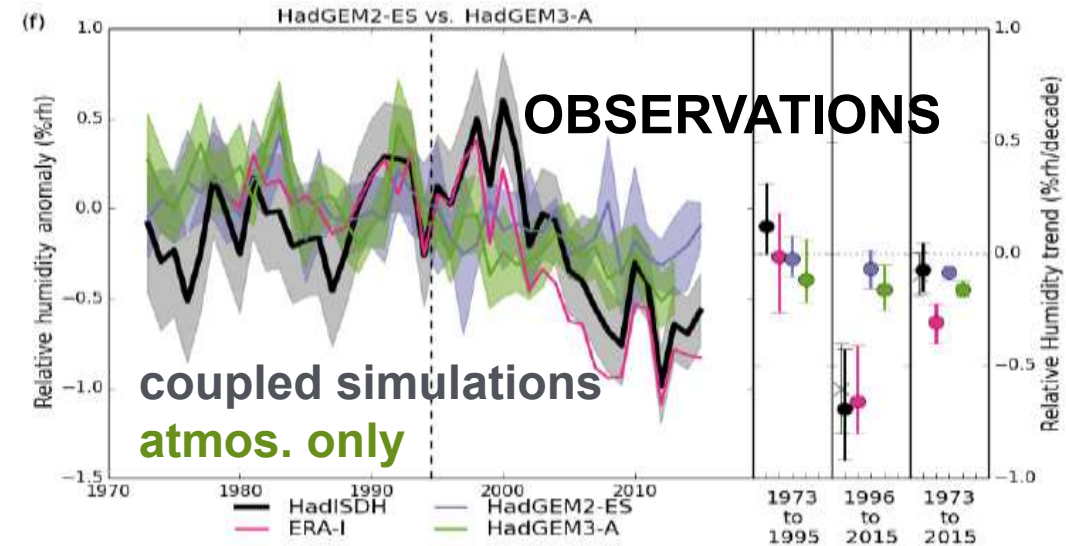
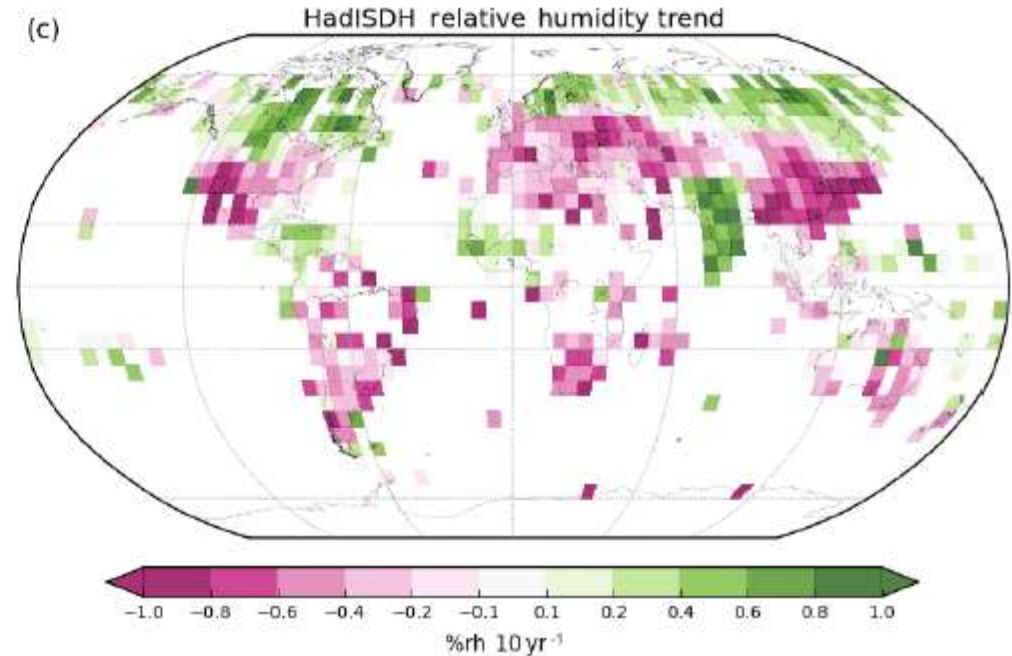
John et al. (2023) in BAMS state of climate 2022

IS CONTINENTAL DRYING UNDERESTIMATED BY MODELS?

- Declining Relative Humidity over land
- Consistent with larger warming over land than sea e.g. O’Gorman & Byrne (2018) PNAS
- Not fully captured by CMIP5/6 simulations even when forced with observed SST e.g. Allan et al. 2022 JGR, Dunn et al. 2017 ESD



Allan et al. 2022 JGR



Dunn et al. 2017 ESD

Can we detect emerging signals of water cycle change?

- Emerging signals of more intense dry seasons over eastern Brazil, southern Africa and Australia (opposite in Sahel)

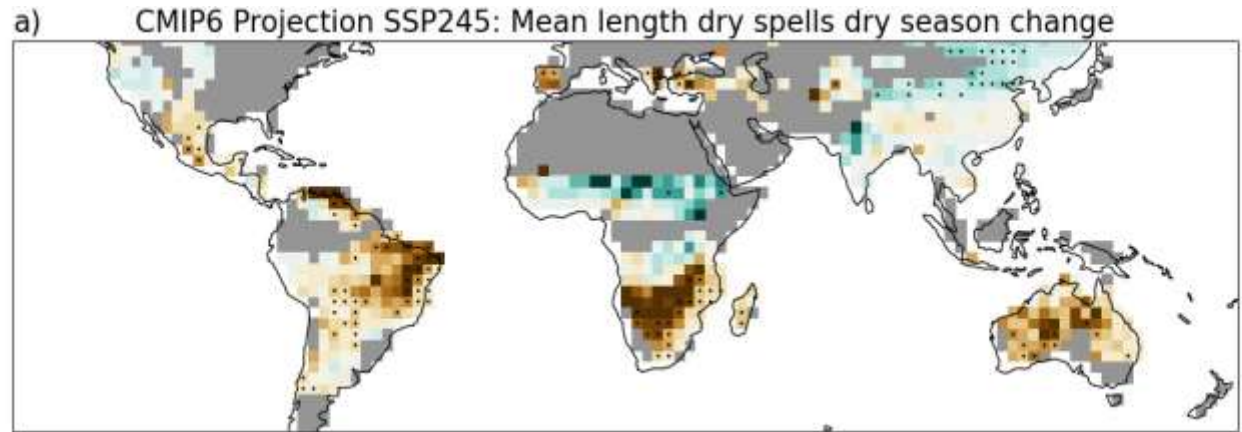
Wainwright et al. (2022) GRL →

Spectral Signatures of Earth's Climate Variability over 5 Years | from IASI

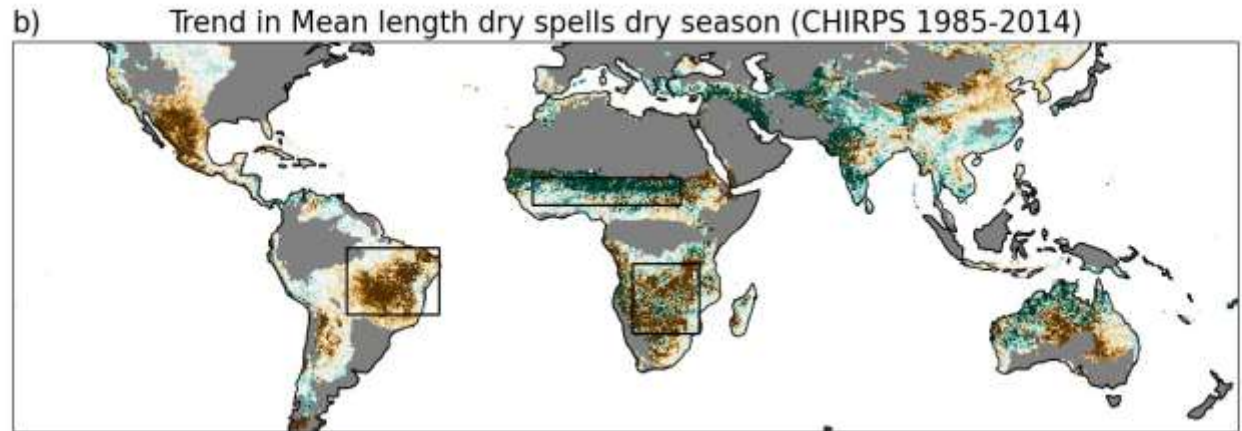
HELEN BRINDLEY, RICHARD BANTGES, JACQUELINE RUSSELL, JONATHAN MURRAY,
CHRISTOPHER DANCEL, CLAUDIO BELOTTI, AND JOHN HARRIES

Space and Atmospheric Physics Group, Imperial College London, London, United Kingdom

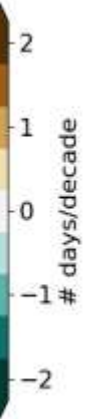
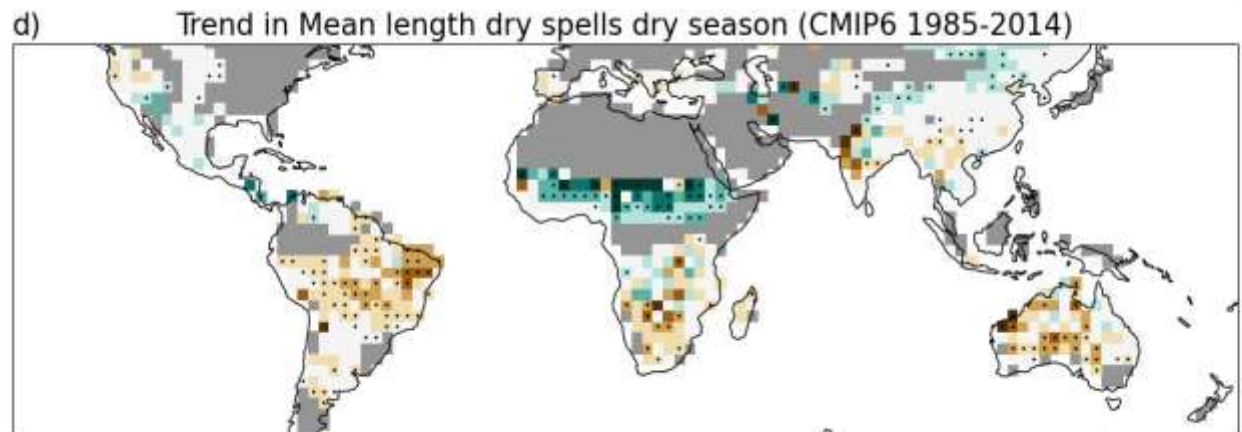
FUTURE
PROJECTIONS



PRESNET DAY
OBSERVATIONS



PRESNET DAY
SIMULATIONS



Energy change (ZJ)

400
300
200
100
0

- Ocean 0-300 m
- Ocean 0-700 m
- Ocean 700-2000 m
- Ocean below 2000 m
- Land
- Ice
- Atmosphere
- Uncertainty

Is climate change accelerating?

0.48 Wm⁻²

0.76 Wm⁻²

Year
1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015

Heat stored in the Earth system 1960–2020: where does the energy go?

Karl-Heinz von Storch¹, Andrey Mikhlin², Elena Goussé³, Francisco José Castro-Valero^{1,4},
 Alfred Kirchgaessner⁵, Soheil Adnanpour⁶, Flaminia Strano⁷, Michael Abide⁸, Richard P. Allan⁹,
 Paul M. Barker¹⁰, Hugo Behrendt¹¹, Alejandro Blazquez¹², Tim Boyer¹³, Lijing Cheng¹⁴,
 John Church¹⁵, Damien Deshayes¹⁶, Han Duan¹⁷, Celia M. Domingos¹⁸,
 Alexandra Garcia-Garcia¹⁹, Daniela Golev²⁰, John E. Harries²¹, Maximilian Geyer²²,
 Leopold Haimberger²³, Maria Z. Hakkar²⁴, Stefan Hoerchle²⁵, Shigeki Hoshino²⁶,
 Gregory C. Johnson²⁷, Keesik Kilik²⁸, Brian Kirtz²⁹, Nicolas Kolev³⁰, Anton Korosov³¹,
 Gerhard Kröner³², Mihail Kuzolev³³, Felix W. Landerer³⁴, Moritz Langer³⁵, Thomas Laveigne³⁶,
 Abel Laverne³⁷, Verban Li³⁸, Julia Lyman³⁹, Florence Marti⁴⁰, Ben Marwan⁴¹, Michael Mayer⁴²,
 Andrew H. MacDonall⁴³, Trevor McDougall⁴⁴, Didier Paoli Mouschonas⁴⁵, Jan Niklas⁴⁶,
 Iku Oonaka⁴⁷, Jun Peng⁴⁸, Sarah Parker⁴⁹, Dean Roemmich⁵⁰, Rensuke Sato⁵¹, Kaimori Sato⁵²,
 Athanasios Scaife⁵³, Axel Schweiger⁵⁴, Andrew Shepherd⁵⁵, Soňa L. Seneviratne⁵⁶, Leon Strasser⁵⁷,
 Donald A. Stammer⁵⁸, Thomas Stuber⁵⁹, Andrea R. Stuber⁶⁰, Tobias Stope⁶¹, Dargut Soyluk⁶²,
 Wan Thery⁶³, Mary-Louise Timmermann⁶⁴, Ina Yasuchika^{65,66,67}, Susan E. Wijffels⁶⁸,
 Benjamin Wu⁶⁹, and Michael Zang⁷⁰

89%

Earth's heat inventory 2022

5%
4%
2%

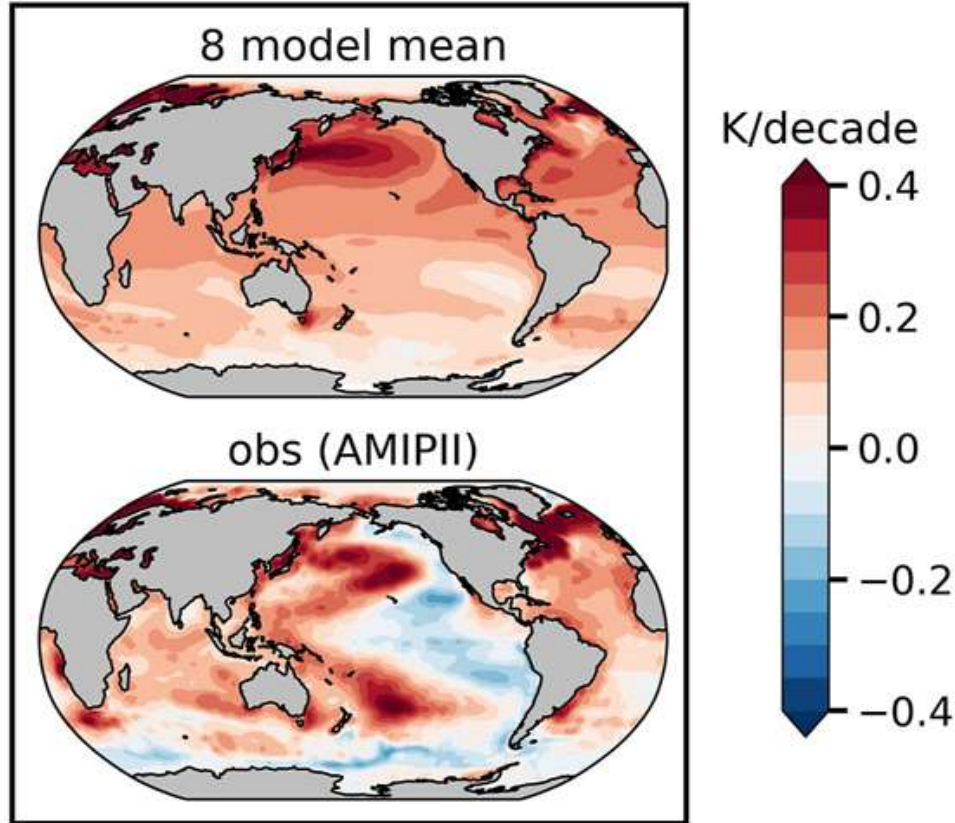
von Shuckmann et al. (2023) ESSD

On the Variability of the Global Net Radiative Energy Balance of the Nonequilibrium Earth

JOHN E. HARRIES AND CLAUDIO BELOTTI
Imperial College, London, United Kingdom

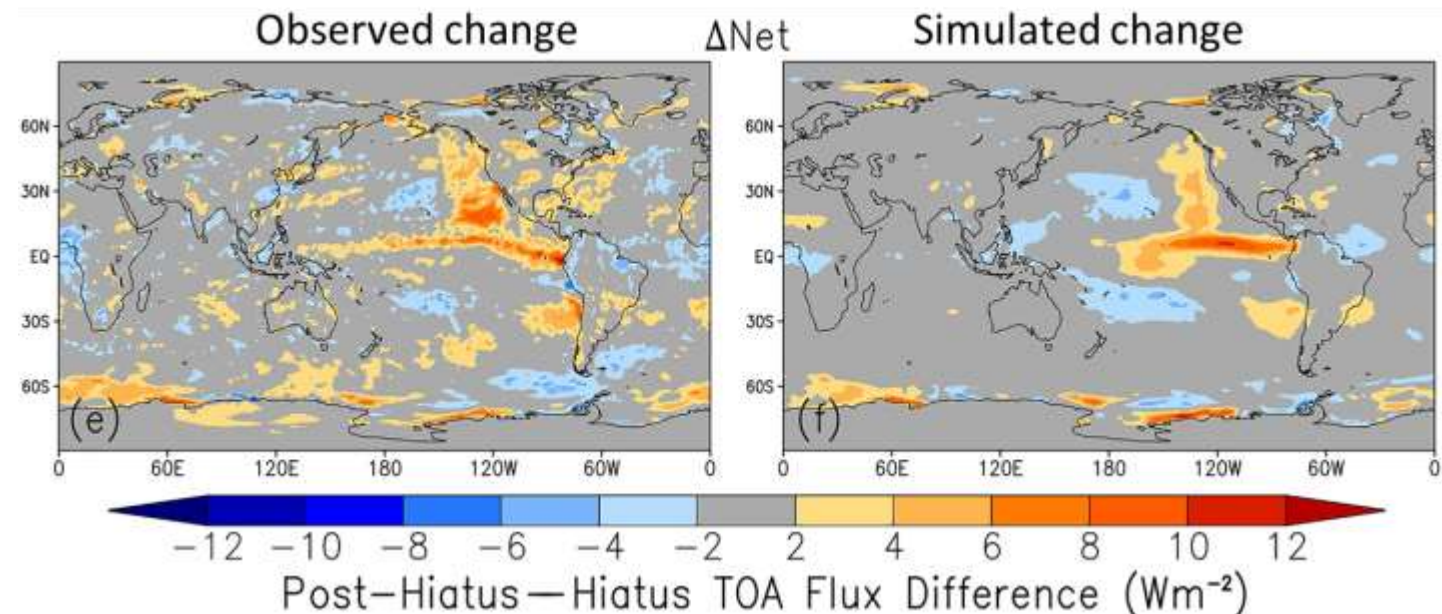
(Manuscript received 20 August 2008, in final form 31 August 2009)

Unexpected pattern of global warming?



This has weakened amplifying climate feedbacks relative to coupled models (Andrews et al. 2022 JGR)

...but new Earth radiation budget measurements and simulations suggest clouds are now awakening and causing more sunlight to be absorbed (Loeb et al. 2020 GRL)



Pattern of observed warming (1979-2014) is unexpected!
Dong et al. (2021) GRL

Can we geoengineer our climate back to safety?

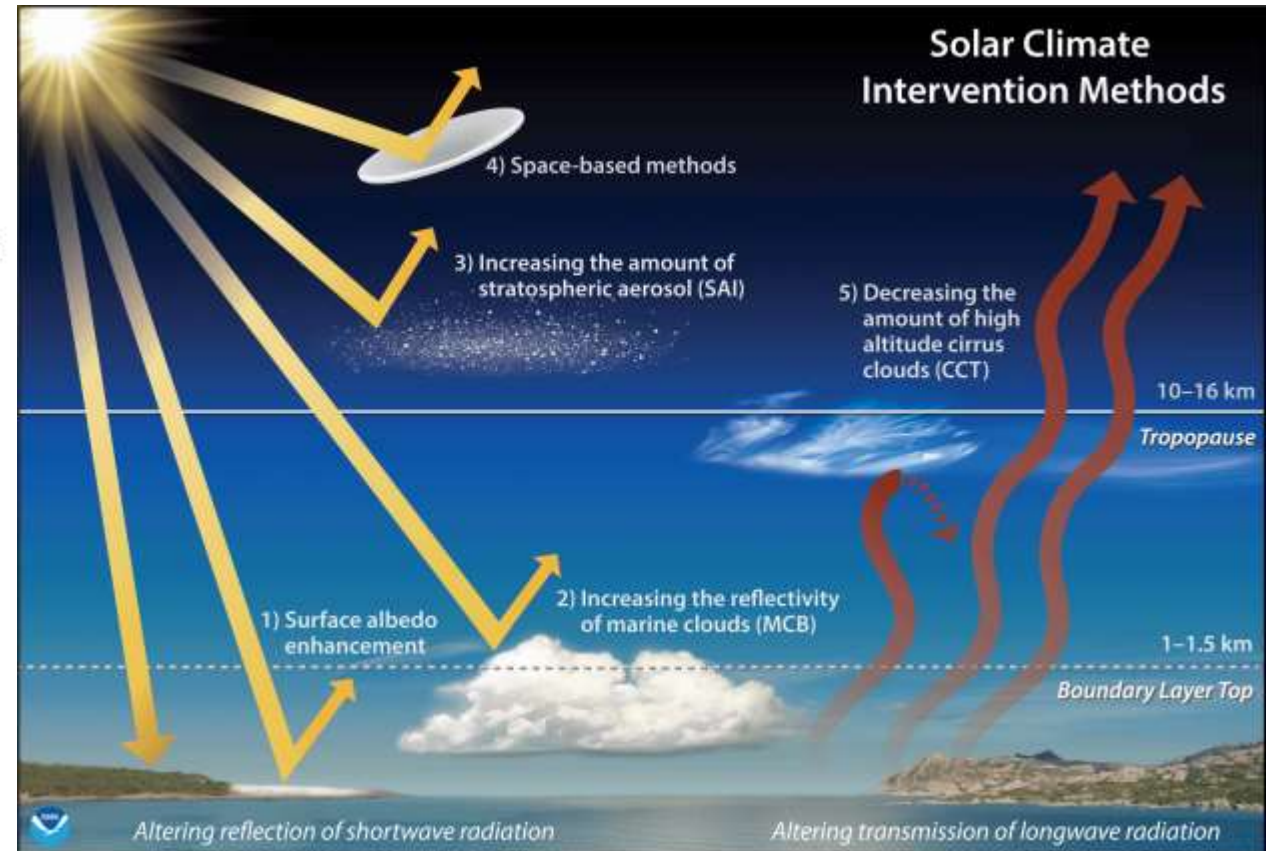
GEOPHYSICAL RESEARCH LETTERS, VOL. 24, NO. 19, PAGES 2355-2358, OCTOBER 1, 1997

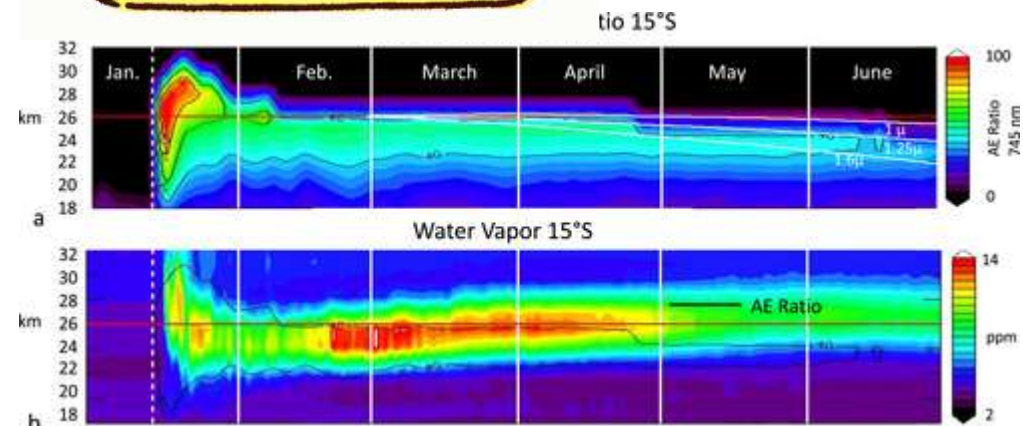
Possible change in climate parameters with zero net radiative forcing

Ashok Sinha and John E. Harries

Space and Atmospheric Physics Group, Blackett Laboratory, Imperial College of Science, Technology and Medicine, Prince Consort Road, London SW7 2BZ

No





Schoeberl et al. (2022) GRL

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, 1.23814, doi:10.1029/2006GL027457, 2006

On the stability of the Earth's radiative energy balance: Response to the Mt. Pinatubo eruption

J. E. Harries¹ and J. M. Fuyuan²

Received 4 July 2006; revised 27 September 2006; accepted 7 November 2006; published 15 December 2006.

REVIEWS OF GEOPHYSICS AND SPACE PHYSICS

NOVEMBER 1976

The Distribution of Water Vapor in the Stratosphere

J. E. HARRIES

Division of Quantum Metrology, National Physical Laboratory, Teddington, Middlesex, England

The Distribution of Water Vapor in the Stratosphere

J. E. HARRIES

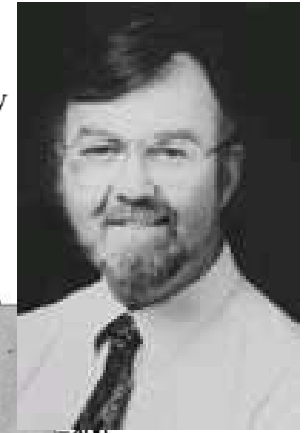
x. Engl

Q. J. R. Meteorol. Soc. (1996), **122**, pp. 799–818

Atmospheric radiation and atmospheric humidity

By J. E. HARRIES*

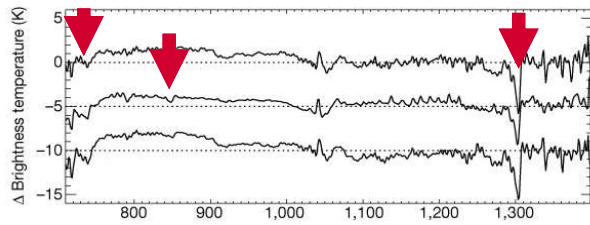
Imperial College, UK



Increases in greenhouse forcing inferred from the outgoing longwave radiation spectra of the Earth in 1970 and 1997

John E. Harries, Helen E. Brindley, Pretty J. Sagoo & Richard J. Bantges

Space and Atmospheric Physics Group, Blackett Laboratory, Imperial College, London SW7 2BW, UK



The greenhouse Earth: A view from space

By J. E. HARRIES*

Imperial College, UK

Presidential address

GEOPHYSICAL RESEARCH LETTERS, VOL. 24, NO. 19, PAGE 2353, 1997

Possible change in climate parameters with zero net radiative forcing

Ashok Sinha and John E. Harries

Space and Atmospheric Physics Group, Blackett Laboratory, Imperial College of Science, Medicine, Prince Consort Road, London SW7 2BZ

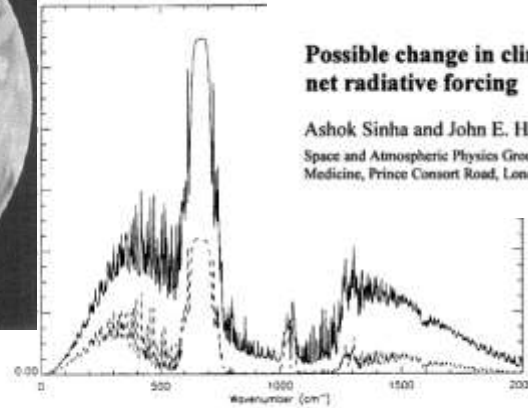
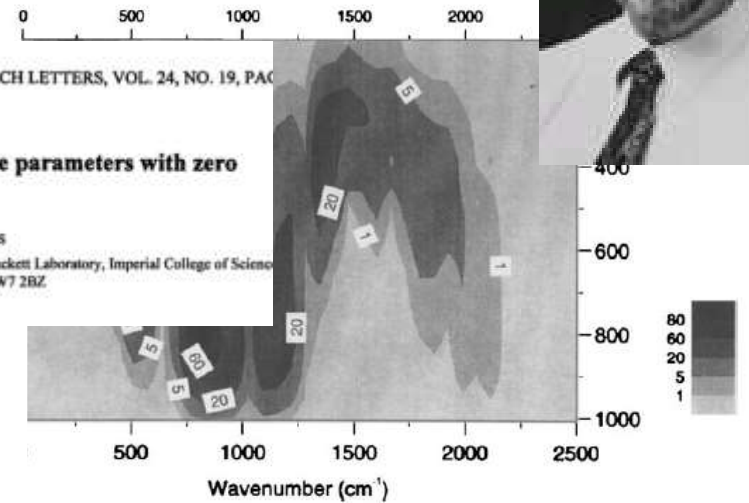


Figure 6. The greenhouse-effect parameter G (see text) for two atmospheres: solid curve, for the moist tropical case shown in Fig. 5; broken curve, for a cold sub-arctic standard atmosphere.



Outgoing long-wave radiation (OLR) calculated using the Shine (1992) model, by removing the 50 mb thick layers and noting the change in OLR. The units are mW m^{-2} per 10 cm^{-1} interval of spectrum. Abscissa gives spectral wave number (= reciprocal of wavelength), and ordinate gives pressure in the atmosphere. Case of a moist tropical standard atmosphere. (Sinha and Harries 1995).

Conclusions

- John’s work remains fundamental to current research challenges
- He has left his own “spectral signature” on many people who continue to pass on this wisdom for the benefit of society

