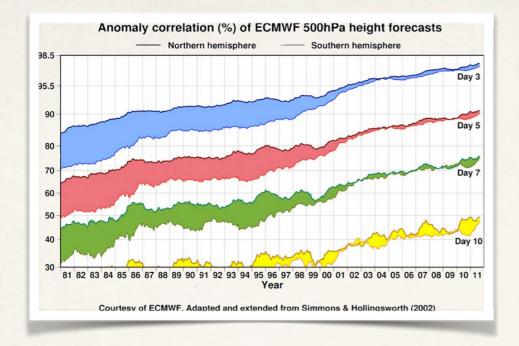


39

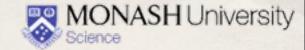




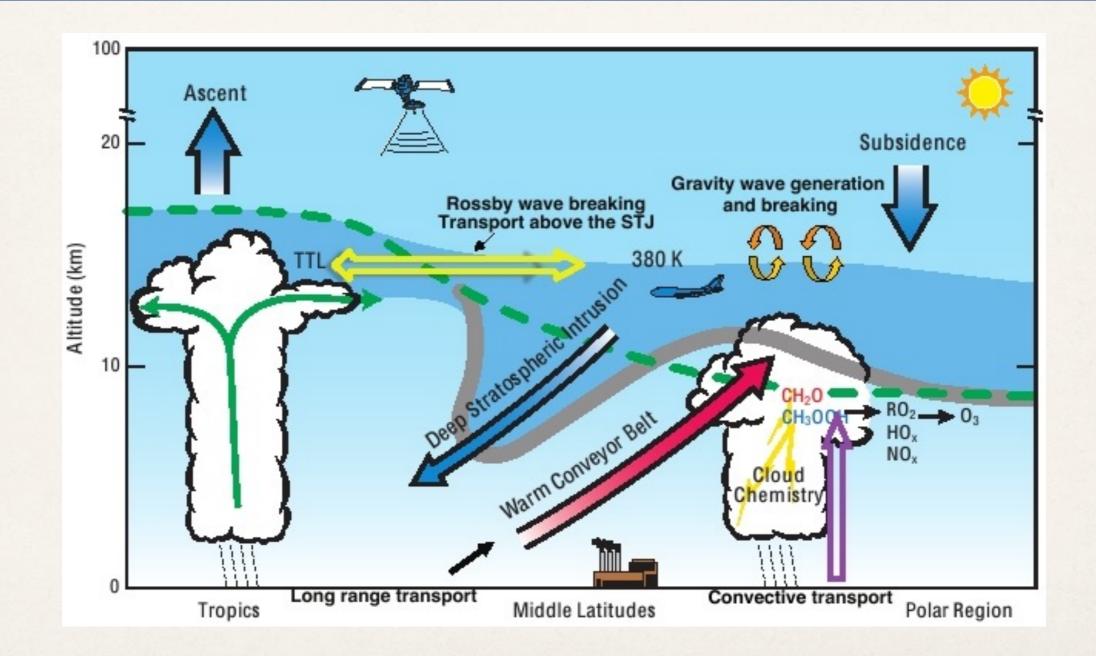
Christian Jakob, ARC Centre of Excellence for Climate System Science, Monash University, Melbourne, Australia

Special Thanks: My Friends And Colleagues On Ipcc Chapter 9

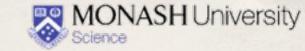




This is going to be a talk about water in the troposphere, so why would you care?



NCAR Atmospheric Chemistry Division



All weather and climate predictions are based on models

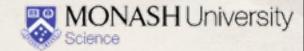


ARC CENTRE OF EXCELLENCE FOR

$$\frac{du}{dt} - \left(f + u \frac{\tan \phi}{a}\right) v = -\frac{1}{a \cos \phi} \frac{1}{\rho} \frac{\partial p}{\partial \lambda} + F_{\lambda}$$
$$\frac{dv}{dt} + \left(f + u \frac{\tan \phi}{a}\right) u = -\frac{1}{\rho a} \frac{\partial p}{\partial \phi} + F_{\phi}$$
$$g = -\frac{1}{\rho} \frac{\partial p}{\partial z}$$
$$\frac{\partial \rho}{\partial t} = -\frac{1}{a \cos \phi} \left[\frac{\partial}{\partial \lambda}(\rho u) + \frac{\partial}{\partial \phi}(\rho v \cos \phi)\right] - \frac{\partial}{\partial z}(\rho w)$$
$$c_{p} \frac{dT}{dt} - \frac{1}{\rho} \frac{dp}{dt} = Q$$
$$p = \rho RT$$

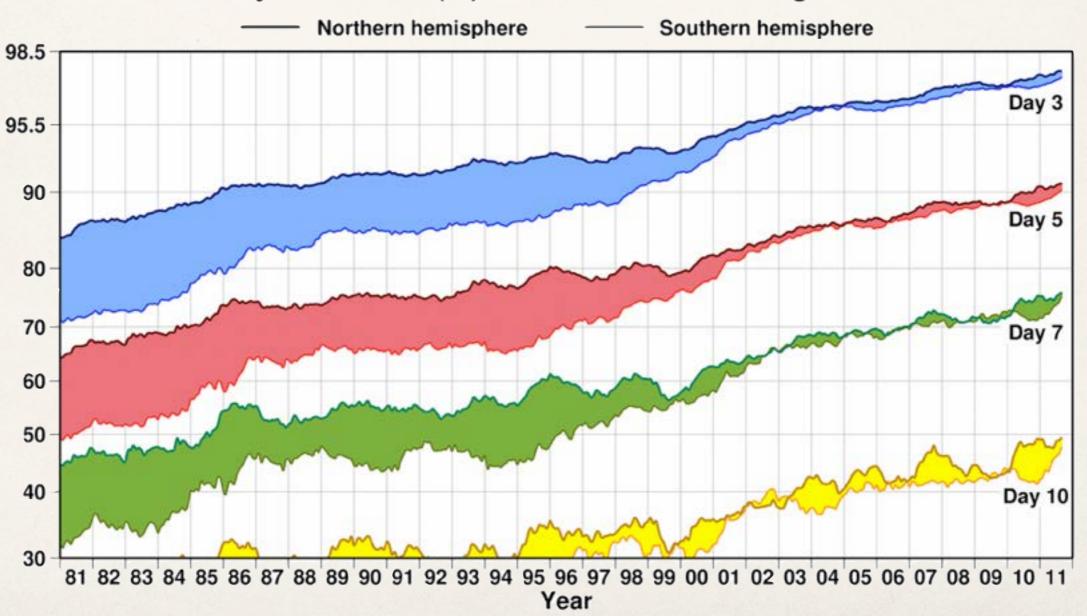






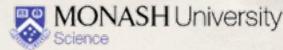
Weather and climate models constitute an unnoticed revolution

Anomaly correlation (%) of ECMWF 500hPa height forecasts



Courtesy of ECMWF. Adapted and extended from Simmons & Hollingsworth (2002)





New components

The models have become more complex extending their use

		1	AOG	SCM		ESM				
Model name		Atmos	Land Surface	Ocean	Sea-Ice	Aerosol	Atmos Chem	Land Carbon	Ocean BGC	
ACCESS1.0, ACCESS1.3	Australia					1	_		_	
BCC-CSM1.1, BCC-CSM1.1(m)	China									
BNU-ESM	China	Real Property lies		1		8				
CanCM4										
CanESM2	Canada									
CCSM4										
CESM1 (BGC)										
CESM1 (WACCM)	USA	HT								
CESM1 (FASTCHEM)	6730									
CESM1 (CAM5)										
CESM1 (CAMS.1-FV2)	USA	1		1						
CMCC-CM, CMCC-CMS	2993	HT								
CMCC-CESM	italy	HT								
CNRM-CM5	France	1		1			-	-		
CSIRO-Mk3.6.0	Australia	-								
EC-EARTH	Europe	6 T		1						
FGOALS-g2										
FGOALS-12	China									
FIO-ESM v1.0	China									
GFDL-ESM2M, GFDL-ESM2G										
GFDL-CM2.1	USA									
GFDL-CM3		HT			l l	R.		-		
GISS-E2-R, GISS-E2-H	USA	HT				pZ,p3*	p7, p3*			
GISS-E2-R-CC, GISS-E2-H-CC		HT				p2,p3*	P2. p3*			
HadGEM2-ES										
HadGEM2-CC	UK	HT						-		
HadCM3		10.00			E					
HadGEM2-AO	Korea				E					
INM-CM4	Russia									
IPSL-CM5A-LR / -CM5A-MR / -CM5B-LR	France	HT								
MIROC4h, MIROCS		HT								
MIROC-ESM	Japan	HT			E					
MIROC-ESM-CHEM	100 C	HT								
MPI-ESM-LR / -ESM-MR / -ESM-P	Germany	HT						-		
MRI-ESM1	and the second se	HT			E E			-		
MRI-CGCM3	Japan	HT			E	1				
NCEP-CF5v2	USA	3 A.		-						
NorESM1-M	1000000000	-				-				
NorESM1-ME	Norway							1		
GFDL-HIRAM C180 / -HIRAM C360	USA	2 1			-				_	
MRI-AGCM3.25 / -AGCM3.2H	Japan					1				

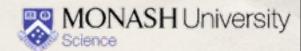
FGOALS-g1.0	China					
ECHAM5/MPI-OM ECHO-G	Germany D/Korea			FC/		
	China					
GFDL-CM2.0	2000					
GFDL-CM2.1	USA					
GISS-AOM						
GISS-EH	USA		Concession in which the local division in which the local division in the local division	10		
GISS-ER	USA					
INGV-ECHAM4	italy	_	and the second s			
				- H2		
INM-CM3.0	Russia			19		
IPSL-CM4	France				_	
MIROC3.2(hires)	Japan	HT				
MIROC3.2(medres)	Value					
MRI-CGCM2.3.2	Japan			FC		
NCAR-PCM	USA		1 million (1997)			
UKMO-HadCM3						
UKMO-HadGEM1	UK		in the second se			

2007 models

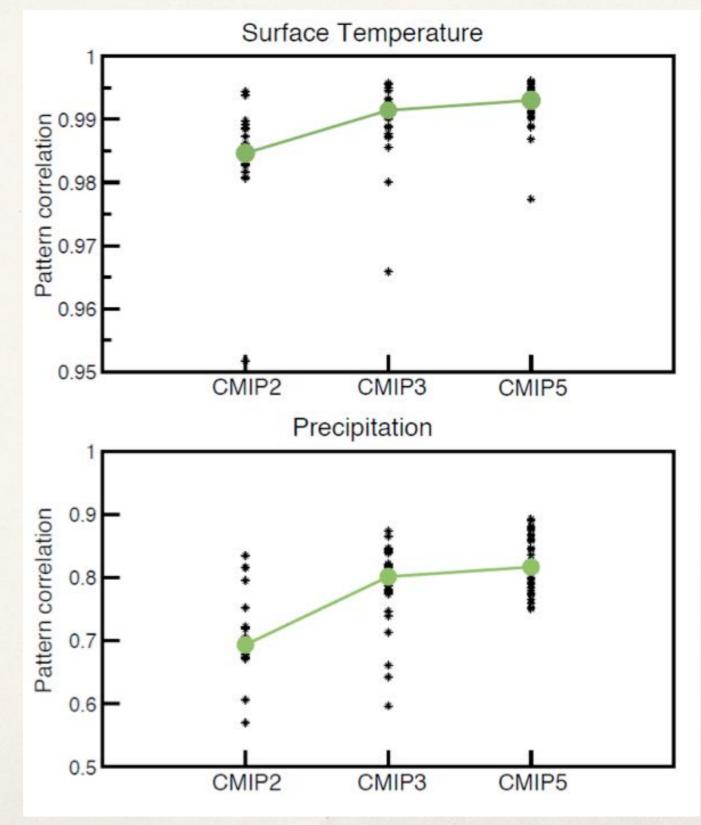


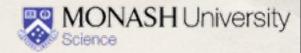
2013 models





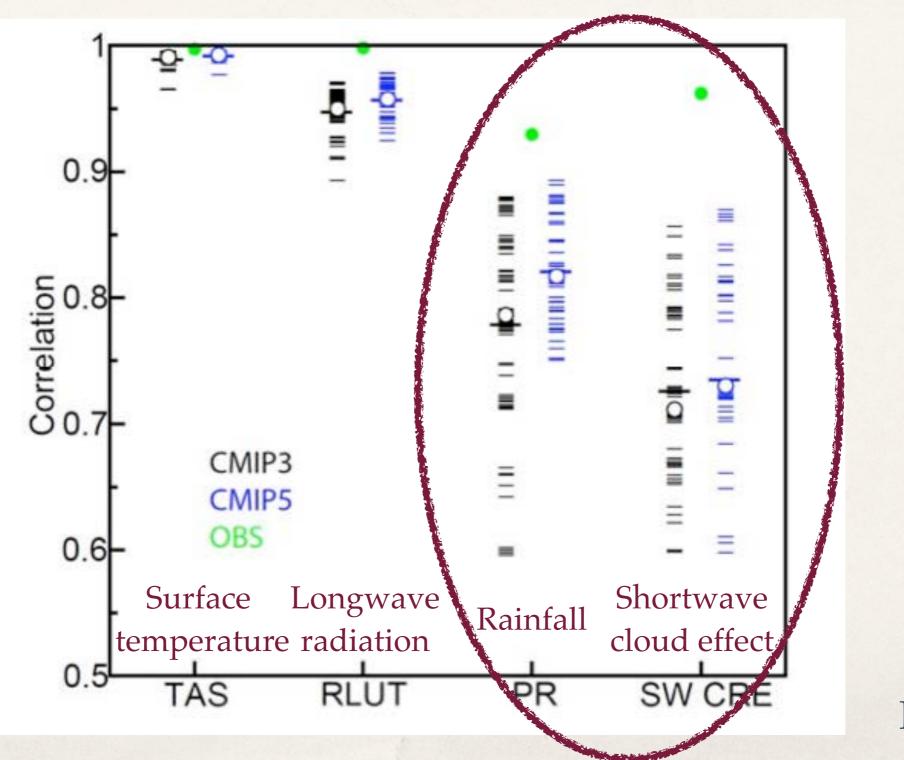
The models are getting better

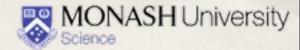






The models are getting better, but water in the atmosphere remains a major challenge

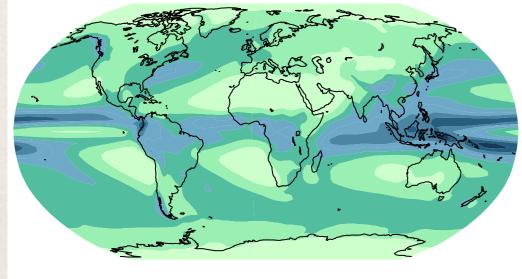




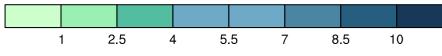


Clouds and precipitation remain a challenge

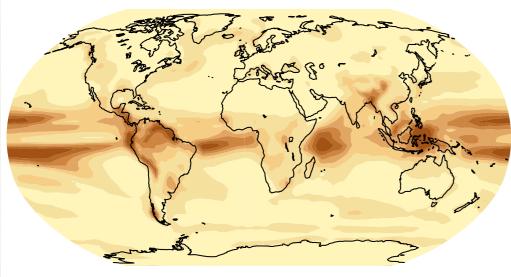
(a) Multi Model Mean Precipitation



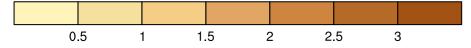
mm day⁻¹



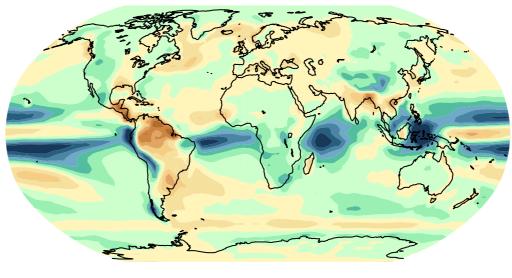
(c) Multi Model Mean of Absolute Error



mm day⁻¹



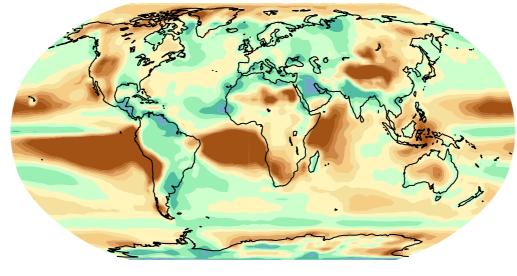
(b) Multi Model Mean Bias

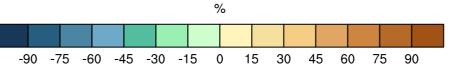


mm day⁻¹

-3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3

(d) Multi Model Mean of Relative Error



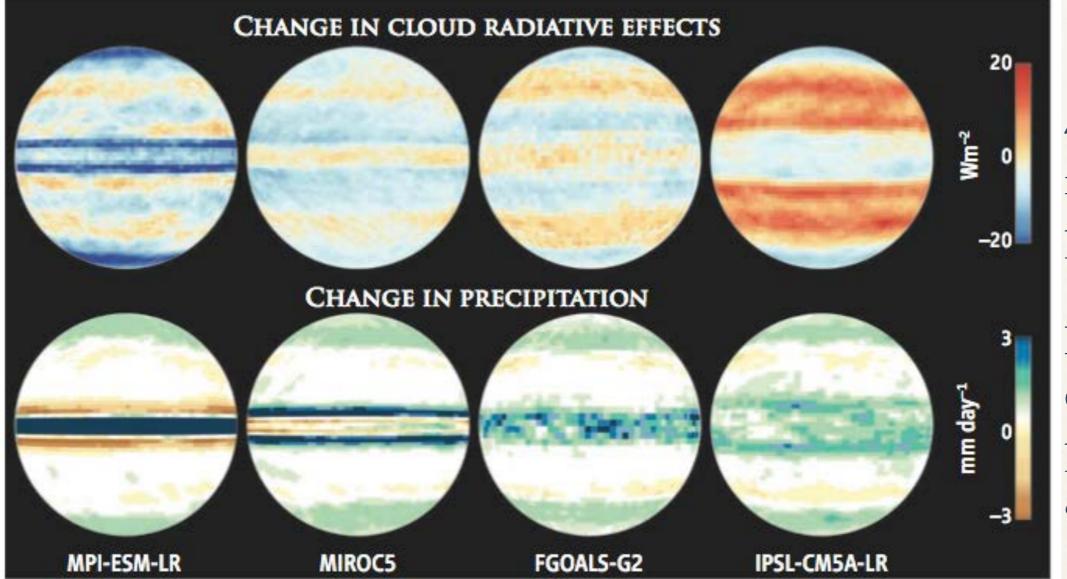


Precipitation CMIP5 multimodel mean





Clouds and precipitation remain a challenge

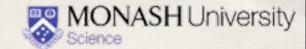


4 CMIP5 models run as a water planet

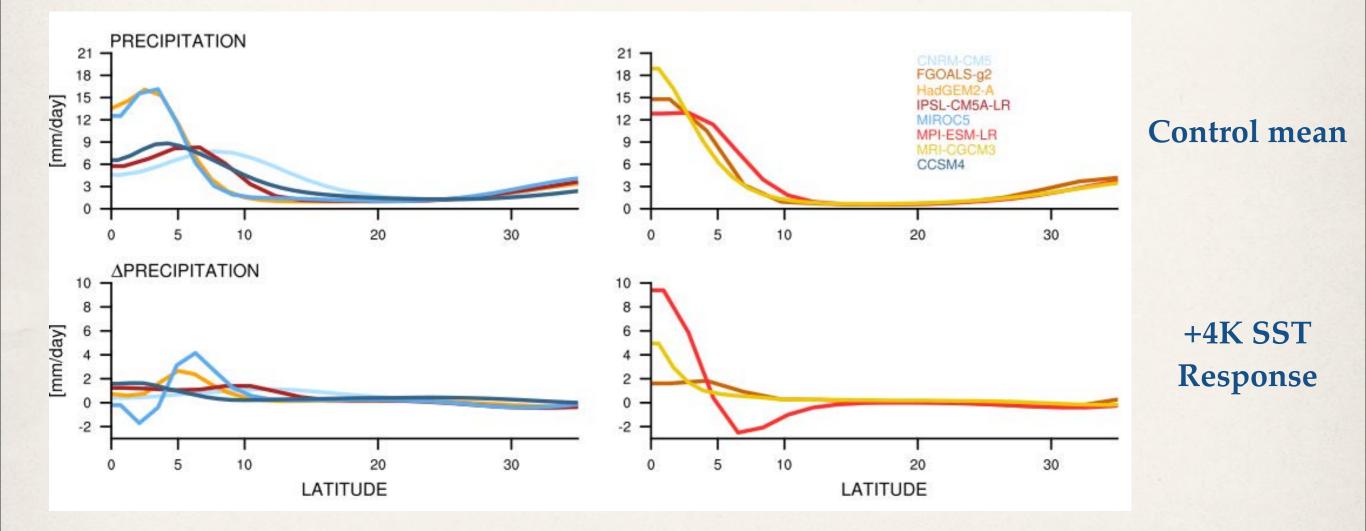
Response in cloud and precipitation to a 4°C warming

Stevens and Bony, Science, 2013

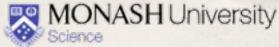




The original model mean state is crucial for the response!

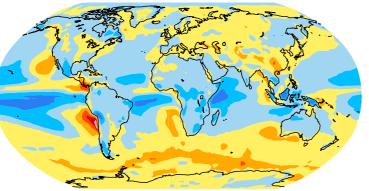


Medeiros et al., 2014, submitted to Clim. Dyn.

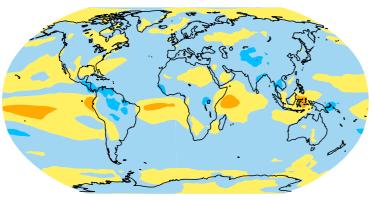


ARC CENTRE OF EXCELLENCE FOR CLIMATE SYSTEM SCIENCE Clouds and precipitation remain a challenge

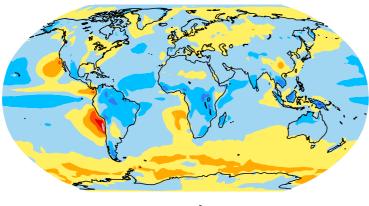
(a) Shortwave cloud radiative effect - MOD-OBS

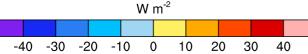


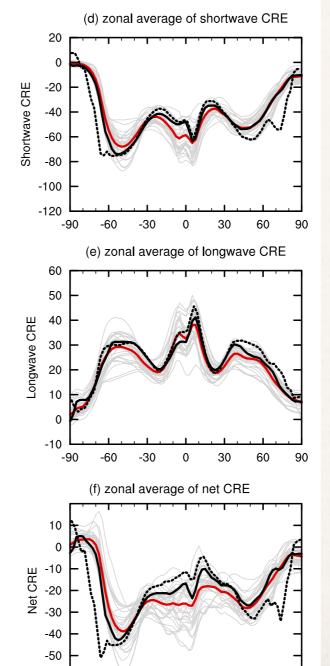
(b) Longwave cloud radiative effect - MOD-OBS



(c) Net cloud radiative effect - MOD-OBS







-60 -90

-60

-30

0

Latitude

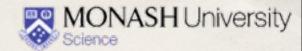
30

60

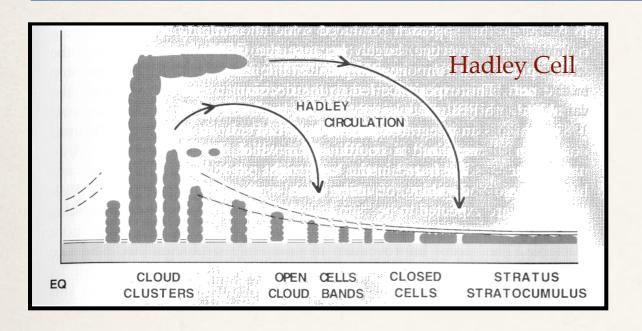
90

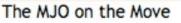
CMIP5 multimodel mean cloudradiative effects

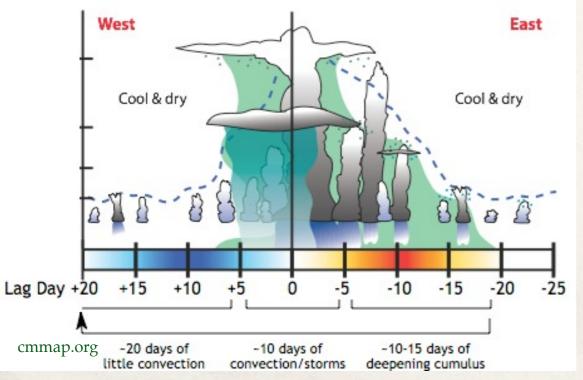




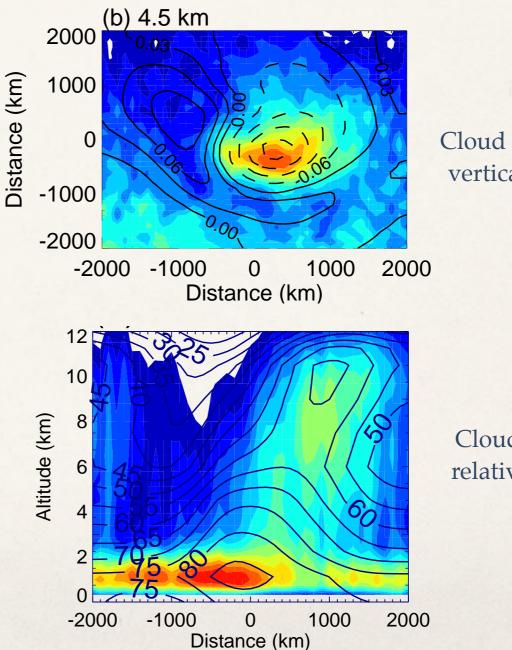
Water in the atmosphere couples to the circulation at many scales







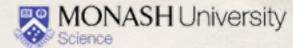
Clouds in Southern Ocean Cyclones



Cloud cover and vertical motion

Cloud cover and relative humidity

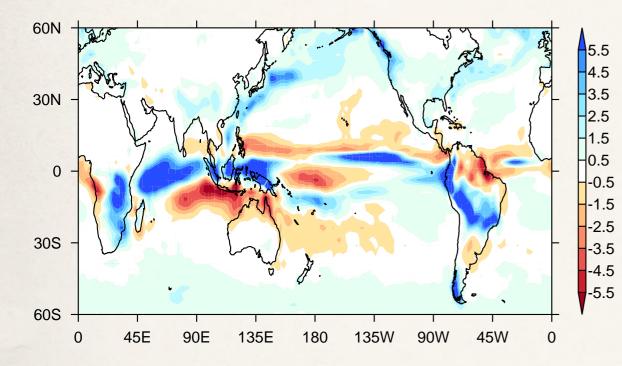




Large rainfall biases often coincide with large circulation biases

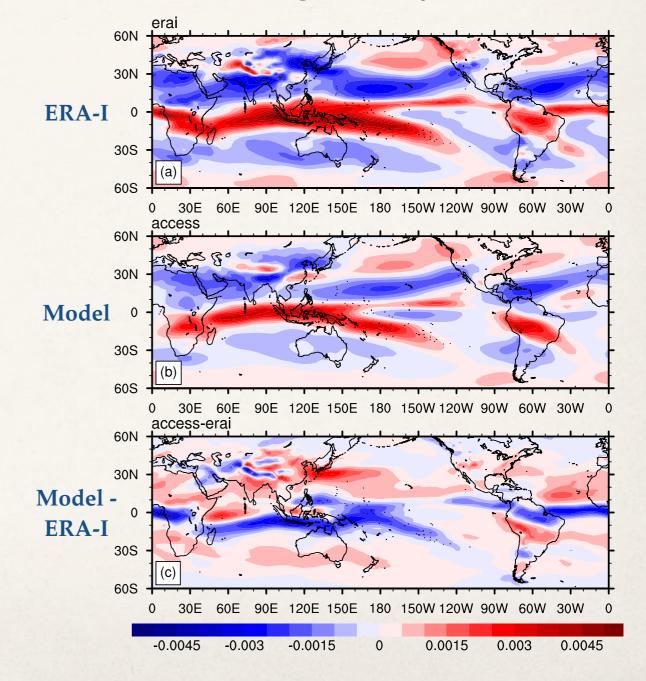
Model rainfall bias

(d) ACCESS1.3 - CMAP precipitation (mm day⁻¹)

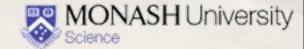


From Duncan Ackerley and Juliane Schwendicke see also Schwendicke et al., JGR2014

Local meridional overturning (Hadley) circulation



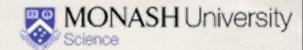




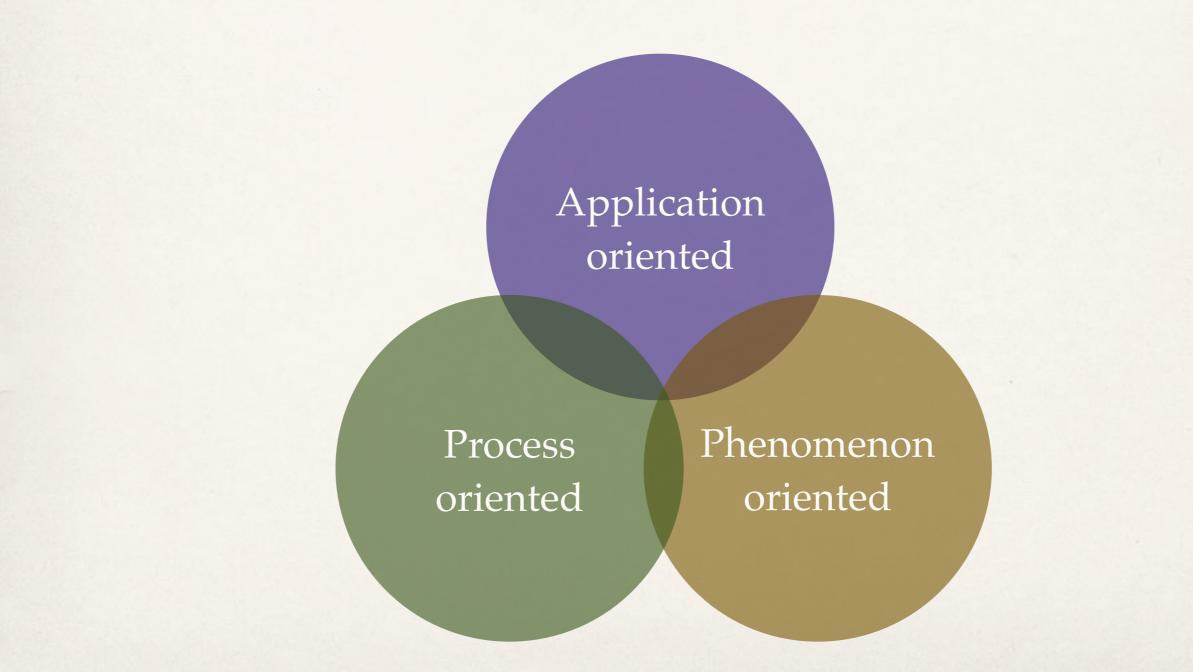
What to do?

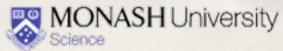






We must develop and employ more insightful evaluation techniques

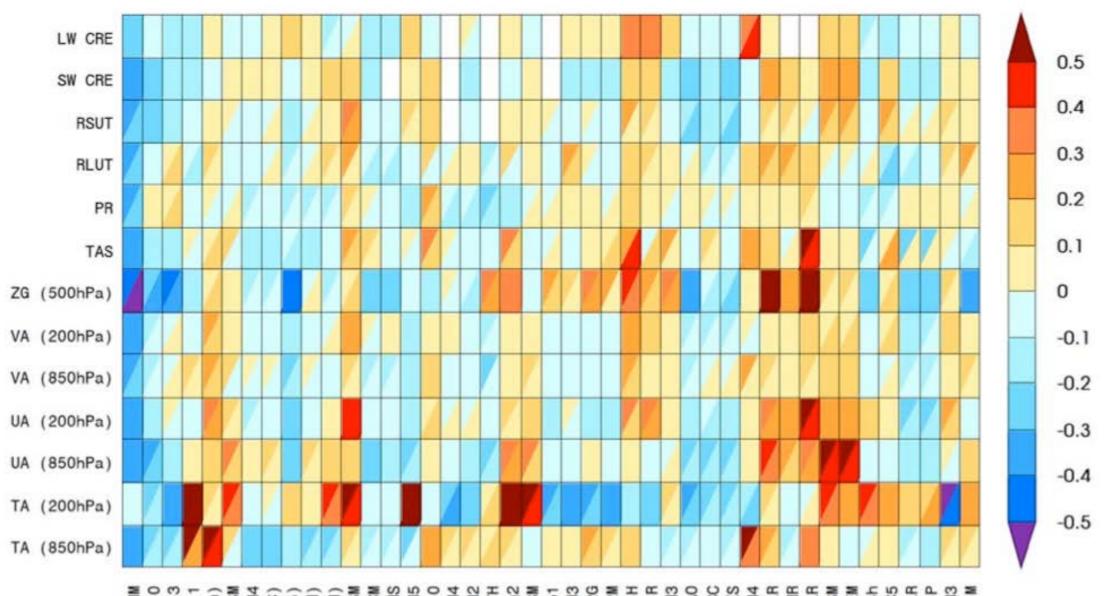




Application-oriented model evaluation sets the scene.

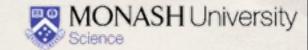
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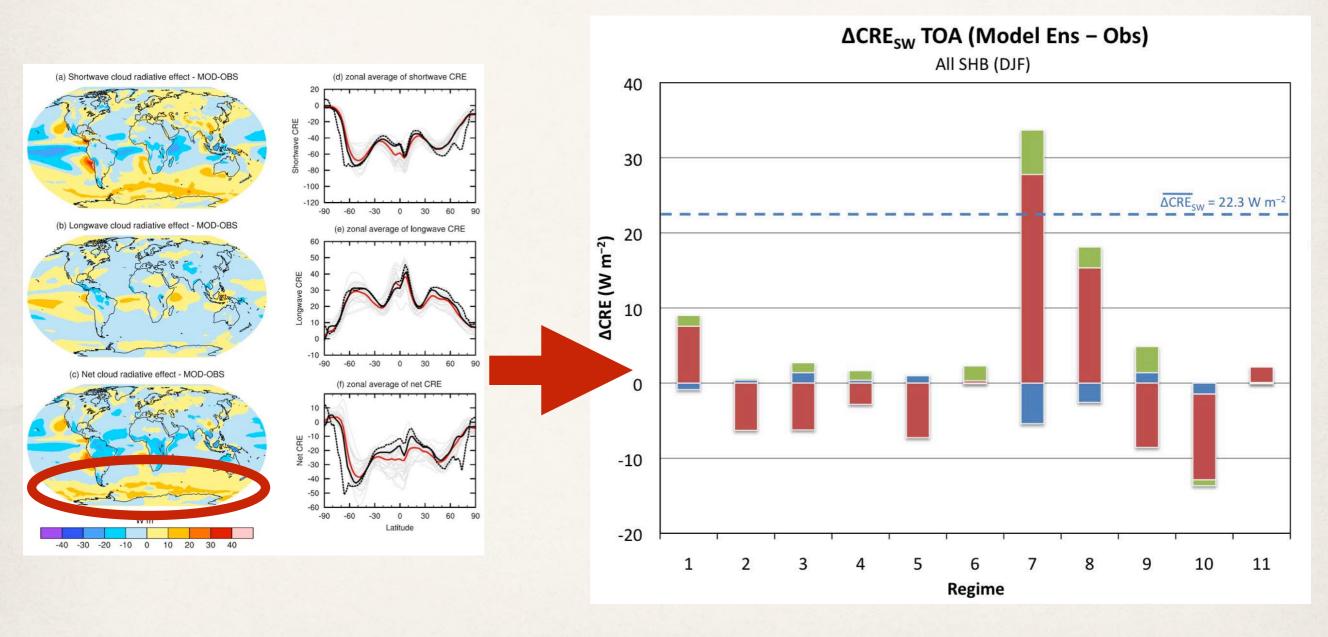


ACCESS1-0 ACCESS1-3 BCC-CSM1.1 BCC-CSM1.1(m) BCC-CSM1.1(m) EC-EARTH FGOALS-g2 FIO-ESM GFDL-ESM2G GFDL-ESM2M GISS-E2-H MP1-ESM-P MR1-CGCM3 CMCC-CMS CNRM-CM5 CanESM2 **CCSM4** CanCM4 MMM CMCC-CESM CMCC-CM CS1R0-Mk3-6-0 GFDL-CM3 HadGEM2-A0 HadGEM2-CC HadGEM2-ES PSL-CM5A-LR IPSL-CM5B-LR MIROC-ESM-CHEM M I ROC5 **MPI-ESM-LR** NorESM1-M HadCM3 INM-CM4 PSL-CM5A-MF MIROC-ESN MIROC4h CESM1 (BGC) GFDL-CM2p1 GISS-E2-F CESM1 (CAM5) CESM1 (FASTCHEM) CESM1 (WACCM)



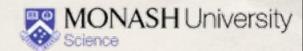


Regime-oriented approaches then allow for decomposition of model errors

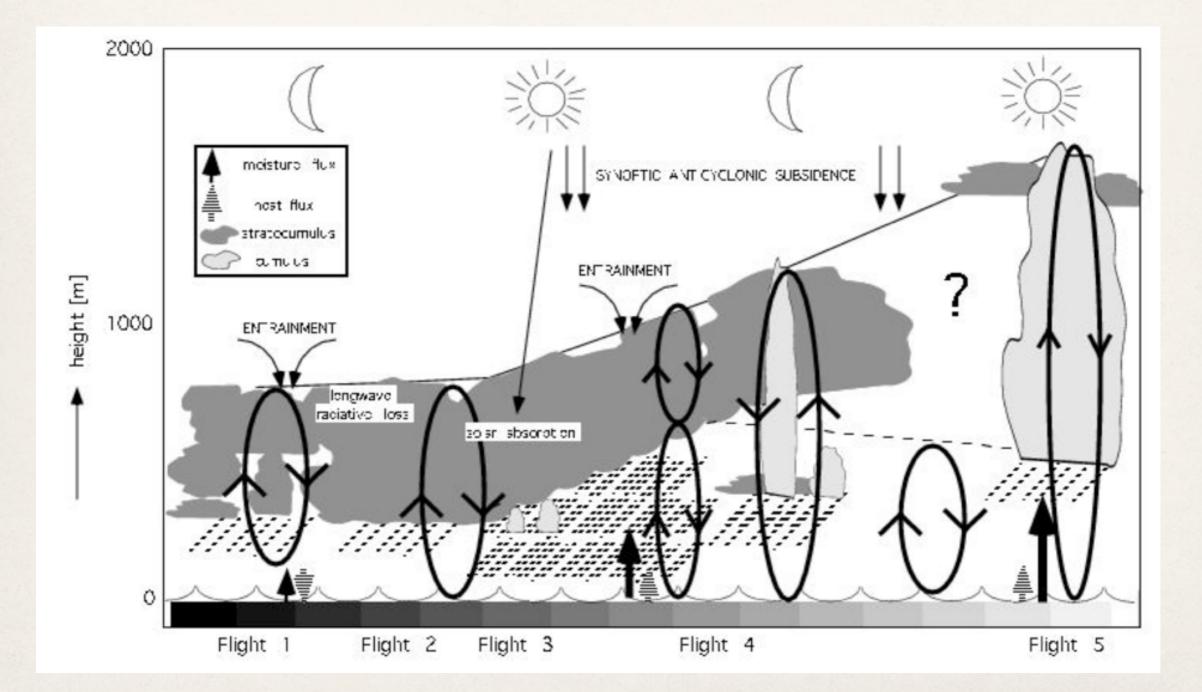


 $\Delta CRE = \sum_{r=1}^{11} RFO_{r} \Delta CRE_{r} + \sum_{r=1}^{11} CRE_{r} \Delta RFO_{r} + \sum_{r=1}^{11} \Delta RFO_{r} \Delta CRE_{r}$ r=1r=1

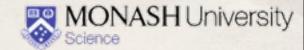




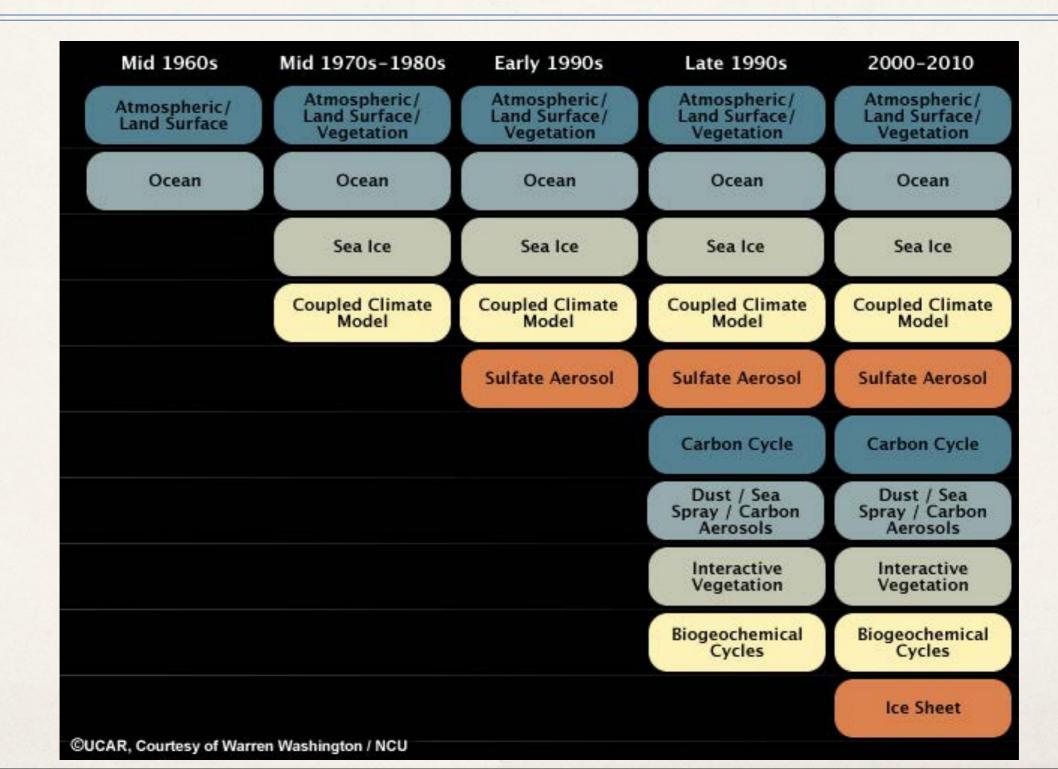
Finally process evaluation gets to the bottom of it all



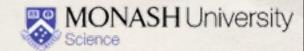




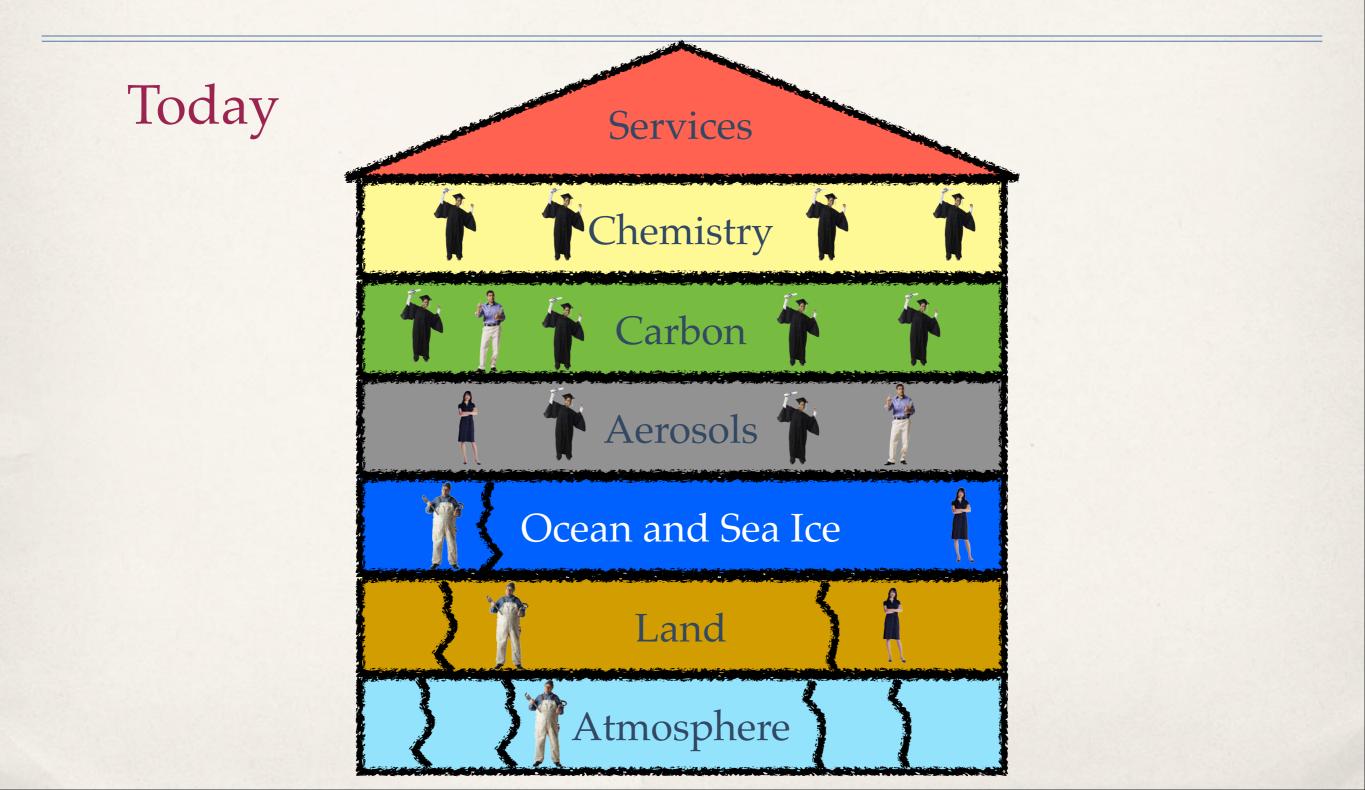
Models are now more complex extending their use in principle



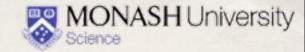




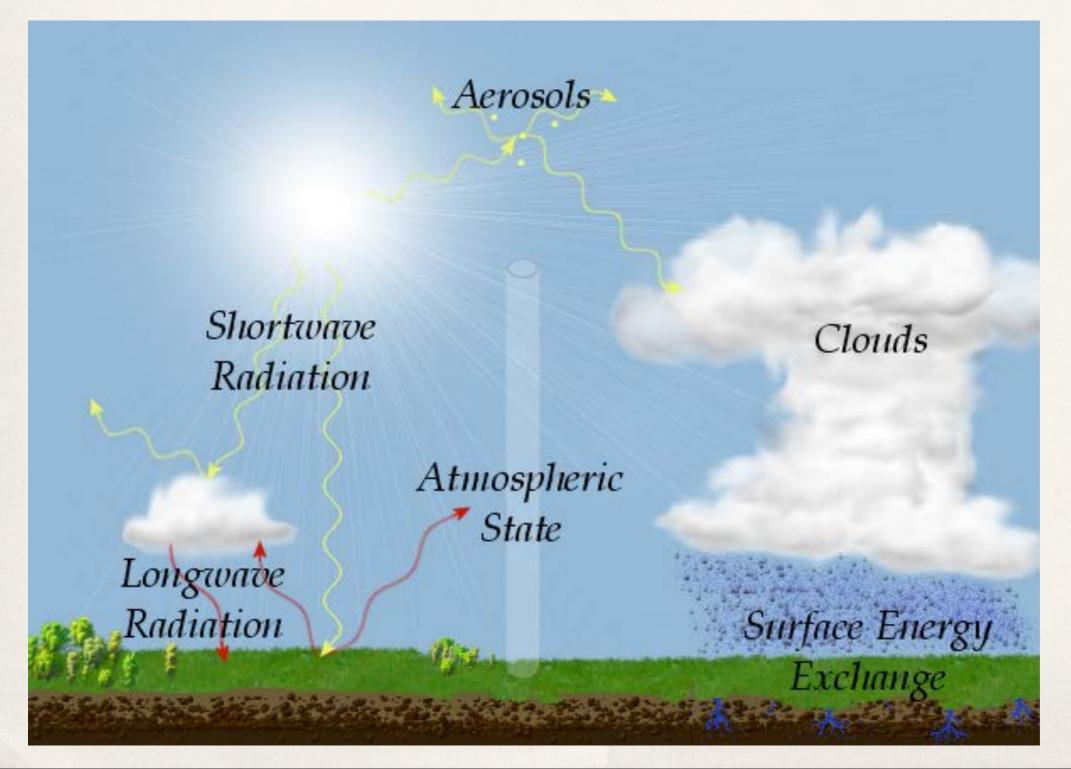
The climate model building - The foundations need more attention!





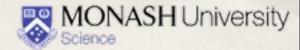


Improving the treatment of water and its link to circulations in the atmosphere is critical



Source: DOE ARM program





Finding solutions requires concerted efforts in model evaluation and development

The World Climate Research Programme Grand Challenge on: *Clouds, Circulation and Climate Sensitivity Bjorn Stevens (MPI) and Sandrine Bony (LMD)*

Climate Sensitivity Steve Sherwood (UNSW) and Mark Webb (UKMO)

Changing Patterns

Ted Shepherd (U Reading) and Adam Sobel (Columbia U)

Towards more reliable models

Christian Jakob (Monash) and Masahiro Watanabe (U Tokyo)

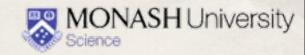
Coupling Clouds To Circulation

Dargan Frierson (U Wash) and Pier Siebesma (KNMI)

Leveraging the Past Record

Robert Pincus (NOAA) and Masa Kageyama (IPSL)





Model developers are in short supply and the problem is hard - we need new people and better collaborative structures!

Modelling Centres

- Open the models to the community
- Change the rewards systems for model developers
- Involve model developers in model application projects
- Involve non-developers in model development projects

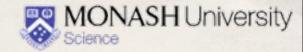
- Strong formal links between Centres and Academia
- Joint PhD to guaranteed Postdoc positions
- Strategic partnerships of Centres with Academic funding programmes
- MANY joint research activities

Highly doted scholarships in model development -Rhodes scholars

Academia

- University chairs in model development
- Change the rewards system for model developers





Summary

- Weather and climate models underpin some of mankind's greatest endeavours. They save lifes. They save property. They affect all aspects of society.
- Improvements in predictions have been underpinned by improvements in models - Future improvements require renewed and increased investment in basic model development.
- Models have become increasingly complex, but some key issues have not been resolved. In particular the treatment of water in the atmosphere requires further improvements through focussed community efforts.
- We need the entire community to express this need and to contribute to finding solutions.