Observational constraints on mixed-phase clouds imply higher climate sensitivity

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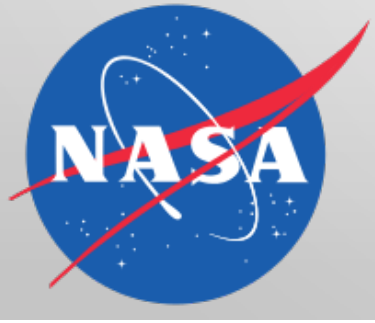
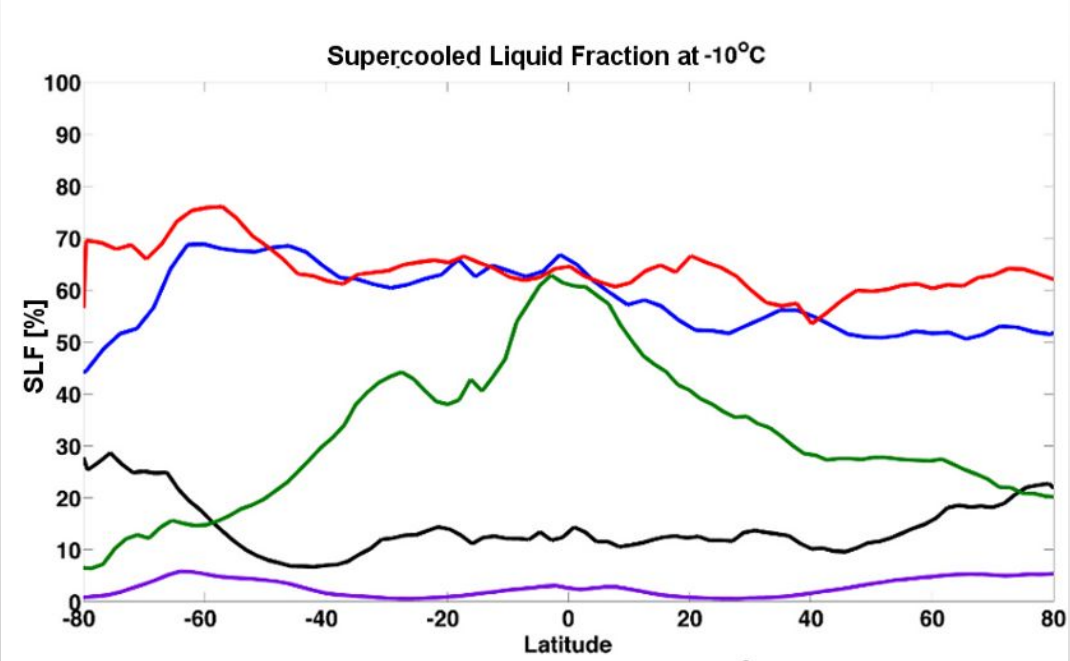


TAKE-HOME MESSAGES

- CALIOP CLOUD TOP PHASE RETRIEVALS SHOW THAT GLOBAL CLIMATE MODELS (GCMS) UNDERESTIMATE THE RELATIVE AMOUNTS OF LIQUID IN MIXED-PHASE CLOUDS
- THIS HAS IMPLICATIONS FOR THEIR ABILITY TO CORRECTLY SIMULATE AN IMPORTANT CLOUD-CLIMATE FEEDBACK INVOLVING MIXED-PHASE CLOUDS

GCM UNDERESTIMATION OF SUPERCOOLED LIQUID



FROM KOMURCU ET AL. (2014)

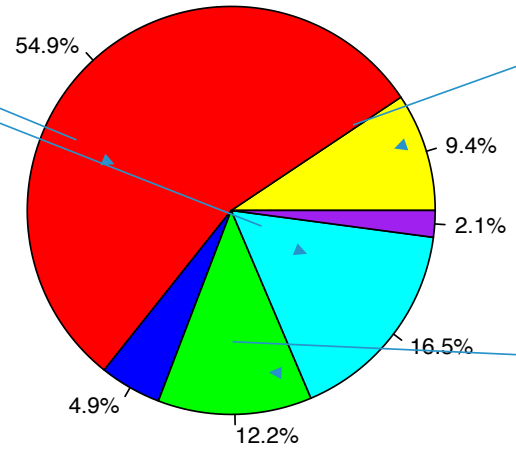
ECHAM6 CAM-IMPACT CAM-Oslo CAM 5.1 MAM7 CALIOP

CESANA ET AL. (2015) AND MCCOY ET AL. (2016) HAVE SINCE CONFIRMED THE GENERAL GCM UNDERESTIMATION OF SUPERCOOLED LIQUID

WHAT CONTROLS SUPERCOOLED LIQUID IN GCMS?

Contribution to cloud phase variability in CAM5

The Wegener-Bergeron-Findeisen (WBF) process



Heterogeneous ice nucleation

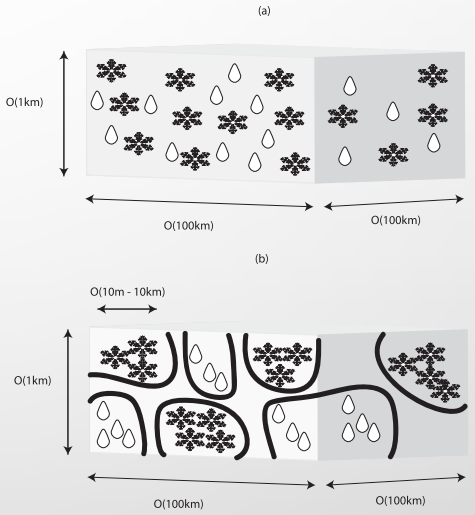
Ice crystal fall speed

10°C isotherm

Tan and Storelvmo (JAS, 2015)

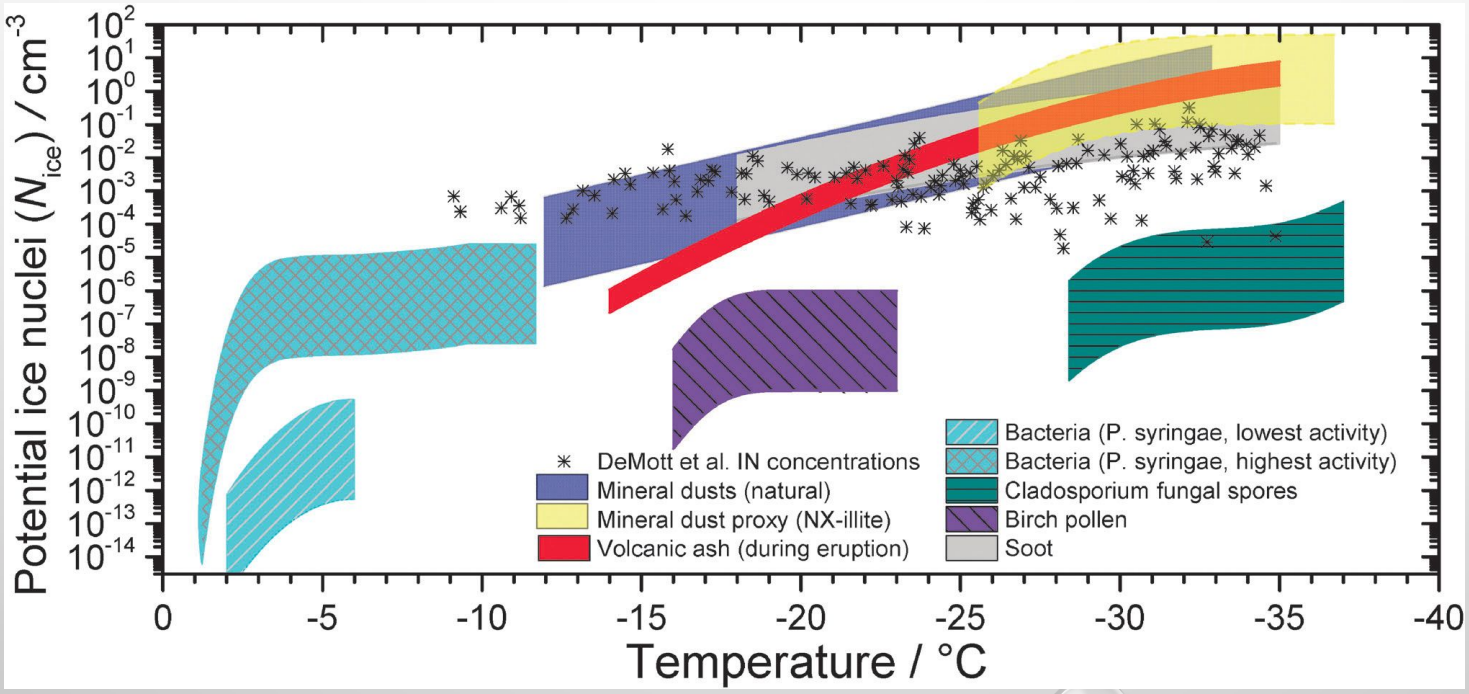
MIXED-PHASE CLOUD SUB-GRIDSCALE STRUCTURE

- "DISCOVERED" ~25 YEARS AGO BY MITCHELL ET AL. (1989) AND LI & LE TREUT (1992)
- THE STANDARD ASSUMPTION IN CLIMATE MODELS IS THAT LIQUID AND ICE ARE UNIFORMLY MIXED THROUGHOUT EACH ENTIRE MODEL GRID BOX
- IN REALITY, FIELD MEASUREMENTS SHOW THAT MIXED-PHASE CLOUDS MORE TYPICALLY CONSIST OF POCKETS CONSISTING SOLELY OF LIQUID OR ICE
- THIS HAS CONSEQUENCES FOR HOW THE WBF PROCESS SHOULD BE PARAMETERIZED IN LARGE-SCALE MODELS



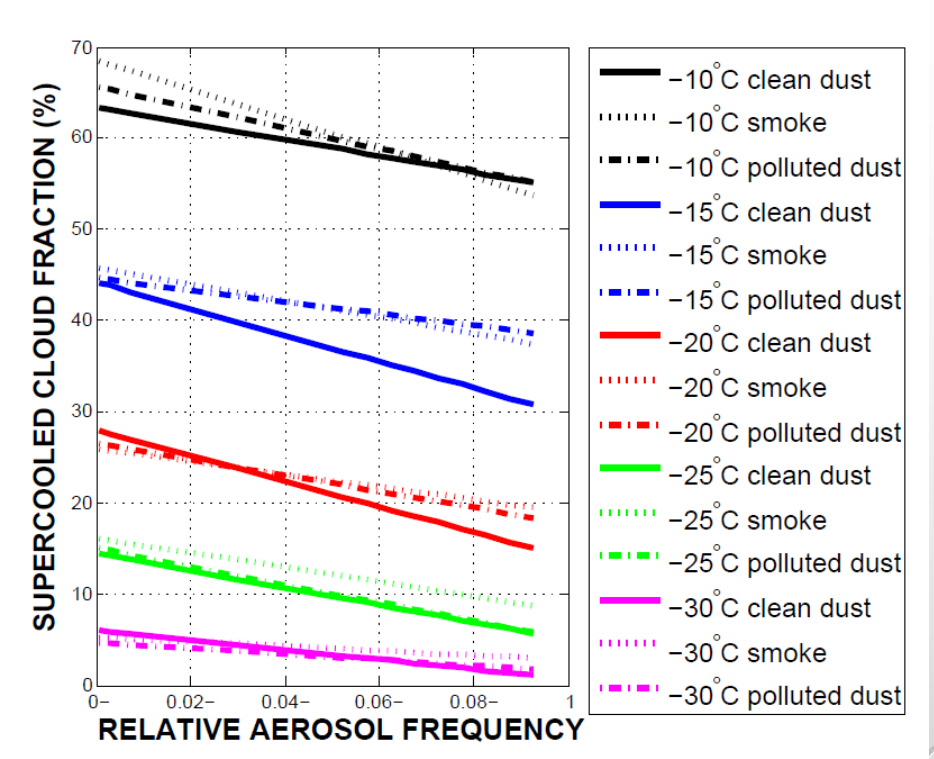
Tan and Storelvmo (JAS, 2015)

WHAT PARTICLES ARE RELEVANT AS ICE NUCLEI IN THE ATMOSPHERE?



Murray et al. (2012)

ICE NUCLEATION SEEN FROM SPACE

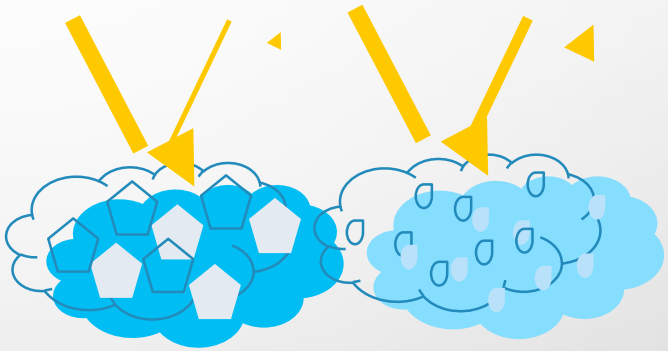


- THE AMOUNT OF SUPERCOOLED LIQUID IS NEGATIVELY CORRELATED WITH (IN ORDER OF STATISTICAL SIGNIFICANCE):
  1. MINERAL DUST
  2. MINERAL DUST MIXED WITH POLLUTION
  3. SMOKE

Aerosol frequency of occurrence and SLF from CALIOP (2007-2014) *Tan, Storelvmo & Choi (JGR, 2014)*

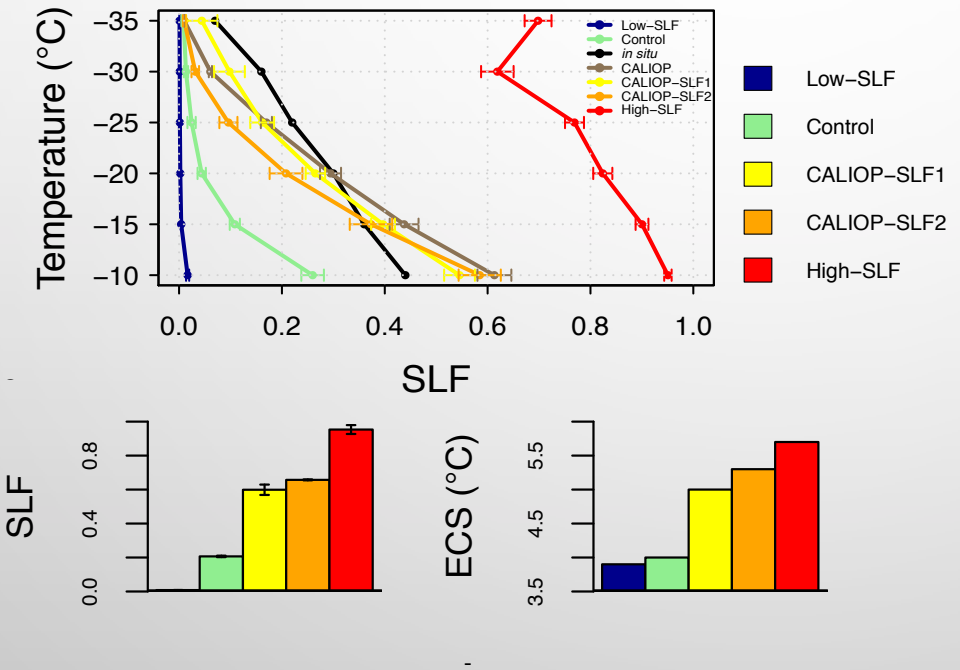
THE "CLOUD PHASE FEEDBACK"

- FOR COMPARABLE CLOUD WATER CONTENTS, LIQUID CLOUDS ARE OPTICALLY MUCH THICKER THAN ICE CLOUDS
- AS THE TROPOSPHERE WARMS DUE TO INCREASING ATMOSPHERIC CO_2, ICE CLOUDS ARE REPLACED BY LIQUID CLOUDS, AND THE OVERALL CLOUD OPTICAL THICKNESS INCREASES.
- THIS AFFECTS BOTH LW AND SW RADIATION, BUT THE SW EFFECT DOMINATES.
- THE RESULTING CLOUD-CLIMATE FEEDBACK IS NEGATIVE, AND MOST IMPORTANT AT MID/HIGH LATITUDES.



Storelvmo, Tan and Korolev (2015)

IMPACT OF SUPERCOOLED LIQUID ON EQUILIBRIUM CLIMATE SENSITIVITY (ECS)

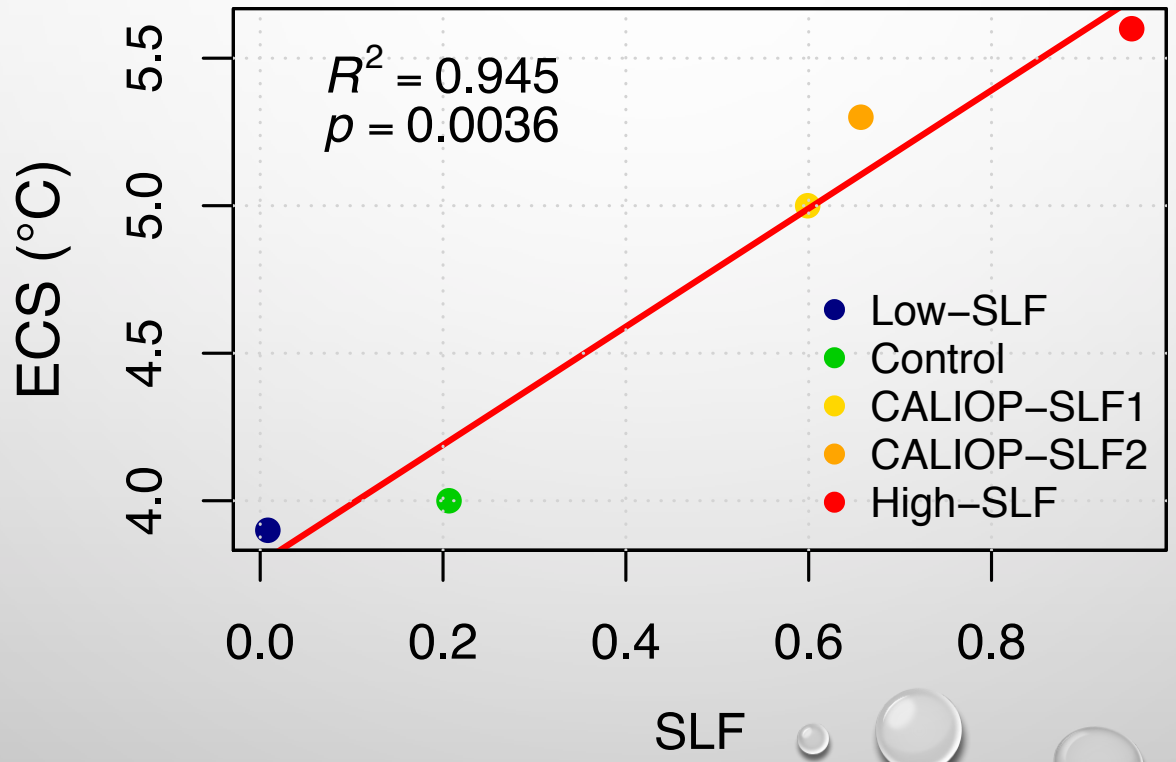


- 5 atmosphere+ocean simulations with very different amounts of super-cooled liquid were run to equilibrium with both present-day and doubled atmospheric CO_2.
- Two of them (CALIOP-SLF1 and CALIOP-SLF2) were designed to have SLFs similar to CALIOP (achieved by reducing IN concentration and retarding WBF process).

Modeling tool: The Community Earth System Model (CESM)

Tan, Storelvmo & Zelinka (2016)

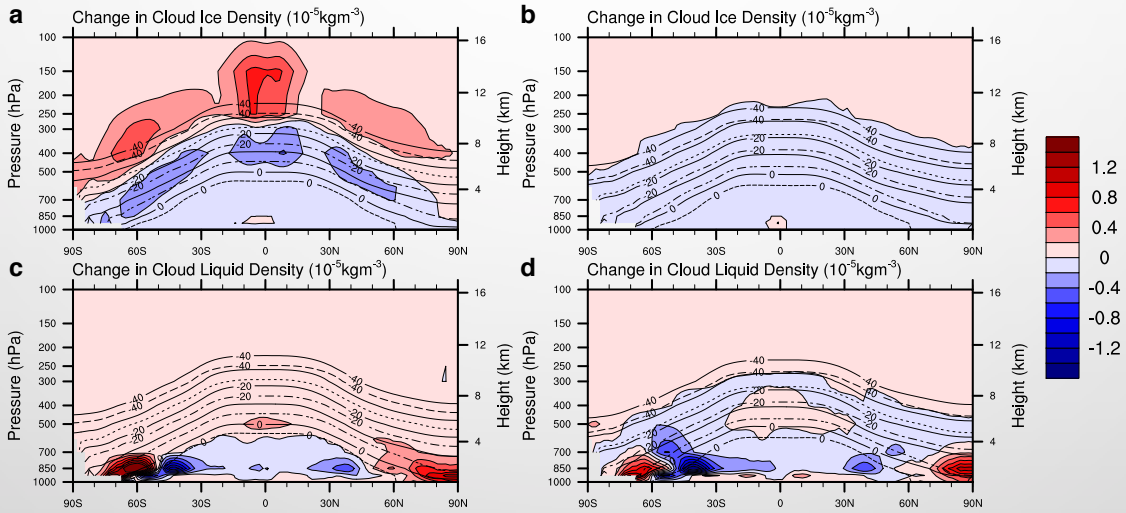
RELATIONSHIP BETWEEN SLF AND ECS



THE CLOUD PHASE FEEDBACK IN ACTION

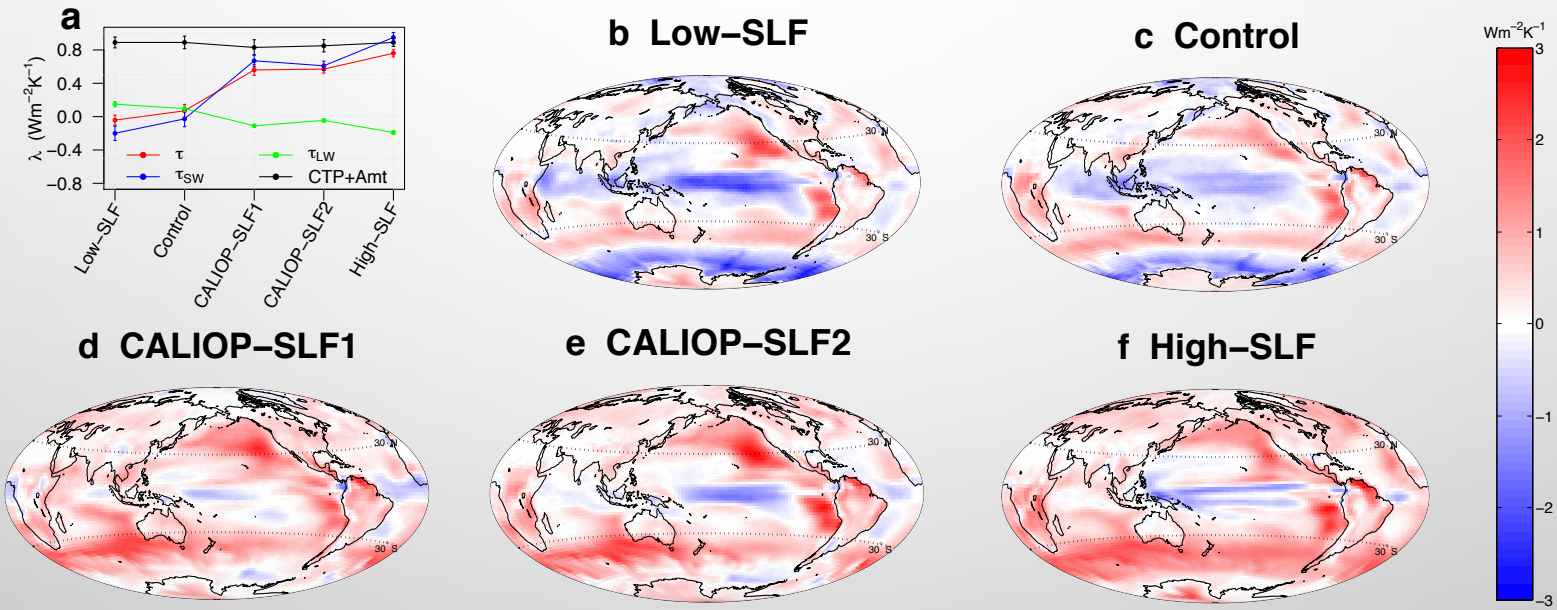
Low-SLF

High-SLF



Tan, Storelvmo & Zelinka (2016)

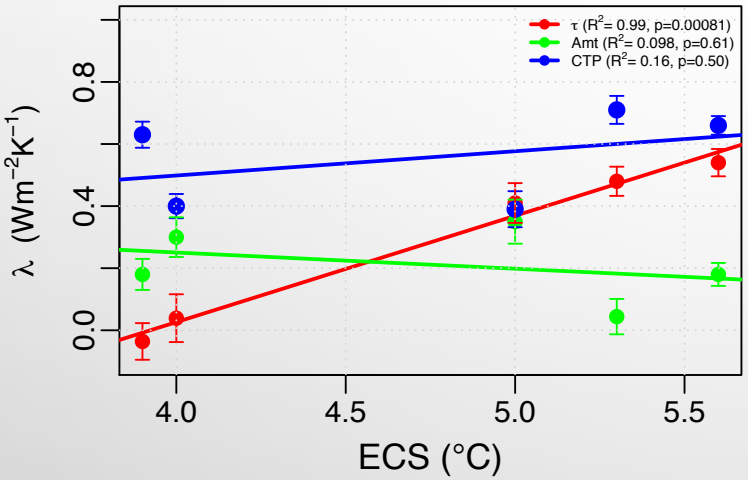
DIFFERENCES IN ECS CAUSED BY DIFFERENCES IN THE CLOUD OPTICAL DEPTH FEEDBACK



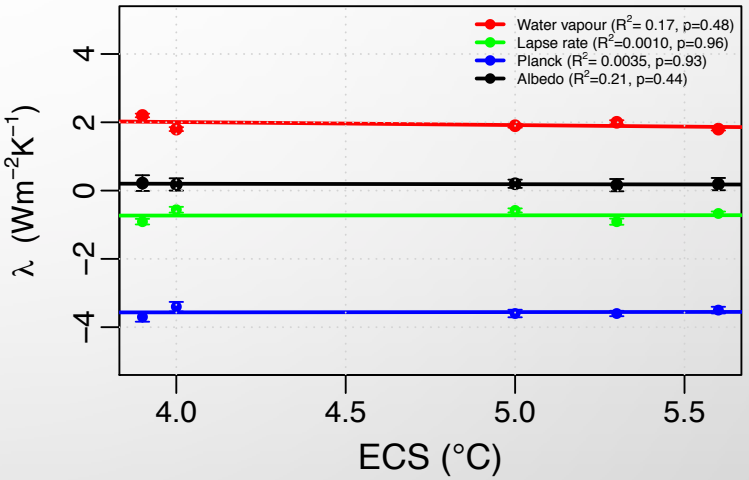
Tan, Storelvmo & Zelinka (2016)

CLOUD VS. NON-CLOUD FEEDBACKS

Cloud feedbacks



Non-cloud feedbacks



Tan, Storelvmo & Zelinka (2016)

CONCLUSION

- CLOUD PHASE EXERTS A DOMINANT INFLUENCE ON THE OVERALL CLOUD-CLIMATE FEEDBACK, AND THEREFORE ON CLIMATE SENSITIVITY
- CLOUD PHASE IS ONE OF ONLY A HANDFUL OF KNOWN EMERGENT CONSTRAINTS ON MODEL PERFORMANCE
- GLOBAL HIGH-QUALITY CLOUD PHASE OBSERVATIONS ARE CRITICALLY IMPORTANT FOR GCM VALIDATION AND ULTIMATELY FOR RELIABLE PROJECTIONS OF FUTURE CLIMATE