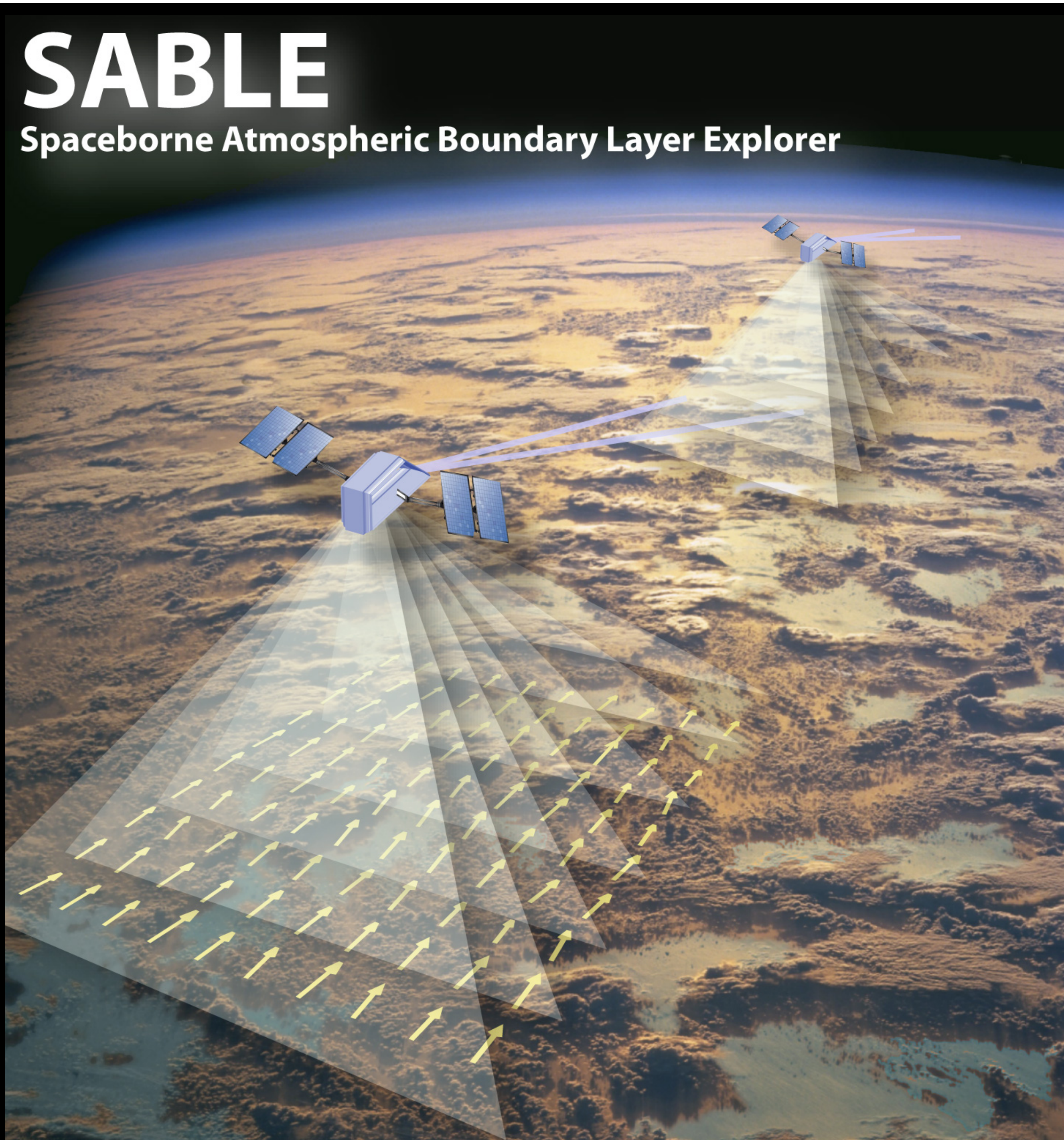
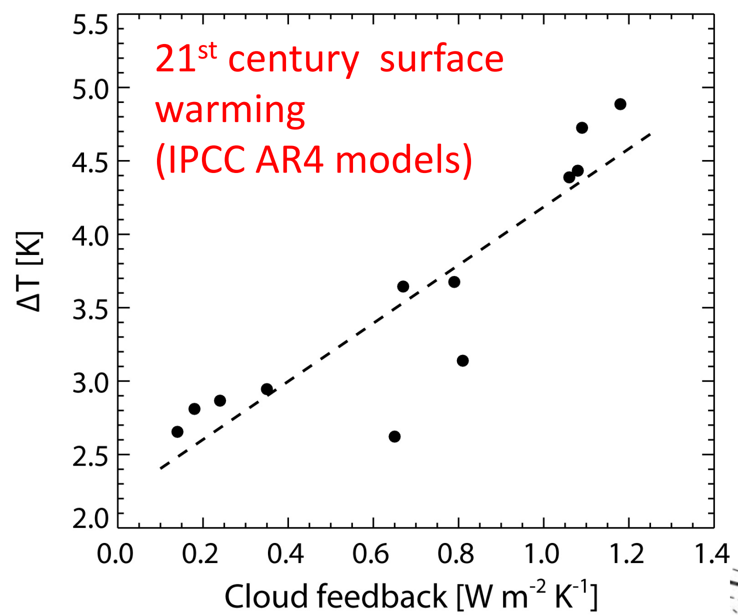
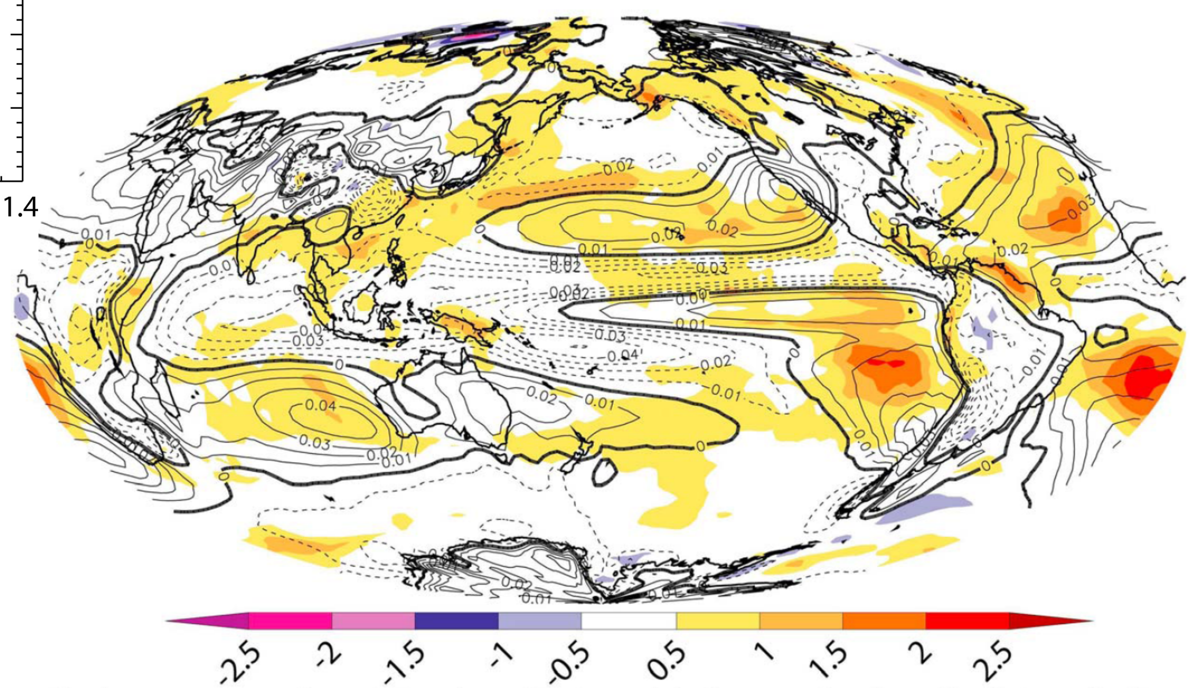

SABLE
Spaceborne Atmospheric Boundary Layer Explorer

Boundary layer clouds are key uncertainty hindering accurate prediction of global warming



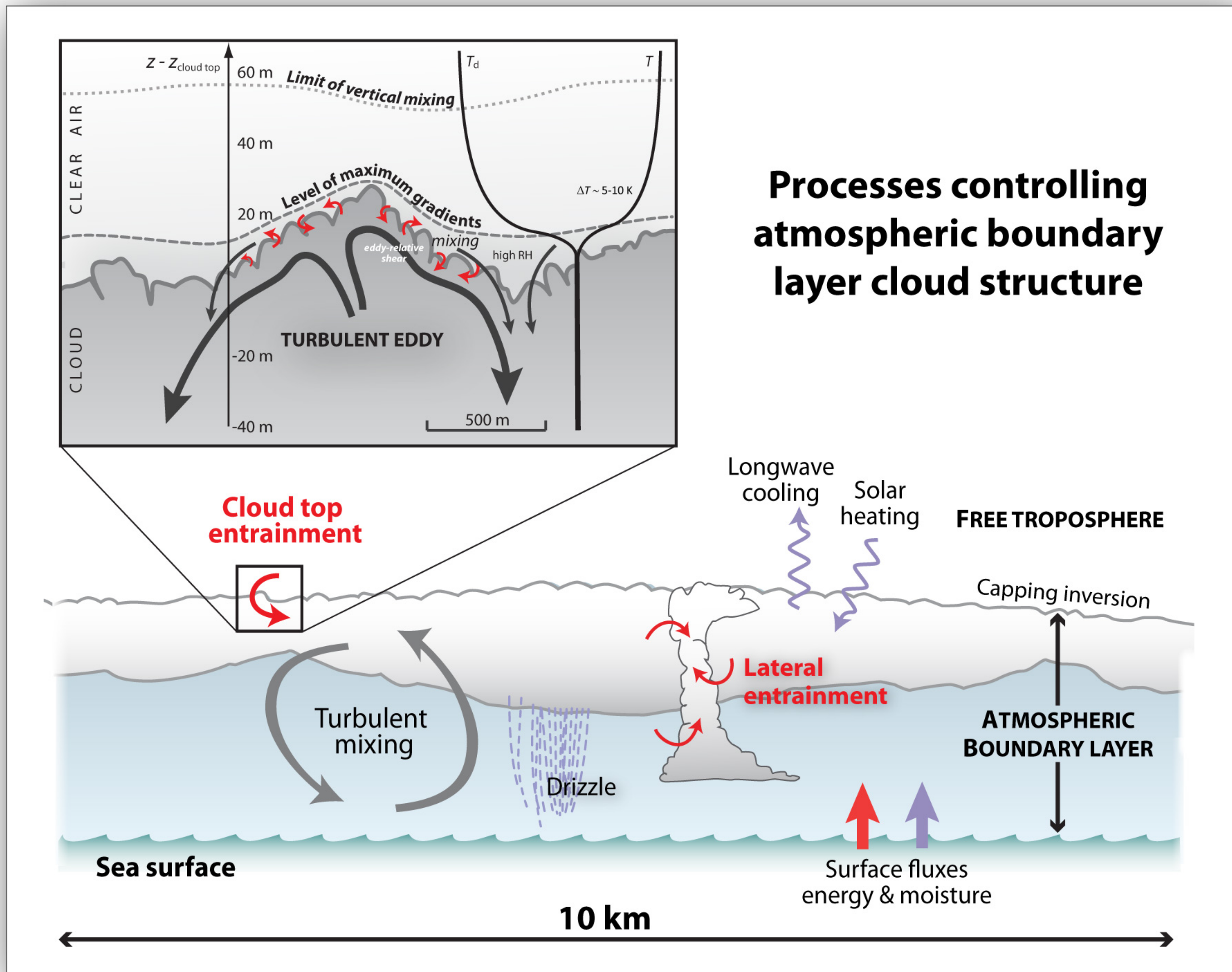
from Soden and Held, *J. Clim*. (2006)

- Cloud feedback uncertainty dominates climate sensitivity uncertainty
- Low clouds are dominant source of cloud feedback uncertainty across models and within models (e.g. PPE)



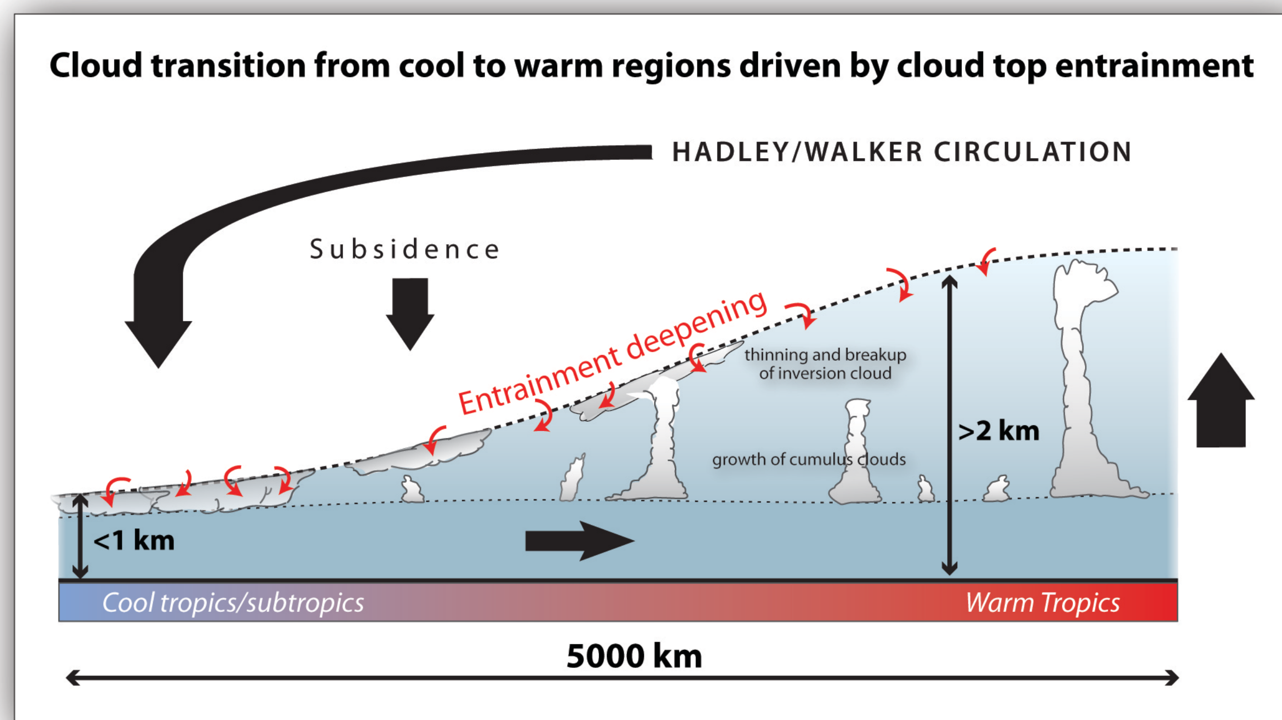
Shade: Regression of Local Cloud Feedback to Global-mean Cloud Feedback ($W \cdot m^{-2} \cdot K^{-1}$)
Contour: Background 500hPa Pressure Velocity ($Pa \cdot s^{-1}$)

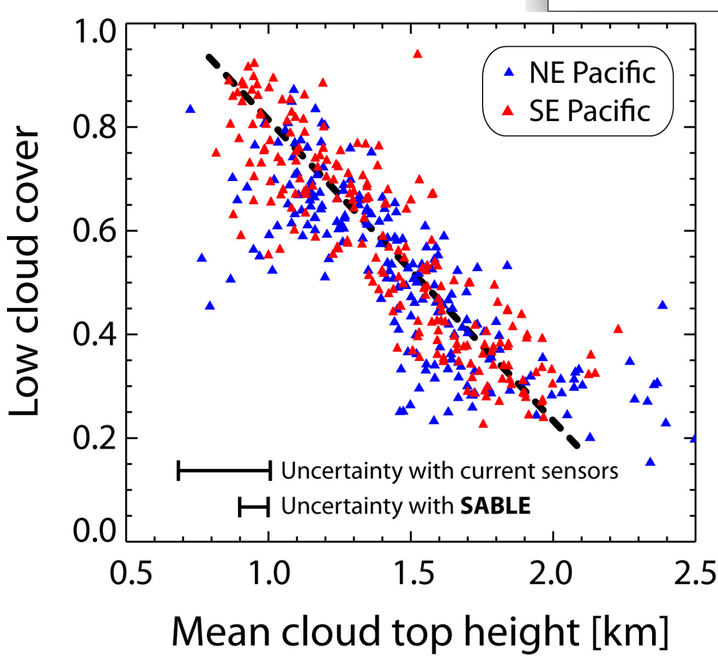
Soden and Vecchi, *Geophys. Res. Lett*. (2011)



Processes controlling atmospheric boundary layer cloud structure
Z - Z cloud top
60 m
40 m
20 m
-20 m
-40 m
Limit of vertical mixing
Level of maximum gradients
CLEAR AIR
CLOUD
Td
T
ΔT ~ 5-10 K
eddy-relative shear
mixing
high RH
TURBULENT EDDY
500 m
Cloud top entrainment
Longwave cooling
Solar heating
FREE TROPOSPHERE
Capping inversion
Turbulent mixing
Lateral entrainment
Drizzle
ATMOSPHERIC BOUNDARY LAYER
Sea surface
Surface fluxes energy & moisture
10 km

Cloud top entrainment



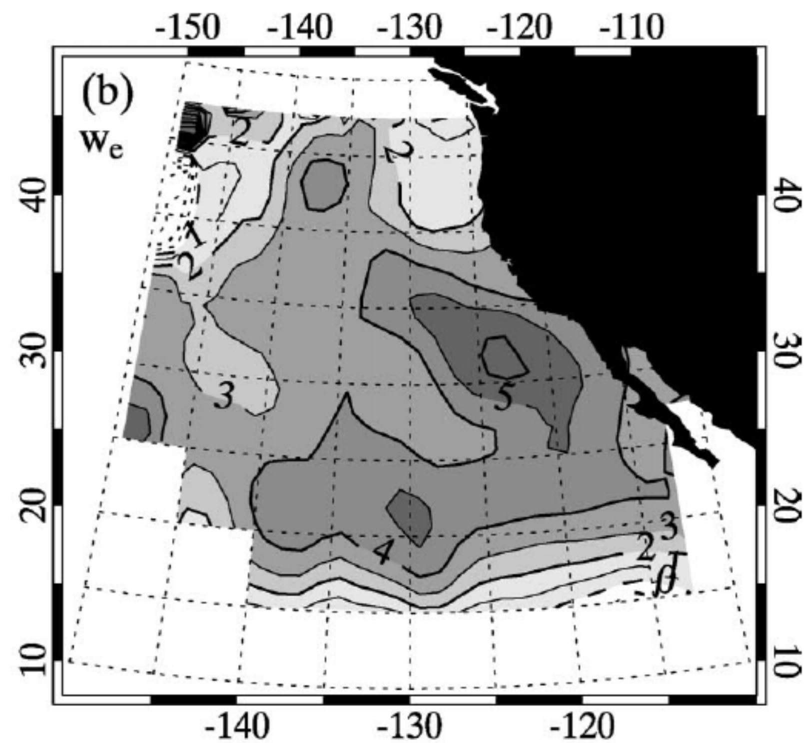


- Cloud top entrainment rate controls ABL structure and subtropical to tropical cloudiness transitions (Sc-to-Cu transition)
- Small scale turbulent process poorly represented in large scale models

Wood and Hartmann (2006)

Measuring cloud top entrainment rate from space

- Mean cloud top entrainment rate can be measured using an ABL mass budget approach (Wood and Bretherton 2004)
- Requires measurements of ABL top height and winds ~5 times better than those currently available from space



Entrainment rate

StereoCam cloudtop vector winds

Subsidence rate from StereoCam cloudtop heights, wind divergence, and reanalysis

$$w_e = \mathbf{u} \cdot \nabla z + w_s$$

High vertical resolution (50 m) StereoCam cloudtop height gradient

Spaceborne Atmospheric Boundary Layer Explorer (SABLE)

- Mission will be proposed to the Earth System Science Pathfinder (ESSP) Program, Earth Venture (EV-2), Sept 2011
- SABLE is a physical process-focused mission to observe the cloudy boundary layer
- SABLE uses tandem satellites to make high resolution measurements of cloud top heights and 3D cloud top winds using a dual stereo technique
- Government-commercial partnership between NASA and Iridium-NEXT for low-cost access to space

Overarching science goal: To reduce the largest source of uncertainty in predicting the magnitude of future greenhouse warming: the response of boundary layer clouds to climate change

Objective 1. Quantify, through observation, global cloud top entrainment rate (ER) —the key parameter that governs cloud lifecycle, structure, and variability in the marine ABL

Objective 2. Explore and quantify relationships between cloud thickness, cover, and ER to understand turbulence processes inside the cloudy boundary layer

Objective 3. Understand ABL cloud transitions by quantifying how ER affects cloud top height distribution and ABL vertical structure.

SABLE Goal: Quantify Entrainment Rates from Space

SABLE Measurements: Cloud top height and wind, ABL top and stratification

Entrainment rate

StereoCam cloud top winds

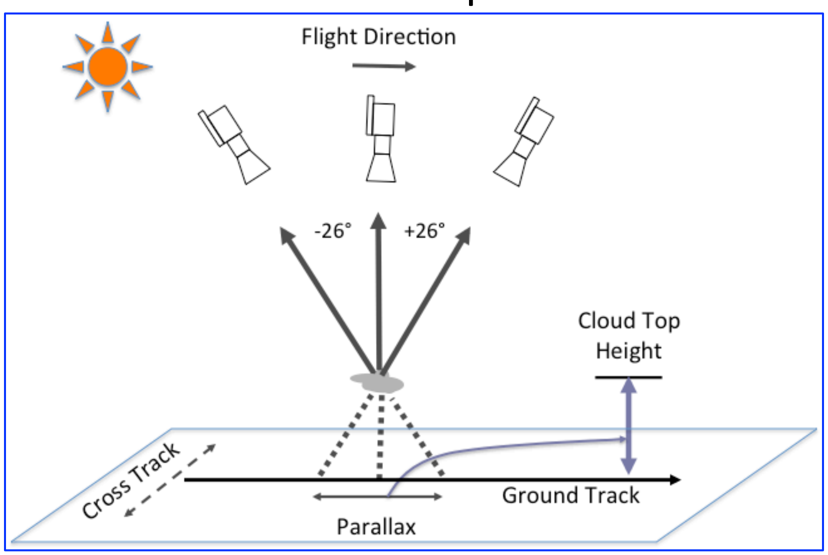
Subsidence rate from StereoCam divergence and reanalysis

$$w_e = \boldsymbol{u} \cdot \nabla z_i + w_s$$

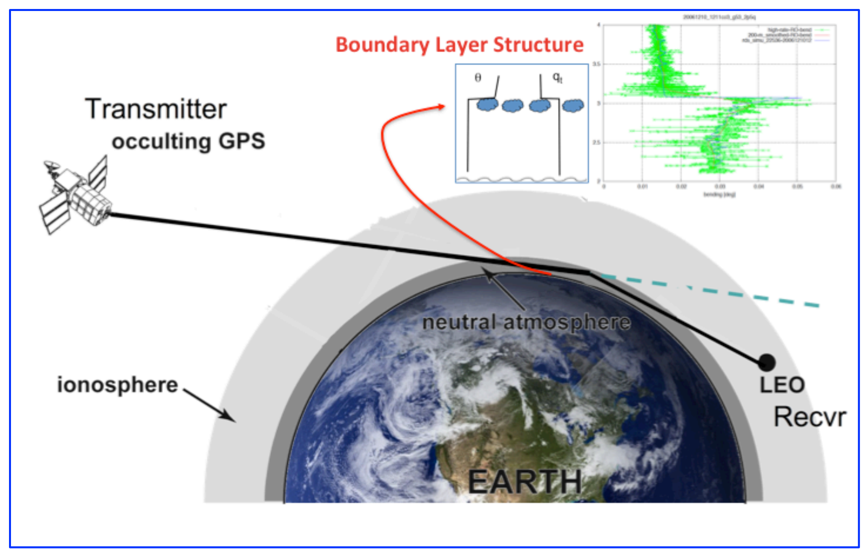
High-resolution (50 m) StereoCam/ GPS RO cloud top height

SABLE Techniques: StereoCam + GPS/RO on Iridium-NEXT

Visible Stereoscopic Camera



GPS Radio Occultation



Observables:

StereoCam

- Cloud top height
(50 m absolute accuracy)

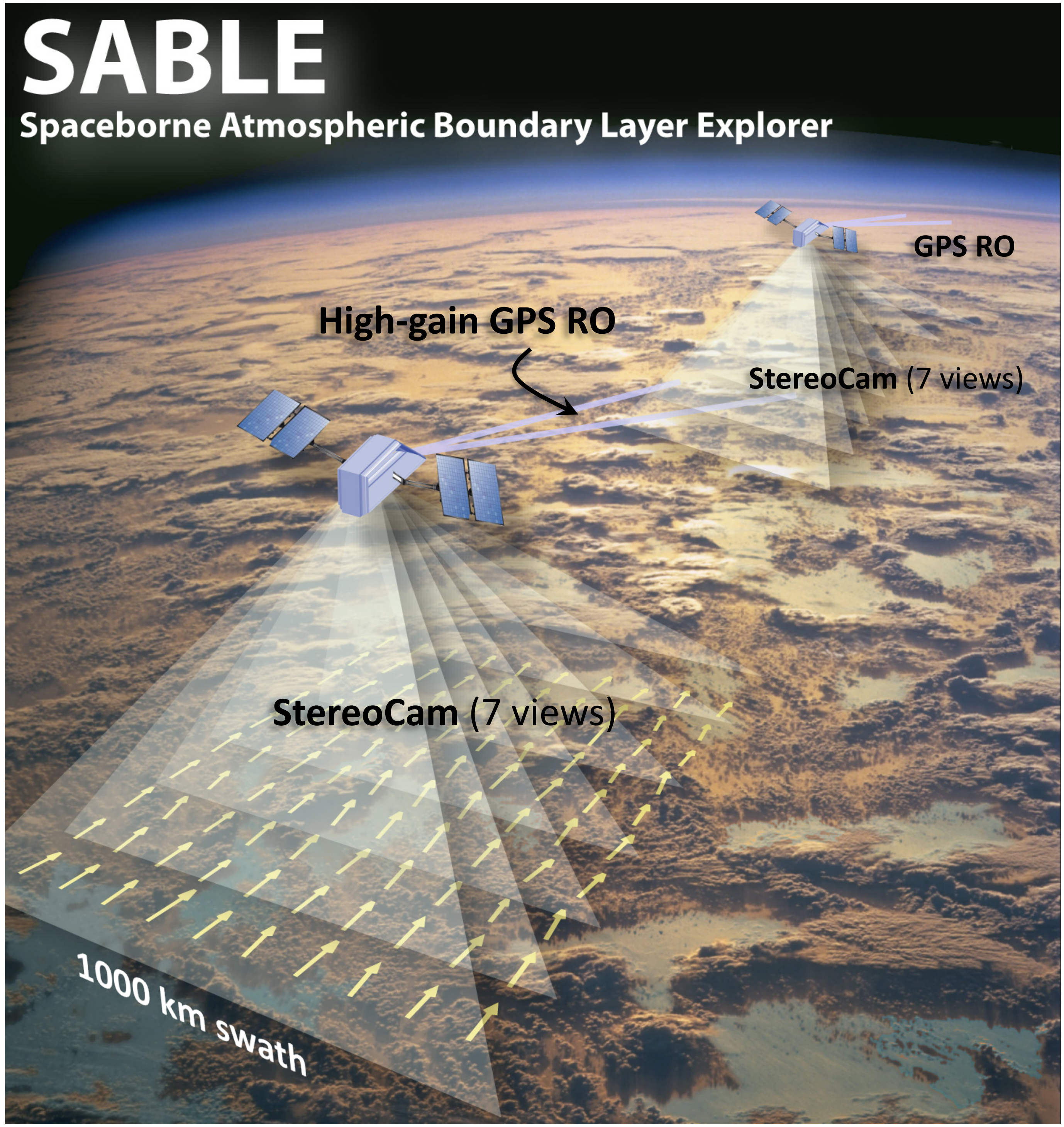
- Cloud top winds [u,v]
(0.3 m s^{-1} accuracy)

- Wind divergence
(3×10^{-7} s^{-1} accuracy)

GPS RO

- ABL top height
[hydrolapse]
(100 m accuracy)

- ABL humidity stratification
[q_v difference between lowest 500m and upper 500 m of ABL]
(0.5-1.0 g kg^{-1} accuracy)



SABLE Science Team

Name	Role
Robert Wood	Principal Investigator
Christopher Bretherton	SABLE observations for model parameterization development
Sandrine Bony	SABLE entrainment estimates to evaluate cloud feedback processes in climate models.
Sergey Sokolovskiy	SABLE GPS RO to improve ABL retrieval
Bjorn Stevens	SABLE observations to constrain entrainment estimates in process and large scale models
Paquita Zuidema	Development of Stereocam cloud top height and thickness estimates including comparisons with in-situ and other data
Robert Atlas	SABLE observations in hurricane research and forecasting
David Diner	Development of Stereocam instrument and data products
Anthony Mannucci	Development of GPS RO instrument and data products
Joao Teixeira	Development of SABLE science including using SABLE observations to improve models and compare to other satellite obs.
Dong Wu	Development of SABLE stereo cloud wind and height retrievals, and ABL humidity retrieval.

SABLE Science Team

Name (Institution)	Role
Robert Wood (UW)	Principal Investigator: Provides science and operations and is responsible for technical, schedule, and cost performance.
Joao Teixeira (JPL)	Project Scientist: Represents the PI and Science Team in day-to-day matters at JPL.
David Diner (JPL)	StereoCam Instrument Scientist: Leads development of the StereoCam instrument.
Larry Di Girolamo (UIUC)	StereoCam Data Scientist: Leads development of StereoCam data products.
Anthony Mannucci (JPL)	GPS RO Instrument Scientist: Leads development of the GPS RO instrument.
Christopher Bretherton (UW)	Model Developer: Ensures application of SABLE results to improve model physical parameterizations of entrainment rate and cumulus convection.
Paquita Zuidema (U. Miami)	Validation Scientist: Compares SABLE observations to in-situ and surface remote sensing data.
Robert Atlas (NOAA AOML)	NOAA Liaison: Ensures use of SABLE observations in hurricane research and NWP.
Dong Wu (GSFC)	StereoCam/GPS RO Fusion Scientist: Ensures synergistic use of SABLE instrument set to meet mission goals.
Sandrine Bony (LMD)	Applies expertise in cloud feedbacks to model assessment using SABLE data.
Bjorn Stevens (Max Planck)	Uses SABLE observations to constrain entrainment estimates in process and large scale models.

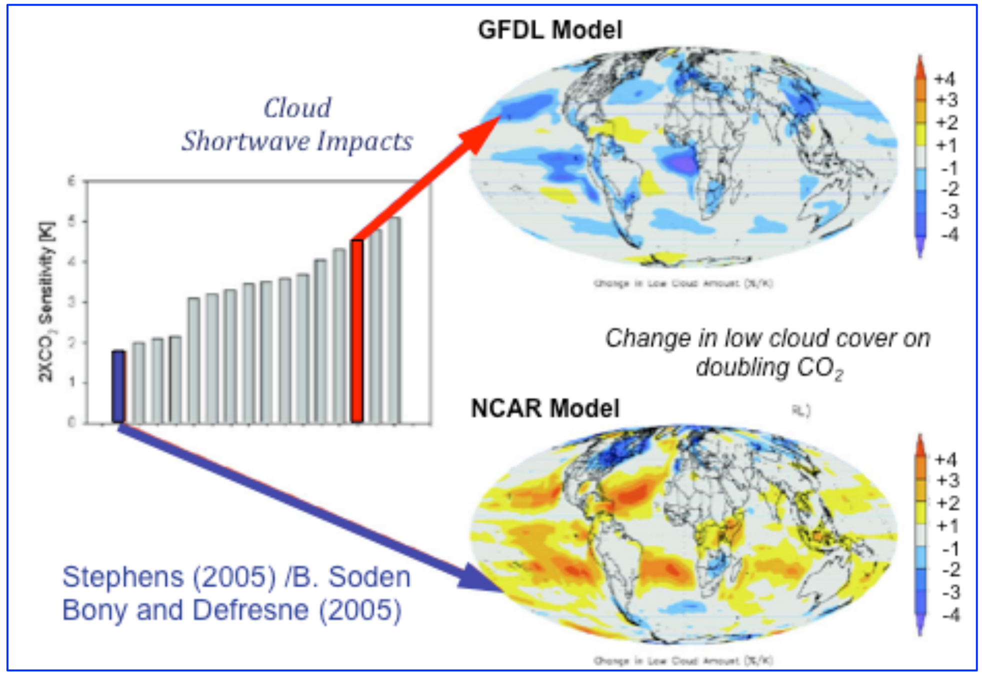
Additional Slides

SABLE will address:

- *How do boundary layer clouds respond to and feedback on climate change globally?*
- *How do clouds respond to meteorological variability in the current climate?*
- *To what extent cloud top entrainment govern cloud lifecycle, structure, and variability in the marine atmospheric boundary layer (ABL)?*
- *How can ABL processes be represented within climate models for better prediction?*

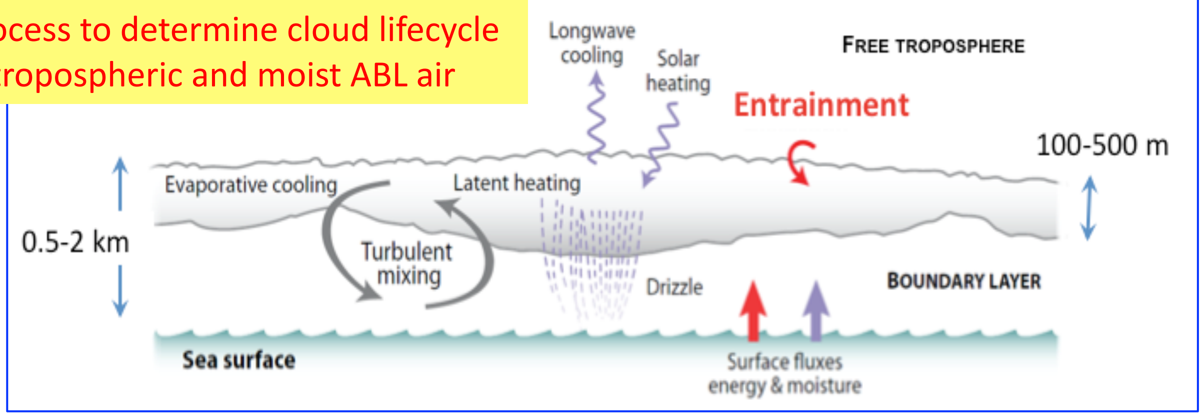
"Cloud feedbacks remain the largest source of uncertainty".

"The shortwave impact of changes in boundary-layer clouds, and to a lesser extent midlevel clouds, constitutes the largest contributor to inter-model differences in global cloud feedbacks". – IPCC (2007)



Cloud top **entrainment** is the key process to determine cloud lifecycle and structure by mixing dry free-tropospheric and moist ABL air

SABLE is a physical process-focused mission to observe the cloudy boundary layer and reduce the largest recognized uncertainty in climate prediction—cloud feedbacks to greenhouse warming (IPCC 2007)



Type	Definition
Cloud-top entrainment	Vertical mixing between the ABL and the free-troposphere.
Lateral entrainment	Horizontal mixing between rising cumulus plumes within the ABL and surrounding air