A proposal for regime-based LES-GCRM-ESM-observation-forward simulation closure studies

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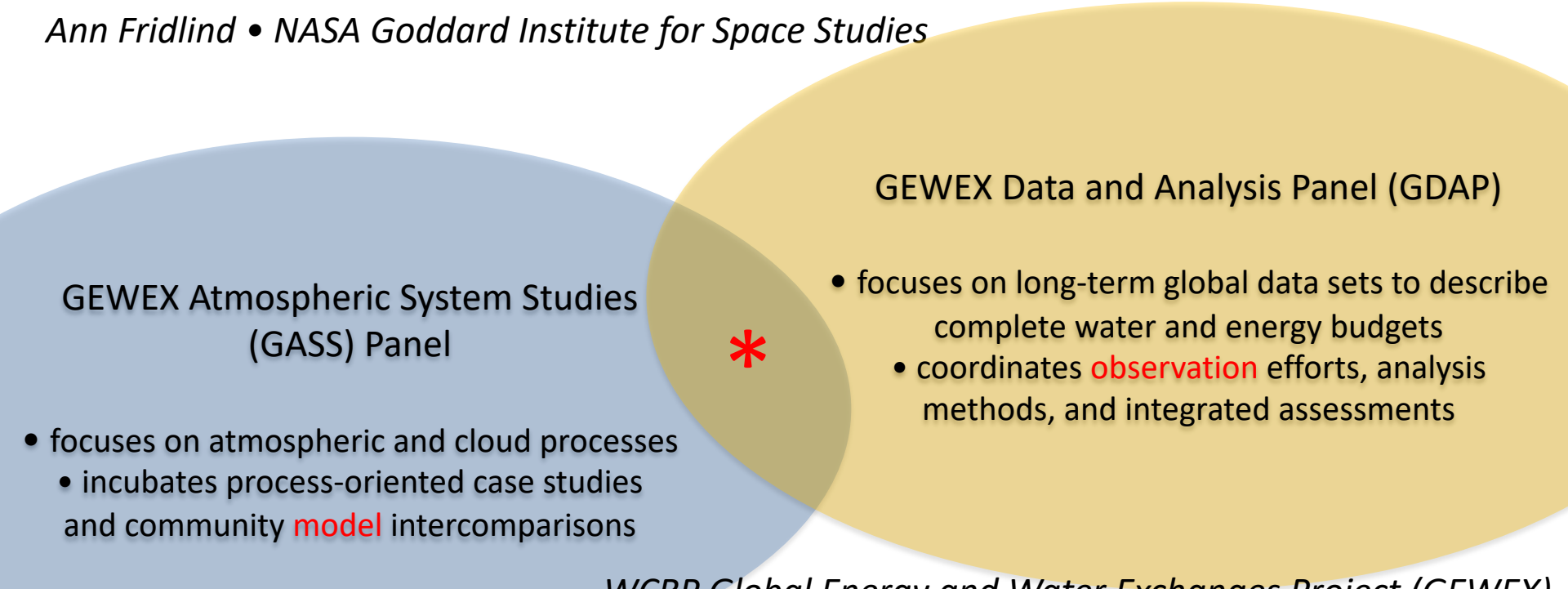


WCRP Global Energy and Water Exchanges Project (GEWEX)

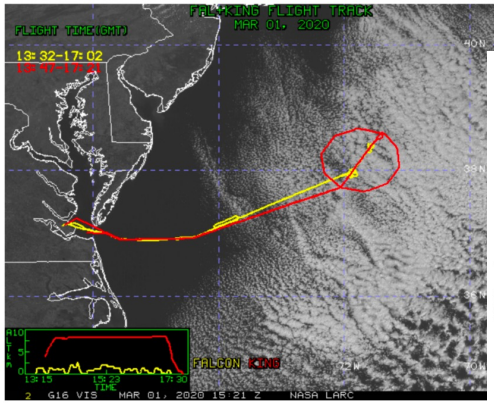
WCRP Lighthouse Activity on 'Explaining and Predicting Earth System Change' — Modeling and Monitoring Earth System Change WG

Heimbach et al. AGU FM '22 Invited GC22C-02

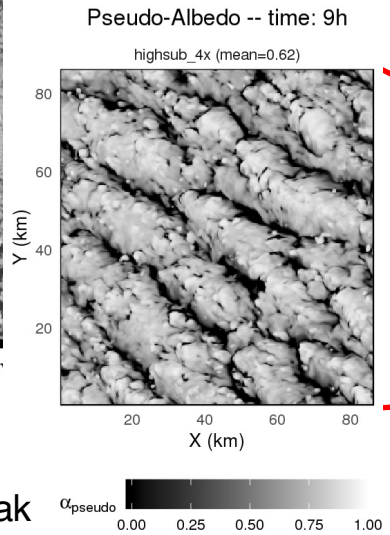
- WG themes
  - observational and modelling requirements to monitor, explain and predict
  - convergence between climate modelling and Earth system data assimilation & reanalysis
- WG identified five relevant gaps/shortcomings
  - persistent model biases
  - underutilization of diverse observational data
  - disconnect between ESM and reanalysis/DA efforts
  - sparse observational sampling of parts of the Earth system
  - insufficient approaches to handle model and observational uncertainty

ModelE3 development approach

Field campaigns → LES → SCM



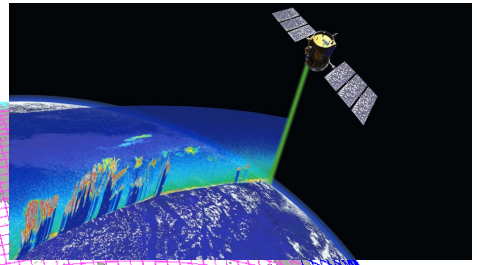
From https://satcorps.larc.nasa.gov



ACTIVATE Flight RF13
1 March 2020
mixed-phase cold-air outbreak

Tornow et al. (ACP 2021, GRL 2022, in prep.)

Global data → ESM tuning



CALIPSO

Elsaesser et al., in prep.

GMAO/cubed-sphere

Field campaigns —> LES —> ESM in SCM mode

Conditions	Case study	Aerosol aware?
dry convective boundary layer	idealized [Bretherton and Park 2009]	—
dry stable boundary layer	GABLS1 [Cuxart et al. 2006]	—
marine stratocumulus	DYCOMS-II RF02 [Ackerman et al. 2009]	observed (2 modes)
marine trade cumulus (shallow)	BOMEX [Siebesma et al. 2003]	—
marine trade cumulus (deep, raining)	RICO [van Zanten et al. 2011]	—
marine stratocumulus-to-cumulus *	SCT [Sandu and Stevens 2011]	—
continental cumulus ^	RACORO [Vogelmann et al. 2015]	observed profile (3 modes)
Arctic mixed-phase stratus	M-PACE [Klein et al. 2009]	observed (2 modes)
Antarctic mixed-phase stratus *	AWARE [Silber et al. 2019, 2021, 2022]	estimated (1 mode)
tropical deep convection	TWP-ICE [Fridlind et al. 2012]	observed profile (3 modes)
mid-latitude synoptic cirrus *	SPARTICUS [cf. Mühlbauer et al. 2014]	—
mid-latitude cold-air outbreak *^	ACTIVATE [Tornow et al., 2021, 2022, in prep.]	observed profile (3 modes)
high-latitude cold-air outbreak *^	COMBLE [Tornow et al., in prep.]	observed/estimated profiles (3 modes, 1 INP)
marine cumulus and congestus *^	CAMP2Ex [Stanford et al., in prep.]	observed profiles (3 modes)
subtropical marine deep convection *^	SEAC4RS [Stanford et al., in prep.]	observed profiles (TBD)
continental sea breeze convection *^	TRACER [Matsui et al., in prep.]	observed profiles (TBD)

*Lagrangian (cf. Neggers JAMES 2015, Pithan et al. NatGeo 2019)

^ensemble (cf. Neggers et al. JAMES 2019)

Tuning Protocol

- 45 ESM cloud and turbulence parameters taken to be poorly constrained
- LES/SCM cases used to estimate parameter uncertainty ranges
- global satellite datasets assembled with estimated uncertainties (also sometimes a latitude range omitted)

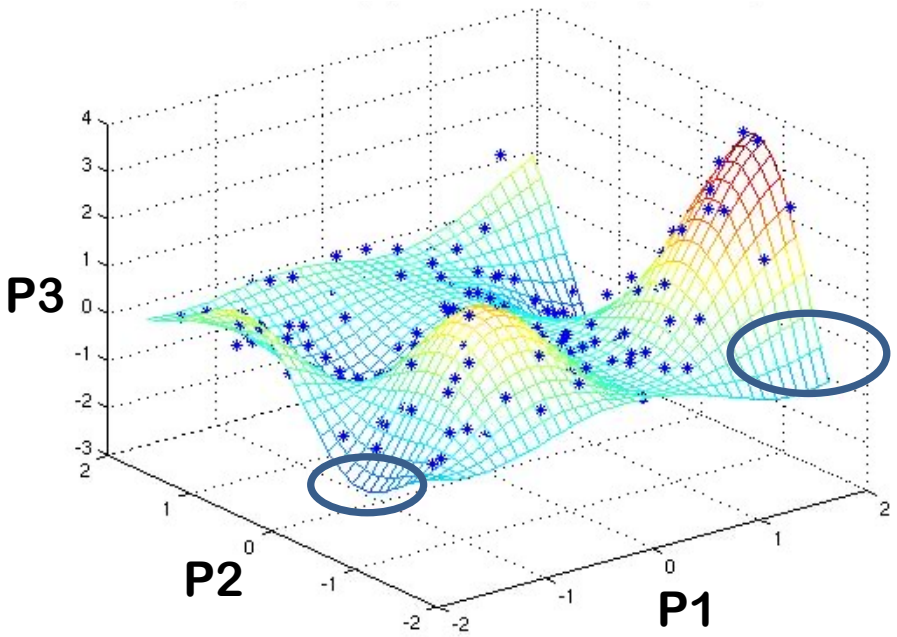
Elsaesser et al. (in prep.)

Metrics (36 in total)	Data Source
Radiation (Longwave [LW], Shortwave [SW])	CERES-EBAF-Ed4.1
Cloud Radiative Forcing (LWcrf, SWcrf)	CERES-EBAF-Ed4.1
Column Water Vapor (CWV)	Obs4MIPS RSS, G-VAP
Specific Humidity profiles (qv)	Obs4MIPS AIRS, MLS
Temperature profiles (T)	Obs4MIPS AIRS, MLS, GNSS-RO
Total Liquid Water Path (TLWP)	MAC-LWP, GPM/TRMM
Total Ice Water Path (TIWP)	CloudSat, MODIS
Total Precipitation (Pr)	GPCP, GPM/TRMM
Convective Precipitation (Prc)	GPM/TRMM
Total Cloud Cover (TCC)	CloudSat/CALIPSO, ISCCP
Low (Shallow Cu, StratoCu) Cloud Cover	CloudSat/CALIPSO
Cloud-top Droplet Number Concentration	MODIS (Bennartz, Grosvenor)
Surface Wind (W)	WindSat, QuikSCAT
Liquid-to-ice transition Temperature/Height	CALIPSO

ModelE3 emulator based on 450 1-year atmosphere runs

Latin Hypercube sampling in a 45-dimensional parameter state space. Lots of empty state space; emulator (neural network) fills in the gaps.

Example Penalty State Space Transect for any given model metric



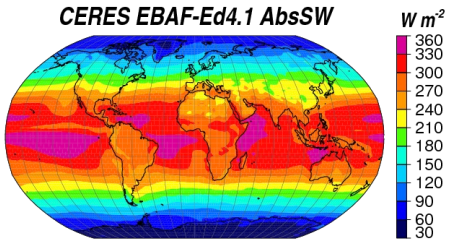
source: Marcus van Lier-Walqui

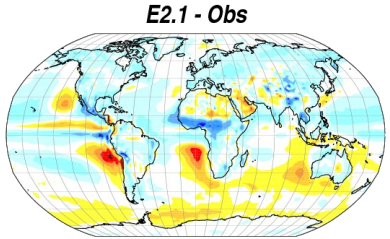
Obs

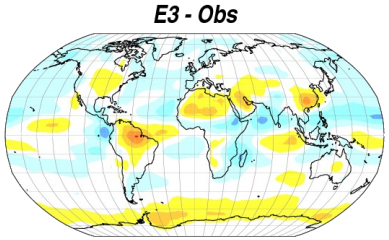
E2.1 – Obs

E3.tun2 – Obs

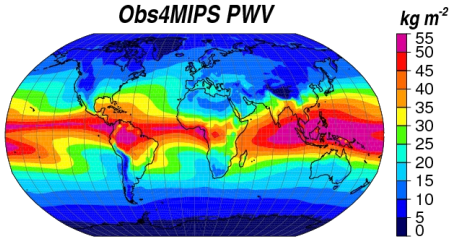
AbsSW

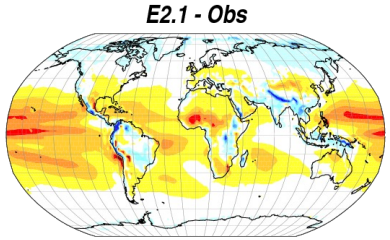


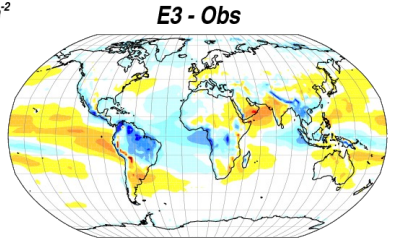




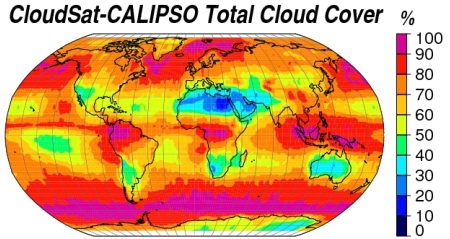
PWV

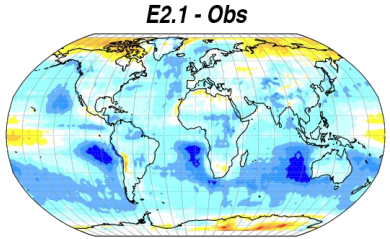


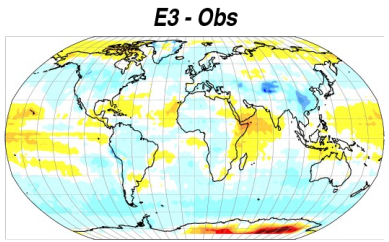




TCC



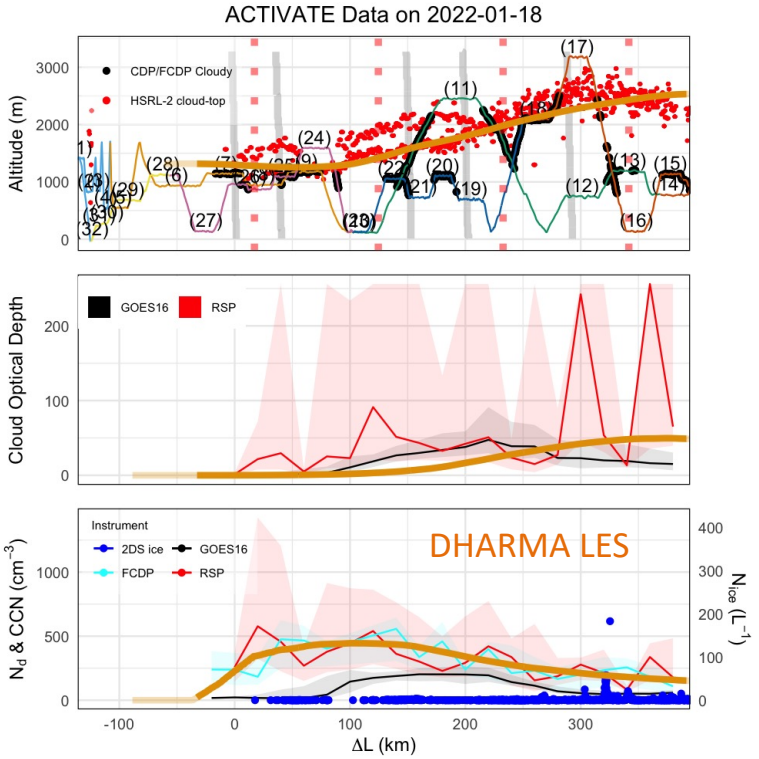


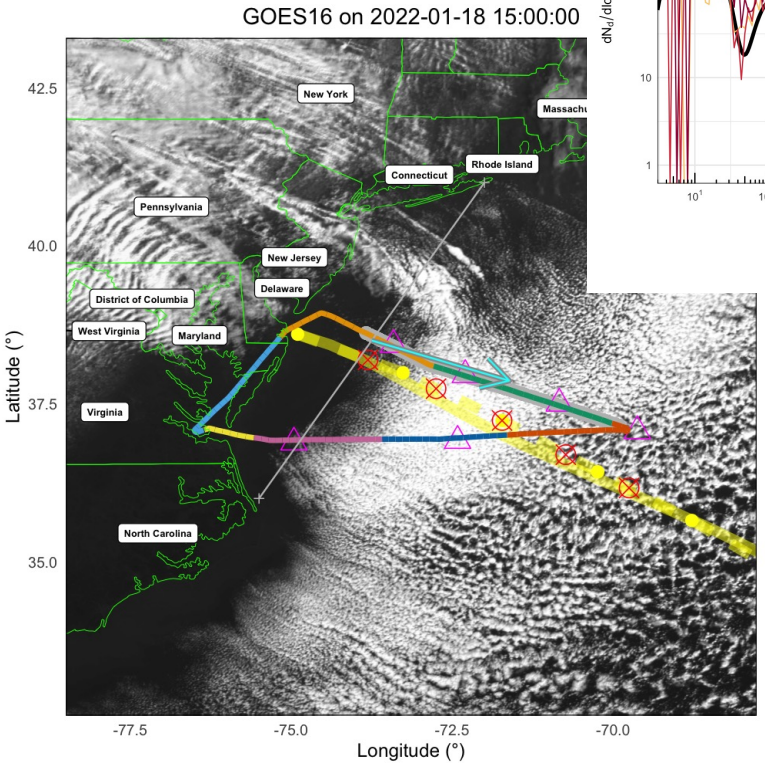


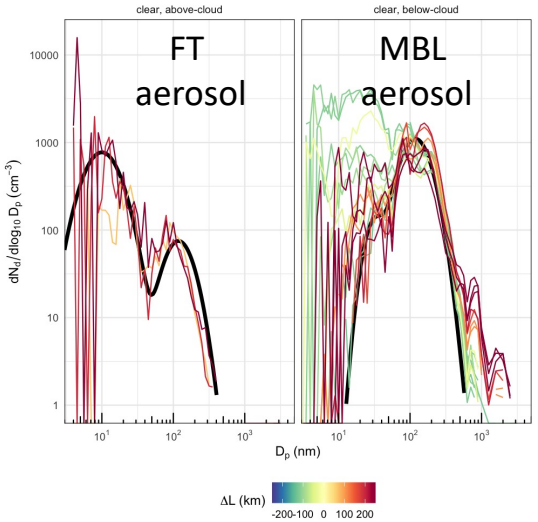
source: Greg Elsaesser

ACTIVATE LES case study selection

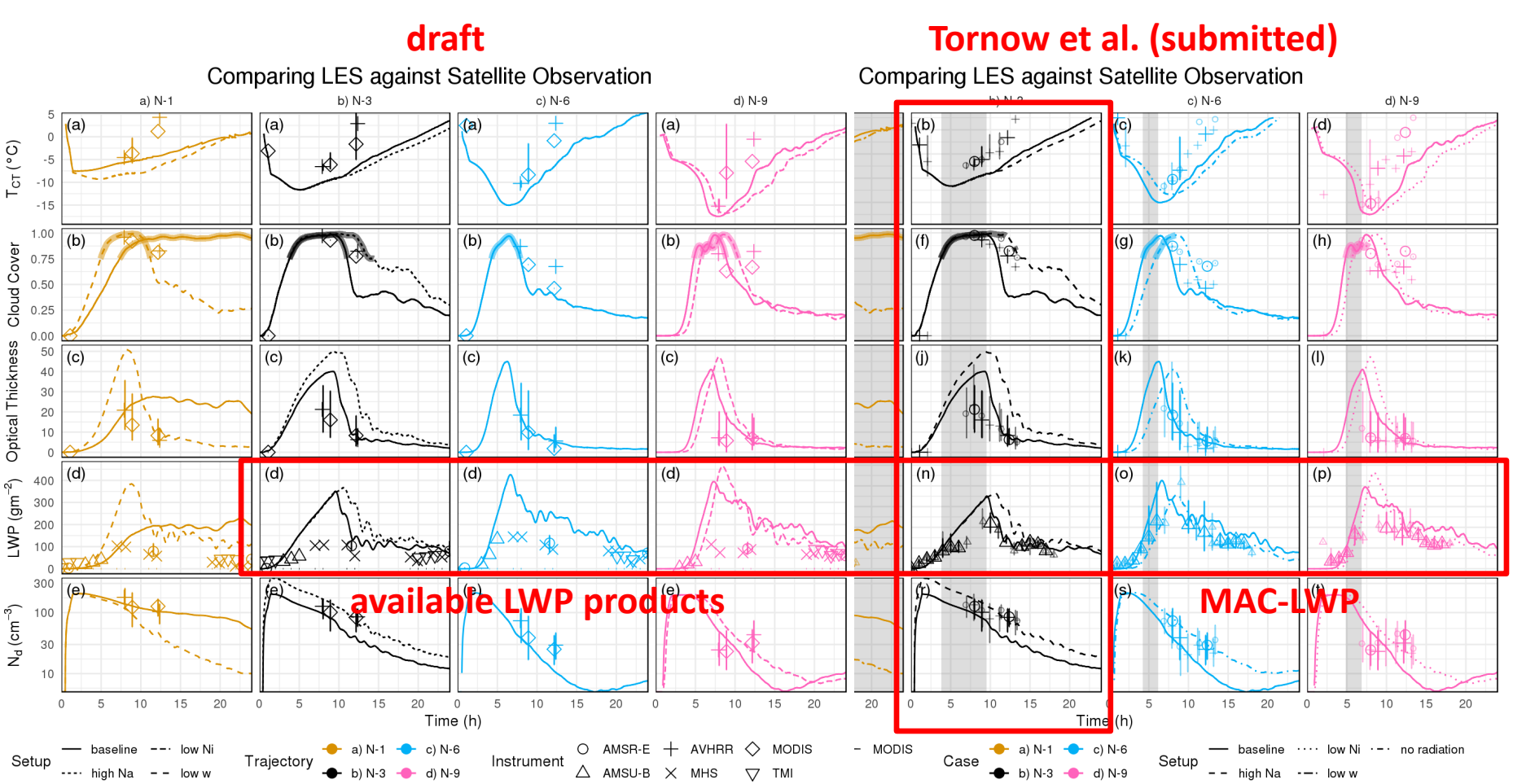
- choose 2020-2022 flights with greatest fetch offshore







Tornow et al. (in prep.)


draft
Tornow et al. (submitted)
Comparing LES against Satellite Observation
Comparing LES against Satellite Observation
a) N-1
b) N-3
c) N-6
d) N-9
T_{CT} (°C)
Cloud Cover
Optical Thickness
LWP (gm^{-2})
N_d (cm^{-3})
Time (h)
available LWP products
MAC-LWP
Setup
baseline
high Na
low Ni
low w
Trajectory
a) N-1
b) N-3
c) N-6
d) N-9
Instrument
AMSR-E
AMSU-B
AVHRR
MHS
MODIS
TMI
MODIS
Case
a) N-1
b) N-3
c) N-6
d) N-9
Setup
baseline
high Na
low Ni
low w
no radiation

LES case study development ~ closure study

- defined as measuring everything that goes into a model and what it predicts, then testing whether a prediction matches the observed results *within experiment (and model) uncertainties*
  - point and column radiative closure (e.g., Quinn et al. 1996)
  - aerosol–CCN or CCN–droplet closure (e.g., Martin et al. 2011)
  - aerosol–INP closure (Knopf et al. BAMS 2020)
  - foundational framework for more robust handling of observational and model uncertainties? at the same time, a strong development test bed
- LES/SCM case studies also used for retrieval development (e.g., Alexandrov et al. 2020), ground-based simulator development (Silber et al. 2022 GMD; EMC^2), satellite simulator refinement (Cesana et al. GRL 2021)

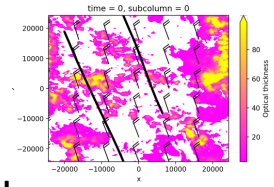
Strawman strategy step-by-step

1) select regime-based case studies from a field campaign (e.g., TOOC)
2) collate appropriate satellite data extractions (e.g., MAC-LWP)
3) derive Lagrangian, aerosol-aware set-up for LES/SCM/1D (GASS-type activity; also amenable to extraction of Lagrangians from GCRMs or ESMs)
4) perform closure calculations (e.g., column radiative)
5) if participating models are treated collectively as representative of model uncertainty, *then* the degree to which individual observational data products are outlying could be quantified (e.g., MAC-LWP on a regime-based basis)

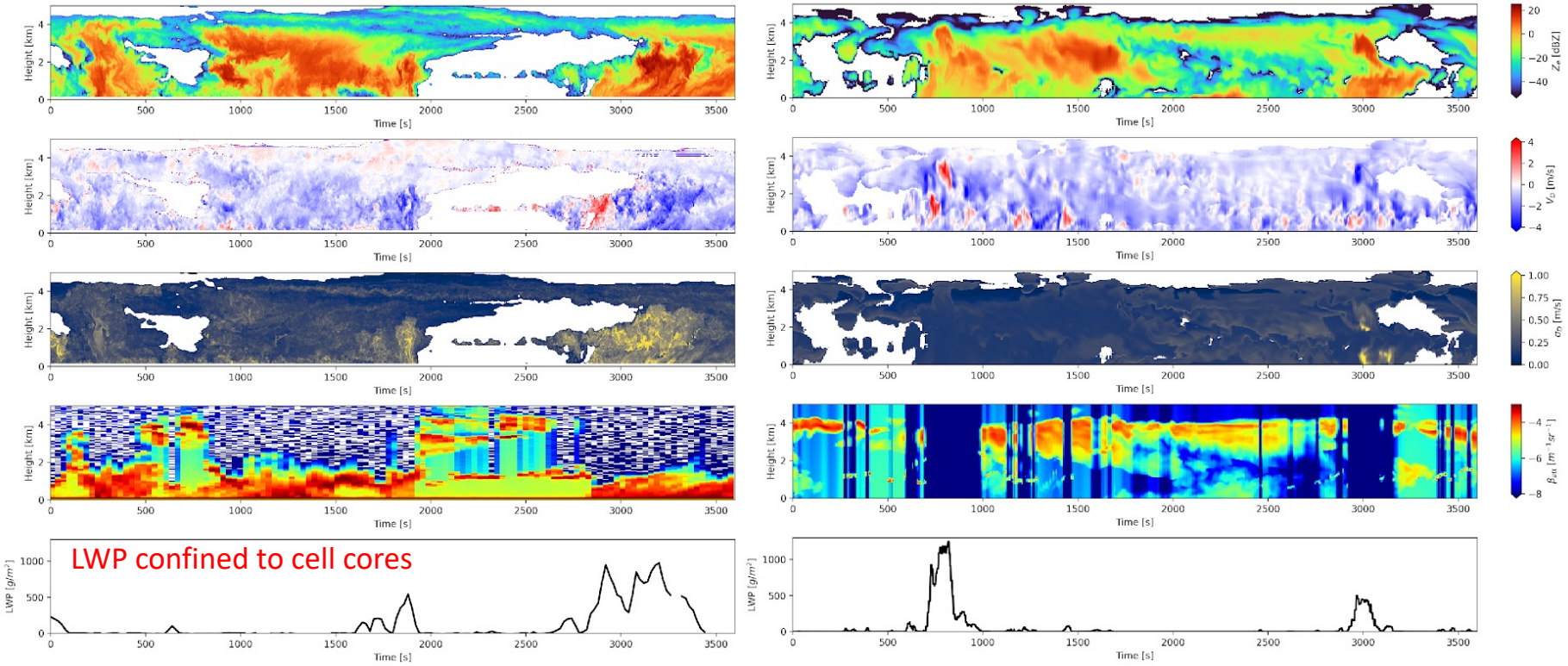
—> foundation for handling model and observational uncertainty regime-wise?

COMBLE observational constraint

Silber et al.
(in prep.)

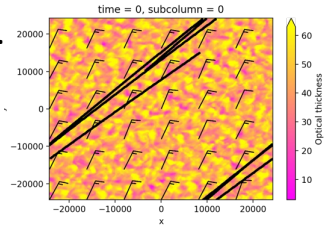


- use EMC^2 (Silber et al. GMD 2022) to evaluate LES vs ground-based radar + lidar

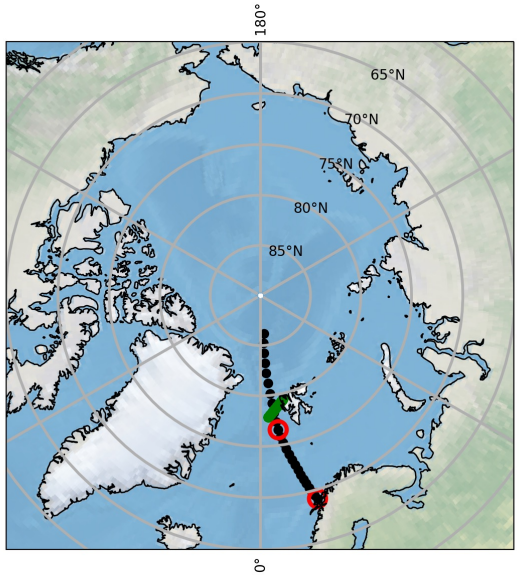


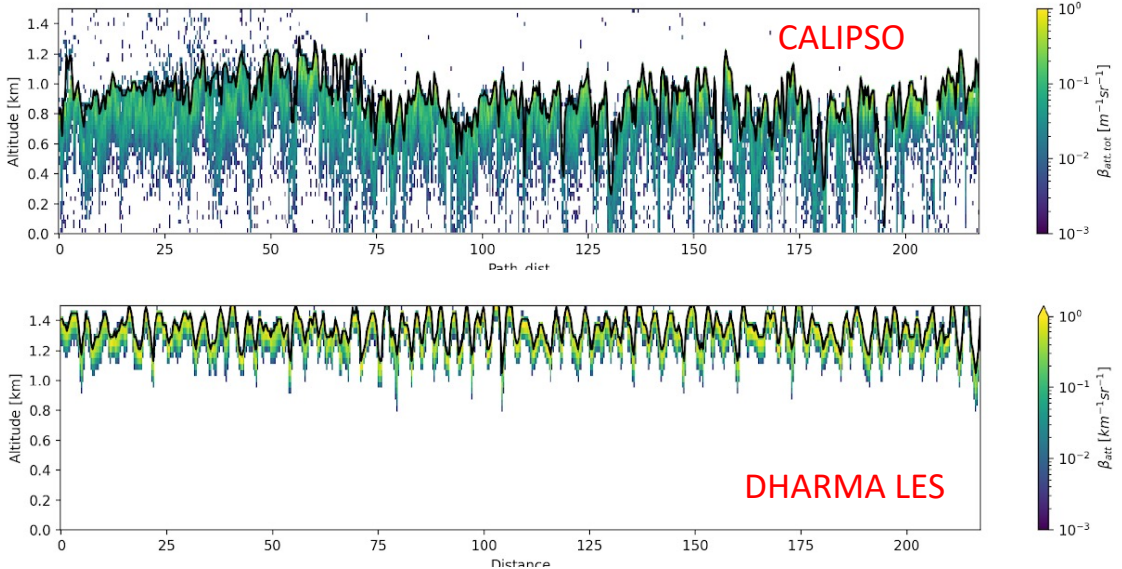
COMBLE observational constraint

Silber et al. (in prep.)



- use EMC^2 (Silber et al. GMD 2022) to evaluate LES vs CALIPSO satellite
- LES clouds too deep + dense

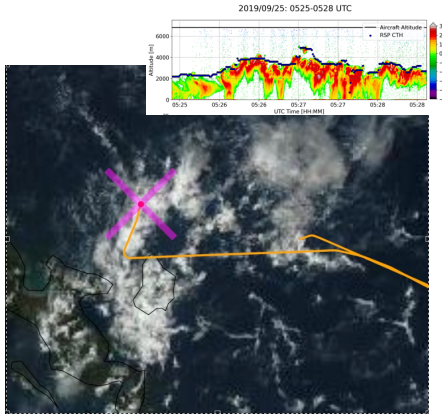




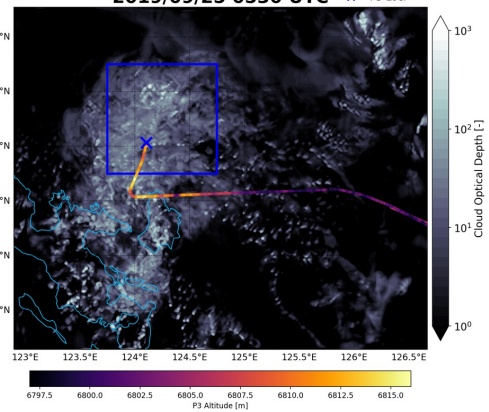
CAMP2Ex tropical convection

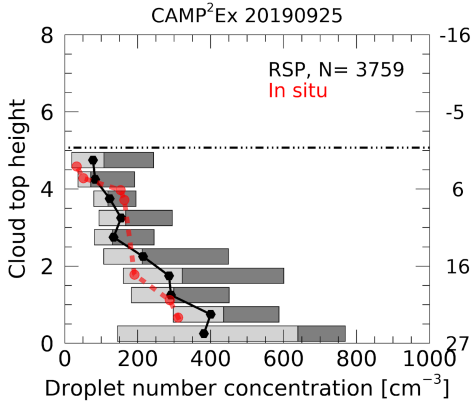
source: McKenna Stanford

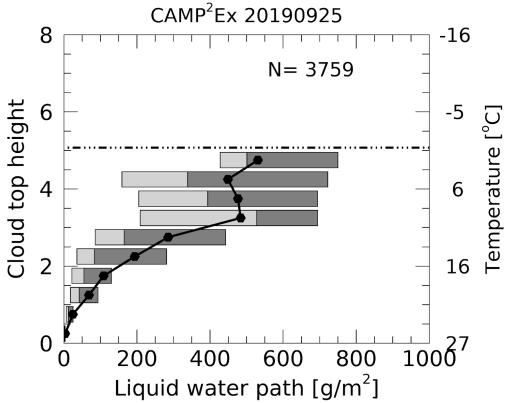
OBSERVED

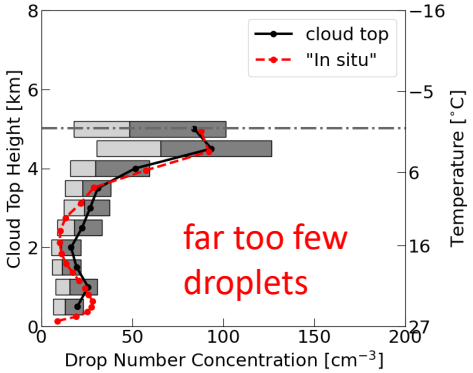


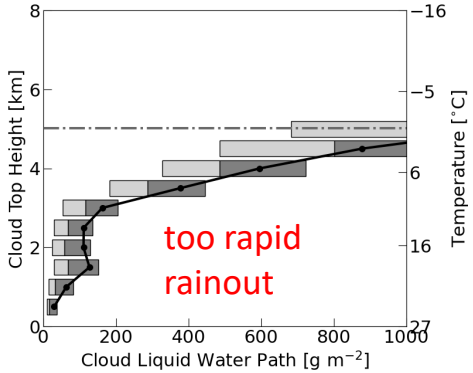
SIMULATED











cloud system location and top heights are well represented by NU-WRF, but not the microphysical processes

It may take a village, but something for everyone?

- LES, climate model or GSRM participant? regime-based analysis of your model's performance, community-based evaluation of diverse observational data, LES/SCM/1D development test bed suitable to fix persistent model biases
- retrieval evaluation and development participant? regime-based test beds ready-made to independently estimate model and observational uncertainties, multiple LES freely available for retrieval development/testing, community results to explain where more funding is needed and why