Significance of Convective Processes in the NASA Investigation of Convective Updrafts (INCUS) Mission

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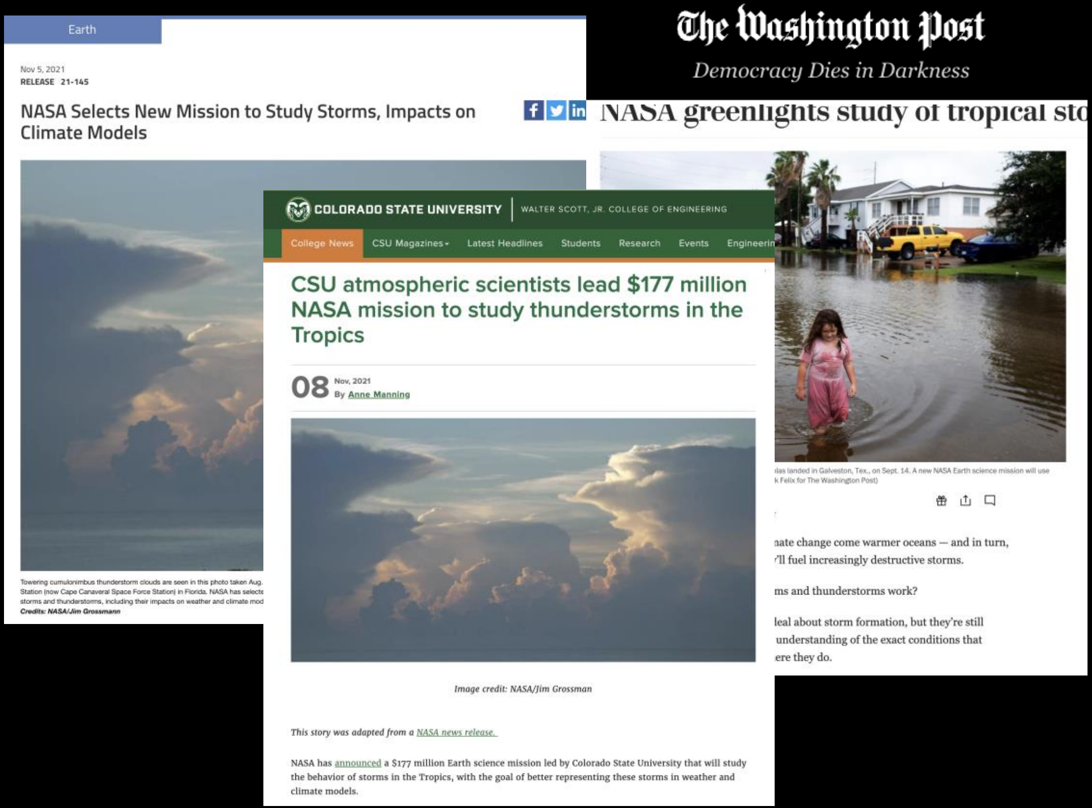
Image: NASA Earth Observatory (https://www.flickr.com/photos/nasa2explore/14991571998/)

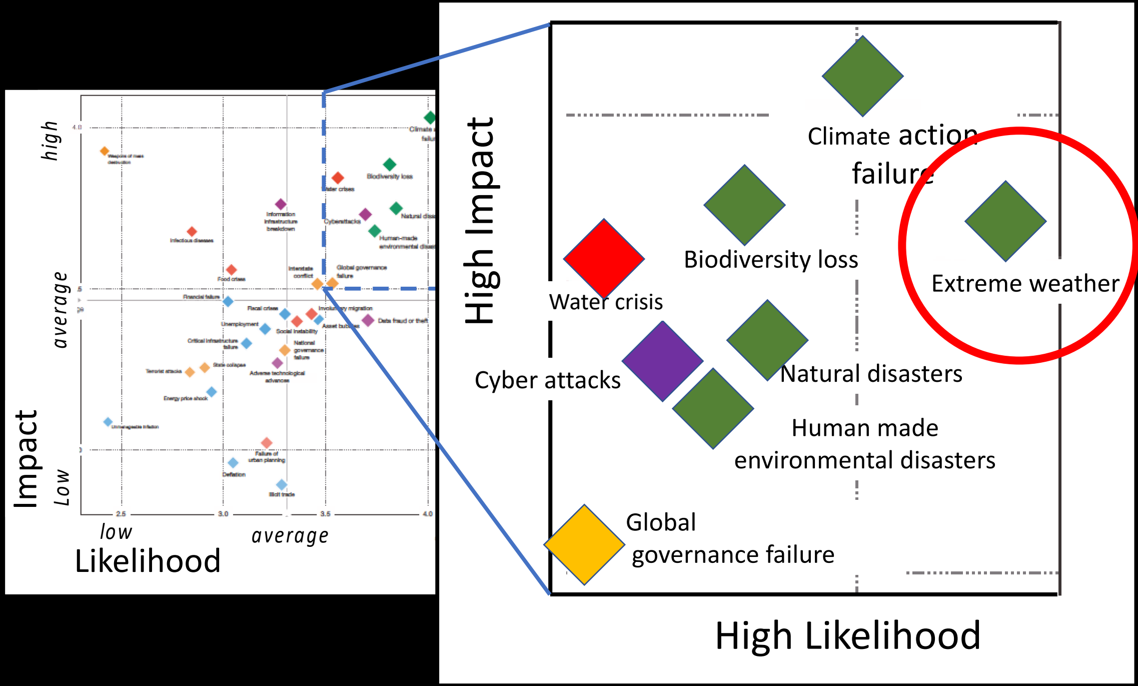
INCUS Selected as Earth Ventures Mission - 3

- INCUS competitively selected in November 2021
- “a series of new science-driven, competitively selected, low cost missions that will provide opportunity for investment in innovative Earth science”



Global Focus on Extreme Weather

World Economic Forum (2020)



INCUS - INvestigation of Convective UpdraftS

Overarching Goal:

To understand why, when and where tropical convective storms form, and why only some storms produce extreme weather.

First global systematic investigation into CMF and its evolution within deep tropical convection

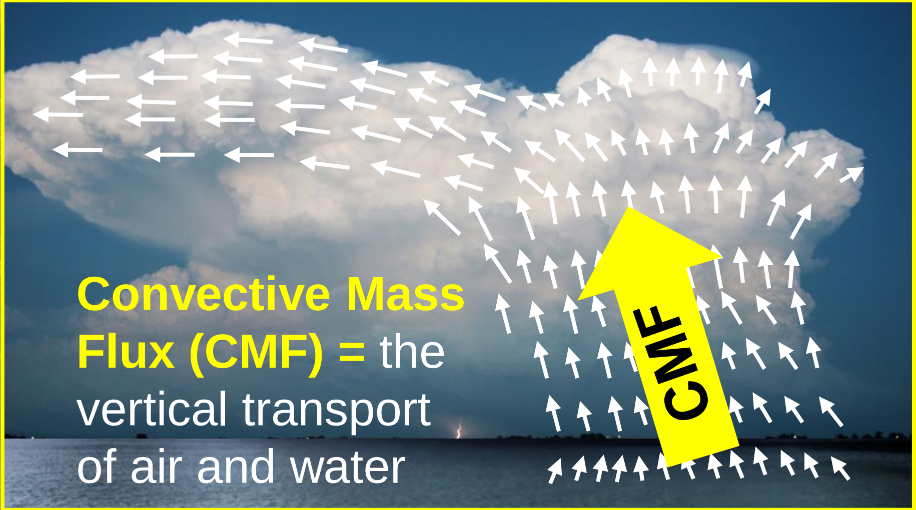
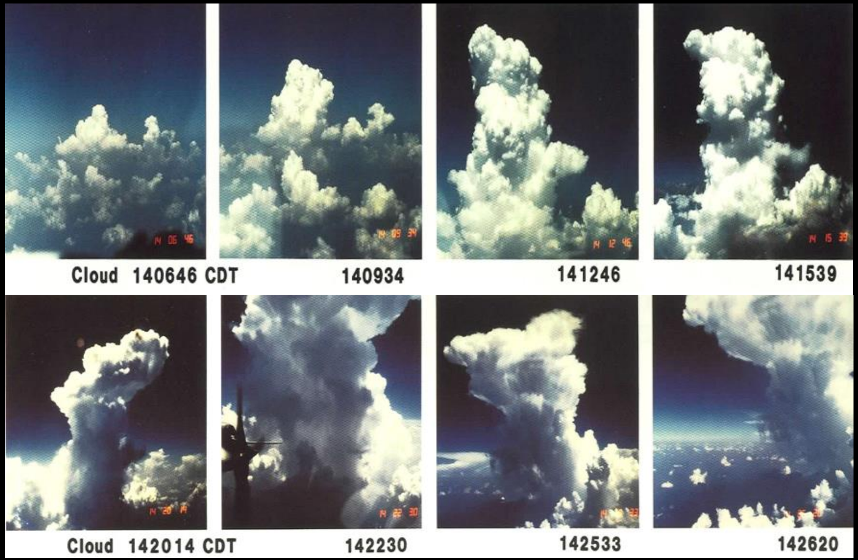


Image: NASA Earth Observatory (https://www.flickr.com/photos/nasa2explore/14991571998/)

Convection Evolves Rapidly

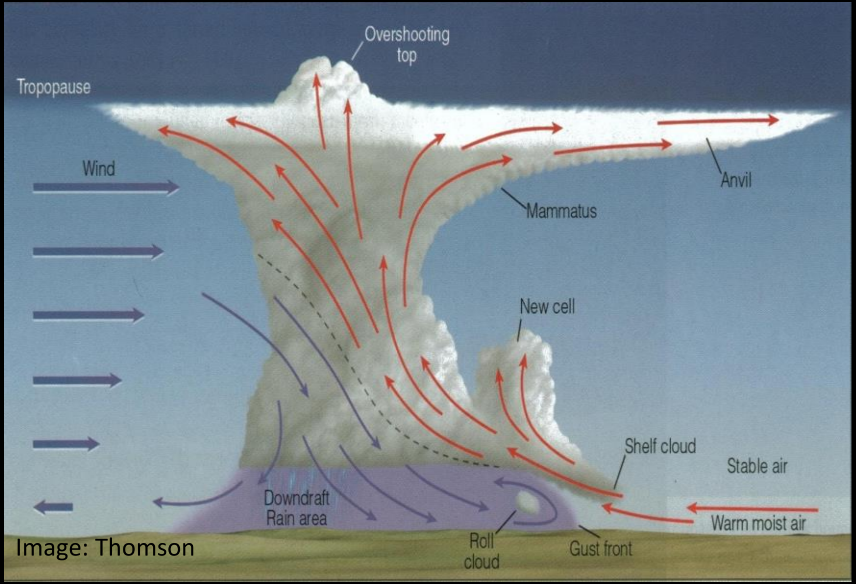


Development of a deep convective cloud over 20 minute time period (images: Ted Fujita)

Convective development - 30 min period

- Convective storms vertically transport and mix the atmosphere

Convective Mass Flux – Storm Scales



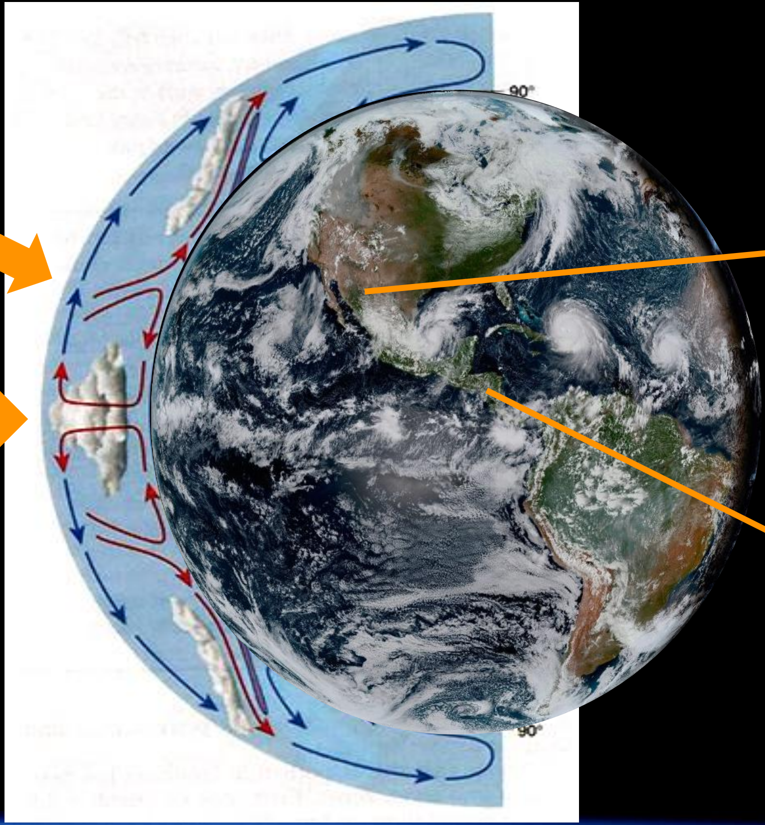
- Rising and sinking motion connects the boundary layer and upper troposphere

Convective Mass Flux – Large Scales

Investigation of Convective Updrafts

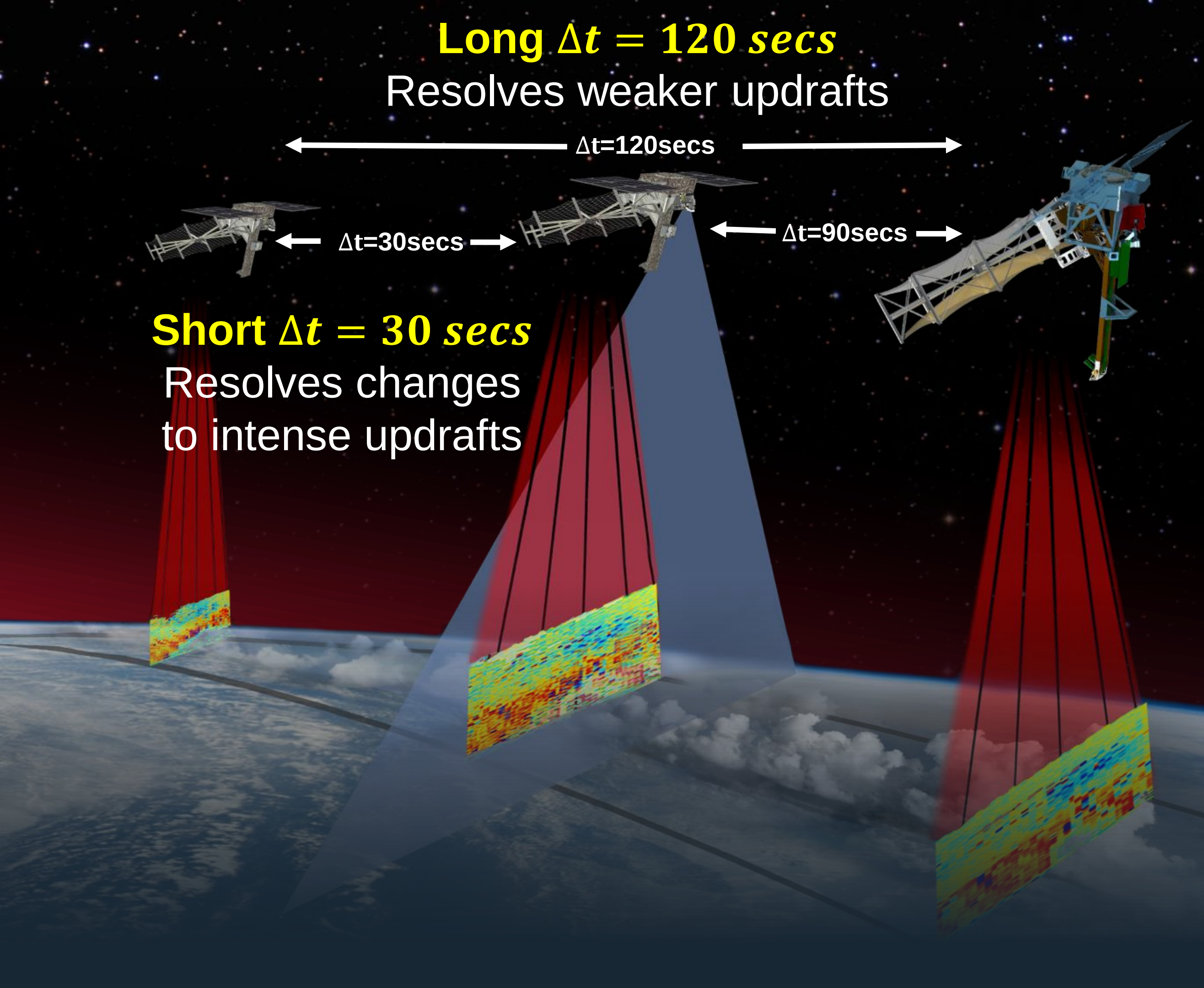
Air sinks establishing dry regions

Air rises within storms establishing moist regions



Dry Regions

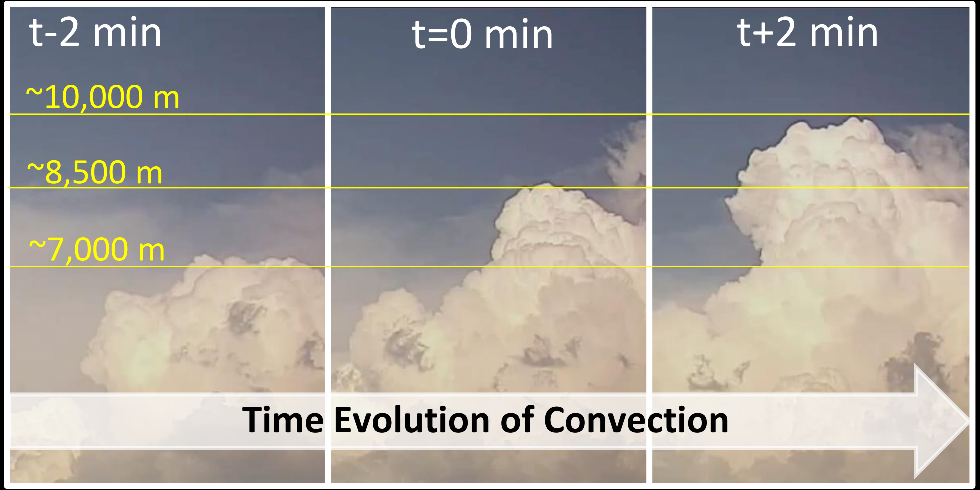
Moist Regions



Novel Δt Approach:

1. To study different parts of the CMF intensity spectrum
2. To quantify duration of the vertical transport
3. Evolution of storm structures

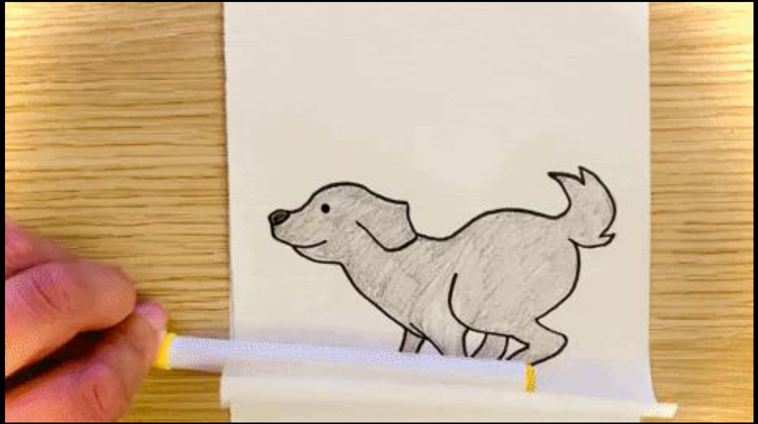
Unique Time Differencing (Δt) Approach



W of 15 m/s corresponds to ~1km/min

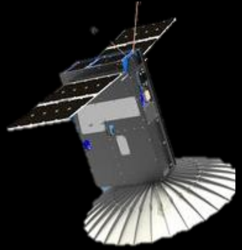
Rapidly sampling the cloud state in time provides information on the storm motion and hence CMF

Exploratorium.edu



INCUS Made Possible by Miniaturization

3 RainCube Ka-band radars



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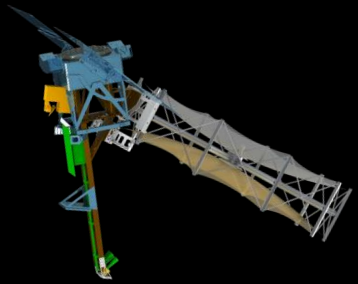
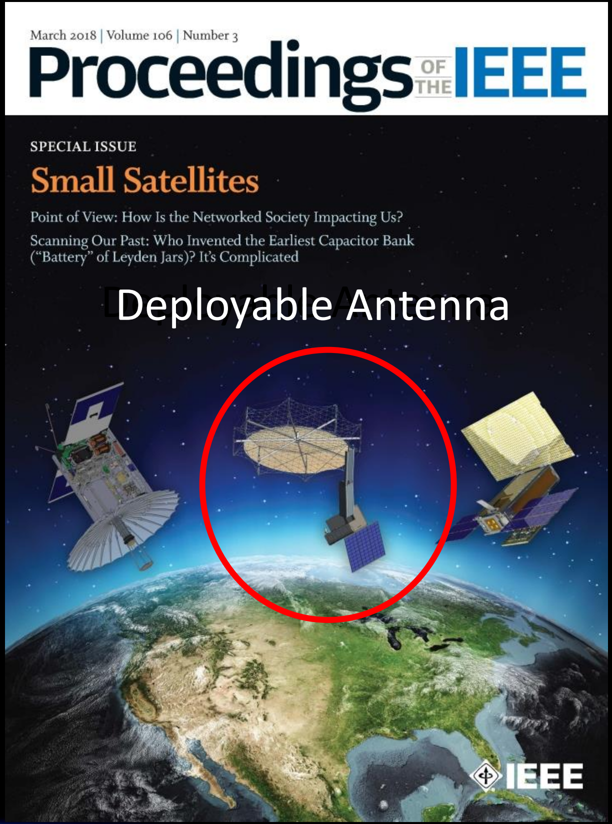
TEMPEST-D mm-wave radiometer

INCUS

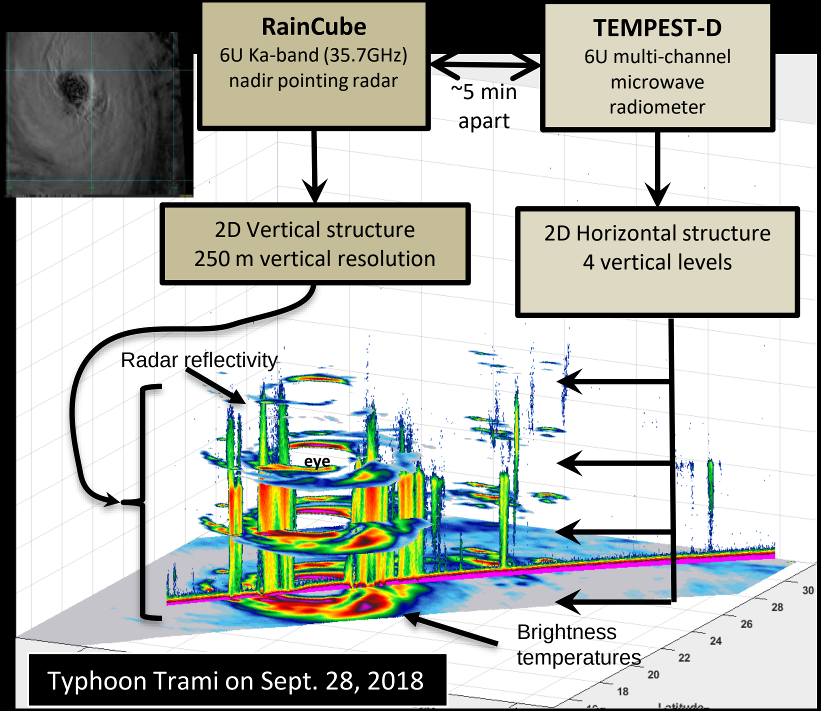




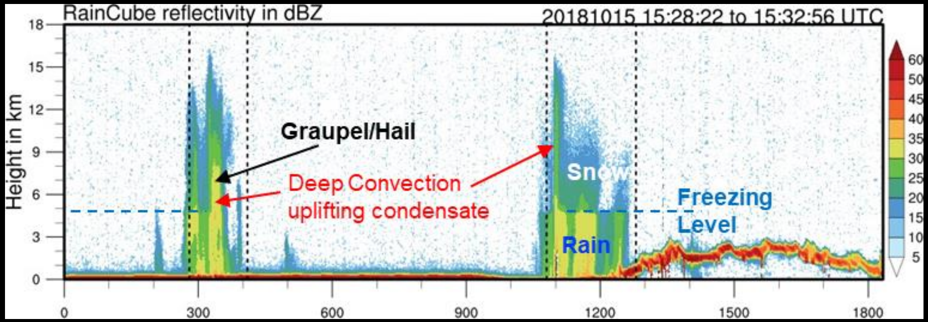
- RainCube and TEMPEST-D implemented as tech demos by NASA's ESTO

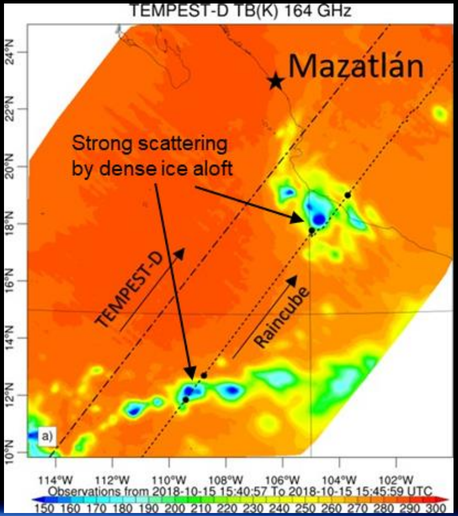
INCUS - Unprecedented 3D Views of Storms

INVESTIGATION OF CONVECTIVE UPDRAFTS



On September 28, 2018, TEMPEST-D and RainCube overflew Typhoon Trami < 5 minutes apart





Correlated storm measurements from RainCube radar and TEMPEST-D radiometer over Texas, Mexico and Pacific Ocean

Images and Animations: Simone Tanelli, Shannon Brown and Steve Reising

The INCUS Team

INVESTIGATION OF CONVECTIVE UPDRAFTS

LEADERSHIP	Role	Inst
Susan van den Heever	PI	CSU
Ziad Haddad	DPI	JPL
Simone Tanelli	PS	JPL
Yunjin Kim	PM	JPL

INDUSTRY	Role
Tendeg	Deployable Antenna
BCT	Spacecraft, Mission Ops

JPL Engineering Team

DATA CENTER	Role	Inst
Phil Partain	SDC	CIRA

SCIENCE TEAM	Role	Inst
George Huffman	Co-I	GSFC
Shannon Brown	Co-I	JPL
Pavlos Kollias	Co-I	SBU
Mark Kulie	Co-I	NOAA
Z. "Johnny" Luo	Co-I	CCNY
Gerald Mace	Co-I	UTAH
Walter Petersen	Co-I	MSFC
Derek Posselt	Co-I	JPL
Kristen L. Rasmussen	Co-I	CSU
Steve Reising	Co-I	CSU
Courtney Schumacher	Co-I	A&M
Graeme Stephens	Co-I	JPL

INTERNAT COLLABS	Role	Inst
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Richard Forbes	Collab	ECMWF
Christopher Holloway	Collab	UofR
Alain Protat	Collab	ABM
Thota Narayana Rao	Collab	NARL
Rémy Roca	Collab	CNRS
Philip Stier	Collab	UofO
Daniel Vila	Collab	INPE

ADVISORY BOARD	Role	Inst
Christian Jakob	Collab	Monash
John Knaff	Collab	NOAA
Mitchell Moncrieff	Collab	NCAR
David Romps	Collab	Berk
Wei-Kuo Tao	Collab	GSFC

INCUS Science Objectives

Objective 1: ENV → CMF

Determine the predominant environmental properties controlling CMF in tropical convective storms

Objective 2: CMF → High Clouds

Determine the relationship between CMF and high anvil clouds (critical to cloud-climate feedbacks)

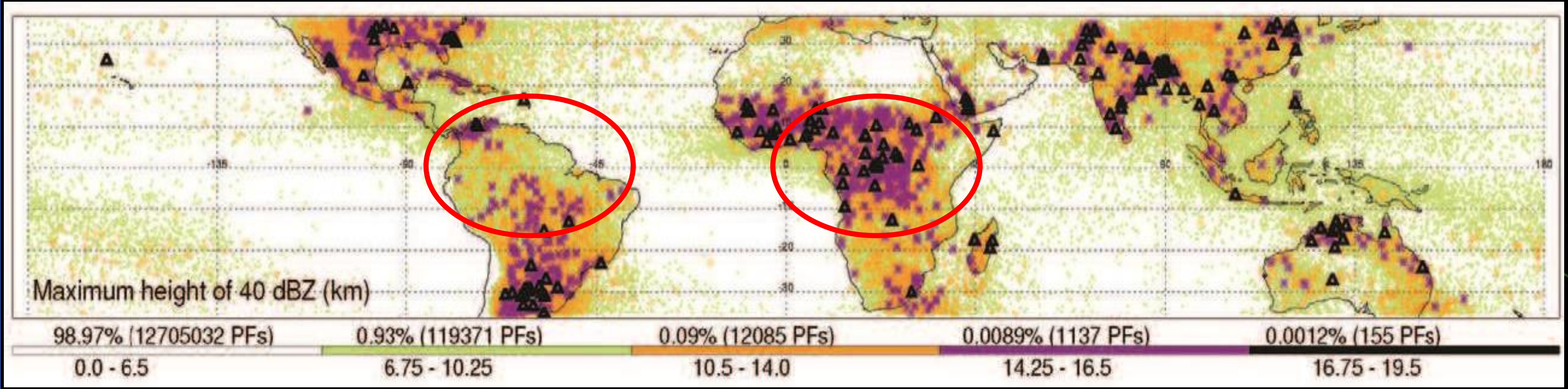
Objective 3: CMF → Current and Future Weather

Assess the relationship between CMF and type and intensity of the weather produced

Objective 4: CMF in Models

Evaluate these CMF observationally determined relationships in weather and climate models.

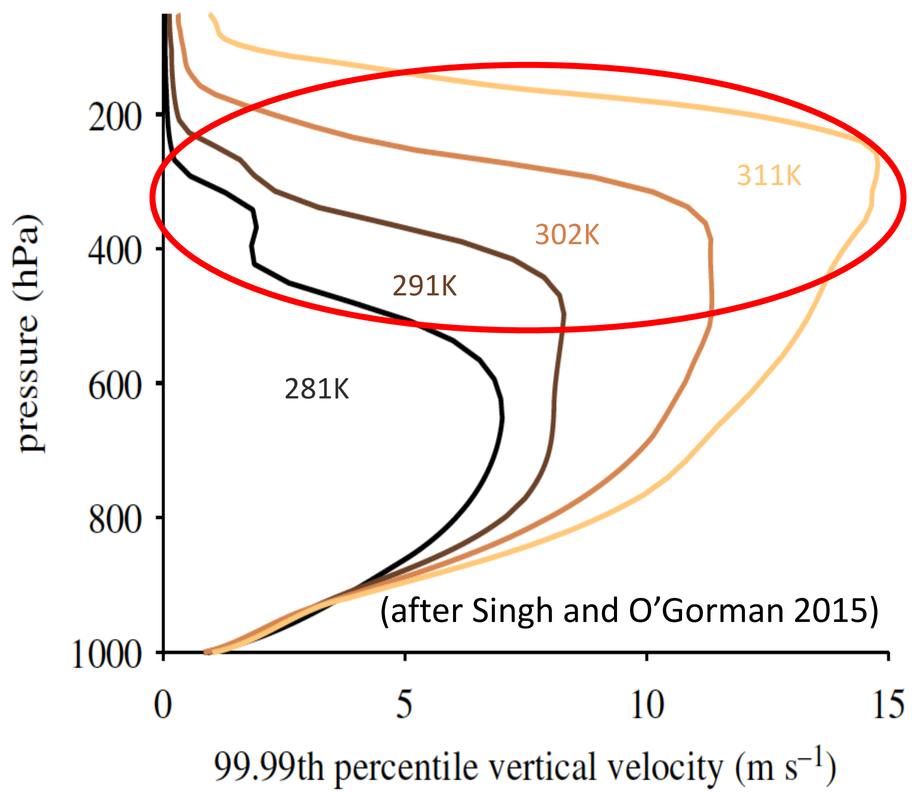
Similar Environments but Different Storms



- Environmental properties fundamentally impact CMF but large gaps in our understanding of these controls
- ***A unified theory of environmental control of CMF does not exist***

Impacts of Changing Future Environments

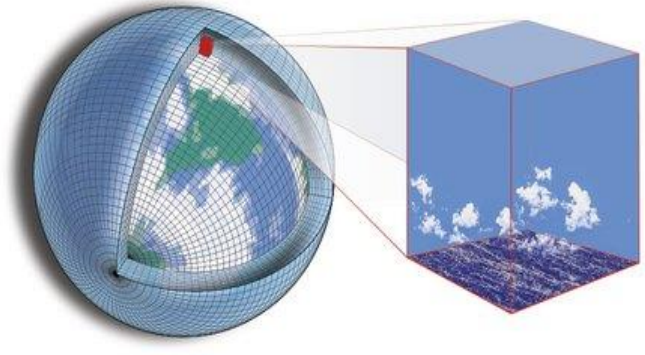
- CMF increases with global warming – largest changes in upper troposphere
- CAPE increases with global warming – but at a much faster fractional rate than CMF



Vertical velocity is challenging to measure and model in convective storms in the current climate

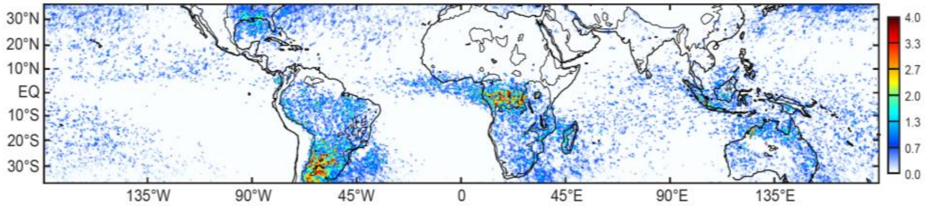
Global Climate Models
Grid spacing: 25-100km
Grid domains: Global
Parameterized convective mass flux (CMF)

(after Schneider)



GCM parameterizations of CMF often built on NWP outputs

Houze, Rasmussen, Zuluaga, and Brodzik (2015)

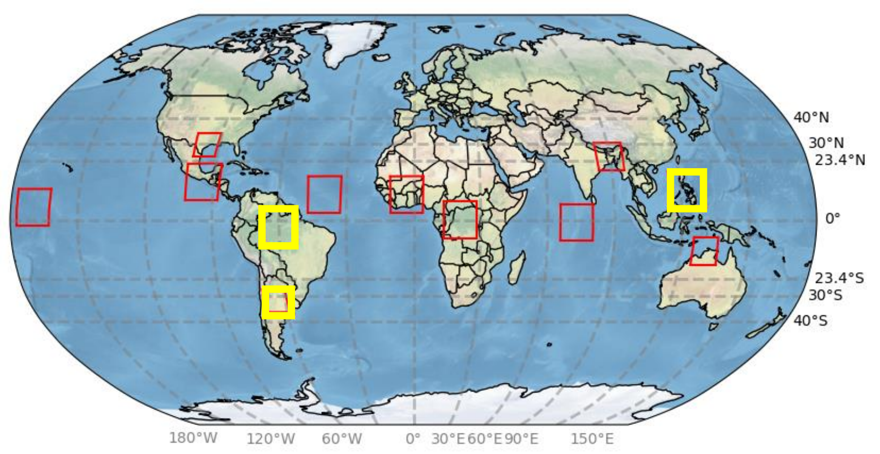


Organized Convection (DJF; 40 dBZ > 1,000 km^2)

Despite advances made by spaceborne radar observations (i.e., TRMM, GPM), **no current platforms measure vertical velocity from space**

Tool: High-Resolution Simulations

- INCUS database of high-resolution simulations of convective systems and updrafts
- Large Eddy Simulation Models
  - Regional Atmospheric Modeling System (RAMS) (Cotton et al., 2003; Saleeby and van den Heever, 2013)
  - Weather Research and Forecasting Model (WRF) (Skamarock et al., 2008)



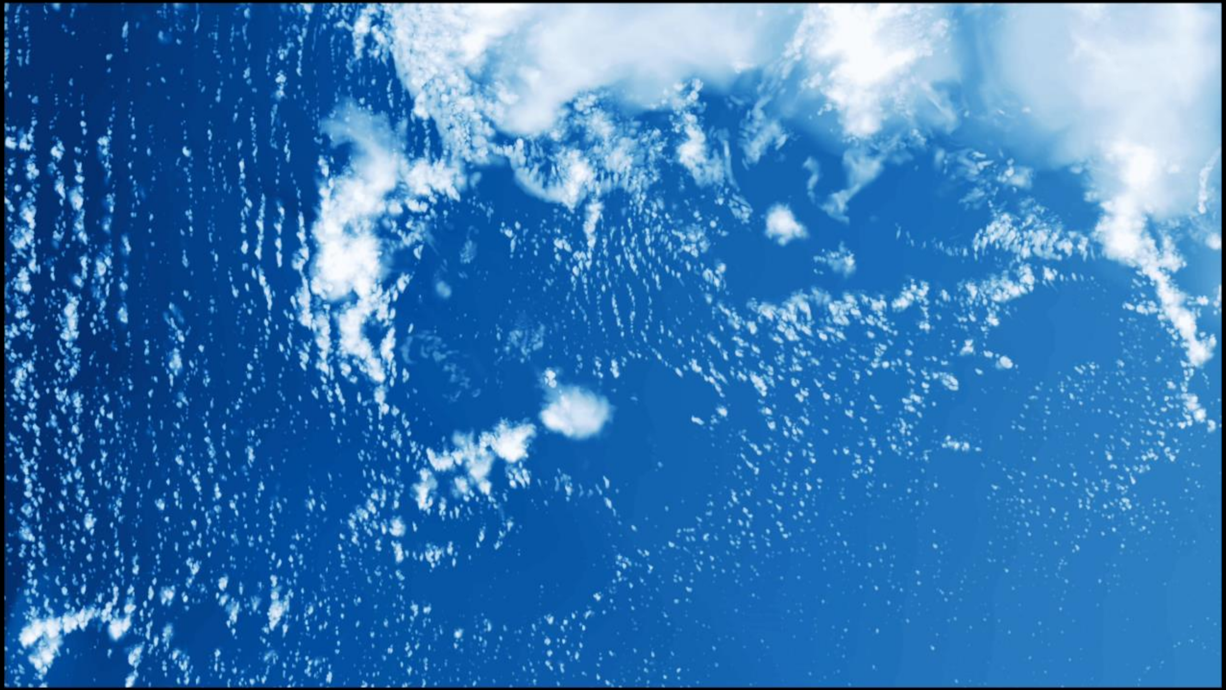
- Simulation details
  - Nested grids with innermost grid at 100m horizontal grid spacing
  - 230 vertical levels, with maximum vertical grid spacing of 125 m
  - 2-moment microphysics
  - ERA-5 initial and boundary condition (Hersbach et al., 2020)
  - 30s model output of key dynamical and thermodynamic variables
    - 100s of TBs of data (Special file compression – H5Z-ZFP; Lindstron 2014)

Tool: High-Resolution Simulations

Ability to track and study the evolution of convective systems

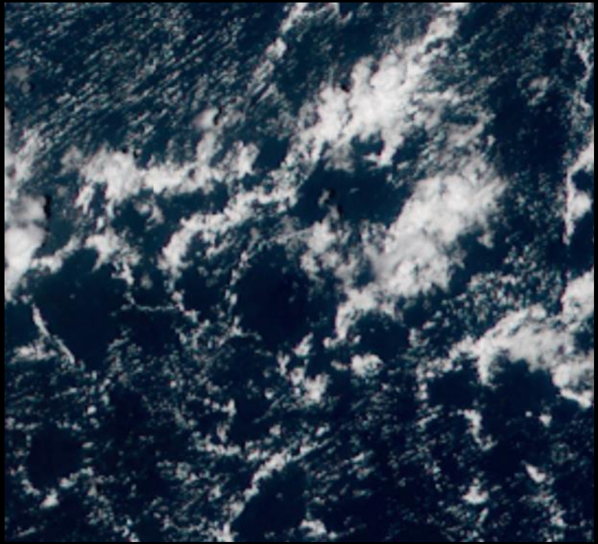
Example of high-resolution model simulation over the Maritime Continent with 30s output for 1 hour of model time

Simulation and animation courtesy of Nick Falk (CSU)



High-Resolution Simulations

- CAMP2Ex Simulations



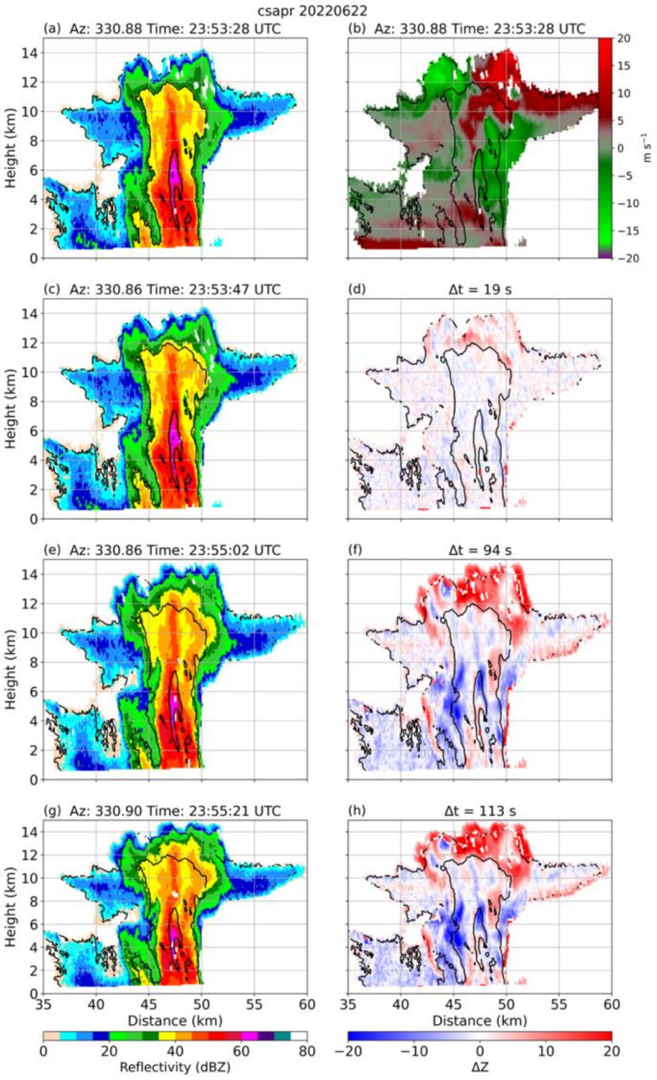
Model Simulation from CAMP^{2}Ex Field Campaign
(simulation from Nick Falk)

vs.

Himawari imagery from 10/9/22
(CIRA RAMMB Slider)

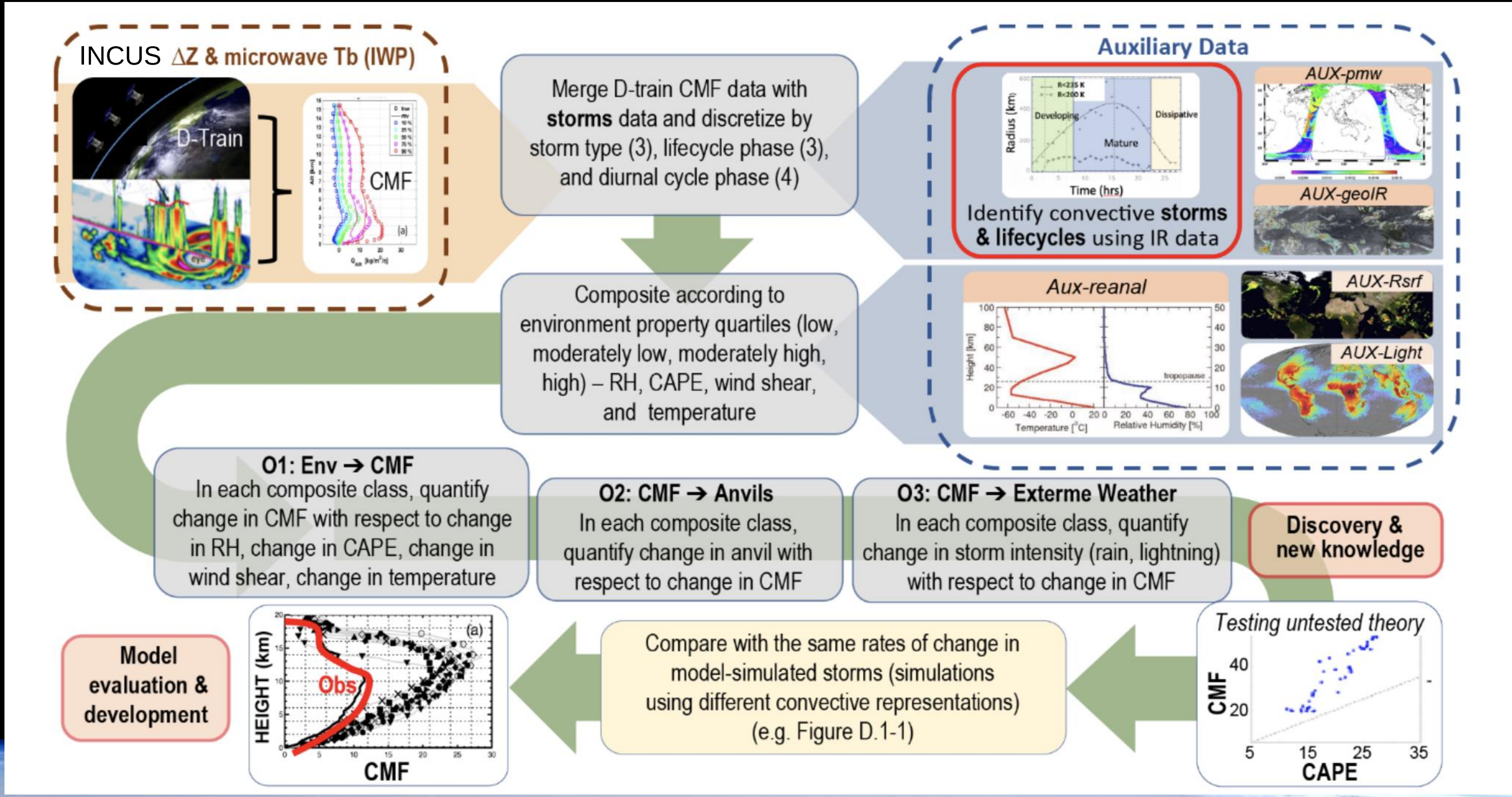
Delta-T Concept in TRACER

- First application of the Delta-T concept in a field campaign
- Multisensor Agile Adaptive Sampling (MAAS; Kollias et al. 2020) applied to track storms and automatically scan specific parts of storms through their life cycle
- Can see growth of the storm > 5 km using unique TRACER observations (Dolan et al. 2023)



Approach to Address INCUS Objectives

INVESTIGATION OF CONVECTIVE UPDRAFTS



INCUS Products

Product	Brief Description and Units	Lead	Val
1B-PWR	Received power from each DAR, calibrated and geolocated [dB]*	Tanelli	IG
1C-Ze	Equivalent radar reflectivity factor (Z_e) [dBZ]* and surface normalized radar cross section (0) [dB]	Tanelli	IG
1B-Tb	Calibrated DMR brightness temperatures (Tb) [K]	Brown	IG
2B-mass	Vertical profile of condensate for each radar profile [kg m ^{3}]*	Stephens	GM
2B-mass-rate	Profile of temporal change in condensate for each radar pair [kg m ^{3} s ^{1}]*	Kahn	GM
2B-Fluxes	Profile of vertical mass flux of air and condensed-water estimated for every detected updraft [kg m ^{2} s^{-1}]*	Haddad	GM
2B-DT	2 min evolution of local advection, condensate, and vertical fluxes in each cloud column	Kollias	GM
2A-HD	IWP [kg m^{-2}], derived from the radiometer brightness temperatures 1B-Tb	Posselt	G
AUX-geoIR	Lifecycle from geo-IR, convection type from cold Tbs, anvil size from IR Tb threshold	Luo	N/A
AUX-reanal	Large-scale environmental variables including convective available potential energy (CAPE), relative humidity (RH), temperature, and wind shear	Posselt	N/A
AUX-pmw	IWP from mm-wave radiometer constellation	Haddad	N/A
AUX-GPM-Ka	Coincident (GPM combined retrievals of ice water content) and (DPR Ka Z_e)	Stephens	N/A
AUX-Rsrf	Surface precipitation from Integrated Multi-satellitE Retrievals for GPM (IMERG)	Braun	N/A
AUX-Light	Lightning locations and flash rates from ground-based networks and spaceborne sensors	Rasmussen	N/A
3A-LIFE	Instantaneous 2B-Fluxes, lightning and geo-IR radiances, labelled by reanalysis data composite class	van den Heever	N/A
3B-CONV	Storm-wide statistics of vertical flux and environmental data, labelled by storm		N/A
3B-CRM	Instantaneous estimates and 2-minute evolution information as in 3A-LIFE, but labelled by storm (to enable evaluation of model simulations)		N/A
4-CONV	Convection nowcasting system, machine-learned from 3B-CONV	Haddad	G

Final Thoughts

- The INCUS mission will provide the first tropics-wide investigation of the evolution of the vertical transport of air and water by convective storms, one of the most influential, yet unmeasured atmospheric processes
- Exciting opportunity to work with the GHRC DAAC 2+ years ahead of the INCUS launch → build capacity to reach more users with our observations
- Interested in ideas from the group on how to take advantage of this pre-launch phase to maximize the impact of INCUS observations!