Strateole-2: Investigating the tropical tropopause layer with long-duration superpressure balloons

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SCRIPPS INSTITUTION OF OCEANOGRAPHY

Reporting on Modeling: Martina Bramberger, postdoc,
NWRA
(with M. Joan Alexander and Alison Grimsdell)
Contributions from Albert Hertzog (LMD) Philippe Cocquerez (CNES)

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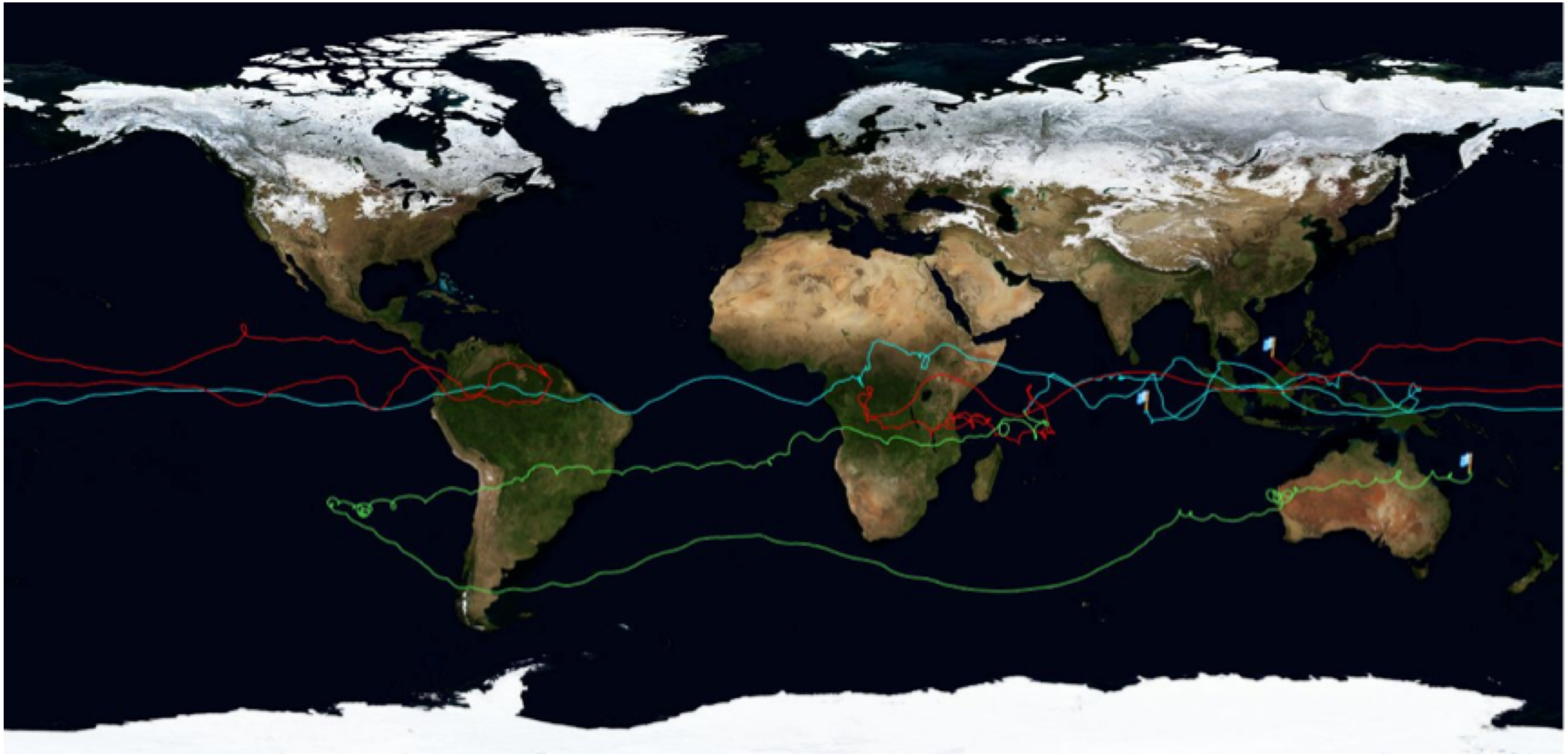
Centre Nationale de la Récherche Scientifique, Centre Nationale des Etudes Spatiales

Prepared for the US CLIVAR Process Study and Model Improvement Panel Webinar Series 25 June 2019

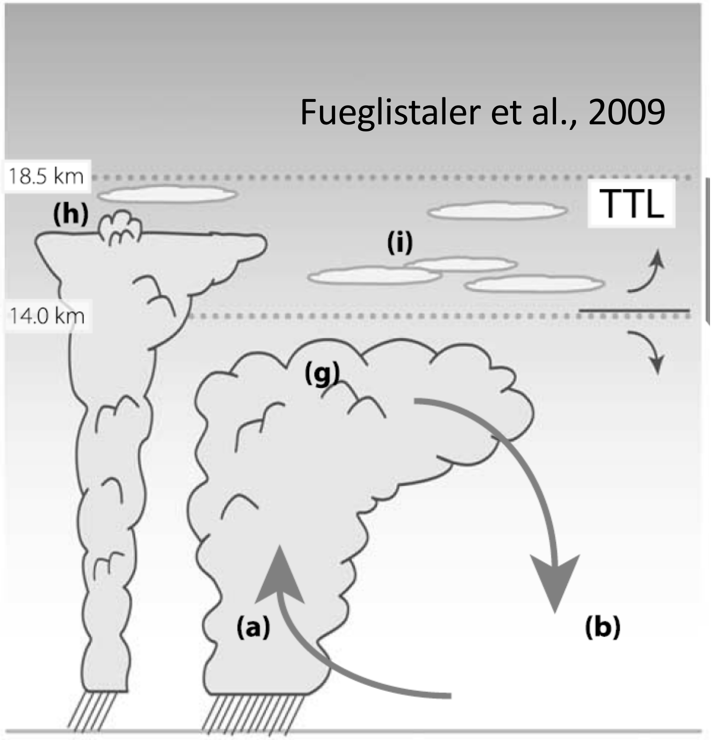
Equatorial waves from superpressure balloons



Early tropical test flights of the superpressure balloon system February - May 2010. The flight duration was approximately 80 days near 20 km altitude. Some wave structures are visible in the balloon paths, and the reversal of the balloon paths when the QBO changed phase is also visible.

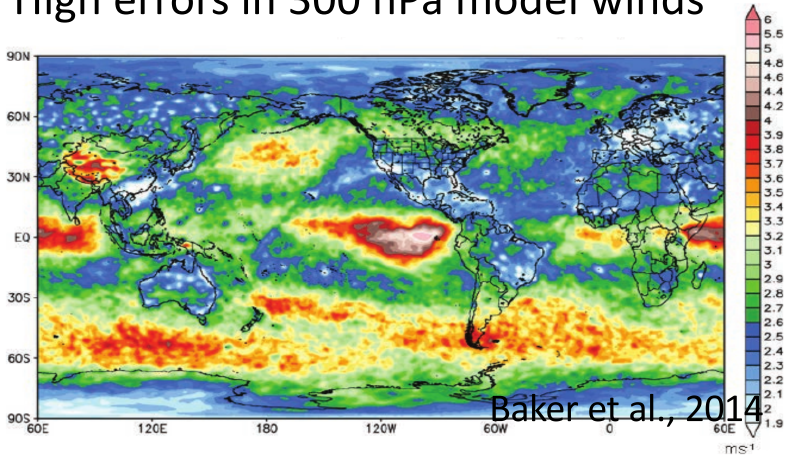
The tropical tropopause layer (TTL)

- The TTL is the gateway to the middle atmosphere
  - Transport through the tropical tropopause sets the chemical composition of the stratosphere, in particular for water vapor and ozone.
  - The stratospheric water vapor content is controlled by the intense dehydration of air parcels that ascend through the cold tropical tropopause... and exhibits large decadal variations that modulate surface warming.
- From a dynamical point of view, the TTL is a very rich and complex region, with important processes covering a wide range of scales
  - Deep convection and cirrus
  - Planetary-scale (Kelvin, Rossby, and Rossby-gravity) waves
  - Quasi-biennial oscillation (QBO)
- A significant part of our knowledge of transport in the TTL relies on NWP model analyses
  - However wind observations are sparse in the tropics
  - Tropical winds are not as well constrained by the mass field as outside the tropics, therefore errors are high.



Fueglistaler et al., 2009

High errors in 300 hPa model winds

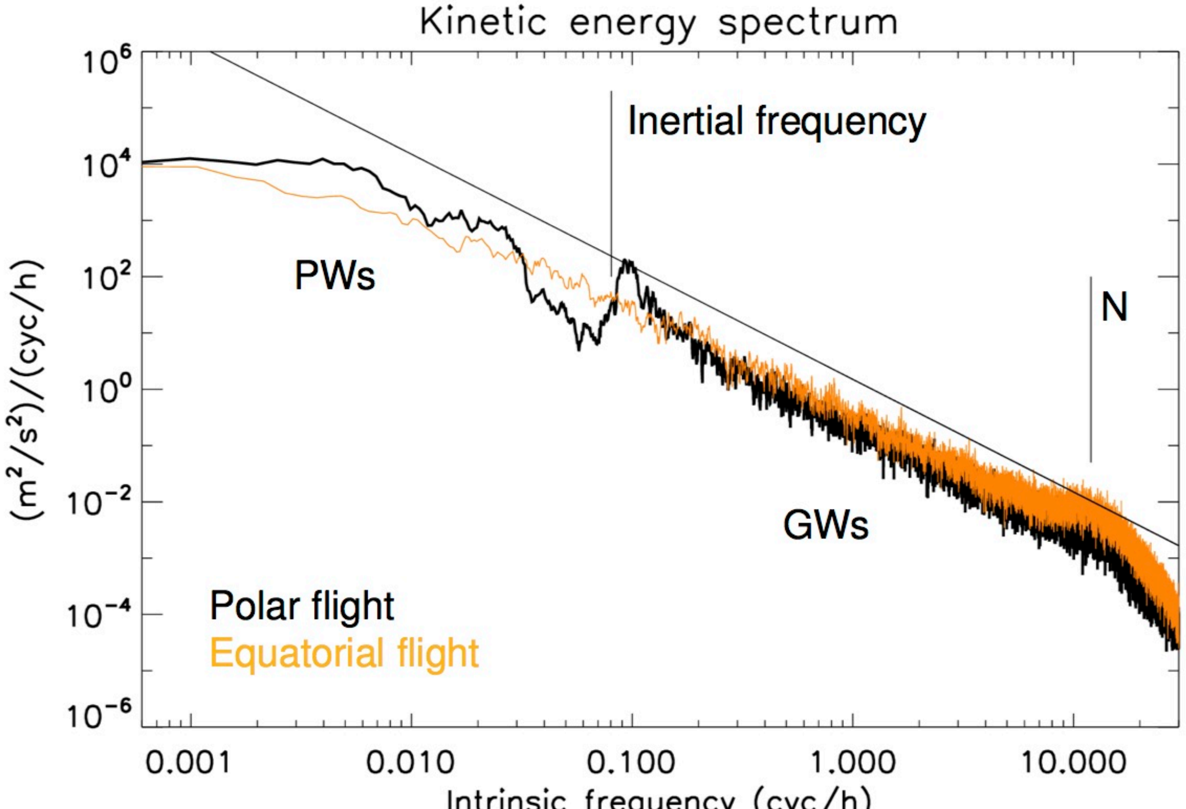


Baker et al., 2014

Gravity wave measurements from previous campaigns

- Observations of gravity wave momentum fluxes at the tropics are needed at all scales.
- Climate models have difficulty generating a realistic QBO because of GW drag parameterization, especially one that captures intermittency of wave sources.

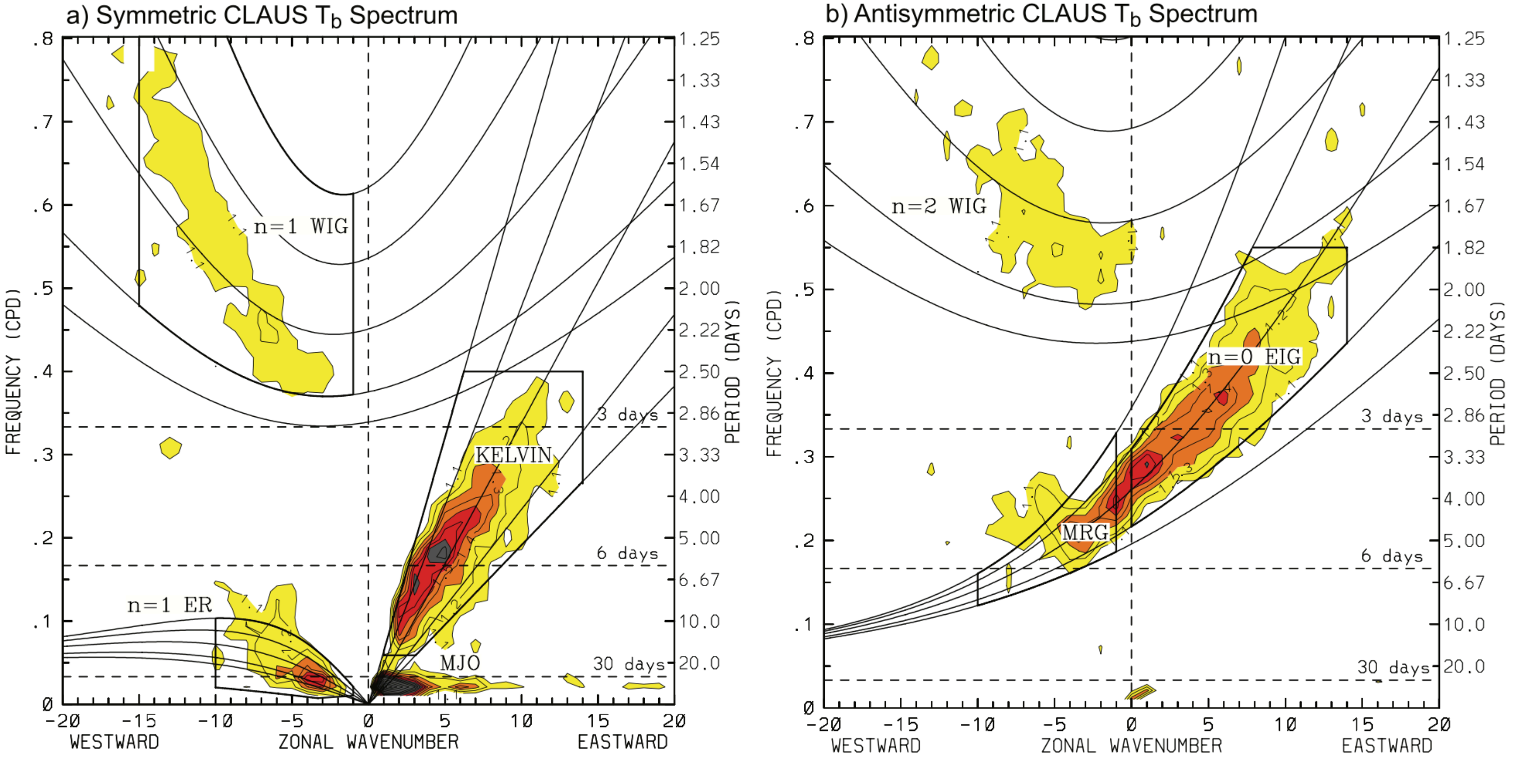
- Momentum fluxes are retrieved from in-situ observations
- 30s obs of balloon motion using
- u’, v’, P’, and z’ and polarization relations
- (Hertzog et al., 2010, Vincent & Hertzog, 2013; Zhang et al., 2016).



New objective: to understand relationship between waves and convection

Convectively-coupled tropical waves in cloud/rain observations

Symmetric **Anti-Symmetric**



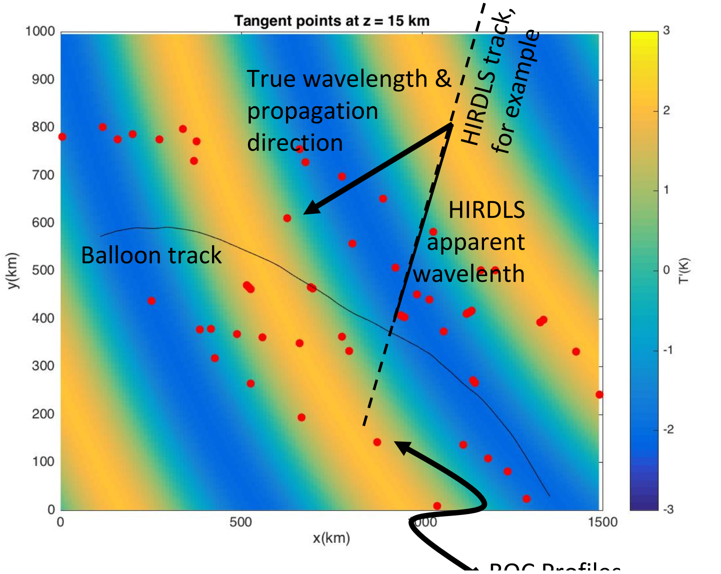
Color = Ratio Spectrum/Background

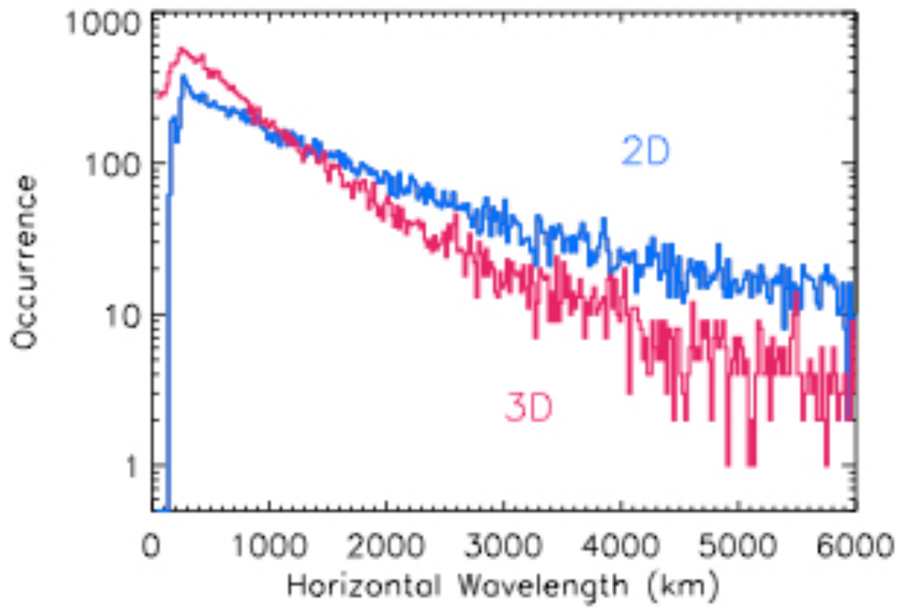
Kiladis et al. [2009]

Requires measurements of horizontal wave properties, not just vertical.

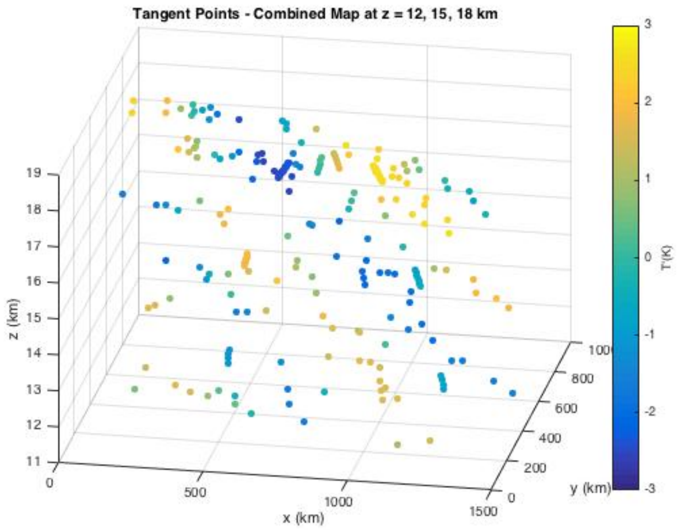
New objective: 3D measurements of waves

- Current methods sample apparent wavelength and phase speed, so momentum flux is biased.





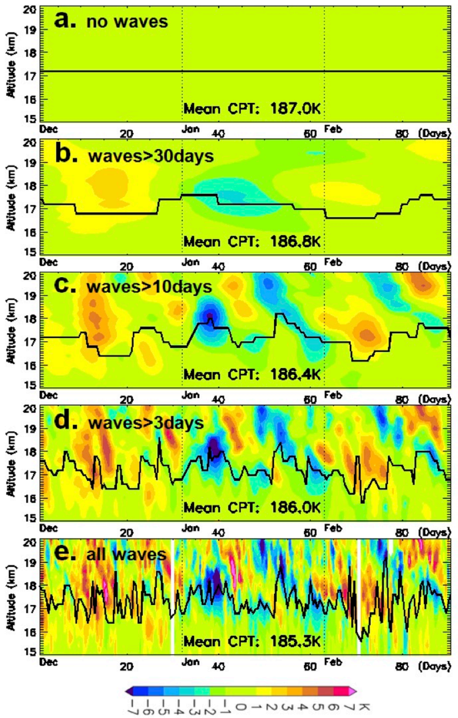
Temperature variation as sampled by ROC in 3D.



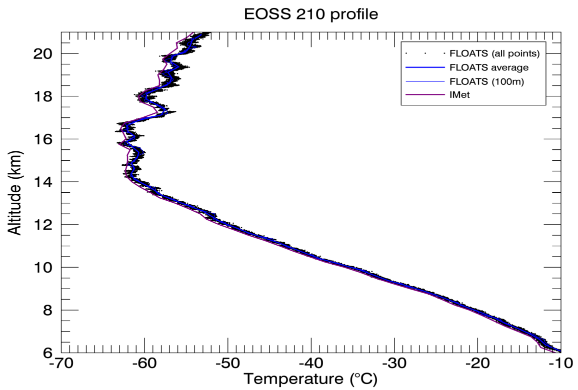
Wave properties are very different for 3D vs 2D.
The Radio Occultation (ROC) profiler attempts to sample large horizontal scale, fine vertical scale waves in 3D.

New objective: wave influences on cold point tropopause, dehydration, and cirrus formation

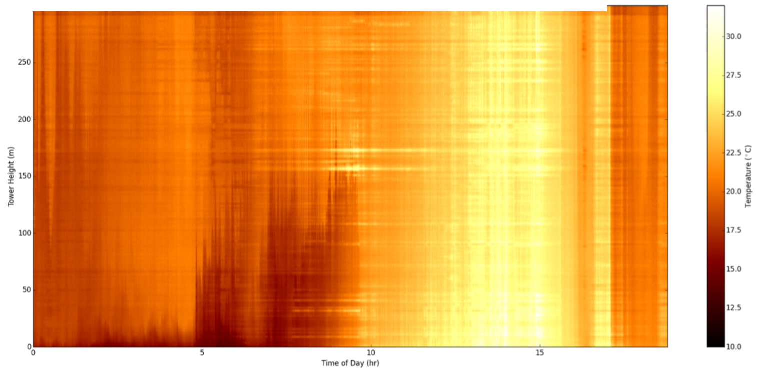
- Waves of all scales lower the Cold-Point Temperature (CPT). Equatorial Rossby waves, Kelvin waves, mixed Rossby-gravity and gravity waves all combine to lower CPT on average 1.6K. Waves decrease H_2O by ~25%



- Above: Radiosonde T' observations of waves at a broad range of scales at one location (Kim and Alexander 2015). FLOATS will quantify waves on comparable spatial scales.



Left: Prototype FLOATS instrument captures fine scale detail not captured by radiosonde.

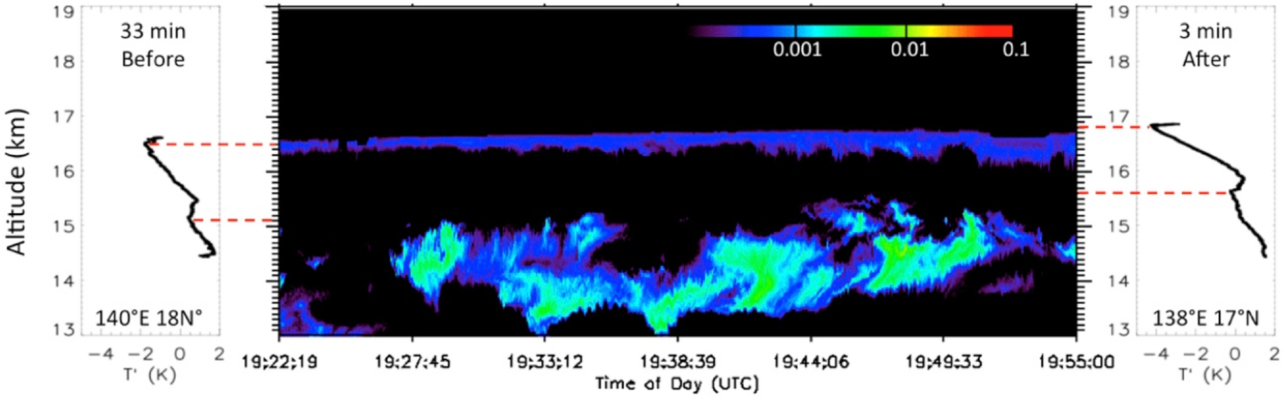


Left: Nocturnal boundary layer structure from FLOATS profiler suspended from tower illustrating 'curtain of measurements'.

- Extremely high resolution continuous T profiles from suspended 2km fiber optical cable (FLOATS) will quantify wave occurrence at fine horizontal and vertical scales.

Wave influences on cold point tropopause, dehydration, and cirrus formation

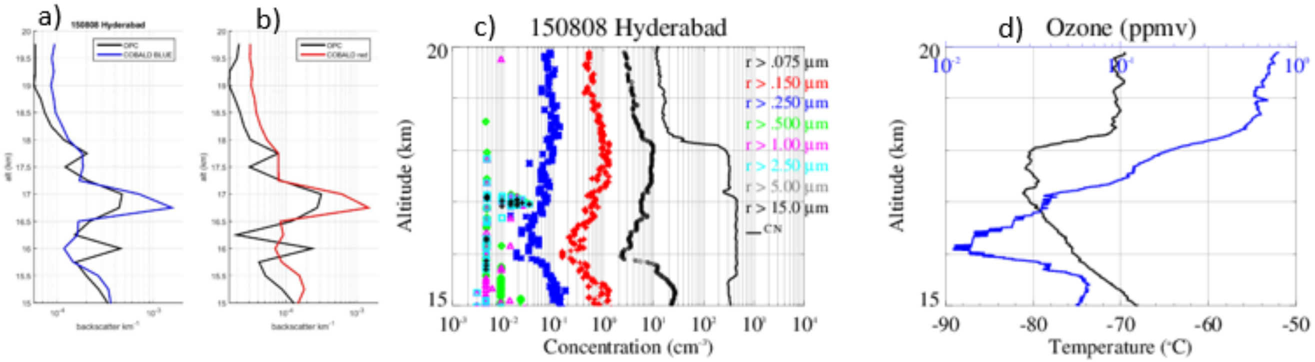
- ATTREX aircraft campaign T profiles and Cloud Physics Lidar (CPL) captured snapshot of wave-induced T anomalies showing cirrus formation in cold (T’ < 0) or cooling layers (dT’/dz < 0).



RACHUTS will lower instruments 2 km through the TTL 10 times/night:

- FLASH-B Water vapor sensor
- COBALD Cloud particle sensor
- TSEN Temperature and pressure sensor

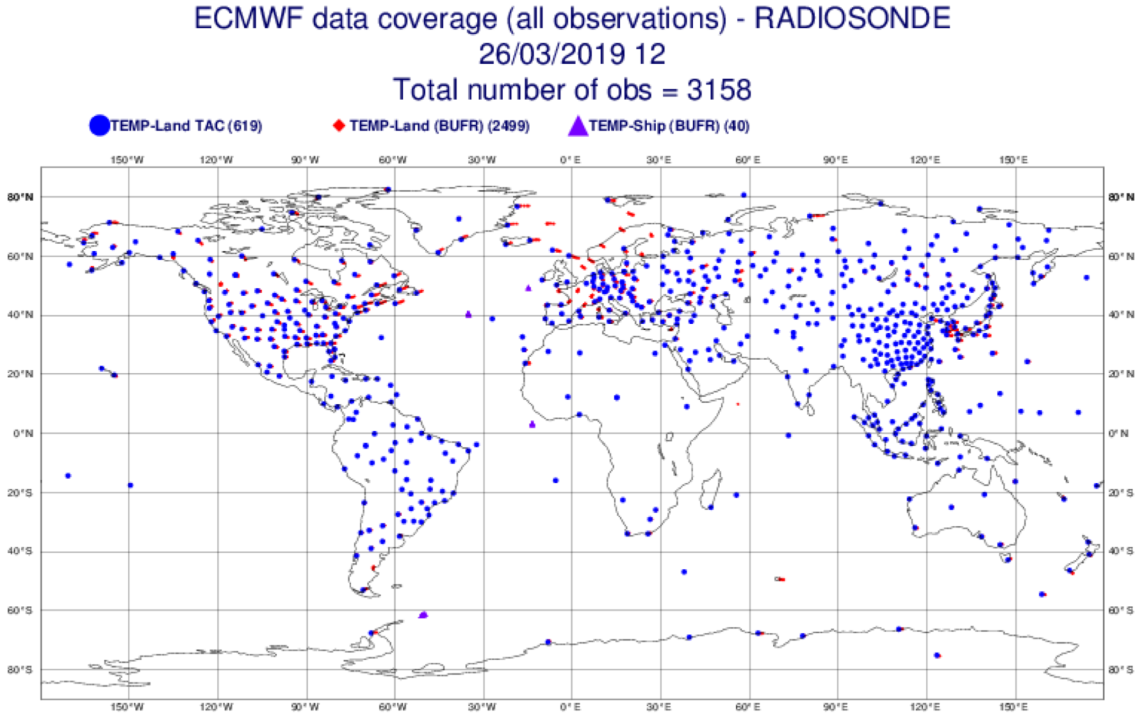
- RACHuTS will link T structure to dehydration processes through continuous measurements of water vapor, cloud particles, and temperature across the cold point during night time.



- Left: a) b) Vertical profiles of aerosol backscatter using a COBALD instrument at 455 and 940 nm, c) aerosol concentration CCN(solid thin line) and particles (colored symbols) and d) temperature in black and ozone in blue.

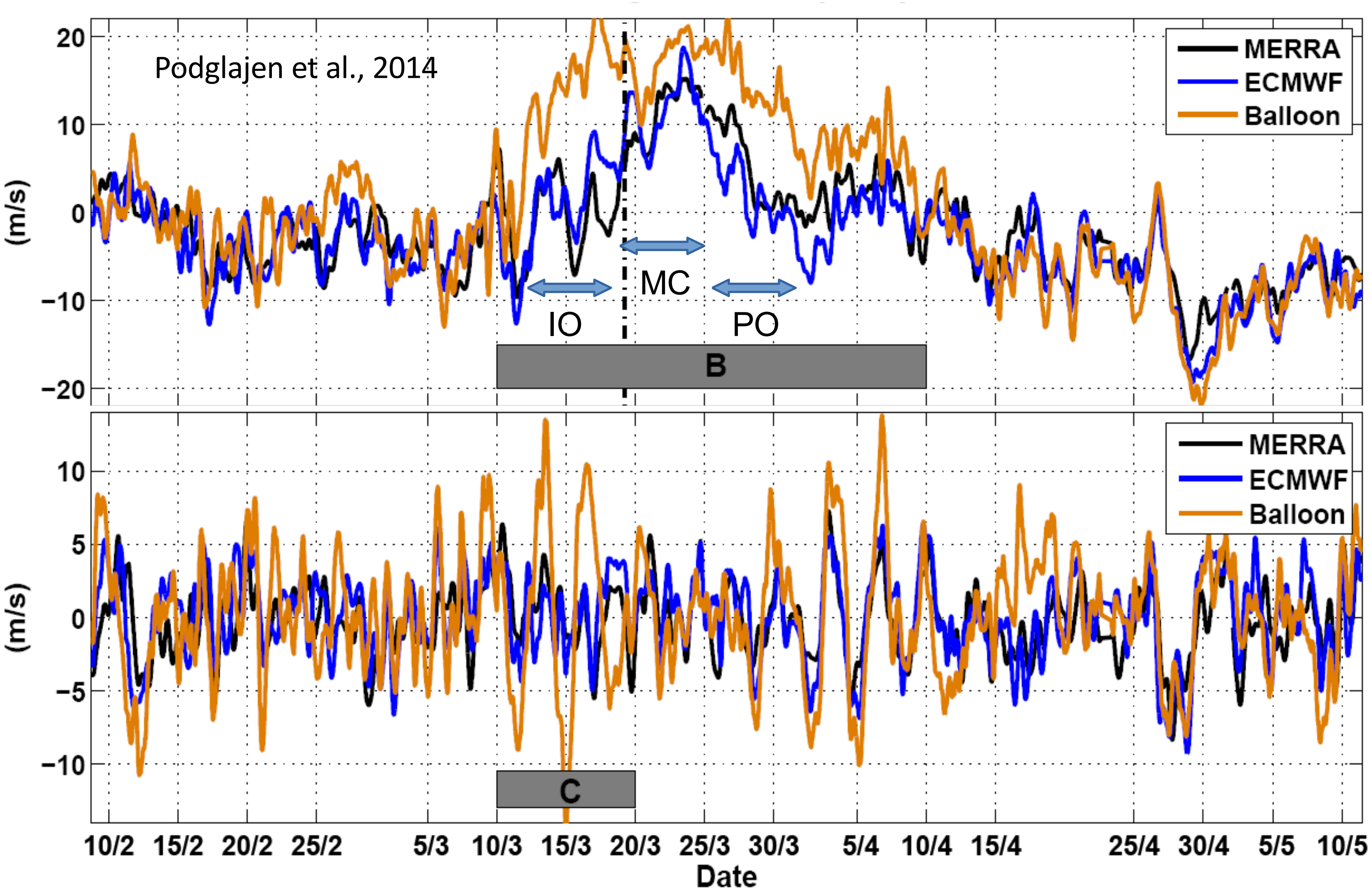
Value added for NWP and Aeolus wind validation

- With the exception of Aeolus products, current direct wind observations in the TTL are associated with radiosoundings
    - Most stations in the Maritime continent and South America
    - Large data-void areas: Indian Ocean and the Eastern Pacific Ocean



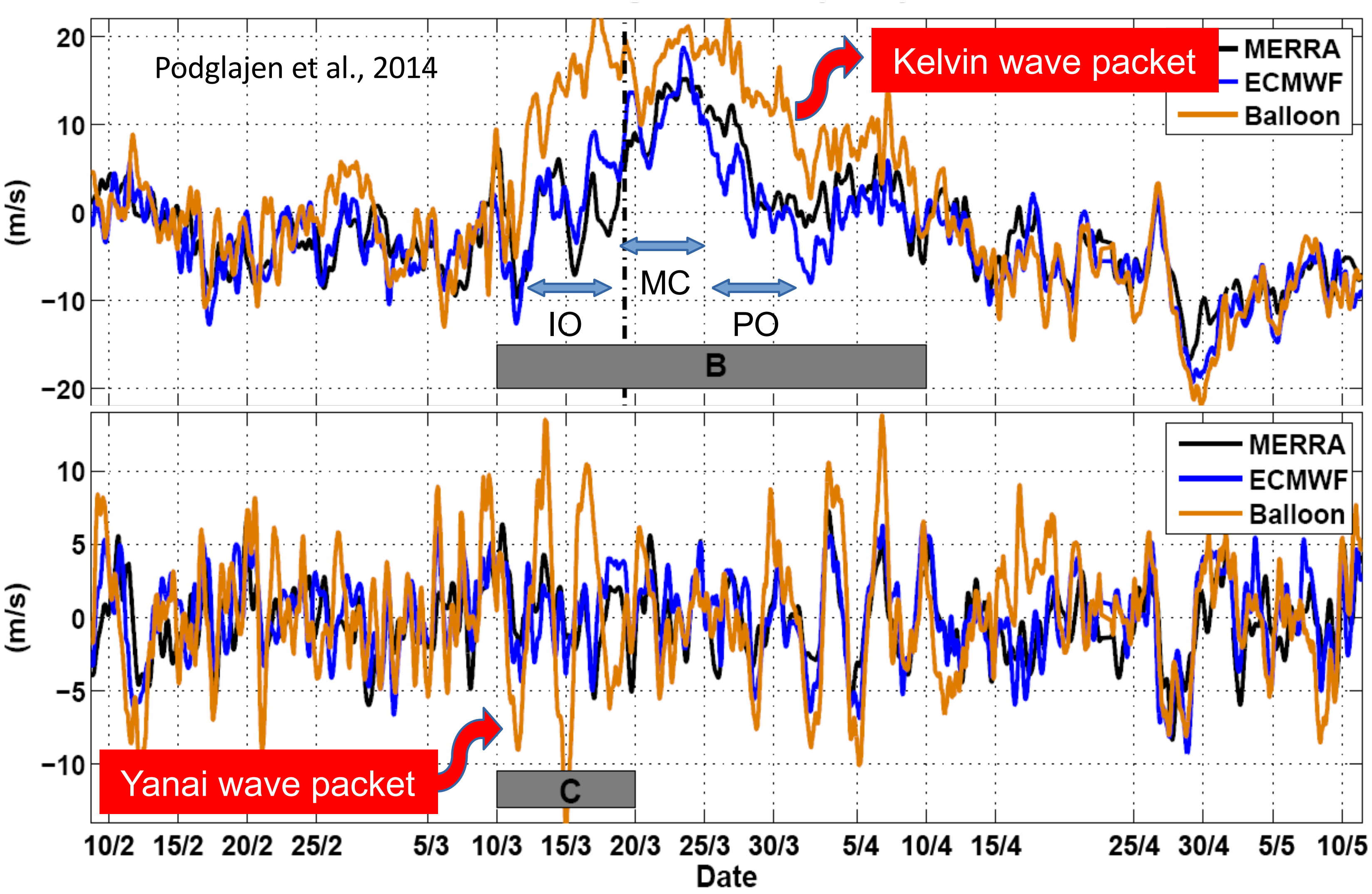
Pre-Concordiasi (2010)
Balloon #1, U

Pre-Concordiasi (2010)
Balloon #1, V


Podglajen et al., 2014

Pre-Concordiasi (2010)
Balloon #1, U

Pre-Concordiasi (2010)
Balloon #1, V



Kelvin wave packet

Yanai wave packet

Flotilla overview for science campaigns

October 2021 – Jan 2022

October 2024 – Jan 2025

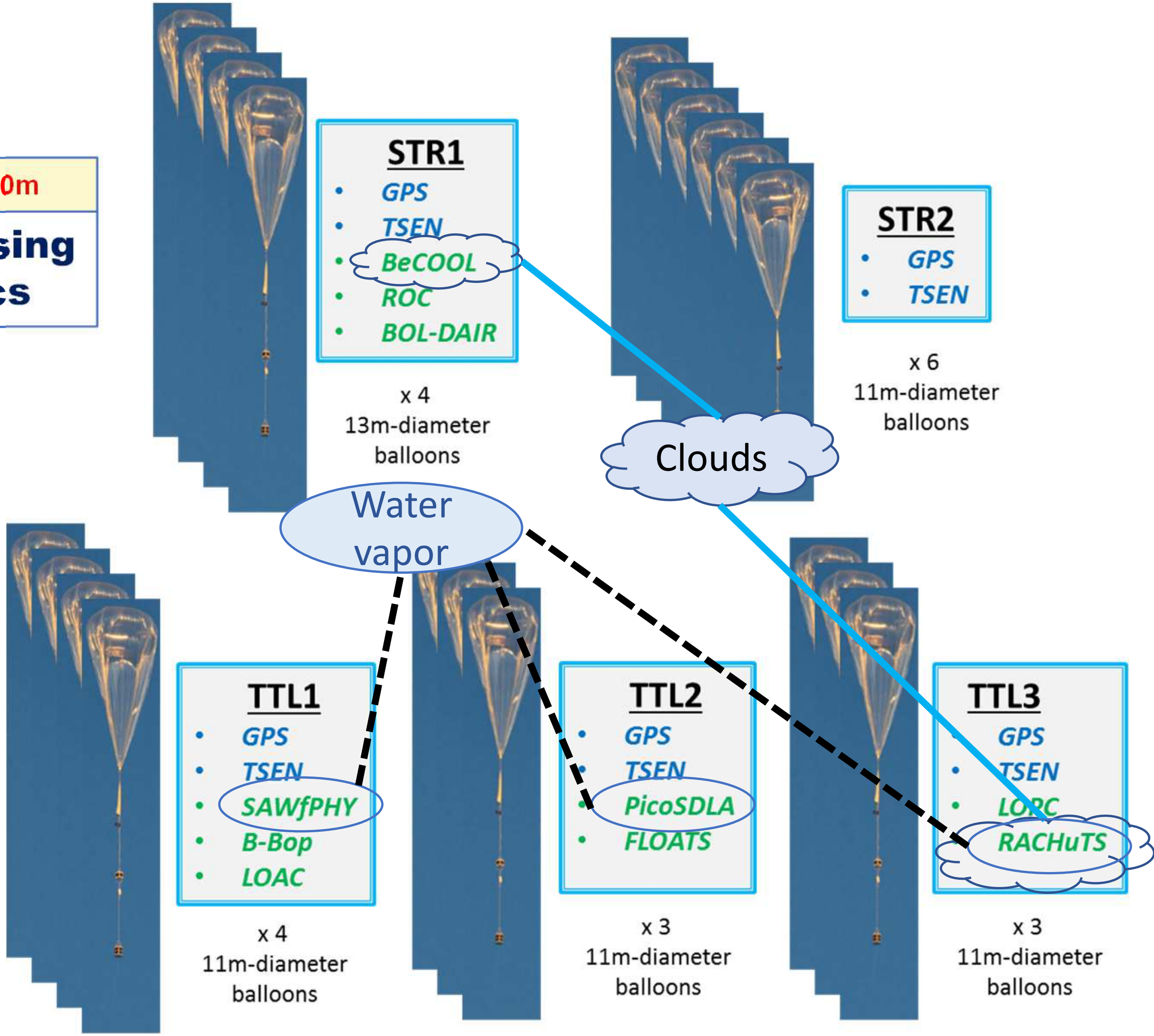
A flotilla of 20 balloons
for each
of the 2 science campaigns

10 Bal. Altitude 20000m

Remote Sensing
& Dynamics

In Situ Sensing
& Dynamics

10 Bal. Altitude 18000m



STR1
- *GPS*
- *TSEN*
- *BeCOOL*
- *ROC*
- *BOL-DAIR*

x 4
13m-diameter
balloons

STR2
- *GPS*
- *TSEN*

x 6
11m-diameter
balloons

Clouds

Water vapor

TTL1
- *GPS*
- *TSEN*
- *SAWfPHY*
- *B-Bop*
- *LOAC*

x 4
11m-diameter
balloons

TTL2
- *GPS*
- *TSEN*
- *PicoSDLA*
- *FLOATS*

x 3
11m-diameter
balloons

TTL3
- *GPS*
- *TSEN*
- *LOPC*
- *RACHuTS*

x 3
11m-diameter
balloons

Instruments and observations

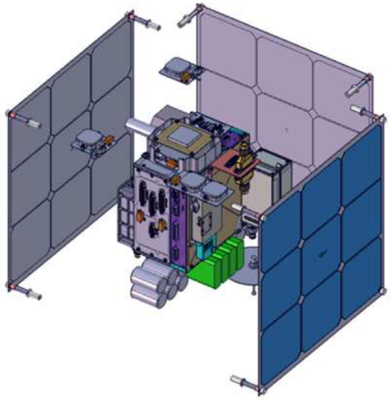
Instrument	Purpose	Institute	Meas. Type	Altitudes	Meas. Rate	Geophysical quantities
GPS (Euros)	Wind (through position)	CNES	in-situ	flight level	every 30 s	3D positions horizontal winds
TSEN	Air Pressure and Temperature	CNRS-LMD	in-situ	flight level	every 30 s every 1 s	temperature pressure
SAWfPHY	Water Vapor (through dew-point)	CNRS-LMD	in-situ	flight level	every 10-15 min (only night)	H2O mixing ratio
B-Bop	Ozone Photometer	CNRS-LMD	in-situ	flight level	every 10-15 min	O3 mixing ratio
LOAC	Optical Particle Counter	CNRS-LPC2E	in-situ	flight level		size resolved particle #
pico-SDLA	Water Vapor and Carbon Dioxide (through light absorption)	CNRS-GSMA / DT-INSU	in-situ	flight level		H2O mixing ratio CO2 mixing ratio
FLOATS	Local Profiler Air Temperature	LASP (USA)	in-situ	flight level down to 2-3 km below	2 profile every 5-10 min	temperature
LOPC	LASP Optical Particle Counter	LASP (USA)	in-situ	flight level	every 8 min	size resolved (8 bins) aerosol number concentration
RACHuTS	Local Profiler Air Temp., Water Vap., Cloud Detection	LASP (USA) & NOAA (USA)	in-situ	flight level down to 2 km below	3/4 profiles per night	temperature H2O mixing ratio Cloud detection
BeCOOL	Nadir Cloud detection trough Long Distance Lidar	LATMOS / CNR France / Italy	remote (nadir)	flight level down to ~5 km below	1 profile every 5-10 min	attenuated backscatter
ROC	Atm. Sounding through GPS Occultation High accuracy GPS position	Scripps Oceanography (USA)	remote (limb)	flight level down to z~4 km	tens of profiles per day	high-precision 3D positions temperature
BOL-DAIR	Up-Welling Infrared Flux	CNRS-LATMOS	in-situ	flight level	every 1 min	total upwelling flux total long wave flux

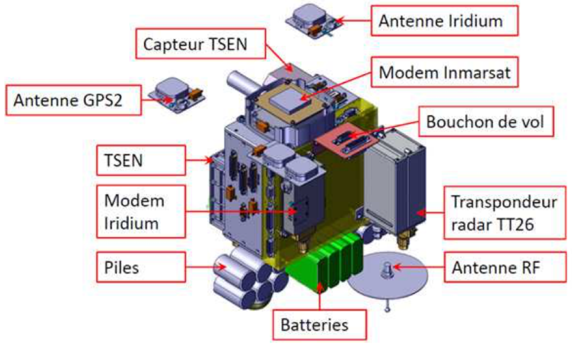
6 balloon campaign – test each configuration

November 2019 – Feb 2020

EUROS

Flight Control Gondola
failure tolerant
Mass: ~13 kg

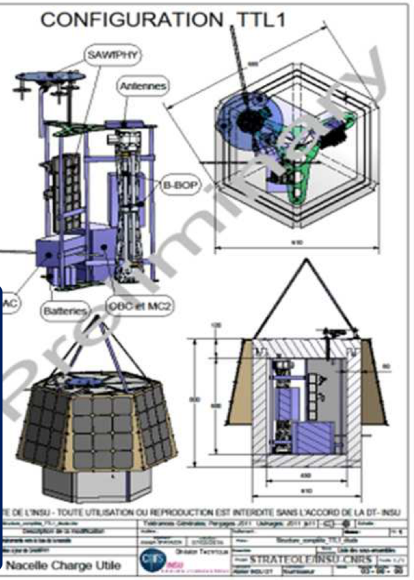


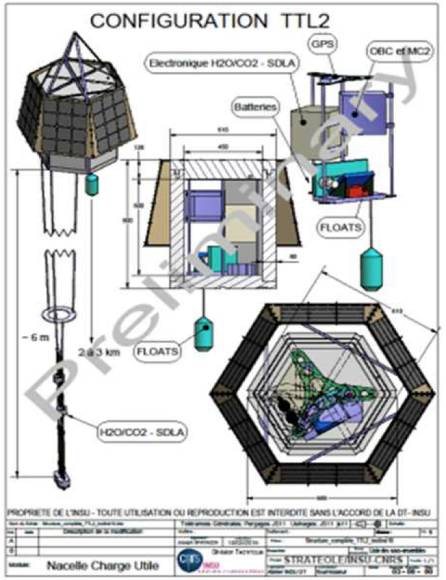


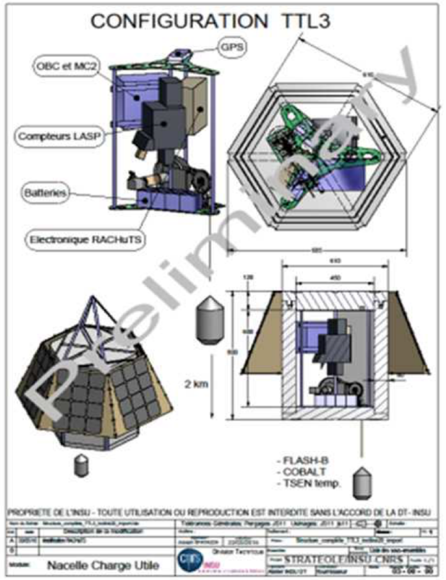
ZEPHYR

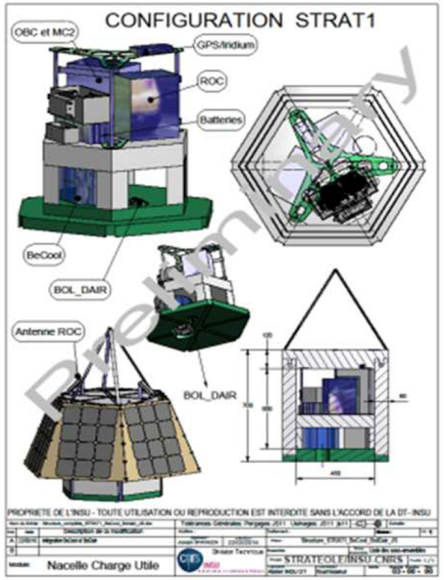
Payload Gondola
Tailored to
instrument combinations
Overall mass: ~22 kg

Overall allocation for scientific instruments, up to:
- ✓ Mass 10 kg
- ✓ Power 20w average
- ✓ Data 12MBytes/day



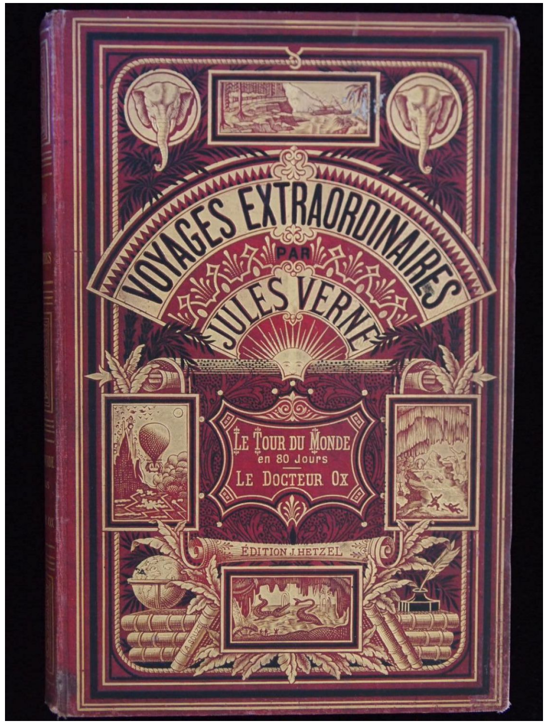




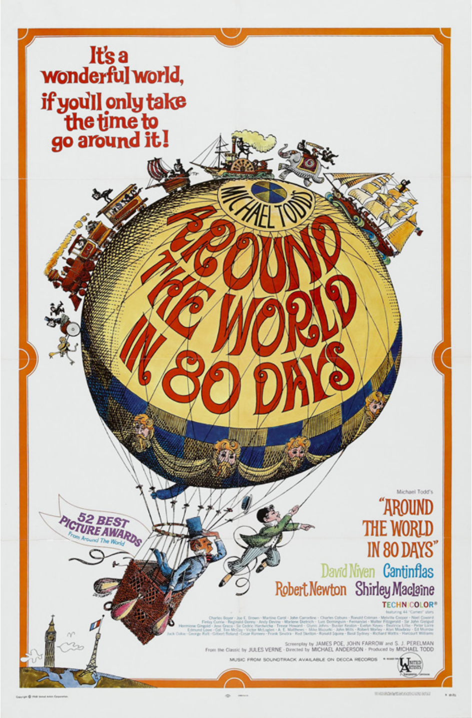


Around the world in 84 days

- American Geophysical Union EOS cover story




72 days 1889-1890



US – French collaborations are interesting, even if some of the details are only approximately correct …


EOS BUZZ
The latest Earth and space science news

Around the World in 84 Days

By Jennifer S. Haase et al. **1 March 2018**

In the Stratéole 2 program, set to launch in November 2018, instruments will ride balloons into the stratosphere and circle the world, observing properties of the air and winds in fine detail.

READ MORE »

Plans for Integration of Modeling and Observations

- Past Workshops and Meetings:
  - 2013 – AGU Planning meeting and white paper
  - 2014 Sparc General Assembly presentations
  - 2015 NSF-CNRS sponsored Stratéole-2 workshop
  - 2017 CLIVAR Summit (included in presentation of Yolande Serra)
  - 2017, 2018 ShOvV presentations
  - 10-13 June 2019 ECMWF Workshop on observational campaigns for better weather forecasts
  - Presentations and splinter meetings at AGU, SPARC
- Future Workshops and Meetings:
  - September 2020 Stratéole Science Preview Workshop at SIO, UCSD
  - BAMS Article
  - AGU 2020
  - September 2021 Stratéole Science Workshop (location TBD)

Summary of science objectives of Stratéole-2

- Dynamics of the Tropical Tropopause Layer and tropical lower stratosphere
  - Planetary scale and gravity waves, driving of the QBO
- Transport and dehydration at the cold point tropopause (CPT) considering wave-microphysical interactions
- Satellite cal/val for ESA Aeolus 3D wind lidar
- Improvement of operational numerical weather prediction (NWP) forecasts and analyses
- Generation of gravity waves by convection and modulation of convection by waves
- ==> Martina Bramberger will continue with more details on integration of modeling and observations…

Stratéole-2 Modeling Studies

Martina Bramberger, M. Joan Alexander, Alison Grimsdell

NorthWest Research Associates, Boulder, Colorado

How Strateole 2 Could Impact Modeling

- Planetary scale waves
  - Strateole 2 will provide 3D structure of equatorial planetary waves
  - Comparison studies to improve their representation in climate models

- Reanalysis and NWP wind errors in the tropics
  - Tropical winds are related with large errors in the reanalysis
  - Strateole-2 flight level winds will be directly assimilated into the NWP and reanalysis models.
  - will provide cal/val data for the Aeolus wind lidar that will also be operationally assimilated.

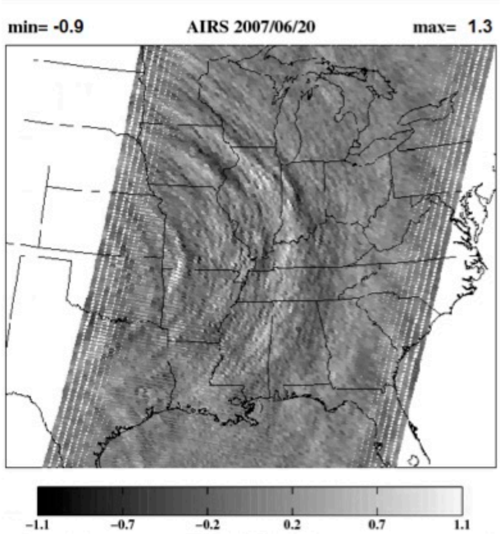
How Strateole 2 Could Impact Modeling

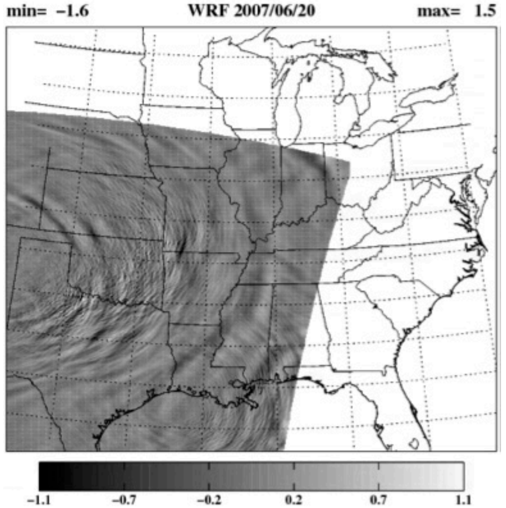
- Improvement of the QBO in climate models
  - High-resolution vertical observations of Strateole 2 to study wave-mean flow interaction
  - New dataset for comparison for the QBO initiative

- Cirrus and tropopause temperature variability
  - Strateole-2 will provide observations of temperature variability of the tropopause
  - Tune parameterizations of this temperature variability in climate models

- Links between Gravity waves and convection.
  - improve a parameterization with GW flux and GW drag
  - Homogeneous launch drag distribution vs a source dependent distribution

Challenge: Generation of gravity waves by convection and modulation of convection by waves





- Parameterization schemes for gravity waves from convection require momentum flux phase speed spectrum at cloud tops.
- The spectral shape depends on depth and strength of convective latent heating.
- Observations of waves and clouds are needed for these schemes to behave realistically both in present day and future climate simulations, especially in the poorly sampled equatorial region.
- Additional instrumentation measures water vapor from overshooting tops, cloud presence, aerosols and ozone, and waves at all scales.

BeCOOL	nadir cloud detection by lidar to 5 km below flight level
ROC	high-precision 3D positions, wind, radio occultation T profiles from flight level to 8 km
BOL-DAIR	Infra-red total upwelling flux and total long wave flux
SAWfPHY	in-situ H2O mixing ratio from dew point
B-Bop	ozone photometer in-situ O3 mixing ratio
LOAC	optical particle counter for size resolved particle number
pico-SDLA	in situ H2O and CO2 mixing ratio from light absorption
FLOATS	fiber optic T profile curtain from flight level to 2km
LPC	size resolved (8 bins) aerosol and number concentration
RACHuTS	reel down night time profiles of T, H2O, Cloud detection

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UC San Diego

cnes

Latent Heating Profiles

Background:

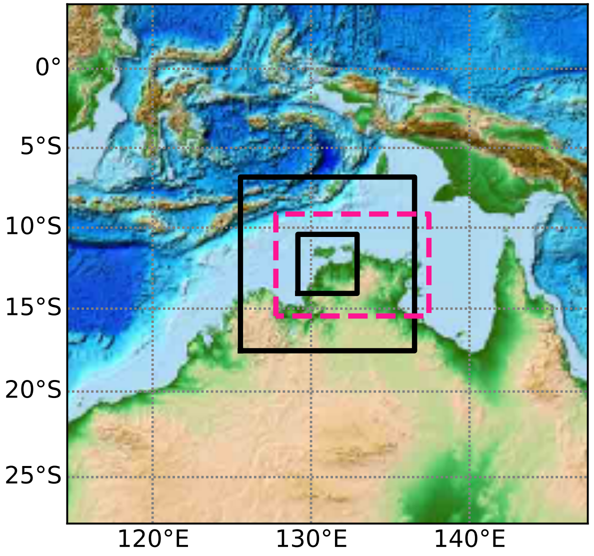
- Stephan and Alexander, 2015 trained an algorithm to characterize the vertical profile of latent heating
- They realistically reproduced characteristics (e.g. amplitudes) of a observed gravity wave field above mature convection
- They associated latent heating profiles to precipitation rates
- Applied algorithm to midlatitude summertime storm conditions over the Continental US

Goal:

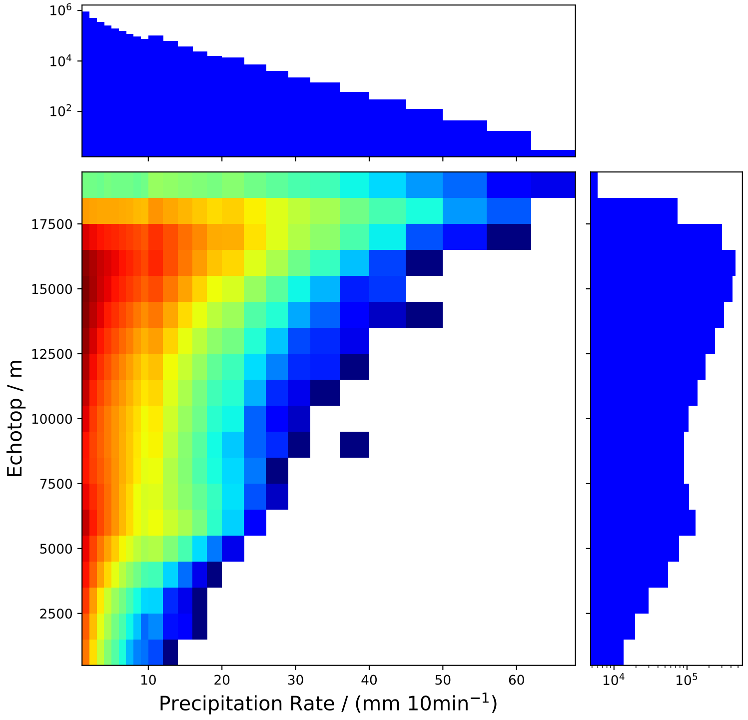
- **Extend approach of Stephan and Alexander, 2016 to tropics**
- **Associate latent heat profile additionally to cloud top heights**

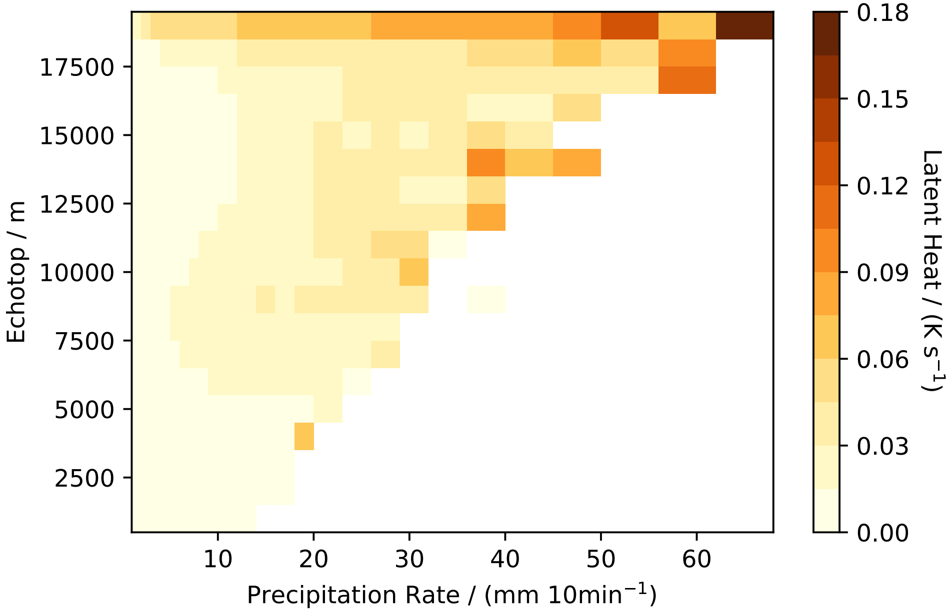
Dataset:

- Ensemble of 4 WRF full-physics runs
- Idealized WRF simulations
- C-Pol radar measurements
- AIRS measurements



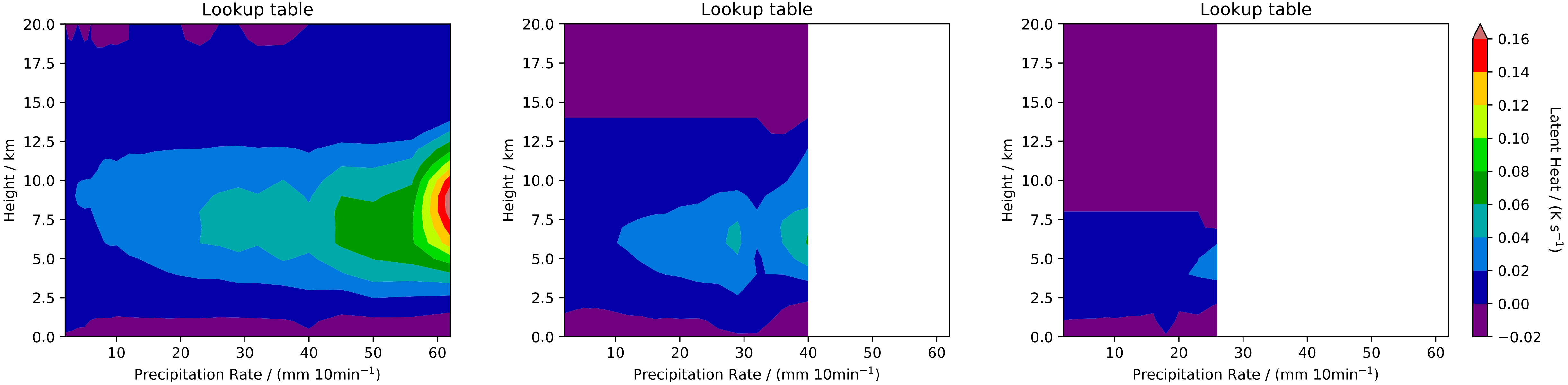
2D Histogram – Echotop vs Precipitation Rate





- High precipitation rates seem to be a sparse event
- High precipitation rates associated with deep convection
- Largest latent heating rates accrue with increasing precipitation rates

Vertical Profiles of Latent Heating



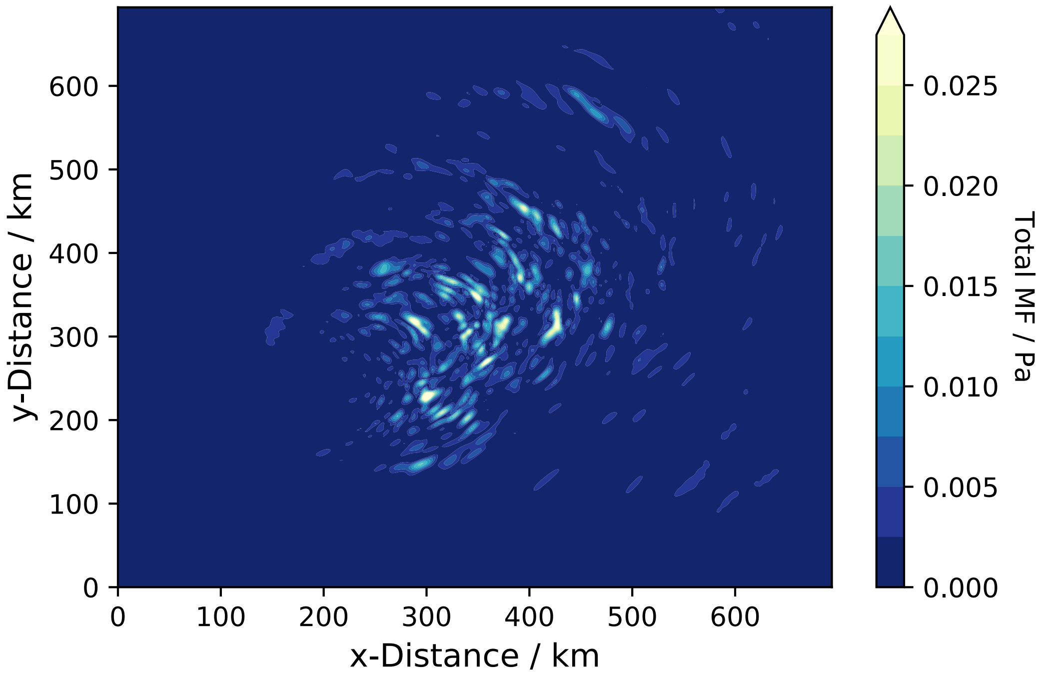
Echotop 13-19km

Echotop 7-13km

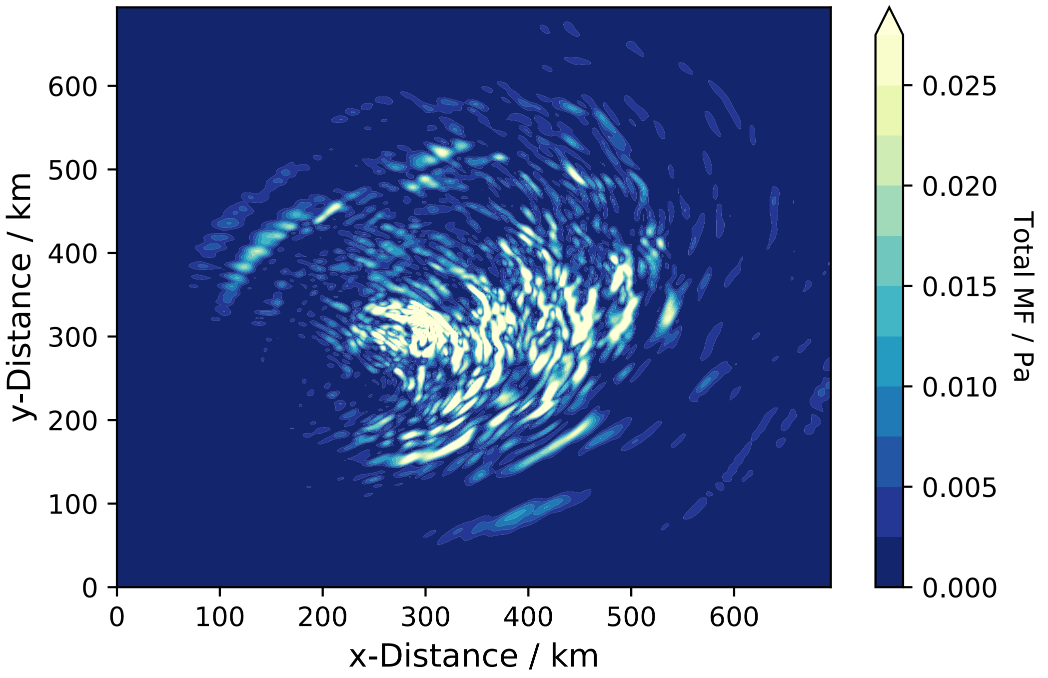
Echotop 2-7km

- Enhanced latent heating related to precipitation rates > 45mm/(10min)
- Majority of latent heating is concentrated between about 3km to 12.5km
- Latent heating and precipitation rates decrease with decreasing echotop heights

Total Horizontal Momentum-fluxes



1D Lookup Table



2D Lookup Table

- Shape of excited gravity waves (GWs) is similar
- Vertical flux of horizontal momentum larger by about a factor of 10 when GWs are generated with 2D lookup table

Summary

- **Strateole 2 will provide observations in a region where otherwise only sparse data is available**

- **Dataset contains 3D observations of GWs and planetary scale waves**

- **Good observational basis to improve GW parameterizations in NWPs and climate models**

Thank you for your attention!

- **Credit:**

Jacques Descloitres,
MODIS Rapid Response Team,
NASA/GSFC

Taken off Australia by
the Terra satellite
on November 11, 2003

Forecasting convective GW Activity

- Based on output of the non-orographic GW parameterization scheme of ECMWF

- $\frac{D(TKE)}{Dt} \approx \frac{DU^2}{Dt} \cdot \frac{Q}{Q_0}$

  with Q as the convective heating rate from 500hPa to cloud top and Q_0 is 1W/m^2.

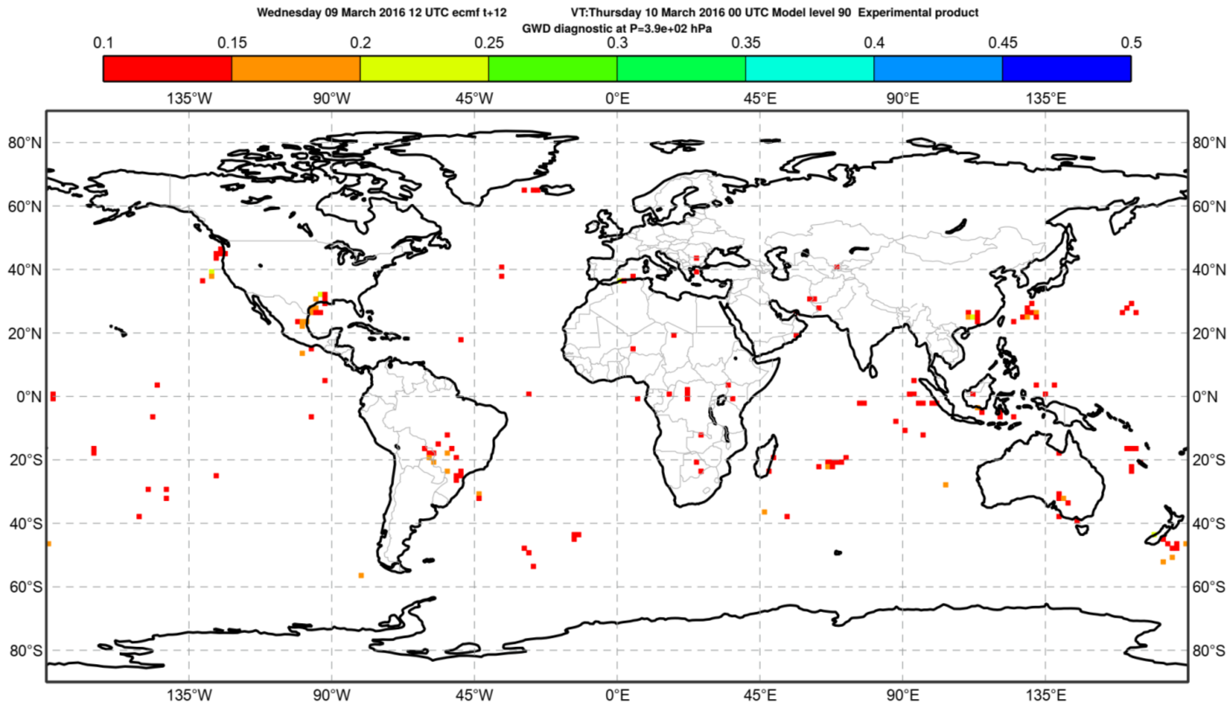
  Q and $\frac{DU}{Dt}$ from ECMWF non-orographic parameterization scheme

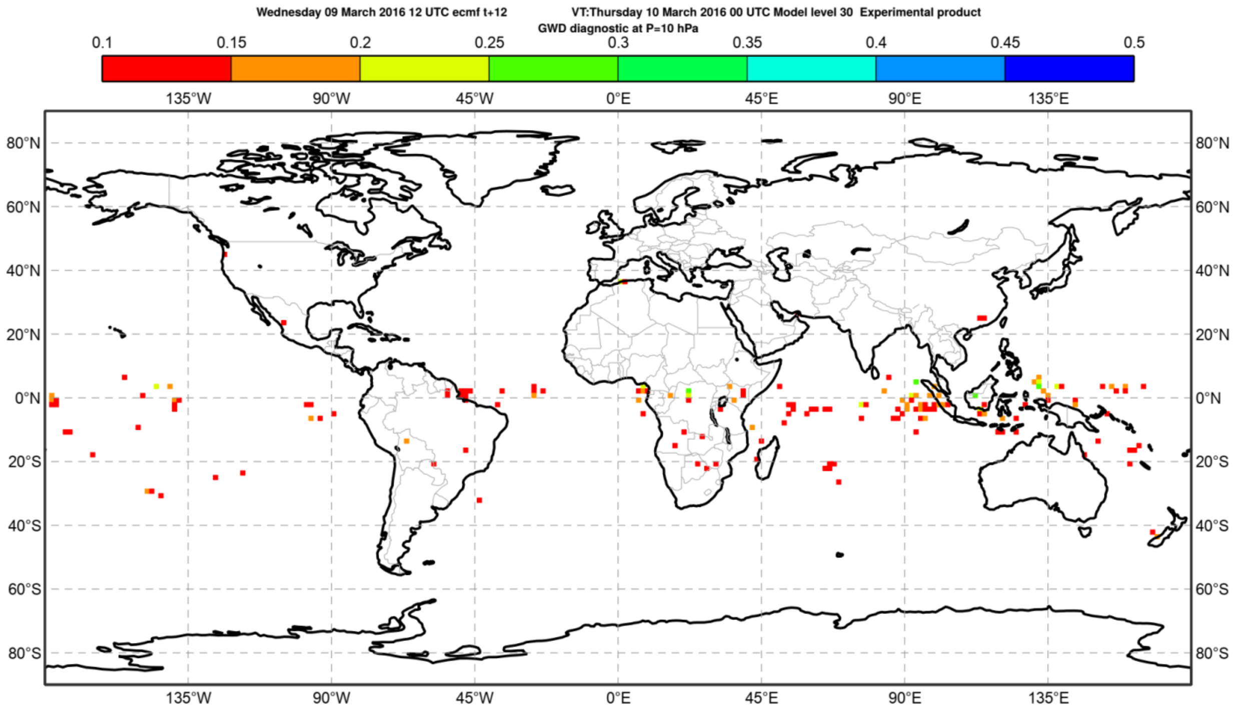
- $EDR \approx \left(C_\varepsilon \frac{D(TKE)}{Dt}\right)^{\frac{1}{3}}$ (based on Lilly (1966))

  with C_ε = 0.93 (Moeng and Wyngaard (1988))

- ➢ Only available above convective clouds
- ➢ First results show EDR in „expected“ order of magnitude
- ➢ Turbulent fields are rather spotty, as expected for convection

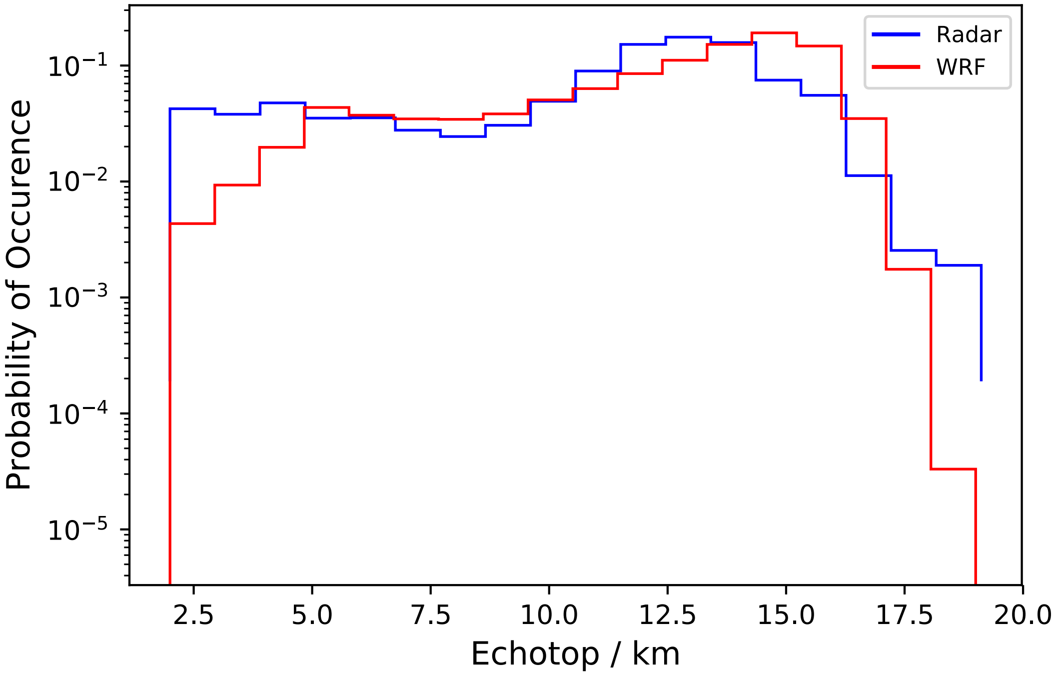
Forecasting convective GW Activity


Wednesday 09 March 2016 12 UTC ecmf t+12 VT:Thursday 10 March 2016 00 UTC Model level 90 Experimental product
GWD diagnostic at P=3.9e+02 hPa

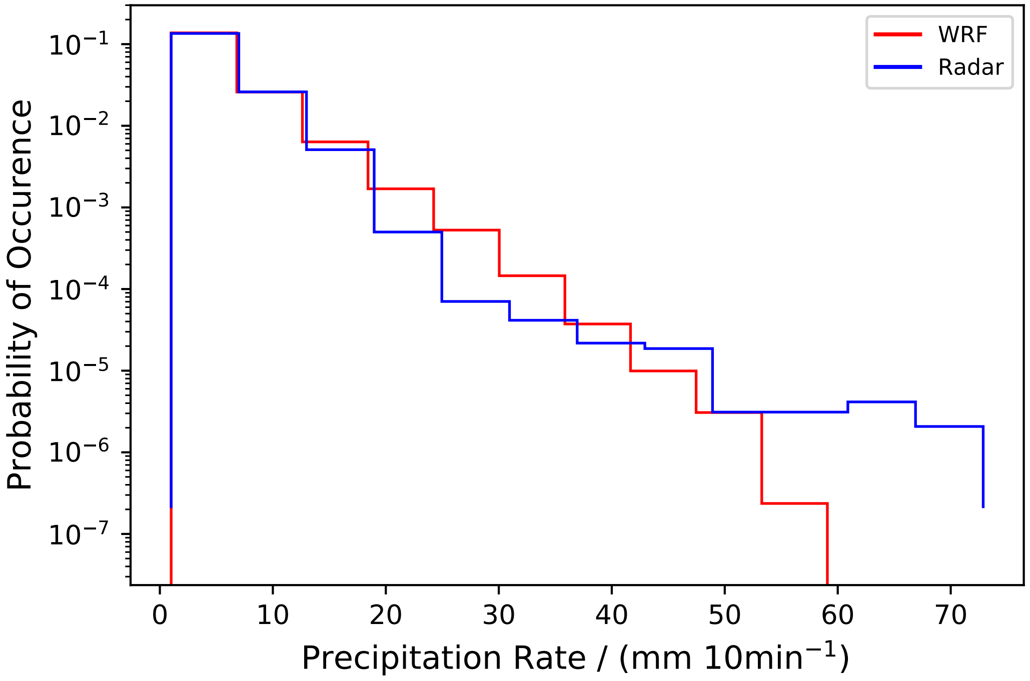

Wednesday 09 March 2016 12 UTC ecmf t+12 VT:Thursday 10 March 2016 00 UTC Model level 30 Experimental product
GWD diagnostic at P=10 hPa

Distribution WRF vs C-Pol Radar

Echotop



Precipitation Rate



Temporal Evolution of Precipitation Rate