harmony

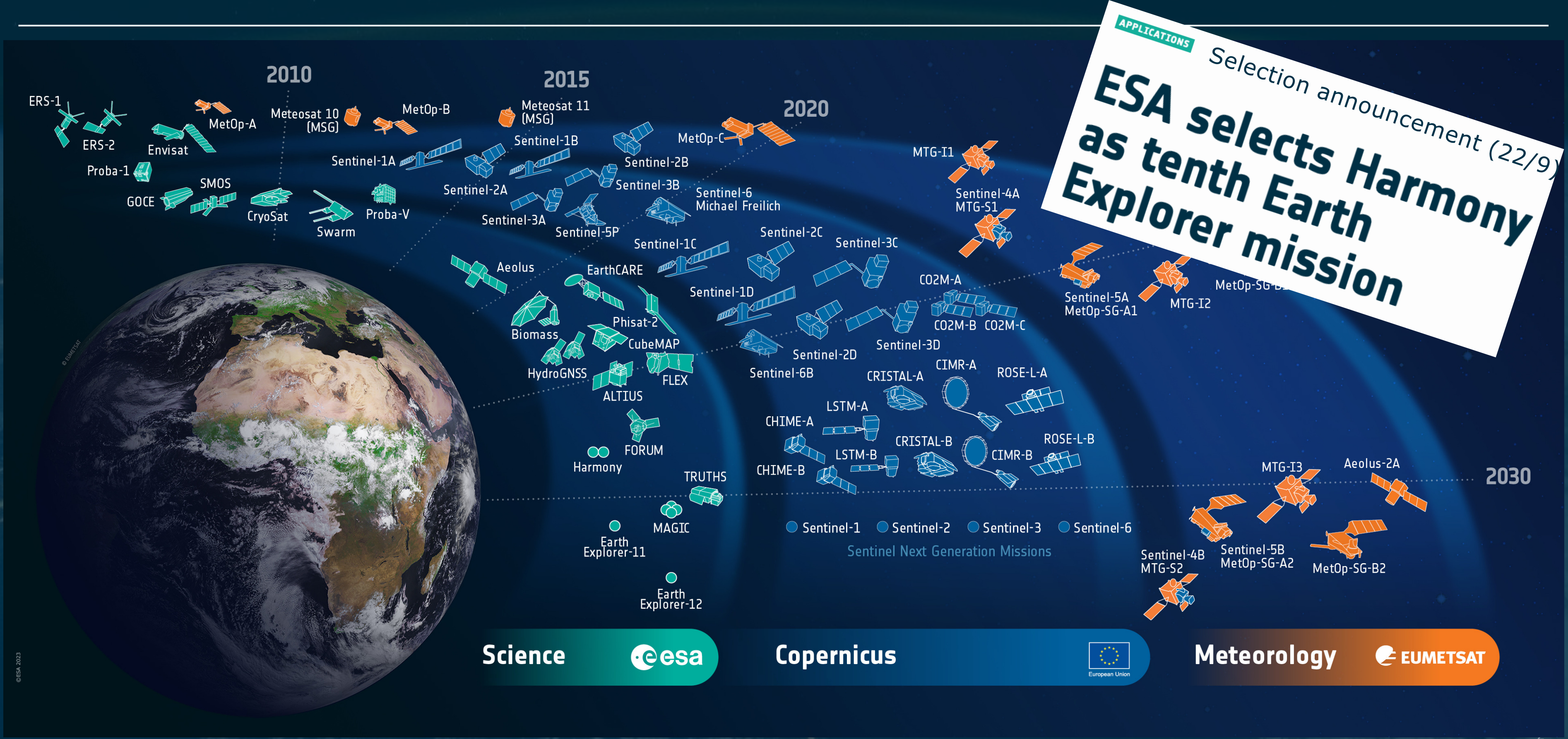
TO RESOLVE STRESS IN THE EARTH SYSTEM

ESA's dynamic surfaces mission

Ad Stoffelen, Björn Rommen (SM), Paco Lopez-Dekker (PI)

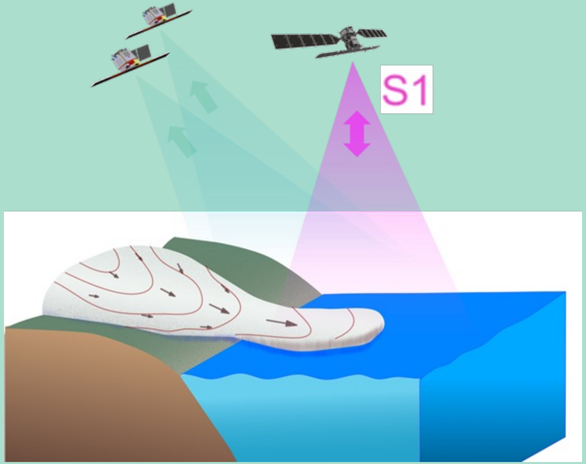
ESA team, ESA SAG

Harmony within ESA’s EO missions landscape

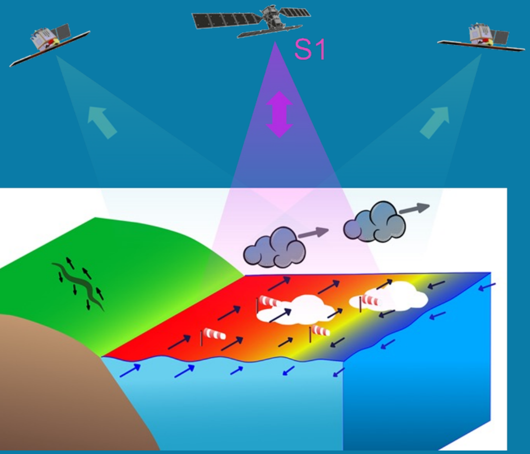


Harmony in a nutshell

Harmony is ESA's Earth Explorer 10 mission, comprised of two companion satellites in a loose convoy with Sentinel-1D (along-track separation ~350 km)
Its payload suite consists of a passive SAR and a multi-view TIR instrument



Cross-track Interferometric phase covering land applications like glaciers, permafrost, volcanoes.



Stereo phase covering 3-D surface deformation ocean applications: surface motion, surface winds, sea surface temperature, cloud motion.

Year 1 | Year 2 | Year 3 | Year 4 | Year 5

Harmony – a multi-domain "Earth System" mission

Upper oceans and ocean-atmosphere interactions

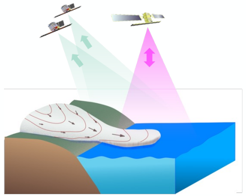
Land ice and sea ice

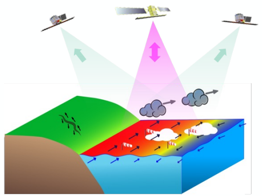
Tectonic strain and volcanic processes

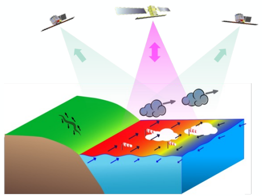
Harmony’s mission objectives / Ocean

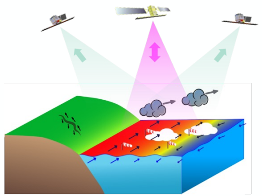
Air-Sea Interactions (H-O1)	
Extend the knowledge of the 2D co-spectra of surface stress, ocean surface wind vector, surface current vectors, and SST from the scatterometer scale (25km) down to O(1km) scales, covering all relevant conditions at the sea surface and in the MABL.	P
Quantify the contribution of small scale processes (down to O(1 km) scales) to the air-sea fluxes of gas (CO_2, H_2O), momentum, and heat.	P
Quantify the vertical fluxes (momentum and buoyancy) within the MABL at 1km horizontal scale.	P
Quantify the contribution of small scale cloud dynamical processes O(1 km) to the vertical fluxes of water, momentum and heat.	P
Marine-Atmosphere Extremes (H-O2)	
Measure surface stress equivalent wind vectors at 1 km scale in extreme wind conditions, to estimate inflow convergence toward the low pressure center and vorticity perturbations embedded in the cyclonic flow.	P
Retrieve directional wave spectra and simultaneous near inertial currents at 5-10 km resolution, during all phases (ahead, during, and in the wake) of the passage of the extreme weather event.	P
Small-scale upper ocean dynamics (H-O3)	
Extend the knowledge of the ocean surface motion power spectrum from currently resolved mesoscales (O(50km)) down to submesoscales (O(1-5km)), capturing the regional variability and the seasonal cycle.	P
Quantify the vorticity and flow divergence in the upper ocean at O(1km) horizontal scale, to estimate the vertical transport of nutrients, heat and, gas across the ocean boundary layer.	P

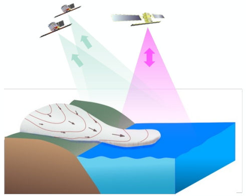
Mission Phases Timeline





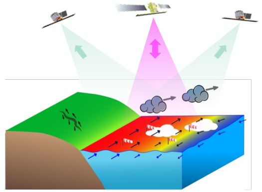


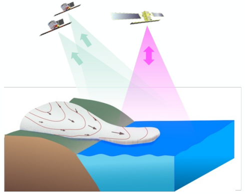




Y1 XTI Phase	Y2 – Y3 – Y4 Stereo Phase	Y5 XTI Phase
Ice Volume change **Glacier dynamics**		**Ice Volume change** **Glacier dynamics**
	3-D Ice surface motion	
	Air-sea interactions and stereo cloud motion	
Ocean topography **(experimental)**	**Atmosphere-ocean-extemes (Tropical Cyclones, Polar lows, etc)**	Ocean topography **(experimental)**
	Upper ocean dynamics	
	Tectonic Strain (3-D deformation)	
Vol. change (volcanoes)		Vol. change (volcanoes)
Iceberg volume	Sea-ice instantaneous motion/deformation	Iceberg volume

Uniqueness





Simultaneous,
O(1 km) scale

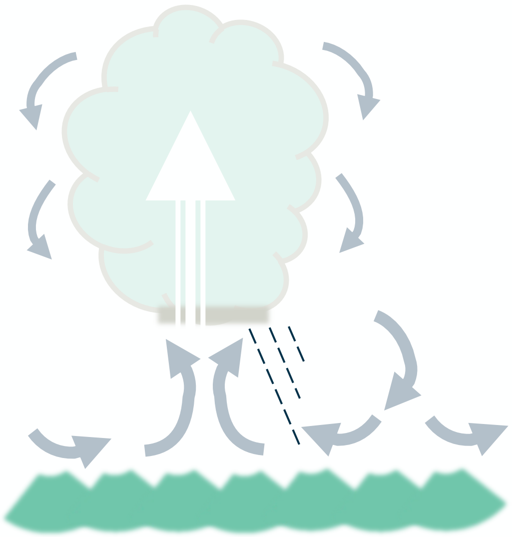
- SST
- Cloud-top Motion
- Directional roughness
- Directional Doppler
- C-band = all weather
- 3-D repeat pass InSAR
- Dense DSM time-series

Simultaneous,
O(50m) scale

- Data driven ocean-atmosphere couplings and statistical. characterization of vertical fluxes in ESM 2.0.
- Understanding of air-sea interactions within extremes.
- Sea-ice dynamics.
- Global strain maps.
- Understand cycles of topographic change at volcanoes.
- Global and temporally consistent map of ice volume change (loss).
- Improved understanding of glacier dynamics.

MABL and clouds in a changing climate

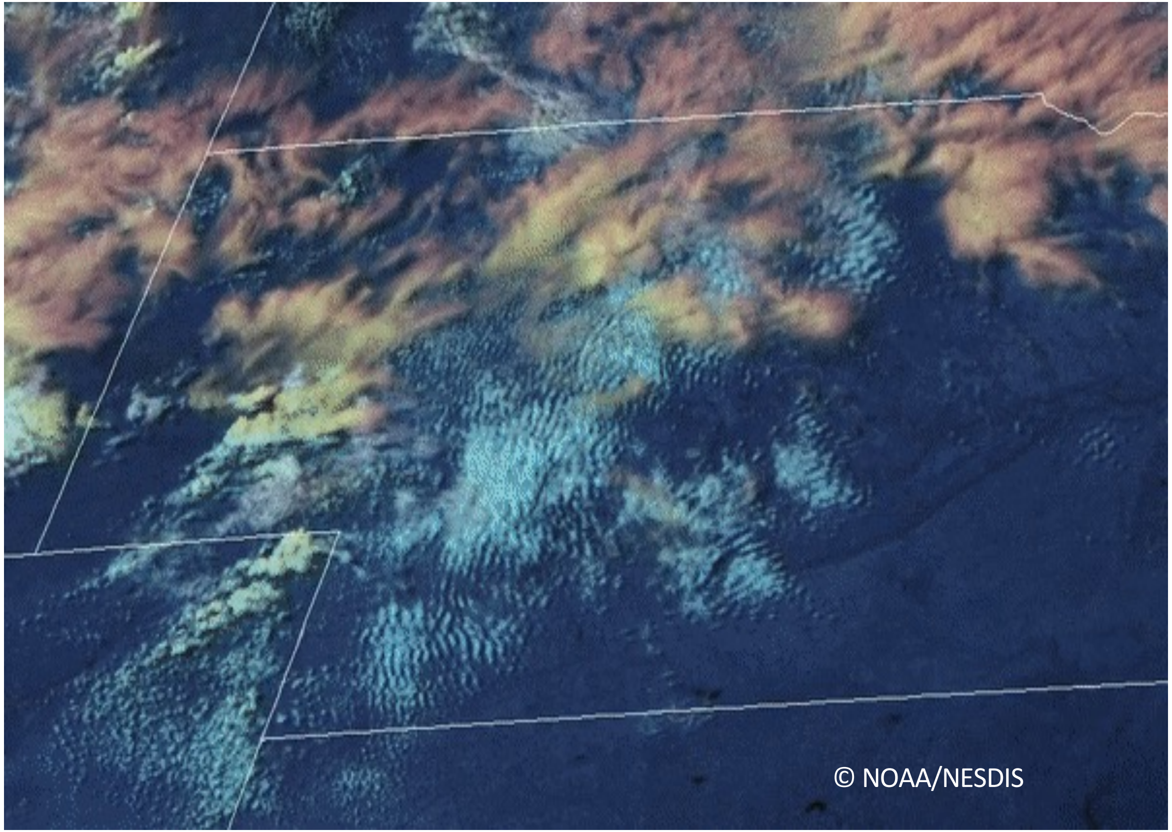
- A warmer world implies more water vapor in the atmosphere
- More evaporation, cloud liquid water/ice and rain
- Enhanced cloud dynamics and organization?
- More updraft/downdraft and wind?
- Associated dynamical mode changes?
- Less cloud / more marine aerosol?
- . . . ?
- Over >70 % of the earth surface



Atmospheric Dynamics and Clouds

- Molecules and particles move with the winds, but do clouds?
- Right: features manifest in a multi-scale 3D turbulent environment
- Do you see atmospheric waves or winds?
- Observed cloud features change due to atmospheric waves, convergence, divergence, mixing, cloud dynamics and, indeed, also wind
- Atmospheric radiances change when air advects, moves up or down, due to temperature, humidity, and cloud dynamics

Stoffelen et al., BAMS, 2020

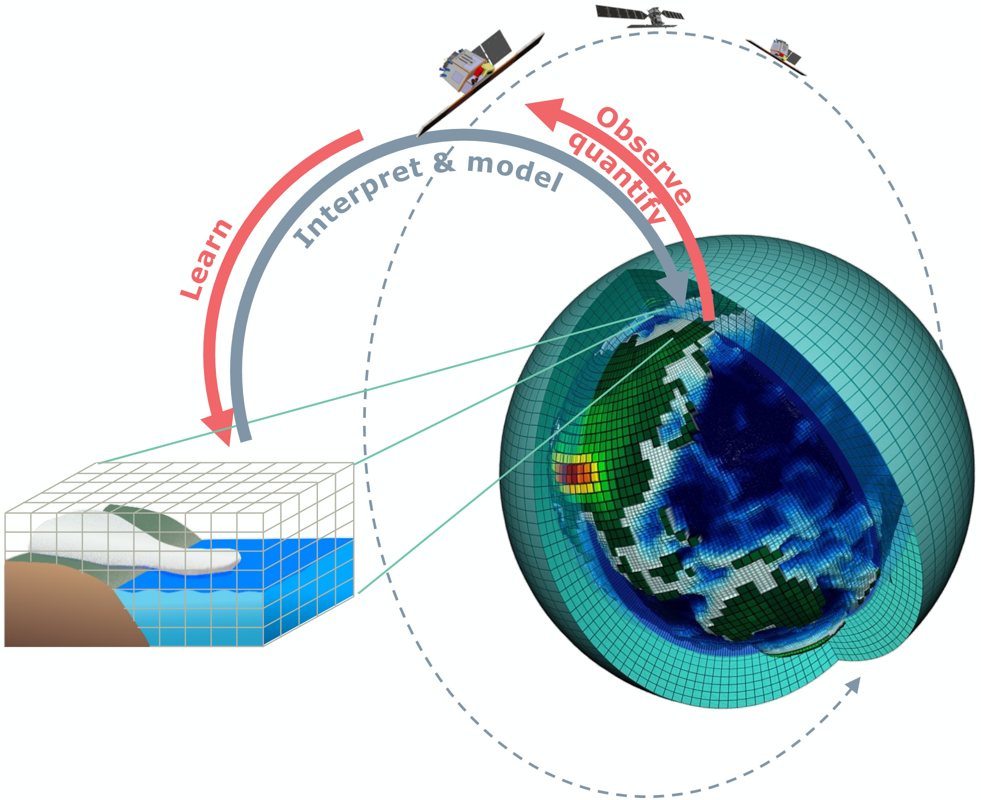


Contributing to data-driven Earth System Modeling

Earth System is highly non-linear → complex couplings and feedbacks between processes at different scales.

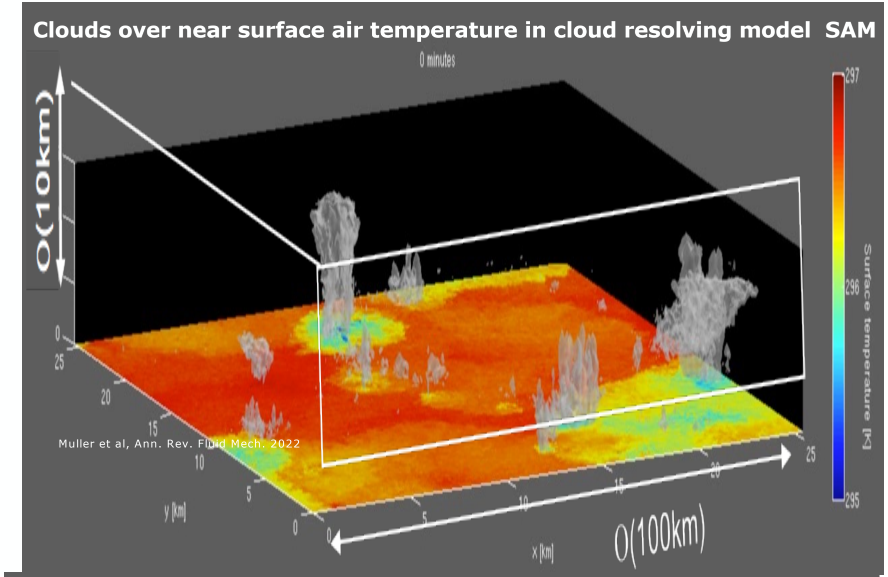
Unresolved O(≲ 1km) processes and couplings in Earth System Models represent major contribution to model uncertainties.

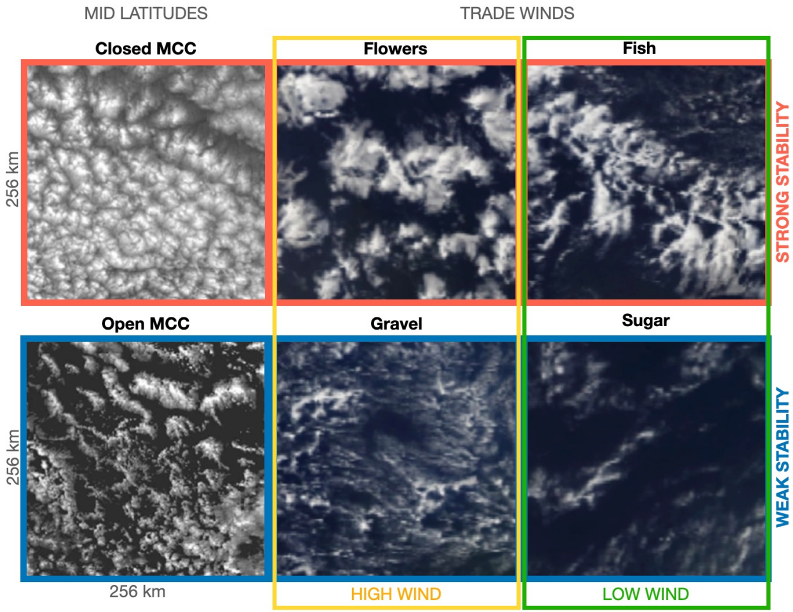
Harmony is set to provide observations needed to develop/train/validate next generations of fully coupled Earth System Models.



https://esamultimedia.esa.int/docs/EarthObservation/EE10_Harmony_Report-for-Selection_21June2022.pdf

Linking surface conditions to clouds

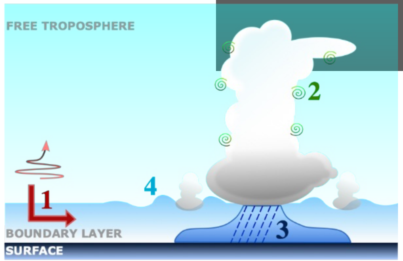




McCoy et al. JGRA 2017
doi: 10.1002/2017JD027031

Bony et al. GRL 2020 doi: 10.1029/2019GL085988

MODIS



Harmony will observe **cloud top position and motion**, providing information on **entrainment and mixing**, together with characterization of the **surface conditions**.

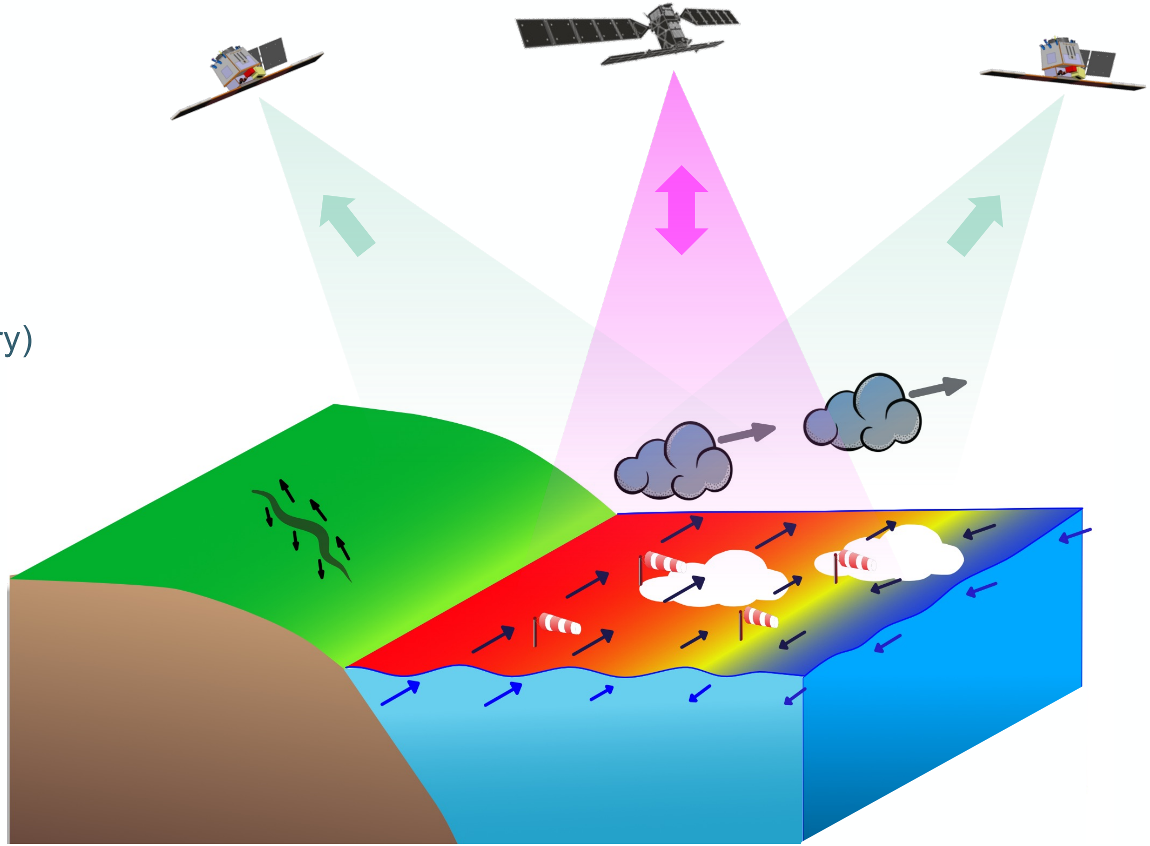
→FUNDAMENTAL

Identify processes that lead to different cloud types under different environmental conditions

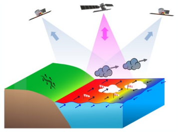
Mission overview and observables

Line-of-sight diversity for high resolution

- Slow (DInSAR) and fast (Doppler) surface motion vectors.
- Directional roughness (→wind scatterometry)
- Improved directional surface wave spectra
- Sea Surface (skin) temperature
- Cloud-top motion vectors (TIR time-lapse) and height (TIR parallax)

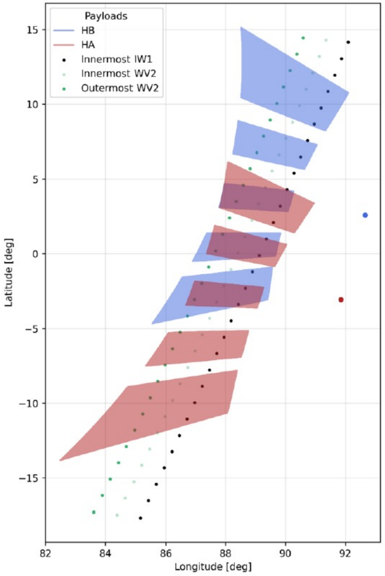


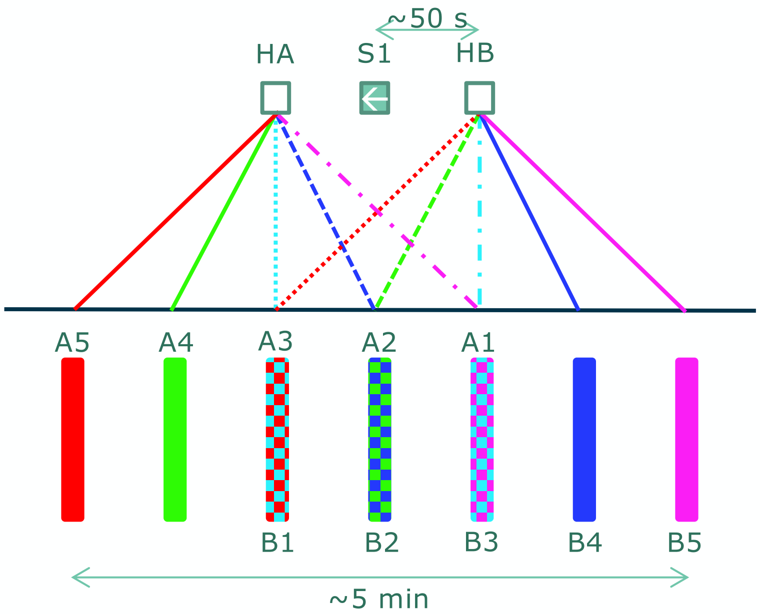
Observation Concept: Thermal-Infrared



STEREO

Band	Spectral Range
PAN	8.0-12.0 µm
CD-1	8.0-9.2 µm
TIR-1	10.4-11.3 µm
TIR-2	11.4-12.5 µm



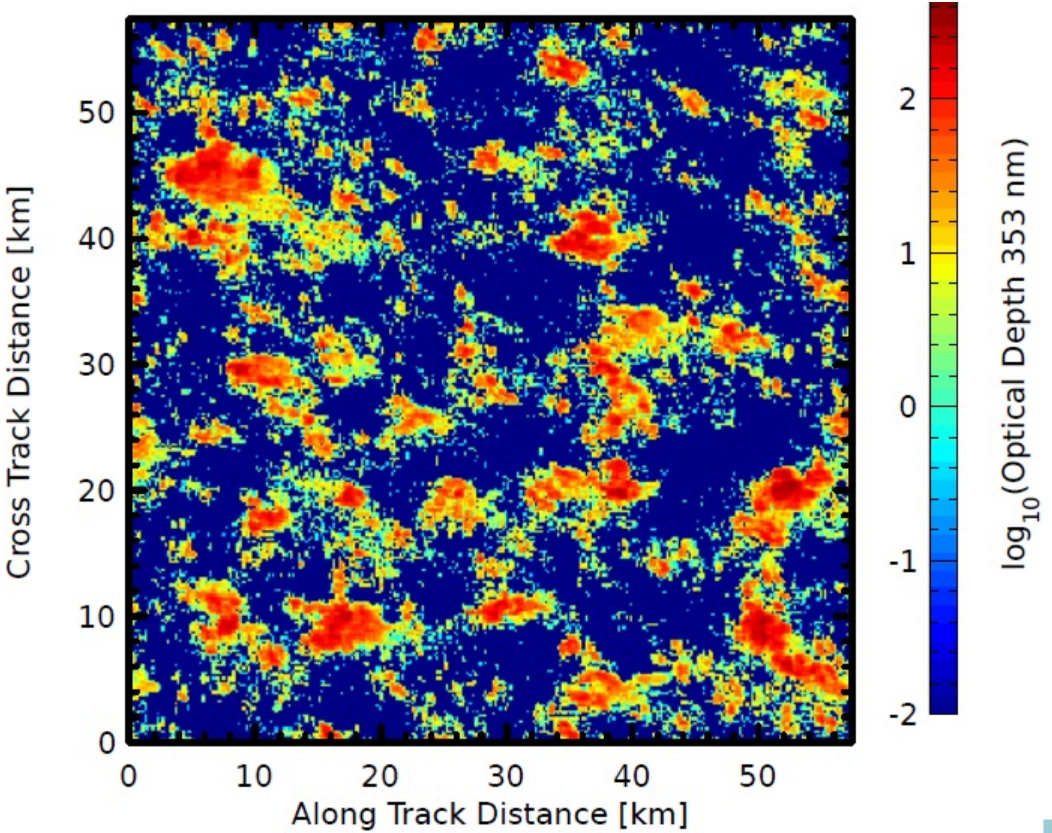


The Harmony TIR instrument is a multi-channel, multi-view instrument that can observe ocean and clouds whilst flying in the twilight of the dawn-dusk orbit.

CRM: simulated cloud processes

A spatial plot of the CRM cloud field

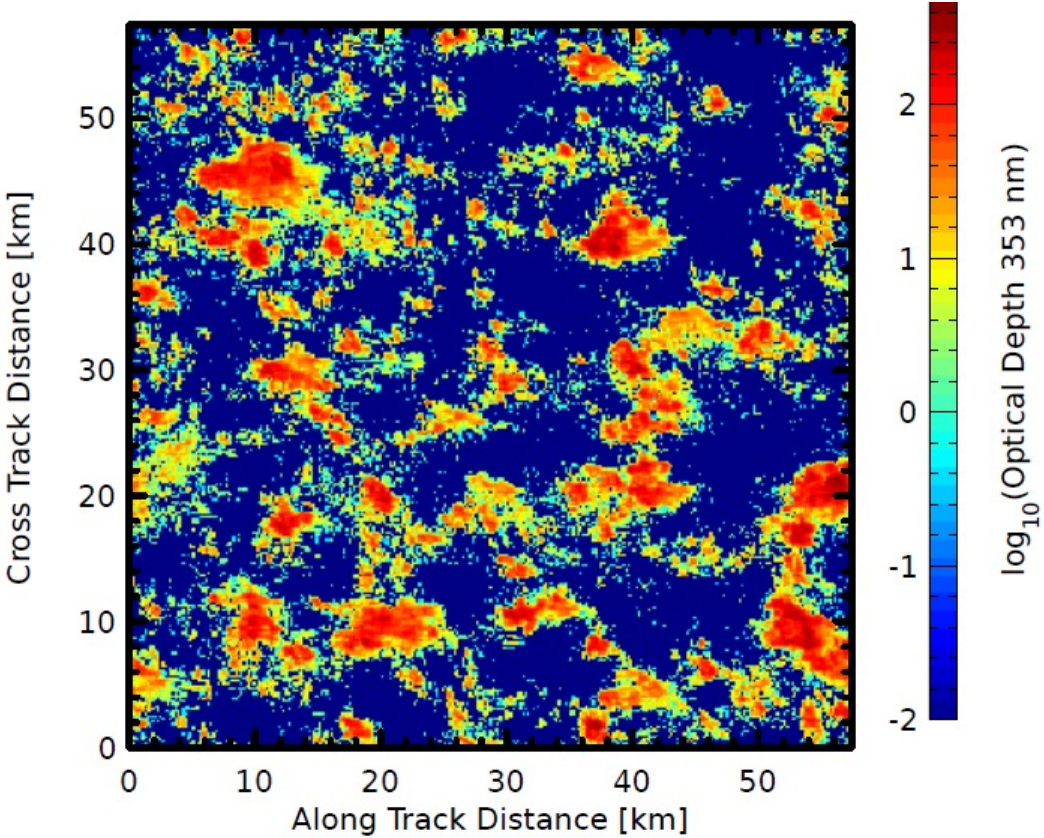
t = 0



DALES Cloud-resolving Model Simulations

A spatial plot of
the CRM cloud field

t = 8 min



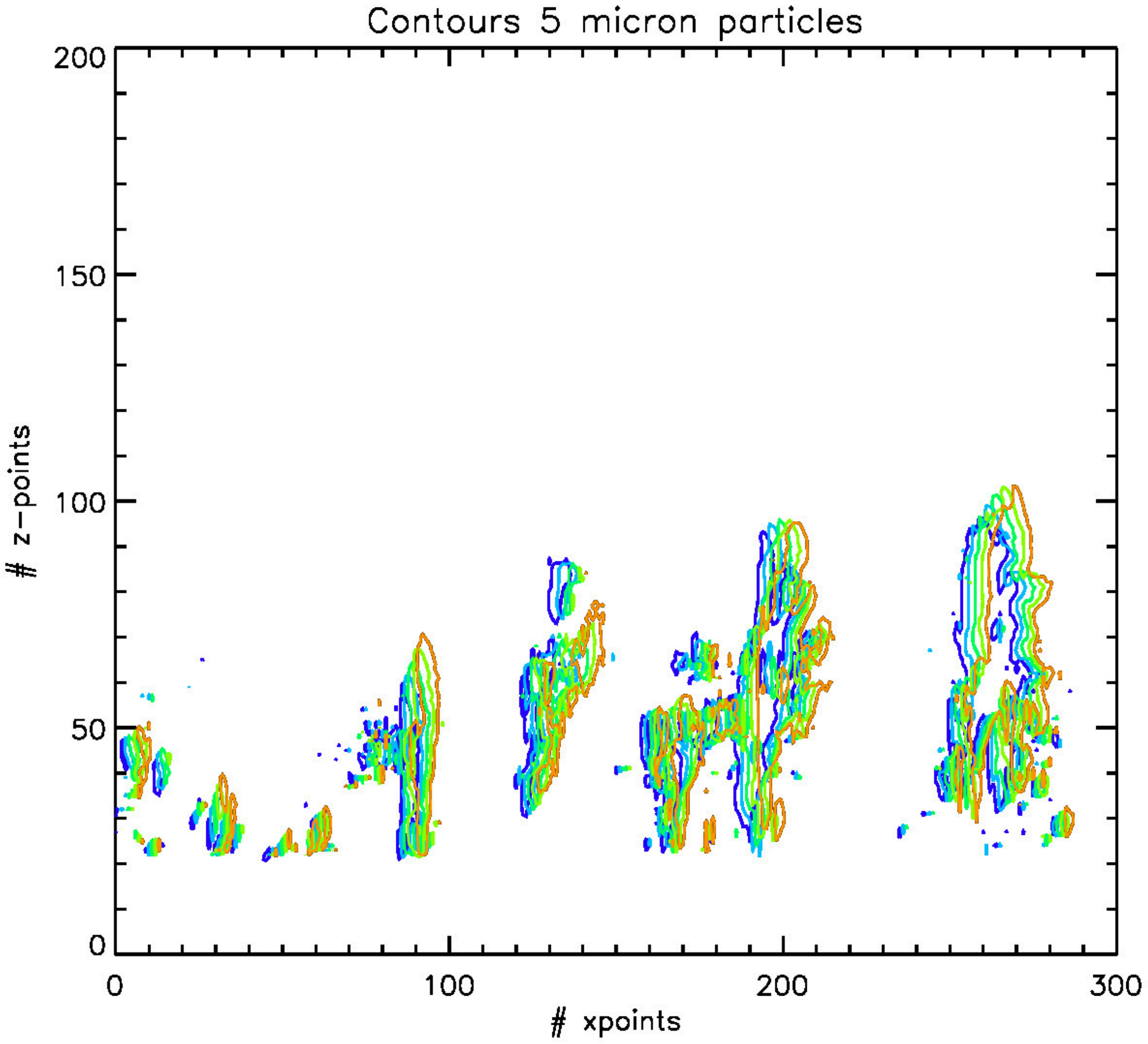
Cloud

Colours in 1-minute steps

u = 3.3 m/s

v = 0

- Clouds move, grow and transform

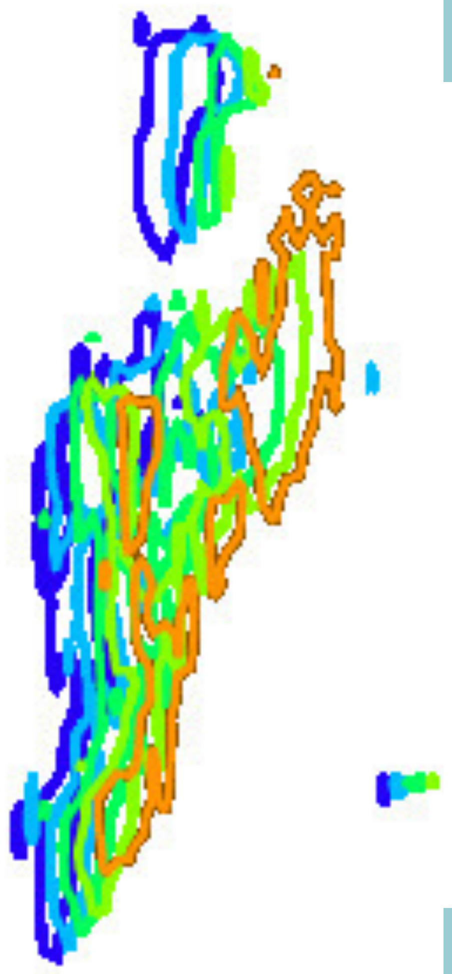


Cloud

B: Cloud boundary

How does d B(x,y,z,t)/d t link to u,v and w ?

- Cloud shape is different every minute:
  - Advection, turbulence, convection
  - Growth (source)
  - Resolve (sink)
- Processes
  - Mass flux upward/downward
  - Condensation (warming)
  - Cloud entrainment processes
  - Evaporation (cooling)
  - Mixing of air



CTH and CMW

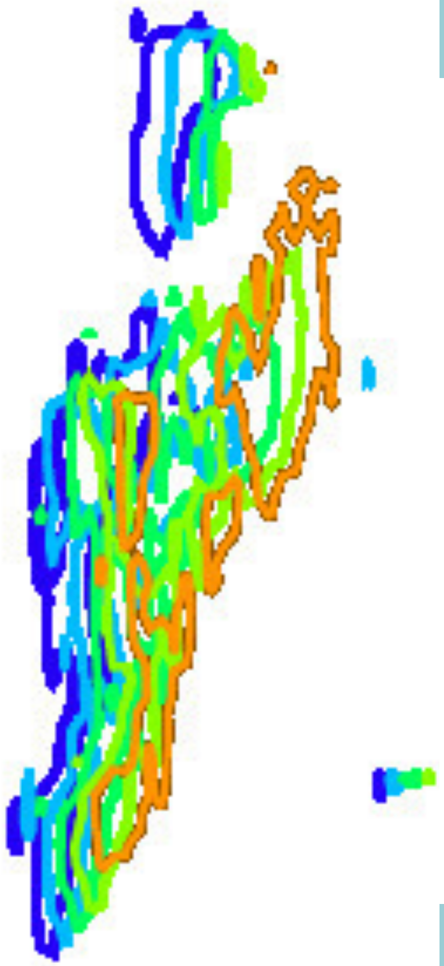
A 1st view provides only a 2D projection at t of B, however complex its 3D geometry

A simultaneous 2nd view provides depth

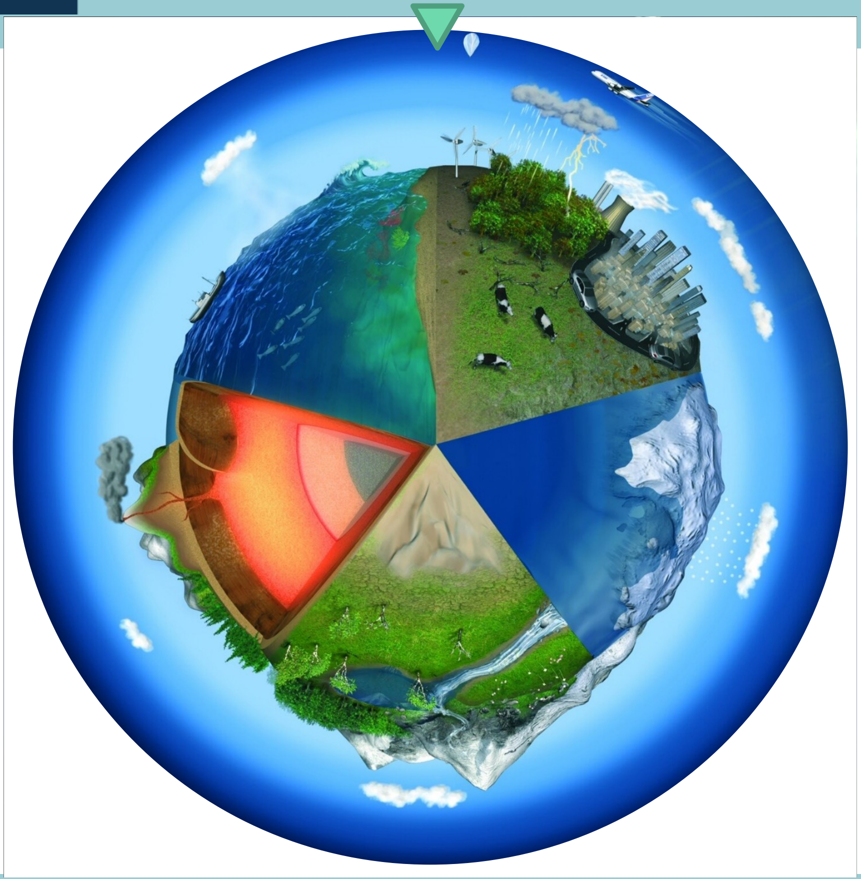
Non-simultaneous views are needed for motion and cloud deformation

Understanding d B(x,y,z,t)/dt needs:

- Solving 3D geometry of B over time by employing cloud deformation model (trend?)
- 3D advection (u,v,w)
- A CRM can learn us how to capture motion and deformations



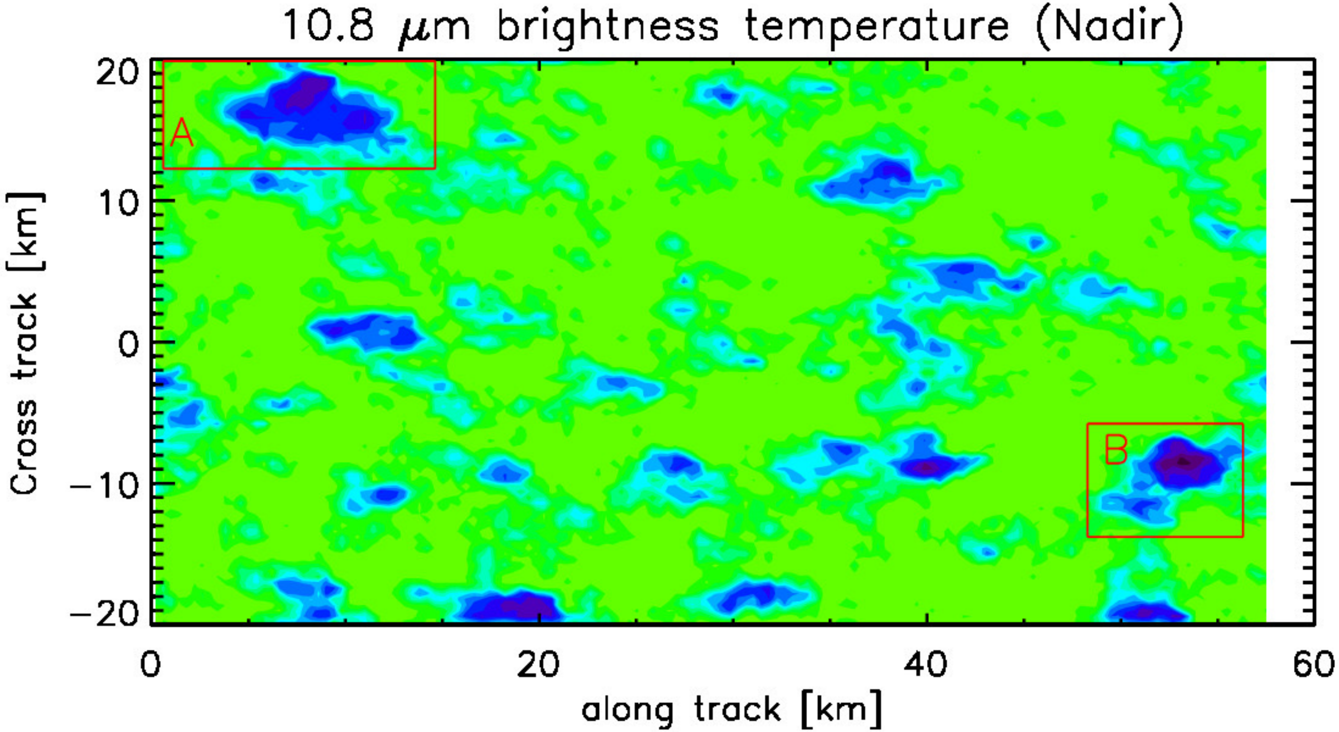
Bringing Harmony to a dynamic world



Harmony will resolve (sub) kilometer scale motion vectors and topography changes associated to dynamic Earth System processes:

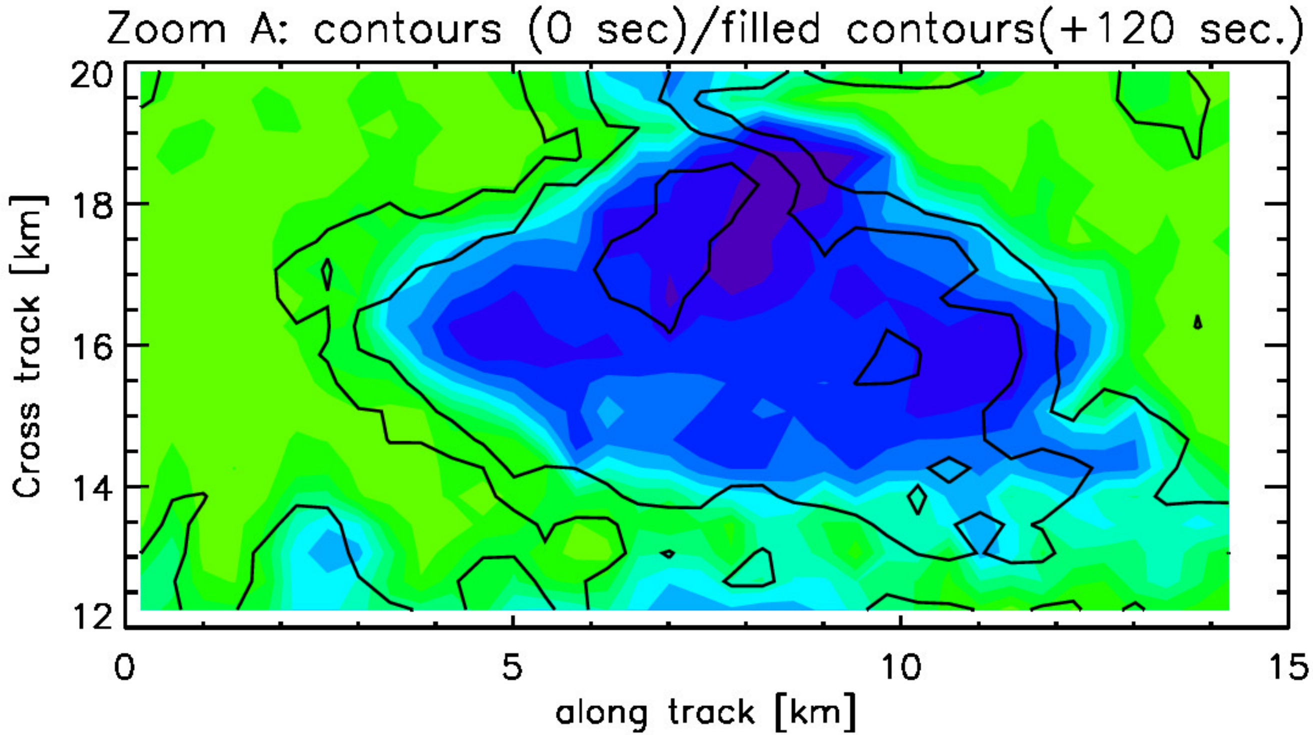
- heat, gas and momentum exchanges at the air-sea interface and cloud dynamics;
- the inner structure of ocean-atmosphere extremes;
- gradual and dynamic volume changes of global mountain and polar glaciers;
- instantaneous sea-ice motions to characterise sea-ice dynamics;
- 3-D deformation vectors associated to tectonic strain;
- topographic change at active volcanoes worldwide.

Images



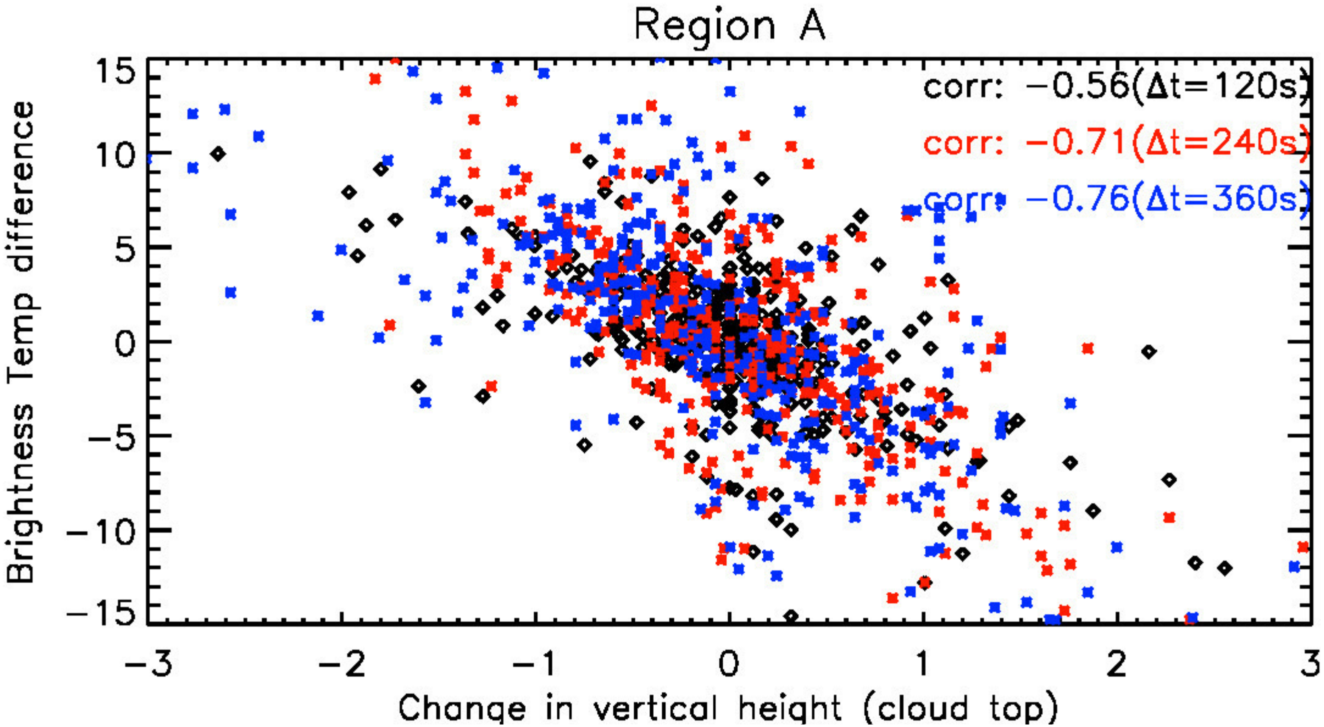
Nadir view

A



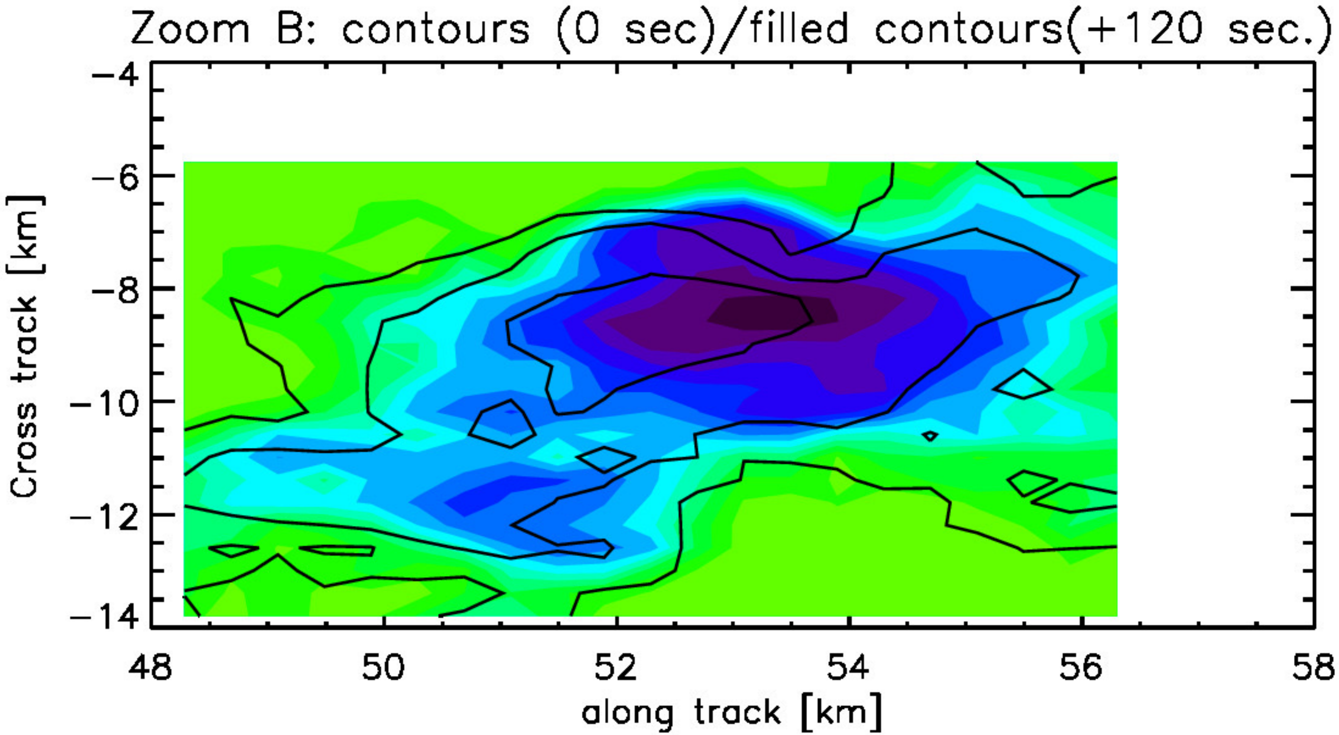
- The mean horizontal motion has been fully and exactly compensated

A



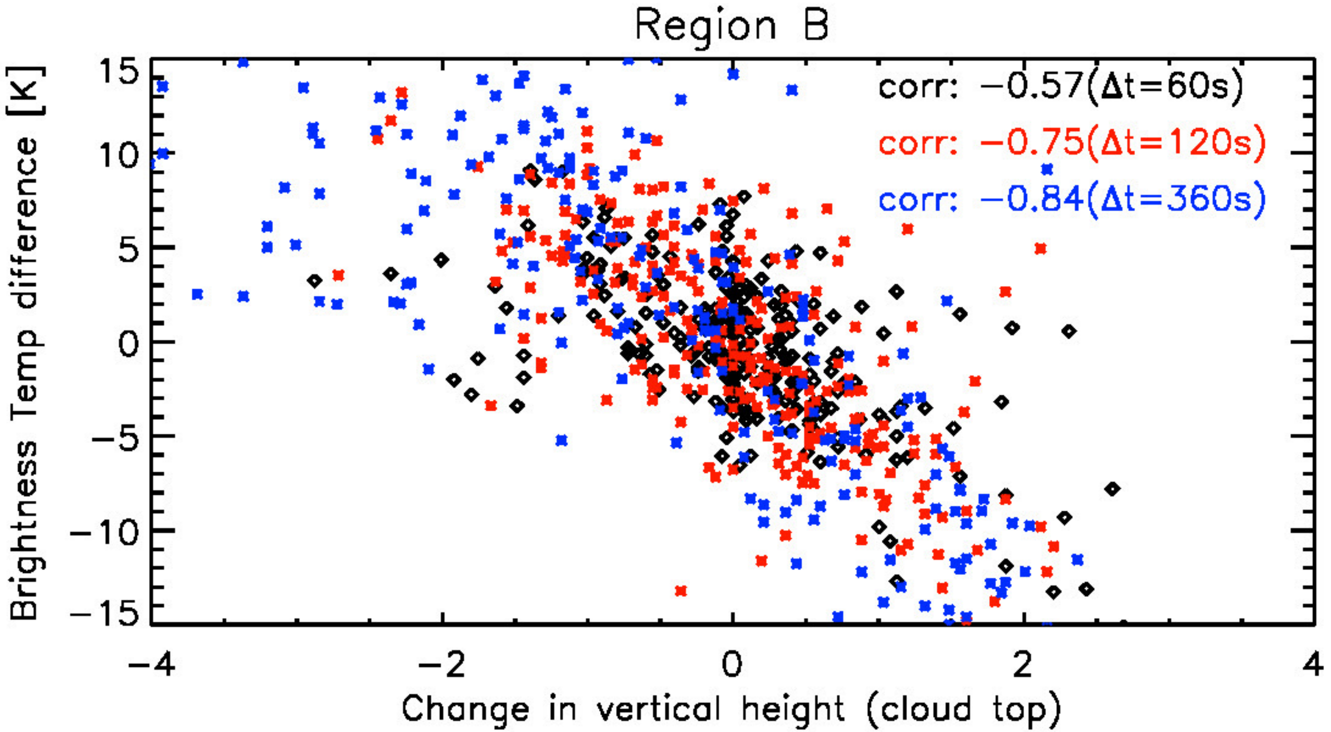
- Effect of noise and time base
- A single MISR compromises both the temporal CTH an BT changes

B



- The mean horizontal motion has been fully and exactly compensated

B

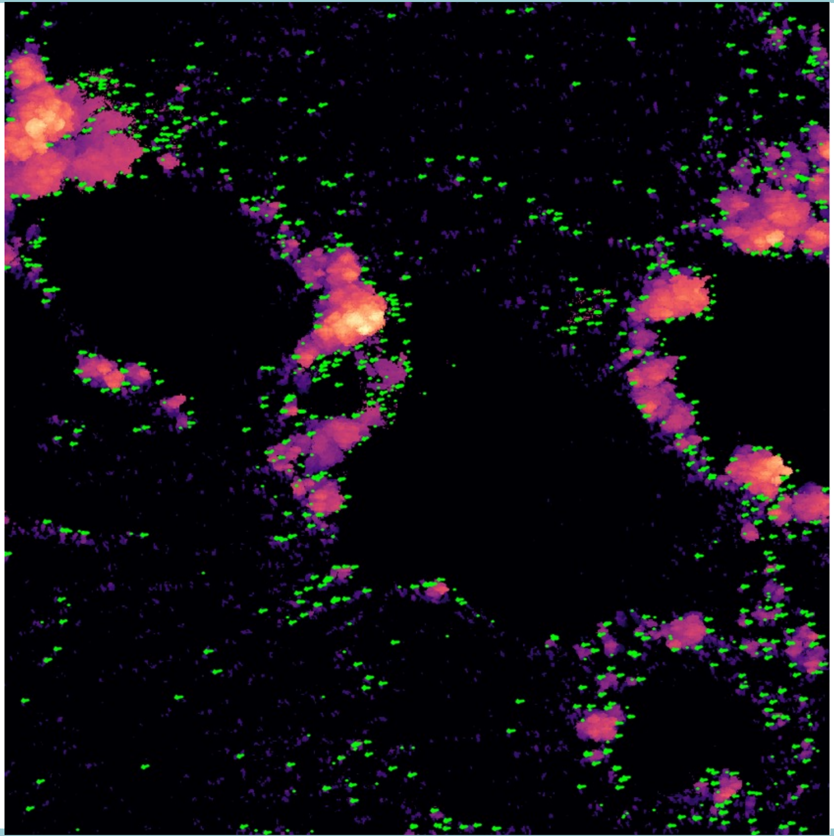

Region B
corr: −0.57(Δt=60s)
corr: −0.75(Δt=120s)
corr: −0.84(Δt=360s)
Brightness Temp difference [K]
Change in vertical height (cloud top)
15
10
5
0
−5
−10
−15
−4
−2
0
2
4

DALES winds at CTH

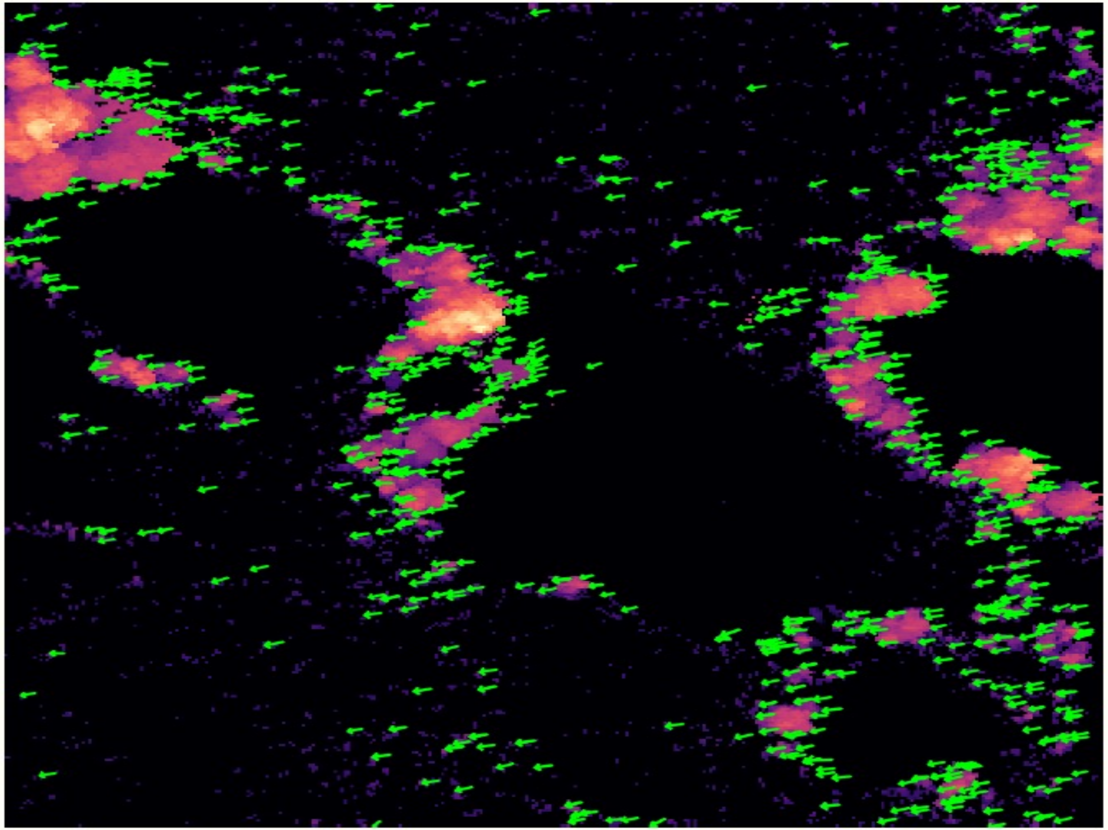
1 min.

Preliminary

Both tracked clouds and u,v,w at CTH will be used for verification and development



Idem, on upscaled image (nearest neighbours)



LK Optical Flow (u and v written as log)