MISRlite : Multi-angle IR Stereo Radiometer using uncooled microbolometer arrays for global winds. An airborne prototype

Jan-Peter Muller,*
Richard Cole, Dave Walton (UCL-MSSL),
Martin Townend (SEA/Thales Alenia Space)

**MISR science team member (NASA EOS)*
j.muller@ucl.ac.uk

Centre for EO Instrumentation & Space Technology

Technology Strategy Board
Driving Innovation

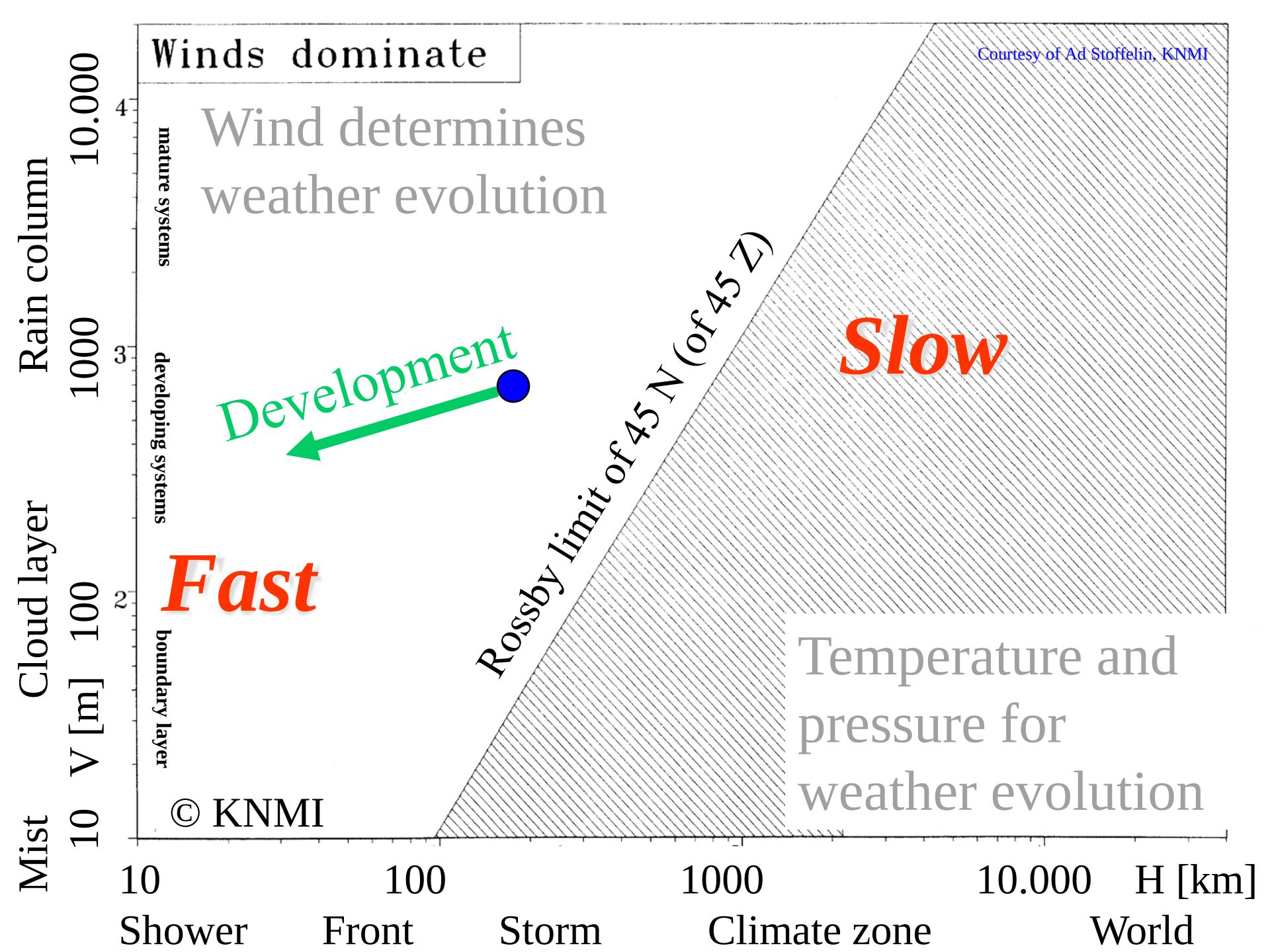
Why do we need Space Winds from MISRlite

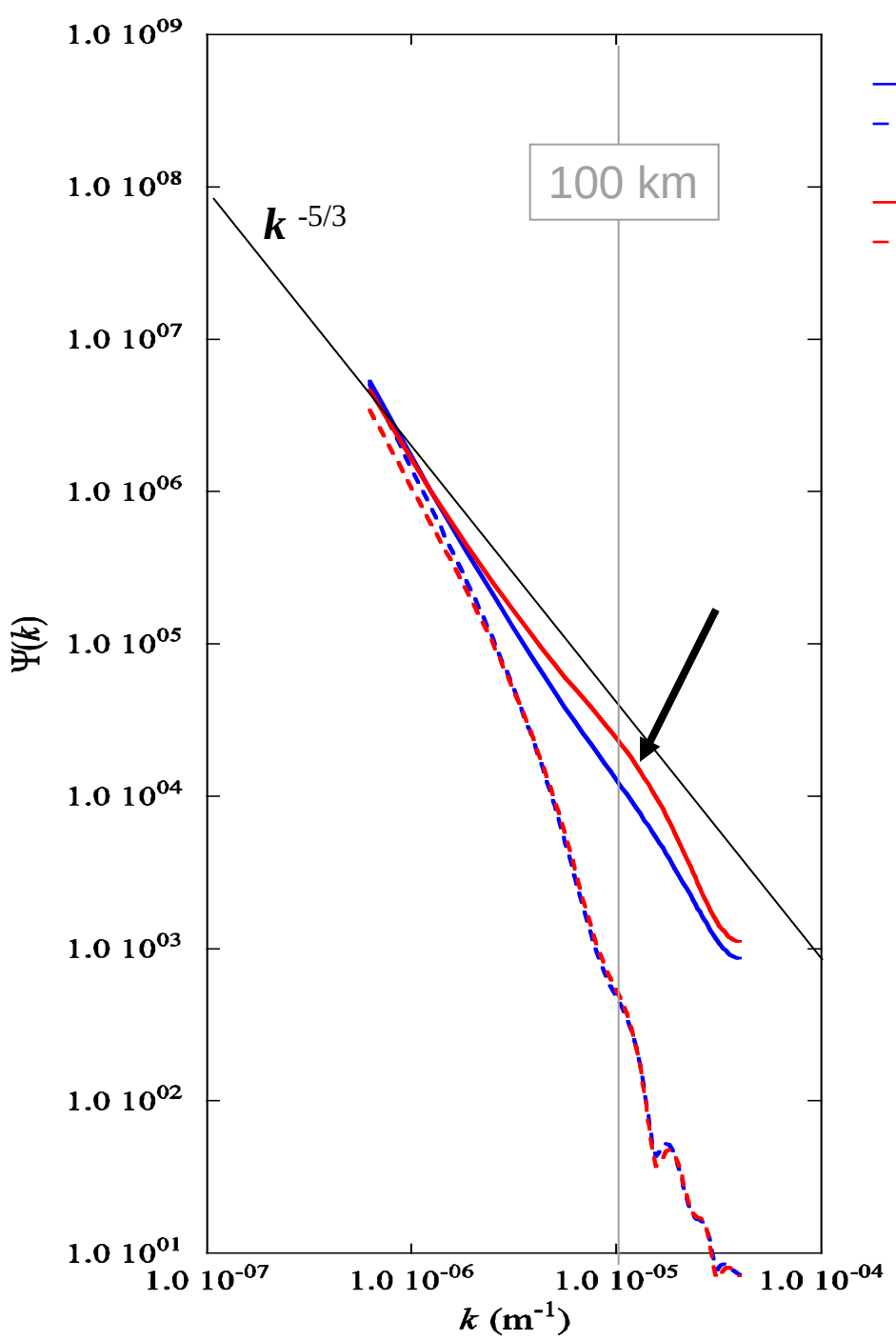
- **Atmospheric Motion Vectors (AMVs) from GEO & LEO-LEO Cloud Motion Vectors have poor height accuracy and have a poor impact on current NWP forecasts (IWW12)**
- **Winds not well resolved, especially in the zone from 50-75º**
- **Wind determines mesoscale dynamics and weather evolution**
- **Wind determines tropical circulation**
- **Over the ocean where storms develop and sparse 3D meteorological observations are present; reduces errors over the ocean**
- **Transport of atmospheric constituents (e.g. SO2)**
- **Circulation component in the climate system**
- **Prime WMO requirement**
- **Need to complement the Line-of-Sight ADM-AEOLUS**

Identified gaps- Meteorology

ID	Atmosphere parameter	Status	Gap
M-G1	Wind profile (WMO OSCAR requirements)	T: Δz > 2 km S: Δz > 2 km RMS > 2 m/s, Δt > 6 hours	CMV lack vertical resolution Aeolus demo in T and S
M-G2	Humidity profile, temperature profile (WMO OSCAR requirements)	T: Δz > 1 km UTLS: Δz > 1 km RMS > 20% (humidity)	Sounders lack vertical resolution and sensitivity in T and S
M-G3	Physical processes, wind, humidity, temperature, cloud, precipitation, aerosol profiles, turbulence and vertical wind profiles are useful as well (WMO OSCAR requirements)	Δt > 10 min (GEO) Δt > 12 hours (LEO) Δz > 3 km (GEO) Δz > 2 km (LEO)	Spatially, temporally, and physically only partially resolved. Generally lacking vertical sampling and resolution and for LEO lacking temporal sampling too. No active instruments after EarthCare
M-G4	Wind, humidity, cloud, precipitation, aerosol profile information (WMO OSCAR requirements)	Δt > 10 min (GEO) Δt > 12 hours (LEO) Δz > 3 km (GEO) Δz > 2 km (LEO)	Spatially, temporally, and physically only partially resolved leading to problematic validation of operational algorithms. No active instruments after EarthCare

Courtesy of Ad Stoffelin, KNMI


Winds dominate
Courtesy of Ad Stoffelin, KNMI
Wind determines weather evolution
mature systems
developing systems
boundary layer
Development
Slow
Fast
Rossby limit of 45 N (of 45 Z)
Temperature and pressure for weather evolution
© KNMI
Rain column
Cloud layer
Mist
10.000
1000
100
10
V [m]
4
3
2
10
100
1000
10.000
H [km]
Shower
Front
Storm
Climate zone
World



u ASCAT
u ECMWF
v ASCAT
v ECMWF

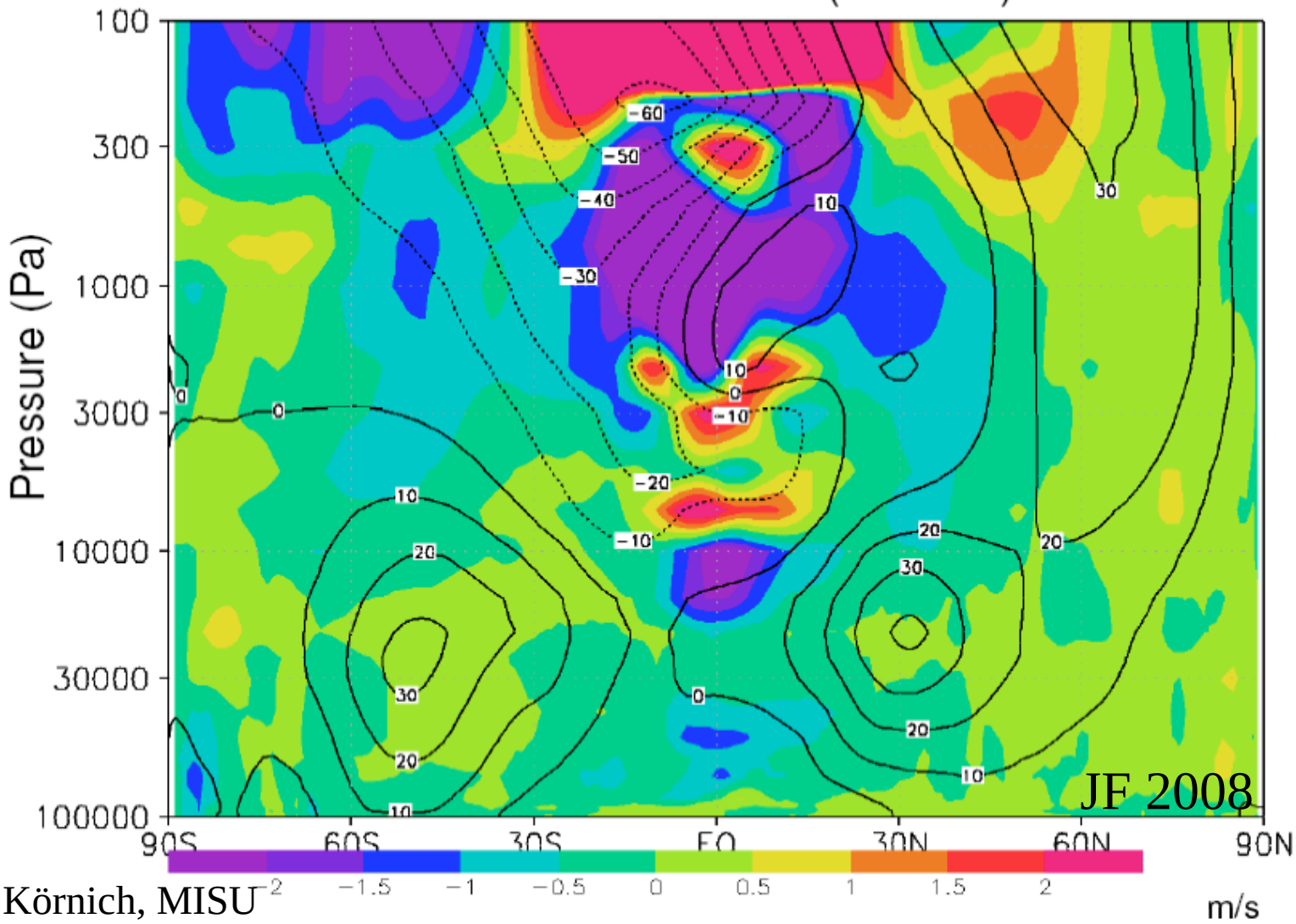
Courtesy of Ad Stoffelin, KNMI

AWDP@12.5

- Nastrom and Gage (1987) established climate spectra
- $k^{-5/3}$ 3D turbulence spectrum
- ASCAT contains small scales down to 25 km which agree well with buoys and climate
- No noise floor
- $k^{-1.9}$
- ECMWF contains order of magnitude too little variance at the 100-km scale

Time and zonal mean u-wind in ECMWF (contours) and difference with UKMO (shaded)

Courtesy of Ad Stoffelin, KNMI

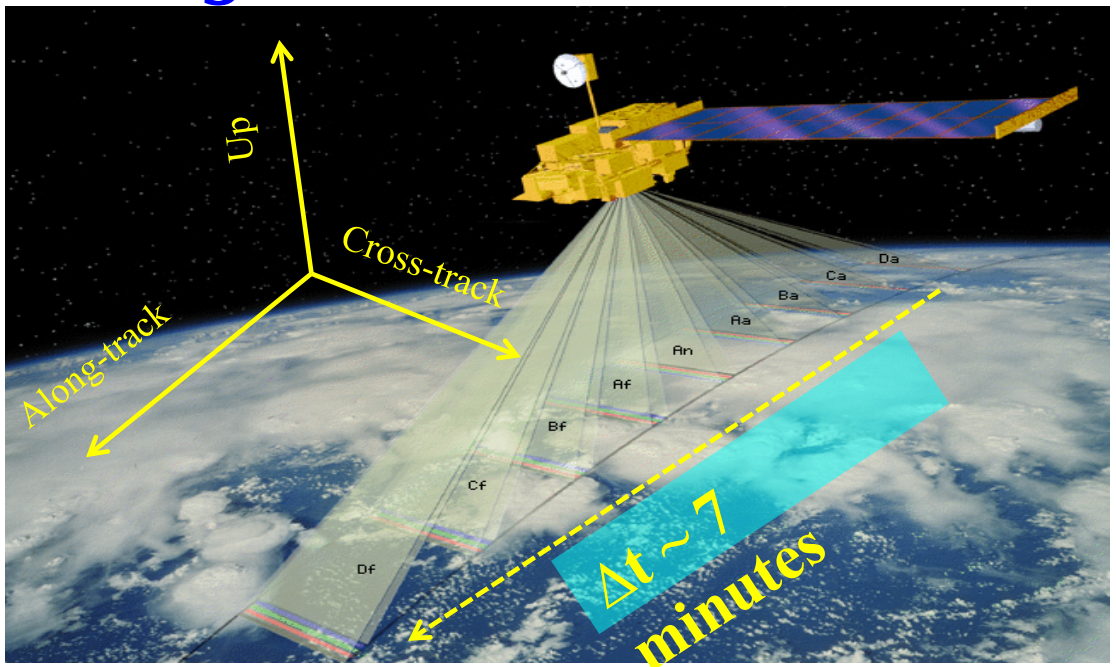


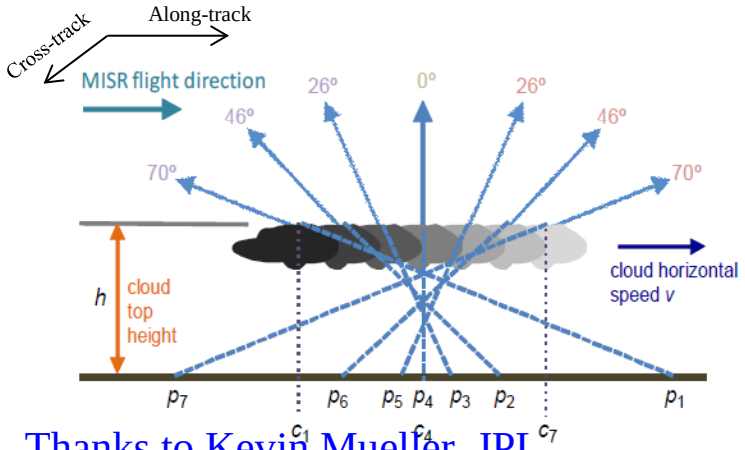
☞ Large uncertainty in tropics on seasonal flow affects climate processes

Multi-Angle Imaging SpectroRadiometer (MISR) – Existing Wind Products

MISR instrument

- **Mission Lifetime**
  - **1999 -> 2018+**
- Swath Width ~ 380 km
- 9 Camera View Angles
  - 0º (Nadir)
  - ±26.1º, ± 45.6º
  - ±60.0º, ± 70.5º
  - 7 minute overpass
- B, G, R, & NIR Bands
- Spatial Resolution
  - **275 m for Nadir and Red Band**
  - 1100 m all else





Thanks to Kevin Mueller, JPL

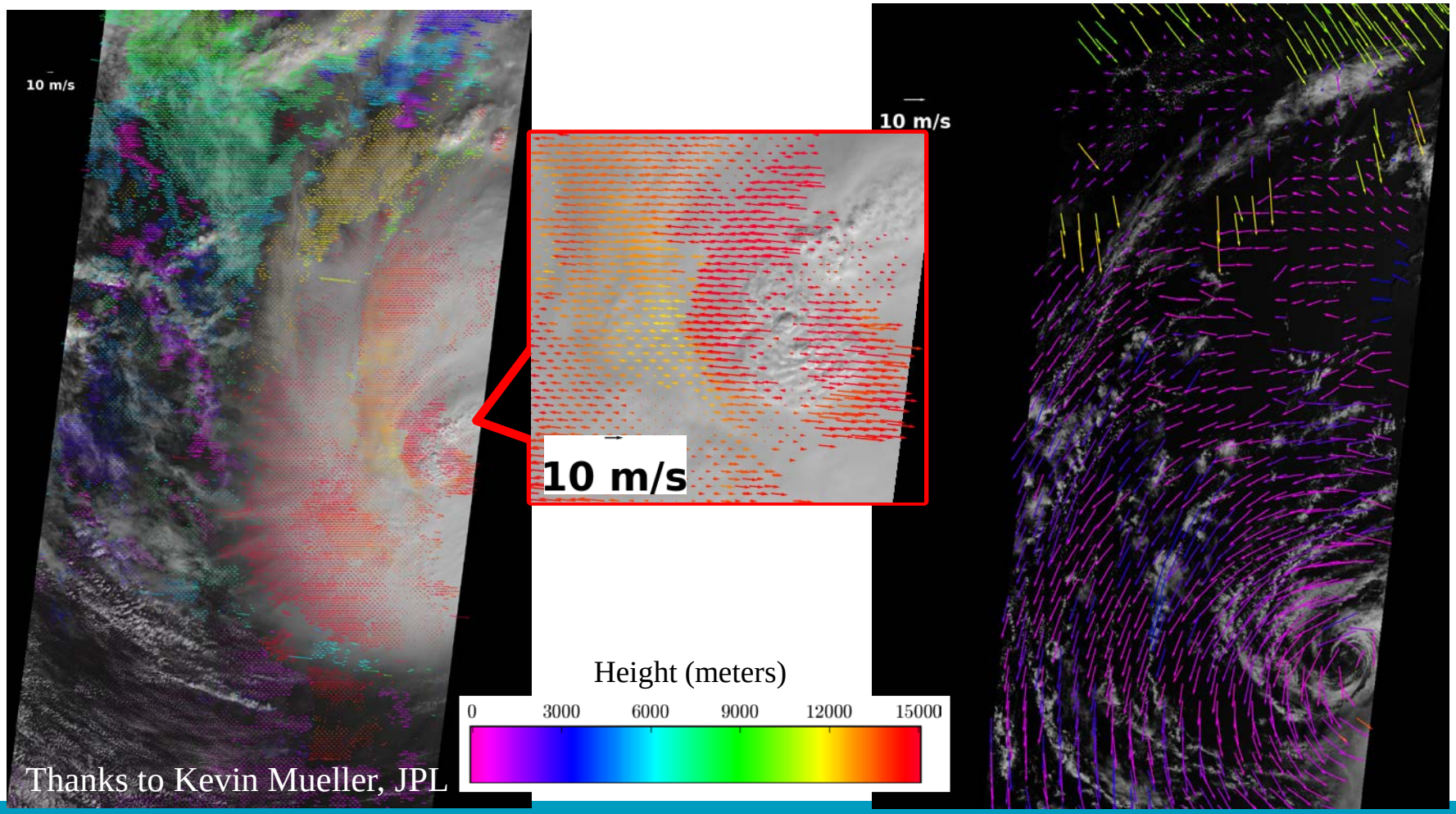
MISR Wind Products

- **Height-resolved Cloud Motion Vectors (CMV)**
  - **Geometric height obtained from parallax**
  - **Retrieved from redundant forward and aft camera triplets**
  - **Time interval Δt = 200 seconds**
  - **Gridded resolution Δx = 17.6 km**
- **Height-resolved cross-track cloud motions:**
  - **Geometric height obtained from parallax**
  - **Retrieved from redundant forward and aft camera pairs**
  - **Time interval Δt = 46 seconds**
  - **Gridded resolution Δx = 1.1 km**
  - **Muller et al. (2003) describes algorithm**

Example MISR Wind Product Retrievals

Height resolved cross-track cloud motion (1.1 km resolution)
(Hurricane Ida)

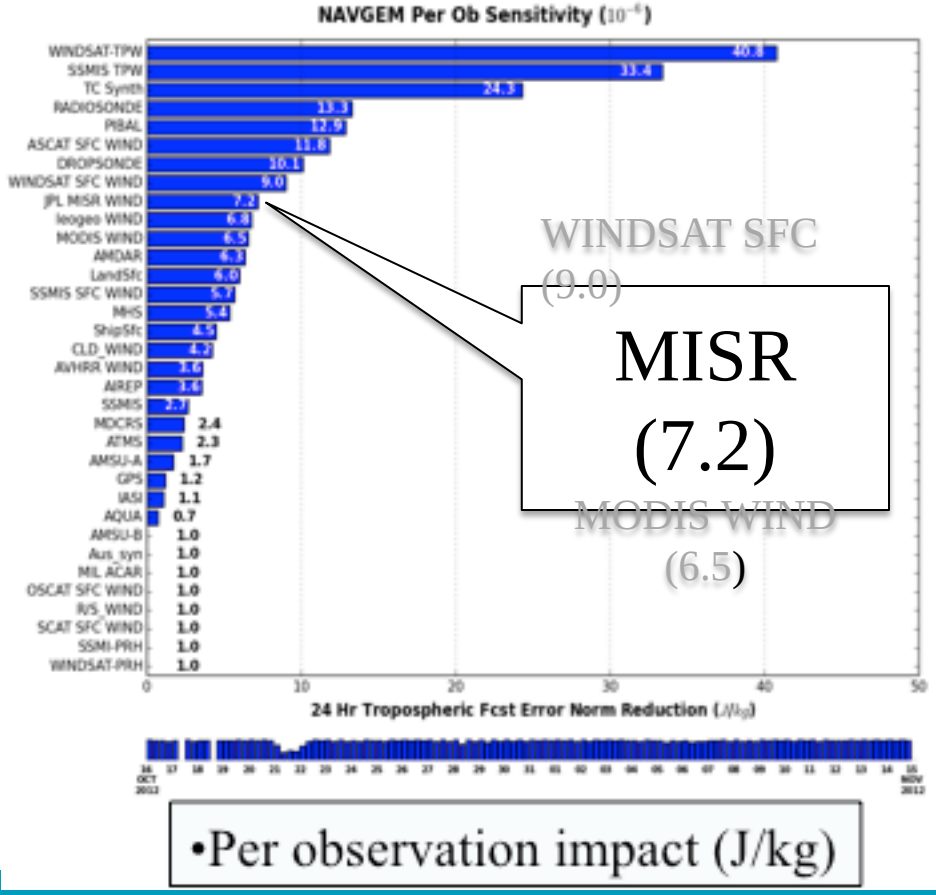
Height resolved cloud motion vectors (17.6 km resolution)
(Hurricane Francis)

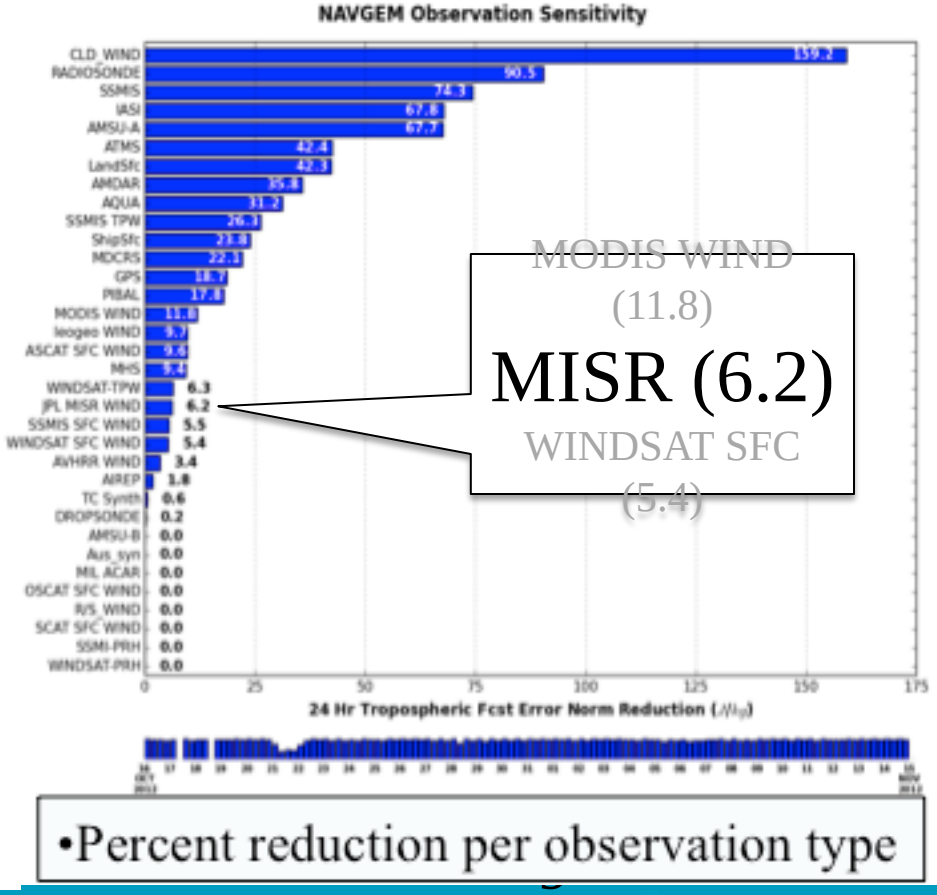


Naval Research Lab. obtains good forecast impact

- **NRL conclusion: Good overall impact from MISR winds**
  - **Low level MISR winds appear to fill data gap**
- ***And now MISR winds are being produced in 2.5 hours and will be broadcast over GTS to all NWP centres from July 2014***

Thanks to Kevin Mueller, JPL





•Per observation impact (J/kg)

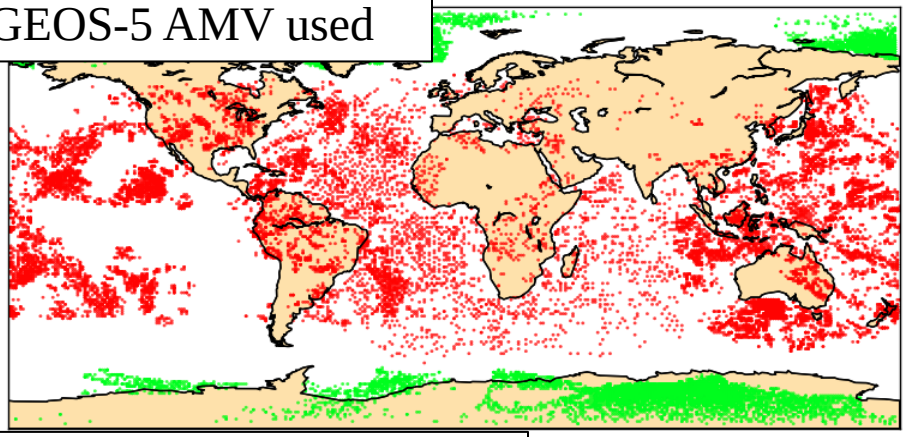
•Percent reduction per observation type

MISR has potential niche in excellent boundary layer sampling

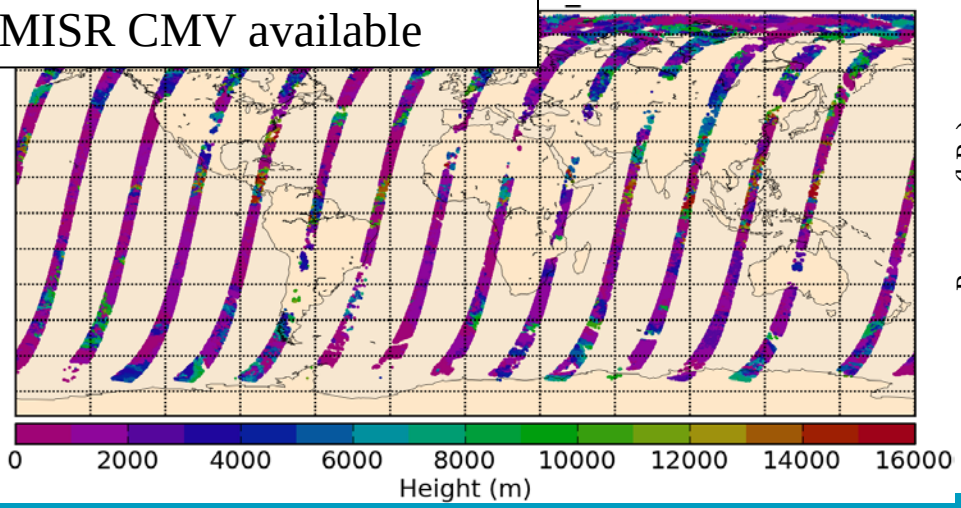
- **Quantity of MISR CMV at low level comparable to quantity currently assimilated by GEOS-5 DAS**
- **MISR produces winds in GOES view where winds from GOES ought to have been assimilated but were not**
- ***Above:* Atmospheric Motion Vectors assimilated in GEOS-5 DAS at 00Z, August 20, 2010**
  - ***Green*: polar orbiting instruments**
  - ***Red*: geostationary instruments**
- ***Below:* MISR Cloud Motion Vectors available that day**

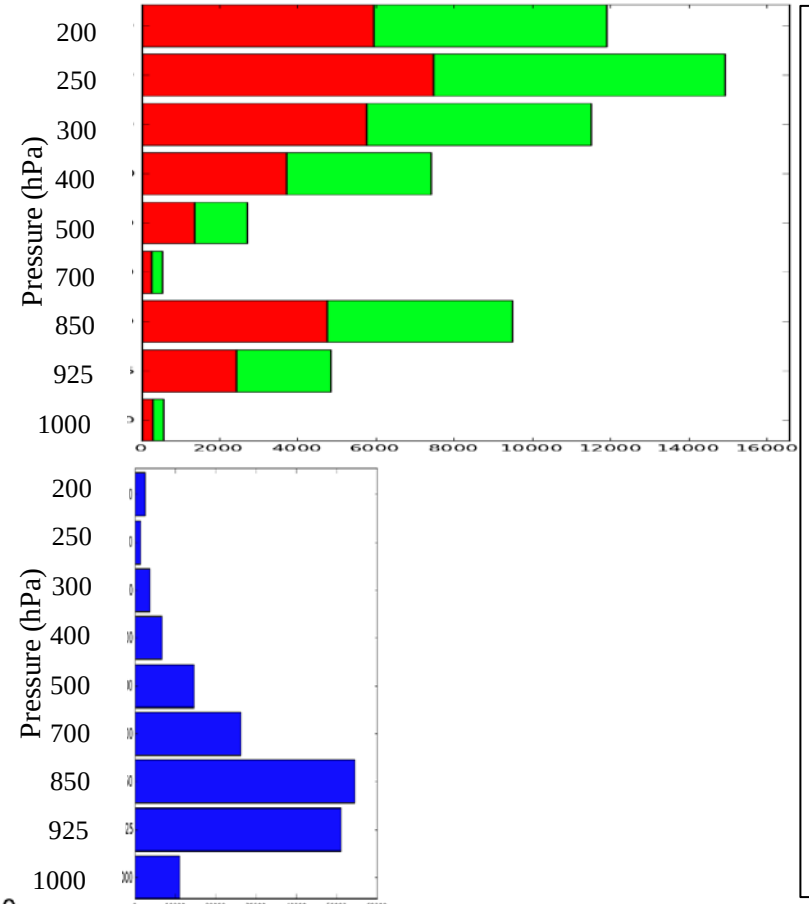
Thanks to Kevin Mueller, JPL

GEOS-5 AMV used



MISR CMV available





Motion vectors per pressure level

Upper figures from Merkova & Gelaro

What heritage apart from MISR do we have?

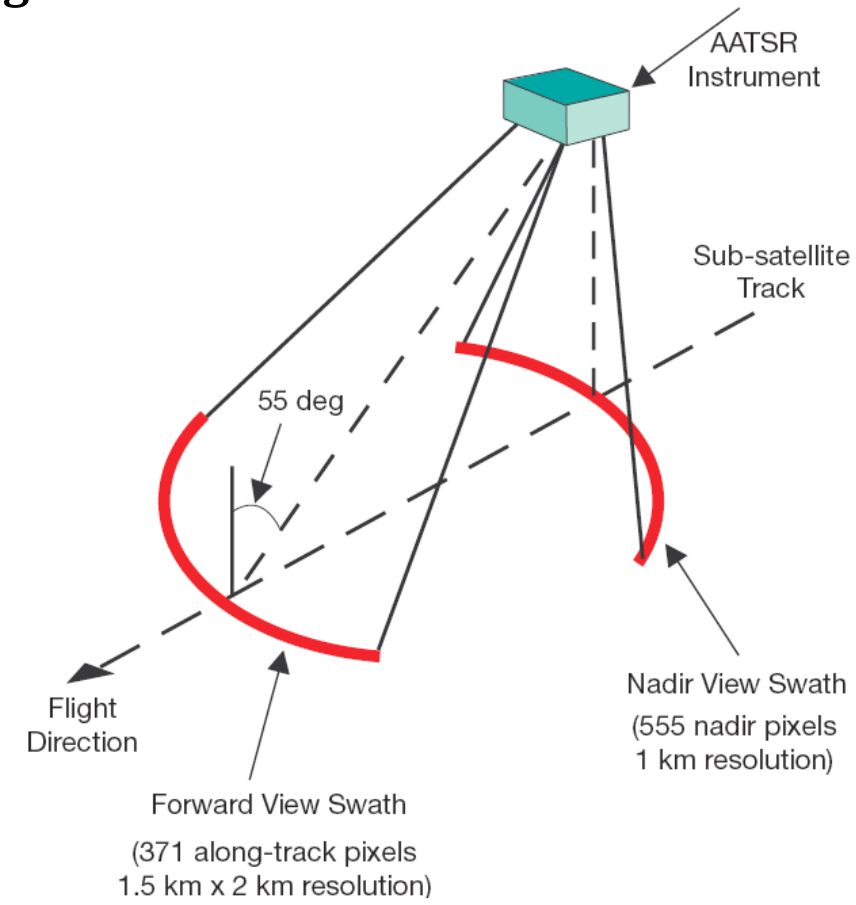
UK (A)ATSR(2)

Why bother with Multi-spectral stereo retrievals?

- **Produces extremely accurate Cloud-Top Heights, the key weakness in existing AMVs/CMVs**
- **Does not rely on external data such as objective analysis T-P profiles**
- **Or assumptions on cloud emissivity**
- **Or accurate thermal radiometric calibration**
- **Technique entirely geometric, relies on accurate pointing information and a robust pattern recognition technique to find corresponding features**
- **Is there a catch?**
- **Need to derive cloud-top winds, preferably using data from the same instrument(s)**
- **Need very accurate information on pointing vector for the imaging instrument**

Heritage: Along-track Scanning Radiometer (ATSR)

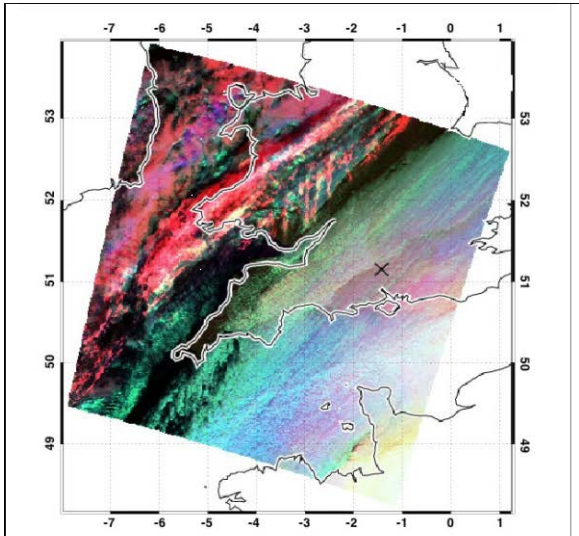
- Monitoring and detecting climate change
  - Sea and Land Surface Temperatures
  - Vegetation
  - Fire Monitoring
- On-board (thermal) calibration
- Conical scanner with dual view
  - Nadir 0-22˚ , Forward 55-52˚
  - 500km swath
- Seven channels
  - Thermal: 11, 12µm
  - SW/NIR: 3.7, 1.6µm
  - Visible (since ATSR-2): 0.55, 0.65, 0.87µm
- 512km swath, 1/1.5km pixel size
- Continuous record since 1991
  - ATSR-1 1991-2000
  - ATSR-2 1995-2009
  - AATSR 2002-2012
- Stereoscopic height retrieval
  - M4 stereo matcher (Muller et al., 2006)

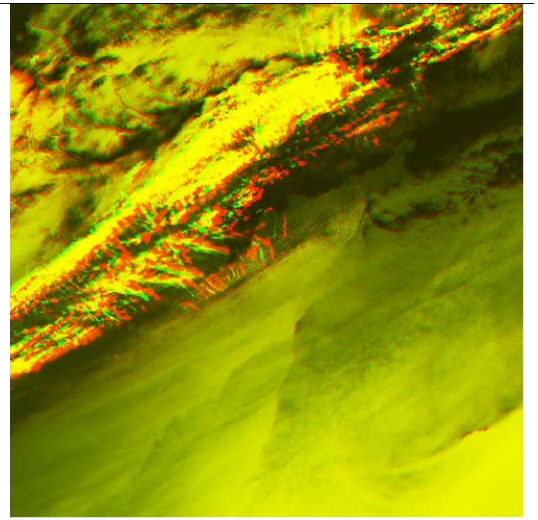


ATSR2-AATSR tandem (30 minutes apart) for 2002/3

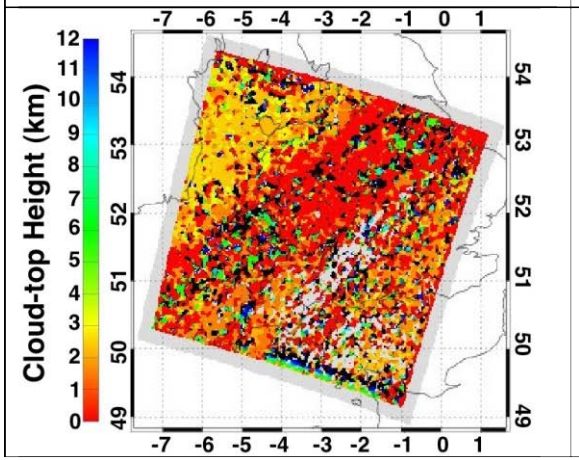
Example of (A)ATSR(2) Multispectral Stereo to sample thin high Ci over dense StCu

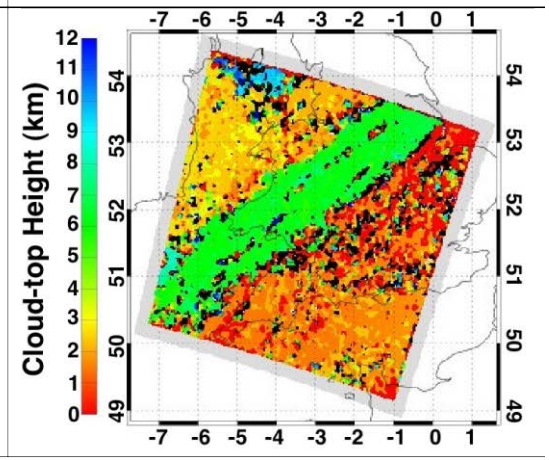
False Colour Composite of 11µm, 1.6µm, 0.68µm (left)
Red/Green stereo anaglyph (right)





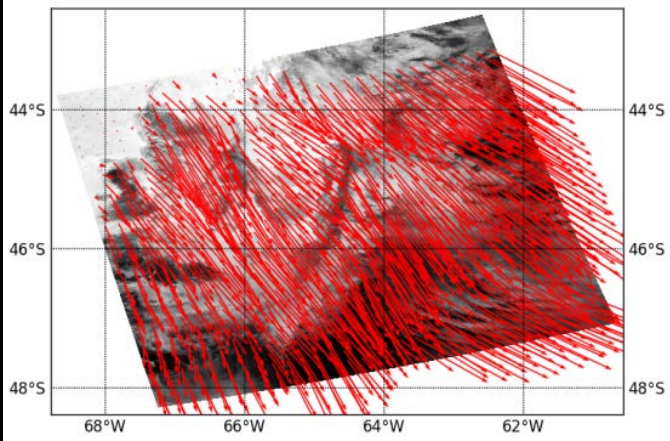
ATSR2 Stereo CTH retrieval at 1.6µm (left) and 11µm (right)

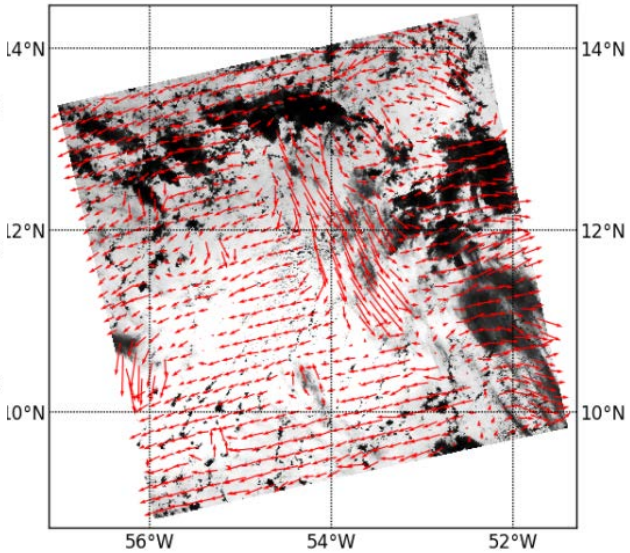


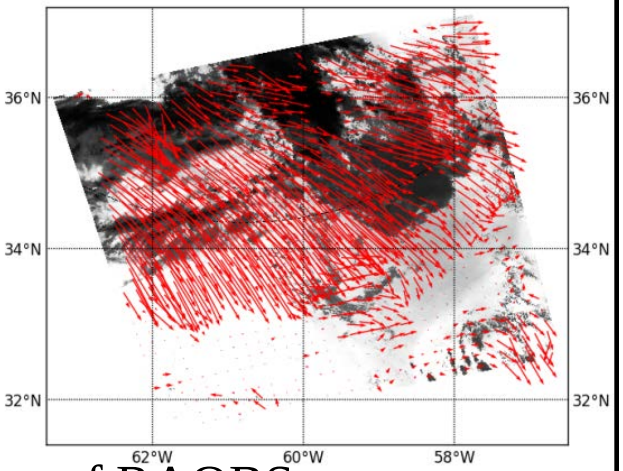


Muller et al., 2007

ATSR2-AATSR tandem (Muller & Fisher, IWW12



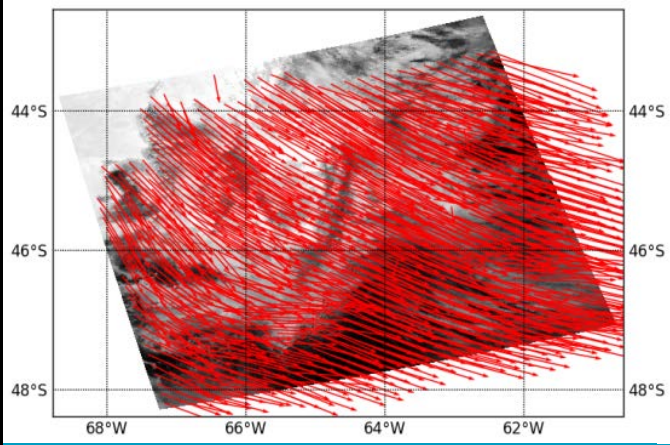


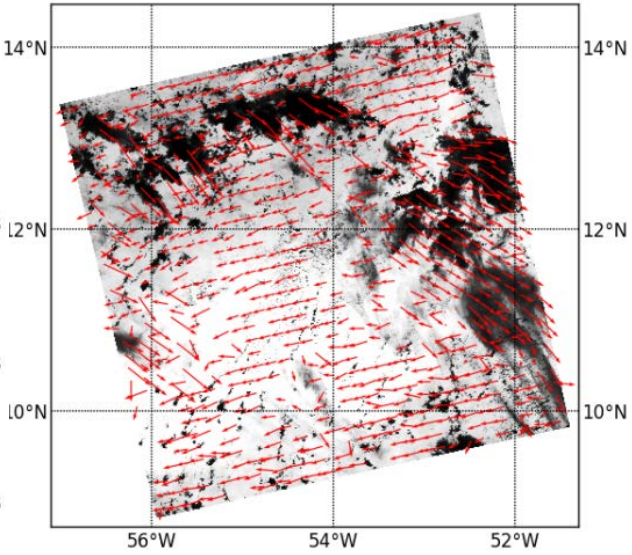


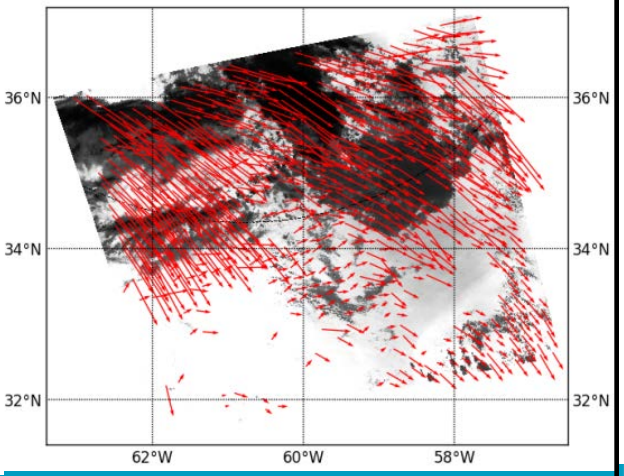
ATSR-2/ AATSR optical flow results

cf RAOBS
<u>-1.96±7.45
<v> 1.63± 4.75

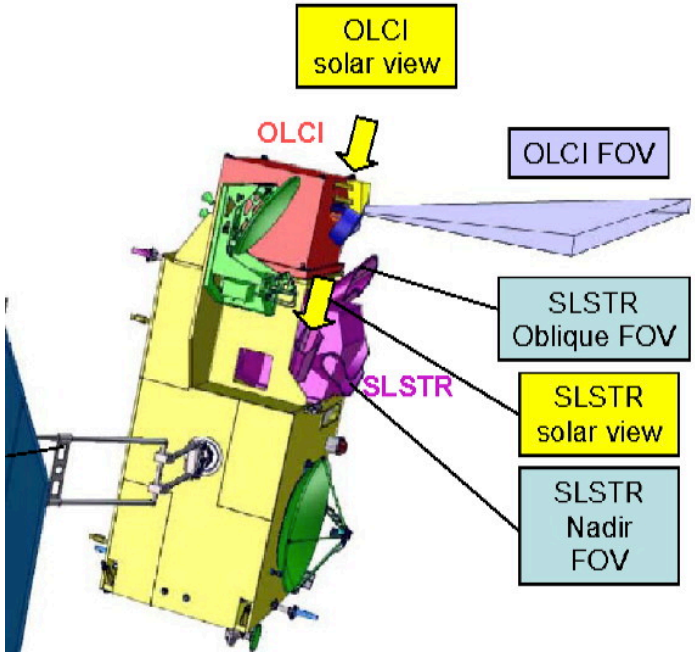
NASA (MER)RA

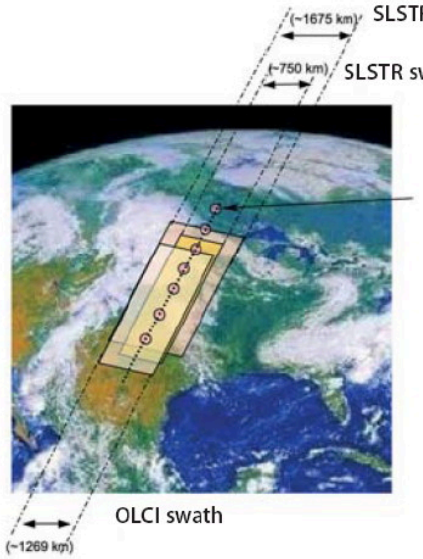


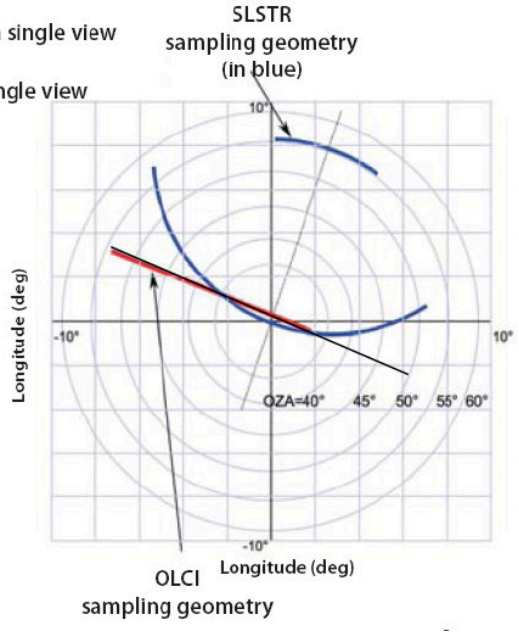




SENTINEL-3 SLSTR (& OLCI) – from 2015

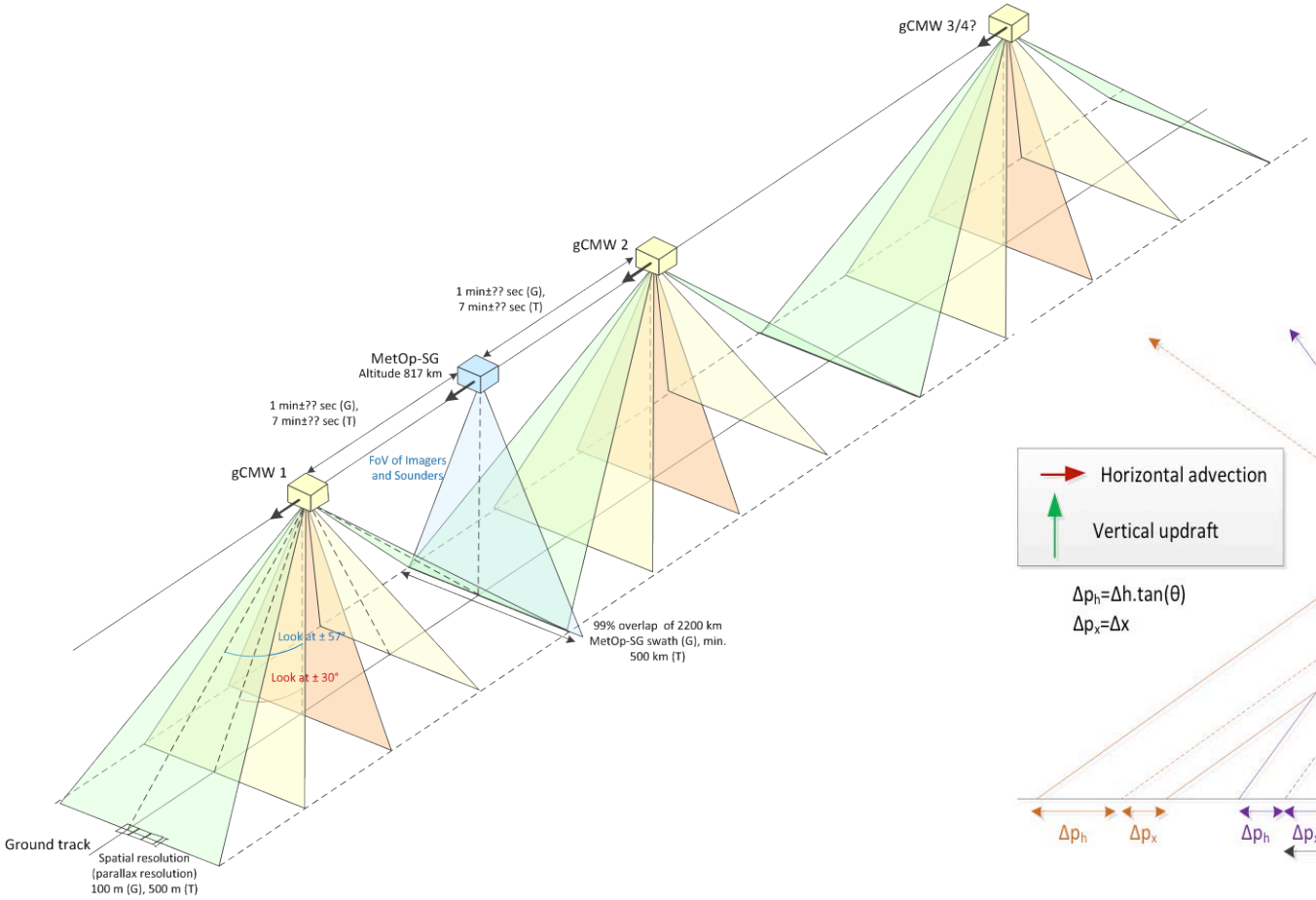


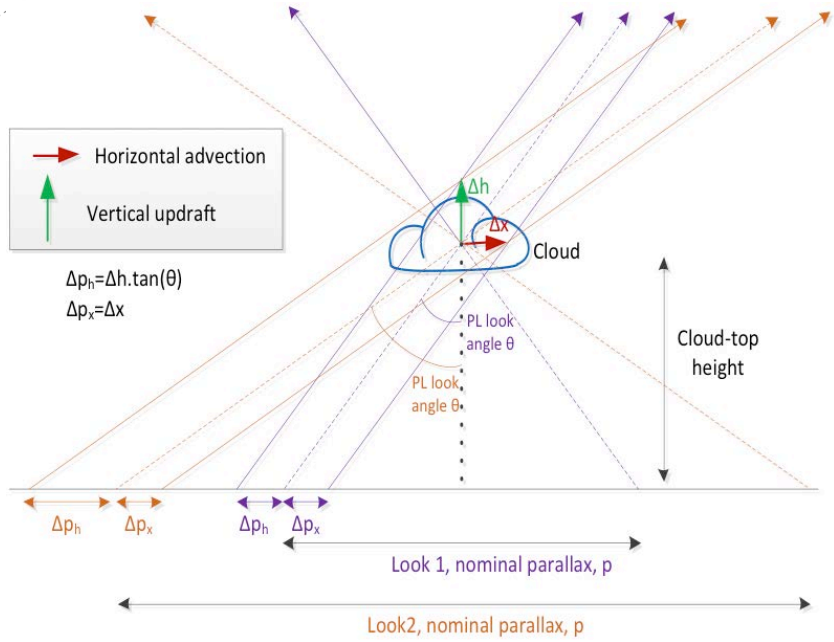




SLSTR 750km overlap could provide stereo (750m) winds from polar Overlap and with 2 SENTINEL-3 spacecraft in 180º orbit could achieve Along-track tandem operation with ≈50 minute time interval

Geometric Cloud Motion Winds from a satellite convoy : a proposal for MetOp-SG





Courtesy of Ad Stoffelen, KNMI; Karl Atkinson, Astrium Ltd., Amanda Regan, ESA-ESTEC

So how do we meet the need: MISRlite

- **We have demonstrated with (A)ATSR(2), that a thermal IR (TIR) multi-look instrument will address the operational needs for more mid-level and upper-level winds**
- **Previous ESA-EE08 bid led to requirements listed below**
- **Need sufficient SNR (NE∂T≤30mK) to have sufficient contrast for stereo matching**
- **Do NOT require absolute temperature calibration**
- **Can produce winds with accurate cloud-top heights using a tandem operation**
- **What about the technology?**

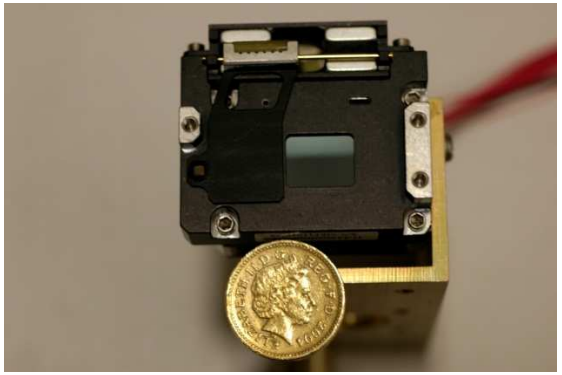
Swath width	1500 km
Pixel size	300m
AMV reporting grid-size	900m, 9km
Wind speed accuracy	±3 m/s
Cloud height accuracy	±300m

Table 1: MISRlite instrument specification

Prior Art for the development of an airborne prototype

Fisheye ferro-electric camera with FPGA installed at Chilbolton operating every 30 seconds 24/7/365

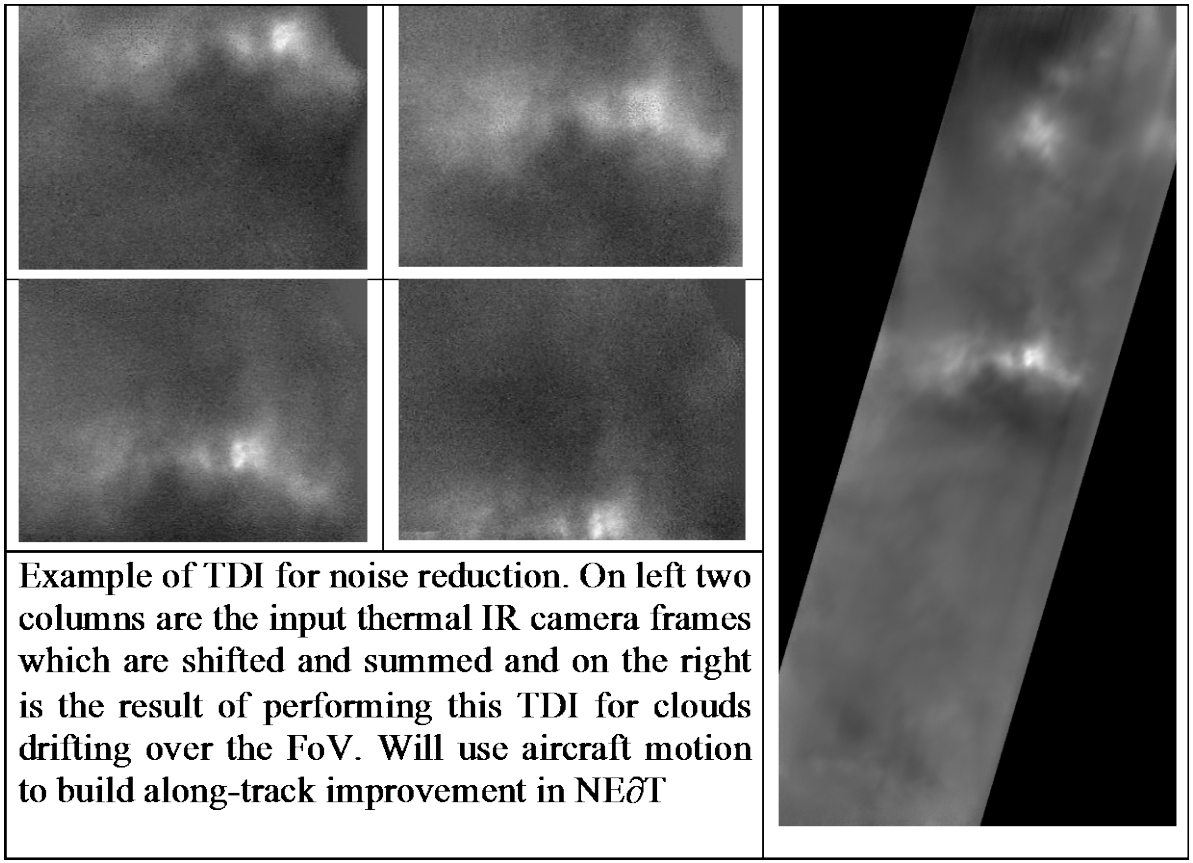
Compact camera unit with FPGA and new ULIS microbolometer camera cores



MISR-Lite : Airborne prototype: sensor development

UK Space Agency CEOI fund airborne prototype development from 7/2014

- Uncooled ULIS microbolometer arrays (320 x 240)
- Operating in TDI mode
- 2 arrays to be mounted side-by-side
- Optics based on previous design



Example of TDI for noise reduction. On left two columns are the input thermal IR camera frames which are shifted and summed and on the right is the result of performing this TDI for clouds drifting over the FoV. Will use aircraft motion to build along-track improvement in NE∂T

MISR-Lite : Airborne prototype

UK Space Agency CEOI fund airborne prototype for flight in Adelaide, SA in 3/2015

- Mounted on a gimbal in a payload pod
- Bore-sighted with scanning lidar
- Test flights with ARA Flinders in association with UCL Australia/MSSL in Adelaide in 3/2015

What next?

- Develop laboratory TIR TDI imager prototype and test at MSSL
- Install in gimbal mount and interface control system to allow automated pointing
- Interface TIR imager with IMU+GPS using protocols from ARA
- Transport system to ARA, implement in pod and test in situ
- Conduct airborne trials with Cumulus in Great Autrsalian Bight and with tropical clouds near Darwin
- Seek funding to take this up to TRL9
- Prepare EEO9 proposal for multi-micro satellite tandem system