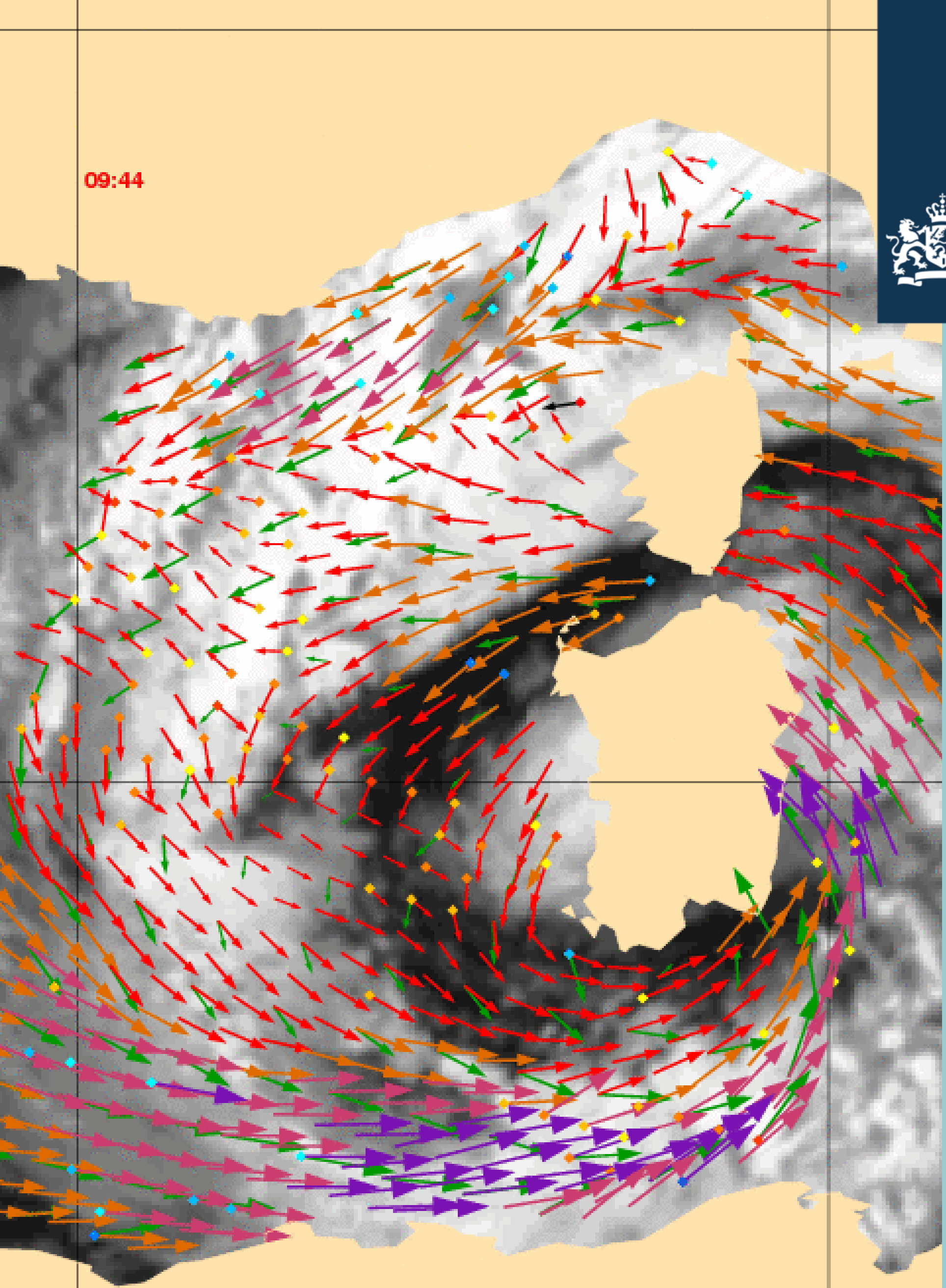



Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure and the Environment*

# Observing Earth System Dynamics

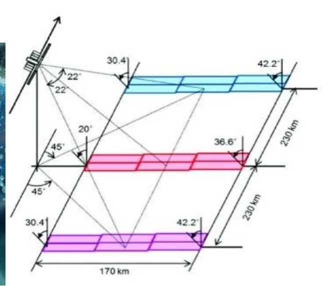
Ad.Stoffelen@knmi.nl, fellow IEEE
Leader active sensing
R&D satellites (RDSW)

earthcare

aeolus

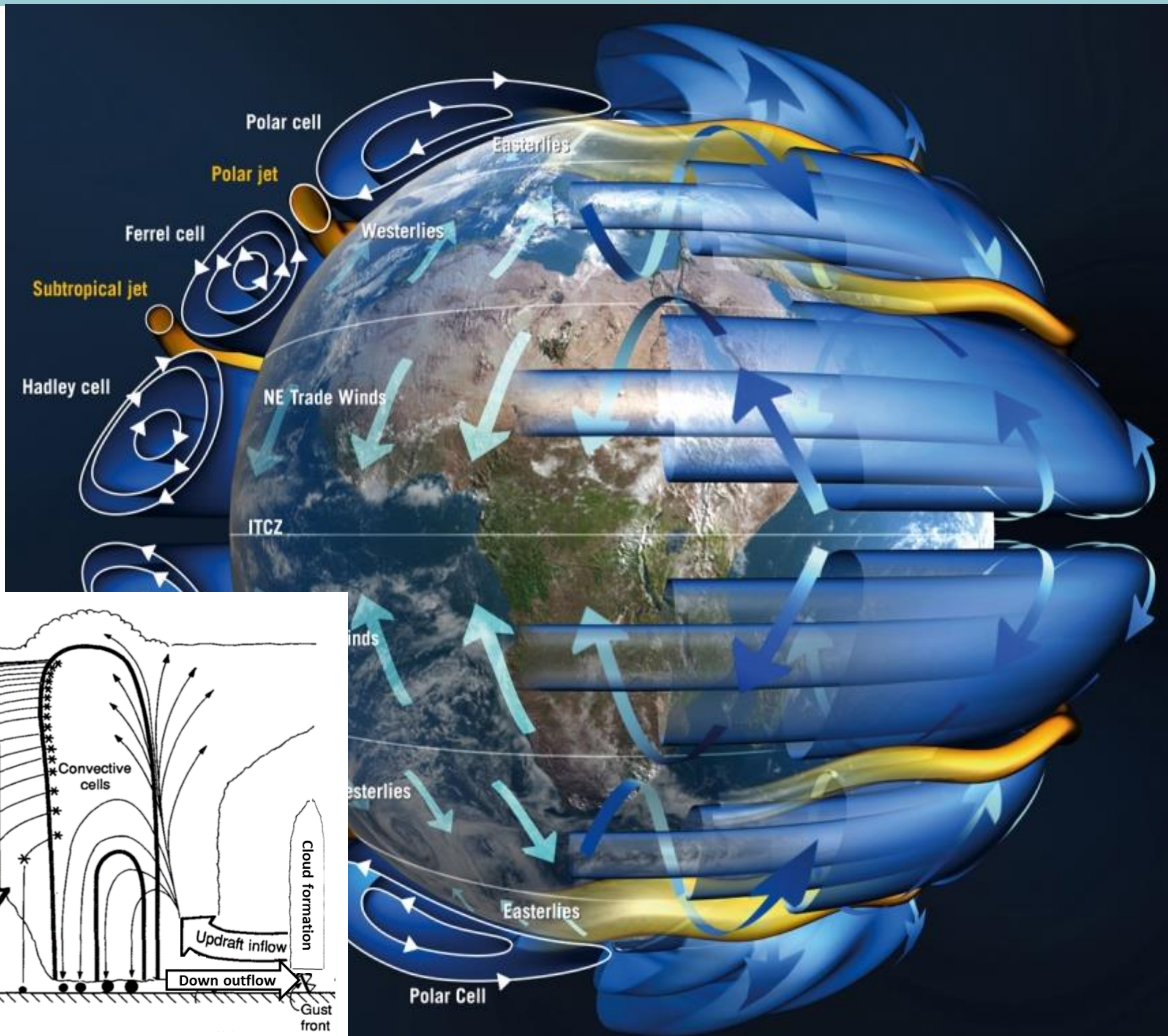
# Overview

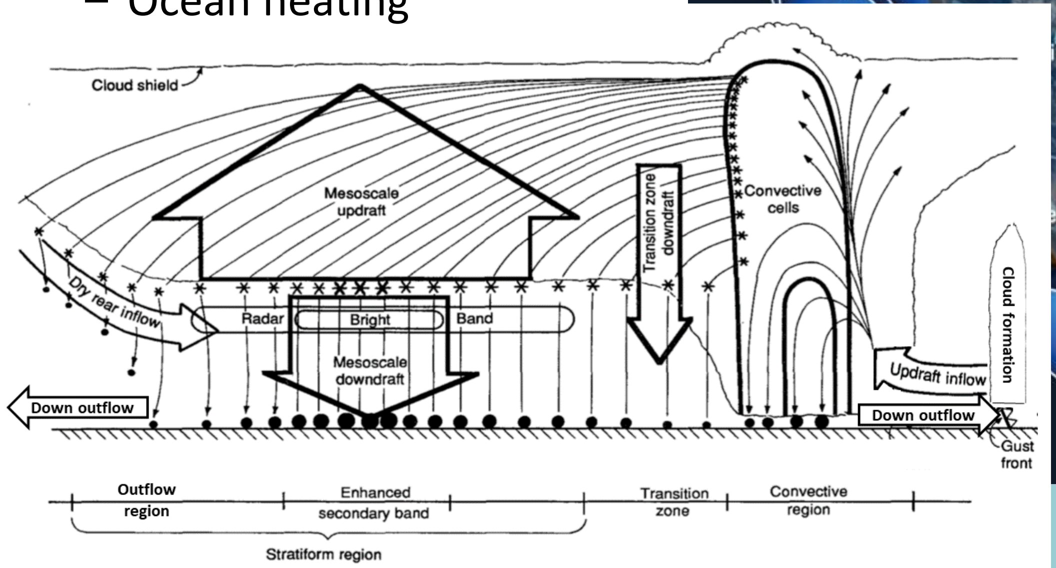
- Relevance, earth system science, dynamical coupling ocean and atmosphere
- Missions (share and enjoy ☺ )
  - ESA ERS-1, ERS-2, EUMETSAT ASCAT, SCA, ocean vector winds, sea ice, soil moisture, rain
  - NASA QuikScat, ISRO OSCAT-1/2(ScatSat)/3, NSOAS HY2A/B/C/D, NASA Zephyr, ‘’
  - NSOAS/CNES CFOSAT, CMA WindRad, ocean vector winds, sea ice, soil moisture, rain
  - NASA CYGNSS, ocean wind speed, ocean waves
  - ESA EE10 HARMONY, ESA EE11 SeaStar, ocean winds, ocean currents, SST, cloud motion
  - ESA Aeolus, winds and aerosol and clouds
  - ESA EarthCare, 3D clouds and radiation
  - Cloud Motion Winds, GEO & LEO
- Involved in mission design, development, Cal/Val, NWP calibration
- Geophysical processing, services
- User applications (extremes, waves, surges, weather, climate processes, climate monitoring, economy, energy, civil protection, . . . )



# Atmospheric dynamics

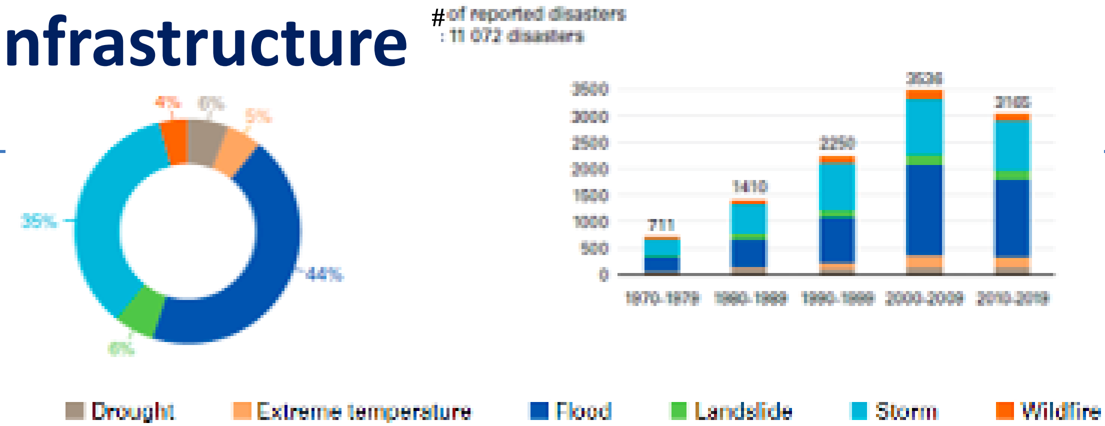
- Climate change
  - Temperature/radiation?
  - Atmospheric stability?
  - Humidity/clouds/rain?
- Dynamics change?
  - Hurricanes/tornado's
  - Jet streams/climate zones
  - Ocean carbon exchange
  - Ocean heating

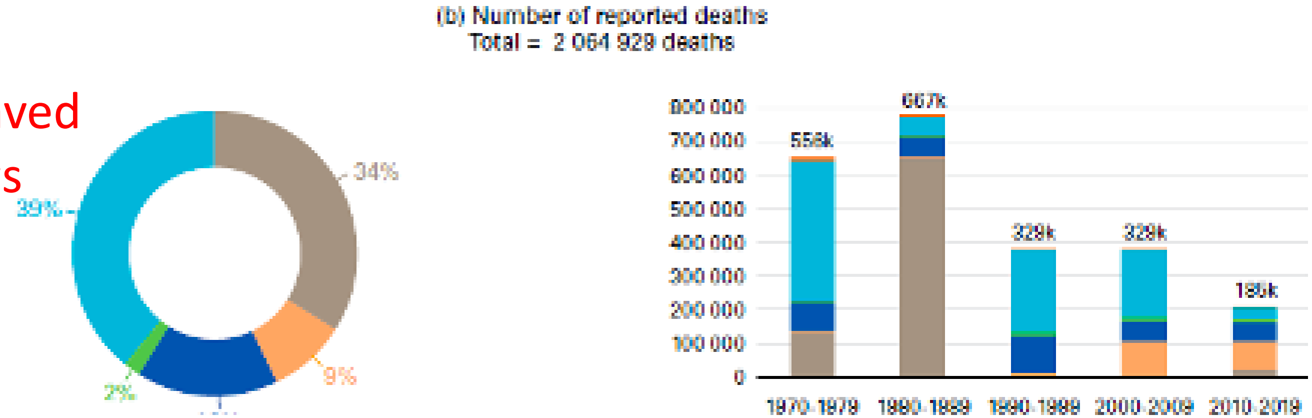


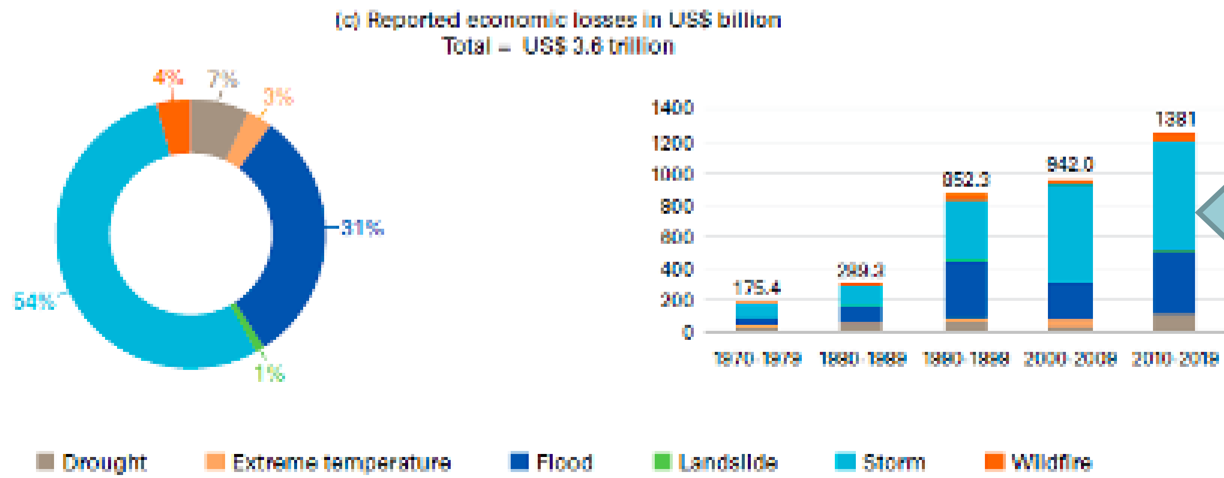



# Protecting people and infrastructure

- Weather losses are frequent, deadly and costly global disasters
- Subject to climate change
- More vulnerable infrastructure
- Lives and costs are saved by weather warnings



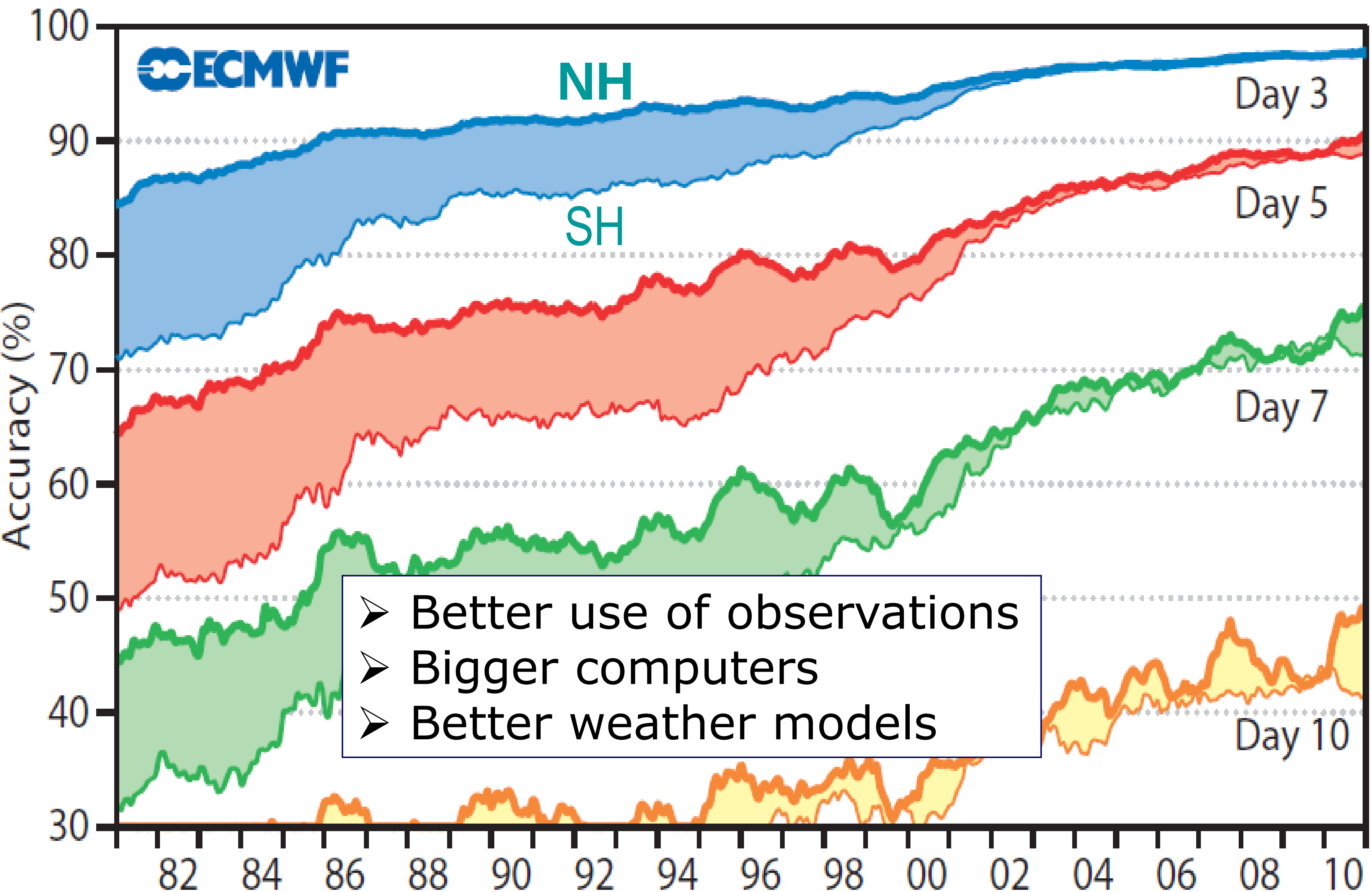



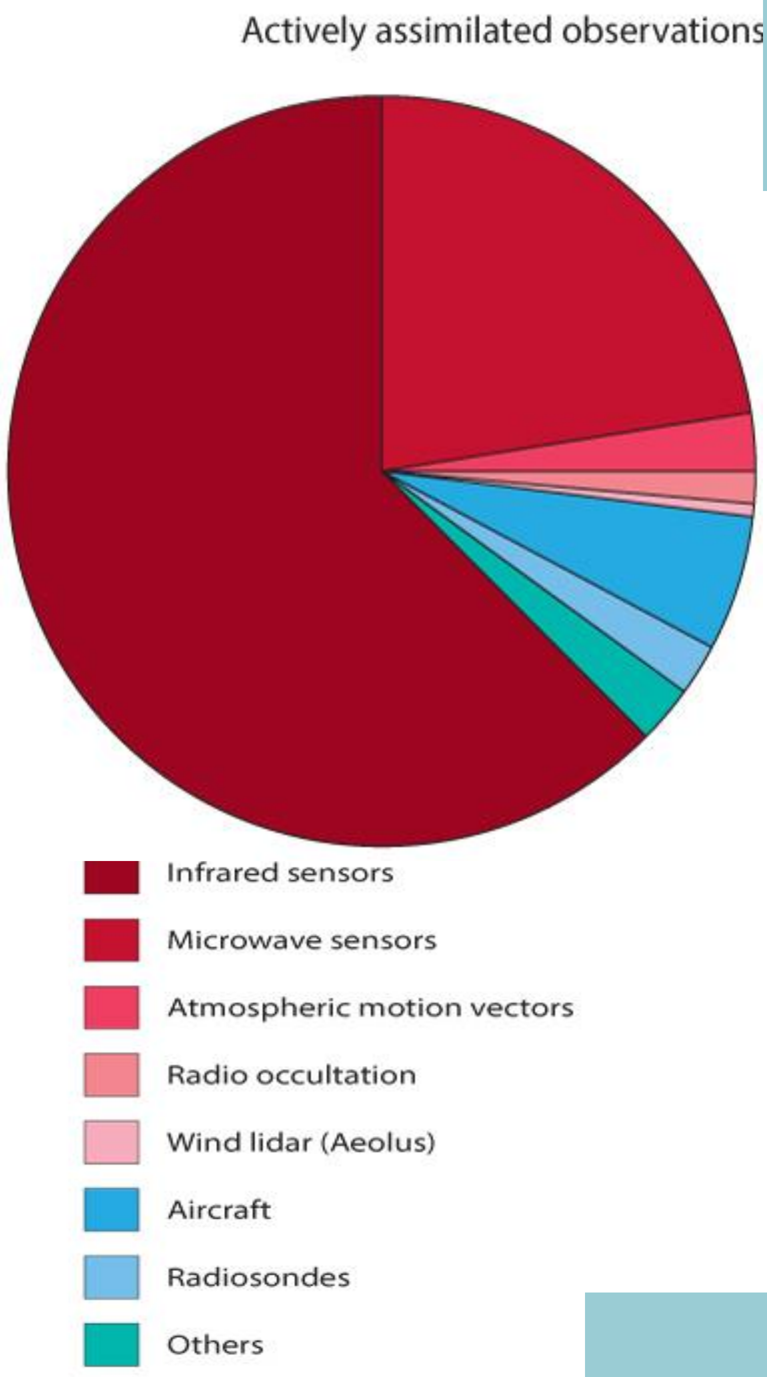

- More losses

- Improved warnings
- More heat

# Weather forecasts continually improve




- Better use of observations
- Bigger computers
- Better weather models

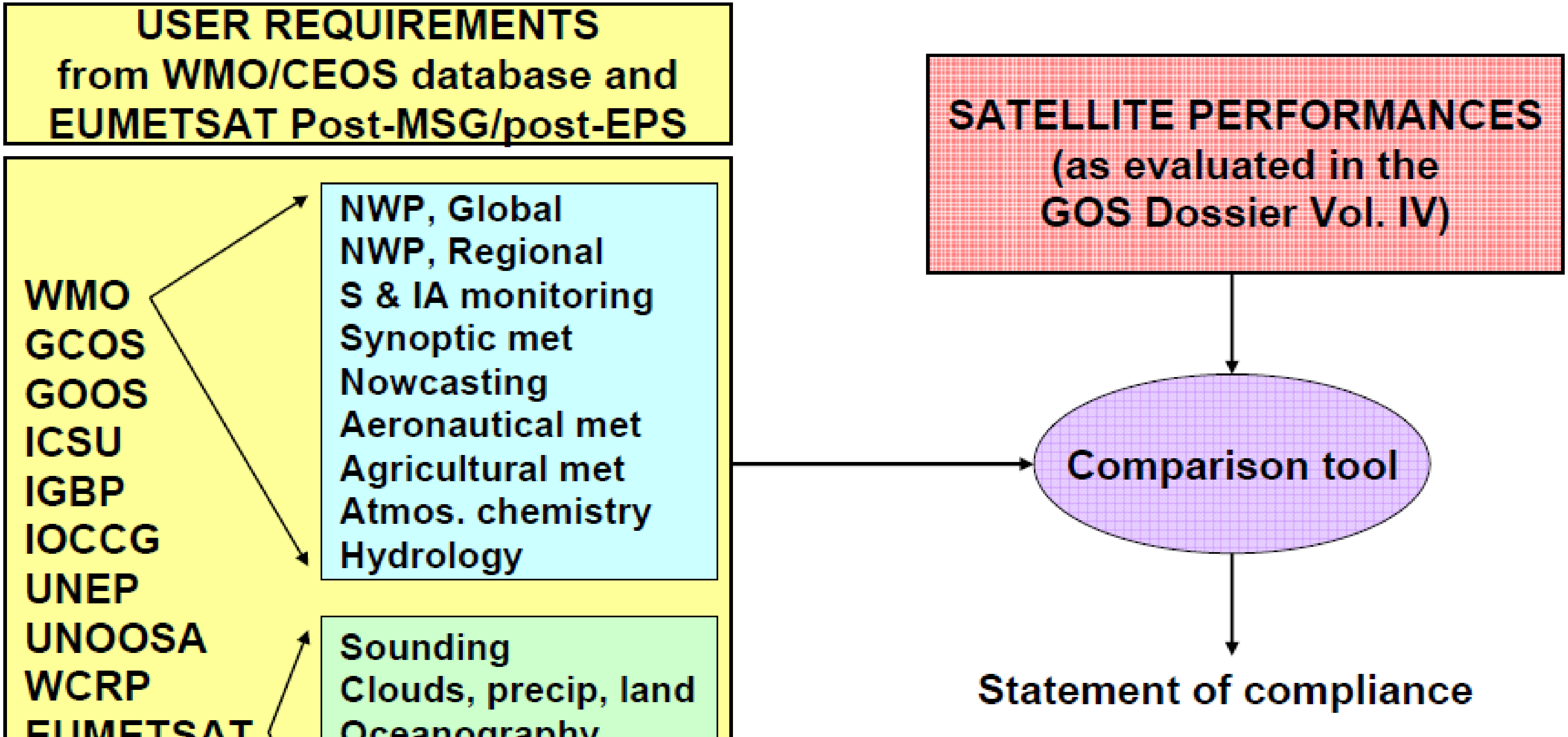



**ECMWF uses ~100 different satellite instruments in near-real time**

- Still new instruments
- What observations are particularly needed ?

www.ecmwf.int

# WMO G(C)OS gap analysis

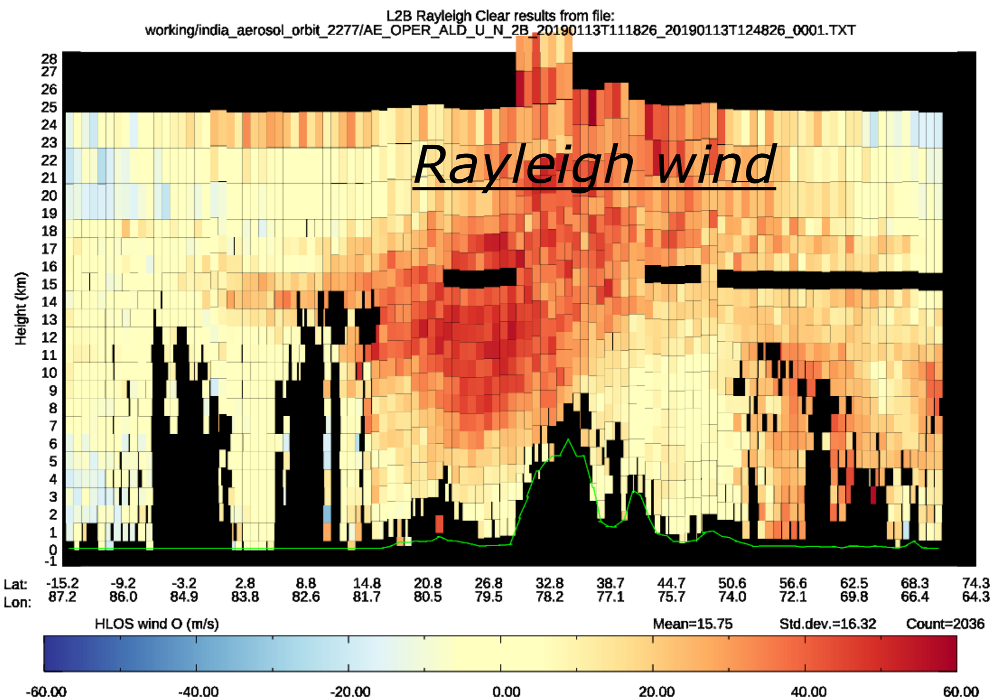


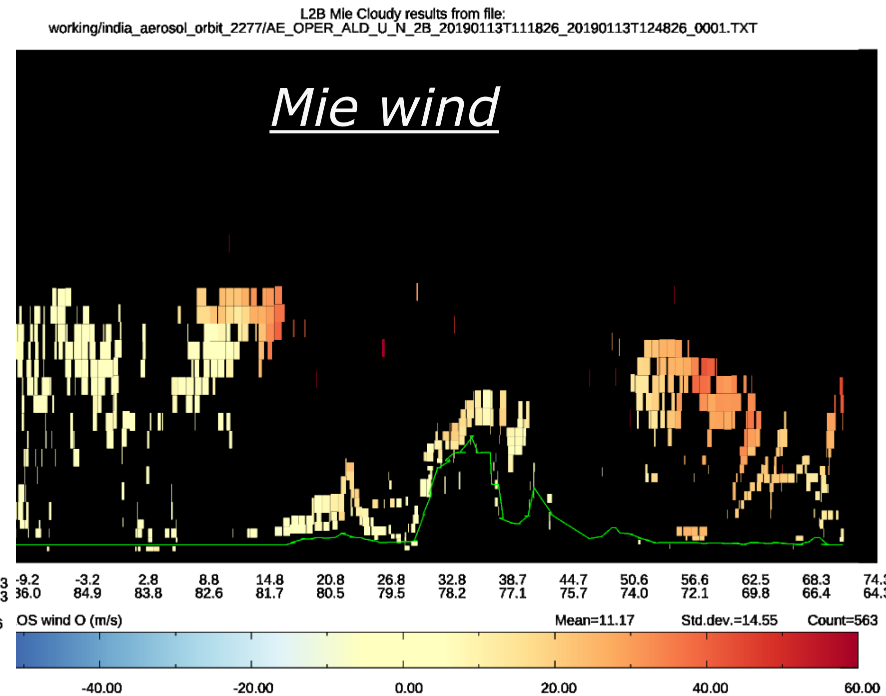

**2040 vision**



http://www.wmo-sat.info/oscar/

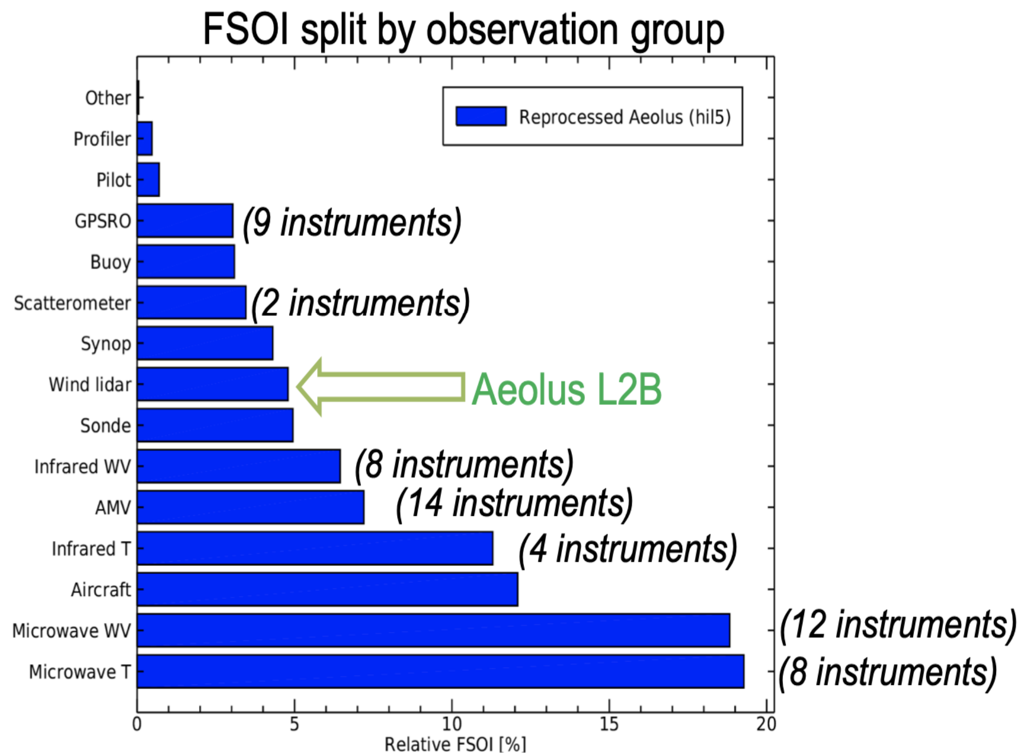
# Aeolus winds

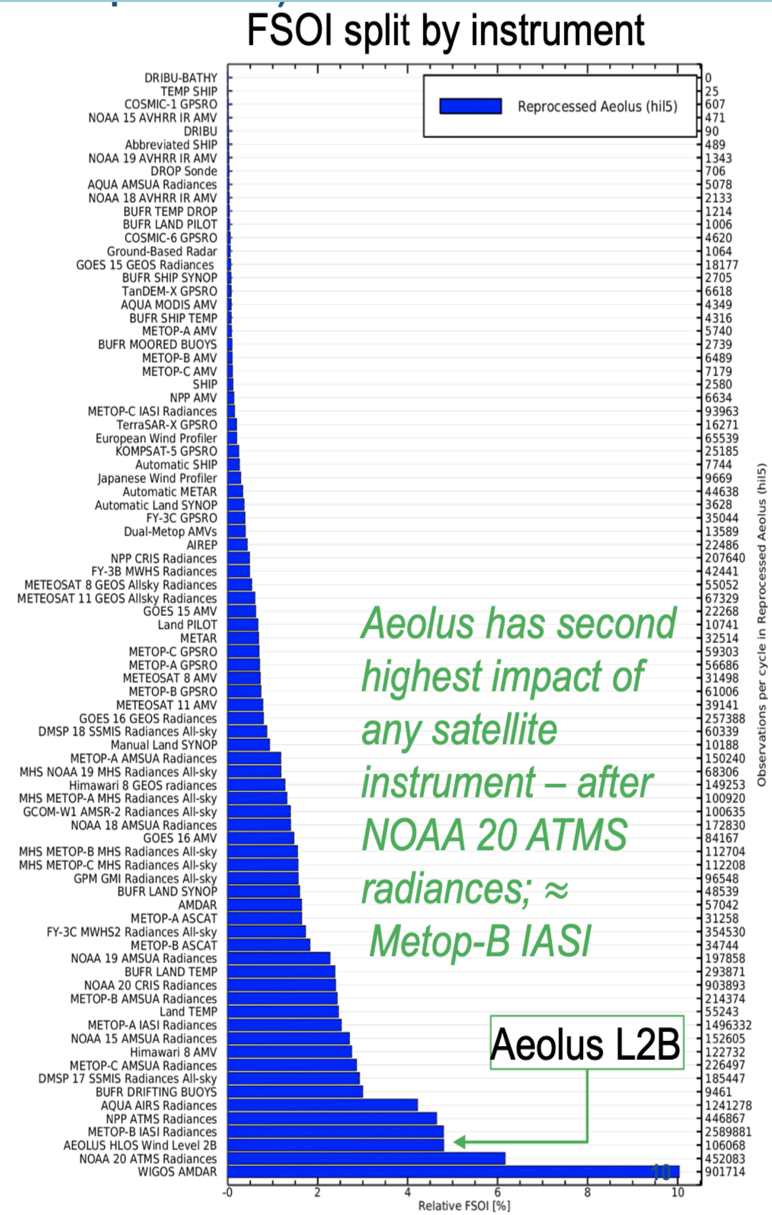



- Molecular clear air (Rayleigh) winds are the mission driver
- Cloud/aerosol particle (Mie) winds are complementary
- No winds below optically dense clouds
- Aeolus atmospheric return factor 3 too low

# FSOI Scores showing impact of Aeolus at ECMWF, reprocessed 3-27 Sept 2019



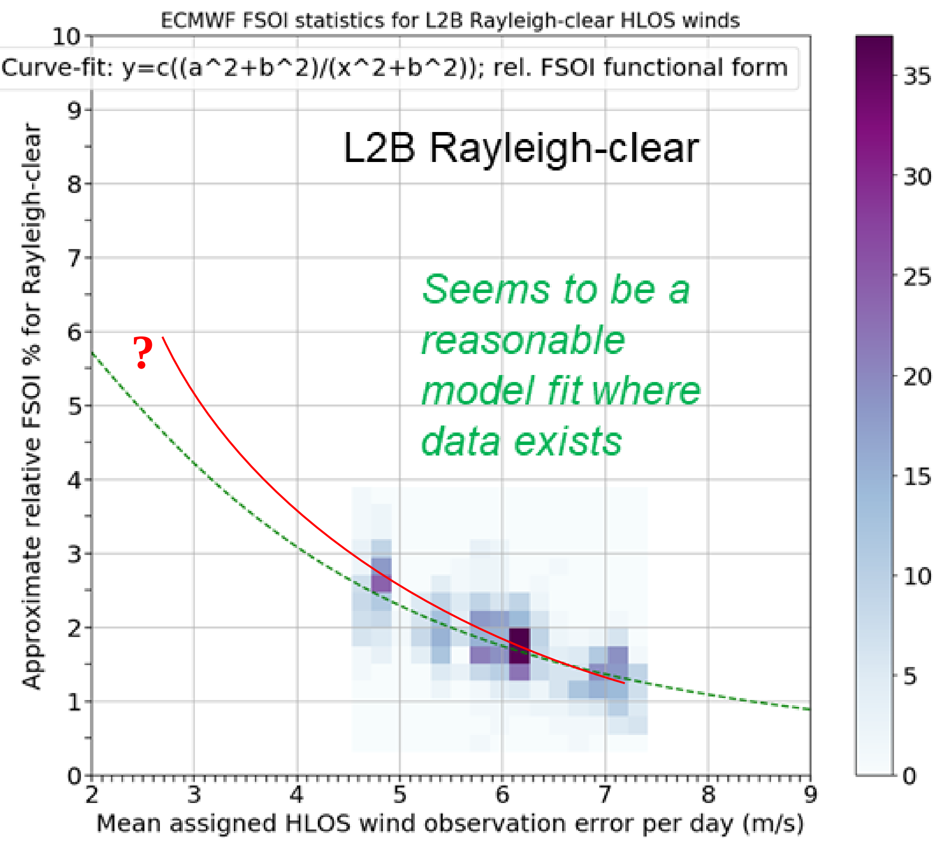




- ***For this period*** with ***good atmospheric signal*** and **reprocessing**, Aeolus provides **4.8% relative FSOI** – compare this to ~3.2% for first half 2020 operations
  - Aeolus ≈ radiosondes, > scatterometer & GPSRO
- **Shows the importance of DWL in NWP**
  - … even with less useful signal than expected pre-launch

ECMWF

Figures courtesy of Michael Rennie, ECMWF

# What NWP impact can we expect from Aeolus-2 DWL with enhanced signal ?




- FSOI is a measure for 24-hour forecast error variance reduction
- Compute enhanced variance contribution (green line)

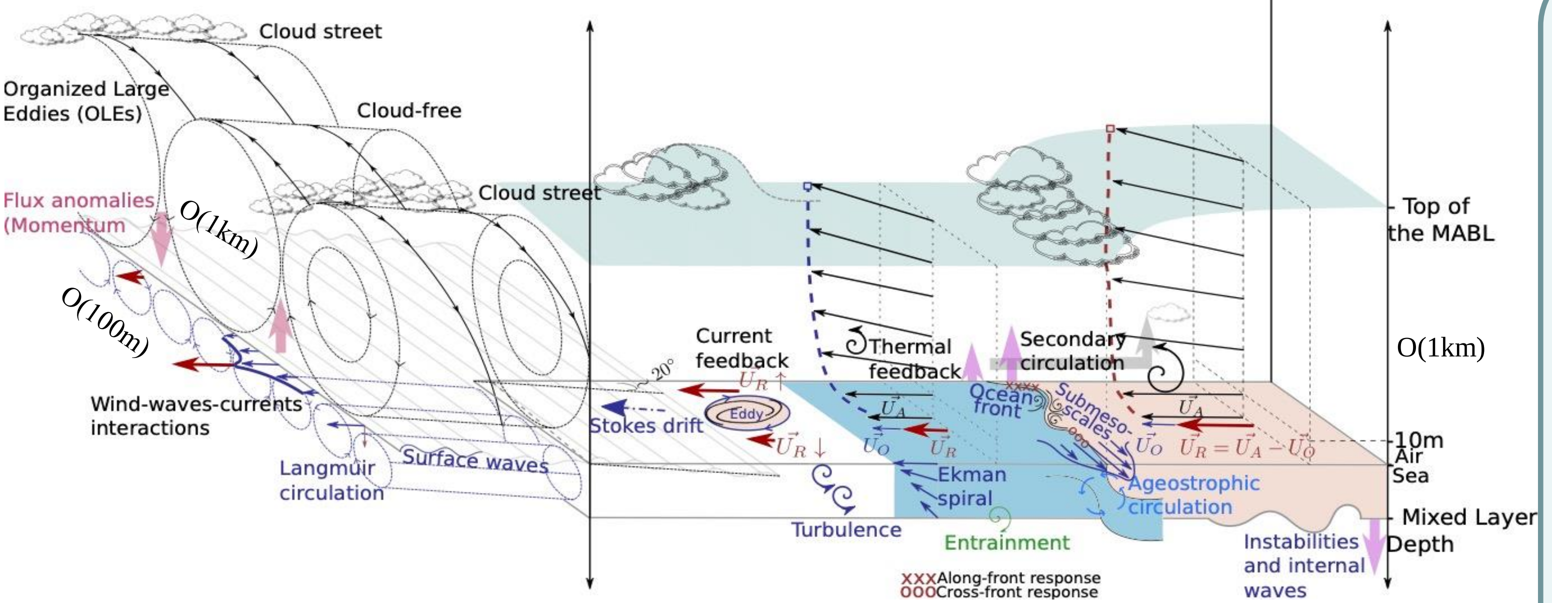
Alternatively:

- Models of dynamical error growth are linear in first 24 hours
- A factor of 2 for small changes and scalable w.r.t. FSOI
- Analysis error $\sigma_A = \text{sqrt}[(\sigma_O^2+\sigma_B^2)/\sigma_O^2.\sigma_B^2)]$
- Background error $\sigma_B$ is about 2 m/s, x = observation error $\sigma_O$
- y = improvement or c.($\sigma_A$ - $\sigma_B$): red line
- Scales sampling and ignores changes in sampling w.r.t. $\sigma_O$
- Can we use OSSE to address this extrapolation?

Figure courtesy of Michael Rennie, ECMWF

# Processes at the air-sea interface

Exchanges of **heat**, **gas**, **momentum** at the air-sea interface depend on the **thermal**, **chemical**, **kinematic** unbalance between ocean and atmosphere that are modulated by many **small-scale processes** that substantially moderate these exchanges.




**Air-sea fluxes**

depend on

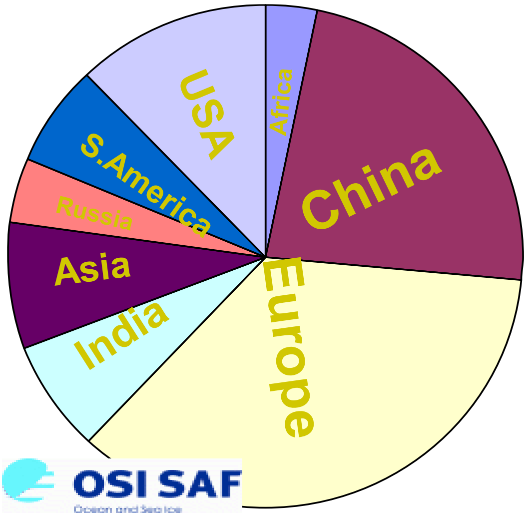
- **Surface stress** (impacted by ocean velocity and by air velocity, which is affected by SST)
- **Boundary layer thickness** (which varies by 2 orders of magnitude in different stability conditions)
- **Km-scale** ocean (eddy) dynamical circulations and phenomena

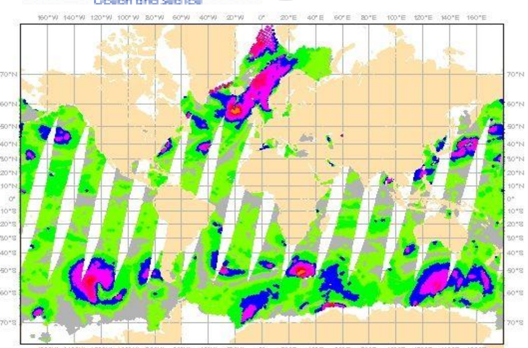
- Atmosphere and ocean are dynamically coupled through parameterizations with errors
- > 70% of earth's surface
- Tropical modes are poorly described (El Nino, MJO, Tropical Instability Waves, ..)
- Will these modes change in a changing climate? With what consequence?

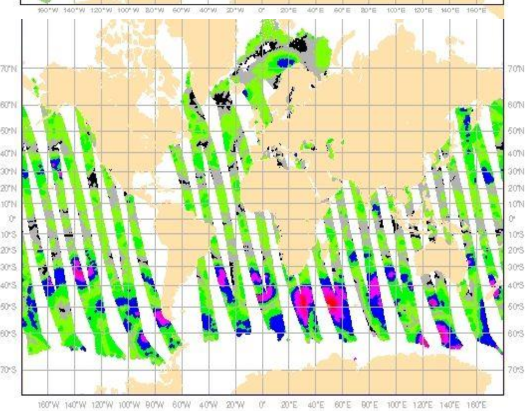
# Ocean/ice dynamics

- 3D circulation/ transport, mixing
- Affects heat/carbon budgets
- Melts sea ice, accelerates land ice
- Sea level rise
- Crucial for climate change impact and understanding
- Satellite capability limited to surface
- Interior dynamics by ARGO floats

# Satellite Wind Services



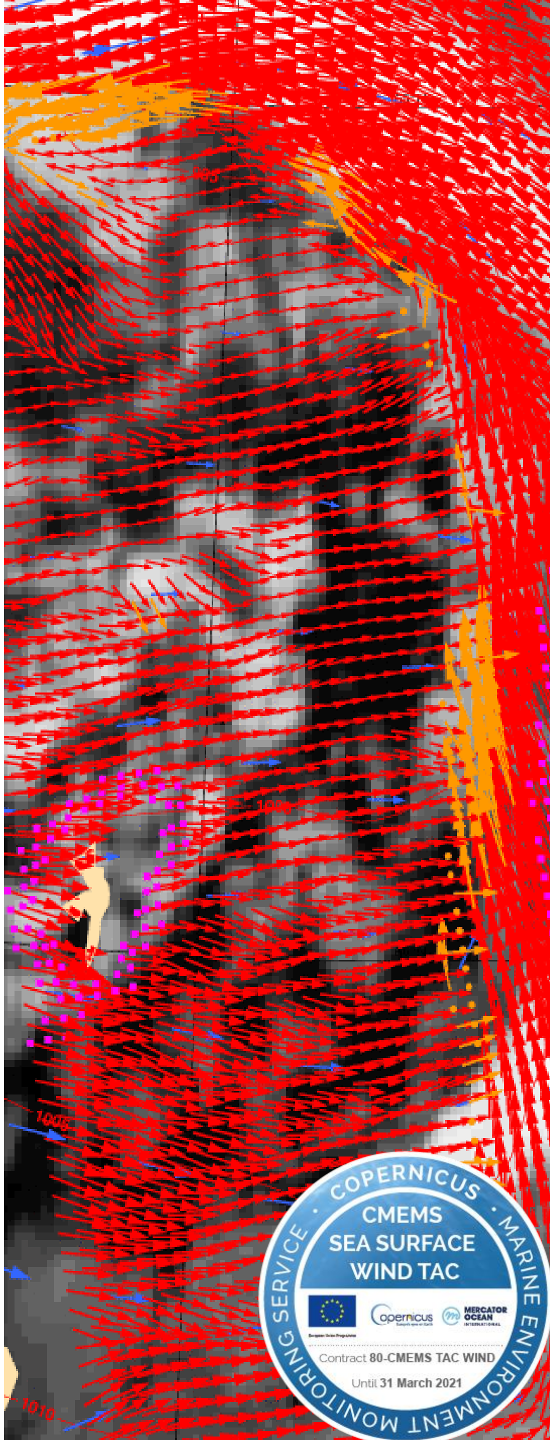


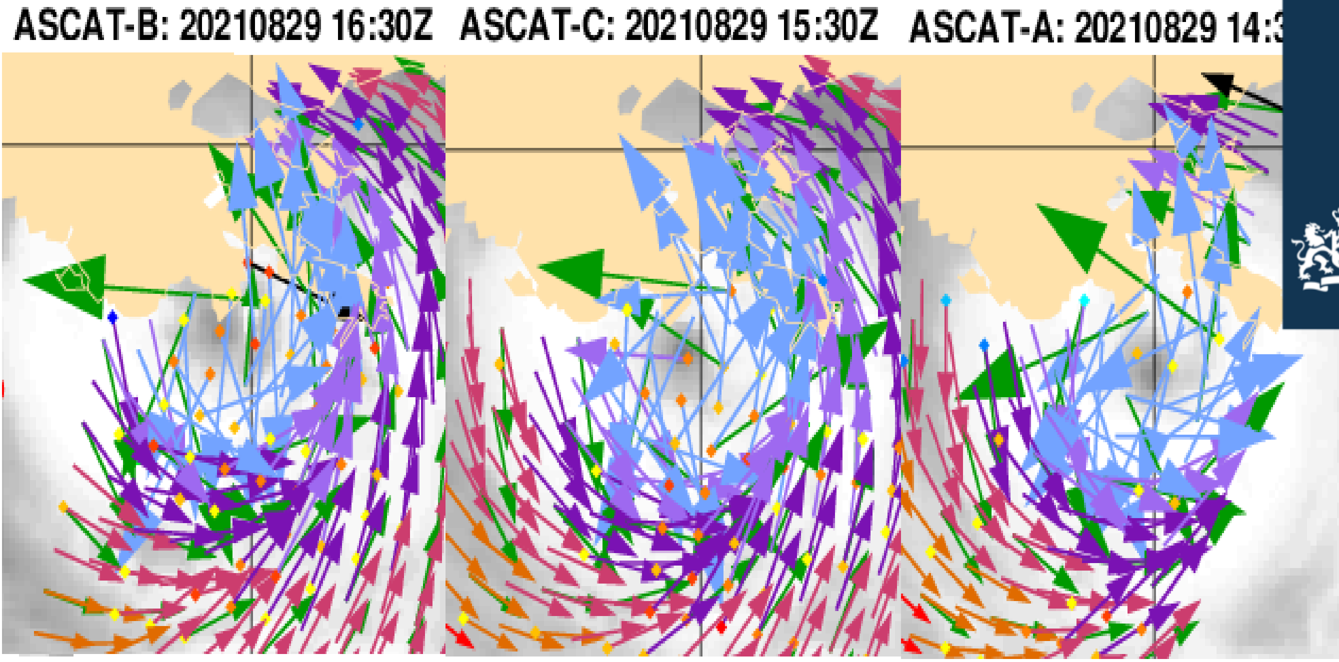
- 24/7 L2 Wind services (EUMETSAT SAF)
  - International constellation of satellites
  - High quality winds, QC
  - Timeliness 30 min. – 2 hours
  - Service messages
  - QA, monitoring
- L2 software services (NWP SAF)
  - Portable Wind Processors
  - ECMWF model comparison
- L2/L3/L4 Climate Data records
- CMEMS Wind services, C3S storm atlas
- Organisations involved: KNMI, EUMETSAT, EU, ESA, NASA, NOAA, ISRO, CMA, WMO, CEOS, ..
- Users: NHC, JTWC, ECMWF, NOAA, NASA, NRL, BoM, UK MetO, M.France, DWD, CMA, JMA, CPTEC, NCAR, . . .

**More information:**

scatterometer.knmi.nl

Wind Scatterometer Support, scat@knmi.nl



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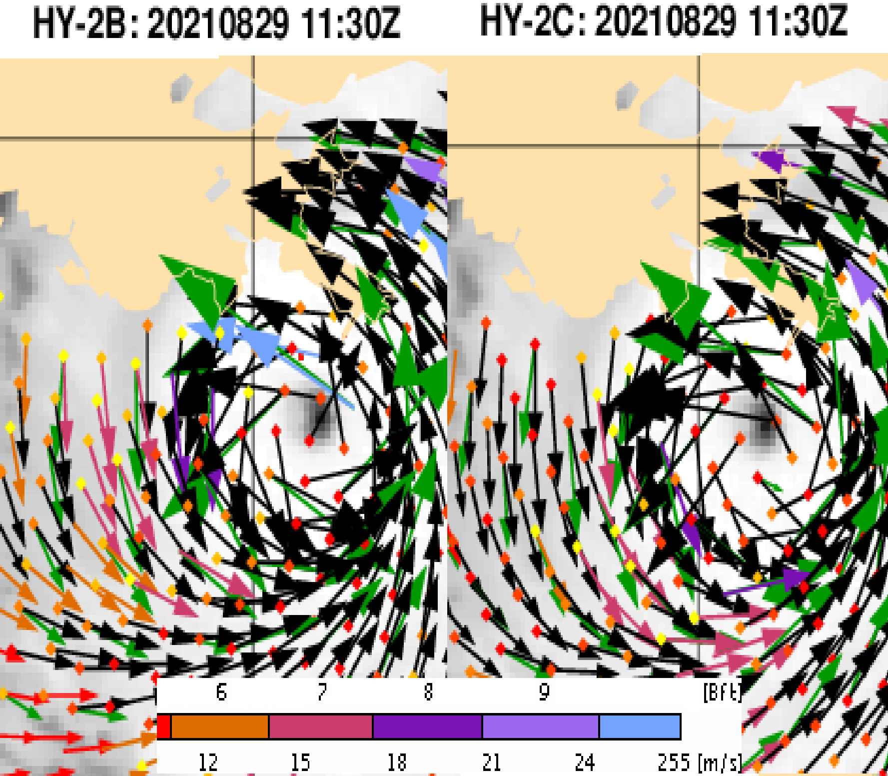
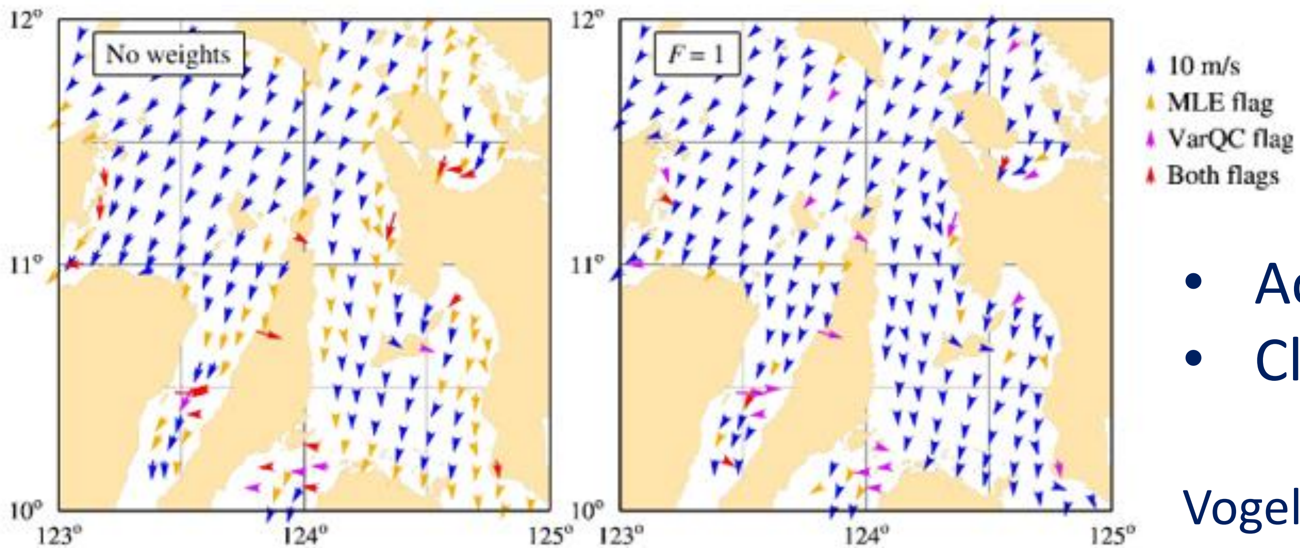
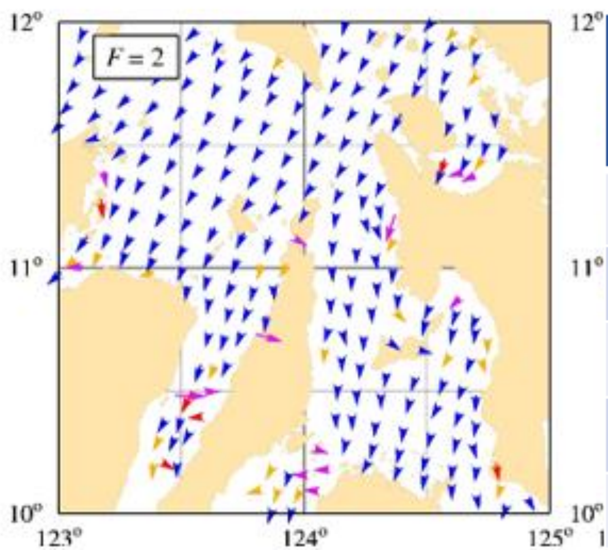



- 5 scatterometers capture landfall of Ida
- Strength consistent with NHC advisories, but . .
- Hurricane in-situ wind speed scale differs from moored buoys, our in-situ speed reference www.eumetsat.int/CHEFS, Polverari et al., '21
- The in-situ reference wind speed scale also determines ocean drag and fluxes, NWP u10
- Scatterometer winds do not need long waves

EUMETSAT OSI SAF, Ida land-fall news story
EU Copernicus Marine Core Services

# Coastal ASCAT and wind quality




- Accurate wind vectors
- Close to the coast

Vogelzang et al, 2021

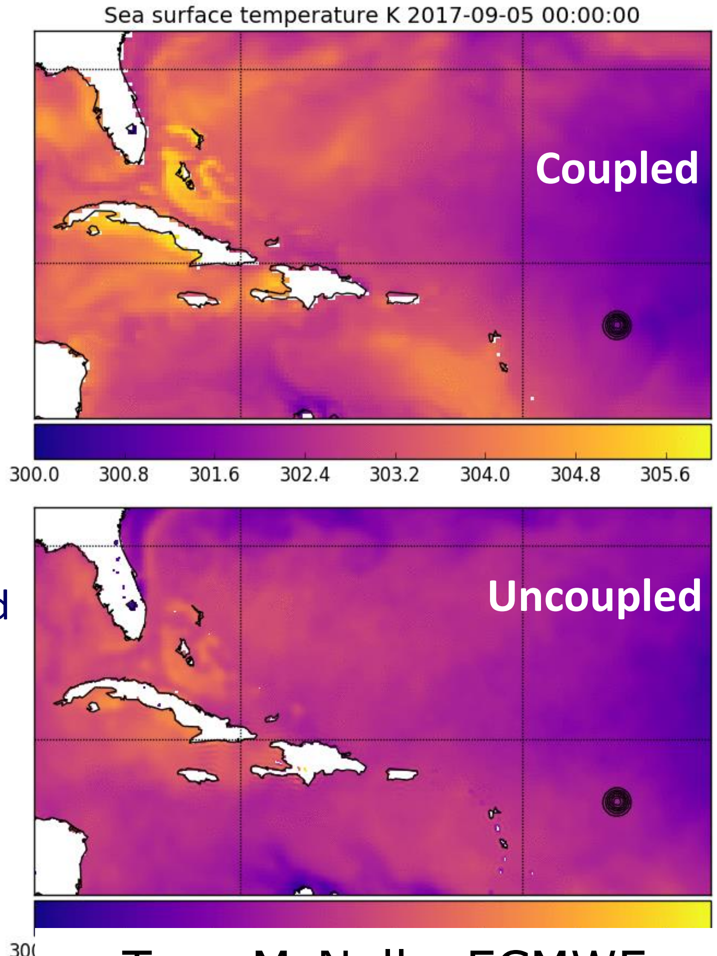
| Subset | Buoys | | ASCAT-A | | ScatSat | | ECMWF | |
|---|---|---|---|---|---|---|---|---|
| | $\sigma_u$ | $\sigma_v$ | $\sigma_u$ | $\sigma_v$ | $\sigma_u$ | $\sigma_v$ | $\sigma_u$ | $\sigma_v$ |
| bAS | 1.03 | 1.12 | 0.41 | 0.49 | 0.78 | 0.65 | -- | -- |
| bAE | 1.06 | 1.15 | 0.34 | 0.41 | -- | -- | 0.94 | 1.03 |
| bSE | 1.09 | 1.21 | -- | -- | 0.72 | 0.59 | 0.92 | 1.03 |
| ASE | -- | -- | 0.43 | 0.49 | 0.76 | 0.65 | 0.90 | 0.98 |
| range | 0.06 | 0.09 | 0.09 | 0.08 | 0.06 | 0.06 | 0.04 | 0.05 |

**Figure 4.1** Part of the Philippines recorded January 1, 2017, with exponential radar cross section weights of various strength.

# Need for accurate extreme winds

- **Nowcasting**, where **dropsondes** are the adopted wind speed reference; if the wind speed reference would change, hurricane categories change too, as everything relies on dropsonde wind speed calibration (SFMR, Dvorak, passive satellite ocean winds, .. )
- **NWP**, to formulate **drag** and air-sea interaction stresses
- **Oceanography**, to determine ocean **mixing depth** in hurricanes (see deep cold water track behind hurricane => )
- **Climate** monitoring, to determine climate **change** at the extremes, i.e., recalibrate past records
- **Climate** prediction, to well describe complex extra-tropical and tropical coupled ocean-atmosphere dynamics ($CO_2$, heat, $H_2O$, … )
- Improved description of hurricane **dynamics**

➢ Satellite ocean surface wind speed calibration for active and passive microwave remote sensing




Tony McNally, ECMWF

# Higher level ocean vector wind services

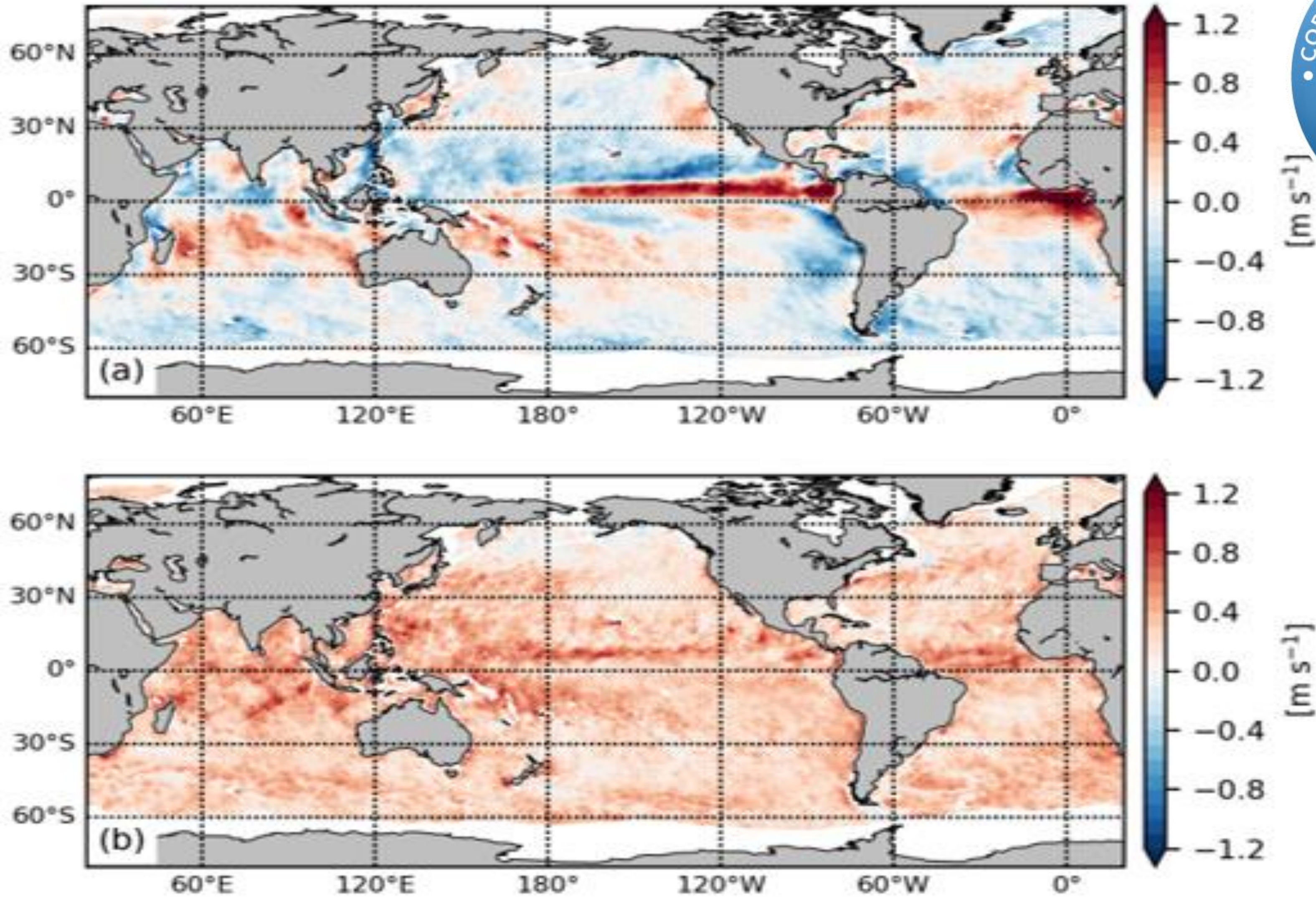
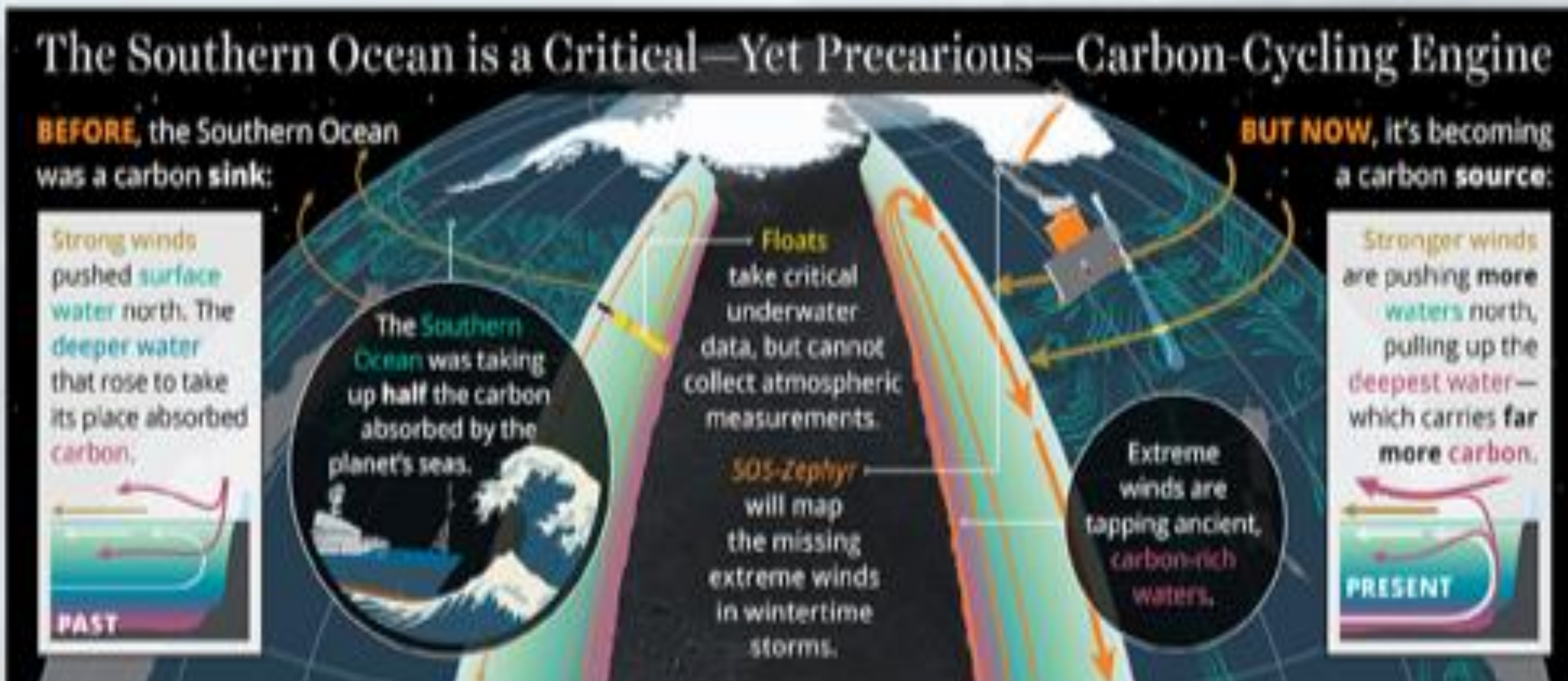



Figure 2: Annual mean meridional (a) wind speed difference and (b) transient wind speed difference between scatterometer (Metop-A ASCAT) and collocated ECMWF ERA5 for 2018.

# SOS ZEPHYR

## Southern Ocean Storms – Zephyr

Measuring Southern Ocean Winds from Space to Close the Carbon Budget



# Earth’s Dynamics from Space

- Winds determine hurricanes, weather, waves and surges, electricity, ocean forcing, heat and carbon budget, sea ice decline, climate change, …
- Are used by marine forecasters, in NWP, by oceanographers, wind engineers, off-shore industry, safety authorities, climate scientists, . . .
- More become available through international exchange (virtual constellation)
- Ongoing technical development of capability
- We can well use new satellites, but certainly more resources for improved exploitation of existing satellites in society
- Open services and computer clouds allow earth collaboration and further scientific progress
- Data science is prominent and advanced statistical physics-informed methods have been developed for instrument monitoring, retrieval and applications

- Share the earth, it’s satellites, it’s science and it’s services!

# Further information . .

Services:

[scatterometer.knmi.nl](scatterometer.knmi.nl)
[osi-saf.eumetsat.int](osi-saf.eumetsat.int)
[marine.copernicus.eu](marine.copernicus.eu)

ESA Aeolus DISC

Google Scholar

## Ad Stoffelen

FOLLOW

Active Instruments group leader, Satellite Division, KNMI
Verified email at knmi.nl - Homepage

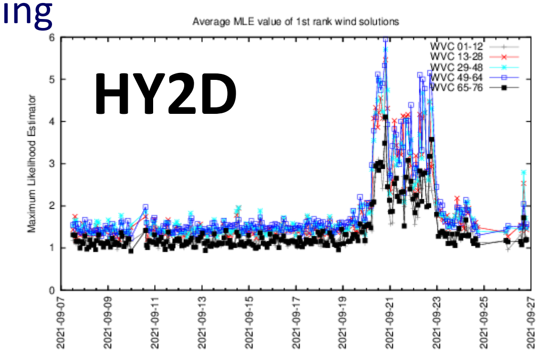
Wind satellite NWP data assimilation

| TITLE | CITED BY | YEAR |
|---|---|---|
| Evaluation of Aeolus L2B wind product with wind profiling radar measurements and numerical weather prediction model equivalents over Australia<br>H Zuo, CB Hasager, I Karagali, A Stoffelen, GJ Marseille, J de Kloe<br>Atmospheric Measurement Techniques Discussions, 1-27 | | 2022 |
| Wind field and gust climatology of the Persian Gulf during 1988–2010 using in-situ, reanalysis and satellite sea surface winds<br>E Owlad, A Stoffelen, P Ghafarian, S Gholami<br>Regional Studies in Marine Science, 102255 | | 2022 |
| Intercomparison of wind observations from ESA's satellite mission Aeolus, ERA5 reanalysis and radiosonde over China<br>B Liu, J Guo, W Gong, Y Zhang, L Shi, Y Ma, J Li, X Guo, A Stoffelen, ...<br>Atmospheric Measurement Techniques Discussions, 1-32 | | 2022 |
| Correlating Extremes in Wind Divergence with Extremes in Rain over the Tropical Atlantic<br>GP King, M Portabella, W Lin, A Stoffelen<br>Remote Sensing 14 (5), 1147 | | 2022 |
| Support vector machine tropical wind speed retrieval in the presence of rain for Ku-band wind scatterometry<br>X Xu, A Stoffelen<br>Atmospheric Measurement Techniques 14 (12), 7435-7451 | 1 | 2021 |
| Investigation of near-global daytime boundary layer height using high-resolution radiosondes: first results and comparison with ERA5, MERRA-2, JRA-55, and NCEP-2 reanalyses<br>J Guo, J Zhang, K Yang, H Liao, S Zhang, K Huang, Y Lv, J Shao, T Yu, ...<br>Atmospheric Chemistry and Physics 21 (22), 17079-17097 | 9 | 2021 |
| CWDP L2A processor Specification and User Manual<br>CWD Processor, Z Li, A Verhoef, A Stoffelen | | 2021 |
| CWDP Test Plan and Test Report<br>CWD Processor, Z Li, A Verhoef, A Stoffelen | | 2021 |
| Numerical Weather Prediction Ocean Calibration for the Chinese-French Oceanography | 1 | 2021 |

# Today’s status of KNMI wind processing

| | | |
|---|---|---|
| • ASCAT-A, MetOp-A : | 2007- 2021 | 9:30 LST, End-of-service announced |
| • ASCAT-B, MetOp-B : | 2012- healthy | 9:30 LST |
| • ASCAT-C, MetOp-C : | 2018- healthy | 9:30 LST, Excellent for wind changes in convection |
| • OSCAT-2, ScatSat-1 : | 2017- Feb 2021 | 8:45 LST, Excellent for Ku/C intercalibration |
| • OSCAT-3, OceanSat3 : | Q1 2022 | 12:00 LST |
| • HSCAT-B, HY2B : | 2018- healthy | 6:00 LST |
| • HSCAT-C, HY2C : | 2020- healthy | Not sun-synchronous, regresses |
| • HSCAT-D, HY2D : | 2021- healthy | Regresses, commissioning |
| • CSCAT, CFOSAT : | 2019- demo | Stability issues, nadir issues |
| • WindRad, FY3E : | 5/7/’21- healthy | 5:30 LST, commissioning |

➢ https://scatterometer.knmi.nl/proc_status/




- Vector wind CDRs for ERS (1991-1999), QuikScat (1999-2009), ASCAT (2007-), OSCAT (2014+), needed to monitor re-analyses
- Reanalyses are subject to changing inputs

➢ https://scatterometer.knmi.nl/archived_prod/

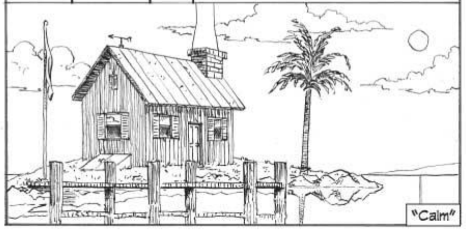
https://scatterometer.knmi.nl/hy2d_25_prod/index.php?cmd=monitoring&period=week&day=0&flag=yes

# The Beaufort Scale

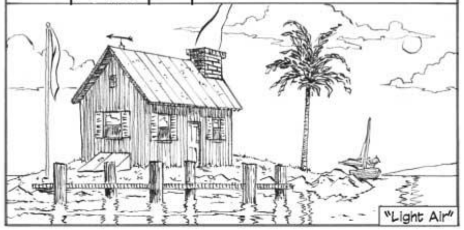
"Over thousands of years sailors have learnt to estimate the speed of the wind just by looking about. This technique matured into what we now call the Beaufort scale. The universe tells you everything you need to know about it as long as you are prepared to watch, to listen, to smell, in short to observe"

.....Howtoons 2006

| FORCE | SPEED | | |
|---|---|---|---|
| 0 | 0 Knots<br>0 mph<br>0 km/h | SEA | Sea like a mirror |
| | | LAND | Smoke rises vertically |

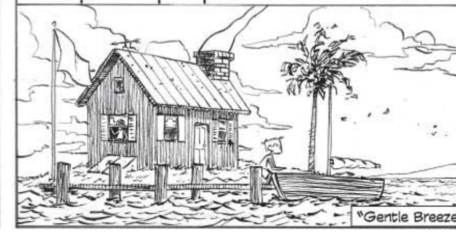



| FORCE | SPEED | | |
|---|---|---|---|
| 1 | 1-3 Knots<br>1-3 mph<br>1-6 km/h | SEA | Ripples with the appearance of scales are formed, but without foam crests |
| | | LAND | Direction of wind shown by smoke but not by wind vanes |




| FORCE | SPEED | | |
|---|---|---|---|
| 2 | 4-6 Knots<br>4-7 mph<br>7-11 km/h | SEA | Small wavelets. Crests have a glassy appearance and do not break |
| | | LAND | Wind felt on face; leaves rustle; ordinary vane moved by wind |

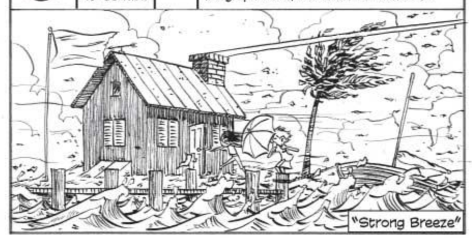

| FORCE | SPEED | | |
|---|---|---|---|
| 3 | 7-10 Knots<br>8-12 mph<br>12-19 km/h | SEA | Large wavelets. Crests begin to break. Foam of glassy appearance. |
| | | LAND | Leaves and small twigs in constant motion; wind extends light flag |




| FORCE | SPEED | | |
|---|---|---|---|
| 4 | 11-16 Knots<br>13-18 mph<br>20-29 km/h | SEA | Small waves, becoming longer, fairly frequent white horses |
| | | LAND | Raises dust and loose paper; small branches are moved |


| FORCE | SPEED | | |
|---|---|---|---|
| 5 | 17-21 Knots<br>19-24 mph<br>30-39 km/h | SEA | Moderate waves, taking a more pronounced long form; many white horses are formed. |
| | | LAND | Small trees in leaf begin to sway; wavelets form on inland waters |


| FORCE | SPEED | | |
|---|---|---|---|
| 6 | 22-27 Knots<br>25-31 mph<br>40-50 km/h | SEA | Large waves begin to form; the white foam crests are more extensive everywhere. |
| | | LAND | Large branches in motion; whistling heard in telegraph wires; umbrellas use difficult. |




| FORCE | SPEED | | |
|---|---|---|---|
| 7 | 28-33 Knots<br>32-38 mph<br>51-62 km/h | SEA | Sea heaps up and white foam from breaking waves starts to blow in streaks with wind. |
| | | LAND | Whole trees in motion; umbrellas discarded; inconvenience felt when walking |


| FORCE | SPEED | | |
|---|---|---|---|
| 8 | 34-40 Knots<br>39-46 mph<br>63-75 km/h | SEA | Moderate high waves of greater length; edges of crests begin to break into spindrift. |
| | | LAND | Breaks twigs off trees; generally impedes progress |


| FORCE | SPEED | | |
|---|---|---|---|
| 9 | 41-47 Knots<br>47-54 mph<br>76-87 km/h | SEA | High waves. Crests of waves begin to tumble and roll over. Spray may affect visibility |
| | | LAND | Slight structural damage occurs, chimney pots and slates removed |


| FORCE | SPEED | | |
|---|---|---|---|
| 10 | 48-55 Knots<br>55-63 mph<br>88-102 km/h | SEA | Very high waves. Surface of the sea takes on a white appearance. Visibility affected |
| | | LAND | Seldom experienced inland; trees uprooted; considerable structural damage occurs |

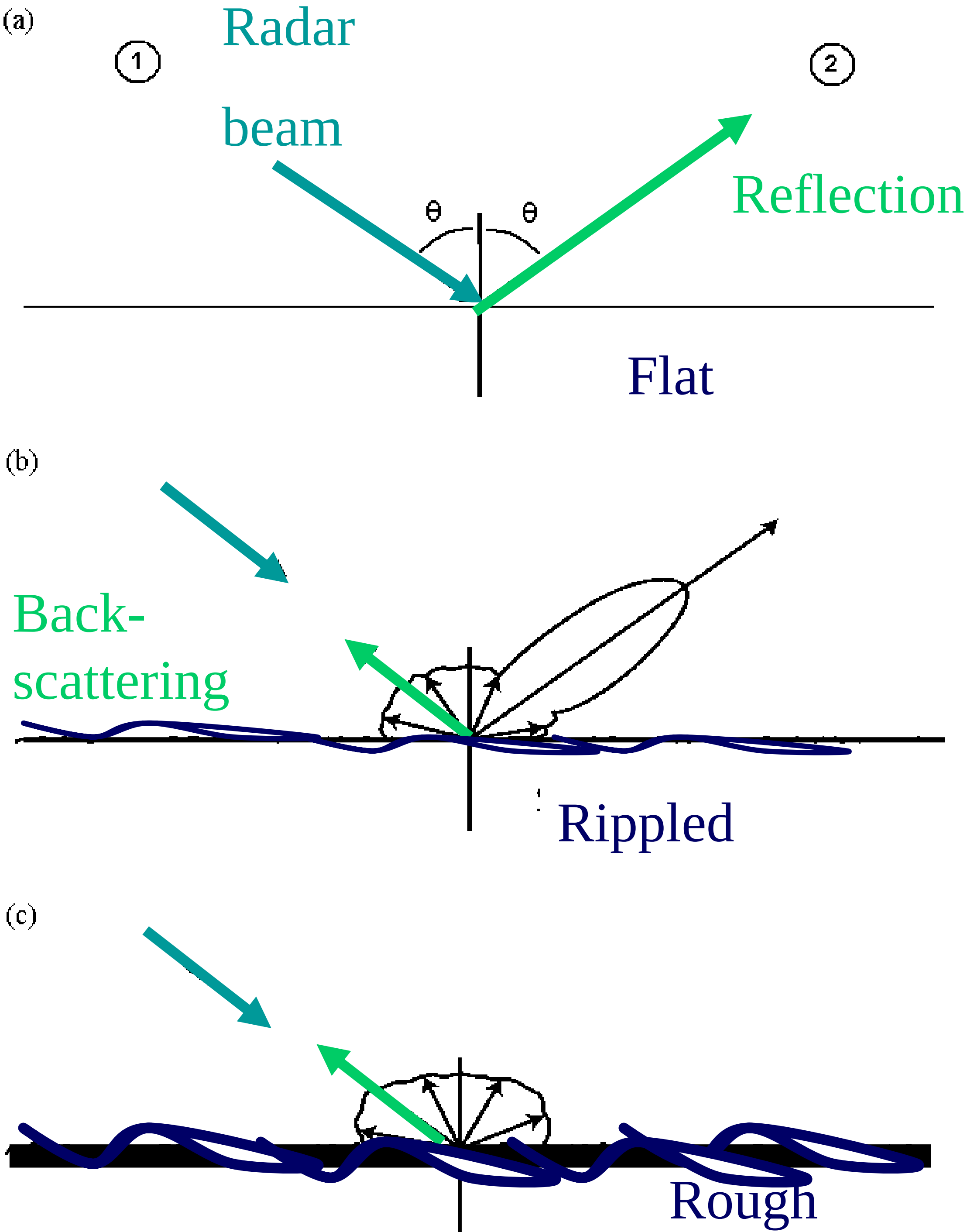

| FORCE | SPEED | | |
|---|---|---|---|
| 11 | 56-63 Knots<br>64-72 mph<br>103-1117 km/h | SEA | Exceptionally high waves. The sea is covered with long white patches of foam. |
| | | LAND | Very rarely experienced on land; accompanied by widespread damage. |


| FORCE | SPEED | | |
|---|---|---|---|
| 12 | over 63 Knots<br>over 72 mph<br>over 117 km/h | SEA | Huge waves; air is filled with foam and spray. Sea white with driving spray; visibility very seriously affected |
| | | LAND | Countryside is devastated |


www.howtoons.com/ toon/the-beaufort-scale/

# Scatterometer research partners abroad

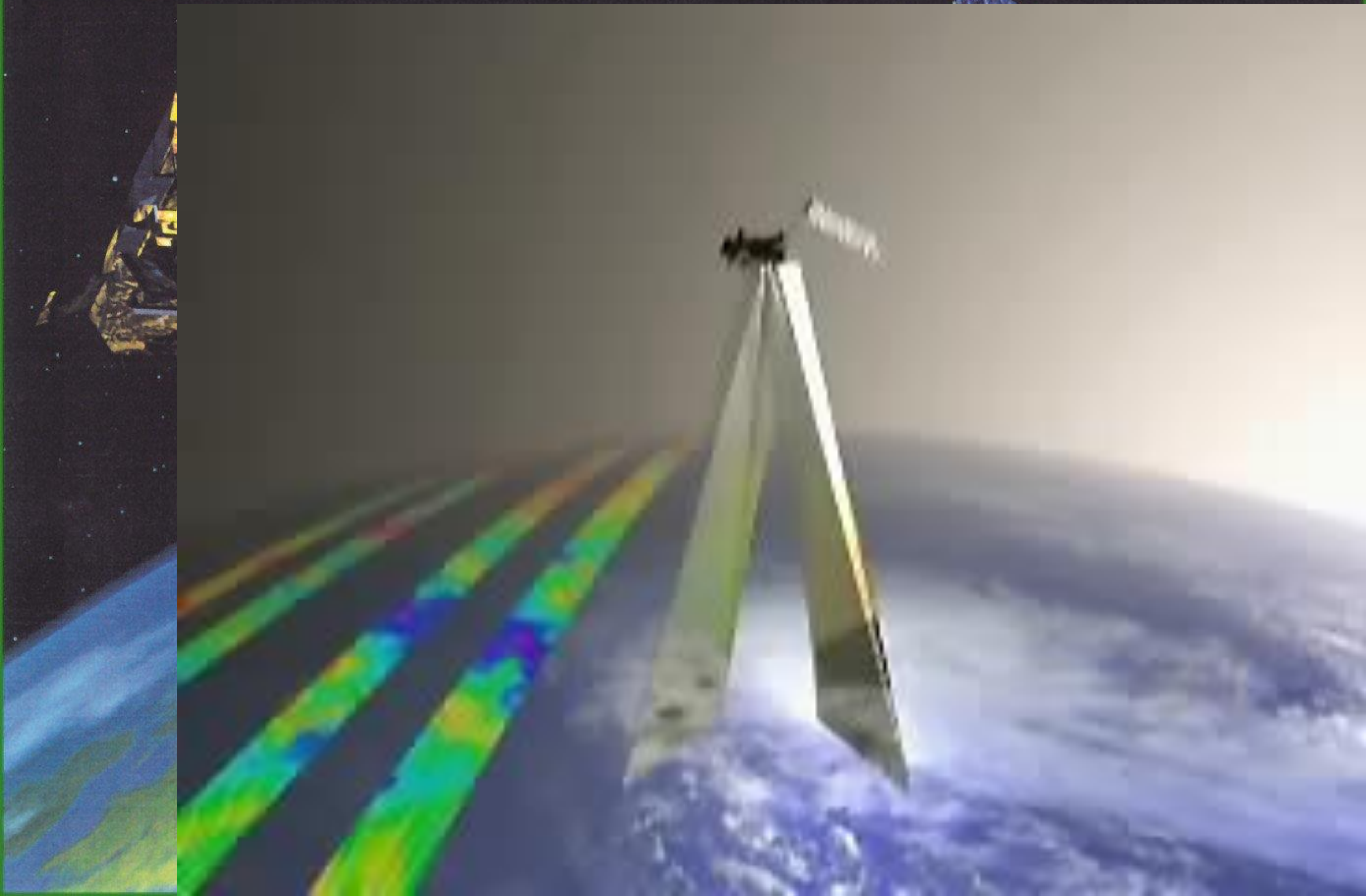
- Marcos Portabella, Ku-band scatterometry, 8 years at KNMI
- Wenming Lin, 7 years at ICM, wind variability/rain; now at NUIST on CFOSAT
- Ana Trindade, ERA*, ICM
- Giuseppe Grieco, 3 years at KNMI, 1 year at ICM, now CNR
- Federico Cossu, EUMETSAT wind fellow at ICM
- Zhixiong Wang, Ku GMF with SST correction, product comparison Ku/C, now prepares data for **ECMWF** data assimilation experiments and WindRad, NUIST
- Xingou Xu at NSSC, Machine Learning, Beijing
- NOAA hurricane hunters, USA
- IFREMER MAXSS, GlobCurrent, SAR winds
- Sean Healy, data assimilation, ECMWF
- Scatterometer Cal/Val: EUMETSAT, NASA, ESA, ISRO, NSOAS, CMA, CNES
- . .




# Scatterometer?

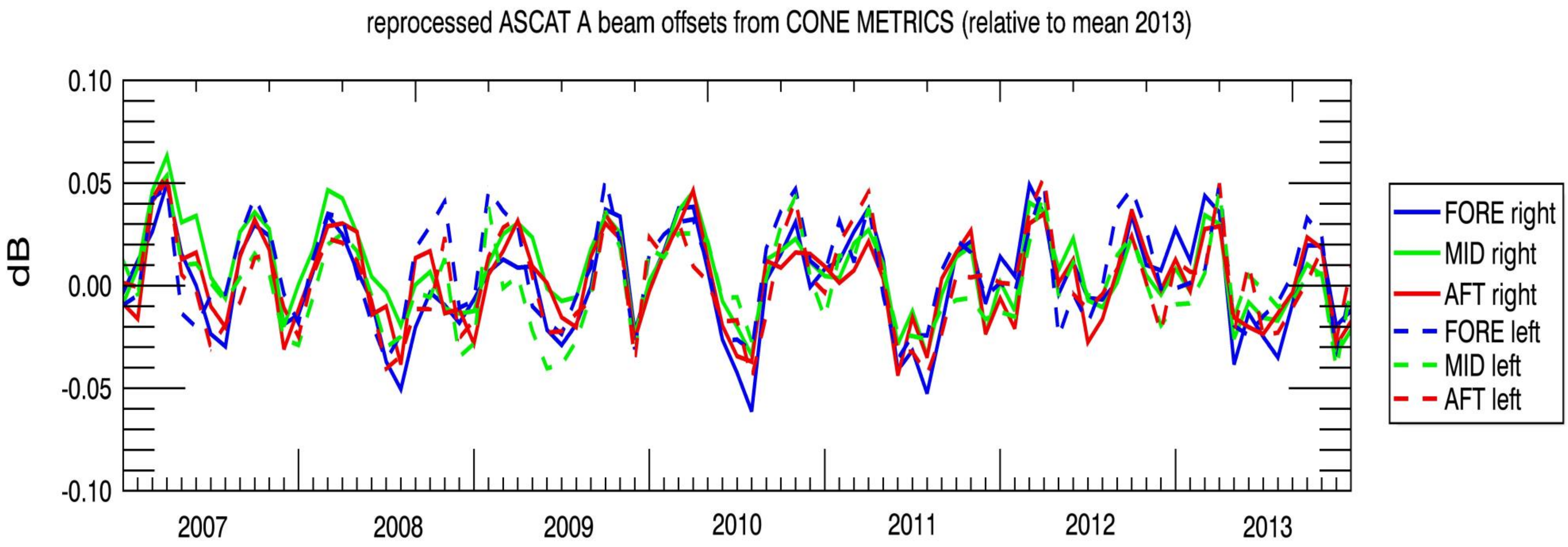
- Interference with cm-waves (Bragg)
- The more wind, the more µgolf scattering
- Also depending on wind direction

# ASCAT scatterometer

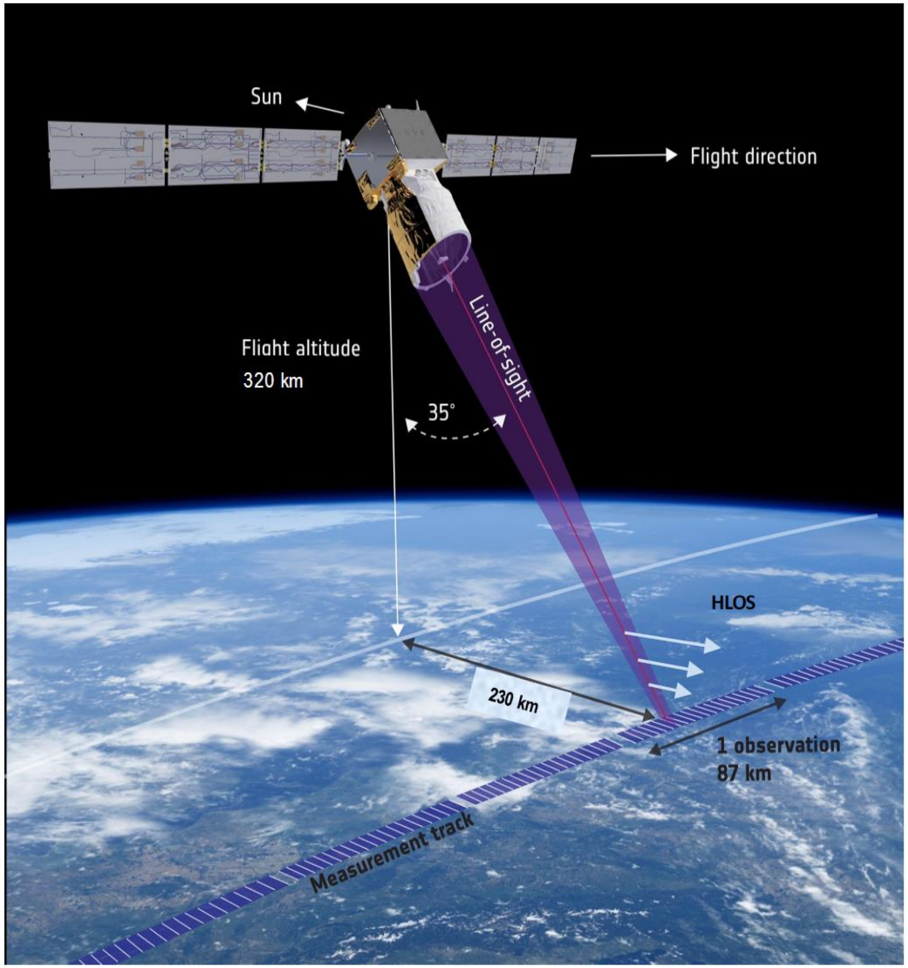


# Scatterometers are very stable

- ASCAT-A beams stay within a few hundreds of a dB (eq. to m/s)
- Cone position variation due to seasonal wind variability
- Reference for climate research (to check reanalyses)



# ADM-Aeolus Measurement Principle (1/2)

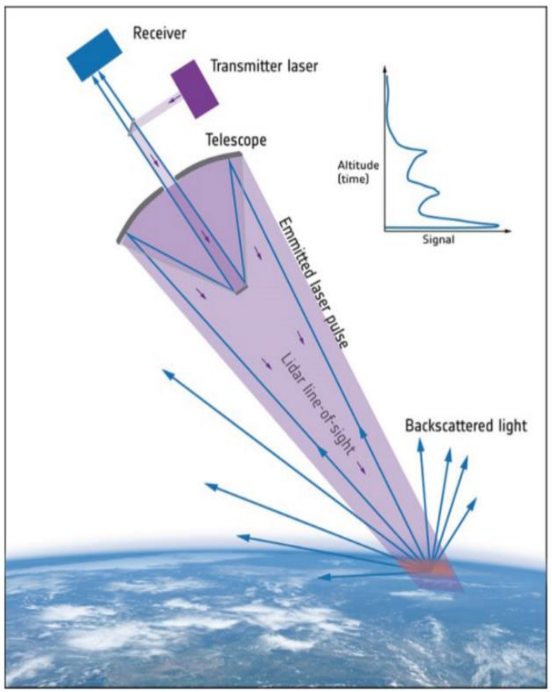


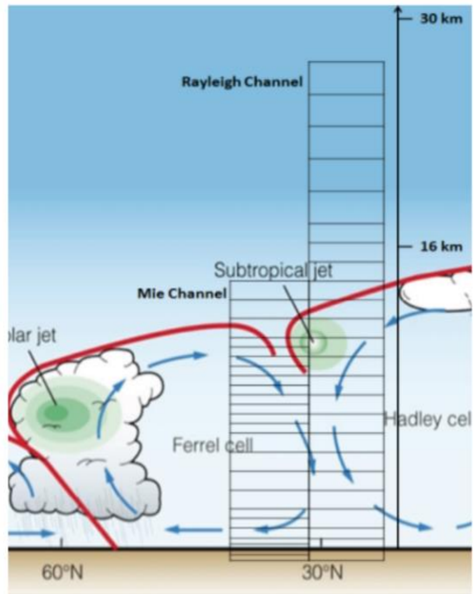

- UV Doppler wind Lidar operating at 355 nm and 50 Hz PRF in continuous mode, with 2 receiver channels (HSRL):
  - Mie receiver (aerosol & cloud backscatter)
  - Rayleigh receiver (molecular backscatter)
- The line-of-sight is pointing 35° from nadir to derive horizontal wind component
- The line-of-sight is pointing orthogonal to the ground track velocity vector to avoid contribution from the satellite velocity
- Spacecraft regularly pointed to nadir for calibration

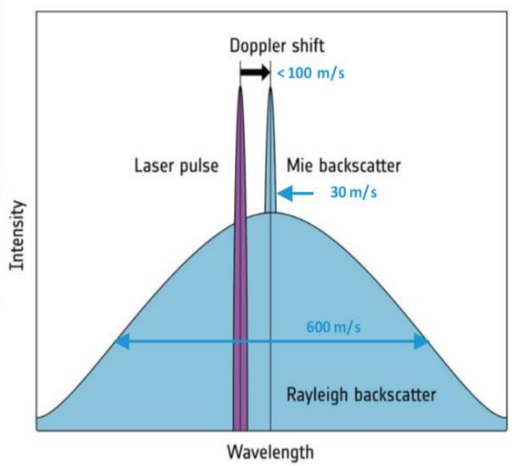
# Measurement Principle (2/2)

Doppler -Equation:

$$\Delta f = 2 f_0 \frac{\mathbf{v}_{LOS}}{c}$$

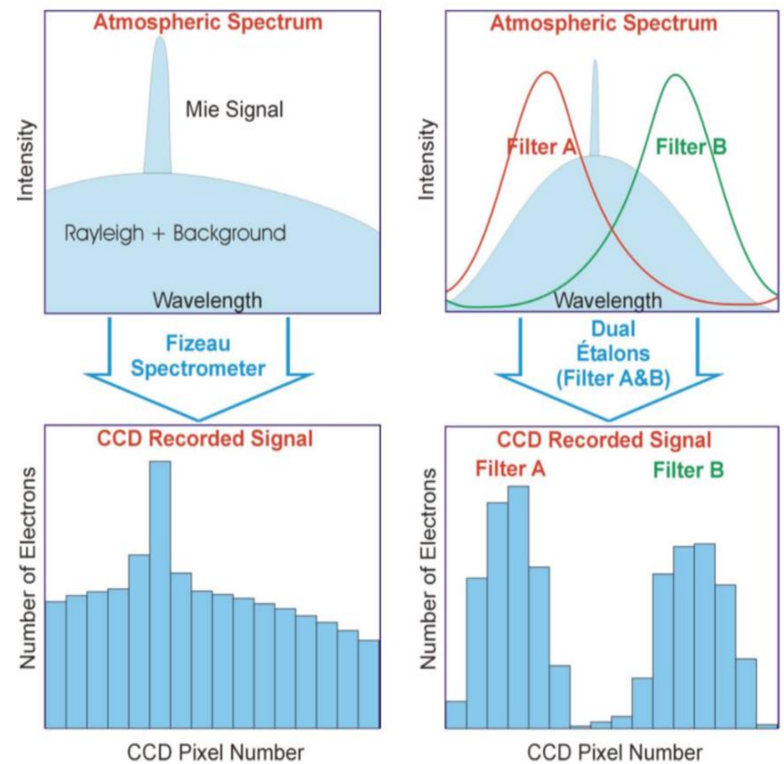


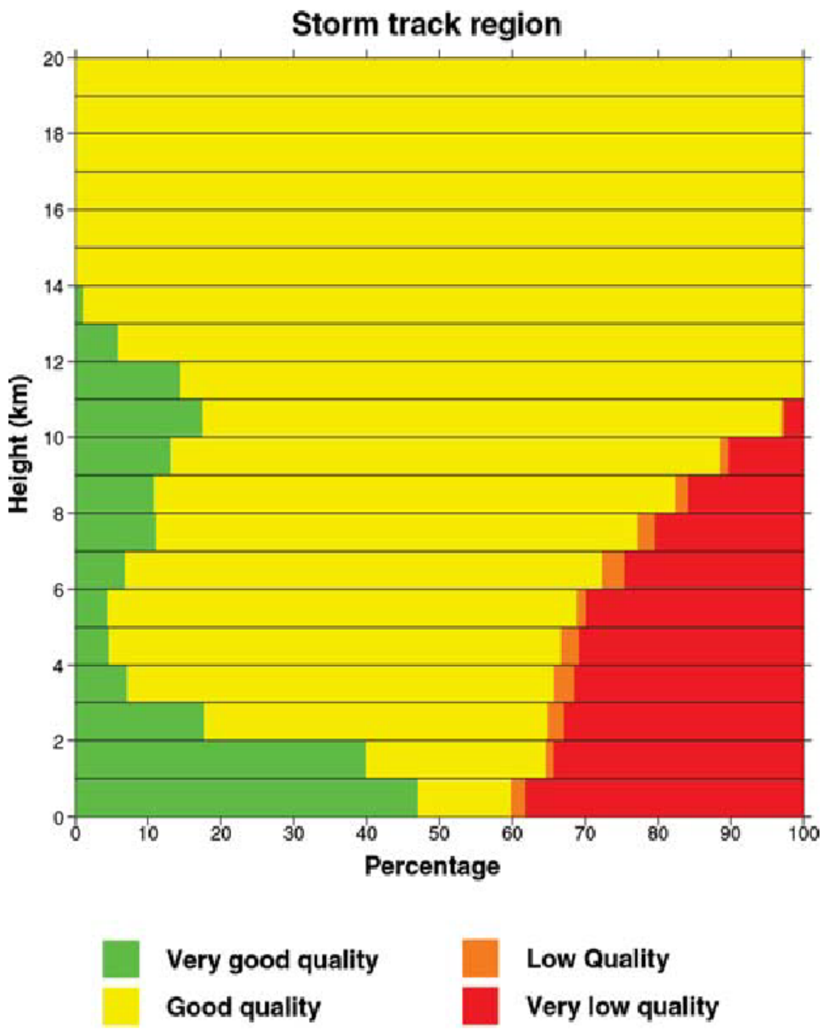




**Mie channel:**
- Aerosol/cloud backscatter
- Imaging technique

**Rayleigh channel:**
- Molecular backscatter
- Double-edge technique



# Aeolus: What did we expect in 1999?




- Molecules most of the time (largely yellow)
- Particles part of the time (largely green)
- Not much in cloudy regions (red)
- Radiosonde quality winds, height resolved
- Improved NWP, 3D turbulence, circulation
- Tropics, UTLS
- Reference for improving satellite winds

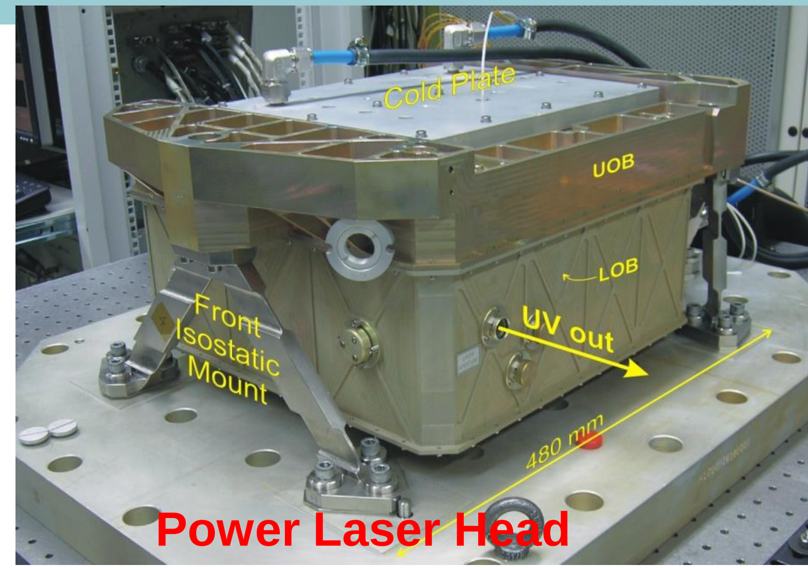
- Why would this 2000 vision still work 20 years later, after a "silent revolution" in NWP?

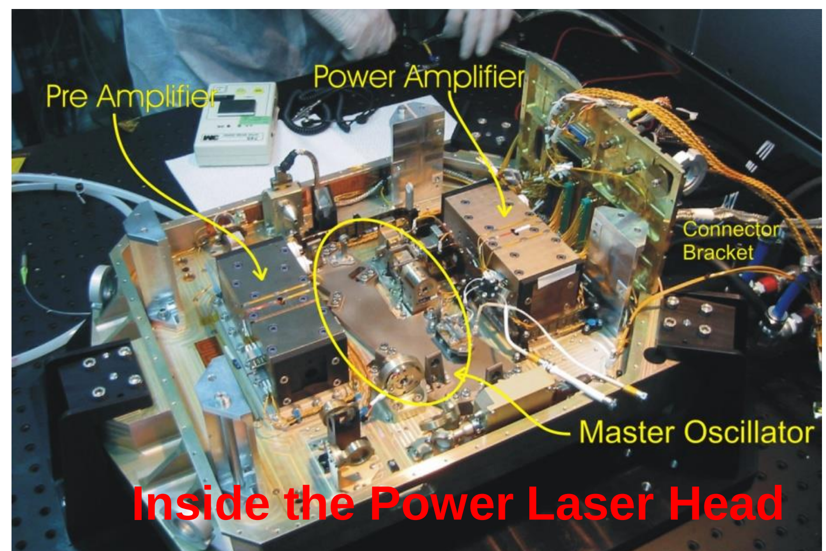



Stoffelen and Marseille, 1998

# ADM-Aeolus was ready in 2017

- Aeolus: the first Doppler wind lidar in space, no heritage in design and testing
- Most of the novel technological developments completed and qualified for flight
- Most demanding is the high energy transmitter laser:
  – 120 mJ pulses (80 mJ initially) with
  - 50 Hz pulse repetition rate,
  - single frequency at
  - 355 nm wavelength,
  designed for long lifetime (3 years)
- This is pushing laser technology in many areas, like
  - optical coatings,
  - harmonic crystals,
  - pump laser diodes…
- And, e.g., satellite gyroscopes . . .



# Launch event Kourou



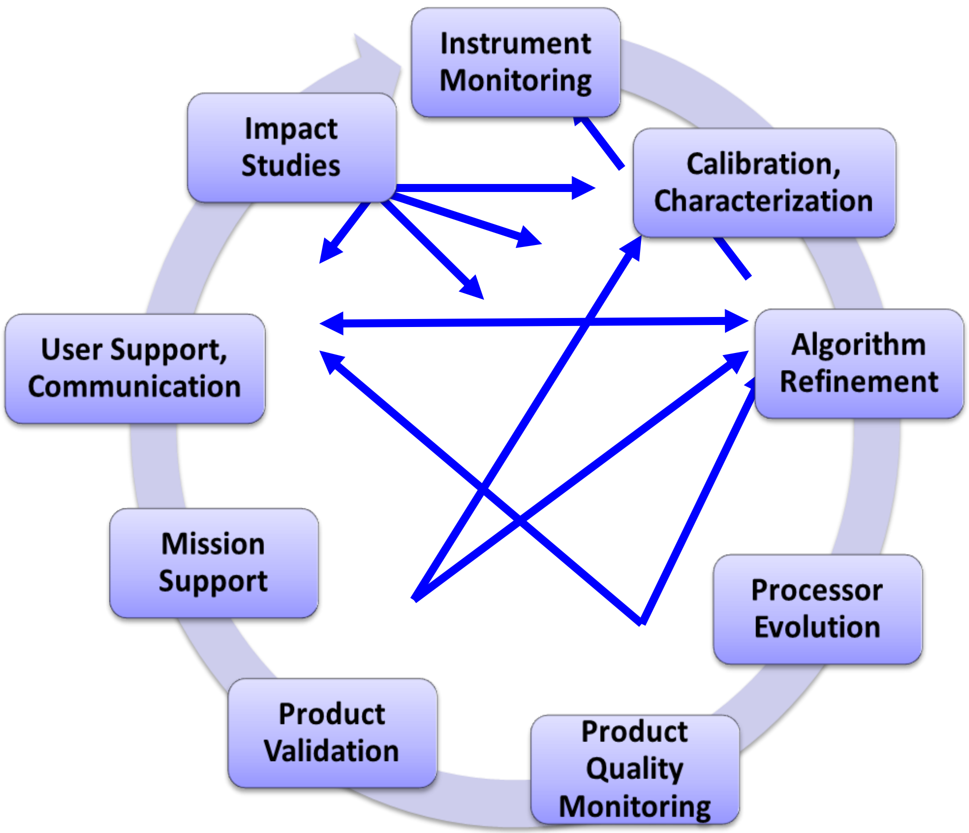

## To be considered by CGMS:

- **Recommendation 1: For consideration by CGMS Plenary the IWWG recommends space agencies to address the gap of global 3D wind profile observations with high priority. Based on the Aeolus experience, a combination of lidar & IR missions can provide complimentary wind observations which look to be very promising.**

- Aeolus shows significant positive impact on global NWP models as shown by ECMWF, Météo-France, Met Office, DWD, NOAA, JMA, NCMRWF and ECCC and is better than expected prior to launch.
- Operational assimilation at ECMWF, Météo-France, DWD and the Met Office.
- Strength within the entire assimilation scheme.
- Valuable as an AMV intercomparison dataset.

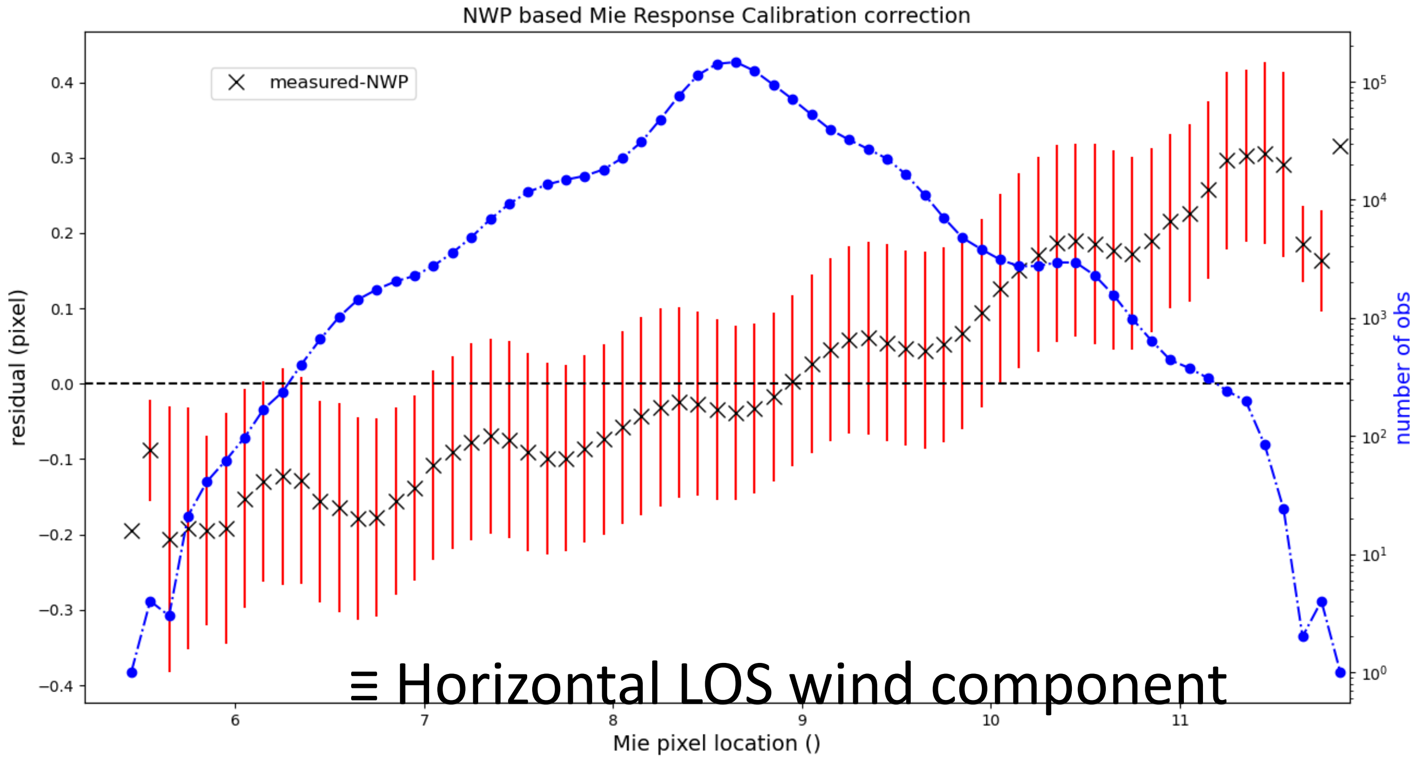
# ESA Aeolus DISC team

**D**ata **I**nnovation and **S**cience **C**luster




DLR
DoRIT
ECMWF
Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Verkeer en Waterstaat
METEO FRANCE
Toujours un temps d'avance
ABB
serco
s[&]t
esa
Physics Solutions
OLA
IB Reissig

# Spectral non-linear correction from NWP calibration



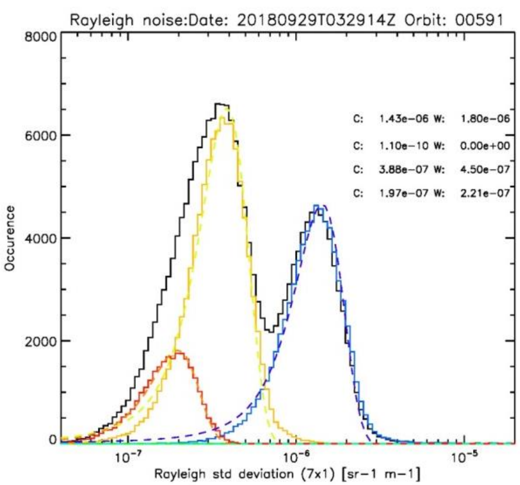

- Oscillation with ~constant periodicity on top of ~linear slope
- Slope is ~double the slope currently used (compare to slide 3)

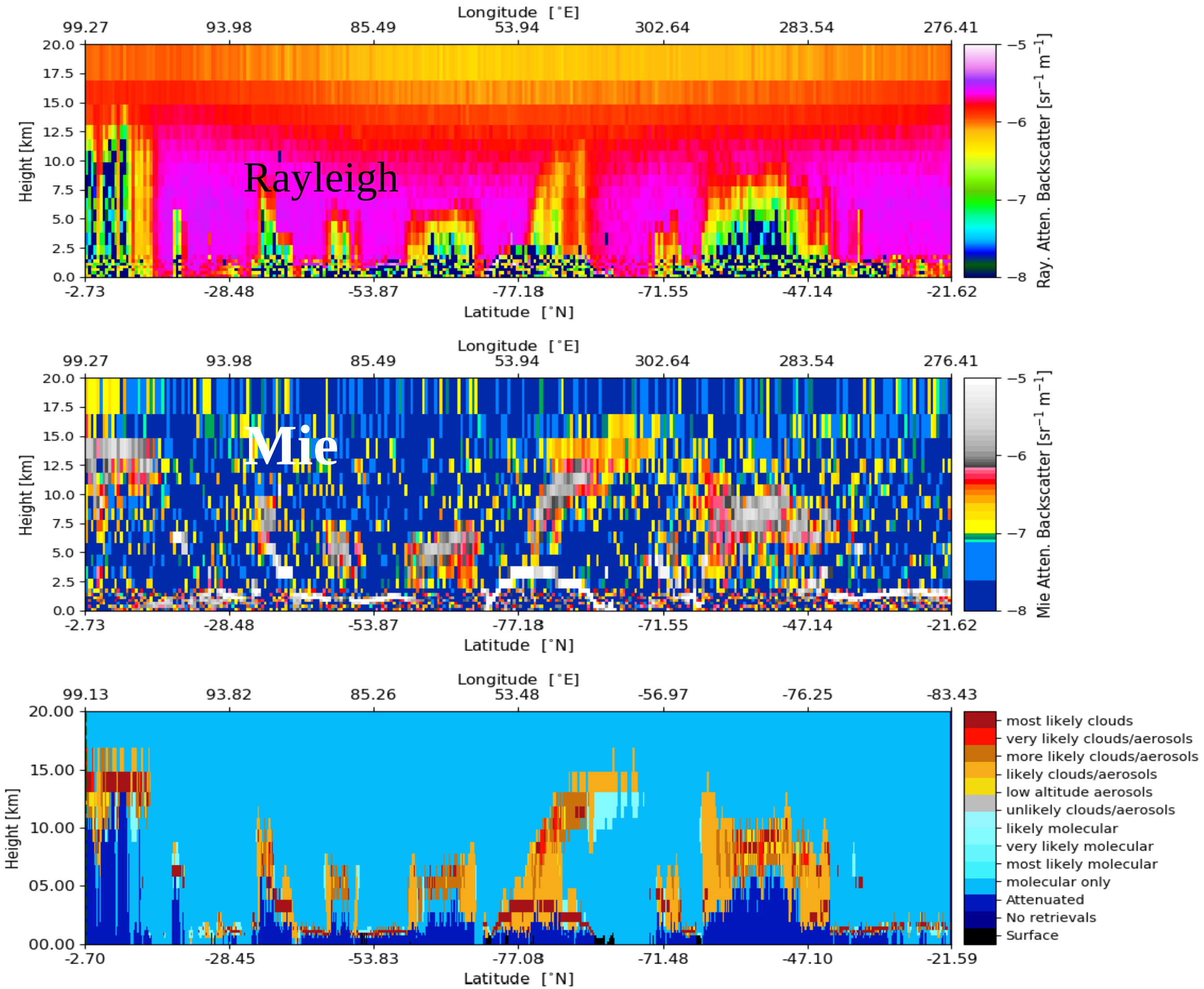


Marseille et al., 2022

# Cloud and aerosol mask

- Noise analysis
- S/N PDFs
- S coherent, N random
- EarthCare ATLID tools
- First Aeolus test

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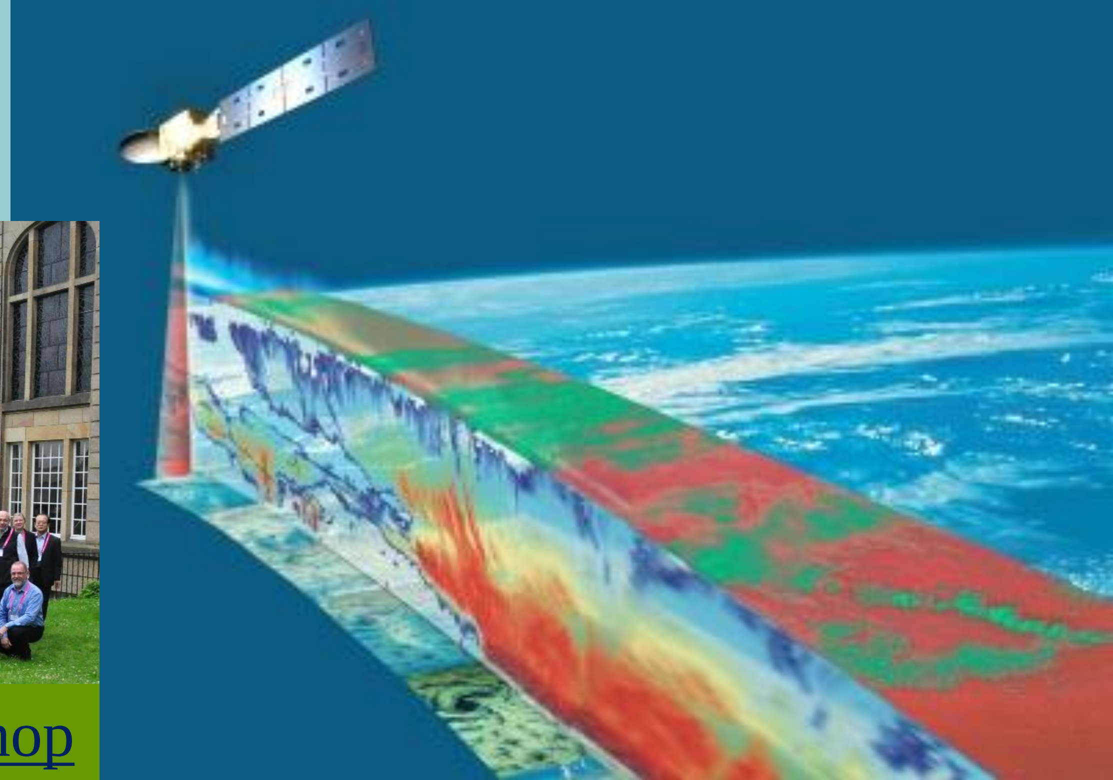
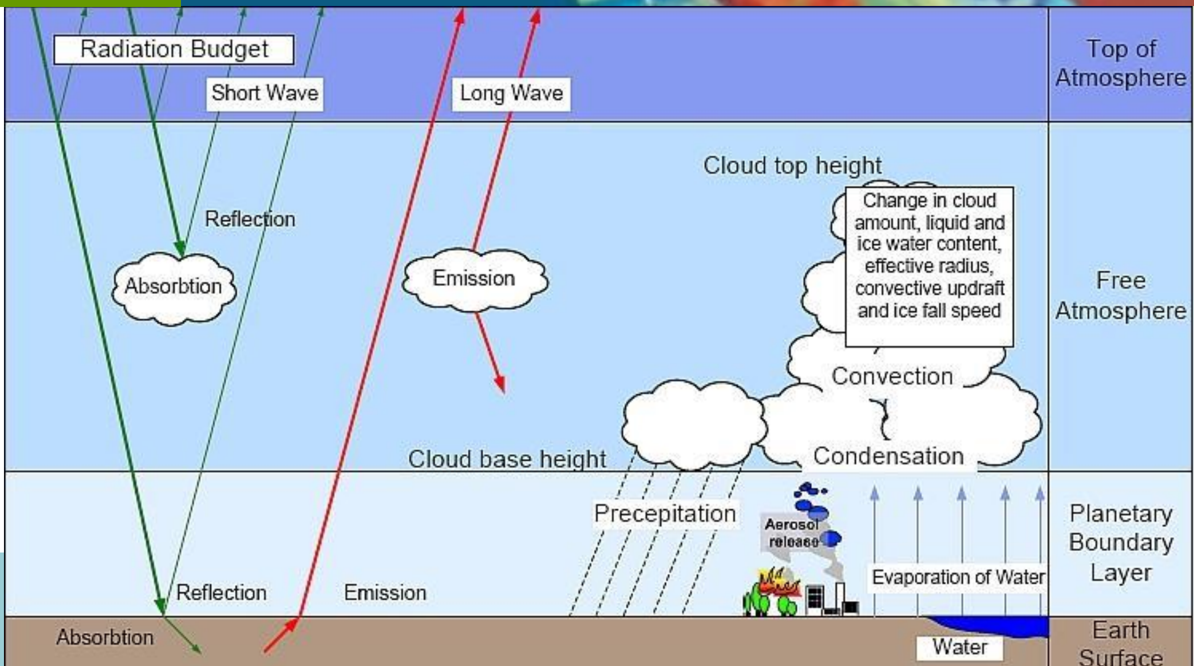
# EarthCare

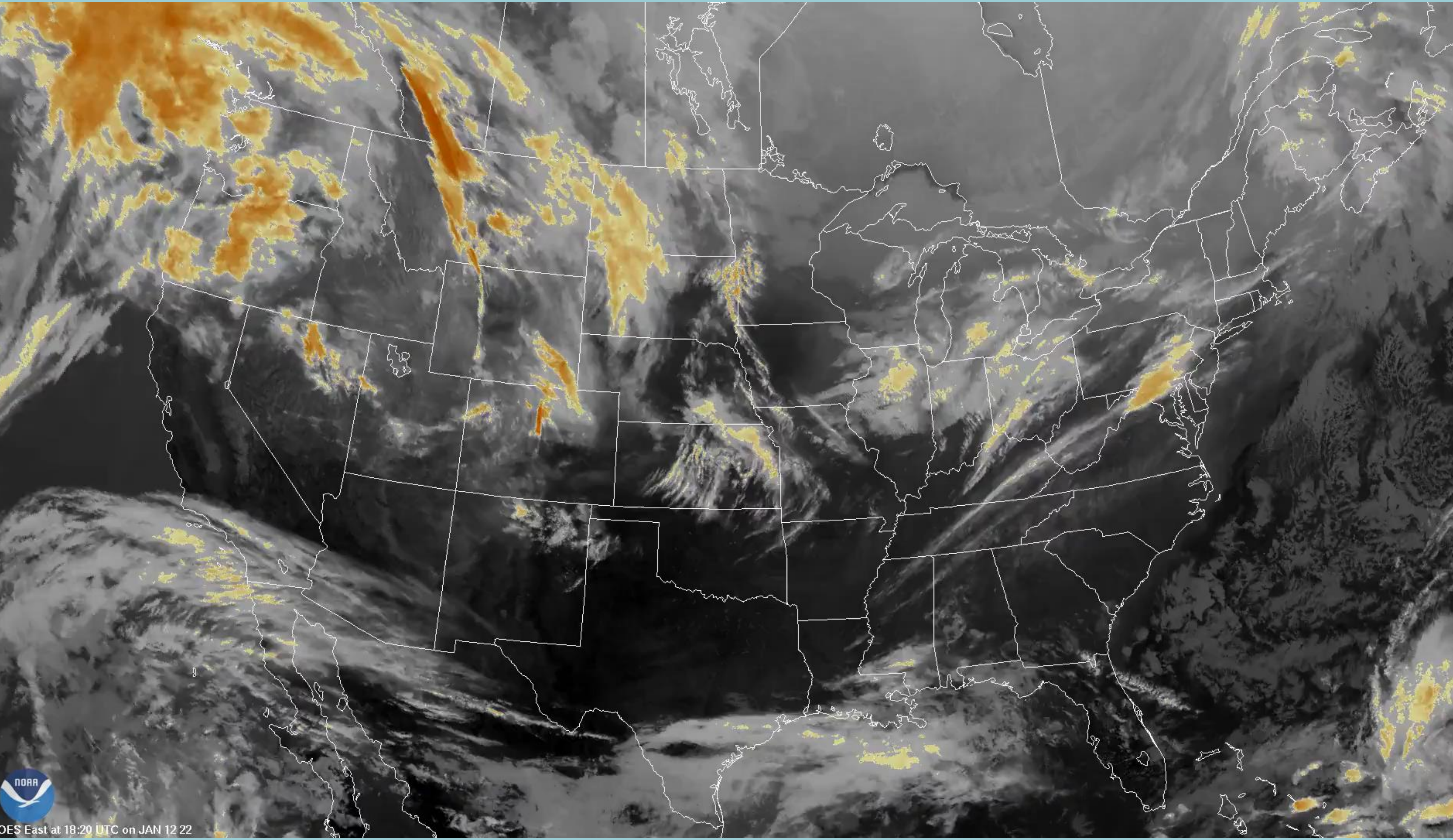


1st EarthCare validation workshop

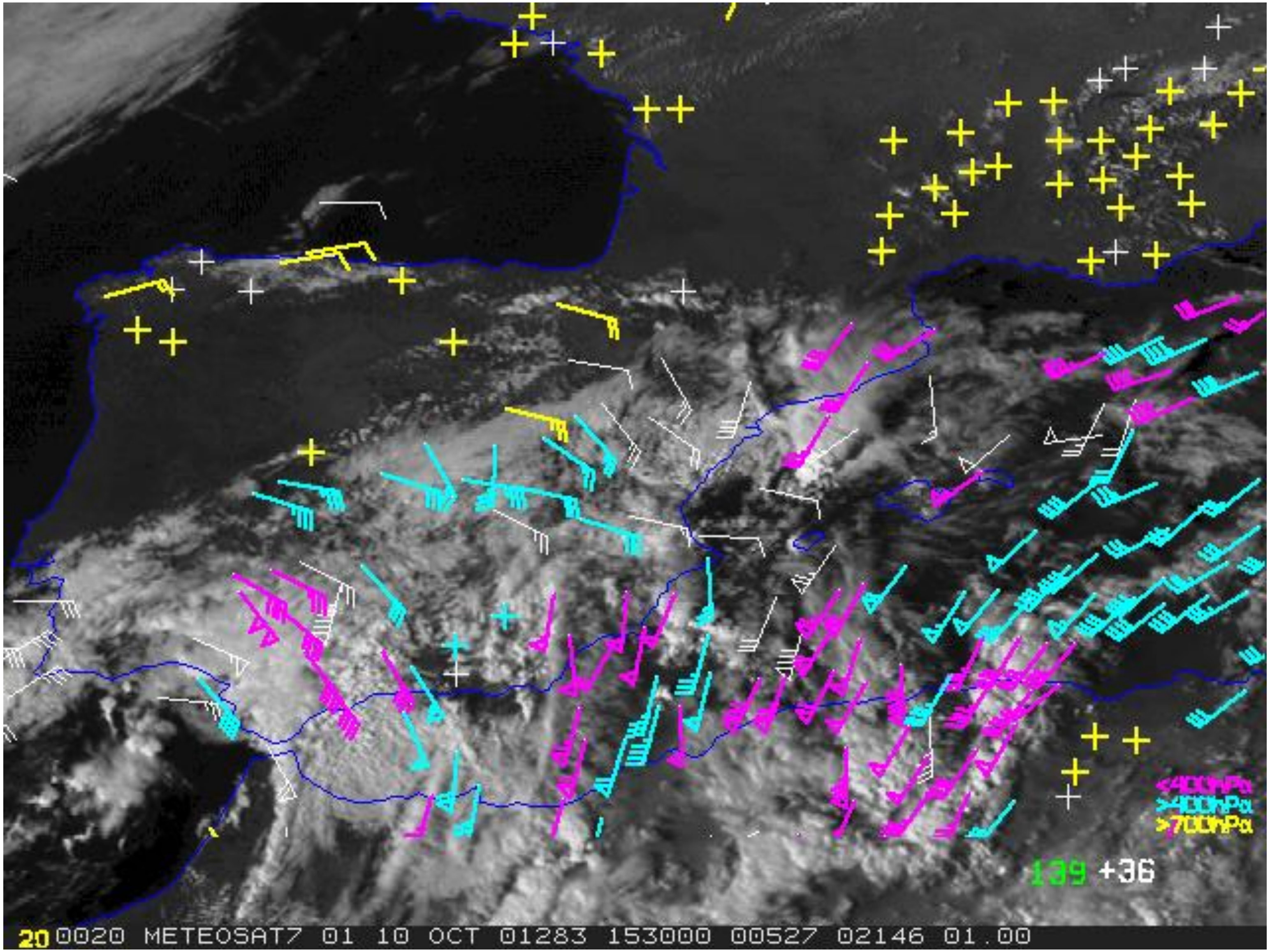
- Lead lidar/radar retrieval
- Cardinal



# Satellite earth views

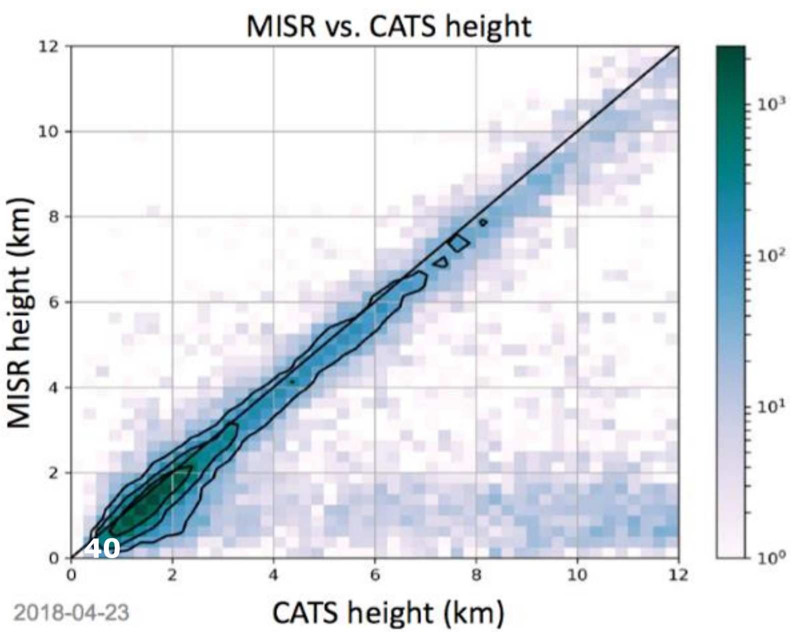


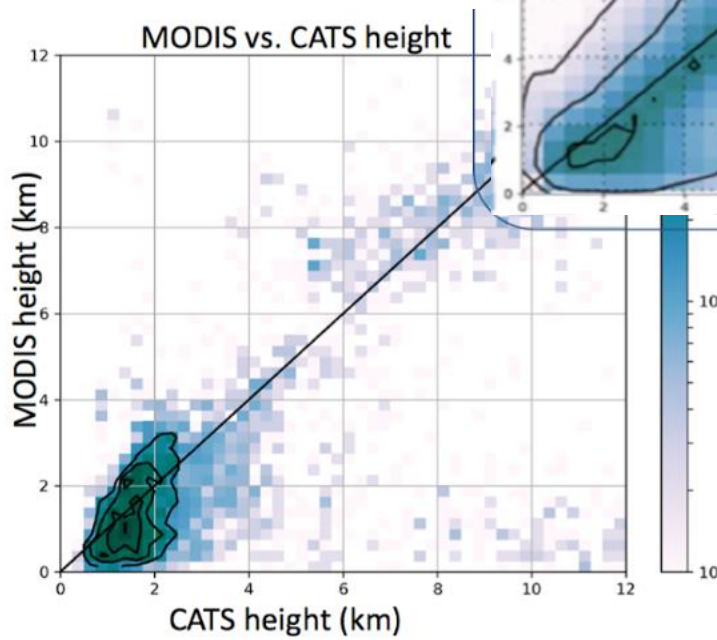
# Upper air GEO and LEO cloud winds

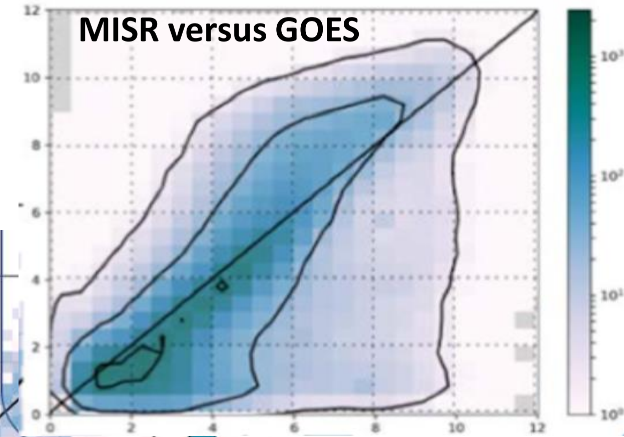


# How does Aeolus complement feature tracked winds?

- Waves, convergence, cloud dynamics and wind; do observed features move with the wind?
- Do we know the height of these features?
- Height uncertainty detriments wind accuracy with average shear of 4 m/s per km up to 30 km; 2 m/s accuracy implies $\sigma_z$ = 500 m
- Accurate geometrical height assignment is needed, e.g., Aeolus

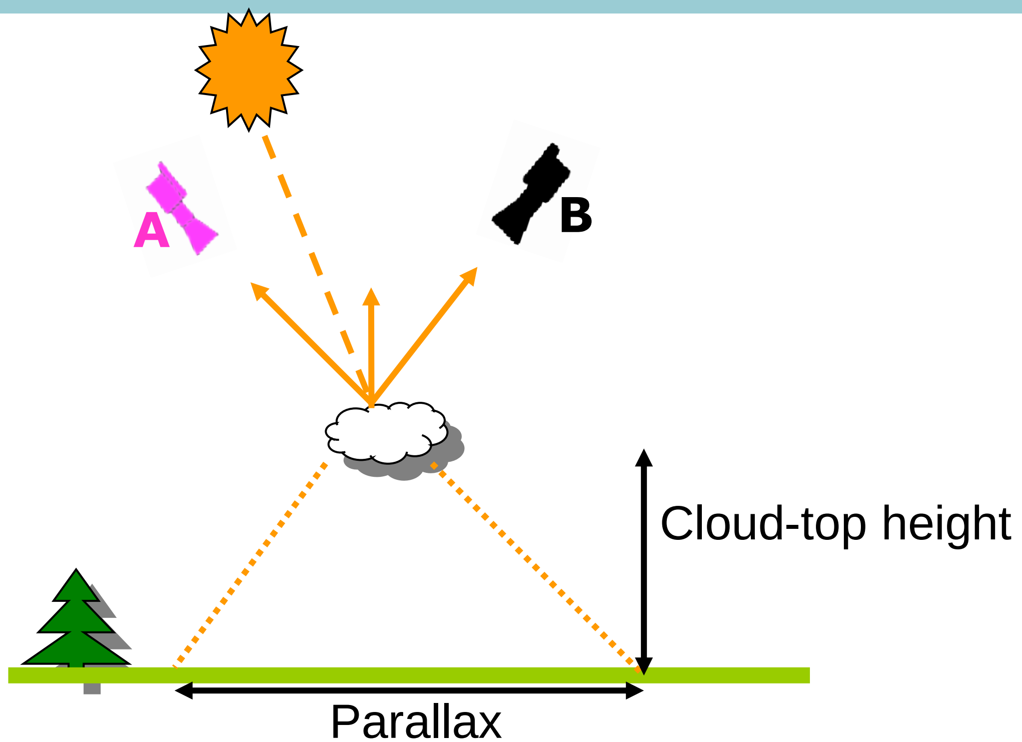


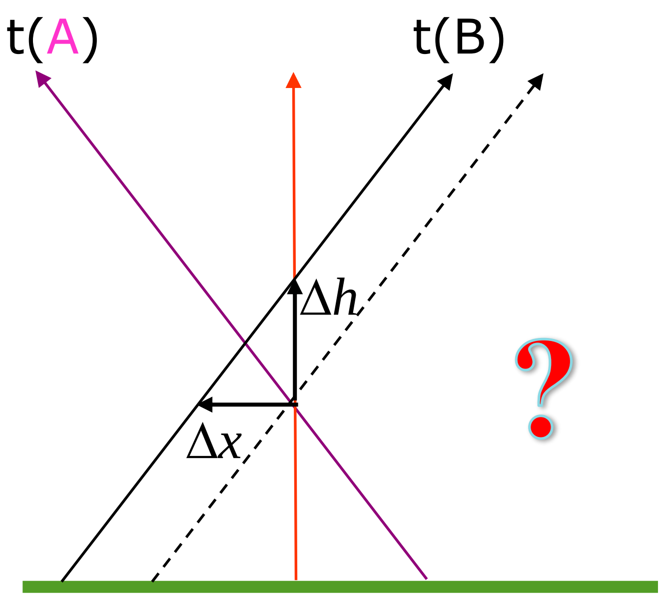




Kevin Mueller, JPL, 2018

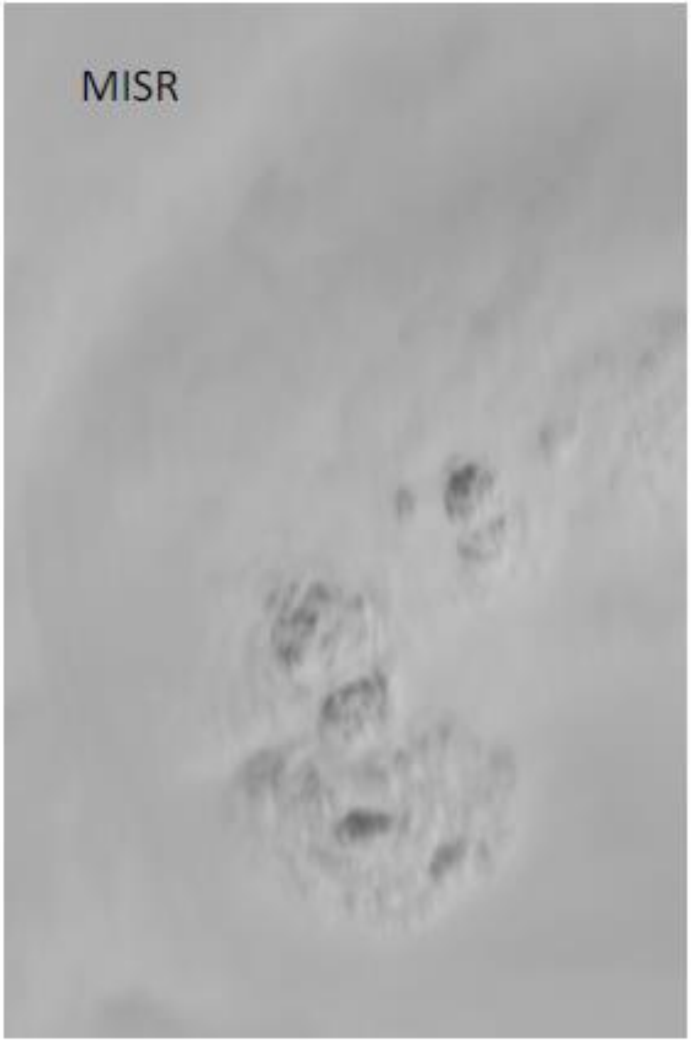
# gCMW: Principle stereo winds

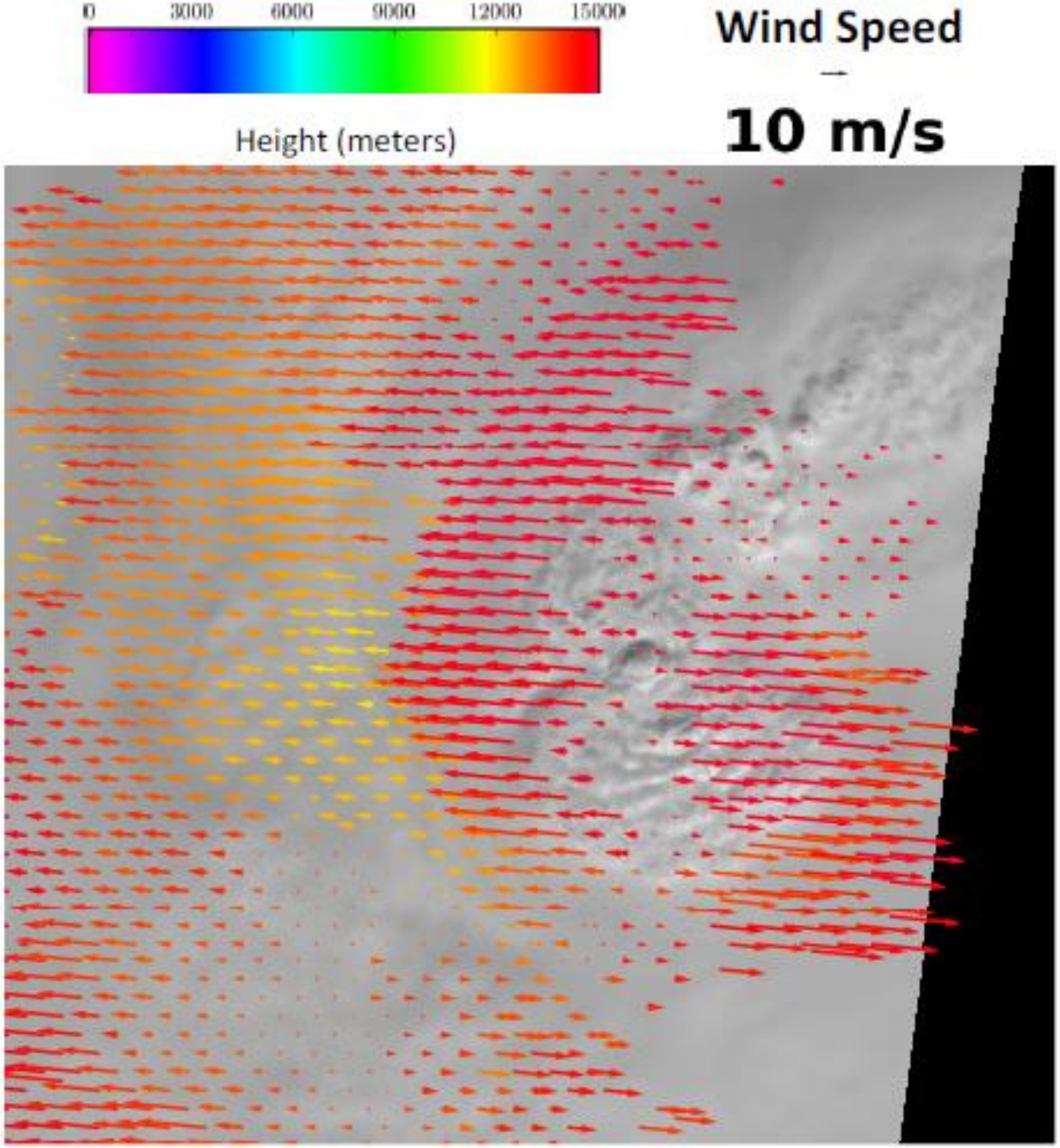


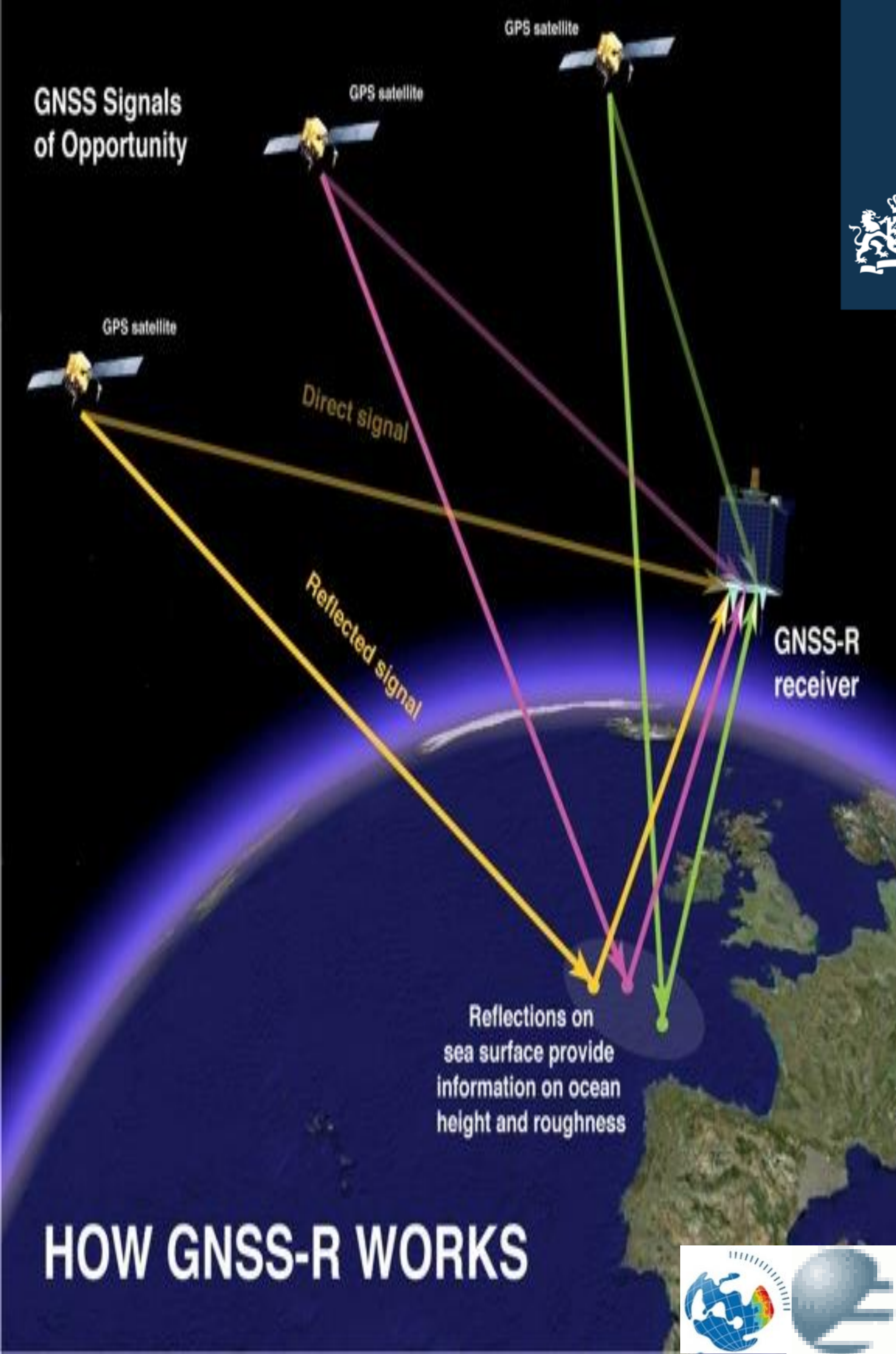

- The cloud transforms in 4 minutes, since for convection $\tau$ ~ 20 minutes
- t(A) ≠ t(B); for $\theta$ = ± 50 deg, Δt ~250s or 4 min. ; $\Delta x \neq 0$ and $\Delta h \neq 0$
- Two satellites could match up fore and aft views, so that t(A) = t(B) ; $\Delta x = 0$ and $\Delta h = 0$ but $h$ can be determined
- HARMONY ESA EE10

# km-scale wind observations on cloud tops in Hurricane Ida (2009)




**ESA EE10 HARMONY**
**Alexandre Payez**




Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure and the Environment*

# GNSS-R

- TechDemoSat since 2014
- CYGNSS launched succesfully on December 12 2016 with Pegasus
- EUMETSAT GOODIE fellow at KNMI from March ’17-’20; now at ICM/CNR

# harmony

## TO RESOLVE STRESS IN THE EARTH SYSTEM

**EARTH EXPLORER 10 PRESENTATION TO ADVISORY COMMITTEE FOR EARTH OBSERVATION**
**30 November-2 December 2020**

esa