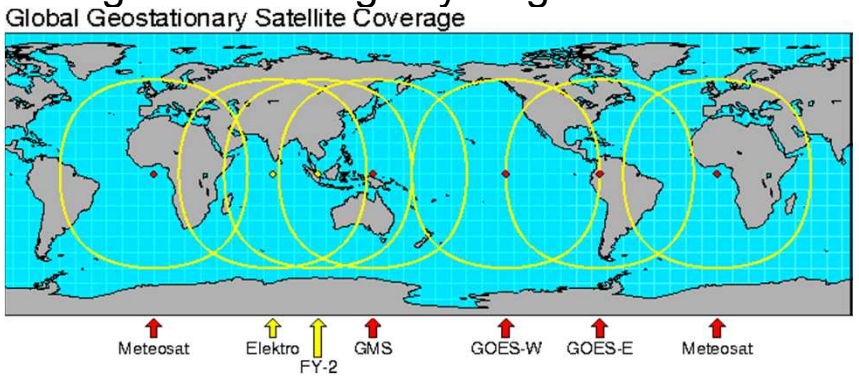
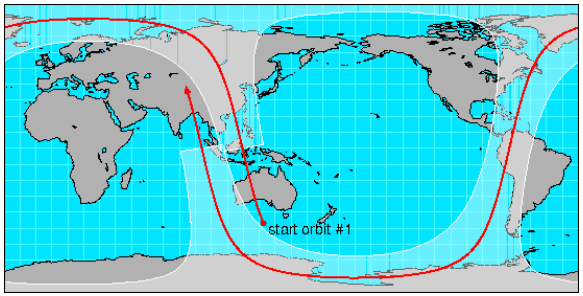
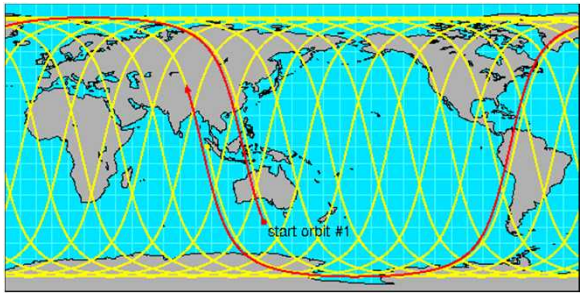
The Satellite Global Observing System

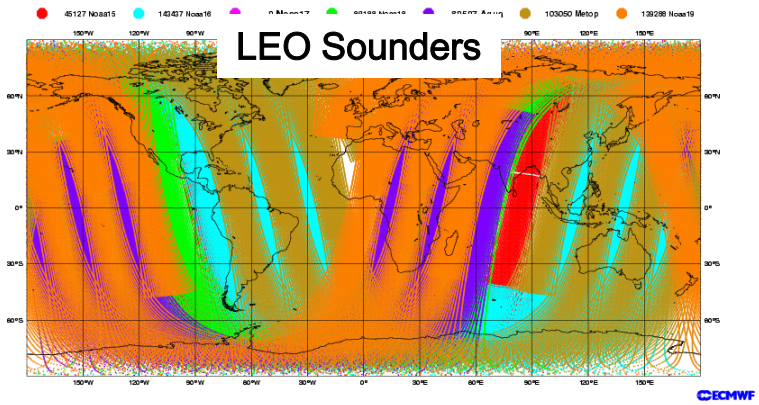
Stephen English

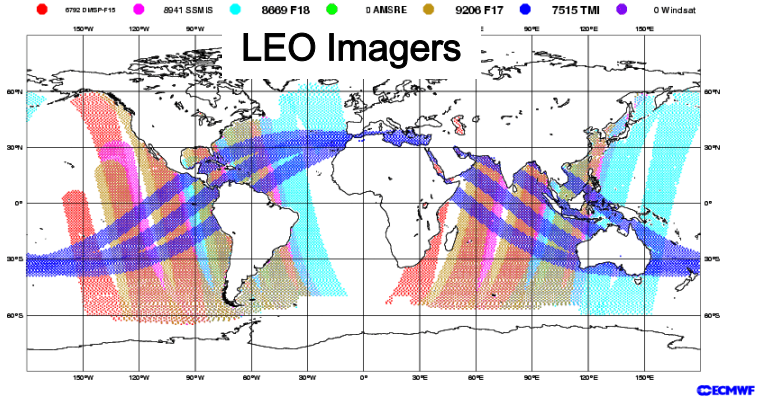
1. A brief introduction to the Satellite GOS
2. OSCAR – WMO's database for information on observations, user requirements and gap-analysis

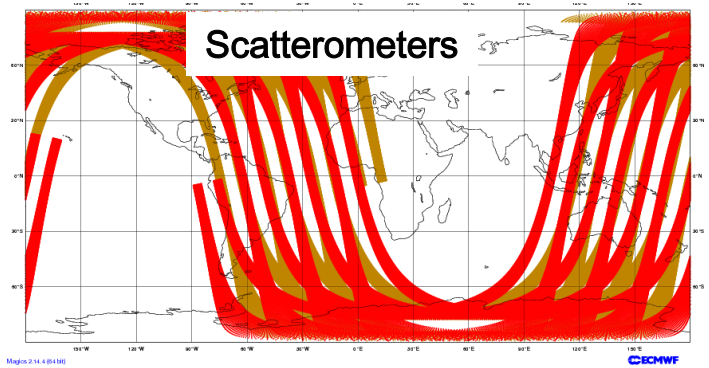
What types of satellites are used in NWP?

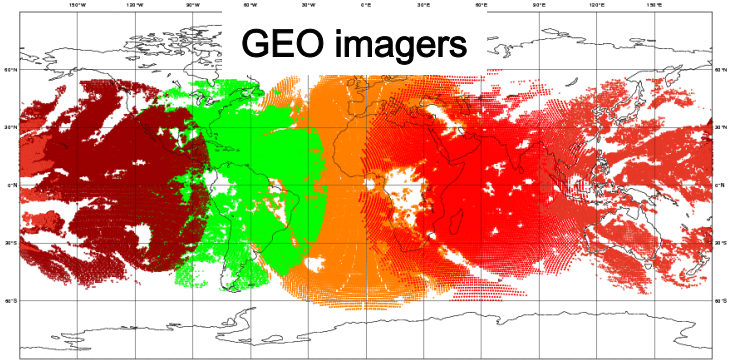
	Advantages	Disadvantages
GEO	- Regional coverage  	No global coverage by single satellite 
	- Temporal coverage	
LEO	- Global coverage with single satellite  	

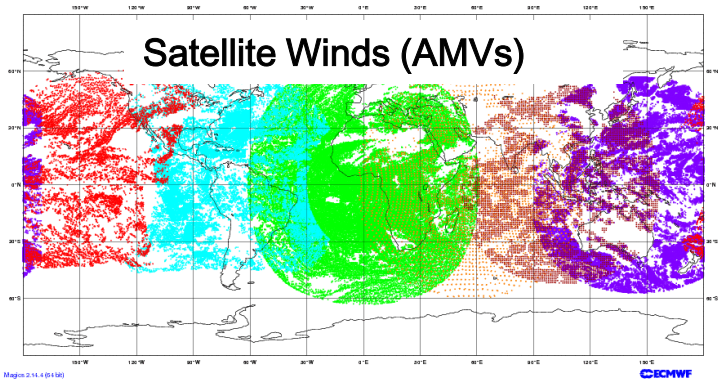
Example of 6-hourly satellite data coverage

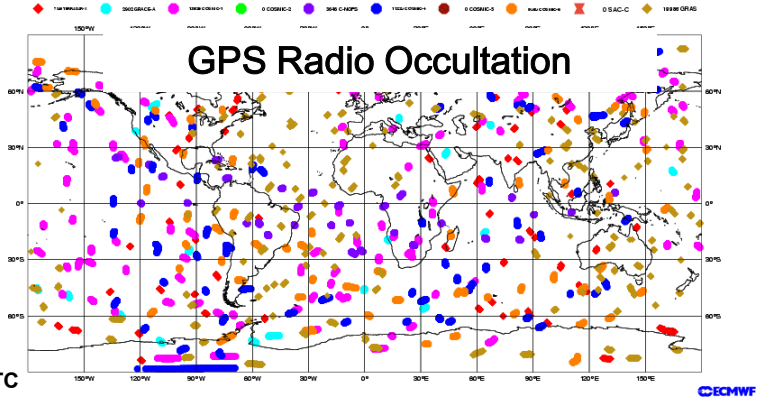










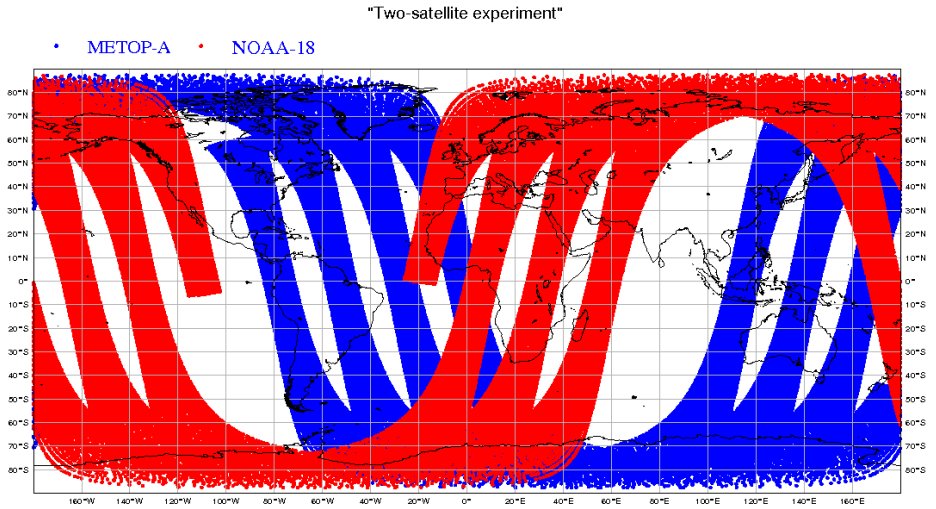


30 March 2012 00 UTC

Satellite orbits

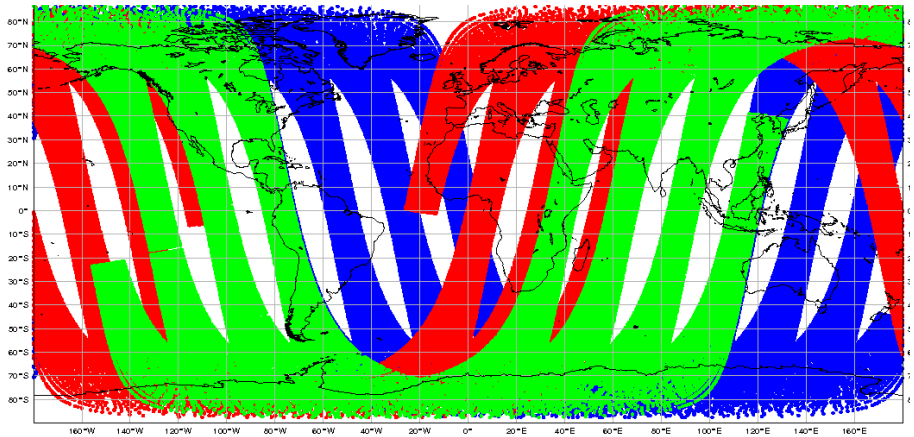
AM + PM

* MetOp-A * NOAA-18



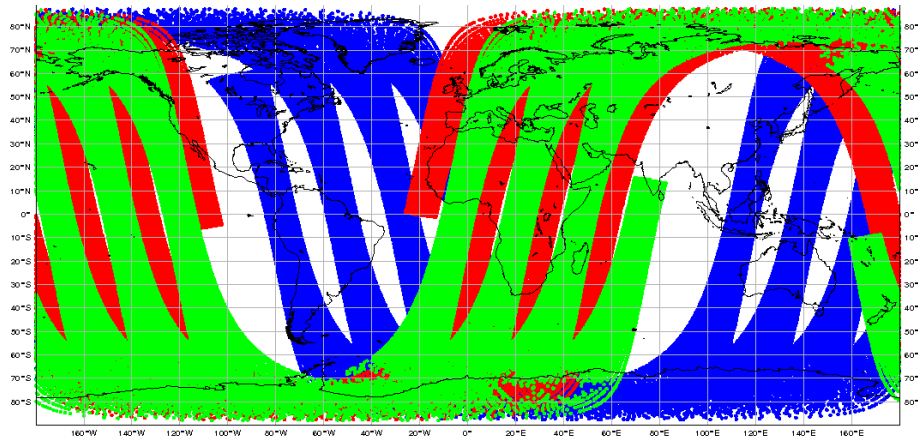
E-AM + AM + PM

* MetOp-A * NOAA-18 * NOAA-15

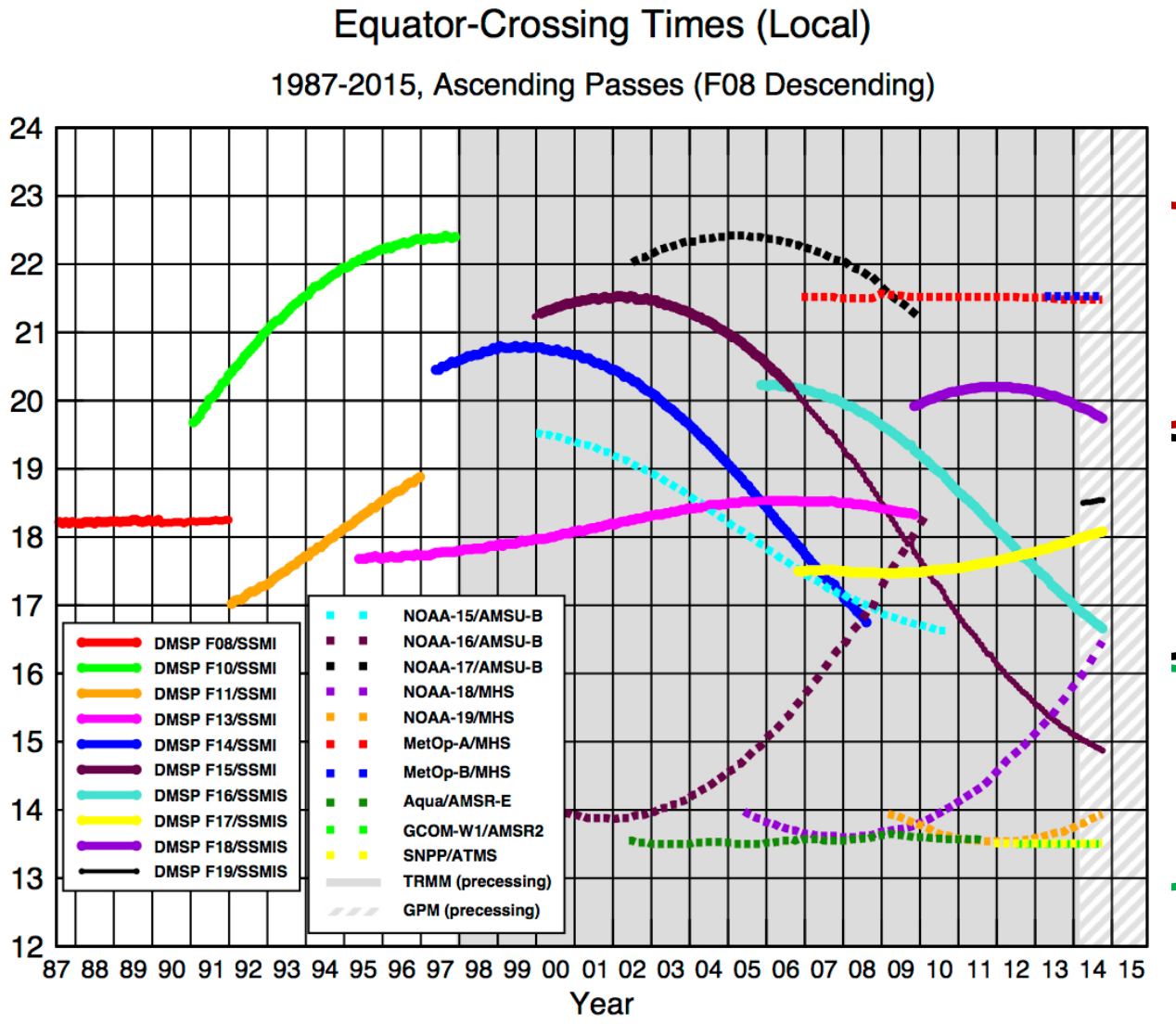


AM + 2 x PM

* MetOp-A * NOAA-18 * NOAA-19



Satellite orbits

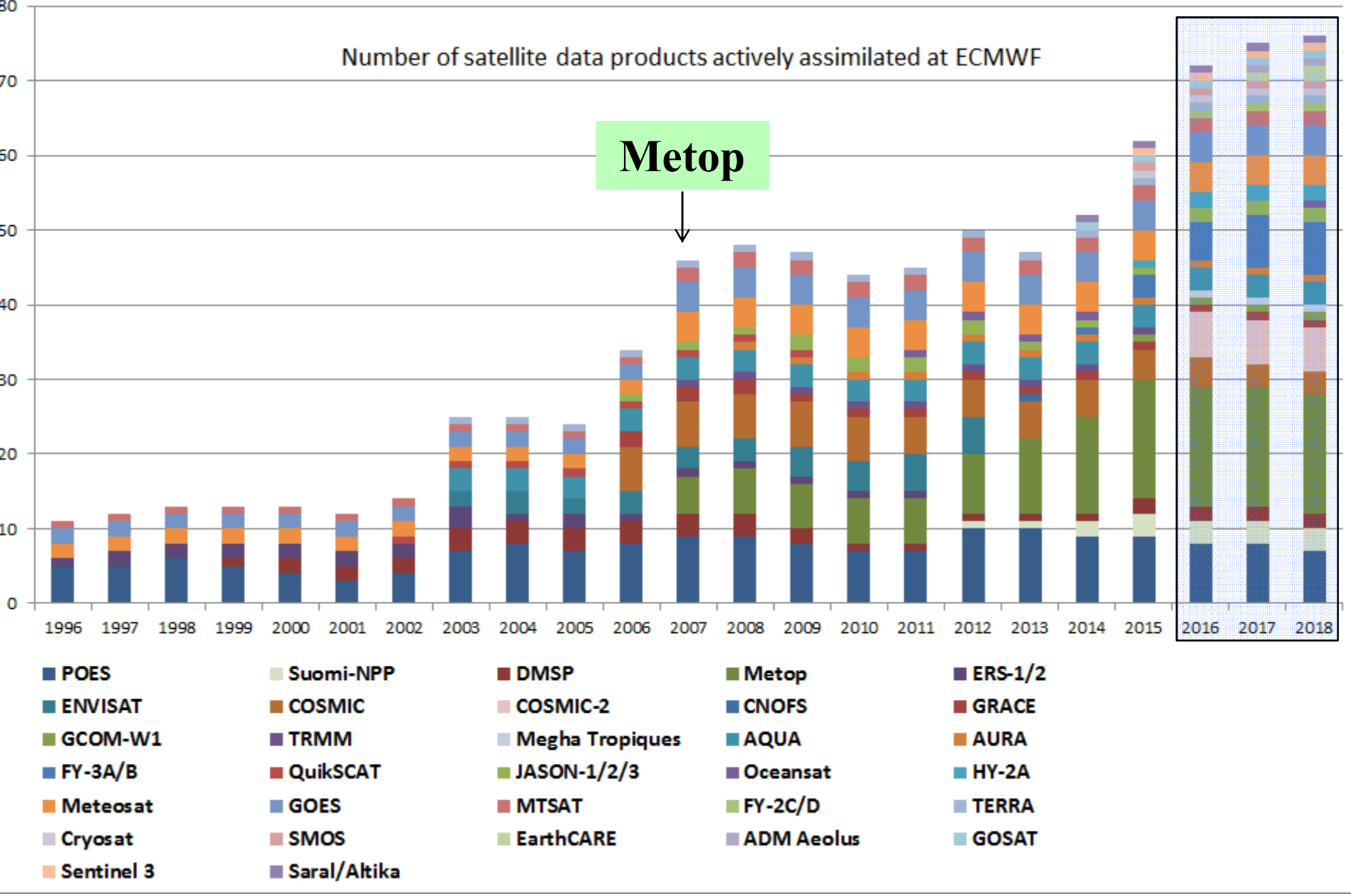


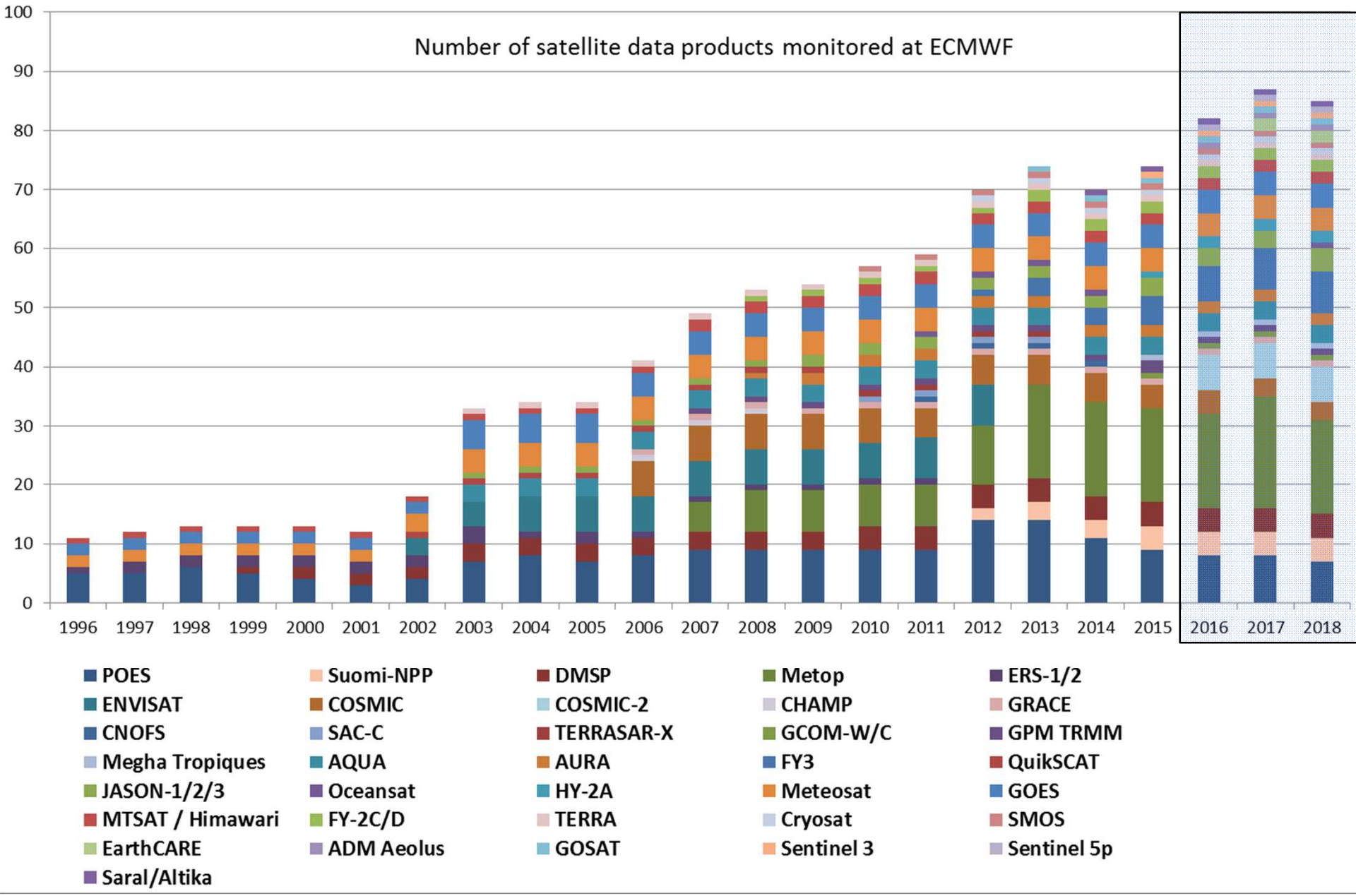
Mid AM — Europe
MetOp-B, A
FY-3A

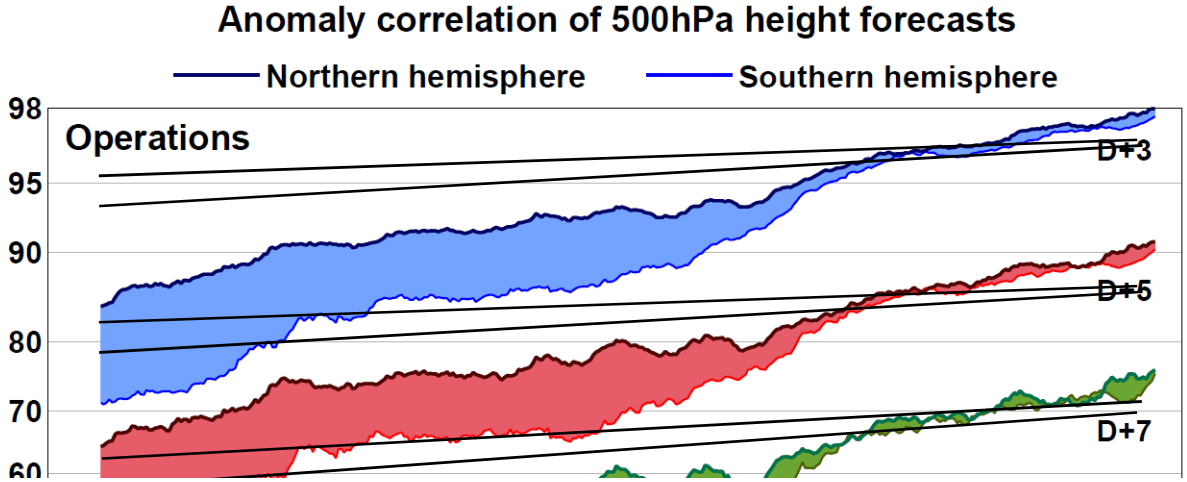
Early AM — China, India
DMSP F17, F18
NOAA-18
NOAA-15

PM — US, China
NOAA-19, S-NPP, Aqua, Terra, Aura, FY-3B

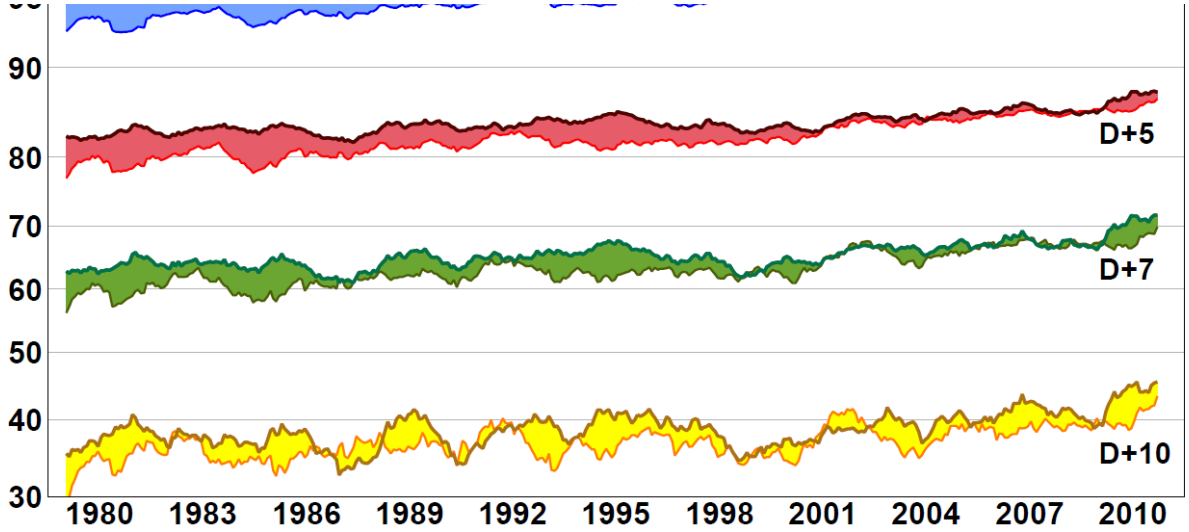
Image by Eric Nelkin (SSAI), 13 November 2014, NASA/Goddard Space Flight Center, Greenbelt, MD.


Number of satellite data products actively assimilated at ECMWF
Metop
0
10
20
30
40
50
70
80
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
POES
Suomi-NPP
DMSP
Metop
ERS-1/2
ENVISAT
COSMIC
COSMIC-2
CNOFS
GRACE
GCOM-W1
TRMM
Megha Tropiques
AQUA
AURA
FY-3A/B
QuikSCAT
JASON-1/2/3
Oceansat
HY-2A
Meteosat
GOES
MTSAT
FY-2C/D
TERRA
Cryosat
SMOS
EarthCARE
ADM Aeolus
GOSAT
Sentinel 3
Saral/Altika

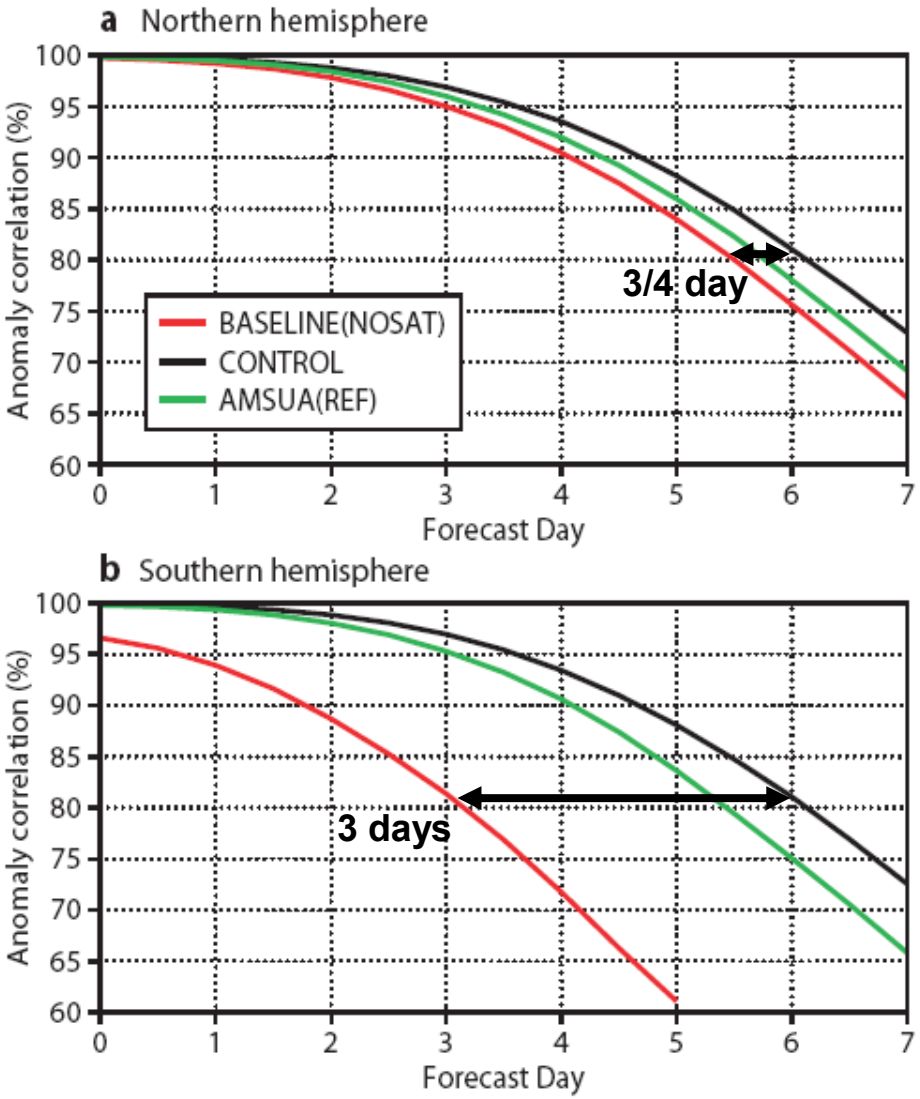

Number of satellite data products monitored at ECMWF
100
90
80
70
60
50
40
30
20
10
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
POES
Suomi-NPP
DMSP
Metop
ERS-1/2
ENVISAT
COSMIC
COSMIC-2
CHAMP
GRACE
CNOFS
SAC-C
TERRASAR-X
GCOM-W/C
GPM TRMM
Megha Tropiques
AQUA
AURA
FY3
QuikSCAT
JASON-1/2/3
Oceansat
HY-2A
Meteosat
GOES
MTSAT / Himawari
FY-2C/D
TERRA
Cryosat
SMOS
EarthCARE
ADM Aeolus
GOSAT
Sentinel 3
Sentinel 5p
Saral/Altika



Dee DP, Balmaseda M, Balsamo G, Engelen R, Simmons AJ, Thépaut J-N. 2014. Toward a consistent reanalysis of the climate system. Bull. Am. Meteorol. Soc. doi: 10.1175/BAMS-D-13-00043.1.



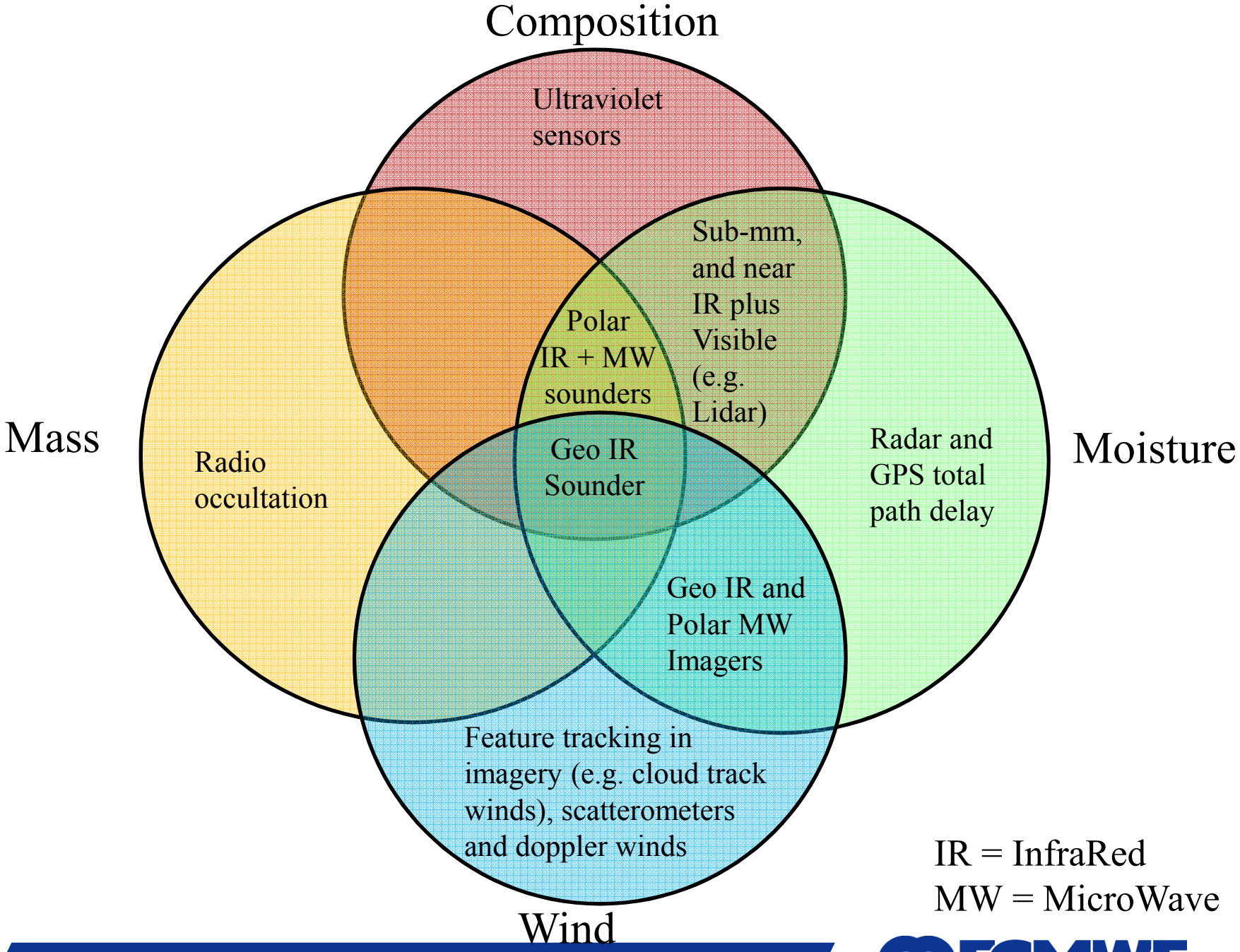
Combined impact of all satellite data



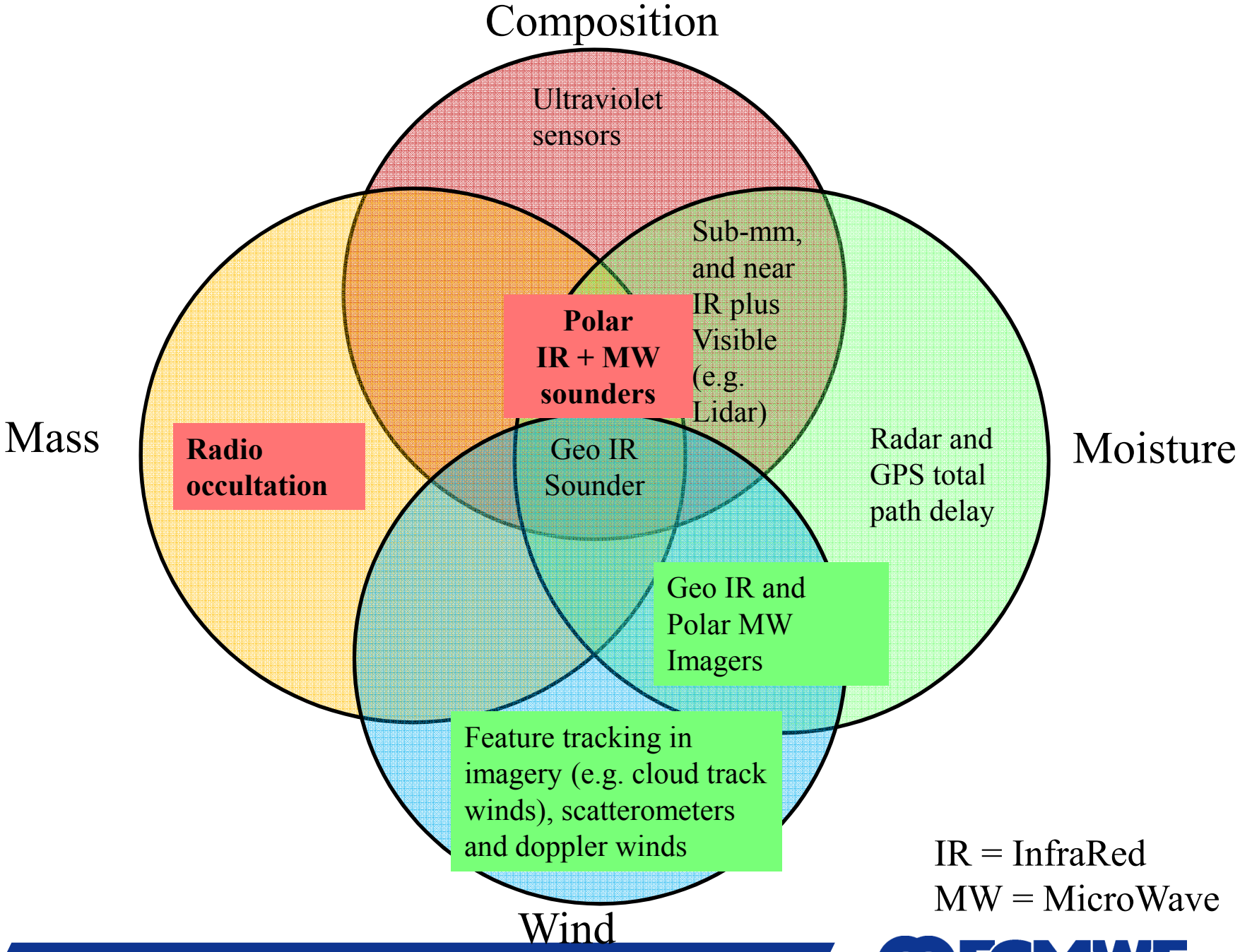
EUCOS Observing System Experiments (OSEs):

- 2007 ECMWF forecasting system,
- winter & summer season,
- different baseline systems:
  - no satellite data (NOSAT),
  - NOSAT + AMVs,
  - NOSAT + 1 AMSU-A,
- general impact of satellites,
- impact of individual systems,
- all conventional observations.

← 500 hPa *geopotential height* anomaly correlation



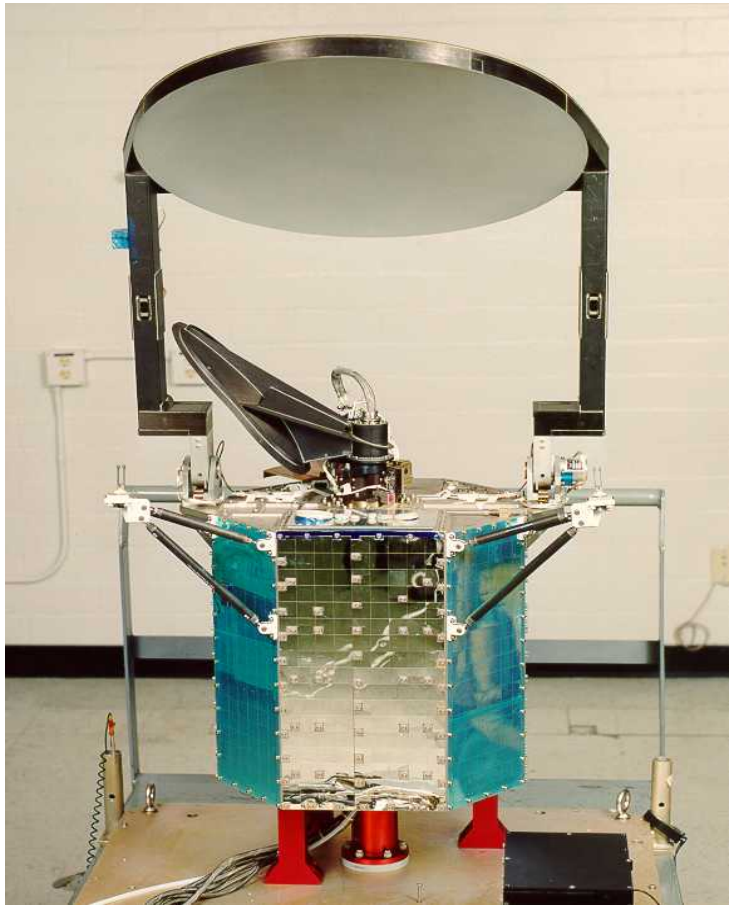
IR = InfraRed
MW = MicroWave



IR = InfraRed
MW = MicroWave

Types of sensor

- Orbit
- View geometry
- Wavelength
- Passive or Active



Issues

- Calibration accuracy
- Signal to noise ratio
- Complexity of interpretation
- 3D spatial and temporal resolution

Strengths / Weakness

	Satellite obs	In situ obs
Data coverage	+++	---
Representitivity error	++	--
Modern formats	+	-
Diversity	++	+
Data quality – random errors	+++	+++
Ease of transmission on GTS	-	+
Data quality – absolute errors	--	-
Complexity of observation operators	---	++
Vertical resolution	---	+++

Global Observing System is essential to weather forecasting

In the past technology driven….a more integrated user driven approach been encouraged by WMO

Mass is well observed: 1. MW sounders; 2. IR sounders; 3. RO

Moisture – satellite observations are data rich but poorly exploited. Radar and lidar will become more important.

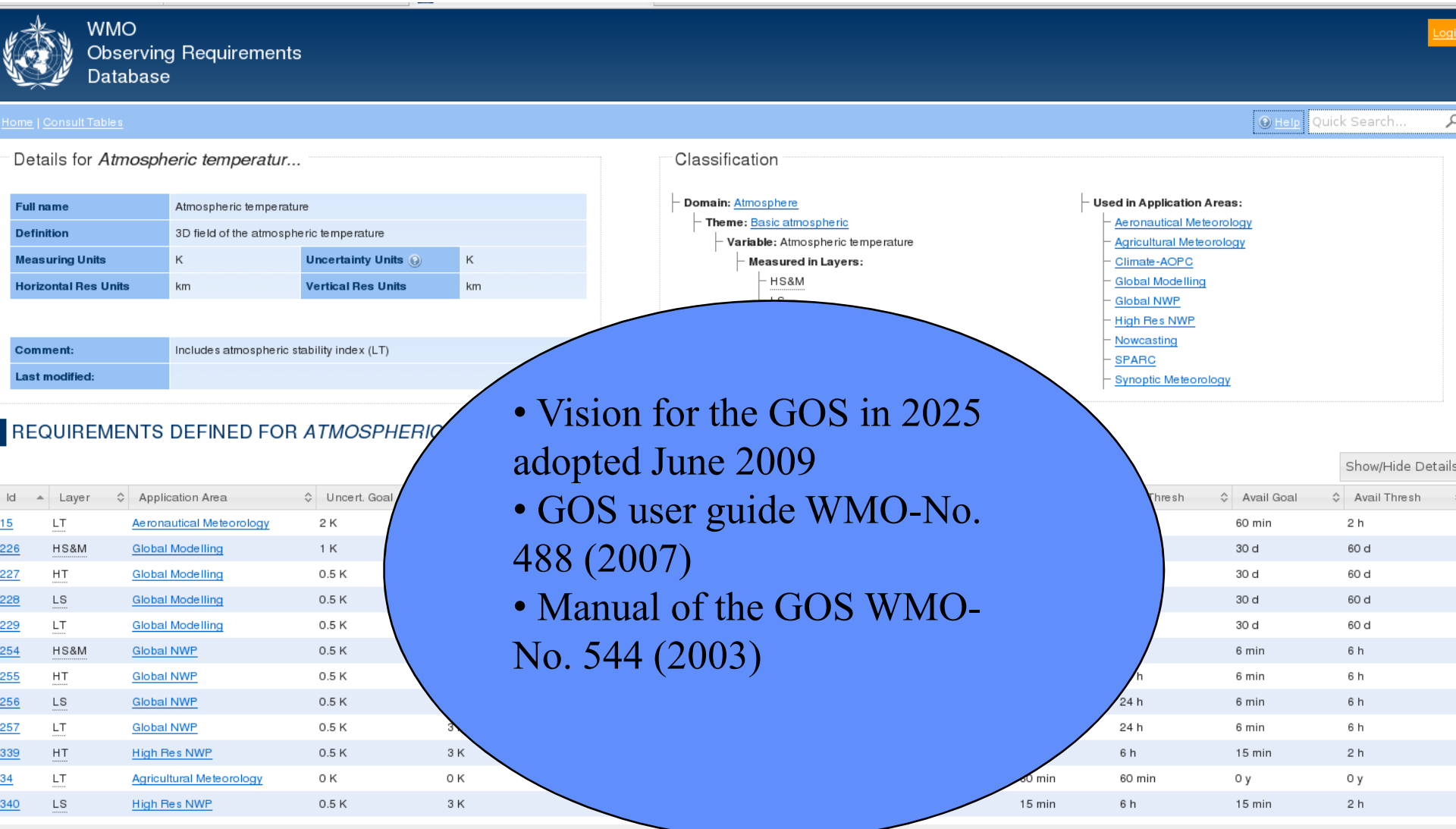
Dynamics – wind observations are scarce in many areas. Methods are indirect e.g. AMVs or surface only e.g. scatterometer

Composition – NWP techniques have been successfully extended to environmental analysis and prediction but more observations are needed.

Surface –SST, sea ice, soil moisture, snow all need real-time analysis; plus climatologies for land use, biomass, albedo, orography, lakes and rivers…)

User requirements

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



- Vision for the GOS in 2025 adopted June 2009
- GOS user guide WMO-No. 488 (2007)
- Manual of the GOS WMO-No. 544 (2003)

OSCAR

- **OSCAR = Observation Systems Capability Analysis and Review**
  - A tool developed by WMO to assist with the “Rolling Requirements Review” and the development of “WMO Integrated Global Observing System” WIGOS
    - What do we need?
    - What is there?
    - Where are the gaps?

- **But OSCAR is more than this. It provides valuable and usually very up to date information both to satellite data specialists and the wider interested meteorological community.**

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

Some details!

Sun-Synchronous Polar Satellites

Instrument	Early morning orbit	Morning orbit	Afternoon orbit
High spectral resolution IR sounder		IASI	Aqua AIRS NPP CrIS
Microwave T sounder	F16, 17 SSMIS	Metop AMSU-A FY3A MWTS DMSP F18 SSMIS Meteor-M N1 MTVZA	NOAA-15, 18, 19 AMSU-A Aqua AMSU-A FY3B MWTS, NPP ATMS
Microwave Q sounder + imagers	F16, 17 SSMIS	Metop MHS DMSP F18 SSMIS FY3A MWHS	NOAA-18, 19 MHS FY3B MWHS, NPP ATMS
Broadband IR sounder		Metop HIRS FY3A IRAS	NOAA-19 HIRS FY3B IRAS
IR Imagers		Metop AVHRR Meteor-M N1 MSU-MR	Aqua+Terra MODIS NOAA-15, 16, 18, 19 AVHRR
Composition (ozone etc).		NOAA-17 SBUV	NOAA-18, 19 SBUV ENVISAT GOMOS AURA OMI, MLS ENVISAT SCIAMACHY GOSAT

Sun-Synchronous Polar Satellites (2)

Instrument	Early morning orbit	Morning orbit	Afternoon orbit
Scatterometer		Metop ASCAT Coriolis Windsat	Oceansat OSCAT
Radar			CloudSat
Lidar			Calipso
Visible reflectance			Parasol
L-band imagery	SMOS SAC-D/Aquarius		

Non Sun-Synchronous Observations

Instrument	High inclination (> 60°)	Low inclination (<60°)
Radio occultation	GRAS, GRACE-A, COSMIC, TerraSarX C-NOFS, (SAC-C), ROSA	
MW Imagers		TRMM TMI Meghatropics SAFIRE MADRAS
Radar Altimeter	ENVISAT RA JASON Cryosat	

Data sources: Geostationary Satellites

Product	Status
SEVIRI Clear sky radiance	Assimilated
SEVIRI All sky radiance	Being tested for overcast radiances, and cloud-free radiances in the ASR dataset
SEVIRI total column ozone	Monitored
SEVIRI AMVs	IR, Vis, WV-cloudy AMVs assimilated
GOES	AMVs
MTSAT	AMVs

Future Satellite Systems

Stephen English

1. EPS Second Generation / Meteosat Third Generation
2. ESA Earth Explorer missions: EarthCARE and Aeolus
3. Quick summary of other missions
4. Beyond 2035?

EPS Second Generation

A little of the history that led to EPS-SG…

- 1970s : Research sounders with a few channels = SCAMS,VTPR+
- 1979 : TOVS (NOAA) = HIRS/2→/3,MSU,SSU,AVHRR
- 1999 : ATOVS (NOAA) = HIRS/3→/4,AMSU-A,AMSU-B→MHS,AVHRR
- 2002 : A-train: AIRS,MODIS,CloudSat,Calipso+
- 2007 : EPS First Generation (Metop) = ATOVS + IASI, ASCAT, GRAS, GOME-2
- 2011 : S-NPP = ATMS, CrIS, VIIRS, OMPS

- ~2021: EPS-SG
  - EPS-SG-A (3 sats) 2021-2042 = mostly EPS follow on instruments
  - EPS-SG-B (3 sats) 2022-2043 = mostly new instruments

EPS Second Generation

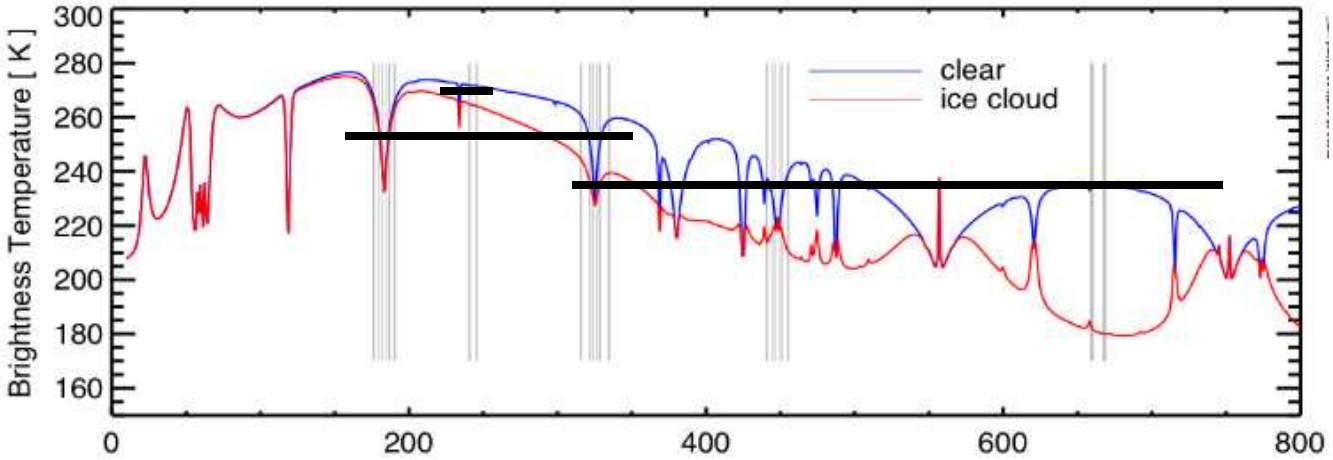
~2021 EPS-SG will have updated counterparts to Metop 2nd generation instruments on EPS-SG-A:

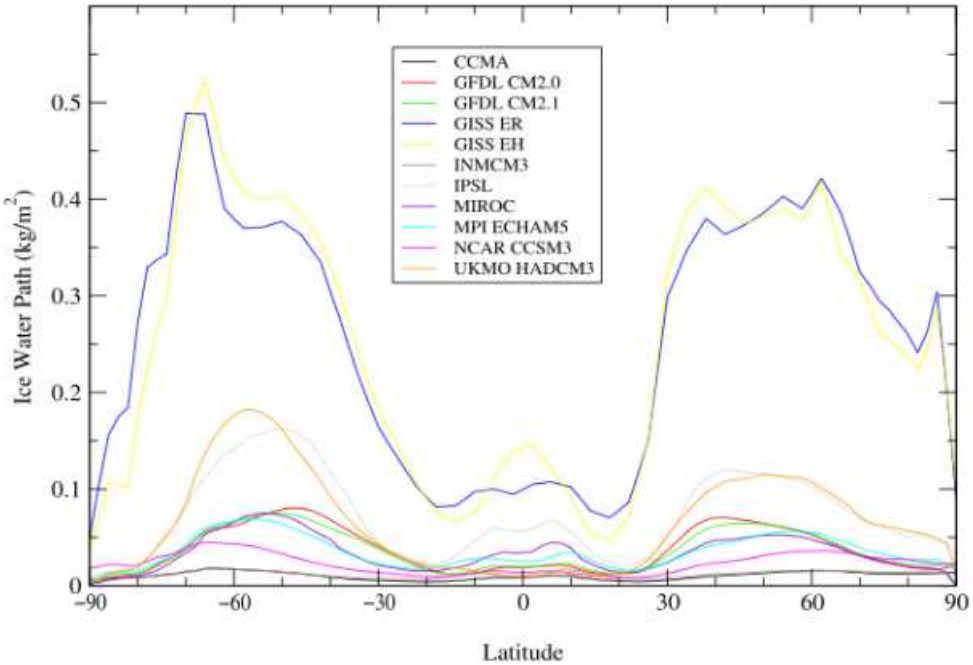
- ATOVS + AVHRR/MODIS → MWS + MetImage
- IASI → IASI-NG
- ASCAT → SCA (on EPS-SG-B)
- GOME-2 → Sentinel-5 UVNS
- GRAS → RO

Plus some instruments new compared to Metop, on EPS-SG-A

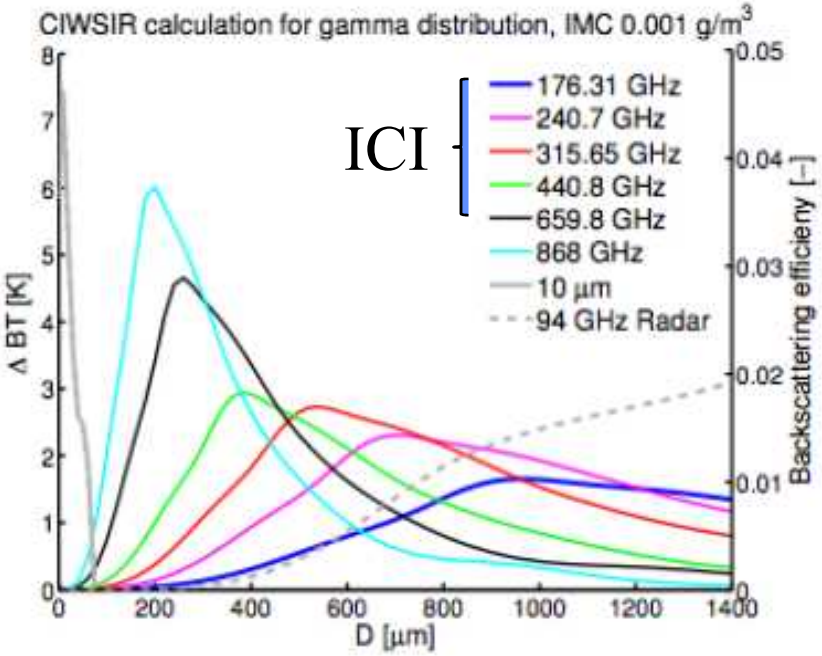
- MWI: based on SSM/I
- 3MI: based on POLDER and PARASOL (VIS/NIR/SWIR)
- ICI: completely new! Sub-mm imager for cloud ice

EPS-SG: Ice Cloud Imager - ICI





From John and Soden (2006)



From CloudIce proposal (Buehler et al.)

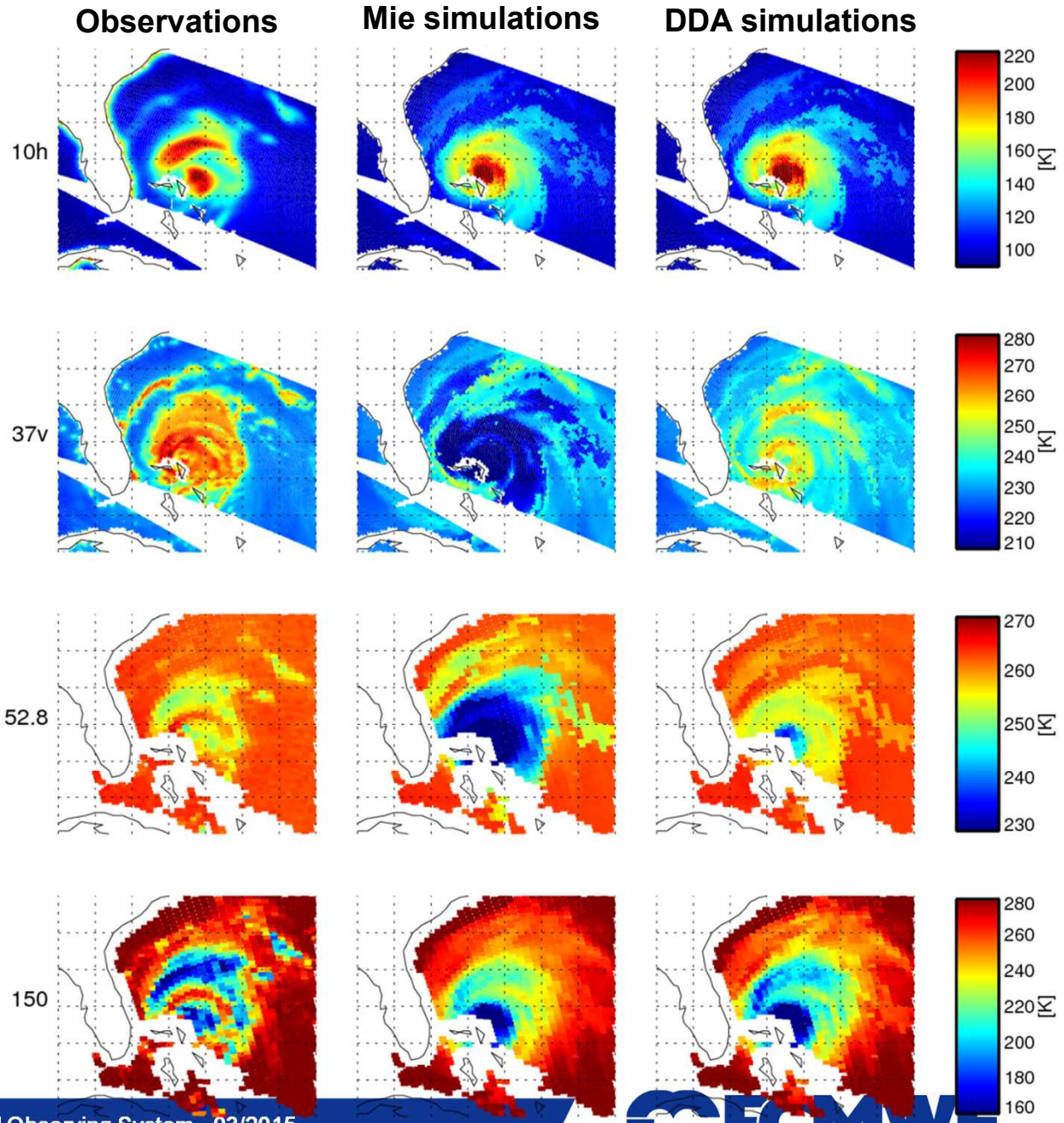
Improving accuracy of scattering radiative transfer

Liu (2008, BAMS) DDA scattering database

Implementation in RTTOV-SCATT: Geer and Baordo (2014, AMT)

Result: We can do all-sky assimilation in convective areas at frequencies above 30 GHz for the first time.

Needed for ICI.



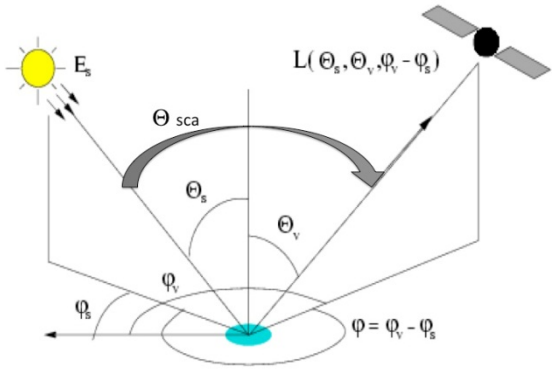
EPS-SG: Multi-Viewing Multi-Channel Multi-Polarisation Imaging Mission - 3MI

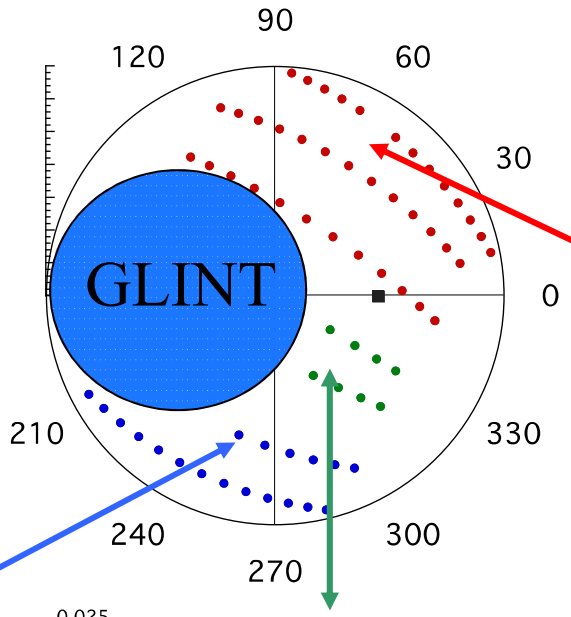
3MI = POLDER + MODIS heritage

- **Multi-directional :** **10-14 views for one pixel**
  Exploits bi-directional reflectivity
- **Multi-polarization :** **±60, 0°**
- **Multi-spectral :** **12 channels**

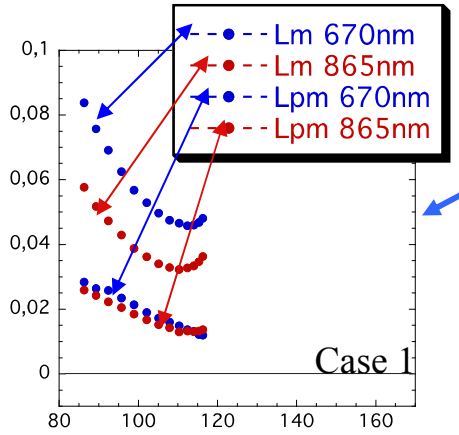
  388 to 2130 nm (close to MODIS specification)

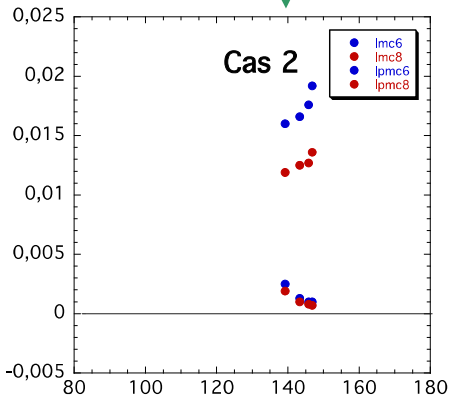
What can be obtained depends on avoiding sun-glint

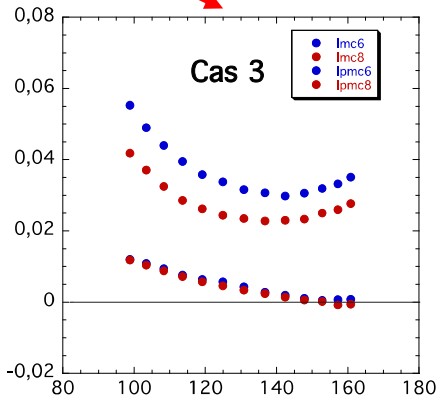




West





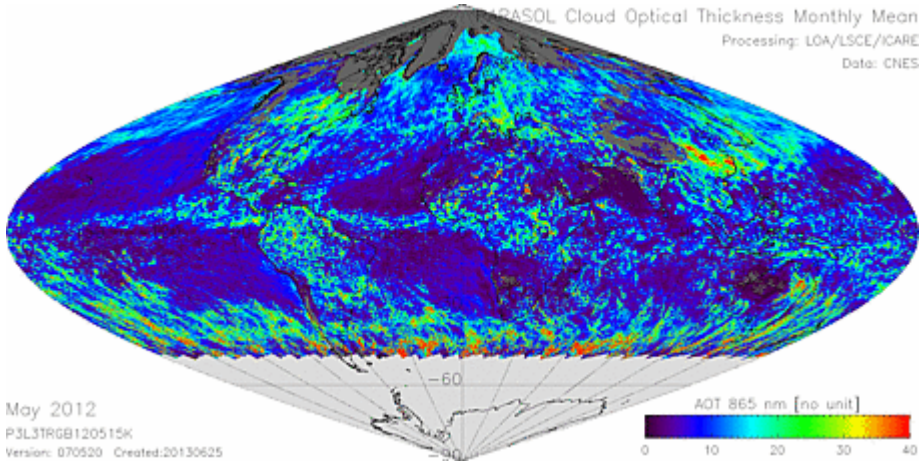


Optical depth + some size and refractive index information

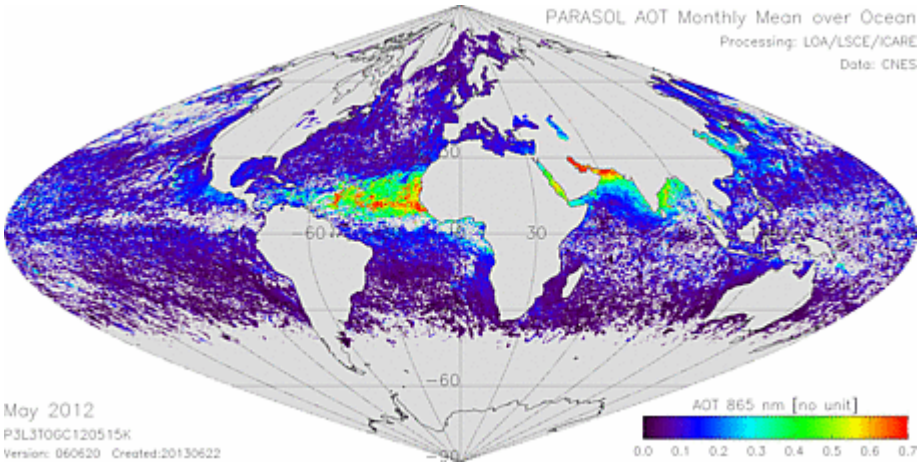
Optical depth

Optical depth + size and refractive index information for coarse and fine particles

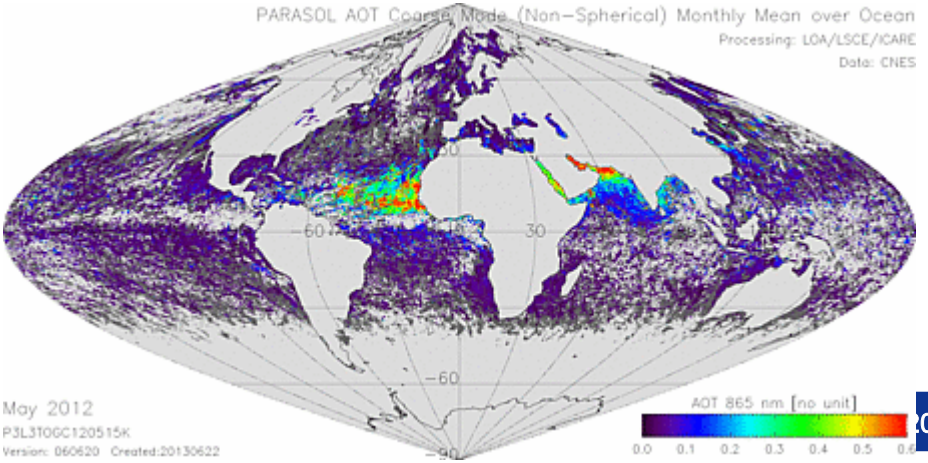
Examples of POLDER products



Cloud Optical Thickness
Mean for May 2012



Aerosol Optical Thickness
Mean for May 2012



Aerosol Optical Thickness for
Non-Spherical coarse mode
Mean for May 2012

ECMWF

Source : www.icare.univ-lille1.fr

Meteosat Third Generation

A little of the history that led to MTG-IRS

- 1977 : Meteosat-1: 3 channel MVIRI instrument (by ESA)
- 1989 : Meteosat-4: first operational Meteosat
- 1995 : EUMETSAT takes over Meteosat operations
- 2002 : 2nd generational Meteosat: 12 channel SEVIRI on Meteosat-8
- 2005 : NASA aspiring to launch first Geo interferometer

~ 2019 Meteosat Third Generation

- MTG-I 2019 (4 sats) 2019-2039
- MTG-S 2021 (2 sats) 2021-2037

Meteosat Third Generation

~2018 MTG-I will have updated counterpart to SEVIRI on MSG:

- SEVIRI → FCI 16 channel imager
  - European rapid scan 2.5 minutes, full disk 10 minutes.

Plus new instruments on MTG-I and MTG-S (from ~2020):

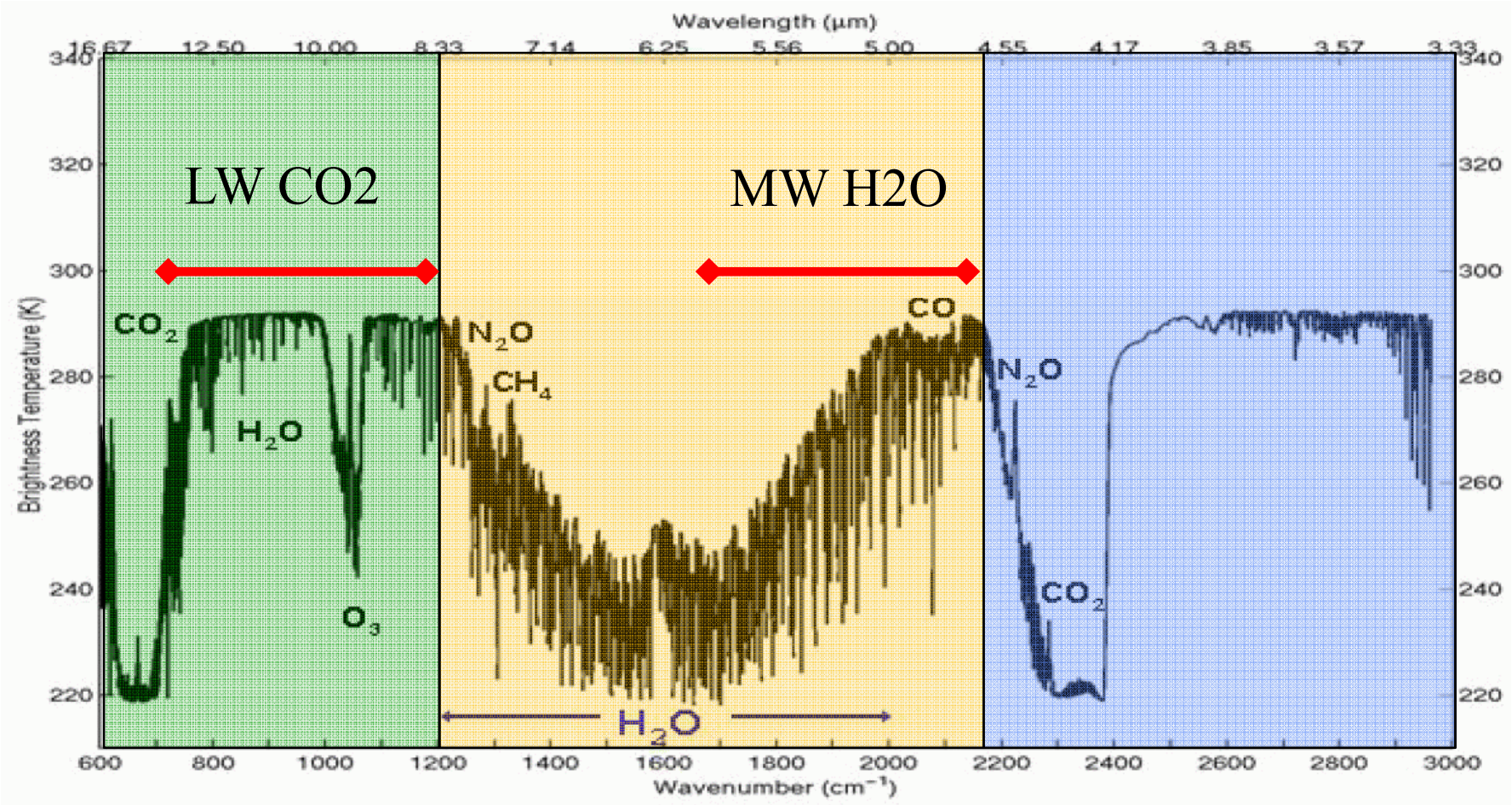
- IRS: IR interferometer (never previously launched in Geo orbit)
- LI: Lightning imager (777.4nm)
- UVN: Ultraviolet, Visible and Near IR imager

MTG: Infrared Sounder - IRS

- An imaging Fourier-interferometer with a hyperspectral resolution of 0.625 cm^{-1} wave-number
- Two bands, the 700–1210 cm^{-1} Long-Wave InfraRed (LWIR) and the 1600–2175 cm^{-1} Mid-Wave InfraRed (MWIR)
- Spatial resolution of 4 km.
- Full Disk basic repeat cycle of 60 min.

- Moisture flux convergence from combination of humidity and wind (through feature tracking)
- High potential for nowcasting
- Also very high resolution NWP (~1 km)

MTG: Infrared Sounder - IRS

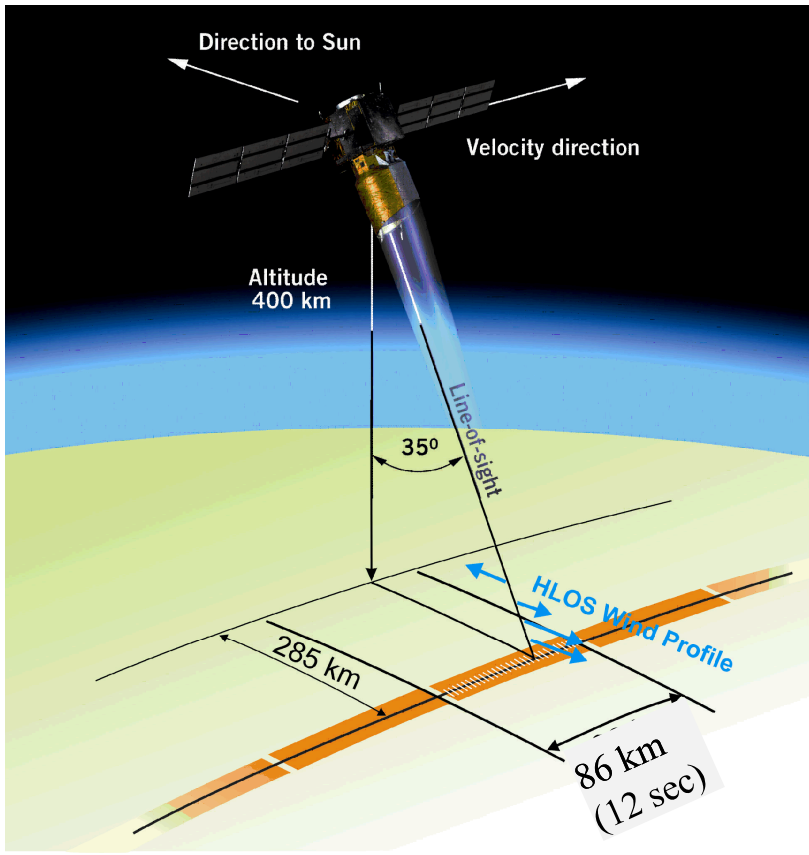


Aeolus: doppler wind lidar

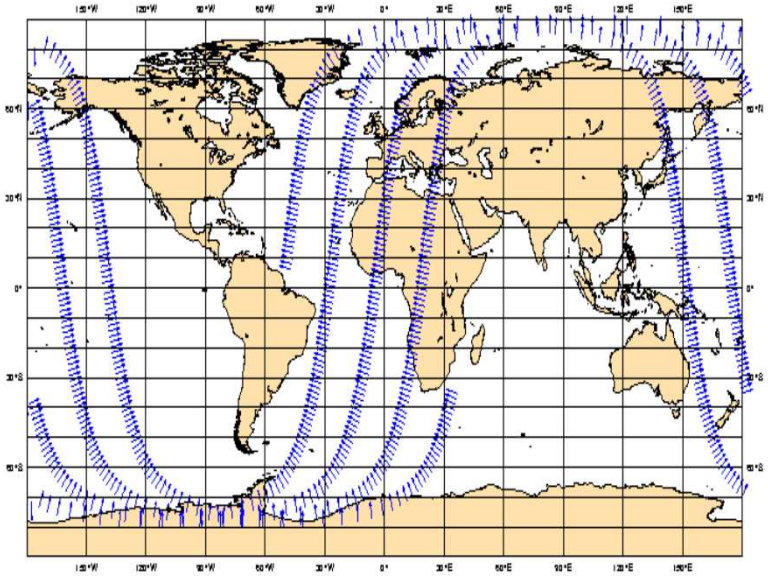
- Aeolus is a Doppler wind lidar
  - Active measurement of Doppler shift in backscattered laser
  - Direct information on horizontal line of sight wind mostly in the zonal direction
  - Provides a “curtain” of observations along orbit (2D cross section)
    - Vertical resolution 250m (PBL) to 2km (Stratosphere)
    - Horizontal resolution ~90km
  - Winds are derived from molecular (Rayleigh) or particulate (Mie) backscattering
  - Technologically challenging and launch date has changed many times. Now expected ~2017.

Aeolus: doppler wind lidar

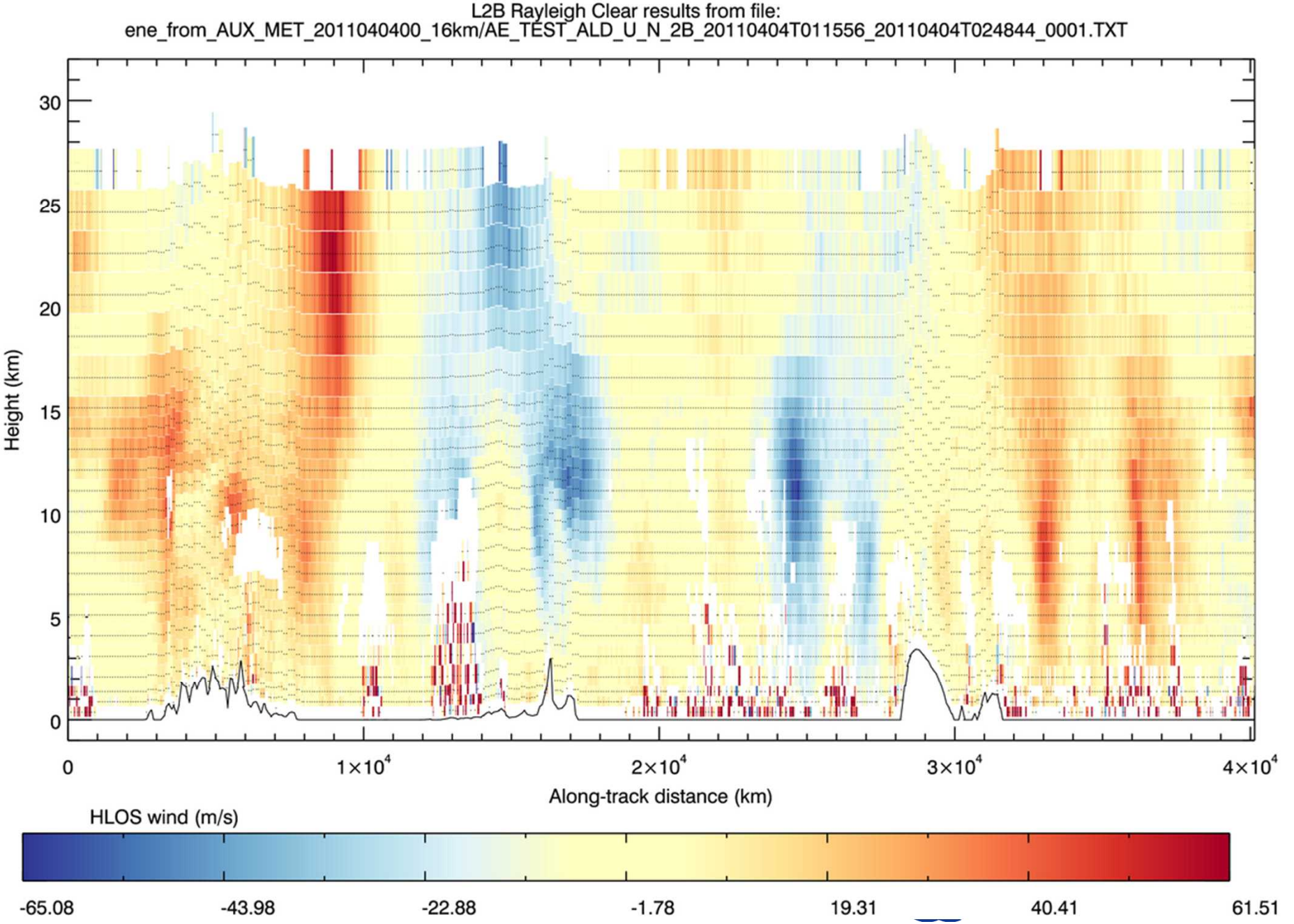
Continuous mode
1 basic repeat cycle
30 x 2.85 km each



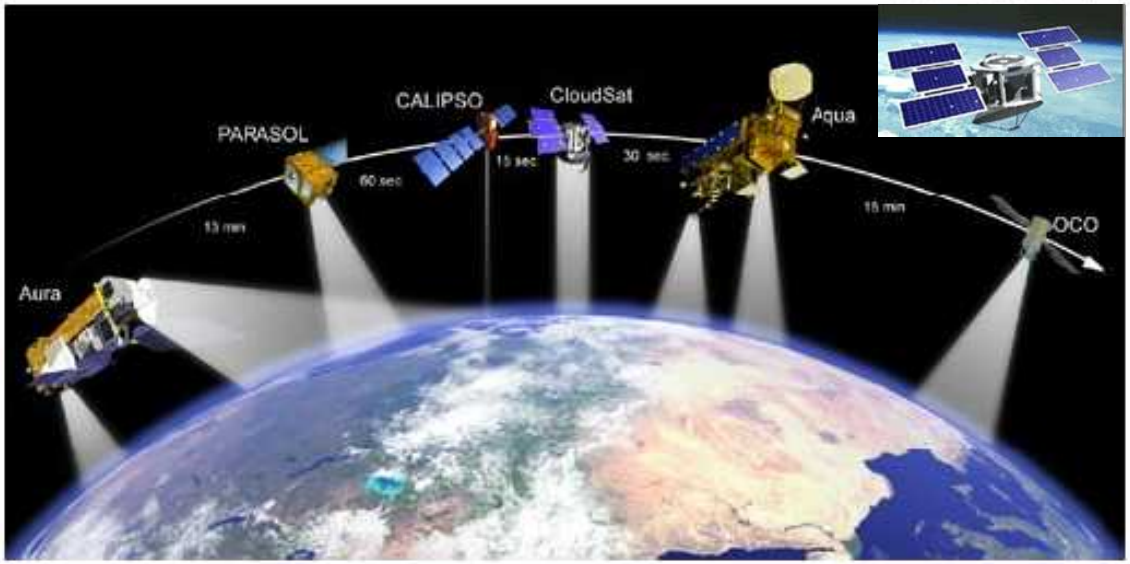
6 hr coverage

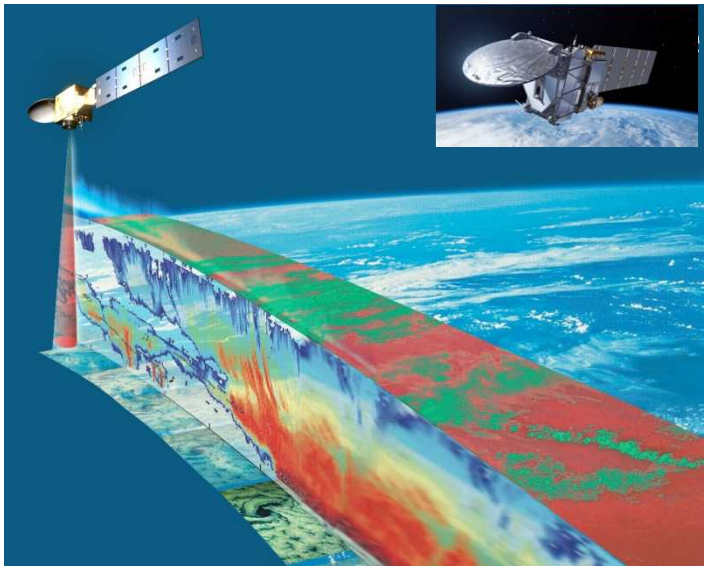


Simulated Aeolus wind observations



EarthCARE: cloud radar and lidar





The A-Train

- Launched 2006
- NASA
- 700-km orbit
- CloudSat 94-GHz radar
- CALIPSO 532/1064-nm lidar
- MODIS, CERES and AMSR-E radiometers

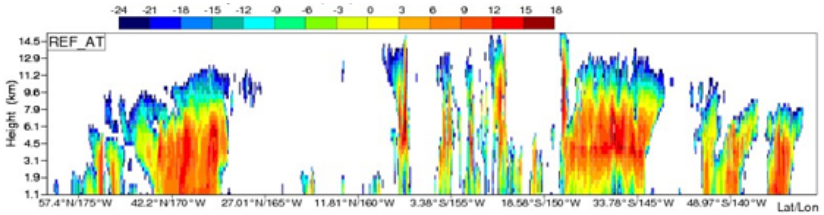
EarthCARE

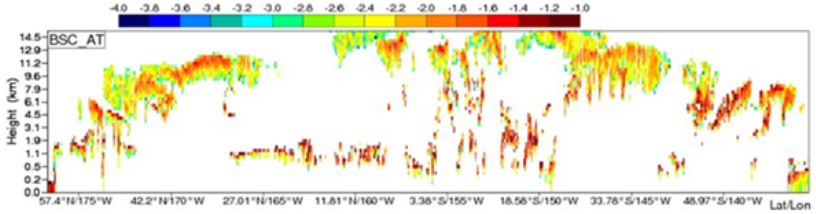
- Expected launch c. 2018
- ESA+JAXA
- 400-km orbit (more sensitive)
- CPR: 94-GHz Doppler radar
- ATLID: 355-nm lidar
- MSI and BBR radiometers

EarthCARE: cloud radar and lidar

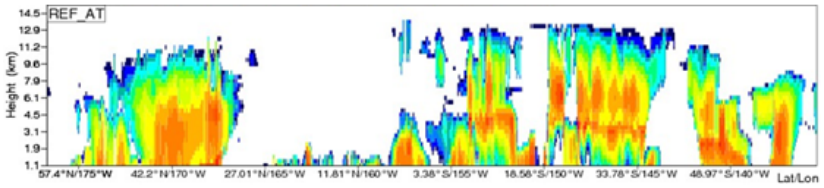
(S Di Michele and M Janisková)

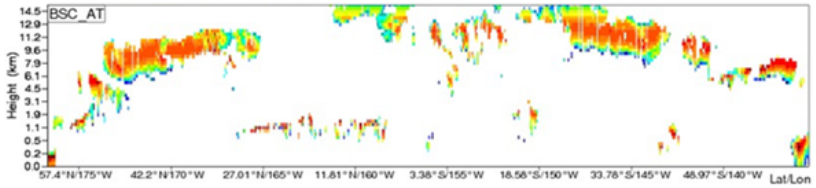
O



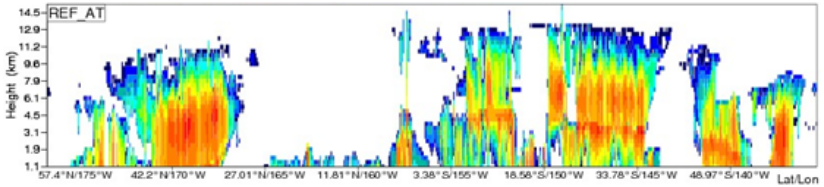


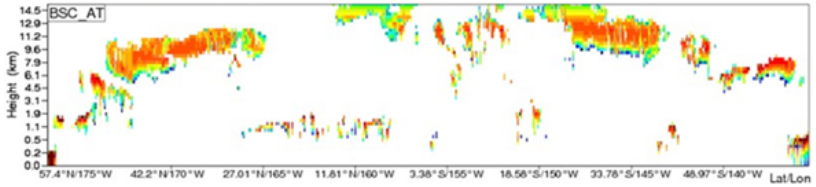
B



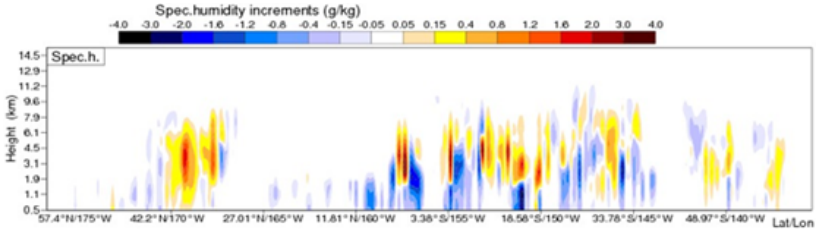


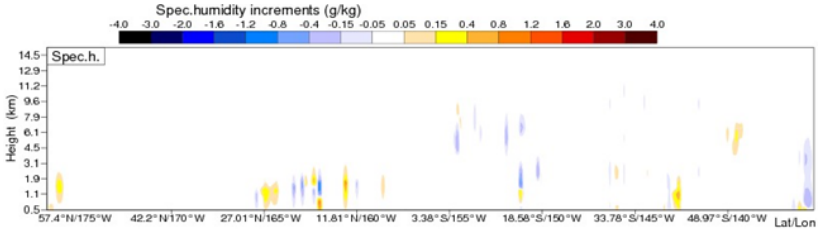
A



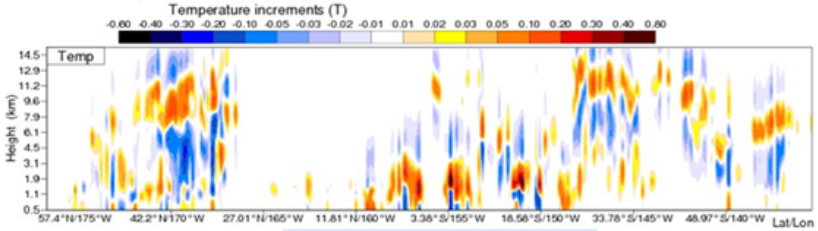


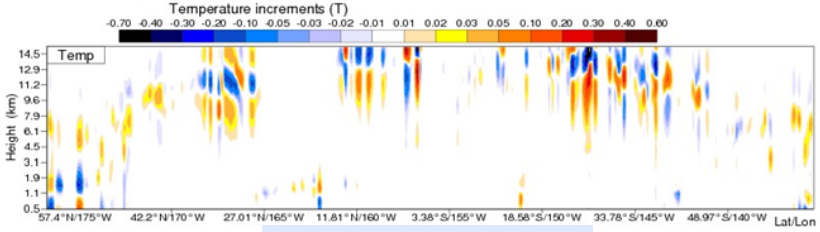
δq





δT





Radar

Lidar

ECMWF

Some other key missions

- **JAXA/JMA**
  - Himawari-8 – "MODIS on GEO!" (as GOES-R) ★
  - GCOM-W1: AMSR2 ★
  - GPM = NASA (US) + INPE (Brazil) + JAXA (Japan) ★
- **CMA**
  - Feng Yun satellite series
    - FY-3C similar to Metop ★
    - FY-4 similar to MTG

Soon!

- **ISRO / CNES**
  - Meghatropiques SAPHIR sounder ★
- **ESA / EUMETSAT / European Commission**
  - Sentinel-1 SAR
  - Begins Sentinel series: 2 to 5 carry many instruments of interest for atmospheric composition, marine and climate.
  - Vital component of Copernicus

Soon!

- **NSPO**
  - **COSMIC-2 (RO)**

Soon!

- **DoD, CSA, RosHydroMet, KMA, NSAOS, UCAR, DLR, CONAE, IMD**

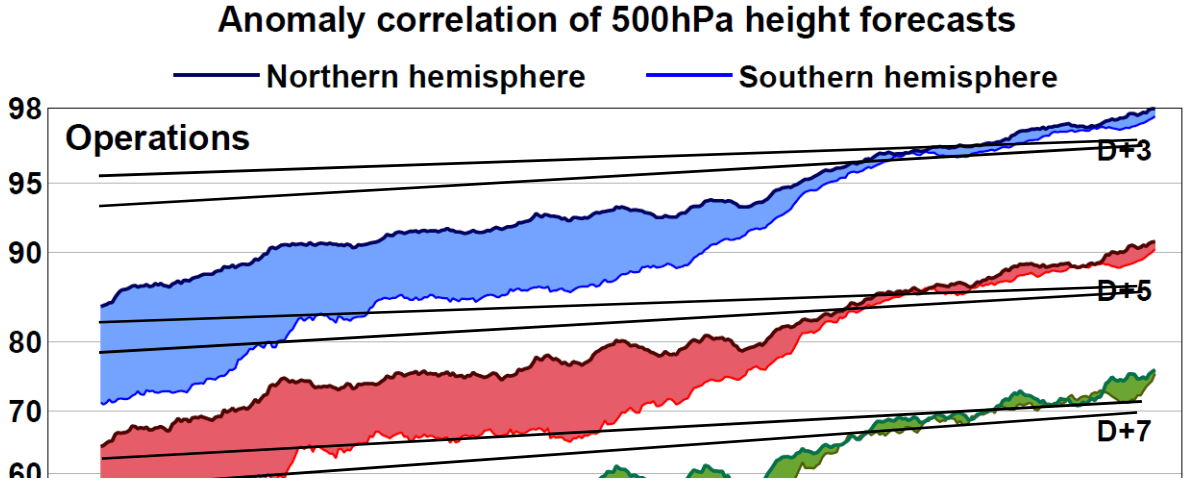
ECMWF

Beyond 2035?

- **MTG and EPS-SG (and equivalent plans elsewhere) mean we (mostly!) know what is coming up to ~2035**

- **What will we need 2035-2050?**
  - What horizontal and vertical resolution will NWP have reached?
  - What quantities will we be interested in?
  - What temporal frequency will we be interested in?
  - If we can't afford what we have now, what will we drop?
  - Will radio-frequency competition have killed passive microwave, which now is the cornerstone of meteorological observation?

- **We will need to be answering these questions in ~5 years time.**



Dee DP, Balmaseda M, Balsamo G, Engelen R, Simmons AJ, Thépaut J-N. 2014. Toward a consistent reanalysis of the climate system. Bull. Am. Meteorol. Soc. doi: 10.1175/BAMS-D-13-00043.1.