3D Winds derivation from infrared sounders

From the model concept to the product

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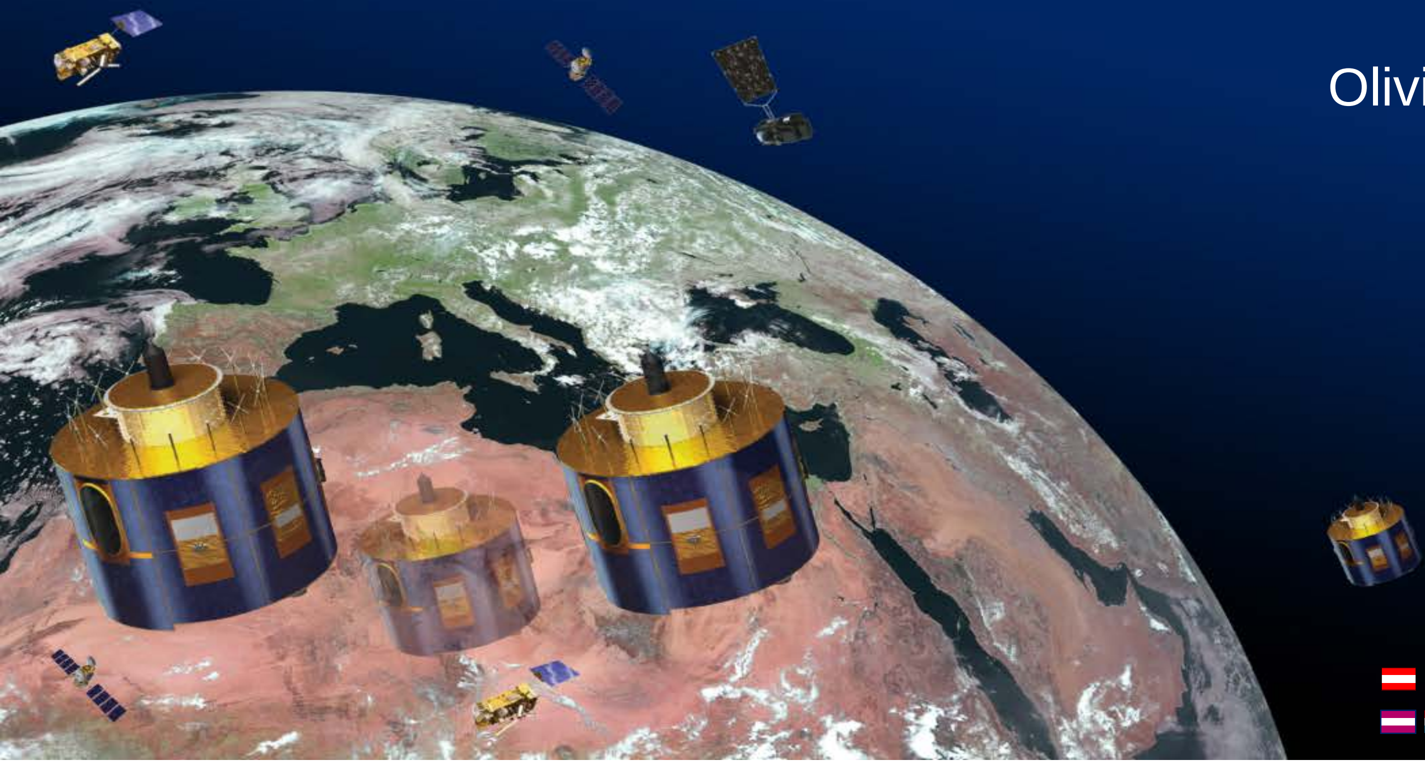


The AMV challenges

✓ Current AMVs limitations:

- AMVs give an information at a single level of the troposphere.
- Height assignment is known to be an important problem.
- Only few vectors at mid-level.
- Recurrent AMV problems in tropics area (fast speed biases) where important mesoscale phenomena impact the medium range forecast.

✓ The challenges:

- Ensure the production
- Better error characterisation
- Better information in Tropics
- Wind profiles

Which strategy adopted at Eumetsat?

✓ Known difficulties with IR sounders data

- Cross correlation tracking methods not very efficient considering smooth temperature/humidity fields. Not enough contrast/entropy for good matching.
- Really difficult to deal with convection.
- Each layer is considered separately.

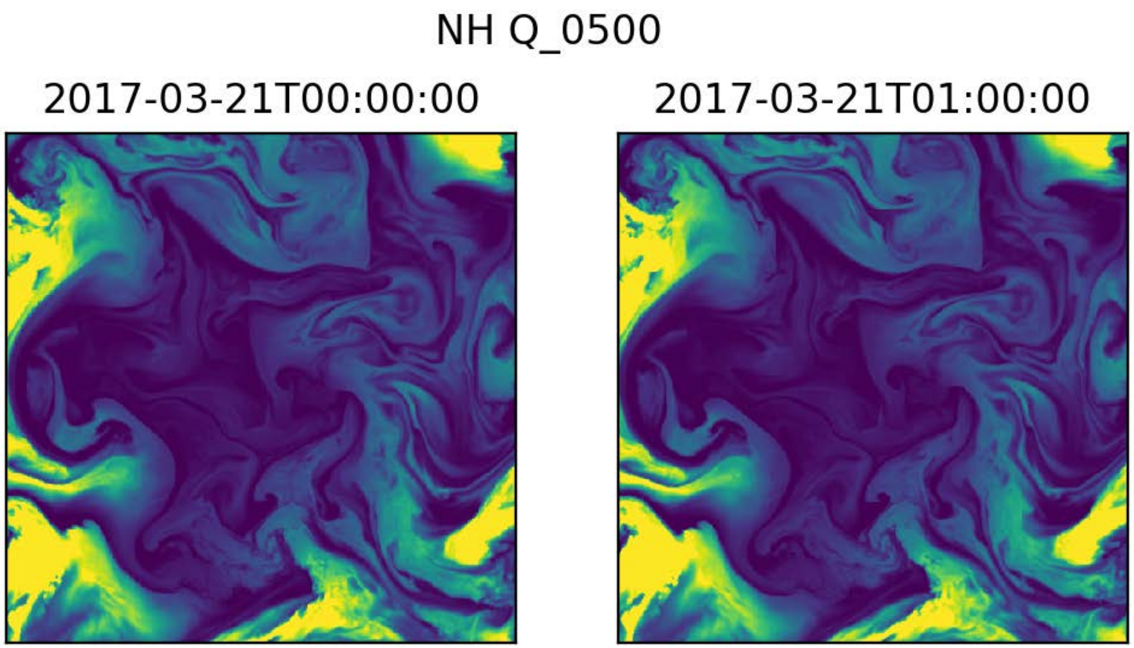
✓ 3D optical flow technique developped

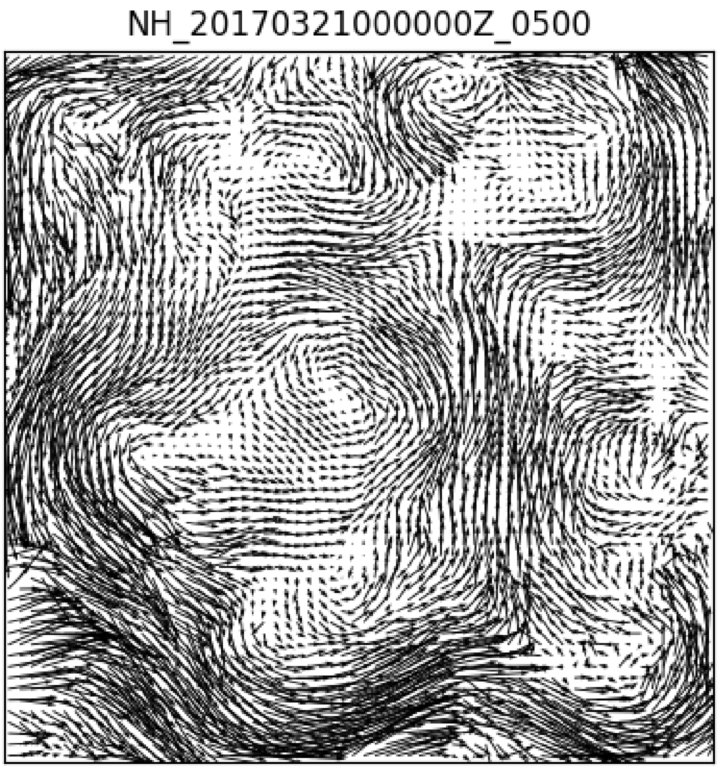
- Collaboration with P. Héas (INRIA)
- Derive winds from IR sounders Level 2 products
- Derivation of all pressure levels in one pass
  - Vertical motion is also considered
  - u, v, ω retrieved at each level on each grid pixel
- Operational model
  - Can run in real-time with reasonable computing resources
- Based on modern mathematics

The concept

Grid

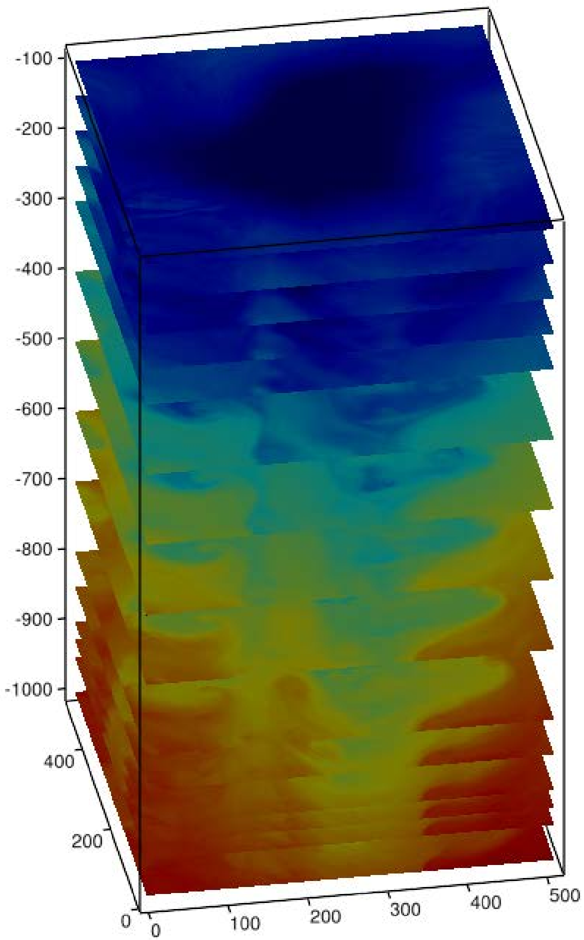
- **Polar stereographic projection**
- **Dimension: 512 × 512**
- **Resolution = 20 km**



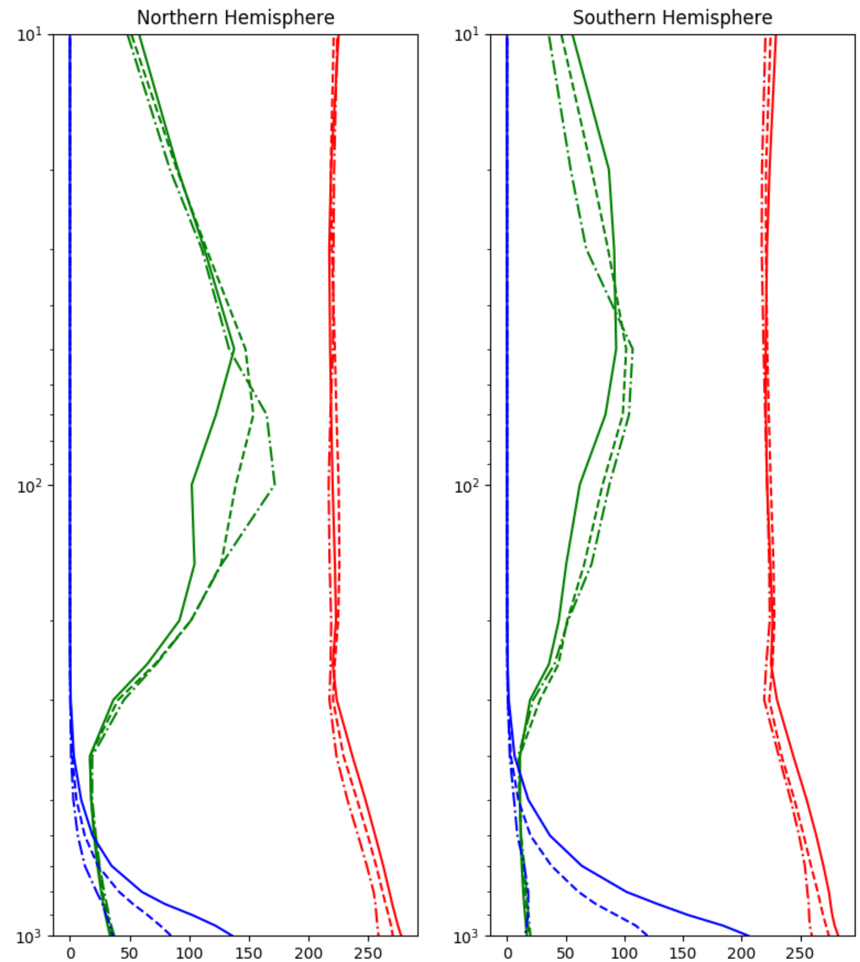


The concept

Joint inversion of all vertical levels



3 geophysical variables considered



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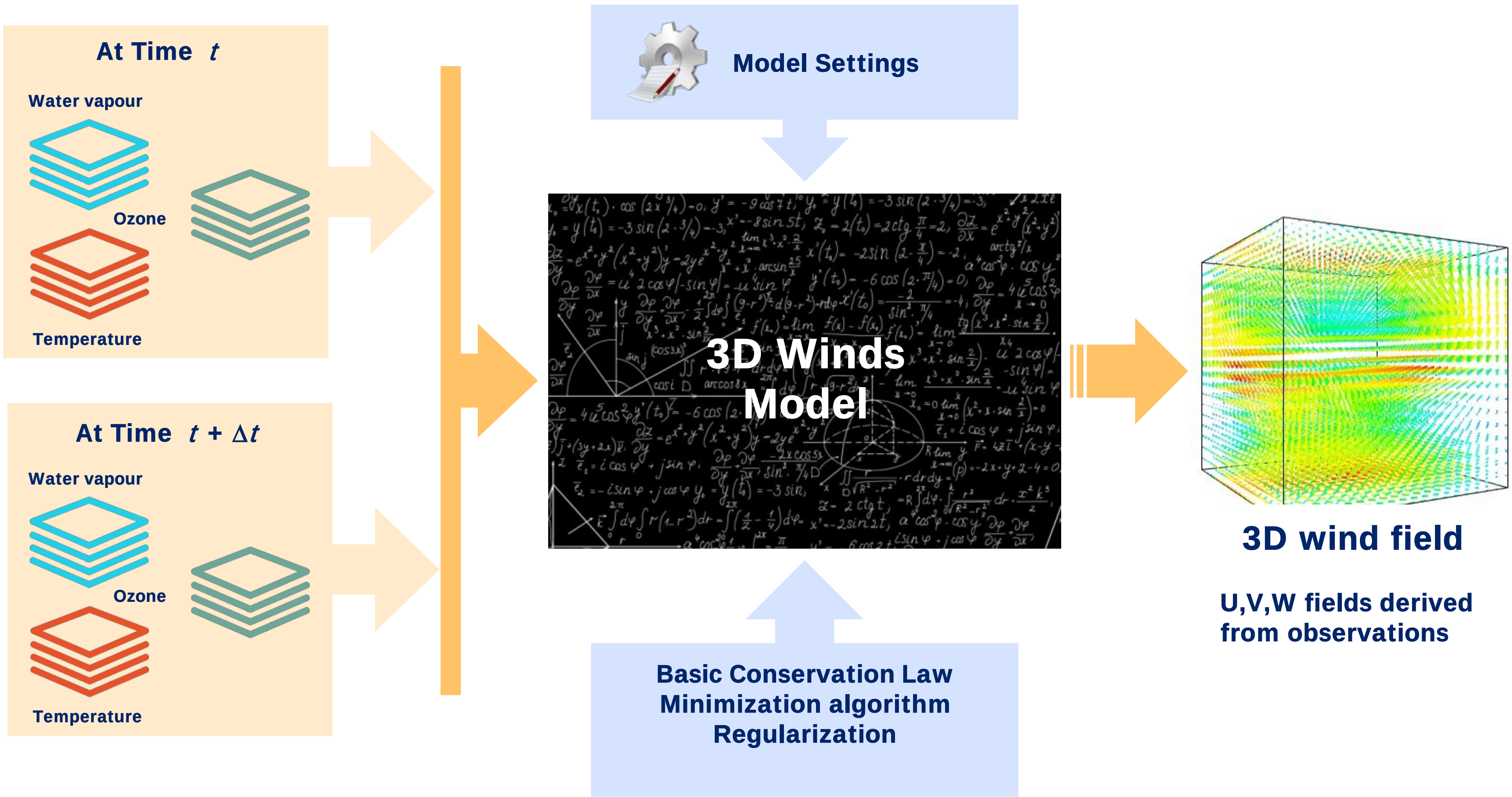
The model



At Time t
Water vapour
Ozone
Temperature
At Time t + Δt
Water vapour
Ozone
Temperature
Model Settings
3D Winds Model
Basic Conservation Law
Minimization algorithm
Regularization
3D wind field
U,V,W fields derived from observations

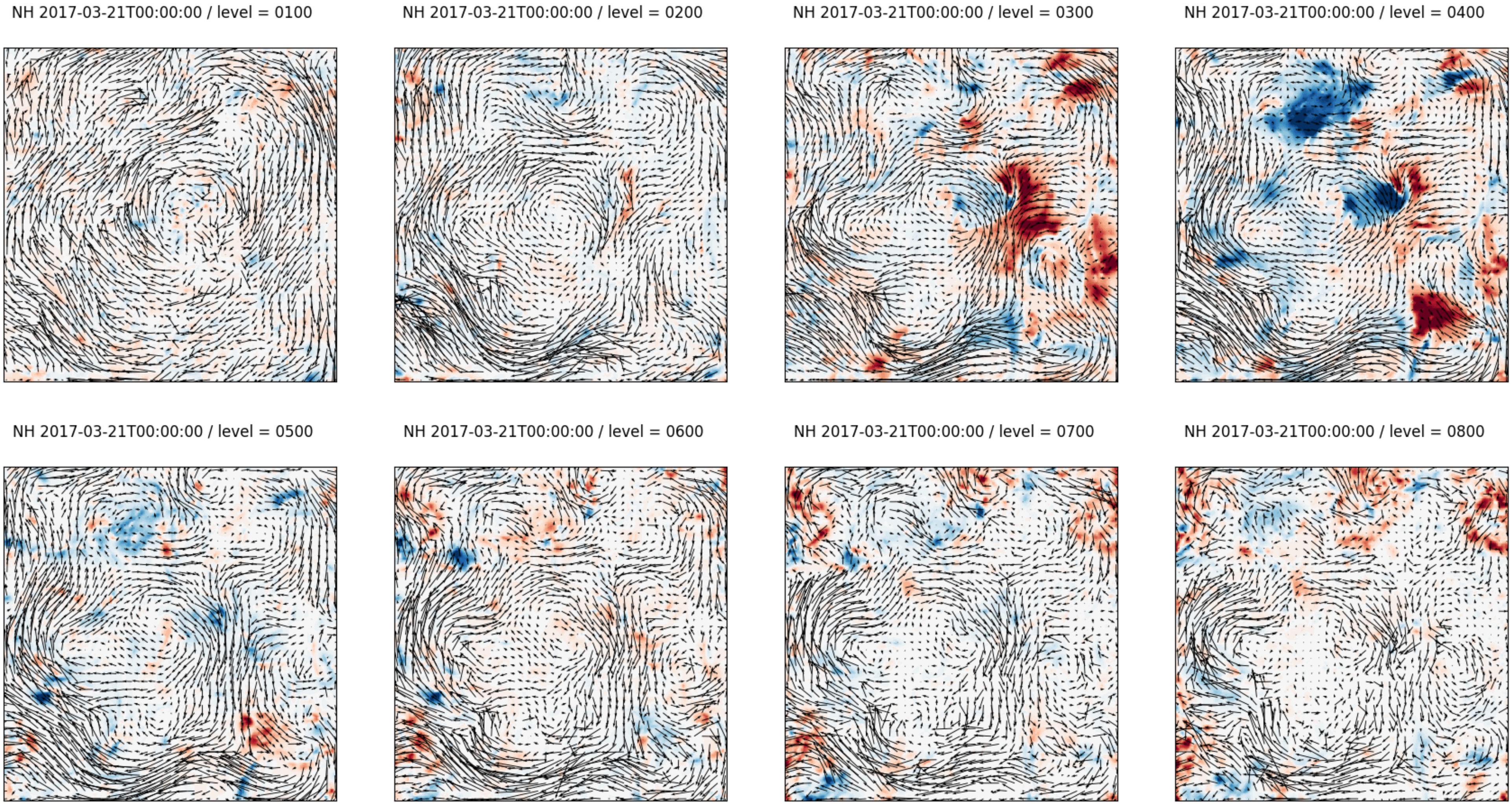
The model

- Atmospheric dynamics equations
  - For one variable at a pressure level:

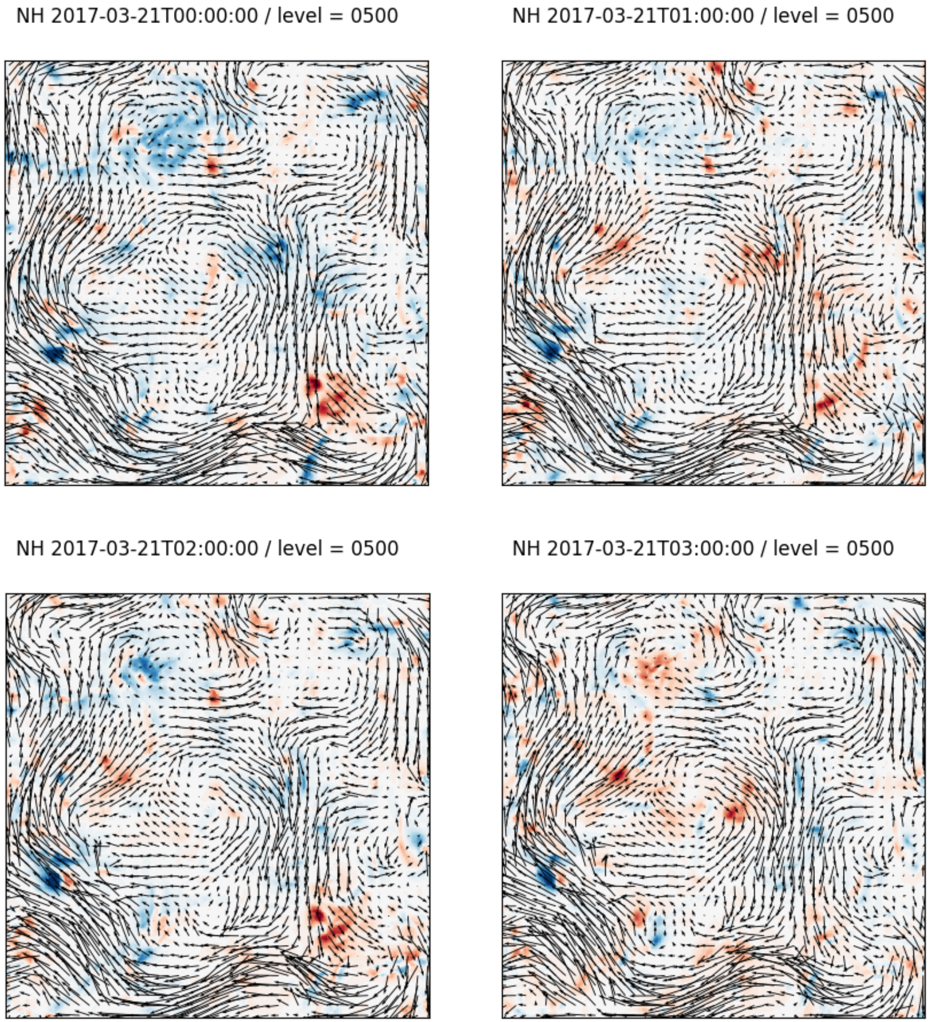
$$\left.\frac{\partial O_3}{\partial t}\right|_p + u\left.\frac{\partial O_3}{\partial x}\right|_p + v\left.\frac{\partial O_3}{\partial y}\right|_p + \omega\frac{\partial O_3}{\partial p} = 0$$

- … and that's all!
  - no Navier-Stokes
  - no Coriolis
  - no friction law
  - no …
- … plus a pinch of mathematics
  - ➢ to resolve the ill-posed problem

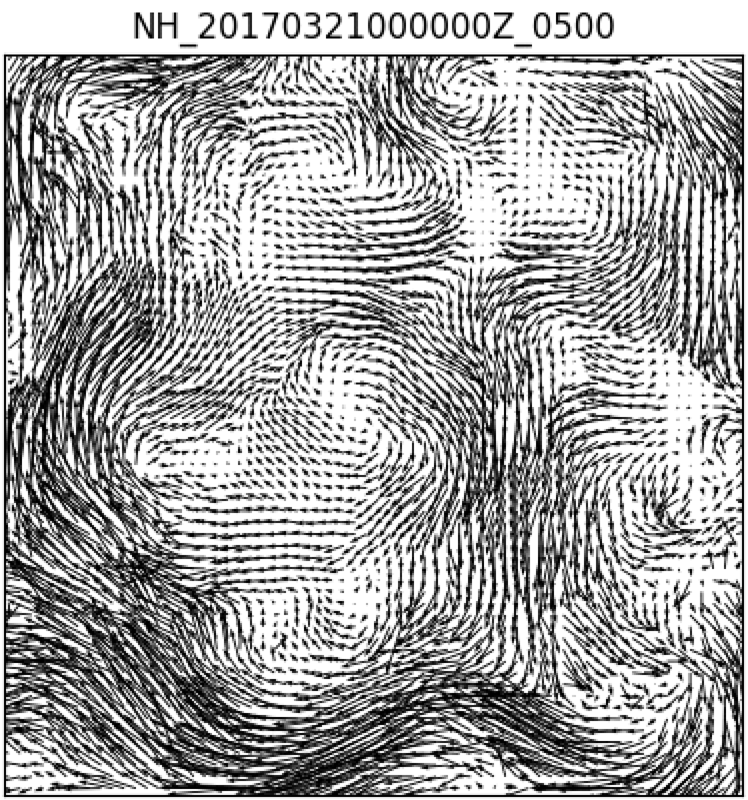
Full 3D winds retrieval



3D + Time dimension



4Dwinds!



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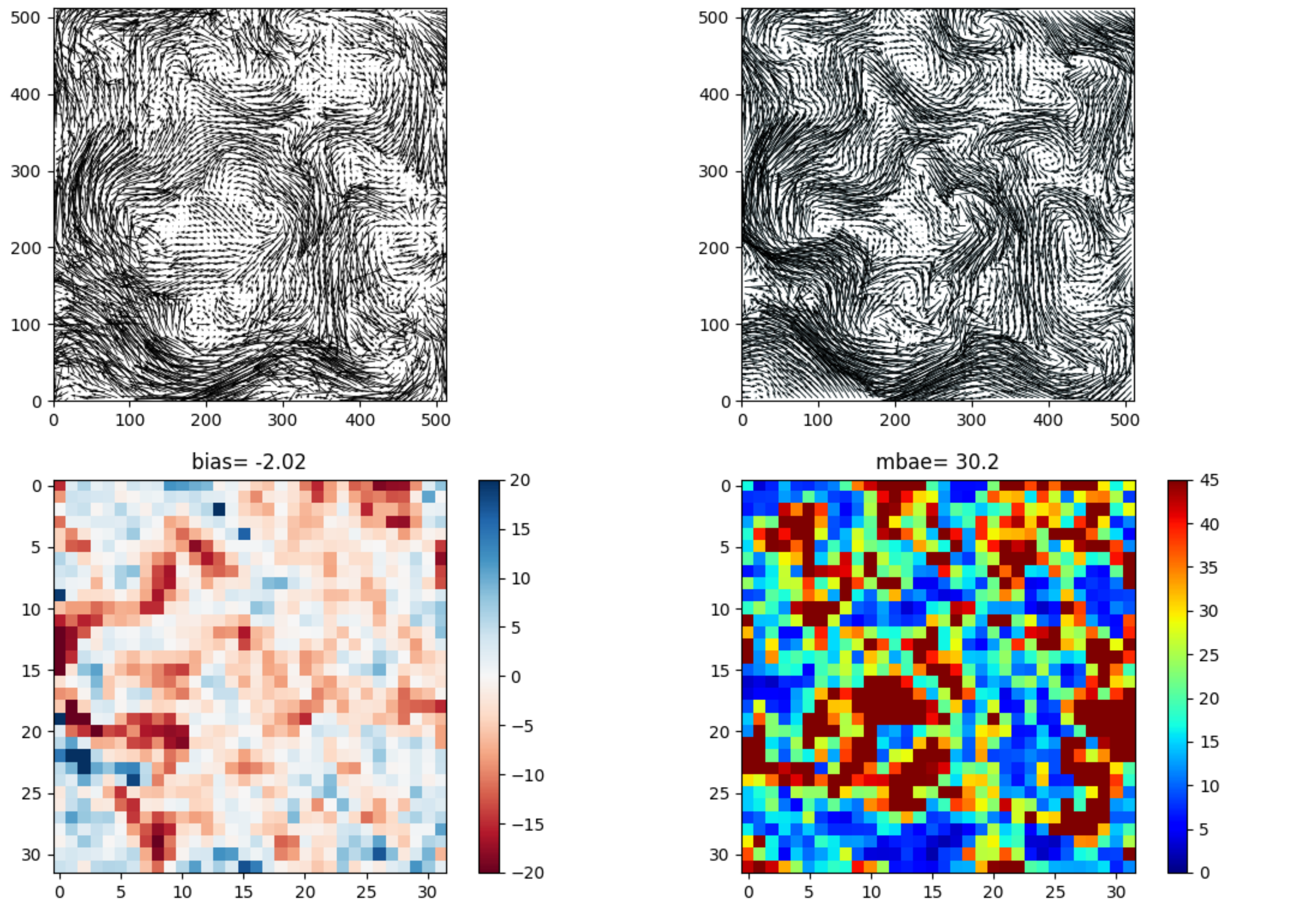
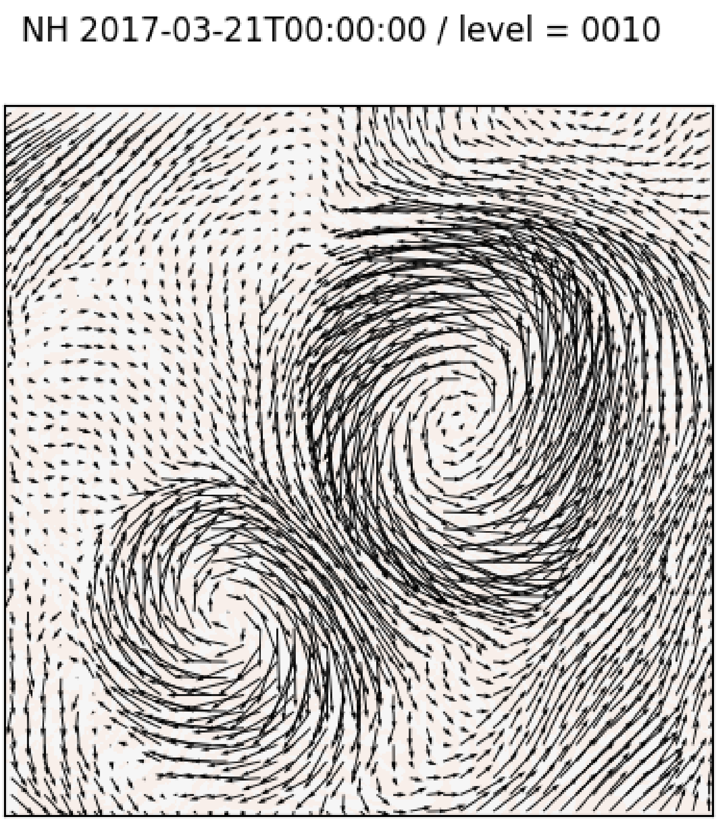
Comparison against forecast (All vectors)

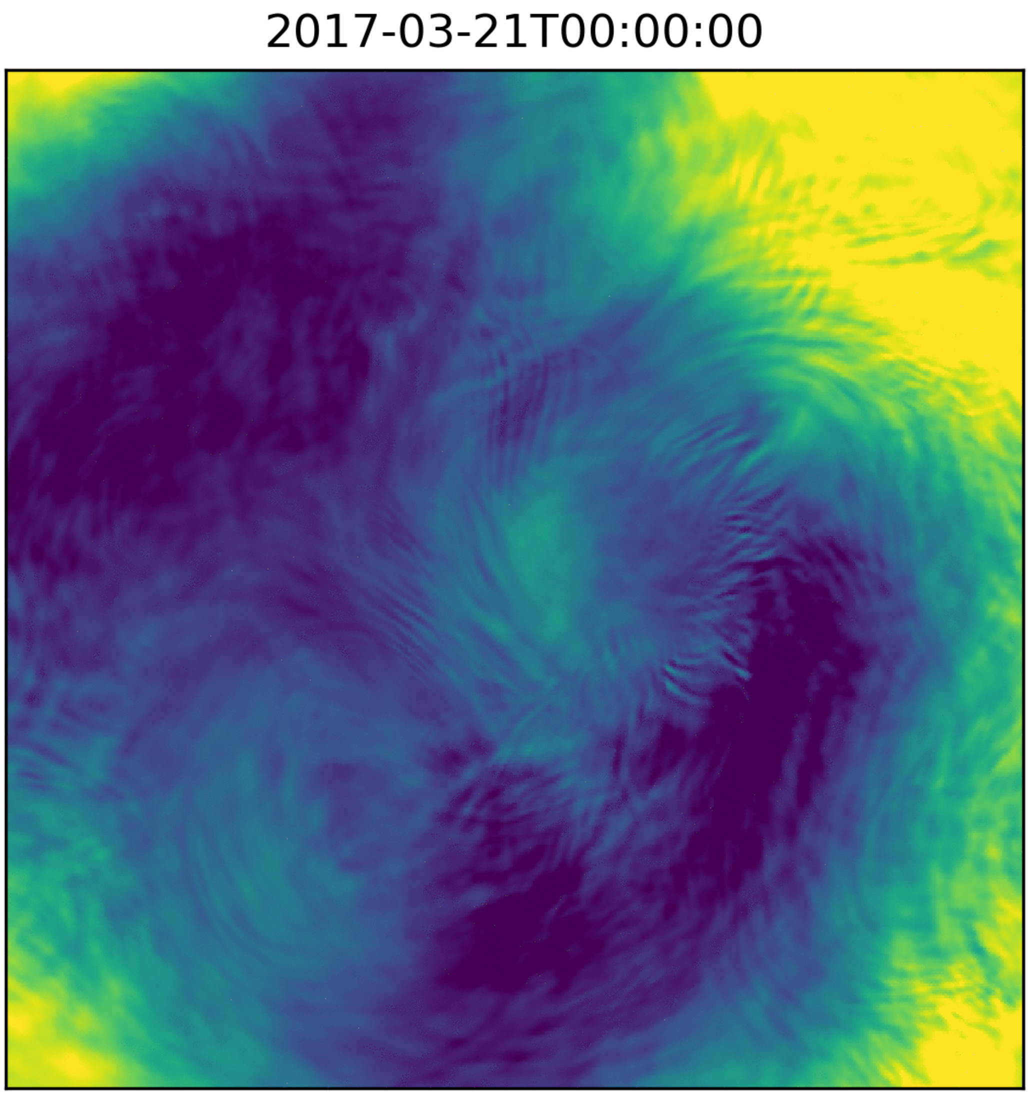
Derived

Forecast winds



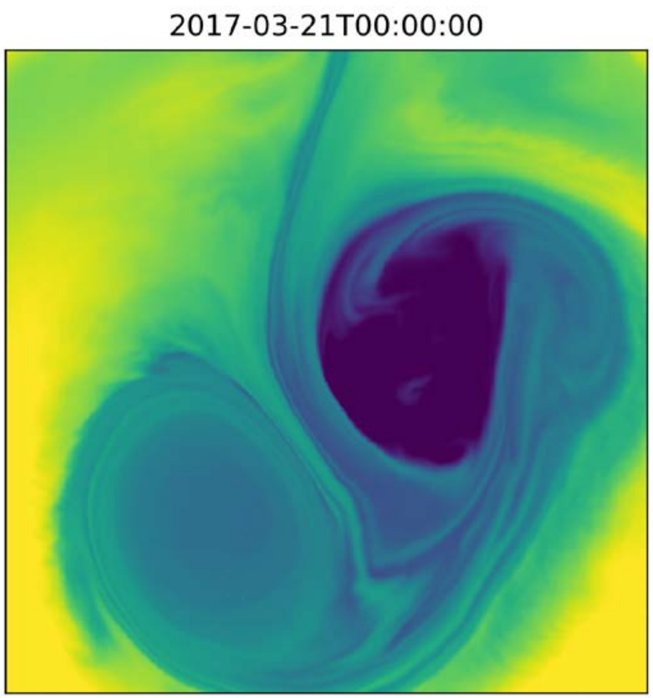
Back to the challenge: the limitations

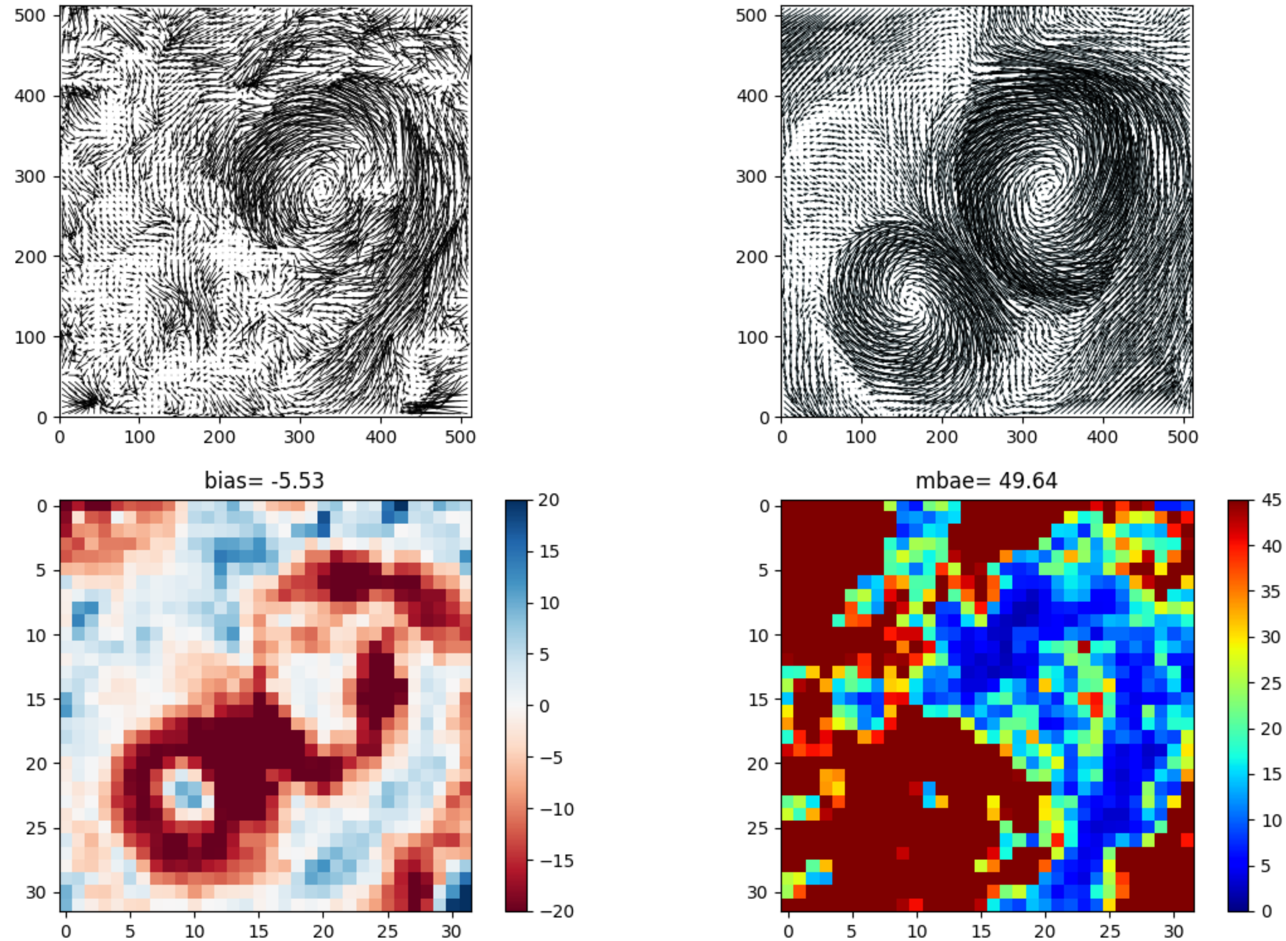




Back to the challenge: the limitations

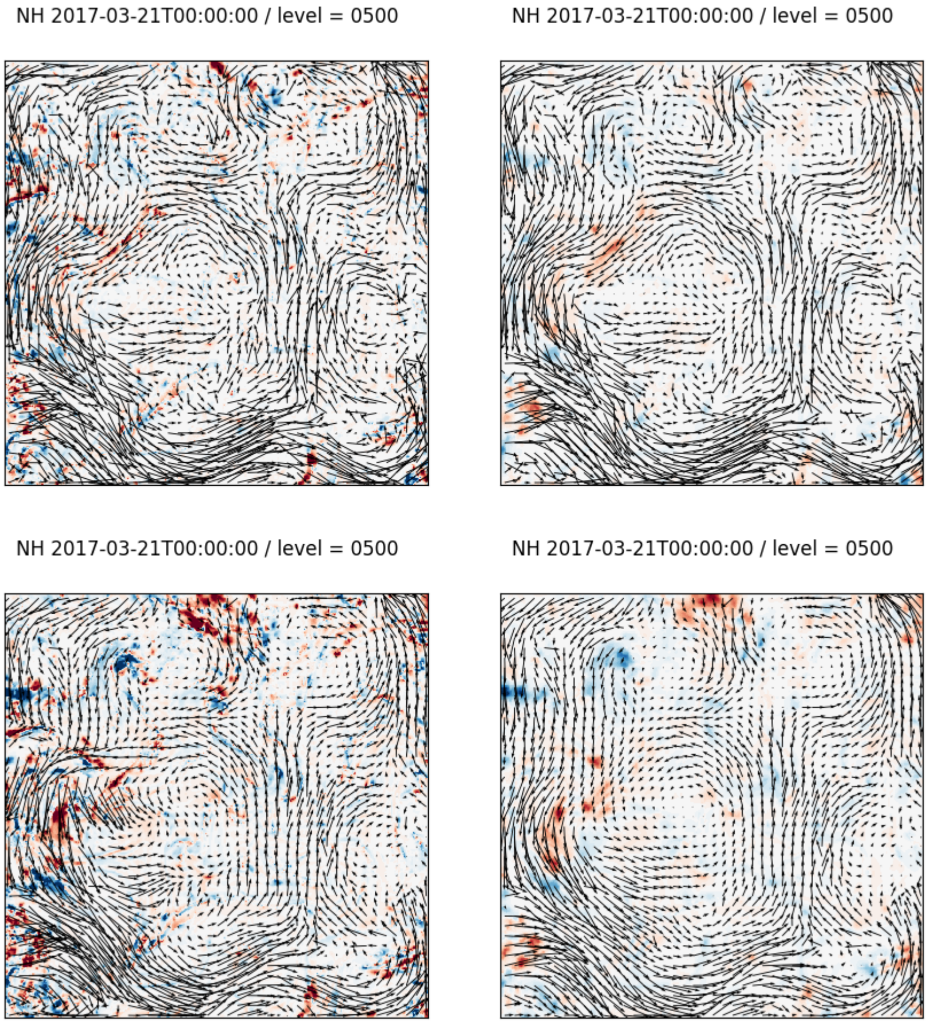
- Large displacements are not a problem, but uniform fields are.



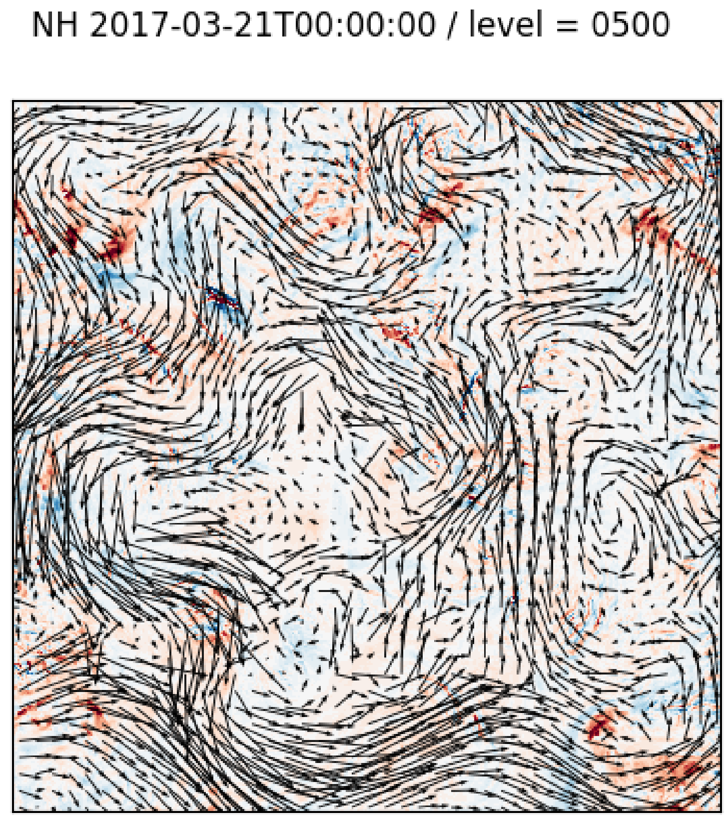


Back to the challenge: hyper-parameters tuning

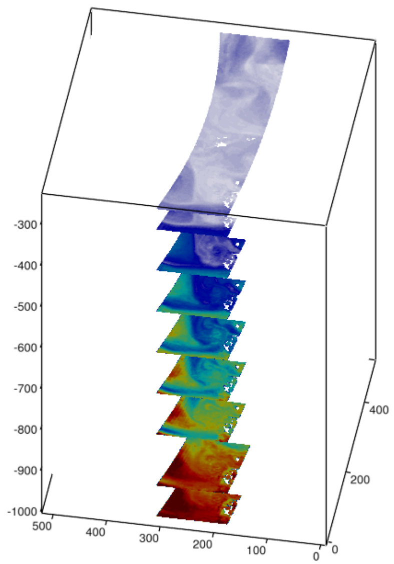
3D winds derivation tests



Forecast winds field



Application to IASI data

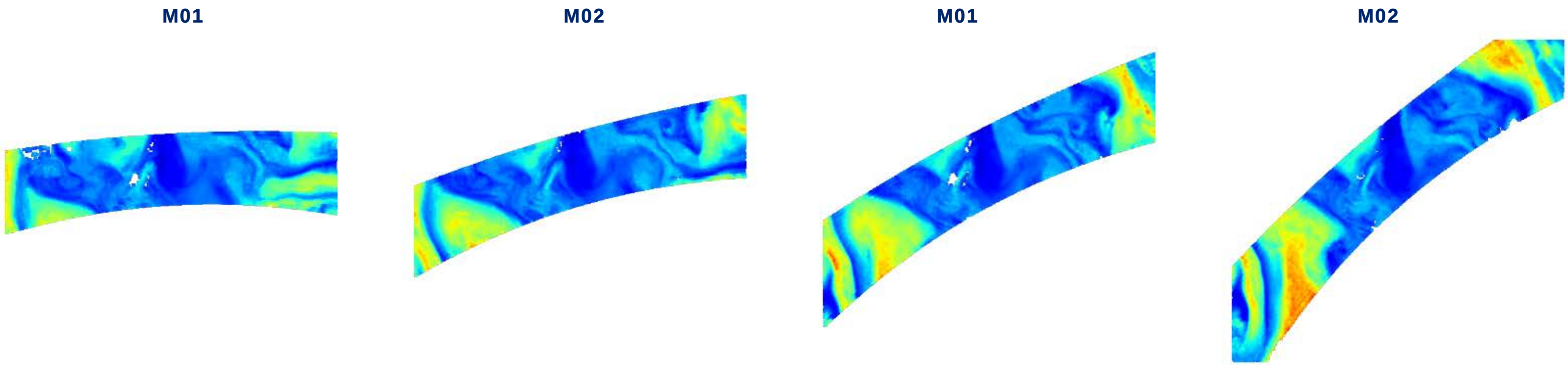


- **Source:**
  PW3 dataset in IASI_SND_02 or EARS products (operational production at Eumetsat)

- **Platform:**
  Metop-A and Metop-B to maximize the overlap between the images

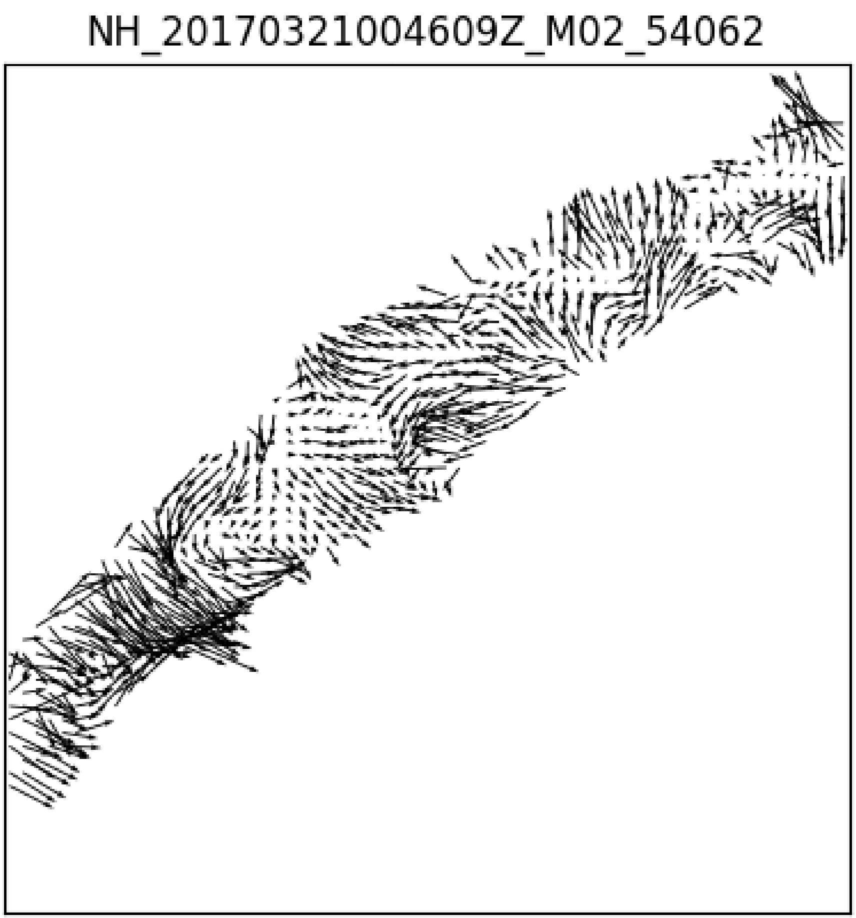
- **Ozone, Water Vapour and Temperature fields**
  Interpolated on standard pressure levels
  Re-gridded on Polar stereographic grid

Humidity at 500 hPa for successive overpasses



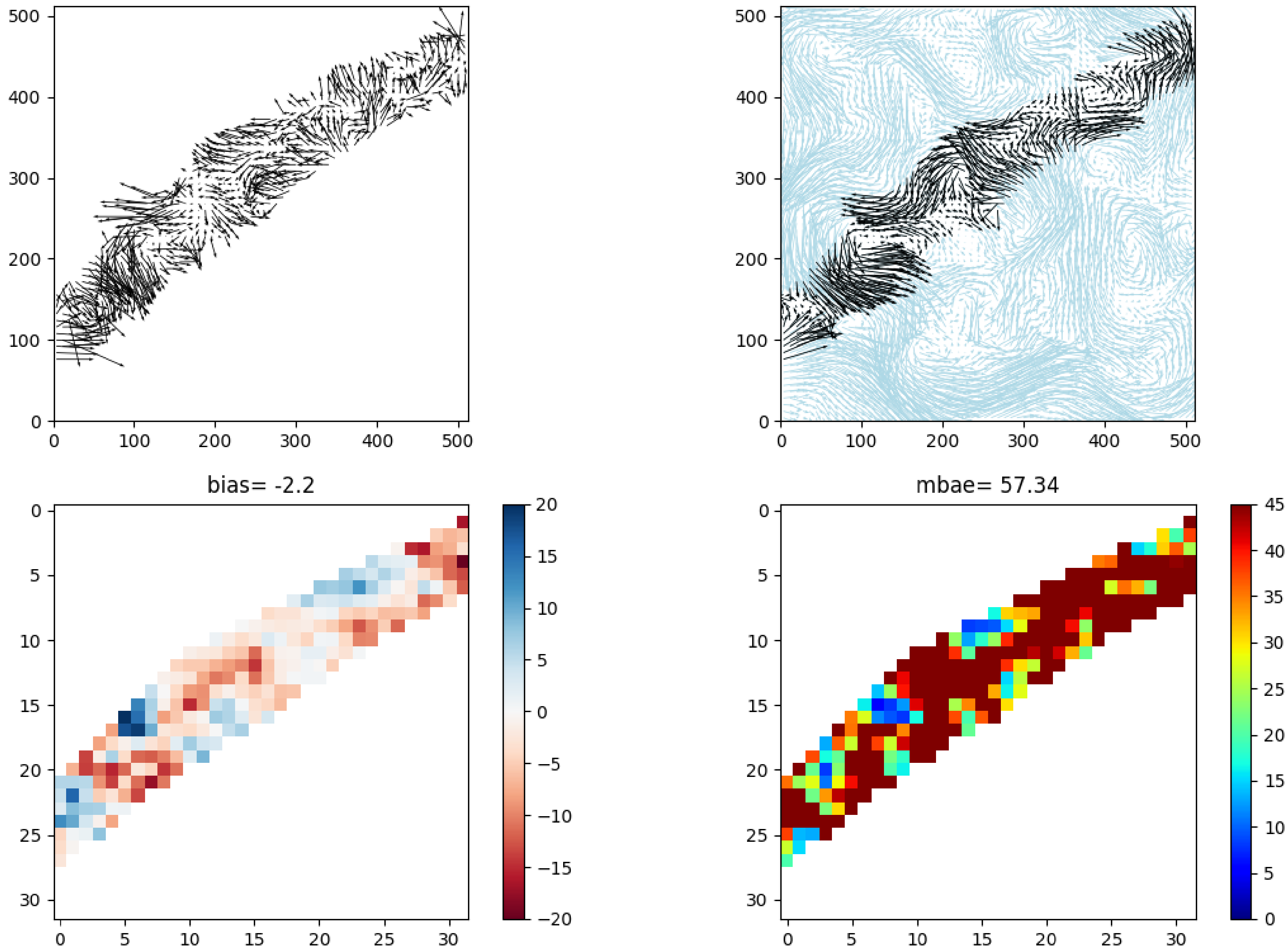
One day of IASI 3D winds

- Northern high-latitudes area
  - ~ 45N polewards
- 21 Mars 2017
- Winds retrieved at 500 hPa using only two orbit passes
- M01 and M02 products used

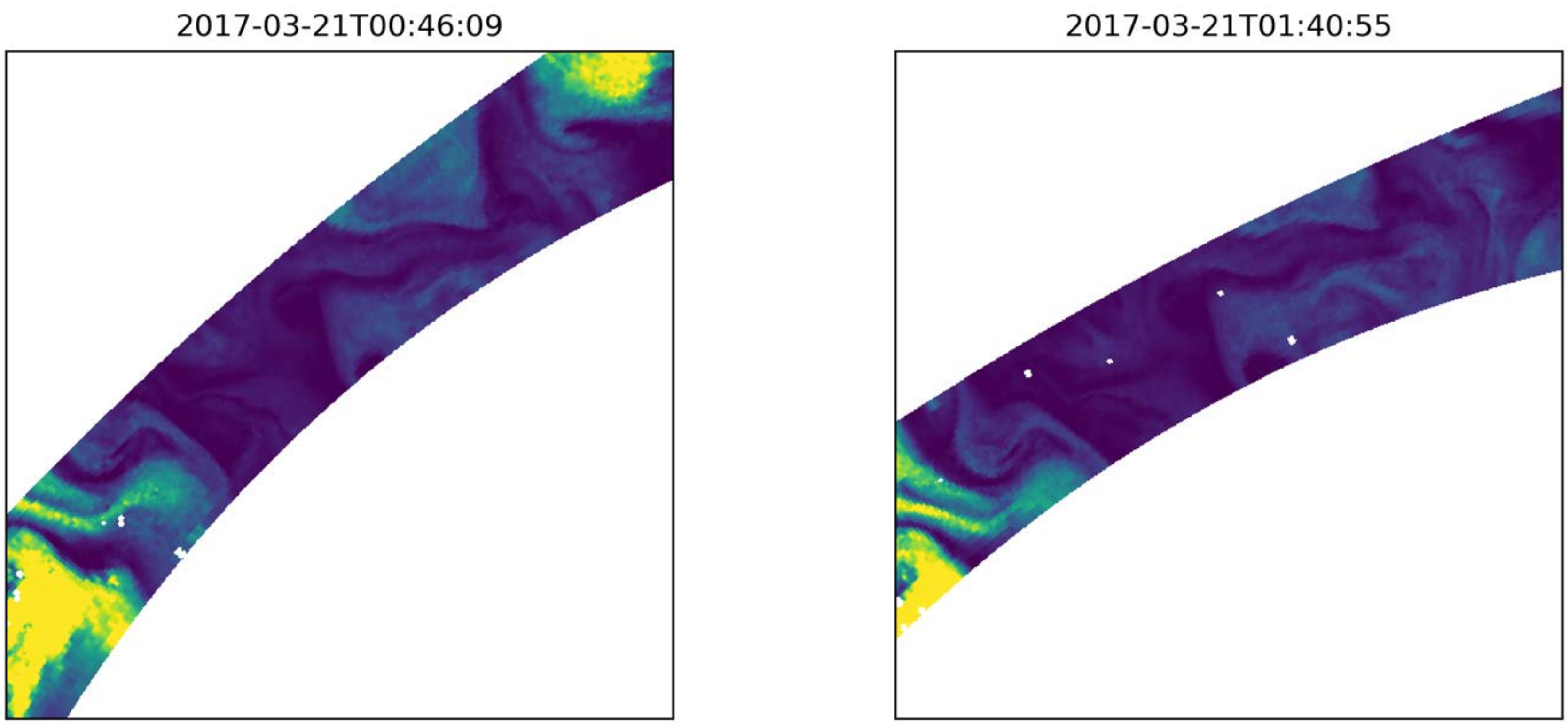


IASI 3D winds

- IASI 3D winds
- 500 hPa
- All vectors considered in statistics

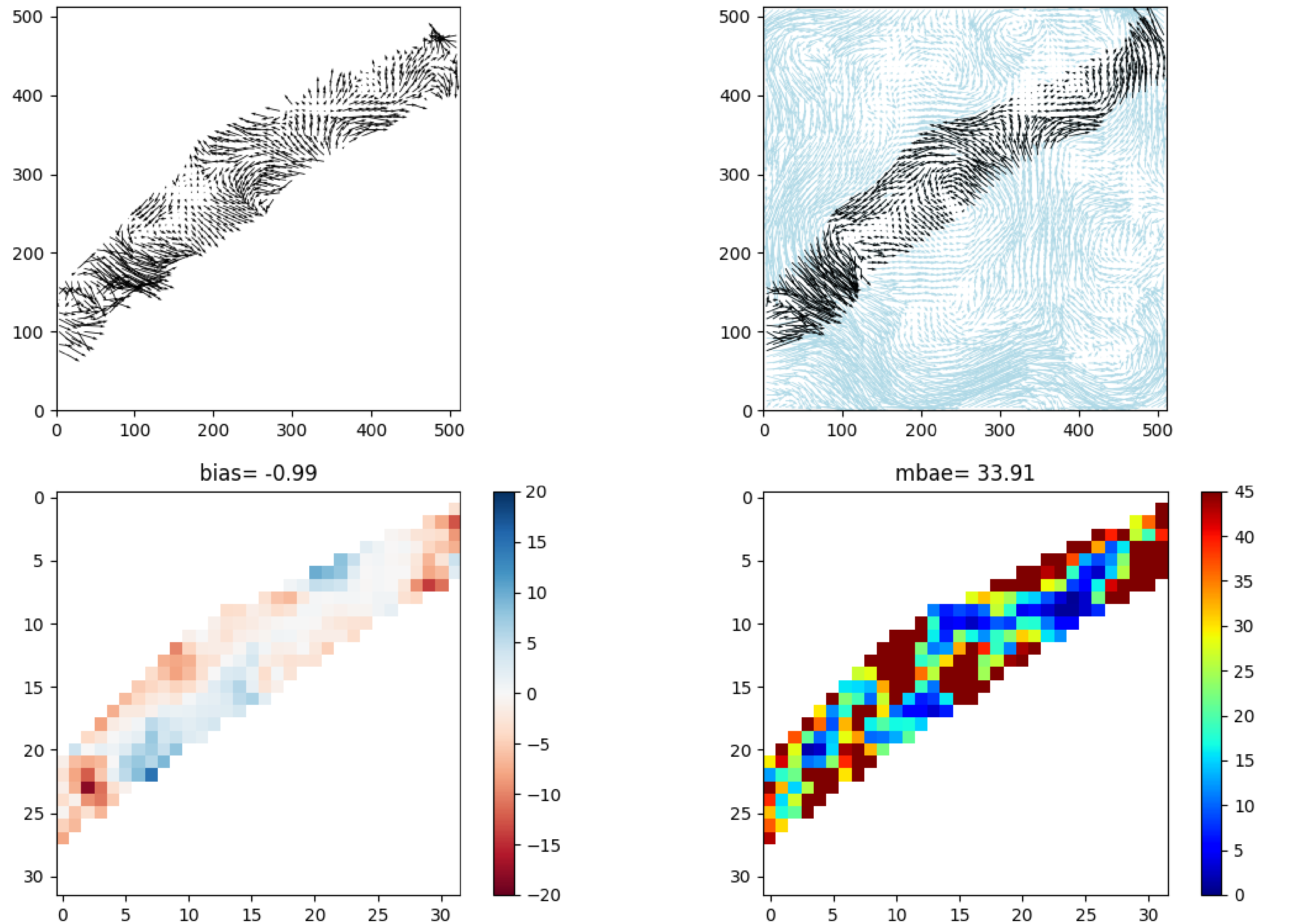


Back to the challenge: effect of orbits swath



Back to the challenge: effect of orbits swath

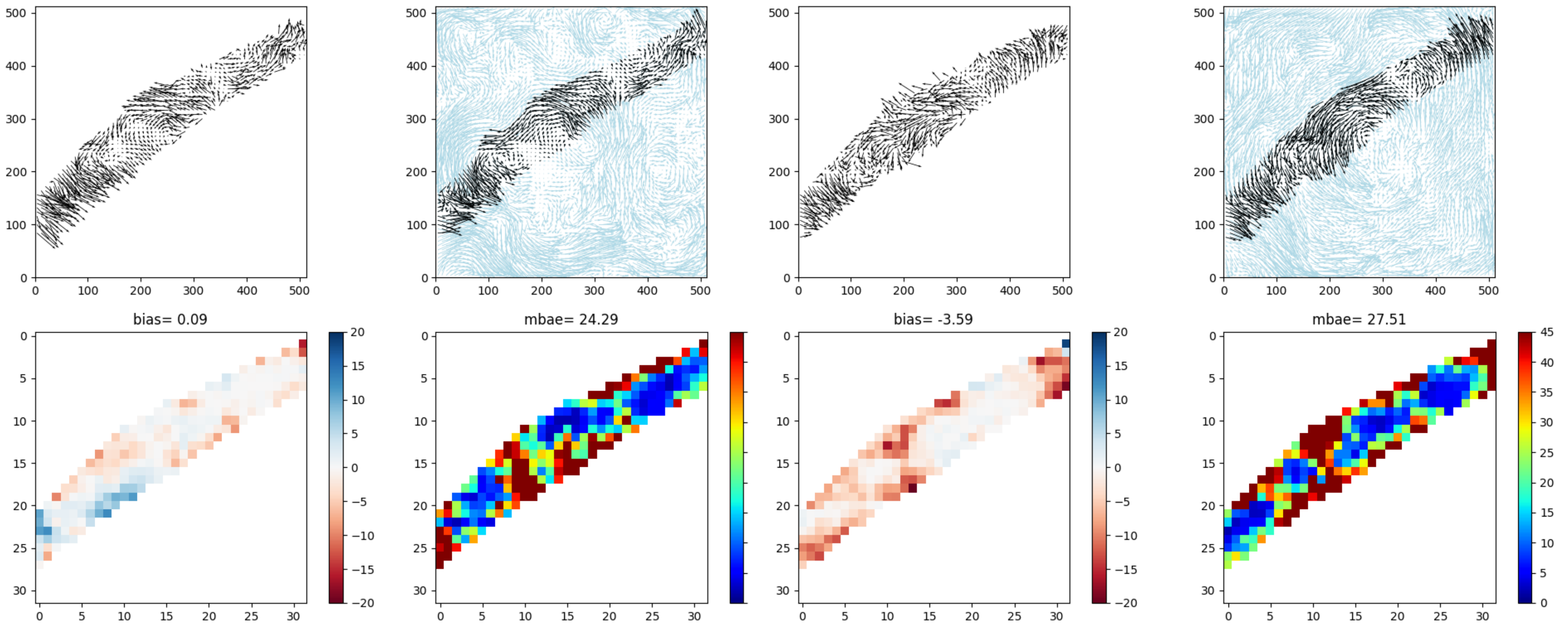
500 hPa



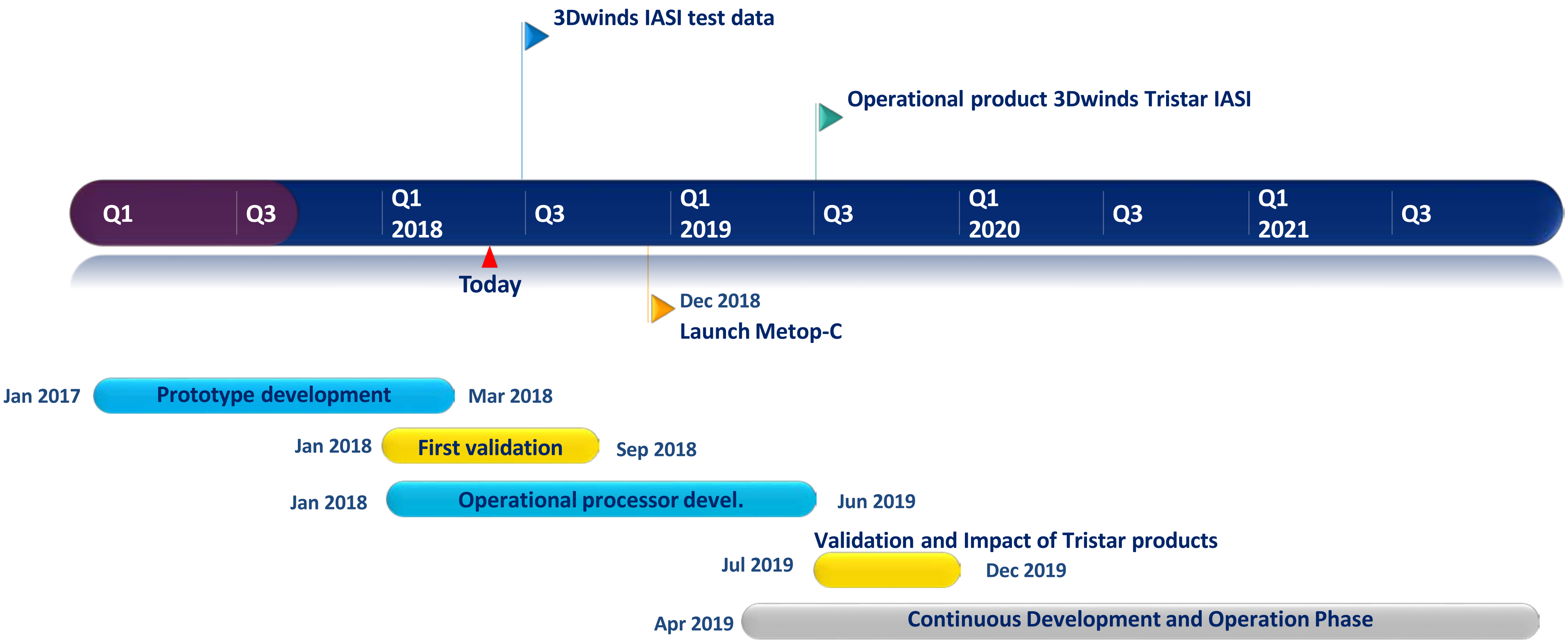
Back to the challenge: effect of orbits swath

- Effect varies upon the scale of phenomenon observed

700 hPa **100 hPa**



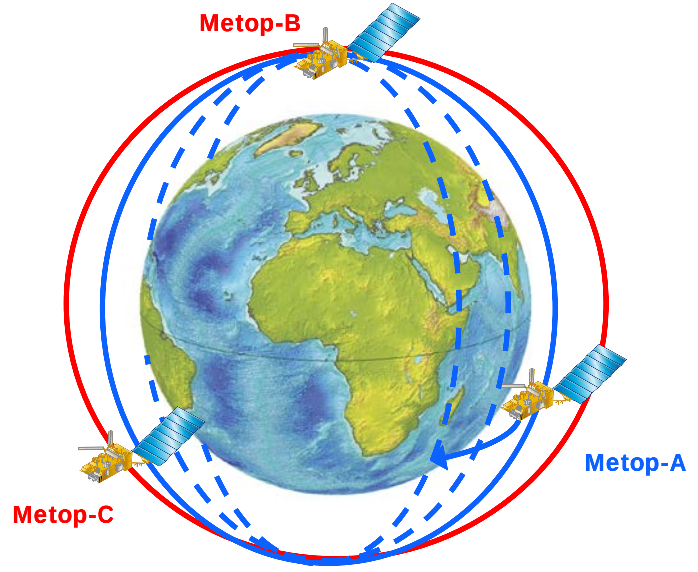
3D winds IASI products development timeline



3D winds IASI product characteristics (*Tristar*)

✓ Tristar configuration on 9:30 orbit

- Production in 2019 after Metop-C commissioning phase
- ~30-35 minutes of separation between successive views
- ➢ *Quality will benefit from the reduced time gap*



✓ Coverage

- Production on Northern and Southern Hemispheres (poleward of 45°)
- Polar Stereographic grid 512x512 pixels, resolution = ~20 km
- ~3-4 successive observations around 9:00-10:00 (local solar time) Same around 21:00-22:00 (ascending part) for latitude 60°.
- ➢ *Time consistency will benefit from successive observations capability*

✓ Profile

- 20 levels from 10 to 1000 hPa, covering Low Stratosphere to Surface
- Vertical resolution: ~0.5 km for LT, ~1.5 km for HT, ~2km for LS

✓ Timeliness (expected)

- For SH products: ~1h - 1h30 after South Pole overpass
- For NH products: ~1h - 2h30 after North Pole overpass (depending on possible secondary dump on McMurdo station)

➢ *Fulfill the Global NWP application requirements, at threshold for High Res NWP.*

Summary

- Algorithm is working
  - Wind fields derived and consistent
  - No guess needed
  - And it's fast (~2-3 minutes for single-threaded version, grid 512×512, 19 levels)
  - Hyper-parameters settings
    - First set of parameters set
    - May be tune during the validation phase

- IASI 3D winds product in development
  - Mask processing to handle missing data introduced
  - Use the same set of hyper-parameters
  - Test data can be generated but they will be analysed previous distribution

Future works planned (or potentiential)

- Quality index
  - Based on the actual model contribution of the data sample
  - Should mask uniform region and noisy pixel
- IASI (better) input data characterisation
  - To tune the data filtering
- Reduce the effect of orbit swath borders
  - In the pre-processing
  - Or / and change the scheme of the data use in the model (in v2)
- Validation and inter-comparison study
  - Scientific validation against lidar network, RadObs, Forecast, Aeolus
  - Comparison with CIMSS AIRS winds, AVHRR winds, …
  - Test on Ensemble Nature Runs (Synthetic data high resolution)
- Adaptation to other input datasets

To be continued…

Thank You!

User Requirements

- Requirements extracted from WMO Oscar database
  - For High Troposphere Level (~700 – 200 hPa)

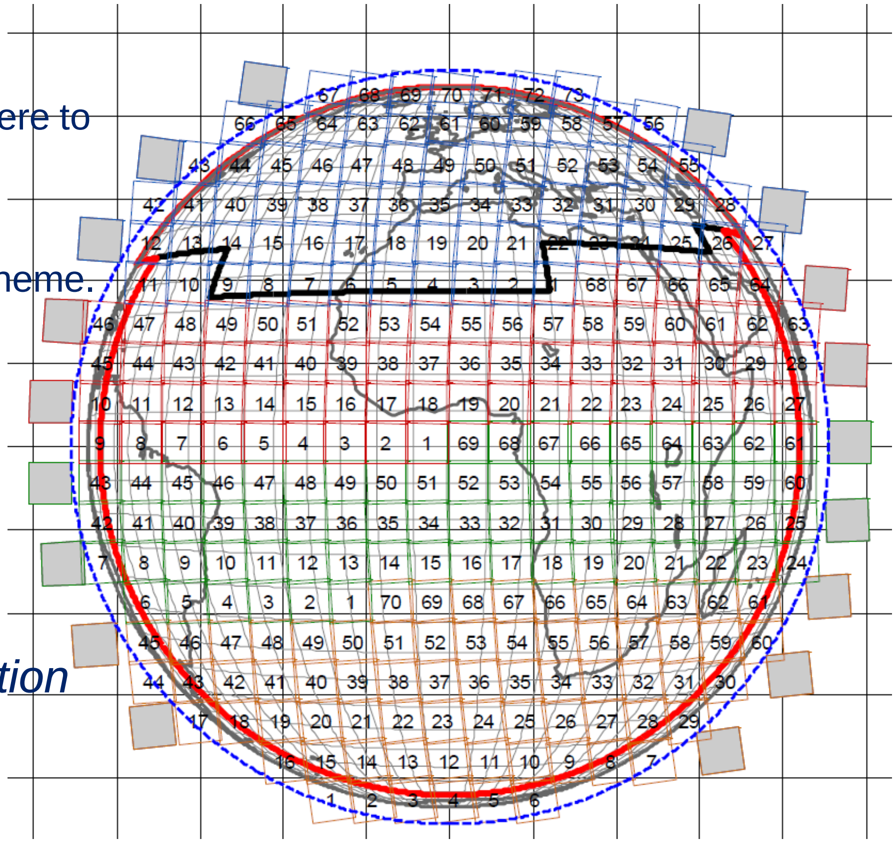
	Application	Uncertainty	Horizontal resolution	Vertical resolution	Observation cycle	Timeliness
Wind (horizontal)	Global NWP	1 m.s^{-1} 3 m.s^{-1} 8 m.s^{-1}	15 km 100 km 500 km	0.5 km 1 km 3 km	60 min 6 h 12 h	6 min 30 min 6 h
	High Res NWP	1 m.s^{-1} 3 m.s^{-1} 8 m.s^{-1}	2 km 10 km 20 km	0.5 km 0.7 km 1 km	15 min 60 min 12 h	15 min 30 min 2 h
Wind (vertical)	Global NWP	1 cm.s^{-1} 5 cm.s^{-1} 5 cm.s^{-1}	15 km 200 km 500 km	0.5 km 2 km 3 km	60 min 6 h 12 h	6 min 30 min 6 h
	High Res NWP	1 cm.s^{-1} 2 cm.s^{-1} 5 cm.s^{-1}	5 km 10 km 20 km	0.5 km 0.65 km 1 km	15 min 60 min 12 h	15 min 30 min 2 h

Colors refers to the goal ; breakthrough ; threshold

3D winds MTG-IRS product characteristics

- Coverage
  - 4 LAC (Local Area Coverage) defined
  - LAC4 covers Europe, Mediterranean Basin and North Atlantic. It is acquired every 30 minutes.
  - Pixel sampling = 4 km at SSP
  - ➢ *Spatial resolution enhanced will allow the use in High Res NWP application*
- Profile
  - 20 levels from 10 to 1000 hPa, covering Low Stratosphere to Surface
- Frequency
  - Number of products per day depends on acquisition scheme.
  - Current baseline:
    - 48 products for LAC4
    - 16 products for LAC3
    - 12 products for LAC2
    - 8 products for LAC1
- Timeliness (expected)
  - ~45 minutes after LAC acquisition

➢ *Fulfill the Global NWP and High Res NWP application requirements*



MTG-IRS User requirements (EURD Version 2, 2008)

MTG-IRS products

- **Temperature and Humidity Profile Product (THPP)**:

The Temperature and Humidity Profile Product will provide infor
of temperature and humidity. It will include surface tem
from IRS observations for clear sky fields of vi
cloud types. The product will be avai

- **Clear Sky Win**

The clear
uct and will
clear sky and for

MTG-IRS wind products are not committed for day 1, but as 'aspirational'.

From: EUMETSAT HQ Level 2 Products Generation and Dissemination baseline for MTG (EUM/MTG/DOC/09/0026, 2013)

uct will be derived from IRS observations for clear sky fields
ormation on ozone and co in broad atmospheric layers.

Cloud Product (IRS-CP):

The IRS-Cloud Product will contain micro and macro physical information of clouds within the field of view, like cloud fraction, cloud top height, cloud effective radius. It will be derived from the IRS instrument for all <pixels>, and will include an error estimation of the various parameters.

State of the art extracting winds from IR sounders

- BACKGROUND

✓ EUMETSAT fellow at Met Office, L. Stewart, study done using simulated spectra generated by Met Office UKV 1.5km model.

✓ External study done by DLR for EUMETSAT in 2006. Humidity fields mimicked from Lokall-Modell LM from DWD.

✓ Product recently developed at CIMSS with AIRS (Santek et al., 2016). Presently in demonstration, showed some potential in assimilation experiment in GEOS-5 model (NOAA/NCEP)

State of the art winds extraction from IR sounders

✓Upcoming products:

- IR sounder 3D winds from EPS-IASI at EUMETSAT
- IR sounder winds from CRiS, IASI at CIMSS

✓Potential mid-term products:

- IR sounder 3D winds from MTG-IRS
- IR sounder 3D winds from EPS-SG - IASI-NG
- New spatial missions with 3D winds as primary product

Thomas Pagano, *NASA/JPL: Status of NASA's Atmospheric Infrared Sounder (AIRS) and CubeSat Infrared Atmospheric Sounder (CIRAS) Projects*, EUMETSAT Satellite conference, 2017

Kevin Maschhoff, *BAE systems: MISTiC Winds, a micro-satellite constellation approach to high resolution observations of the atmosphere using infrared sounding and 3D wind measurements*, IWW13, 2016

…etc

International interest and support

✓CGMS-45: Jeju Island, Republic of Korea, 11-16 June 2017

A45:03: IWWG to liaise with the NOAA representative on PSTG (Jeff Key, jeff.key@noaa.gov) regarding the potential use of 3D winds from AIRS for Year of Polar Prediction studies.

✓Sixth WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction, Shanghai, China, 10-13 May 2016:

Recommendation 4: Additional data impact studies for new AMV products (e.g. LEO-GEO winds, IR sounder winds, MISR winds) are strongly encouraged.

✓IWW13: Monterey, USA, 27 June-1 July 2016

Recommendation to space agencies: to implement satellite missions that allow the provision of wind profile information with global coverage (e.g., DWL, hyperspectral IR with high temporal frequency and spatial resolution).