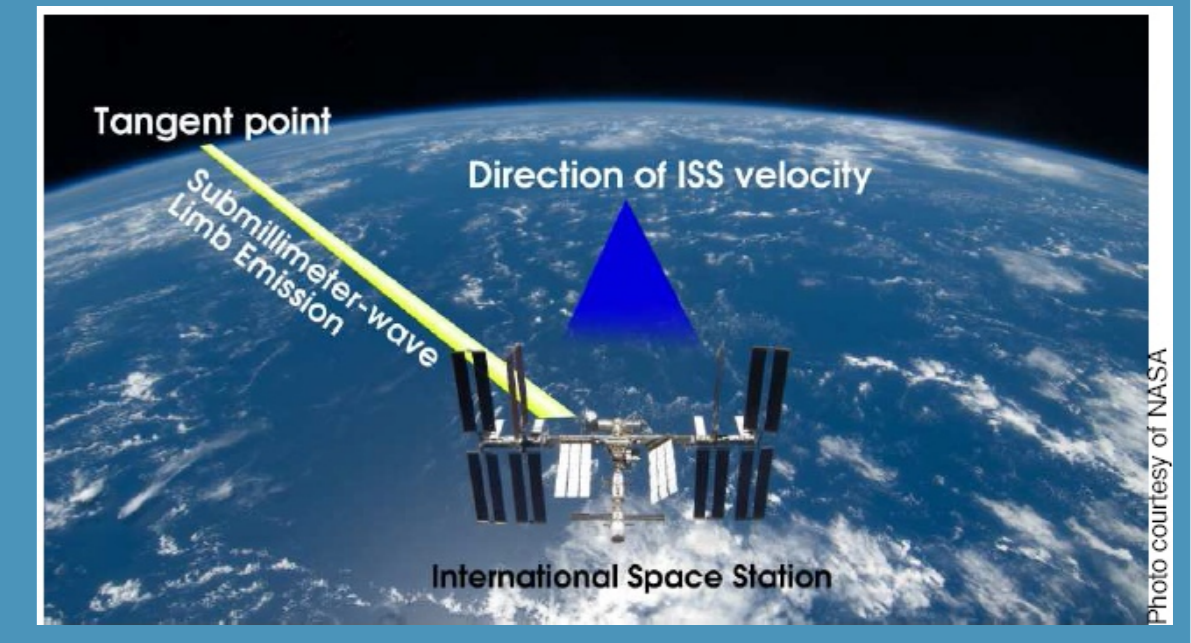


Measurement of middle and upper atmospheric horizontal winds with a submillimeter wave limb sounder: results from JEM/SMILES and simulation study for SMILES-2

Philippe Baron¹, 眞子直弘², 落合啓¹, 鈴木睦³ and the SMILES-2 working group



- 1: 情報通信研究機構電磁波計測研究所
- 2: 千葉大学環境リモートセンシング研究センター
- 3: 宇宙航空研究開発機構宇宙科学研究所



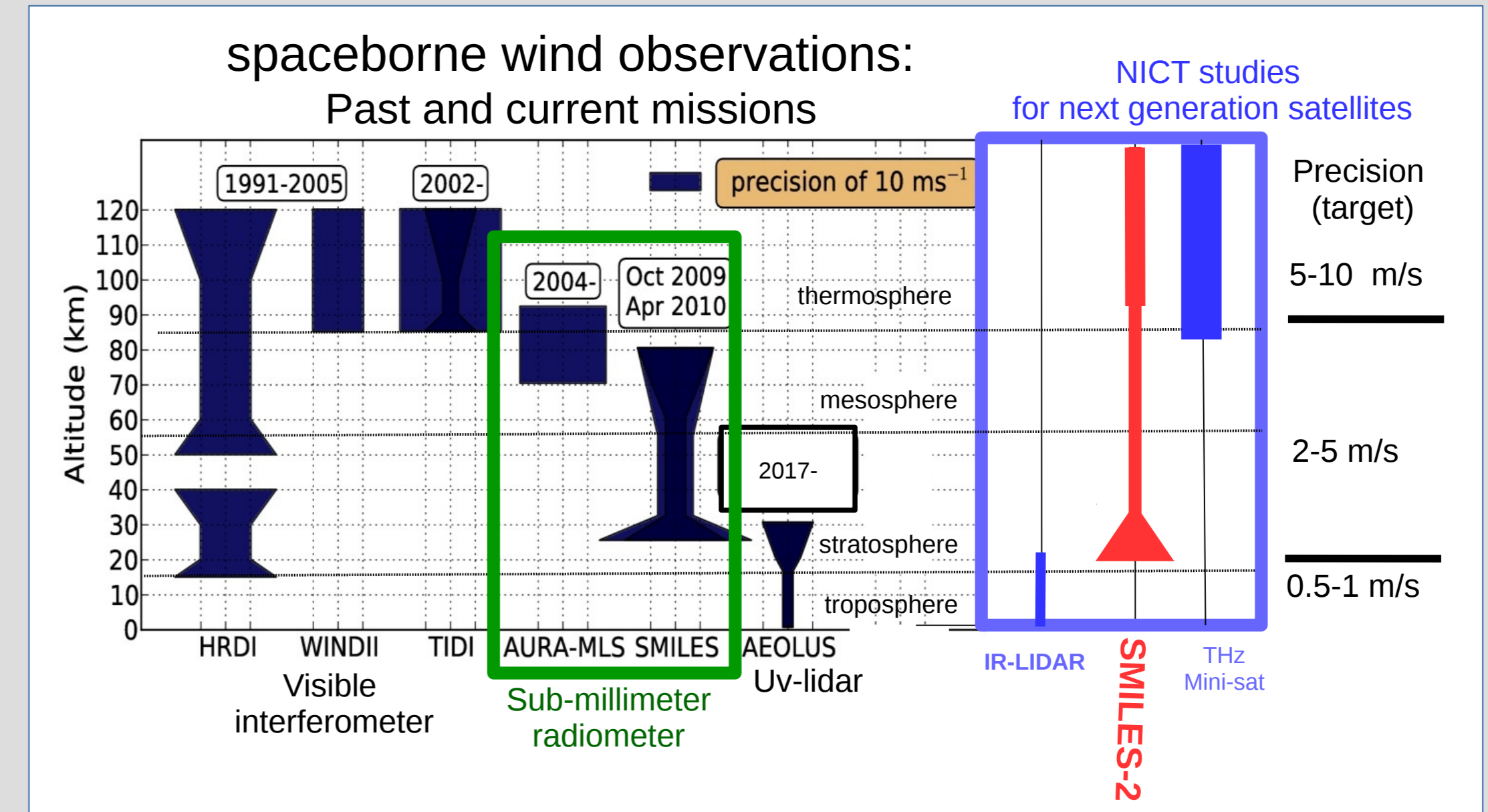
Winds are the key parameter to study atmospheric dynamics. Global scale measurements are required to improve circulation, chemistry and climate models.

Middle atmospheric winds (20-80 km) are also a promising parameter to improve tropospheric **long-term weather forecast**.

No mission with the capability to measure middle-atmosphere wind is planned.

SMILES-2 [1,2] is a project of a sub-millimeter (SMM) and THz limb sounder (616-150 μm) dedicated to the study of the dynamics and chemistry of the middle and upper atmosphere. If realized, it will inherit the 4-K cooling technology tested with the Superconducting Submillimeter Wave Limb Emission Sounder (**SMILES**, JAXA/NICT)

SMILES-2 has the potential to measure horizontal winds from 20 km up to more than 160 km. The best performances are found in 35-90 km (precision <3 m/s and vertical resolution of 2-3 km) [3].



Few spaceborne observations are available and most of the past observations were performed in the upper atmosphere using visible airglow lines.

It has been demonstrated with **JEM/SMILES** that a 4-K cooled SMM limb sounder can provide good quality wind between 35-70 km where other satellite instruments lack sensitivity [4].

Line-of-sight wind from JEM/SMILES

SMILES was a JAXA/NICT joint mission that operated from the ISS (09/2009-04/2010).

Line-of-sight winds were retrieved from the Doppler shift of the strongest O₃ and H³⁵Cl lines

The frequency shift is retrieved from the spectral residual after the VMR and temperature retrievals.

The retrieval range is 35-80 km (~100 km during night time)

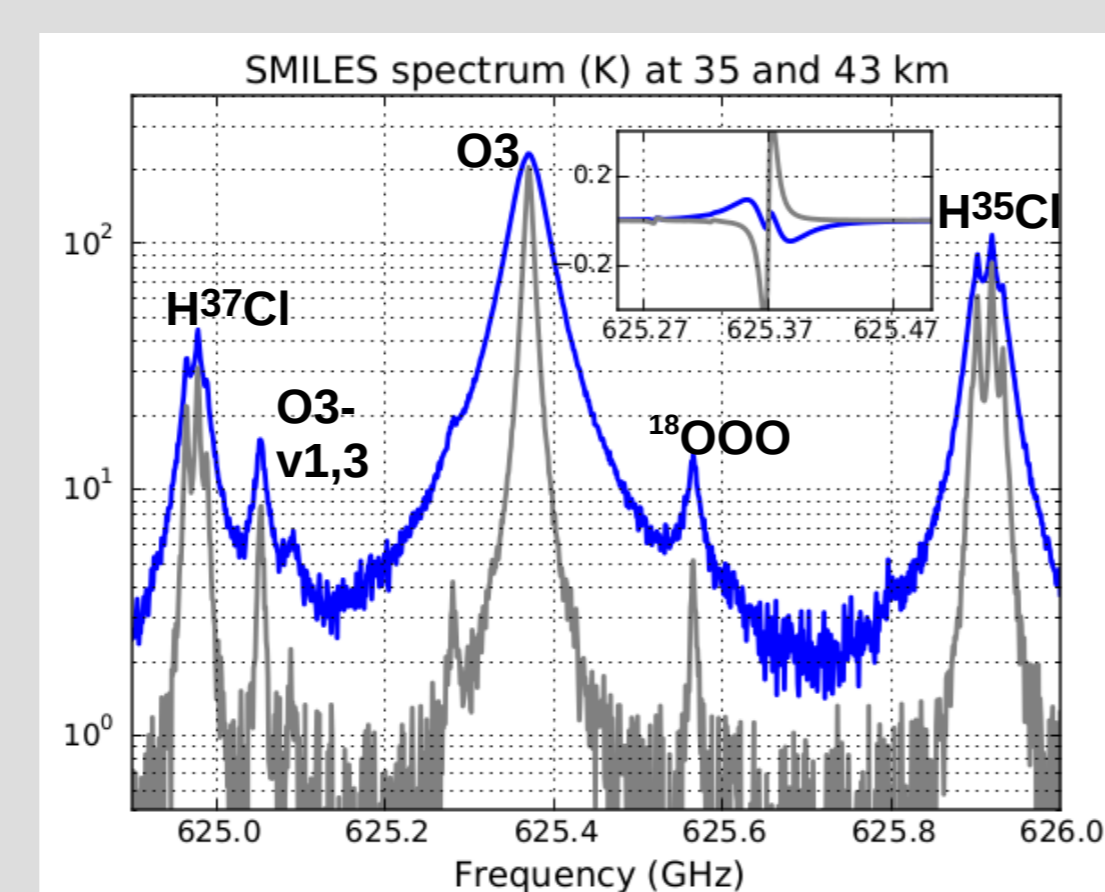
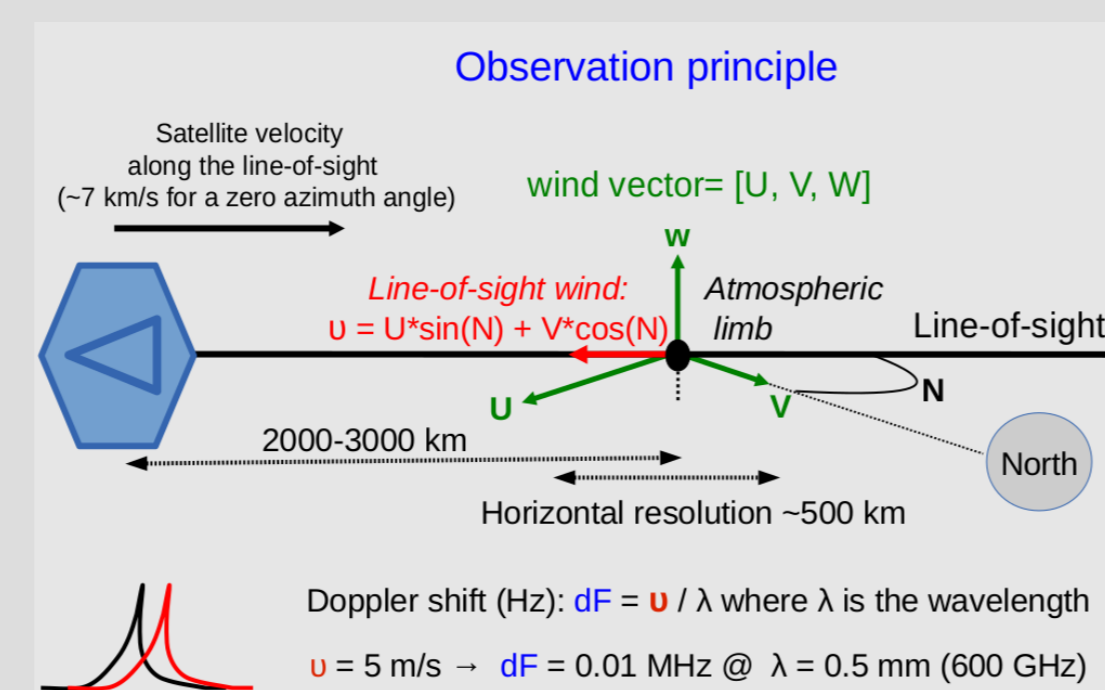
SMILES was not designed for wind measurements:

No good performances at altitudes below 35 km because of too few lines with moderate intensity(*) and of intensity calibration uncertainties.

Limited performances at altitudes >70 km because the lines are not strong enough, and the spectral resolution is too large (1.2 MHz).

Bias of 20-50 m/s (0.04-0.1 MHz) induced by the optical spectrometer. It is mitigated by postprocessing using Tropical meridional winds.

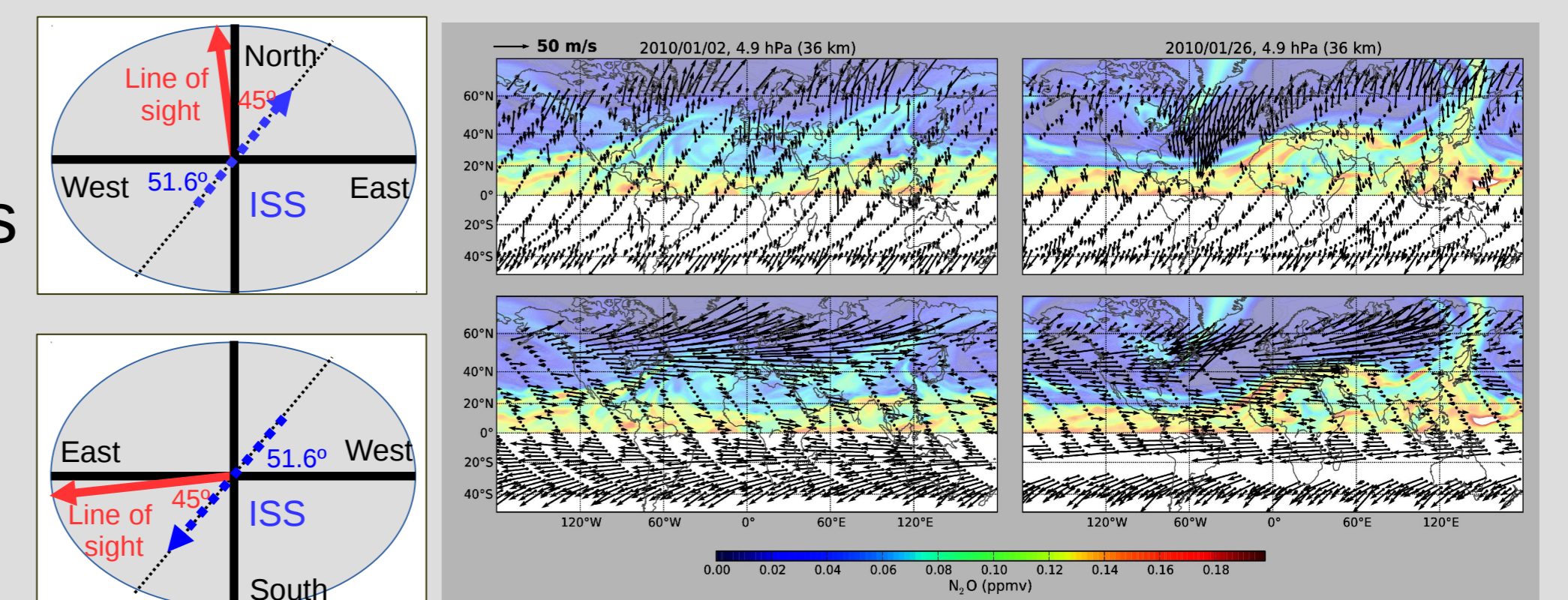
* The strength of the wind signal decreases with the broadening of the lines (>30 MHz below 30 km). Below 35 km, good retrievals need a large number of lines with moderate intensity such as the SMILES O₃ one at 625.37 GHz.



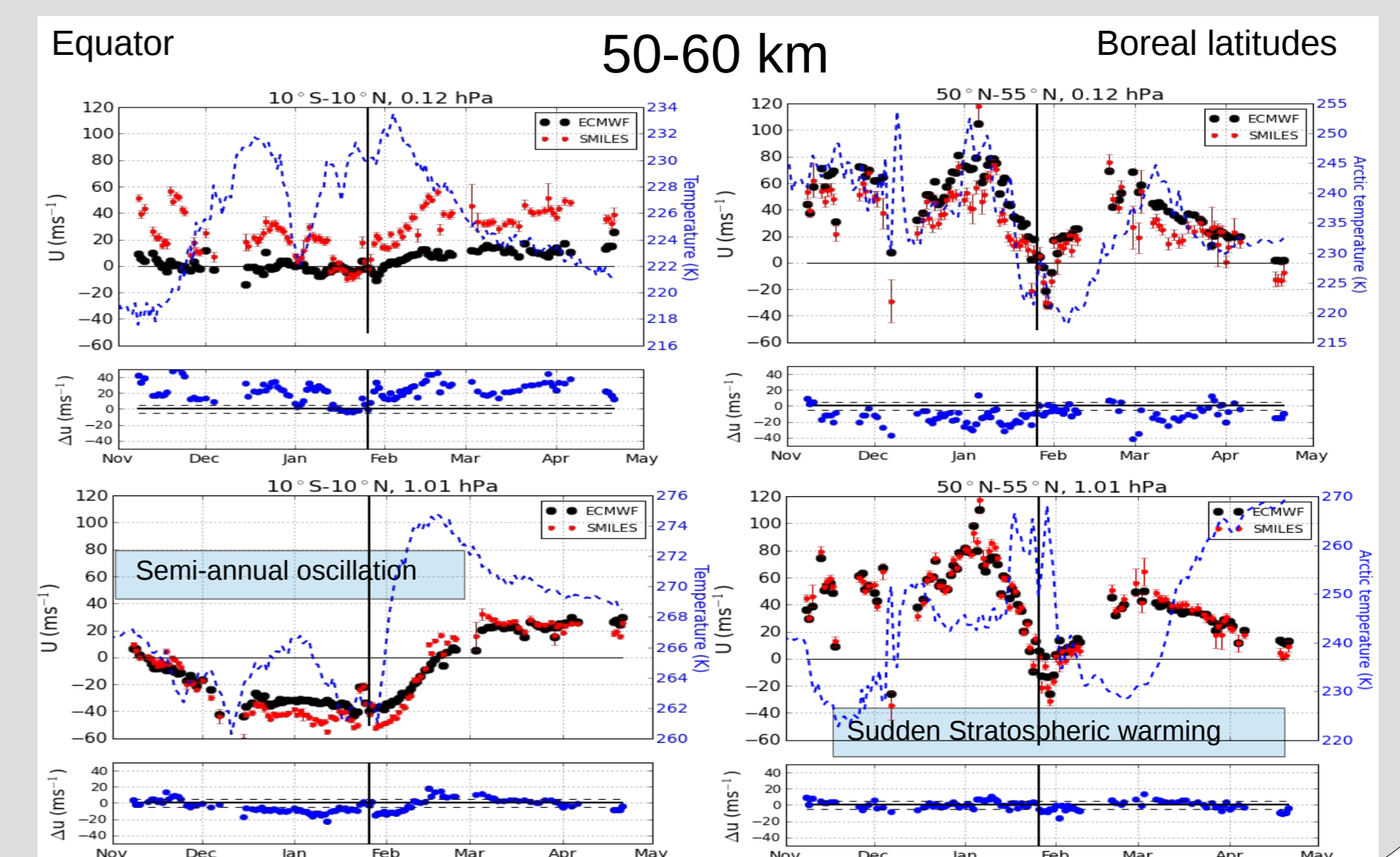
JEM/SMILES spectra simulations and spectral signature of a line-of-sight wind (inner panel). The wind is +10 m/s below 40 km and -10 m/s above.

Some results from JEM/SMILES

Line-of-sight wind retrievals at 36 km



Zonal and daily average of line-of-sight winds near the zonal direction and comparison with ECMWF forecast.



Simulation setting for SMILES-2

Double sidband (DSB) radiance (brightness temperature) and measurement noise:

$$T_{atm}^{dsb}(F_i) = \frac{1}{2} (T_{atm}(F_{lo} - F_i) + T_{atm}(F_{hi} + F_i))$$

$$\sigma_m^{dsb} = \frac{T_{sys}^{dsb} + T_{atm}^{dsb}}{\sqrt{w \times \Delta T}}$$

T_{sys}: DSB system temperature (K)
w: spectral resolution (FWHM, Hz)
 ΔT : integration time (s)

Table 1. Radiometer characteristics for SMILES-2¹

SIS-1, DSB, T _{sys} ^{dsb} =150 K	
4 GHz bandwidth, 0.25 MHz resolution	
(1) 485-489 GHz	T, Wind, O ₂ , H ₂ O, O ₃ , HO ₂
(2) 525-529 GHz	BrO, NO ₂ , H ₂ CO, N ₂ O, HO ₂
SIS-2, DSB, T _{sys} ^{dsb} =150 K	
4 GHz bandwidth, 0.25 MHz resolution	
(3) 623-627 GHz	O ₃ , HCl, BrO, HNO ₃ , HO ₂ , N ₂ O, HOCl, CH ₃ Cl
(4) 648-652 GHz	O ₃ , ClO, HO ₂ , BrO, NO

HEB, SSB, T _{sys} ^{dsb} =1000 K	
1 GHz bandwidth, 0.5 MHz resolution	
(5) 2.06 THz	O-atom, upper atmospheric wind and temperature
(6) 1.8 THz	OH, H ₂ O, O ₃

¹The spectral resolution is 0.5 MHz for all bands.

Table 2. Observation characteristics¹

Antenna diameter (vertical axis)	1 m (40 cm)
Antenna FOV FWHM	0.035° at 600 GHz (0.09°)
Platform altitude	400 km (350 km)
Vertical velocity	0.1° s ⁻¹ (0.11° s ⁻¹)
Spectrum integration time	0.1 s (0.5 s)
Vertical sampling	0.38 km
Limb resolution at 30 km	1.34 km at 600 GHz (4.1 km) 0.4 km at 2 THz
Atmospheric scan duration	≈30 s for 120 km vertical range
Calibration phase duration	25 s for JEM/SMILES
along-track sampling	≈450 km for JEM/SMILES
Scans per day	≈1600 for JEM/SMILES

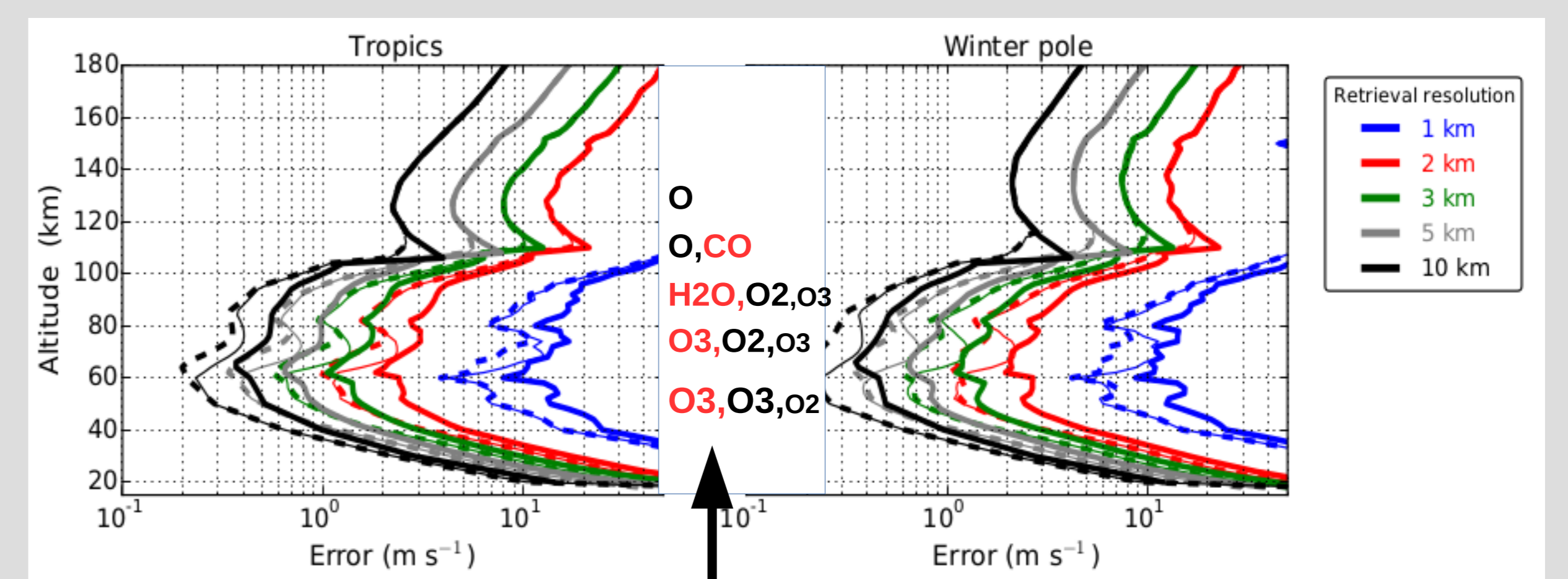
¹The parameters for JEM/SMILES are given in parenthesis

Alternative spectral band setting for improving wind retrievals

- Better sensitivity in 30-80 km with the dense cluster of strong O₃ lines at 655 GHz
- Better sensitivity in 70-100 km using the strong H₂O and CO lines at 557 and 577 GHz, respectively.

- 624/652 GHz, DSB with 8 GHz bandwidth and 1 MHz resolution
- 557/577 GHz, DSB with 2 GHz bandwidth and 0.25 MHz resolution

Wind measurement error for SMILES-2



Molecules associated with the spectral lines providing wind information per altitude level. Names in red are for the **alternative bands**.

Colored lines: Vertical resolution
Thick lines: default spectral bands (**night time**)

Dashed lines includes **alternative** spectral bands (**night time**)
Thin lines are the same as dashed-lines but for **day time**.

[1] Manago, N et al., "Band selection study for the sub-MM limb sounder, SMILES-2," IEEE Geoscience and Remote Sensing Symposium, 13-18 July, Quebec City, 4153-4156, 2014
[2] Suzuki, M. et al., "Sensitivity study of SMILES-2 for chemical species," Proc. of SPIE Remote sensing, 96390M-96390M-15, 2015
[3] Baron, P. et al., "Measurement of stratospheric and mesospheric winds with a Submillimeter wave limb sounder: Results from JEM/SMILES and simulation study for SMILES-2," Proc. of SPIE Remote sensing, 96390N-96390N-20, 2015
[4] Baron, P. et al., "Observation of horizontal winds in the middle-atmosphere between 30S and 55N during the northern winter 2009-2010," Atmospheric Chemistry and Physics 13(13), 6049-6064, 2013.