Observing convection from space: assessment of performances for next-generation Doppler radars on Low Earth Orbit

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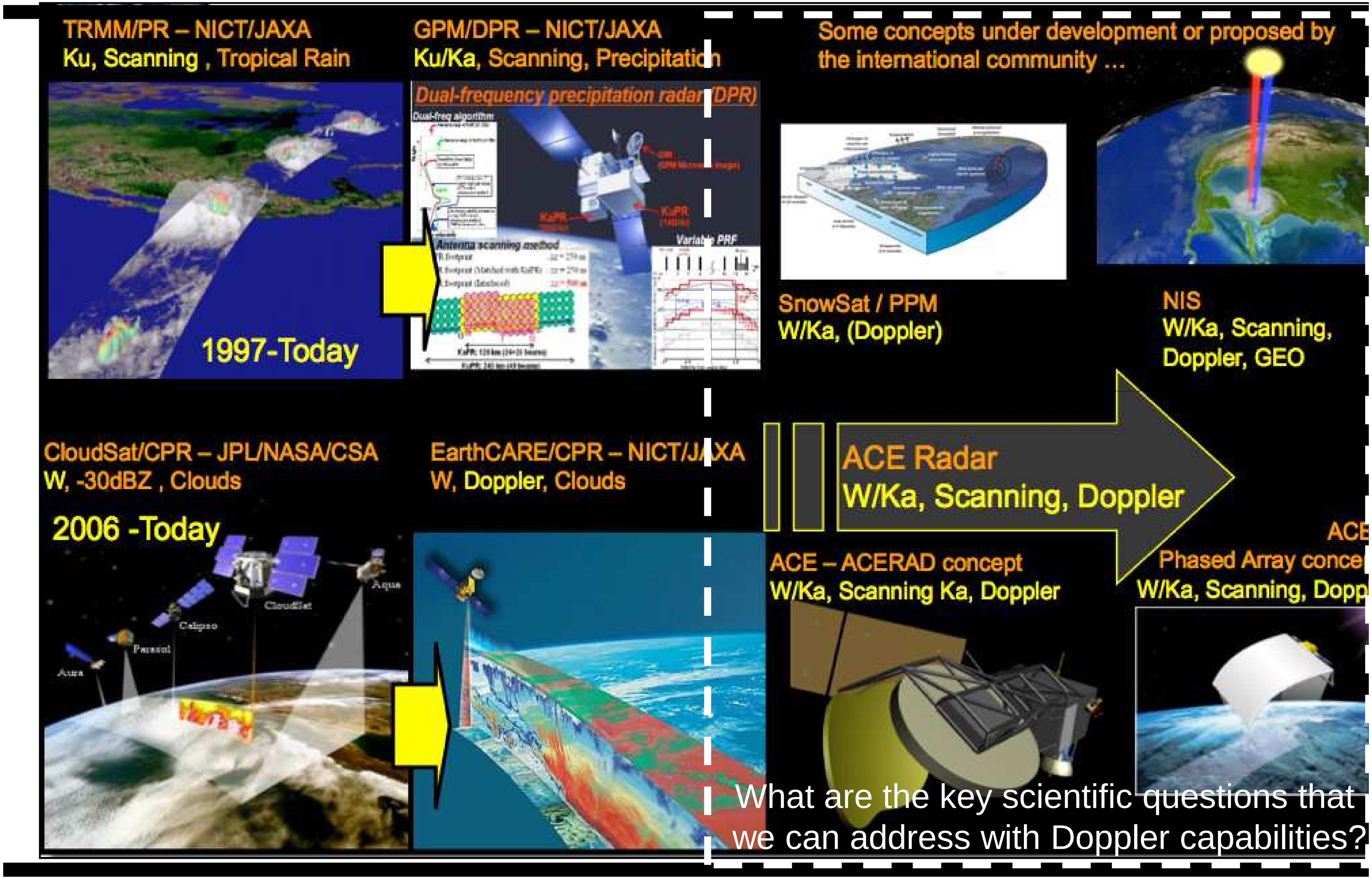
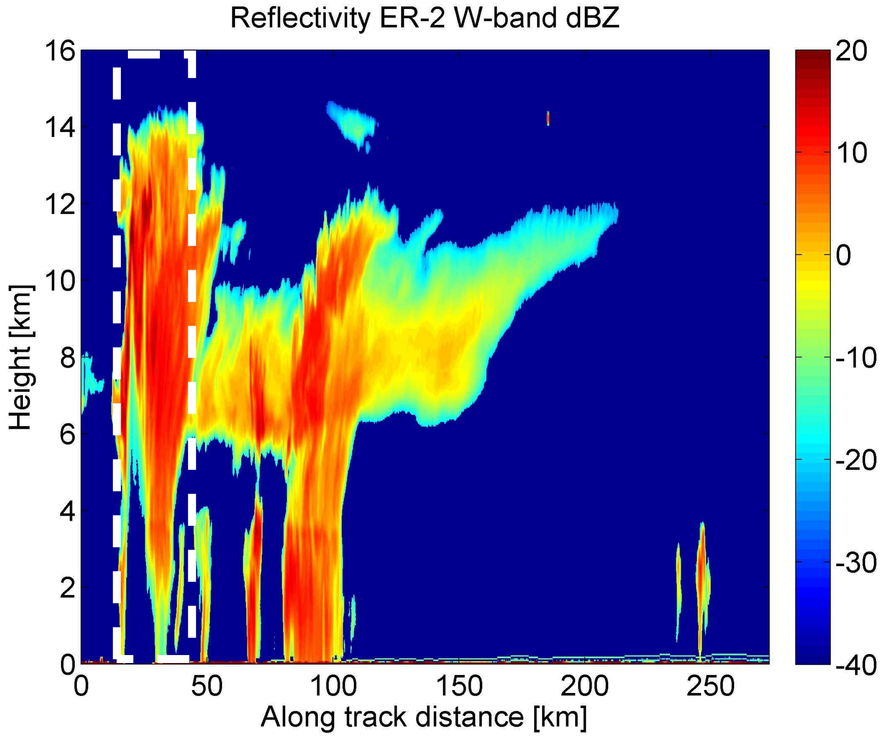
'Aetas aurea' for space-borne Radars



Why Doppler from space?

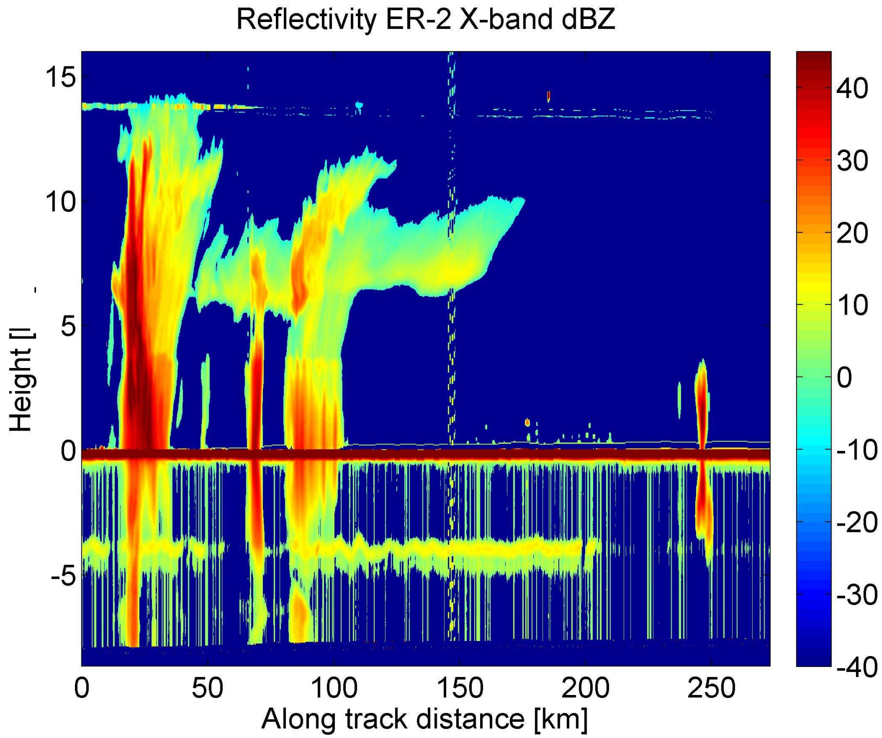
Goal	Potential of Doppler	Alternative spaceborne observing systems & methods	Contribution to Weather and Climate knowledge
Measurement of Vertical (and horizontal for scanning?) air motion/ Characterization of Convection	**Essential**	None in precipitation – Potential use of lidar in clear air	- Understanding of precipitation processes and dynamics on a global scale - Improvement in the characterization of convection (vertical profiling and temporal evolution) - Improvement in GCM's skills by assimilating vertical velocity
Hydrometeor Classification	Moderate	Radiometers - *limited vertical resolution*. Non-Doppler multi-frequency radars - *performances to be verified*.	- Cloud microphysics
Estimation of Precipitation and DSD parameters	High in stratiform Low in convection	Multiparametric approaches (multifrequency, combined radar/radiometer) - *limted accuracy and/or vertical resolution*	- Improvement in rainfall rate estimates for assimilation in GCM's
Convective/Stratiform Classification	Moderate	Non-Doppler Radar - *acceptable performances over the tropics(TRMM) - to be verified on a global scale (GPM)*	- Improvement in Latent Heating global maps - Improvement in radiation budget studies - Improvement in rainfall rate estimates
Latent Heat	**High**	Multiparametric approaches (multifrequency, radar/radiometer) - *good in estimating maximum, unreliable performances in vertical profiling (especially in convection)*	- Improvement in Latent Heating vertical profiling for assimilation in atmospheric models

Airborne observations of convection



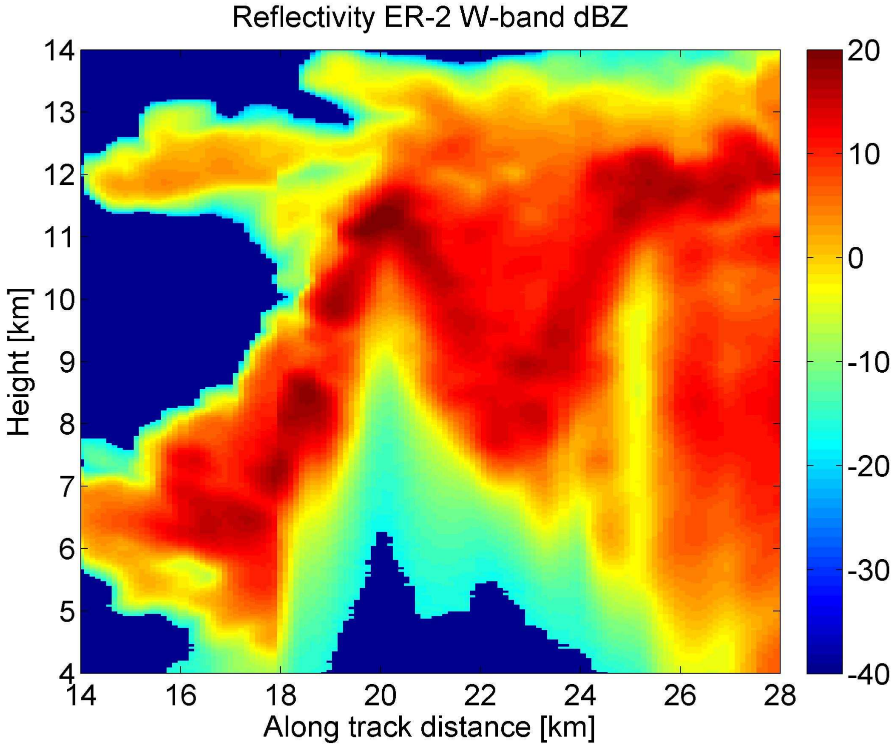
23 July 2002 CRYSTAL-FACE

EDOP 9.6 GHz PRF 4400 Antenna BW 2.9 de



Data, courtesy, J. Heymsfield (NASA-Goddard)

Convective tower: ER-2 observations



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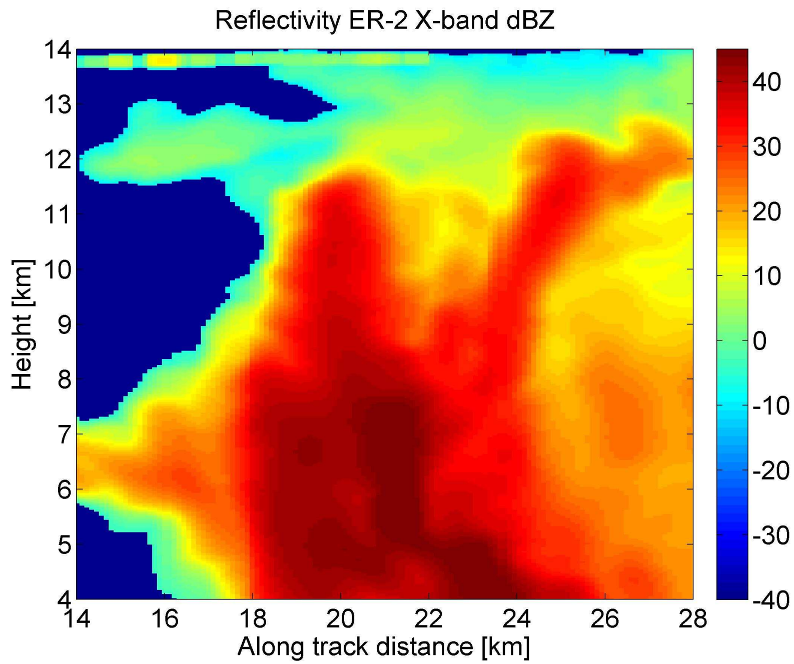
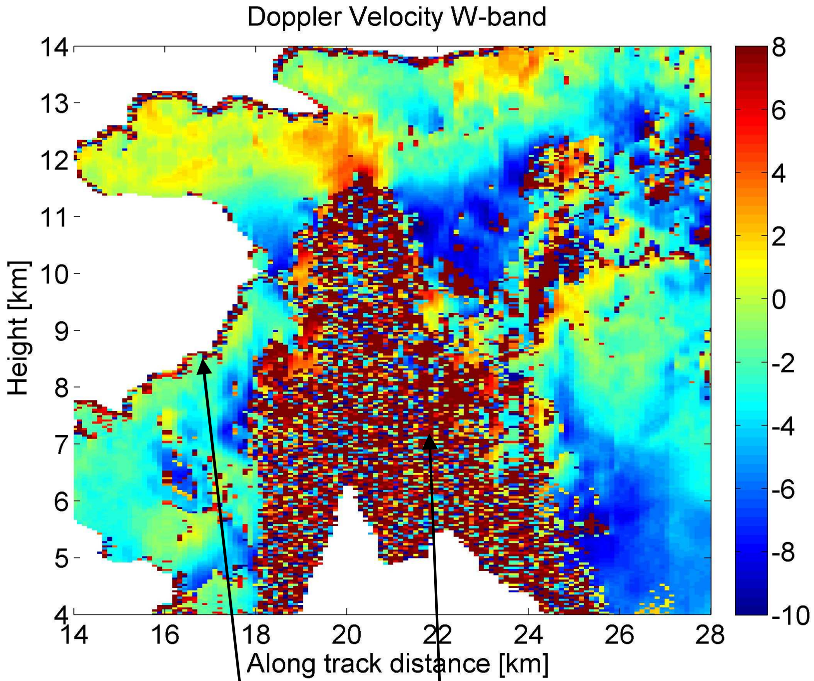
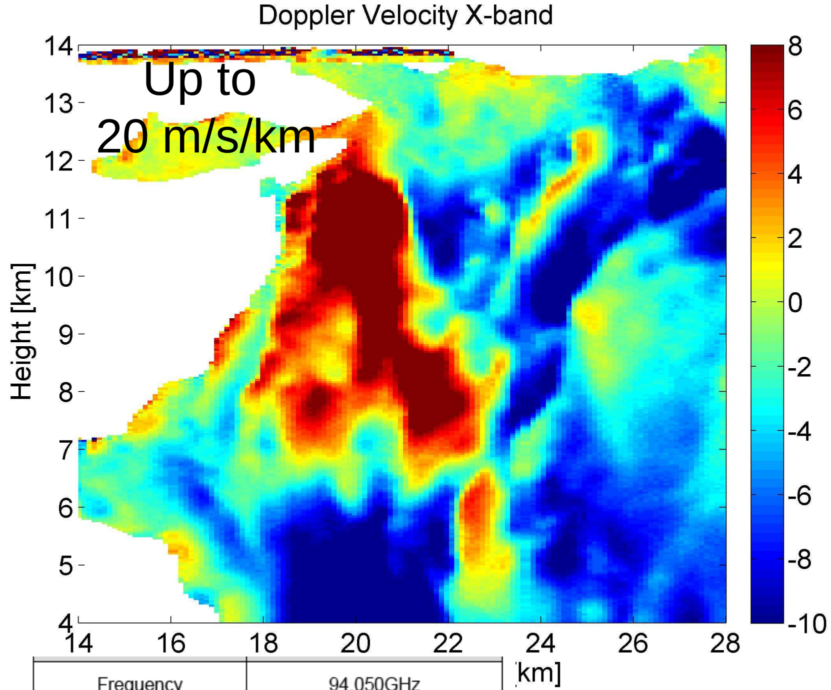


Convective tower: Doppler velocities

Staggered PRF 4/5 kHz
(V_{NYQ}=15.9 m /s)





Critical regions:

1) low SNR
2) strong wind gradients (blurred region)

For LEO satellites

3) multiple scattering
4) **Doppler fading (accuracy, aliasing)**
5) NUBF biases
6) pointing accuracy

Tanelli et al.,2003-2004
Battaglia et al,.2011

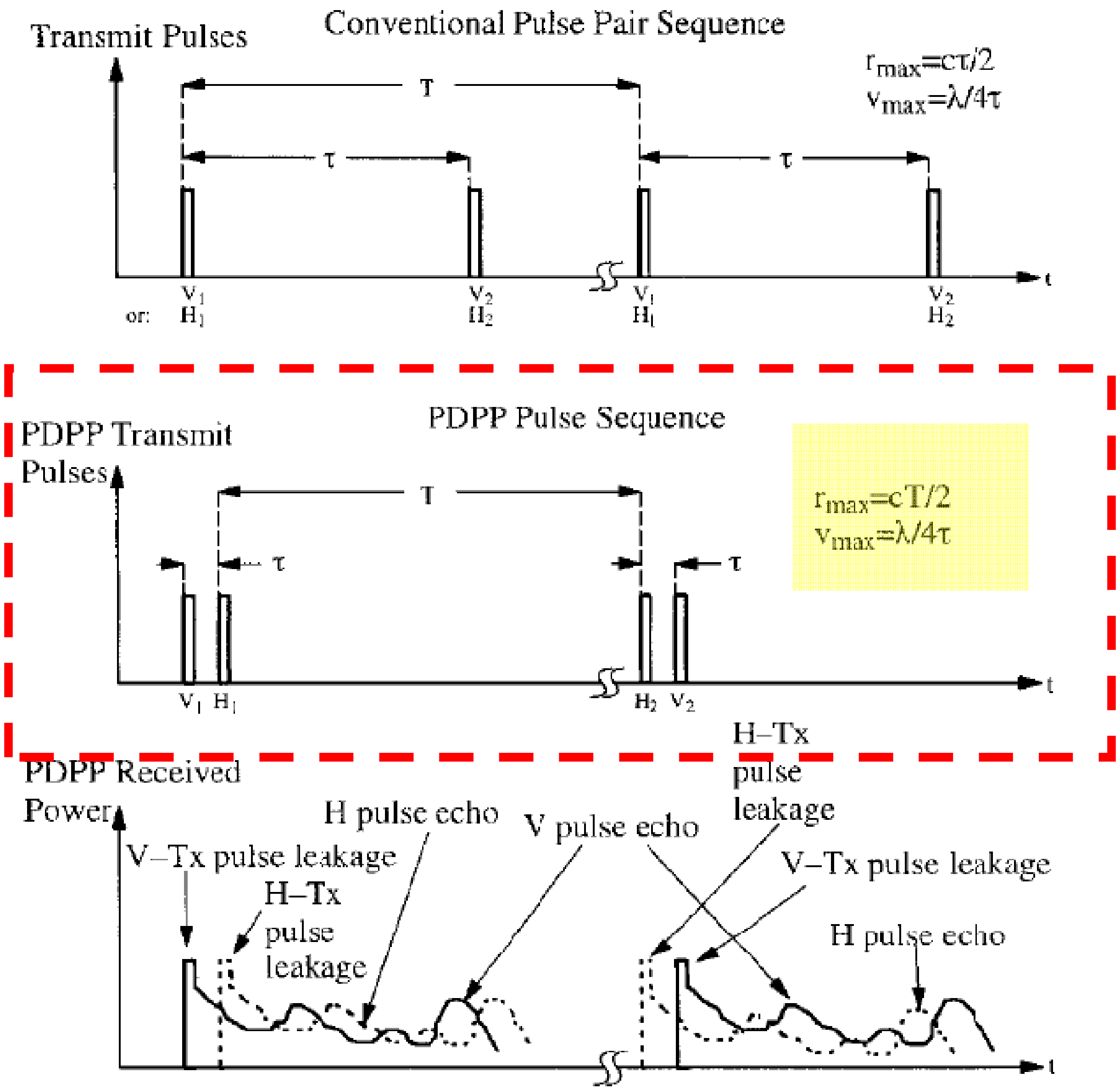
Frequency	94.050GHz
Peak power	1.5kW (EOL)
PRF	6100Hz to 7500Hz (during nominal observation)
Antenna diameter	2.5m
Beam width (Beam foot print)	0.095deg (800m)
Vertical resolution (Pulse width)	500m (3.3us)
Horizontal resolution	500m
Minimum sensitivity	-35dBZ (10km integration, uniform cloud)
Doppler measurement accuracy	1m/s (10km integration, -19dBZ clouds)

v_{Nyq}=4.8-6

EarthCARE
Cloud Profiling Radar
specs

We have a Doppler dilemma even if EC is operated in nadir pointing configurations (low dynamic in the unambiguous range)

Polarization diversity technique



High degree of correlation between the orthogonal copolarized backscatter coefficients (S_{vv} and S_{hh}) of atmospheric particles

The isolation between orthogonally polarized signals prevents ambiguity.

This practically decouples r_{max} from u_{max}.

Doviak and Sirmans (1973)
Pazmany et al. (1999)
Kobayashi et al., 2002

Polarization diversity technique: contra

1) Technological-issues ➔ PDPP requires

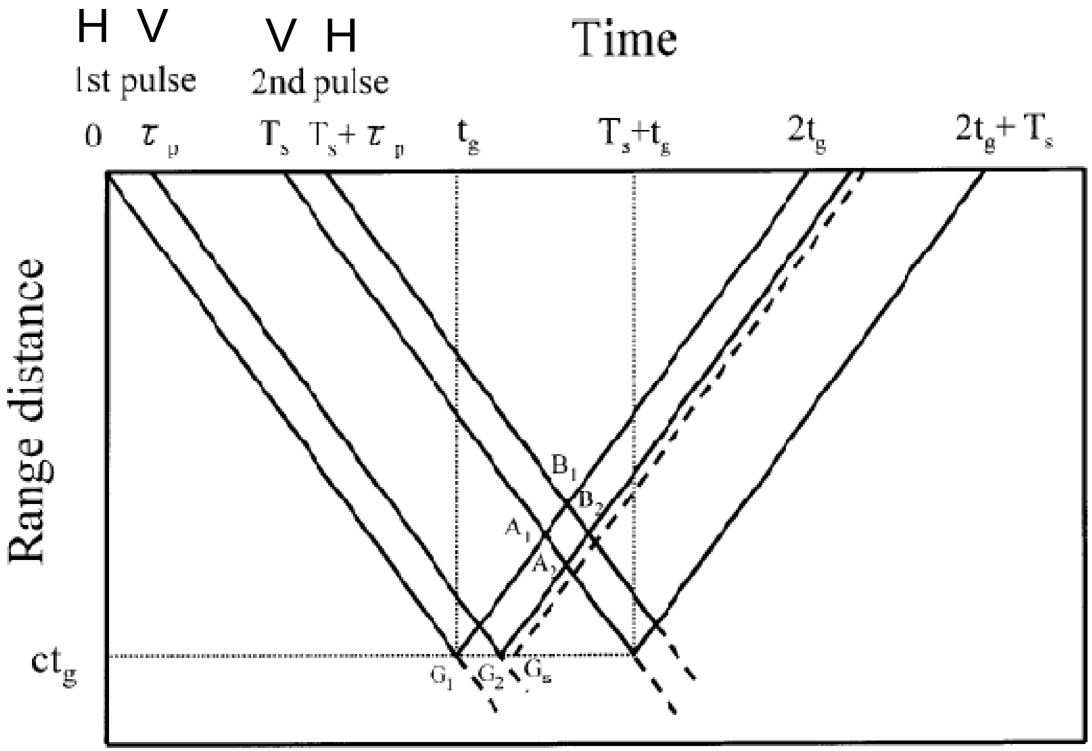
- two receiver channels that can simultaneously measure the orthogonal polarization components
- transmitter has to switch polarization from pulse to pulse

2) Blind-layer issues

surface, MS,
depolarizing hydrometeor
Introduce cross-talk

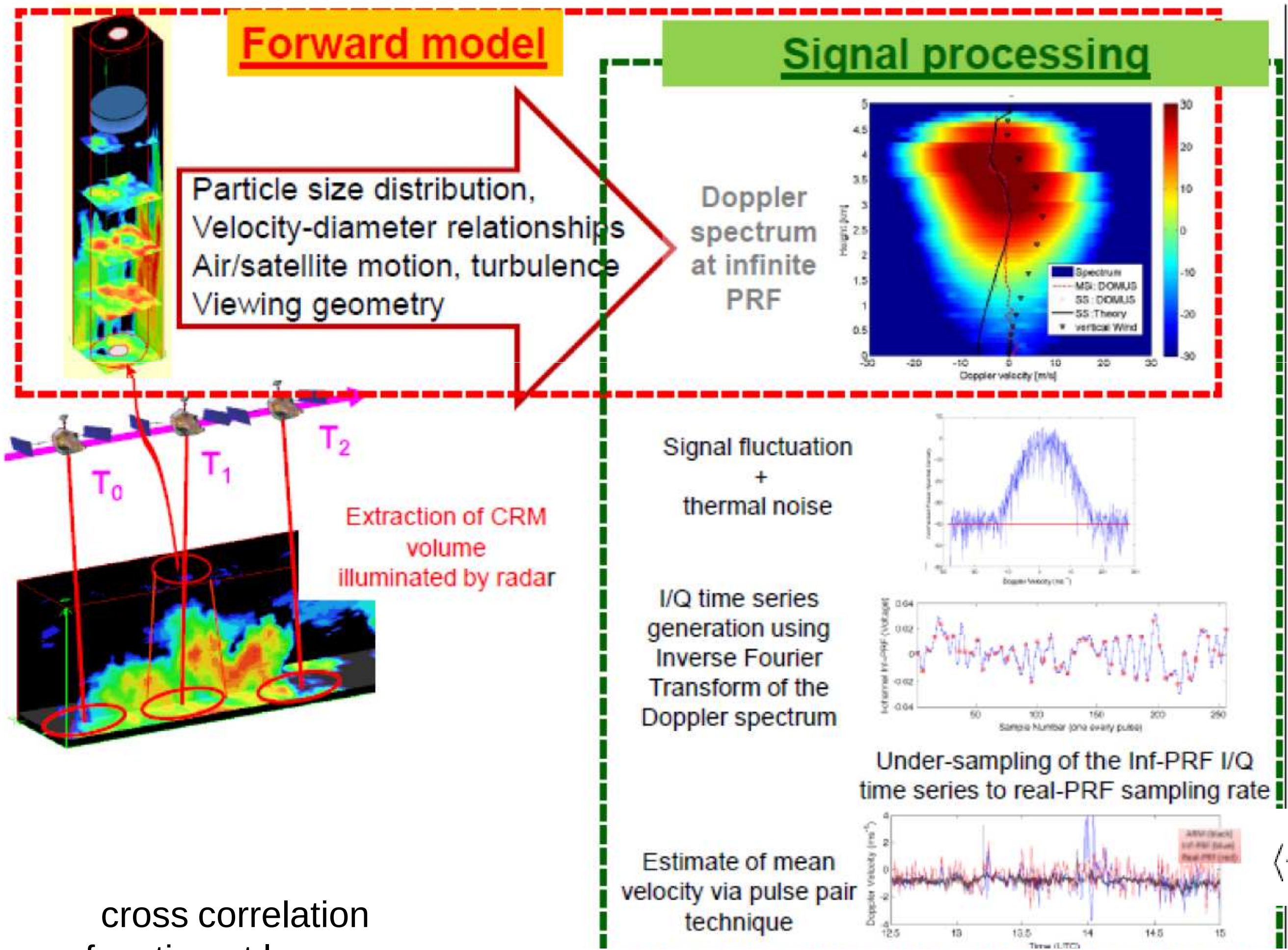
$S_H(r)=S_{co}(r)+S_{cx}(r-c/2T_{HV})$

$S_V(r)=S_{co}(r)+S_{cx}(r+c/2T_{HV})$



End to end instrument simulator

DOMUS (Battaglia and Tanelli, 2011) is coupled with a signal processing simulator



The output of the forward model produce co-polar and cross-polar periodograms of the return radar power (inclusive of MS/sat-vel) and then the radar complex signal

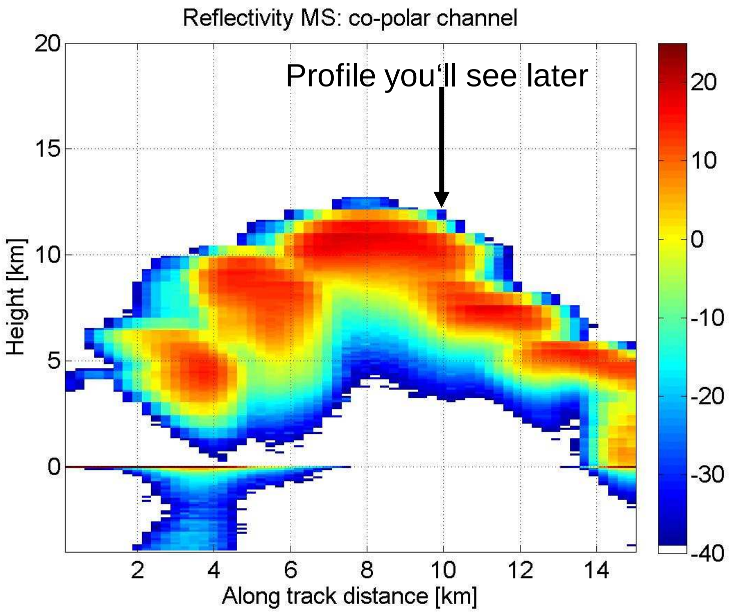
$$\boldsymbol{V_H}(t)=\boldsymbol{I_H}(t)+j\boldsymbol{Q_H}(t)$$
$$\boldsymbol{V_V}(t)=\boldsymbol{I_V}(t)+j\boldsymbol{Q_V}(t)$$

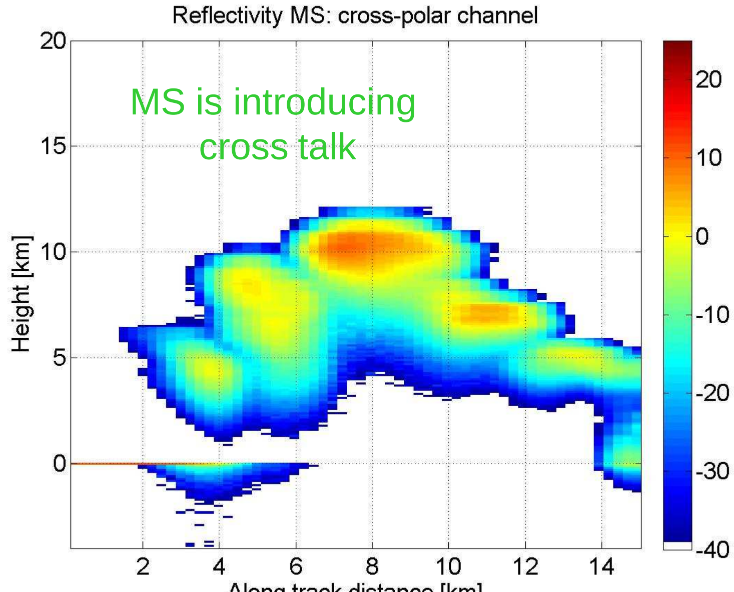
$$\langle v_D\rangle = \frac{\lambda}{4\pi\tau}\arg\sqrt{\hat{R}_{HV}(\tau)\,\hat{R}_{VH}(\tau)}$$

cross correlation function at lag-one

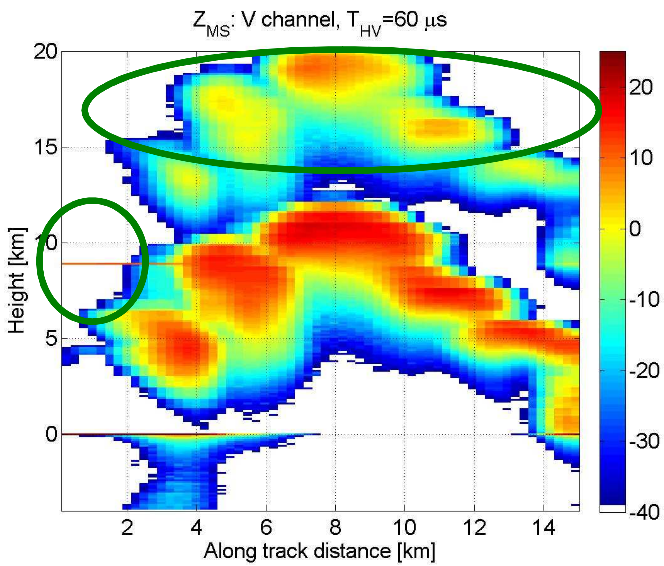
$$\hat{R}_{HV}(\tau)=\frac{1}{M-1}\sum_{i=1}^{M-1} V_H^*(i)\,V_V(i)=\hat{R}_{HV}(0)\,e^{j\,(2\pi\,f_D\,\tau+\Phi_b)-2\pi^2\sigma_f^2\tau^2}$$

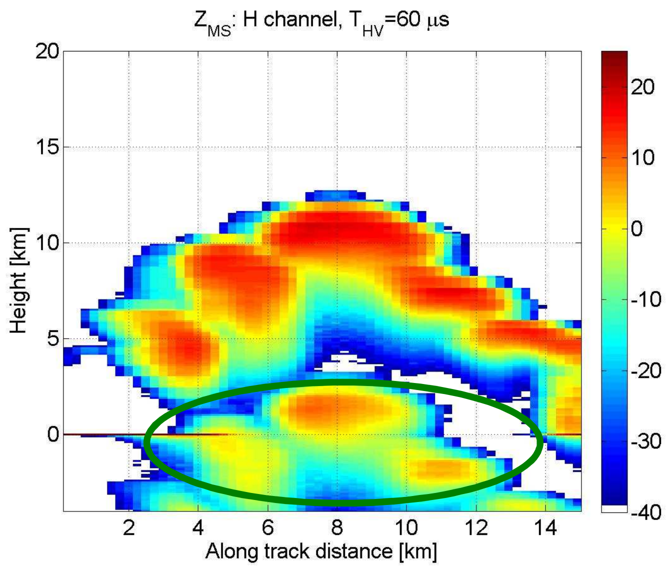
Merging co and cross-pol signals





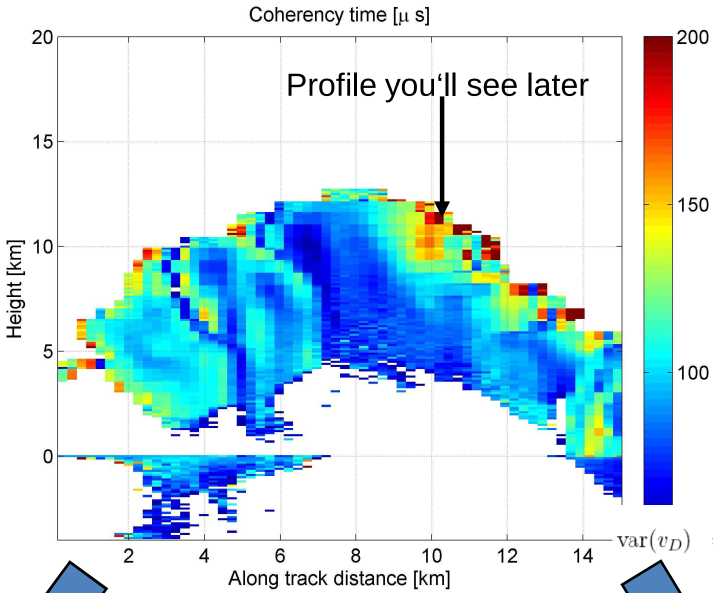
Not only surface echoes but area MS contaminated are producing ‚ghost echoes'





Accuracy of Doppler estimates

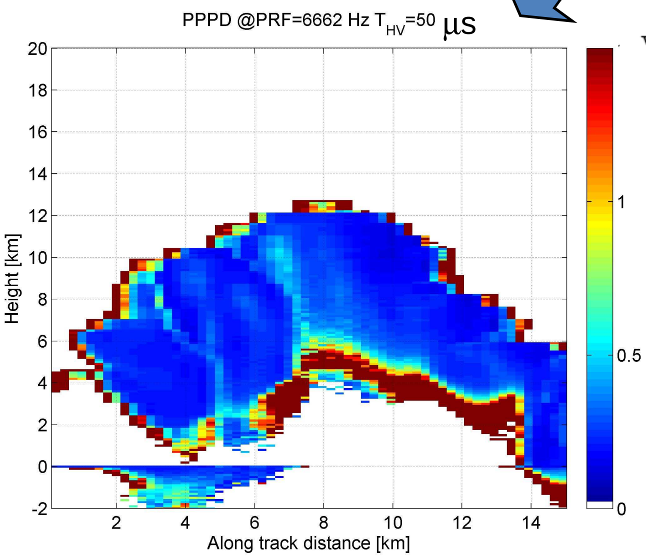
$$\sigma_v^2 = \sigma_D^2 + \sigma_T^2 + \sigma_K^2 + \sigma_{sat}^2$$

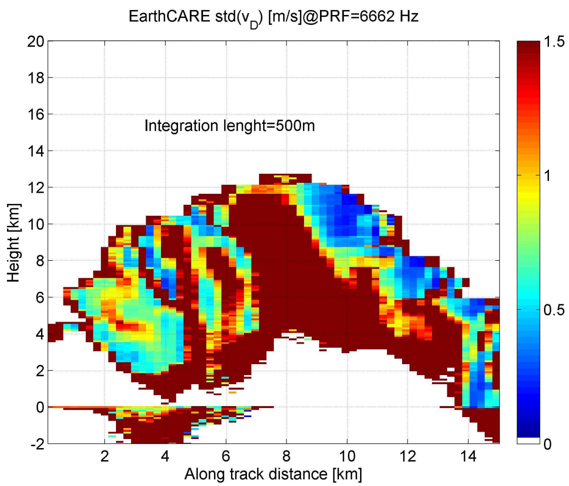


Zrnic 1977

$$\mathrm{var}(v_D) = \frac{\lambda^2}{16\pi^2 T_s^2 \rho^2(T_s)} \left\{ \frac{1-\rho^2(T_s)}{2M^2} \sum_{m=-(M-1)}^{M-1} \rho^2(mT_{pri})(M-|m|) + \frac{1}{2M\,(\mathrm{SNR})^2} + \frac{1}{\mathrm{SNR}\;M}\left[1-(1-\frac{1}{M})\rho(2\,T_s)\delta_{T_{pri},T_s}\right] \right\} \quad (27$$

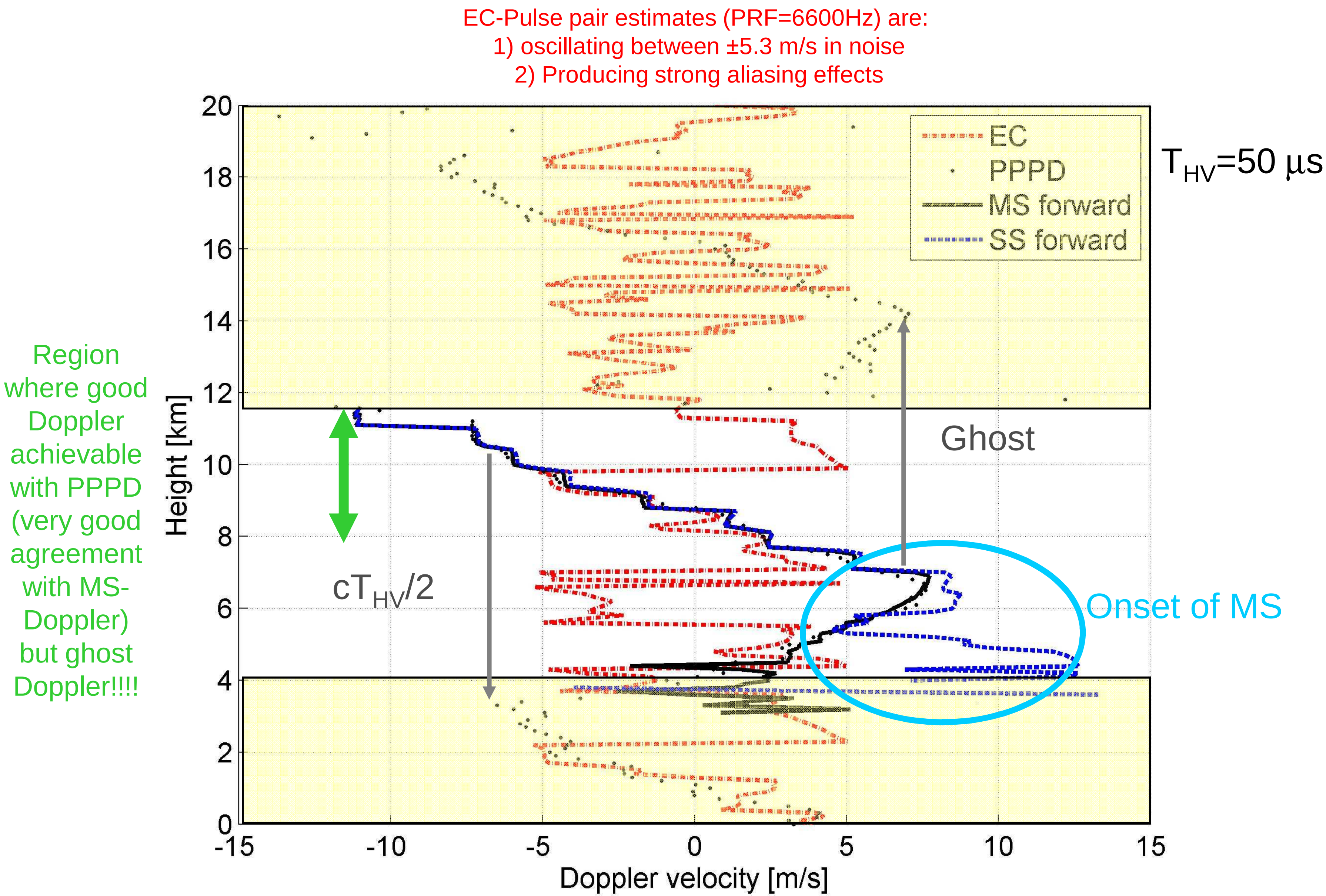
$$\mathrm{var}(\langle \hat{v}_Z \rangle) = f(w_N, \mathrm{SNR}, v_{ZN})/M^{1/2}$$



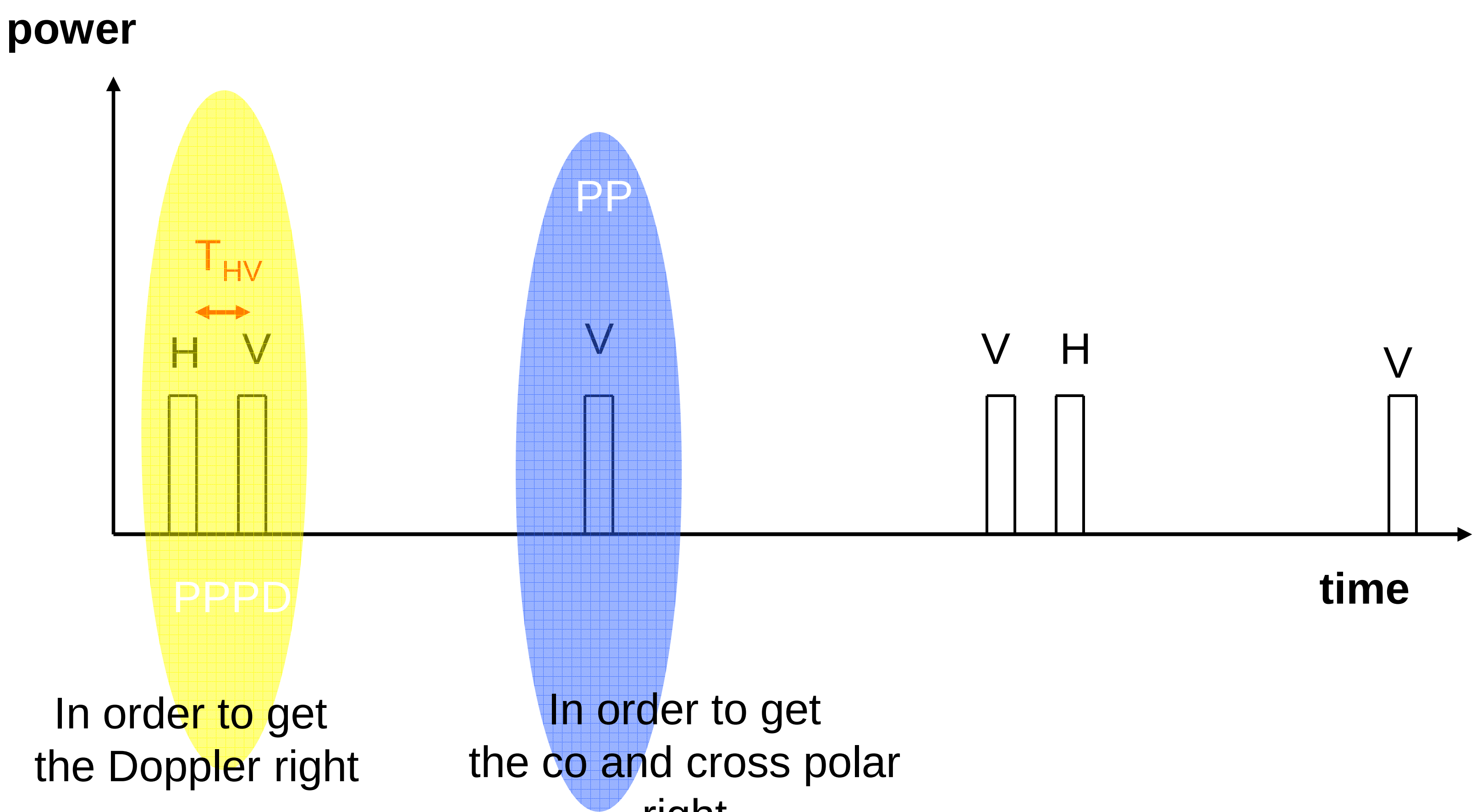


PPPD is performing significantly better than simple PP

Single profile: EC vs EC-PolDiv



Interlaced mode



In order to get
the Doppler right

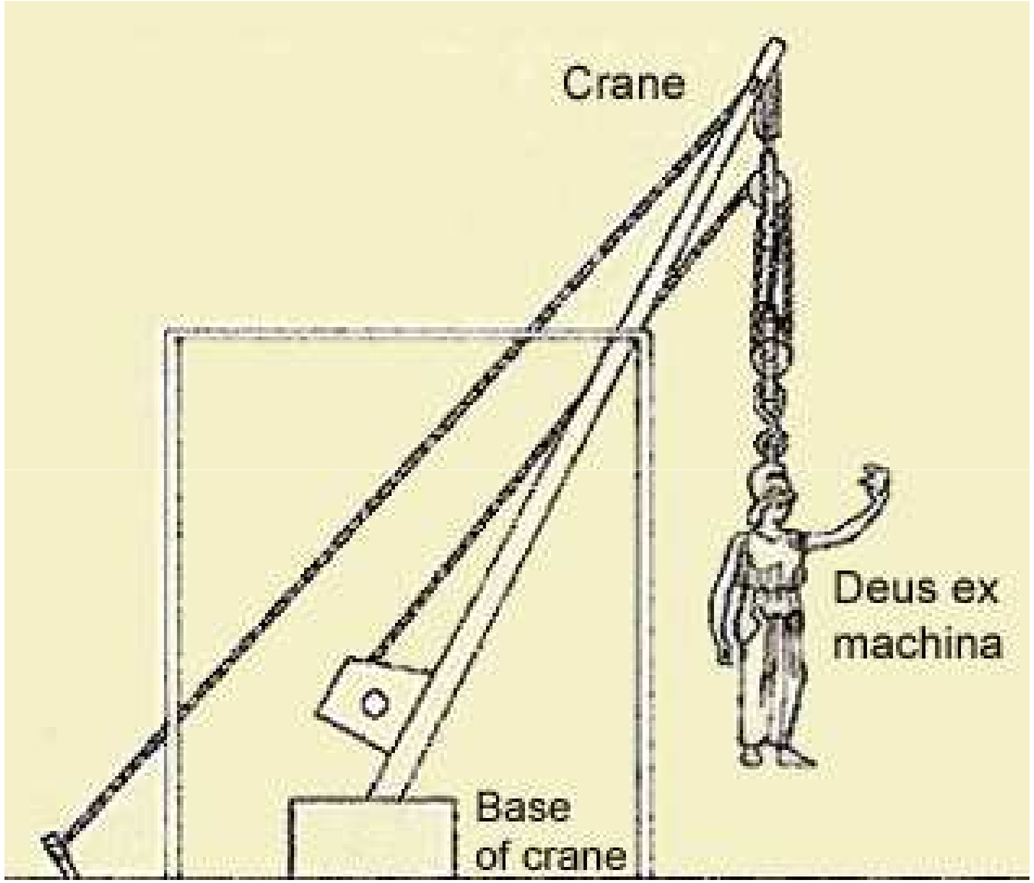
In order to get
the co and cross polar
right

Conclusions

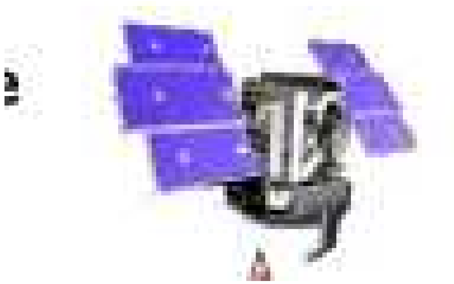
1) Aliasing (5-6 m/s Nyquist velocity for EarthCARE) is the primary concern when considering W-band Doppler observations of convection.
2) Polarization diversity technique can provide a viable (but more expensive) solution to significantly increase folding interval (factor 3-4) and reduce estimate errors (factor 2-3).
3) Preliminary results show that T_{HV}~30-50 μs is the best choice for optimal velocity estimates
4) Cross-talk introduced by multiple scattering, by surface return and by hydrometeor depolarization tend to introduce ghost echoes (blind layers). An interlaced mode is deemed necessary for identifying ghost echoes and regions where MS occurs.

Doppler estimates are believed to be reliable and useful for regions with SNR>5dB and not-affected by MS.

Conclusions



W-band radars



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